2020 Facility Planning Project

Final Memorandum

Project Name:	MMSD – 2020 Facility Planning Project	MMSD Contract No:	M03002P01
DMS Folder Name:	Technology Analysis	MMSD File Code:	M009PE000.P7300-WQ1
Document Name:	Hydrologic Calibration and Validation Results for the Kinnickinnic River Model (Task 3)	HNTB Charge No:	34568-PL-400-115

Date: November 16, 2007
To: Michael Hahn, SEWRPC
Bill Krill, HNTB
From: Leslie Shoemaker, Tetra Tech, Inc.
Subject: Hydrologic Calibration and Validation Results for the Kinnickinnic River Model (Task 3)

1.0 EXECUTIVE SUMMARY

An important component of the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU) is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. The purpose of this memorandum is to describe the modeling process and provide the results of the final hydrologic and hydraulic calibration and validation of the Kinnickinnic River watershed model.

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for a variety of reasons, including that existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds. The Loading Simulation Program in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms but has the advantage of no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original Kinnickinnic River HSPF model has been migrated to LSPC for the 2020 Facilities Planning Project.

Configuration of the Kinnickinnic River LSPC model involved consideration of five major components: waterbody representation, watershed segmentation, meteorological data, land use representation, and point sources. The representation of the Kinnickinnic River and its tributaries in LSPC is based on the HSPF model provided by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) with several modifications (e.g., redirecting runoff from subbasins to different routing reaches and adding two new routing reaches). The model was configured to simulate the watershed as a series of 30 hydrologically connected subwatersheds.

The Kinnickinnic River model relies on weather data from two gages. Precipitation is based on the Milwaukee Metropolitan Sewerage District (MMSD) Rain Gage 1203 and General Mitchell International Airport (GMIA), based on the proximity of each gage to the various subwatersheds. Other climatologic data (e.g., temperature, cloud cover, wind speed) are from GMIA.

Land cover classifications from the SEWRPC 2000 land use codes were re-classified to develop the land use representation in the LSPC model. The final land use representation for the Kinnickinnic River LSPC model indicates that the two most common land covers are urban grasses on C soils (63 percent of the total watershed) and impervious cover associated with commercial land uses (18 percent).

There are a number of "point sources" in the Kinnickinnic River watershed, including sanitary sewer overflows (SSOs), combined sewer overflows (CSOs), and industrial facilities. Flows from these point sources were input directly into the LSPC model using the methodology outlined in the December 13, 2004 memorandum entitled *Point Source Loading Calculations for Purposes of Watercourse Modeling*.

The calibration results for the Kinnickinnic River model indicate good agreement between observed and simulated streamflows. Baseflows are well represented for each season for the entire calibration period. The timing of almost all storms is captured, as are the shapes of the hydrographs. Key parameters that were adjusted during the calibration process included those addressing infiltration, lower zone soil capacity, and snowmelt.

2.0 CONCLUSIONS

The following are the conclusions resulting from the hydrologic calibration and validation process for the Kinnickinnic River model:

- The setup of the final HSPF model has been completed.
- Conversion of the HSPF model to LSPC was successful and will result in improved efficiencies as the project progresses.
- The calibration results for both the Kinnickinnic River and Wilson Park Creek gages indicate good agreement between observed and simulated streamflows with almost all tolerance criteria being met.
- Deviations from criteria can be attributed to uncertainties associated with estimates of urban hydrologic features, primarily:
    - Industrial and other point dischargers
    - Delineation of Directly Connected Impervious Areas (DCIAs)
    - Storm water retention structures, particularly those in the General Mitchell International Airport

3.0 RECOMMENDATIONS

We recommend that the hydrologic calibration and validation of the Kinnickinnic River model be considered complete.

4.0 INTRODUCTION

The Milwaukee Metropolitan Sewerage District (MMSD) is in the midst of a long-range planning effort to identify improvements needed for its facilities to accommodate growth and protect water quality through the year 2020. This effort is known as the MMSD 2020 Facility Plan. A related planning effort is being conducted by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) to update the regional water quality management plan for the Kinnickinnic River, Menomonee River, Milwaukee River, Root River, and Oak Creek watersheds, the Milwaukee Harbor estuary, and the adjacent nearshore Lake Michigan area. This effort is known as the Regional Water Quality Management Plan Update (RWQMPU). The two planning efforts are being coordinated and implemented in parallel.

One important component of both the 2020 Facility Plan and the RWQMPU is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. Watershed models are being developed for the following five watersheds:

- Kinnickinnic River
- Menomonee River
- Milwaukee River
- Oak Creek
- Root River

The Kinnickinnic, Menomonee, and Milwaukee River models will then be linked to a model of the Lake Michigan estuary so that the benefits of upstream water quality improvements can be simulated by the Lake Michigan Harbor / Estuary Model.

The following seven tasks have been identified for performing the system modeling:

1) Establish the model structure, including the delineation of subwatersheds, connectivity, and cross sections, etc.
2) Develop the model data sets using physical measurements, maps, and other appropriate information
3) Perform hydrologic and hydraulic calibration and validation

4) Perform watercourse water quality calibration and validation
5) Perform harbor/estuary and lake water quality calibration
6) Perform production runs as required for project planning
7) Document results.

The purpose of this report is to document the hydrologic and hydraulic calibration and validation for the Kinnickinnic River watershed model (Task 3). The model being used is described in Section 5.0, Model Description. The configuration of the model, including waterbody representation, watershed segmentation, meteorological data, and land cover representation, is described in Section 6.0, Modeling Approach. The modeling process is described in Section 7.0, Calibration and Validation Process, and the calibration and validation results are presented in Section 8.0, Results of Hydrologic Calibration and Validation.

A separate memorandum documents the water quality calibration process and results (Task 4) and similar reports have been prepared for the Root River, Milwaukee River, Oak Creek, and Menomonee River watersheds.

5.0 MODEL DESCRIPTION

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. Many watershed models, including the one used for this project, are also capable of simulating in-stream processes using the land-based calculations as input. Once a model has been adequately set up and calibrated for a watershed it can be used to quantify the existing loading of pollutants from subwatersheds or from land use categories. The model can also be used to simulate the potential impacts of various management alternatives.

The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for the following reasons:

- Existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds
- HSPF applies to watersheds with rural, suburban, and urban land uses
- HSPF simulates the necessary constituents: Total Suspended Solids, Total Nitrogen, (Total Kjeldahl Nitrogen, Ammonia, Ammonium, Nitrate, and Nitrite), Total Phosphorus, Orthophosphate, Fecal Coliforms, Copper and Zinc (as conservative substances), Dissolved Oxygen, Biochemical Oxygen Demand, Total Organic Carbon, Temperature, Benthic Algae, and Chlorophyll-a.
- HSPF allows long-term continuous simulations to predict hydrologic variability
- HSPF provides adequate temporal resolution (i.e., hourly or daily) to facilitate a direct comparison to water quality standards
- HSPF simulates both surface runoff and groundwater flows

A brief description of the HSPF model is provided below.

5.1 Overview of HSPF

HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970's and is generally considered one of the most advanced hydrologic and watershed loading models available. The hydrologic portion of HSPF is based on the Stanford Watershed Model (Crawford and Linsley, 1966), which was one of the pioneering watershed models developed in the 1960's. The HSPF framework is developed in a modular fashion with many different components that can be assembled in different ways, depending on the objectives of the individual project. The model includes three major modules:

- PERLND for simulating watershed processes on pervious land areas
- IMPLND for simulating processes on impervious land areas
- RCHRES for simulating processes in streams and vertically mixed lakes.

All three of these modules include many submodules that calculate the various hydrologic and water quality processes in the watershed. Many options are available for both simplified and complex process formulations. Spatially, the watershed is divided into a series of subbasins representing the drainage areas that contribute to each of the stream reaches. These subbasins are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into the pervious (PERLND) and impervious (IMPLND) fractions. The stream network (RCHRES) links the surface runoff and groundwater flow contributions from each of the land segments and subbasins and routes them through the waterbodies using storage routing techniques. The stream/reservoir model includes precipitation and evaporation from the water surfaces, as well as flow contributions from the watershed, tributaries, and upstream stream reaches. Flow withdrawals can also be accommodated. The stream network is constructed to represent all of the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur.

Like the watershed components, several options are available for simulating water quality in the receiving waters. The simpler options consider transport through the waterways and represent all transformations and removal processes using simple first-order decay approaches. More advanced options for simulating nutrient cycling and biological processes are also available. The framework is flexible and allows different combinations of constituents to be modeled depending on data availability and the objectives of the study. A more detailed discussion of HSPF simulated processes and model parameters is presented in the Kinnickinnic River water quality report and is also available in the HSPF User's Manual (Bicknell et al. 1996).

5.2 Overview of Loading Simulation Program in C++

The Loading Simulation Program, in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms for simulating hydrology, sediment, and general water quality on land as well as in the water column. LSPC is currently maintained by the EPA Office of Research and Development in Athens, Georgia, and during the past several years it has been used to develop hundreds of water quality restoration plans across the country through the Clean Water Act Total Maximum Daily Load (TMDL) Program. A key advantage of LSPC is that it has no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original Kinnickinnic River HSPF model has been migrated to LSPC for the 2020 Facilities Planning Project. A memorandum dated October 18, 2004 (*Confirmation of the Underwood Creek LSPC Model using selected HSPF Modules)* presents the results of a benchmark testing methodology that was developed to compare the underlying computational algorithms of the LSPC model to known HSPF solutions for Underwood Creek. Near identical results were found between the two models.

6.0 MODELING APPROACH

The Kinnickinnic River watershed is one of three watersheds that drain to Lake Michigan through the Milwaukee River Estuary, with the Milwaukee and Menomonee River watersheds being the other two. The majority of the Kinnickinnic River watershed, approximately 75 percent of the 24.78 square mile drainage area, lies within the City of Milwaukee. The remainder of the watershed is contained within the Cities of Cudahy, Greenfield, West Allis, and St. Francis, and the Village of West Milwaukee. The watershed is mostly urbanized with the only “undeveloped” land contained within limited agricultural areas, parkland, cemeteries, and the stream corridor.

Configuration of the Kinnickinnic River LSPC model involved consideration of five major components: waterbody representation, watershed segmentation, meteorological data, land use representation, and point sources. These components provide the basis for the model’s ability to estimate flow and water quality and are described in greater detail below.

6.1 Waterbody Representation

The Kinnickinnic River watershed is shown in Figure 1. The watershed contains six perennial streams that have a total length of approximately 17.5 miles. These watercourses include the Kinnickinnic River (8.1 miles), Lyons Park Creek (1.3 miles), Wilson Park Creek (5.3 miles), South 43rd Street Ditch (1.1 miles), Villa Mann Creek (0.8 miles) and Villa Mann Creek Tributary (0.9 miles). There is an additional 0.8 miles of intermittent stream along the Edgerton Channel portion of Wilson Park Creek. Also, there are about 15.6 miles of physically altered channel along the six perennial streams (plus 0.8 miles along Edgerton Channel).

Modeling an entire watershed requires routing flow and pollutants from upstream portions of the watershed to the watershed outlet through the stream network. In LSPC, the stream network is a tabular representation of the actual stream system. Attribute data pair individual stream segments with a corresponding delineated subbasin. Data associated with individual reaches identify the location of the particular reach within the overall stream network, defining the connectivity of the subwatersheds.

The representation of the Kinnickinnic River and its tributaries in LSPC is based on the HSPF model provided by SEWRPC as defined in the SEWRPC/ MMSD MCAMLIS Floodplain Mapping Project. Changes to the original SEWRPC HSPF model are documented in a memorandum dated November 5, 2004 (*Draft Task 1 Deliverables Memorandum and Associated Appendices*). Changes consisted mainly of redirecting runoff from subbasins to different routing reaches. Two new routing reaches were also added for the Edgerton Channel portion of Wilson Park Creek (City of Cudahy). A schematic representation of the final Kinnickinnic River LSPC model is presented in Figure 2. The origin of the HSPF watershed / watercourse model for the Kinnickinnic River is described in detail in the April 11, 2003 Technical Memorandum, *Characterize Existing Watershed / Watercourse Models.*

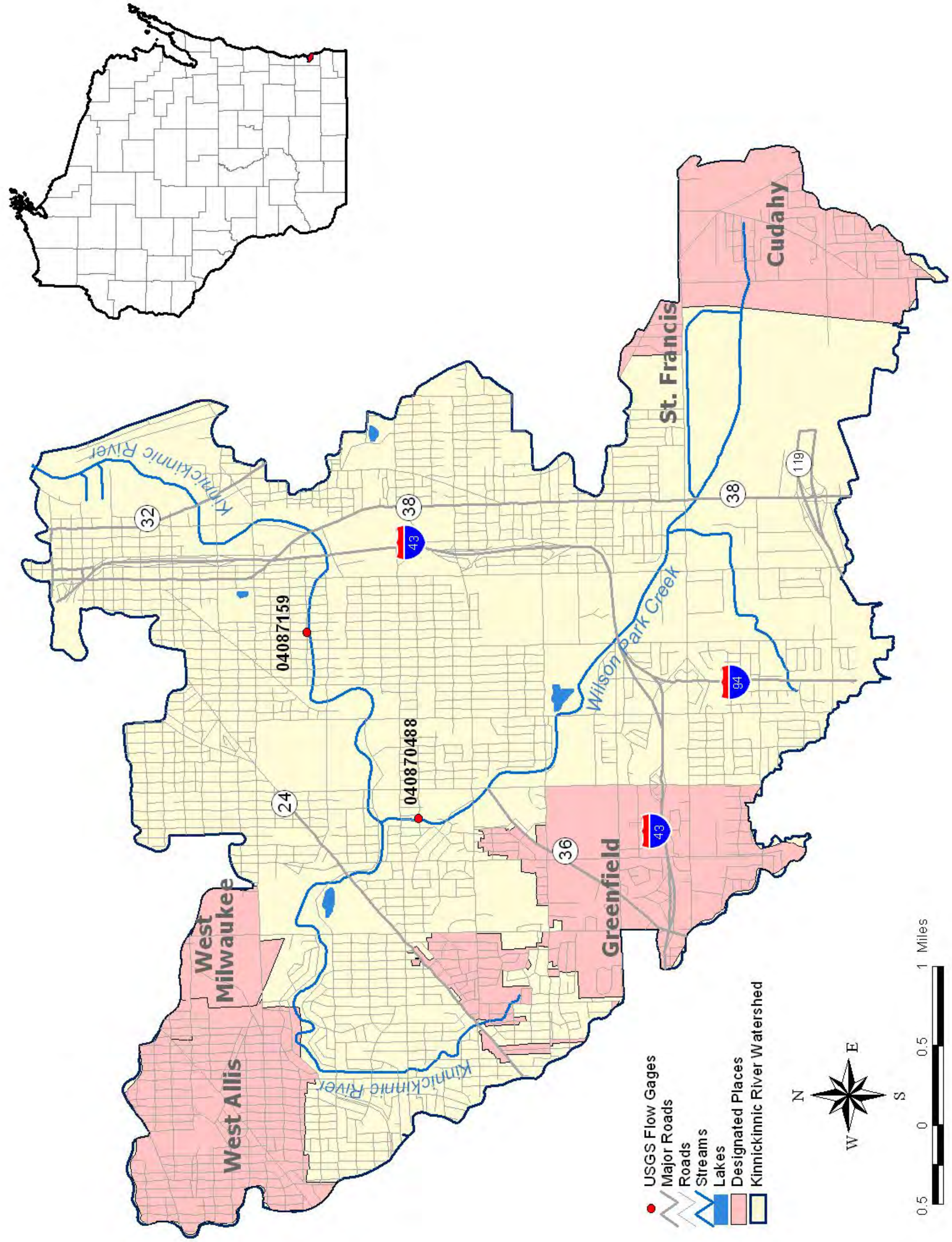


Figure 1. Location of the Kinnickinnic River watershed.

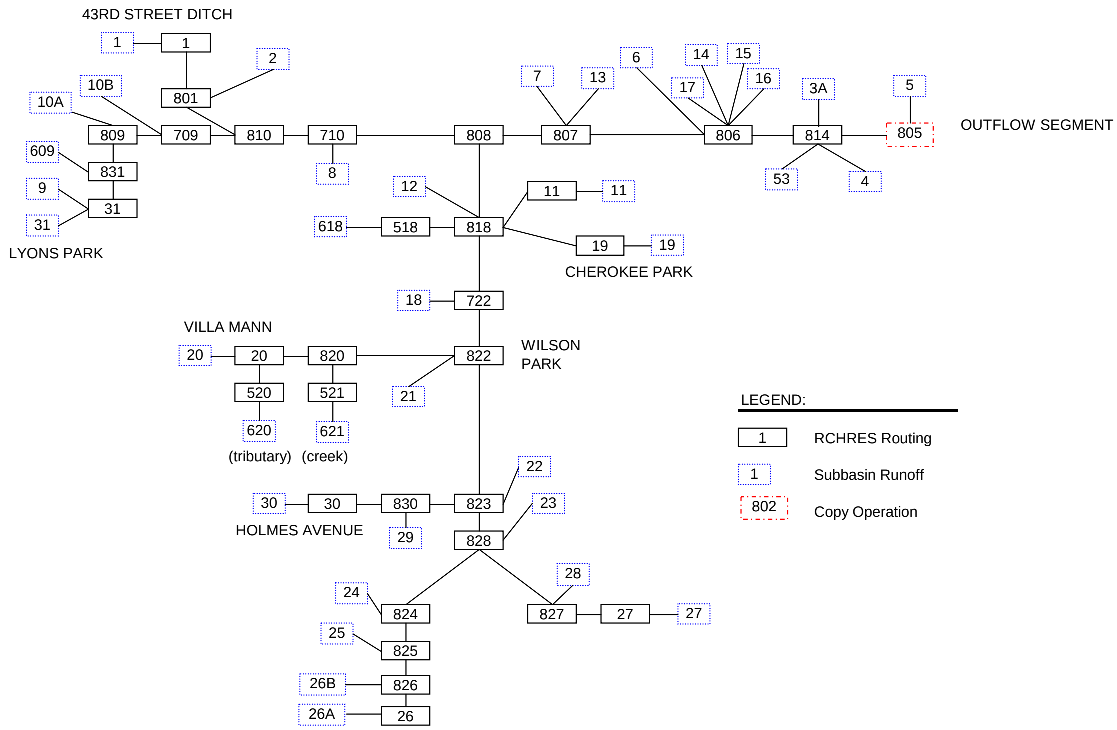


Figure 2. Schematic representation of the Kinnickinnic River LSPC model.

6.2 Watershed Segmentation

LSPC was configured for the Kinnickinic River to simulate the watershed as a series of 30 hydrologically connected subwatersheds. The delineation of the subwatersheds was based partially on topography but also took into consideration human-influenced drainage patterns. The spatial subdivision of the watershed allows for a more refined representation of pollutant sources and a more realistic description of hydrologic factors. The subwatersheds and primary streams in the Kinnickinic River watershed are shown in Figure 3. It should be noted that a portion of the watershed is in a MMSD combined sewer service area (CSSA). Because hydrology in this portion of the watershed is being separately modeled using the MOUSE model, it is not explicitly included in the LSPC model. Instead, inflows to the Kinnickinnic River in the CSSA are input directly to the LSPC model based on either observed CSO and SSO data (for model calibration) or on the results of the MOUSE modeling (for production runs).

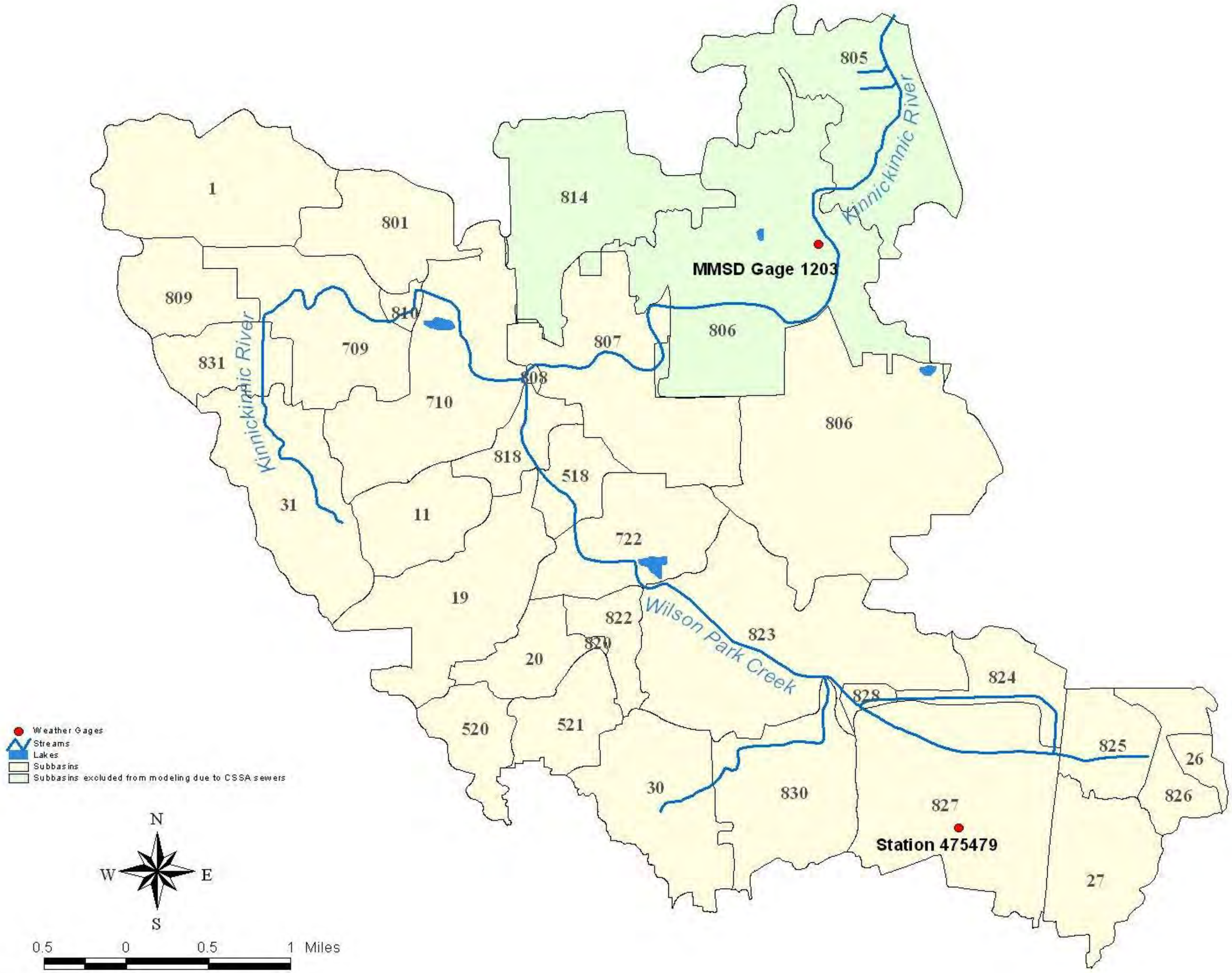


Figure 3. Kinnickinnic River LSPC modeling subwatersheds and location of weather stations.

6.3 Weather Data

Hydrologic processes are time varying and depend on changes in environmental conditions including precipitation, temperature, and wind speed. As a result, meteorological data are a critical component of he watershed model. Appropriate representation of precipitation, wind movement, solar radiation, potential evapotranspiration, cloud cover, temperature, and dew point are required to develop a valid model. These data provide necessary input to model algorithms for hydrologic and water quality representation.

The Kinnickinnic River model relies on weather data from two stations. A single rain gage was assigned to each of the original HSPF subwatersheds in consultation with SEWRPC based on the proximity of gages with acceptable data quality. Precipitation for the downstream part of the Kinnickinnic watershed is based on MMSD Rain Gage 1203, which is located in the northern portion of the watershed (Figure 3) while precipitation for the Wilson Park Creek portion of the watershed uses precipitation from GMIA (National Weather Service (NWS) 475479), located in the southern part of the watershed. Data for the following additional meteorological parameters use observations from GMIA:

- Temperature
- Cloud cover
- Wind movement
- Solar radiation
- Potential evapotranspiration
- Dew point

Precipitation, temperature, cloud cover, wind speed, and dew point are gage monitored, while potential evapotranspiration (PEVT) and solar radiation were computed. Model performance is particularly sensitive to PEVT, as this controls the fraction of precipitation that is evaporated back to the atmosphere. A variety of methods are available for estimation of PEVT, each yielding slightly different results. SEWRPC provided a time series of PEVT calculated for Mitchell Field using the Penman method, which calculates PEVT by first estimating evaporation from a standard Class A pan, then converts it to a PEVT estimate by application of a monthly coefficient.

6.4 Land Use Representation

LSPC requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the basin, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices.

Land cover classifications from the SEWRPC 2000 land use codes were used to develop the land cover representation in the LSPC model. Included below is a table that defines specific terminology associated with the processes of deriving land cover classifications from SEWRPC land use codes.

Table 1. Terminology associated with the process of deriving land cover classifications from SEWRPC land use codes.

Land Use Terminology	Definition
Land Use Code	A SEWRPC three-digit code that describes the land use for a specified area.
Land Use Group	A simplification of the land use codes into groups of several land use codes which share hydrologic and water quality characteristics.
Land Use Category	SEWRPC term that corresponds to the definition of land use group, with slight variation in name and number.
Land Cover Classification	A classification of soil composition and natural or manmade land practices which comprises a portion or all of a land use.

The original HSPF models were developed during the MMSD Phase 1 Watercourse Management Plans (WMPs) as documented in the April 11, 2003 Technical Memorandum, *Characterize Existing Watershed / Watercourse Models.*

Six pervious land covers and a single impervious land cover were used to model hydrology and surface runoff in the Phase 1 WMP models. The MMSD Phase 1 WMP model land covers are listed below:

- Impervious
- Lawn / B Soil
- Lawn / C Soil
- Forest
- Agriculture / B Soil
- Agriculture / C Soil
- Wetland

To develop the distribution of these land covers throughout a single subbasin, the following procedures were completed in the Phase 1 WMP Models:

1) The 1990 SEWRPC Land Use Codes were categorized into 20 MMSD Phase 1 WMP land use groups.
2) The 20 MMSD Phase 1 WMP land use groups were reclassified into the seven selected HSPF land covers.
3) The final HSPF land cover input for modeling is an aggregate summation of the reclassified MMSD Phase 1 WMP landuse areas.

This procedure was revised for an expanded number of land use groups (25) and land cover classifications (17 – 6 impervious and 11 pervious) and documented in the October 27, 2003 Technical Memorandum *Definition of HSPF Land Cover Classifications.* Figure 4 displays the distribution of these 25 land use groups within the basin.

The model algorithms require that each land use group be represented as separate pervious and impervious land units. NRCS hydrologic soil groups further categorize pervious land uses. The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting. Typically, clay soils that are poorly drained have lower infiltration rates, while well-drained sandy soils have the greatest infiltration rates. NRCS (2001) has defined four hydrologic groups for soils as listed in Table 2. The final land use representation for the Kinnickinnic River LSPC model is summarized in Table 3 and indicates that the two most common land covers are grasses on C soils (63 percent) and commercial impervious (18 percent).

Table 2. NRCS Hydrologic Soil Groups

Hydrologic Soil Group	Description
A	Soils with high infiltrations rates. Usually deep, well drained sands or gravels. Little runoff.
B	Soils with moderate infiltration rates. Usually moderately deep, moderately well drained soils.
C	Soils with slow infiltration rates. Soils with finer textures and slow water movement.
D	Soils with very slow infiltration rates. Soils with high clay content and poor drainage. High amounts of runoff.

Table 3. Land cover in the Kinnickinic River watershed (does not include CSSA).

Category	Land Use	Area		Percent of Watershed
		Acres	Square Miles	
IMPERVIOUS	COMMERCIAL	2342.8	3.66	18.30
	GOVT_INSTIT	94.7	0.15	0.74
	INDUSTRIAL	449.5	0.70	3.51
	RESIDENTIAL	752.2	1.18	5.87
	TRANS_FREE	269.6	0.42	2.11
	ULTRA_LOW	82.3	0.13	0.64
PERVIOUS	CROP_B	57.4	0.09	0.45
	CROP_C	10.3	0.02	0.08
	CROP_D	0.0	0.00	0.00
	FOREST	291.9	0.46	2.28
	GRASS_B	202.0	0.32	1.58
	GRASS_C	8045.5	12.57	62.83
	GRASS_D	4.7	0.01	0.04
	PASTURE_B	2.5	0.00	0.02
	PASTURE_C	0.0	0.00	0.00
	PASTURE_D	0.0	0.00	0.00
	WETLAND	199.1	0.31	1.56
	Total	12804.3	20.01	100

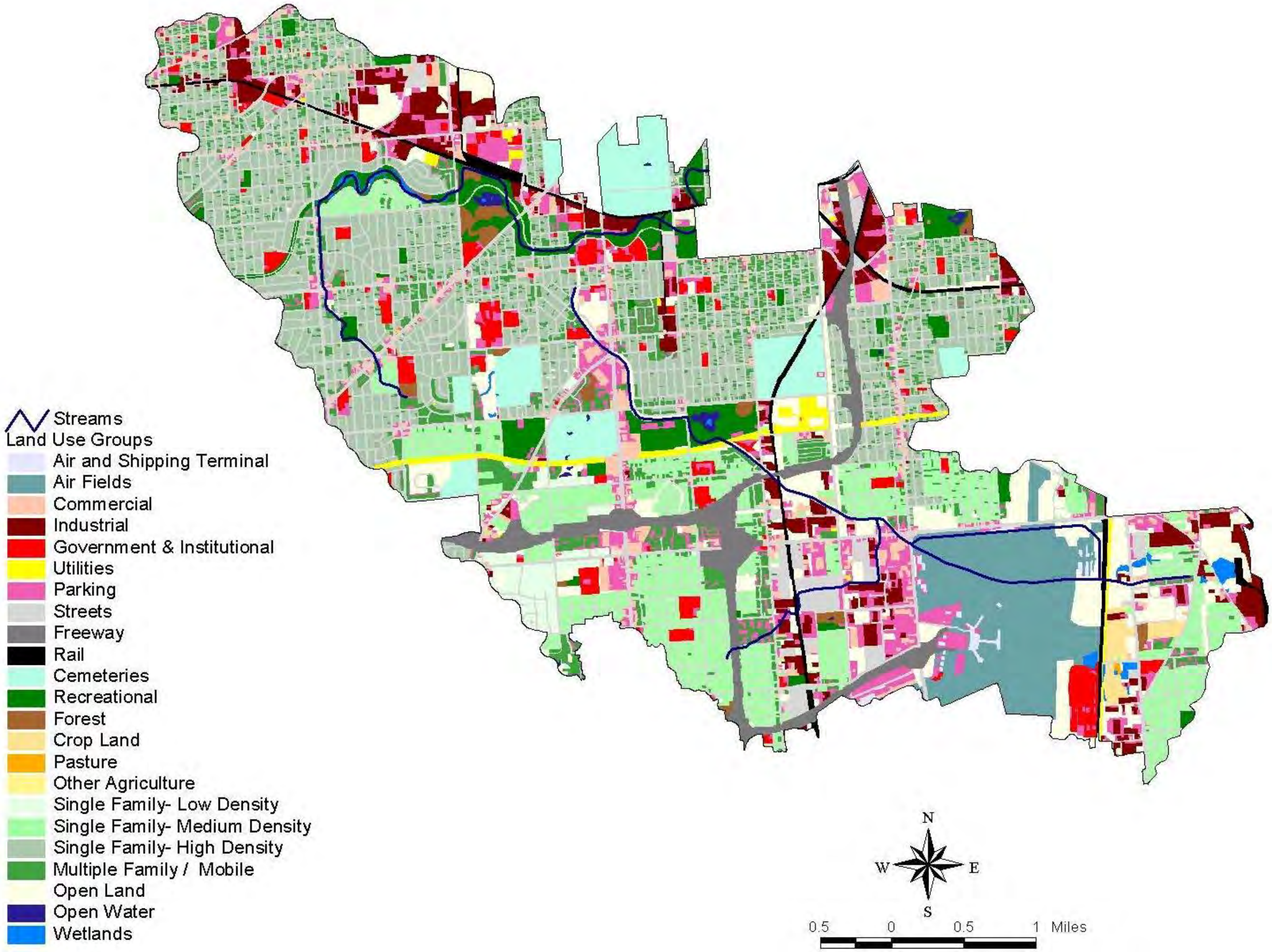


Figure 4. Modeling land use in the Kinnickinnic River watershed.

6.5 Point Sources

There are a number of “point sources” in the Kinnickinnic River watershed. These consist of sanitary sewer overflows (SSOs), combined sewer overflows (CSOs), and discharges from seventeen industrial facilities. Flows from these point sources were input directly into the LSPC model using methodology outlined in the December 13, 2004 memorandum entitled *Point Source Loading Calculations for Purposes of Watercourse Modeling*.

During dry weather, a significant portion of the total flow in the Kinnickinnic River may derive from point source discharges; therefore, characterization of these discharges is important to the representation of the flow in this system. Flows from the two largest dischargers (General Electric Medical Systems Group and Ladish Company) were therefore obtained and input on a monthly basis, rather than using long-term average flows.

As noted in Section 6.4, the portion of the Kinnickinnic River watershed located in the MMSD combined sewer service area (CSSA) was not modeled in LSPC. Flows from this area were instead based on the reported point source data.

7.0 CALIBRATION AND VALIDATION PROCESS

The model calibration and validation processes are described in this section. Background information on the locations of available flow data and the time periods of calibration/validation are first presented, followed by a description of how key parameters were modified.

7.1 Background

Hydrologic calibration of the Kinnickinnic River model was performed after configuring the LSPC model. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. For LSPC, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. It is required for parameters that cannot be deterministically and uniquely evaluated from topographic, climatic, physical, and chemical characteristics of the watershed and compounds of interest. Fortunately, the majority of LSPC parameters do not fall in this category. Calibration is based on several years of simulation to allow parameter evaluation under a variety of climatic conditions. The calibration procedure results in parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period.

Calibration included the comparison of monthly, seasonal, and annual values, and individual storm events. All of these comparisons must be evaluated for a proper calibration of hydrologic parameters. In addition, simulated and observed stream flow values were analyzed on a frequency basis and their resulting cumulative distributions (e.g., flow duration curves) compared to assess the model behavior and agreement over the full range of observations.

Model validation tested the performance of the calibrated model using a different time period, without further parameter adjustment. If the model cannot properly simulate conditions for the independent data set, the calibration is not acceptable and requires additional work until validation is achieved. As described in the January 14, 2004 *Watershed and Receiving Water Quality Model Calibration and Validation Data and Procedures* memorandum, the calibration time period was January 1, 1995 through December 31, 1998. The validation time period was January 1, 1999 through December 31, 2002. To permit model spin up time and minimize numerical errors inherent in modeling, the model was run for the time period January 1, 1993 to December 31, 1998 for calibration purposes.

The model calibration and validation was performed using the flow record from the USGS gage on the Kinnickinnic River at S. 11th Street (USGS gage 04087159). Results of the model were also evaluated using the flow record from the USGS gage on Wilson Park Creek (USGS gage 040871488). Figure 1 shows the location of both of these gages.

7.2 Initial Calibration

The initial hydrologic calibration involved a comparison of observed data from the in-stream USGS flow gaging station to modeled in-stream flow and an adjustment of key hydrologic parameters. Various modeling parameters were varied within physically realistic bounds and in accordance to observed temporal trends and land use classifications. An attempt was made to remain within the guidelines for parameter values set out in BASINS Technical Note 6 (USEPA, 2000). Hydraulic calibration was undertaken simultaneously across the Menomonee River, Oak Creek, and Kinnickinnic River watersheds with the intention of developing a unified parameter set in which most variations between watersheds are explained by documented differences in land cover and physical parameters such as soil characteristics. This cross-sectional calibration approach helps ensure a robust parameter set that is not unduly biased by anomalies in individual gage records.

Graphical results of model performance and error statistics were evaluated following each model simulation run. Model parameters were adjusted following each iteration to improve model performance. The parameters that were adjusted include those that account for the partitioning of surface versus subsurface flow, infiltration rate, surface and subsurface storage, evapotranspiration, and surface runoff.

The model performance is most sensitive to the specification of the water-holding capacity of the soil profile (expressed through LZSN, the nominal lower-zone storage) and the infiltration rate index (INFILT), which together control the partitioning of water between surface and subsurface flow. LZSN is an index of nominal storage of water in the soil zone subject to evapotranspiration (root depth plus capillary fringe), while LZS represents the actual water storage in this zone. LZSN is often characterized as the median of field capacity storage in this zone (i.e., available water capacity times rooting depth with capillary fringe). Functionally, however, the meaning of LZS and LZSN may differ somewhat from this ideal interpretation. LZS does represent the depth of water that is available for transpiration from the soil; however, this value may exceed LZSN by a significant amount. More important is the ratio LZRAT (LZS/LZSN). This ratio (in inverse form) first determines the variation of actual infiltration rate relative to the nominal value, INFILT. LZRAT also determines the rate at which water percolates from the lower soil zone to groundwater. LZSN thus varies with precipitation pattern as well as vegetation type. In addition, it is difficult to relate LZSN to a single vegetation type, because a dominant vegetation (e.g., grass) with a low rooting depth may also contain other plants (e.g., trees) with a much greater rooting depth, which increases the amount of soil moisture that is available for ET. As a result, while initial values of LZSN can be estimated from soils and vegetation data, final values must be determined through calibration.

Viessman et al. (1989) suggest as initial estimates for LZSN a value between one-quarter and one-eighth of the annual rainfall plus four inches. USEPA (2000) show typical values for LZSN ranging from 5 inches to 14 inches in typical applications. Values found through calibration for the Kinnickinnic watershed are well within this range. A value of 9 inches for LZSN provided reasonable results in initial calibration of the Kinnickinnic.

INFILT in HSPF is an *index* of infiltration rate and is not directly interpretable from measured field infiltration rates. BASINS Technical Note 6 recommends values in the range of 0.1-0.4 for B soils, 0.05- 0.1 for C soils, and 0.01-0.05 in/hr for D soils. Values were re-optimized by starting from the center of the recommended ranges and modifying the value for each soil class proportionately – yielding final values of 0.365, 0.105-0.125, and 0.055-0.075 for B, C, and D soils, respectively. For C and D soils, the higher values were applied to tilled agriculture, while the lower values were applied to grass and pasture.

Key parameters for the subsurface flow response include the ground water recession coefficient (AGWRC), and the interflow inflow (INTFW and IRC). AGWRC was set by optimizing model performance for baseflow recession, with relative variation among land uses based on past experience, resulting in initial values from 0.921-0.970. Interflow inflow was initially set in the range of 1-3.

Monthly variability in hydrologic response was specified by setting monthly values for interflow inflow, the interflow recession coefficient, the upper zone nominal soil storage, and the lower zone ET parameter. In each case, the values specified are consistent with recommendations in BASINS Technical Note 6, as well as experience in calibrating multiple HSPF models for the Minnesota River basin (Tetra Tech, 2002).

For the winter simulation, the model is very sensitive to parameters that control snow accumulation and snowmelt. Considerable uncertainty is present in hydrologic models when temperatures are near the transition point between liquid and frozen precipitation, and prediction of rain-on-snow melting events can be particularly difficult. Key calibration parameters for the winter snow simulation were revised from defaults during optimization and included the snow catch factor (CCFACT, ratio that accounts for undercatch of snow in standard precipitation gages), the field adjustment parameter for heat accumulation in the snow pack (CCFACT), the maximum rate of snow melt by ground heating (MGMELT), and the depth of snow at which all land area is considered to be covered (COVIND, set to a higher value for impervious lands to account for snow removal/consolidation).

7.3 Model Recalibration

To recalibrate the model all Ftables, stream reach characteristics, and land use assignments were carefully reconciled with the latest information from SEWRPC. Calibration improvements were then sought and achieved, based largely on experience with recalibration of the Underwood Creek portion of the Menomonee River watershed. Specifically, most of the parameters for urban grass were made consistent with the same land use in Underwood Creek, with a few exceptions. The following changes were made consistent with the Underwood Creek/Menomonee River recalibration:

- The groundwater recession coefficient for urban grass (AGWRC) was increased.
- LZSN for grass was reduced from 9 to 8 inches, as soil compaction is likely to reduce soil ET. (Note, while urban grasses typically have rather small rooting depths, the “grass” landuse class also typically includes shrubs and trees with deeper roots.)
- Interflow inflow (INTFW) for grass was reduced to 0.5, again reflecting the likely role of soil compaction in urban areas.
- KVARY (the parameter that controls the nonlinear shape of the recession) on grass was reduced to 0.
- Losses to deep groundwater from pervious lands other than wetlands were increased.
- Basetp for grass was increased to 0.02 and agwetp decreased to 0.

The following changes needed for Underwood Creek were *not* implemented in the Kinnickinnic River model:

- Snow catch factors were not reduced, as this degraded the general hydrologic fit.
- Surface retention factors for impervious land were not increased.

In addition, it was found that the calibration for the Kinnickinnic River could be significantly improved by reducing the infiltration rates for urban grass slightly below the values appropriate for the Menomonee River model. Specifically, the infiltration rate for grass on B soils was reduced from 0.365 to 0.330 and the infiltration rate for grass on C soils was reduced from 0.125 to 0.090 in/hr.

8.0 RESULTS OF HYDROLOGIC CALIBRATION AND VALIDATION

The model calibration results are presented in this section both graphically and statistically. Graphical comparisons are extremely useful for judging the results of model calibration because time-variable plots of observed versus modeled flow provide insight into the model’s representation of storm hydrographs, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons.

Graphical comparisons consist of time series plots of observed and simulated values for flows, observed versus simulated scatter plots with a 45_o linear regression line displayed, and cumulative frequency distributions (flow duration curves). Statistical comparisons focus on the relative error method. A small relative error indicates a better goodness of fit for calibration. Secondly, results from correlation tests (e.g. linear correlation coefficient, coefficient of model-fit efficiency, etc.) are also presented.

8.1 Tolerances

Model tolerance values for this project have been identified and are described in the January 14, 2004 *Watershed and Receiving Water Quality Model Calibration and Validation Data and Procedures* memorandum and in the December 18, 2002, *MMSD Comprehensive Modeling and Real Time Control Strategies* Technical Memorandum 2.4. Hydrologic parameters to be calibrated include annual flow volumes, low flow volumes, storm flow volumes, and seasonal flow volumes. The following tolerances (i.e., accepted level of error between modeled and observed flows) are used:

Total runoff volume: ± 10 percent
High flow volumes: ± 15 percent
Low flow volumes: ± 10 percent
Seasonal flow volumes: ± 20 percent
Error in storm volumes: ± 20 percent[1]

A comparison of simulated and observed storm hydrographs for selected storm events is addressed in a separate memorandum.

[1] A comparison of simulated and observed storm hydrographs for selected storm events is addressed in a separate memorandum.

The same tolerances are used for model validation. Error statistics are calculated for each month and year of the calibration time period; however, a calibration is deemed appropriate when the tolerances for the entire calibration period have been met. The same applies for the validation period.

8.2 Re-Calibration and Validation Results

The calibration and validation results for the Kinnickinnic River at USGS gage 04087159 are presented below in Figure 5 through Figure 24 and in Table 4 through Table 7. The changes described in Section 7.2 result in an improved fit compared to the initial calibration. The lowest 10 percent flows continue to be underpredicted in drier years – perhaps because the addition of water through lawn irrigation is not addressed in the model.

These results indicate good agreement between observed and simulated streamflows. Baseflows are well represented for each season for the entire calibration period. The timing of almost all storms is captured, as are the shapes of the hydrographs. The timing and magnitude of most snowmelt events appears to be well simulated, although a few are shifted early or late by a few days. Most large storms are well simulated. The composite graphs shown in Figure 13 and Figure 23 indicate the model simulates seasonal patterns effectively. The largest error is a slight overprediction of flows during June. The observed and simulated cumulative flow duration curves are aligned well with one another, with the model slightly overpredicting some moderate-to-high flows and slightly underpredicting the lowest flows.

The quality of hydrologic model fit for individual daily observations is summarized by the Nash-Sutcliffe coefficient of model fit efficiency (E). This parameter ranges from minus infinity to 1, with higher values indicating better fit, and is formed as the ratio of the mean square error to the variance in the observed data, subtracted from unity. A value of 0 implies that the observed mean is as good a predictor as the model. Values close to 1 are thus desirable. It should be recalled, however, that the Nash-Sutcliffe coefficient is based on matched daily records, and does not account for phase errors. It is also subject to leverage by outliers. Thus, if a large flow is estimated with the right magnitude, but off by one day, this can substantially degrade the Nash-Sutcliffe coefficient, even though annual sums and flow duration percentiles are unaffected.

The Nash-Sutcliffe coefficient was not used in the model calibration process. Therefore, it is appropriate to use it as post-validation model evaluation tool applied over the entire calibration and validation period of 1995-2002. Results for the Kinnickinnic River gages are shown in Table 10 and indicate acceptable results (E = 0.71) for both gages.

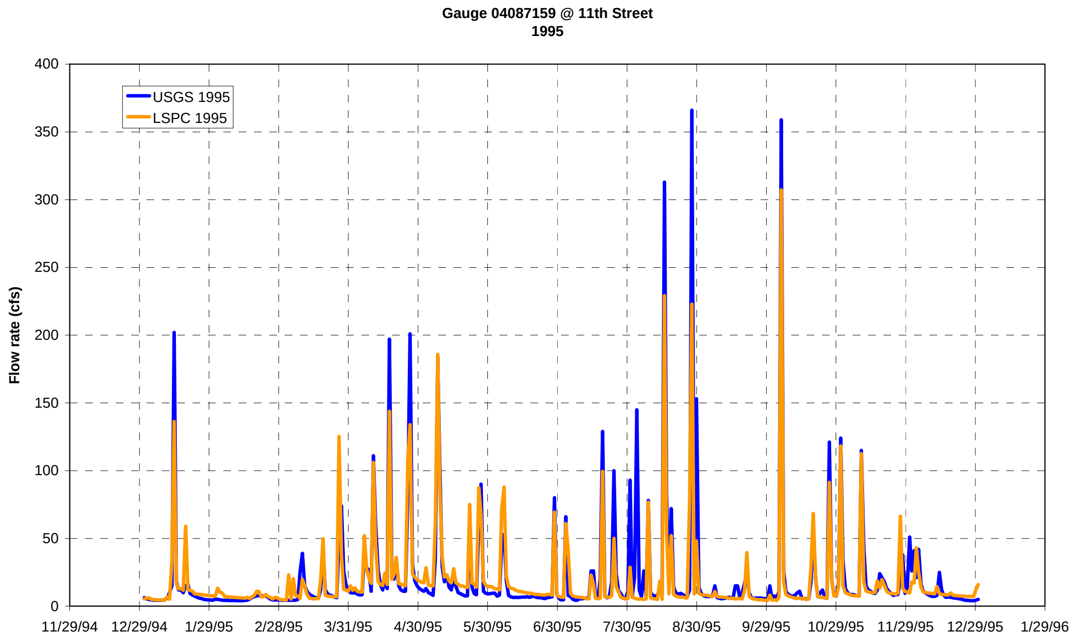


Figure 5. Time series hydrologic calibration results (daily mean) for the Kinnickinnic River at USGS gage 04087159 (1995).

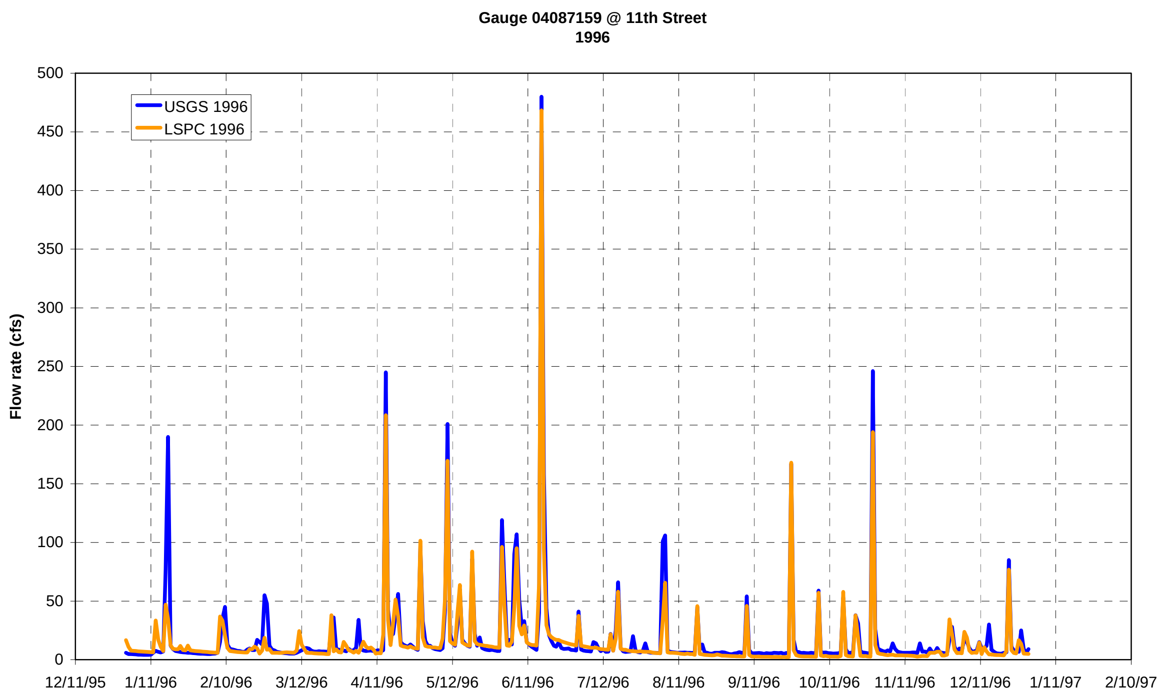


Figure 6. Time series hydrologic calibration results (daily mean) for the Kinnickinnic River at USGS gage 04087159 (1996).

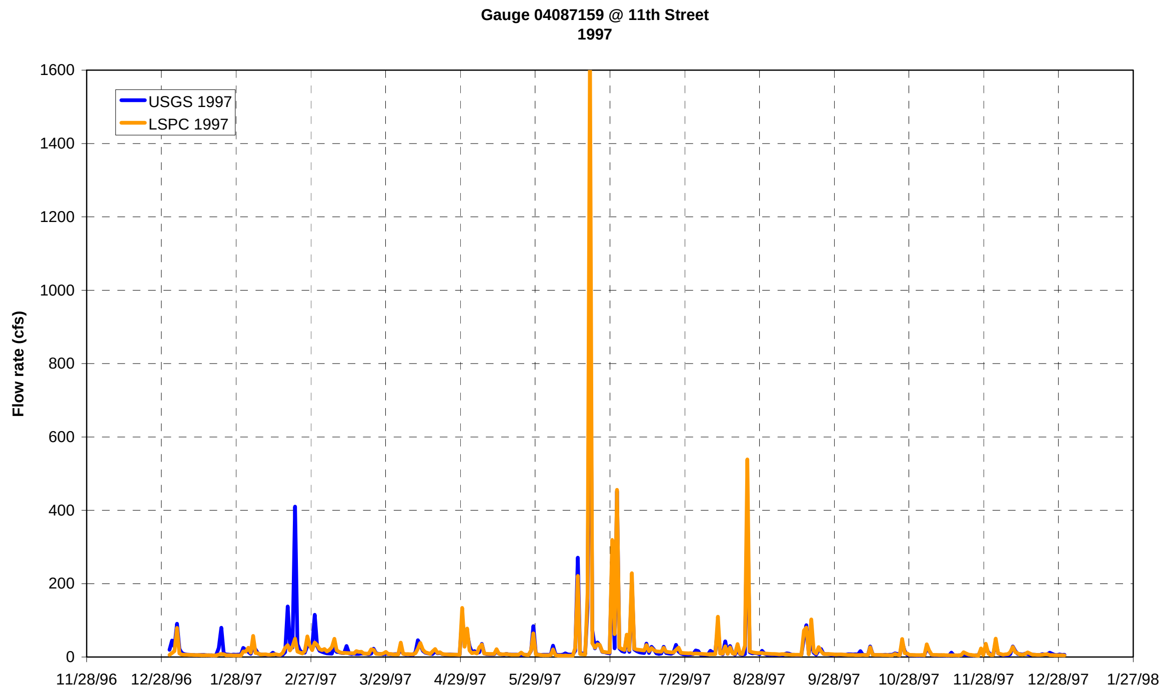


Figure 7. Time series hydrologic calibration results (daily mean) for the Kinnickinnic River at USGS gage 04087159 (1997).

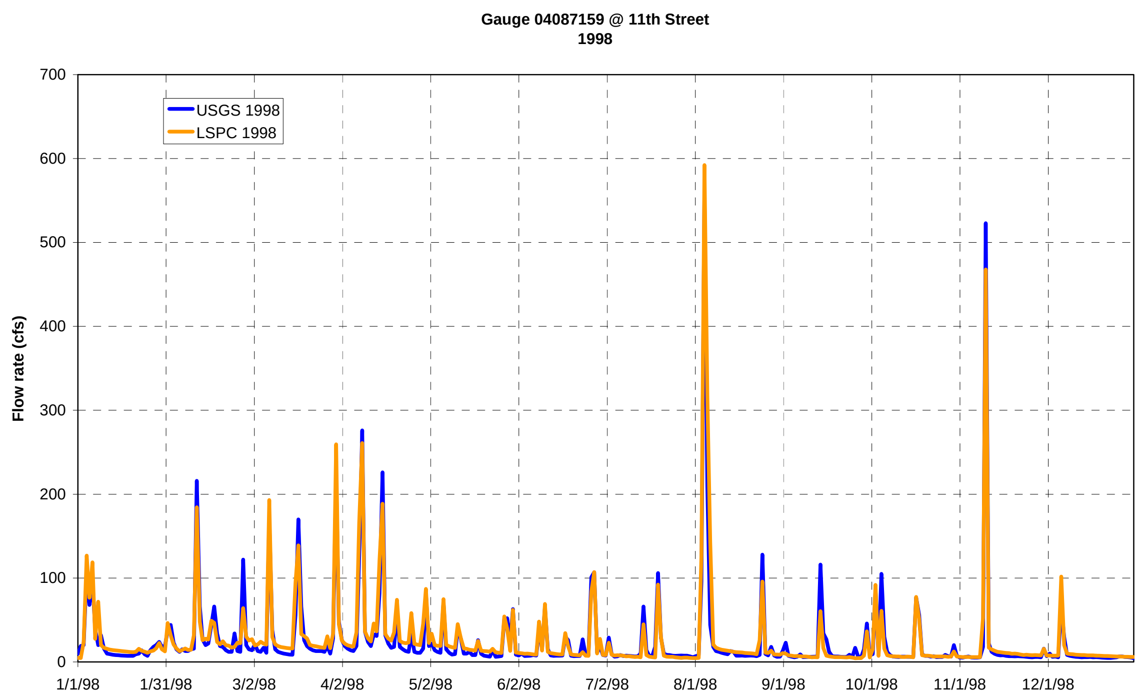


Figure 8. Time series hydrologic calibration results (daily mean) for the Kinnickinnic River at USGS gage 04087159 (1998).

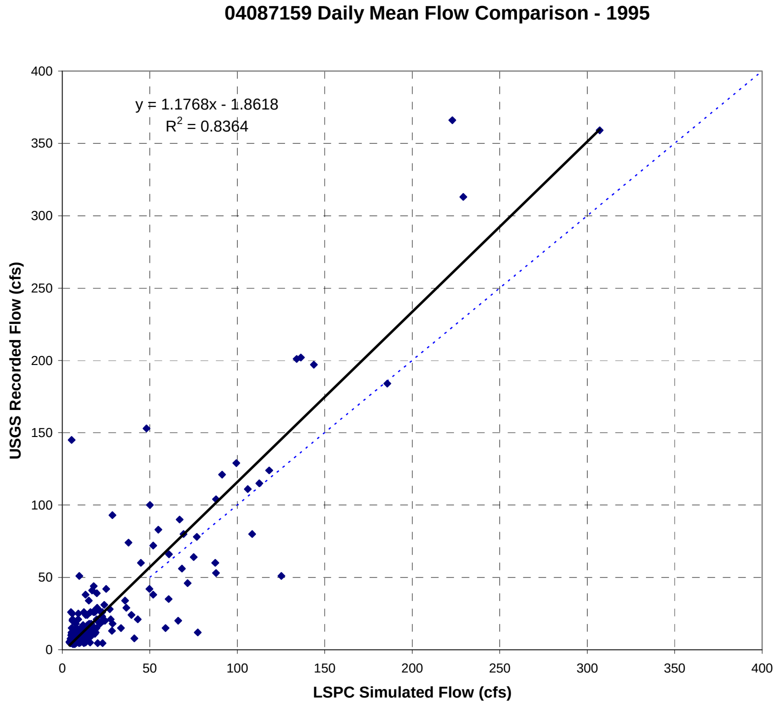


Figure 9. Observed versus simulated scatter plot with a linear regression line for the Kinnickinnic River at USGS gage 04087159 (1995).

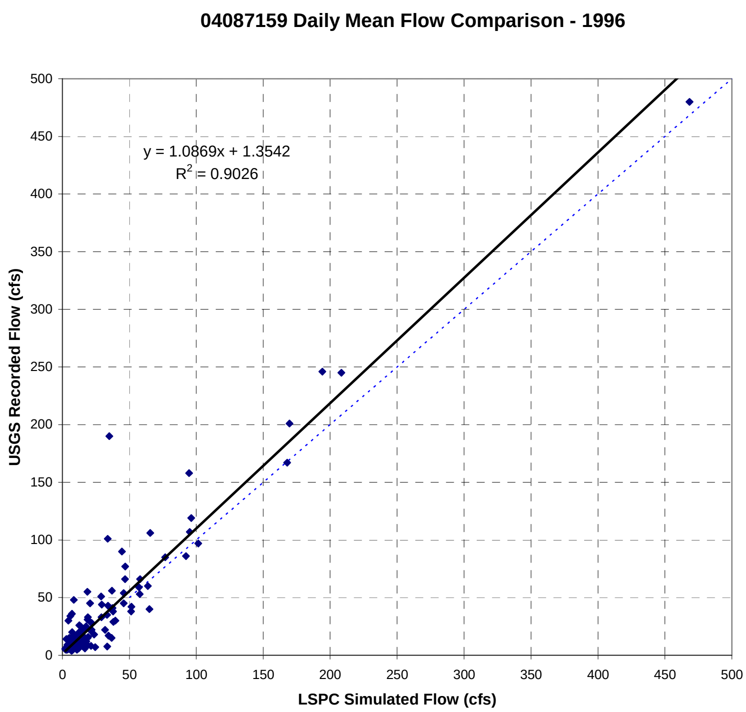


Figure 10. Observed versus simulated scatter plot with a linear regression line for the Kinnickinnic River at USGS gage 04087159 (1996).

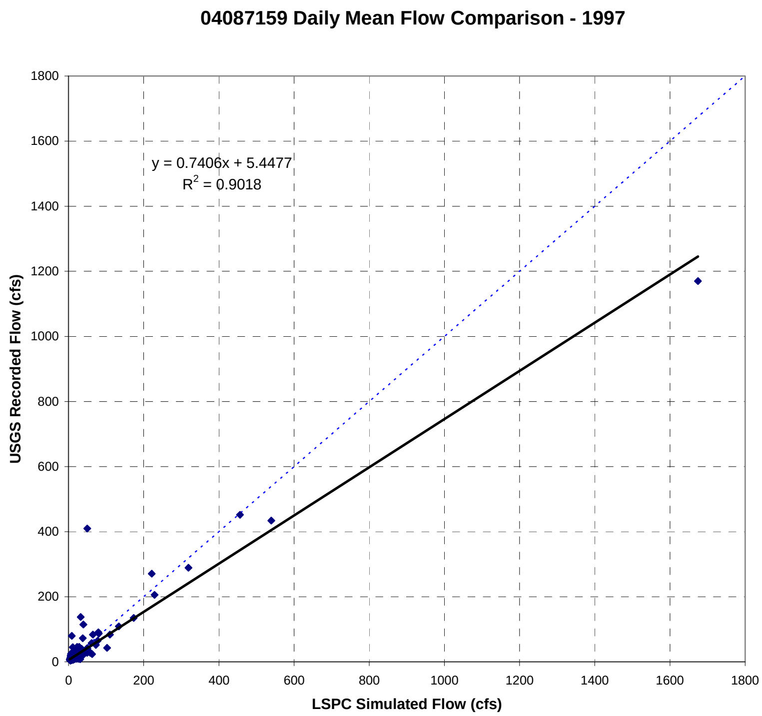


Figure 11. Observed versus simulated scatter plot with a linear regression line for the Kinnickinnic River at USGS gage 04087159 (1997).

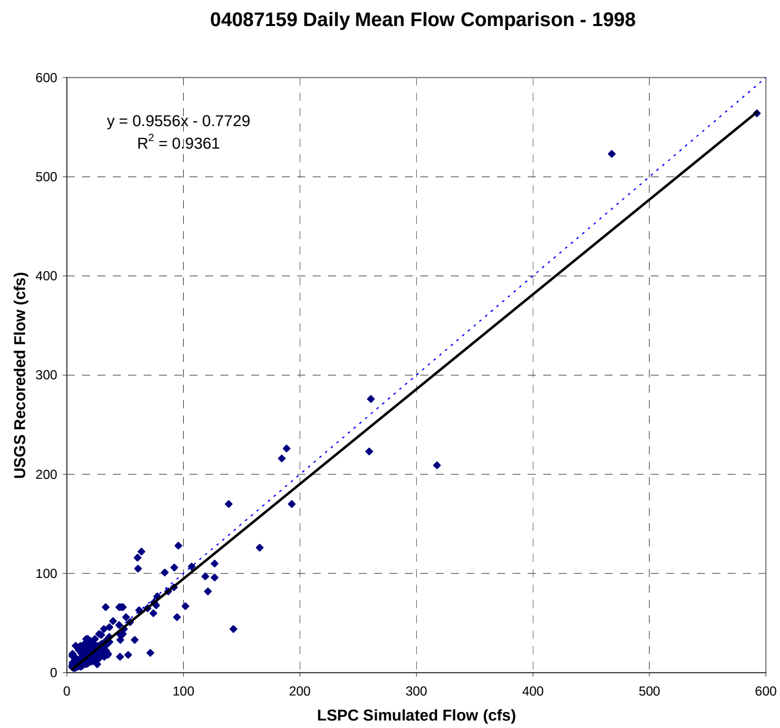


Figure 12. Observed versus simulated scatter plot with a linear regression line for the Kinnickinnic River at USGS gage 04087159 (1998).

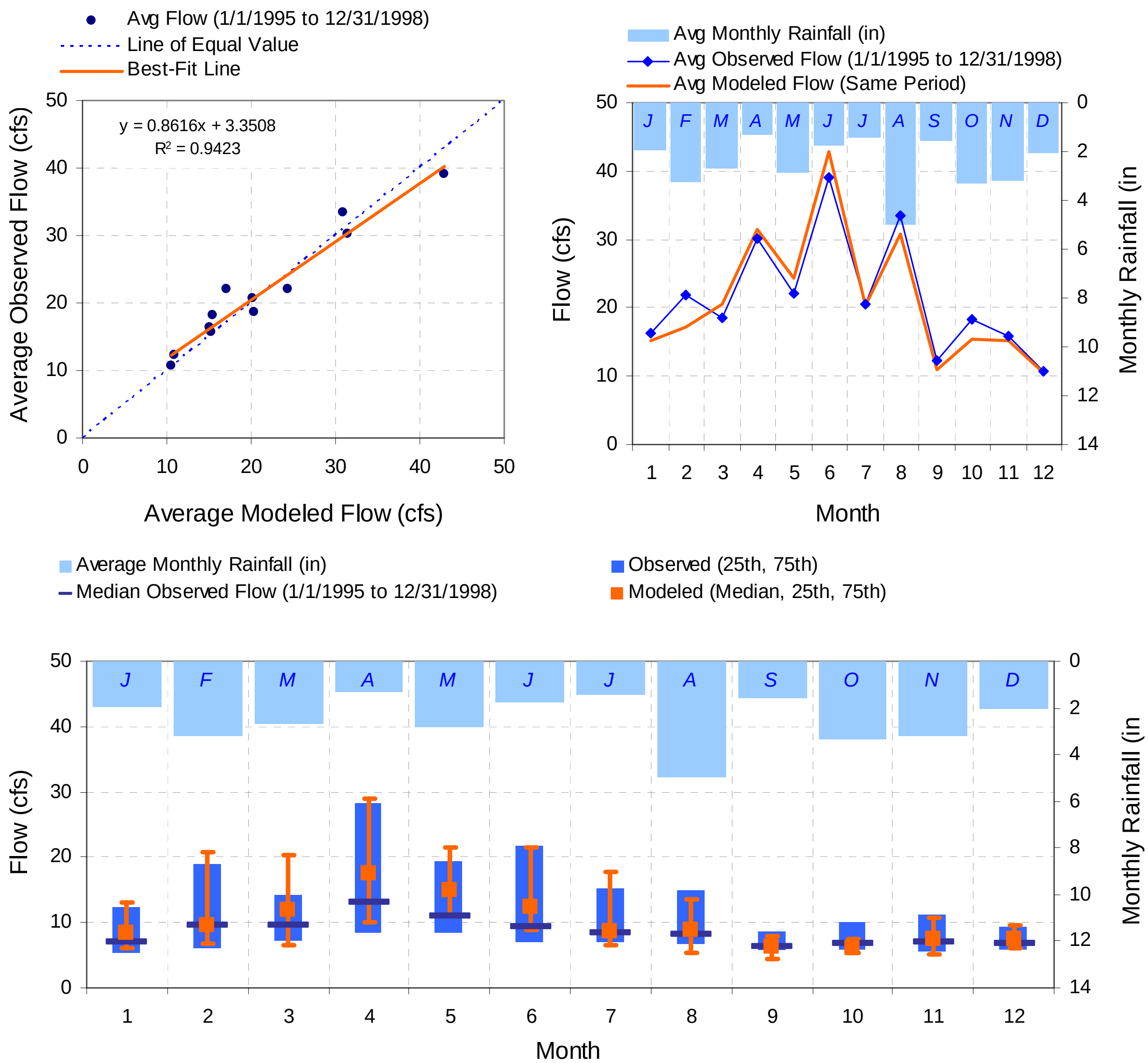


Figure 13. Composite (average monthly) hydrologic calibration results for the Kinnickinnic River at USGS gage 04087159 (1995 to 1998).

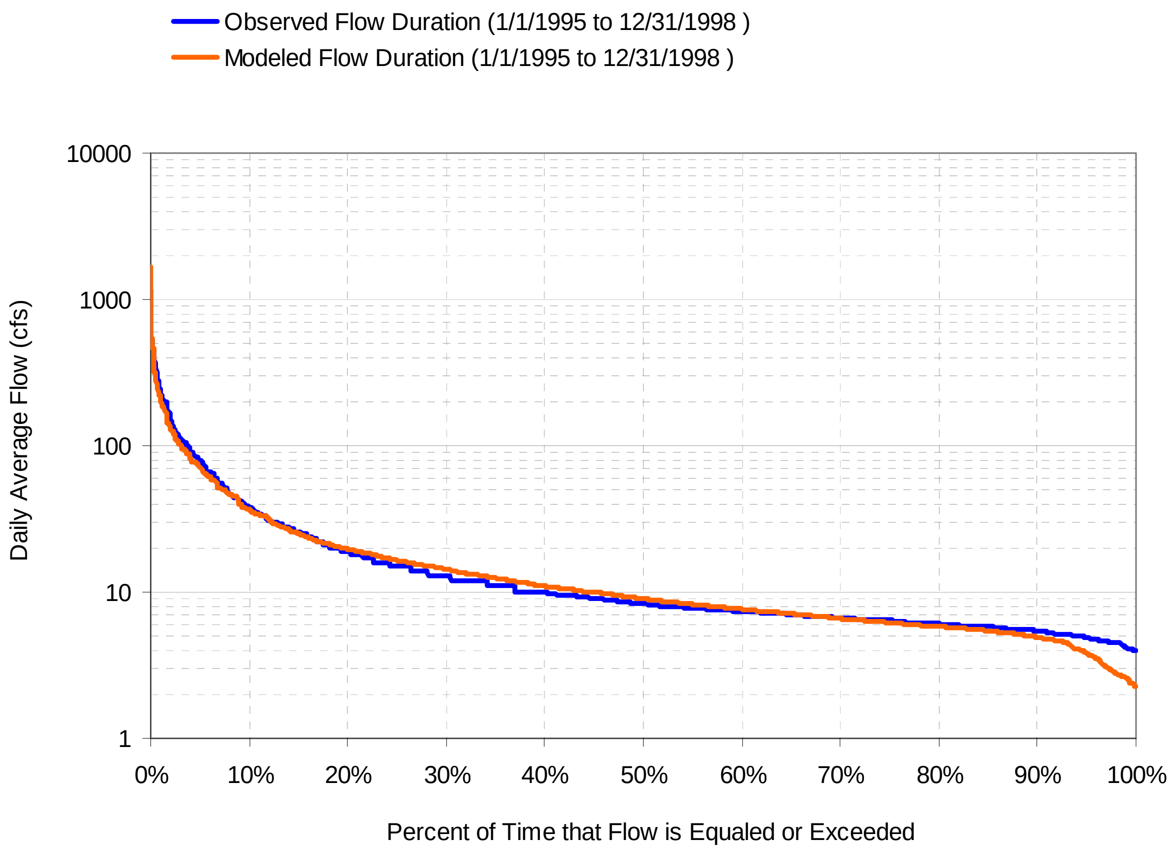


Figure 14. Flow duration curve hydrologic calibration results for the Kinnickinnic River at USGS gage 04087159 (1995-1998).

Table 4. Error statistics for hydrologic calibration results for the Kinnickinnic River at USGS gage 04087159 (1995-1998).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1995			1996			1997			1998			TOTAL		
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month JAN	734	902	22.89%	901	725	-19.5%	943	549	-41.8%	2,203	1,552	-29.6%	4,782	3,729	-22.0%
FEB	220	413	88.2%	500	583	16.6%	1,506	1,027	-31.8%	1,929	1,809	-6.2%	4,154	3,833	-7.7%
MAR	831	935	12.5%	562	523	-7.0%	1,238	1,025	-17.2%	2,769	2,547	-8.0%	5,401	5,030	-6.9%
APR	1,446	2,032	40.5%	1,625	1,409	-13.3%	1,005	964	-4.1%	3,610	3,071	-14.9%	7,687	7,476	-2.7%
MAY	1,601	2,031	26.9%	1,841	1,457	-20.8%	1,229	941	-23.5%	1,608	1,574	-2.1%	6,278	6,004	-4.4%
JUN	913	1,045	14.4%	3,207	2,581	-19.5%	6,294	5,361	-14.8%	1,318	1,217	-7.7%	11,732	10,204	-13.0%
JUL	579	922	59.3%	549	738	34.5%	3,119	2,582	-17.2%	704	727	3.3%	4,950	4,969	0.4%
AUG	1,692	1,886	11.5%	459	553	20.4%	2,302	2,013	-12.6%	3,450	3,141	-9.0%	7,904	7,592	-3.9%
SEP	367	454	23.7%	679	587	-13.6%	861	991	15.1%	268	570	113.0%	2,175	2,603	19.7%
OCT	1,631	1,413	-13.3%	1,081	900	-16.7%	507	508	0.3%	1,177	960	-18.4%	4,397	3,782	-14.0%
NOV	1,107	1,191	7.6%	659	340	-48.3%	791	534	-32.4%	2,246	1,549	-31.0%	4,803	3,615	-24.7%
DEC	798	705	-11.6%	1,233	611	-50.4%	969	583	-39.9%	760	673	-11.5%	3,760	2,572	-31.6%

Season	1995 Recorded USGS Volume (ac-ft)	1995 Simulated LSPC Volume (ac-ft)	1995 Percent Diff.	1995 Var. from Tolerance	1996 Recorded USGS Volume (ac-ft)	1996 Simulated LSPC Volume (ac-ft)	1996 Percent Diff.	1996 Var. from Tolerance	1997 Recorded USGS Volume (ac-ft)	1997 Simulated LSPC Volume (ac-ft)	1997 Percent Diff.	1997 Var. from Tolerance	1998 Recorded USGS Volume (ac-ft)	1998 Simulated LSPC Volume (ac-ft)	1998 Percent Diff.	1998 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Jan-Mar	1,786	2,251	26.1%	6.1%	1,963	1,831	-6.7%		3,687	2,602	-29.4%	9.4%	6,901	5,908	-14.4%		**14,337**	**12,592**	**-12.2%**	
Apr-Jun	3,960	5,108	29.0%	9.0%	6,673	5,448	-18.4%		8,528	7,265	-14.8%		6,536	5,863	-10.3%		**25,697**	**23,684**	**-7.8%**	
Jul-Sep	2,638	3,262	23.7%	3.7%	1,688	1,878	11.3%		6,282	5,586	-11.1%		4,421	4,438	0.4%		**15,029**	**15,164**	**0.9%**	
Oct-Dec	3,536	3,310	-6.4%		2,973	1,852	-37.7%	17.7%	2,267	1,625	-28.3%	8.3%	4,184	3,182	-23.9%	3.9%	**12,959**	**9,970**	**-23.1%**	**3.1%**

Calibration Tolerance =20%

	1995 Recorded USGS Volume (ac-ft)	1995 Simulated LSPC Volume (ac-ft)	1995 Percent Diff.	1995 Var. from Tolerance	1996 Recorded USGS Volume (ac-ft)	1996 Simulated LSPC Volume (ac-ft)	1996 Percent Diff.	1996 Var. from Tolerance	1997 Recorded USGS Volume (ac-ft)	1997 Simulated LSPC Volume (ac-ft)	1997 Percent Diff.	1997 Var. from Tolerance	1998 Recorded USGS Volume (ac-ft)	1998 Simulated LSPC Volume (ac-ft)	1998 Percent Diff.	1998 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Year	11,919	13,931	16.9%	6.9%	13,296	11,009	-17.2%	7.2%	20,764	17,078	-17.8%	7.8%	22,042	19,390	-12.0%	2.0%	**68,022**	**61,408**	**-9.7%**	

Calibration Tolerance =10%

Table 5. High-Low flow error statistics for hydrologic calibration results for the Kinnickinnic River at USGS gage 04087159 (1995-1998).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	33,547	35,371	-5.2%	15%
Total Highest 20% volume	41,159	43,063	-4.4%	15%
Total Highest 50% volume	52,526	53,366	-1.6%	15%
Total Lowest 10% volume	1,094	1,413	-22.6%	10%
Total Lowest 30% volume	4,458	4,927	-9.5%	10%
Total Lowest 50% volume	8,936	9,239	-3.3%	10%

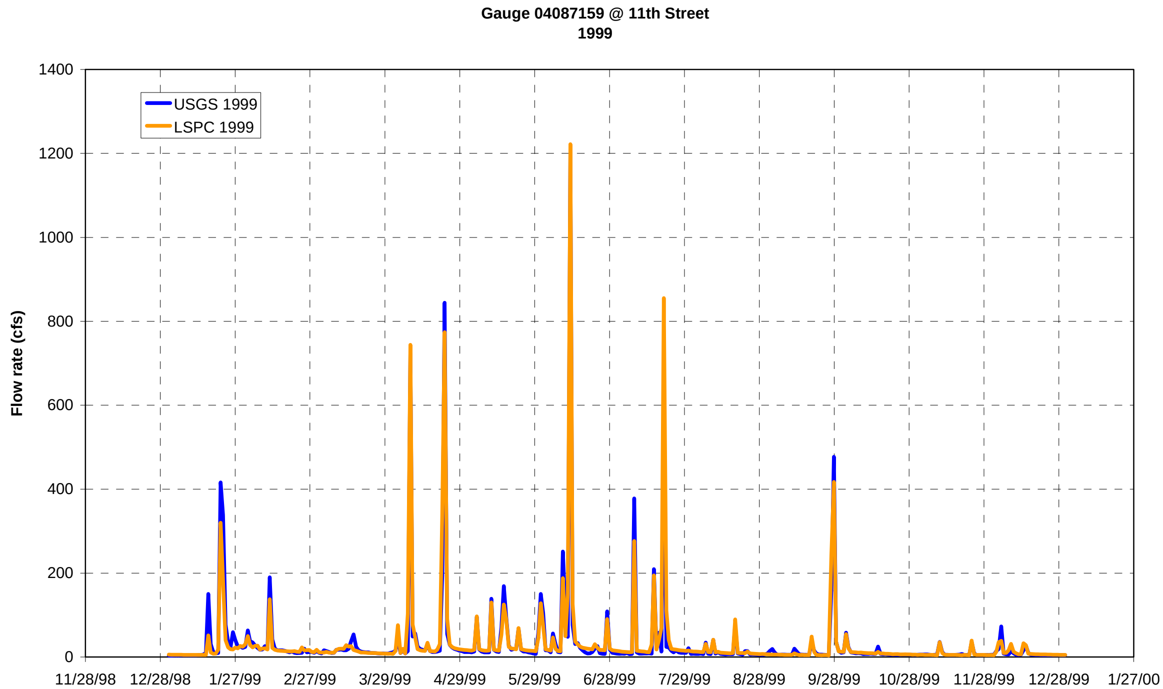


Figure 15. Time series hydrologic validation results (daily mean) for the Kinnickinnic River at USGS gage 04087159 (1999).

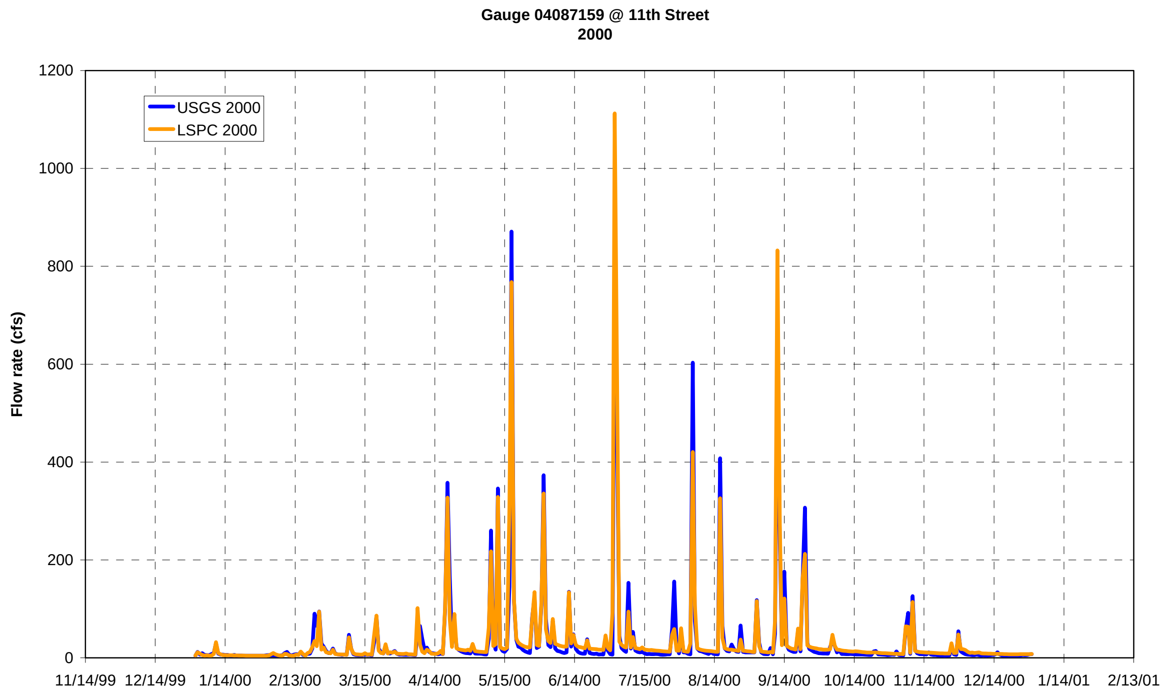


Figure 16. Time series hydrologic validation results (daily mean) for the Kinnickinnic River at USGS gage 04087159 (2000).

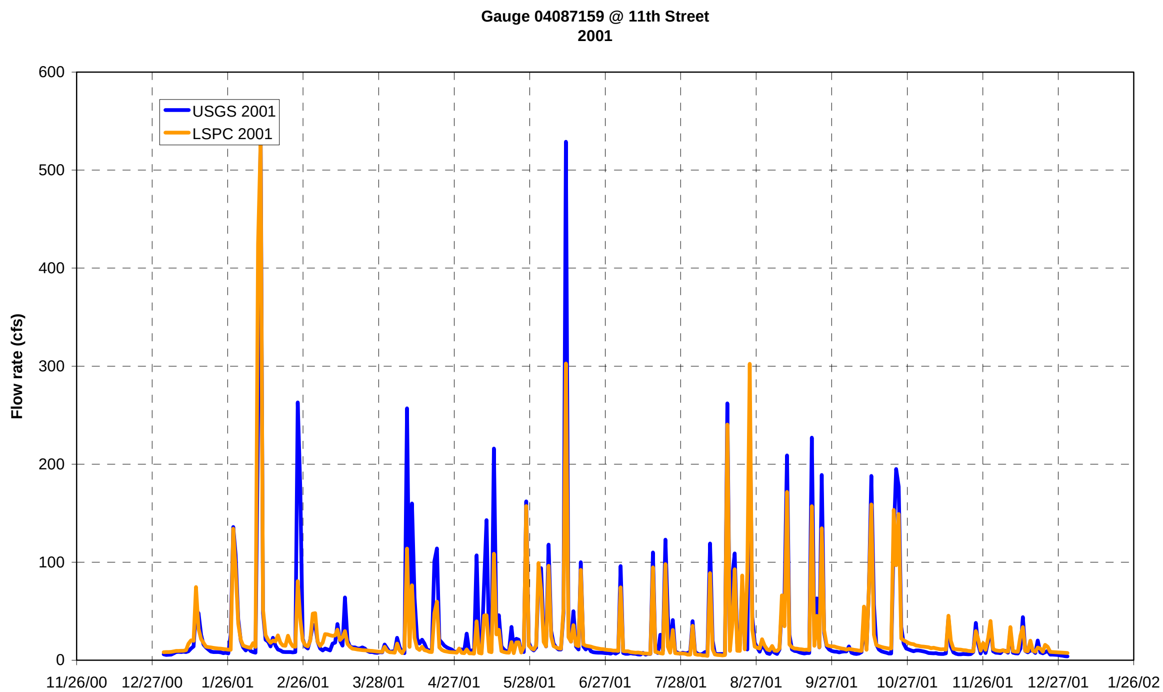


Figure 17. Time series hydrologic validation results (daily mean) for the Kinnickinnic River at USGS gage 04087159 (2001).

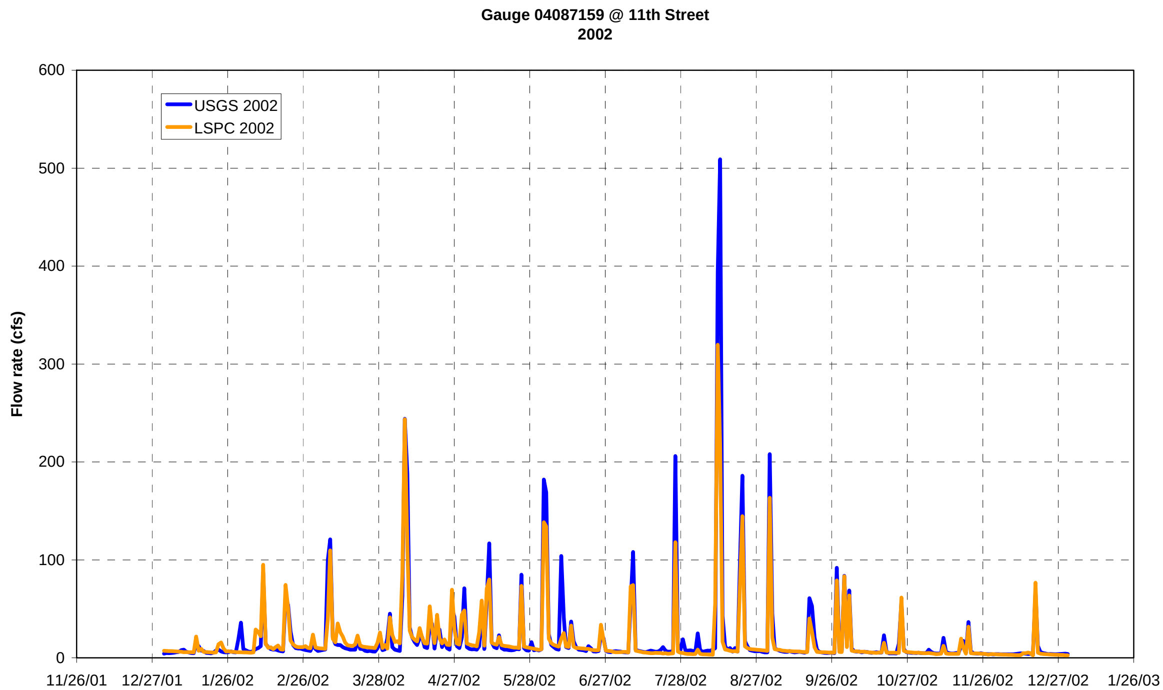


Figure 18. Time series hydrologic validation results (daily mean) for the Kinnickinnic River at USGS gage 04087159 (2002).

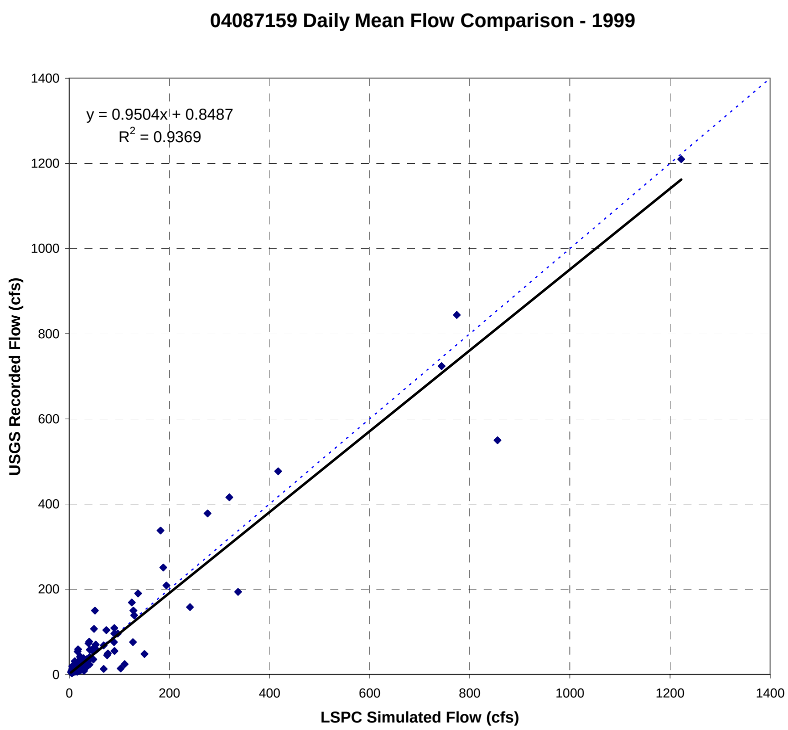


Figure 19. Observed versus simulated scatter plot with a linear regression line for the Kinnickinnic River at USGS gage 04087159 (1999).

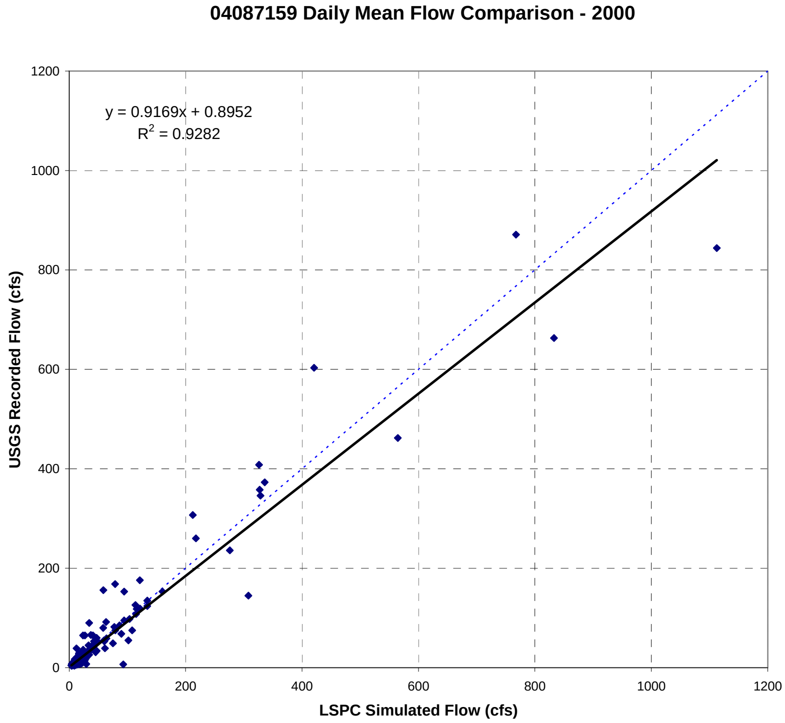


Figure 20. Observed versus simulated scatter plot with a linear regression line for the Kinnickinnic River at USGS gage 04087159 (2000).

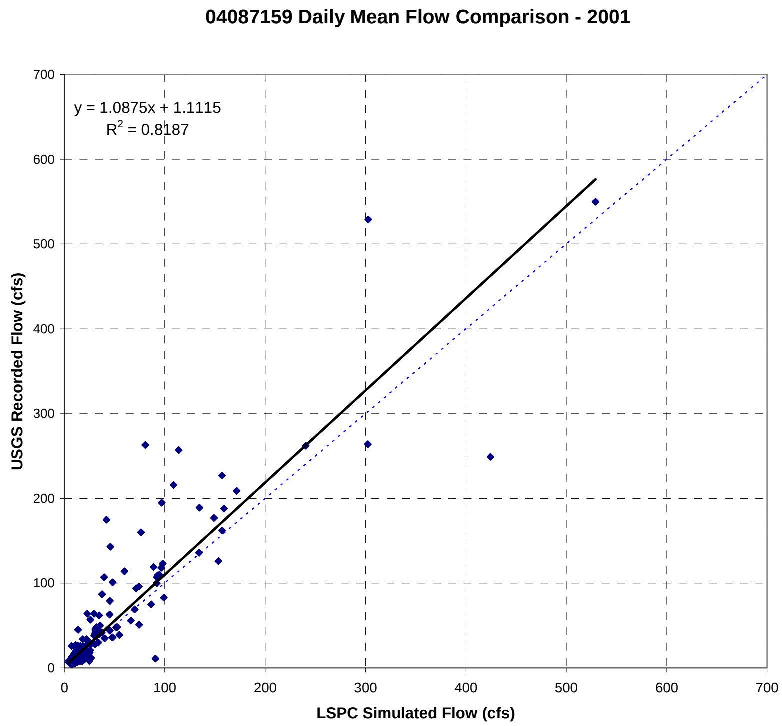


Figure 21. Observed versus simulated scatter plot with a linear regression line for the Kinnickinnic River at USGS gage 04087159 (2001).

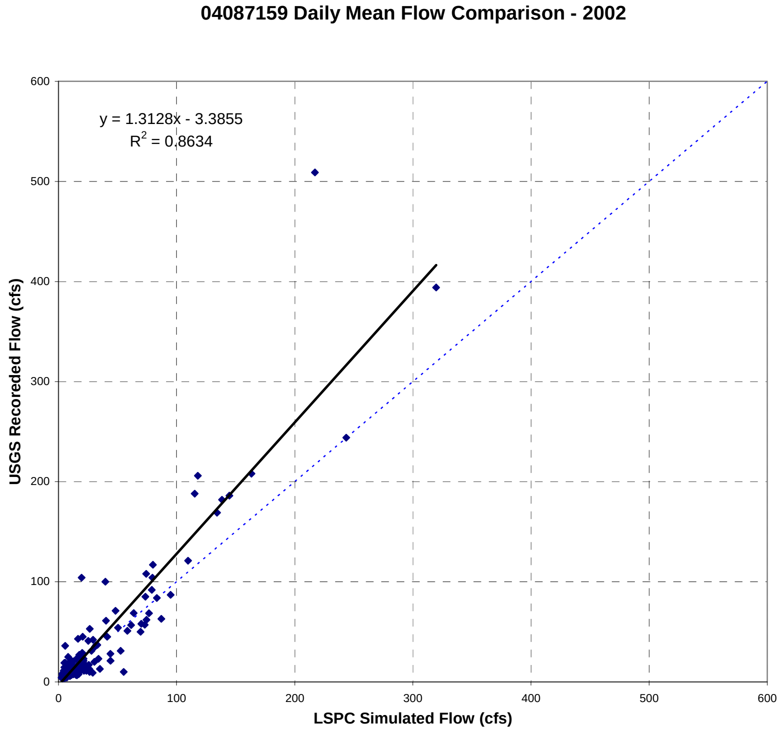


Figure 22. Observed versus simulated scatter plot with a linear regression line for the Kinnickinnic River at USGS gage 04087159 (2002).

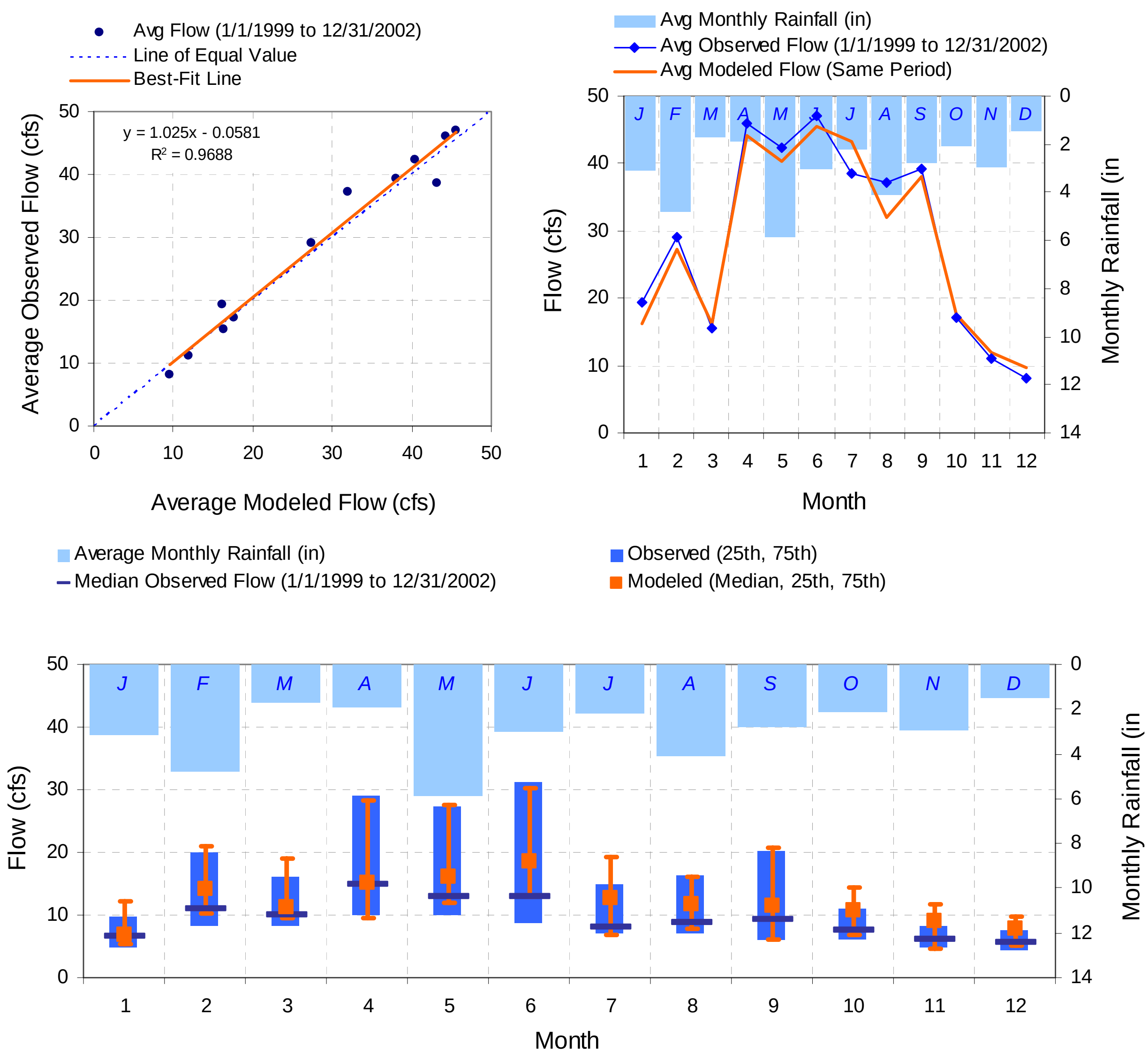


Figure 23. Composite (average monthly) hydrologic validation results for the Kinnickinnic River at USGS gage 04087159 (1999 to 2002).

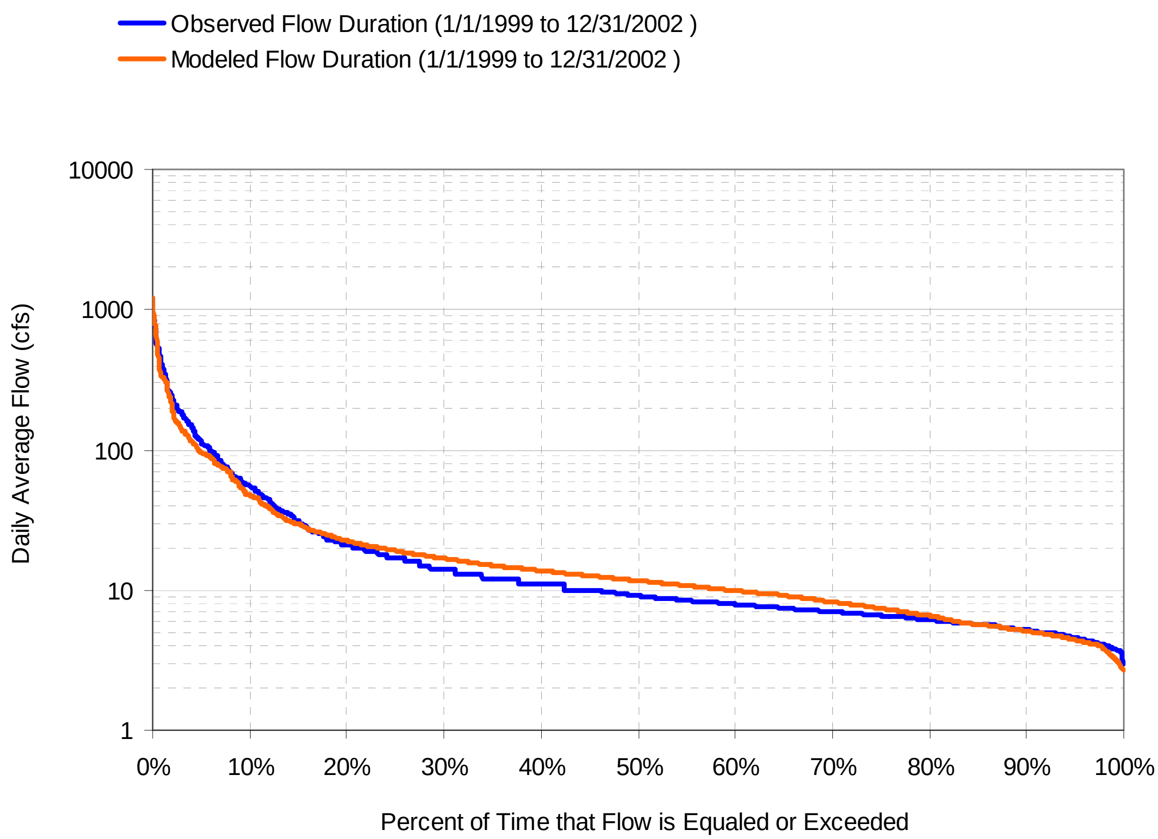


Figure 24. Flow duration curve hydrologic validation results for the Kinnickinnic River at USGS gage 04087159 (1999 to 2002).

Table 6. Error statistics for hydrologic validation results for the Kinnickinnic River at USGS gage 04087159 (1999 to 2002).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1999 Recorded USGS Volume (ac-ft)	1999 Simulated LSPC Volume (ac-ft)	1999 Percent Diff.	2000 Recorded USGS Volume (ac-ft)	2000 Simulated LSPC Volume (ac-ft)	2000 Percent Diff.	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2002 Recorded USGS Volume (ac-ft)	2002 Simulated LSPC Volume (ac-ft)	2002 Percent Diff.	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.
Month JAN	2,661	1,738	-34.68%	405	395	-2.5%	1,282	1,371	6.9%	416	458	10.1%	**4,765**	**3,963**	**-16.8%**
FEB	1,462	1,312	-10.2%	978	758	-22.5%	3,128	3,036	-2.9%	934	1,018	9.0%	**6,502**	**6,124**	**-5.8%**
MAR	906	828	-8.7%	849	889	4.8%	1,032	1,140	10.5%	1,011	1,152	14.0%	**3,798**	**4,009**	**5.6%**
APR	4,642	5,223	12.5%	2,198	2,022	-8.0%	2,059	1,135	-44.9%	2,043	2,147	5.1%	**10,941**	**10,527**	**-3.8%**
MAY	2,033	2,011	-1.1%	4,869	5,164	6.1%	2,196	1,392	-36.6%	1,299	1,376	5.9%	**10,397**	**9,943**	**-4.4%**
JUN	4,858	4,968	2.3%	2,115	2,478	17.1%	2,632	2,148	-18.4%	1,582	1,262	-20.3%	**11,187**	**10,855**	**-3.0%**
JUL	2,988	3,864	29.3%	4,107	4,920	19.8%	1,239	1,018	-17.9%	1,147	822	-28.3%	**9,481**	**10,624**	**12.1%**
AUG	727	887	22.0%	3,048	2,641	-13.4%	2,472	2,373	-4.0%	2,904	1,979	-31.9%	**9,151**	**7,879**	**-13.9%**
SEP	1,830	1,773	-3.1%	4,138	4,459	7.7%	2,115	1,838	-13.1%	1,250	984	-21.3%	**9,333**	**9,053**	**-3.0%**
OCT	619	652	5.3%	604	868	43.8%	2,199	2,057	-6.5%	813	763	-6.2%	**4,235**	**4,339**	**2.5%**
NOV	468	429	-8.4%	1,070	1,142	6.8%	687	916	33.2%	423	372	-12.2%	**2,649**	**2,858**	**7.9%**
DEC	604	708	17.3%	379	560	47.7%	603	740	22.7%	395	364	-7.7%	**1,981**	**2,372**	**19.8%**

Season	1999 Recorded USGS Volume (ac-ft)	1999 Simulate d LSPC Volume (ac-ft)	1999 Percent Diff.	1999 Var. from Tolerance	2000 Recorded USGS Volume (ac-ft)	2000 Simulate d LSPC Volume (ac-ft)	2000 Percent Diff.	2000 Var. from Tolerance	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2001 Var. from Tolerance	2002 Recorded USGS Volume (ac-ft)	2002 Simulate d LSPC Volume (ac-ft)	2002 Percent Diff.	2002 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Jan-Mar	5,029	3,878	-22.9%	2.9%	2,232	2,042	-8.5%		5,442	5,547	1.9%		2,362	2,629	11.3%		**15,064**	**14,096**	**-6.4%**	
Apr-Jun	11,533	12,202	5.8%		9,182	9,664	5.2%		6,886	4,675	-32.1%	12.1%	4,924	4,785	-2.8%		**32,525**	**31,325**	**-3.7%**	
Jul-Sep	5,544	6,523	17.7%		11,293	12,020	6.4%		5,826	5,228	-10.3%		5,301	3,784	-28.6%	8.6%	**27,964**	**27,556**	**-1.5%**	
Oct-Dec	1,691	1,789	5.8%		2,052	2,570	25.2%	5.2%	3,490	3,712	6.4%		1,631	1,499	-8.1%		**8,864**	**9,570**	**8.0%**	

Calibration Tolerance =20%

	1999 Recorded USGS Volume (ac-ft)	1999 Simulate d LSPC Volume (ac-ft)	1999 Percent Diff.	1999 Var. from Tolerance	2000 Recorded USGS Volume (ac-ft)	2000 Simulate d LSPC Volume (ac-ft)	2000 Percent Diff.	2000 Var. from Tolerance	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2001 Var. from Tolerance	2002 Recorded USGS Volume (ac-ft)	2002 Simulate d LSPC Volume (ac-ft)	2002 Percent Diff.	2002 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Year	23,797	24,391	2.5%		24,760	26,295	6.2%		21,644	19,162	-11.5%	1.5%	14,217	12,697	-10.7%	0.7%	**84,418**	**82,546**	**-2.2%**	

Calibration Tolerance =10%

Table 7. High-Low flow error statistics for hydrologic validation results for the Kinnickinnic River at USGS gage 04087159 (1999-2002).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	49,000	53,806	-8.9%	15%
Total Highest 20% volume	58,143	63,518	-8.5%	15%
Total Highest 50% volume	71,767	74,965	-4.3%	15%
Total Lowest 10% volume	1,255	1,319	-4.8%	10%
Total Lowest 30% volume	5,064	4,872	4.0%	10%
Total Lowest 50% volume	10,849	9,508	14.1%	10%

Wilson Park Creek Results

The performance of the model was also evaluated by comparing simulated results to observed flows recorded at the USGS gage on Wilson Park Creek. Continuous observed flow is only available for the period November 1, 1997 to September 30, 2003 and therefore the modeling results cover the period 1998 to 2002[2]. Separate calibration and validation modeling runs were not made for this gage.

The results are presented in Figure 25 to Figure 36 and indicate that the model correctly simulates the timing of flow events and the magnitude of peak flows across all years simulated. The low flows are slightly over-predicted at this gage – even though the same portion of the flow regime tends to be a little under-predicted at the downstream gage. The over-prediction by the model may be a result of one or more of the following factors:

- Uncertainty associated with estimated flows for point sources.
- Delineation of Directly Connected Impervious Areas (DCIAs)
- Uncertainty in the specification of stage-discharge relationships (Ftables)
- Storm water retention structures, particularly those in the General Mitchell International Airport

[2] The period of record at gage 040871488 is from November 18, 1996 to September 30, 2004; however, no data are reported for the period May 14, 1997 to October 31, 1997.

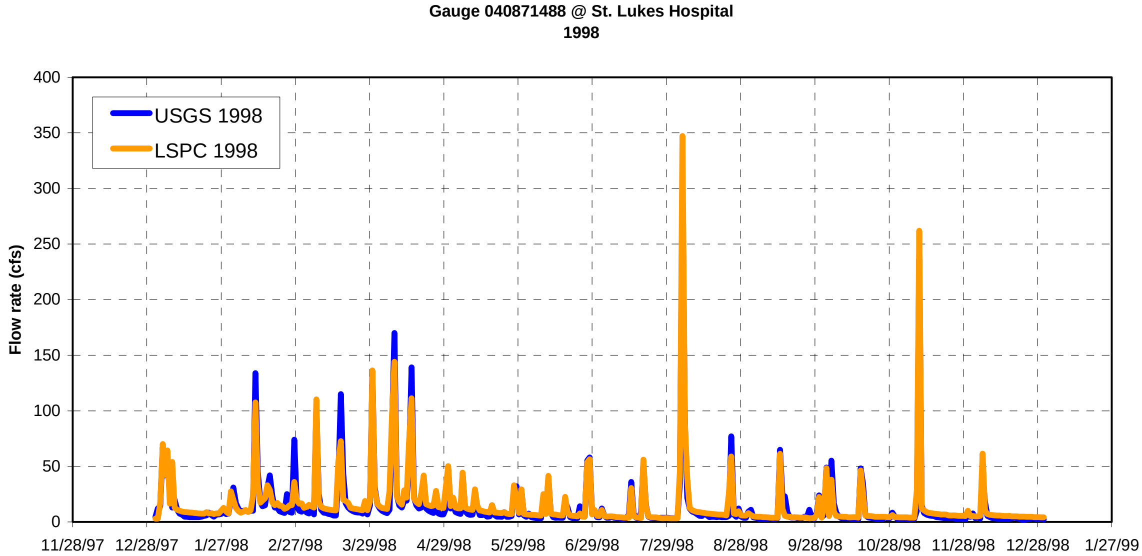


Figure 25. Time series hydrologic results (daily mean) for Wilson Park Creek at USGS gage 040871488 (1998).

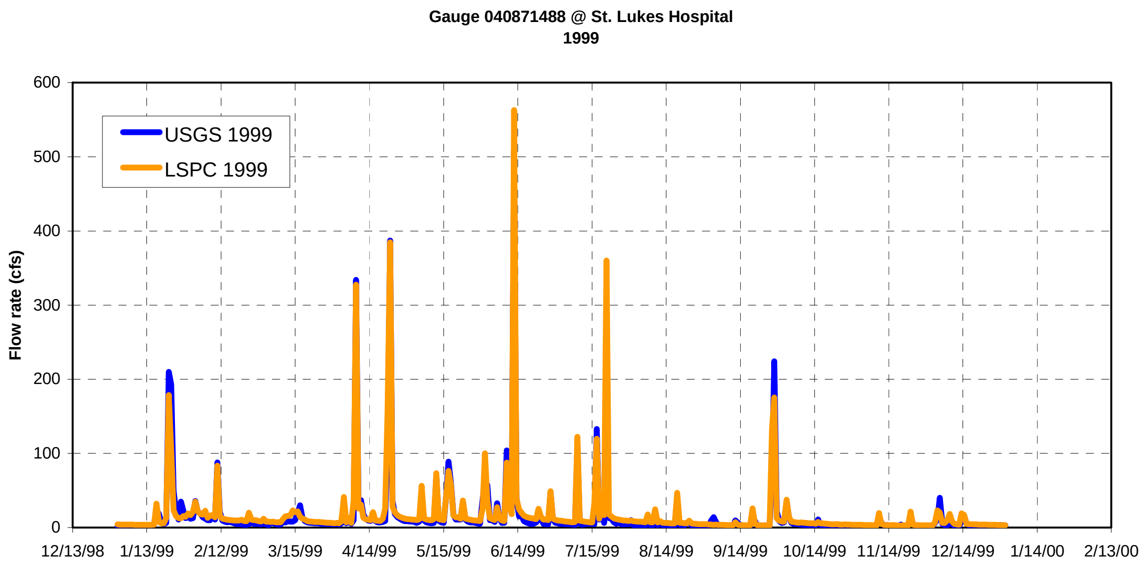


Figure 26. Time series hydrologic results (daily mean) for Wilson Park Creek at USGS gage 040871488 (1999).

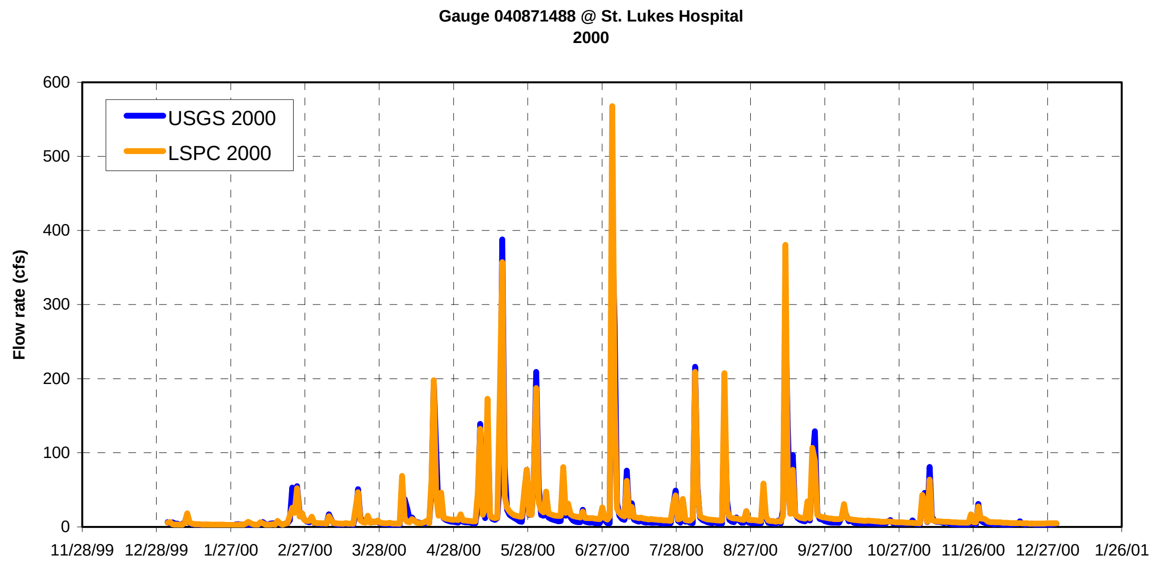


Figure 27. Time series hydrologic results (daily mean) for Wilson Park Creek at USGS gage 040871488 (2000).

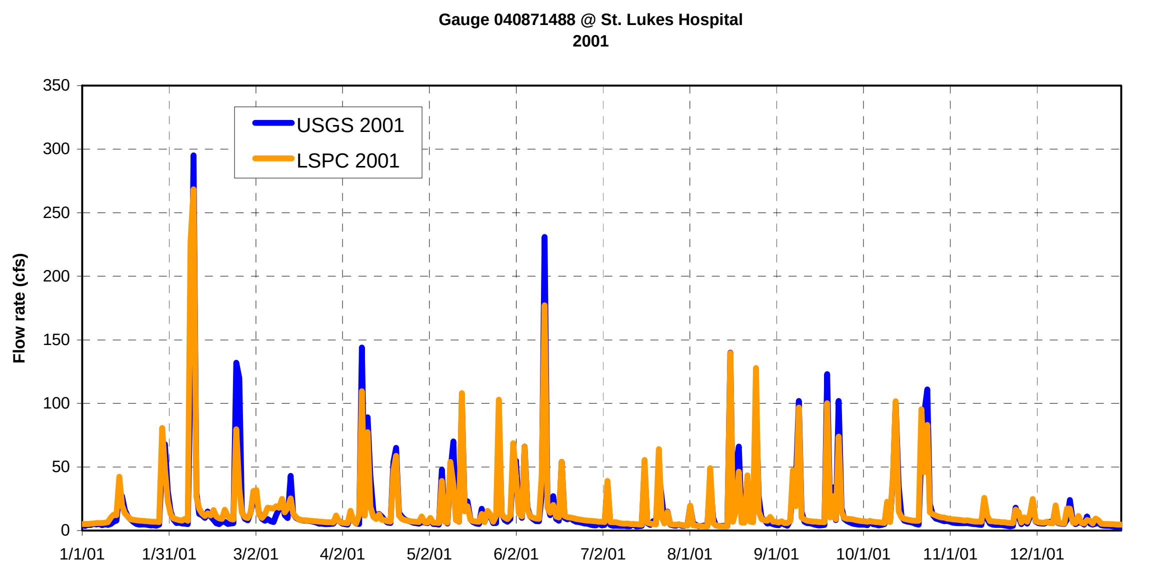


Figure 28. Time series hydrologic results (daily mean) for Wilson Park Creek at USGS gage 0408714889 (2001).

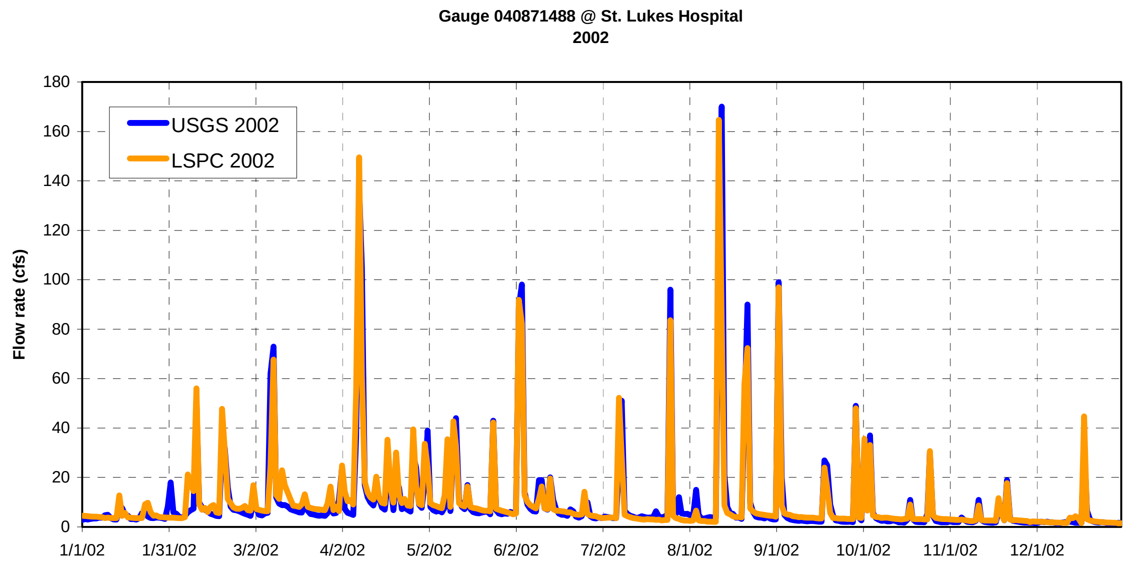


Figure 29. Time series hydrologic results (daily mean) for Wilson Park Creek at USGS gage 040871488 (2002).

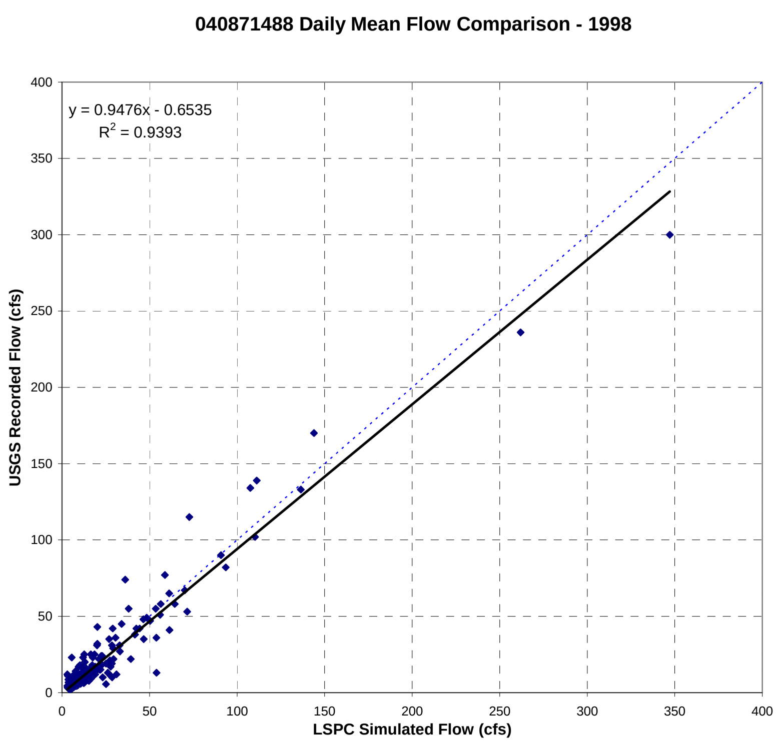


Figure 30. Observed versus simulated scatter plot with a linear regression line for Wilson Park Creek at USGS gage 040871488 (1998).

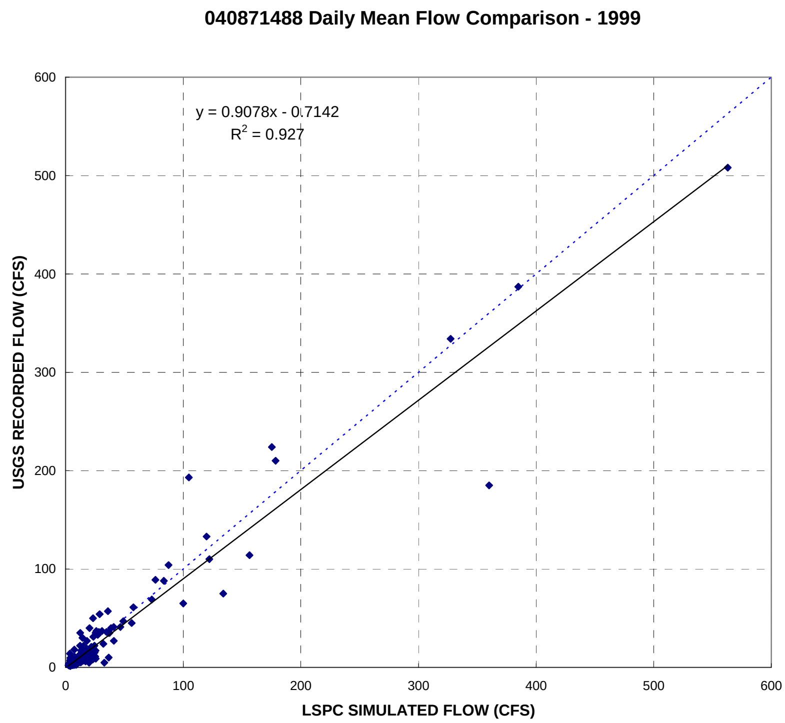


Figure 31. Observed versus simulated scatter plot with a linear regression line for Wilson Park Creek at USGS gage 040871488 (1999).

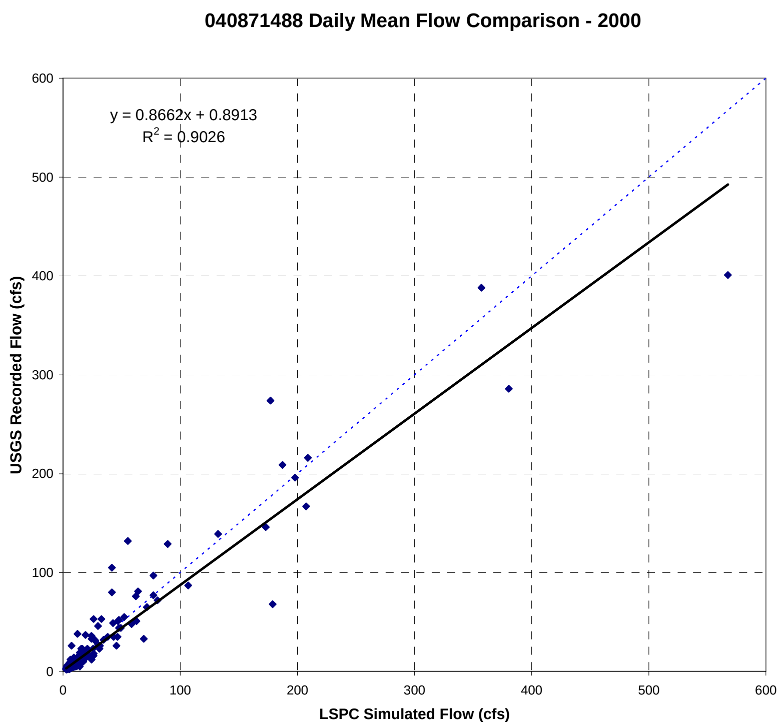


Figure 32. Observed versus simulated scatter plot with a linear regression line for Wilson Park Creek at USGS gage 040871488 (2000).

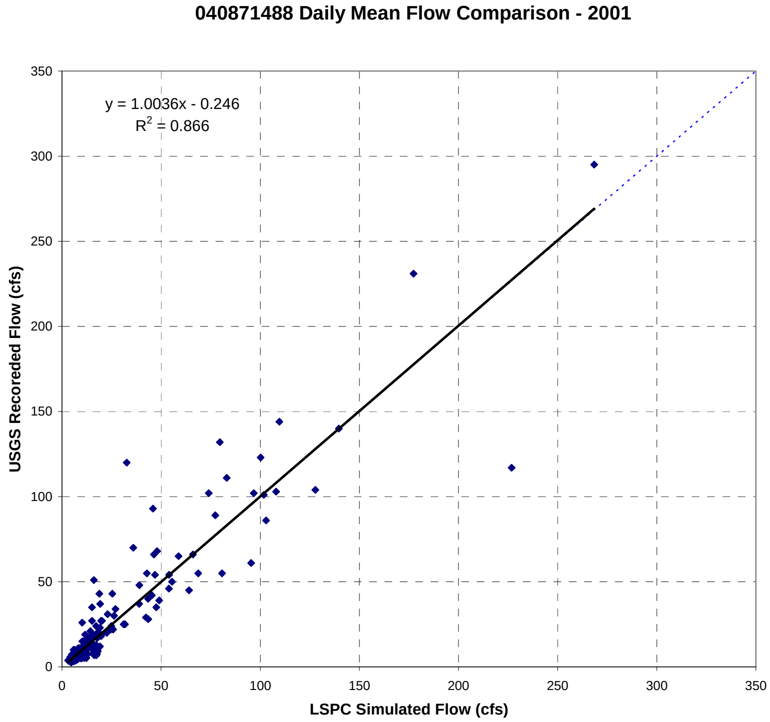


Figure 33. Observed versus simulated scatter plot with a linear regression line for Wilson Park Creek at USGS gage 040871488 (2001).

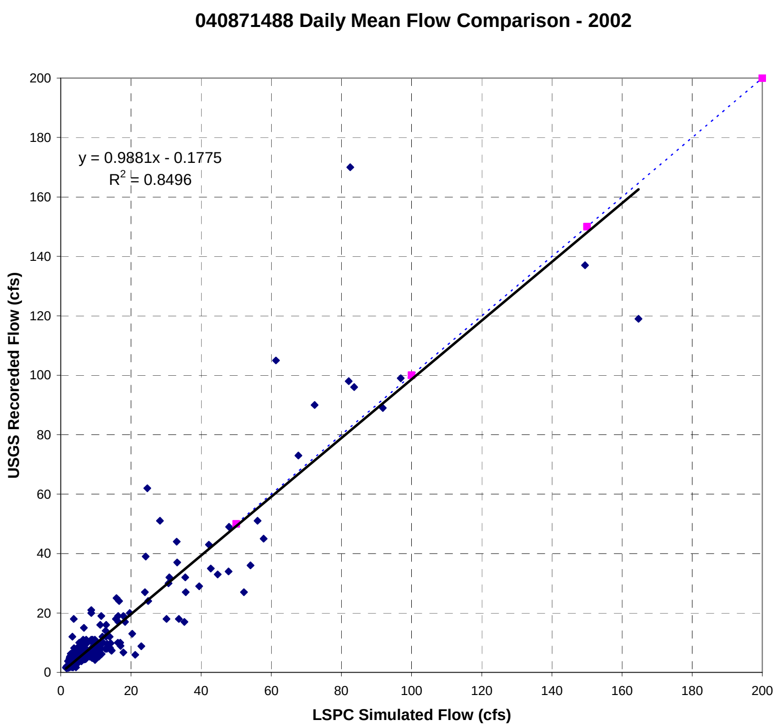


Figure 34. Observed versus simulated scatter plot with a linear regression line for Wilson Park Creek at USGS gage 040871488 (2002).

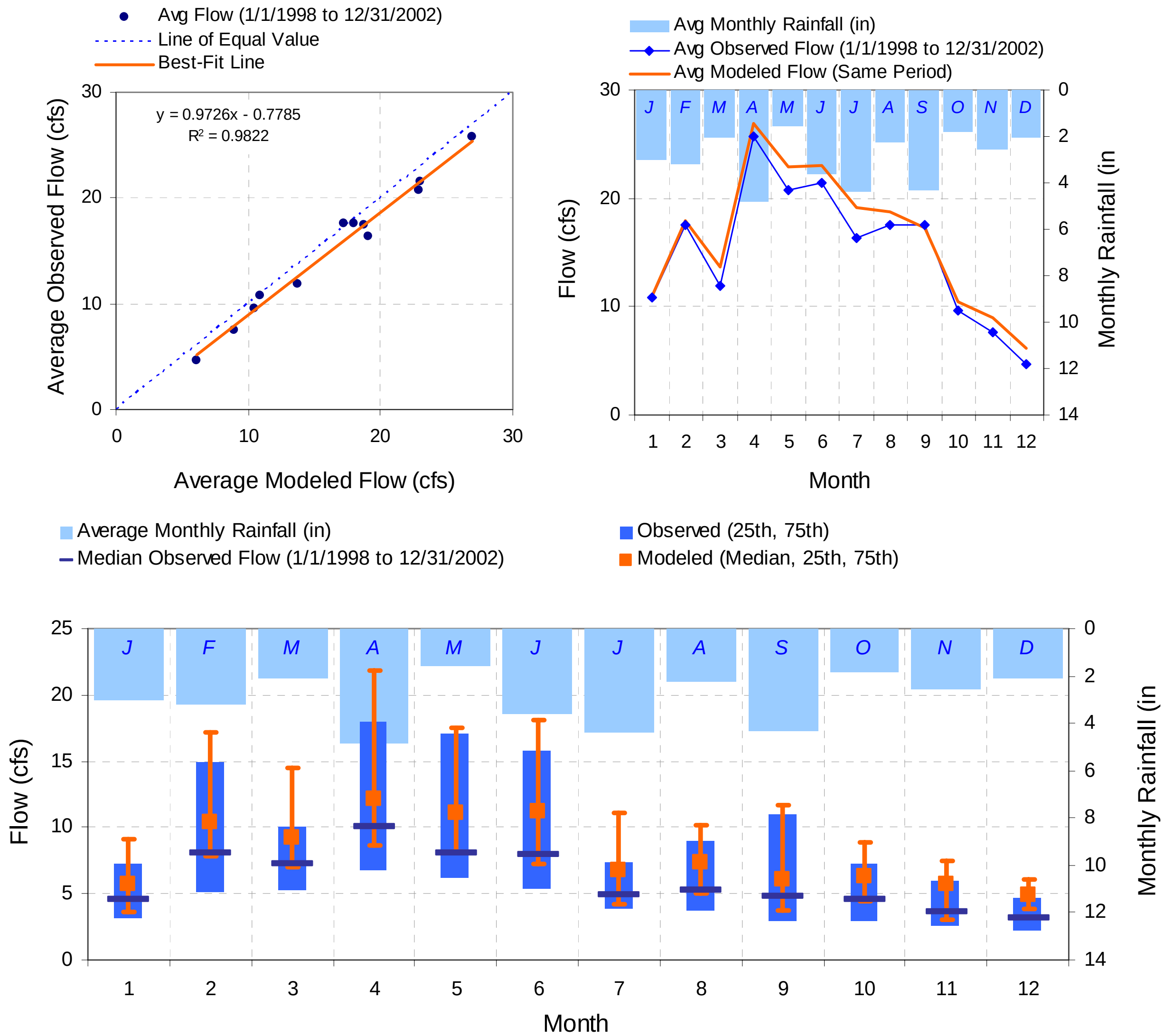


Figure 35. Composite (average monthly) hydrologic calibration results for Wilson Park Creek at USGS gage 040871488 (1998 to 2002).

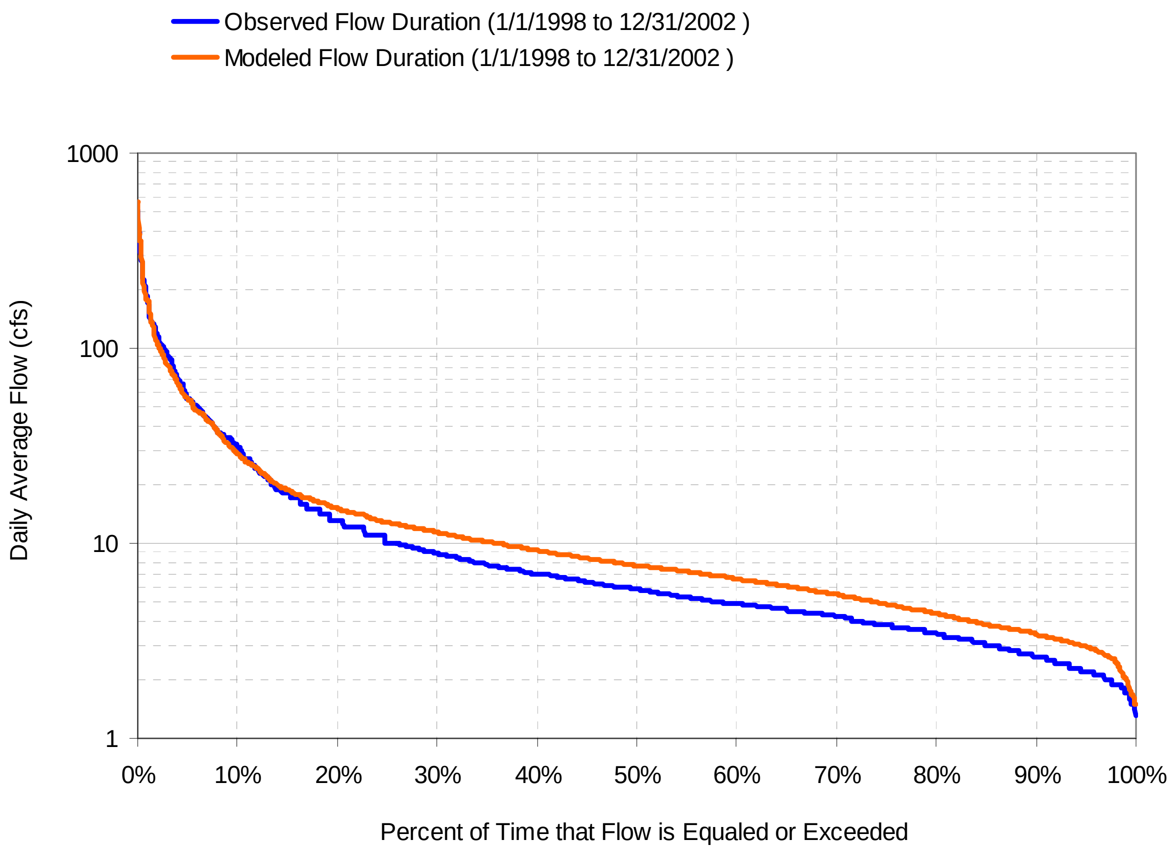


Figure 36. Flow duration curve hydrologic calibration results for the Kinnickinnic River at USGS gage 040871488 (1998-2002).

Table 8. Error statistics for hydrologic calibration results for the Kinnickinnic River at USGS gage 040871488 (1999-2002).

Monthly / Seasonal / Yearly Volume Comparison

	Time Period	1999			2000			2001			2002			TOTAL		
		Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month	JAN	1,345	1,070	-20.42%	231	376	63.0%	710	1,120	57.8%	285	244	-14.4%	**2,570**	**2,810**	**9.3%**
Month	FEB	722	656	-9.1%	573	358	-37.5%	1,762	1,450	-17.7%	591	620	4.9%	**3,648**	**3,084**	**-15.5%**
Month	MAR	455	296	-34.9%	486	535	10.1%	699	248	-64.5%	659	644	-2.3%	**2,299**	**1,723**	**-25.0%**
Month	APR	2,356	2,080	-11.7%	1,279	1,110	-13.2%	1,211	89	-92.6%	1,210	1,210	0.0%	**6,057**	**4,489**	**-25.9%**
Month	MAY	1,136	1,270	11.8%	2,547	2,480	-2.6%	1,160	355	-69.4%	966	858	-11.2%	**5,809**	**4,963**	**-14.6%**
Month	JUN	2,204	2,270	3.0%	1,282	1,510	17.8%	1,438	1,140	-20.7%	900	800	-11.1%	**5,824**	**5,720**	**-1.8%**
Month	JUL	1,232	1,910	55.1%	2,172	1,960	-9.8%	571	710	24.4%	590	491	-16.8%	**4,564**	**5,071**	**11.1%**
Month	AUG	337	518	53.8%	1,330	1,330	0.0%	1,235	1,450	17.4%	1,220	1,200	-1.6%	**4,122**	**4,498**	**9.1%**
Month	SEP	895	983	9.9%	2,049	1,990	-2.9%	1,182	1,280	8.3%	735	661	-10.1%	**4,860**	**4,914**	**1.1%**
Month	OCT	310	560	80.5%	395	535	35.3%	1,261	1,300	3.1%	658	599	-9.0%	**2,625**	**2,994**	**14.1%**
Month	NOV	218	285	30.6%	677	727	7.5%	428	475	11.0%	301	250	-16.9%	**1,624**	**1,737**	**7.0%**
Month	DEC	309	451	45.9%	239	505	110.9%	392	399	1.8%	246	205	-16.7%	**1,186**	**1,560**	**31.5%**

		1999				2000				2001				2002				TOTAL			
		Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Season	Jan-Mar	2,522	2,022	-19.8%		1,289	1,269	-1.6%		3,171	2,818	-11.1%		1,535	1,508	-1.8%		**8,517**	**7,617**	**-10.6%**	
Season	Apr-Jun	5,696	5,620	-1.3%		5,108	5,100	-0.2%		3,810	1,584	-58.4%	38.4%	3,076	2,868	-6.8%		**17,690**	**15,172**	**-14.2%**	
Season	Jul-Sep	2,463	3,411	38.5%	18.5%	5,550	5,280	-4.9%		2,988	3,440	15.1%		2,545	2,352	-7.6%		**13,546**	**14,483**	**6.9%**	
Season	Oct-Dec	837	1,296	54.8%	34.8%	1,311	1,767	34.8%	14.8%	2,081	2,174	4.5%		1,205	1,054	-12.5%		**5,435**	**6,291**	**15.8%**	

Calibration Tolerance =20%

	1999				2000				2001				2002				TOTAL			
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	11,518	12,349	7.2%		13,259	13,416	1.2%		12,050	10,016	-16.9%	6.9%	8,361	7,782	-6.9%		**45,187**	**43,563**	**-3.6%**	

Calibration Tolerance =10%

Table 9. High-Low flow error statistics for hydrologic calibration results for the Kinnickinnic River at USGS gage 040871488 (1998-2002).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	31,408	31,827	-1.3%	15%
Total Highest 20% volume	38,614	38,759	-0.4%	15%
Total Highest 50% volume	50,078	47,743	4.9%	15%
Total Lowest 10% volume	1,031	794	29.8%	10%
Total Lowest 30% volume	4,208	3,274	28.6%	10%
Total Lowest 50% volume	8,985	6,845	31.3%	10%

Table 10. Coefficient of Model Fit Efficiency (E) for the Kinnickinnic River Hydrologic Model (Daily Flows, 1995 to 2002)

USGS Gage Number	Station Name	E
04087159	Kinnickinnic River @ S. 11th Street @ Milwaukee, WI	0.71
040871488	Wilson Park Creek @ St. Lukes Hospital @ Milwaukee, WI	0.71

9.0 REFERENCES

Bicknell, B.R., J.C. Imhoff, J. Kittle, A.S. Donigian, and R.C. Johansen. 1996. *Hydrological Simulation Program !FORTRAN, User's Manual for Release H*. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. *Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage*, 89(IR4): 15-41.

Jensen, M.E., D.C.N. Rob, and C.E. Franzoy. 1969. Scheduling irrigations using climate-crop-soil data. Proceedings, National Conference on Water Resources Engineering of the American Society of Civil Engineers, New Orleans, LA.

Tetra Tech. 2002. Minnesota River Basin Model, Model Calibration and Validation Report. Prepared for Minnesota Pollution Control Agency, St. Paul, MN by Tetra Tech, Inc., Research Triangle Park, NC.

U.S. Environmental Protection Agency (USEPA). 2000. *BASINS Technical Note 6. Estimating Hydrology and Hydraulic Parameters for HSPF*. EPA-823-R00-012. U.S. Environmental Protection Agency. Office of Water. July 2000.

Viessman, W., G.L. Lewis, and J.W. Knapp. 1989. *Introduction to Hydrology*, 3rd Edition. Harper Collins, New York.

2020 Facility Planning Project

Final Memorandum

Project Name:	MMSD – 2020 Facility Planning Project	MMSD Contract No:	M03002P01
DMS Folder Name:	Technology Analysis	MMSD File Code:	M009PE000.P7300-WQ1
Document Name:	Hydrologic Calibration and Validation Results for the Menomonee River Model (Task 3)	HNTB Charge No:	34568-PL-400-115

Date: October 31, 2007

To: Michael Hahn, SEWRPC
Bill Krill, HNTB

From: Leslie Shoemaker, Tetra Tech, Inc.

Subject: Hydrologic Calibration and Validation Results for the Menomonee River Model (Task 3)

1.0 EXECUTIVE SUMMARY

An important component of the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU) is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. The purpose of this memorandum is to describe the modeling process and provide final results of the hydrologic and hydraulic calibration and validation of the Menomonee River watershed model.

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for a variety of reasons, including that existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds. The Loading Simulation Program in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms but has the advantage of no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original Menomonee River HSPF model has been migrated to LSPC for the 2020 Facilities Planning Project.

Configuration of the Menomonee River LSPC model involved consideration of five major components: waterbody representation, watershed segmentation, meteorological data, land use representation, and point sources. The representation of the Menomonee River and its tributaries in LSPC is based on the structure of the HSPF model provided by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) with several modifications (e.g., re-directing runoff from subbasins to different routing reaches). The model was configured to simulate the watershed as a series of 95 hydrologically connected subwatersheds.

The Menomonee River model is driven by precipitation data and other climatologic data (e.g., temperature, cloud cover, wind speed). Precipitation data are taken from five MMSD rain gauges (1204, 1207, 1209, 1216, and 1218) and a single weather gage was assigned to each of the original nine HSPF subwatersheds in consultation with SEWRPC based on the proximity of gages with acceptable data quality. Air temperature data for the upper portion of the watershed uses the Hartford Cooperative station, while temperatures for the remainder of the watershed and other climatologic series are from the General Mitchell International Airport.

Land cover classifications from the SEWRPC 2000 land use codes were re-classified to develop the land use representation in the LSPC model. The final land cover representation for the Menomonee River LSPC model indicates that the two most common land covers are grasses on C soils (39 percent of the total watershed) and impervious cover associated with commercial land uses (12 percent). There remain, however, significant amounts of agricultural land in the upper portions of the watershed.

There are a number of "point sources" in the Menomonee River watershed, including sanitary sewer overflows (SSOs), combined sewer overflows (CSOs), and industrial facilities. Flows from these point sources were input directly into the LSPC model using the methodology outlined in the December 13, 2004 memorandum entitled *Point Source Loading Calculations for Purposes of Watercourse Modeling*.

The March 4, 2005 version of the model was revised to address comments provided by SEWRPC. All Ftables, stream reach characteristics, and land use assignments were carefully reconciled with the latest information from SEWRPC, resulting in various changes in the model that affect the existing calibration. While much of the uncertainty in the March 4, 2005 draft calibration appeared to be due to spatial variability in precipitation depth and the timing of snowmelt, there was also improvement to be made in the parameter specification. In particular, it seemed advisable to address the relatively poor calibration fit observed for Underwood Creek. It was found, however, that this could not be accomplished while maintaining a single consistent set of parameters across the entire watershed. Therefore, the model was broken into two groups, with slightly different parameters: the upstream, less urban area consisting of the Upper Menomonee, Willow Creek, Little Menomonee, Lily Creek, and Middle Menomonee watersheds, and the downstream, more urban area consisting of the Underwood Creek, Honey Creek, Butler Ditch, and Lower Menomonee watersheds. Parameters between the two groups differ primarily in regard to urban grass and urban impervious surface and are described in Section 7.3 below.

These changes result in a much better fit on Underwood Creek, with little change at the upstream Pilgrim Road gage. Results at 70th Street differ from the March 4, 2005 draft calibration in large part due to the changes in land area specification and routing identified by SEWRPC. Certain problems remain with the final model. In particular, mid-range flows are over-predicted at 70th Street during the validation period, while high flows are under-predicted for the validation period at Pilgrim Road. These problems are likely to be mostly due to extrapolation from a limited number of point rainfall stations, which are not always representative of total precipitation across a large watershed, particularly during summer convective storms. In addition, low flows tend to be slightly under predicted, perhaps due to unmonitored urban low flow sources such as lawn watering, car washing, or other dry weather water use.

2.0 CONCLUSIONS

The following are the conclusions resulting from the hydrologic calibration and validation process for the Menomonee River model:

- The setup of the final HSPF model has been completed.
- Conversion of the HSPF model to LSPC was successful and will result in increased efficiency as the project progresses.
- Ftables, stream reach characteristics, and land use assignments were carefully reconciled with the latest information from SEWRPC.
- The calibration results for the Menomonee River model indicate acceptable agreement between observed and simulated streamflows.

Deviations from criteria appear to be related primarily to the uncertainties inherent in translating a limited number of point rain gauges to a large watershed. In addition, the lowest 10 percent flows continue to be underpredicted in many cases – perhaps because the addition of water through lawn irrigation is not addressed in the model.

3.0 RECOMMENDATIONS

We recommend that the hydrologic calibration and validation of the Menomonee River model be considered complete.

4.0 INTRODUCTION

The Milwaukee Metropolitan Sewerage District (MMSD) is in the midst of a long-range planning effort to identify improvements needed for its facilities to accommodate growth and protect water quality through the year 2020. This effort is known as the MMSD 2020 Facility Plan. A related planning effort is being conducted by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) to update the regional water quality management plan for the Kinnickinnic River, Menomonee River, Milwaukee River, Root River, and Oak Creek watersheds, the Milwaukee Harbor estuary, and the adjacent nearshore Lake

Michigan area. This effort is known as the Regional Water Quality Management Plan Update (RWQMPU). The two planning efforts are being coordinated and implemented in parallel.

One important component of both the 2020 Facility Plan and the RWQMPU is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. Watershed models are being developed for the following five watersheds:

- Kinnickinnic River
- Menomonee River
- Milwaukee River
- Oak Creek
- Root River

The Kinnickinnic, Menomonee, and Milwaukee River models will then be linked to a model of the Lake Michigan estuary so that the benefits of upstream water quality improvements can be simulated by the Lake Michigan Harbor / Estuary Model.

The following seven tasks have been identified for performing the system modeling:

1) Establish the model structure, including the delineation of subwatersheds, connectivity, and cross sections, etc.
2) Develop the model data sets using physical measurements, maps, and other appropriate information
3) Perform hydrologic and hydraulic calibration and validation
4) Perform watercourse water quality calibration and validation
5) Perform harbor/estuary and lake water quality calibration
6) Perform production runs as required for project planning
7) Document results.

The purpose of this report is to document the hydrologic and hydraulic calibration and validation for the Menomonee River watershed model (Task 3). The model being used is described in Section 5.0, Model Description. The configuration of the model, including waterbody representation, watershed segmentation, meteorological data, and land cover representation, is described in Section 6.0, Modeling Approach. The modeling process is described in Section 7.0, Calibration and Validation Process, and the calibration and validation results are presented in Section 8.0, Results of Hydrologic Calibration and Validation.

A separate memorandum documents the water quality calibration process and results (Task 4) and similar reports have been prepared for the Root River, Milwaukee River, Oak Creek, and Kinnickinnic River watersheds.

5.0 MODEL DESCRIPTION

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. Many watershed models, including the one used for this project, are also capable of simulating in-stream processes using the land-based calculations as input. Once a model has been adequately set up and calibrated for a watershed it can be used to quantify the existing loading of pollutants from subwatersheds or from land use categories. The model can also be used to simulate the potential impacts of various management alternatives.

The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for the following reasons:

- Existing HSPF models were available for Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds
- HSPF applies to watersheds with rural, suburban, and urban land uses
- HSPF simulates the necessary constituents: TSS, TN (TKN, NH4, NH3, NO3 and NO2), TP, Orthophosphate, Fecal Coliforms, Copper and Zinc (as conservative substances), DO, BOD, TOC, Temperature, Benthic Algae, and Chlorophyll-a.
- HSPF allows long-term continuous simulations to predict hydrologic variability.

- HSPF provides adequate temporal resolution (i.e., hourly or daily) to facilitate a direct comparison to water quality standards
- HSPF simulates both surface runoff and groundwater flows

A brief description of the HSPF model is provided below.

5.1 Overview of HSPF

HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970's and is generally considered one of the most advanced hydrologic and watershed loading models available. The hydrologic portion of HSPF is based on the Stanford Watershed Model (Crawford and Linsley, 1966), which was one of the pioneering watershed models developed in the 1960's. The HSPF framework is developed in a modular fashion with many different components that can be assembled in different ways, depending on the objectives of the individual project. The model includes three major modules:

- PERLND for simulating watershed processes on pervious land areas
- IMPLND for simulating processes on impervious land areas
- RCHRES for simulating processes in streams and vertically mixed lakes.

All three of these modules include many submodules that calculate the various hydrologic and water quality processes in the watershed. Many options are available for both simplified and complex process formulations. Spatially, the watershed is divided into a series of subbasins representing the drainage areas that contribute to each of the stream reaches. These subbasins are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into the pervious (PERLND) and impervious (IMPLND) fractions. The stream network (RCHRES) links the surface runoff and groundwater flow contributions from each of the land segments and subbasins and routes them through the waterbodies using storage routing techniques. The stream/reservoir model includes precipitation and evaporation from the water surfaces, as well as flow contributions from the watershed, tributaries, and upstream stream reaches. Flow withdrawals can also be accommodated. The stream network is constructed to represent all of the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur.

Like the watershed components, several options are available for simulating water quality in the receiving waters. The simpler options consider transport through the waterways and represent all transformations and removal processes using simple first-order decay approaches. More advanced options for simulating nutrient cycling and biological processes are also available. The framework is flexible and allows different combinations of constituents to be modeled depending on data availability and the objectives of the study. A more detailed discussion of HSPF simulated processes and model parameters will be presented in the Menomonee River water quality report and is also available in the HSPF User's Manual (Bicknell et al. 1996).

5.2 Overview of Loading Simulation Program in C++

The Loading Simulation Program, in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms for simulating hydrology, sediment, and general water quality on land as well as in the water column. LSPC is currently maintained by the EPA Office of Research and Development in Athens, Georgia, and during the past several years it has been used to develop hundreds of water quality restoration plans across the country through the Clean Water Act Total Maximum Daily Load (TMDL) Program. A key advantage of LSPC is that it has no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original Menomonee River HSPF model has been migrated to LSPC for the 2020 Facilities Planning Project. A memorandum dated October 18, 2004 (*Confirmation of the Underwood Creek LSPC Model using selected HSPF Modules)* presents the results of a benchmark testing methodology that was developed to compare the underlying computational algorithms of the LSPC model to known HSPF solutions for Underwood Creek. Near identical results were found between the two models.

6.0 MODELING APPROACH

The Menomonee River Watershed encompasses approximately 137 square miles in Milwaukee, Waukesha, Ozaukee and Washington Counties, with approximately 56 square miles of this area contained within Milwaukee County. The entire watershed is contained within the MMSD watercourse planning area. Configuration of the Menomonee River LSPC model involved consideration of five major components: waterbody representation, watershed segmentation, meteorological data, land use representation, and point sources. These components provide the basis for the model's ability to estimate flow and water quality and are described in greater detail below. The entire watershed modeled with LSPC encompasses approximately 129 square miles. The portion of the watershed in the combined sewer service area is not included in the LSPC model because it is treated as a series of point sources and, therefore, runoff from that area is not explicitly modeled. A portion of the watershed is also downstream of the model boundary and is contained within the estuary model.

6.1 Waterbody Representation

The Menomonee River watershed is shown in Figure 1. The watershed contains 12 perennial streams that include the Menomonee River (27.9 miles), the Little Menomonee River (9.6 miles), the Little Menomonee Creek (8.9 miles), Butler Ditch (3.7 miles), the West Branch Menomonee River (1.8 miles), Underwood Creek (8.2 miles), South Branch Underwood Creek (1.1 miles), Dousman Ditch (2.6 miles), Honey Creek (8.8 miles), Woods Creek (1.1 miles), South Menomonee Canal (0.9 mile) and Burnham Canal (0.6 mile). The Menomonee River discharges into the Milwaukee River just upstream of the Milwaukee Harbor, which is tributary to Lake Michigan. The downstream portion of the Menomonee River watershed is almost fully urbanized while the upstream portion is undergoing rapid development.

Modeling an entire watershed requires routing flow and pollutants from upstream portions of the watershed to the watershed outlet through the stream network. In LSPC, the stream network is a tabular representation of the actual stream system. Attribute data pair individual stream segments with a corresponding delineated subbasin. Data associated with individual reaches identify the location of the particular reach within the overall stream network, defining the connectivity of the subwatersheds.

The representation of Menomonee River and its tributaries in LSPC is based on the HSPF model provided by SEWRPC as defined in the SEWRPC/ MMSD MCAMLIS Floodplain Mapping Project. Changes to the original SEWRPC HSPF model are documented in a memorandum dated November 5, 2004 (*Draft Task 1 Deliverables Memorandum and Associated Appendices*). Changes consisted mainly of redirecting runoff from subbasins to different routing reaches. A schematic representation of the final Menomonee River LSPC model is presented in Figure 2. The origin of the HSPF watershed / watercourse model for Menomonee River is described in detail in the April 11, 2003 Technical Memorandum, *Characterize Existing Watershed / Watercourse Models.*

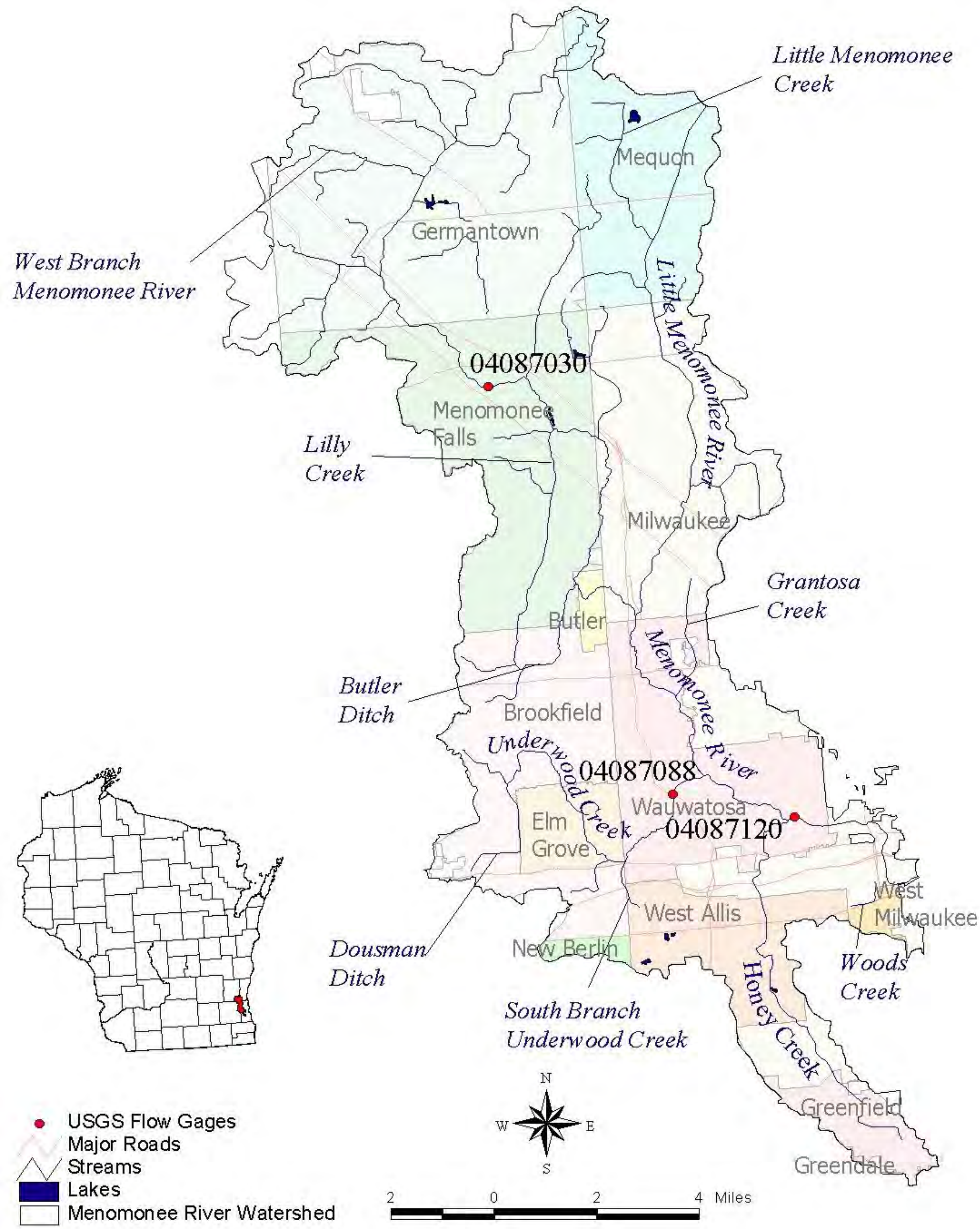


Figure 1. Location of the Menomonee River watershed.

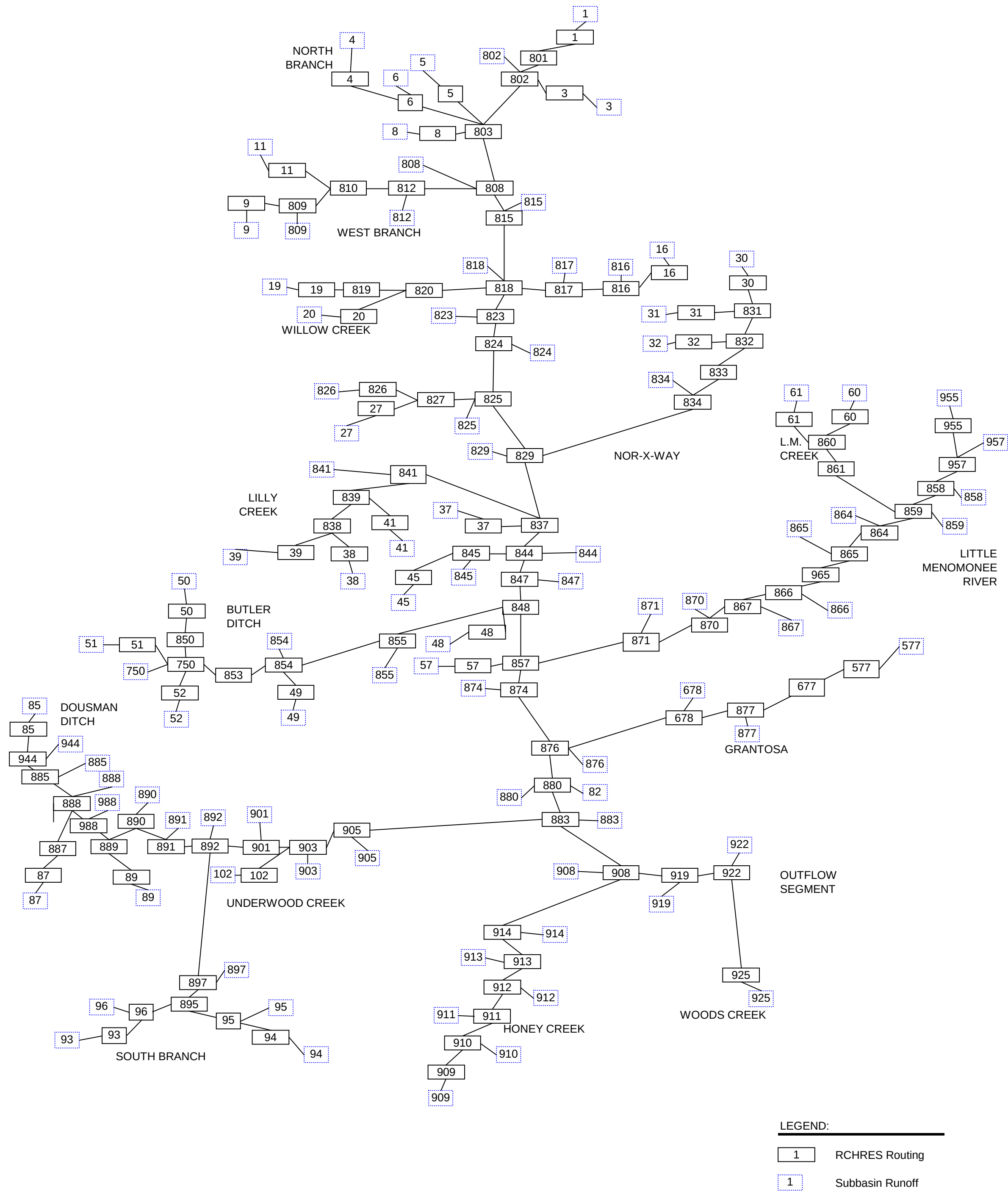


Figure 2. Schematic representation of the Menomonee River LSPC model.

6.2 Watershed Segmentation

LSPC was configured for the Menomonee River to simulate the watershed as a series of 95 hydrologically connected subwatersheds. The delineation of the subwatersheds was based partially on topography but also took into consideration human-influenced drainage patterns. The spatial subdivision of the watershed allows for a more refined representation of pollutant sources and a more realistic description of hydrologic factors. The subwatersheds and primary streams in the Menomonee River watershed are shown in Figure 3.

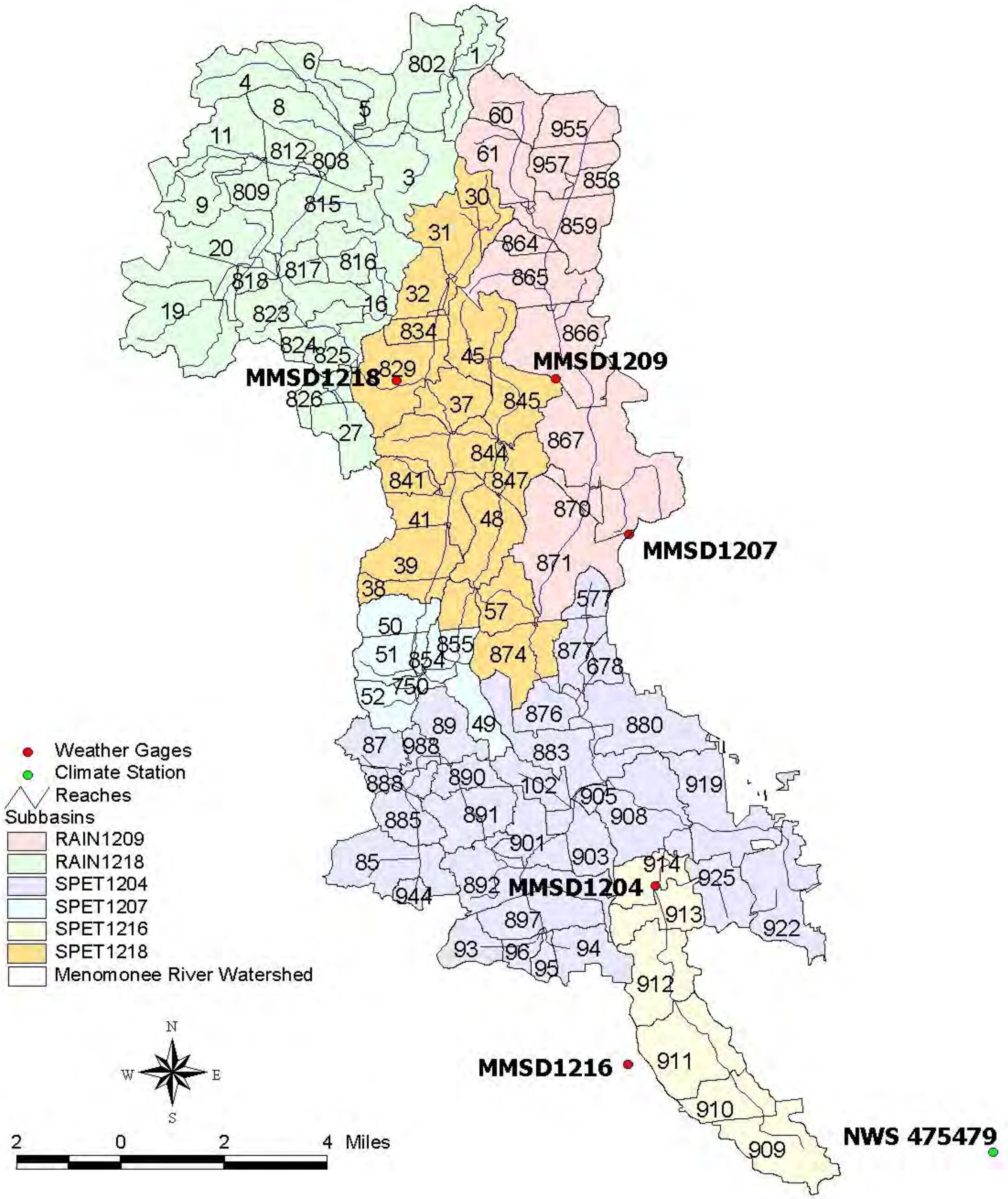


Figure 3. Menomonee River LSPC modeling subwatersheds, location of weather gages, and weather gage assignments.

6.3 Weather Data

Hydrologic processes are time varying and depend on changes in environmental conditions including precipitation, temperature, and wind speed. As a result, meteorological data are a critical component of the watershed model. Appropriate representation of precipitation, wind movement, solar radiation, potential evapotranspiration, cloud cover, temperature, and dew point are required to develop a valid model. These data provide necessary input to model algorithms for hydrologic and water quality representation.

Due to its large size, substantial variability in meteorology is likely to be present across the Menomonee watershed. Precipitation data are taken from five MMSD weather gages (1204, 1207, 1209, 1216, and 1218) and distributed to appropriate areas of the watershed as shown in Figure 3. A single weather gage was assigned to each of the original nine HSPF subwatersheds in consultation with SEWRPC based on the proximity of gages with acceptable data quality.

Air temperature data for the upper portion of the watershed was from the National Weather Service (NWS) Hartford cooperating observer station 473453, while temperatures for the remainder of the watershed and other climatologic series are from the Milwaukee General Mitchell International Airport (NWS 475479).

Other weather data were obtained from Milwaukee General Mitchell International Airport, which is located south of the watershed (Figure 3). Data for the following parameters are based on the Milwaukee Mitchell Field Station for the entire watershed:

- Cloud cover
- Wind movement
- Potential evapotranspiration
- Dew point
- Solar radiation

Precipitation, temperature, cloud cover, wind speed, and dew point are gage monitored, while potential evapotranspiration (PEVT) and solar radiation were computed. Model performance is particularly sensitive to PEVT, as this controls the fraction of precipitation that is evaporated back to the atmosphere. A variety of methods are available for estimation of PEVT, each yielding slightly different results. SEWRPC provided a time series of PEVT calculated for Milwaukee General Mitchell International Airport using the Penman method, which calculates PEVT by first estimating evaporation from a standard Class A pan and then converting it to a PEVT estimate by application of a monthly coefficient. Initial evaluation of calibration results suggested that PEVT was underestimated by the Penman method for the summer period, while use of the alternative Jensen-Haise method (Jensen and Haise, 1963; Jensen et al., 1969) provided a much better fit, especially for the rural areas of the watershed. This method is based on daily air temperature and solar radiation, with a seasonal correction factor, and, unlike the Penman method, does not depend on measured wind speed and relative humidity. Improved fit with this method is likely due to the fact that humidity and wind speed measured at Milwaukee General Mitchell International Airport are imprecise representations of the distribution of these variables over the whole watershed. Further testing suggested, however, that the Jensen-Haise method over-estimates PEVT for the spring period. Therefore, a combined PEVT series was created, using the SEWRPC Penman PEVT estimates for the April-June period and Jensen-Haise estimates for the remainder of the year. The combined PEVT series is used for the upper parts of the Menomonee River watershed that are 35 percent or more rural and the original SEWRPC Penman series are used for the areas of the watershed that are more than 65 percent urban. (Figure 6-3 identifies the subbasins that that use the combined PEVT (RAIN1218 and RAIN1209) and those that use the original SEWRPC Penman time series (SPET1204, SPET1207, SPET1216, and SPET1218).

6.4 Land Use Representation

LSPC requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the basin, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices.

Land cover classifications from the SEWRPC 2000 land use codes were used to develop the land use representation in the LSPC model. Included below is a table that defines specific terminology associated with the processes of deriving land cover classifications from SEWRPC land use codes.

Table 1. Terminology associated with the process of deriving land cover classifications from SEWRPC land use codes.

Land Use Terminology	Definition
Land Use Code	A SEWRPC three-digit code that describes the land use for a specified area.
Land Use Group	A simplification of the land use codes into groups of several land use codes which share hydrologic and water quality characteristics.
Land Use Category	SEWRPC term that corresponds to the definition of land use group, with slight variation in name and number.
Land Cover Classification	A classification of soil composition and natural or manmade land practices which comprises a portion or all of a land use.

The original HSPF models were developed during the MMSD Phase 1 Watercourse Management Plans (WMPs) as documented in the April 11, 2003 Technical Memorandum, *Characterize Existing Watershed / Watercourse Models.*

Six pervious land covers and a single impervious land cover were used to model hydrology and surface runoff in the Phase 1 WMP models. The MMSD Phase 1 WMP model land covers are listed below:

- Impervious
- Lawn / B Soil
- Lawn / C Soil
- Forest
- Agriculture / B Soil
- Agriculture / C Soil
- Wetland

To develop the distribution of these land covers throughout a single subbasin, the following procedures were completed in the Phase 1 WMP Models:

1. The 1990 SEWRPC Land Use Codes were categorized into 20 MMSD Phase 1 WMP land use groups.
2. The 20 MMSD Phase 1 WMP land use groups were reclassified into the seven selected LSPC land covers.
3. The final LSPC land cover input for modeling is an aggregate summation of the reclassified MMSD Phase 1 WMP landuse areas.

This procedure was revised for an expanded number of land use groups (25) and land cover classifications (17 – 6 impervious and 11 pervious) and documented in the October 27, 2003 Technical Memorandum *Definition of HSPF Land Cover Classifications.* Figure 4 displays the distribution of these 25 land use groups within the basin.

The model algorithms require that each land use group be represented as separate pervious and impervious land units. Pervious land uses are further categorized by NRCS hydrologic soil groups. The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting. Typically, clay soils that are poorly drained have lower infiltration rates, while well-drained sandy soils have the greatest infiltration rates. NRCS (2001) has defined four hydrologic groups for soils as listed in Table 2. The final land use representation for the Menomonee River LSPC model is summarized in Table 3 and indicates that the two most common land covers are grasses on C soils (39 percent) and impervious cover associated with commercial land uses (12 percent).

Table 2. NRCS Hydrologic Soil Groups

Hydrologic Soil Group	Description
A	Soils with high infiltrations rates. Usually deep, well drained sands or gravels. Little runoff.
B	Soils with moderate infiltration rates. Usually moderately deep, moderately well drained soils.
C	Soils with slow infiltration rates. Soils with finer textures and slow water movement.
D	Soils with very slow infiltration rates. Soils with high clay content and poor drainage. High amounts of runoff.

Table 3. Land cover in the Menomonee River watershed.

Category	Land Cover	Area		Percent of Watershed
		Acres	Square Miles	
IMPERVIOUS	COMMERCIAL	10009.0	15.64	12.09
	GOVT_INSTIT	479.1	0.75	0.58
	INDUSTRIAL	1567.9	2.45	1.89
	RESIDENTIAL	3340.5	5.22	4.04
	TRANS_FREE	879.7	1.37	1.06
	ULTRA_LOW	609.4	0.95	0.74
PERVIOUS	CROP_B	3986.2	6.23	4.82
	CROP_C	6161.3	9.63	7.44
	CROP_D	448.9	0.70	0.54
	FOREST	3139.3	4.91	3.79
	GRASS_B	7260.1	11.34	8.77
	GRASS_C	32337.0	50.53	39.06
	GRASS_D	756.4	1.18	0.91
	PASTURE_B	1374.4	2.15	1.66
	PASTURE_C	2412.3	3.77	2.91
	PASTURE_D	238.7	0.37	0.29
	WETLAND	7784.6	12.16	9.40
	Total	**82784.9**	**129.35**	**100**

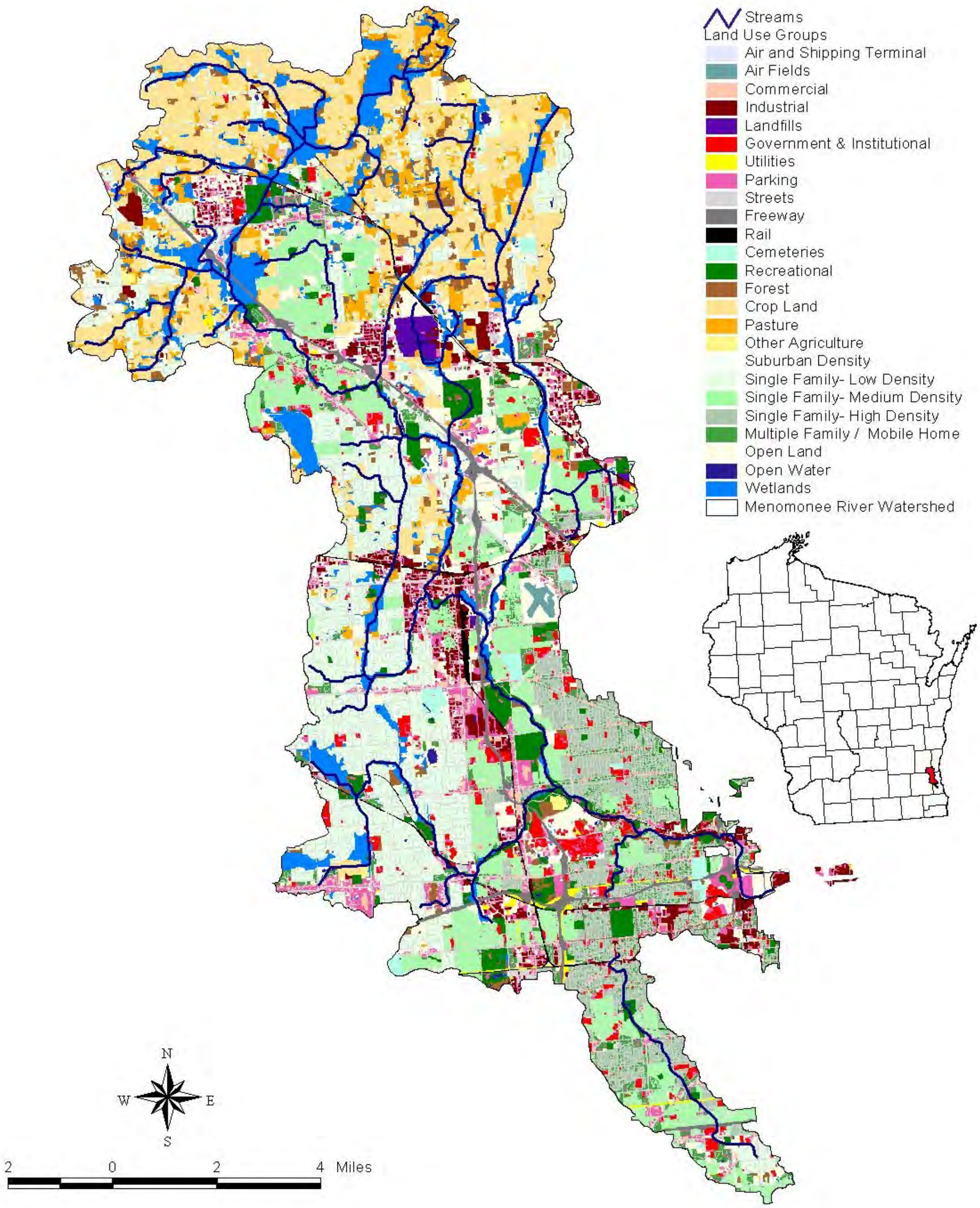


Figure 4. Modeling land uses in the Menomonee River watershed.

6.5 Point Sources

There are a number of "point sources" in the Menomonee River watershed. These consist of sanitary sewer overflows (SSOs), three combined sewer overflow (CSO) discharges, and discharges from 55 industrial facilities. Flows from these point sources were input directly into the LSPC model using the methodology outlined in the April 9, 2004 memorandum entitled *Point Source Loading Calculations for Purposes of Watercourse Modeling*.

7.0 CALIBRATION AND VALIDATION PROCESS

The model calibration and validation processes are described in this section. Background information on the locations of available flow data and the time periods of calibration/validation are first presented, followed by a description of how key parameters were modified.

7.1 Background

Hydrologic calibration of the Menomonee River model was performed after configuring the LSPC model. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. For LSPC, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. It is required for parameters that cannot be deterministically and uniquely evaluated from topographic, climatic, physical, and chemical characteristics of the watershed and compounds of interest. Fortunately, the majority of LSPC parameters do not fall in this category. Calibration is based on several years of simulation to allow parameter evaluation under a variety of climatic conditions. The calibration procedure results in parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period.

Calibration included the comparison of monthly, seasonal, and annual values, and individual storm events. All of these comparisons must be evaluated for a proper calibration of hydrologic parameters. In addition, simulated and observed stream flow values were analyzed on a frequency basis and their resulting cumulative distributions (e.g., flow duration curves) compared to assess the model behavior and agreement over the full range of observations.

Model validation tested the calibrated model using input from a different time period, without further parameter adjustment. If the model cannot properly simulate conditions for the independent data set, the calibration is not acceptable and requires additional work until validation is achieved. As described in the January 14, 2004 *Watershed and Receiving Water Quality Model Calibration and Validation Data and Procedures* memorandum, the calibration time period was January 1, 1995 through December 31, 1998. The validation time period was January 1, 1999 through December 31, 2002. To permit model spin up time and minimize numerical errors inherent in modeling, the model was run for the time period January 1, 1993 through December 31, 1998 for calibration purposes.

The model calibration and validation for the mainstem was performed using the flow record from the USGS gages along the Menomonee River at Pilgrim Road in the Village of Menomonee Falls (04087030) and at 70th Street in the City of Wauwatosa (04087120). Additional checks were made against gaging on Underwood Creek at USH 41 in the City of Wauwatosa (04087088). Figure 1 shows the location of these gages.

7.2 Initial Calibration

Hydrologic calibration involved a comparison of observed data from the in-stream USGS flow gaging station to modeled in-stream flow and an adjustment of key hydrologic parameters. Various modeling parameters were varied within physically realistic bounds and in accordance to observed temporal trends and land use classifications. An attempt was made to remain within the guidelines for parameter values set out in BASINS Technical Note 6 (USEPA, 2000). Hydraulic calibration was undertaken simultaneously across the Menomonee River, Oak Creek, and Kinnickinnic River watersheds with the intention of developing a unified parameter set in which most variations between watersheds are explained by documented differences in land use and physical parameters such as soil characteristics. This cross-sectional calibration approach helps ensure a robust parameter set that is not unduly biased by anomalies in individual gage records. It was found to be necessary to address some variations in parameter values between watersheds to optimize fit; however, the large majority of parameters are derived as a unified set.

Graphical results of model performance and error statistics were evaluated following each model simulation run. Model parameters were adjusted following each iteration to improve model performance. The parameters that were adjusted include those that account for the partitioning of surface versus subsurface flow, infiltration rate, surface and subsurface storage, evapotranspiration, and surface runoff. A discussion of the key parameters and how they were adjusted is presented below.

The model performance is most sensitive to the specification of the water-holding capacity of the soil profile (expressed through LZSN, the nominal lower-zone storage) and the infiltration rate index (INFILT), which together control the partitioning of water between surface and subsurface flow. LZSN is an index of nominal storage of water in the soil zone subject to evapotranspiration (root depth plus capillary fringe), while LZS represents the actual water storage in this zone. LZSN is often characterized as the median of field capacity storage in this zone (i.e., available water capacity times rooting depth with capillary fringe). Functionally, however, the meaning of LZS and LZSN may differ somewhat from this ideal interpretation. LZS does represent the depth of water that is available for transpiration from the soil; however, this value may exceed LZSN by a significant amount. More important is the ratio LZRAT (LZS/LZSN). This ratio (in inverse form) first determines the variation of actual infiltration rate relative to the nominal value, INFILT. LZRAT also determines the rate at which water percolates from the lower soil zone to groundwater. LZSN thus varies with precipitation pattern as well as vegetation type. In addition, it is difficult to relate LZSN to a single vegetation type, because a dominant vegetation (e.g., grass) with a low rooting depth may also contain other plants (e.g., trees) with a much greater rooting depth, which increases the amount of soil moisture that is available for ET. As a result, while initial values of LZSN can be estimated from soils and vegetation data, final values must be determined through calibration.

Viessman et al. (1989) suggest as initial estimates for LZSN a value between one-quarter and one-eighth of the annual rainfall plus four inches. USEPA (2000) show typical values for LZSN ranging from 5 inches to 14 inches in typical applications. Values found through calibration for the Menomonee watershed are well within this range. A uniform value of 9 inches for LZSN provided reasonable results in initial calibration of the Menomonee, but some further refinement was undertaken during model re-calibration.

INFILT in LSPC is an *index* of infiltration rate and is not directly interpretable from measured field infiltration rates. BASINS Technical Note 6 recommends values in the range of 0.1-0.4 for B soils, 0.05-0.1 for C soils, and 0.01-0.05 in/hr for D soils. Values were re-optimized by starting from the center of the recommended ranges and modifying the value for each soil class proportionately – yielding final values of 0.365, 0.105-0.125, and 0.055-0.075 for B, C, and D soils, respectively. For D soils, the higher values were applied to tilled agriculture, while the lower values were applied to grass and pasture; for C soils the lower values were applied to pasture only.

Key parameters for the subsurface flow response include the ground water recession coefficient (AGWRC), and the interflow inflow and recession parameters (INTFW and IRC). AGWRC was set by optimizing model performance for baseflow recession. Interflow volume and persistence should be comparatively low in the urban portions of this landscape, so for urban grass on C soils the INTFW was set to 1.0 and the IRC was set to 0.3; higher values of these parameters were used to model other land uses.

Monthly variability in hydrologic response was specified by setting monthly values for the upper zone nominal soil storage, lower zone ET intensity factor, and interflow recession coefficient. In each case, the values specified are consistent with recommendations in BASINS Technical Note 6, as well as experience in calibrating multiple LSPC models for the Minnesota River basin (Tetra Tech, 2002).

For the winter simulation, the model is very sensitive to parameters that control snow accumulation and snowmelt. Considerable uncertainty is present in hydrologic models when temperatures are near the transition point between liquid and frozen precipitation, and prediction of rain-on-snow melting events can be particularly difficult. Key calibration parameters for the winter snow simulation were revised from defaults during optimization and included the snow catch factor (CCFACT, ratio that accounts for under-catch of snow in standard precipitation gages), the field adjustment parameter for heat accumulation in the snow pack (CCFACT), the maximum rate of snow melt by ground heating (MGMELT), and the depth of snow at which all land area is considered to be covered (COVIND, set to a higher value for impervious lands to account for snow removal/consolidation).

7.3 Model Re-Calibration

All Ftables, stream reach characteristics, and land use assignments were carefully reconciled with the latest information from SEWRPC, resulting in various changes in the model that affect the March 4, 2005 calibration. While much of the uncertainty in the March 4, 2005 calibration appeared to be due to spatial variability in precipitation depth and the timing of snowmelt, there was also improvement to be made in the parameter specification. In particular, it seemed advisable to address the relatively poor calibration fit observed for Underwood Creek. It was found, however, that this could not be accomplished while maintaining a single consistent set of parameters across the entire watershed. Therefore, the model was broken into two groups, with slightly different parameters: the upstream, less urban area consisting of the Upper Menomonee, Willow Creek, Little Menomonee, Lily Creek, and Middle Menomonee watersheds, and the downstream, more urban area consisting of the Underwood Creek, Honey Creek, Butler Ditch, and Lower Menomonee watersheds. Parameters between the two groups differ primarily in regard to urban grass and urban impervious surface.

This was accomplished by varying the parameters for urban grass (which dominates the pervious surface in the Underwood Creek watershed) consistent with findings in the calibration for the Kinnickinnic River, while adjusting several of the parameters for agricultural lands in the opposite direction to retain fit at the Menomonee Pilgrim Road gage. A discussion of the key parameters and how they were adjusted is presented below:

- The groundwater recession coefficient for urban grass (AGWRC) was increased, with higher values assigned in the downstream group.
- LZSN for grass was reduced from 9 to 8 inches in the downstream group, where soil compaction is likely to reduce soil ET. (Note, while urban grasses typically have rather small rooting depths, the “grass” landuse class also typically includes shrubs and trees with deeper roots.)
- Interflow inflow (INTFW) for grass was reduced to the range of 0.4 to 0.5 for the downstream group, again reflecting the likely role of soil compaction in urban areas.
- KVARY (the parameter that controls the nonlinear shape of the recession) on grass was reduced to 0.
- Snow catch factors were reduced in the downstream group. This reflects the potential influence of out-of-basin snow removal.
- Impervious surface retention coefficients were increased in the downstream group. This compensates for the presence of some unsimulated stormwater retention facilities.
- Losses to deep groundwater from pervious lands other than wetlands were increased in the downstream area.

The revised calibration and validation results are presented and discussed in the next section.

8.0 RESULTS OF HYDROLOGIC CALIBRATION AND VALIDATION

The model calibration results are presented in this section both graphically and statistically. Graphical comparisons are extremely useful for judging the results of model calibration because time-variable plots of observed versus modeled flow provide insight into the model's representation of storm hydrographs, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. Graphing model results with precipitation data can also provide insights into how the model reacts to different storms.

Graphical comparisons consist of time series plots of observed and simulated values for flows, observed versus simulated scatter plots with a 45^{o} linear regression line displayed, and cumulative frequency distributions (flow duration curves). Statistical comparisons focus on the relative error method. A small relative error indicates a better goodness of fit for calibration. Secondly, results from correlation tests (e.g. linear correlation coefficient, coefficient of model-fit efficiency, etc.) are also presented. A comparison of simulated and observed storm hydrographs for selected storm events is addressed in a separate memorandum.

8.1 Tolerances

Model tolerance values for this project have been identified and are described in the January 14, 2004 *Watershed and Receiving Water Quality Model Calibration and Validation Data and Procedures* memorandum and in the December 18, 2002, *MMSD Comprehensive Modeling and Real Time Control Strategies* Technical Memorandum 2.4. Hydrologic parameters to be calibrated include annual flow volumes, low flow volumes, storm flow volumes, and seasonal flow volumes. The following tolerances (i.e., accepted level of error between modeled and observed flows) are used:

Total runoff volume: ± 10 percent
High flow volumes: ± 15 percent
Low flow volumes: ± 10 percent
Seasonal flow volumes: ± 20 percent
Error in storm volumes: ± 20 percent[1]

The same tolerances are used for model validation. Error statistics are calculated for each month and year of the calibration time period; however, a calibration is deemed appropriate when the tolerances for the entire calibration period have been met. The same applies for the validation period.

8.2 Calibration and Validation Results

The calibration and validation results are presented below in Figure 5 to Figure 64 and Table 4 to Table 15. The changes described in Section 7.2 result in a much better fit on Underwood Creek, with little change at the upstream Pilgrim Road gage. Results at 70th Street differ from the March 4, 2005 draft calibration in large part due to the changes in land area specification and routing identified by SEWRPC. Certain problems remain with the final model. In particular, mid-range flows are over-predicted at 70th Street during the validation period, while high flows are under-predicted for the validation period at Pilgrim Road. These problems are likely to be mostly due to extrapolation from a limited number of point rainfall stations, which are not always representative of total precipitation across a large watershed, particularly during summer convective storms. In addition, low flows tend to be slightly under predicted, perhaps due to unmonitored urban low flow sources such as lawn watering, car washing, or other dry weather water use.

The quality of hydrologic model fit for individual daily observations is summarized by the Nash-Sutcliffe coefficient of model fit efficiency (E). This parameter ranges from minus infinity to 1, with higher values indicating better fit, and is formed as the ratio of the mean square error to the variance in the observed data, subtracted from unity. A value of 0 implies that the observed mean is as good a predictor as the model. Values close to 1 are thus desirable. It should be recalled, however, that the Nash-Sutcliffe coefficient is based on matched daily records, and does not account for phase errors. It is also subject to leverage by outliers. Thus, if a large flow is estimated with the right magnitude, but off by one day, this can substantially degrade the Nash-Sutcliffe coefficient, even though annual sums and flow duration percentiles are unaffected.

---

[1] A comparison of simulated and observed storm hydrographs for selected storm events will be addressed in a separate memorandum.

The Nash-Sutcliffe coefficient was not used in the model calibration process. Therefore, it is appropriate to use it as post-validation model evaluation tool applied over the entire calibration and validation period of 1995-2002. Results for the Menomonee River gages are shown in Table 16 and indicate acceptable results for all three gages.

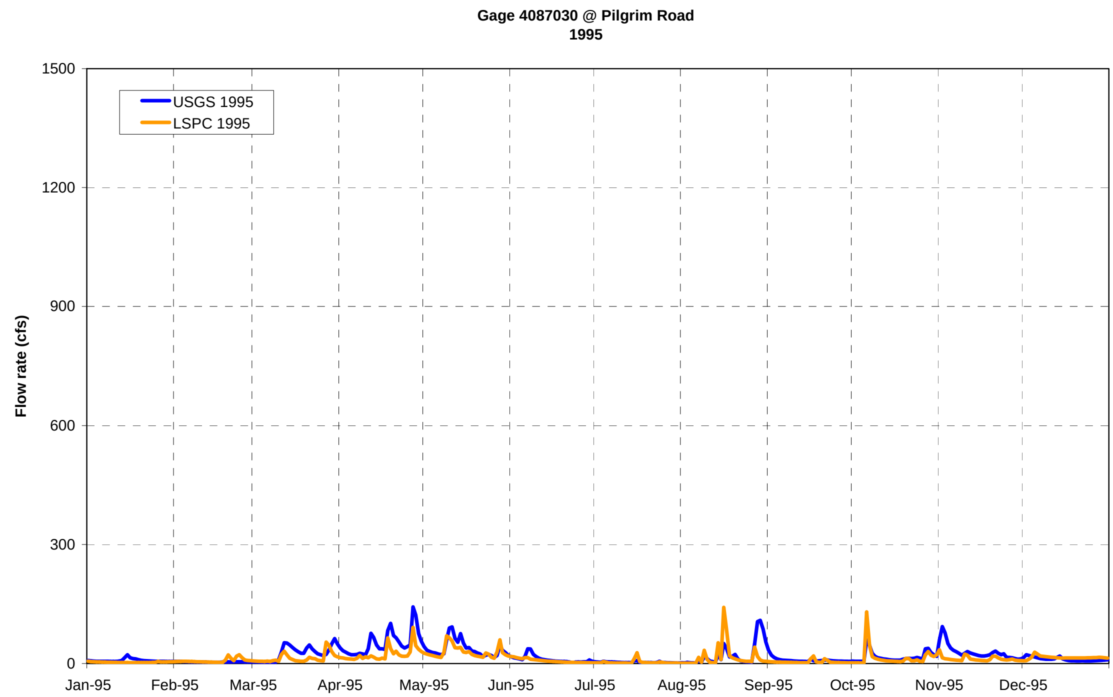


Figure 5. Time series hydrologic calibration results (daily mean) for Menomonee River at USGS gage 04087030 (1995).

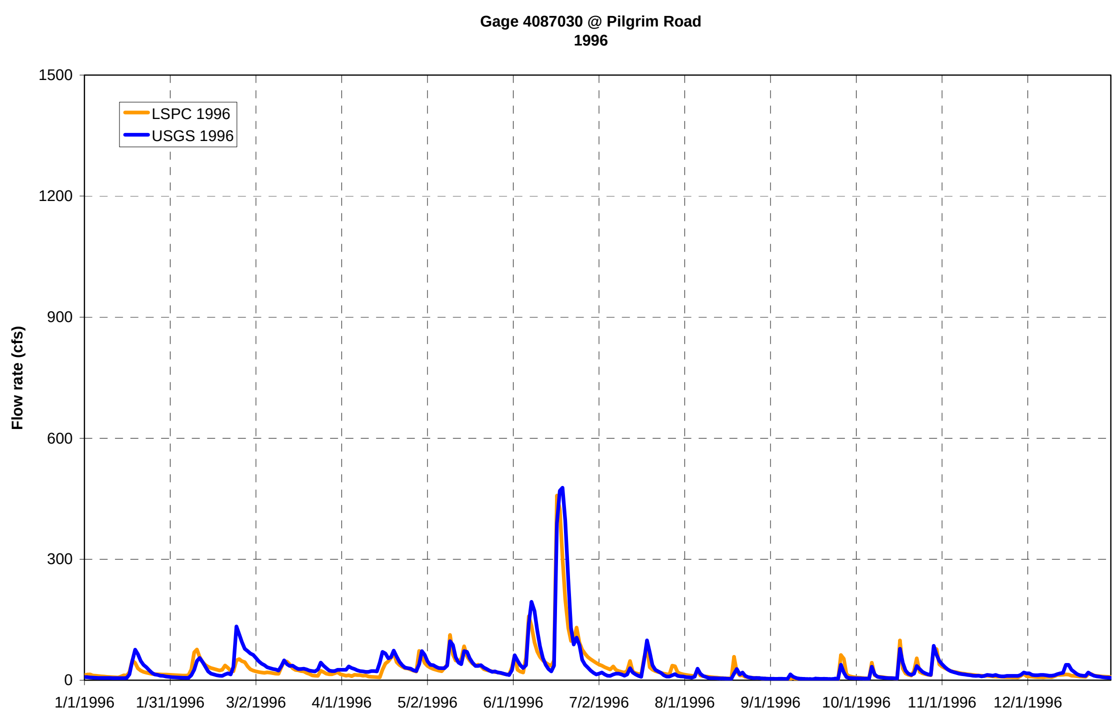


Figure 6. Time series hydrologic calibration results (daily mean) for Menomonee River at USGS gage 04087030 (1996).

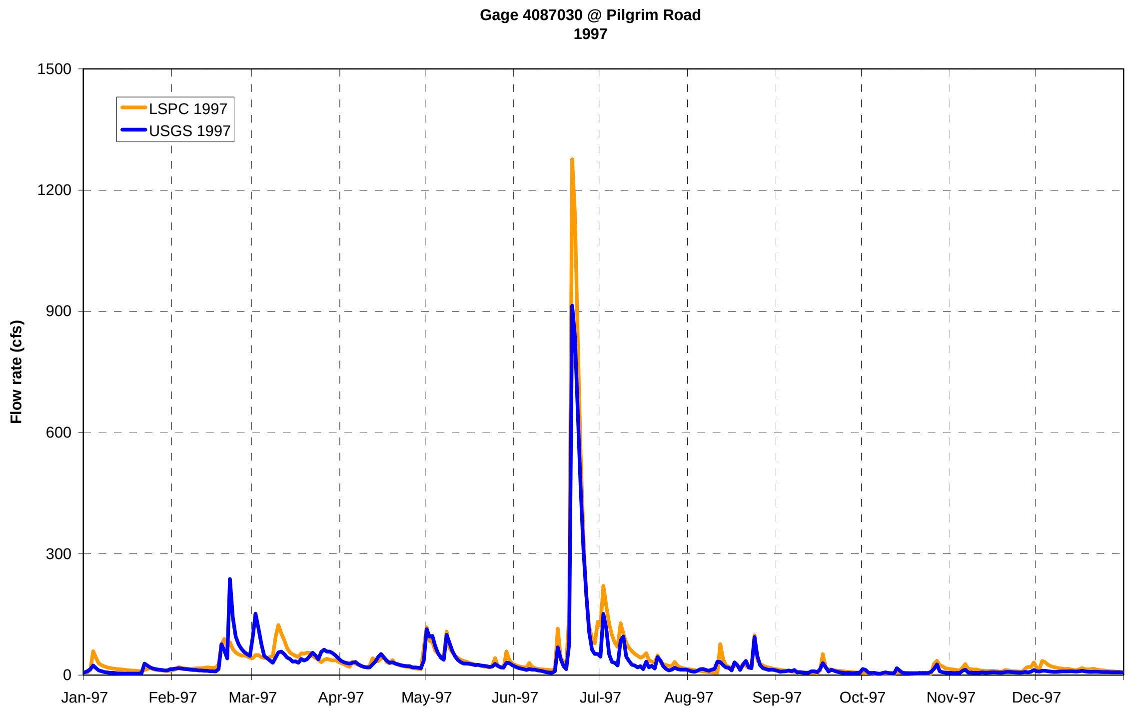


Figure 7. Time series hydrologic calibration results (daily mean) for Menomonee River at USGS gage 04087030 (1997).

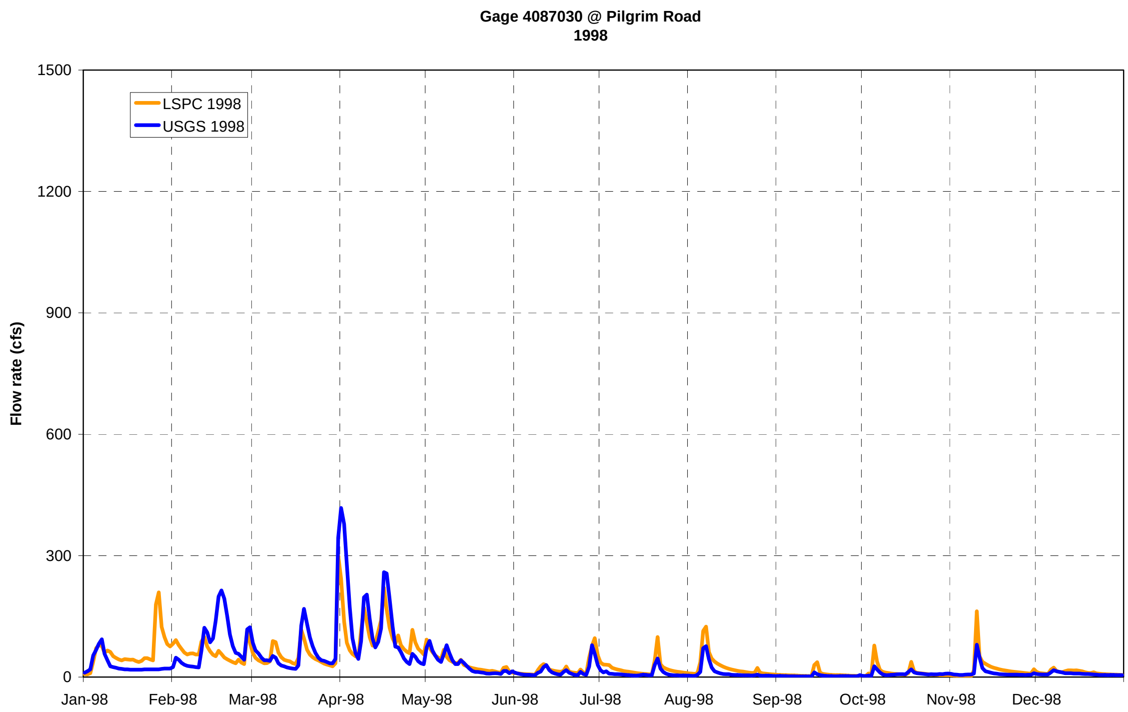


Figure 8. Time series hydrologic calibration results (daily mean) for Menomonee River at USGS gage 04087030 (1998).

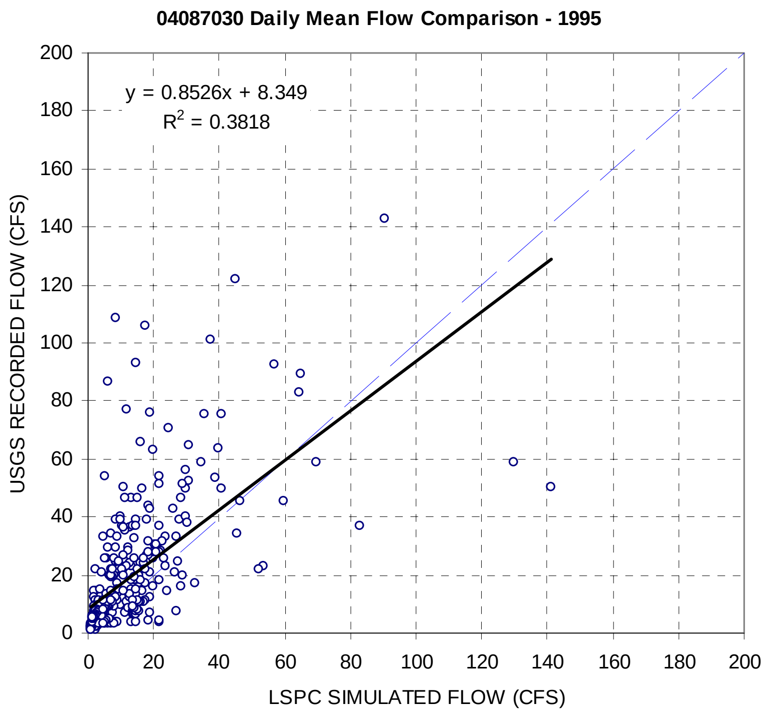


Figure 9. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087030 (1995).

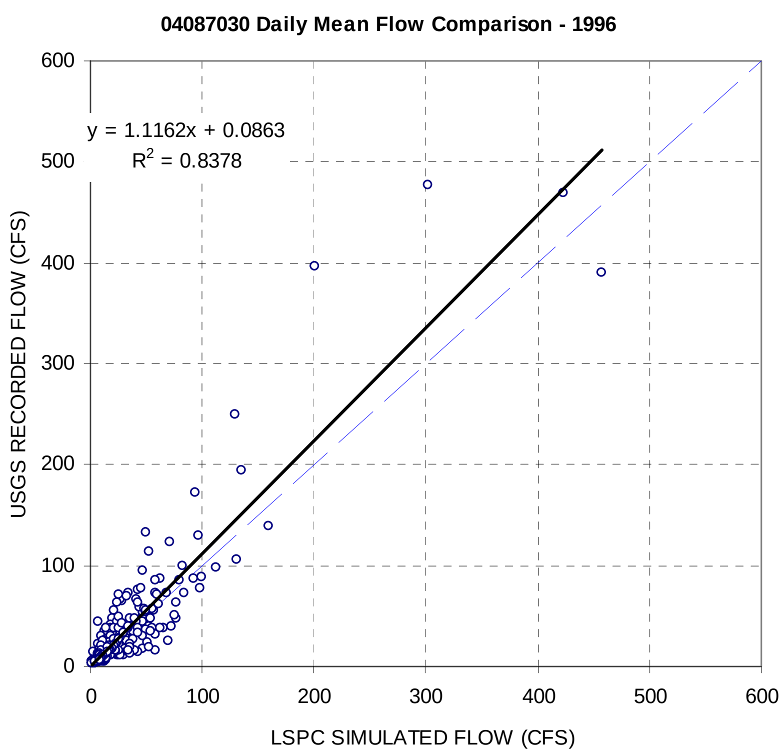


Figure 10. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087030 (1996).

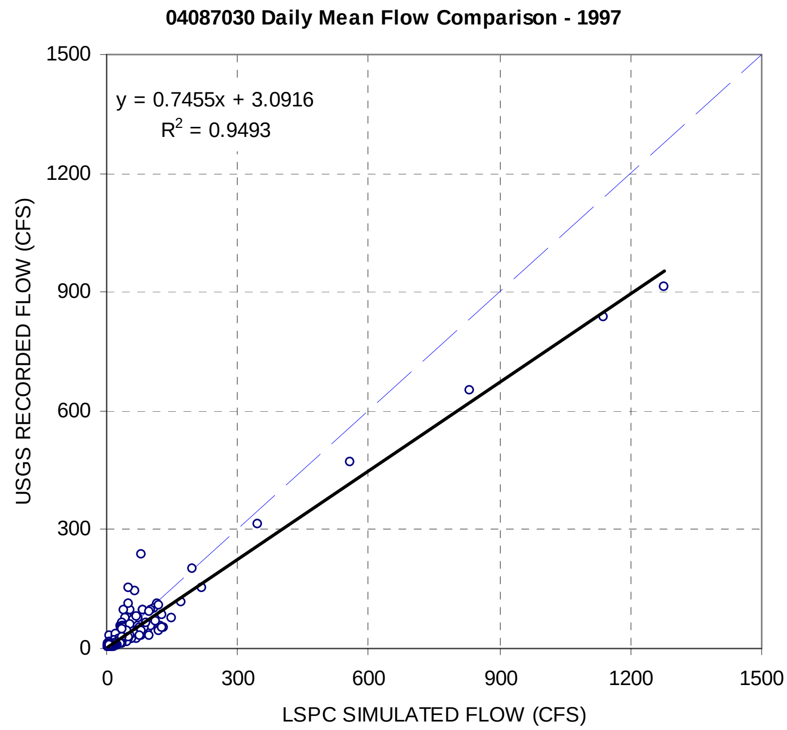


Figure 11. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087030 (1997).

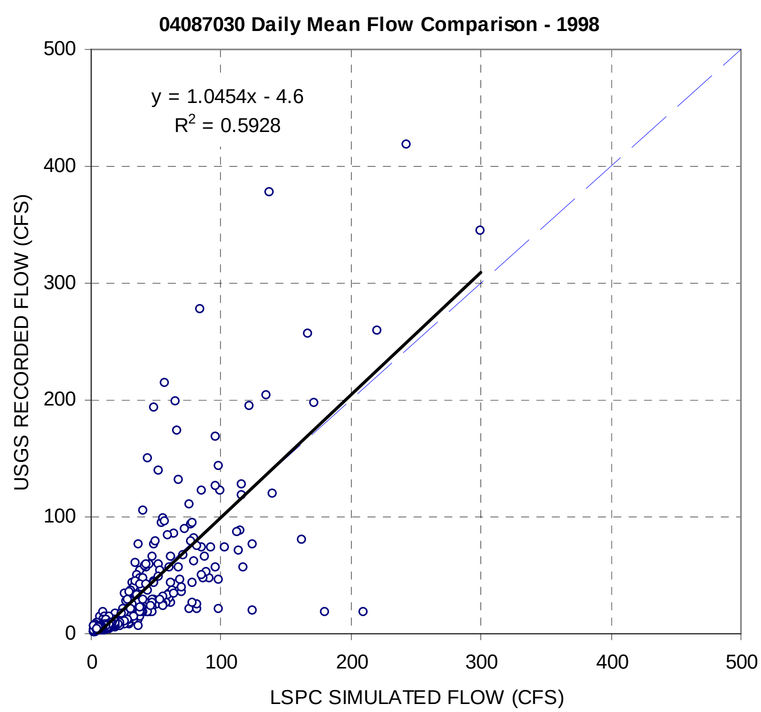


Figure 12. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087030 (1998).

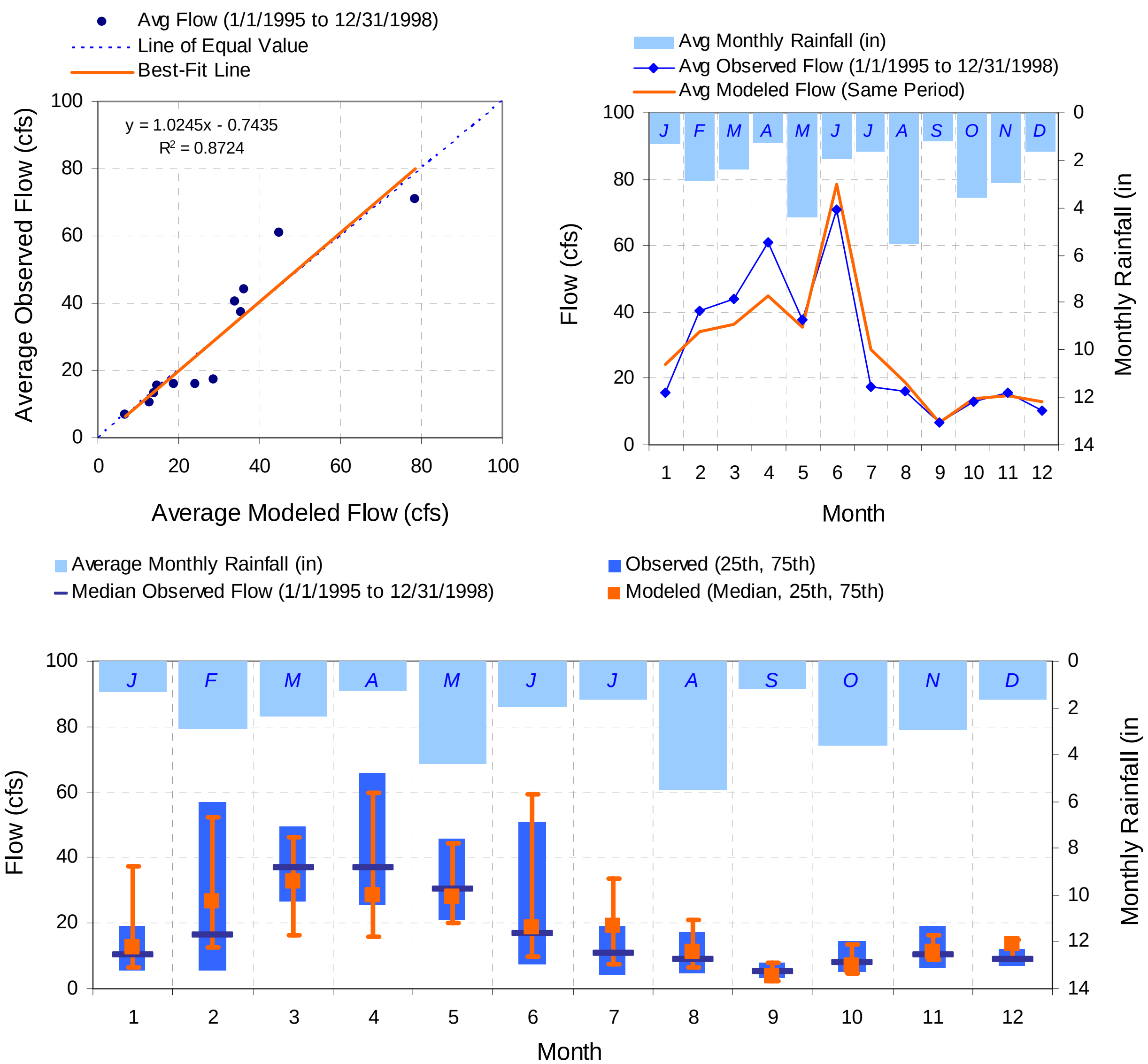


Figure 13. Composite (average monthly) hydrologic calibration results for Menomonee River at USGS gage 04087030 (1995 to 1998).

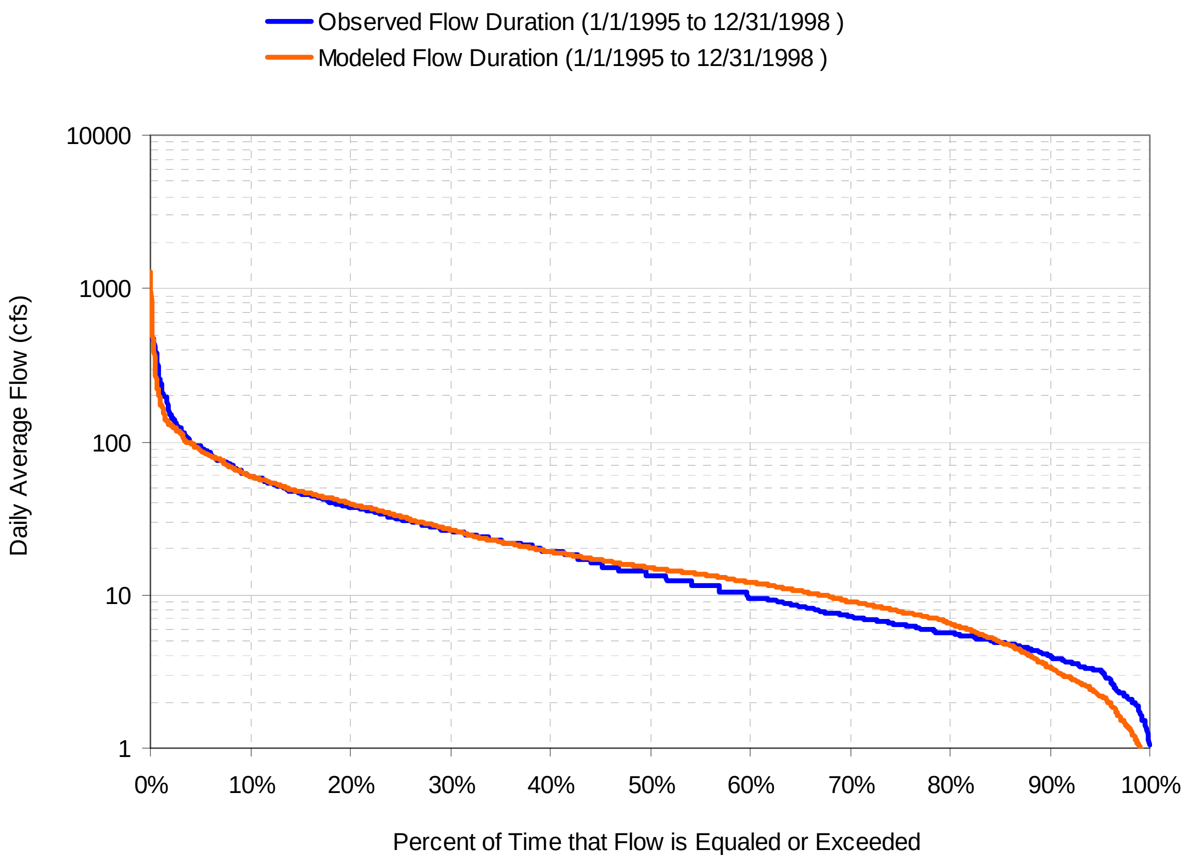


Figure 14. Flow duration curve hydrologic calibration results for Menomonee River at USGS gage 04087030 (1995-1998).

Table 4. Error statistics for hydrologic calibration results for Menomonee River at USGS gage 04087030 (1995-1998).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1995			1996			1997			1998			TOTAL		
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month JAN	455	192	-57.9%	1,043	966	-7.3%	635	999	57.3%	1,743	3,760	115.7%	3,876	5,917	52.6%
FEB	213	401	88.0%	1,963	1,857	-5.4%	2,278	1,920	-15.7%	4,602	3,442	-25.2%	9,057	7,620	-15.9%
MAR	1,619	832	-48.6%	2,035	1,341	-34.1%	3,304	3,241	-1.9%	3,917	3,519	-10.2%	10,875	8,933	-17.9%
APR	3,055	1,384	-54.7%	2,192	1,549	-29.3%	1,681	1,657	-1.4%	7,583	6,092	-19.7%	14,511	10,682	-26.4%
MAY	2,282	1,773	-22.3%	2,432	2,271	-6.6%	2,601	2,691	3.5%	1,901	2,013	5.9%	9,216	8,749	-5.1%
JUN	626	417	-33.3%	7,308	6,312	-13.6%	8,020	10,718	33.6%	905	1,274	40.9%	16,859	18,722	11.1%
JUL	186	176	-5.4%	1,296	1,734	33.8%	2,237	3,880	73.4%	552	1,245	125.4%	4,272	7,035	64.7%
AUG	1,349	1,036	-23.3%	541	654	20.8%	1,319	1,383	4.8%	721	1,552	115.4%	3,931	4,625	17.6%
SEP	511	240	-53.0%	358	399	11.3%	555	640	15.3%	159	374	135.1%	1,583	1,653	4.4%
OCT	1,021	897	-12.1%	1,261	1,317	4.5%	454	476	4.9%	515	742	43.9%	3,251	3,432	5.6%
NOV	1,721	698	-59.4%	889	832	-6.4%	422	798	89.2%	683	1,193	74.7%	3,715	3,521	-5.2%
DEC	660	923	39.9%	911	624	-31.6%	528	954	80.4%	480	694	44.8%	2,579	3,195	23.9%

Season	Recorded USGS Volume (ac-ft)	Simulate d LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulate d LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulate d LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Jan-Mar	2,287	1,425	-37.7%	17.7%	5,041	4,164	-17.4%		6,217	6,161	-0.9%		10,263	10,721	4.5%		**23,808**	**22,470**	**-5.6%**	
Apr-Jun	5,963	3,575	-40.0%	20.0%	11,932	10,132	-15.1%		12,302	15,067	22.5%	2.5%	10,389	9,379	-9.7%		**40,586**	**38,153**	**-6.0%**	
Jul-Sep	2,046	1,452	-29.1%	9.1%	2,196	2,787	26.9%	6.9%	4,111	5,902	43.6%	23.6%	1,432	3,171	121.4%	101.4%	**9,786**	**13,312**	**36.0%**	**16.0%**
Oct-Dec	3,402	2,518	-26.0%	6.0%	3,061	2,773	-9.4%		1,404	2,228	58.6%	38.6%	1,678	2,629	56.7%	36.7%	**9,545**	**10,148**	**6.3%**	

Calibration Tolerance =20%

	Recorded USGS Volume (ac-ft)	Simulate d LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulate d LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulate d LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	13,698	8,970	-34.5%	24.5%	22,230	19,855	-10.7%	0.7%	24,035	29,357	22.1%	12.1%	23,761	25,900	9.0%		**83,725**	**84,083**	**0.4%**	

Calibration Tolerance =10%

Table 5. High-Low flow error statistics for hydrologic calibration results for Menomonee River at USGS gage 04087030 (1995-1998).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	37,768	39,737	-5.0%	15%
Total Highest 20% volume	51,864	53,470	-3.0%	15%
Total Highest 50% volume	72,772	73,873	-1.5%	15%
Total Lowest 10% volume	626	844	-25.9%	10%
Total Lowest 30% volume	4,343	4,121	5.4%	10%
Total Lowest 50% volume	11,401	9,986	14.2%	10%

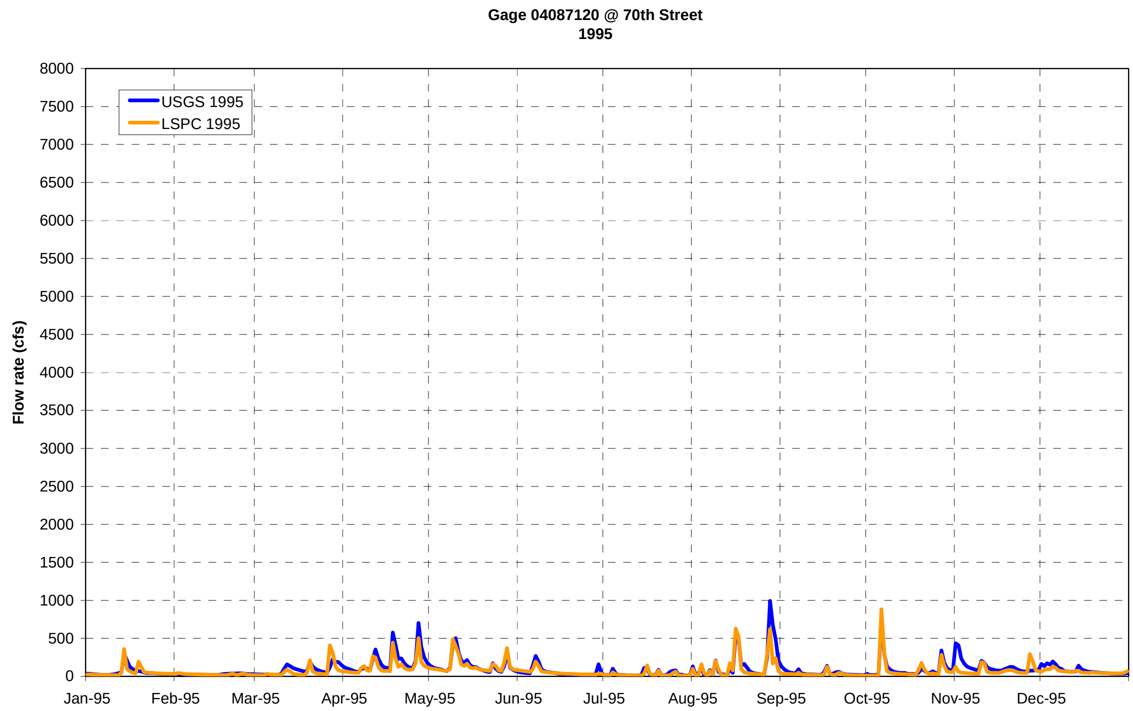


Figure 15. Time series hydrologic calibration results (daily mean) for Menomonee River at USGS gage 04087120 (1995).

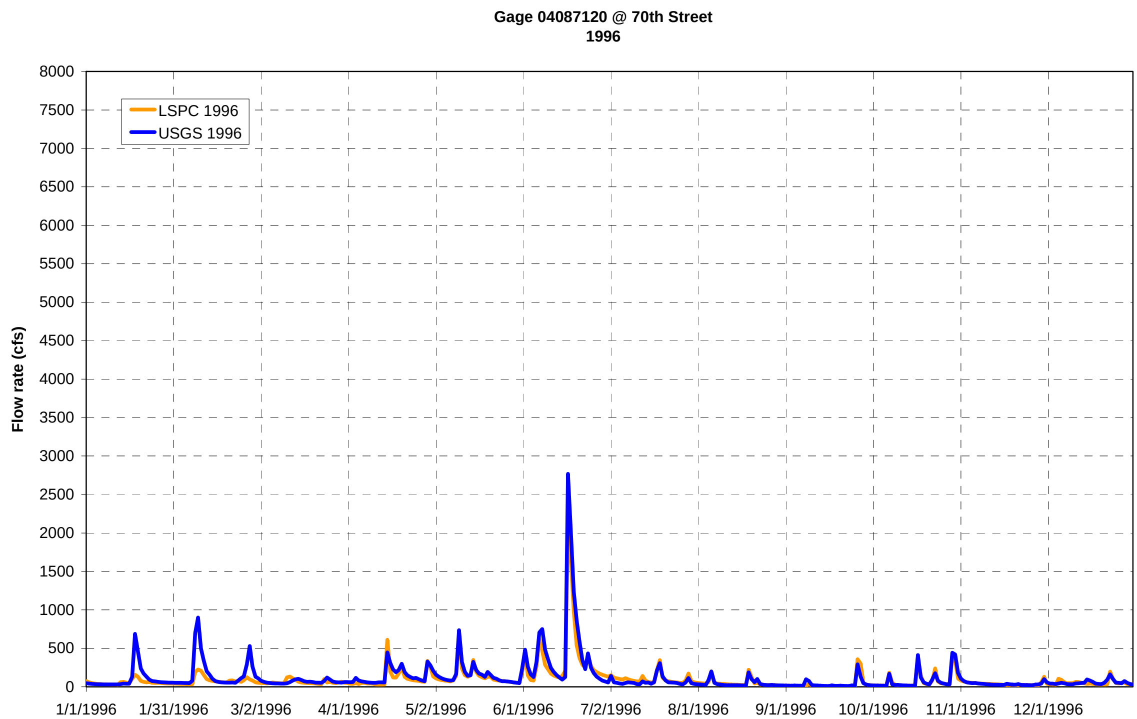


Figure 16. Time series hydrologic calibration results (daily mean) for Menomonee River at USGS gage 04087120 (1996).

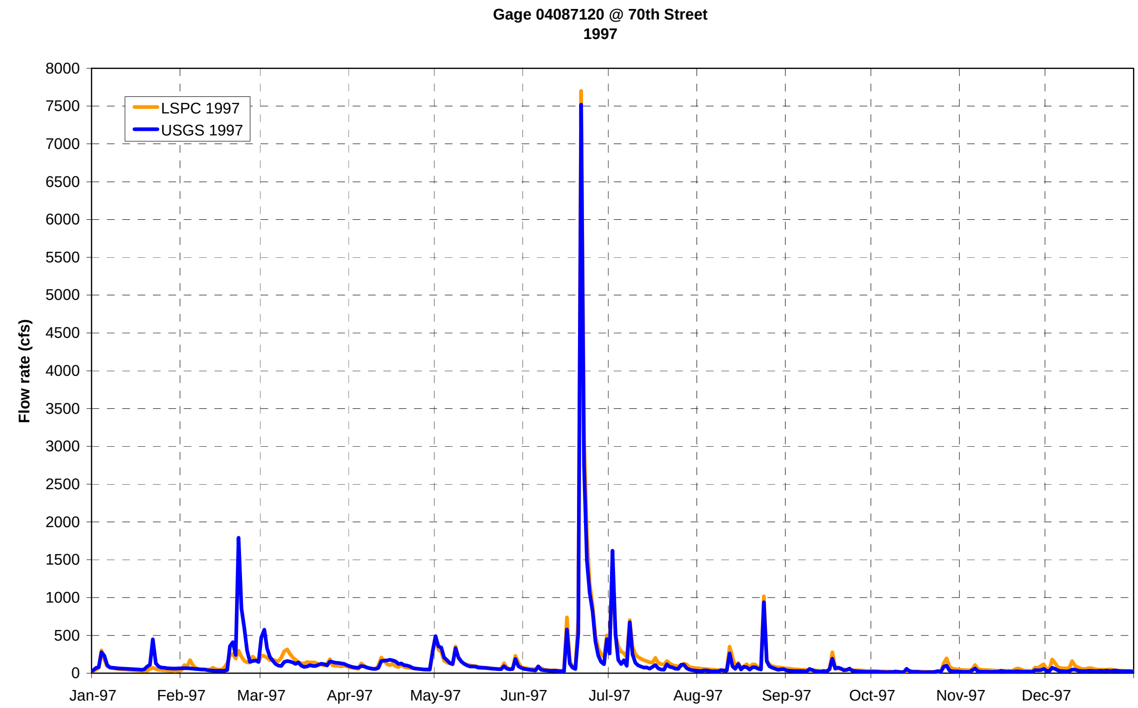


Figure 17. Time series hydrologic calibration results (daily mean) for Menomonee River at USGS gage 04087120 (1997).

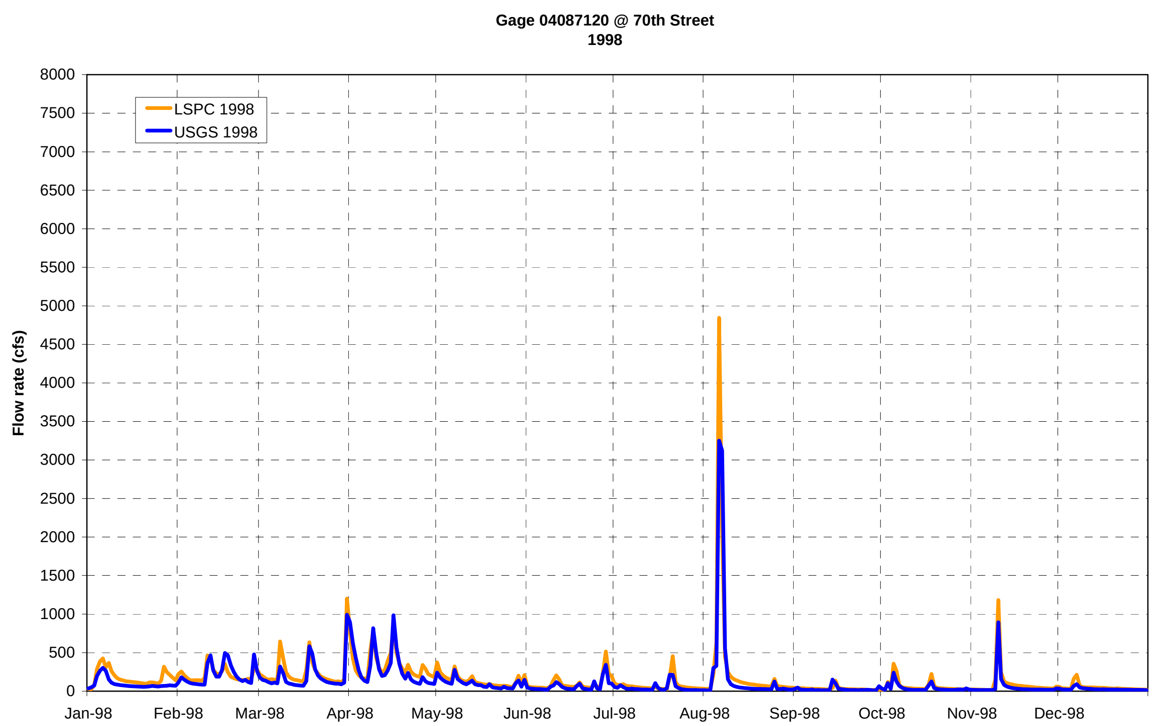


Figure 18. Time series hydrologic calibration results (daily mean) for Menomonee River at USGS gage 04087120 (1998).

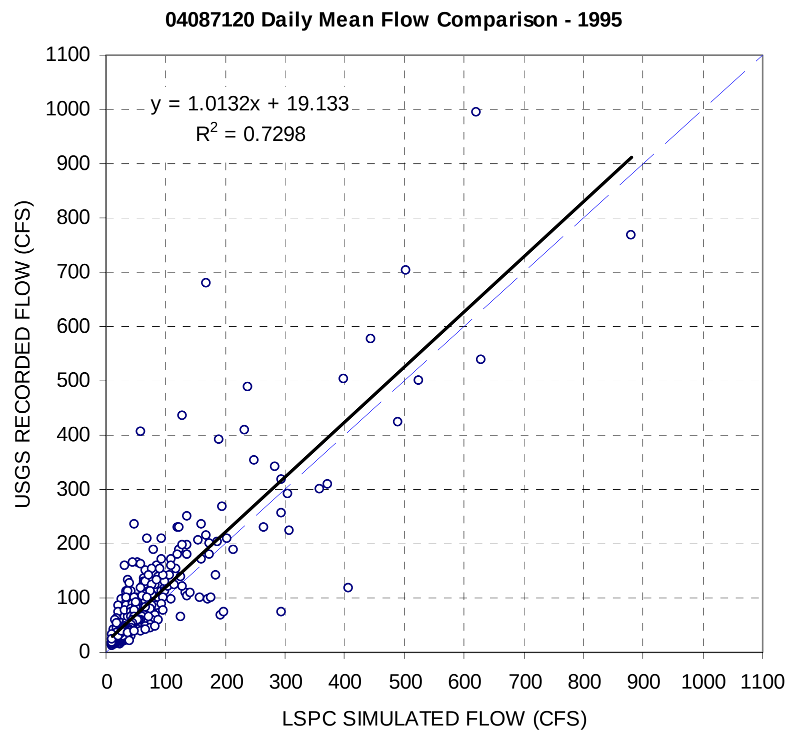


Figure 19. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087120 (1995).

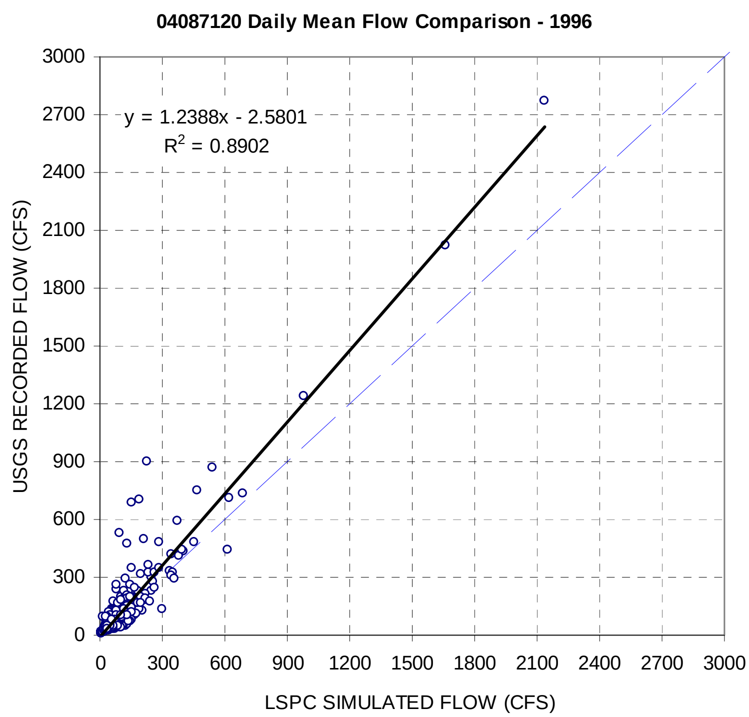


Figure 20. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087120 (1996).

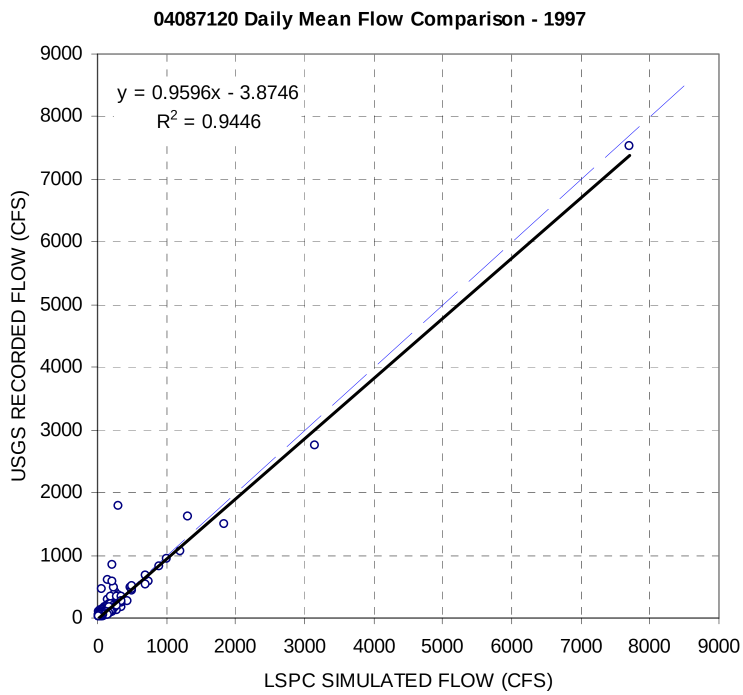


Figure 21. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087120 (1997).

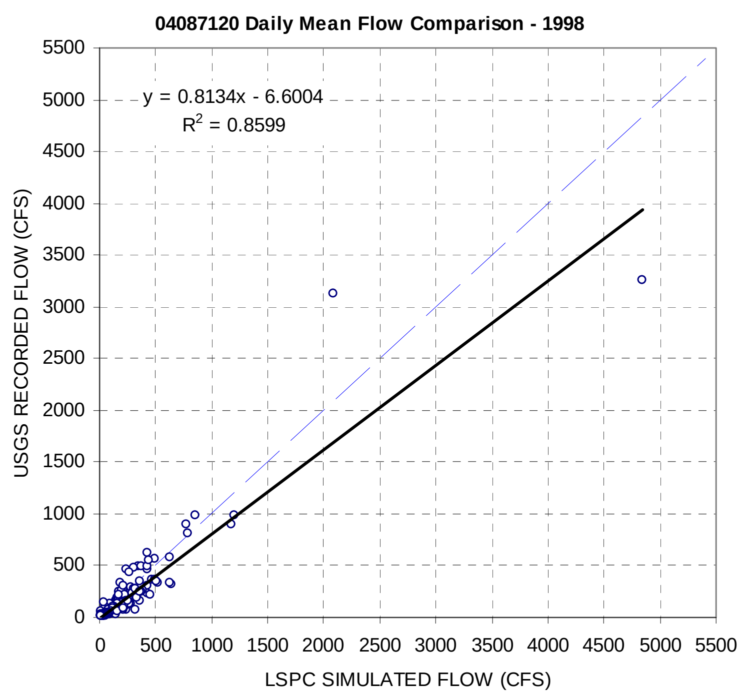


Figure 22. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087120 (1998).

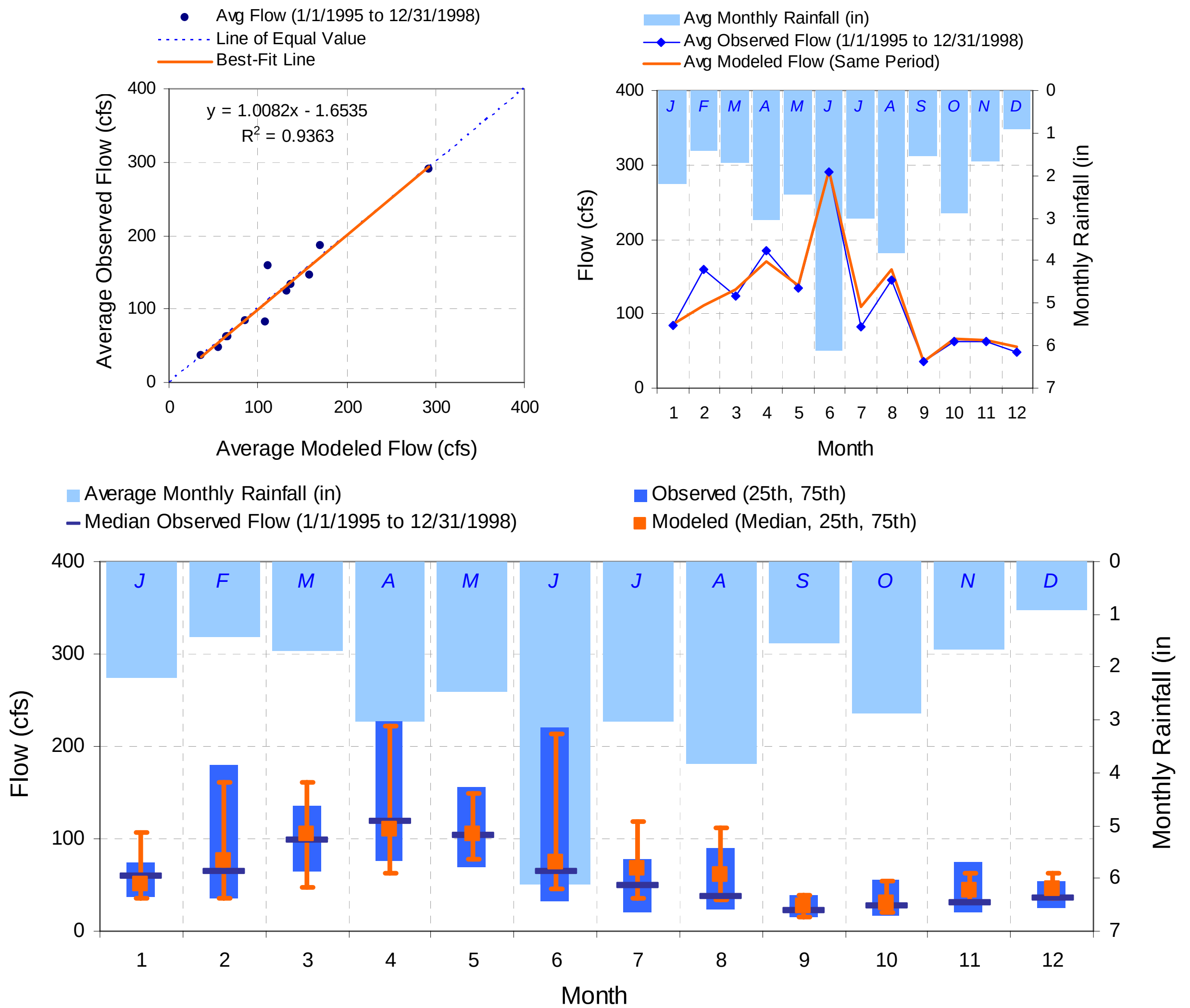


Figure 23. Composite (average monthly) hydrologic calibration results for Menomonee River at USGS gage 04087120 (1995 to 1998).

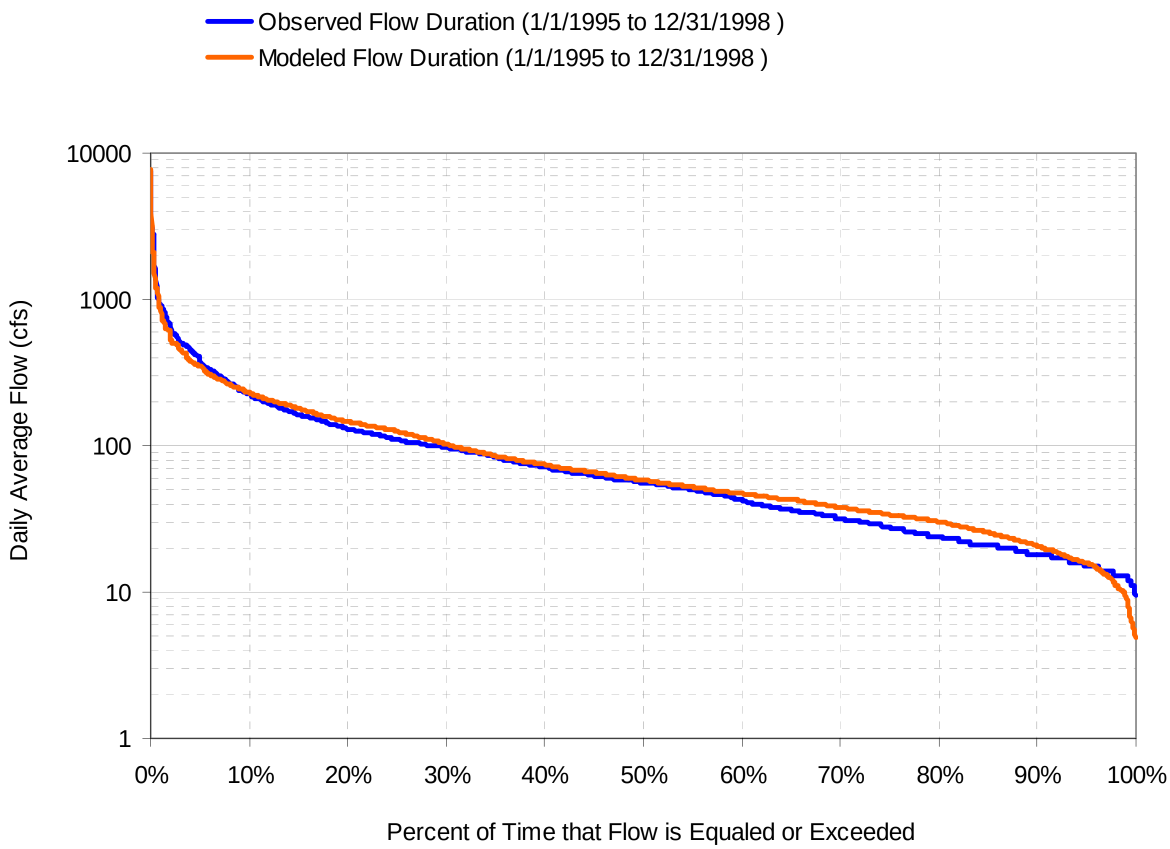


Figure 24. Flow duration curve hydrologic calibration results for Menomonee River at USGS gage 04087120 (1995-1998).

Table 6. Error statistics for hydrologic calibration results for Menomonee River at USGS gage 04087120 (1995-1998).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1995			1996			1997			1998			TOTAL		
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month: JAN	3,377	3,268	-3.24%	5,921	3,414	-42.3%	5,692	3,652	-35.8%	5,797	10,649	83.7%	**20,788**	**20,983**	**0.9%**
FEB	1,529	1,346	-11.9%	10,522	4,825	-54.1%	11,953	6,819	-43.0%	11,880	11,971	0.8%	**35,884**	**24,962**	**-30.4%**
MAR	5,309	3,986	-24.9%	4,104	3,690	-10.1%	9,713	9,879	1.7%	11,444	15,227	33.1%	**30,570**	**32,782**	**7.2%**
APR	11,681	8,114	-30.5%	8,222	6,585	-19.9%	6,019	5,457	-9.3%	18,240	20,390	11.8%	**44,162**	**40,547**	**-8.2%**
MAY	9,017	8,750	-3.0%	9,454	8,171	-13.6%	8,270	8,381	1.4%	6,132	8,495	38.5%	**32,873**	**33,798**	**2.8%**
JUN	3,434	3,071	-10.6%	28,055	22,826	-18.6%	33,707	37,814	12.2%	3,892	5,921	52.1%	**69,087**	**69,631**	**0.8%**
JUL	2,062	1,556	-24.5%	4,397	6,201	41.0%	11,034	14,718	33.4%	2,682	4,350	62.2%	**20,175**	**26,826**	**33.0%**
AUG	10,359	7,805	-24.7%	2,681	2,935	9.5%	5,659	7,450	31.6%	17,136	20,879	21.8%	**35,835**	**39,068**	**9.0%**
SEP	2,597	1,633	-37.1%	2,033	2,007	-1.3%	2,328	3,104	33.3%	1,569	1,844	17.6%	**8,527**	**8,588**	**0.7%**
OCT	5,981	5,423	-9.3%	5,249	4,978	-5.2%	1,464	2,171	48.3%	2,564	3,812	48.7%	**15,258**	**16,383**	**7.4%**
NOV	7,512	4,577	-39.1%	2,316	2,342	1.1%	1,472	2,899	96.9%	3,528	5,749	62.9%	**14,829**	**15,566**	**5.0%**
DEC	4,923	3,704	-24.8%	3,377	3,197	-5.3%	1,966	3,890	97.9%	1,625	2,835	74.4%	**11,892**	**13,626**	**14.6%**

Season	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Jan-Mar	10,215	8,600	-15.8%		20,547	11,929	-41.9%	21.9%	27,359	20,351	-25.6%	5.6%	29,122	37,847	30.0%	10.0%	**87,242**	**78,727**	**-9.8%**	
Apr-Jun	24,132	19,935	-17.4%		45,731	37,582	-17.8%		47,995	51,652	7.6%		28,263	34,806	23.1%	3.1%	**146,122**	**143,975**	**-1.5%**	
Jul-Sep	15,018	10,995	-26.8%	6.8%	9,111	11,143	22.3%	2.3%	19,022	25,271	32.9%	12.9%	21,387	27,073	26.6%	6.6%	**64,537**	**74,482**	**15.4%**	
Oct-Dec	18,416	13,703	-25.6%	5.6%	10,943	10,517	-3.9%		4,903	8,960	82.8%	62.8%	7,717	12,395	60.6%	40.6%	**41,978**	**45,576**	**8.6%**	

Calibration Tolerance =20%

	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	67,781	53,233	-21.5%	11.5%	86,331	71,172	-17.6%	7.6%	99,278	106,234	7.0%		86,489	112,121	29.6%	19.6%	**339,879**	**342,760**	**0.8%**	

Calibration Tolerance =10%

Table 7. High-Low flow error statistics for hydrologic calibration results for Menomonee River at USGS gage 04087120 (1995-1998).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	160,416	172,072	-6.8%	15%
Total Highest 20% volume	213,539	221,248	-3.5%	15%
Total Highest 50% volume	293,860	296,202	-0.8%	15%
Total Lowest 10% volume	4,369	4,440	-1.6%	10%
Total Lowest 30% volume	21,619	18,543	16.6%	10%
Total Lowest 50% volume	49,248	43,757	12.6%	10%

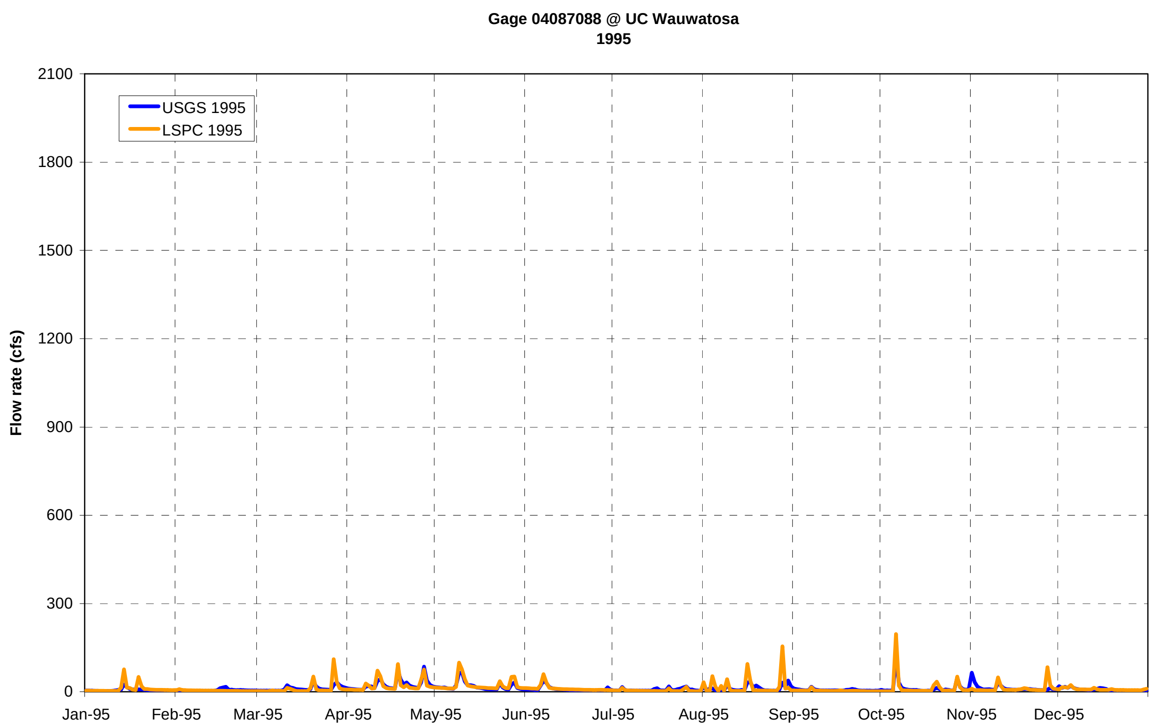


Figure 25. Time series hydrologic calibration results (daily mean) for Underwood Creek at USGS gage 04087088 (1995).

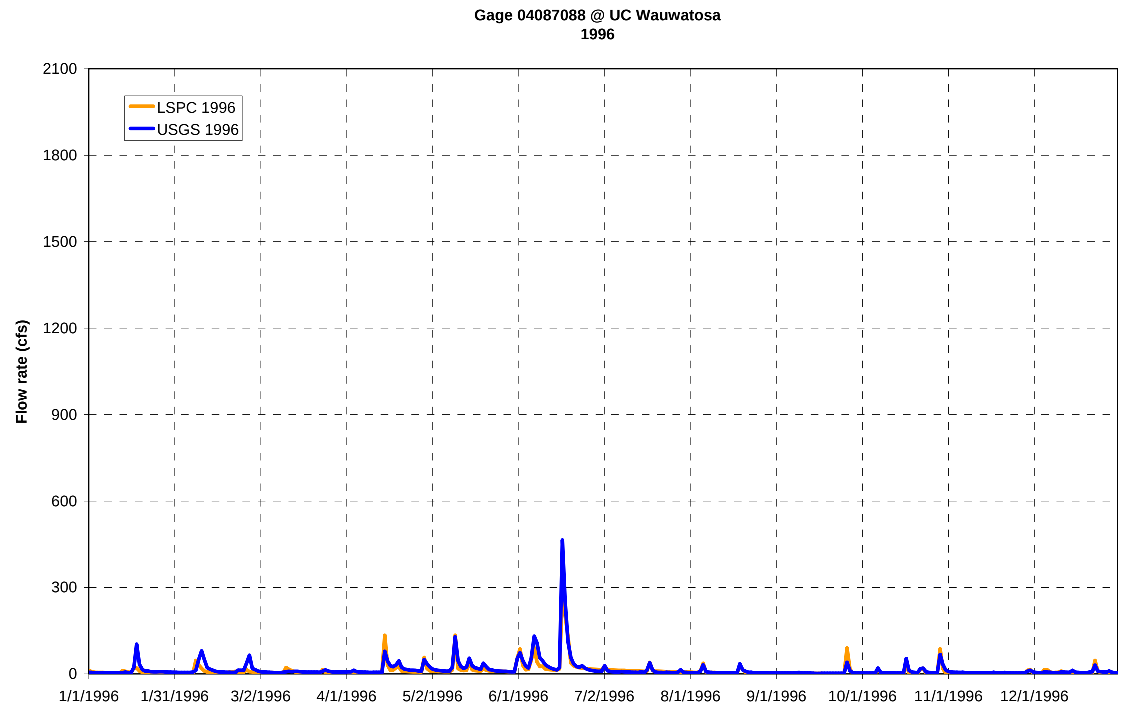


Figure 26. Time series hydrologic calibration results (daily mean) for Underwood Creek at USGS gage 04087088 (1996).

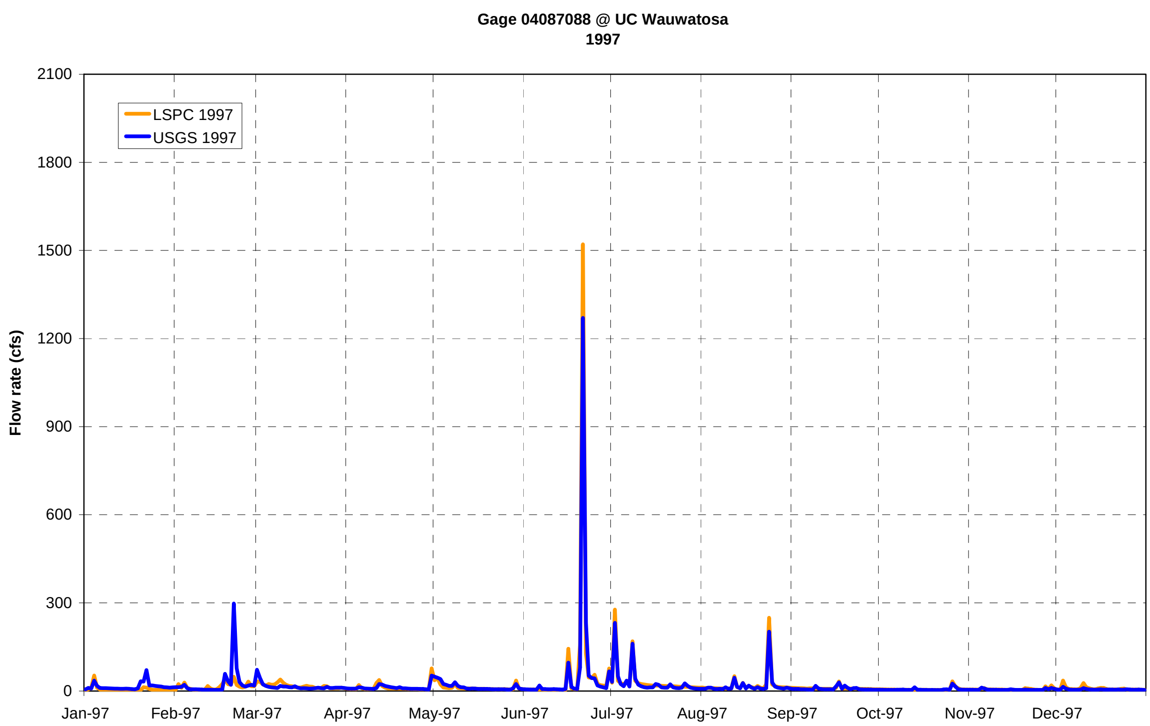


Figure 27. Time series hydrologic calibration results (daily mean) for Underwood Creek at USGS gage 04087088 (1997).

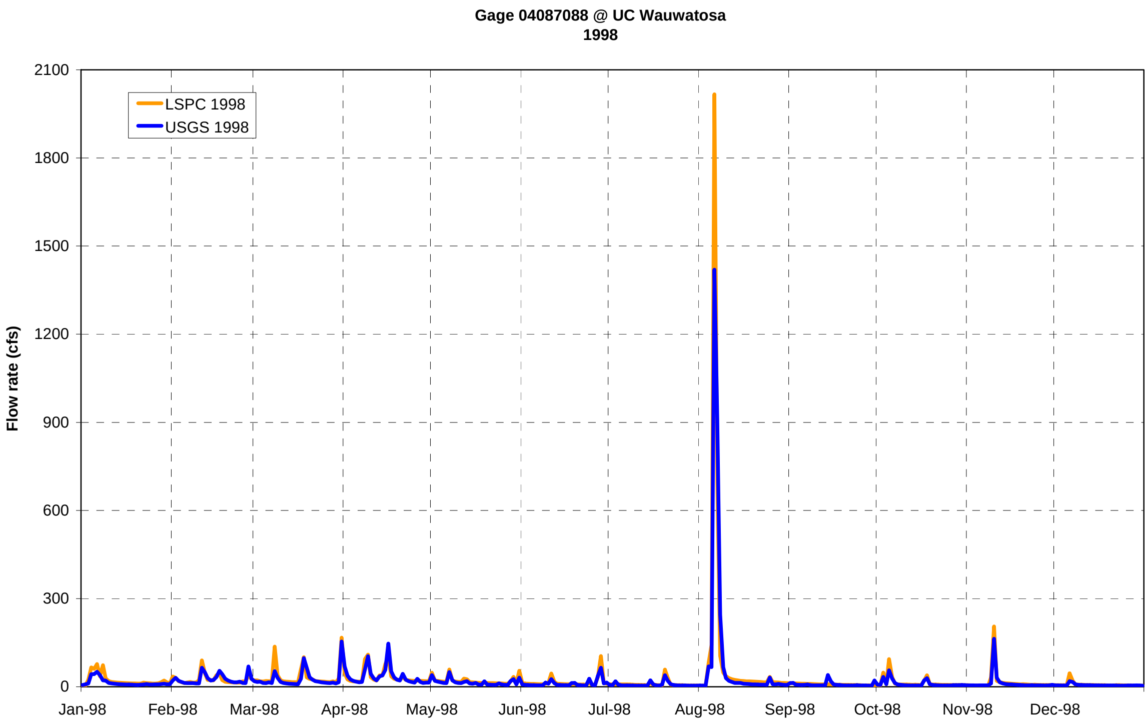


Figure 28. Time series hydrologic calibration results (daily mean) for Underwood Creek at USGS gage 04087088 (1998).

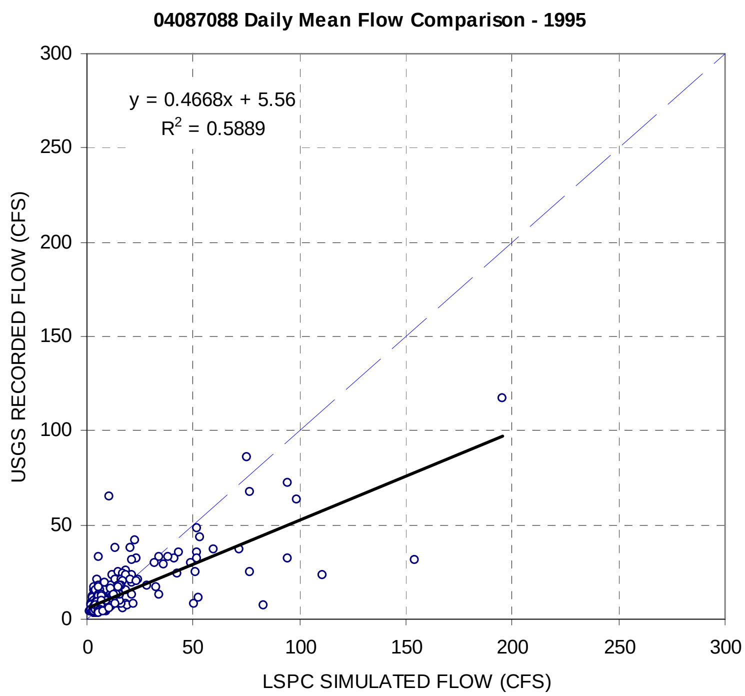


Figure 29. Observed versus simulated scatter plot with a linear regression line for Underwood Creek at USGS gage 04087088 (1995).

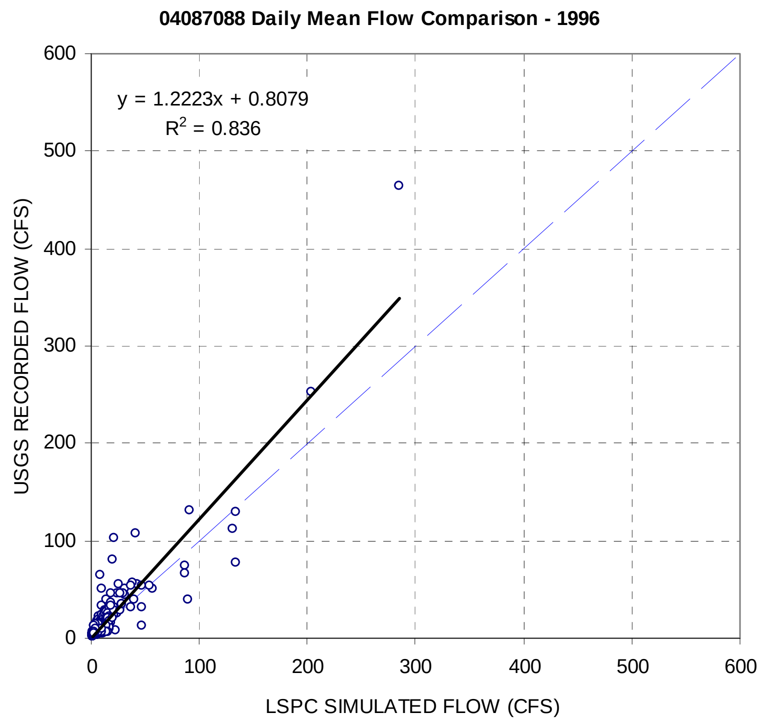


Figure 30. Observed versus simulated scatter plot with a linear regression line for Underwood Creek at USGS gage 04087088 (1996).

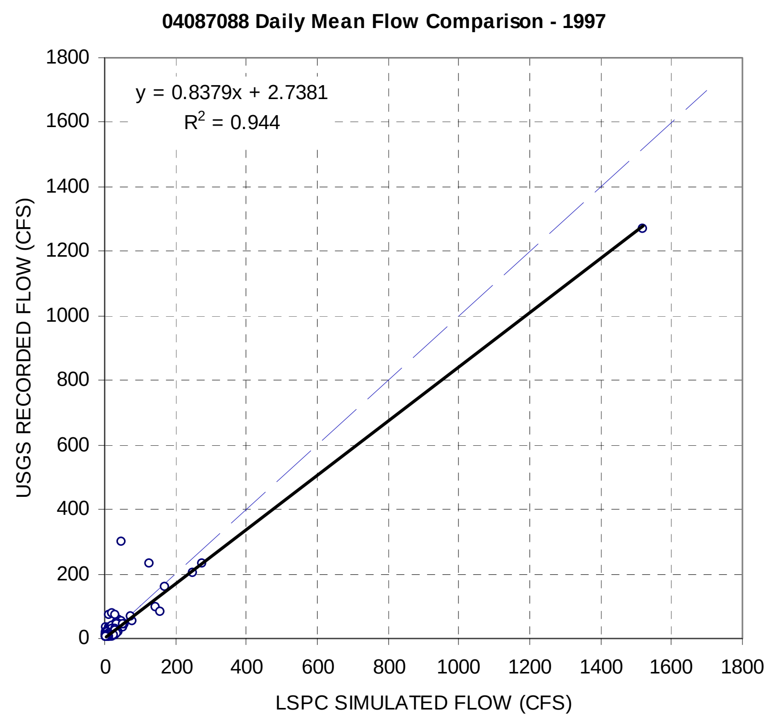


Figure 31. Observed versus simulated scatter plot with a linear regression line for Underwood Creek at USGS gage 04087088 (1997).

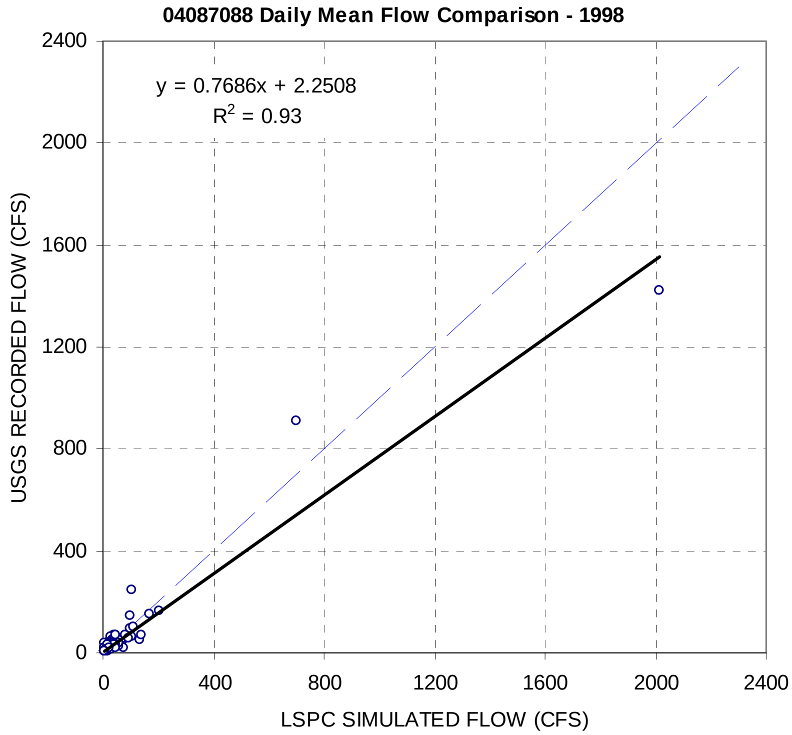


Figure 32. Observed versus simulated scatter plot with a linear regression line for Underwood Creek at USGS gage 04087088 (1998).

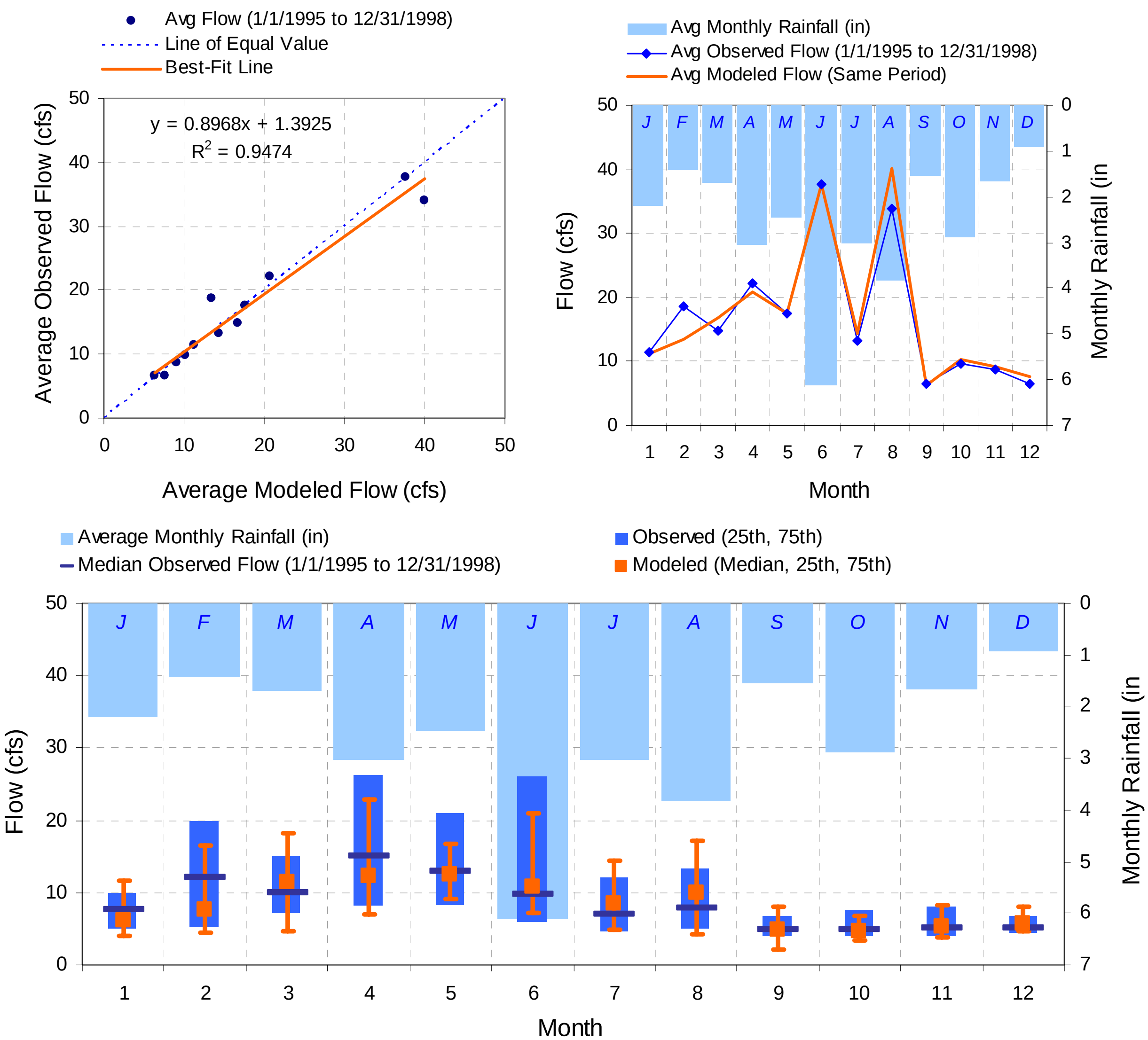


Figure 33. Composite (average monthly) hydrologic calibration results for Underwood Creek at USGS gage 04087088 (1995 to 1998).

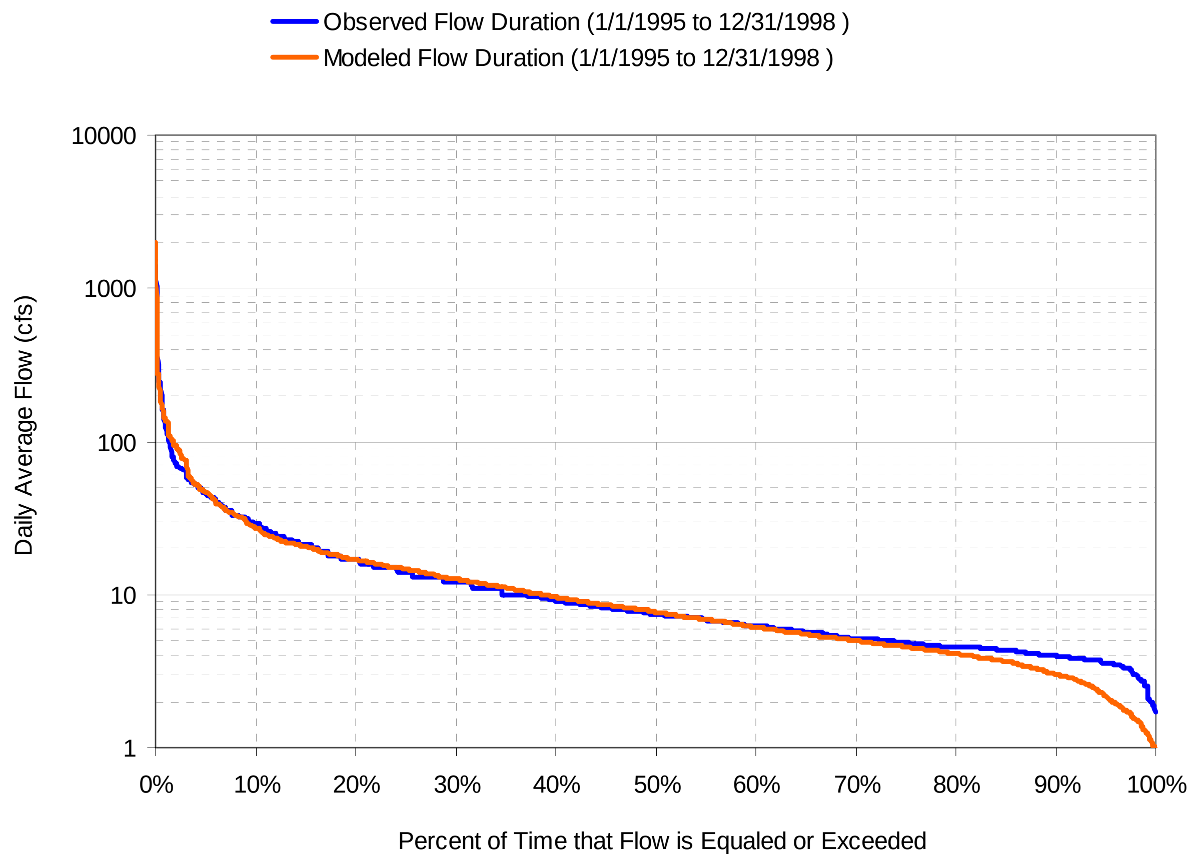


Figure 34. Flow duration curve hydrologic calibration results for Underwood Creek at USGS gage 04087088 (1995-1998).

Table 8. Error statistics for hydrologic calibration results for Underwood Creek at USGS gage 04087088 (1995-1998).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1995			1996			1997			1998			TOTAL		
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month JAN	381	642	68.6%	660	434	-34.2%	918	396	-56.9%	855	1,312	53.6%	**2,813**	**2,784**	**-1.0%**
FEB	318	232	-27.0%	1,015	518	-49.0%	1,471	874	-40.6%	1,400	1,376	-1.8%	**4,204**	**2,999**	**-28.7%**
MAR	694	684	-1.4%	451	388	-14.1%	916	1,067	16.5%	1,588	1,992	25.4%	**3,649**	**4,131**	**13.2%**
APR	1,412	1,348	-4.5%	1,085	856	-21.1%	687	714	3.9%	2,112	2,031	-3.8%	**5,296**	**4,949**	**-6.6%**
MAY	1,148	1,414	23.2%	1,344	965	-28.2%	867	724	-16.5%	937	1,217	29.9%	**4,296**	**4,319**	**0.5%**
JUN	568	701	23.3%	3,613	2,737	-24.3%	4,093	4,652	13.7%	677	877	29.6%	**8,951**	**8,966**	**0.2%**
JUL	448	279	-37.7%	550	712	29.6%	1,816	2,021	11.3%	456	541	18.7%	**3,270**	**3,553**	**8.7%**
AUG	768	1,138	48.3%	429	408	-4.7%	1,113	1,313	18.0%	6,022	7,000	16.2%	**8,332**	**9,860**	**18.3%**
SEP	370	228	-38.4%	249	303	21.6%	477	528	10.7%	461	453	-1.7%	**1,557**	**1,512**	**-2.9%**
OCT	783	896	14.4%	656	465	-29.1%	332	354	6.6%	624	811	29.9%	**2,396**	**2,526**	**5.4%**
NOV	744	716	-3.8%	291	177	-39.1%	296	370	25.1%	726	902	24.1%	**2,058**	**2,166**	**5.2%**
DEC	511	551	7.8%	433	373	-13.9%	329	513	55.8%	338	433	28.1%	**1,611**	**1,870**	**16.0%**

Season	1995 Recorded USGS Volume (ac-ft)	1995 Simulated LSPC Volume (ac-ft)	1995 Percent Diff.	1995 Var. from Tolerance	1996 Recorded USGS Volume (ac-ft)	1996 Simulated LSPC Volume (ac-ft)	1996 Percent Diff.	1996 Var. from Tolerance	1997 Recorded USGS Volume (ac-ft)	1997 Simulated LSPC Volume (ac-ft)	1997 Percent Diff.	1997 Var. from Tolerance	1998 Recorded USGS Volume (ac-ft)	1998 Simulated LSPC Volume (ac-ft)	1998 Percent Diff.	1998 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Jan-Mar	1,392	1,558	11.9%		2,127	1,340	-37.0%	17.0%	3,305	2,337	-29.3%	9.3%	3,843	4,680	21.8%	1.8%	**10,667**	**9,915**	**-7.0%**	
Apr-Jun	3,128	3,463	10.7%		6,042	4,557	-24.6%	4.6%	5,647	6,089	7.8%		3,726	4,125	10.7%		**18,543**	**18,235**	**-1.7%**	
Jul-Sep	1,586	1,645	3.8%		1,228	1,424	16.0%		3,406	3,862	13.4%		6,939	7,994	15.2%		**13,158**	**14,926**	**13.4%**	
Oct-Dec	2,038	2,163	6.1%		1,380	1,015	-26.4%	6.4%	958	1,238	29.2%	9.2%	1,688	2,145	27.1%	7.1%	**6,065**	**6,561**	**8.2%**	

Calibration Tolerance =20%

	1995 Recorded USGS Volume (ac-ft)	1995 Simulated LSPC Volume (ac-ft)	1995 Percent Diff.	1995 Var. from Tolerance	1996 Recorded USGS Volume (ac-ft)	1996 Simulated LSPC Volume (ac-ft)	1996 Percent Diff.	1996 Var. from Tolerance	1997 Recorded USGS Volume (ac-ft)	1997 Simulated LSPC Volume (ac-ft)	1997 Percent Diff.	1997 Var. from Tolerance	1998 Recorded USGS Volume (ac-ft)	1998 Simulated LSPC Volume (ac-ft)	1998 Percent Diff.	1998 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Year	8,144	8,828	8.4%		10,777	8,336	-22.6%	12.6%	13,316	13,526	1.6%		16,196	18,945	17.0%	7.0%	**48,433**	**49,636**	**2.5%**	

Calibration Tolerance =10%

Table 9. High-Low flow error statistics for hydrologic calibration results for Underwood Creek at USGS gage 04087088 (1995-1998).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	27,023	25,380	6.5%	15%
Total Highest 20% volume	33,089	31,638	4.6%	15%
Total Highest 50% volume	43,050	41,146	4.6%	15%
Total Lowest 10% volume	628	992	-36.7%	10%
Total Lowest 30% volume	2,997	3,646	-17.8%	10%
Total Lowest 50% volume	6,611	7,307	-9.5%	10%

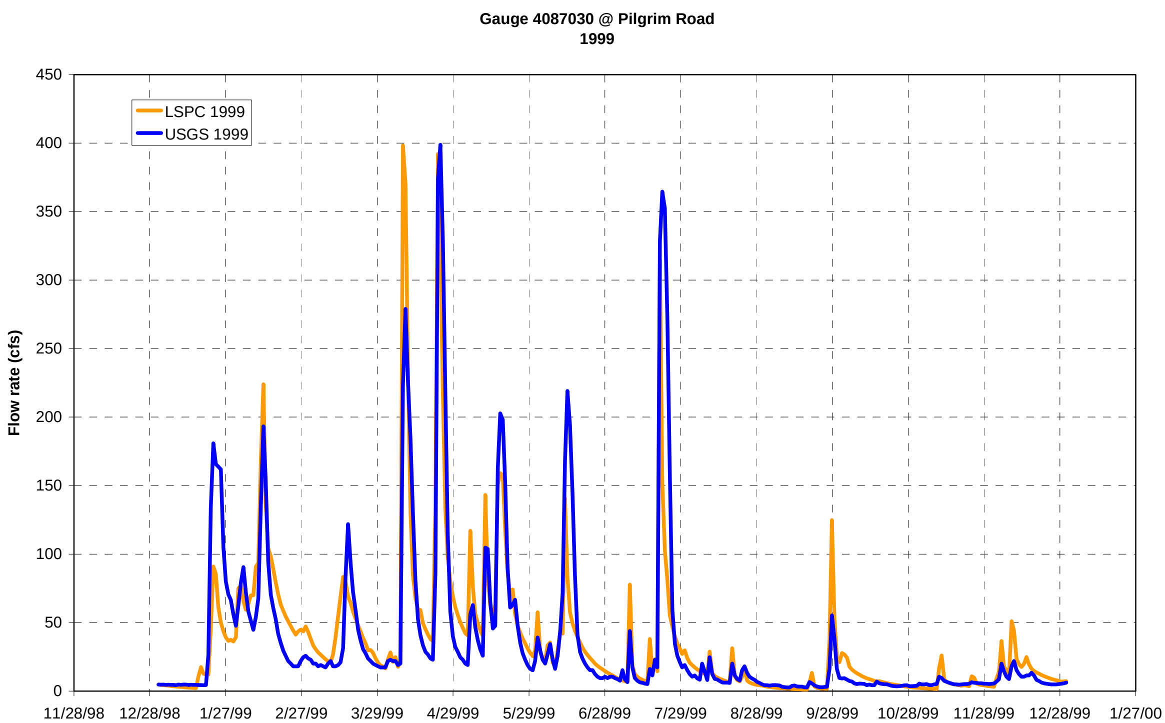


Figure 35. Time series hydrologic validation results (daily mean) for Menomonee River at USGS gage 04087030 (1999).

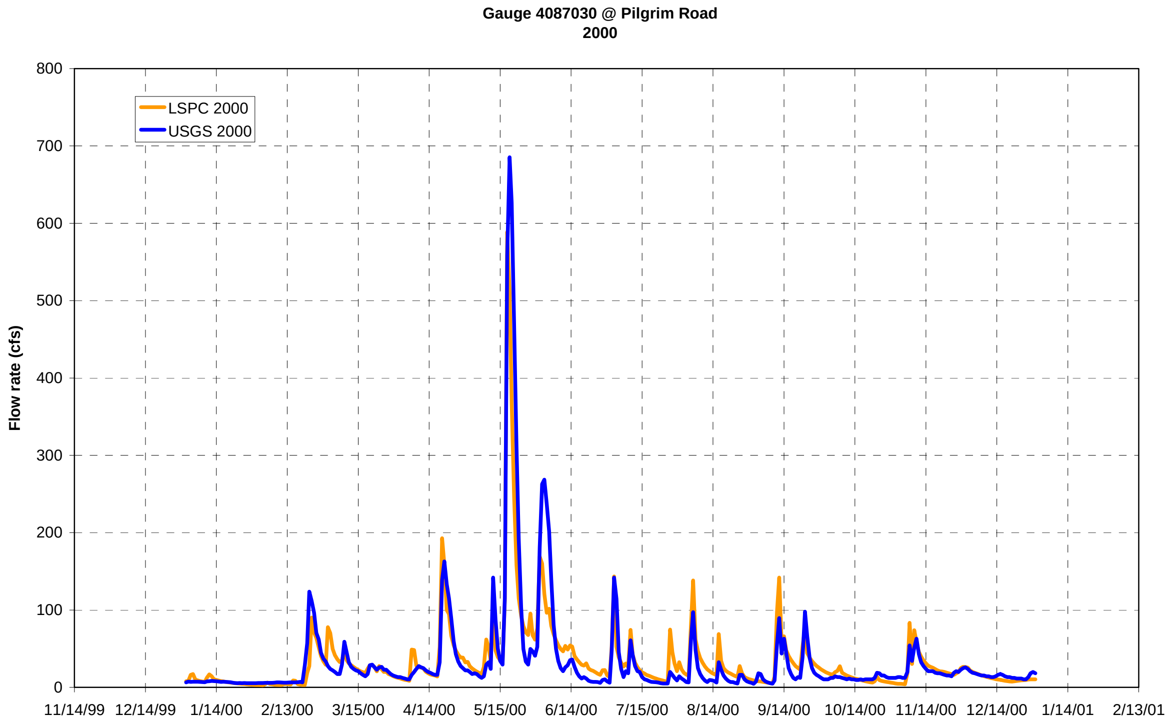


Figure 36. Time series hydrologic validation results (daily mean) for Menomonee River at USGS gage 04087030 (2000).

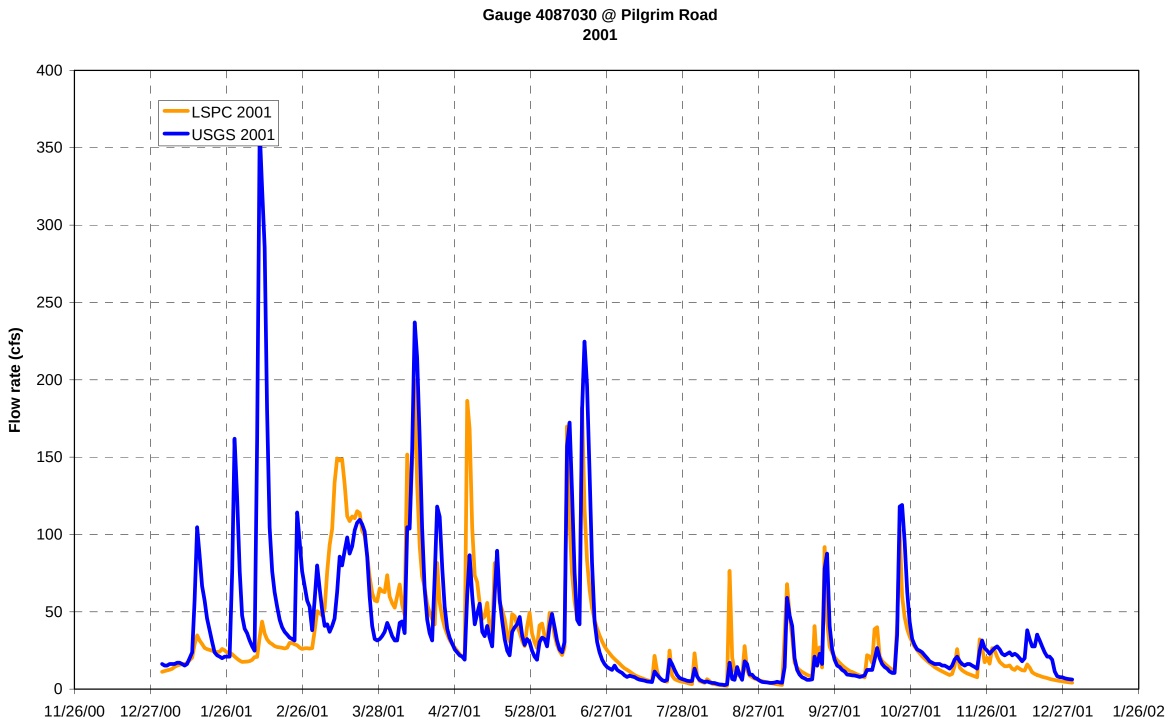


Figure 37. Time series hydrologic validation results (daily mean) for Menomonee River at USGS gage 04087030 (2001).

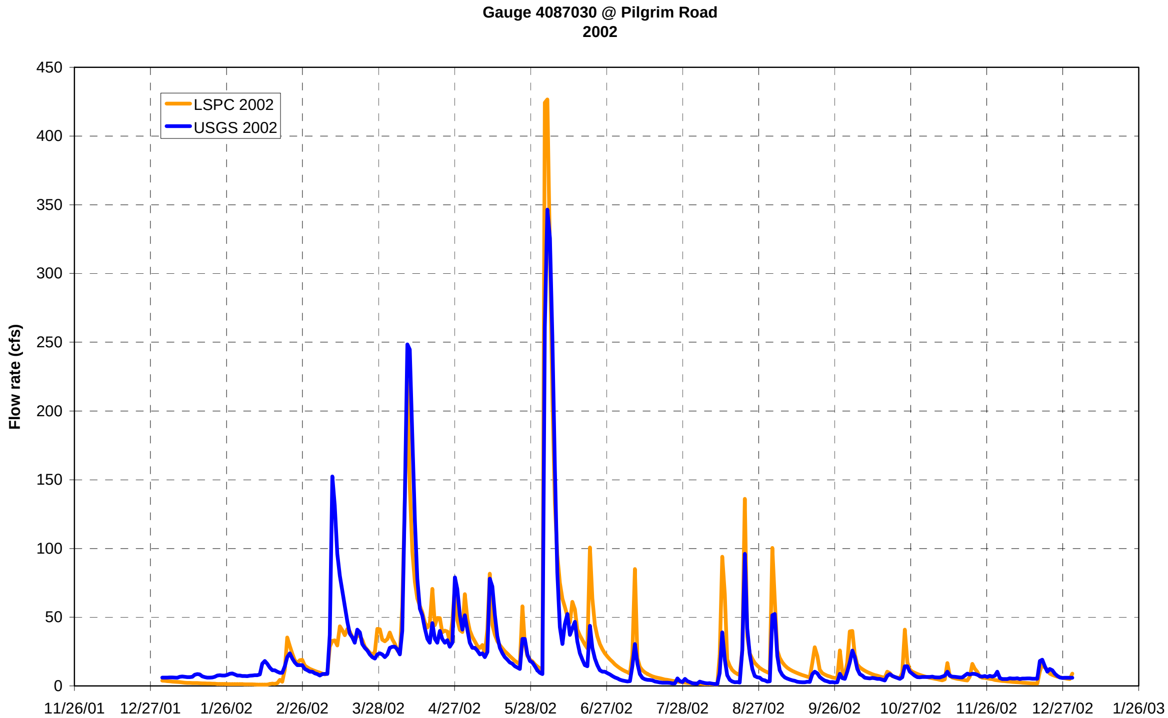


Figure 38. Time series hydrologic validation results (daily mean) for Menomonee River at USGS gage 04087030 (2002).

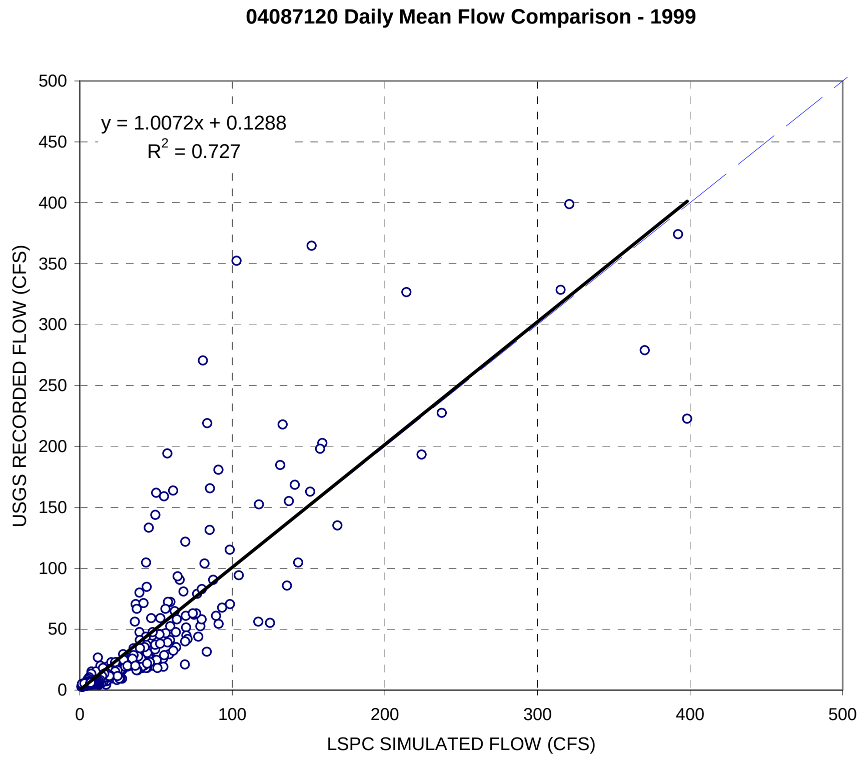


Figure 39. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087030 (1999).

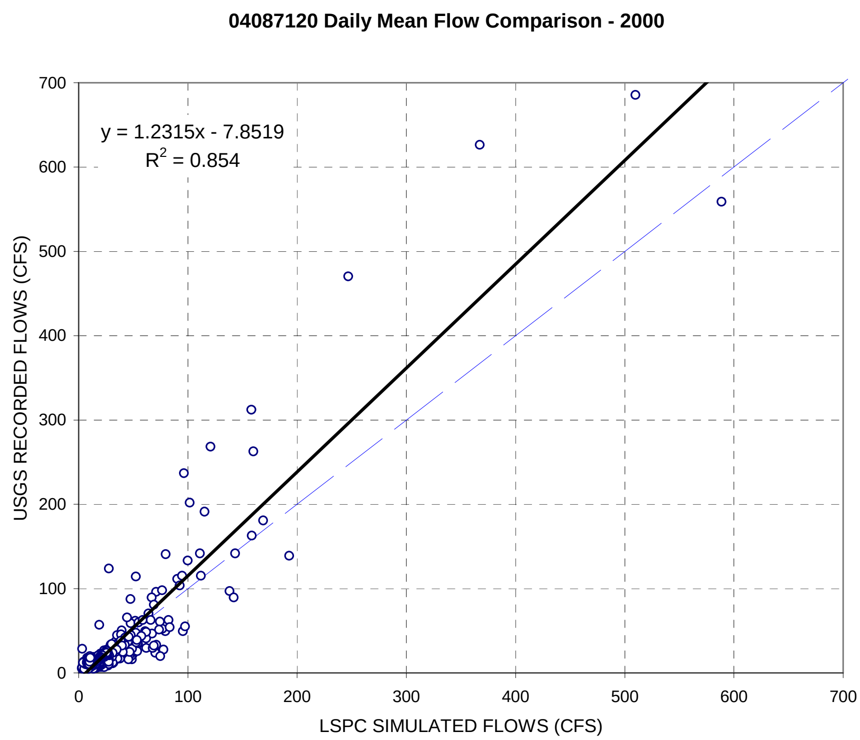


Figure 40. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087030 (2000).

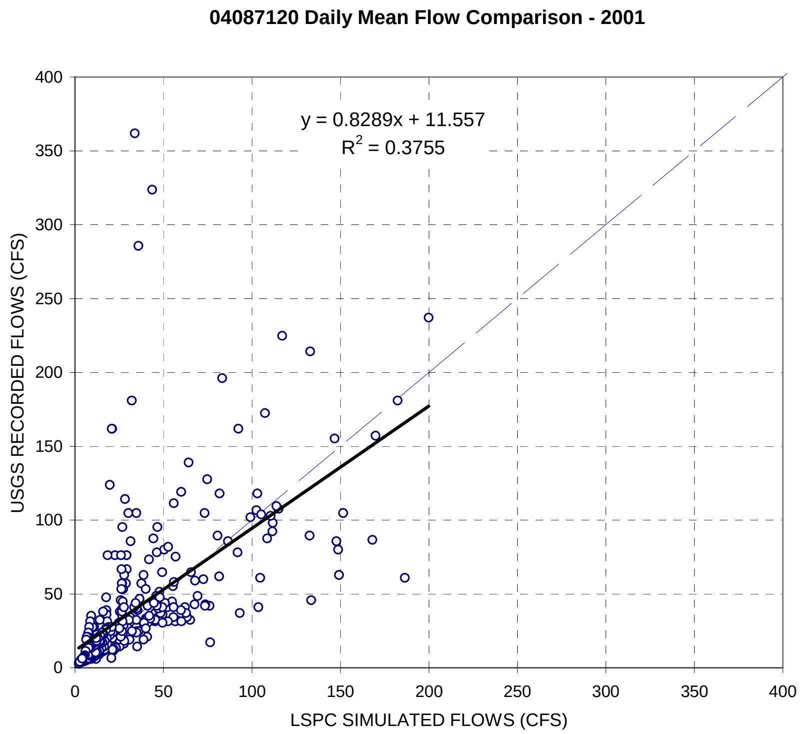


Figure 41. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087030 (2001).

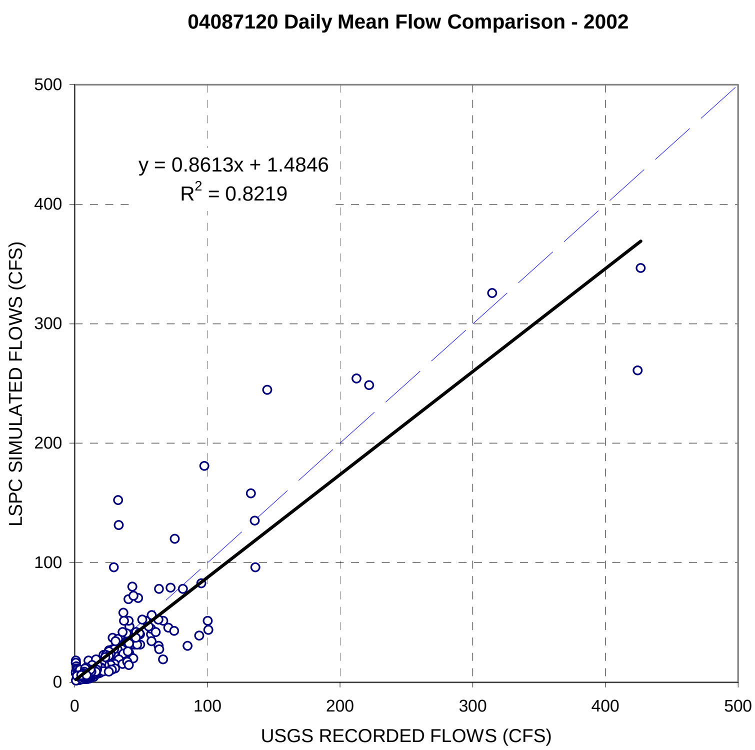


Figure 42. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087030 (2002).

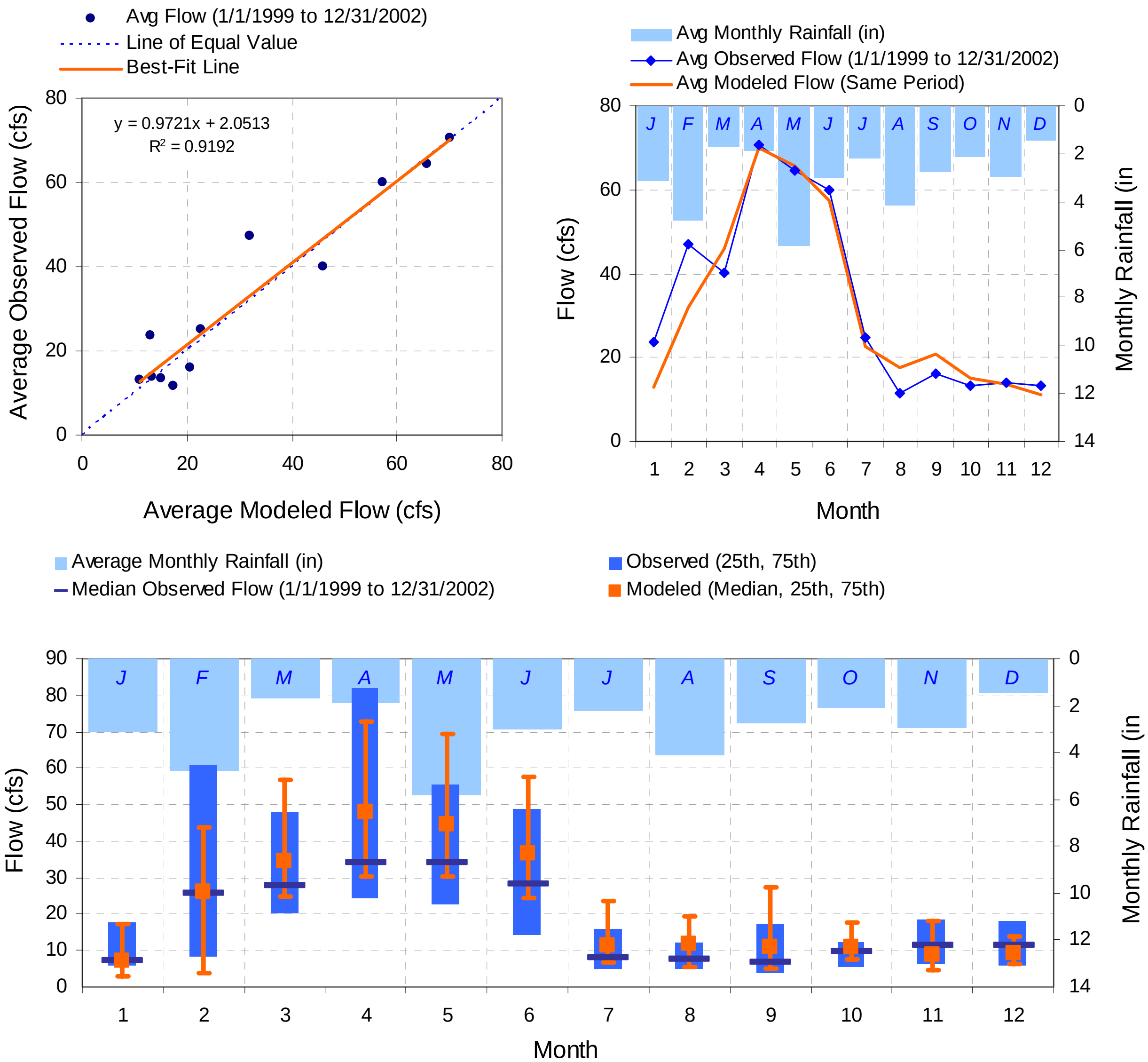


Figure 43. Composite (average monthly) hydrologic validation results for Menomonee River at USGS gage 04087030 (1999 to 2002).

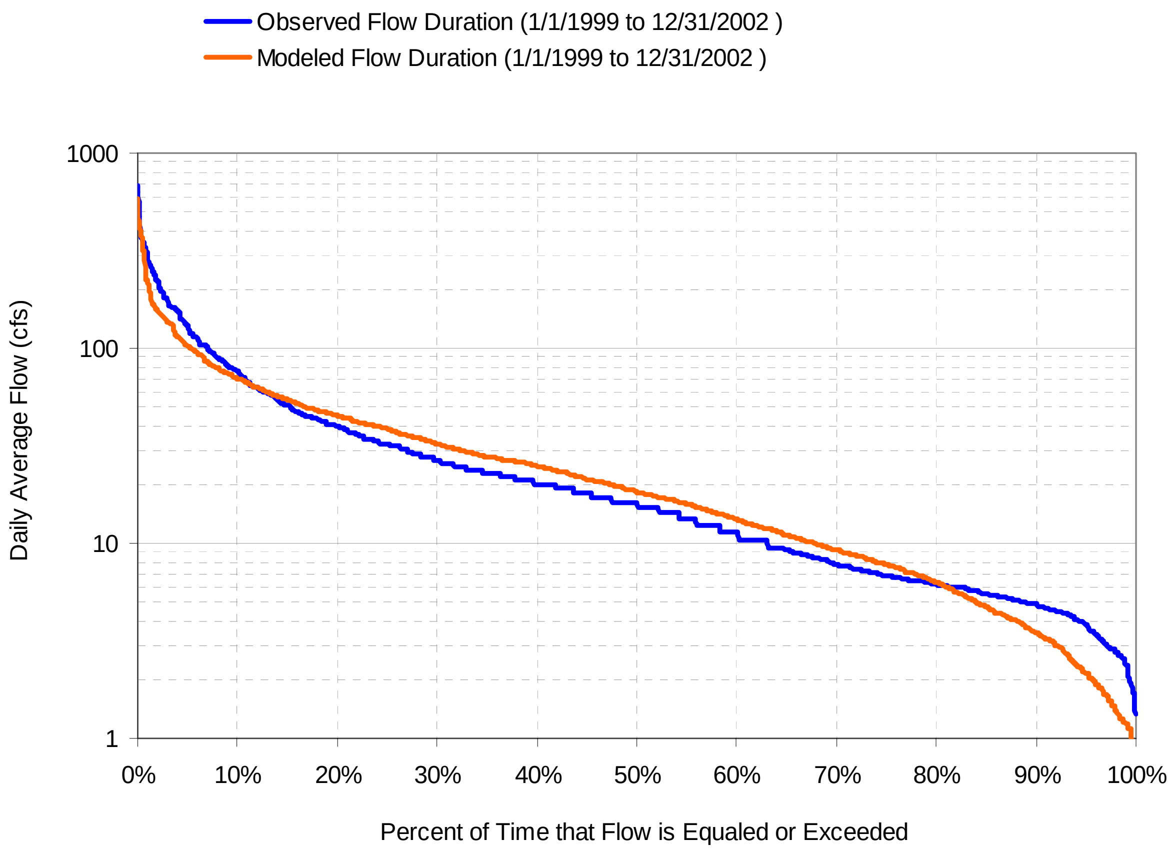


Figure 44. Flow duration curve hydrologic validation results for Menomonee River at USGS gage 04087030 (1999 to 2002).

Table 10. Error statistics for hydrologic validation results for Menomonee River at USGS gage 04087030 (1999 to 2002).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1999			2000			2001			2002			TOTAL		
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month: JAN	2,572	1,276	-50.4%	410	492	19.9%	2,415	1,300	-46.2%	434	133	-69.4%	**5,832**	**3,201**	**-45.1%**
FEB	3,301	4,299	30.3%	1,492	967	-35.2%	5,072	1,467	-71.1%	694	452	-34.9%	**10,560**	**7,186**	**-32.0%**
MAR	2,033	2,480	22.0%	1,499	1,838	22.6%	4,026	5,303	31.7%	2,313	1,702	-26.4%	**9,871**	**11,324**	**14.7%**
APR	6,285	6,535	4.0%	2,394	2,545	6.3%	4,300	4,018	-6.6%	3,830	3,576	-6.6%	**16,810**	**16,673**	**-0.8%**
MAY	3,802	4,248	11.7%	7,789	6,570	-15.7%	2,491	3,403	36.6%	1,769	1,956	10.5%	**15,852**	**16,177**	**2.1%**
JUN	2,791	2,116	-24.2%	3,564	3,165	-11.2%	3,926	3,226	-17.8%	3,989	5,146	29.0%	**14,270**	**13,653**	**-4.3%**
JUL	3,765	2,437	-35.3%	1,511	1,919	27.0%	519	586	12.9%	337	654	94.3%	**6,132**	**5,595**	**-8.8%**
AUG	659	733	11.3%	1,037	1,820	75.5%	438	603	37.6%	682	1,171	71.7%	**2,815**	**4,326**	**53.7%**
SEP	438	610	39.4%	1,596	2,031	27.3%	1,251	1,290	3.2%	522	1,009	93.4%	**3,806**	**4,941**	**29.8%**
OCT	328	599	82.7%	743	776	4.4%	1,685	1,534	-9.0%	536	801	49.5%	**3,292**	**3,710**	**12.7%**
NOV	336	322	-4.0%	1,429	1,557	9.0%	1,131	932	-17.6%	429	393	-8.4%	**3,325**	**3,205**	**-3.6%**
DEC	577	957	65.9%	953	777	-18.4%	1,259	635	-49.5%	462	332	-28.2%	**3,251**	**2,702**	**-16.9%**

Season	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Jan-Mar	7,906	8,056	1.9%		3,402	3,297	-3.1%		11,514	8,071	-29.9%	9.9%	3,442	2,287	-33.6%	13.6%	**26,263**	**21,711**	**-17.3%**	
Apr-Jun	12,879	12,899	0.2%		13,747	12,280	-10.7%		10,717	10,647	-0.7%		9,589	10,677	11.3%		**46,932**	**46,503**	**-0.9%**	
Jul-Sep	4,862	3,780	-22.3%	2.3%	4,144	5,769	39.2%	19.2%	2,208	2,479	12.3%		1,540	2,834	84.0%	64.0%	**12,754**	**14,862**	**16.5%**	
Oct-Dec	1,241	1,879	51.4%	31.4%	3,125	3,111	-0.4%		4,075	3,101	-23.9%	3.9%	1,427	1,526	6.9%		**9,868**	**9,617**	**-2.5%**	

Calibration Tolerance =20%

	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	26,888	26,613	-1.0%		24,417	24,458	0.2%		28,514	24,298	-14.8%	4.8%	15,998	17,324	8.3%		**95,816**	**92,693**	**-3.3%**	

Calibration Tolerance =10%

Table 11. High-Low flow error statistics for hydrologic validation results for Menomonee River at USGS gage 04087030 (1999-2002).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	38,922	47,869	-18.7%	15%
Total Highest 20% volume	55,080	63,273	-12.9%	15%
Total Highest 50% volume	80,636	84,584	-4.7%	15%
Total Lowest 10% volume	644	1,063	-39.4%	10%
Total Lowest 30% volume	4,302	4,680	-8.1%	10%
Total Lowest 50% volume	12,166	11,332	7.4%	10%

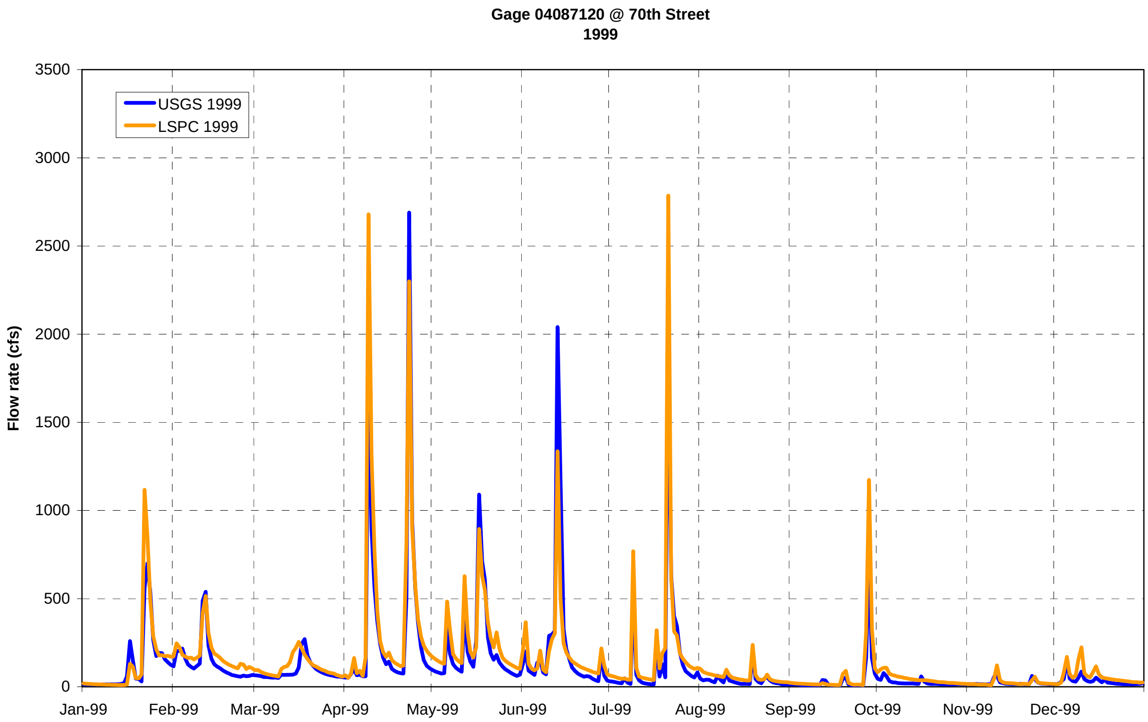


Figure 45. Time series hydrologic validation results (daily mean) for Menomonee River at USGS gage 04087120 (1999).

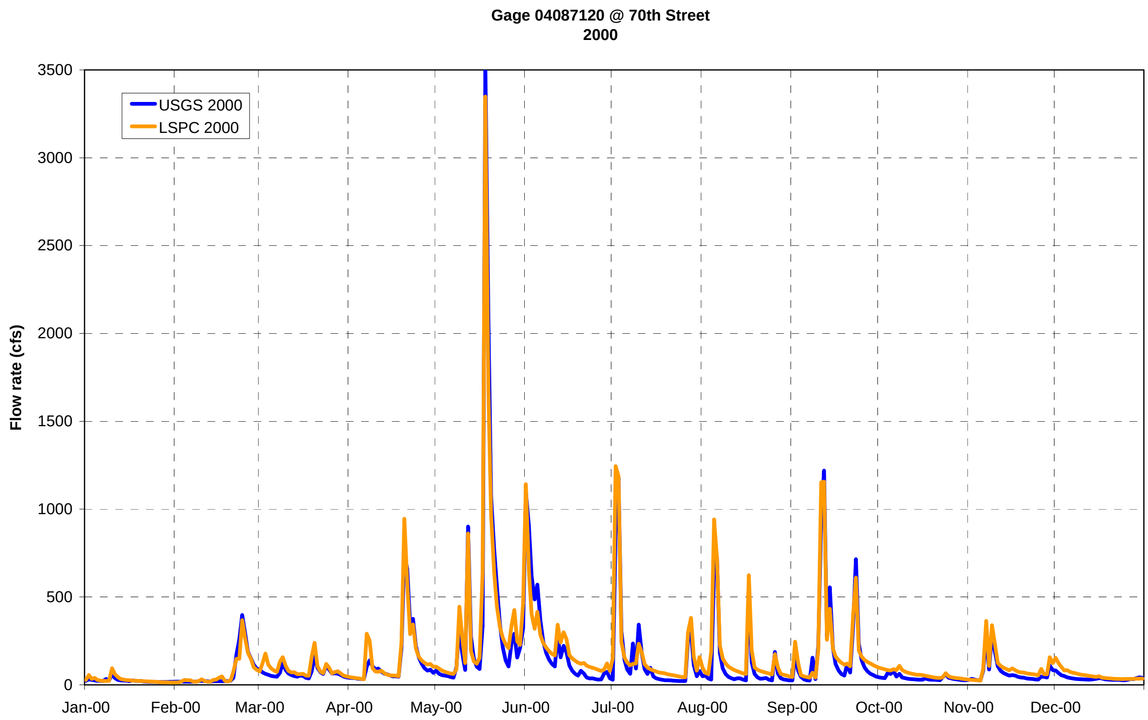


Figure 46. Time series hydrologic validation results (daily mean) for Menomonee River at USGS gage 04087120 (2000).

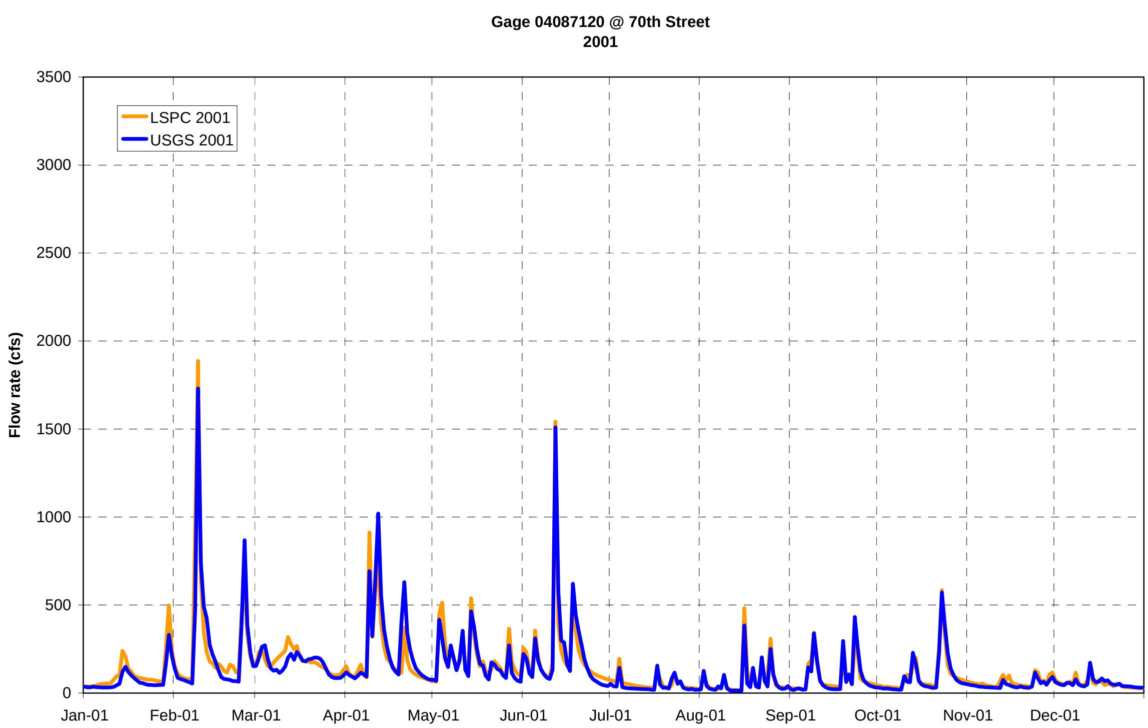


Figure 47. Time series hydrologic validation results (daily mean) for Menomonee River at USGS gage 04087120 (2001).

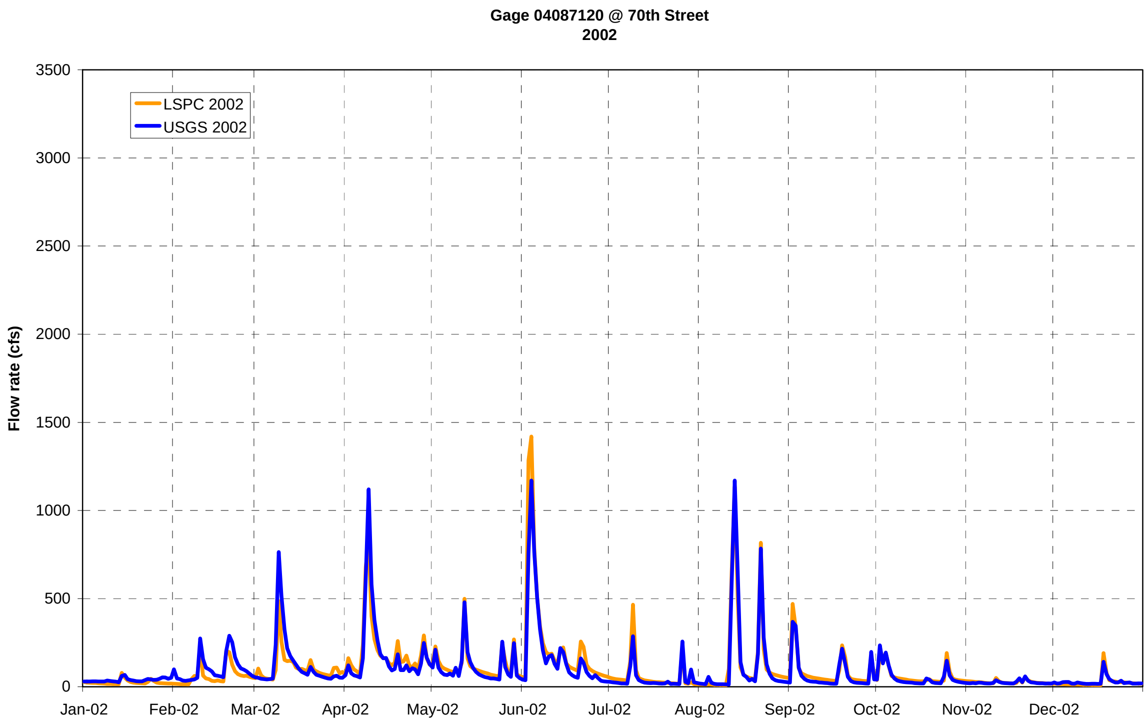


Figure 48. Time series hydrologic validation results (daily mean) for Menomonee River at USGS gage 04087120 (2002).

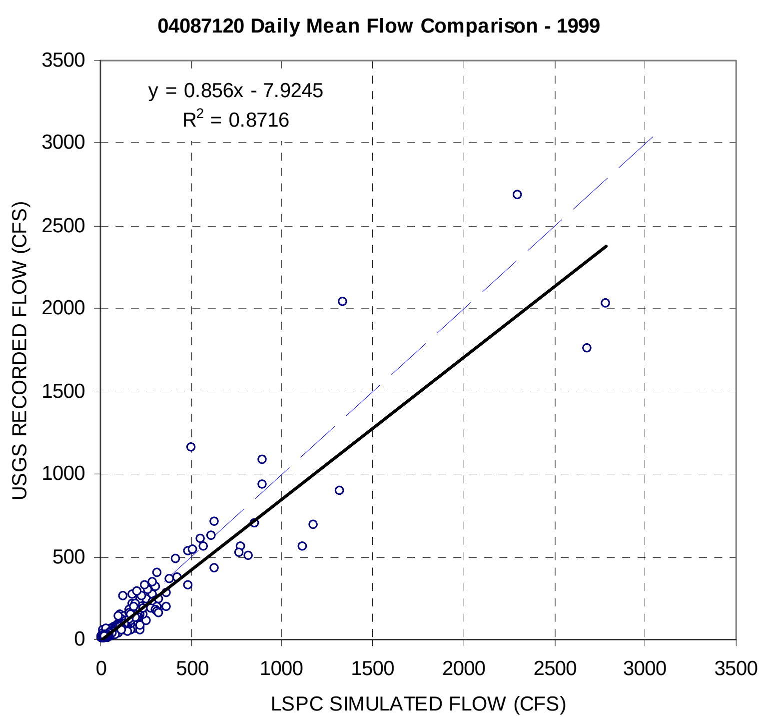


Figure 49. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087120 (1999).

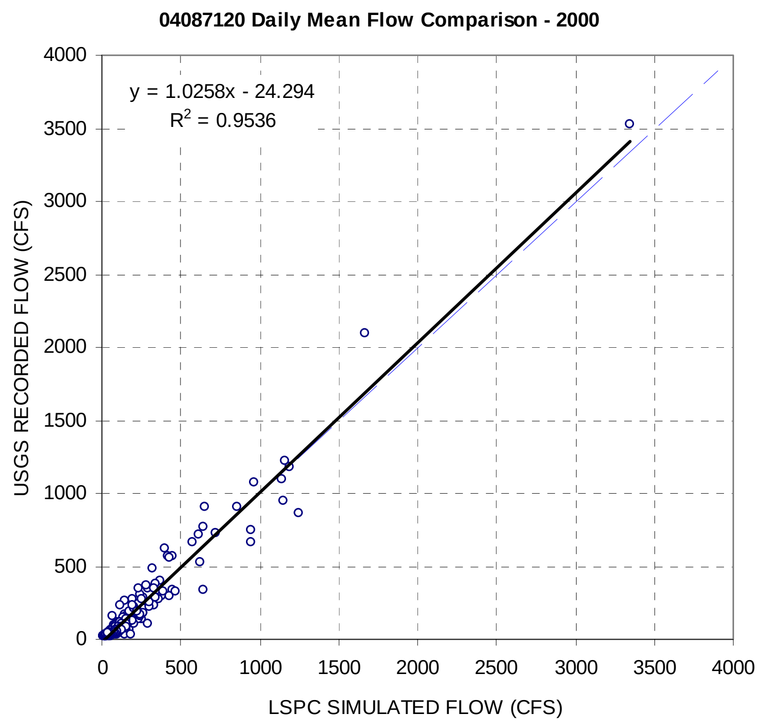


Figure 50. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087120 (2000).

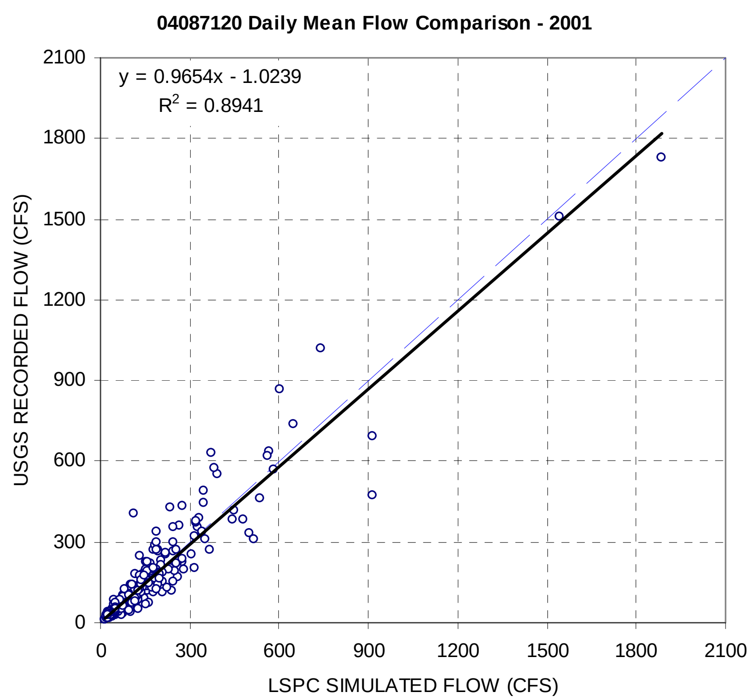


Figure 51. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087120 (2001).

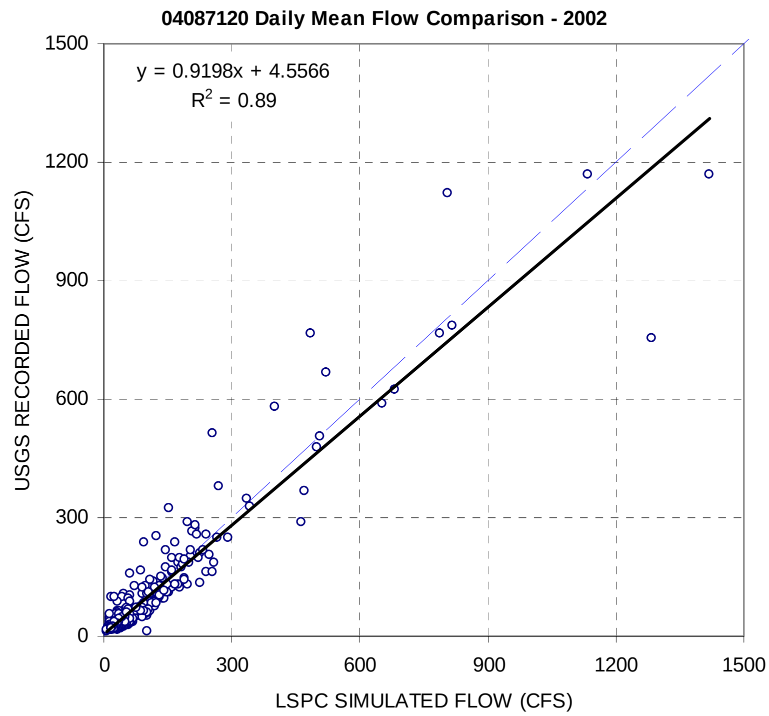


Figure 52. Observed versus simulated scatter plot with a linear regression line for Menomonee River at USGS gage 04087120 (2002).

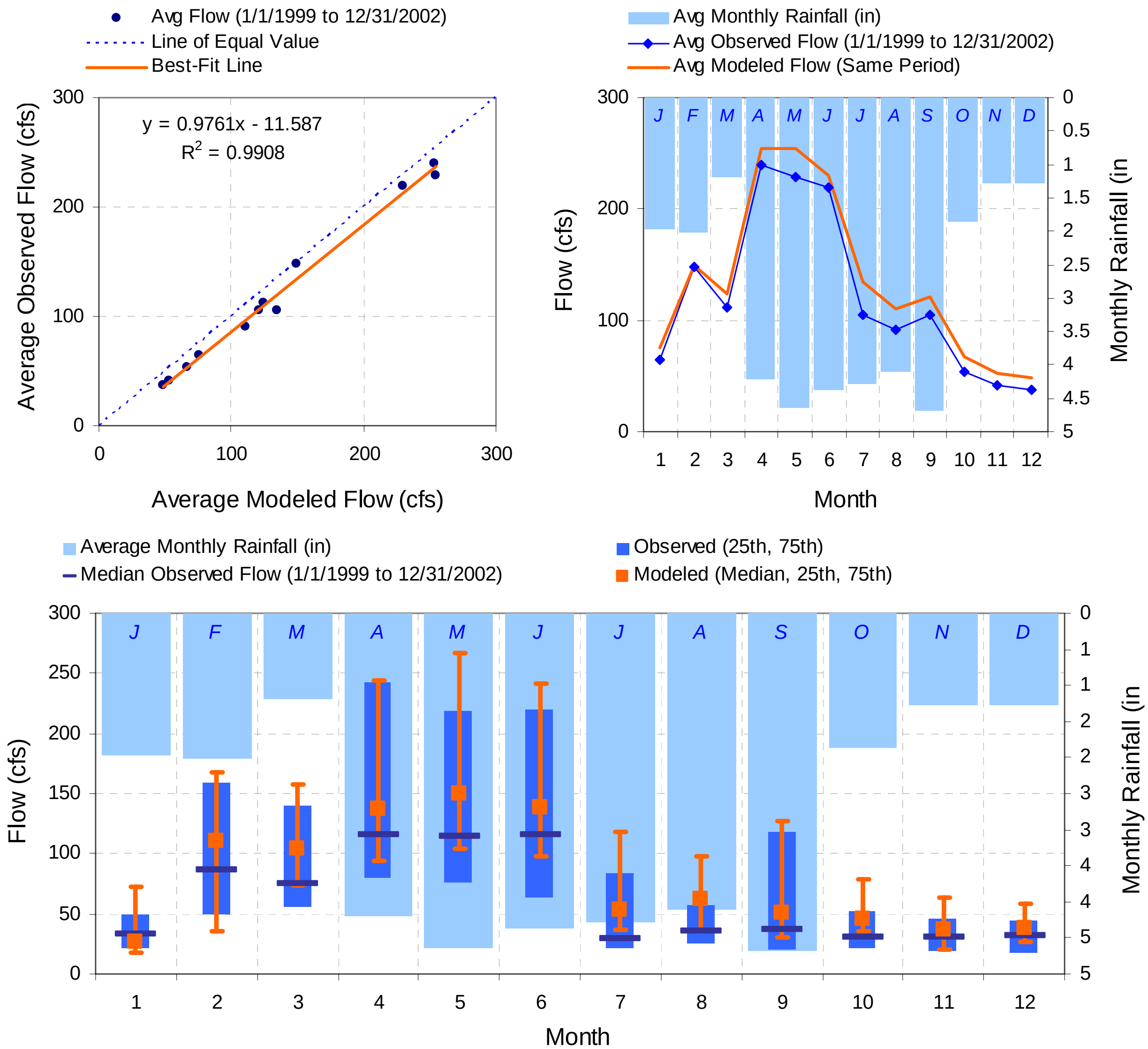


Figure 53. Composite (average monthly) hydrologic validation results for Menomonee River at USGS gage 04087120 (1999 to 2002).

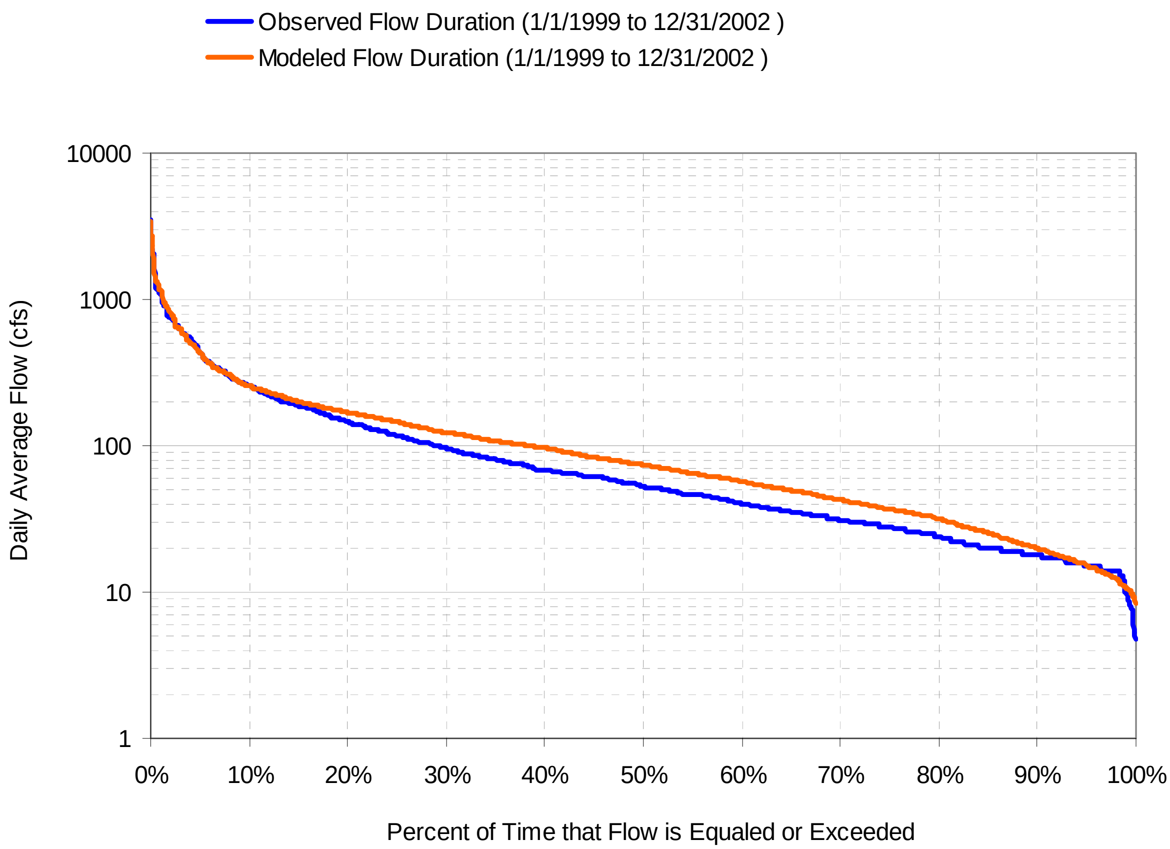


Figure 54. Flow duration curve hydrologic validation results for Menomonee River at USGS gage 04087120 (1999 to 2002).

Table 12. Error statistics for hydrologic validation results for Menomonee River at USGS gage 04087120 (1999 to 2002).

Monthly / Seasonal / Yearly Volume Comparison

Time Period		1999			2000			2001			2002			TOTAL		
		Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month	JAN	7,612	8,871	16.54%	1,454	1,717	18.0%	4,483	6,533	45.7%	2,325	1,518	-34.7%	15,874	18,639	17.4%
	FEB	7,956	10,187	28.0%	4,149	3,970	-4.3%	15,398	15,962	3.7%	5,641	3,484	-38.2%	33,144	33,603	1.4%
	MAR	5,348	6,895	28.9%	4,172	5,742	37.6%	10,209	11,192	9.6%	7,745	6,685	-13.7%	27,474	30,514	11.1%
	APR	21,603	26,395	22.2%	8,554	9,515	11.2%	15,144	12,587	-16.9%	11,714	11,973	2.2%	57,015	60,470	6.1%
	MAY	12,784	16,005	25.2%	25,762	26,547	3.0%	11,008	12,431	12.9%	6,692	7,543	12.7%	56,246	62,526	11.2%
	JUN	13,310	12,013	-9.7%	12,933	13,922	7.7%	14,019	13,633	-2.8%	11,925	15,176	27.3%	52,187	54,745	4.9%
	JUL	10,897	14,561	33.6%	9,722	11,865	22.0%	2,575	3,287	27.7%	2,747	3,407	24.0%	25,940	33,120	27.7%
	AUG	2,244	3,624	61.5%	6,836	9,877	44.5%	4,022	4,487	11.5%	9,247	9,270	0.3%	22,349	27,258	22.0%
	SEP	2,928	4,870	66.3%	12,456	13,587	9.1%	5,461	5,251	-3.8%	4,239	5,236	23.5%	25,084	28,945	15.4%
	OCT	1,525	2,796	83.3%	2,410	3,752	55.6%	5,962	6,186	3.8%	3,302	3,721	12.7%	13,200	16,455	24.7%
	NOV	1,323	1,461	10.4%	4,258	5,858	37.6%	2,795	3,743	33.9%	1,431	1,551	8.3%	9,807	12,613	28.6%
	DEC	2,043	3,727	82.4%	2,277	3,368	47.9%	3,378	3,318	-1.8%	1,670	1,518	-9.1%	9,369	11,931	27.3%

		1999				2000				2001				2002				TOTAL			
		Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Season	Jan-Mar	20,916	25,954	24.1%	4.1%	9,775	11,429	16.9%		30,089	33,687	12.0%		15,711	11,687	-25.6%	5.6%	**76,492**	**82,756**	**8.2%**	
	Apr-Jun	47,697	54,414	14.1%		47,249	49,984	5.8%		40,171	38,651	-3.8%		30,331	34,693	14.4%		**165,448**	**177,741**	**7.4%**	
	Jul-Sep	16,069	23,055	43.5%	23.5%	29,014	35,330	21.8%	1.8%	12,058	13,025	8.0%		16,233	17,913	10.4%		**73,373**	**89,323**	**21.7%**	**1.7%**
	Oct-Dec	4,892	7,984	63.2%	43.2%	8,945	12,978	45.1%	25.1%	12,135	13,247	9.2%		6,404	6,790	6.0%		**32,376**	**40,998**	**26.6%**	**6.6%**

Calibration Tolerance =20%

	1999				2000				2001				2002				TOTAL			
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	89,574	111,406	24.4%	14.4%	94,983	109,721	15.5%	5.5%	94,453	98,609	4.4%		68,679	71,083	3.5%		347,688	390,818	12.4%	2.4%

Calibration Tolerance =10%

Table 13. High-Low flow error statistics for hydrologic validation results for Menomonee River at USGS gage 04087120 (1999-2002).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	176,956	174,141	1.6%	15%
Total Highest 20% volume	237,003	230,167	3.0%	15%
Total Highest 50% volume	335,217	305,688	9.7%	15%
Total Lowest 10% volume	4,405	4,333	1.7%	10%
Total Lowest 30% volume	22,579	18,384	22.8%	10%
Total Lowest 50% volume	56,045	42,350	32.3%	10%

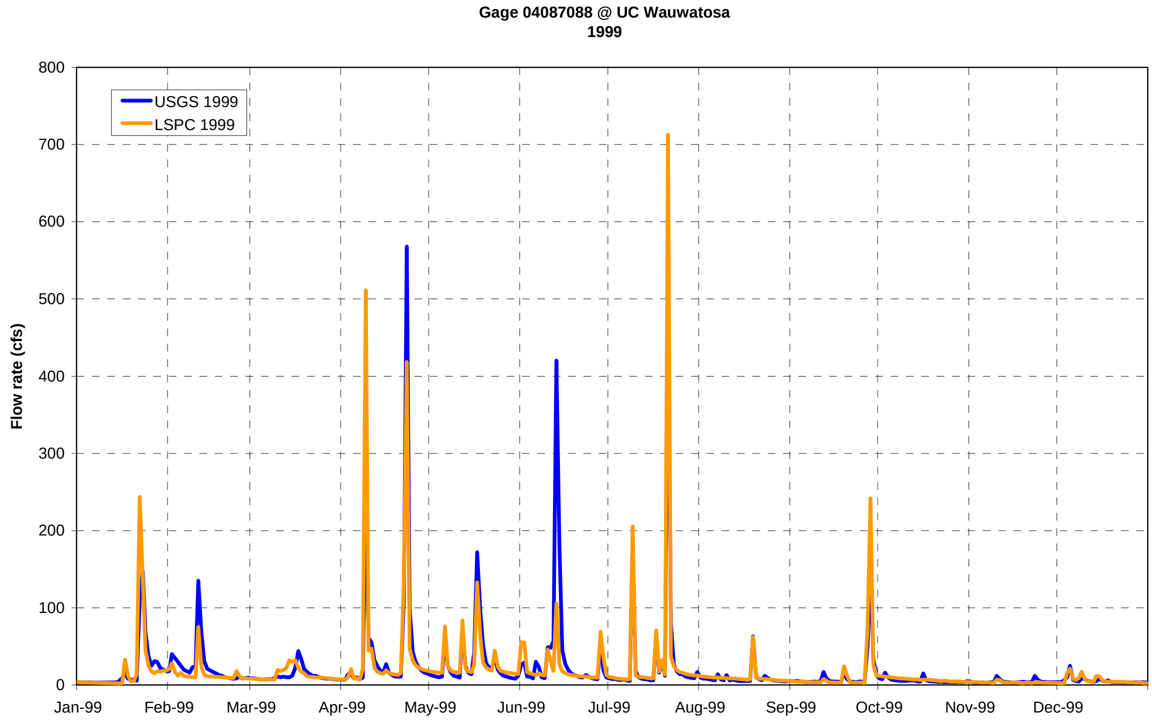


Figure 55. Time series hydrologic validation results (daily mean) for Underwood Creek at USGS gage 04087088 (1999).

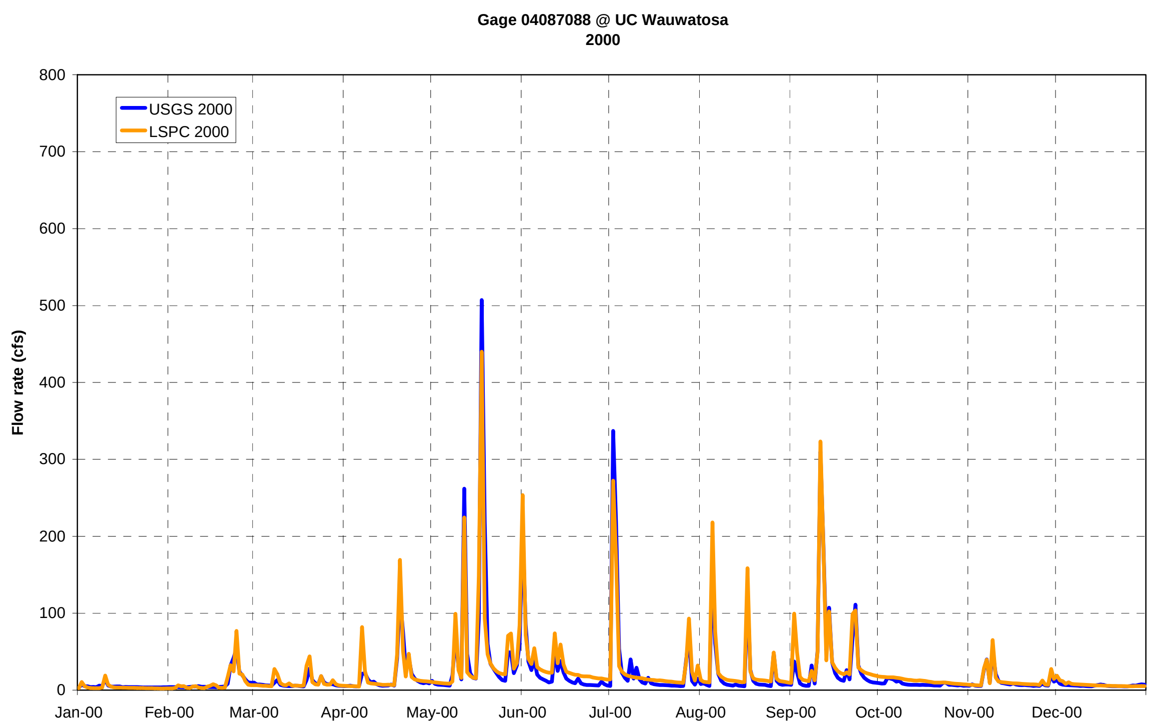


Figure 56. Time series hydrologic validation results (daily mean) for Underwood Creek at USGS gage 04087088 (2000).

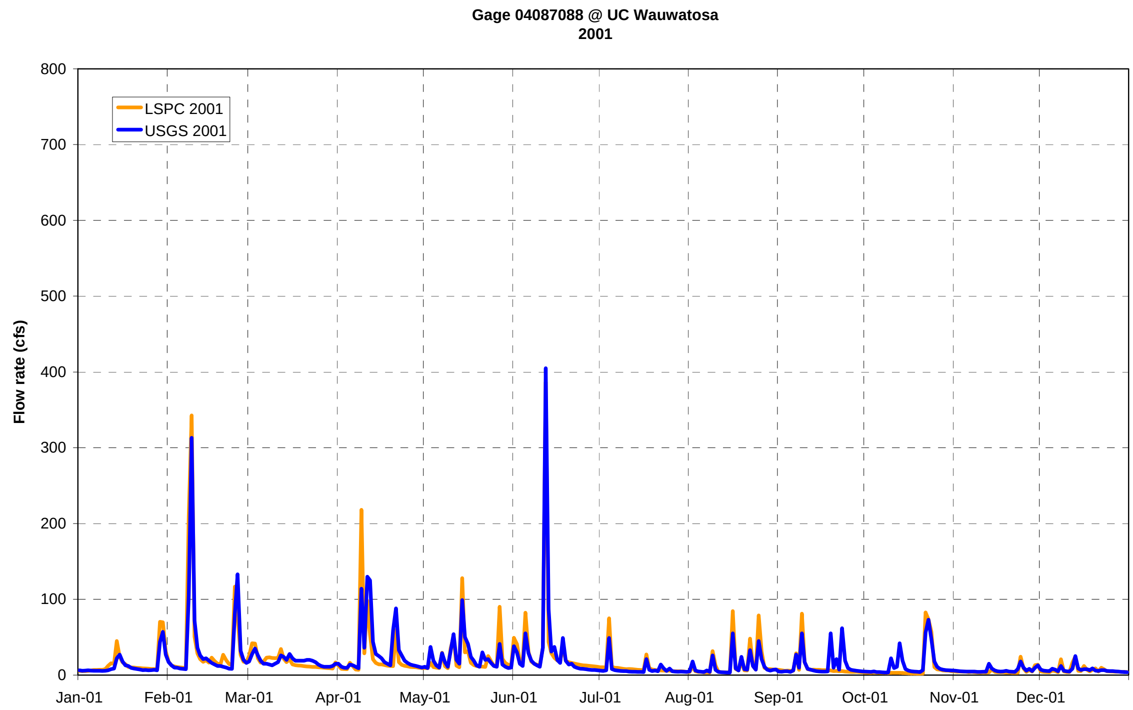


Figure 57. Time series hydrologic validation results (daily mean) for Underwood Creek at USGS gage 04087088 (2001).

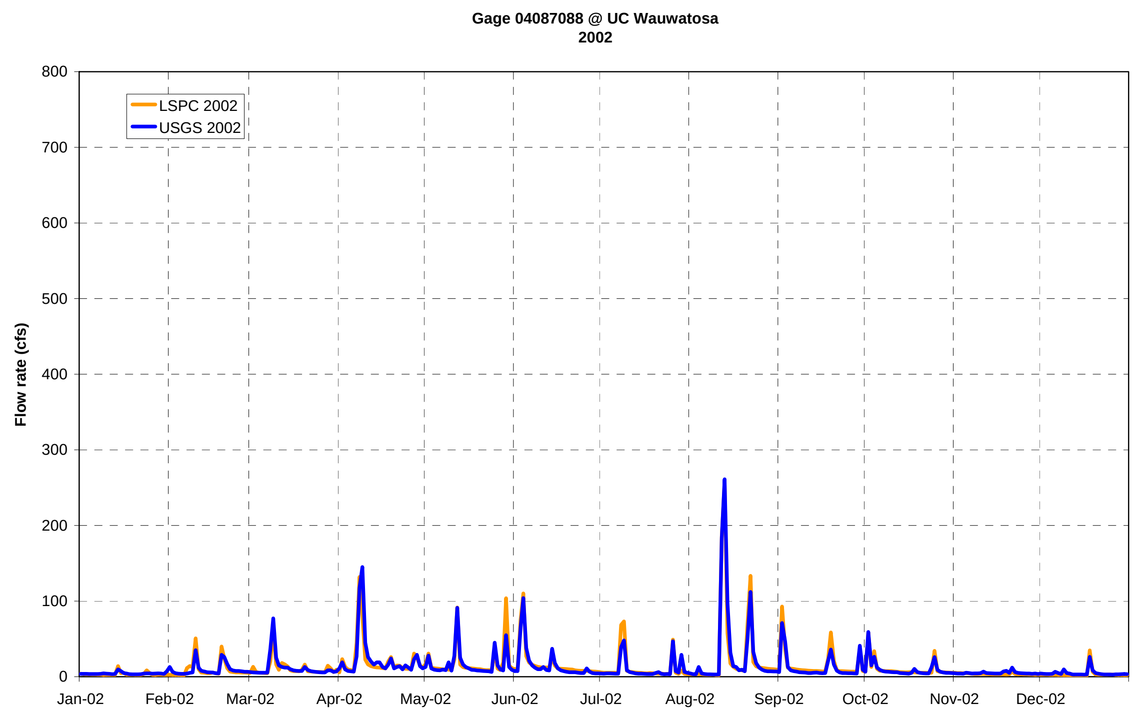


Figure 58. Time series hydrologic validation results (daily mean) for Underwood Creek at USGS gage 04087088 (2002).

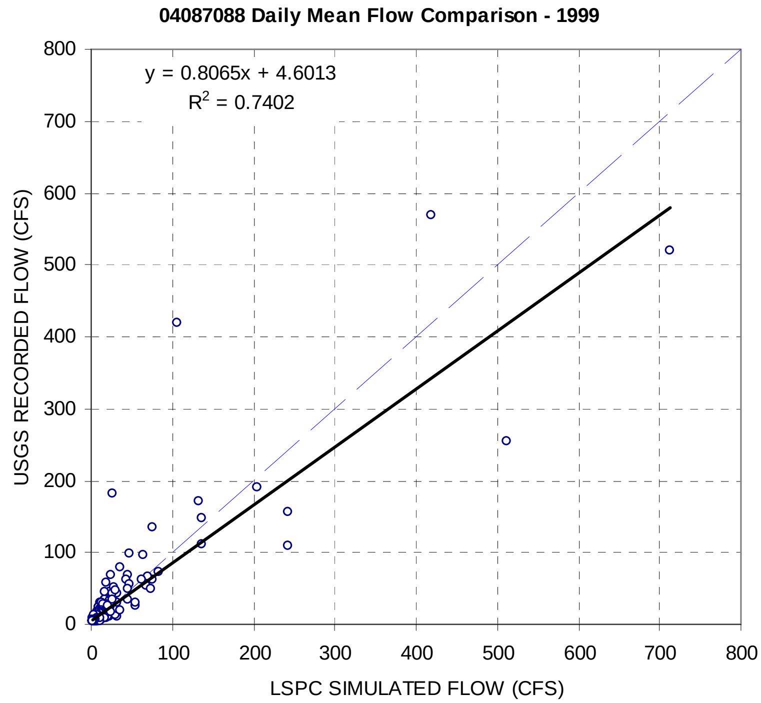


Figure 59. Observed versus simulated scatter plot with a linear regression line for Underwood Creek at USGS gage 04087088 (1999).

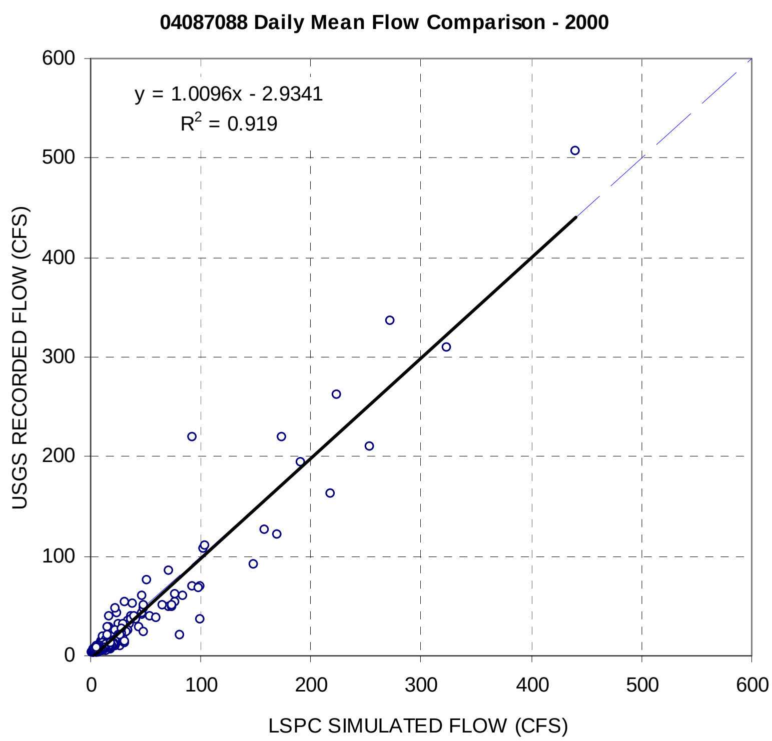


Figure 60. Observed versus simulated scatter plot with a linear regression line for Underwood Creek at USGS gage 04087088 (2000).

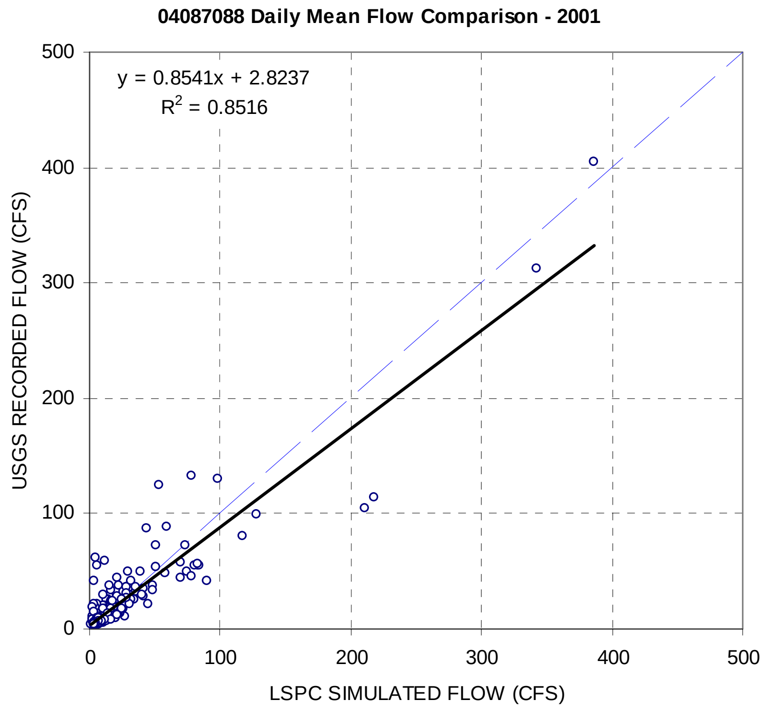


Figure 61. Observed versus simulated scatter plot with a linear regression line for Underwood Creek at USGS gage 04087088 (2001).

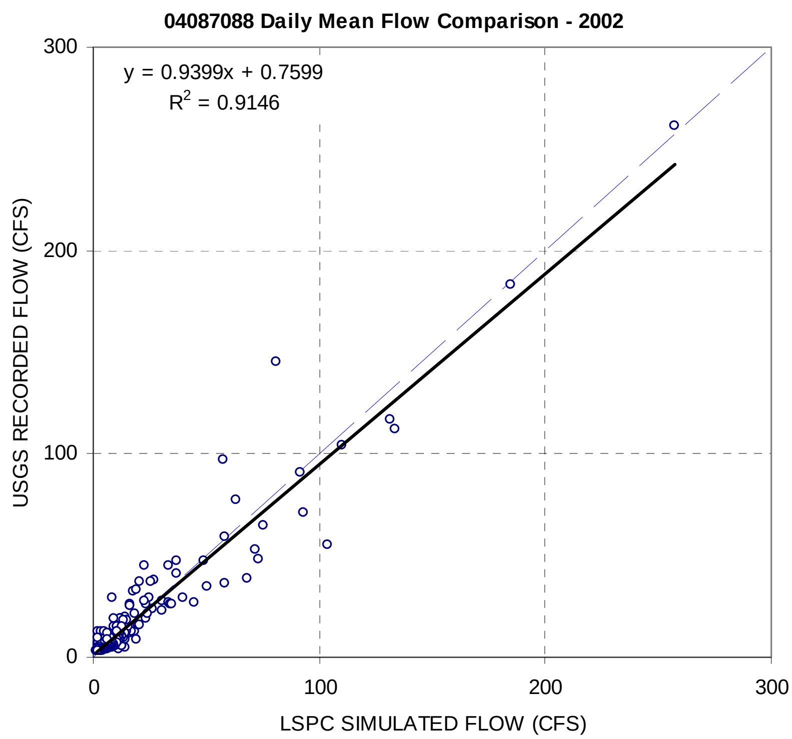


Figure 62. Observed versus simulated scatter plot with a linear regression line for Underwood Creek at USGS gage 04087088 (2002).

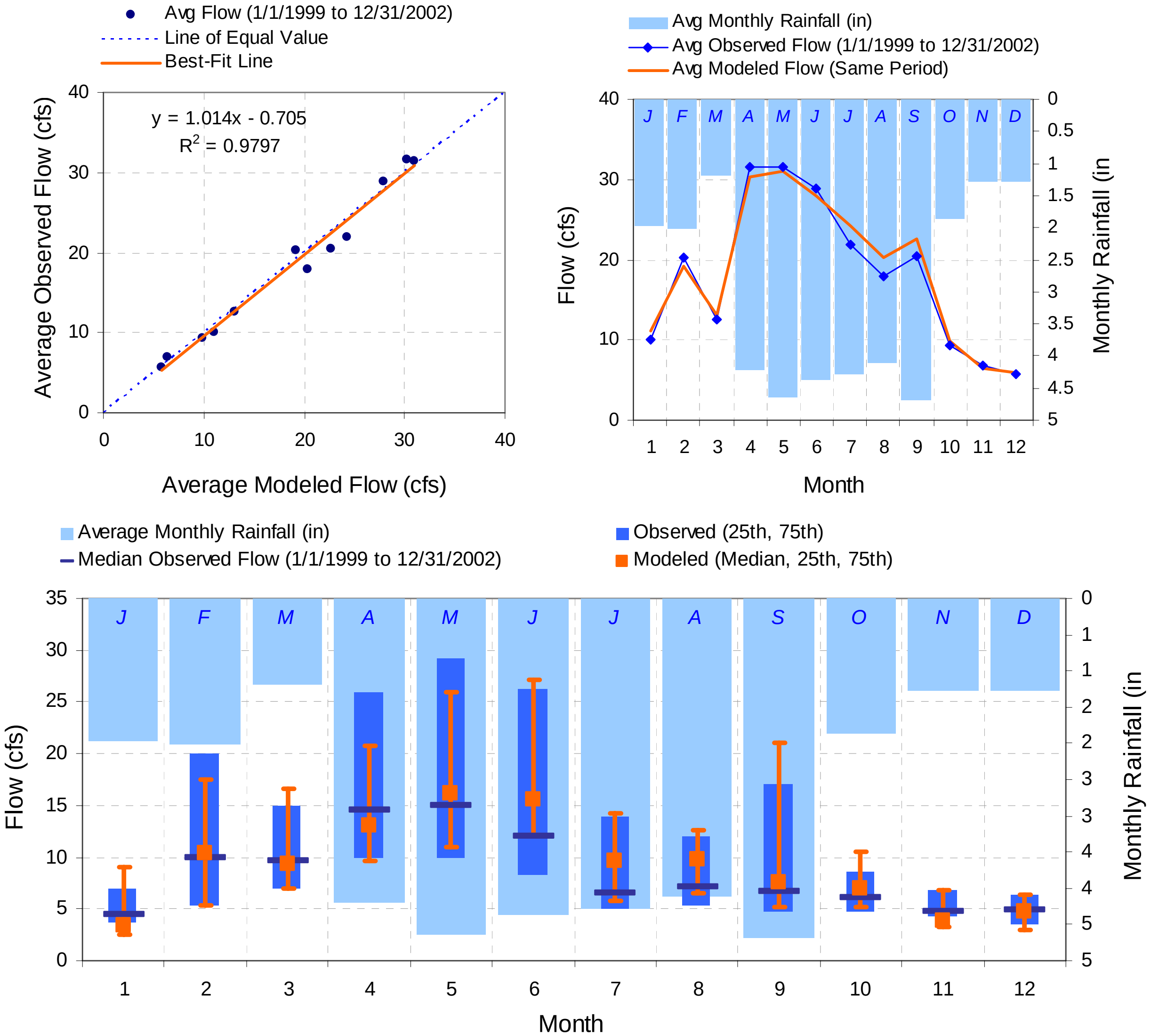


Figure 63. Composite (average monthly) hydrologic validation results for Underwood Creek at USGS gage 04087088 (1999 to 2002).

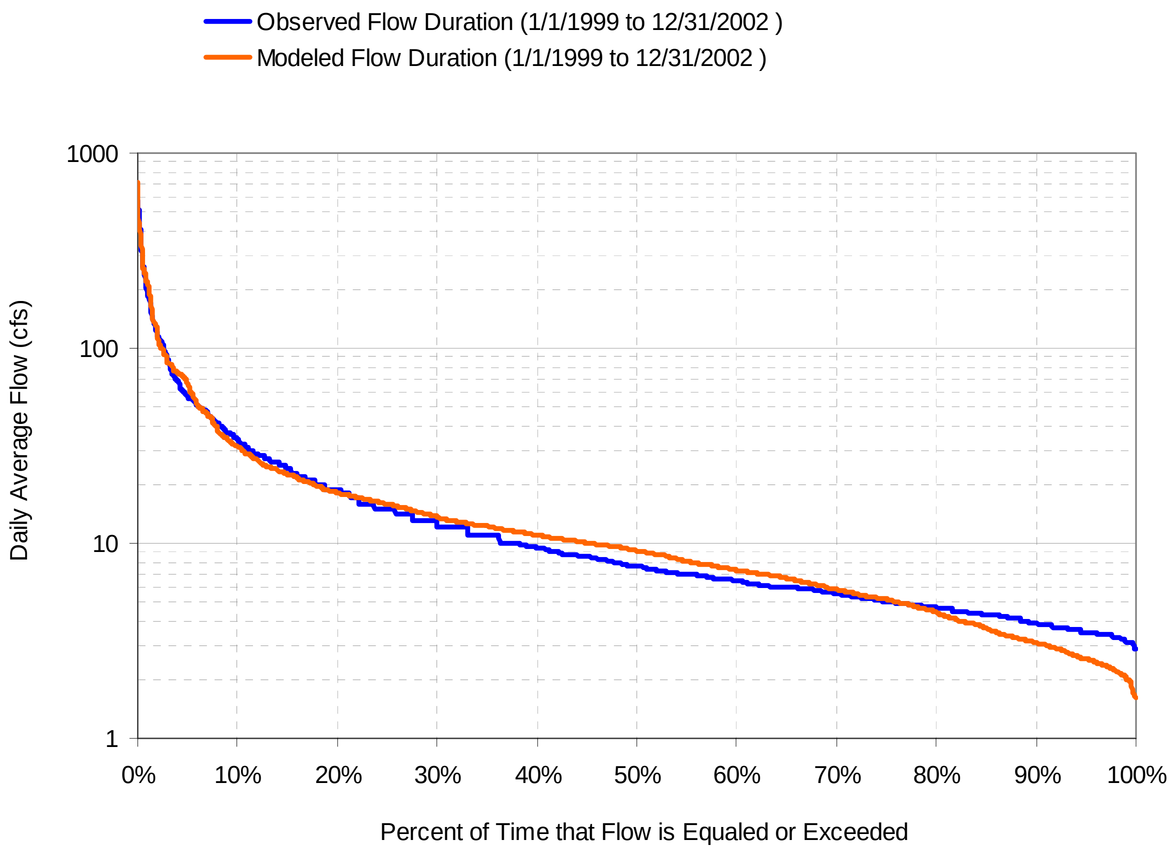


Figure 64. Flow duration curve hydrologic validation results for Underwood Creek at USGS gage 04087088 (1999 to 2002).

Table 14. Error statistics for hydrologic validation results for Underwood Creek at USGS gage 04087088 (1999 to 2002).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1999			2000			2001			2002			TOTAL		
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month JAN	1,222	1,330	8.8%	276	229	-17.2%	739	947	28.2%	264	216	-18.3%	**2,501**	**2,721**	**8.8%**
FEB	1,321	828	-37.3%	586	594	1.5%	2,107	2,360	12.0%	524	519	-0.8%	**4,537**	**4,302**	**-5.2%**
MAR	746	806	8.0%	515	639	24.1%	1,137	1,100	-3.2%	713	679	-4.8%	**3,111**	**3,224**	**3.6%**
APR	3,079	3,160	2.6%	1,082	1,259	16.4%	1,909	1,500	-21.4%	1,428	1,289	-9.7%	**7,497**	**7,207**	**-3.9%**
MAY	1,755	1,751	-0.2%	3,500	3,342	-4.5%	1,447	1,404	-3.0%	1,042	1,139	9.3%	**7,745**	**7,636**	**-1.4%**
JUN	2,368	1,412	-40.4%	1,491	2,134	43.1%	2,058	2,098	1.9%	937	1,017	8.5%	**6,854**	**6,660**	**-2.8%**
JUL	2,306	2,715	17.8%	2,027	1,982	-2.2%	472	622	31.7%	574	657	14.5%	**5,379**	**5,976**	**11.1%**
AUG	552	610	10.5%	1,253	1,694	35.1%	731	891	21.9%	1,877	1,810	-3.5%	**4,414**	**5,006**	**13.4%**
SEP	799	961	20.2%	2,540	2,956	16.4%	786	558	-29.1%	746	922	23.6%	**4,871**	**5,396**	**10.8%**
OCT	361	437	21.1%	500	748	49.6%	831	632	-24.0%	594	615	3.6%	**2,286**	**2,432**	**6.4%**
NOV	268	205	-23.7%	674	770	14.1%	393	333	-15.3%	299	222	-25.8%	**1,635**	**1,529**	**-6.4%**
DEC	337	379	12.3%	375	428	14.3%	424	427	0.7%	292	214	-26.6%	**1,428**	**1,448**	**1.4%**

Season	1999 Recorded USGS Volume (ac-ft)	1999 Simulated LSPC Volume (ac-ft)	1999 Percent Diff.	1999 Var. from Tolerance	2000 Recorded USGS Volume (ac-ft)	2000 Simulated LSPC Volume (ac-ft)	2000 Percent Diff.	2000 Var. from Tolerance	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2001 Var. from Tolerance	2002 Recorded USGS Volume (ac-ft)	2002 Simulated LSPC Volume (ac-ft)	2002 Percent Diff.	2002 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Jan-Mar	3,288	2,964	-9.9%		1,377	1,463	6.2%		3,982	4,407	10.7%		1,501	1,414	-5.8%		**10,148**	**10,248**	**1.0%**	
Apr-Jun	7,202	6,323	-12.2%		6,073	6,735	10.9%		5,414	5,002	-7.6%		3,407	3,444	1.1%		**22,095**	**21,504**	**-2.7%**	
Jul-Sep	3,658	4,287	17.2%		5,821	6,632	13.9%		1,989	2,070	4.1%		3,197	3,389	6.0%		**14,664**	**16,378**	**11.7%**	
Oct-Dec	967	1,021	5.6%		1,549	1,946	25.6%	5.6%	1,648	1,392	-15.5%		1,185	1,051	-11.2%		**5,349**	**5,410**	**1.2%**	

Calibration Tolerance =20%

	1999 Recorded USGS Volume (ac-ft)	1999 Simulated LSPC Volume (ac-ft)	1999 Percent Diff.	1999 Var. from Tolerance	2000 Recorded USGS Volume (ac-ft)	2000 Simulated LSPC Volume (ac-ft)	2000 Percent Diff.	2000 Var. from Tolerance	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2001 Var. from Tolerance	2002 Recorded USGS Volume (ac-ft)	2002 Simulated LSPC Volume (ac-ft)	2002 Percent Diff.	2002 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Year	15,114	14,594	-3.4%		14,819	16,775	13.2%	3.2%	13,034	12,871	-1.2%		9,289	9,299	0.1%		**52,257**	**53,539**	**2.5%**	

Calibration Tolerance =10%

Table 15. High-Low flow error statistics for hydrologic validation results for Underwood Creek at USGS gage 04087088 (1999-2002).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	28,155	27,601	2.0%	15%
Total Highest 20% volume	34,919	34,768	0.4%	15%
Total Highest 50% volume	45,982	44,766	2.7%	15%
Total Lowest 10% volume	741	1,032	-28.1%	10%
Total Lowest 30% volume	3,300	3,754	-12.1%	10%
Total Lowest 50% volume	7,601	7,514	1.2%	10%

Table 16. Coefficient of Model Fit Efficiency (E) for Root River Hydrologic Model (Daily Flows, 1995-2002)

USGS Gage Number	Station Name	E
04087030	Menomonee River at Menomonee Falls, WI	0.72
04087088	Underwood Creek at Wauwatosa, WI	0.88
04087120	Menomonee River at Wauwatosa, WI	0.89

9.0 REFERENCES

Bicknell, B.R., J.C. Imhoff, J. Kittle, A.S. Donigian, and R.C. Johansen. 1996. *Hydrological Simulation Program –FORTRAN, User's Manual for Release H*. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Crawford, N.H. and K. Linsley. 1966. Digital Simulation in Hydrology: Stanford Watershed Model IV, Stanford University, Department of Civil Engineering, Technical Report 39.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. *Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage*, 89(IR4): 15-41.

Jensen, M.E., D.C.N. Rob, and C.E. Franzoy. 1969. Scheduling irrigations using climate-crop-soil data. Proceedings, National Conference on Water Resources Engineering of the American Society of Civil Engineers, New Orleans, LA.

NRCS (Natural Resources Conservation Service). 2001. *National Soil Survey Handbook .* U.S. Department of Agriculture, Natural Resources Conservation Service. Available at http://www.statlab.iastate.edu/soils/nssh/.

Tetra Tech. 2002. Minnesota River Basin Model, Model Calibration and Validation Report. Prepared for Minnesota Pollution Control Agency, St. Paul, MN by Tetra Tech, Inc., Research Triangle Park, NC.

U.S. Environmental Protection Agency (USEPA). 2000. *BASINS Technical Note 6. Estimating Hydrology and Hydraulic Parameters for HSPF*. EPA-823-R00-012. U.S. Environmental Protection Agency. Office of Water. July 2000.

2020 Facility Planning Project

Technical Memorandum

MMSD Contract #: M03002P01
MMSD File Code #: M009PE000.P7300-WQ1

Project Name: 2020 Facilities Planning Project

To: Robert Biebel, SEWRPC, Bill Krill, HNTB

From: Leslie Shoemaker, Tetra Tech

Date: May 22, 2006

Subject: Revised Draft Hydrologic Calibration and Validation Results for the Milwaukee River Model

1.0 EXECUTIVE SUMMARY

An important component of the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU) is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. The purpose of this memorandum is to describe the modeling process and provide results of the hydrologic and hydraulic calibration and validation of the Milwaukee River watershed model.

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for a variety of reasons, including that existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds. The Loading Simulation Program in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms but has the advantage of no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original HSPF models for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds have been migrated to LSPC and the Milwaukee River model has been developed within LSPC for the 2020 Facilities Planning Project[1].

Configuration of the Milwaukee River LSPC model involved consideration of five major components: waterbody representation, watershed segmentation, meteorological data, land cover representation, and point sources. The structure for the Milwaukee River and tributaries is derived from Southeastern Wisconsin Regional Planning Commission (SEWRPC) HSP models with modifications supervised by SEWRPC staff. The model was configured to simulate the watershed as a series of 362 hydrologically connected subwatersheds.

[1] The only previous HSPF model within the Milwaukee River watershed was for Brown Deer Park Creek, a tributary to the Milwaukee River.

The Milwaukee River model is driven by precipitation data and other climatologic data (e.g., temperature, cloud cover, wind speed). Precipitation data are taken from four National Weather Service and three Milwaukee Metropolitan Sewerage District (MMSD) gages; a single weather gage was assigned to each of the subwatersheds based on a Thiessen polygon analysis.

Land cover classifications from the SEWRPC 2000 land use codes were re-classified to develop the land cover representation in the LSPC model. The final land cover representation for the Milwaukee River LSPC model indicates that the two most common land covers are crops on B soils (28 percent of the total watershed) and wetlands (16 percent).

There are a number of “point sources” in the Milwaukee River watershed, including wastewater treatment plants, sanitary sewer overflows (SSOs), combined sewer overflows (CSOs), and industrial facilities. Flows from these point sources were input directly into the LSPC model using the methodology outlined in the December 13, 2004 memorandum entitled *Point Source Loading Calculations for Purposes of Watercourse Modeling*.

In general, the hydrologic calibration and validation results indicate acceptable agreement between observed and simulated streamflows. Baseflows are well represented for each season for both the calibration and validation periods. The timing of most storms is captured, as are the shapes of the hydrographs. The model meets most tolerance criteria for both the calibration and validation periods at gages 04086600 and 04087000. The model does not perform as well at gage 04086500 along Cedar Creek.

The most significant cause of deviation between the model and observations is likely due to the specification of meteorological forcing. Although seven rain gages were used to simulate the Milwaukee River watershed, these stations are distributed unevenly. The three MMSD stations are clustered downstream and only cover a small part of the large watershed. At the upper portion of the watershed, a single station covers a large area where precipitation and other meteorological inputs vary significantly. Errors for the Cedar Creek subwatershed are likely also due to poor representation of certain snowmelt events and a limited ability to simulate the hydrologic impacts of numerous small lakes and wetlands.

2.0 CONCLUSIONS

The following are the conclusions resulting from the hydrologic calibration and validation process for the Milwaukee River model:

- The setup of the final LSPC model has been completed.
- The calibration results for the Milwaukee River model indicate acceptable agreement between observed and simulated streamflows.

Deviations from criteria appear to be related primarily to the uncertainties inherent in translating a limited number of point rain gauges to a very large watershed.

3.0 RECOMMENDATIONS

We recommend that the hydrologic calibration and validation of the Milwaukee River model be considered essentially complete so that the water quality calibration/validation can also be finalized to facilitate production runs as required for project planning.

4.0 INTRODUCTION

The Milwaukee Metropolitan Sewerage District (MMSD) is in the midst of a long-range planning effort to identify improvements needed for its facilities to accommodate growth and protect water quality through the year 2020. This effort is known as the MMSD 2020 Facility Plan. A related planning effort is being conducted by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) to update the regional water quality management plan for the Kinnickinnic River, Menomonee River, Milwaukee River, Root River, and Oak Creek watersheds, the Milwaukee Harbor estuary, and the adjacent nearshore Lake Michigan area. This effort is known as the Regional Water Quality Management Plan Update (RWQMPU). The two planning efforts are being coordinated and implemented in parallel.

One important component of both the 2020 Facility Plan and the RWQMPU is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. Watershed models are being developed for the following five watersheds:

- Kinnickinnic River
- Menomonee River
- Milwaukee River
- Oak Creek
- Root River

The Oak Creek, Kinnickinnic, Menomonee, and Milwaukee River models will then be linked to a model of the Lake Michigan estuary so that the benefits of upstream water quality improvements can be simulated by the Lake Michigan Harbor / Estuary Model.

The following seven tasks have been identified for performing the system modeling:

1) Establish the model structure, including the delineation of subwatersheds, connectivity, and cross sections, etc.
2) Develop the model data sets using physical measurements, maps, and other appropriate information

3) Perform hydrologic and hydraulic calibration and validation
4) Perform watercourse water quality calibration and validation
5) Perform harbor/estuary and lake water quality calibration
6) Perform production runs as required for project planning
7) Document results.

The purpose of this report is to document the hydrologic and hydraulic calibration and validation for the Milwaukee River watershed model (Task 3). The model being used is described in Section 5.0, Model Description. The configuration of the model, including waterbody representation, watershed segmentation, meteorological data, and land cover representation, is described in Section 6.0, Modeling Approach. The modeling process is described in Section 7.0, Calibration and Validation Process, and the calibration and validation results are presented in Section 8.0, Results of Hydrologic Calibration and Validation. A separate memorandum presents the water quality calibration results.

5.0 MODEL DESCRIPTION

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. Many watershed models, including the one used for this project, are also capable of simulating in-stream processes using the land-based calculations as input. Once a model has been adequately set up and calibrated for a watershed it can be used to quantify the existing loading of pollutants from subwatersheds or from land use categories. The model can also be used to simulate the potential impacts of various management alternatives.

The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for the following reasons:

- Existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds
- HSPF applies to watersheds with rural, suburban, and urban land uses
- HSPF simulates the necessary constituents: TSS, TN (TKN, NH4, NH3, NO3 and NO2), TP, Orthophosphate, Fecal Coliforms, Copper and Zinc (as conservative substances), DO, BOD, TOC, Temperature, Benthic Algae, and Chlorophyll-a.
- HSPF allows long-term continuous simulations to predict hydrologic variability.
- HSPF provides adequate temporal resolution (i.e., hourly or daily) to facilitate a direct comparison to water quality standards
- HSPF simulates both surface runoff and groundwater flows

A brief description of the HSPF model is provided below.

5.1 Overview of HSPF

HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970’s and is generally considered one of the most advanced hydrologic and watershed loading models available. The hydrologic portion of HSPF is based on the Stanford Watershed Model (Crawford and Linsley, 1966), which was one of the pioneering watershed models developed in the 1960’s. The HSPF framework is developed in a modular fashion with many different components that can be assembled in different ways, depending on the objectives of the individual project. The model includes three major modules:

- PERLND for simulating watershed processes on pervious land areas

- IMPLND for simulating processes on impervious land areas
- RCHRES for simulating processes in streams and vertically mixed lakes.

All three of these modules include many submodules that calculate the various hydrologic and water quality processes in the watershed. Many options are available for both simplified and complex process formulations. Spatially, the watershed is divided into a series of subbasins representing the drainage areas that contribute to each of the stream reaches. These subbasins are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into the pervious (PERLND) and impervious (IMPLND) fractions. The stream network (RCHRES) links the surface runoff and groundwater flow contributions from each of the land segments and subbasins and routes them through the waterbodies using storage routing techniques. The stream/reservoir model includes precipitation and evaporation from the water surfaces, as well as flow contributions from the watershed, tributaries, and upstream stream reaches. Flow withdrawals can also be accommodated. The stream network is constructed to represent all of the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur.

Like the watershed components, several options are available for simulating water quality in the receiving waters. The simpler options consider transport through the waterways and represent all transformations and removal processes using simple first-order decay approaches. More advanced options for simulating nutrient cycling and biological processes are also available. The framework is flexible and allows different combinations of constituents to be modeled depending on data availability and the objectives of the study. A more detailed discussion of HSPF simulated processes and model parameters is presented in the Menomonee River water quality calibration memorandum and is also available in the HSPF User's Manual (Bicknell et al. 1996).

5.2 Overview of Loading Simulation Program in C++

The Loading Simulation Program, in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms for simulating hydrology, sediment, and general water quality on land as well as in the water column. LSPC is currently maintained by the EPA Office of Research and Development in Athens, Georgia, and during the past several years it has been used to develop hundreds of water quality restoration plans across the country through the Clean Water Act Total Maximum Daily Load (TMDL) Program. A key advantage of LSPC is that it has no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the Milwaukee River model was developed in LSPC for the 2020 Facilities Planning Project. A memorandum dated October 18, 2004 (*Confirmation of the Underwood Creek LSPC Model using selected HSPF Modules)* presents the results of a benchmark testing methodology that was developed to compare the underlying computational algorithms of the LSPC model to known HSPF solutions for Underwood Creek, a tributary to the Menomonee River. Near identical results were found between the two models.

6.0 MODELING APPROACH

The Milwaukee River watershed encompasses approximately 693.8 square miles in Dodge, Fond du Lac, Sheboygan, Washington, Ozaukee and Milwaukee Counties. However, only the portion located downstream of the Cedar Creek confluence is within the MMSD watercourse planning area (representing a drainage area of approximately 57 square miles or about 8 percent of the total watershed area). Within Milwaukee County, the watershed is almost completely developed for urban use. Urbanization within the remaining portion of the watershed, upstream of Milwaukee County, is much less prevalent.

Configuration of the Milwaukee River LSPC model involved consideration of five major components: waterbody representation, watershed segmentation, meteorological data, land use representation, and point sources. These components provide the basis for the model's ability to estimate flow and water quality and are described in greater detail below. The entire watershed modeled with LSPC encompasses approximately 668 square miles (including some modeling subwatersheds that are internally drained). The portion of the watershed in the combined sewer service area is not explicitly modeled in LSPC, but rather is included in the MMSD conveyance (MOUSE) model. Within the LSPC model it is treated as a series of point sources reflecting either reported combined sewer bypassing (model calibration) or output from the MOUSE model (production runs). A portion of the watershed is also downstream of the LSPC model boundary and is contained within the estuary model.

6.1 Waterbody Representation

The Milwaukee River watershed is shown in Figure 6-1. The watershed contains 30 perennial streams as shown in Table 6-1. Within the MMSD watercourse planning area, there are three perennial tributary streams that are a part of the Milwaukee River watershed with a total length of 12.8 miles, which include Indian Creek (1.9 miles), Lincoln Creek (7.9 miles), and Pigeon Creek (2.4 miles). The Milwaukee River has a total length of 26.2 miles within the MMSD watercourse planning area. The Milwaukee River discharges into the Milwaukee Harbor, which is tributary to Lake Michigan.

Table 6-1. Perennial Streams in the Milwaukee River Watershed.

Stream Name	Length (Miles)
Batavia Creek	5.0
Cedar Creek	31.5
Cedarburg Creek	3.0
Chambers Creek	2.9
East Branch Milwaukee River	14.3
Engmon Creek	1.5
Evergreen Creek	4.9
Gooseville Creek	1.8
Indian Creek	1.9
Kewaskum Creek	6.4
Kressin Brook	4.7
Lake Fifteen Creek	7.4
Lincoln Creek	7.9
Little Cedar Creek	6.0
Melius Creek	3.3
Milwaukee River	101.0
Mink Creek	17.3
Myra Creek	2.6
Nichols Creek	3.3
North Branch Cedar Creek	7.3
North Branch Milwaukee River	30.0
Pigeon Creek	2.4
Quas Creek	5.9
Silver Creek (Washington County)	4.0
Silver Creek (Sheboygan County)	7.1
Stony Creek	10.0
Virgin Creek	4.5
Wallace Creek	8.6
Water Cress Creek	6.5
West Branch Milwaukee River	20.1
Total	**333.1**

The Milwaukee River watershed also contains 20 major lakes (defined as those having a surface area greater then 50 acres) (Table 6-2).

Table 6-2. Major Lakes in the Milwaukee River Watershed.

Lake Name	Acreage
Cedar	932
Long	427
Little Cedar	246
Mud (Ozaukee County)	245
Kettle Moraine	227
Random	209
Ellen	121
Silver	118
Auburn (Fifteen)	107
Crooked	91
Smith (Drickens)	86
Mauthe	78
Lucas	78
Green	71
Barton Pond	67
Spring	57
Mud (Fond du Lac County)	55
Twelve	53
Wallace	52
Forest	51

Modeling an entire watershed requires routing flow and pollutants from upstream portions of the watershed to the watershed outlet through the stream network. In LSPC, the stream network is a tabular representation of the actual stream system. Attribute data pair individual stream segments with a corresponding delineated subbasin. Data associated with individual reaches identify the location of the particular reach within the overall stream network, defining the connectivity of the subwatersheds.

The representation of the Milwaukee River and its tributaries in LSPC is based on SEWRPC HSP models with modifications supervised by SEWRPC staff. A schematic representation of the final Milwaukee River LSPC model is presented in Attachment A.

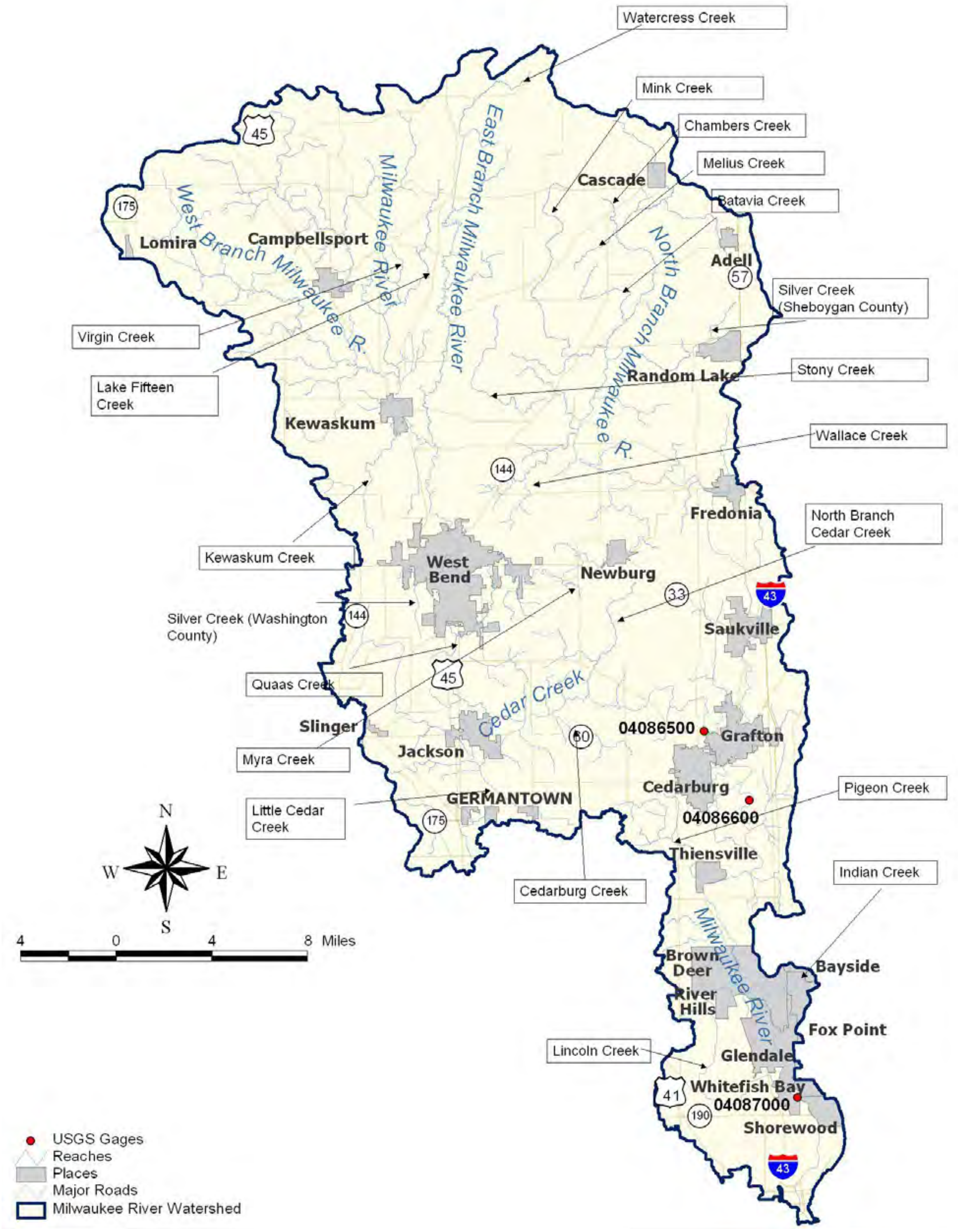


Figure 6-1. Location of the Milwaukee River watershed and the USGS gages used for calibration/validation.

6.2 Watershed Segmentation

LSPC was configured for the Milwaukee River to simulate the watershed as a series of 362 hydrologically connected subwatersheds. The delineation of the subwatersheds was based partially on topography but also took into consideration human-influenced drainage patterns. The spatial subdivision of the watershed allows for a more refined representation of pollutant sources and a more realistic description of hydrologic factors. The subwatersheds and primary streams in the Milwaukee River watershed are shown in Figure 6-2.

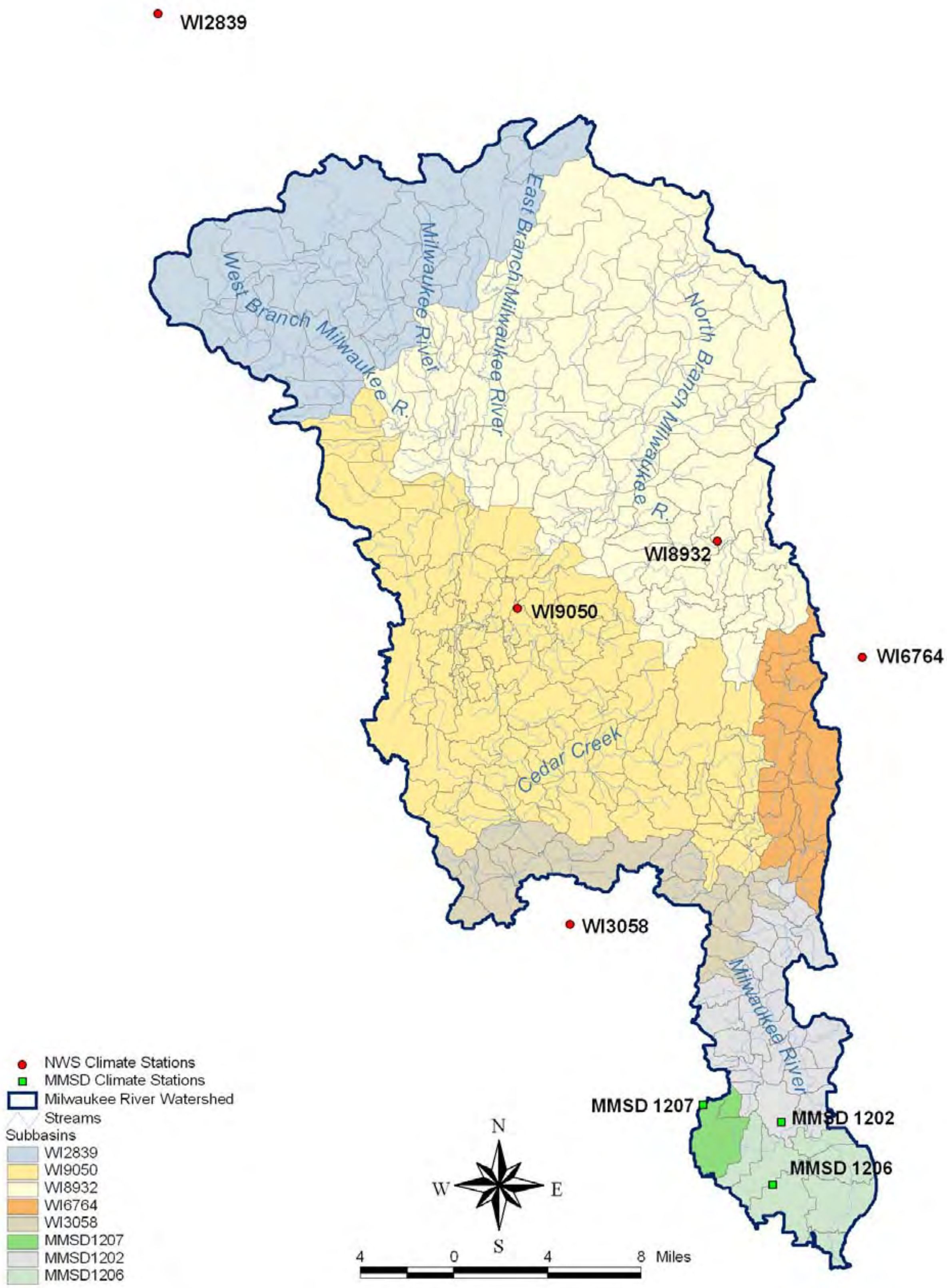


Figure 6-2. Milwaukee River LSPC modeling subwatersheds, location of weather gages, and weather gage assignments.

6.3 Weather Data

Hydrologic processes are time varying and depend on changes in environmental conditions including precipitation, temperature, and wind speed. As a result, meteorological data are a critical component of the watershed model. Appropriate representation of precipitation, wind movement, solar radiation, potential evapotranspiration, cloud cover, temperature, and dew point are required to develop a valid model. These data provide necessary input to model algorithms for hydrologic and water quality representation.

Due to its large size, substantial variability in meteorology is likely to be present across the Milwaukee River watershed. Five National Weather Services (NWS) cooperating observer stations with daily rainfall and temperature records and three MMSD stations with hourly rainfall and temperature records were used to represent weather patterns as shown in Figure 6-2 and Table 6-3.

During the calibration process many different combinations of weather station assignments to different subwatersheds were used to try and correct a chronic underprediction of observed flows. Eventually it was determined that the very use of the rainfall data from the West Bend station was the source of the problem (regardless of the assignment of subwatersheds) and the Fond du Lac rainfall was eventually chosen to replace the West Bend rainfall. A possible explanation for this might be that since the Fond du Lac community has much more of a problem with wet weather events than does West Bend, the operators of the Fond du Lac rain gage might pay more attention to detail when collecting their data (Bill Krill, personal communications). The use of the Fond du Lac rainfall in place of the West Bend data may also be justified by the fact the prevailing weather patterns in the study area are from North to South and West to East. The final assignment of weather data as shown in Table 6-3 and Figure 6-2 produced significantly better results than any combination of subwatersheds modeled with the West Bend data.

Table 6-3. LSPC air file timeseries components for the Milwaukee River Watershed Model.

LSPC Air Filename	Station Description	Rainfall	PEVT	Temperature	Wind Speed	Solar Radiation	Dewpoint Temperature
WI8932	Waubeka	WI8932	COMBO[a]	Port Washington	GMIA[b]	GMIA	GMIA
WI2839	Fond du Lac	WI2839	COMBO[a]	Fond du Lac	GMIA	GMIA	GMIA
WI6764	Port Washington	WI6764	COMBO[a]	Port Washington	GMIA	GMIA	GMIA
WI2839wb	West Bend	WI2839[c]	COMBO[a]	West Bend	GMIA	GMIA	GMIA
WI3058	Germantown	WI3058	Penman	GMIA	GMIA	GMIA	GMIA
Rain1202	MMSD 1202	1202	Penman	GMIA	GMIA	GMIA	GMIA
Rain1206	MMSD 1206	1206	Penman	GMIA	GMIA	GMIA	GMIA
SPET1207	MMSD 1207	1207	Penman	GMIA	GMIA	GMIA	GMIA

[a] COMBO = Combined PEVT timeseries (Penman for April through June; Jensen-Haise for remainder of year)
[b] GMIA = Data source is General Mitchell International Airport
[c] West Bend rainfall was replaced with Fond du Lac rainfall during calibration due to poor representation; however, the station location was maintained because of the temperature time series.

Since the four NWS stations used in the Milwaukee River watershed model only recorded daily precipitation, and hourly or subhourly timeseries are required for LSPC simulation, disaggregation was necessary. Disaggregated precipitation data for the Port Washington station was previously provided by SEWRPC, requiring disaggregation of the records for the three remaining stations. In addition, these stations also contained markers for missing data. Missing data were estimated using a distance weighting and long-term annual average method. A detailed description of this process is provided in Attachment B (*Proposed Approach for Developing Surrogate Precipitation Data for Production Runs* (Revised May 10, 2006)).

Precipitation, temperature, cloud cover, wind speed, and dew point are gage monitored, while potential evapotranspiration (PEVT) and solar radiation are computed. Model performance is particularly sensitive to PEVT, as this controls the fraction of precipitation that is evaporated back to the atmosphere. A variety of methods are available for estimation of PEVT, each yielding slightly different results. SEWRPC provided a time series of PEVT calculated for Milwaukee General Mitchell International Airport using the Penman method, which calculates PEVT by first estimating evaporation from a standard Class A pan and then converting it to a PEVT estimate by application of a monthly coefficient. Initial evaluation of calibration results suggested that PEVT was underestimated by the Penman method for the summer period, while use of the alternative Jensen-Haise method (Jensen and Haise, 1963; Jensen et al., 1969) provided a much better fit, especially for the rural areas of the watershed. This method is based on daily air temperature and solar radiation, with a seasonal correction factor, and, unlike the Penman method, does not depend on measured wind speed and relative humidity. Improved fit with this method is likely due to the fact that humidity and wind speed measured at Milwaukee General Mitchell International Airport are imprecise representations of the distribution of these variables over the whole watershed. Further testing suggested, however, that the Jensen-Haise method over-estimates PEVT for the spring period. Therefore, a combined PEVT series was created, using the SEWRPC Penman PEVT estimates for the April-June period and Jensen-Haise estimates for the remainder of the year. The combined PEVT series is used for the upper parts of the Milwaukee River watershed that are more rural and the original SEWRPC Penman series are used for the areas of the watershed that are more urban. Table 6-3 indicates which timeseries data are used for each of the eight weather files.

6.4 Land Cover Representation

LSPC requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the basin, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices.

Land cover classifications from the SEWRPC 2000 land use codes were used to develop the land cover representation in the LSPC model. Figure 6-3 displays the distribution of these land use groups within the basin.

The model algorithms require that each land cover classification be represented as separate pervious and impervious land units. Pervious land uses are further categorized by NRCS hydrologic soil groups. The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting. Typically, clay soils that are poorly drained have lower infiltration rates, while well-drained sandy soils have the greatest infiltration rates. NRCS (2001) has defined four hydrologic groups for soils as listed in Table 6-4. The final land cover representation for the Milwaukee River LSPC model is summarized in Table 6-5 and indicates that the two most common land covers are crops on B soils (28 percent) and wetlands (16 percent).

Table 6-4. NRCS Hydrologic Soil Groups

Hydrologic Soil Group	Description
A	Soils with high infiltrations rates. Usually deep, well drained sands or gravels. Little runoff.
B	Soils with moderate infiltration rates. Usually moderately deep, moderately well drained soils.
C	Soils with slow infiltration rates. Soils with finer textures and slow water movement.
D	Soils with very slow infiltration rates. Soils with high clay content and poor drainage. High amounts of runoff.

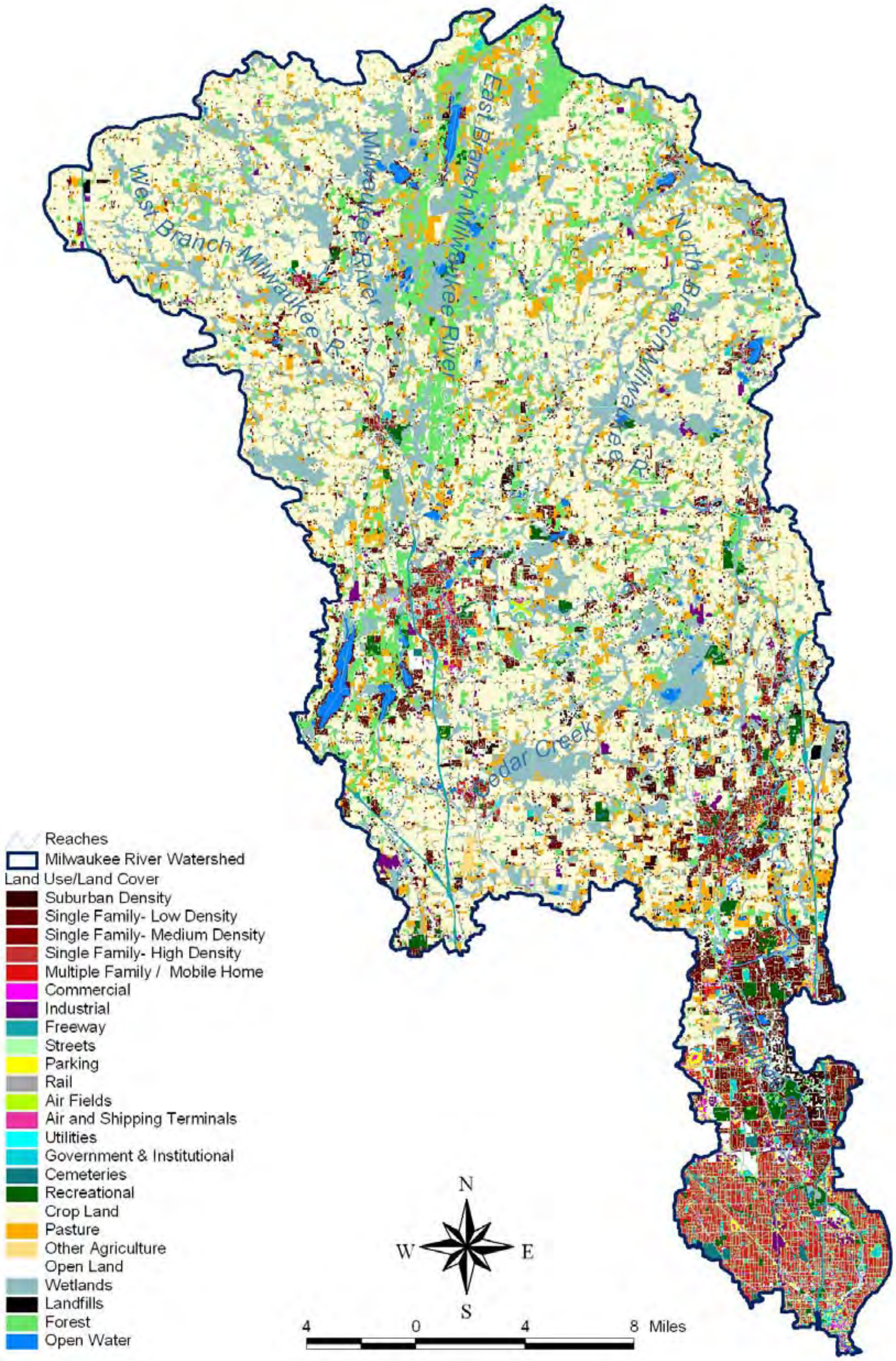


Figure 6-3. Land use in the Milwaukee River watershed.

Table 6-5. Modeling land cover in the Milwaukee River watershed.

Category	Land Cover	Area		Percent of Watershed
		Acres	Square Miles	
IMPERVIOUS	COMMERCIAL	14,578	22.78	3.4%
	GOVT_INSTIT	500	0.78	0.1%
	INDUSTRIAL	1,853	2.89	0.4%
	RESIDENTIAL	5,078	7.93	1.2%
	TRANS_FREE	1,248	1.95	0.3%
	ULTRA_LOW	7,716	12.06	1.8%
PERVIOUS	CROP_B_CS	29,750	46.48	7.0%
	CROP_B_DR	87,643	136.94	20.5%
	CROP_B_OC	5,720	8.94	1.3%
	CROP_C_CS	13,420	20.97	3.1%
	CROP_C_DR	37,480	58.56	8.8%
	CROP_C_OC	2,244	3.51	0.5%
	CROP_D_CS	223	0.35	0.1%
	CROP_D_DR	584	0.91	0.1%
	CROP_D_OC	24	0.04	0.0%
	FOREST	40,233	62.86	9.4%
	GRASS_B	36,848	57.57	8.6%
	GRASS_C	30,594	47.80	7.2%
	GRASS_D	5,255	8.21	1.2%
	PASTURE_B	21,826	34.10	5.1%
	PASTURE_C	8,568	13.39	2.0%
	PASTURE_D	5,249	8.20	1.2%
	WETLAND	70,778	110.59	16.6%
	Total	427,412	667.81	99.9

Notes: CS is Corn-Soy; DR is Dairy Silage; OC is Other Corn

6.5 Point Sources

There are a number of "point sources" in the Milwaukee River watershed. These consist of wastewater treatment plants, sanitary sewer overflows (SSOs), combined sewer overflow (CSO) discharges, and discharges from industrial facilities. Flows from these point sources were input directly into the LSPC model using the methodology outlined in the December 13, 2004 memorandum entitled *Point Source Loading Calculations for Purposes of Watercourse Modeling*.

7.0 CALIBRATION AND VALIDATION PROCESS

The model calibration and validation processes are described in this section. Background information on the locations of available flow data and the time periods of calibration/validation are first presented, followed by a description of how key parameters were modified.

7.1 Background

Hydrologic calibration of the Milwaukee River model was performed after configuring the LSPC model. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. For LSPC, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. It is required for parameters that cannot be deterministically and uniquely evaluated from topographic, climatic, physical, and chemical characteristics of the watershed and compounds of interest. Fortunately, the majority of LSPC parameters do not fall in this category. Calibration is based on several years of simulation to allow parameter evaluation under a variety of climatic conditions. The calibration procedure results in parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period.

Calibration included the comparison of monthly, seasonal, and annual values, and individual storm events. All of these comparisons must be evaluated for a proper calibration of hydrologic parameters. In addition, simulated and observed stream flow values were analyzed on a frequency basis and their resulting cumulative distributions (e.g., flow duration curves) compared to assess the model behavior and agreement over the full range of observations.

Model validation tested the calibrated model using input from a different time period, without further parameter adjustment. If the model cannot properly simulate conditions for the independent data set, the calibration is not acceptable and requires additional work until validation is achieved. As described in the January 14, 2004 *Watershed and Receiving Water Quality Model Calibration and Validation Data and Procedures* memorandum, the calibration time period was January 1, 1995 through December 31, 1998. The validation time period was January 1, 1999 through December 31, 2002. To permit model spin up time and minimize numerical errors inherent in modeling, the model was run for the time period January 1, 1993 through December 31, 1998 for calibration purposes.

The model calibration and validation for the Milwaukee River mainstem was performed using the flow record from along the Milwaukee River near Cedarburg (04086600) and at Estabrook Park in the City of Milwaukee (04087000). The primary calibration and validation gage is the one at Estabrook Park (04087000). This gage drains most of the watershed and accurate simulation of the hydrology at this location provides reliable flow data to the Lake Michigan Harbor/Estuary Model. Additional checks of model performance were made using the gage along Cedar Creek near Cedarburg (04086500). Figure 6-1 shows the location of these gages.

Although the Cedar Creek gage drains a large area of the watershed, it is also heavily influenced by multiple upstream lakes/impoundments, and internally drained areas. While much effort was taken to address the response of the model to these features, the imperfections in the calibration are more pronounced at this location due to these watershed features. The other two gages, which are further downstream, drain a much larger area and the Cedar Creek drainage area is a subset of both of these gage's drainage areas. More emphasis was placed on matching these two gages during calibration because (1) they include additional portions of the watershed that are not as influenced by lakes/internal-drainage, and (2) they better represent the downstream boundary condition required for linkage to the Lake Michigan Harbor / Estuary Model.

7.2 Parameter Estimation

Hydrologic calibration involved a comparison of observed data from the in-stream USGS flow gaging station to modeled in-stream flow and an adjustment of key hydrologic parameters. Various modeling parameters were varied within physically realistic bounds and in accordance to observed temporal trends and land cover classifications. An attempt was made to remain within the guidelines for parameter values set out in BASINS Technical Note 6 (USEPA, 2000) and to remain consistent with the calibration parameters used for the Menomonee River, Oak Creek, and Kinnickinnic River watersheds. The intent was to develop a unified parameter set in which most variations between watersheds are explained by documented differences in land cover and physical parameters such as soil characteristics. This cross-sectional calibration approach helps ensure a robust parameter set that is not unduly biased by anomalies in individual gage records. It was found to be necessary to address some variations in parameter values between watersheds to optimize fit; however, the large majority of parameters are derived as a unified set.

Graphical results of model performance and error statistics were evaluated following each model simulation run. Model parameters were adjusted following each iteration to improve model performance. The parameters that were adjusted include those that account for the partitioning of surface versus subsurface flow, infiltration rate, surface and subsurface storage, evapotranspiration, and surface runoff. The full set of hydrologic parameters from the revised calibration can be seen in the file *MilwaukeeHydro v2 04-10-2006.inp* and a discussion of the key parameters and how they were adjusted is presented below. Most values are the same as were used for the Menomonee River calibration/validation.

The model performance is most sensitive to the specification of the water-holding capacity of the soil profile (expressed through LZSN, the nominal lower-zone storage) and the infiltration rate index (INFILT), which together control the partitioning of water between surface and subsurface flow. LZSN is an index of nominal storage of water in the soil zone subject to evapotranspiration (root depth plus capillary fringe), while LZS represents the actual water storage in this zone. LZSN is often characterized as the median of field capacity storage in this zone (i.e., available water capacity times rooting depth with capillary fringe). Functionally, however, the meaning of LZS and LZSN may differ somewhat from this ideal interpretation. LZS does represent the depth of water that is available for transpiration from the soil; however, this value may exceed LZSN by a significant amount. More important is the ratio LZRAT (LZS/LZSN). This ratio (in inverse form) first determines the variation of actual infiltration rate relative to the nominal value, INFILT. LZRAT also determines the rate at which water percolates from the lower soil zone to groundwater. LZSN thus varies with precipitation pattern as well as vegetation type. In addition, it is difficult to relate LZSN to a single vegetation type, because a dominant vegetation (e.g., grass) with a low rooting depth may also contain other plants (e.g., trees) with a much greater rooting depth, which increases the amount of soil moisture that is available for ET. As a result, while initial values of LZSN can be estimated from soils and vegetation data, final values must be determined through calibration.

Viessman et al. (1989) suggest as initial estimates for LZSN a value between one-quarter and one-eighth of the annual rainfall plus four inches. USEPA (2000) show values for LZSN ranging from 5 inches to 14 inches in typical applications. A value of 5 inches for LZSN for wetlands and 9 inches for all other land cover categories provided reasonable results.

INFILT in HSPF is an *index* of infiltration rate and is not directly interpretable from measured field infiltration rates. BASINS Technical Note 6 recommends values in the range of 0.1-0.4 for B soils, 0.05-0.1 for C soils, and 0.01-0.05 in/hr for D soils. Values were re-optimized by starting from the center of the recommended ranges and modifying the value for each soil class proportionately – yielding final values of 0.365, 0.105-0.125, and 0.055-0.075 for B, C, and D soils, respectively. For D soils, the higher values were applied to tilled agriculture, while the lower values were applied to grass and pasture; for C soils the lower values were applied to pasture only.

Key parameters for the subsurface flow response include the ground water recession coefficient (AGWRC), and the interflow inflow and recession parameters (INTFW and IRC). These parameters were chosen by using values from the Menomonee River model and optimizing model performance for baseflow recession.

Monthly variability in hydrologic response was specified by setting monthly values for the upper zone nominal soil storage, lower zone ET intensity factor, and interflow recession coefficient. In each case, the values specified are consistent with recommendations in BASINS Technical Note 6, as well as experience in calibrating multiple HSPF models for the Minnesota River basin (Tetra Tech, 2002).

For the winter simulation, the model is very sensitive to parameters that control snow accumulation and snowmelt. Considerable uncertainty is present in hydrologic models when temperatures are near the transition point between liquid and frozen precipitation, and prediction of rain-on-snow melting events can be particularly difficult. Key calibration parameters for the winter snow simulation were revised from defaults during optimization and included the snow catch factor (CCFACT, ratio that accounts for under-catch of snow in standard precipitation gages), the field adjustment parameter for heat accumulation in the snow pack (CCFACT), the maximum rate of snow melt by ground heating (MGMELT), and the depth of snow at which all land area is considered to be covered (COVIND, set to a higher value for impervious lands to account for snow removal/consolidation).

7.3 Simulation of Internally Drained Basins

The Milwaukee River watershed includes several internally drained basins (sinks) that never contribute surface runoff to a reach. To simulate such basins, no surface runoff should be simulated but infiltration rates and soil storages should continue to reflect local soil properties. Water must thus be held as ponded surface storage until it either infiltrates or evaporates. In the LSPC PWATER module, this will happen when the routing variable SRC goes to zero, where SRC = 1020 x (SQRT(SLSUR)/(NSURxLSUR)). Impervious areas in internally drained basins were modeled as GRASS_C pervious lands because runoff from the impervious lands was assumed to drain to pervious areas rather than to the stream.

SRC determines the rate at which surface storage runs off. The desired effect can’t be accomplished by setting slope, SLSUR to zero, as it is constrained to be greater than zero and calculation of other routing variables would result in a divide by zero if it was. Similarly, the Manning’s roughness coefficient (NSUR) is constrained to be less than or equal to 1. There is, however, no upper bound constraint on slope length, LSUR. Therefore, SLSUR for internally drained basins was set to the allowed minimum of 0.000001, NSUR to 1, and LSUR to an artificially large number.

This concept was tested by creating an artificial subbasin that has an equal mix of all eleven PERLND types used in the Menomonee model. Under normal conditions, about 9 percent of the total runoff (for 1993 to 1999) or 6.7 inches is direct surface runoff over the 7-year simulation (Figure 7-1). A representation of internal drainage was then implemented by setting LSUR = 1.0E20, NSUR = 1, and SLSUR = 0.000001, and INTFW = 0, eliminating interflow. With these parameters, almost all flow exits the basin as ground water discharge (AGWO) (Figure 7-2).

Conversion to internal drainage results in a slightly smaller net water yield, because more water is held available for evapotranspiration. Total water yield for the base case is 74.7 inches (over 7 years) compared to 70.9 in with internal drainage. The water that would previously have been surface runoff is held temporarily in surface storage. The model simulates it as spread out across the entire basin, rather than concentrated in an ephemeral pond. Surface storages during the period of simulation presented in Figure 7-2 peaks as high as 3.4 inches. The amount would be greater for basins that are comprised predominantly poorly drained soils.

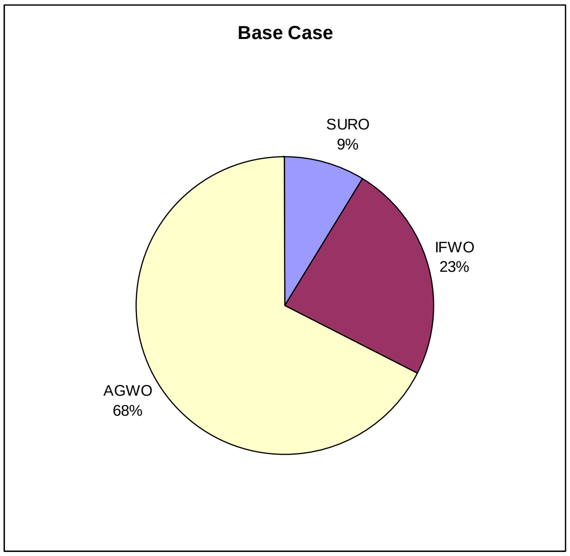


Figure 7-1. Base Case Flow Components.

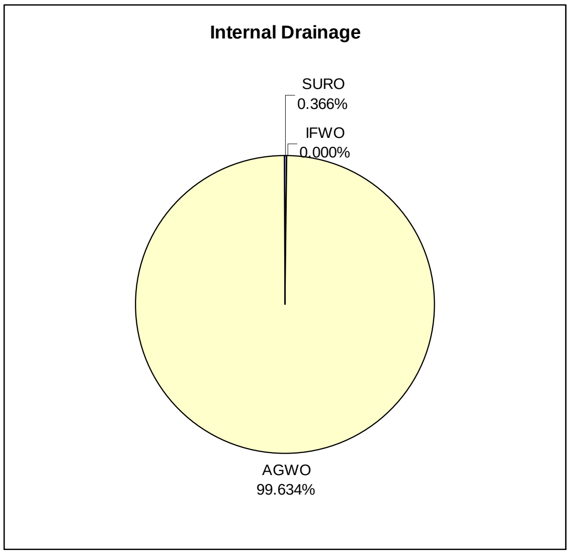


Figure 7-2. Flow Components for Internal Drainage Simulation with Interflow Off.

8.0 RESULTS OF HYDROLOGIC CALIBRATION AND VALIDATION

The model calibration results are presented in this section both graphically and statistically. Graphical comparisons are extremely useful for judging the results of model calibration because time-variable plots of observed versus modeled flow provide insight into the model's representation of storm hydrographs, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. Graphing model results with precipitation data can also provide insights into how the model reacts to different storms.

Graphical comparisons consist of time series plots of observed and simulated values for flows, observed versus simulated scatter plots with a 45^o linear regression line displayed, and cumulative frequency distributions (flow duration curves). Statistical comparisons focus on the relative error method. A small relative error indicates a better goodness of fit for calibration. Secondly, results from correlation tests (e.g. linear correlation coefficient, coefficient of model-fit efficiency, etc.) are also presented. A comparison of simulated and observed storm hydrographs for selected storm events will be addressed in a separate memorandum.

8.1 Tolerances

Model tolerance values for this project have been identified and are described in the January 14, 2004 *Watershed and Receiving Water Quality Model Calibration and Validation Data and Procedures* memorandum and in the December 18, 2002, *MMSD Comprehensive Modeling and Real Time Control Strategies* Technical Memorandum 2.4. Hydrologic parameters to be calibrated include annual flow volumes, low flow volumes, storm flow volumes, and seasonal flow volumes. The following tolerances (i.e., accepted level of error between modeled and observed flows) are used:

Total runoff volume: ± 10 percent
High flow volumes: ± 15 percent
Low flow volumes: ± 10 percent
Seasonal flow volumes: ± 20 percent
Error in storm volumes: ± 20 percent[2]

The same tolerances are used for model validation. Error statistics are calculated for each month and year of the calibration time period; however, a calibration is deemed appropriate when the tolerances for the entire calibration period have been met. The same applies for the validation period.

8.2 Calibration and Validation Results

The calibration and validation results are presented below in Figure 8-1 to Figure 8-66 and Table 8-3 to Table 8-14. In general, the calibration and validation results indicate acceptable agreement between observed and simulated streamflows. Baseflows are well represented for each season for both the calibration and validation periods. The timing of most storms is captured, as are the shapes of the hydrographs. The model meets most tolerance criteria for both the calibration and validation periods at gages 04086600 and 04087000. The model does not perform as well at gage 04086500 along Cedar Creek. As noted in Section 7.1, this is likely due to poor representation of certain snowmelt events and a limited ability to simulate the hydrologic impacts of numerous small lakes and wetlands.

[2] A comparison of simulated and observed storm hydrographs for selected storm events will be addressed in a separate memorandum.

Discrepancies between model predictions and observations can occur for a variety of reasons, including uncertainty in the specification of meteorological forcing, unrepresented processes, sub-optimal parameter values, and errors in observed flow response. While further fine-tuning of parameter values might provide some improvement to results for Milwaukee River, the fact that the same set of parameters provides a reasonable fit across multiple watersheds suggests that this is not a major source of discrepancy. The most significant cause of deviation between the model and observations is likely due to the specification of meteorological forcing. Although seven rain gages were used to simulate the Milwaukee River watershed, these stations are distributed unevenly. The three MMSD stations are clustered downstream and only cover a small part of the large watershed. At the upper portion of the watershed, a single station covers a large area where precipitation and other meteorological inputs vary significantly. For instance, rainfall depth from summer convective storms can vary significantly over short distances, and representation by a single gage leads to inaccuracy in the simulation of responses to individual storm events and imprecision in the simulation of long term response. Some parameters such as humidity, temperature, net solar radiation, may also vary systematically in space and time (e.g., depending on proximity to the lake) which can lead to systematic biases when the precipitation at these stations are extrapolated to an entire watershed.

The composite graphs shown in Figure 8-10, Figure 8-21, Figure 8-32, Figure 8-43, Figure 8-54, and Figure 8-65 indicate the model simulates seasonal patterns effectively. The largest error during the calibration period is between January and April when snow accumulation and melting occur. Simulation of snow processes is highly dependant on the air temperature, wind, solar radiation, and dew point temperature and these factors vary strongly in space and time. The validation results for the same months show a better match between observed and modeled total volume.

The coefficient of model efficiency (E) provides another method for judging the results of the modeling effort. Physically, E is the ratio of the mean square error in model predictions to the variance in the observed data, subtracted from unity. If E is equal to zero, then the observed mean is as good a predicator as the model, while negative values indicate that the observed mean is a better predictor than the model. Possible values range from minus infinity to 1.0, with higher values indicating better agreement. As summarized in Tables 8-1 and 8-2, the coefficient of efficiency ranges from 0.21 to 0.72 with the highest value obtained for the primary calibration and validation gage at Estabrook Park (04087000).

Table 8-1. Coefficient of Efficiency Results for Milwaukee River Calibration (1995 to 1999).

USGS Gage	Coefficient of Efficiency
04086500	0.21
04086600	0.51
04087000	0.68

Table 8-2. Coefficient of Efficiency Results for Milwaukee River Validation (1999 to 2002).

USGS Gage	Coefficient of Efficiency
04086500	0.52
04086600	0.69
04087000	0.72

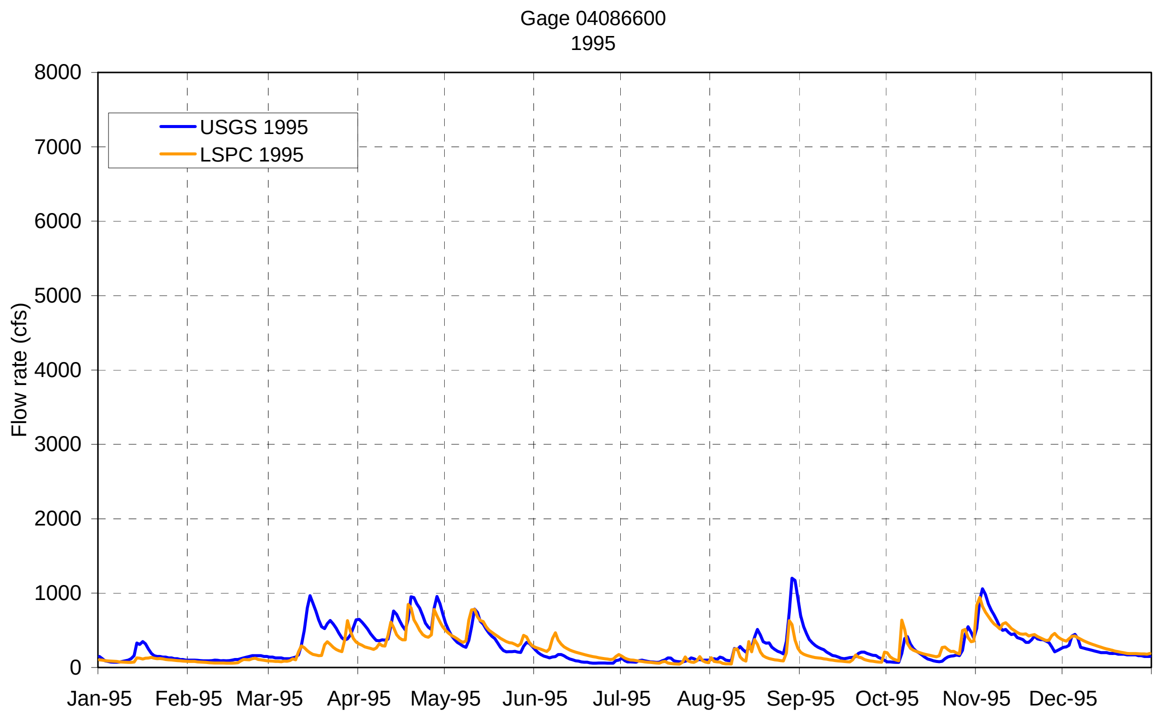


Figure 8-1. Time series hydrologic calibration results (daily mean) for Milwaukee River at USGS gage 04086600 (1995).

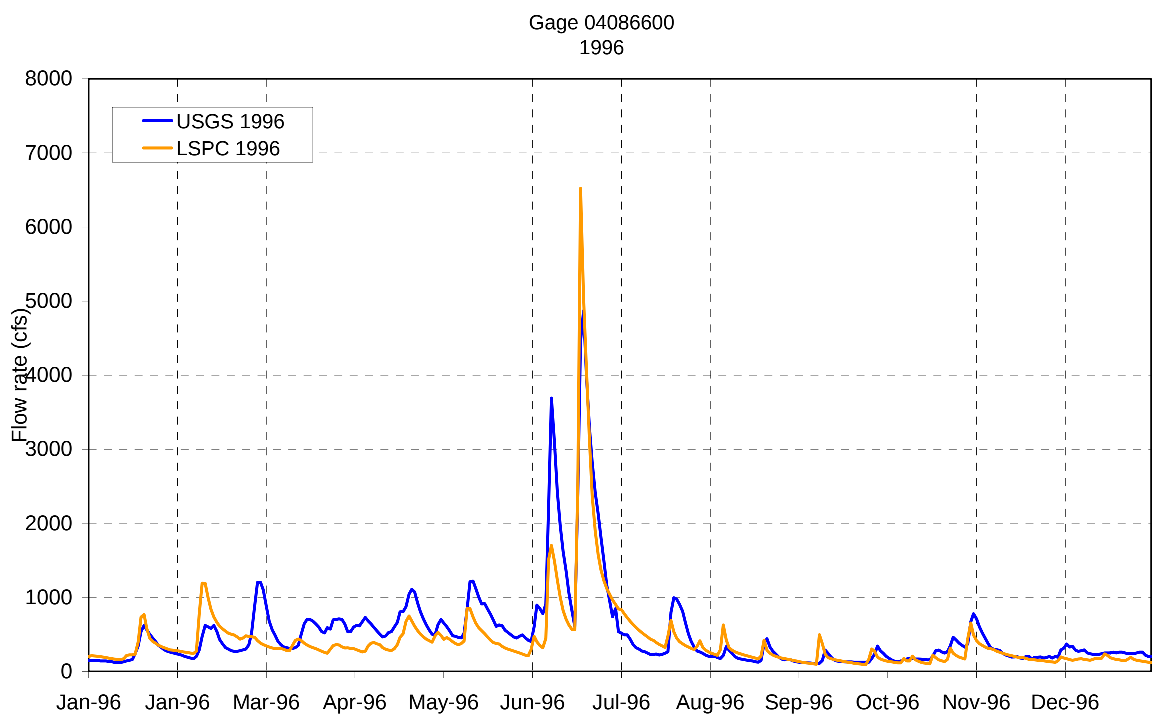


Figure 8-2. Time series hydrologic calibration results (daily mean) for Milwaukee River at USGS gage 04086600 (1996).

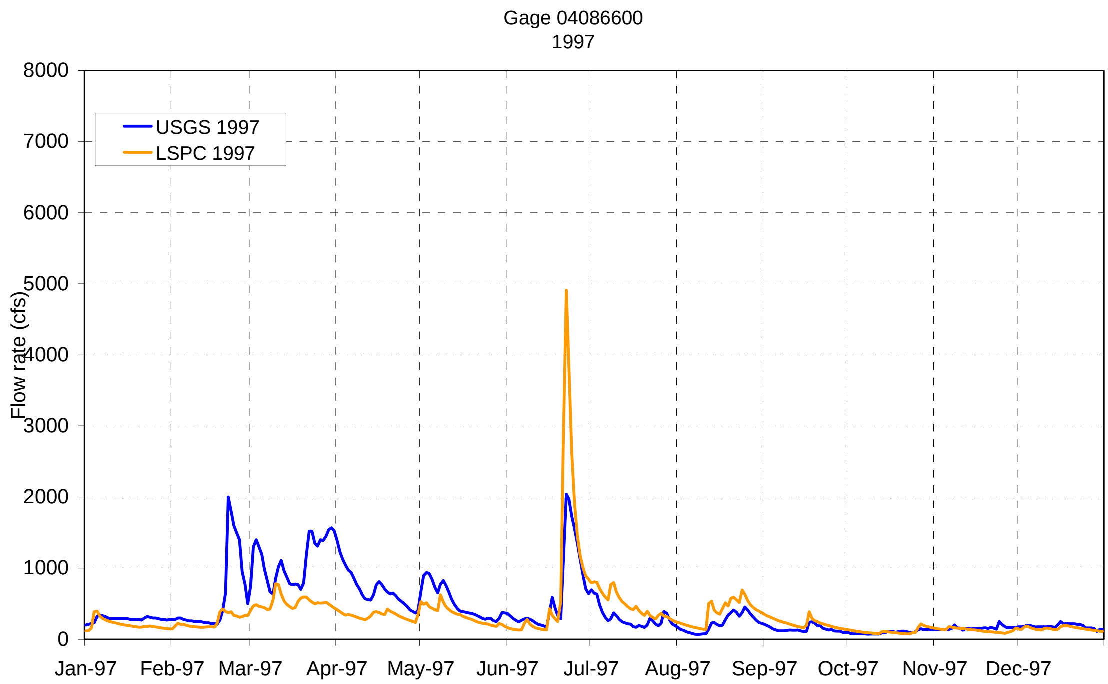


Figure 8-3. Time series hydrologic calibration results (daily mean) for Milwaukee River at USGS gage 04086600 (1997).

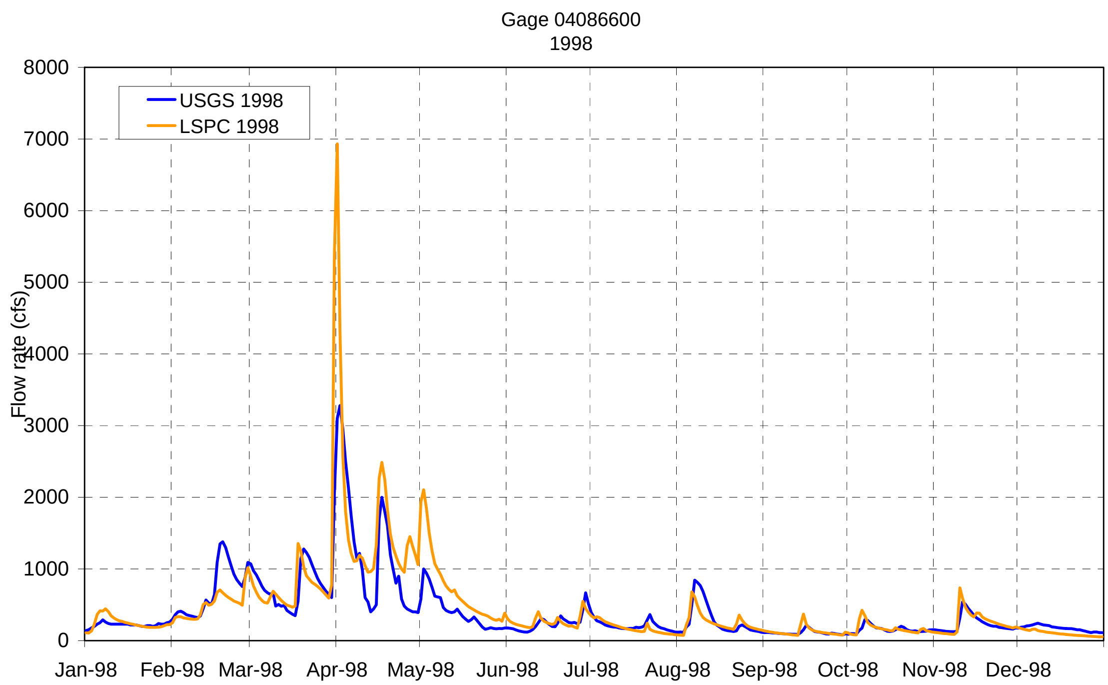


Figure 8-4. Time series hydrologic calibration results (daily mean) for Milwaukee River at USGS gage 04086600 (1998).

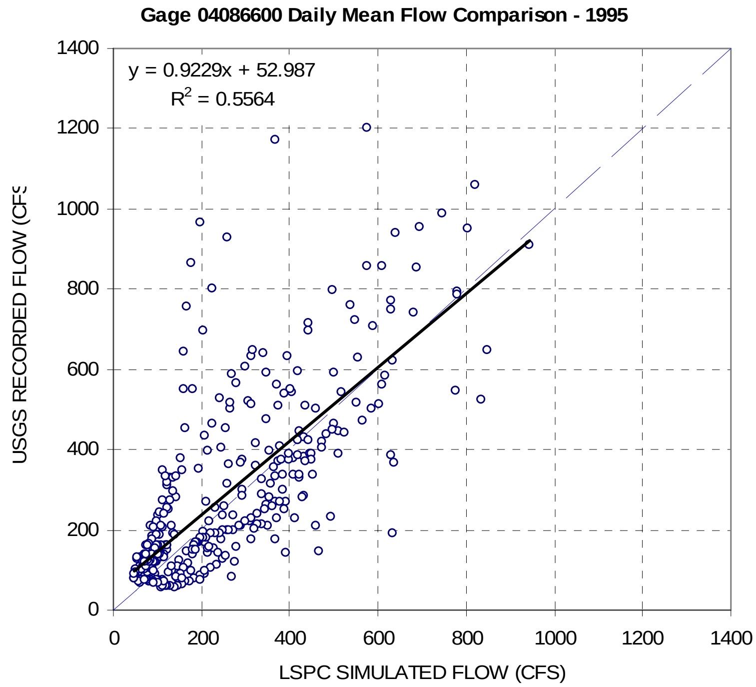


Figure 8-5. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04086600 (1995).

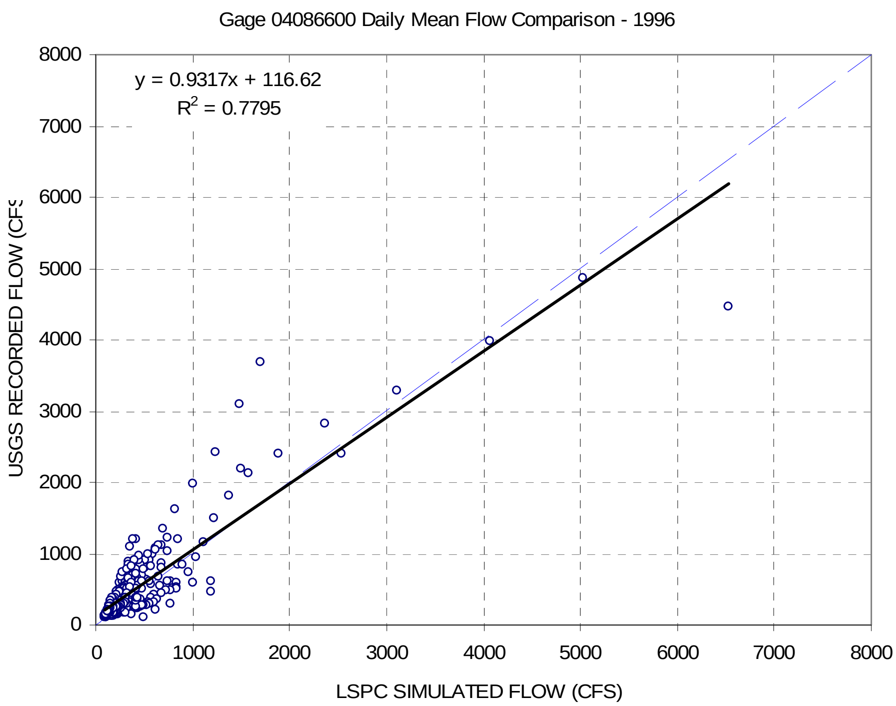


Figure 8-6. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04086600 (1996).

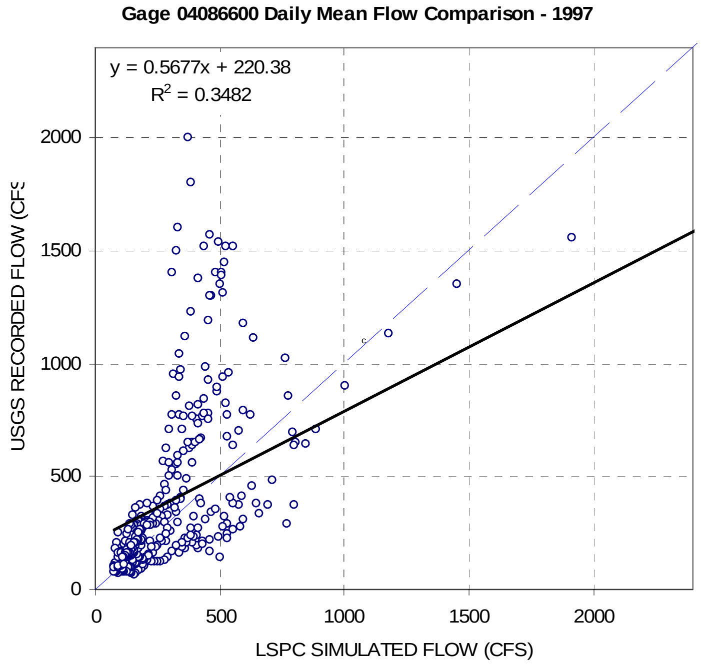


Figure 8-7. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04086600 (1997).

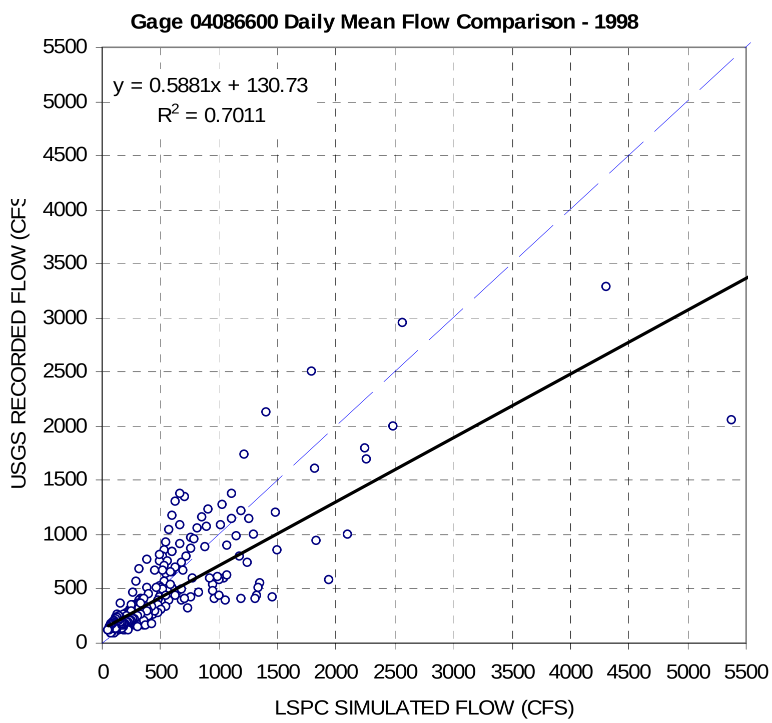


Figure 8-8. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04086600 (1998).

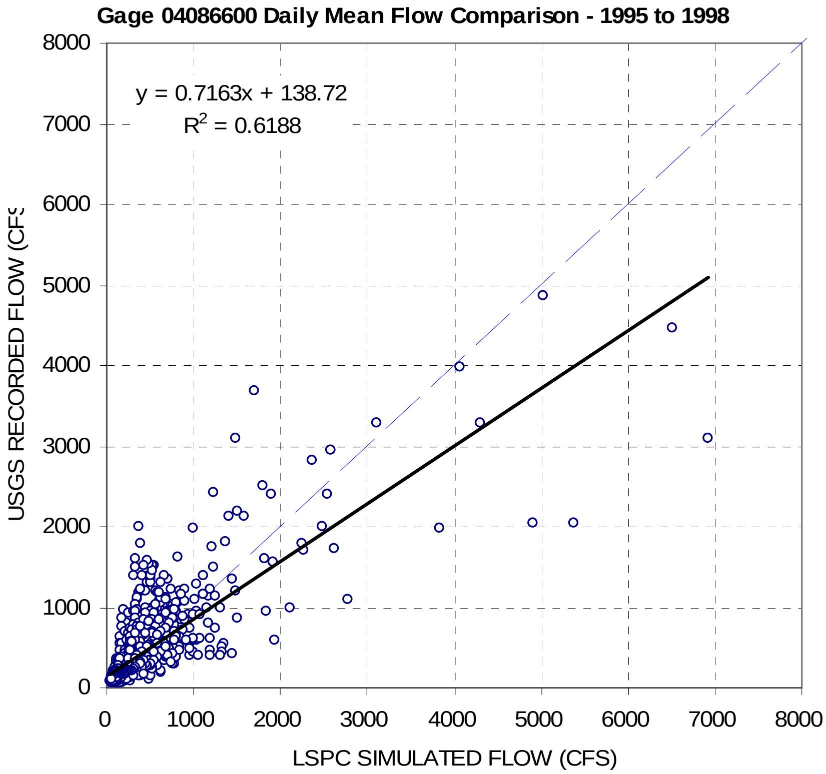


Figure 8-9. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04086600 (1995 to 1998).

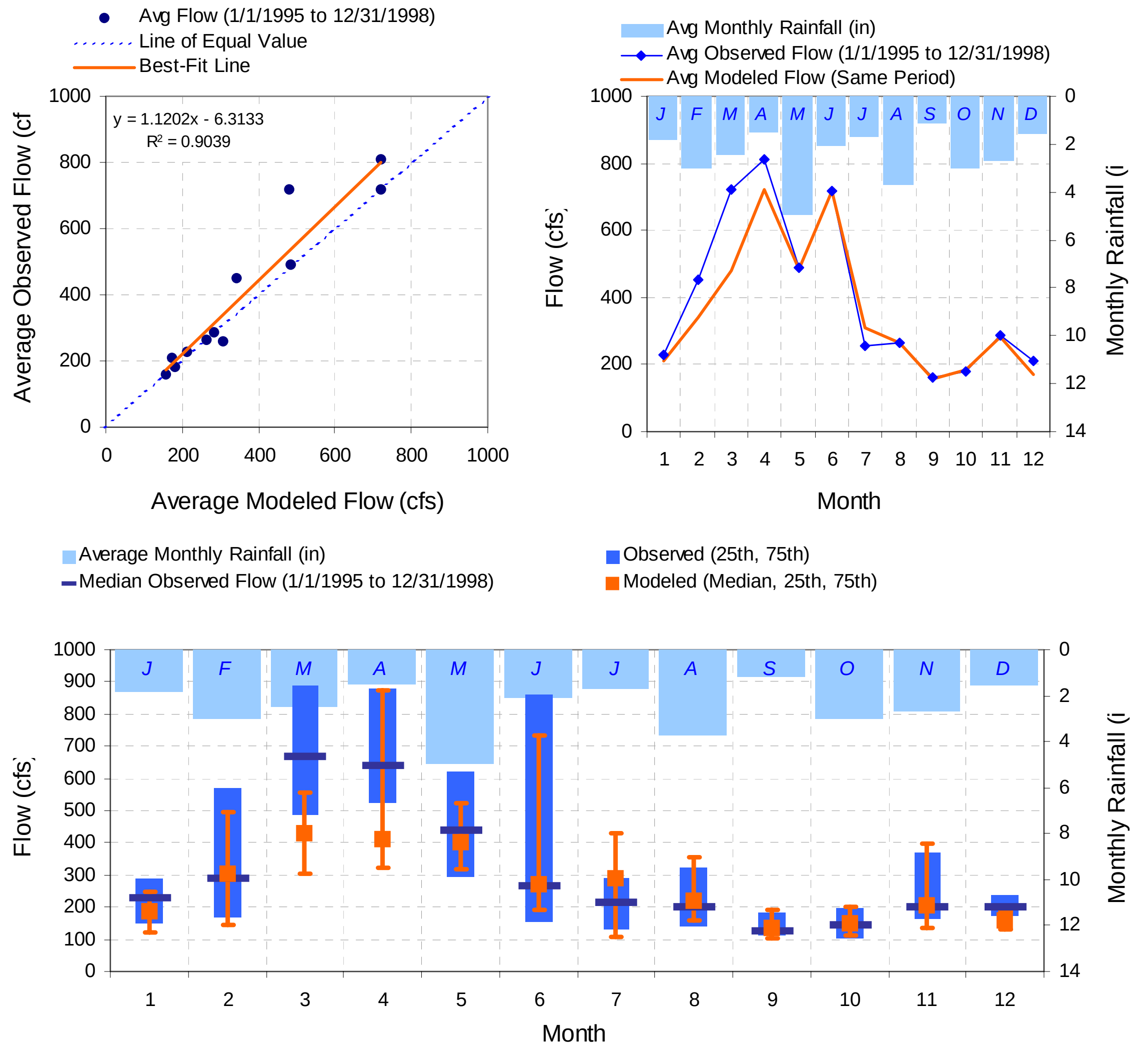


Figure 8-10. Composite (average monthly) hydrologic calibration results for Milwaukee River at USGS gage 04086600 (1995 to 1998).

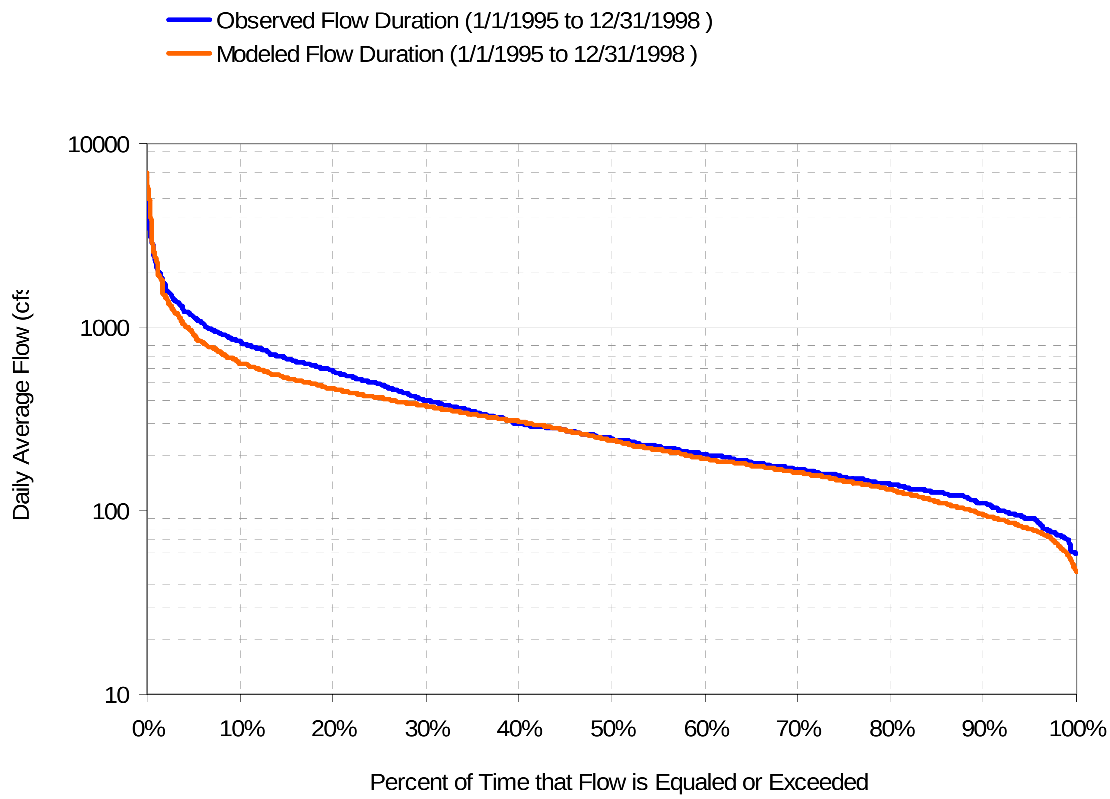


Figure 8-11. Flow duration curve hydrologic calibration results for Milwaukee River at USGS gage 04086600 (1995-1998).

Table 8-3. Error statistics for hydrologic calibration results for Milwaukee River at USGS gage 04086600 (1995-1998).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1995			1996			1997			1998			TOTAL		
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month JAN	9,092	6,087	-33.0%	15,556	18,177	16.8%	17,479	12,713	-27.3%	13,594	15,192	11.8%	55,721	52,169	-6.4%
FEB	6,377	4,463	-30.0%	24,533	30,658	25.0%	32,044	13,958	-56.4%	38,094	27,506	-27.8%	101,049	76,586	-24.2%
MAR	25,647	13,664	-46.7%	34,914	20,146	-42.3%	67,764	31,667	-53.3%	48,566	52,792	8.7%	176,891	118,268	-33.1%
APR	36,935	27,143	-26.5%	40,443	24,905	-38.4%	41,964	19,821	-52.8%	73,370	99,562	35.7%	192,712	171,430	-11.0%
MAY	23,539	27,607	17.3%	40,813	26,099	-36.1%	31,275	20,818	-33.4%	24,633	44,856	82.1%	120,259	119,379	-0.7%
JUN	6,548	12,702	94.0%	112,158	91,540	-18.4%	37,714	50,950	35.1%	14,635	15,873	8.5%	171,054	171,065	0.0%
JUL	5,717	5,098	-10.8%	26,311	29,632	12.6%	18,418	29,883	62.3%	12,855	11,174	-13.1%	63,301	75,787	19.7%
AUG	20,875	11,475	-45.0%	12,588	14,994	19.1%	13,866	23,345	68.4%	17,276	15,331	-11.3%	64,605	65,145	0.8%
SEP	13,392	6,971	-47.9%	9,387	9,840	4.8%	8,650	13,489	55.9%	6,550	7,358	12.3%	37,979	37,658	-0.8%
OCT	12,283	15,658	27.5%	16,337	11,953	-26.8%	6,129	6,945	13.3%	9,625	10,229	6.3%	44,374	44,785	0.9%
NOV	29,311	31,395	7.1%	15,901	12,923	-18.7%	9,417	7,655	-18.7%	13,739	15,196	10.6%	68,369	67,169	-1.8%
DEC	13,777	16,698	21.2%	15,921	10,013	-37.1%	11,222	9,251	-17.6%	10,614	6,308	-40.6%	51,534	42,270	-18.0%

Season	1995 Recorded USGS Volume (ac-ft)	1995 Simulated LSPC Volume (ac-ft)	1995 Percent Diff.	1995 Var. from Tolerance	1996 Recorded USGS Volume (ac-ft)	1996 Simulated LSPC Volume (ac-ft)	1996 Percent Diff.	1996 Var. from Tolerance	1997 Recorded USGS Volume (ac-ft)	1997 Simulated LSPC Volume (ac-ft)	1997 Percent Diff.	1997 Var. from Tolerance	1998 Recorded USGS Volume (ac-ft)	1998 Simulated LSPC Volume (ac-ft)	1998 Percent Diff.	1998 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Jan-Mar	41,116	24,214	-41.1%	21.1%	75,003	68,981	-8.0%		117,287	58,338	-50.3%	30.3%	100,254	95,489	-4.8%		333,661	247,023	-26.0%	6.0%
Apr-Jun	67,021	67,452	0.6%		193,414	142,543	-26.3%	6.3%	110,953	91,589	-17.5%		112,638	160,291	42.3%	22.3%	484,026	461,874	-4.6%	
Jul-Sep	39,985	23,543	-41.1%	21.1%	48,286	54,467	12.8%		40,934	66,717	63.0%	43.0%	36,681	33,863	-7.7%		165,886	178,590	7.7%	
Oct-Dec	55,371	63,751	15.1%		48,159	34,889	-27.6%	7.6%	26,769	23,852	-10.9%		33,978	31,733	-6.6%		164,277	154,224	-6.1%	

Calibration Tolerance =20%

	1995 Recorded USGS Volume (ac-ft)	1995 Simulated LSPC Volume (ac-ft)	1995 Percent Diff.	1995 Var. from Tolerance	1996 Recorded USGS Volume (ac-ft)	1996 Simulated LSPC Volume (ac-ft)	1996 Percent Diff.	1996 Var. from Tolerance	1997 Recorded USGS Volume (ac-ft)	1997 Simulated LSPC Volume (ac-ft)	1997 Percent Diff.	1997 Var. from Tolerance	1998 Recorded USGS Volume (ac-ft)	1998 Simulated LSPC Volume (ac-ft)	1998 Percent Diff.	1998 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Year	203,493	178,960	-12.1%	2.1%	364,863	300,880	-17.5%	7.5%	295,943	240,496	-18.7%	8.7%	283,552	321,376	13.3%	3.3%	1,147,850	1,041,712	-9.2%	

Calibration Tolerance =10%

Table 8-4. High-Low flow error statistics for hydrologic calibration results for Milwaukee River at USGS gage 04086600 (1995-1998).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	378,184	403,617	-6.3%	15%
Total Highest 20% volume	535,255	604,189	-11.4%	15%
Total Highest 50% volume	832,313	924,837	-10.0%	15%
Total Lowest 10% volume	22,572	25,609	-11.9%	10%
Total Lowest 30% volume	97,579	106,435	-8.3%	10%
Total Lowest 50% volume	211,776	225,511	-6.1%	10%

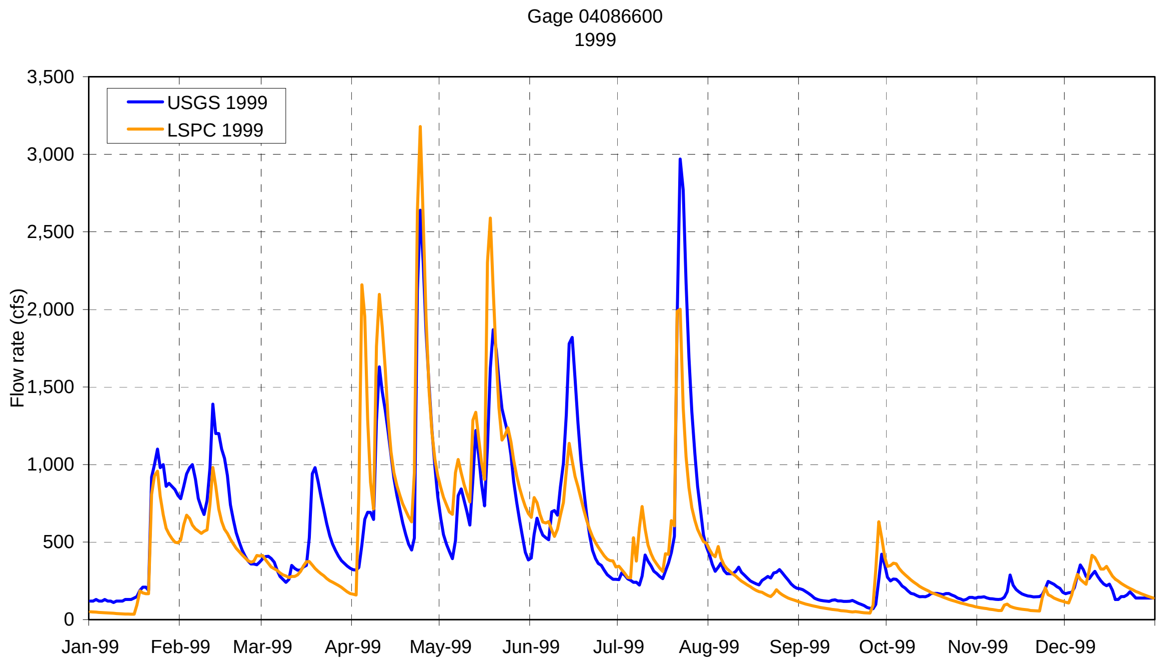


Figure 8-12. Time series hydrologic validation results (daily mean) for Milwaukee River at USGS gage 04086600 (1999).

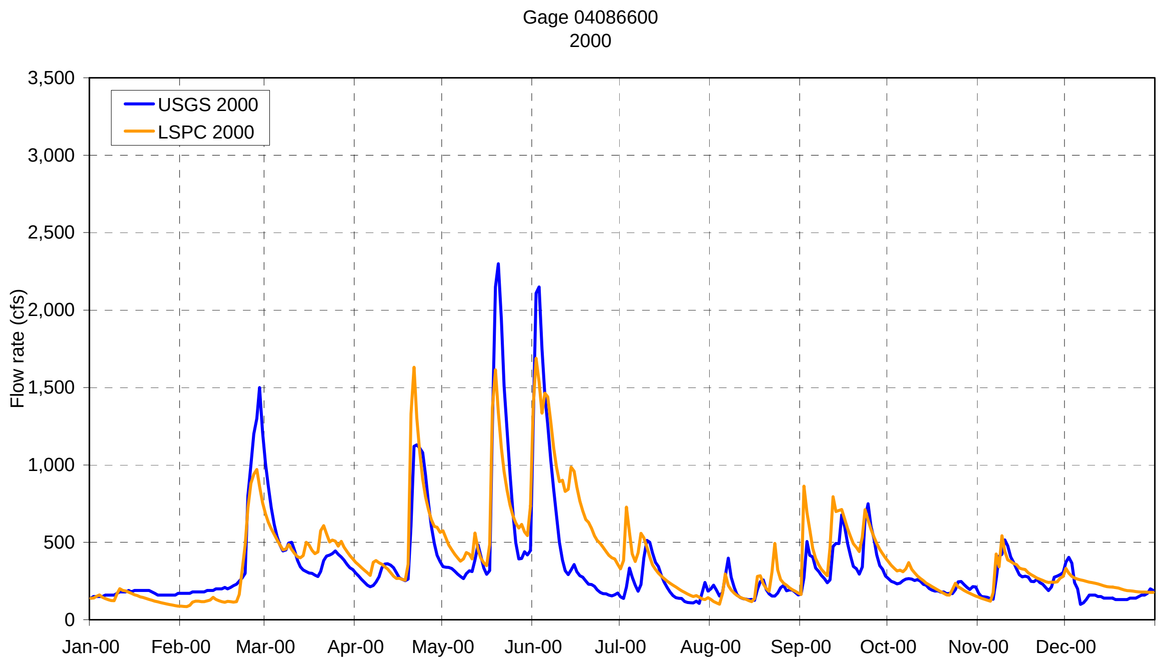


Figure 8-13. Time series hydrologic validation results (daily mean) for Milwaukee River at USGS gage 04086600 (2000).

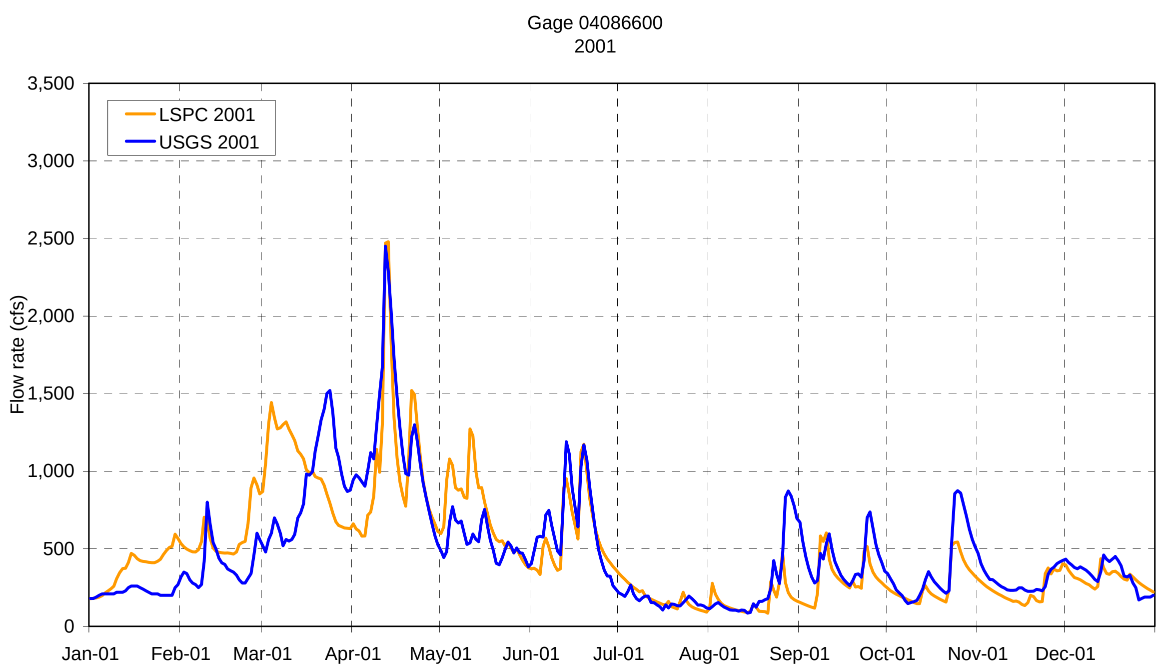


Figure 8-14. Time series hydrologic validation results (daily mean) for Milwaukee River at USGS gage 04086600 (2001).

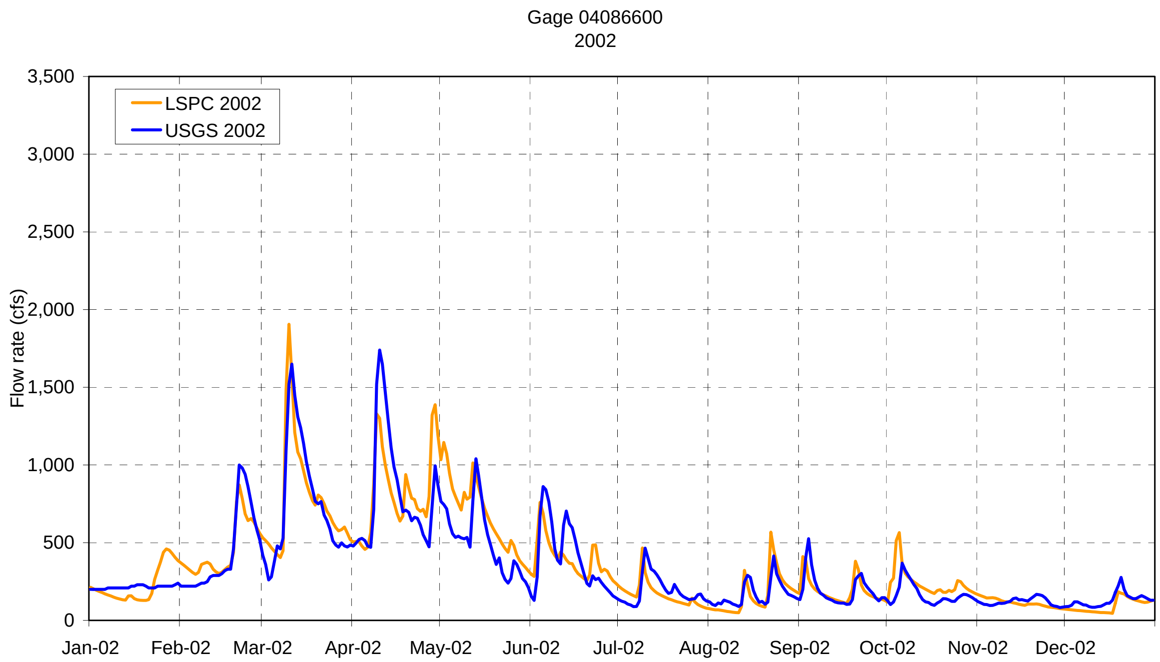


Figure 8-15. Time series hydrologic validation results (daily mean) for Milwaukee River at USGS gage 04086600 (2002).

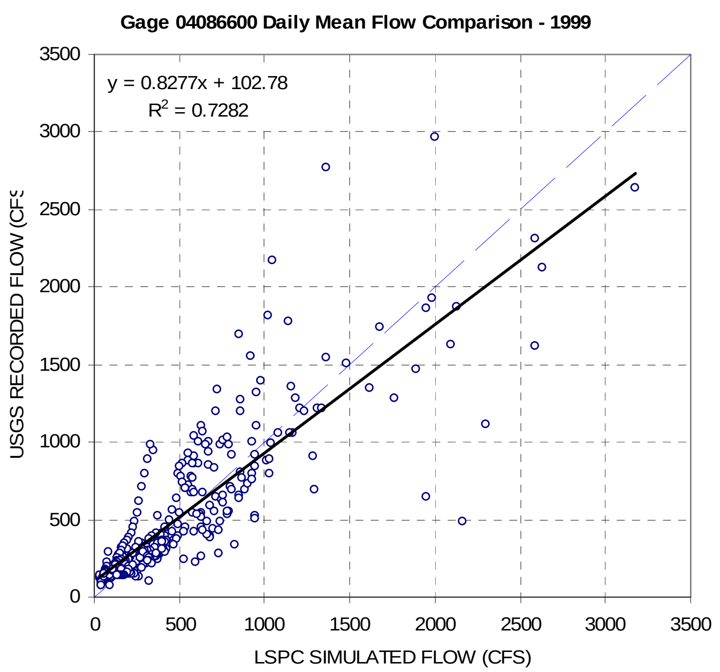


Figure 8-16. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04086600 (1999).

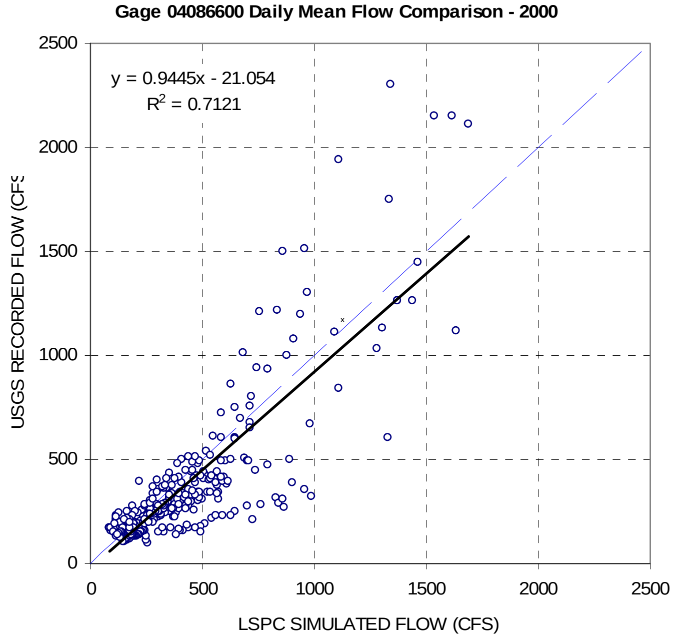


Figure 8-17. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04086600 (2000).

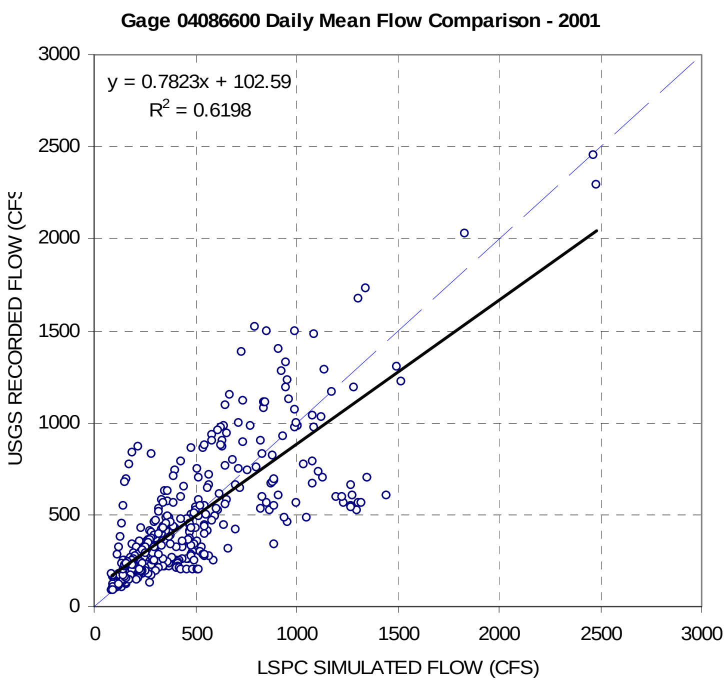


Figure 8-18. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04086600 (2001).

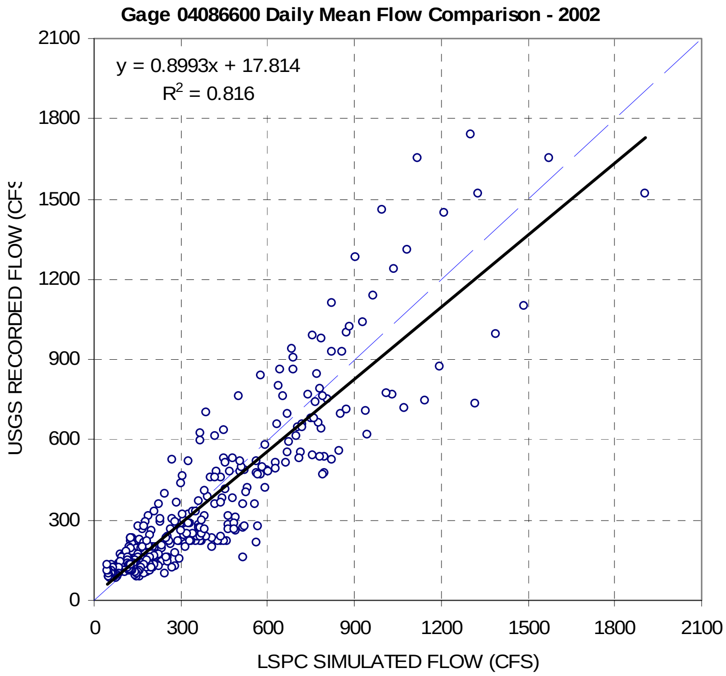


Figure 8-19. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04086600 (2002).

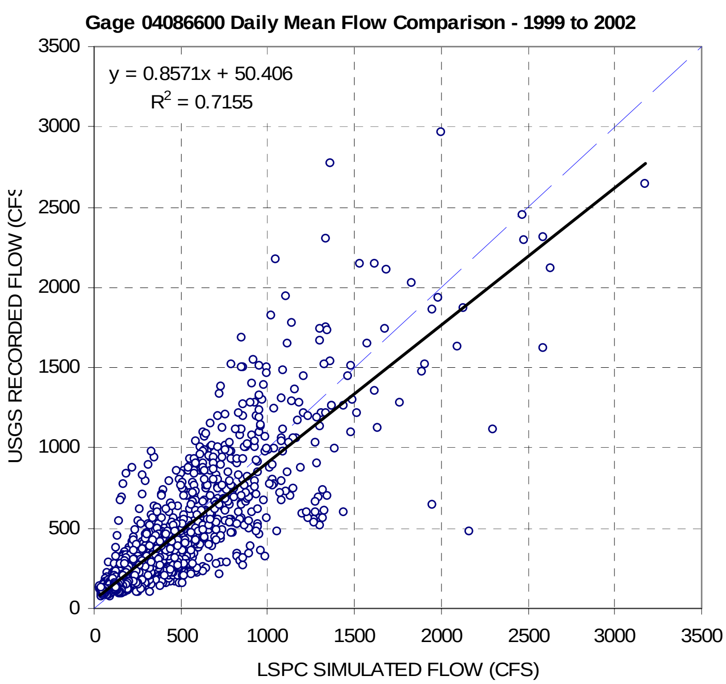


Figure 8-20. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04086600 (1999 to 2002).

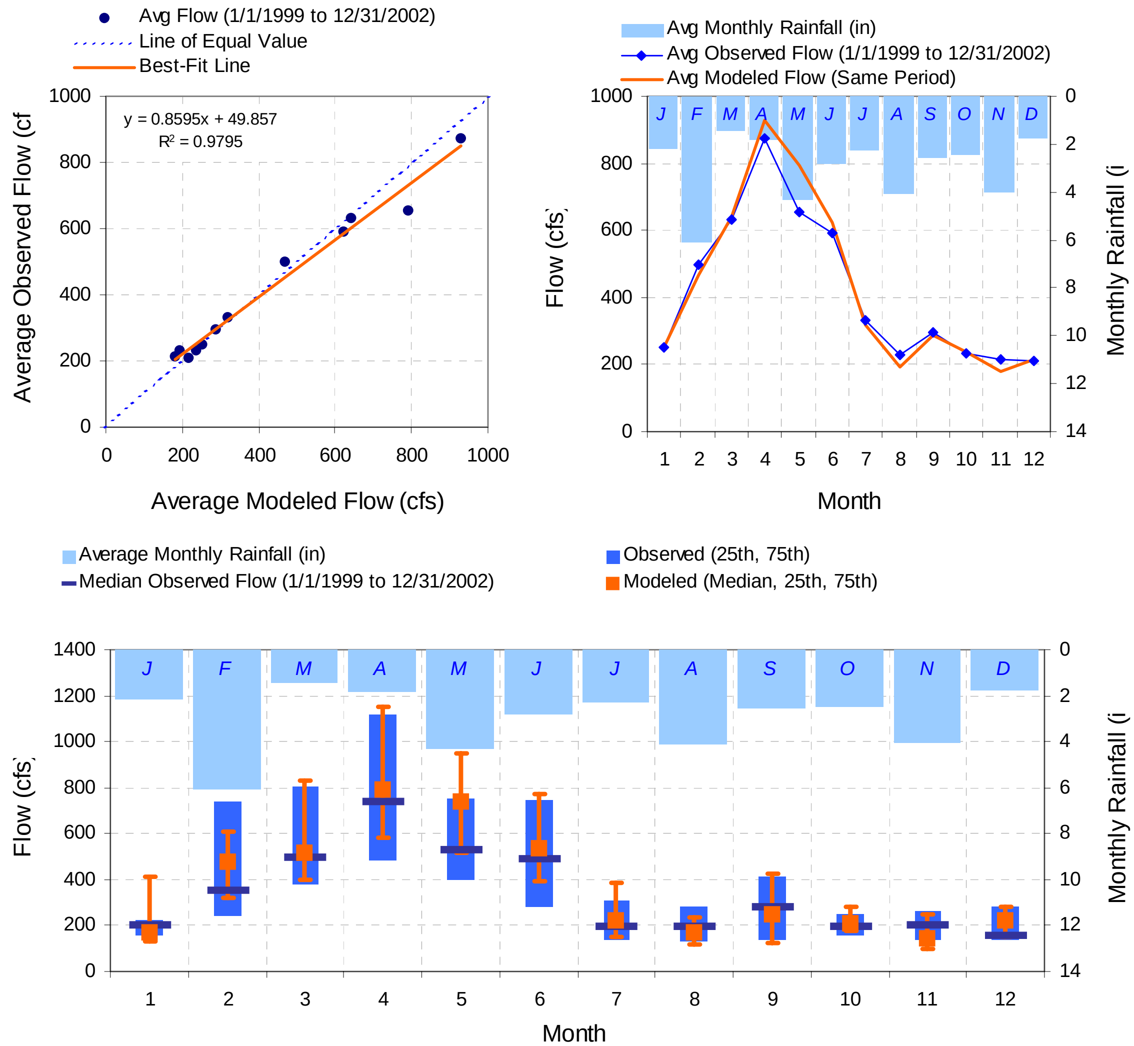


Figure 8-21. Composite (average monthly) hydrologic validation results for Milwaukee River at USGS gage 04086600 (1999 to 2002).

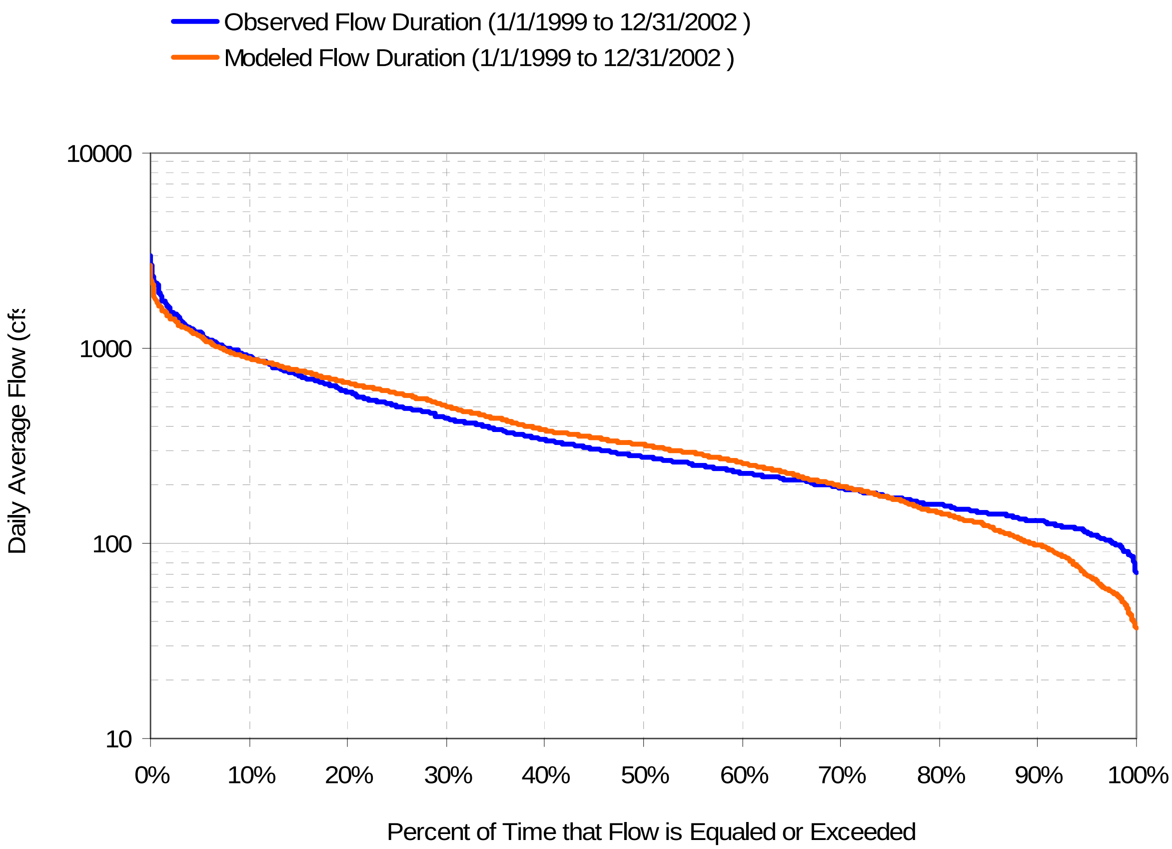


Figure 8-22. Flow duration curve hydrologic validation results for Milwaukee River at USGS gage 04086600 (1999 to 2002).

Table 8-5. Error statistics for hydrologic validation results for Milwaukee River at USGS gage 04086600 (1999 to 2002).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1999 Recorded USGS Volume (ac-ft)	1999 Simulated LSPC Volume (ac-ft)	1999 Percent Diff.	2000 Recorded USGS Volume (ac-ft)	2000 Simulated LSPC Volume (ac-ft)	2000 Percent Diff.	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2002 Recorded USGS Volume (ac-ft)	2002 Simulated LSPC Volume (ac-ft)	2002 Percent Diff.	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.
Month JAN	24,117	16,420	-31.9%	10,384	8,476	-18.4%	13,495	22,855	69.4%	13,178	13,840	5.0%	61,175	61,591	0.7%
FEB	42,371	31,063	-26.7%	23,087	16,599	-28.1%	21,977	32,082	46.0%	24,197	25,117	3.8%	111,631	104,861	-6.1%
MAR	27,966	18,018	-35.6%	27,189	30,152	10.9%	54,380	61,912	13.9%	45,520	47,581	4.5%	155,054	157,663	1.7%
APR	60,753	77,709	27.9%	27,716	32,305	16.6%	70,778	62,466	-11.7%	48,508	48,454	-0.1%	207,755	220,934	6.3%
MAY	55,422	68,617	23.8%	40,195	39,278	-2.3%	33,548	44,668	33.1%	31,362	42,014	34.0%	160,528	194,577	21.2%
JUN	42,599	38,330	-10.0%	35,371	51,193	44.7%	38,907	35,298	-9.3%	24,056	23,156	-3.7%	140,933	147,977	5.0%
JUL	45,207	38,525	-14.8%	14,019	18,622	32.8%	10,126	11,175	10.4%	11,803	10,178	-13.8%	81,155	78,499	-3.3%
AUG	17,708	14,848	-16.2%	11,799	12,376	4.9%	16,658	10,196	-38.8%	10,329	10,170	-1.5%	56,494	47,590	-15.8%
SEP	8,719	7,327	-16.0%	24,403	31,236	28.0%	25,695	18,331	-28.7%	11,658	11,397	-2.2%	70,475	68,291	-3.1%
OCT	10,759	12,183	13.2%	13,594	15,022	10.5%	22,970	16,343	-28.9%	10,119	14,684	45.1%	57,442	58,232	1.4%
NOV	10,297	5,395	-47.6%	16,240	16,827	3.6%	17,576	14,048	-20.1%	7,172	6,743	-6.0%	51,284	43,012	-16.1%
DEC	12,431	14,697	18.2%	10,628	13,582	27.8%	20,530	18,890	-8.0%	8,012	5,802	-27.6%	51,601	52,970	2.7%

Season	1999 Recorded USGS Volume (ac-ft)	1999 Simulated LSPC Volume (ac-ft)	1999 Percent Diff.	1999 Var. from Tolerance	2000 Recorded USGS Volume (ac-ft)	2000 Simulated LSPC Volume (ac-ft)	2000 Percent Diff.	2000 Var. from Tolerance	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2001 Var. from Tolerance	2002 Recorded USGS Volume (ac-ft)	2002 Simulated LSPC Volume (ac-ft)	2002 Percent Diff.	2002 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Jan-Mar	94,454	65,501	-30.7%	10.7%	60,660	55,227	-9.0%		89,852	116,848	30.0%	10.0%	82,895	86,538	4.4%		327,860	324,114	-1.1%	
Apr-Jun	158,774	184,655	16.3%		103,282	122,776	18.9%		143,233	142,432	-0.6%		103,926	113,625	9.3%		509,216	563,488	10.7%	
Jul-Sep	71,634	60,700	-15.3%		50,220	62,234	23.9%	3.9%	52,479	39,701	-24.3%	4.3%	33,790	31,745	-6.1%		208,124	194,380	-6.6%	
Oct-Dec	33,487	32,275	-3.6%		40,462	45,430	12.3%		61,076	49,280	-19.3%		25,302	27,228	7.6%		160,327	154,214	-3.8%	

Calibration Tolerance =20%

	1999 Recorded USGS Volume (ac-ft)	1999 Simulated LSPC Volume (ac-ft)	1999 Percent Diff.	1999 Var. from Tolerance	2000 Recorded USGS Volume (ac-ft)	2000 Simulated LSPC Volume (ac-ft)	2000 Percent Diff.	2000 Var. from Tolerance	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2001 Var. from Tolerance	2002 Recorded USGS Volume (ac-ft)	2002 Simulated LSPC Volume (ac-ft)	2002 Percent Diff.	2002 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Year	358,349	343,132	-4.2%		254,625	285,667	12.2%	2.2%	346,641	348,262	0.5%		245,913	259,136	5.4%		1,205,528	1,236,196	2.5%	

Calibration Tolerance =10%

Table 8-6. High-Low flow error statistics for hydrologic validation results for Milwaukee River at USGS gage 04086600 (1999-2002).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	370,357	383,939	-3.5%	15%
Total Highest 20% volume	591,195	599,389	-1.4%	15%
Total Highest 50% volume	986,788	948,149	4.1%	15%
Total Lowest 10% volume	21,564	32,463	-33.6%	10%
Total Lowest 30% volume	107,183	124,417	-13.9%	10%
Total Lowest 50% volume	252,417	260,116	-3.0%	10%

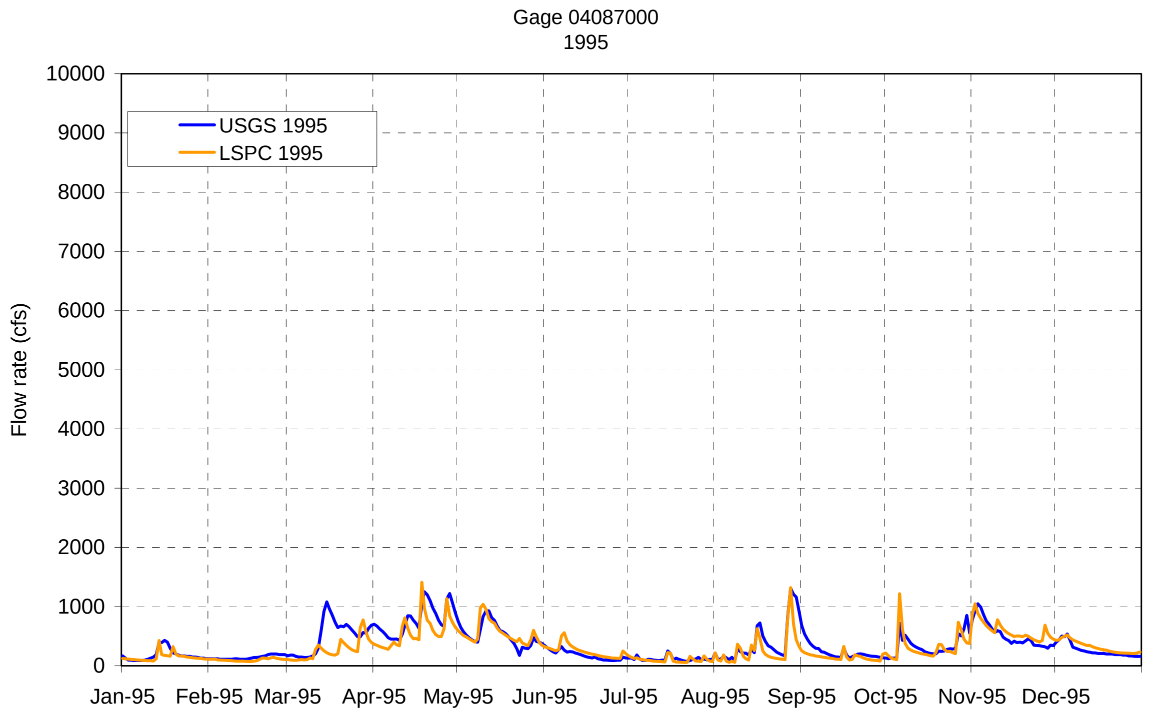


Figure 8-23. Time series hydrologic calibration results (daily mean) for Milwaukee River at USGS gage 04087000 (1995).

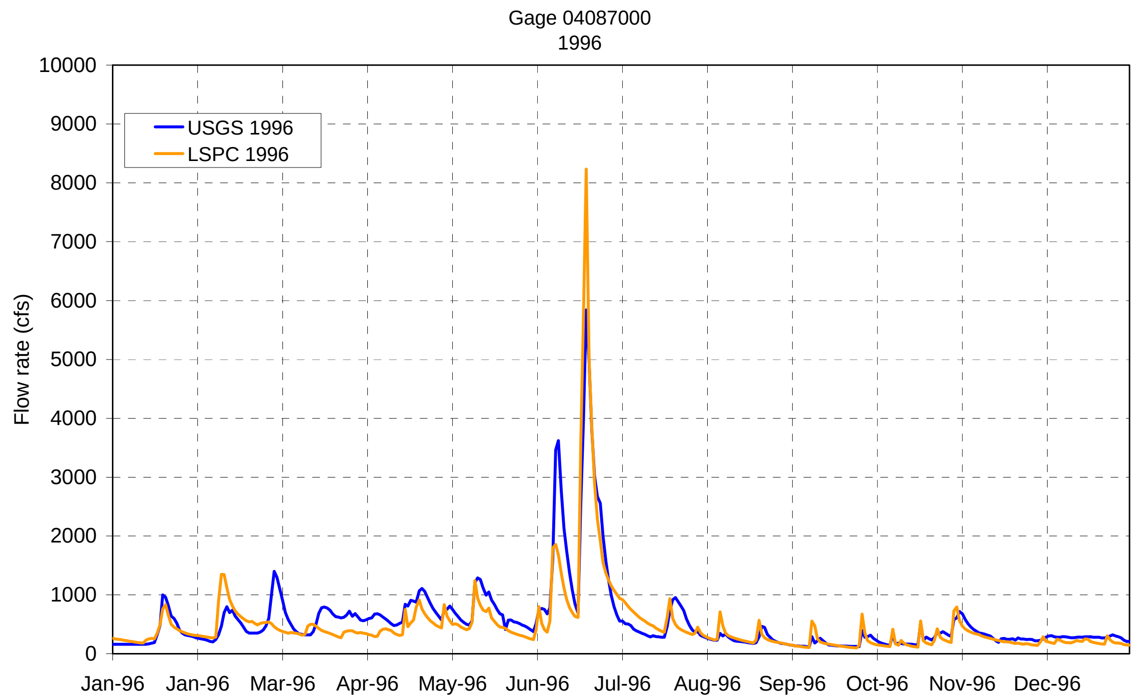


Figure 8-24. Time series hydrologic calibration results (daily mean) for Milwaukee River at USGS gage 04087000 (1996).

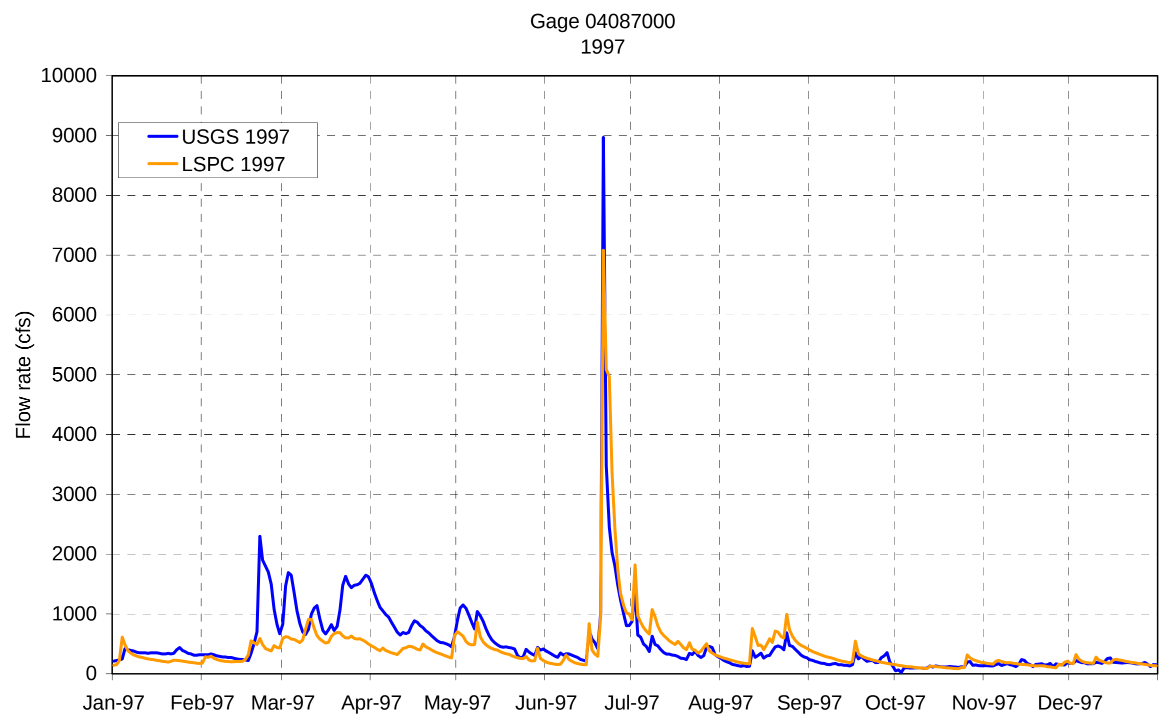


Figure 8-25. Time series hydrologic calibration results (daily mean) for Milwaukee River at USGS gage 04087000 (1997).

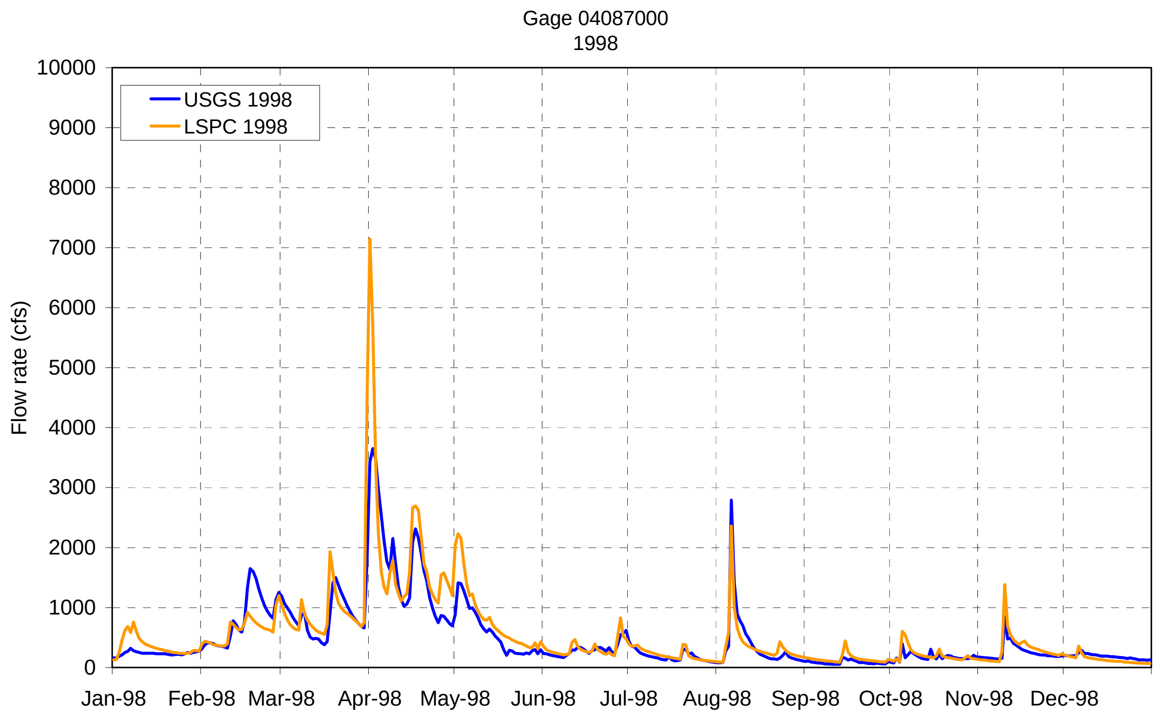


Figure 8-26. Time series hydrologic calibration results (daily mean) for Milwaukee River at USGS gage 04087000 (1998).

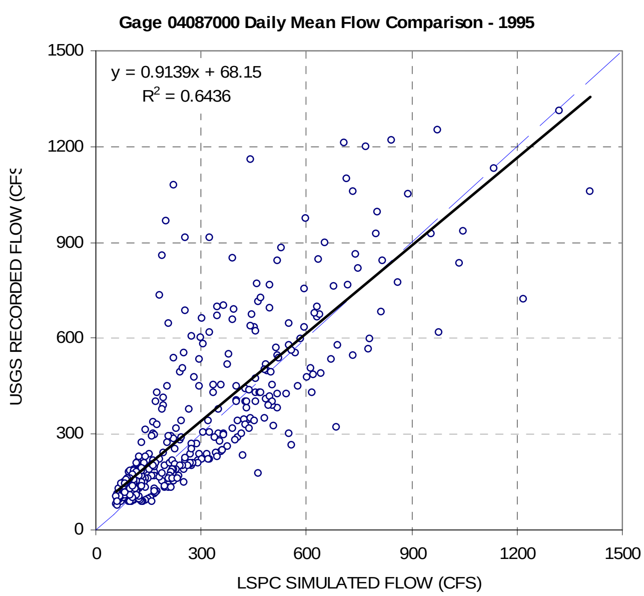


Figure 8-27. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04087000 (1995).

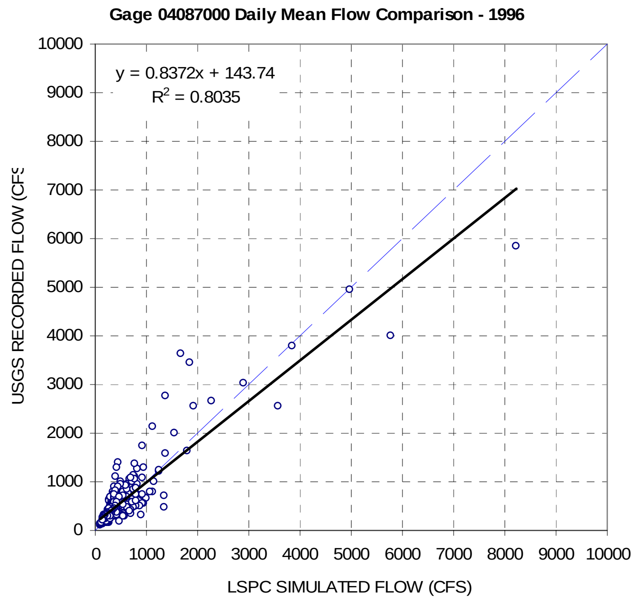


Figure 8-28. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04087000 (1996).

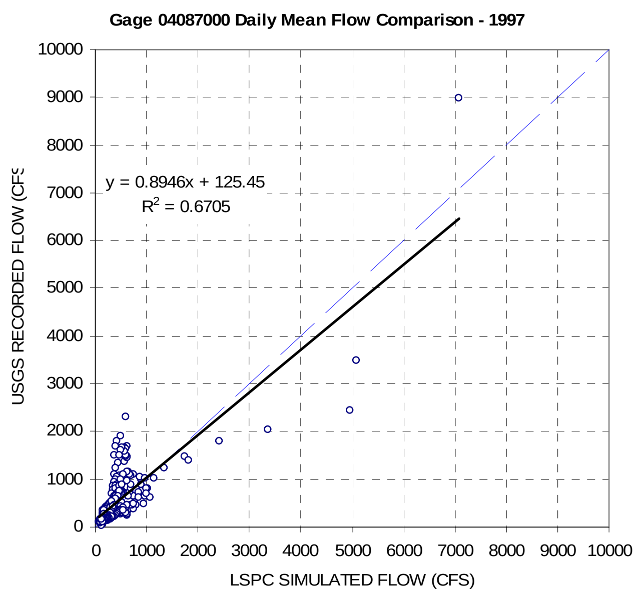


Figure 8-29. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04087000 (1997).

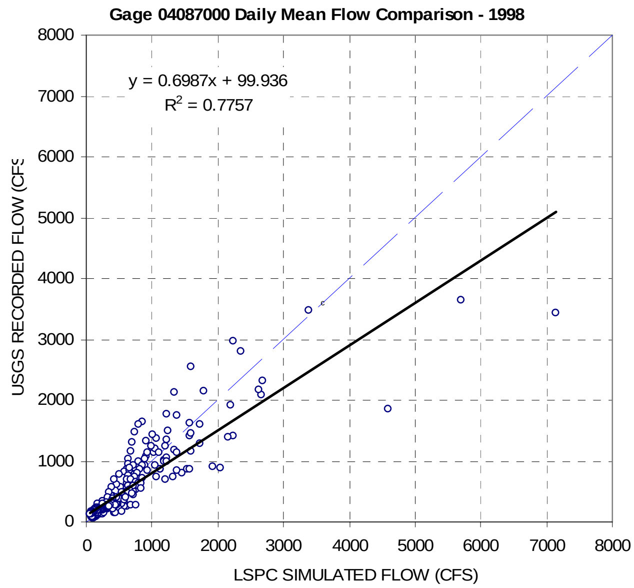


Figure 8-30. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04087000 (1998).

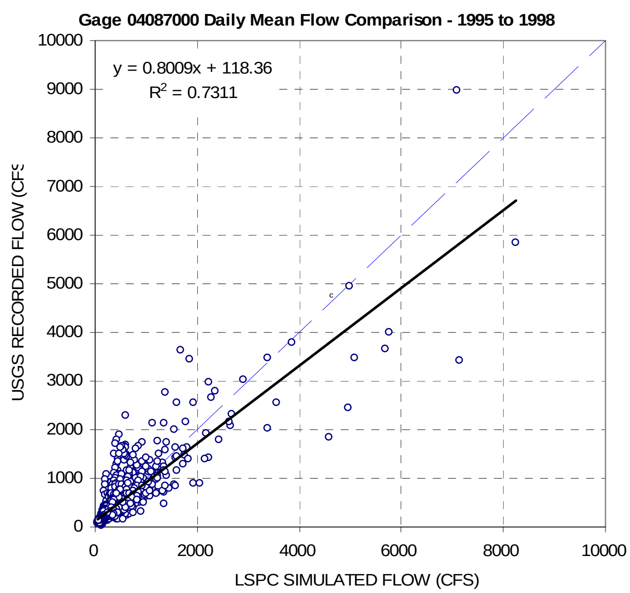


Figure 8-31. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04087000 (1995 to 1998).

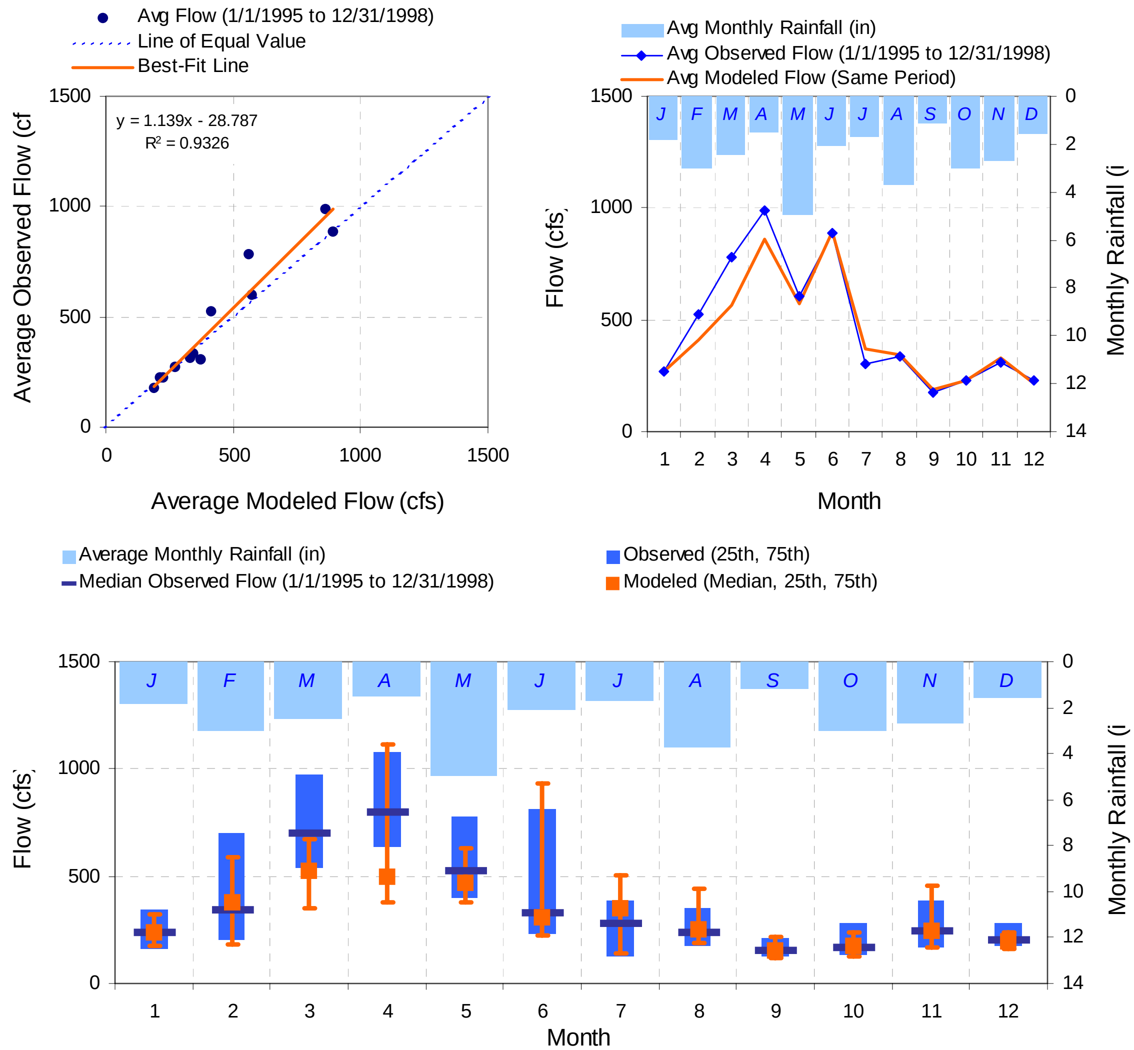


Figure 8-32. Composite (average monthly) hydrologic calibration results for Milwaukee River at USGS gage 04087000 (1995 to 1998).

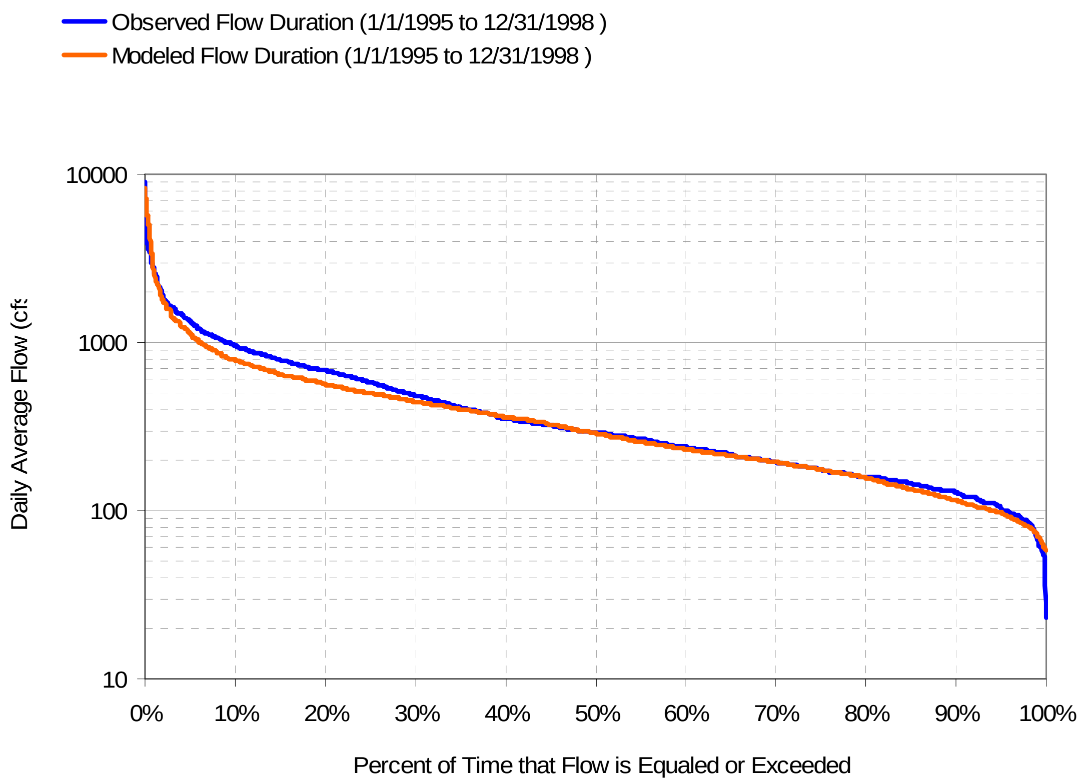


Figure 8-33. Flow duration curve hydrologic calibration results for Milwaukee River at USGS gage 04087000 (1995-1998).

Table 8-7. Error statistics for hydrologic calibration results for Milwaukee River at USGS gage 04087000 (1995-1998).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1995			1996			1997			1998			TOTAL		
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month JAN	10,963	8,968	-18.2%	20,233	20,843	3.0%	20,847	15,334	-26.4%	14,387	21,577	50.0%	66,431	66,722	0.4%
FEB	7,867	5,645	-28.2%	29,468	34,158	15.9%	35,786	18,088	-49.5%	44,085	34,647	-21.4%	117,206	92,538	-21.0%
MAR	30,050	16,501	-45.1%	36,628	22,873	-37.6%	71,444	38,100	-46.7%	53,863	60,608	12.5%	191,985	138,082	-28.1%
APR	46,176	34,353	-25.6%	42,937	29,582	-31.1%	46,822	23,625	-49.5%	99,963	117,138	17.2%	235,898	204,697	-13.2%
MAY	32,060	33,736	5.2%	42,854	31,045	-27.6%	37,319	25,306	-32.2%	35,708	50,787	42.2%	147,942	140,875	-4.8%
JUN	10,814	14,873	37.5%	119,304	109,907	-7.9%	63,076	69,037	9.5%	17,582	18,916	7.6%	210,776	212,734	0.9%
JUL	7,102	6,340	-10.7%	29,355	33,487	14.1%	26,505	38,112	43.8%	11,710	13,422	14.6%	74,672	91,362	22.4%
AUG	24,177	16,955	-29.9%	15,132	16,537	9.3%	18,586	27,883	50.0%	24,117	23,338	-3.2%	82,013	84,713	3.3%
SEP	14,044	8,926	-36.4%	10,713	11,609	8.4%	12,140	15,549	28.1%	5,057	8,479	67.7%	41,955	44,562	6.2%
OCT	20,628	19,456	-5.7%	17,114	15,412	-9.9%	6,894	8,270	20.0%	10,915	12,730	16.6%	55,551	55,868	0.6%
NOV	31,222	35,439	13.5%	18,364	14,753	-19.7%	9,225	9,504	3.0%	15,184	18,782	23.7%	73,995	78,479	6.1%
DEC	16,040	19,666	22.6%	17,132	12,280	-28.3%	11,216	12,020	7.2%	11,236	8,180	-27.2%	55,624	52,147	-6.3%

Season	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Jan-Mar	48,881	31,115	-36.3%	16.3%	86,329	77,874	-9.8%		128,077	71,521	-44.2%	24.2%	112,335	116,832	4.0%		375,621	297,342	-20.8%	0.8%
Apr-Jun	89,050	82,962	-6.8%		205,096	170,534	-16.9%		147,217	117,968	-19.9%		153,253	186,841	21.9%	1.9%	594,615	558,306	-6.1%	
Jul-Sep	45,323	32,221	-28.9%	8.9%	55,200	61,633	11.7%		57,231	81,544	42.5%	22.5%	40,884	45,239	10.7%		198,640	220,637	11.1%	
Oct-Dec	67,889	74,561	9.8%		52,610	42,445	-19.3%		27,336	29,794	9.0%		37,335	39,693	6.3%		185,170	186,494	0.7%	

Calibration Tolerance =20%

	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	251,143	220,860	-12.1%	2.1%	399,235	352,485	-11.7%	1.7%	359,861	300,828	-16.4%	6.4%	343,807	388,605	13.0%	3.0%	1,354,046	1,262,779	-6.7%	

Calibration Tolerance =10%

Table 8-8. High-Low flow error statistics for hydrologic calibration results for Milwaukee River at USGS gage 04087000 (1995-1998).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	462,111	480,754	-3.9%	15%
Total Highest 20% volume	654,712	713,127	-8.2%	15%
Total Highest 50% volume	1,011,155	1,094,543	-7.6%	15%
Total Lowest 10% volume	27,356	29,211	-6.3%	10%
Total Lowest 30% volume	117,438	122,186	-3.9%	10%
Total Lowest 50% volume	254,466	262,441	-3.0%	10%

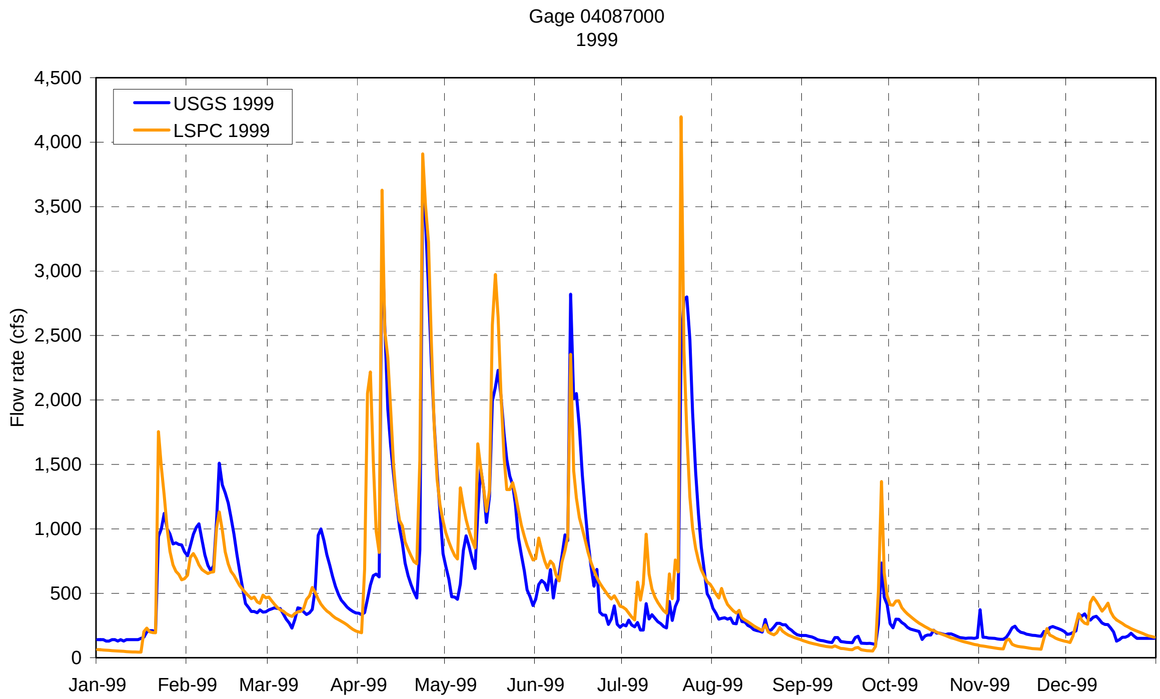


Figure 8-34. Time series hydrologic validation results (daily mean) for Milwaukee River at USGS gage 04087000 (1999).

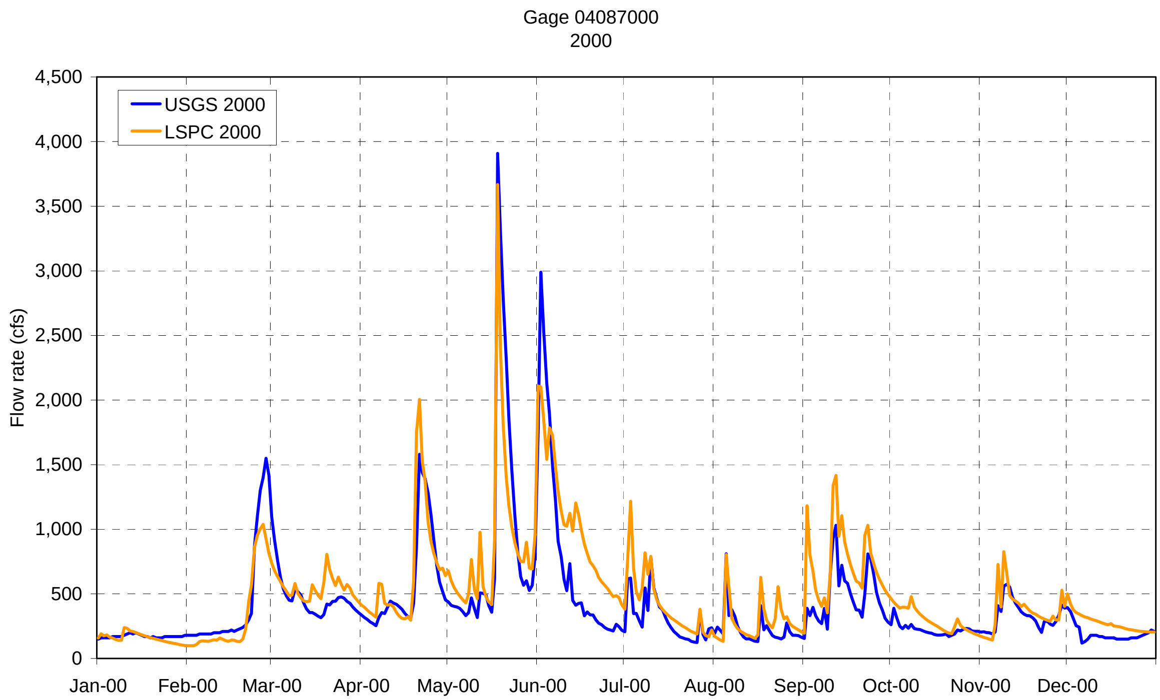


Figure 8-35. Time series hydrologic validation results (daily mean) for Milwaukee River at USGS gage 04087000 (2000).

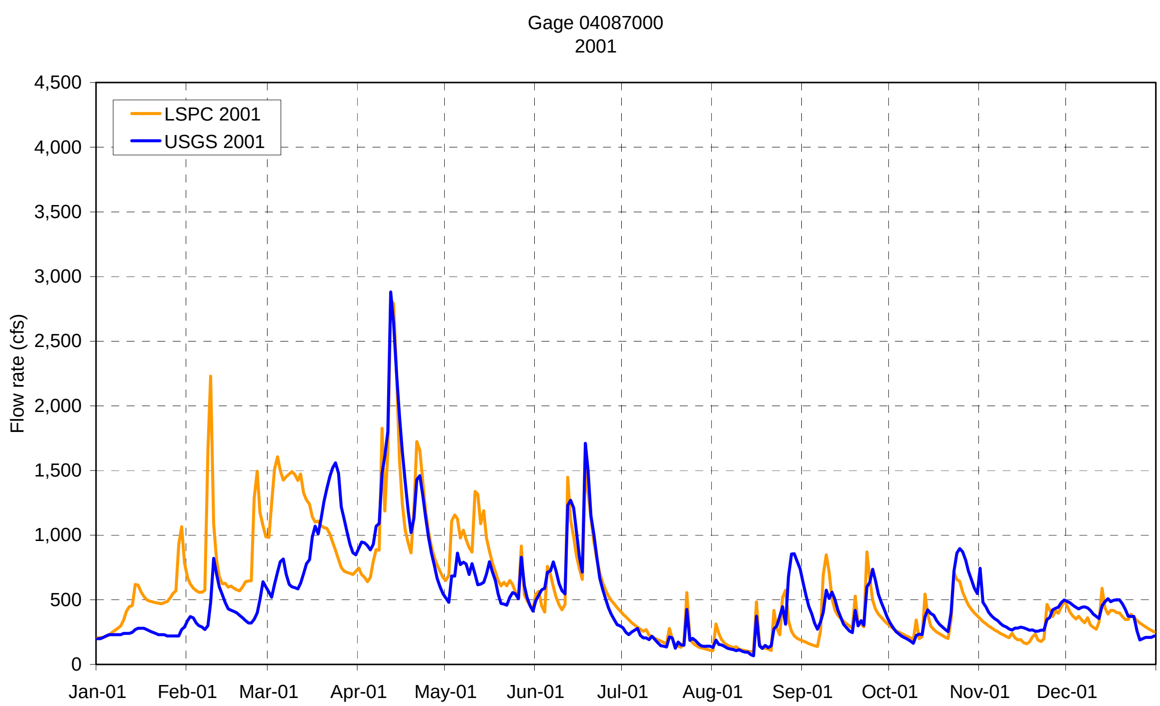


Figure 8-36. Time series hydrologic validation results (daily mean) for Milwaukee River at USGS gage 04087000 (2001).

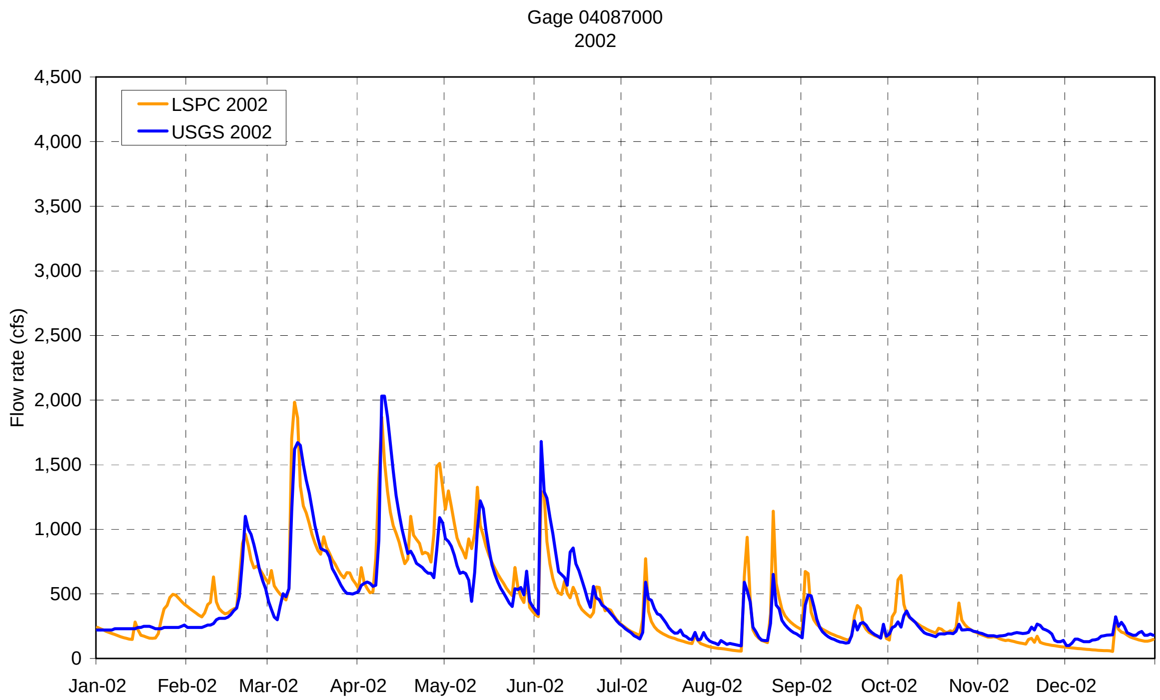


Figure 8-37. Time series hydrologic validation results (daily mean) for Milwaukee River at USGS gage 04087000 (2002).

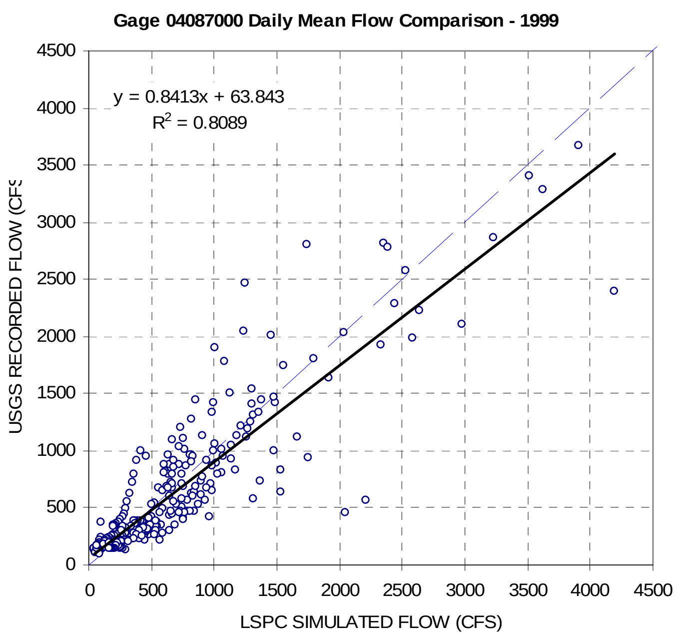


Figure 8-38. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04087000 (1999).

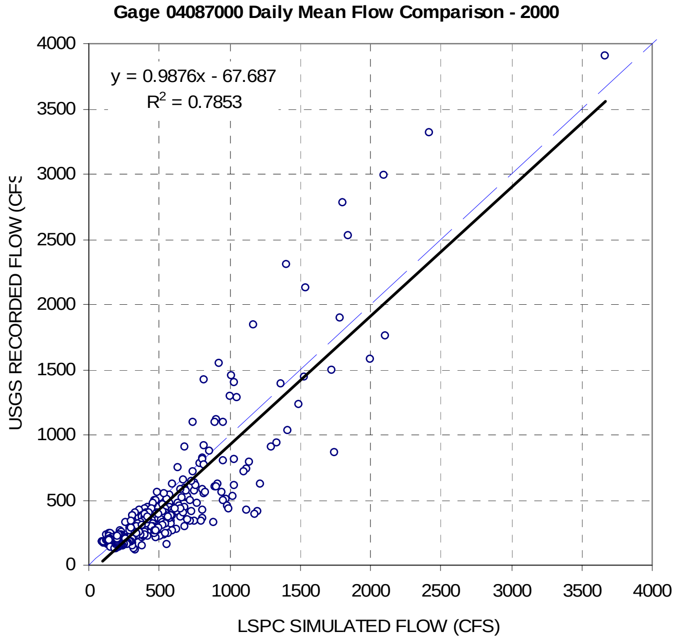


Figure 8-39. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04087000 (2000).

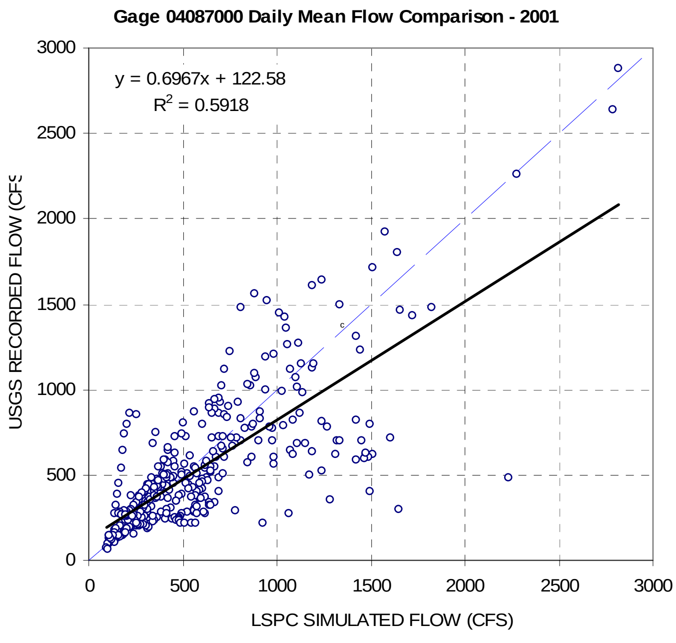


Figure 8-40. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04087000 (2001).

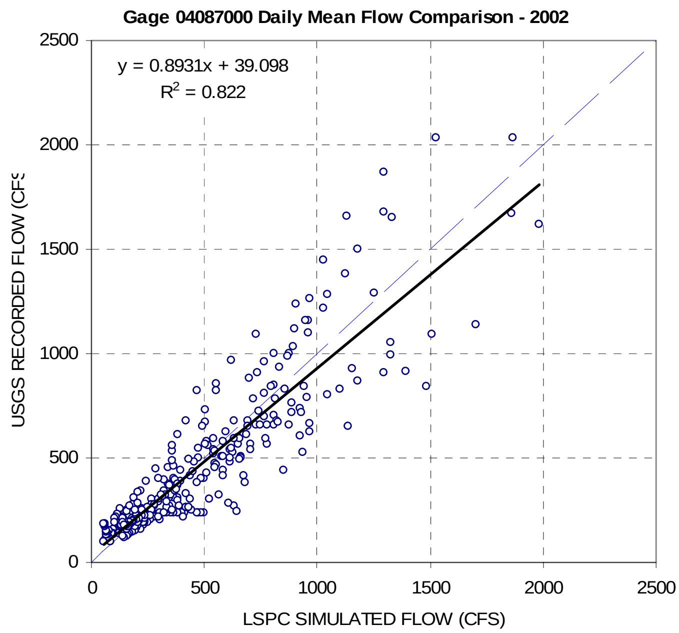


Figure 8-41. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04087000 (2002).

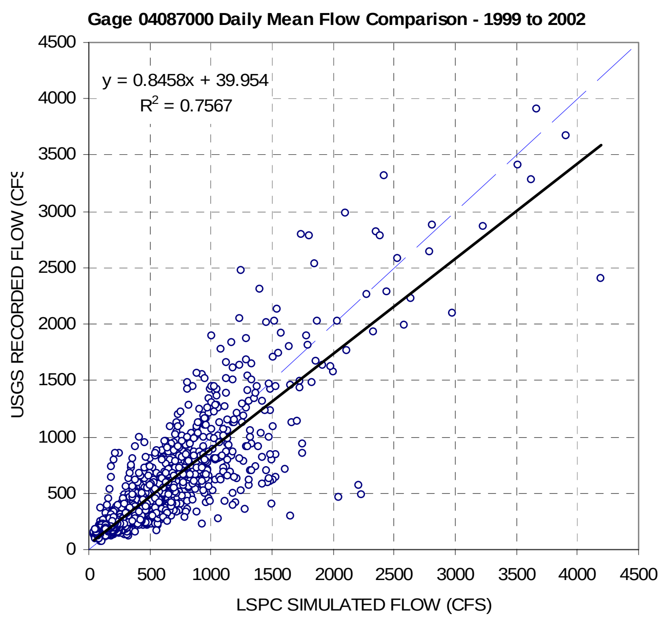


Figure 8-42. Observed versus simulated scatter plot with a linear regression line for Milwaukee River at USGS gage 04087000 (1999 to 2002).

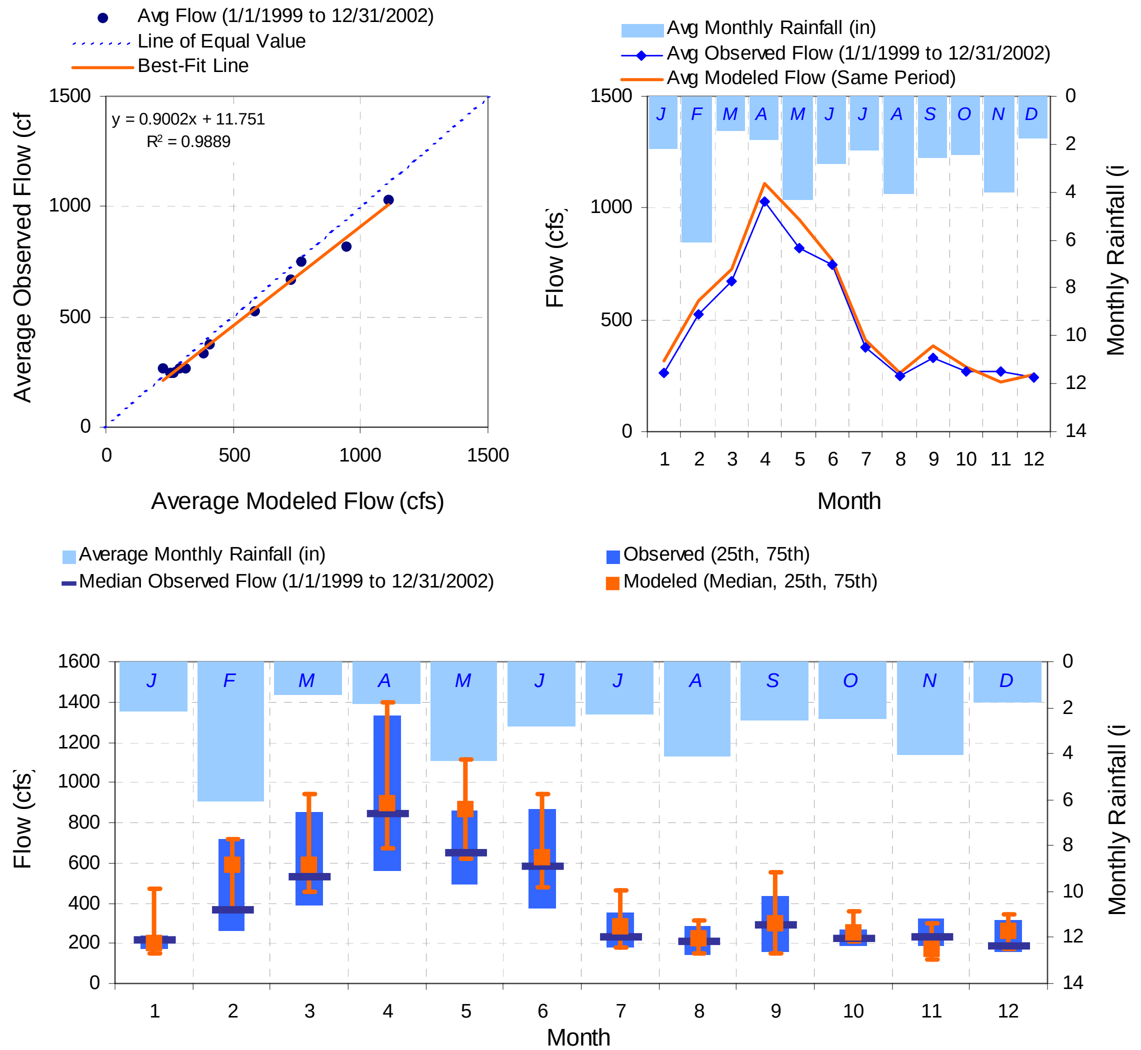


Figure 8-43. Composite (average monthly) hydrologic validation results for Milwaukee River at USGS gage 04087000 (1999 to 2002).

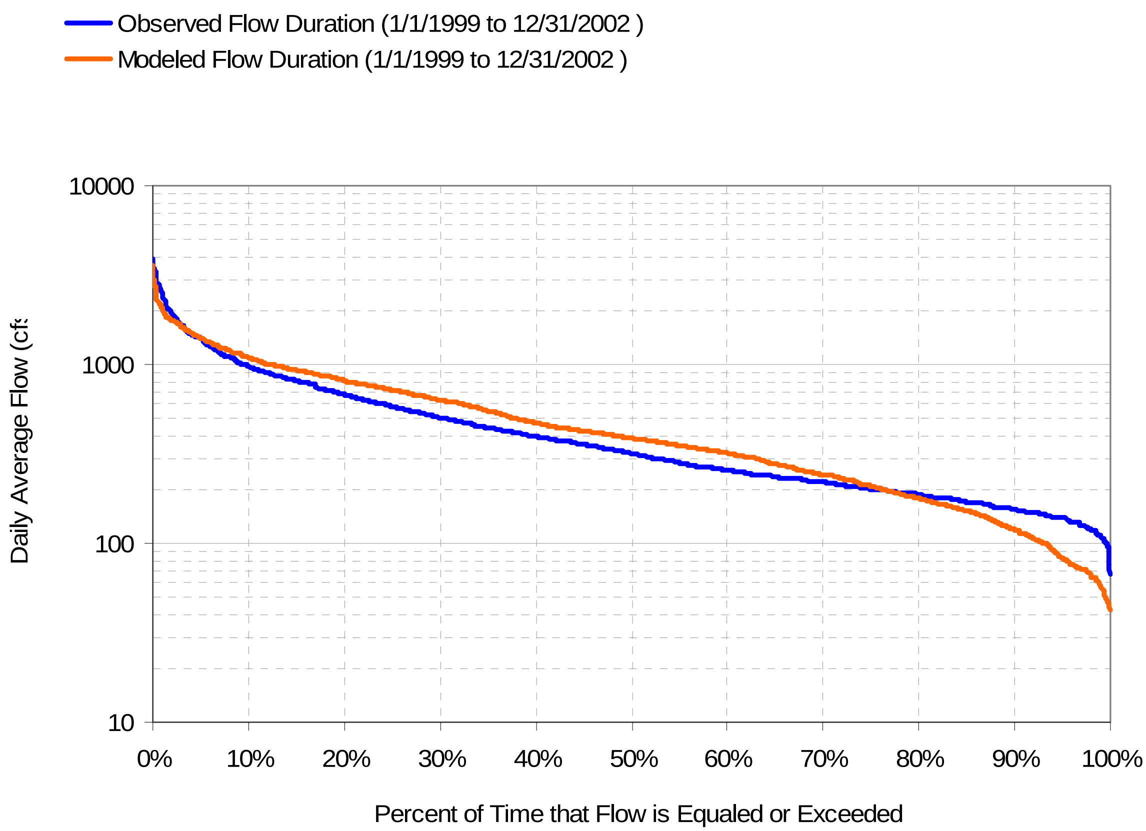


Figure 8-44. Flow duration curve hydrologic validation results for Milwaukee River at USGS gage 04087000 (1999 to 2002).

Table 8-9. Error statistics for hydrologic validation results for Milwaukee River at USGS gage 04087000 (1999 to 2002).

Monthly / Seasonal / Yearly Volume Comparison

Time Period		1999			2000			2001			2002			TOTAL		
		Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month	JAN	24,890	22,664	-8.9%	10,543	9,819	-6.9%	14,724	28,562	94.0%	14,407	15,880	10.2%	64,564	76,925	19.1%
	FEB	43,407	36,566	-15.8%	24,910	18,789	-24.6%	23,860	46,282	94.0%	25,584	28,762	12.4%	117,761	130,399	10.7%
	MAR	28,634	22,275	-22.2%	29,389	33,962	15.6%	57,194	70,115	22.6%	49,739	52,810	6.2%	164,955	179,163	8.6%
	APR	77,459	95,028	22.7%	34,771	39,098	12.4%	76,208	72,007	-5.5%	56,300	57,346	1.9%	244,738	263,479	7.7%
	MAY	65,345	79,376	21.5%	56,255	54,881	-2.4%	38,382	50,466	31.5%	41,800	47,944	14.7%	201,781	232,667	15.3%
	JUN	48,193	47,586	-1.3%	45,847	61,570	34.3%	45,375	42,969	-5.3%	38,259	30,509	-20.3%	177,673	182,634	2.8%
	JUL	46,237	48,895	5.7%	18,989	25,639	35.0%	12,146	13,710	12.9%	14,756	12,396	-16.0%	92,127	100,640	9.2%
	AUG	15,905	17,588	10.6%	14,114	17,652	25.1%	16,807	13,018	-22.5%	14,151	16,517	16.7%	60,977	64,775	6.2%
	SEP	10,664	10,340	-3.0%	28,723	43,116	50.1%	26,097	23,155	-11.3%	13,600	15,092	11.0%	79,084	91,702	16.0%
	OCT	12,160	14,438	18.7%	13,717	18,406	34.2%	25,501	21,087	-17.3%	14,132	17,292	22.4%	65,509	71,223	8.7%
	NOV	11,528	6,291	-45.4%	19,635	22,086	12.5%	20,953	16,554	-21.0%	11,387	8,072	-29.1%	63,502	53,003	-16.5%
	DEC	13,260	16,751	26.3%	11,664	16,980	45.6%	23,986	21,982	-8.4%	10,856	7,186	-33.8%	59,766	62,900	5.2%

		Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Season	Jan-Mar	96,931	81,506	-15.9%		64,841	62,570	-3.5%		95,778	144,960	51.4%	31.4%	89,729	97,452	8.6%		347,279	386,487	11.3%	
	Apr-Jun	190,996	221,990	16.2%		136,872	155,548	13.6%		159,965	165,443	3.4%		136,359	135,799	-0.4%		624,192	678,779	8.7%	
	Jul-Sep	72,806	76,823	5.5%		61,825	86,407	39.8%	19.8%	55,050	49,883	-9.4%		42,507	44,005	3.5%		232,188	257,118	10.7%	
	Oct-Dec	36,947	37,480	1.4%		45,016	57,472	27.7%	7.7%	70,440	59,623	-15.4%		36,374	32,550	-10.5%		188,777	187,125	-0.9%	

Calibration Tolerance =20%

	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	397,680	417,799	5.1%		308,555	361,997	17.3%	7.3%	381,232	419,909	10.1%	0.1%	304,970	309,805	1.6%		1,392,436	1,509,509	8.4%	

Calibration Tolerance =10%

Table 8-10. High-Low flow error statistics for hydrologic validation results for Milwaukee River at USGS gage 04087000 (1999-2002).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	462,789	456,559	1.4%	15%
Total Highest 20% volume	726,646	694,001	4.7%	15%
Total Highest 50% volume	1,206,871	1,096,562	10.1%	15%
Total Lowest 10% volume	25,760	39,015	-34.0%	10%
Total Lowest 30% volume	128,930	147,523	-12.6%	10%
Total Lowest 50% volume	306,287	299,016	2.4%	10%

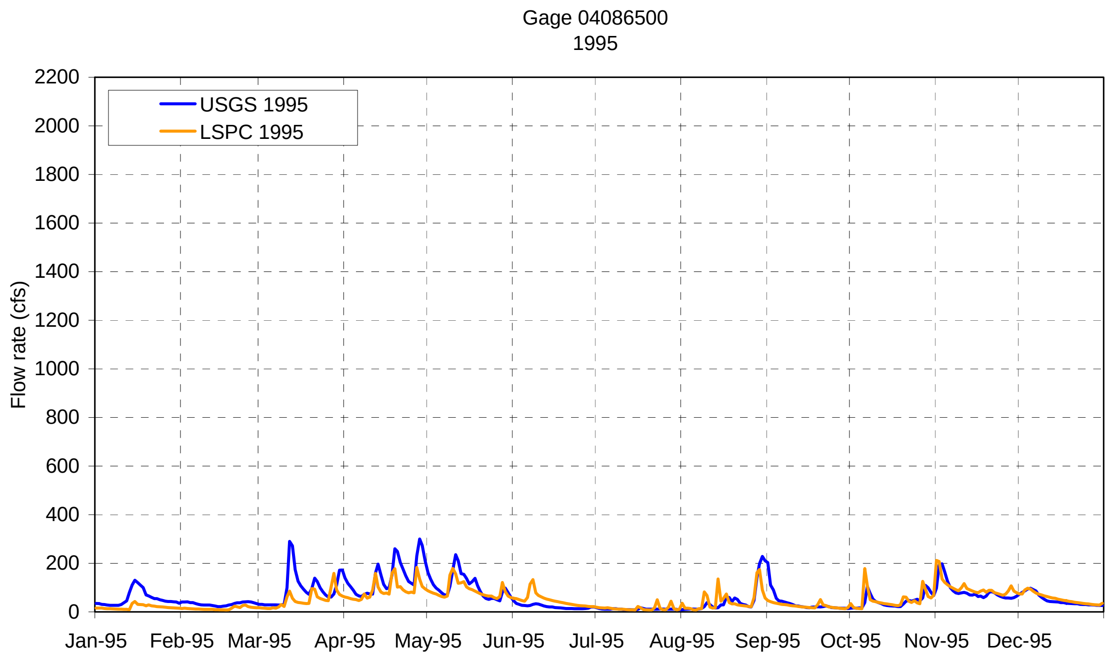


Figure 8-45. Time series hydrologic calibration results (daily mean) for Cedar Creek at USGS gage 04086500 (1995).

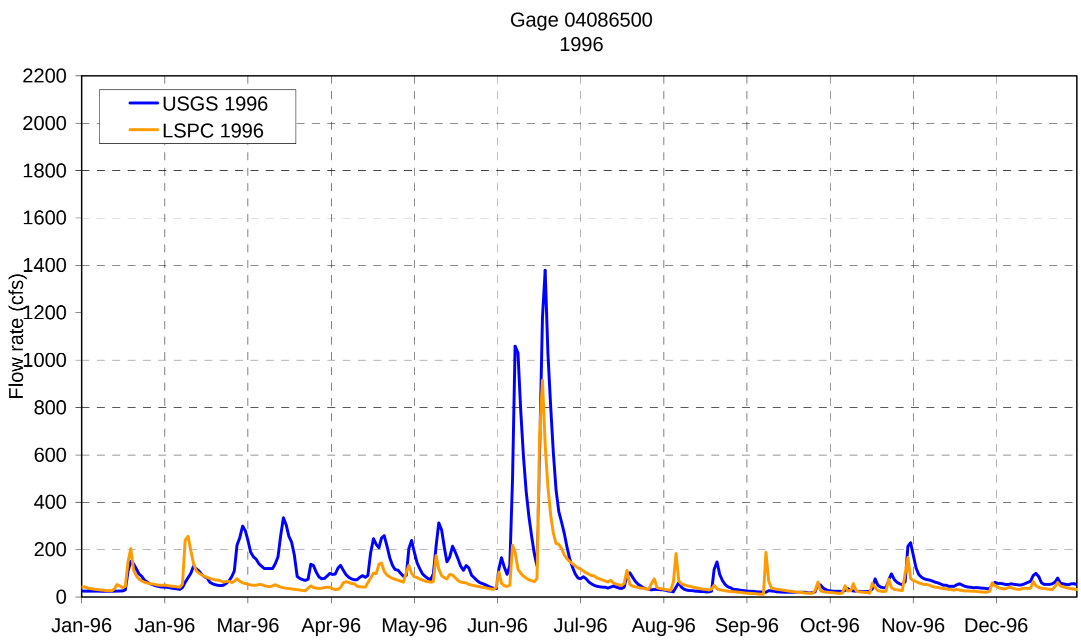


Figure 8-46. Time series hydrologic calibration results (daily mean) for Cedar Creek at USGS gage 04086500 (1996).

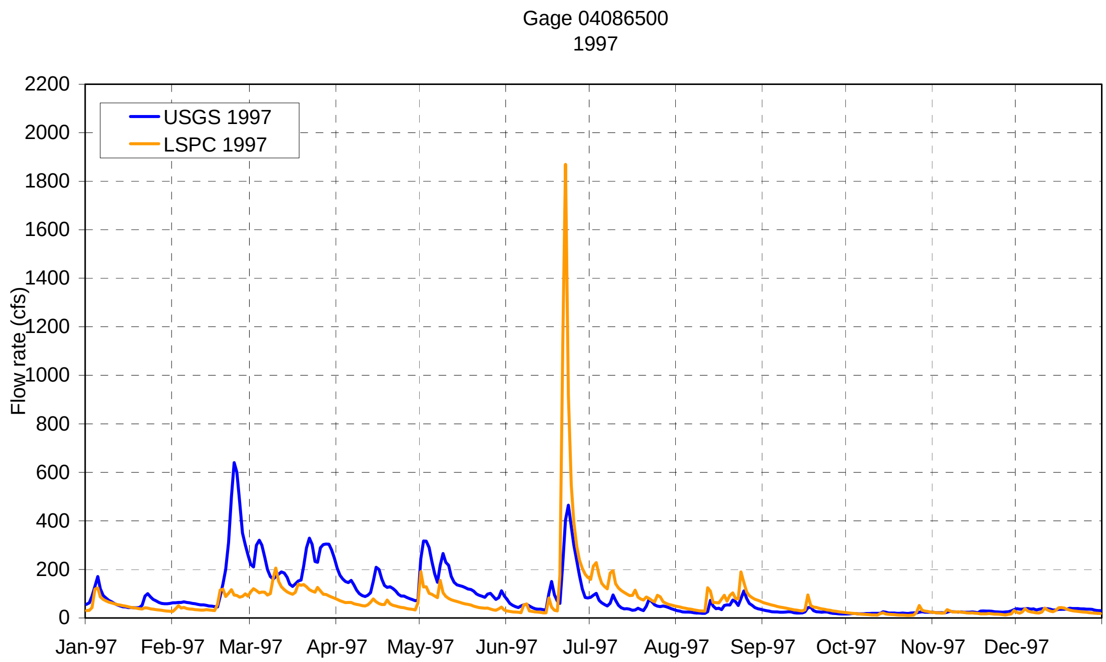


Figure 8-47. Time series hydrologic calibration results (daily mean) for Cedar Creek at USGS gage 04086500 (1997).

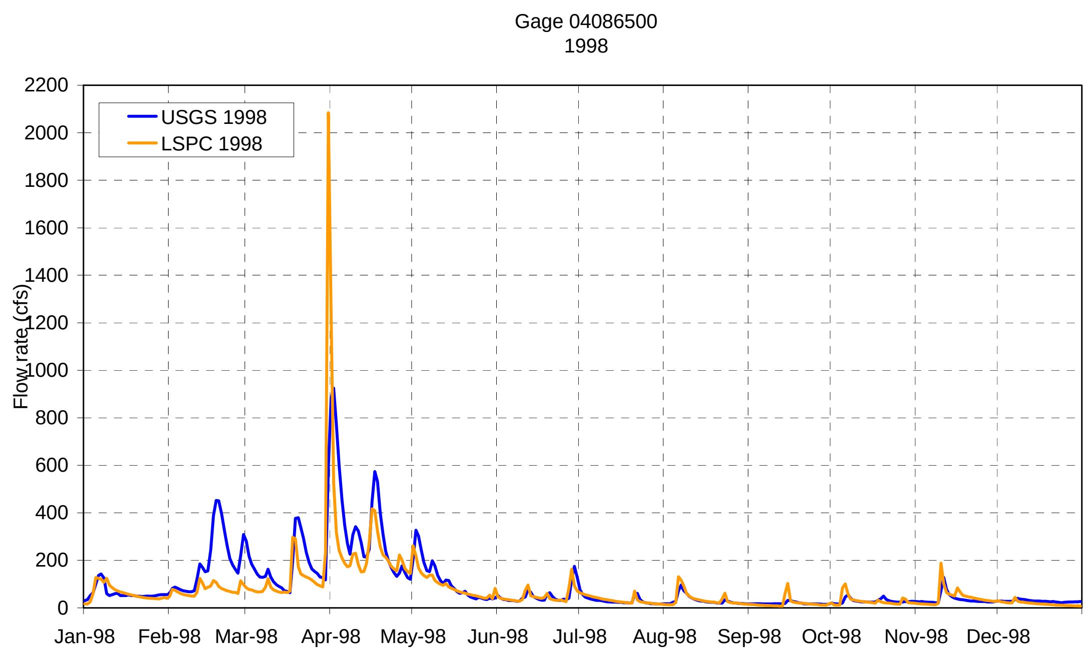


Figure 8-48. Time series hydrologic calibration results (daily mean) for Cedar Creek at USGS gage 04086500 (1998).

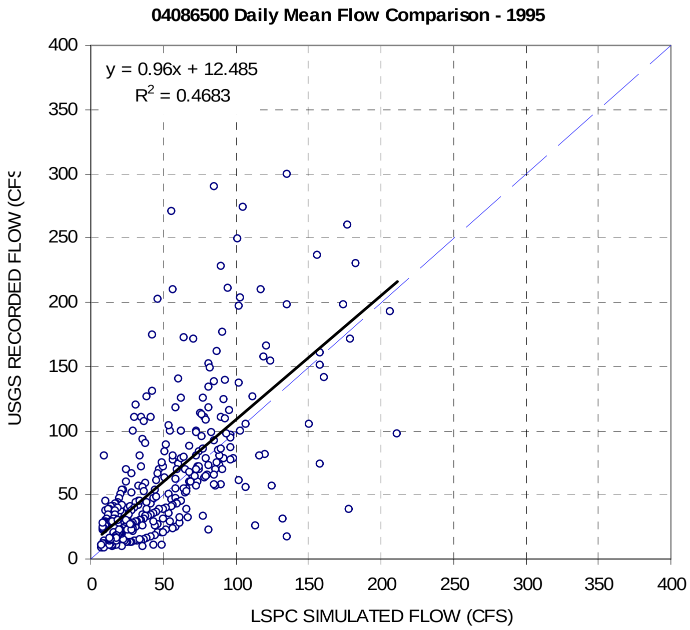


Figure 8-49. Observed versus simulated scatter plot with a linear regression line for Cedar Creek at USGS gage 04086500 (1995).

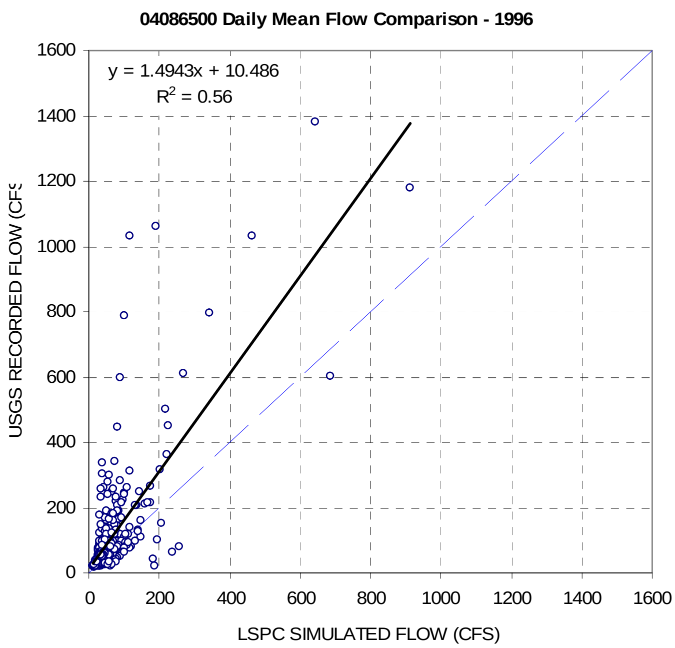


Figure 8-50. Observed versus simulated scatter plot with a linear regression line for Cedar Creek at USGS gage 04086500 (1996).

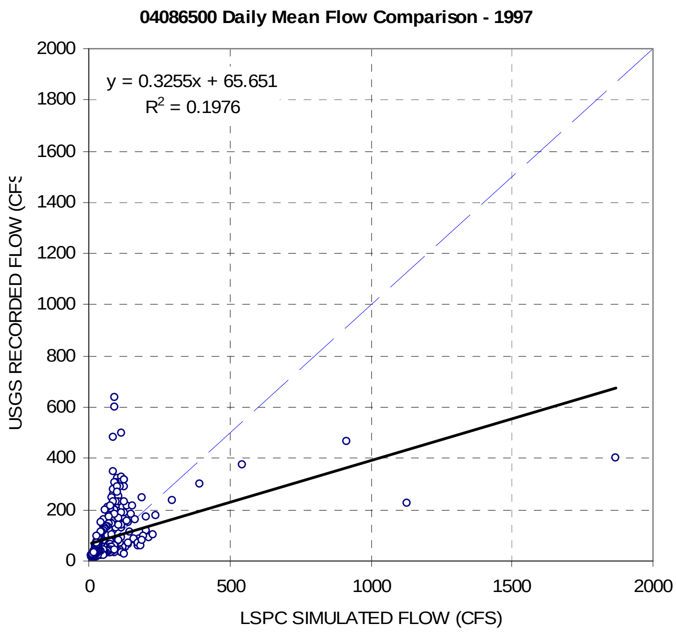


Figure 8-51. Observed versus simulated scatter plot with a linear regression line for Cedar Creek at USGS gage 04086500 (1997).

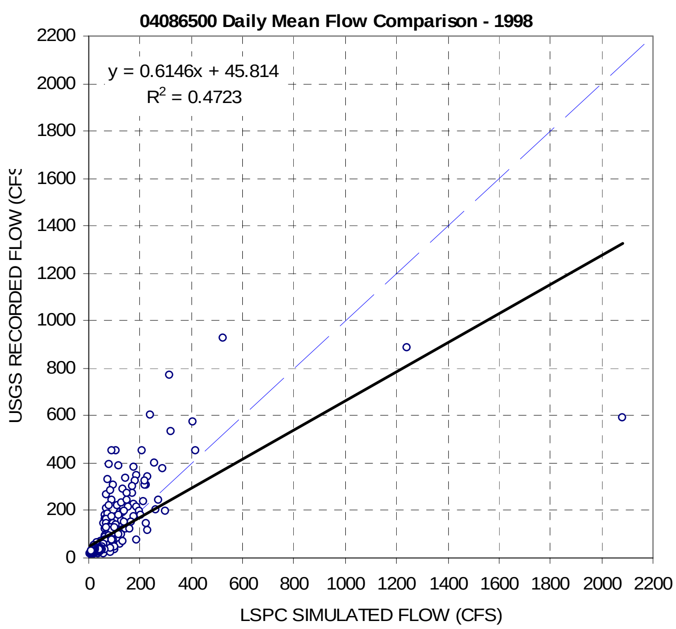


Figure 8-52. Observed versus simulated scatter plot with a linear regression line for Cedar Creek at USGS gage 04086500 (1998).

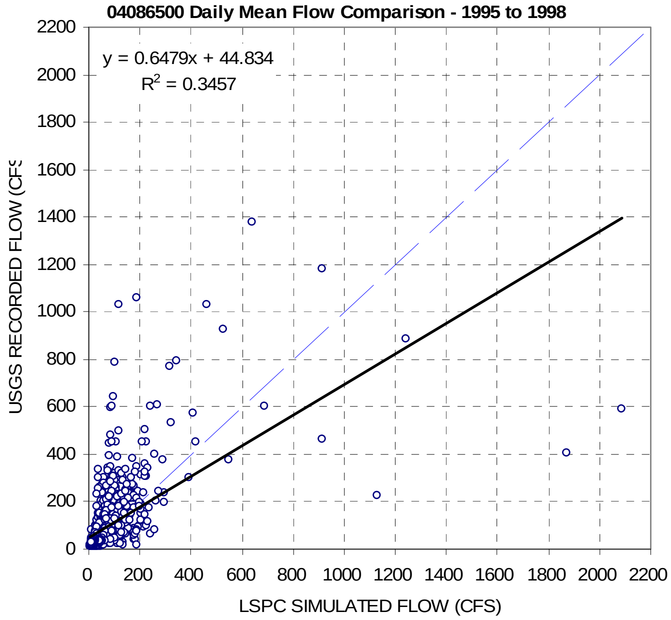


Figure 8-53. Observed versus simulated scatter plot with a linear regression line for Cedar Creek at USGS gage 04086500 (1995 to 1998).

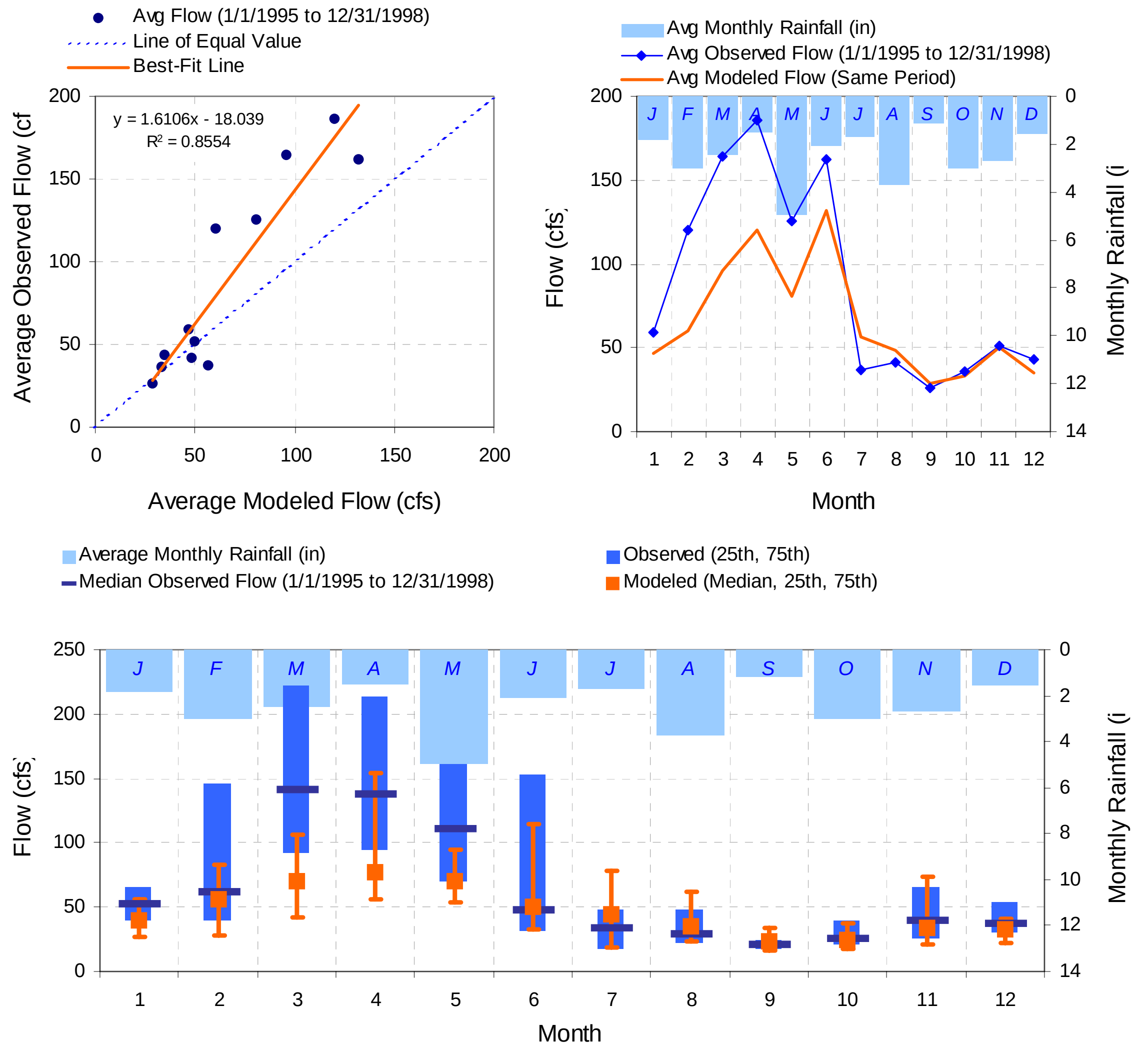


Figure 8-54. Composite (average monthly) hydrologic calibration results for Cedar Creek at USGS gage 04086500 (1995 to 1998).

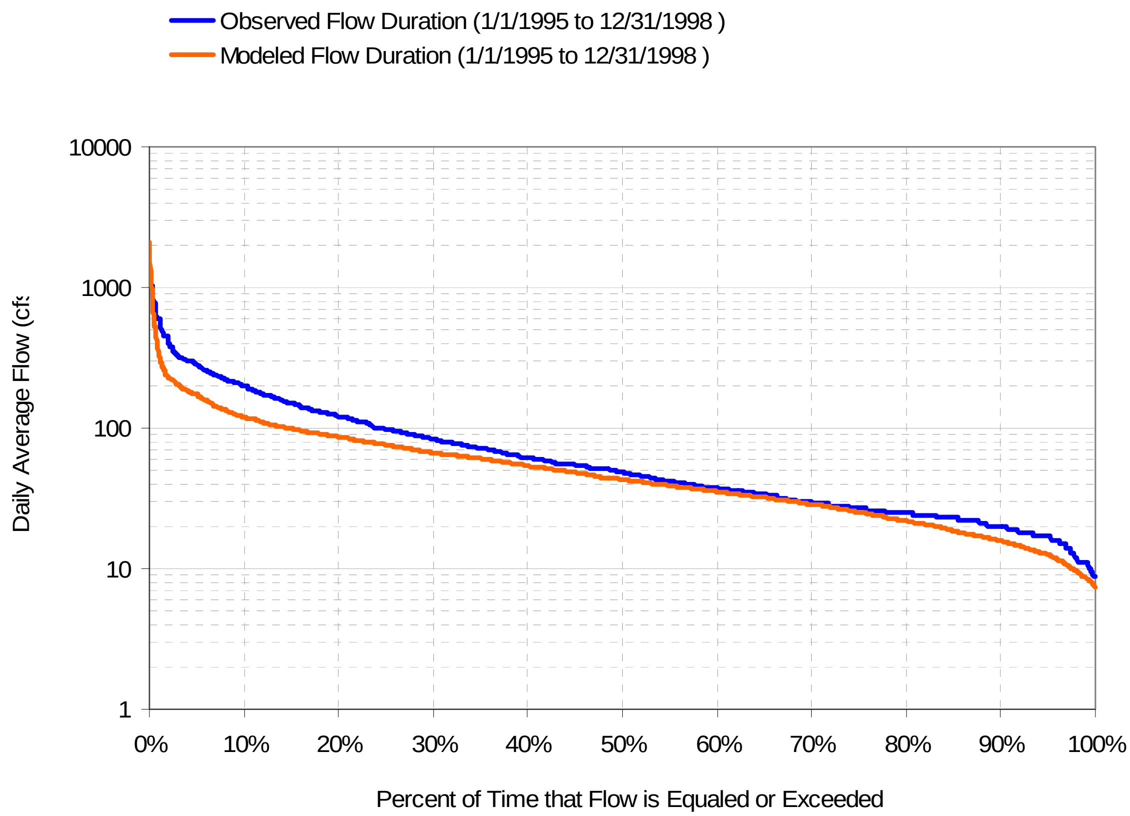


Figure 8-55. Flow duration curve hydrologic calibration results for Cedar Creek at USGS gage 04086500 (1995-1998).

Table 8-11. Error statistics for hydrologic calibration results for Cedar Creek at USGS gage 04086500 (1995-1998).

Monthly / Seasonal / Yearly Volume Comparison

Time Period		1995			1996			1997			1998			TOTAL		
		Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month	JAN	3,321	1,180	-64.5%	3,084	3,487	13.1%	4,324	3,079	-28.8%	3,783	3,795	0.3%	14,512	11,541	-20.5%
	FEB	1,819	793	-56.4%	5,030	5,021	-0.2%	9,585	3,399	-64.5%	10,448	4,281	-59.0%	26,882	13,494	-49.8%
	MAR	5,684	3,063	-46.1%	9,429	2,581	-72.6%	13,993	7,116	-49.1%	11,300	10,717	-5.2%	40,405	23,477	-41.9%
	APR	8,561	5,333	-37.7%	7,929	4,276	-46.1%	7,366	3,315	-55.0%	20,356	15,655	-23.1%	44,212	28,579	-35.4%
	MAY	6,433	5,397	-16.1%	8,060	4,290	-46.8%	9,629	4,405	-54.3%	6,817	5,829	-14.5%	30,938	19,921	-35.6%
	JUN	1,296	2,826	118.1%	26,963	12,212	-54.7%	7,229	13,342	84.6%	3,052	2,954	-3.2%	38,540	31,334	-18.7%
	JUL	697	900	29.1%	3,222	4,124	28.0%	3,307	6,803	105.7%	1,885	2,037	8.1%	9,111	13,864	52.2%
	AUG	3,013	2,825	-6.2%	2,519	2,465	-2.1%	2,695	4,461	65.5%	1,942	2,199	13.2%	10,169	11,951	17.5%
	SEP	2,124	1,504	-29.2%	1,459	1,804	23.7%	1,470	2,430	65.2%	1,124	1,129	0.5%	6,177	6,867	11.2%
	OCT	2,693	3,024	12.3%	3,198	2,314	-27.7%	1,221	1,092	-10.6%	1,772	1,787	0.9%	8,884	8,217	-7.5%
	NOV	5,043	5,893	16.8%	3,545	2,217	-37.5%	1,488	1,204	-19.1%	2,148	2,591	20.6%	12,225	11,905	-2.6%
	DEC	2,980	3,339	12.0%	3,714	2,425	-34.7%	2,212	1,689	-23.6%	1,750	1,109	-36.6%	10,656	8,561	-19.7%

		Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Season	Jan-Mar	10,824	5,036	-53.5%	33.5%	17,542	11,089	-36.8%	16.8%	27,902	13,595	-51.3%	31.3%	25,530	18,792	-26.4%	6.4%	81,799	48,512	-40.7%	20.7%
	Apr-Jun	16,290	13,556	-16.8%		42,951	20,777	-51.6%	31.6%	24,224	21,062	-13.1%		30,225	24,438	-19.1%		113,690	79,833	-29.8%	9.8%
	Jul-Sep	5,835	5,229	-10.4%		7,200	8,394	16.6%		7,473	13,694	83.2%	63.2%	4,950	5,365	8.4%		25,457	32,682	28.4%	8.4%
	Oct-Dec	10,717	12,256	14.4%		10,457	6,956	-33.5%	13.5%	4,921	3,985	-19.0%		5,670	5,487	-3.2%		31,765	28,683	-9.7%	

Calibration Tolerance =20%

	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	43,665	36,077	-17.4%	7.4%	78,150	47,216	-39.6%	29.6%	64,520	52,336	-18.9%	8.9%	66,375	54,082	-18.5%	8.5%	252,711	189,711	-24.9%	14.9%

Calibration Tolerance =10%

Table 8-12. High-Low flow error statistics for hydrologic calibration results for Cedar Creek at USGS gage 04086500 (1995-1998).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	70,178	101,679	-31.0%	15%
Total Highest 20% volume	99,451	146,390	-32.1%	15%
Total Highest 50% volume	153,113	212,196	-27.8%	15%
Total Lowest 10% volume	3,546	4,574	-22.5%	10%
Total Lowest 30% volume	16,320	18,927	-13.8%	10%
Total Lowest 50% volume	37,024	41,032	-9.8%	10%

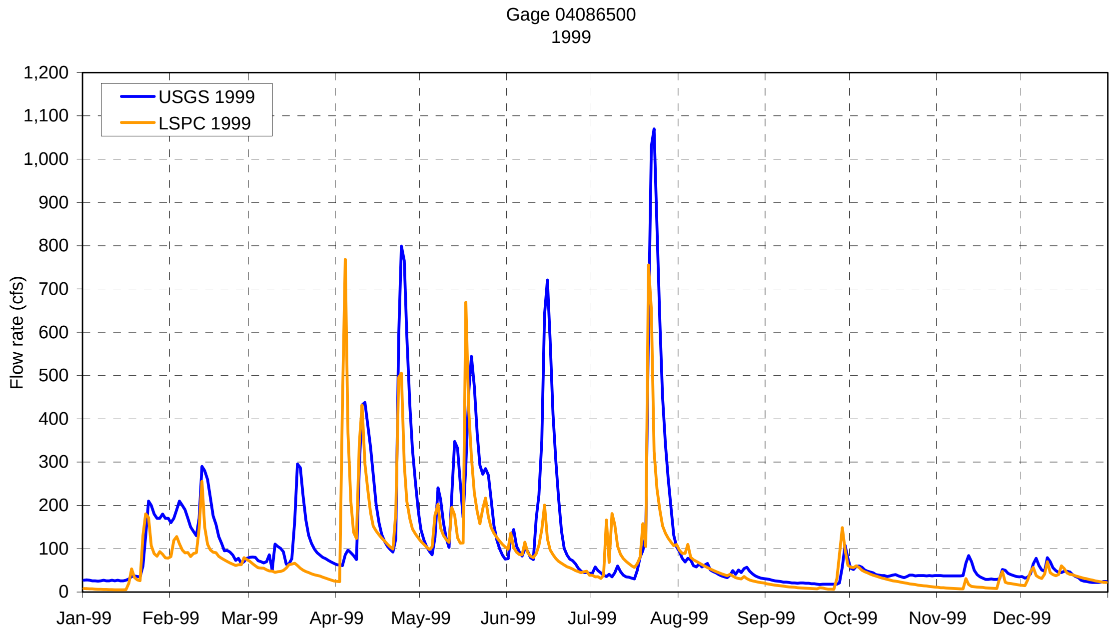


Figure 8-56. Time series hydrologic validation results (daily mean) for Cedar Creek at USGS gage 04086500 (1999).

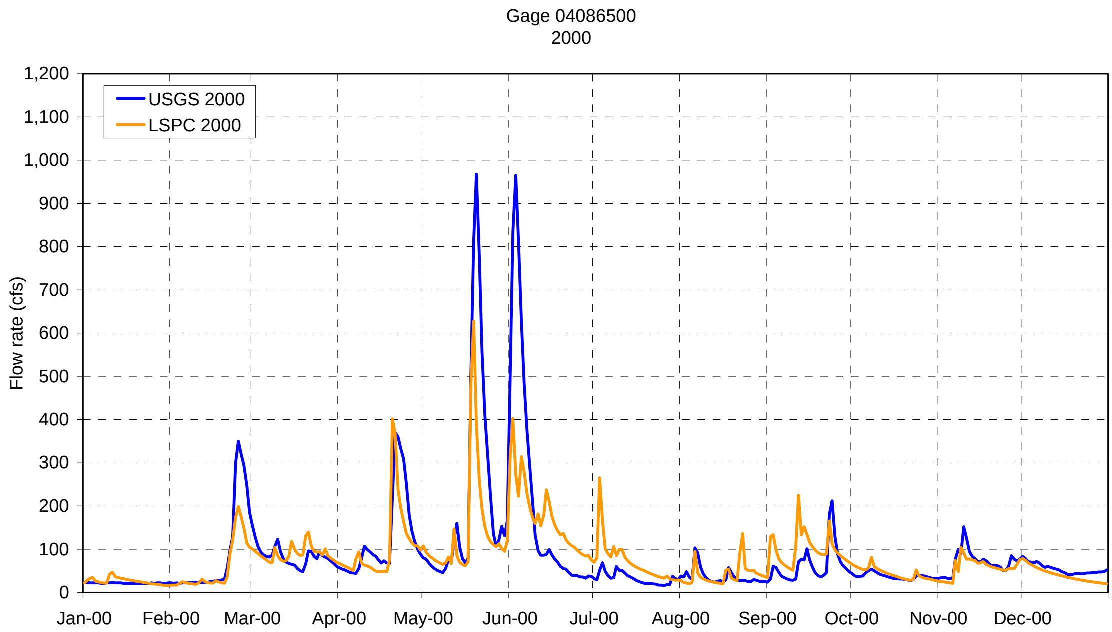


Figure 8-57. Time series hydrologic validation results (daily mean) for Cedar Creek at USGS gage 04086500 (2000).

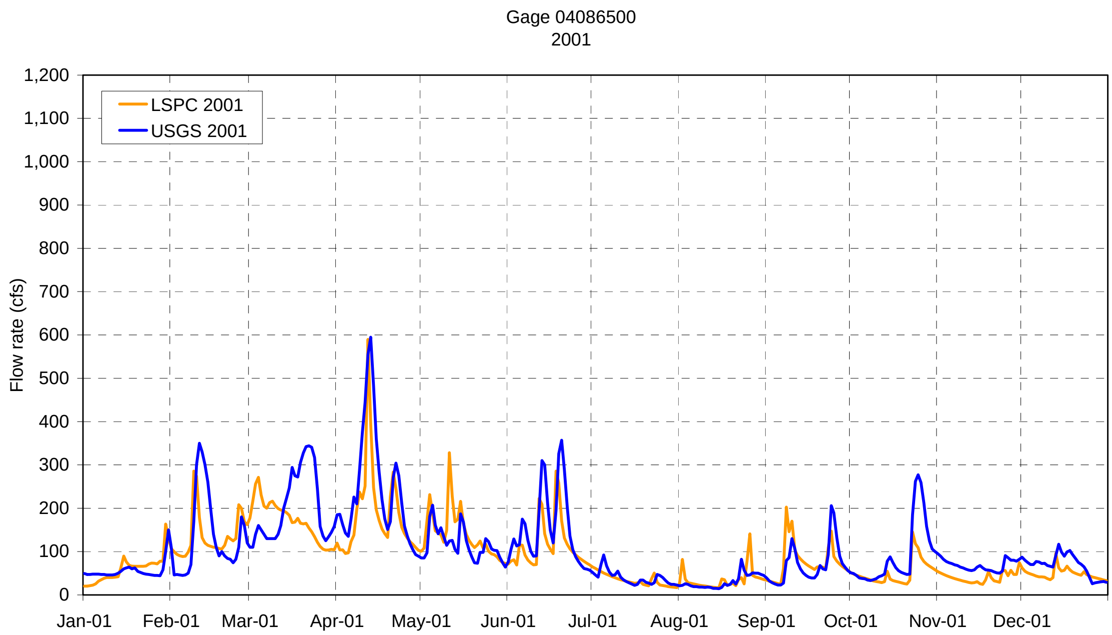


Figure 8-58. Time series hydrologic validation results (daily mean) for Cedar Creek at USGS gage 04086500 (2001).

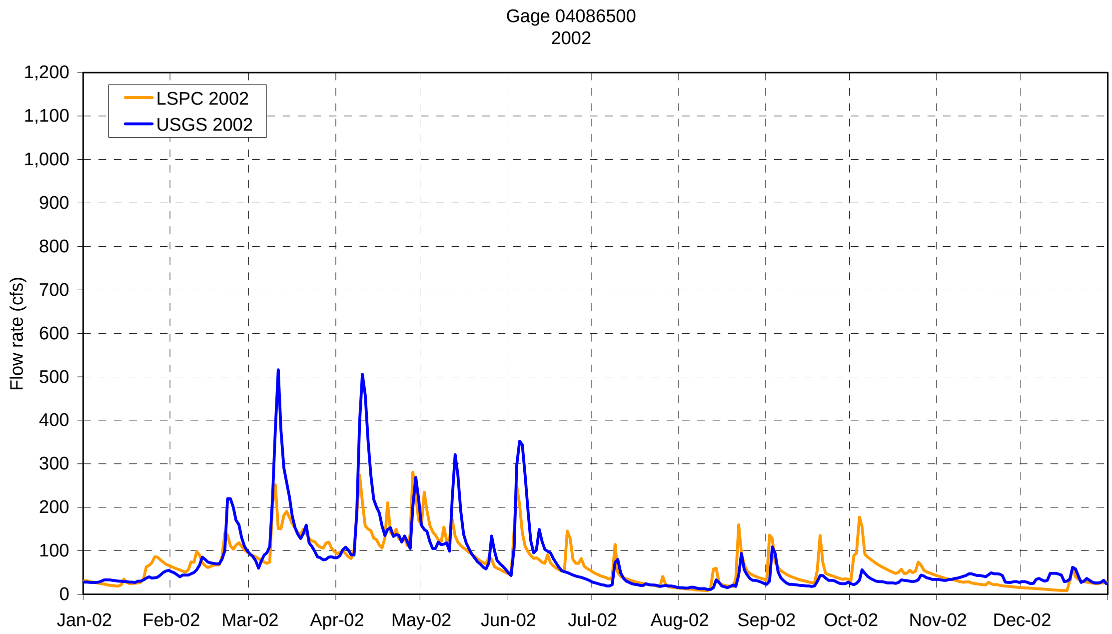


Figure 8-59. Time series hydrologic validation results (daily mean) for Cedar Creek at USGS gage 04086500 (2002).

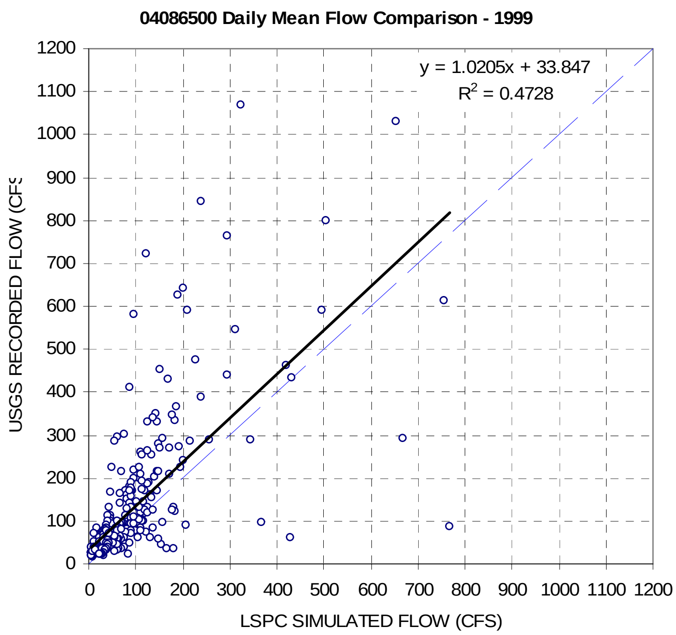


Figure 8-60. Observed versus simulated scatter plot with a linear regression line for Cedar Creek at USGS gage 04086500 (1999).

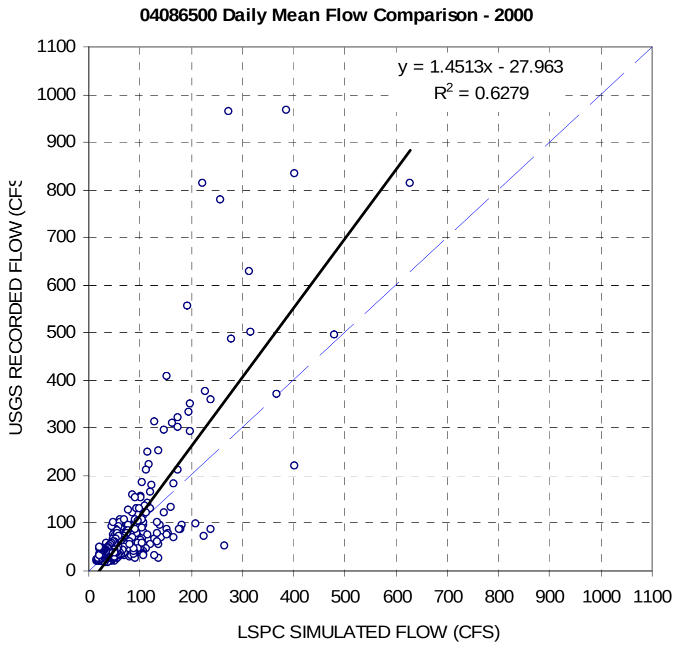


Figure 8-61. Observed versus simulated scatter plot with a linear regression line for Cedar Creek at USGS gage 04086500 (2000).

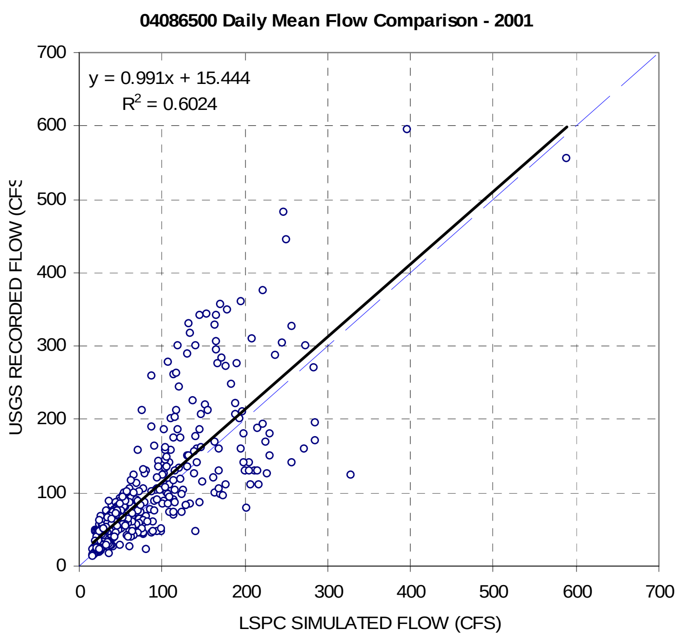


Figure 8-62. Observed versus simulated scatter plot with a linear regression line for Cedar Creek at USGS gage 04086500 (2001).

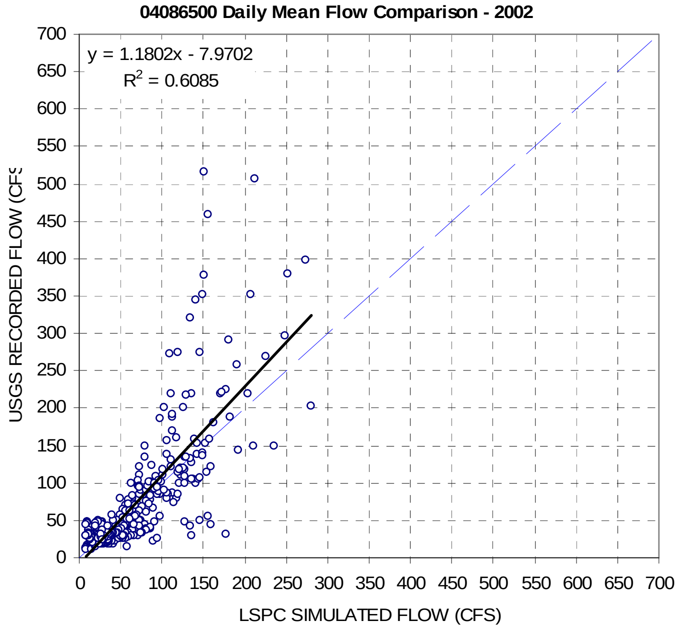


Figure 8-63. Observed versus simulated scatter plot with a linear regression line for Cedar Creek at USGS gage 04086500 (2002).

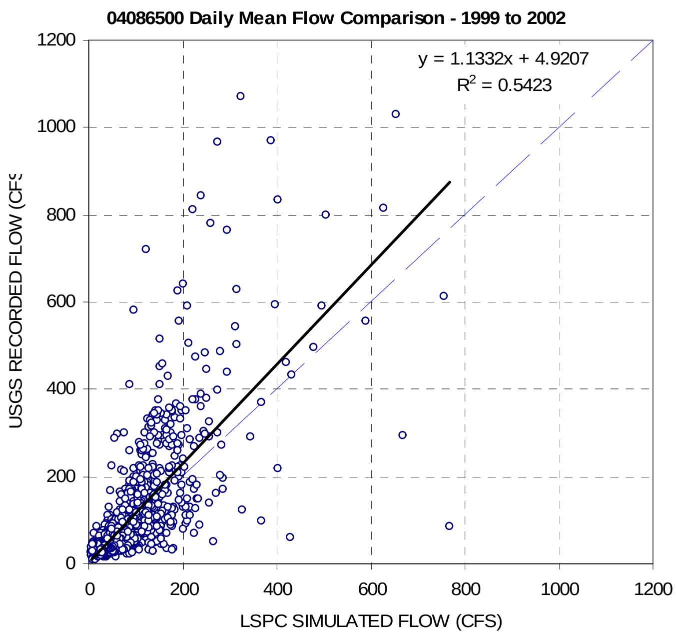


Figure 8-64. Observed versus simulated scatter plot with a linear regression line for Cedar Creek at USGS gage 04086500 (1999 to 2002).

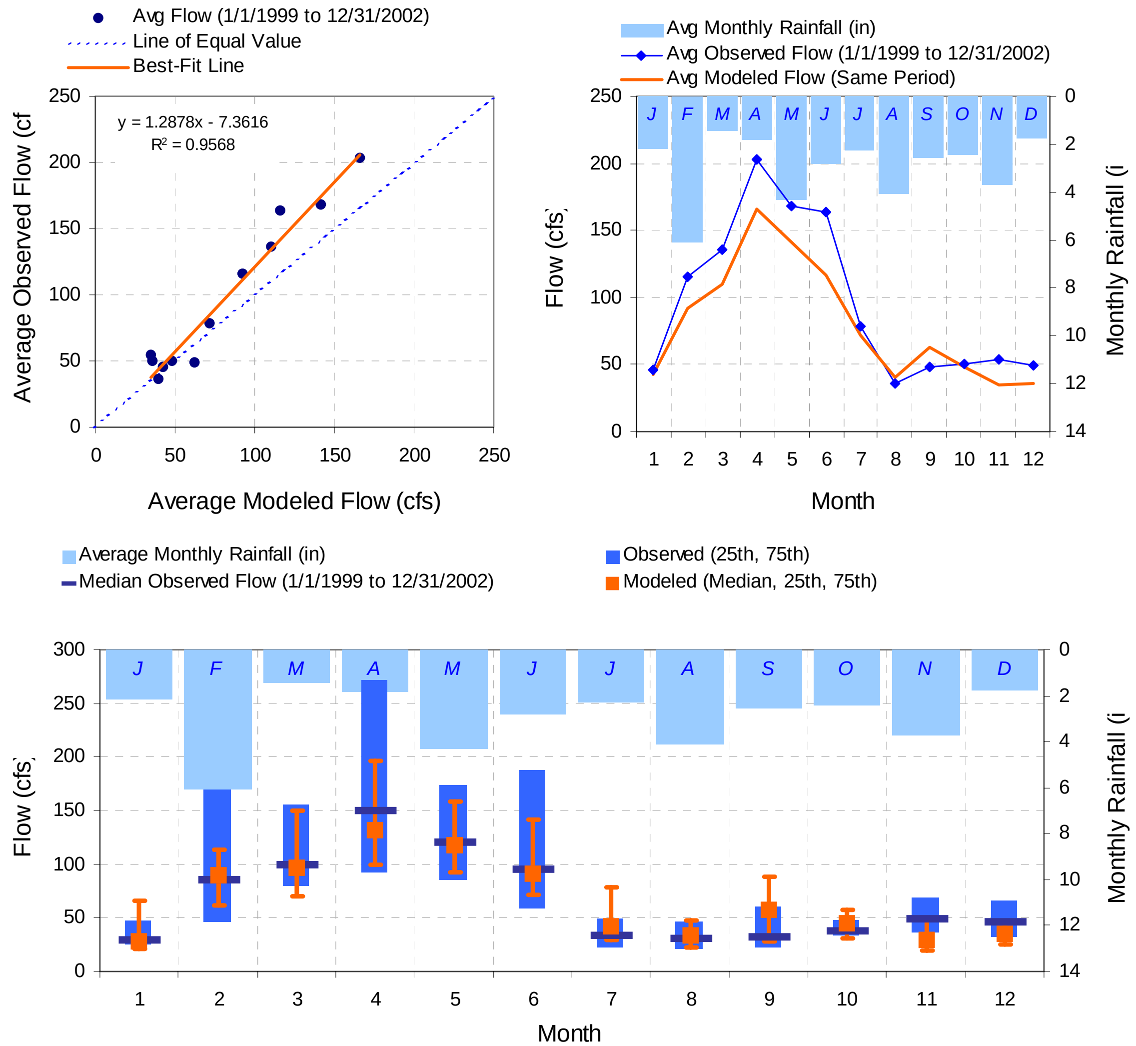


Figure 8-65. Composite (average monthly) hydrologic validation results for Cedar Creek at USGS gage 04086500 (1999 to 2002).

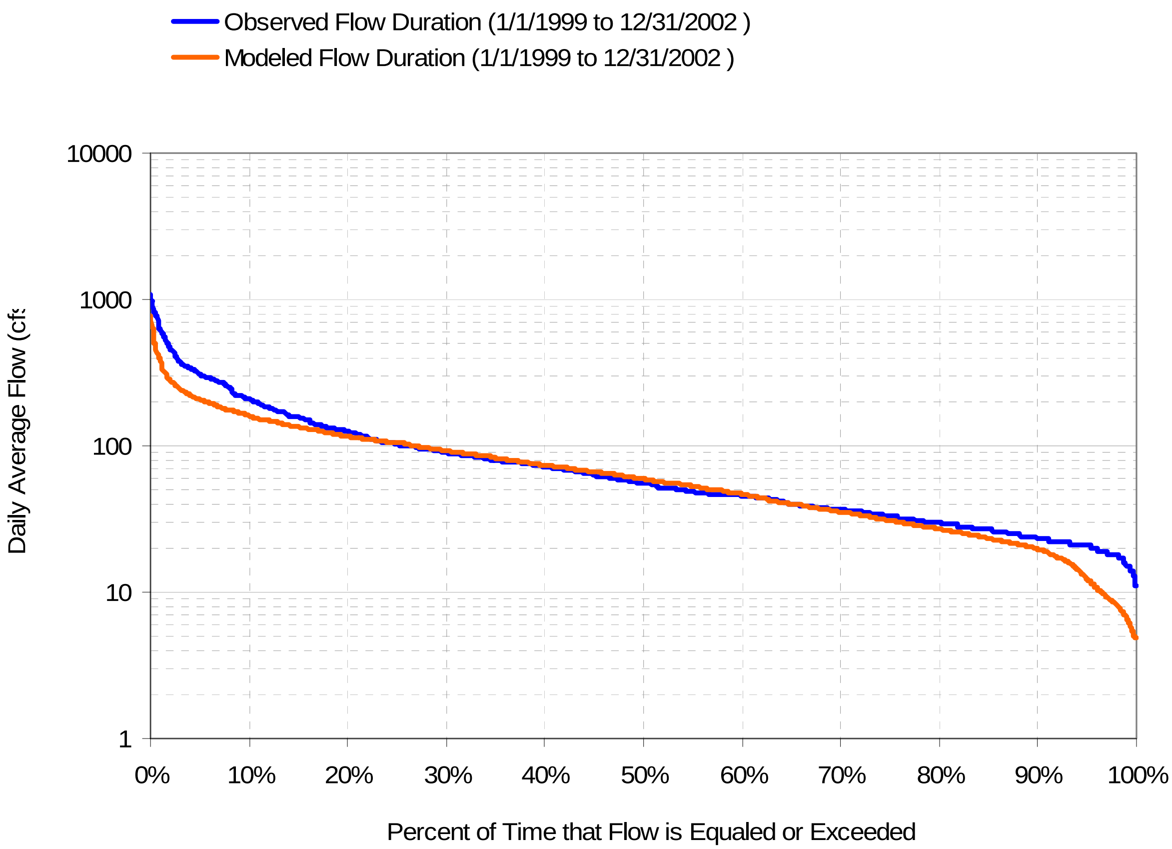


Figure 8-66. Flow duration curve hydrologic validation results for Cedar Creek at USGS gage 04086500 (1999 to 2002).

Table 8-13. Error statistics for hydrologic validation results for Cedar Creek at USGS gage 04086500 (1999 to 2002).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1999 Recorded USGS Volume (ac-ft)	1999 Simulated LSPC Volume (ac-ft)	1999 Percent Diff.	2000 Recorded USGS Volume (ac-ft)	2000 Simulated LSPC Volume (ac-ft)	2000 Percent Diff.	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2002 Recorded USGS Volume (ac-ft)	2002 Simulated LSPC Volume (ac-ft)	2002 Percent Diff.	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.
Month JAN	4,433	2,688	-39.4%	1,330	1,610	21.1%	3,401	3,663	7.7%	2,069	2,428	17.4%	11,232	10,388	-7.5%
FEB	8,391	5,348	-36.3%	4,881	3,173	-35.0%	7,515	7,532	0.2%	5,053	4,588	-9.2%	25,839	20,642	-20.1%
MAR	6,524	2,999	-54.0%	5,156	5,544	7.5%	12,320	10,603	-13.9%	9,439	7,877	-16.5%	33,439	27,023	-19.2%
APR	15,348	13,513	-12.0%	7,483	6,353	-15.1%	14,425	10,980	-23.9%	11,129	8,564	-23.1%	48,385	39,410	-18.5%
MAY	13,577	10,802	-20.4%	13,228	8,627	-34.8%	7,162	8,591	20.0%	7,396	6,819	-7.8%	41,362	34,839	-15.8%
JUN	10,638	5,022	-52.8%	12,762	10,392	-18.6%	9,096	6,839	-24.8%	6,385	5,420	-15.1%	38,881	27,673	-28.8%
JUL	13,264	9,093	-31.4%	2,007	4,313	114.9%	2,402	2,103	-12.4%	1,629	2,059	26.4%	19,302	17,569	-9.0%
AUG	3,189	3,072	-3.6%	2,251	2,537	12.7%	1,865	2,146	15.1%	1,526	2,041	33.8%	8,830	9,796	10.9%
SEP	1,623	1,382	-14.9%	3,799	5,890	55.0%	4,124	4,545	10.2%	1,948	3,025	55.3%	11,494	14,841	29.1%
OCT	2,574	1,841	-28.5%	2,303	2,713	17.8%	5,491	3,138	-42.9%	2,000	4,156	107.8%	12,368	11,847	-4.2%
NOV	2,422	851	-64.9%	4,120	3,432	-16.7%	4,068	2,408	-40.8%	2,271	1,542	-32.1%	12,881	8,233	-36.1%
DEC	2,533	2,216	-12.5%	3,331	2,491	-25.2%	4,223	2,962	-29.9%	2,134	1,255	-41.2%	12,221	8,925	-27.0%

Season	1999 Recorded USGS Volume (ac-ft)	1999 Simulated LSPC Volume (ac-ft)	1999 Percent Diff.	1999 Var. from Tolerance	2000 Recorded USGS Volume (ac-ft)	2000 Simulated LSPC Volume (ac-ft)	2000 Percent Diff.	2000 Var. from Tolerance	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2001 Var. from Tolerance	2002 Recorded USGS Volume (ac-ft)	2002 Simulated LSPC Volume (ac-ft)	2002 Percent Diff.	2002 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Jan-Mar	19,347	11,035	-43.0%	23.0%	11,367	10,327	-9.1%		23,235	21,798	-6.2%		16,561	14,894	-10.1%		70,511	58,053	-17.7%	
Apr-Jun	39,563	29,337	-25.8%	5.8%	33,473	25,372	-24.2%	4.2%	30,683	26,410	-13.9%		24,910	20,803	-16.5%		128,628	101,921	-20.8%	0.8%
Jul-Sep	18,075	13,547	-25.1%	5.1%	8,058	12,740	58.1%	38.1%	8,391	8,794	4.8%		5,103	7,125	39.6%	19.6%	39,626	42,206	6.5%	
Oct-Dec	7,528	4,908	-34.8%	14.8%	9,754	8,636	-11.5%		13,783	8,507	-38.3%	18.3%	6,405	6,953	8.6%		37,470	29,004	-22.6%	2.6%

Calibration Tolerance =20%

	1999 Recorded USGS Volume (ac-ft)	1999 Simulated LSPC Volume (ac-ft)	1999 Percent Diff.	1999 Var. from Tolerance	2000 Recorded USGS Volume (ac-ft)	2000 Simulated LSPC Volume (ac-ft)	2000 Percent Diff.	2000 Var. from Tolerance	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2001 Var. from Tolerance	2002 Recorded USGS Volume (ac-ft)	2002 Simulated LSPC Volume (ac-ft)	2002 Percent Diff.	2002 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Year	84,514	58,827	-30.4%	20.4%	62,651	57,075	-8.9%		76,091	65,509	-13.9%	3.9%	52,979	49,774	-6.0%		276,235	231,185	-16.3%	6.3%

Calibration Tolerance =10%

Table 8-14. High-Low flow error statistics for hydrologic validation results for Cedar Creek at USGS gage 04086500 (1999-2002).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	71,939	109,107	-34.1%	15%
Total Highest 20% volume	111,496	155,425	-28.3%	15%
Total Highest 50% volume	185,045	227,468	-18.7%	15%
Total Lowest 10% volume	3,696	5,766	-35.9%	10%
Total Lowest 30% volume	19,493	23,096	-15.6%	10%
Total Lowest 50% volume	46,701	49,347	-5.4%	10%

References

Bicknell, B.R., J.C. Imhoff, J. Kittle, A.S. Donigian, and R.C. Johansen. 1996. *Hydrological Simulation Program‒FORTRAN, User's Manual for Release H*. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Crawford, N.H. and K. Linsley. 1966. Digital Simulation in Hydrology: Stanford Watershed Model IV, Stanford University, Department of Civil Engineering, Technical Report 39.

Dunn, T. and L.B. Leopold. 1978. *Water in Environmental Planning*. W. H. Freeman and Company. New York.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. *Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage,* 89(IR4): 15-41.

Jensen, M.E., D.C.N. Rob, and C.E. Franzoy. 1969. Scheduling irrigations using climate-crop-soil data. Proceedings, National Conference on Water Resources Engineering of the American Society of Civil Engineers, New Orleans, LA.

NRCS (Natural Resources Conservation Service). 2001. *National Soil Survey Handbook* . U.S. Department of Agriculture, Natural Resources Conservation Service. Available at http://www.statlab.iastate.edu/soils/nssh/.

Tetra Tech. 2002. Minnesota River Basin Model, Model Calibration and Validation Report. Prepared for Minnesota Pollution Control Agency, St. Paul, MN by Tetra Tech, Inc., Research Triangle Park, NC.

U.S. Environmental Protection Agency (USEPA). 2000. *BASINS Technical Note 6. Estimating Hydrology and Hydraulic Parameters for HSPF*. EPA-823-R00-012. U.S. Environmental Protection Agency. Office of Water. July 2000.

Viessman, W., G.L. Lewis, and J.W. Knapp. 1989. *Introduction to Hydrology*, 3rd Edition. Harper Collins, New York.

ATTACHMENT A –SCHEMATIC REPRESENTATION OF THE MILWAUKEE RIVER LSPC MODEL

(Note that the schematic is formatted to a
45” by 41” page and therefore must be printed using a plotter.)


WEST BRANCH MILWAUKEE RIVER
UPPER MILWAUKEE RIVER
NORTH BRANCH MILWAUKEE RIVER
NORTH BRANCH MILWAUKEE RIVER
UPPER MILWAUKEE RIVER
NORTH BRANCH MILWAUKEE RIVER
East Branch Milwaukee River
CEDAR CREEK
UPPER MIDDLE MILWAUKEE RIVER
CEDAR CREEK
UPPER MIDDLE MILWAUKEE RIVER
LOWER MILWAUKEE RIVER
CEDAR CREEK
MILWAUKEE RIVER (AT MILWAUKEE)
MILWAUKEE RIVER (AT MILWAUKEE)
MILWAUKEE RIVER (AT MILWAUKEE)
LAKE

ATTACHMENT B – PROPOSED APPROACH FOR DEVELOPING SURROGATE PRECIPITATION DATA FOR PRODUCTION RUNS (REVISED 5/22/06)

2020 Facility Planning Project

Technical Memorandum

MMSD Contract #: M03002P01
MMSD File Code #: M009PE000.P7300-WQ1

Project Name: 2020 Facilities Planning Project

To: Michael G. Hahn and Ronald J. Printz, SEWRPC

cc: Bill Krill, HNTB

From: Leslie Shoemaker, Tetra Tech

Date: May 22, 2006

Subject: Proposed Approach for Developing Surrogate Precipitation Data for Production Runs (Revised)

1.0 EXECUTIVE SUMMARY

The purpose of this revised memorandum is to describe the approach used for developing surrogate hourly precipitation data for the MMSD, City of Milwaukee, and National Weather Service (NWS) gages for the 1988 to 1992 period for which hourly rainfall data are not currently available. The general strategy to develop the surrogate records is to first create (or "patch") daily records where gaps were present in the original data. The daily records were then disaggregated to hourly based on the records of 1) Milwaukee General Mitchell International Airport (GMIA; NWS Station 475479) and 2) Hartford 2 W (NWS Station 473453). In the absence of a corresponding disaggregation template at either GMIA or Hartford, the daily total was disaggregated by following a rainfall distribution provided by SEWRPC.

2.0 CONCLUSIONS

It was originally proposed to run simulations for 1988 to 1992 using rainfall data from GMIA only. This presents two problems. First, the GMIA data may not be representative of rainfall in other parts of the watershed. Second, use of a single rainfall record for all parts of the watershed will implicitly result in a situation in which rainfall events occur everywhere at exactly the same time. This could lead to significant overestimation of the impact of major storm events. Using the same rainfall gages that were used in the calibration/validation process will address both of these problems. This memorandum proposes a method for doing so.

3.0 RECOMMENDATIONS

We recommend that the proposed approach be adopted so that the data can be used for the Production runs.

4.0 INTRODUCTION

Model calibration and validation utilized hourly precipitation data from MMSD, City of Milwaukee, and NWS gages to properly account for spatial and temporal variation across the watersheds. With only a few exceptions that data was available from 1993 to the present. However, sub-daily data were missing at a number of stations for the period 1988 to 1992.

The original modeling plan had been to use recorded hourly precipitation only from GMIA for production runs, once the model calibrations had been completed. Use of the single GMIA station for production runs would have been consistent with the approach used in the MMSD watercourse system planning. However, for water quality modeling this approach could result in problems related to unrealistic pollutant loading estimates due to a lack of spatial and temporal variability. The purpose of this revised memorandum is to describe the proposed approach for developing surrogate precipitation data for the 11 calibration/validation rainfall gages (eight MMSD and three Summary of the Day (SOD)) for the period for which sub-daily rainfall data were not previously available. A subsequent memo will discuss the creation of an extended rainfall record for the period 1940 to 1987.

This memo also proposes to use the GMIA rainfall record for 1987 to “spin up” all five models for the production runs. The use of GMIA rainfall for spin-up purposes is valid because it is a regionally representative record and the modeling results for 1987 will not be presented as part of the production run output.

5.0 PROPOSED APPROACH

A total of 20 rainfall gages were used as either direct inputs to the models or as index stations to help amend and/or disaggregate rainfall totals at other stations. These stations are summarized in Table 5-1 and shown in Figure 5-1.

Table 5-1. Rainfall Stations in Study Area Used for Model Application.

Station ID	Description	Source	Application
MMSD1203	245 W Lincoln Av	MMSD	Kinnickinnic River Model
MMSD1204	300 S 84th St	MMSD	Menomonee River Model
MMSD1207	8414 W Florist Av	MMSD	Menomonee River Model Milwaukee River Model
MMSD1209	8463 N Granville Rd	MMSD	Menomonee River Model
MMSD1216	3563 S. 97th St	MMSD	Menomonee River Model Root River Model
MMSD1218	W152 N8634 Margaret Rd	MMSD	Menomonee River Model
472839	Fond du Lac	EarthInfo SOD	Milwaukee River Model
473058	Germantown	EarthInfo SOD	Milwaukee River Model
476764	Port Washington	SEWRPC	Milwaukee River Model
478932	Waubeka	EarthInfo SOD	Milwaukee River Model
479050	West Bend	SEWRPC	Milwaukee River Model
MMSD1202	5335 N. Teutonia Av	MMSD	Milwaukee River Model
MMSD1206	3626 W Fond Du Lac Av	MMSD	Milwaukee River Model
475479	General Mitchell International Airport (GMIA)	SEWRPC	Oak Creek Model Root River Model Kinnickinnic River Model Verify/Amend Rainfall Totals Disaggregate Daily Records
476922	Racine	SEWRPC	Root River Model
478723	Union Grove	SEWRPC	Root River Model
473453	Hartford 2 W	SEWRPC	Verify/Amend Rainfall Totals Disaggregate Daily Records
475474	Milwaukee Mt Mary College	EarthInfo SOD	Verify/Amend Rainfall Totals
476330	Oshkosh	EarthInfo SOD	Verify/Amend Rainfall Totals
477209	Ripon 5 N	EarthInfo SOD	Verify/Amend Rainfall Totals

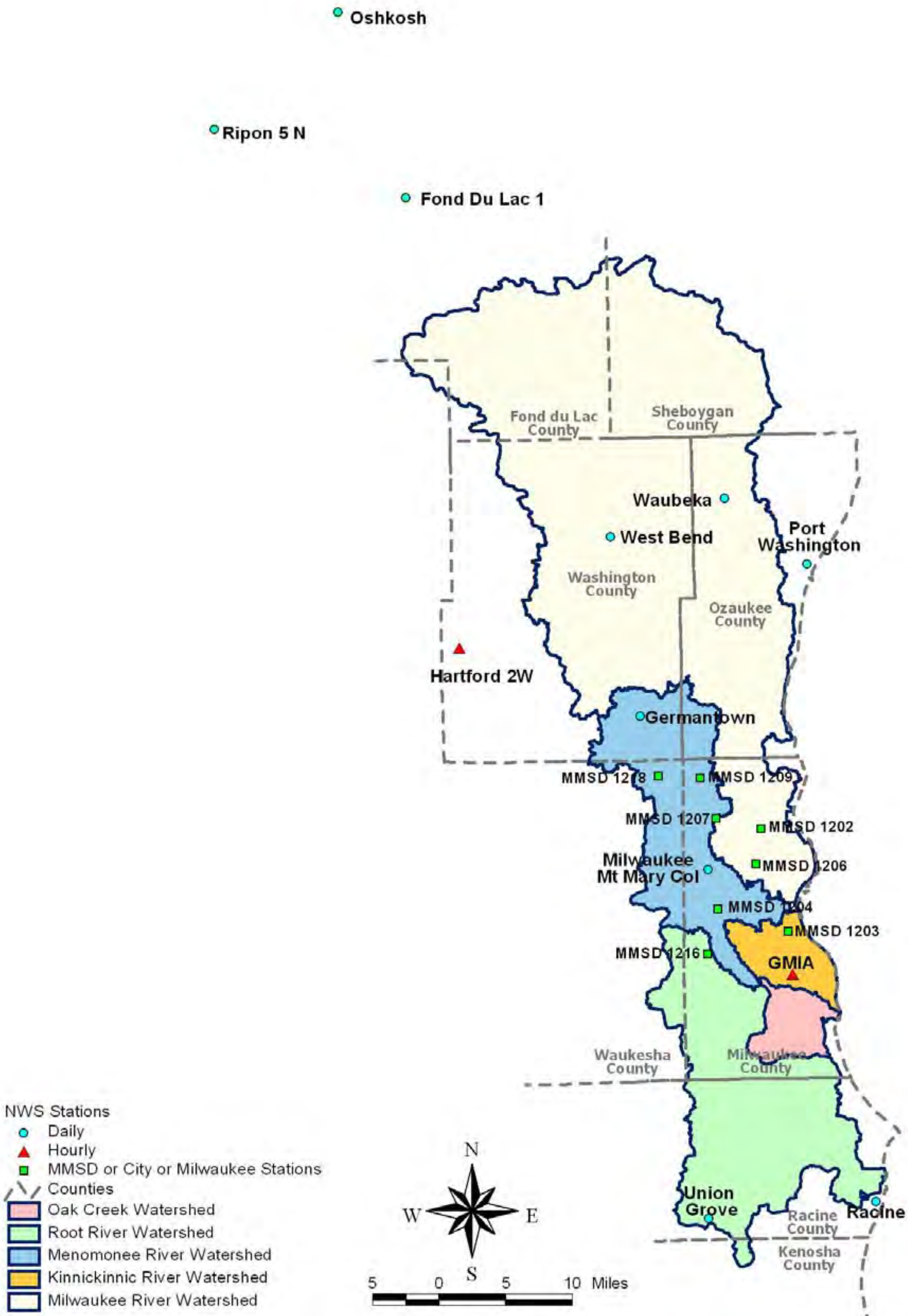


Figure 5-1. Rainfall Stations in Study Area Used for Model Application.

The eleven stations shown in Table 5-2 require surrogate rainfall records for the period 1988 to 1992 because raw data at the hourly scale were not previously available.

Table 5-2. Rain Gage Station Descriptions.

Rain Gage ID	Description	Source
MMSD1202	5335 N. Teutonia	MMSD
MMSD1203	245 W Lincoln Av	MMSD
MMSD1204	300 S 84th St	MMSD
MMSD1206	3626 W Fond Du Lac Av	MMSD
MMSD1207	8414 W Florist Av	MMSD
MMSD1209	8463 N Granville Rd	MMSD
MMSD1216	3563 S. 97th St	MMSD
MMSD1218	W152 N8634 Margaret Rd	MMSD
472839	Fond du Lac	EarthInfo SOD
473058	Germantown	EarthInfo SOD
478932	Waubeka	EarthInfo SOD

5.1 Evaluation of Event Peaks

The timing of rainfall events in the study area was first investigated to evaluate potential impacts from Lake Michigan. The investigation compared the hourly records at GMIA to hourly records at several MMSD stations. This was evaluated through a cross-correlation analysis of the 1993 to 2002 hourly data using a Fast Fourier Transform (FFT) algorithm. If a significant pattern was observed during this analysis, the results would influence the surrogate development process. For example, if there were a strong cross correlation at an hourly offset, then the disaggregation should be shifted in time.

The results (as summarized in Figure 5-2) indicate a lack of a consistent time shift in rainfall patterns at the hourly scale, although the asymmetry of the forward and backward lags does suggest the presence of some sub-hourly shifts. The development of the surrogate data therefore does not need to account for consistent time shifts between rainfall at GMIA and other stations.

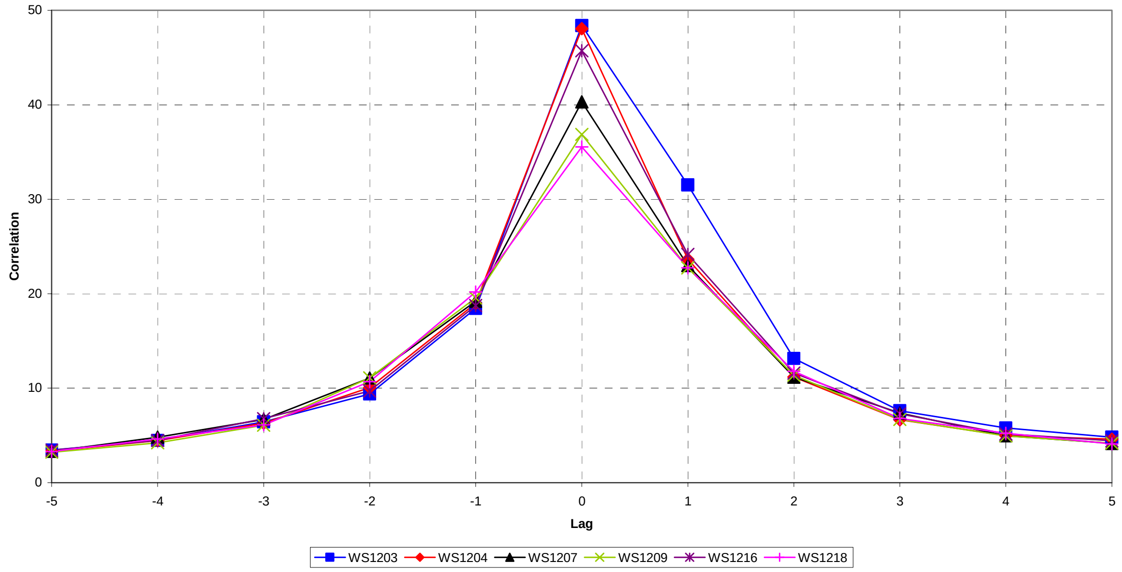


Figure 5-2. Cross-Correlation of MMSD Gages with GMIA Hourly Rainfall.

5.2 Obtaining Data from EarthInfo

Daily rainfall values for the MMSD and City of Milwaukee stations for the period 1988 to 1992 were obtained directly from SEWRPC. The daily values for Fond du Lac and Germantown, however, were obtained from EarthInfo. Quality assurance was performed by "spot-checking" EarthInfo monthly values against NOAA Climatological Data Reports provided by SEWRPC. Table 5-3 presents this comparison for two sample months for several representative stations. This exercise verified the validity of the EarthInfo data.

Table 5-3. Quality Assurance Spot-Check Comparison of Monthly Rain Totals (inches).

	March 1988		January 1989	
Station	**NOAA Climatological Data Report (from SEWRPC)**	**EarthInfo**	**NOAA Climatological Data Report (from SEWRPC)**	**EarthInfo**
Germantown	1.12	1.12	0.37	0.37
Milwaukee Mt Mary College	0.99	0.99	0.46	0.46
Port Washington	0.41 M	0.41 M	0.57 M	0.57 M
West Bend	0.62	0.62	0.70	0.70

5.3 Patching Missing Daily Records

Three of the eight daily MMSD rainfall records had periods which required patching for 1988 to 1992:

- MMSD1206 needed to be patched for January 01, 1988 through April 30,1988 and December 01-27, 1989.
- MMSD1209 needed to be patched for January through April 1988.

- MMSD1218 needed to be patched for Decemeber 01, 1988 through January 26, 1989 and June 09, 1992 through June 30, 1992.

The gaps in the MMSD data were patched as follows:

1) The annual average precipitation totals (1993 to 2002) were compared between the station being patched and two index stations to develop factors to ensure long-term average spatial relationships (Table 5-4 and Table 5-5).
2) The distances between the station being patched and the two index stations were used to develop distance weighting factors (Table 5-6 and Table 5-7).
3) The time stamps of observation for the NWS stations were used to develop factors to apportion rainfall sums to the appropriate 24-hour period.

Fond du Lac and Germantown also had several gaps in daily records for the period 1988 to 2002. The gaps for these two stations were patched using the same methodology as was used for the MMSD stations except that the annual average precipitation totals for the entire period of record were used rather than just the period 1993 to 2002.

The Waubeka station did not become active until 1993 and therefore had no values for the period 1988 to 1992. It was patched using the same methodology described above using Port Washington and West Bend as the index stations.

Table 5-4. Annual Average Rainfall Values for 1993 to 2002.

Station	Source	Annual Average (in)
Fond du Lac	EarthInfo	29.47 (POR)
Germantown	EarthInfo	34.36 (31.22 POR)
Milwaukee Mt Mary College	EarthInfo	31.57
GMIA	SEWRPC	32.92 (31.71 POR)
Oshkosh	EarthInfo	29.86 (POR)
Port Washington	SEWRPC	32.59
Ripon 5 NE	EarthInfo	30.78 (POR)
West Bend	SEWRPC	32.10 (30.82 POR)
MMSD1206	MMSD	30.71
MMSD1209	MMSD	32.23
MMSD1218	MMSD	31.48
Waubeka	EarthInfo	31.41

POR = Entire Period of Record at Station Rather than 1993 to 2002. Annual average based on period of record.

Table 5-5. Ratio of Annual Rainfall Averages from 1993 to 2002.

Station	Type/ Agency	Ratio to Germantown	Ratio to Milwaukee Mt Mary College	Ratio to Oshkosh	Ratio to GMIA	Ratio to Port Washington	Ratio to Ripon 5 NE	Ratio to West Bend
MMSD1206	MMSD	NA	0.9728	NA	0.9328	NA	NA	NA
MMSD1209	MMSD	0.9382	1.0211	NA	NA	NA	NA	NA
MMSD1218	MMSD	0.9163	0.9973	NA	NA	NA	NA	NA
Fond du Lac	EarthInfo SOD	NA	NA	0.9869 (POR)	NA	NA	0.9574 (POR)	NA
Germantown	EarthInfo SOD	NA	NA	NA	0.9845 (POR)	NA	NA	1.0130 (POR)
Waubeka	EarthInfo SOD	NA	NA	NA	NA	1.0390	NA	1.0699

Table 5-6. Distance Between Stations (mi).

Station	German-town	Mt Mary Col	GMIA	Oshkosh	Port Washington	Ripon 5 NE	West Bend
MMSD1206	NA	3.7	9.3	NA	NA	NA	NA
MMSD1209	5.8	6.9	NA	NA	NA	NA	NA
MMSD1218	3.9	7.9	NA	NA	NA	NA	NA
Fond du Lac	NA	NA	NA	15.8	NA	15.9	NA
Germantown	NA	NA	22.4	NA	NA	NA	9.1
Waubeka	NA	NA	NA	NA	8.0	NA	8.8

Table 5-7. Distance weighting Factors.

Station	German-town	Mt Mary Col	GMIA	Oshkosh	Port Washington	Ripon 5 NE	West Bend
MMSD1206	NA	0.717	0.283	NA	NA	NA	NA
MMSD1209	0.541	0.459	NA	NA	NA	NA	NA
MMSD1218	0.667	0.333	NA	NA	NA	NA	NA
Fond du Lac	NA	NA	NA	0.502	NA	0.498	NA
Germantown	NA	NA	0.289	NA	NA	NA	0.711
Waubeka	NA	NA	NA	NA	0.524	NA	0.476

The following equation was applied using the factors presented in Table 5-5 through Table 5-7:

$P_d = D_i * A_i * X_i + D_{i+1} * A_{i+1} * X_{i+1}$

where:

P_d = Daily value at location being patched
D_i , D_{i+1} = Daily Rain at index station(s), revised for time stamp
A_i , A_{i+1} = Annual average ratio for patched station to index station
X_i , X_{i+1} = Distance weighting factor

5.4 Disaggregated Daily Rainfall Totals to Hourly

The GMIA and Hartford 2 W hourly rain records provided by SEWRPC were used as index stations to disaggregate daily rainfall values at the 11 daily stations to hourly. Two stations were used to provide a more robust disaggregation process. The use of only one station could result in a situation where there might be no hourly rain at the index station. The use of two stations in this specific exercise resulted in a template always being found. When templates were available at both index stations, they were combined to provide a weighted distribution.

There is no distance consideration in the disaggregation from daily rainfall to hourly rainfall. The equation for determining hourly values for a daily station from an hourly index station or stations is:

$P_p = (P_i + P_{i+1})/Sum_{(i) + (i+1)} * P_h$

where:

P_p = Hourly value at patched station
P_i, P_{i+1} = Hourly value(s) at index station(s)
$Sum_{(i) + (i+1)}$ = Sum of rain at index station(s) for coincident period identified as accumaulated for station to be patched
P_h = Amount of accumulated rain at patched station to be disaggregated

Table 5-8 presents the yearly totals at each of the 11 stations before and after the processing from daily to hourly. The fact that the pre- and post-values are equivalent indicates that the integrity of the patched daily data was maintained during the disaggregation process.

Table 5-8. Annual Rainfall Totals.

Station	MMSD1203		MMSD1204		MMSD1207		MMSD1209		MMSD1216		MMSD1218	
Year	Daily	Hourly	Daily	Hourly	Daily	Hourly	Daily	Hourly	Daily	Hourly	Daily	Hourly
1988	28.29	28.29	28.50	28.50	25.09	25.09	25.51	25.51	28.09	28.09	24.00	24.00
1989	25.69	25.69	26.86	26.86	24.81	24.81	24.69	24.69	26.20	26.20	24.86	24.86
1990	41.66	41.66	39.78	39.78	35.45	35.45	36.88	36.88	38.56	38.56	34.73	34.73
1991	38.37	38.37	35.70	35.70	35.64	35.64	33.43	33.43	37.20	37.20	31.06	31.06
1992	27.99	27.99	27.53	27.53	29.23	29.23	26.56	26.56	29.33	29.33	28.05	28.05

Table 5-9. Annual Rainfall Totals (continued).

Station	MMSD1202		MMSD1206		Fond du Lac		Germantown		Waubeka	
Year	Daily	Hourly	Daily	Hourly	Daily	Hourly	Daily	Hourly	Daily	Hourly
1988	29.23	29.23	26.40	26.40	24.58	24.58	25.33	25.33	27.67	27.67
1989	27.37	27.37	25.39	25.39	24.52	24.52	28.51	28.51	29.98	29.98
1990	40.50	40.50	34.62	34.62	38.68	38.68	37.93	37.93	34.22	34.22
1991	35.32	35.32	32.76	32.76	34.19	34.19	38.20	38.20	35.56	35.56
1992	27.86	27.86	25.17	25.17	25.48	25.48	30.78	30.78	28.06	28.06

2020 Facility Planning Project

Final Memorandum

Project Name:	MMSD – 2020 Facility Planning Project	MMSD Contract No:	M03002P01
DMS Folder Name:	Technology Analysis	MMSD File Code:	M009PE000.P7300-WQ1
Document Name:	Hydrologic Calibration and Validation Results for the Oak Creek Model (Task 3)	HNTB Charge No:	34568-PL-400-115

Date: December 5, 2007
To: Michael Hahn, SEWRPC
Bill Krill, HNTB
From: Leslie Shoemaker, Tetra Tech, Inc.
Subject: Hydrologic Calibration and Validation Results for the Oak Creek Model (Task 3)

1.0 EXECUTIVE SUMMARY

An important component of the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU) is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. The purpose of this memorandum is to describe the modeling process and provide the results of the hydrologic and hydraulic calibration and validation of the Oak Creek watershed model.

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for a variety of reasons, including that existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds. The Loading Simulation Program in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms but has the advantage of no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original Oak Creek HSPF model has been migrated to LSPC for the 2020 Facilities Planning Project.

Configuration of the Oak Creek LSPC model involved consideration of five major components: waterbody representation, watershed segmentation, meteorological data, land use representation, and point sources. The representation of Oak Creek and its tributaries in LSPC is based on the structure of the HSPF model provided by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) with several modifications (e.g., redirecting runoff from subbasins to different routing reaches). The model was configured to simulate the watershed as a series of 70 hydrologically connected subwatersheds.

The Oak Creek model relies on precipitation data and other climatologic data (e.g., temperature, cloud cover, wind speed) from the General Mitchell International Airport.

Land cover classifications from the SEWRPC 2000 land use codes were re-classified to develop the land cover representation in the LSPC model. The final land cover representation for the Oak Creek LSPC model indicates that the two most common land cover classifications are grasses on C soils (43 percent of the total watershed) and impervious cover associated with commercial land uses (12 percent).

There are a number of “point sources” in the Oak Creek watershed, including sanitary sewer overflows (SSOs) and industrial facilities. Flows from these point sources were input directly into the LSPC model using the methodology outlined in the December 13, 2004 memorandum entitled *Point Source Loading Calculations for Purposes of Watercourse Modeling*.

The July 5, 2005 version of the LSPC model was revised to address comments provided by SEWRPC on August 22, 2005. All Ftables, stream reach characteristics, and land cover assignments were carefully reconciled with the latest information from SEWRPC and the final calibration and validation results are presented below.

2.0 CONCLUSIONS

The following are the conclusions resulting from the hydrologic calibration and validation process for the Oak Creek model:

- The setup of the final HSPF model has been completed.
- Conversion of the HSPF model to LSPC was successful.
- Ftables, stream reach characteristics, and land cover classification assignments were carefully reconciled with the latest information from SEWRPC.
- The calibration results for the Oak Creek model indicate acceptable agreement between observed and simulated streamflows.

3.0 RECOMMENDATIONS

We recommend that the hydrologic calibration and validation of the Oak Creek model be considered complete.

4.0 INTRODUCTION

The Milwaukee Metropolitan Sewerage District (MMSD) is in the midst of a long-range planning effort to identify improvements needed for its facilities to accommodate growth and protect water quality through the year 2020. This effort is known as the MMSD 2020 Facility Plan. A related planning effort is being conducted by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) to update the regional water quality management plan for the Kinnickinnic River, Menomonee River, Milwaukee River, Root River, and Oak Creek watersheds, the Milwaukee Harbor estuary, and the adjacent nearshore Lake Michigan area. This effort is known as the Regional Water Quality Management Plan Update (RWQMPU). The two planning efforts are being coordinated and implemented in parallel.

One important component of both the 2020 Facility Plan and the RWQMPU is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. Watershed models are being developed for the following five watersheds:

- Kinnickinnic River
- Menomonee River
- Milwaukee River
- Oak Creek
- Root River

The Kinnickinnic, Menomonee, Milwaukee River, and Oak Creek models will then be linked to a model of the Lake Michigan estuary so that the benefits of upstream water quality improvements can be simulated by the Lake Michigan Harbor / Estuary Model.

The following seven tasks have been identified for performing the system modeling:

1) Establish the model structure, including the delineation of subwatersheds, connectivity, and cross sections, etc.
2) Develop the model data sets using physical measurements, maps, and other appropriate information
3) Perform hydrologic and hydraulic calibration and validation
4) Perform watercourse water quality calibration and validation
5) Perform harbor/estuary and lake water quality calibration
6) Perform production runs as required for project planning
7) Document results.

The purpose of this report is to document the hydrologic and hydraulic calibration and validation for the Oak Creek watershed model (Task 3). An accompanying memorandum documents the results of the revised water quality calibration and validation. The model being used is described in Section 5.0, Model Description. The configuration of the model, including waterbody representation, watershed segmentation, meteorological data, and land use representation, is described in Section 6.0, Modeling Approach. The modeling process is described in Section 7.0, Calibration and Validation Process, and the calibration and validation results are presented in Section 8.0, Results of Hydrologic Calibration and Validation.

5.0 MODEL DESCRIPTION

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. Many watershed models, including the one used for this project, are also capable of simulating in-stream processes using the land-based calculations as input. Once a model has been adequately set up and calibrated for a watershed it can be used to quantify the existing loading of pollutants from subwatersheds or from land use categories. The model can also be used to simulate the potential impacts of various management alternatives.

The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for the following reasons:

- Existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds
- HSPF applies to watersheds with rural, suburban, and urban land uses
- HSPF simulates the necessary constituents: TSS, TN (TKN, NH4, NH3, NO3 and NO2), TP, Orthophosphate, Fecal Coliforms, Copper and Zinc (as conservative substances), DO, BOD, TOC, Temperature, Benthic Algae, and Chlorophyll-a.
- HSPF allows long-term continuous simulations to predict hydrologic variability
- HSPF provides adequate temporal resolution (i.e., hourly or daily) to facilitate a direct comparison to water quality standards
- HSPF simulates both surface runoff and groundwater flows

A brief description of the HSPF model is provided below.

5.1 Overview of HSPF

HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970's and is generally considered one of the most advanced hydrologic and watershed loading models available. The hydrologic portion of HSPF is based on the Stanford Watershed Model (Crawford and Linsley, 1966), which was one of the pioneering watershed models developed in the 1960's. The HSPF framework is developed in a modular fashion with many different components that can be assembled in different ways, depending on the objectives of the individual project. The model includes three major modules:

- PERLND for simulating watershed processes on pervious land areas
- IMPLND for simulating processes on impervious land areas
- RCHRES for simulating processes in streams and vertically mixed lakes.

All three of these modules include many submodules that calculate the various hydrologic and water quality processes in the watershed. Many options are available for both simplified and complex process formulations. Spatially, the watershed is divided into a series of subbasins representing the drainage areas that contribute to each of the stream reaches. These subbasins are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into the pervious (PERLND) and impervious (IMPLND) fractions. The stream network (RCHRES) links the surface runoff and groundwater flow contributions from each of the land segments and subbasins and routes them through the waterbodies using storage routing techniques. The stream/reservoir model includes precipitation and evaporation from the water surfaces, as well as flow contributions from the watershed, tributaries, and upstream stream reaches. Flow withdrawals can also be accommodated. The stream network is constructed to represent all of the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur.

Like the watershed components, several options are available for simulating water quality in the receiving waters. The simpler options consider transport through the waterways and represent all transformations and removal processes using simple first-order decay approaches. More advanced options for simulating nutrient cycling and biological processes are also available. The framework is flexible and allows different combinations of constituents to be modeled depending on data availability and the objectives of the study. A more detailed discussion of HSPF simulated processes and model parameters is presented in the Oak Creek water quality memorandum and is also available in the HSPF User's Manual (Bicknell et al. 1996).

5.2 Overview of Loading Simulation Program in C++

The Loading Simulation Program, in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms for simulating hydrology, sediment, and general water quality on land as well as in the water column. LSPC is currently maintained by the EPA Office of Research and Development in Athens, Georgia, and during the past several years it has been used to develop hundreds of water quality restoration plans across the country through the Clean Water Act Total Maximum Daily Load (TMDL) Program. A key advantage of LSPC is that it has no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original Oak Creek HSPF model has been migrated to LSPC for the 2020 Facilities Planning Project. A memorandum dated October 18, 2004 (*Confirmation of the Underwood Creek LSPC Model using selected HSPF Modules)* presents the results of a benchmark testing methodology that was developed to compare the underlying computational algorithms of the LSPC model to known HSPF solutions for Underwood Creek, located in the Menomonee River watershed. Near identical results were found between the two models.

6.0 MODELING APPROACH

The Oak Creek watershed lies in the southern portion of Milwaukee County. Parts of the watershed are located within the Cities of Milwaukee, South Milwaukee, Cudahy, Franklin, Greenfield and Oak Creek. The entire watershed encompasses approximately 27 square miles, with approximately 64 percent of the watershed located within the City of Oak Creek. The watershed is a mix of urbanized, agricultural and undeveloped land.

Configuration of the Oak Creek LSPC model involved consideration of five major components: waterbody representation, watershed segmentation, meteorological data, land use representation, and point sources. These components provide the basis for the model's ability to estimate flow and water quality and are described in greater detail below.

6.1 Waterbody Representation

The Oak Creek watershed is shown in Figure 6-1. There are three major streams contained within the watershed: the Mitchell Field Drainage Ditch, the North Branch of Oak Creek and Oak Creek. The longest stream of the three, Oak Creek, has a perennial length equal to approximately 13.1 miles. The North Branch of Oak Creek and the Mitchell Field Drainage Ditch, which are tributaries to Oak Creek, have perennial lengths of approximately 5.8 and 2.4 miles, respectively.

Modeling an entire watershed requires routing flow and pollutants from upstream portions of the watershed to the watershed outlet through the stream network. In LSPC, the stream network is a tabular representation of the actual stream system. Attribute data pair individual stream segments with a corresponding delineated subbasin. Data associated with individual reaches identify the location of the particular reach within the overall stream network, defining the connectivity of the subwatersheds.

The representation of Oak Creek and its tributaries in LSPC is based on the HSPF model provided by SEWRPC as defined in the SEWRPC/ MMSD MCAMLIS Floodplain Mapping Project. Changes to the original SEWRPC HSPF model are documented in a memorandum dated November 5, 2004 (*Draft Task 1 Deliverables Memorandum and Associated Appendices*). Changes consisted mainly of redirecting runoff from subbasins to different routing reaches. A schematic representation of the final Oak Creek LSPC model is presented in Figure 6-2. The origin of the HSPF watershed / watercourse model for Oak Creek is described in detail in the April 11, 2003 Technical Memorandum, *Characterize Existing Watershed / Watercourse Models.*

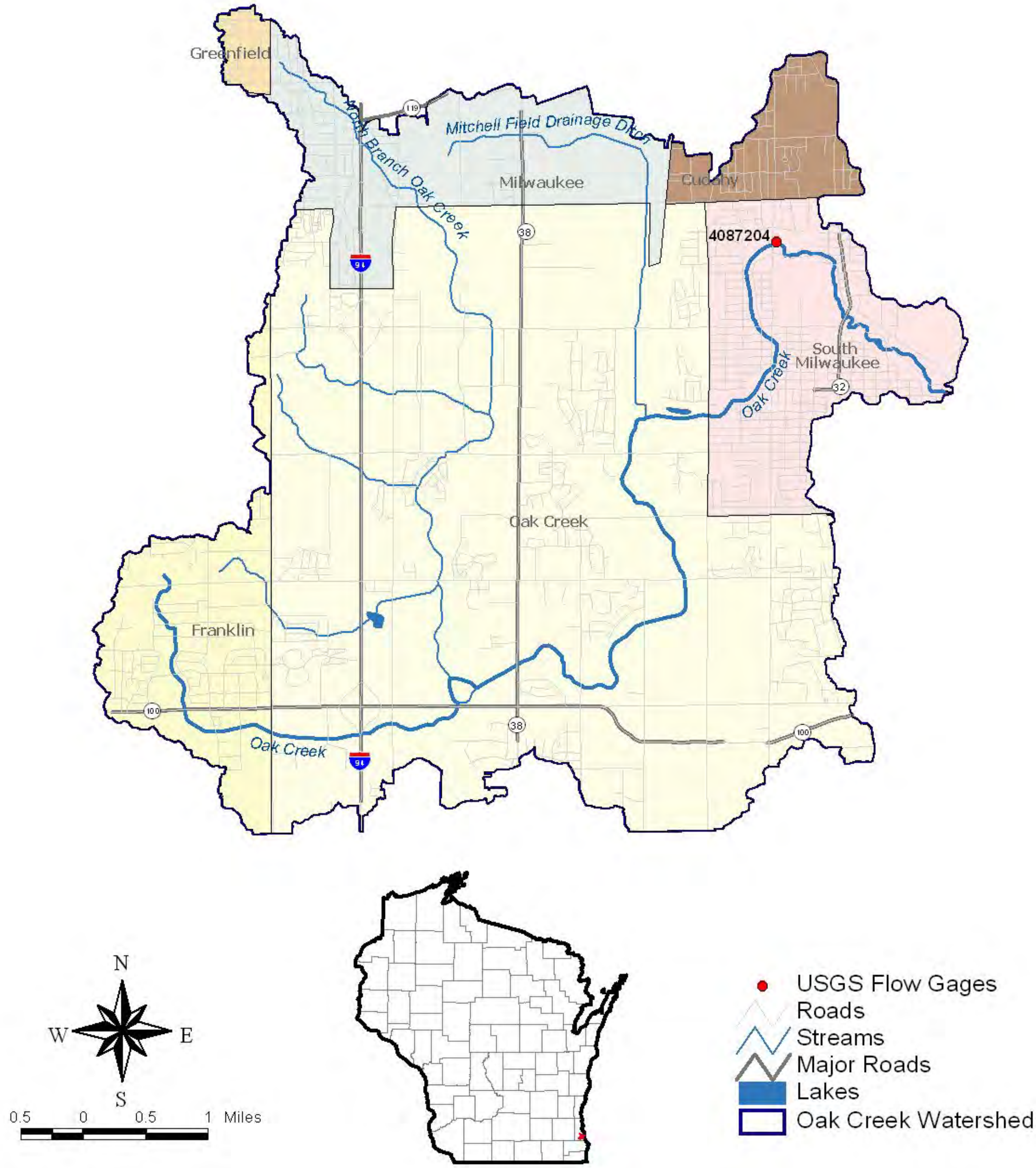


Figure 6-1. Location of the Oak Creek watershed.

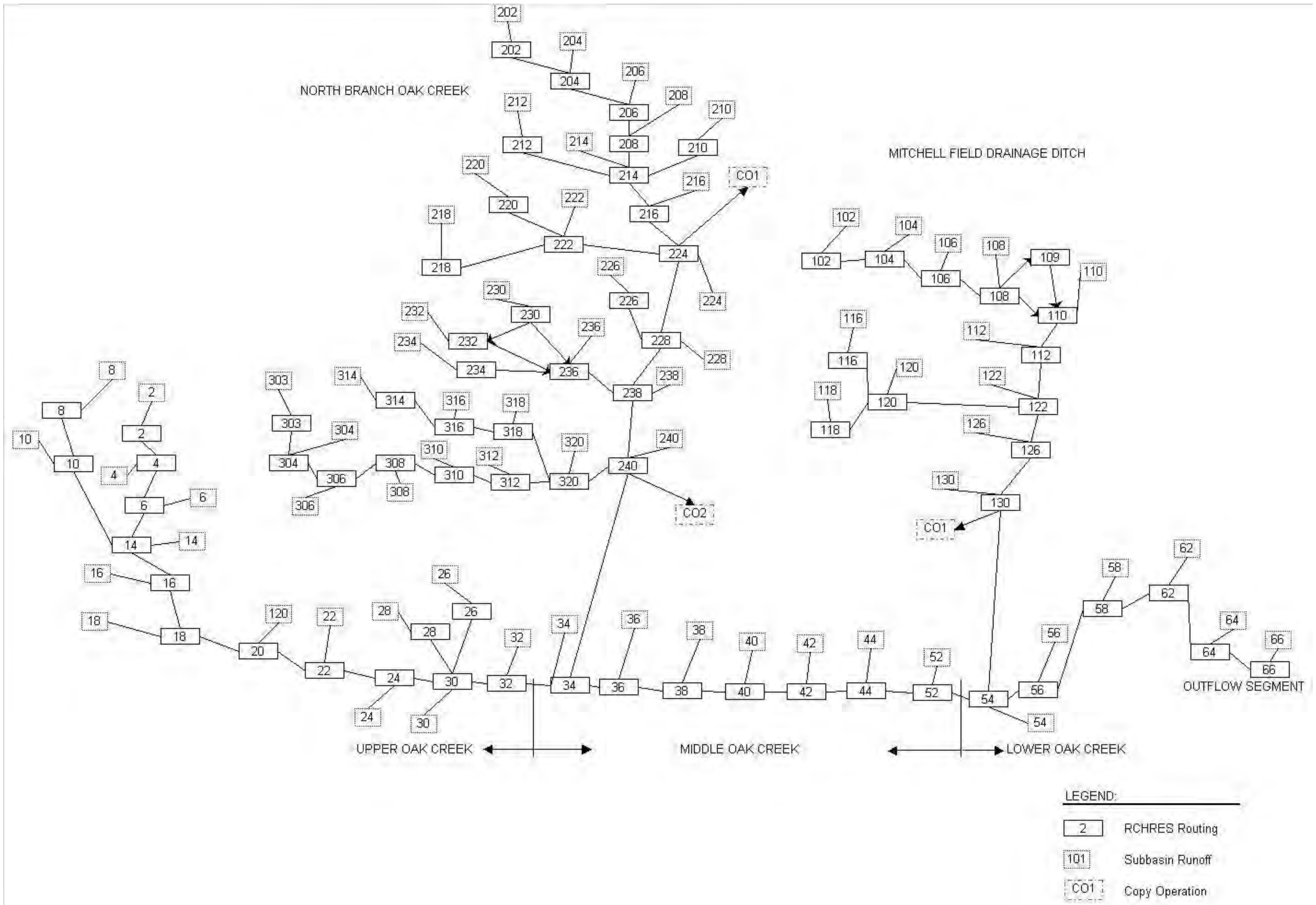


Figure 6-2. Schematic representation of the Oak Creek LSPC model.

6.2 Watershed Segmentation

LSPC was configured for Oak Creek to simulate the watershed as a series of 70 hydrologically connected subwatersheds. The delineation of the subwatersheds was based partially on topography but also took into consideration human-influenced drainage patterns. The spatial subdivision of the watershed allows for a more refined representation of pollutant sources and a more realistic description of hydrologic factors. The subwatersheds and primary streams in the Oak Creek watershed are shown in Figure 6-3.

Figure 6-3. Oak Creek LSPC modeling subwatersheds and location of weather station.

6.3 Weather Data

Hydrologic processes are time varying and depend on changes in environmental conditions including precipitation, temperature, and wind speed. As a result, meteorological data are a critical component of the watershed model. Appropriate representation of precipitation, wind movement, solar radiation, potential evapotranspiration, cloud cover, temperature, and dew point are required to develop a valid model. These data provide necessary input to model algorithms for hydrologic and water quality representation.

The Oak Creek model relies on weather data from Milwaukee General Mitchell International Airport (GMIA; National Weather Service (NWS) Station 475479), which is located north of the watershed (Figure 6-3). Data for the following parameters are based on GMIA:

- Precipitation
- Temperature
- Cloud cover
- Wind movement
- Potential evapotranspiration
- Dew point
- Solar radiation

Precipitation, temperature, cloud cover, wind speed, and dew point are gage monitored, while potential evapotranspiration (PEVT) and solar radiation were computed by SEWRPC. No modifications of the SEWRPC-generated PEVT time series were made (some modifications were found to be necessary for portions of the Menomonee River watershed model).

6.4 Land Cover Representation

LSPC requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the basin, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices.

Land cover classifications from the SEWRPC 2000 land use codes were used to develop the land use representation in the LSPC model. Included below is a table that defines specific terminology associated with the processes of deriving land cover classifications from SEWRPC land use codes.

Table 6-1. Terminology associated with the process of deriving land cover classifications from SEWRPC land use codes.

Land Use Terminology	**Definition**
Land Use Code	A SEWRPC three-digit code that describes the land use for a specified area.
Land Use Group	A simplification of the land use codes into groups of several land use codes which share hydrologic and water quality characteristics.
Land Use Category	SEWRPC term that corresponds to the definition of land use group, with slight variation in name and number.
Land Cover Classification	A classification of soil composition and natural or manmade land practices which comprises a portion or all of a land use.

The original HSPF model was developed by SEWRPC as part of a refinement of their comprehensive plan for the Oak Creek watershed. This model was also adopted for use in the MMSD Phase 1 Watercourse Management Plans (WMPs) as documented in the April 11, 2003 Technical Memorandum, *Characterize Existing Watershed / Watercourse Models.*

Two pervious covers (rural and urban) and a single impervious cover were used to model hydrology and surface runoff in the original SEWRPC HSPF models. New land cover classifications for the 2020 Facilities Planning Project were determined using 2000 land use data. The land use was classified for an expanded number of land use groups (25) and land cover classifications

(17 – 6 impervious and 11 pervious) and documented in the October 27, 2003 *Technical Memorandum Definition of HSPF Land Cover Classifications*. Figure 6-4 displays these 25 land use groups.

The model algorithms require that land cover categories be divided into separate pervious and impervious land units for modeling. Pervious land covers are further categorized by NRCS hydrologic soil groups. The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting. Typically, clay soils that are poorly drained have lower infiltration rates, while well-drained sandy soils have the greatest infiltration rates. NRCS (2001) has defined four hydrologic groups for soils as listed in Table 6-2. The final land cover classification representation for the Oak Creek LSPC model is summarized in Table 6-3 and indicates that the two most common land covers are grasses on C soils (43 percent) and impervious land cover associated with commercial land uses (12 percent).

Table 6-2. NRCS Hydrologic Soil Groups

Hydrologic Soil Group	Description
A	Soils with high infiltrations rates. Usually deep, well drained sands or gravels. Little runoff.
B	Soils with moderate infiltration rates. Usually moderately deep, moderately well drained soils.
C	Soils with slow infiltration rates. Soils with finer textures and slow water movement.
D	Soils with very slow infiltration rates. Soils with high clay content and poor drainage. High amounts of runoff.

Table 6-3. Land cover in the Oak Creek watershed.

Category	Land Cover	Area		Percent of Watershed
		Acres	Square Miles	
IMPERVIOUS	COMMERCIAL	2095.2	3.27	11.70
	GOVT_INSTIT	105.9	0.17	0.59
	INDUSTRIAL	403.3	0.63	2.25
	RESIDENTIAL	607.5	0.95	3.39
	TRANS_FREE	229.2	0.36	1.28
	ULTRA_LOW	58.0	0.09	0.32
PERVIOUS	CROP_B	380.4	0.59	2.12
	CROP_C	1394.6	2.18	7.79
	CROP_D	126.6	0.20	0.71
	FOREST	1087.1	1.70	6.07
	GRASS_B	1183.1	1.85	6.61
	GRASS_C	7782.0	12.16	43.45
	GRASS_D	230.8	0.36	1.29
	PASTURE_B	156.0	0.24	0.87
	PASTURE_C	692.5	1.08	3.87
	PASTURE_D	109.8	0.17	0.61
	WETLAND	1269.5	1.98	7.09
	Total	**17911.5**	**27.99**	**100**

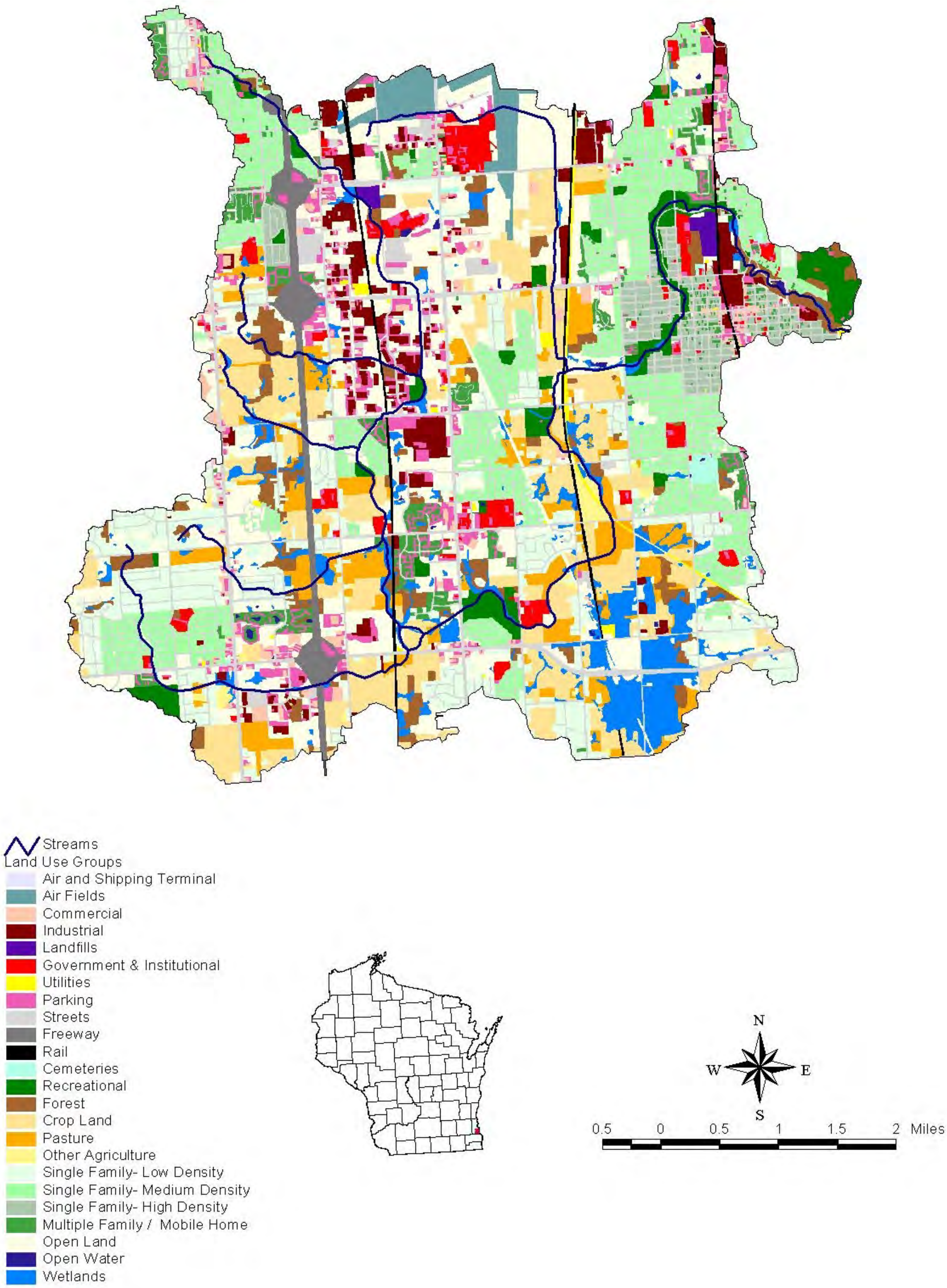


Figure 6-4. Modeling land uses in the Oak Creek watershed.

6.5 Point Sources

There are a number of “point sources” in the Oak Creek watershed. These consist of sanitary sewer overflows (SSOs) and discharges from seventeen industrial facilities. Flows from these point sources were input directly into the LSPC model using methodology outlined in the December 13, 2004 memorandum entitled *Point Source Loading Calculations for Purposes of Watercourse Modeling*.

7.0 CALIBRATION AND VALIDATION PROCESS

The model calibration and validation processes are described in this section. Background information on the locations of available flow data and the time periods of calibration/validation are first presented, followed by a description of how key parameters were modified.

7.1 Background

Hydrologic calibration of the Oak Creek model was performed after configuring the LSPC model. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. For LSPC, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. It is required for parameters that cannot be deterministically and uniquely evaluated from topographic, climatic, physical, and chemical characteristics of the watershed and compounds of interest. Fortunately, the majority of LSPC parameters do not fall in this category. Calibration is based on several years of simulation to allow parameter evaluation under a variety of climatic conditions. The calibration procedure results in parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period.

Calibration included the comparison of monthly, seasonal, and annual values, and individual storm events. All of these comparisons must be evaluated for a proper calibration of hydrologic parameters. In addition, simulated and observed stream flow values were analyzed on a frequency basis and their resulting cumulative distributions (e.g., flow duration curves) compared to assess the model behavior and agreement over the full range of observations.

Model validation tested the calibrated model using input from a different time period, without further parameter adjustment. If the model cannot properly simulate conditions for the independent data set, the calibration is not acceptable and requires additional work until validation is achieved. As described in the January 14, 2004 *Watershed and Receiving Water Quality Model Calibration and Validation Data and Procedures* memorandum, the calibration time period was January 1, 1995 to December 31, 1998. The validation time period was January 1, 1999 through December 31, 2002. To permit model spin up time and minimize numerical errors inherent in modeling, the model was run for the time period January 1, 1993 through December 31, 1998 for calibration purposes.

The model calibration and validation was performed using the flow record from the USGS gage along Oak Creek in the City of South Milwaukee (04087204). Figure 6-1 shows the location of this gage.

7.2 Initial Model Calibration

Hydrologic calibration involved a comparison of observed data from the in-stream USGS flow gaging station to modeled in-stream flow and an adjustment of key hydrologic parameters. Various modeling parameters were varied within physically realistic bounds and in accordance to observed temporal trends and land cover classifications. An attempt was made to remain within the guidelines for parameter values set out in BASINS Technical Note 6 (USEPA, 2000). Hydraulic calibration was undertaken simultaneously across the Menomonee River, Kinnickinnic River, and Oak Creek watersheds to develop a unified parameter set in which variations between watersheds are explained by documented differences in land use and physical parameters such as soil characteristics. This cross-sectional calibration approach helps ensure a robust parameter set that is not unduly biased by anomalies in individual gage records.

Graphical results of model performance and error statistics were evaluated following each model simulation run. Model parameters were adjusted following each iteration to improve model performance.

The parameters that were adjusted include those that account for the partitioning of surface versus subsurface flow, infiltration rate, surface and subsurface storage, evapotranspiration, and surface runoff. A discussion of the key parameters and how they were adjusted is presented below.

The model performance is most sensitive to the specification of the water-holding capacity of the soil profile (expressed through LZSN, the nominal lower-zone storage) and the infiltration rate index (INFILT), which together control the partitioning of water between surface and subsurface flow. LZSN is an index of nominal storage of water in the soil zone subject to evapotranspiration (root depth plus capillary fringe), while LZS represents the actual water storage in this zone. LZSN is often characterized as the median of field capacity storage in this zone (i.e., available water capacity times rooting depth with capillary fringe). Functionally, however, the meaning of LZS and LZSN may differ somewhat from this ideal interpretation. More important to model behavior is the ratio LZRAT (LZS/LZSN). This ratio (in inverse form) first determines the variation of actual infiltration rate relative to the nominal value, INFILT. LZRAT also determines the rate at which water percolates from the lower soil zone to groundwater. LZSN thus varies with precipitation pattern as well as vegetation type. In addition, it is difficult to relate LZSN to a single vegetation type, because a dominant vegetation (e.g., grass) with a low rooting depth may also contain other plants (e.g., trees) with a much greater rooting depth, which increases the amount of soil moisture that is available for ET. As a result, while initial values of LZSN can be estimated from soils and vegetation data, final values must be determined through calibration.

Viessman et al. (1989) suggest as initial estimates for LZSN a value between one-quarter and one-eighth of the annual rainfall plus four inches. USEPA (2000) show typical values for LZSN ranging from 5 inches to 14 inches in typical applications. Values found through calibration for the Oak Creek watershed are well within this range. A value of 9 inches provided reasonable results for all pervious land uses except urban grass where a value of 5 provided optimal results, perhaps due to the lower rooting depth of grasses.

INFILT in HSPF is an *index* of infiltration rate and is not directly interpretable from measured field infiltration rates. BASINS Technical Note 6 recommends values in the range of 0.1-0.4 for B soils, 0.05-0.1 for C soils, and 0.01-0.05 in/hr for D soils. Values were re-optimized by starting from the center of the recommended ranges and modifying the value for each soil class proportionately – yielding final values of 0.365, 0.105-0.125, and 0.055-0.075 for B, C, and D soils, respectively. For C and D soils, the higher values were applied to tilled agriculture, while the lower values were applied to grass and pasture.

Key parameters for the subsurface flow response include the ground water recession coefficient (AGWRC), and the interflow inflow and recession parameters (INTFW and IRC). AGWRC was set by optimizing model performance for baseflow recession, with relative variation among land uses based on past experience, resulting in values from 0.921-0.970. Interflow inflow was set to 1 and interflow recession coefficient to 0.3 for urban grass on B soils, with higher values for other land uses.

Monthly variability in hydrologic response was specified by setting monthly values for the upper zone nominal soil storage and the lower zone ET parameter. In each case, the values specified are consistent with recommendations in BASINS Technical Note 6, as well as experience in calibrating multiple HSPF models for the Minnesota River basin (Tetra Tech, 2002).

For the winter simulation, the model is very sensitive to parameters that control snow accumulation and snowmelt. Considerable uncertainty is present in hydrologic models when temperatures are near the transition point between liquid and frozen precipitation, and prediction of rain-on-snow melting events can be particularly difficult. Key calibration parameters for the winter snow simulation were revised from defaults during optimization and included the snow catch factor (CCFACT, ratio that accounts for under-catch of snow in standard precipitation gages), the field adjustment parameter for heat accumulation in the snow pack (CCFACT), the maximum rate of snow melt by ground heating (MGMELT), and the depth of snow at which all land area is considered to be covered (COVIND, set to a higher value for impervious lands to account for snow removal/consolidation).

7.3 Model Re-Calibration

During model re-calibration all Ftables, stream reach characteristics, and land cover assignments were carefully reconciled with the latest information from SEWRPC. Calibration improvements were then sought and achieved, based largely on experience with recalibration of the Underwood Creek portion of the Menomonee River and the Kinnickinnic River watershed models. Specifically, changes to the parameters for urban grass were carefully examined.

The draft calibration of the Oak Creek model had parameters for grass that differed significantly from the other basins, especially a lower value of LZSN. This may in part be due to differences in soils, but also might reflect large expanses of grass land without deep rooted trees and shrubs around the airport.

Bringing the full set of the Kinnickinnic River model urban grass parameters into the Oak Creek model resulted in a significant degradation in performance. This set was, however, used as a starting point for recalibration. It was first determined that the difference in LZSN needed to be maintained for Oak Creek, and this value was set back to 5.0 inches. In addition, it was found that better hydrologic calibration could be obtained for Oak Creek using somewhat lower values for groundwater recession and infiltration from urban grass, coupled with higher deep fraction losses. On all soils, groundwater recession rates for grass were lowered to 0.85, and deep fraction losses raised to 10 percent. Infiltration rates were reduced to 0.295 for B soils, 0.085 for C soils, and 0.050 for D soils.

During water quality simulation, it was noted that the predicted stream depth declined to less than 1 inch at various times. When average depth declines to less than 2 inches, LSPC turns off the algal simulation creating problems for the DO simulation. Based on these observations in the original calibration, SEWRPC re-evaluated the FTables in Lower Oak Creek and the model was updated to hold slightly more water within the stream reaches during low flow periods. The FTable changes generally improved the fit to observed flow durations, bringing both the simulated 10 percent high and 50 percent low flows better in line with observations over the full simulation period. Seasonal fit improved for Fall, Winter, and Spring (although Summer was slightly worse).

The resulting model fits the data well. Remaining discrepancies are mostly due to the imputation across the watershed of large convective storms occurring in summer 1998 and 1999. The General Mitchell weather station estimates of depth are probably biased high relative to the entire watershed, and this causes an increased replenishment of ground water that results in overestimates of summer and fall runoff in the months following each storm.

8.0 RESULTS OF HYDROLOGIC CALIBRATION AND VALIDATION

The model calibration results are presented in this section both graphically and statistically. Graphical comparisons are extremely useful for judging the results of model calibration because time-variable plots of observed versus modeled flow provide insight into the model's representation of storm hydrographs, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. Graphing model results with precipitation data can also provide insights into how the model reacts to different storms.

Graphical comparisons consist of time series plots of observed and simulated values for flows, observed versus simulated scatter plots with a 45^{o} linear regression line displayed, and cumulative frequency distributions (flow duration curves). Statistical comparisons focus on the relative error method. A small relative error indicates a better goodness of fit for calibration. Secondly, results from correlation tests (e.g. linear correlation coefficient, coefficient of model-fit efficiency, etc.) are also presented. A comparison of simulated and observed storm hydrographs for selected storm events will be addressed in a separate memorandum.

8.1 Tolerances

Model tolerance values for this project have been identified and are described in the January 14, 2004 *Watershed and Receiving Water Quality Model Calibration and Validation Data and Procedures* memorandum and in the December 18, 2002, *MMSD Comprehensive Modeling and Real Time Control Strategies* Technical Memorandum 2.4. Hydrologic parameters to be calibrated include annual flow volumes, low flow volumes, storm flow volumes, and seasonal flow volumes. The following tolerances (i.e., accepted level of error between modeled and observed flows) are used:

Total runoff volume: ± 10 percent
High flow volumes: ± 15 percent
Low flow volumes: ± 10 percent
Seasonal flow volumes: ± 20 percent

Error in storm volumes: ± 20 percent[1]

The same tolerances are used for model validation. Error statistics are calculated for each month and year of the calibration time period; however, a calibration is deemed appropriate when the tolerances for the entire calibration period have been met. The same applies for the validation period.

8.2 Calibration and Validation Results

The final calibration and validation results are presented below in Figure 8-1 to Figure 8-20 and Table 8-1 to Table 8-4. The changes described in Section 7.3 result in an improved performance of the model, especially during the validation period where the initial model showed a fairly consistent oversimulation of peak flow during precipitation events. Remaining discrepancies are mostly due to the imputation across the watershed of large convective storms occurring in summer 1997 and 1999. The GMIA station estimates of depth are probably biased high relative to the entire watershed, and this causes an increased replenishment of ground water that results in overestimates of summer and fall runoff in the months following each storm.

The quality of hydrologic model fit for individual daily observations is summarized by the Nash-Sutcliffe coefficient of model fit efficiency (E). This parameter ranges from minus infinity to 1, with higher values indicating better fit, and is formed as the ratio of the mean square error to the variance in the observed data, subtracted from unity. A value of 0 implies that the observed mean is as good a predictor as the model. Values close to 1 are thus desirable. It should be recalled, however, that the Nash-Sutcliffe coefficient is based on matched daily records, and does not account for phase errors. It is also subject to leverage by outliers. Thus, if a large flow is estimated with the right magnitude, but off by one day, this can substantially degrade the Nash-Sutcliffe coefficient, even though annual sums and flow duration percentiles are unaffected.

The Nash-Sutcliffe coefficient was not used in the model calibration process. Therefore, it is appropriate to use it as post-validation model evaluation tool applied over the entire calibration and validation period of 1995-2002. Results for the Oak Creek gage are shown in Table 8-5 and an E value of 0.76 indicates a satisfactory fit.

[1] A comparison of simulated and observed storm hydrographs for selected storm events will be addressed in a separate memorandum.

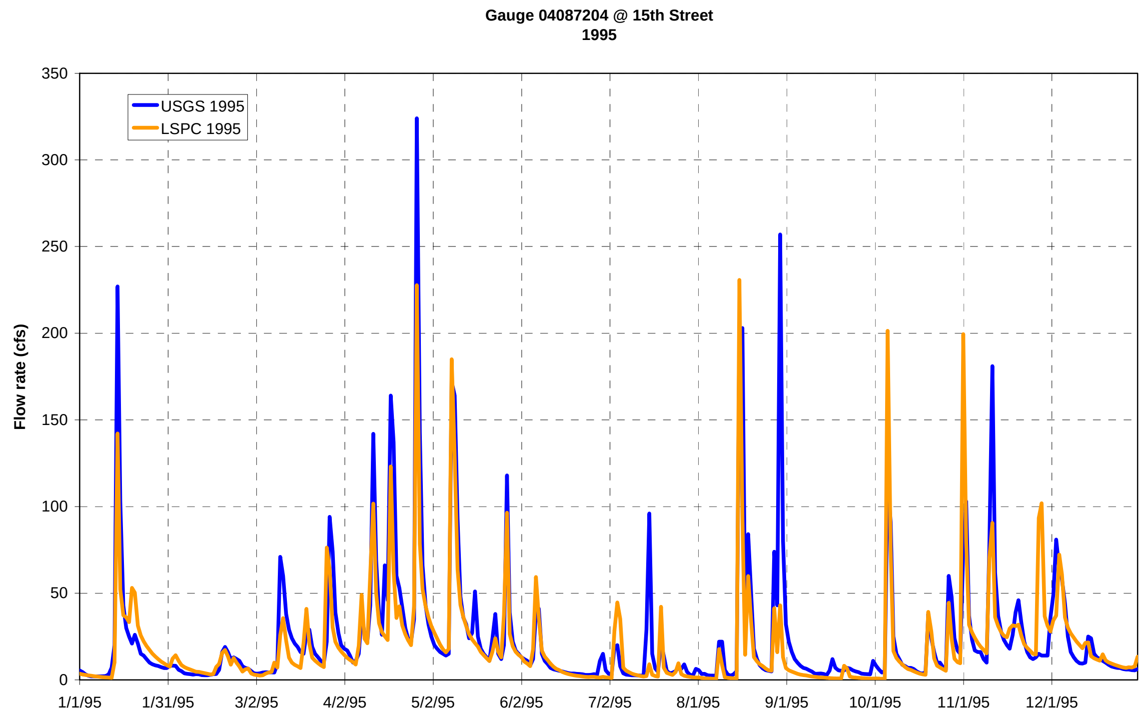


Figure 8-1. Time series hydrologic calibration results for Oak Creek at USGS gage 04087204 (1995).

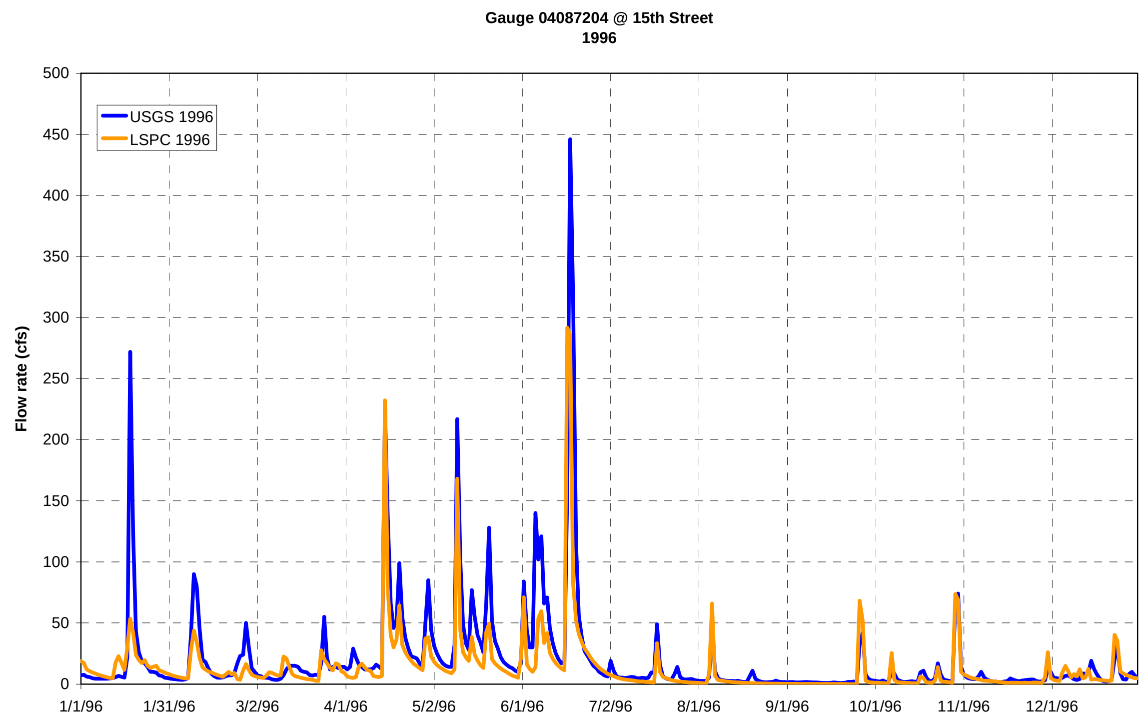


Figure 8-2. Time series hydrologic calibration results for Oak Creek at USGS gage 04087204 (1996).

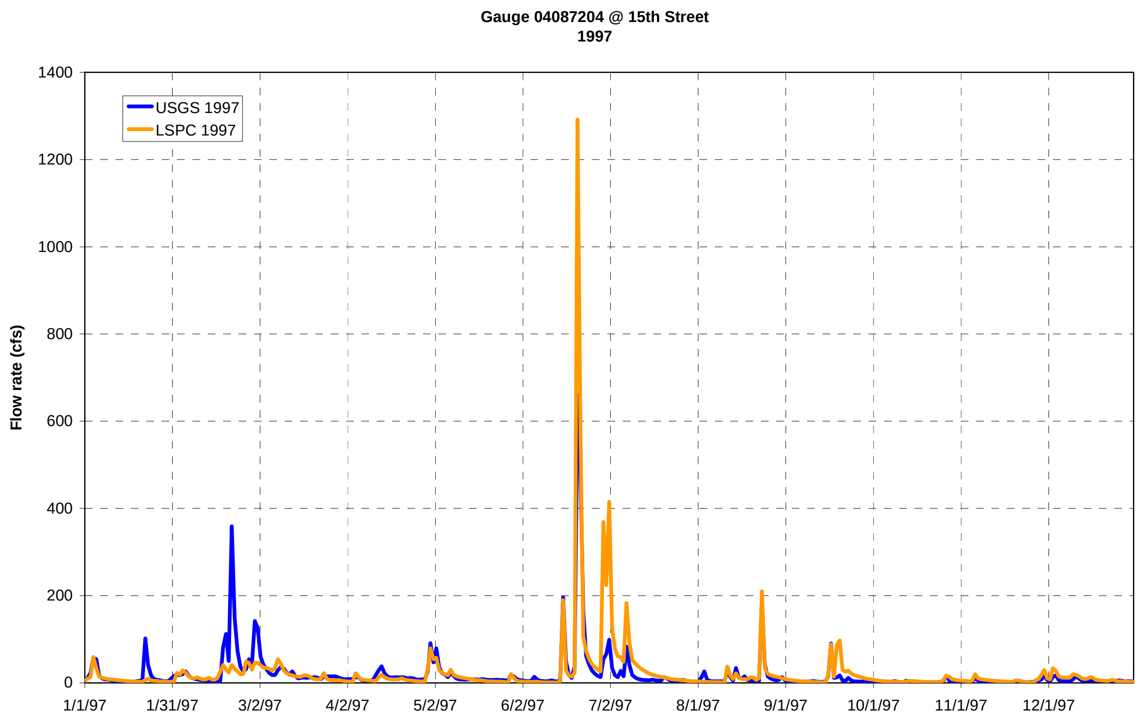


Figure 8-3. Time series hydrologic calibration results for Oak Creek at USGS gage 04087204 (1997).

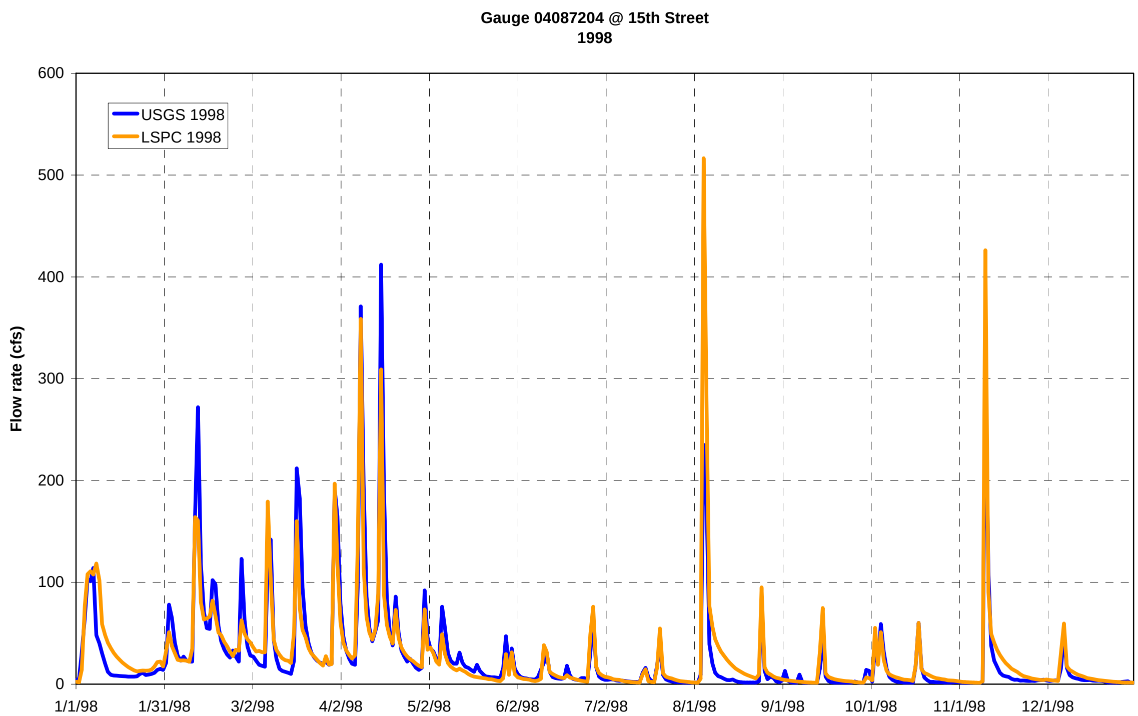


Figure 8-4. Time series hydrologic calibration results for Oak Creek at USGS gage 04087204 (1998).

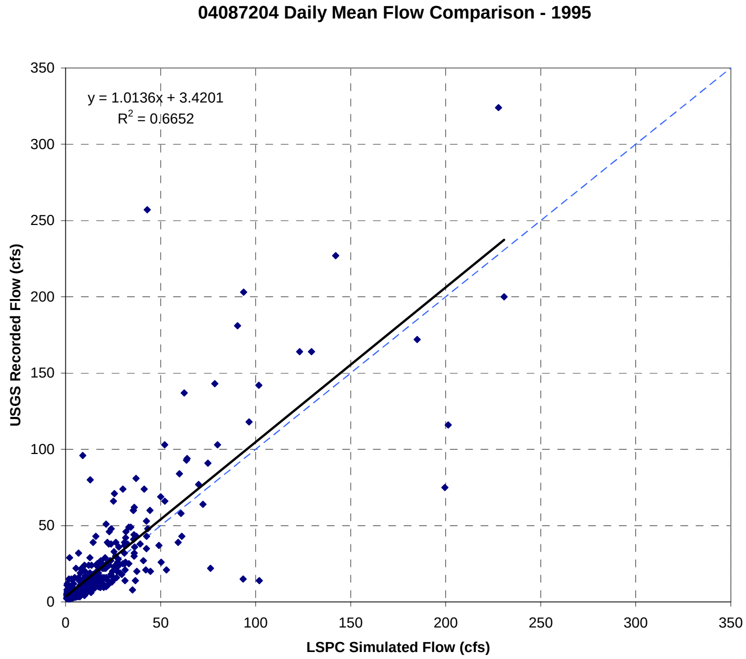


Figure 8-5. Observed versus simulated scatter plot with a linear regression line for Oak Creek at USGS gage 04087204 (1995).

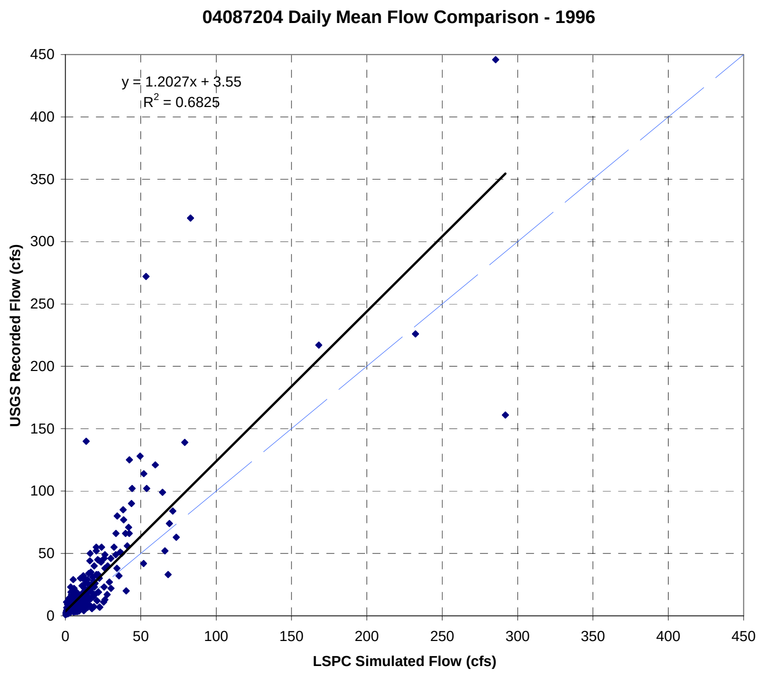


Figure 8-6. Observed versus simulated scatter plot with a linear regression line for Oak Creek at USGS gage 04087204 (1996).

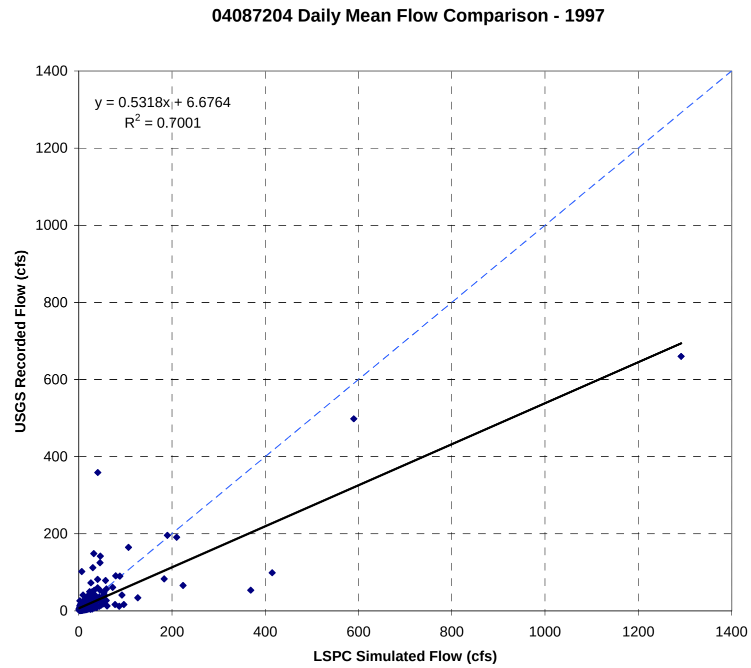


Figure 8-7. Observed versus simulated scatter plot with a linear regression line for Oak Creek at USGS gage 04087204 (1997).

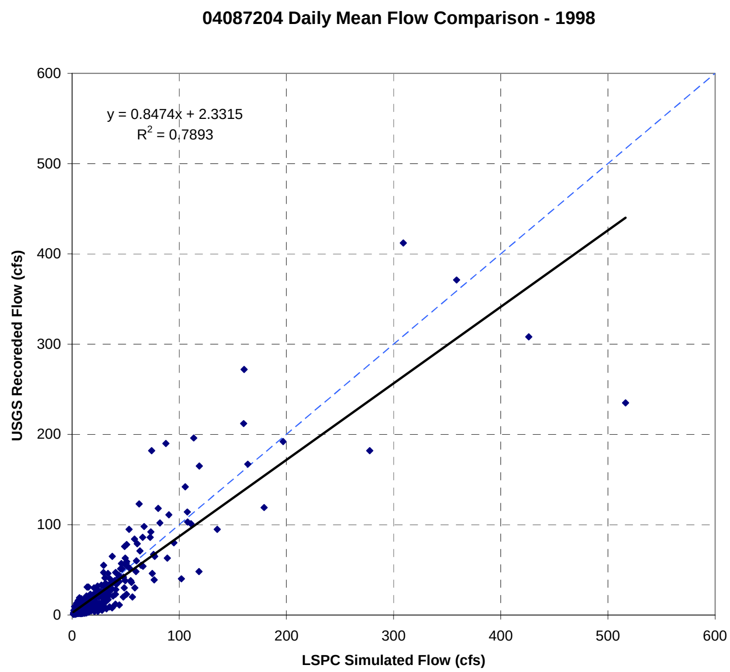


Figure 8-8. Observed versus simulated scatter plot with a linear regression line for Oak Creek at USGS gage 04087204 (1998).

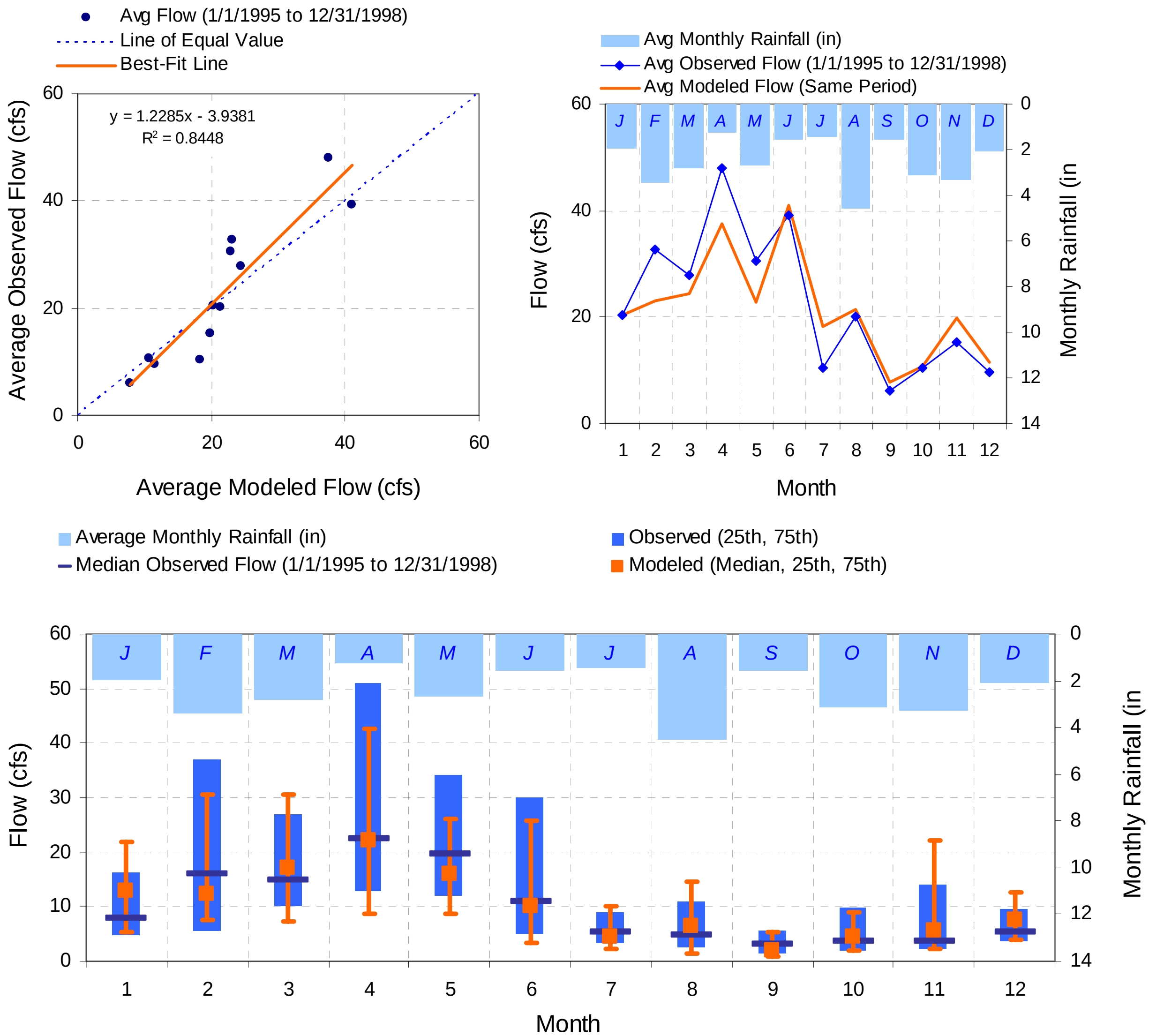


Figure 8-9. Composite (average monthly) hydrologic calibration results for Oak Creek at USGS gage 04087204 (1995 to 1998).

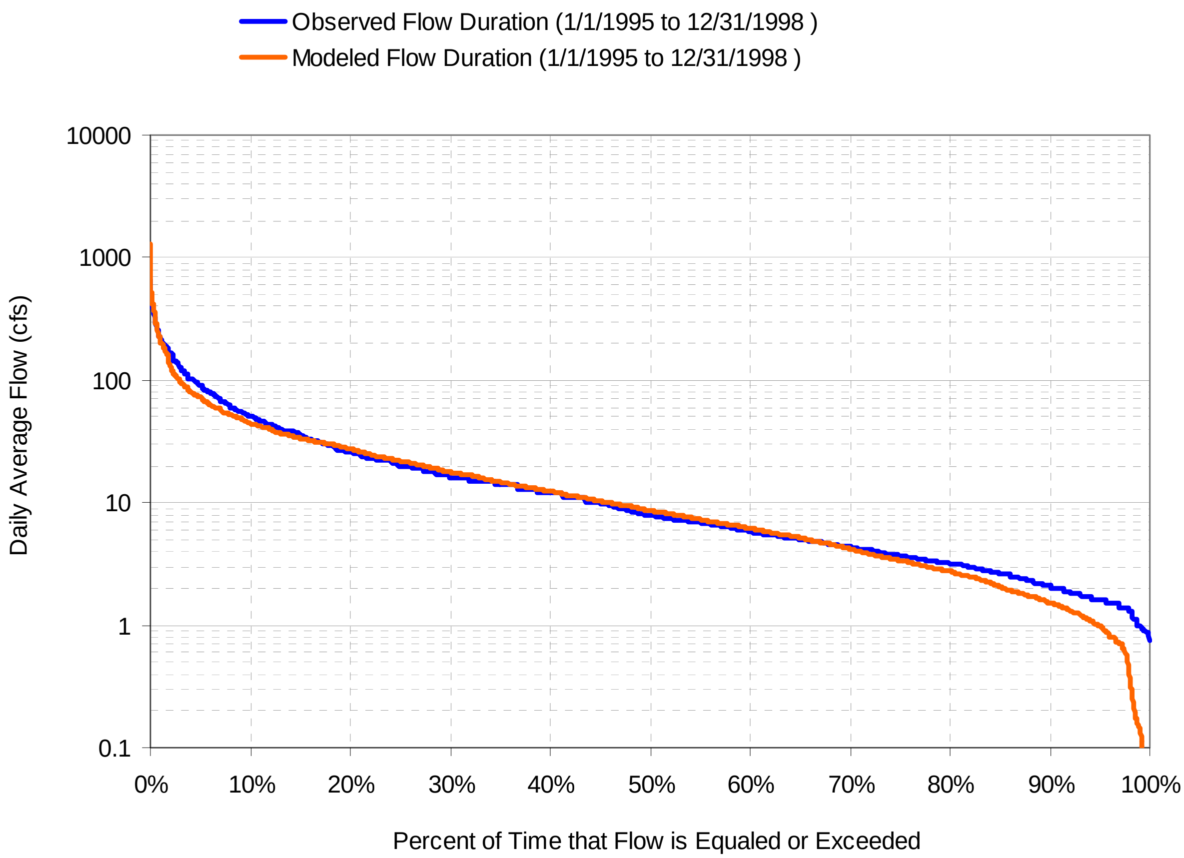


Figure 8-10. Flow duration curve hydrologic calibration results for Oak Creek at USGS gage 04087204 (1995-1998).

Table 8-1. Error statistics for hydrologic calibration results for Oak Creek at USGS gage 04087204 (1995-1998).

Monthly / Seasonal / Yearly Volume Comparison

Time Period		1995			1996			1997			1998			TOTAL		
		Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month	JAN	1,295	1,240	-4.26%	1,360	965	-29.0%	888	527	-40.6%	1,502	2,277	51.6%	5,046	5,009	-0.7%
	FEB	398	447	12.3%	1,101	659	-40.1%	2,407	1,175	-51.2%	3,451	2,904	-15.8%	7,357	5,185	-29.5%
	MAR	1,442	1,026	-28.8%	702	612	-12.8%	1,663	1,333	-19.8%	3,085	3,041	-1.4%	6,892	6,013	-12.8%
	APR	3,499	2,612	-25.3%	2,366	1,662	-29.8%	741	492	-33.6%	4,827	4,166	-13.7%	11,433	8,931	-21.9%
	MAY	2,360	2,156	-8.6%	2,558	1,423	-44.4%	1,031	954	-7.5%	1,544	1,080	-30.0%	7,492	5,612	-25.1%
	JUN	557	544	-2.4%	4,208	2,717	-35.4%	3,871	5,801	49.8%	689	716	3.9%	9,326	9,777	4.8%
	JUL	630	487	-22.7%	490	275	-43.9%	1,097	3,315	202.2%	340	408	20.0%	2,557	4,485	75.4%
	AUG	2,348	1,274	-45.8%	296	223	-24.8%	997	1,029	3.2%	1,323	2,740	107.1%	4,965	5,266	6.1%
	SEP	442	144	-67.4%	246	256	4.0%	476	1,073	125.5%	283	397	40.5%	1,446	1,870	29.3%
	OCT	1,235	1,138	-7.9%	543	469	-13.7%	171	279	63.5%	639	761	19.0%	2,588	2,647	2.3%
	NOV	2,049	2,459	20.0%	237	197	-16.9%	195	379	94.3%	1,166	1,671	43.3%	3,648	4,706	29.0%
	DEC	1,209	1,233	2.0%	477	503	5.5%	358	612	70.8%	340	471	38.5%	2,384	2,819	18.3%

		1995				1996				1997				1998				TOTAL			
		Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Season	Jan-Mar	3,135	2,713	-13.5%		3,163	2,236	-29.3%	9.3%	4,958	3,035	-38.8%	18.8%	8,039	8,222	2.3%		**19,295**	**16,207**	**-16.0%**	
	Apr-Jun	6,415	5,311	-17.2%		9,132	5,801	-36.5%	16.5%	5,644	7,246	28.4%	8.4%	7,060	5,961	-15.6%		**28,251**	**24,320**	**-13.9%**	
	Jul-Sep	3,420	1,904	-44.3%	24.3%	1,033	754	-27.0%	7.0%	2,570	5,416	110.8%	90.8%	1,946	3,546	82.2%	62.2%	**8,969**	**11,620**	**29.6%**	**9.6%**
	Oct-Dec	4,493	4,829	7.5%		1,257	1,169	-7.0%		724	1,270	75.4%	55.4%	2,146	2,903	35.3%	15.3%	**8,620**	**10,172**	**18.0%**	

Calibration Tolerance =20%

	1995				1996				1997				1998				TOTAL			
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	17,463	14,758	-15.5%	5.5%	14,585	9,960	-31.7%	21.7%	13,896	16,968	22.1%	12.1%	19,190	20,633	7.5%		**65,134**	**62,320**	**-4.3%**	

Calibration Tolerance =10%

Table 8-2. High-Low flow error statistics for hydrologic calibration results for Oak Creek at USGS gage 04087204 (1995-1998).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	33,049	35,780	-7.6%	15%
Total Highest 20% volume	43,120	46,334	-6.9%	15%
Total Highest 50% volume	56,861	59,289	-4.1%	15%
Total Lowest 10% volume	262	455	-42.5%	10%
Total Lowest 30% volume	1,860	2,316	-19.7%	10%
Total Lowest 50% volume	5,510	5,778	-4.6%	10%

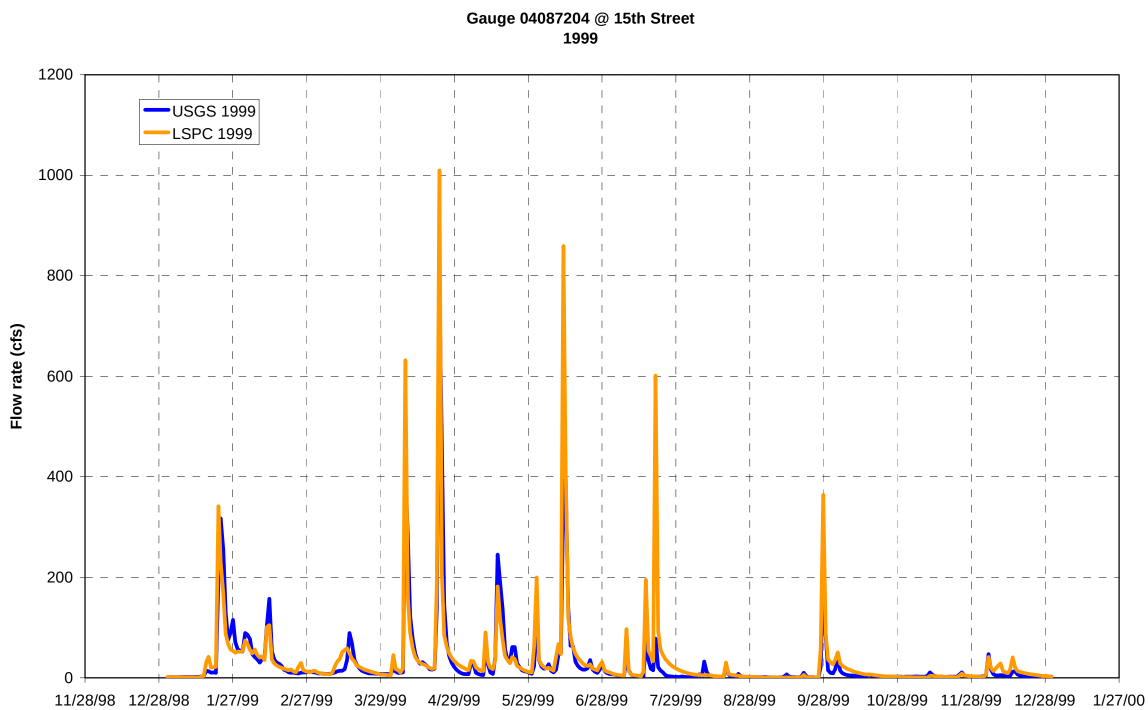


Figure 8-11. Time series hydrologic validation results for Oak Creek at USGS gage 04087204 (1999).

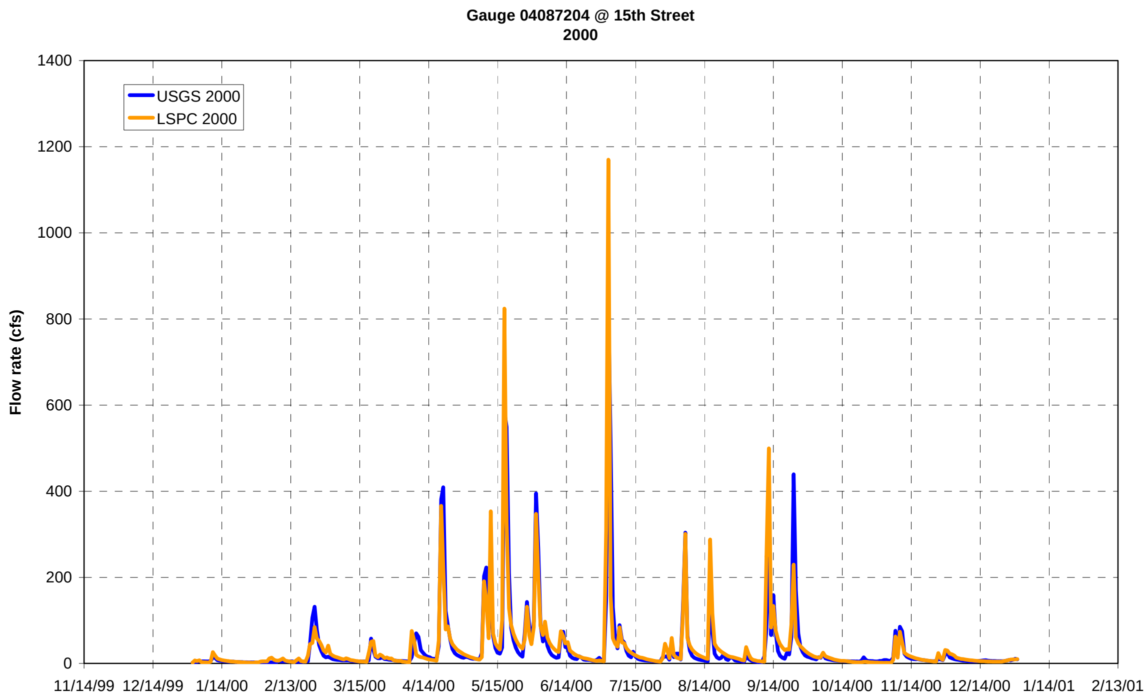


Figure 8-12. Time series hydrologic validation results for Oak Creek at USGS gage 04087204 (2000).

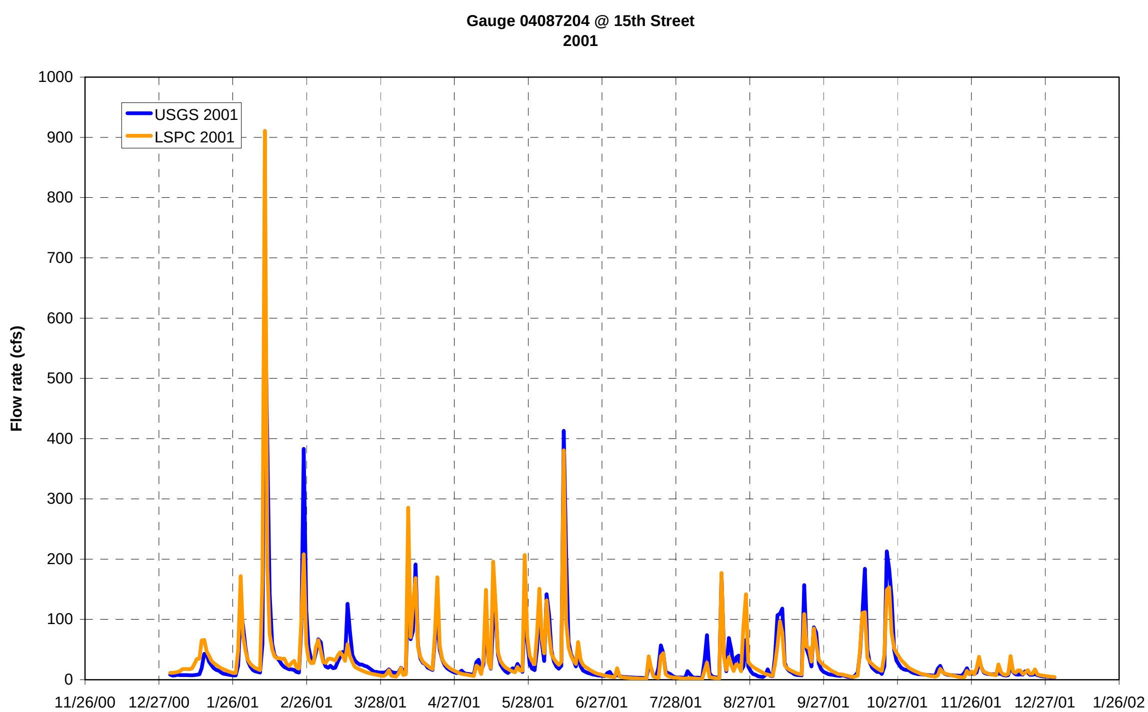


Figure 8-13. Time series hydrologic validation results for Oak Creek at USGS gage 04087204 (2001).

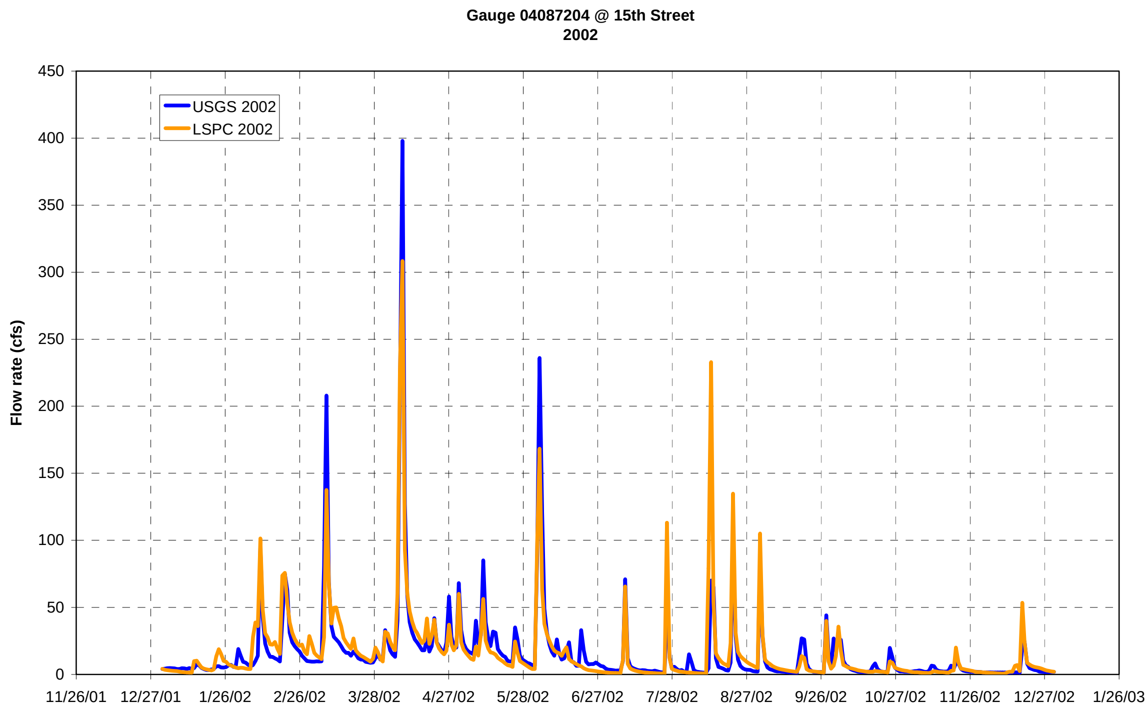


Figure 8-14. Time series hydrologic validation results for Oak Creek at USGS gage 04087204 (2002).

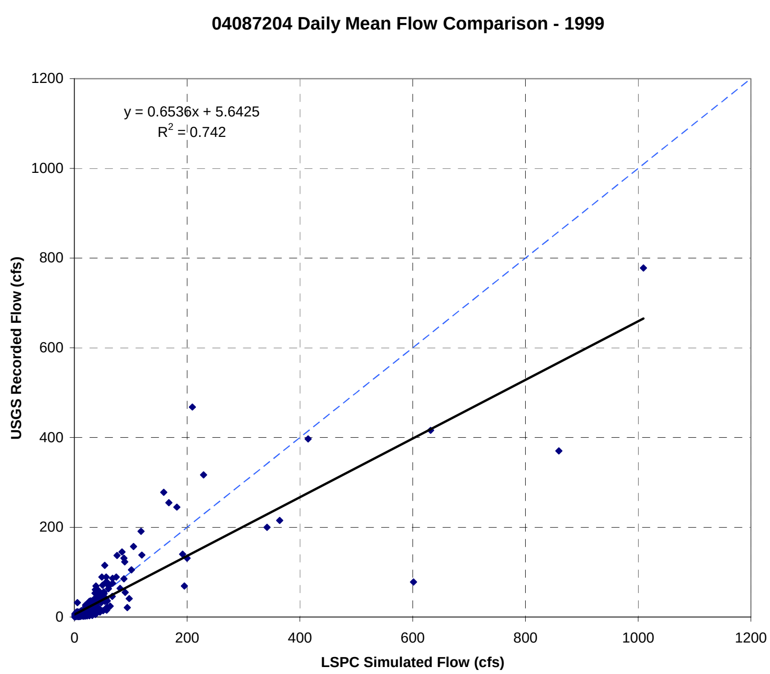


Figure 8-15. Observed versus simulated scatter plot with a linear regression line for Oak Creek at USGS gage 04087204 (1999).

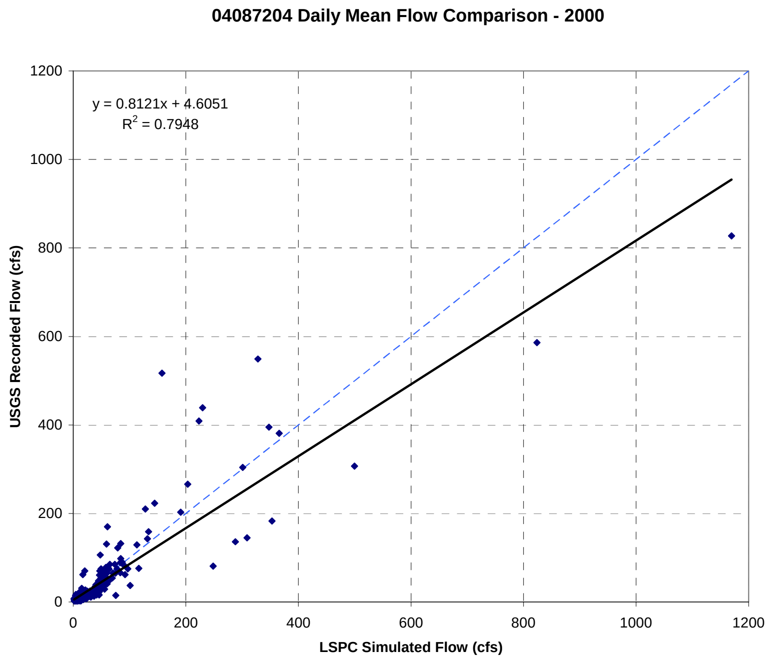


Figure 8-16. Observed versus simulated scatter plot with a linear regression line for Oak Creek at USGS gage 04087204 (2000).

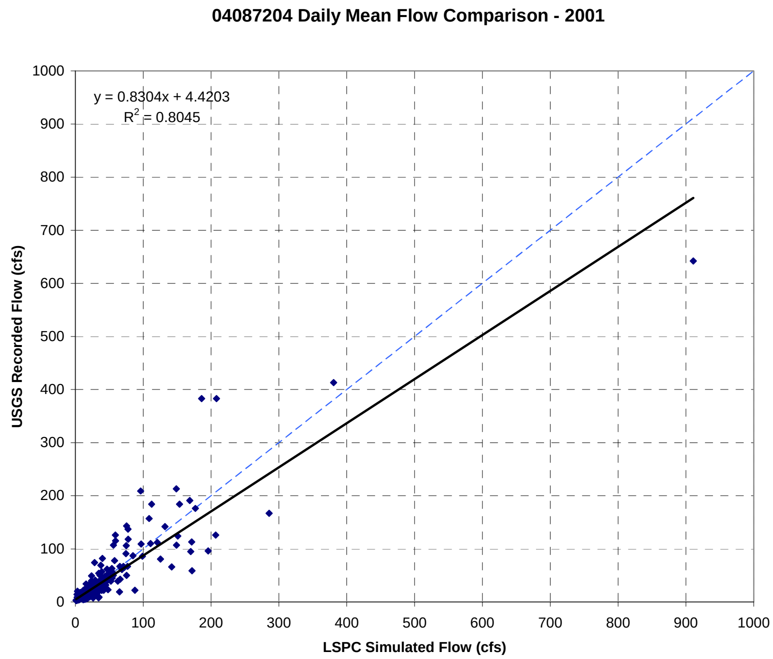


Figure 8-17. Observed versus simulated scatter plot with a linear regression line for Oak Creek at USGS gage 04087204 (2001).

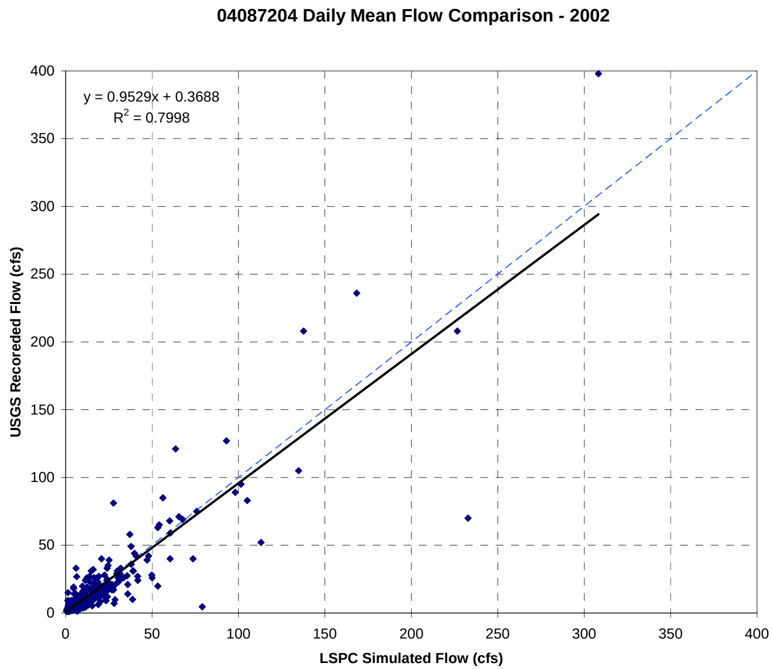


Figure 8-18. Observed versus simulated scatter plot with a linear regression line for Oak Creek at USGS gage 04087204 (2002).

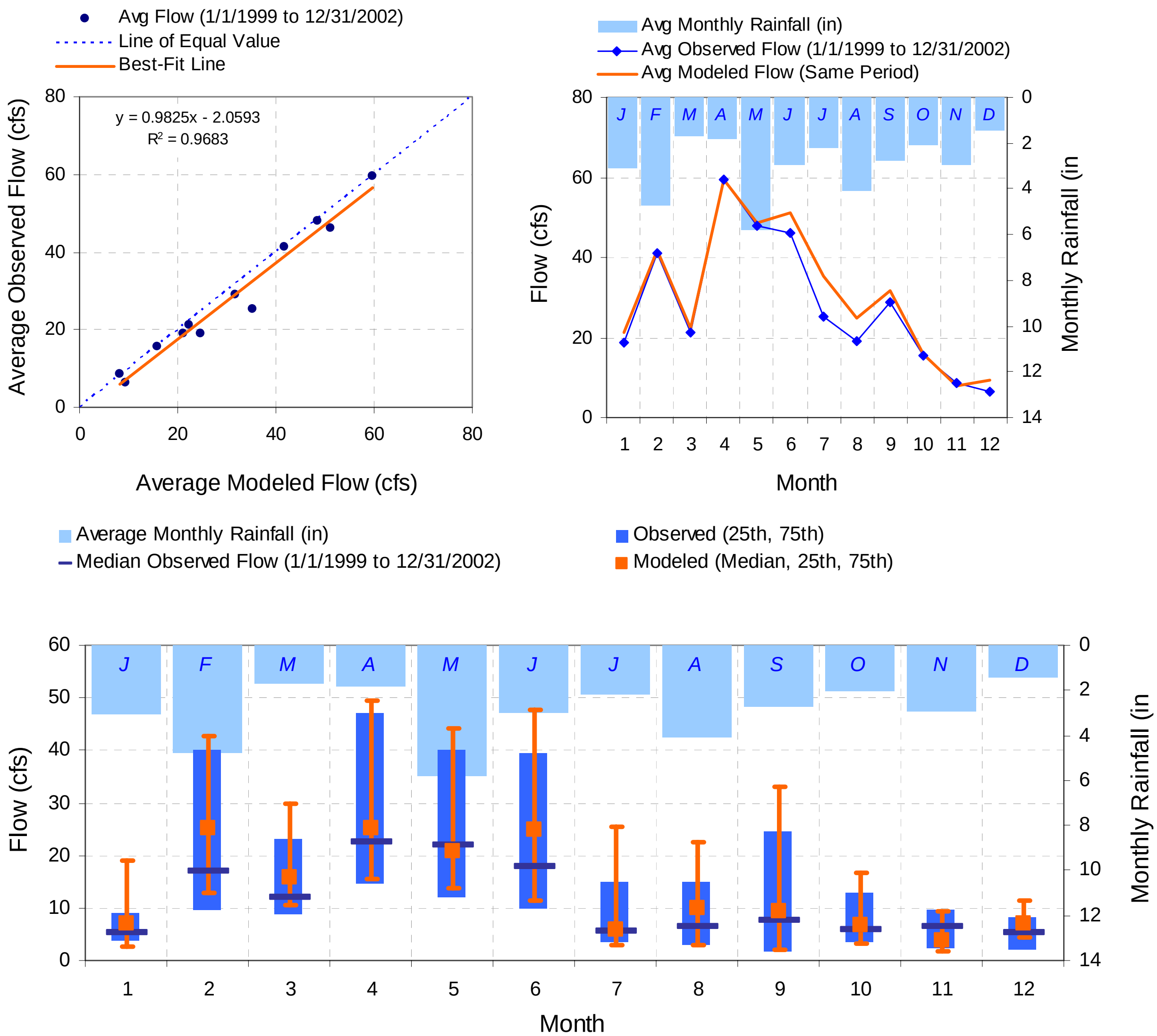


Figure 8-19. Composite (average monthly) hydrologic validation results for Oak Creek at USGS gage 04087204 (1999 to 2002).

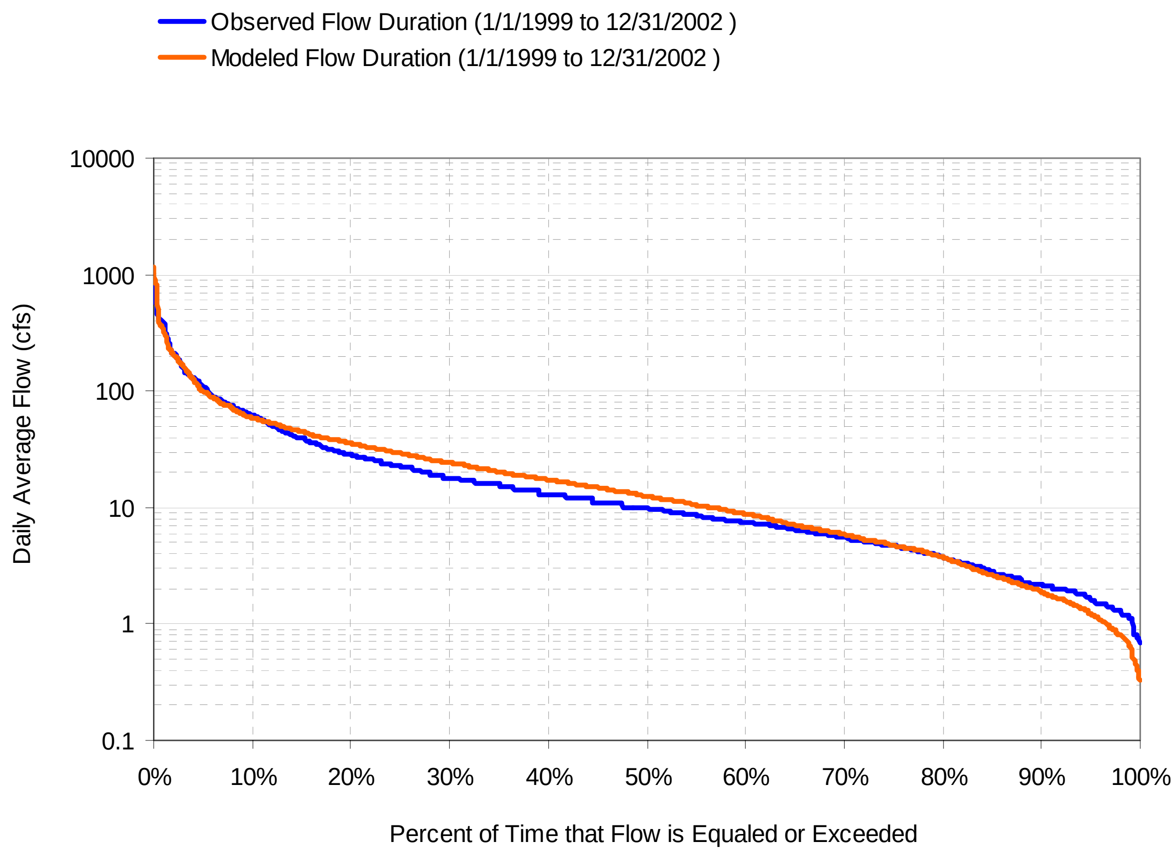


Figure 8-20. Flow duration curve hydrologic validation results for Oak Creek at USGS gage 04087204 (1999 to 2002).

Table 8-3. Error statistics for hydrologic validation results for Oak Creek at USGS gage 04087204 (1999 to 2002).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1999			2000			2001			2002			TOTAL		
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month JAN	2,872	2,606	-9.28%	291	341	17.4%	1,179	1,908	61.8%	301	346	14.8%	4,644	5,201	12.0%
FEB	2,164	2,054	-5.11%	1,088	1,081	-0.7%	4,693	4,623	-1.5%	1,283	1,634	27.3%	9,228	9,391	1.8%
MAR	1,045	1,262	20.69%	670	938	39.9%	1,983	1,655	-16.6%	1,518	1,666	9.8%	5,217	5,520	5.8%
APR	5,812	5,957	2.51%	3,141	2,641	-15.9%	2,323	2,776	19.5%	2,862	2,805	-2.0%	14,137	14,180	0.3%
MAY	2,368	2,180	-7.96%	5,944	6,230	4.8%	1,980	2,489	25.7%	1,471	1,045	-29.0%	11,763	11,943	1.5%
JUN	3,375	4,862	44.07%	2,736	2,927	7.0%	3,176	3,121	-1.7%	1,670	1,248	-25.3%	10,957	12,158	11.0%
JUL	811	2,967	265.74%	4,352	4,679	7.5%	598	498	-16.8%	481	506	5.2%	6,242	8,650	38.6%
AUG	271	353	30.16%	2,065	2,787	35.0%	1,554	1,551	-0.2%	782	1,406	79.9%	4,671	6,097	30.5%
SEP	764	1,130	47.94%	3,441	3,916	13.8%	2,063	1,898	-8.0%	603	608	0.8%	6,871	7,553	9.9%
OCT	362	724	100.12%	495	493	-0.6%	2,534	2,311	-8.8%	438	345	-21.1%	3,829	3,873	1.2%
NOV	195	135	-30.70%	1,036	971	-6.2%	645	646	0.3%	191	174	-8.7%	2,067	1,927	-6.7%
DEC	352	722	104.95%	443	527	18.9%	560	714	27.5%	209	330	57.9%	1,564	2,292	46.6%

Season	Recorded USGS Volume (ac-ft)	Simulate d LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulate d LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulate d LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Jan-Mar	6,082	5,921	-2.6%		2,049	2,360	15.1%		7,856	8,186	4.2%		3,102	3,645	17.5%		**19,089**	**20,112**	**5.4%**	
Apr-Jun	11,555	12,999	12.5%		11,820	11,798	-0.2%		7,478	8,386	12.1%		6,004	5,098	-15.1%		**36,857**	**38,281**	**3.9%**	
Jul-Sep	1,846	4,450	141.0%	121.0%	9,857	11,382	15.5%		4,215	3,947	-6.3%		1,866	2,521	35.1%	15.1%	**17,784**	**22,300**	**25.4%**	**5.4%**
Oct-Dec	909	1,581	73.9%	53.9%	1,975	1,991	0.8%		3,738	3,671	-1.8%		838	850	1.4%		**7,460**	**8,093**	**8.5%**	

Calibration Tolerance =20%

	Recorded USGS Volume (ac-ft)	Simulate d LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulate d LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulate d LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	20,392	24,951	22.4%	12.4%	25,702	27,530	7.1%		23,287	24,191	3.9%		11,810	12,113	2.6%		**81,191**	**88,786**	**9.4%**	

Calibration Tolerance =10%

Table 8-4. High-Low flow error statistics for hydrologic validation results for Oak Creek at USGS gage 04087204 (1999-2002).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	49,109	47,855	2.6%	15%
Total Highest 20% volume	62,405	59,865	4.2%	15%
Total Highest 50% volume	81,144	74,213	9.3%	15%
Total Lowest 10% volume	353	471	-25.0%	10%
Total Lowest 30% volume	2,524	2,653	-4.9%	10%
Total Lowest 50% volume	7,715	7,036	9.7%	10%

Table 8-5. Coefficient of Model Fit Efficiency (E) for the Oak Creek Hydrologic Model (Daily Flows, 1995-2002)

USGS Gage Number	Station Name	E
04087204	Oak Creek at South Milwaukee, WI near the 15th Street Bridge	0.76

REFERENCES

Bicknell, B.R., J.C. Imhoff, J. Kittle, A.S. Donigian, and R.C. Johansen. 1996. *Hydrological Simulation Program –FORTRAN, User's Manual for Release H*. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. *Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage*, 89(IR4): 15-41.

Jensen, M.E., D.C.N. Rob, and C.E. Franzoy. 1969. Scheduling irrigations using climate-crop-soil data. Proceedings, National Conference on Water Resources Engineering of the American Society of Civil Engineers, New Orleans, LA.

Tetra Tech. 2002. Minnesota River Basin Model, Model Calibration and Validation Report. Prepared for Minnesota Pollution Control Agency, St. Paul, MN by Tetra Tech, Inc., Research Triangle Park, NC.

U.S. Environmental Protection Agency (USEPA). 2000. *BASINS Technical Note 6. Estimating Hydrology and Hydraulic Parameters for HSPF*. EPA-823-R00-012. U.S. Environmental Protection Agency. Office of Water. July 2000.

Viessman, W., G.L. Lewis, and J.W. Knapp. 1989. *Introduction to Hydrology*, 3rd Edition. Harper Collins, New York.

Final Memorandum

Project Name:	MMSD – 2020 Facility Planning Project	MMSD Contract No:	M03002P01
DMS Folder Name:	Technology Analysis	MMSD File Code:	M009PE000.P2000
Document Name:	Hydrologic Calibration and Validation Results for the Root River Model (Task 3)	HNTB Charge No:	34568-PL-400-115

Date: October 31, 2007
To: Michael Hahn, SEWRPC
Bill Krill, HNTB
From: Leslie Shoemaker, Tetra Tech, Inc.
Subject: Hydrologic Calibration and Validation Results for the Root River Model (Task 3)

1 EXECUTIVE SUMMARY

An important component of the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU) is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. The purpose of this memorandum is to describe the modeling process and provide the results of the hydrologic and hydraulic calibration and validation of the Root River watershed model.

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for a variety of reasons, including that existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds. The Loading Simulation Program in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms but has the advantage of no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, an LSPC model of the Root River was also developed for the 2020 Facilities Planning Project.

Configuration of the Root River LSPC model involved consideration of five major components: waterbody representation, watershed segmentation, meteorological data, land use representation, and point sources. The representation of the Upper Root River and its tributaries in LSPC is based on the HSPF model provided by the MMSD with several modifications made by the Southeastern Wisconsin Regional Planning Commission (SEWRPC). The structure for the Root River Canal and the Lower Root River is derived from SEWRPC HSP models with modifications supervised by SEWRPC staff. The model was configured to simulate the watershed as a series of 125 hydrologically connected subwatersheds.

The Root River model relies on weather data from four gages. Precipitation for the Upper Root River segments is based on the Milwaukee Metropolitan Sewerage District (MMSD) Rain Gage 1216 and General Mitchell International Airport (GMIA), based on proximity to subwatersheds. Precipitation for the Root River Canal and Lower Root River is based on monitoring performed at Union Grove and the City of Racine, respectively. Air temperature for the Upper Root River is based upon monitoring at GMIA. Air temperature for the Root River Canal and Lower Root River is based on monitoring performed at Union Grove and the City of Racine, respectively. Other climatologic data (e.g., solar radiation, cloud cover, wind speed) are from GMIA.

Land cover for 2000 was provided by SEWRPC. The 2000 land use codes were re-classified to develop the land use representation in the LSPC model. The final land cover representation for the Root River LSPC model indicates that the two most common land covers are urban grasses on C soils (34 percent of the total watershed) and cropland on C soils land cover (23 percent).

There are a number of “point sources” in the Root River watershed, including sanitary sewer overflows (SSOs), waste water treatment plants, and industrial facilities. Flows from these point sources were input directly into the LSPC model using methodology outlined in the December 13, 2004 memorandum entitled *Point Source Loading Calculations for Purposes of Watercourse Modeling*.

The calibration results for the LSPC model indicate good agreement between observed and simulated streamflows for the Upper Root River and fair agreement for the Root River Canal and the Lower Root River. Total flow volumes are well represented for the entire calibration period. The timing of almost all storms is captured, as are the shapes of the hydrographs, although the recession on some storms is slightly slow and over-predicted. The model meets most seasonal and monthly tolerance criteria for the entire calibration period. However, a seasonal bias of the observed data is apparent but not well represented by the model. Winter storm events are often under-predicted and summer storm volume and summer total volume is usually over-predicted by the model. These errors are potentially due to the effects of tile drains or the lack of resolution for the stage-discharge relationships of the Root River Canal and Lower Root River. Similar results are observed for the validation period. Key parameters that were adjusted during the calibration process included those addressing infiltration, lower zone soil capacity, summer storage and evaporation, and snowmelt. The lack of resolution in the lower flow regimes as represented by many of the hydraulic Functional Tables (F-tables) in the model can potentially have a large effect on storm timing and replication of storm peaks. In addition, poor F-table resolution is likely to significantly affect simulation of algal growth and dissolved oxygen concentrations due to errors in the estimation of stream surface area and depth.

2 CONCLUSIONS

The following are the conclusions resulting from the hydrologic calibration and validation process for the Root River model:

- The setup of the final LSPC model has been completed.
- The calibration results for the Upper Root River gages indicate good agreement between observed and simulated streamflows with almost all tolerance criteria being met. The results for the Root River Canal and Lower Root River show less agreement with observed data. This is most likely the result of limited characterization of the stage-discharge relationships in these areas.
- Deviations from criteria can be attributed to uncertainties associated with estimates of urban hydrologic features, primarily:
    - Industrial and other point dischargers
    - Delineation of Directly Connected Impervious Areas (DCIAs)
    - Storm water retention structures
    - Poor resolution of sub-storm event stage-discharge relationships
    - Uncharacterized instream storage capacity

3 RECOMMENDATIONS

We recommend that the hydrologic calibration and validation of the Root River model be considered complete.

4 INTRODUCTION

The Milwaukee Metropolitan Sewerage District (MMSD) is in the midst of a long-range planning effort to identify improvements needed for its facilities to accommodate growth and protect water quality through the year 2020. This effort is known as the MMSD 2020 Facility Plan. A related planning effort is being conducted by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) to update the regional water quality management plan for the Kinnickinnic River, Menomonee River, Milwaukee River, Root River, and Oak Creek watersheds, the Milwaukee Harbor estuary, and the adjacent nearshore Lake Michigan area. This effort is known as the Regional Water Quality Management Plan Update (RWQMPU). The two planning efforts are being coordinated and implemented in parallel.

One important component of both the 2020 Facility Plan and the RWQMPU is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. Watershed models are being developed for the following five watersheds:

- Kinnickinnic River
- Menomonee River
- Milwaukee River
- Oak Creek
- Root River

The Oak Creek, Kinnickinnic, Menomonee, and Milwaukee River models will then be linked to a model of the Lake Michigan estuary so that the benefits of upstream water quality improvements can be simulated by the Lake Michigan Harbor / Estuary Model.

The following seven tasks have been identified for performing the system modeling:

1) Establish the model structure, including the delineation of subwatersheds, connectivity, and cross sections, etc.
2) Develop the model data sets using physical measurements, maps, and other appropriate information
3) Perform hydrologic and hydraulic calibration and validation
4) Perform watercourse water quality calibration and validation
5) Perform harbor/estuary and lake water quality calibration
6) Perform production runs as required for project planning
7) Document results.

The purpose of this report is to document the hydrologic and hydraulic calibration and validation for the Root River watershed model (Task 3). The model being used is described in Section 5.0, Model Description. The configuration of the model, including waterbody representation, watershed segmentation, meteorological data, and land cover representation, is described in Section 6.0, Modeling Approach. The modeling process is described in Section 7.0, Calibration and Validation Process, and the calibration and validation results are presented in Section 8.0, Results of Hydrologic Calibration and Validation.

A separate memorandum documents the water quality calibration process and results (Task 4) and similar reports have been prepared for the Menomonee River, Milwaukee River, Oak Creek, and Kinnickinnic River watersheds.

5 MODEL DESCRIPTION

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. Many watershed models, including the one used for this project, are also capable of simulating in-stream processes using the land-based calculations as input. Once a model has been adequately set up and calibrated for a watershed it can be used to quantify the existing loading of pollutants from subwatersheds or from land cover categories. The model can also be used to simulate the potential impacts of various management alternatives.

The Root River and its tributaries are simulated for this project using the LSPC model which is derived from the Hydrologic Simulation Program in Fortran (HSPF). The HSPF model was originally chosen for the 2020 Facility Planning Project for the following reasons:

- Existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds
- HSPF applies to watersheds with rural, suburban, and urban land uses
- HSPF simulates the necessary constituents: TSS, TN (TKN, NH_4, NH_3, NO_3 and NO_2), TP, Orthophosphate, Fecal Coliforms, Copper and Zinc (as conservative substances), DO, BOD, TOC, Temperature, Benthic Algae, and Chlorophyll-a
- HSPF allows long-term continuous simulations to predict hydrologic variability
- HSPF provides adequate temporal resolution (i.e., hourly or daily) to facilitate a direct comparison to water quality standards

- HSPF simulates both surface runoff and groundwater flows.

A brief description of the HSPF model is provided below.

5.1 Overview of HSPF

HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970's and is generally considered one of the most advanced hydrologic and watershed loading models available. The hydrologic portion of HSPF is based on the Stanford Watershed Model (Crawford and Linsley, 1966), which was one of the pioneering watershed models developed in the 1960's. The HSPF framework is developed in a modular fashion with many different components that can be assembled in different ways, depending on the objectives of the individual project. The model includes three major modules:

- PERLND for simulating watershed processes on pervious land areas
- IMPLND for simulating processes on impervious land areas
- RCHRES for simulating processes in streams and vertically mixed lakes.

All three of these modules include many submodules that calculate the various hydrologic and water quality processes in the watershed. Many options are available for both simplified and complex process formulations. Spatially, the watershed is divided into a series of subbasins representing the drainage areas that contribute to each of the stream reaches. These subbasins are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into the pervious (PERLND) and impervious (IMPLND) fractions. The stream network (RCHRES) links the surface runoff and groundwater flow contributions from each of the land segments and subbasins and routes them through the waterbodies using storage routing techniques. The stream/reservoir model includes precipitation and evaporation from the water surfaces, as well as flow contributions from the watershed, tributaries, and upstream stream reaches. Flow withdrawals can also be accommodated. The stream network is constructed to represent all of the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur.

Like the watershed components, several options are available for simulating water quality in the receiving waters. The simpler options consider transport through the waterways and represent all transformations and removal processes using simple first-order decay approaches. More advanced options for simulating nutrient cycling and biological processes are also available. The framework is flexible and allows different combinations of constituents to be modeled depending on data availability and the objectives of the study. A more detailed discussion of HSPF simulated processes and model parameters will be presented in the Root River water quality report and is also available in the HSPF User's Manual (Bicknell et al., 1996).

5.2 Overview of Loading Simulation Program in C++

The Loading Simulation Program, in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms for simulating hydrology, sediment, and general water quality on land as well as in the water column. LSPC is currently maintained by the EPA Office of Research and Development in Athens, Georgia, and during the past several years it has been used to develop hundreds of water quality restoration plans across the country through the Clean Water Act Total Maximum Daily Load (TMDL) Program. A key advantage of LSPC is that it has no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original Upper Root River HSPF model has been migrated to LSPC for the 2020 Facilities Planning Project. A memorandum dated October 18, 2004 (*Confirmation of the Underwood Creek LSPC Model using selected HSPF Modules)* presents the results of a benchmark testing methodology that was developed to compare the underlying computational algorithms of the LSPC model to known HSPF solutions for Underwood Creek, a tributary to the Menomonee River. Near identical results were found between the two models.

6 MODELING APPROACH

The Root River watershed lies to the south of the City of Milwaukee and drains to Lake Michigan through the City of Racine. The Root River watershed contains approximately 197 square miles in portions of Milwaukee, Waukesha, Racine and Kenosha Counties. The portion of the watershed contained within the MMSD watercourse planning area includes the area located upstream of the Root River Canal confluence as well as the Crayfish Creek drainage basin. These two areas have a drainage area equal to approximately 65 square miles, and are contained within portions of Racine, Waukesha and Milwaukee Counties. The Root River watershed discharges into Lake Michigan and is surrounded by the Menomonee River, Kinnickinnic River, Fox River, Des Plaines River, Pike River and Oak Creek Watersheds. The watershed drains portions of 18 municipalities within these 4 counties. The upper portion of the Root River Watershed is mostly urbanized with the only "undeveloped" land contained within limited agricultural areas, parkland, cemeteries, and the stream corridor. The Root River Canal watershed is primarily agricultural, while the Lower Root River contains agricultural lands before transitioning into urbanized development in the City of Racine

Configuration of the Root River LSPC model involved consideration of five major components: waterbody representation, watershed segmentation, meteorological data, land use representation, and point sources. These components provide the basis for the model's ability to estimate flow and water quality and are described in greater detail below.

6.1 Waterbody Representation

The Root River watershed is shown in Figure 1. Within the MMSD watercourse planning area there are nine streams for which the MMSD has assumed jurisdiction., These streams have a total perennial length equal to approximately 24.9 miles. The streams, along with the length under MMSD jurisdiction, are the North Branch Root River (16.5 miles), the East Branch Root River (4.7 miles), Tess Corner's Creek (2.6 miles), Whitnall Park Creek (1.8 miles), North Branch Whitnall Park Creek (0.8 miles), Northwest Branch of Whitnall Park Creek (0.4 miles), Crayfish Creek (0.5 miles), Caledonia Branch of Crayfish Creek (0.4 miles) and an unnamed tributary to the Root River (unofficially referred to as the 104th Street Branch) (0.4 miles). Outside of the MMSD watercourse planning area, major streams in the Root River watershed consists of the West Branch of the Root River Canal (perennial length of 10.4 miles), the East Branch of the Root River Canal (11.6 miles), Root River Canal (5.8 miles), Hoods Creek (9.2 miles), Husher's Creek (3.5 miles) and the Lower Root River (25.6 miles).

Modeling an entire watershed requires routing flow and pollutants from upstream portions of the watershed to the watershed outlet through the stream network. In LSPC, the stream network is a tabular representation of the actual stream system. Attribute data pair individual stream segments with a corresponding delineated subbasin. Data associated with individual reaches identify the location of the particular reach within the overall stream network, defining the connectivity of the subwatersheds.

The representation of the Lower Root River and its major tributaries in LSPC is based on HEC-2 hydrologic models provided by SEWRPC. Similarly, representation of the North Branch of the Root River and its major tributaries is based on HEC-RAS models developed for the MMSD. Changes to the original MMSD HSPF model for the Upper Root River model are documented in a memorandum dated November 5, 2004 (*Draft Task 1 Deliverables Memorandum and Associated Appendices*). Changes consisted mainly of redirecting runoff from subbasins to different routing reaches. A schematic representation of the final Root River LSPC model is presented in Appendix A. The origin of the HSPF watershed / watercourse model for the Upper Root River is described in detail in the April 11, 2003 Technical Memorandum, *Characterize Existing Watershed / Watercourse Models.*

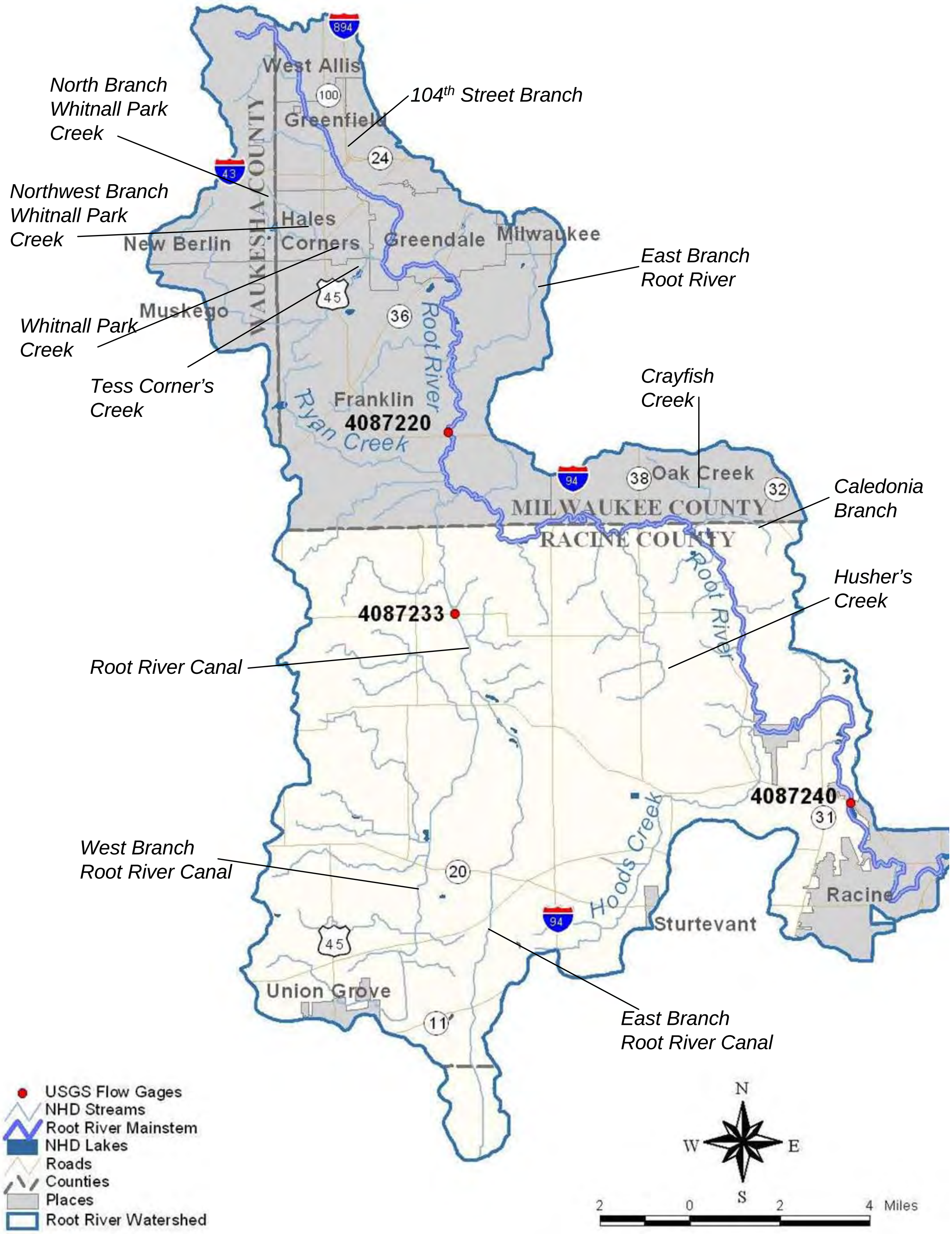


Figure 1. Location of the Root River watershed.

6.2 Watershed Segmentation

LSPC was configured for the Root River to simulate the watershed as a series of 125 hydrologically connected subwatersheds. The delineation of the subwatersheds was based partially on topography but also took into consideration human-influenced drainage patterns. The spatial subdivision of the watershed allows for a more refined representation of pollutant sources and a more realistic description of hydrologic factors. The subwatersheds and primary streams in the Root River watershed are shown in Figure 2. Inflows to the Root River from sanitary sewers are input directly to the LSPC model based on observed SSO data.

Many of the F-tables, which represent the hydraulic structure of the watercourse in LSPC, are derived from HEC-RAS and HEC-2 models obtained from SEWRPC for the Lower Root River and its major tributaries. A series of escalating flows were input into the HEC-2 and HEC-RAS models to determine the stage, volume, surface area, and discharge relationships. A similar method had been used to develop F-tables for the original MMSD HSPF model for the Upper Root River basin.

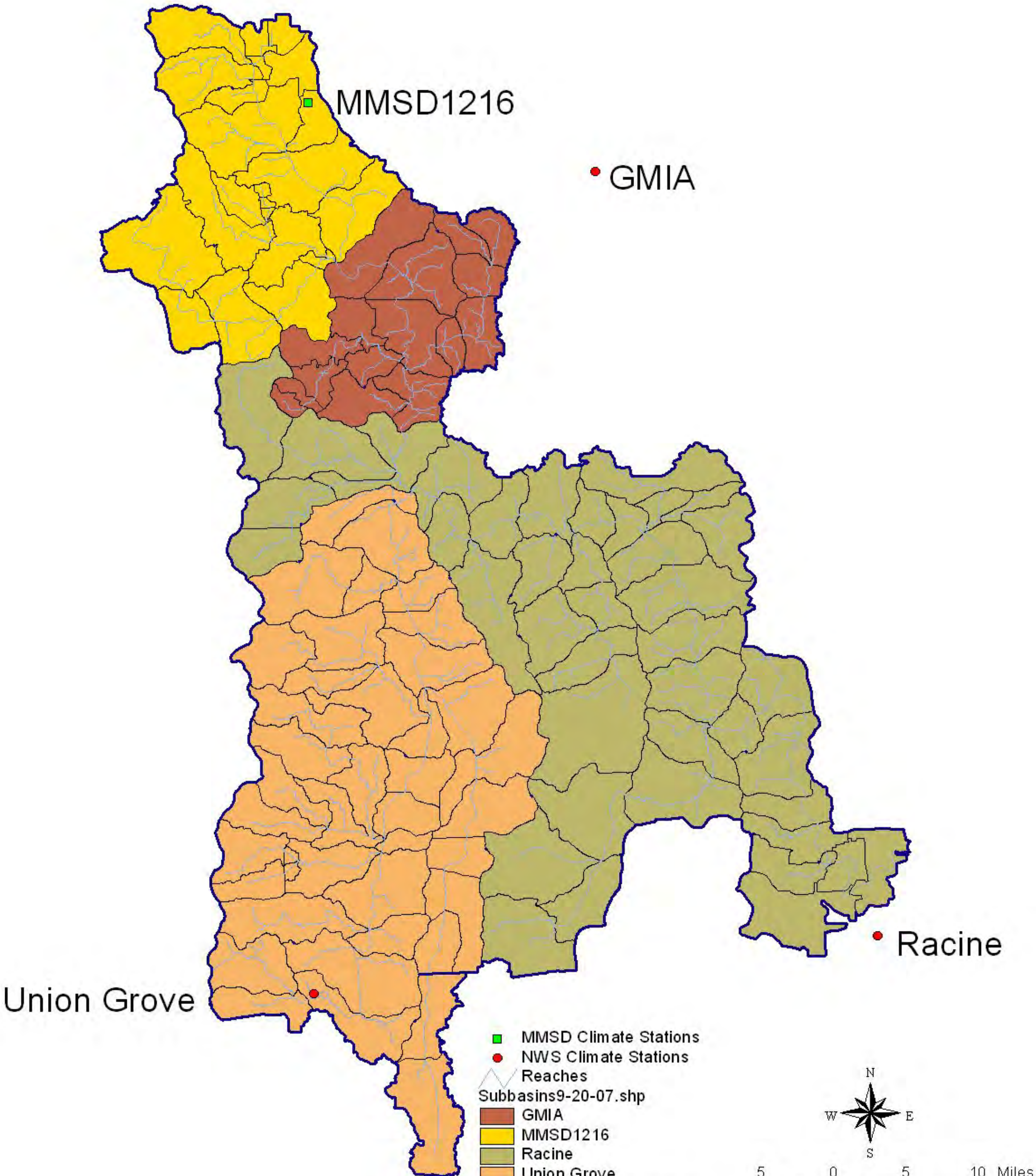


Figure 2. Root River LSPC modeling subwatersheds and location of weather stations.

6.3 Weather Data

Hydrologic processes are time varying and depend on changes in environmental conditions including precipitation, temperature, and wind speed. As a result, meteorological data are a critical component of the watershed model. Appropriate representation of precipitation, wind movement, solar radiation, potential evapotranspiration, cloud cover, temperature, and dew point are required to develop a valid model. These data provide necessary input to model algorithms for hydrologic and water quality representation.

The Root River model relies on precipitation data from four stations as shown in Figure 2:

- MMSD station 1216
- Racine (National Weather Services (NWS) cooperating observer station 476922)
- GMIA (NWS 475479)
- Union Grove (NWS 478723)

The model simulation is based on relatively sparse rain gage data, and large portions of the watershed are simulated based on a single rain gage that may not be representative of average precipitation across the assigned area. This may lead to problems in matching hydrographs observed for individual storm events.

Air temperature for the Upper Root River is based upon monitoring at GMIA. Air temperature for the Root River Canal and Lower Root River is based on monitoring performed at Union Grove and the City of Racine, respectively.

Data for the following additional meteorological parameters required by the LSPC model use observations from GMIA:

- Cloud cover
- Wind movement
- Solar radiation
- Potential evapotranspiration
- Dew point

Precipitation, temperature, cloud cover, wind speed, and dew point are gage monitored, while potential evapotranspiration (PEVT) and solar radiation was computed. Model performance is particularly sensitive to PEVT, as this controls the fraction of precipitation that is evaporated back to the atmosphere. A variety of methods are available for estimation of PEVT, each yielding slightly different results. SEWRPC provided a time series of PEVT calculated for GMIA using the Penman method, which calculates PEVT by first estimating evaporation from a standard Class A evaporation pan, then converts it to a PEVT estimate by application of a monthly coefficient.

6.4 Land Cover Representation

LSPC requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the basin, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices.

Land cover classifications from the SEWRPC 2000 land use codes were used to develop the land cover representation in the LSPC model. Included below is a table that defines specific terminology associated with the processes of deriving land cover classifications from SEWRPC land use codes.

Table 1. Terminology associated with the process of deriving land cover classifications from SEWRPC land use codes.

Land Use Terminology	Definition
Land Use Code	A SEWRPC three-digit code that describes the land use for a specified area.
Land Use Group	A simplification of the land use codes into groups of several land use codes which share hydrologic and water quality characteristics.
Land Use Category	SEWRPC term that corresponds to the definition of land use group, with slight variation in name and number.
Land Cover Classification	A classification of soil composition and natural or manmade land practices which comprises a portion or all of a land use.

The original HSPF models were developed during the MMSD Phase 1 Watercourse Management Plans (WMPs) as documented in the April 11, 2003 Technical Memorandum, Characterize *Existing Watershed / Watercourse Models.*

Six pervious land covers and a single impervious land cover were used to model hydrology and surface runoff in the Phase 1 WMP models. The pervious land covers are subdivided by the hydrologic soil group identified in the soil surveys. The MMSD Phase 1 WMP model land covers are listed below:

- Impervious
- Lawn / B Soil
- Lawn / C Soil
- Forest
- Agriculture / B Soil
- Agriculture / C Soil
- Wetland

To develop the distribution of these land covers throughout a single subbasin, the following procedures were completed in the Phase 1 WMP Models:

1. The 1990 SEWRPC Land Use Codes were categorized into 20 MMSD Phase 1 WMP land use groups.
2. The 20 MMSD Phase 1 WMP land use groups were reclassified into the seven selected HSPF land covers.
3. The final HSPF land cover input for modeling is an aggregate summation of the reclassified MMSD Phase 1 WMP landuse areas.

This procedure was revised for an expanded number of land use groups (25) and land cover classifications (17 – 6 impervious and 11 pervious) and documented in the October 27, 2003 Technical Memorandum *Definition of HSPF Land Cover Classifications.* Figure 3 displays the distribution of these 25 land use groups within the basin.

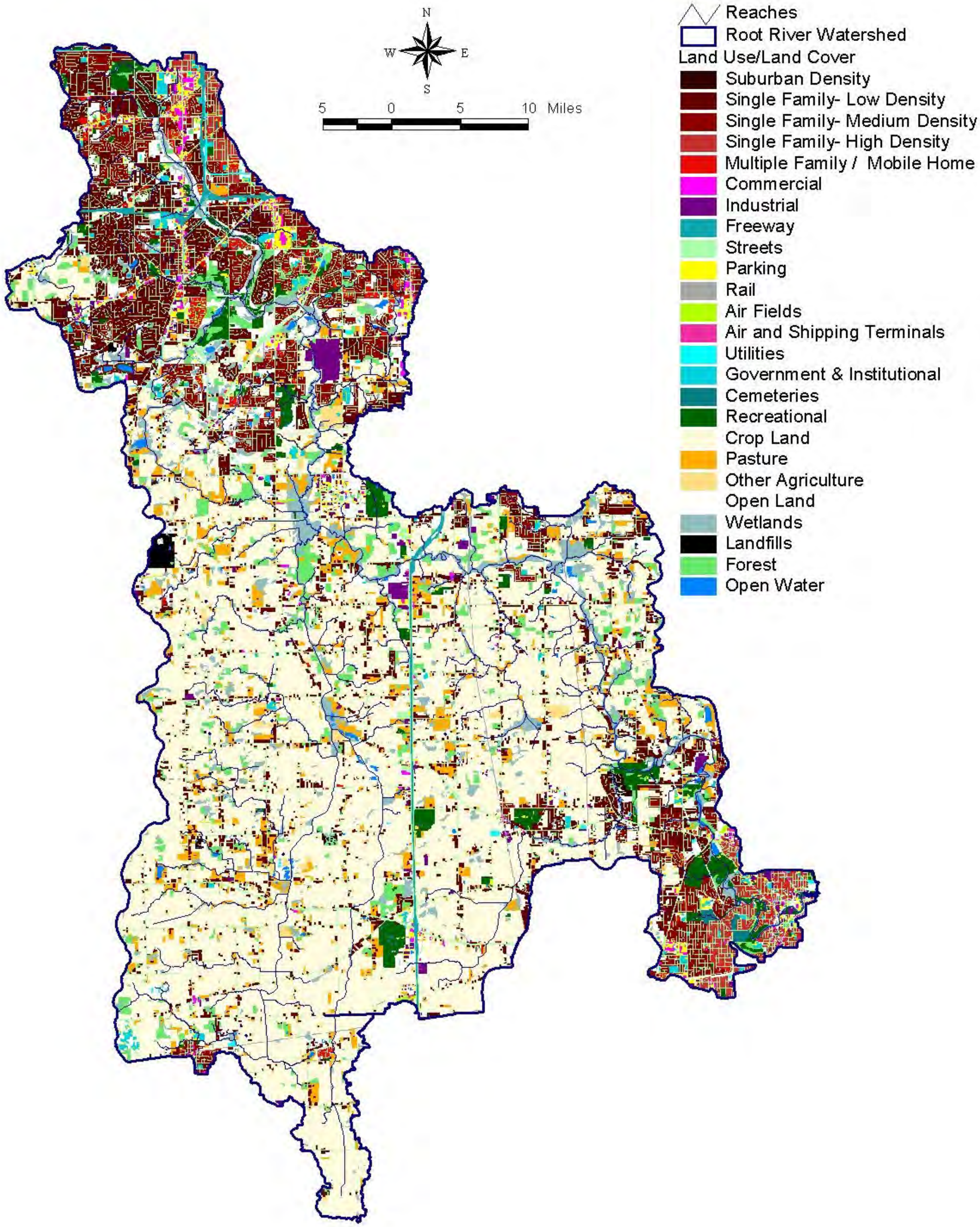


Figure 3. Land use in the Root River watershed.

The model algorithms require that each land use group be represented as separate pervious and impervious land units. Pervious land uses are further categorized by NRCS hydrologic soil groups. The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting. Typically, clay soils that are poorly drained have lower infiltration rates, while well-drained sandy soils have the greatest infiltration rates. NRCS (2001) has defined four hydrologic groups for soils as listed in Table 2. The final land cover representation for the Root River LSPC model is summarized in Table 3 and indicates that the two most common land covers are grasses on C soils (34 percent) and cropland on C soils land uses (23 percent).

Review of available data indicate that tile drain systems are commonly used in the Root River Canal and the Lower Root River drainages. While these tile drains are not directly modeled in HPSF, hydrological parameter values for cropland were adjusted to partially capture the hydrological behavior seen in these two watersheds.

Table 2. NRCS Hydrologic Soil Groups

Hydrologic Soil Group	Description
A	Soils with high infiltrations rates. Usually deep, well drained sands or gravels. Little surface runoff.
B	Soils with moderate infiltration rates. Usually moderately deep, moderately well drained soils.
C	Soils with slow infiltration rates. Soils with finer textures and slow water movement.
D	Soils with very slow infiltration rates. Soils with high clay content and poor drainage. High amounts of runoff.

Table 3. Modeling land cover in the Root River watershed.

Category	Land Cover	Area		Percent of Watershed
		Acres	Square Miles	
IMPERVIOUS	COMMERCIAL	6,872.4	10.74	5.51
	GOVT_INSTIT	264.1	0.41	0.21
	INDUSTRIAL	588.4	0.92	0.47
	RESIDENTIAL	2,842.6	4.44	2.28
	TRANS_FREE	590.4	0.92	0.47
	ULTRA_LOW	1,173.6	1.83	0.94
PERVIOUS	CROP_B	3907.4	6.11	3.13
	CROP_C	28703.0	44.85	23.0
	CROP_D	4000.8	6.25	3.21
	FOREST	5718.8	8.94	4.58
	GRASS_B	11200.0	17.50	8.98
	GRASS_C	42357.1	66.18	33.95
	GRASS_D	2217.4	3.46	1.78
	PASTURE_B	575.7	0.90	0.46
	PASTURE_C	4836.4	7.56	3.88
	PASTURE_D	1088.5	1.70	0.87
	WETLAND	7843.1	12.25	6.29
	Total	**124,779.8**	**194.97**	**100**

6.5 Point Sources

There are a number of “point sources” in the Root River watershed. These consist of sanitary sewer overflows (SSOs) and discharges from fourteen industrial facilities. Flows from these point sources were input directly into the LSPC model using methodology outlined in the December 13, 2004 memorandum entitled *Point Source Loading Calculations for Purposes of Watercourse Modeling*.

7 CALIBRATION AND VALIDATION PROCESS

The model calibration and validation processes are described in this section. Background information on the locations of available flow data and the time periods of calibration/validation are first presented, followed by a description of how key parameters were modified.

7.1 Background

Hydrologic calibration of the Root River model was performed after configuring the LSPC model. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. For LSPC, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. It is required for parameters that cannot be deterministically and uniquely evaluated from topographic, climatic, physical, and chemical characteristics of the watershed and compounds of interest. Fortunately, the majority of LSPC parameters do not fall in this category. Calibration is based on several years of simulation to allow parameter evaluation under a variety of climatic conditions. The calibration procedure results in parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period.

Calibration included the comparison of monthly, seasonal, and annual values, and individual storm events. All of these comparisons must be evaluated for a proper calibration of hydrologic parameters. In addition, simulated and observed stream flow values were analyzed on a frequency basis and their resulting cumulative distributions (e.g., flow duration curves) compared to assess the model behavior and agreement over the full range of observations.

Model validation tested the performance of the calibrated model using a different time period, without further parameter adjustment. If the model cannot properly simulate conditions for the independent data set, the calibration is not acceptable and requires additional work until validation is achieved. As described in the January 14, 2004 *Watershed and Receiving Water Quality Model Calibration and Validation Data and Procedures* memorandum, the calibration time period was January 1, 1995 through December 31, 1998. The validation time period was January 1, 1999 through December 31, 2002. To permit model spin up time and minimize numerical errors inherent in modeling, the model was run for the time period January 1, 1994 to December 31, 1998 for calibration purposes.

The model calibration and validation was performed using the flow record from the USGS gages on the Root River near Franklin (USGS gage 04087220), Root River Canal (USGS gage 04087233), and Root River at Racine (USGS gage 04087240). Figure 1 shows the location of the gages used for model calibration and validation.

7.2 Calibration

Hydrologic calibration involved a comparison of observed data from the in-stream USGS flow gaging station to modeled in-stream flow and an adjustment of key hydrologic parameters. Various modeling parameters were varied within physically realistic bounds and in accordance to observed temporal trends and land cover classifications. An attempt was made to remain within the guidelines for parameter values set out in BASINS Technical Note 6 (USEPA, 2000) and to remain consistent with the calibration parameters used for the Menomonee River, Oak Creek, and Kinnickinnic River watersheds. The intent was to develop a unified parameter set in which most variations between watersheds are explained by documented differences in land cover and physical parameters such as soil characteristics. This approach was successful for the Upper Root River which has fairly detailed stage-discharge relationships for each reach. The stage-discharge relationships for the Root River Canal and Lower Root River were based on extreme event HEC-2 modeling. In many cases, these HEC-2 models only described flows above those recorded at any time during the calibration and validation period and the cross-sections did not resolve the low flow channel adequately to simulate stage-discharge responses at flows below bankfull. Flows below extreme event stage are therefore represented by the model as a linear stage-discharge relationship that leads to considerable uncertainty in the shape and timing of flow response.

Graphical results of model performance and error statistics were evaluated following each model simulation run. Model parameters were adjusted following each iteration to improve model performance.
The parameters that were adjusted include those that account for the partitioning of surface versus subsurface flow, infiltration rate, surface and subsurface storage, evapotranspiration, and surface runoff. The full set hydrologic parameters from the original calibration can be seen in the file *RootHydro.inp* and a discussion of the key parameters and how they were adjusted is presented below.

The model performance is most sensitive to the specification of the water-holding capacity of the soil profile (expressed through LZSN, the nominal lower-zone storage) and the infiltration rate index (INFILT), which together control the partitioning of water between surface and subsurface flow. LZSN is an index of nominal storage of water in the soil zone subject to evapotranspiration (root depth plus capillary fringe), while LZS represents the actual water storage in this zone. LZSN is often characterized as the median of field capacity storage in this zone (i.e., available water capacity times rooting depth with capillary fringe). Functionally, however, the meaning of LZS and LZSN may differ somewhat from this ideal interpretation. LZS does represent the depth of water that is available for transpiration from the soil; however, this value may exceed LZSN by a significant amount. More important to the ratio is the ratio LZRAT (LZS/LZSN). This ratio (in inverse form) first determines the variation of actual infiltration rate relative to the nominal value, INFILT. LZRAT also determines the rate at which water percolates from the lower soil zone to groundwater. LZSN thus varies with precipitation pattern as well as vegetation type. In addition, it is difficult to relate LZSN to a single vegetation type, because a dominant vegetation (e.g., grass) with a low rooting depth may also contain other plants (e.g., trees) with a much greater rooting depth, which increases the amount of soil moisture that is available for ET. As a result, while initial values of LZSN can be estimated from soils and vegetation data, final values must be determined through calibration.

Viessman et al. (1989) suggest as initial estimates for LZSN a value between one-quarter and one-eighth of the annual rainfall plus four inches. USEPA (2000) show values for LZSN ranging from 5 inches to 14 inches in typical applications. Values found through calibration for the Root watershed are well within this range. LZSN values in the range of 7 to 9 inches (with lower values for wetlands) provided reasonable results in the calibration of the Root River watershed model.

INFILT in HSPF is an *index* of infiltration rate and is not directly interpretable from measured field infiltration rates. BASINS Technical Note 6 recommends values in the range of 0.1 to 0.4 for B soils, 0.05 to 0.1 for C soils, and 0.01 to 0.05 in/hr for D soils. Values were re-optimized by starting from the center of the recommended ranges and modifying the value for each soil class proportionately – yielding final values of 0.260 to 0.320, 0.06 to 0.095, and 0.035 to 0.055 for B, C, and D soils, respectively. For each soil group, the higher values were applied to the Upper Root River watersheds, while the lower values were applied to the Root River Canal and Lower Root River watersheds to account for poorly drained soils.

Key parameters for the subsurface flow response include the ground water recession coefficient (AGWRC), and the interflow inflow (INTFW). AGWRC was set by optimizing model performance for baseflow recession, with relative variation among land uses and subwatersheds based on past experience, resulting in initial values from 0.901-0.970. Interflow inflow was initially set in the range of 1 to 3.

Monthly variability in hydrologic response was specified by setting monthly values for interflow inflow, the interflow recession coefficient, the upper zone nominal soil storage, and the lower zone ET parameter. In each case, the values specified are consistent with recommendations in BASINS Technical Note 6, as well as experience in calibrating multiple HSPF models for the Minnesota River basin (Tetra Tech, 2002). The greatest deviation from the parameter set used for the Menomonee River model occurs in the summer monthly values. The Root River Canal and Lower Root River exhibited consistent overestimation of summer volume and summer storm volumes. These areas have a much higher percentage of cropland and are also partially drained by tile systems. Parameter values for interception, storage, and evaporation during the period from May through September were increased to represent these factors.

For the winter simulation, the model is very sensitive to parameters that control snow accumulation and snowmelt. Considerable uncertainty is present in hydrologic models when temperatures are near the transition point between liquid and frozen precipitation, and prediction of rain-on-snow melting events can be particularly difficult. Key calibration parameters for the winter snow simulation were revised from defaults during optimization and included the snow catch factor (CCFACT, ratio that accounts for under-catch of snow in standard precipitation gages), the field adjustment parameter for heat accumulation in the snow pack (CCFACT), the maximum rate of snow melt by ground heating (MGMELT), and the depth of snow at which all land area is considered to be covered (COVIND, set to a higher value for impervious lands to account for snow removal/consolidation).

8 RESULTS OF HYDROLOGIC CALIBRATION AND VALIDATION

The model calibration results are presented in this section both graphically and statistically. Graphical comparisons are extremely useful for judging the results of model calibration because time-variable plots of observed versus modeled flow provide insight into the model's representation of storm hydrographs, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. Graphing model results with precipitation data can also provide insights into how the model reacts to different storms. Graphical comparisons consist of time series plots of observed and simulated values for flows, observed versus simulated scatter plots with a 45^{o} linear regression line displayed, and cumulative frequency distributions (flow duration curves). Statistical comparisons focus on the relative error method. A small relative error indicates a better goodness of fit for calibration. Secondly, results from correlation tests (e.g. linear correlation coefficient, coefficient of model-fit efficiency, etc.) are also presented.

8.1 Tolerances

Model tolerance values for this project have been identified and are described in the January 14, 2004 *Watershed and Receiving Water Quality Model Calibration and Validation Data and Procedures* memorandum and in the December 18, 2002, *MMSD Comprehensive Modeling and Real Time Control Strategies* Technical Memorandum 2.4. Hydrologic parameters to be calibrated include annual flow volumes, low flow volumes, storm flow volumes, and seasonal flow volumes. The following tolerances (i.e., accepted level of error between modeled and observed flows) are used:

Total runoff volume: ± 10 percent
High flow volumes: ± 15 percent
Low flow volumes: ± 15 percent
Seasonal flow volumes: ± 20 percent
Error in storm volumes: ± 20 percent[1]

The same tolerances are used for model validation. Error statistics are calculated for each month and year of the calibration time period; however, a calibration is deemed appropriate when the tolerances for the entire calibration period have been met. The same applies for the validation period.

8.2 Calibration and Validation Results

The calibration and validation results are presented separately for each of the three USGS gages.

8.2.1 Root River at USGS gage 04087220

The calibration and validation results for the Root River at USGS gage 04087220 are presented below in Figure 4 through Figure 23 and in Table 4 through Table 7. These results indicate good agreement between observed and simulated streamflows. Baseflows are well represented for each season for the entire calibration period. The timing of almost all storms is captured, as are the shapes of the hydrographs, although the recession on some storms is slightly slow and over-predicted. The timing and magnitude of most snowmelt events appears to be well simulated, although a few are shifted early or late by a few days. Most large storms are well simulated. The composite graphs shown in Figure 12 and Figure 22 indicate the model simulates seasonal patterns for fall and winter fairly effectively but overestimates flow in the late spring and the summer. The observed and simulated cumulative flow duration curves are aligned fairly well with one another, with the model overpredicting moderate-to-high flows and underpredicting the lowest flows.

The quality of hydrologic model fit for individual daily observations is summarized by the Nash-Sutcliffe coefficient of model fit efficiency (E). This parameter ranges from minus infinity to 1, with higher values indicating better fit, and is formed as the ratio of the mean square error to the variance in the observed data, subtracted from unity. A value of 0 implies that the observed mean is as good a predictor as the model. Values close to 1 are thus desirable. It should be recalled, however, that the Nash-Sutcliffe coefficient is based on matched daily records, and does not account for phase errors. It is also subject to leverage by outliers. Thus, if a large flow is estimated with the right magnitude, but off by one day, this can substantially degrade the Nash-Sutcliffe coefficient, even though annual sums and flow duration percentiles are unaffected.

The Nash-Sutcliffe coefficient was not used in the model calibration process. Therefore, it is appropriate to use it as post-validation model evaluation tool applied over the entire calibration and validation period of 1995 to 2002. Results for the Root River gages are shown in Table 16. The results are satisfactory for the two Root River gages, with a poorer quality of fit for the Root River Canal, as expected from the results presented above.

[1] A comparison of simulated and observed storm hydrographs for selected storm events is addressed in a separate memorandum.

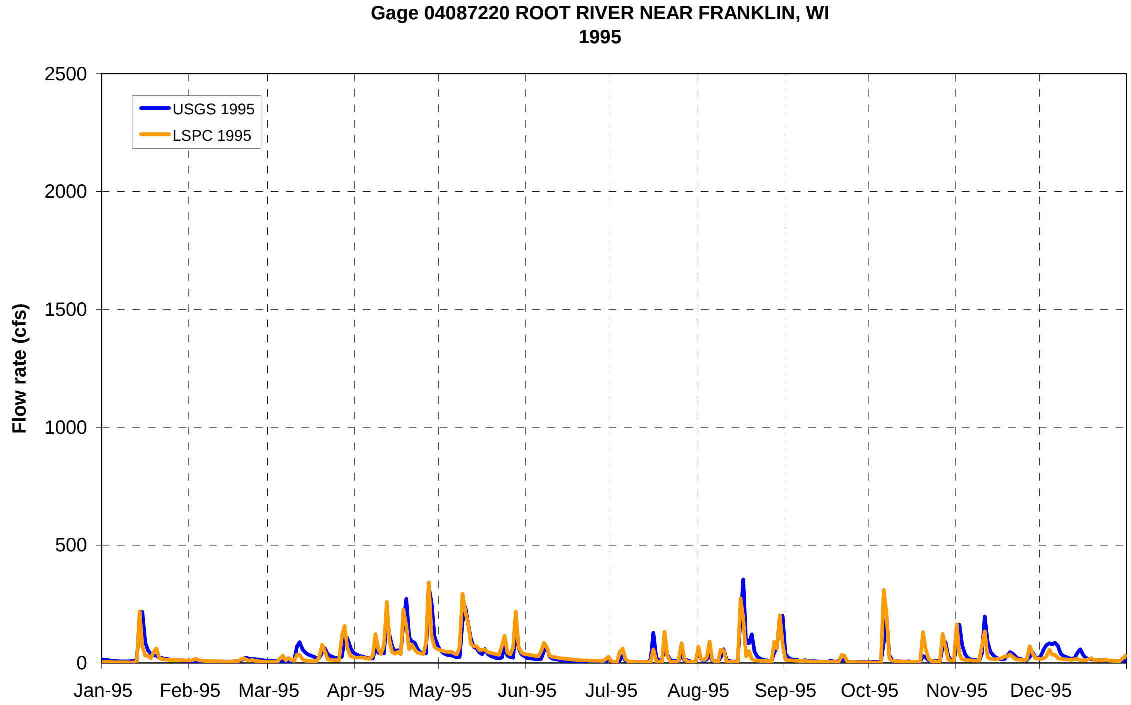


Figure 4. Time series hydrologic calibration results (daily mean) for the Upper Root River at USGS gage 04087220 (1995).

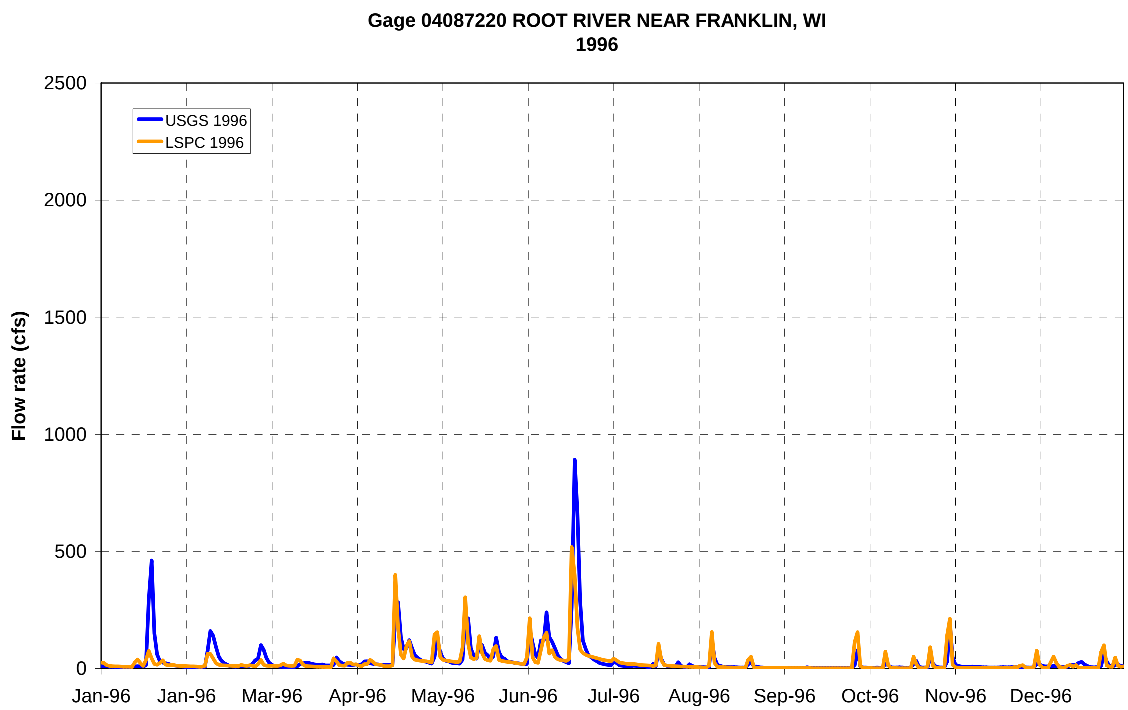


Figure 5. Time series hydrologic calibration results (daily mean) for the Upper Root River at USGS gage 04087220 (1996).

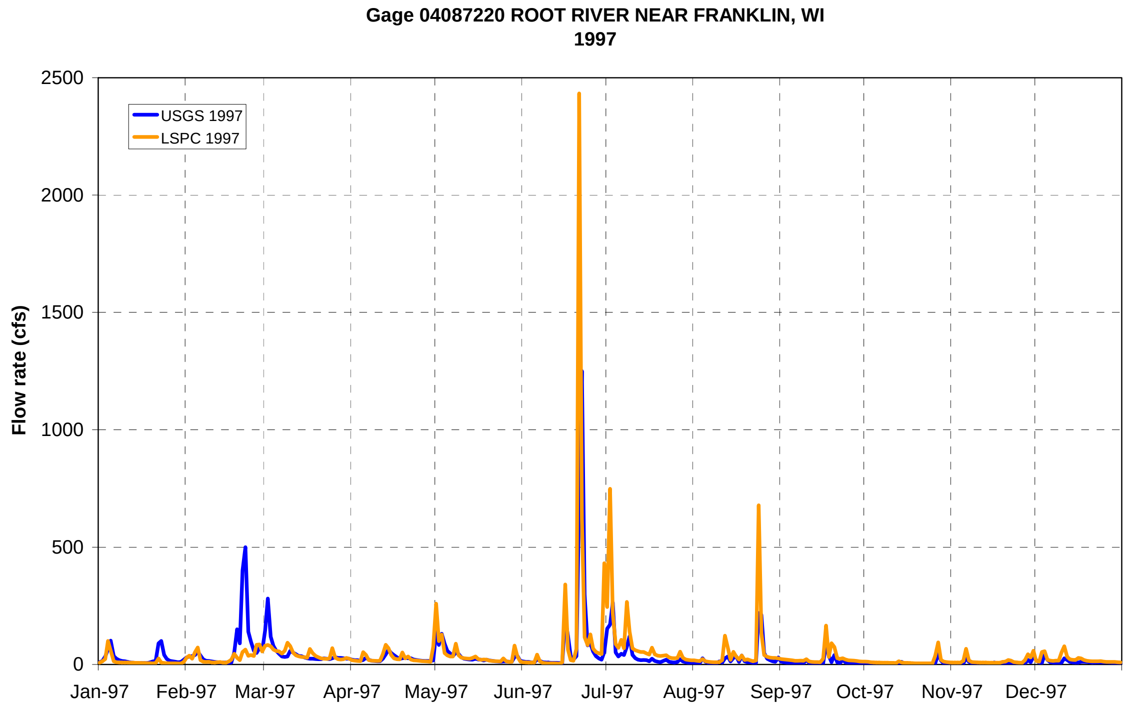


Figure 6. Time series hydrologic calibration results (daily mean) for the Upper Root River at USGS gage 04087220 (1997).

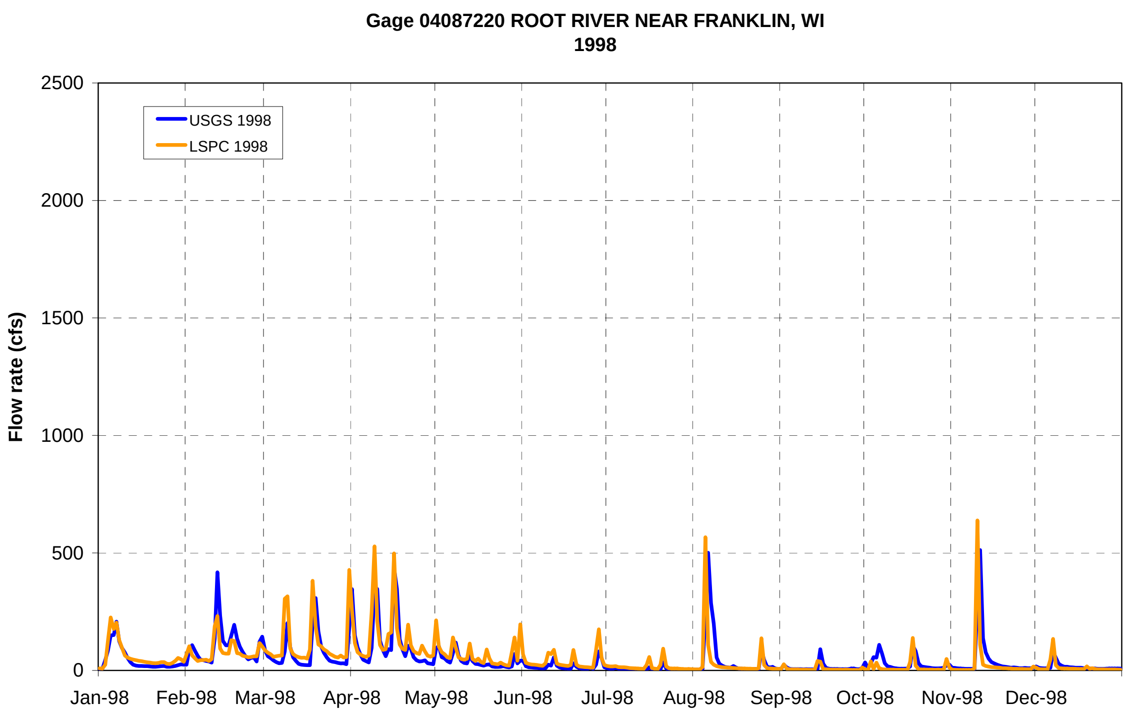


Figure 7. Time series hydrologic calibration results (daily mean) for the Upper Root River at USGS gage 04087220 (1998).

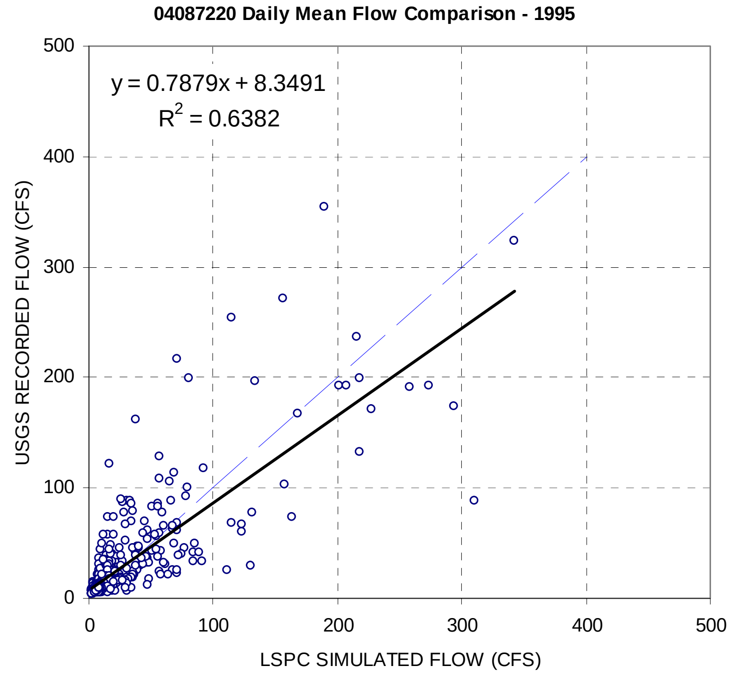


Figure 8. Observed versus simulated scatter plot with a linear regression line for the Upper Root River at USGS gage 04087220 (1995).

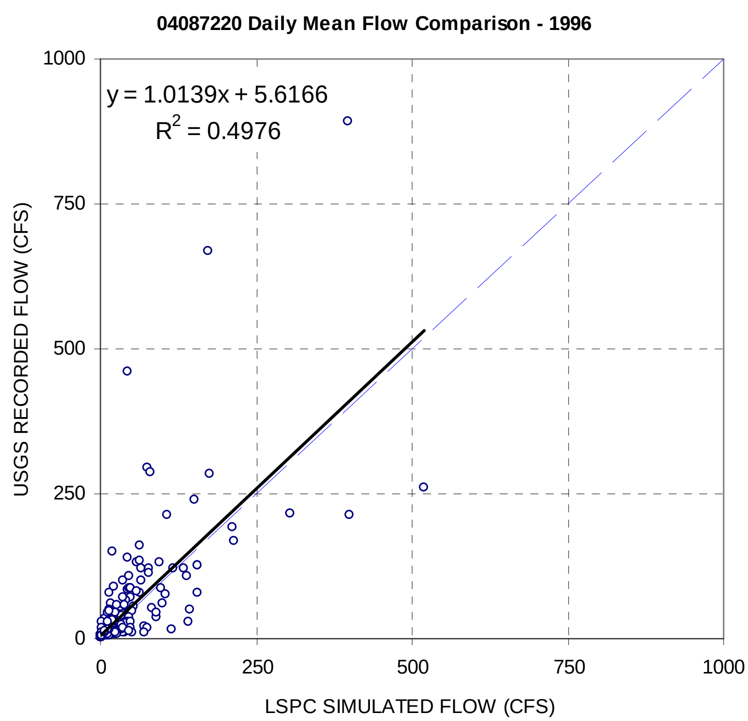


Figure 9. Observed versus simulated scatter plot with a linear regression line for the Upper Root River at USGS gage 04087220 (1996).

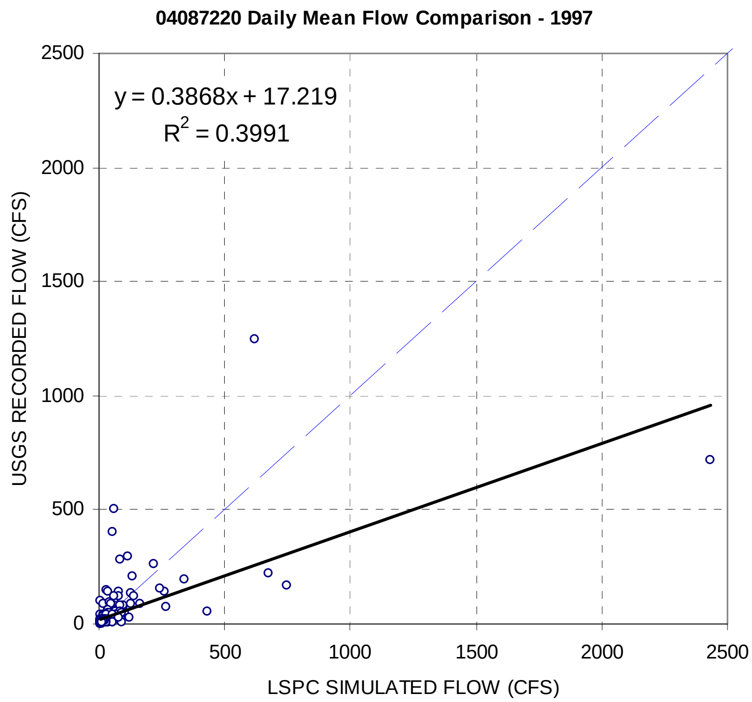


Figure 10. Observed versus simulated scatter plot with a linear regression line for the Upper Root River at USGS gage 04087220 (1997).

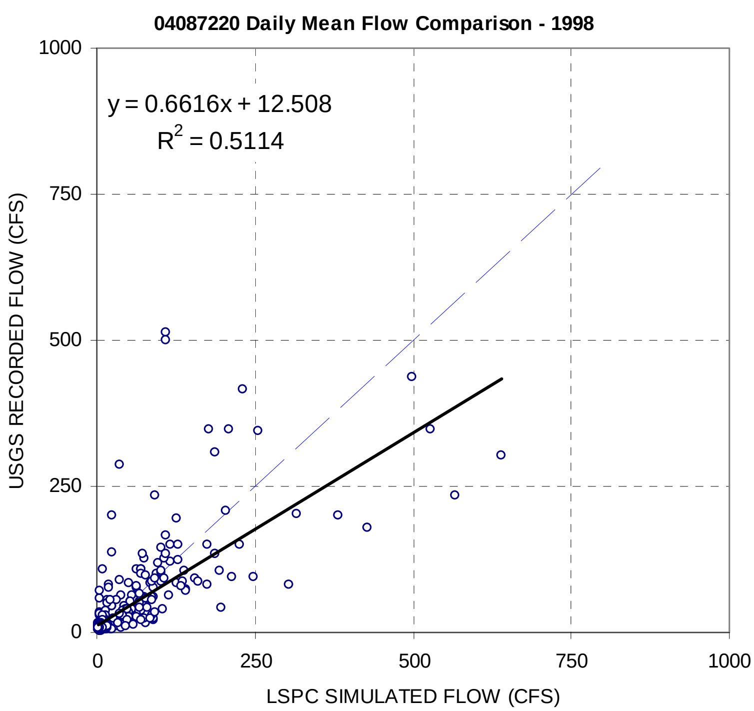


Figure 11. Observed versus simulated scatter plot with a linear regression line for the Upper Root River at USGS gage 04087220 (1998).

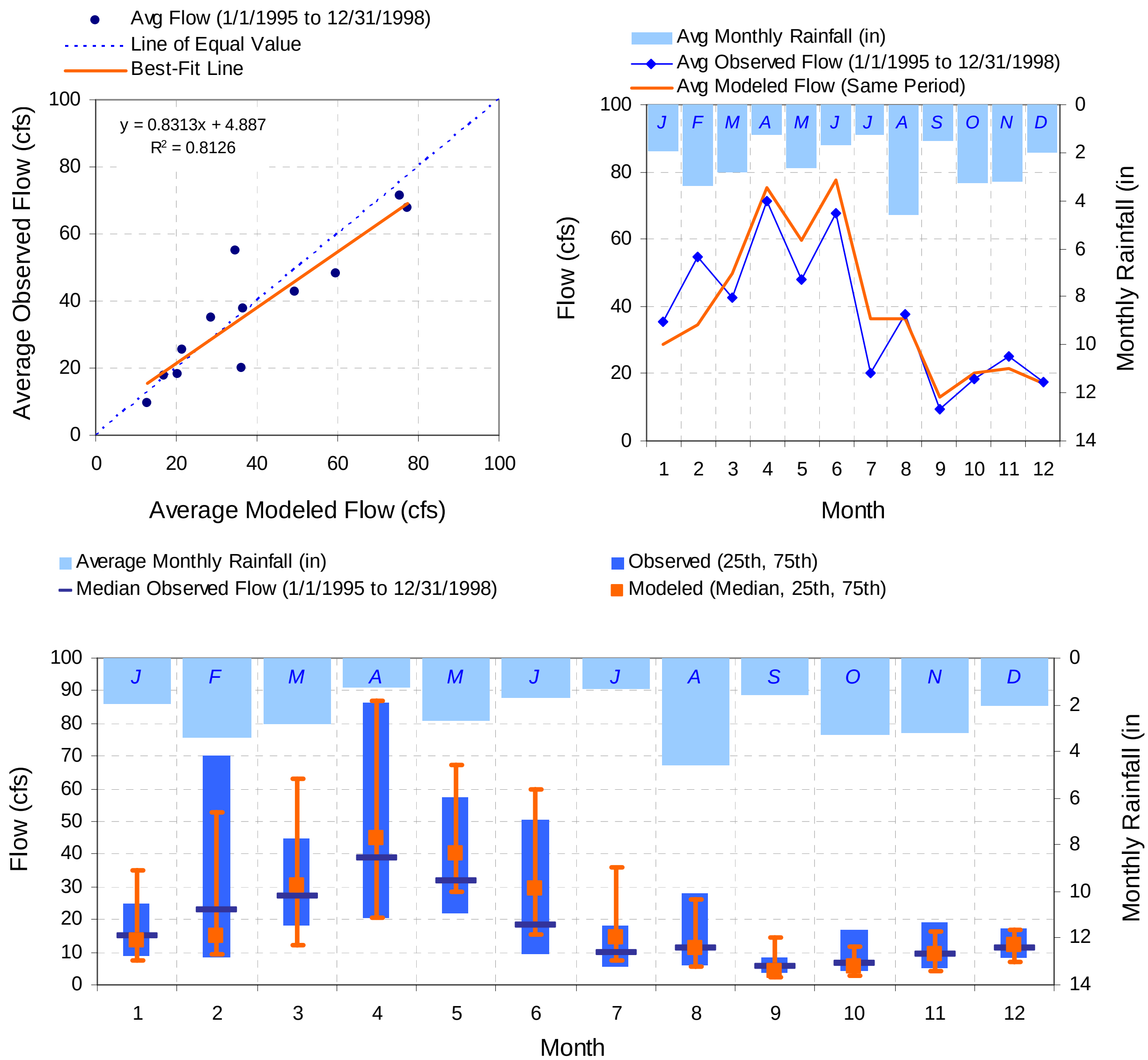


Figure 12. Composite (average monthly) hydrologic calibration results for the Upper Root River at USGS gage 04087220 (1995 to 1998).

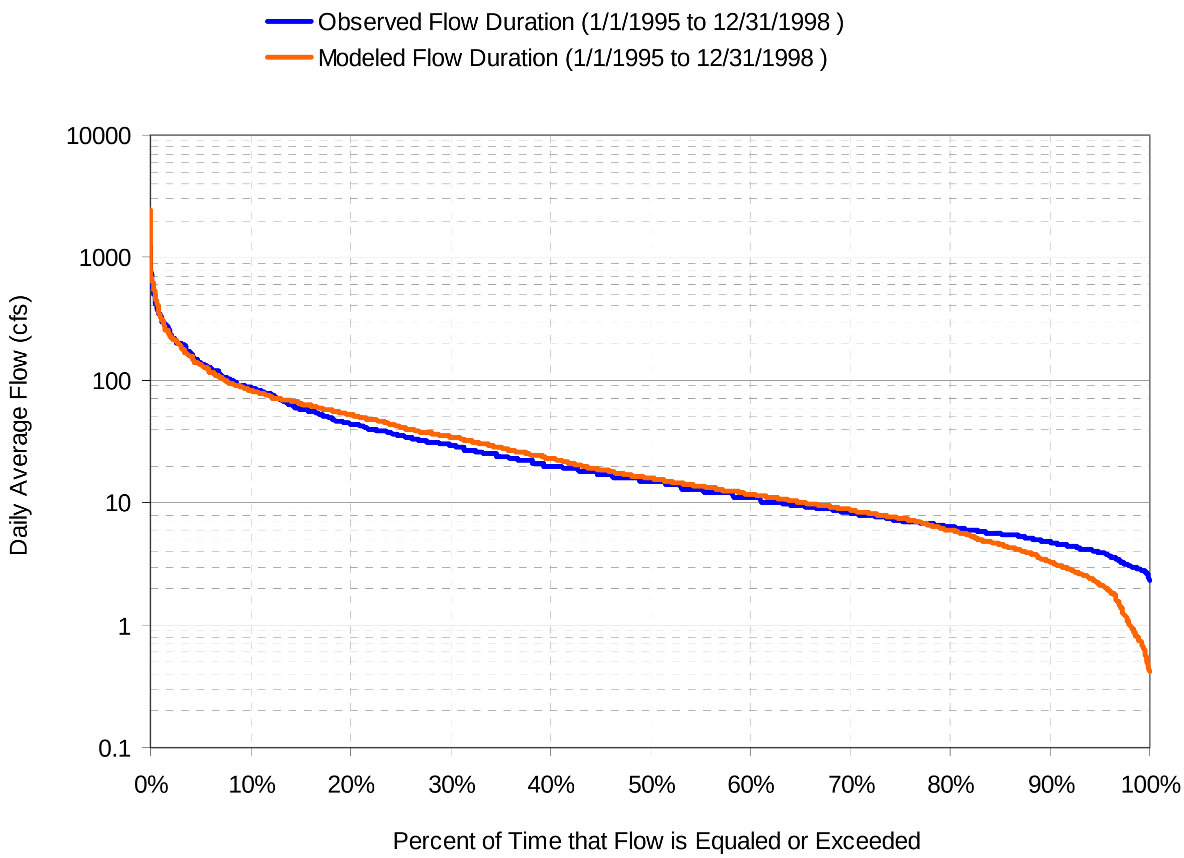


Figure 13. Flow duration curve hydrologic calibration results for the Upper Root River at USGS gage 04087220 (1995-1998).

Table 4. Error statistics for hydrologic calibration results for the Upper Root River at USGS gage 04087220 (1995-1998).

Monthly / Seasonal / Yearly Volume Comparison

Time Period		1995 Recorded USGS Volume (ac-ft)	1995 Simulated LSPC Volume (ac-ft)	1995 Percent Diff.	1996 Recorded USGS Volume (ac-ft)	1996 Simulated LSPC Volume (ac-ft)	1996 Percent Diff.	1997 Recorded USGS Volume (ac-ft)	1997 Simulated LSPC Volume (ac-ft)	1997 Percent Diff.	1998 Recorded USGS Volume (ac-ft)	1998 Simulated LSPC Volume (ac-ft)	1998 Percent Diff.	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.
Month	JAN	1,849	1,337	-27.69%	2,531	1,171	-53.7%	1,508	790	-47.6%	2,772	3,715	34.1%	**8,659**	**7,013**	**-19.0%**
	FEB	534	508	-5.0%	2,058	1,006	-51.1%	4,008	1,781	-55.6%	5,697	4,468	-21.6%	**12,297**	**7,763**	**-36.9%**
	MAR	2,086	1,678	-19.6%	1,001	936	-6.5%	2,945	2,787	-5.4%	4,483	6,798	51.6%	**10,516**	**12,200**	**16.0%**
	APR	5,098	4,634	-9.1%	3,358	3,363	0.1%	1,418	1,702	20.0%	7,135	8,242	15.5%	**17,008**	**17,941**	**5.5%**
	MAY	3,540	4,668	31.8%	3,576	3,279	-8.3%	2,192	2,542	16.0%	2,493	4,182	67.7%	**11,802**	**14,671**	**24.3%**
	JUN	860	1,401	62.9%	7,835	5,421	-30.8%	6,310	9,266	46.8%	1,142	2,334	104.3%	**16,147**	**18,423**	**14.1%**
	JUL	1,030	1,098	6.6%	934	1,187	27.1%	2,590	5,650	118.1%	397	944	137.6%	**4,951**	**8,879**	**79.3%**
	AUG	3,451	2,816	-18.4%	749	756	0.9%	1,803	3,168	75.8%	3,284	2,241	-31.8%	**9,286**	**8,981**	**-3.3%**
	SEP	543	449	-17.4%	372	607	63.1%	708	1,624	129.2%	625	411	-34.2%	**2,248**	**3,090**	**37.4%**
	OCT	1,405	2,129	51.6%	1,042	1,303	25.1%	353	717	103.2%	1,717	819	-52.3%	**4,516**	**4,968**	**10.0%**
	NOV	2,392	1,861	-22.2%	406	356	-12.1%	427	928	117.3%	2,794	1,948	-30.3%	**6,019**	**5,093**	**-15.4%**
	DEC	1,895	1,079	-43.1%	852	976	14.6%	698	1,345	92.6%	905	761	-15.9%	**4,351**	**4,160**	**-4.4%**

		1995 Recorded USGS Volume (ac-ft)	1995 Simulated LSPC Volume (ac-ft)	1995 Percent Diff.	1995 Var. from Tolerance	1996 Recorded USGS Volume (ac-ft)	1996 Simulated LSPC Volume (ac-ft)	1996 Percent Diff.	1996 Var. from Tolerance	1997 Recorded USGS Volume (ac-ft)	1997 Simulated LSPC Volume (ac-ft)	1997 Percent Diff.	1997 Var. from Tolerance	1998 Recorded USGS Volume (ac-ft)	1998 Simulated LSPC Volume (ac-ft)	1998 Percent Diff.	1998 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Season	Jan-Mar	4,470	3,523	-21.2%	1.2%	5,590	3,113	-44.3%	24.3%	8,462	5,359	-36.7%	16.7%	12,951	14,981	15.7%		**31,472**	**26,976**	**-14.3%**	
	Apr-Jun	9,498	10,703	12.7%		14,769	12,063	-18.3%		9,920	13,510	36.2%	16.2%	10,770	14,758	37.0%	17.0%	**44,957**	**51,034**	**13.5%**	
	Jul-Sep	5,025	4,363	-13.2%		2,055	2,550	24.1%	4.1%	5,101	10,442	104.7%	84.7%	4,306	3,596	-16.5%		**16,486**	**20,950**	**27.1%**	**7.1%**
	Oct-Dec	5,692	5,069	-11.0%		2,299	2,636	14.6%		1,478	2,989	102.3%	82.3%	5,416	3,527	-34.9%	14.9%	**14,886**	**14,221**	**-4.5%**	

Calibration Tolerance =20%

	1995 Recorded USGS Volume (ac-ft)	1995 Simulated LSPC Volume (ac-ft)	1995 Percent Diff.	1995 Var. from Tolerance	1996 Recorded USGS Volume (ac-ft)	1996 Simulated LSPC Volume (ac-ft)	1996 Percent Diff.	1996 Var. from Tolerance	1997 Recorded USGS Volume (ac-ft)	1997 Simulated LSPC Volume (ac-ft)	1997 Percent Diff.	1997 Var. from Tolerance	1998 Recorded USGS Volume (ac-ft)	1998 Simulated LSPC Volume (ac-ft)	1998 Percent Diff.	1998 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Year	24,684	23,657	-4.2%		24,713	20,362	-17.6%	7.6%	24,960	32,299	29.4%	19.4%	33,443	36,862	10.2%	0.2%	**107,801**	**113,181**	**5.0%**	

Calibration Tolerance =10%

Table 5. High-Low flow error statistics for hydrologic calibration results for the Upper Root River at USGS gage 04087220 (1995-1998).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	57,146	56,049	2.0%	15%
Total Highest 20% volume	76,254	74,108	2.9%	15%
Total Highest 50% volume	102,241	96,547	5.9%	15%
Total Lowest 10% volume	591	1,112	-46.8%	10%
Total Lowest 30% volume	4,077	4,834	-15.7%	10%
Total Lowest 50% volume	11,034	11,342	-2.7%	10%

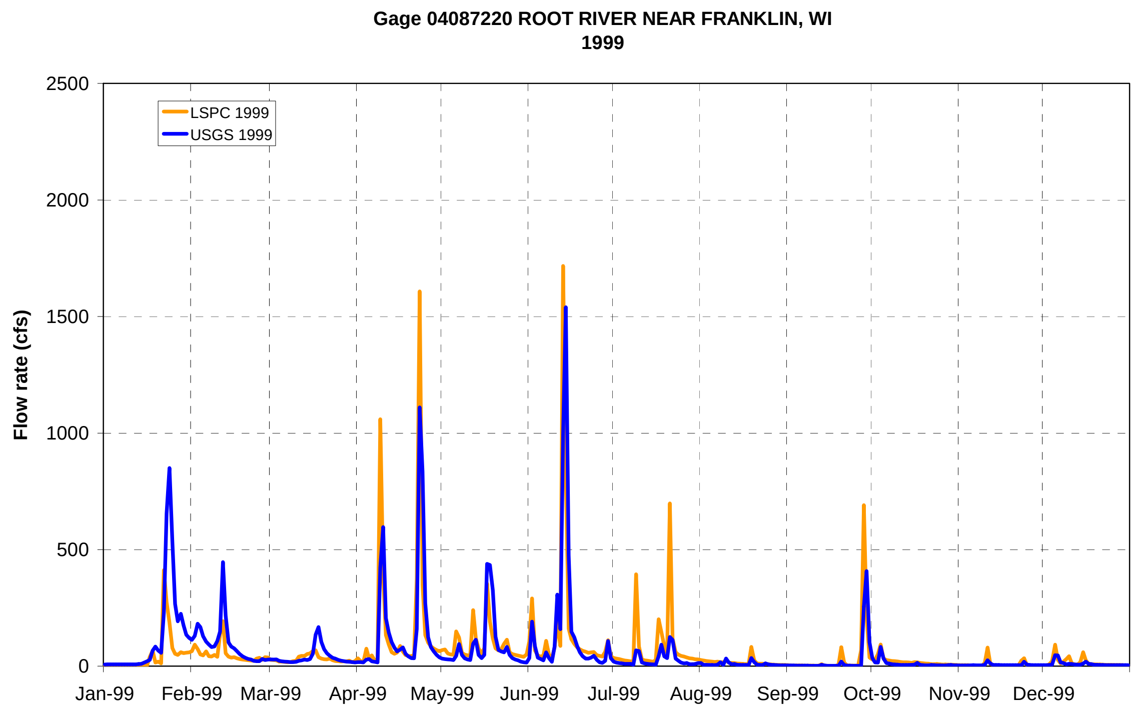


Figure 14. Time series hydrologic validation results (daily mean) for the Upper Root River at USGS gage 04087220 (1999).

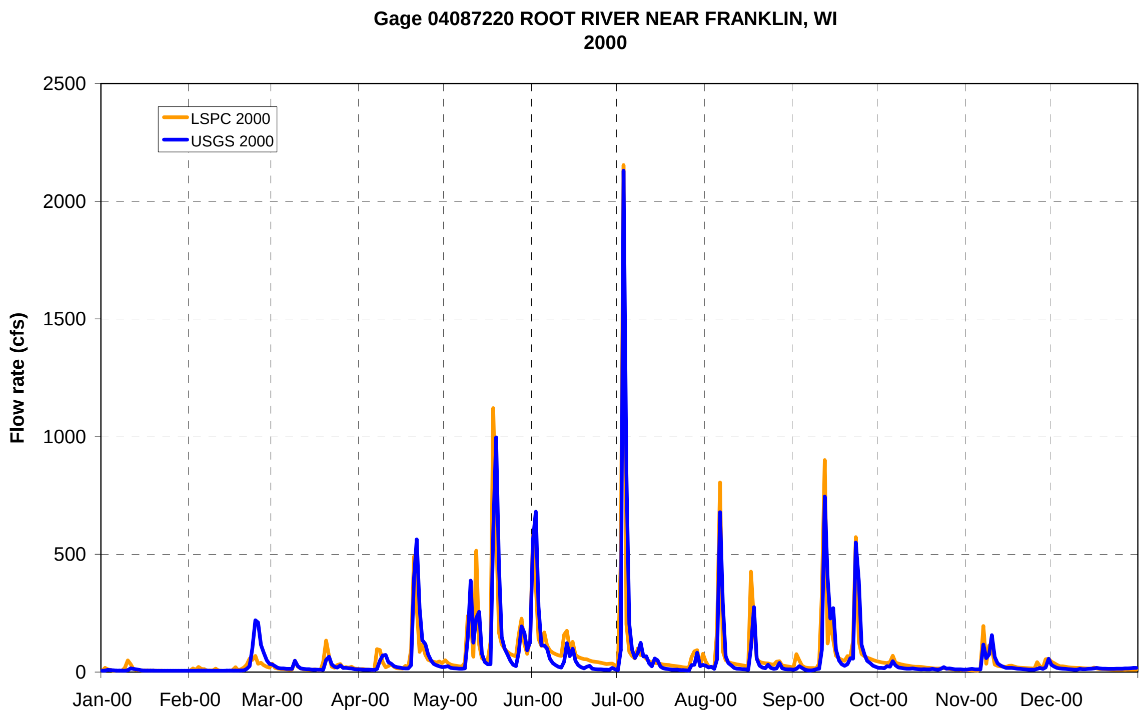


Figure 15. Time series hydrologic validation results (daily mean) for the Upper Root River at USGS gage 04087220 (2000).

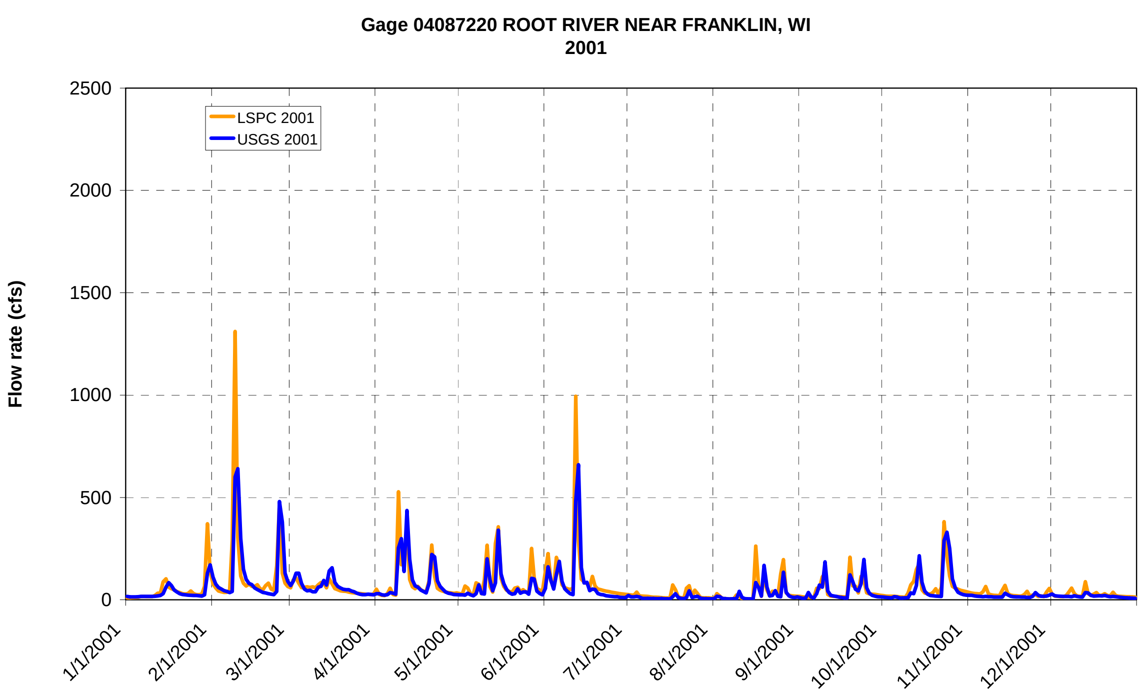


Figure 16. Time series hydrologic validation results (daily mean) for the Upper Root River at USGS gage 04087220 (2001).

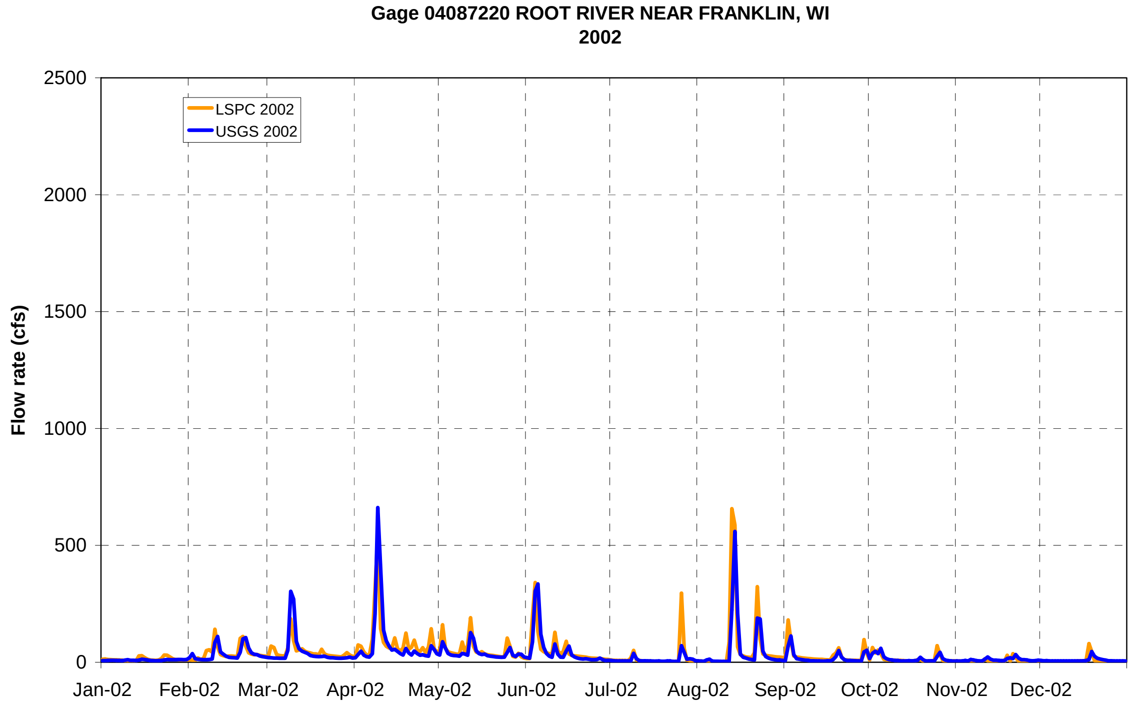


Figure 17. Time series hydrologic validation results (daily mean) for the Upper Root River at USGS gage 04087220 (2002).

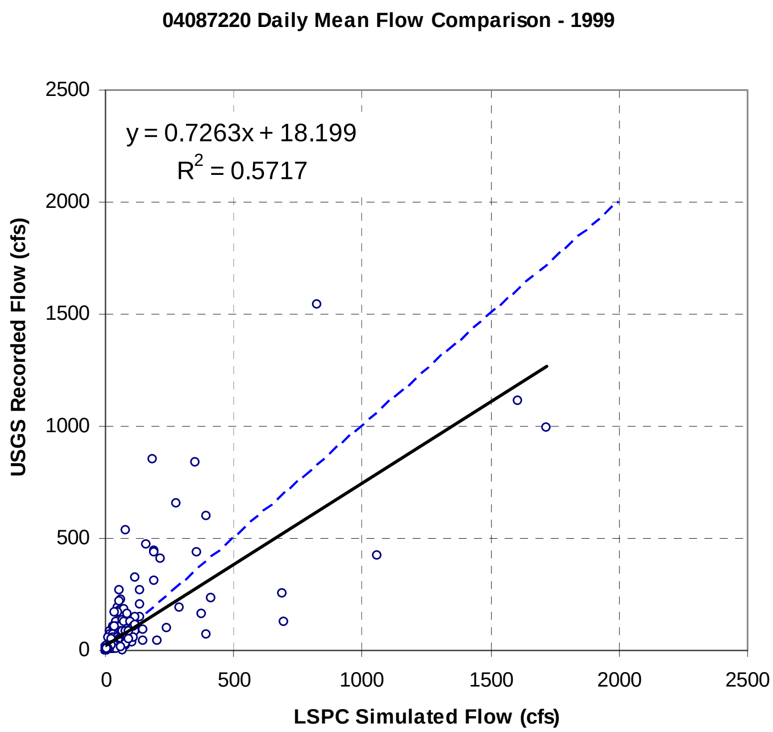


Figure 18. Observed versus simulated scatter plot with a linear regression line for the Upper Root River at USGS gage 04087220 (1999).

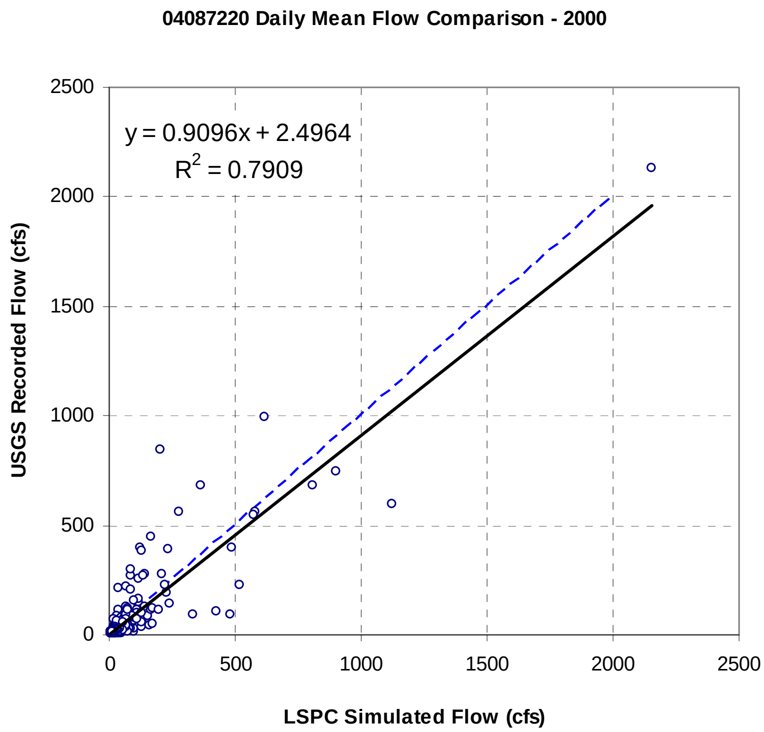


Figure 19. Observed versus simulated scatter plot with a linear regression line for the Upper Root River at USGS gage 04087220 (2000).

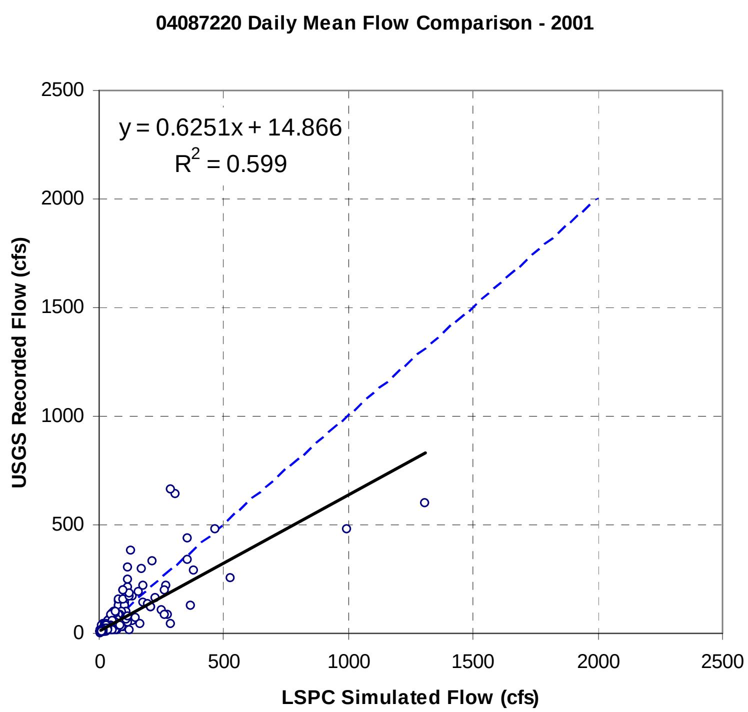


Figure 20. Observed versus simulated scatter plot with a linear regression line for the Upper Root River at USGS gage 04087220 (2001).

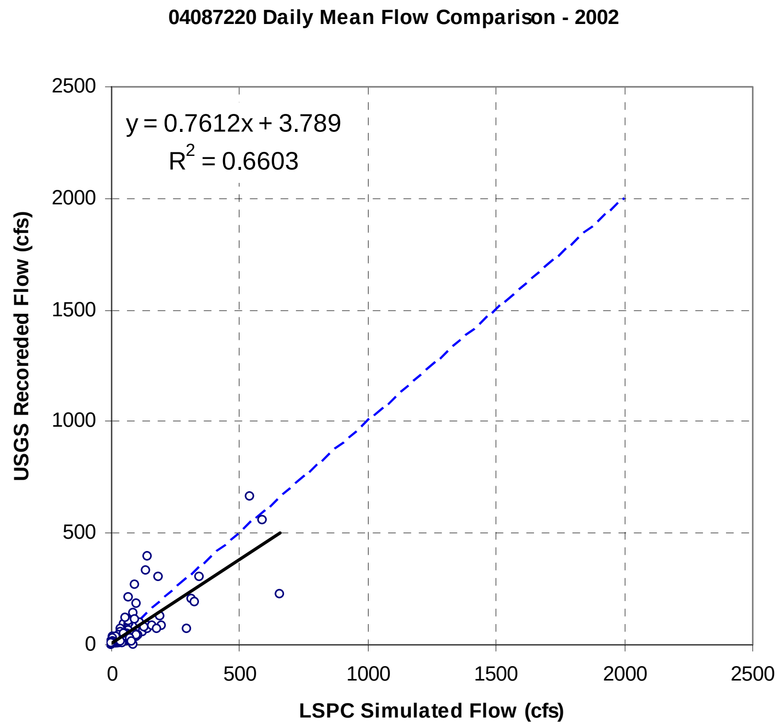


Figure 21. Observed versus simulated scatter plot with a linear regression line for the Upper Root River at USGS gage 04087220 (2002).

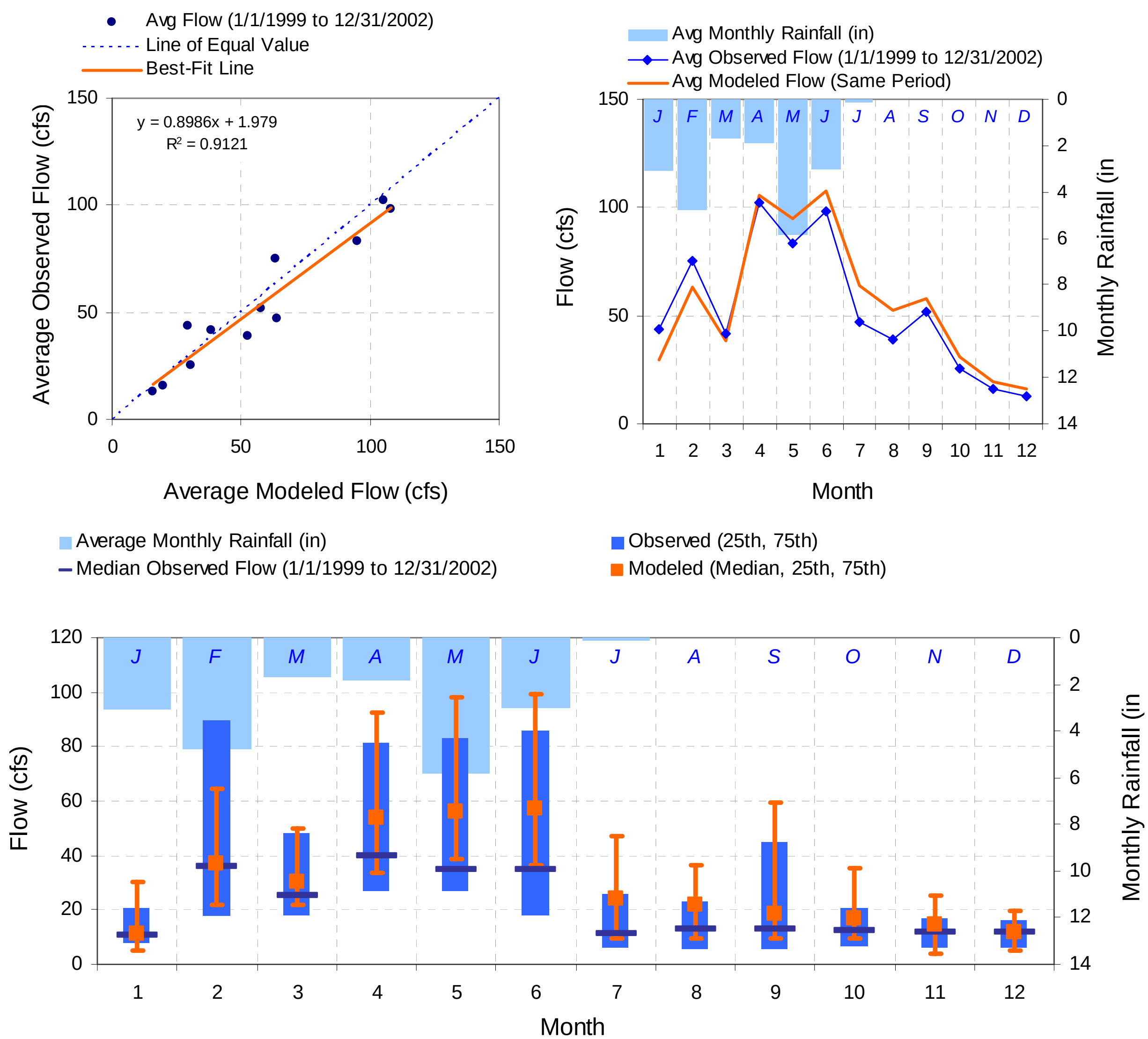


Figure 22. Composite (average monthly) hydrologic validation results for the Upper Root River at USGS gage 04087220 (1999 to 2002).

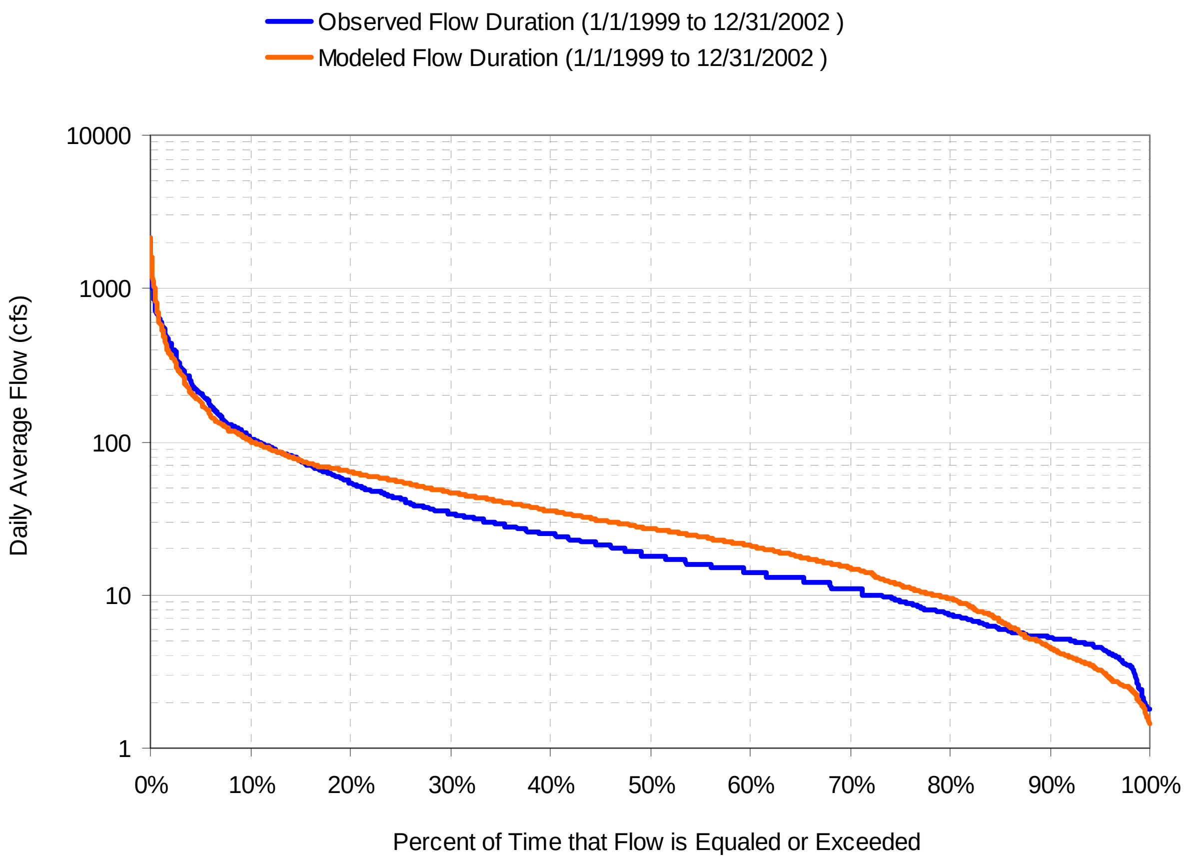


Figure 23. Flow duration curve hydrologic validation results for the Upper Root River at USGS gage 04087220 (1999 to 2002).

Table 6. Error statistics for hydrologic validation results for the Upper Root River at USGS gage 04087220 (1999 to 2002).

Monthly / Seasonal / Yearly Volume Comparison

Time Period		1999 Recorded USGS Volume (ac-ft)	1999 Simulated LSPC Volume (ac-ft)	1999 Percent Diff.	2000 Recorded USGS Volume (ac-ft)	2000 Simulated LSPC Volume (ac-ft)	2000 Percent Diff.	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2002 Recorded USGS Volume (ac-ft)	2002 Simulated LSPC Volume (ac-ft)	2002 Percent Diff.	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.
Month	JAN	7,613	2,934	-61.46%	415	537	29.6%	2,124	2,896	36.3%	577	840	45.6%	**10,728**	**7,207**	**-32.8%**
	FEB	5,308	2,834	-46.6%	1,914	1,093	-42.9%	7,587	8,031	5.9%	2,007	2,223	10.7%	**16,816**	**14,181**	**-15.7%**
	MAR	2,390	1,870	-21.7%	1,236	1,452	17.6%	3,840	3,420	-10.9%	2,713	2,748	1.3%	**10,179**	**9,491**	**-6.8%**
	APR	9,580	10,557	10.2%	4,355	3,743	-14.0%	5,496	5,342	-2.8%	4,943	5,477	10.8%	**24,374**	**25,119**	**3.1%**
	MAY	5,066	5,481	8.2%	9,126	9,642	5.7%	3,792	5,151	35.8%	2,458	3,127	27.3%	**20,442**	**23,402**	**14.5%**
	JUN	9,737	9,654	-0.8%	5,172	6,187	19.6%	5,407	6,720	24.3%	3,004	3,132	4.3%	**23,319**	**25,693**	**10.2%**
	JUL	1,737	4,971	186.3%	8,454	8,262	-2.3%	659	1,358	106.0%	668	1,145	71.5%	**11,517**	**15,737**	**36.6%**
	AUG	553	978	77.0%	3,934	5,126	30.3%	1,729	2,394	38.5%	3,336	4,422	32.6%	**9,551**	**12,920**	**35.3%**
	SEP	1,699	2,350	38.3%	6,890	7,064	2.5%	2,610	2,597	-0.5%	1,146	1,707	49.0%	**12,344**	**13,717**	**11.1%**
	OCT	669	1,155	72.7%	976	1,514	55.1%	3,664	3,951	7.8%	961	967	0.6%	**6,270**	**7,586**	**21.0%**
	NOV	357	510	43.1%	1,770	1,998	12.9%	1,039	1,787	71.9%	644	391	-39.3%	**3,810**	**4,687**	**23.0%**
	DEC	608	954	57.0%	904	1,018	12.7%	1,049	1,521	45.0%	548	439	-19.8%	**3,109**	**3,933**	**26.5%**

Time Period		1999 Recorded USGS Volume (ac-ft)	1999 Simulate d LSPC Volume (ac-ft)	1999 Percent Diff.	1999 Var. from Tolerance	2000 Recorded USGS Volume (ac-ft)	2000 Simulate d LSPC Volume (ac-ft)	2000 Percent Diff.	2000 Var. from Tolerance	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2001 Var. from Tolerance	2002 Recorded USGS Volume (ac-ft)	2002 Simulate d LSPC Volume (ac-ft)	2002 Percent Diff.	2002 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Season	Jan-Mar	15,311	7,639	-50.1%	30.1%	3,564	3,083	-13.5%		13,551	14,347	5.9%		5,297	5,811	9.7%		**37,723**	**30,880**	**-18.1%**	
	Apr-Jun	24,383	25,693	5.4%		18,653	19,573	4.9%		14,696	17,213	17.1%		10,404	11,736	12.8%		**68,135**	**74,214**	**8.9%**	
	Jul-Sep	3,988	8,300	108.1%	88.1%	19,278	20,452	6.1%		4,998	6,349	27.0%	7.0%	5,149	7,274	41.3%	21.3%	**33,413**	**42,375**	**26.8%**	**6.8%**
	Oct-Dec	1,633	2,619	60.4%	40.4%	3,650	4,530	24.1%	4.1%	5,753	7,260	26.2%	6.2%	2,153	1,797	-16.5%		**13,189**	**16,206**	**22.9%**	**2.9%**

Calibration Tolerance =20%

	1999 Recorded USGS Volume (ac-ft)	1999 Simulate d LSPC Volume (ac-ft)	1999 Percent Diff.	1999 Var. from Tolerance	2000 Recorded USGS Volume (ac-ft)	2000 Simulate d LSPC Volume (ac-ft)	2000 Percent Diff.	2000 Var. from Tolerance	2001 Recorded USGS Volume (ac-ft)	2001 Simulated LSPC Volume (ac-ft)	2001 Percent Diff.	2001 Var. from Tolerance	2002 Recorded USGS Volume (ac-ft)	2002 Simulate d LSPC Volume (ac-ft)	2002 Percent Diff.	2002 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Year	45,315	44,250	-2.3%		45,145	47,638	5.5%		38,997	45,168	15.8%	5.8%	23,004	26,617	15.7%	5.7%	**152,460**	**163,674**	**7.4%**	

Calibration Tolerance =10%

Table 7. High-Low flow error statistics for hydrologic validation results for the Upper Root River at USGS gage 04087220 (1999-2002).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	85,774	89,290	-3.9%	15%
Total Highest 20% volume	108,540	111,681	-2.8%	15%
Total Highest 50% volume	145,254	138,573	4.8%	15%
Total Lowest 10% volume	926	1,225	-24.4%	10%
Total Lowest 30% volume	6,372	5,672	12.3%	10%
Total Lowest 50% volume	18,581	13,994	32.8%	10%

8.2.2 Root River Canal Results

The performance of the model was also evaluated by comparing simulated results to observed flows recorded at the USGS gage on the Root River Canal (04087233). The results are presented in Figure 24 to Figure 43 and indicate that the model correctly simulates the timing of flow events and the magnitude of peak flows across all years simulated. The low flows are under-predicted at this gage – even though the same portion of the flow regime tends to be a little over-predicted at the downstream gage. The uncertainty in the model may be a result of one or more of the following factors:

- Uncertainty associated with estimated flows for point sources.
- Delineation of Directly Connected Impervious Areas (DCIAs)
- Uncertainty in the specification of stage-discharge relationships (Ftables)

The composite graphs shown in Figure 32 and Figure 42 indicate the model simulates seasonal patterns for fall and winter fairly effectively but overestimates flow in the summer. The observed and simulated cumulative flow duration curves are aligned fairly well with one another, with the model overpredicting moderate-to-high flows and underpredicting the lowest flows.

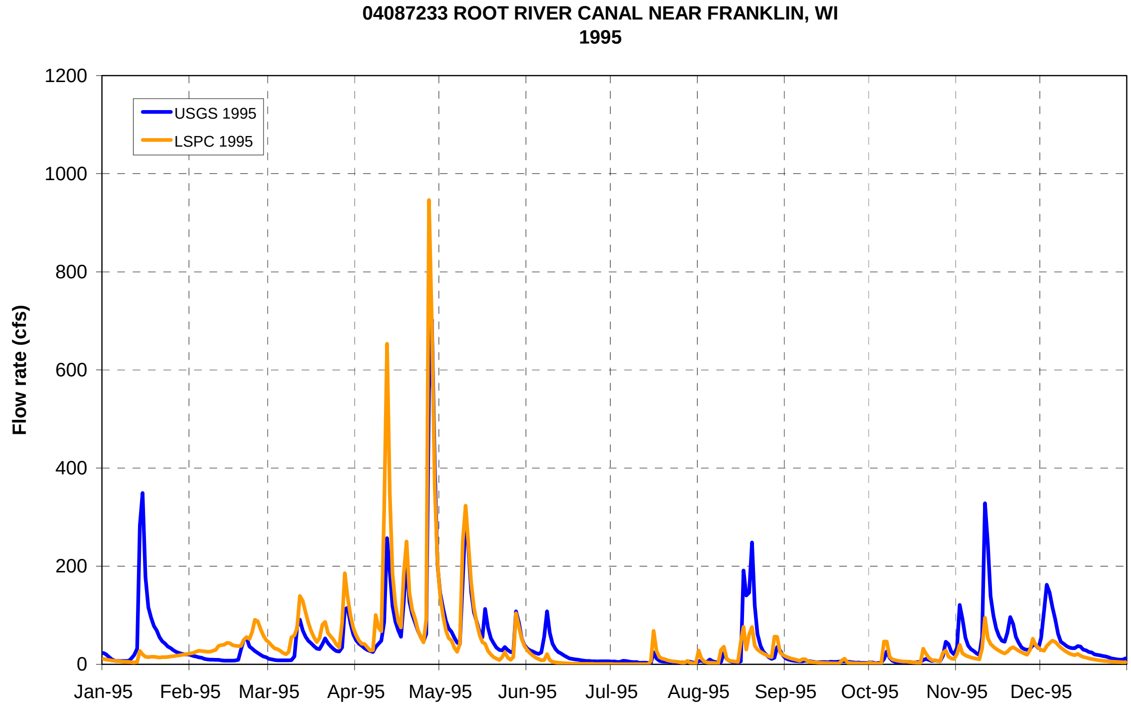


Figure 24. Time series hydrologic calibration results (daily mean) for the Root River Canal at USGS gage 04087233 (1995).

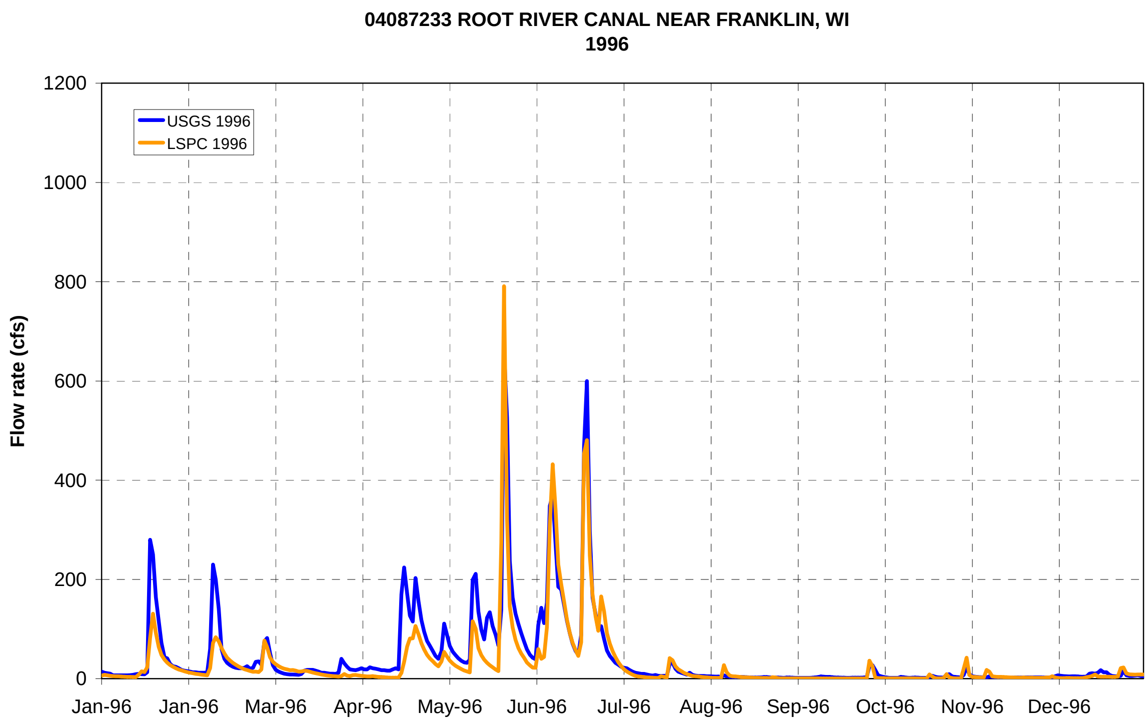


Figure 25. Time series hydrologic calibration results (daily mean) for the Root River Canal at USGS gage 04087233 (1996).

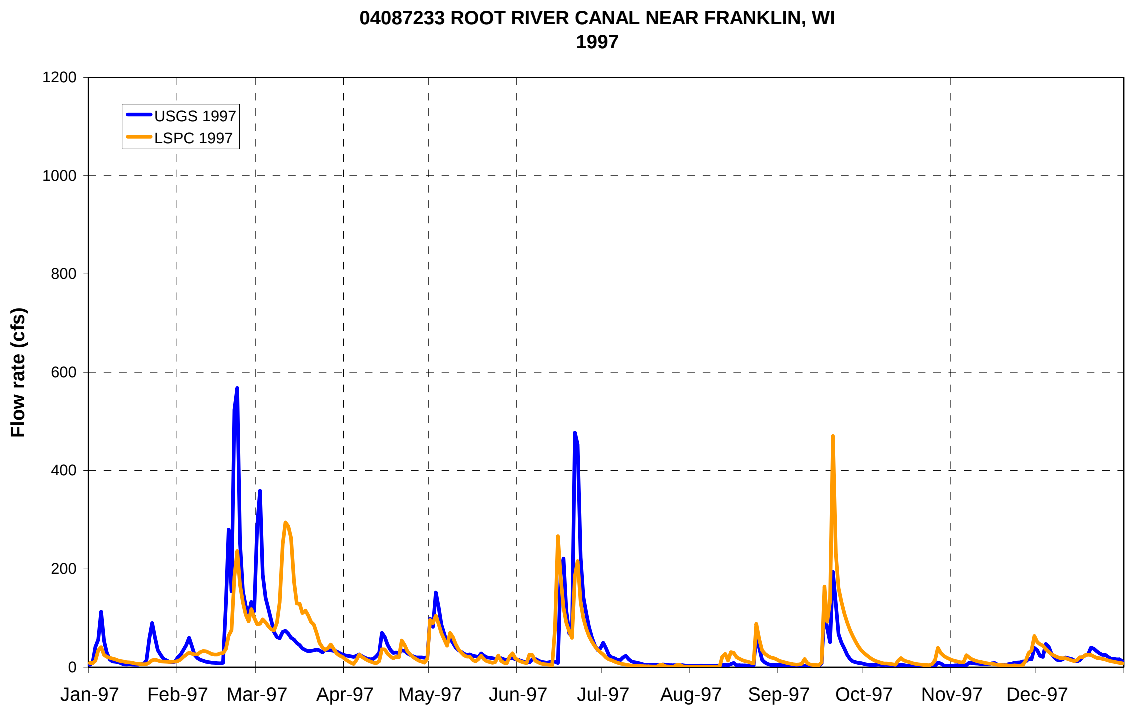


Figure 26. Time series hydrologic calibration results (daily mean) for the Root River Canal at USGS gage 04087233 (1997).

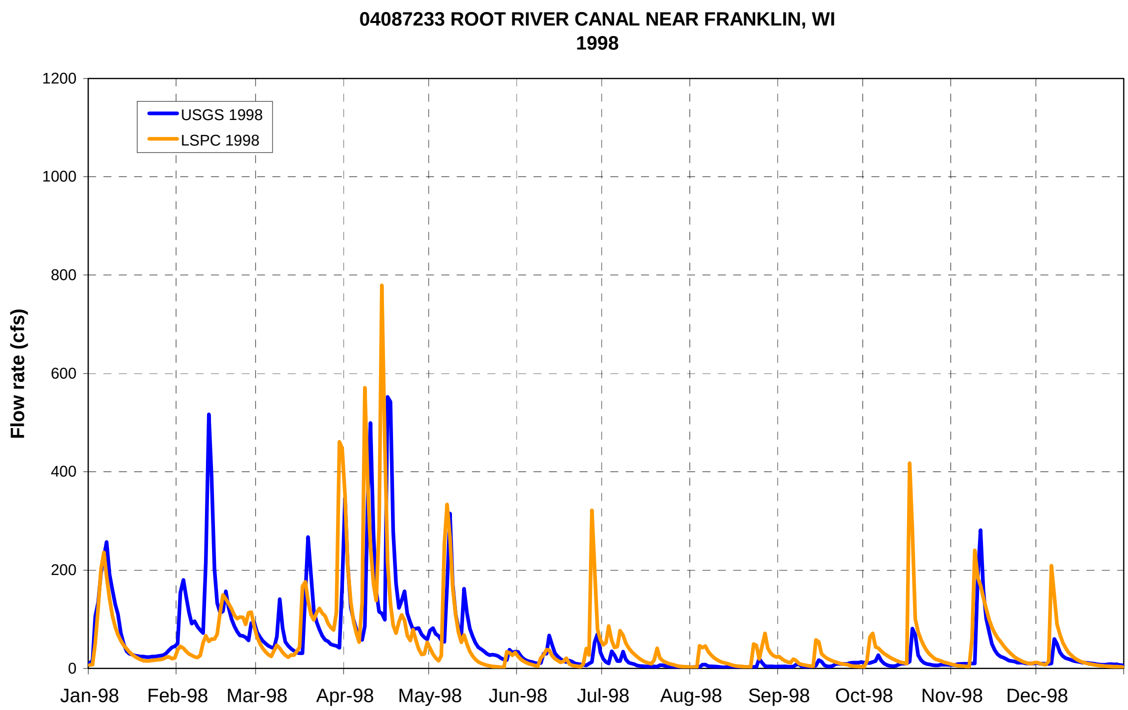


Figure 27. Time series hydrologic calibration results (daily mean) for the Root River Canal at USGS gage 04087233 (1998).

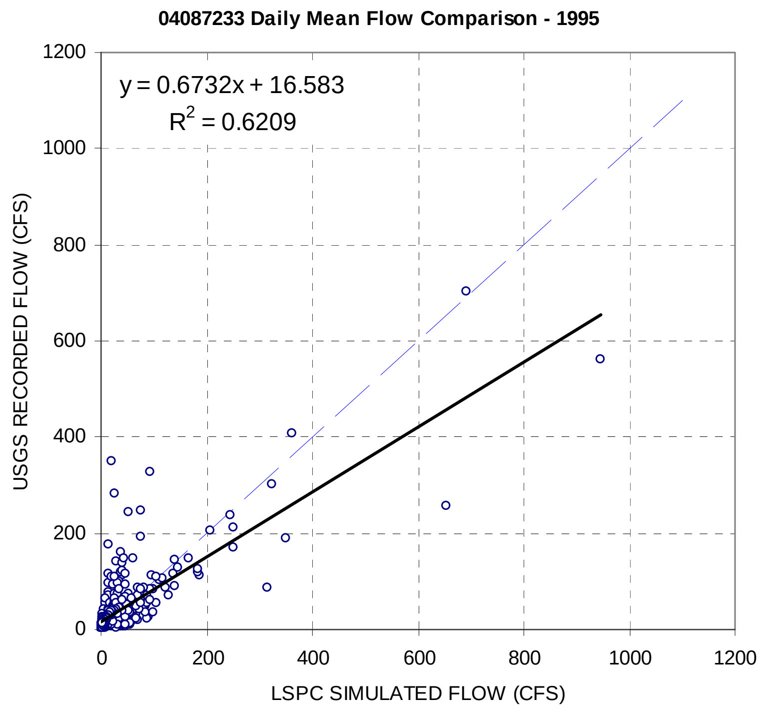


Figure 28. Observed versus simulated scatter plot with a linear regression line for the Root River Canal at USGS gage 04087233 (1995).

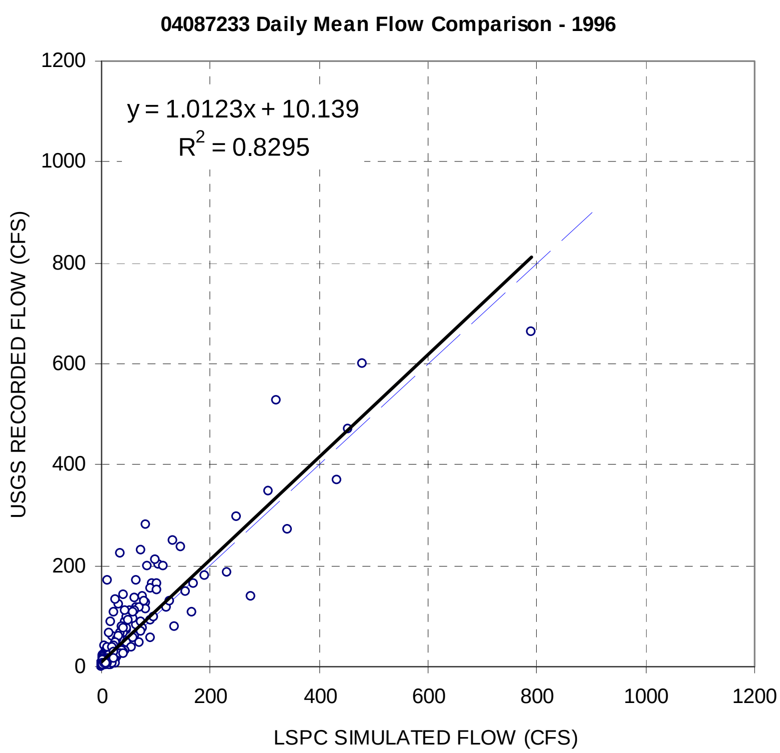


Figure 29. Observed versus simulated scatter plot with a linear regression line for the Root River Canal at USGS gage 04087233 (1996).

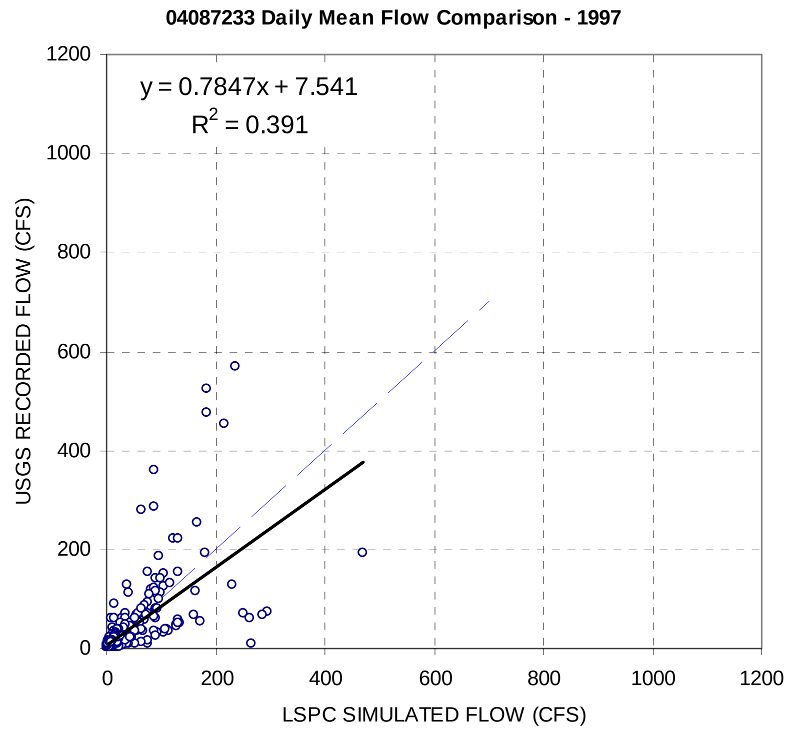


Figure 30. Observed versus simulated scatter plot with a linear regression line for the Root River Canal at USGS gage 04087233 (1997).

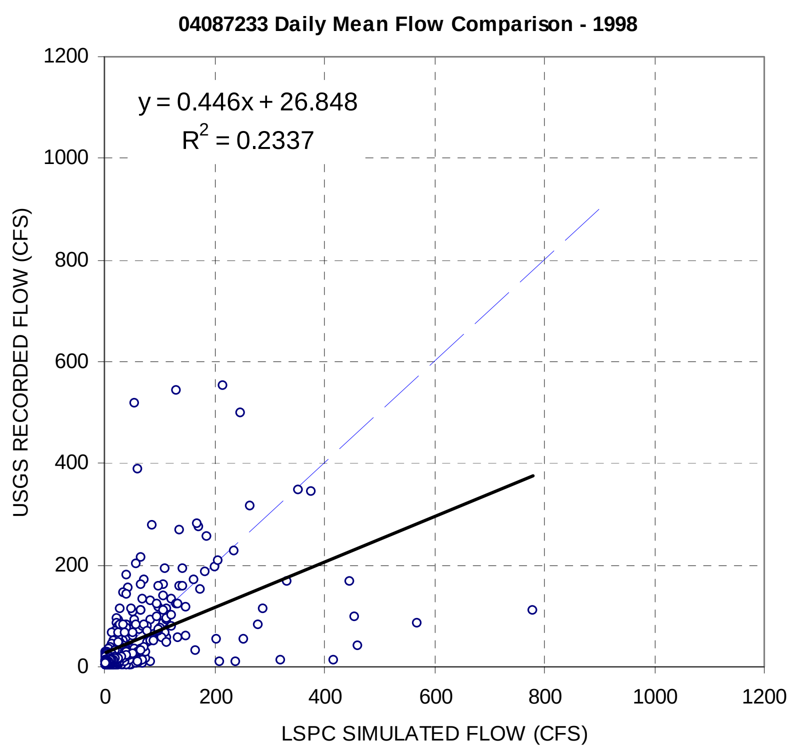


Figure 31. Observed versus simulated scatter plot with a linear regression line for the Root River Canal at USGS gage 04087233 (1998).

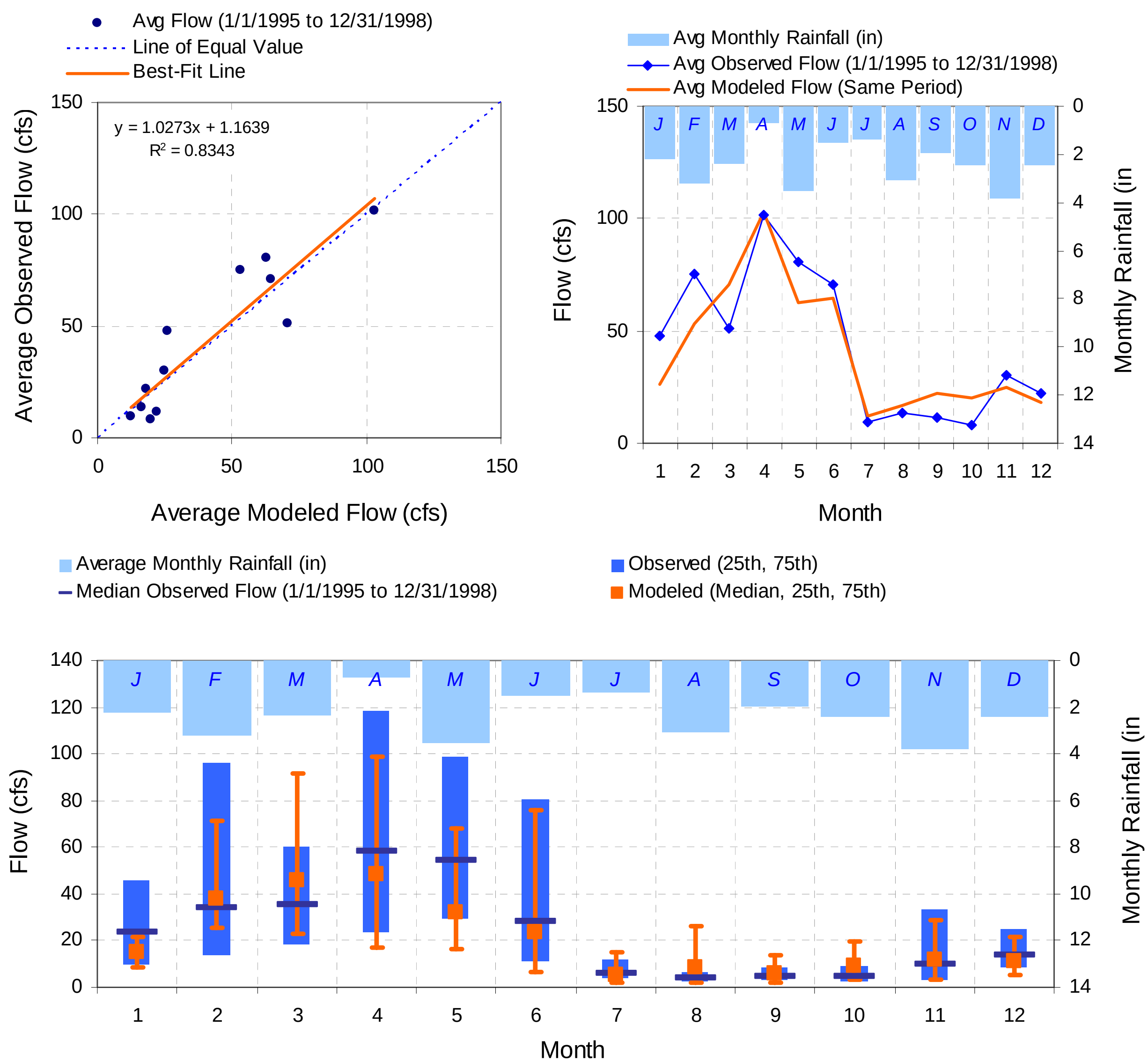


Figure 32. Composite (average monthly) hydrologic calibration results for the Root River Canal at USGS gage 04087233 (1995 to 1998).

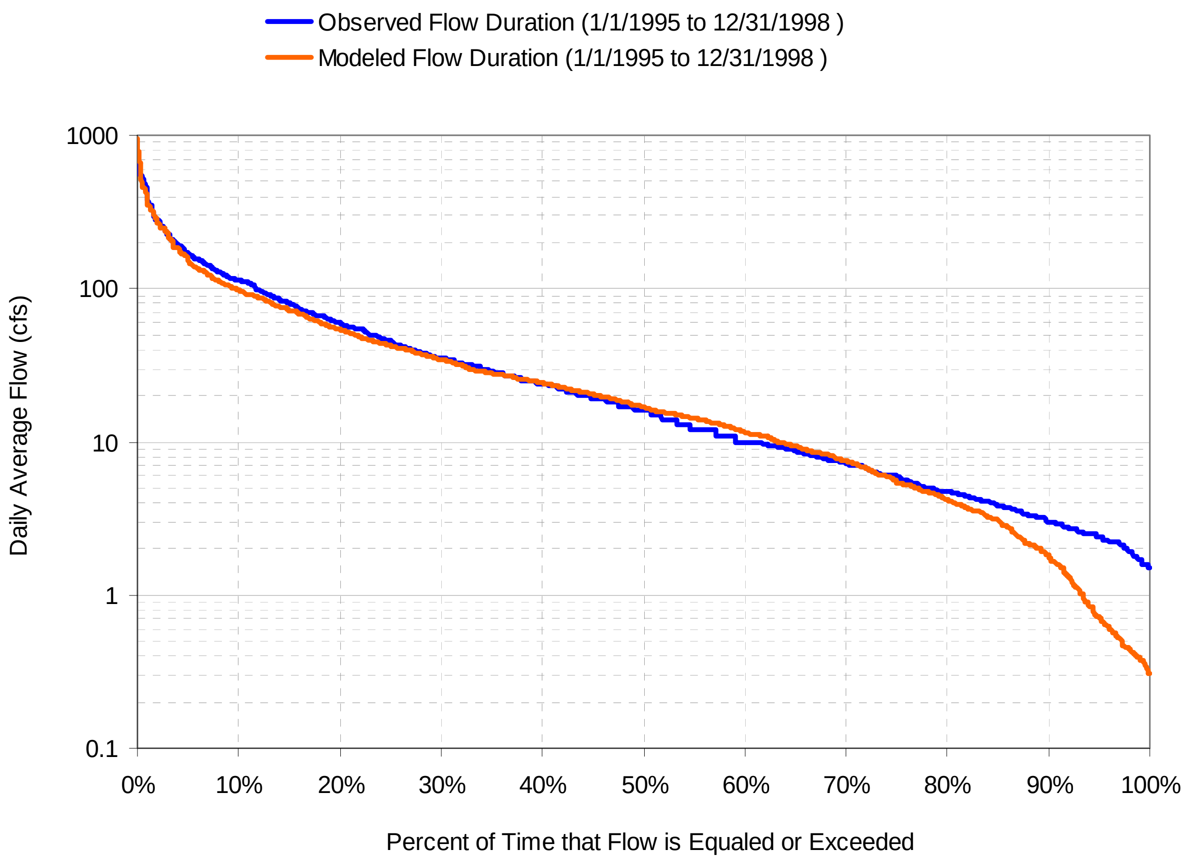


Figure 33. Flow duration curve hydrologic calibration results for the Root River Canal at USGS gage 04087233 (1995 to 1998).

Table 8. Error statistics for hydrologic calibration results for the Root River Canal at USGS gage 04087233 (1995-1998).

Monthly / Seasonal / Yearly Volume Comparison

Time Period		1995 Recorded USGS Volume (ac-ft)	1995 Simulated LSPC Volume (ac-ft)	1995 Percent Diff.	1996 Recorded USGS Volume (ac-ft)	1996 Simulated LSPC Volume (ac-ft)	1996 Percent Diff.	1997 Recorded USGS Volume (ac-ft)	1997 Simulated LSPC Volume (ac-ft)	1997 Percent Diff.	1998 Recorded USGS Volume (ac-ft)	1998 Simulated LSPC Volume (ac-ft)	1998 Percent Diff.	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.
Month	JAN	3,354	779	-76.76%	2,516	1,479	-41.2%	1,501	834	-44.4%	4,324	3,378	-21.9%	**11,694**	**6,471**	**-44.7%**
	FEB	977	2,364	142.1%	2,700	1,803	-33.2%	5,770	3,483	-39.6%	7,408	4,219	-43.1%	**16,855**	**11,869**	**-29.6%**
	MAR	2,459	4,174	69.7%	947	788	-16.8%	4,554	6,439	41.4%	4,687	5,945	26.8%	**12,647**	**17,346**	**37.2%**
	APR	7,916	11,042	39.5%	4,157	1,812	-56.4%	1,626	1,196	-26.5%	10,455	10,504	0.5%	**24,155**	**24,554**	**1.7%**
	MAY	5,086	4,485	-11.8%	7,855	5,257	-33.1%	2,503	2,184	-12.8%	4,378	3,495	-20.2%	**19,821**	**15,421**	**-22.2%**
	JUN	1,287	339	-73.7%	9,271	9,040	-2.5%	4,981	3,866	-22.4%	1,343	2,173	61.8%	**16,882**	**15,419**	**-8.7%**
	JUL	330	387	17.0%	730	606	-16.9%	699	327	-53.2%	584	1,733	197.0%	**2,342**	**3,053**	**30.4%**
	AUG	2,423	1,523	-37.2%	187	195	4.4%	453	999	120.4%	262	1,344	412.9%	**3,325**	**4,061**	**22.1%**
	SEP	318	319	0.4%	276	151	-45.2%	1,705	3,922	130.0%	437	888	103.3%	**2,736**	**5,281**	**93.0%**
	OCT	638	724	13.5%	243	218	-10.2%	238	807	239.0%	909	3,154	246.9%	**2,029**	**4,905**	**141.7%**
	NOV	4,181	1,780	-57.4%	159	205	28.7%	500	735	47.1%	2,348	3,161	34.6%	**7,188**	**5,881**	**-18.2%**
	DEC	2,606	1,153	-55.8%	450	333	-26.0%	1,414	1,311	-7.3%	907	1,721	89.8%	**5,377**	**4,518**	**-16.0%**

		1995 Recorded USGS Volume (ac-ft)	1995 Simulated LSPC Volume (ac-ft)	1995 Percent Diff.	1995 Var. from Tolerance	1996 Recorded USGS Volume (ac-ft)	1996 Simulated LSPC Volume (ac-ft)	1996 Percent Diff.	1996 Var. from Tolerance	1997 Recorded USGS Volume (ac-ft)	1997 Simulated LSPC Volume (ac-ft)	1997 Percent Diff.	1997 Var. from Tolerance	1998 Recorded USGS Volume (ac-ft)	1998 Simulated LSPC Volume (ac-ft)	1998 Percent Diff.	1998 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Season	Jan-Mar	6,789	7,317	7.8%		6,162	4,070	-34.0%	14.0%	11,825	10,757	-9.0%		16,419	13,542	-17.5%		**41,196**	**35,686**	**-13.4%**	
	Apr-Jun	14,289	15,866	11.0%		21,283	16,109	-24.3%	4.3%	9,110	7,246	-20.5%	0.5%	16,176	16,173	0.0%		**60,857**	**55,394**	**-9.0%**	
	Jul-Sep	3,071	2,228	-27.4%	7.4%	1,193	953	-20.1%	0.1%	2,857	5,248	83.7%	63.7%	1,283	3,965	209.2%	189.2%	**8,403**	**12,394**	**47.5%**	**27.5%**
	Oct-Dec	7,425	3,657	-50.8%	30.8%	852	756	-11.3%		2,152	2,854	32.6%	12.6%	4,164	8,037	93.0%	73.0%	**14,594**	**15,304**	**4.9%**	

Calibration Tolerance =20%

	1995 Recorded USGS Volume (ac-ft)	1995 Simulated LSPC Volume (ac-ft)	1995 Percent Diff.	1995 Var. from Tolerance	1996 Recorded USGS Volume (ac-ft)	1996 Simulated LSPC Volume (ac-ft)	1996 Percent Diff.	1996 Var. from Tolerance	1997 Recorded USGS Volume (ac-ft)	1997 Simulated LSPC Volume (ac-ft)	1997 Percent Diff.	1997 Var. from Tolerance	1998 Recorded USGS Volume (ac-ft)	1998 Simulated LSPC Volume (ac-ft)	1998 Percent Diff.	1998 Var. from Tolerance	TOTAL Recorded USGS Volume (ac-ft)	TOTAL Simulated LSPC Volume (ac-ft)	TOTAL Percent Diff.	TOTAL Var. from Tolerance
Year	31,574	29,068	-7.9%		29,490	21,888	-25.8%	15.8%	25,945	26,105	0.6%		38,042	41,717	9.7%		**125,050**	**118,778**	**-5.0%**	

Calibration Tolerance =10%

Table 9. High-Low flow error statistics for hydrologic calibration results for the Root River Canal at USGS gage 04087233 (1995-1998).

Category	**LSPC volume (ac-ft)**	**USGS volume (ac-ft)**	**Percent Difference**	**Tolerance**
Total Highest 10% volume	61,089	64,005	-4.6%	15%
Total Highest 20% volume	82,568	88,003	-6.2%	15%
Total Highest 50% volume	109,210	115,382	-5.3%	15%
Total Lowest 10% volume	250	687	-63.6%	10%
Total Lowest 30% volume	2,772	3,519	-21.2%	10%
Total Lowest 50% volume	9,668	9,763	-1.0%	10%

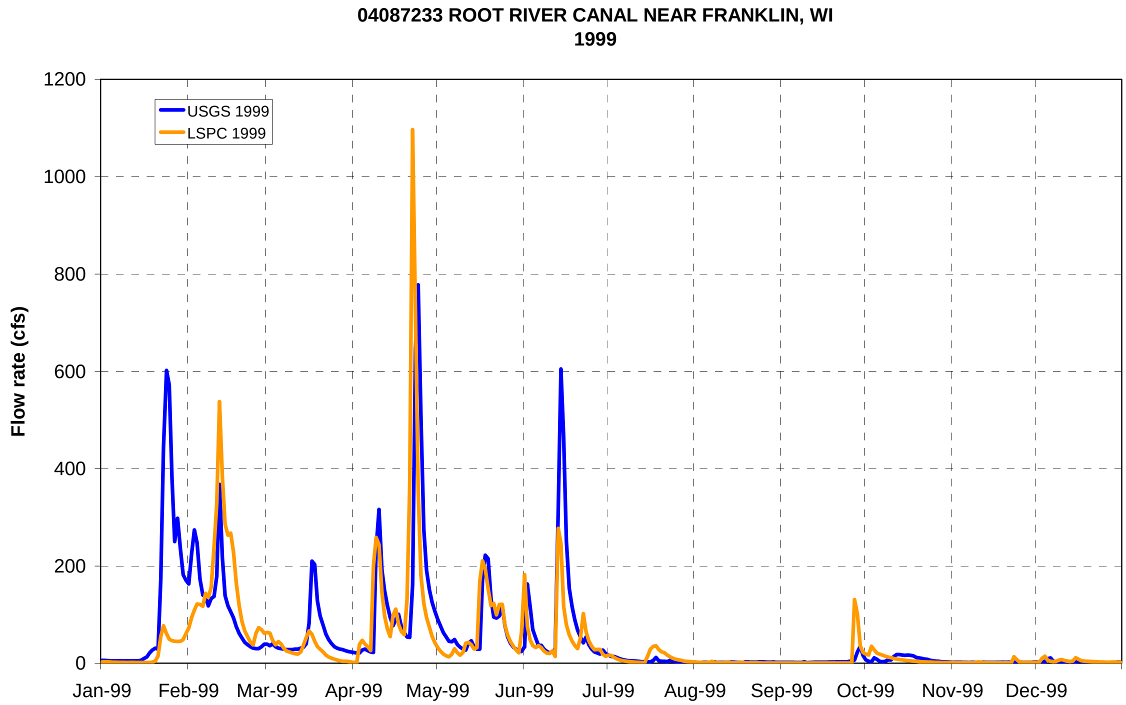


Figure 34. Time series hydrologic validation results (daily mean) for the Root River Canal at USGS gage 04087233 (1999).

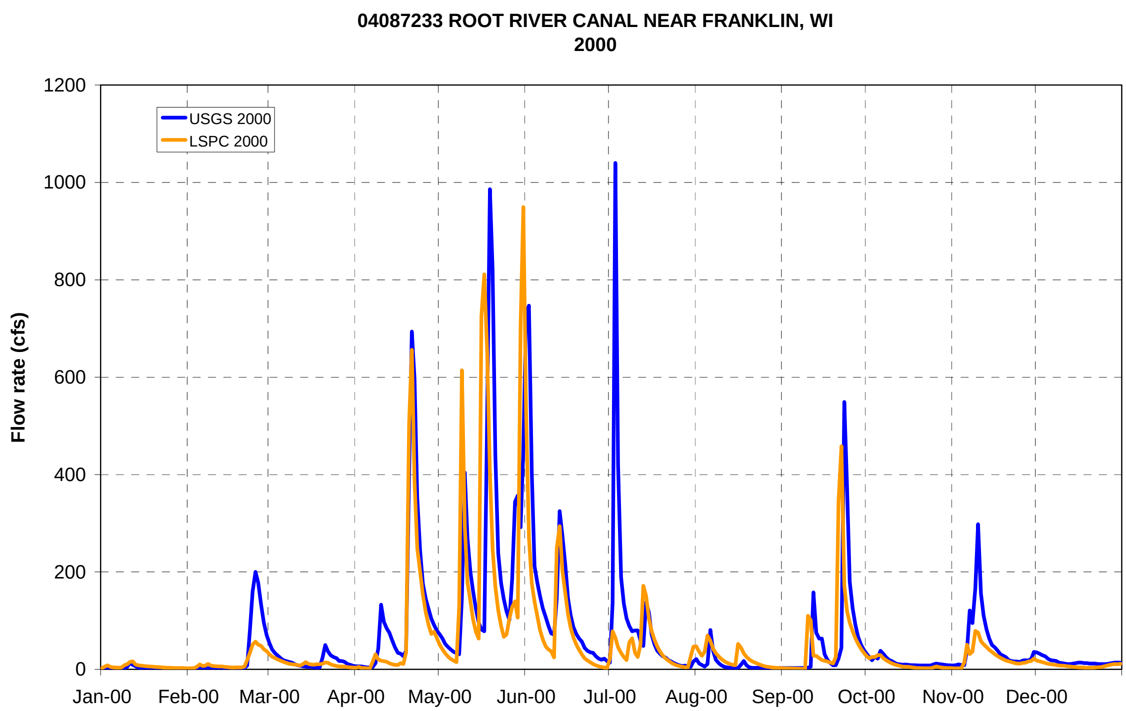


Figure 35. Time series hydrologic validation results (daily mean) for the Root River Canal at USGS gage 04087233 (2000).

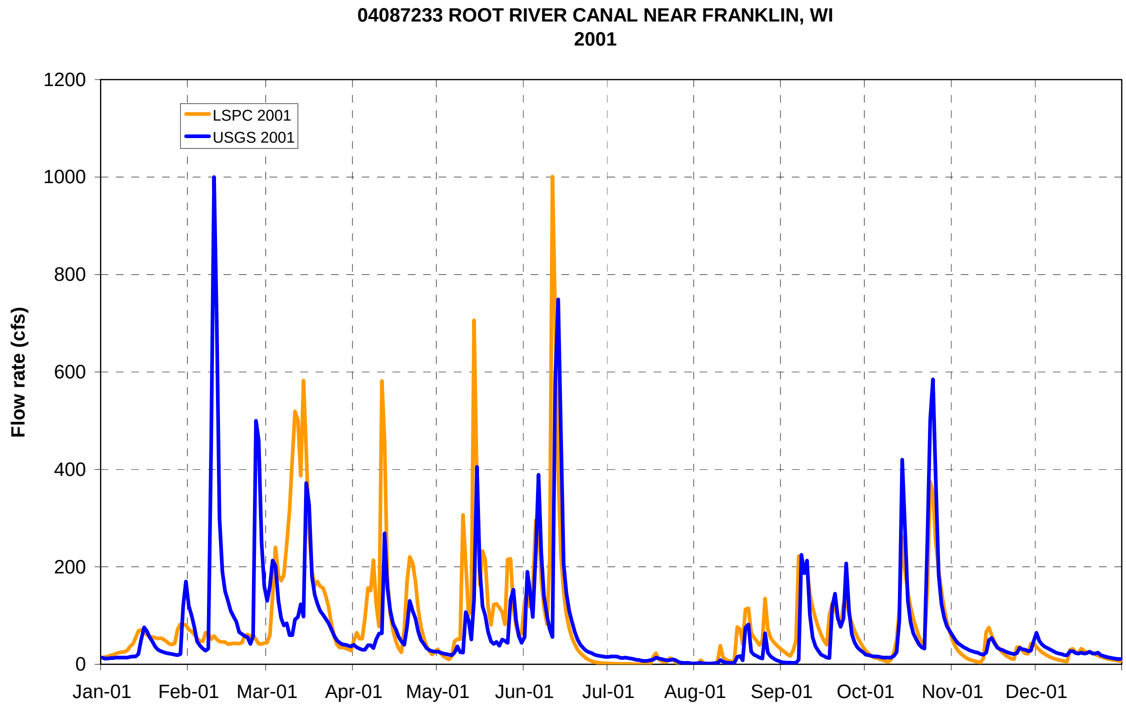


Figure 36. Time series hydrologic validation results (daily mean) for the Root River Canal at USGS gage 04087233 (2001).

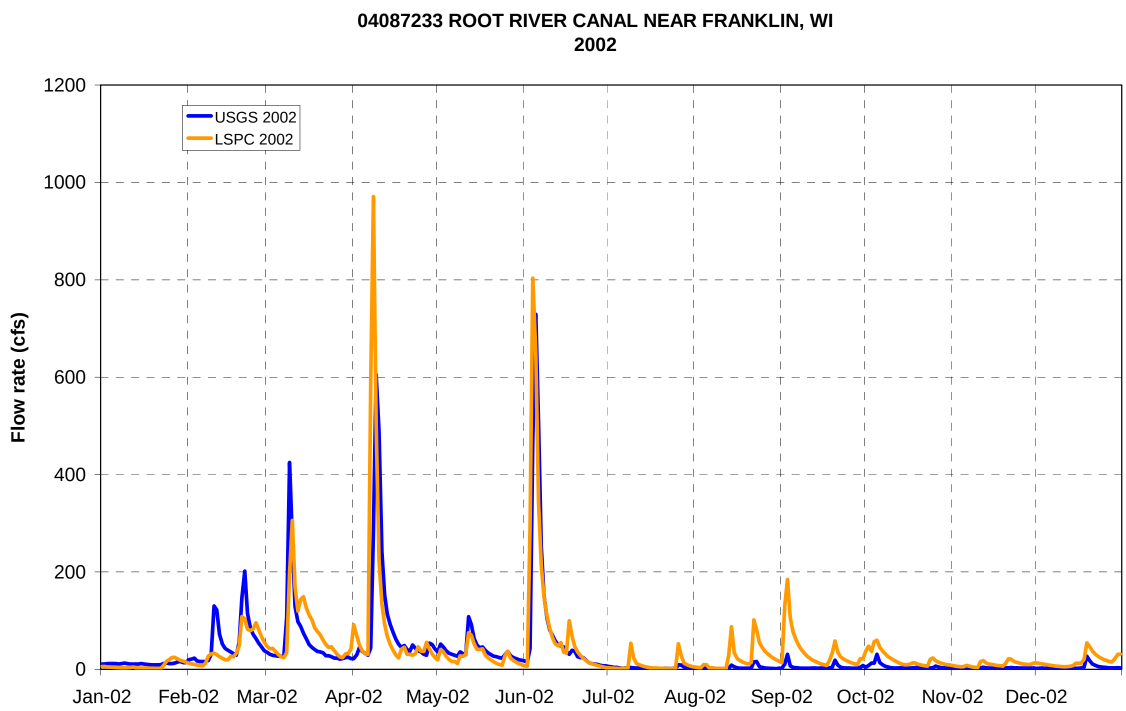


Figure 37. Time series hydrologic validation results (daily mean) for the Root River Canal at USGS gage 04087233 (2002).

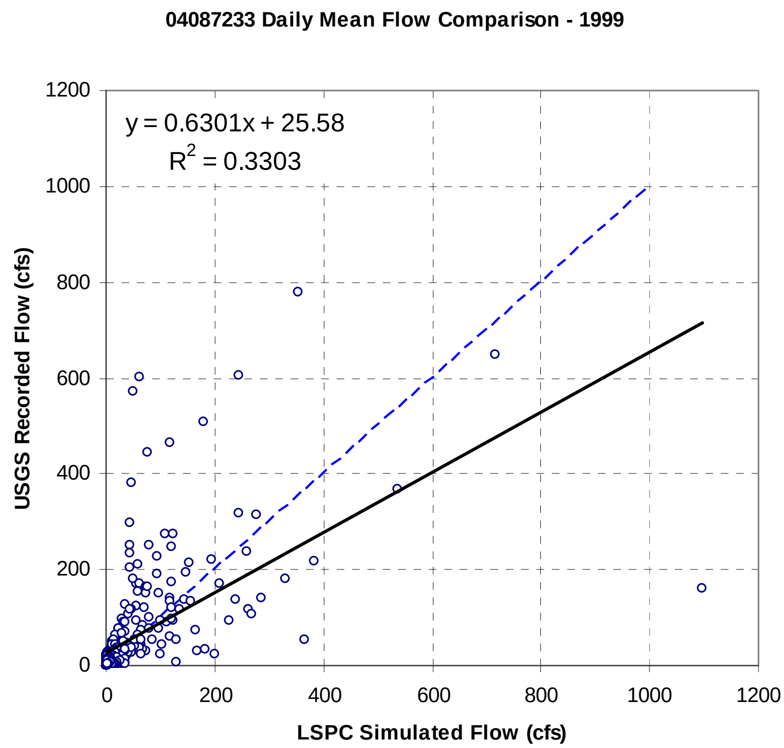


Figure 38. Observed versus simulated scatter plot with a linear regression line for the Root River Canal at USGS gage 04087233 (1999).

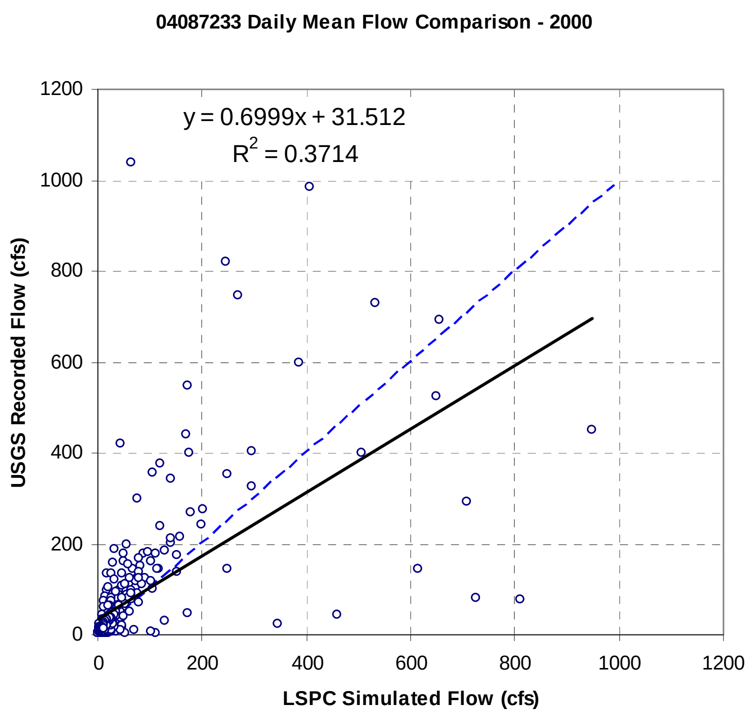


Figure 39. Observed versus simulated scatter plot with a linear regression line for the Root River Canal at USGS gage 04087233 (2000).

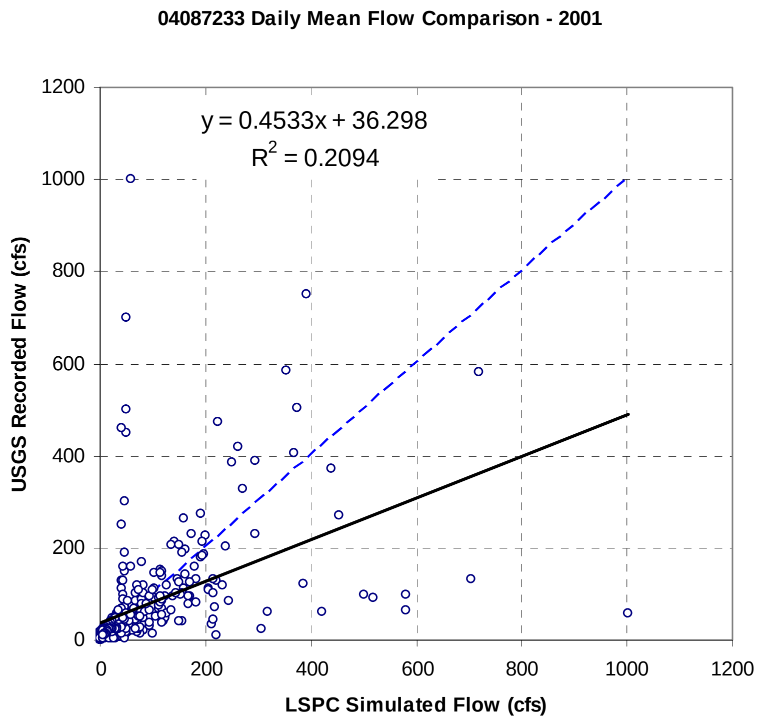


Figure 40. Observed versus simulated scatter plot with a linear regression line for the Root River Canal at USGS gage 04087233 (2001).

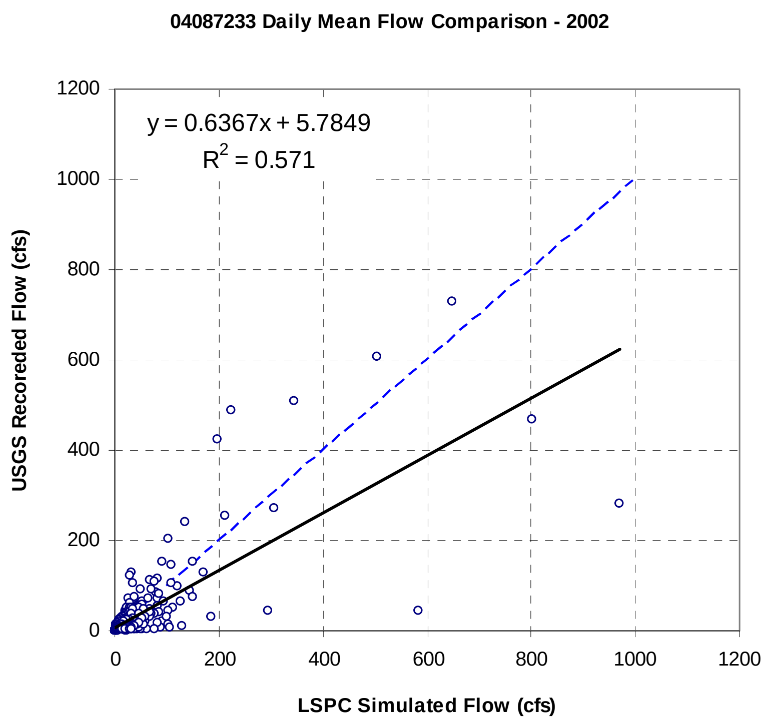


Figure 41. Observed versus simulated scatter plot with a linear regression line for the Root River Canal at USGS gage 04087233 (2002).

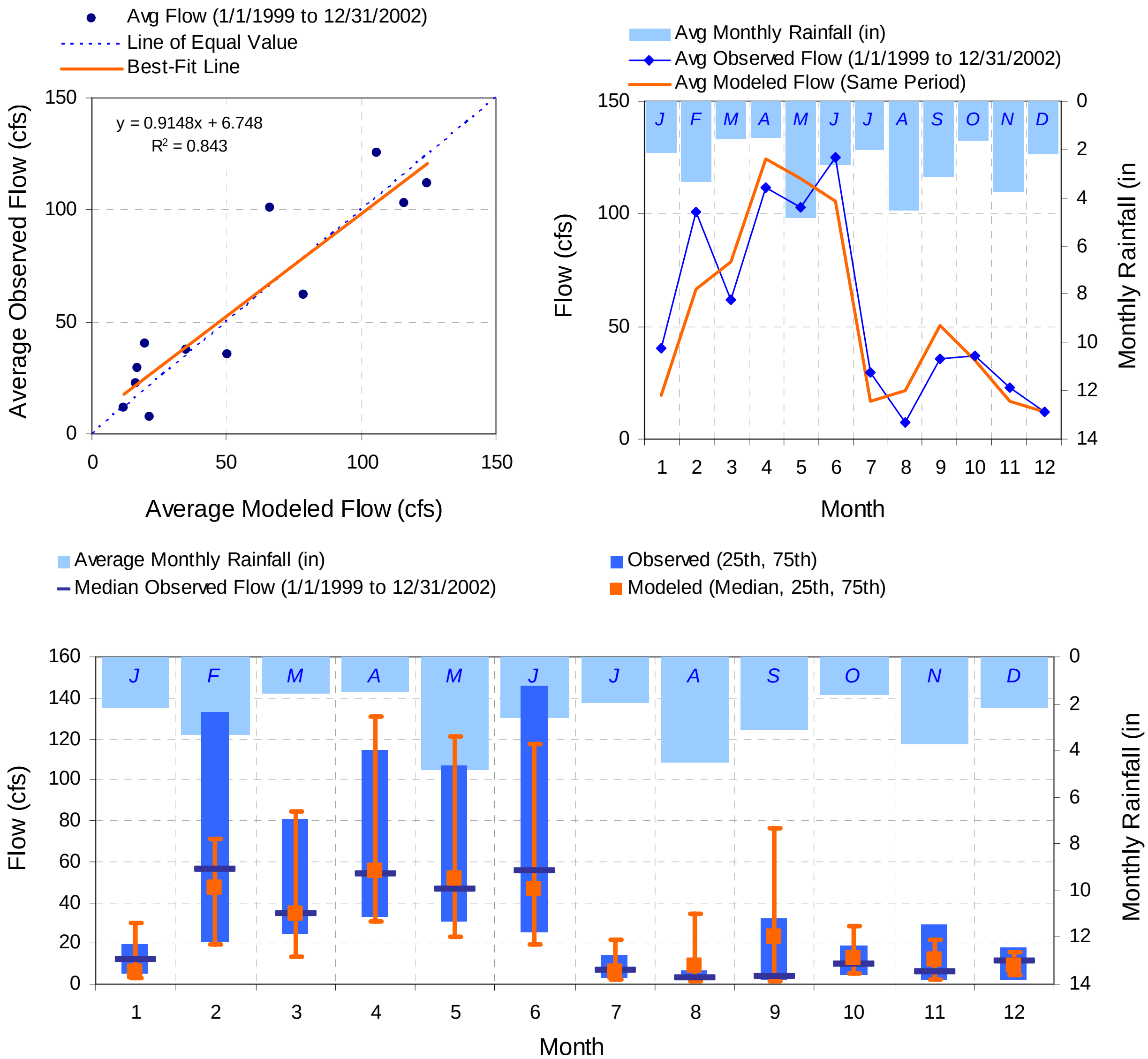


Figure 42. Composite (average monthly) hydrologic validation results for the Root River Canal at USGS gage 04087233 (1999 to 2002).

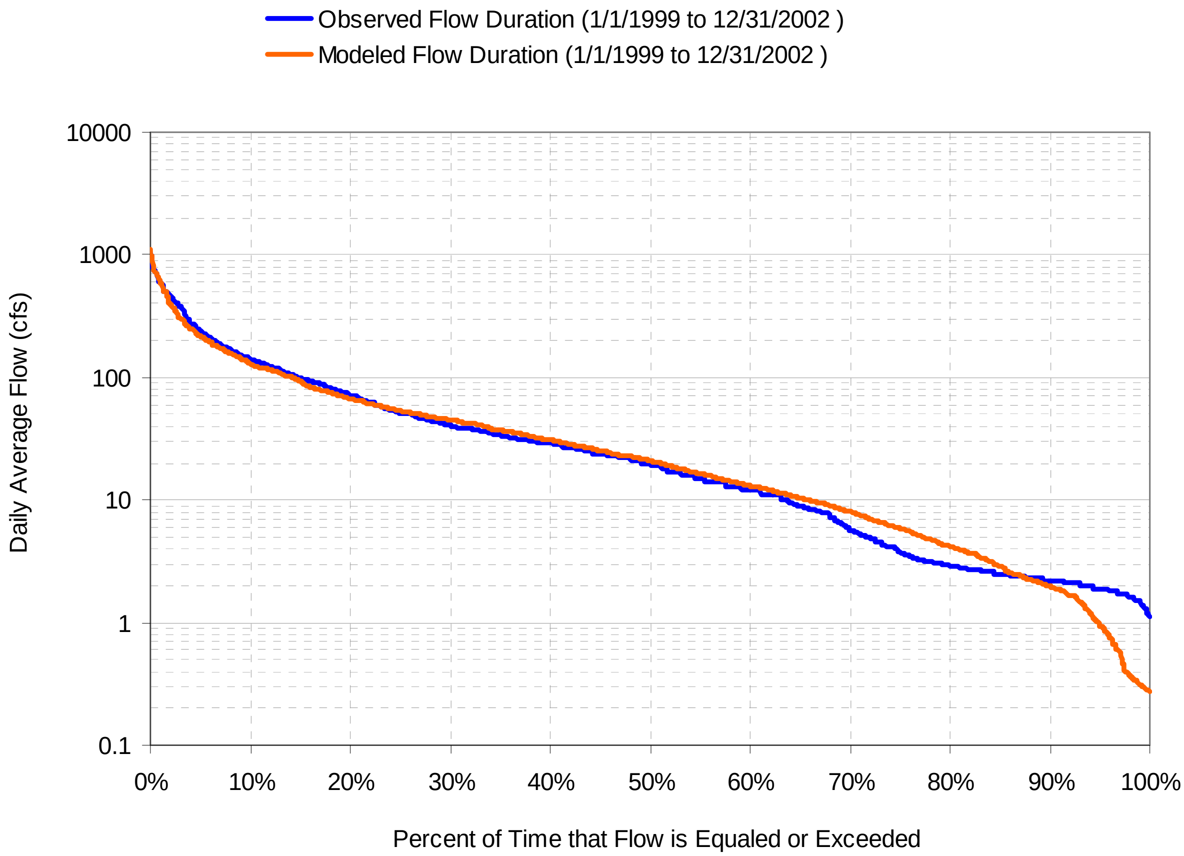


Figure 43. Flow duration curve hydrologic validation results for the Root River Canal at USGS gage 04087233 (1999 to 2002).

Table 10. Error Statistics for hydrologic validation results for the Root River Canal at USGS gage 04087233 (1999 to 2002).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1999			2000			2001			2002			TOTAL		
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month JAN	6,973	1,172	-83.19%	191	354	85.0%	2,049	2,815	37.4%	719	481	-33.0%	**9,932**	**4,822**	**-51.4%**
FEB	6,815	8,804	29.2%	1,929	903	-53.2%	10,713	2,873	-73.2%	3,195	2,324	-27.3%	**22,652**	**14,904**	**-34.2%**
MAR	3,231	1,738	-46.2%	1,129	729	-35.4%	7,020	12,184	73.6%	3,852	4,706	22.2%	**15,231**	**19,357**	**27.1%**
APR	9,429	9,731	3.2%	7,391	5,572	-24.6%	3,923	7,389	88.3%	5,857	6,969	19.0%	**26,601**	**29,661**	**11.5%**
MAY	4,278	4,031	-5.8%	14,106	14,479	2.6%	4,564	8,268	81.2%	2,335	1,700	-27.2%	**25,283**	**28,478**	**12.6%**
JUN	5,996	3,679	-38.6%	9,205	5,753	-37.5%	8,743	9,140	4.5%	5,851	6,600	12.8%	**29,796**	**25,172**	**-15.5%**
JUL	356	693	94.9%	6,111	2,700	-55.8%	589	230	-60.9%	191	538	181.9%	**7,247**	**4,161**	**-42.6%**
AUG	133	73	-45.1%	616	1,418	130.2%	913	2,306	152.7%	219	1,442	559.1%	**1,880**	**5,239**	**178.6%**
SEP	277	590	112.7%	4,011	3,712	-7.5%	3,931	5,415	37.8%	299	2,235	648.2%	**8,518**	**11,952**	**40.3%**
OCT	532	549	3.1%	899	637	-29.2%	7,365	6,154	-16.4%	348	1,321	279.5%	**9,144**	**8,661**	**-5.3%**
NOV	124	108	-13.1%	3,150	1,580	-49.8%	1,950	1,650	-15.4%	164	619	277.1%	**5,388**	**3,957**	**-26.6%**
DEC	190	284	49.1%	964	495	-48.7%	1,505	1,109	-26.4%	272	1,084	298.8%	**2,932**	**2,971**	**1.3%**

Season	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Jan-Mar	17,019	11,714	-31.2%	11.2%	3,250	1,986	-38.9%	18.9%	19,781	17,871	-9.7%		7,766	7,512	-3.3%		**47,816**	**39,083**	**-18.3%**	
Apr-Jun	19,704	17,440	-11.5%		30,703	25,804	-16.0%		17,230	24,798	43.9%	23.9%	14,043	15,270	8.7%		**81,680**	**83,311**	**2.0%**	
Jul-Sep	766	1,356	77.1%	57.1%	10,738	7,830	-27.1%	7.1%	5,433	7,952	46.4%	26.4%	708	4,215	495.0%	475.0%	**17,645**	**21,352**	**21.0%**	**1.0%**
Oct-Dec	847	941	11.1%		5,013	2,712	-45.9%	25.9%	10,820	8,912	-17.6%		784	3,024	285.7%	265.7%	**17,463**	**15,589**	**-10.7%**	

Calibration Tolerance =20%

	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	38,335	31,451	-18.0%	8.0%	49,703	38,331	-22.9%	12.9%	53,264	59,533	11.8%	1.8%	23,301	30,020	28.8%	18.8%	**164,604**	**159,335**	**-3.2%**	

Table 11. High-Low flow error statistics for hydrologic validation results for the Root River Canal at USGS gage 04087233 (1999-2002).

Category	**LSPC volume (ac-ft)**	**USGS volume (ac-ft)**	**Percent Difference**	**Tolerance**
Total Highest 10% volume	86,991	93,029	-6.5%	15%
Total Highest 20% volume	114,556	122,840	-6.7%	15%
Total Highest 50% volume	148,653	155,143	-4.2%	15%
Total Lowest 10% volume	304	543	-44.0%	10%
Total Lowest 30% volume	2,890	2,443	18.3%	10%
Total Lowest 50% volume	10,807	9,580	12.8%	10%

8.2.3 Lower Root River Results

The performance of the model was also evaluated by comparing simulated results to observed flows recorded at the USGS gage on the Lower Root River (04087240). The results are presented in Figure 44 to Figure 63 and indicate that the model correctly simulates the timing of flow events and the magnitude of peak flows across all years simulated. The low flows are slightly over-predicted at this gage The over-prediction by the model may be a result of one or more of the following factors:

- Uncertainty associated with estimated flows for point sources.
- Delineation of Directly Connected Impervious Areas (DCIAs)
- Uncertainty in the specification of stage-discharge relationships (Ftables)
- Storm water retention structures

The composite graphs shown in Figure 52 and Figure 62 indicate the model simulates seasonal patterns for fall and winter fairly effectively but overestimates flow in the late spring and the summer. The observed and simulated cumulative flow duration curves are aligned fairly well with one another, with the model overpredicting moderate-to-high flows and underpredicting the lowest flows.

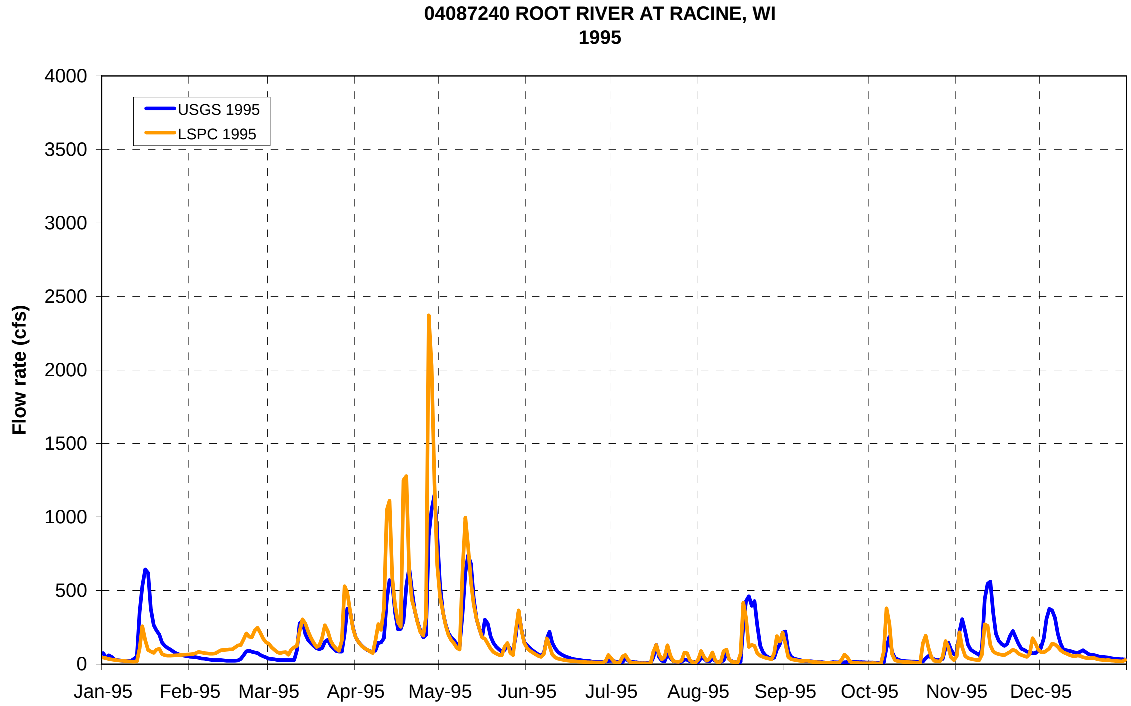


Figure 44. Time series hydrologic calibration results (daily mean) for the Lower Root River at USGS gage 04087240 (1995).

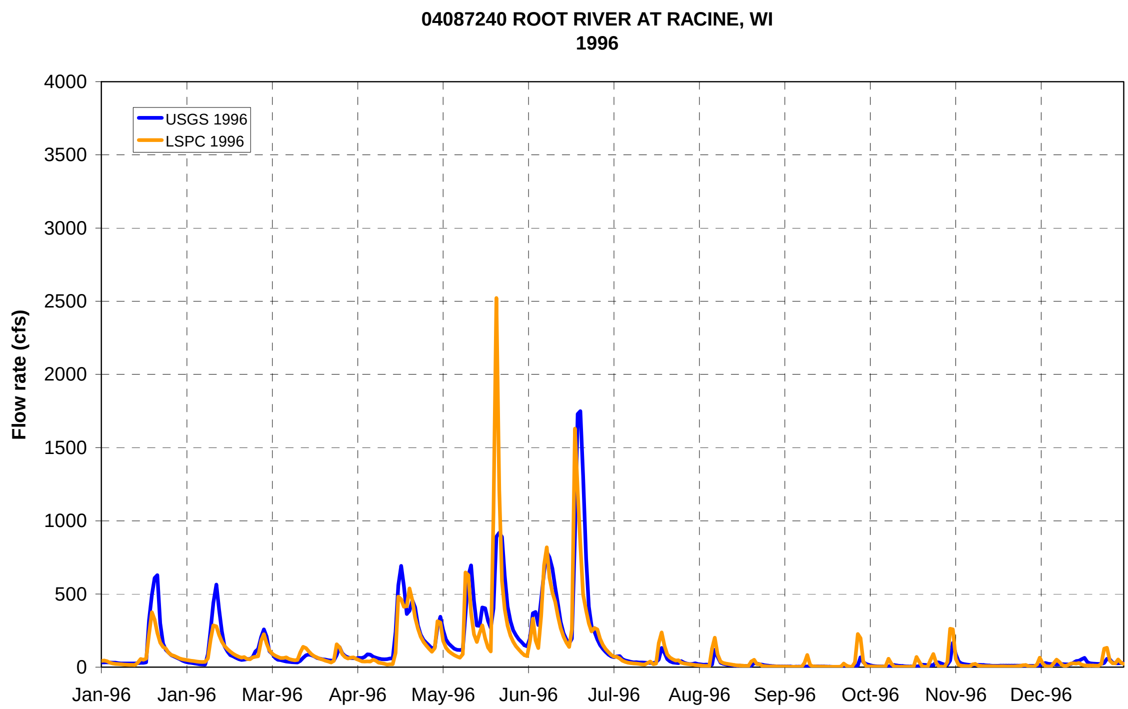


Figure 45. Time series hydrologic calibration results (daily mean) for the Lower Root River at USGS gage 04087240 (1996).

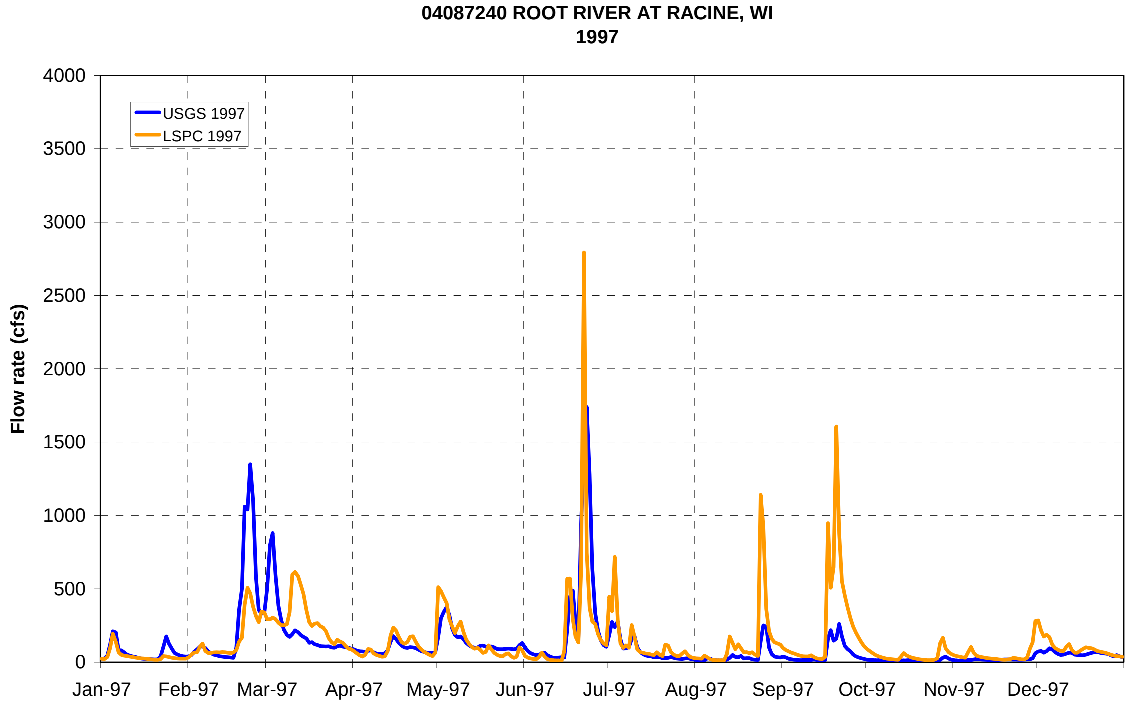


Figure 46. Time series hydrologic calibration results (daily mean) for the Lower Root River at USGS gage 04087240 (1997).

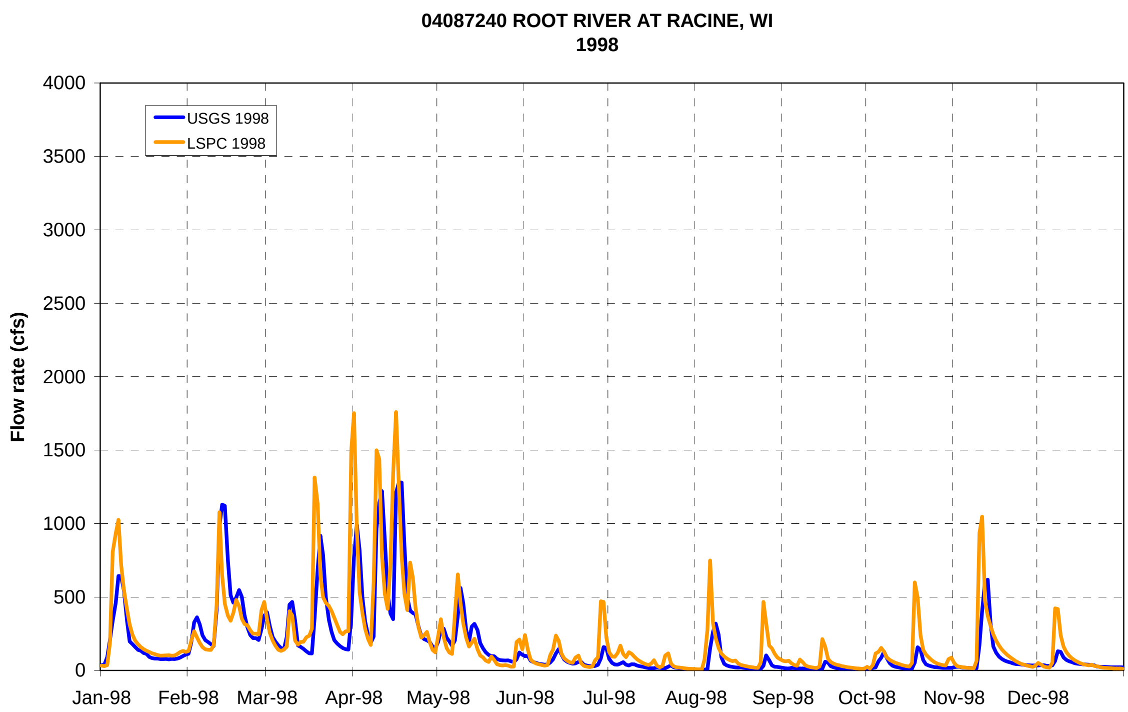


Figure 47. Time series hydrologic calibration results (daily mean) for the Lower Root River at USGS gage 04087240 (1998).

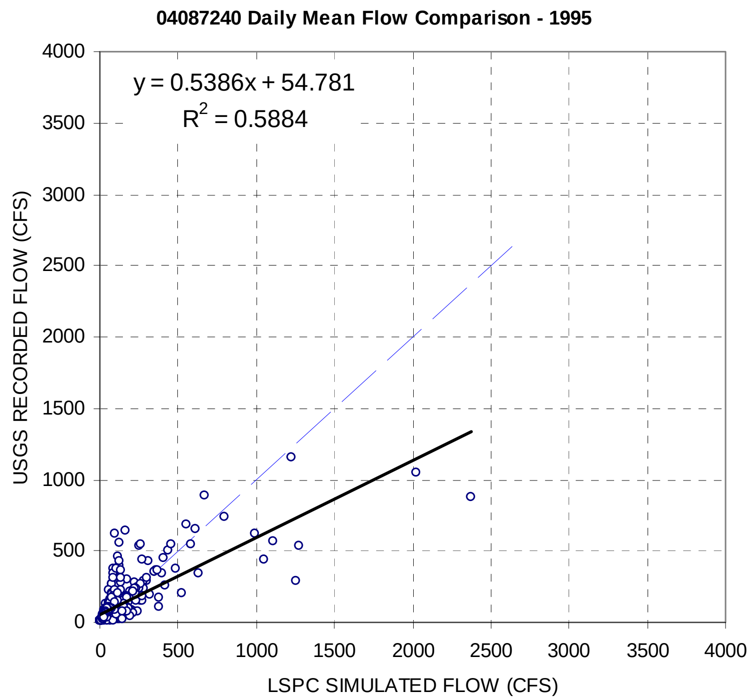


Figure 48. Observed versus simulated scatter plot with linear regression line for the Lower Root River at USGS gage 04087240 (1995).

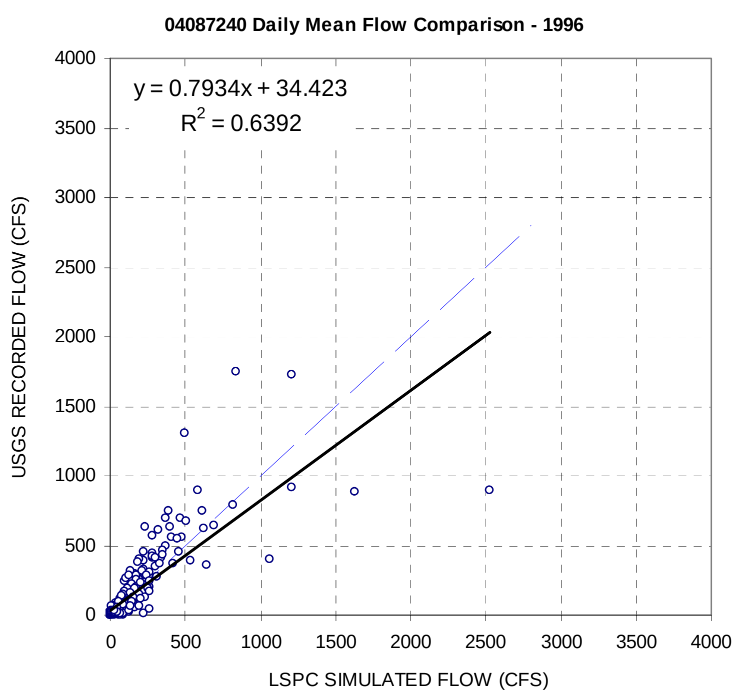


Figure 49. Observed versus simulated scatter plot with linear regression line for the Lower Root River at USGS gage 04087240 (1996).

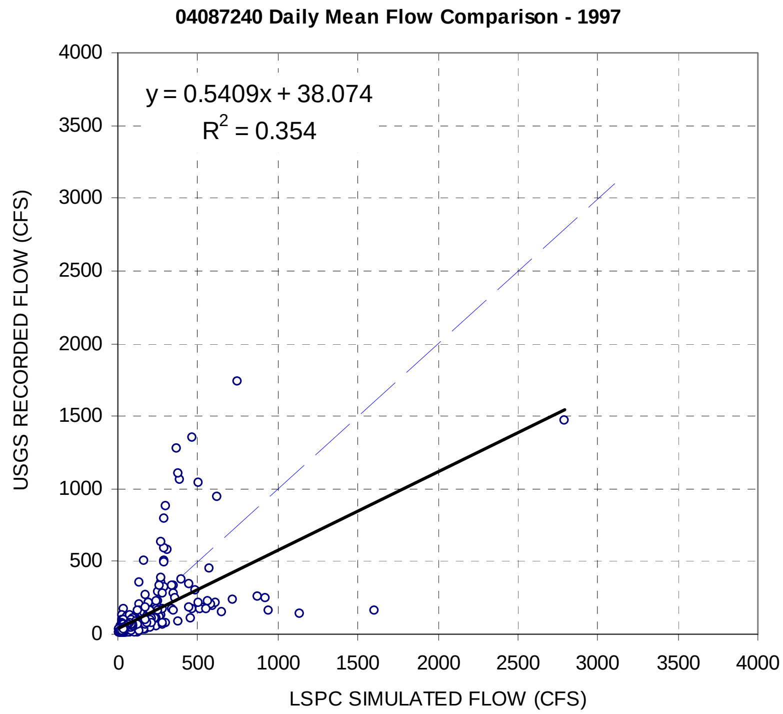


Figure 50. Observed versus simulated scatter plot with linear regression line for the Lower Root River at USGS gage 04087240 (1997).

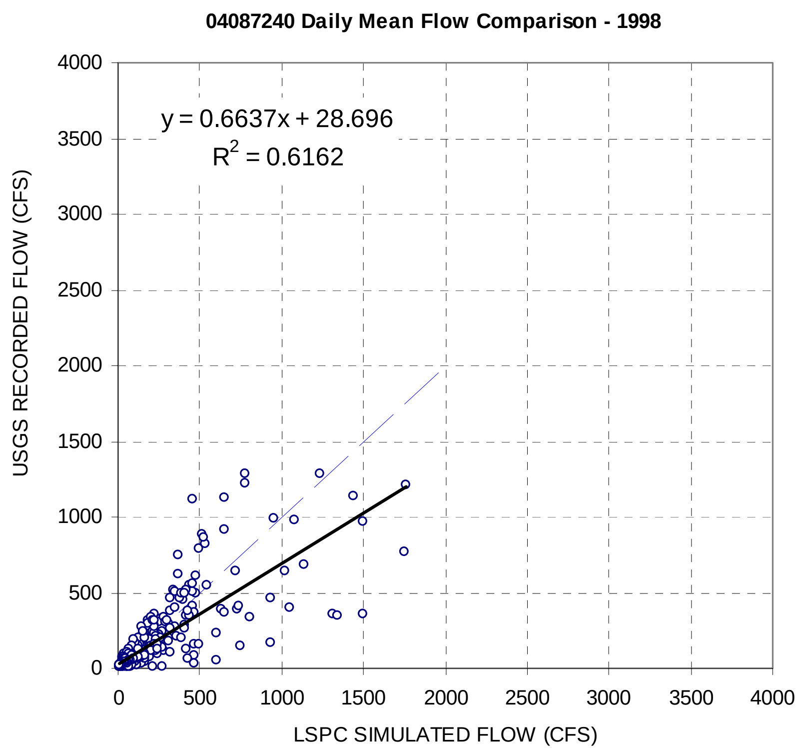


Figure 51. Observed versus simulated scatter plot with linear regression line for the Lower Root River at USGS gage 04087240 (1998).

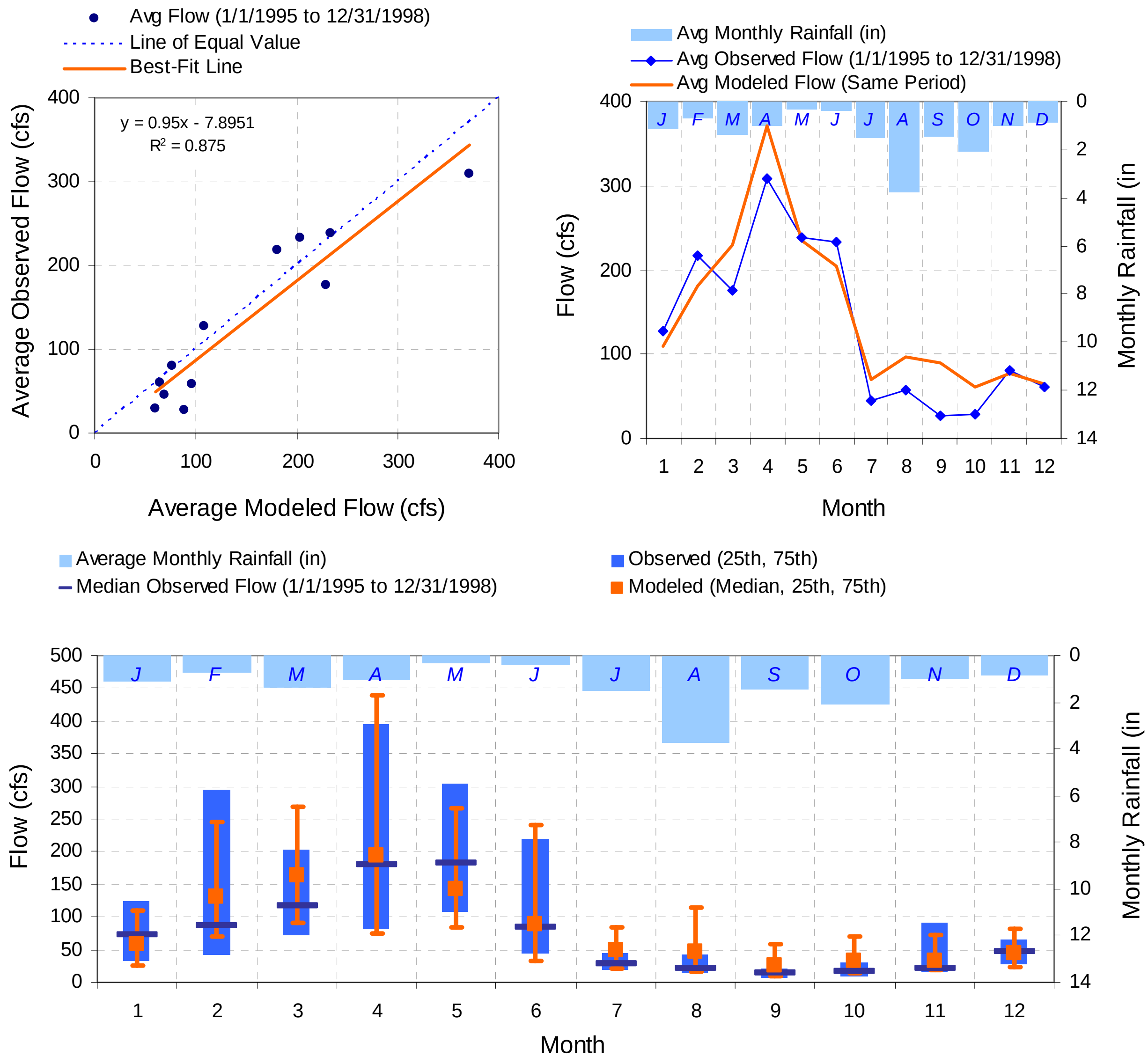


Figure 52. Composite (average monthly) hydrologic calibration results for the Lower Root River at USGS gage 04087240 (1995 to 1998).

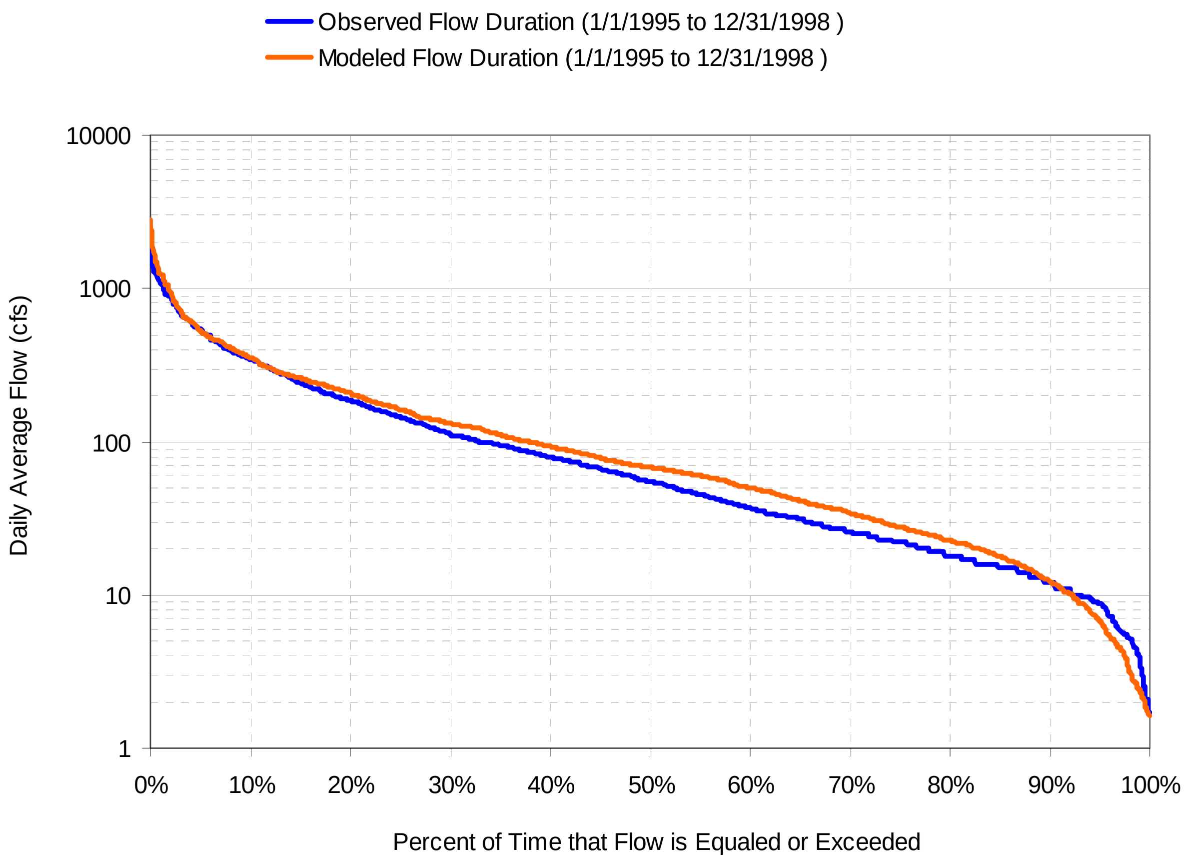


Figure 53. Flow duration curve hydrologic calibration results for the Lower Root River at USGS gage 04087240 (1995 to 1998).

Table 12. Error statistics for hydrologic calibration results for the Lower Root River at USGS gage 04087240 (1995-1998).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1995			1996			1997			1998			TOTAL		
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month JAN	9,084	3,831	-57.83%	7,095	5,173	-27.1%	3,939	2,539	-35.6%	11,020	15,224	38.1%	**31,139**	**26,766**	**-14.0%**
FEB	2,465	6,778	174.9%	7,678	6,212	-19.1%	16,064	9,093	-43.4%	22,635	18,433	-18.6%	**48,843**	**40,516**	**-17.0%**
MAR	7,718	11,037	43.0%	3,890	4,696	20.7%	13,720	16,995	23.9%	18,083	23,702	31.1%	**43,410**	**56,430**	**30.0%**
APR	21,727	33,318	53.3%	12,133	10,257	-15.5%	5,193	5,777	11.3%	34,334	38,886	13.3%	**73,386**	**88,238**	**20.2%**
MAY	16,044	15,757	-1.8%	22,050	21,870	-0.8%	9,102	9,701	6.6%	11,599	10,345	-10.8%	**58,796**	**57,674**	**-1.9%**
JUN	3,673	2,604	-29.1%	29,310	23,633	-19.4%	18,492	15,534	-16.0%	4,013	6,792	69.3%	**55,488**	**48,563**	**-12.5%**
JUL	1,527	2,154	41.0%	2,743	3,220	17.4%	5,010	7,826	56.2%	1,712	3,963	131.5%	**10,992**	**17,162**	**56.1%**
AUG	6,885	5,369	-22.0%	1,220	1,653	35.5%	2,755	8,816	220.0%	3,343	7,890	136.0%	**14,203**	**23,729**	**67.1%**
SEP	1,559	1,326	-15.0%	460	1,431	211.3%	3,695	15,663	323.9%	879	2,742	211.9%	**6,593**	**21,163**	**221.0%**
OCT	2,679	3,812	42.3%	1,118	1,963	75.5%	835	2,718	225.5%	2,533	6,376	151.7%	**7,166**	**14,870**	**107.5%**
NOV	10,631	5,419	-49.0%	970	633	-34.7%	1,086	2,799	157.8%	6,500	9,640	48.3%	**19,187**	**18,491**	**-3.6%**
DEC	6,776	3,489	-48.5%	1,805	1,858	2.9%	3,636	5,993	64.8%	2,709	4,552	68.0%	**14,926**	**15,893**	**6.5%**

Season	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Jan-Mar	19,267	21,646	12.3%		18,662	16,081	-13.8%		33,723	28,626	-15.1%		51,739	57,360	10.9%		**123,392**	**123,712**	**0.3%**	
Apr-Jun	41,445	51,679	24.7%	4.7%	63,493	55,760	-12.2%		32,787	31,013	-5.4%		49,946	56,023	12.2%		**187,670**	**194,474**	**3.6%**	
Jul-Sep	9,971	8,850	-11.2%		4,423	6,304	42.5%	22.5%	11,461	32,305	181.9%	161.9%	5,934	14,595	146.0%	126.0%	**31,789**	**62,053**	**95.2%**	**75.2%**
Oct-Dec	20,086	12,720	-36.7%	16.7%	3,893	4,454	14.4%		5,557	11,511	107.1%	87.1%	11,743	20,569	75.2%	55.2%	**41,279**	**49,254**	**19.3%**	

Calibration Tolerance =20%

	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	90,770	94,895	4.5%		90,472	82,598	-8.7%		83,527	103,454	23.9%	13.9%	119,361	148,546	24.5%	14.5%	**384,130**	**429,494**	**11.8%**	**1.8%**

Calibration Tolerance =10%

Table 13. High-Low flow error statistics for hydrologic calibration results for the Lower Root River at USGS gage 04087240 (1995-1998).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	205,014	186,589	9.9%	15%
Total Highest 20% volume	282,349	259,912	8.6%	15%
Total Highest 50% volume	385,067	349,065	10.3%	15%
Total Lowest 10% volume	1,981	2,316	-14.4%	10%
Total Lowest 30% volume	15,266	13,104	16.5%	10%
Total Lowest 50% volume	44,831	35,392	26.7%	10%

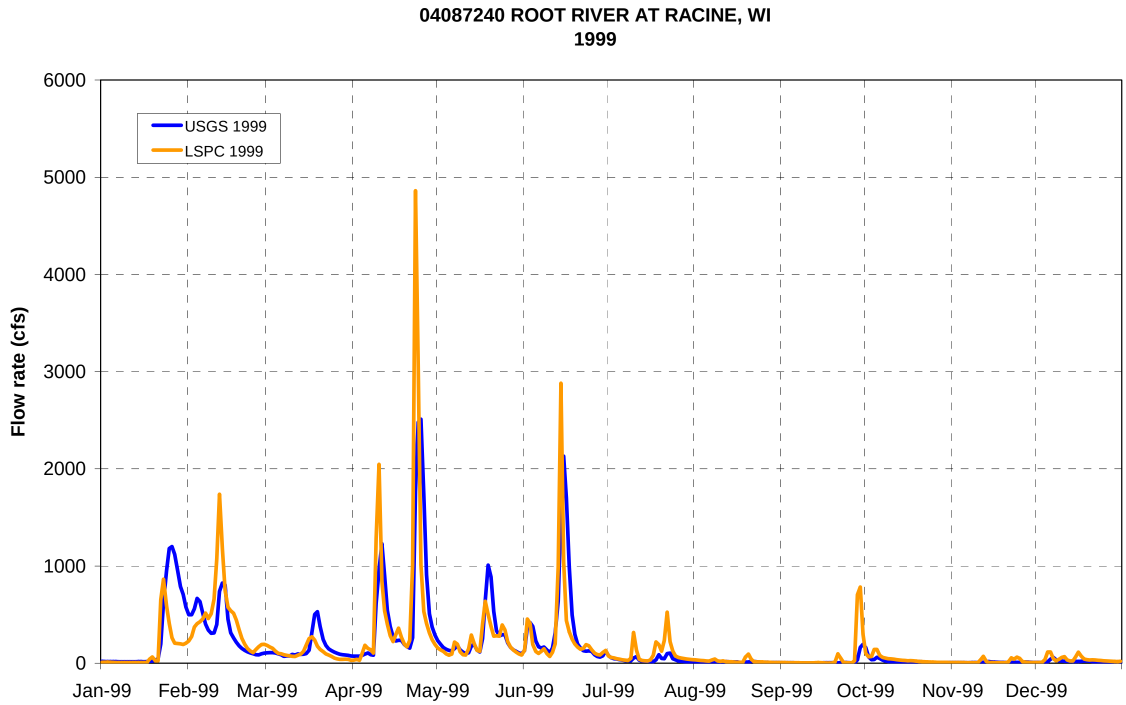


Figure 54. Time series hydrologic validation results (daily mean) for the Lower Root River at USGS gage 04087240 (1999).

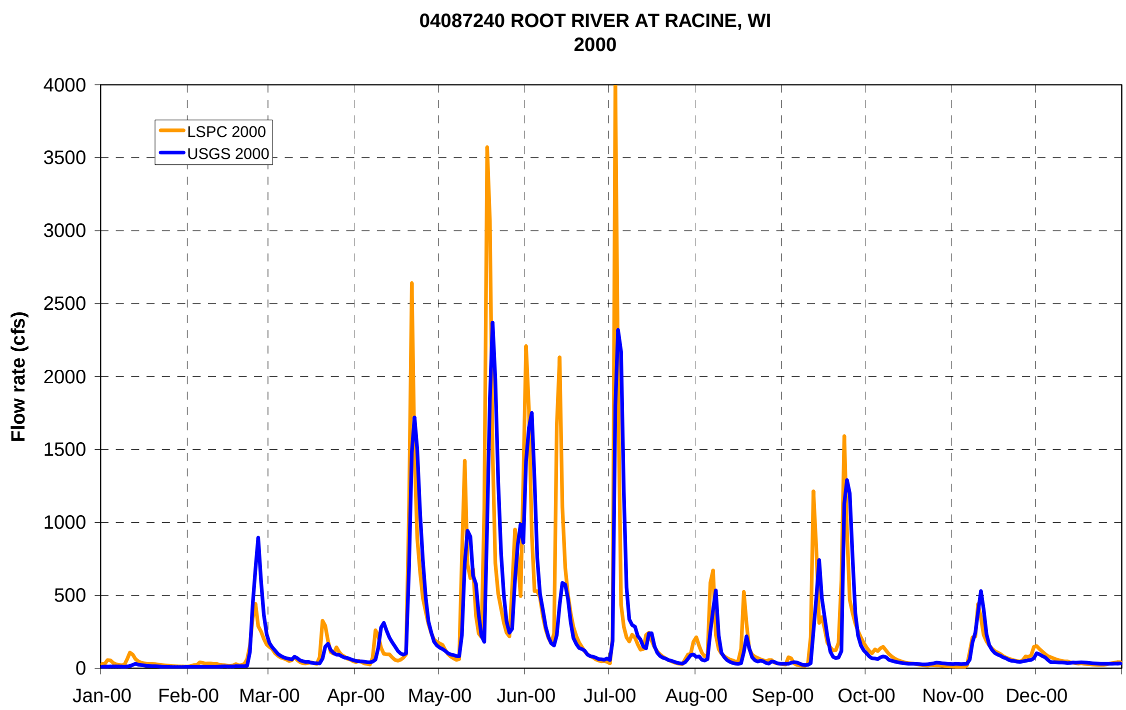


Figure 55. Time series hydrologic validation results (daily mean) for the Lower Root River at USGS gage 04087240 (2000).

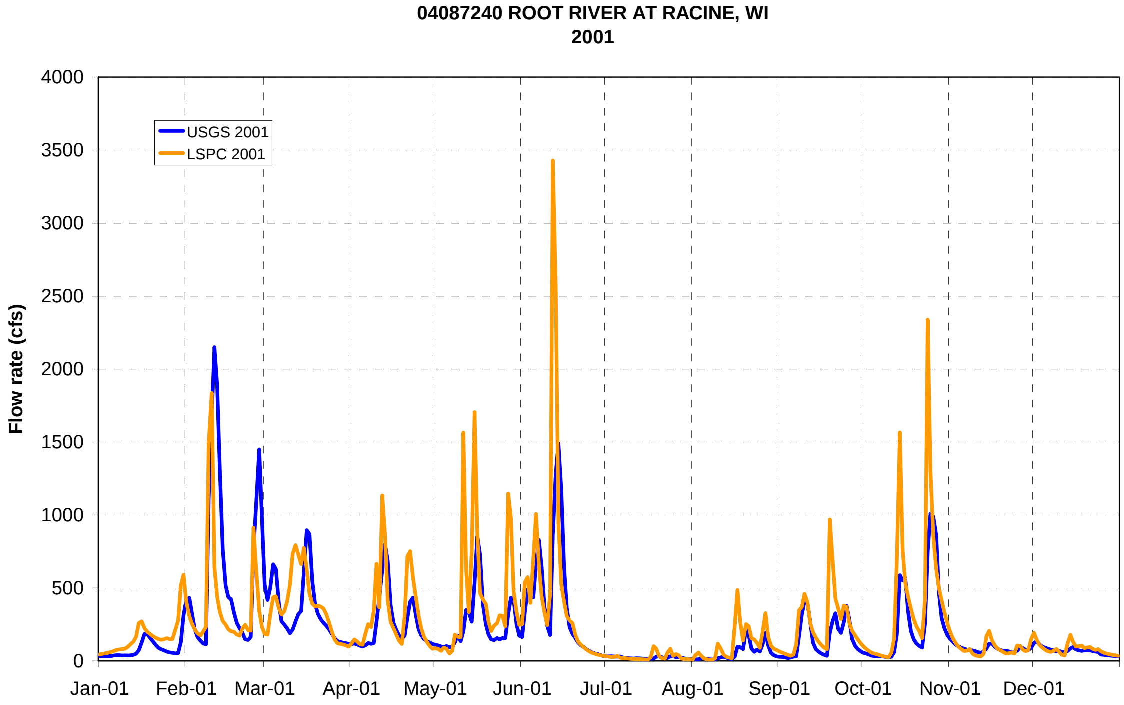


Figure 56. Time series hydrologic validation results (daily mean) for the Lower Root River at USGS gage 04087240 (2001).

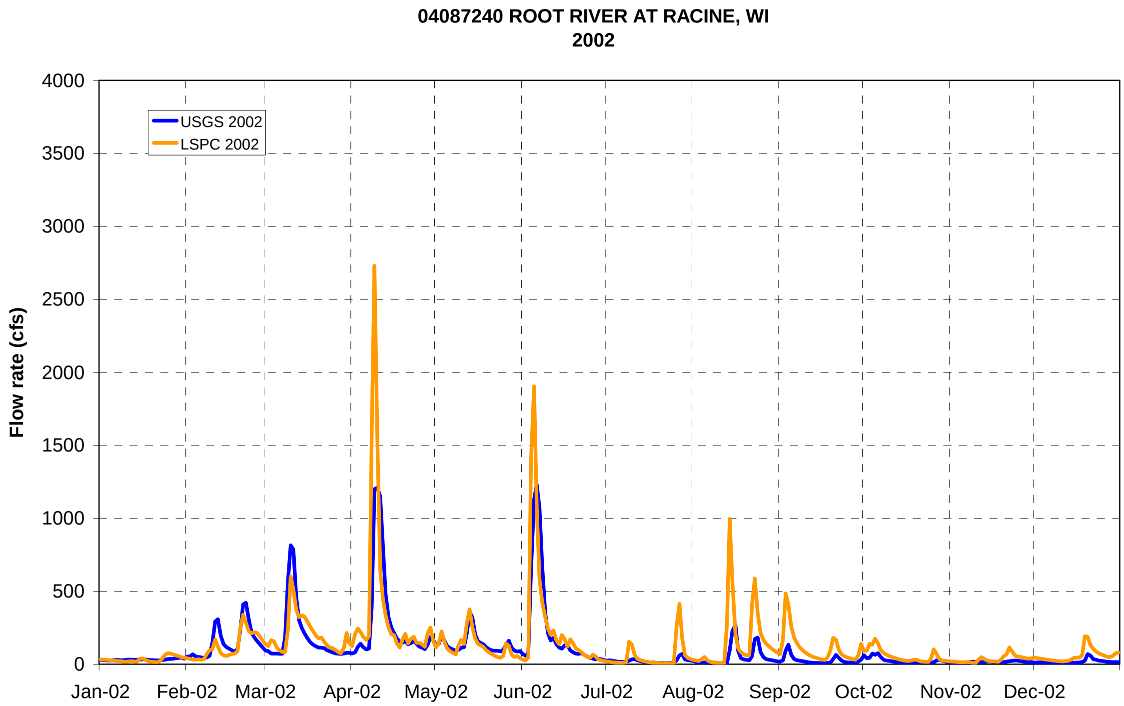


Figure 57. Time series hydrologic validation results (daily mean) for the Lower Root River at USGS gage 04087240 (2002).

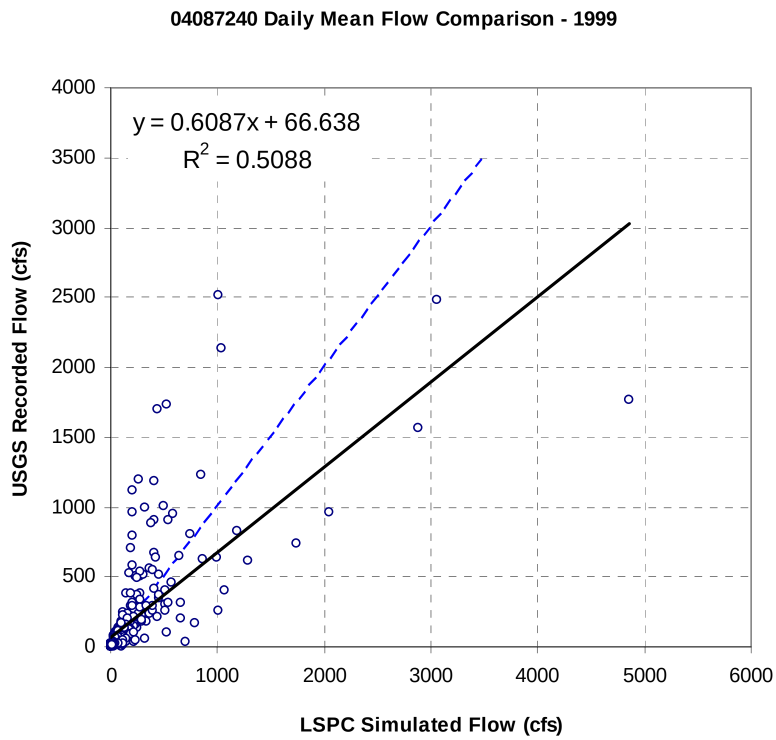


Figure 58. Observed versus simulated scatter plot with a linear regression line for the Lower Root River at USGS gage 04087240 (1999).

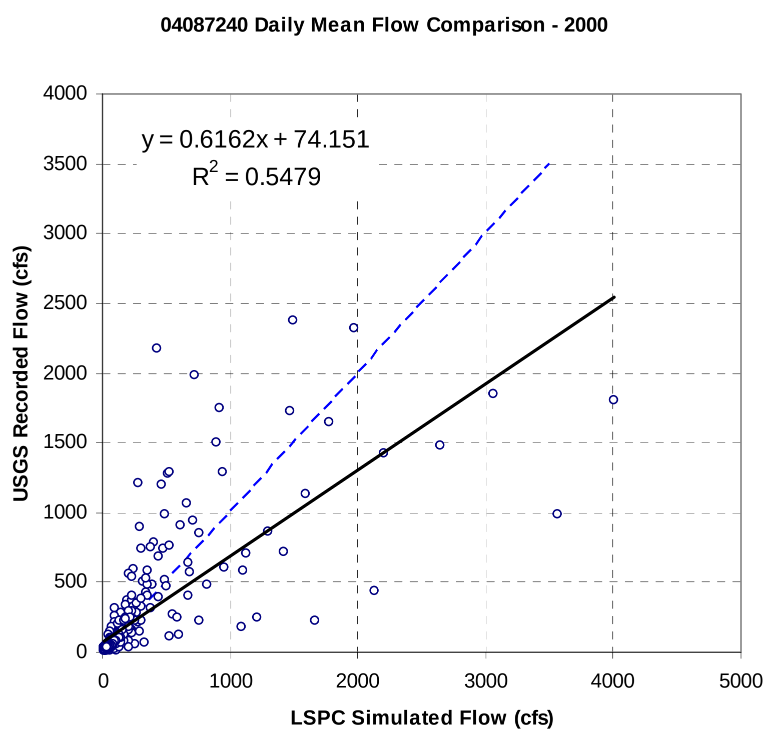


Figure 59. Observed versus simulated scatter plot with a linear regression line for the Lower Root River at USGS gage 04087240 (2000).

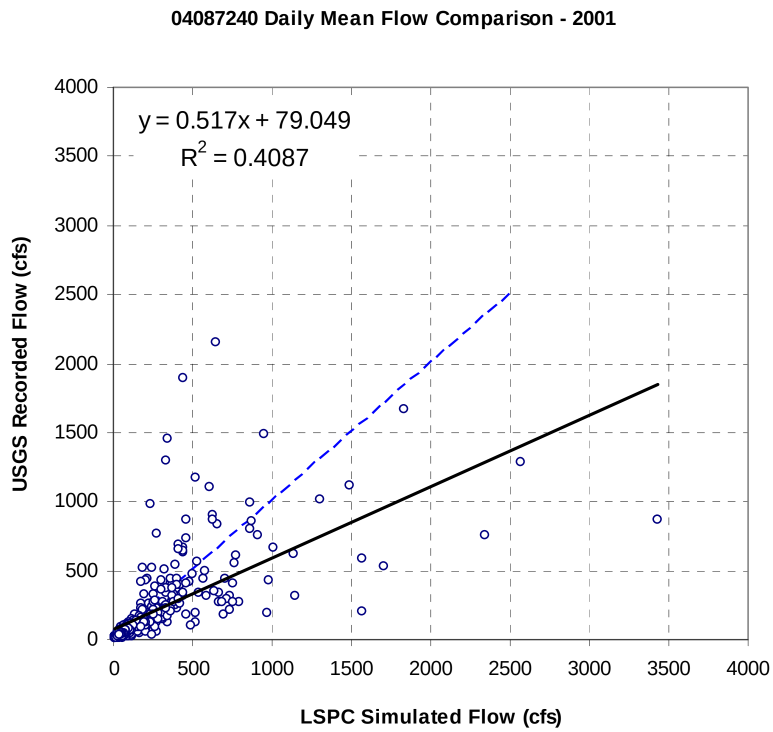


Figure 60. Observed versus simulated scatter plot with a linear regression line for the Lower Root River at USGS gage 04087240 (2001).

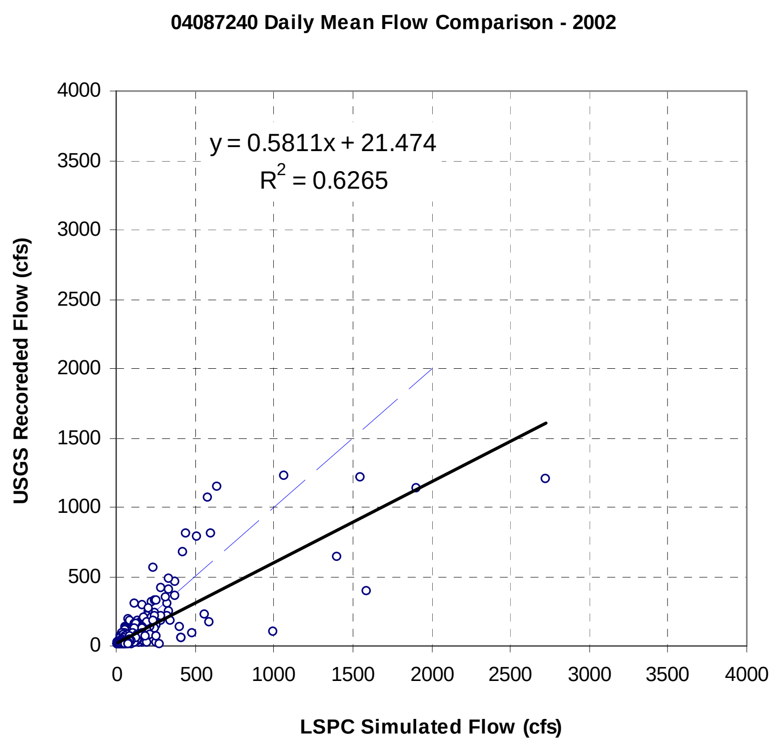


Figure 61. Observed versus simulated scatter plot with a linear regression line for the Lower Root River at USGS gage 04087240 (2002).

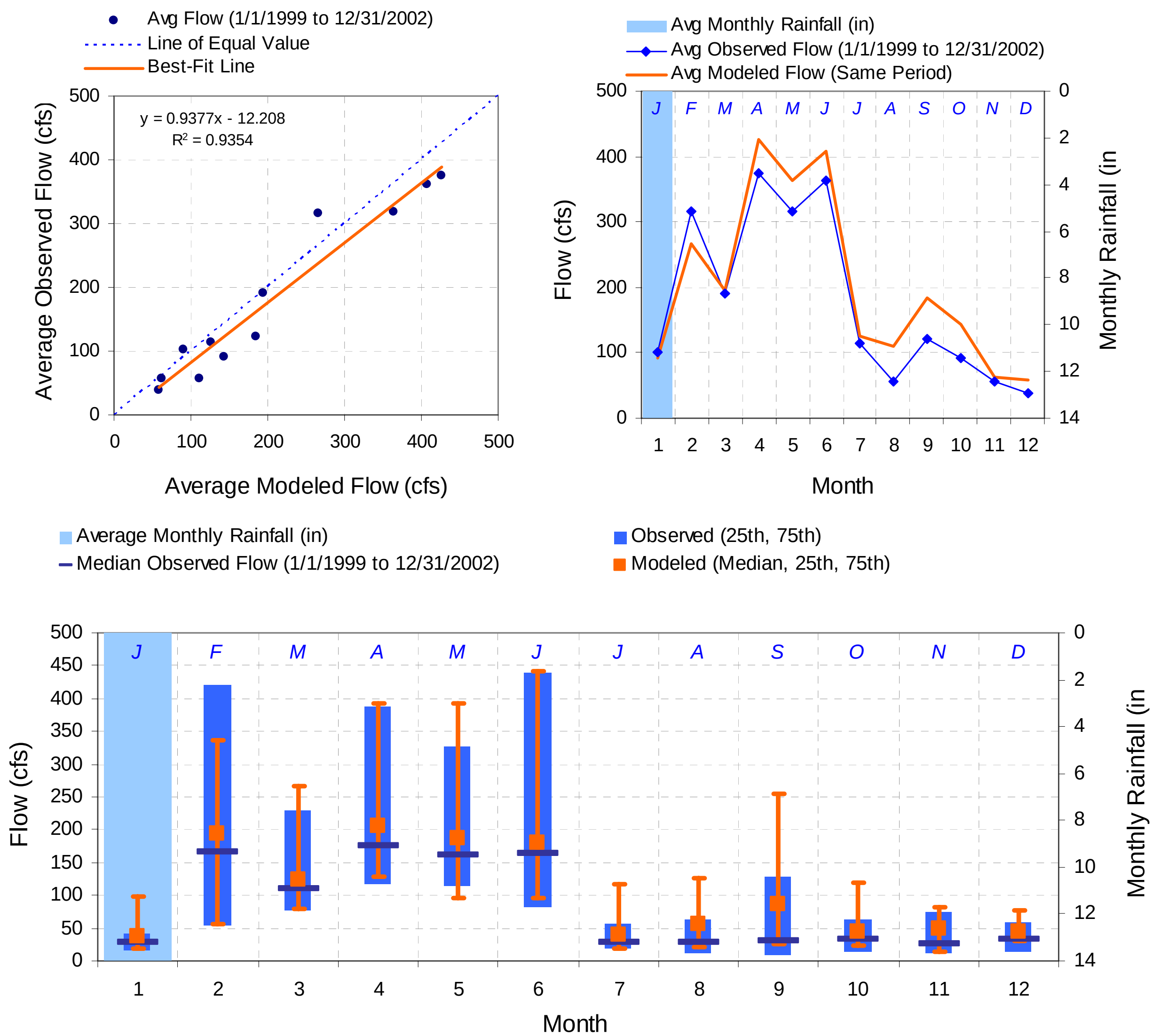


Figure 62. Composite (average monthly) hydrologic validation results for the Lower Root River at USGS gage 04087240 (1999 to 2002).

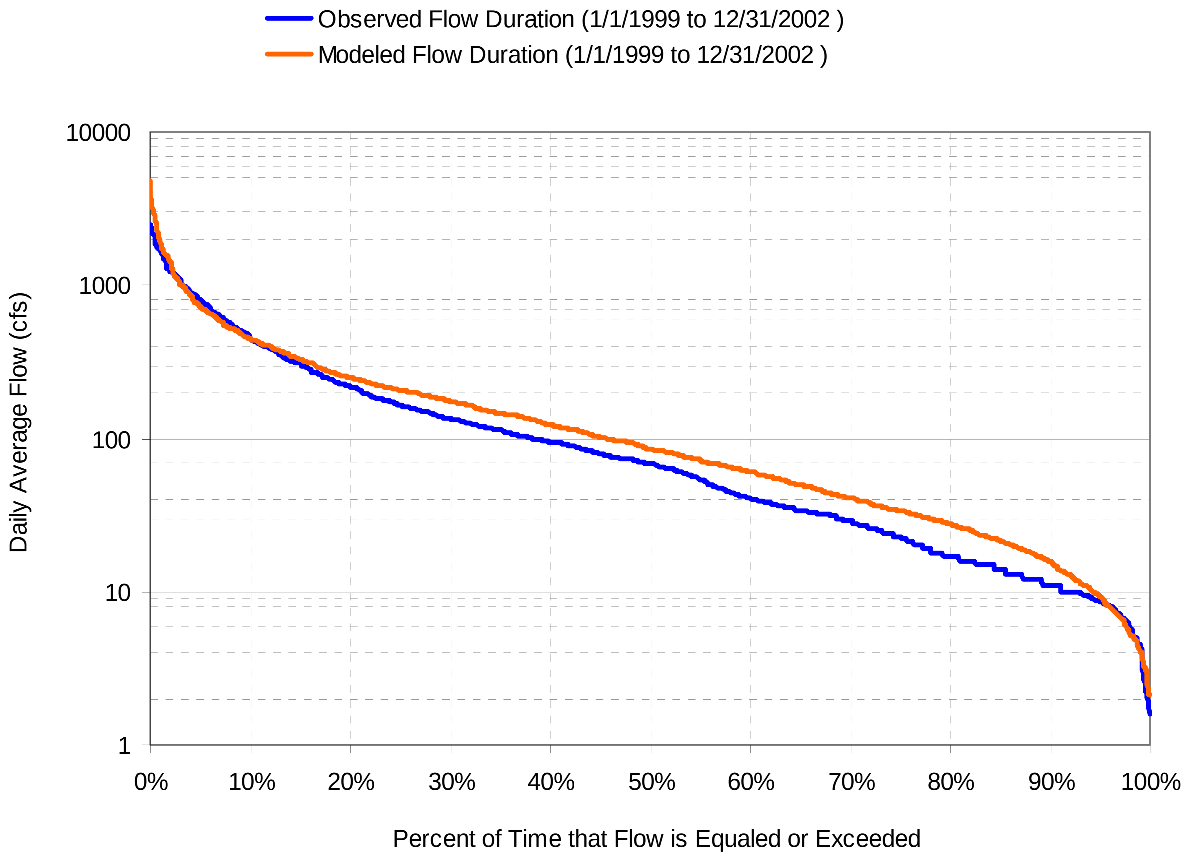


Figure 63. Flow duration curve hydrologic validation results for the Lower Root River at USGS gage 04087240 (1999 to 2002).

Table 14. Error Statistics for hydrologic validation results for the Lower Root River at USGS gage 04087240 (1999 to 2002).

Monthly / Seasonal / Yearly Volume Comparison

Time Period	1999			2000			2001			2002			TOTAL		
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.
Month JAN	17,270	8,103	-53.08%	855	2,093	144.7%	4,921	10,163	106.5%	1,930	2,066	7.1%	24,976	22,425	-10.2%
FEB	19,640	25,801	31.4%	7,114	4,839	-32.0%	35,607	22,254	-37.5%	8,436	6,712	-20.4%	70,797	59,606	-15.8%
MAR	9,132	6,812	-25.4%	4,992	5,659	13.4%	21,495	23,158	7.7%	11,393	12,377	8.6%	47,012	48,006	2.1%
APR	34,943	38,811	11.1%	21,640	20,208	-6.6%	15,029	19,511	29.8%	17,478	23,022	31.7%	89,090	101,553	14.0%
MAY	15,433	13,104	-15.1%	38,719	42,704	10.3%	15,372	26,205	70.5%	8,501	7,580	-10.8%	78,026	89,593	14.8%
JUN	23,455	19,408	-17.3%	24,920	30,934	24.1%	23,629	30,187	27.8%	14,273	16,341	14.5%	86,277	96,870	12.3%
JUL	2,450	6,156	151.3%	22,683	19,913	-12.2%	1,422	1,806	27.0%	1,357	3,274	141.2%	27,912	31,149	11.6%
AUG	684	1,418	107.2%	6,212	8,786	41.4%	3,523	7,208	104.6%	3,296	9,850	198.8%	13,716	27,262	98.8%
SEP	995	4,109	312.9%	17,034	18,225	7.0%	9,289	14,722	58.5%	1,660	6,748	306.5%	28,978	43,803	51.2%
OCT	1,447	2,432	68.1%	2,824	3,594	27.3%	16,635	25,861	55.5%	1,634	3,544	116.8%	22,541	35,432	57.2%
NOV	563	1,002	78.0%	6,831	6,579	-3.7%	5,030	5,389	7.1%	950	2,072	118.1%	13,374	15,042	12.5%
DEC	1,145	2,486	117.0%	2,715	3,146	15.8%	4,374	5,204	19.0%	1,119	3,612	222.8%	9,353	14,448	54.5%

	1999				2000				2001				2002				TOTAL			
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Season Jan-Mar	46,042	40,716	-11.6%		12,961	12,591	-2.9%		62,023	55,576	-10.4%		21,759	21,155	-2.8%		**142,785**	**130,037**	**-8.9%**	
Apr-Jun	73,831	71,323	-3.4%		85,279	93,846	10.0%		54,030	75,904	40.5%	20.5%	40,253	46,943	16.6%		**253,392**	**288,016**	**13.7%**	
Jul-Sep	4,129	11,683	182.9%	162.9%	45,929	46,923	2.2%		14,233	23,736	66.8%	46.8%	6,314	19,872	214.7%	194.7%	**70,606**	**102,214**	**44.8%**	**24.8%**
Oct-Dec	3,155	5,920	87.6%	67.6%	12,371	13,319	7.7%		26,039	36,454	40.0%	20.0%	3,704	9,229	149.2%	129.2%	**45,269**	**64,922**	**43.4%**	**23.4%**
Calibration Tolerance =20%																				
	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance	Recorded USGS Volume (ac-ft)	Simulated LSPC Volume (ac-ft)	Percent Diff.	Var. from Tolerance
Year	127,158	129,642	2.0%		156,540	166,679	6.5%		156,325	191,669	22.6%	12.6%	72,029	97,199	34.9%	24.9%	**512,052**	**585,189**	**14.3%**	**4.3%**
Calibration Tolerance =10%																				

Table 15. High-Low flow error statistics for hydrologic validation results for the Lower Root River at USGS gage 04087240 (1999 to 2002).

Category	LSPC volume (ac-ft)	USGS volume (ac-ft)	Percent Difference	Tolerance
Total Highest 10% volume	299,970	277,277	8.2%	15%
Total Highest 20% volume	397,657	368,511	7.9%	15%
Total Highest 50% volume	531,129	473,697	12.1%	15%
Total Lowest 10% volume	2,681	2,340	14.6%	10%
Total Lowest 30% volume	18,780	12,945	45.1%	10%
Total Lowest 50% volume	54,565	38,764	40.8%	10%

Table 16. Coefficient of Model Fit Efficiency (E) for Root River Hydrologic Model (Daily Flows, 1995 to 2002)

USGS Gage Number	Station Name	E
04087220	Root River nr. Franklin	0.48
04087233	Root River Canal nr Franklin	0.25
04087240	Root River at Racine	0.30

9 REFERENCES

Bicknell, B.R., J.C. Imhoff, J. Kittle, A.S. Donigian, and R.C. Johansen. 1996. *Hydrological Simulation Program –FORTRAN, User's Manual for Release H*. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. *Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage*, 89(IR4): 15-41.

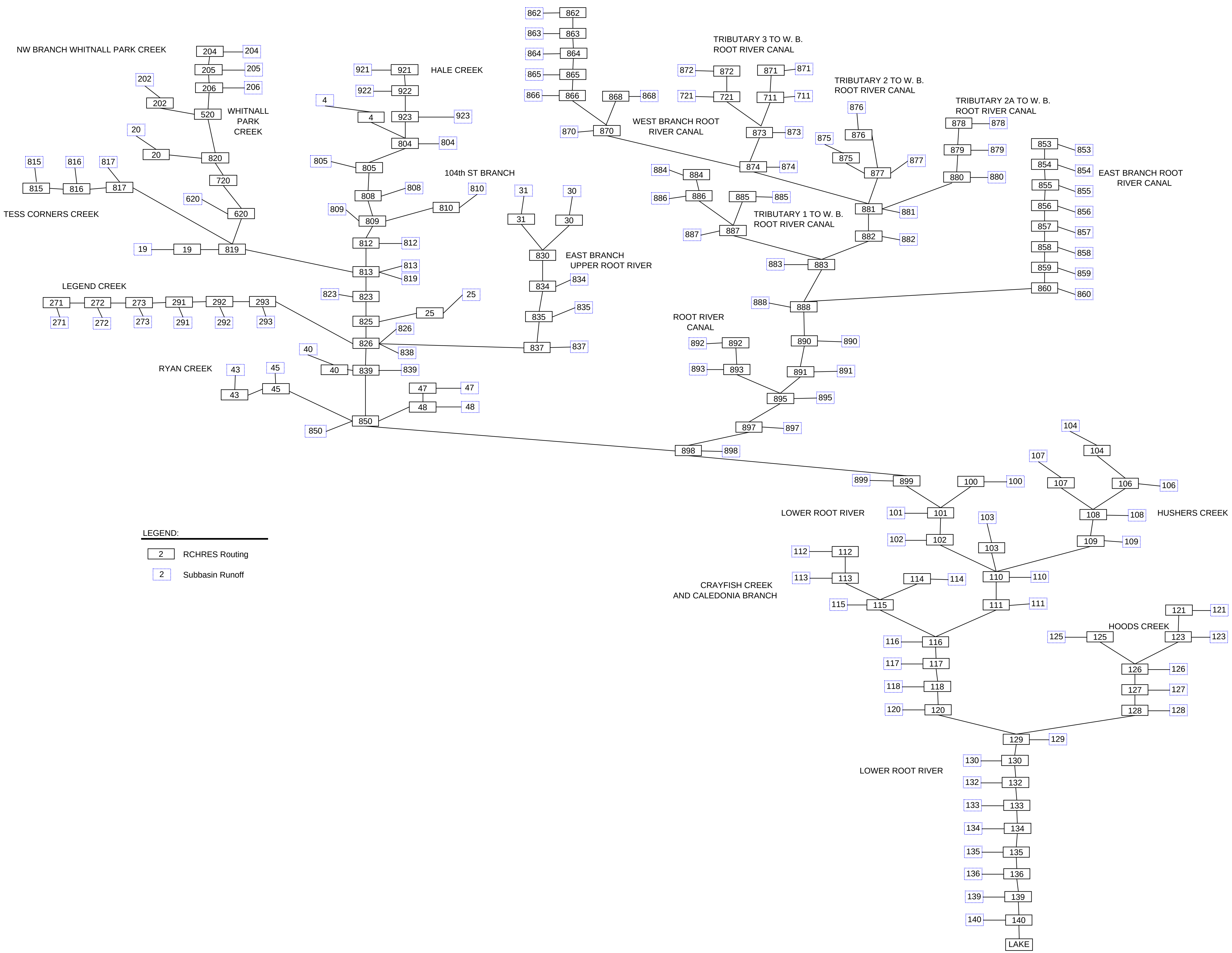
Jensen, M.E., D.C.N. Rob, and C.E. Franzoy. 1969. Scheduling irrigations using climate-crop-soil data. Proceedings, National Conference on Water Resources Engineering of the American Society of Civil Engineers, New Orleans, LA.

Tetra Tech. 2002. Minnesota River Basin Model, Model Calibration and Validation Report. Prepared for Minnesota Pollution Control Agency, St. Paul, MN by Tetra Tech, Inc., Research Triangle Park, NC.

U.S. Environmental Protection Agency (USEPA). 2000. *BASINS Technical Note 6. Estimating Hydrology and Hydraulic Parameters for HSPF*. EPA-823-R00-012. U.S. Environmental Protection Agency. Office of Water. July 2000.

Viessman, W., G.L. Lewis, and J.W. Knapp. 1989. *Introduction to Hydrology*, 3rd Edition. Harper Collins, New York.

ATTACHMENT A –SCHEMATIC REPRESENTATION OF THE ROOT RIVER LSPC MODEL


NW BRANCH WHITNALL PARK CREEK
WHITNALL PARK CREEK
HALE CREEK
104th ST BRANCH
TESS CORNERS CREEK
EAST BRANCH UPPER ROOT RIVER
LEGEND CREEK
RYAN CREEK
TRIBUTARY 3 TO W. B. ROOT RIVER CANAL
TRIBUTARY 2 TO W. B. ROOT RIVER CANAL
TRIBUTARY 2A TO W. B. ROOT RIVER CANAL
WEST BRANCH ROOT RIVER CANAL
EAST BRANCH ROOT RIVER CANAL
TRIBUTARY 1 TO W. B. ROOT RIVER CANAL
ROOT RIVER CANAL
LOWER ROOT RIVER
HUSHERS CREEK
CRAYFISH CREEK AND CALEDONIA BRANCH
HOODS CREEK
LOWER ROOT RIVER
LAKE
LEGEND:
2 RCHRES Routing
2 Subbasin Runoff

2020 Facility Planning Project

Final Memorandum

Project Name:	MMSD – 2020 Facility Planning Project	MMSD Contract No:	M03002P01
DMS Folder Name:	Technology Analysis	MMSD File Code:	M009PE000.P7300-WQ1
Document Name:	Water Quality Calibration and Validation Results for the Kinnickinnic River Model (Task 4)	HNTB Charge No:	34568-PL-400-115

Date: December 18, 2007
To: Michael Hahn, SEWRPC
Bill Krill, HNTB
From: Leslie Shoemaker, Tetra Tech, Inc.
Subject: Water Quality Calibration and Validation Results for the Kinnickinnic River Model (Task 4)

1.0 EXECUTIVE SUMMARY

An important component of the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU) is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. The purpose of this memorandum is to describe the modeling process and provide the results of the water quality calibration and validation of the Kinnickinnic River watershed model.

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for a variety of reasons, including that existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds. The Loading Simulation Program in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms but has the advantage of no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original Kinnickinnic River HSPF model has been migrated to LSPC for the 2020 Facilities Planning Project.

Calibration of LSPC followed a sequential, hierarchical process that begins with hydrology, followed by sediment erosion and transport, and, finally, calibration of chemical water quality. Water quality calibration for the Kinnickinnic River relied on comparison of model predictions to observations and estimated loads at two stations on the mainstem of the system. Because concentrations and loads of many constituents in the Kinnickinnic River are strongly affected by point source loads, the ability of the model to match observations is constrained by the limited knowledge of the actual time course of point source loading. As a result, the Kinnickinnic model is not able to achieve the same high degree of agreement between model and observations that was seen in the Menomonee and Oak Creek models. However, a general qualitative agreement is achieved.

2.0 CONCLUSIONS

Water quality calibration for the Kinnickinnic River relied on comparison of model predictions to observations and estimated loads at two stations on the mainstem of the system. (Three other stations on the Kinnickinnic River are located within the domain of the estuary model.) Achieving water quality calibration involves adjusting many parameters that interact with one another. The upland model represents expected loading associated with runoff events from specified land uses, but cannot represent unusual events that are outside the scope of events simulated in the model (for instance, discharge or breach of a waste lagoon). In addition, observed data – which consist of point in time and point in space measurements – may not be fully representative of conditions in the waterbody, and may also be subject to considerable analytical uncertainty. The model provides an estimate of average conditions across the stream width and depth as a result of known upland sources. For this application, the long-term average loading from these upland sources has been constrained to be consistent with results from SWAT modeling of agriculture and SLAMM modeling of loading from urban land uses. Fit between model and observations is best judged graphically and statistically: the model should represent the central tendency and trends seen in observations, but may not replicate all individual observations. Model fit for water quality is thus evaluated in three ways: (1) through graphical comparison of simulated and observed data, (2) through statistical tests on the equivalence of means on paired observed and simulated concentration data, and (3) through evaluation of the ability of the model to represent apparent observed load delivery rates. A single set of parameter values (by land use) is specified throughout the watershed; thus, the ability of the model to replicate differences in concentrations between different sample points is as important as the ability to match concentrations at individual sites.

Because concentrations and loads of many constituents in the Kinnickinnic River are strongly affected by point source loads, the ability of the model to match observations is constrained by the limited knowledge of the actual time course of point source loading. As a result, the Kinnickinnic model is not able to achieve the same high degree of agreement between model and observations that was seen in the Menomonee and Oak Creek models. However, a general qualitative agreement is achieved.

3.0 RECOMMENDATIONS

We recommend that the water quality calibration and validation of the Kinnickinnic River model be considered.

4.0 INTRODUCTION

The Milwaukee Metropolitan Sewerage District (MMSD) is in the midst of a long-range planning effort to identify improvements needed for its facilities to accommodate growth and protect water quality through the year 2020. This effort is known as the MMSD 2020 Facility Plan. A related planning effort is being conducted by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) to update the regional water quality management plan for the Kinnickinnic River, Menomonee River, Milwaukee River, Root River, and Oak Creek watersheds, the Milwaukee Harbor estuary, and the adjacent nearshore Lake Michigan area. This effort is known as the Regional Water Quality Management Plan Update (RWQMPU). The two planning efforts are being coordinated and implemented in parallel.

One important component of both the 2020 Facility Plan and the RWQMPU is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. Watershed models are being developed for the following five watersheds:

- Kinnickinnic River
- Menomonee River
- Milwaukee River
- Oak Creek
- Root River

The Kinnickinnic, Menomonee, and Milwaukee River models will then be linked to a model of the Lake Michigan estuary so that the benefits of upstream water quality improvements can be simulated by the Lake Michigan Harbor / Estuary Model.

The following seven tasks have been identified for performing the system modeling:

1) Establish the model structure, including the delineation of subwatersheds, connectivity, and cross sections, etc.
2) Develop the model data sets using physical measurements, maps, and other appropriate information
3) Perform hydrologic and hydraulic calibration and validation
4) Perform watercourse water quality calibration and validation
5) Perform harbor/estuary and lake water quality calibration
6) Perform production runs as required for project planning
7) Document results.

The purpose of this report is to document the watercourse water quality calibration and validation for the Kinnickinnic River watershed model (Task 4). The modeling approach and results, by parameter, are presented below.

5.0 MODELING APPROACH AND RESULTS

The calibration process for LSPC is sequential, beginning with the calibration of flow. Sediment and dissolved pollutant transport depend directly on the representation of flow, while sorbed pollutant transport depends on the simulation of sediment. (In the model, sorption to sediment within stream reaches is currently simulated for phosphorus, ammonium, and bacteria.) Thus, any inaccuracies in the flow and sediment simulation will propagate forward into the water quality simulation, and the accuracy of the hydrologic simulation provides an inherent limitation on the potential accuracy of the water quality simulation.

Instream water quality kinetics are also highly linked with one another. For instance most kinetic rates depend on temperature, while nutrient balances and dissolved oxygen are strongly linked to the algal simulation. Accordingly, the water quality calibration uses the following sequential process:

1) Calibration of flow
2) Calibration of sediment
3) Calibration of water temperature
4) Initial calibration of gross nutrient transport
5) Initial calibration of BOD and DO
6) Calibration of algae
7) Final calibration of nutrient species and DO
8) Calibration of fecal coliform bacteria
9) Calibration of metals

SEWRPC and WDNR directed that loads from the land surface should be, to the extent compatible with achieving water quality calibration, consistent with the loads predicted by SWAT for agricultural land uses and by SLAMM for urban land uses. The SLAMM model in particular is preferred by the WDNR for use in assessing compliance with State urban nonpoint source pollutant regulations. Therefore, the loading rates produced by these models form the starting point for the LSPC water quality calibration.

The adequacy of the water quality calibration was assessed through comparison to observed water quality data. It should be noted that the observed water quality data are primarily point-in-time grab samples, which may exhibit significant temporal variability relative to the (unobserved) daily mean concentration. A key objective is to have the model replicate actual loads through the system. Unfortunately, loads are not directly observed, and can only be estimated from the point-in-time concentrations multiplied by daily average flow. While model adjustments are made to obtain general agreement between simulated loads and estimated observed loads, it should be recalled that the estimates of observed loads are highly uncertain.

Hydrologic calibration precedes sediment and water quality calibration because runoff is the transport mechanism by which nonpoint pollution occurs. The hydrologic calibration results for the Kinnickinnic River model indicate acceptable agreement between observed and simulated streamflows. Baseflows are well represented for each season for the entire calibration period. The timing of almost all storms is captured, as are the shapes of the hydrographs. The successful hydrologic calibration provides a good basis for water quality calibration.

Water quality simulation for the Kinnickinnic River is largely based on the successful calibration of the model for Oak Creek. There are a few differences, however, as described below.

5.1 Point Source Discharges

One important feature of the Kinnickinnic River is that there is a significant amount of permitted effluent discharge in the system. During dry weather flows (less than the median flow of about 10 cfs at the 11th Street gage), approximately 25 percent of the total flow in the Kinnickinnic River may be derived from point source discharges. This means that the model can be very sensitive to the specification of point source loads. The model sensitivity applies to both regulated and non-regulated constituents. For instance, the concentrations of phosphorus in the Kinnickinnic River at low flow appear to be dominated by regulated industrial discharges of phosphorus, which are estimated to contribute about 4 pounds per day. The point sources may also have an important influence on concentrations of constituents such as nitrate nitrogen that are not currently regulated, and thus not reported in monitoring data.

Unfortunately, monitoring data on effluent quality is somewhat sparse. For instance, phosphorus concentrations in most of the industrial discharges are estimated from annual samples taken between 1999 and 2003. The true phosphorus load from these sources is highly uncertain, particularly prior to 1999. Because dry weather concentrations of many constituents are largely governed by effluent quality, the lack of precision in specifying effluent loads directly results in a limit in the precision that can be attained in the water quality model.

The two industrial dischargers with the largest effluent flows to the Kinnickinnic River are the Ladish Company, Incorporated of Cudahy, with a discharge of about 0.63 million gallons per day (MGD) to Reach 825 in the Wilson Park tributary and GE Medical Systems Group, with a discharge of about 0.19 MGD to Reach 801 in the Lyons Park subwatershed. (Ladish has a variety of other outfalls, some of which go directly to Lake Michigan and one to a tributary of Oak Creek). Both of these discharges can vary significantly from month to month. To improve model performance, these large discharges were entered on a monthly basis from records reported to WDNR. All other permitted industrial point sources in the basin were entered based on constant average characteristics. CSO and SSO contributions are based on detailed time series of flow estimates.

For unmonitored parameters, it was assumed that the industrial point sources had a concentration of 2.4 mg/L each of nitrate nitrogen and organic nitrogen (as N), which is in the typical range for industrial point sources, along with 7 mg/L DO and a thermal load based on a temperature of 55 ºF.

5.2 Concrete Channels

Large portions of the Kinnickinnic River flow through artificial concrete channels (Figure 1). The effects of these channels on hydraulics are already incorporated into the model via the Ftables. However, there are also a variety of other effects on water quality.

Figure 1. Kinnickinnic River near 15th Street.

In addition to speeding flows, concrete channels reduce the availability of bed sediment for scour, although transient storage may occur. This is addressed by setting the initial bed depth to 0.25 feet and allowing the bed sediment to scour out where appropriate to the hydraulics. Concrete segments also tend to have poor shading, and the surface exposed was raised accordingly.

5.3 Periphyton and Dissolved Oxygen

One very important aspect of concrete reaches is that they may support dense growths of attached benthic (periphytic) algae, such as *Cladophora*. Studies of Lincoln Creek, a channelized tributary of the Milwaukee River, have revealed dense standing crops of periphyton, in excess of 100,000 μg/cm^2 particulate carbon during summer (Ehlinger et al., 2003). Direct measurements of benthic algal density are not available for the Kinnickinnic River; however, there is indirect evidence to indicate the presence of high levels of benthic algal production.

At station RI-12 (see Figure 5 for location), reported dissolved oxygen concentrations tend to remain high at all times, even during summer low flow periods (Figure 2). The mean is 12.5 mg/L and the range is from 6.2 to 20.4 mg/L.

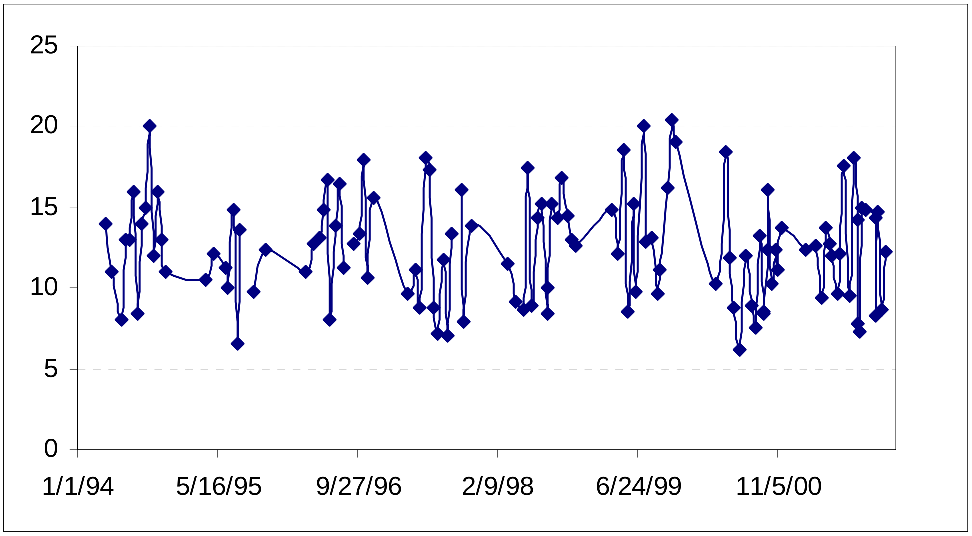


Figure 2. Reported DO Concentrations (mg/L) at Kinnickinnic River RI-12

Planktonic algal concentrations are generally not high (mean 7.7 μg/L). If we then compute the saturation DO concentration (without salinity or pressure corrections), we find that the reported DO values range up to 250 percent of saturation, and never fall below 68 percent, with a median of 125 percent (Figure 3). Similar results are seen at monitoring station RI-13 (See Figure 5 for location).

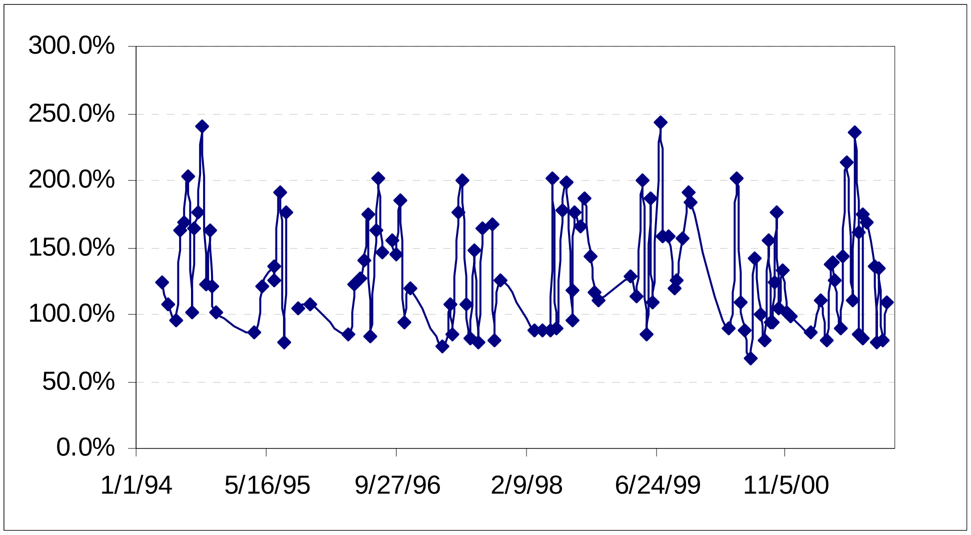


Figure 3. DO Percent of Saturation at Kinnickinnic River RI-12

All the Kinnickinnic River samples were obtained in early afternoon, near the period of maximum algal production. (This contrasts with Oak Creek, where most observations are from mid-morning, which should be near the daily mean). DO supersaturation this high would only be seen, however, with very robust photosynthetic production, which does not seem to be due to planktonic algae, given the reported concentrations. Therefore, the excess production must be due to a robust periphytic algal population. Simulation of enhanced benthic algal growth was first initiated by increasing the maximum density parameter (MBAL) to 1×10^6 mg/m^2, consistent with the densities reported for Lincoln Creek. On assumption that *Cladophora* are important, it is also appropriate to increase the maximum algal growth rate (MALGR) to 0.3 per hour and revise the optimal temperature range to reflect the preference of bluegreen algae for warmer temperatures. Finally, because these types of algae form long filaments that float in the water they are less sensitive to light limitation and light extinction coefficients in the water column were reduced.

A problem is encountered in the simulation of benthic algae in the Kinnickinnic River because LSPC turns off the algal simulation when average depth in a reach is predicted to be less than 0.17 feet. If this occurs, the benthic algal mass is simply preserved, neither growing nor dying. In the concrete channels, the Ftables provided do not have a detailed representation of the low flow channel, as is often the case, and have a tendency to predict average depths that are too low for algal simulation. To remedy this, the Ftable must be augmented to hold a small amount of depth. For these situations, the Ftables were modified by introducing two new rows (Rows 2 and 3), above the first non-zero row in the existing Ftable (referred to as Row 4). Row 3 is assumed to represent a top width of 10 feet (if the width implied by Row 4 is greater than 10 feet), and Row 2 is assumed to represent a top width of 5 feet. This approach provides for a linear interpolation of outflow demand consistent with the existing Ftable down to a small residual volume (typically around 0.1 acre-feet) while maintaining depth sufficient to simulate growth of benthic algae, except in severe drought conditions. This approach was used to augment the Ftables in the lower Kinnickinnic (reaches 722, 818, 808, 807, and 806), where DO monitoring suggests the presence of dense periphytic algal growths in summer. The modification was not applied to reach 814, as this reach represents the start of deeper waters of the estuary. For other upstream concrete reaches shallow water depth may limit benthic algal growth, so no Ftable modifications were made.

In the presence of dense benthic algal growth, water quality is expected to show strong diurnal shifts, both for DO and inorganic nutrients. Because almost all observations from the Kinnickinnic River are near the expected time of the DO maximum, it is most appropriate to compare simulated DO daily maxima to observations.

5.4 Fecal Coliform Bacteria

During revisions to the Oak Creek model, it was determined that loads from impervious surfaces needed to be increased by a factor of 5 to achieve agreement with the data. This same factor appears to yield reasonable results for the Kinnickinnic River. The industrial point sources in the Kinnickinnic are not expected to be a significant source of bacterial load.

5.5 Calibration and Validation Time Periods

Extensive water quality observations collected by MMSD were provided for 1994 through 2001 and were used to calibrate and validate the water quality model. Years 1994 through 1998 were used for calibration. The parameters were then applied to 1999 through 2001 observations as a validation check. Unless noted otherwise, the time series calibration and validation plots are based on the daily mean values of simulated output.

The calibration and validation periods used for water quality differ from those used in the hydrologic calibration due to constraints of data availability. Quality-controlled monitoring data were not available for 2002 at the initial time of the calibration, so this year was not included in the water quality analysis. In addition, the calibration period for water quality was started in 1994 (versus 1995 for the hydrology) to take full advantage of the available data. For both hydrology and water quality, simulations were started in January 1993 to minimize model spin-up effects. Hydrologic simulation for 1994 appears to be reasonable at the 11th Street gage (Figure 4) and observed 1994 flow data are not available for the Wilson Park Creek gage.

Figure 5 displays the location of the water quality sampling stations that were used during the calibration process.

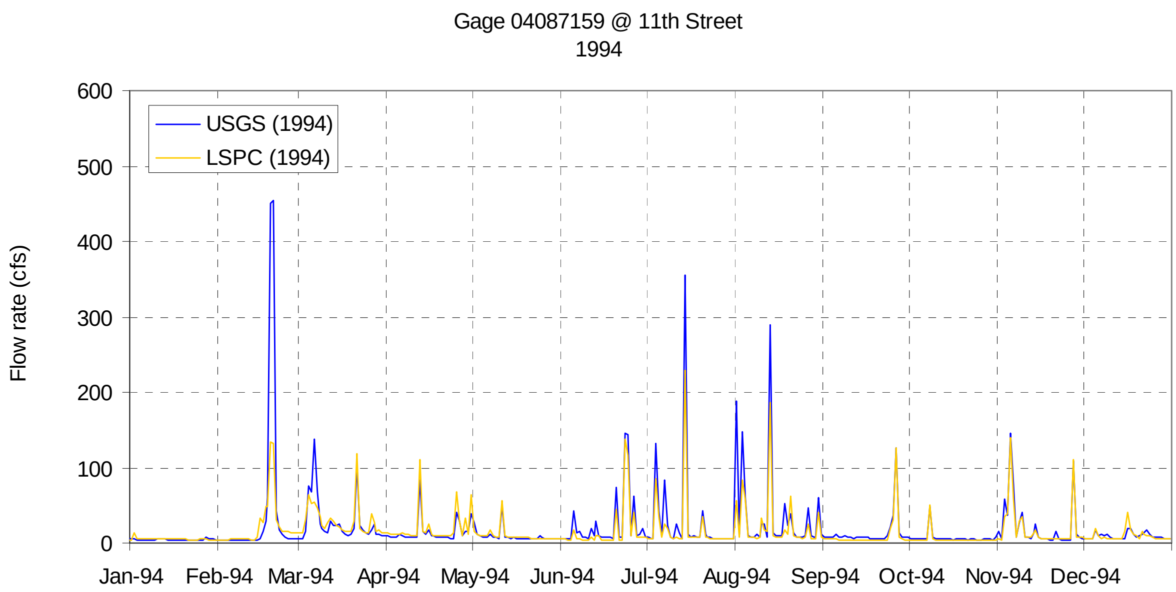


Figure 4. Time series hydrologic calibration results (daily mean) for the Kinnickinnic River at USGS gage 04087159 (1994).

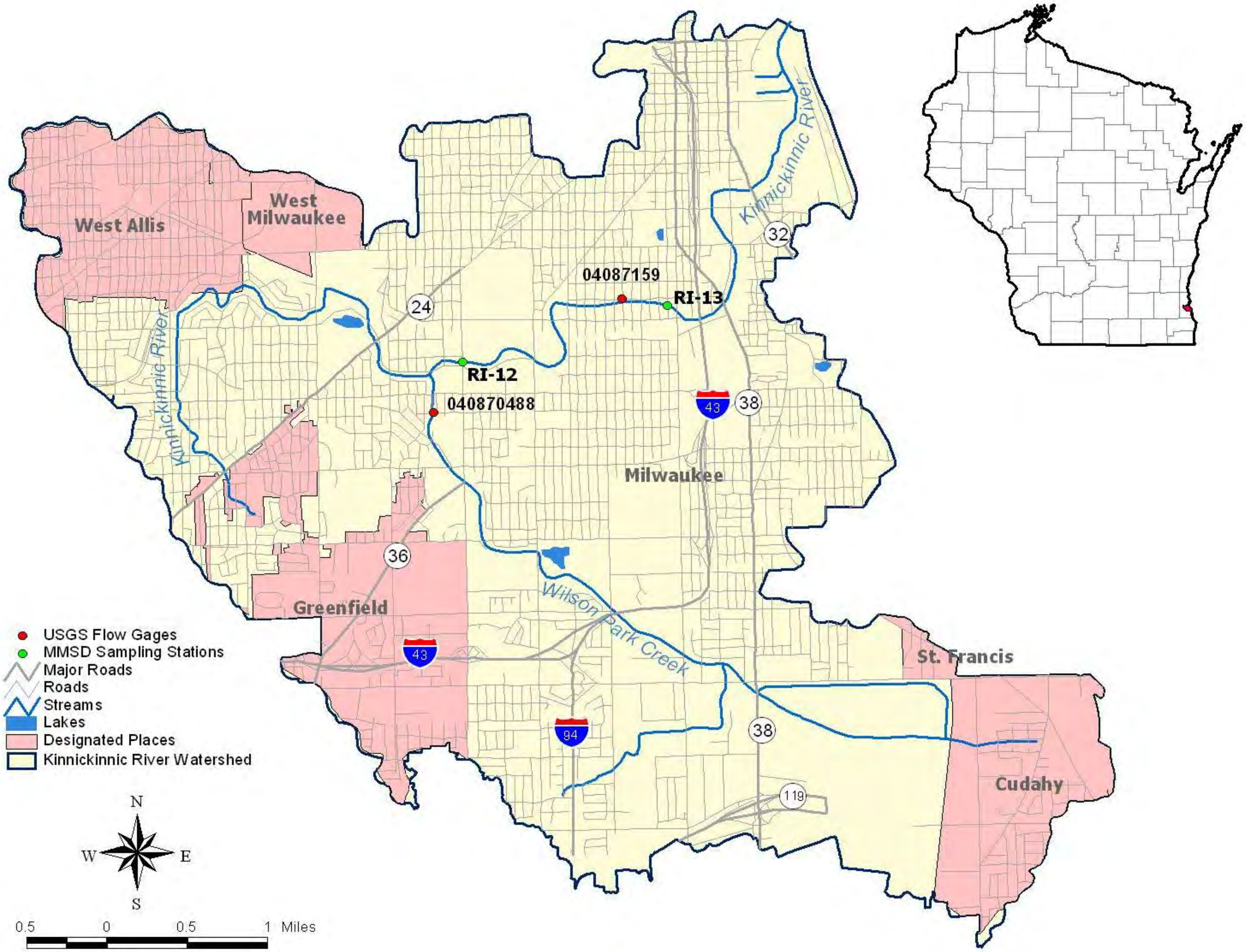


Figure 5. Location of MMSD sampling stations and USGS flow gages on the Kinnickinnic River.

5.6 Sediment Calibration

The general sequence for sediment calibration is described in the previous Menomonee River and Oak Creek water quality memorandums. Comparisons of observed and simulated TSS are shown at the two available monitoring stations within the LSPC modeling domain, arranged in upstream-to-downstream order (Figure 6 to Figure 9). Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment A.

A statistical comparison of paired sediment observations and simulated daily mean values and sediment loads along with observed and simulated sediment transport plots are provided at the end of this memorandum. Statistics on paired loads are adequate, but suggest the model may underestimate solids loads. However, the log-log plots of load versus flow suggest that the model and data are similar, but that the model may be a little high. Concentration exceedance plots agree well, except for a few very high observations. The observed data may present problems for estimating loads due to the influence of transient disturbances of mobile sediments in the concrete channels.

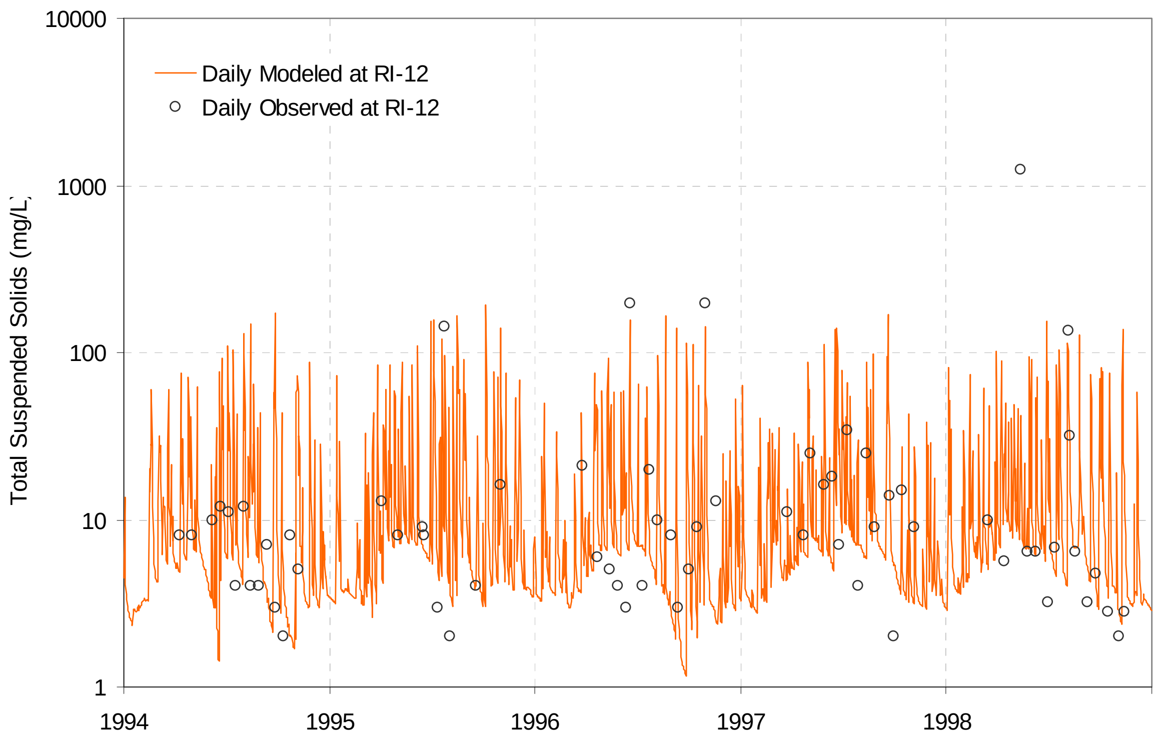


Figure 6. Total suspended solids time series calibration at Kinnickinnic River RI-12.

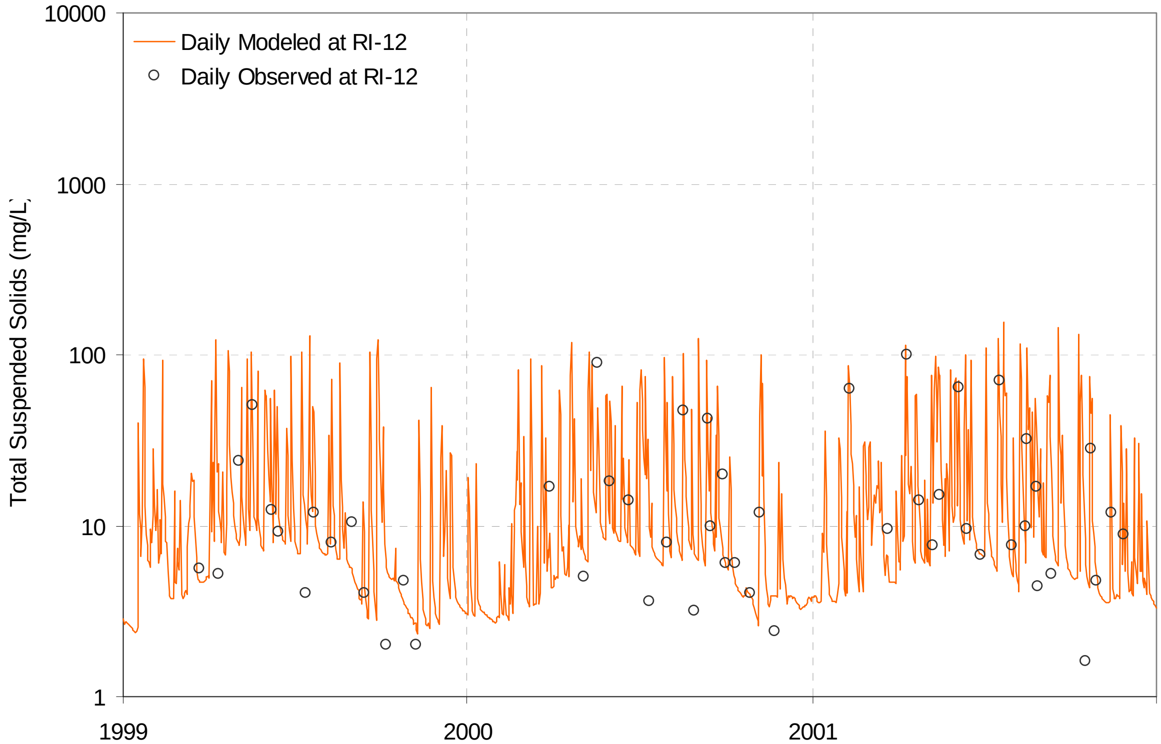


Figure 7. Total suspended solids time series validation at Kinnickinnic River RI-12.

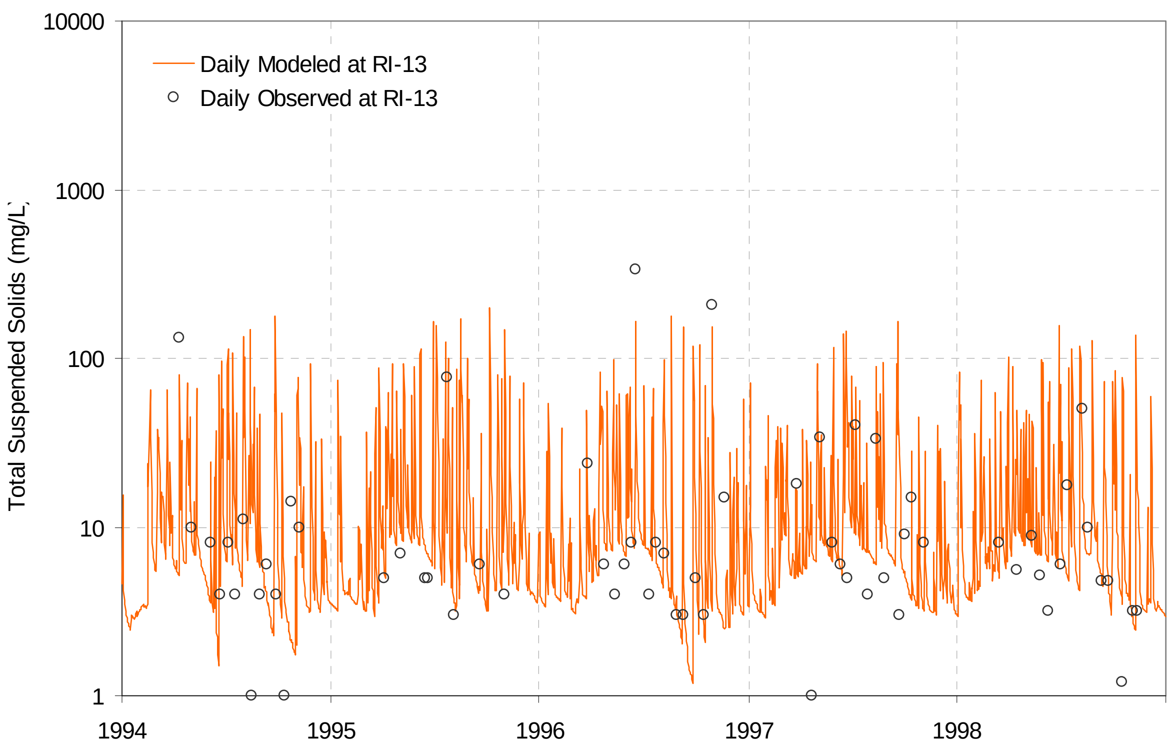


Figure 8. Total suspended solids time series calibration at Kinnickinnic River RI-13.

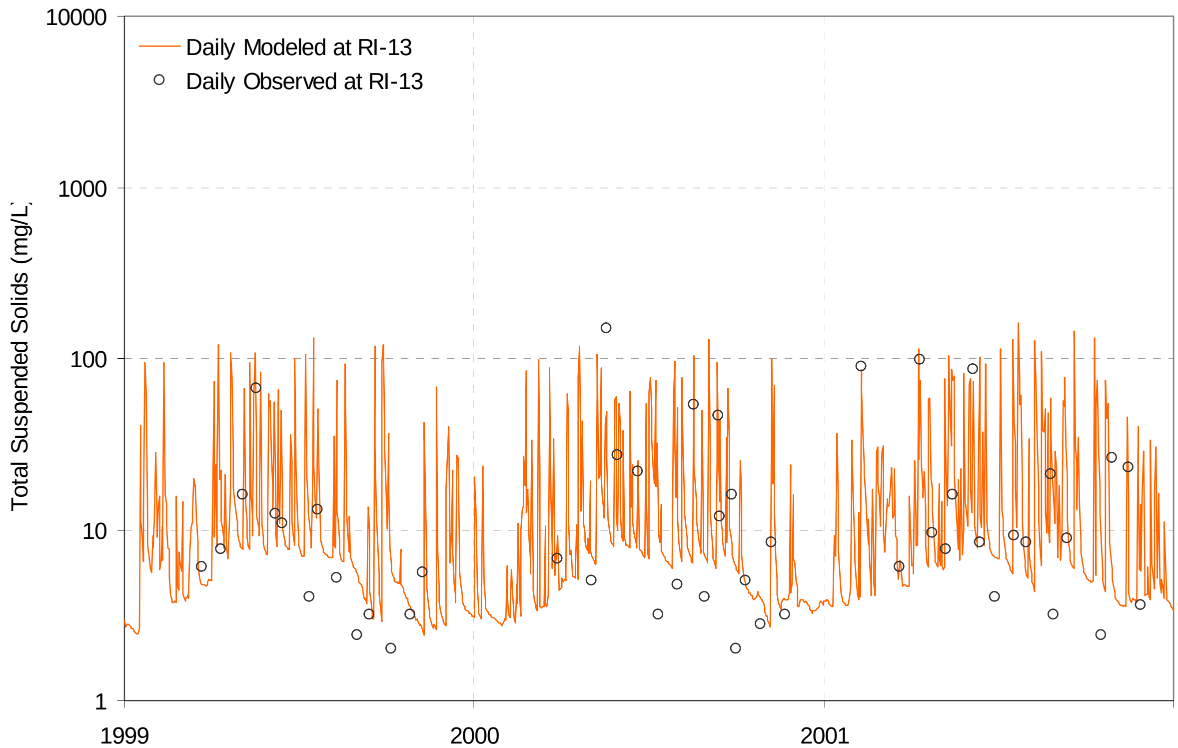


Figure 9. Total suspended solids time series validation at Kinnickinnic River RI-13.

5.7 Water Temperature Calibration

Water temperature simulation is not an explicit goal of the water quality modeling. However, a reasonable simulation of water temperature is necessary because many kinetic reaction rates are temperature dependent. Temperature simulation was therefore checked visually for consistency with observations, but a full statistical analysis was not performed.

The Kinnickinnic River temperature simulation relies on the same set of parameters as used for the Menomonee. PERLND soil temperature and reach water temperature parameters were adopted from successful Minnesota River model applications. IMPLND runoff temperature was revised to provide a slight increase above ambient air temperature, with constant AWTF = 35 and BWTF = 1.05.

Fit to observed water temperature appears generally good for both the calibration and validation time periods (comparison is shown to daily averages from the model as many of the observations do not report time of day) (Figure 10 to Figure 13).

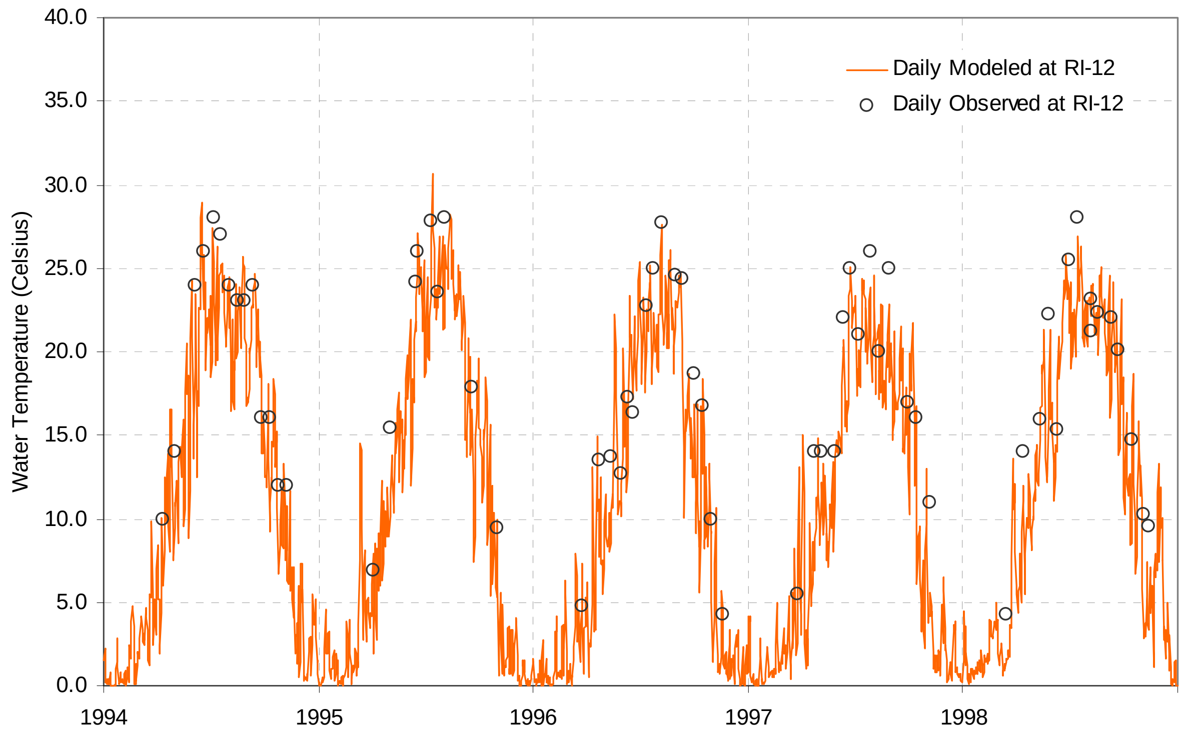


Figure 10. Temperature time series calibration at Kinnickinnic River RI-12.

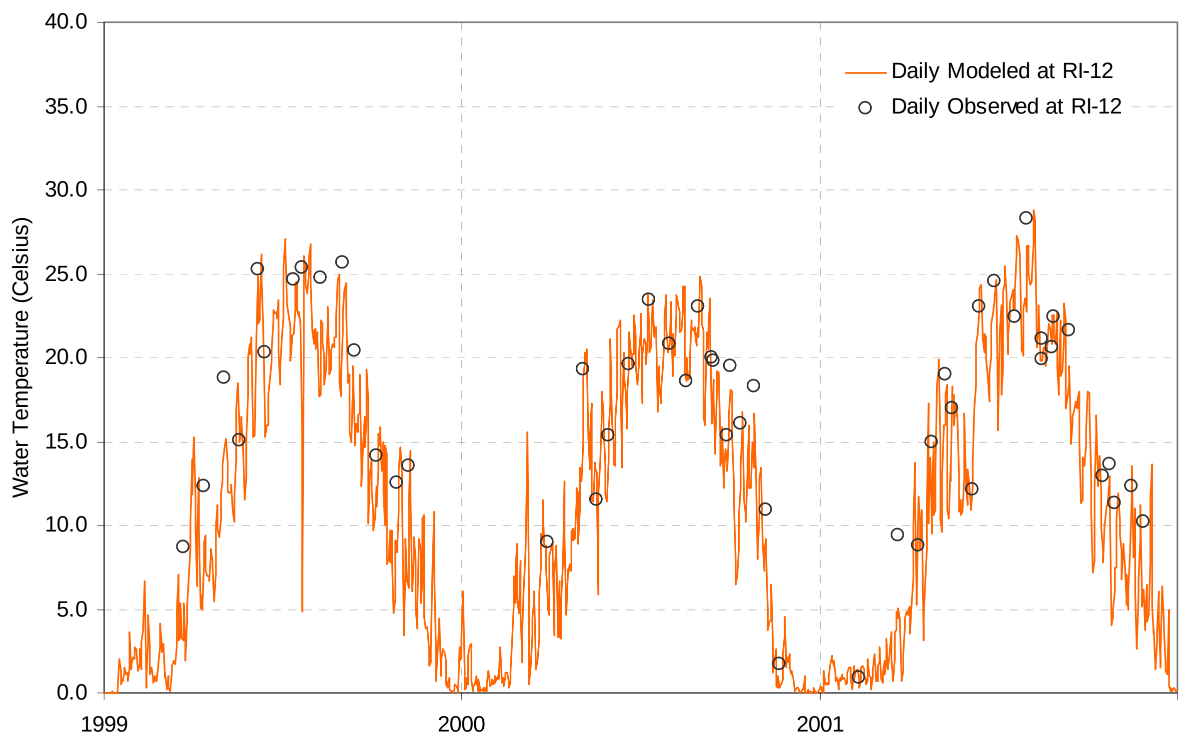


Figure 11. Temperature time series validation at Kinnickinnic River RI-12.

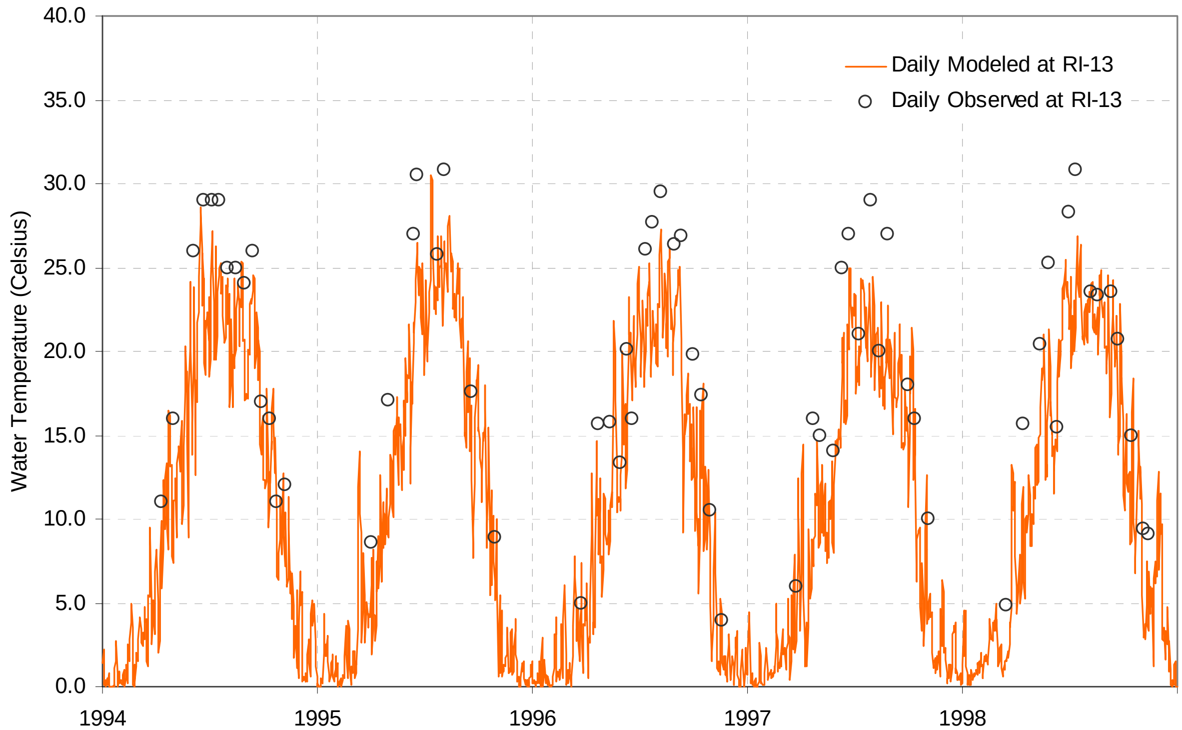


Figure 12. Temperature time series calibration at Kinnickinnic River RI-13.

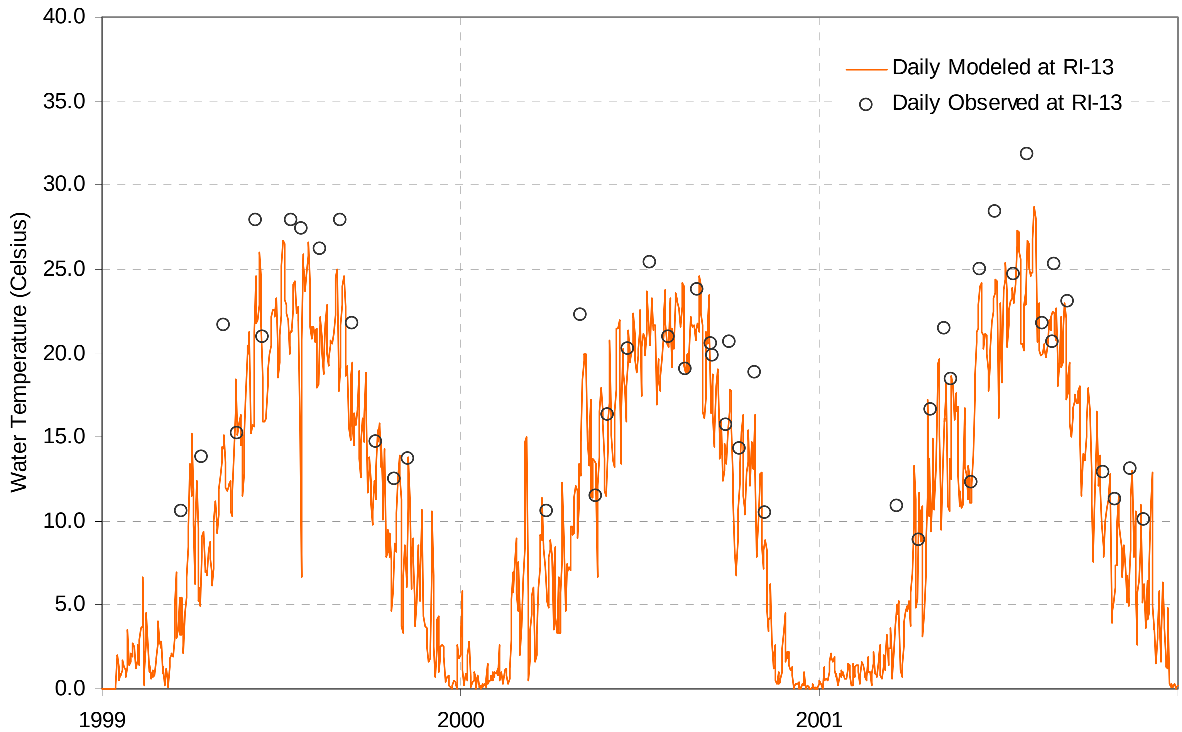


Figure 13. Temperature time series validation at Kinnickinnic River RI-13.

5.8 Nutrient and Algal Calibration

Simulation of nutrient water quality in the Kinnickinnic River uses the same parameters as the Menomonee model. For those buildup/washoff parameters that vary by basin in the Menomonee River model according to agricultural land use, the Kinnickinnic River model uses the same values as used for the downstream, more heavily urbanized, portion of the Menomonee River.

Modeling results are presented graphically below, arranged by parameter from upstream to downstream (Figure15 to Figure 34). A statistical assessment of concentrations and loads is provided at the end of the memorandum and exceedance curve plots that compare the observed data to the modeling results are presented in Attachment A.

The simulation of nitrogen species provides only an approximate match to observations and does not meet statistical tests. The primary cause of this is likely the specification of point source loads. For the industrial point sources, only the ammonia component of nitrogen load is regulated and therefore monitored. Concentrations of other nitrogen species must be guessed. Significant seasonal variability in speciation may also be present, but the model is constrained to represent loads by long-term average factors.

Both total phosphorus and ortho-phosphate fit pretty well in 1997 to 1998 and 2000 to 2001; however, concentrations and loads are drastically over-predicted in 1994 to 1996. We suspect this is due to a change in point source discharges. No information on the phosphorus content of the industrial discharges to the Kinnickinnic River was available prior to 1999. In addition, the simulation of very high densities of periphytic algae leads to a situation in which there is significant diurnal cycling of inorganic nutrients with daytime depletion, further complicating the comparison (Figure 14). Thus, apparent overprediction of phosphorus may occur when samples are taken during periods of maximum algal growth.

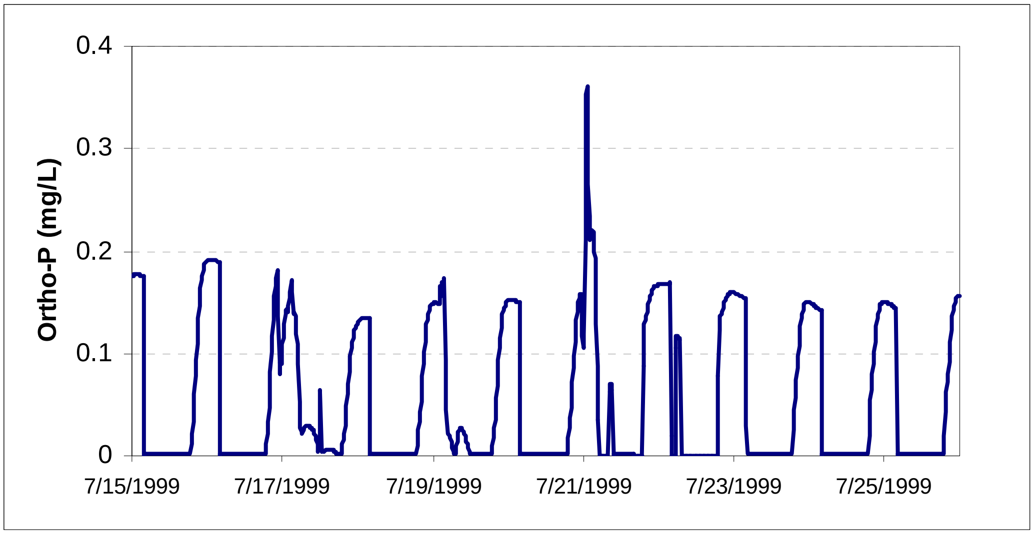


Figure 14. Predicted Diurnal Cycling of Orthophosphate at Kinnickinnic River Station RI-13, July 1999.

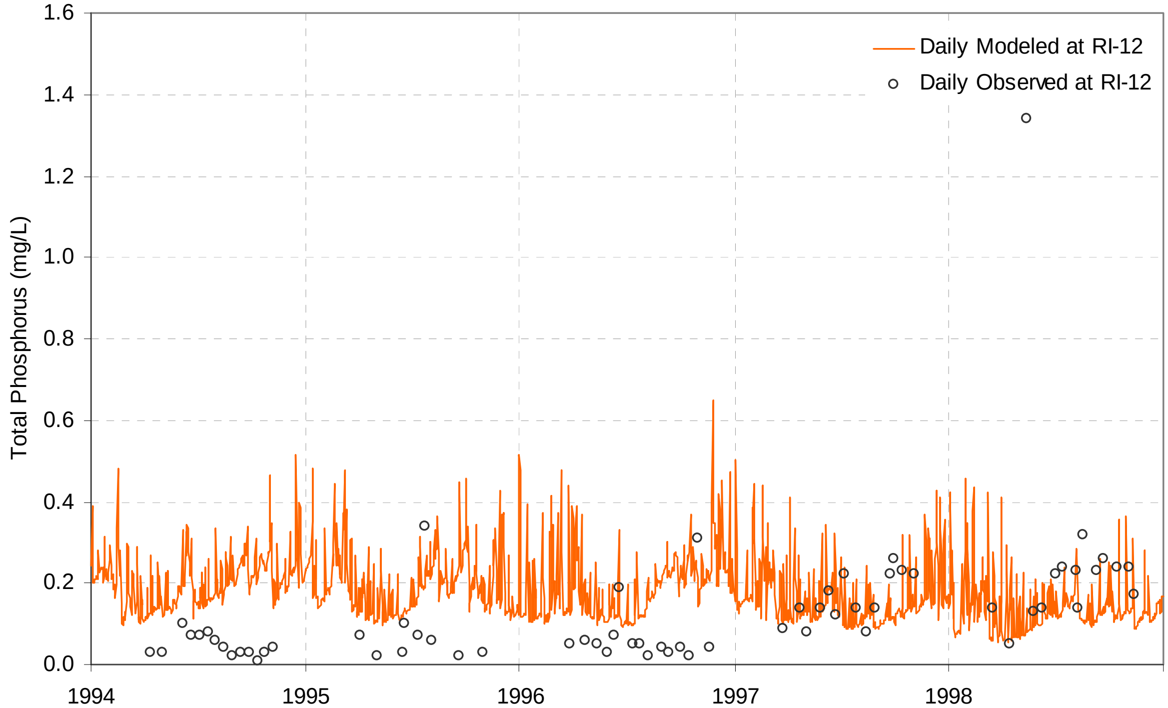


Figure 15. Total phosphorus time series calibration at Kinnickinnic River RI-12.

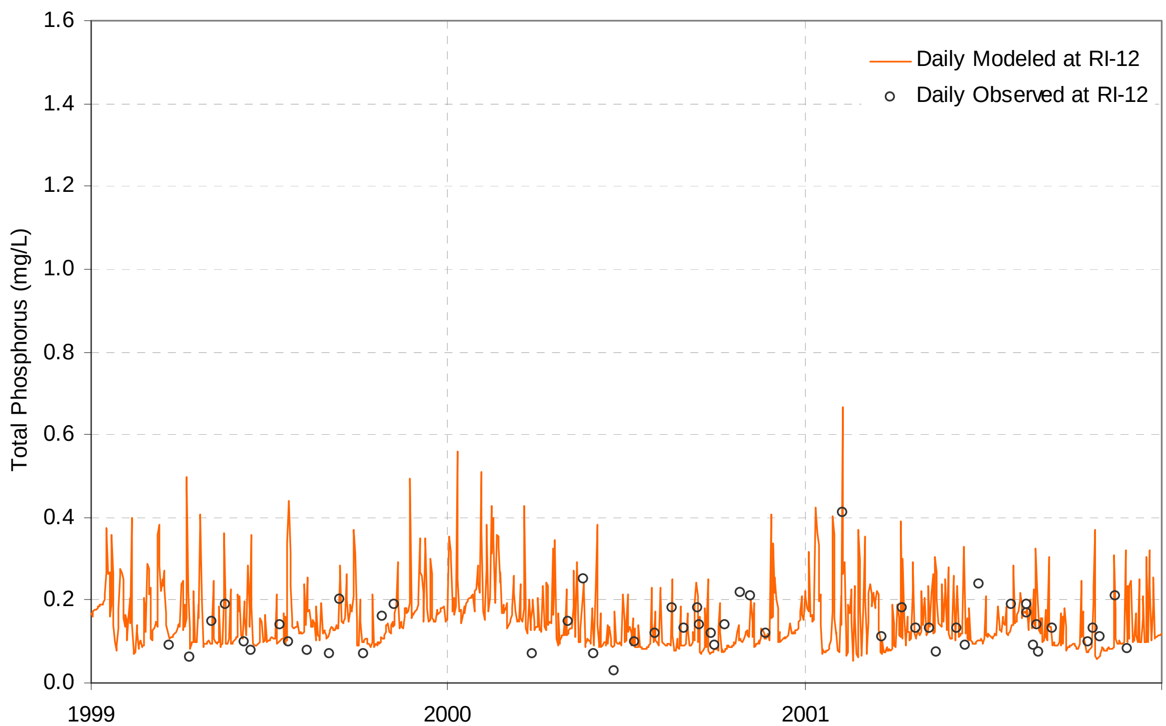


Figure 16. Total phosphorus time series validation at Kinnickinnic River RI-12.

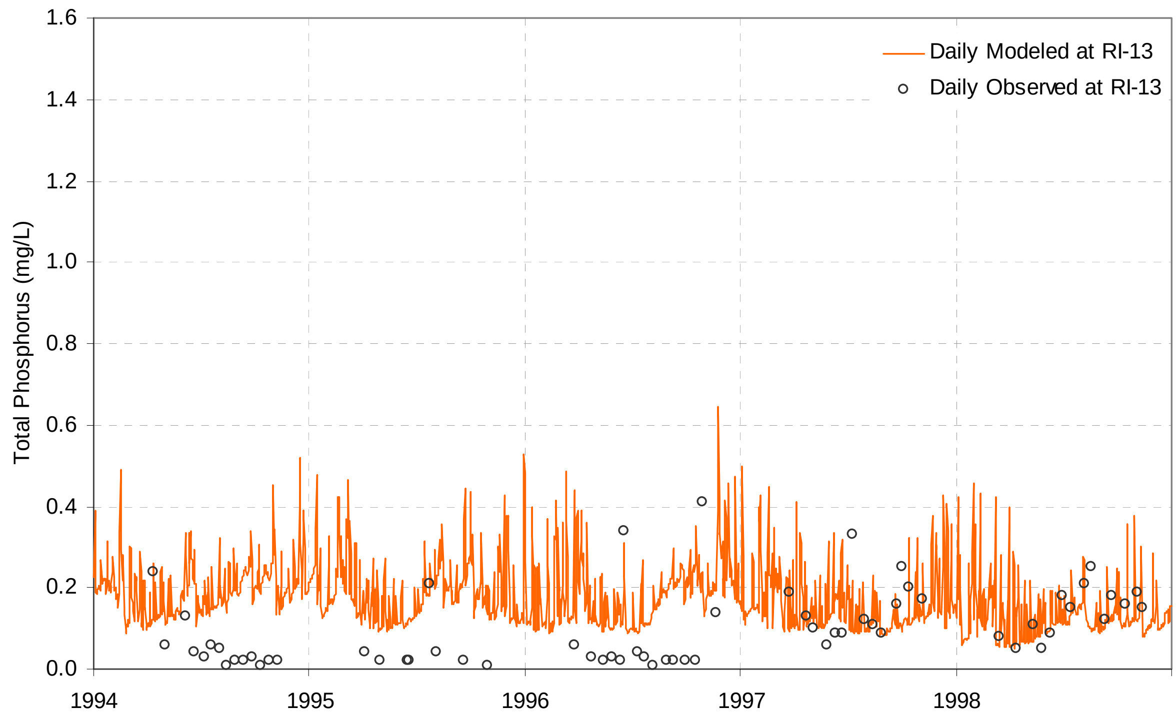


Figure 17. Total phosphorus time series calibration at Kinnickinnic River RI-13.

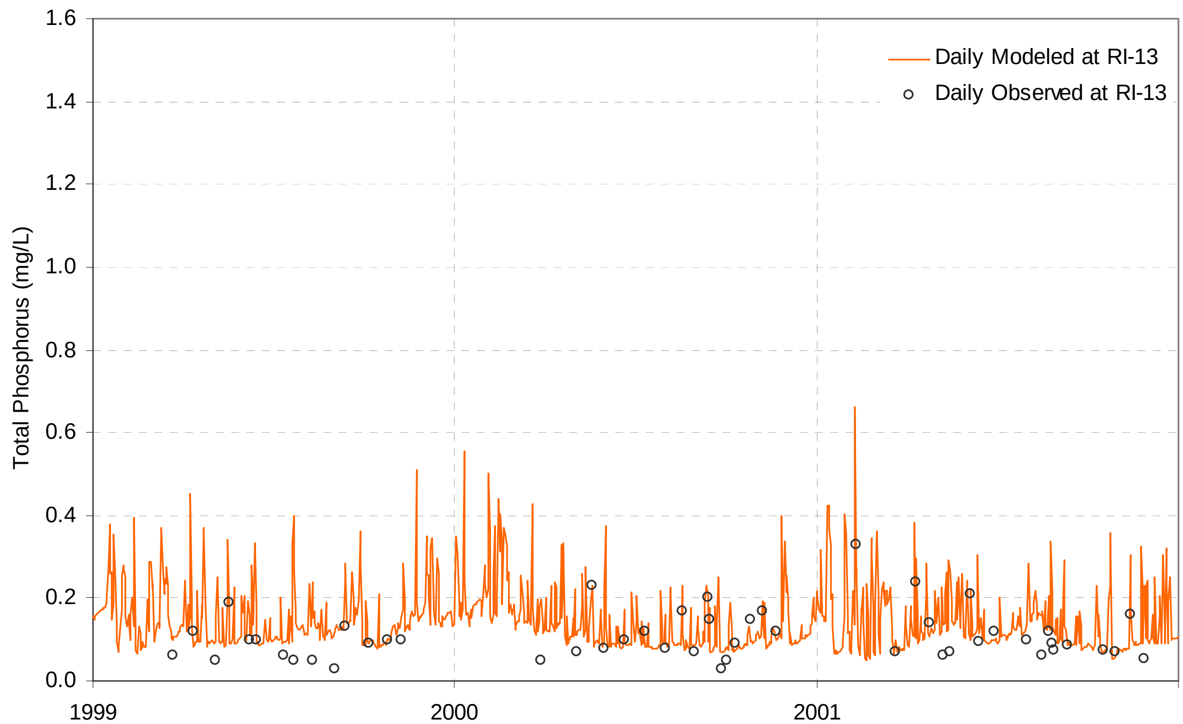


Figure 18. Total phosphorus time series validation at Kinnickinnic River RI-13.

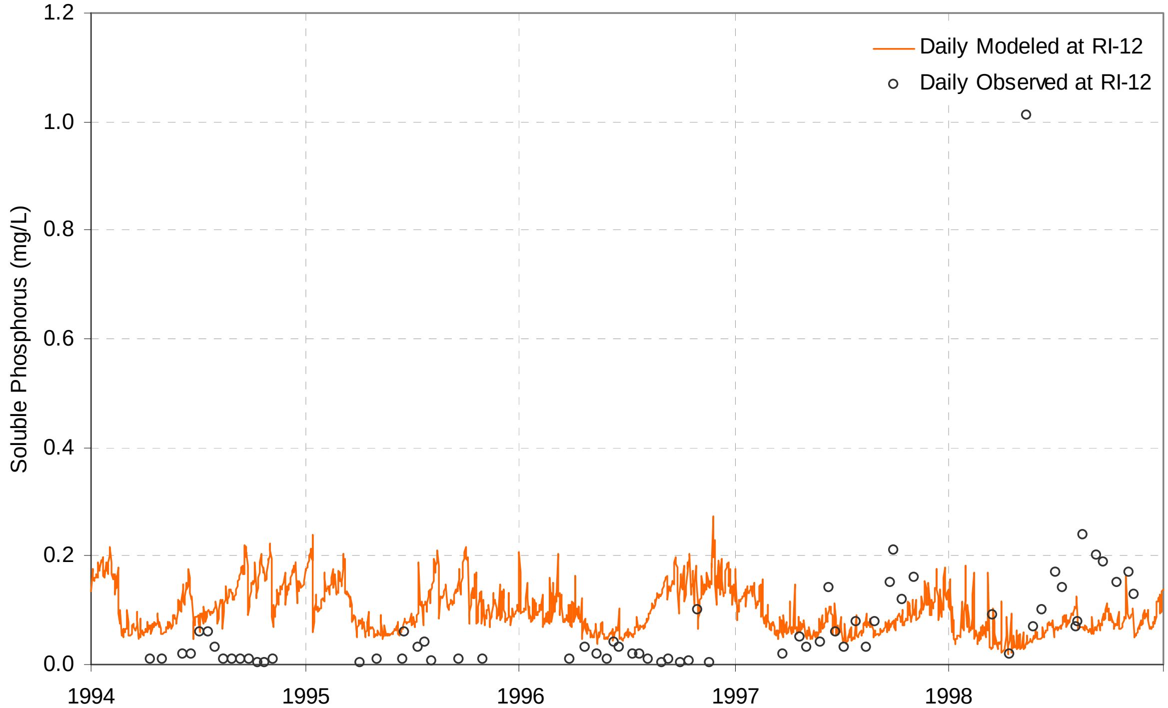


Figure 19. Soluble phosphorus time series calibration at Kinnickinnic River RI-12.

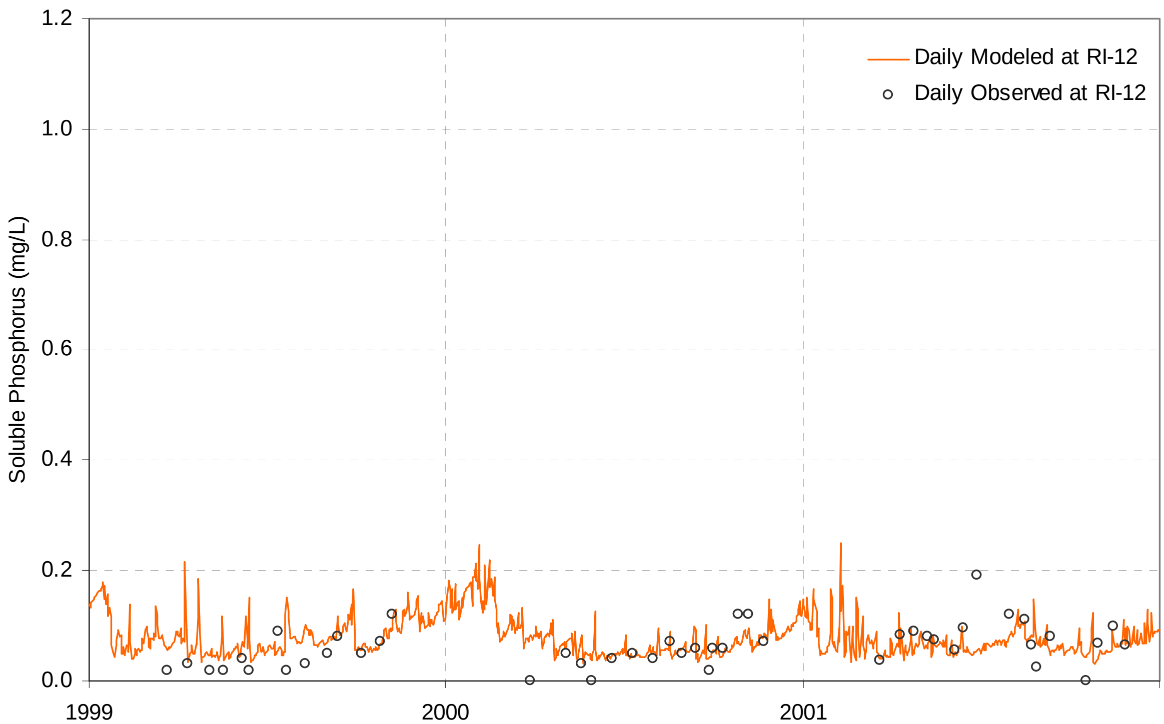


Figure 20. Soluble phosphorus time series validation at Kinnickinnic River RI-12.

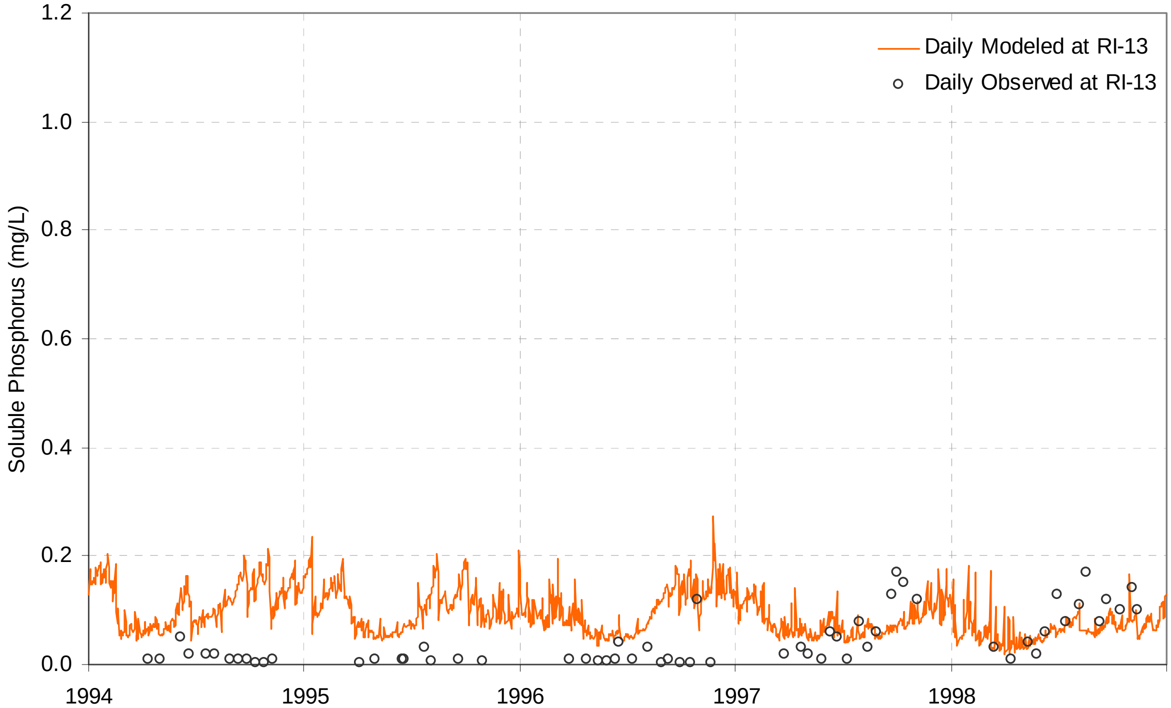


Figure 21. Soluble phosphorus time series calibration at Kinnickinnic River RI-13.

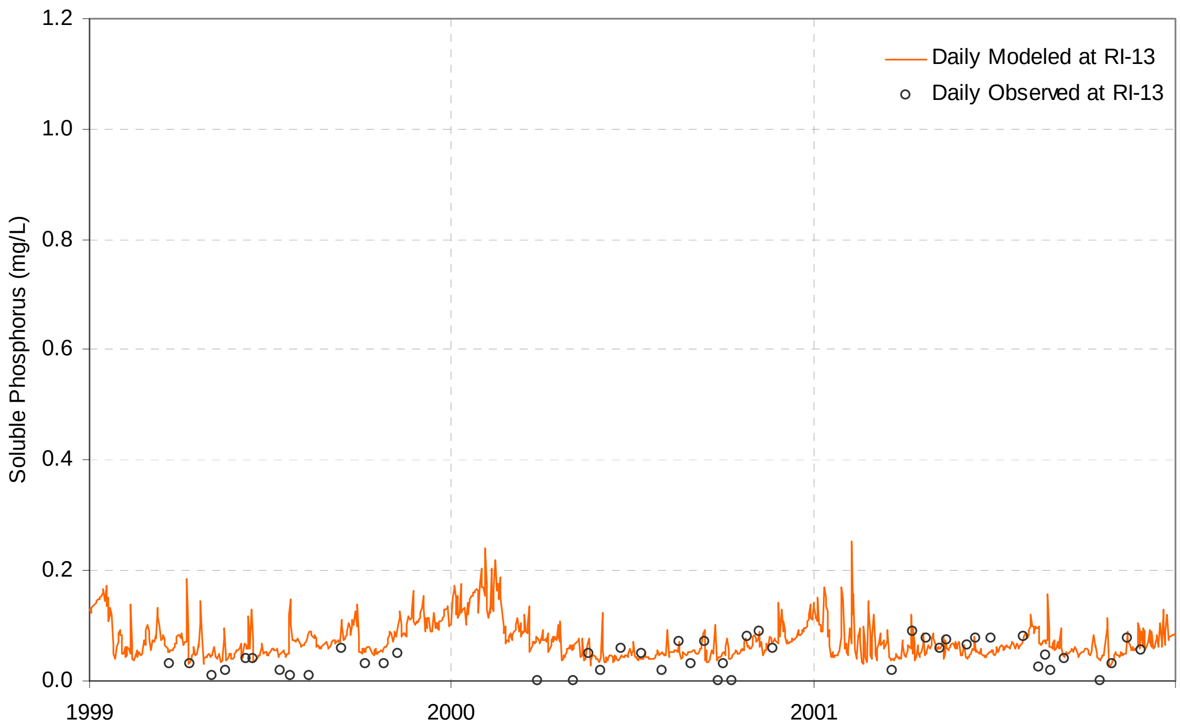


Figure 22. Soluble phosphorus time series validation at Kinnickinnic River RI-13.

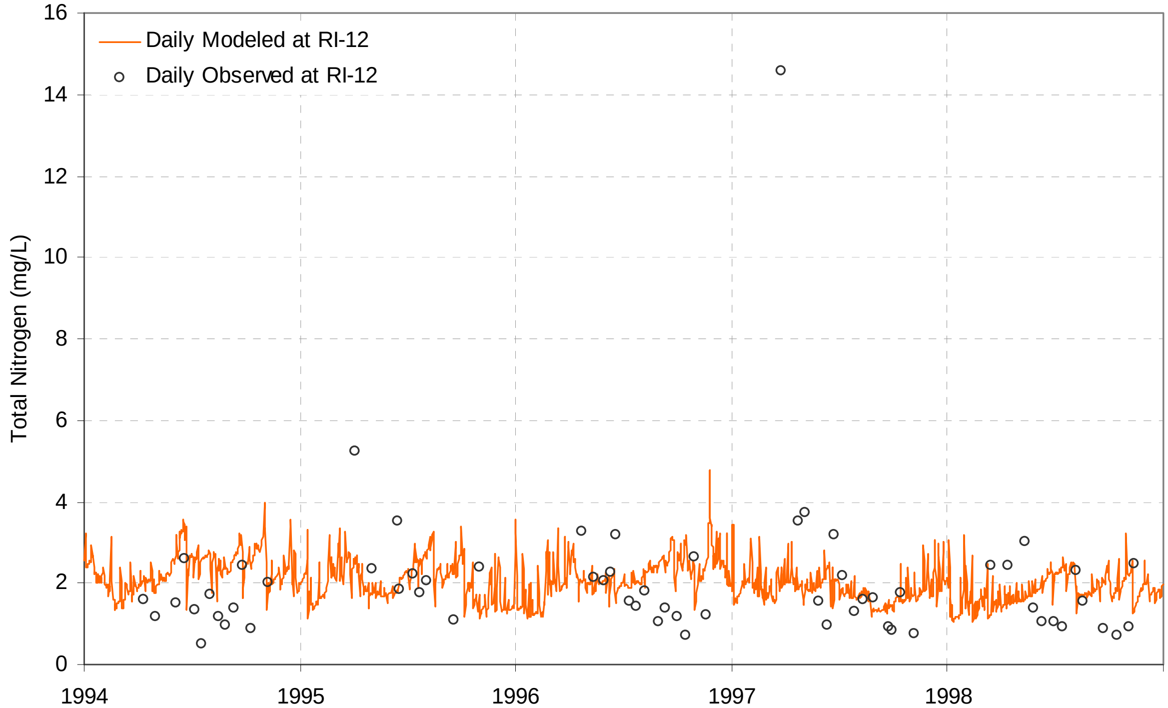


Figure 23. Total Nitrogen time series calibration at Kinnickinnic River RI-12.

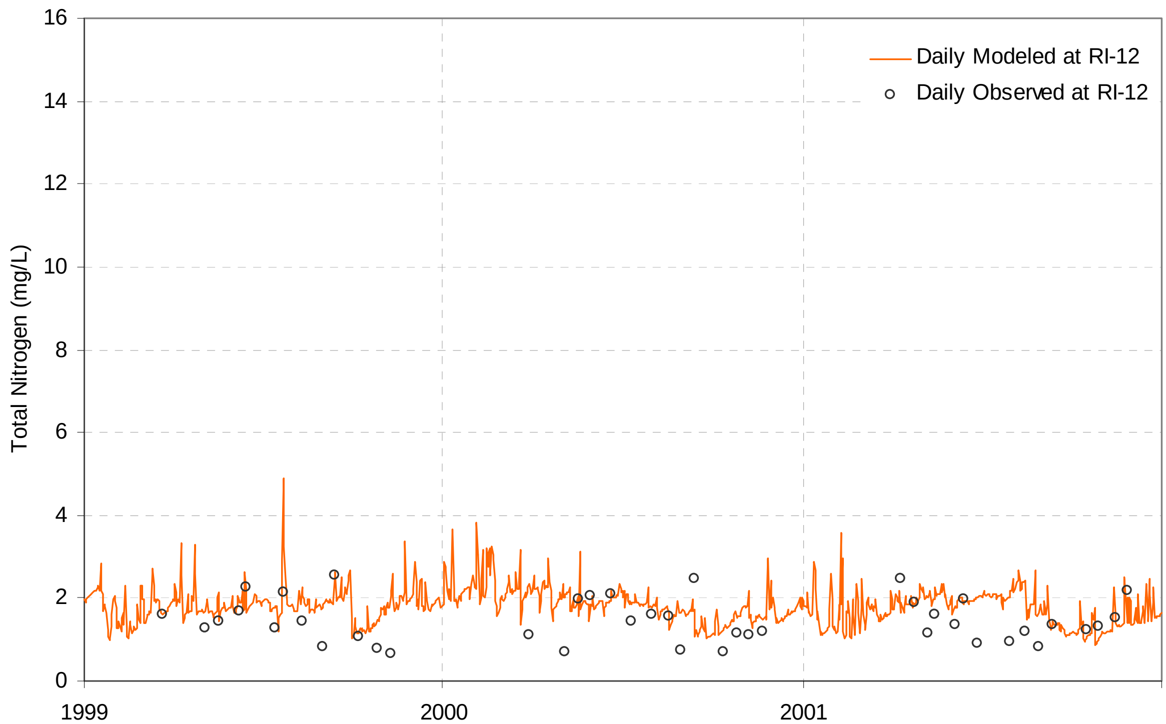


Figure 24. Total Nitrogen time series validation at Kinnickinnic River RI-12.

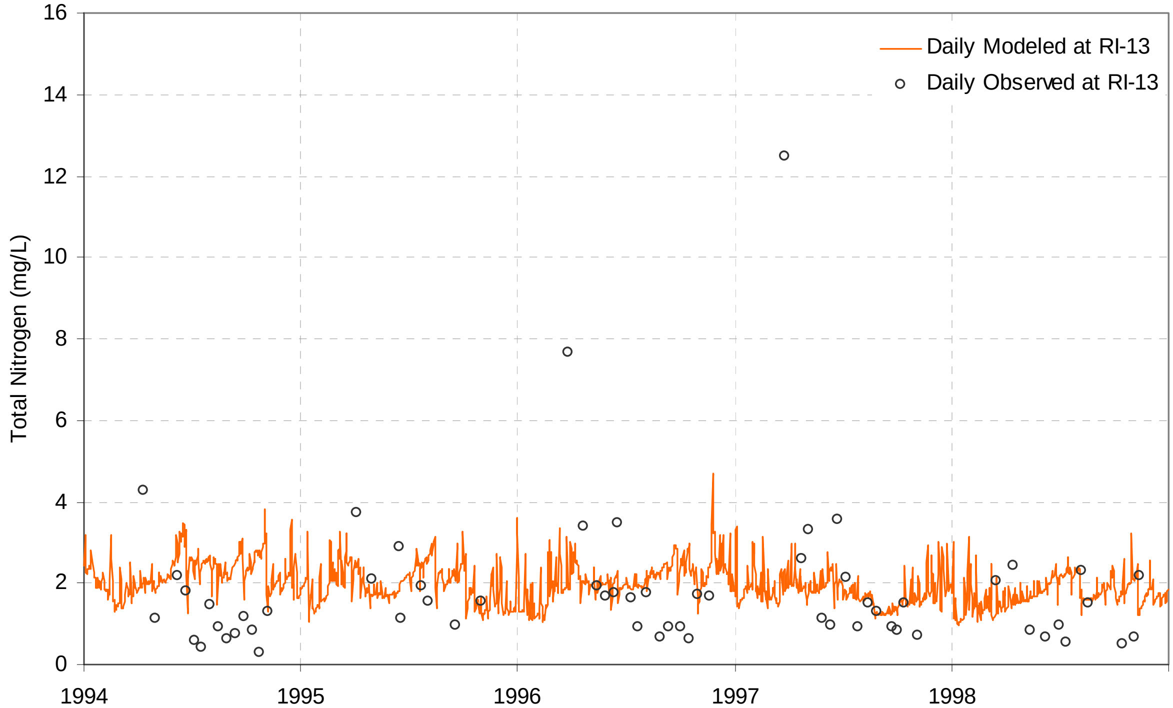


Figure 25. Total Nitrogen time series calibration at Kinnickinnic River RI-13.

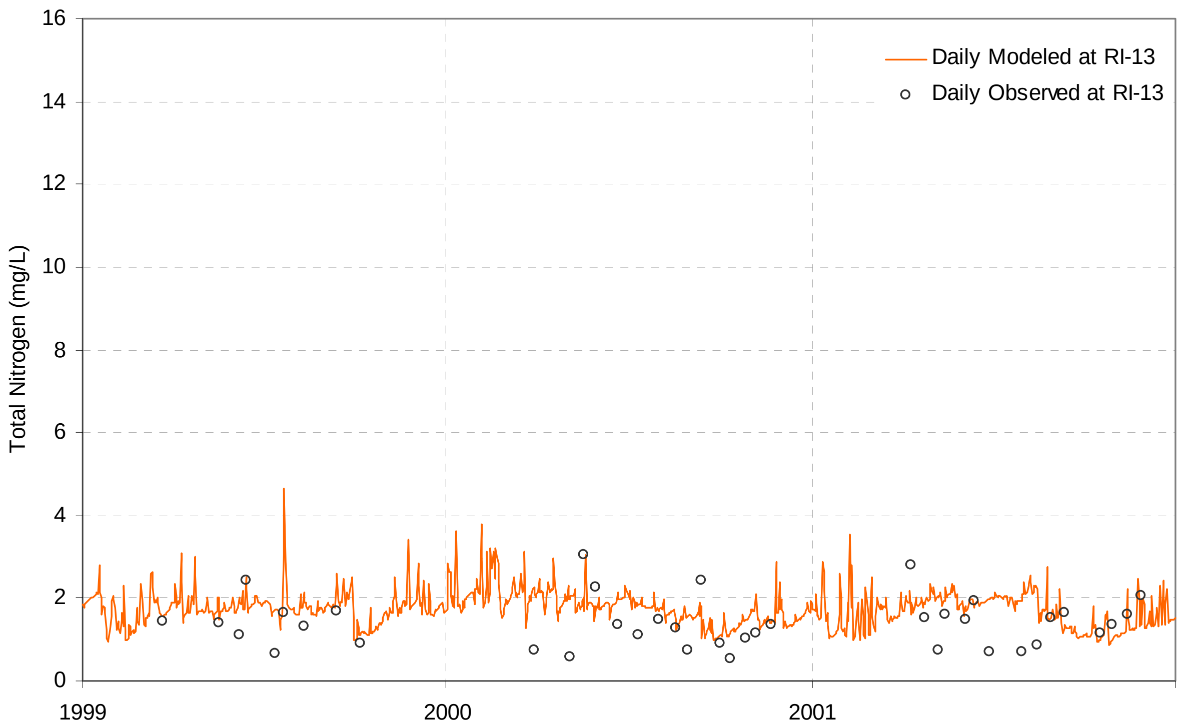


Figure 26. Total Nitrogen time series validation at Kinnickinnic River RI-13.

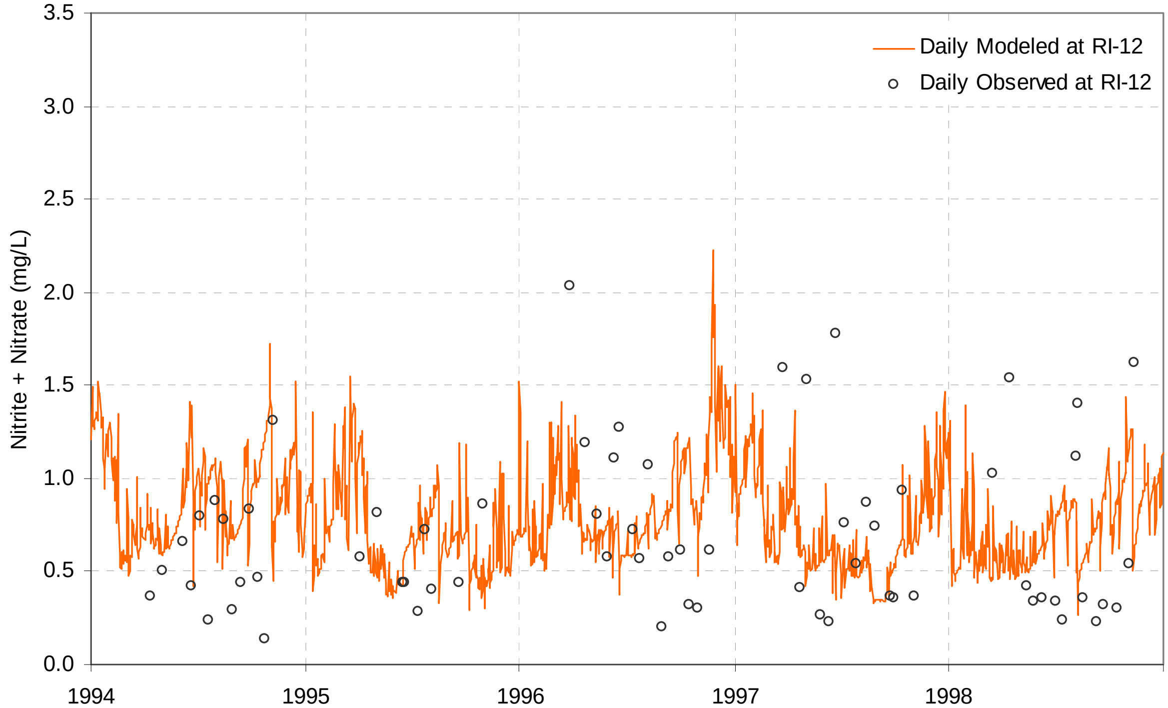


Figure 27. Nitrite+Nitrate time series calibration at Kinnickinnic River RI-12.

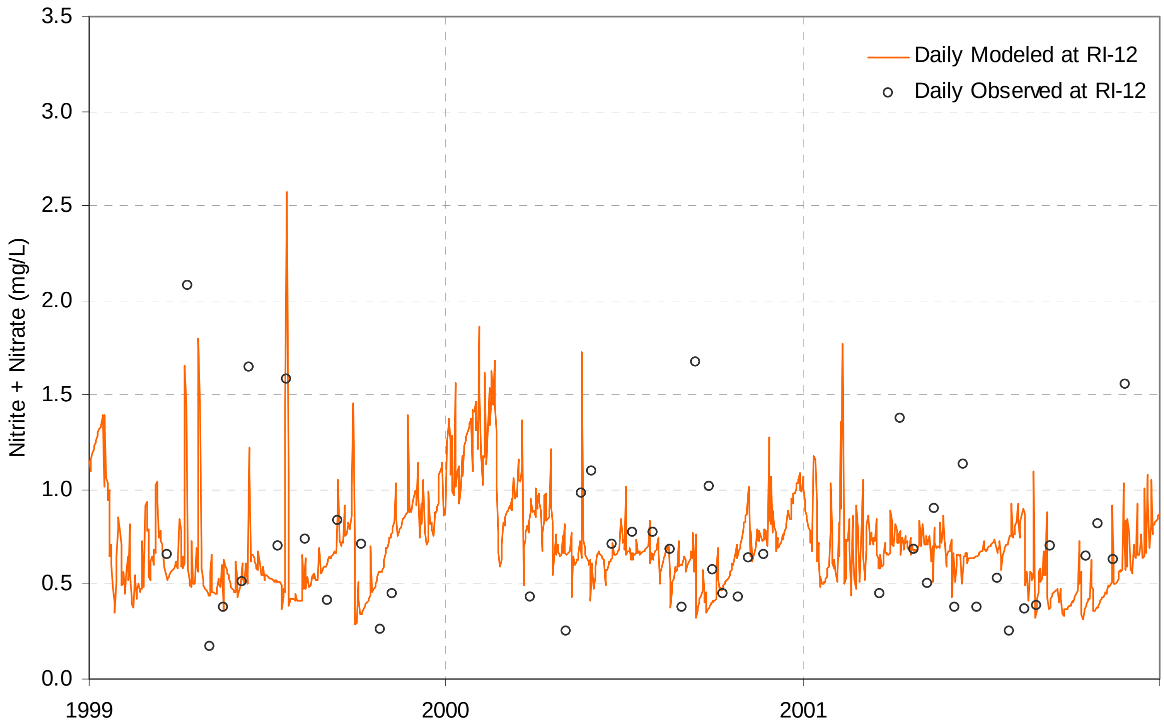


Figure 28. Nitrite+Nitrate time series validation at Kinnickinnic River RI-12.

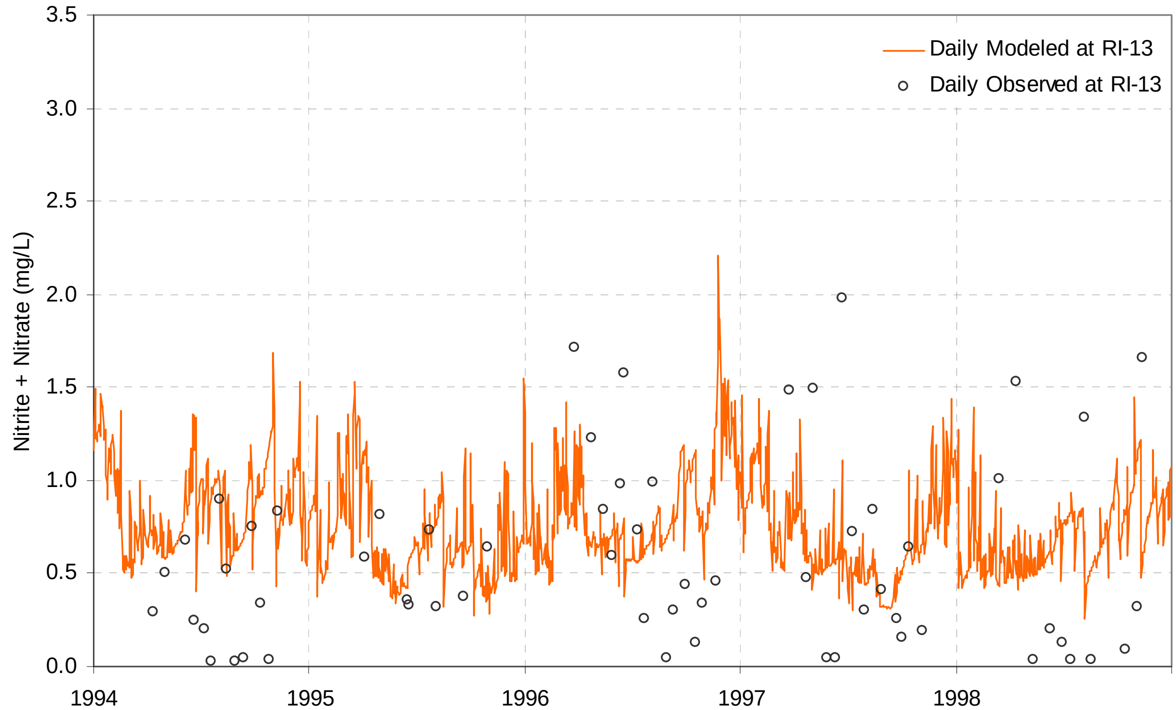


Figure 29. Nitrite+Nitrate time series calibration at Kinnickinnic River RI-13.

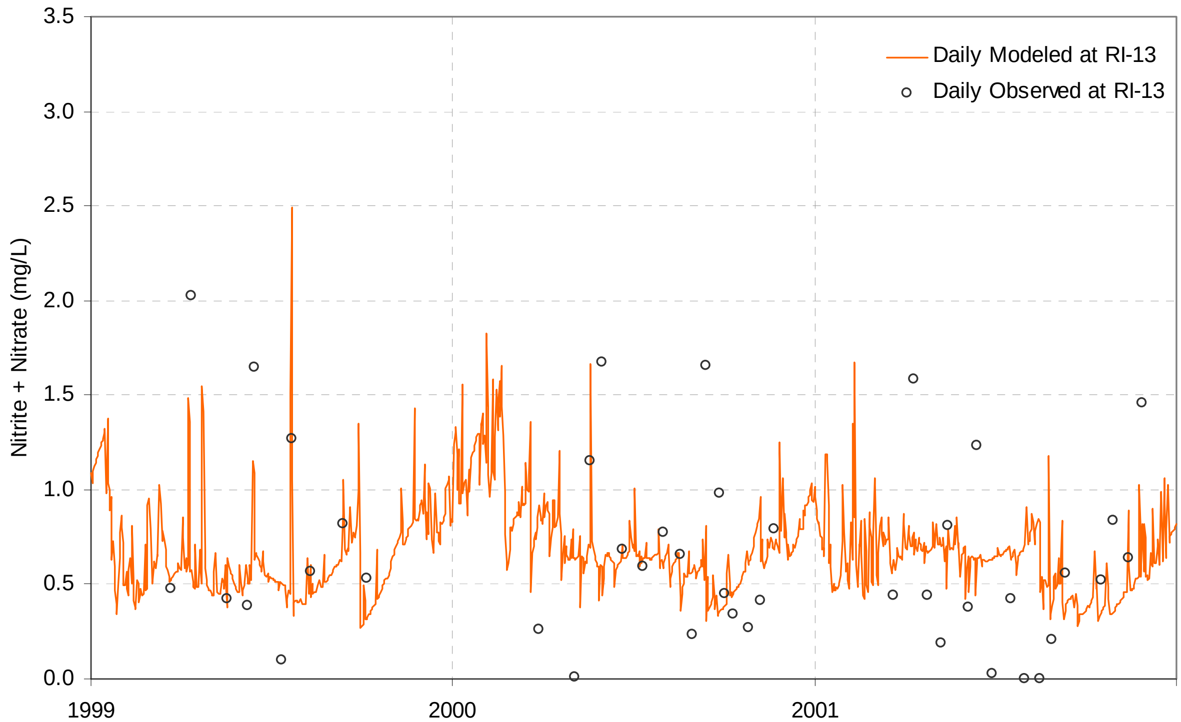


Figure 30. Nitrite+Nitrate time series validation at Kinnickinnic River RI-13.

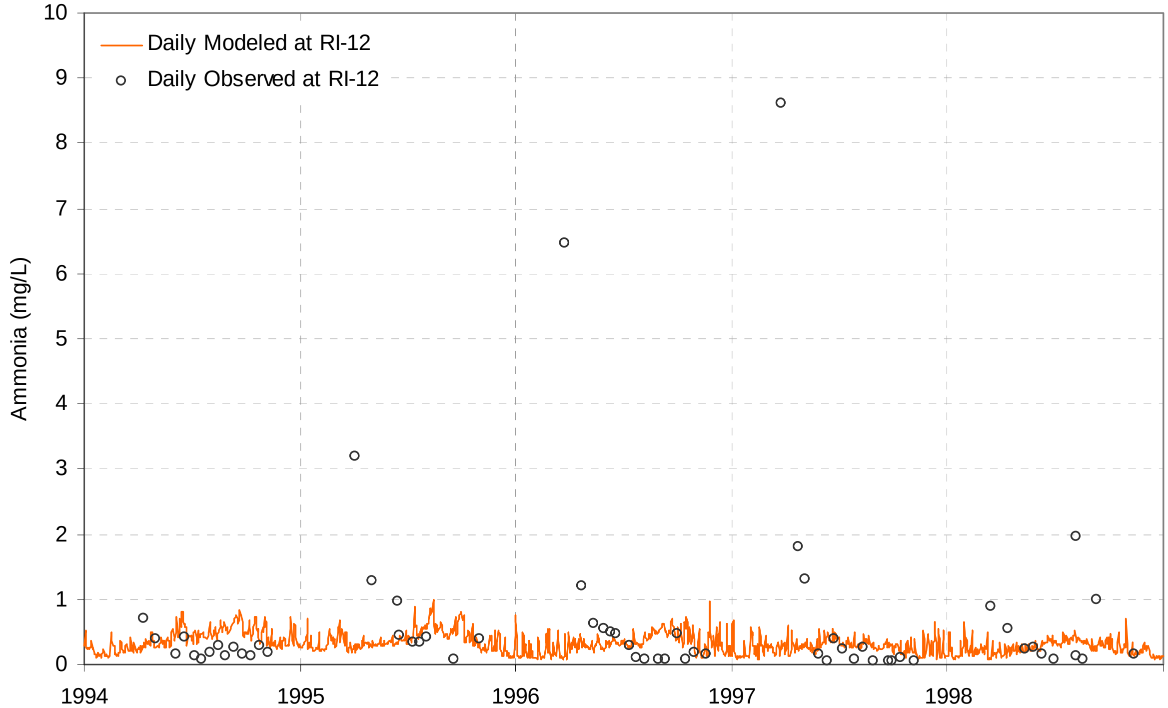


Figure 31. Ammonia time series calibration at Kinnickinnic River RI-12.

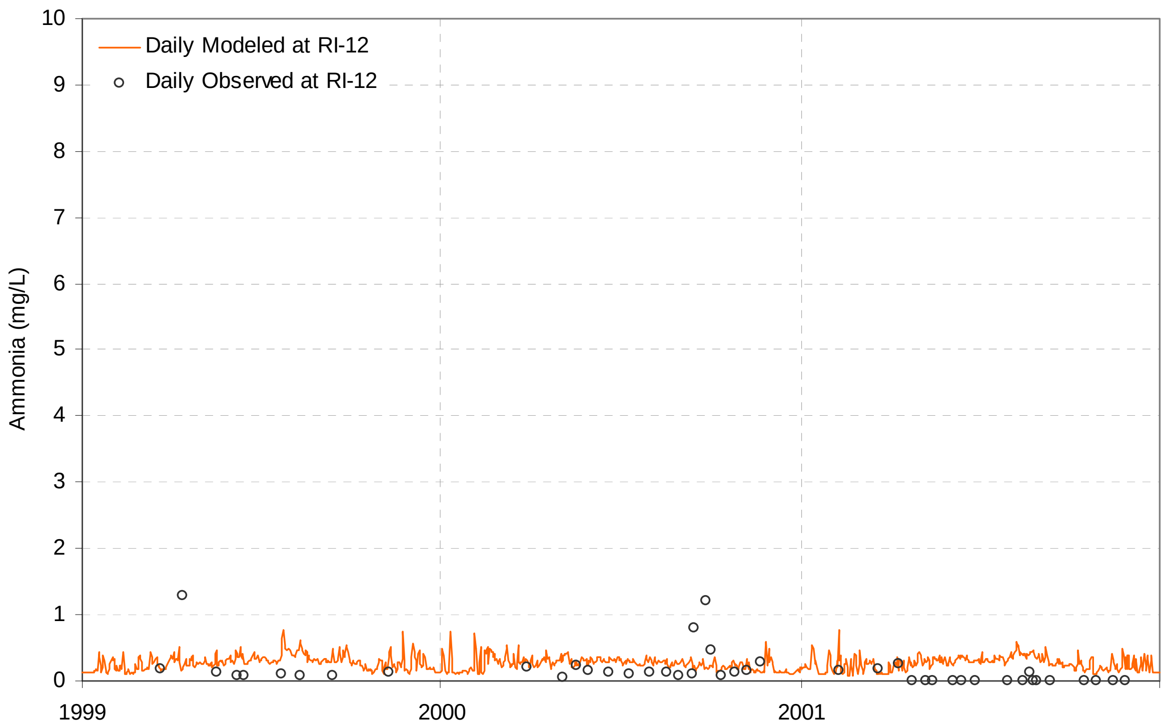


Figure 32. Ammonia time series validation at Kinnickinnic River RI-12.

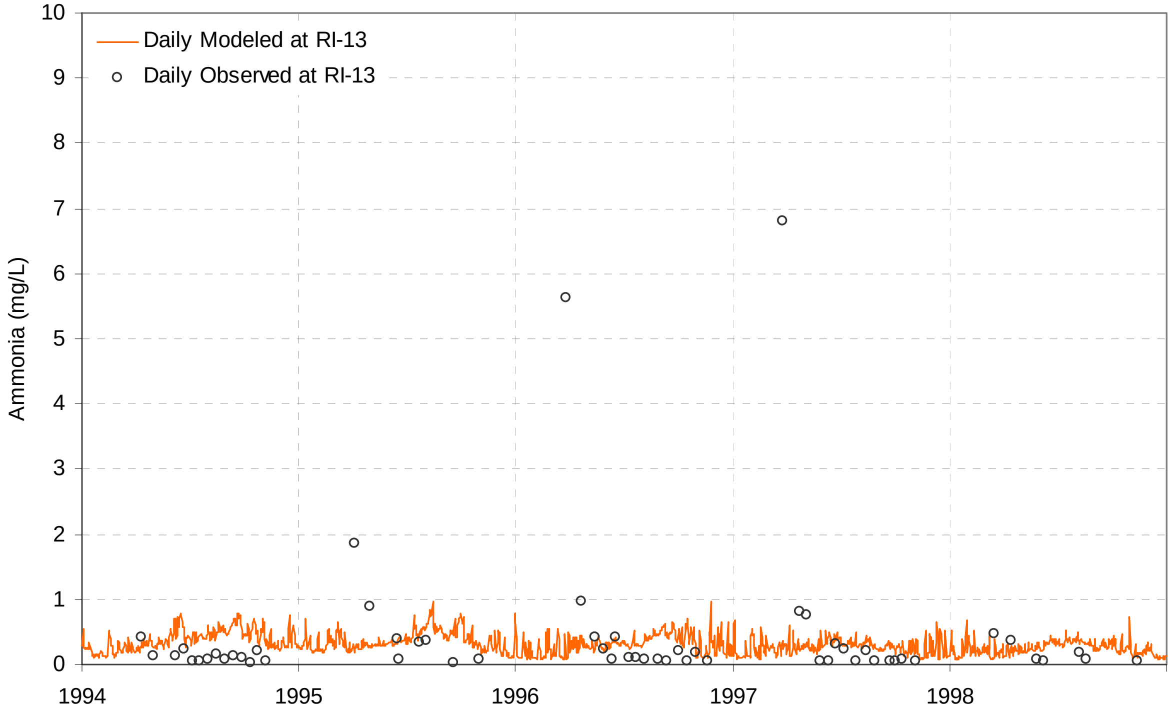


Figure 33. Ammonia time series calibration at Kinnickinnic River RI-13.

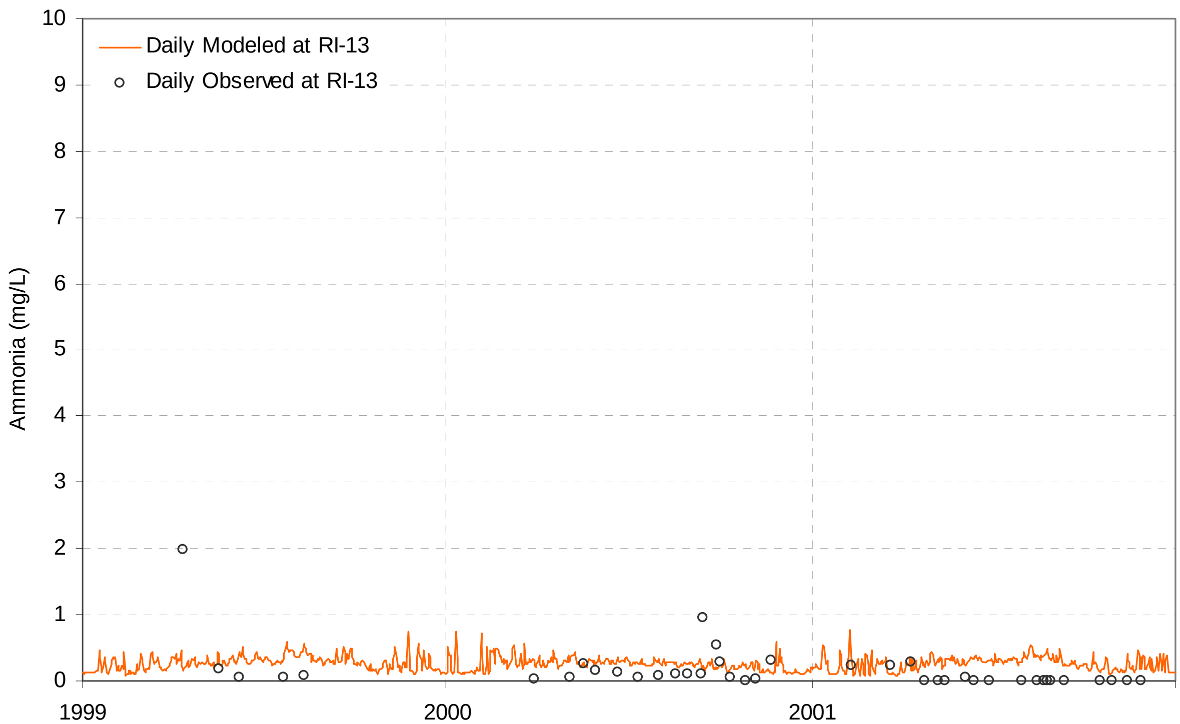


Figure 34. Ammonia time series validation at Kinnickinnic River RI-13.

5.9 Algae and Chlorophyll a

Model calibration for planktonic chlorophyll *a* is challenging, because (1) algae respond in a complex way to a wide number of environmental factors, including self-shading, (2) chlorophyll *a* laboratory analyses are typically subject to a relatively high level of imprecision, and (3) algal response is naturally highly variable. Simulation of chlorophyll *a* in the Kinnickinnic River uses similar parameters as the Menomonee model but has been modified to focus on the benthic algal simulation. Maximum algal growth rates are shared between the planktonic and benthic algal simulations, and the rates used in the Kinnickinnic River model are thus for periphyton, which is more important in this system.

Model results for the calibration and validation time periods are provided below (Figure 35 to Figure 38). Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment A. The model is in range of the data for most observations of planktonic chlorophyll *a*. A few very large observations of chlorophyll *a* are present in the data. These likely represent sloughing of periphytic algae and not truly planktonic algae, and so are not represented in the model simulation of plankton.

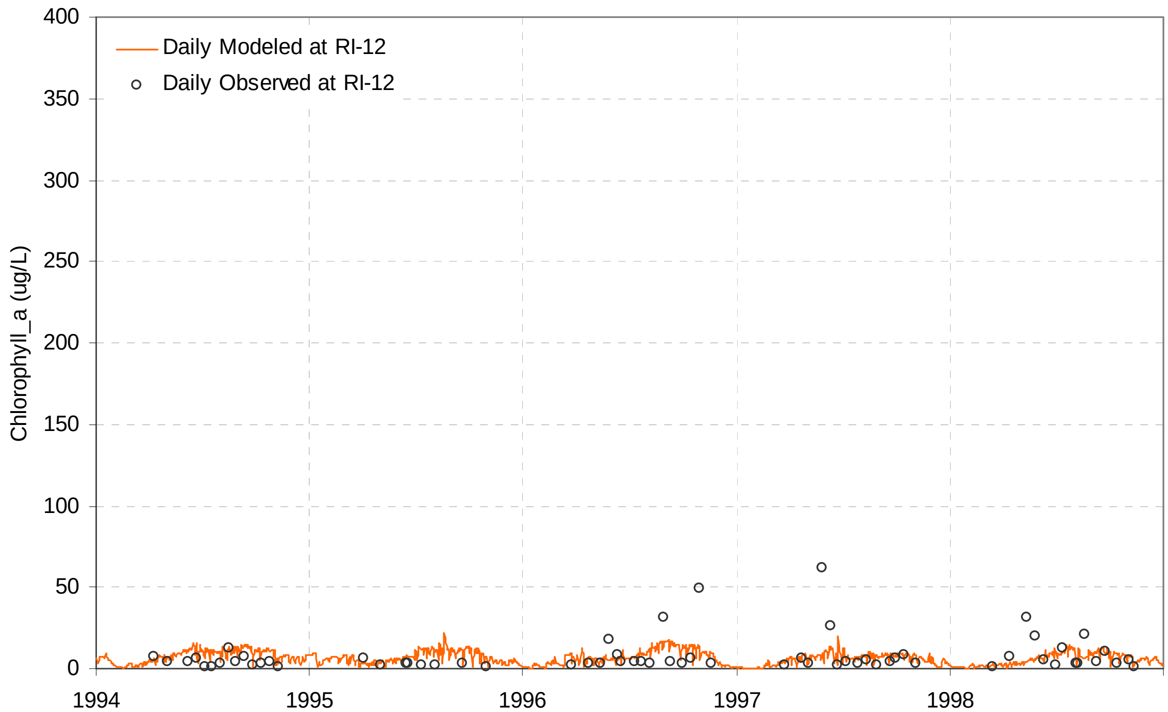


Figure 35. Chlorophyll time series calibration at Kinnickinnic River RI-12.

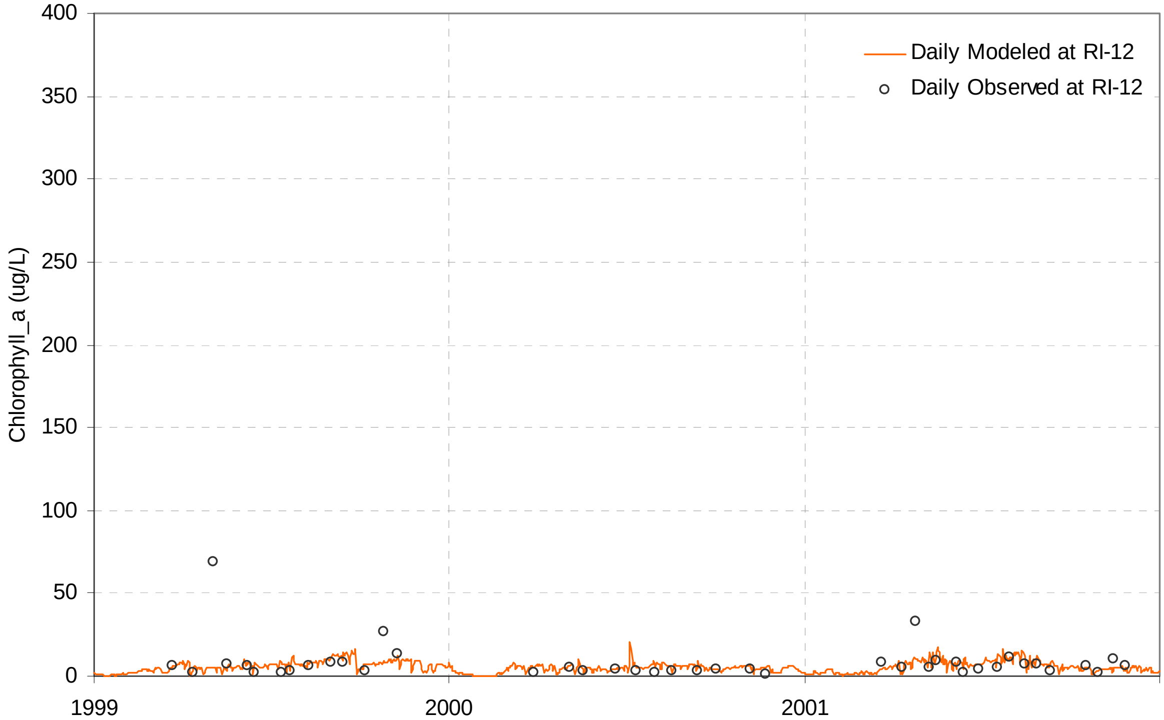


Figure 36. Chlorophyll time series validation at Kinnickinnic River RI-12.

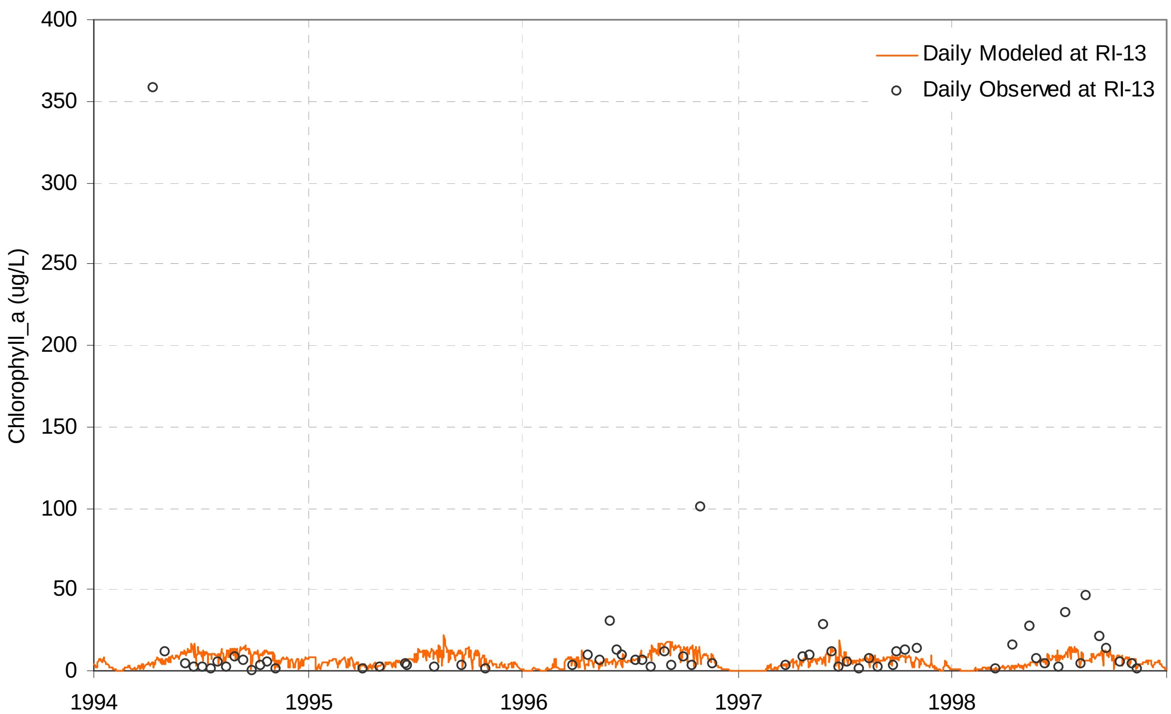


Figure 37. Chlorophyll time series calibration at Kinnickinnic River RI-13.

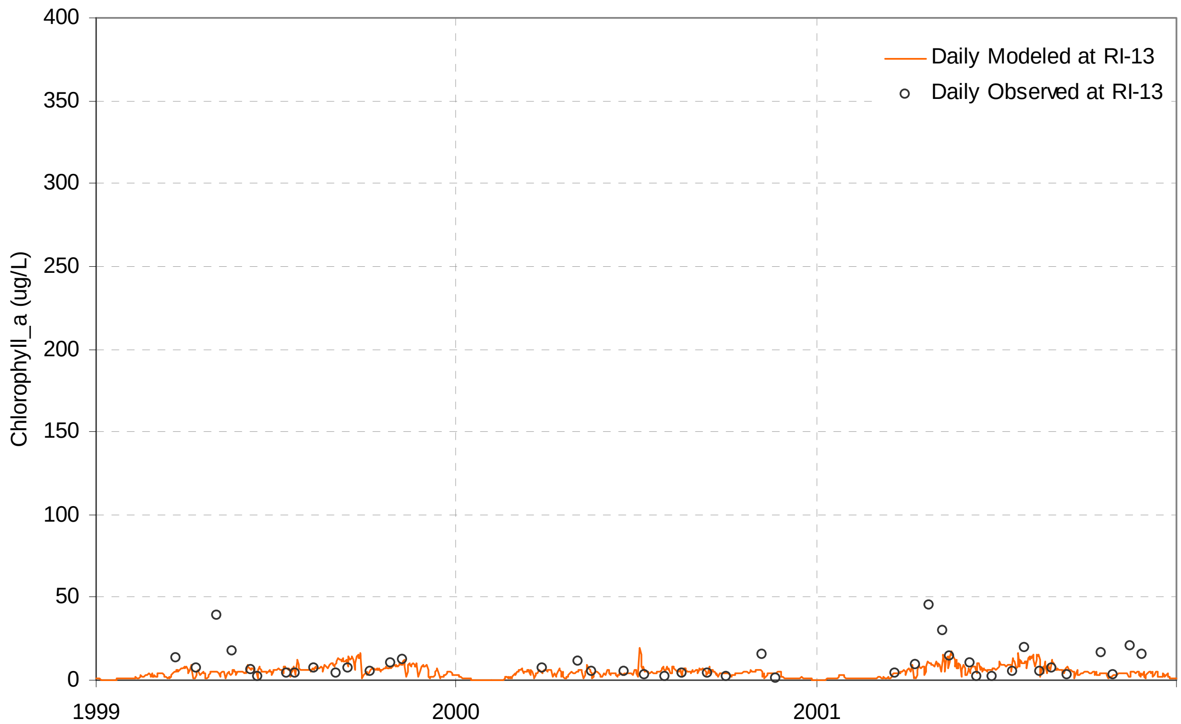


Figure 38. Chlorophyll time series validation at Kinnickinnic River RI-13.

5.10 BOD/DO Calibration

Simulation of BOD and DO in the Kinnickinnic River uses the same parameters as the Menomonee River model except that the maximum level of supersaturation was increased to 200 percent to reflect observed values. This allows occasional very high DO concentrations during periods of high algal production. The excess DO will in fact be present as gas bubbles trapped in the algal mat, rather than mixed concentrations in the water column. As photosynthetic rates decrease, the excess DO gradually diffuses into the atmosphere.

As in the Menomonee, a rigorous calibration for biochemical oxygen demand (BOD) is problematic, because what is represented in the model is not fully equivalent to what is analyzed from ambient samples. BOD has been primarily monitored in the Kinnickinnic River using APHA (1998) Standard Method 5210B. This yields estimates of 5-day (short-term) BOD from whole-water samples, including both the carbonaceous and nitrogenous components. The detection limit in later samples is 0.2 mg/L; however, those samples obtained through 1995 appear to have had a detection limit of 2 mg/L. The LSPC model simulates a single dissolved carbonaceous BOD (CBOD) component as a state variable, while the oxygen demand exerted by reduced nitrogen compounds (ammonia and nitrite) is simulated separately. Under most conditions in natural waters without significant wastewater treatment plant effluent loading the nitrogenous component of BOD is relatively small. However, organic matter that exerts a carbonaceous oxygen demand via bacterial digestion is a complex mixture of chemicals with variable reaction rates. The LSPC variable is a summary compromise that, when combined with an average reaction rate, yields the observed rate of oxygen depletion. It is not necessarily equivalent to either a CBOD5 or an ultimate CBOD (CBODu), but rather an ad hoc hybrid. For flowing systems with relatively short residence times, an approximation in terms of CBOD5 is usually adequate, although the reaction rate may need to be modified from 5-day laboratory rates to compensate for the mixture of organic compounds actually exerting a demand.

A further complication is that the LSPC state variable represents the non-living component of BOD. Method 5210B uses unfiltered samples, and these samples also include living algae. Algae are not allowed to grow during the BOD test, but may continue to exert a respiration demand or die and become part of the non-living BOD. This component of measured BOD is not included in the LSPC state variable. A correction can be calculated to account for the long-term CBODu represented by algal cells, but the effect on CBOD5 is more variable and less clear. Accordingly, if LSPC is set up to simulate BOD as an approximation of dissolved CBOD5, the model should generally provide a slight underestimation of BOD5 measured by Method 5210B. A rigorous comparison between simulated and observed BOD is not, however, feasible.

Model results for the calibration and validation time periods are provided below for both BOD5 and dissolved oxygen (Figure 40 to Figure 47).

The statistical comparison of observed DO to daily average predicted DO is not meaningful because the majority of samples were collected in the early afternoon, when algal DO production is likely to be at its maximum. Therefore, the daily average concentration simulated by the model is, as expected, generally less than the observed concentration. The plot for DO shows daily average, minimum, and maximum, with a wide predicted diurnal range. Almost all DO observations fall in this range. The DO simulation is driven by the benthic algal simulation, for which there are no reported data for direct calibration. Predicted benthic algal densities are shown in Figure 39 for model reaches 806 (R806) and 807 (R807). Monitoring station RI-13 is located along reach 806 and monitoring station RI-12 is located along reach 807.

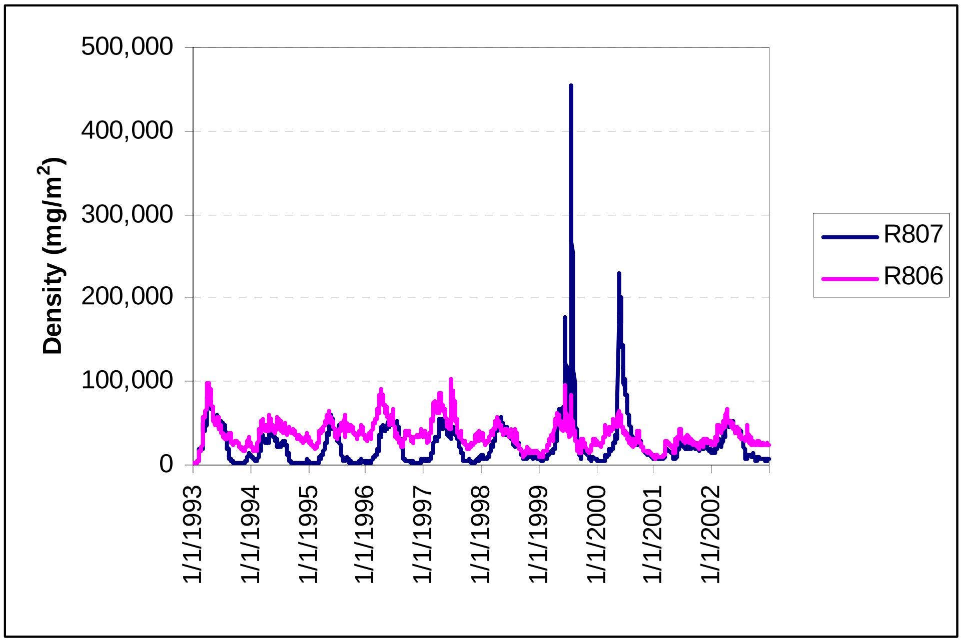


Figure 39.   Predicted Benthic Algal Densities in Lower Kinnickinnic River

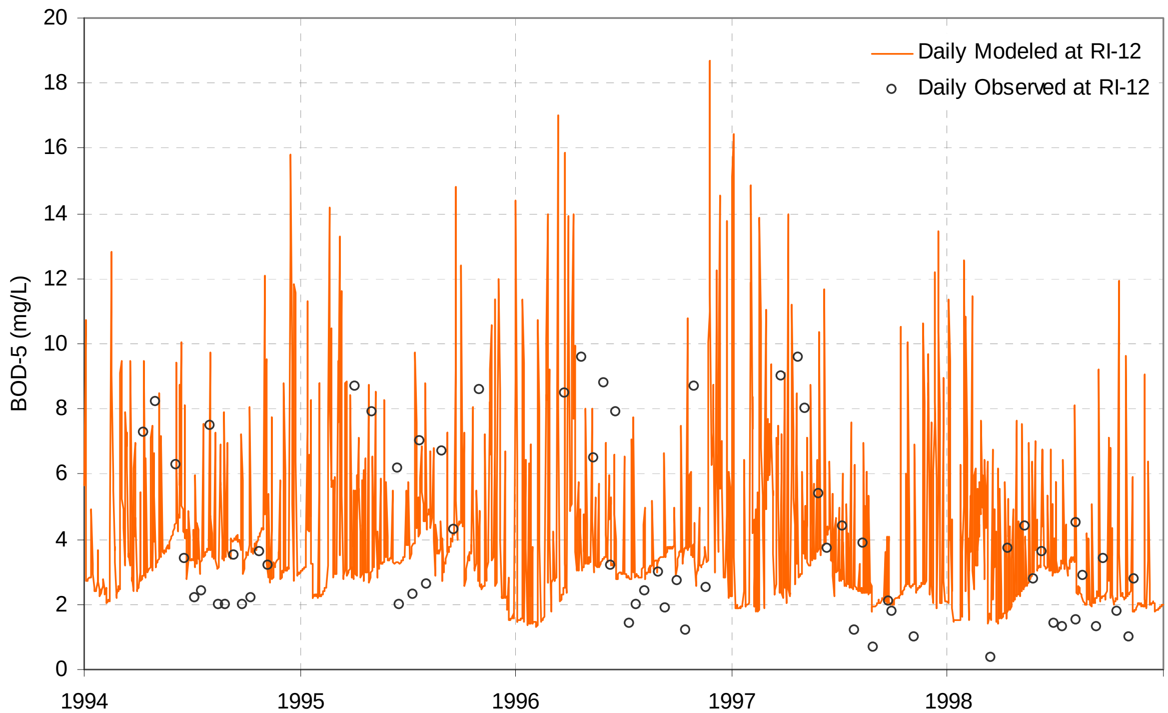


Figure 40. BOD5 time series calibration at Kinnickinnic River RI-12.

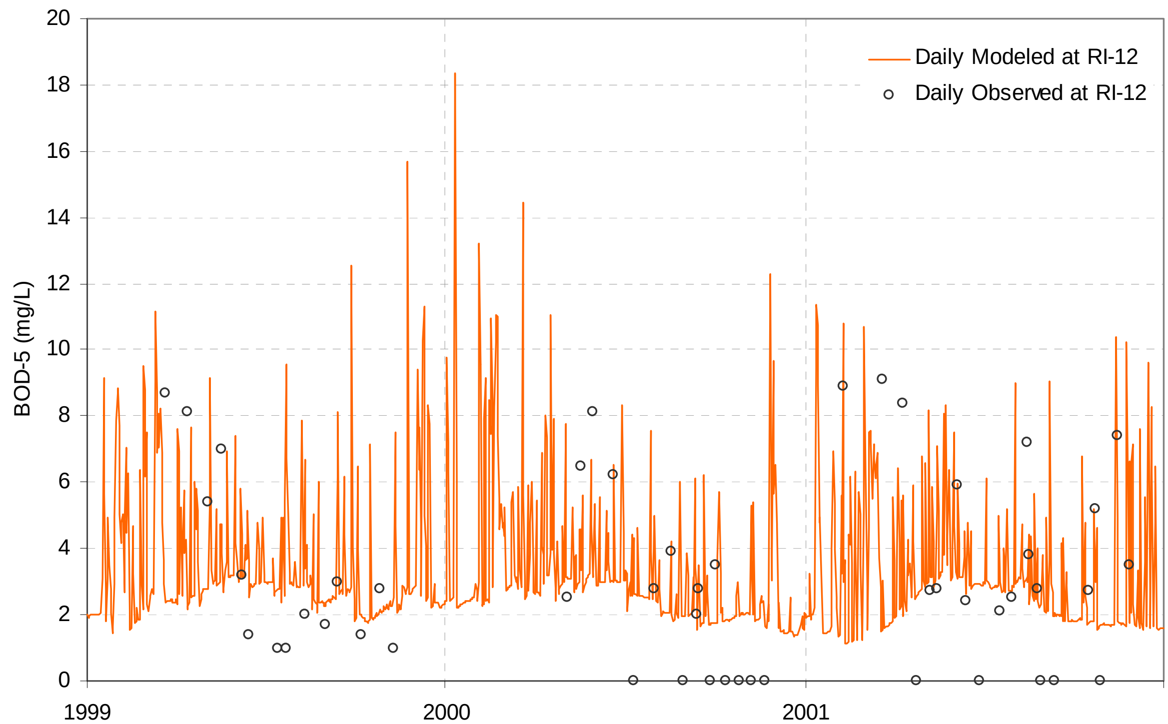


Figure 41. BOD5 time series validation at Kinnickinnic River RI-12.

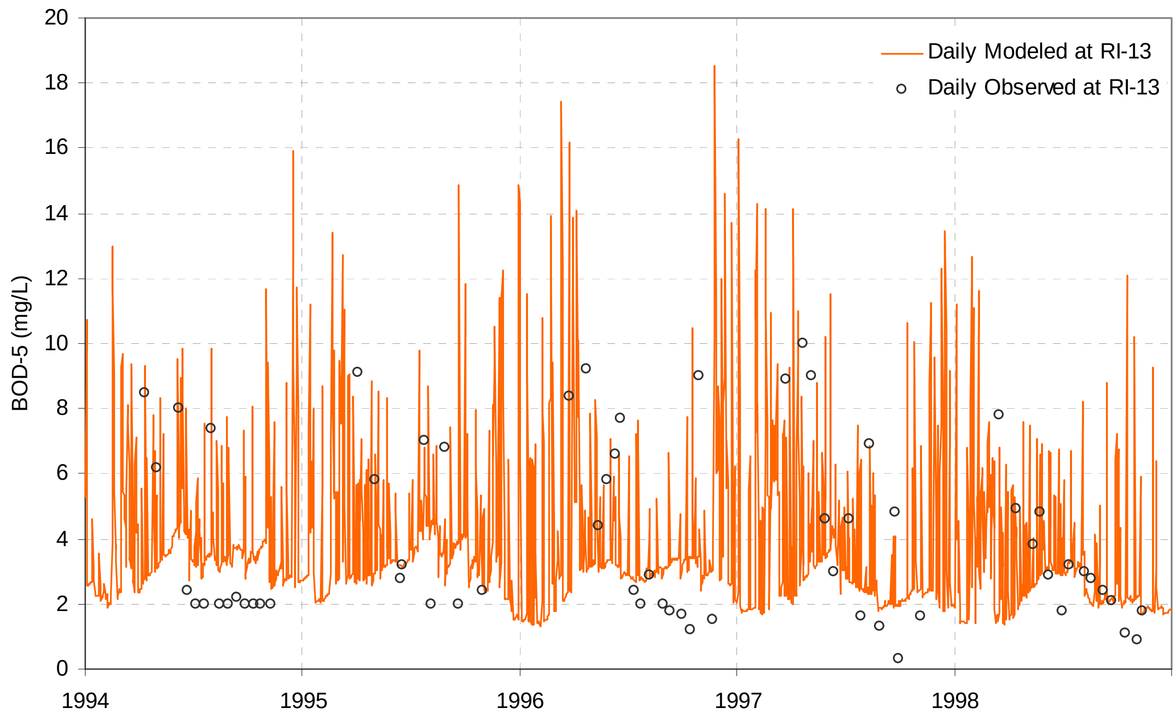


Figure 42. BOD5 time series calibration at Kinnickinnic River RI-13.

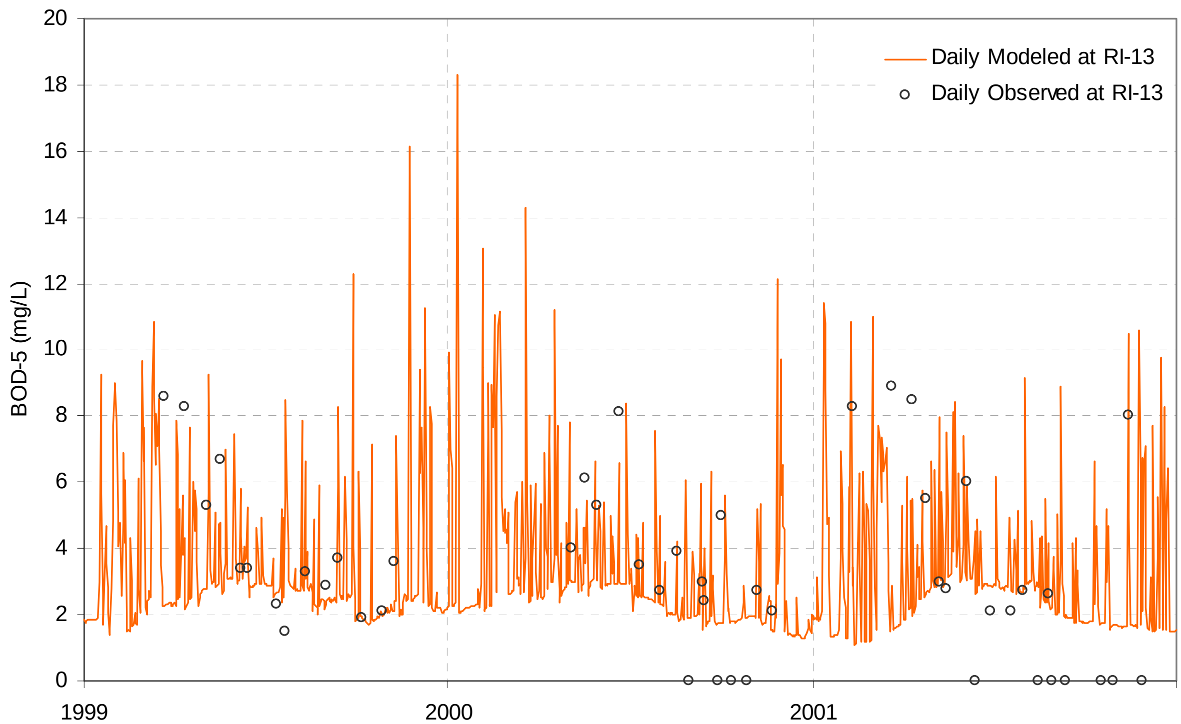


Figure 43. BOD5 time series validation at Kinnickinnic River RI-13.

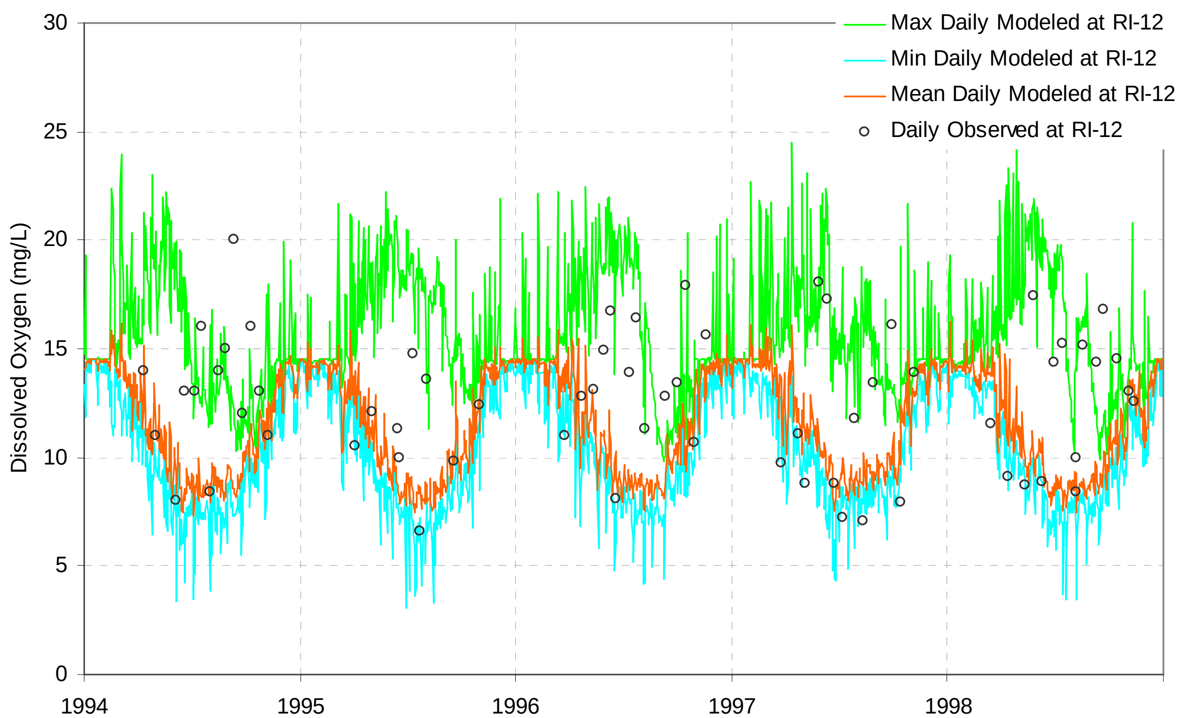


Figure 44. Dissolved oxygen time series calibration at Kinnickinnic River RI-12.

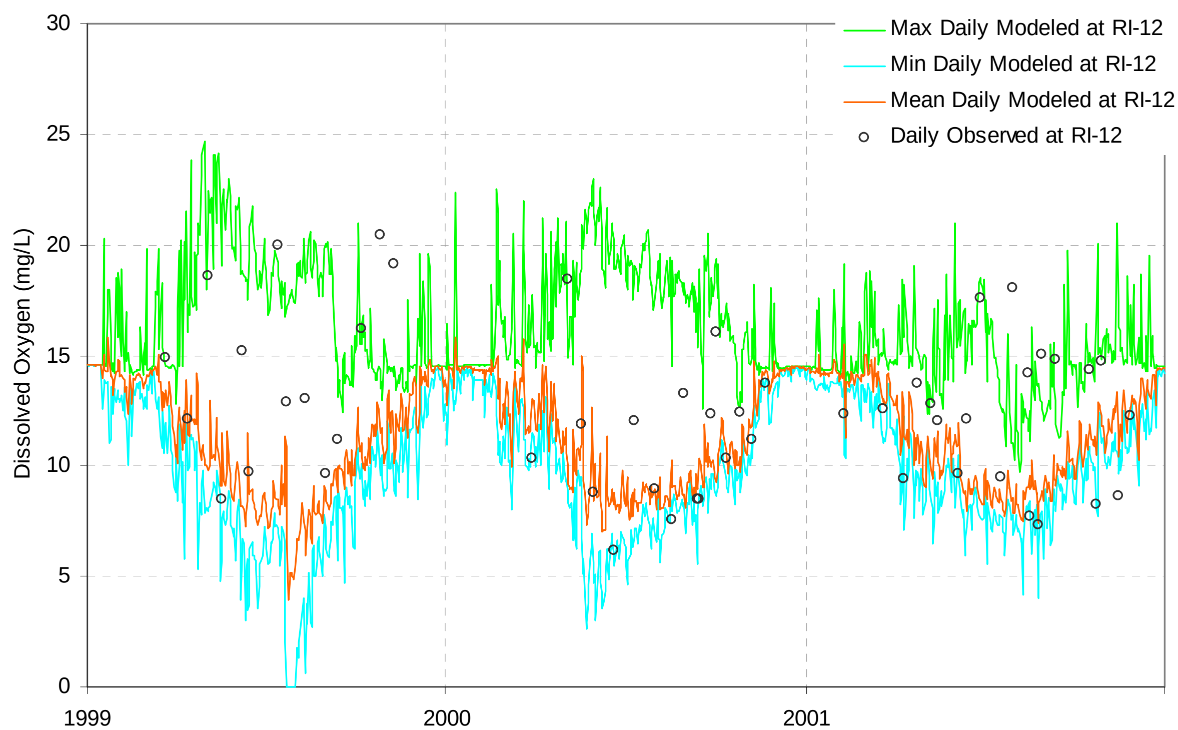


Figure 45. Dissolved oxygen time series validation at Kinnickinnic River RI-12.

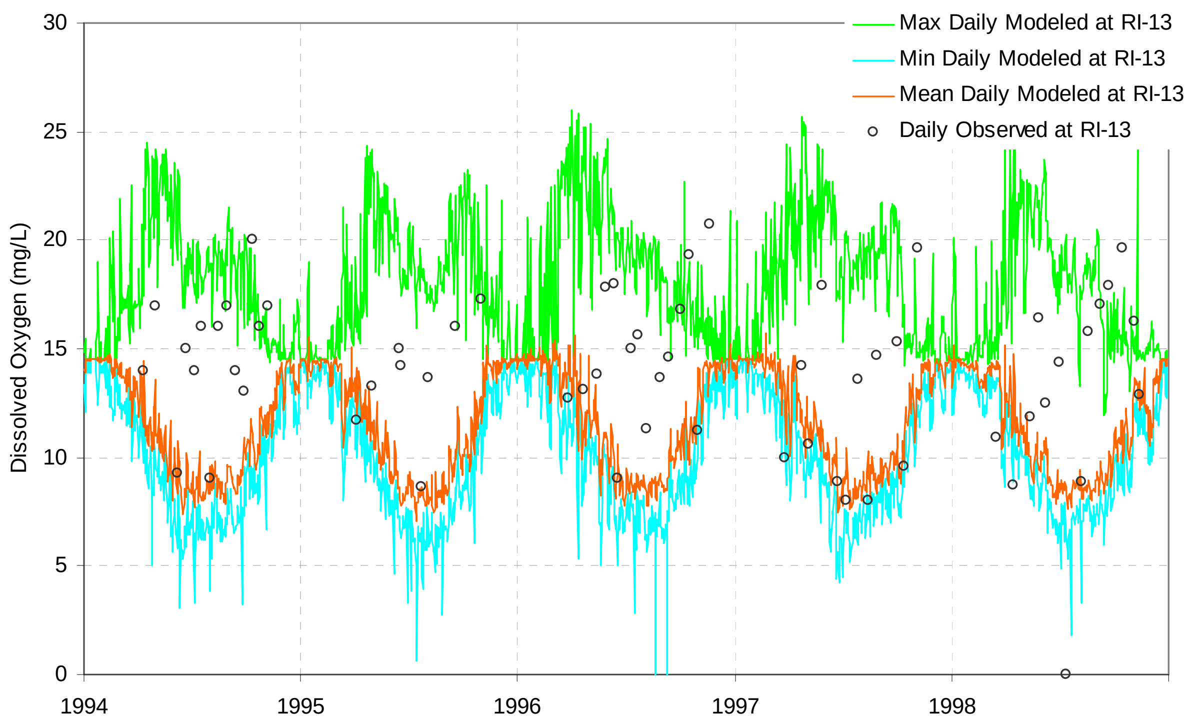


Figure 46. Dissolved oxygen time series calibration at Kinnickinnic River RI-13.

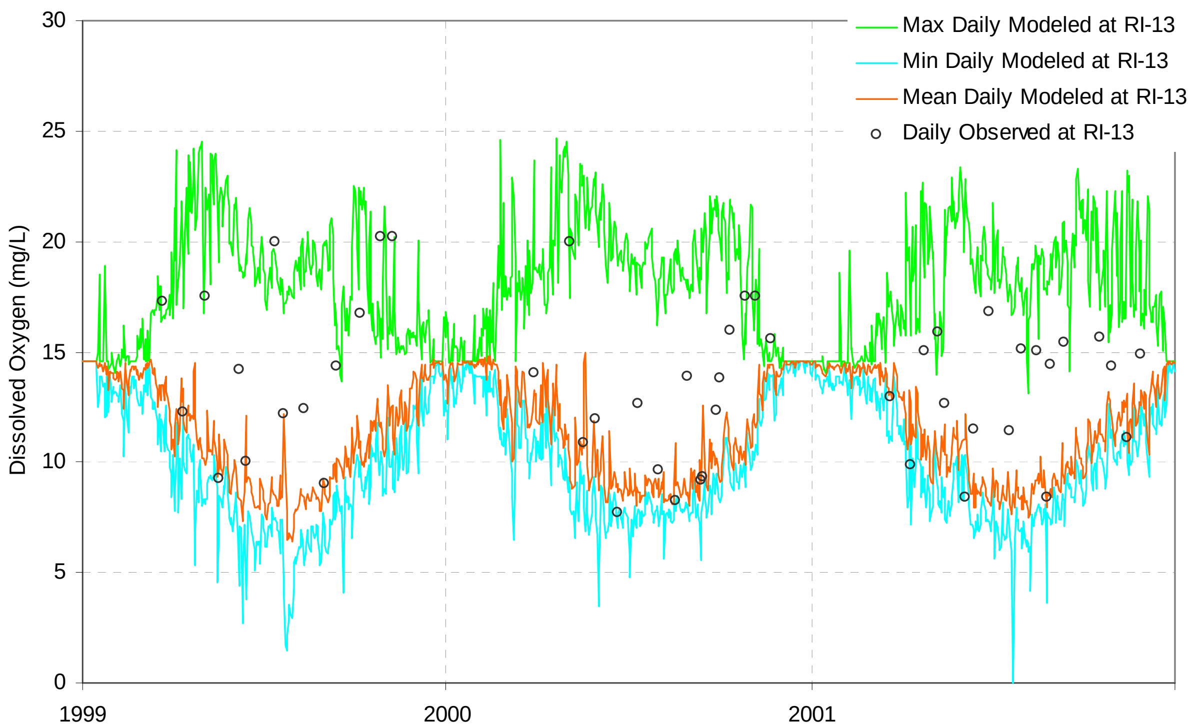


Figure 47. Dissolved oxygen time series validation at Kinnickinnic River RI-13.

5.11 Fecal Coliform Bacteria

Simulation of fecal coliform in the Kinnickinnic River uses the same parameters as the Oak Creek model. Model results for the calibration and validation time periods are provided below (Figure 48 to Figure 51). Simulation results show a reasonable general agreement between observed and simulated fecal coliform concentrations. However, certain individual observations are under-estimated by the model. This type of phenomenon is commonly found in bacterial models, and may reflect a case in which there are strong local inputs (whether from leaky sewer lines, septic systems, or animals) that are not included in the model representation of diffuse upland sources. Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment A.

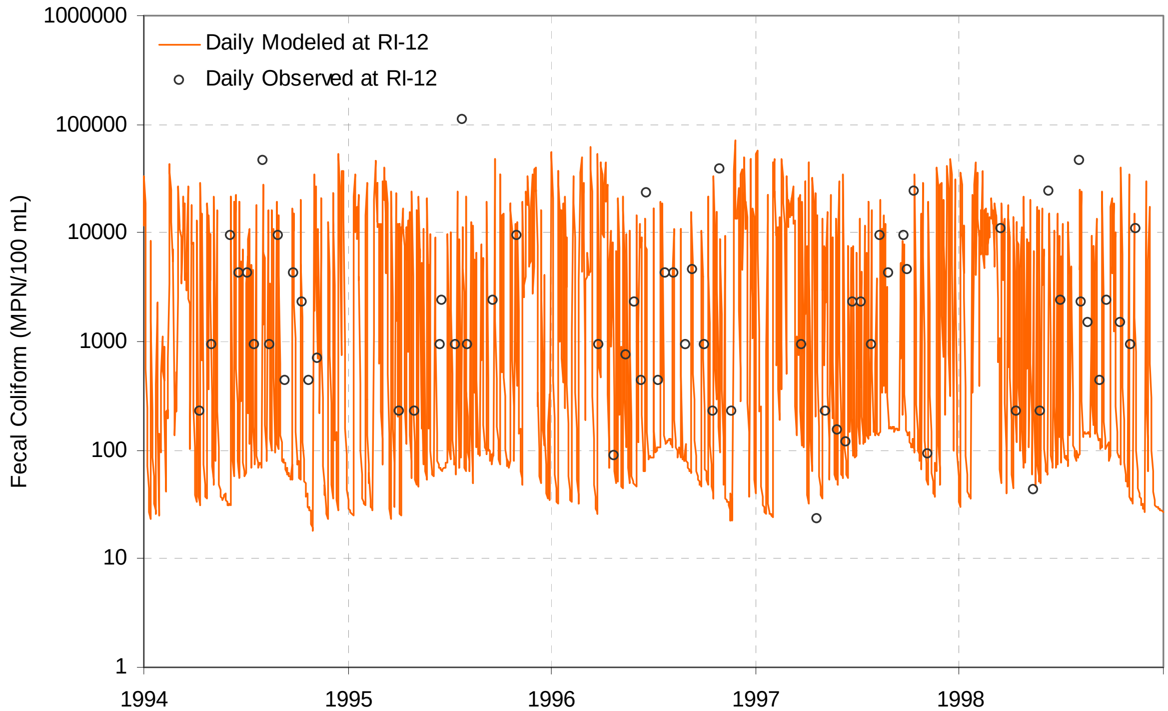


Figure 48. Fecal coliform time series calibration at Kinnickinnic River RI-12.

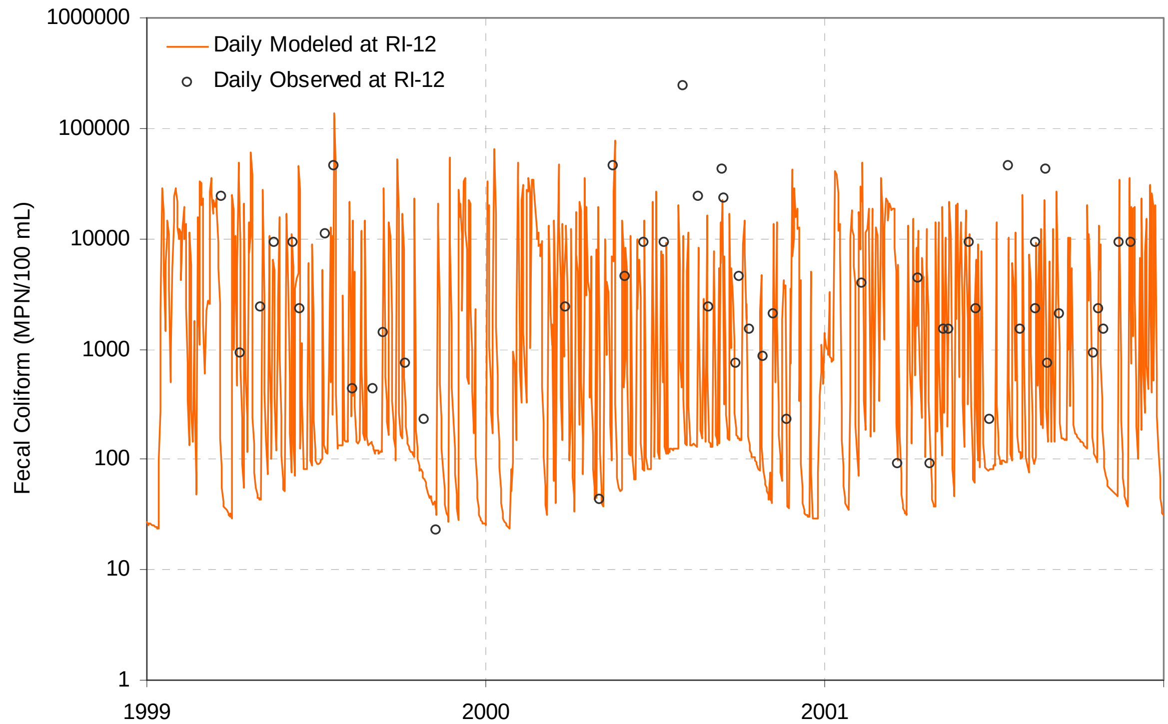


Figure 49. Fecal coliform time series validation at Kinnickinnic River RI-12.

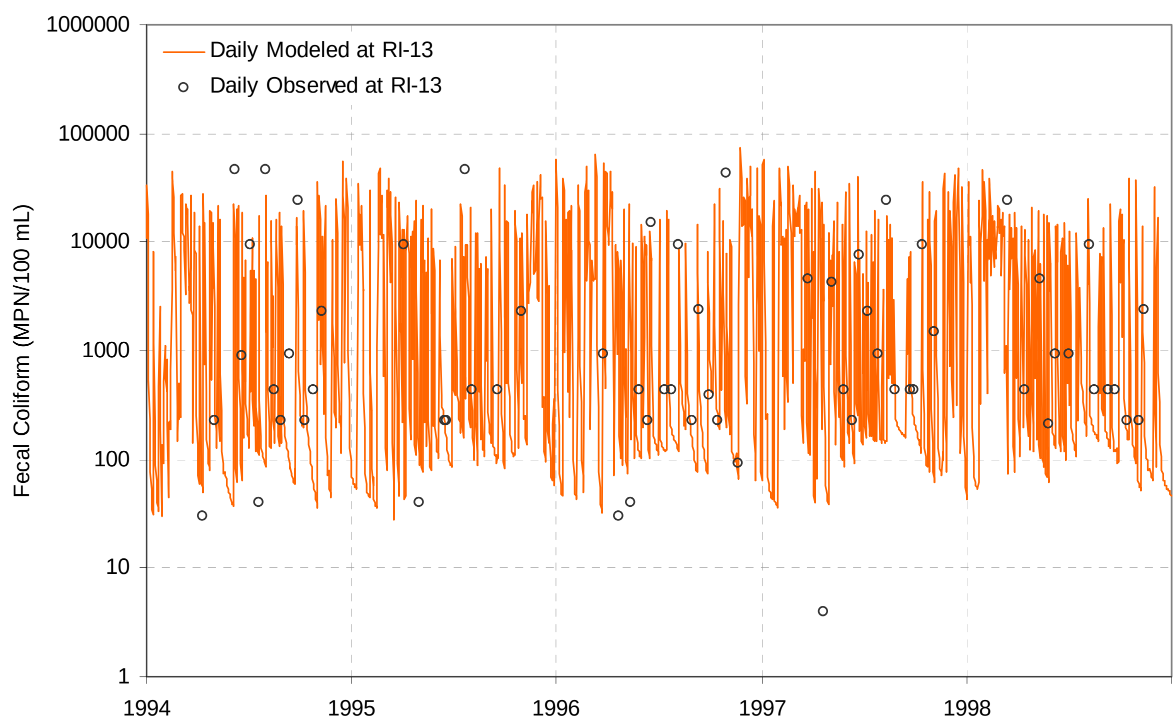


Figure 50. Fecal coliform time series calibration at Kinnickinnic River RI-13.

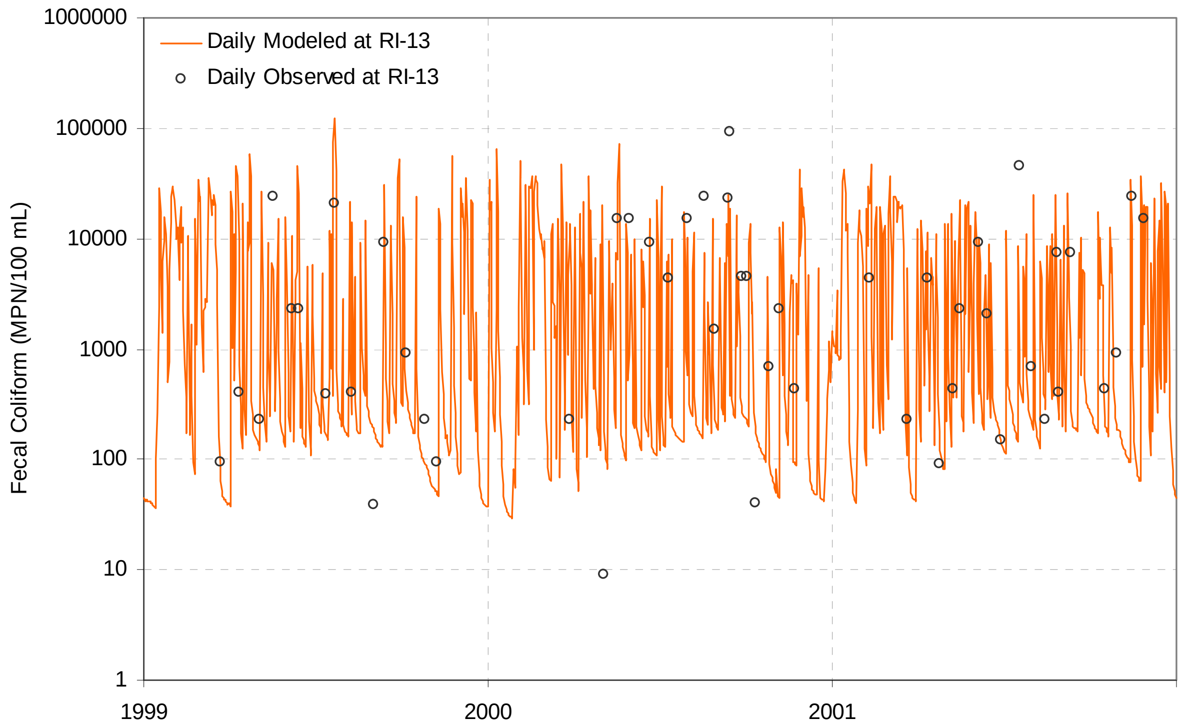


Figure 51. Fecal coliform time series validation at Kinnickinnic River RI-13.

5.12 Metals

As requested by SEWRPC, the model includes simulations for copper and zinc, but at a highly simplified level. Both copper and zinc are simulated as total metals, and treated as conservative substances within stream reaches. This neglects the actual kinetics of these constituents, which sorb to particulate matter and exchange with the sediments. Such refinements may be added to the model at a future date.

Copper and zinc are also not rigorously calibrated. While there are observations for both total copper and total zinc, many of the observations (particularly) for copper are at or near method detection limits, and thus provide limited information on exact concentrations. Further, neglect of sorption kinetics means that the simulation will only be approximate. Therefore, the strategy was to base the metals simulation on independent loading estimates and adjust these only to the extent necessary to achieve approximate agreement with the range of concentrations reported instream.

Results for the two Kinnickinnic River monitoring stations are shown in the following figures and indicate an approximate agreement in range between model predictions and observations. Note that many of the reported values appear to be quantitations at a detection limit of 0.01 mg/L. Also note that the model appears to under-predict copper prior to 1998; this is likely due to incomplete knowledge about point source contributions in this system.

Copper and zinc are simulated as conservative substances in the water column and are not rigorously calibrated. For this reason, exceedance plots and load analysis of these constituents are not presented.

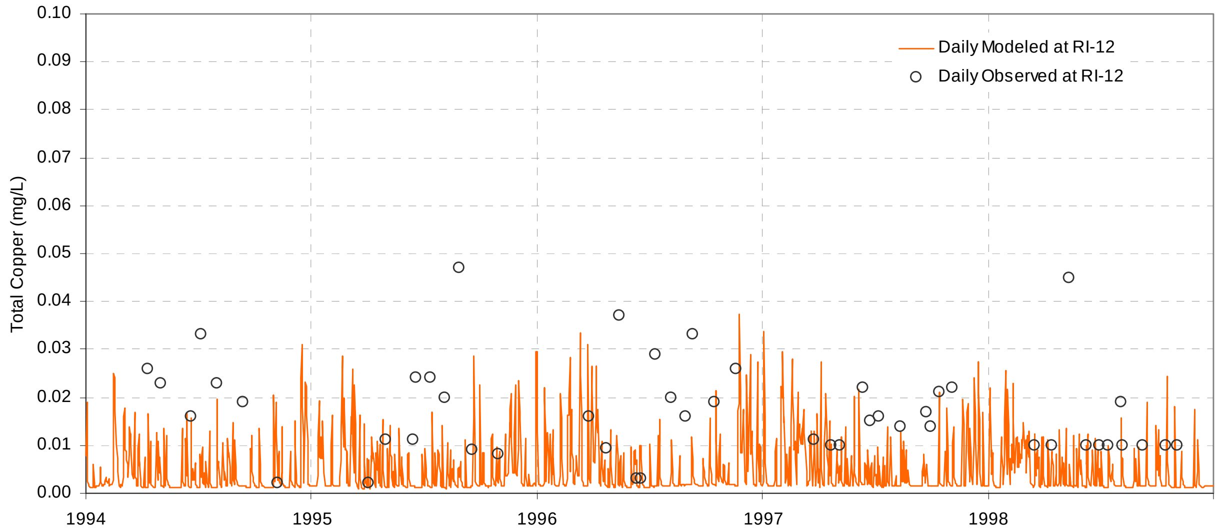


Figure 52. Total Copper simulation for calibration period at Kinnickinnic River RI-12.

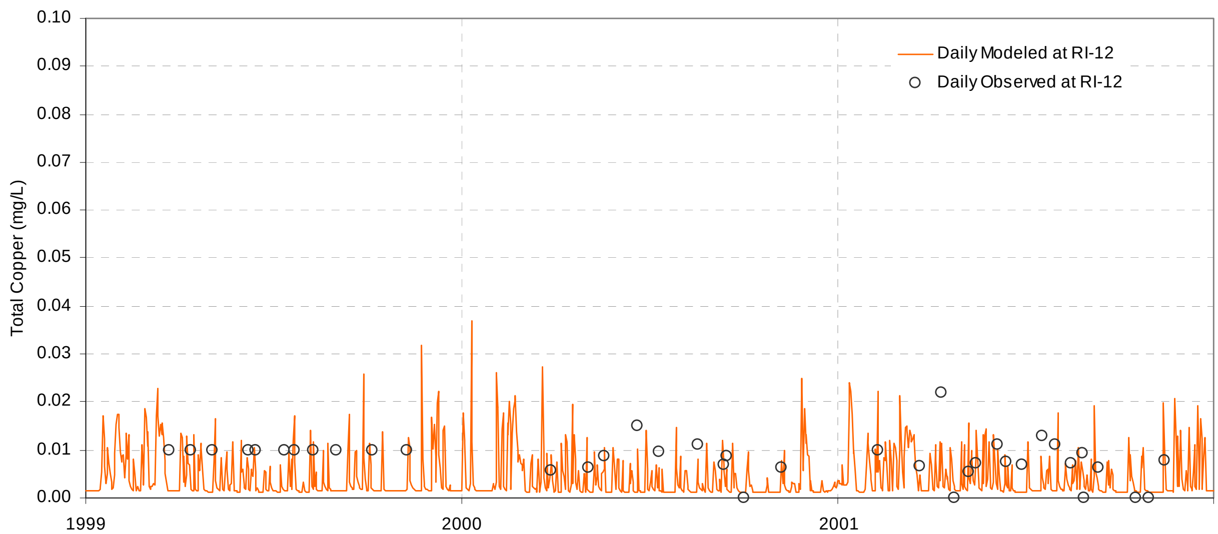


Figure 53. Total Copper simulation for validation period at Kinnickinnic River RI-12.

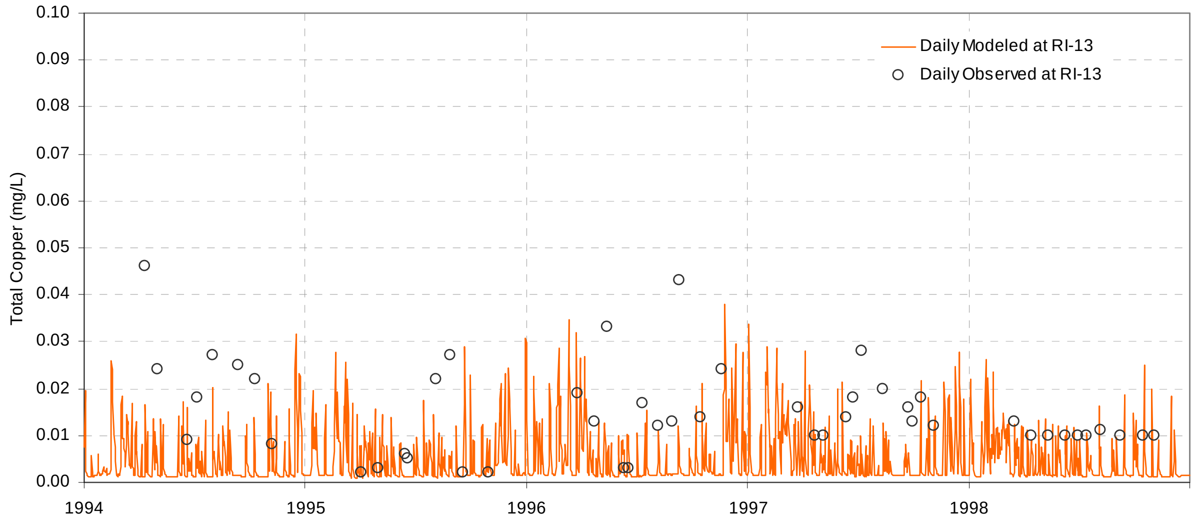


Figure 54. Total Copper simulation for calibration period at Kinnickinnic River RI-13.

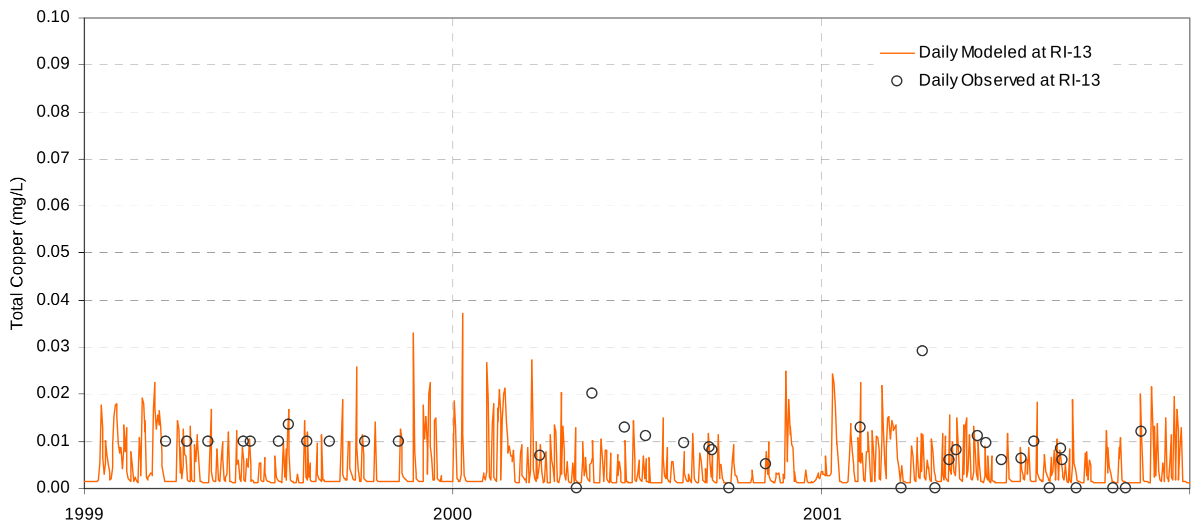


Figure 55. Total Copper simulation for validation period at Kinnickinnic River RI-13.

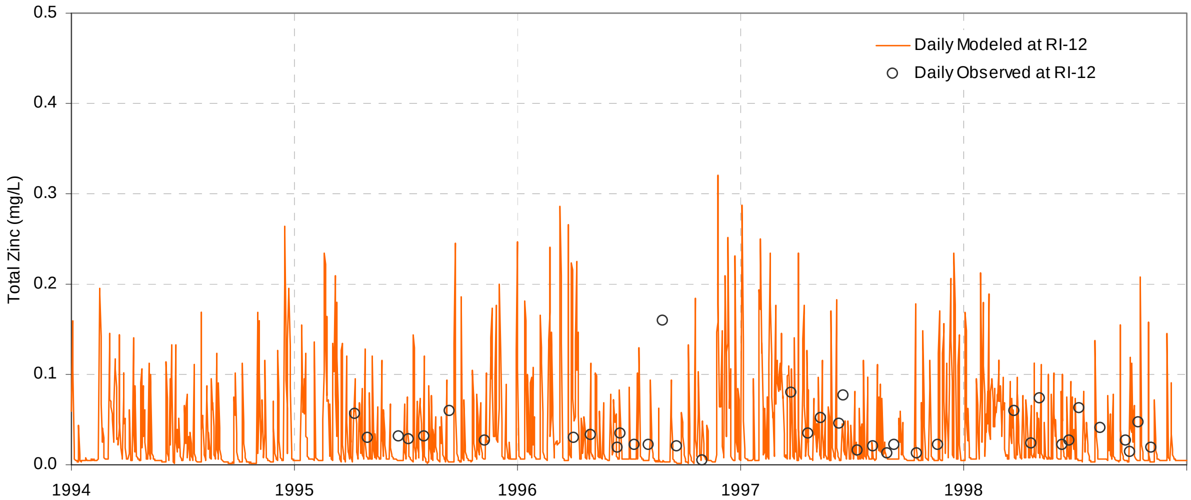


Figure 56. Total Zinc simulation for calibration period at Kinnickinnic River RI-12.

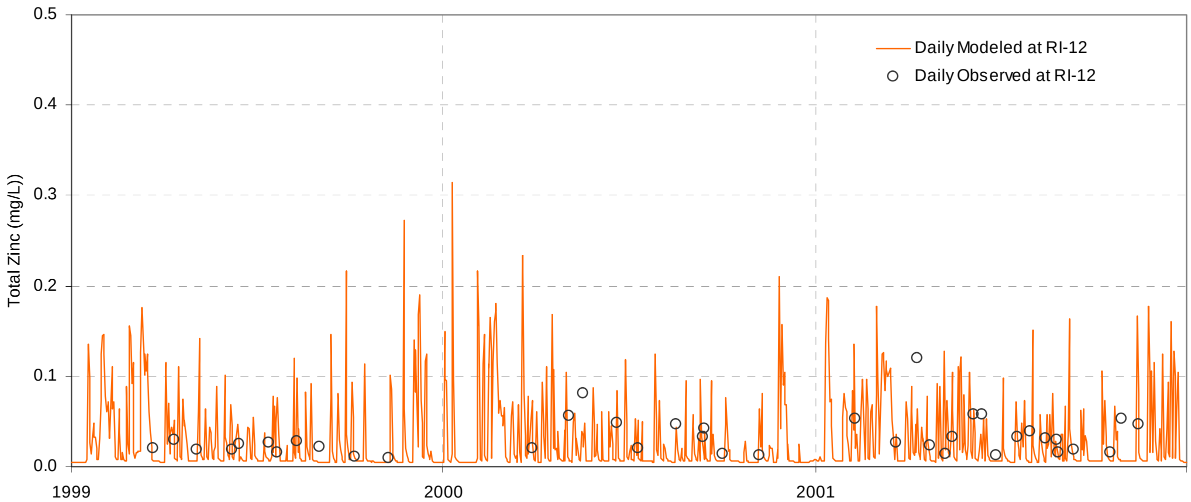


Figure 57. Total Zinc simulation for validation period at Kinnickinnic River RI-12.

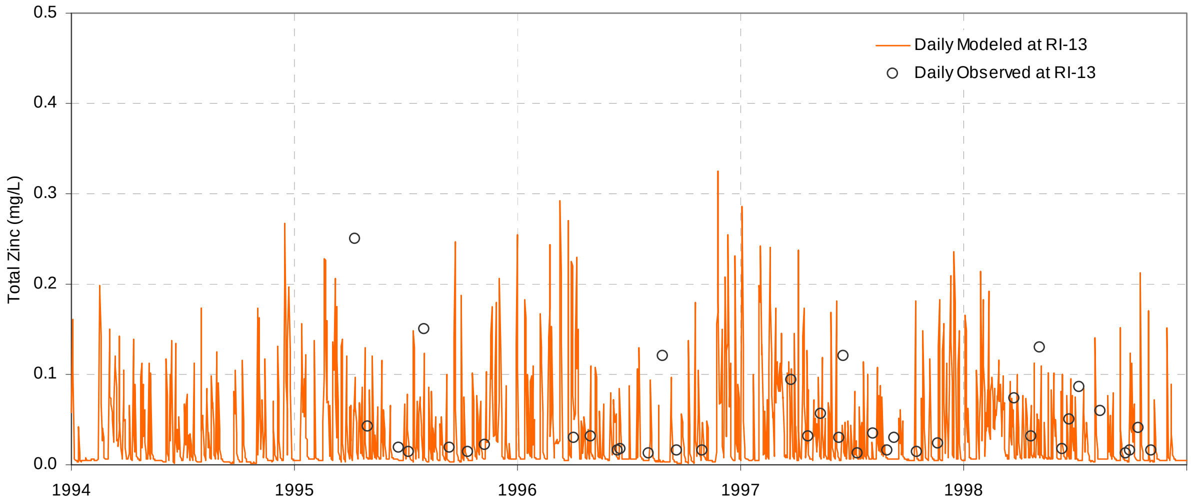


Figure 58. Total Zinc simulation for calibration period at Kinnickinnic River RI-13.

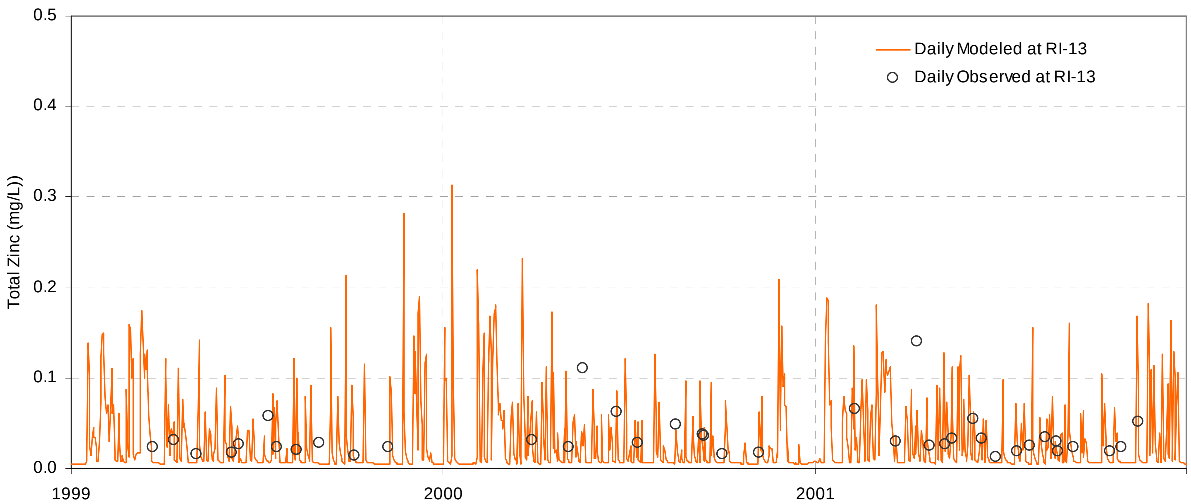


Figure 59. Total Zinc simulation for validation period at Kinnickinnic River RI-13.

5.13 Statistical Assessment of Concentrations

An ideal simulation model would conclusively prove its credibility by matching exactly every observed data point. Unfortunately, this ideal cannot be achieved, for a variety of reasons. In the first place, any watershed model is a simplification of complex natural processes. Secondly, the model is capable of representing only those events that are specified to it in the forcing functions, which generally represent the response from the land surface of hydrologic events. Events that are unknown to the model, such as illicit discharges, cannot be replicated by the model. Water quality simulation in particular is constrained to be no better than the quality of the simulation of hydrology, which in turn is limited by the availability of representative meteorological data. For instance, a small error in the representation of the timing or magnitude of a surface washoff event can result in apparently large discrepancies between simulated and observed actual concentrations at a given location and point in time. Finally, the observed values also cannot be considered as fixed and certain.

First, there is analytical uncertainty in reported observations that derives from the inherent imprecision of analytical techniques, and, occasionally, from laboratory analysis and reporting errors. Perhaps more importantly, grab samples submitted for chemical analysis represent a specific location and point in time that is not entirely consistent with the spatial and temporal support of the model. LSPC represents waterbodies as discrete reaches, which are assumed to be fully mixed. Real waterbodies vary continuously in both longitudinal and lateral dimensions, as well as in time. A sample taken from a specific location may not be representative of the average concentration across the stream cross section, and even less representative of the average across an entire model reach. Further, a sample taken at a discrete point in time may not be representative of the average concentration that would be observed across a modeling time step – particularly when the sample is taken near a source of discharge or during the course of a runoff event.

Several additional explanations as to why the quality of model fit may differ between simulated and observed data include the following:

- Observed data for calibration and/or validation periods could be inadequate in terms of representing an adequate range in flow conditions during dry-weather and wet-weather events.
- Point sources included in the model generally do not account for temporal changes and may differ between the calibration and validation periods.
- As pointed out previously, in the case of chlorophyll-a concentrations, there may be some inherent physiological processes not accounted for in the model that may be causing the discrepancy between actual versus calibrated and calibrated versus validated comparisons.

For these reasons, it is important to evaluate model performance based on statistical criteria. In essence, the model and observations may differ on individual points, but should be in general agreement over larger spans of time and space. This testing is accomplished using a weight of evidence approach. It is first important to realize that the model uses a single set of parameters, by land use, across the entire watershed, with minimal local adjustments. Thus, achieving an acceptable fit across multiple stations (with one set of parameters) is a better indication of the validity of the model than any discrepancies at individual stations. Second, the model is developed using a calibration/validation approach, in which the model was developed on one set of observations (1994 to 1998), then tested on a subsequent set of observations (1999 to 2001). Where the quality of model fit differs between the calibration and validation periods this may indicate either that the apparent discrepancy is due to random variability or that the discrepancy arises from temporal changes in land use and discharges, which are not included in the model.

Statistical tests are applied to both concentrations and estimated loads. Both comparisons are important, and reveal different features of the model. For instance, a simulation that is problematic with regard to concentrations but provides a good estimate of loads can be judged as providing a good representation of pollutant source loading that is corrupted by a sub-optimal representation of the timing of their delivery.

The primary test for model performance on concentrations is a Student's *t*-test of equality of means on paired observed and simulated daily data over the entire calibration or validation period. (There are not sufficient data to adequately evaluate performance on individual seasons or years, particularly given the presence of analytical and sampling uncertainty.) In these tests, the equality of observed and sample means on paired daily average data is taken as the null hypothesis or a rebuttable proposition. That is, model performance is judged acceptable unless the statistical analysis proves otherwise.

The *t*-test is developed on assumptions that samples are drawn from a normal distribution and the variances are equal across distributions. Both of these assumptions are not met for various observed and simulated parameters in the Kinnickinnic River. However, the tests presented here are on means, not individual observations, and the distribution of means converges to a normal distribution under the Central Limit Theorem. Further, Box et al. (1978) have shown that the *t*-test on means is robust against violations of the assumptions of normality and equality of variances.

Tests for equality of means, at each station, for the calibration and validation periods are presented in Tables 1 and 2. A probability value ("pval") for each contrast is presented, with higher probability values indicating a better quality of fit. A probability value less than 5 percent is judged to represent proof of a discrepancy between the model and data – although it does not reveal to what extent the discrepancy is the result of the model and to what extent it is a result of the data. Also note that this test does not address whether the difference, even if statistically significant, is meaningful in terms of environmental impact. As noted above, the statistical comparison of observed DO to daily average predicted DO is not meaningful because the majority of samples were collected in the early afternoon, when algal DO production is likely to be at its maximum.

Across multiple parameters and stations, the model meets the *t*-test criteria in a majority of cases for both the calibration and validation periods. The quality of model fit is further buttressed by a good agreement between simulated and estimated loads. An additional evaluation of the model quality of fit for individual observations was conducted by plotting observations against simulated results with confidence bounds that represent one and two standard deviations for the day. The standard deviations are calculated on a daily basis from the sub-daily model output. The confidence limits are assumed to be either normally or lognormally distributed based on the distribution which most reduces skew (in most cases, log transformation reduces skew as is common for environmental data that are constrained to be greater than or equal to zero and contain sporadic high values associated with washoff events). Comparison can be made both visually and by tabulating the number of observations that fall within one and two-standard deviation confidence limits. These results are provided in Attachment C and summarized in Table 3

There are parameter-location contrasts for which the model-data comparison does not pass the statistical criterion. Where both the inequality and the direction of deviation is consistently shown in both the calibration and validation tests, there may be a need for additional investigation and potential model improvement (unless the unrepresentativeness is due to the sampling location not being a good indicator of conditions in the model reach as a whole). On sum, however, the model is believed to provide a reasonable representation of water quality processes in the Kinnickinnic River that is suitable for the evaluation and comparison of management scenarios.

Table 1. Kinnickinnic River Concentration Calibration Statistics (1994-1998).

	RI-12	RI-13
BOD5 (mg/L)		
Sample Size	66	64
Observed Mean	4.090	4.036
Observed Standard Deviation	2.707	2.710
Simulated Mean	3.711	3.604
Simulated Standard Deviation	1.418	1.454
RMSE	2.541	2.573
Paired t-test (pval)	0.228	0.182
Fail t-test?	No	No
Chlorophyll a (mg/L)		
Sample Size	66	64
Observed Mean	7.569	14.983
Observed Standard Deviation	10.785	45.977
Simulated Mean	8.266	7.943
Simulated Standard Deviation	3.837	3.963
RMSE	11.386	46.813
Paired t-test (pval)	0.623	0.231
Fail t-test?	No	No
Dissolved Oxygen (mg/L)		
Sample Size	65	63
Observed Mean	12.547	13.860
Observed Standard Deviation	3.111	3.732
Simulated Mean	10.210	10.289
Simulated Standard Deviation	1.794	1.845
RMSE	4.380	5.272
Paired t-test (pval)	0.000	0.000
Fail t-test?	Yes	Yes
Total Nitrogen (mg/L)		
Sample Size	63	62
Observed Mean	2.020	1.821
Observed Standard Deviation	1.843	1.819
Simulated Mean	2.107	2.035
Simulated Standard Deviation	0.458	0.445
RMSE	1.902	1.892
Paired t-test (pval)	0.720	0.377
Fail t-test?	No	No

Table 1. Kinnickinnic River Concentration Calibration Statistics (1994-1998). (continued)

	RI-12	RI-13
Total Phosphorus (mg/L)		
Sample Size	67	65
Observed Mean	0.131	0.098
Observed Standard Deviation	0.174	0.091
Simulated Mean	0.172	0.162
Simulated Standard Deviation	0.061	0.059
RMSE	0.196	0.125
Paired t-test (pval)	0.084	0.000
Fail t-test?	No	Yes
Total Suspended Solids (mg/l)		
Sample Size	67	65
Observed Mean	36.931	19.809
Observed Standard Deviation	154.283	50.416
Simulated Mean	20.453	17.796
Simulated Standard Deviation	31.381	26.204
RMSE	150.609	45.931
Paired t-test (pval)	0.374	0.727
Fail t-test?	No	No
NO2+NO3 (mg/L)		
Sample Size	67	62
Observed Mean	0.686	0.575
Observed Standard Deviation	0.435	0.498
Simulated Mean	0.739	0.711
Simulated Standard Deviation	0.243	0.238
RMSE	0.546	0.616
Paired t-test (pval)	0.432	0.084
Fail t-test?	No	No
NH3 (mg/L)		
Sample Size	63	58
Observed Mean	0.652	0.439
Observed Standard Deviation	1.381	1.149
Simulated Mean	0.375	0.364
Simulated Standard Deviation	0.145	0.141
RMSE	1.438	1.177
Paired t-test (pval)	0.128	0.632
Fail t-test?	No	No

Table 1. Kinnickinnic River Concentration Calibration Statistics (1994-1998). (continued)

	RI-12	RI-13
Orthophosphorus (mg/l)		
Sample Size	67	62
Observed Mean	0.071	0.043
Observed Standard Deviation	0.132	0.048
Simulated Mean	0.091	0.083
Simulated Standard Deviation	0.036	0.035
RMSE	0.147	0.077
Paired t-test (pval)	0.290	0.000
Fail t-test?	No	Yes
Fecal Coliform (count/100 mL)		
Sample Size	66	64
Observed Mean	6919.985	5689.172
Observed Standard Deviation	16,299.149	11,728.668
Simulated Mean	3,703.202	3,707.713
Simulated Standard Deviation	6,802.082	6,747.627
RMSE	15,059.592	10,358.140
Paired t-test (pval)	0.083	0.127
Fail t-test?	No	No

Table 2. Kinnickinnic River Concentration Validation Statistics (1999-2001).

	RI-12	RI-13
BOD5 (mg/L)		
Sample Size	51	49
Observed Mean	3.203	3.394
Observed Standard Deviation	2.867	2.737
Simulated Mean	3.526	3.484
Simulated Standard Deviation	1.815	1.819
RMSE	3.093	2.925
Paired t-test (pval)	0.461	0.832
Fail t-test?	No	No
Chlorophyll a (mg/L)		
Sample Size	42	42
Observed Mean	7.912	9.819
Observed Standard Deviation	11.331	9.661
Simulated Mean	6.762	6.367
Simulated Standard Deviation	3.414	3.379
RMSE	11.346	10.081
Paired t-test (pval)	0.518	0.025
Fail t-test?	No	Yes
Dissolved Oxygen (mg/L)		
Sample Size	52	49
Observed Mean	12.474	13.566
Observed Standard Deviation	3.534	3.394
Simulated Mean	10.297	10.406
Simulated Standard Deviation	1.819	1.775
RMSE	4.493	4.848
Paired t-test (pval)	0.000	0.000
Fail t-test?	Yes	Yes
Total Nitrogen (mg/L)		
Sample Size	42	39
Observed Mean	1.448	1.393
Observed Standard Deviation	0.531	0.608
Simulated Mean	1.882	1.819
Simulated Standard Deviation	0.598	0.604
RMSE	0.784	0.896
Paired t-test (pval)	0.000	0.002
Fail t-test?	Yes	Yes

Table 2. Kinnickinnic River Concentration Validation Statistics (1999-2001). (continued)

	RI-12	RI-13
Total Phosphorus (mg/L)		
Sample Size	52	50
Observed Mean	0.137	0.108
Observed Standard Deviation	0.064	0.060
Simulated Mean	0.162	0.154
Simulated Standard Deviation	0.075	0.073
RMSE	0.091	0.088
Paired t-test (pval)	0.042	0.000
Fail t-test?	Yes	Yes
Total Suspended Solids (mg/l)		
Sample Size	52	50
Observed Mean	18.331	19.276
Observed Standard Deviation	22.697	29.948
Simulated Mean	26.760	20.748
Simulated Standard Deviation	29.706	22.775
RMSE	26.207	25.208
Paired t-test (pval)	0.020	0.684
Fail t-test?	Yes	No
NO2+NO3 (mg/L)		
Sample Size	47	43
Observed Mean	0.731	0.672
Observed Standard Deviation	0.426	0.514
Simulated Mean	0.676	0.660
Simulated Standard Deviation	0.334	0.341
RMSE	0.434	0.531
Paired t-test (pval)	0.388	0.878
Fail t-test?	No	No
NH3 (mg/L)		
Sample Size	45	41
Observed Mean	0.162	0.154
Observed Standard Deviation	0.276	0.344
Simulated Mean	0.298	0.287
Simulated Standard Deviation	0.100	0.094
RMSE	0.347	0.401
Paired t-test (pval)	0.007	0.032
Fail t-test?	Yes	Yes

Table 2. Kinnickinnic River Concentration Validation Statistics (1999-2001). (continued)

	RI-12	RI-13
Orthophosphorus (mg/l)		
Sample Size	47	46
Observed Mean	0.060	0.042
Observed Standard Deviation	0.038	0.027
Simulated Mean	0.068	0.064
Simulated Standard Deviation	0.024	0.023
RMSE	0.041	0.039
Paired t-test (pval)	0.179	0.000
Fail t-test?	No	Yes
Fecal Coliform (count/100 mL)		
Sample Size	52	50
Observed Mean	12,962.808	8,012.080
Observed Standard Deviation	34,738.047	15,422.698
Simulated Mean	8,843.172	9,085.856
Simulated Standard Deviation	19,797.227	19,029.477
RMSE	36,505.597	20,996.224
Paired t-test (pval)	0.421	0.722
Fail t-test?	No	No

Table 3. Confidence limit results for Kinnickinnic River water quality calibration and validation.

Station	Parameter	Within 1 Standard Deviation	Within 2 Standard Deviations
RI-12	Total Phosphorus	48%	69%
	Total Nitrogen	50%	83%
	Total Suspended Solids	39%	58%
	Fecal Coliform	35%	58%
RI-13	Total Phosphorus	47%	66%
	Total Nitrogen	42%	74%
	Total Suspended Solids	35%	52%
	Fecal Coliform	39%	54%

5.14 Statistical Assessment of Loads

For the evaluation of impacts on downstream receiving waters, correct model representation of total loads is as important as the representation of concentration. Unfortunately, load is not observed directly. Estimates of observed load on those days with observations can be formed by multiplying concentration by daily average flow. However, because the concentrations represent point-in-time grab samples, these represent highly uncertain estimates of daily load.

Load estimates require both concentration and flow. For the Kinnickinnic River, flow is gaged only at the USGS gage at S. 11th Street (USGS gauge 04087159) (approximately corresponding to water quality station RI-13). Observed load estimates can be calculated for only this station.

Because loads depend on both flow and concentration, it is unreasonable to expect that all observed and simulated data points will match closely. That is, apparent discrepancies will arise due to any errors in the timing or magnitude of flows, in addition to the uncertainty introduced by point-in-time concentration observations. However, the mean loads on paired observations should be in general agreement between the model and predictions. In addition, the relationship between load and flow should be similar.

Equality of observed and simulated mean concentrations is evaluated using a paired *t*-test. Results, with probability values (pvals) are shown in Table 4 and Table 5. As shown in the tables, the agreement between the model and estimated observed loads is in general good.

Table 4. Kinnickinnic River Load Calibration Statistics (1994-1998).

	RI-13
Total Nitrogen (lb/d)	
Sample Size	62
Observed Mean	335.417
Simulated Mean	269.664
RMSE	418.468
Paired t-test (pval)	0.219
Fail t-test?	No
Total Phosphorus (lb/d)	
Sample Size	65
Observed Mean	26.491
Simulated Mean	27.567
RMSE	47.406
Paired t-test (pval)	0.856
Fail t-test?	No
NO2+NO3 (lb/d)	
Sample Size	62
Observed Mean	121.532
Simulated Mean	86.968
RMSE	195.235
Paired t-test (pval)	0.165
Fail t-test?	No
Total Suspended Solids (lb/d)	
Sample Size	65
Observed Mean	10,660.846
Simulated Mean	7,993.640
RMSE	37,103.840
Paired t-test (pval)	0.566
Fail t-test?	No

Table 5. Kinnickinnic River Load Validation Statistics (1999-2001)

	RI-13
Total Nitrogen (lb/d)	
Sample Size	39
Observed Mean	753.974
Simulated Mean	684.258
RMSE	1,253.444
Paired t-test (pval)	0.733
Fail t-test?	No
Total Phosphorus (lb/d)	
Sample Size	50
Observed Mean	73.972
Simulated Mean	82.160
RMSE	66.509
Paired t-test (pval)	0.389
Fail t-test?	No
NO2+NO3 (lb/d)	
Sample Size	43
Observed Mean	321.723
Simulated Mean	252.518
RMSE	517.896
Paired t-test (pval)	0.387
Fail t-test?	No
Total Suspended Solids (lb/d)	
Sample Size	50
Observed Mean	27,569.011
Simulated Mean	16,102.656
RMSE	79,370.944
Paired t-test (pval)	0.312
Fail t-test?	No

5.15 Load-Flow Relationships

An additional test of the pollutant load calibration is provided by developing log-log transport plots. These can be estimated only at RI-13, where flow gaging is available, and are shown in the following figures. The observed load:flow relationships (Figure 60 to Figure 63) overlies the simulated load:flow relationship except at lower flows, which is believed to be due to point source load estimates.

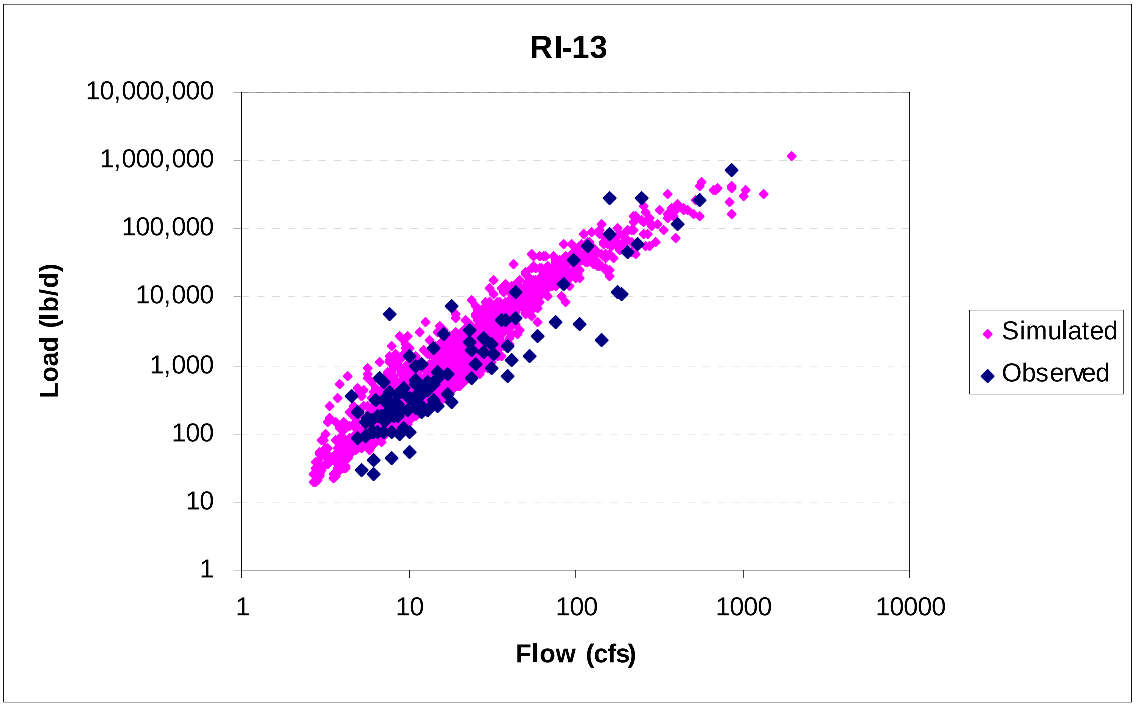


Figure 60. Log-log transport plot of sediment load at Kinnickinnic River RI-13, 1994-2001.

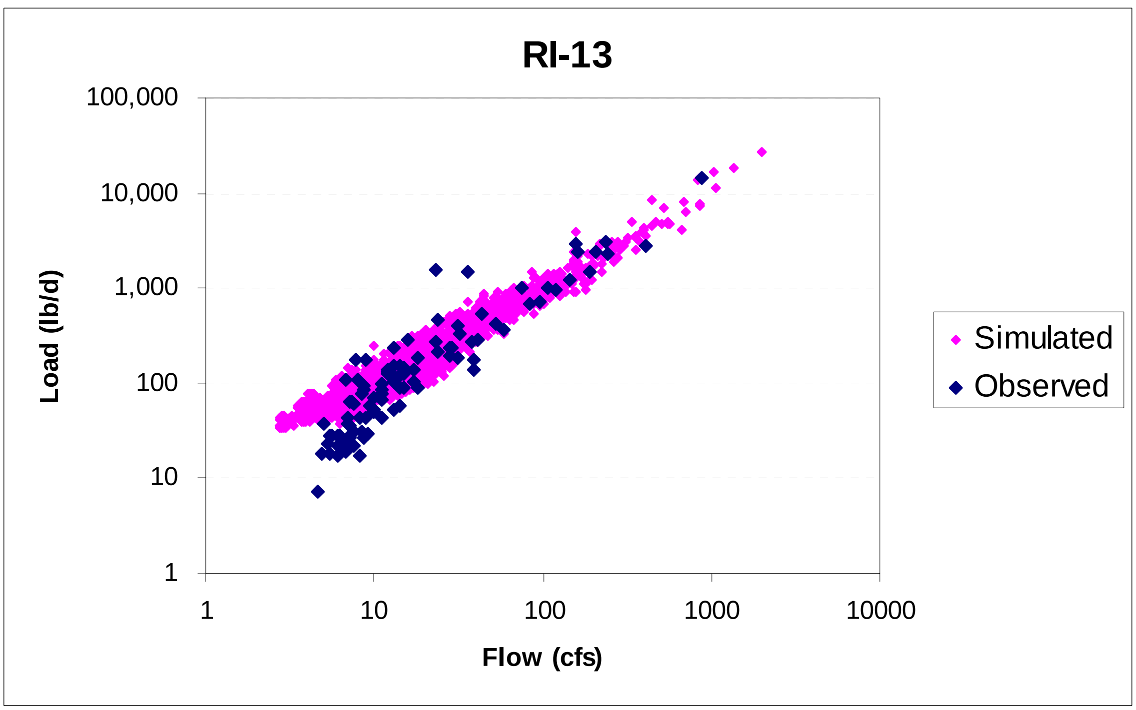


Figure 61. Transport Plots for Total Nitrogen, 1994-2001.

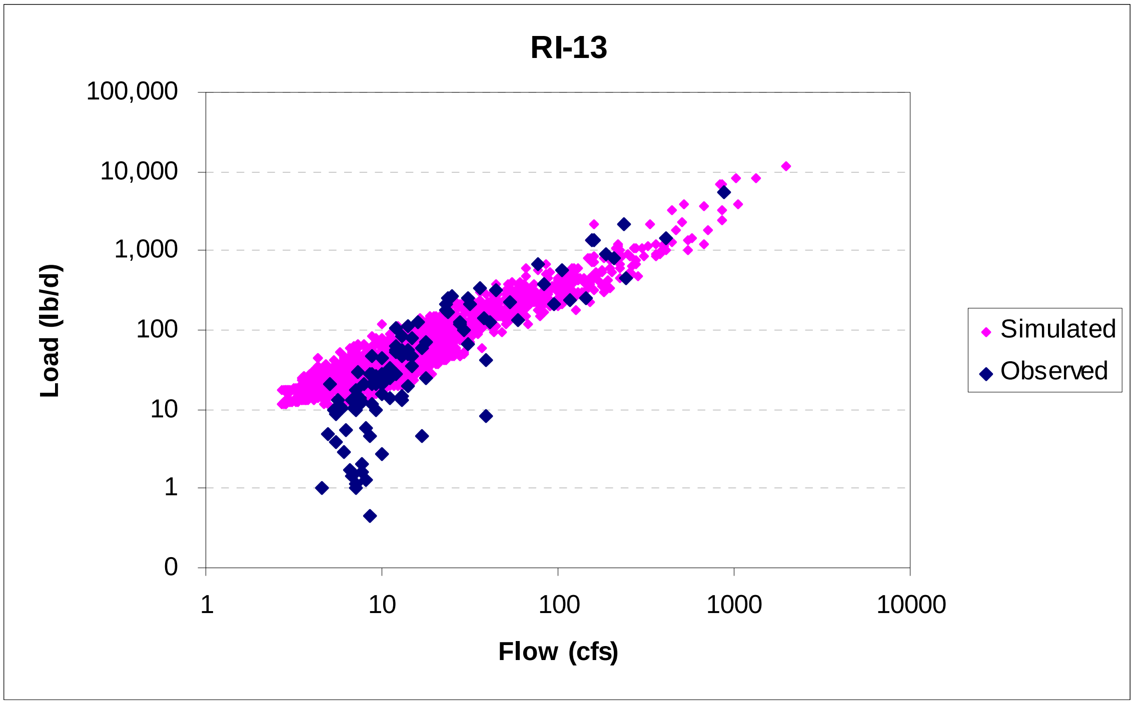


Figure 62. Transport Plots for Nitrite + Nitrate Nitrogen, 1994-2001.

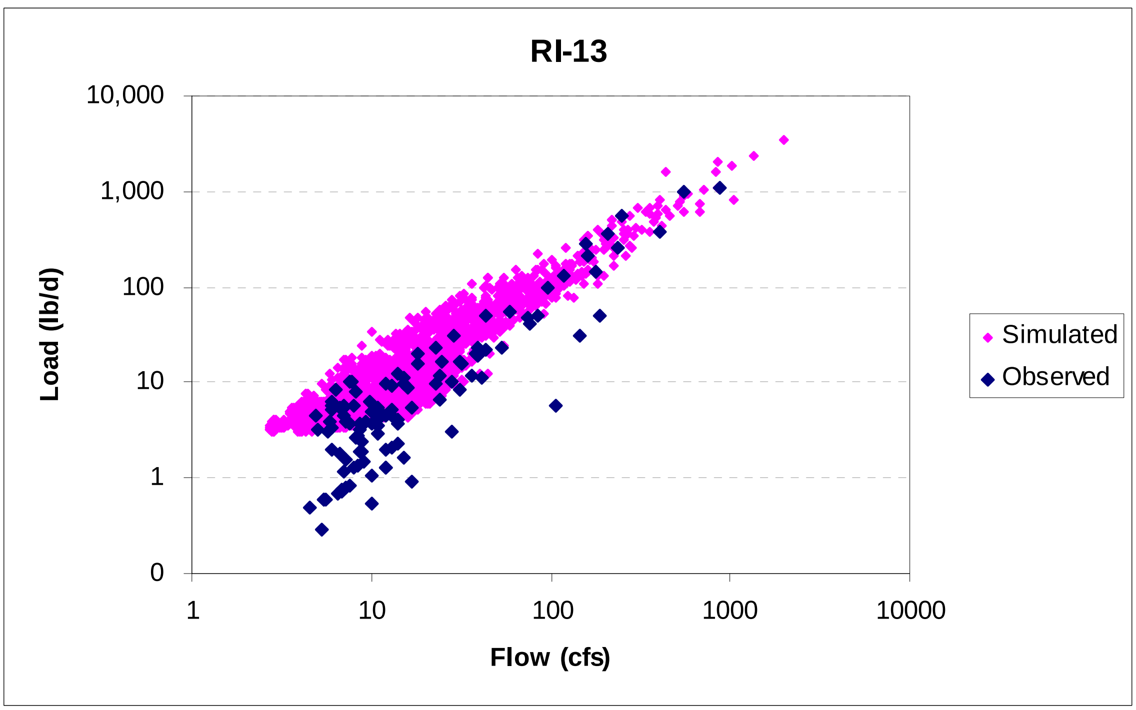


Figure 63. Transport Plots for Total Phosphorus, 1994-2001

Another useful test of representation of the load-flow relationships is obtained by plotting simulated and observed loads against the probability of exceedance of a given flow value, based on the period of record at the gage. These are known as load-duration curves. As a general rule, the portion of this relationship corresponding to flows that are exceeded less than 20 percent of the time can be assumed to represent high-flow, washoff events, while the remainder of the relationship corresponds to moderate and low flows.

The untransformed load-duration curve relationship is highly nonlinear. These plots can be linearized by plotting the natural logarithm of load versus the logit of flow, where the logit is defined as the natural log of (P/(1-P)), given P is the flow exceedance probability (Pindyck and Rubinfeld, 1981). After the loglogit transformation, separate linear regressions can be performed on the natural logarithms of observed and simulated loads versus logit of flow for the 0-20 percent and 20-100 percent flow ranges. (The breakpoint between these ranges corresponds to a logit of –1.386.) When the model is simulating accurately, the slope coefficients of the observed and simulated regressions should be in agreement within each of the two flow ranges based on visual comparison of 95-percent confidence intervals about the slope estimates. The analysis shows that this test is generally met in the Kinnickinnic River model. Full results are provided in Attachment B.

6.0 REFERENCES

APHA. 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed. American Public Health Association (APHA), 1015 15th Street, NW, Washington, DC.

Bicknell, B.R., J.C. Imhoff, J. Kittle, A.S. Donigian, and R.C. Johansen. 1996. *Hydrological Simulation Program !FORTRAN, User's Manual for Release H*. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Bowie, G.L., et al. 1985. Rates, Constants, and Kinetic Formulations in Surface Water Quality Modeling, 2d. ed. EPA/600/3-85/040. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Box, G.E.P., J.S. Hunter and W.G. Hunter. 1978. *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building.* John Wiley and Sons, New York.

Chapra, S. and G. Pelletier. 2003. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

Donigian, A.S., Jr., and J.T. Love. 2002. Sediment Calibration Procedures and Guidelines for Watershed Modeling. Aqua Terra Consultants, Mountain View, CA.

Donigian, A.S., Jr., J.C. Imhoff, B.R. Bicknell, and J.L. Kittle, Jr. 1984. Application Guide for Hydrological Simulation Program – FORTRAN (HSPF). EPA-600/3-84-065. Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Ehlinger, T.J., C.D. Sandgren, and L.S. DeThorne. 2003. Monitoring of Stream Habitat & Aquatic Biotic Integrity, Lincoln Creek, Milwaukee County, Wisconsin. Submitted to Great Lakes Protection Fund and Milwaukee Metropolitan Sewerage District. Department of Biological Sciences, University of Wisconsin – Milwaukee.

Haith, D.A. and D.E. Merrill. 1987. Evaluation of a daily rainfall erosivity model. *Trans. Amer. Soc. Agric. Eng.*, 28(6): 1916-1920.

Haith, D.A., R. Mandel, and R.S. Wu. 1992. *GWLF - Generalized watershed loading functions, Version 2.0 - User's manual*. Department of Agricultural Engineering, Cornell University, Ithaca, NY.

Hartigan, J.P., T.F. Quasebarth, and E. Southerland. 1983. Calibration of NPS model loading factors. *Journal of Environmental Engineering*, 109(6): 1259-1272.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. *Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage*, 89(IR4): 15-41.

Jensen, M.E., D.C.N. Rob, and C.E. Franzoy. 1969. Scheduling irrigations using climate-crop-soil data. Proceedings, National Conference on Water Resources Engineering of the American Society of Civil Engineers, New Orleans, LA.

Mancini, J.L. 1978. Numerical estimates of coliform mortality rates under various conditions. *J. Water Poll. Contr. Fed.*, 50(11): 2477-2484.

MPCA. 2001. Status of a Model Simulation of Nonpoint-Source Contamination in the Minnesota River Basin, April 1999. Final report submitted by the USGS to Minnesota Pollution Control Agency.

Pindyck, R.S. and D.L. Rubinfeld. 1981. *Econometric Models and Economic Forecasts, Second Edition.* McGraw-Hill, New York.

Richardson, C.W., G.R. Foster, and D.A. Wright. 1983. Estimation of erosion index from daily rainfall amount. *Trans. Am. Soc. Agric. Eng*., 26(1): 153-157, 160.

Tetra Tech, Inc. and CH2M HILL. 1999. Gwinnett County Watershed Assessment and Modeling Study, Watershed Model Calibration Technical Memorandum. Prepared for Gwinnett County, GA by Tetra Tech, Inc., Research Triangle Park, NC.

Tetra Tech. 2002. Minnesota River Basin Model, Model Calibration and Validation Report. Prepared for Minnesota Pollution Control Agency, St. Paul, MN by Tetra Tech, Inc., Research Triangle Park, NC.

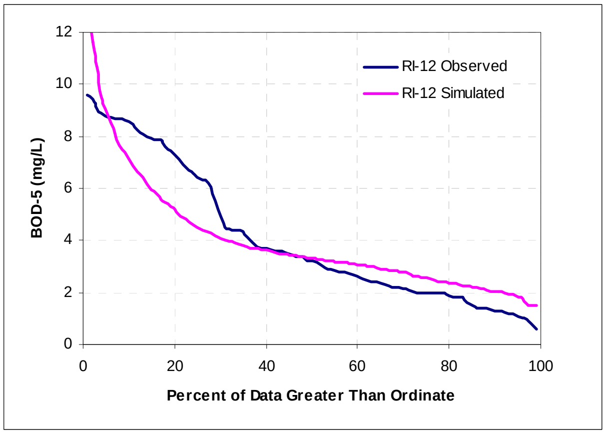
Thomann*n,* R.V. and J.A. Mueller. 1987*.* Principles of Surface Water Quality Modeling and Control. Harper & Row, New York.

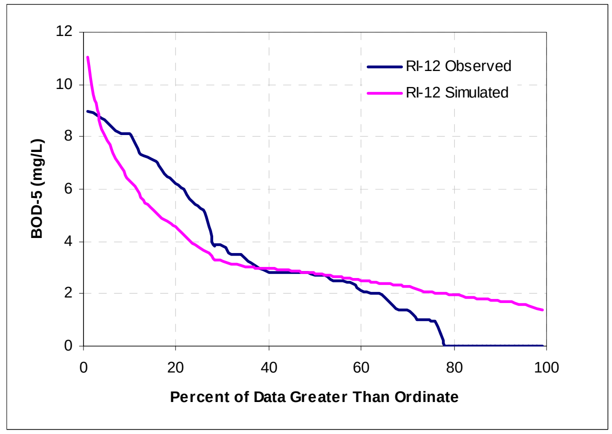
U.S. Environmental Protection Agency (USEPA). 2000. *BASINS Technical Note 6. Estimating Hydrology and Hydraulic Parameters for HSPF*. EPA-823-R00-012. U.S. Environmental Protection Agency. Office of Water. July 2000.

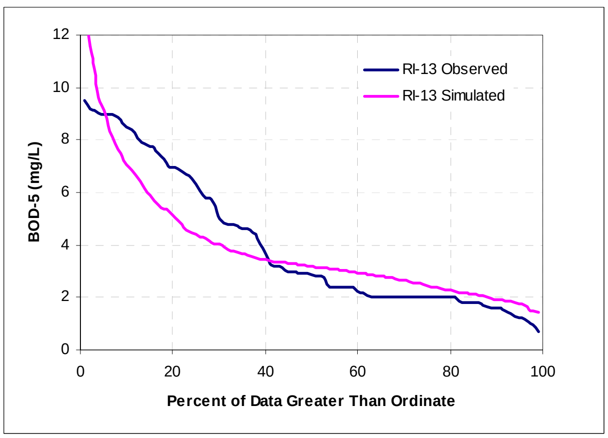
ATTACHMENT A – CONCENTRATION EXCEEDANCE CURVE PLOTS

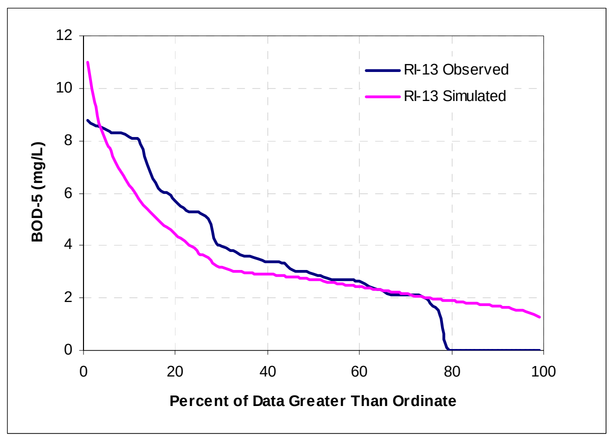
BOD5 Calibration Exceedance Plots

BOD5 Validation Exceedance Plots

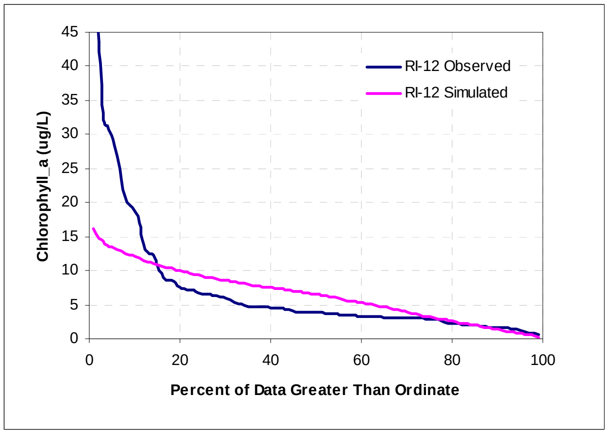


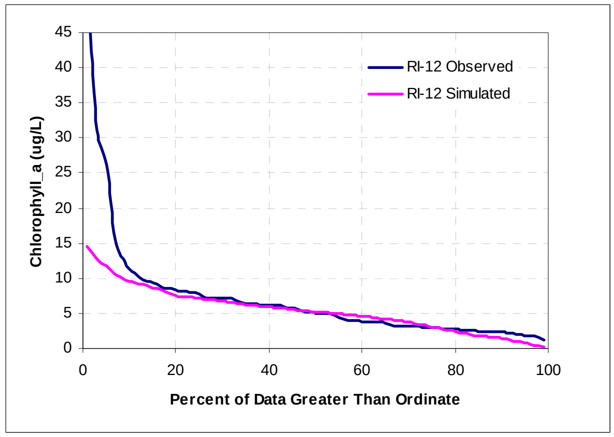


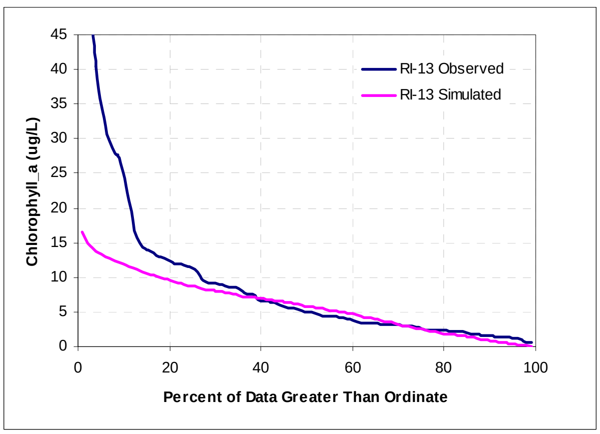


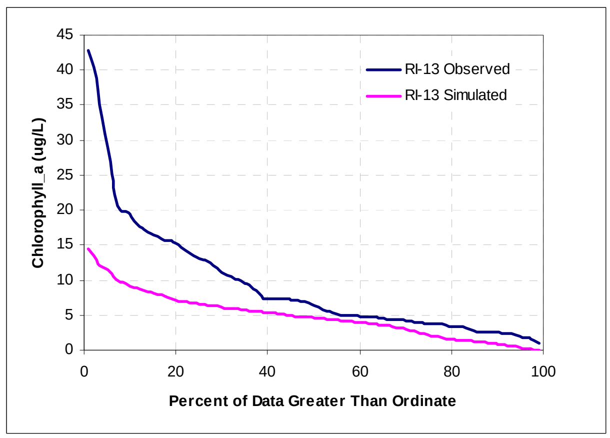


CHLA Calibration Exceedance Plots **CHLA Validation Exceedance Plots**

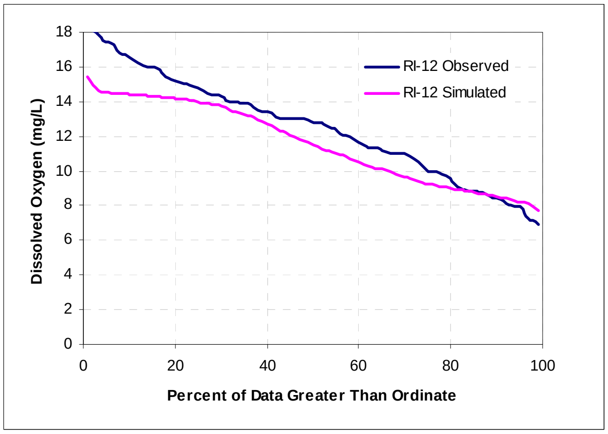


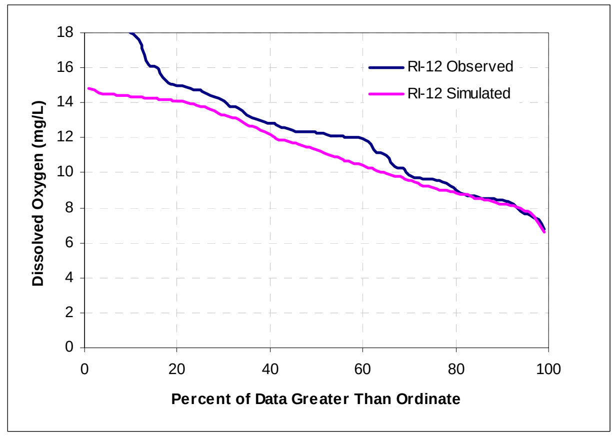


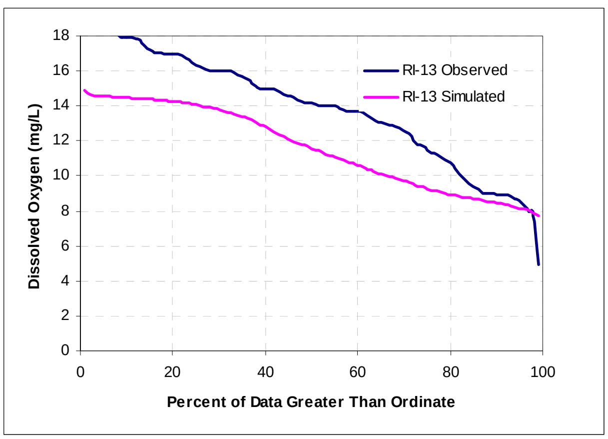


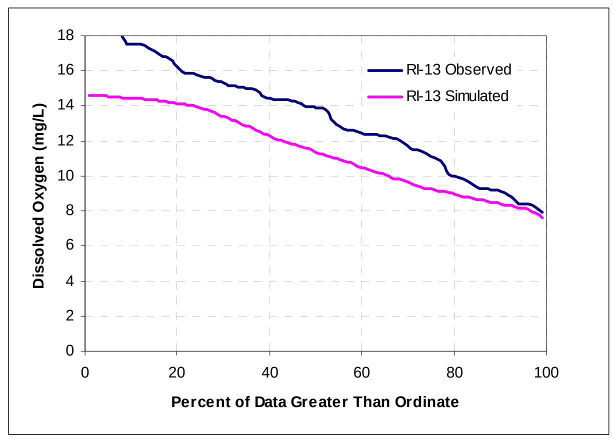


DOX Calibration Exceedance Plots **DOX Validation Exceedance Plots**

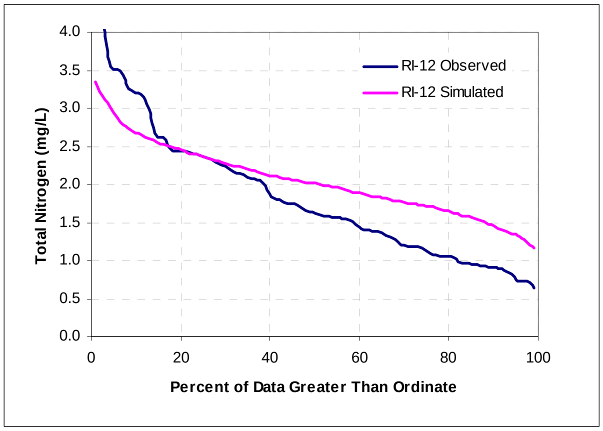


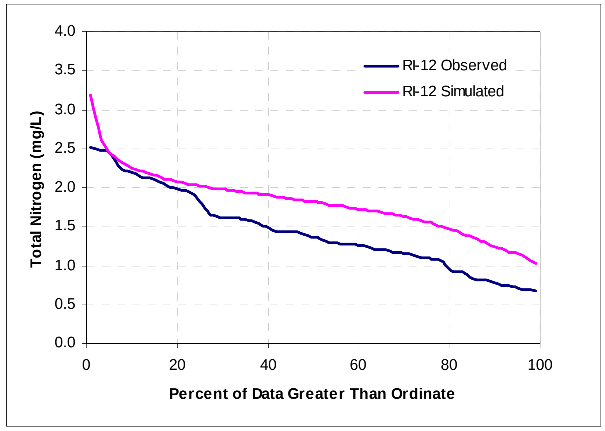


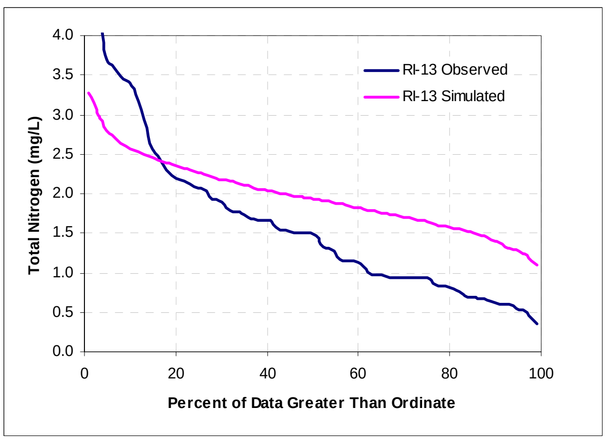


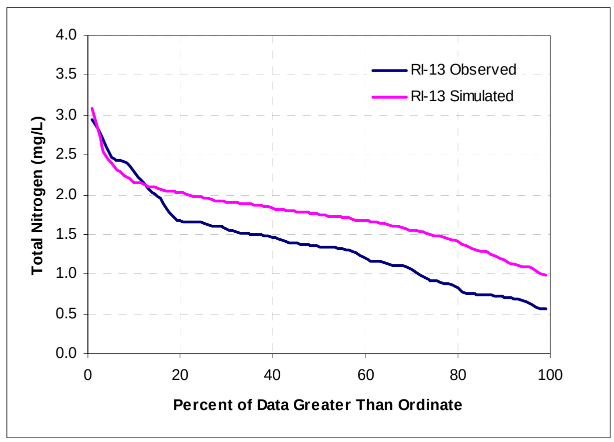


TOTN Calibration Exceedance Plots **TOTN Validation Exceedance Plots**



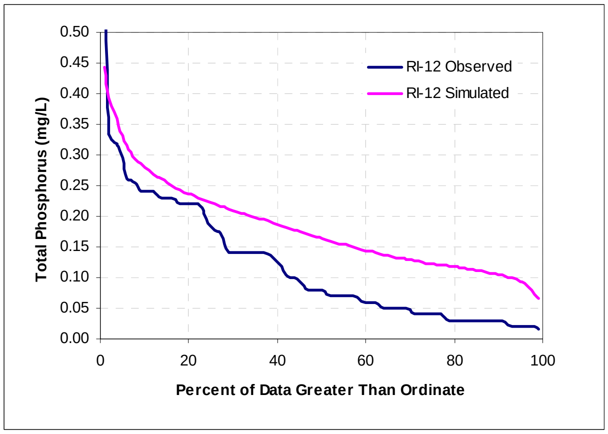


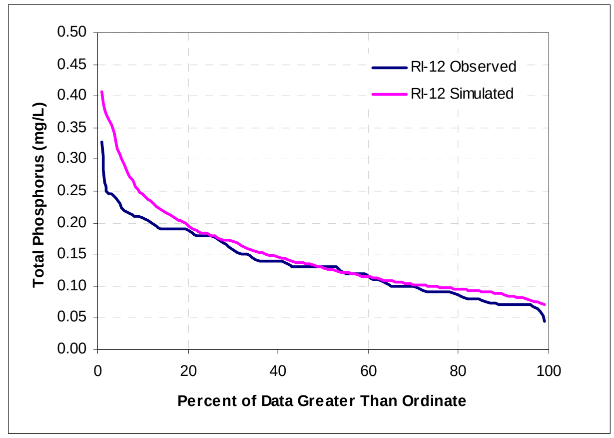


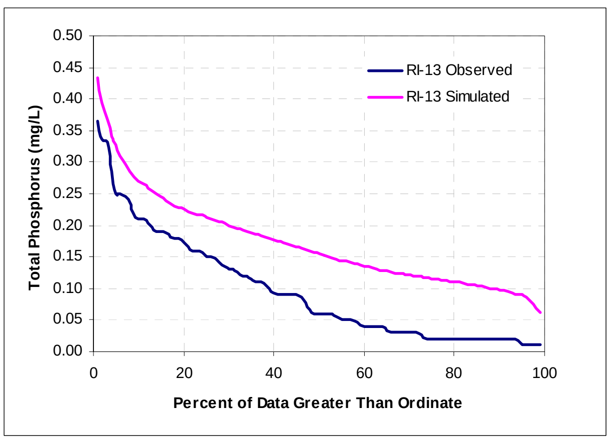


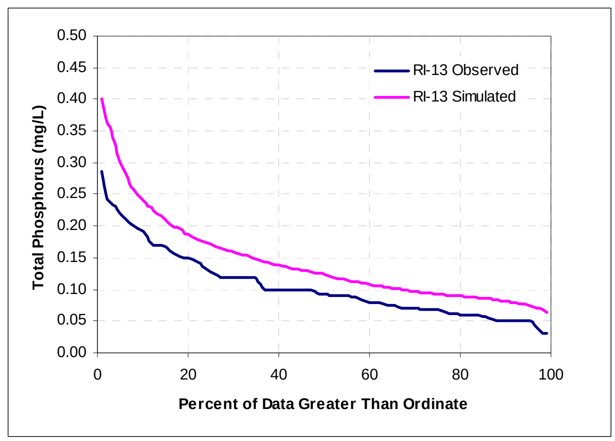
TOTP Calibration Exceedance Plots

TOTP Validation Exceedance Plots



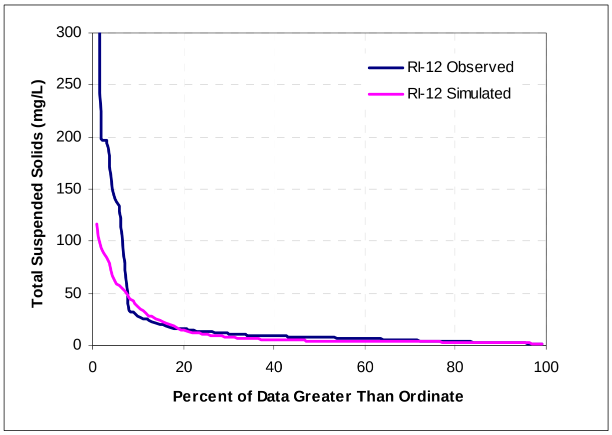


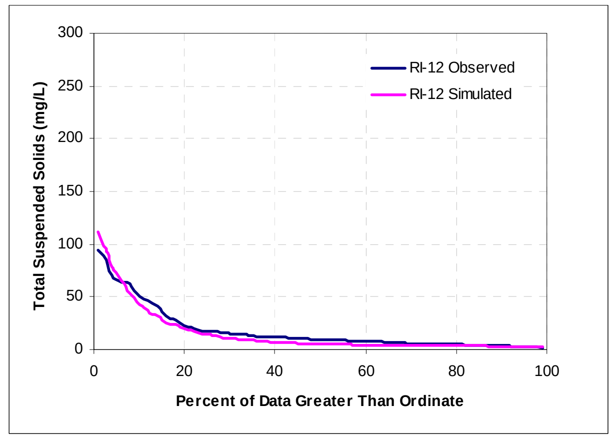


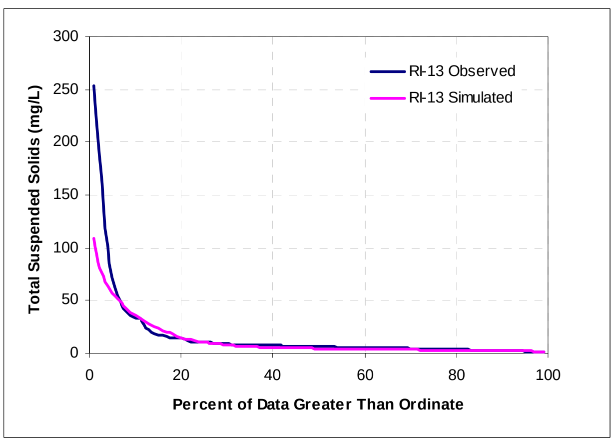


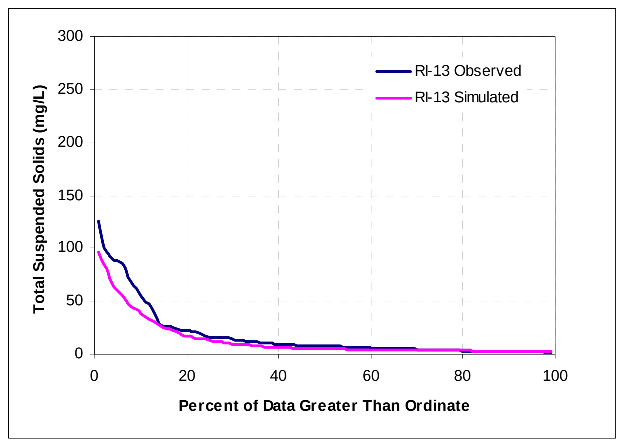
TSS Calibration Exceedance Plots

TSS Validation Exceedance Plots

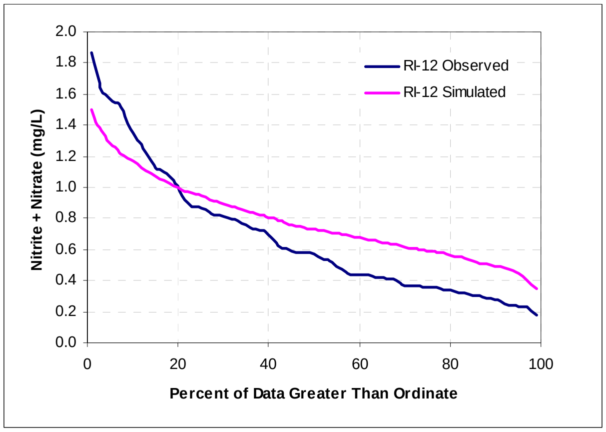


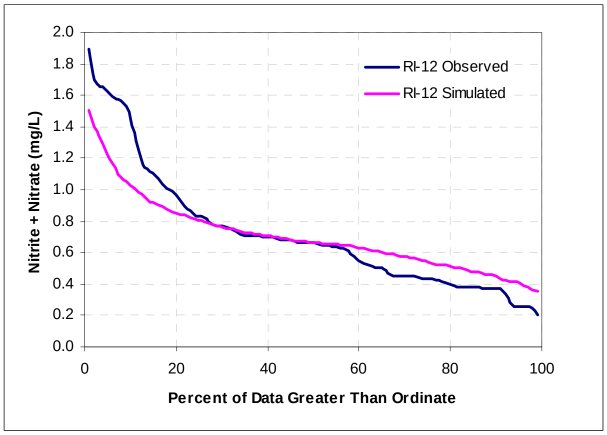


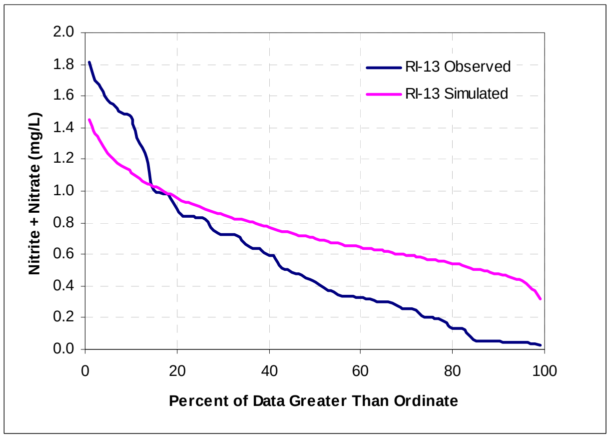


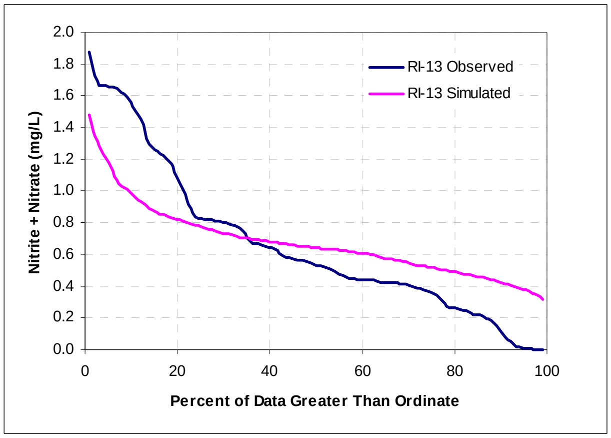


NO23 Calibration Exceedance Plots **NO23 Validation Exceedance Plots**



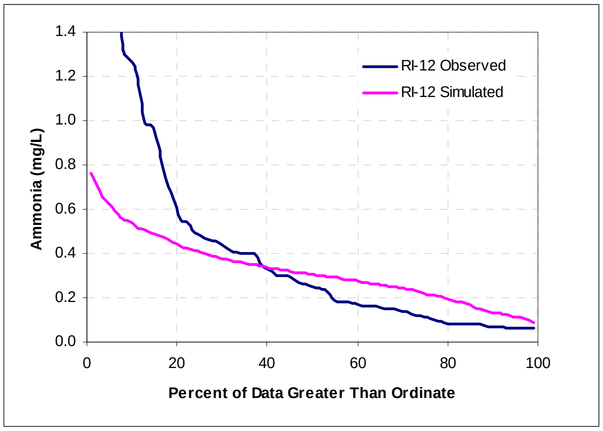


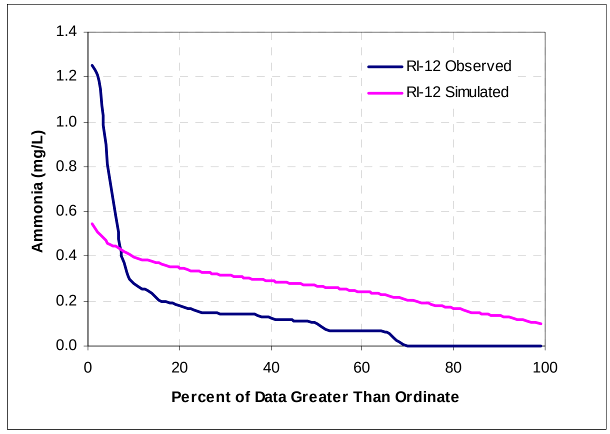


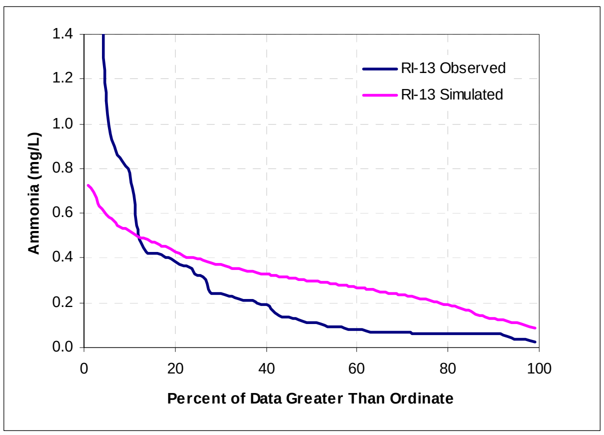


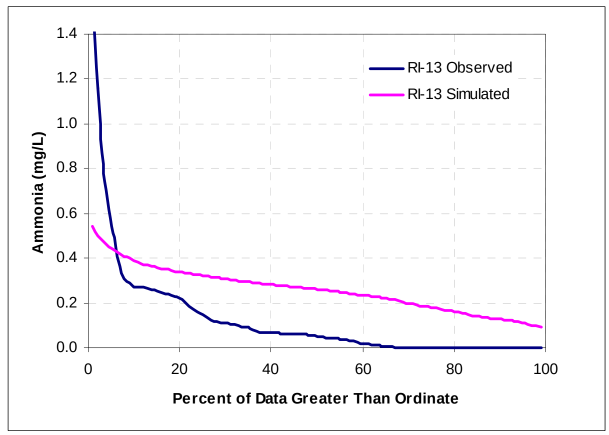
NH3 Calibration Exceedance Plots

NH3 Validation Exceedance Plots



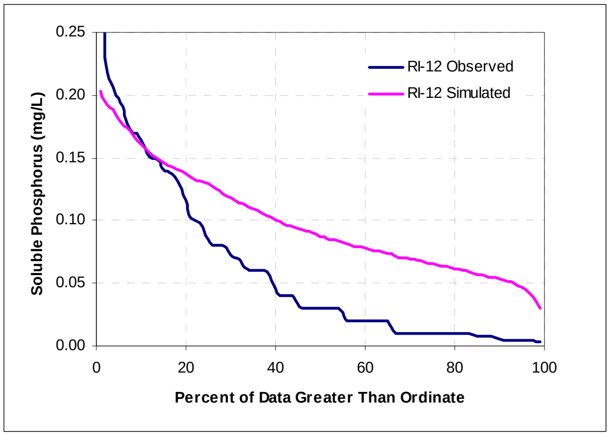


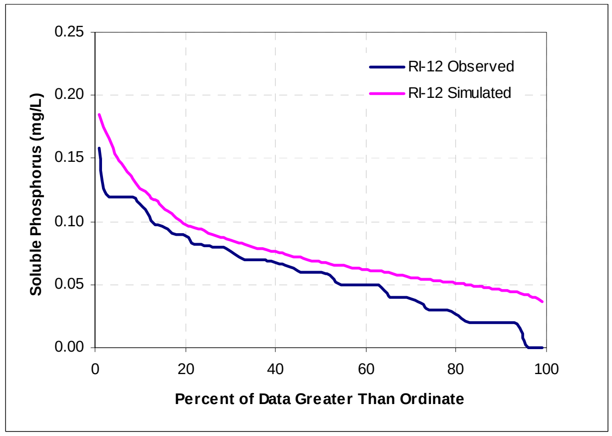


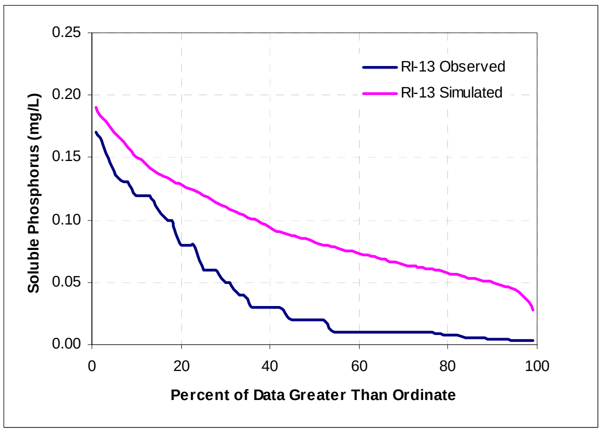


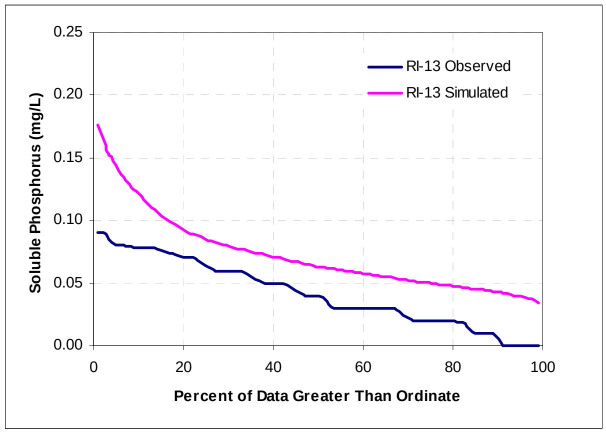
PORTH Calibration Exceedance Plots

PORTH Validation Exceedance Plots



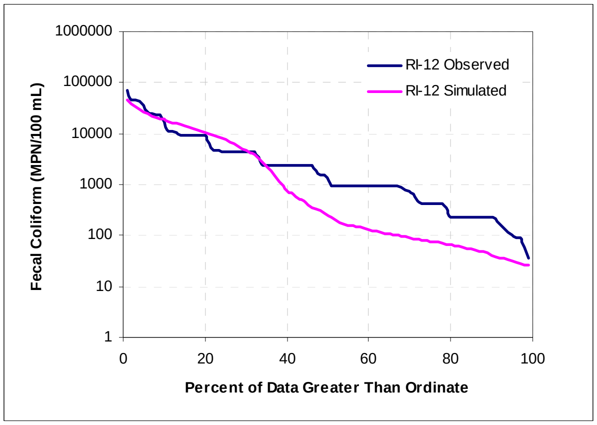


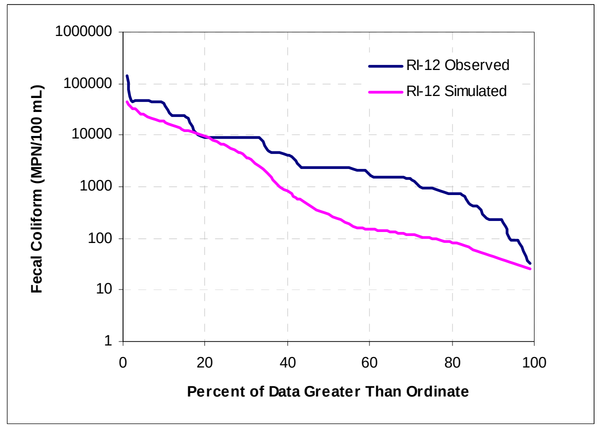


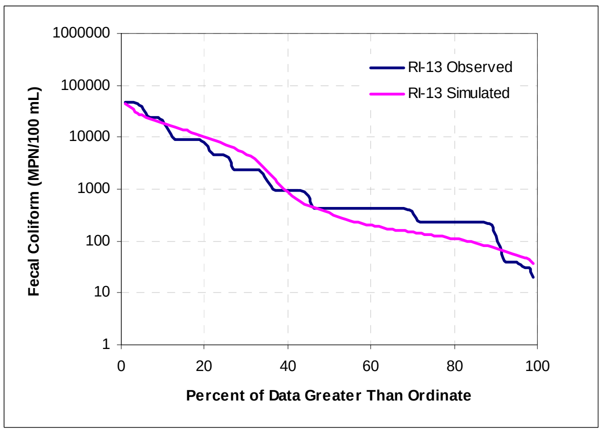


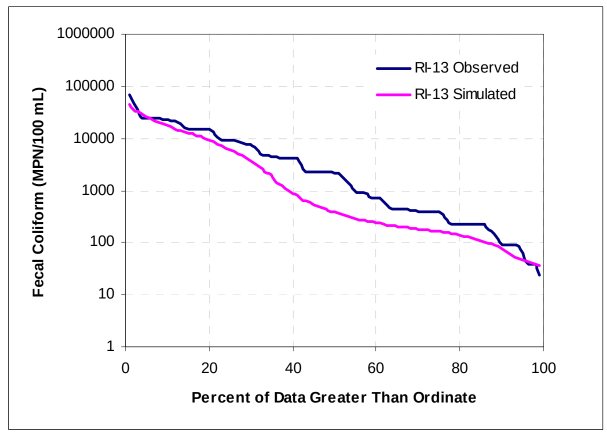
FCOL Calibration Exceedance Plots

FCOL Validation Exceedance Plots

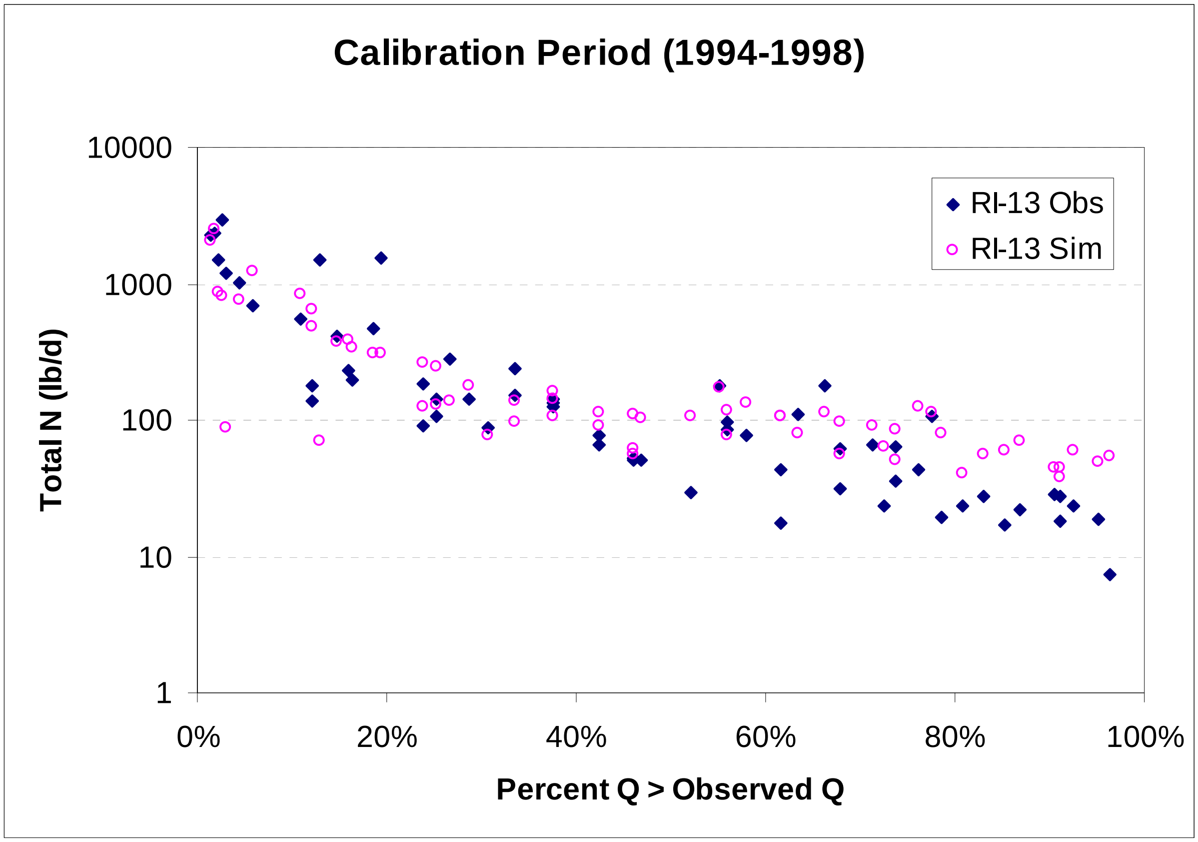


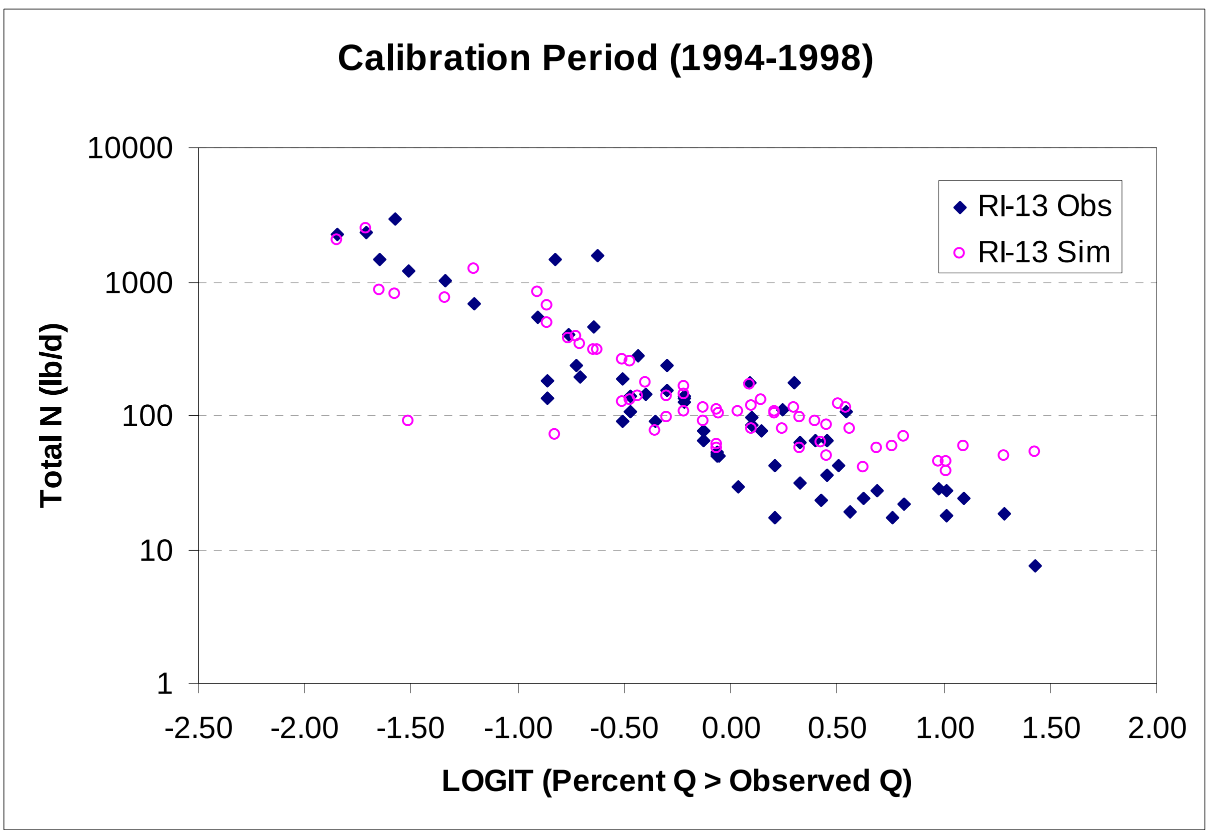






ATTACHMENT B – LOAD-DURATION ANALYSIS RESULTS


Calibration Period (1994-1998)
10000
1000
100
10
1
Total N (lb/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-13 Obs
RI-13 Sim


Calibration Period (1994-1998)
10000
1000
100
10
1
Total N (lb/d)
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
RI-13 Obs
RI-13 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.614627	4.787436
0.446942	0.529369
0.482458	0.743518
13.05095	14
2.144787	
0.958595	
-2.573222	
-0.656032	

0-20% - Sim

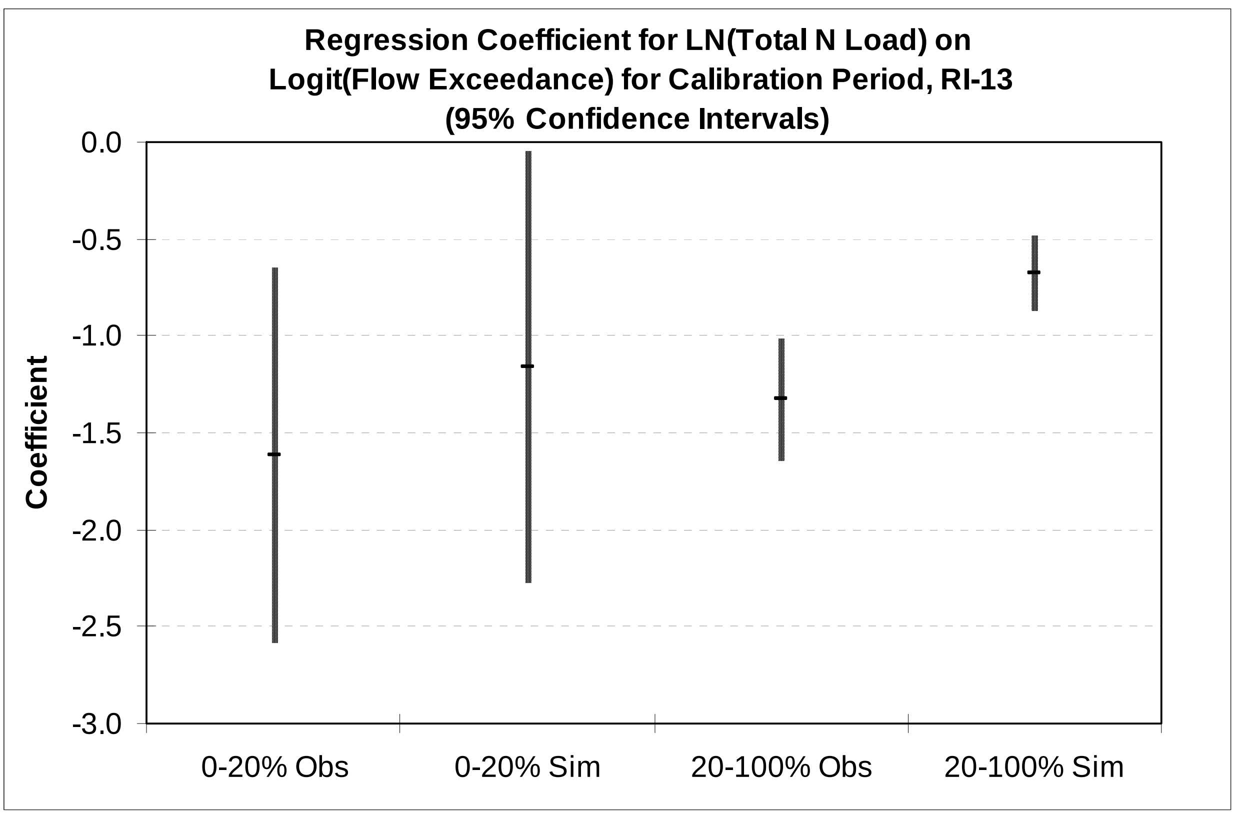
-1.163609	4.96042
0.513459	0.608153
0.268384	0.854174
5.135734	14
2.144787	
1.10126	
-2.264869	
-0.062349	

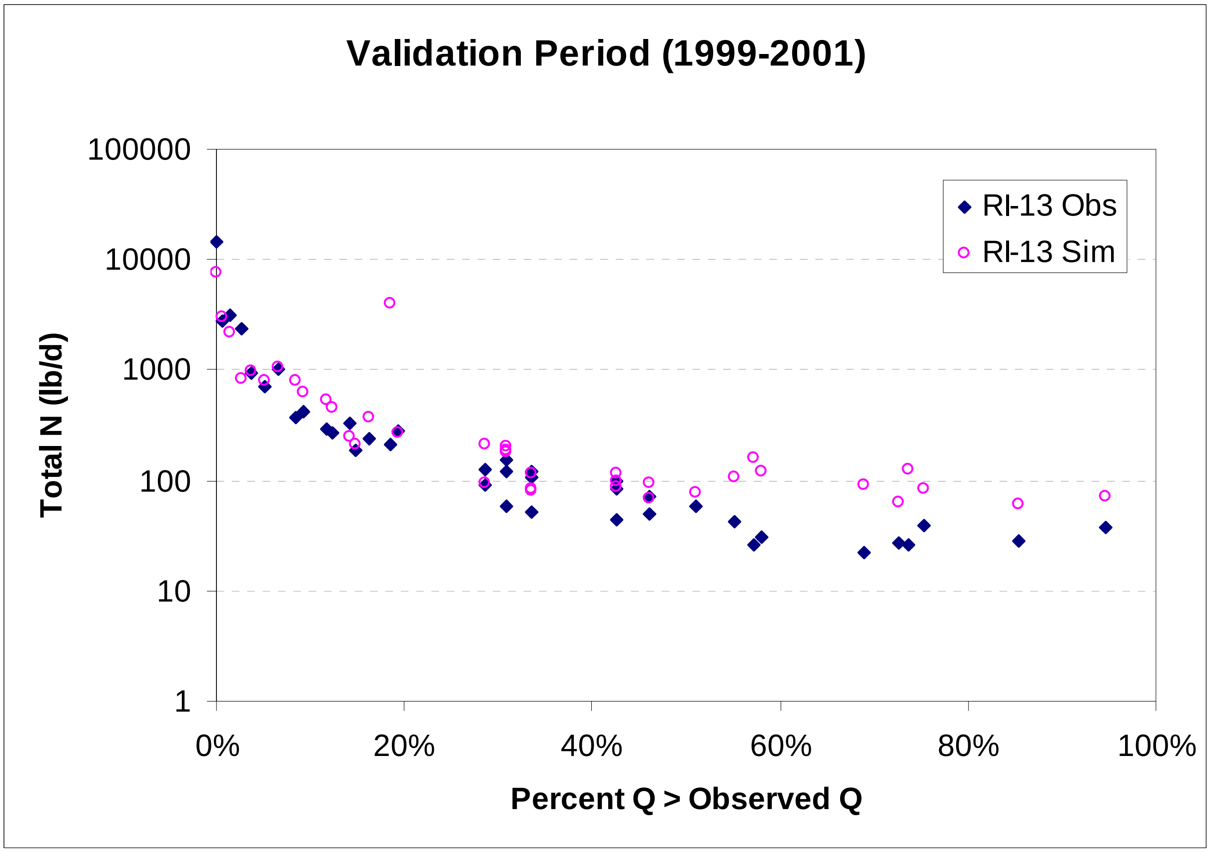
20-100% - Obs

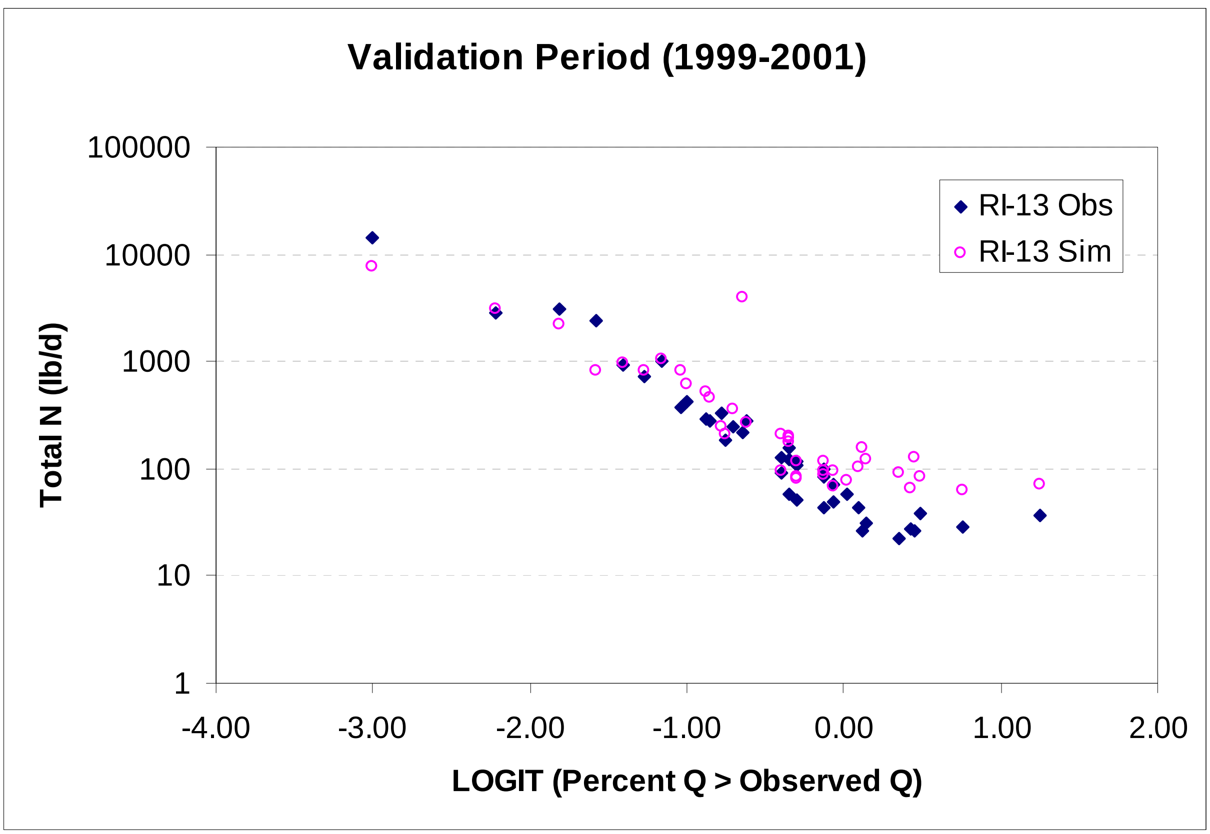
-1.329845	4.347396
0.151905	0.083566
0.635279	0.518861
76.64007	44
2.015368	
0.306145	
-1.63599	
-1.0237	

20-100% - Sim

-0.678431	4.657676
0.090525	0.0498
0.560727	0.309206
56.16557	44
2.015368	
0.182442	
-0.860873	
-0.495989	




Validation Period (1999-2001)
Total N (lb/d)
100000
10000
1000
100
10
1
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-13 Obs
RI-13 Sim


Validation Period (1999-2001)
Total N (lb/d)
100000
10000
1000
100
10
1
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-13 Obs
RI-13 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.833953	4.267619
0.128883	0.178445
0.935329	0.325565
202.4808	14
2.144787	
0.276427	
-2.11038	
-1.557526	

0-20% - Sim

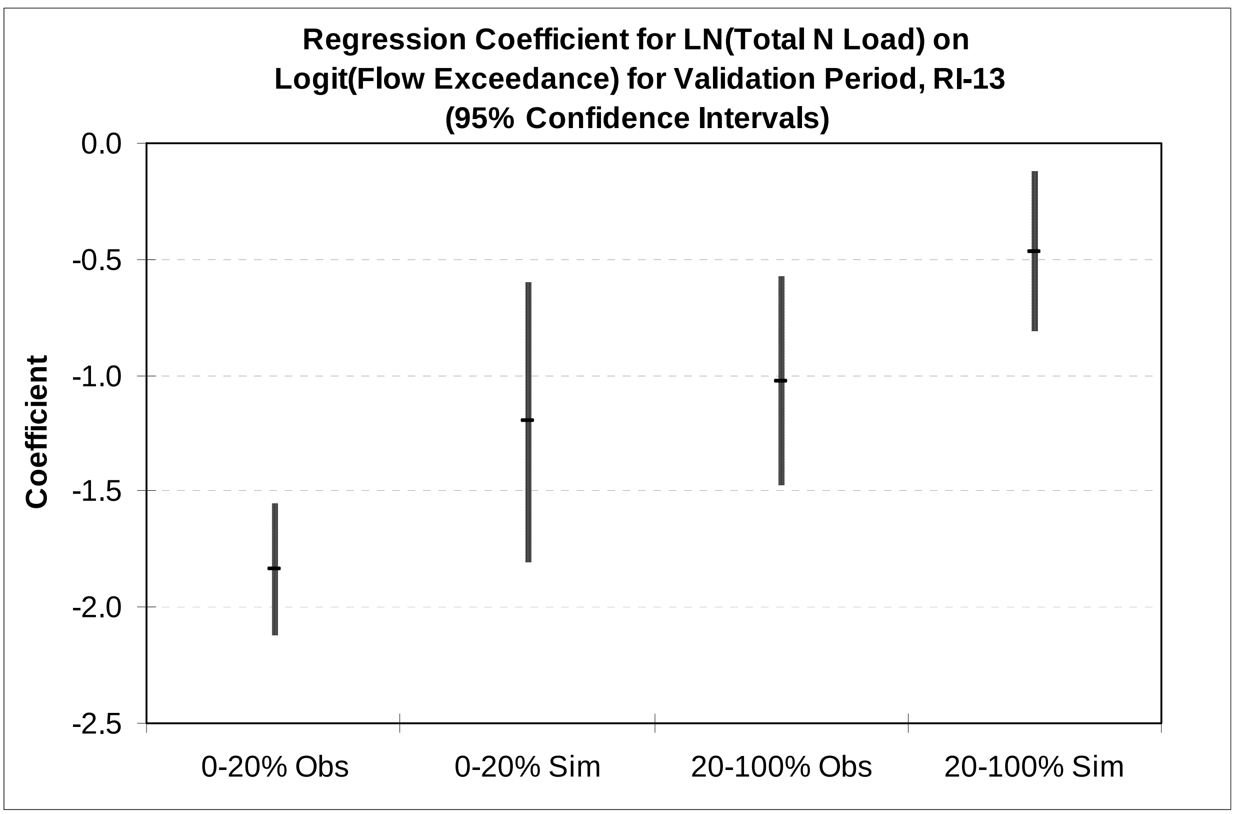
-1.199934	5.274453
0.278209	0.385194
0.570586	0.702768
18.60257	14
2.144787	
0.596698	
-1.796632	
-0.603235	

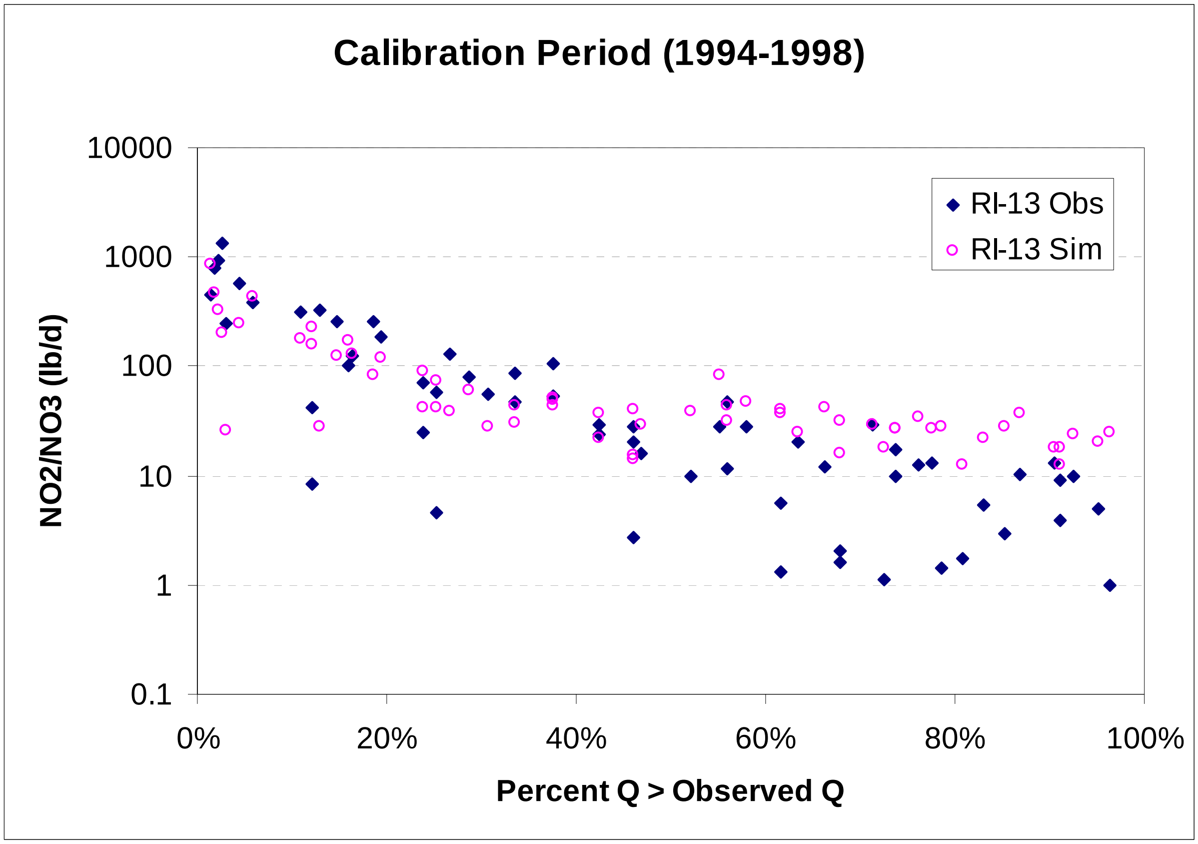
20-100% - Obs

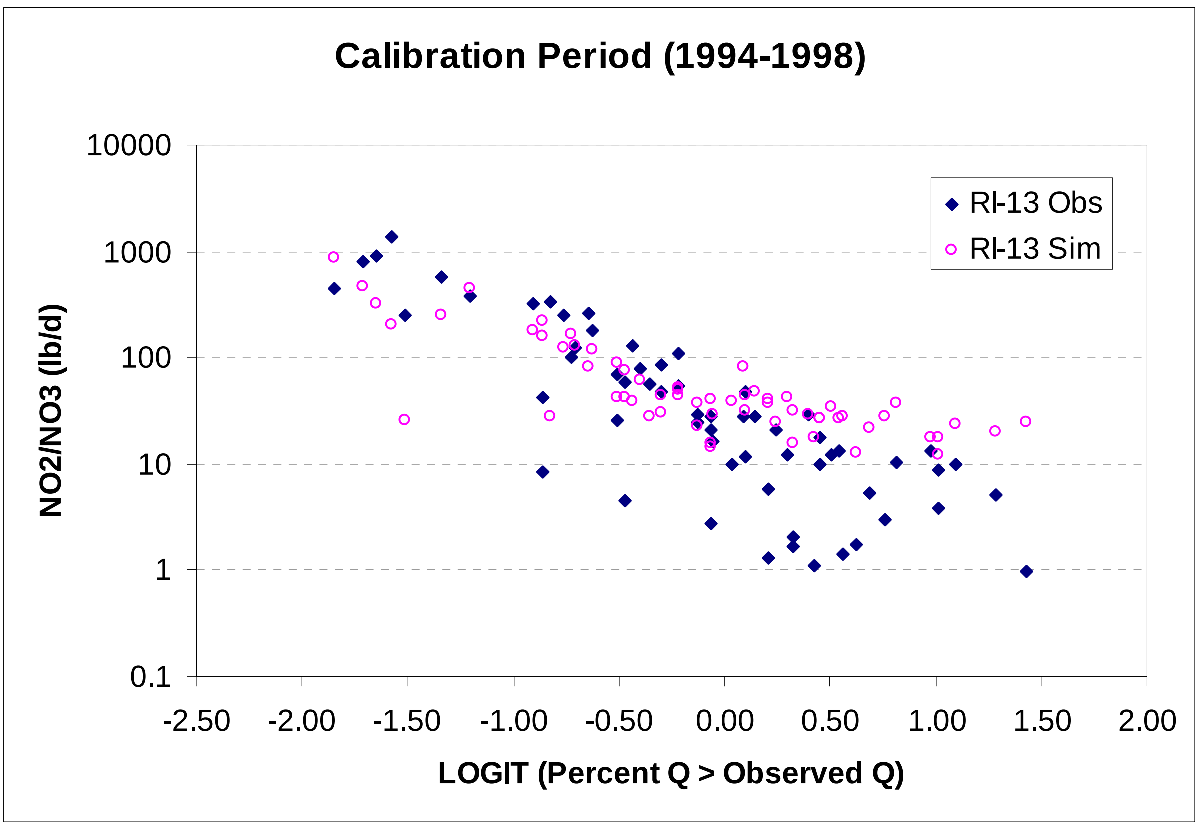
-1.026845	4.054712
0.212043	0.087811
0.527569	0.41956
23.45094	21
2.079614	
0.440968	
-1.467813	
-0.585877	

20-100% - Sim

-0.465323	4.666722
0.161165	0.066741
0.284162	0.318889
8.336241	21
2.079614	
0.33516	
-0.800484	
-0.130163	







Stats	**0-20% - Obs**	**0-20% - Sim**

Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

-1.717469	3.582131
0.624343	0.739487
0.350864	1.038637
7.567125	14
2.144787	
1.339083	
-3.056551	
-0.378386	

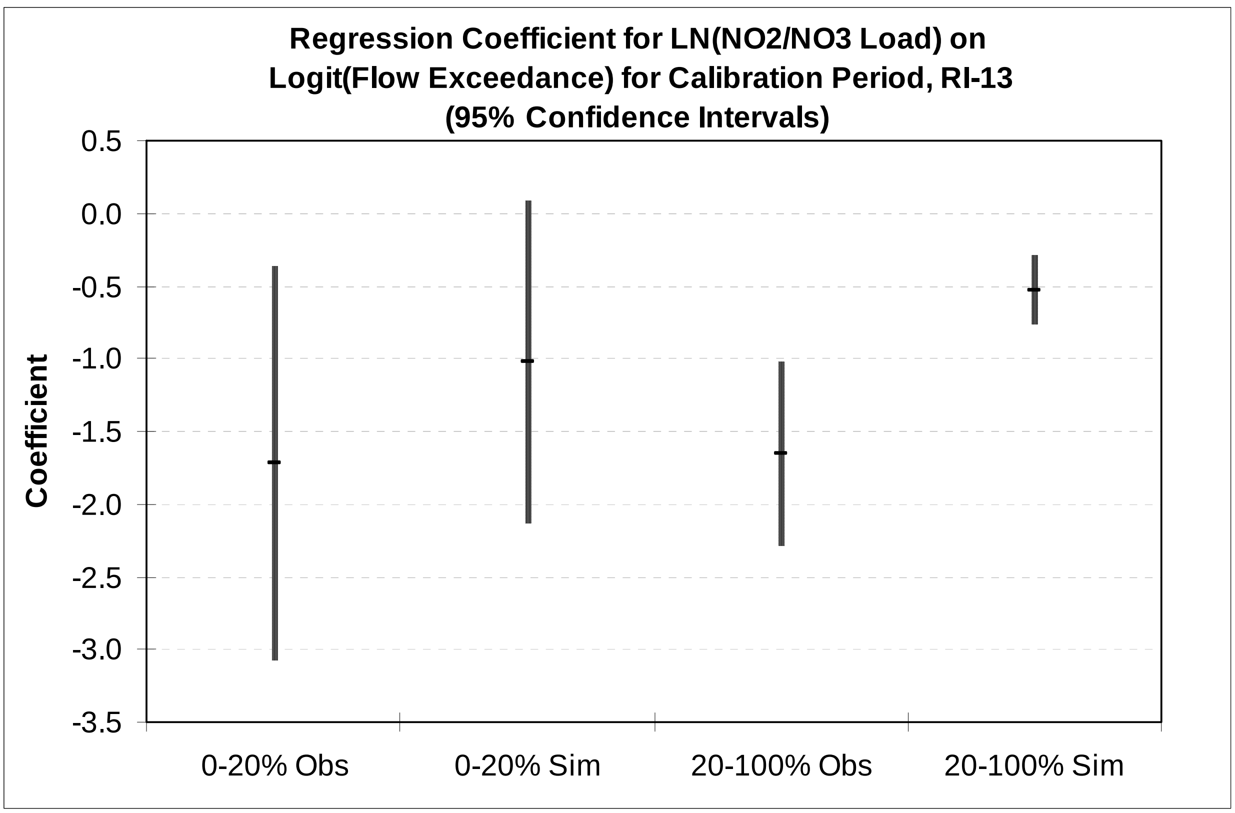
-1.024481	3.980907
0.509251	0.603169
0.224252	0.847173
4.047106	14
2.144787	
1.092235	
-2.116716	
0.067753	

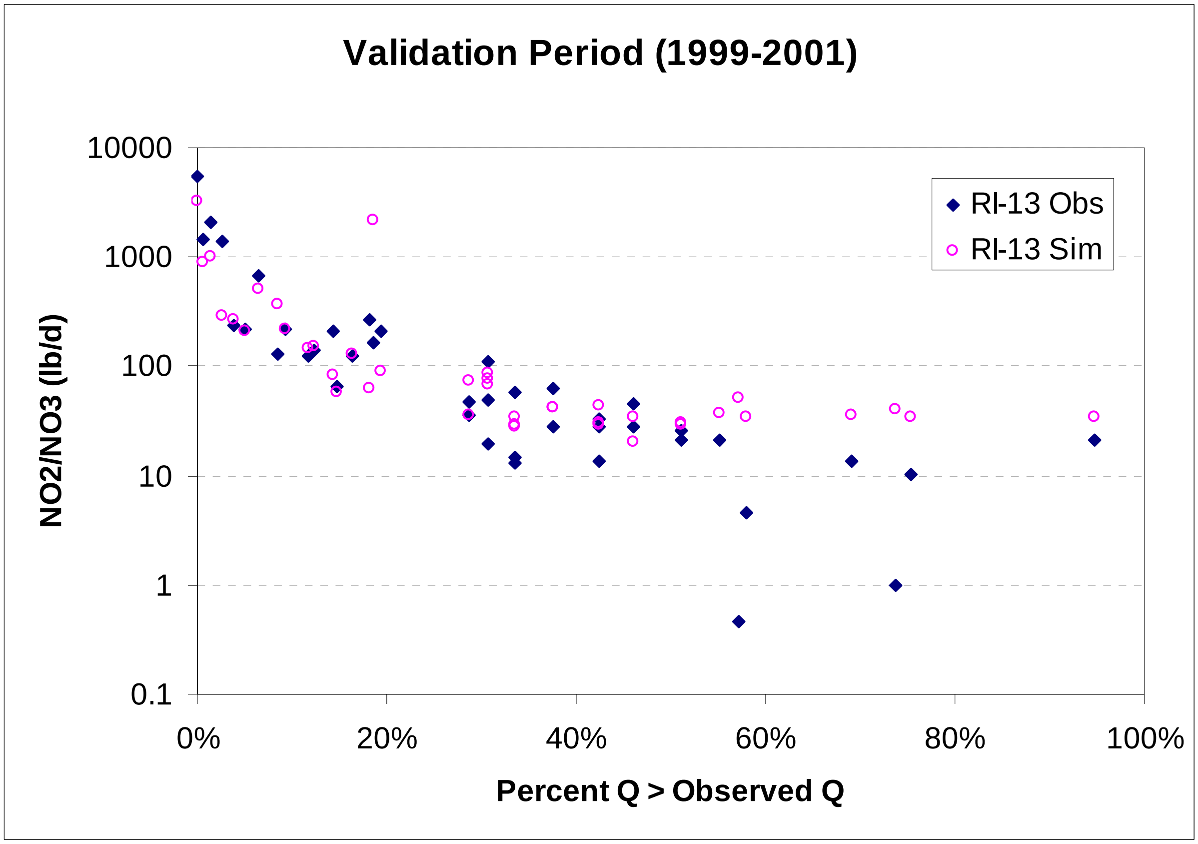
20-100% - Obs

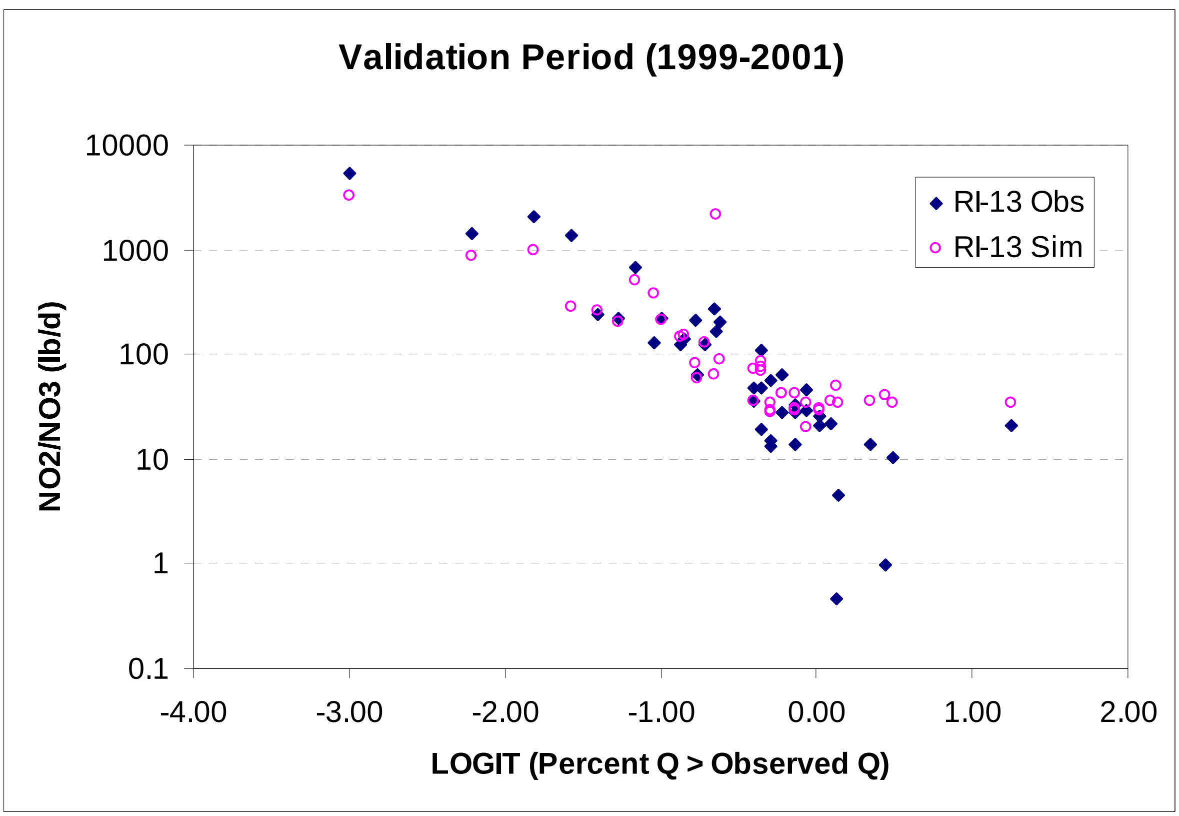
-1.654278	2.926567
0.306634	0.168685
0.39813	1.047366
29.10551	44
2.015368	
0.617981	
-2.272259	
-1.036297	

20-100% - Sim

-0.531075	3.558037
0.112327	0.061793
0.336882	0.383675
22.35325	44
2.015368	
0.226381	
-0.757457	
-0.304694	




Validation Period (1999-2001)
10000
1000
100
10
1
0.1
NO2/NO3 (lb/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-13 Obs
RI-13 Sim


Validation Period (1999-2001)
10000
1000
100
10
1
0.1
NO2/NO3 (lb/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-13 Obs
RI-13 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.655751	3.813514
0.22646	0.306308
0.780885	0.585904
53.4573	15
2.13145	
0.482688	
-2.138439	
-1.173063	

0-20% - Sim

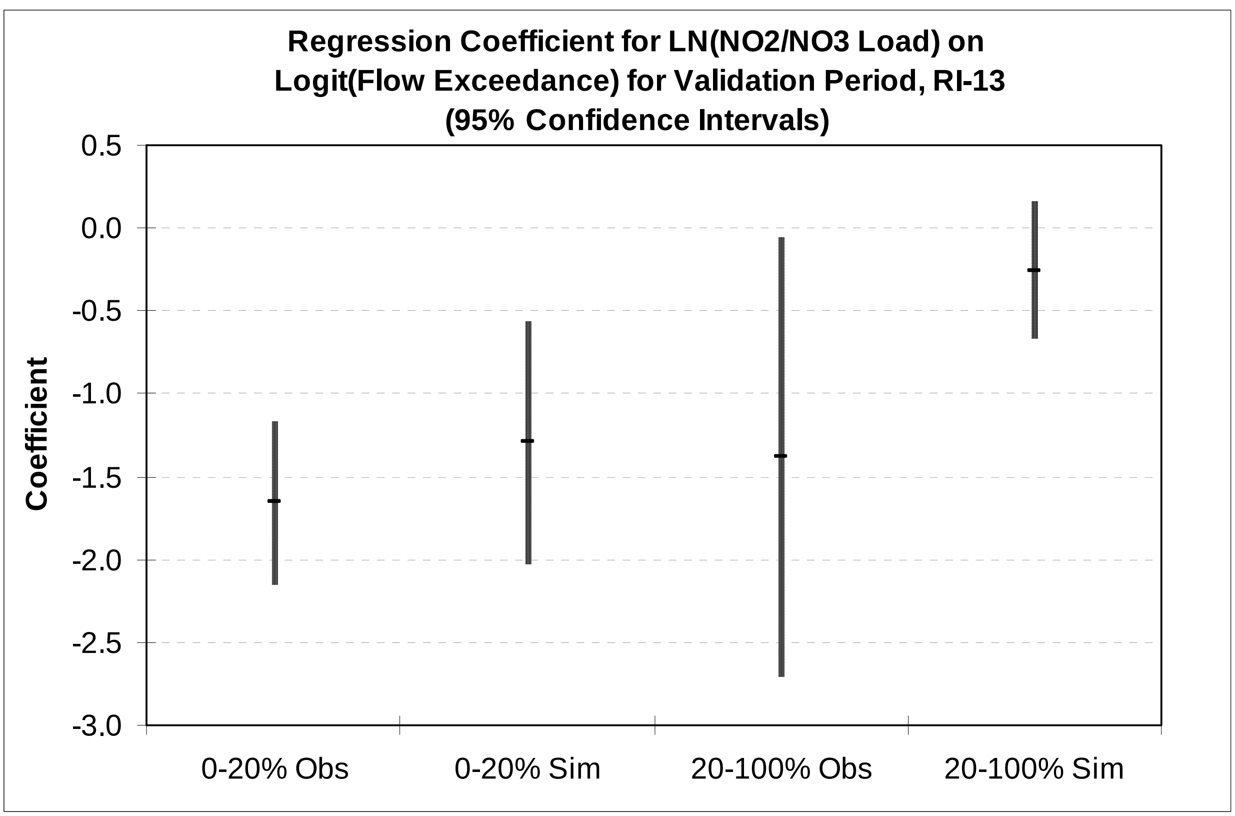
-1.294026	4.067327
0.335802	0.454203
0.497483	0.868797
14.84974	15
2.13145	
0.715745	
-2.009771	
-0.57828	

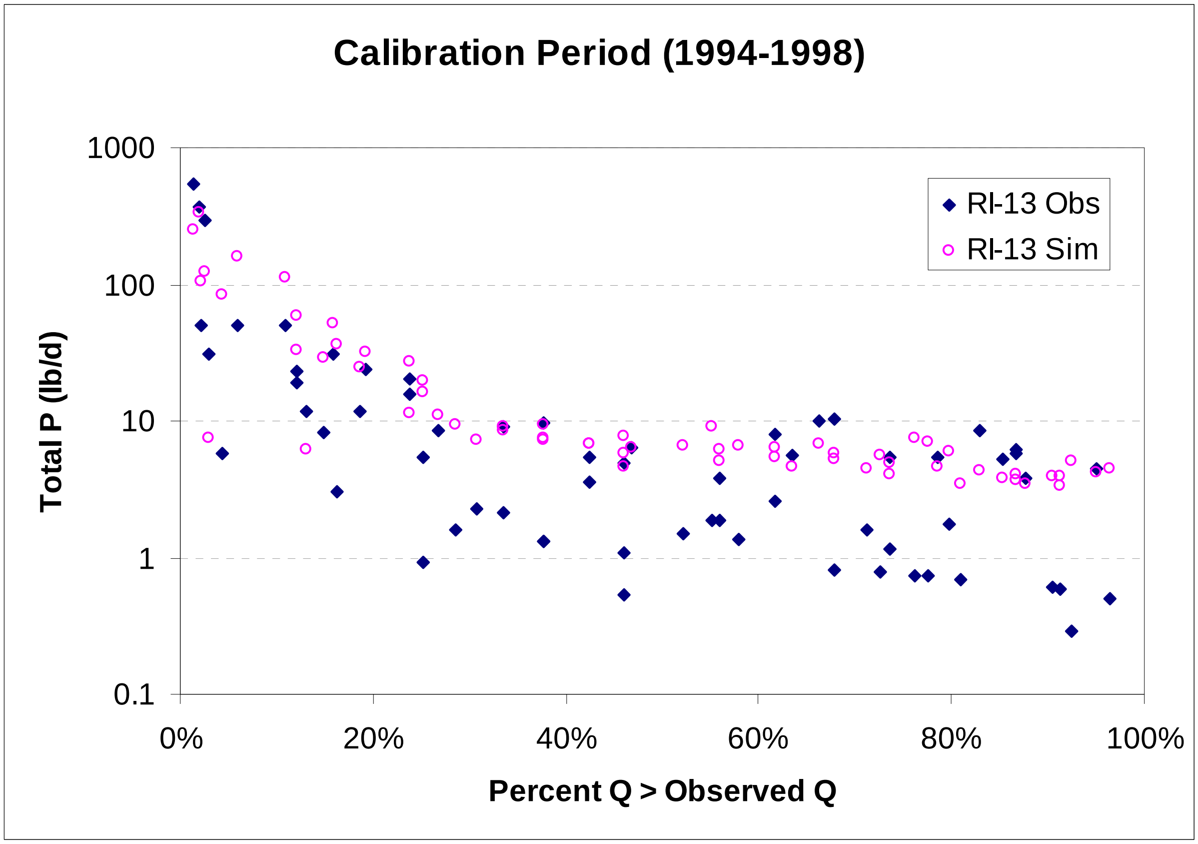
20-100% - Obs

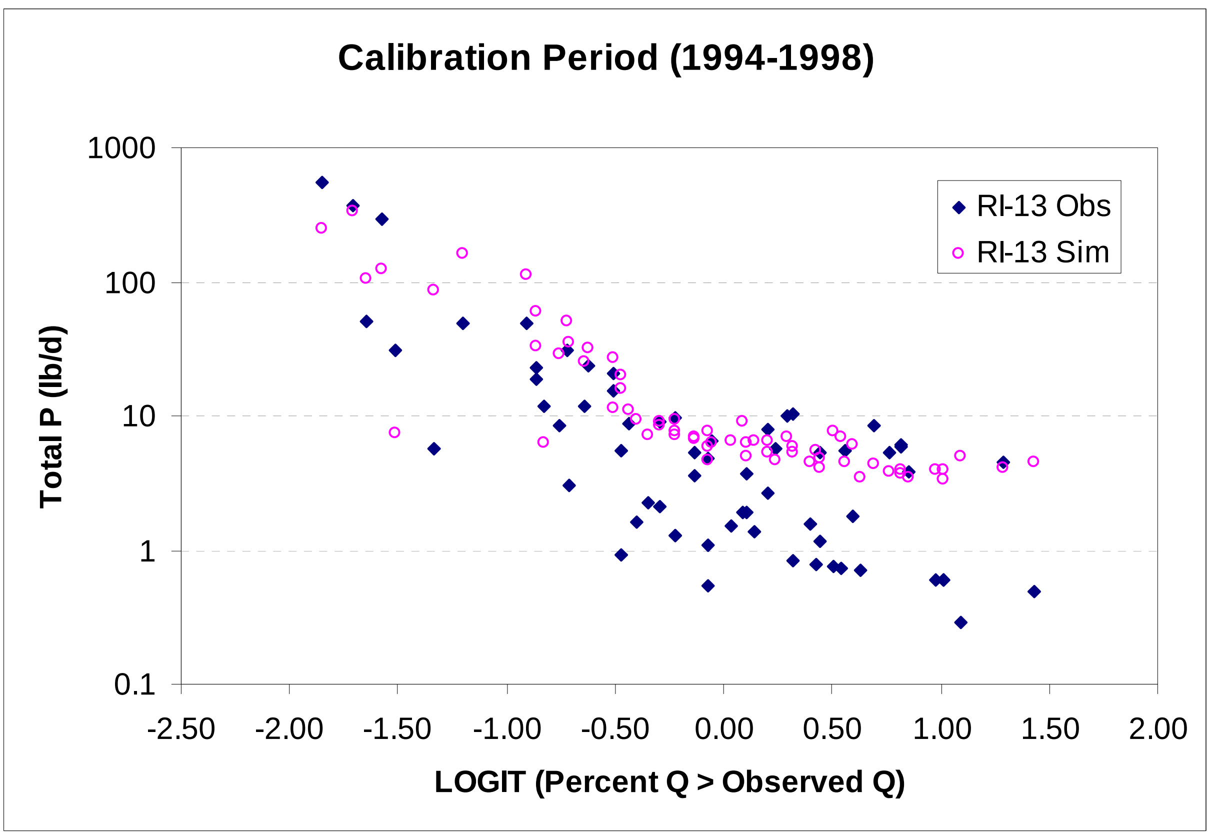
-1.377266	2.894687
0.633932	0.234329
0.17665	1.143444
4.720095	22
2.073873	
1.314694	
-2.69196	
-0.062572	

20-100% - Sim

-0.253392	3.649874
0.194091	0.071745
0.071903	0.350088
1.704419	22
2.073873	
0.40252	
-0.655912	
0.149128	




Calibration Period (1994-1998)
1000
100
10
1
0.1
Total P (lb/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-13 Obs
RI-13 Sim


Calibration Period (1994-1998)
1000
100
10
1
0.1
Total P (lb/d)
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
RI-13 Obs
RI-13 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.502022	0.70197
0.621438	0.736046
0.536579	1.033805
16.21011	14
2.144787	
1.332853	
-3.834875	
-1.169169	

0-20% - Sim

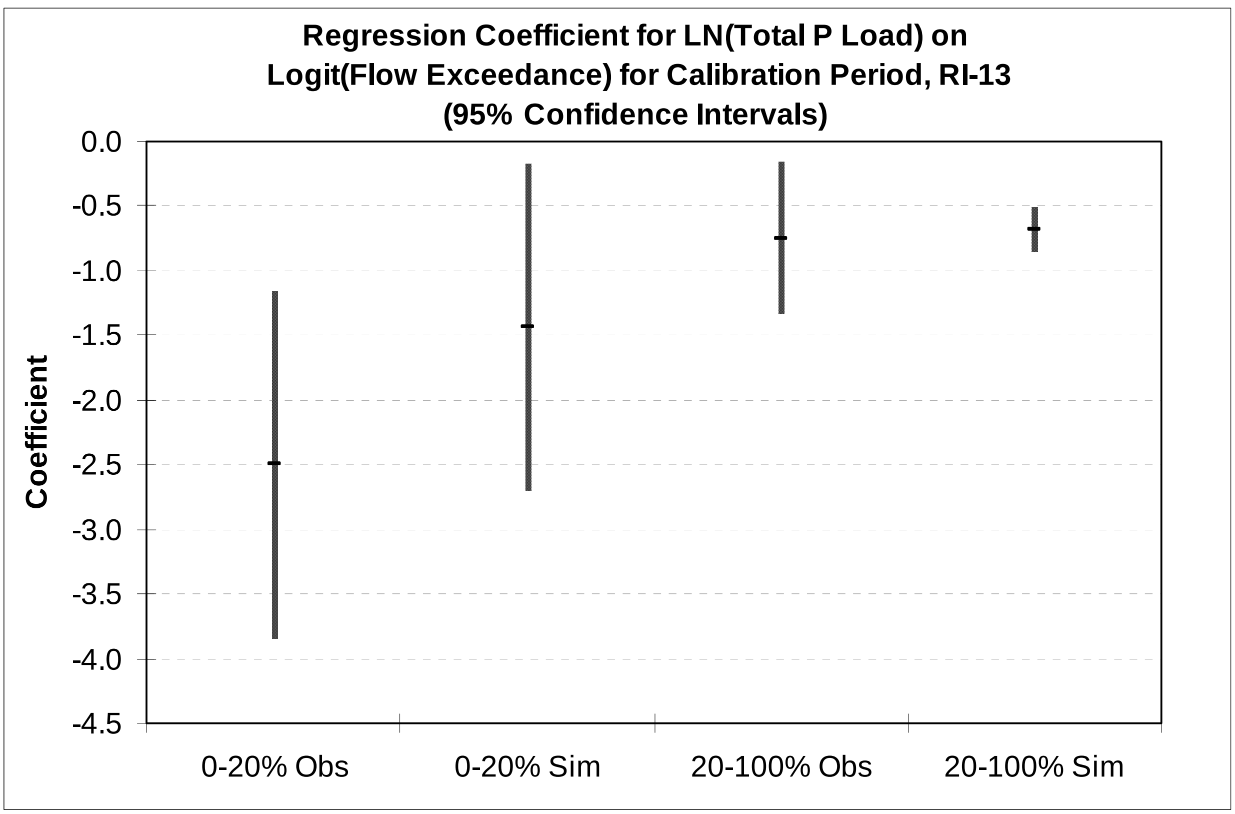
-1.436523	2.409484
0.585075	0.692977
0.300992	0.973312
6.028394	14
2.144787	
1.254862	
-2.691385	
-0.181661	

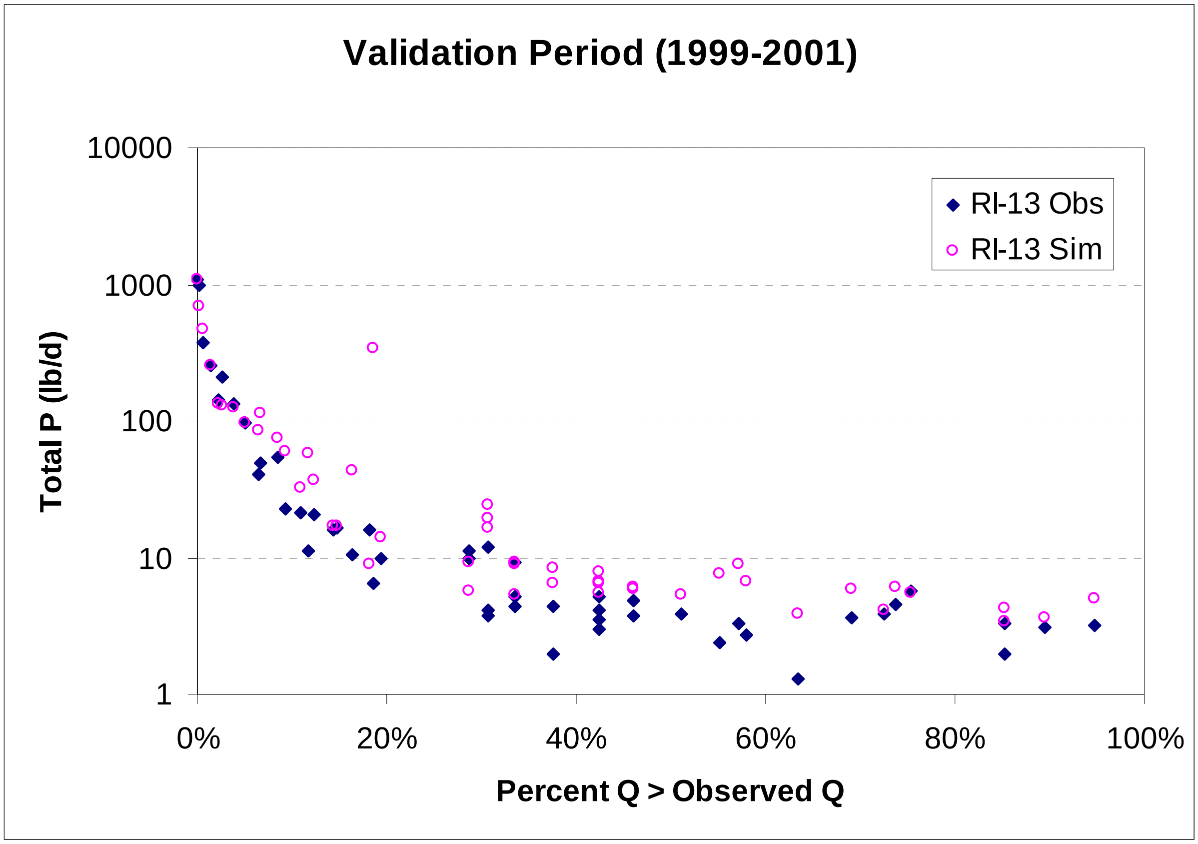
20-100% - Obs

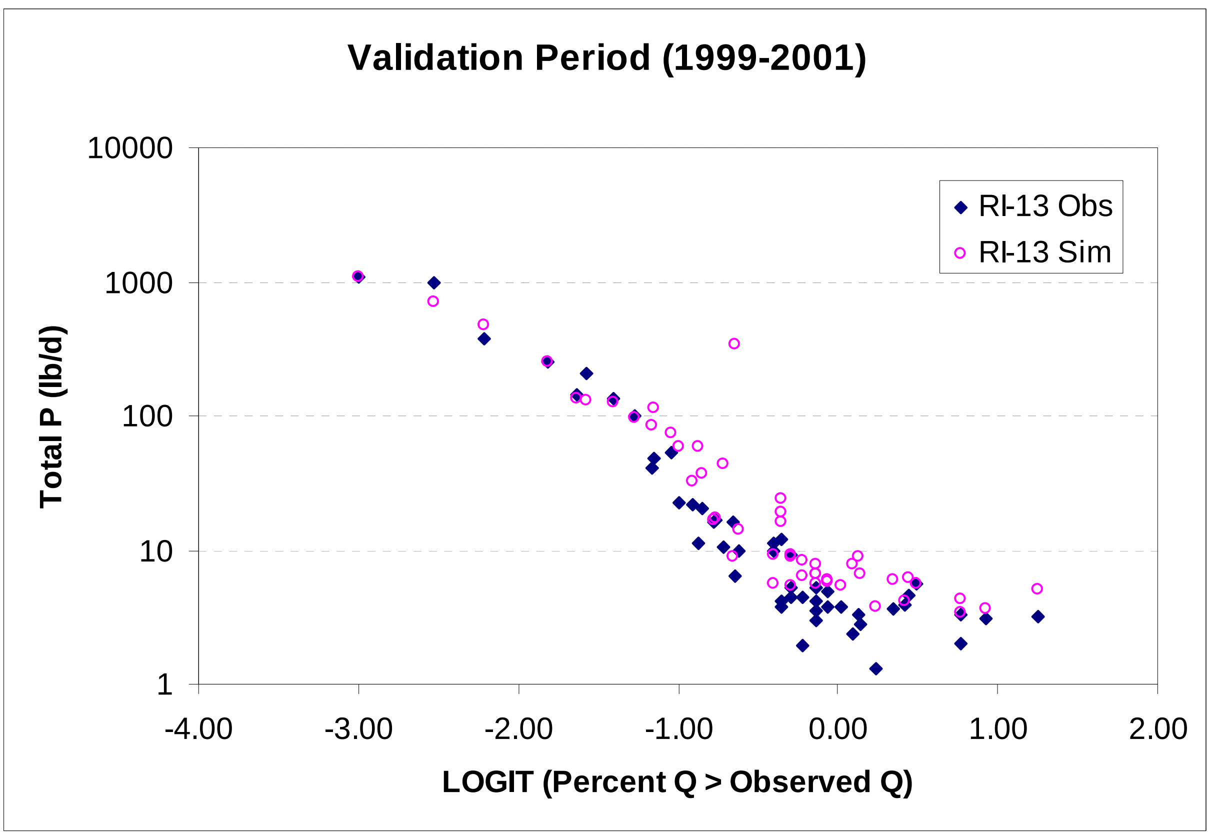
-0.74971	1.107821
0.283543	0.160364
0.129487	1.002887
6.991164	47
2.01174	
0.570415	
-1.320125	
-0.179296	

20-100% - Sim

-0.681	1.999531
0.077571	0.043872
0.621187	0.274368
77.07176	47
2.01174	
0.156053	
-0.837053	
-0.524947	




Validation Period (1999-2001)
10000
1000
100
10
1
Total P (lb/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-13 Obs
RI-13 Sim


Validation Period (1999-2001)
10000
1000
100
10
1
Total P (lb/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-13 Obs
RI-13 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.23815	1.129539
0.151241	0.214547
0.920167	0.444063
218.9983	19
2.093024	
0.316551	
-2.5547	
-1.921599	

0-20% - Sim

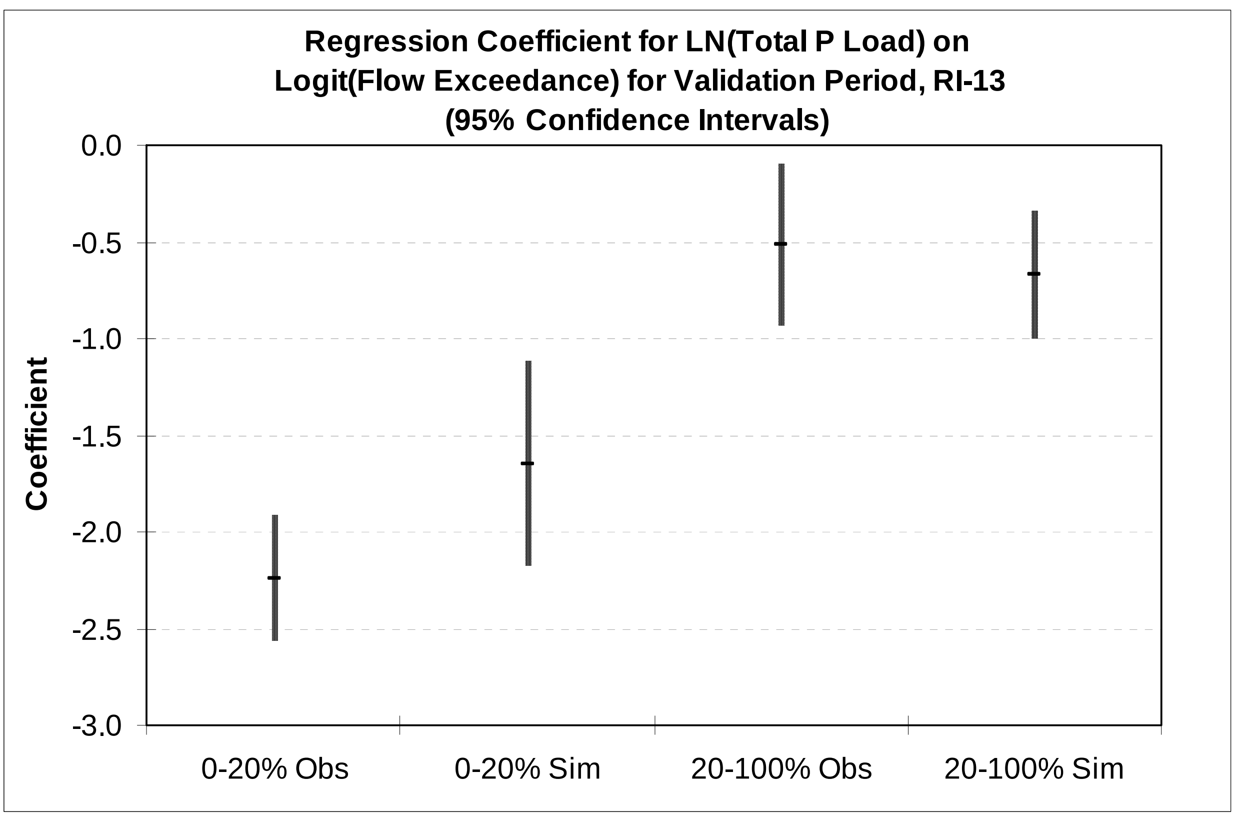
-1.646766	2.354743
0.248767	0.352896
0.697551	0.730414
43.82054	19
2.093024	
0.520676	
-2.167442	
-1.12609	

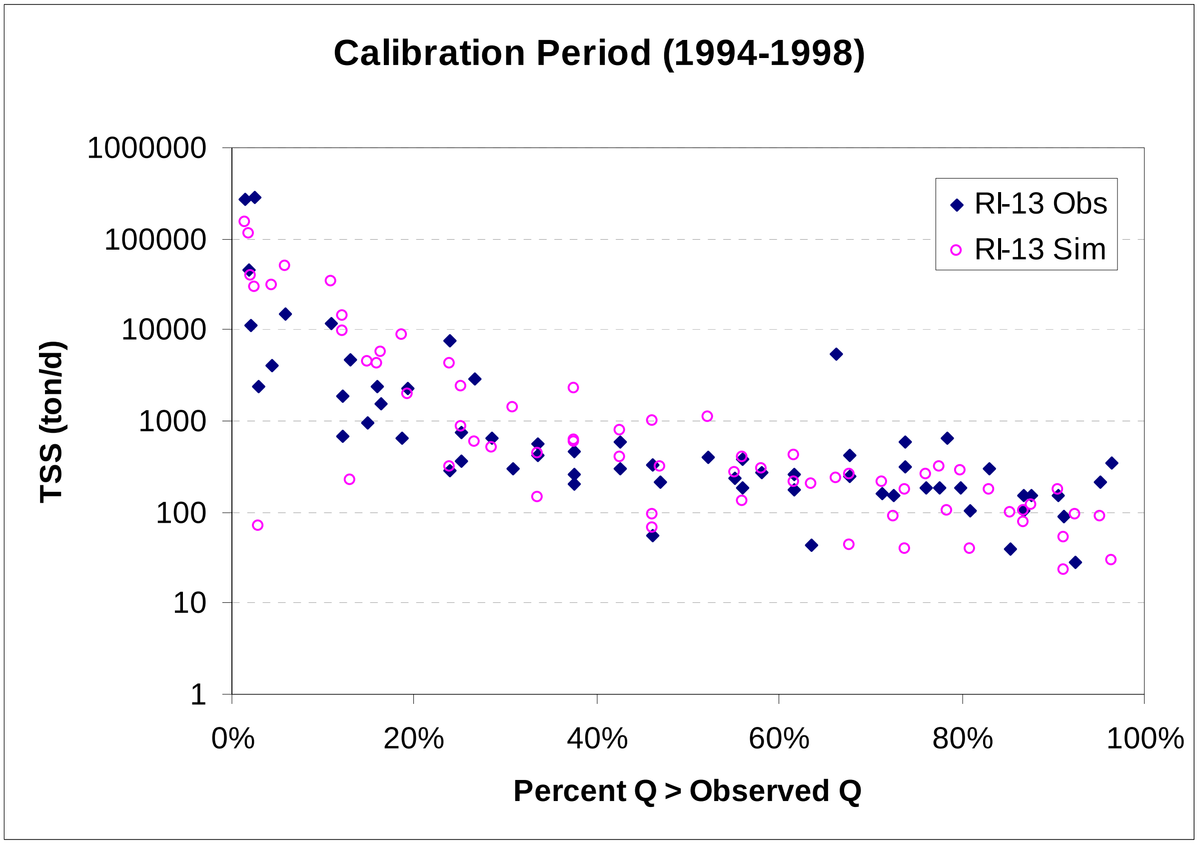
20-100% - Obs

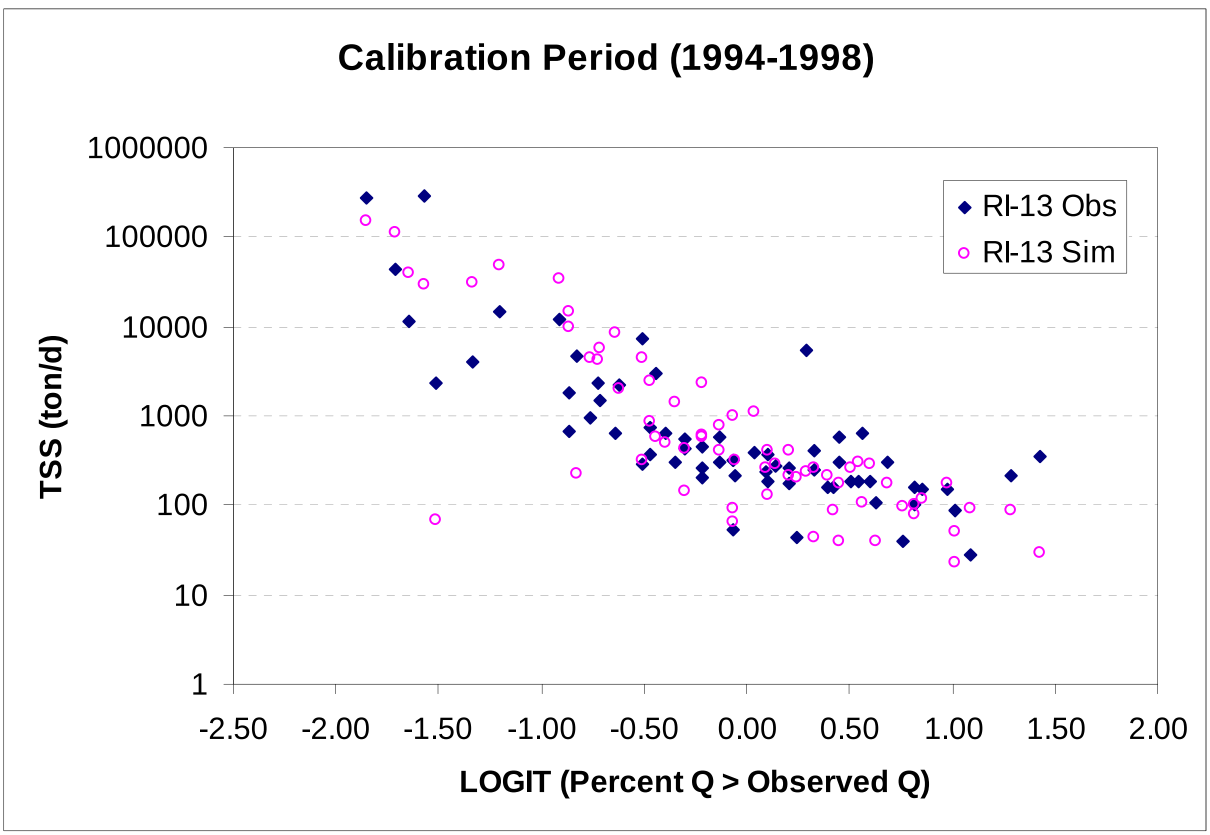
-0.51591	1.434935
0.197598	0.086563
0.201582	0.459216
6.816853	27
2.05183	
0.405437	
-0.921347	
-0.110473	

20-100% - Sim

-0.668814	1.965486
0.155029	0.067915
0.408045	0.360287
18.61159	27
2.05183	
0.318094	
-0.986908	
-0.350721	




Calibration Period (1994-1998)
1000000
100000
10000
1000
100
10
1
TSS (ton/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-13 Obs
RI-13 Sim


Calibration Period (1994-1998)
1000000
100000
10000
1000
100
10
1
TSS (ton/d)
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
RI-13 Obs
RI-13 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-3.481028	4.811181
0.738799	0.875051
0.613265	1.229042
22.20048	14
2.144787	
1.584566	
-5.065595	
-1.896462	

0-20% - Sim

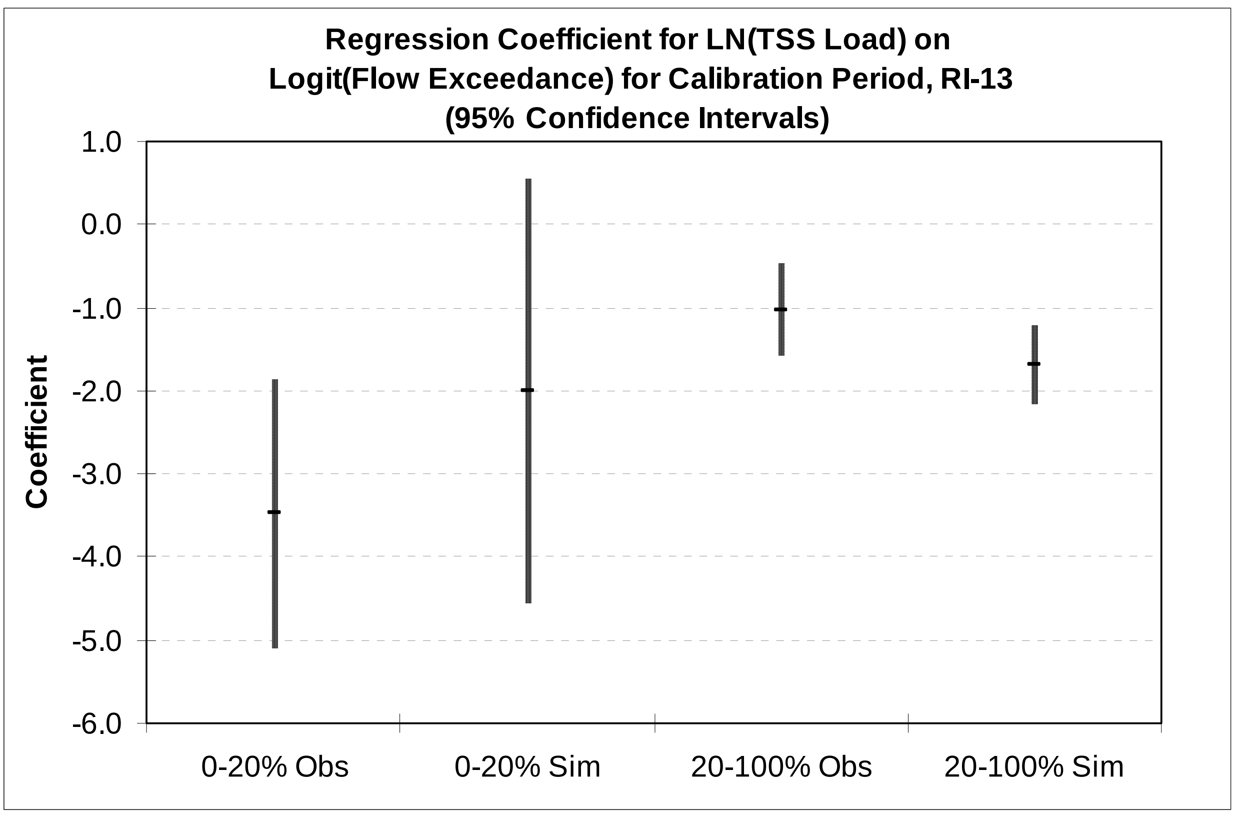
-1.998741	6.943992
1.180337	1.398018
0.170001	1.96357
2.867486	14
2.144787	
2.531571	
-4.530312	
0.532829	

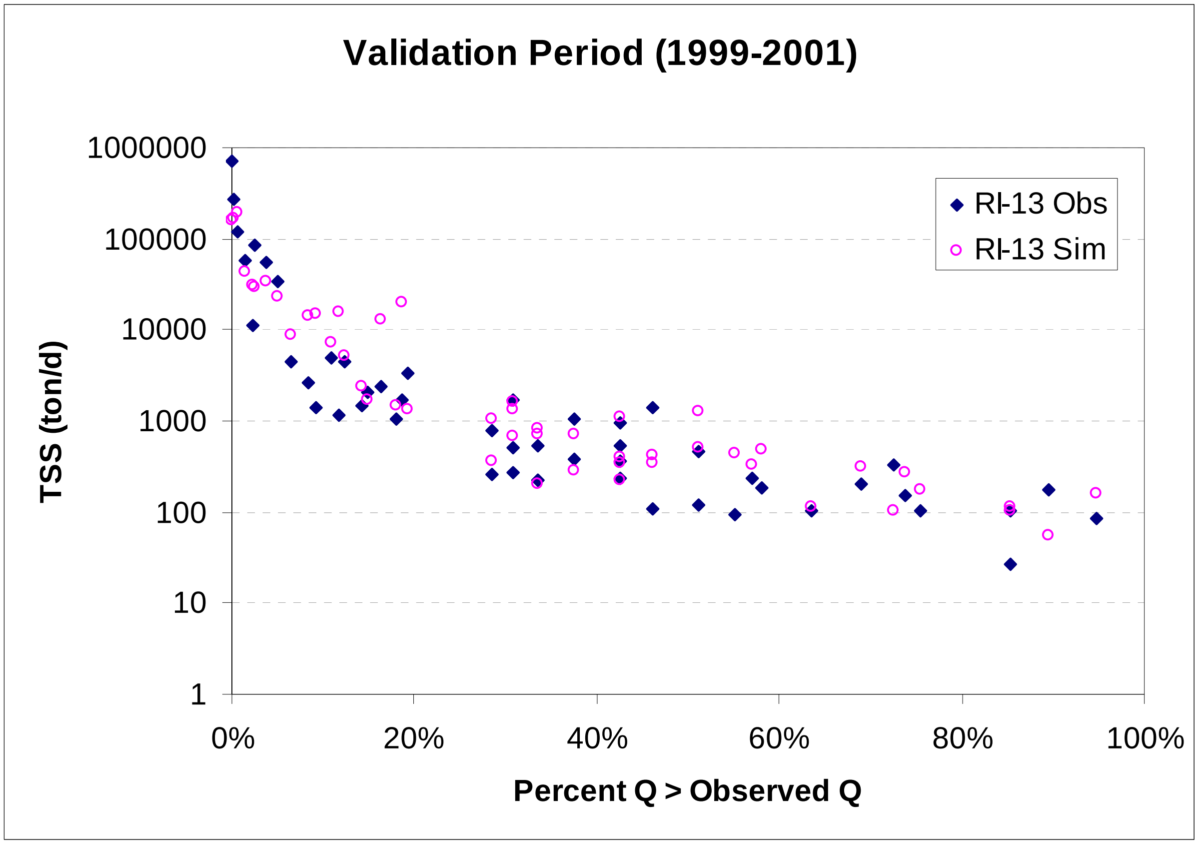
20-100% - Obs

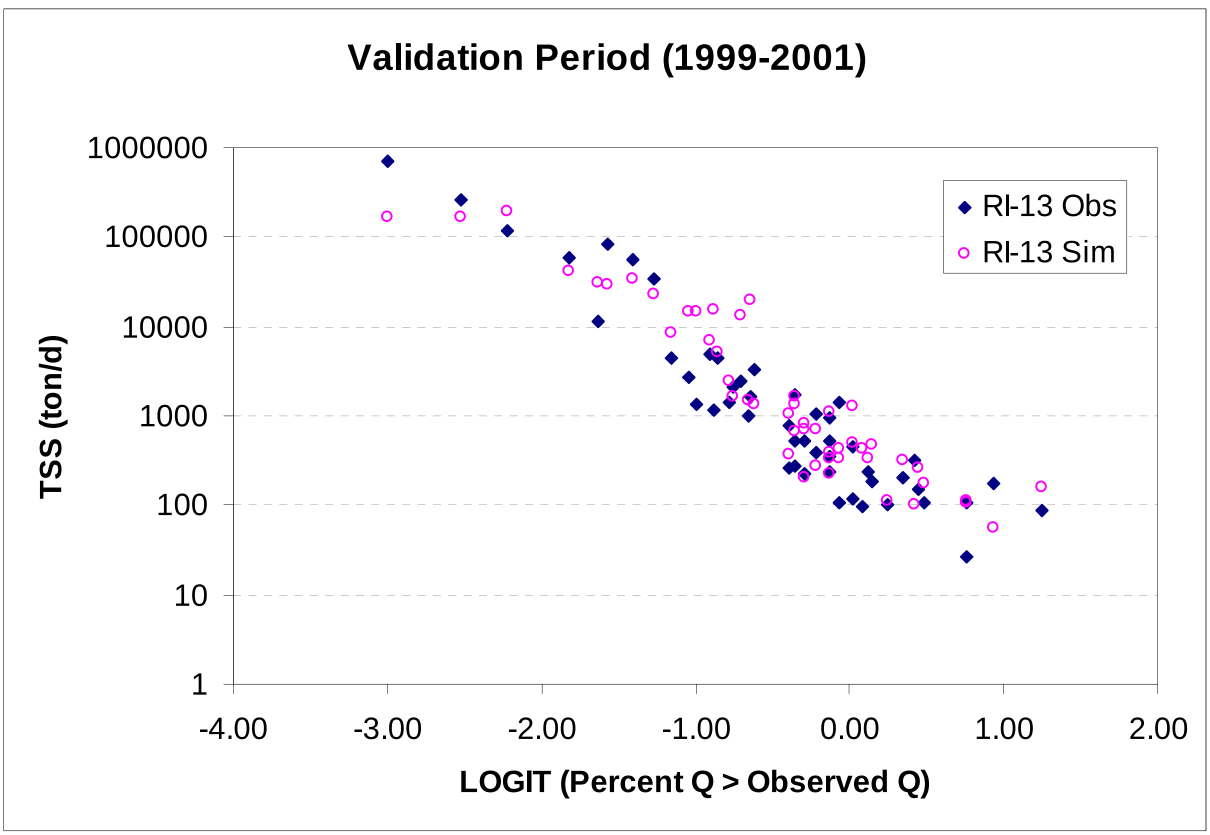
-1.022272	5.853809
0.259536	0.146787
0.248174	0.917976
15.51447	47
2.01174	
0.522119	
-1.544391	
-0.500152	

20-100% - Sim

-1.691598	5.879663
0.226353	0.128019
0.543023	0.800608
55.84974	47
2.01174	
0.455364	
-2.146962	
-1.236234	




Validation Period (1999-2001)
1000000
100000
10000
1000
100
10
1
TSS (ton/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-13 Obs
RI-13 Sim


Validation Period (1999-2001)
1000000
100000
10000
1000
100
10
1
TSS (ton/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-13 Obs
RI-13 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.773118	5.642134
0.265413	0.379713
0.858455	0.778661
109.1676	18
2.100922	
0.557611	
-3.330729	
-2.215507	

0-20% - Sim

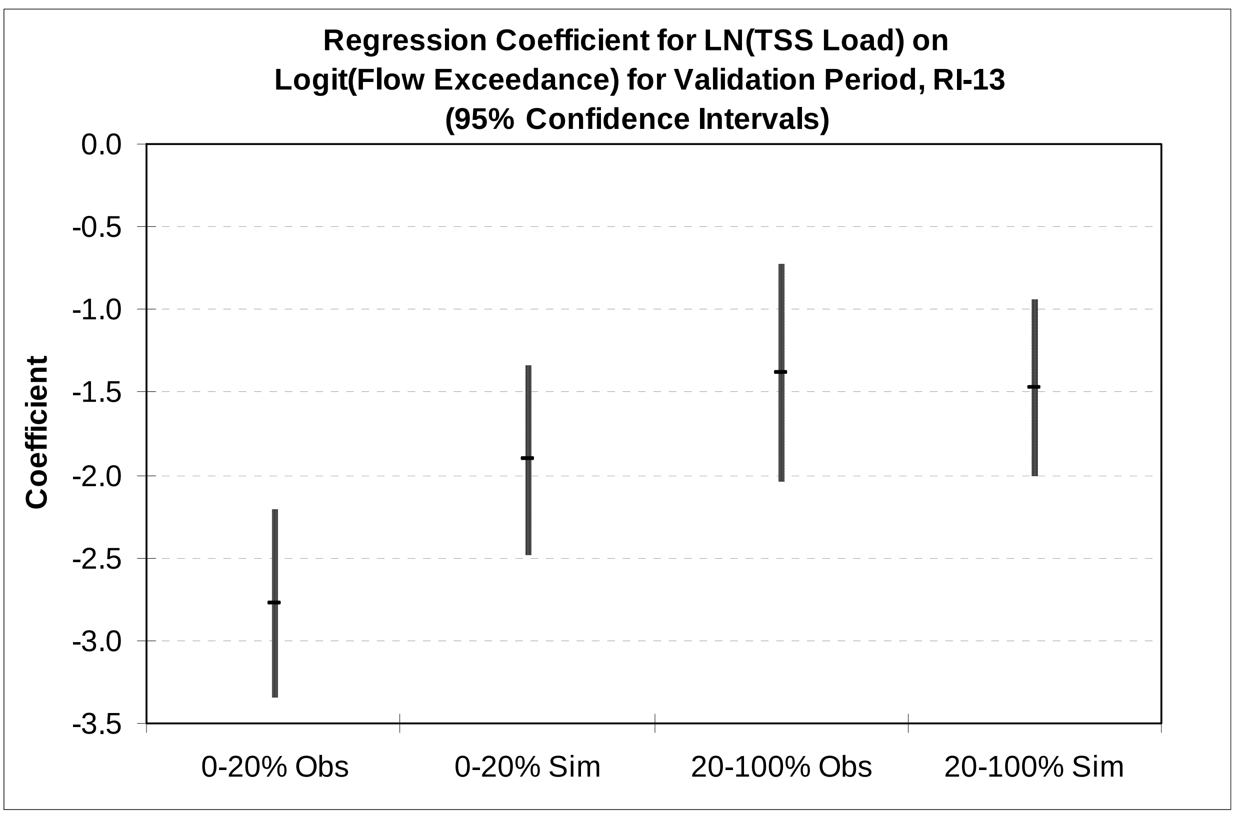
-1.907518	7.189116
0.268536	0.384182
0.737066	0.787825
50.4582	18
2.100922	
0.564173	
-2.471691	
-1.343344	

20-100% - Obs

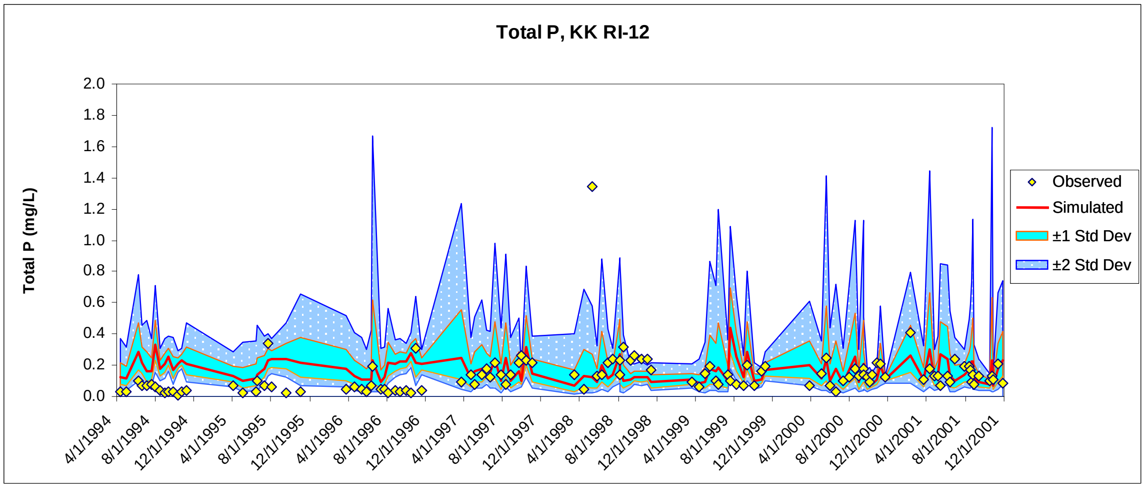
-1.384308	5.668705
0.314841	0.135611
0.408437	0.731895
19.33228	28
2.048407	
0.644923	
-2.029231	
-0.739386	

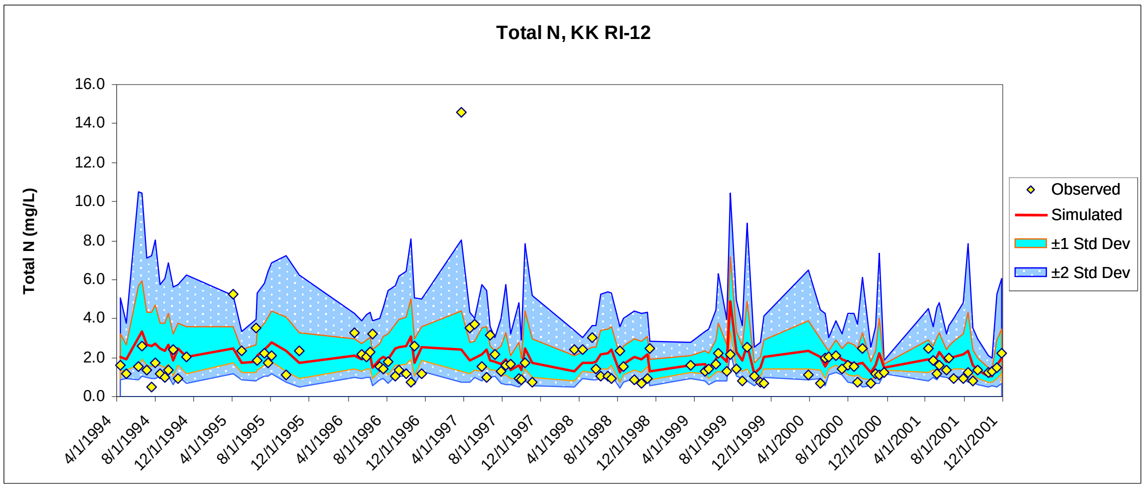
20-100% - Sim

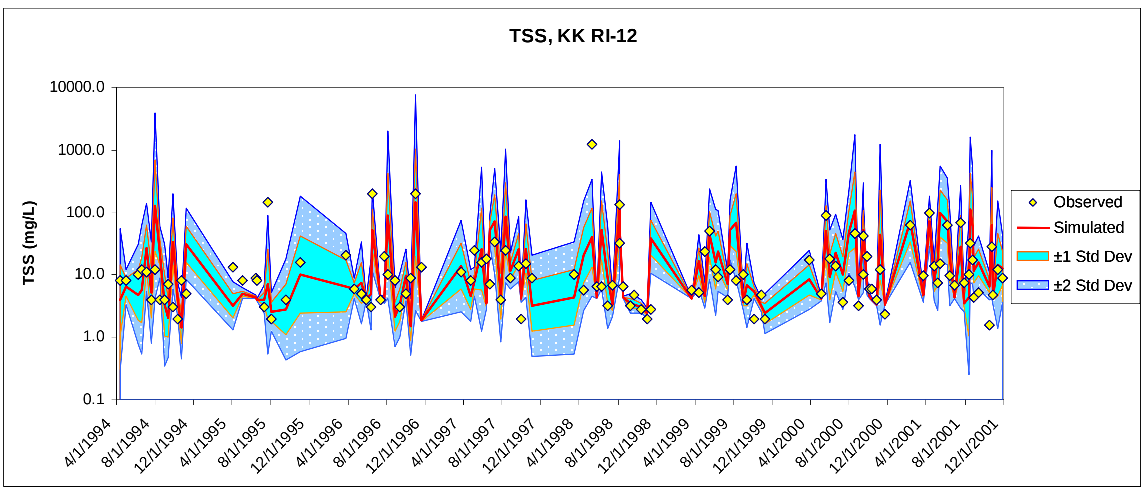
-1.47263	5.998196
0.255422	0.110017
0.542789	0.593766
33.24082	28
2.048407	
0.523208	
-1.995838	
-0.949423	

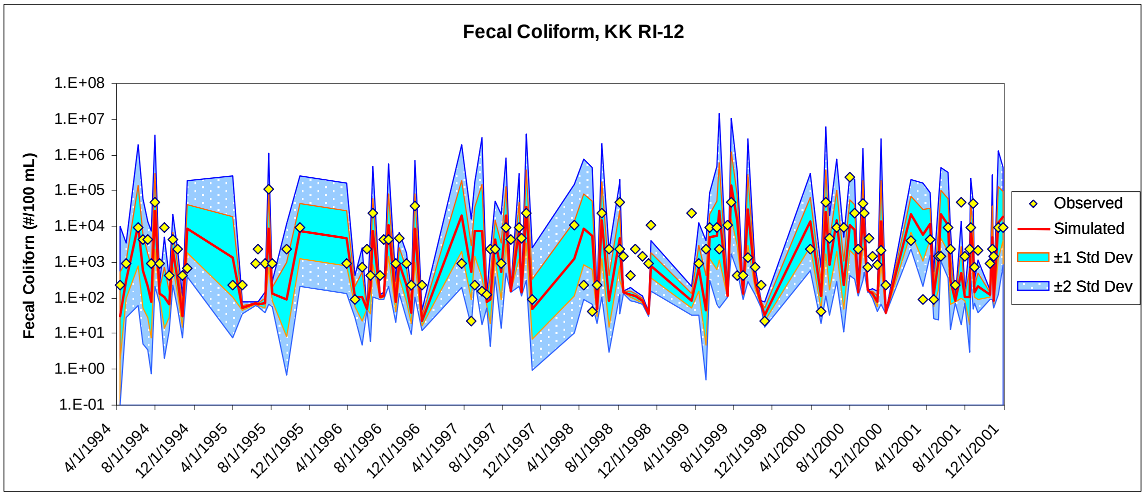


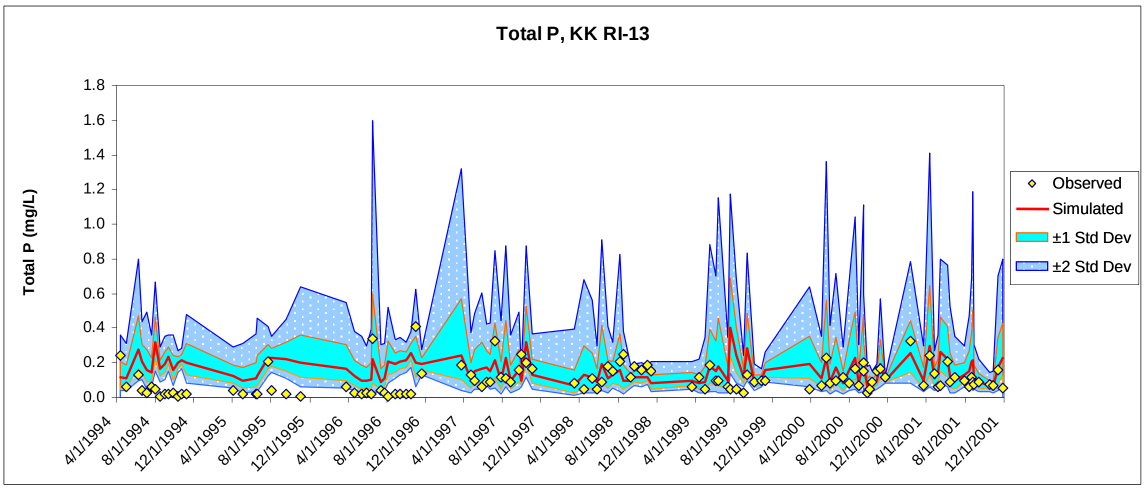
ATTACHMENT C– CONTROL CHARTS

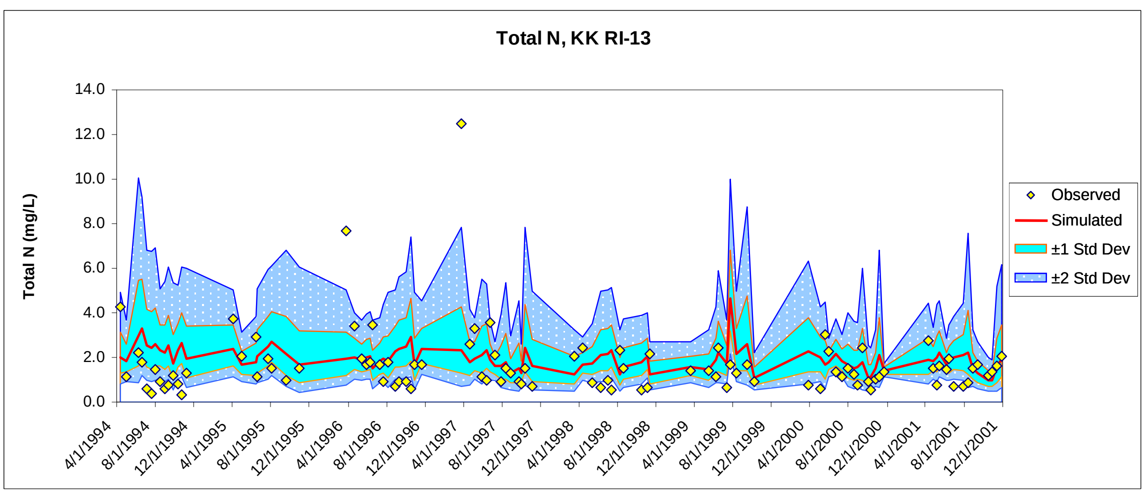

Total P, KK RI-12
Total P (mg/L)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

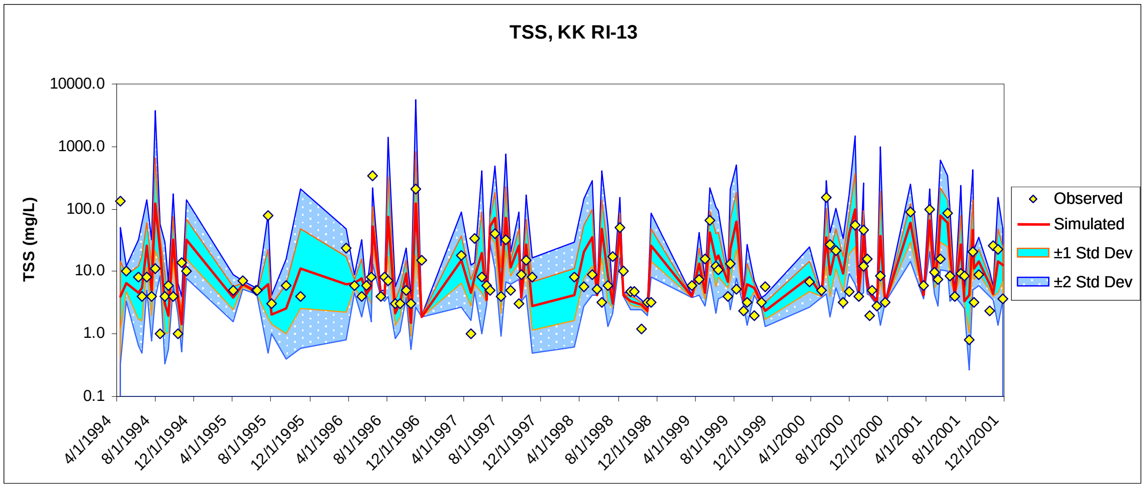

Total N, KK RI-12
Total N (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

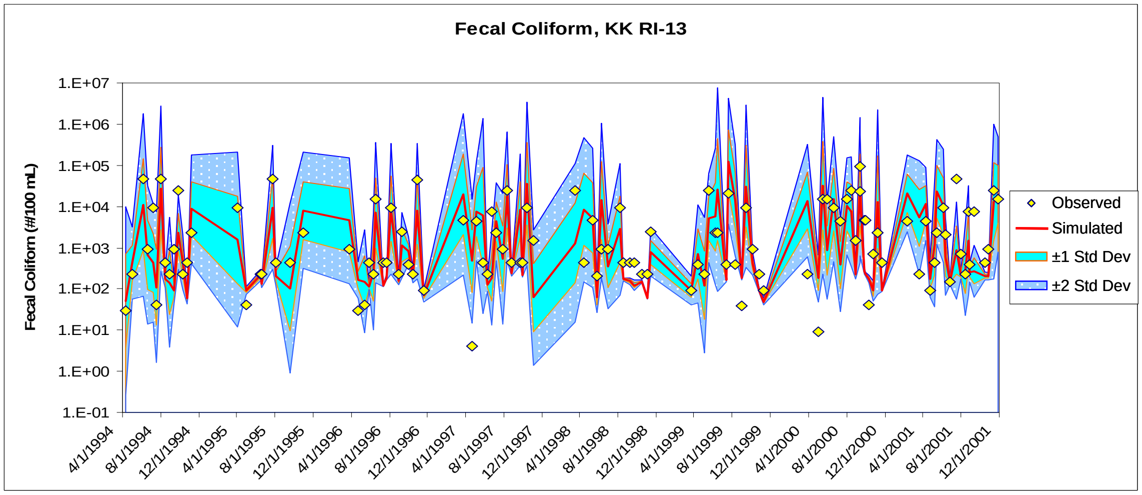

TSS, KK RI-12
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Fecal Coliform, KK RI-12
Fecal Coliform (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Total P, KK RI-13
Total P (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Total N, KK RI-13
Total N (mg/L)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


TSS, KK RI-13
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Fecal Coliform, KK RI-13
Fecal Coliform (#/100 mL)
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

2020 Facility Planning Project

Final Memorandum

Project Name:	MMSD – 2020 Facility Planning Project	MMSD Contract No:	M03002P01
DMS Folder Name:	Technology Analysis	MMSD File Code:	M009PE000.P7300-WQ1
Document Name:	Water Quality Calibration and Validation Results for the Menomonee River Model (Task 4)	HNTB Charge No:	34568-PL-400-115

Date: December 18, 2007

To: Michael Hahn, SEWRPC
Bill Krill, HNTB

From: Leslie Shoemaker, Tetra Tech, Inc.

Subject: Water Quality Calibration and Validation Results for the Menomonee River Model (Task 4)

1.0 EXECUTIVE SUMMARY

An important component of the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU) is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. The purpose of this memorandum is to describe the modeling process and provide the results of the water quality calibration and validation of the Menomonee River watershed model.

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for a variety of reasons, including that existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds. The Loading Simulation Program in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms but has the advantage of no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original Menomonee River HSPF model has been migrated to LSPC for the 2020 Facilities Planning Project.

Calibration of HSPF/LSPC followed a sequential, hierarchical process that begins with hydrology, followed by sediment erosion and transport, and, finally, calibration of chemical water quality. The original hydrologic calibration for the Menomonee River watershed model is described in the memorandum entitled *Draft Hydrologic Calibration and Validation Results for the Menomonee River Model (March 4, 2005)*. A revised hydrologic calibration, described in the memorandum entitled *Revised Draft Hydrologic Calibration and Validation Results for the Menomonee River Model*, addressed various comments provided by SEWRPC. This memorandum provides revised results of the water quality calibration that are consistent with the revised hydrologic calibration and various other improvements that were made during re-calibration efforts. This memorandum also addresses comments provided by SEWRPC on the original water quality calibration memorandum (*Draft Water Quality Calibration Results for the Menomonee River (February 17, 2005*).

2.0 CONCLUSIONS

Water quality calibration for the Menomonee River relied on comparison of model predictions to observations and estimated loads at four stations on the mainstem of the system. Achieving water quality calibration involves adjusting many parameters that interact with one another. The upland model represents expected loading associated with runoff events from specified land uses, but cannot represent unusual events that are outside the scope of events simulated in the model (for instance, discharge or breach of a waste lagoon). Any errors present in the simulation of hydrology (whether due to model formulation or the inherent uncertainty of predicting watershed-scale response from point rain gage monitoring) will propagate into the water quality simulation. In addition, observed data – which consist of point in time and point in space measurements – may not be fully representative of conditions in the waterbody, and may also be subject to considerable analytical uncertainty. The model provides an estimate of average conditions across the stream width and depth as a result of known upland sources. For this application, long-term average loading from these upland sources has been constrained to be consistent with results from SWAT modeling of agriculture and SLAMM modeling of loading from urban land uses. Fit between model and observations is best judged graphically and statistically: the model should represent the central tendency and trends seen in observations, but may not replicate all individual observations. Model fit for water quality is thus evaluated in three ways: (1) through graphical comparison of simulated and observed data, (2) through statistical tests on the equivalence of means on paired observed and simulated concentration data, and (3) through evaluation of the ability of the model to represent apparent observed load delivery rates. A single set of parameter values (by land use) is specified throughout the watershed; thus, the ability of the model to replicate differences in concentrations between different sample points is as important as the ability to match concentrations at individual sites.

In general, the current water quality calibration attains a reasonable fit to observations, with some discrepancies for individual parameters at individual locations. The quality of fit is sufficiently good that the model is judged ready for application to management scenarios.

3.0 RECOMMENDATIONS

We recommend that the water quality calibration and validation of the Menomonee River model be considered complete.

4.0 INTRODUCTION

The Milwaukee Metropolitan Sewerage District (MMSD) is in the midst of a long-range planning effort to identify improvements needed for its facilities to accommodate growth and protect water quality through the year 2020. This effort is known as the MMSD 2020 Facility Plan. A related planning effort is being conducted by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) to update the regional water quality management plan for the Kinnickinnic River, Menomonee River, Milwaukee River, Root River, and Oak Creek watersheds, the Milwaukee Harbor estuary, and the adjacent nearshore Lake Michigan area. This effort is known as the Regional Water Quality Management Plan Update (RWQMPU). The two planning efforts are being coordinated and implemented in parallel.

One important component of both the 2020 Facility Plan and the RWQMPU is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. Watershed models are being developed for the following five watersheds:

- Kinnickinnic River
- Menomonee River
- Milwaukee River
- Oak Creek
- Root River

The Kinnickinnic, Menomonee, and Milwaukee River models will then be linked to a model of the Lake Michigan estuary so that the benefits of upstream water quality improvements can be simulated by the Lake Michigan Harbor / Estuary Model.

The following seven tasks have been identified for performing the system modeling:

1) Establish the model structure, including the delineation of subwatersheds, connectivity, and cross sections, etc.
2) Develop the model data sets using physical measurements, maps, and other appropriate information
3) Perform hydrologic and hydraulic calibration and validation
4) Perform watercourse water quality calibration and validation
5) Perform harbor/estuary and lake water quality calibration
6) Perform production runs as required for project planning
7) Document results.

Tasks 1, 2, and 3 have already been completed for the Menomonee River watershed model. The purpose of this report is to document the revised watercourse water quality calibration and validation for the Menomonee River watershed model (Task 4). The modeling approach and results, by parameter, are presented below.

5.0 MODELING APPROACH AND RESULTS

The calibration process for LSPC is sequential, beginning with the calibration of flow (*Draft Hydrologic Calibration and Validation Results for the Menomonee River Model*). Sediment and dissolved pollutant transport depend directly on the representation of flow, while sorbed pollutant transport depends on the simulation of sediment. (In the model, sorption to sediment within stream reaches is currently simulated for phosphorus, ammonium, and bacteria.) Thus, any inaccuracies in the flow and sediment simulation will propagate forward into the water quality simulation, and the accuracy of the hydrologic simulation provides an inherent limitation on the potential accuracy of the water quality simulation.

Instream water quality kinetics are also highly linked with one another. For instance most kinetic rates depend on temperature, while nutrient balances and dissolved oxygen are strongly linked to the algal simulation. Accordingly, the water quality calibration uses the following sequential process:

1. Calibration of flow (*Draft Hydrologic Calibration and Validation Results for the Menomonee River Model*)
2. Calibration of sediment
3. Calibration of water temperature
4. Initial calibration of gross nutrient transport
5. Initial calibration of BOD and DO
6. Calibration of algae
7. Final calibration of nutrient species and DO
8. Calibration of fecal coliform bacteria
9. Calibration of metals

SEWRPC and WI DNR directed that loads from the land surface should be, to the extent compatible with achieving water quality calibration, consistent with the loads predicted by SWAT for agricultural land uses and by SLAMM for urban land uses. The SLAMM model in particular is preferred by WDNR for use in assessing compliance with State urban nonpoint pollution regulations. Therefore, the loading rates produced by these models form the starting point for the LSPC water quality calibration.

The adequacy of the water quality calibration was assessed through comparison to observed water quality data. It should be noted that the observed water quality data are primarily point-in-time grab samples, which may exhibit significant temporal variability relative to the (unobserved) daily mean concentration.

A key objective is to have the model replicate actual loads through the system. Unfortunately, loads are not directly observed, and can only be estimated from the point-in-time concentrations multiplied by daily average flow. While model adjustments are made to obtain general agreement between simulated loads and estimated observed loads, it should be recalled that the estimates of observed loads are highly uncertain.

The hydrologic calibration results for the Menomonee River model generally indicate good agreement between observed and simulated streamflows. Baseflows are well represented for each season on average over the entire calibration period. The timing of almost all storms is captured, as are the shapes of the hydrographs, although the recession on some storms is slightly slow with the flow being over-predicted. The model meets all seasonal and most monthly tolerance criteria for the entire calibration period. Similar results are observed for the validation period. The successful hydrologic calibration provides a good basis for water quality calibration; however, discrepancies between observed and predicted values do occur for individual months and storm events.

Hydrologic calibration precedes sediment and water quality calibration because runoff is the transport mechanism by which nonpoint pollution occurs and the hydrologic calibration of the Menomonee River watershed model is described in a separate memorandum (*Hydrologic Calibration and Validation Results for the Menomonee River Model*). The approach that was used to calibrate the model for sediment and the other water quality parameters is described in detail below. Figure 3 displays the location of the water quality sampling stations that were used during the calibration process.

Extensive water quality observations collected by MMSD were provided for 1994 through 2001 and were used to calibrate and validate the water quality model. Years 1994 through 1998 were used for calibration. The parameters were then applied to 1999 through 2001 observations as a validation check. Unless noted otherwise, the time series calibration and validation plots are based on the daily mean values of simulated output.

The calibration and validation periods used for water quality differ from those used in the hydrologic calibration due to constraints of data availability. Quality-controlled monitoring data were not available for 2002 at the initial time of the calibration, so this year was not included in the water quality analysis. In addition, the calibration period for water quality was started in 1994 (versus 1995 for the hydrology) to take full advantage of the available data. For both hydrology and water quality, simulations were started in January 1993 to minimize model spin-up effects. Hydrologic simulation for 1994 appears to be fair at the upstream station (1) and good downstream (Figure 2). 1994 was a dry year, and there is a relatively poor correlation between simulated and observed flows for much of the year at the upstream station (Menomonee River at Pilgrim Falls), which may affect model performance for water quality prediction at this location. As seen in the *Hydrologic Calibration and Validation* report, hydrologic results were generally better in later years than in earlier years at this station – perhaps reflecting changes in land use and land management practices as well as relatively sparse precipitation gaging. Observations from 1994 are retained in the water quality calibration to provide a broad range of responses, but do degrade the quality of fit somewhat.

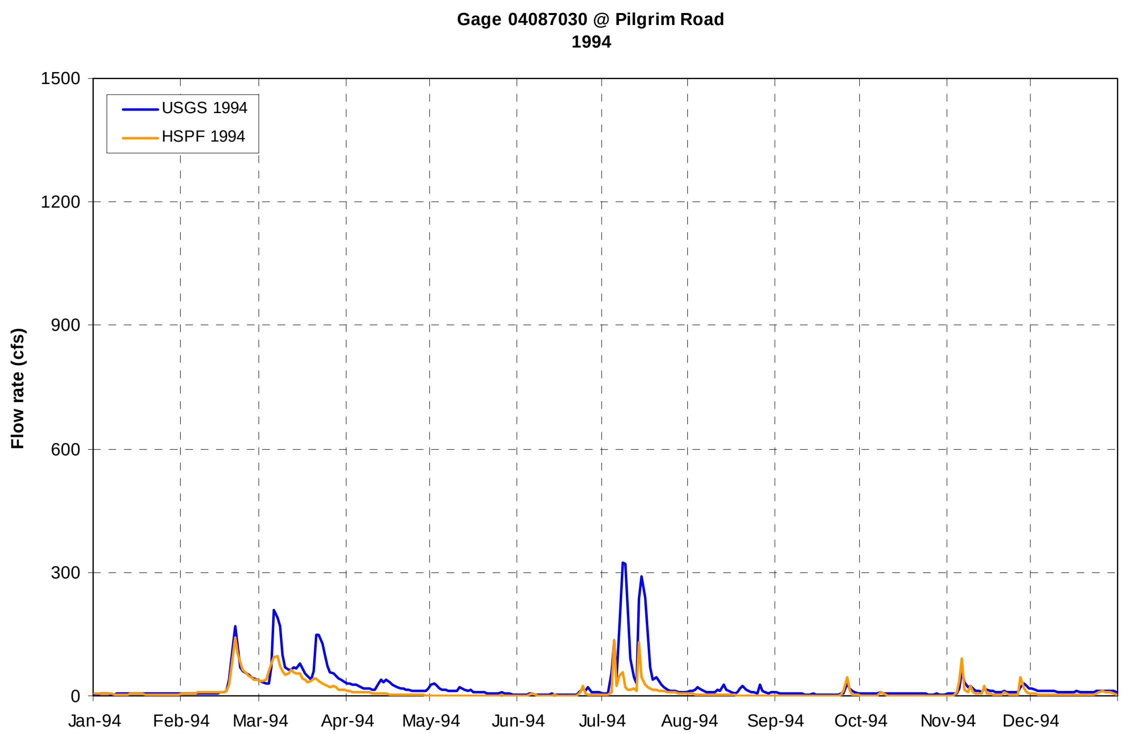


Figure 1. Time series hydrologic results (daily mean) for Menomonee River at USGS gage 04087030 (1994).

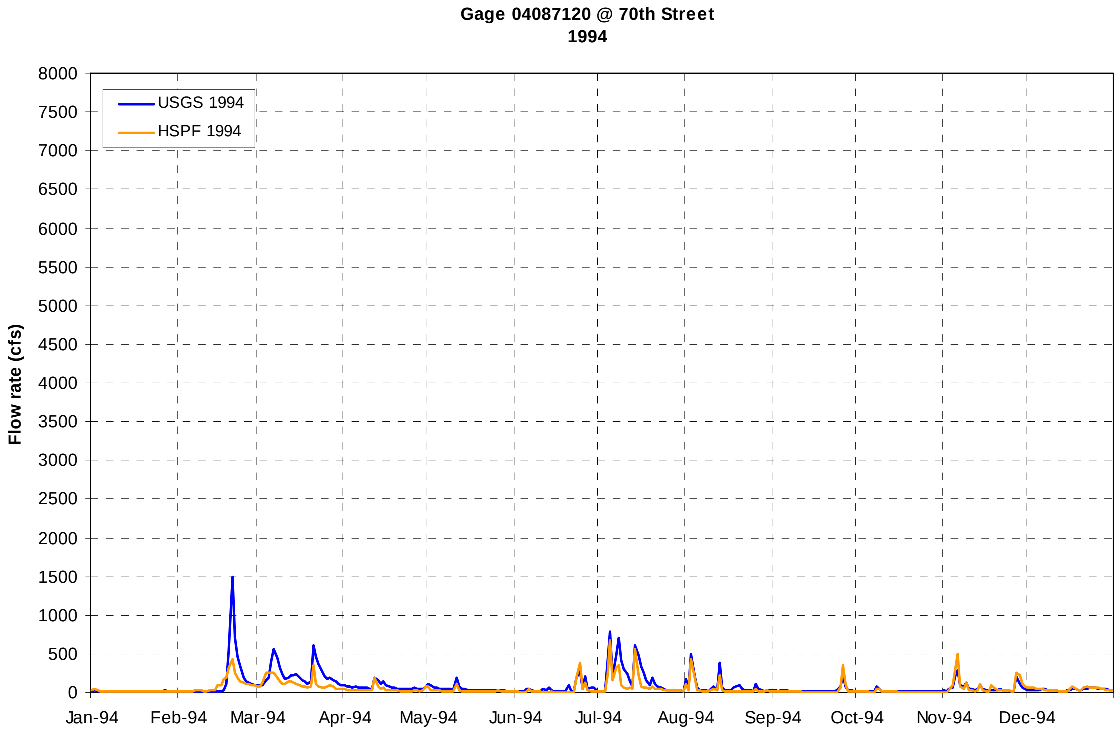


Figure 2. Time series hydrologic results (daily mean) for Menomonee River at USGS gage 04087120 (1994).

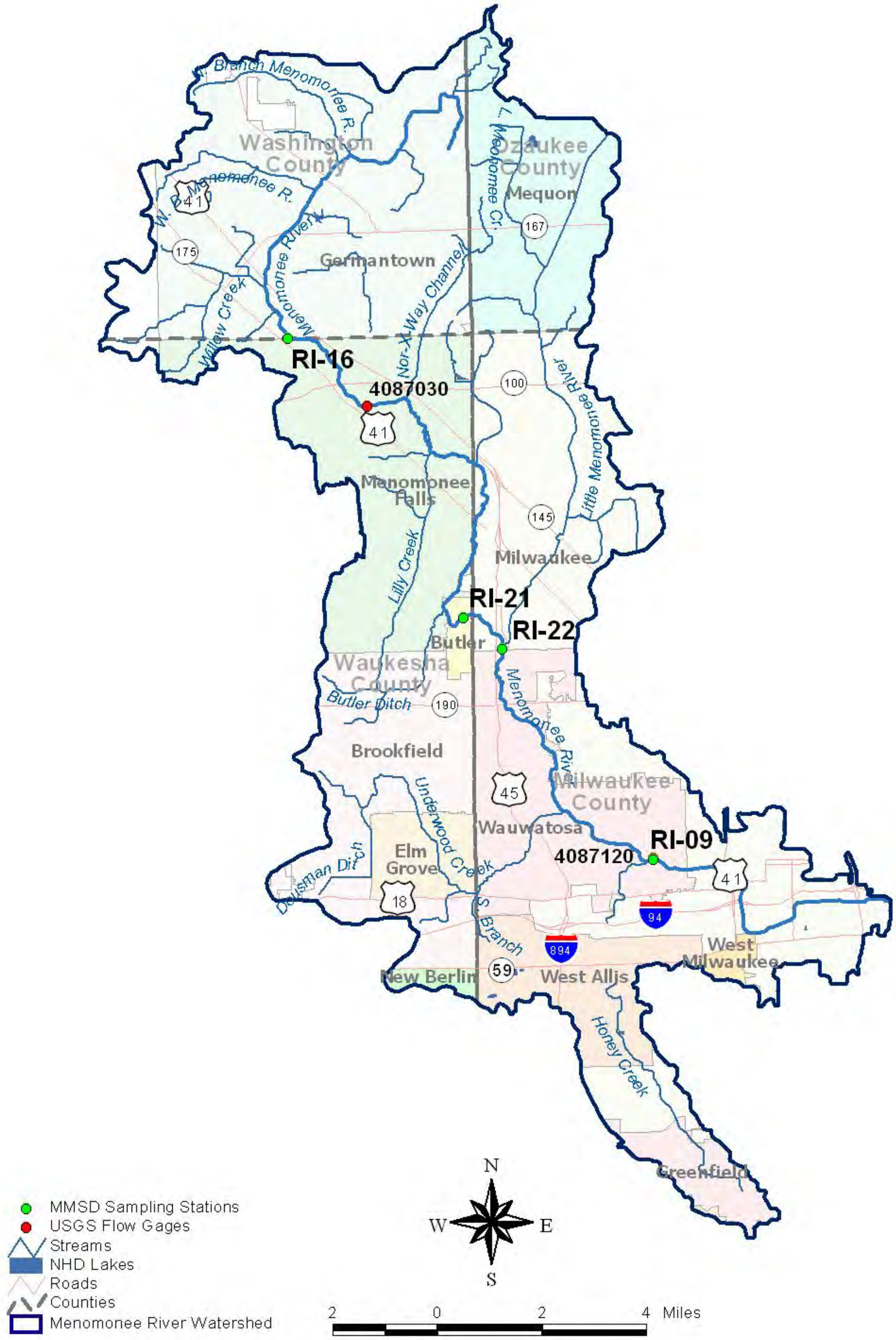


Figure 3. Location of MMSD sampling stations and USGS flow gages on the Menomonee River.

5.1 Sediment Calibration

The general sequence for sediment calibration in LSPC (Donigian and Love, 2002; Donigian et al., 1984) is to (1) estimate target sediment loading rates from the landscape, (2) calibrate the model loading rates to the target rates, and (3) adjust scour, deposition, and transport parameters in the stream channel to mimic behavior of the streams/waterbodies.

Sediment loading from agricultural land uses in the Menomonee River watershed is derived from SWAT simulations and implemented by buildup/washoff coefficients (rather than LSPC sediment routines), as described in a separate memorandum (January 10, 2005 memorandum entitled *Revised and Expanded Discussion of SWAT Application*). The model uses three categories of cropland (by soil hydrologic group); however, the parameters for these groups are modified to reflect the mix of agricultural rotations present in each watershed. Other land uses are simulated using the sediment/solids routines. Parameters for impervious land uses were derived to match SLAMM output as described in the February 16, 2004 memorandum entitled *Urban Non-Point Source Unit Loading Rates*. For grass, forest, and wetlands, the sediment routines were used and parameters were developed based on theoretical relationship to USLE – as discussed below.

Figure 4 displays a comparison of surface washoff loads from PERLNDs with predictions from SWAT for the period 1993 to 1999. Slight differences are expected due to the different simulation of hydrology, but the general agreement is good.

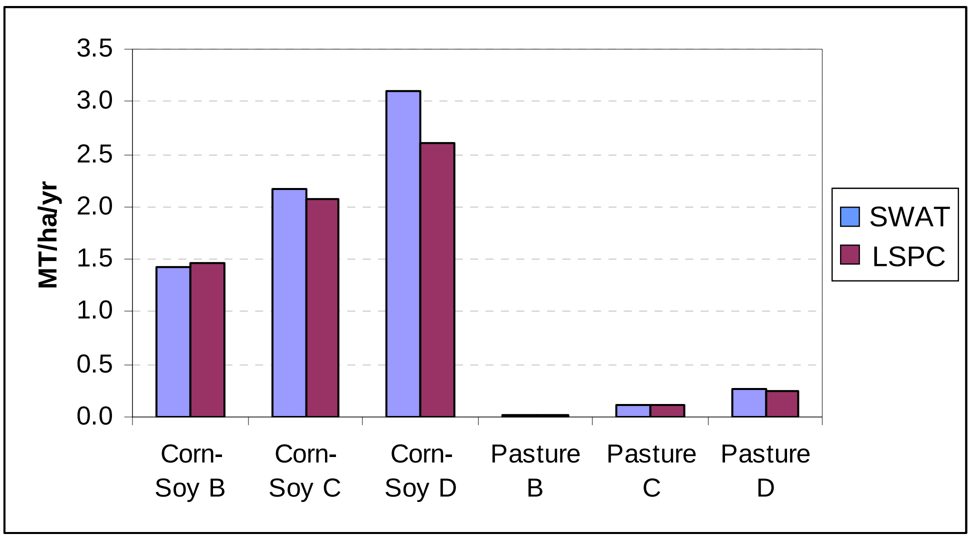


Figure 4. Correspondence of SWAT and LSPC Sediment Loading Rates for 1993-1999, Upper Menomonee.

For urban land uses (and forest), loads were initially set to approximately reproduce estimates produced by SLAMM model applications for 1995 to 1997, as reported in the February 16, 2004 memorandum *Urban Non-Point Source Unit Loading Rates*. The sediment/solids routines in LSPC are used for these land uses. The memorandum reports LSPC parameter values designed to match SLAMM loads. However, significant changes have been made to the parameters controlling flow response from pervious lands since those calculations were done. Therefore, it was necessary to re-estimate the pervious land parameters.

LSPC parameters for pervious land uses were estimated based on a theoretical relationship between LSPC algorithms and documented soil parameters, ensuring consistency in relative estimates of erosion based on soil type and cover. LSPC calculates the detachment rate of sediment by rainfall (in tons/acre) as

$$DETS = (1 - COVER) \bullet SMPF \bullet KRER \bullet P^{JRER} \bullet \frac{1}{1 - AFFIX}$$

where P is precipitation in inches. Actual sediment storage available for transport ($DETS$) is a function of accumulation over time and the reincorporation rate, $AFFIX$. The equation for DET is formally similar to the USLE equation,

$$Sediment\ yield = RE \cdot K \cdot LS \cdot C \cdot P.$$

USLE predicts sediment loss from one or a series of events at the field scale, and thus incorporates local transport as well as sediment detachment. For a large event with a significant antecedent dry period, it is reasonable to assume that $DET \approx DETS$ if $AFFIX$ is greater than zero. Further, during a large event, sediment yield at the field scale is assumed to be limited by supply, rather than transport capacity. Under those conditions, the USLE yield from an event should approximate DET in LSPC.

With these assumptions, the LSPC variable $SMPF$ may be taken as fully analogous to the USLE P factor. The complement of $COVER$ is equivalent to the USLE C factor (i.e., (1 - $COVER$) = C). This leaves the following equivalence:

$$\frac{KRER}{1 - AFFIX} \bullet P^{JRER} \quad = \quad RE \bullet K \bullet LS$$

The empirical equation of Richardson et al. (1983) as further tested by Haith and Merrill (1987) gives an expression for RE (in units of MJ-mm/ha-h) in terms of precipitation:

$$RE \quad = \quad 64.6 \bullet a_t \bullet R^{1.81}$$

where R is precipitation in cm and a_t is an empirical factor that varies by location and season. For southeast Wisconsin (USLE Region 14), a_t is estimated to average about 0.20 (Richardson et al., 1983). As LSPC does not implement $KRER$ on a seasonal basis, the average value is most relevant.

As shown in Haith et al. (1992), the expression for RE can be re-expressed in units of tonnes/ha as:

$$RE \quad = \quad 0.132 \bullet 64.6 \bullet a_t \bullet R^{1.81}$$

This relationship suggests that the LSPC exponent on precipitation, $JRER$, should be set to 1.81.

The remainder of the terms in the calculation of RE must be subsumed into the $KRER$ term of LSPC, with a units conversion. Writing RE in terms of tons/acre and using precipitation in inches:

$$RE\,(tons/ac) \quad = \quad \left[0.132 \bullet 64.6 \bullet a_t\right] \bullet R\,(in)^{1.81} \bullet (2.54\,cm/in)^{1.81} \bullet (1\,ton/ac)/(2.24\,tonnes/ha)$$

or, at the average value for a_t for this region, 4.115 · R (in)1.81.

The power term for precipitation can then be eliminated from both sides of the equation, leaving the following expression for the $KRER$ term in LSPC (English units) in terms of the USLE K factor:

$$KRER \quad = \quad 3.7032 \bullet K \bullet LS \bullet (1 - AFFIX)$$

The K factor is available directly from soil surveys, while the LS factor can be estimated from slope. This approach establishes initial values for $KRER$ that are consistent with USLE information. Further calibration can then modify all $KRER$ values by a single multiplicative factor (thus preserving the relationship among different land use:soil pairs) or by modifying the transport coefficient, $KSER$.

Because SLAMM is a simple model, and was only run for a three-year period, the SLAMM loads were considered to be appropriate as approximate "soft" targets only. The resulting comparison is shown below. Note that SLAMM produces a single loading estimate for B and C soils; however, LSPC simulates very different hydrology, and thus should show different loading rates for these soils. In the case of forest, the solids loading estimate in the February 16, 2004 memorandum was not developed from modeling, but rather is taken from a nonpoint source control plan for the Menomonee River priority watershed project. Undisturbed forest has very low sediment loading rates. However, the major sources of sediment load in areas identified as forest are roads, trails, and other clearings – not the intact forest itself. Most forest land use in the Milwaukee area will have these types of disturbances present. Therefore, it seems appropriate to use a net forest sediment loading rate, based on theoretical parameters, that is significantly greater than the loading of 1.8 lb/ac/yr (0.003 MT/ha/yr) cited in the February 16, 2004 memorandum.

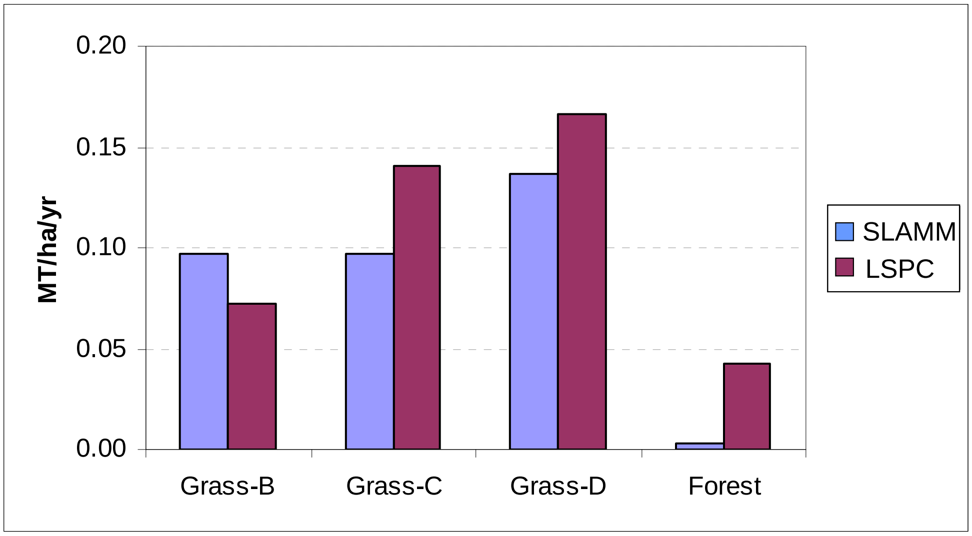


Figure 5. Correspondence of SLAMM and LSPC Sediment Loading Rates for 1995 to 1997.

In addition to surface loads, a fine sediment concentration was associated with ground water discharge from pervious lands. This is necessary to match low-flow (non-scouring) total suspended solids (TSS) observations, and represents miscellaneous non-washoff sources of fine sediment load, including disturbances in the stream channel (by people, vehicles, farm animals, or wildlife) as well as fine sediment actually associated with ground water influx.

Input of these loads directly to the simulated stream reaches results in a consistent over-prediction of sediment concentration and load observed in-stream. This is largely because the first order and ephemeral streams are not simulated and, in these areas as well as in riparian wetlands, substantial trapping may occur. A sediment trapping rate for sediment and sediment-associated pollutants (implemented in the MASS-LINK block) was taken as a general calibration parameter that effectively removes loads from the system. This approach simulates trapping losses as a fixed fraction of influent load, but is only applied to the surface washoff fraction of load. While this is a simplification of actual processes, monitoring of small tributaries is not available to support a more detailed representation of dependence on flow. In fact, the rate of trapping by settling within the stream channel is likely to be greater for smaller, less energetic flows; however, losses that are due to export in the flood plain are greater for higher flows. Actual trapping is also likely to vary by season, depending on vegetation condition. In essence, the trapping factors that are assumed are a simplified, empirical representation of the *net* difference between the estimated loading from the land surface and the event-associated load observed in streams.

Material that is trapped in the floodplain may eventually be eroded back into the stream. This is included as part of the general simulation of loading from the riparian area. Material that is “trapped” through deposition into bed sediments may also be re-entrained during high flow events. For small streams that are not simulated, the model can only represent this sediment source as part of the erosion of the bed material that is present at the start of the simulation in larger reaches. For sediment-associated pollutants, LSPC does not provide a complete sediment diagenesis model, so a mass balance of these constituents in sediment is not maintained in the model. Instead, the user must specify concentrations associated with resuspended sediment.

Setting a trapping rate of 80 percent for sediment loads from pervious surfaces and 30 percent for solids loads from impervious surfaces brings simulated and observed loads approximately into line. In further refinements during calibration, a slightly higher trapping rate was determined to be appropriate for the upstream (Washington County) portion of the basin, probably due to the presence of more extensive riparian wetlands in this area, while a somewhat lower trapping rate for loads from impervious surfaces was used in the downstream, urban portions of the watershed, where direct conveyance to the stream through lined drainage ways is more likely to occur. (Alternatively, the need to employ trapping rates to achieve agreement between the model and data may indicate that the load estimates obtained from SLAMM and SWAT are simply too high.)

The instream parameters controlling scour and deposition mainly serve to modulate the movement of load derived from the uplands. Model simulation of scour and deposition depends on the simulation of shear stress, which in turn depends on the specification of F-tables. Given the simple one-dimensional representation of reaches in LSPC, values of critical shear stress are site-specific. We began with values successfully used in the Minnesota River watershed (Tetra Tech, 2002) and modified them to achieve a reasonable fit. Two sets of parameters were fit: one for the smaller streams, and one for the main channel from Pilgrim Road downstream.

Calibration of LSPC to observed instream suspended sediment concentrations is a difficult process, and an exact match cannot be expected for a number of reasons:

- Because suspended sediments often vary rapidly in time, point-in-time grab sample observations may not be representative of daily-average concentrations. Sediment load peaks are likely to be shifted slightly between the model and observations, resulting in larger apparent errors.
- Any errors in the hydrologic simulation of storm events also propagate into the sediment simulation. Both the washoff of sediment from the land surface and the scour of sediment within streams depend on the shape of the storm hydrograph at a fine temporal scale. But the spatial resolution of the rain gages representing broad geographic areas in the model limits the accuracy.
- Stream reaches are represented as relatively long segments, with average properties. The accuracy of the scour/deposition simulation is limited by the relatively simplified representation of hydraulic conditions in the LSPC model.
- Because of the scale of the model, low-order streams are not explicitly simulated. As a result, sediment dynamics in the smaller streams are also not simulated.
- The timing of snowmelt peak flows is often not accurately captured by the models. These are often also peak sediment transport events.
- LSPC is a one-dimensional model, and thus simulates an average concentration for a cross-section. Samples that are not spatially integrated may not provide an accurate representation of the cross-sectional average concentration. This phenomenon can be particularly important at higher flows where there may be enhanced movement and higher concentrations of sediment near the sediment bed.

Calibration for sediment, as with any other water quality parameter, involves visual and statistical comparison of observed and predicted concentrations. However, the match on individual points is expected to be inexact, for the reasons cited above. For this reason, it is most important to reproduce observed transport curves (Donigian and Love, 2002; MPCA, 2001). That is, a log-log power plot of observed sediment load versus observed flow should match a similar plot of simulated sediment load and simulated flow.

Comparisons of observed and simulated TSS are shown at four available monitoring stations within the LSPC modeling domain, arranged in upstream-to-downstream order (Figure 6 to Figure 13). Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment A.

A statistical comparison of paired sediment observations and simulated daily mean values are provided in Section 5.7 and Section 5.8 below. These comparisons are fairly good, and, as noted above, much of the error in individual point predictions is anticipated to be due to temporal shifts. Observed and simulated sediment transport plots are presented in Section 5.9.

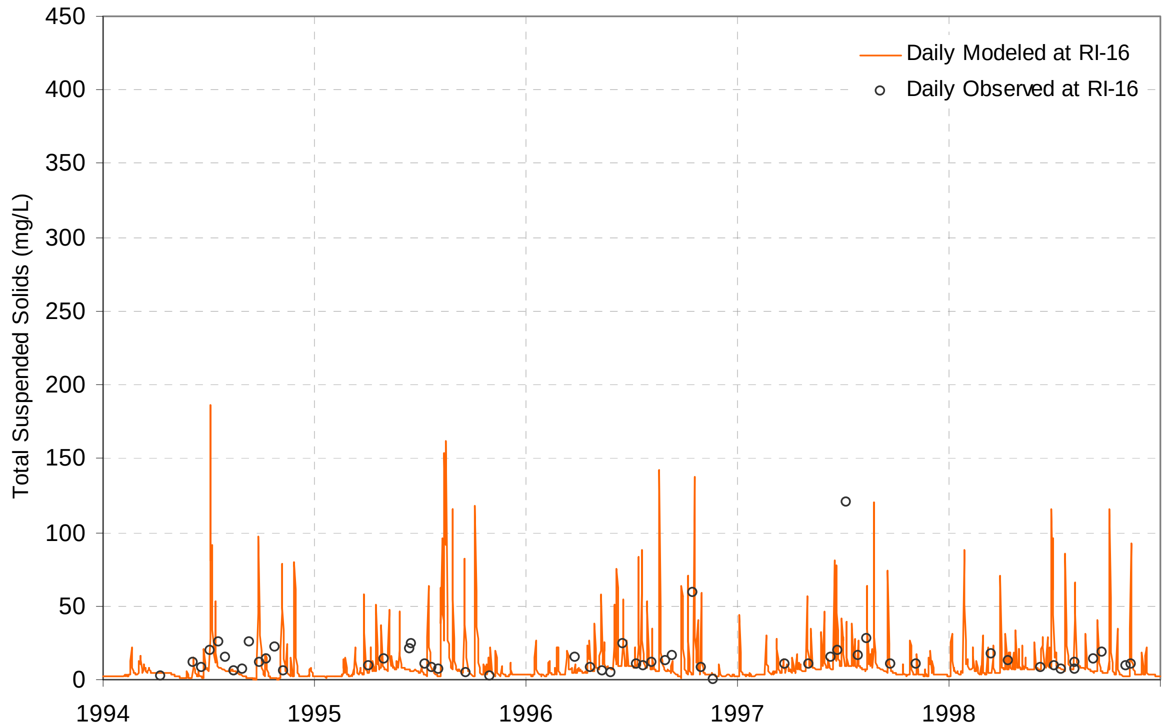


Figure 6. Total suspended solids time series calibration at Menomonee River Station RI-16.

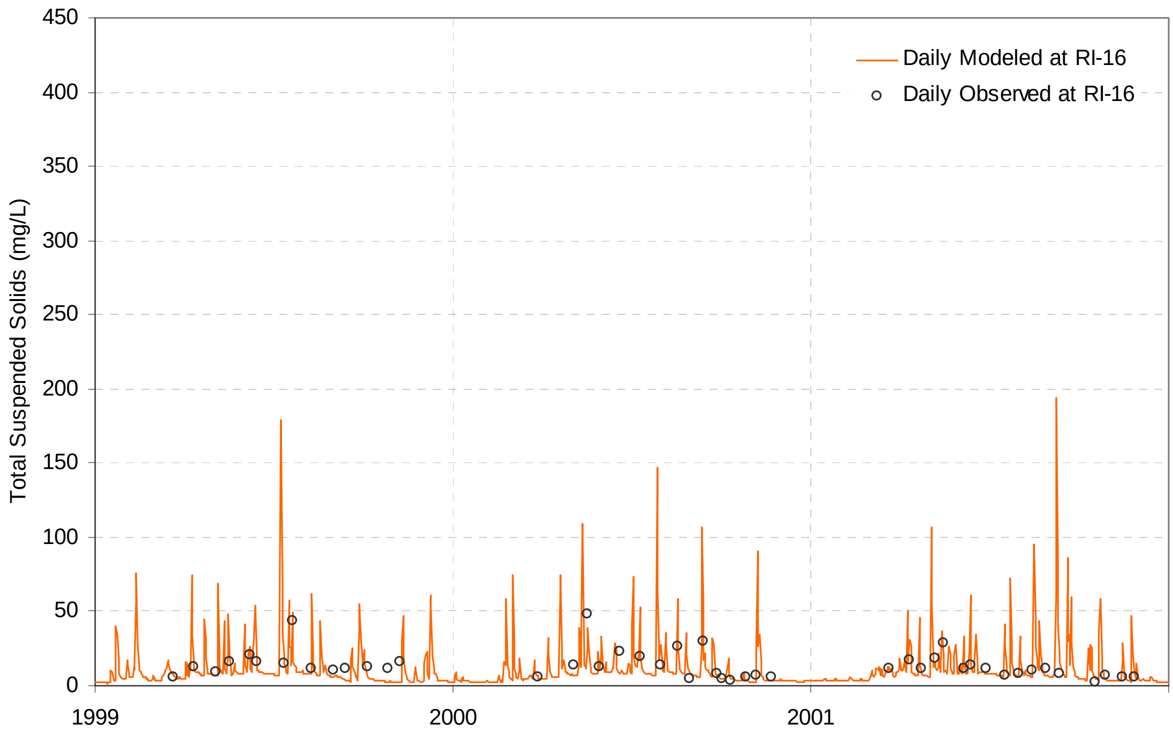


Figure 7. Total suspended solids time series validation at Menomonee River Station RI-16.

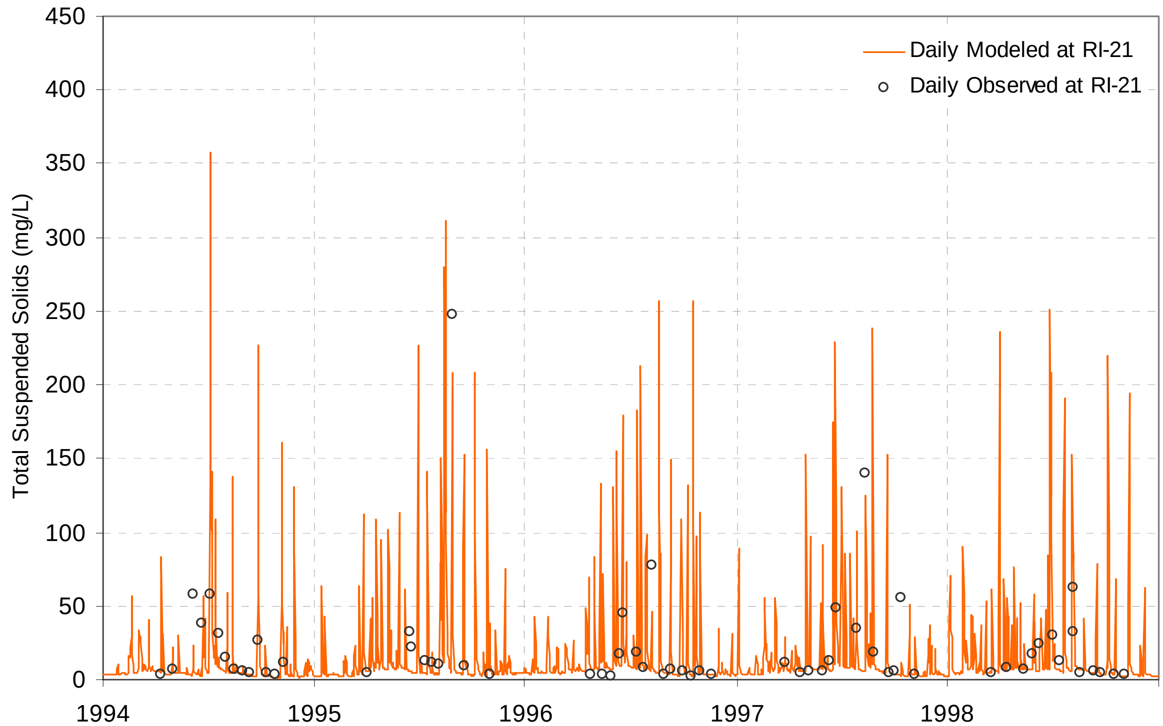


Figure 8. Total suspended solids time series calibration at Menomonee River Station RI-21.

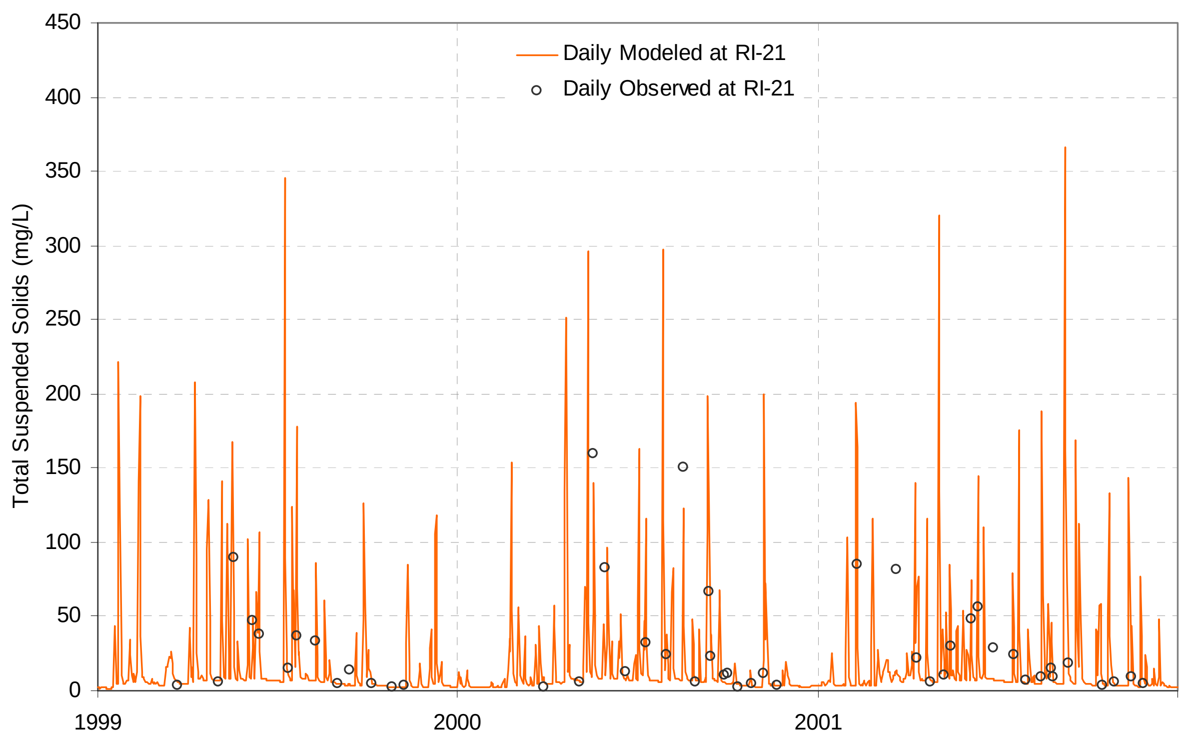


Figure 9. Total suspended solids time series validation at Menomonee River Station RI-21.

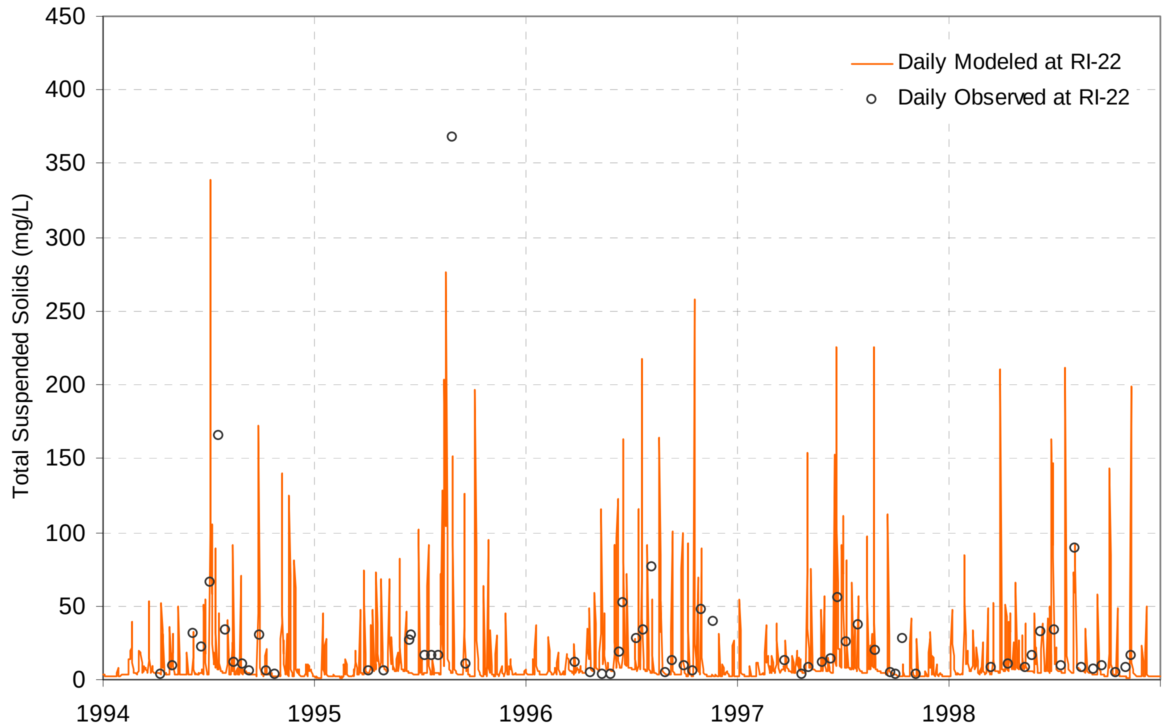


Figure 10. Total suspended solids time series calibration at Menomonee River Station RI-22.

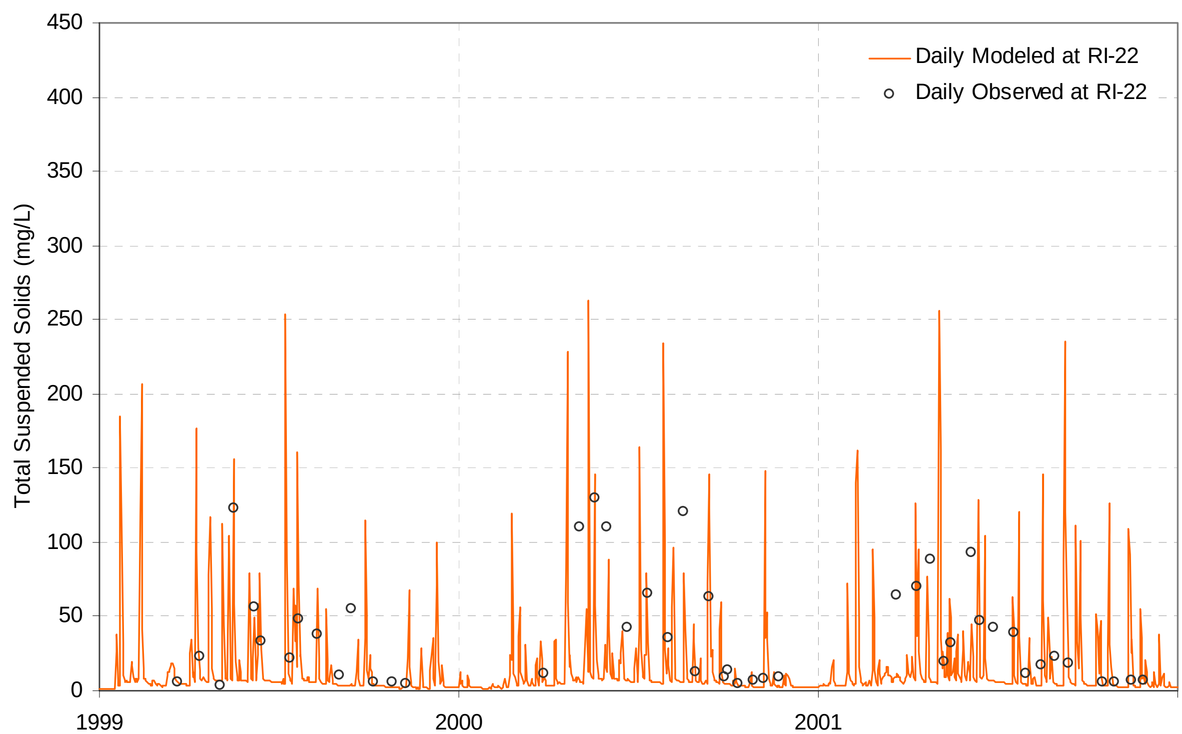


Figure 11. Total suspended solids time series validation at Menomonee River Station RI-22.

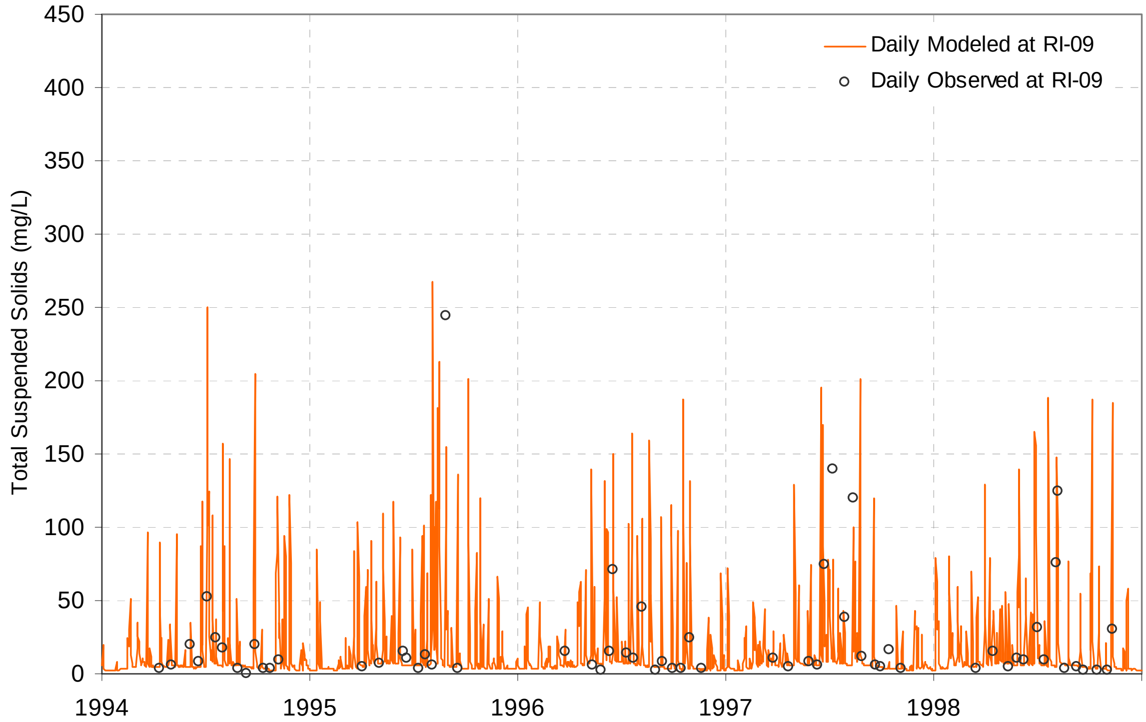


Figure 12. Total suspended solids time series calibration at Menomonee River Station RI-09.

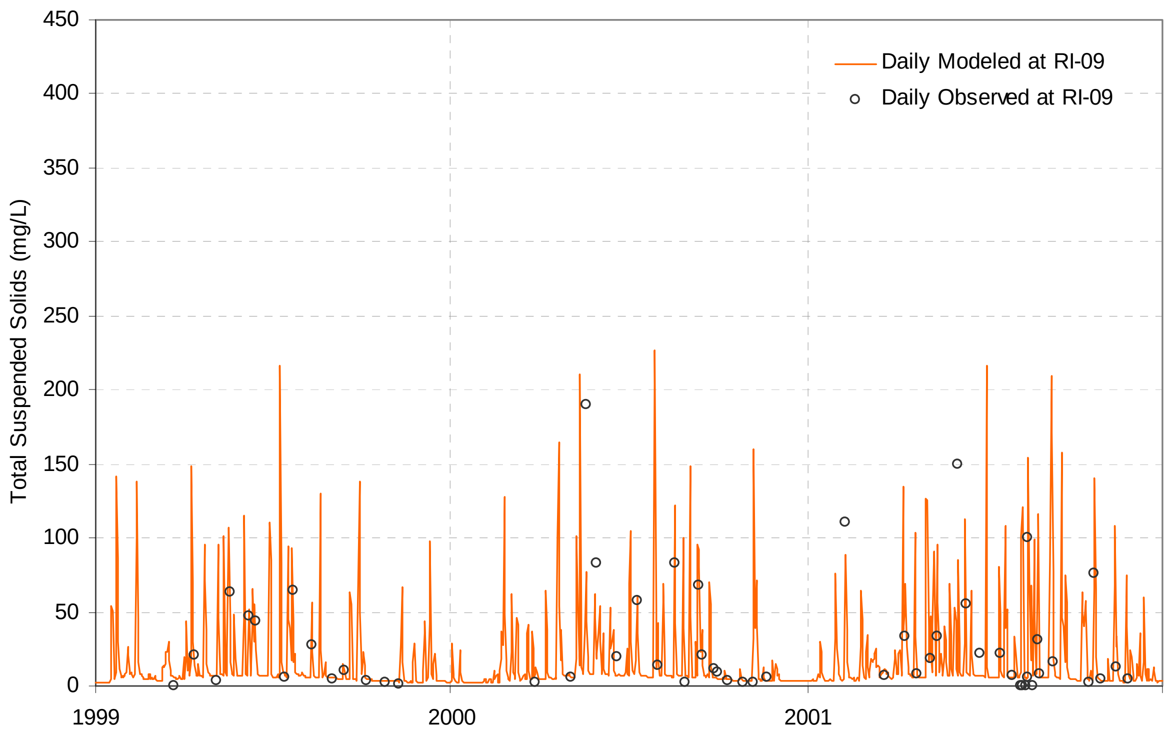


Figure 13. Total suspended solids time series validation at Menomonee River Station RI-09.

5.2 Temperature Calibration

Water temperature simulation is not an explicit goal of the water quality modeling. However, a reasonable simulation of water temperature is necessary because many kinetic reaction rates are temperature dependent. Temperature simulation was therefore checked visually for consistency with observations, but a full statistical analysis has not been provided at this time.

PERLND soil temperature and reach water temperature parameters were adopted from successful Minnesota River model applications. IMPLND runoff temperature was revised to provide a slight increase above ambient air temperature, with constant AWTF = 35 and BWTF = 1.05.

Fit to observed water temperature appears good for both the calibration and validation time periods (comparison is shown to daily averages from the model as many of the observations do not report time of day) (Figure 14 to Figure 21).

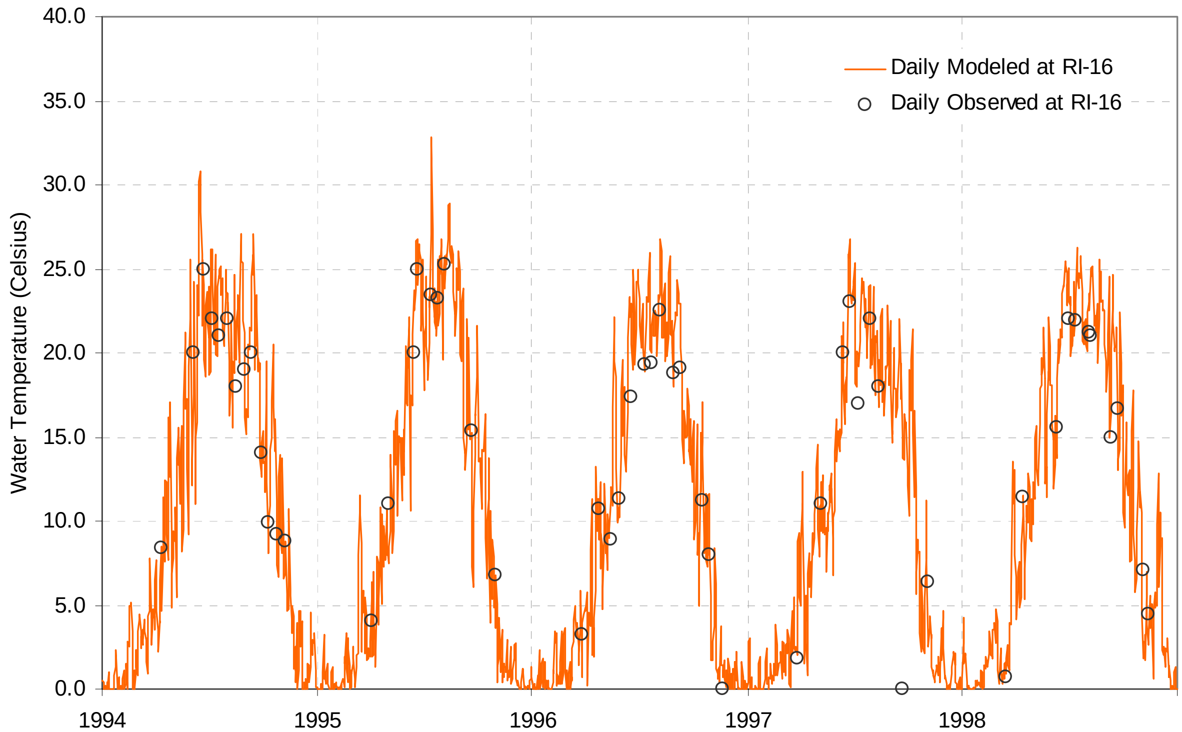


Figure 14. Temperature time series calibration at Menomonee River Station RI-16.

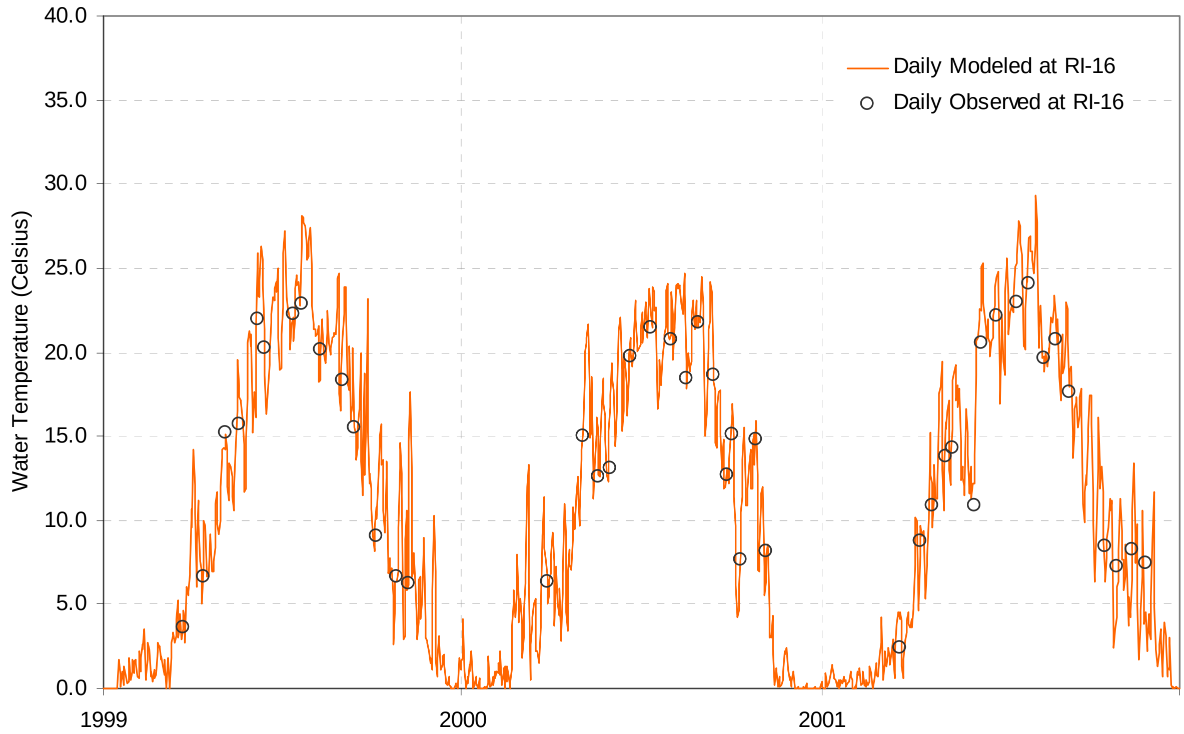


Figure 15. Temperature time series validation at Menomonee River Station RI-16.

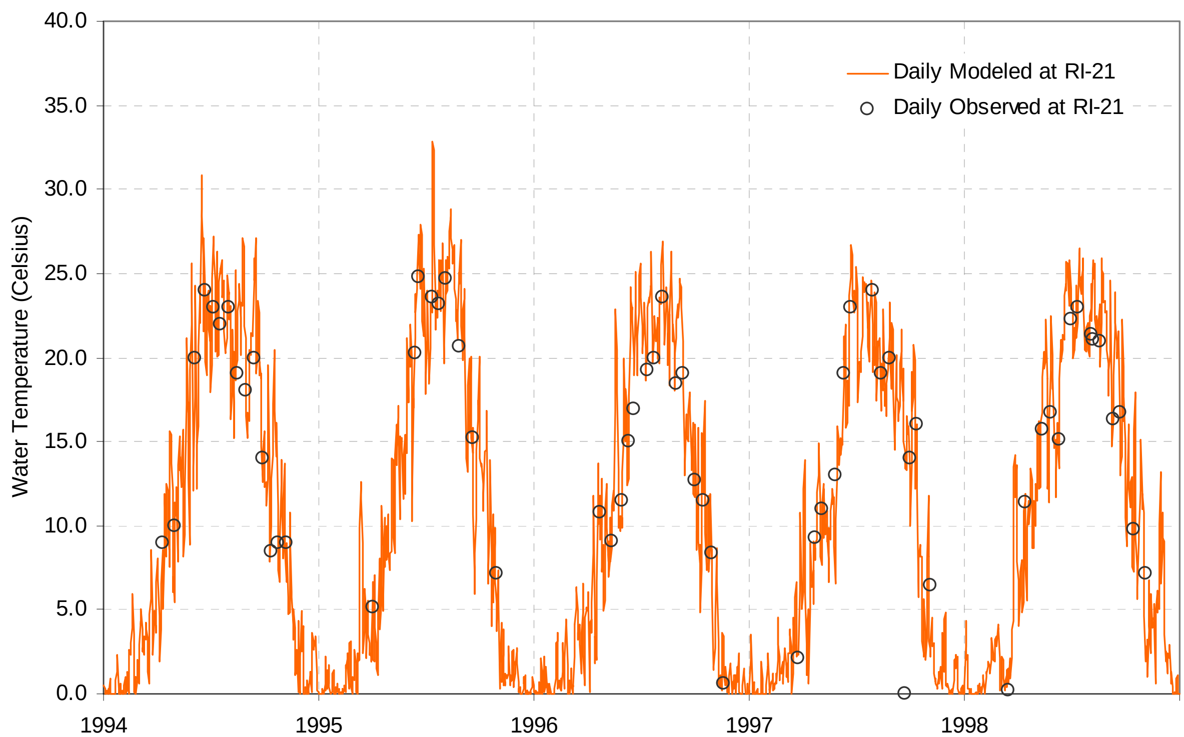


Figure 16. Temperature time series calibration at Menomonee River Station RI-21.

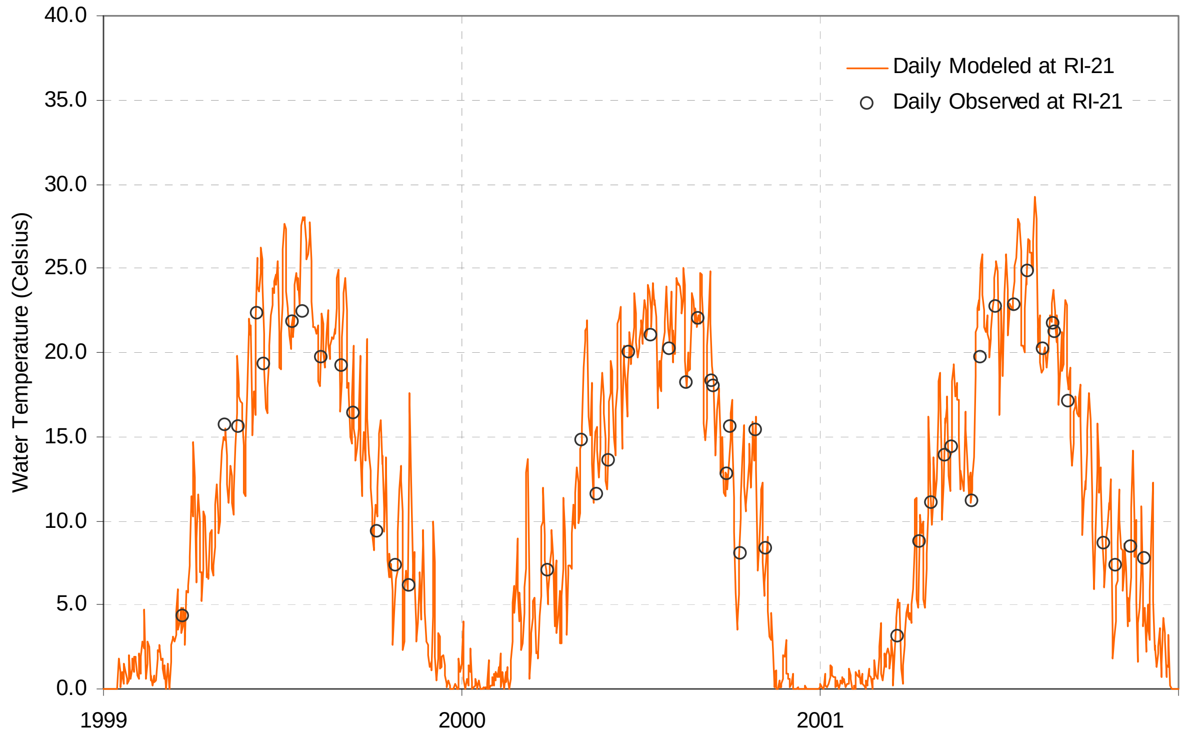


Figure 17. Temperature time series validation at Menomonee River Station RI-21.

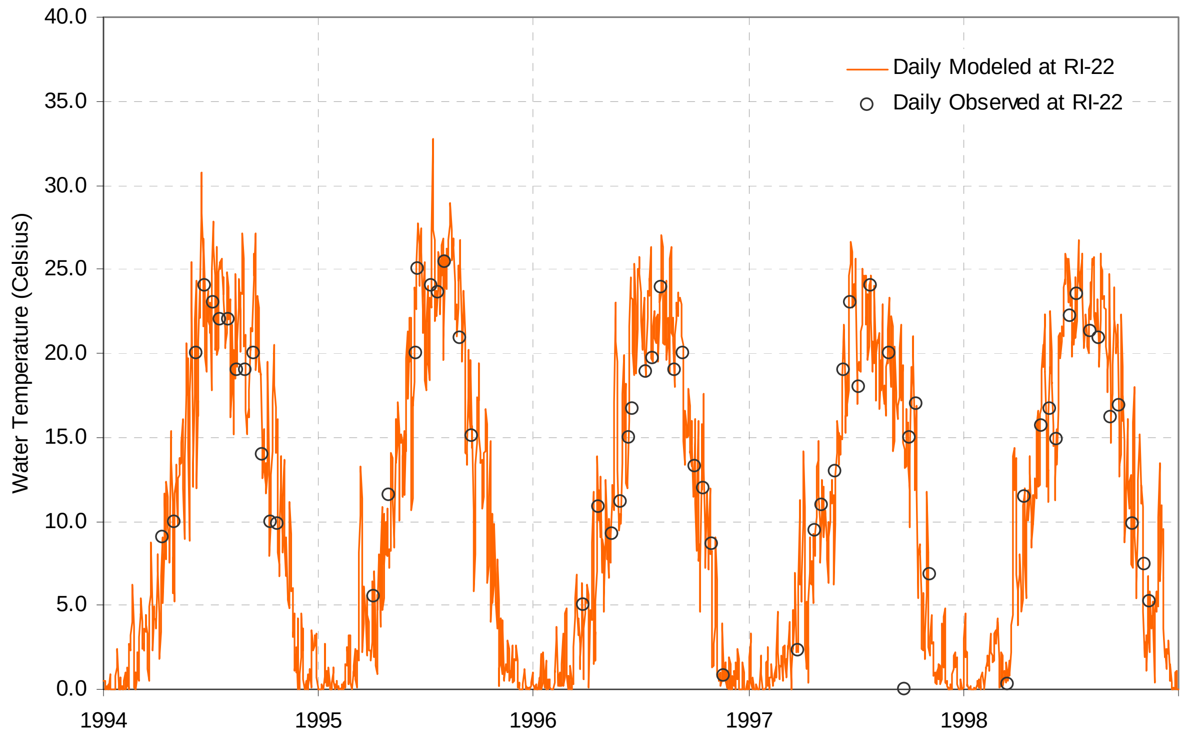


Figure 18. Temperature time series calibration at Menomonee River Station RI-22.

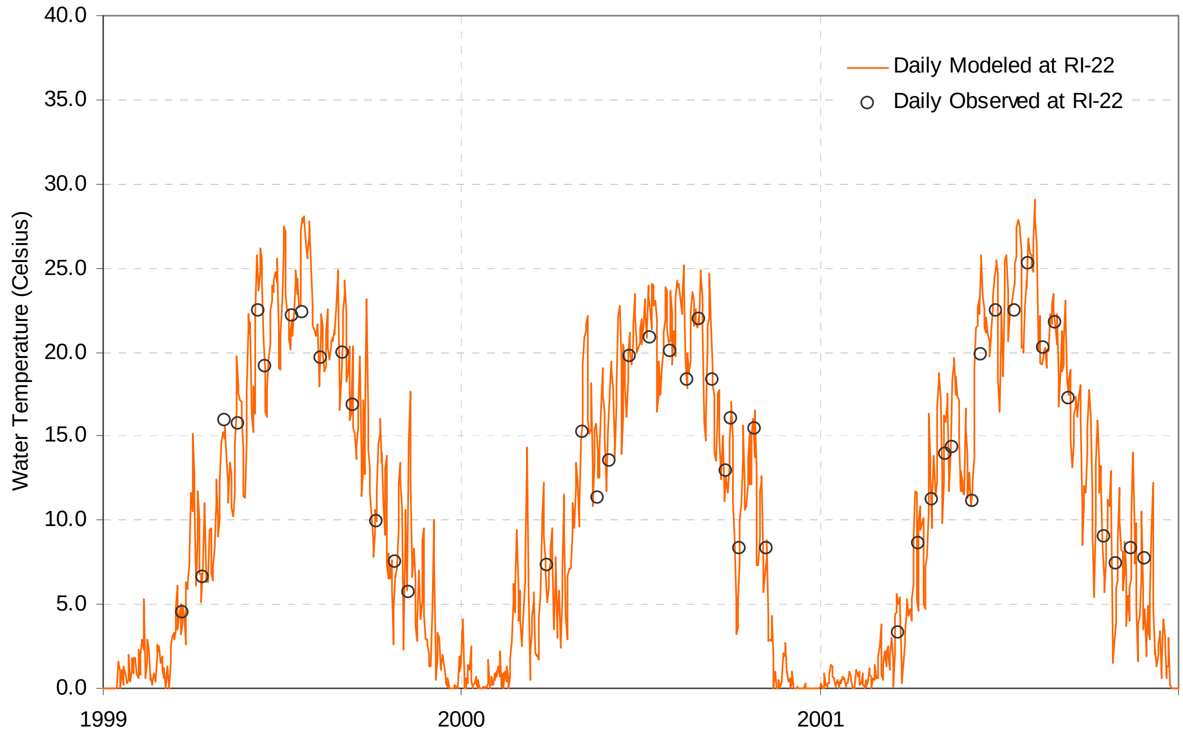


Figure 19. Temperature time series validation at Menomonee River Station RI-22.

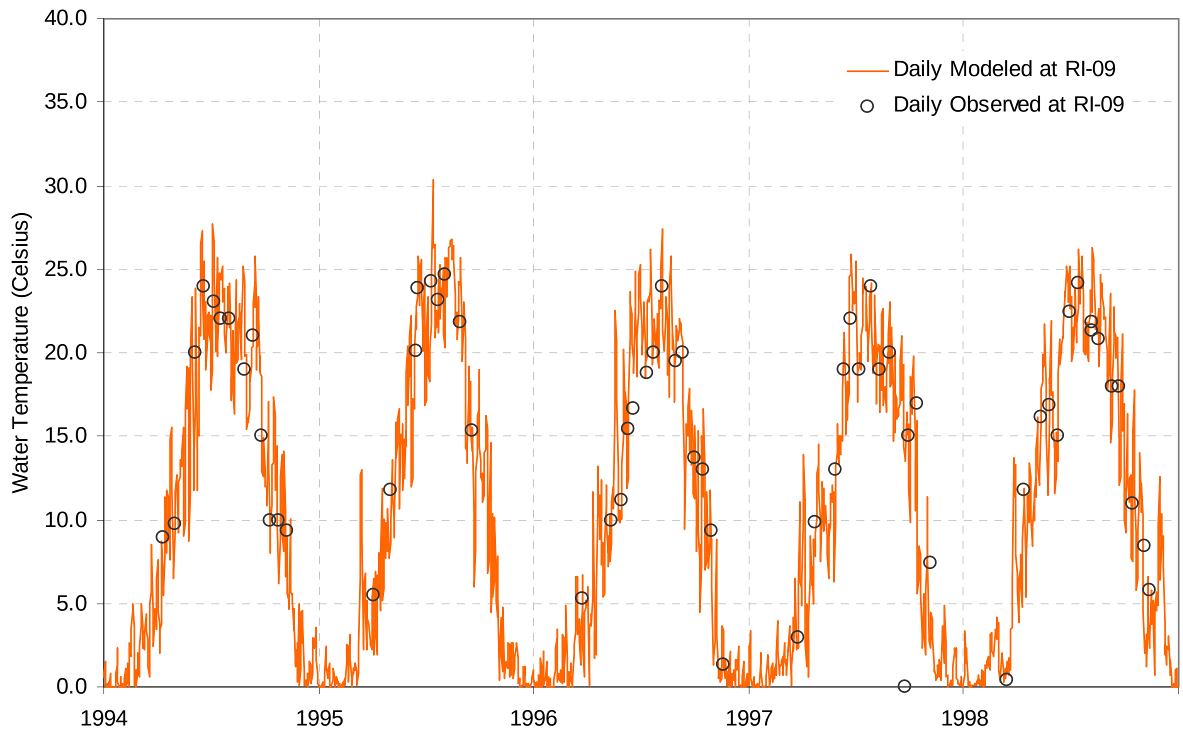


Figure 20. Temperature time series calibration at Menomonee River Station RI-09.

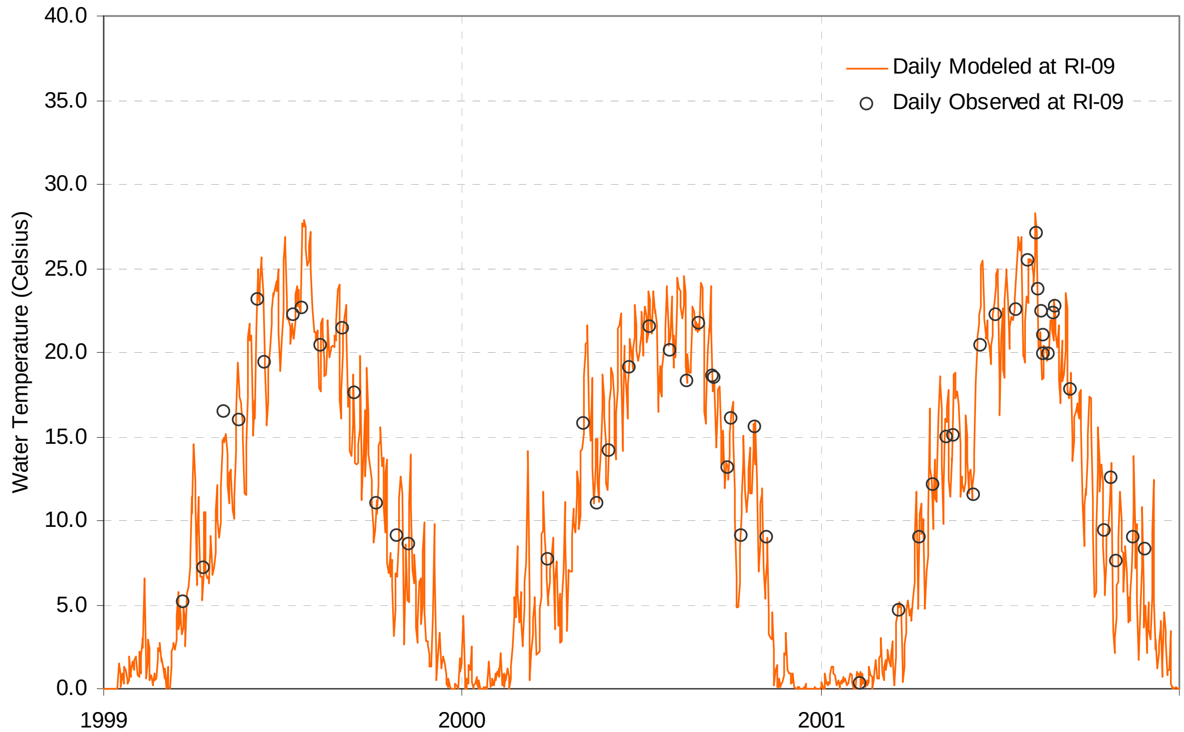


Figure 21. Temperature time series validation at Menomonee River Station RI-09.

5.3 Menomonee Nutrient and Algal Calibration

As with sediment, the starting points for nutrient calibration in the model are the loading estimates for specific land uses derived from the SWAT application (for agricultural lands, 1993 to 1999) and the SLAMM application (for urban lands, 1995 to 1997). This ensures consistency with other tools endorsed by the Wisconsin Department of Natural Resources.

The general strategy for nutrient calibration is as follows: Nutrient loads from the land surface are represented by buildup/washoff formulations, and adjusted to approximately match loads from SWAT and SLAMM. In the case of SWAT, these formulations are implemented on a monthly pattern; in the case of SLAMM, an annual average is used. (This approach is reasonable, as the greatest monthly variability is expected for agricultural lands, due to annual patterns of tillage and fertilization). Because SWAT and SLAMM represent nutrient species in different ways, the buildup/washoff formulations are specified for total nitrogen and total phosphorus. These are then partitioned at the land/water interface into inorganic and organic nutrient species via the LSPC MASS-LINK block. Phosphorus is not simulated as sediment-associated in washoff from the land surface in this model. Within the stream, equilibrium partitioning assumptions are used to spit inorganic phosphorus into sorbed and dissolved fractions, ensuring that the sediment-sorbed fraction is consistent with the available sediment supply in stream.

For agricultural croplands, the loads predicted by SWAT differ significantly by crop and management type. Information on the distribution of crop types in the Menomonee River watershed is provided in the 2003 NASS cropland data layer. This information was used to infer the distribution of cropland into corn (grain)-soybean, dairy silage, alfalfa, and straight corn rotations. Loading rates and associated parameters for each sub-watershed were then adjusted to reflect the crop distribution in that subwatershed.

The model must be adjusted to achieve calibration to observed instream nutrient concentrations. In general, the mass of nutrients observed instream are significantly less than the nutrient export from the land surface predicted by SWAT and SLAMM. This is believed to reflect trapping (of sediment-associated pollutants) and biological uptake (of labile forms), which primarily occurs in the small first-order and ephemeral streams. These small streams are not represented as reaches in the LSPC model, therefore the use of trapping factors is appropriate, and also enables calibration to be achieved while maintaining the relative loading magnitude for different land uses predicted by the SWAT and SLAMM models. Secondary adjustments to calibration are achieved by (1) adjusting the subsurface nutrient concentration components, and (2) adjusting instream nutrient kinetic parameters.

5.3.1 Unit Area Loads

SWAT and SLAMM unit area nutrient export loads from the land surface for various land uses have been reported in previous memoranda. However, the LSPC parameters previously proposed to match SLAMM predictions are no longer valid, due to refinements in the LSPC hydrology representation, and have been recalibrated to match the SLAMM loads. Because each model represents the runoff response in a different way, an exact match cannot be obtained. However, the calibrated response is in general quite close.

Comparison of the SWAT/SLAMM and LSPC loading rates for phosphorus is shown in Figure 22 and Figure 23, indicating a close match. The forest results are those provided in the SLAMM memo, but are derived not from SLAMM, but rather from the recommended phosphorus export coefficient for forested watersheds.

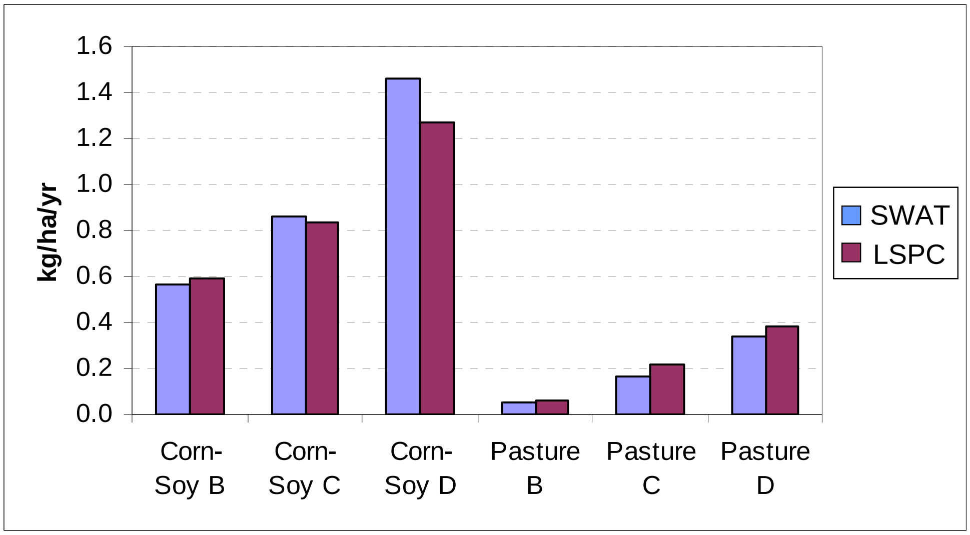


Figure 22. SWAT and LSPC Concordance for Total Phosphorus Loading from Agricultural Land Uses, 1993-1999

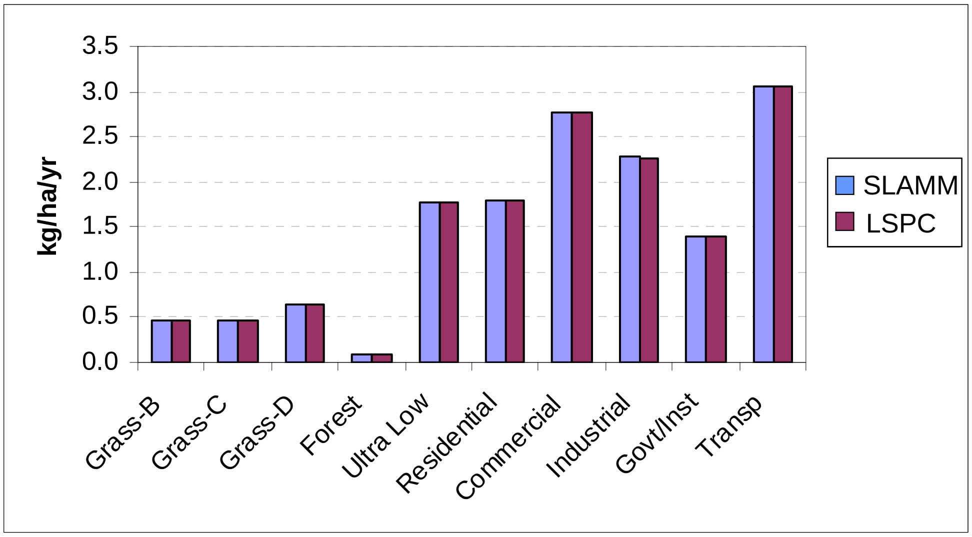


Figure 23. SLAMM and LSPC Concordance for Total Phosphorus Loading from Urban Land Use and Forest, 1995-1997.

Calibration for nitrogen is somewhat more problematic. First, SWAT predicts complete nitrogen species, including both organic and inorganic forms of load. SLAMM, in contrast, provides estimates only for nitrate and ammonium loading. A second issue is that much of the annual nitrate export from a pervious land area occurs through subsurface pathways. While total nitrogen is simulated in the LSPC application, comparison is made in terms of the nitrate fraction, using the nutrient speciation described below for LSPC, and applied only to the portion of the nitrate load generated transported through surface event washoff. For SWAT, the nitrate load is compared to the nitrate load from LSPC. For SLAMM, the sum of estimated nitrate and ammonia loading is converted to a constant fraction nitrate and compared to the nitrate fraction from LSPC. Results are shown in Figure 24 and Figure 25.

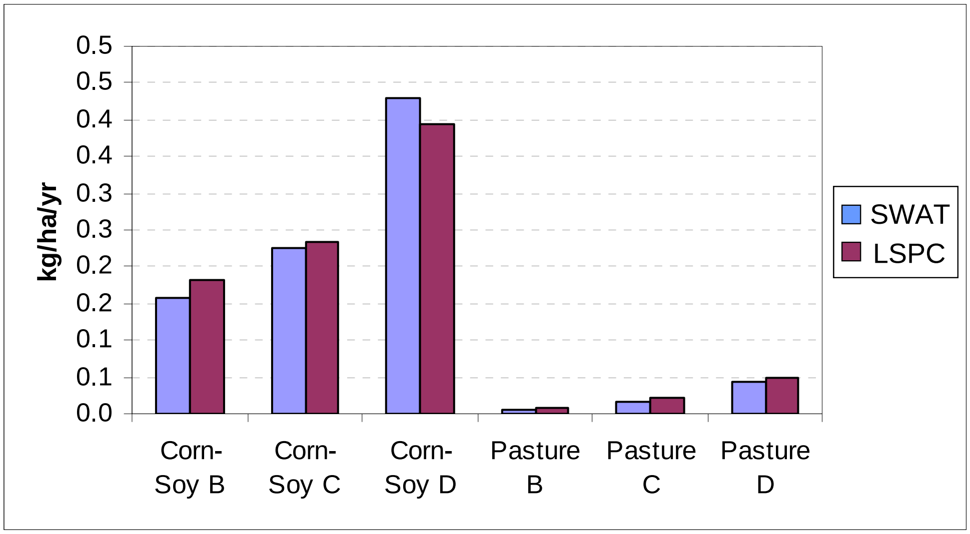


Figure 24. SWAT and LSPC Concordance for Nitrate Loading from Agricultural Land Uses, 1993-1999

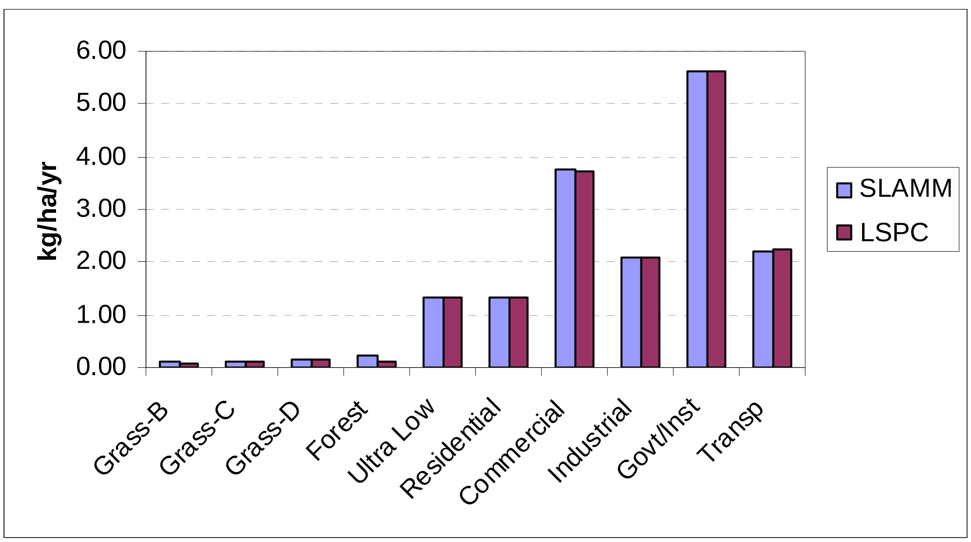


Figure 25. SLAMM and LSPC Concordance for Nitrate Loading from Urban Land Use and Forest, 1995-1997.

In Figure 25, a close match is purposely *not* imposed between LSPC and the estimate reported in the SLAMM memo for forest, noted as “derived from SLAMM model output using ratios.” The resulting inorganic nitrogen export rate presented in that memo for forest (0.36 lb/ac/yr) is nearly three times that presented for urban grass, which seems unrealistic for the surface washoff pathways – probably because it also accounts for subsurface loadings. Therefore, the surface loading for nitrogen from forest was set to a lower rate of 0.106 kg/ha/yr inorganic N (0.88 kg/ha/yr total N), consistent with work in the Minnesota River and the LSPC application of Hartigan et al. (1983).

For the agricultural lands, seasonality was incorporated into the simulation by specifying monthly buildup rates and accumulation limits. These were calculated from the annual average rate by adjusting each month according to the ratio of the monthly load to the average load.

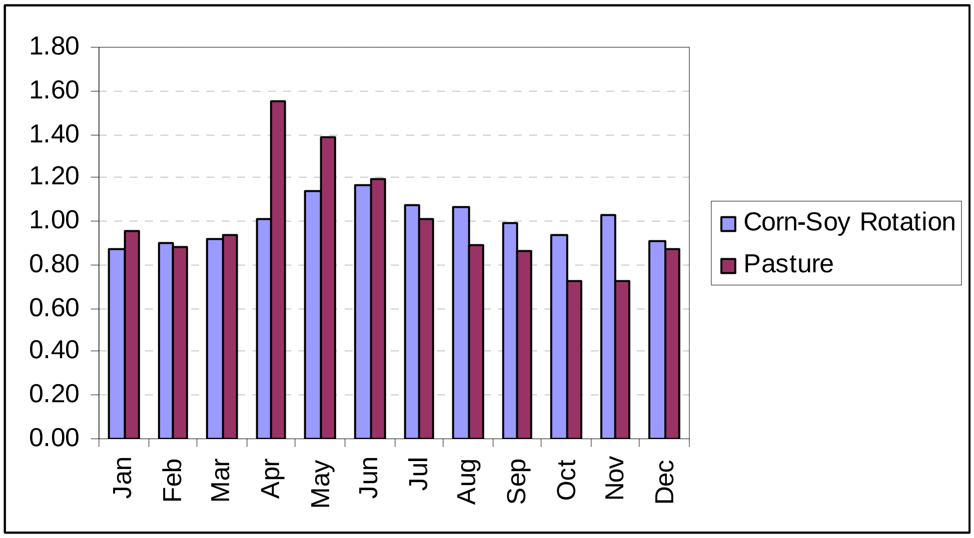


Figure 26. Monthly Adjustment Factors for Phosphorus Buildup/Washoff from Agricultural Land

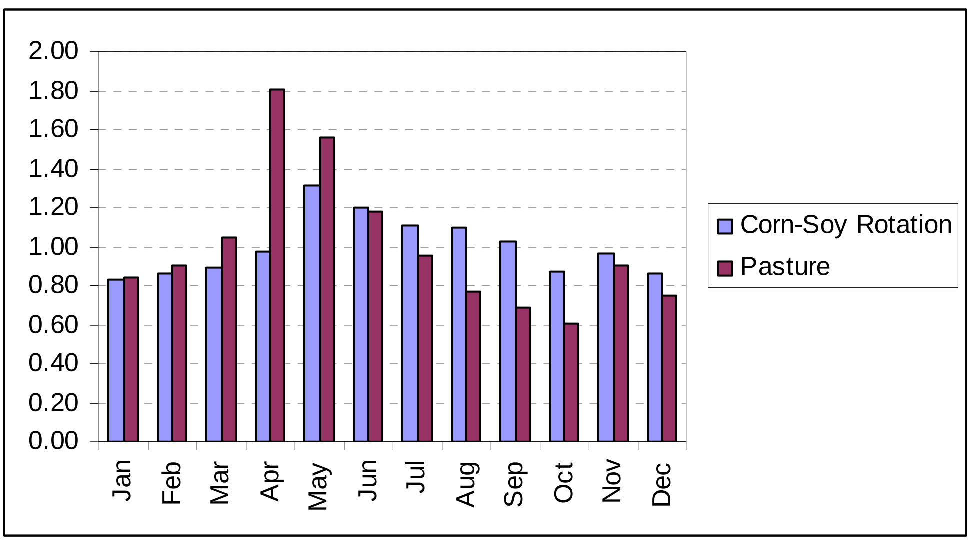


Figure 27. Monthly Adjustment Factors for Nitrogen Buildup/Washoff from Agricultural Land

5.3.2 Subsurface Loads

Subsurface loading of phosphorus, which is relatively insoluble, forms an insignificant portion of the annual mass load. Concentrations were set to reflect instream observations during baseflow periods, with concentrations of 0.01 to 0.04 mg/L in interflow and 0.01 mg/L in ground water for all land uses.

For nitrogen, subsurface flow is a major pathway, particularly for fertilized agricultural land. Loading from crop land typically shows a distinct seasonal pattern. For example, USGS NAWQA studies in agricultural watersheds of northeastern Iowa (Becher et al., 2000) showed a peak baseflow concentration of total nitrogen in May and June, a minimum in September/October, and a secondary peak in November/December. This pattern reflects spring fertilization, plant sequestration of nitrogen during the growing season, and late fall application of fertilizer to about one-third of the row crops in the studied watersheds. Similar patterns were observed in the Minnesota River watershed (Tetra Tech, 2003). Seasonal patterns are also likely to apply for residential/urban grass.

For the Menomonee, the subsurface nitrate concentrations from agricultural lands appear to be much lower than in Minnesota and Iowa; however, a similar temporal pattern is likely. The lower loads may reflect a lower intensity of agriculture, different fertilization practices, and different soil characteristics. Seasonal values assigned to fertilized cropland and grass are shown in Figure 28. All other land uses were assigned values around 0.4 mg/L with minor or no seasonal variation.

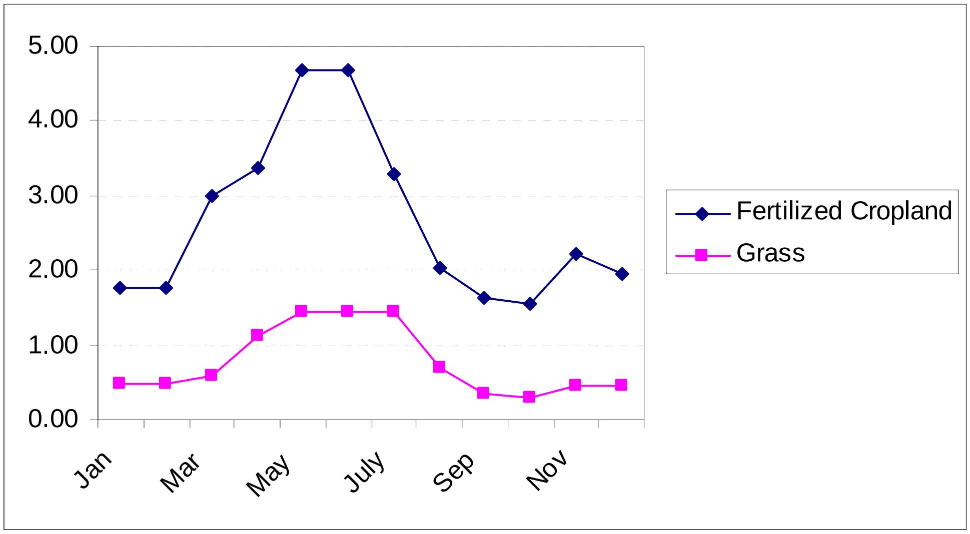


Figure 28. Assignment of Seasonal Subsurface Total Nitrogen Concentrations

5.3.3 Partitioning of Nutrient Species

As noted above, total nitrogen and total phosphorus are simulated on the land surface, and are partitioned into various species at the point of entry to simulated reaches. It should be noted that this partitioning is not expected to be identical to the speciation that would be observed in field-scale runoff. This is because there may be extensive transformations (e.g., adsorption, oxidation, uptake by bacteria) that occur within the small first-order streams that are not explicitly represented in the LSPC model.

Phosphorus is first separated into labile orthophosphate and "organic" species – where the organic group is also used as a repository for refractory (non-bioavailable) inorganic phosphorus. The orthophosphate is then divided between dissolved and sediment-sorbed fractions. Because phosphorus is strongly associated with sediment, a trapping factor is applied to account for losses in first-order streams consistent with the simulation of sediment. This phosphorus trapping factor was set to 50 percent in most of the basin, with slightly higher rates in the Washington Co. portion of the watershed where higher sediment trapping rates were determined through calibration.

Detailed phosphorus speciation has not been studied in the Menomonee River; however, a possible starting point for speciation is provided by the highly detailed study of the Redwood River (MN) undertaken by the USACE (James et al., 2001). While this provides some guidance, the correspondence is not expected to be exact, due to differing soil chemistry. The results of James et al. were therefore adjusted during calibration for the Menomonee. Nitrogen partitioning was set to generally represent results observed in the Menomonee while maintaining consistency with organic:inorganic fractionation predicted by SWAT. No trapping was assumed for nitrogen, which is much more mobile than phosphorus. The implemented nutrient partitioning for loads from pervious land areas is shown in Figure 29.

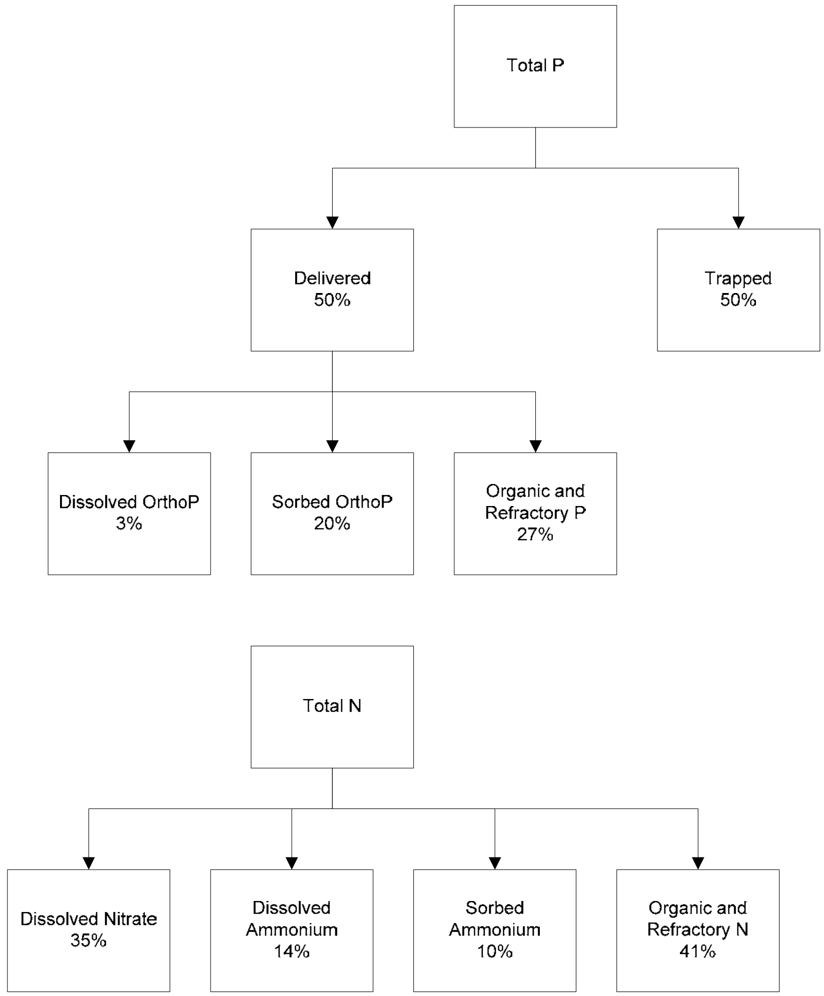


Figure 29. Partitioning of Nutrients in Surface Washoff Loads from Pervious Lands

Surface phosphorus loads from impervious land areas were assumed to partition the same as for loads from pervious lands. Nitrogen from impervious land was, however, assumed to have a higher ammonium content, consistent with the SLAMM results. Subsurface loads of phosphorus were assigned to the dissolved orthophosphate component, while subsurface loads of nitrogen were split between the dissolved nitrate, dissolved ammonium, and organic nitrogen fractions, with a shift toward organic and refractory N in ground water (62%). Little direct data are available on which to base these assignments. Nutrient fractions present in shallow ground wells often do not well represent the effective concentration of nutrient species in discharging ground water because of high rates of biological activity in organic sediments of the stream bed. Therefore, specification focused on approximate matching of nutrient speciation observed instream during baseflow conditions.

5.3.4 Instream Nutrient Kinetics

Both total concentration and speciation of nutrients instream are affected by a number of factors, including sorption and settling of orthophosphate and ammonium, scour of bed material, settling of organic material, decay of organic material, and uptake/release by algae.

The sorption/settling/scour process is particularly important for orthophosphate. A wide range of partition coefficients have been reported in the literature for orthophosphate, covering several orders of magnitude. The partition coefficient of orthophosphate to silt and clay was set at 1000 mL/g, consistent with experience at other sites and in general agreement of the value of 863 mL/g estimated by James et al. (2001) for the Redwood River. Nutrient bed concentrations affect concentrations observed during high flow events, and were adjusted during calibration to 100 mg/kg for ammonium and 75 mg/kg for orthophosphate (on fine sediment). The other parameters were set to appropriate default values, then further refined during calibration for algae and DO.

5.3.5 Nutrient Calibration

Calibration for nutrients addresses both total nutrient concentration and individual nutrient species. This calibration process is inherently somewhat inexact for a number of reasons. First, there is typically significant analytical uncertainty in reported results – which is clearly evidenced by the fact that reported orthophosphate is sometimes greater than total phosphorus. This is particularly problematic when concentrations are near detection limits. Another problem is often observed at high flows, where substantial amounts of nutrients may move either as parts of larger debris or associated with sediment bedload, both of which are likely to be omitted from surface grab samples.

Modeling results are presented graphically below, arranged by parameter from upstream to downstream (Figure 30 to Figure 69). It should be noted that the environmental samples include a contribution to nutrients from living algal cells that is not present in the LSPC simulations. Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment A.

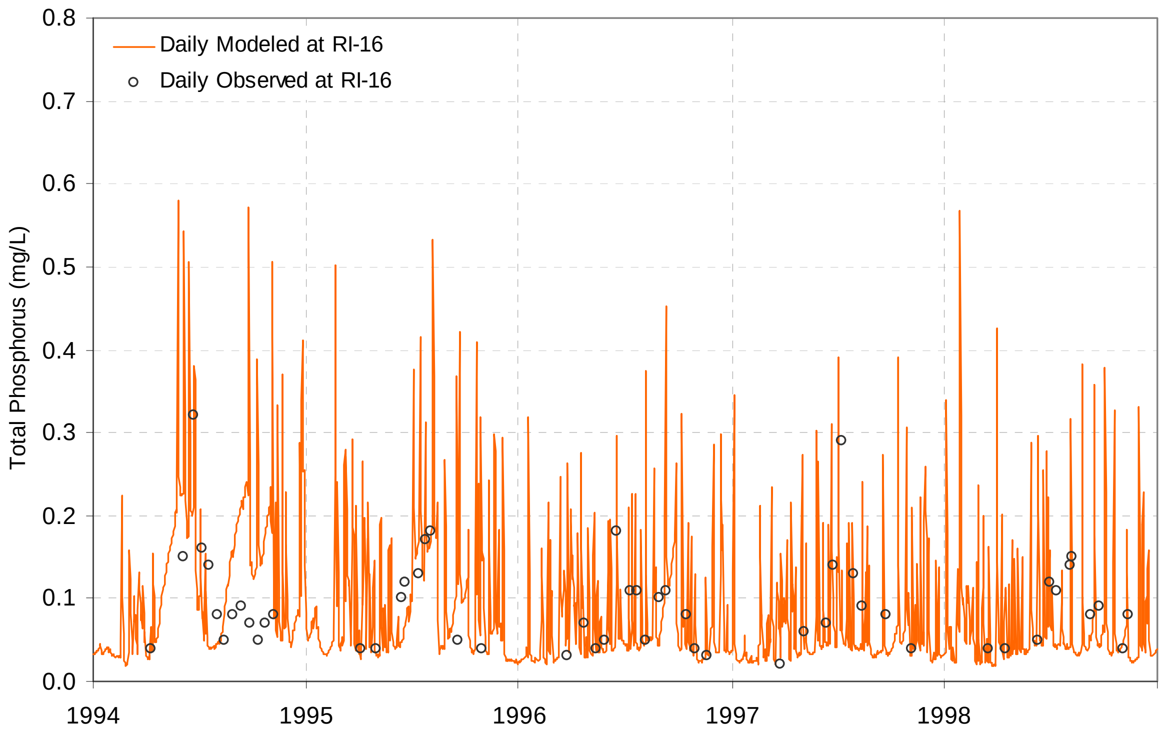


Figure 30. Total phosphorus time series calibration at Menomonee River Station RI-16.

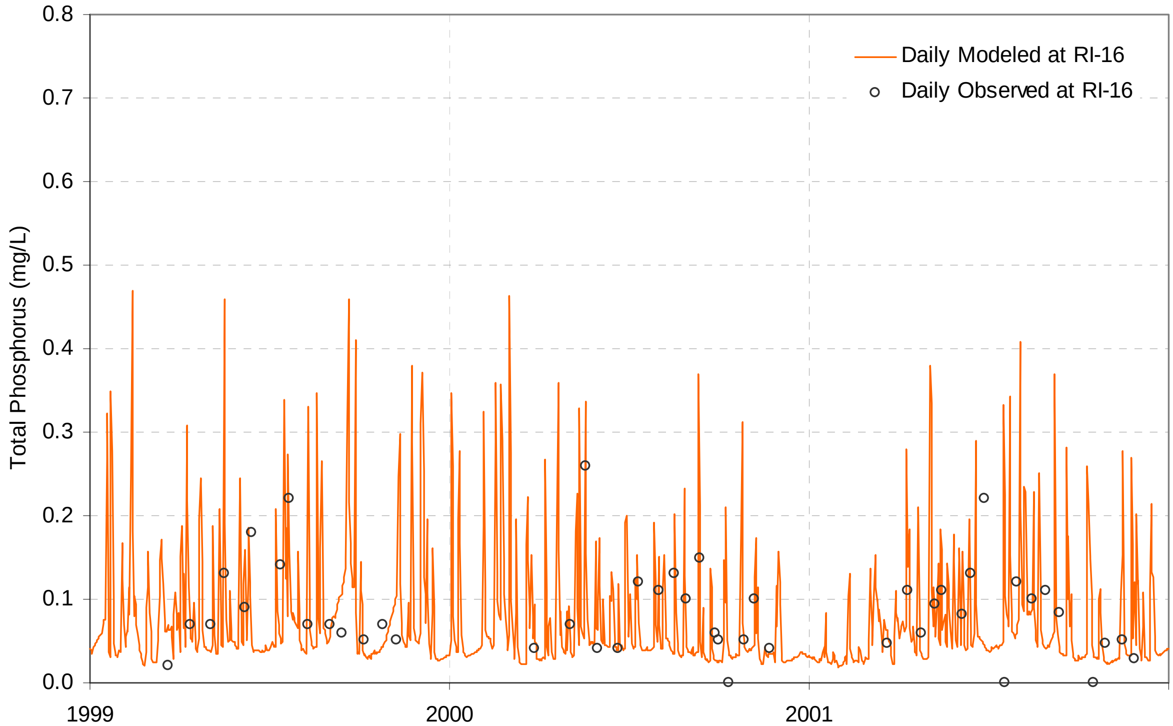


Figure 31. Total phosphorus time series validation at Menomonee River Station RI-16.

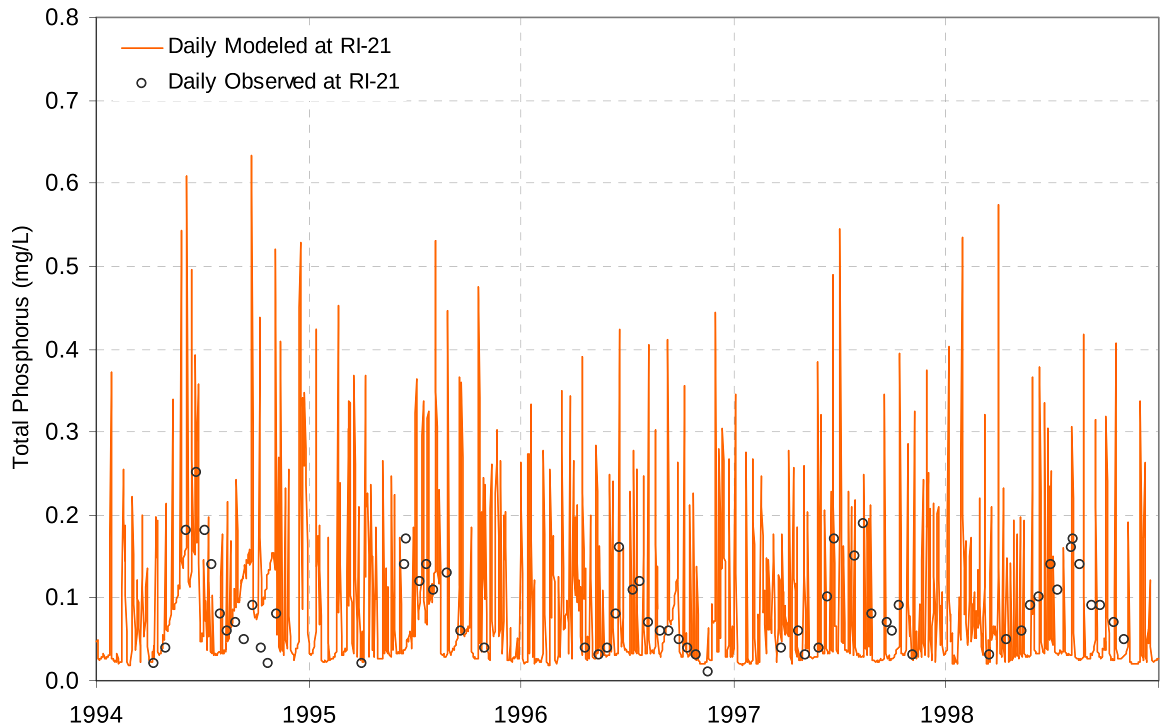


Figure 32. Total phosphorus time series calibration at Menomonee River Station RI-21.

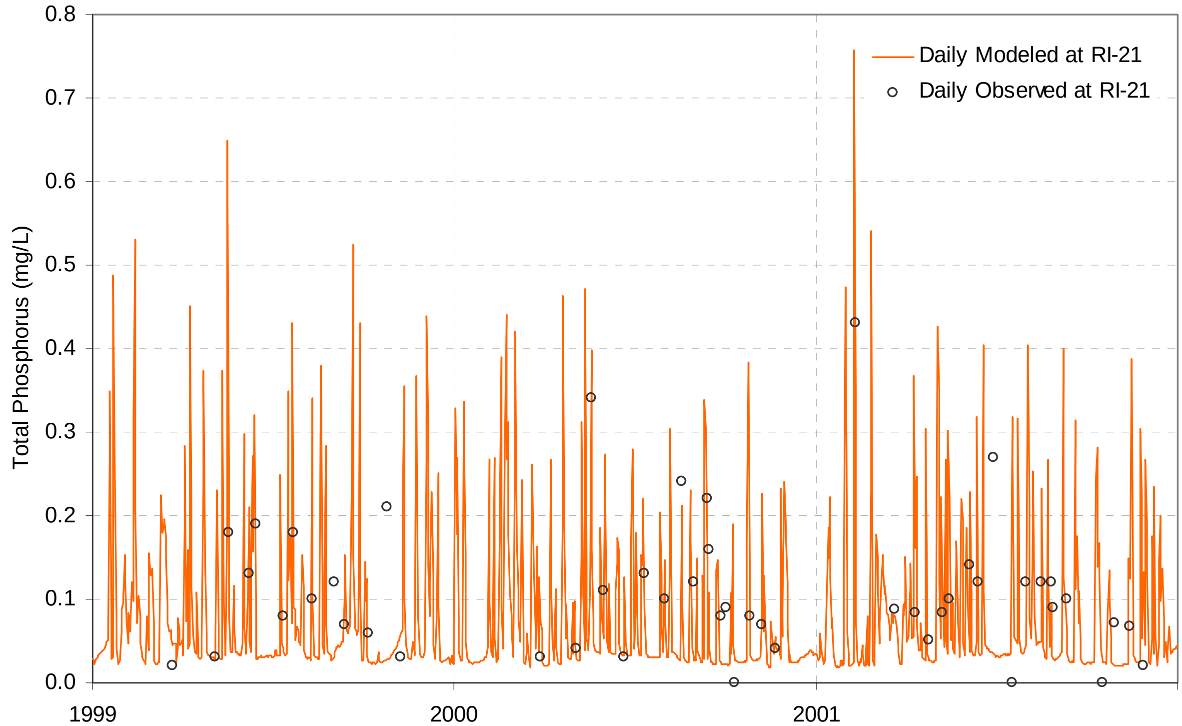


Figure 33. Total phosphorus time series validation at Menomonee River Station RI-21.

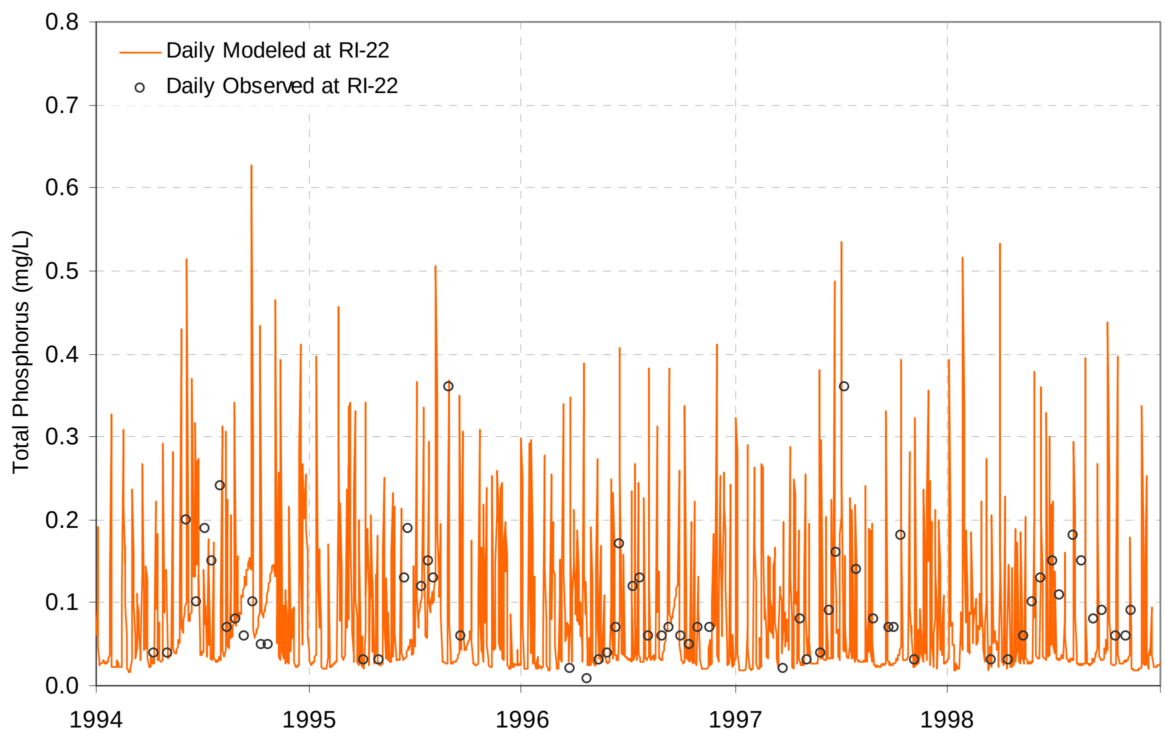


Figure 34. Total phosphorus time series calibration at Menomonee River Station RI-22.

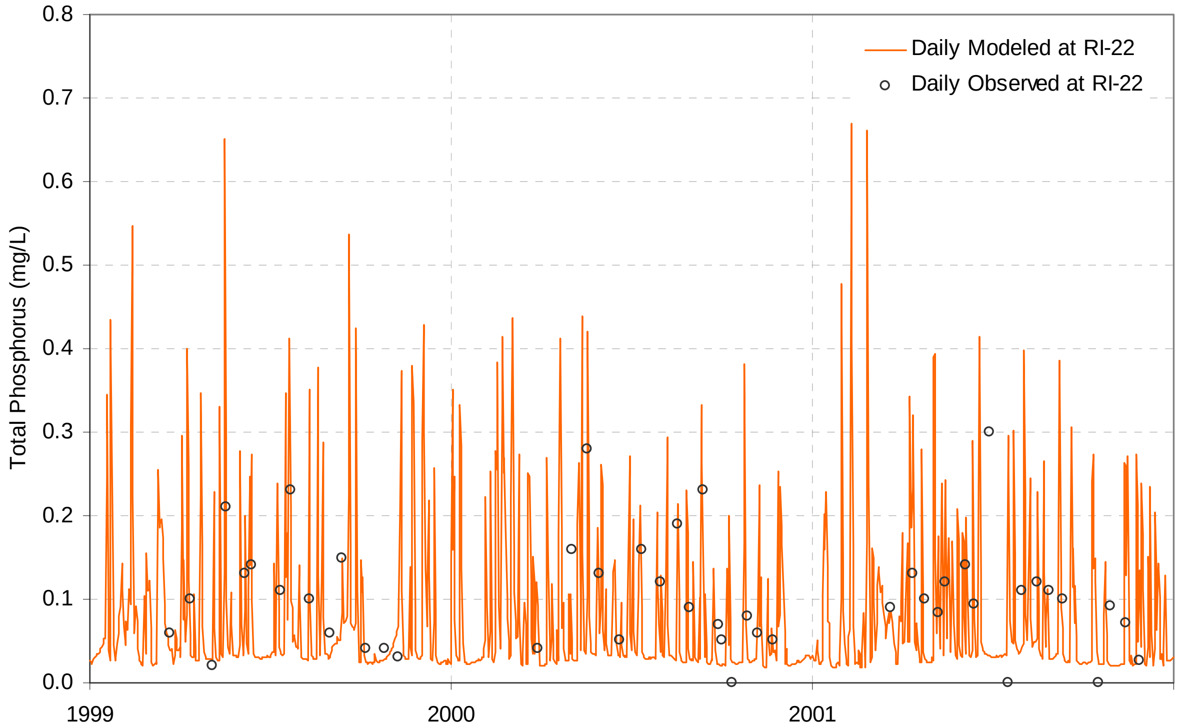


Figure 35. Total phosphorus time series validation at Menomonee River Station RI-22.

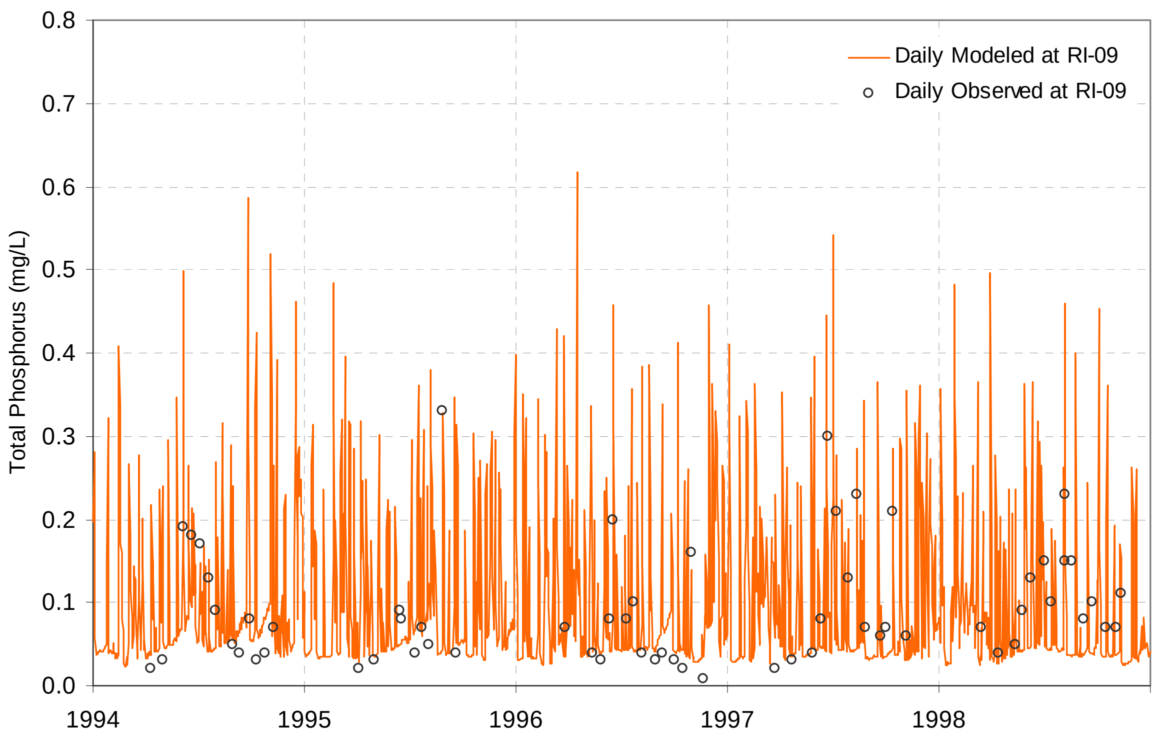


Figure 36. Total phosphorus time series calibration at Menomonee River Station RI-09.

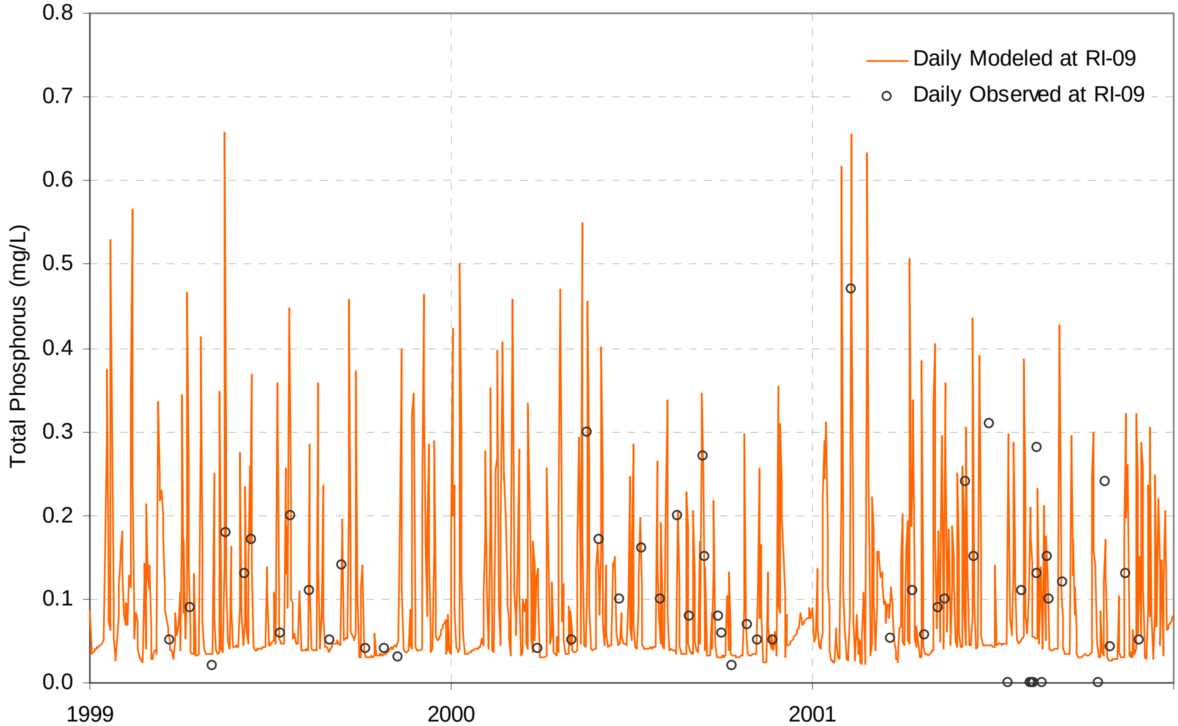


Figure 37. Total phosphorus time series validation at Menomonee River Station RI-09.

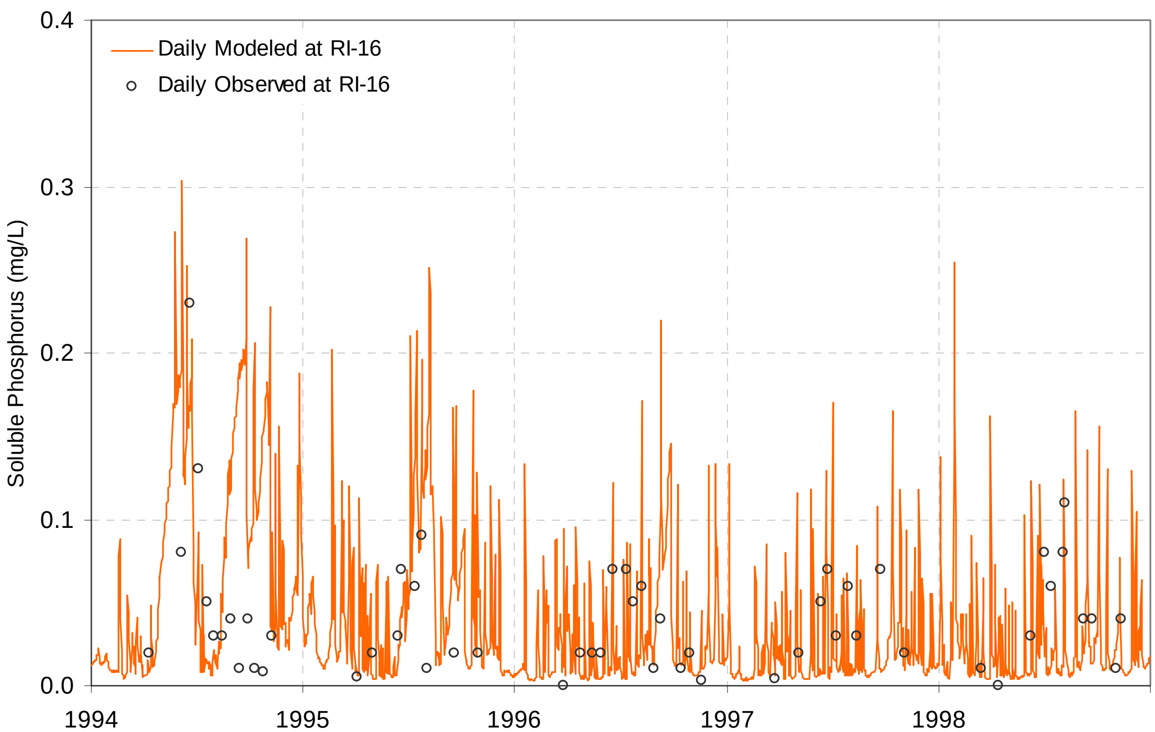


Figure 38. Soluble phosphorus time series calibration at Menomonee River Station RI-16.

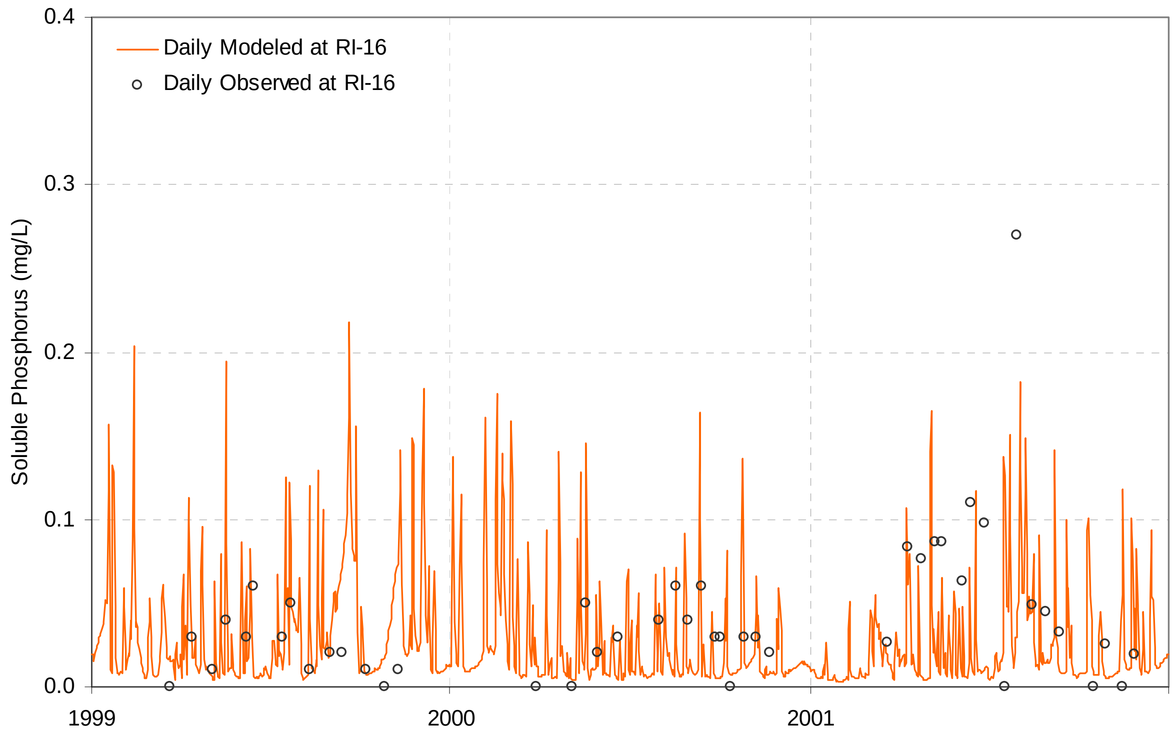


Figure 39. Soluble phosphorus time series validation at Menomonee River Station RI-16.

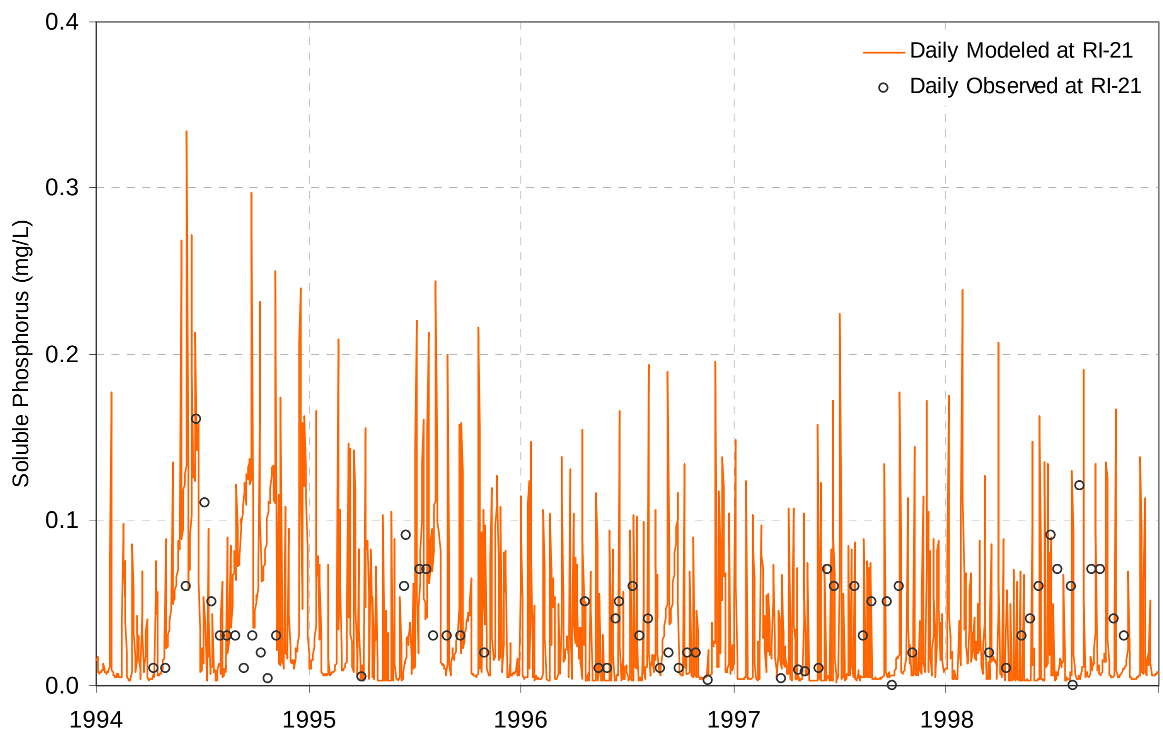


Figure 40. Soluble phosphorus time series calibration at Menomonee River Station RI-21.

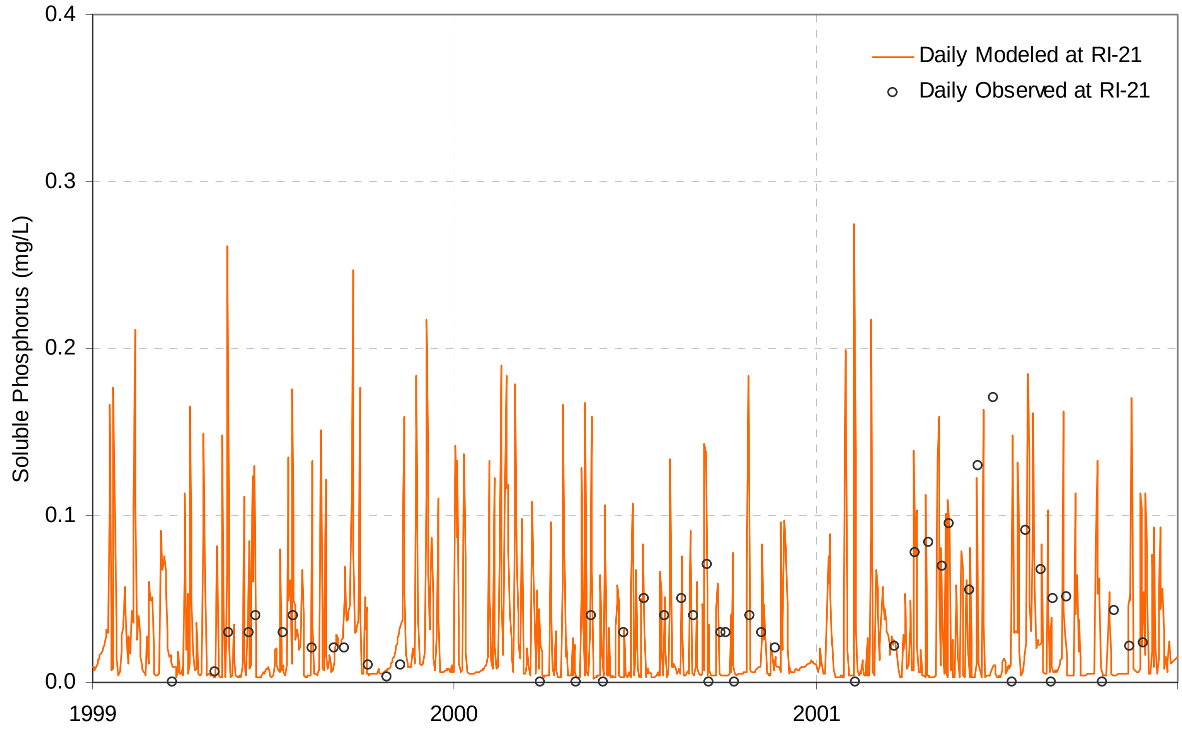


Figure 41. Soluble phosphorus time series validation at Menomonee River Station RI-21.

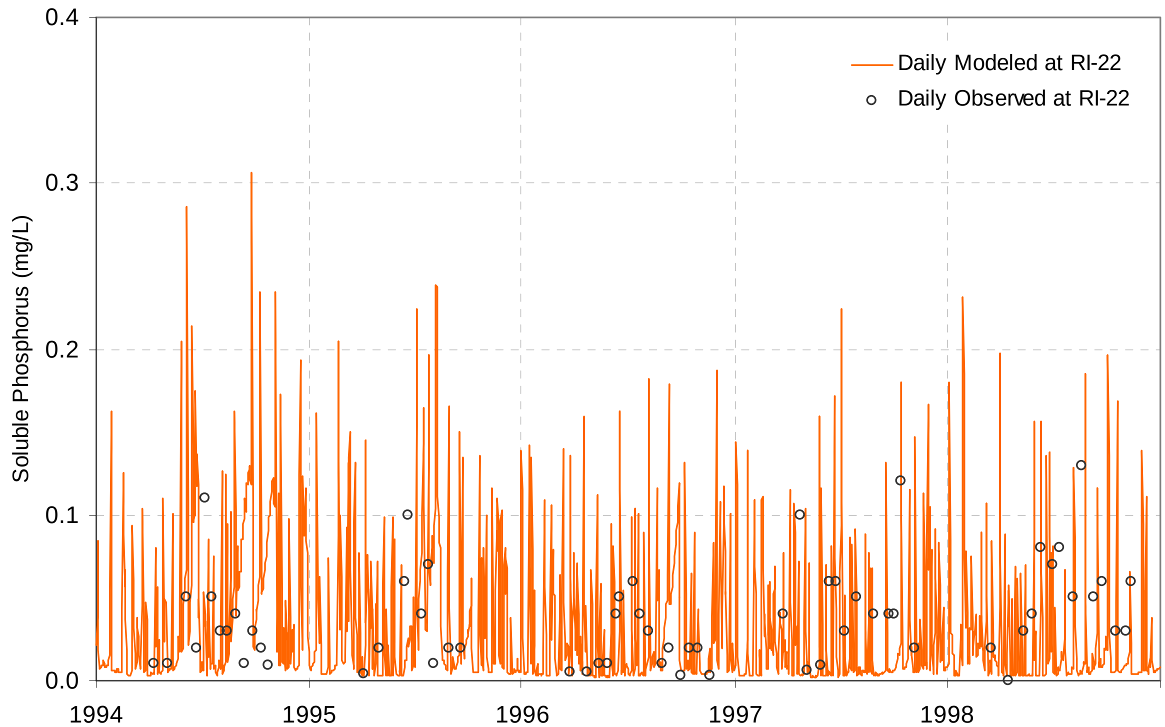


Figure 42. Soluble phosphorus time series calibration at Menomonee River Station RI-22.

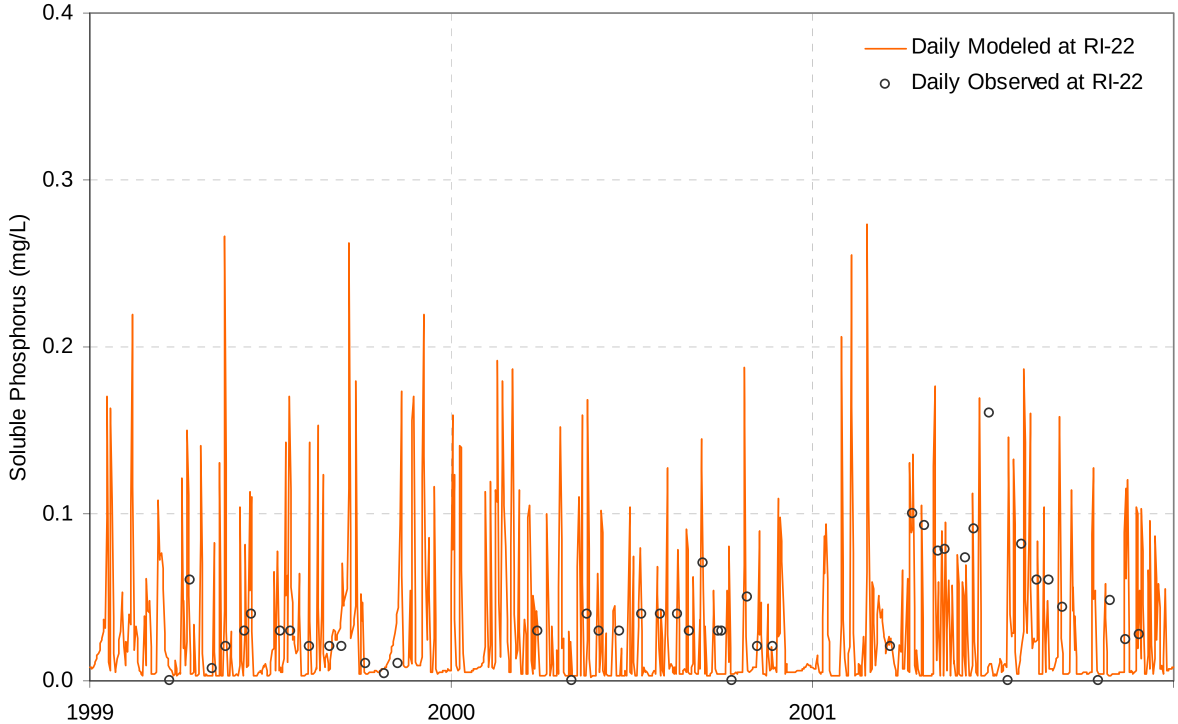


Figure 43. Soluble phosphorus time series validation at Menomonee River Station RI-22.

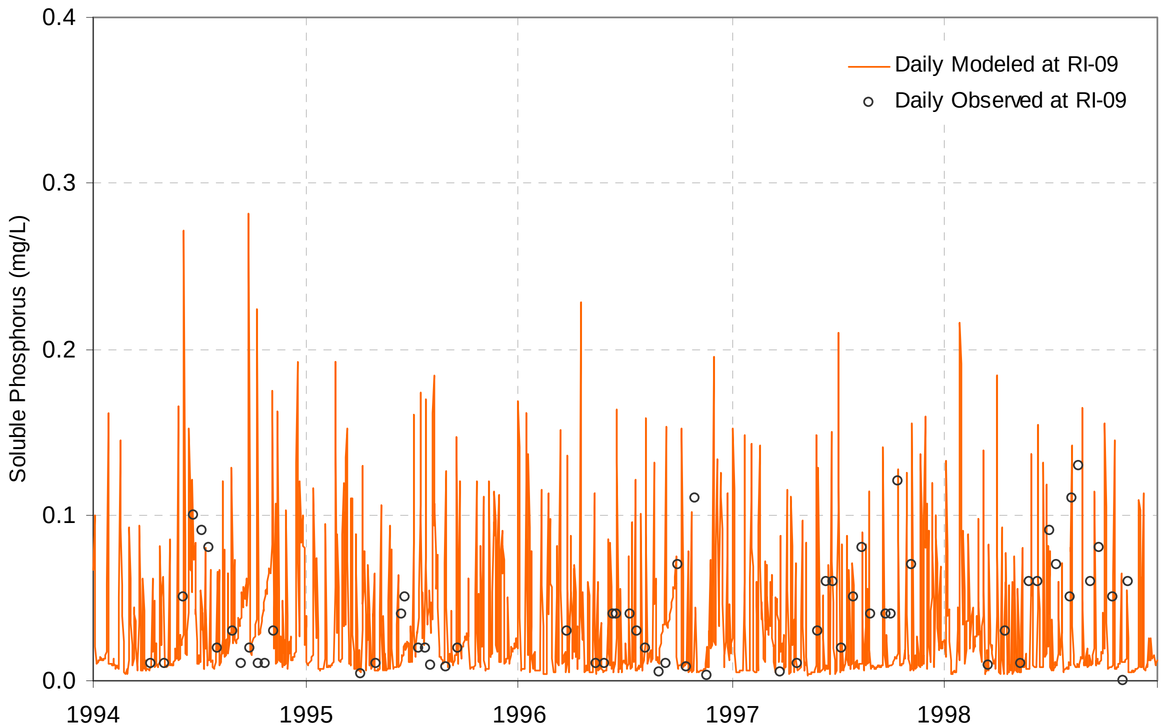


Figure 44. Soluble phosphorus time series calibration at Menomonee River Station RI-09.

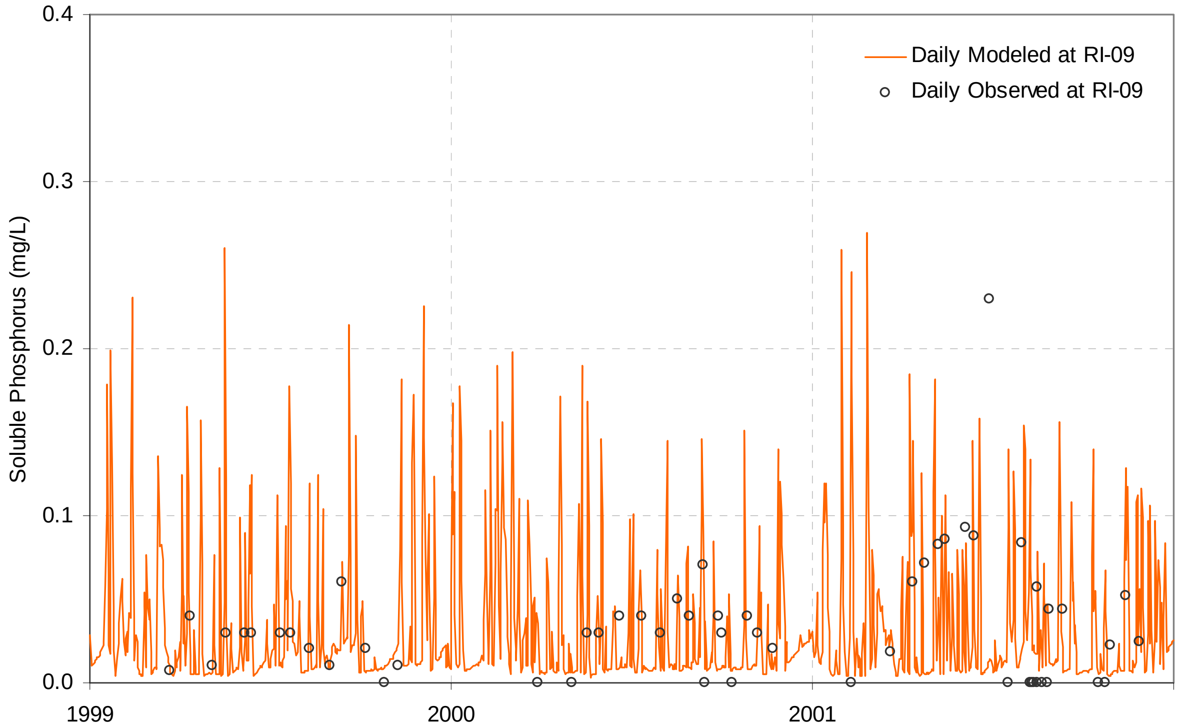


Figure 45. Soluble phosphorus time series validation at Menomonee River Station RI-09.

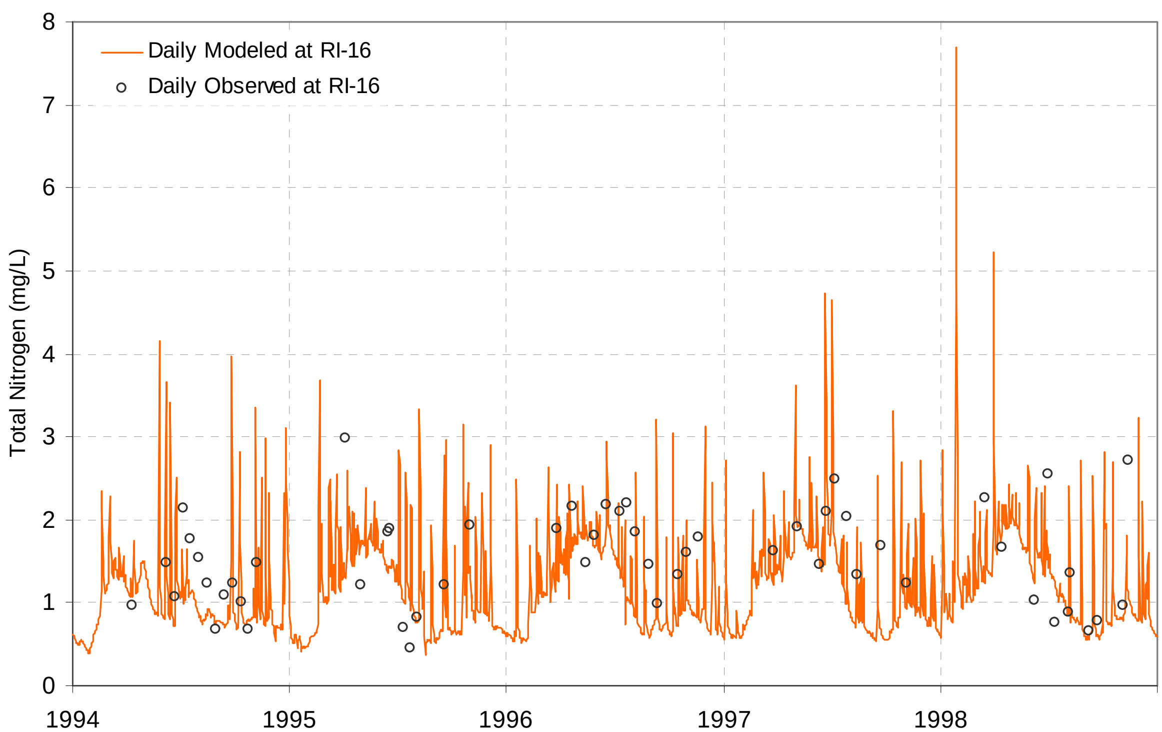


Figure 46. Total Nitrogen time series calibration at Menomonee River Station RI-16.

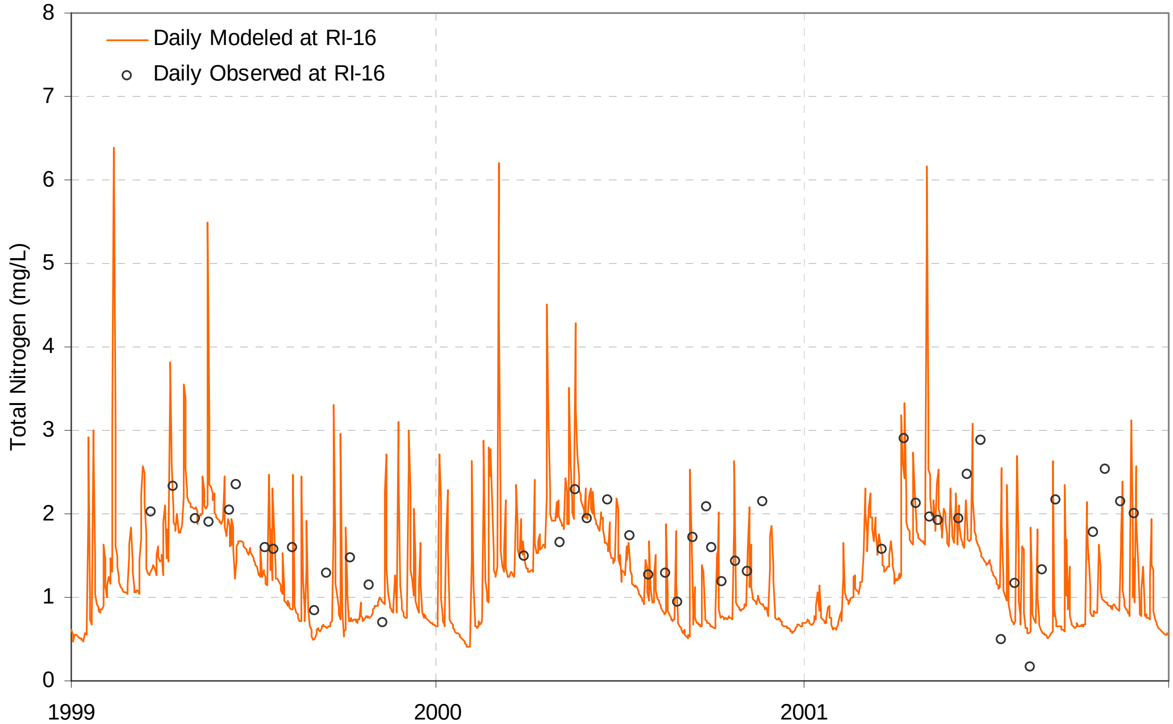


Figure 47. Total Nitrogen time series validation at Menomonee River Station RI-16.

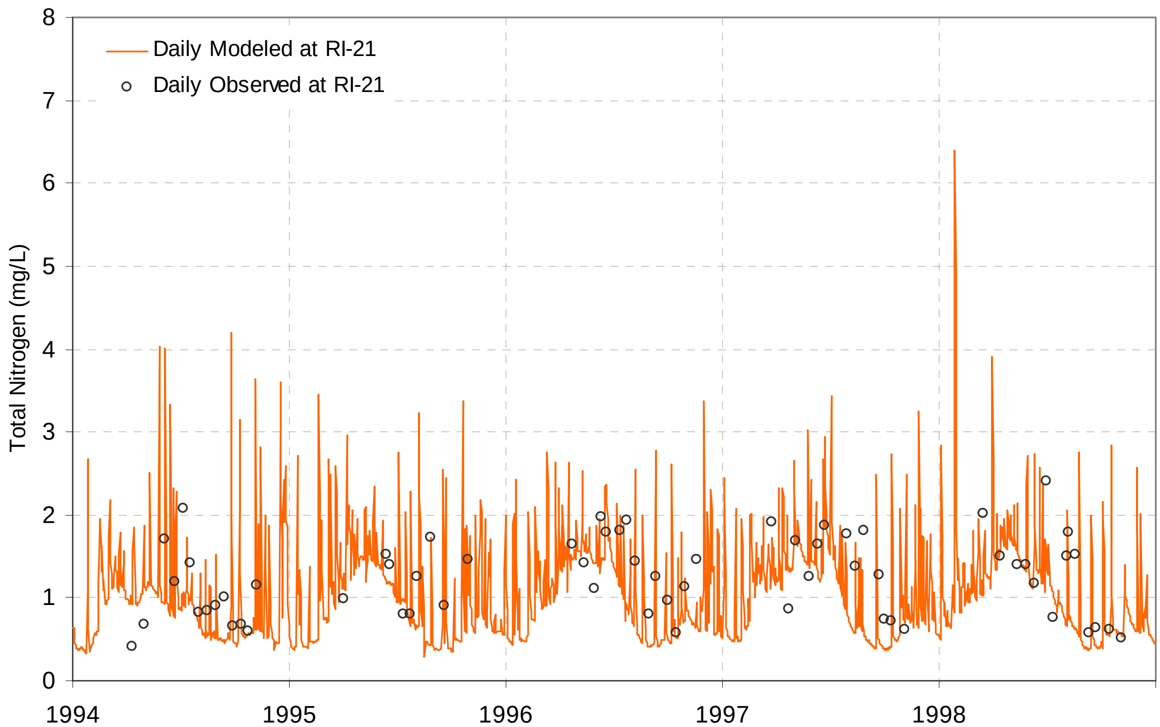


Figure 48. Total Nitrogen time series calibration at Menomonee River Station RI-21.

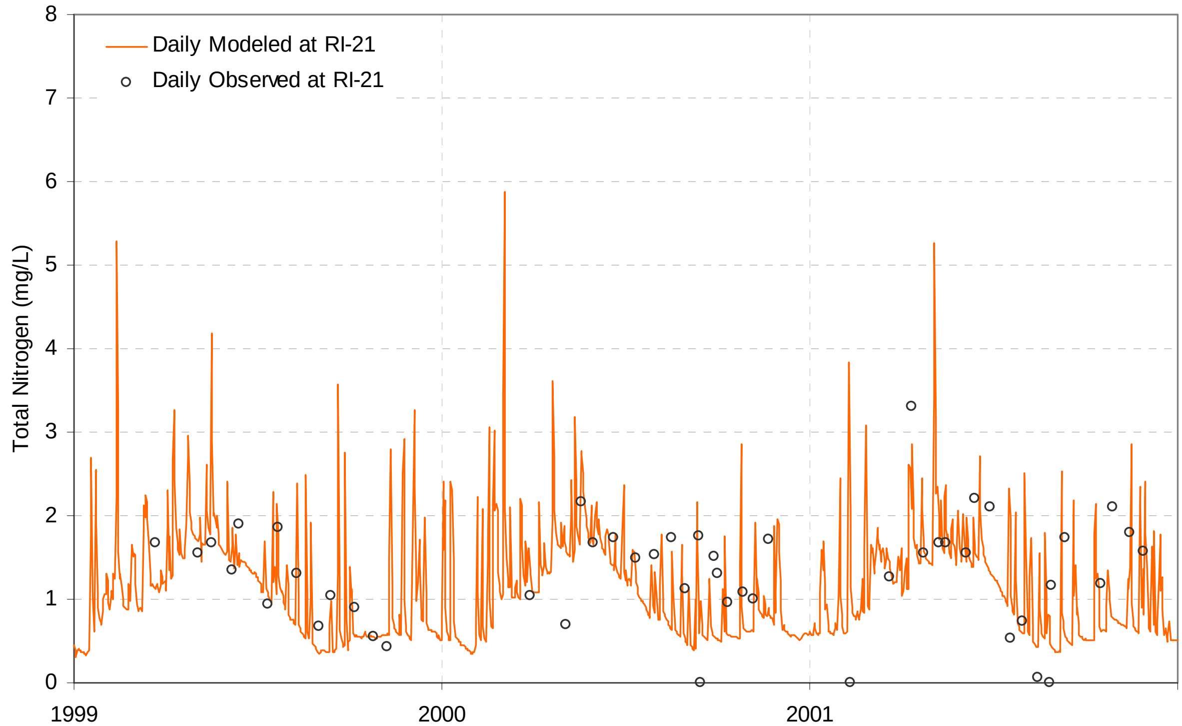


Figure 49. Total Nitrogen time series validation at Menomonee River Station RI-21.

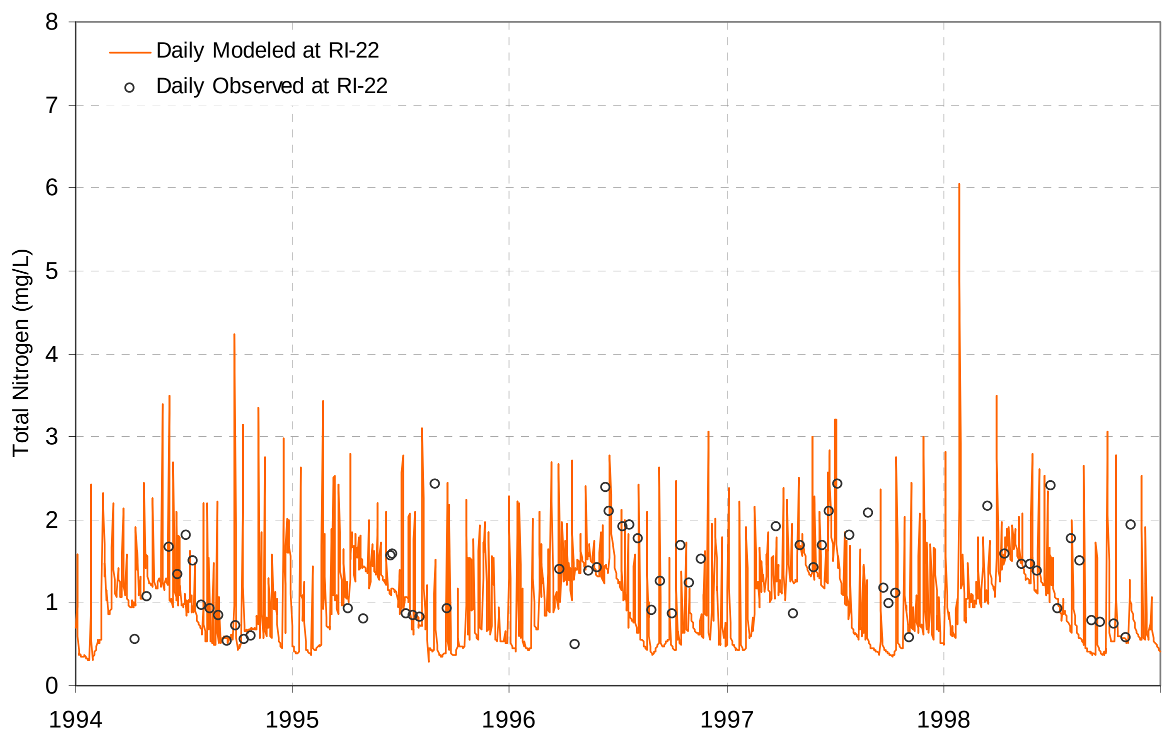


Figure 50. Total Nitrogen time series calibration at Menomonee River Station RI-22.

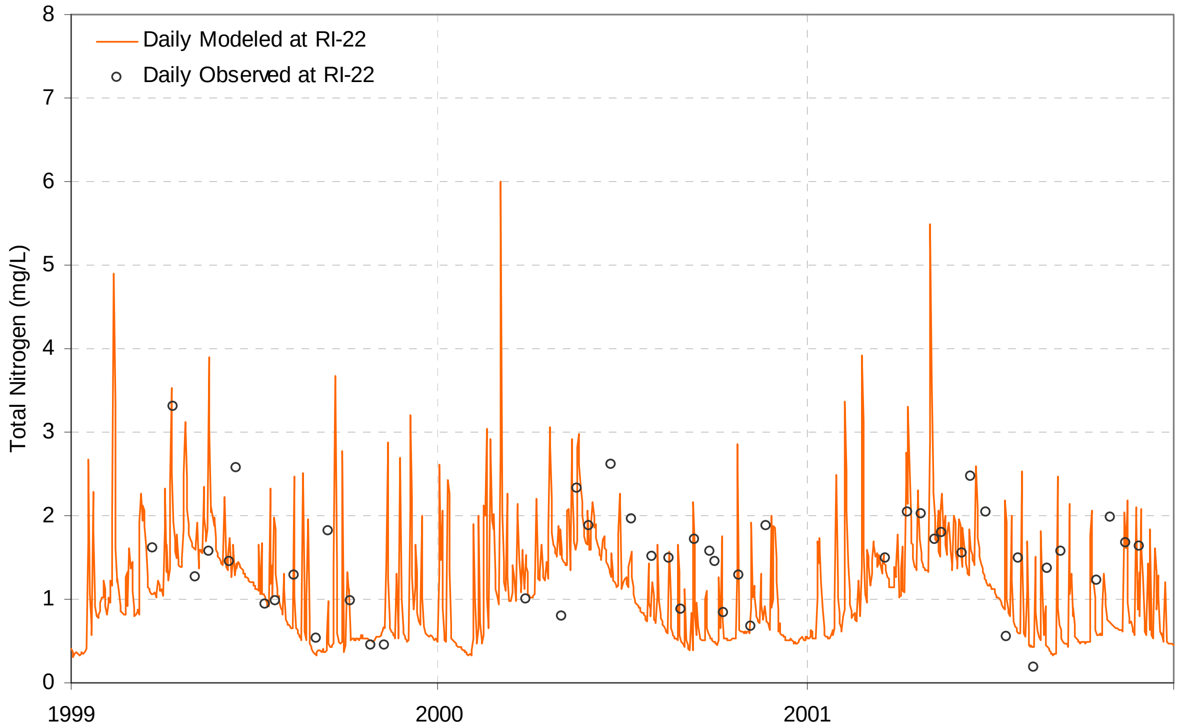


Figure 51. Total Nitrogen time series validation at Menomonee River Station RI-22.

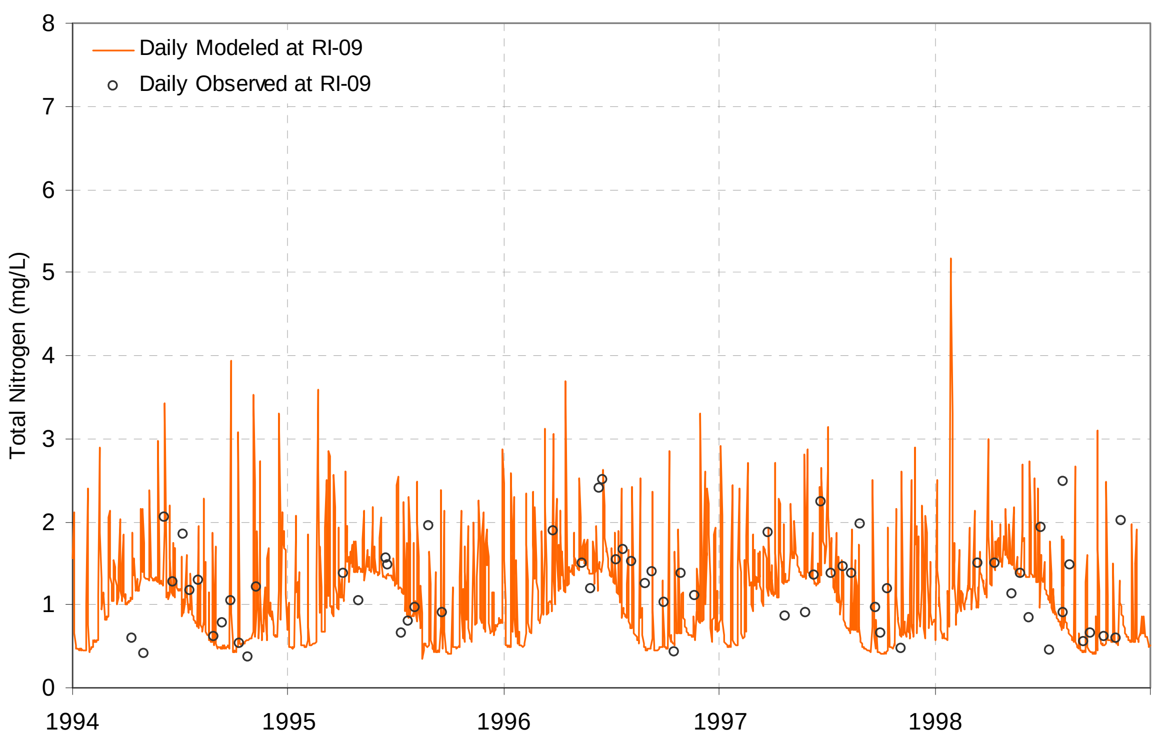


Figure 52. Total Nitrogen time series calibration at Menomonee River Station RI-09.

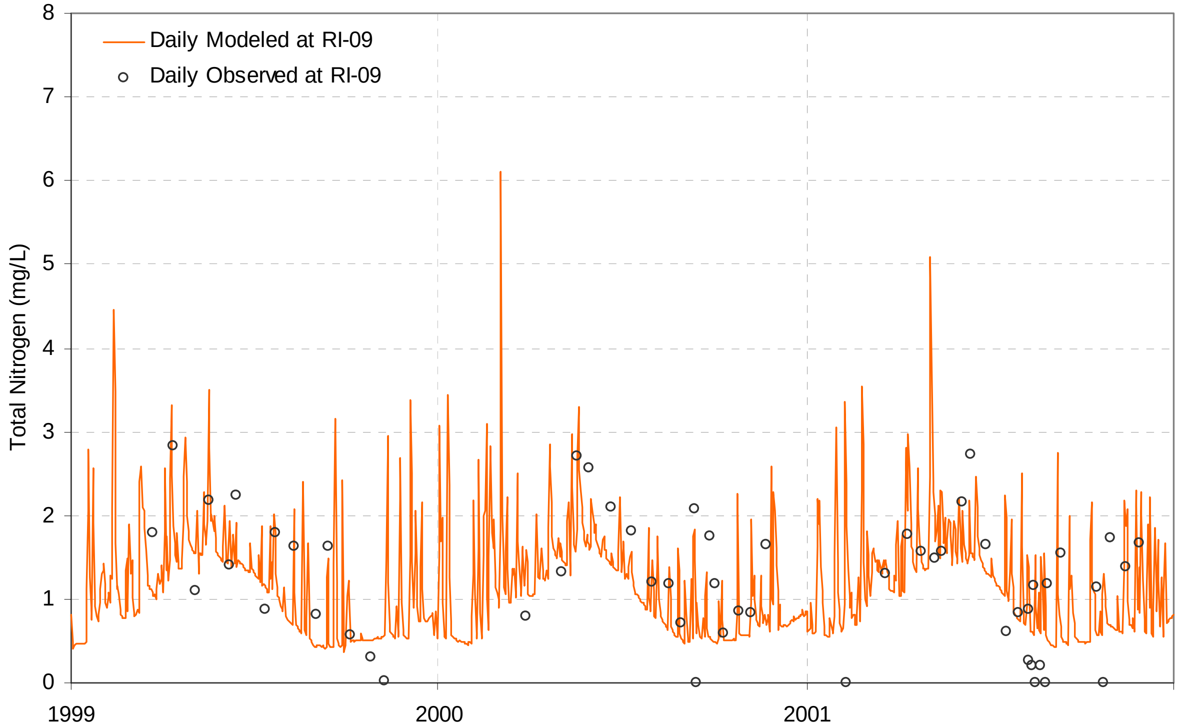


Figure 53. Total Nitrogen time series validation at Menomonee River Station RI-09.

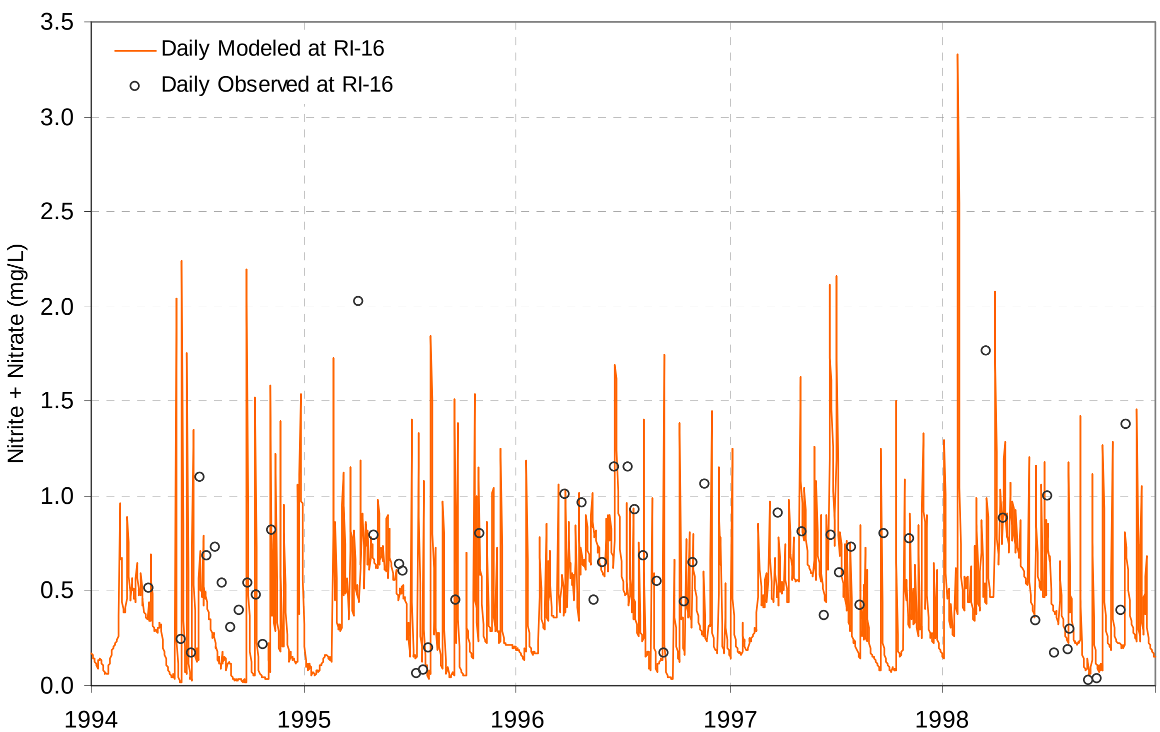


Figure 54. Nitrite+Nitrate time series calibration at Menomonee River Station RI-16.

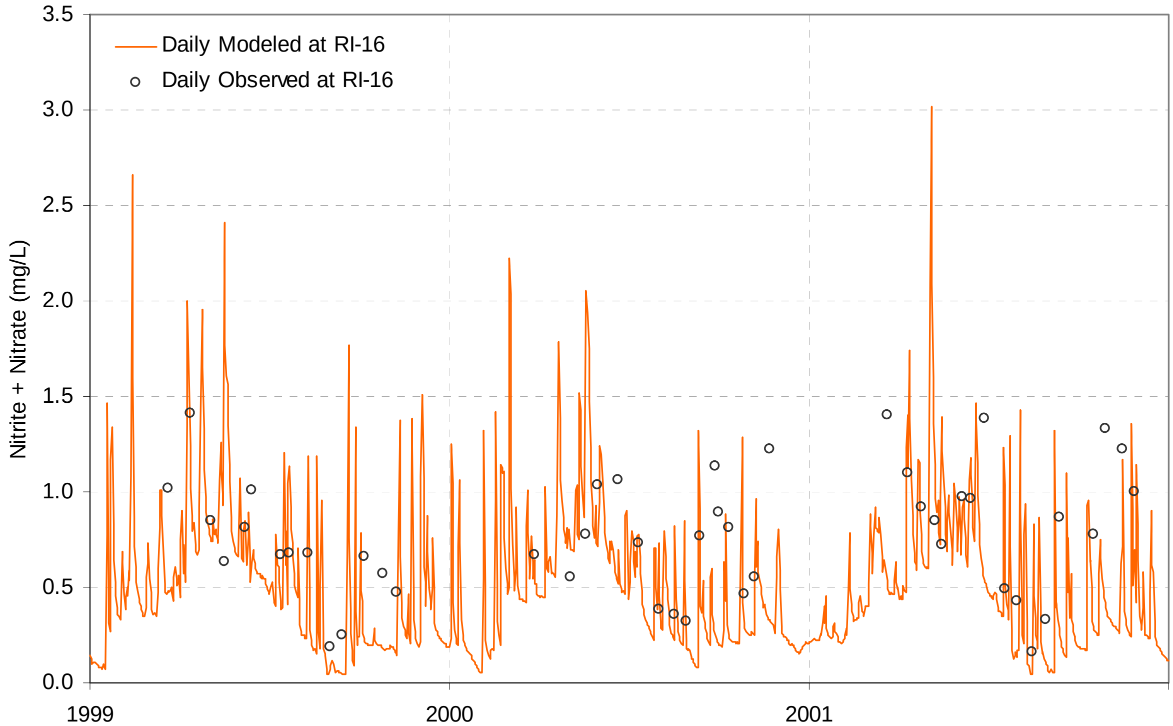


Figure 55. Nitrite+Nitrate time series validation at Menomonee River Station RI-16.

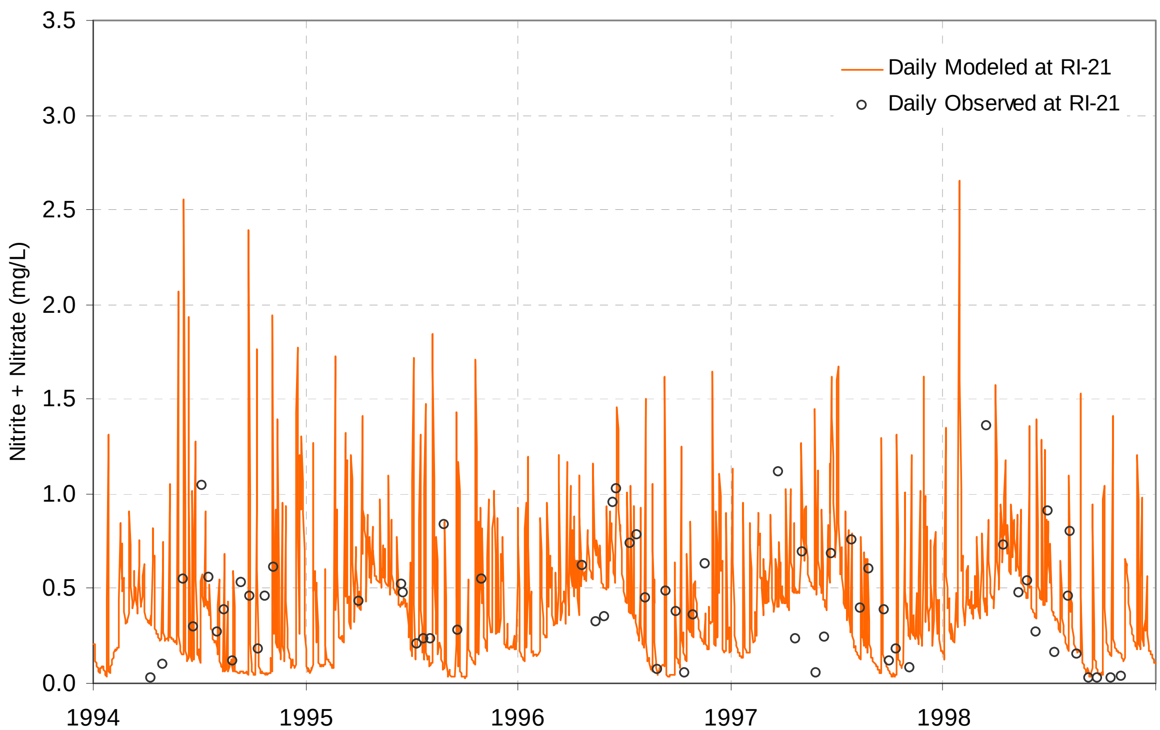


Figure 56. Nitrite+Nitrate time series calibration at Menomonee River Station RI-21.

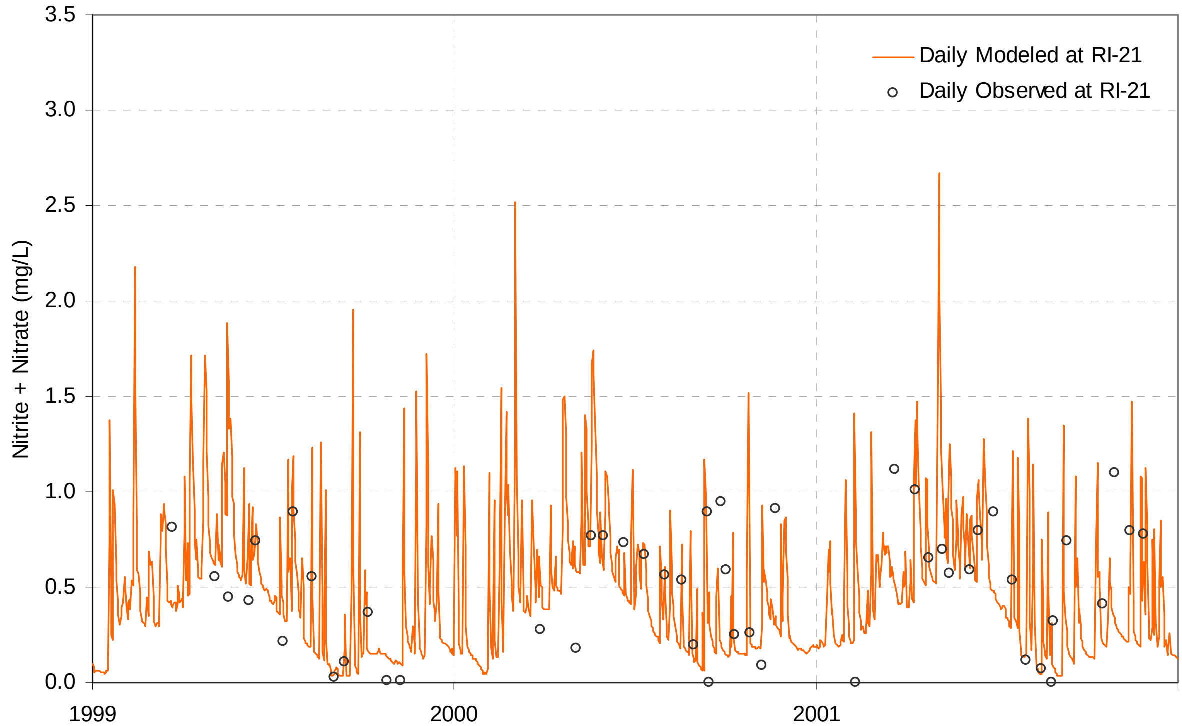


Figure 57. Nitrite+Nitrate time series validation at Menomonee River Station RI-21.

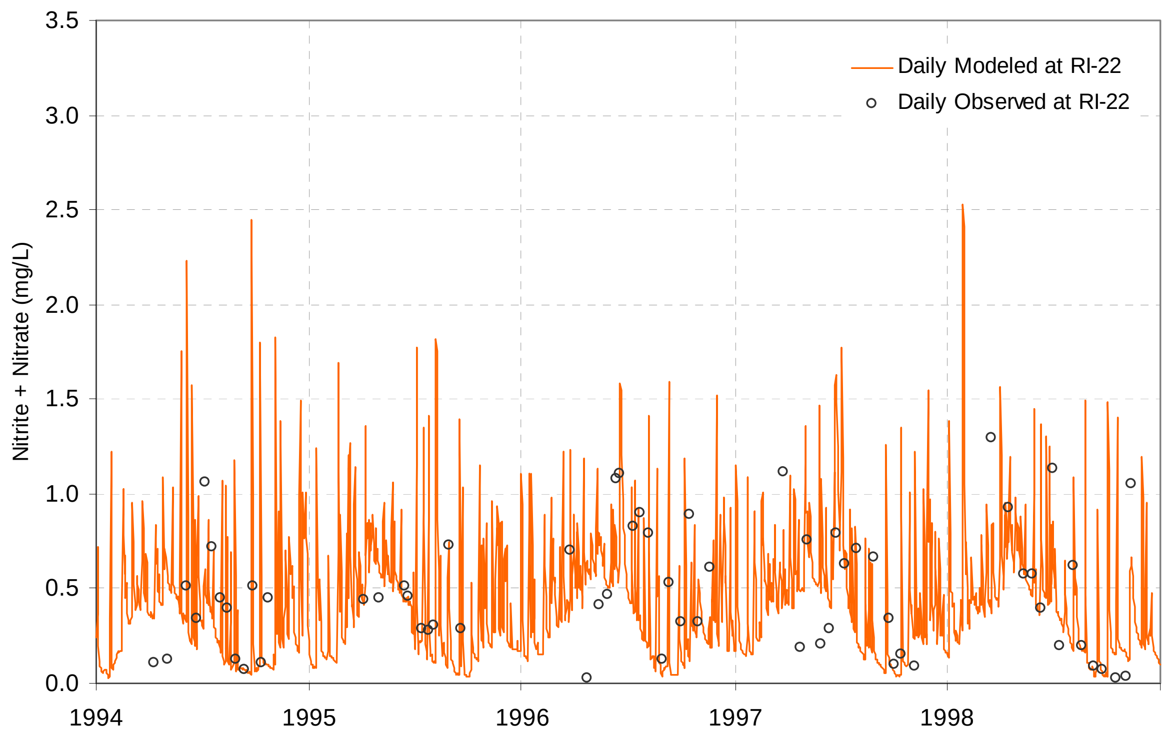


Figure 58. Nitrite+Nitrate time series calibration at Menomonee River Station RI-22.

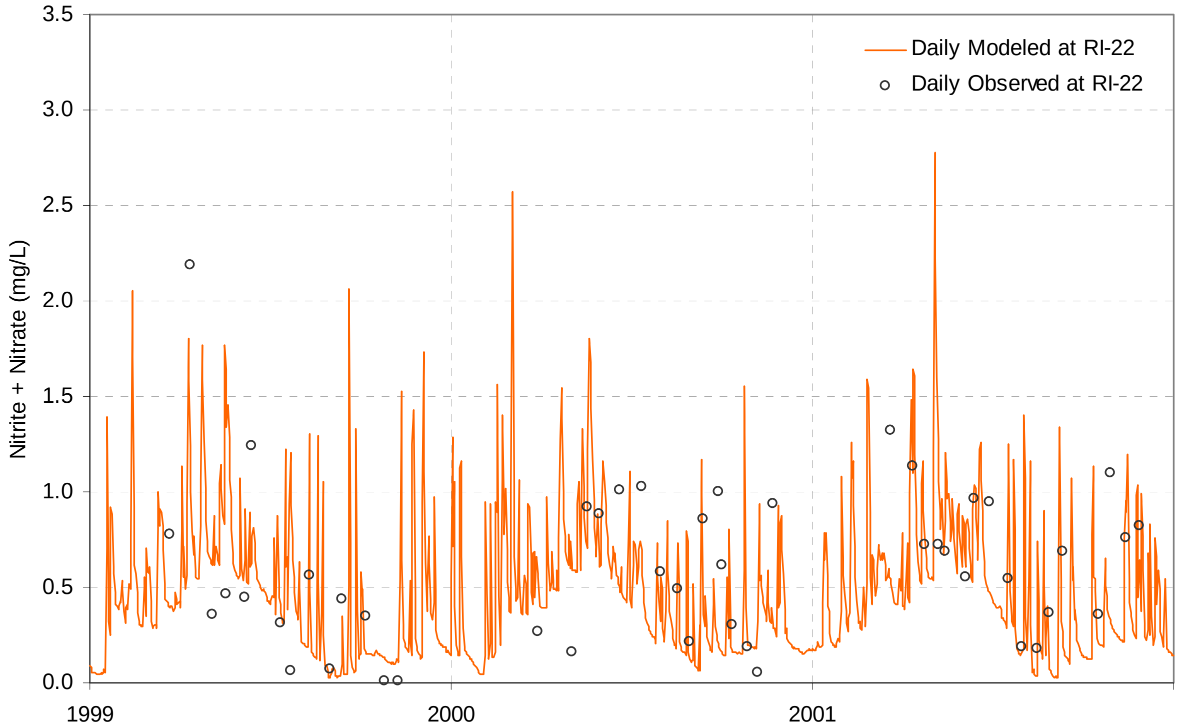


Figure 59. Nitrite+Nitrate time series validation at Menomonee River Station RI-22.

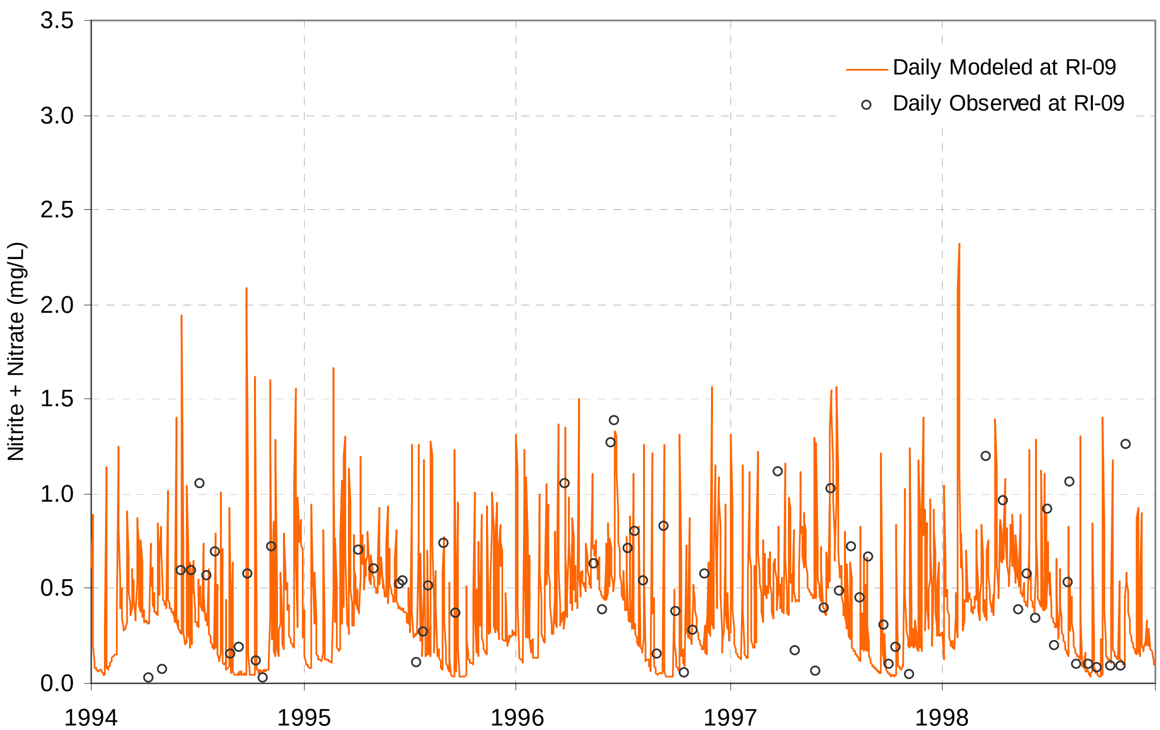


Figure 60. Nitrite+Nitrate time series calibration at Menomonee River Station RI-09.

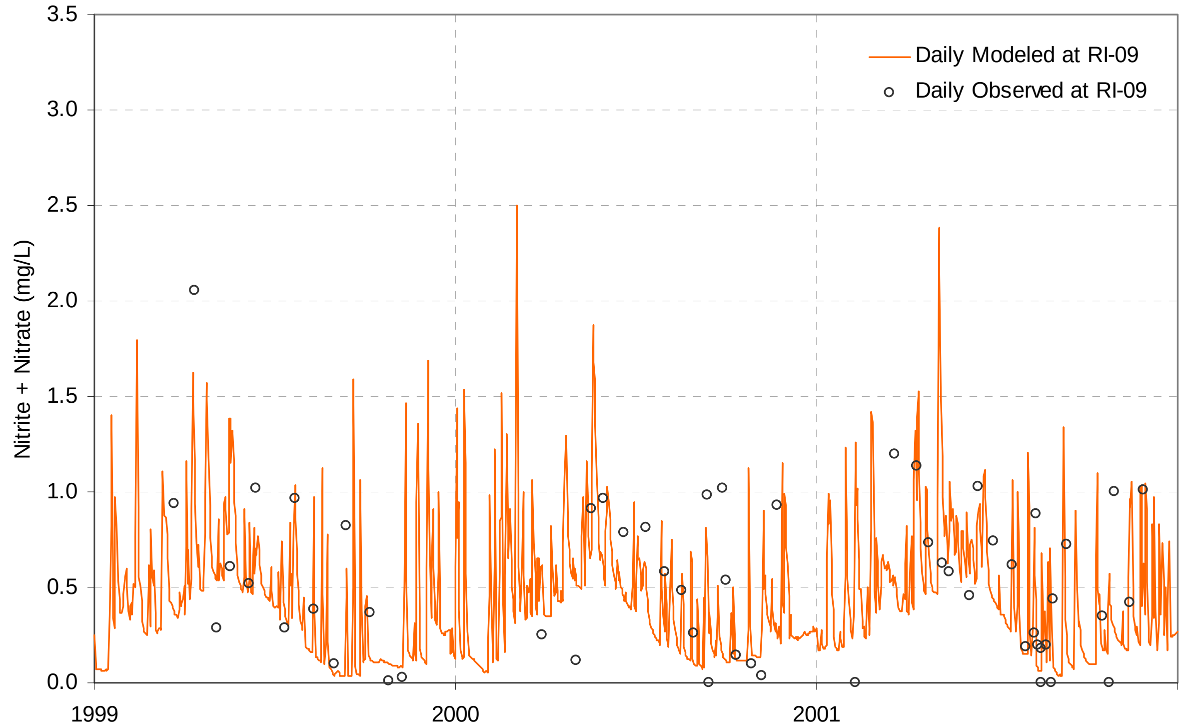


Figure 61. Nitrite+Nitrate time series validation at Menomonee River Station RI-09.

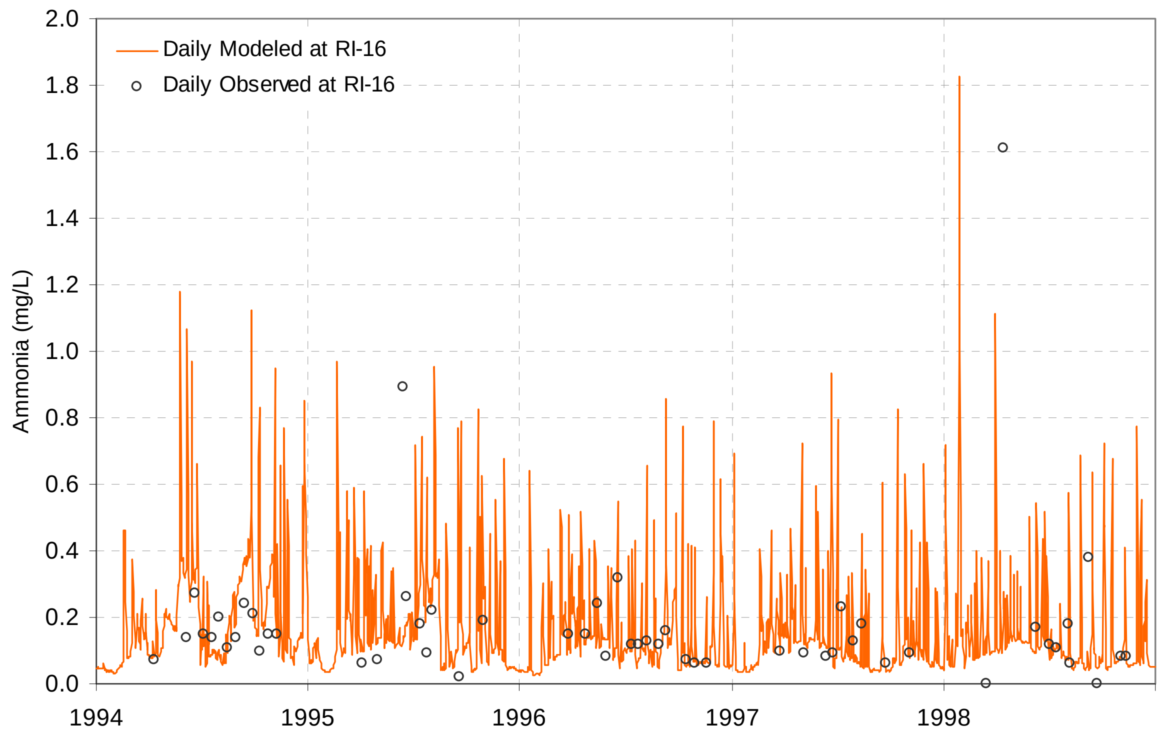


Figure 62. Ammonia time series calibration at Menomonee River Station RI-16.

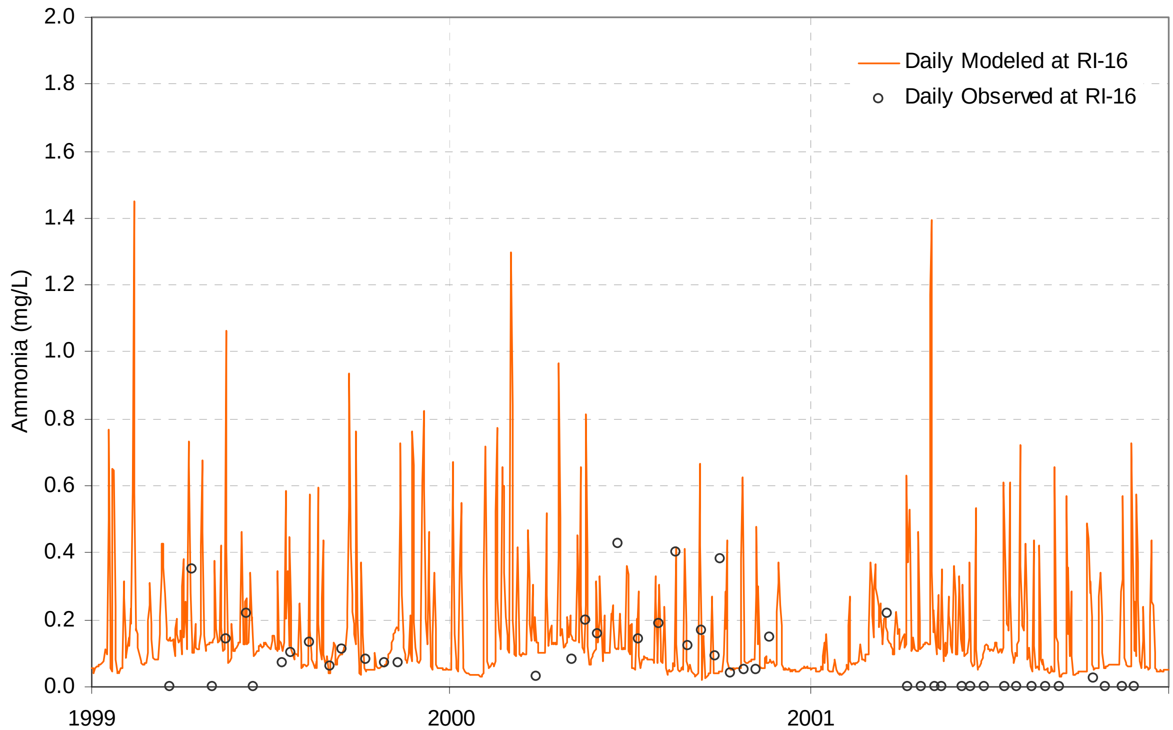


Figure 63. Ammonia time series validation at Menomonee River Station RI-16.

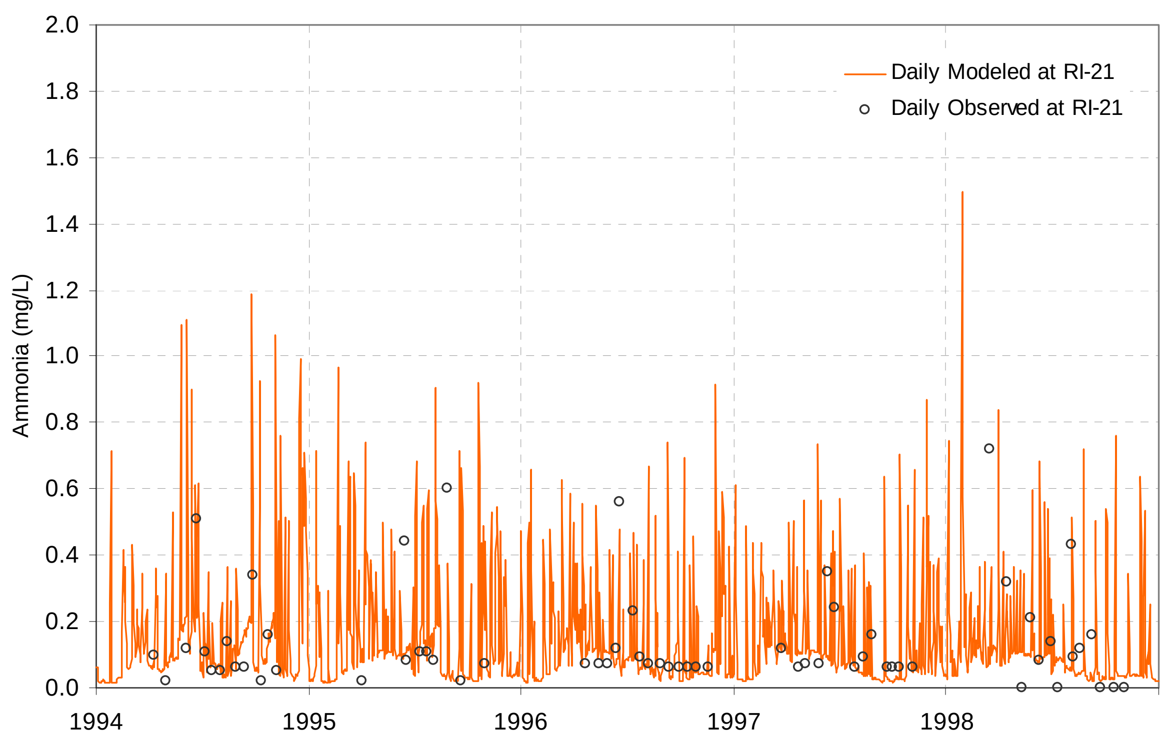


Figure 64. Ammonia time series calibration at Menomonee River Station RI-21.

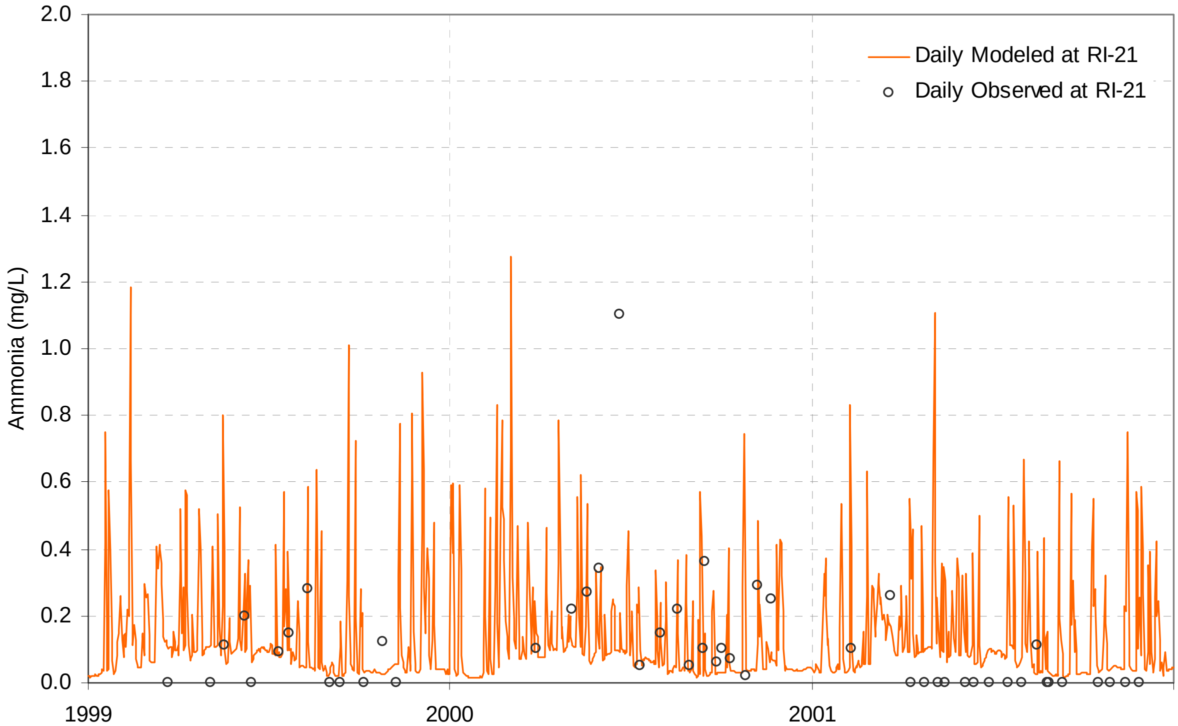


Figure 65. Ammonia time series validation at Menomonee River Station RI-21.

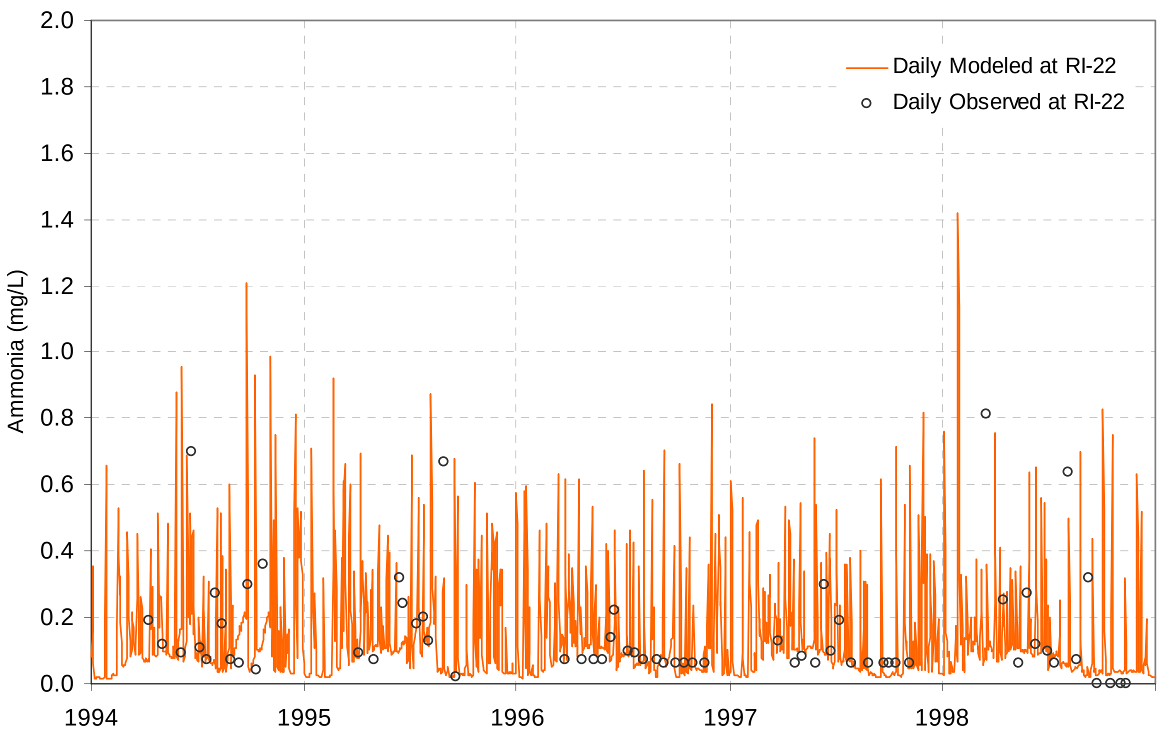


Figure 66. Ammonia time series calibration at Menomonee River Station RI-22.

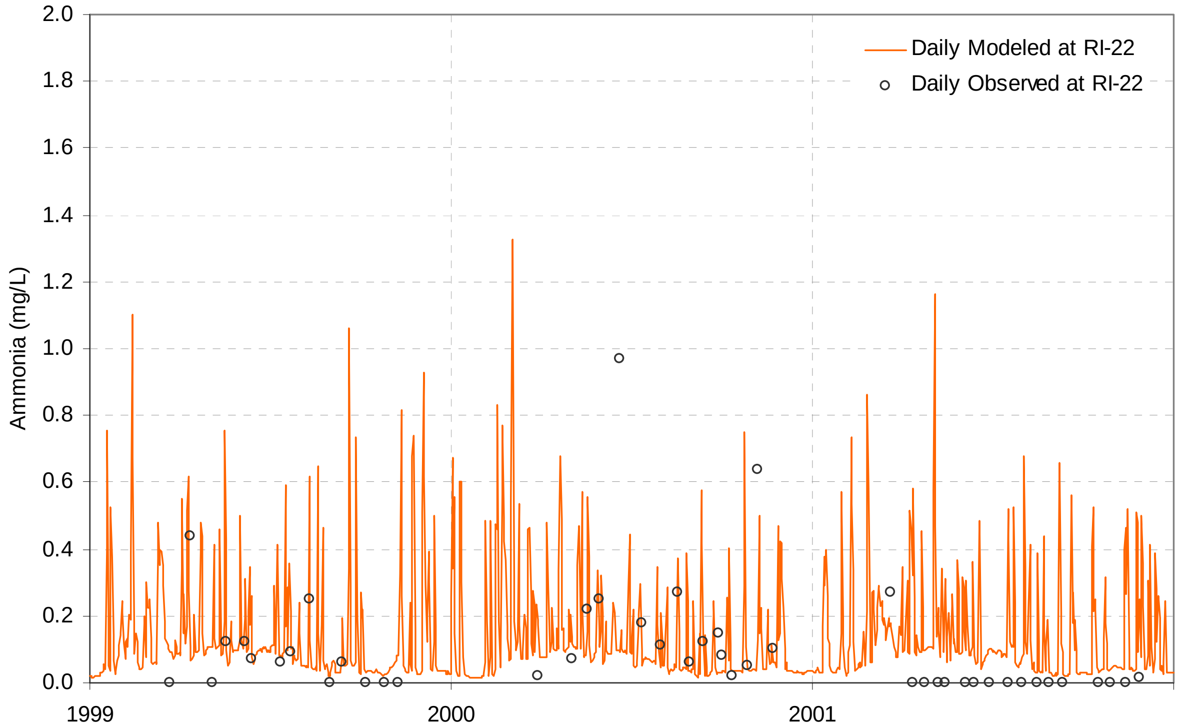


Figure 67. Ammonia time series validation at Menomonee River Station RI-22.

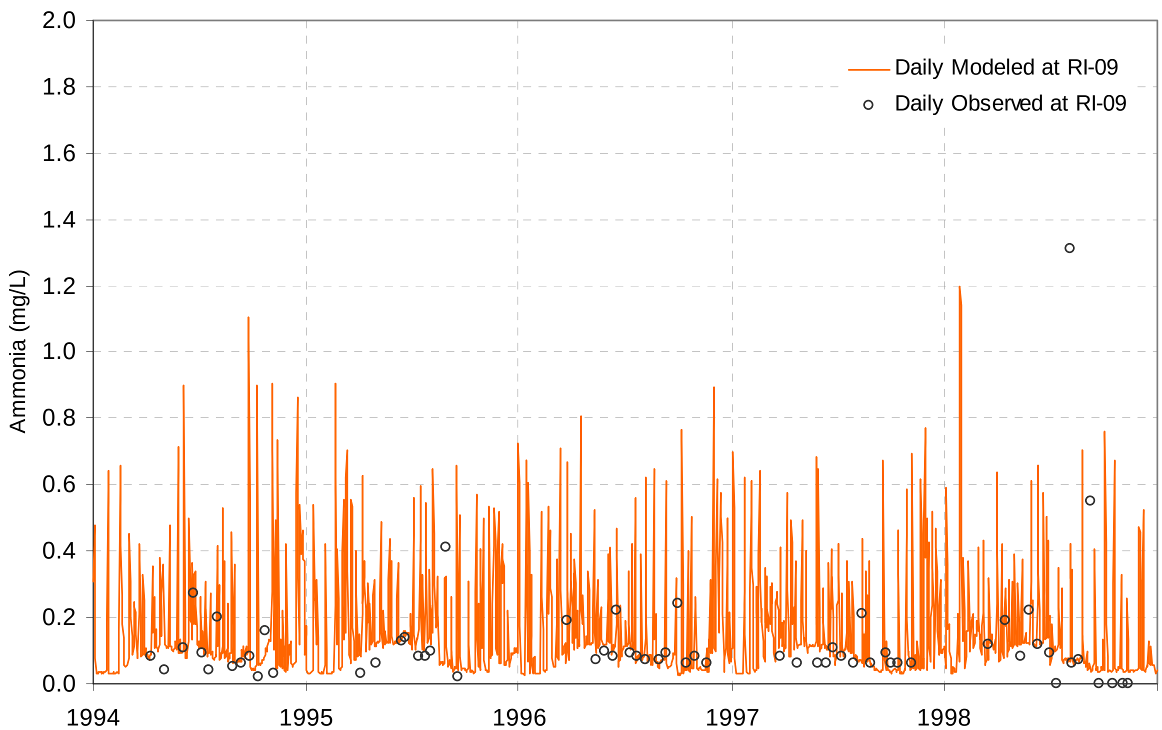


Figure 68. Ammonia time series calibration at Menomonee River Station RI-09.

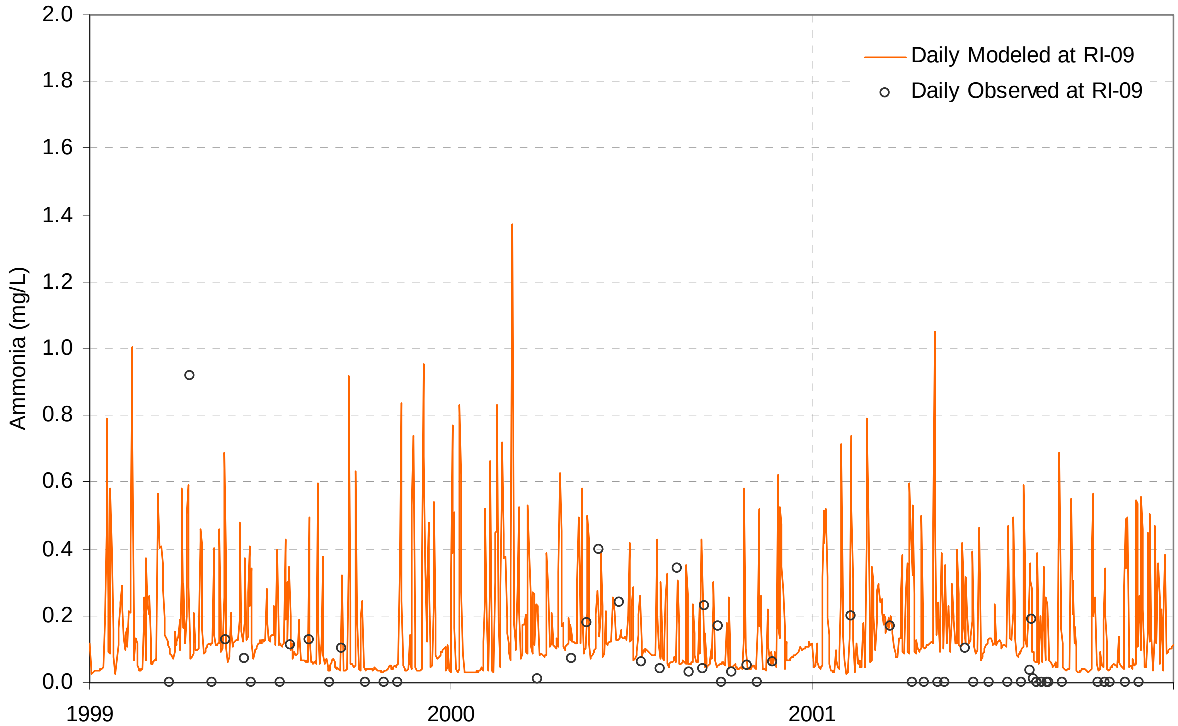


Figure 69. Ammonia time series validation at Menomonee River Station RI-09.

5.3.6 Chlorophyll *a*

Model calibration for chlorophyll *a* is difficult, because (1) algae respond in a complex way to a wide number of environmental factors, including self-shading, (2) chlorophyll *a* laboratory analyses are typically subject to a relatively high level of imprecision, (3) LSPC predicts a cross-sectional average algal concentration, while many environmental samples represent the (typically greater) algal density present near surface, and (4) algal response is naturally highly variable.

Plots of chlorophyll *a* concentrations versus total suspended solids (TSS), flow, and nutrient concentrations in the Menomonee show only weak correlations (Figure 70). The highest concentrations do occur at low TSS, indicating that light availability is a significant controlling factor. Little or no correlation, however, is found between chlorophyll *a* and either flow or inorganic nutrient concentrations. Indeed, some of the highest chlorophyll concentrations coincide with low dissolved nutrient concentrations. This suggests a situation where nutrients are typically present in concentrations that are less limiting than other factors.

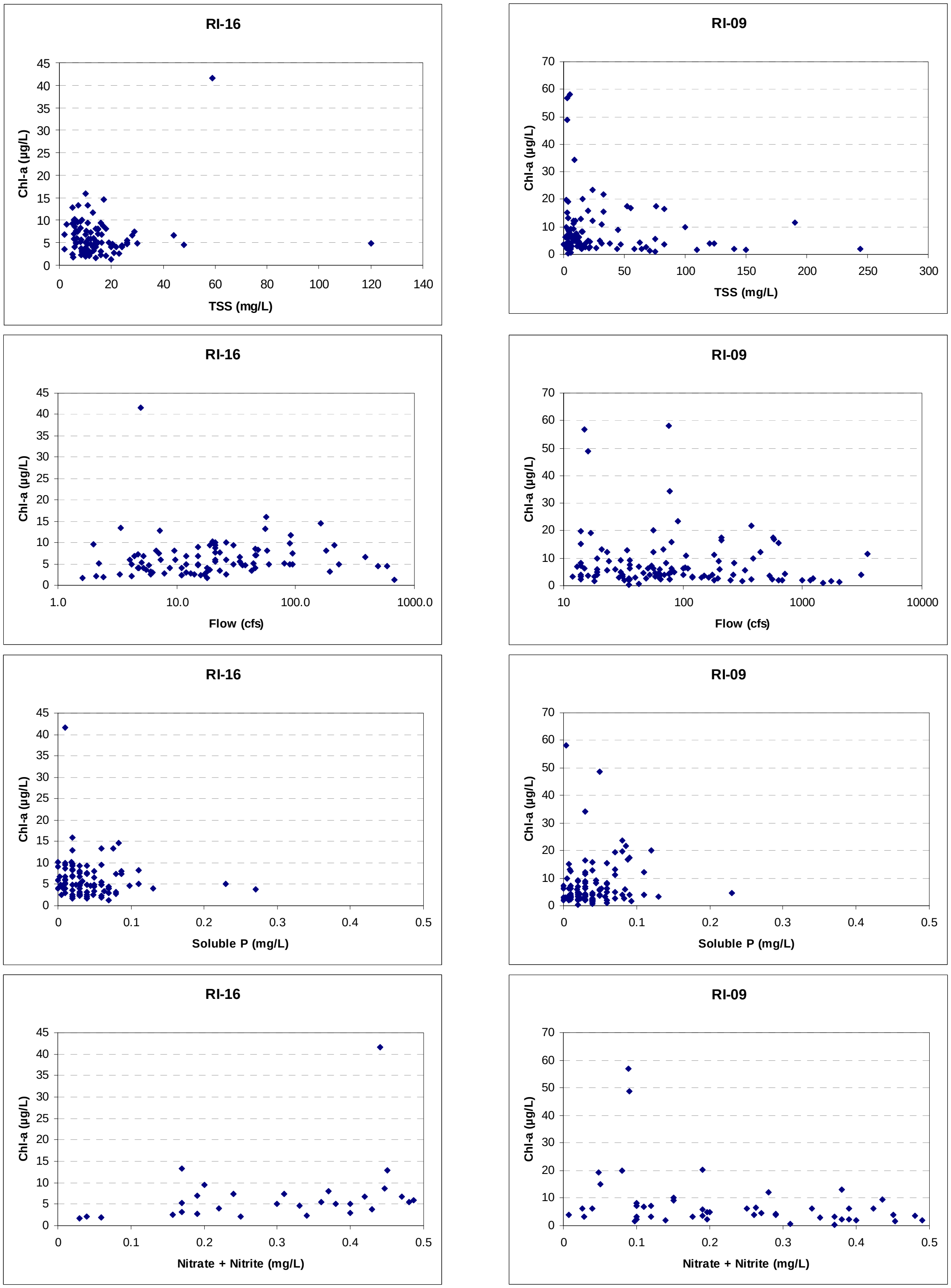


Figure 70. Chlorophyll *a* Correlation to Other Environmental Variables

LSPC defaults for the Michaelis-Menten nutrient half-saturation constants for algal growth are outdated, and have been replaced by newer research. Specifically, we adopted the kinetic constants that are documented in the new QUAL2K model (Chapra and Pelletier, 2003): 0.015 mg/L for inorganic nitrogen and 0.002 mg/L for inorganic phosphorus.

For light extinction in the water column, Thomann and Mueller (1987) suggest that the extinction coefficient (in metric units) is related to inorganic solids (mg/L) by a factor of 0.52 and to organic solids by a factor of 0.174. The expected range of the factor for dependence on total suspended solids should thus be in the range of 0.016 to 0.053 (ft^{-1} per mg/L). However, it should be recalled that LSPC simulates a reach as vertically and laterally mixed, and thus estimates light attenuation over the whole reach cross section. In fact, various algal species can adjust their position in the water column to maximize light availability, given sufficiently low turbulence. Therefore, the theoretical extinction coefficient tends to overestimate the actual impacts of TSS light limitation on algae. A value around 0.01 for the coefficient on TSS appears to provide reasonable results.

The chlorophyll *a* simulation is also sensitive to the specification of maximum algal growth rate in the absence of light and nutrient limitation. Thomann and Mueller (1987) suggest that the maximum growth rate should be on the order of 1.5 to 2.5 per day; however, when converting to the hourly rate used by LSPC, it is necessary to compensate for the fact that this growth only occurs during daylight hours. Thus, the hourly maximum rate should be in the range of 0.12 to 0.3 per hour. For the Menomonee, a value of 0.16 appears to provide reasonable results.

Net settling velocities for algae were set to 0.0012 ft/hr for smaller tributaries, and 0.0025 ft/hr for the mainstem, consistent with the range of values cited in Bowie et al. (1985). Finally, an upland source of algae (consistent with seeding from wetlands and small impoundments) was specified as a constant phytoplankton concentration on PERLND flow equivalent to about 1.3 μg/L chlorophyll *a* (implemented in the MASS-LINK block). Model results for the calibration and validation time periods are provided below (Figure 71 to Figure 78). Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment A. The model generally predicts trends and relative concentrations of chlorophyll *a* well, but does not represent occasional bloom conditions. In many cases, these samples may not be representative of average conditions throughout the stream cross-section. In other cases, sample results may have been increased by the inclusion of detached benthic algae.

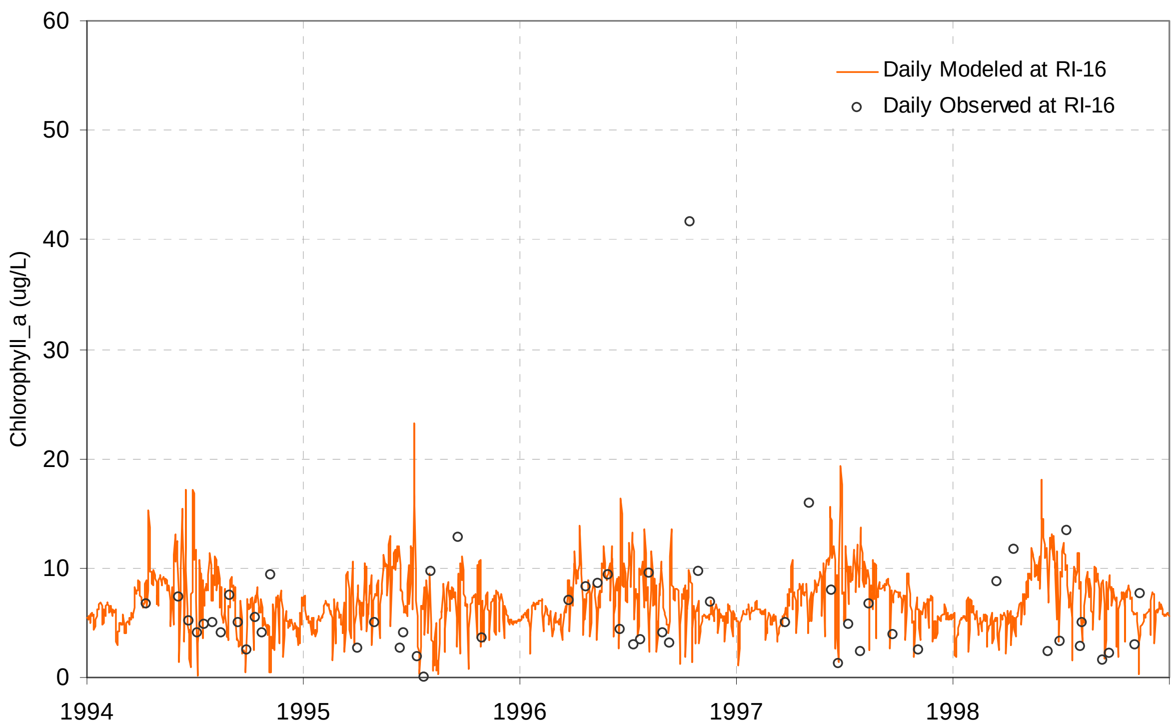


Figure 71. Chlorophyll time series calibration at Menomonee River Station RI-16.

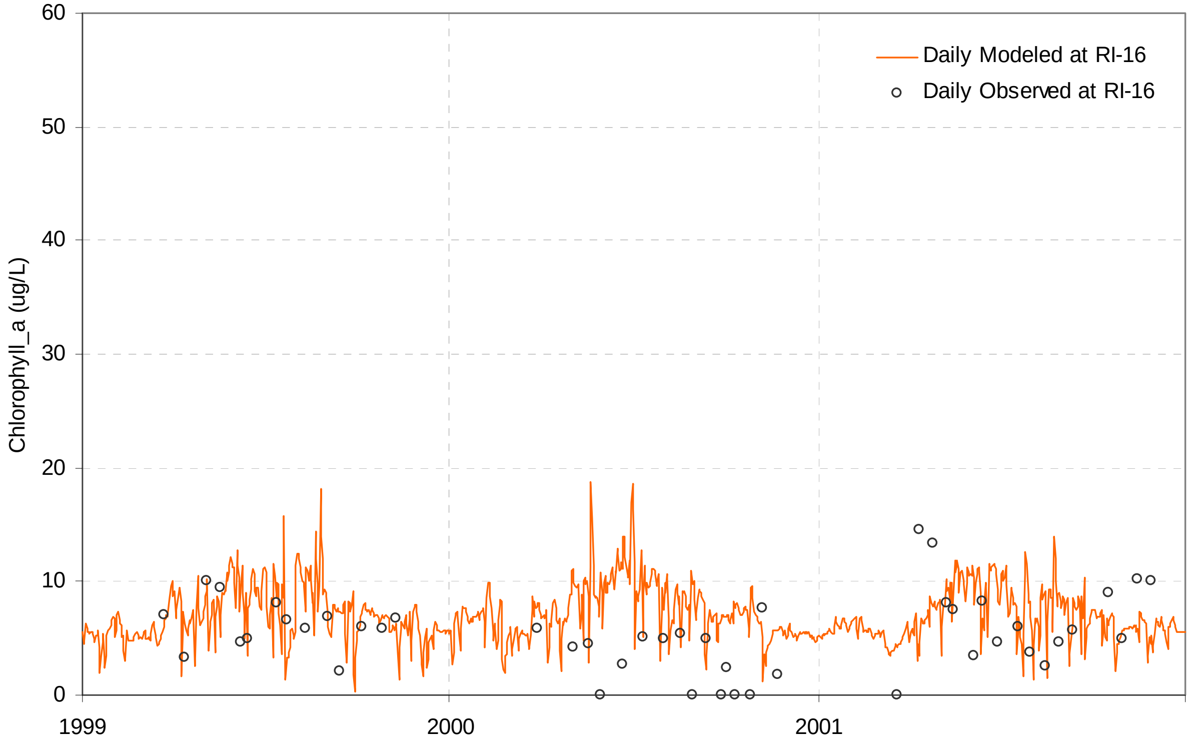


Figure 72. Chlorophyll time series validation at Menomonee River Station RI-16.

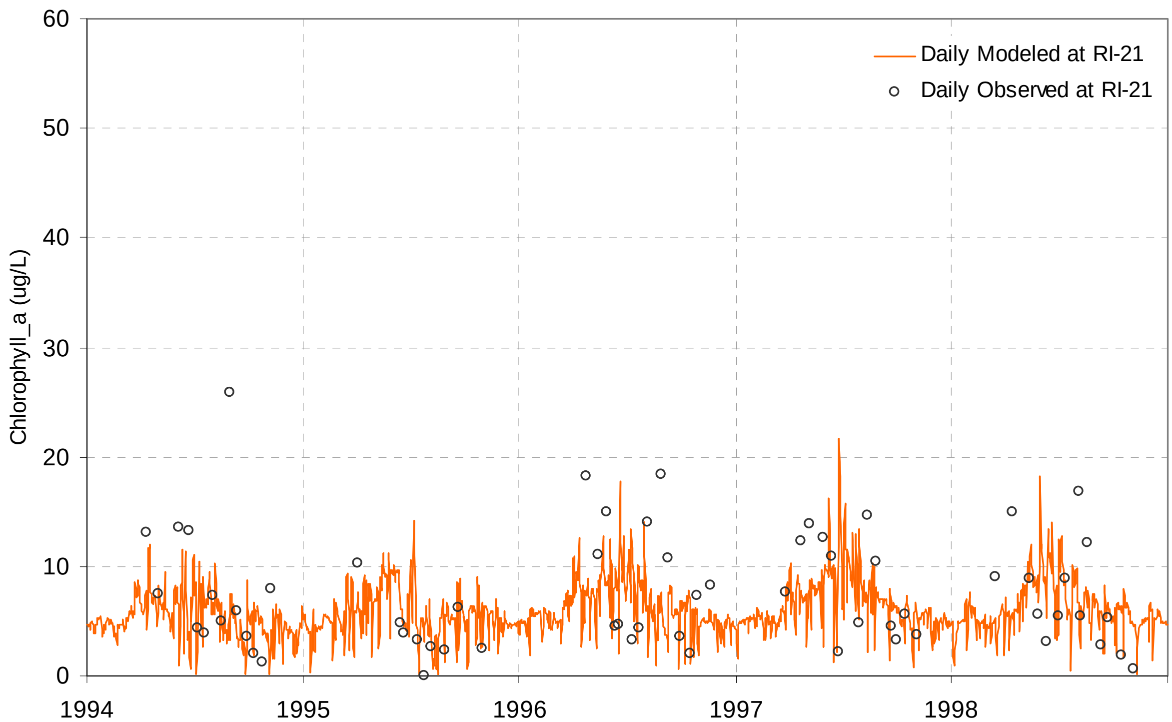


Figure 73. Chlorophyll time series calibration at Menomonee River Station RI-21.

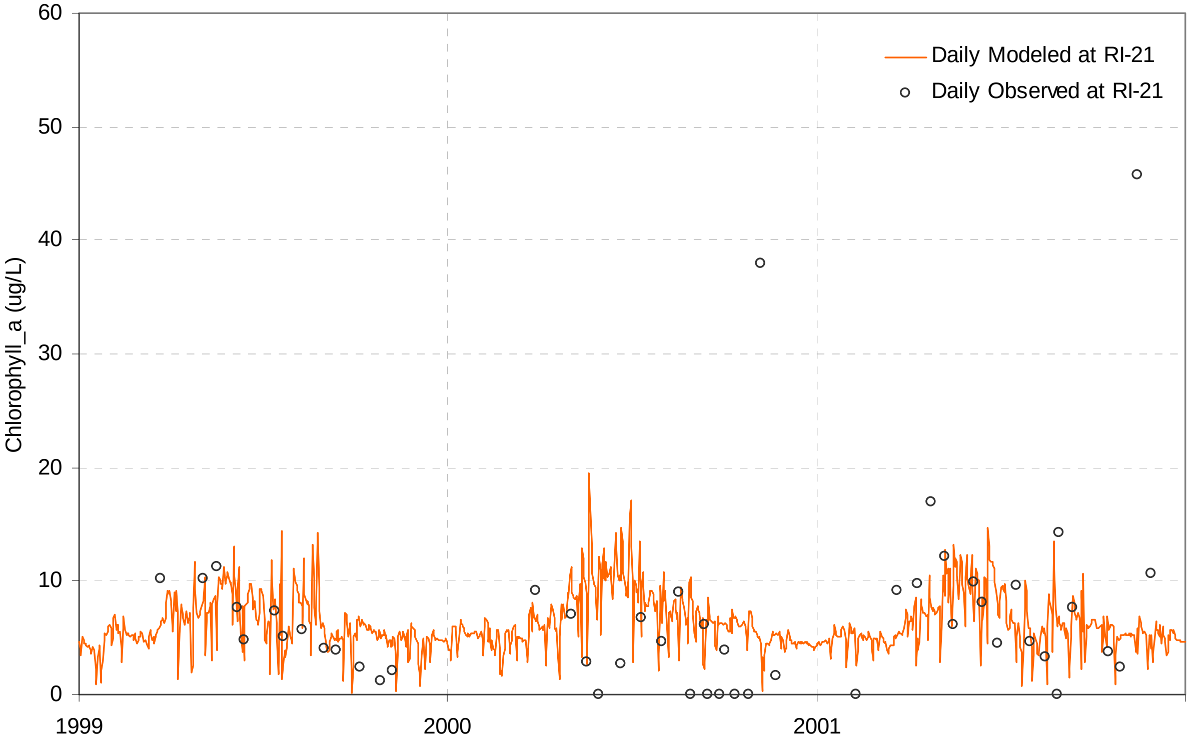


Figure 74. Chlorophyll time series validation at Menomonee River Station RI-21.

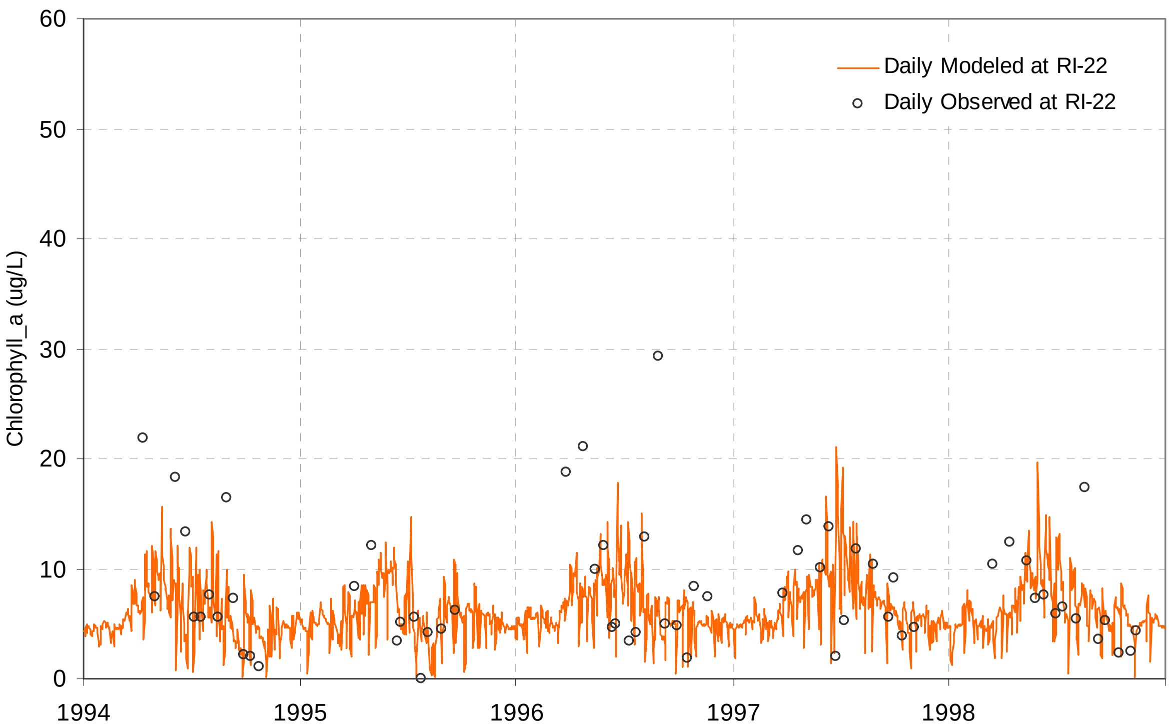


Figure 75. Chlorophyll time series calibration at Menomonee River Station RI-22.

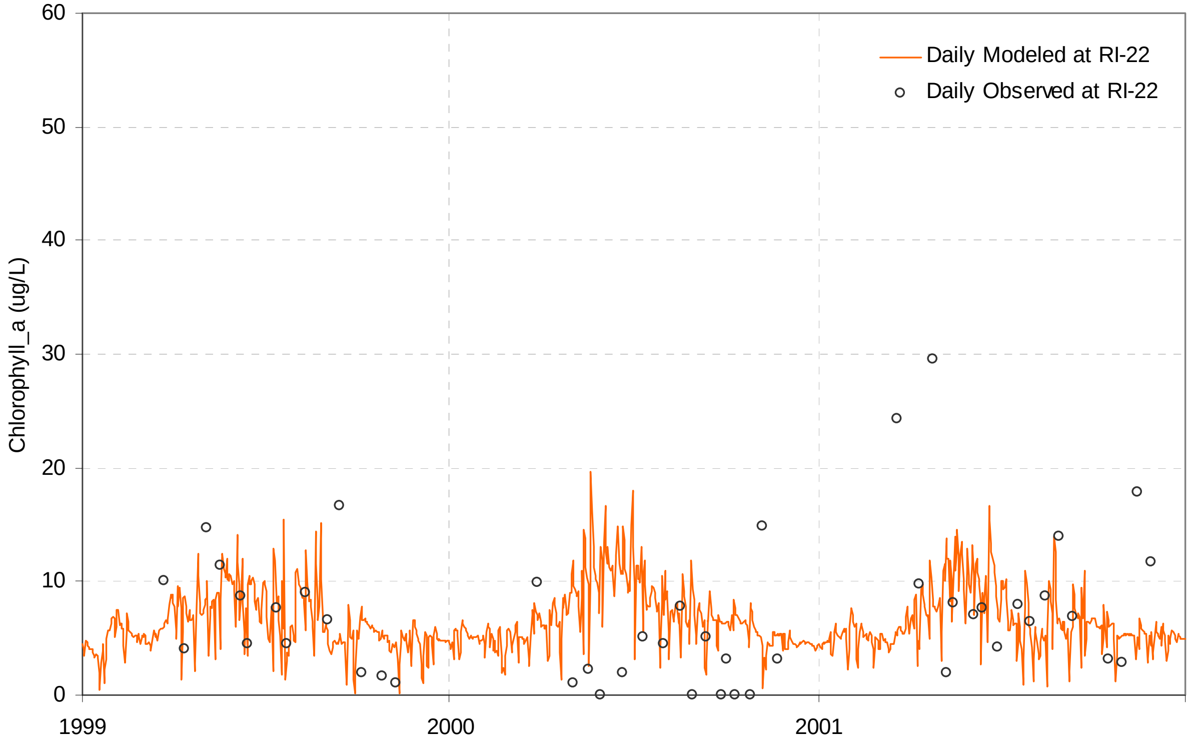


Figure 76. Chlorophyll time series validation at Menomonee River Station RI-22.

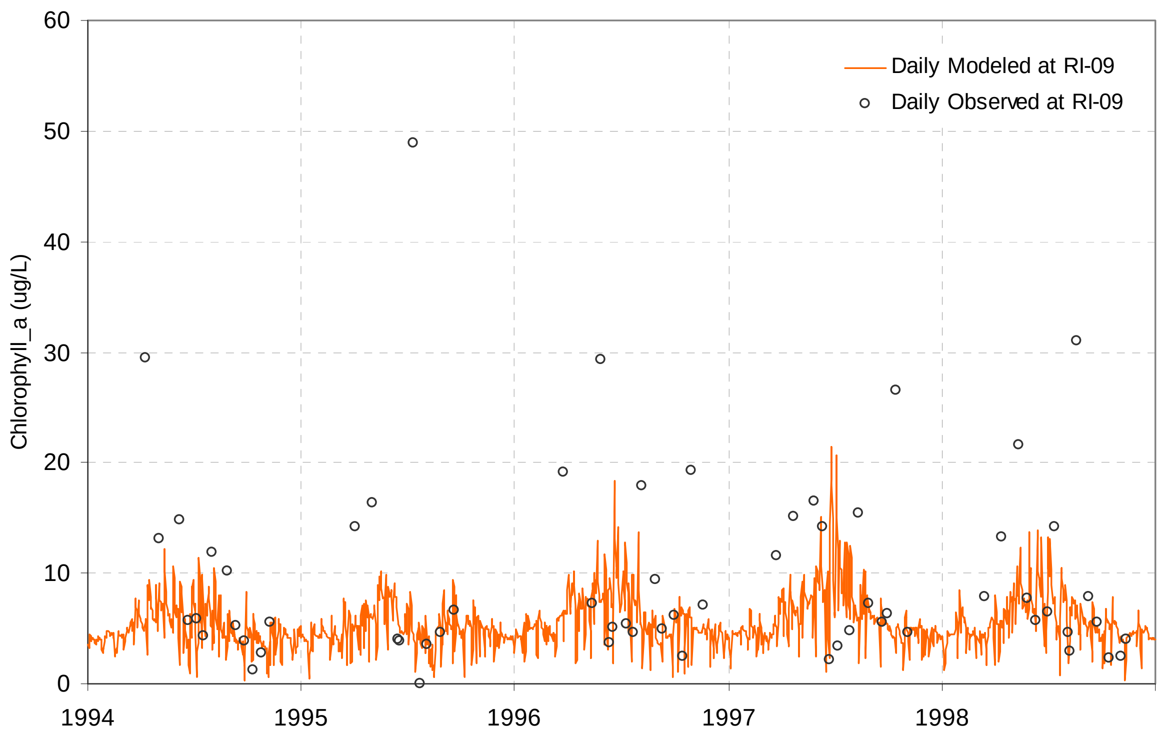


Figure 77. Chlorophyll time series calibration at Menomonee River Station RI-09.

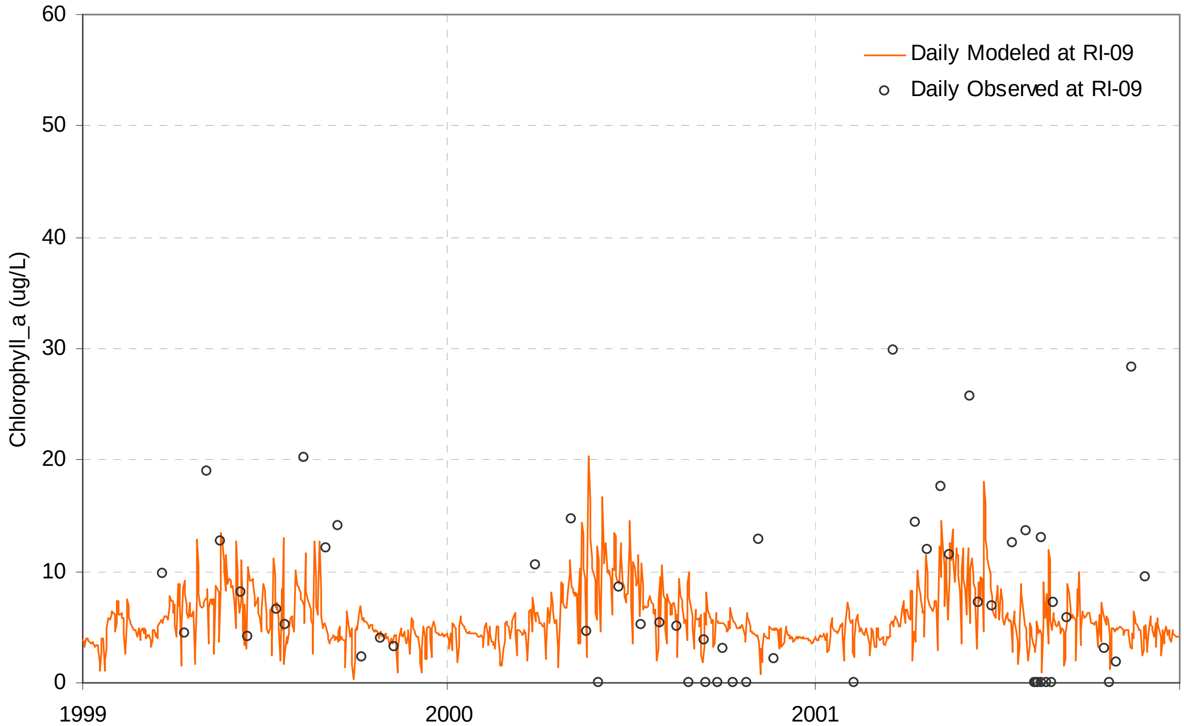


Figure 78. Chlorophyll time series validation at Menomonee River Station RI-09.

5.4 BOD/DO Calibration

Biochemical oxygen demand (BOD) has been primarily monitored in the Menomonee River using APHA (1998) Standard Method 5210B without nitrification inhibition. This yields estimates of 5-day (short-term) total BOD (BOD5) from whole-water samples. Most samples are reported at a detection limit of 2 mg/L - due to the need to deplete 2.0 ppm DO for a test to be acceptable according to the method. Some samples are reported at a detection limit of 0.2 mg/L; however, in most cases samples with less than 2 mg/L BOD5 have been reported as zeros.

The LSPC model simulates a single dissolved carbonaceous BOD (CBOD) component as a state variable, while simulating nitrogenous demand separately. In fact, organic matter that exerts an oxygen demand via bacterial digestion is a complex mixture of chemicals with variable reaction rates. The LSPC variable is a summary compromise that, when combined with an average reaction rate, yields the observed rate of oxygen depletion. It is not necessarily equivalent to either a CBOD5 or an ultimate CBOD (CBODu), but rather an *ad hoc* hybrid. For flowing systems with relatively short residence times, an approximation in terms of CBOD5 is usually adequate, although the reaction rate may need to be modified from 5-day laboratory rates to compensate for the mixture of organic compounds actually exerting a demand.

A further complication is that the LSPC variable represents the non-living component of BOD. Method 5210B uses unfiltered samples, and these samples also include living algae. Algae are not allowed to grow during the BOD test, but may continue to exert a respiration demand or die and become part of the non-living BOD. This component of measured BOD is not included in the LSPC state variable. A correction can be calculated to account for the long-term CBODu represented by algal cells, but the effect on BOD5 is more variable and less clear. The lack of filtration and analysis for total rather than carbonaceous BOD both tend to cause reported BOD5 to overestimate CBOD5; however, use of only a 5-day test underestimates the effective CBOD needed by the model to achieve approximate mass balance in the DO simulation. As a result of all these factors, there is no direct correspondence between model simulated CBOD and observed BOD5; rather, only a general qualitative agreement can be shown.

The LSPC model is set up to simulate washoff of total organic carbon from the land surface, consistent with the output from SWAT. This load can be converted into a theoretical CBODu by multiplying by 2.7, reflecting the oxygen requirement for complete oxidation of typical organic matter (Thomann and Mueller, 1986). To convert to an approximation of CBOD5, the resulting value is then divided by an Fratio of 3.1, reflecting fairly recalcitrant organic matter. (A high F-ratio is appropriate because the more labile organic material is often oxidized before being washed into simulated stream segments.) Despite these caveats, the fit between simulated CBOD and observed BOD5 is fairly good, as is the DO prediction. There are some discrepancies in DO. Some points are under-predicted because photosynthetic production of oxygen is underestimated. Several of the higher values represent highly supersaturated conditions that are likely associated with localized algal mats.

Model results for the calibration and validation time periods are provided below for both BOD5 and dissolved oxygen (Figure 79 to Figure 94).

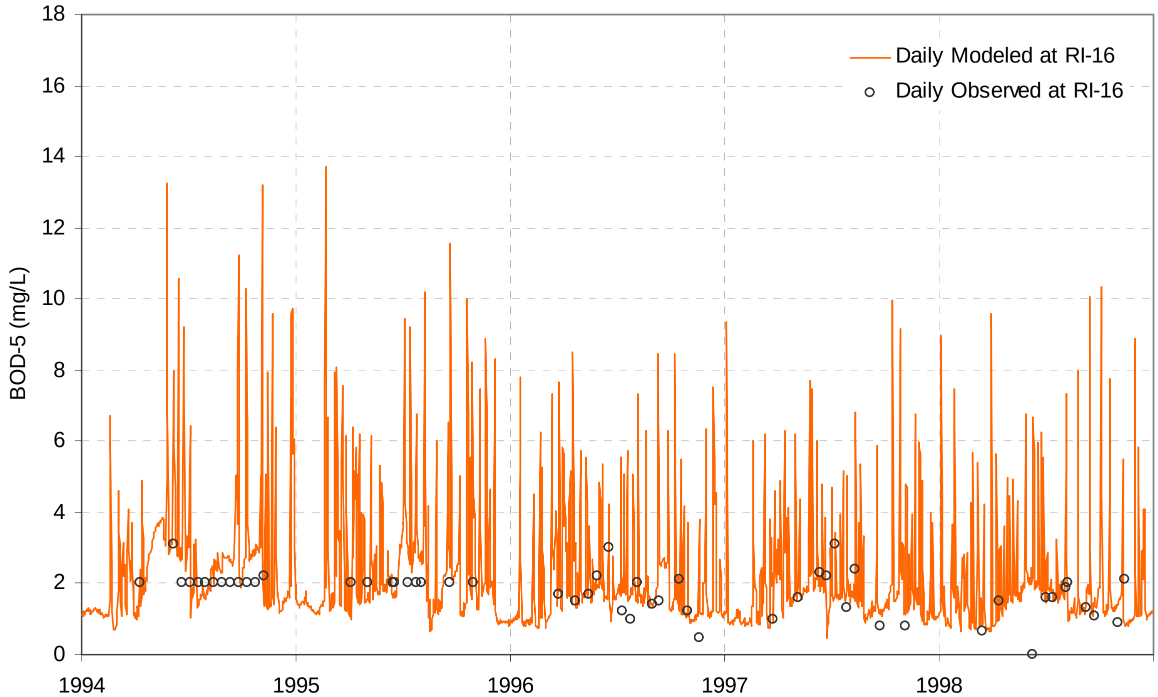


Figure 79. Simulated BOD compared to observed BOD5 time series at Menomonee River Station RI-16, calibration period.

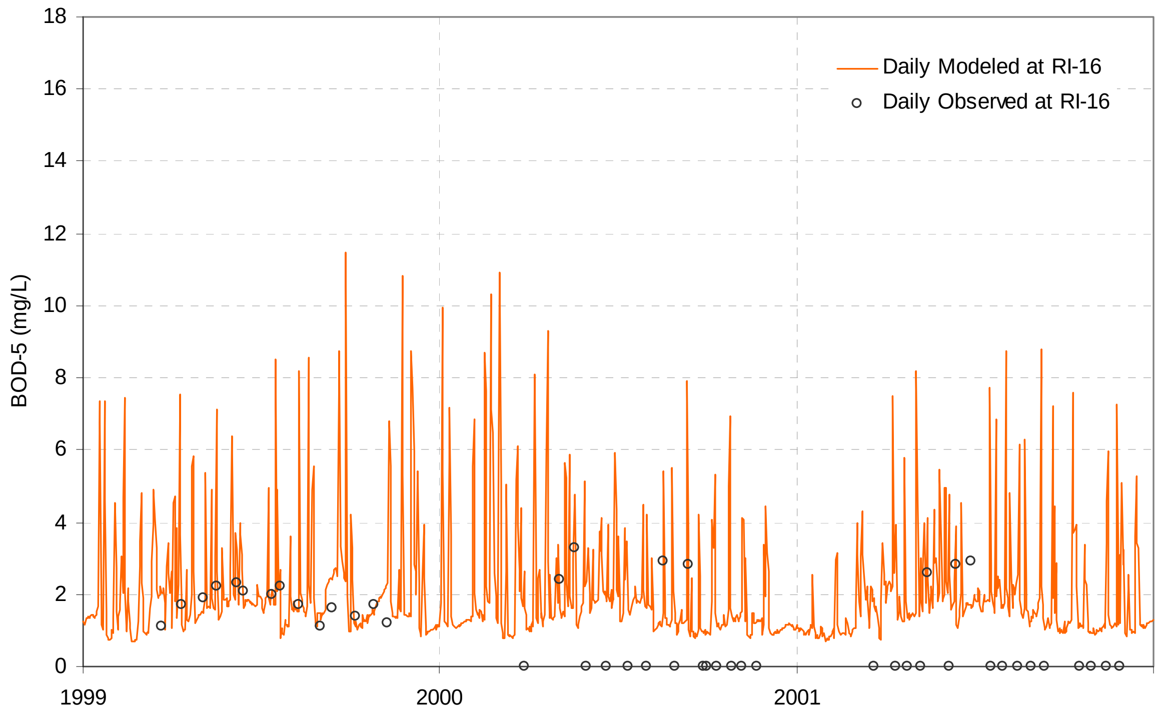


Figure 80. Simulated BOD compared to observed BOD5 time series at Menomonee River Station RI-16, validation period.

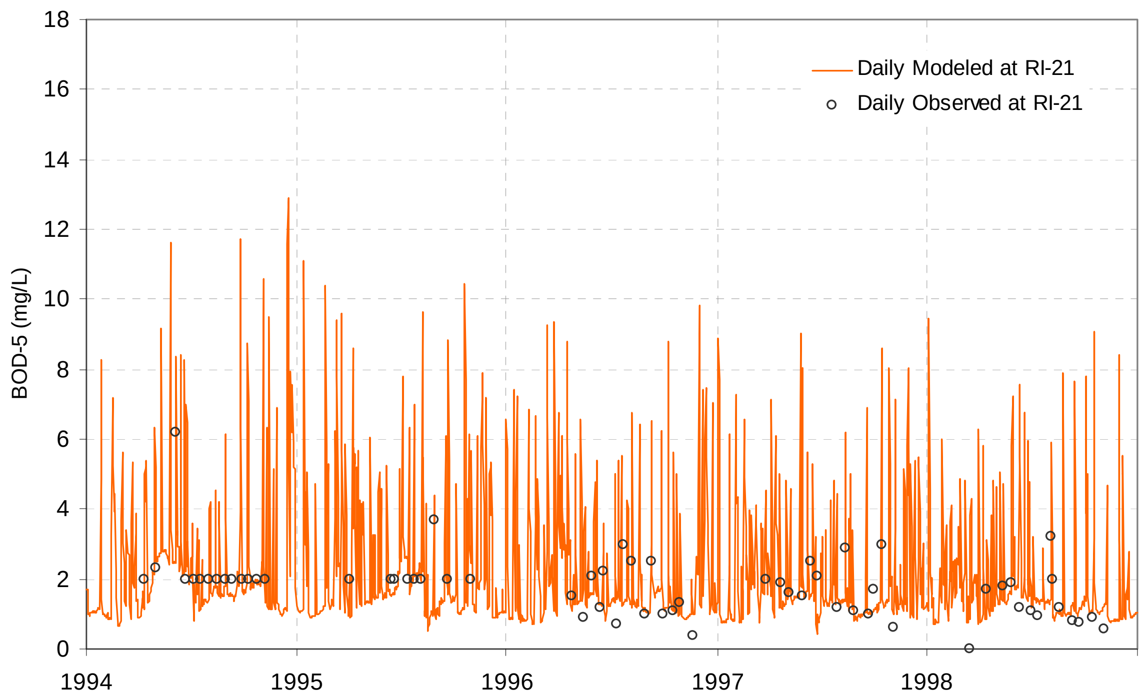


Figure 81. Simulated BOD compared to observed BOD5 time series at Menomonee River Station RI-21, calibration period.

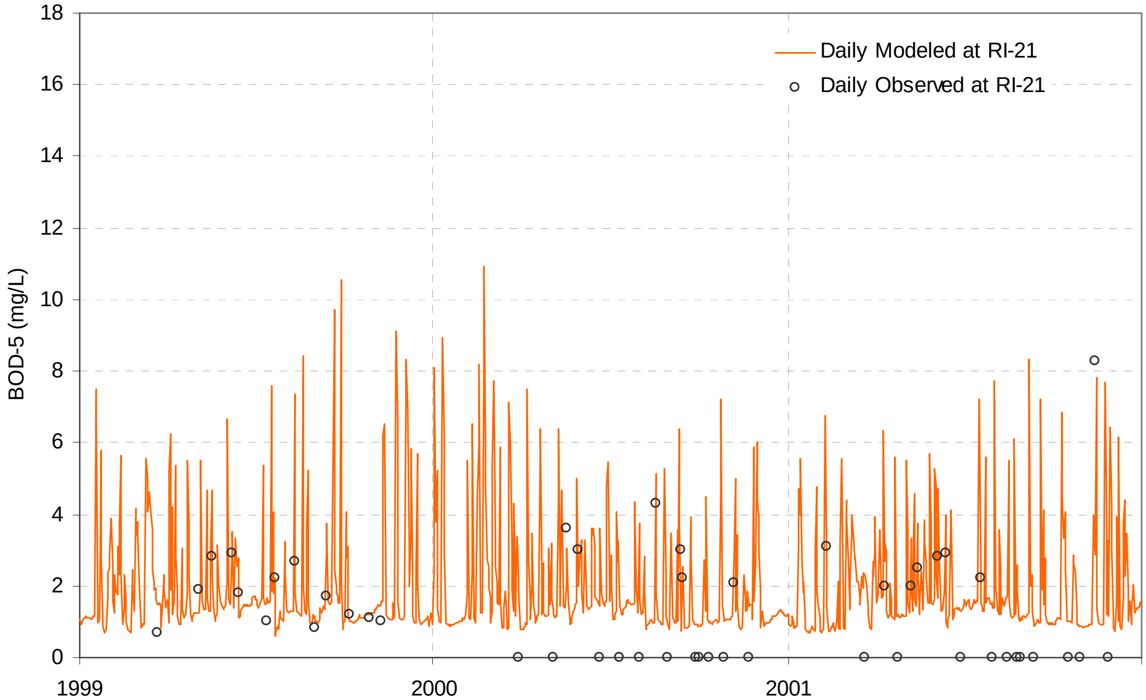


Figure 82. Simulated BOD compared to observed BOD5 time series at Menomonee River Station RI-21, validation period.

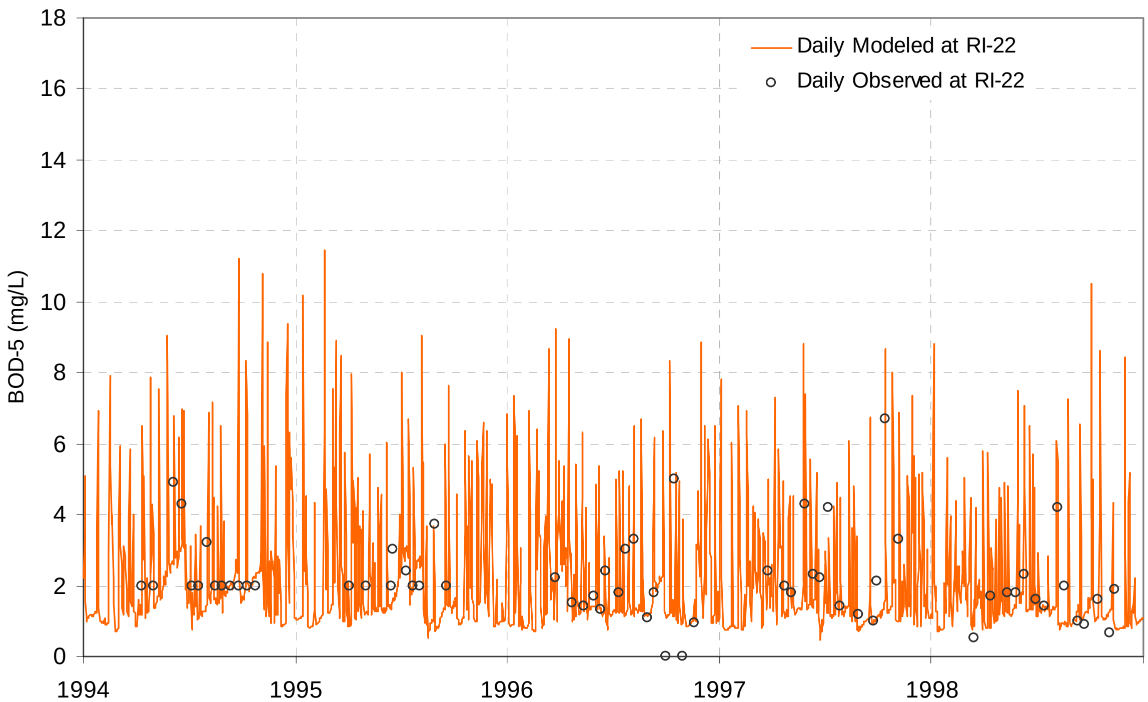


Figure 83. Simulated BOD compared to observed BOD5 time series at Menomonee River Station RI-22, calibration period.

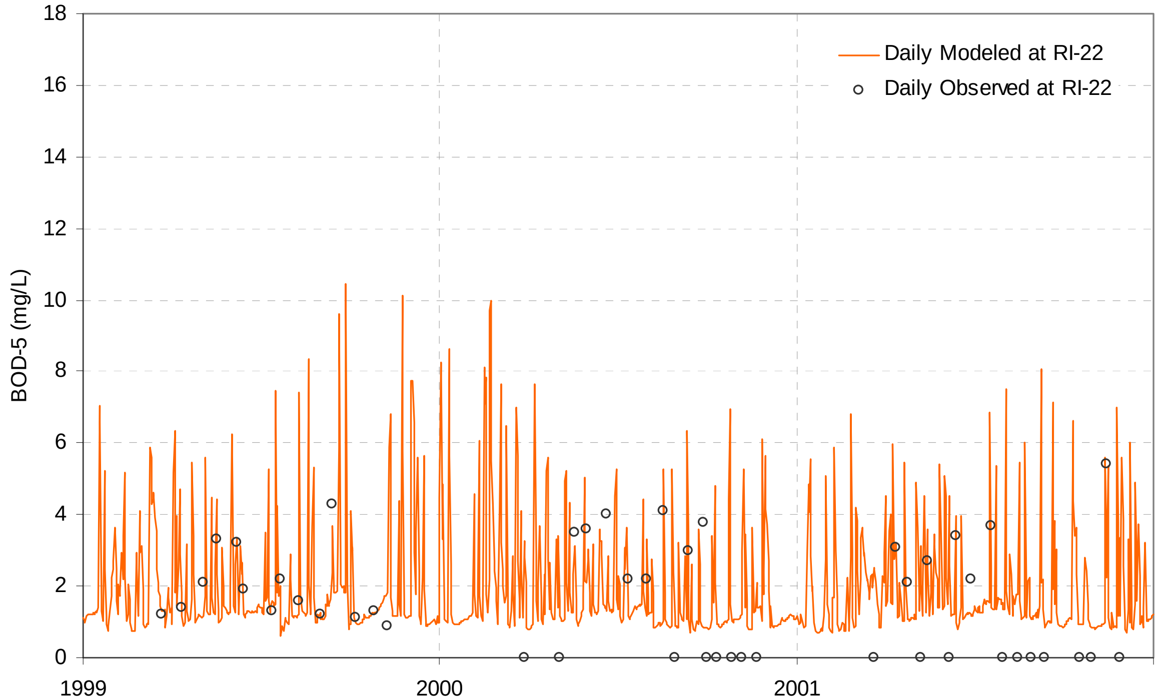


Figure 84. Simulated BOD compared to observed BOD5 time series at Menomonee River Station RI-22, validation period.

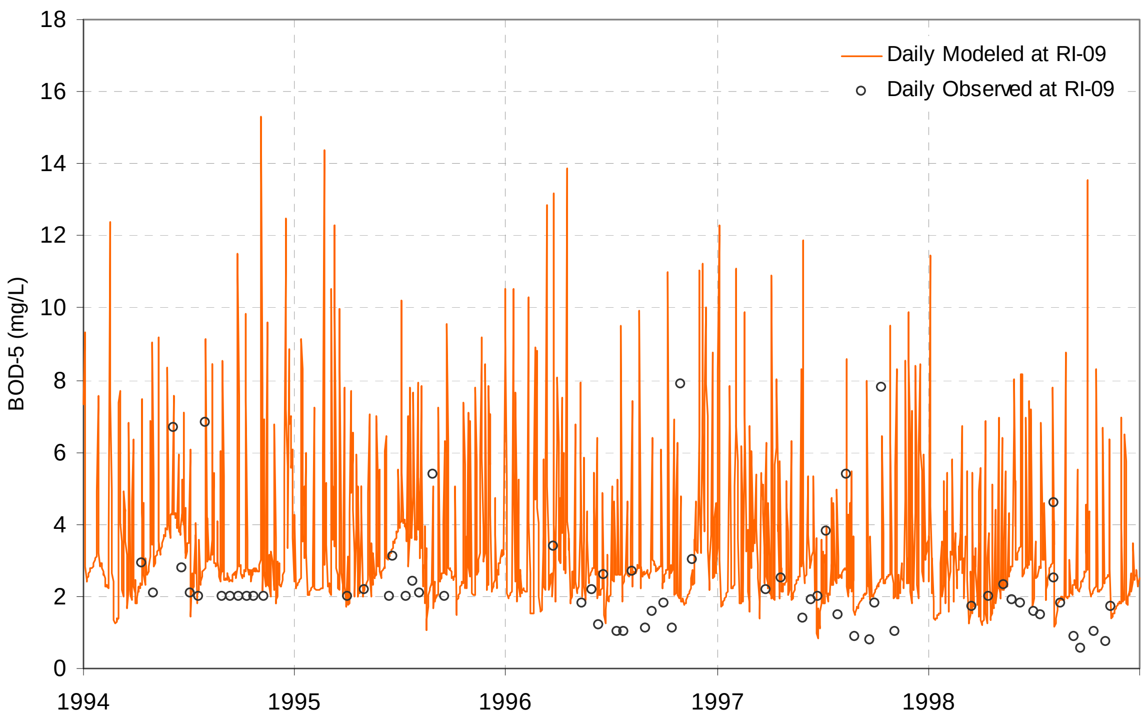


Figure 85. Simulated BOD compared to observed BOD5 time series at Menomonee River Station RI-09, calibration period.

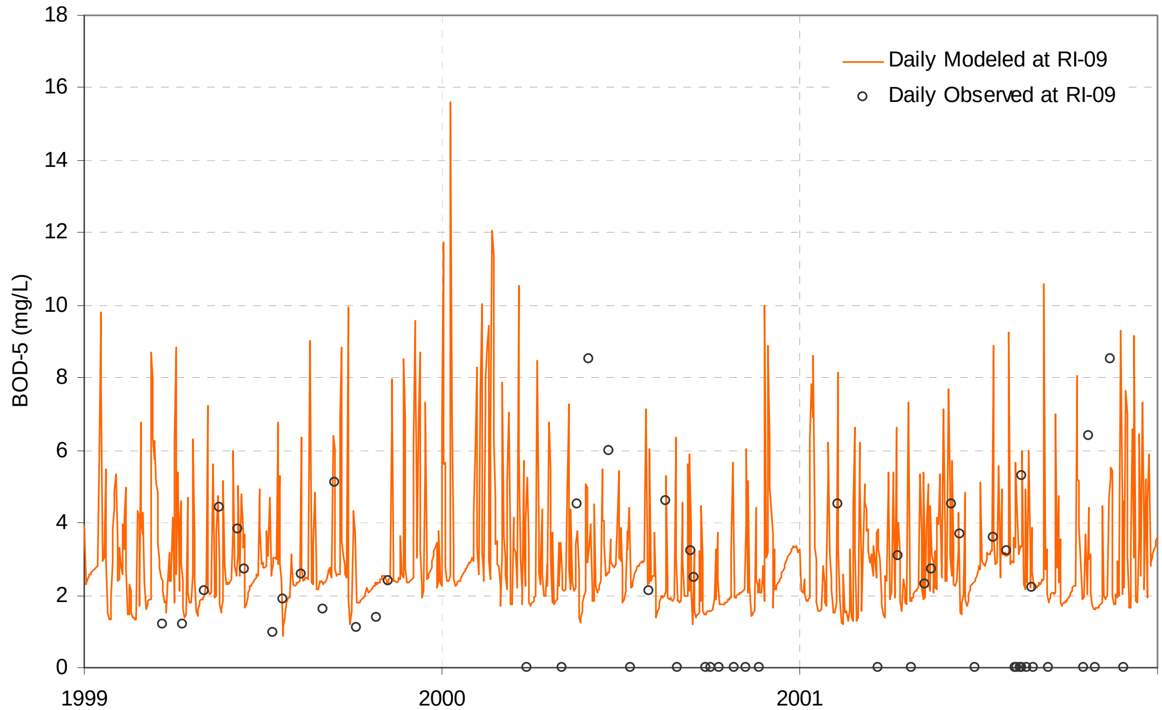


Figure 86. Simulated BOD compared to observed BOD5 time series at Menomonee River Station RI-09, validation period.

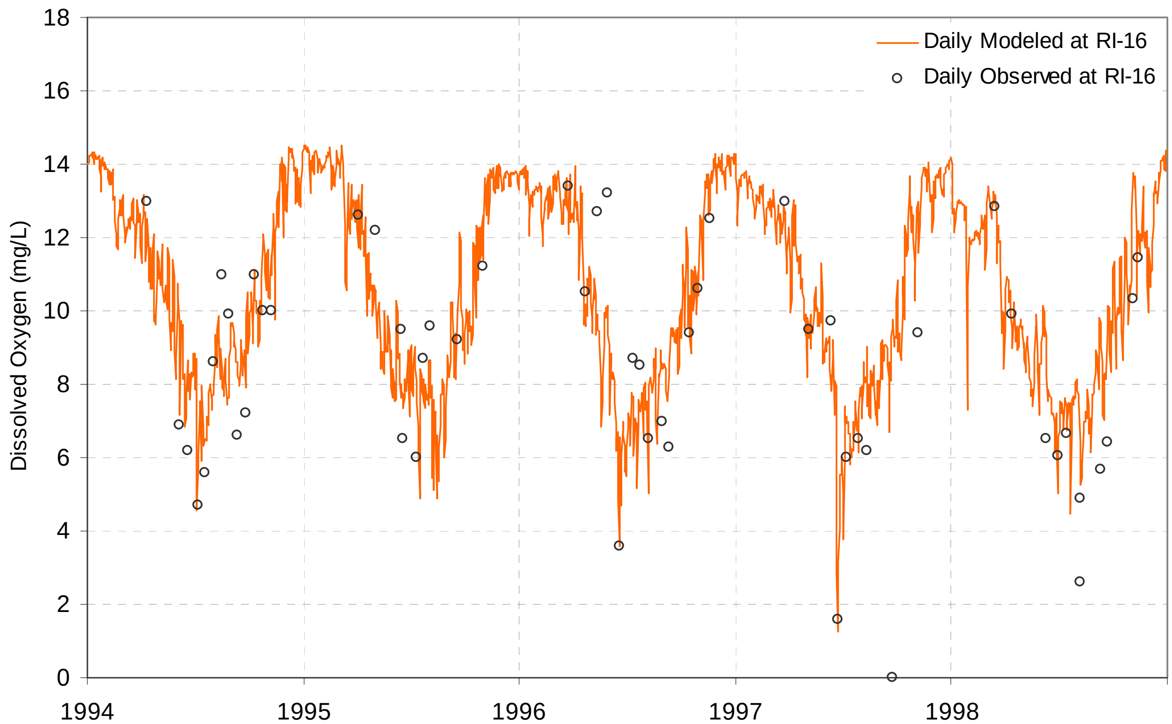


Figure 87. Dissolved oxygen time series calibration at Menomonee River Station RI-16.

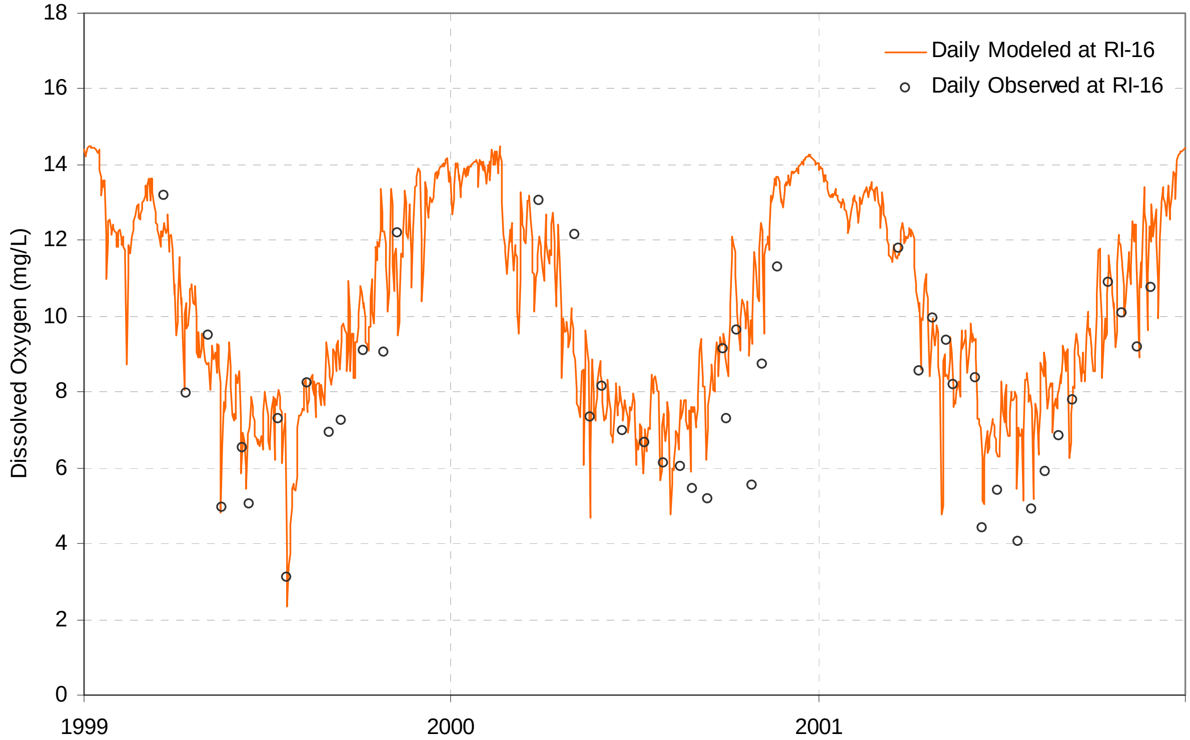


Figure 88. Dissolved oxygen time series validation at Menomonee River Station RI-16.

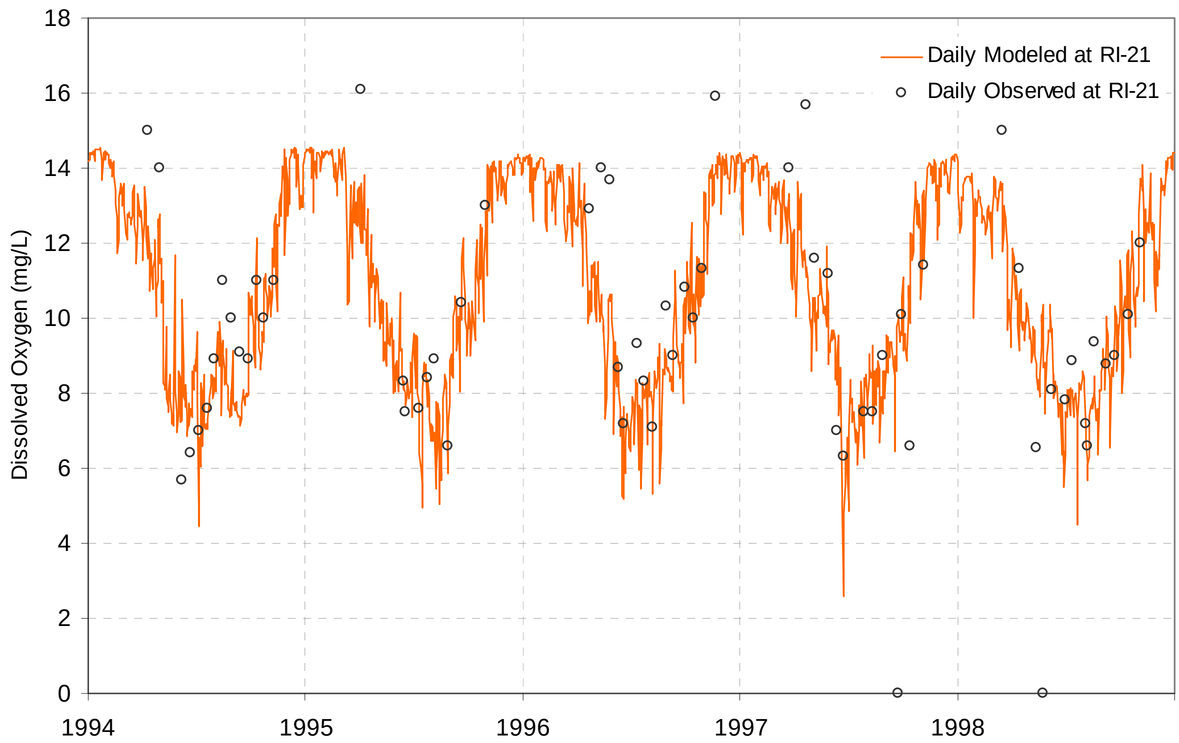


Figure 89. Dissolved oxygen time series calibration at Menomonee River Station RI-21.

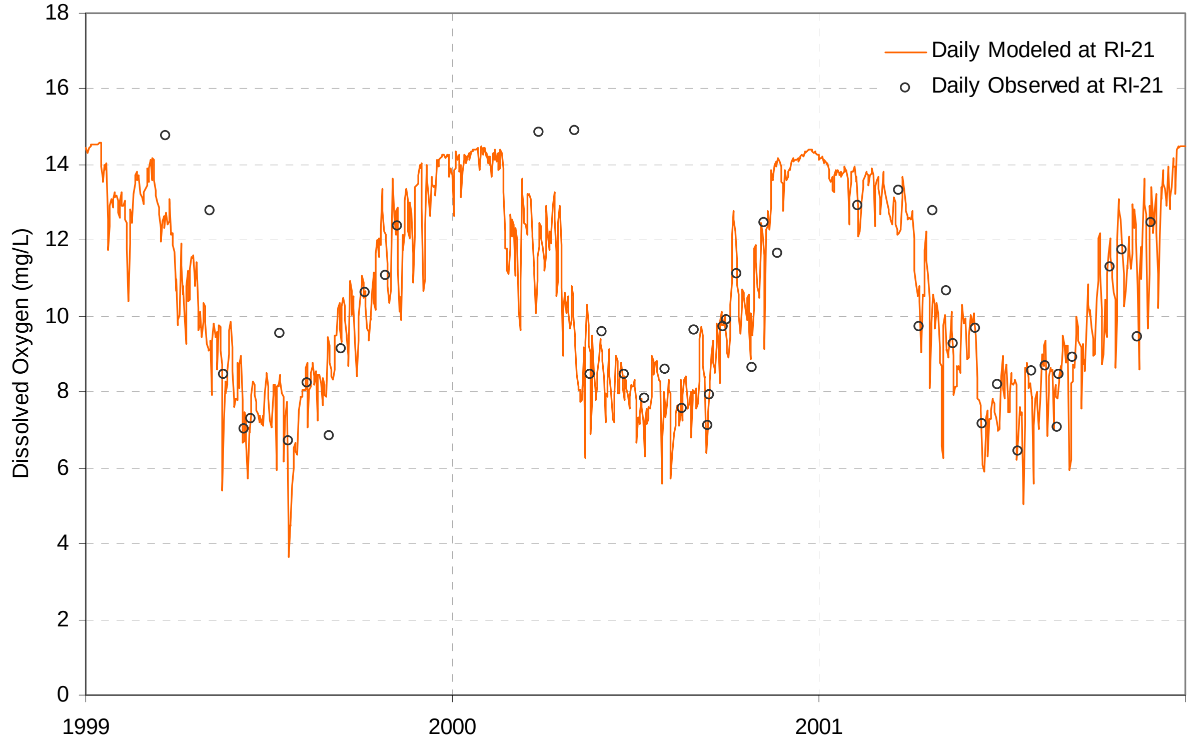


Figure 90. Dissolved oxygen time series validation at Menomonee River Station RI-21.

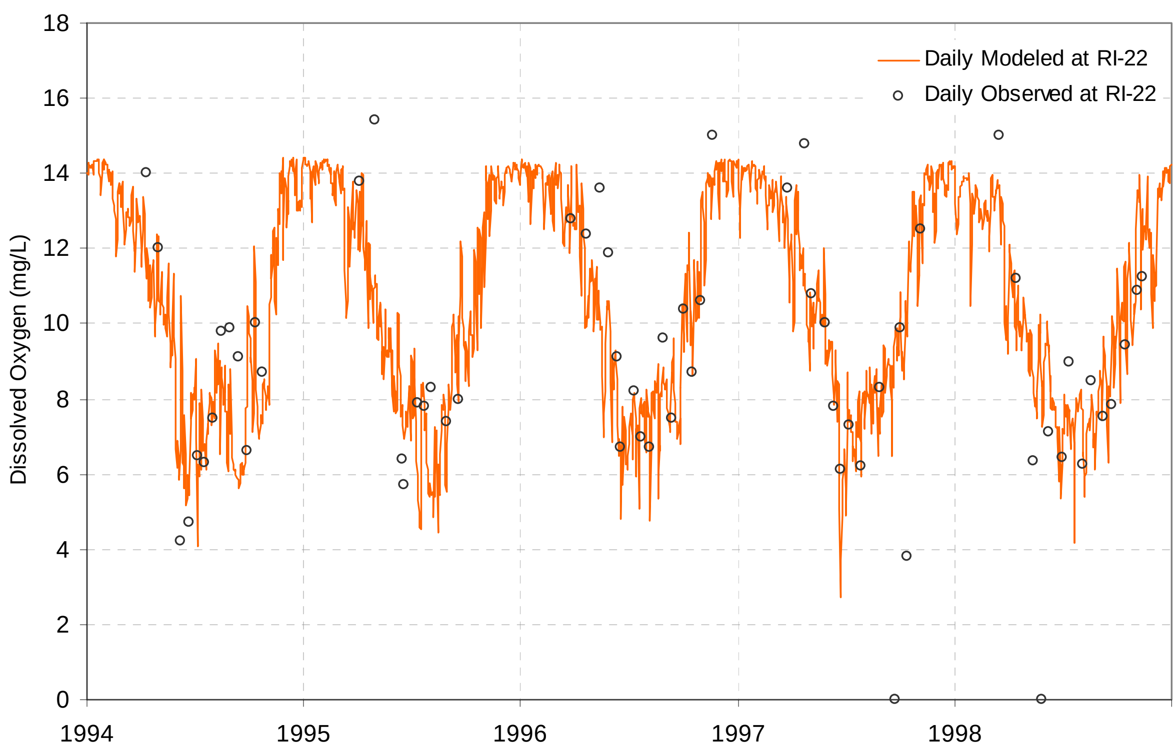


Figure 91. Dissolved oxygen time series calibration at Menomonee River Station RI-22.

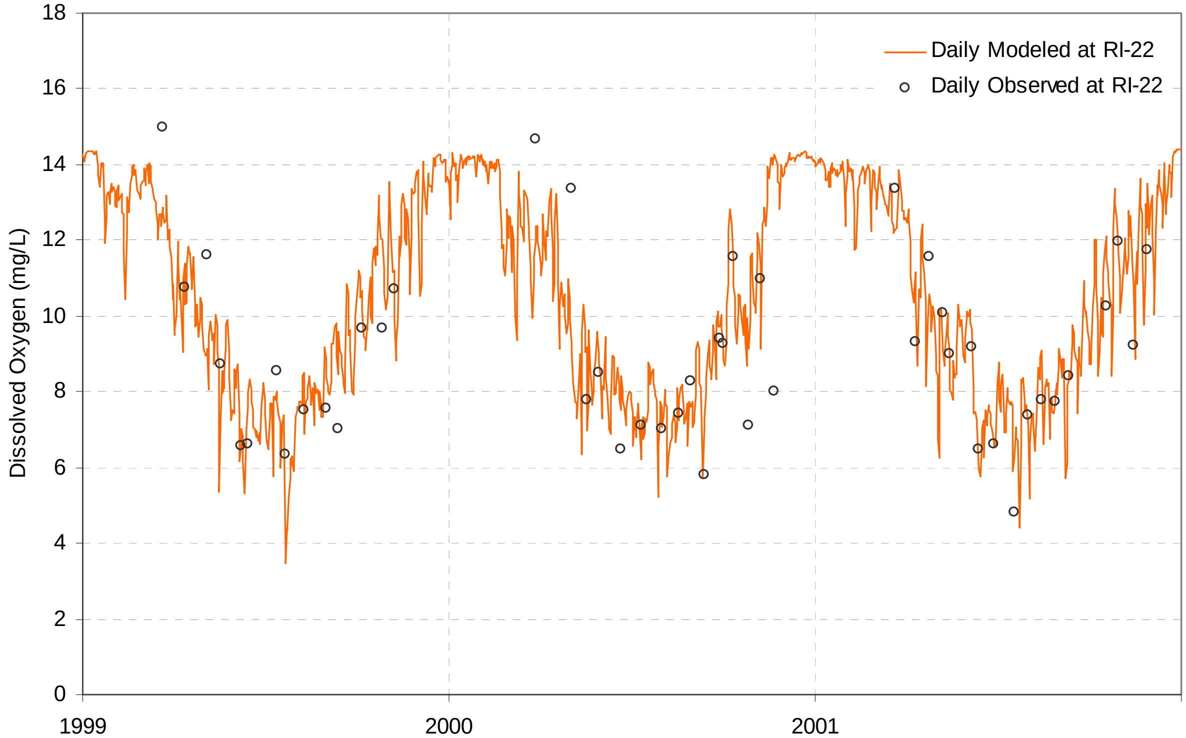


Figure 92. Dissolved oxygen time series validation at Menomonee River Station RI-22.

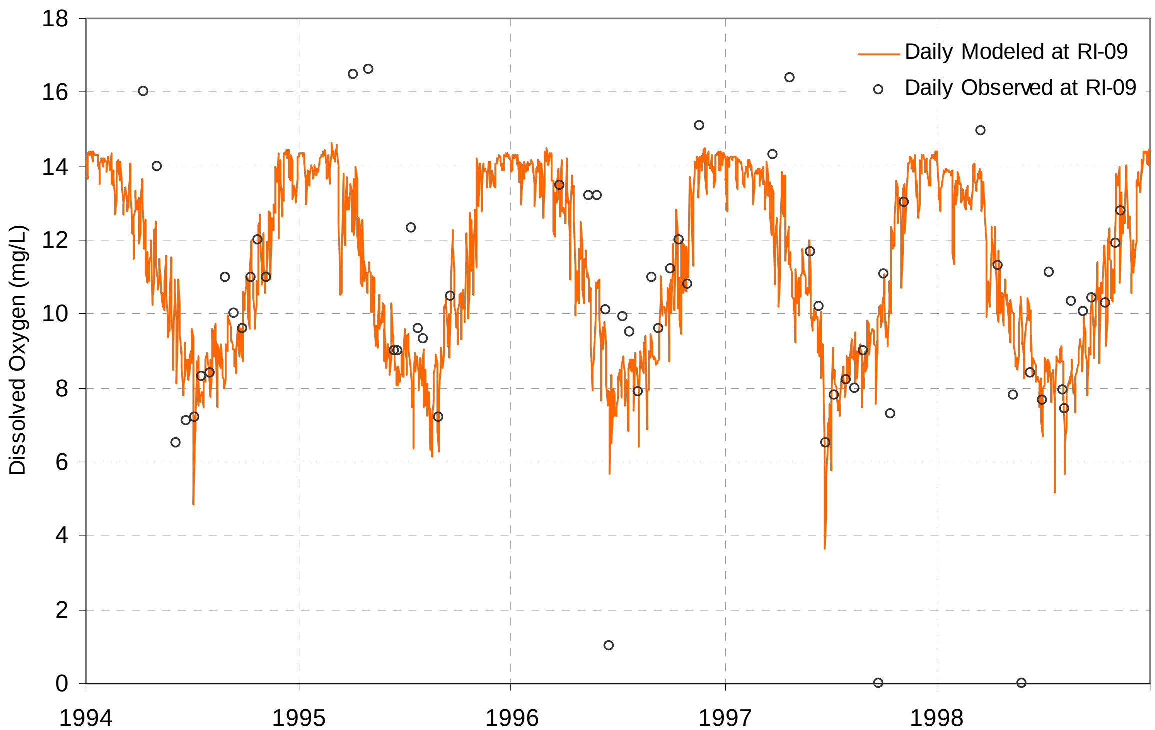


Figure 93. Dissolved oxygen time series calibration at Menomonee River Station RI-09.

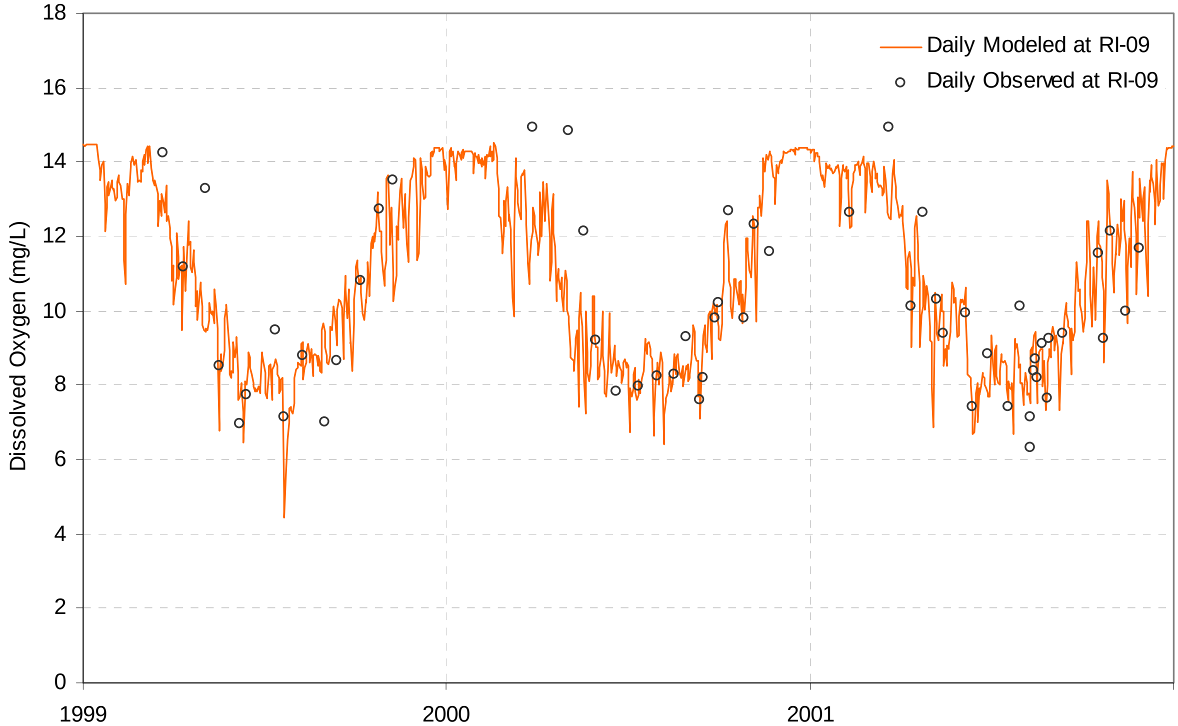


Figure 94. Dissolved oxygen time series validation at Menomonee River Station RI-09.

5.5 Fecal Coliform

Simulation of fecal coliform bacteria concentrations often presents a challenge for watershed modeling. Observed concentrations tend to be highly variable in both space and time - due to both natural variability and analytical uncertainty. Further, instream concentrations may be elevated by sources which are not explicitly included in the model (e.g., water fowl, wildlife, illicit connections to storm sewers, or illegal dumping into storm drain systems), or which may be included in the model in a general way, but have large and unmonitored variability (e.g., occasional loads from wastewater pumping station spills or malfunctioning septic tanks). The watershed models represent average loads from the land surface as a washoff process. In addition, background loading is represented as a ground water concentration. In fact, the load attributed to ground water includes both true ground water load and other unmodeled sources of loading that are not flow-dependent.

The basis for setup of bacteria export from pervious land surfaces was the Fecal Coliform Loading Estimation spreadsheet. This tool was developed by Tetra Tech and NRCS for the purpose of compiling fecal coliform bacteria based on available local agency and national literature information. For agricultural lands, monthly estimates of fecal coliform loadings were estimated using agricultural census counts, literature values for manure production rates and bacteria counts, and estimates of manure application or deposition. Cattle waste is either applied as manure to cropland and pastureland or contributed directly to pastureland. Cattle are assumed to be either kept in feedlots or allowed to graze (depending on the season). Chicken waste is applied as manure to cropland and pasture. Swine manure is assumed to be collected and applied to cropland only.

Buildup and washoff rates for forest and wetland were not calculated in the spreadsheet, but were instead adopted from the successful application of the Minnesota River models (Tetra Tech, 2002). Loading rates for urban pervious surfaces are constant throughout the year and were derived primarily from estimates of domestic pet densities and pet waste characteristics. Loads from impervious surfaces were tuned to replicate loading predicted by SLAMM for 1995-1997. Some revisions to the parameters described in early memos were needed to insure that the SLAMM loads were replicated. The current good agreement for annual loading rates from impervious land surfaces is shown in Figure 95.

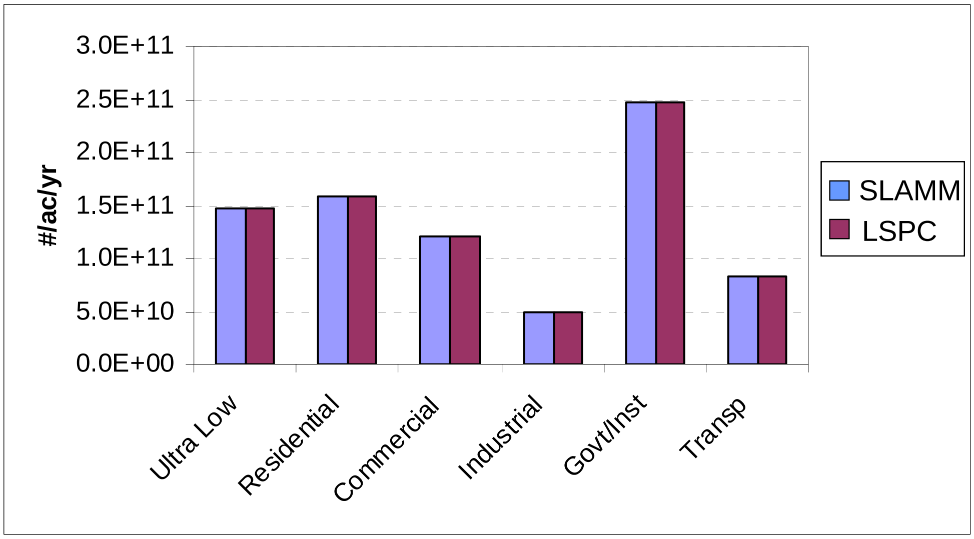


Figure 95. LSPC and SLAMM Loading Rates for Fecal Coliform Bacteria from Impervious Surfaces.

Fecal coliform concentrations in streams during baseflow are simulated based on a combination of recycling from organic sediment and ground water loading. Ground water concentrations were varied on a seasonal basis to reproduce the general pattern of observed dry-weather baseflow concentrations and vary for rural versus urban land use. The baseflow concentration, which is simulated by assigning a ground water concentration, in part represents actual ground water loading, such as may occur from malfunctioning septic systems or leaky sewer lines, but also reflects direct non-washoff additions of bacteria into waterbodies from wildlife, waterfowl, and domestic animals.

Observed concentrations of fecal coliform bacteria instream are strongly affected by the die off rate of fecal coliform bacteria. As these organisms reside in the mammalian gut, they do not prosper in surface waters. Die off rates are increased by a variety of factors including temperature, sunlight, salinity, settling, and predation. Mancini (1978) suggests a base loss rate of 0.8 per day, with increases above the base rate due to these factors and an Arrhenius temperature coefficient of 1.07. Based on trial and error, a loss rate of 1.15 per day appeared to provide a reasonable fit to observations.

Sorption to sediment may also play an important role in observed fecal coliform concentrations. It is well established (see Thomann and Mueller, 1987, Section 5.3.1) that coliform bacteria may be stored in stream sediment, where they experience a lower die off rate, and diffuse back into the water column, resulting in a slower recovery of stream concentrations to baseflow levels after washoff events. Accordingly, fecal coliform bacteria within stream reaches were simulated as weakly sediment-associated with the silt fraction, and with a lower decay rate (0.125-0.180) while in storage in the stream bed.

Initial simulation results showed a relatively weak representation of observed fecal coliform bacteria concentrations under both low flow and high flow conditions . The most significant discrepancies were found at monitoring station RI-09 located near the downstream end of the Menomonee. Fecal coliform bacteria observations in this urbanized area are much higher than those seen upstream and are under predicted by the model.. This type of phenomenon is commonly found in bacterial models, and may reflect a case in which there are strong local inputs (whether from leaky sewer lines, septic systems, or animals) that are not included in the model representation of diffuse upland sources.

Two efforts were undertaken to improve the fecal coliform simulation results: 1) Adjust base flow conditions by specifying seasonally varying concentrations based on individual monitoring location data, and 2) Increase the impervious surface contributions for fecal coliform.

The initial model runs used seasonally varying groundwater bacterial concentrations based on the median values of the entire set of baseflow fecal coliform concentrations. The observed dataset was re-analyzed to provide seasonal median values at each monitoring location. These values were then incorporated into the watershed model that drains to each monitoring location.

Concentrations during summer washoff events in the urbanized portion of the watershed were also clearly under predicted through use of the SLAMM buildup/washoff parameters. The overall level of instream fecal coliform concentrations increases in an upstream to downstream fashion. This also coincides with the higher level of imperviousness seen in the more urbanized, downstream stream segments. The buildup and washoff rates were therefore increased for impervious areas through introduction of a multiplicative calibration factor. This allows for concentrations in the rural areas to remain relatively unchanged while improving model agreement in the more urbanized areas. A factor of 8 on impervious surface loads was required to achieve a reasonable fit in the downstream area.

Model results for the calibration and validation time periods are provided below (Figure 96 to Figure 103). Exceedance curves are presented in Appendix A.

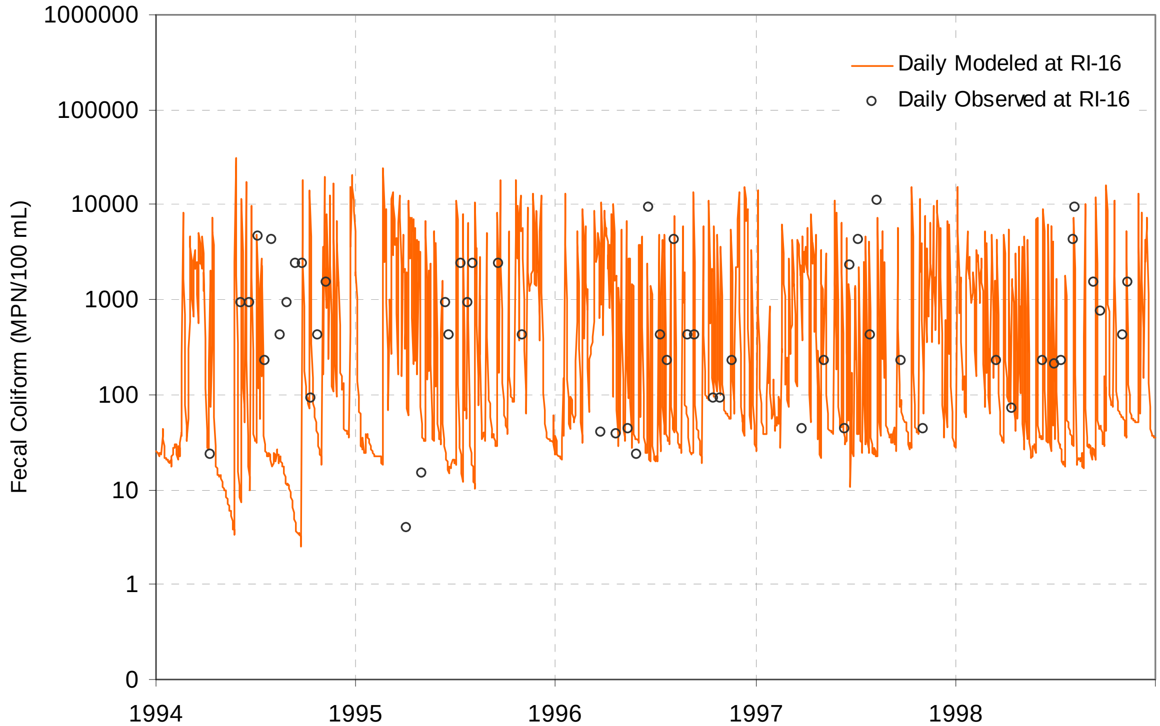


Figure 96. Fecal coliform time series calibration at Menomonee River Station RI-16.

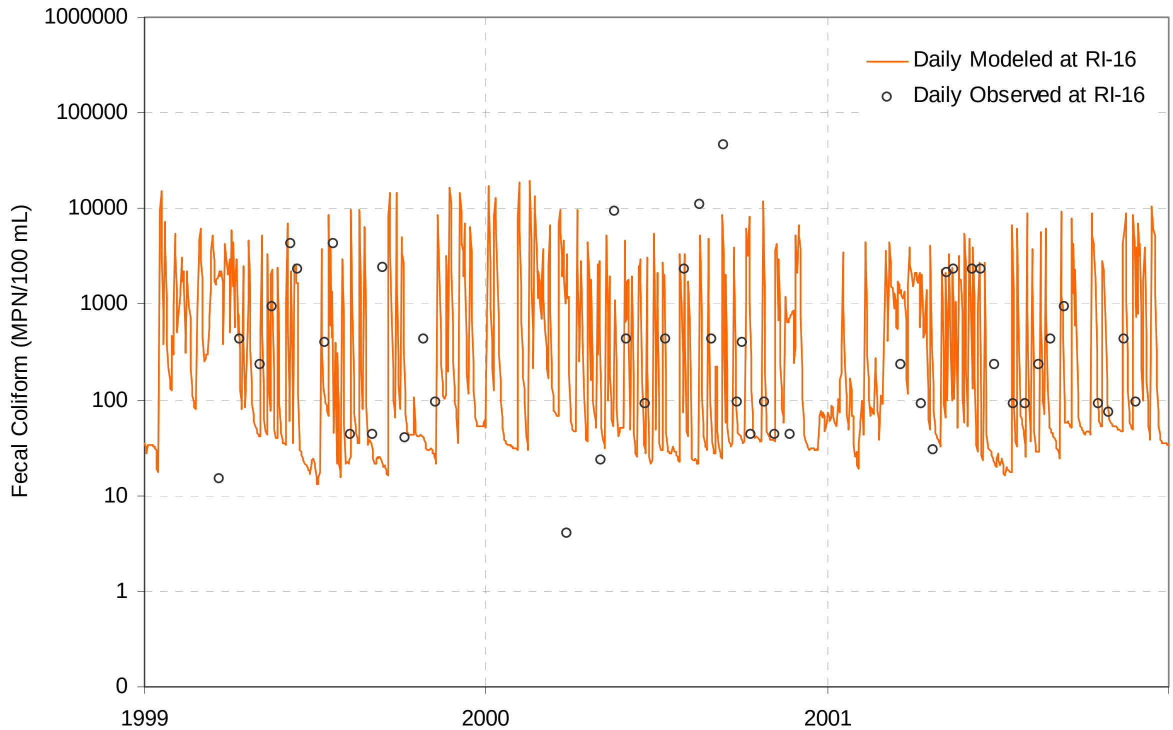


Figure 97. Fecal coliform time series validation at Menomonee River Station RI-16.

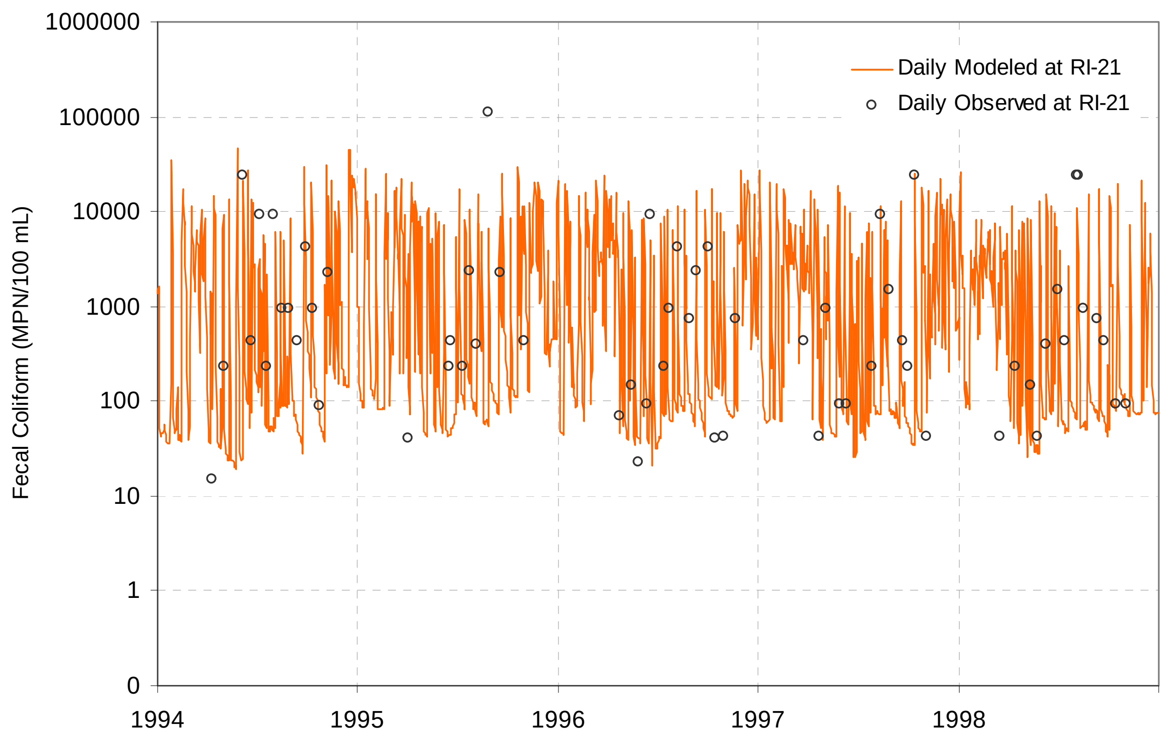


Figure 98. Fecal coliform time series calibration at Menomonee River Station RI-21.

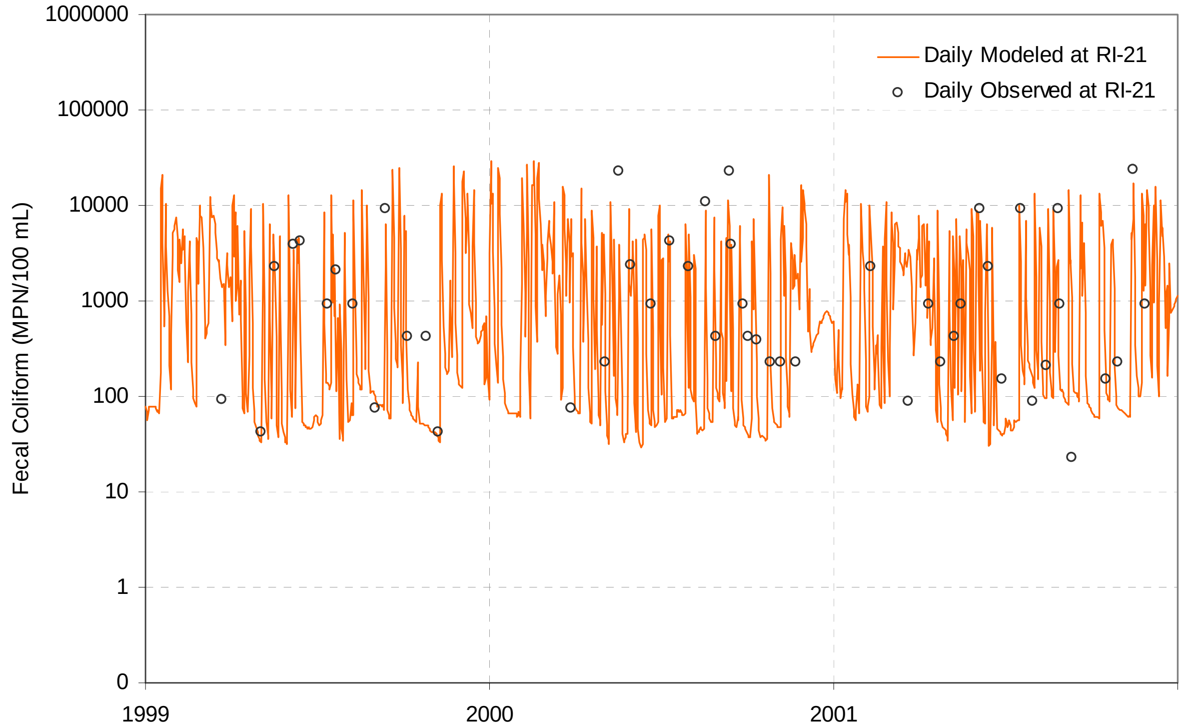


Figure 99. Fecal coliform time series validation at Menomonee River Station RI-21.

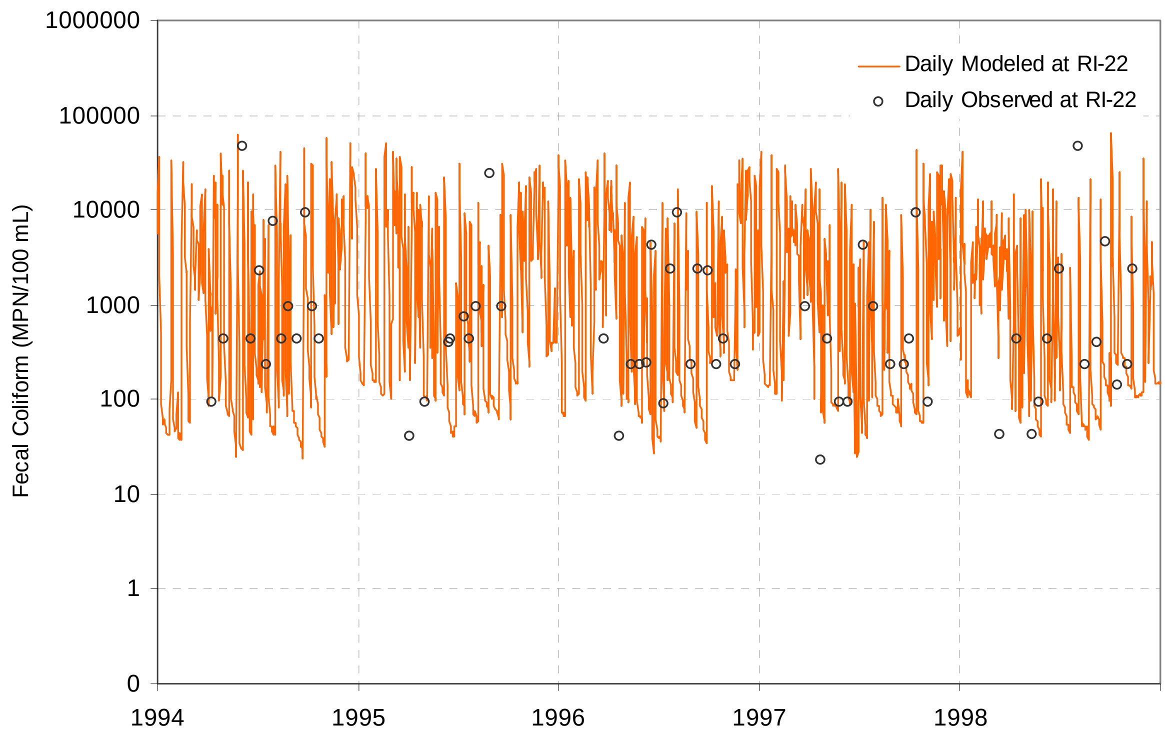


Figure 100. Fecal coliform time series calibration at Menomonee River Station RI-22.

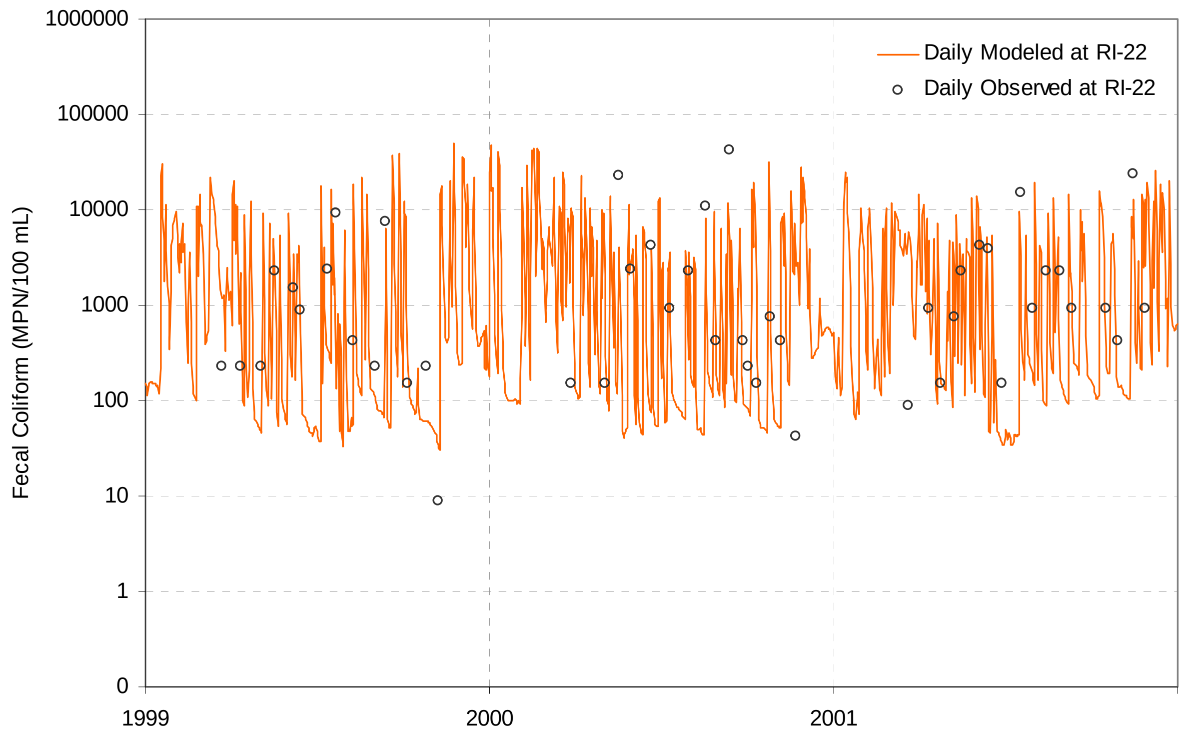


Figure 101. Fecal coliform time series validation at Menomonee River Station RI-22.

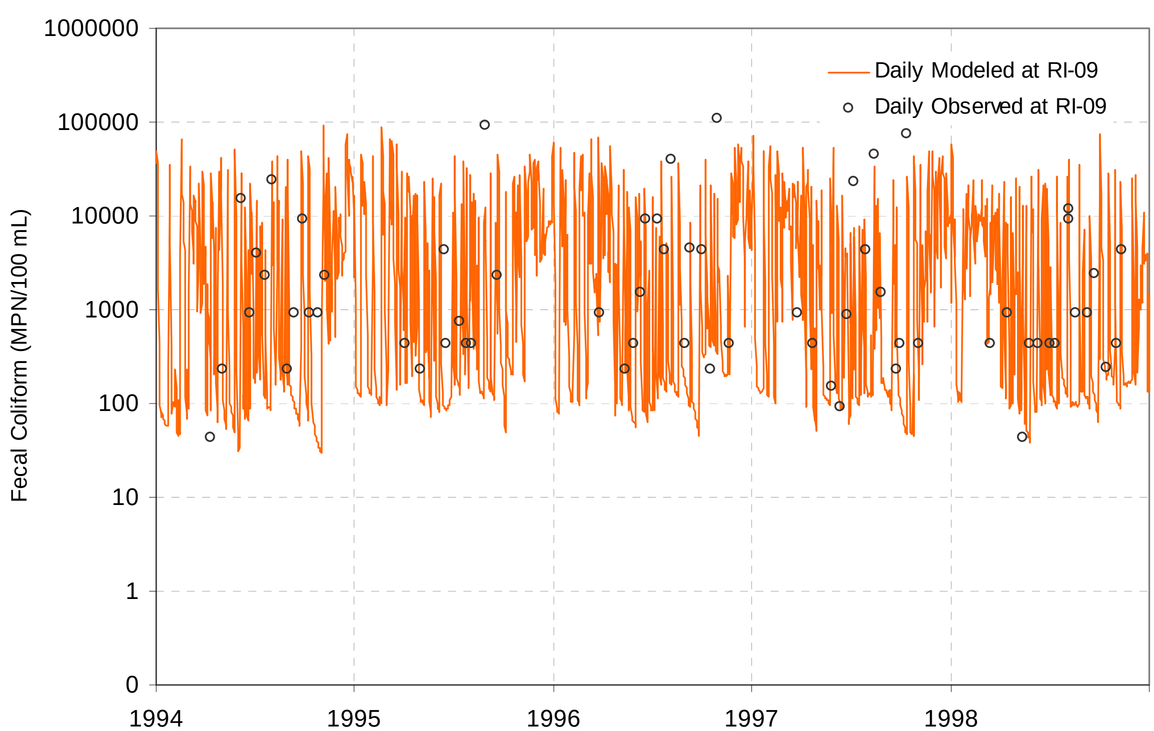


Figure 102. Fecal coliform time series calibration at Menomonee River Station RI-09.

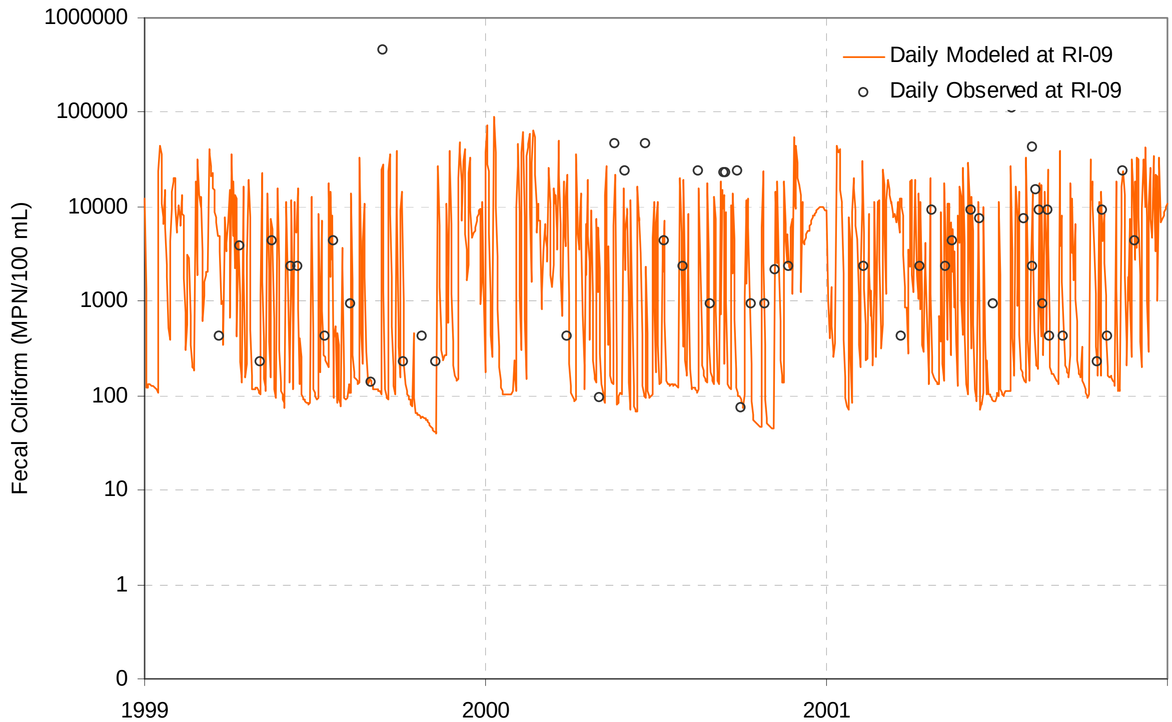


Figure 103. Fecal coliform time series validation at Menomonee River Station RI-09.

5.6 Metals

As requested by SEWRPC, the model includes simulations for copper and zinc, but at a highly simplified level and without calibration. Both copper and zinc are simulated as total metals, and treated as conservative substances within stream reaches. This neglects the actual kinetics of these constituents, which sorb to particulate matter and exchange with the sediments. Such refinements may be added to the model at a future date.

Copper and zinc are also not rigorously calibrated. While there are observations for both total copper and total zinc, many of the observations (particularly) for copper are at or near method detection limits, and thus provide limited information on exact concentrations. Further, neglect of sorption kinetics means that the simulation will only be approximate. Therefore, the strategy was to base the metals simulation on independent loading estimates and adjust these only to the extent necessary to achieve approximate agreement with the range of concentrations reported instream.

For loading from impervious surfaces, the LSPC buildup and washoff rates developed from the SLAMM simulation are used (see February 16, 2004 memorandum entitled *Urban Non-Point Source Unit Loading Rates).* The SLAMM work did not provide estimates of copper loading from pervious surfaces, and use of the buildup/washoff coefficients provided for zinc on pervious surfaces yielded instream concentrations that were more than an order-of-magnitude greater than observed concentrations. Therefore, the starting point for the copper and zinc buildup and washoff coefficients on pervious lands were adopted from a similar model application conducted for Gwinnett County, GA (Tetra Tech and CH2M HILL, 1999).

Use of the Gwinnett County buildup rates for pervious lands and the Milwaukee SLAMM estimates for impervious surfaces directly yielded copper concentrations that are consistent with observations in the Menomonee River. Zinc predictions were still high, however, so a trapping factor of 0.5 was added in the mass-link block for pervious lands. Because zinc is particle reactive, trapping losses in small streams and wetlands is expected, and the 0.5 factor is consistent with the trapping rate applied to phosphorus. No trapping was applied to copper. This constituent is also expected to be particle reactive and could be subject to trapping; however, no adjustment was judged necessary to obtain rough and uncalibrated approximate agreement with observed data.

Finally, concentrations in ground water were set at levels sufficient to replicate concentrations observed at baseflow in the Menomonee (1.3 µg/L total copper and 7.2 µg/L total zinc).

Results for the four Menomonee monitoring stations are shown in the following figures and indicate an approximate agreement in range between model predictions and observations. As noted above, copper and zinc are simulated as conservative substances in the water column and not rigorously calibrated. For this reason, exceedance plots and load analysis of these constituents are not presented.

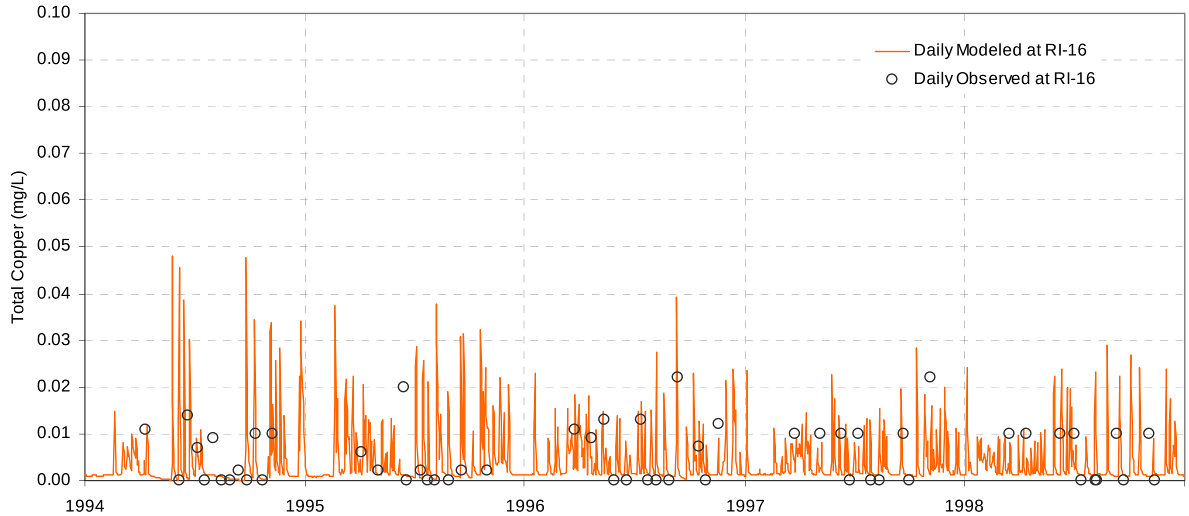


Figure 104. Total Copper time series calibration at Menomonee River Station RI-16.

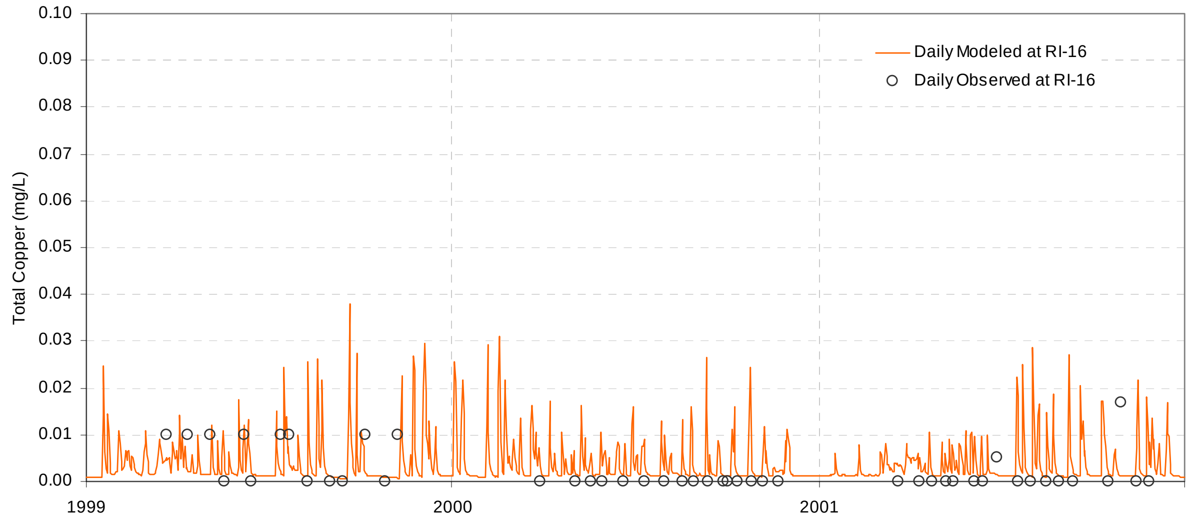


Figure 105. Total Copper time series validation at Menomonee River Station RI-16.

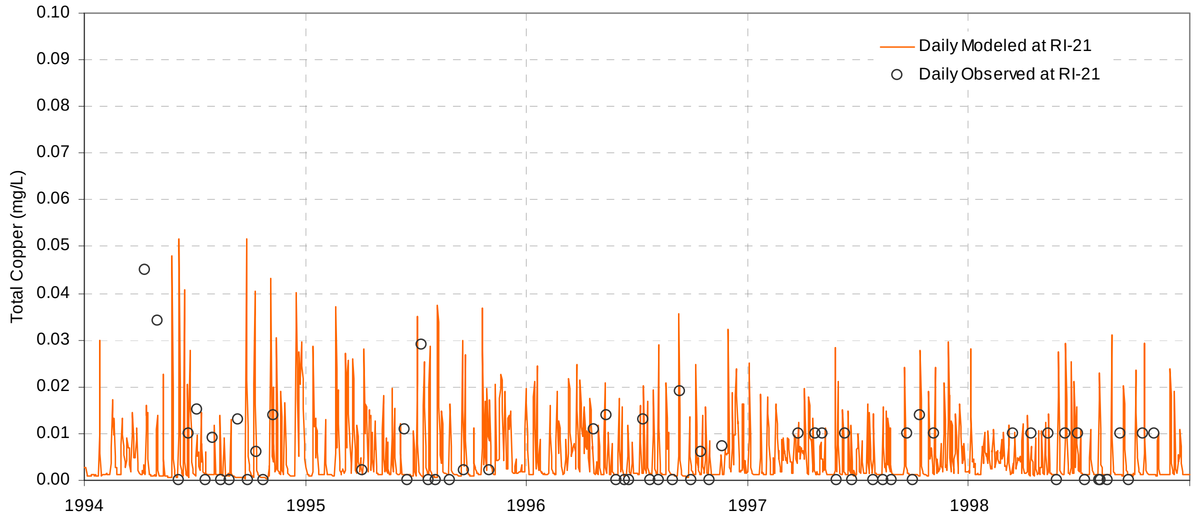


Figure 106. Total Copper time series calibration at Menomonee River Station RI-21.

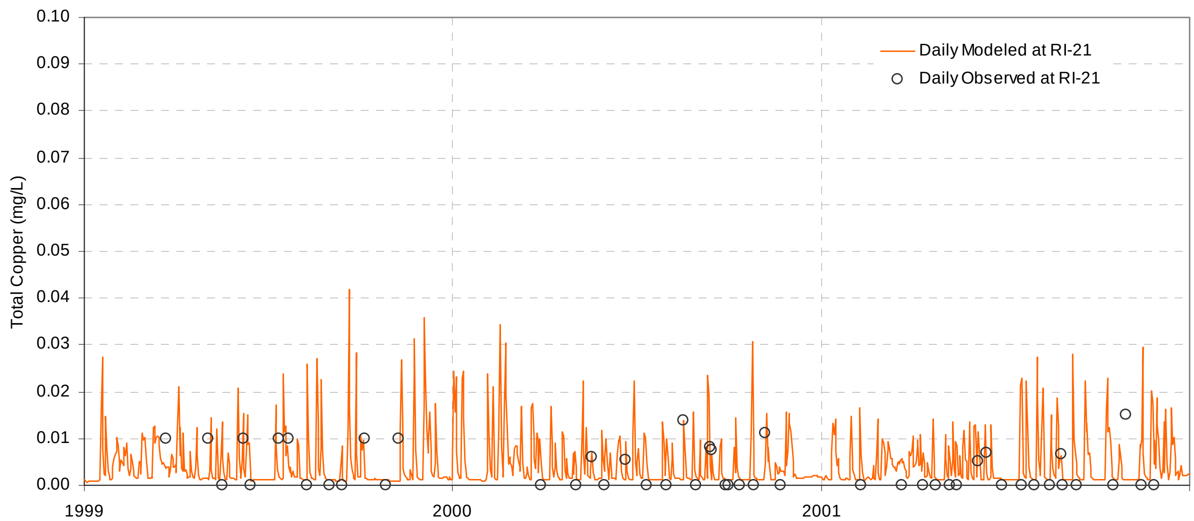


Figure 107. Total Copper time series validation at Menomonee River Station RI-21.

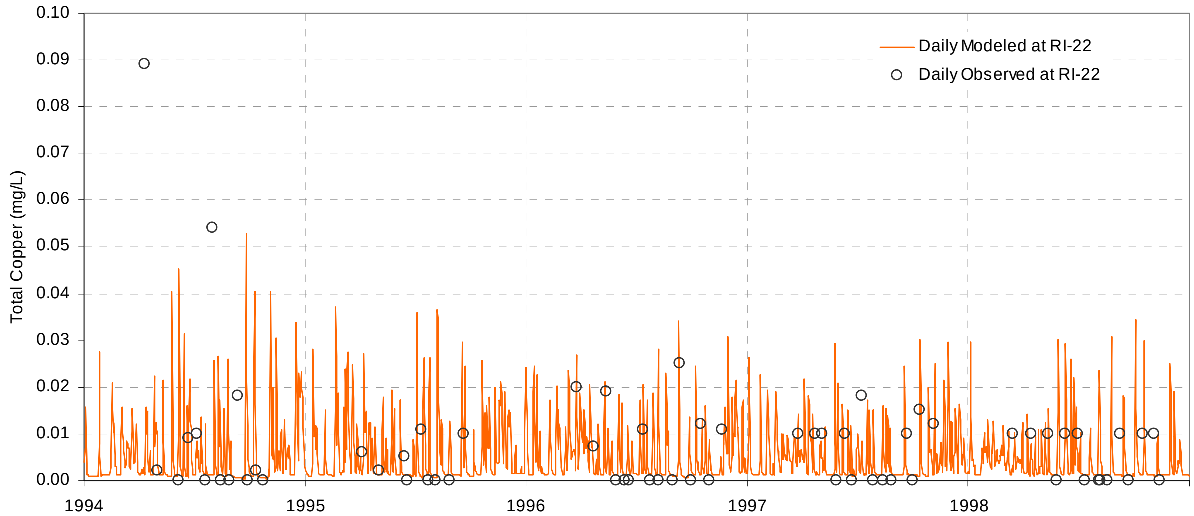


Figure 108. Total Copper time series calibration at Menomonee River Station RI-22.

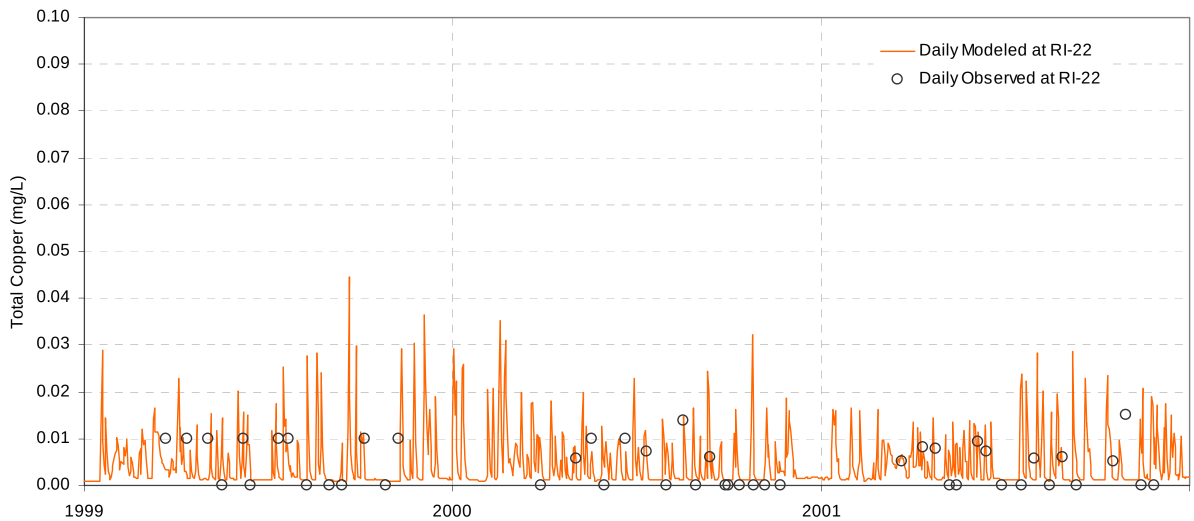


Figure 109. Total Copper time series validation at Menomonee River Station RI-22.

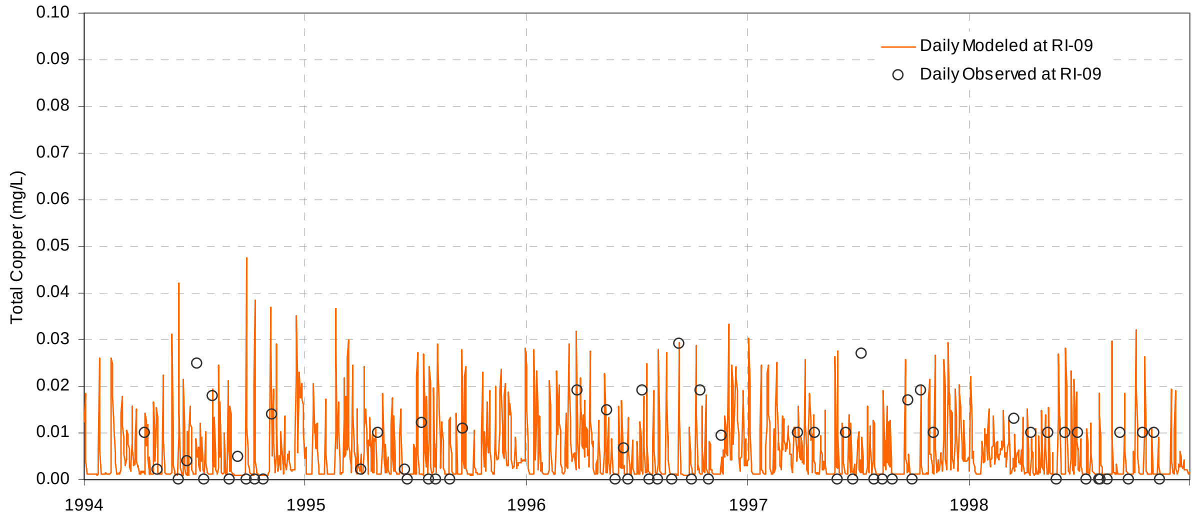


Figure 110. Total Copper time series calibration at Menomonee River Station RI-09.

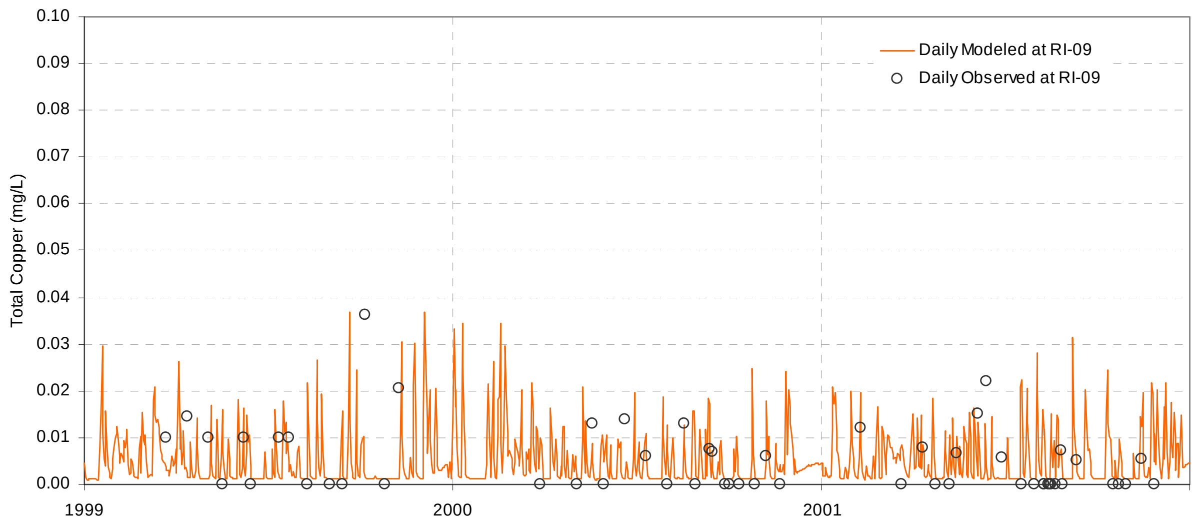


Figure 111. Total Copper time series validation at Menomonee River Station RI-09.

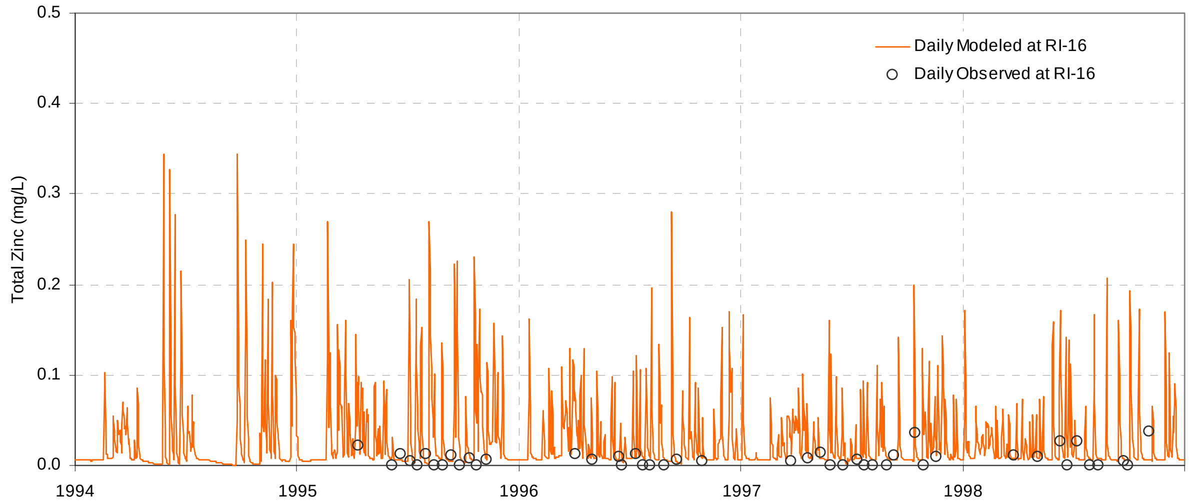


Figure 112. Total Zinc time series calibration at Menomonee River Station RI-16.

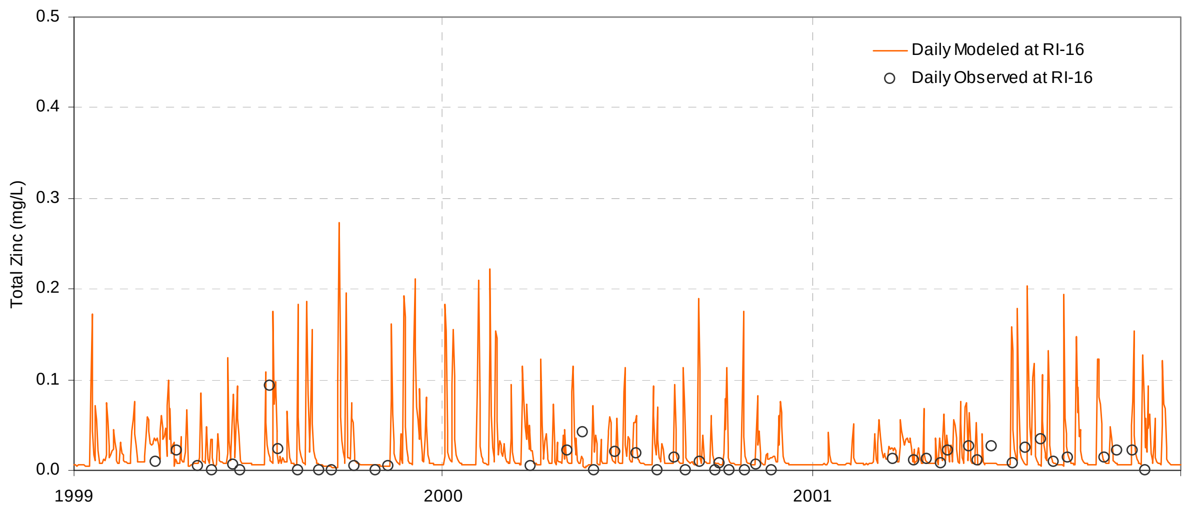


Figure 113. Total Zinc time series validation at Menomonee River Station RI-16.

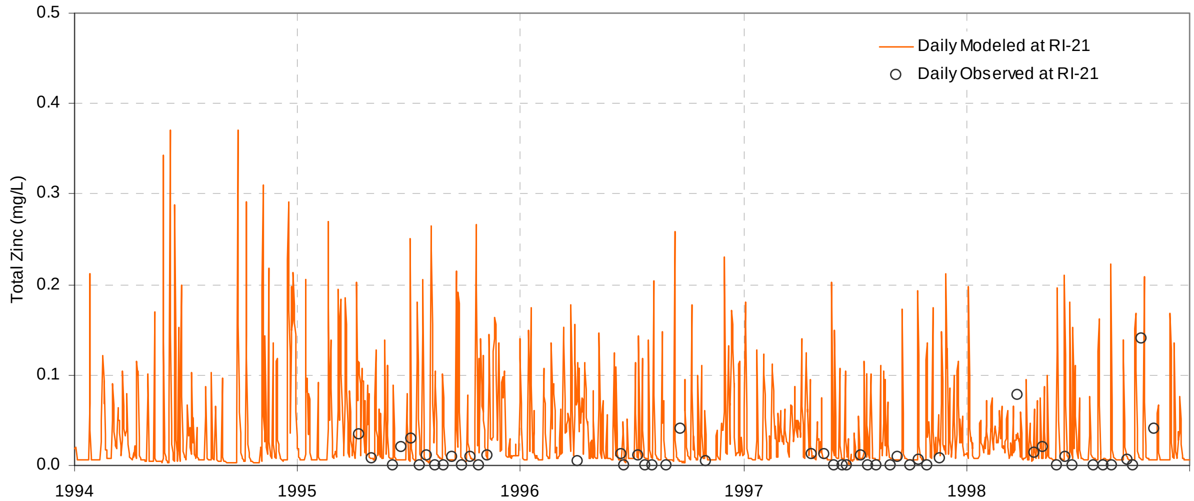


Figure 114. Total Zinc time series calibration at Menomonee River Station RI-21.

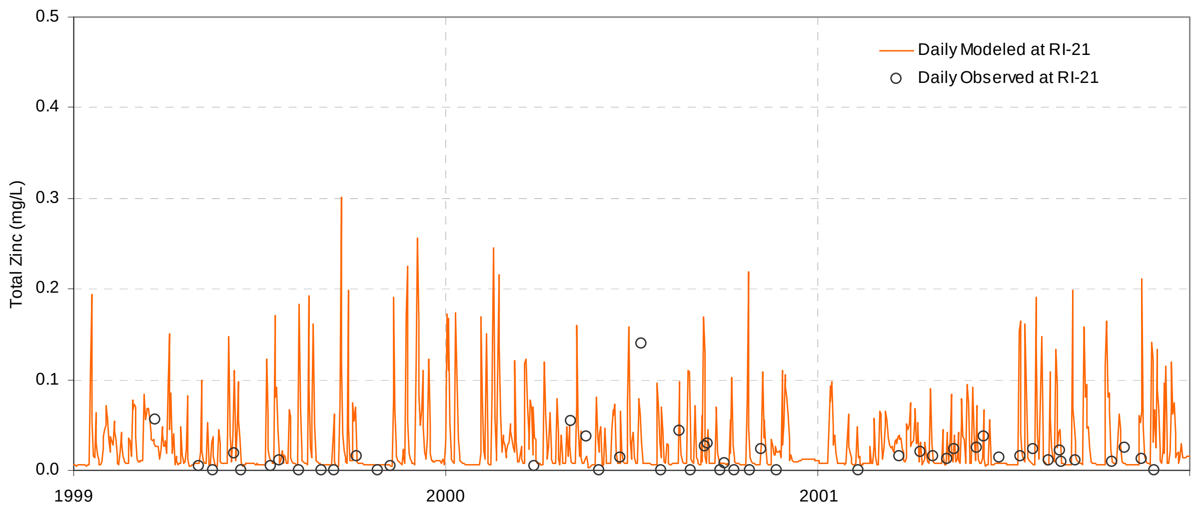


Figure 115. Total Zinc time series validation at Menomonee River Station RI-21.

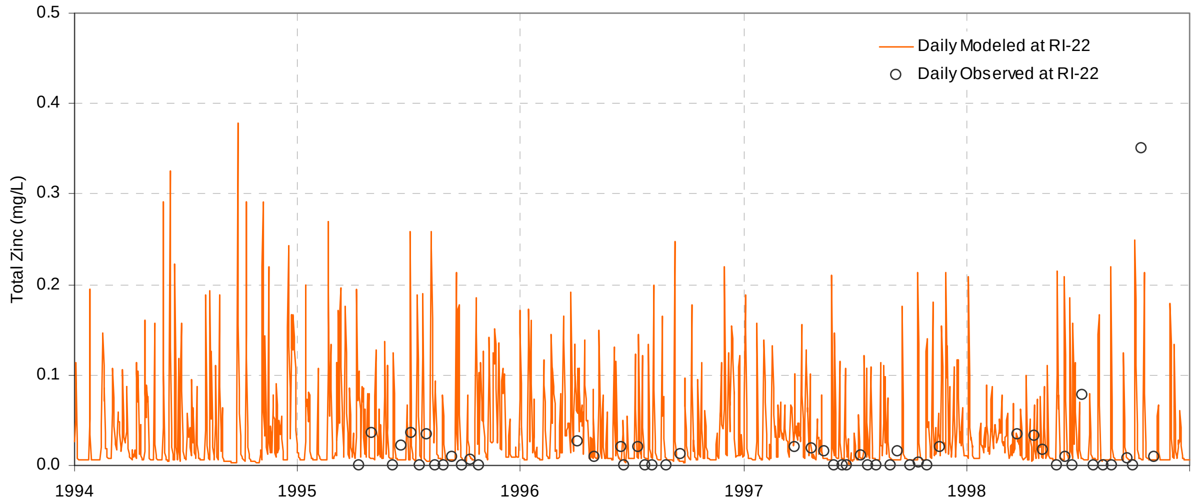


Figure 116. Total Zinc time series calibration at Menomonee River Station RI-22.

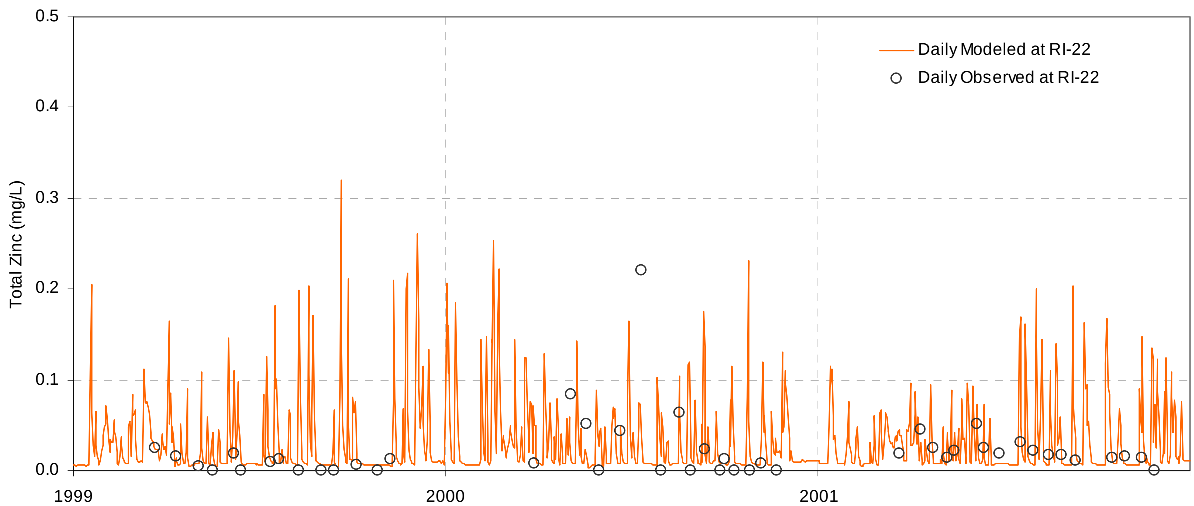


Figure 117. Total Zinc time series validation at Menomonee River Station RI-22.

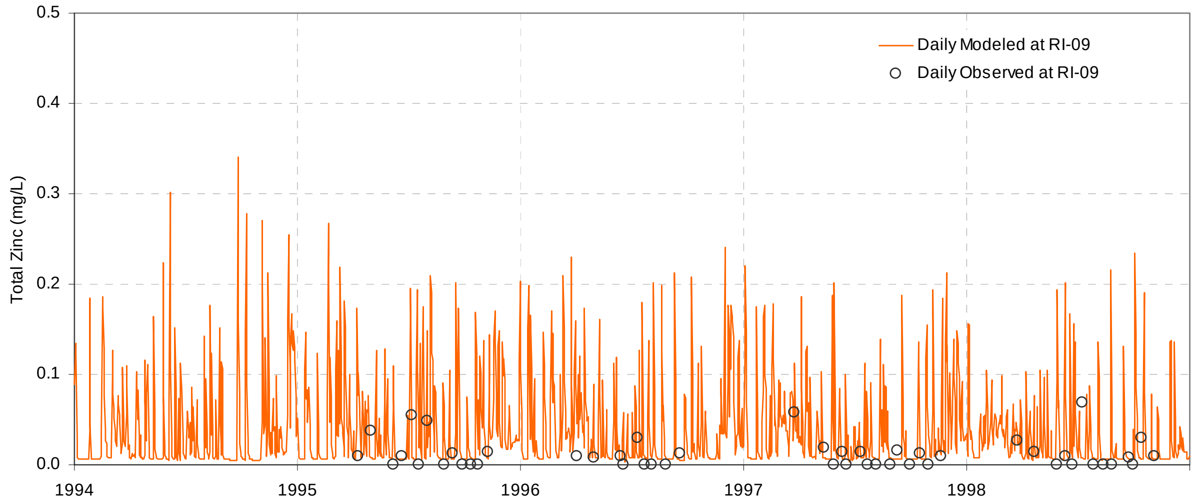


Figure 118. Total Zinc time series calibration at Menomonee River Station RI-09.

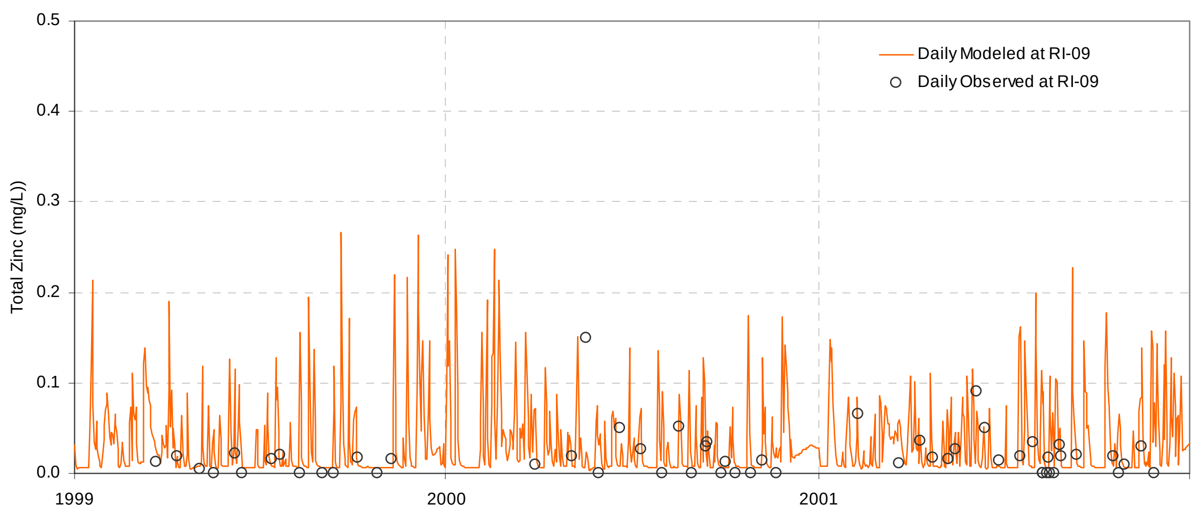


Figure 119. Total Zinc time series validation at Menomonee River Station RI-09.

5.7 Statistical Assessment of Concentrations

An ideal simulation model would conclusively prove its credibility by matching exactly every observed data point. Unfortunately, this ideal cannot be achieved, for a variety of reasons. In the first place, any watershed model is a simplification of complex natural processes. Secondly, the model is capable of representing only those events that are specified to it in the forcing functions, which generally represent the response from the land surface of hydrologic events. Events that are unknown to the model, such as illicit discharges, cannot be replicated by the model. Water quality simulation in particular is constrained to be no better than the quality of the simulation of hydrology, which in turn is limited by the availability of representative meteorological data. For instance, a small error in the representation of the timing or magnitude of a surface washoff event can result in apparently large discrepancies between simulated and observed actual concentrations at a given location and point in time. Finally, the observed values also cannot be considered as fixed and certain.

First, there is analytical uncertainty in reported observations that derives from the inherent imprecision of analytical techniques, and, occasionally, from laboratory analysis and reporting errors. Perhaps more importantly, grab samples submitted for chemical analysis represent a specific location and point in time that is not entirely consistent with the spatial and temporal support of the model. LSPC represents waterbodies as discrete reaches, which are assumed to be fully mixed. Real waterbodies vary continuously in both longitudinal and lateral dimensions, as well as in time. A sample taken from a specific location may not be representative of the average concentration across the stream cross section, and even less representative of the average across an entire model reach. Further, a sample taken at a discrete point in time may not be representative of the average concentration that would be observed across a modeling time step – particularly when the sample is taken near a source of discharge or during the course of a runoff event.

Several additional explanations for discrepancies between model predictions and observed data include the following:

- Point sources included in the model generally do not account for temporal changes and may differ between the calibration and validation periods.
- There may be some inherent physiological processes not accounted for in the model that may be causing the discrepancy between actual versus calibrated and calibrated versus validated comparisons.

For these reasons, it is important to evaluate model performance based on statistical criteria. In essence, the model and observations may differ on individual points, but should be in general agreement over large spans of time and space. This testing is accomplished using a weight of evidence approach. It is first important to realize that the model uses a single set of parameters, by land use, across the entire watershed, without local adjustments. Thus, achieving an acceptable fit across multiple stations (with one set of parameters) is a better indication of the validity of the model than any discrepancies at individual stations. Second, the model is developed using a calibration/validation approach, in which the model was developed on one set of observations (1994 to 1998), then tested on a subsequent set of observations (1999 to 2001). Where the quality of model fit differs between the calibration and validation periods this may indicate either that the apparent discrepancy is due to random variability or that the discrepancy arises from temporal changes in land use and discharges, which are not included in the model.

Statistical tests are applied to both concentrations and estimated loads. Both comparisons are important, and reveal different features of the model. For instance, a simulation that is problematic with regard to concentrations but provides a good estimate of loads can be judged as providing a good representation of pollutant source loading that is corrupted by a sub-optimal representation of the timing of their delivery.

The primary test for model performance on concentrations is a Student's *t*-test of equality of means on paired observed and simulated daily data over the entire calibration or validation period. (There are not sufficient data to adequately evaluate performance on individual seasons or years, particularly given the presence of analytical and sampling uncertainty.) In these tests, the equality of observed and sample means on paired daily average data is taken as the null hypothesis or a rebuttable proposition. That is, model performance is judged acceptable unless the statistical analysis proves otherwise.

The *t*-test is developed on assumptions that samples are drawn from a normal distribution and the variances are equal across distributions. Both of these assumptions are not met for various observed and simulated parameters in the Menomonee River. However, the tests presented here are on means, not individual observations, and the distribution of means converges to a normal distribution under the Central Limit Theorem. Further, Box et al. (1978) have shown that the *t*-test on means is robust against violations of the assumptions of normality and equality of variances.

Tests for equality of means, at each station, for the calibration and validation periods are presented in Tables 1 and 2. A probability value ("pval") for each contrast is presented, with higher probability values indicating a better quality of fit. A probability value less than 5 percent is judged to represent proof of a discrepancy between the model and data – although it does not reveal to what extent the discrepancy is the result of the model and to what extent it is a result of the data. Also note that this test does not address whether the difference, even if statistically significant, is meaningful in terms of environmental impact.

Across multiple parameters and stations, the model meets the *t*-test criteria in a majority of cases for both the calibration and validation periods. The quality of model fit is further buttressed by a good agreement between simulated and estimated loads (see Section 5.9). An additional evaluation of the model quality of fit for individual observations was conducted by plotting observations against simulated results with confidence bounds that represent one and two standard deviations for the day. The standard deviations are calculated on a daily basis from the sub-daily model output. The confidence limits are assumed to be either normally or lognormally distributed based on the distribution which most reduces skew (in most cases, log transformation reduces skew as is common for environmental data that are constrained to be greater than or equal to zero and contain sporadic high values associated with washoff events). Comparison can be made both visually and by tabulating the number of observations that fall within one and two-standard deviation confidence limits. These results are provided in Attachment C and summarized in Table 3.

There are parameter-location contrasts for which the model-data comparison does not pass the statistical criterion. Where both the inequality and the direction of deviation is consistently shown in both the calibration and validation tests, there may be a need for additional investigation and potential model improvement (unless the unrepresentativeness is due to the sampling location not being a good indicator of conditions in the model reach as a whole). On sum, however, the model is believed to provide a reasonable representation of water quality processes in the Menomonee River that is suitable for the evaluation and comparison of management scenarios.

Table 1. Menomonee River Concentration Calibration Statistics (1994-1998).

	RI-16	RI-21	RI-22	RI-09
BOD5 (mg/L)				
Sample Size	54	63	62	64
Observed Mean	1.785	1.821	2.246	2.384
Observed St. Dev.	0.557	0.879	1.136	1.594
Simulated Mean	2.575	2.191	2.066	3.211
Simulated St. Dev.	1.893	1.839	1.656	1.720
RMSE	1.931	1.545	1.326	1.661
Paired t-test (pval)	0.002	0.056	0.288	0.000
pass t-test?	No	Yes	Yes	No
Chlorophyll a (mg/L)				
Sample Size	54	63	63	63
Observed Mean	6.370	7.679	8.333	9.989
Observed St. Dev.	5.870	5.182	5.585	8.755
Simulated Mean	6.673	6.197	6.650	5.639
Simulated St. Dev.	2.540	2.525	2.880	2.636
RMSE	6.418	6.037	6.375	10.284
Paired t-test (pval)	0.732	0.051	0.035	0.000
pass t-test?	Yes	Yes	No	No
Dissolved Oxygen (mg/L)				
Sample Size	54	62	62	62
Observed Mean	8.599	9.830	9.162	10.420
Observed St. Dev.	2.890	2.695	2.859	2.875
Simulated Mean	9.001	9.191	8.966	9.698
Simulated St. Dev.	2.580	2.334	2.503	2.203
RMSE	1.756	1.700	1.901	1.873
Paired t-test (pval)	0.092	0.002	0.419	0.002
pass t-test?	Yes	No	Yes	No
Total Nitrogen (mg/L)				
Sample Size	55	64	64	64
Observed Mean	1.523	1.245	1.333	1.241
Observed St. Dev.	0.579	0.480	0.543	0.543
Simulated Mean	1.383	1.163	1.161	1.186
Simulated St. Dev.	0.655	0.679	0.645	0.613
RMSE	0.768	0.661	0.661	0.572
Paired t-test (pval)	0.177	0.327	0.036	0.446
pass t-test?	Yes	Yes	No	Yes
Total Phosphorus (mg/L)				
Sample Size	55	64	64	64

	RI-16	RI-21	RI-22	RI-09
Observed Mean	0.093	0.087	0.098	0.092
Observed St. Dev.	0.060	0.053	0.071	0.070
Simulated Mean	0.117	0.102	0.094	0.106
Simulated St. Dev.	0.104	0.188	0.106	0.100
RMSE	0.107	0.109	0.097	0.087
Paired t-test (pval)	0.095	0.283	0.732	0.211
pass t-test?	Yes	Yes	Yes	Yes
Total Suspended Solids (mg/l)				
Sample Size	54	64	64	64
Observed Mean	15.215	22.063	27.128	23.066
Observed St. Dev.	17.016	36.952	50.389	40.743
Simulated Mean	19.772	22.967	16.679	28.116
Simulated St. Dev.	24.859	30.654	23.207	42.563
RMSE	27.575	27.008	42.731	36.467
Paired t-test (pval)	0.228	0.748	0.050	0.271
pass t-test?	Yes	Yes	No	Yes
NO2+NO3 (mg/L)				
Sample Size	55	64	64	64
Observed Mean	0.635	0.439	0.487	0.507
Observed St. Dev.	0.406	0.306	0.332	0.365
Simulated Mean	0.557	0.484	0.504	0.449
Simulated St. Dev.	0.445	0.450	0.427	0.366
RMSE	0.552	0.445	0.420	0.370
Paired t-test (pval)	0.302	0.424	0.748	0.210
pass t-test?	Yes	Yes	Yes	Yes
NH3 (mg/L)				
Sample Size	53	59	60	59
Observed Mean	0.182	0.147	0.162	0.129
Observed St. Dev.	0.236	0.155	0.170	0.181
Simulated Mean	0.229	0.173	0.168	0.180
Simulated St. Dev.	0.194	0.197	0.180	0.159
RMSE	0.298	0.234	0.229	0.223
Paired t-test (pval)	0.261	0.409	0.839	0.084
pass t-test?	Yes	Yes	Yes	Yes
Orthophosphorus (mg/l)				
Sample Size	53	62	63	63
Observed Mean	0.043	0.040	0.039	0.041
Observed St. Dev.	0.039	0.031	0.030	0.033
Simulated Mean	0.057	0.047	0.041	0.040

	RI-16	RI-21	RI-22	RI-09
Simulated St. Dev.	0.065	0.064	0.057	0.047
RMSE	0.066	0.066	0.062	0.055
Paired t-test (pval)	0.115	0.447	0.768	0.890
pass t-test?	Yes	Yes	Yes	Yes
Fecal Coliform (count/100 mL)				
Sample Size	55	63	62	64
Observed Mean	1,494.273	4,502.349	3,145.435	8,364.828
Observed St. Dev.	2,412.139	14,791.097	8,694.449	20,900.495
Simulated Mean	1,546.184	2,347.516	3,279.115	3,108.799
Simulated St. Dev.	2,872.631	4,972.092	7,513.113	7,063.965
RMSE	3,372.215	14,257.078	8,020.605	19,241.944
Paired t-test (pval)	0.910	0.233	0.897	0.028
pass t-test?	Yes	Yes	Yes	No

Table 2. Menomonee River Concentration Validation Statistics (1999-2001)

	RI-16	RI-21	RI-22	RI-09
BOD5 (mg/L)				
Sample Size	46	49	47	52
Observed Mean	0.954	1.343	1.616	2.189
Observed St. Dev.	1.136	1.633	1.575	2.276
Simulated Mean	2.189	2.034	1.968	3.059
Simulated St. Dev.	1.456	1.317	1.344	1.443
RMSE	2.078	1.662	1.846	2.228
Paired t-test (pval)	0.000	0.003	0.195	0.004
pass t-test?	No	No	Yes	No
Chlorophyll a (mg/L)				
Sample Size	41	41	42	42
Observed Mean	6.194	8.449	7.939	10.038
Observed St. Dev.	2.854	8.508	6.111	6.959
Simulated Mean	7.075	6.427	6.687	6.125
Simulated St. Dev.	2.026	2.183	2.467	2.504
RMSE	3.854	8.917	6.827	8.163
Paired t-test (pval)	0.145	0.149	0.239	0.001
pass t-test?	Yes	Yes	Yes	No
Dissolved Oxygen (mg/L)				
Sample Size	47	49	47	56
Observed Mean	7.986	9.795	9.020	9.956
Observed St. Dev.	2.458	2.274	2.341	2.257
Simulated Mean	8.791	9.230	9.109	9.573
Simulated St. Dev.	2.267	2.144	2.203	1.903
RMSE	1.664	1.504	1.642	1.520
Paired t-test (pval)	0.001	0.007	0.713	0.058
pass t-test?	No	No	Yes	Yes
Total Nitrogen (mg/L)				
Sample Size	45	44	45	45
Observed Mean	1.774	1.453	1.535	1.496
Observed St. Dev.	0.502	0.527	0.596	0.600
Simulated Mean	1.485	1.263	1.255	1.295
Simulated St. Dev.	0.764	0.654	0.669	0.632
RMSE	0.761	0.616	0.734	0.581
Paired t-test (pval)	0.009	0.039	0.009	0.019
pass t-test?	No	No	No	No
Total Phosphorus (mg/L)				
Sample Size	46	48	46	52

	RI-16	RI-21	RI-22	RI-09
Observed Mean	0.088	0.112	0.106	0.121
Observed St. Dev.	0.055	0.084	0.067	0.091
Simulated Mean	0.089	0.103	0.099	0.129
Simulated St. Dev.	0.073	0.096	0.095	0.109
RMSE	0.070	0.082	0.081	0.078
Paired t-test (pval)	0.915	0.472	0.578	0.505
pass t-test?	Yes	Yes	Yes	Yes
Total Suspended Solids (mg/l)				
Sample Size	47	49	47	51
Observed Mean	13.472	28.241	37.740	31.514
Observed St. Dev.	9.399	35.679	36.603	40.172
Simulated Mean	21.070	29.931	24.333	32.793
Simulated St. Dev.	23.005	38.658	31.741	38.180
RMSE	20.469	25.257	33.214	29.768
Paired t-test (pval)	0.009	0.644	0.004	0.762
pass t-test?	No	Yes	No	Yes
NO2+NO3 (mg/L)				
Sample Size	47	46	47	51
Observed Mean	0.777	0.543	0.614	0.593
Observed St. Dev.	0.326	0.312	0.425	0.400
Simulated Mean	0.630	0.553	0.580	0.509
Simulated St. Dev.	0.449	0.400	0.417	0.359
RMSE	0.505	0.397	0.467	0.388
Paired t-test (pval)	0.044	0.865	0.620	0.124
pass t-test?	No	Yes	Yes	Yes
NH3 (mg/L)				
Sample Size	43	41	40	45
Observed Mean	0.101	0.126	0.120	0.091
Observed St. Dev.	0.116	0.190	0.192	0.159
Simulated Mean	0.177	0.166	0.164	0.194
Simulated St. Dev.	0.159	0.145	0.145	0.136
RMSE	0.194	0.228	0.231	0.221
Paired t-test (pval)	0.008	0.266	0.234	0.001
pass t-test?	No	Yes	Yes	No
Orthophosphorus (mg/l)				
Sample Size	44	41	44	40
Observed Mean	0.110	0.042	0.042	0.044
Observed St. Dev.	0.448	0.035	0.032	0.039
Simulated Mean	0.034	0.036	0.037	0.041

	RI-16	RI-21	RI-22	RI-09
Simulated St. Dev.	0.034	0.041	0.043	0.043
RMSE	0.452	0.052	0.052	0.055
Paired t-test (pval)	0.270	0.417	0.552	0.736
pass t-test?	Yes	Yes	Yes	Yes
Fecal Coliform (count/100 mL)				
Sample Size	47	46	47	47
Observed Mean	2,099.872	2,949.935	3,737.277	23,828.894
Observed St. Dev.	6,905.383	5,230.179	7,922.452	75,502.000
Simulated Mean	1,121.249	1,879.893	2,717.276	3,769.633
Simulated St. Dev.	1,950.784	2,610.916	4,028.761	6,332.683
RMSE	7,151.321	5,005.457	8,595.499	74,801.432
Paired t-test (pval)	0.354	0.149	0.422	0.065
pass t-test?	Yes	Yes	Yes	Yes

Table 3. Confidence limit results for Menomonee River water quality calibration and validation.

Station	Parameter	Within 1 Standard Deviation	Within 2 Standard Deviations
RI-16	Total Phosphorus	29%	47%
	Total Nitrogen	25%	43%
	Total Suspended Solids	20%	41%
	Fecal Coliform	26%	47%
RI-21	Total Phosphorus	36%	55%
	Total Nitrogen	28%	46%
	Total Suspended Solids	46%	58%
	Fecal Coliform	34%	54%
RI-22	Total Phosphorus	34%	48%
	Total Nitrogen	23%	45%
	Total Suspended Solids	42%	51%
	Fecal Coliform	36%	56%
RI-09	Total Phosphorus	36%	58%
	Total Nitrogen	32%	55%
	Total Suspended Solids	48%	67%
	Fecal Coliform	49%	62%

5.8 Statistical Assessment of Loads

For the evaluation of impacts on downstream receiving waters, correct model representation of total loads is as important as the representation of concentration. Unfortunately, load is not observed directly. Estimates of observed load on those days with observations can be formed by multiplying concentration by daily average flow. However, because the concentrations represent point-in-time grab samples, these represent highly uncertain estimates of daily load.

Load estimates require both concentration and flow. For the Menomonee River, flow is gaged upstream at Pilgrim Road (downstream of water quality station RI-16) and downstream at RI-09. Observed load estimates can be calculated for these two stations only. (For analysis of data from RI-16, loads are calculated using RI-16 concentrations and observed and predicted flows at the USGS gage location for consistency.)

Because loads depend on both flow and concentration, it is unreasonable to expect that all observed and simulated data points will match closely. That is, apparent discrepancies will arise due to any errors in the timing or magnitude of flows, in addition to the uncertainty introduced by point-in-time concentration observations. However, the mean loads on paired observations should be in general agreement between the model and predictions. In addition, the relationship between load and flow should be similar.

Equality of observed and simulated mean concentrations is evaluated using a paired *t*-test. Results, with probability values (pvals) are shown in Tables 4 and 5. As shown in the tables, the agreement between the model and estimated observed loads is in general good, with no contrasts failing the *t*-test – and this agreement is achieved while also preserving the relationship to SWAT and SLAMM loading rates from the uplands.

Table 4. Menomonee River Load Calibration Statistics (1994-1998).

	RI-16	RI-09
Total Nitrogen (lb/d)		
Sample Size	55	64
Observed Mean	450.551	2,150.401
Observed St. Dev.	1,272.475	6,558.317
Simulated Mean	560.367	1,790.026
Simulated St. Dev.	1,976.658	5,077.624
RMSE	737.370	4,384.559
Paired t-test (pval)	0.273	0.515
pass t-test?	Yes	Yes
Total Phosphorus (lb/d)		
Sample Size	55	64
Observed Mean	28.553	209.925
Observed St. Dev.	94.263	652.789
Simulated Mean	41.443	194.143
Simulated St. Dev.	142.258	528.031
RMSE	54.540	329.020
Paired t-test (pval)	0.079	0.704
pass t-test?	Yes	Yes
NO2+NO3 (lb/d)		
Sample Size	55	64
Observed Mean	196.297	979.718
Observed St. Dev.	556.531	3,048.317
Simulated Mean	314.191	865.797
Simulated St. Dev.	1,231.780	2,817.630
RMSE	722.115	2,172.209
Paired t-test (pval)	0.229	0.678
pass t-test?	Yes	Yes
Total Suspended Solids (lb/d)		
Sample Size	54	64
Observed Mean	4,906.822	93,084.872
Observed St. Dev.	14,926.113	328,238.504
Simulated Mean	6,622.303	62,677.232
Simulated St. Dev.	18,135.597	150,508.310
RMSE	9,038.514	206,430.959
Paired t-test (pval)	0.165	0.242
pass t-test?	Yes	Yes

Table 5. Menomonee River Load Validation Statistics (1999-2001)

	RI-16	RI-09
Total Nitrogen (lb/d)		
Sample Size	45	45
Observed Mean	738.933	3,210.055
Observed St. Dev.	1,303.847	8,101.588
Simulated Mean	804.616	2,987.766
Simulated St. Dev.	2,330.090	7,969.639
RMSE	1,308.438	1,781.665
Paired t-test (pval)	0.740	0.409
pass t-test?	Yes	Yes
Total Phosphorus (lb/d)		
Sample Size	46	51
Observed Mean	52.159	384.508
Observed St. Dev.	139.542	43.150
Simulated Mean	73.439	474.202
Simulated St. Dev.	273.444	1,401.919
RMSE	156.290	475.507
Paired t-test (pval)	0.361	0.181
pass t-test?	Yes	Yes
NO2+NO3 (lb/d)		
Sample Size	48	51
Observed Mean	304.491	1,172.340
Observed St. Dev.	498.141	2,757.762
Simulated Mean	375.131	1,186.247
Simulated St. Dev.	1,072.131	3,163.824
RMSE	719.699	1,033.595
Paired t-test (pval)	0.507	0.925
pass t-test?	Yes	Yes
Total Suspended Solids (lb/d)		
Sample Size	47	51
Observed Mean	8,694.495	147,541.349
Observed St. Dev.	25,447.317	523,368.906
Simulated Mean	8,134.211	112,893.348
Simulated St. Dev.	21,771.066	266,444.840
RMSE	12,048.687	303,086.389
Paired t-test (pval)	0.754	0.420
pass t-test?	Yes	Yes

5.9 Load-Flow Relationships

An additional test of the sediment and nutrient load calibration is provided by developing log-log transport plots. These can be estimated at the upstream station (RI-16) and the downstream station (RI- 09), where flow gaging is available, and are shown in the following figures. At both stations, the observed load:flow relationship overlies the simulated load:flow relationship very closely, indicating that the model is correctly representing the long-term sediment transport in the system.

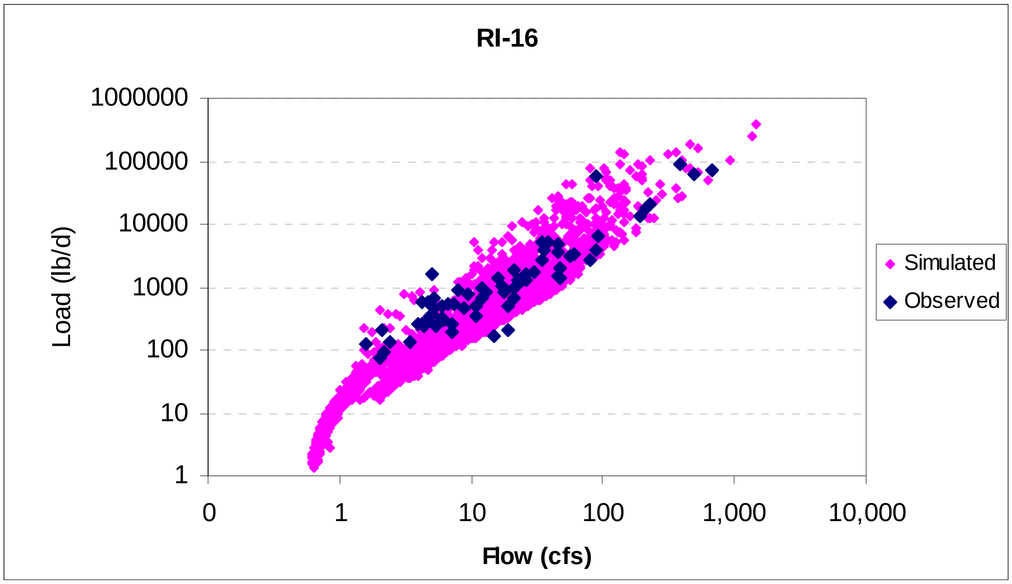


Figure 120. Log-log transport plot of sediment load at Menomonee River Station RI-16, 1994- 2001.

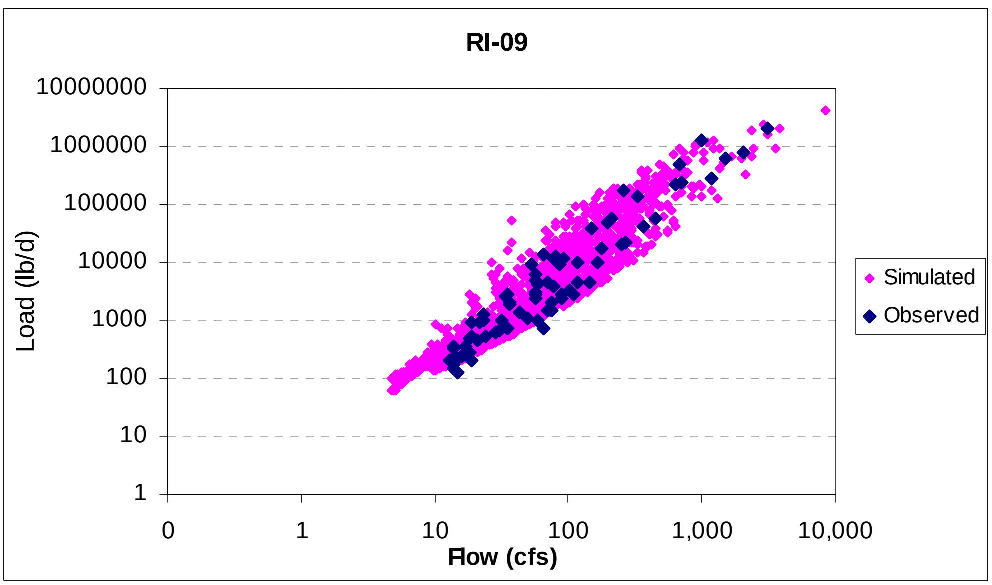


Figure 121. Log-log transport plot of sediment load at Menomonee River Station RI-09, 1994-2001.

As is implied by the load plots, the relationships between TSS concentration and flow also provide a good match.

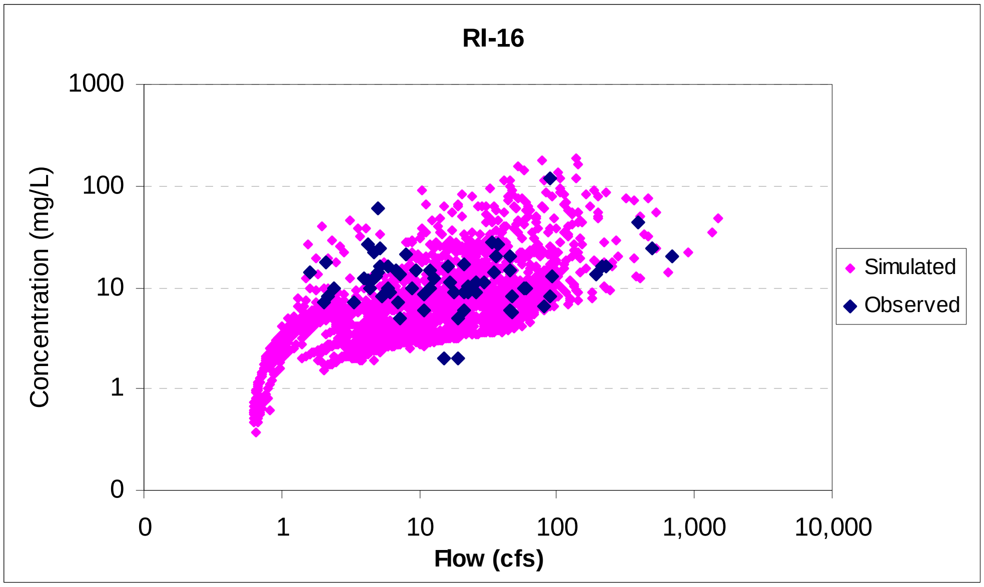


Figure 122. Relationships between TSS concentration and flow at RI-16, 1994-2001.

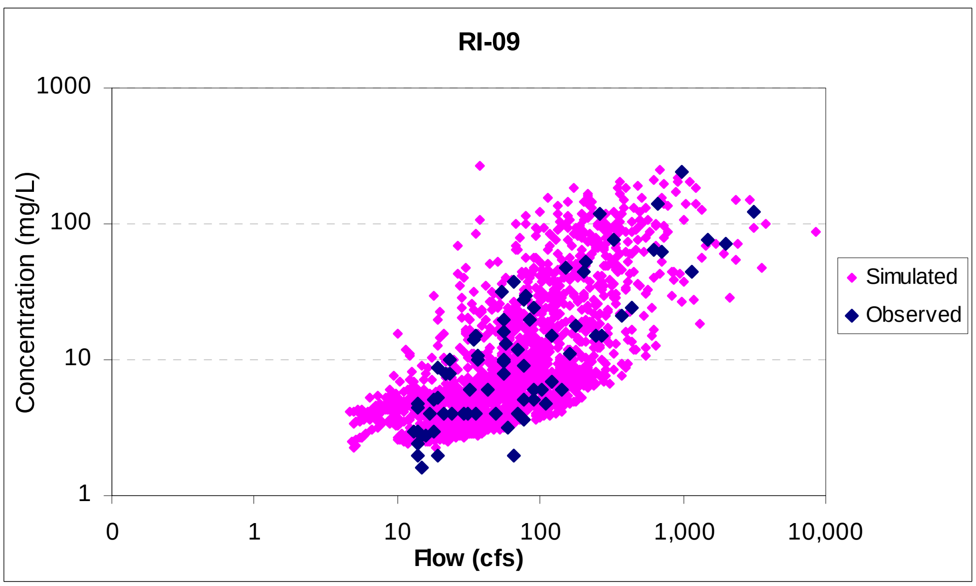


Figure 123. Relationships between TSS concentration and flow at RI-09, 1994- 2001.

As with the sediment results discussed above, the nutrient load simulation can also be evaluated in a qualitative graphical manner by log-log plots of load versus flow. In general, the observed load points should fall within the cloud defined by the simulation output and also show a similar slope. This is indeed the case, as shown in Figure 124 through Figure 126. Some discrepancy is seen at the lower flow end of the spectrum, where the model predicts occasional flows lower than those that are observed.

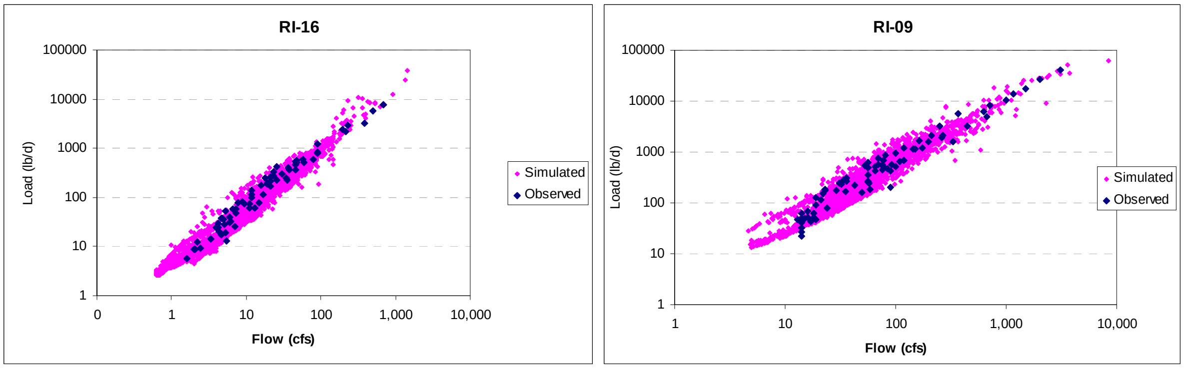


Figure 124. Transport Plots for Total Nitrogen, 1994-2001.

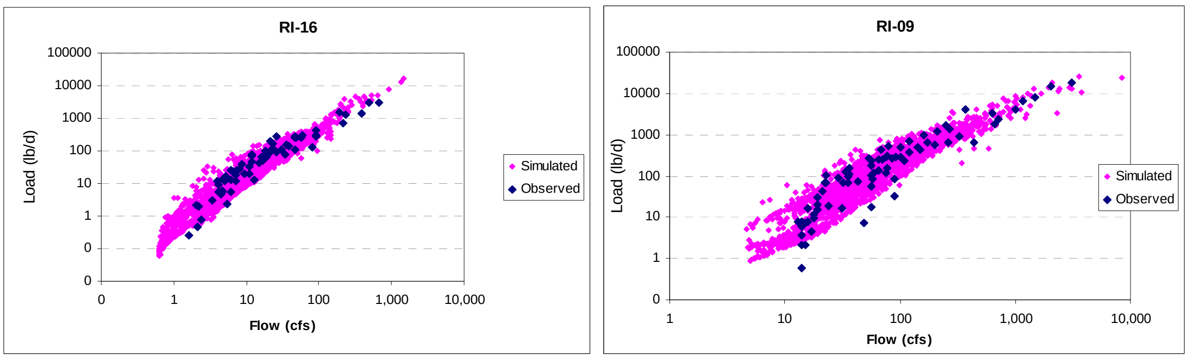


Figure 125. Transport Plots for Nitrite + Nitrate Nitrogen, 1994-2001.

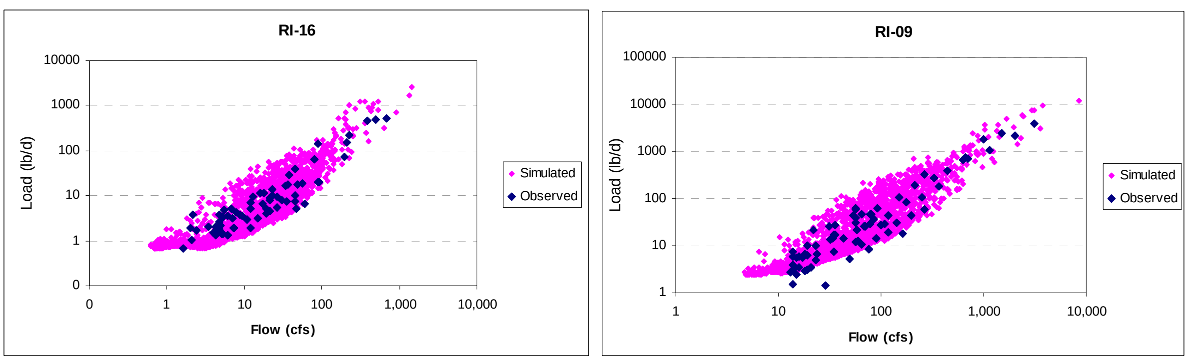


Figure 126. Transport Plots for Total Phosphorus, 1994-2001

Another useful test of representation of the load-flow relationships is obtained by plotting simulated and observed loads against the probability of exceedance of a given flow value, based on the period of record at the gage. These are known as load-duration curves. As a general rule, the portion of this relationship corresponding to flows that are exceeded less than 20 percent of the time can be assumed to represent high-flow, washoff events, while the remainder of the relationship corresponds to moderate and low flows.

The untransformed load-duration curve relationship is highly nonlinear. These plots can be linearized by plotting the natural logarithm of load versus the logit of flow, where the logit is defined as the natural log of (P/(1-P)), given P is the flow exceedance probability (Pindyck and Rubinfeld, 1981). After the loglogit transformation, separate linear regressions can be performed on the natural logarithms of observed and simulated loads versus logit of flow for the 0-20 percent and 20-100 percent flow ranges. (The breakpoint between these ranges corresponds to a logit of –1.386.) When the model is simulating accurately, the slope coefficients of the observed and simulated regressions should be in agreement within each of the two flow ranges. The analysis shows that this test is generally met in the model. Full results are provided in Attachment B.

6.0 REFERENCES

APHA. 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed. American Public Health Association (APHA), 1015 15th Street, NW, Washington, DC 20005.

Bicknell, B.R., J.C. Imhoff, J. Kittle, A.S. Donigian, and R.C. Johansen. 1996. *Hydrological Simulation Program* !*FORTRAN, User's Manual for Release H*. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Bowie, G.L., et al. 1985. Rates, Constants, and Kinetic Formulations in Surface Water Quality Modeling, 2d. ed. EPA/600/3-85/040. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Box, G.E.P., J.S. Hunter and W.G. Hunter. 1978. *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building.* John Wiley and Sons, New York.

Chapra, S. and G. Pelletier. 2003. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

Donigian, A.S., Jr., and J.T. Love. 2002. Sediment Calibration Procedures and Guidelines for Watershed Modeling. Aqua Terra Consultants, Mountain View, CA.

Donigian, A.S., Jr., J.C. Imhoff, B.R. Bicknell, and J.L. Kittle, Jr. 1984. Application Guide for Hydrological Simulation Program – FORTRAN (HSPF). EPA-600/3-84-065. Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Haith, D.A. and D.E. Merrill. 1987. Evaluation of a daily rainfall erosivity model. *Trans. Amer. Soc. Agric. Eng.*, 28(6): 1916-1920.

Haith, D.A., R. Mandel, and R.S. Wu. 1992. *GWLF - Generalized watershed loading functions, Version 2.0 - User's manual*. Department of Agricultural Engineering, Cornell University, Ithaca, NY.

Hartigan, J.P., T.F. Quasebarth, and E. Southerland. 1983. Calibration of NPS model loading factors. *Journal of Environmental Engineering*, 109(6): 1259-1272.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. *Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage*, 89(IR4): 15-41.

Jensen, M.E., D.C.N. Rob, and C.E. Franzoy. 1969. Scheduling irrigations using climate-crop-soil data. Proceedings, National Conference on Water Resources Engineering of the American Society of Civil Engineers, New Orleans, LA.

Mancini, J.L. 1978. Numerical estimates of coliform mortality rates under various conditions. *J. Water Poll. Contr. Fed.*, 50(11): 2477-2484.

MPCA. 2001. Status of a Model Simulation of Nonpoint-Source Contamination in the Minnesota River Basin, April 1999. Final report submitted by the USGS to Minnesota Pollution Control Agency.

Pindyck, R.S. and D.L. Rubinfeld. 1981. *Econometric Models and Economic Forecasts, Second Edition.* McGraw-Hill, New York.

Richardson, C.W., G.R. Foster, and D.A. Wright. 1983. Estimation of erosion index from daily rainfall amount. *Trans. Am. Soc. Agric. Eng*., 26(1): 153-157, 160.

Tetra Tech, Inc. and CH2M HILL. 1999. Gwinnett County Watershed Assessment and Modeling Study, Watershed Model Calibration Technical Memorandum. Prepared for Gwinnett County, GA by Tetra Tech, Inc., Research Triangle Park, NC.

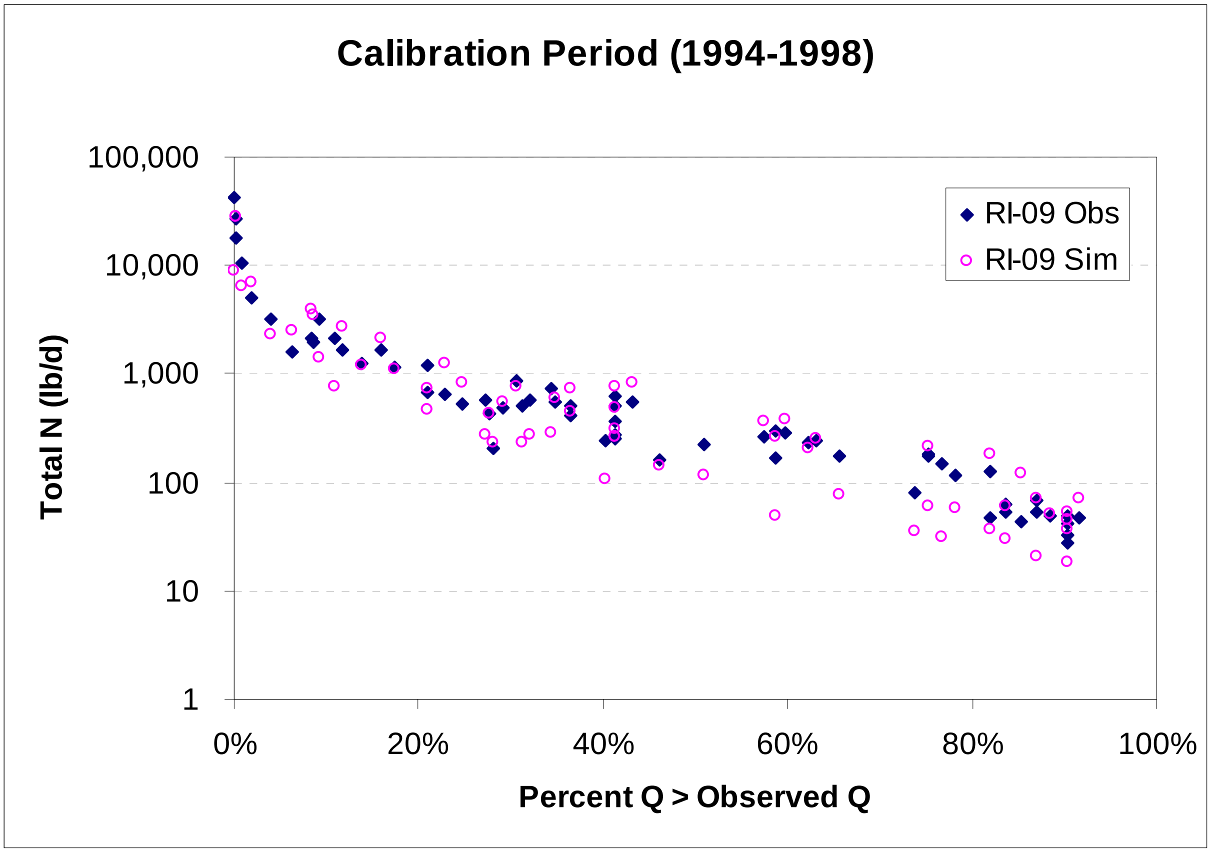
Tetra Tech. 2002. Minnesota River Basin Model, Model Calibration and Validation Report. Prepared for Minnesota Pollution Control Agency, St. Paul, MN by Tetra Tech, Inc., Research Triangle Park, NC.

Thomann*,* R.V. and J.A. Mueller. 1987*.* Principles of Surface Water Quality Modeling and Control. Harper & Row, New York.

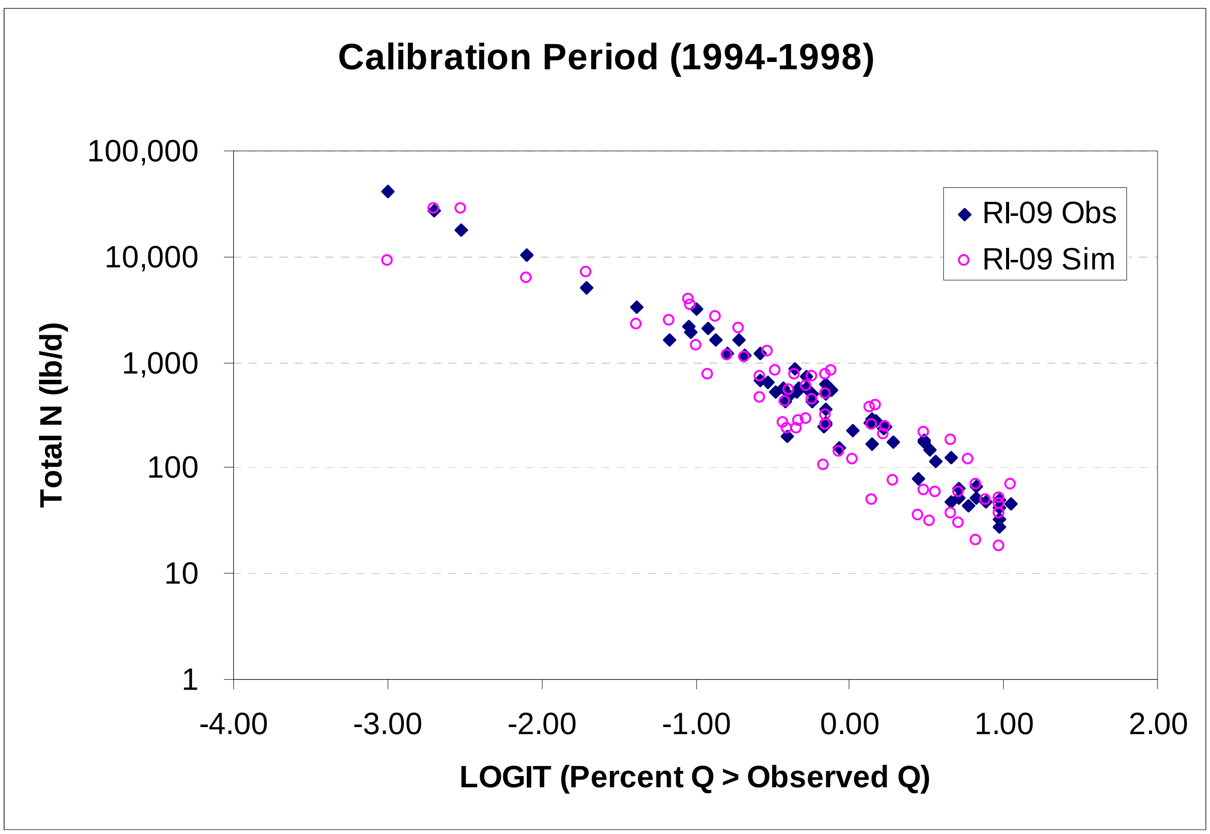
U.S. Environmental Protection Agency (USEPA). 2000. *BASINS Technical Note 6. Estimating Hydrology and Hydraulic Parameters for HSPF*. EPA-823-R00-012. U.S. Environmental Protection Agency. Office of Water. July 2000.

ATTACHMENT A – EXCEEDANCE CURVE PLOTS

ATTACHMENT B – LOAD-DURATION ANALYSIS RESULTS



Calibration Period (1994-1998)
100,000
10,000
1,000
100
10
1
Total N (lb/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-09 Obs
RI-09 Sim



Calibration Period (1994-1998)
100,000
10,000
1,000
100
10
1
Total N (lb/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-09 Obs
RI-09 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.486316	6.112544
0.075433	0.122519
0.9676	0.218619
388.2376	13
2.160369	
0.162963	
-1.64928	
-1.323353	

0-20% - Sim

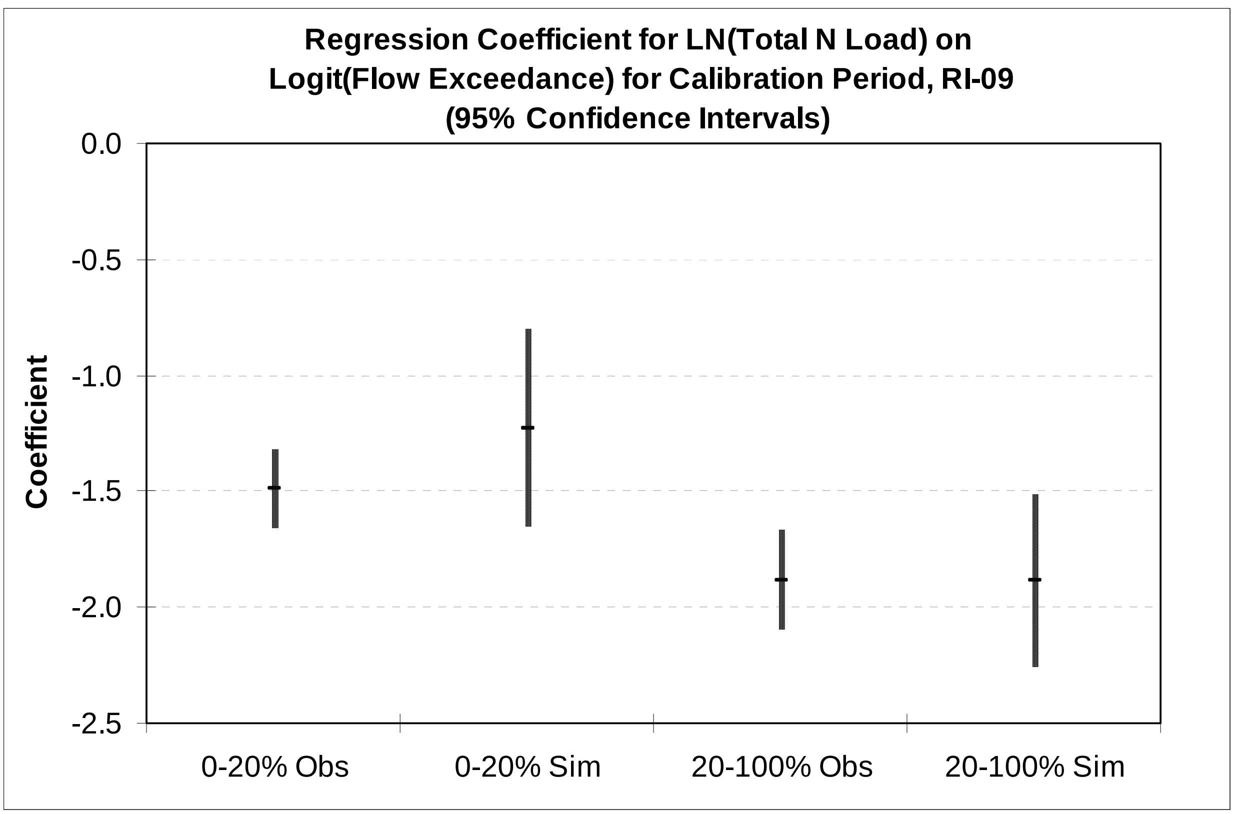
-1.22715	6.414592
0.193046	0.313546
0.756596	0.55948
40.40906	13
2.160369	
0.41705	
-1.6442	
-0.81011	

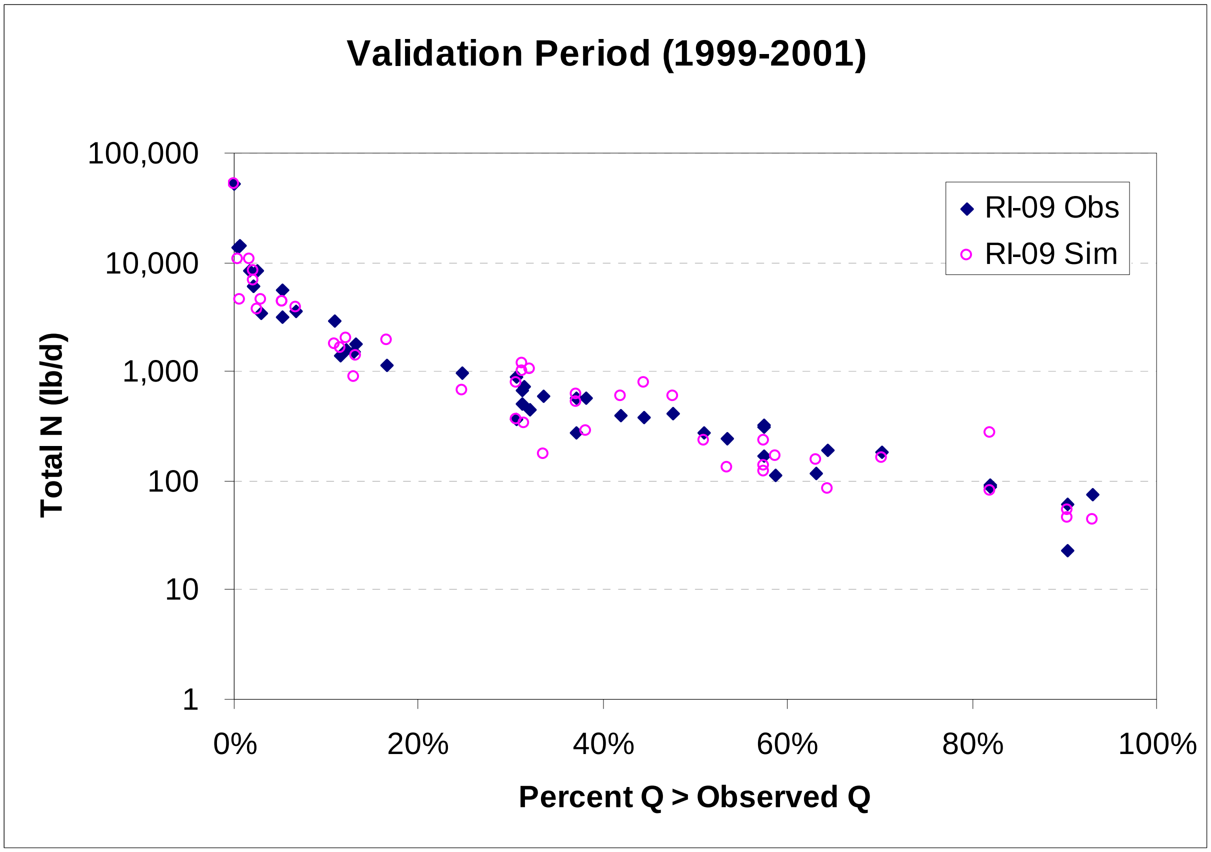
20-100% - Obs

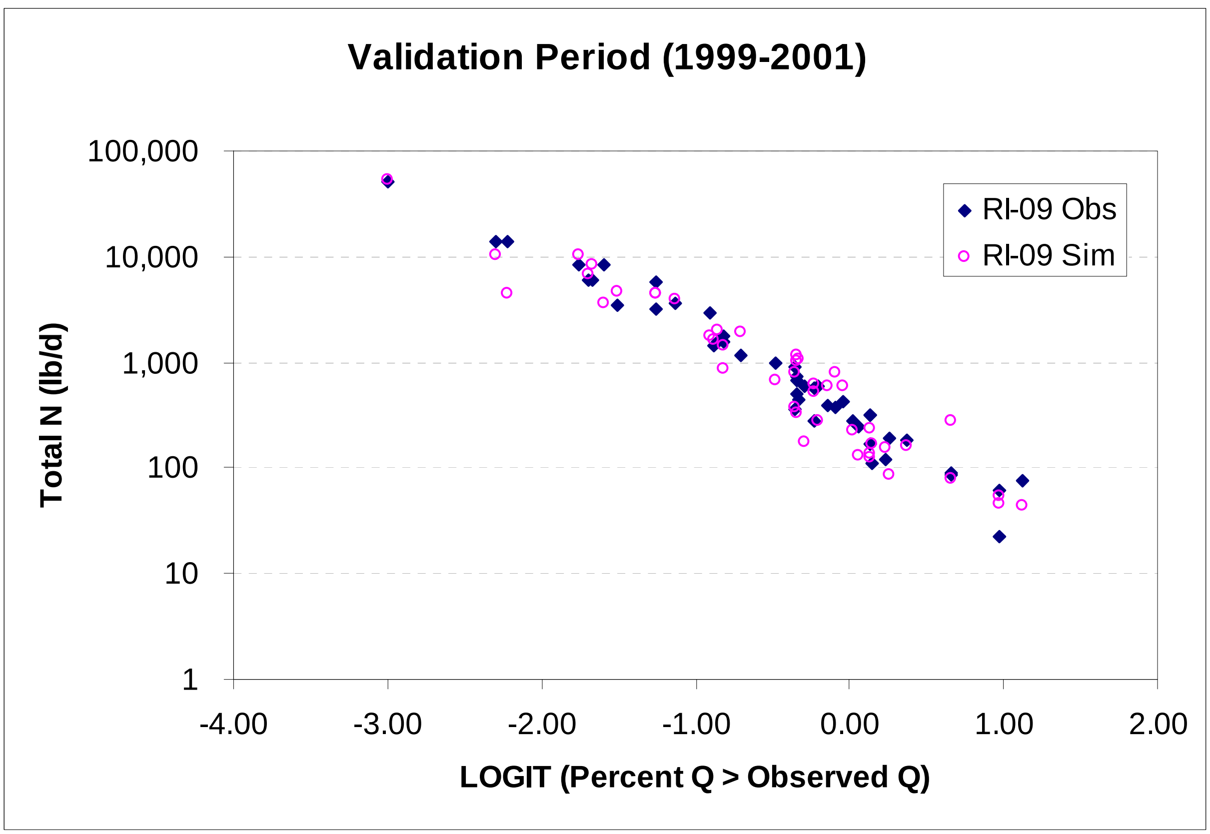
-1.884174	5.613341
0.102412	0.053926
0.878076	0.359759
338.4869	47
2.01174	
0.206026	
-2.0902	
-1.678148	

20-100% - Sim

-1.88249	5.42658
0.181153	0.095389
0.69675	0.636367
107.9874	47
2.01174	
0.364433	
-2.24692	
-1.51806	




Validation Period (1999-2001)
Total N (lb/d)
100,000
10,000
1,000
100
10
1
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-09 Obs
RI-09 Sim


Validation Period (1999-2001)
Total N (lb/d)
100,000
10,000
1,000
100
10
1
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-09 Obs
RI-09 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.54174	6.192482
0.103957	0.162246
0.936155	0.263573
219.9434	15
2.13145	
0.22158	
-1.76332	
-1.32016	

0-20% - Sim

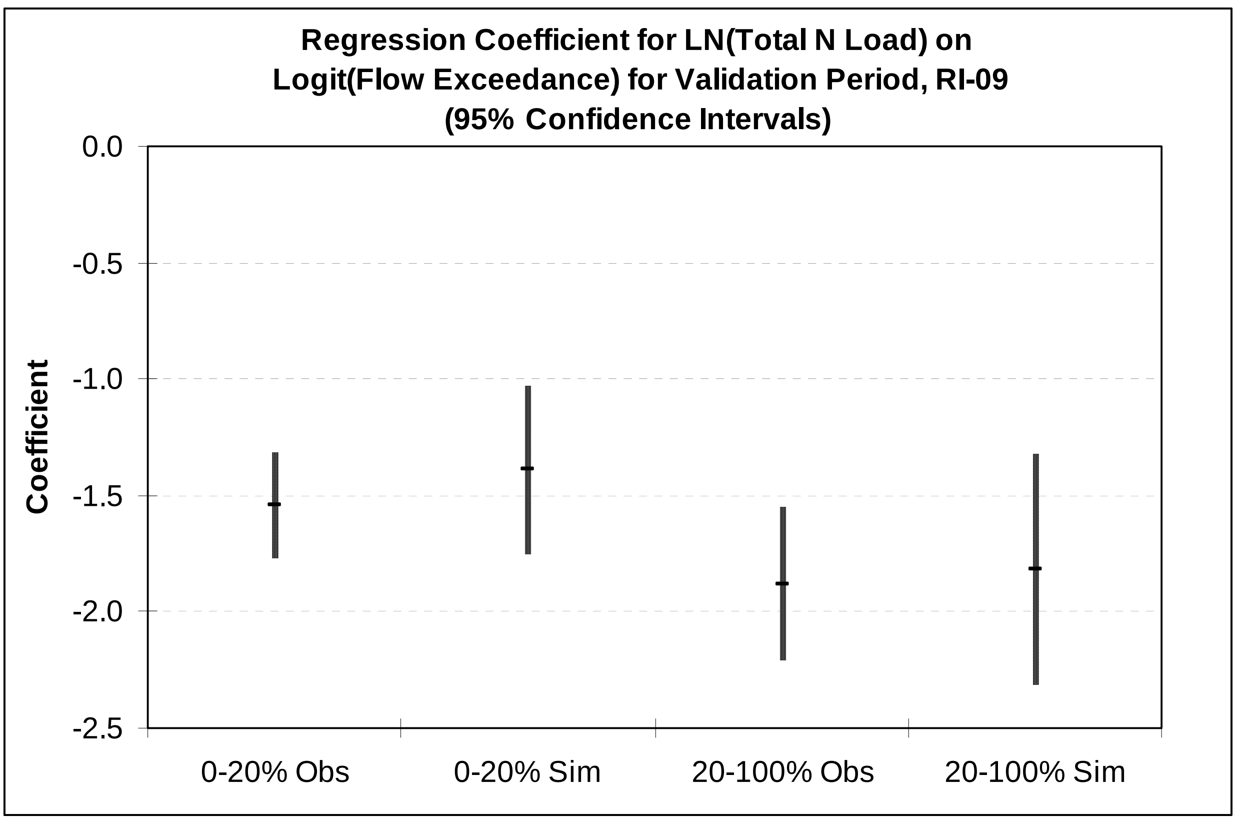
-1.39176	6.324073
0.16719	0.260933
0.822054	0.423894
69.29546	15
2.13145	
0.356357	
-1.74811	
-1.0354	

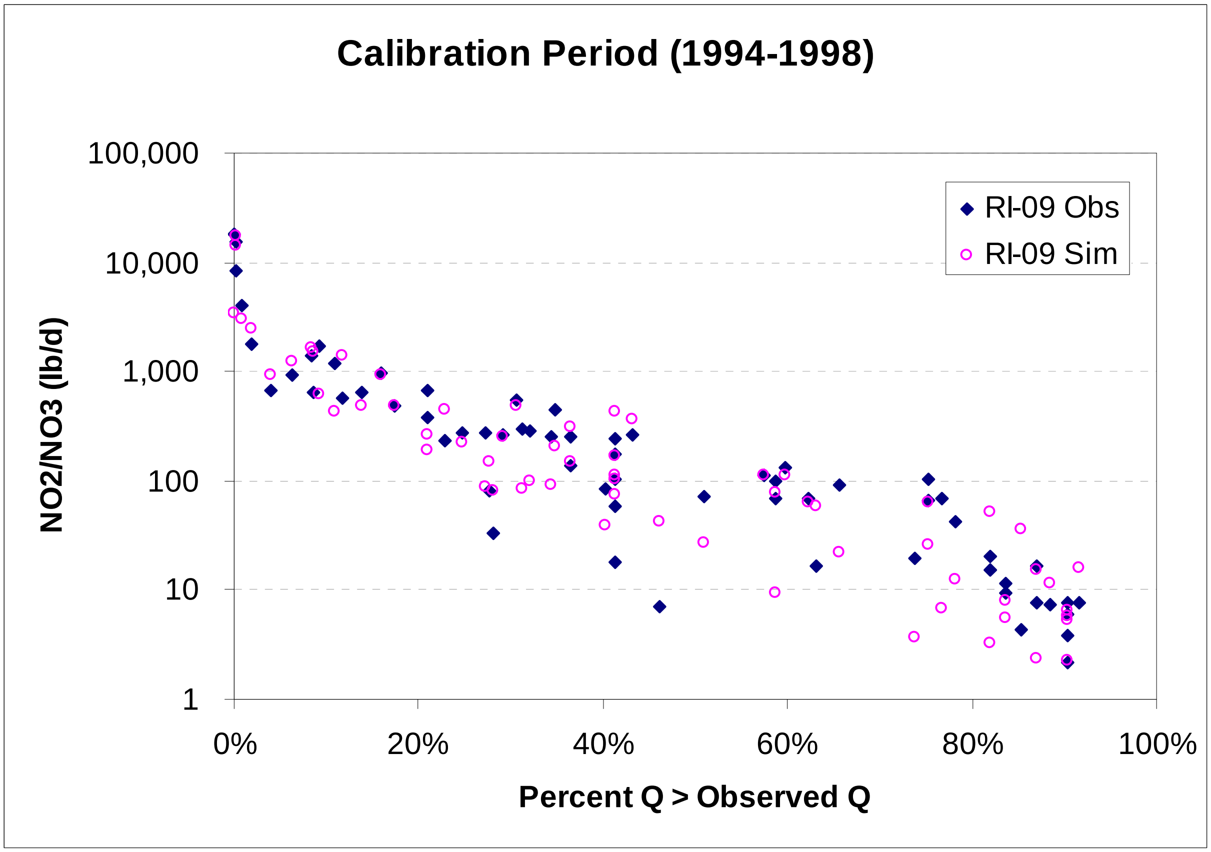
20-100% - Obs

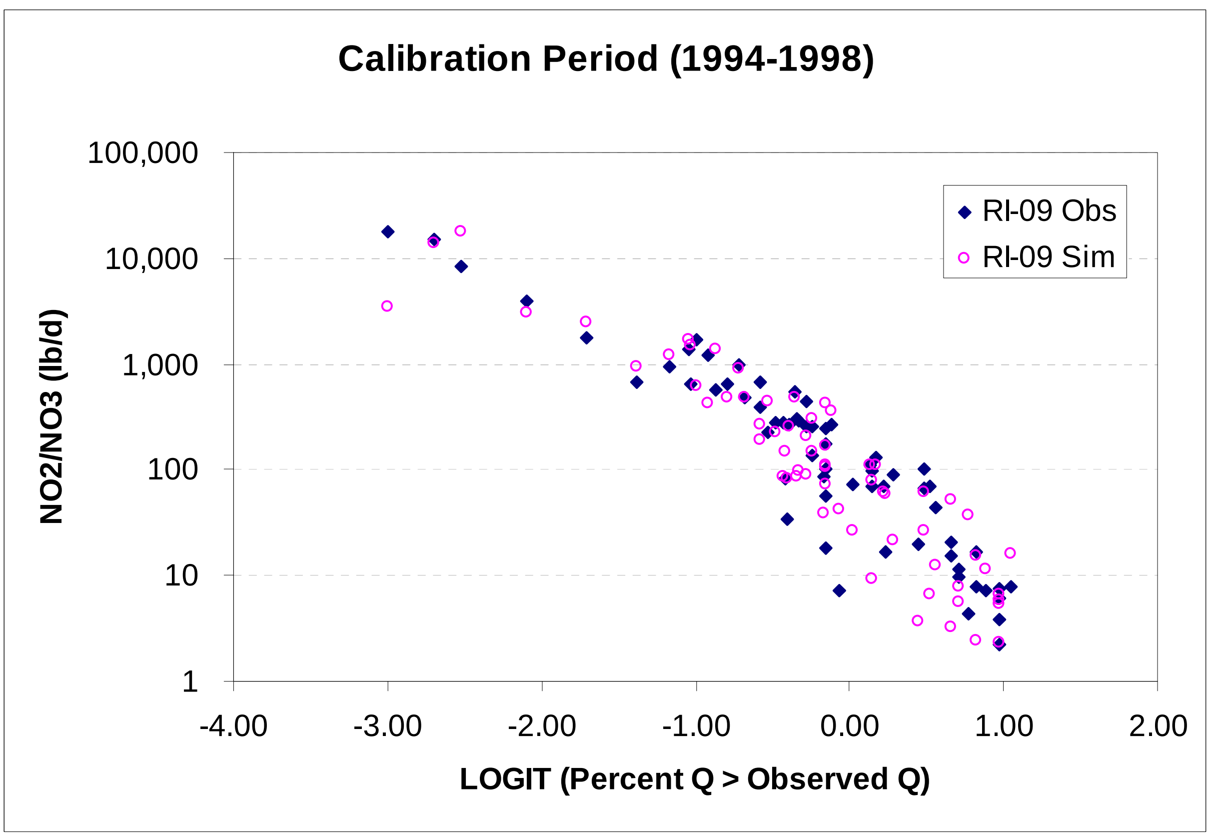
-1.88067	5.706484
0.155611	0.069246
0.848894	0.361335
146.0647	26
2.055529	
0.319862	
-2.20053	
-1.5608	

20-100% - Sim

-1.8172	5.692876
0.237246	0.105573
0.692921	0.550896
58.66874	26
2.055529	
0.487666	
-2.30486	
-1.32953	




Calibration Period (1994-1998)
100,000
10,000
1,000
100
10
1
NO2/NO3 (lb/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-09 Obs
RI-09 Sim


Calibration Period (1994-1998)
100,000
10,000
1,000
100
10
1
NO2/NO3 (lb/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-09 Obs
RI-09 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.44697	5.359391
0.143499	0.233073
0.886638	0.415886
101.6765	13
2.160369	
0.310011	
-1.75698	
-1.13696	

0-20% - Sim

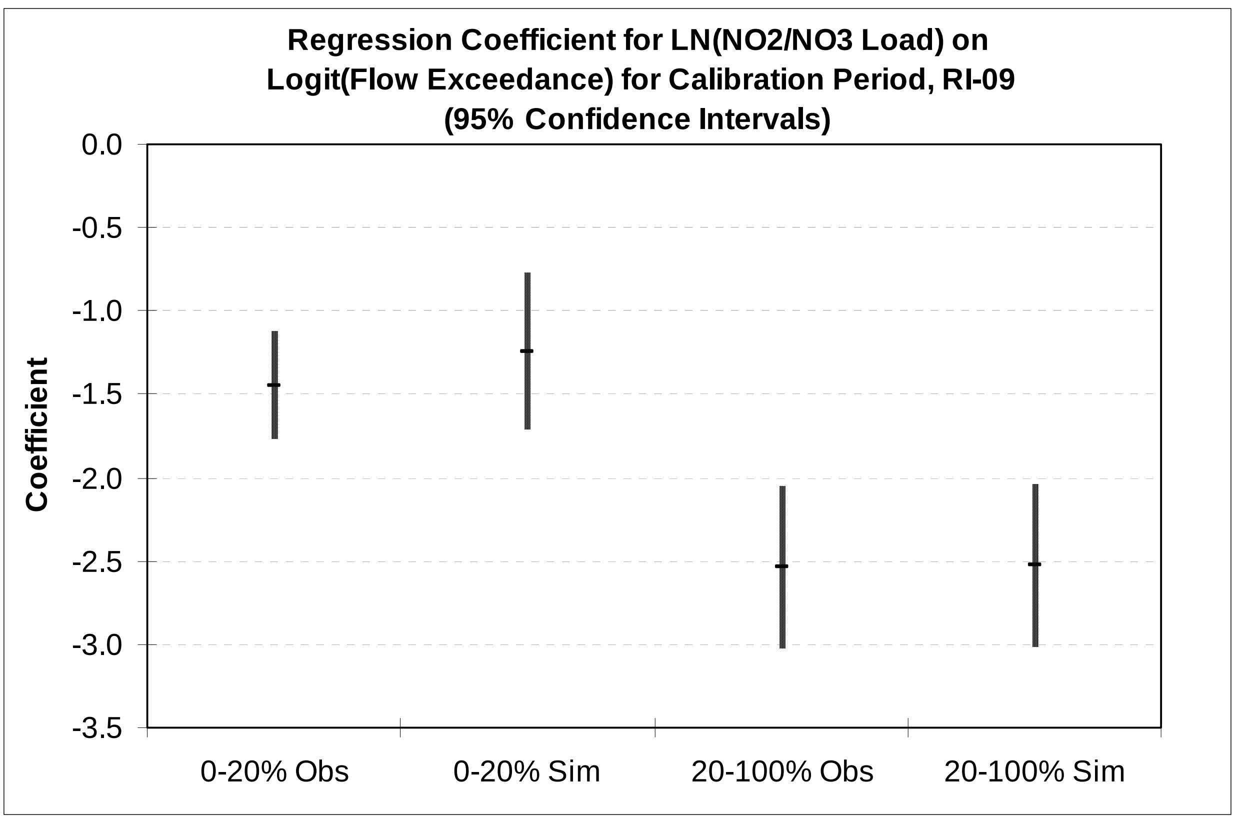
-1.24355	5.596457
0.211794	0.343997
0.726169	0.613815
34.47459	13
2.160369	
0.457552	
-1.7011	
-0.786	

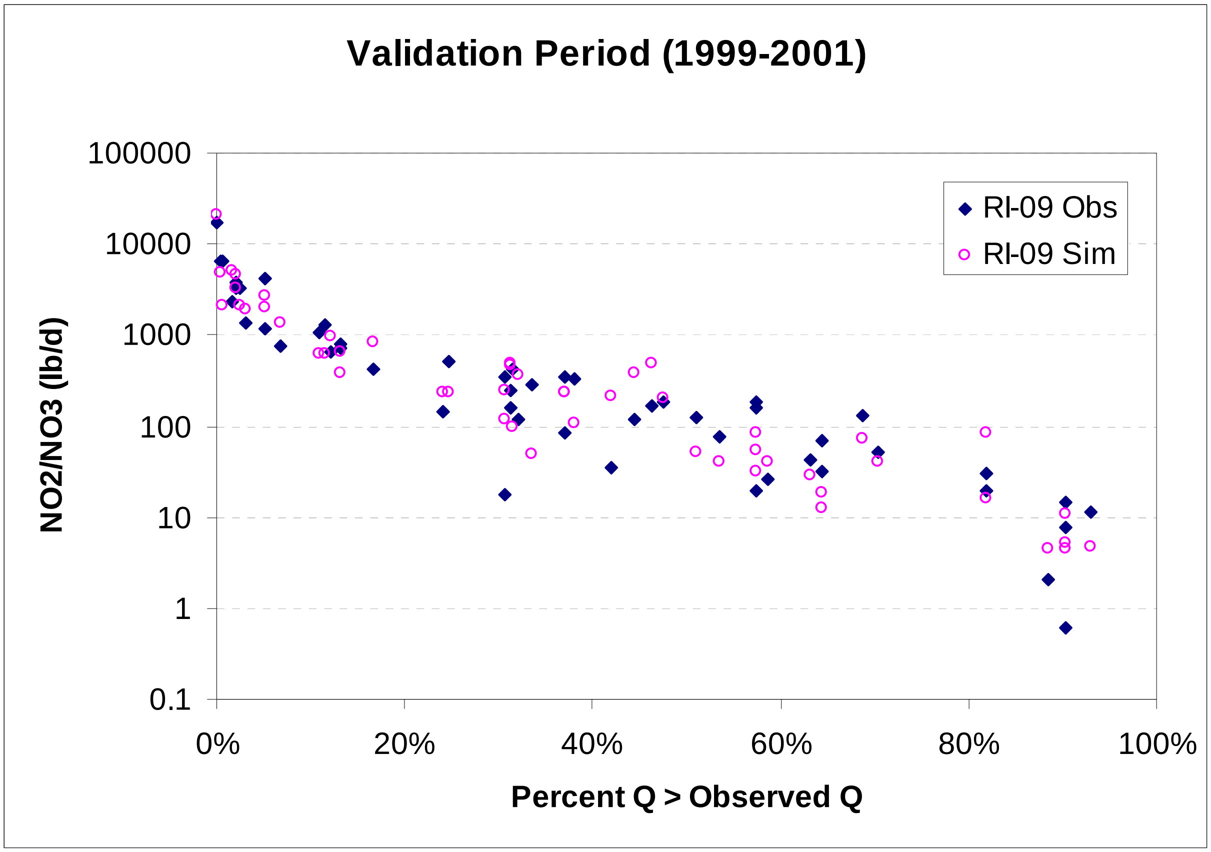
20-100% - Obs

-2.54002	4.434972
0.237068	0.124831
0.709511	0.832787
114.7963	47
2.01174	
0.476919	
-3.01693	
-2.0631	

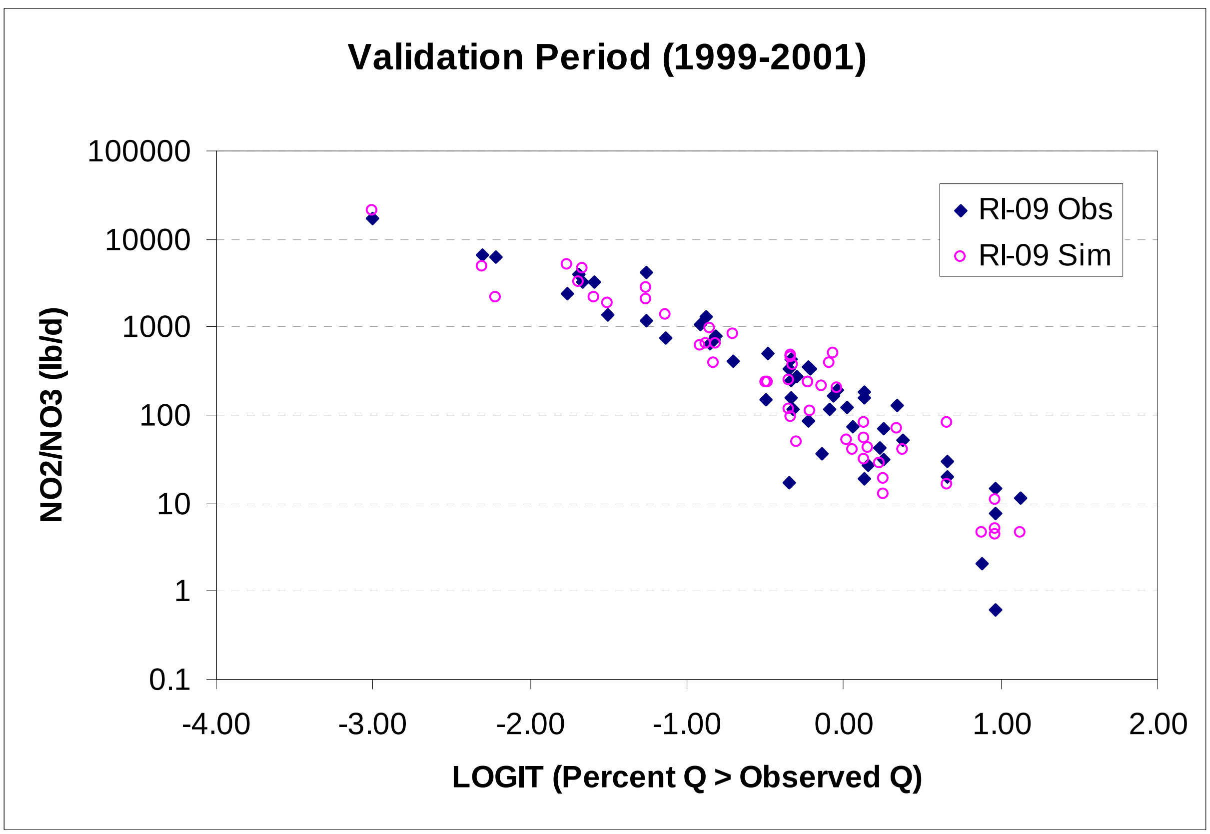
20-100% - Sim

-2.52671	4.216108
0.238113	0.125382
0.705516	0.836461
112.6012	47
2.01174	
0.479022	
-3.00573	
-2.04769	





Validation Period (1999-2001)
100000
10000
1000
100
10
1
0.1
0%
20%
40%
60%
80%
100%
NO2/NO3 (lb/d)
Percent Q > Observed Q
RI-09 Obs
RI-09 Sim



Validation Period (1999-2001)
100000
10000
1000
100
10
1
0.1
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
NO2/NO3 (lb/d)
LOGIT (Percent Q > Observed Q)
RI-09 Obs
RI-09 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.4754	5.451415
0.15491	0.241767
0.858105	0.392759
90.71176	15
2.13145	
0.330183	
-1.80559	
-1.14522	

0-20% - Sim

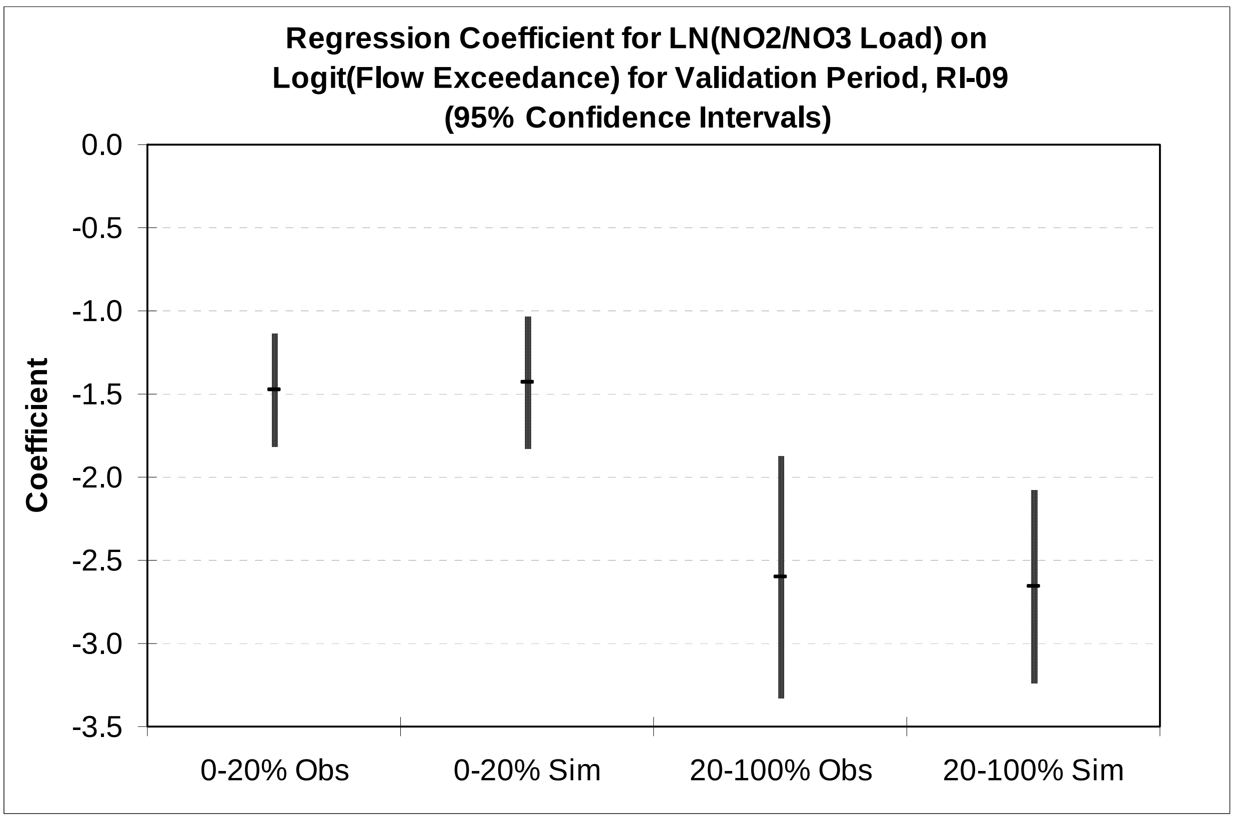
-1.43494	5.476572
0.181235	0.282853
0.80692	0.459503
62.6882	15
2.13145	
0.386293	
-1.82124	
-1.04865	

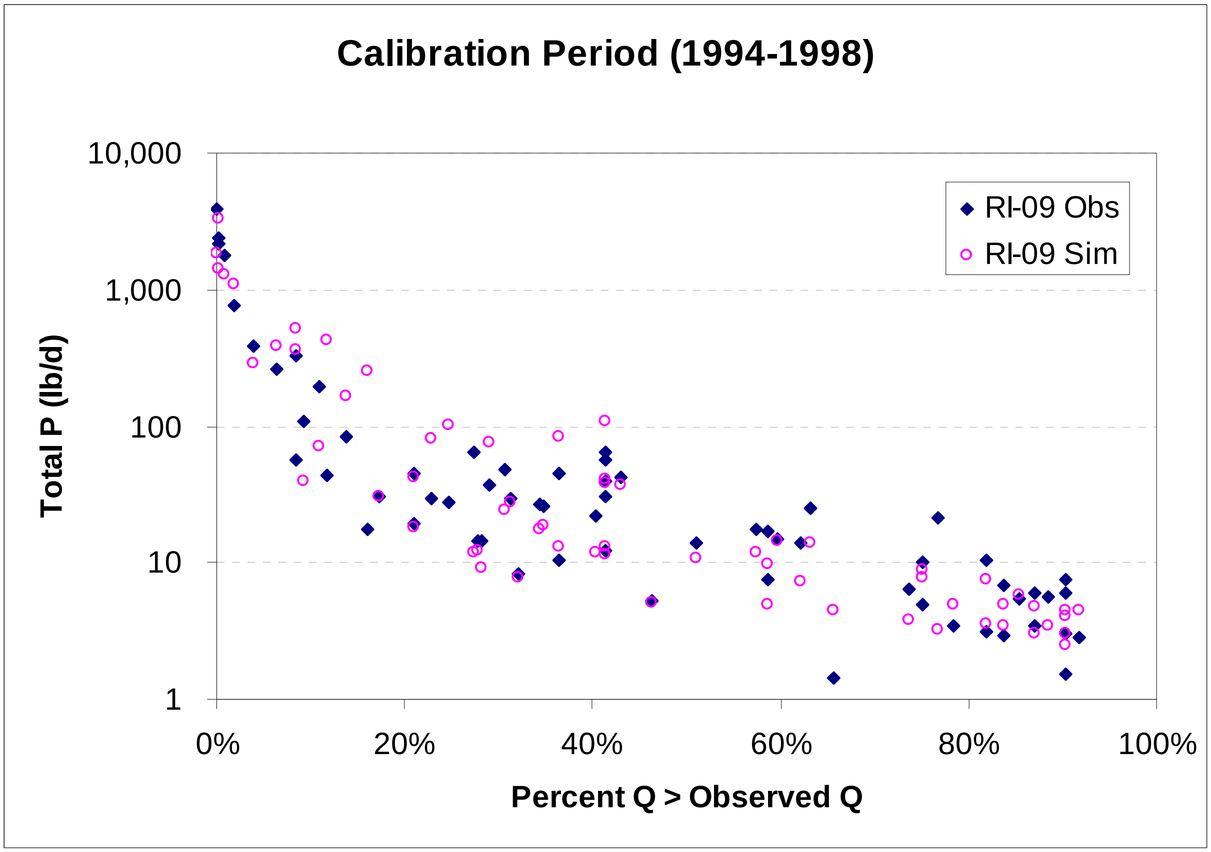
20-100% - Obs

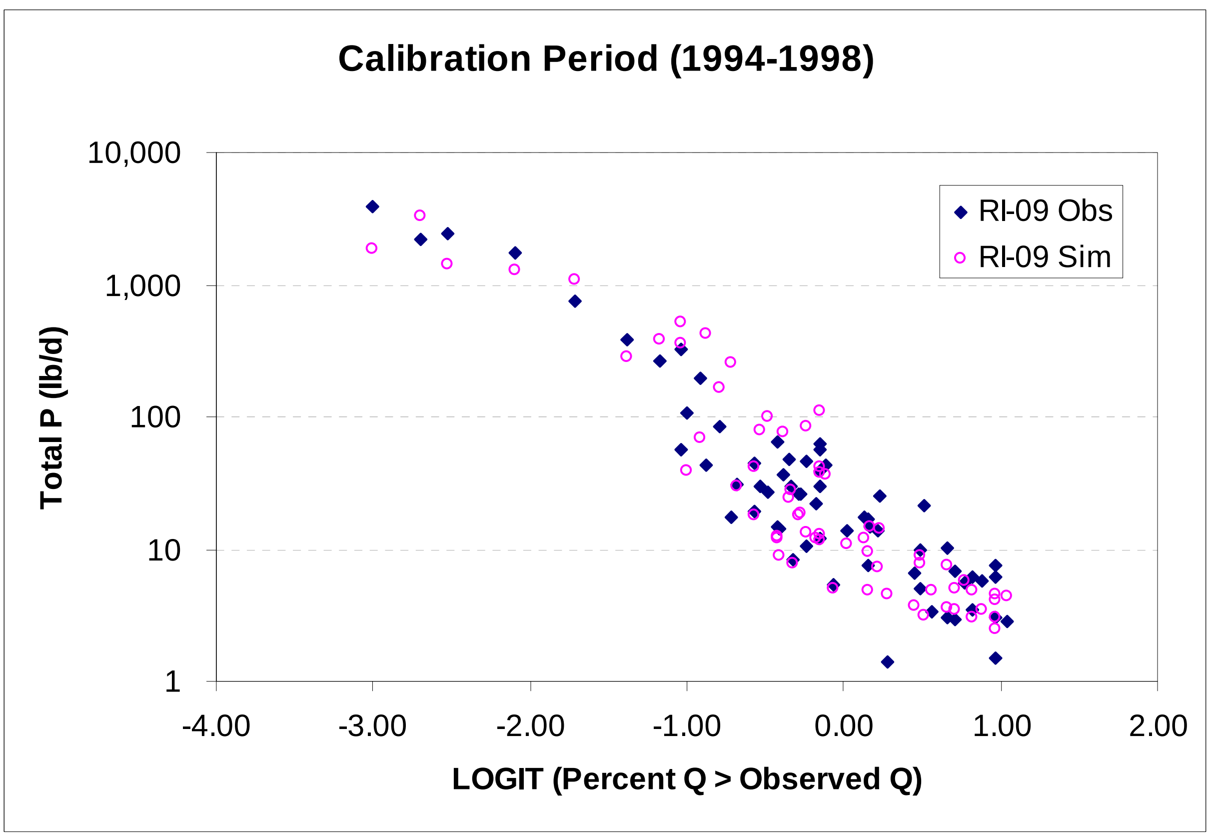
-2.60079	4.462123
0.351489	0.167275
0.631125	0.945824
54.75028	32
2.036933	
0.715959	
-3.31674	
-1.88483	

20-100% - Sim

-2.6594	4.486771
0.277532	0.132078
0.741562	0.746812
91.82079	32
2.036933	
0.565314	
-3.22471	
-2.09408	




Calibration Period (1994-1998)
10,000
1,000
100
10
1
Total P (lb/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-09 Obs
RI-09 Sim


Calibration Period (1994-1998)
10,000
1,000
100
10
1
Total P (lb/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-09 Obs
RI-09 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.045375	2.627864
0.236516	0.384151
0.851914	0.685464
74.78695	13
2.160369	
0.510961	
-2.556337	
-1.534414	

0-20% - Sim

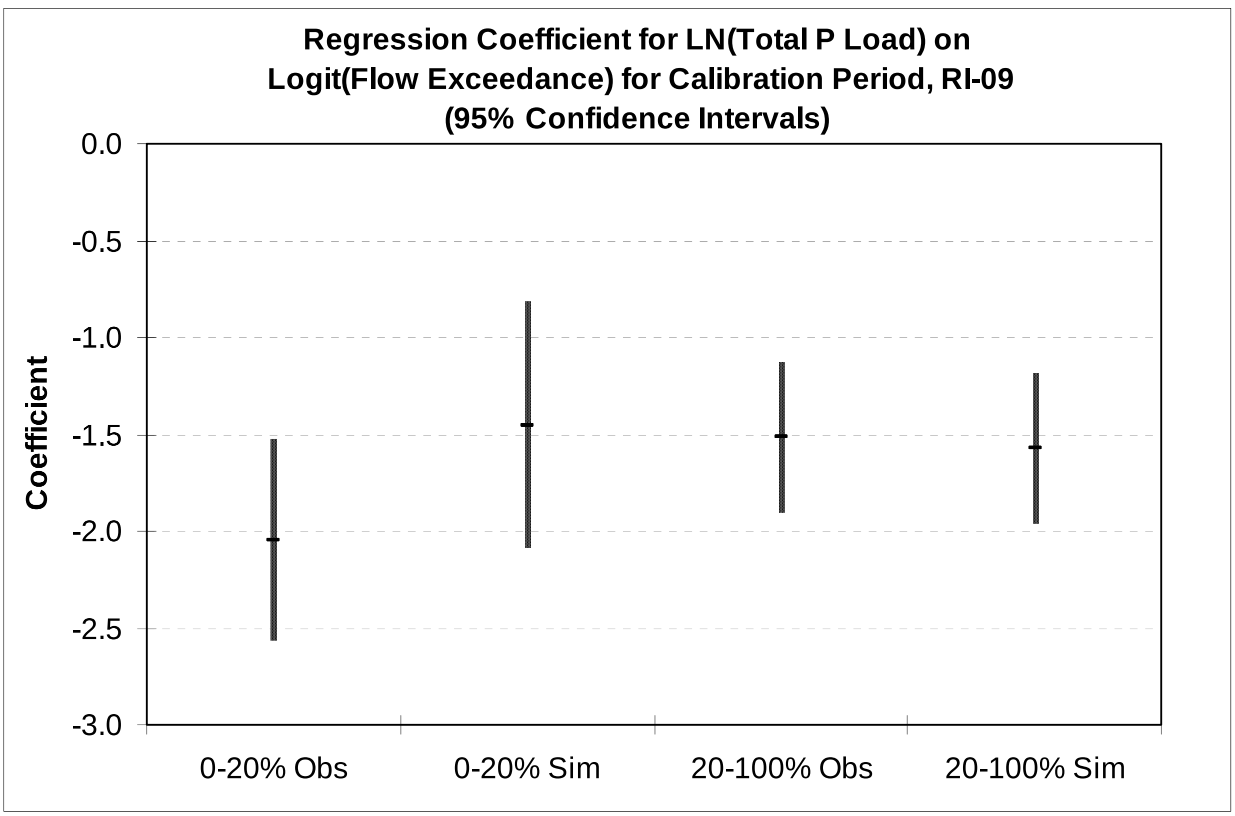
-1.45387	3.822855
0.290394	0.471661
0.658481	0.841614
25.06525	13
2.160369	
0.627359	
-2.08122	
-0.82651	

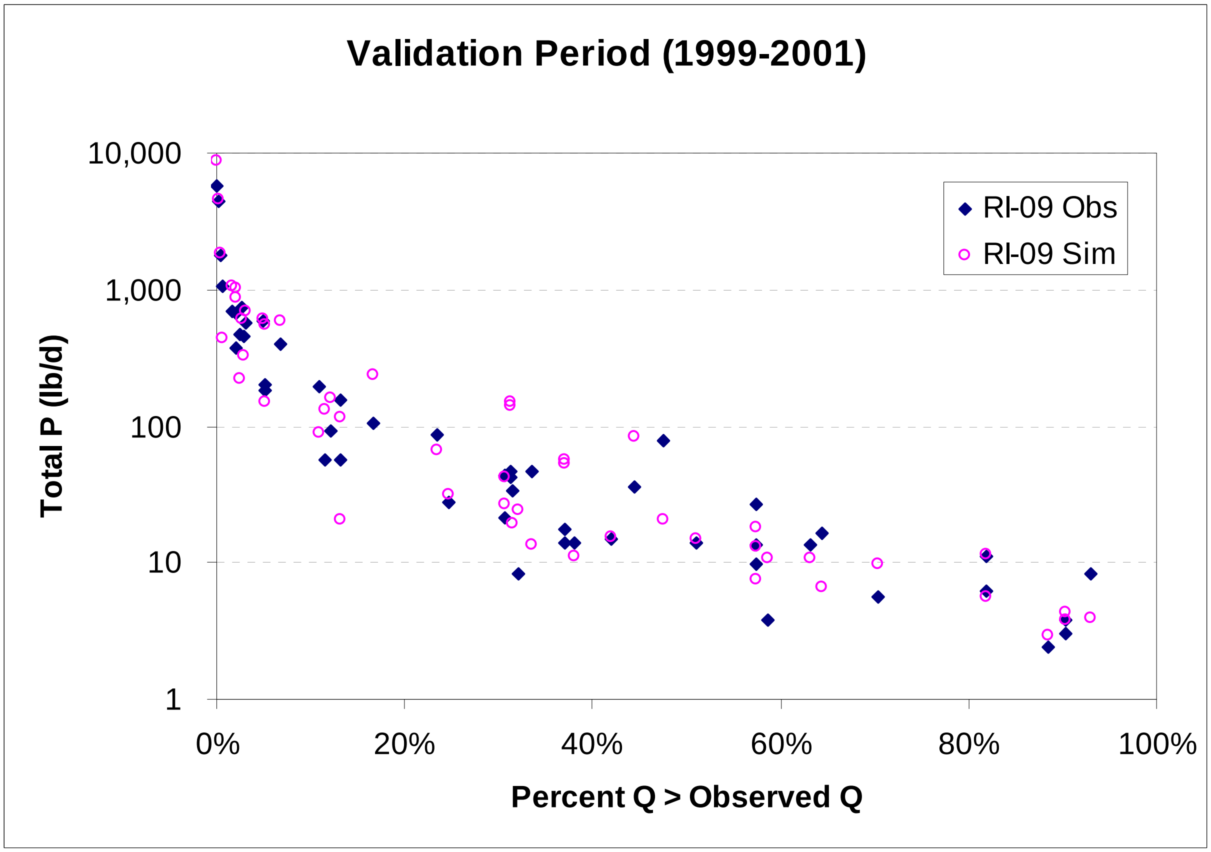
20-100% - Obs

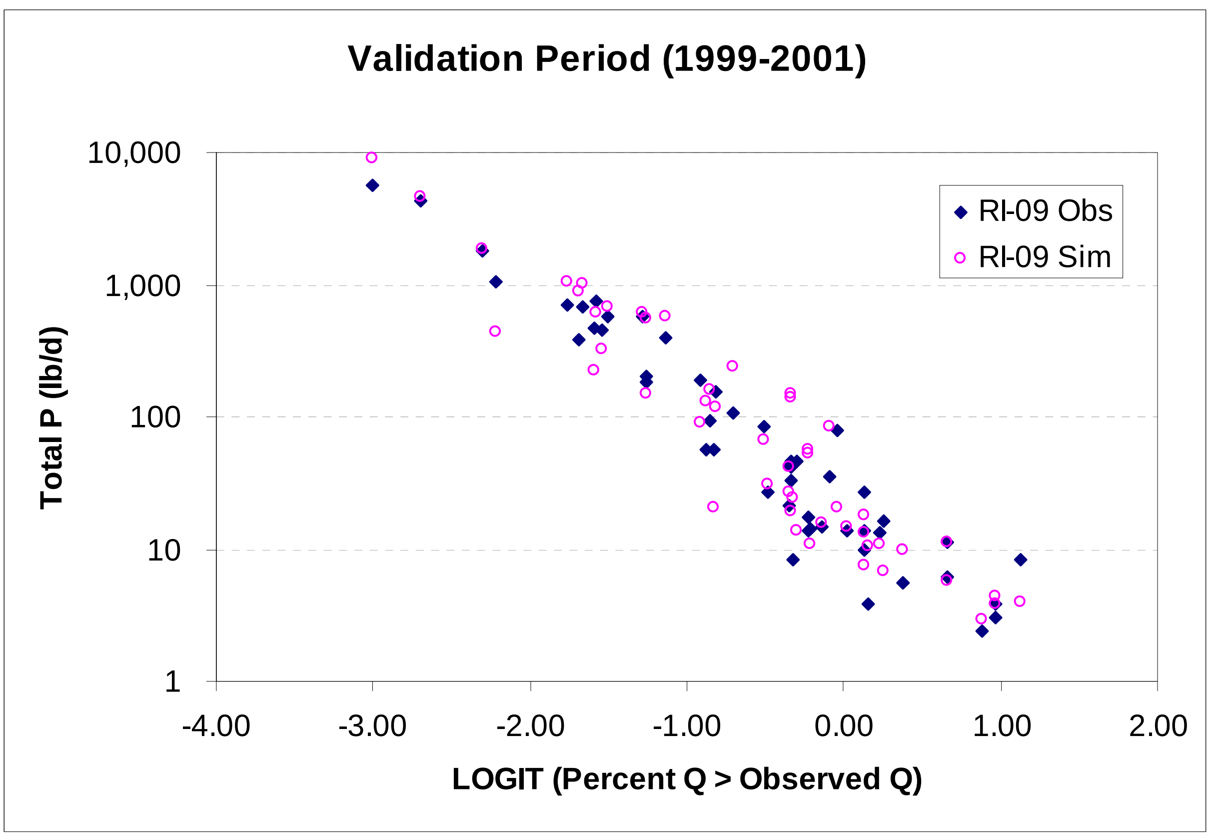
-1.510535	2.760039
0.188246	0.099123
0.578054	0.661283
64.38865	47
2.01174	
0.378702	
-1.889237	
-1.131832	

20-100% - Sim

-1.56931	2.645743
0.187675	0.098822
0.598019	0.659276
69.92094	47
2.01174	
0.377553	
-1.94686	
-1.19176	




Validation Period (1999-2001)
Total P (lb/d)
10,000
1,000
100
10
1
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-09 Obs
RI-09 Sim


Validation Period (1999-2001)
Total P (lb/d)
10,000
1,000
100
10
1
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-09 Obs
RI-09 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.86793	3.205483
0.15136	0.245336
0.889084	0.427916
152.3007	19
2.093024	
0.3168	
-2.18473	
-1.55113	

0-20% - Sim

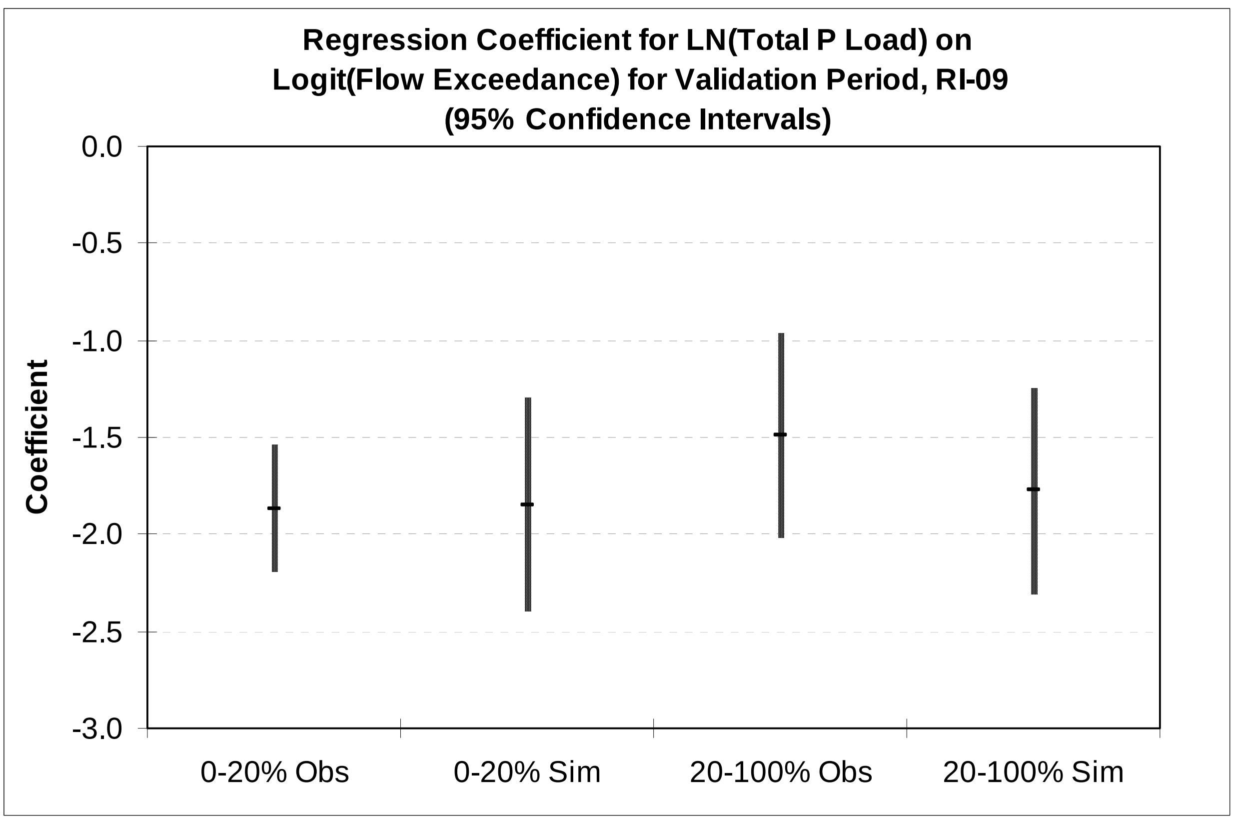
-1.84821	3.314739
0.257386	0.417193
0.730734	0.727667
51.56215	19
2.093024	
0.538715	
-2.38692	
-1.30949	

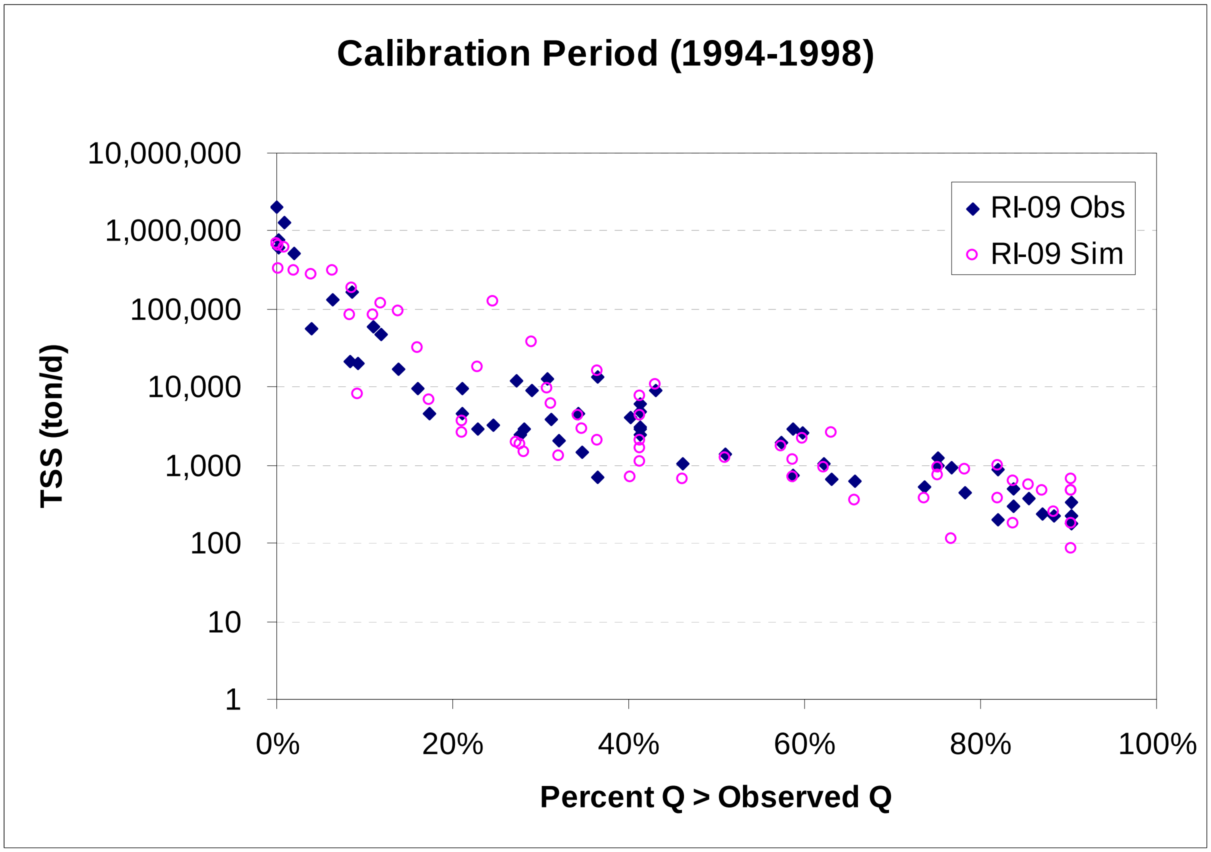
20-100% - Obs

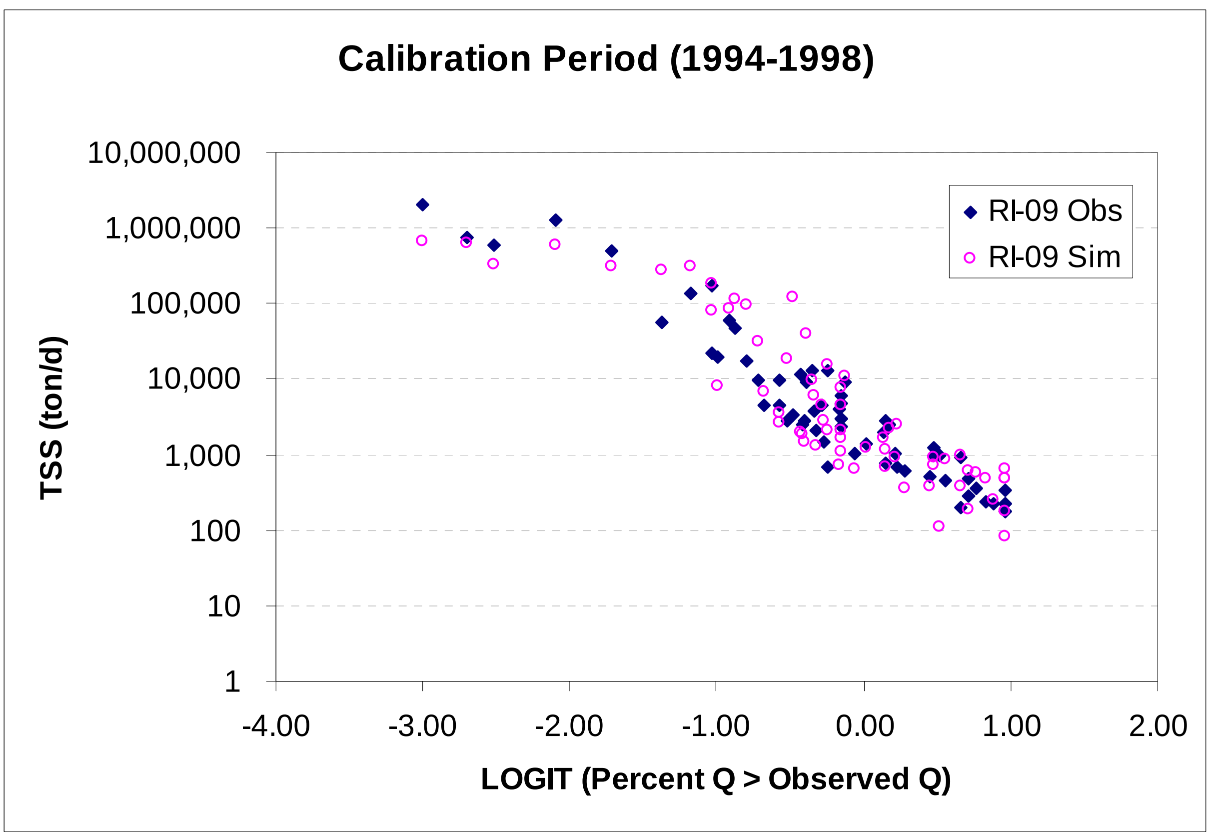
-1.49326	2.857153
0.252259	0.120176
0.564804	0.637511
35.04108	27
2.05183	
0.517593	
-2.01085	
-0.97567	

20-100% - Sim

-1.77649	2.990833
0.252733	0.120402
0.646638	0.638708
49.40881	27
2.05183	
0.518565	
-2.29506	
-1.25793	




Calibration Period (1994-1998)
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
TSS (ton/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-09 Obs
RI-09 Sim


Calibration Period (1994-1998)
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
TSS (ton/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-09 Obs
RI-09 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.178343	8.357402
0.309356	0.502459
0.792277	0.896569
49.58323	13
2.160369	
0.668324	
-2.846667	
-1.51002	

0-20% - Sim

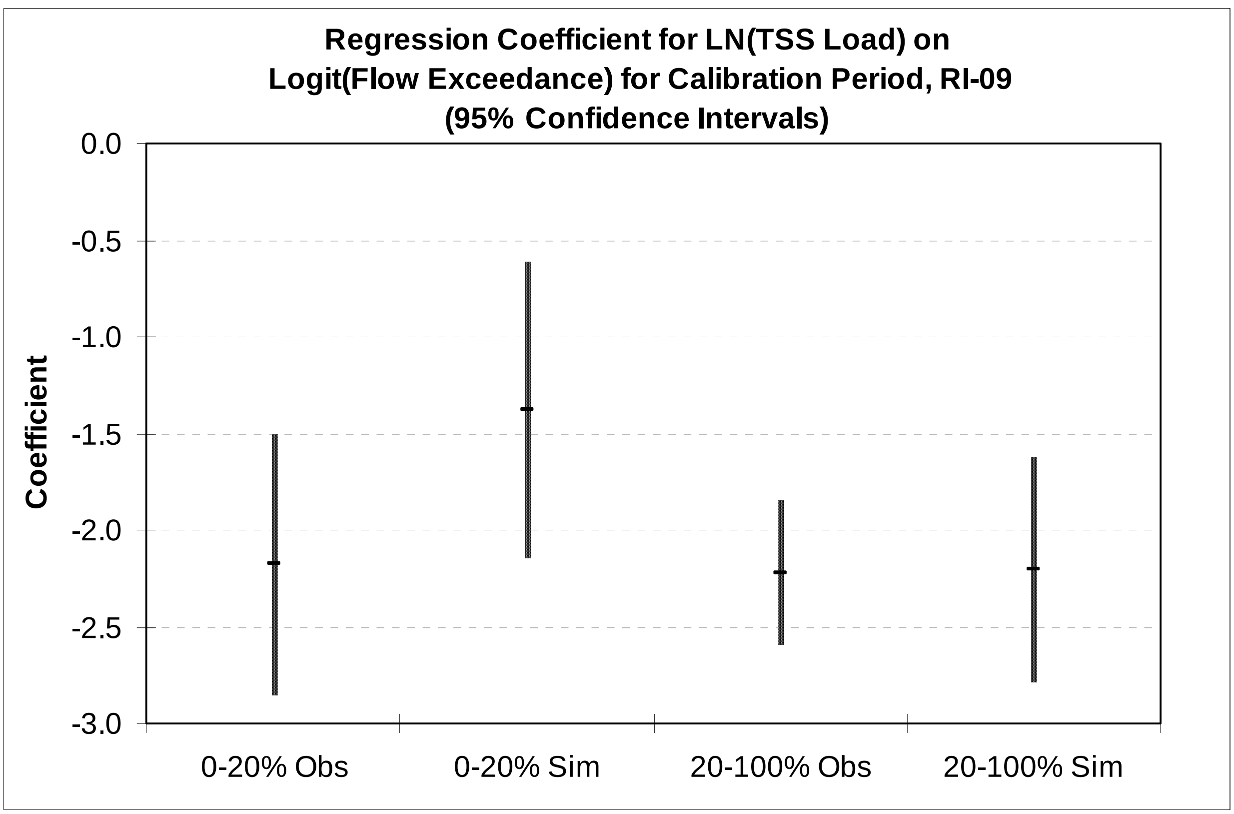
-1.37888	9.788747
0.351773	0.571353
0.541686	1.0195
15.36482	13
2.160369	
0.75996	
-2.13884	
-0.61892	

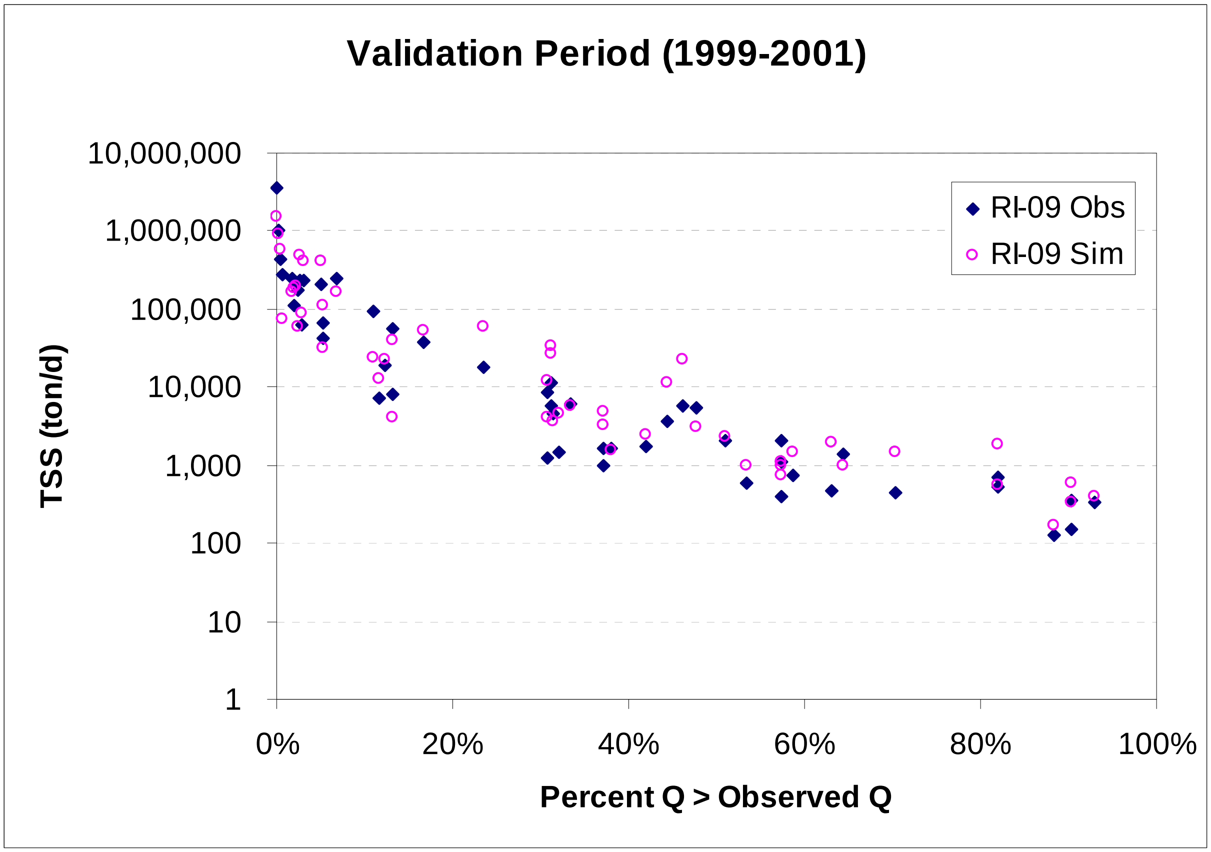
20-100% - Obs

-2.219982	7.581006
0.181837	0.093735
0.764164	0.623549
149.0505	46
2.012896	
0.366019	
-2.586001	
-1.853963	

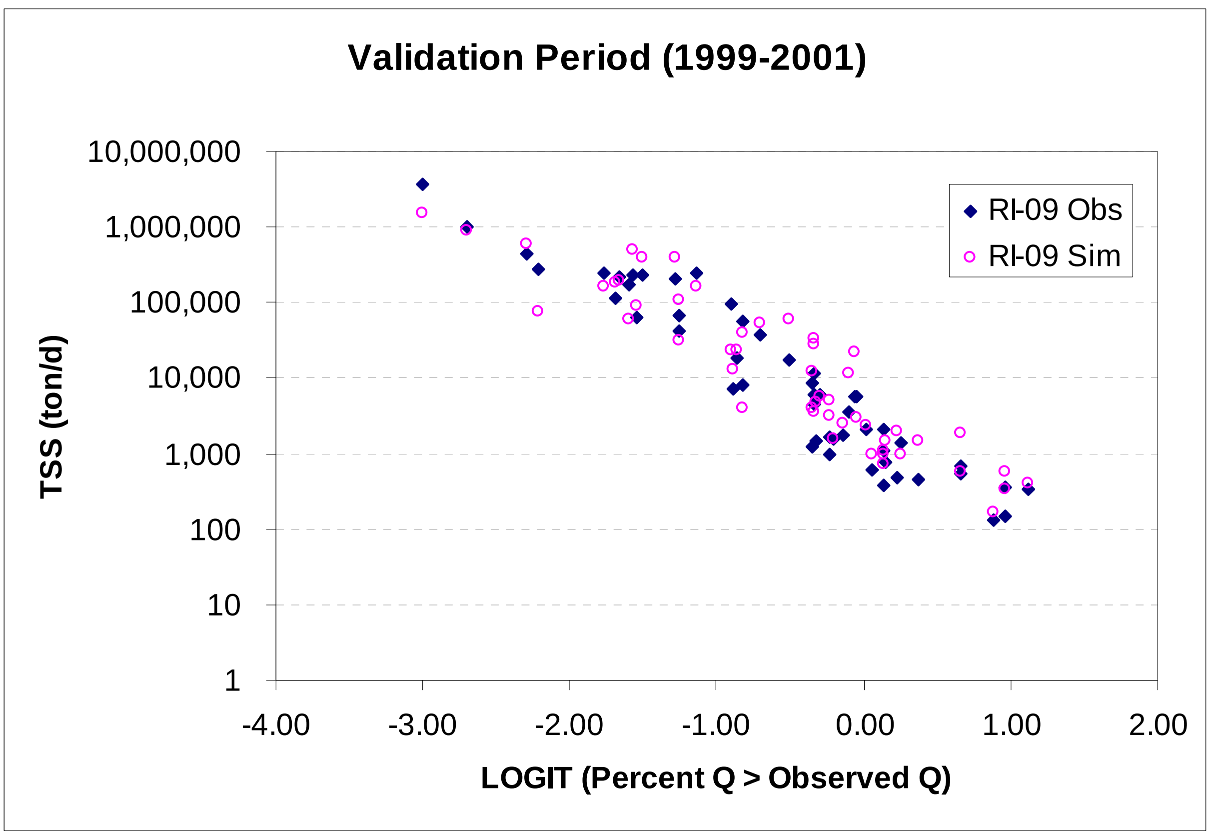
20-100% - Sim

-2.20482	7.590537
0.285179	0.147006
0.56511	0.977925
59.77392	46
2.012896	
0.574035	
-2.778856	
-1.630785	





Validation Period (1999-2001)
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
TSS (ton/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-09 Obs
RI-09 Sim



Validation Period (1999-2001)
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
TSS (ton/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-09 Obs
RI-09 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.99776	8.709623
0.2766	0.448336
0.733015	0.781988
52.16506	19
2.093024	
0.578931	
-2.57669	
-1.41882	

0-20% - Sim

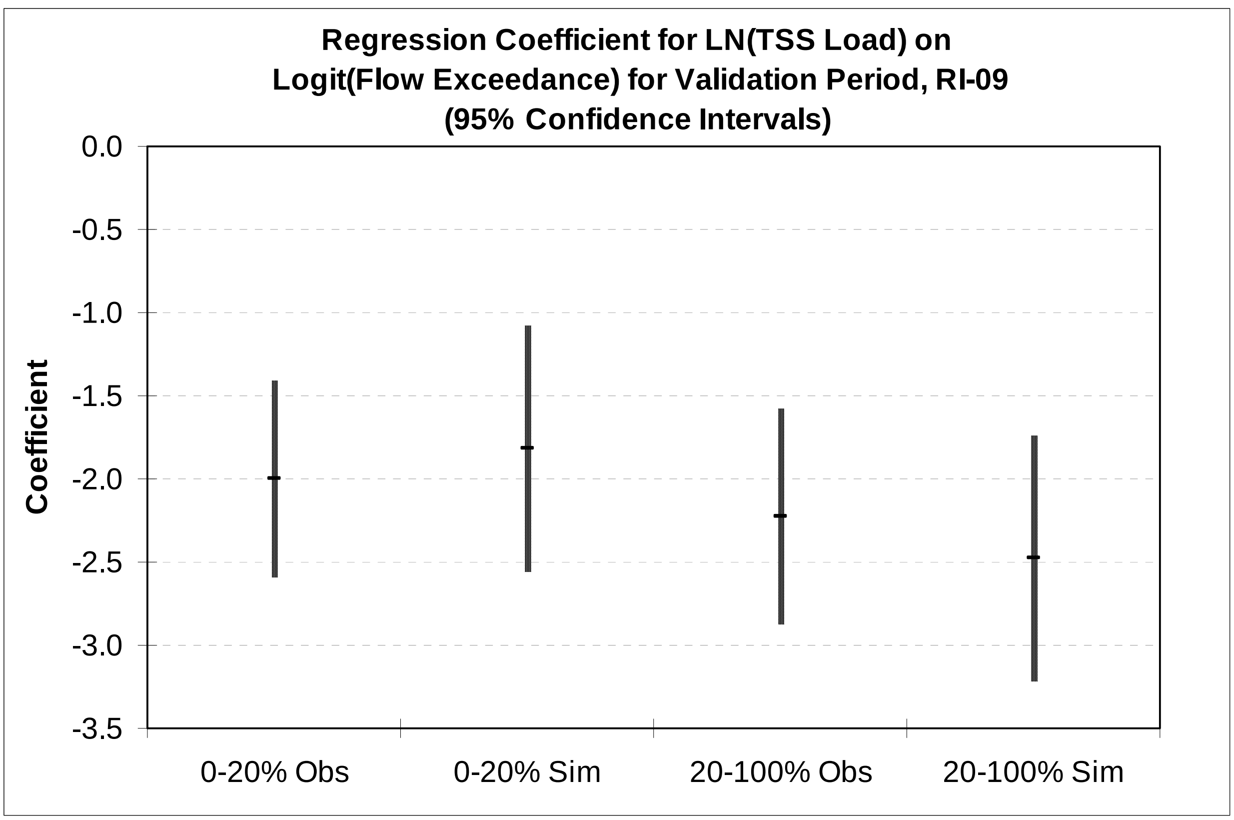
-1.81645	8.871074
0.345737	0.560399
0.592301	0.977447
27.60306	19
2.093024	
0.723636	
-2.54009	
-1.09282	

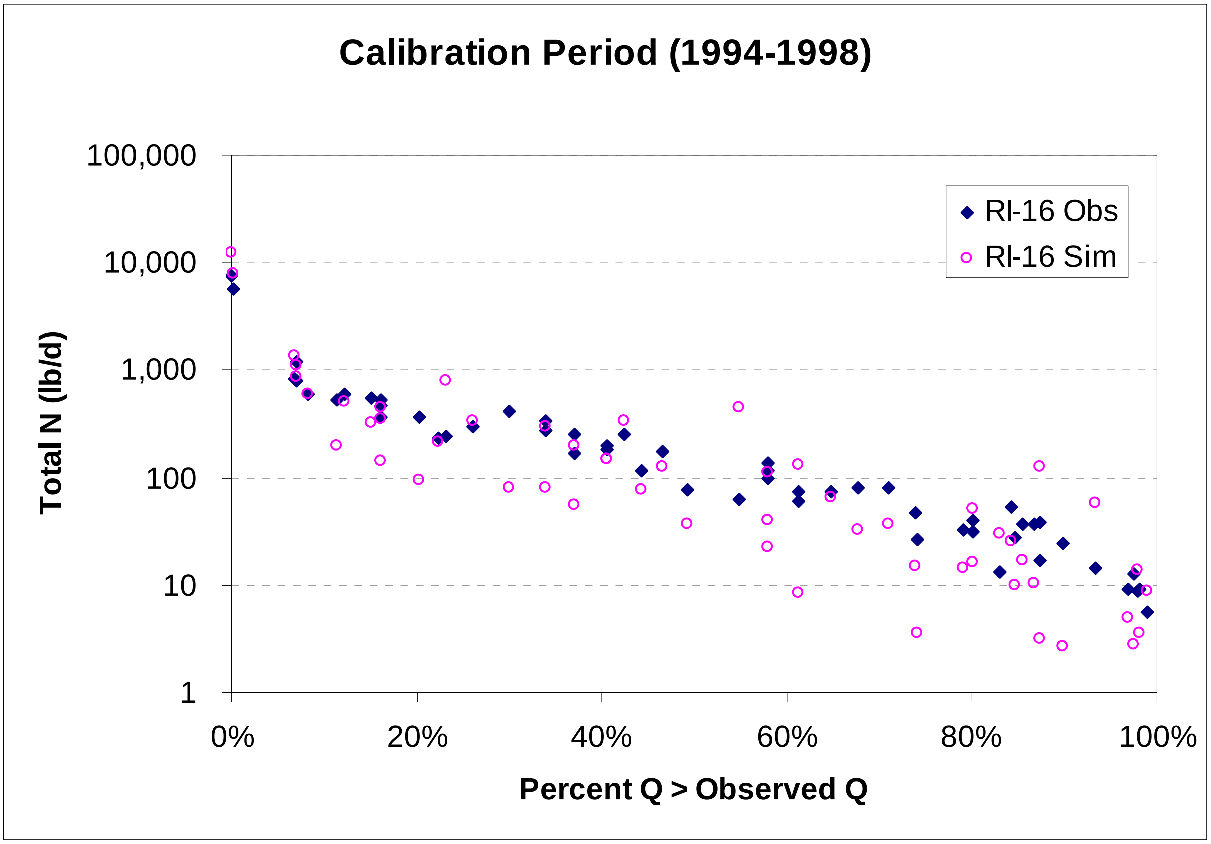
20-100% - Obs

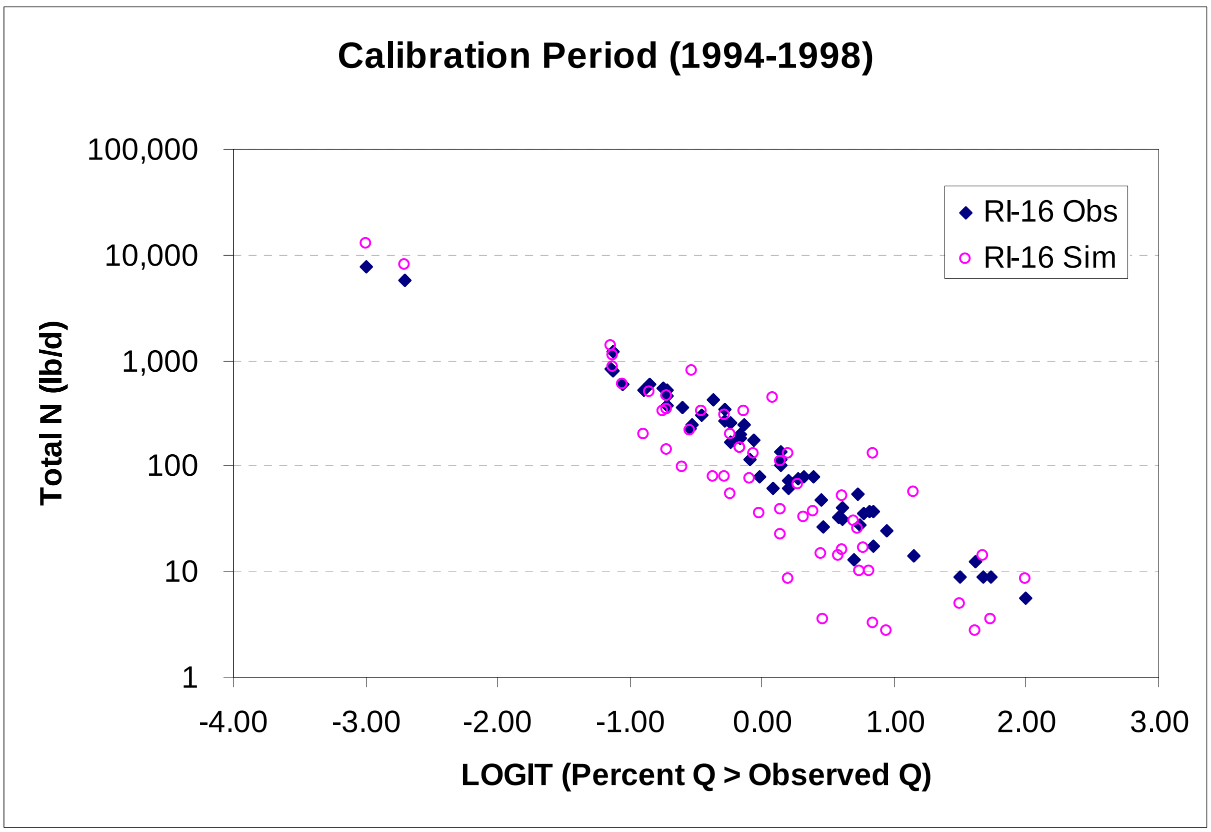
-2.22453	7.485642
0.309538	0.142468
0.64845	0.763472
51.64739	28
2.048407	
0.634059	
-2.85859	
-1.59047	

20-100% - Sim

-2.47848	8.071192
0.357087	0.164354
0.632426	0.880752
48.17511	28
2.048407	
0.73146	
-3.20994	
-1.74702	




Calibration Period (1994-1998)
100,000
10,000
1,000
100
10
1
Total N (lb/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-16 Obs
RI-16 Sim


Calibration Period (1994-1998)
100,000
10,000
1,000
100
10
1
Total N (lb/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
RI-16 Obs
RI-16 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.255126	5.256666
0.067272	0.093629
0.969368	0.177951
348.103	11
2.200986	
0.148064	
-1.403191	
-1.107062	

0-20% - Sim

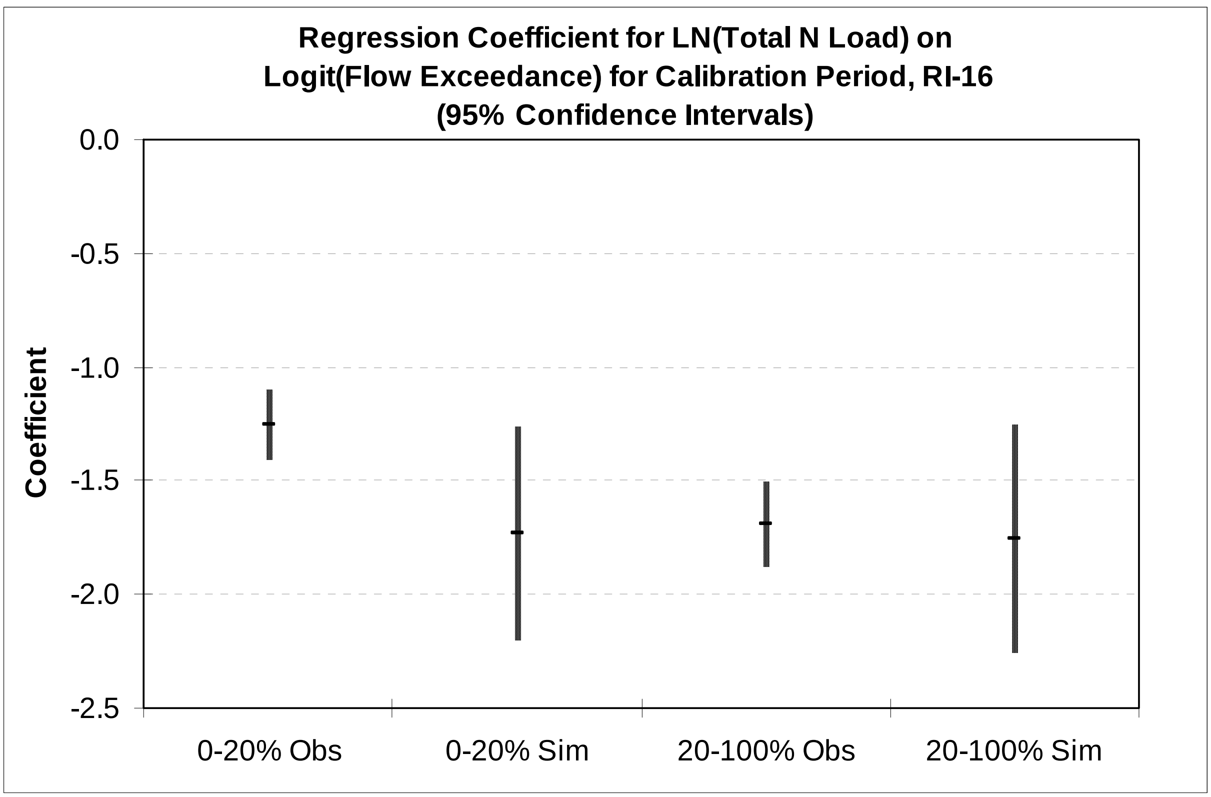
-1.732621	4.460427
0.210742	0.29331
0.86004	0.557465
67.59362	11
2.200986	
0.46384	
-2.196461	
-1.268781	

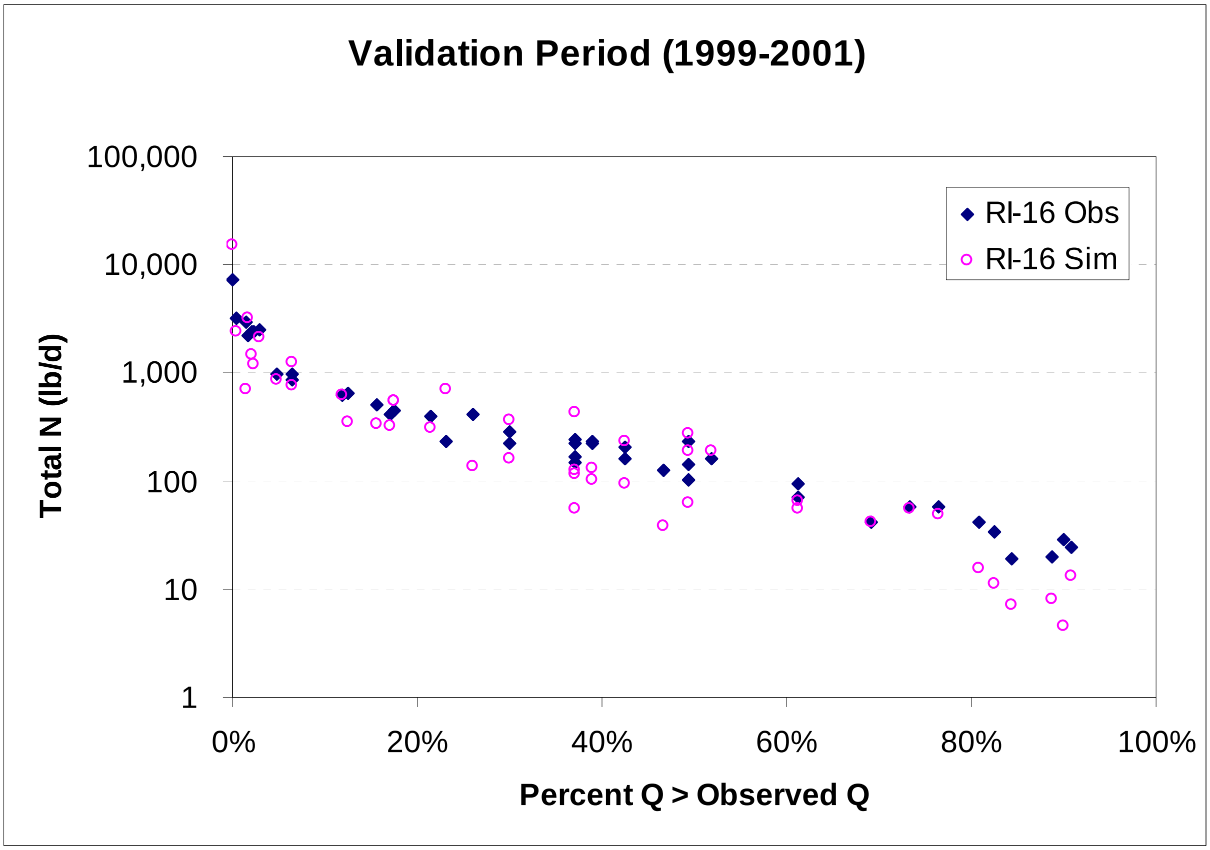
20-100% - Obs

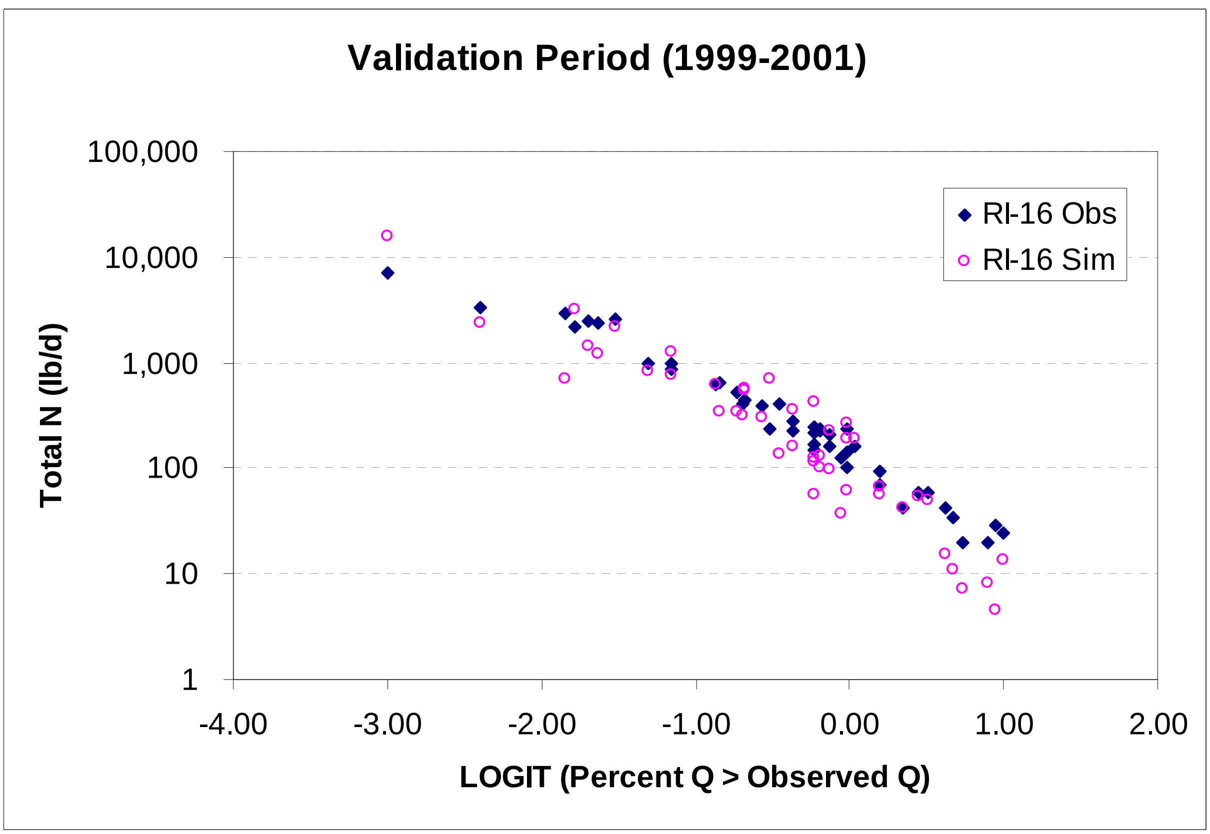
-1.693641	4.80445
0.088278	0.067102
0.901979	0.367658
368.0763	40
2.021075	
0.178416	
-1.872058	
-1.515225	

20-100% - Sim

-1.754353	4.360166
0.242968	0.184685
0.565859	1.011905
52.1359	40
2.021075	
0.491056	
-2.245408	
-1.263297	




Validation Period (1999-2001)
100,000
10,000
1,000
100
10
1
Total N (lb/d)
RI-16 Obs
RI-16 Sim
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q


Validation Period (1999-2001)
100,000
10,000
1,000
100
10
1
Total N (lb/d)
RI-16 Obs
RI-16 Sim
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.267773	5.37938
0.095355	0.144967
0.926611	0.247792
176.764	14
2.144789	
0.204517	
-1.47229	
-1.063256	

0-20% - Sim

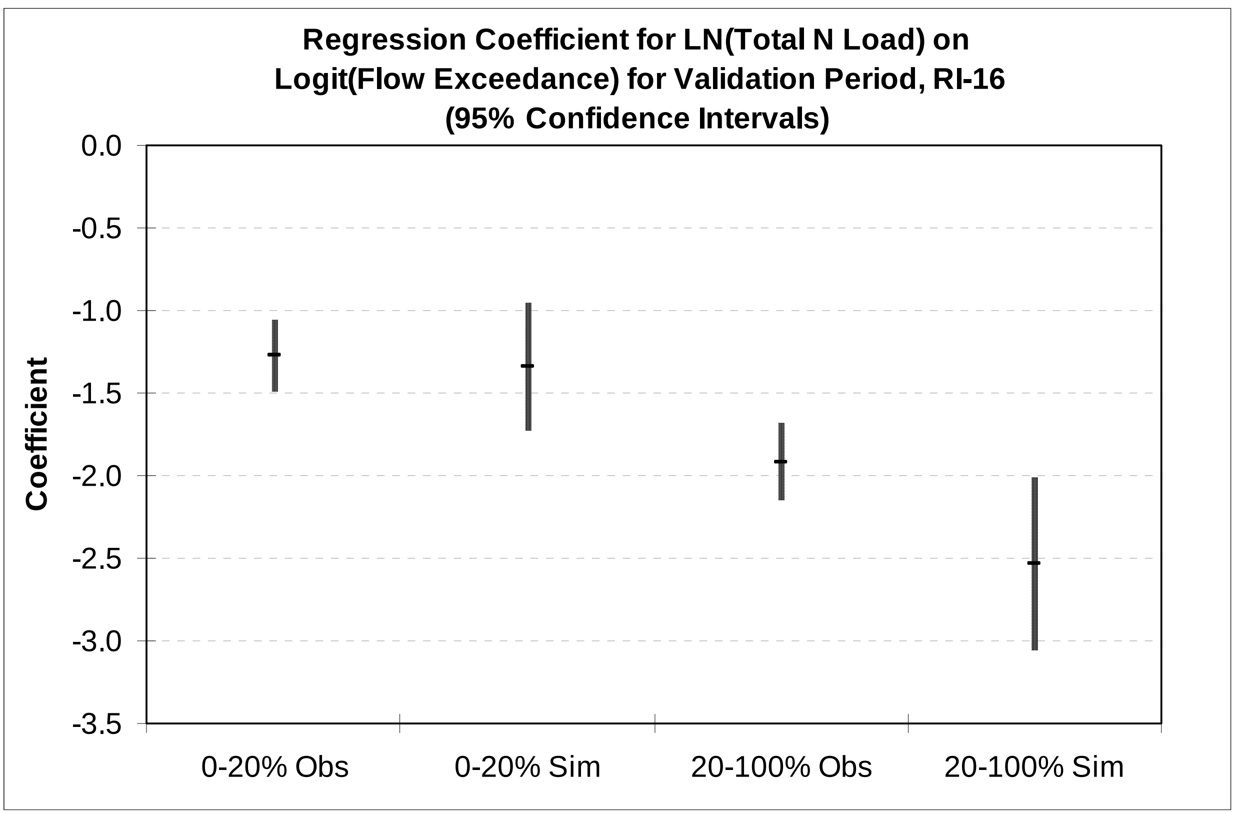
-1.343297	5.101405
0.176099	0.26772
0.806062	0.457613
58.18787	14
2.144789	
0.377694	
-1.720991	
-0.965603	

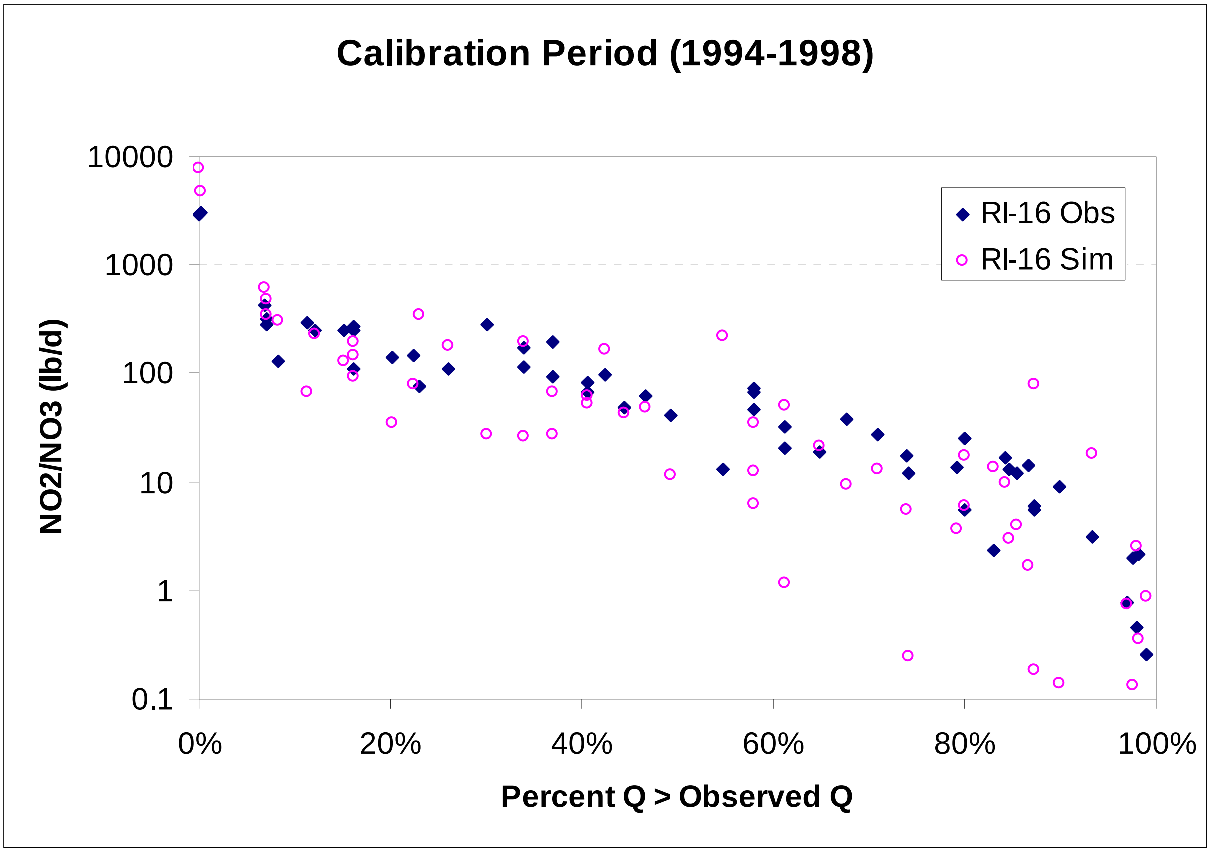
20-100% - Obs

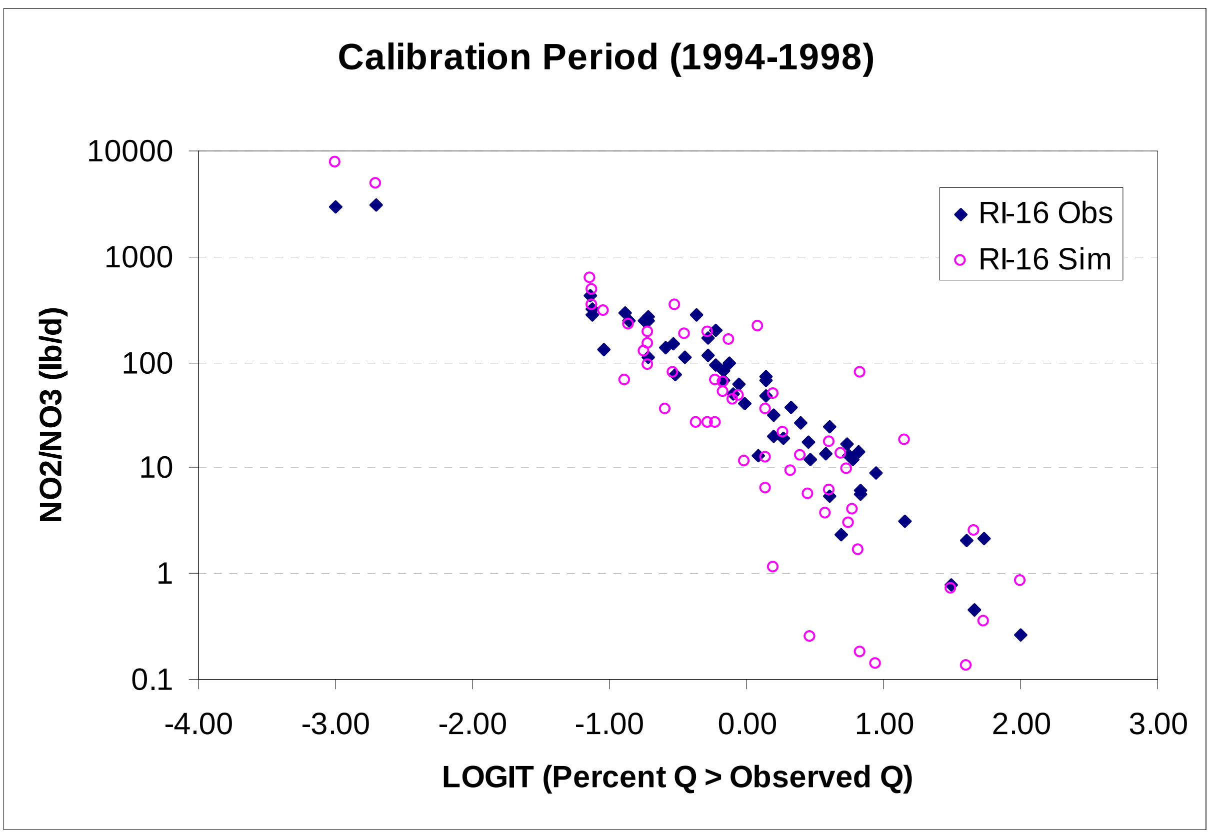
-1.914813	4.87175
0.107053	0.049195
0.922174	0.259649
319.9292	27
2.051829	
0.219655	
-2.134467	
-1.695158	

20-100% - Sim

-2.532698	4.519621
0.251202	0.115438
0.790133	0.609271
101.6528	27
2.051829	
0.515424	
-3.048122	
-2.017274	




Calibration Period (1994-1998)
10000
1000
100
10
1
0.1
NO2/NO3 (lb/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-16 Obs
RI-16 Sim


Calibration Period (1994-1998)
10000
1000
100
10
1
0.1
NO2/NO3 (lb/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
RI-16 Obs
RI-16 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.276219	4.324587
0.138187	0.192328
0.885766	0.365539
85.29337	11
2.200986	
0.304148	
-1.580367	
-0.972071	

0-20% - Sim

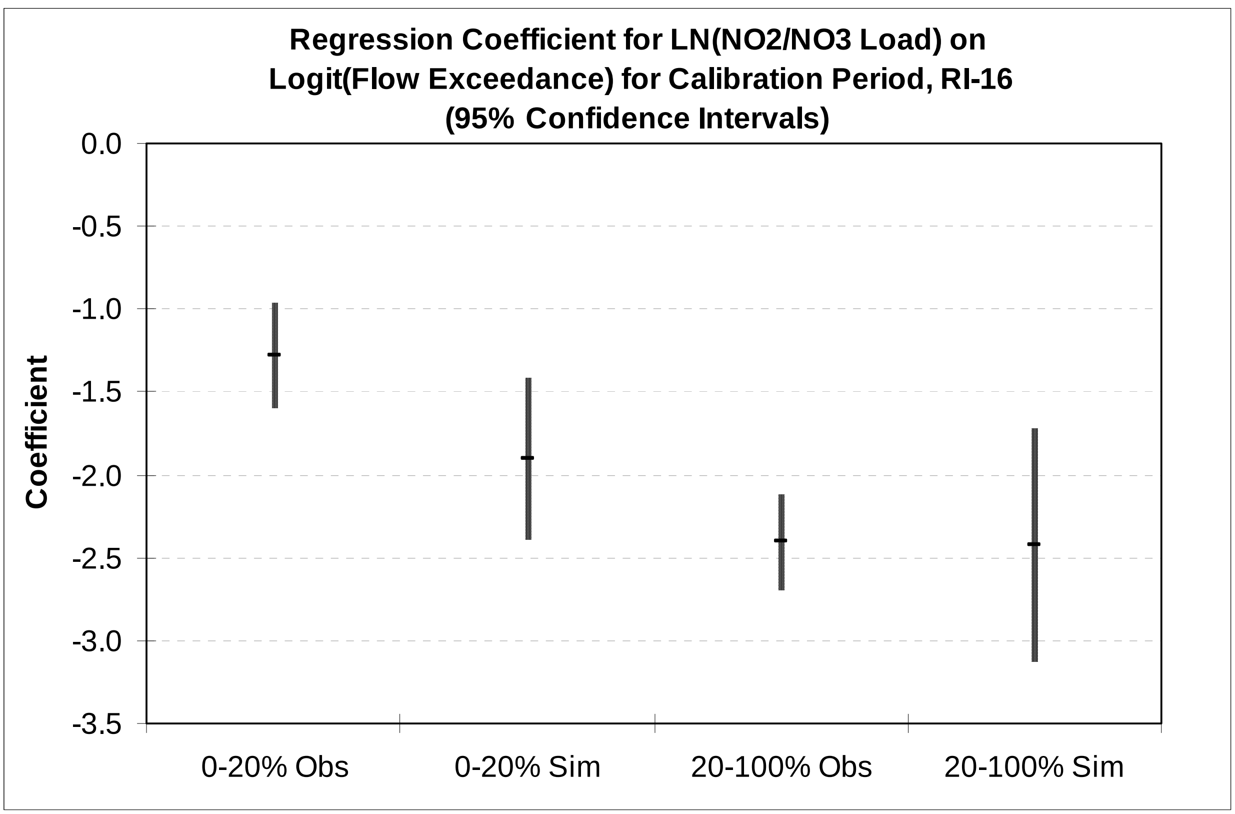
-1.902264	3.481991
0.214561	0.298626
0.877236	0.567568
78.60291	11
2.200986	
0.472246	
-2.37451	
-1.430017	

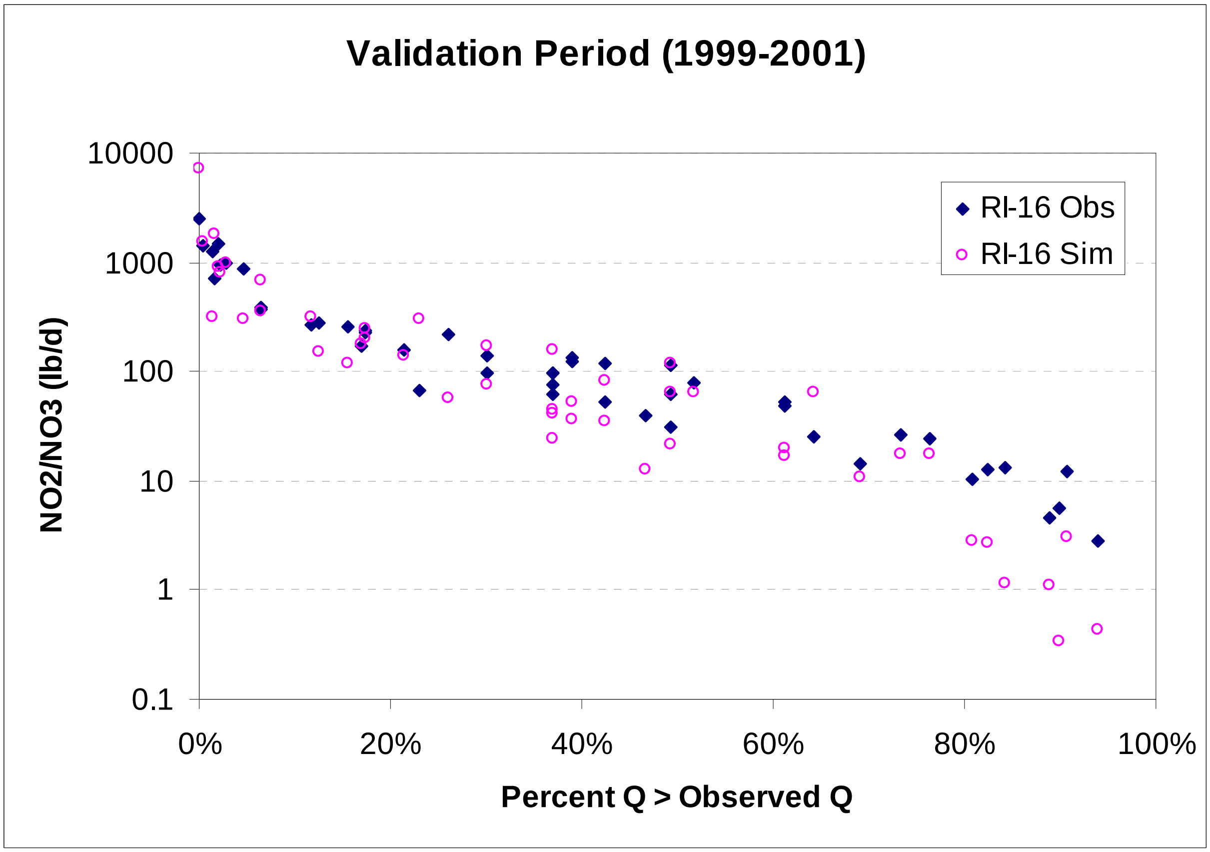
20-100% - Obs

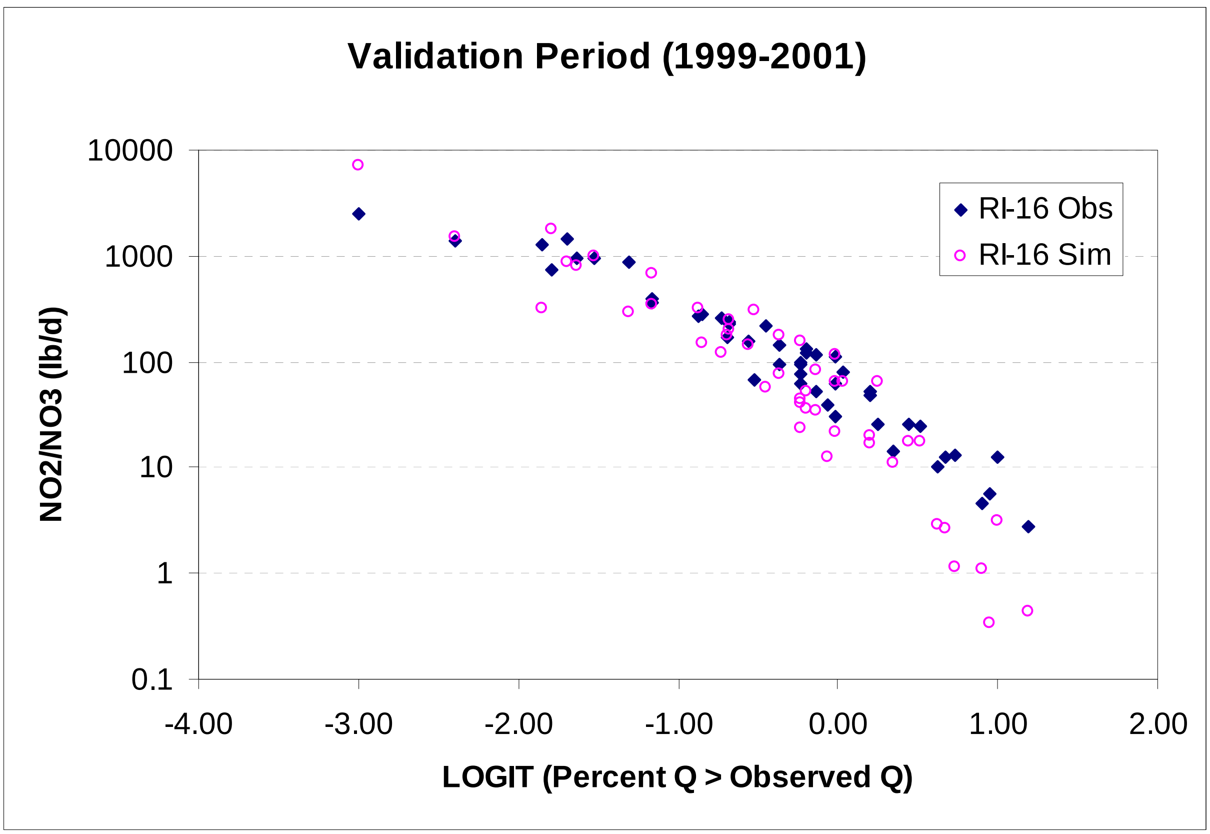
-2.402285	3.97208
0.136965	0.10411
0.884935	0.57043
307.6295	40
2.021075	
0.276817	
-2.679102	
-2.125468	

20-100% - Sim

-2.422979	3.329141
0.341864	0.259859
0.556705	1.423787
50.23334	40
2.021075	
0.690933	
-3.113913	
-1.732046	




Validation Period (1999-2001)
10000
1000
100
10
1
0.1
NO2/NO3 (lb/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-16 Obs
RI-16 Sim


Validation Period (1999-2001)
10000
1000
100
10
1
0.1
NO2/NO3 (lb/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-16 Obs
RI-16 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.150123	4.747476
0.121614	0.184888
0.864652	0.31603
89.43728	14
2.144789	
0.260837	
-1.410961	
-0.889286	

0-20% - Sim

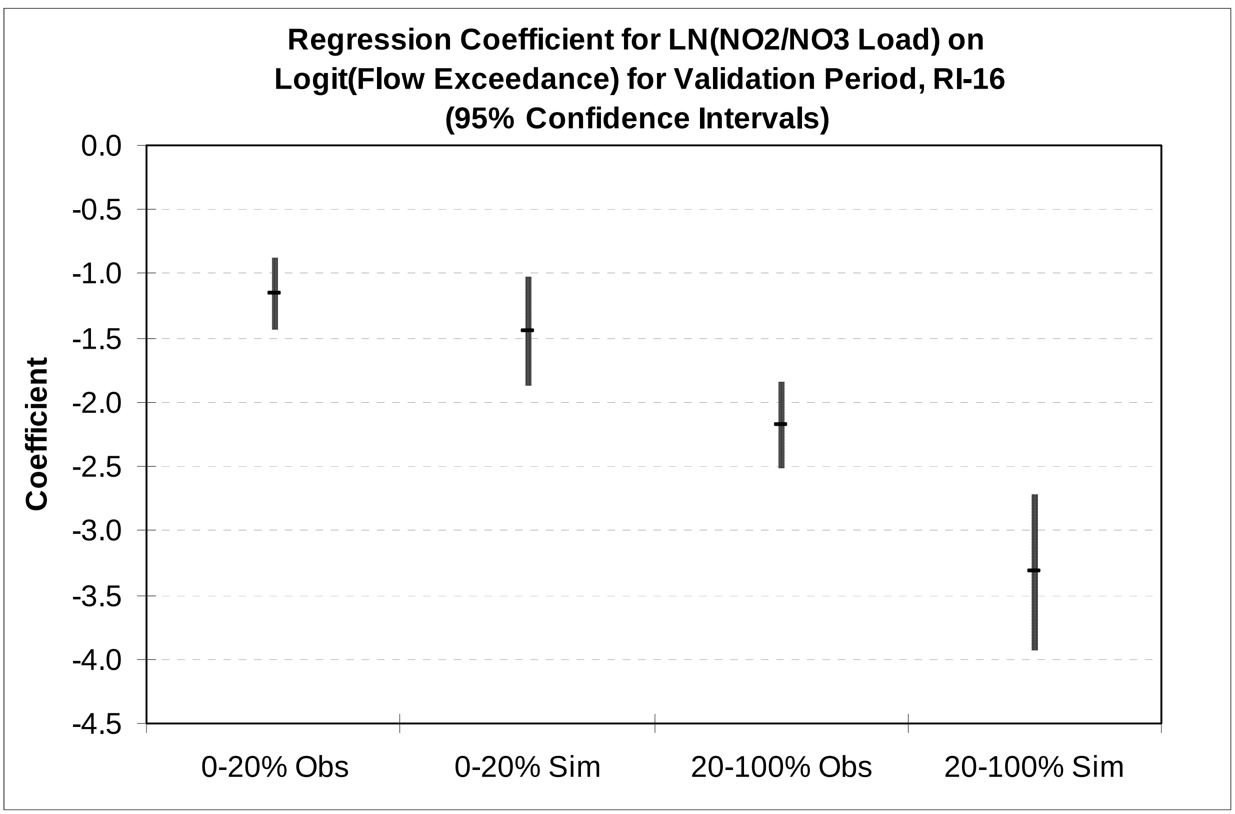
-1.452983	4.221281
0.19039	0.289447
0.806205	0.494752
58.24124	14
2.144789	
0.408347	
-1.86133	
-1.044635	

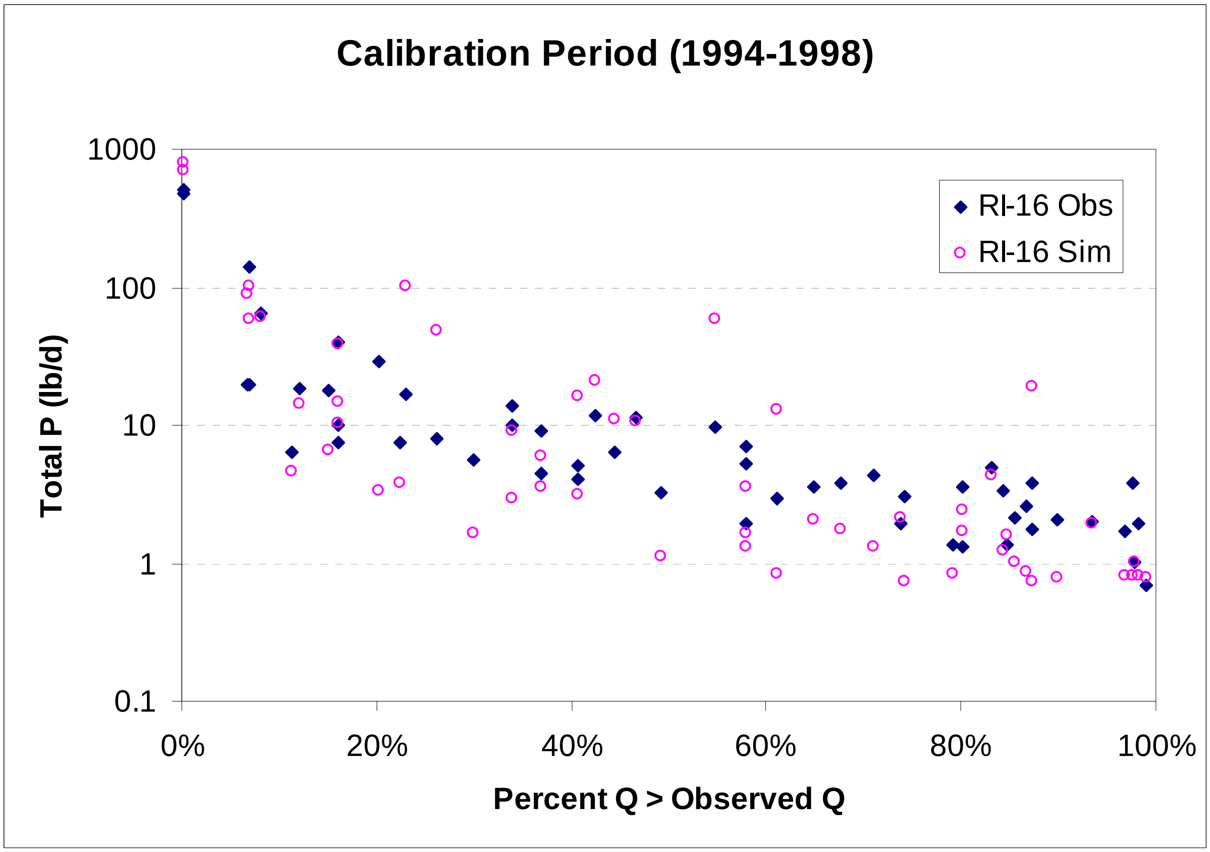
20-100% - Obs

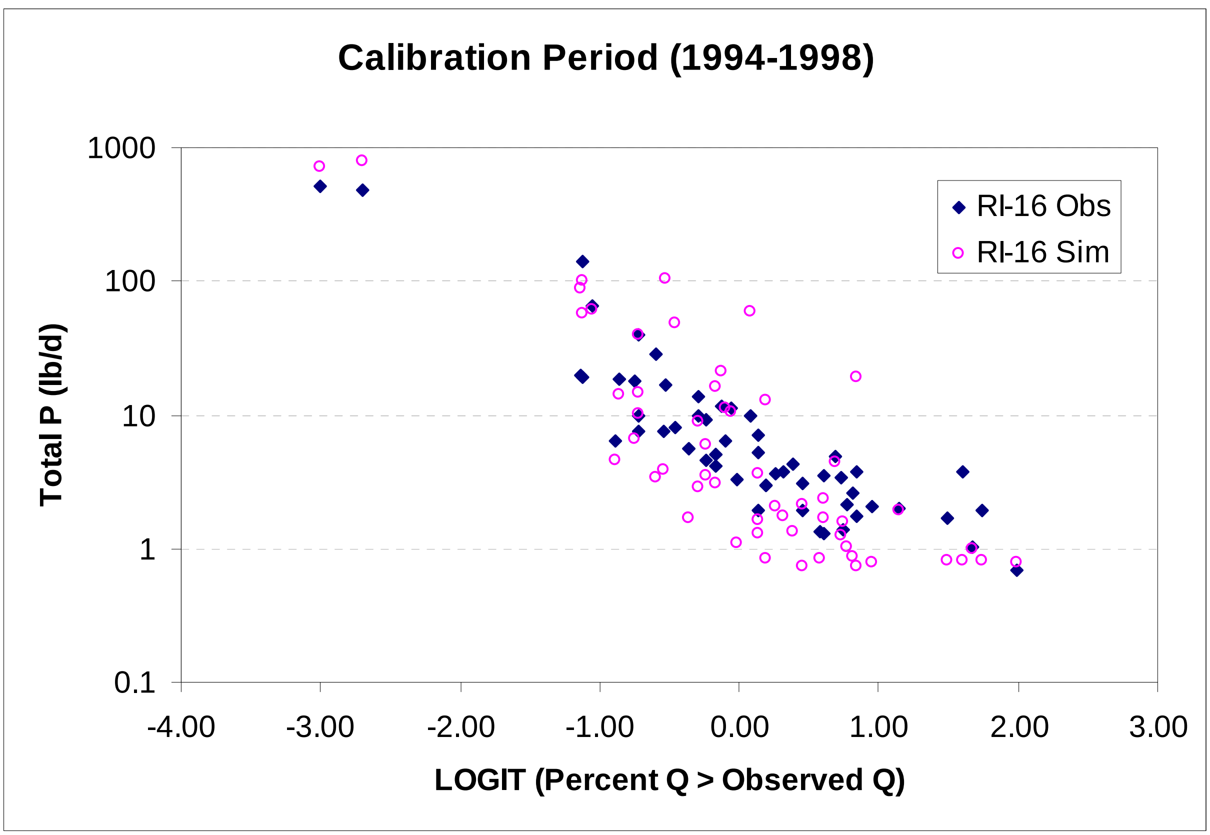
-2.173895	3.99462
0.157551	0.078001
0.867813	0.418602
190.3866	29
2.045231	
0.322228	
-2.496123	
-1.851668	

20-100% - Sim

-3.321982	3.461572
0.290395	0.143769
0.818594	0.771561
130.8628	29
2.045231	
0.593925	
-3.915907	
-2.728057	




Calibration Period (1994-1998)
Total P (lb/d)
1000
100
10
1
0.1
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-16 Obs
RI-16 Sim


Calibration Period (1994-1998)
Total P (lb/d)
1000
100
10
1
0.1
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
RI-16 Obs
RI-16 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.586384	1.700451
0.305678	0.425441
0.710017	0.808594
26.93325	11
2.200986	
0.672793	
-2.259177	
-0.913591	

0-20% - Sim

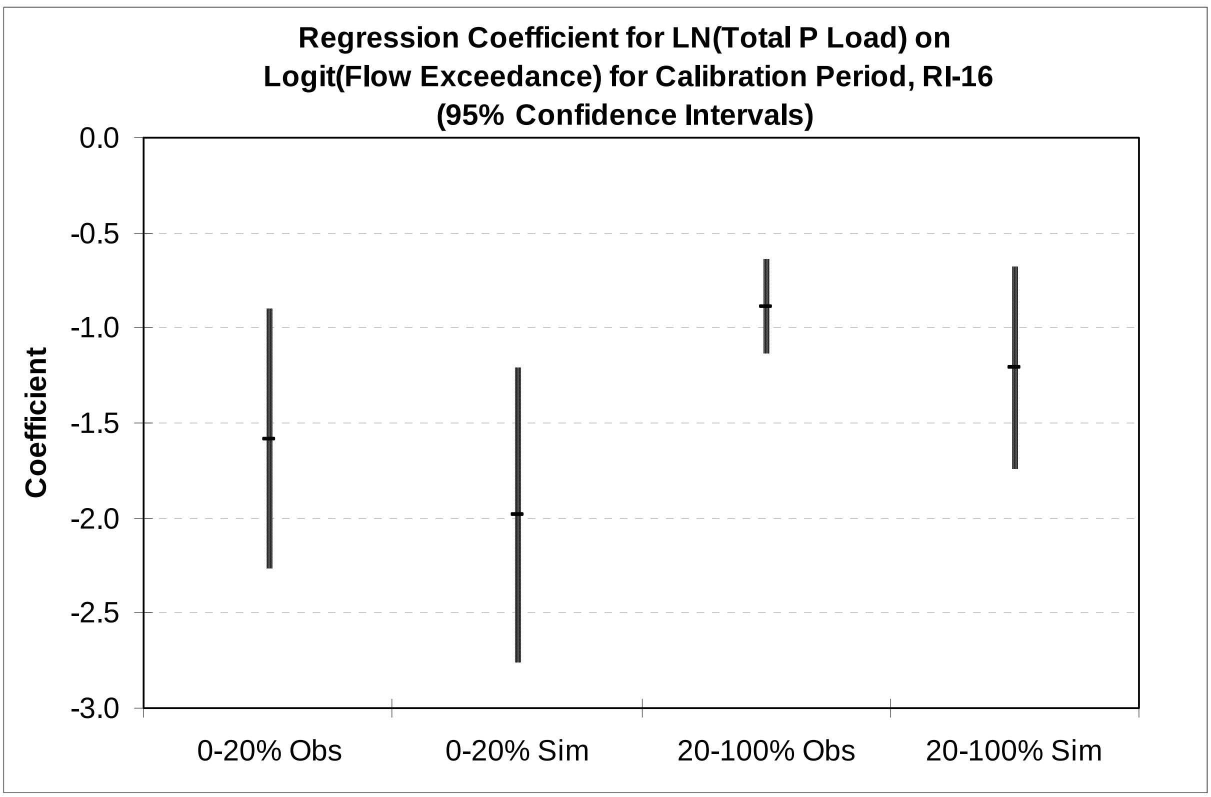
-1.986392	1.225559
0.346426	0.482154
0.749306	0.916384
32.87824	11
2.200986	
0.762479	
-2.748871	
-1.223913	

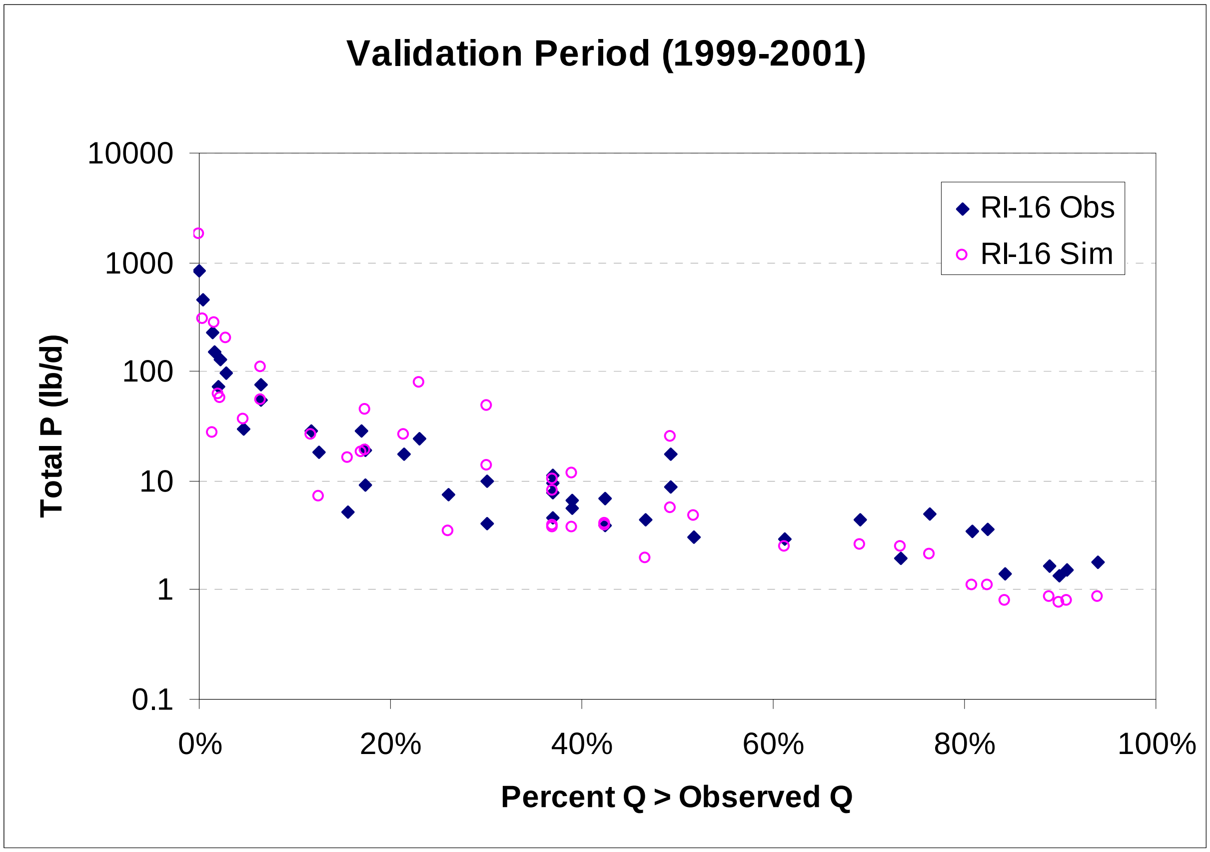
20-100% - Obs

-0.886579	1.668259
0.115729	0.087968
0.594683	0.481985
58.6881	40
2.021075	
0.233897	
-1.120476	
-0.652682	

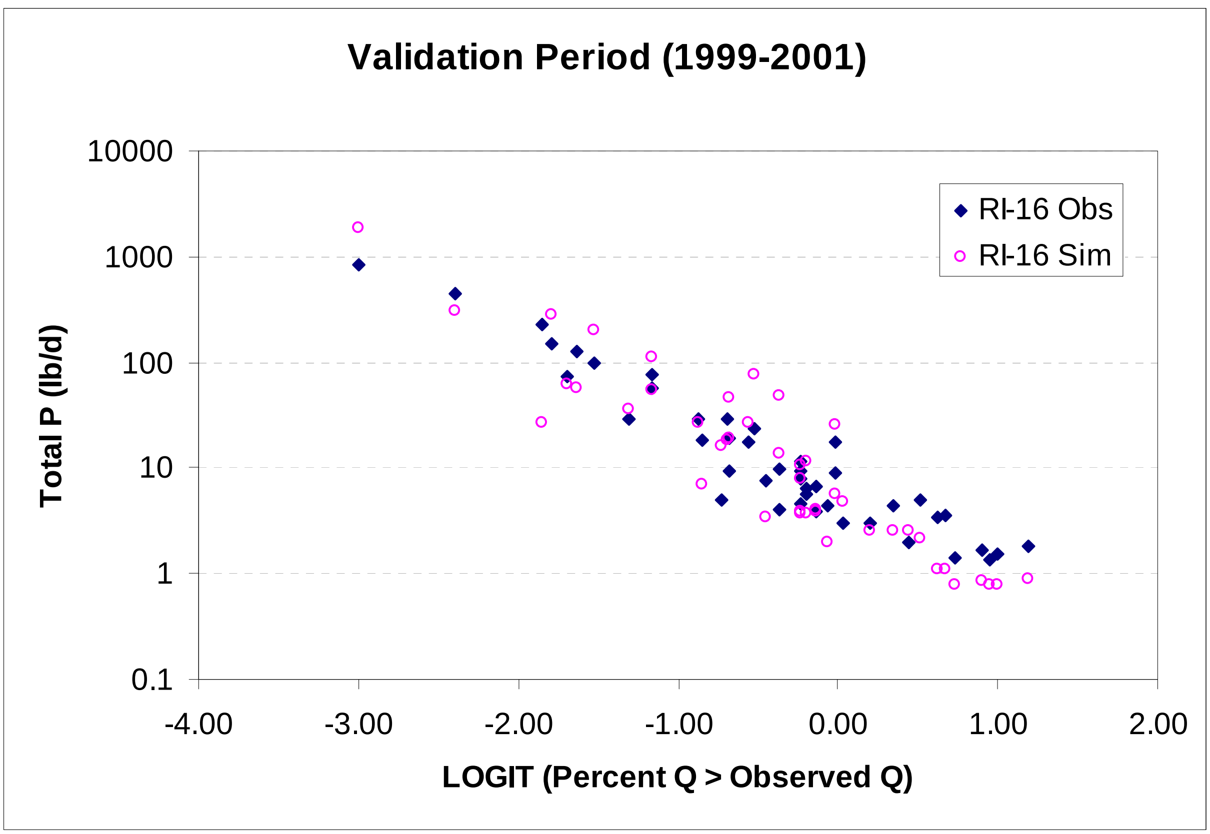
20-100% - Sim

-1.210587	1.551087
0.258329	0.196361
0.35443	1.07588
21.96075	40
2.021075	
0.522101	
-1.732688	
-0.688486	





Validation Period (1999-2001)
Total P (lb/d)
10000
1000
100
10
1
0.1
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-16 Obs
RI-16 Sim



Validation Period (1999-2001)
Total P (lb/d)
10000
1000
100
10
1
0.1
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-16 Obs
RI-16 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.90433	1.450947
0.201851	0.306871
0.864086	0.524534
89.00628	14
2.144789	
0.432928	
-2.33725	
-1.4714	

0-20% - Sim

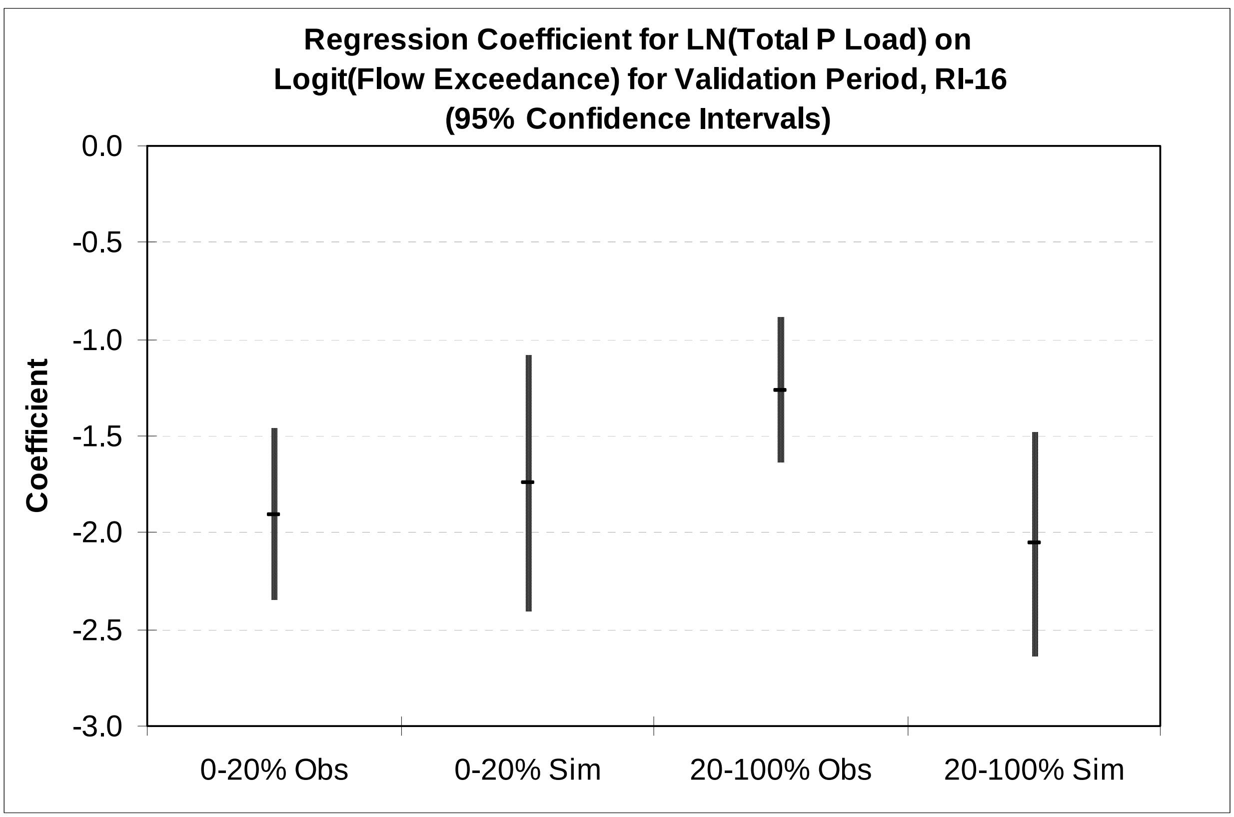
-1.74516	1.702022
0.303412	0.461272
0.702653	0.788453
33.08297	14
2.144789	
0.650755	
-2.39592	
-1.09441	

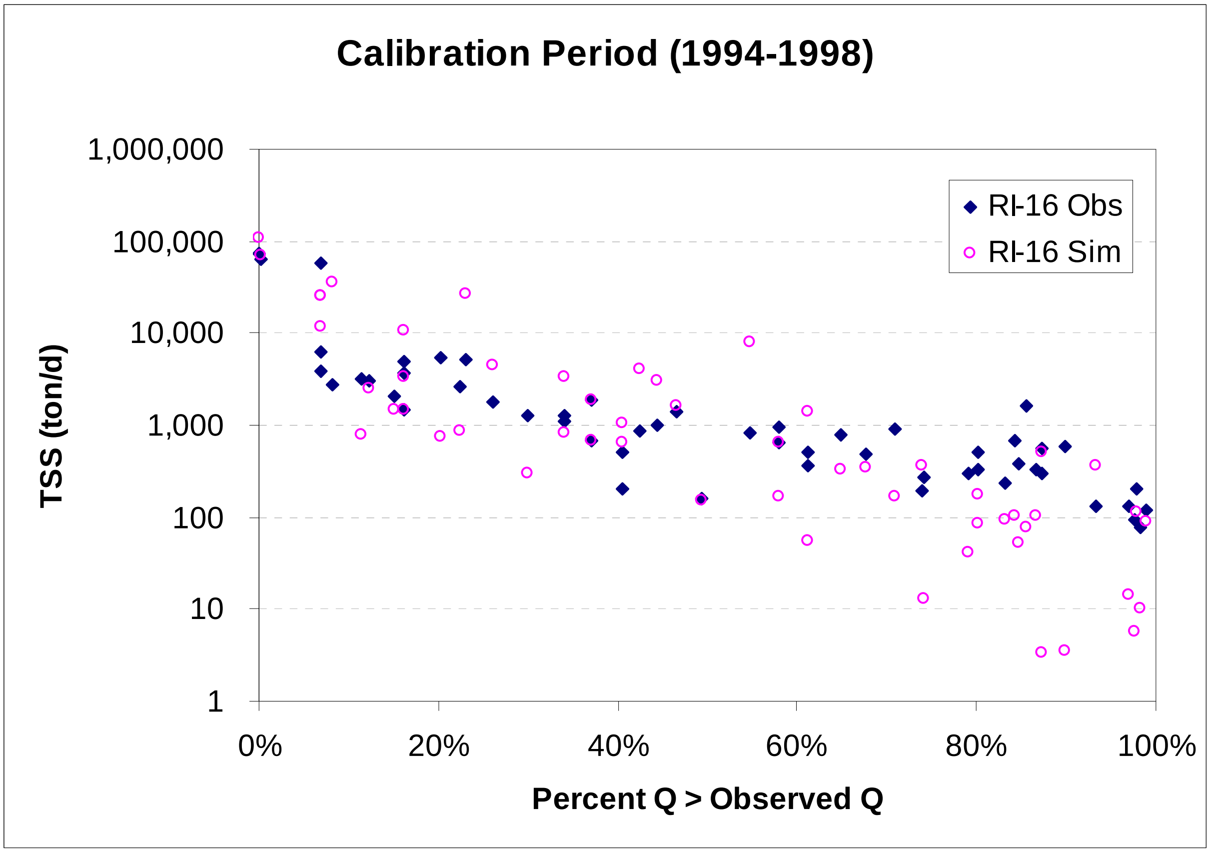
20-100% - Obs

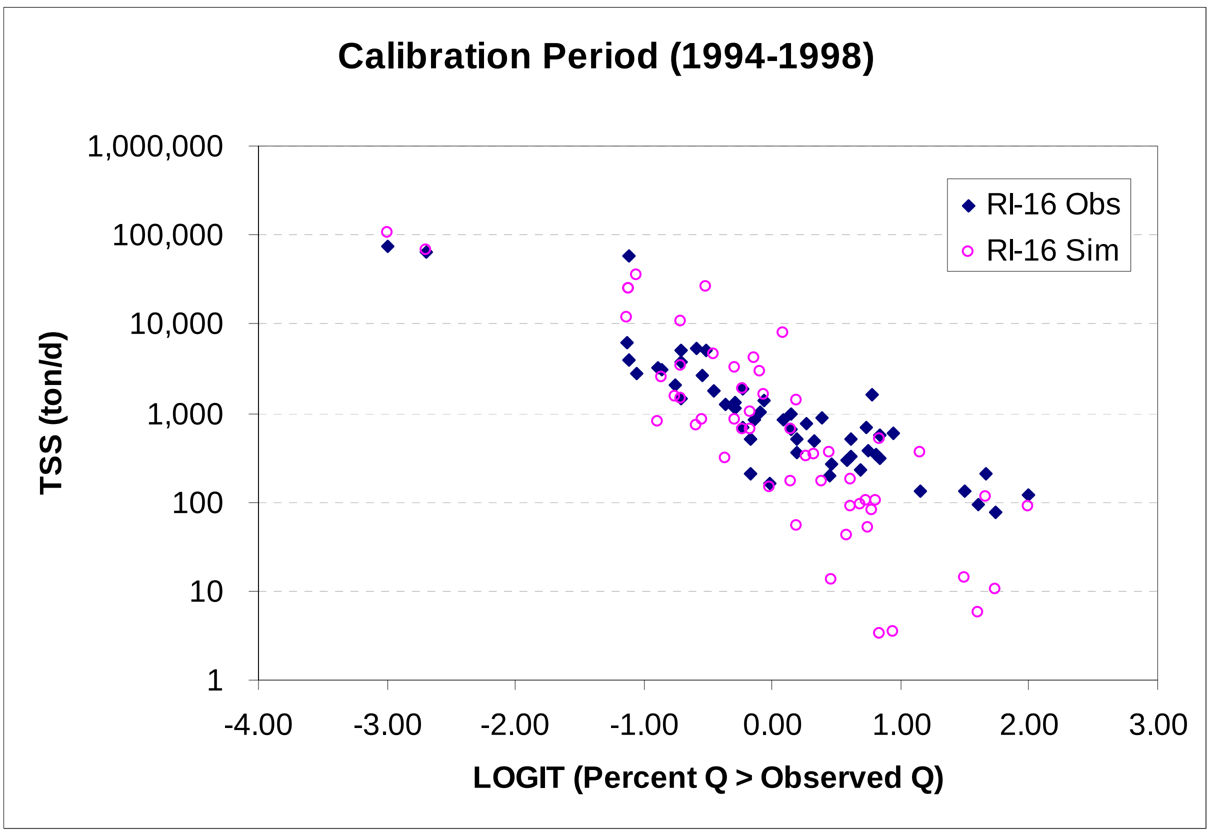
-1.26225	1.737286
0.176054	0.091084
0.664101	0.466438
51.40426	26
2.055531	
0.361885	
-1.62414	
-0.90037	

20-100% - Sim

-2.0586	1.659094
0.276684	0.143146
0.680424	0.733044
55.35783	26
2.055531	
0.568732	
-2.62734	
-1.48987	




Calibration Period (1994-1998)
RI-16 Obs
RI-16 Sim
1,000,000
100,000
10,000
1,000
100
10
1
TSS (ton/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q


Calibration Period (1994-1998)
RI-16 Obs
RI-16 Sim
1,000,000
100,000
10,000
1,000
100
10
1
TSS (ton/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.431969	7.117482
0.312365	0.434749
0.656417	0.826284
21.0156	11
2.200986	
0.687511	
-2.11948	
-0.744457	

0-20% - Sim

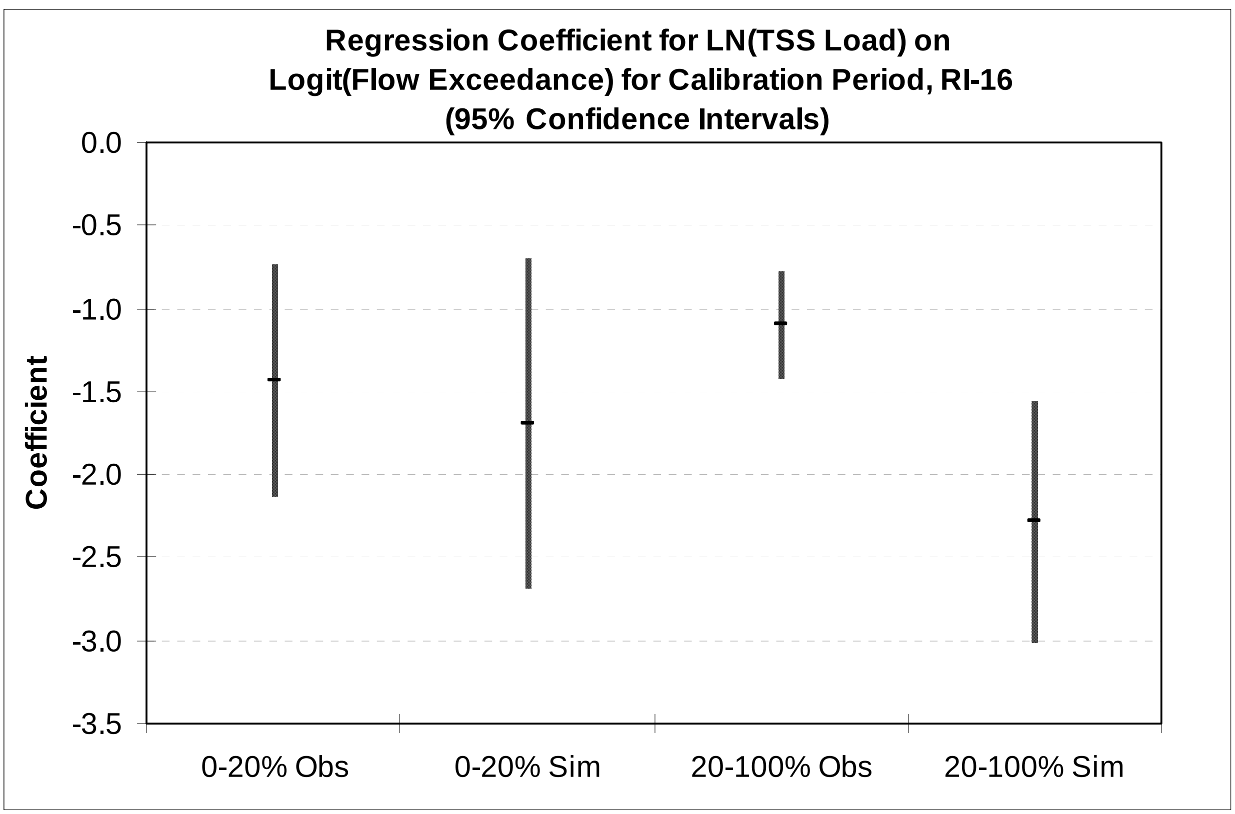
-1.693488	6.916209
0.444933	0.619256
0.568405	1.17696
14.48687	11
2.200986	
0.979292	
-2.67278	
-0.714196	

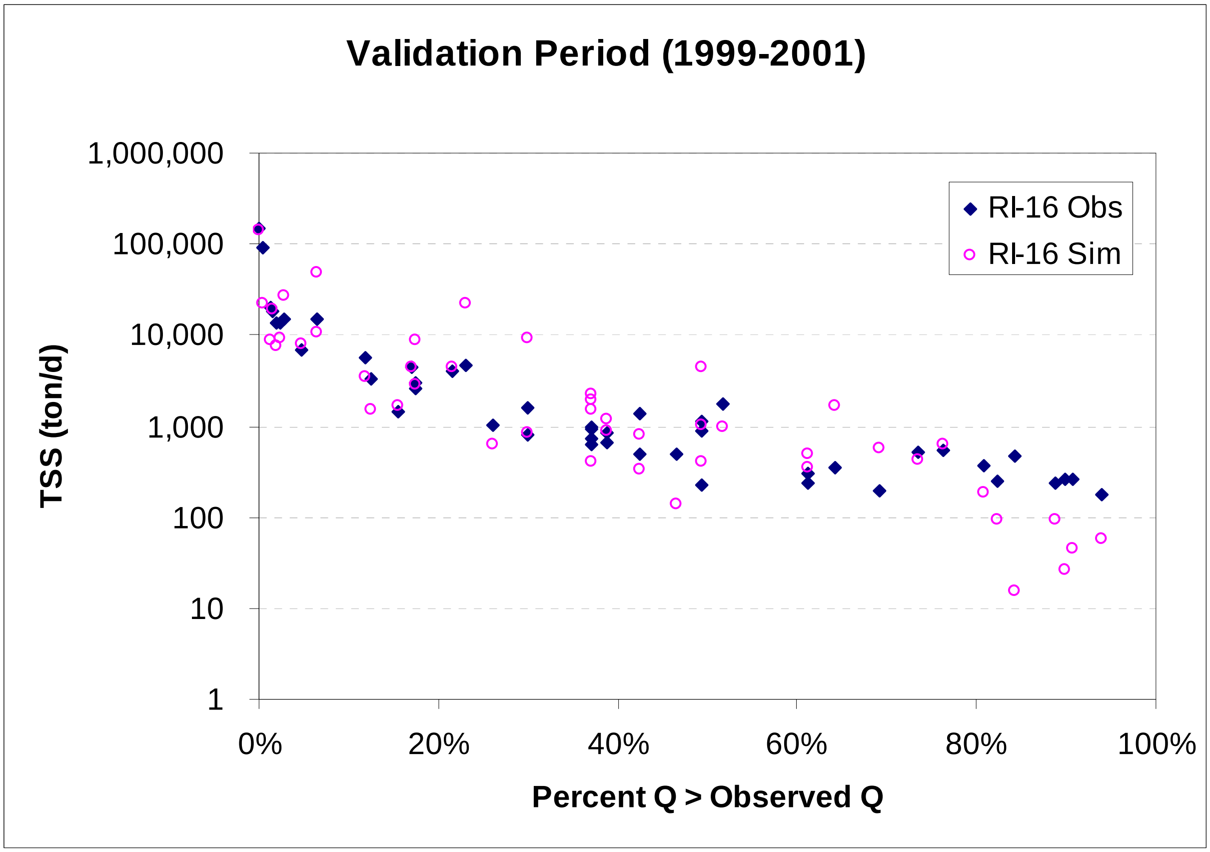
20-100% - Obs

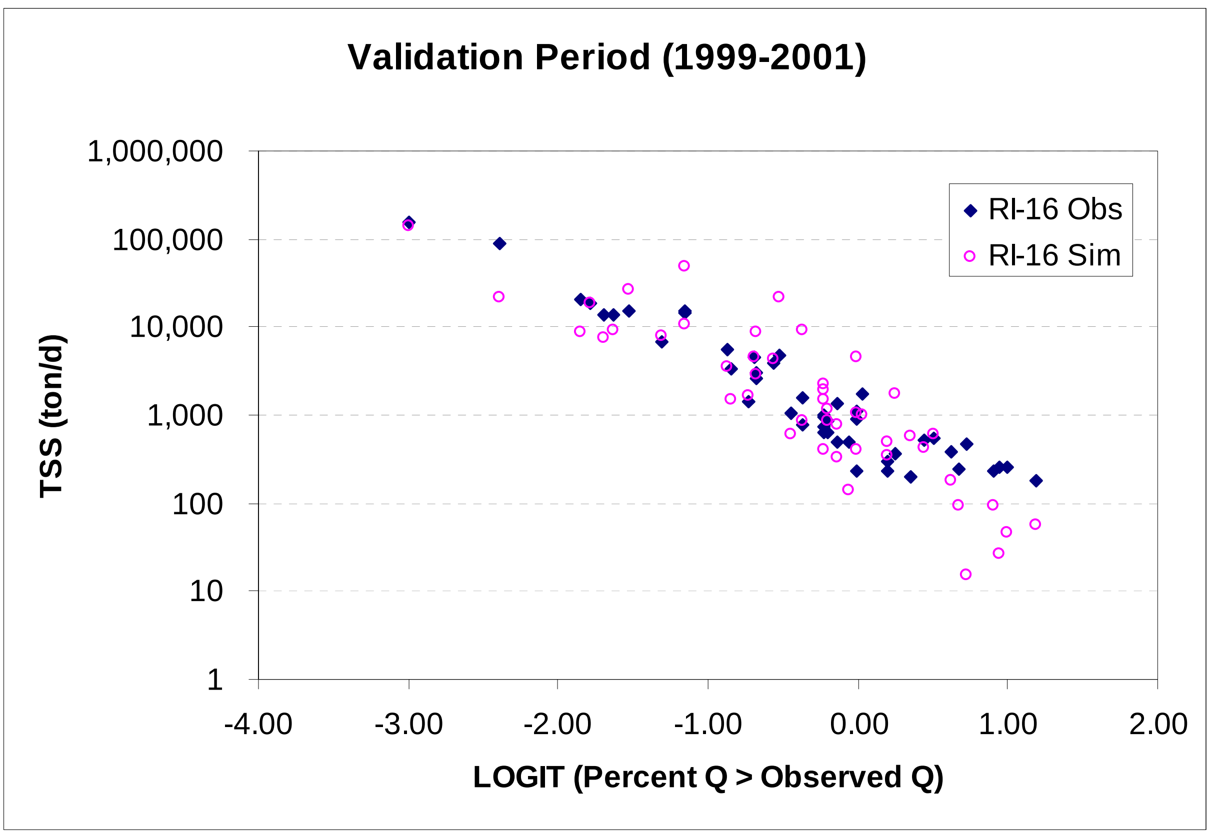
-1.10039	6.684572
0.151671	0.116639
0.574405	0.630358
52.63637	39
2.022689	
0.306784	
-1.407174	
-0.793606	

20-100% - Sim

-2.284906	6.435704
0.355586	0.273454
0.514262	1.477843
41.29021	39
2.022689	
0.71924	
-3.004146	
-1.565666	




Validation Period (1999-2001)
1,000,000
100,000
10,000
1,000
100
10
1
TSS (ton/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-16 Obs
RI-16 Sim


Validation Period (1999-2001)
1,000,000
100,000
10,000
1,000
100
10
1
TSS (ton/d)
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RI-16 Obs
RI-16 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.750115	6.849669
0.164633	0.250289
0.889769	0.427818
113.0055	14
2.144789	
0.353103	
-2.103218	
-1.397012	

0-20% - Sim

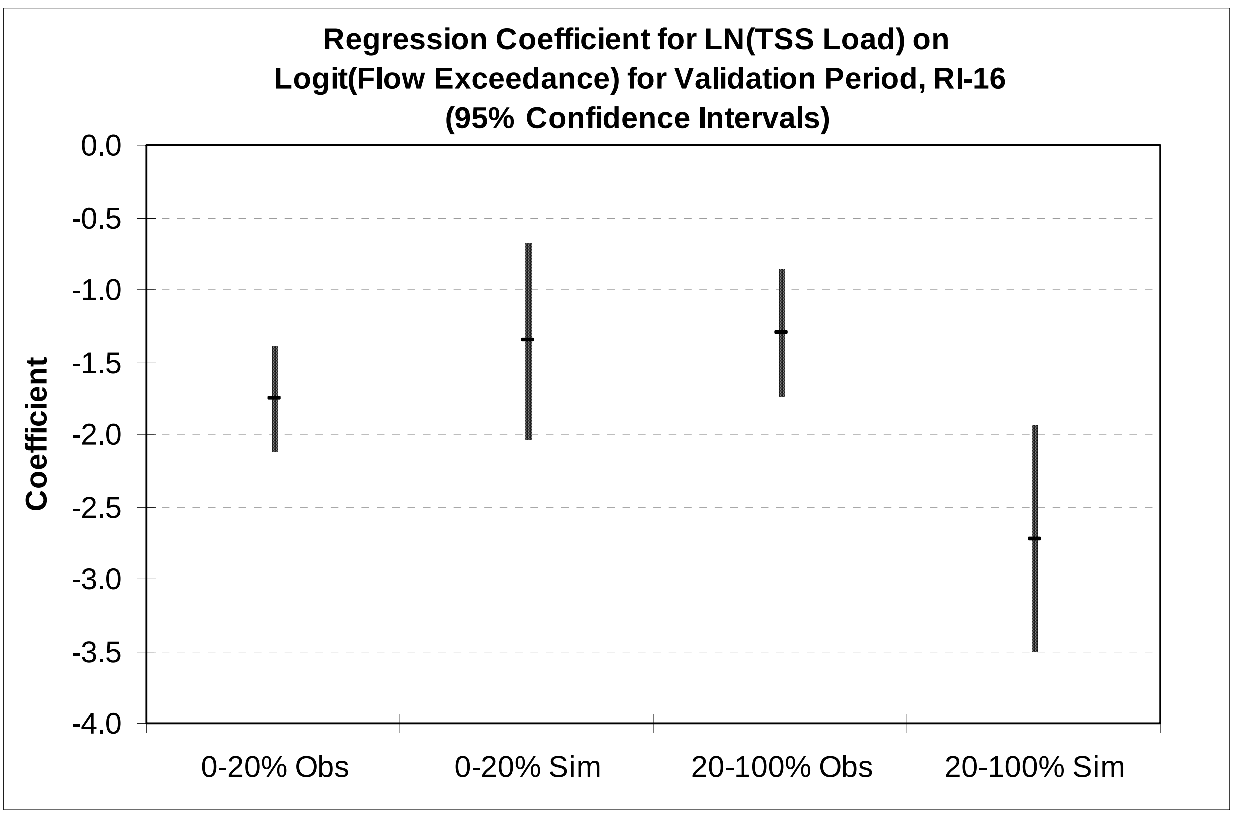
-1.35507	7.293046
0.31179	0.47401
0.574319	0.810224
18.8885	14
2.144789	
0.668724	
-2.02379	
-0.68634	

20-100% - Obs

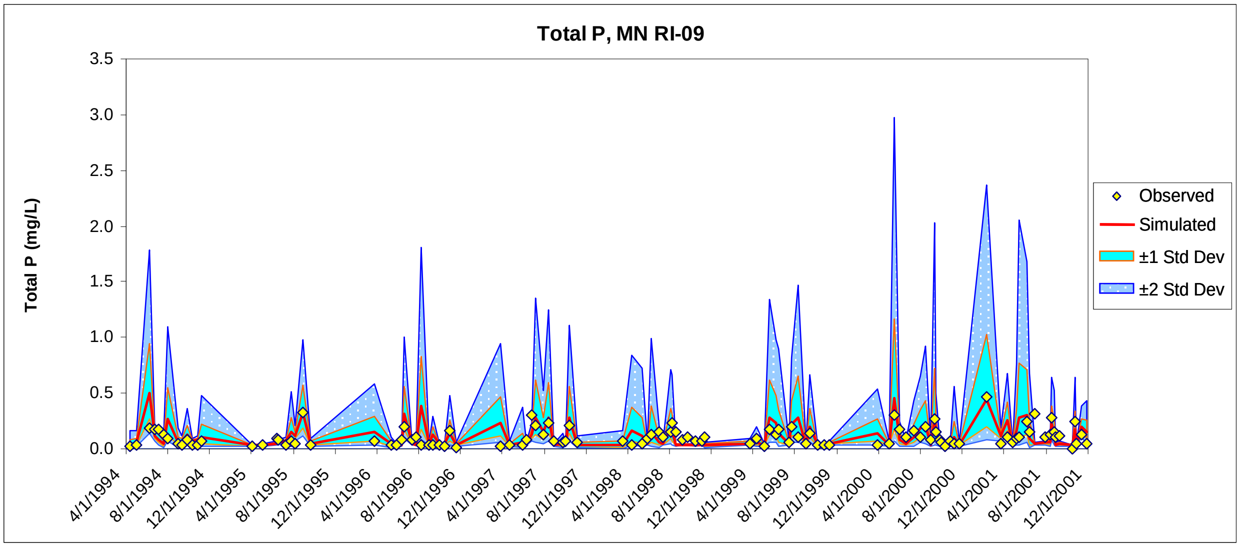
-1.301795	6.568202
0.208658	0.103303
0.573051	0.554391
38.92374	29
2.045231	
0.426754	
-1.728549	
-0.875041	

20-100% - Sim

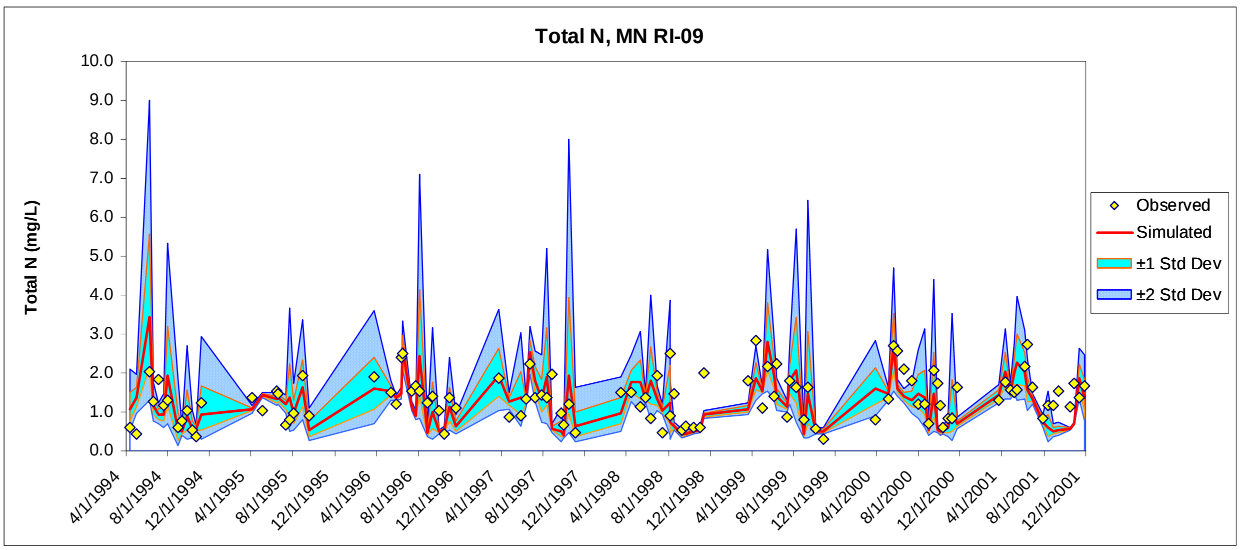
-2.72166	6.656046
0.375767	0.186036
0.643998	0.99839
52.46011	29
2.045231	
0.768531	
-3.49019	
-1.95313	



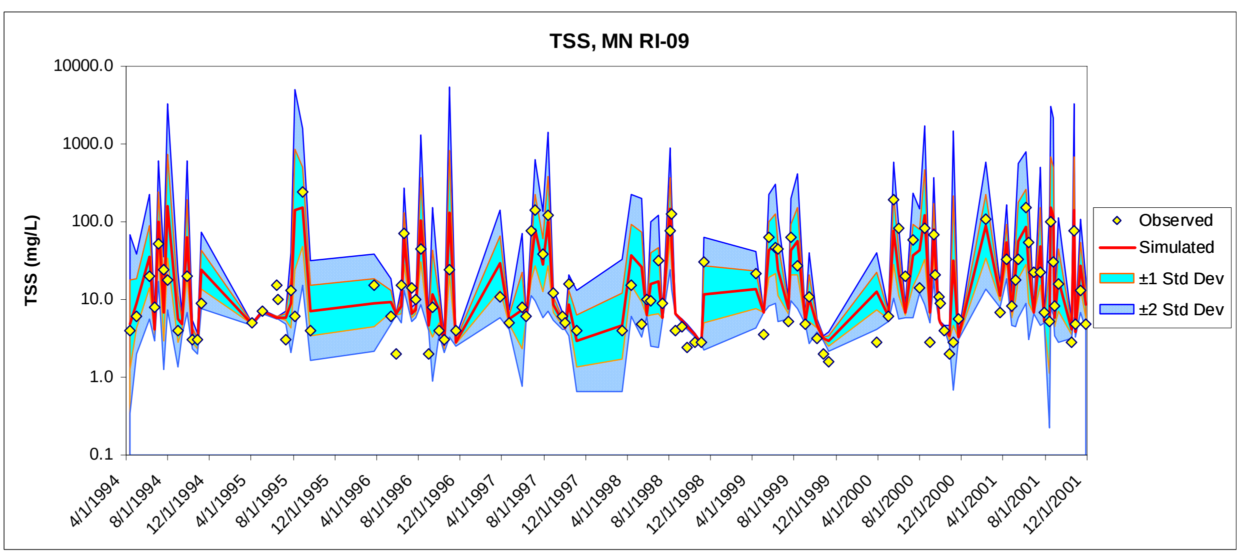
ATTACHMENT C – CONTROL CHARTS



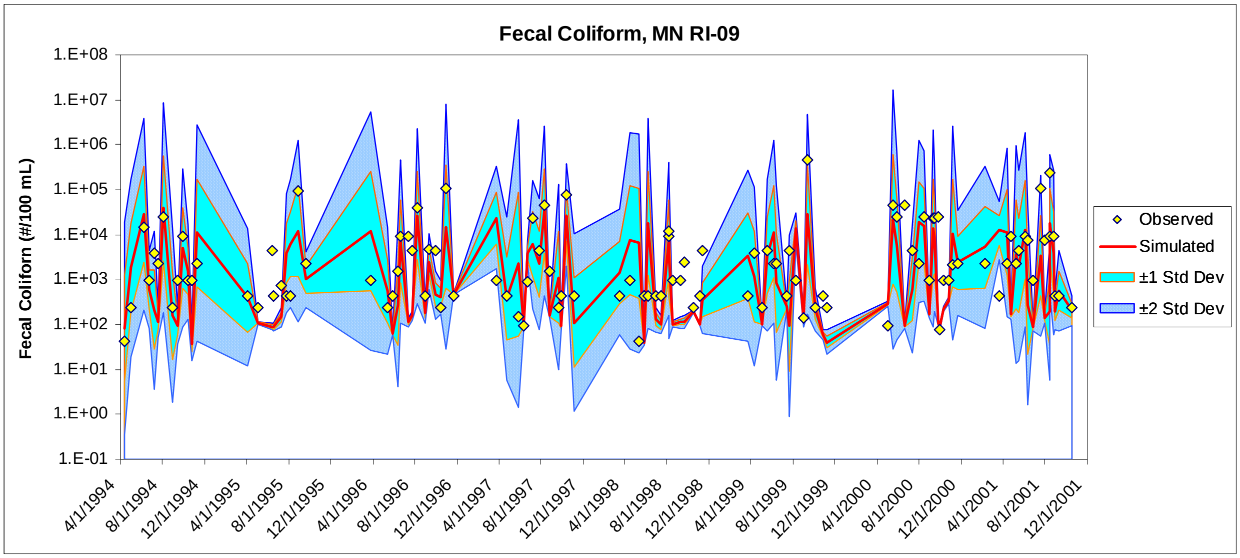
Total P, MN RI-09
Total P (mg/L)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

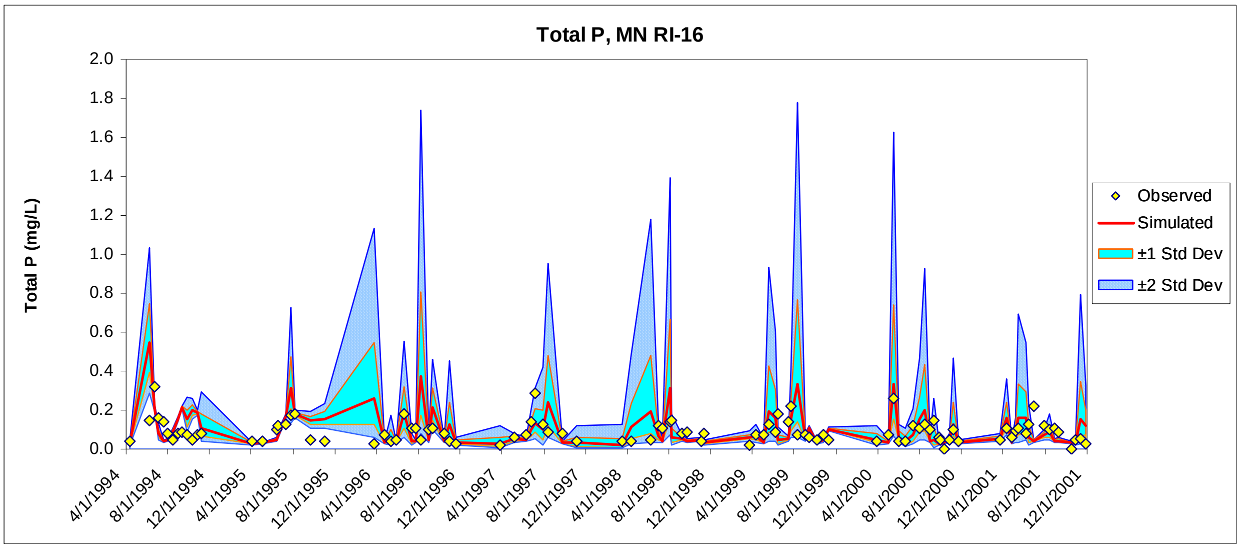


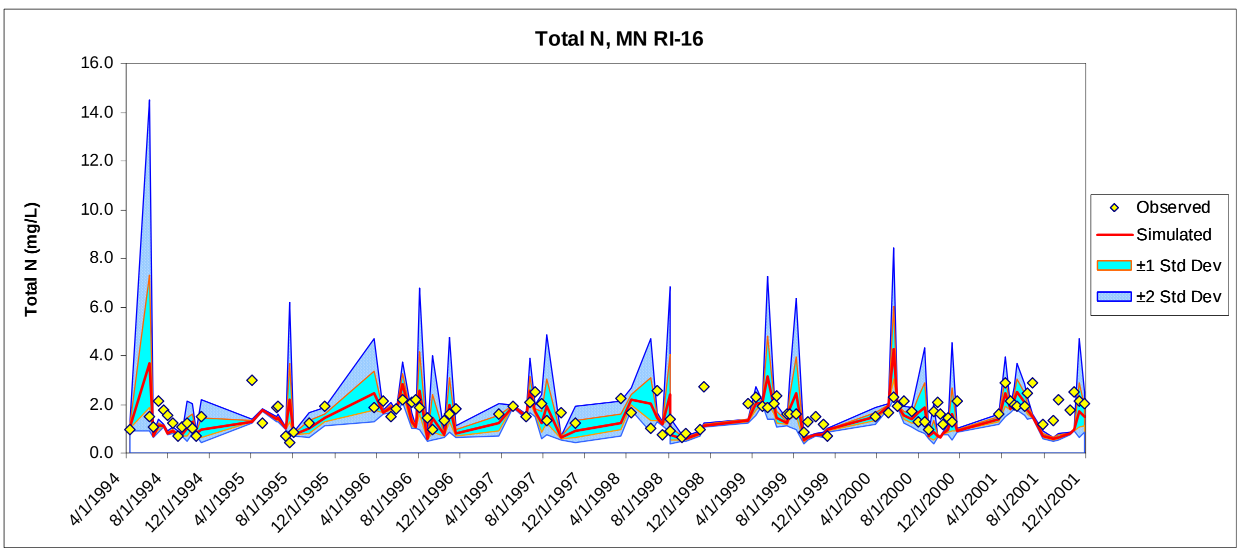
Total N, MN RI-09
Total N (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

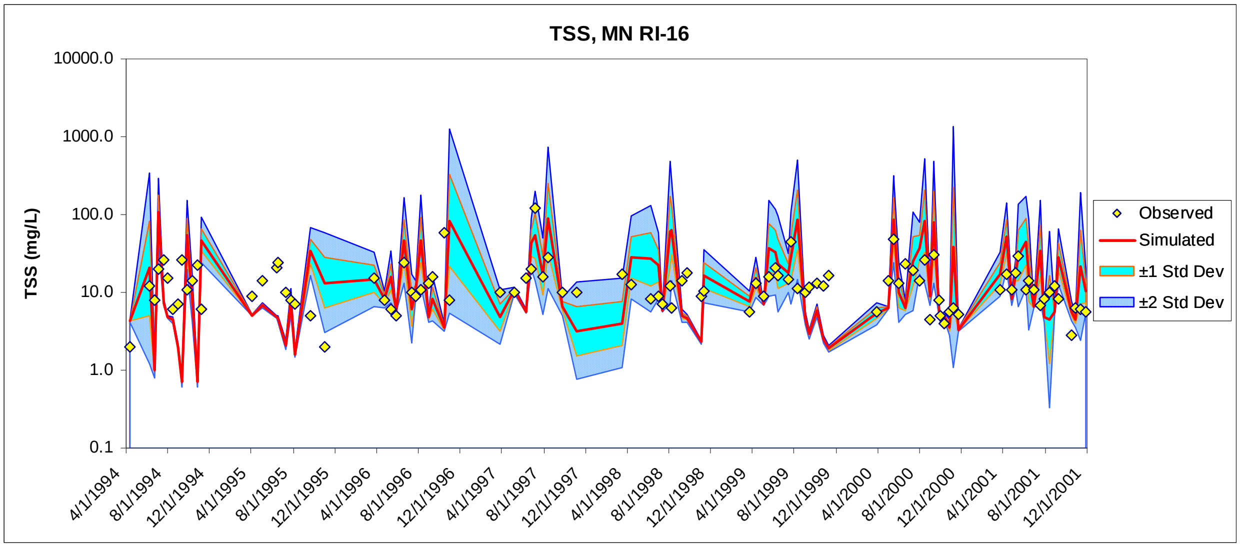


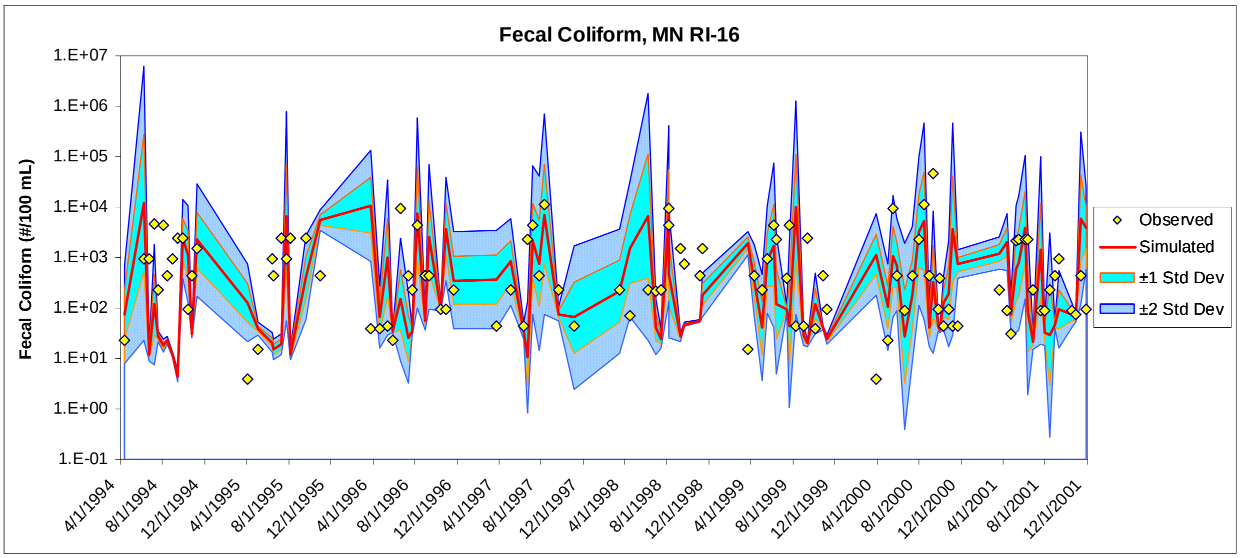
TSS, MN RI-09
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

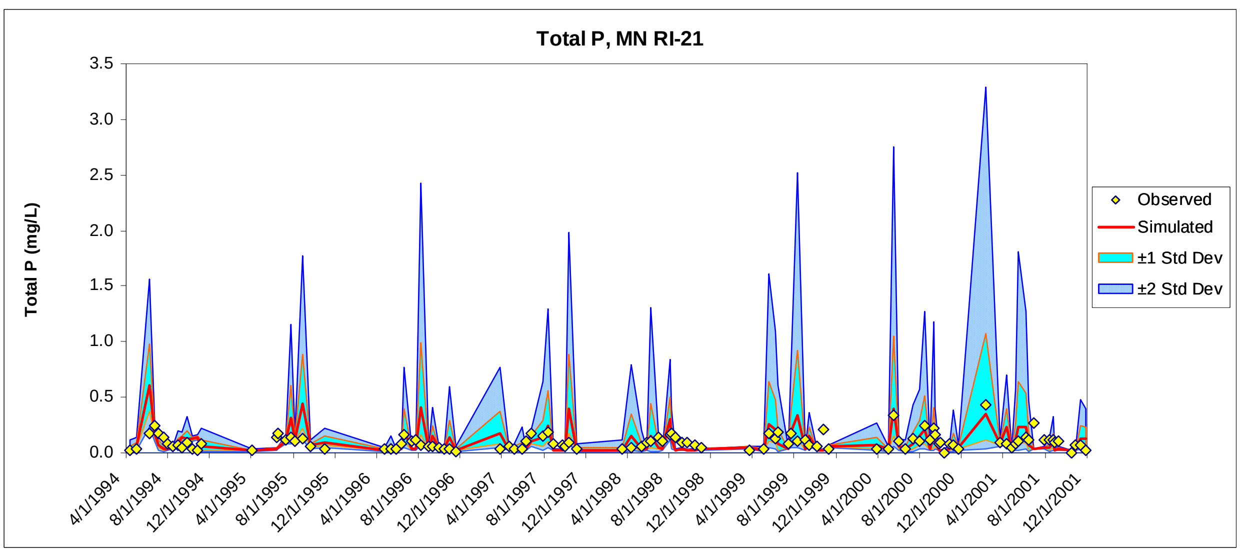

Fecal Coliform, MN RI-09
Fecal Coliform (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

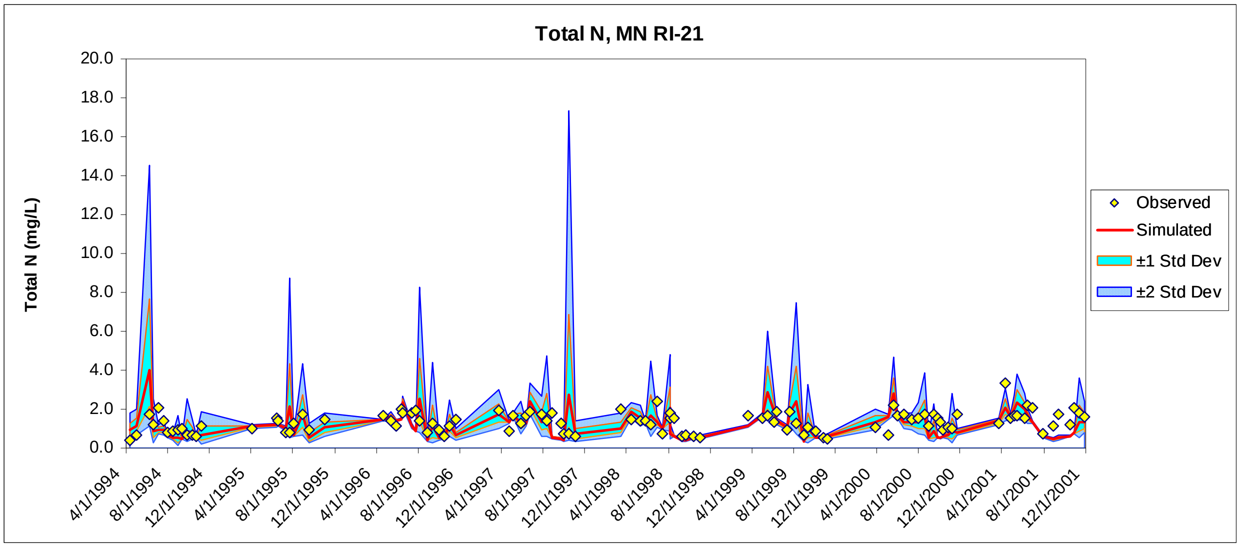

Total P, MN RI-16
Total P (mg/L)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

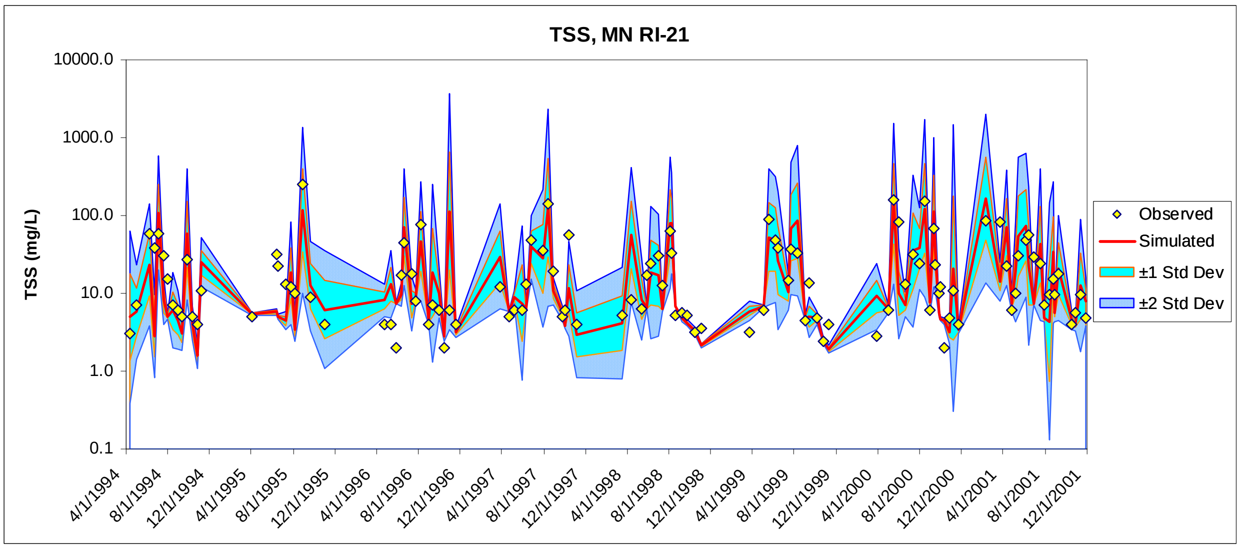

Total N, MN RI-16
Total N (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

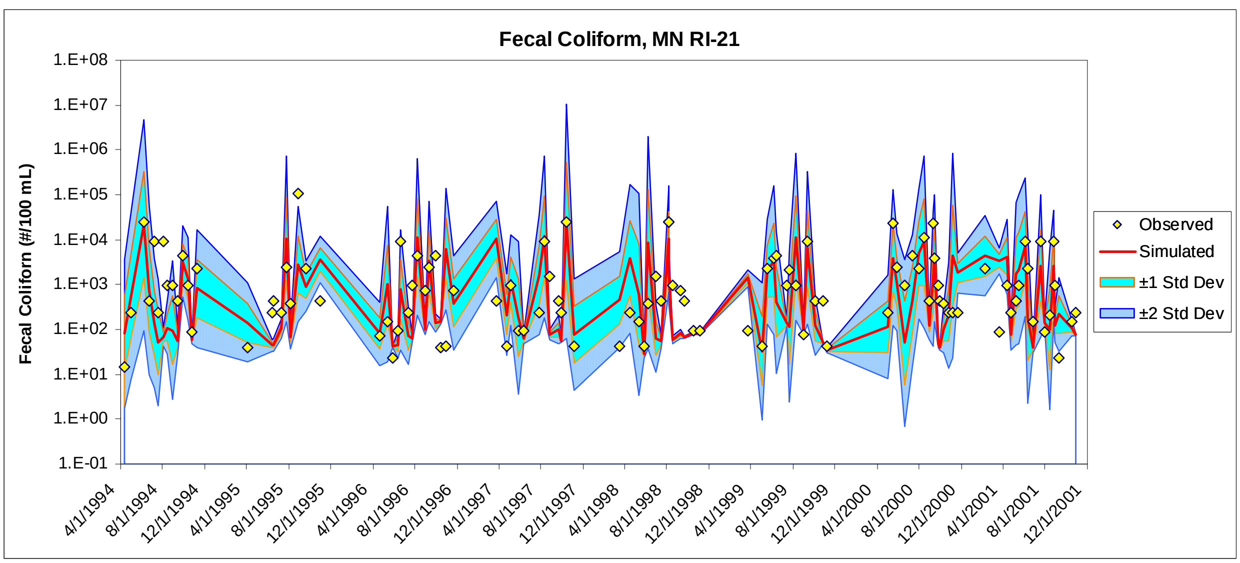

TSS, MN RI-16
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

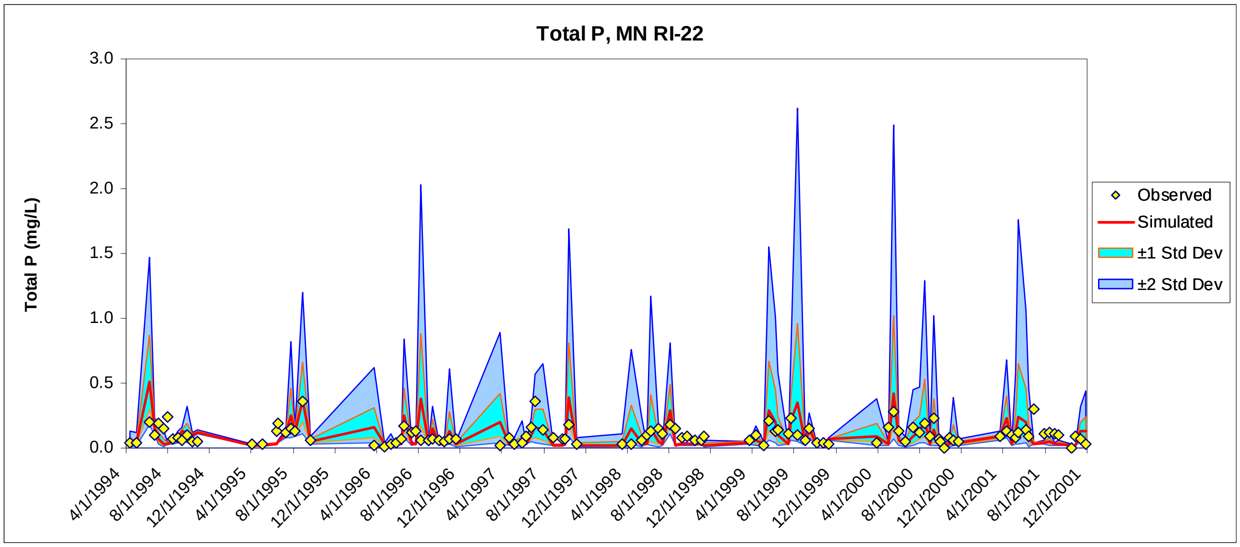

Fecal Coliform, MN RI-16
Fecal Coliform (#/100 mL)
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

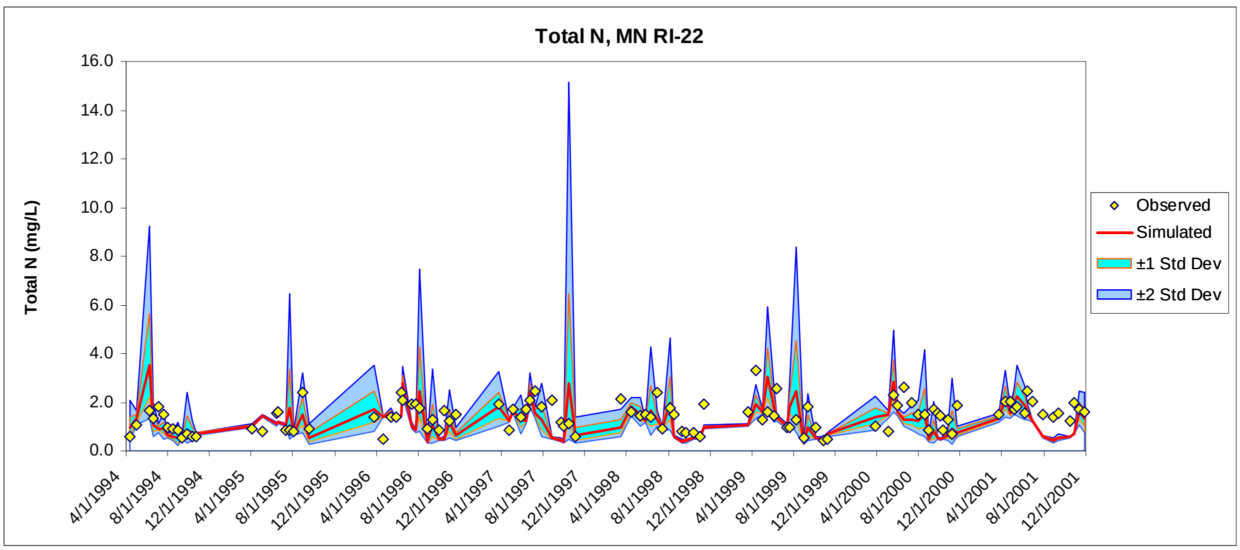

Total P, MN RI-21
Total P (mg/L)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

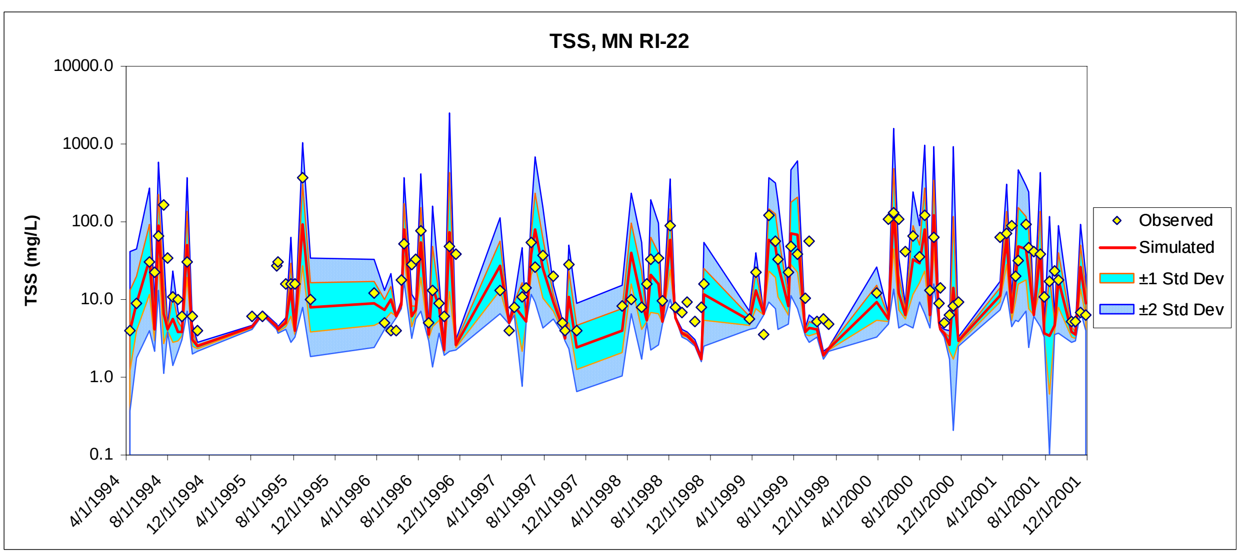

Total N, MN RI-21
Total N (mg/L)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

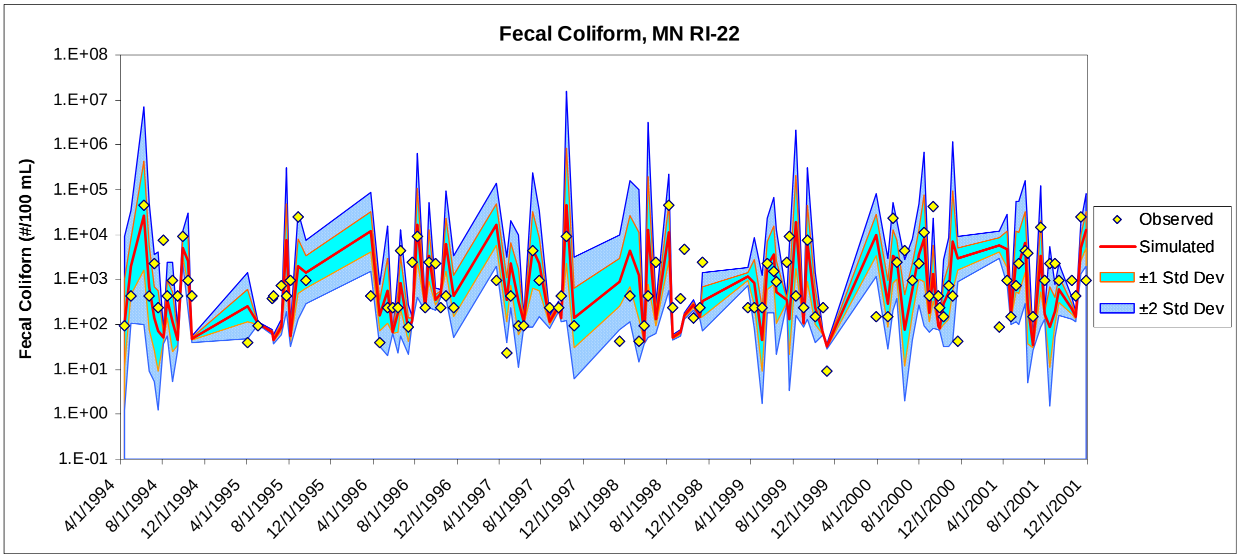

TSS, MN RI-21
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Fecal Coliform, MN RI-21
Fecal Coliform (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Total P, MN RI-22
Total P (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Total N, MN RI-22
Total N (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


TSS, MN RI-22
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Fecal Coliform, MN RI-22
Fecal Coliform (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

2020 Facility Planning Project

Final Memorandum

Project Name:	MMSD – 2020 Facility Planning Project	MMSD Contract No:	M03002P01
DMS Folder Name:	Technology Analysis	MMSD File Code:	M009PE000.P7300-WQ1
Document Name:	Water Quality Calibration and Validation Results for the Milwaukee River Model (Task 4)	HNTB Charge No:	34568-PL-400-115

Date: February 29, 2008
To: Michael Hahn, SEWRPC
Bill Krill, HNTB
From: Leslie Shoemaker, Tetra Tech, Inc.
Subject: Water Quality Calibration and Validation Results for the Milwaukee River Model (Task 4)

1.0 EXECUTIVE SUMMARY

An important component of the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU) is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. The purpose of this memorandum is to describe the modeling process and provide results of the water quality calibration and validation of the Milwaukee River watershed model.

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for a variety of reasons, including that existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds. The Loading Simulation Program in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms but has the advantage of no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original HSPF models for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds have been migrated to LSPC and the Milwaukee River model has been developed within LSPC for the 2020 Facilities Planning Project[1].

Calibration of LSPC followed a sequential, hierarchical process that begins with hydrology, followed by sediment erosion and transport, and, finally, calibration of chemical water quality. The original hydrologic calibration for the Milwaukee River watershed model is described in the memorandum entitled *Draft Hydrologic Calibration and Validation Results for the Milwaukee River Model*. A revised hydrologic calibration, described in the memorandum entitled *Revised Draft Hydrologic Calibration and Validation Results for the Milwaukee River Model* (May 12, 2006), addressed various comments provided by SEWRPC. This memorandum provides the results of the water quality calibration that are consistent with the revised hydrologic calibration.

2.0 CONCLUSIONS

Water quality calibration for the Milwaukee River relied on comparison of model predictions to observed concentrations at 11 water quality sampling sites located along the Milwaukee River and several tributaries. Predicted loads were compared at two modeling reaches where both flow and concentration data were available. Achieving water quality calibration involves adjusting many parameters that interact with one another. The upland model represents expected loading associated with runoff events from specified land uses, but cannot represent unusual events that are outside the scope of events simulated in the model (for

[1] The only previous HSPF model within the Milwaukee River watershed was for Brown Deer Park Creek, a tributary to the Milwaukee River.

instance, discharge or breach of a waste lagoon). In addition, observed data – which consist of point in time and point in space measurements – may not be fully representative of conditions in the waterbody, and may also be subject to analytical uncertainty. The model provides an estimate of average conditions across the stream width and depth as a result of known upland sources. For this application, the long-term average loading from these upland sources has been constrained to be consistent with results from SWAT modeling of agriculture and SLAMM modeling of loading from urban land uses. Fit between model and observations is best judged graphically and statistically; the model should represent the central tendency and trends seen in observations, but may not replicate all individual observations. Model fit for water quality is thus evaluated in three ways: (1) through graphical comparison of simulated and observed data, (2) through statistical tests on the equivalence of means on paired observed and simulated concentration data, and (3) through evaluation of the ability of the model to represent apparent observed load delivery rates. A single set of parameter values (by land cover) is specified throughout the watershed; thus, the ability of the model to replicate differences in concentrations between different sample points is as important as the ability to match concentrations at individual sites.

In general, the water quality calibration attains a good fit to observations, with some discrepancies for individual parameters at individual locations. The quality of fit is sufficiently good that the model is judged ready for application to management scenarios; however, further effort and fine-tuning can always further improve the quality of fit.

3.0 RECOMMENDATIONS

We recommend that the water quality calibration and validation of the Milwaukee River model be considered complete.

4.0 INTRODUCTION

The Milwaukee Metropolitan Sewerage District (MMSD) is in the midst of a long-range planning effort to identify improvements needed for its facilities to accommodate growth and protect water quality through the year 2020. This effort is known as the MMSD 2020 Facility Plan. A related planning effort is being conducted by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) to update the regional water quality management plan for the Kinnickinnic River, Menomonee River, Milwaukee River, Root River, and Oak Creek watersheds, the Milwaukee Harbor estuary, and the adjacent nearshore Lake Michigan area. This effort is known as the Regional Water Quality Management Plan Update (RWQMPU). The two planning efforts are being coordinated and implemented in parallel.

One important component of both the 2020 Facility Plan and the RWQMPU is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. Watershed models are being developed for the following five watersheds:

- Kinnickinnic River
- Menomonee River
- Milwaukee River
- Oak Creek
- Root River

The Kinnickinnic, Menomonee, Milwaukee River and Oak Creek models are linked to a model of the Lake Michigan estuary so that the benefits of upstream water quality improvements can be simulated by the Lake Michigan Harbor / Estuary Model.

The following seven tasks have been identified for performing the system modeling:

1) Establish the model structure, including the delineation of subwatersheds, connectivity, and cross sections, etc.
2) Develop the model data sets using physical measurements, maps, and other appropriate information
3) Perform hydrologic and hydraulic calibration and validation
4) Perform watercourse water quality calibration and validation
5) Perform harbor/estuary and lake water quality calibration
6) Perform production runs as required for project planning
7) Document results.

Tasks 1, 2, and 3 have already been completed for the Milwaukee River watershed model. The purpose of this report is to document the watercourse water quality calibration and validation for the Milwaukee River watershed model (Task 4). The modeling approach and results, by parameter, are presented below.

5.0 MODELING APPROACH AND RESULTS

The calibration process for LSPC is sequential, beginning with the calibration of flow (refer to the *Revised Draft Hydrologic Calibration and Validation Results for the Milwaukee River Model*). Sediment and dissolved pollutant transport depend directly on the representation of flow, while sorbed pollutant transport depends on the simulation of sediment. (In the model, sorption to sediment within stream reaches is currently simulated for phosphorus, ammonium, and bacteria.) The implementation of the model represents pollutant loading from the land surface by buildup-washoff formulations (independent of erosion); however, sorption to sediment and settling is simulated in the stream reaches and has an important effect on the downstream transport of particle-reactive pollutants including phosphorus, ammonium, and bacteria. Thus, any inaccuracies in the flow and sediment simulation will propagate forward into the water quality simulation, and the accuracy of the hydrologic simulation provides an inherent limitation on the potential accuracy of the water quality simulation.

Instream water quality kinetics are also highly linked with one another. For instance most kinetic rates depend on temperature, while nutrient balances and dissolved oxygen are strongly linked to the algal simulation. Accordingly, the water quality calibration uses the following sequential process:

1. Calibration of flow
2. Calibration of sediment
3. Calibration of water temperature
4. Initial calibration of gross nutrient transport
5. Initial calibration of BOD and DO
6. Calibration of algae
7. Final calibration of nutrient species and DO
8. Calibration of fecal coliform bacteria
9. Calibration of metals

SEWRPC and WDNR directed that loads from the land surface should be, to the extent compatible with achieving water quality calibration, consistent with the loads predicted by SWAT for agricultural land uses and by SLAMM for urban land uses. The SLAMM model in particular is preferred by the WDNR for use in assessing compliance with State urban nonpoint source pollutant regulations. Therefore, the loading rates produced by these models form the starting point for the water quality calibration.

The adequacy of the water quality calibration was assessed through comparison to observed water quality data. It should be noted that the observed water quality data are primarily point-in-time grab samples, which may exhibit significant temporal variability relative to the (unobserved) daily mean concentration. A key objective is to have the model replicate actual loads through the system. Unfortunately, loads are not directly observed, and can only be estimated from the point-in-time concentrations multiplied by daily average flow. While model adjustments are made to obtain general agreement between simulated loads and estimated observed loads, it should be recalled that the estimates of observed loads are highly uncertain.

Hydrologic calibration precedes sediment and water quality calibration because runoff is the transport mechanism by which nonpoint pollution occurs and the hydrologic calibration of the Milwaukee River watershed model is described in a separate memorandum (*Revised Draft Hydrologic Calibration and Validation Results for the Milwaukee River Model*). The revised calibration results for the Milwaukee River model indicate acceptable agreement between observed and simulated streamflows. The successful hydrologic calibration provides a good basis for water quality calibration.

The approach that was used to calibrate the Milwaukee River model for sediment and the other water quality parameters is described in detail in previous memorandums (e.g., *Revised Draft Water Quality Calibration Results for the Menomonee River)*. Simulation of water quality in the Milwaukee River started with parameters from the revised upper Menomonee River model. Kinetic rates for BOD, nutrients, and algae are site-specific, which depend on a variety factors such as hydraulic characteristics and local chemical-biological factors. The final parameters were obtained through a fine-tuning process starting with the Menomonee parameters.

Water quality observations collected by MMSD were provided for 1994 through 2001 and were used to calibrate and validate the water quality model. Years 1994 through 1998 were used for calibration. The parameters were then applied to 1999 through 2001 as a validation check. Unless noted otherwise, the time series calibration and validation plots are based on the daily mean values of simulated output.

The calibration and validation periods used for water quality differ from those used in the hydrologic calibration due to constraints of data availability. The calibration period for water quality was started in 1994 (versus 1995 for the hydrology) to take full advantage of the available data. For both hydrology and water quality, simulations were started in January 1993 to minimize the effects of the initial conditions. Hydrologic simulation for 1994 appears to be suboptimal but could not be re-calibrated due to project scheduling constraints (Figure 5-1 to Figure 5-3). The water quality calibration therefore focused on matching the post-1994 results, although the 1994 water quality results are included here for review.

Limited USGS data collected in 2004 were also used as a validation check because no MMSD data were available for the most upstream portions of the watershed. Comparisons of the observed and simulated flows for 2004 are displayed in Attachment L and indicate relatively good agreement. However, the 2004 water quality observations are typically limited to less than 10 samples at each monitoring location which was considered an inadequate data set for full calibration of the model. As such, statistical assessments of the modeled versus observed loads and concentrations were not completed. Similarly, other data available for the upstream portions of the watershed were considered inadequate for calibration purposes due to sparse spatial or temporal coverage.

Figure 5-4 displays the location of the water quality sampling stations that were used during the calibration process.

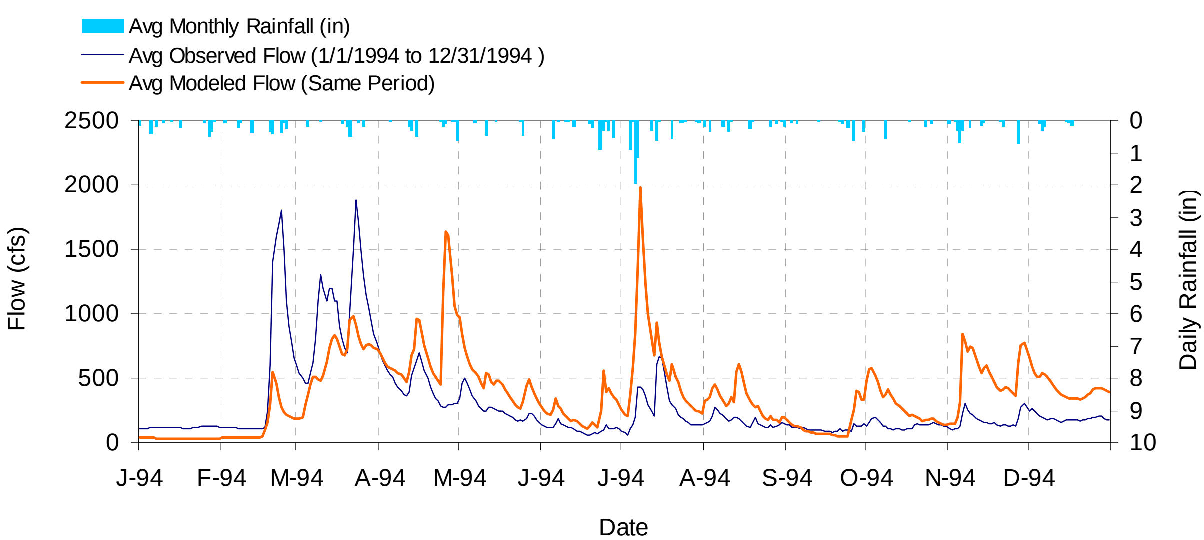


Figure 5-1. Time series hydrologic comparison for the Milwaukee River at USGS gage 04086600 (1994).

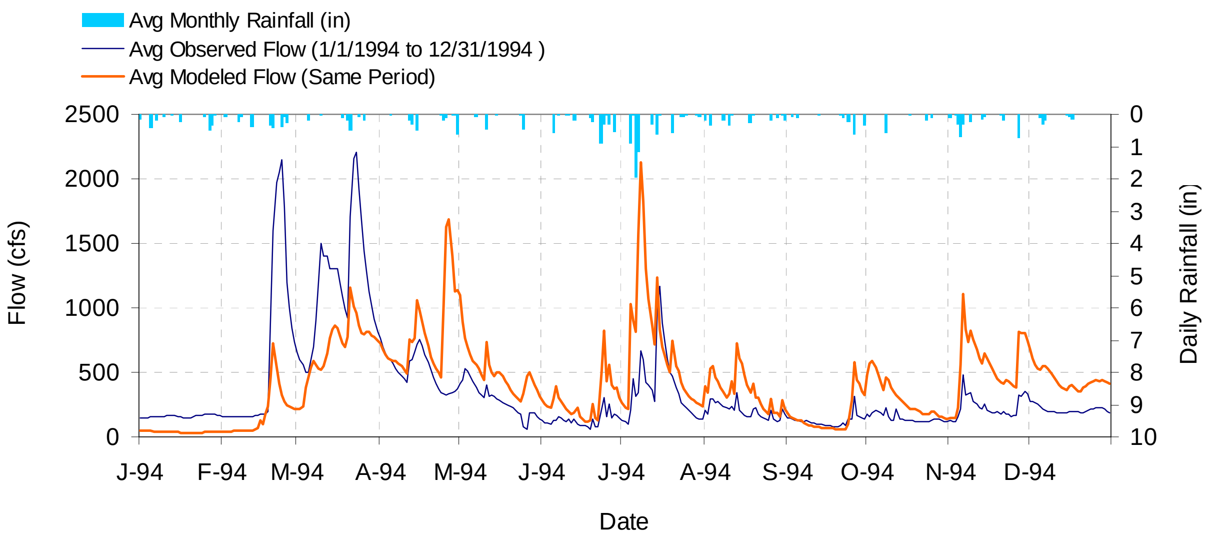


Figure 5-2. Time series hydrologic comparison for the Milwaukee River at USGS gage 04087000 (1994).

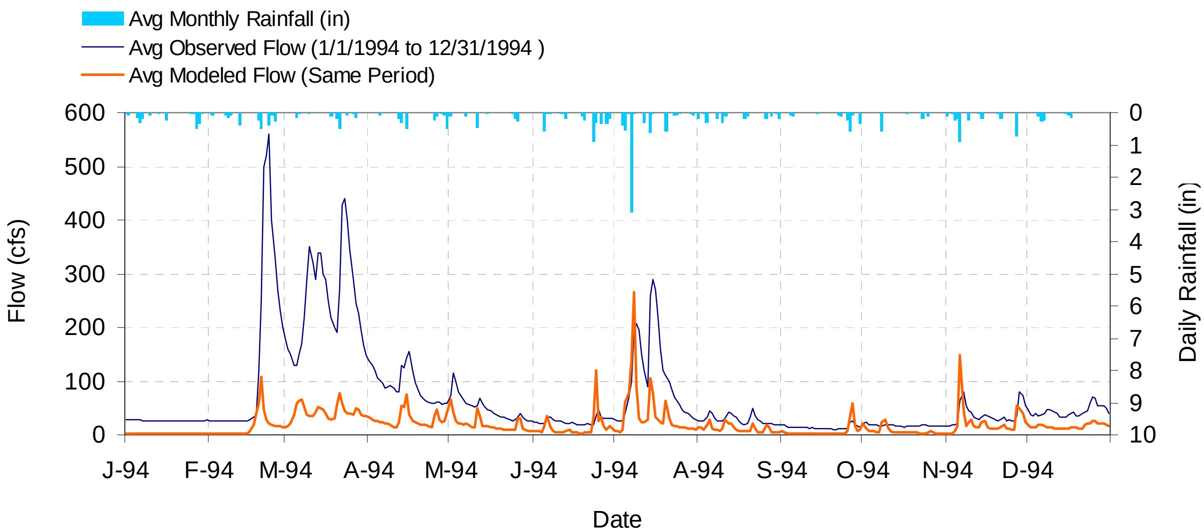


Figure 5-3. Time series hydrologic comparison for Cedar Creek at USGS gage 04086500 (1994).

Figure 5-4. Location of MMSD and USGS sampling stations and USGS flow gages on the Milwaukee River.

5.1 Sediment Calibration

The general sequence for sediment calibration in HSPF (Donigian and Love, 2002; Donigian et al., 1984) is to (1) estimate target sediment loading rates from the landscape, (2) calibrate the model loading rates to the target rates, and (3) adjust scour, deposition, and transport parameters in the stream channel to mimic behavior of the streams/waterbodies.

Sediment loading from agricultural land uses in the Milwaukee River watershed is derived from SWAT simulations and implemented by buildup/washoff coefficients (rather than HSPF sediment routines), as described in a separate memorandum (January 10, 2005 memorandum entitled *Revised and Expanded Discussion of SWAT Application*). The model uses twelve categories of cropland based on different soil and crop types; however, the parameters for these groups are modified to reflect the mix of agricultural rotations present in each watershed. Other land covers are simulated using the sediment/solids routines. Parameters for impervious land covers were derived to match SLAMM output as described in the February 16, 2004 memorandum entitled *Urban Non-Point Source Unit Loading Rates*. For grass, forest, and wetlands, the sediment routines were used and parameters were developed based on theoretical relationship to USLE as described below[2].

HSPF parameters for pervious land uses were estimated based on a theoretical relationship between HSPF parameters and documented soil parameters, ensuring consistency in relative estimates of erosion based on soil type and cover. HSPF calculates the detachment rate of sediment by rainfall (in tons/acre) as

$$DET = (1 - COVER) \bullet SMPF \bullet KRER \bullet P^{JRER}$$

where P is precipitation in inches. Actual sediment storage available for transport (*DETS*) is a function of accumulation over time and the reincorporation rate, *AFFIX*. The equation for *DET* is formally similar to the USLE equation,

$$\textit{Sediment Yield} = RE \cdot K \cdot LS \cdot C \cdot P.$$

USLE predicts sediment loss from one or a series of events at the field scale, and thus incorporates local transport as well as sediment detachment. For a large event with a significant antecedent dry period, it is reasonable to assume that *DET≈DETS* if *AFFIX* is greater than zero so that detached sediment storage from previous events is depleted. Further, during a large event, sediment yield at the field scale is assumed to be limited by supply, rather than transport capacity. Under those conditions, the USLE sediment yield from an event should approximate *DET* in HSPF.

With these assumptions, the HSPF variable *SMPF* may be taken as fully analogous to the USLE P factor. The complement of *COVER* is equivalent to the USLE C factor (i.e., (1 - *COVER*) = C). This leaves the following equivalence:

$$KRER \bullet P^{JRER} \quad = \quad RE \bullet K \bullet LS$$

The empirical equation of Richardson et al. (1983) as further tested by Haith and Merrill (1987) gives an expression for RE (in units of MJ-mm/ha-h) in terms of precipitation:

$$RE \quad = \quad 64.6 \bullet a_t \bullet R^{1.81}$$

where R is precipitation in cm and a_t is an empirical factor that varies by location and season. For southeast Wisconsin (USLE Region 14), a_t is estimated to average about 0.20 (Richardson et al., 1983). As HSPF does not implement *KRER* on a seasonal basis, the average value is most relevant.

As shown in Haith et al. (1992), the expression for RE can be re-expressed in units of tonnes/ha as:

$$RE \quad = \quad 0.132 \bullet 64.6 \bullet a_t \bullet R^{1.81}$$

This relationship suggests that the HSPF exponent on precipitation, *JRER*, should be set to 1.81.

The remainder of the terms in the calculation of *RE* must be subsumed into the *KRER* term of HSPF, with a units conversion. Writing *RE* in terms of tons/acre and using precipitation in inches:

---

[2] The discussion of the theoretical relationship between LSPC and USLE was modified to address comments on the *Draft Water Quality Calibration Results for the Menomonee River*.

$$RE\,(tons/ac) \quad = \quad \left[0.132 \bullet 64.6 \bullet a_t\right] \bullet R\,(in)^{1.81} \bullet (2.54\,cm/in)^{1.81} \bullet (1\,ton/ac)/(2.24\,tonnes/ha)$$

or, at the average value for a_t for this region, 4.115 · R (in)$^{1.81}$.

The power term for precipitation can then be eliminated from both sides of the equation, leaving the following expression for the *KRER* term in HSPF (English units) in terms of the USLE K factor:

$$KRER \quad = \quad 3.7032 \bullet K \bullet LS$$

The K factor is available directly from soil surveys, while the LS factor can be estimated from slope. This approach establishes initial values for *KRER* that are consistent with USLE information. Further calibration can then modify all *KRER* values by a single multiplicative factor (thus preserving the relationship among different land use:soil pairs) or by modifying the transport coefficient, *KSER.*

In addition to surface loads, a sediment concentration was associated with ground water discharge from pervious lands. This is necessary to match low-flow (non-scouring) total suspended solids (TSS) observations, and represents miscellaneous non-washoff sources of fine sediment load, including disturbances in the stream channel (by people, vehicles, farm animals, or wildlife) as well as fine sediment actually associated with ground water influx.

Input of these loads directly to the simulated stream reaches results in a consistent over-prediction of sediment concentration and load observed in-stream. This is largely because the first order and ephemeral streams are not simulated and, in these areas, as well as in riparian wetlands, substantial trapping may occur. In addition, the load estimates from the approved SLAMM and SWAT models could be too high. A net trapping rate for sediment and sediment-associated pollutants (using a mapping table for linking the sediment load from land to in-stream sediment) was taken as a general calibration parameter that effectively removes loads from the system. This approach simulates trapping losses as a fixed fraction of influent load, but is only applied to the surface washoff fraction of load. While this is a simplification of actual processes, monitoring of small tributaries is not available to support a more detailed representation of dependence on flow. In fact, the rate of trapping by settling within the stream channel is likely to be greater for smaller, less energetic flows; however, losses that are due to export in the flood plain are greater for higher flows. Actual trapping is also likely to vary by season, depending on vegetation condition. In essence, the trapping factors that are assumed are a simplified, empirical representation of the *net* difference between the estimated loading from the land surface and the event-associated load observed in streams.

Material that is trapped in the floodplain may eventually be eroded back into the stream. This is included as part of the general simulation of loading from the riparian area. Material that is “trapped” through deposition into bed sediments may also be re-entrained during high flow events. For small streams that are not simulated, the model can only represent this sediment source as part of the erosion of the bed material that is present at the start of the simulation in larger reaches.

The trapping factors were instituted in the Milwaukee River calibration to account for losses that occur in small first-order streams, riparian areas, and wetlands not explicitly included in the model reach network. The trapping factors were considered as calibration parameters and the final values were obtained after the modeled sediment concentration agreed well with the observed data. The final trapping factor for non-agricultural pervious land is 60 percent; the trapping factor for impervious land is 20 percent; and the trapping factor for agricultural pervious land is 90 percent. The reason for using lower trapping factor for impervious land is that direct conveyance to the stream through lined drainage ways is more likely to occur for impervious land.

Calibration of LSPC to observed instream suspended sediment concentrations is a difficult process, and an exact match cannot be expected for a number of reasons:

- Because suspended sediments often vary rapidly in time, point-in-time grab sample observations may not be representative of daily-average concentrations. Sediment load peaks are likely to be shifted slightly between the model and observations, resulting in larger apparent errors.

- Any errors in the hydrologic simulation of storm events also propagate into the sediment simulation. Both the washoff of sediment from the land surface and the scour of sediment within streams depend on the shape of the storm hydrograph at a fine temporal scale. But the spatial resolution of the rain gages representing broad geographic areas in the model limits the accuracy.

- Stream reaches are represented as relatively long segments, with average properties. The accuracy of scour/deposition simulation is limited by the relatively simplified representation of hydraulic conditions in the LSPC model.

- Because of the scale of the model, low-order streams are not explicitly simulated. As a result, sediment dynamics in the smaller streams are also not simulated.

- The timing of snowmelt peak flows are often not accurately captured by the models. These are often also peak sediment transport events.

- LSPC is a one-dimensional model, and thus simulates an average concentration for a cross-section. Samples that are not spatially integrated may not provide an accurate representation of the cross-sectional average concentration. This phenomenon can be particularly important at higher flows where there may be enhanced movement and higher concentrations of sediment near the sediment bed.

Calibration for sediment, as with any other water quality parameter, involves visual and statistical comparison of observed and predicted concentrations. However, the match on individual points is expected to be inexact, for the reasons cited above. For this reason, it is most important to reproduce observed transport curves (Donigian and Love, 2002; MPCA, 2001). That is, a log-log power plot of observed sediment load versus observed flow should match a similar plot of simulated sediment load and simulated flow.

Comparisons of observed and simulated TSS are shown in Attachment A. Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment J.

A statistical comparison of paired sediment observations and simulated daily mean values are provided in Section 5.6 below. A statistical evaluation of observed and simulated sediment loads is provided in Section 5.7. These comparisons are fairly good, and, as noted above, much of the error in individual point predictions is anticipated to be due to temporal shifts. Observed and simulated sediment transport plots are presented in Section 5.7.

5.2 Water Temperature Calibration

Water temperature simulation is not an explicit goal of the water quality modeling. However, a reasonable simulation of water temperature is necessary because many kinetic reaction rates are temperature dependent. Temperature simulation was therefore checked visually for consistency with observations, but a full statistical analysis has not been provided at this time.

The Milwaukee River temperature simulation relies on the same set of parameters as used for the Menomonee River. PERLND soil temperature and reach water temperature parameters were adopted from successful Minnesota River model applications. IMPLND runoff temperature was revised to provide a slight increase above ambient air temperature, with constant AWTF = 35 and BWTF = 1.05.

Fit to observed water temperature at the MMSD monitoring stations appears generally good for both the calibration and validation time periods (comparison is shown to daily averages from the model as many of the observations do not report time of day) (Attachment B). The fit to the 2004 USGS continuous temperature monitoring stations also appears to be good.

5.3 Nutrient and Algal Calibration

As with sediment, the starting points for nutrient calibration in the model are the loading estimates for specific land uses derived from the SWAT application (for agricultural lands, 1993 to 1999) and the SLAMM application (for urban lands, 1995 to 1997). This ensures consistency with other tools endorsed by the Wisconsin Department of Natural Resources. A detailed discussion of the comparison of unit area loads estimated by SWAT, SLAMM and HSPF is provided in the memorandum *Draft Water Quality Calibration Results for the Menomonee River.*

The model must be adjusted to achieve calibration to observed instream nutrient concentrations. In general, the mass of phosphorus observed instream is significantly less than the export from the land surface predicted by SWAT and SLAMM. This reflects trapping (of sediment-associated pollutants) and biological uptake (of labile forms), which primarily occurs in the small first-order and ephemeral streams. These small streams are not represented as reaches in the LSPC model, therefore the use of trapping factors is appropriate, and also enables calibration to be achieved while maintaining the relative loading magnitude for different land uses predicted by the SWAT and SLAMM models. Secondary adjustments to calibration are achieved by (1) adjusting the subsurface nutrient concentration components, and (2) adjusting instream nutrient kinetic parameters. A detailed discussion of the subsurface nutrient concentrations and instream nutrient kinetic parameters used in the Milwaukee River model is provided in the memorandum *Draft Water Quality Calibration Results for the Menomonee River.* Simulation of nutrient water quality in the Milwaukee River initially was based on parameters from the Menomonee River model. The parameters were fine-tuned to achieve agreement of model results with observed data in the Milwaukee River watershed.

Calibration for nutrients addresses both total nutrient concentration and individual nutrient species. This calibration process is inherently somewhat inexact for a number of reasons. First, available samples represent individual points in time and space (grab samples) that may not be representative of average conditions throughout a stream reach. In addition, there is typically significant analytical uncertainty in reported results – which is clearly evidenced by the fact that reported orthophosphate is sometimes greater than total phosphorus. This is particularly problematic when concentrations are near detection limits. Another problem is often observed at high flows, where substantial amounts of nutrients may move either as parts of larger debris or associated with sediment bedload, both of which are likely to be omitted from surface grab samples.

Modeling results are presented graphically in Attachments C (total phosphorus and dissolved phosphorus) and Attachment D (total nitrogen, nitrite and nitrate, and ammonia). A statistical assessment of concentrations is provided in Section 5.6, while a statistical assessment of loads is provided in Section 5.7. Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment J. While the model generally performs adequately, some higher-concentration events are missed. These may reflect localized events (such as timing of fertilizer application relative to storm events) that are beyond the spatial and temporal resolution of the model.

5.3.1 Algae and Chlorophyll a

Model calibration for chlorophyll *a* is challenging, because (1) algae respond in a complex way to a wide number of environmental factors, including self-shading, (2) chlorophyll *a* laboratory analyses are typically subject to a relatively high level of imprecision, and (3) algal response is naturally highly variable. Simulation of chlorophyll *a* in the Milwaukee River initially was based on parameters from the Menomonee River model. The parameters were fine-tuned to achieve agreement of model results with observed data in the Milwaukee River watershed.

The model also simulates benthic algae, which often constitute the major fraction of the algal biomass in shallow streams. Unfortunately, no reported data are available to calibrate the benthic algal concentration.

Model results for the calibration and validation time periods are provided in Attachment E. The model represents the general spatial and temporal trends in planktonic algal concentration, but does not predict a few isolated algal blooms that likely represent localized conditions in pooled backwaters during summer conditions or detachment of benthic algal biomass. Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment I.

5.3.2 BOD/DO Calibration

A rigorous calibration for biochemical oxygen demand (BOD) is problematic, because what is represented in the model is not fully equivalent to what is analyzed from ambient samples. BOD has been primarily monitored in the Milwaukee River using APHA (1998) Standard Method 5210B. This yields estimates of 5-day (short-term) BOD from whole-water samples, including both the carbonaceous and nitrogenous components.

The LSPC model simulates a single dissolved CBOD component as a state variable. In fact, organic matter that exerts an oxygen demand via bacterial digestion is a complex mixture of chemicals with variable reaction rates. The LSPC variable is a summary compromise that, when combined with an average reaction rate, yields the observed rate of oxygen depletion. It is not necessarily equivalent to either a CBOD5 or an ultimate CBOD (CBODu), but rather an *ad hoc* hybrid. For flowing systems with relatively short residence times, an approximation in terms of CBOD5 is usually adequate, although the reaction rate may need to be modified from 5-day laboratory rates to compensate for the mixture of organic compounds actually exerting a demand.

A further complication is that the LSPC variable represents the non-living component of BOD. Method 5210B uses unfiltered samples, and these samples also include living algae. Algae are not allowed to grow during the BOD test, but may continue to exert a respiration demand or die and become part of the non-living BOD. This component of measured BOD is not included in the LSPC state variable. A correction can be calculated to account for the long-term CBODu represented by algal cells, but the effect on CBOD5 is more variable and less clear. Accordingly, if LSPC is set up to simulate BOD as an approximation of dissolved CBOD5, the model should generally provide a slight underestimation of CBOD5 measured by Method 5210B.

Model results for the calibration and validation time periods are provided in Attachment F for both BOD5 and dissolved oxygen. The fit for both parameters is in general good. It should be noted that many of the reported post-2000 BOD5 concentrations are zeroes . The presence of these zeros in the database artificially increases the apparent discrepancy between the simulation model and observed data.

5.4 Fecal Coliform Bacteria

Simulation of fecal coliform bacteria concentrations often presents a challenge for watershed modeling. Observed concentrations tend to be highly variable in both space and time - due to both natural variability and analytical uncertainty. Further, instream concentrations may be elevated by sources which are not explicitly included in the model (e.g., water fowl, wildlife, illicit connections to storm sewers, or illegal dumping into storm drain systems), or which may be included in the model in a general way, but have large and unmonitored variability (e.g., occasional loads from wastewater pumping station spills or malfunctioning septic tanks). The watershed models represent average loads from the land surface as a washoff process. In addition, background loading is represented as a ground water concentration. In fact, the load attributed to ground water includes both true ground water load and other unmodeled sources of loading that are not flow-dependent.

The basis for setup of bacteria export from pervious land surfaces was the Fecal Coliform Loading Estimation spreadsheet. This tool was developed by Tetra Tech and NRCS for the purpose of compiling fecal coliform bacteria based on available local agency and national literature information. For agricultural lands, monthly estimates of fecal coliform loadings were estimated using agricultural census counts, literature values for manure production rates and bacteria counts, and estimates of manure application or deposition. Cattle waste is either applied as manure to cropland and pastureland or contributed directly to pastureland. Cattle are assumed to be either kept in feedlots or allowed to graze (depending on the season). Chicken waste is applied as manure to cropland and pasture. Swine manure is assumed to be collected and applied to cropland only.

Buildup and washoff rates for forest and wetland were not calculated in the spreadsheet, but were instead adopted from the successful application of the Minnesota River models (Tetra Tech, 2002). Loading rates for urban pervious surfaces are constant throughout the year and were derived primarily from estimates of domestic pet densities and pet waste characteristics. Loads from impervious surfaces were tuned to replicate loading predicted by SLAMM for 1995-1997 as described in *Draft Water Quality Calibration Results for the Menomonee River*.

Fecal coliform concentrations in streams during baseflow are simulated based on a combination of recycling from organic sediment and ground water loading. Ground water concentrations were varied on a seasonal basis to reproduce the general pattern of observed dry-weather baseflow concentrations and vary for rural versus urban land use. The baseflow concentration, which is simulated by assigning a ground water concentration, in part represents actual ground water loading, such as may occur from malfunctioning septic systems or leaky sewer lines, but also reflects direct non-washoff additions of bacteria into waterbodies from wildlife, waterfowl, and domestic animals. Ground water concentrations for non-urban pervious land ranged from 40 to 230 colonies per 100 ml, while higher rates were set for urban grass to reflect the potential for contributions from subsurface sewer leaks.

Observed concentrations of fecal coliform bacteria instream are strongly affected by the die off rate of fecal coliform bacteria. As these organisms reside in the mammalian gut, they do not prosper in surface waters. Die off rates are increased by a variety of factors including temperature, sunlight, salinity, settling, and predation. Mancini (1978) suggests a base loss rate of 0.8 per day, with increases above the base rate due to these factors and an Arrhenius temperature coefficient of 1.07. Based on trial and error, a loss rate of 1.00 per day appeared to provide a reasonable fit to observations.

Model results for the calibration and validation time periods are provided in Attachment G. Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment I.

5.5 Metals

As requested by SEWRPC, the model includes simulations for copper and zinc, but at a highly simplified level. Both copper and zinc are simulated as total metals, and treated as conservative substances within stream reaches. This neglects the actual kinetics of these constituents, which sorb to particulate matter and exchange with the sediments. Such refinements may be added to the model at a future date.

Copper and zinc are also not rigorously calibrated. While there are observations for both total copper and total zinc, many of the observations (particularly) for copper are at or near method detection limits, and thus provide limited information on exact concentrations. Further, neglect of sorption kinetics means that the simulation will only be approximate. Therefore, the strategy was to base the metals simulation on independent loading estimates and adjust these only to the extent necessary to achieve approximate agreement with the range of concentrations reported instream.

For copper and zinc loading from impervious surfaces, the LSPC buildup and washoff rates developed from the SLAMM simulation are used (see February 16, 2004 memorandum entitled *Urban Non-Point Source Unit Loading Rates).* The SLAMM work did not provide estimates of copper loading from pervious surfaces, and use of the buildup/washoff coefficients provided for zinc on pervious surfaces yielded instream concentrations that were more than an order-of-magnitude greater than observed concentrations. Therefore, the starting point for the copper and zinc buildup and washoff coefficients on pervious lands were adopted from a similar model application conducted for Gwinnett County, GA (Tetra Tech and CH2M HILL, 1999).

Use of the Gwinnett County buildup rates for pervious lands and the SLAMM estimates for impervious surfaces directly yielded copper concentrations that are consistent with observations in the Milwaukee River. Zinc predictions were still high, however, so a trapping factor of 40 percent (pass-through of 60 percent) was added in the mass-link block for pervious lands. Because zinc is particle reactive, trapping losses in small streams and wetlands is expected, and the factor is consistent with the trapping rate applied to phosphorus. No trapping was applied to copper.

Finally, concentrations in ground water were set at levels sufficient to replicate concentrations observed at baseflow in Milwaukee-area streams (1.3 μg/L total copper and 7.2 μg/L total zinc).

Results for the Milwaukee River monitoring stations are shown in Attachment H and indicate an approximate agreement in range between model predictions and observations. Note that many of the reported values appear to be quantitations at a detection limit of 0.01 mg/L.

As noted above, copper and zinc are simulated as conservative substances in the water column and not rigorously calibrated. For this reason, exceedance plots and load analysis of these constituents are not presented.

5.6 Statistical Assessment of Concentrations

An ideal simulation model would conclusively prove its credibility by matching exactly every observed data point. Unfortunately, this ideal cannot be achieved, for a variety of reasons. In the first place, any watershed model is a simplification of complex natural processes. Secondly, the model is capable of representing only those events that are specified to it in the forcing functions, which generally represent the response from the land surface of hydrologic events. Events that are unknown to the model, such as illicit discharges, cannot be replicated by the model. Water quality simulation in particular is constrained to be no better than the quality of the simulation of hydrology, which in turn is limited by the availability of representative meteorological data. For instance, a small error in the representation of the timing or magnitude of a surface washoff event can result in apparently large discrepancies between simulated and observed actual concentrations at a given location and point in time. Finally, the observed values also cannot be considered as fixed and certain.

First, there is the possibility of analytical uncertainty in any reported observation that derives from the inherent imprecision of analytical techniques, and, occasionally, from laboratory analysis and reporting errors. Perhaps more importantly, grab samples submitted for chemical analysis represent a specific location and point in time that is not entirely consistent with the spatial and temporal support of the model. LSPC represents waterbodies as discrete reaches, which are assumed to be fully mixed. Real waterbodies vary continuously in both longitudinal and lateral dimensions, as well as in time. A sample taken from a specific location may not be representative of the average concentration across the stream cross section, and even less representative of the average across an entire model reach. Further, a sample taken at a discrete point in time may not be representative of the average concentration that would be observed across a modeling time step – particularly when the sample is taken near a source of discharge or during the course of a runoff event.

Several additional explanations as to why the quality of model fit may differ between simulated and observed data include the following:

- Point sources included in the model generally do not account for temporal changes and may differ between the calibration and validation periods.

- As pointed out in section 5.4.1 in the case of chlorophyll-a concentrations, there may be some inherent physiological processes not accounted for in the model that may be causing the discrepancy between actual versus calibrated and calibrated versus validated comparisons.

For these reasons, it is important to evaluate model performance based on statistical criteria. In essence, the model and observations may differ on individual points, but should be in general agreement over larger spans of time and space. This testing is accomplished using a weight of evidence approach. It is first important to realize that the model uses a single set of parameters, by land use, across the entire watershed, with minimal local adjustments. Thus, achieving an acceptable fit across multiple stations (with one set of parameters) is a better indication of the validity of the model than any discrepancies at individual stations. Second, the model is developed using a calibration/validation approach, in which the model was developed on one set of observations (1994 to 1998), then tested on a subsequent set of observations (1999 to 2004). Where the quality of model fit differs between the calibration and validation periods this may indicate either that the apparent discrepancy is due to random variability or that the discrepancy arises from temporal changes in land use and discharges, which are not included in the model.

Statistical tests are applied to both concentrations and estimated loads. Both comparisons are important, and reveal different features of the model. For instance, a simulation that is problematic with regard to concentrations but provides a good estimate of loads can be judged as providing a good representation of pollutant source loading that is corrupted by a sub-optimal representation of the timing of their delivery.

The primary test for model performance on concentrations is a Student's *t*-test of equality of means over the entire calibration or validation period. (There are not sufficient data to adequately evaluate performance on individual seasons or years, particularly given the presence of analytical and sampling uncertainty.) In these tests, the equality of observed and sample means on paired daily average data is taken as the null hypothesis or a rebuttable proposition. That is, model performance is judged acceptable unless the statistical analysis proves otherwise.

The *t*-test is developed on assumptions that samples are drawn from a normal distribution and the variances are equal across distributions. Both of these assumptions are not met for various observed and simulated parameters in the Milwaukee River.

However, the tests presented here are on means, not individual observations, and the distribution of means converges to a normal distribution under the Central Limit Theorem. Further, Box et al. (1978) have shown that the *t*-test is somewhat robust against violations of the assumptions of normality and equality of variances.

Tests for equality of means, at each station, for the calibration and validation periods are presented in Tables 5-1 through 5-10 and the confidence limit results are summarized in Table 5-11. A probability value less than 5 percent is judged to represent proof of a discrepancy between the model and data – although it does not reveal to what extent the discrepancy is the result of the model and to what extent it is a result of the data. Also note that this test does not address whether the difference, even if statistically significant, is meaningful in terms of environmental impact.

Across multiple parameters and stations, the model meets the *t*-test criteria in a majority of cases for both the calibration and validation periods. The quality of model fit is further buttressed by a good agreement between simulated and estimated loads (Section 5.7). The model fit is considered to be acceptable given the data quality objectives and schedule; error statistics are presented to guide the interpretation of the results.

An additional evaluation of the model quality of fit for individual observations was conducted by plotting observations against simulated results with confidence bounds that represent one and two standard deviations for the day. The standard deviations are calculated on a daily basis from the sub-daily model output. The confidence limits are assumed to be either normally or lognormally distributed based on the distribution which most reduces skew (in most cases, log transformation reduces skew as is common for environmental data that are constrained to be greater than or equal to zero and contain sporadic high values associated with washoff events). Comparison can be made both visually and by tabulating the number of observations that fall within one and two-standard deviation confidence limits. These results are provided in Attachment K and summarized in Table 5-11. In general, the results are not as good as were obtained for the other four watersheds modeled during this study because the 3-day variance is mostly very small, yielding small confidence intervals. This may be due to the fact these are all stations on the mainstem of a large river, with significant point sources, and it doesn't look as though there are many high flow samples. Because day-to-day variations in the point source loading were not available as inputs to the model, none of that source of variability is included in the confidence limits.

There are, of course, parameter-location contrasts for which the model-data comparison does not pass the statistical criterion. Where both the inequality and the direction of deviation is consistently shown in both the calibration and validation tests, there may be a need for additional investigation and potential model improvement (unless the unrepresentativeness is due to the sampling location not being a good indicator of conditions in the model reach as a whole). However, the existing calibration/validation provides a reasonable representation of overall fit based on evaluation of multiple stations.

Table 5-1. Milwaukee River Station RI-01 Concentration Calibration Statistics (1994-1998).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	26.59365	0.940782	0.219333	2.104666	0.054742	0.134127	11.90918	2.563871	30.04081	1500.365
	Paired Simulated	26.61052	0.467587	0.099982	1.792991	0.058417	0.114075	10.15546	1.377021	39.85627	693.5121
	Full Simulated	20.04452	0.570212	0.158685	1.754999	0.092203	0.137213	10.94854	1.38529	24.96553	983.0883
Median	Observed	12.8	0.90829	0.125	2.01	0.04	0.09	11.7	2.1	14.53	230
	Paired Simulated	20.4176	0.377864	0.045173	1.67552	0.048129	0.098951	10.3154	1.20236	46.6845	350.901
	Full Simulated	13.14	0.533925	0.14772	1.579461	0.086197	0.121573	11.43835	1.128385	9.821755	583.9175
Count		63	63	60	62	62	63	61	62	62	63
Mean Error		0.016872	-0.4732	-0.12153	-0.31	0.002607	-0.02005	-1.78163	-1.19372	9.699318	-806.853
Mean Absolute Error		22.7343	0.555242	0.191933	0.568076	0.062979	0.096076	2.572886	1.408299	34.08483	1565.004
Mean Squared Error		3369.595	0.463809	0.16405	0.539626	0.006	0.022151	9.913078	4.492932	2213.214	35101320
RMSE		58.04821	0.681035	0.405031	0.734593	0.077458	0.148832	3.148504	2.119654	47.04481	5924.6367
pval, paired t-test		0.998181	1.9E-10	0.018807	0.000571	0.793395	0.288484	1.64E-06	1.55E-06	0.104988	0.2832602
alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE
t-test?		Yes	No	No	No	Yes	Yes	No	No	Yes	Yes

Table 5-2. Milwaukee River Station RI-01 Concentration Validation Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	26.75769	1.284322	0.297878	2.366162	0.059622	0.130863	11.5175	0.947115	12.00707	1217.75
	Paired Simulated	27.16397	0.780392	0.136915	2.124219	0.073307	0.13382	10.5559	2.00978	36.15865	794.6853
	Full Simulated	17.75671	0.733785	0.161535	1.982885	0.091081	0.139974	11.06131	1.614283	25.02985	950.8287
Median	Observed	14	1.305	0.076	2.4485	0.05	0.11	11.15	0	11.3	410
	Paired Simulated	14.8931	0.586789	0.046988	1.840662	0.050096	0.097399	10.7749	1.205395	41.00995	605.9995
	Full Simulated	9.40136	0.586145	0.123995	1.729958	0.075343	0.110031	11.41235	1.080225	11.2909	563.949
Count		52	46	49	42	45	51	52	52	41	52
Mean Error		0.40628	-0.53272	-0.15546	-0.29646	0.012638	0.004477	-0.9616	1.062664	24.11617	-423.0647
Mean Absolute Error		18.60008	0.801682	0.331596	0.789202	0.075701	0.09197	1.831267	1.452613	31.82311	1310.03
Mean Squared Error		1652.815	0.830737	0.520438	1.065641	0.011126	0.014445	6.037469	4.76542	1378.975	6568577
RMSE		40.65482	0.911448	0.721414	1.032299	0.10548	0.120185	2.457126	2.182984	37.13456	2562.923
pval, paired t-test		0.943382	1.61E-05	0.132854	0.061866	0.427723	0.793165	0.003759	0.000219	3.27E-06	0.237521
alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE	FALSE
Pass t-test?		Yes	No	Yes	Yes	Yes	Yes	No	No	No	Yes

Table 5-3. Milwaukee River Station RI-02 Concentration Calibration Statistics (1994-1998).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	25.00323	0.85029	0.142642	2.060984	0.037623	0.118065	9.958667	2.865574	37.73935	6051.968
	Paired Simulated	31.28459	0.528502	0.119717	1.83183	0.06801	0.12849	9.878436	1.429312	33.8275	891.3285
	Full Simulated	22.61083	0.574109	0.157961	1.737579	0.092261	0.141082	10.74827	1.327513	23.1689	1261.55
Median	Observed	19.5	0.7885	0.07	1.927	0.03	0.095	9.55	2.3	21.575	235
	Paired Simulated	21.15925	0.440014	0.054706	1.719821	0.046423	0.111561	10.2505	1.240295	40.5454	448.49
	Full Simulated	15.3742	0.5475	0.148711	1.575706	0.087104	0.125191	11.2073	1.08639	11.1034	627.7335
Count		62	62	53	61	61	62	60	61	62	62
Mean Error		6.281359	-0.32179	-0.01851	-0.22747	0.031219	0.010425	-0.08998	-1.43438	-3.91185	-5160.639
Mean Absolute Error		14.62528	0.483062	0.134849	0.569153	0.062577	0.080626	1.521944	1.71971	27.84519	6082.389
Mean Squared Error		474.106	0.441959	0.051605	0.548854	0.006688	0.009809	3.333751	5.534621	2616.072	9.68E+08
RMSE		21.77397	0.6648	0.227168	0.740847	0.08178	0.099041	1.825856	2.352578	51.14755	31107.53
pval, paired t-test		0.021855	5.84E-05	0.558144	0.015206	0.002202	0.411623	0.706051	1.44E-07	0.551327	0.193799
alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Pass t-test?		No	No	Yes	No	No	Yes	Yes	No	Yes	Yes

Table 5-4. Milwaukee River Station RI-02 Concentration Validation Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	26.92075	1.09	0.077705	2.191273	0.059413	0.138712	9.552264	1.279245	13.4631	3128.019
	Paired Simulated	30.87372	0.757981	0.135199	2.062451	0.075942	0.143051	10.42394	2.076462	36.40172	1123.905
	Full Simulated	20.57353	0.738232	0.161314	1.960184	0.09095	0.143995	10.99714	1.641506	24.73643	1174.507
Median	Observed	19	1.08	0.04	2.211	0.06	0.12	8.87	1.4	10.8	430
	Paired Simulated	17.3722	0.593433	0.049017	1.753099	0.043345	0.095737	10.2669	1.35039	41.2804	862.085
	Full Simulated	11.1434	0.587721	0.107595	1.711478	0.075921	0.11283	11.4371	1.105325	18.49515	628.697
Count		53	18	44	44	46	52	53	53	42	53
Mean Error		3.952967	-0.10128	0.074117	-0.17324	0.014896	0.005672	0.871675	0.797216	22.79566	-2004.114
Mean Absolute Error		13.64317	0.604191	0.137918	0.659051	0.072026	0.082814	1.611995	1.499902	29.83677	3273.946
Mean Squared Error		417.2764	0.508328	0.048719	0.704213	0.010738	0.012495	3.78783	4.564239	1211.177	47754796
RMSE		20.42734	0.712971	0.220724	0.839174	0.103625	0.111781	1.946235	2.136408	34.80197	6910.484
pval, paired t-test		0.160901	0.561856	0.024129	0.173633	0.335045	0.718246	0.000684	0.00545	1.88E-06	0.033402
alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE
Pass t-test?		Yes	Yes	No	Yes	Yes	Yes	No	No	No	No

Table 5-5. Milwaukee River Station RI-04 Concentration Calibration Statistics (1994-1998).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	38.28136	0.645552	0.174038	1.851965	0.034186	0.13322	9.193729	3.411525	44.87293	5328.983
	Paired Simulated	40.14298	0.47161	0.12341	1.758978	0.067675	0.133912	9.382755	1.349723	34.95391	989.0225
	Full Simulated	26.18408	0.571774	0.160061	1.70115	0.094813	0.147111	10.64965	1.283137	23.07477	1461.95
Median	Observed	18	0.63	0.07	1.72	0.03	0.1	9.3	2.9	25.3	230
	Paired Simulated	27.266	0.325458	0.062804	1.622801	0.04195	0.110412	9.72469	1.22226	41.4195	477.702
	Full Simulated	18.4386	0.546463	0.155042	1.542112	0.089915	0.133254	11.09085	1.036715	12.62965	663.3385
Count		59	58	52	57	59	59	59	59	58	59
Mean Error		1.861621	-0.17199	-0.05157	-0.08813	0.033488	0.000692	0.189026	-2.0618	-10.0507	-4339.961
Mean Absolute Error		29.02843	0.320619	0.162613	0.456059	0.06189	0.089225	1.601199	2.319105	30.5187	5497.777
Mean Squared Error		5925.429	0.197367	0.080049	0.345644	0.00701	0.017562	5.176585	9.128845	2347.224	4.17E+08
RMSE		76.97681	0.44426	0.282929	0.587915	0.083726	0.132521	2.275211	3.021398	48.44816	20415.73
pval, paired t-test		0.854472	0.002453	0.19146	0.261408	0.001544	0.968424	0.527978	1.92E-09	0.114889	0.102955
alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Pass t-test?		Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes

Table 5-6. Milwaukee River Station RI-04 Concentration Validation Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	35.10943	1.038489	0.09125	2.142233	0.053523	0.139962	8.843019	1.833962	14.68225	4299.113
	Paired Simulated	37.06363	0.711117	0.134045	1.931205	0.083497	0.156873	10.28372	2.015303	36.1338	1393.037
	Full Simulated	23.13175	0.722789	0.161573	1.90284	0.092691	0.148926	10.91087	1.589688	25.08353	1355.456
Median	Observed	20.4	1.04	0.04	2.2	0.0535	0.12	8.68	2.1	12.1	430
	Paired Simulated	26.3636	0.571303	0.06247	1.697499	0.058062	0.119046	10.1805	1.41314	38.5201	1138
	Full Simulated	12.37435	0.587848	0.11011	1.670512	0.077343	0.117007	11.37065	1.09921	21.7722	694.3885
Count		53	45	44	43	44	52	53	53	40	53
Mean Error		1.954199	-0.32698	0.041535	-0.16525	0.027532	0.018329	1.440706	0.18134	21.19934	-2906.077
Mean Absolute Error		19.33461	0.618083	0.145068	0.644666	0.071368	0.07883	1.785826	1.560347	29.76852	4073.116
Mean Squared Error		1023.598	0.508227	0.049254	0.713427	0.010182	0.011777	4.297585	3.691084	1214.696	84240796
RMSE		31.99372	0.7129	0.221933	0.844646	0.100907	0.108523	2.073062	1.921219	34.8525	9178.279
pval, paired t-test		0.660837	0.001347	0.218316	0.203123	0.06978	0.226683	5.53E-09	0.497203	2.46E-05	0.019667
alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	TRUE	TRUE
Pass t-test?		Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	No

Table 5-7. Milwaukee River Station RI-05 Concentration Calibration Statistics (1994-1998).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	33.06038	0.661846	0.1578	1.84438	0.032717	0.128679	9.041346	3.5225	38.85453	3824.151
	Paired Simulated	40.11633	0.520387	0.150106	1.809183	0.100966	0.166877	9.165789	1.46414	33.43325	1075.486
	Full Simulated	26.35409	0.55418	0.180063	1.665536	0.128784	0.181216	10.35318	1.347871	22.01168	1285.099
Median	Observed	29	0.57	0.085	1.7	0.03	0.11	8.925	2.8	25.99	430
	Paired Simulated	30.40305	0.317874	0.117081	1.616915	0.089785	0.151798	9.71316	1.232315	37.0515	525.06
	Full Simulated	18.5382	0.523259	0.178273	1.507407	0.119755	0.17111	11.0453	1.11041	10.82265	578.4375
Count		53	53	50	50	53	53	52	52	53	53
Mean Error		4.310054	-0.13721	-0.00532	-0.00379	0.067485	0.037432	0.177169	-2.08054	-5.43628	-2809.436
Mean Absolute Error		19.66367	0.319162	0.158715	0.352214	0.078503	0.0901	1.767058	2.241412	25.69094	3787.755
Mean Squared Error		828.2566	0.196789	0.103595	0.231142	0.011291	0.012741	4.94621	8.229433	1860.815	2.31E+08
RMSE		28.77945	0.443609	0.321862	0.480773	0.106259	0.112875	2.224008	2.868699	43.13717	15214.96
pval, paired t-test		0.279752	0.022855	0.90836	0.956184	2.49E-07	0.014299	0.5707	8.14E-10	0.36386	0.181331
alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		FALSE	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE
Pass t-test?		Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes

Table 5-8. Milwaukee River Station RI-05 Concentration Validation Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	44.08	1.003222	0.083667	2.157136	0.054205	0.149205	8.955778	1.997778	17.2725	5167.133
	Paired Simulated	32.28312	0.600785	0.138379	1.832278	0.096882	0.162495	9.944795	1.746595	35.29666	1833.317
	Full Simulated	23.71768	0.703898	0.177325	1.871923	0.11731	0.174269	10.78477	1.63781	24.99776	1299.539
Median	Observed	30	1.01	0.06	2.265	0.05	0.115	8.62	2.1	12.4	430
	Paired Simulated	19.9626	0.511577	0.104113	1.621537	0.0662	0.131346	10.4844	1.29812	37.6101	837.197
	Full Simulated	12.52905	0.565128	0.139558	1.632894	0.106301	0.146636	11.1919	1.188165	22.3132	624.1025
Count		45	45	39	44	44	44	45	45	40	45
Mean Error		-11.7969	-0.40244	0.064458	-0.31769	0.044257	0.014709	0.989017	-0.25118	17.60328	-3333.817
Mean Absolute Error		21.84719	0.581274	0.157057	0.663962	0.074057	0.074475	1.575834	1.572586	27.39928	4448.109
Mean Squared Error		1347.114	0.451545	0.053426	0.640102	0.010604	0.010005	3.770767	3.489057	1068.621	1.38E+08
RMSE		36.70305	0.671971	0.231141	0.800064	0.102978	0.100027	1.941846	1.867902	32.68977	11756.19
pval, paired t-test		0.029398	1.1E-05	0.081414	0.006917	0.003215	0.335084	0.0003	0.372931	0.000281	0.056158
alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE
Pass t-test?		No	No	Yes	No	No	Yes	No	Yes	No	Yes

Table 5-9. Milwaukee River Station RI-06 Concentration Calibration Statistics (1994-1998).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	35.74706	0.653693	0.173468	1.836828	0.036831	0.135049	8.608284	3.017164	39.78841	9586.379
	Paired Simulated	38.0464	0.475375	0.145227	1.739806	0.100709	0.164849	9.206121	1.401197	32.71716	980.0143
	Full Simulated	26.35409	0.55418	0.180063	1.665536	0.128784	0.181216	10.35318	1.347871	22.01168	1285.099
Median	Observed	24.56667	0.6075	0.096667	1.675	0.03	0.106667	8.75	2.6	27.07333	230
	Paired Simulated	28.19175	0.319758	0.122498	1.580275	0.093851	0.152977	9.81833	1.175825	37.01615	360.619
	Full Simulated	18.5382	0.523259	0.178273	1.507407	0.119755	0.17111	11.0453	1.11041	10.82265	578.4375
Count		68	68	62	65	68	68	68	67	67	66
Mean Error		2.299342	-0.17832	-0.02679	-0.09128	0.063878	0.0298	0.597837	-1.61206	-7.0938	-8620.045
Mean Absolute Error		21.64445	0.342636	0.14845	0.415811	0.08116	0.086831	1.89993	1.819902	25.93913	9501.242
Mean Squared Error		1348.957	0.204786	0.063617	0.34191	0.010926	0.013256	6.265836	5.702792	1448.387	1.74E+09
RMSE		36.72815	0.452533	0.252224	0.584731	0.104529	0.115135	2.503165	2.388052	38.05768	41758.94
pval, paired t-test		0.609329	0.000808	0.407393	0.210689	2.45E-08	0.031757	0.048115	2.73E-10	0.128025	0.093746
alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		FALSE	TRUE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE
Pass t-test?		Yes	No	Yes	Yes	No	No	No	No	Yes	Yes

Table 5-10. Milwaukee River Station RI-06 Concentration Validation Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	47.82264	0.951957	0.138804	2.035467	0.050685	0.153712	8.817358	1.419811	15.6925	6842.551
	Paired Simulated	36.92666	0.694816	0.159792	1.937278	0.10799	0.180159	9.897028	2.033883	34.29029	1976.601
	Full Simulated	23.71768	0.703898	0.177325	1.871923	0.11731	0.174269	10.78477	1.63781	24.99776	1299.539
Median	Observed	25	0.99	0.0625	2.065	0.0425	0.12	8.395	1.3	10.2	930
	Paired Simulated	23.1363	0.559174	0.105198	1.675642	0.073998	0.142026	10.3629	1.50757	36.7865	1065.22
	Full Simulated	12.52905	0.565128	0.139558	1.632894	0.106301	0.146636	11.1919	1.188165	22.3132	624.1025
Count		53	47	46	46	46	52	53	53	42	49
Mean Error		-10.896	-0.27135	0.034847	-0.08697	0.056077	0.027988	1.07967	0.614072	18.05884	-4784.48
Mean Absolute Error		23.76473	0.562162	0.190477	0.58985	0.085037	0.079731	1.668494	1.309605	26.20129	6071.072
Mean Squared Error		3324.048	0.44278	0.116218	0.592821	0.013398	0.012676	4.47447	2.467754	967.605	5.98E+08
RMSE		57.65456	0.665417	0.340907	0.769949	0.115752	0.112588	2.115294	1.570909	31.10635	24462.26
pval, paired t-test		0.171111	0.004014	0.494165	0.449654	0.000559	0.072676	8.05E-05	0.003471	4.48E-05	0.173447
alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE
Pass t-test?		Yes	No	Yes	Yes	No	Yes	No	No	No	Yes

Table 5-11. Confidence limit results for Milwaukee River water quality calibration and validation.

Station	Parameter	Within 1 Standard Deviation	Within 2 Standard Deviations
RI-01	Total Phosphorus	11%	16%
	Total Nitrogen	7%	15%
	Total Suspended Solids	15%	25%
	Fecal Coliform	22%	35%
RI-02	Total Phosphorus	11%	21%
	Total Nitrogen	8%	18%
	Total Suspended Solids	27%	37%
	Fecal Coliform	4%	8%
RI-04	Total Phosphorus	17%	26%
	Total Nitrogen	12%	15%
	Total Suspended Solids	23%	31%
	Fecal Coliform	25%	45%
RI-05	Total Phosphorus	14%	20%
	Total Nitrogen	12%	19%
	Total Suspended Solids	17%	26%
	Fecal Coliform	23%	40%
RI-06	Total Phosphorus	16%	24%
	Total Nitrogen	14%	23%
	Total Suspended Solids	21%	31%
	Fecal Coliform	24%	47%

5.7 Statistical Assessment of Loads

For the evaluation of impacts on downstream receiving waters, correct model representation of total loads is as important as the representation of concentration. Unfortunately, load is not observed directly. Estimates of observed load on those days with observations can be formed by multiplying concentration by daily average flow. However, because the concentrations represent point-in-time grab samples, these represent highly uncertain estimates of daily load.

Load estimates require both concentration and flow. For the Milwaukee River watershed, flow and water quality are monitored at 04086500, 04086600 (RI-01), and 04087000 (RI-04). Water quality data at 04086500 are only available for the year 2004, however.

Because loads depend on both flow and concentration, it is unreasonable to expect that all observed and simulated data points will match closely. That is, apparent discrepancies will arise due to any errors in the timing or magnitude of flows, in addition to the uncertainty introduced by point-in-time concentration observations. However, the mean loads on paired observations should be in general agreement between the model and predictions. In addition, the relationship between load and flow should be similar.

Equality of observed and simulated mean concentrations is evaluated using a paired *t*-test. Results, with probability values (pvals) are shown in Table 5-12 to Table 5-15. As shown in the tables, the agreement between the model and estimated observed loads is good, with no contrasts failing the *t*-test – and this agreement is achieved while also preserving the relationship to SWAT and SLAMM loading rates from the uplands. Log-log transport plots for sediment, total nitrogen, nitrite+nitrate, and total phosphorus are shown in Figure 5-5 and Figure 5-6.

Table 5-12. Milwaukee River Station RI-01 Load Calibration Statistics (1994-1998).

		TSS (tons/day)	NO2+NO3 (kg/day)	TN (kg/day)	TP (kg/day)
Mean	Observed	39.33144	1032.472	2221.307	132.9974
	Paired Sim	26.71778	915.2515	2150.681	148.6866
	Full Sim	23.29643	920.8298	2046.688	153.6991
Median	Observed	7.443403	522.1971	1199.581	54.31398
	Paired Sim	9.84706	200.7819	908.0614	44.82626
	Full Sim	7.55105	237.4257	834.1079	55.82441

Count	63	63	62	63
Mean Error	-12.6137	-117.221	-50.584	15.68916
Mean Absolute Error	28.39272	788.1376	1350.818	131.1969
Mean Squared Error	13093.62	5549086	10752553	239121.4
RMSE	114.4273	2355.65	3279.109	489.0004
pval, paired t-test	0.385871	0.696176	0.904486	0.801289
alpha	0.05	0.05	0.05	0.05
Fail t-test?	FALSE	FALSE	FALSE	FALSE
Pass t-test	Yes	Yes	Yes	Yes

Table 5-13. Milwaukee River Station RI-01 Load Validation Statistics (1999-2001).

		TSS (tons/day)	NO2+NO3 (kg/day)	TN (kg/day)	TP (kg/day)
Mean	Observed	83.18107	2010.859	3908.009	283.6556
	Paired Sim	62.80518	2047.253	4417.47	334.7326
	Full Sim	31.02266	1371.573	2988.313	220.1273
Median	Observed	14.23955	1181.623	2662.56	96.8844
	Paired Sim	13.6544	672.7325	2176.169	78.8283
	Full Sim	8.92882	490.3702	1450.667	73.88195

Count	52	46	42	51
Mean Error	-20.3759	-153.398	-19.0614	57.20401
Mean Absolute Error	62.01722	1512.399	2099.859	252.2872
Mean Squared Error	23192.38	8407907	18266525	295892.8
RMSE	152.2904	2899.639	4273.935	543.9603
pval, paired t-test	0.339513	0.723967	0.977356	0.458111
alpha	0.05	0.05	0.05	0.05
Fail t-test?	FALSE	FALSE	FALSE	FALSE
Pass t-test?	Yes	Yes	Yes	Yes

Table 5-14. Milwaukee River Station RI-04 Load Calibration Statistics (1994-1998).

		TSS (tons/day)	NO2+NO3 (kg/day)	TN (kg/day)	TP (kg/day)
Mean	Observed	106.1033	1283.644	2896.8	225.4934
	Paired Sim	87.17326	1697.76	3532.443	333.4475
	Full Sim	36.2619	1058.369	2328.546	196.8478
Median	Observed	12.85659	383.0848	1279.828	64.39388
	Paired Sim	16.3331	230.0714	1045.081	58.20846
	Full Sim	11.63735	305.7654	1005.942	73.37675

Count	59	58	57	59
Mean Error	-18.9301	440.1474	706.534	107.954
Mean Absolute Error	64.21589	1085.924	1904.245	240.2158
Mean Squared Error	64360.91	15384629	36409236	776440.9
RMSE	253.6945	3922.324	6034.007	881.1589
pval, paired t-test	0.570974	0.397451	0.381383	0.351056
alpha	0.05	0.05	0.05	0.05
Fail t-test?	FALSE	FALSE	FALSE	FALSE
Pass t-test?	Yes	Yes	Yes	Yes

Table 5-15. Milwaukee River Station RI-04 Load Validation Statistics (1999-2001).

		TSS (tons/day)	NO2+NO3 (kg/day)	TN (kg/day)	TP (kg/day)
Mean	Observed	130.3929	2141.915	4532.382	353.0943
	Paired Sim	123.2728	2494.182	5251.565	541.9247
	Full Sim	51.11647	1617.607	3466.632	297.4575
Median	Observed	25.74986	1012.882	2197.563	132.5065
	Paired Sim	29.2279	719.2096	2293.875	128.4227
	Full Sim	14.54035	594.785	1701.706	98.59455

Count	53	45	43	52
Mean Error	-7.1201	186.8825	522.7302	198.4833
Mean Absolute Error	67.6434	1493.598	2119.65	321.6387
Mean Squared Error	24084.16	7724174	16434377	503030.6
RMSE	155.1907	2779.24	4053.933	709.2465
pval, paired t-test	0.741831	0.657034	0.404177	0.042406
alpha	0.05	0.05	0.05	0.05
Fail t-test?	FALSE	FALSE	FALSE	TRUE
Pass t-test?	Yes	Yes	Yes	No

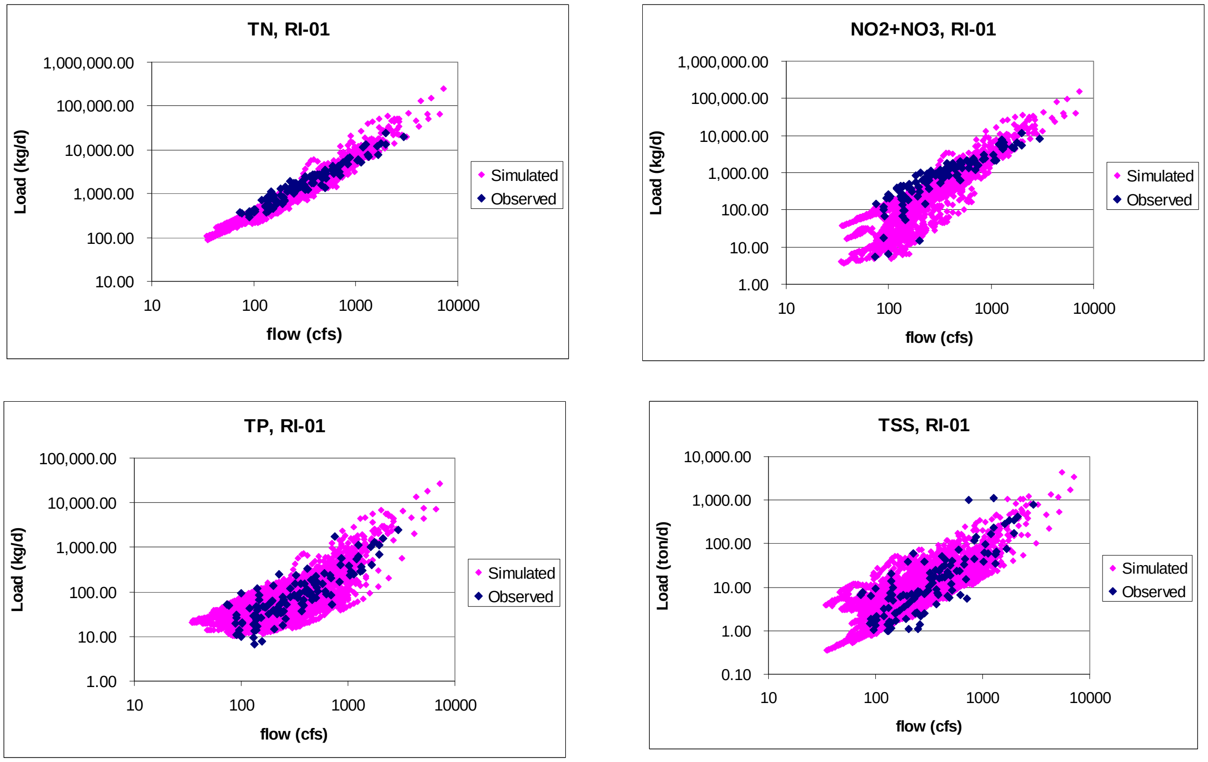


Figure 5-5. Log-log transport plot for nutrient and sediment loads at RI-01, 1994-2001.

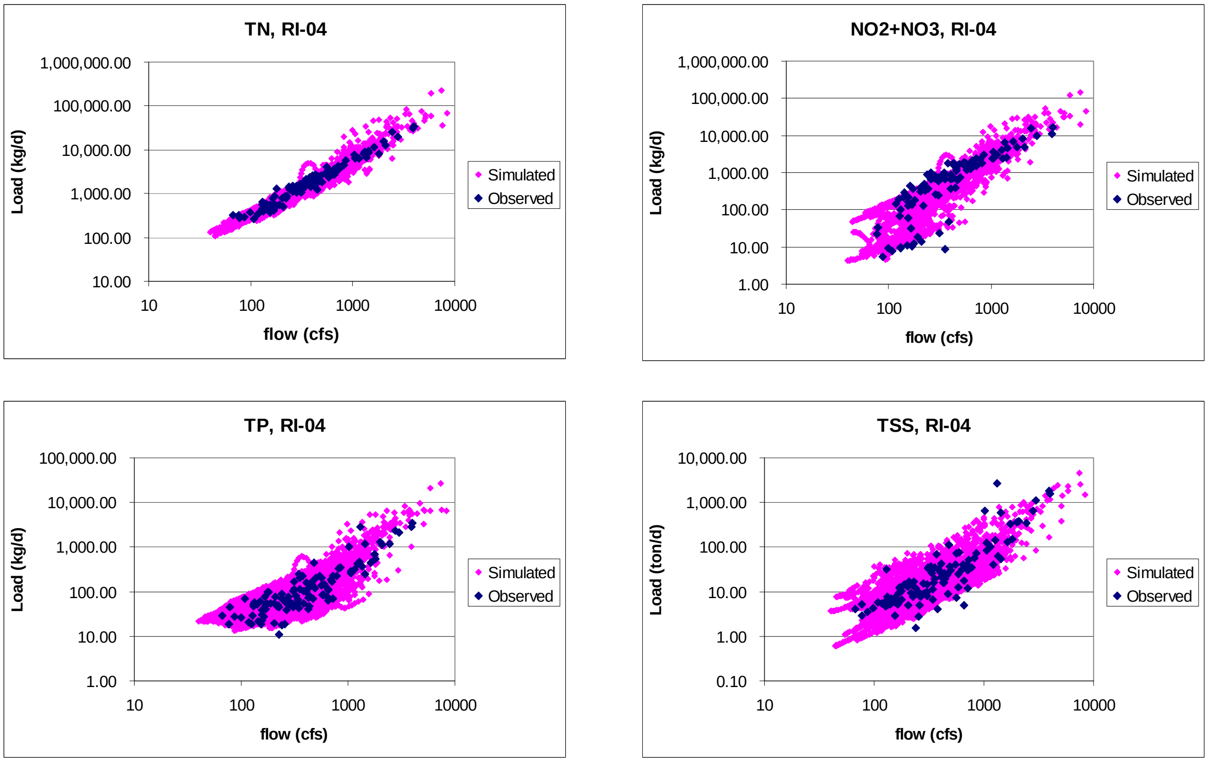


Figure 5-6. Log-log transport plot for nutrient and sediment loads at RI-04, 1994-2001.

Another useful test of representation of the load-flow relationships is obtained by plotting simulated and observed loads against the probability of exceedance of a given flow value, based on the period of record at the gage. These are known as load-duration curves. As a general rule, the portion of this relationship corresponding to flows that are exceeded less than 20 percent of the time can be assumed to represent high-flow, washoff events, while the remainder of the relationship corresponds to moderate and low flows.

The untransformed load-duration curve relationship is highly nonlinear. These plots can be linearized by plotting the natural logarithm of load versus the logit of flow, where the logit is defined as the natural log of (P/(1-P)), given P is the flow exceedance probability (Pindyck and Rubinfeld, 1981). After the log-logit transformation, separate linear regressions can be performed on the natural logarithms of observed and simulated loads versus logit of flow for the 0-20 percent and 20-100 percent flow ranges. (The breakpoint between these ranges corresponds to a logit of –1.386.) When the model is simulating accurately, the slope coefficients of the observed and simulated regressions should be in agreement within each of the two flow ranges. The analysis shows that this test is generally met in the Milwaukee River model. Full results are provided in Attachment I.

REFERENCES

APHA. 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed. American Public Health Association (APHA), 1015 15th Street, NW, Washington, DC.

Bicknell, B.R., J.C. Imhoff, J. Kittle, A.S. Donigian, and R.C. Johansen. 1996. *Hydrological Simulation Program –FORTRAN, User's Manual for Release H*. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Bowie, G.L., et al. 1985. Rates, Constants, and Kinetic Formulations in Surface Water Quality Modeling, 2d. ed. EPA/600/3-85/040. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Box, G.E.P., J.S. Hunter and W.G. Hunter. 1978. *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building.* John Wiley and Sons, New York.

Chapra, S. and G. Pelletier. 2003. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

Donigian, A.S., Jr., and J.T. Love. 2002. Sediment Calibration Procedures and Guidelines for Watershed Modeling. Aqua Terra Consultants, Mountain View, CA.

Donigian, A.S., Jr., J.C. Imhoff, B.R. Bicknell, and J.L. Kittle, Jr. 1984. Application Guide for Hydrological Simulation Program – FORTRAN (HSPF). EPA-600/3-84-065. Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Haith, D.A. and D.E. Merrill. 1987. Evaluation of a daily rainfall erosivity model. *Trans. Amer. Soc. Agric. Eng.*, 28(6): 1916-1920.

Haith, D.A., R. Mandel, and R.S. Wu. 1992. *GWLF - Generalized watershed loading functions, Version 2.0 - User's manual*. Department of Agricultural Engineering, Cornell University, Ithaca, NY.

Hartigan, J.P., T.F. Quasebarth, and E. Southerland. 1983. Calibration of NPS model loading factors. *Journal of Environmental Engineering*, 109(6): 1259-1272.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. *Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage*, 89(IR4): 15-41.

Jensen, M.E., D.C.N. Rob, and C.E. Franzoy. 1969. Scheduling irrigations using climate-crop-soil data. Proceedings, National Conference on Water Resources Engineering of the American Society of Civil Engineers, New Orleans, LA.

Mancini, J.L. 1978. Numerical estimates of coliform mortality rates under various conditions. *J. Water Poll. Contr. Fed.*, 50(11): 2477-2484.

MPCA. 2001. Status of a Model Simulation of Nonpoint-Source Contamination in the Minnesota River Basin, April 1999. Final report submitted by the USGS to Minnesota Pollution Control Agency.

Pindyck, R.S. and D.L. Rubinfeld. 1981. *Econometric Models and Economic Forecasts, Second Edition.* McGraw-Hill, New York.

Richardson, C.W., G.R. Foster, and D.A. Wright. 1983. Estimation of erosion index from daily rainfall amount. *Trans. Am. Soc. Agric. Eng*., 26(1): 153-157, 160.

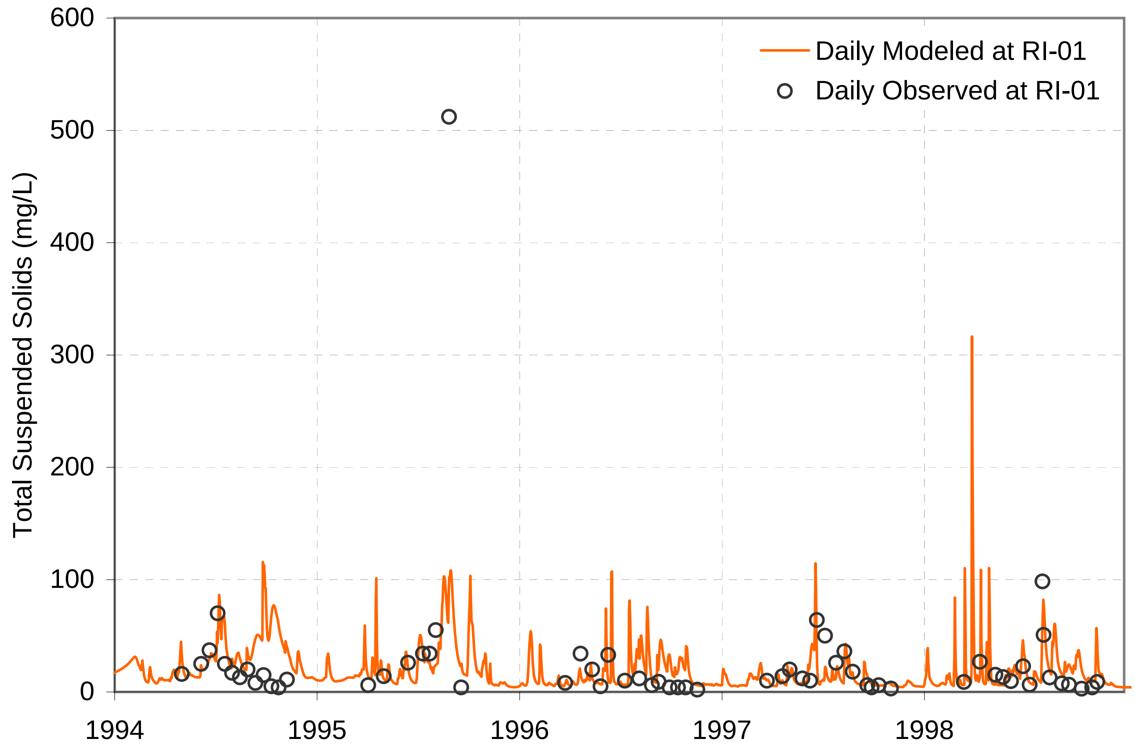
Tetra Tech, Inc. and CH2M HILL. 1999. Gwinnett County Watershed Assessment and Modeling Study, Watershed Model Calibration Technical Memorandum. Prepared for Gwinnett County, GA by Tetra Tech, Inc., Research Triangle Park, NC.

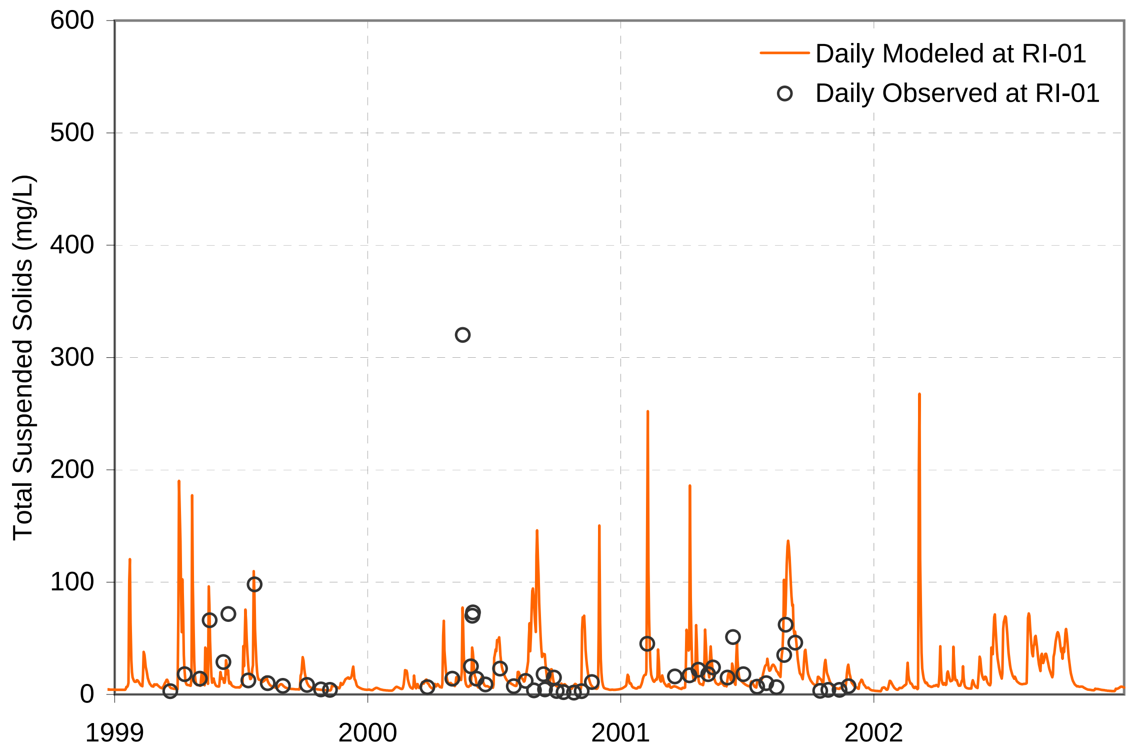
Tetra Tech. 2002. Minnesota River Basin Model, Model Calibration and Validation Report. Prepared for Minnesota Pollution Control Agency, St. Paul, MN by Tetra Tech, Inc., Research Triangle Park, NC.

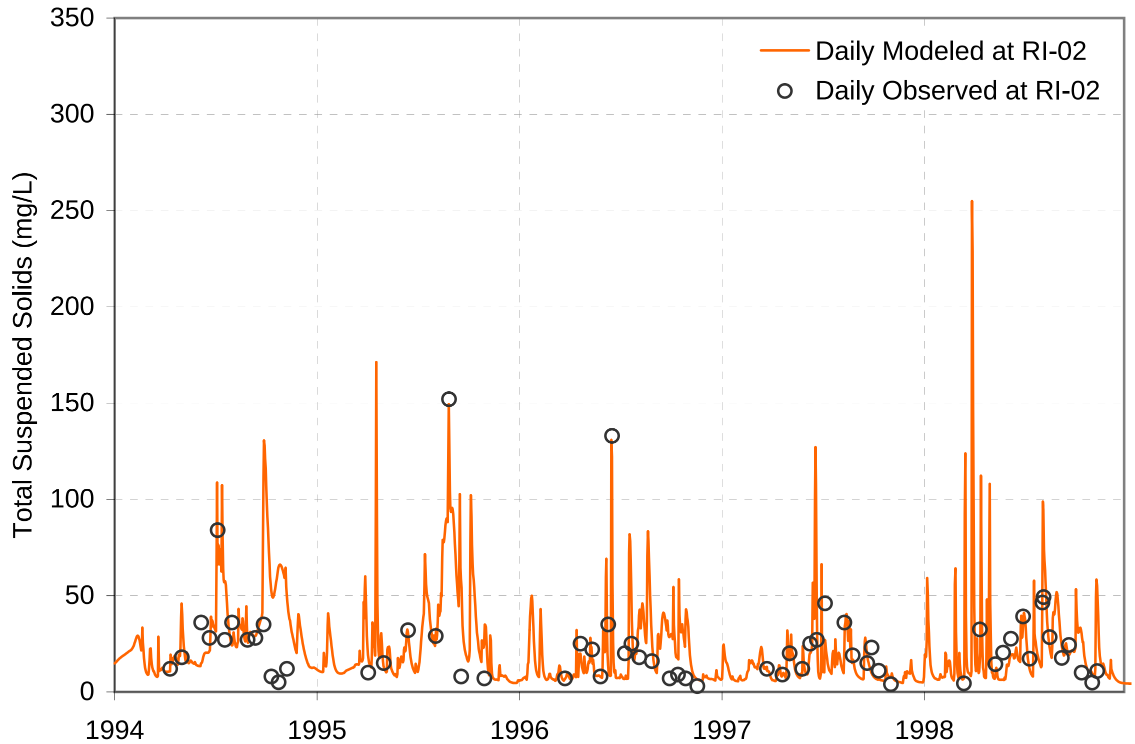
Thomann, R.V. and J.A. Mueller. 1987. Principles of Surface Water Quality Modeling and Control. Harper & Row, New York.

U.S. Environmental Protection Agency (USEPA). 2000. *BASINS Technical Note 6. Estimating Hydrology and Hydraulic Parameters for HSPF*. EPA-823-R00-012. U.S. Environmental Protection Agency. Office of Water. July 2000.

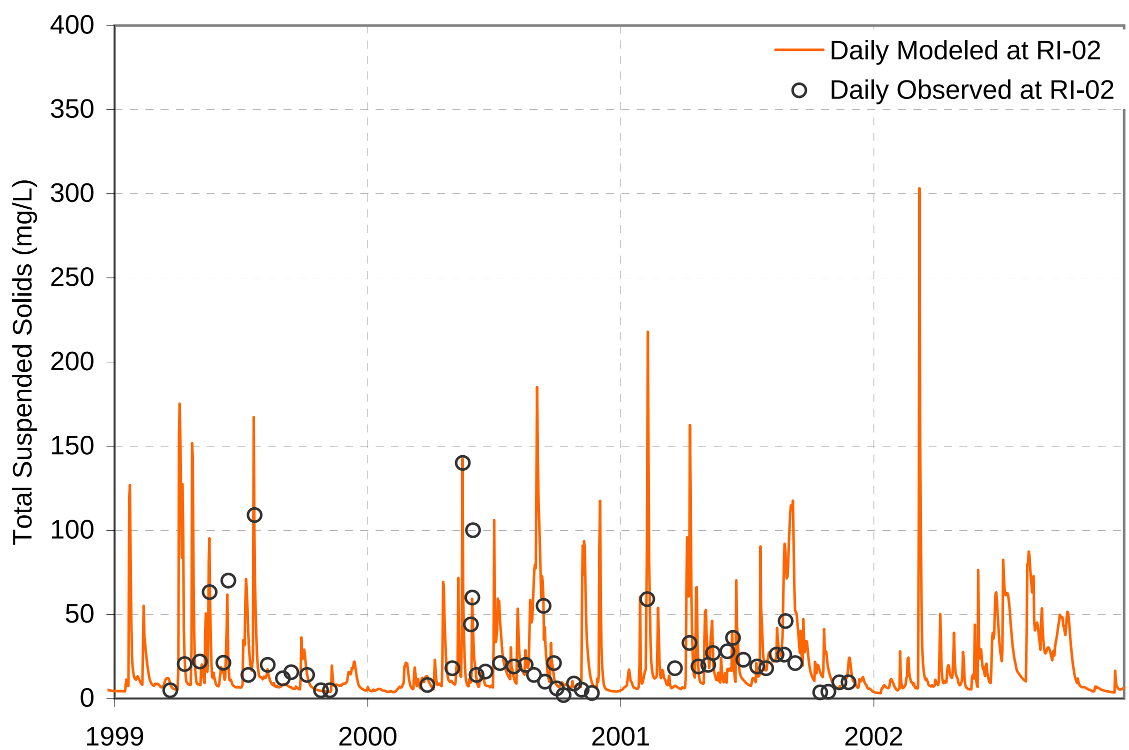
ATTACHMENT A – CALIBRATION AND VALIDATION PLOTS FOR TOTAL SUSPENDED SOLIDS


Daily Modeled at RI-01
Daily Observed at RI-01
Total Suspended Solids (mg/L)
0
100
200
300
400
500
600
1994
1995
1996
1997
1998

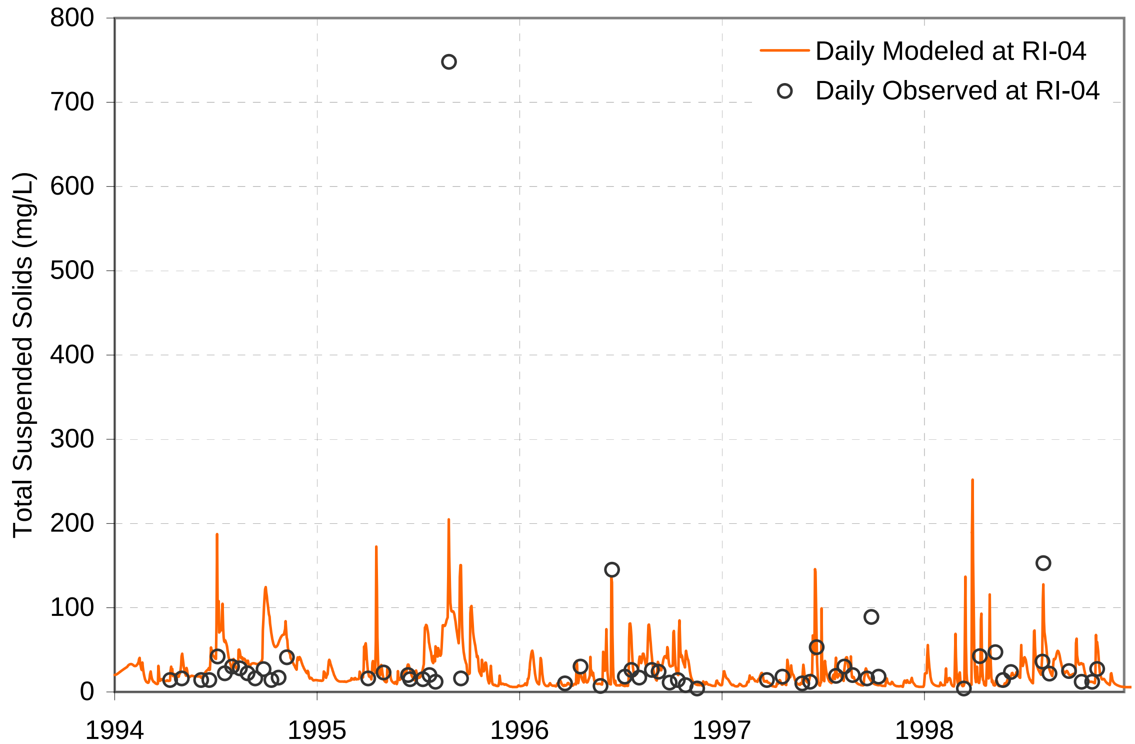

Daily Modeled at RI-01
Daily Observed at RI-01
Total Suspended Solids (mg/L)
0
100
200
300
400
500
600
1999
2000
2001
2002



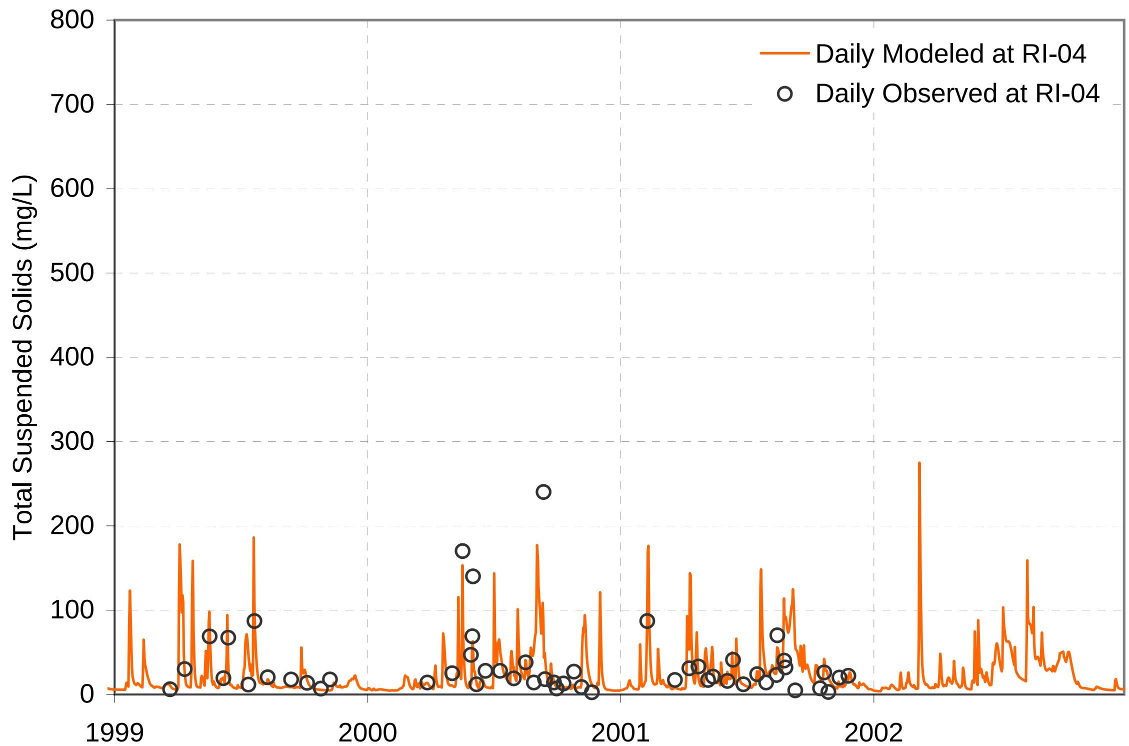
Daily Modeled at RI-02
Daily Observed at RI-02
Total Suspended Solids (mg/L)
350
300
250
200
150
100
50
0
1994
1995
1996
1997
1998



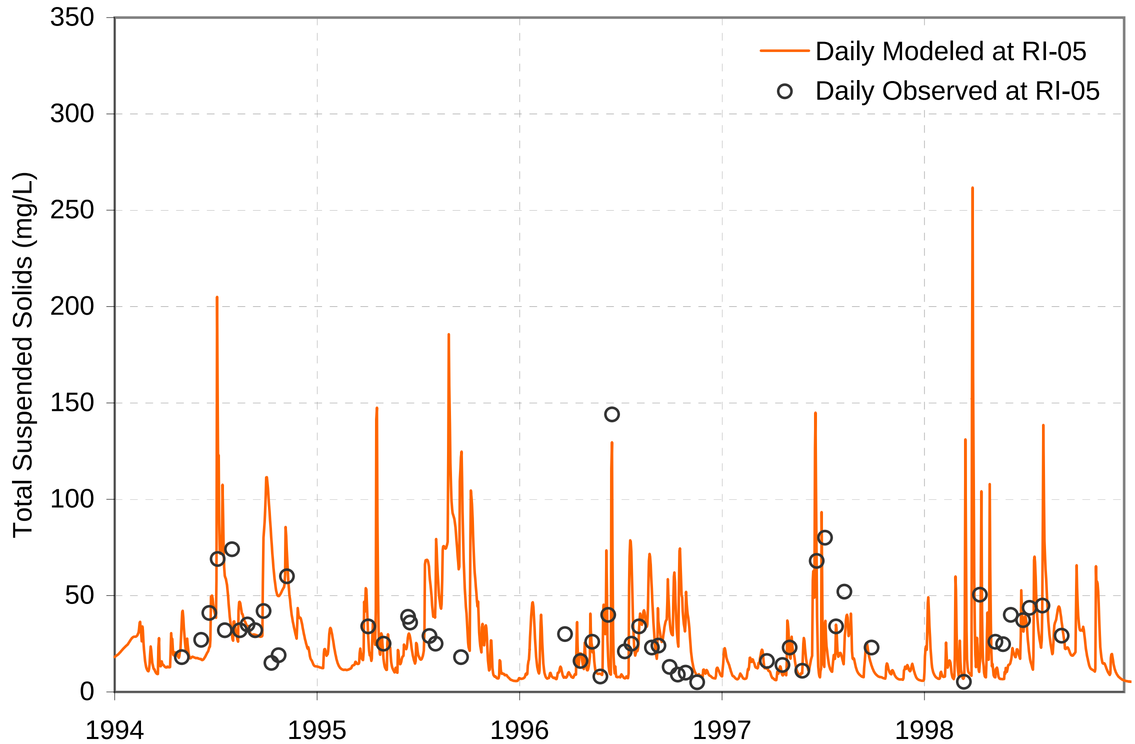
Daily Modeled at RI-02
Daily Observed at RI-02
Total Suspended Solids (mg/L)
400
350
300
250
200
150
100
50
0
1999
2000
2001
2002



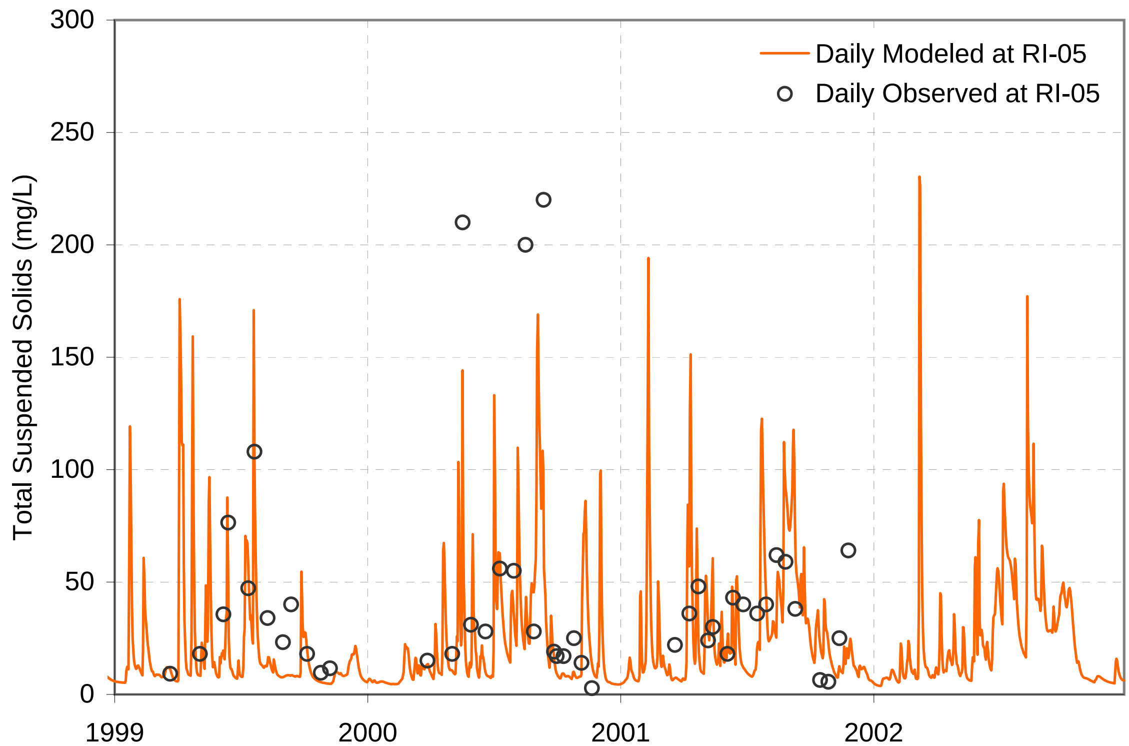
Daily Modeled at RI-04
Daily Observed at RI-04
Total Suspended Solids (mg/L)
0
100
200
300
400
500
600
700
800
1994
1995
1996
1997
1998



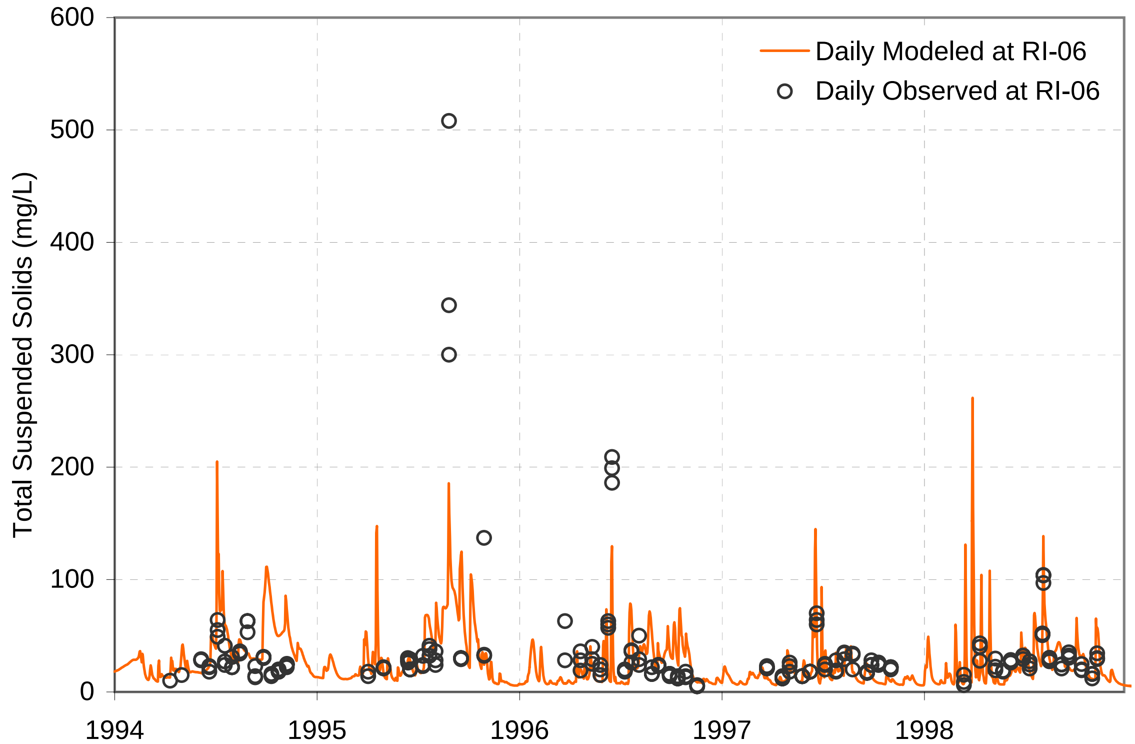
Daily Modeled at RI-04
Daily Observed at RI-04
Total Suspended Solids (mg/L)
0
100
200
300
400
500
600
700
800
1999
2000
2001
2002



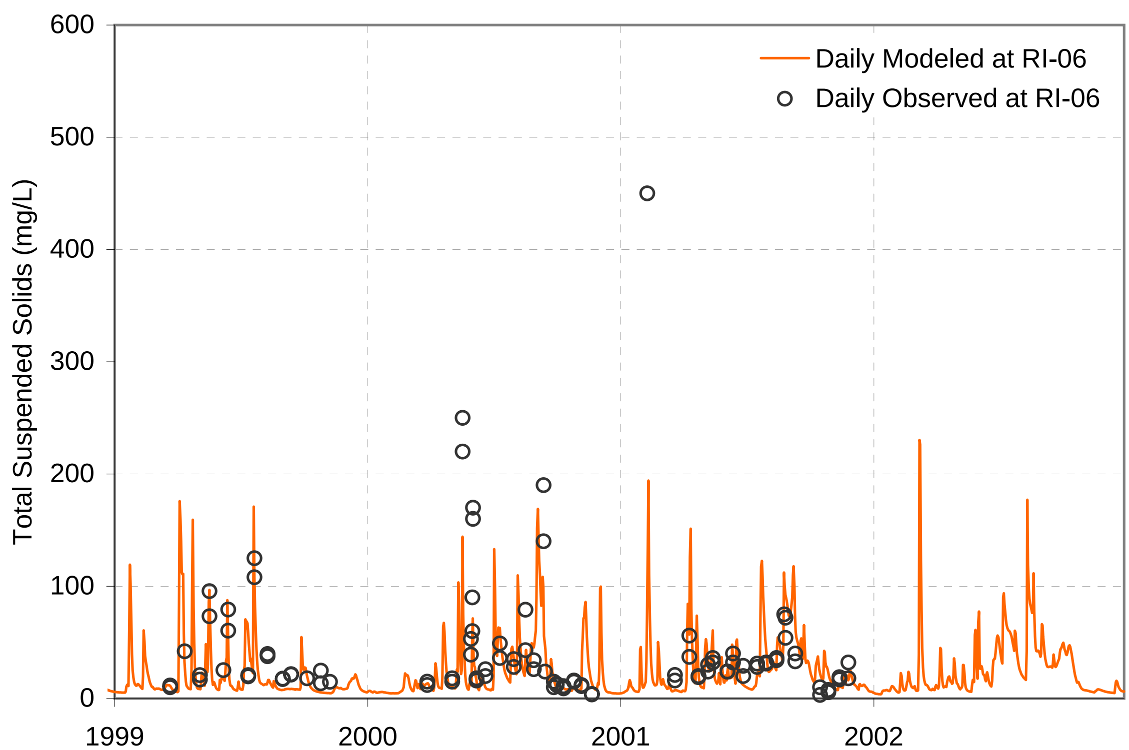
Daily Modeled at RI-05
Daily Observed at RI-05
Total Suspended Solids (mg/L)
0
50
100
150
200
250
300
350
1994
1995
1996
1997
1998



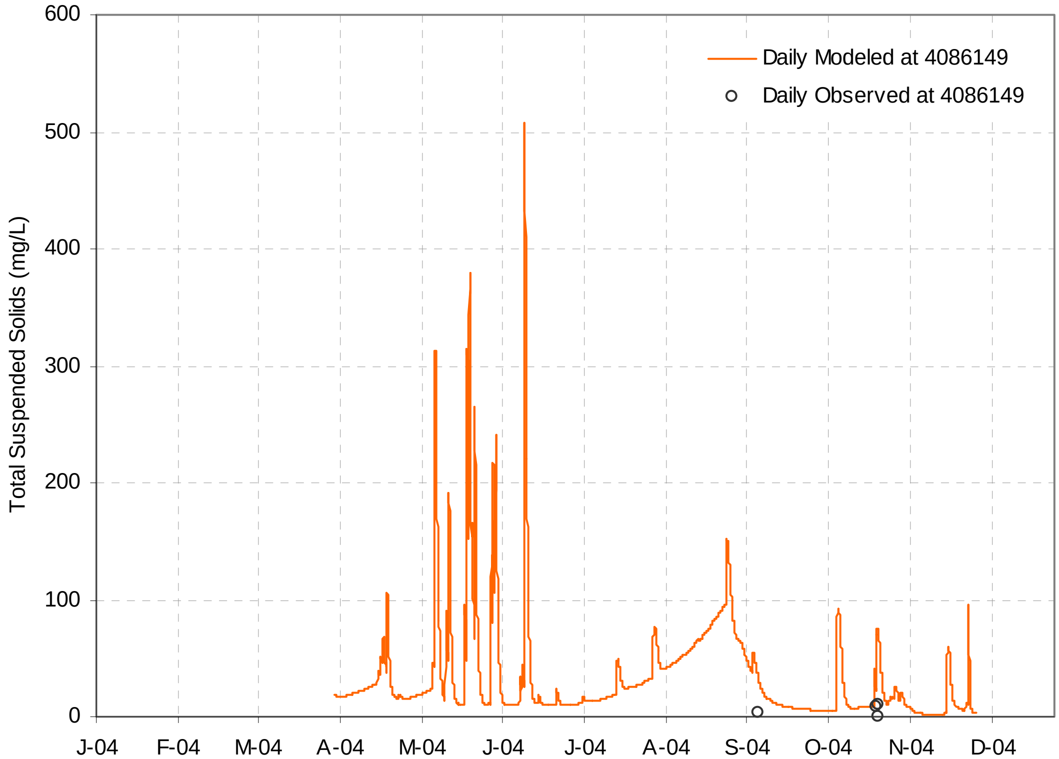
Daily Modeled at RI-05
Daily Observed at RI-05
Total Suspended Solids (mg/L)
0
50
100
150
200
250
300
1999
2000
2001
2002

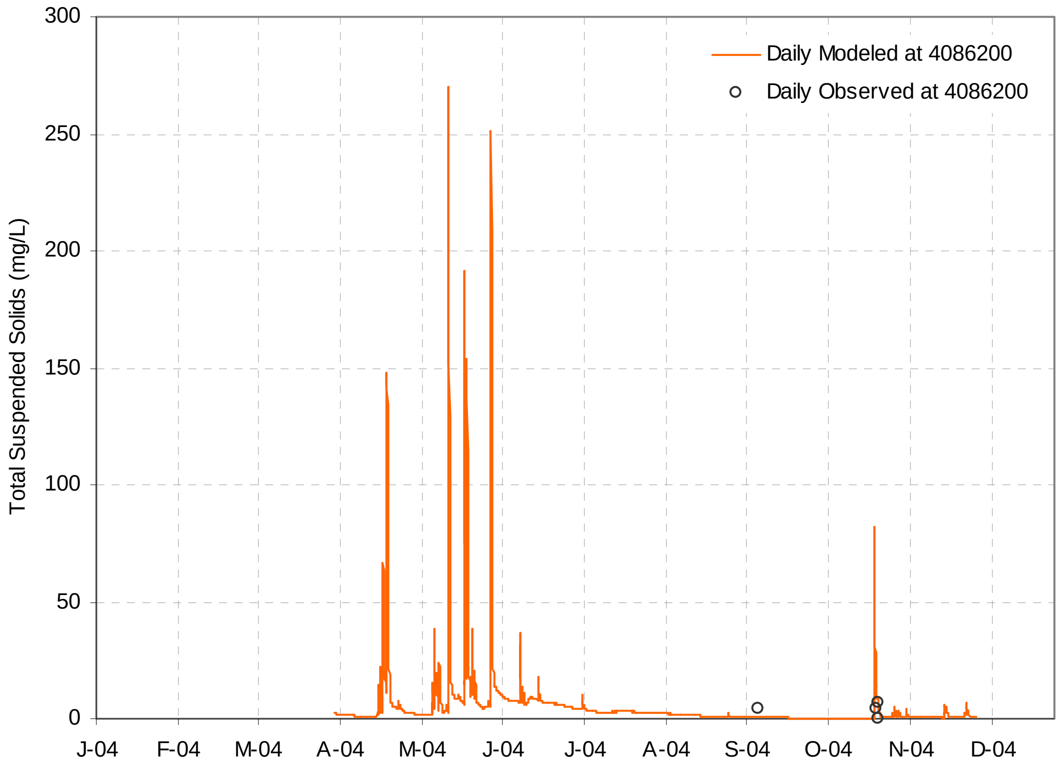


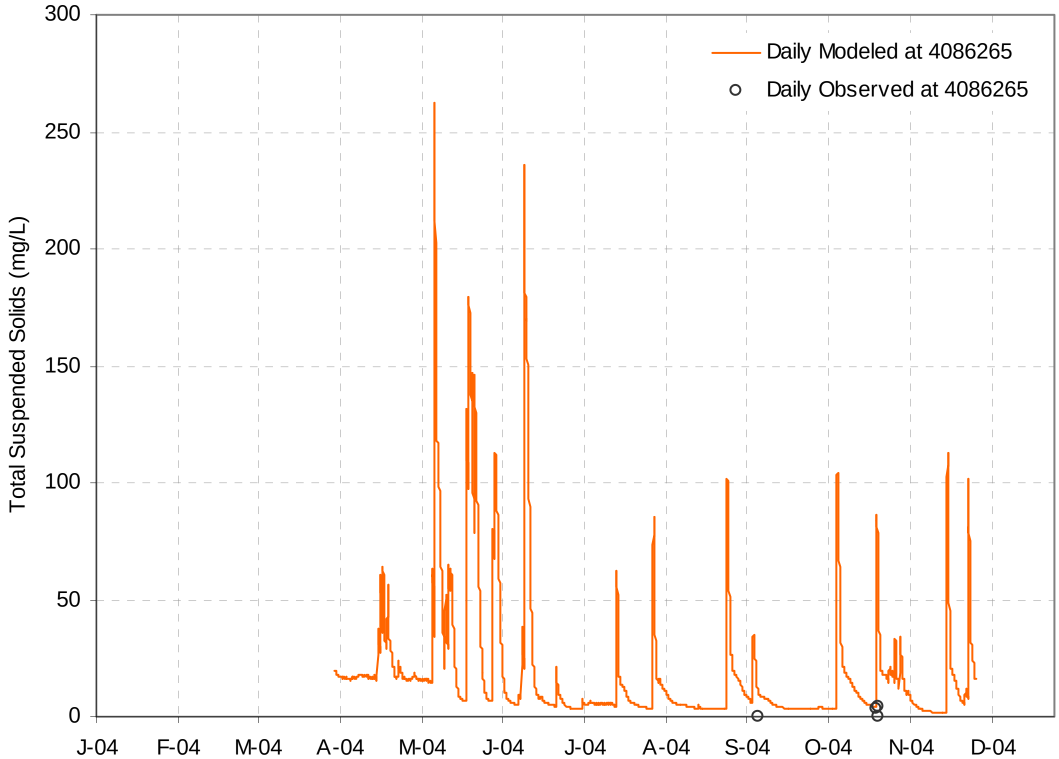
Total Suspended Solids (mg/L)
600
500
400
300
200
100
0
1994
1995
1996
1997
1998
Daily Modeled at RI-06
Daily Observed at RI-06



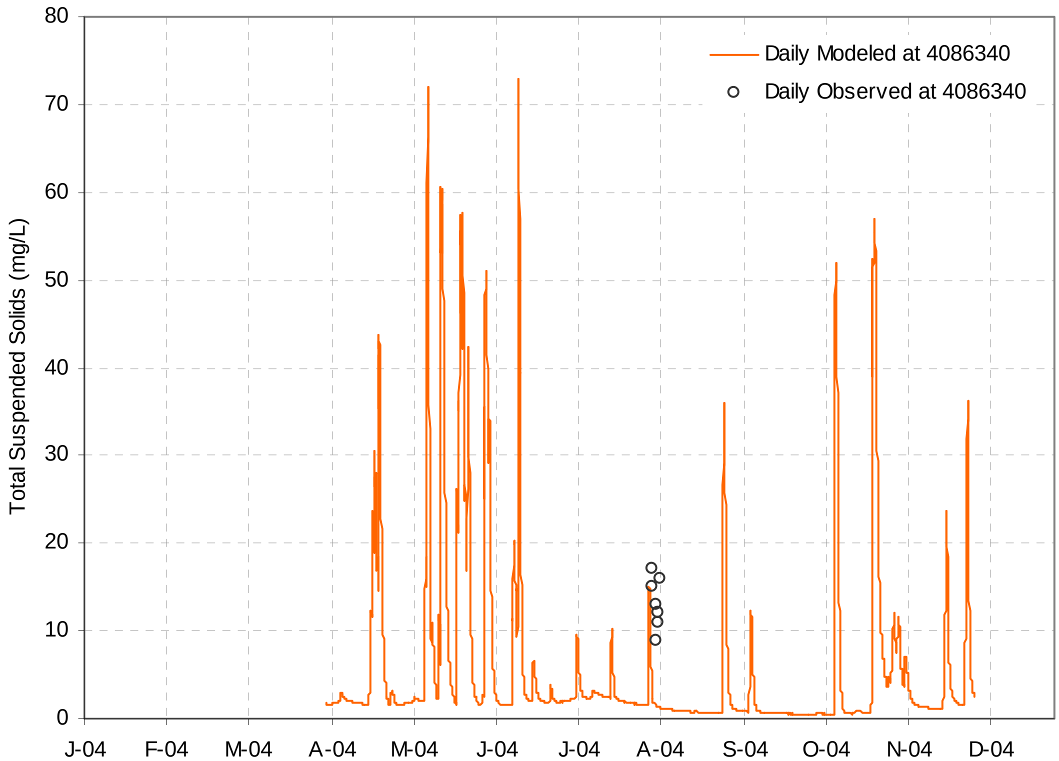
Total Suspended Solids (mg/L)
600
500
400
300
200
100
0
1999
2000
2001
2002
Daily Modeled at RI-06
Daily Observed at RI-06


Daily Modeled at 4086149
Daily Observed at 4086149
Total Suspended Solids (mg/L)
600
500
400
300
200
100
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

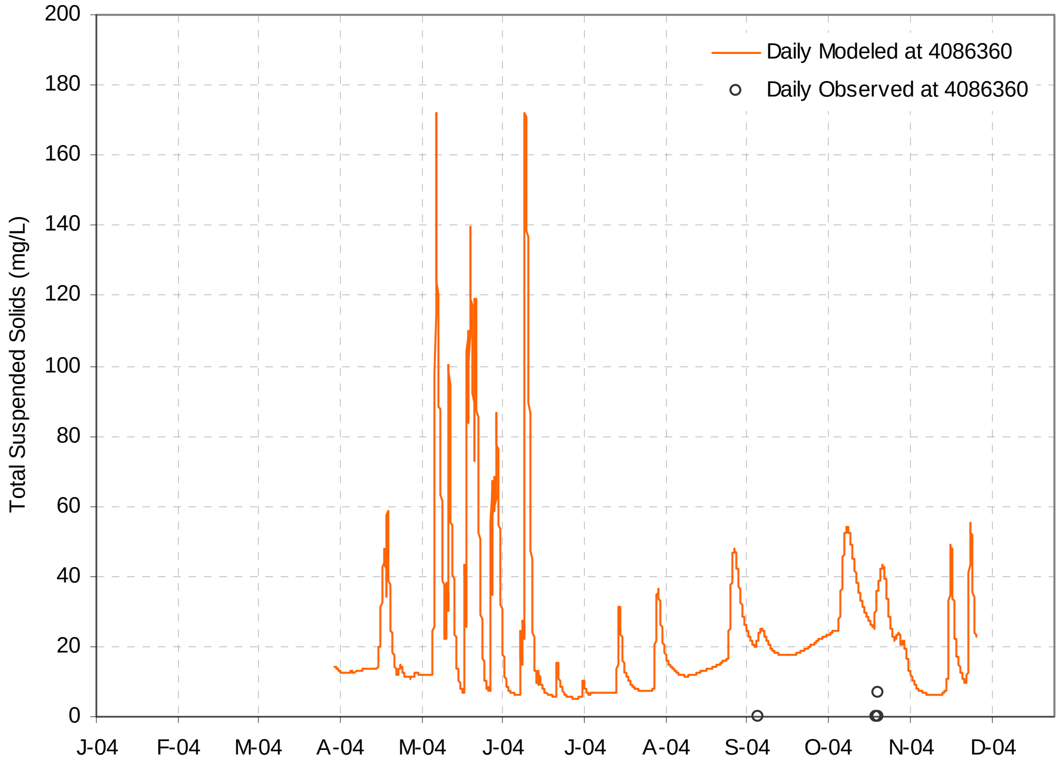

Daily Modeled at 4086200
Daily Observed at 4086200
Total Suspended Solids (mg/L)
300
250
200
150
100
50
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04



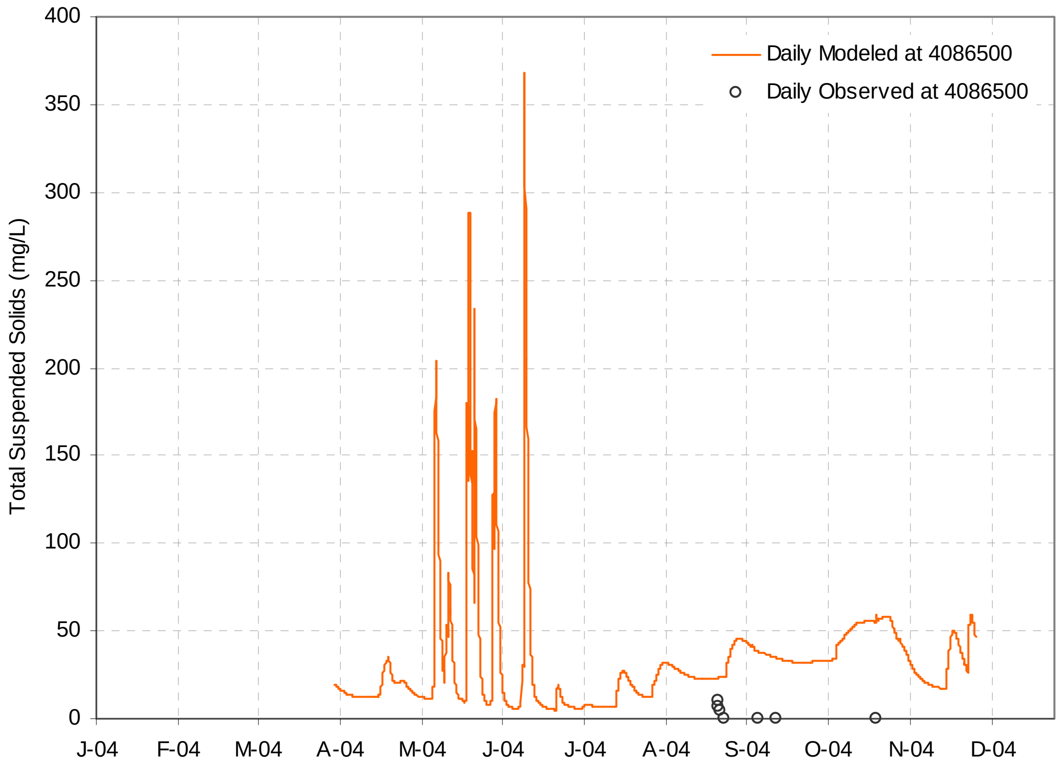
Total Suspended Solids (mg/L)
300
250
200
150
100
50
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086265
Daily Observed at 4086265



Total Suspended Solids (mg/L)
80
70
60
50
40
30
20
10
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086340
Daily Observed at 4086340

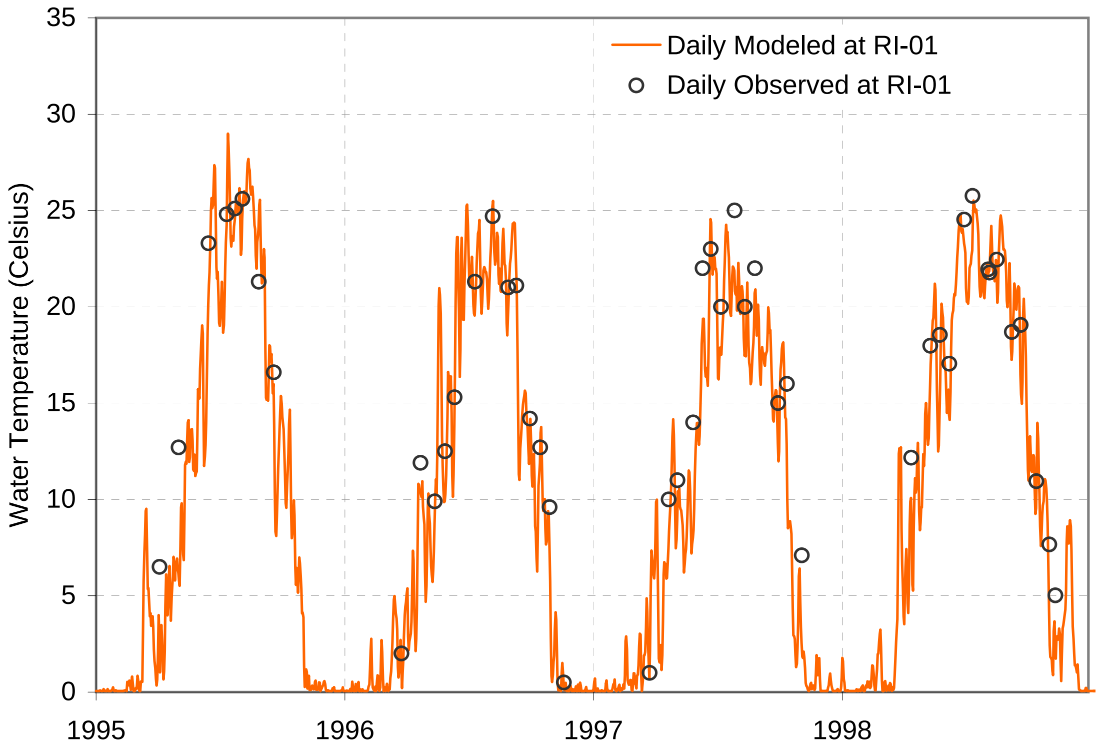


Total Suspended Solids (mg/L)
200
180
160
140
120
100
80
60
40
20
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086360
Daily Observed at 4086360

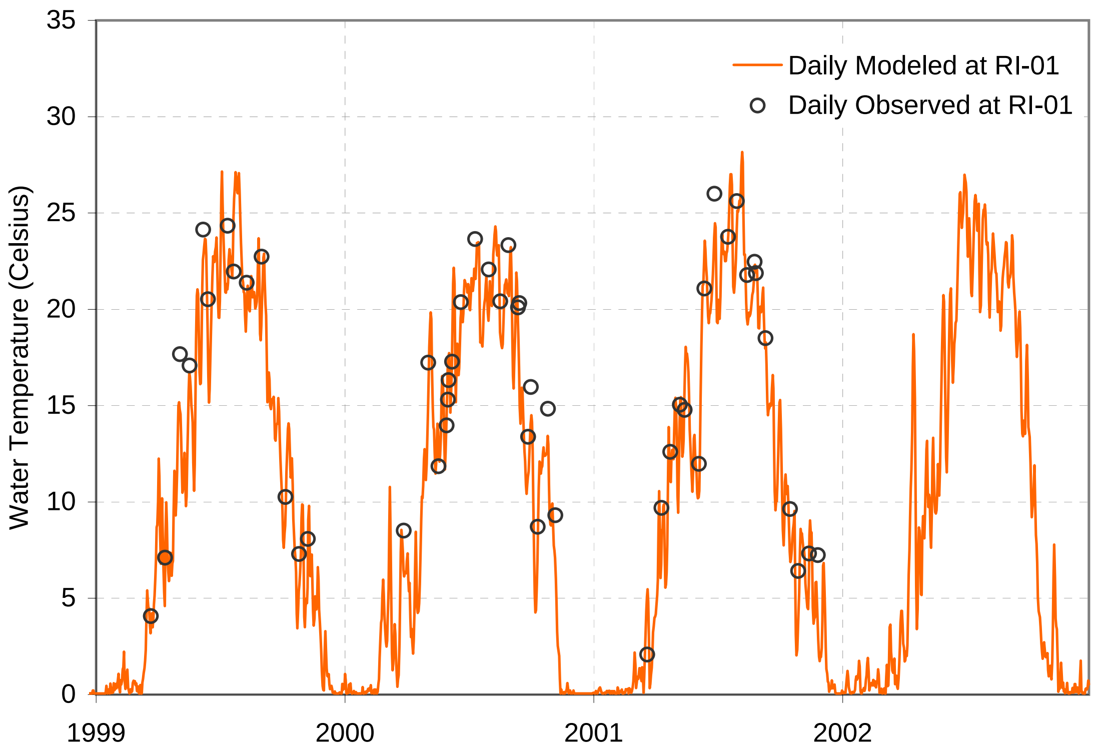


Total Suspended Solids (mg/L)
400
350
300
250
200
150
100
50
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086500
Daily Observed at 4086500

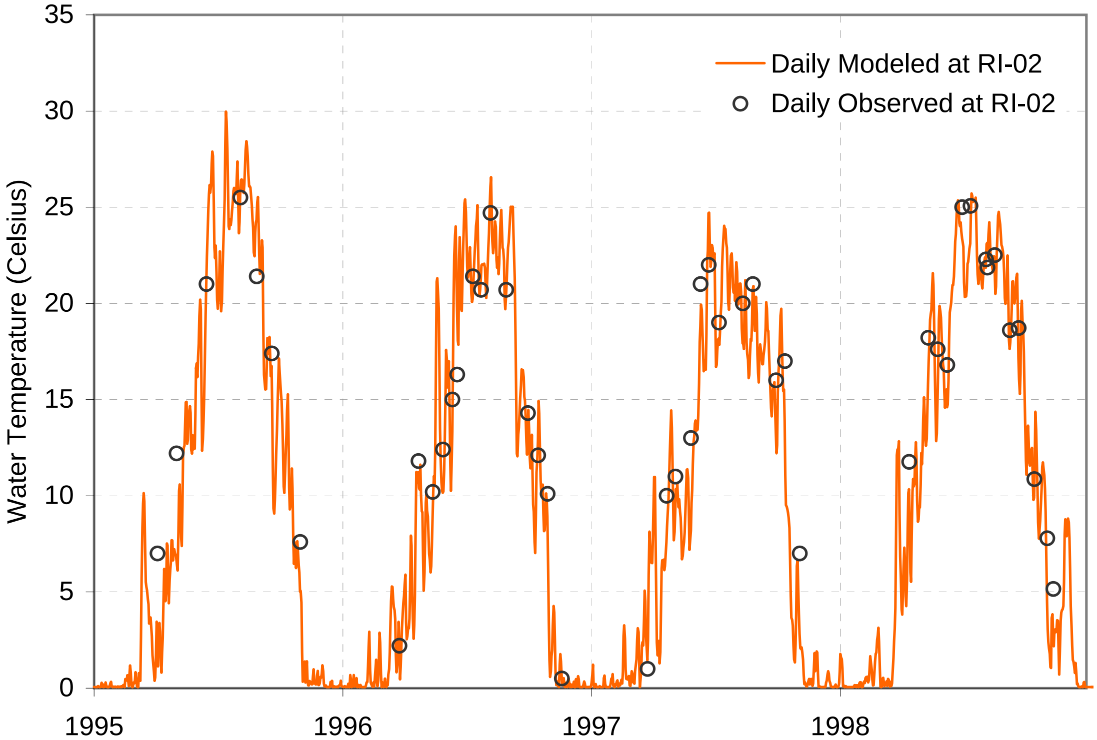
ATTACHMENT B – CALIBRATION AND VALIDATION PLOTS FOR TEMPERATURE



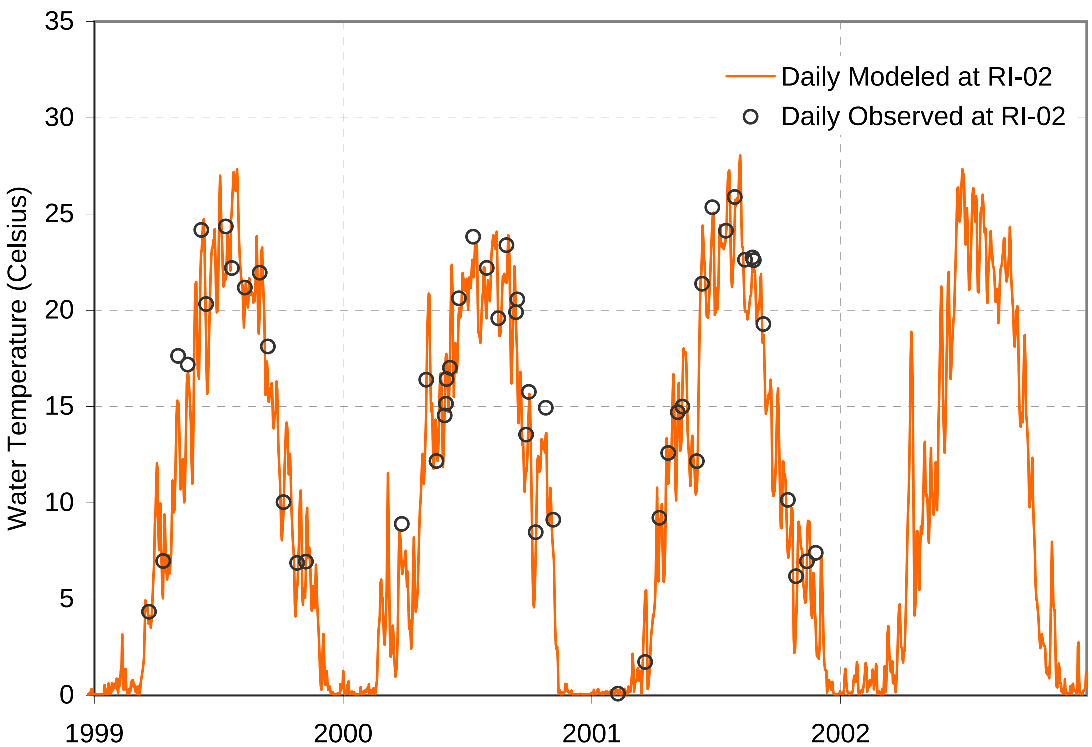
Daily Modeled at RI-01
Daily Observed at RI-01
Water Temperature (Celsius)
35
30
25
20
15
10
5
0
1995
1996
1997
1998



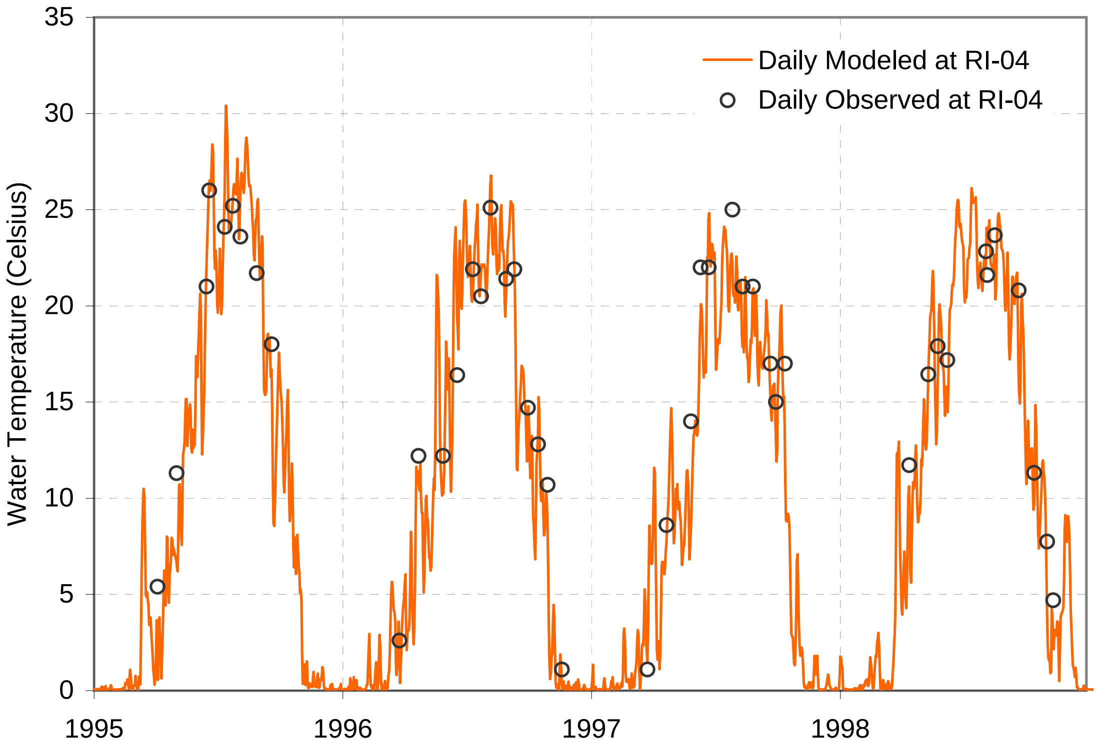
Daily Modeled at RI-01
Daily Observed at RI-01
Water Temperature (Celsius)
35
30
25
20
15
10
5
0
1999
2000
2001
2002

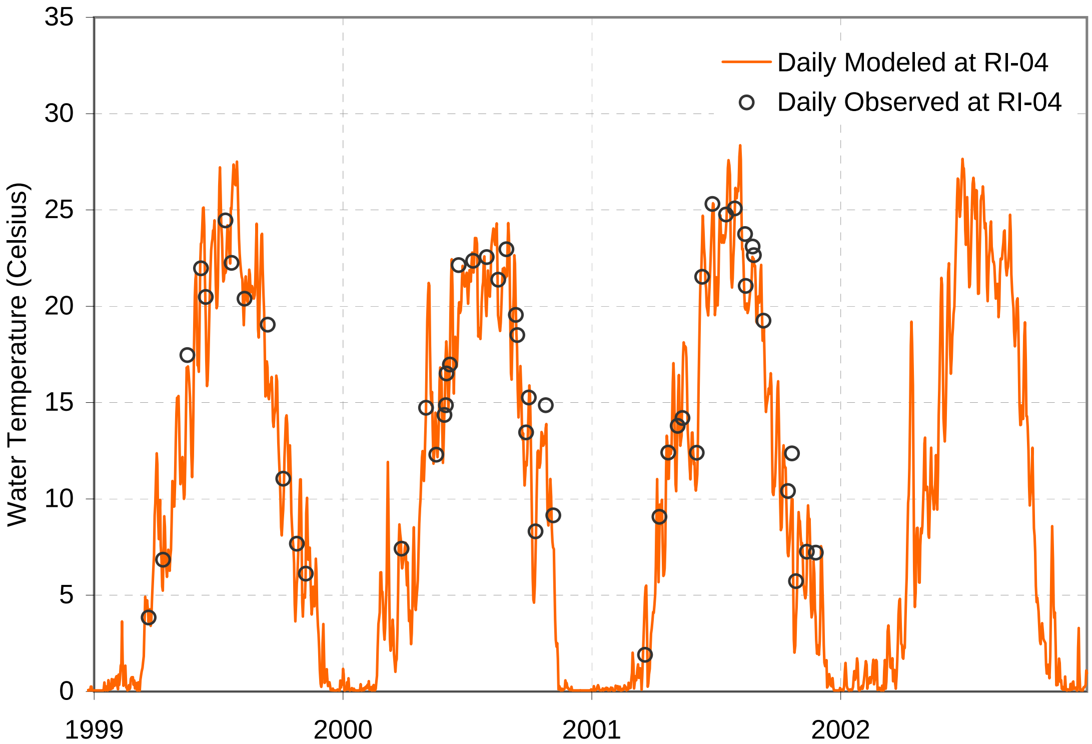


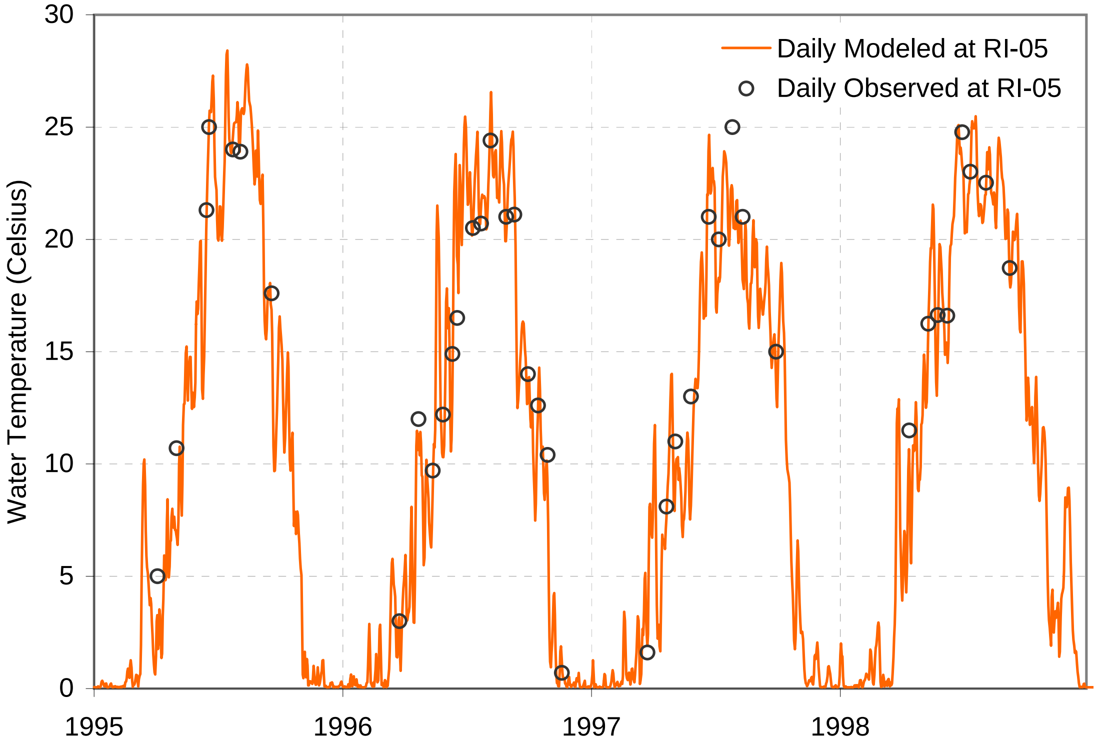
Daily Modeled at RI-02
Daily Observed at RI-02
Water Temperature (Celsius)
35
30
25
20
15
10
5
0
1995
1996
1997
1998



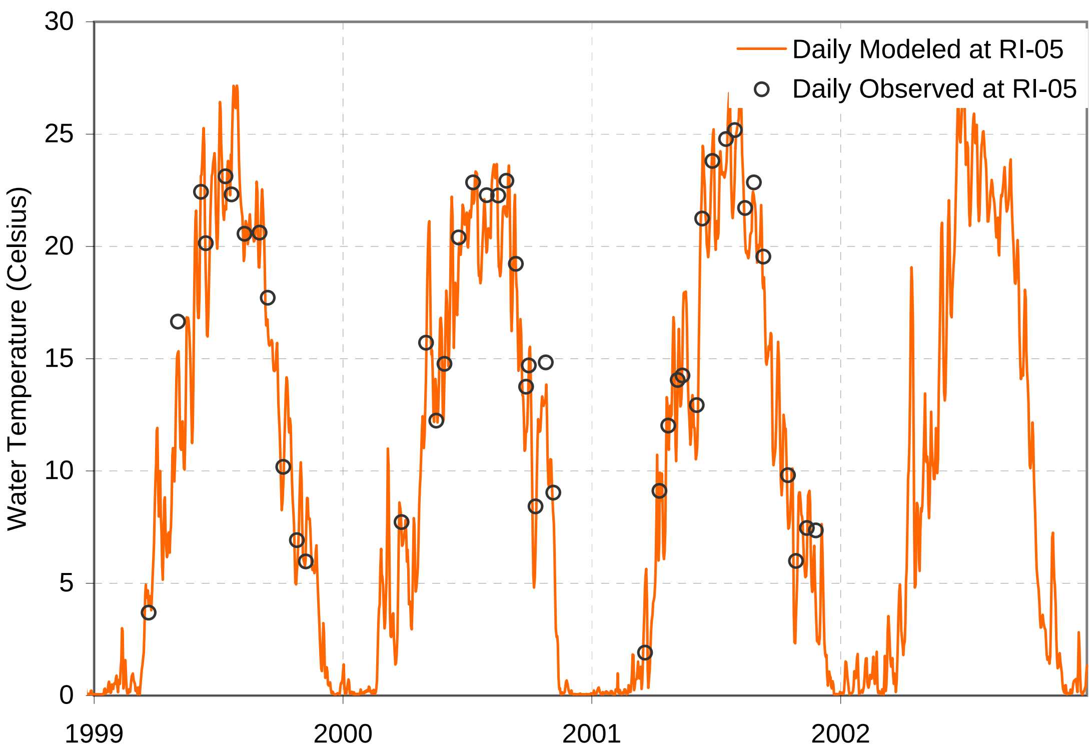
Daily Modeled at RI-02
Daily Observed at RI-02
Water Temperature (Celsius)
35
30
25
20
15
10
5
0
1999
2000
2001
2002


Daily Modeled at RI-04
Daily Observed at RI-04
Water Temperature (Celsius)
35
30
25
20
15
10
5
0
1995
1996
1997
1998

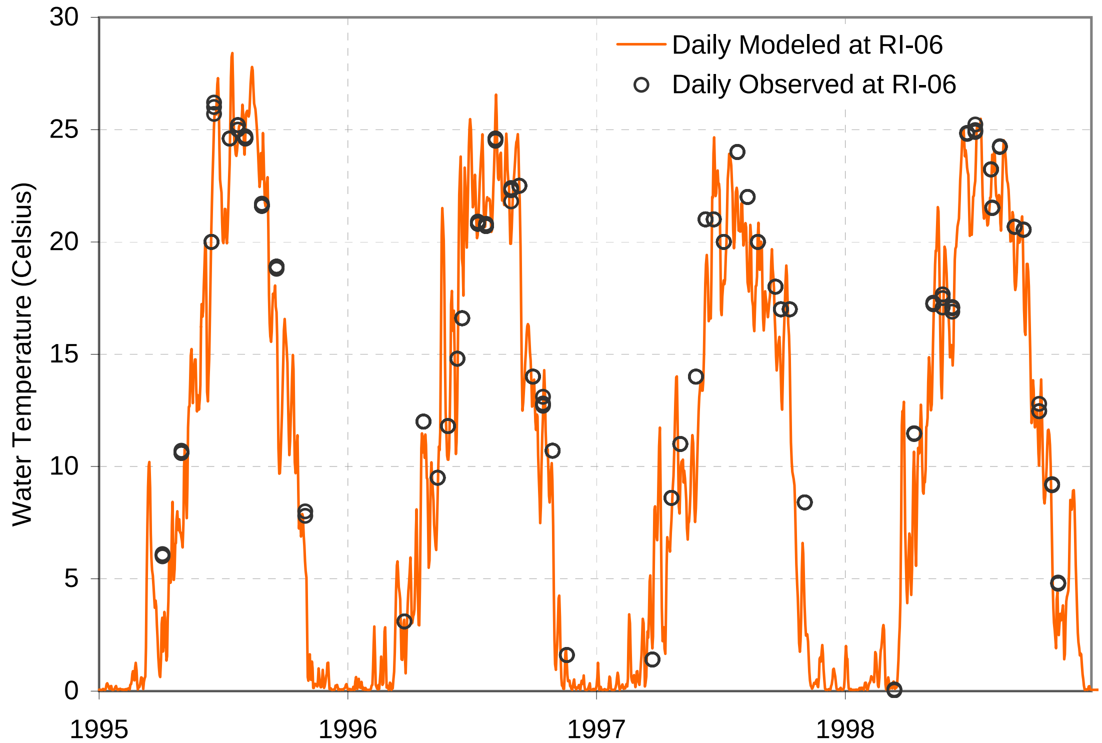

Daily Modeled at RI-04
Daily Observed at RI-04
Water Temperature (Celsius)
35
30
25
20
15
10
5
0
1999
2000
2001
2002



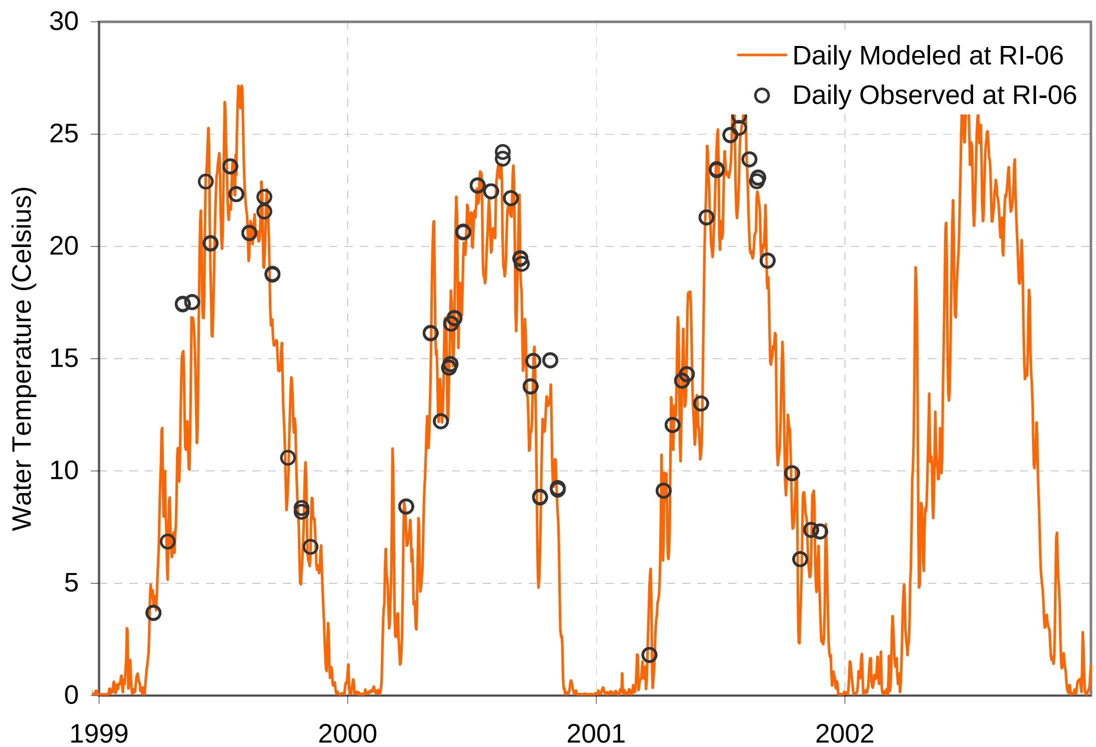
Daily Modeled at RI-05
Daily Observed at RI-05
Water Temperature (Celsius)
0
5
10
15
20
25
30
1995
1996
1997
1998



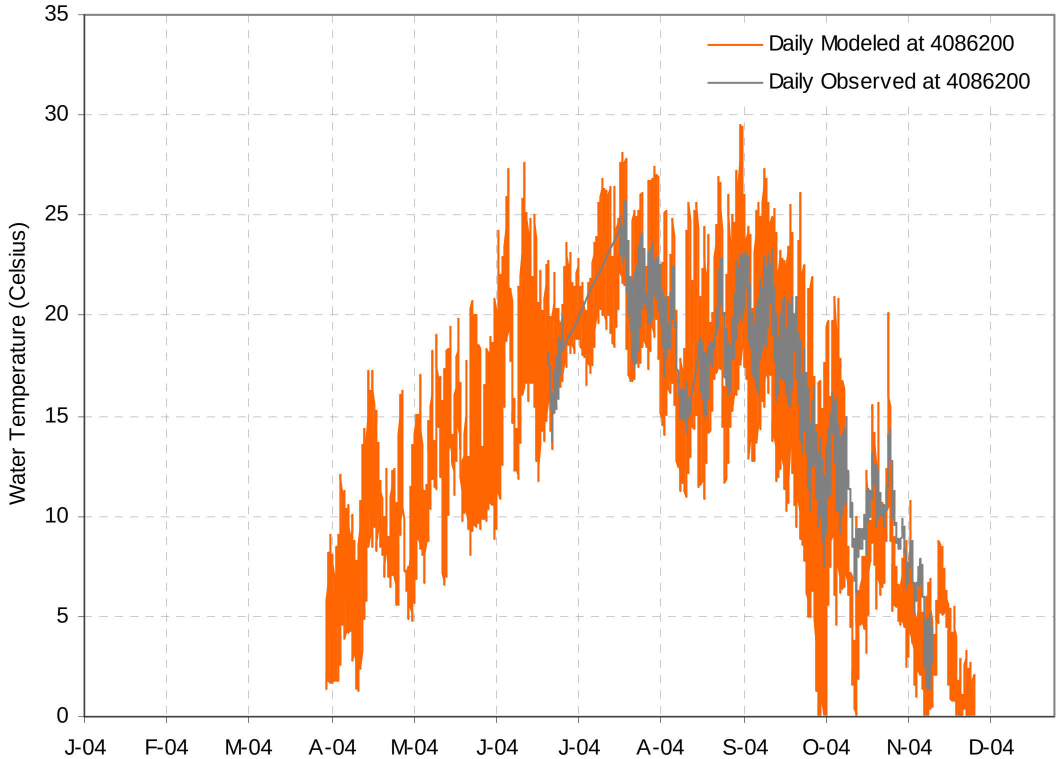
Daily Modeled at RI-05
Daily Observed at RI-05
Water Temperature (Celsius)
0
5
10
15
20
25
30
1999
2000
2001
2002



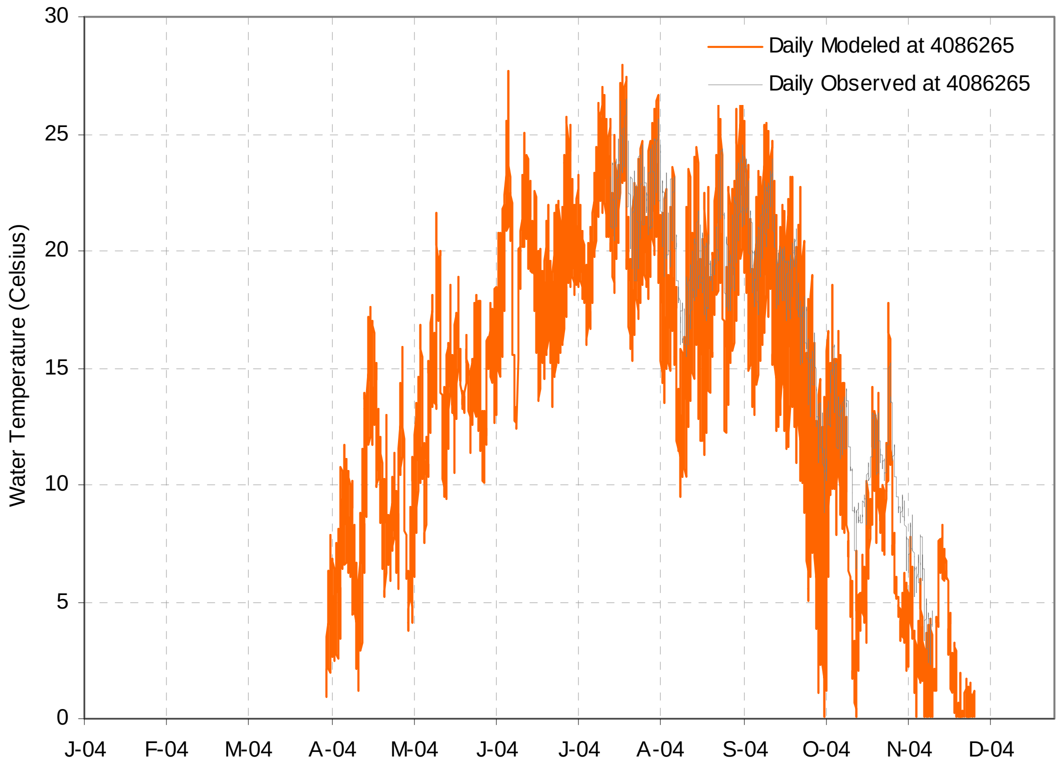
Daily Modeled at RI-06
Daily Observed at RI-06
Water Temperature (Celsius)
0
5
10
15
20
25
30
1995
1996
1997
1998



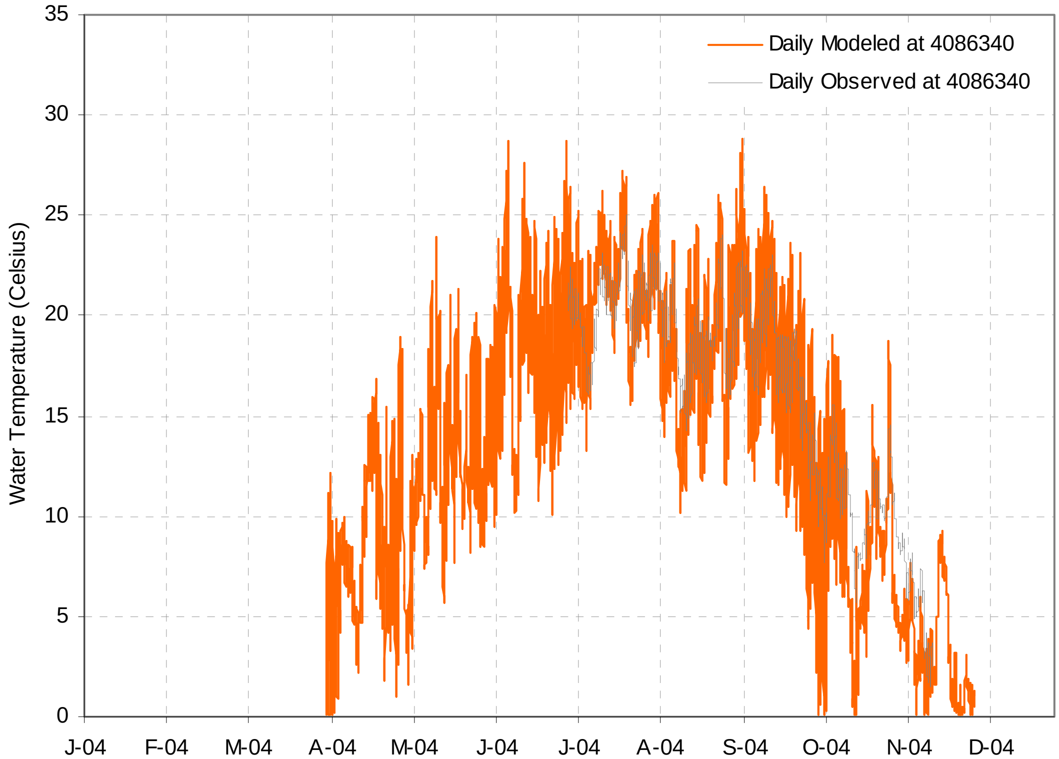
Daily Modeled at RI-06
Daily Observed at RI-06
Water Temperature (Celsius)
0
5
10
15
20
25
30
1999
2000
2001
2002



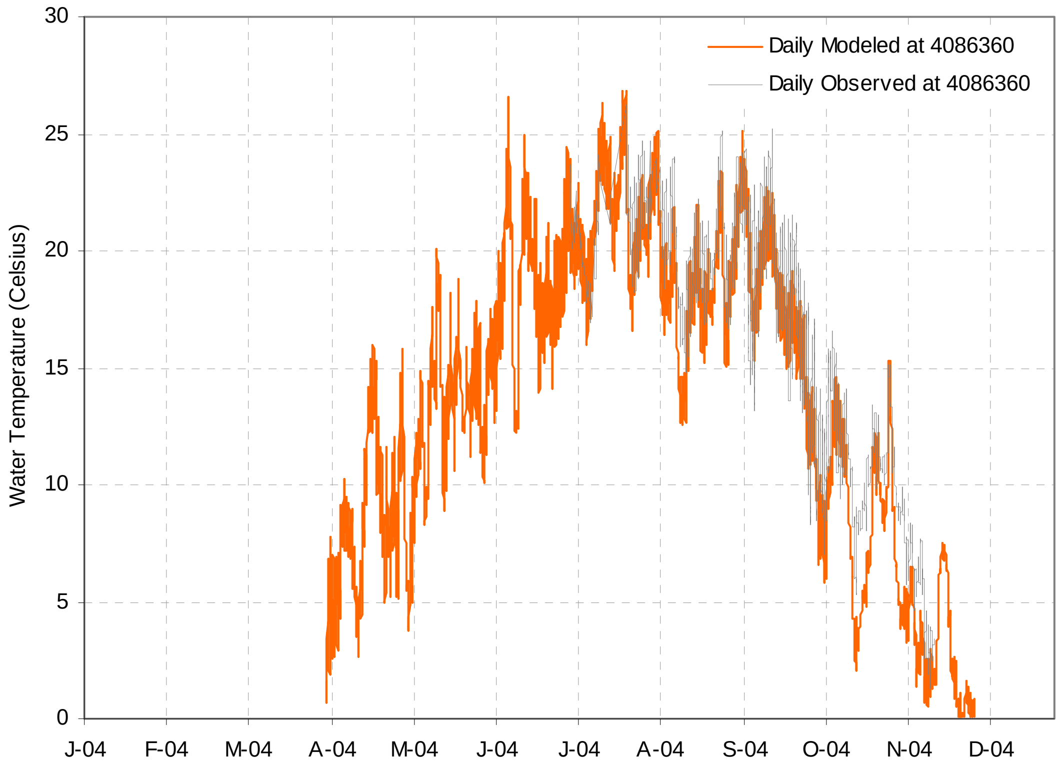
Daily Modeled at 4086200
Daily Observed at 4086200
Water Temperature (Celsius)
35
30
25
20
15
10
5
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04



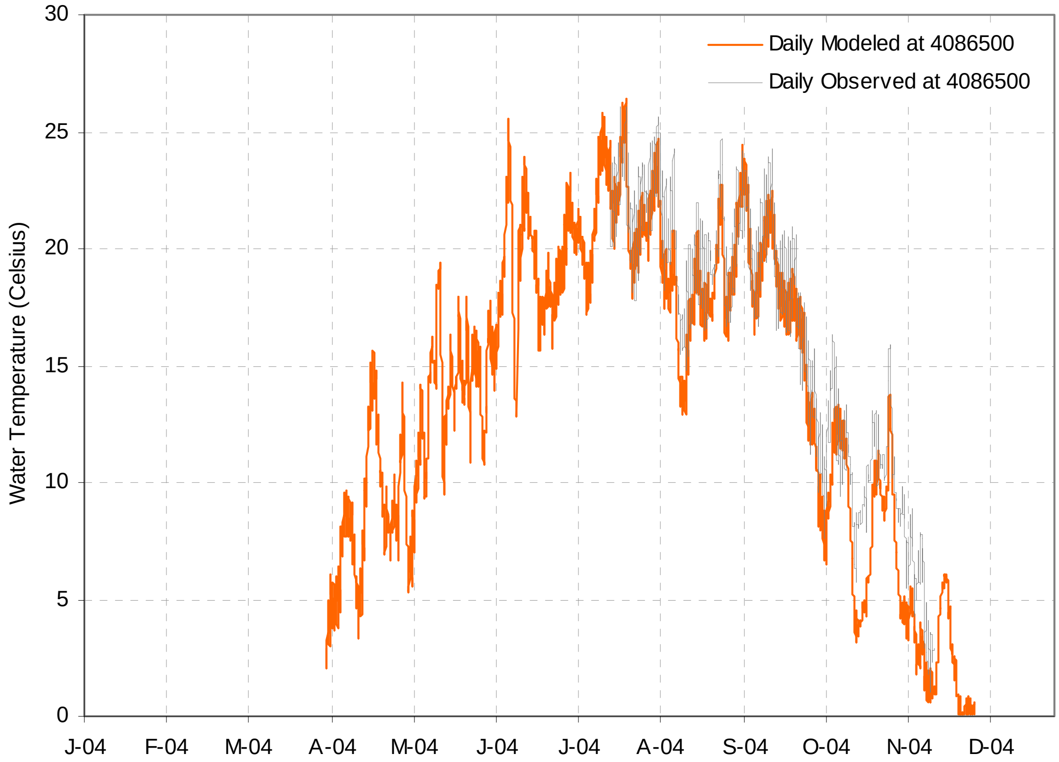
Daily Modeled at 4086265
Daily Observed at 4086265
Water Temperature (Celsius)
30
25
20
15
10
5
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04



35
30
25
20
15
10
5
0
Water Temperature (Celsius)
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086340
Daily Observed at 4086340

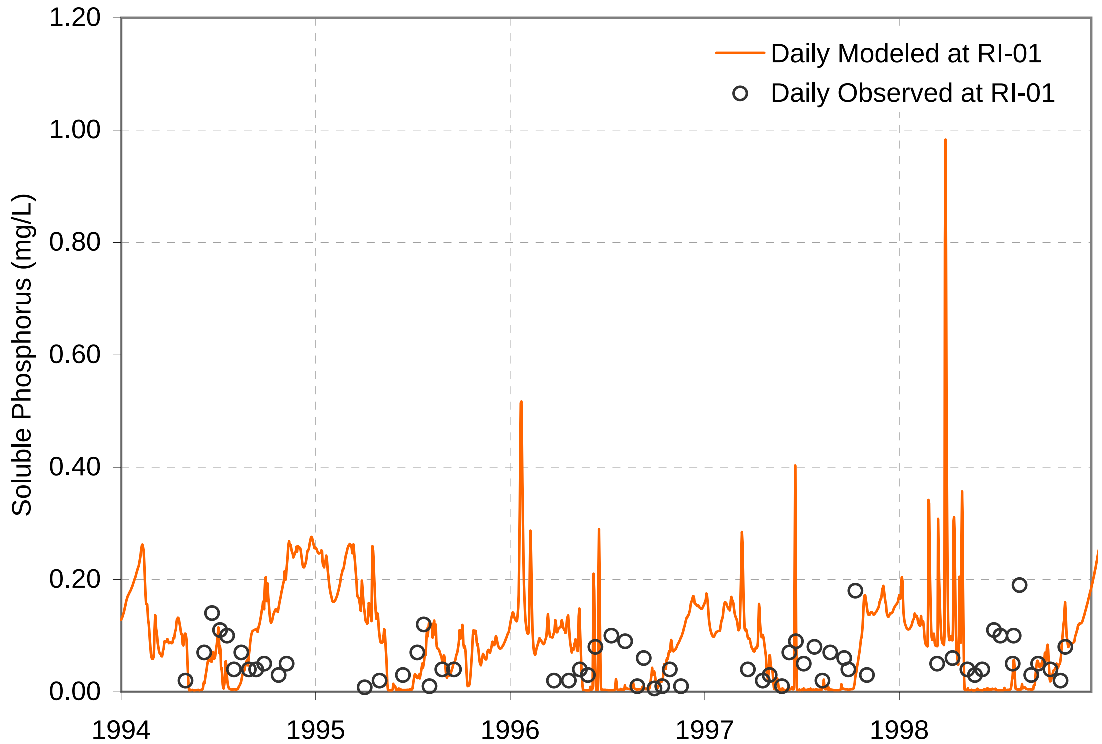


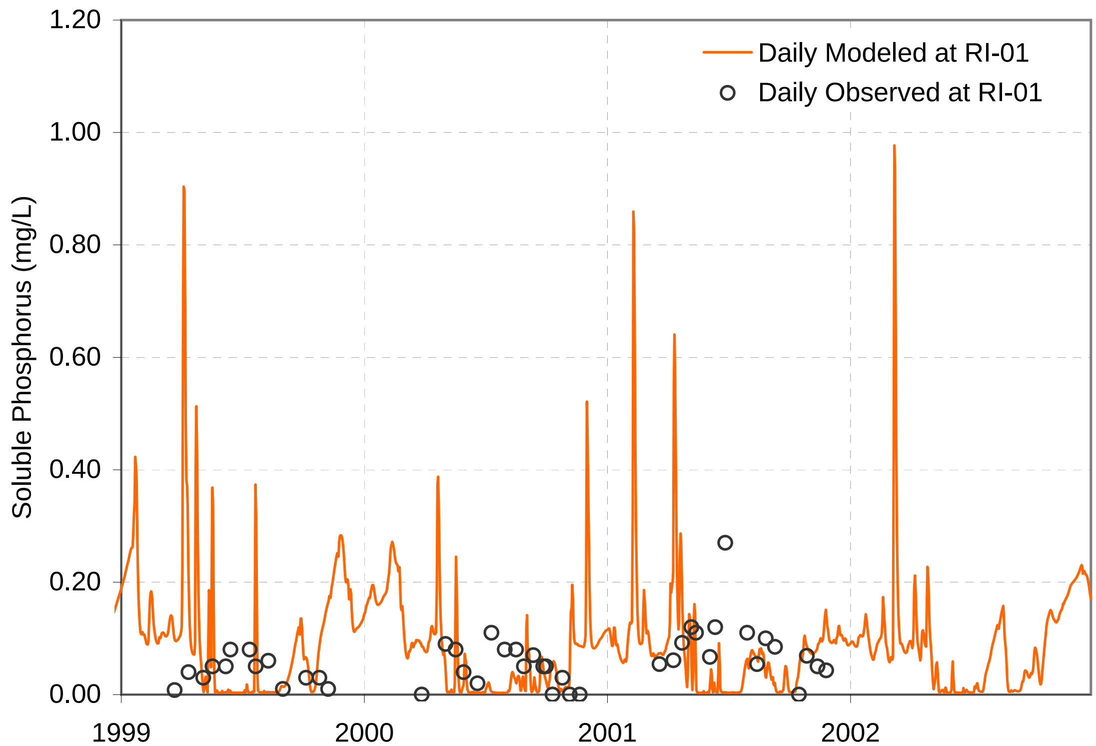
30
25
20
15
10
5
0
Water Temperature (Celsius)
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086360
Daily Observed at 4086360

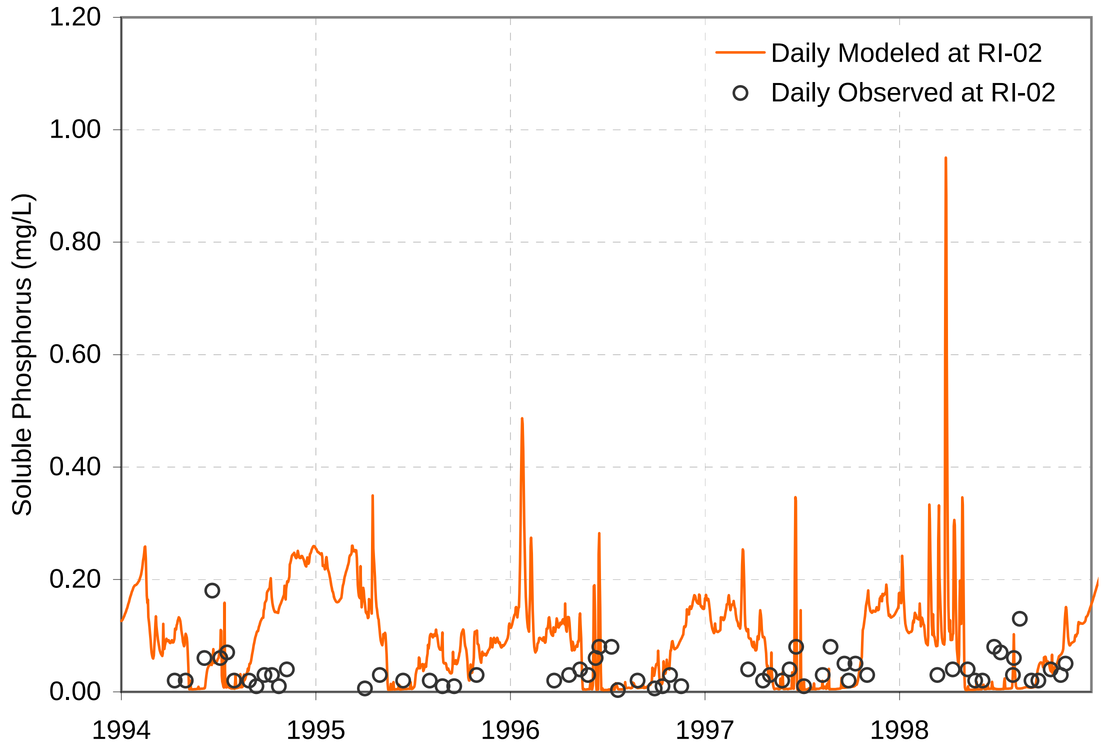


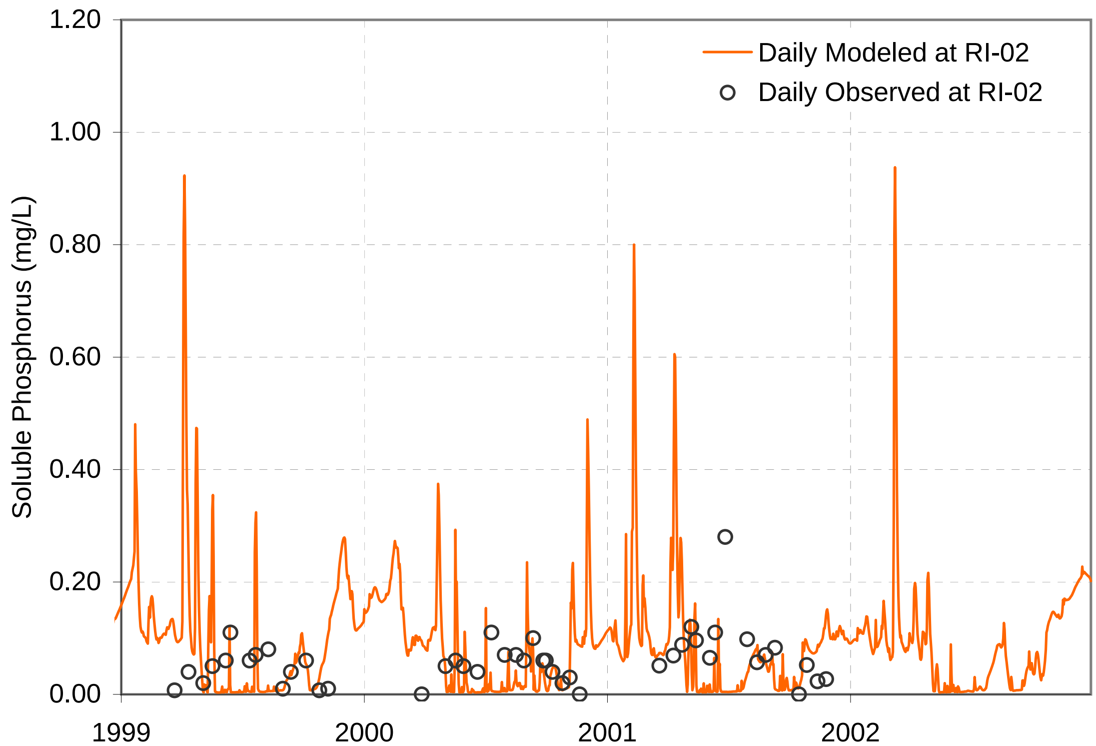
Daily Modeled at 4086500
Daily Observed at 4086500
Water Temperature (Celsius)
0
5
10
15
20
25
30
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

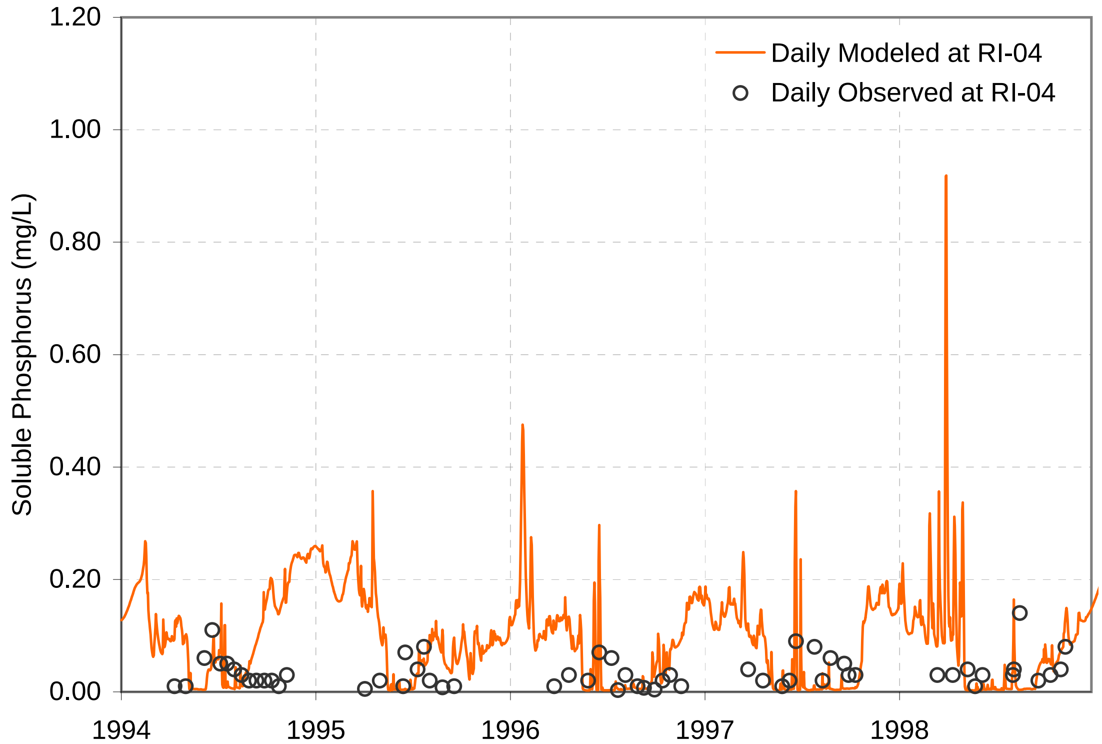
ATTACHMENT C – CALIBRATION AND VALIDATION PLOTS FOR TOTAL PHOSPHORUS AND SOLUBLE PHOSPHORUS


Daily Modeled at RI-01
Daily Observed at RI-01
Soluble Phosphorus (mg/L)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1994
1995
1996
1997
1998

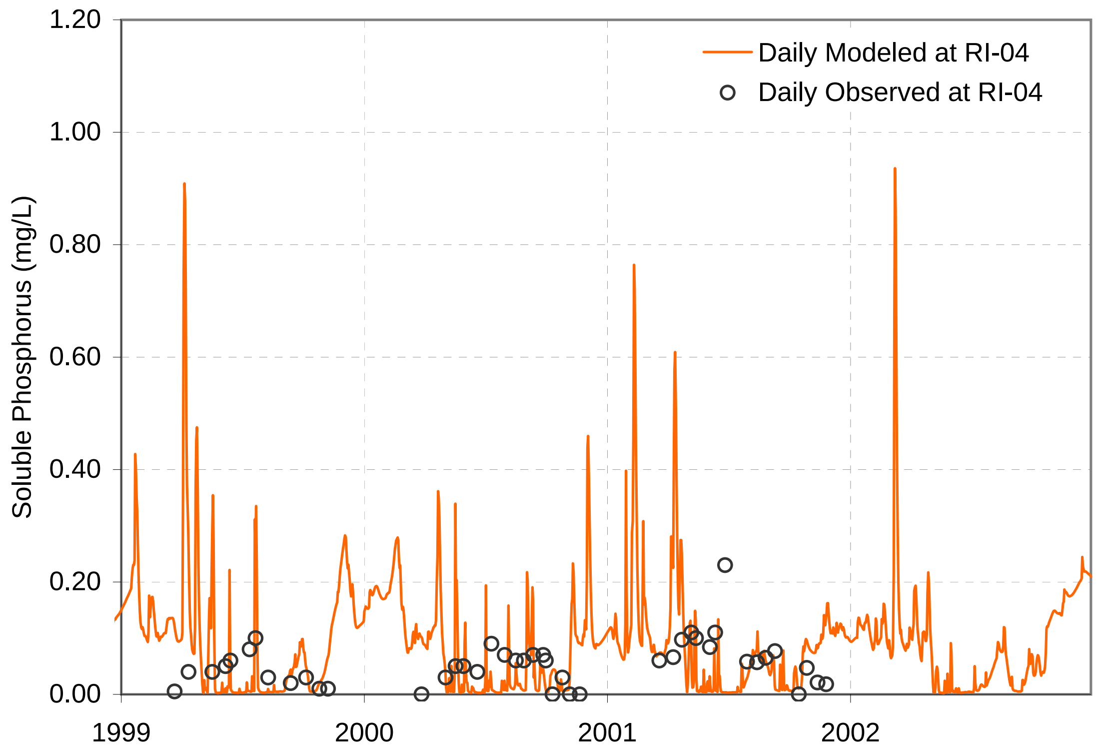

Daily Modeled at RI-01
Daily Observed at RI-01
Soluble Phosphorus (mg/L)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1999
2000
2001
2002


Daily Modeled at RI-02
Daily Observed at RI-02
Soluble Phosphorus (mg/L)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1994
1995
1996
1997
1998

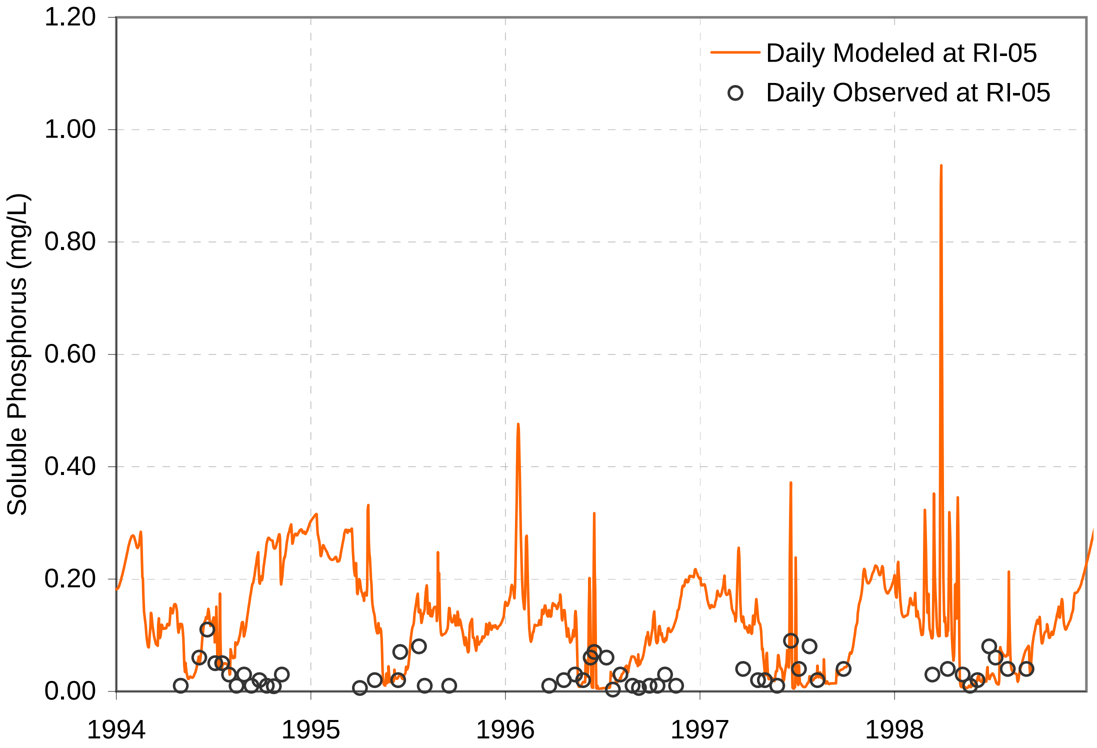

Daily Modeled at RI-02
Daily Observed at RI-02
Soluble Phosphorus (mg/L)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1999
2000
2001
2002



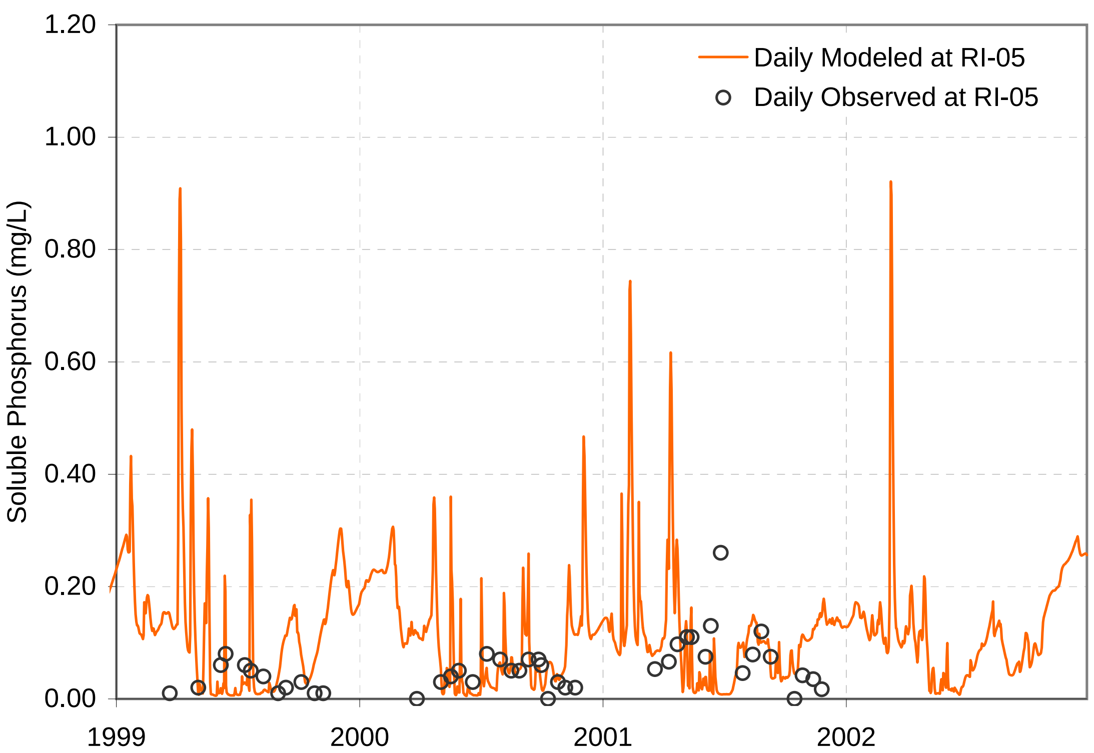
Soluble Phosphorus (mg/L)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1994
1995
1996
1997
1998
Daily Modeled at RI-04
Daily Observed at RI-04



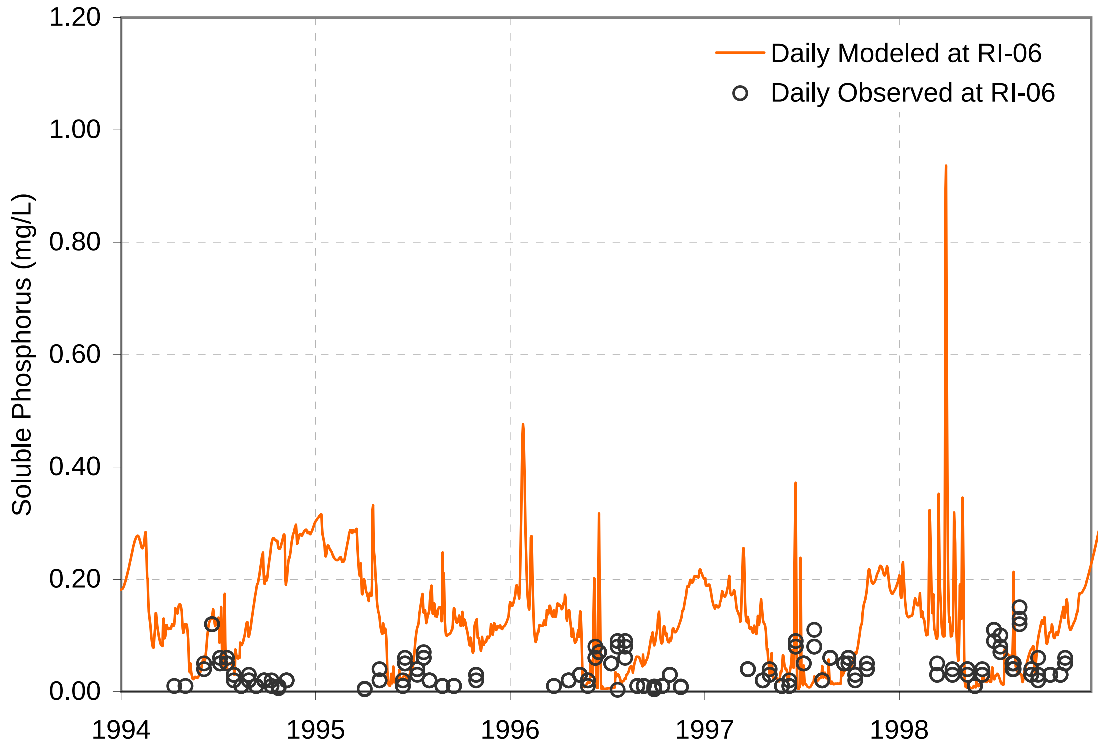
Soluble Phosphorus (mg/L)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1999
2000
2001
2002
Daily Modeled at RI-04
Daily Observed at RI-04



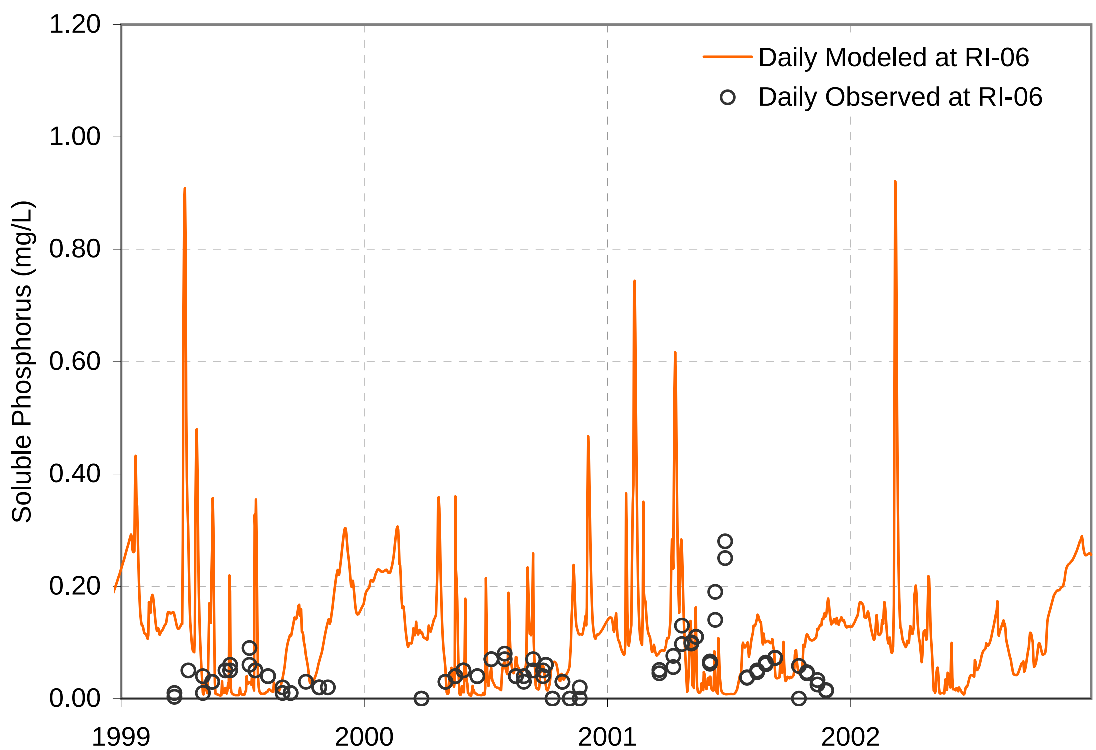
Soluble Phosphorus (mg/L)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1994
1995
1996
1997
1998
Daily Modeled at RI-05
Daily Observed at RI-05



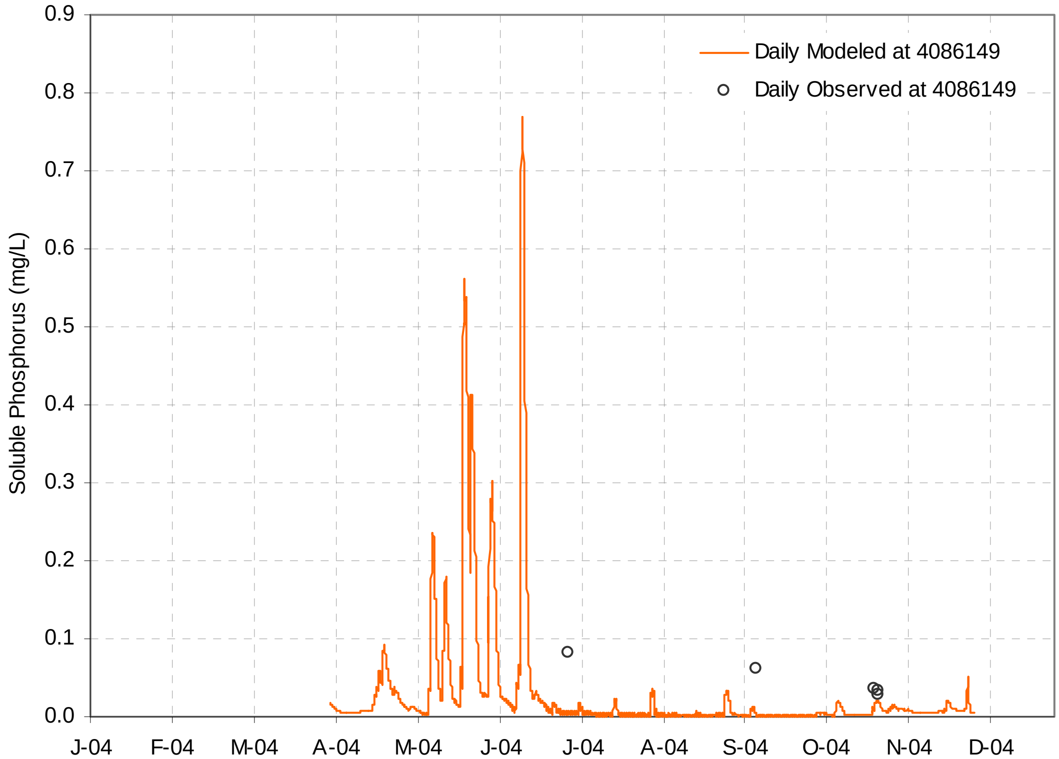
Soluble Phosphorus (mg/L)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1999
2000
2001
2002
Daily Modeled at RI-05
Daily Observed at RI-05

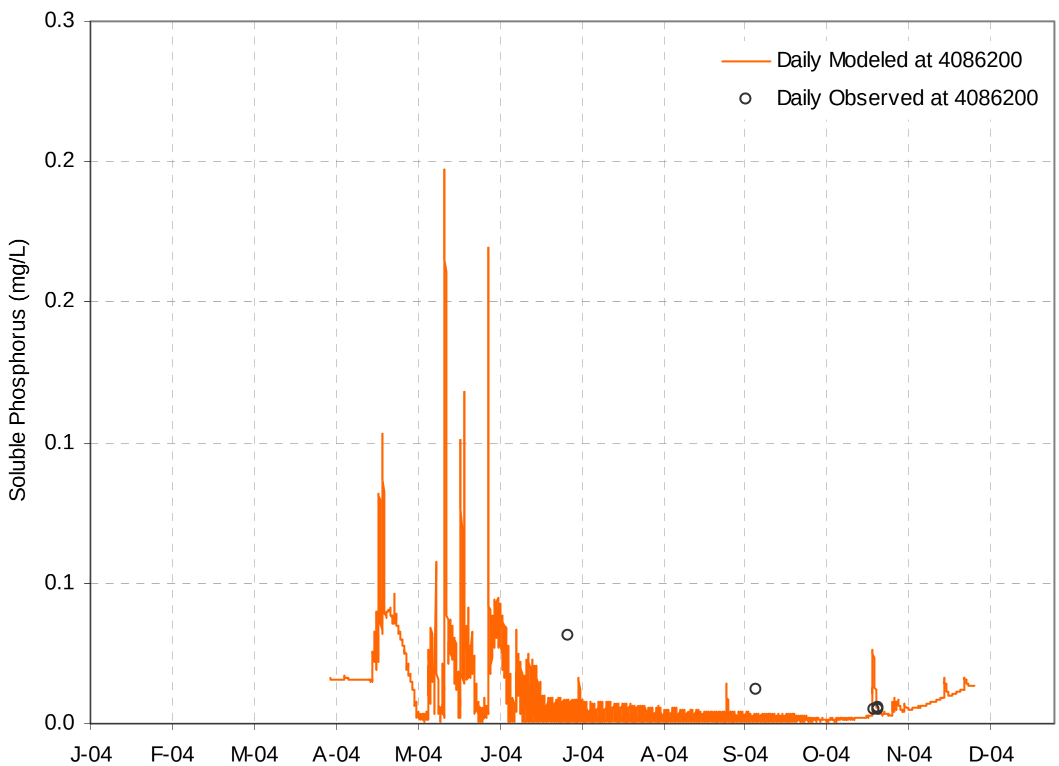


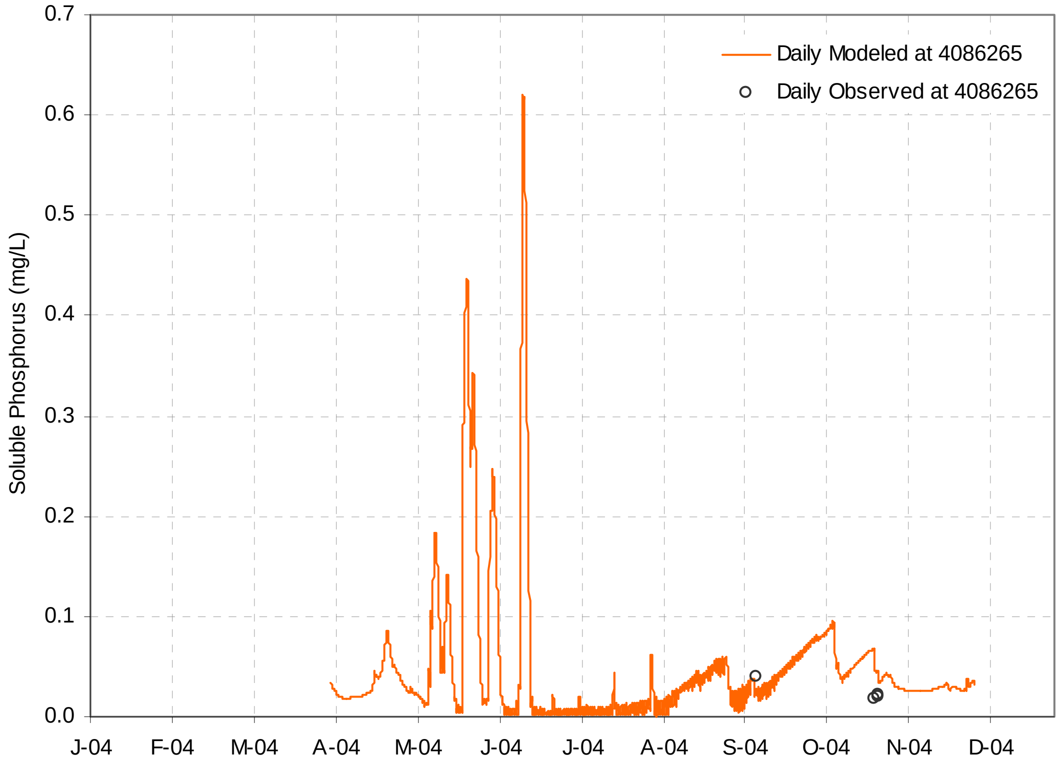
Daily Modeled at RI-06
Daily Observed at RI-06
Soluble Phosphorus (mg/L)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1994
1995
1996
1997
1998



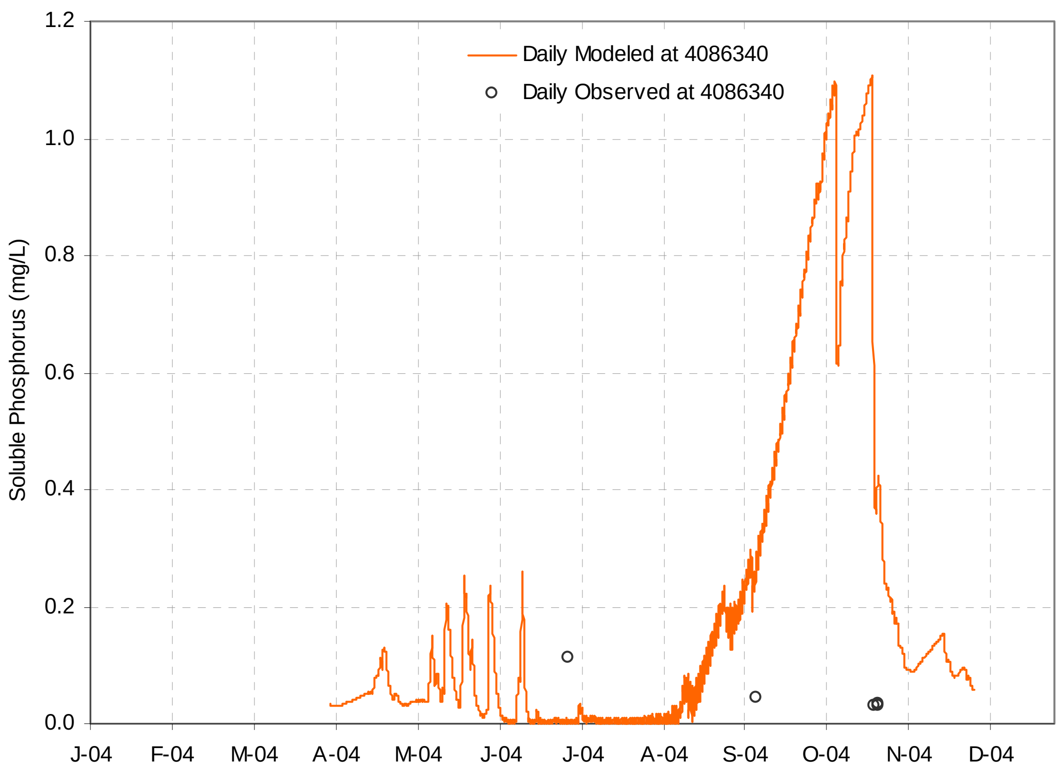
Daily Modeled at RI-06
Daily Observed at RI-06
Soluble Phosphorus (mg/L)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1999
2000
2001
2002


Daily Modeled at 4086149
Daily Observed at 4086149
Soluble Phosphorus (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

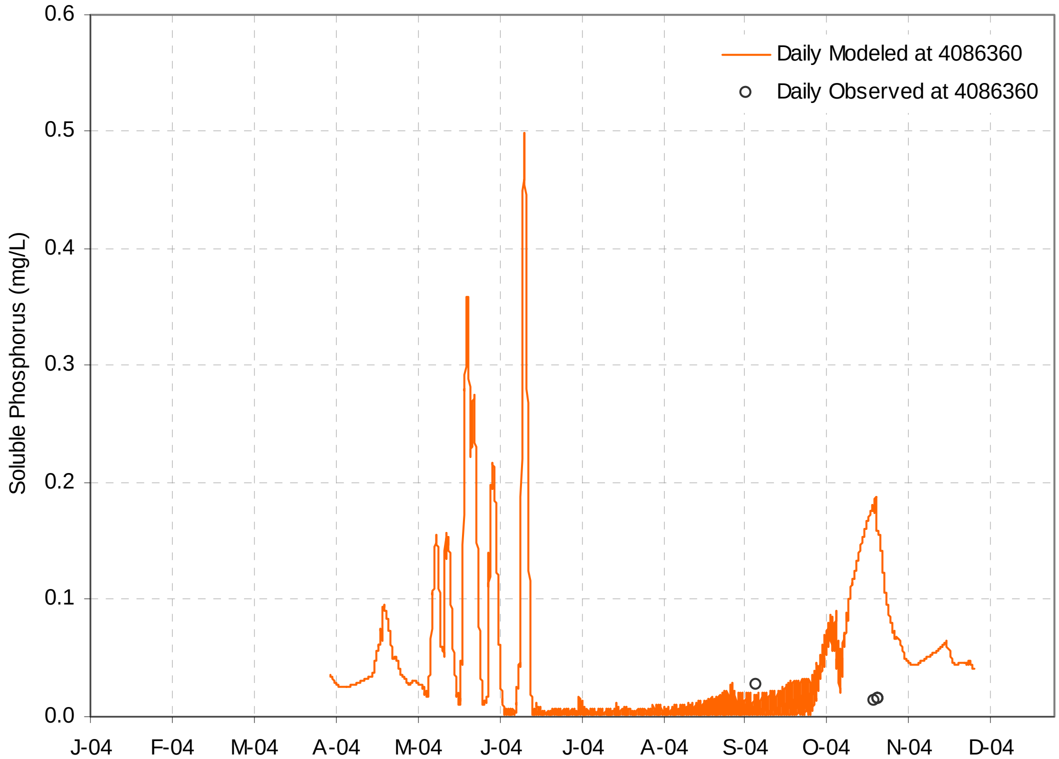

Daily Modeled at 4086200
Daily Observed at 4086200
Soluble Phosphorus (mg/L)
0.3
0.2
0.2
0.1
0.1
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

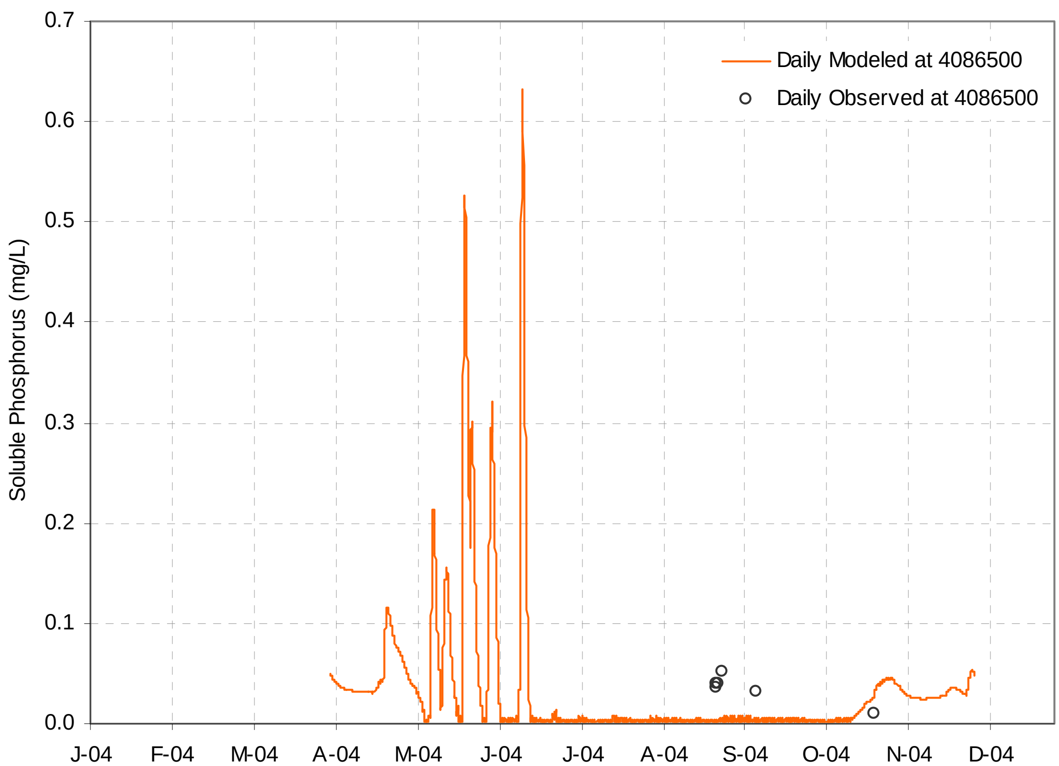


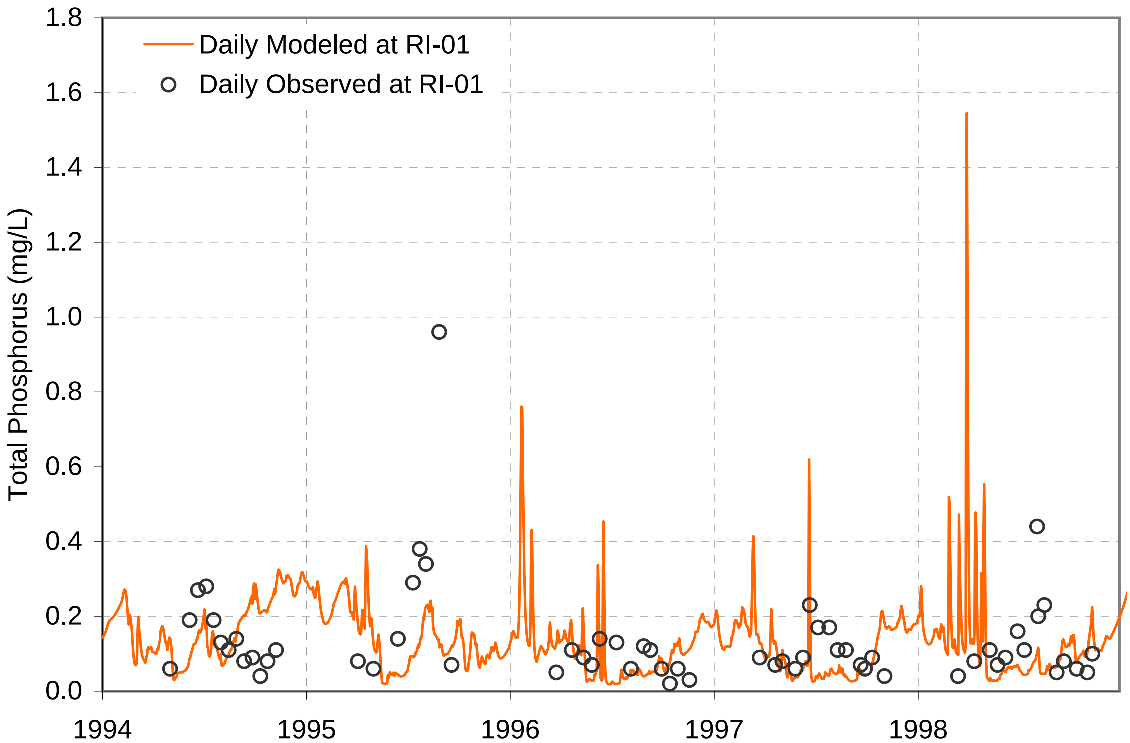
Daily Modeled at 4086265
Daily Observed at 4086265
Soluble Phosphorus (mg/L)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

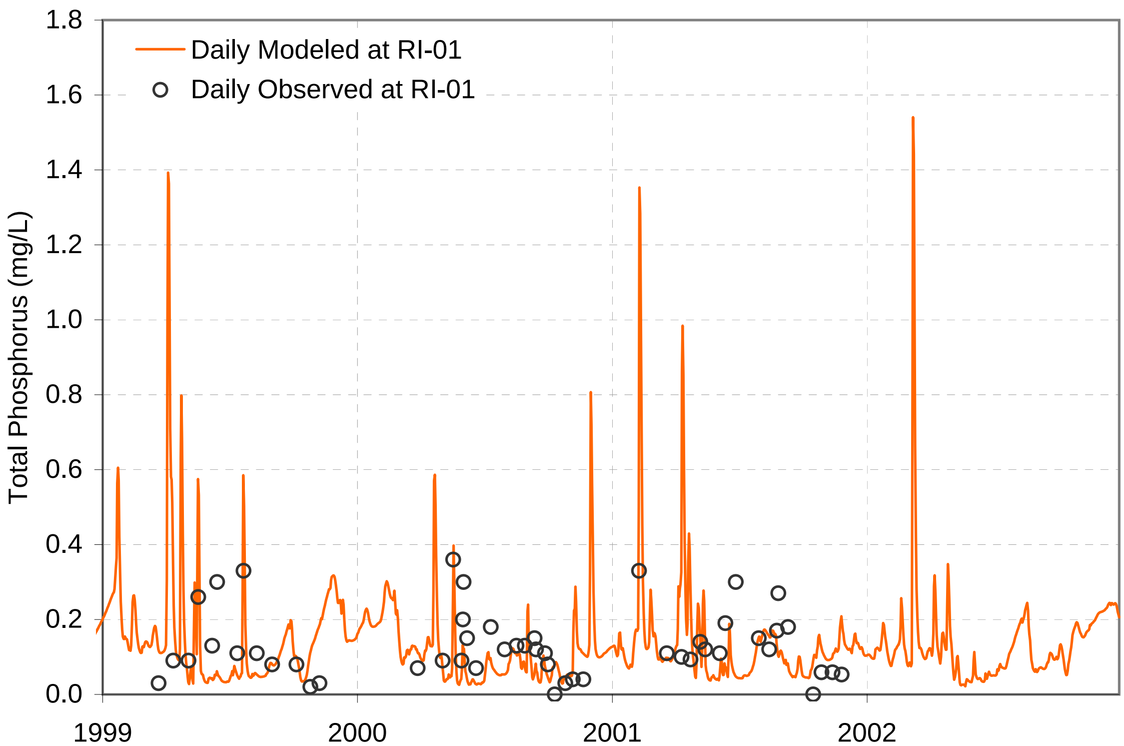


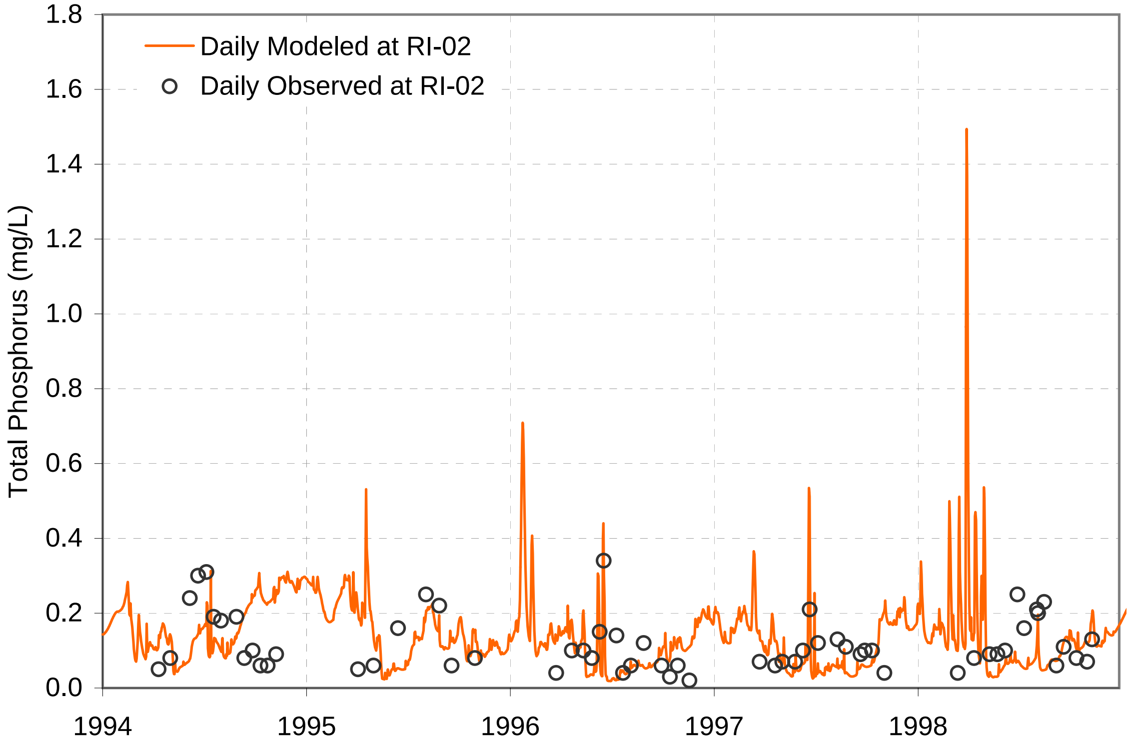
Daily Modeled at 4086340
Daily Observed at 4086340
Soluble Phosphorus (mg/L)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04


0.6
0.5
0.4
0.3
0.2
0.1
0.0
Soluble Phosphorus (mg/L)
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086360
Daily Observed at 4086360

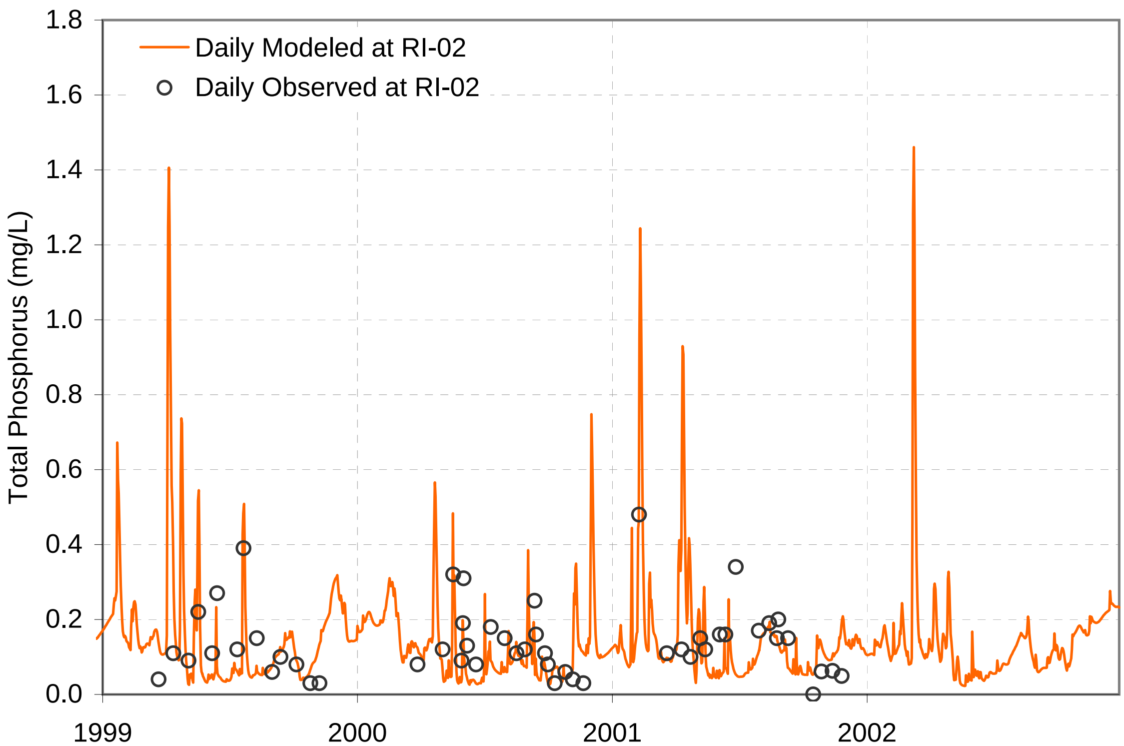

0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Soluble Phosphorus (mg/L)
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086500
Daily Observed at 4086500


Daily Modeled at RI-01
Daily Observed at RI-01
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1994
1995
1996
1997
1998

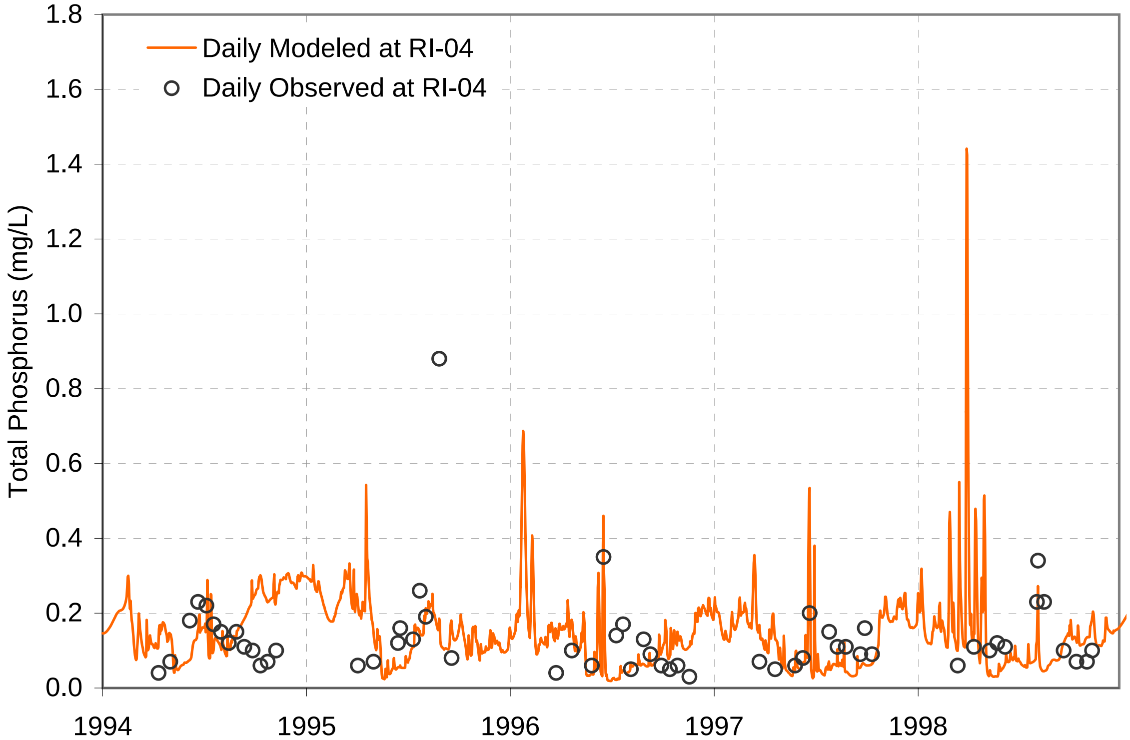

Daily Modeled at RI-01
Daily Observed at RI-01
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1999
2000
2001
2002



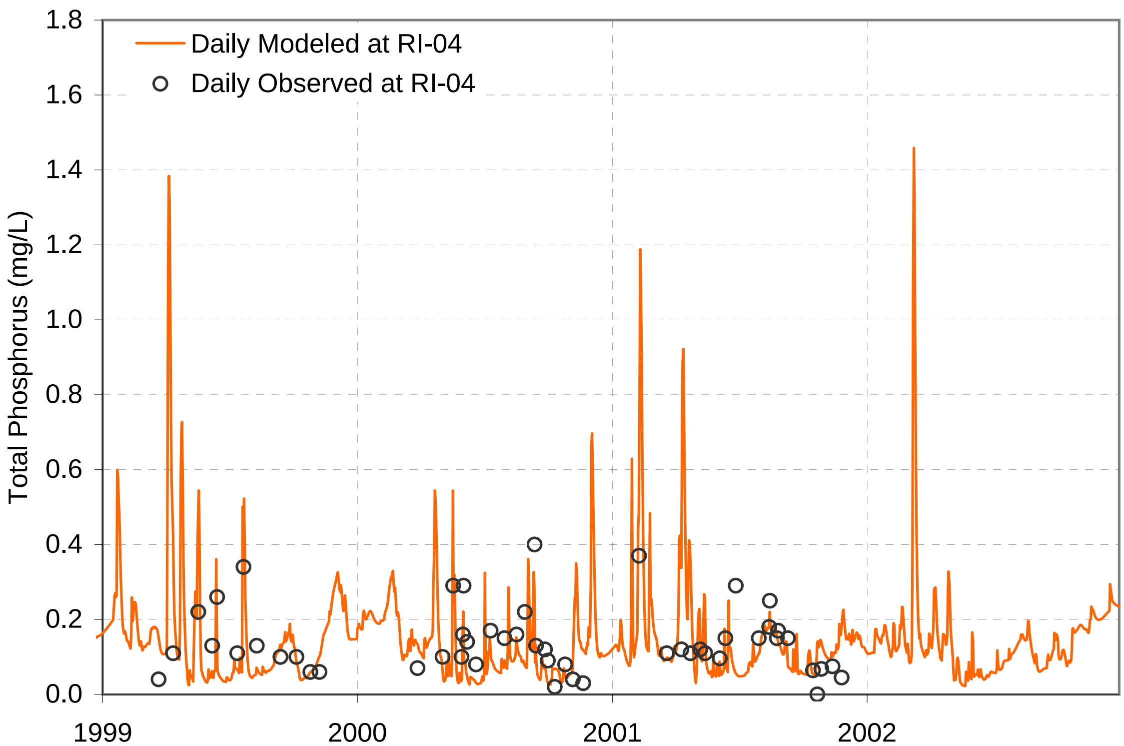
Daily Modeled at RI-02
Daily Observed at RI-02
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1994
1995
1996
1997
1998



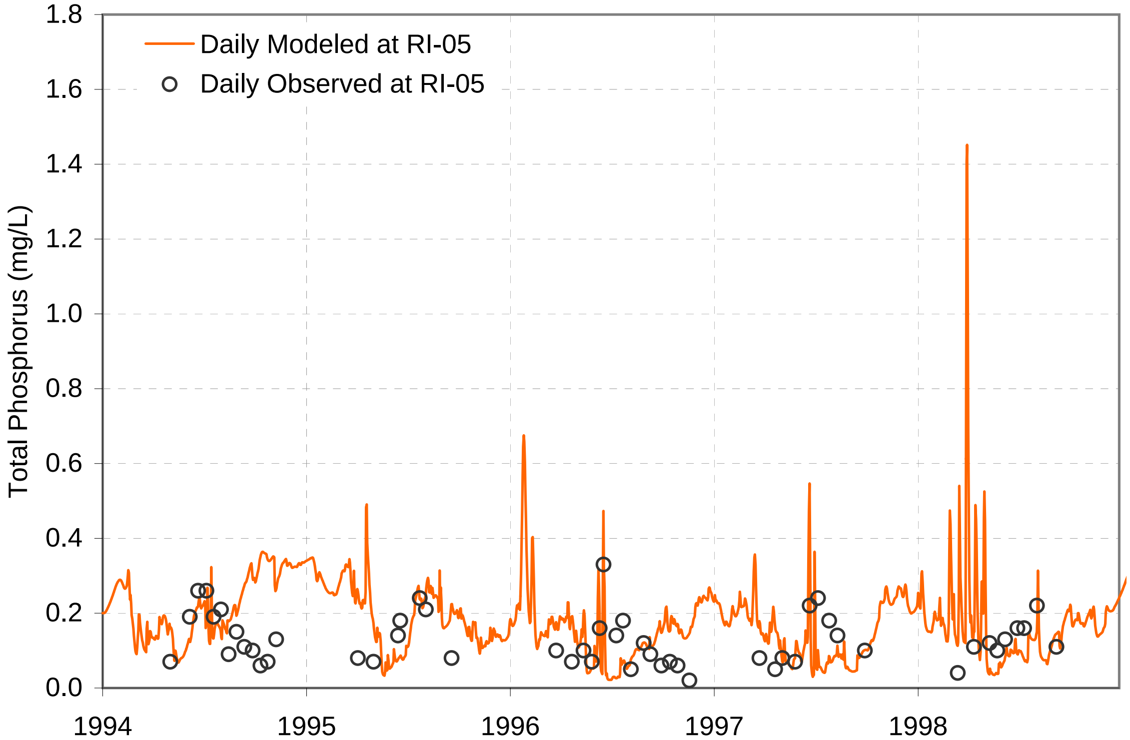
Daily Modeled at RI-02
Daily Observed at RI-02
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1999
2000
2001
2002

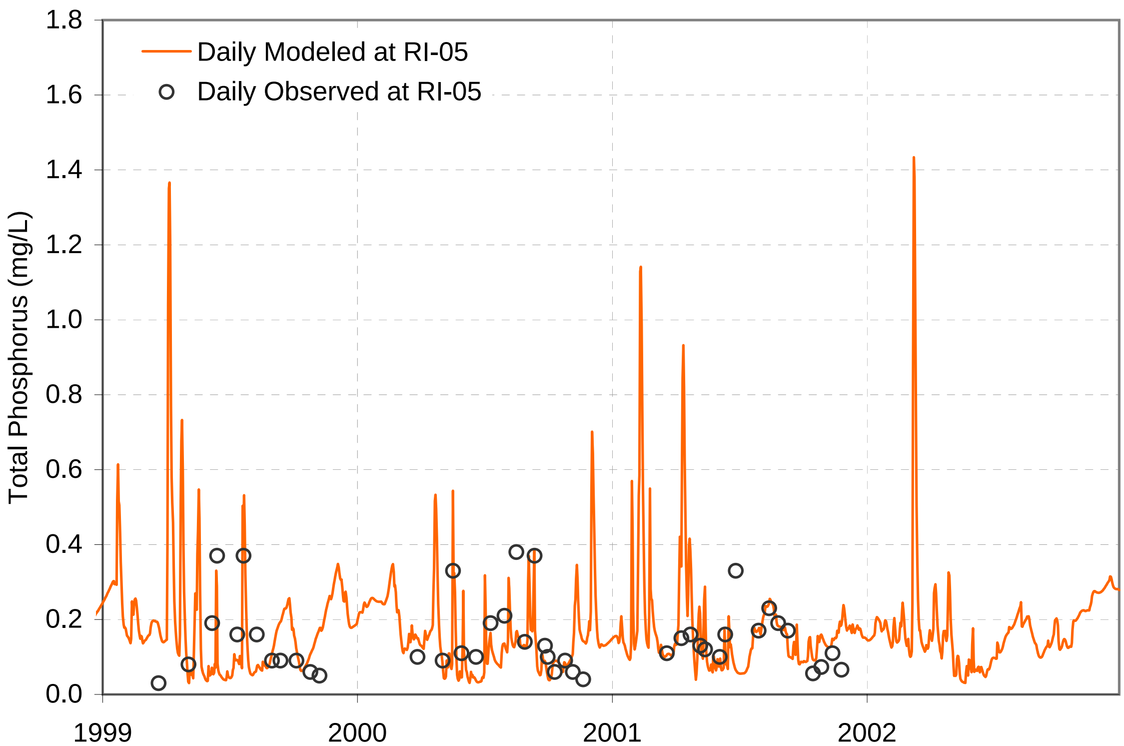


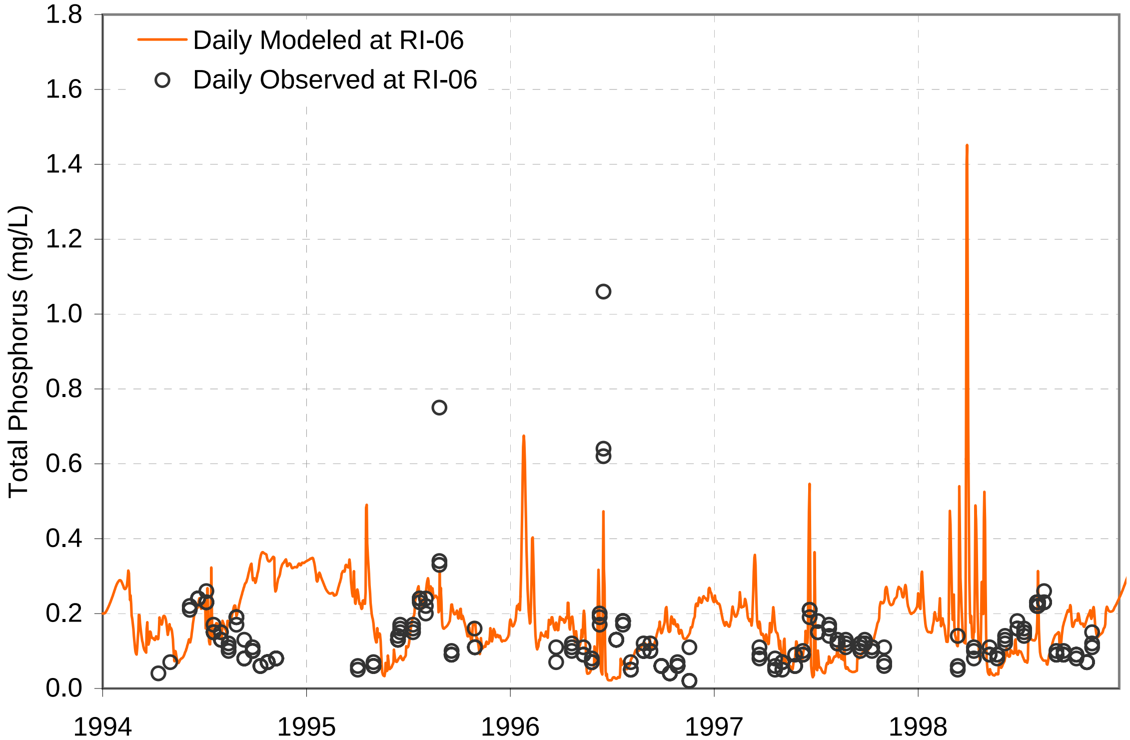
Daily Modeled at RI-04
Daily Observed at RI-04
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1994
1995
1996
1997
1998

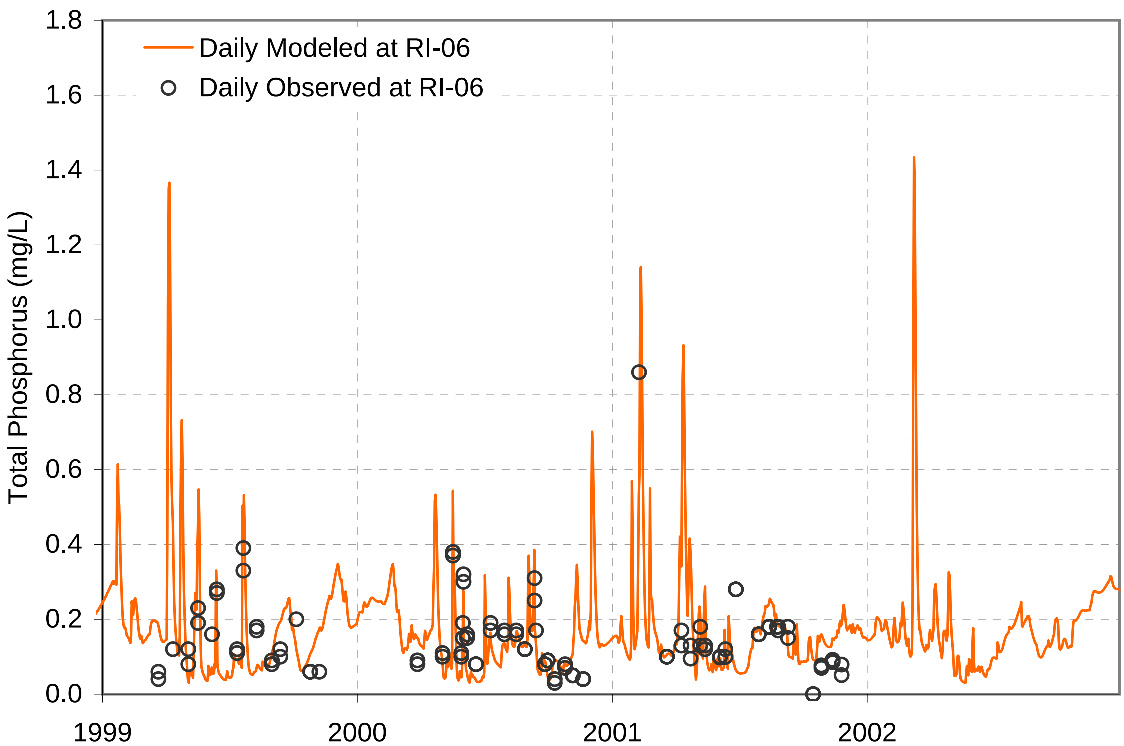


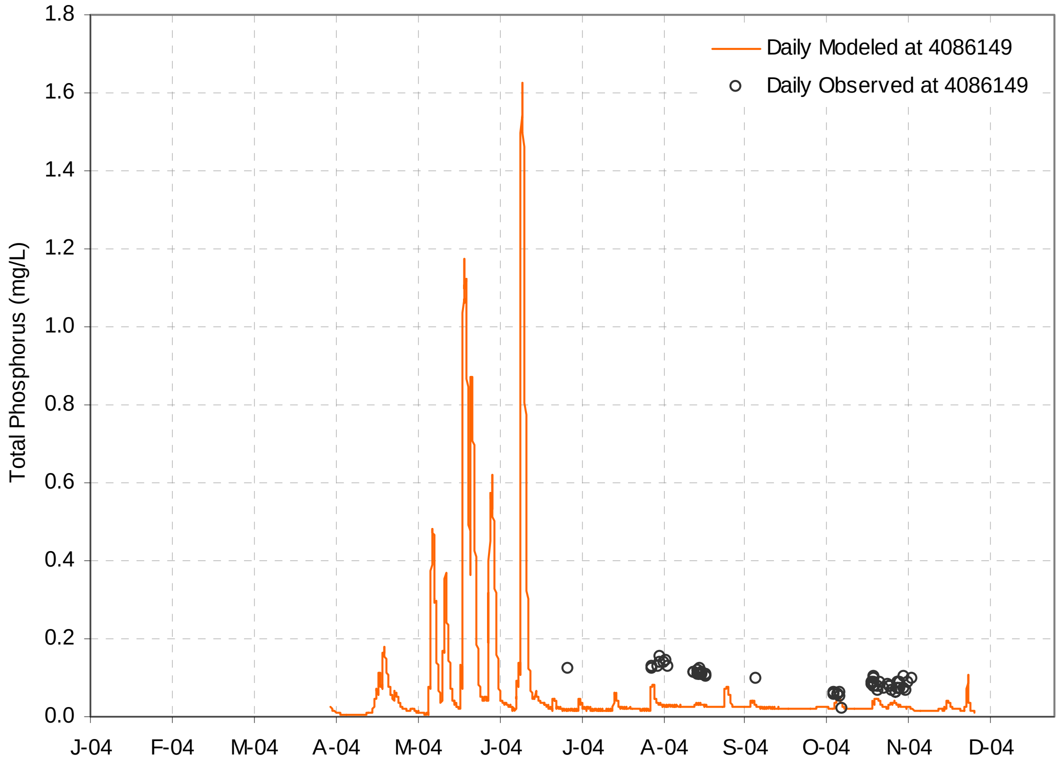
Daily Modeled at RI-04
Daily Observed at RI-04
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1999
2000
2001
2002

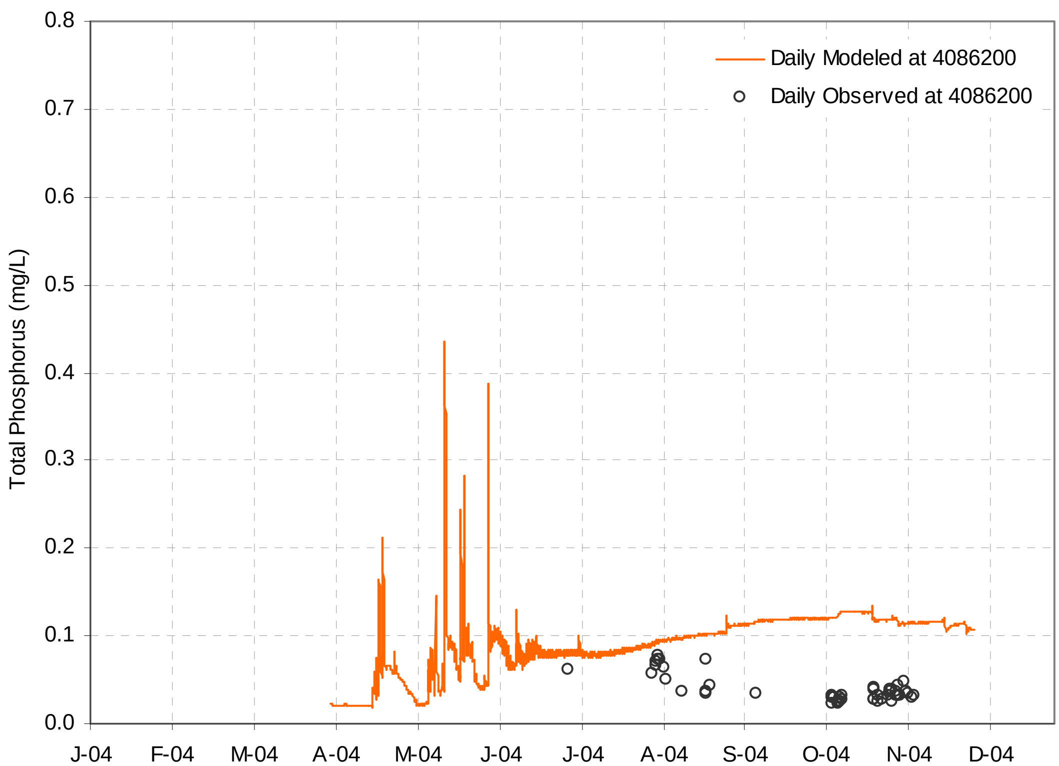

Daily Modeled at RI-05
Daily Observed at RI-05
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1994
1995
1996
1997
1998

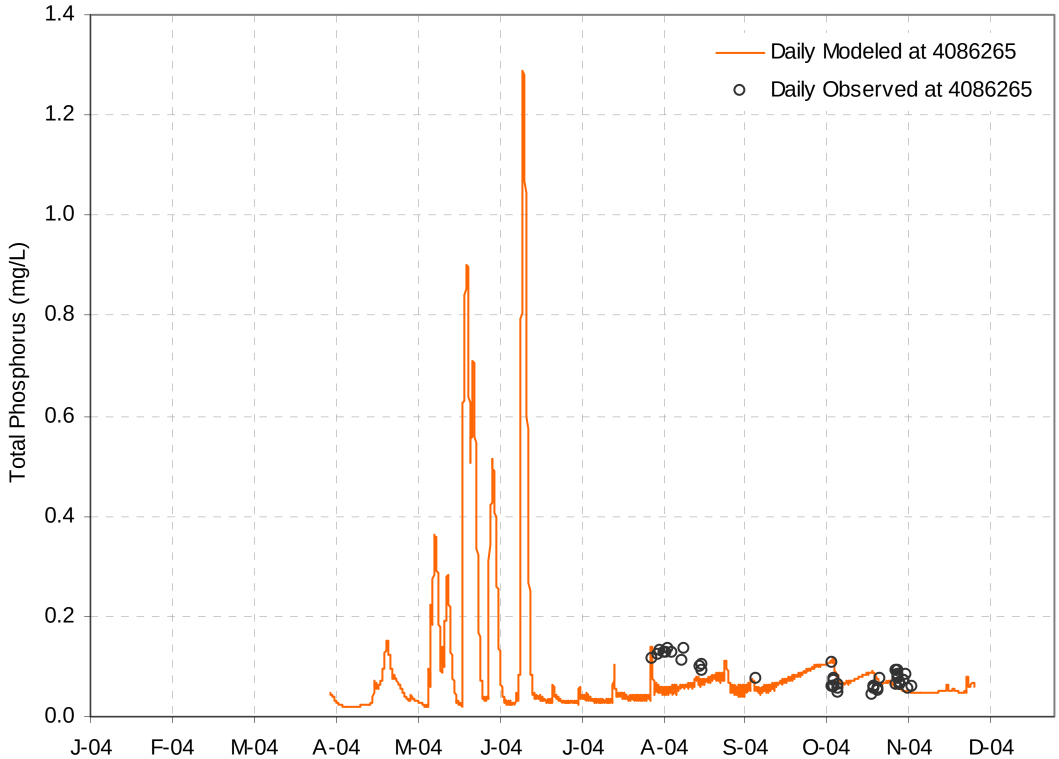

Daily Modeled at RI-05
Daily Observed at RI-05
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1999
2000
2001
2002

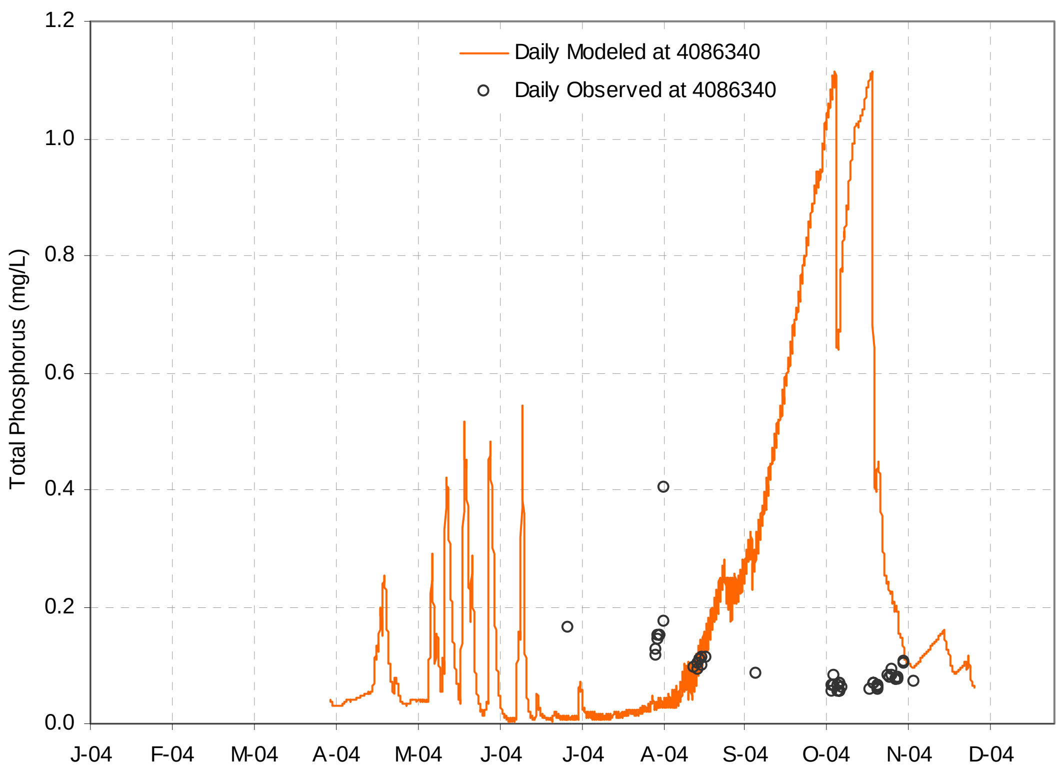

Daily Modeled at RI-06
Daily Observed at RI-06
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1994
1995
1996
1997
1998

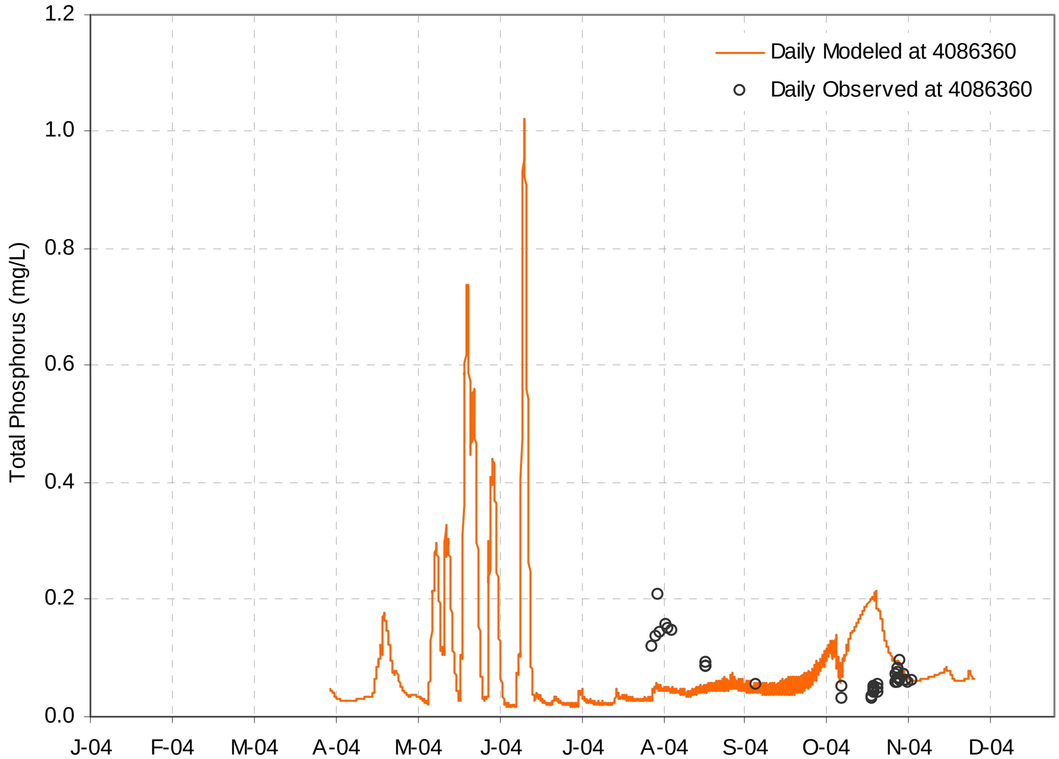

Daily Modeled at RI-06
Daily Observed at RI-06
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1999
2000
2001
2002


Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086149
Daily Observed at 4086149

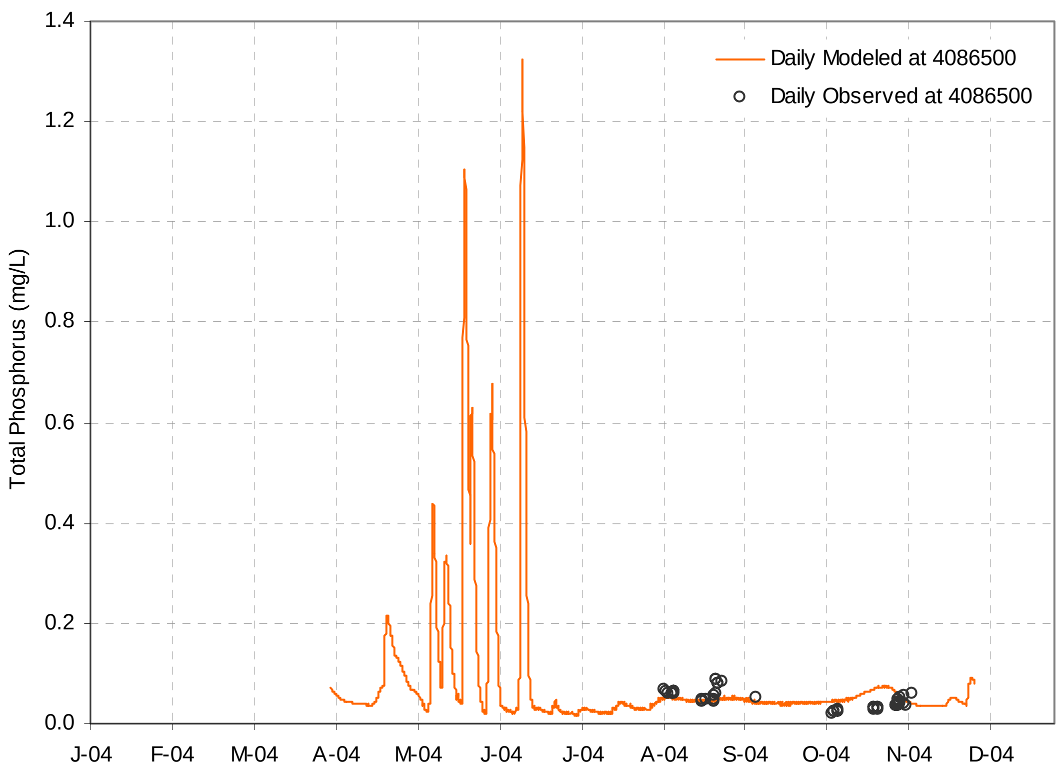

Total Phosphorus (mg/L)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086200
Daily Observed at 4086200


Daily Modeled at 4086265
Daily Observed at 4086265
Total Phosphorus (mg/L)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04


Daily Modeled at 4086340
Daily Observed at 4086340
Total Phosphorus (mg/L)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

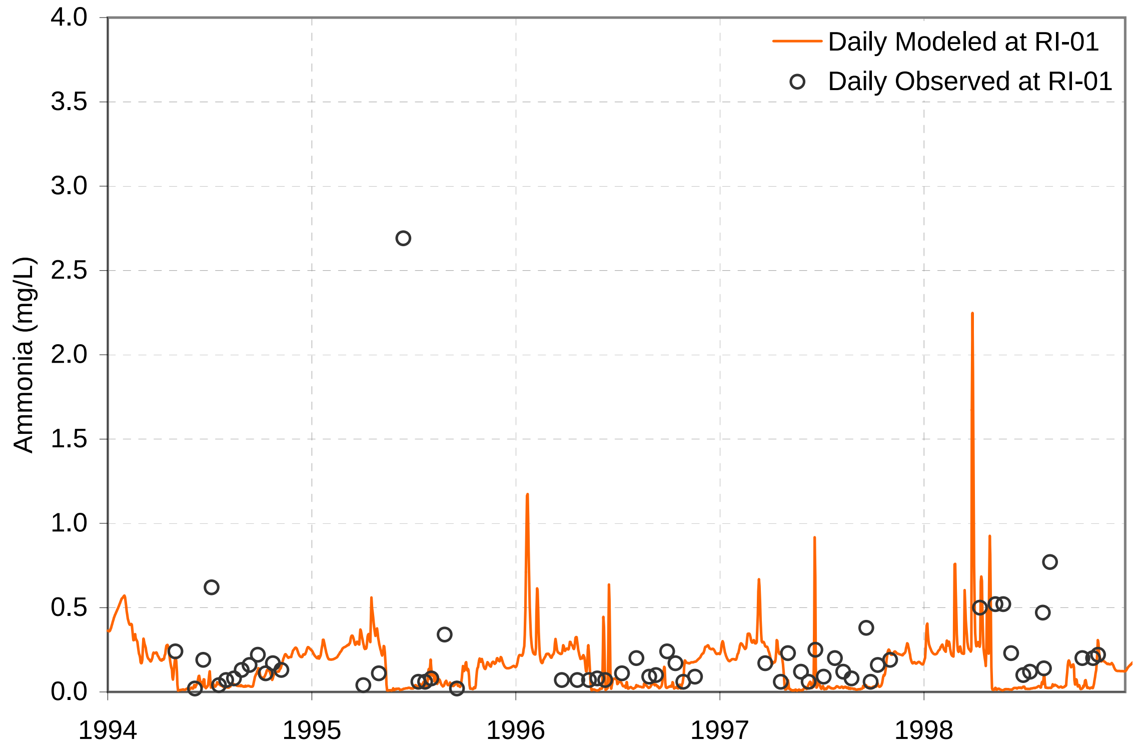


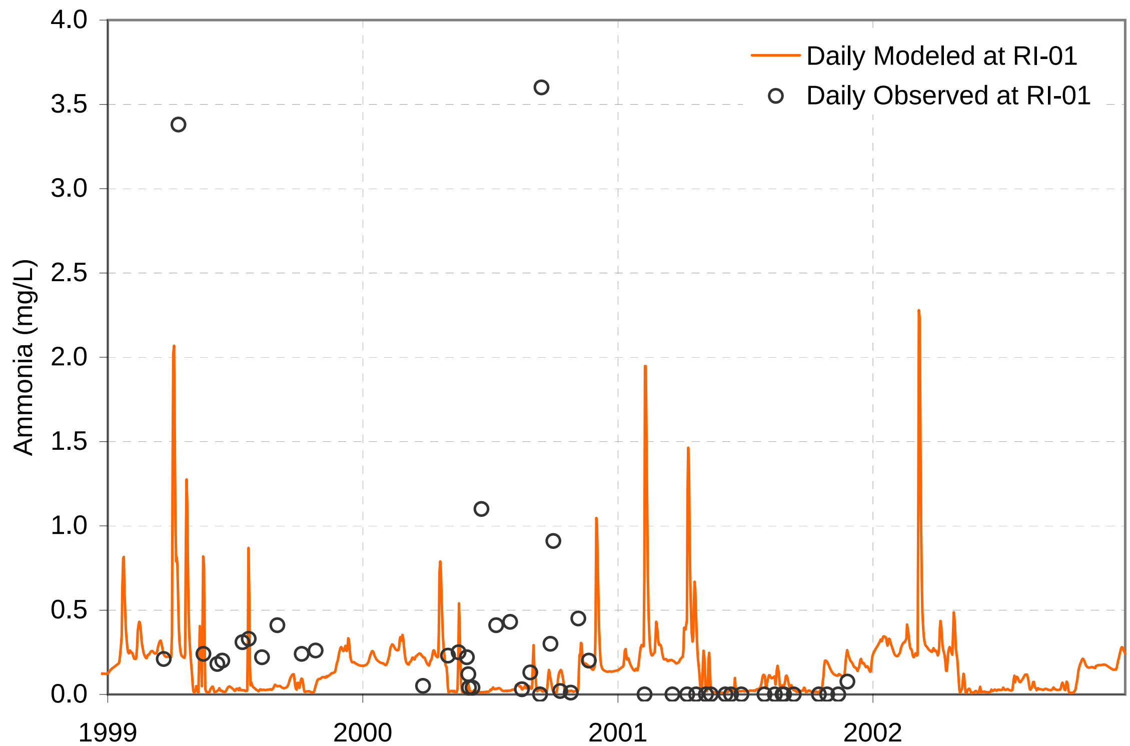
Total Phosphorus (mg/L)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086360
Daily Observed at 4086360

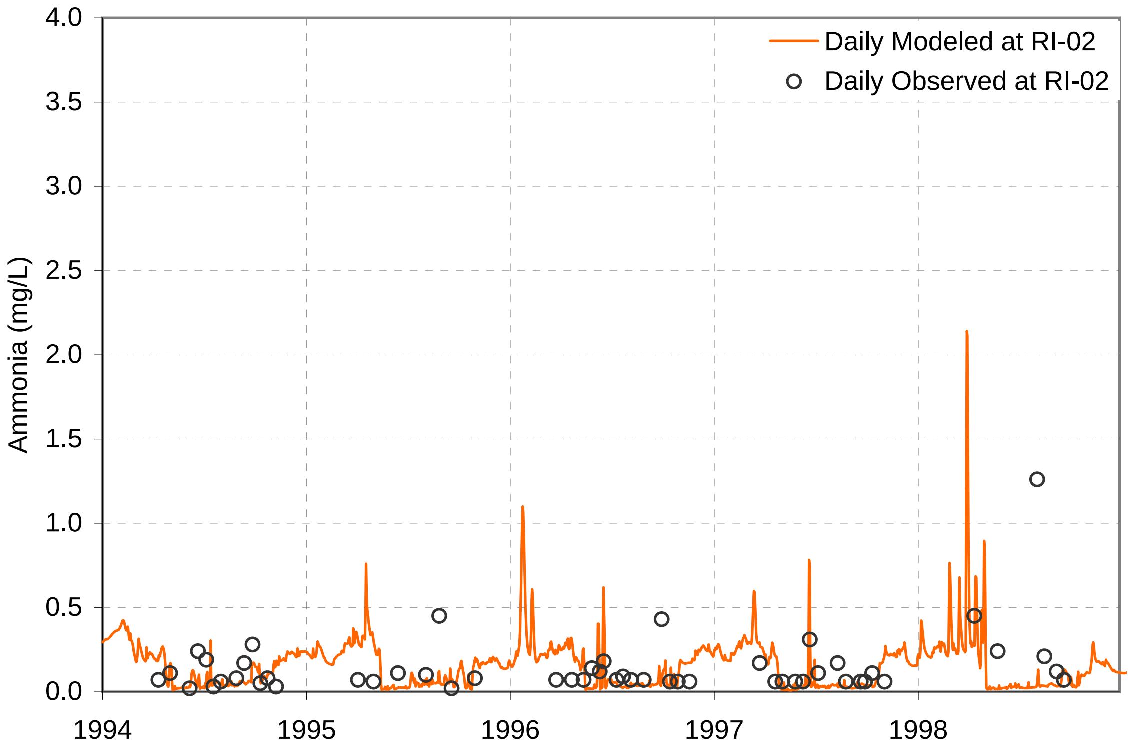


Total Phosphorus (mg/L)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086500
Daily Observed at 4086500

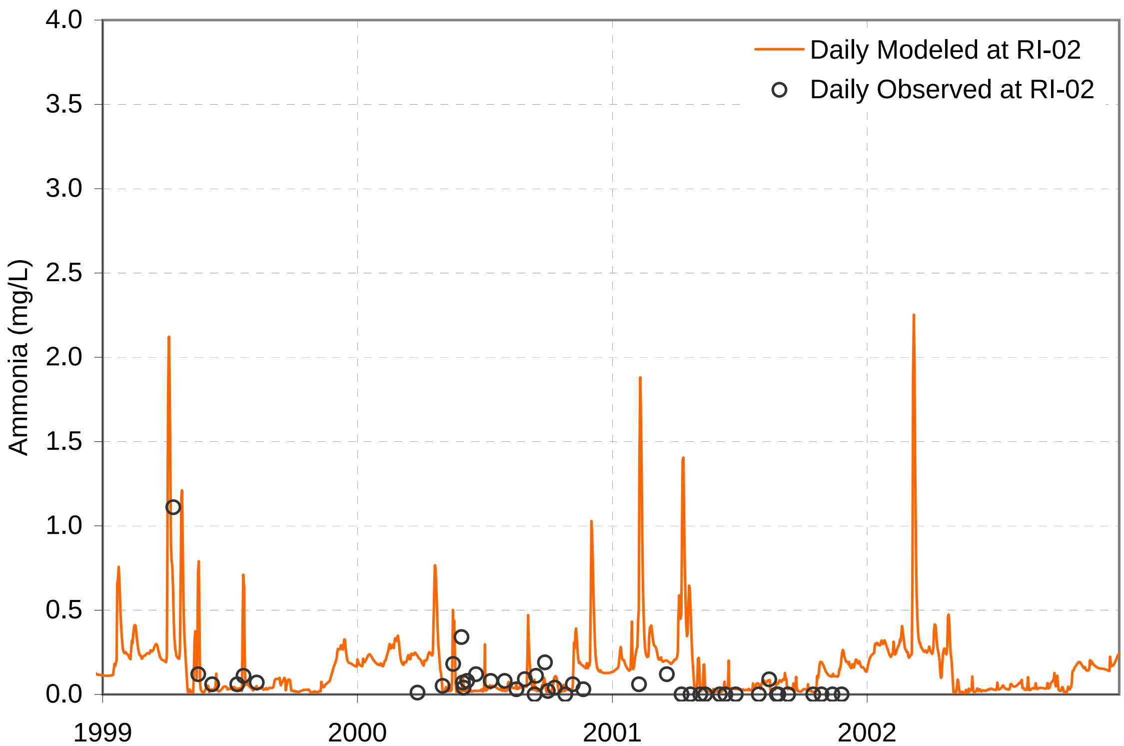
ATTACHMENT D – CALIBRATION AND VALIDATION PLOTS FOR TOTAL NITROGEN, NITRITE+NITRATE, AND AMMONIA


Daily Modeled at RI-01
Daily Observed at RI-01
Ammonia (mg/L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1994
1995
1996
1997
1998

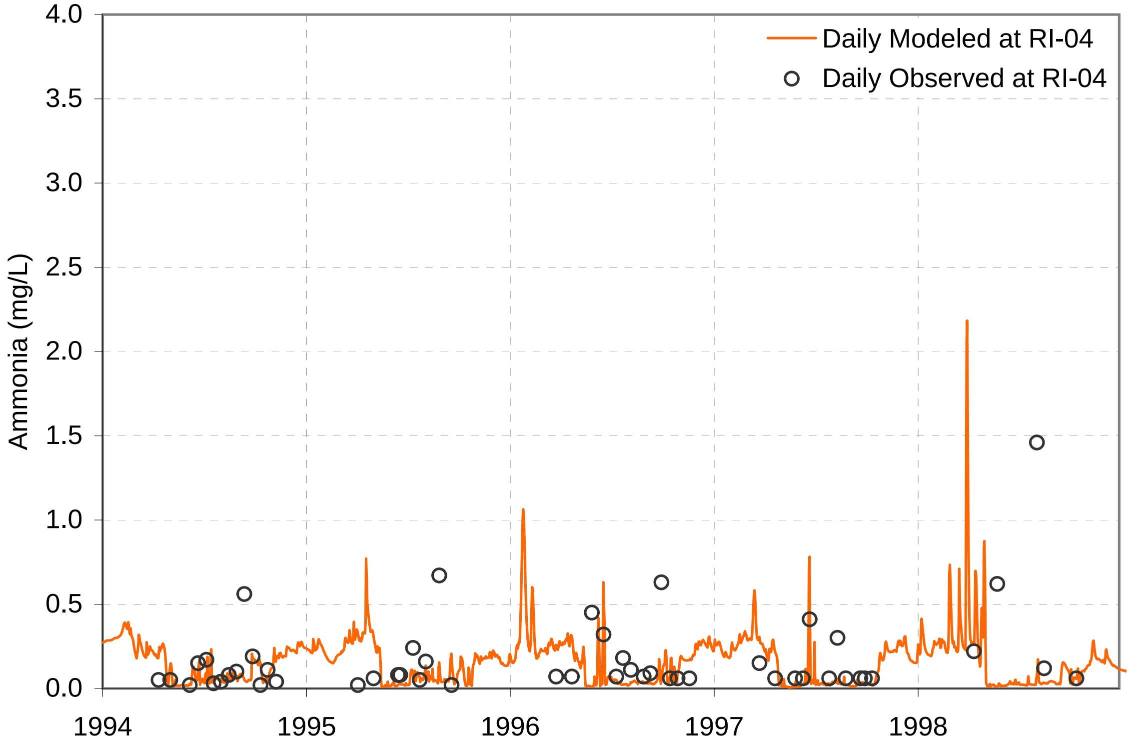

Daily Modeled at RI-01
Daily Observed at RI-01
Ammonia (mg/L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002

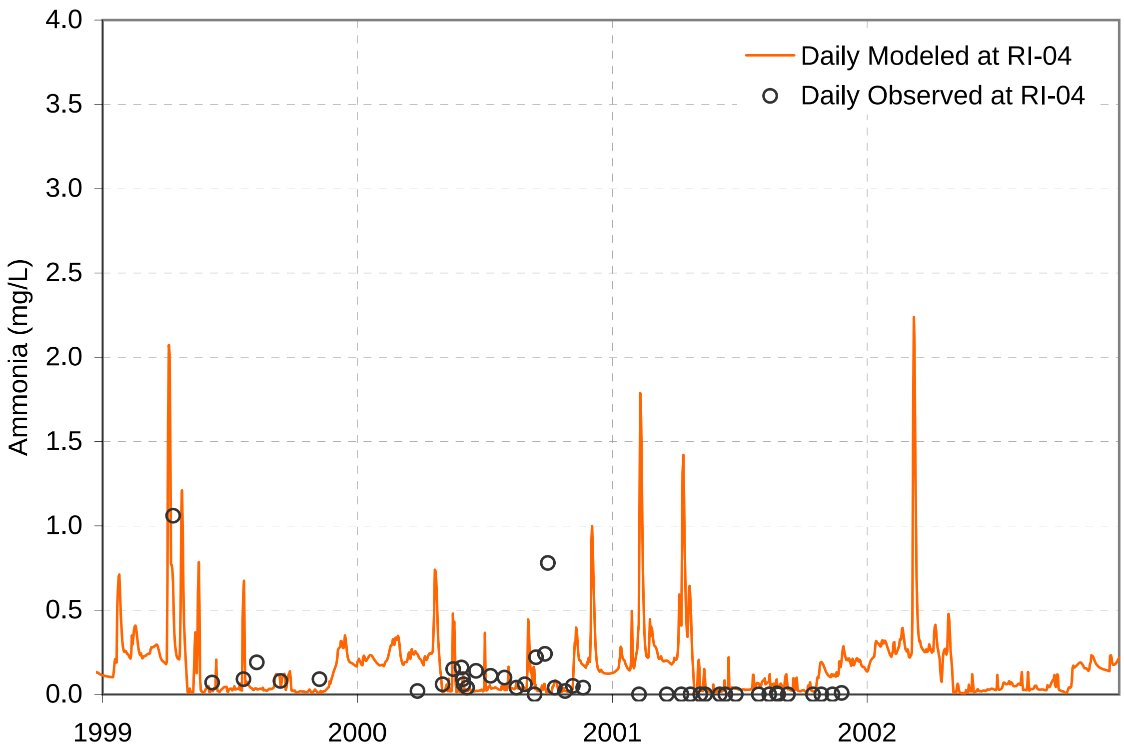


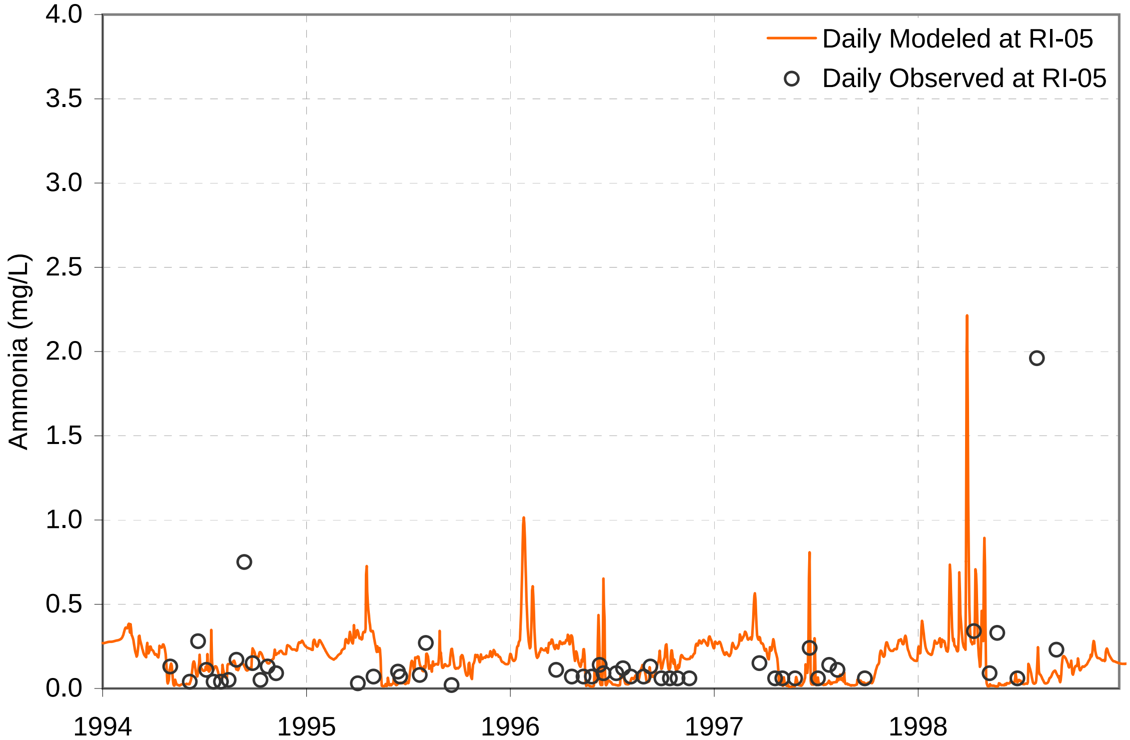
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Ammonia (mg/L)
1994
1995
1996
1997
1998
Daily Modeled at RI-02
Daily Observed at RI-02



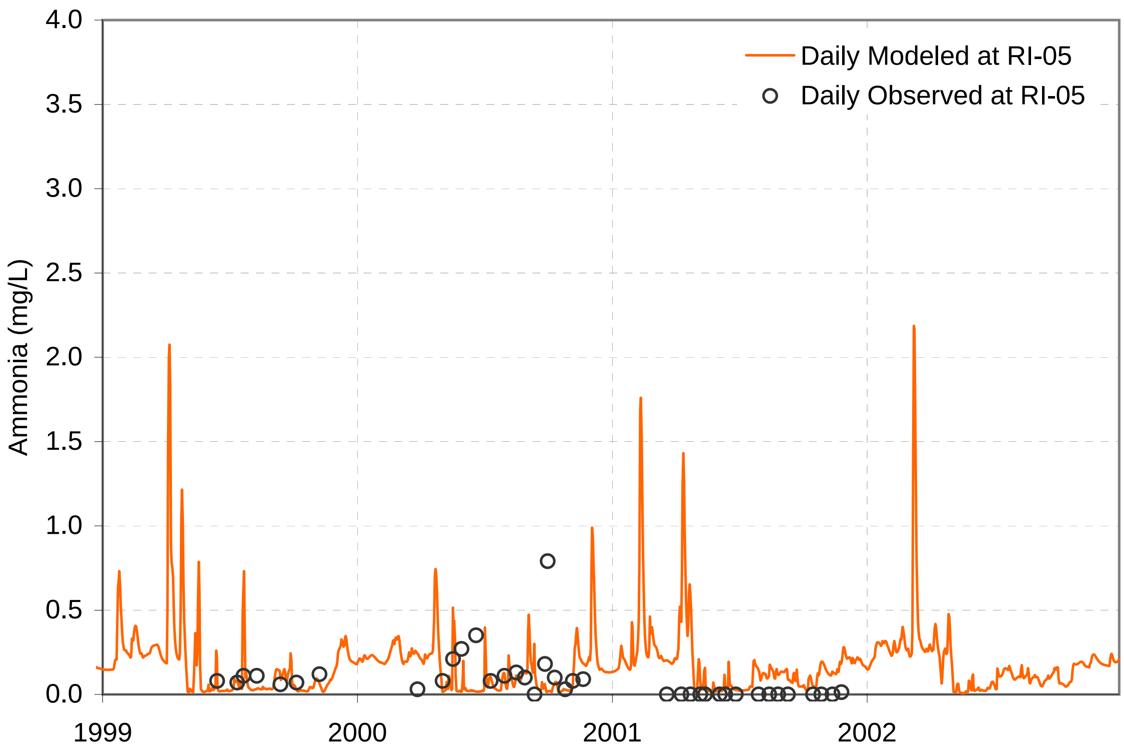
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Ammonia (mg/L)
1999
2000
2001
2002
Daily Modeled at RI-02
Daily Observed at RI-02


4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Ammonia (mg/L)
1994
1995
1996
1997
1998
Daily Modeled at RI-04
Daily Observed at RI-04

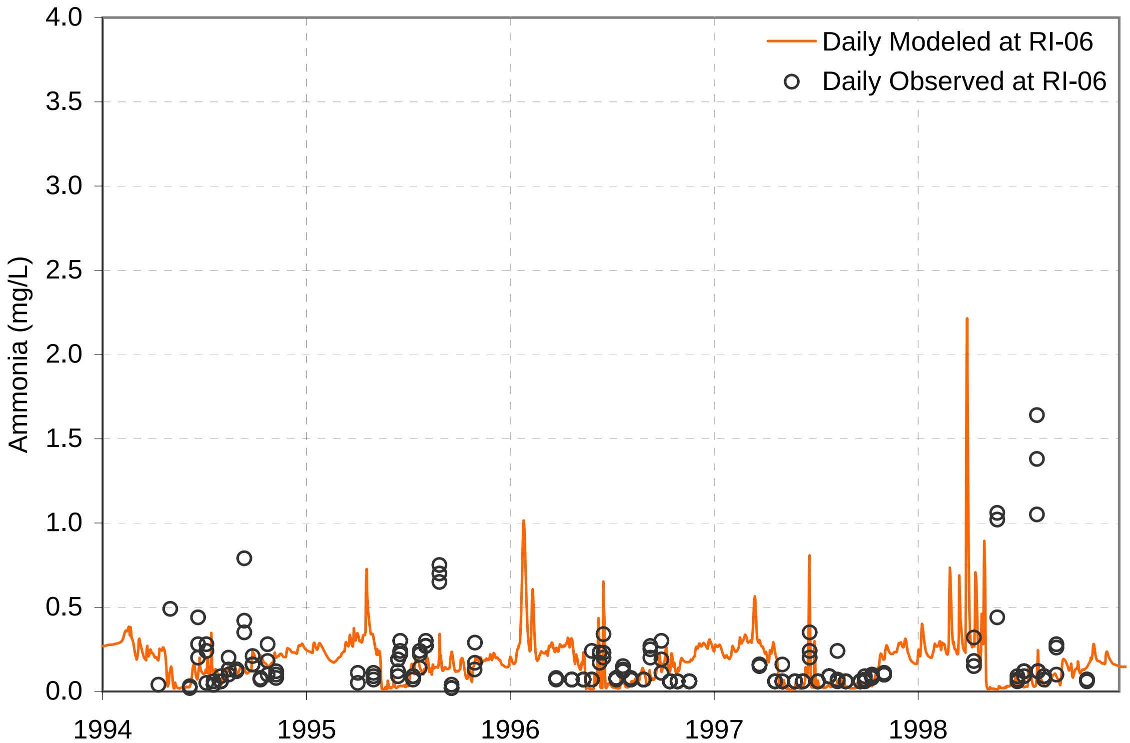

4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Ammonia (mg/L)
1999
2000
2001
2002
Daily Modeled at RI-04
Daily Observed at RI-04



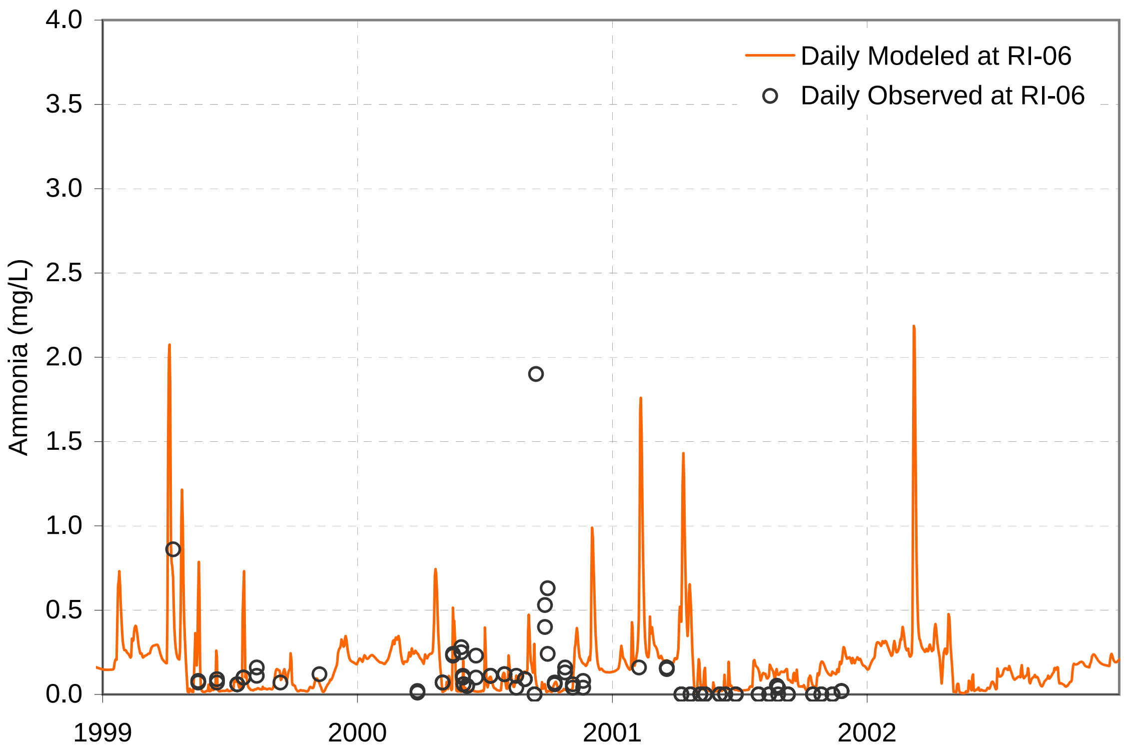
Daily Modeled at RI-05
Daily Observed at RI-05
Ammonia (mg/L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1994
1995
1996
1997
1998



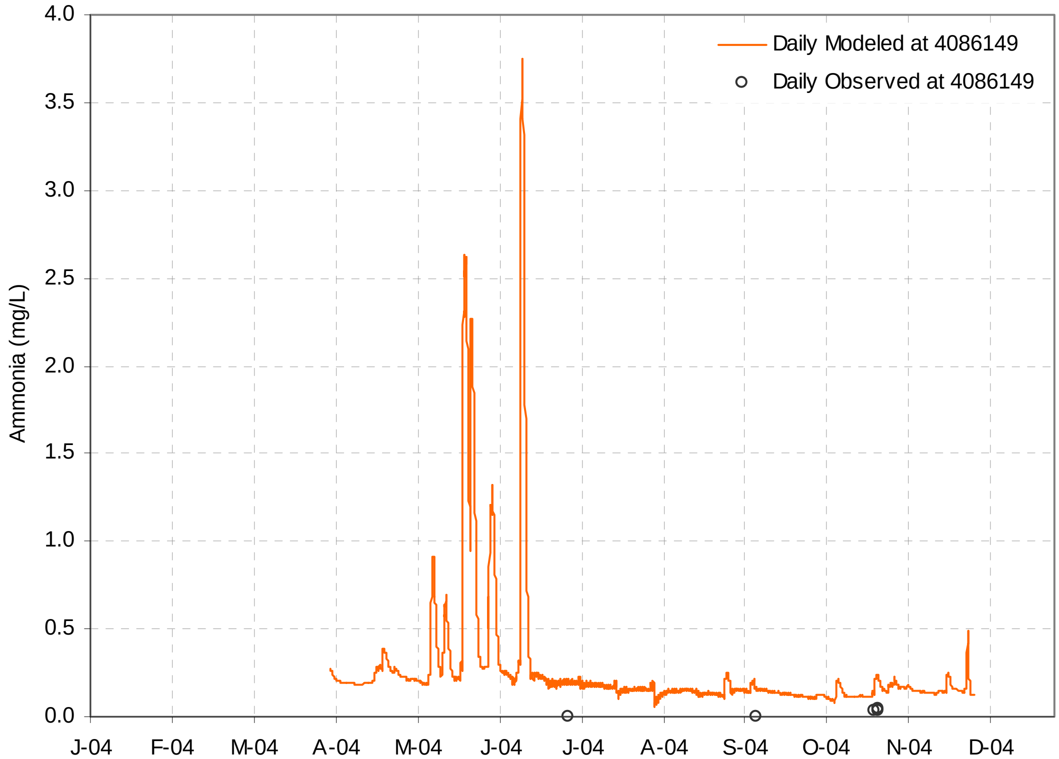
Daily Modeled at RI-05
Daily Observed at RI-05
Ammonia (mg/L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002



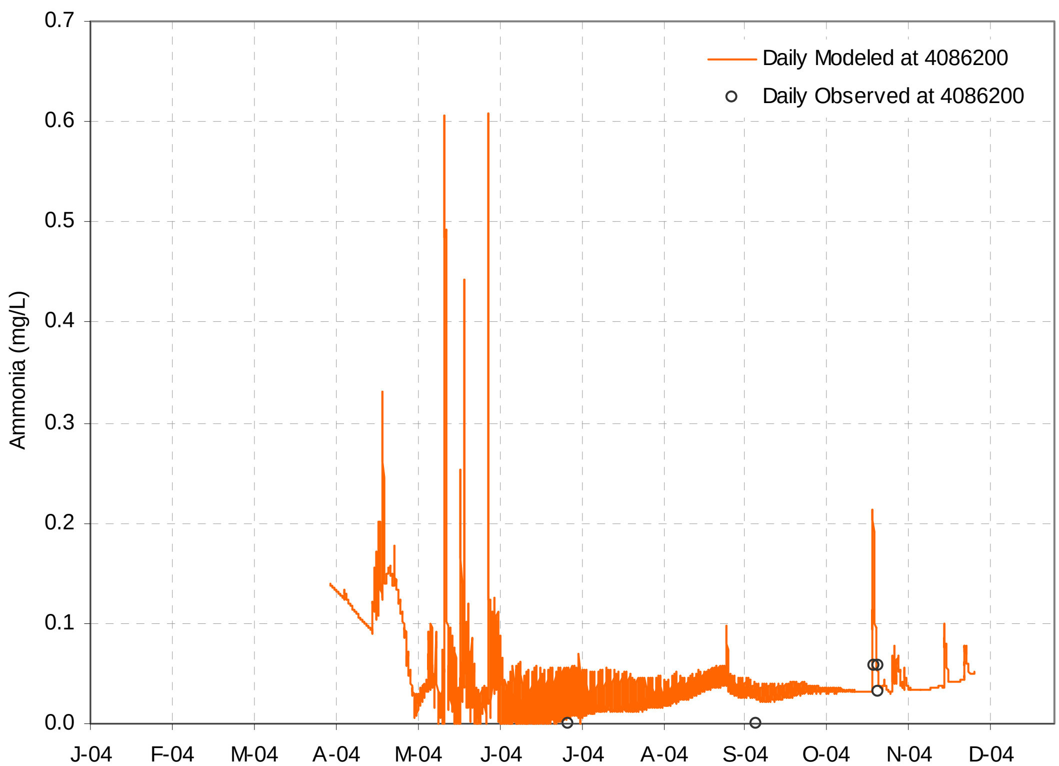
Daily Modeled at RI-06
Daily Observed at RI-06
Ammonia (mg/L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1994
1995
1996
1997
1998



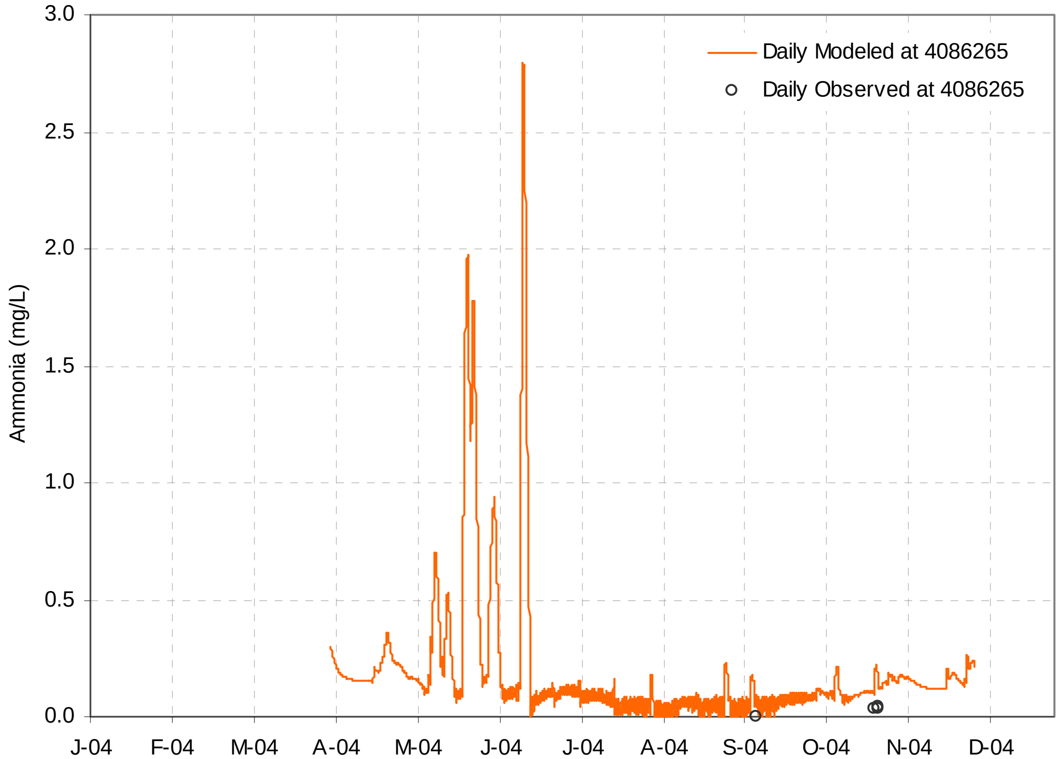
Daily Modeled at RI-06
Daily Observed at RI-06
Ammonia (mg/L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002



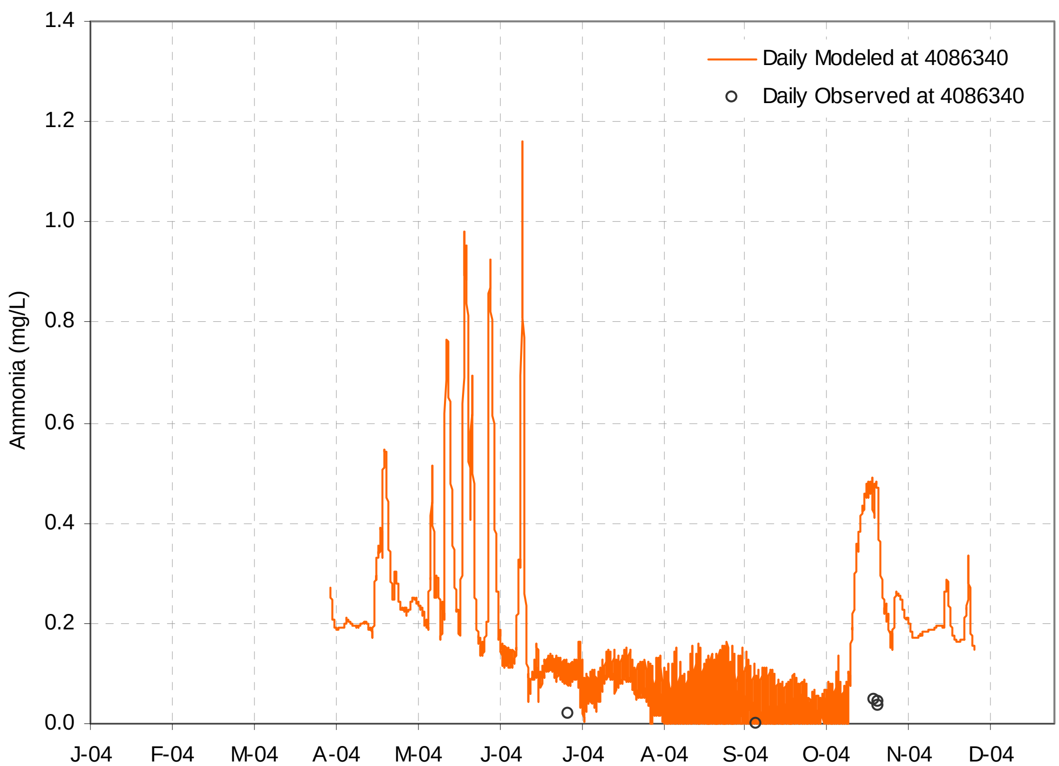
Daily Modeled at 4086149
Daily Observed at 4086149
Ammonia (mg/L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04



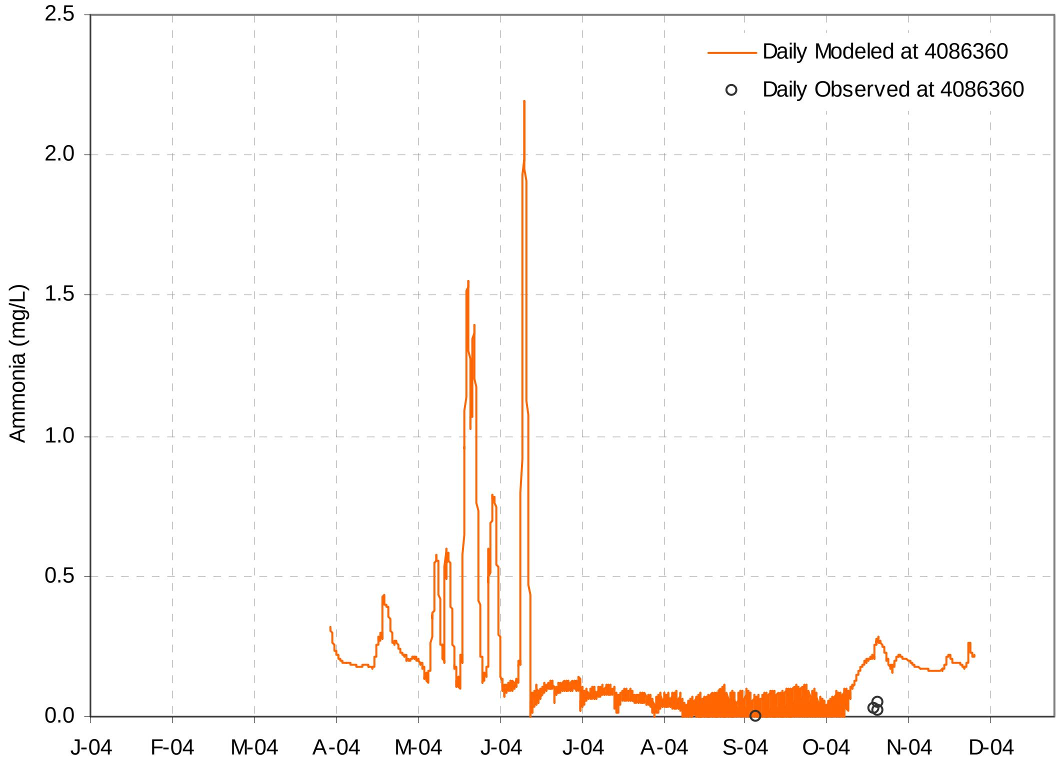
Daily Modeled at 4086200
Daily Observed at 4086200
Ammonia (mg/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

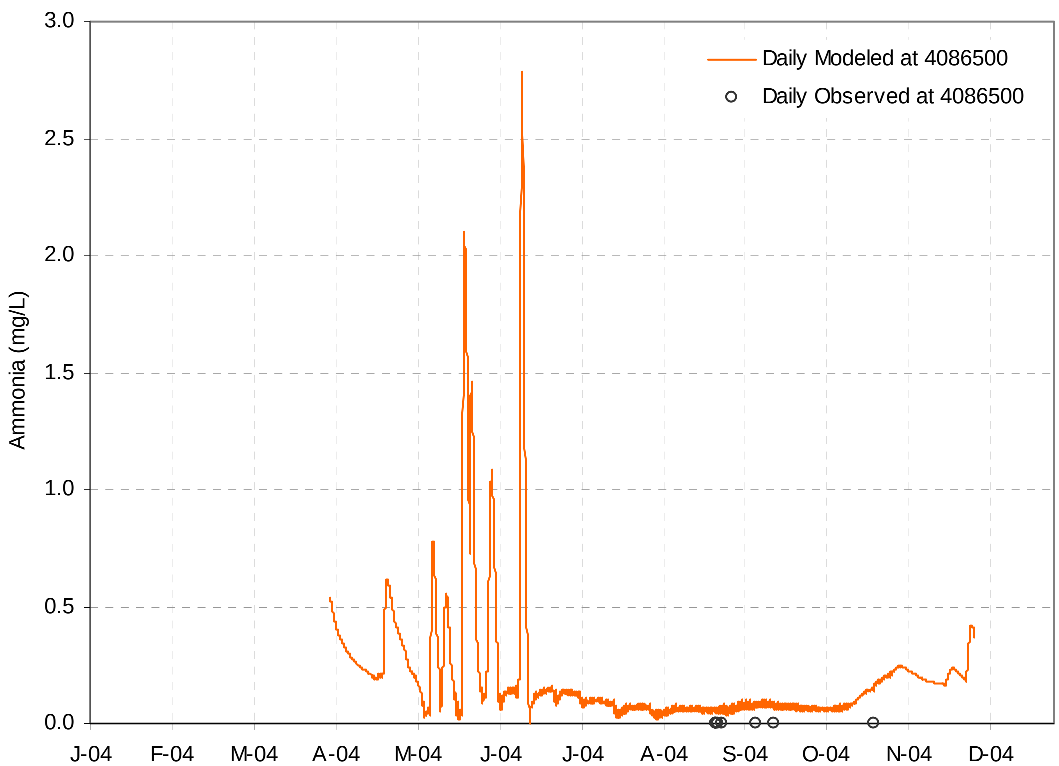


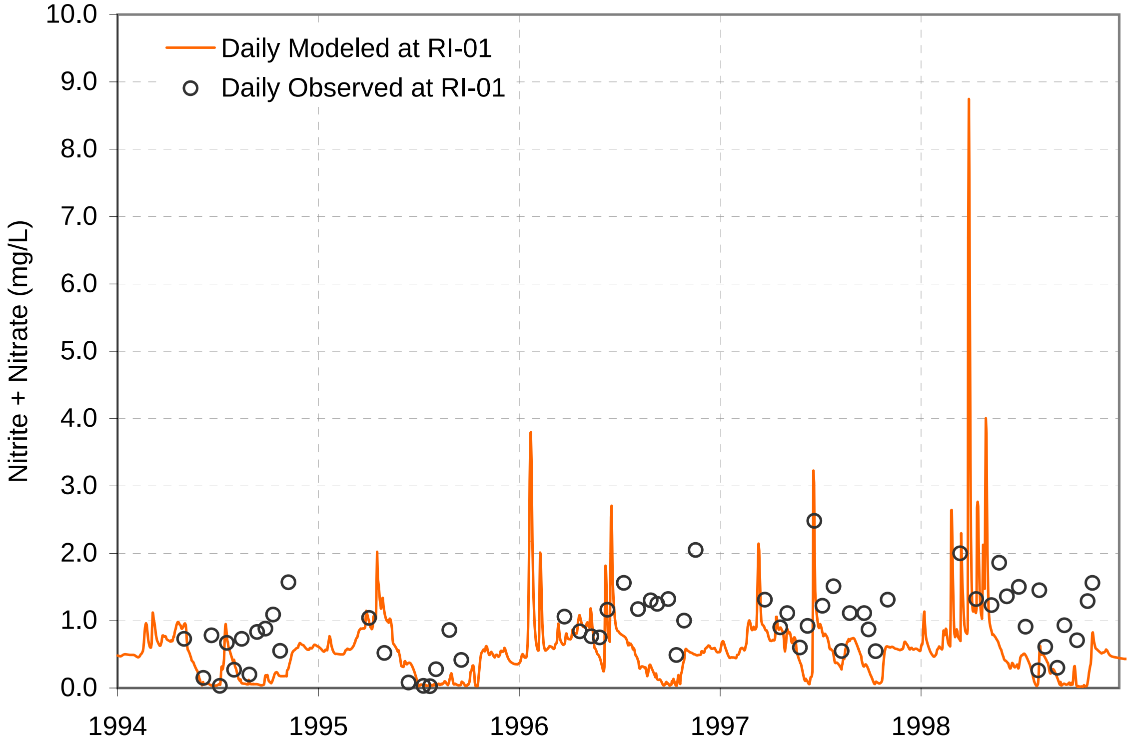
Daily Modeled at 4086265
Daily Observed at 4086265
Ammonia (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

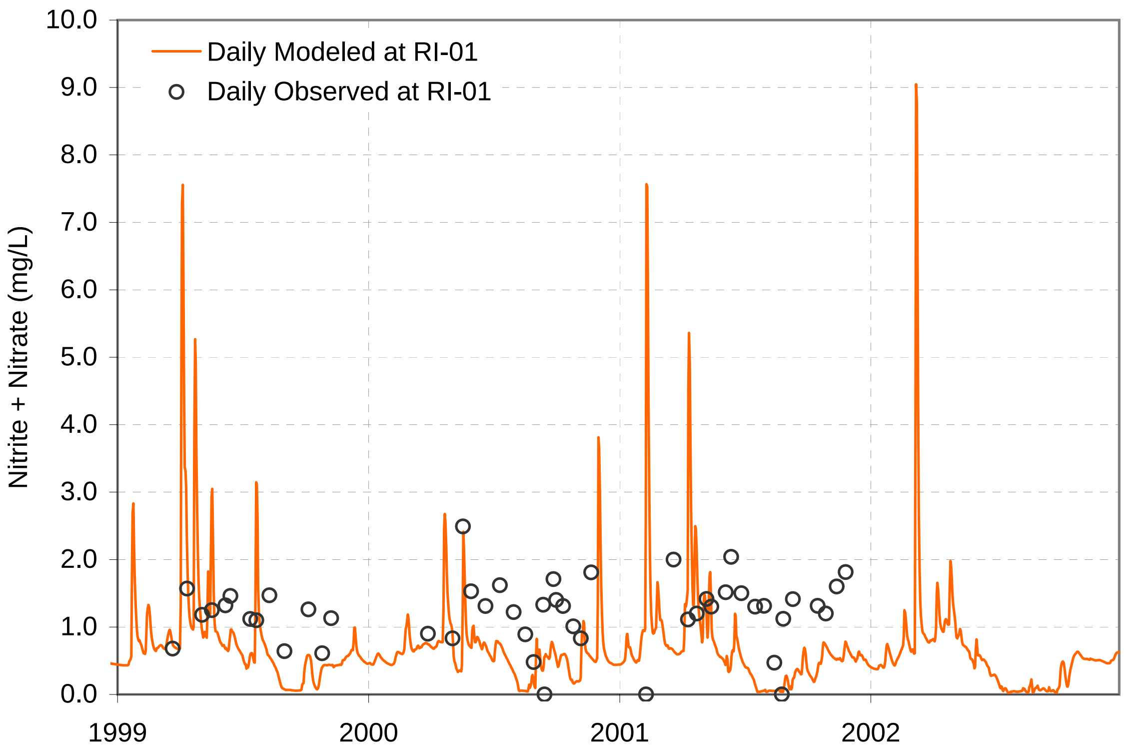


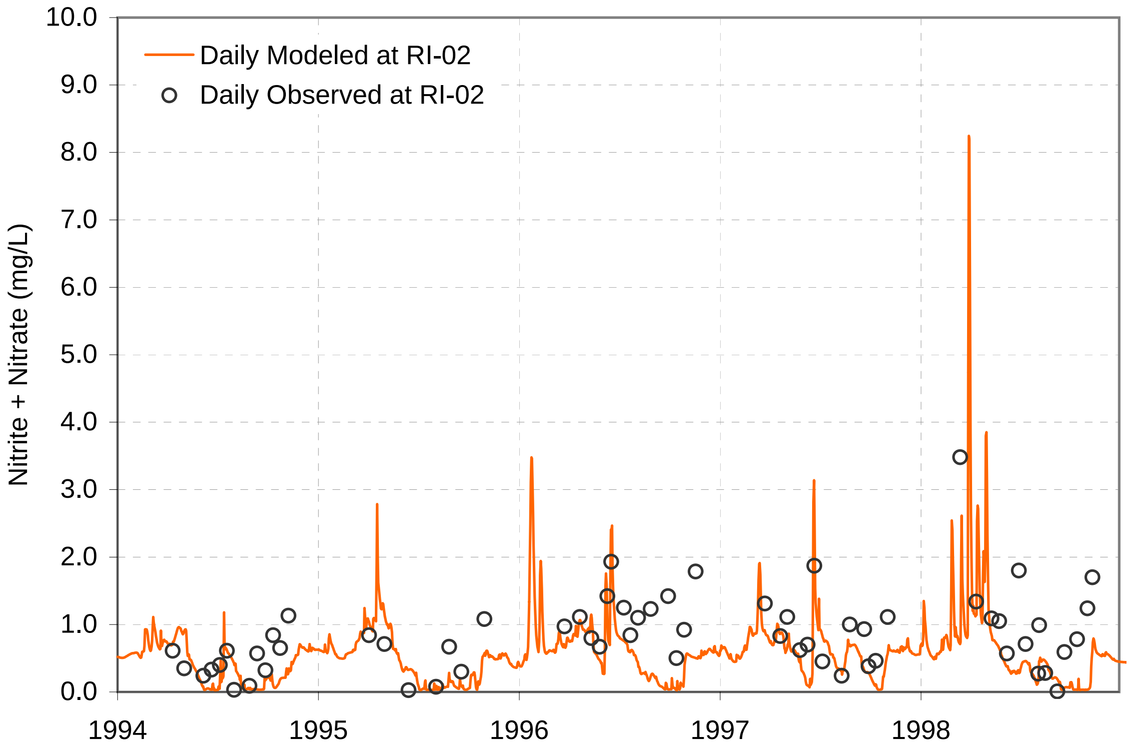
Daily Modeled at 4086340
Daily Observed at 4086340
Ammonia (mg/L)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

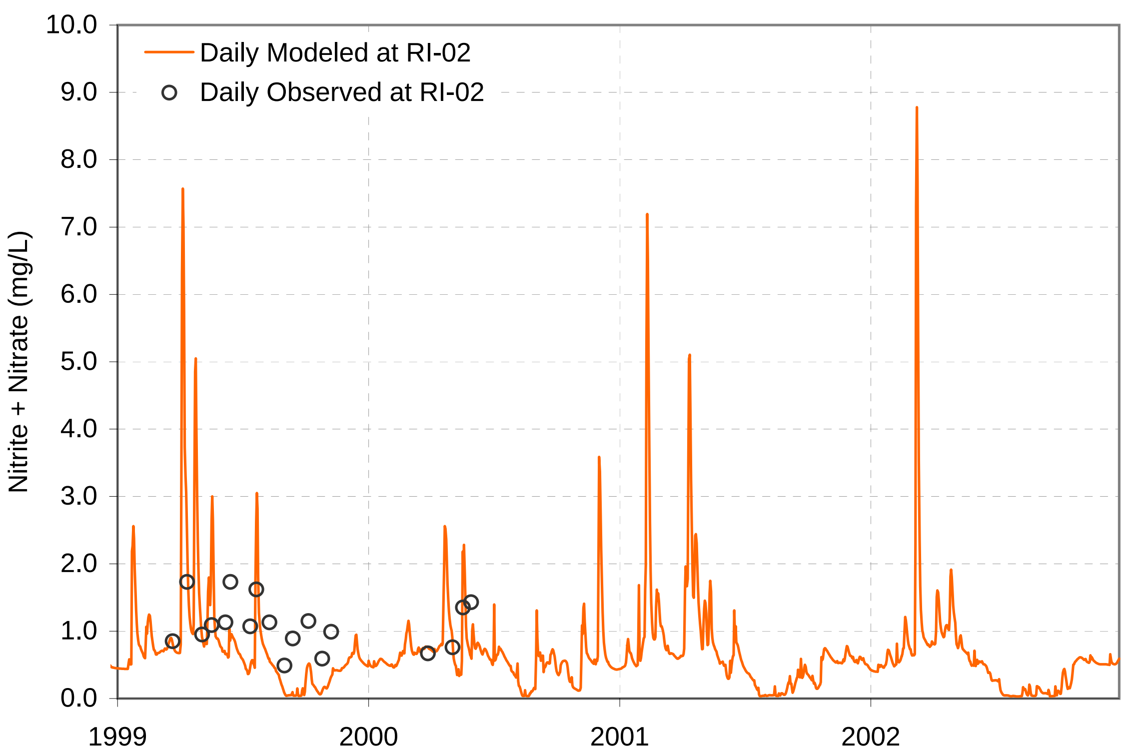

Ammonia (mg/L)
0.0
0.5
1.0
1.5
2.0
2.5
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086360
Daily Observed at 4086360

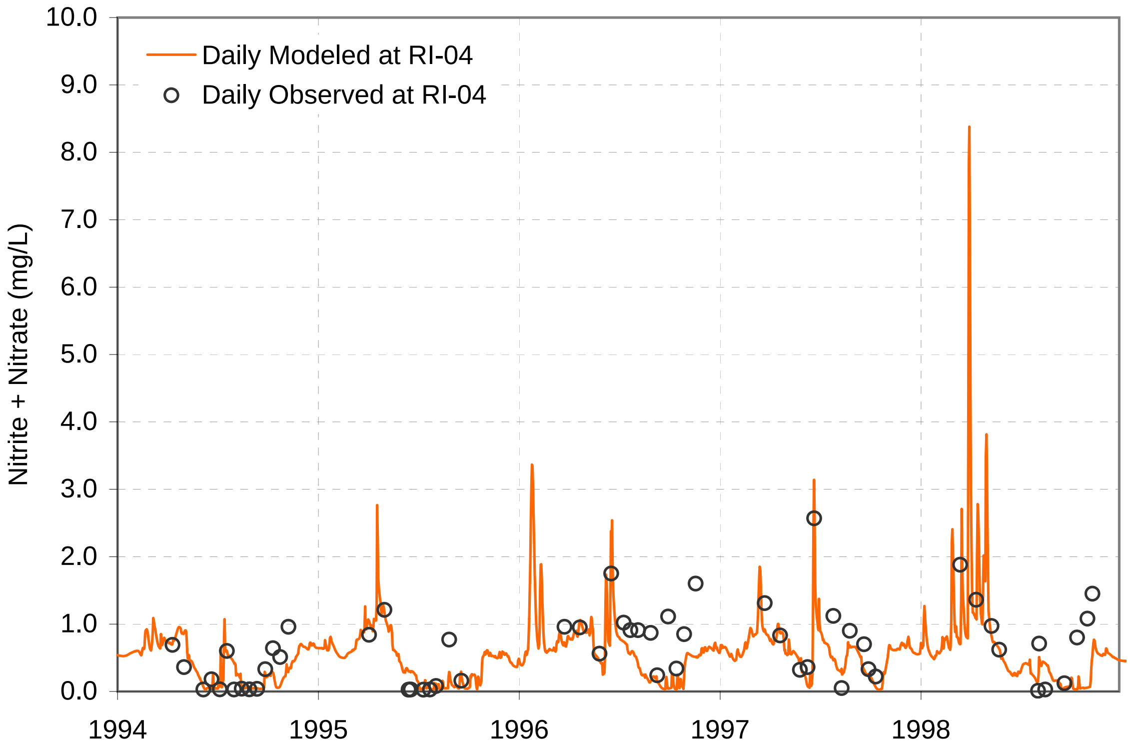

Ammonia (mg/L)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086500
Daily Observed at 4086500

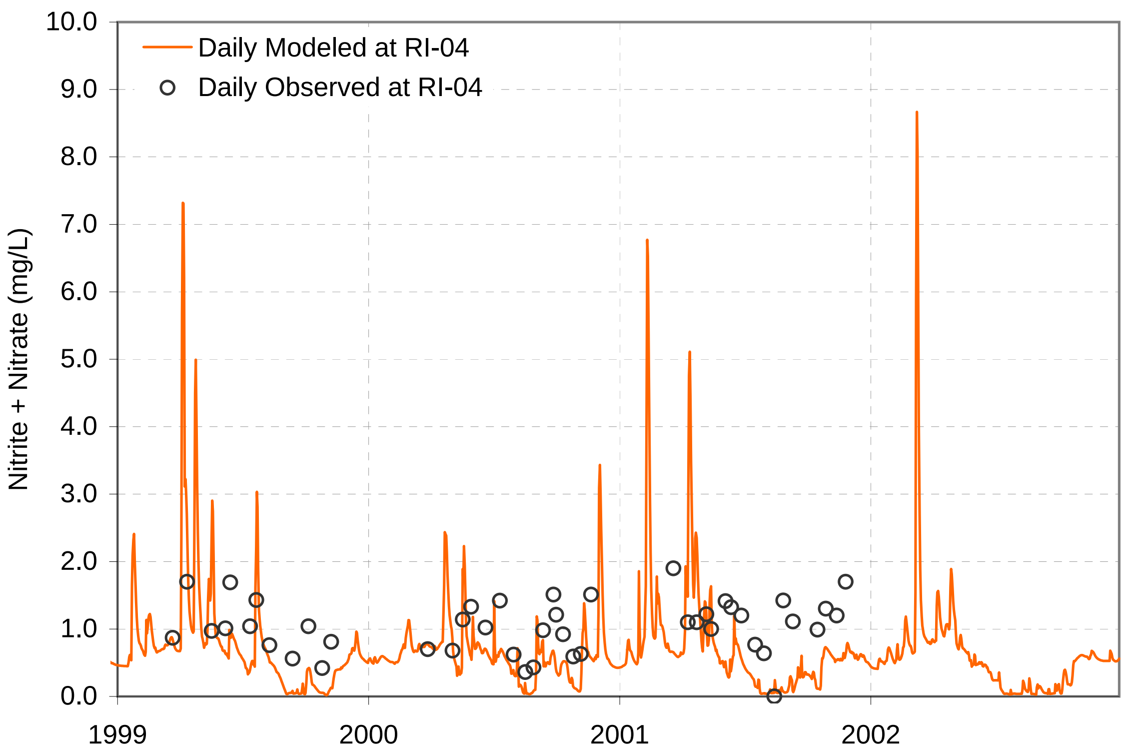

Daily Modeled at RI-01
Daily Observed at RI-01
Nitrite + Nitrate (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1994
1995
1996
1997
1998

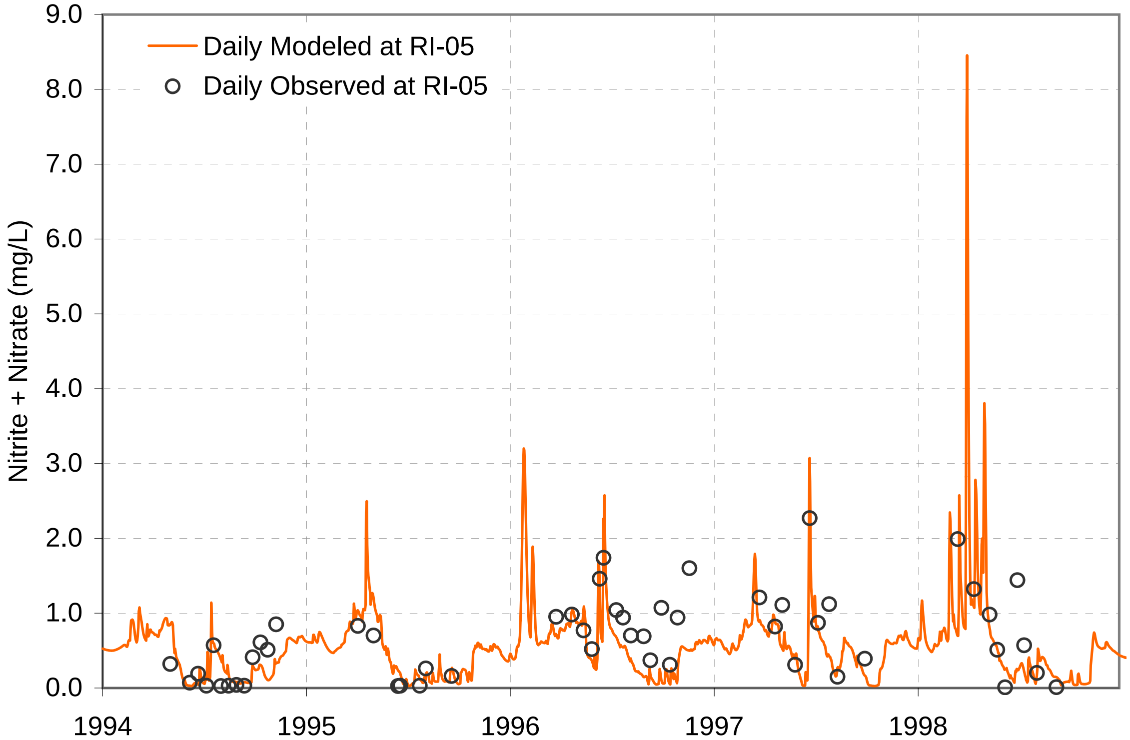

Daily Modeled at RI-01
Daily Observed at RI-01
Nitrite + Nitrate (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1999
2000
2001
2002


Daily Modeled at RI-02
Daily Observed at RI-02
Nitrite + Nitrate (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1994
1995
1996
1997
1998

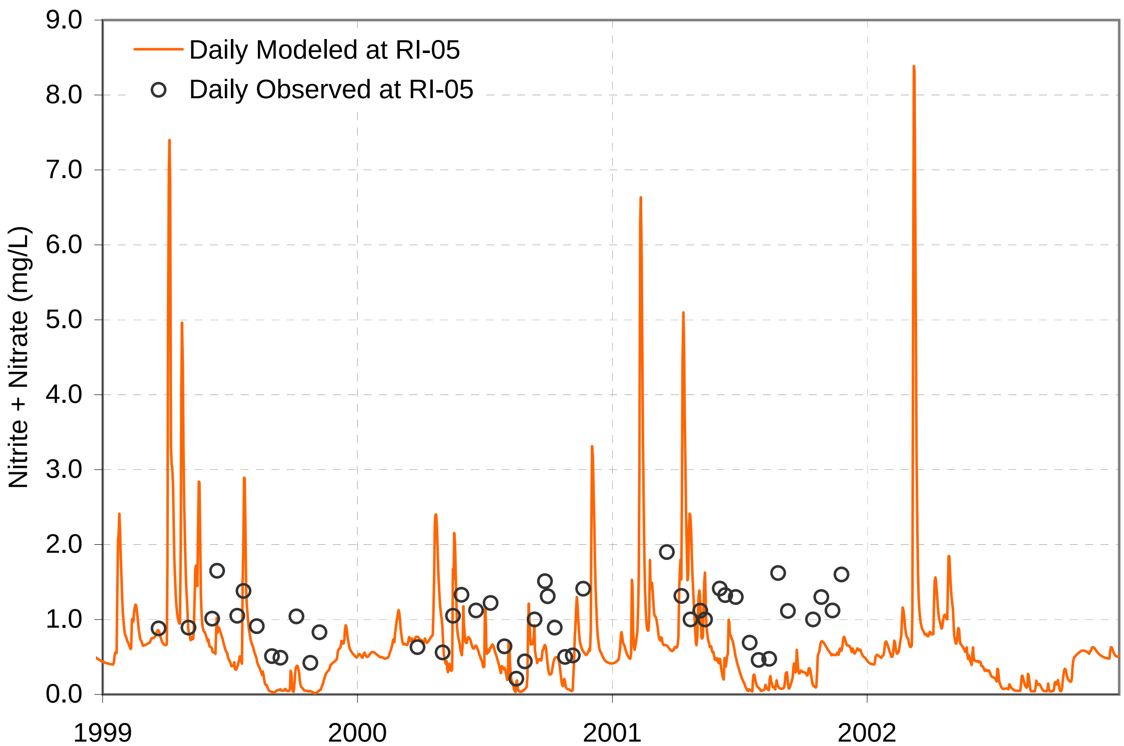

Daily Modeled at RI-02
Daily Observed at RI-02
Nitrite + Nitrate (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1999
2000
2001
2002


Daily Modeled at RI-04
Daily Observed at RI-04
Nitrite + Nitrate (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1994
1995
1996
1997
1998

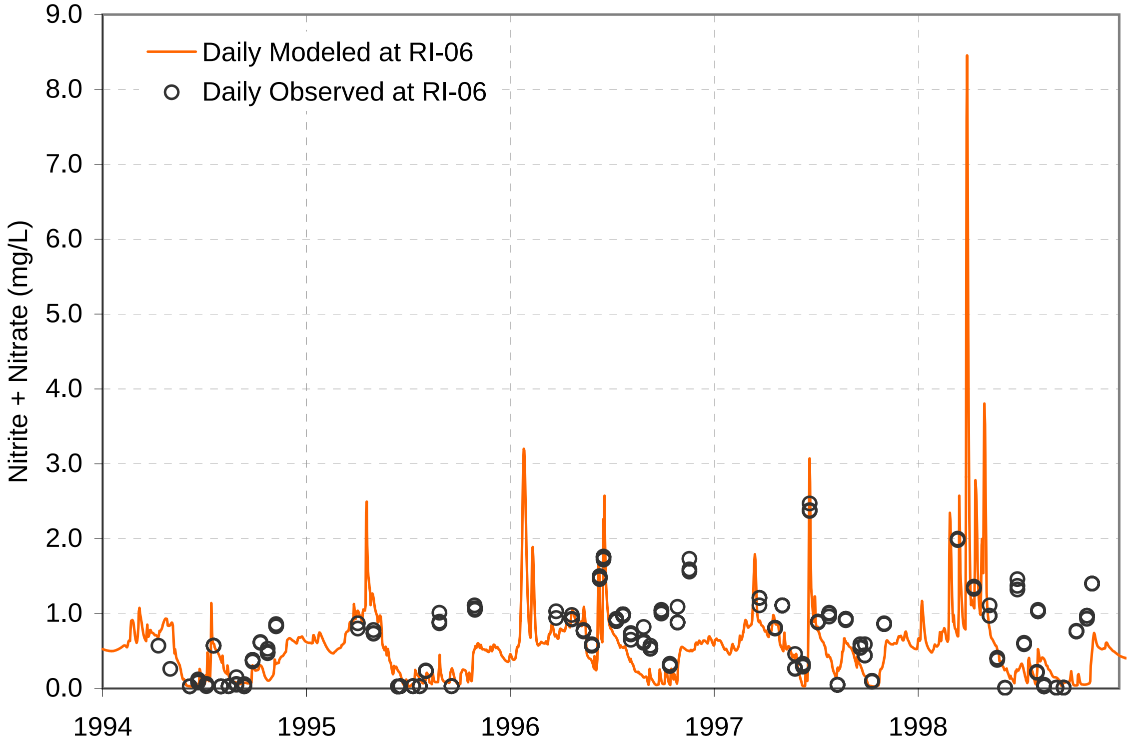

Daily Modeled at RI-04
Daily Observed at RI-04
Nitrite + Nitrate (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1999
2000
2001
2002



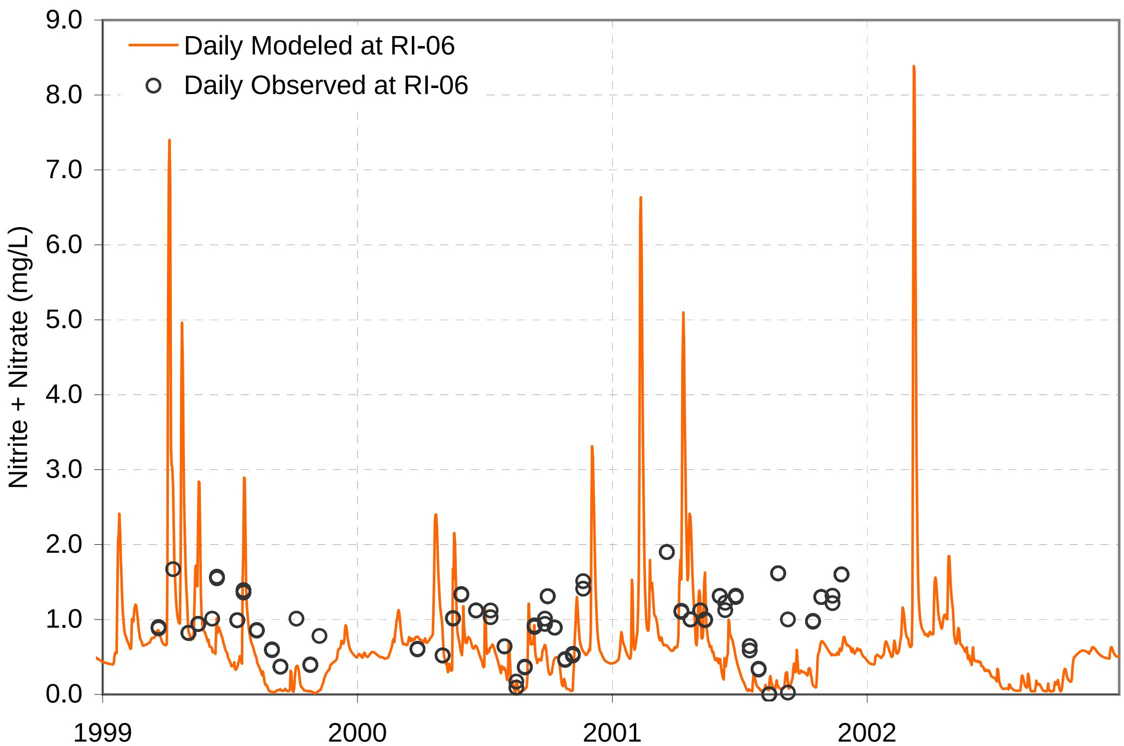
Daily Modeled at RI-05
Daily Observed at RI-05
Nitrite + Nitrate (mg/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1994
1995
1996
1997
1998



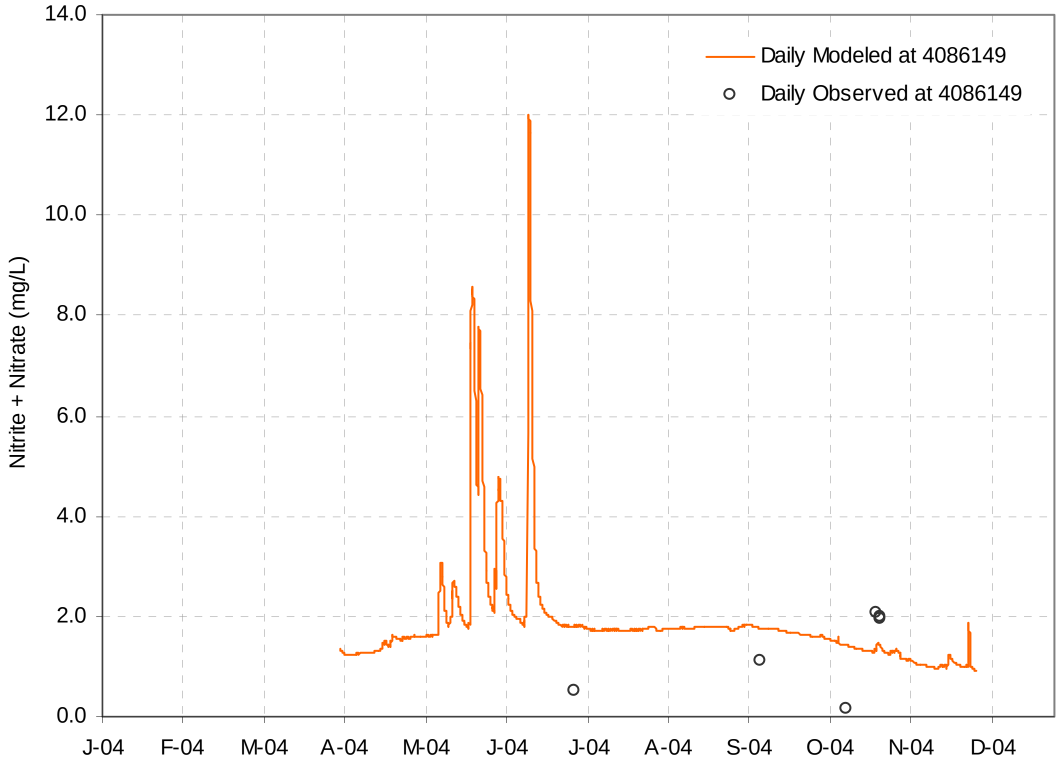
Daily Modeled at RI-05
Daily Observed at RI-05
Nitrite + Nitrate (mg/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1999
2000
2001
2002

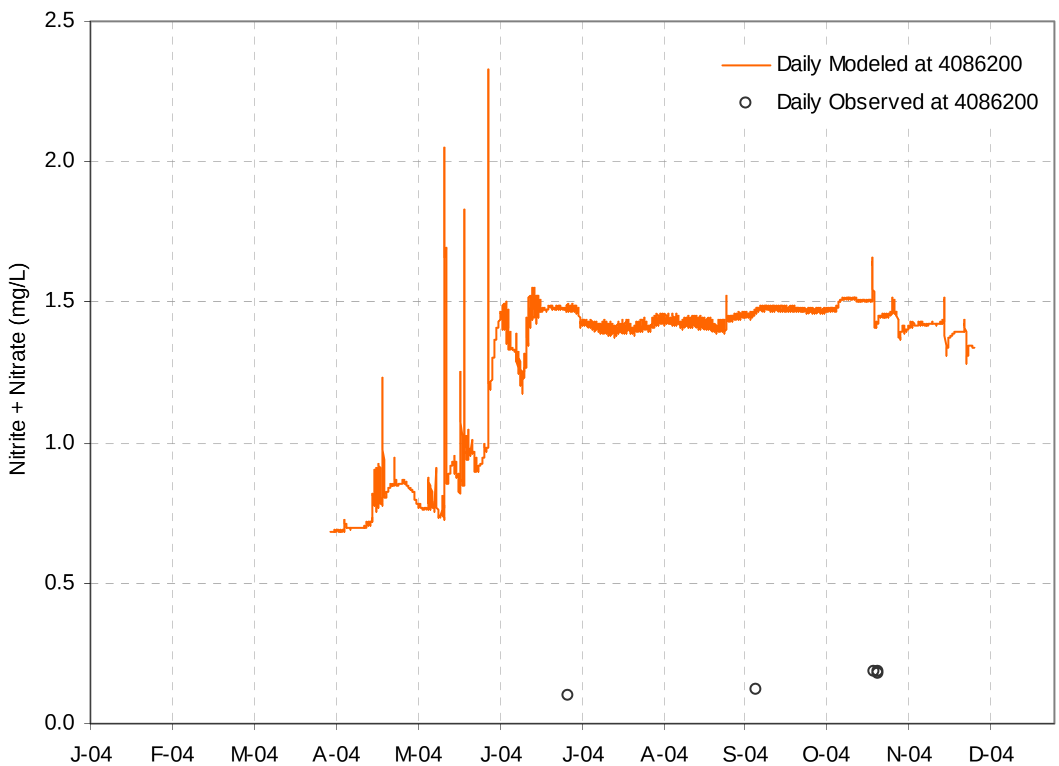


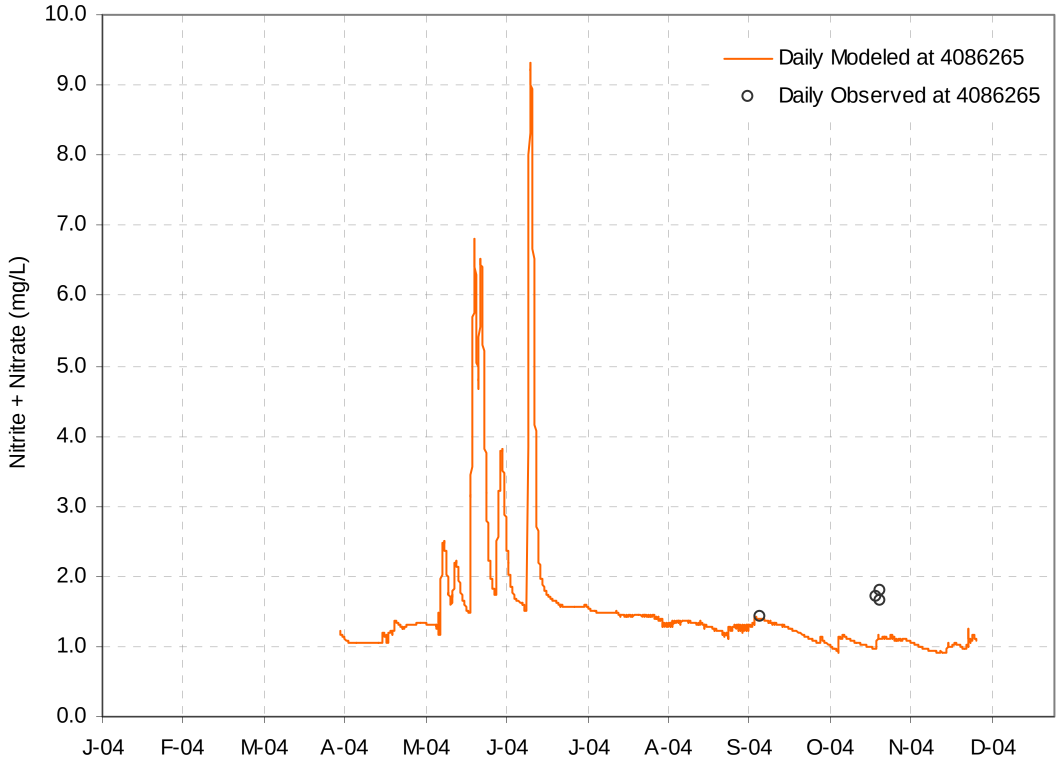
Daily Modeled at RI-06
Daily Observed at RI-06
Nitrite + Nitrate (mg/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1994
1995
1996
1997
1998

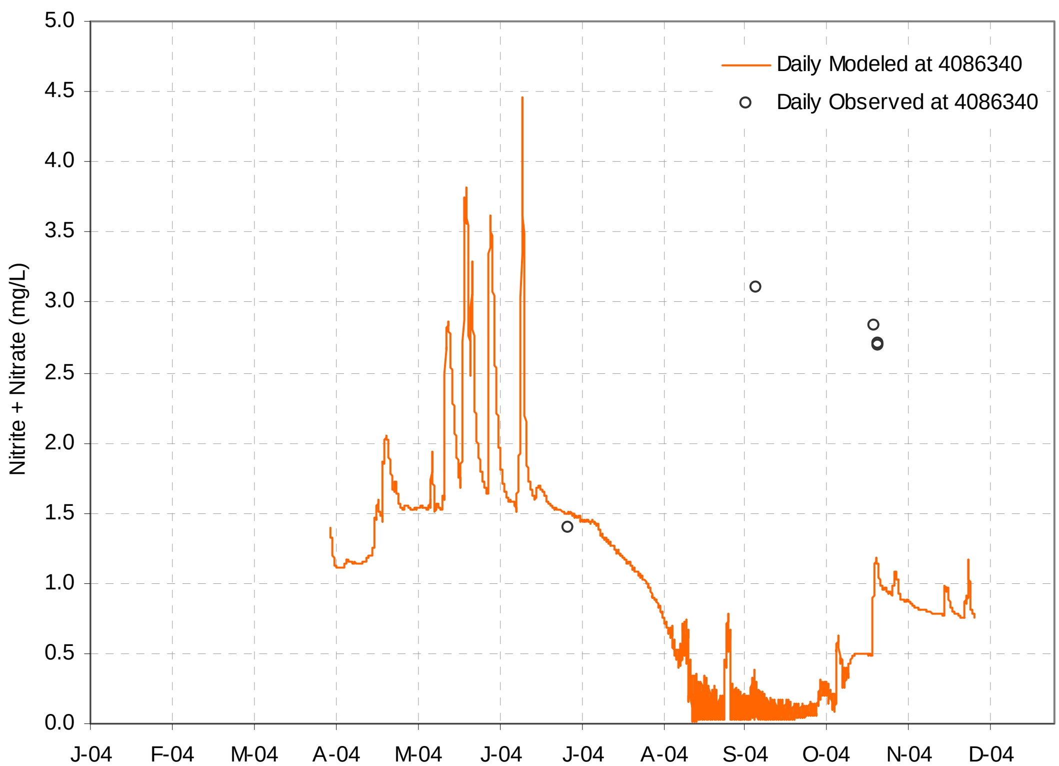


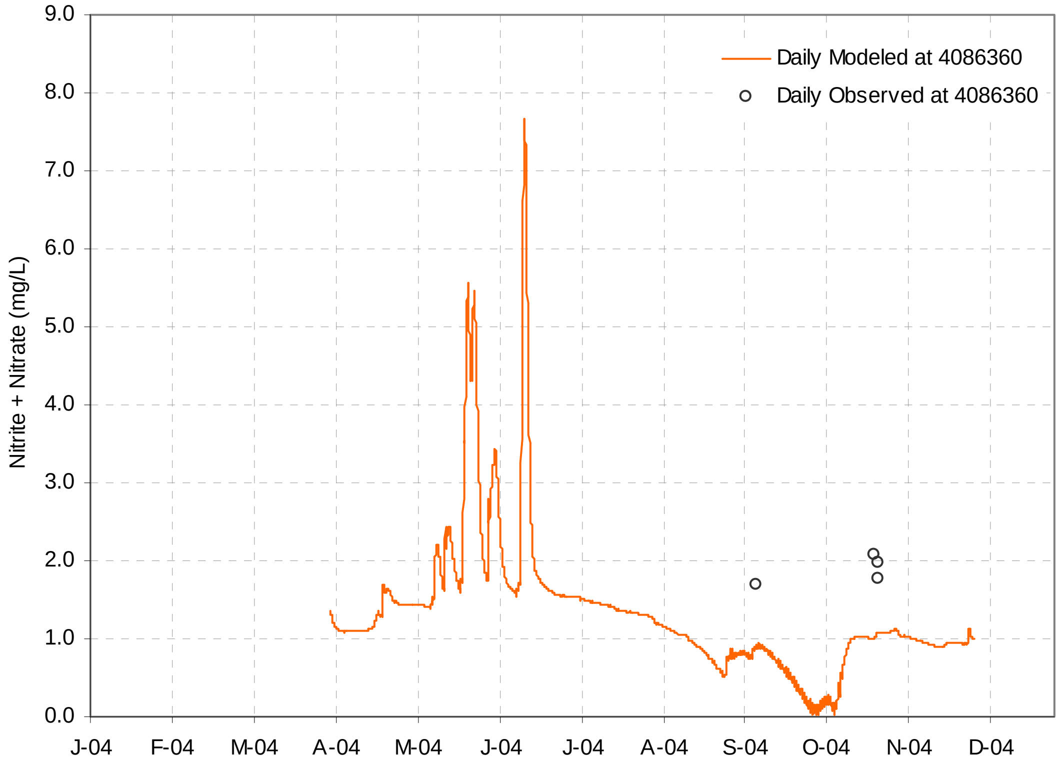
Daily Modeled at RI-06
Daily Observed at RI-06
Nitrite + Nitrate (mg/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1999
2000
2001
2002

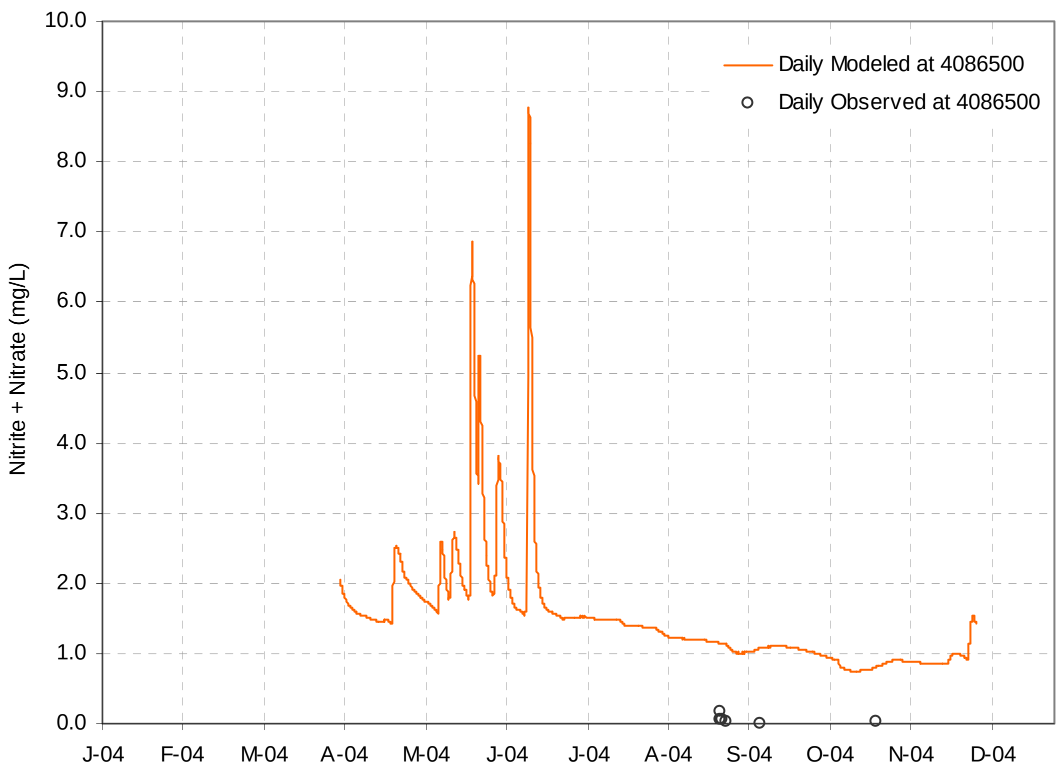

Daily Modeled at 4086149
Daily Observed at 4086149
Nitrite + Nitrate (mg/L)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

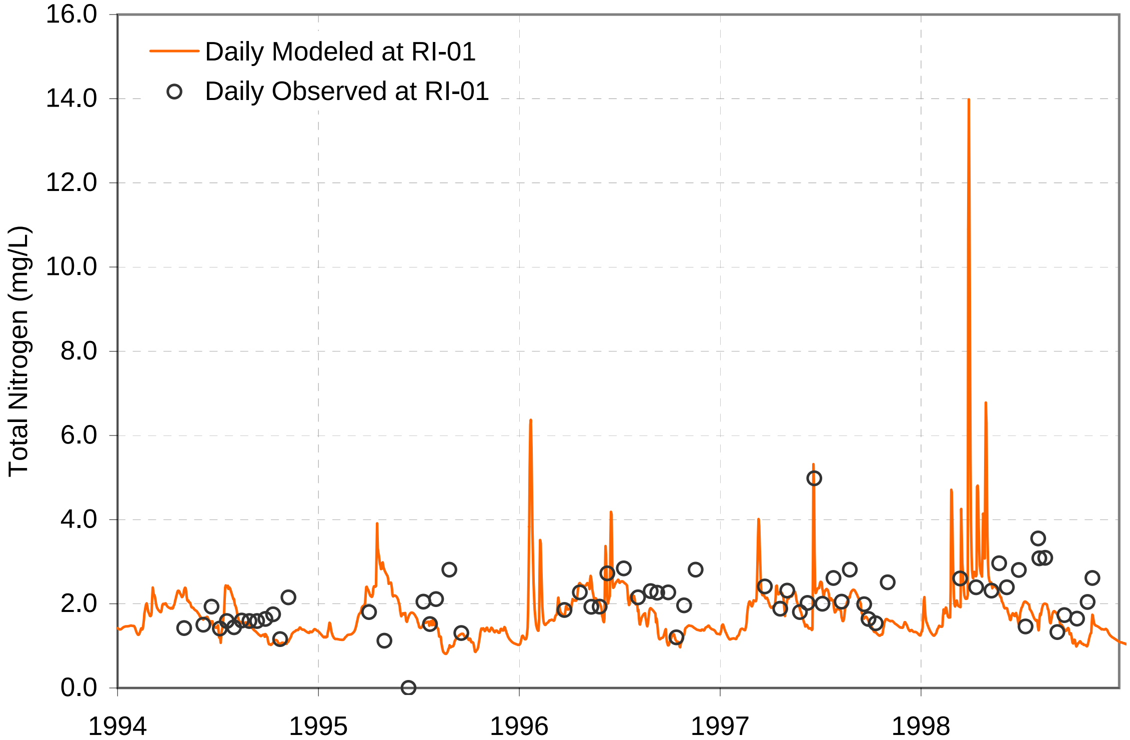

Daily Modeled at 4086200
Daily Observed at 4086200
Nitrite + Nitrate (mg/L)
2.5
2.0
1.5
1.0
0.5
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

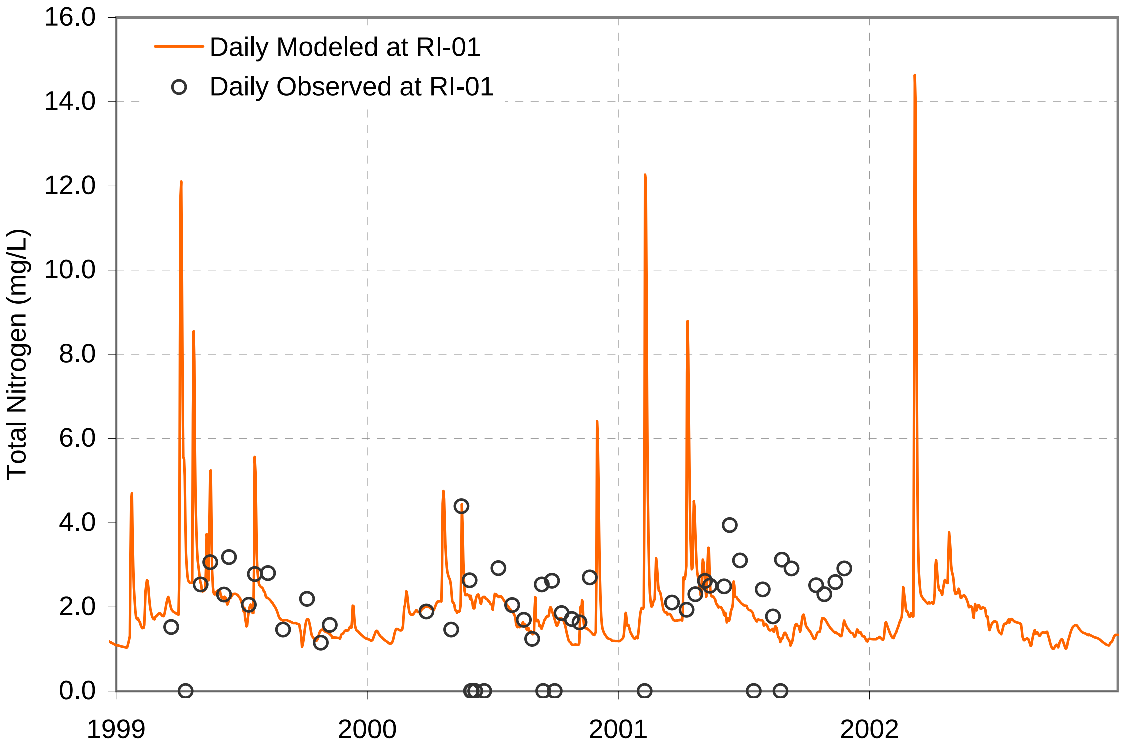

10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Nitrite + Nitrate (mg/L)
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086265
Daily Observed at 4086265

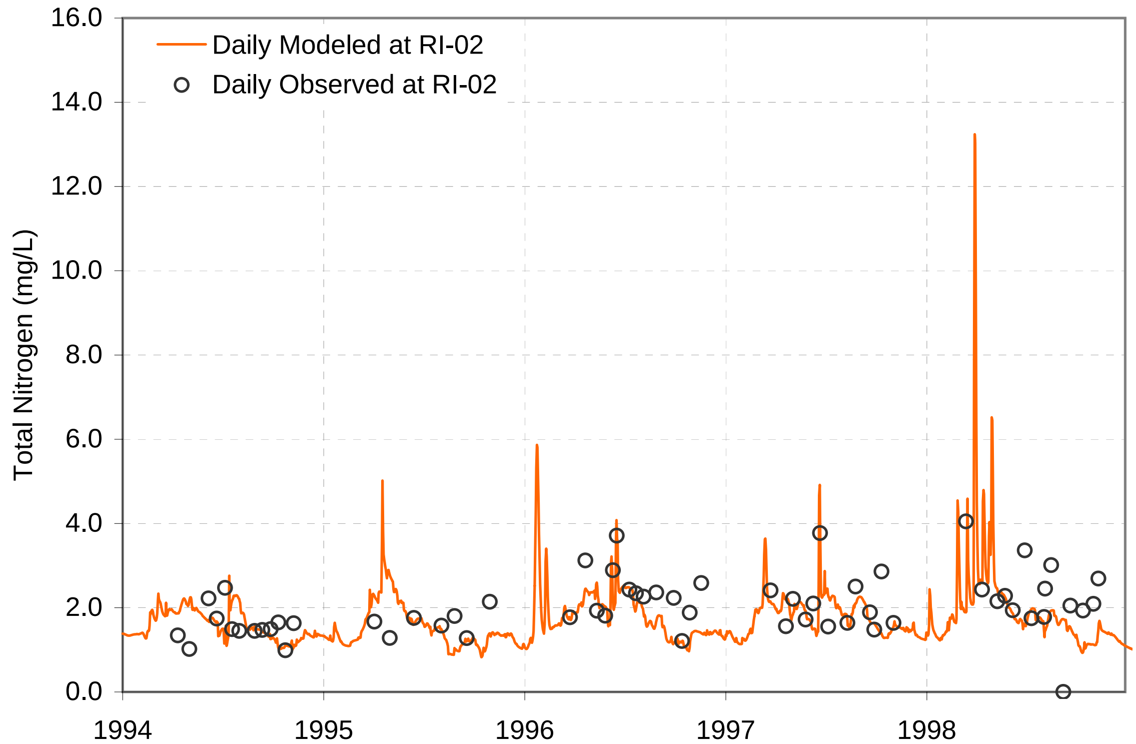

5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Nitrite + Nitrate (mg/L)
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086340
Daily Observed at 4086340

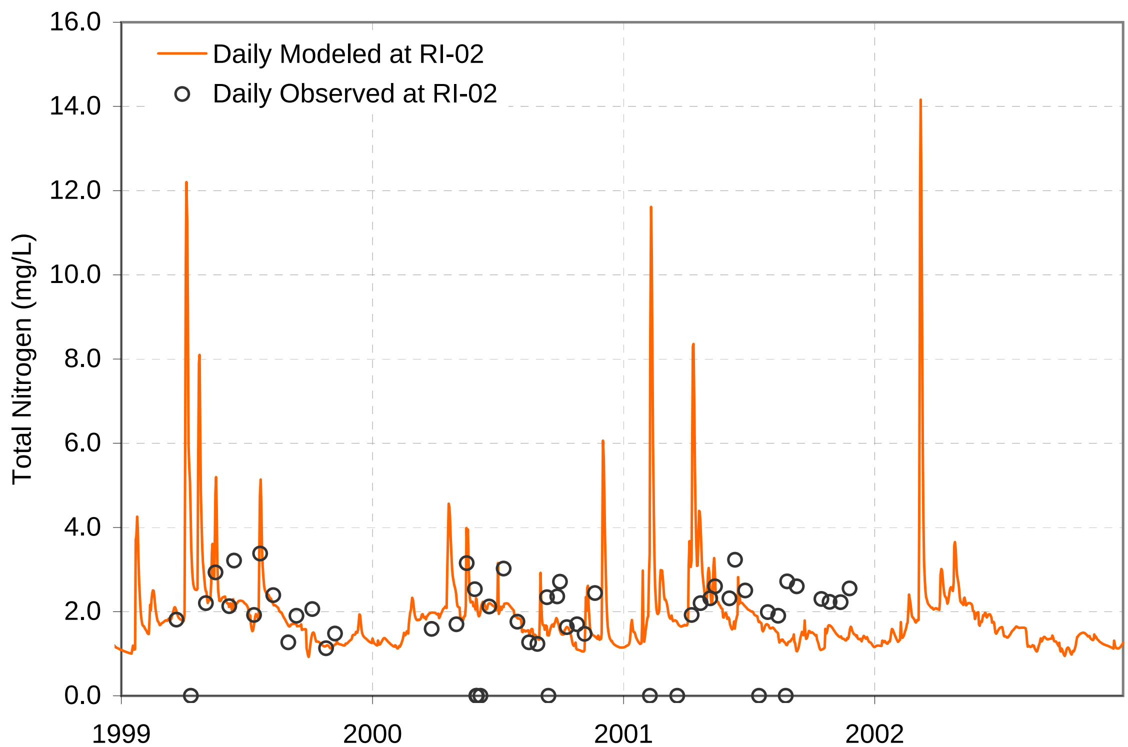

Daily Modeled at 4086360
Daily Observed at 4086360
Nitrite + Nitrate (mg/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

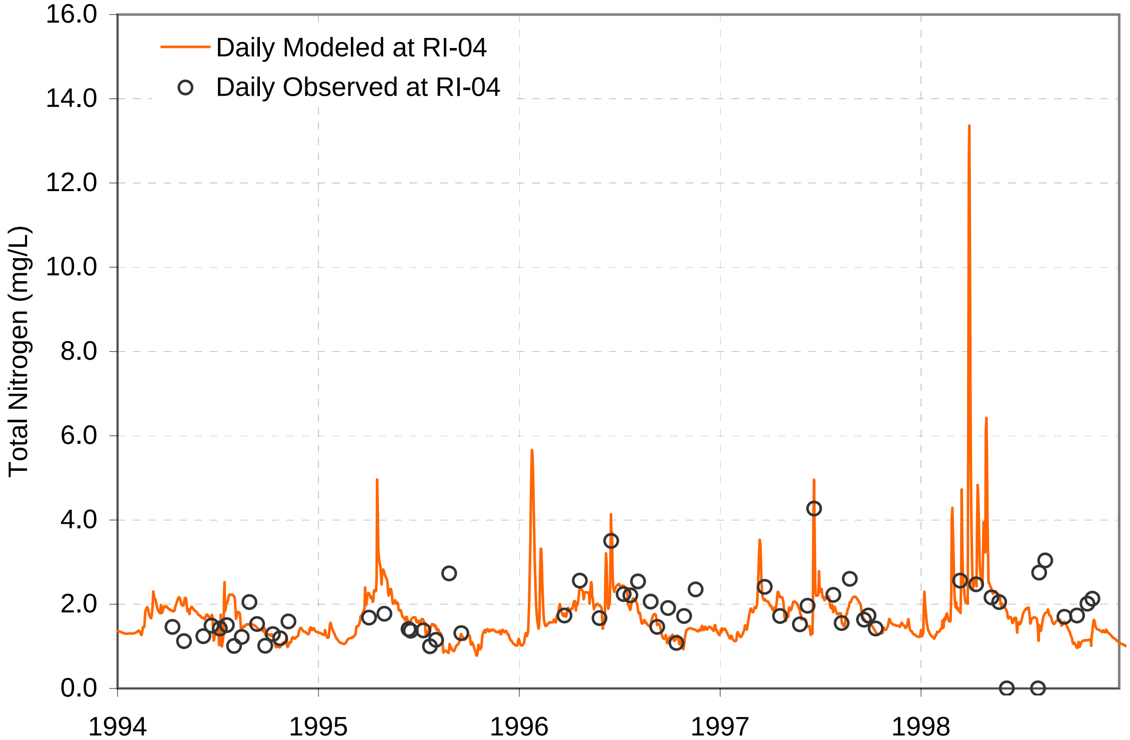

Daily Modeled at 4086500
Daily Observed at 4086500
Nitrite + Nitrate (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04


Daily Modeled at RI-01
Daily Observed at RI-01
Total Nitrogen (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1994
1995
1996
1997
1998

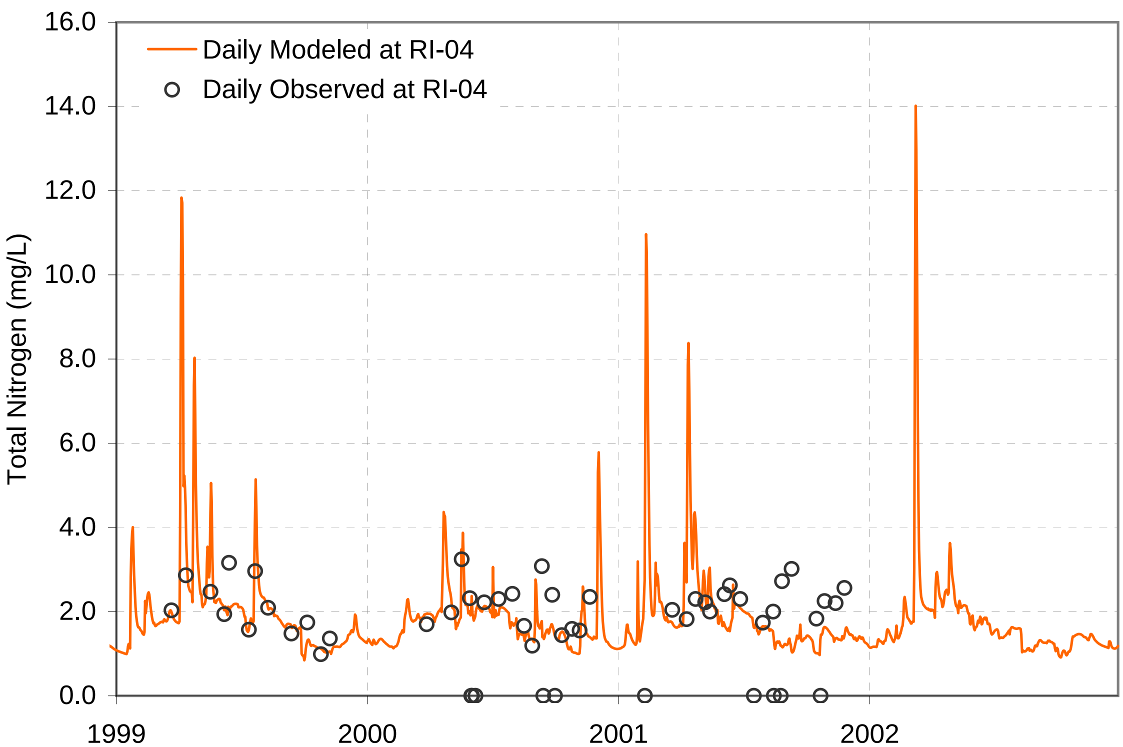

Daily Modeled at RI-01
Daily Observed at RI-01
Total Nitrogen (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1999
2000
2001
2002


Daily Modeled at RI-02
Daily Observed at RI-02
Total Nitrogen (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1994
1995
1996
1997
1998

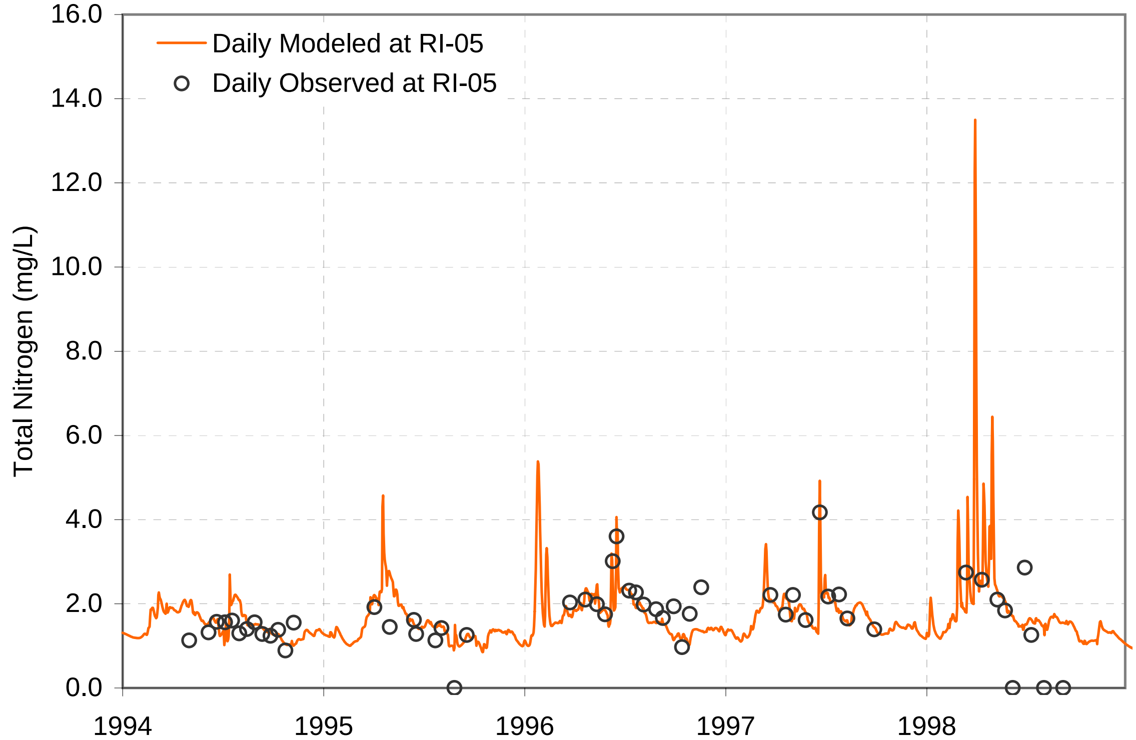

Daily Modeled at RI-02
Daily Observed at RI-02
Total Nitrogen (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1999
2000
2001
2002



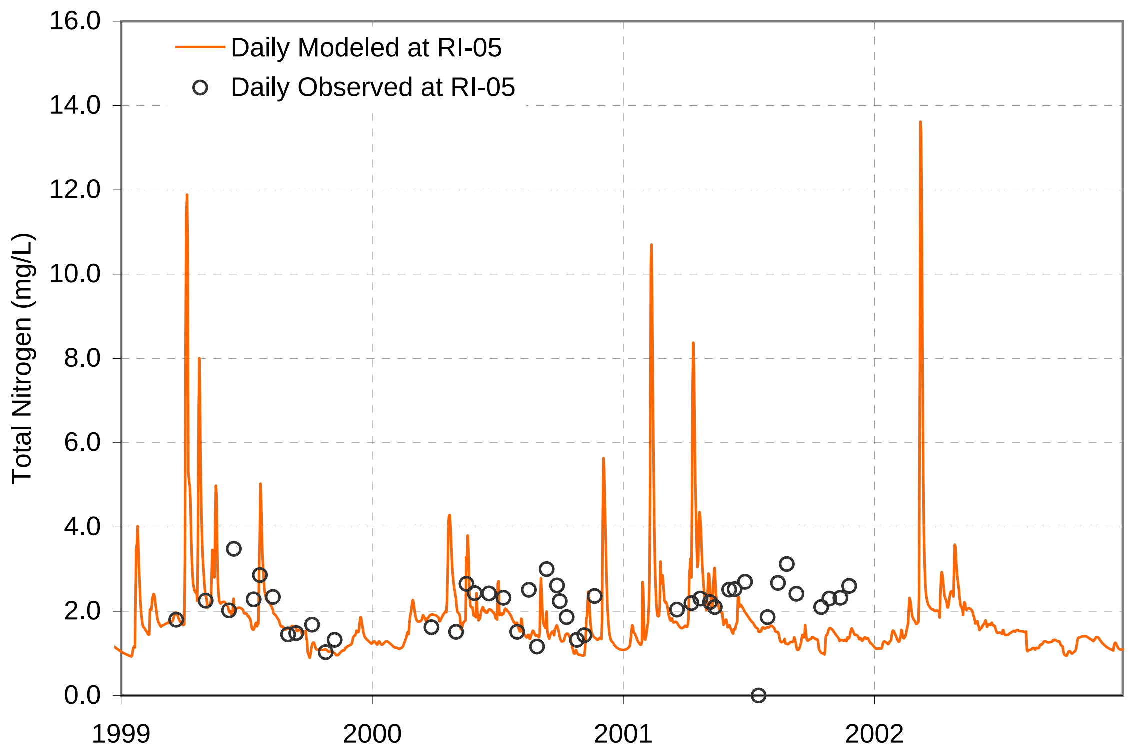
Daily Modeled at RI-04
Daily Observed at RI-04
Total Nitrogen (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1994
1995
1996
1997
1998



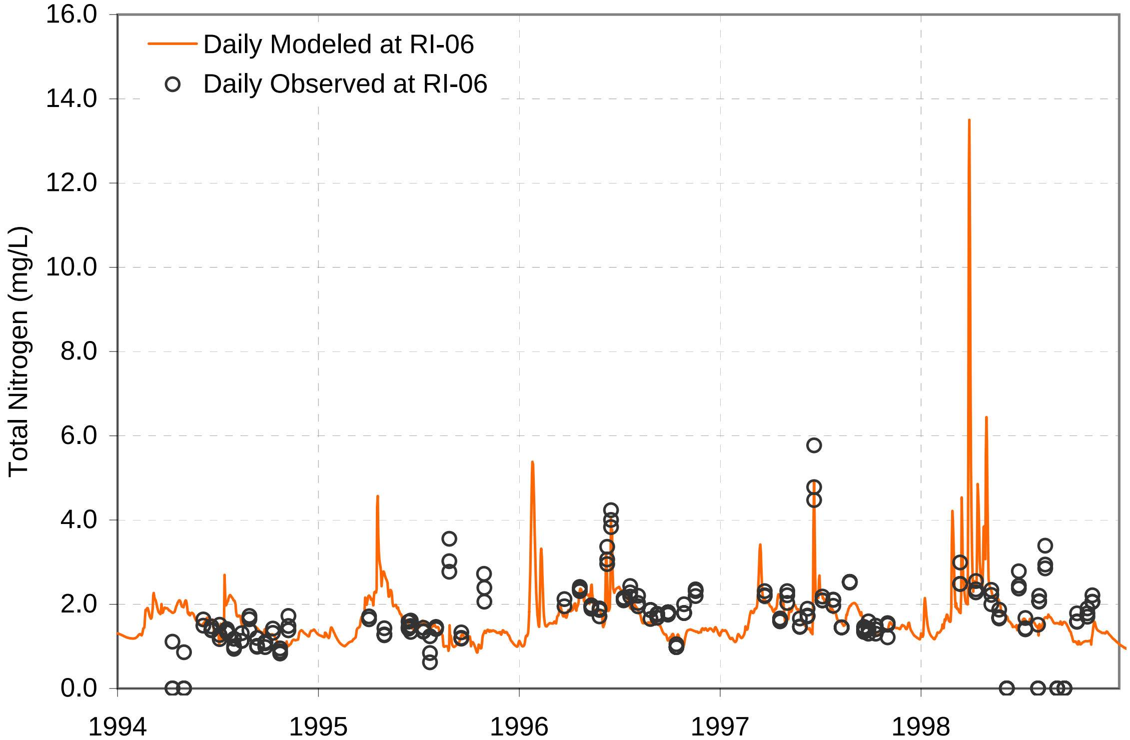
Daily Modeled at RI-04
Daily Observed at RI-04
Total Nitrogen (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1999
2000
2001
2002



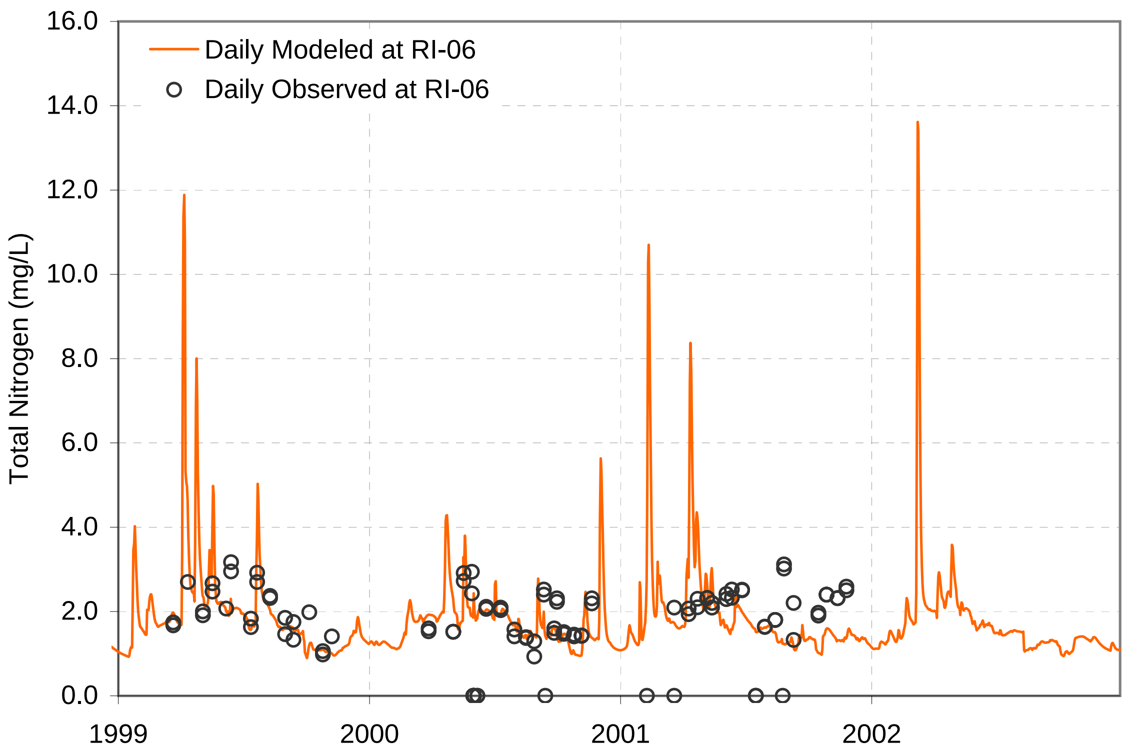
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Total Nitrogen (mg/L)
Daily Modeled at RI-05
Daily Observed at RI-05
1994
1995
1996
1997
1998



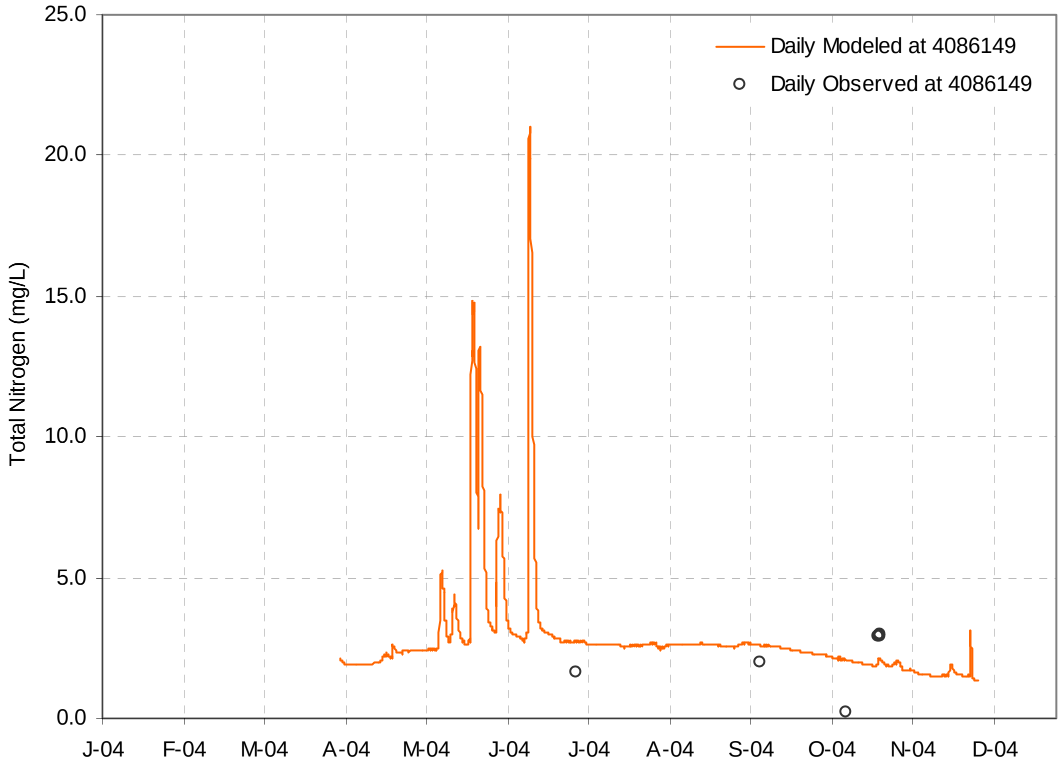
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Total Nitrogen (mg/L)
Daily Modeled at RI-05
Daily Observed at RI-05
1999
2000
2001
2002



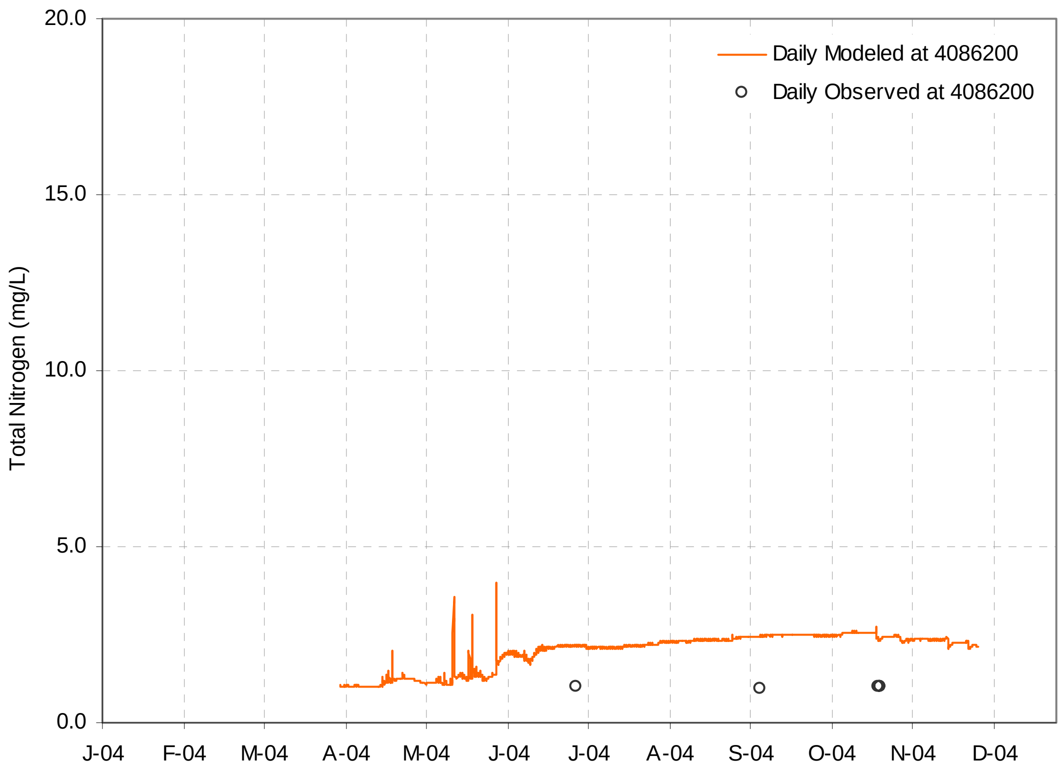
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Total Nitrogen (mg/L)
1994
1995
1996
1997
1998
Daily Modeled at RI-06
Daily Observed at RI-06



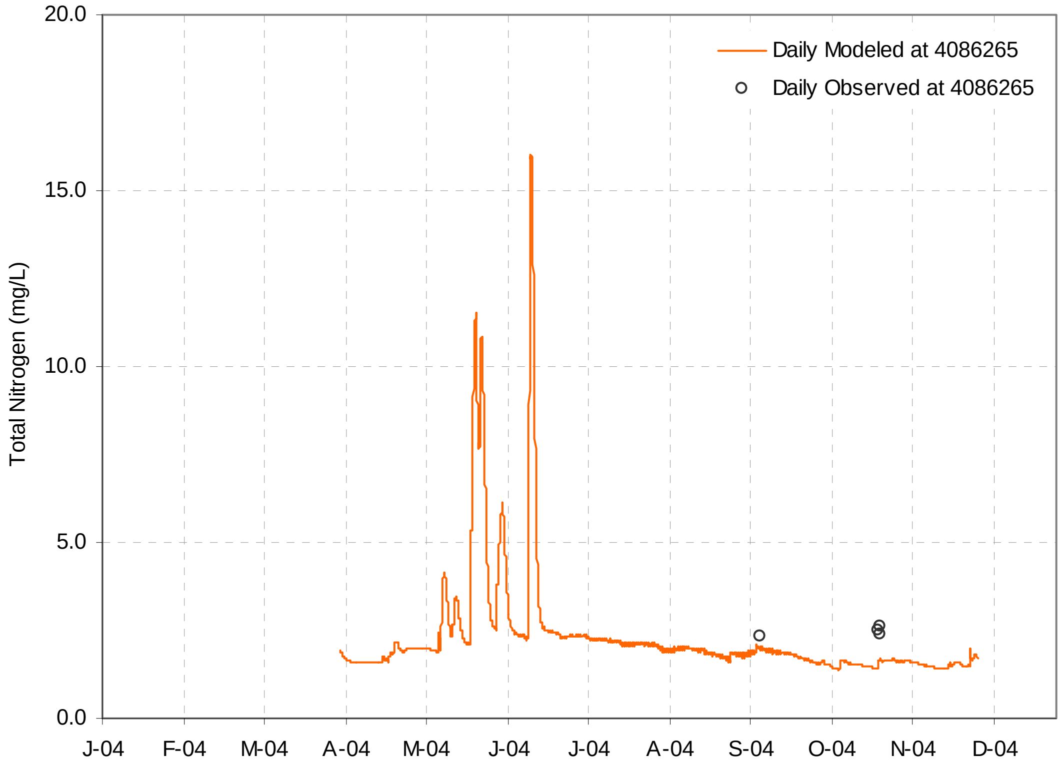
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Total Nitrogen (mg/L)
1999
2000
2001
2002
Daily Modeled at RI-06
Daily Observed at RI-06



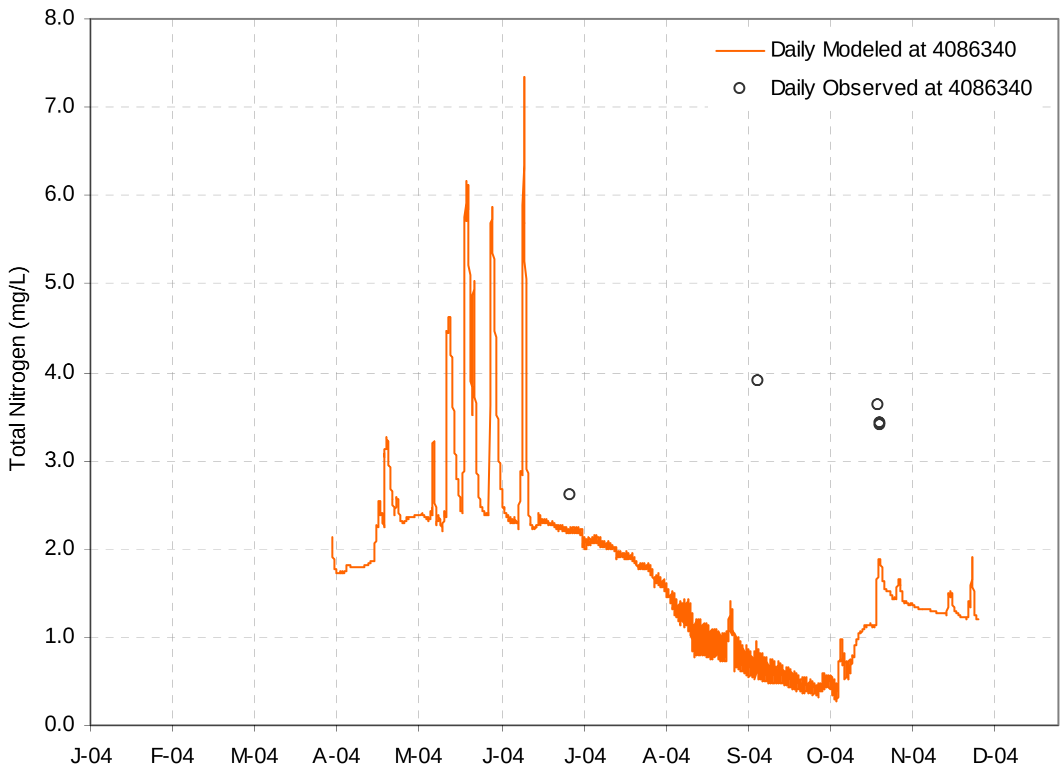
Daily Modeled at 4086149
Daily Observed at 4086149
Total Nitrogen (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04



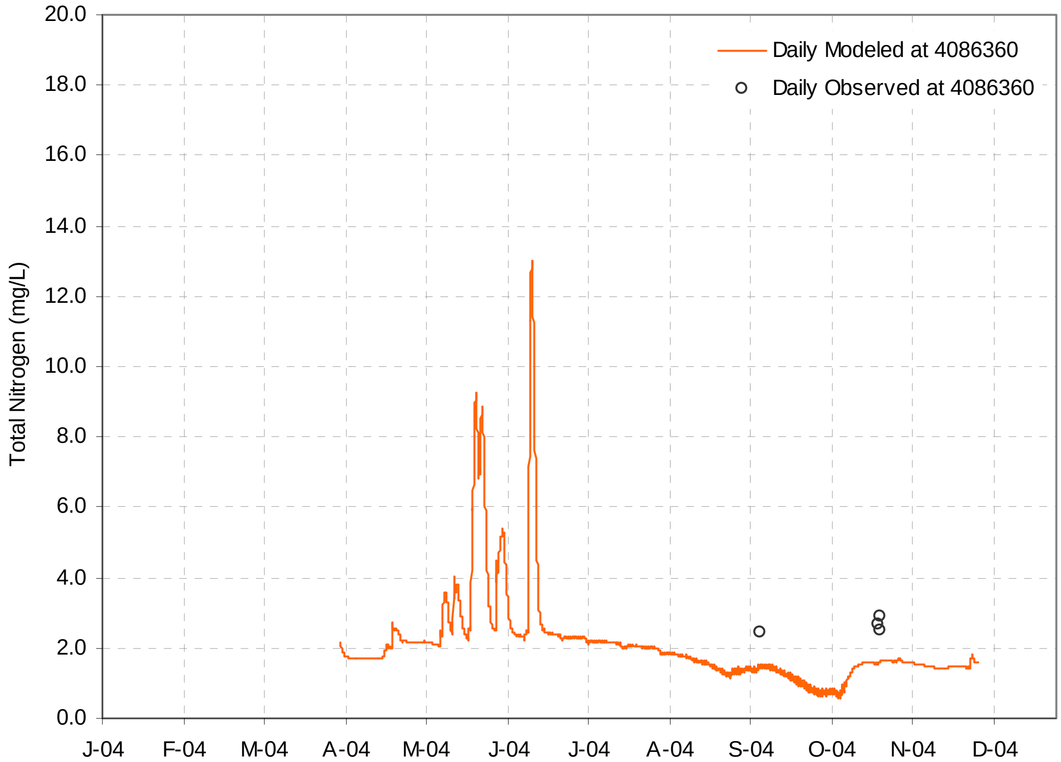
Daily Modeled at 4086200
Daily Observed at 4086200
Total Nitrogen (mg/L)
20.0
15.0
10.0
5.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

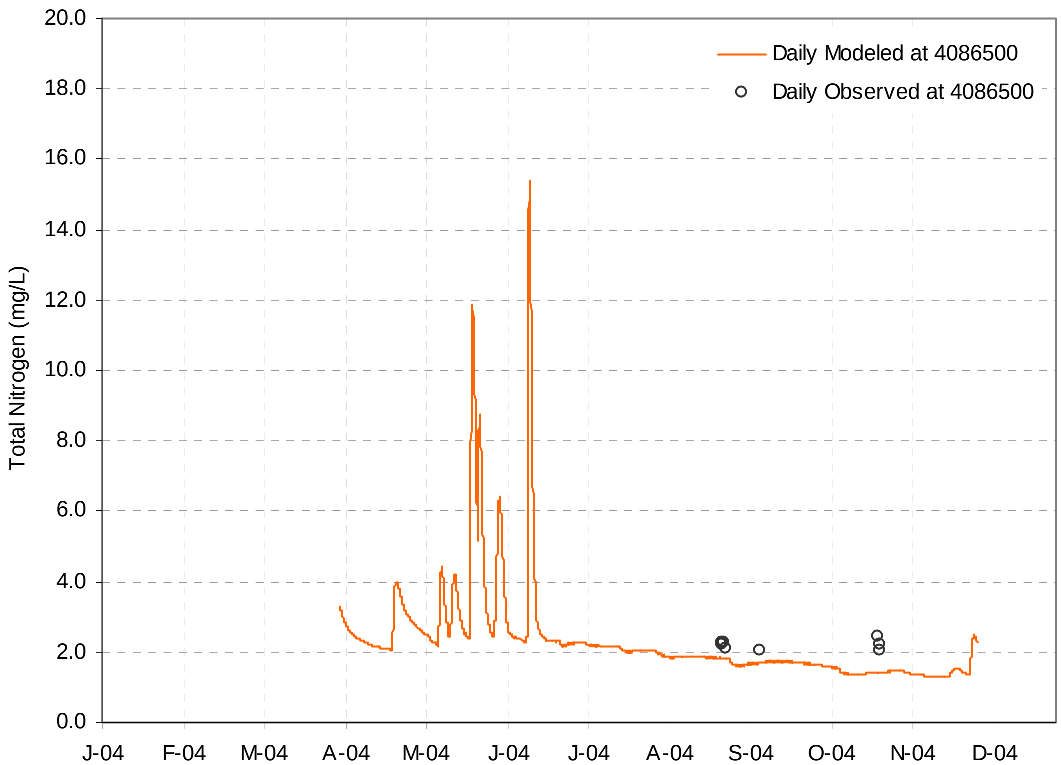


Total Nitrogen (mg/L)
20.0
15.0
10.0
5.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086265
Daily Observed at 4086265

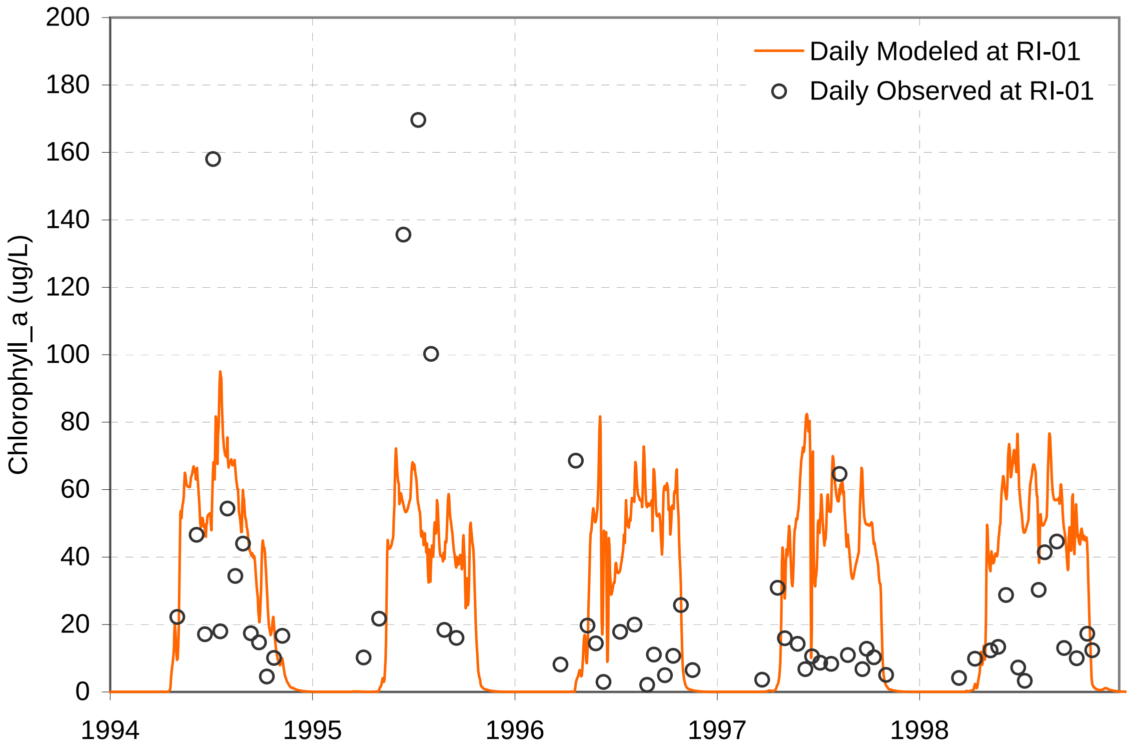


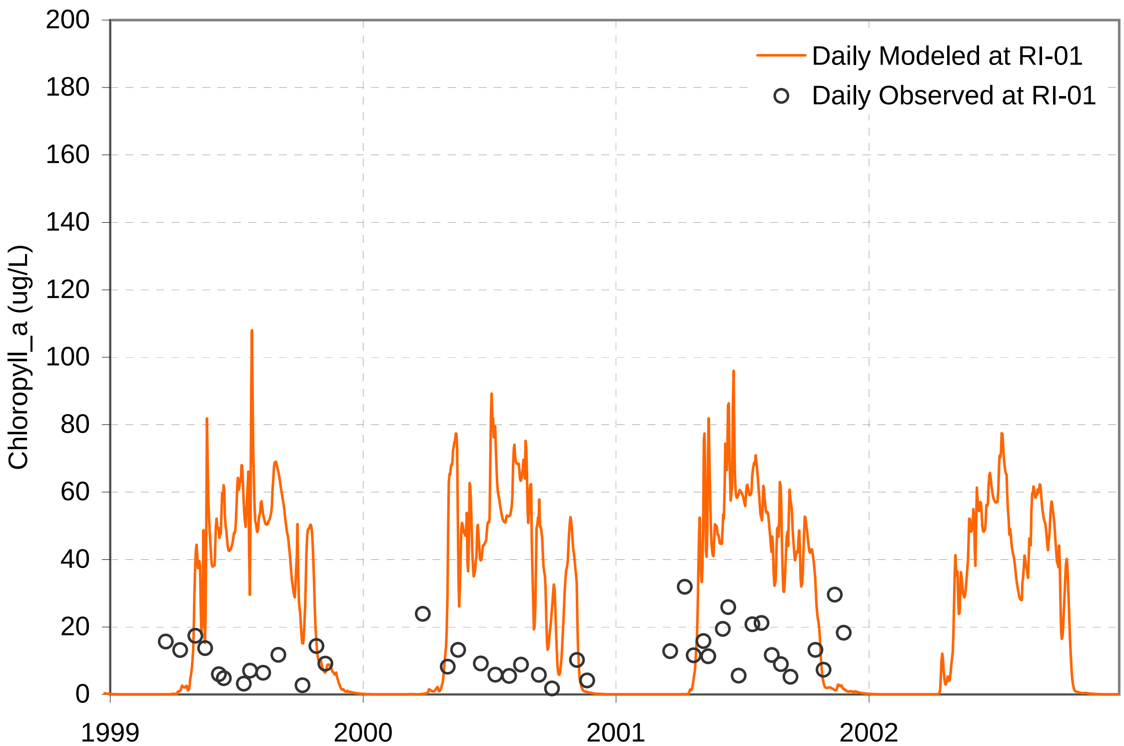
Total Nitrogen (mg/L)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086340
Daily Observed at 4086340

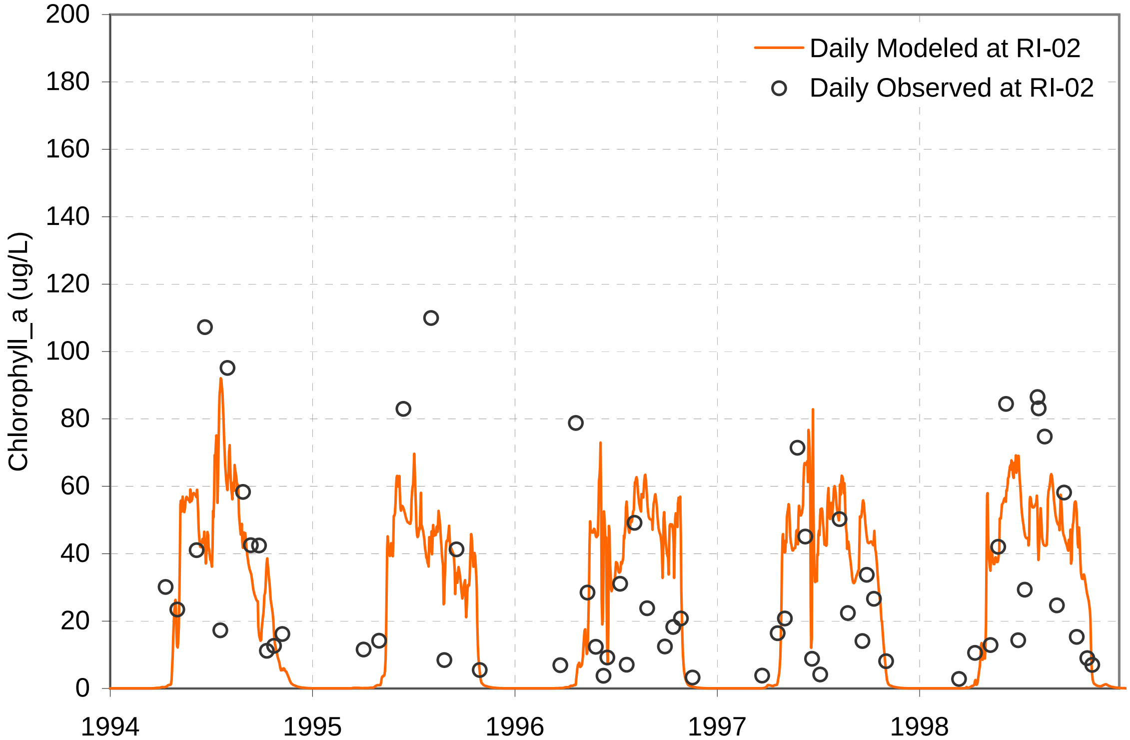

Total Nitrogen (mg/L)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086360
Daily Observed at 4086360

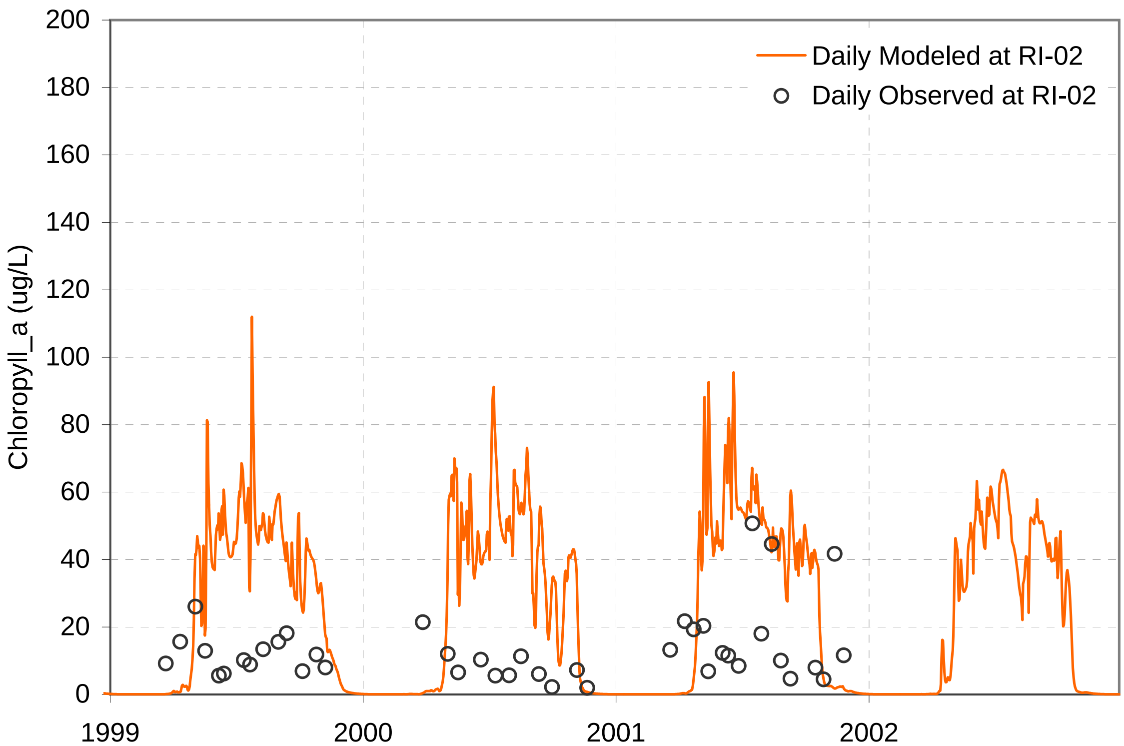

Total Nitrogen (mg/L)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086500
Daily Observed at 4086500

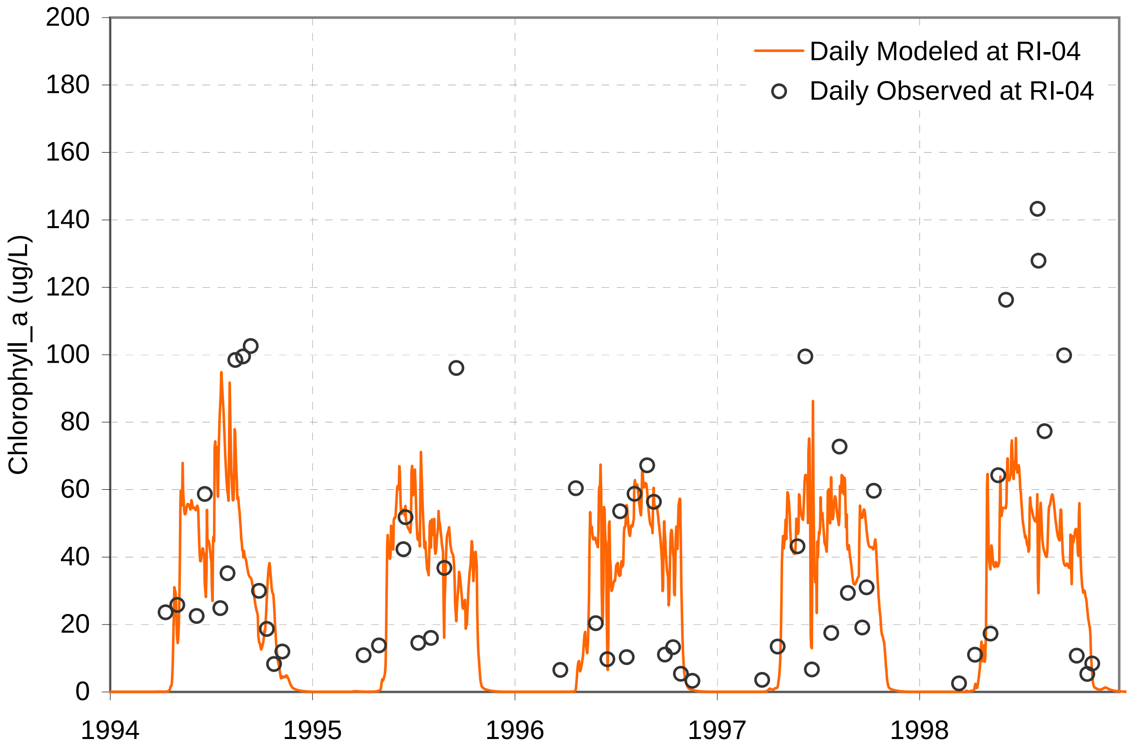
ATTACHMENT E – CALIBRATION AND VALIDATION PLOTS FOR CHLOROPHYLL *A*


Daily Modeled at RI-01
Daily Observed at RI-01
Chlorophyll_a (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1994
1995
1996
1997
1998

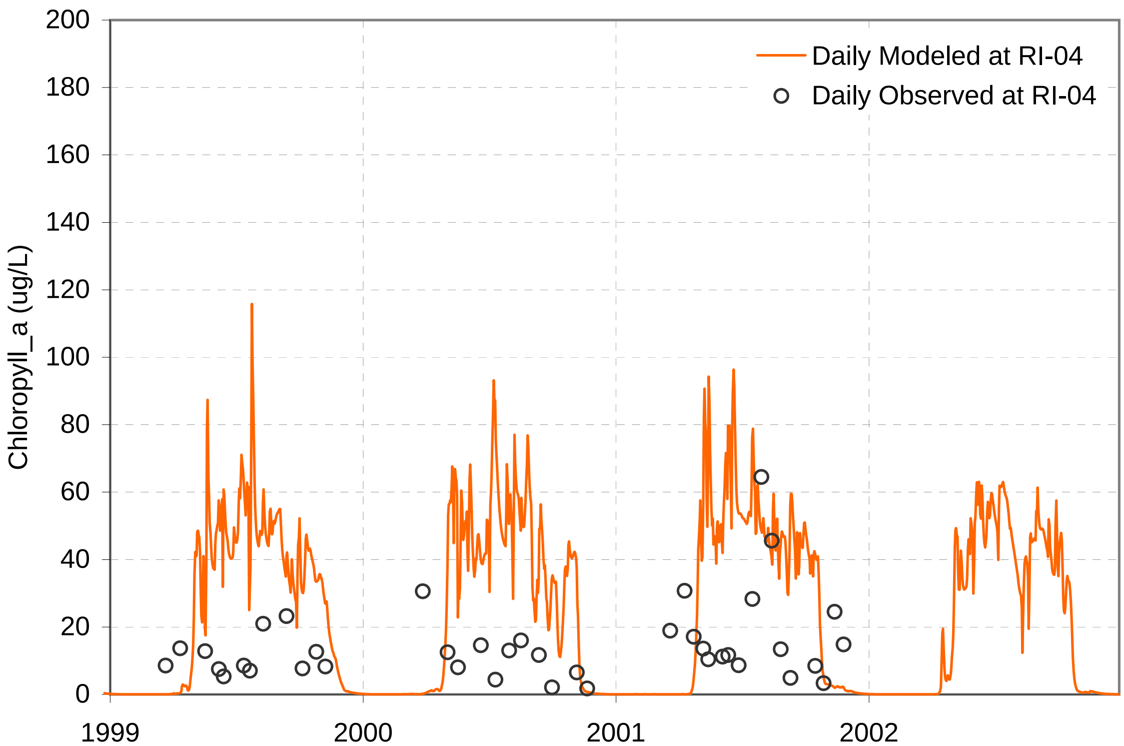

Daily Modeled at RI-01
Daily Observed at RI-01
Chloropyll_a (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1999
2000
2001
2002


Daily Modeled at RI-02
Daily Observed at RI-02
Chloropyll_a (ug/L)
0
20
40
60
80
100
120
140
160
180
200
1994
1995
1996
1997
1998

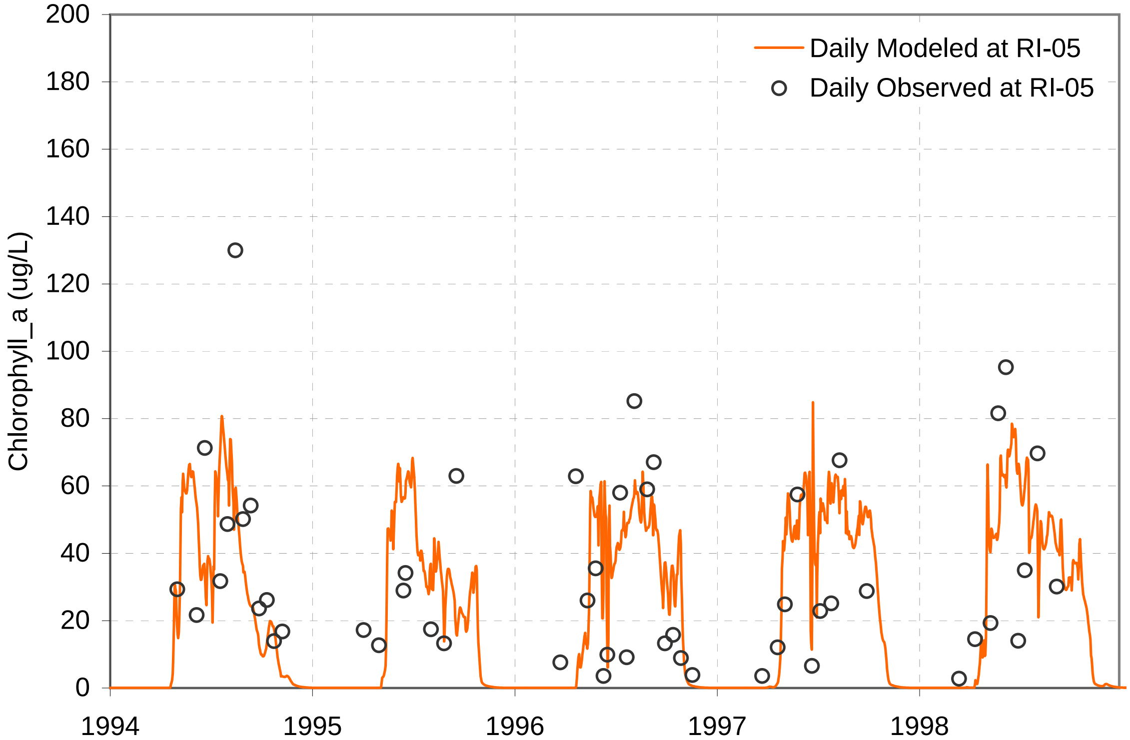

Daily Modeled at RI-02
Daily Observed at RI-02
Chloropyll_a (ug/L)
0
20
40
60
80
100
120
140
160
180
200
1999
2000
2001
2002



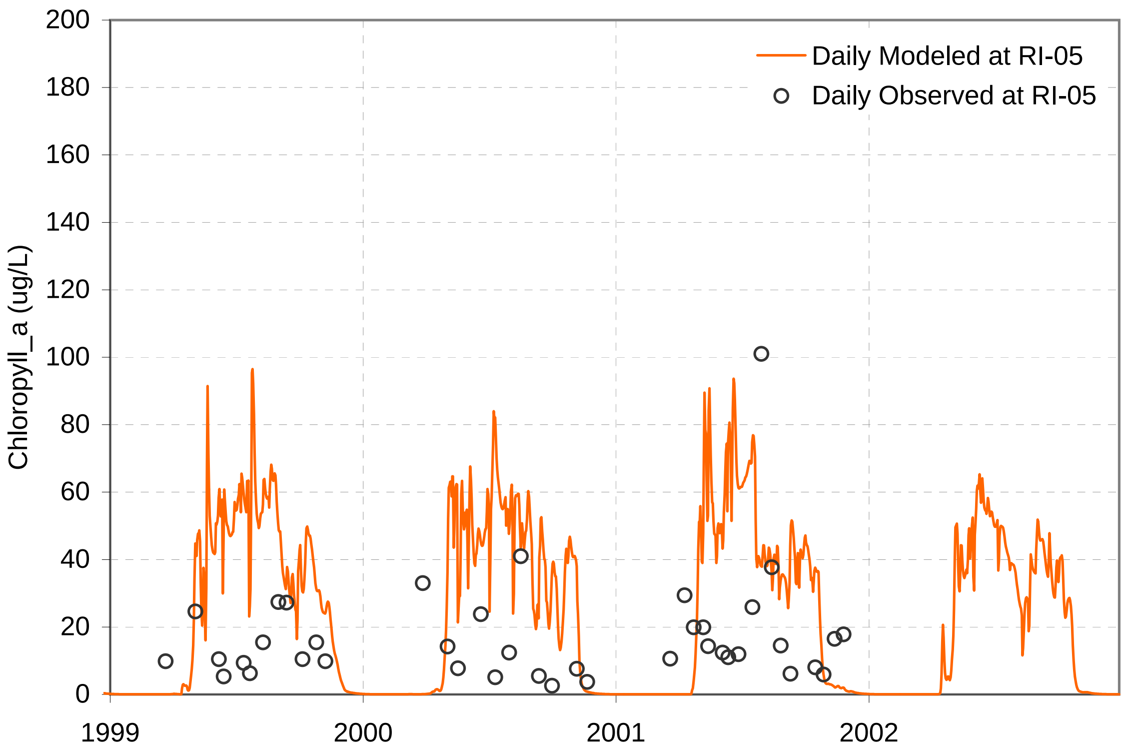
200
180
160
140
120
100
80
60
40
20
0
Chloropyll_a (ug/L)
1994
1995
1996
1997
1998
Daily Modeled at RI-04
Daily Observed at RI-04



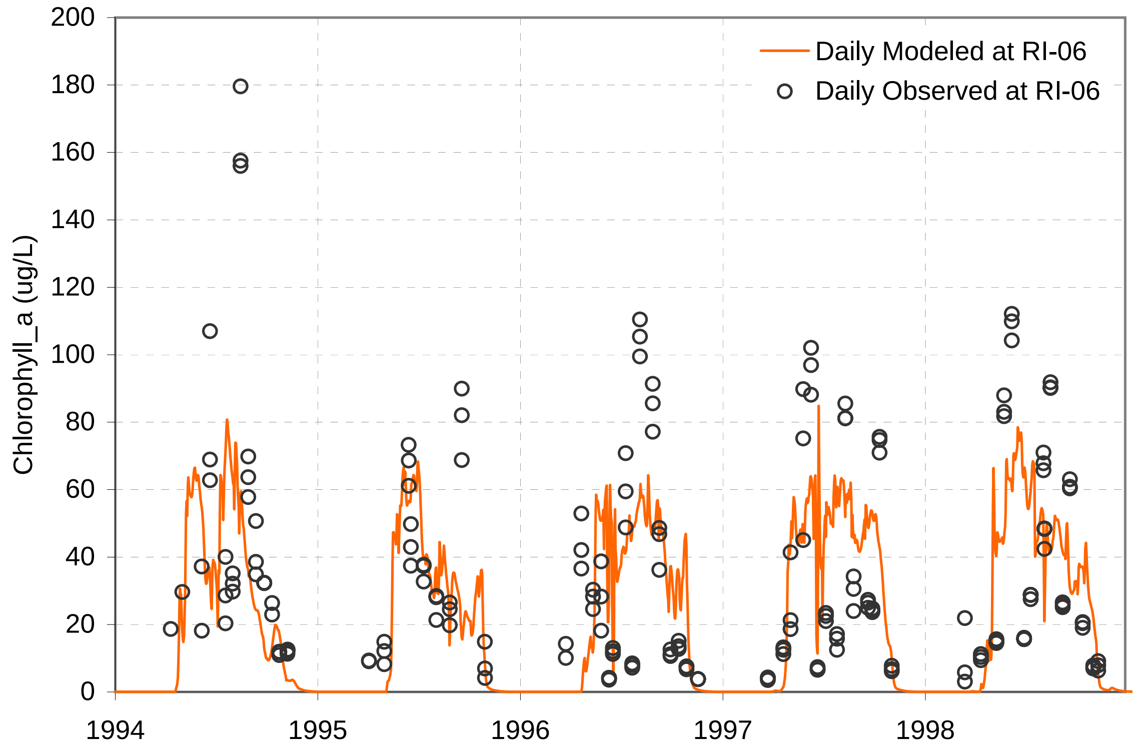
200
180
160
140
120
100
80
60
40
20
0
Chloropyll_a (ug/L)
1999
2000
2001
2002
Daily Modeled at RI-04
Daily Observed at RI-04



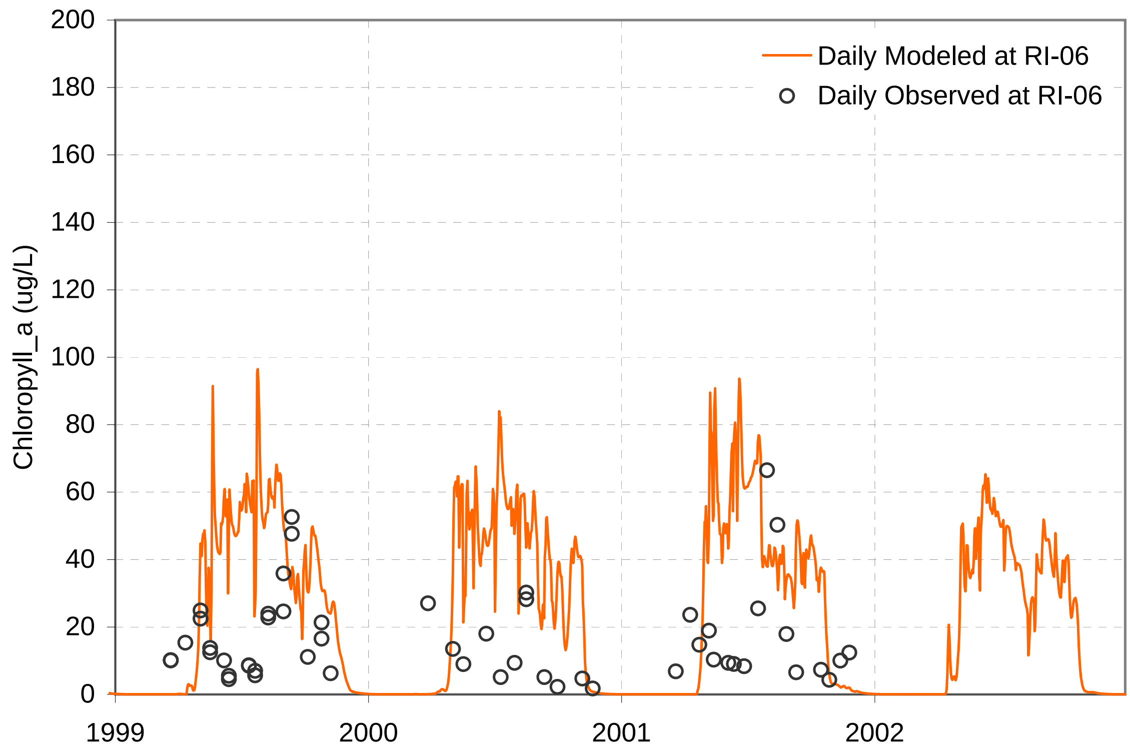
Daily Modeled at RI-05
Daily Observed at RI-05
Chlorophyll_a (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1994
1995
1996
1997
1998



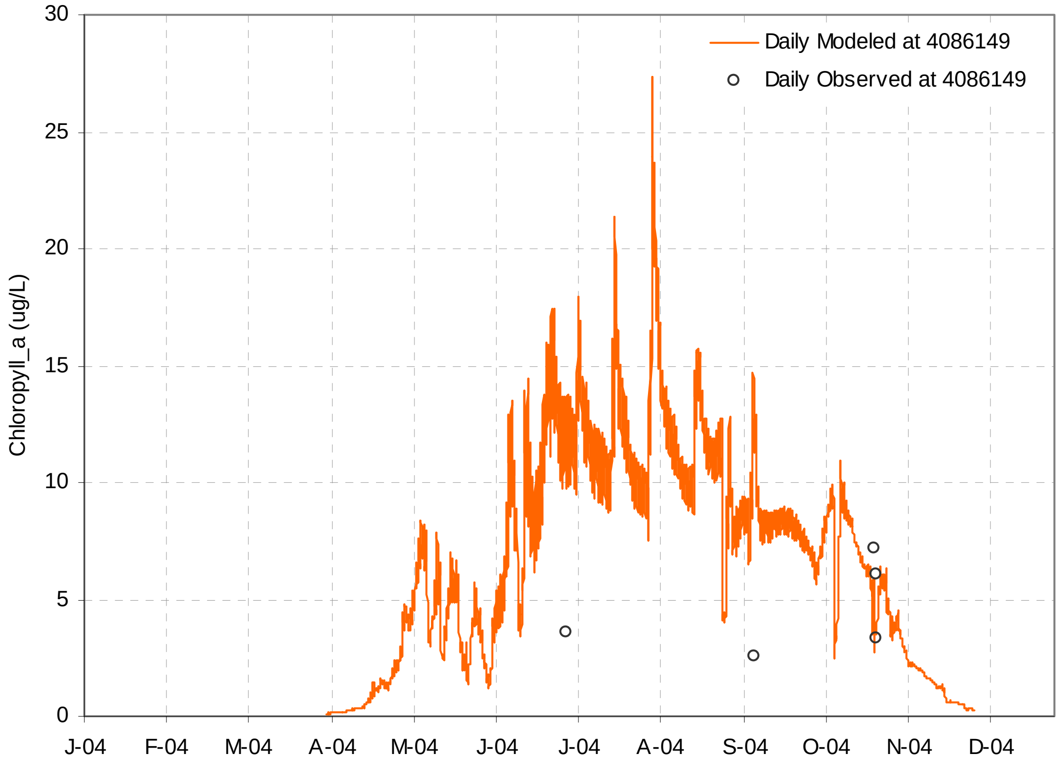
Daily Modeled at RI-05
Daily Observed at RI-05
Chlorophyll_a (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1999
2000
2001
2002

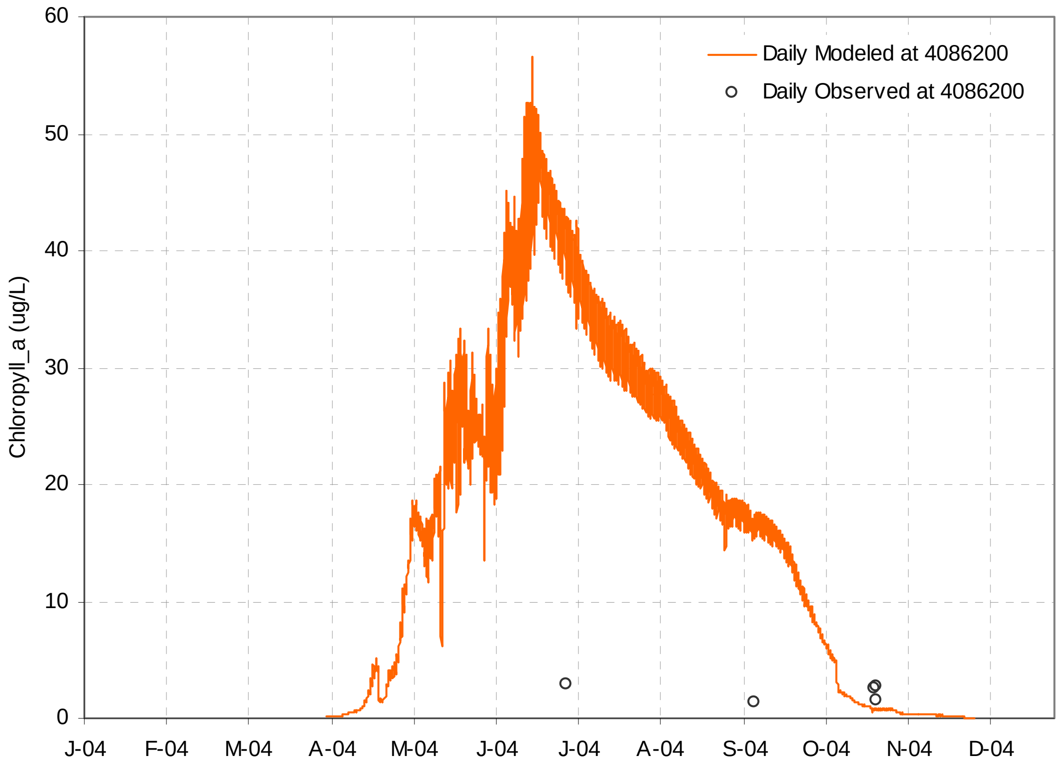


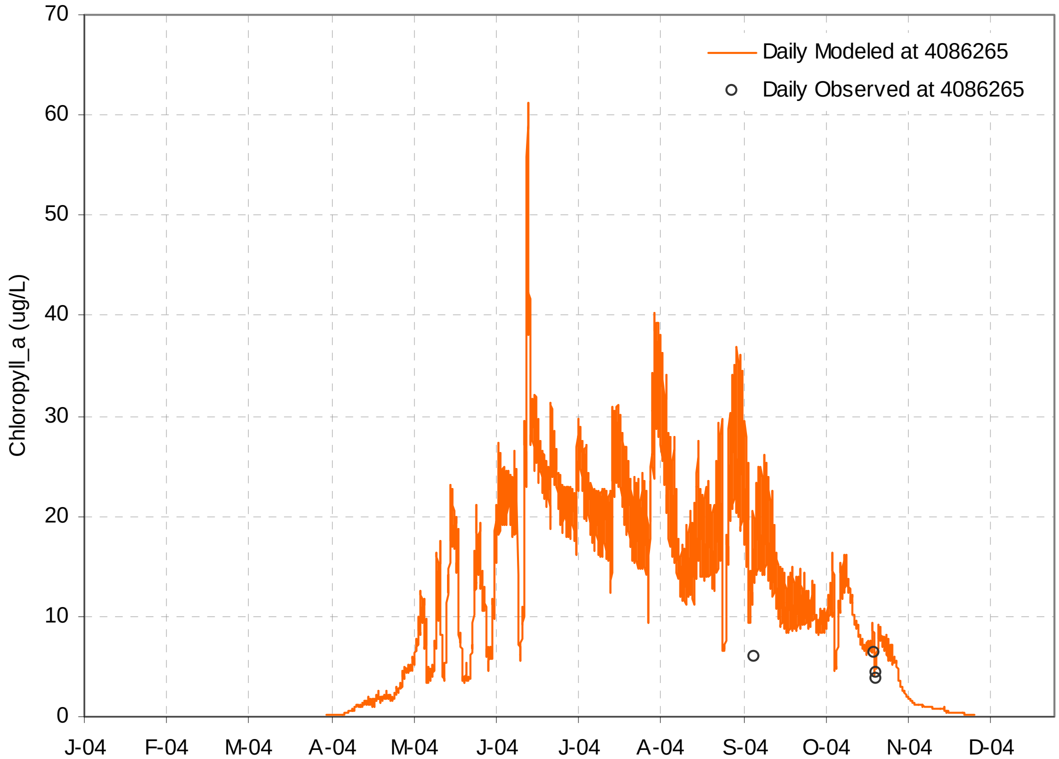
Chlorophyll_a (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1994
1995
1996
1997
1998
Daily Modeled at RI-06
Daily Observed at RI-06

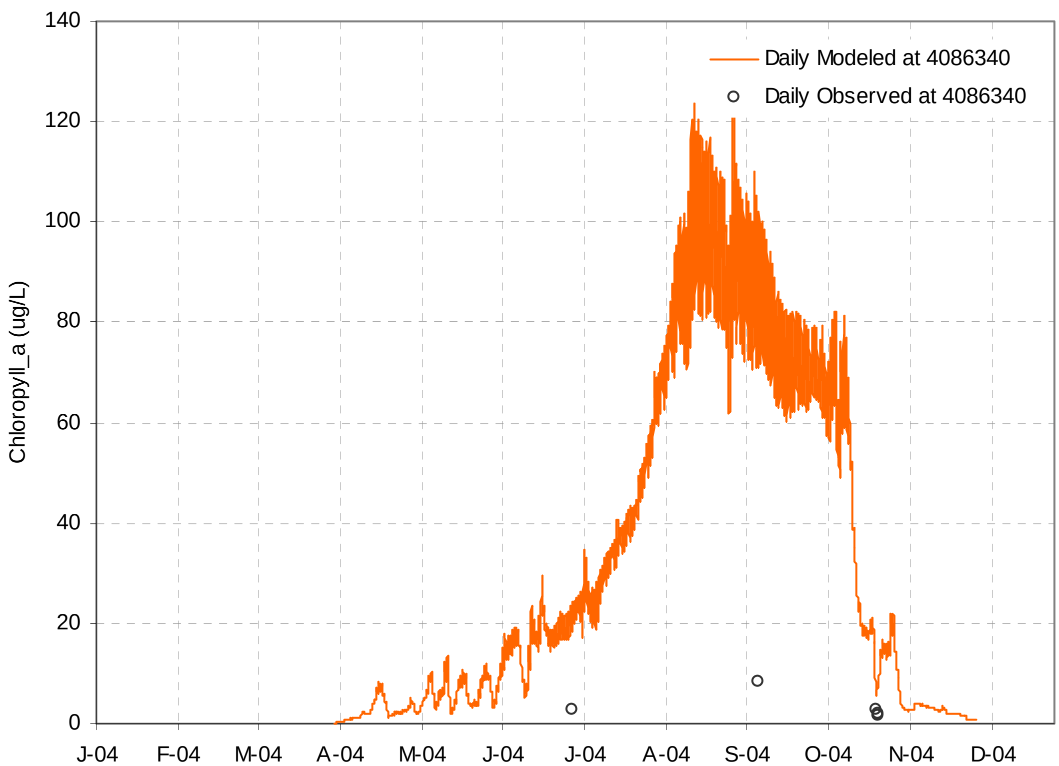


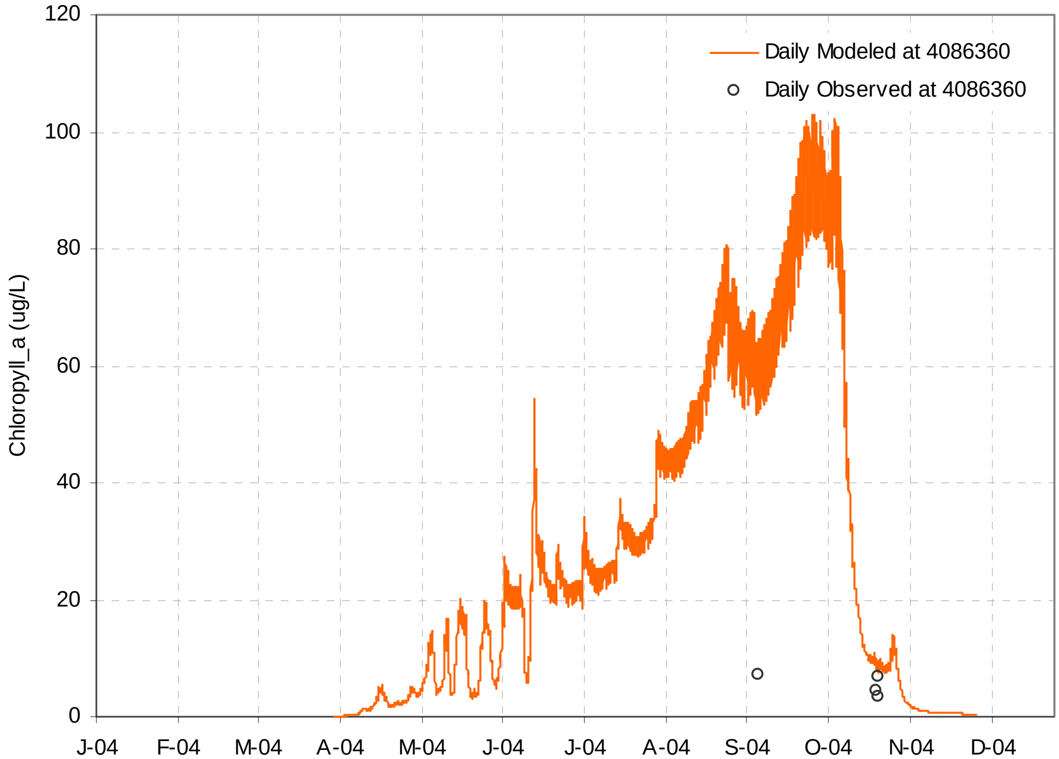
Chloropyll_a (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1999
2000
2001
2002
Daily Modeled at RI-06
Daily Observed at RI-06


30
25
20
15
10
5
0
Chloropyll_a (ug/L)
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086149
Daily Observed at 4086149

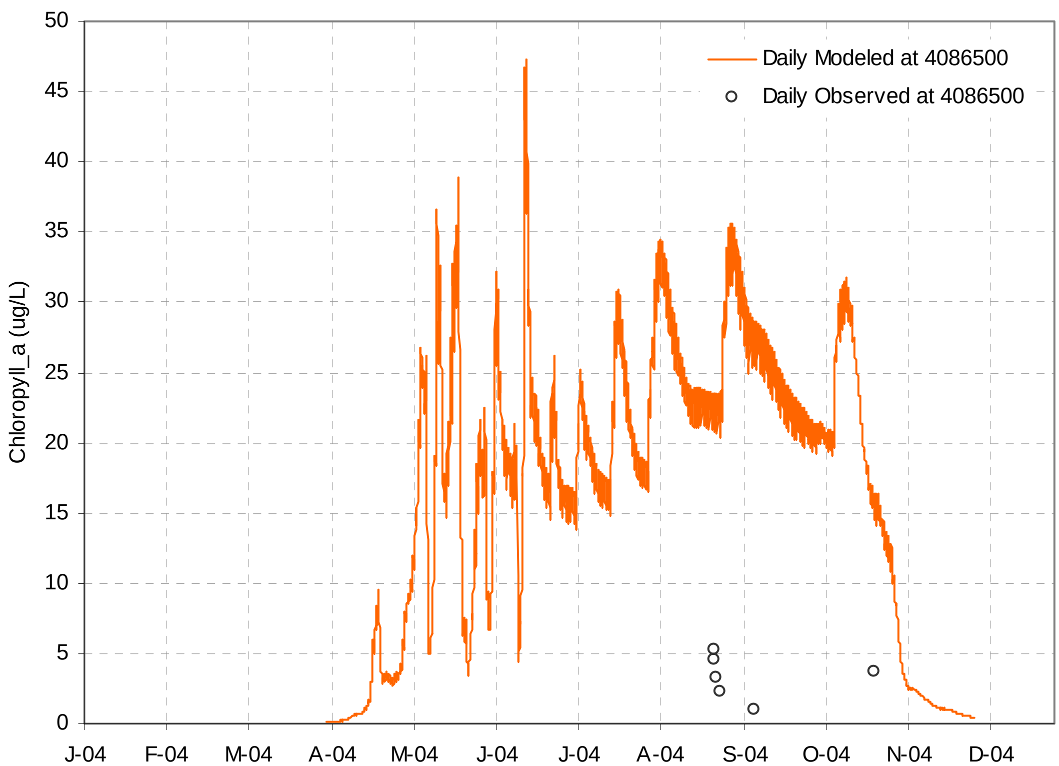

60
50
40
30
20
10
0
Chloropyll_a (ug/L)
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086200
Daily Observed at 4086200


Daily Modeled at 4086265
Daily Observed at 4086265
Chloropyll_a (ug/L)
70
60
50
40
30
20
10
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04


Daily Modeled at 4086340
Daily Observed at 4086340
Chloropyll_a (ug/L)
140
120
100
80
60
40
20
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

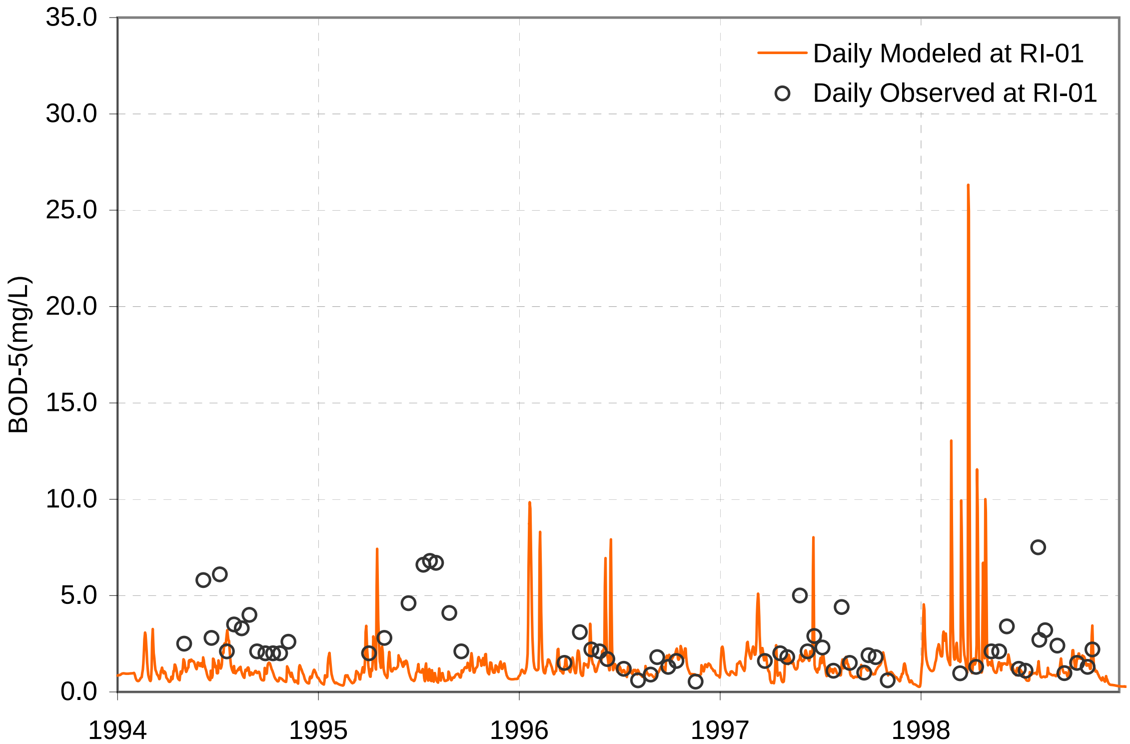


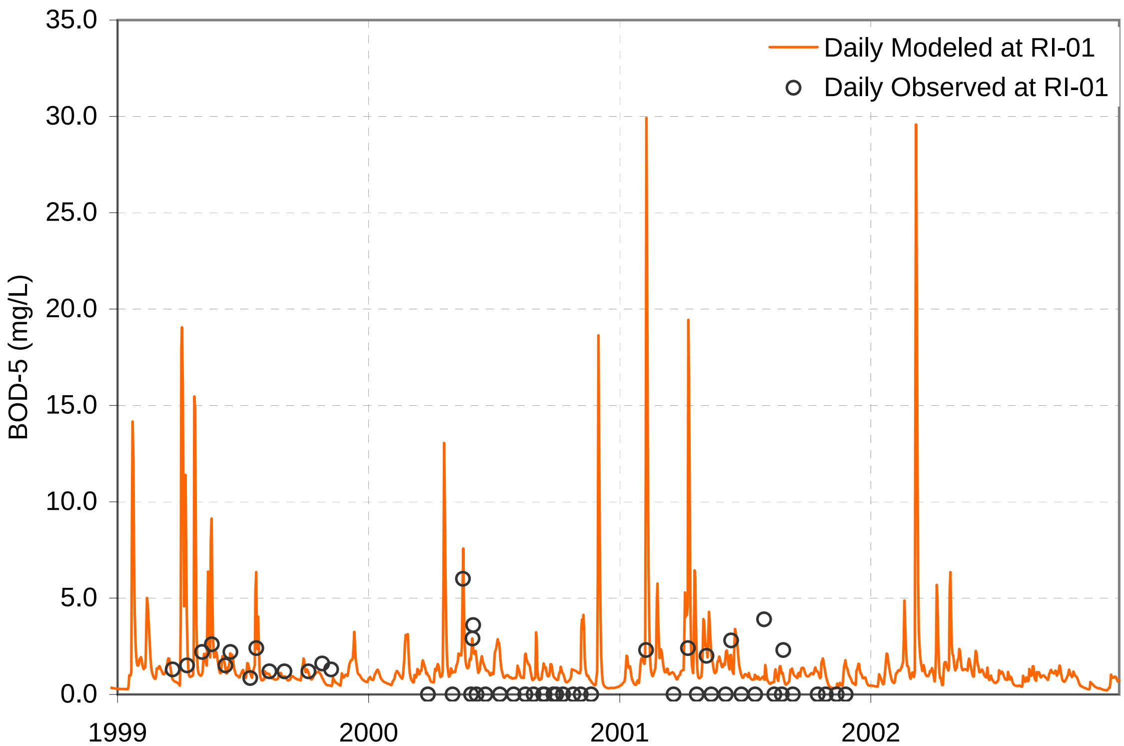
120
100
80
60
40
20
0
Chloropyll_a (ug/L)
Daily Modeled at 4086360
Daily Observed at 4086360
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

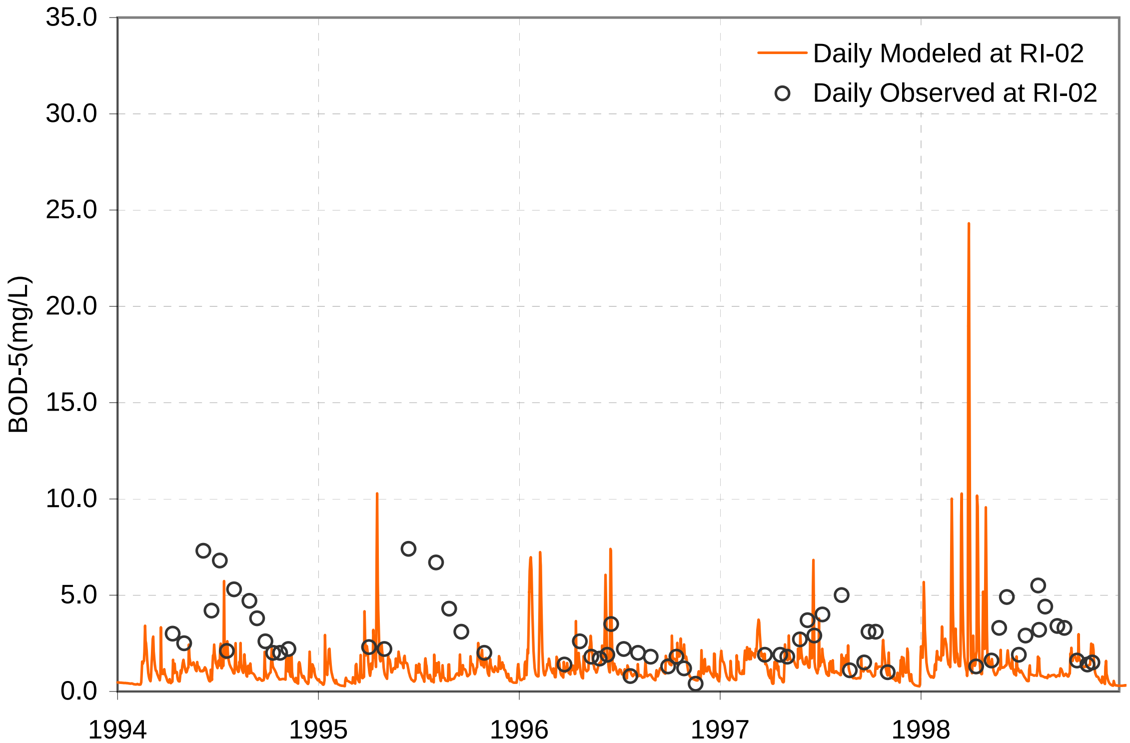


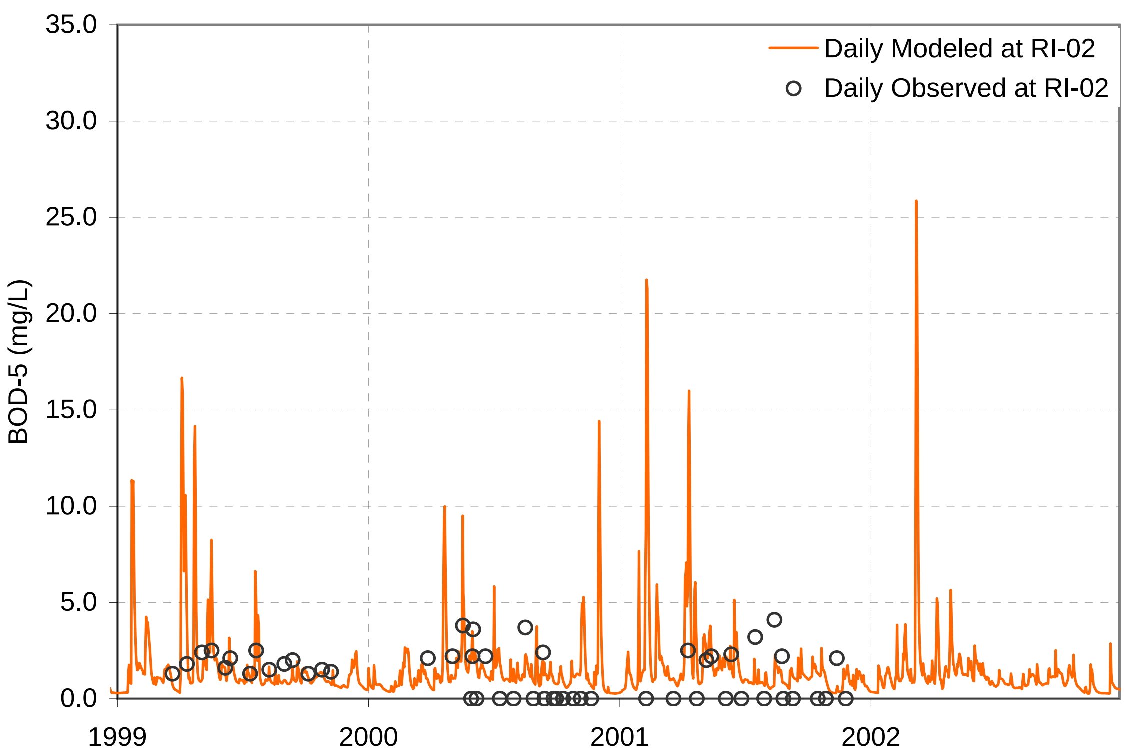
50
45
40
35
30
25
20
15
10
5
0
Chloropyll_a (ug/L)
Daily Modeled at 4086500
Daily Observed at 4086500
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

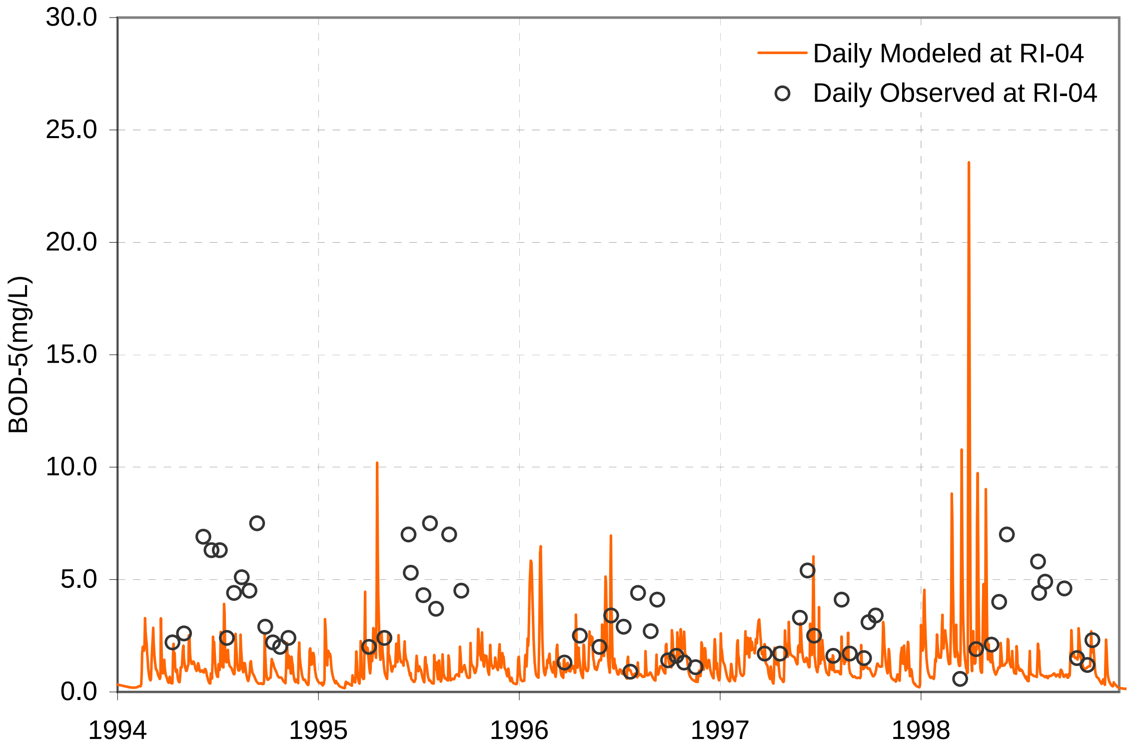
ATTACHMENT F – CALIBRATION AND VALIDATION PLOTS FOR BOD AND DISSOLVED OXYGEN


Daily Modeled at RI-01
Daily Observed at RI-01
BOD-5(mg/L)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1994
1995
1996
1997
1998

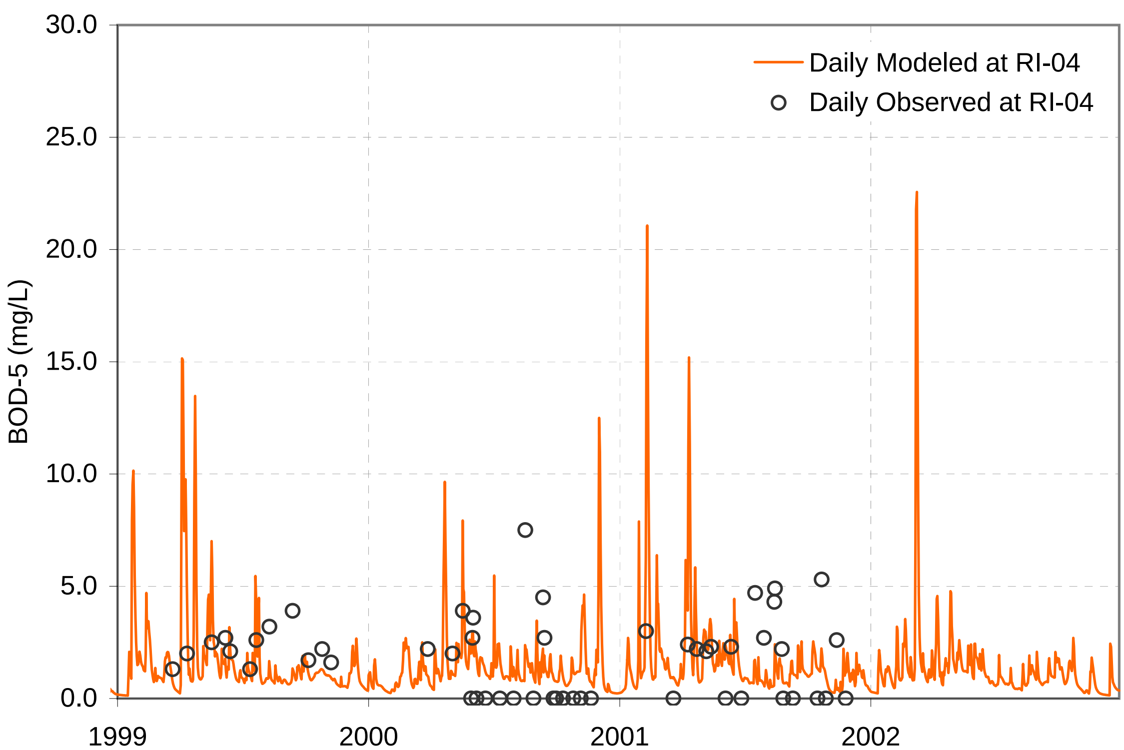

Daily Modeled at RI-01
Daily Observed at RI-01
BOD-5 (mg/L)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1999
2000
2001
2002


35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
BOD-5(mg/L)
1994
1995
1996
1997
1998
Daily Modeled at RI-02
Daily Observed at RI-02

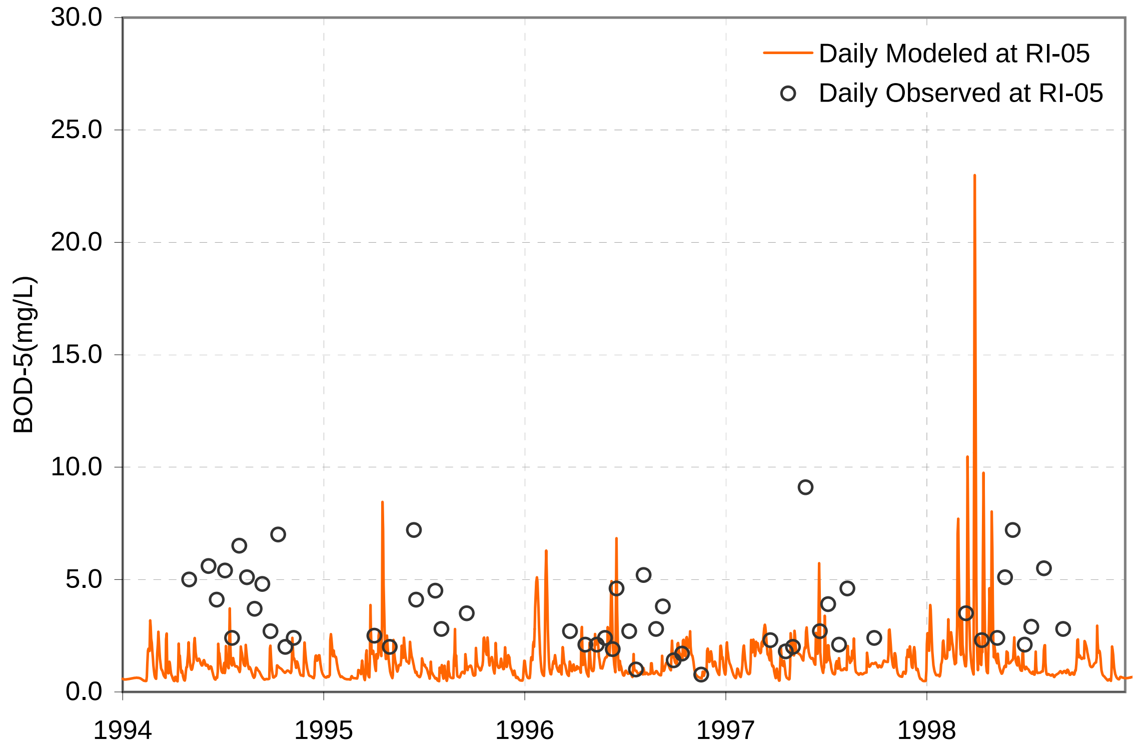

35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
BOD-5 (mg/L)
1999
2000
2001
2002
Daily Modeled at RI-02
Daily Observed at RI-02

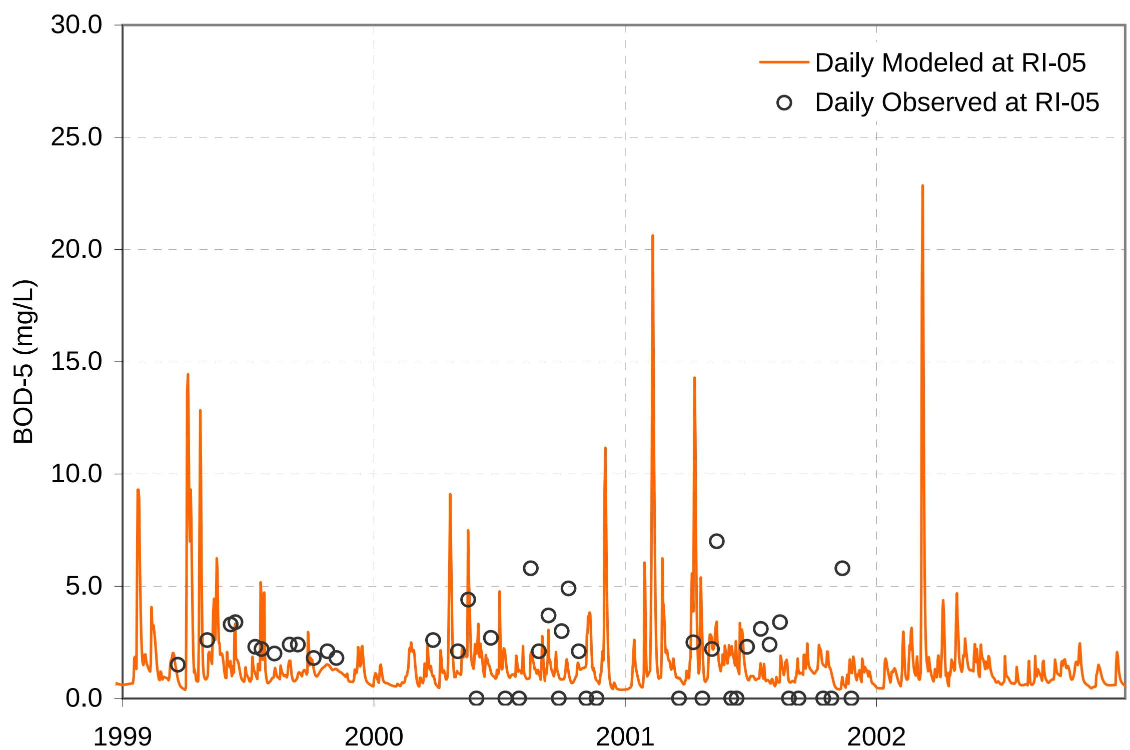


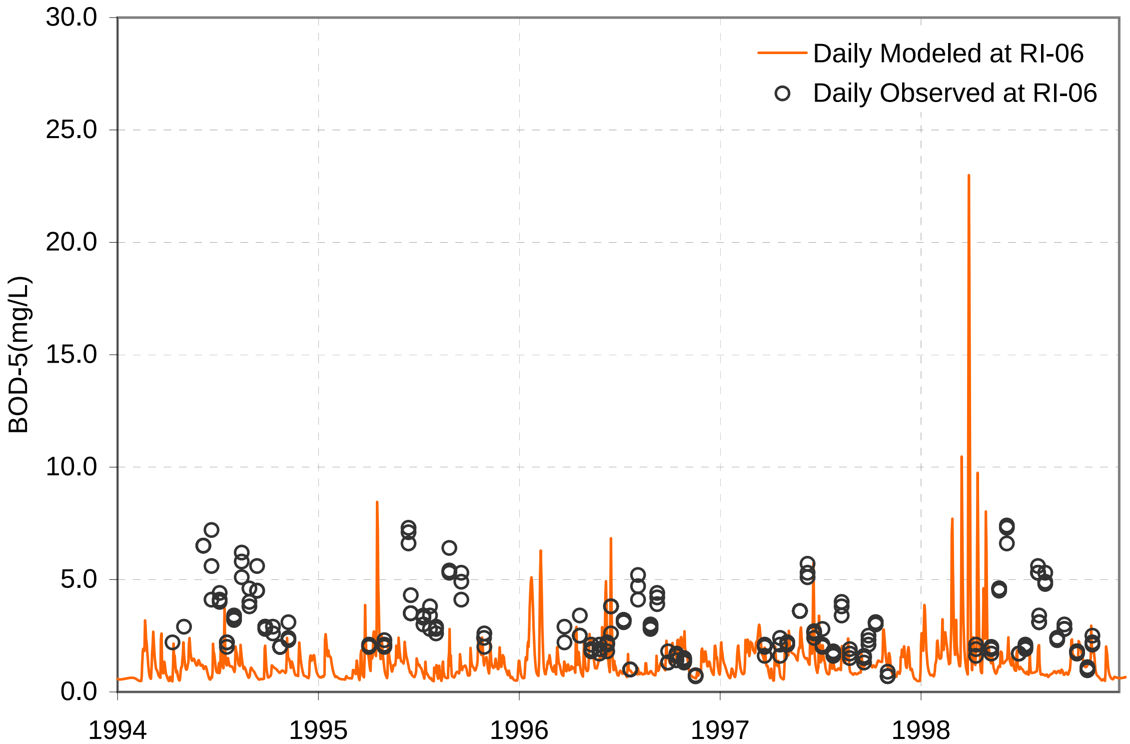
30.0
25.0
20.0
15.0
10.0
5.0
0.0
BOD-5(mg/L)
1994
1995
1996
1997
1998
Daily Modeled at RI-04
Daily Observed at RI-04



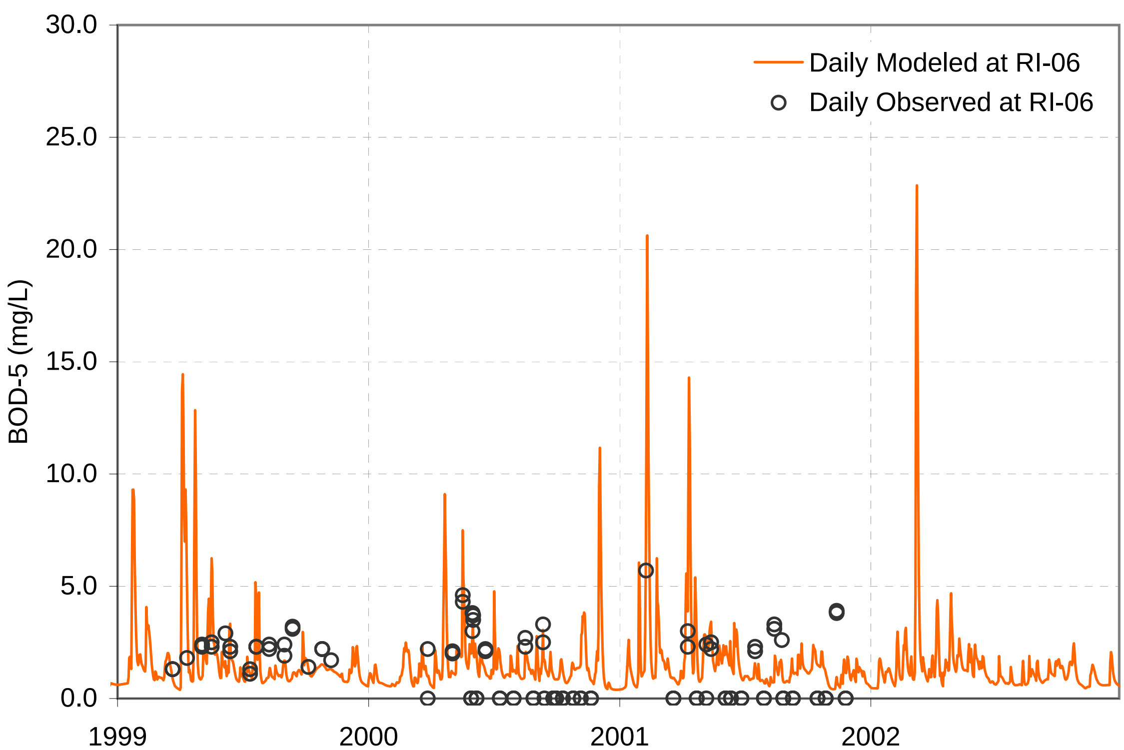
30.0
25.0
20.0
15.0
10.0
5.0
0.0
BOD-5 (mg/L)
1999
2000
2001
2002
Daily Modeled at RI-04
Daily Observed at RI-04


30.0
25.0
20.0
15.0
10.0
5.0
0.0
BOD-5(mg/L)
1994
1995
1996
1997
1998
Daily Modeled at RI-05
Daily Observed at RI-05

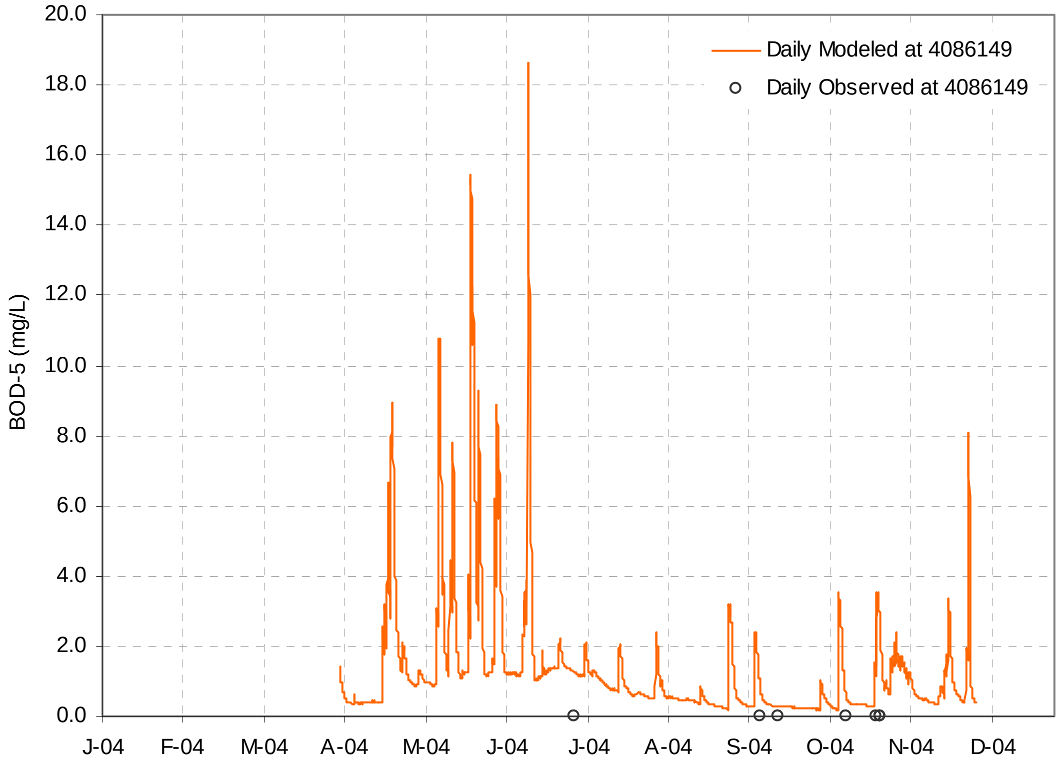

30.0
25.0
20.0
15.0
10.0
5.0
0.0
BOD-5 (mg/L)
1999
2000
2001
2002
Daily Modeled at RI-05
Daily Observed at RI-05



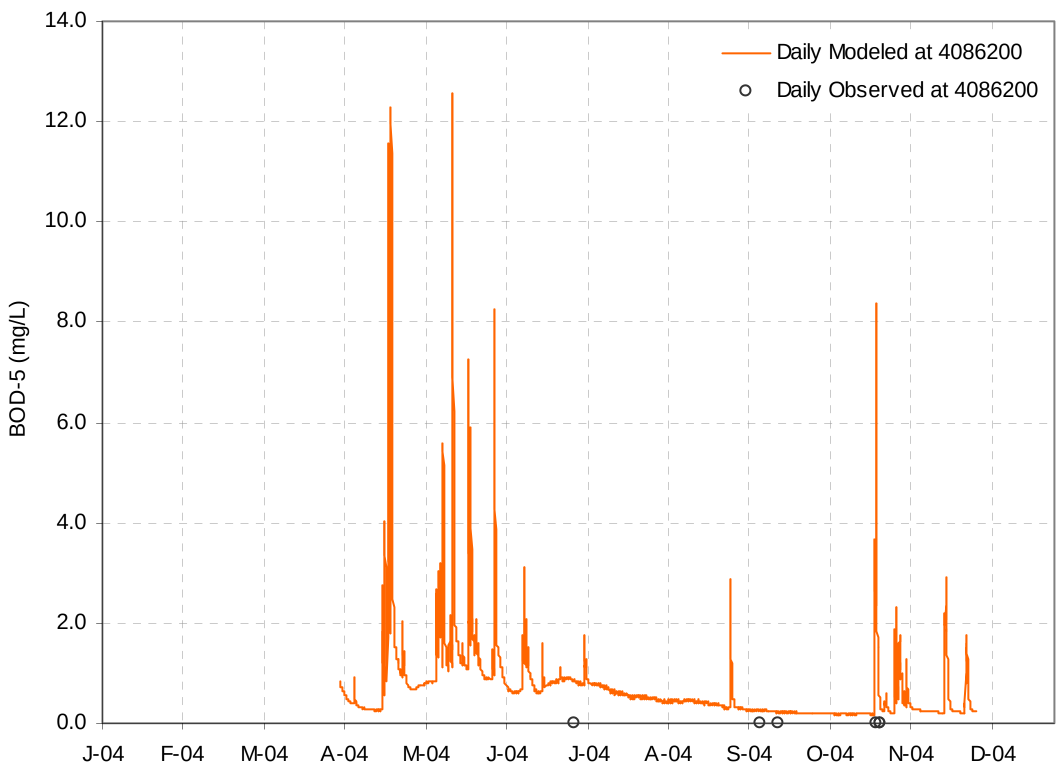
Daily Modeled at RI-06
Daily Observed at RI-06
BOD-5(mg/L)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1994
1995
1996
1997
1998



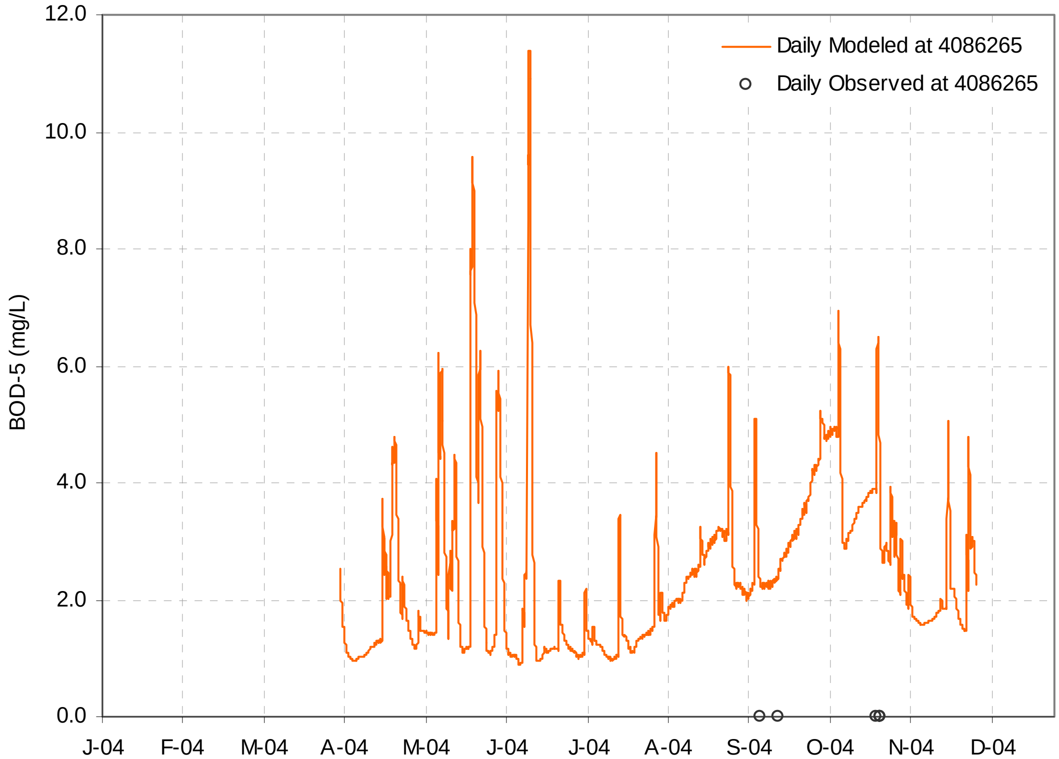
Daily Modeled at RI-06
Daily Observed at RI-06
BOD-5 (mg/L)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1999
2000
2001
2002

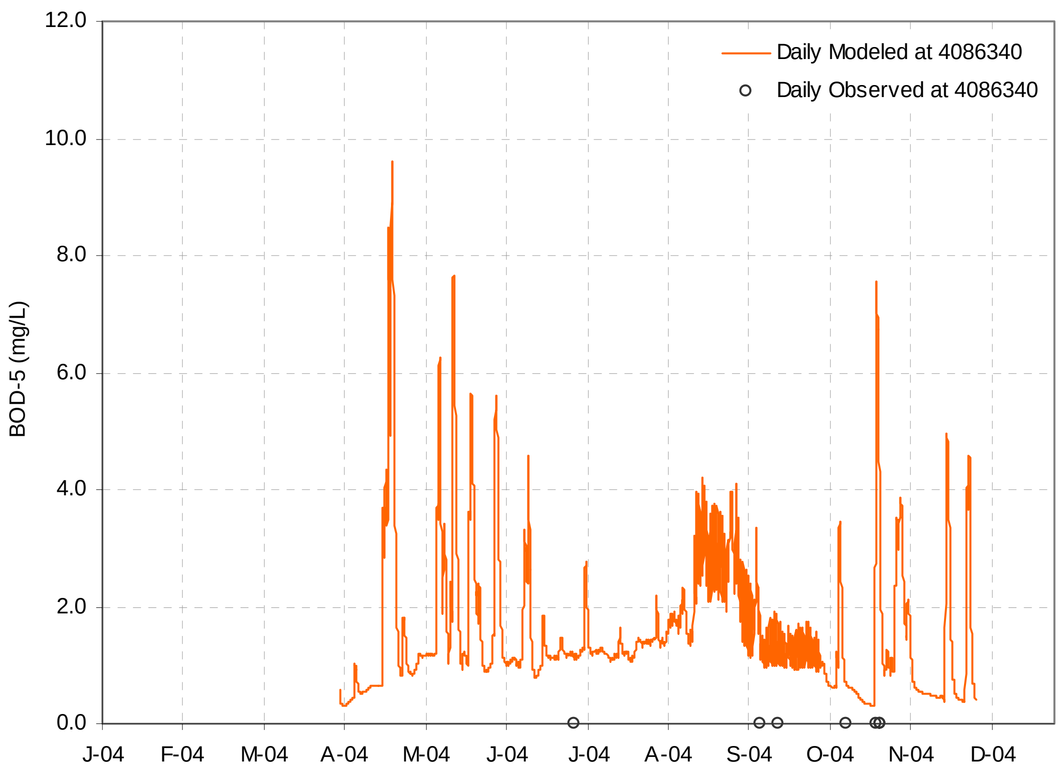


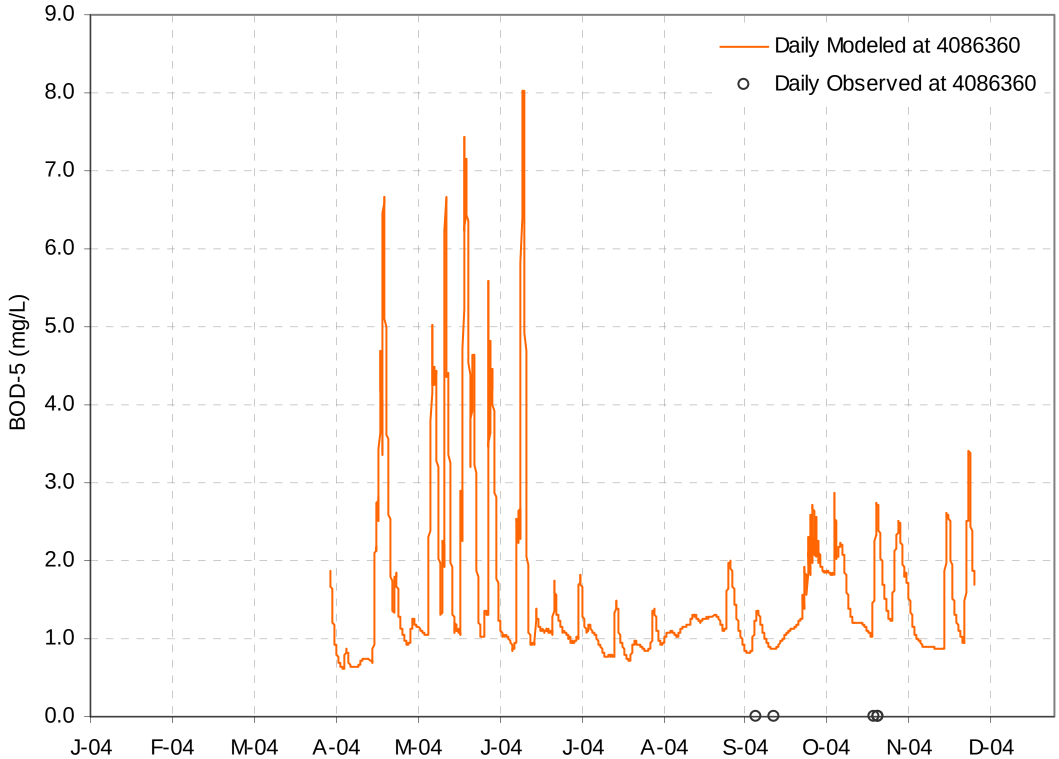
BOD-5 (mg/L)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086149
Daily Observed at 4086149



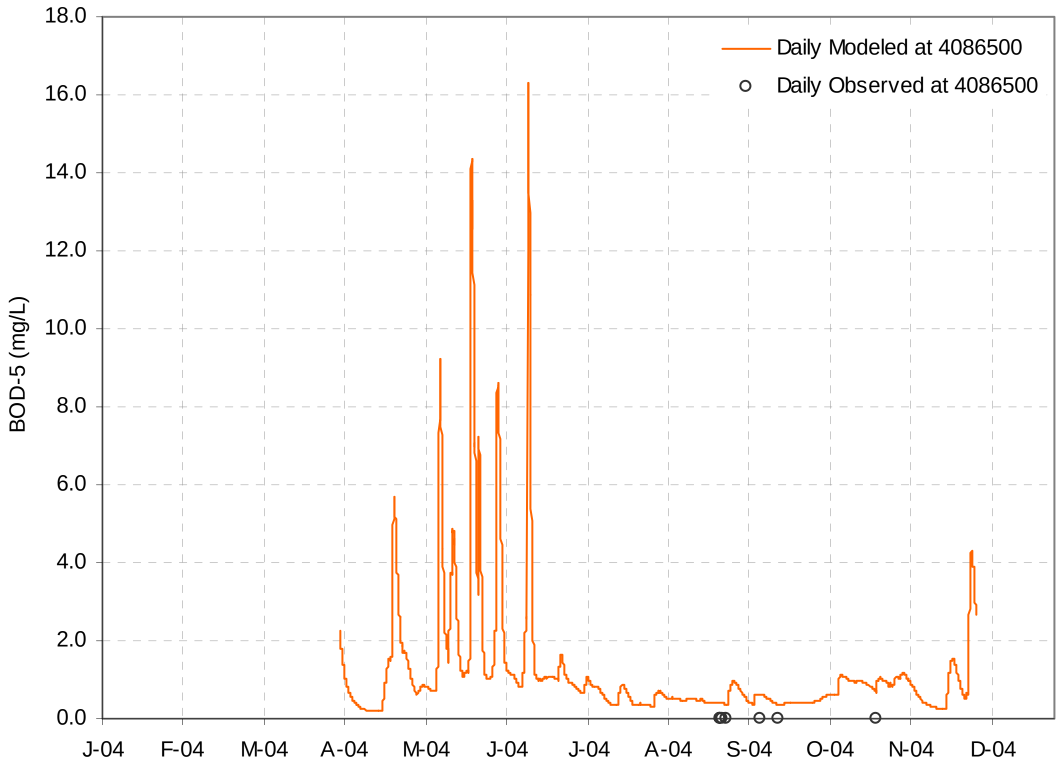
BOD-5 (mg/L)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086200
Daily Observed at 4086200


Daily Modeled at 4086265
Daily Observed at 4086265
BOD-5 (mg/L)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

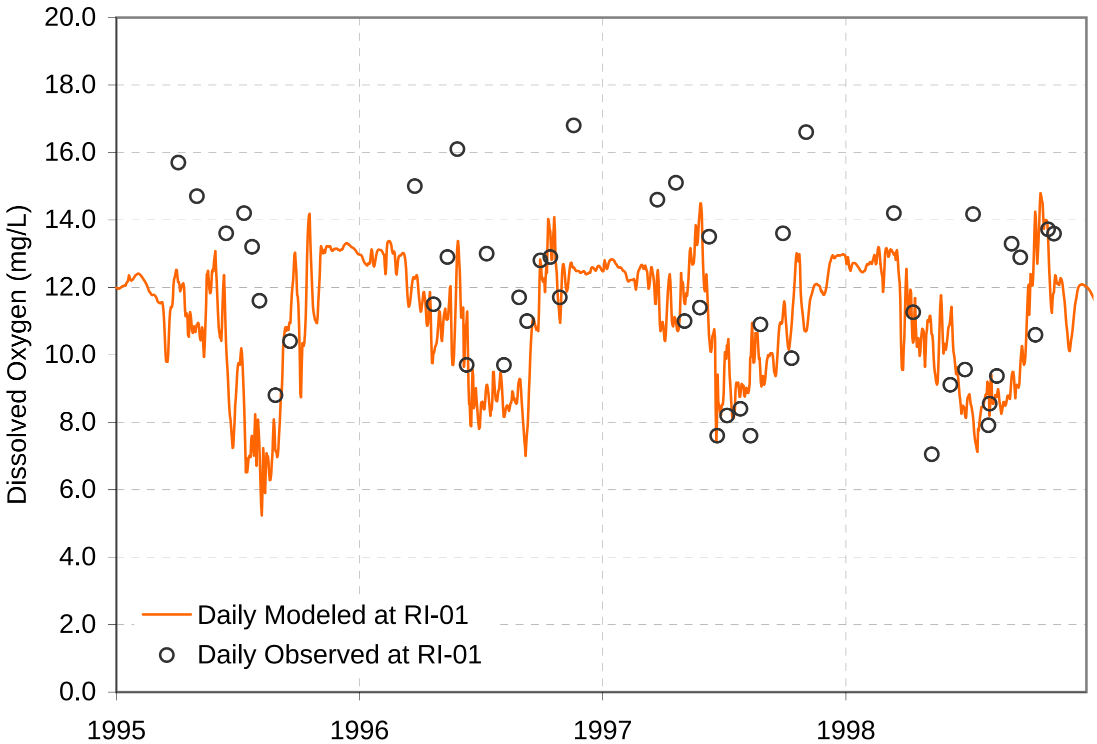

Daily Modeled at 4086340
Daily Observed at 4086340
BOD-5 (mg/L)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

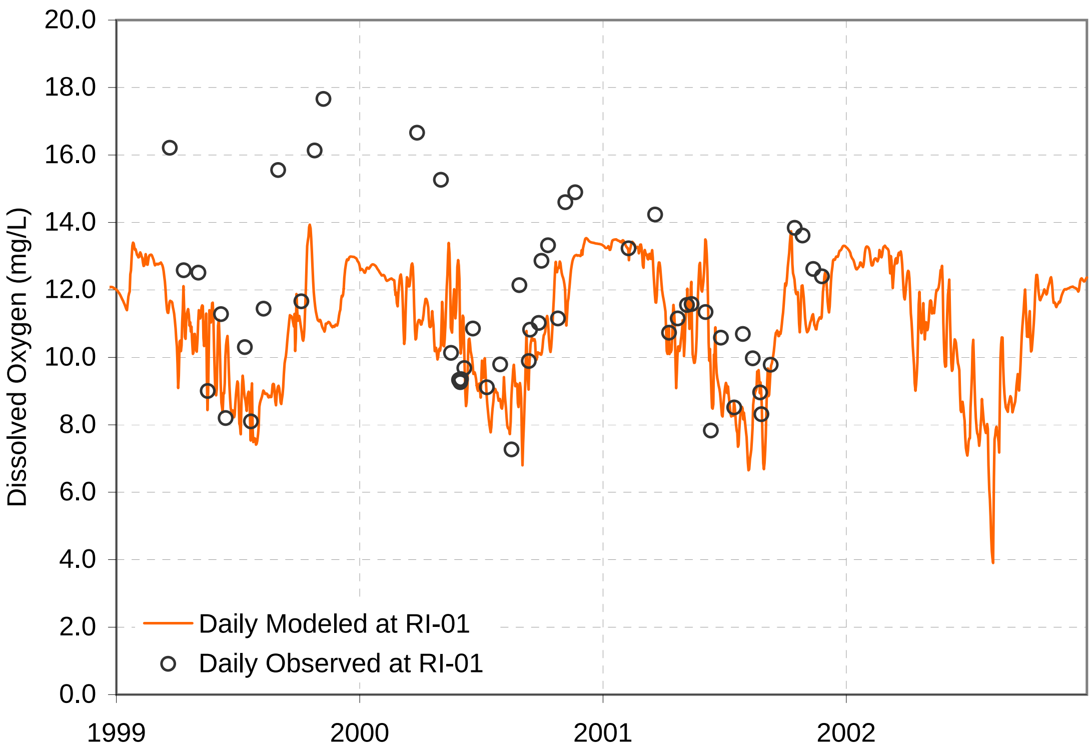


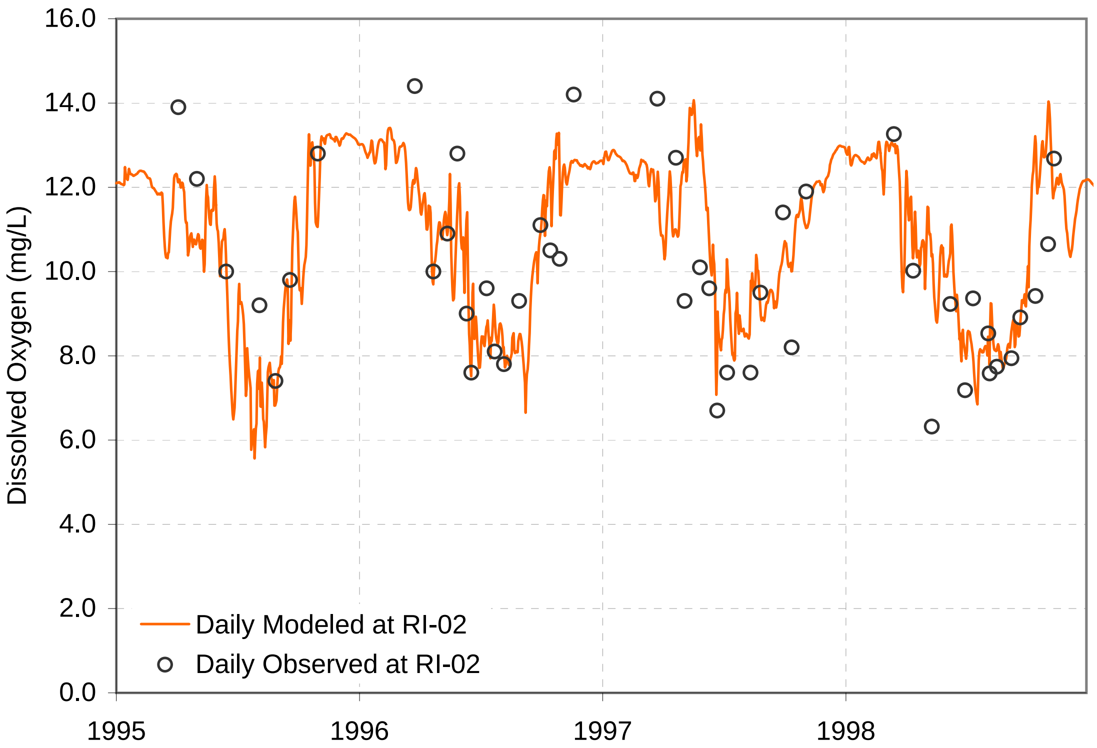
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
BOD-5 (mg/L)
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086360
Daily Observed at 4086360

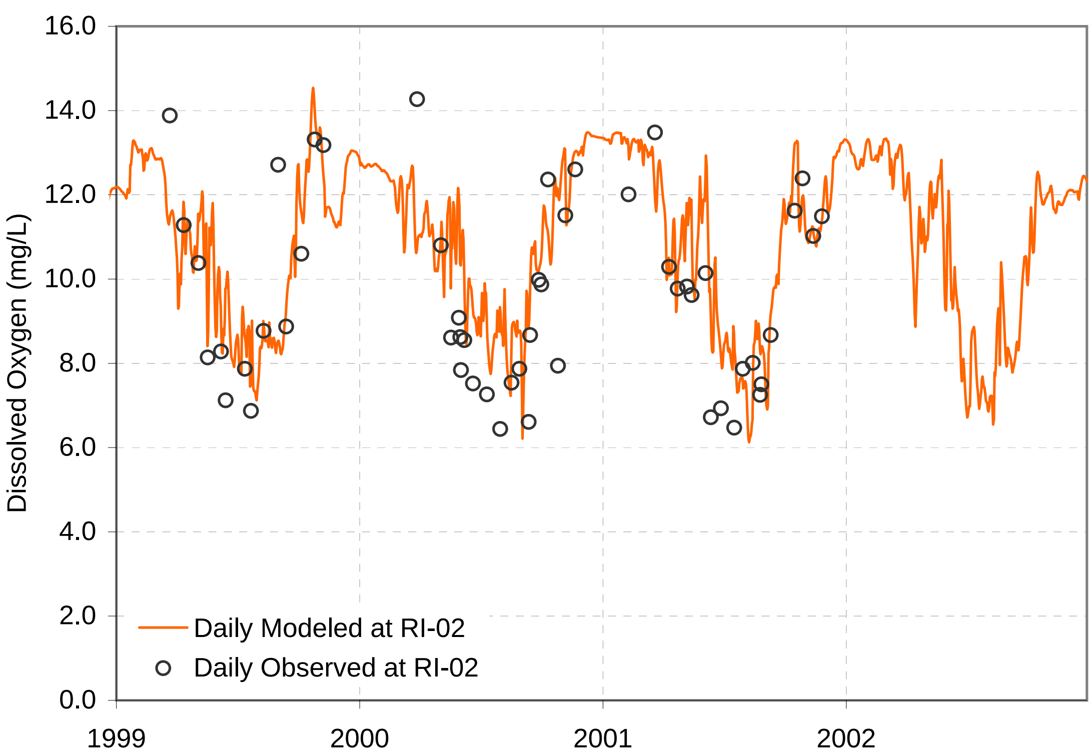


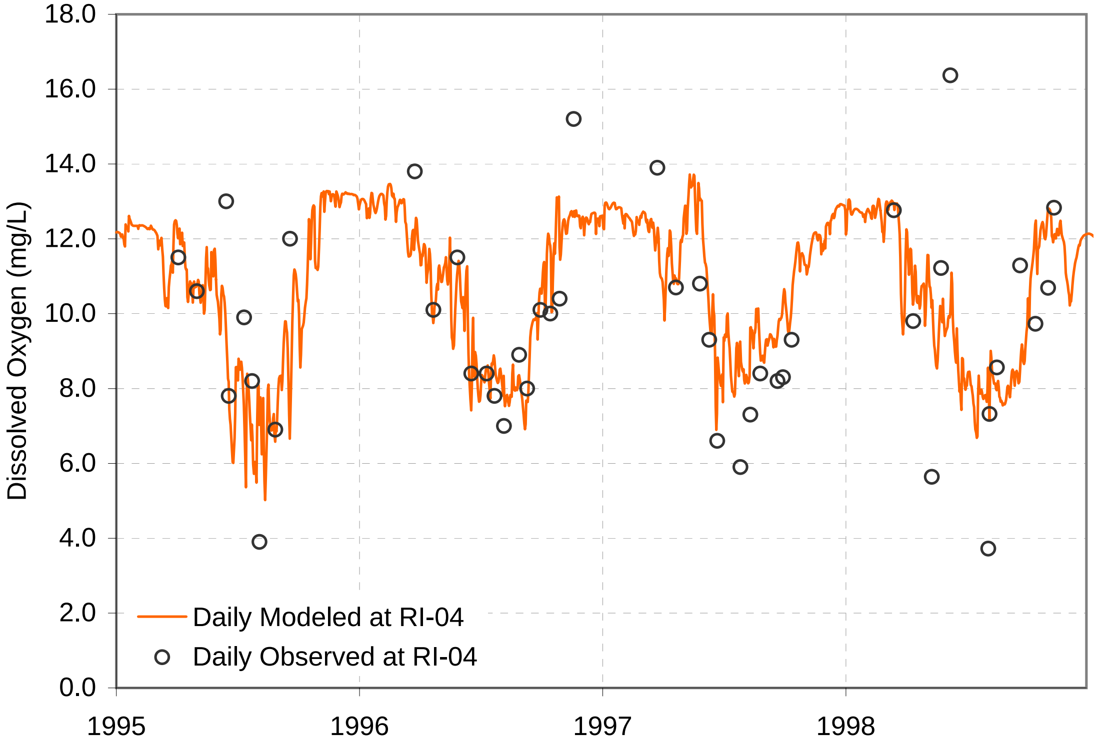
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
BOD-5 (mg/L)
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086500
Daily Observed at 4086500


20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Dissolved Oxygen (mg/L)
1995
1996
1997
1998
Daily Modeled at RI-01
Daily Observed at RI-01

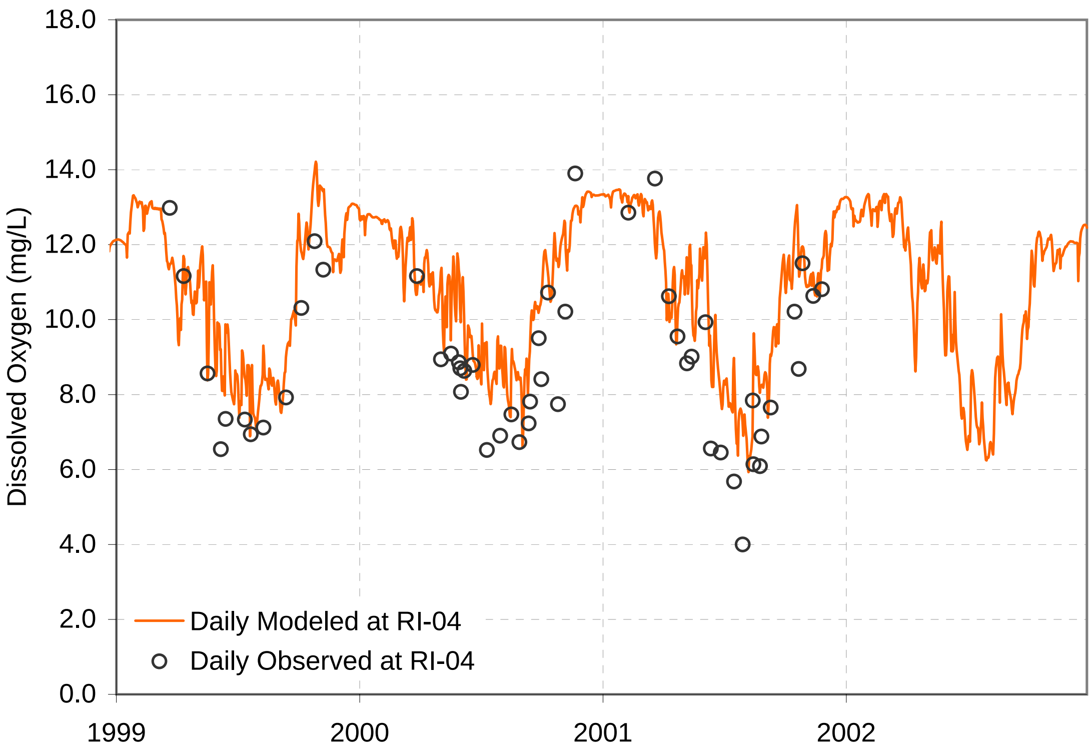

20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Dissolved Oxygen (mg/L)
1999
2000
2001
2002
Daily Modeled at RI-01
Daily Observed at RI-01


16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Dissolved Oxygen (mg/L)
1995
1996
1997
1998
Daily Modeled at RI-02
Daily Observed at RI-02

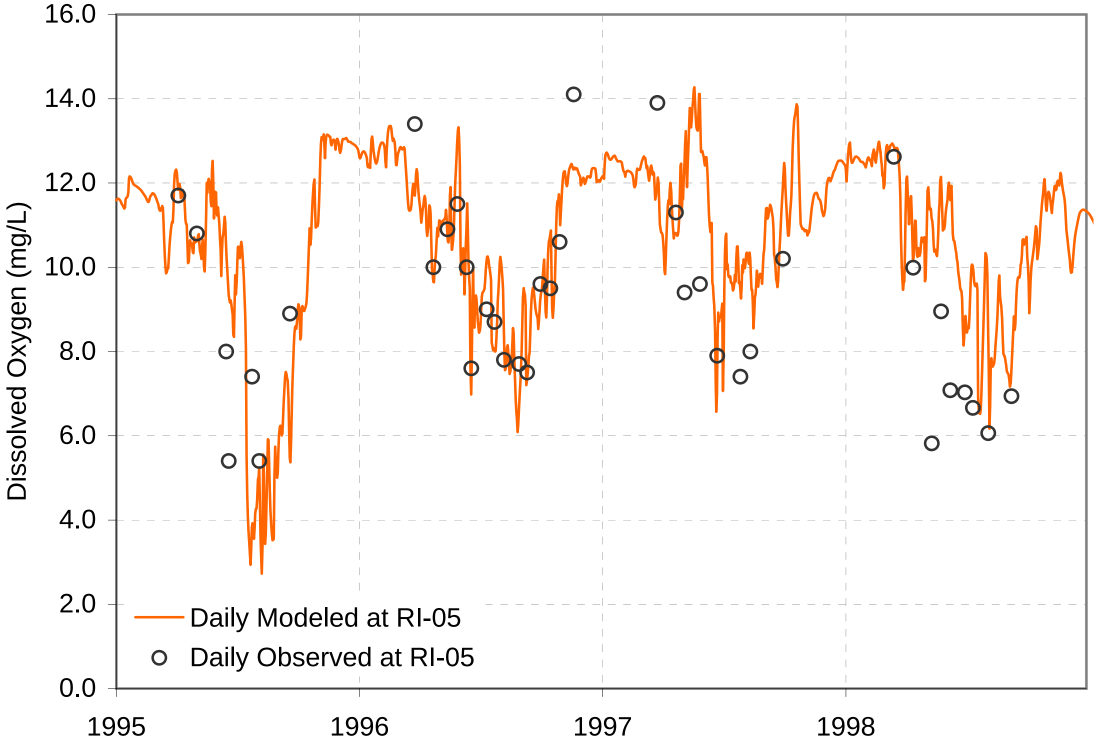

16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Dissolved Oxygen (mg/L)
1999
2000
2001
2002
Daily Modeled at RI-02
Daily Observed at RI-02



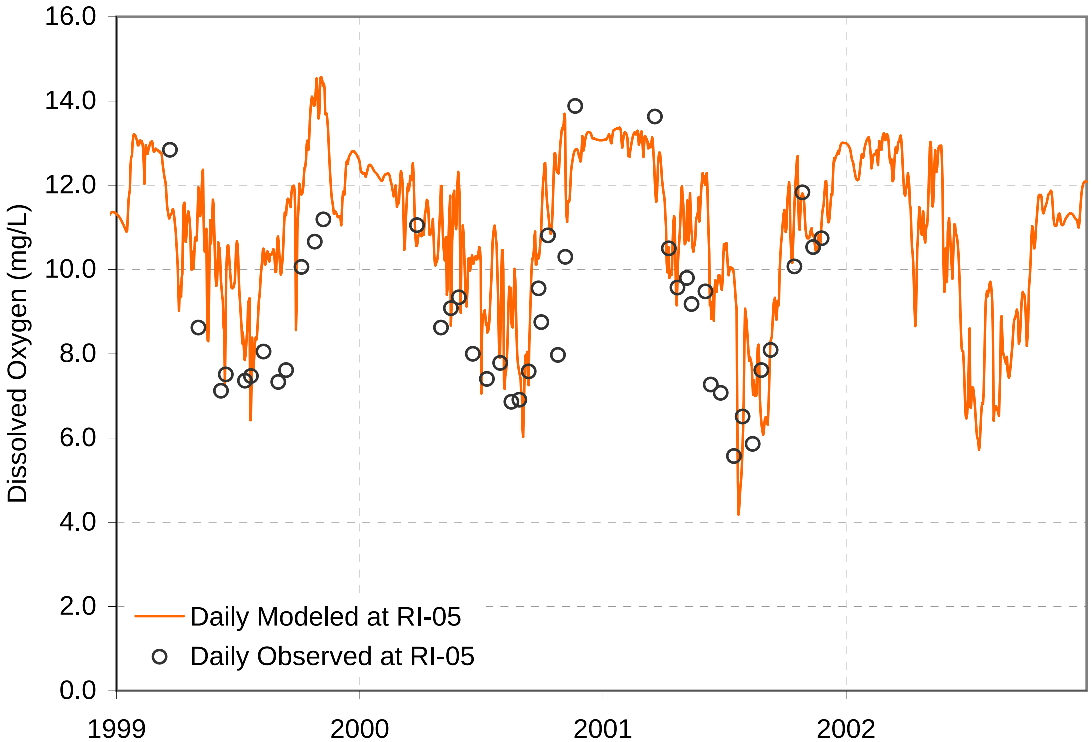
Dissolved Oxygen (mg/L)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1995
1996
1997
1998
Daily Modeled at RI-04
Daily Observed at RI-04



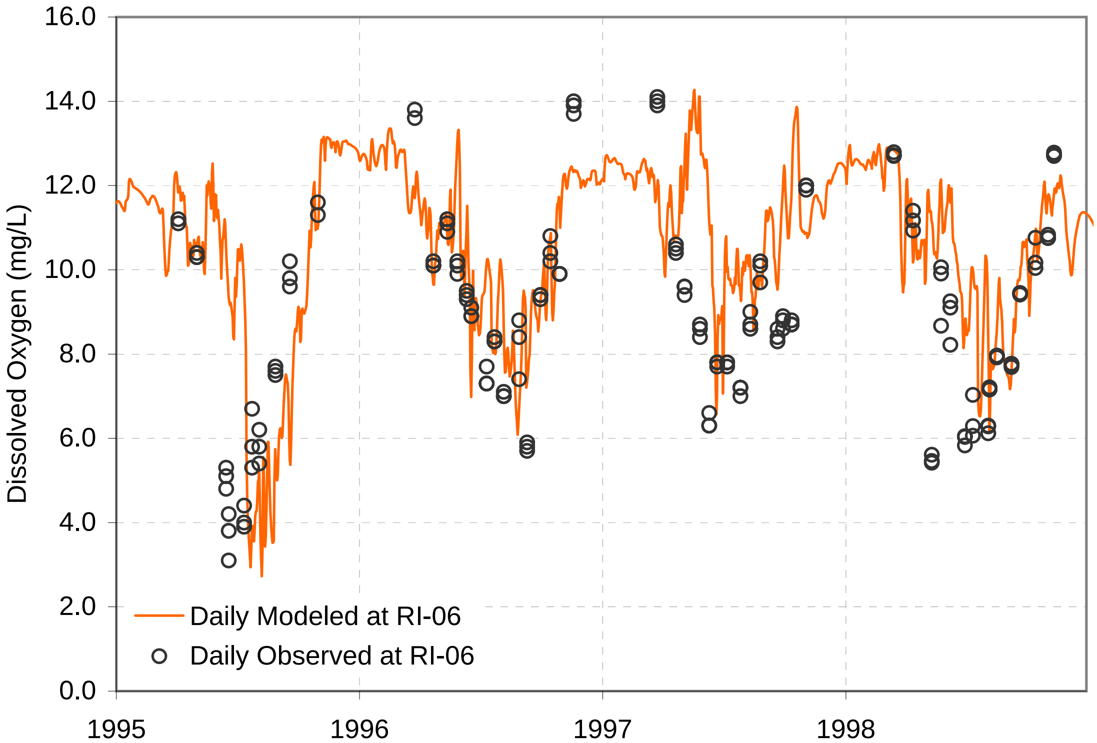
Dissolved Oxygen (mg/L)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1999
2000
2001
2002
Daily Modeled at RI-04
Daily Observed at RI-04



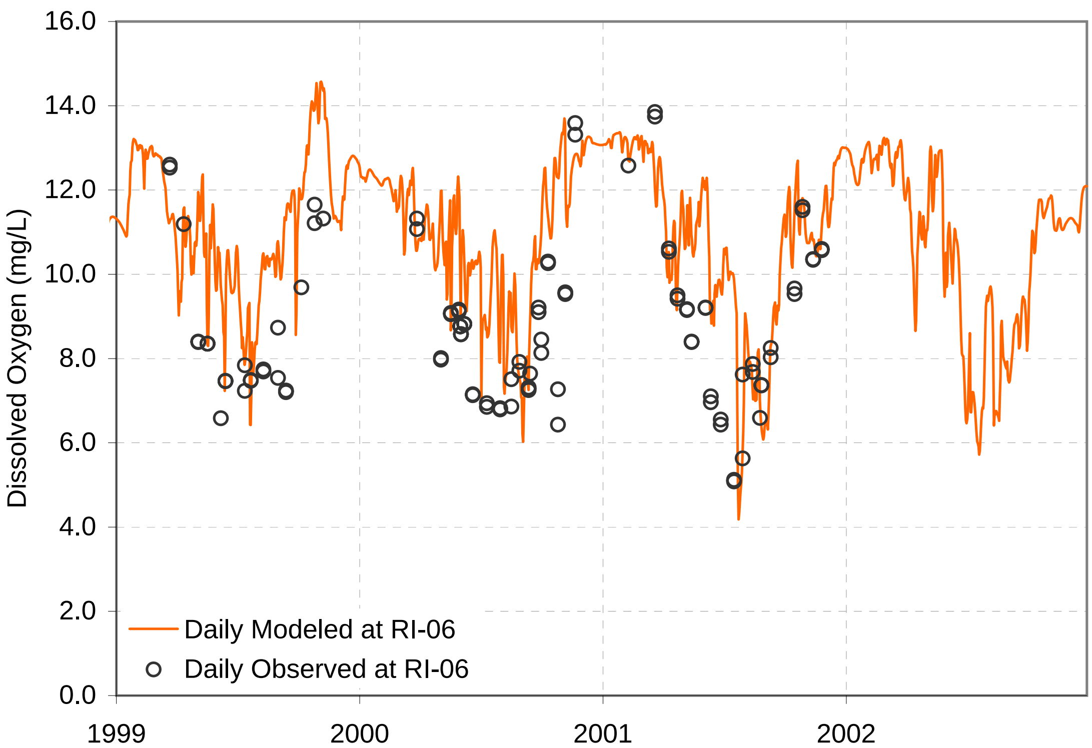
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Dissolved Oxygen (mg/L)
1995
1996
1997
1998
Daily Modeled at RI-05
Daily Observed at RI-05



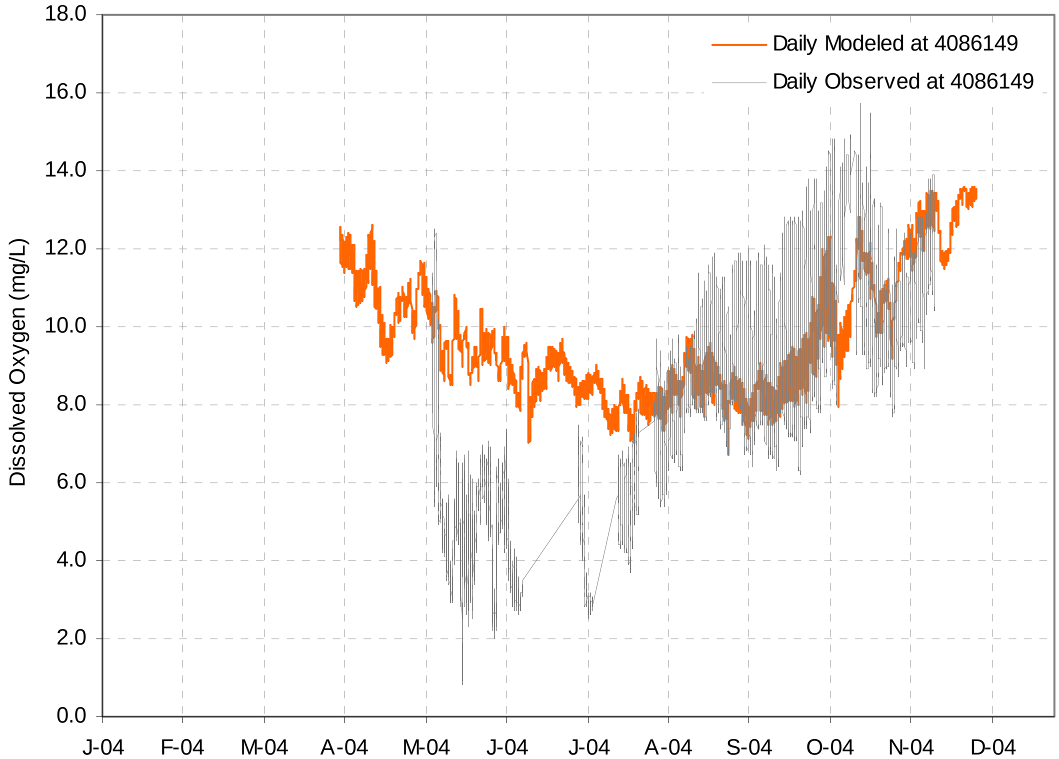
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Dissolved Oxygen (mg/L)
1999
2000
2001
2002
Daily Modeled at RI-05
Daily Observed at RI-05



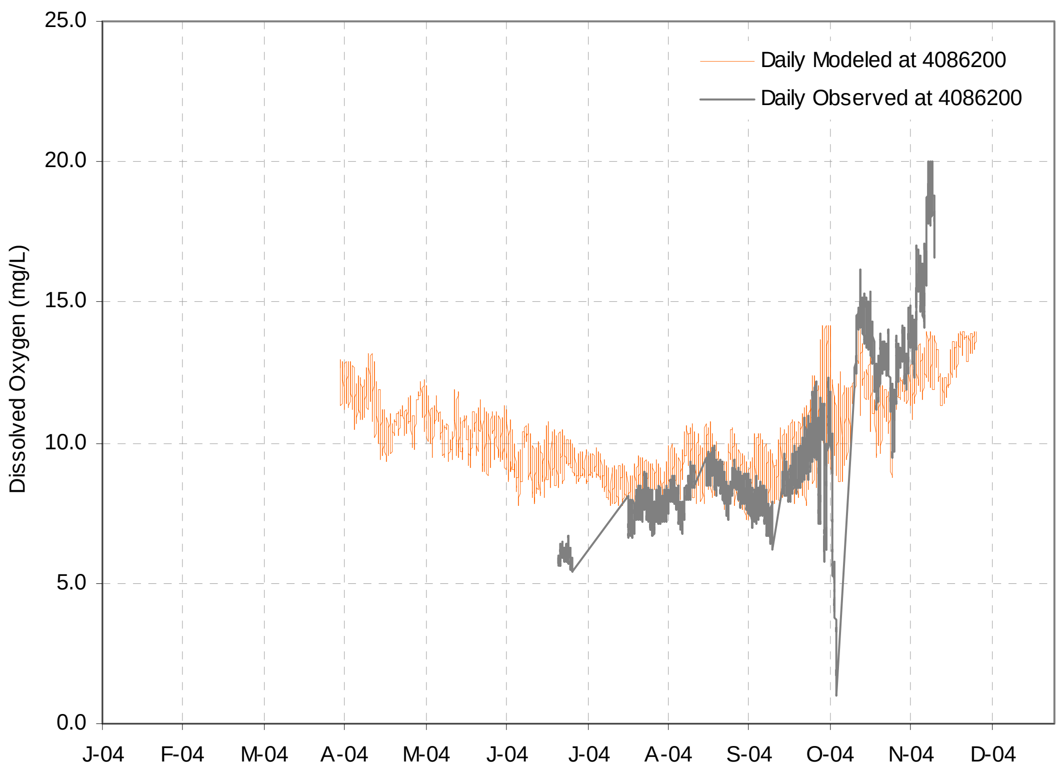
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Dissolved Oxygen (mg/L)
Daily Modeled at RI-06
Daily Observed at RI-06
1995
1996
1997
1998



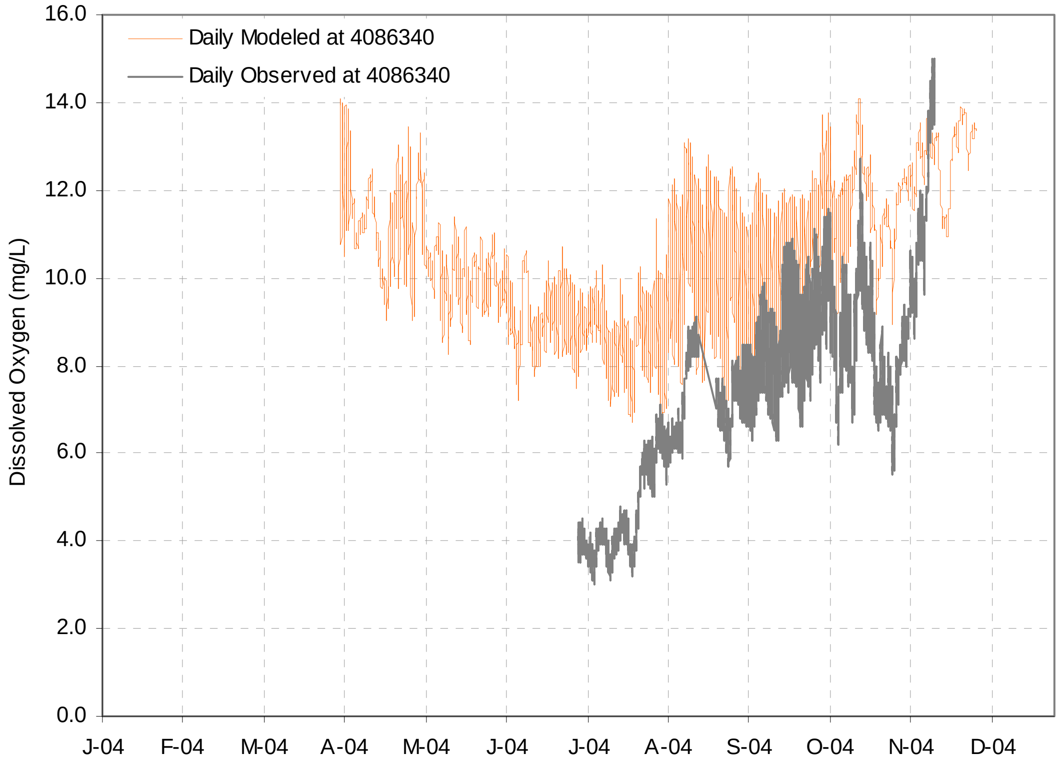
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Dissolved Oxygen (mg/L)
Daily Modeled at RI-06
Daily Observed at RI-06
1999
2000
2001
2002

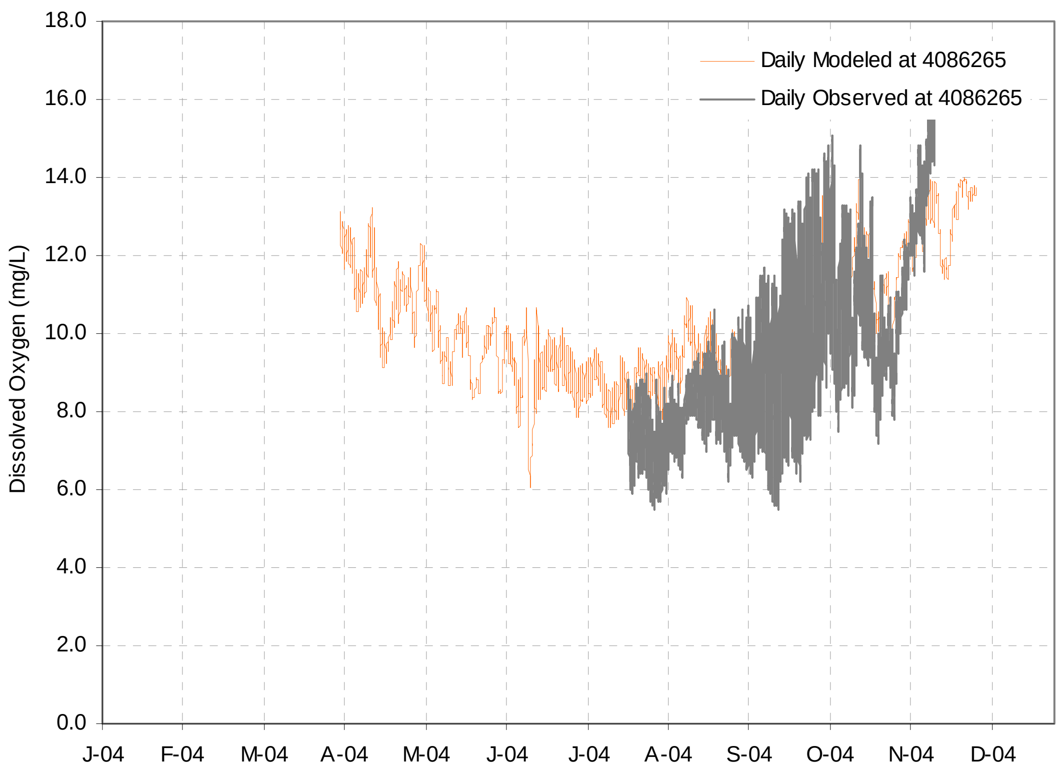


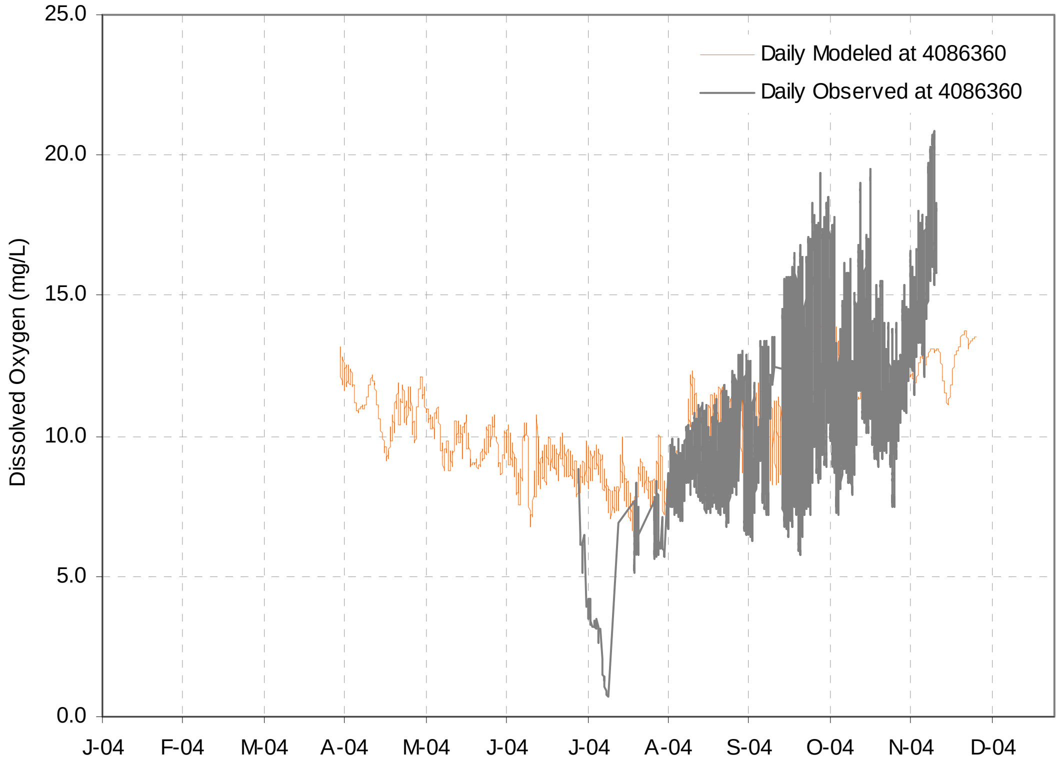
Dissolved Oxygen (mg/L)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086149
Daily Observed at 4086149



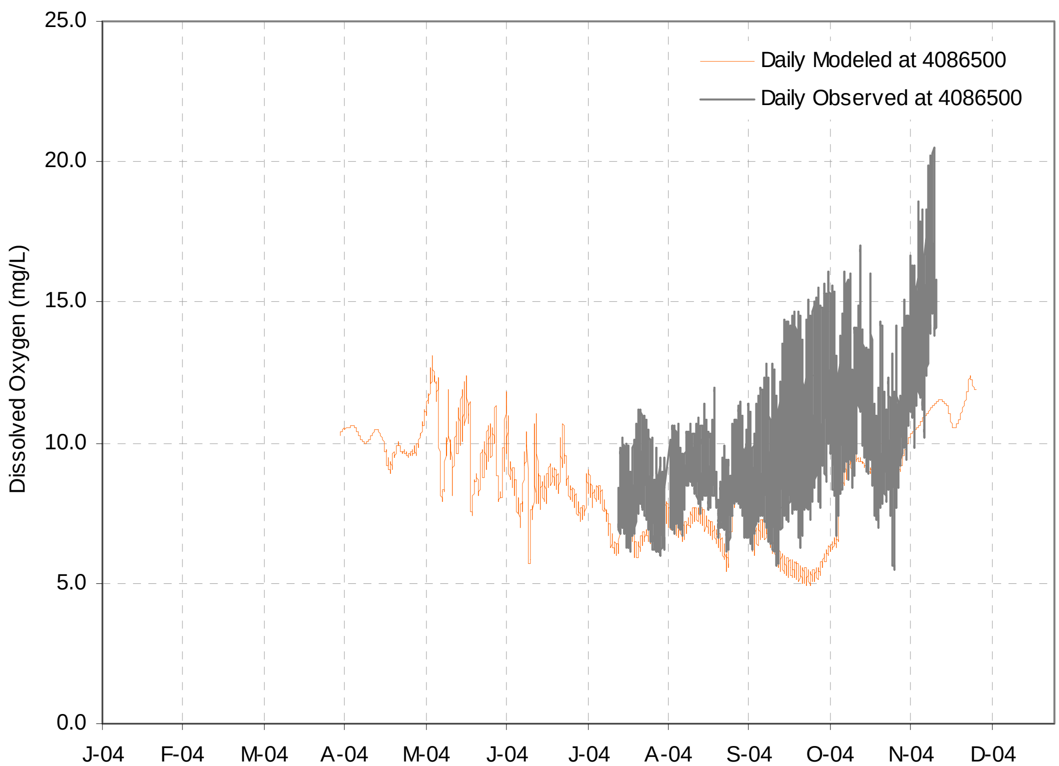
Dissolved Oxygen (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04
Daily Modeled at 4086200
Daily Observed at 4086200


Daily Modeled at 4086340
Daily Observed at 4086340
Dissolved Oxygen (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04


Daily Modeled at 4086265
Daily Observed at 4086265
Dissolved Oxygen (mg/L)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

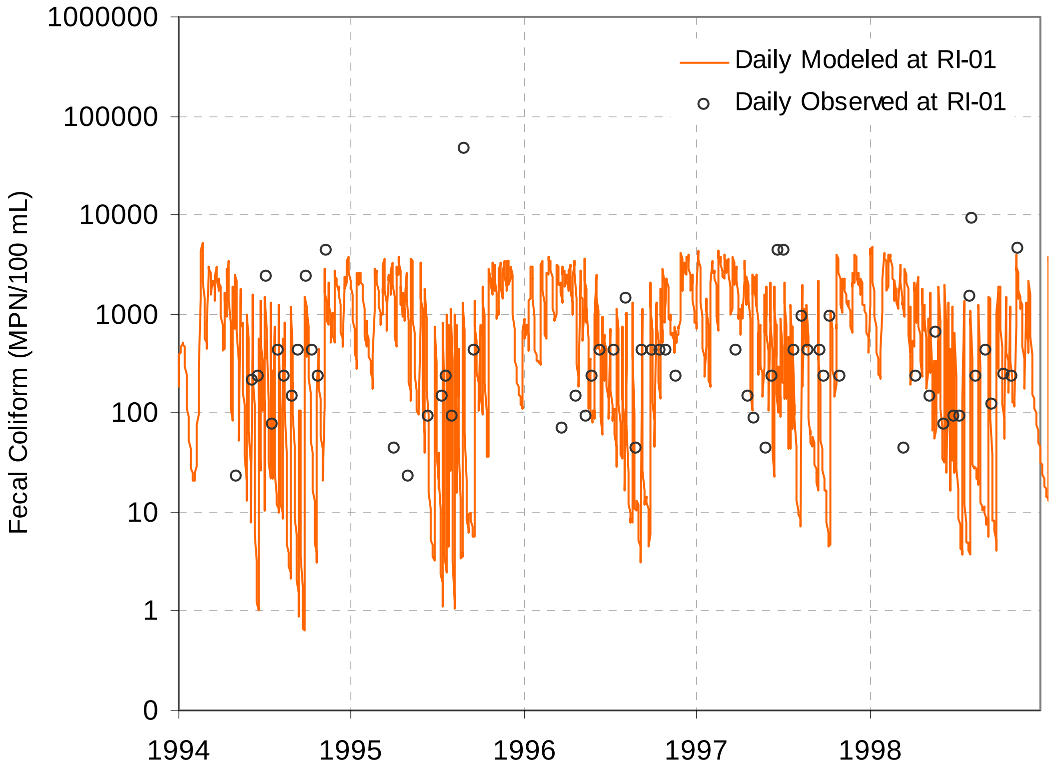


Daily Modeled at 4086360
Daily Observed at 4086360
Dissolved Oxygen (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

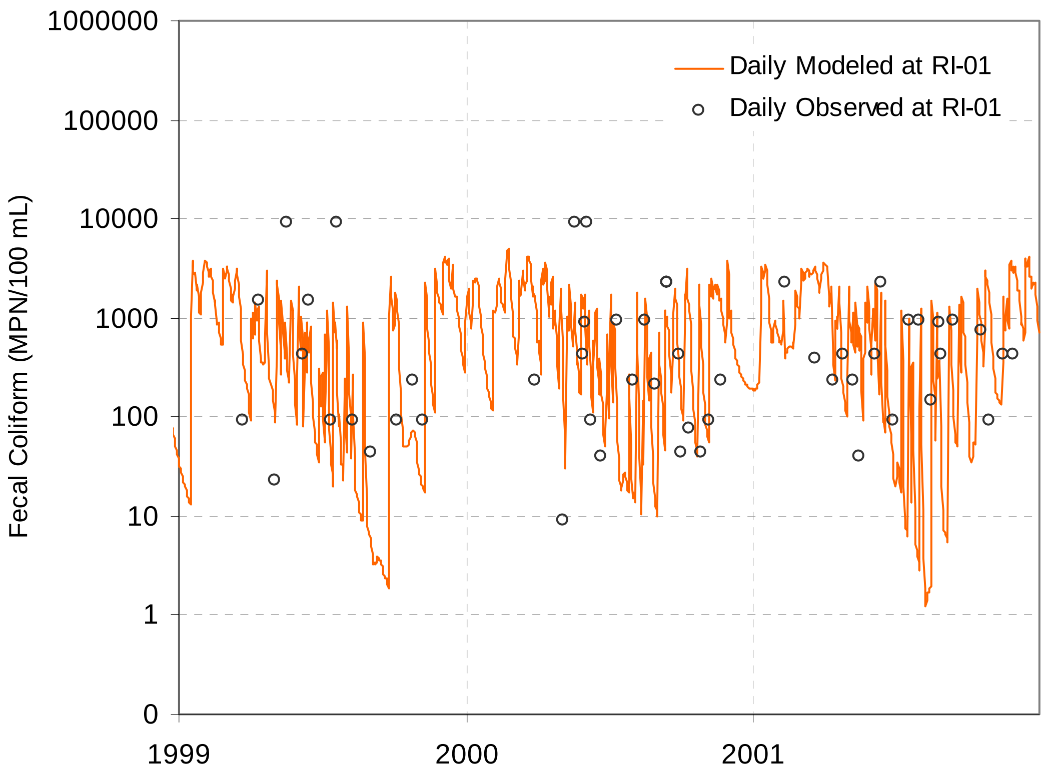


Daily Modeled at 4086500
Daily Observed at 4086500
Dissolved Oxygen (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

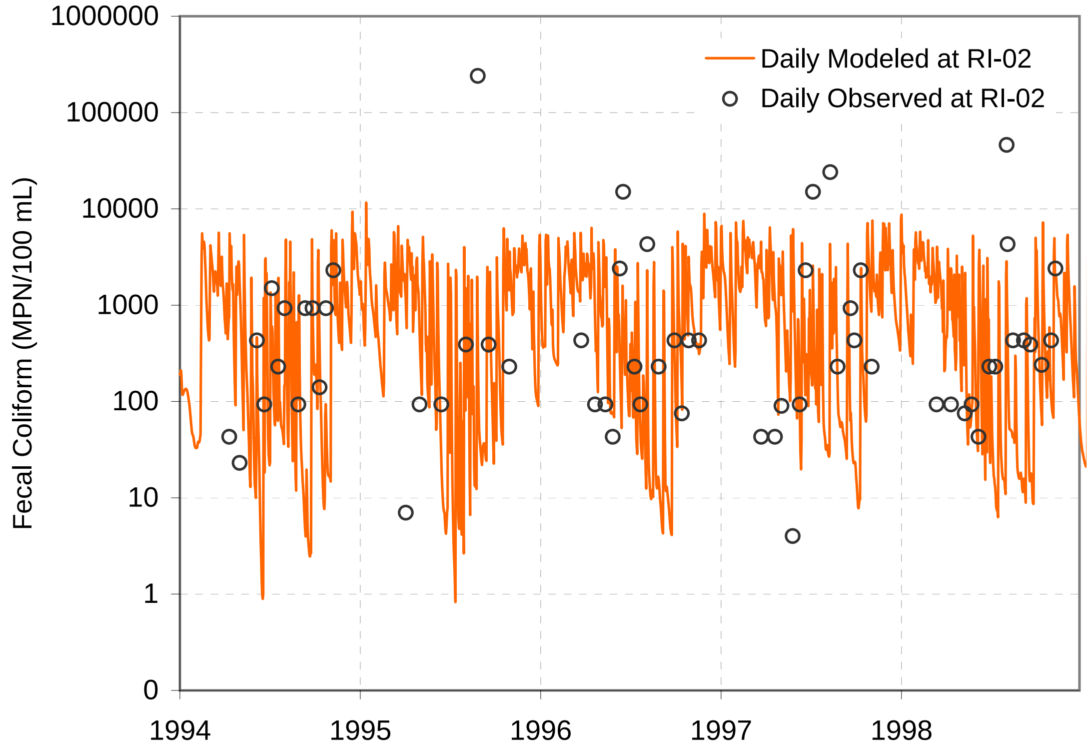
ATTACHMENT G – CALIBRATION AND VALIDATION PLOTS FOR FECAL COLIFORM



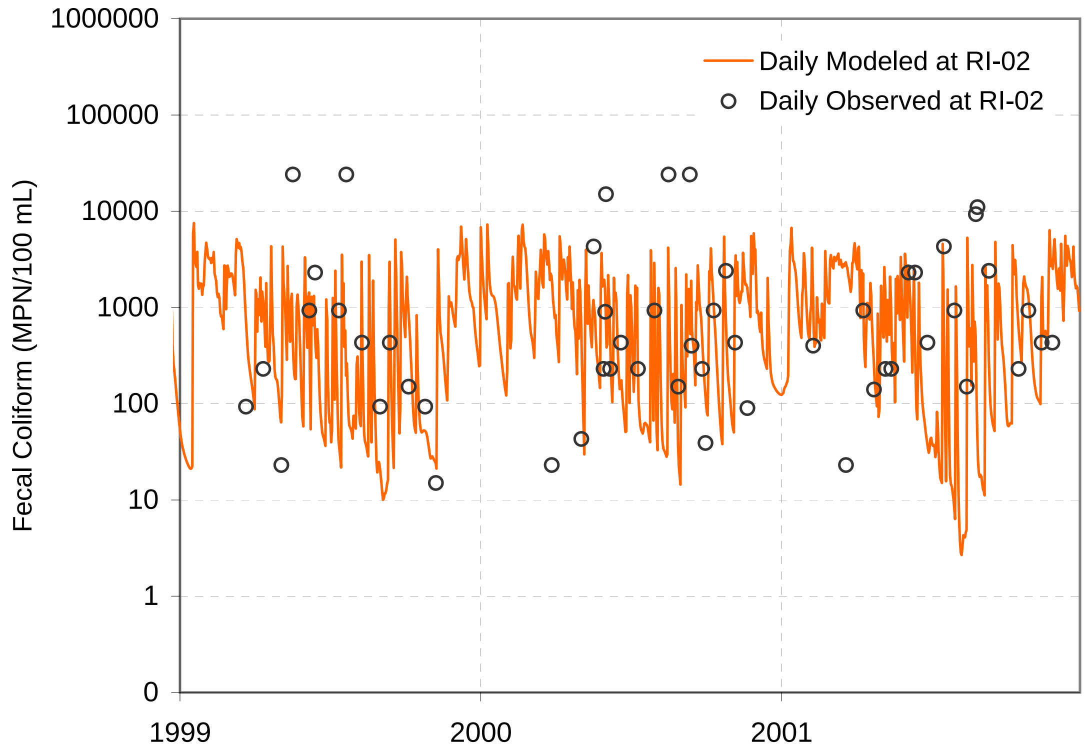
1000000
100000
10000
1000
100
10
1
0
Fecal Coliform (MPN/100 mL)
1994
1995
1996
1997
1998
Daily Modeled at RI-01
Daily Observed at RI-01



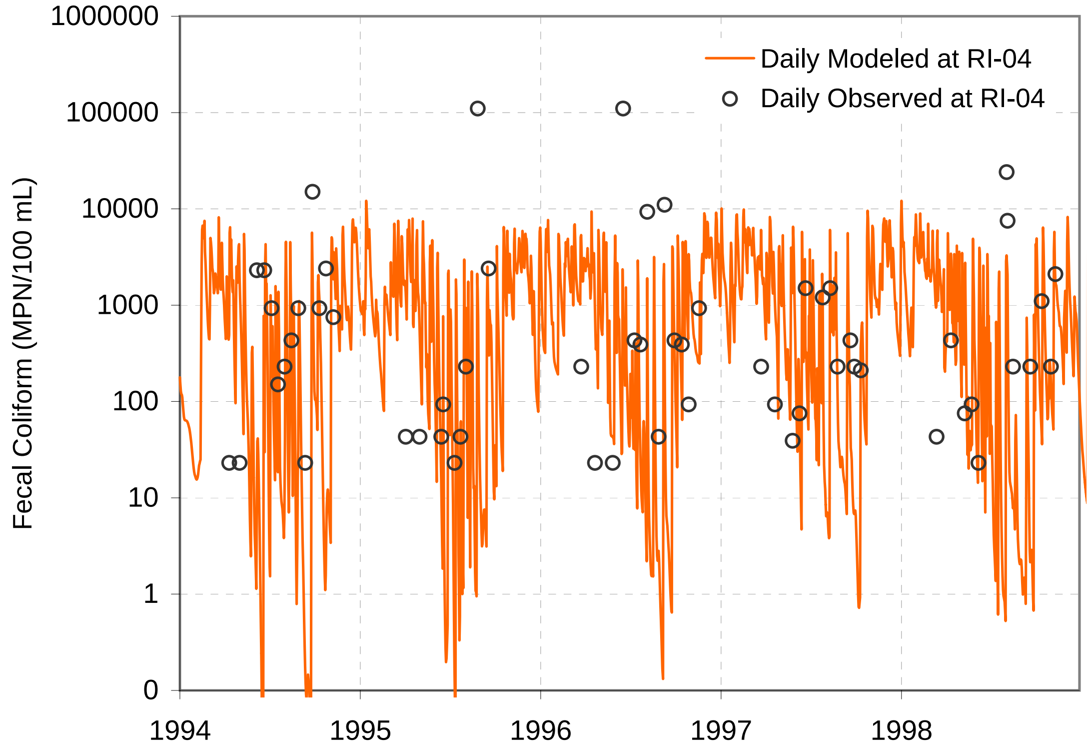
1000000
100000
10000
1000
100
10
1
0
Fecal Coliform (MPN/100 mL)
1999
2000
2001
Daily Modeled at RI-01
Daily Observed at RI-01

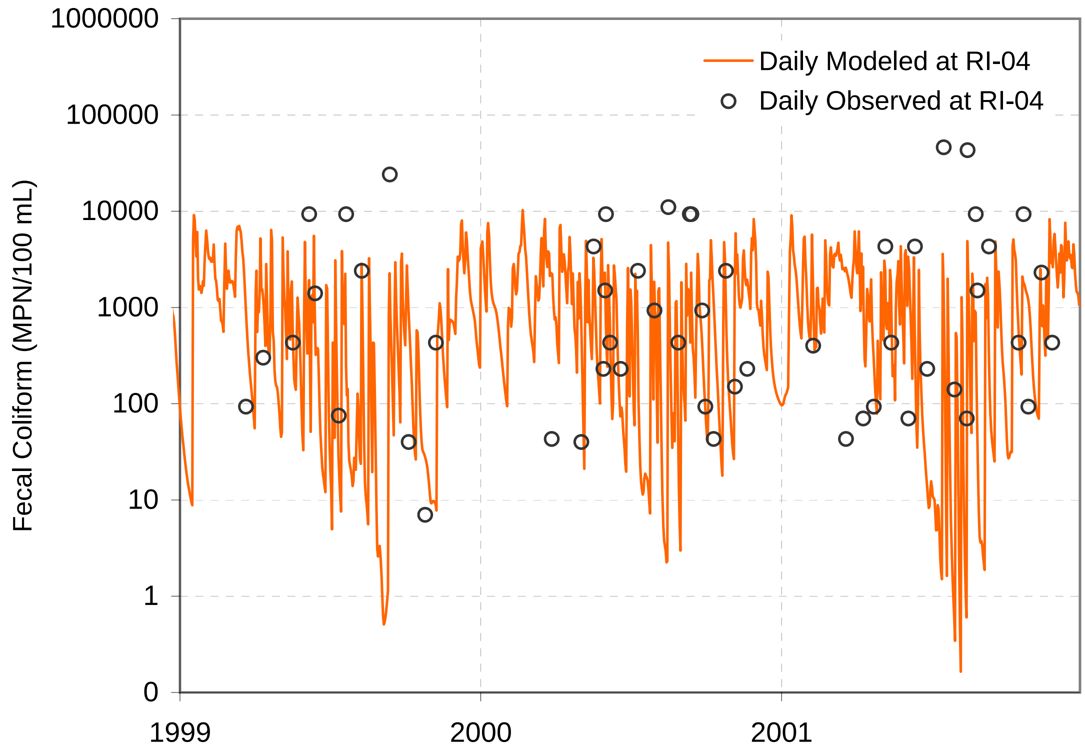


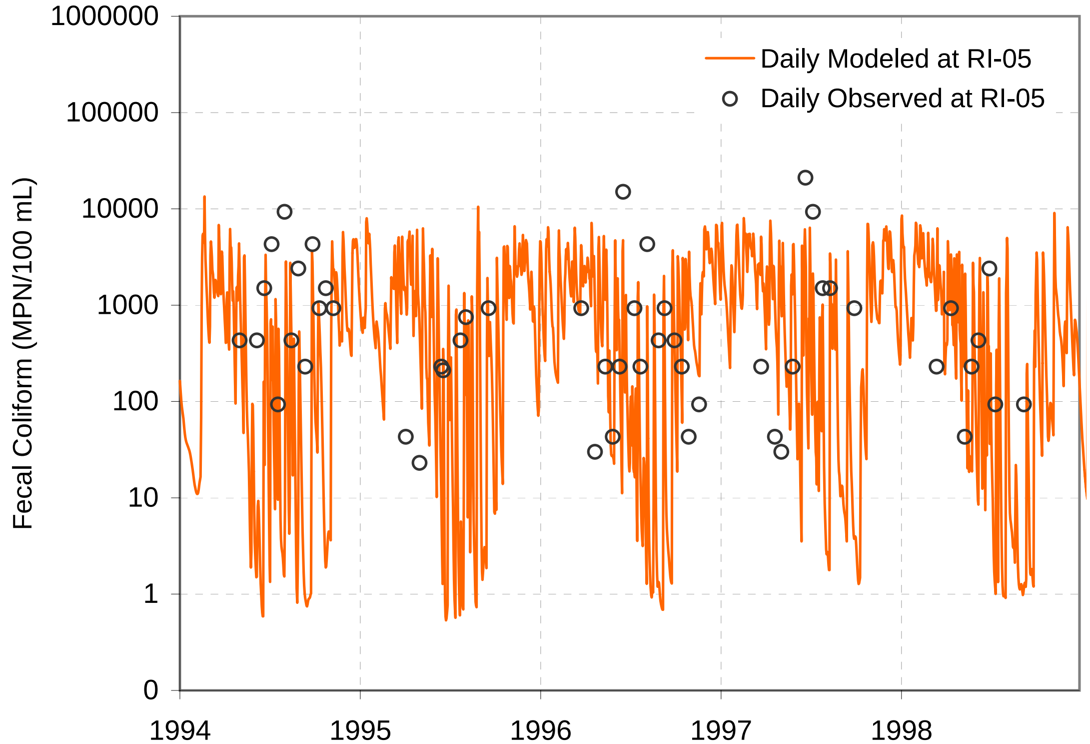
Daily Modeled at RI-02
Daily Observed at RI-02
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
0
1994
1995
1996
1997
1998

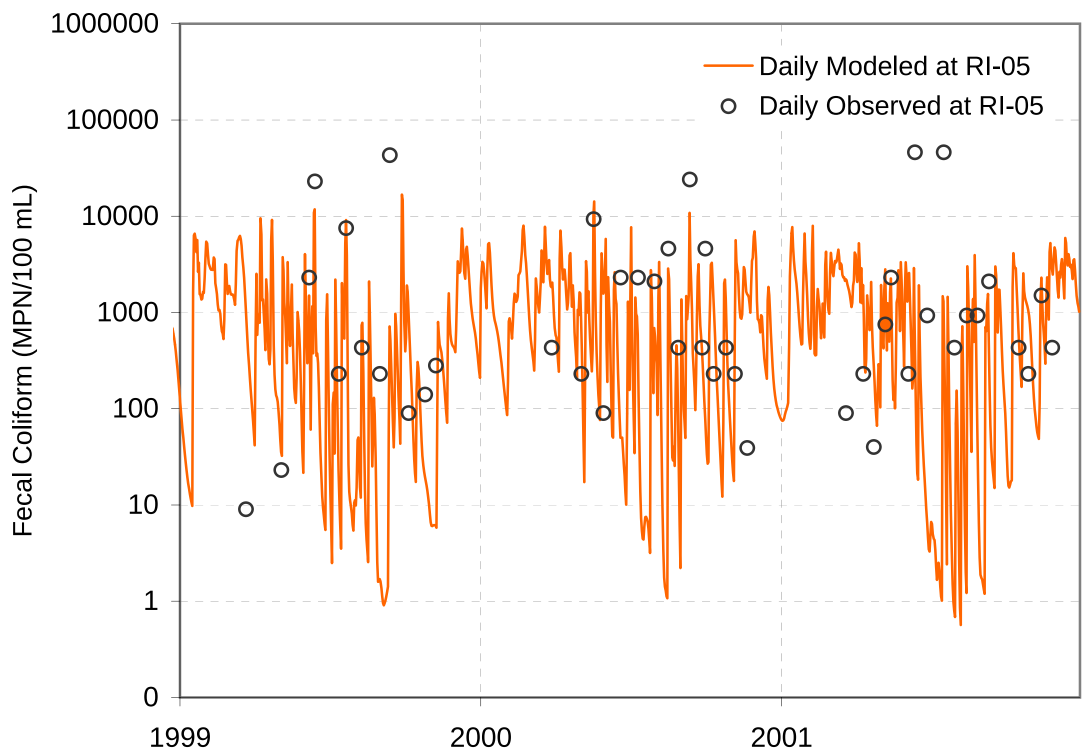


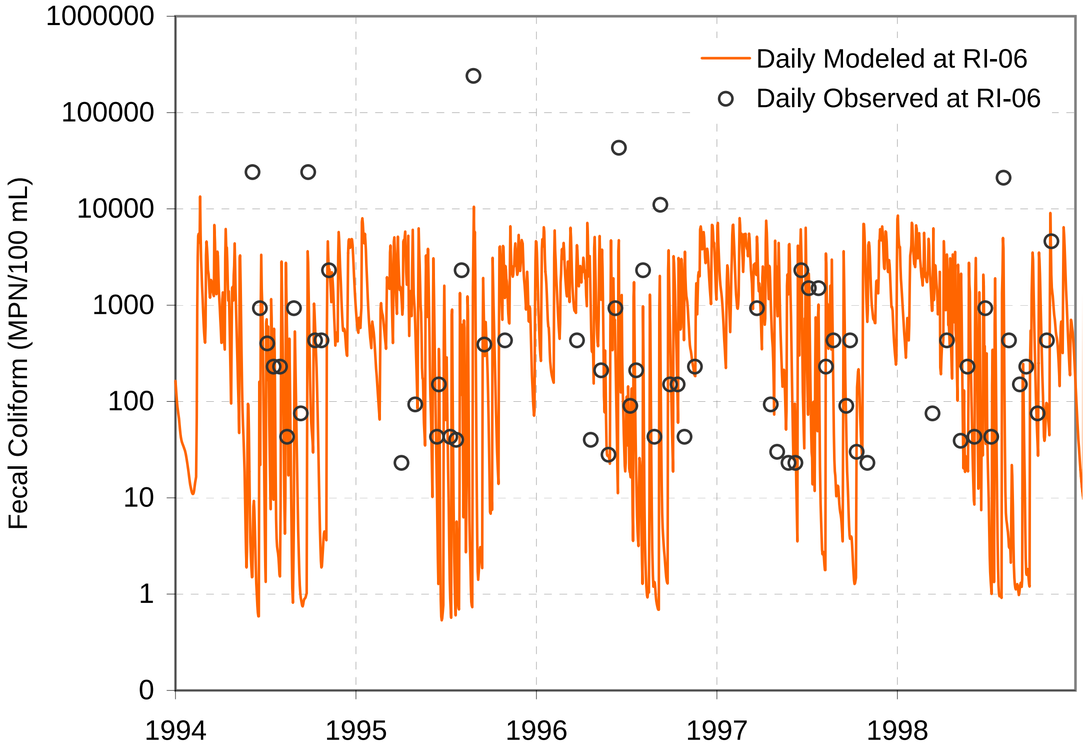
Daily Modeled at RI-02
Daily Observed at RI-02
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
0
1999
2000
2001

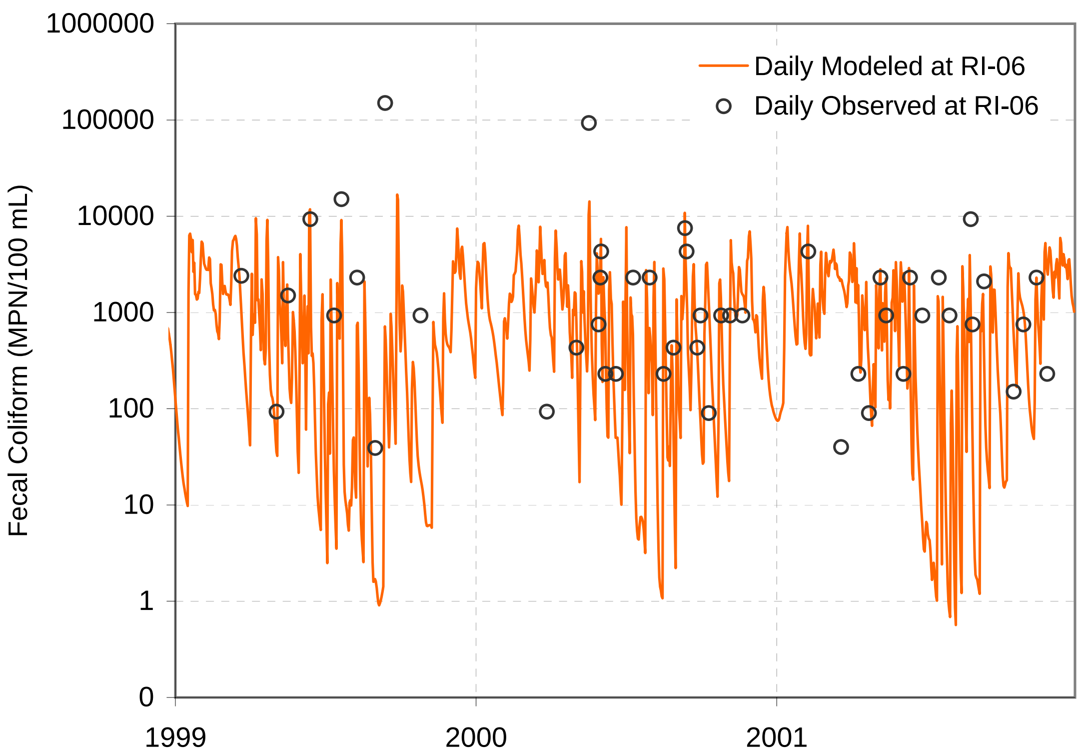

Daily Modeled at RI-04
Daily Observed at RI-04
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
0
1994
1995
1996
1997
1998

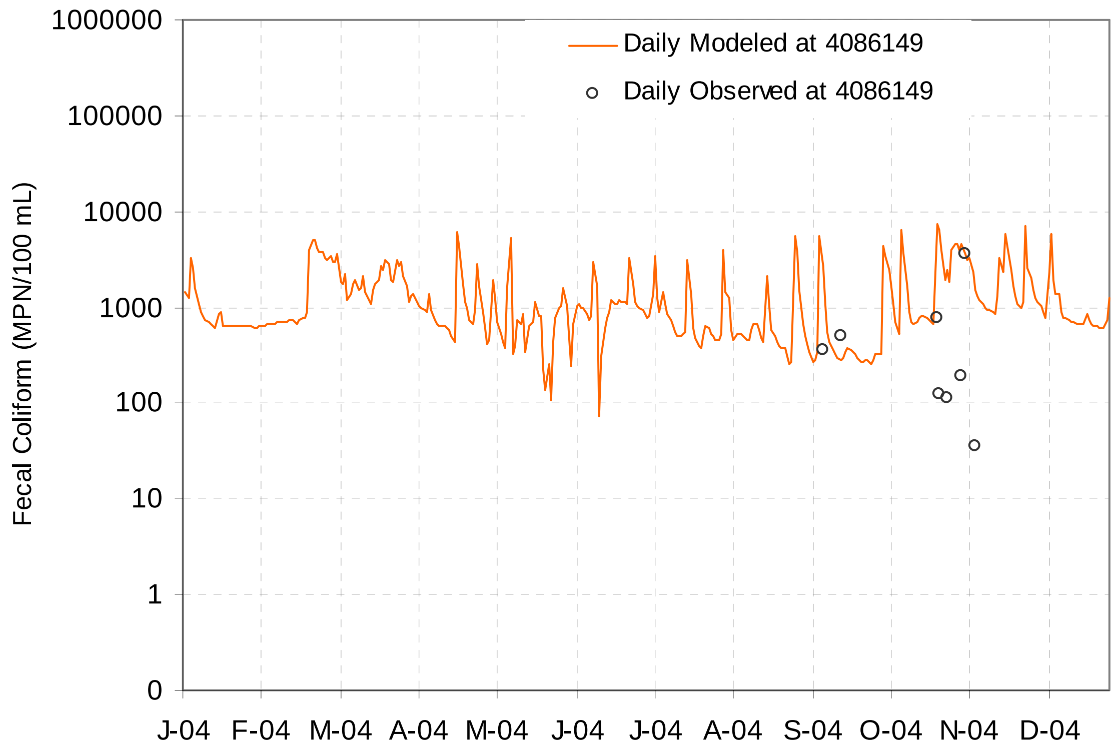

Daily Modeled at RI-04
Daily Observed at RI-04
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
0
1999
2000
2001

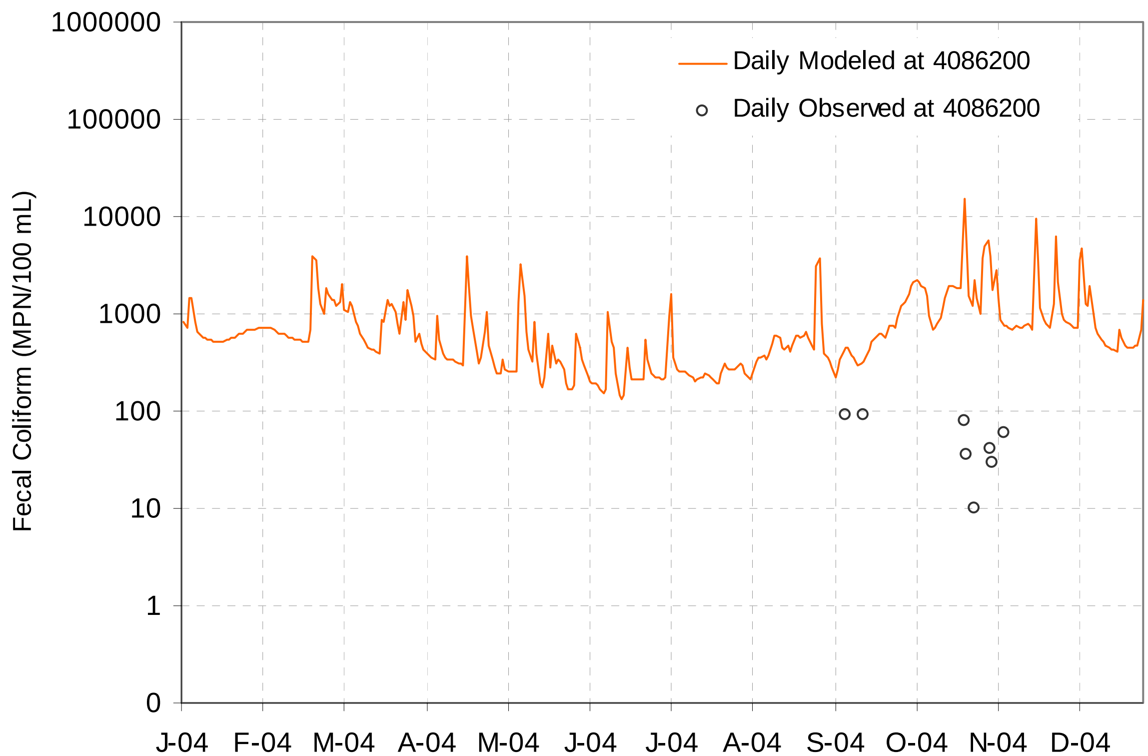

1000000
100000
10000
1000
100
10
1
0
Fecal Coliform (MPN/100 mL)
1994
1995
1996
1997
1998
Daily Modeled at RI-05
Daily Observed at RI-05

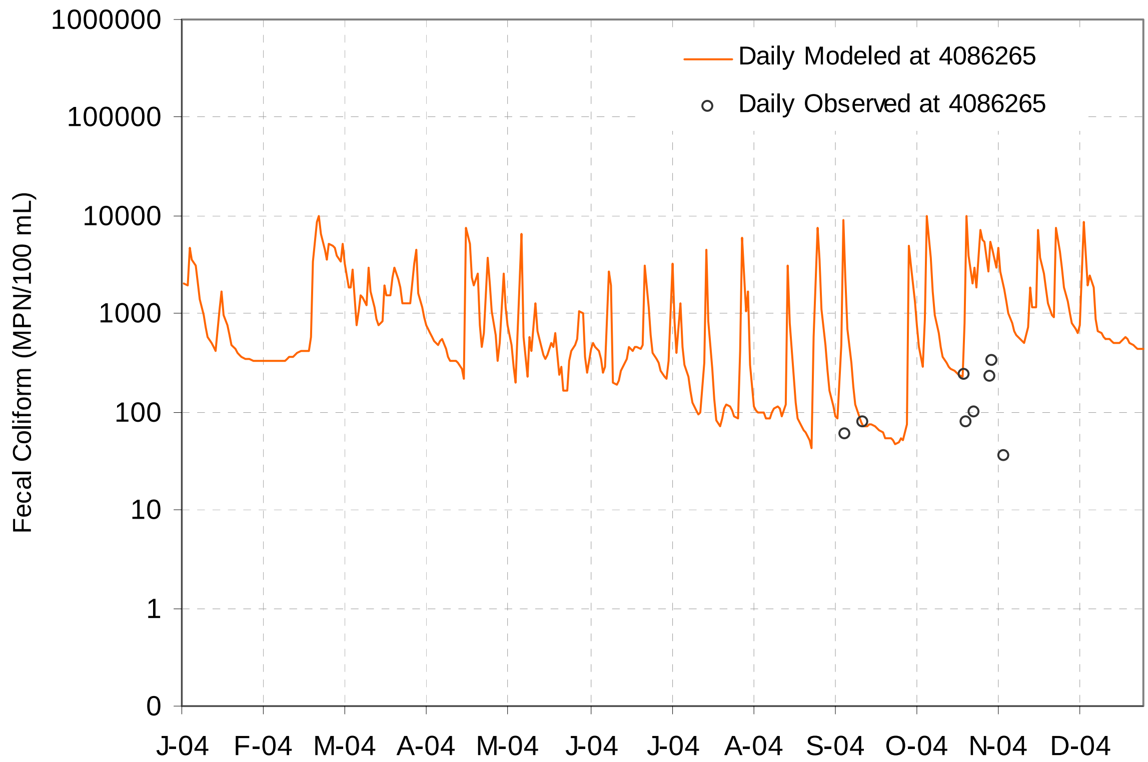

1000000
100000
10000
1000
100
10
1
0
Fecal Coliform (MPN/100 mL)
1999
2000
2001
Daily Modeled at RI-05
Daily Observed at RI-05

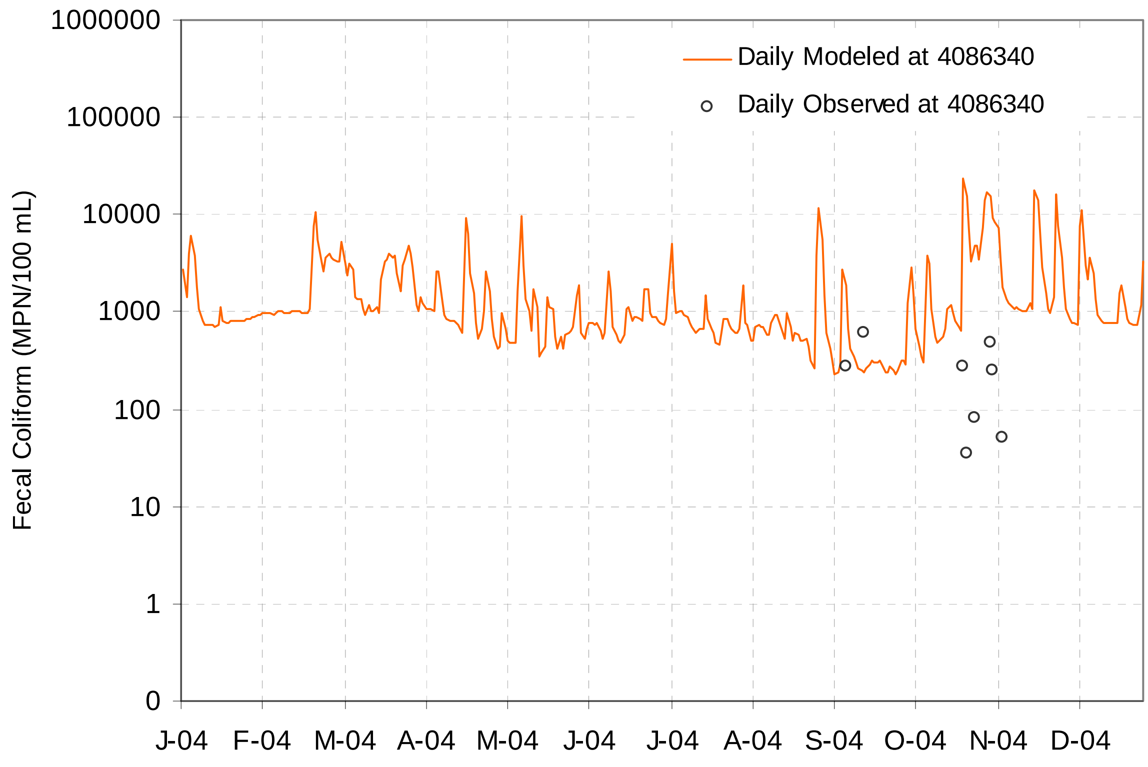

Daily Modeled at RI-06
Daily Observed at RI-06
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
0
1994
1995
1996
1997
1998

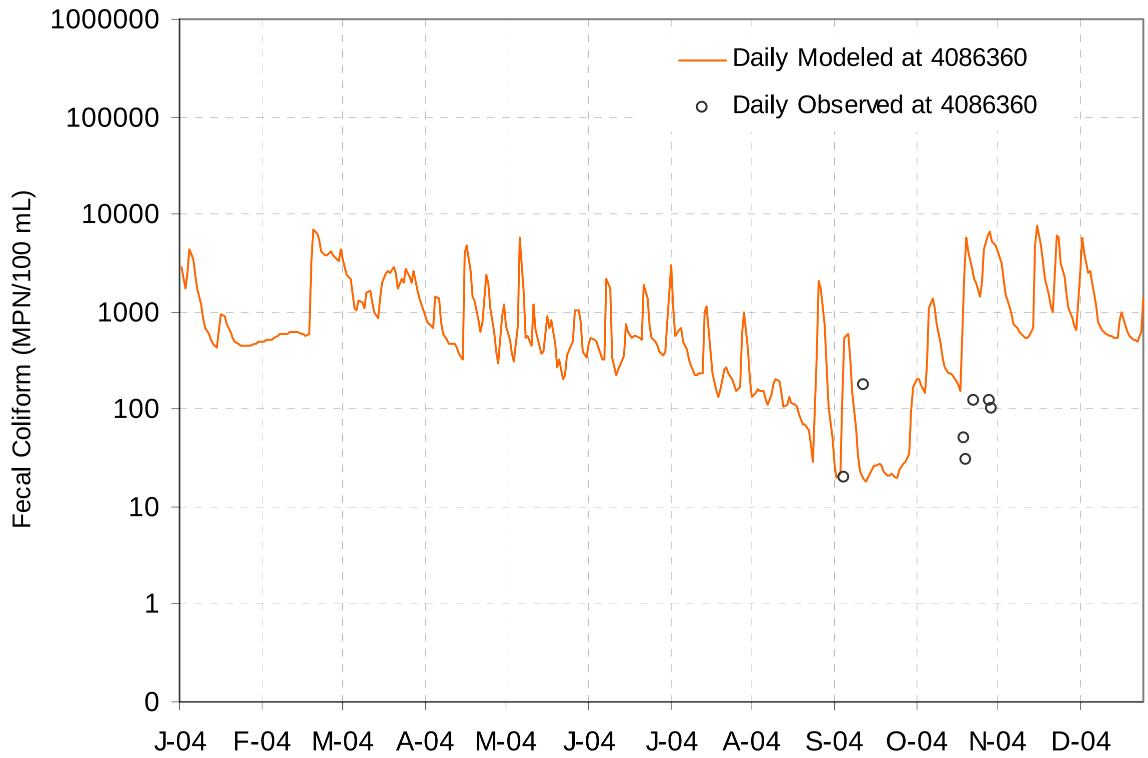

Daily Modeled at RI-06
Daily Observed at RI-06
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
0
1999
2000
2001

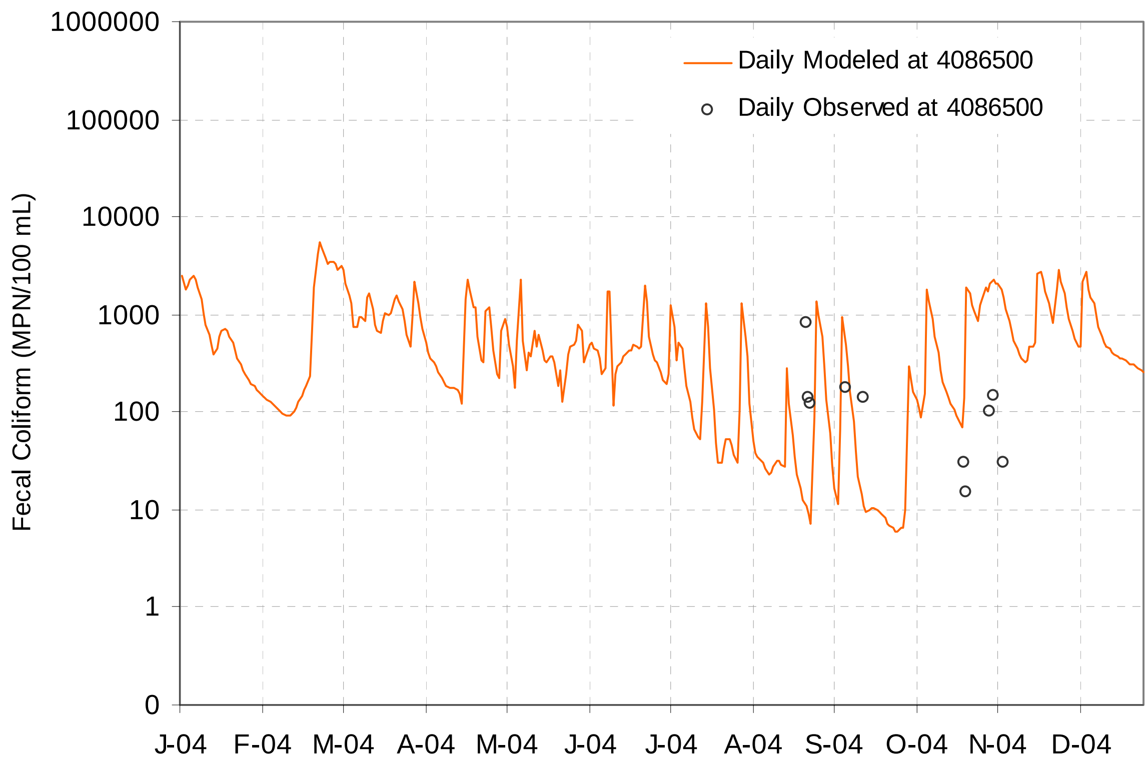

Daily Modeled at 4086149
Daily Observed at 4086149
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04


Daily Modeled at 4086200
Daily Observed at 4086200
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

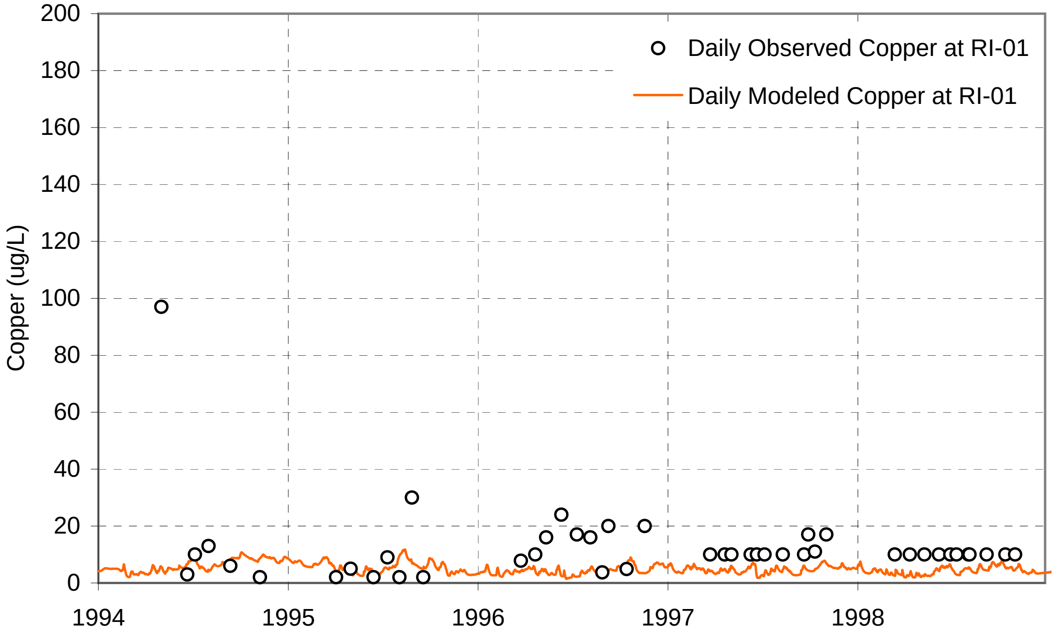

Daily Modeled at 4086265
Daily Observed at 4086265
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

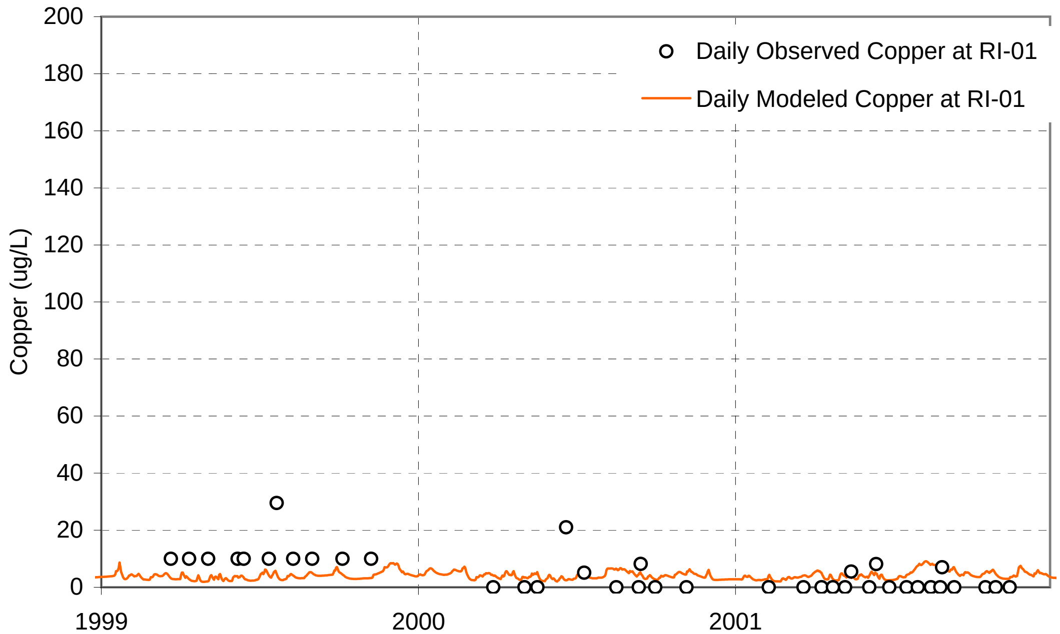

Daily Modeled at 4086340
Daily Observed at 4086340
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

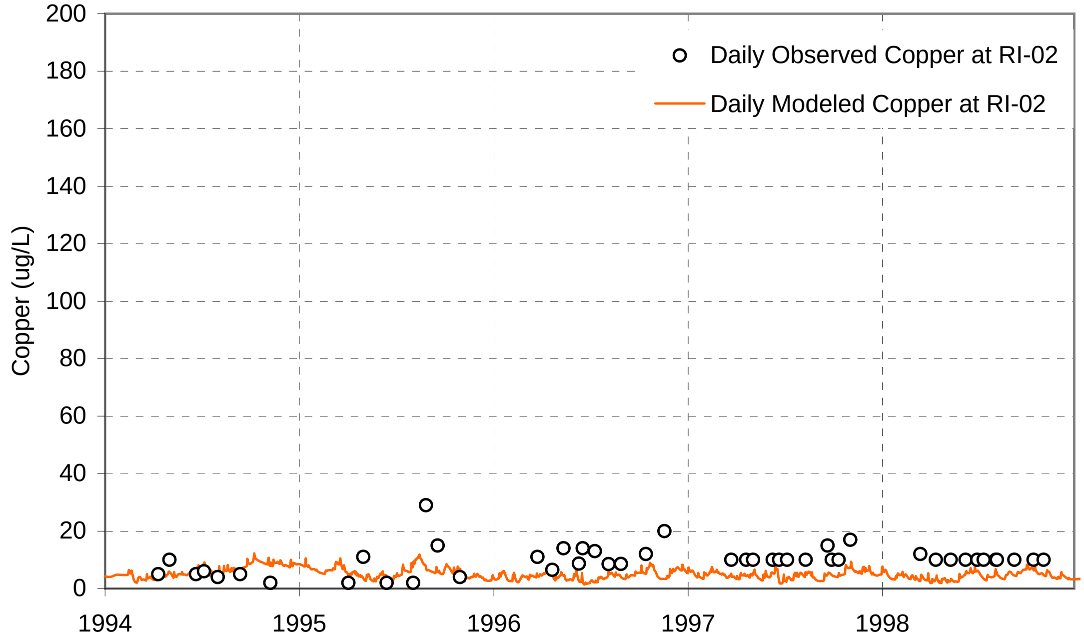

Daily Modeled at 4086360
Daily Observed at 4086360
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

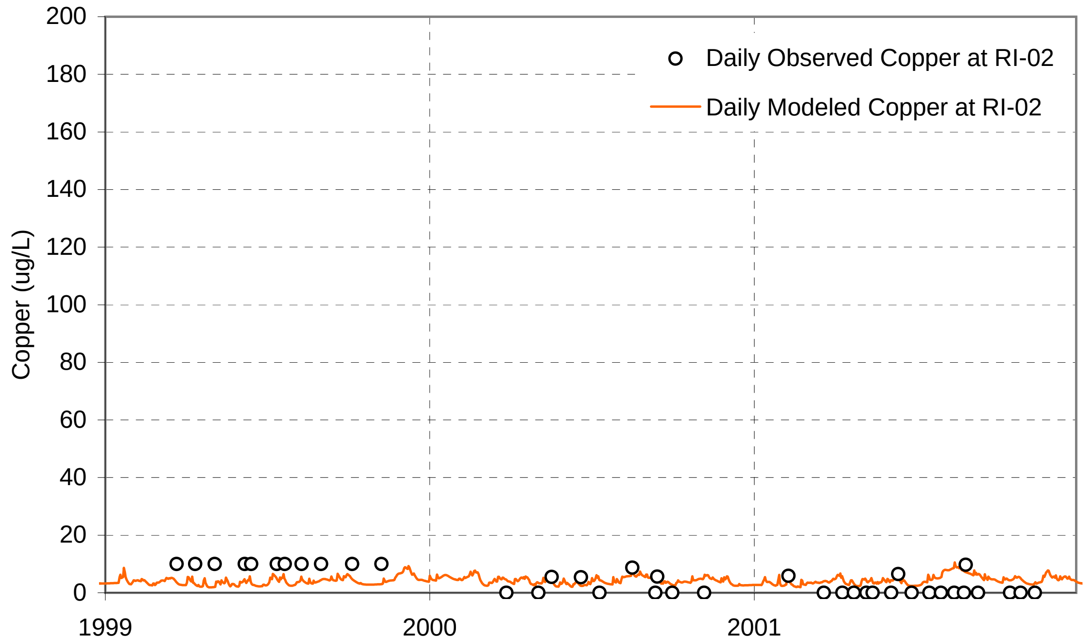

Daily Modeled at 4086500
Daily Observed at 4086500
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04
D-04

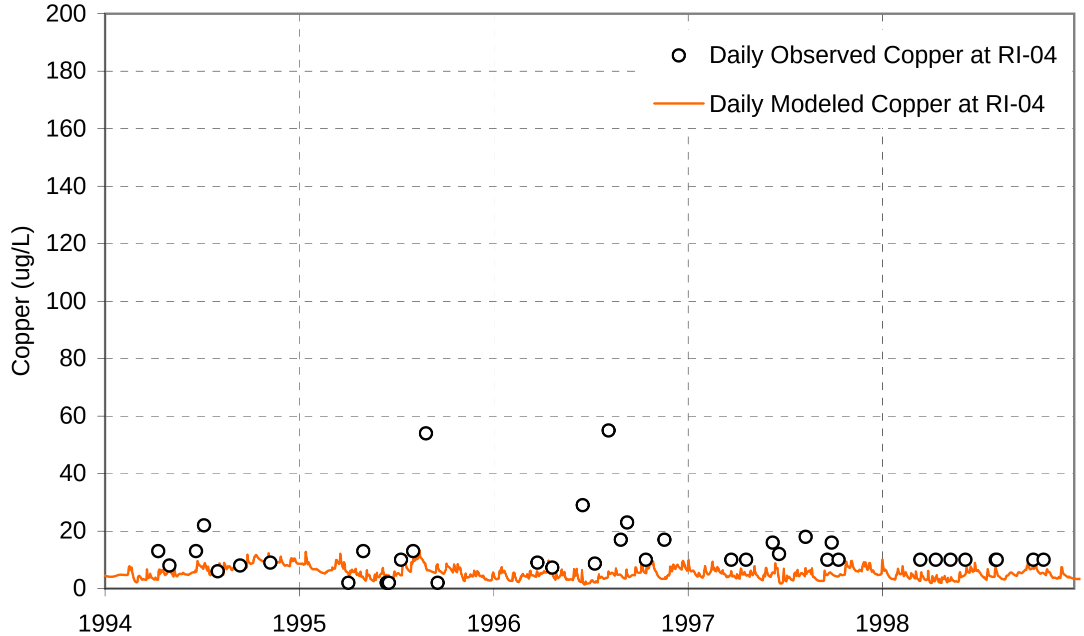
ATTACHMENT H – CALIBRATION AND VALIDATION PLOTS FOR COPPER AND ZINC

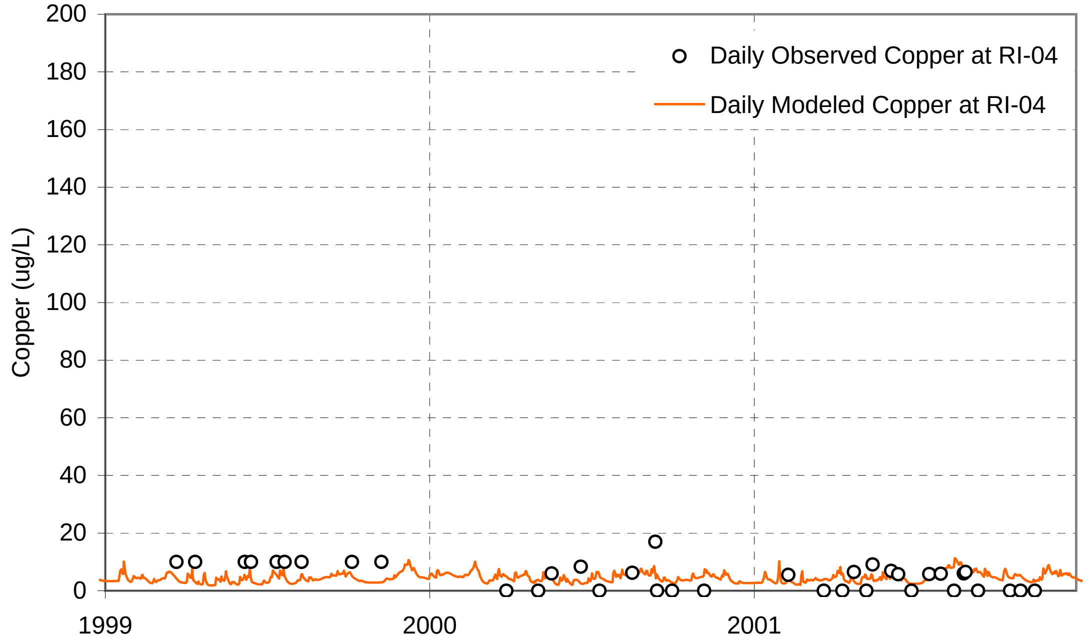

Daily Observed Copper at RI-01
Daily Modeled Copper at RI-01
Copper (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1994
1995
1996
1997
1998

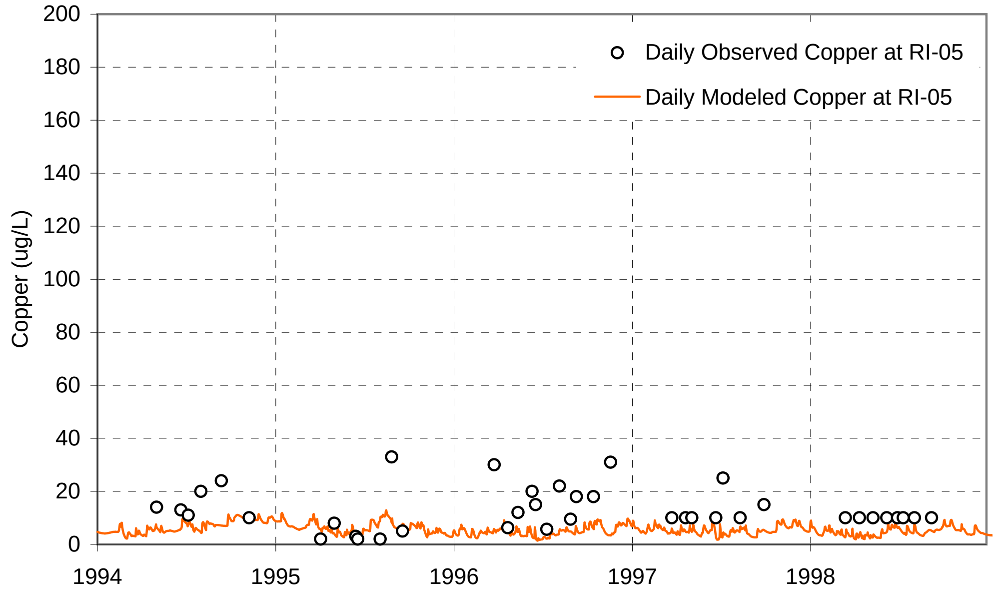

Daily Observed Copper at RI-01
Daily Modeled Copper at RI-01
Copper (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1999
2000
2001


Daily Observed Copper at RI-02
Daily Modeled Copper at RI-02
Copper (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1994
1995
1996
1997
1998

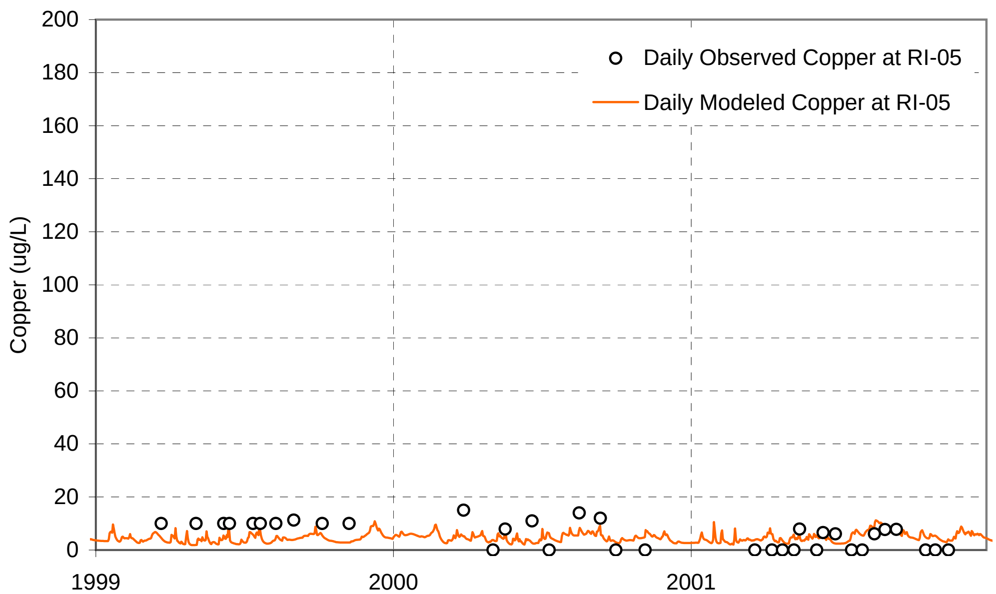

Daily Observed Copper at RI-02
Daily Modeled Copper at RI-02
Copper (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1999
2000
2001


Daily Observed Copper at RI-04
Daily Modeled Copper at RI-04
Copper (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1994
1995
1996
1997
1998

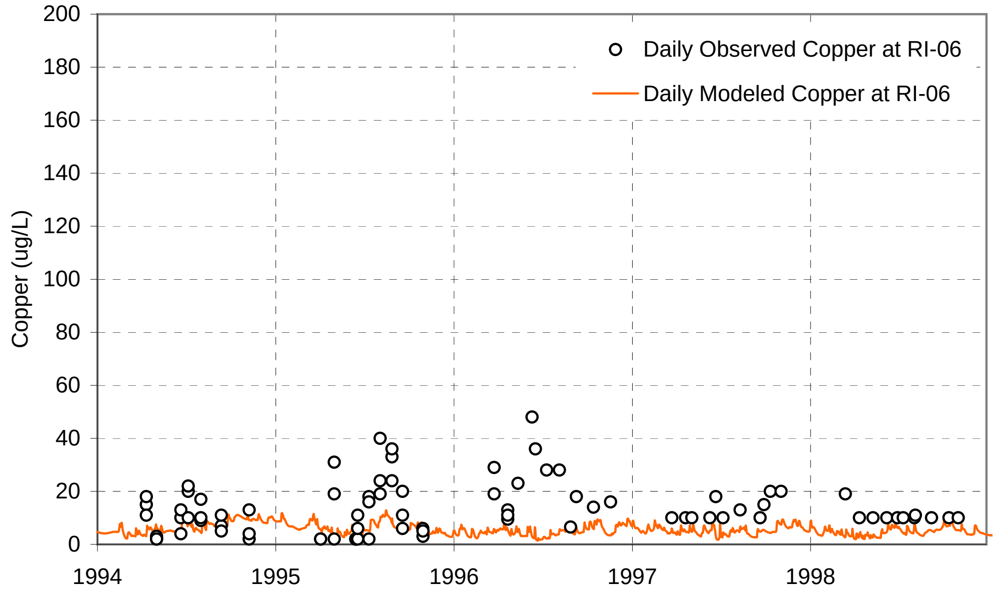

Daily Observed Copper at RI-04
Daily Modeled Copper at RI-04
Copper (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1999
2000
2001

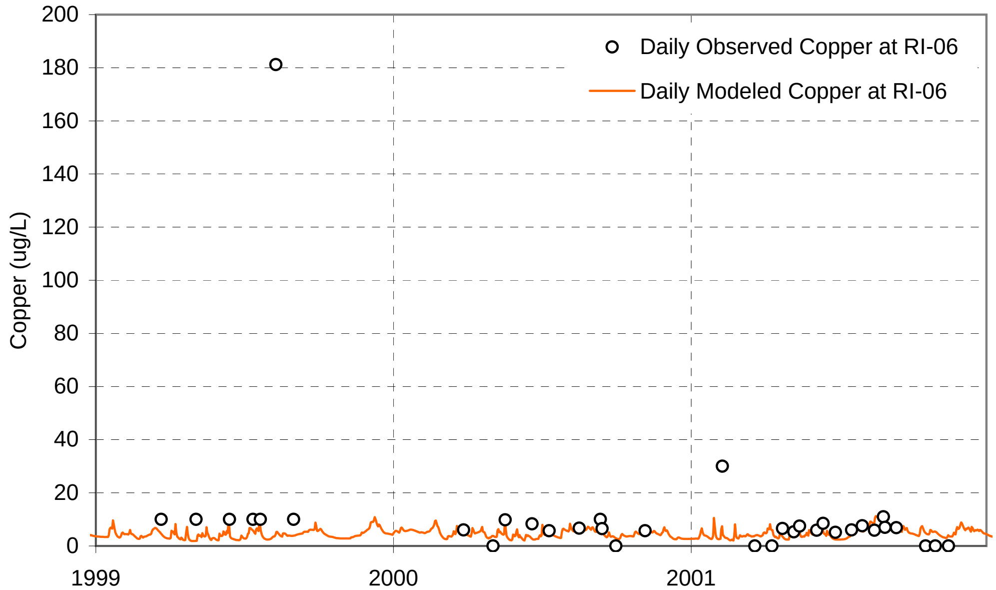


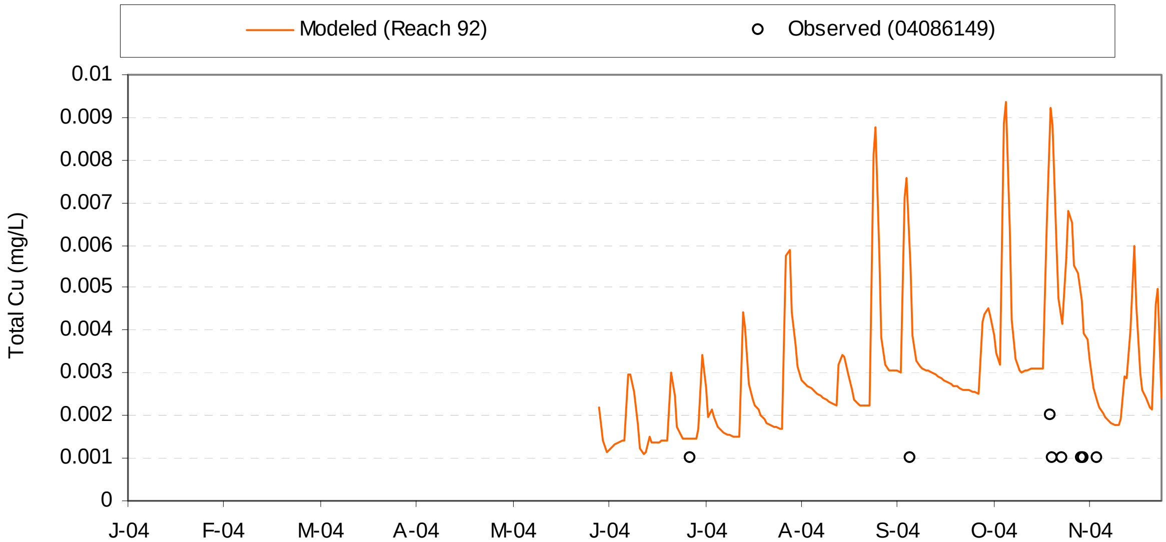
Daily Observed Copper at RI-05
Daily Modeled Copper at RI-05
Copper (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1994
1995
1996
1997
1998

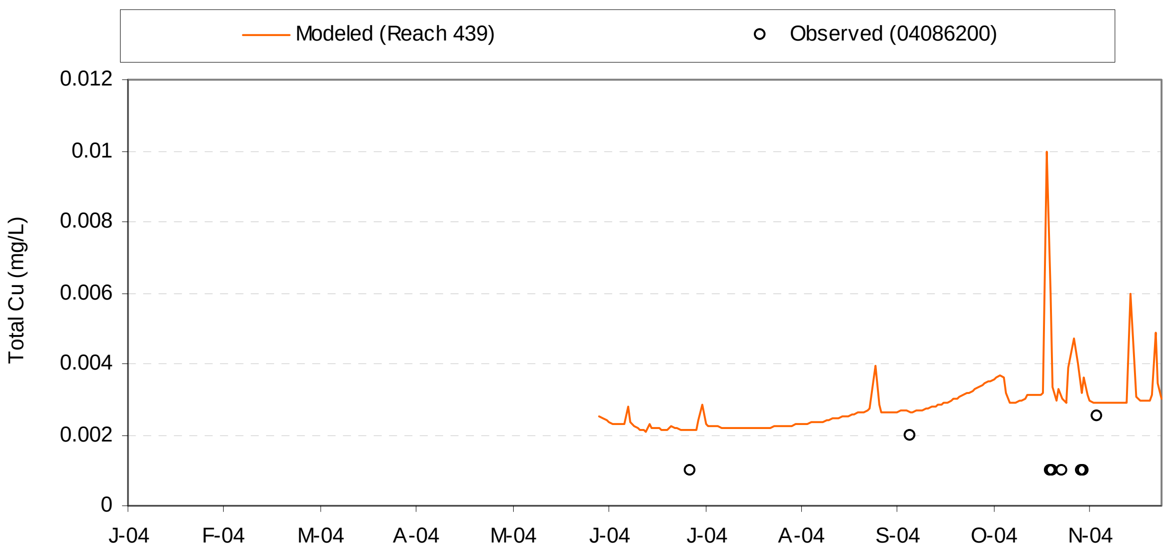


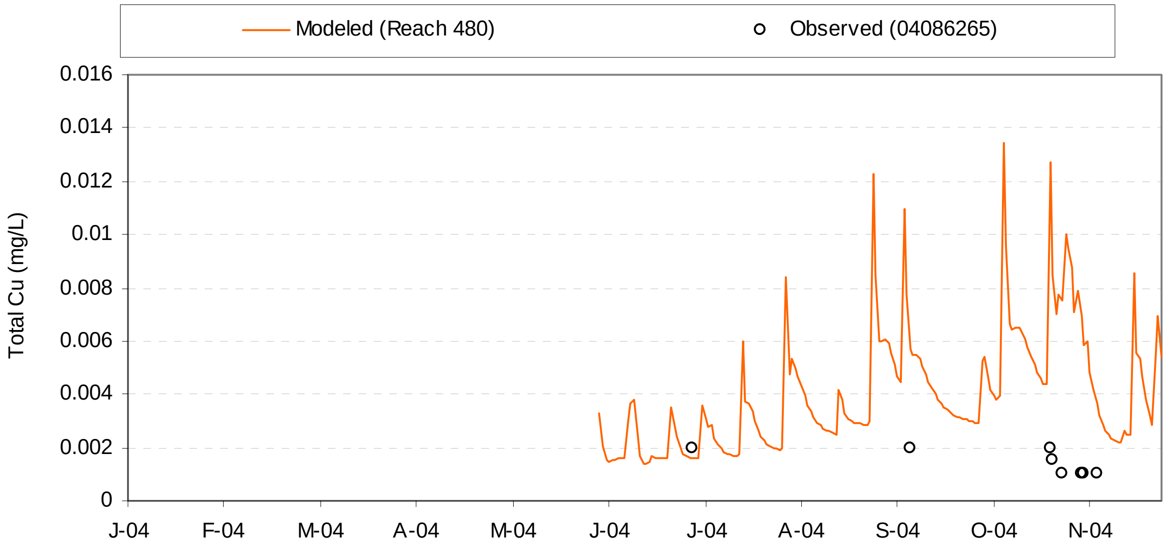
Daily Observed Copper at RI-05
Daily Modeled Copper at RI-05
Copper (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1999
2000
2001

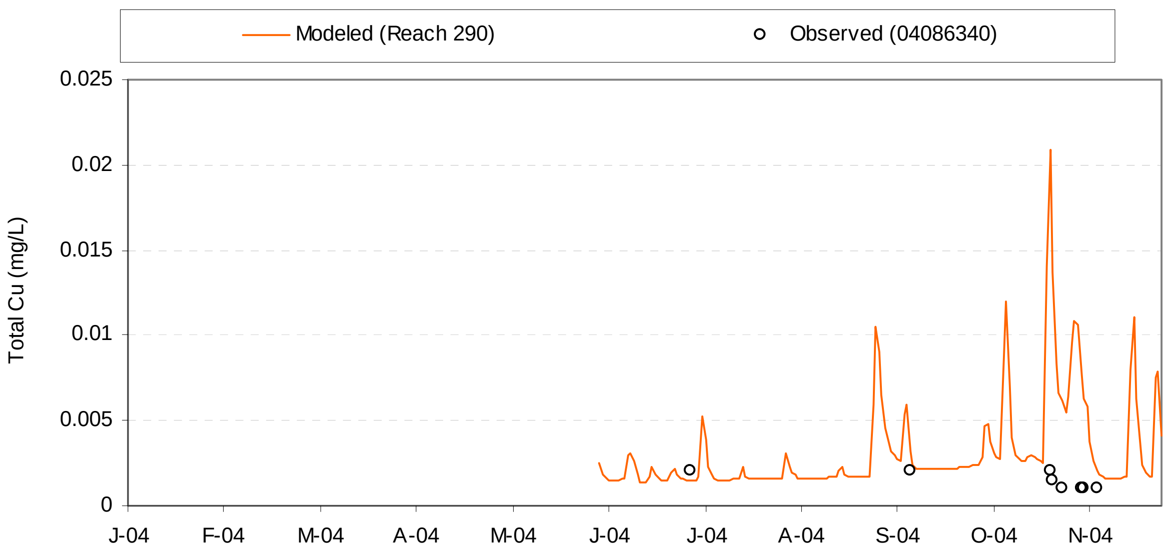

Daily Observed Copper at RI-06
Daily Modeled Copper at RI-06
Copper (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1994
1995
1996
1997
1998

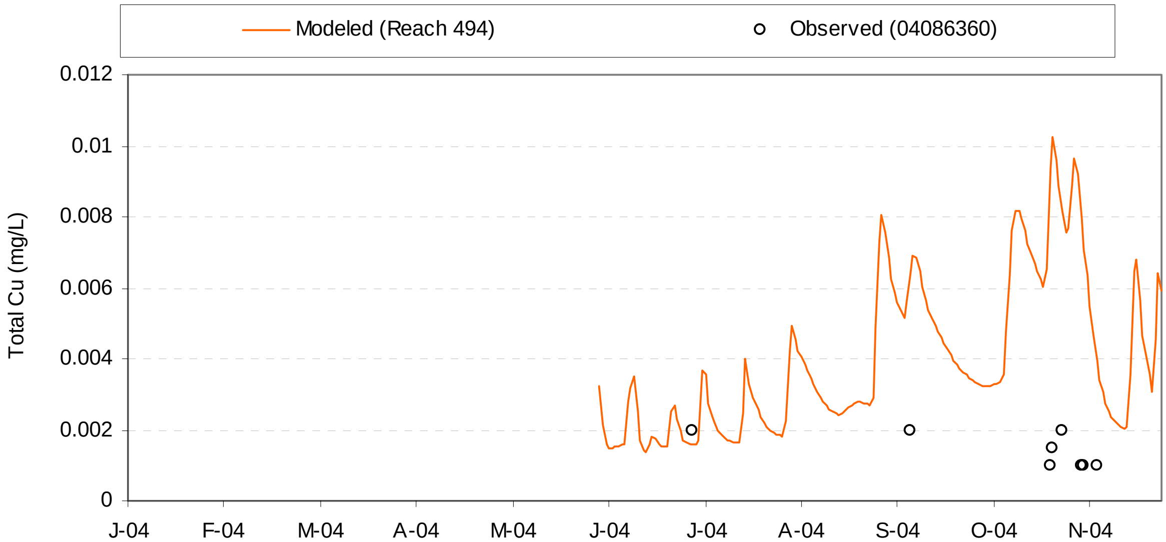

Daily Observed Copper at RI-06
Daily Modeled Copper at RI-06
Copper (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1999
2000
2001

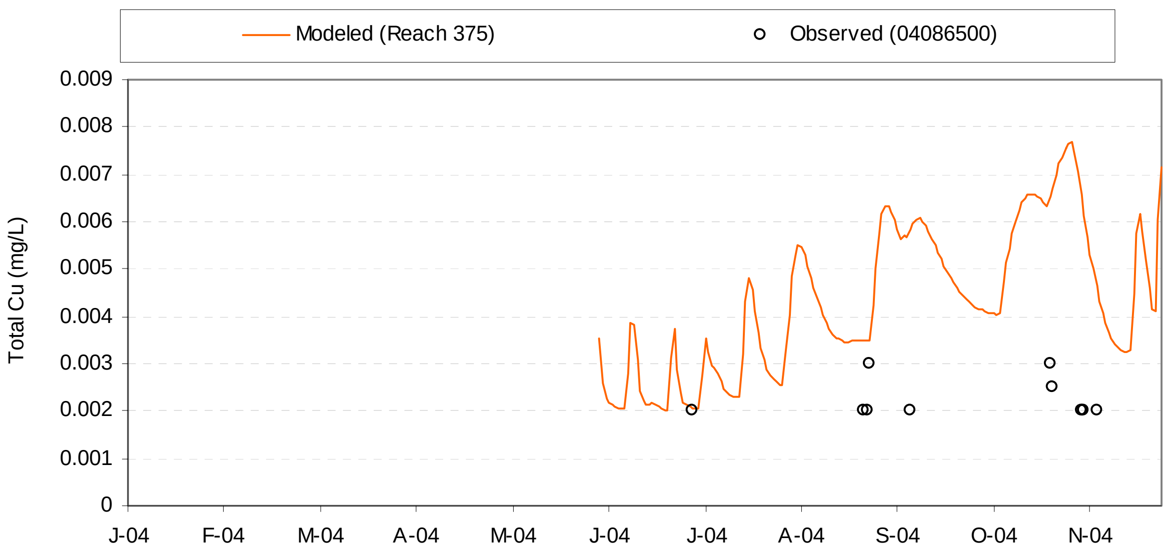

Modeled (Reach 92)
Observed (04086149)
Total Cu (mg/L)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04

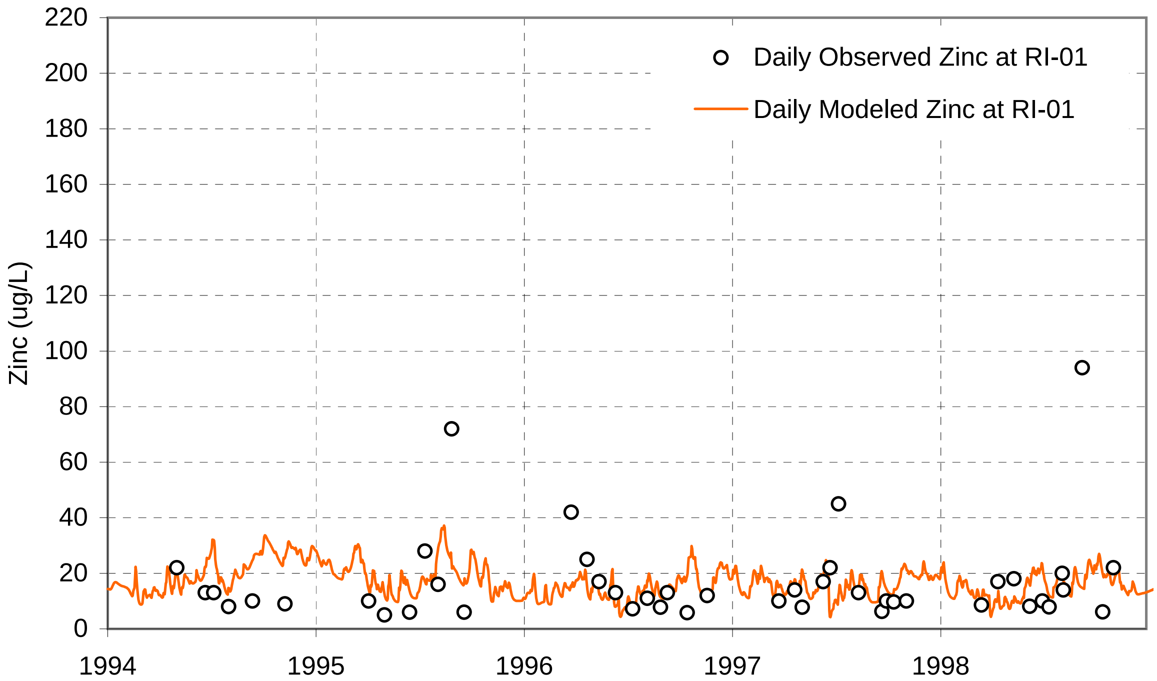

Modeled (Reach 439)
Observed (04086200)
Total Cu (mg/L)
0.012
0.01
0.008
0.006
0.004
0.002
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04


Modeled (Reach 480)
Observed (04086265)
Total Cu (mg/L)
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04

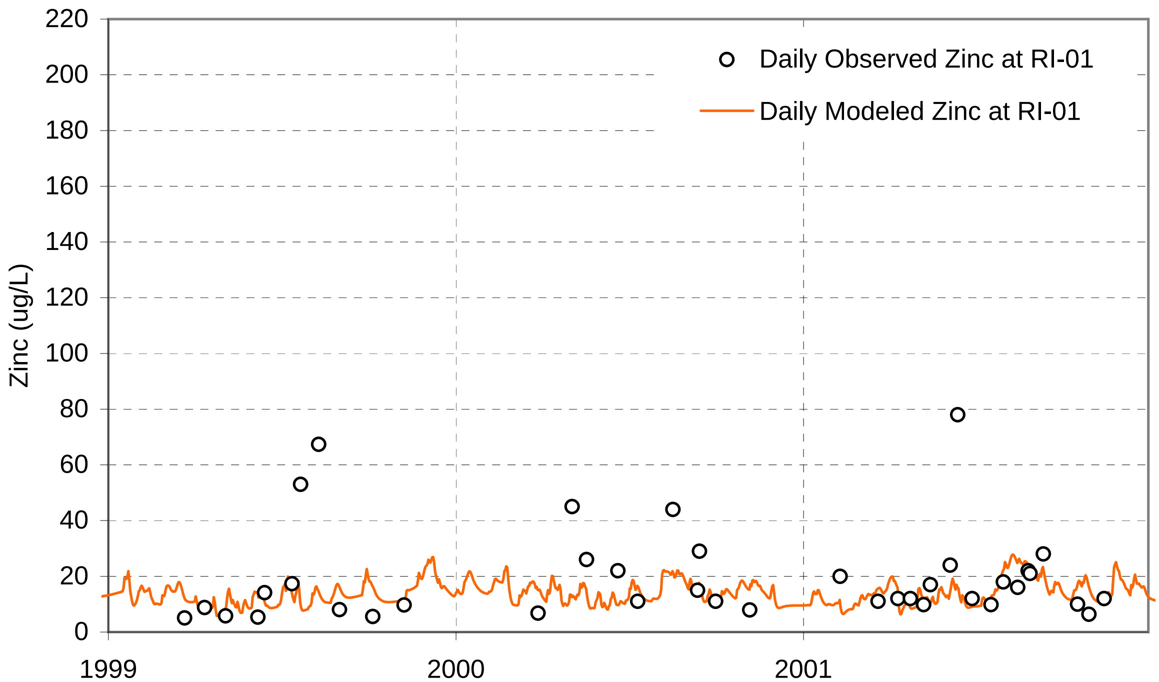

Modeled (Reach 290)
Observed (04086340)
Total Cu (mg/L)
0.025
0.02
0.015
0.01
0.005
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04


Modeled (Reach 494)
Observed (04086360)
Total Cu (mg/L)
0.012
0.01
0.008
0.006
0.004
0.002
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04

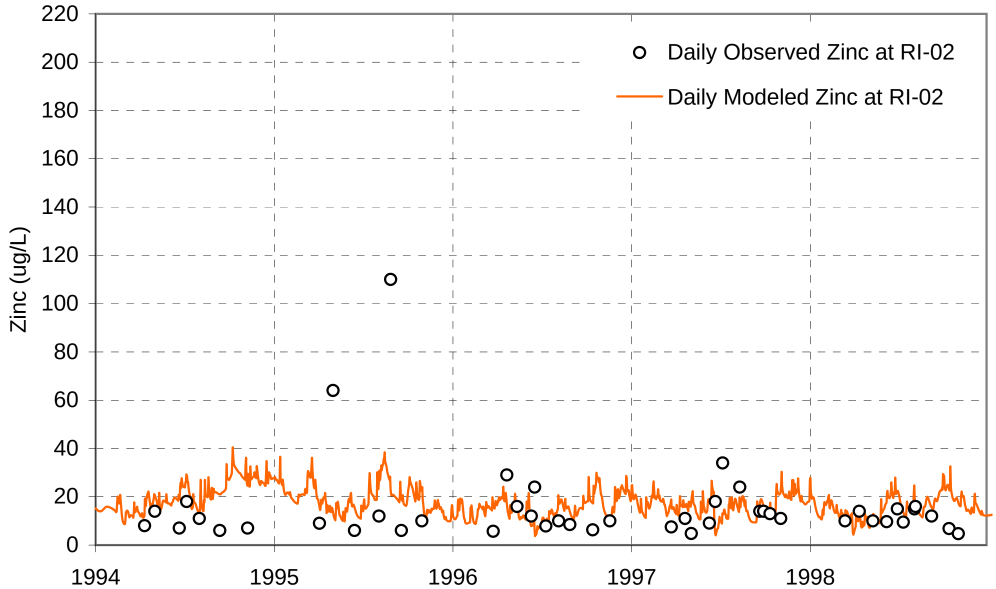

Modeled (Reach 375)
Observed (04086500)
Total Cu (mg/L)
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04



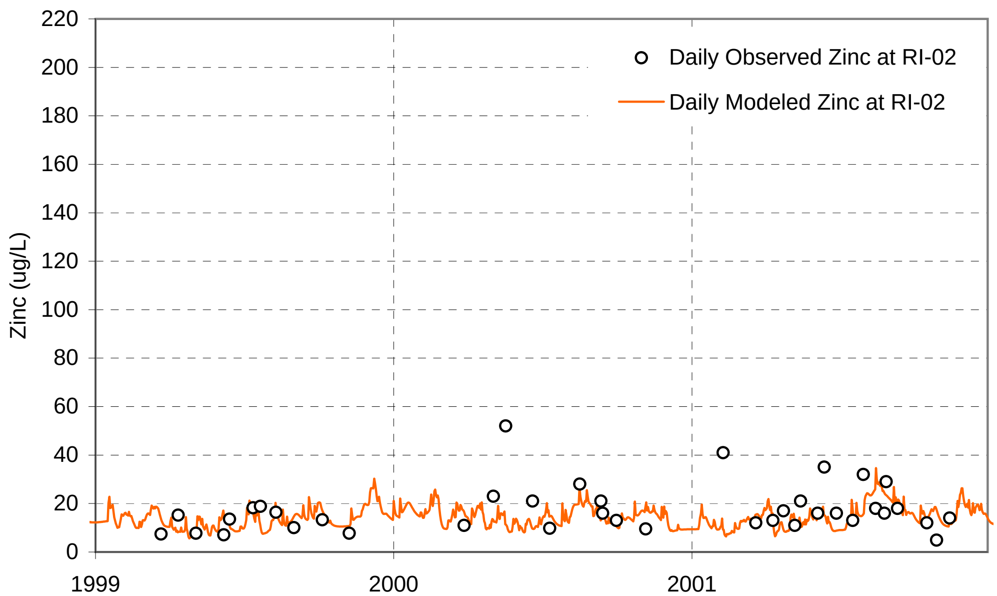
Daily Observed Zinc at RI-01
Daily Modeled Zinc at RI-01
Zinc (ug/L)
220
200
180
160
140
120
100
80
60
40
20
0
1994
1995
1996
1997
1998



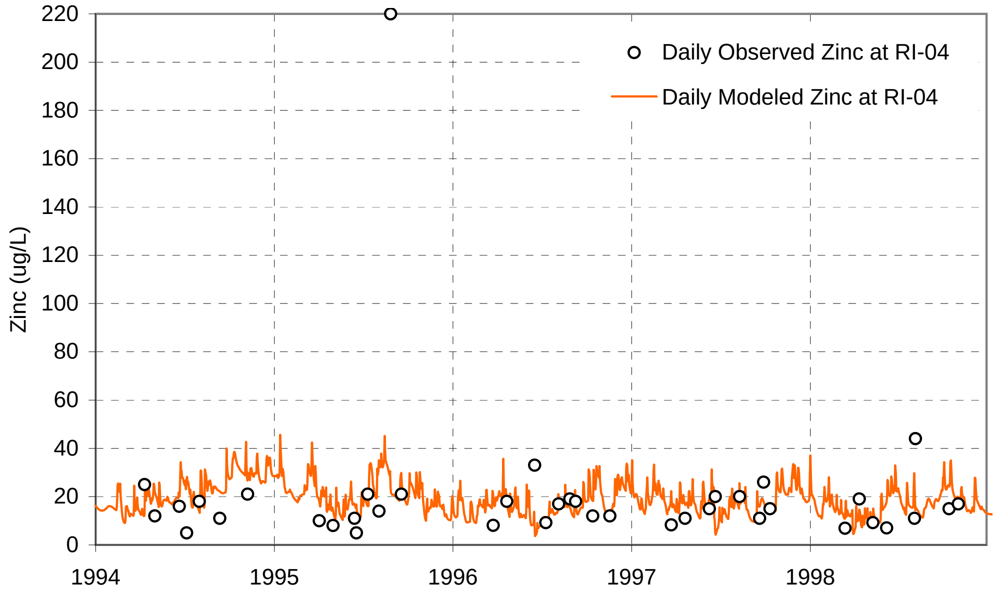
Daily Observed Zinc at RI-01
Daily Modeled Zinc at RI-01
Zinc (ug/L)
220
200
180
160
140
120
100
80
60
40
20
0
1999
2000
2001



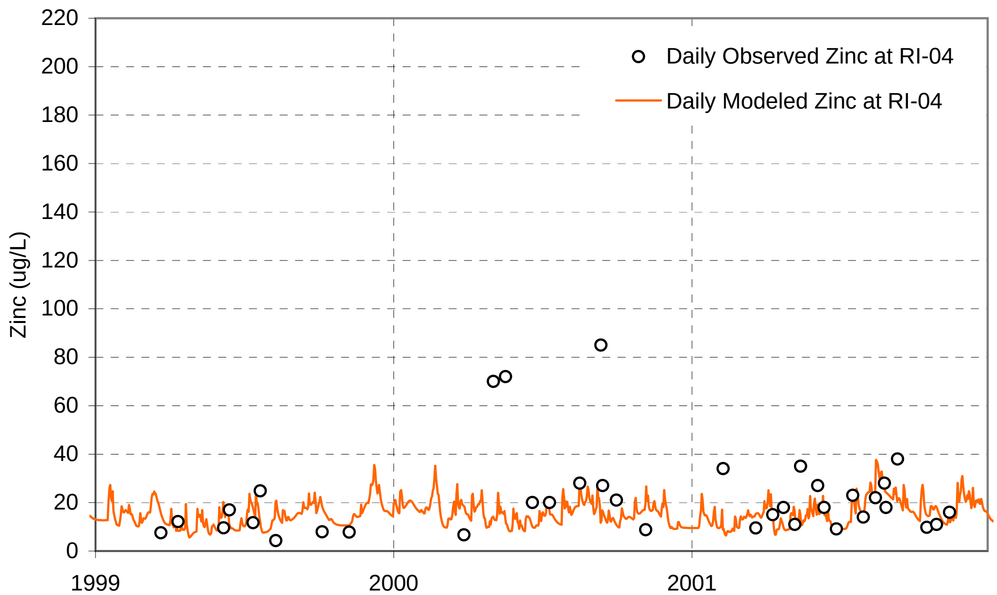
220
200
180
160
140
120
100
80
60
40
20
0
Zinc (ug/L)
1994
1995
1996
1997
1998
Daily Observed Zinc at RI-02
Daily Modeled Zinc at RI-02



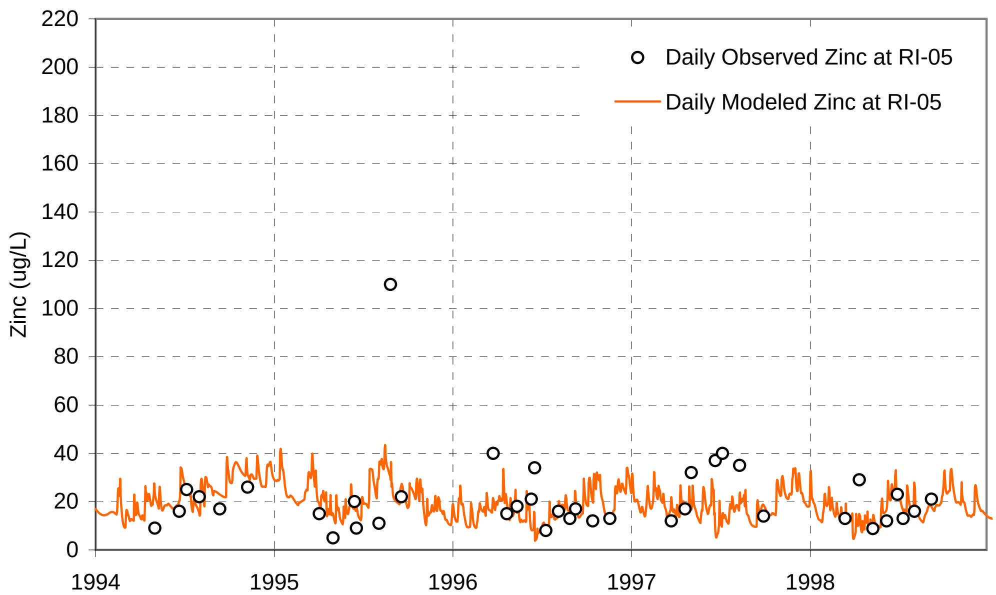
220
200
180
160
140
120
100
80
60
40
20
0
Zinc (ug/L)
1999
2000
2001
Daily Observed Zinc at RI-02
Daily Modeled Zinc at RI-02



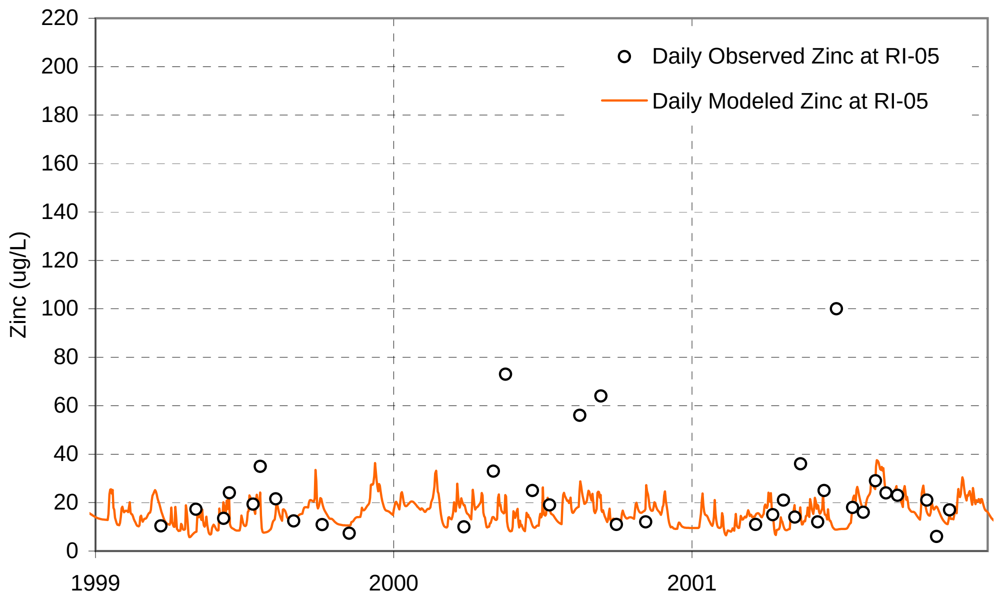
220
200
180
160
140
120
100
80
60
40
20
0
Zinc (ug/L)
1994
1995
1996
1997
1998
Daily Observed Zinc at RI-04
Daily Modeled Zinc at RI-04



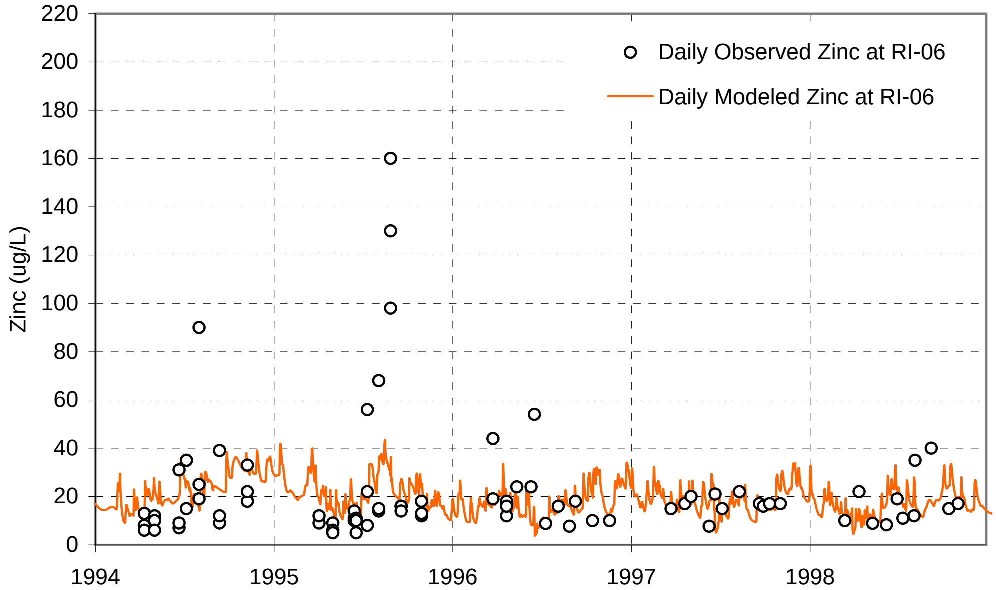
220
200
180
160
140
120
100
80
60
40
20
0
Zinc (ug/L)
1999
2000
2001
Daily Observed Zinc at RI-04
Daily Modeled Zinc at RI-04

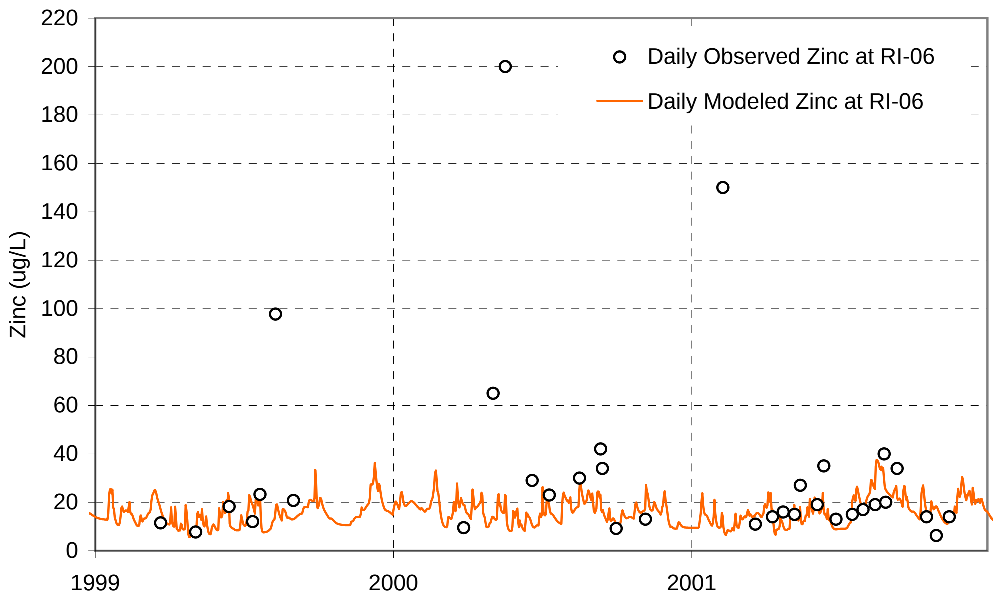


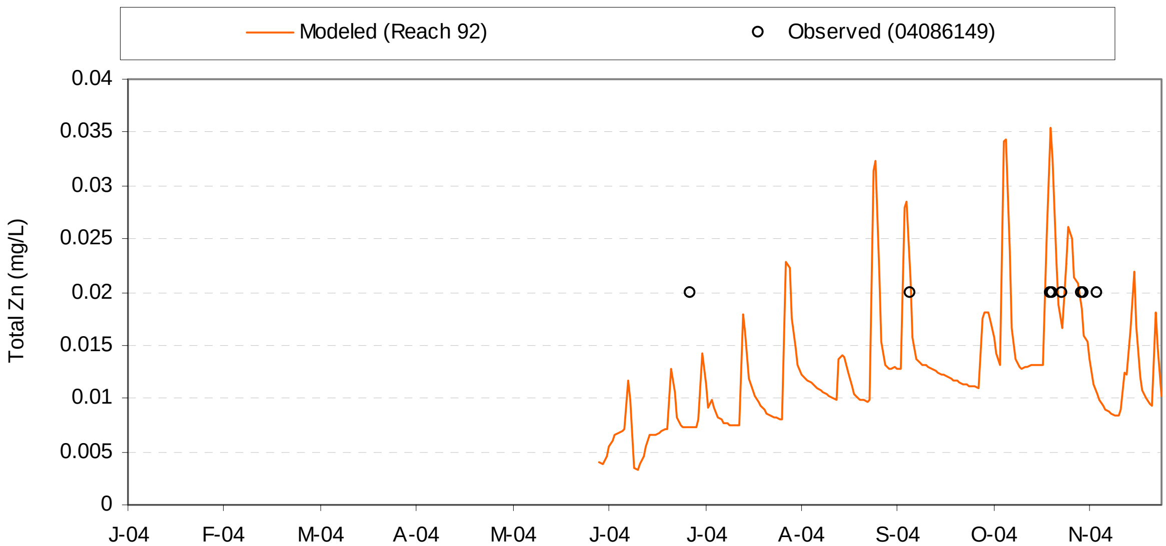
Daily Observed Zinc at RI-05
Daily Modeled Zinc at RI-05
Zinc (ug/L)
220
200
180
160
140
120
100
80
60
40
20
0
1994
1995
1996
1997
1998

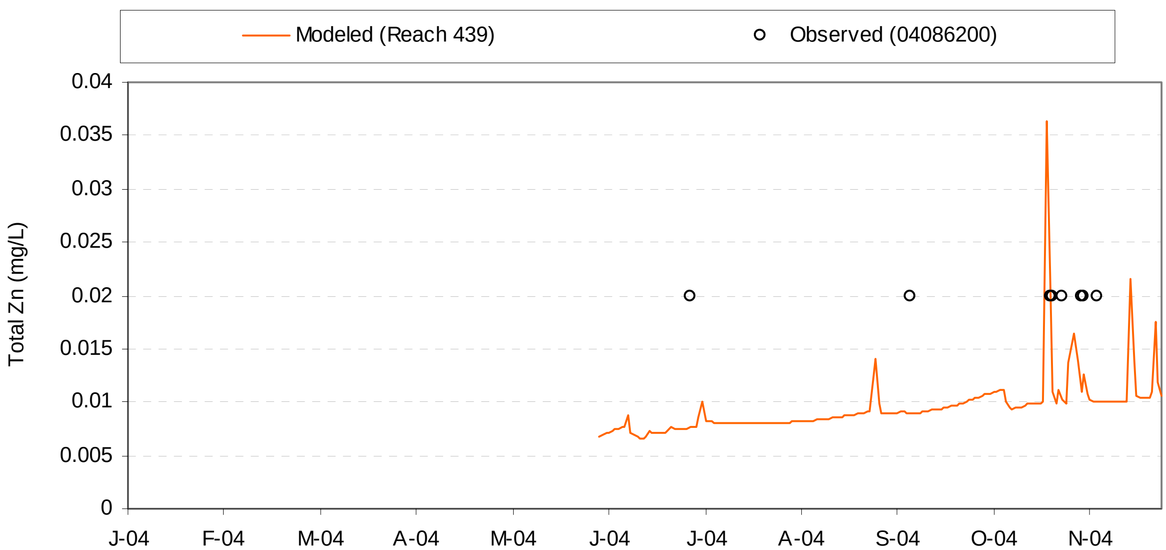


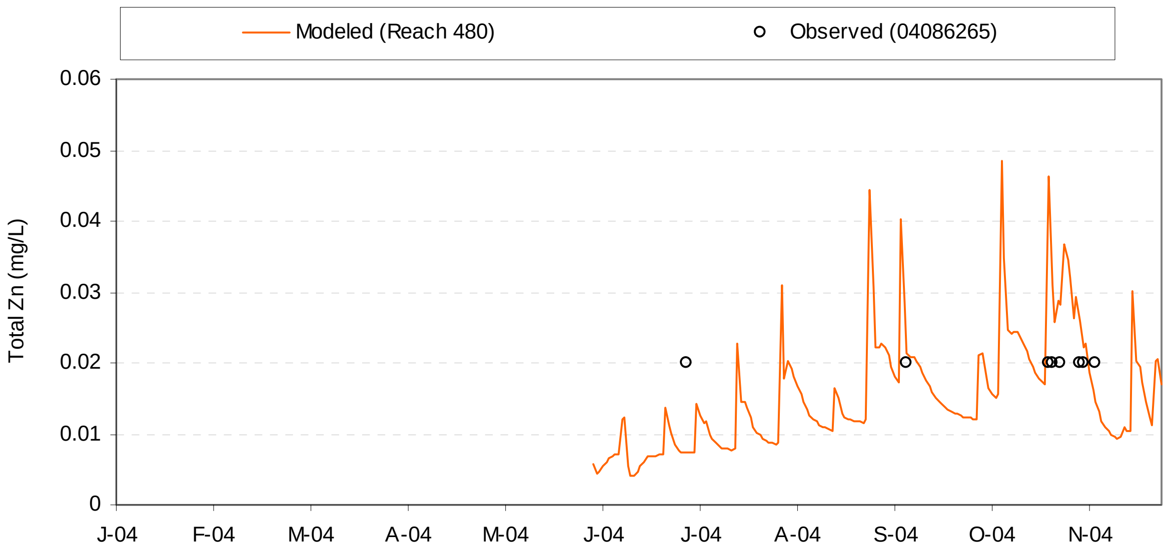
Daily Observed Zinc at RI-05
Daily Modeled Zinc at RI-05
Zinc (ug/L)
220
200
180
160
140
120
100
80
60
40
20
0
1999
2000
2001

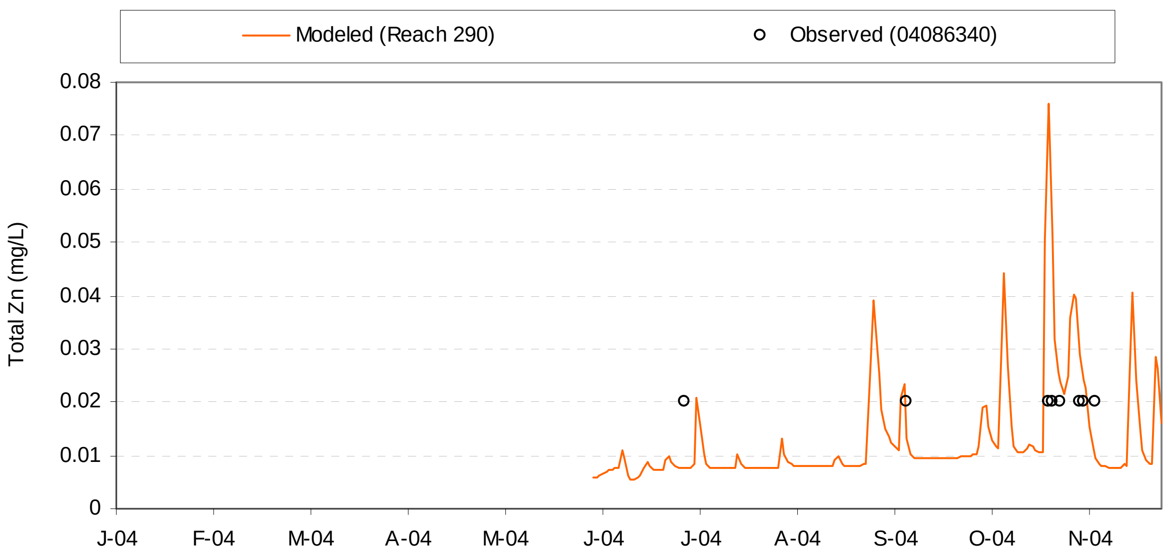

Daily Observed Zinc at RI-06
Daily Modeled Zinc at RI-06
Zinc (ug/L)
220
200
180
160
140
120
100
80
60
40
20
0
1994
1995
1996
1997
1998

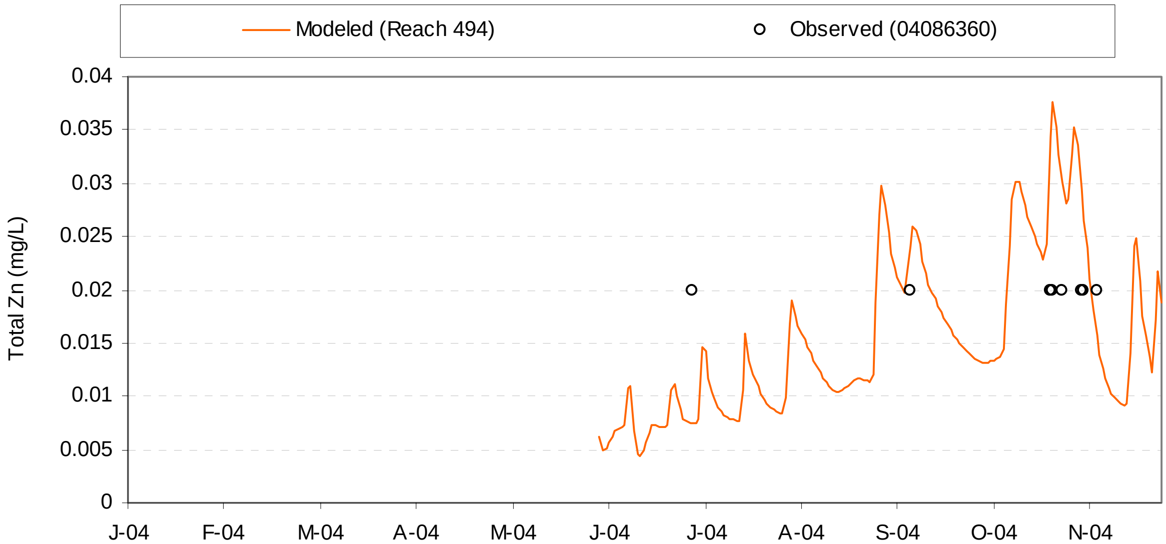

Daily Observed Zinc at RI-06
Daily Modeled Zinc at RI-06
Zinc (ug/L)
220
200
180
160
140
120
100
80
60
40
20
0
1999
2000
2001

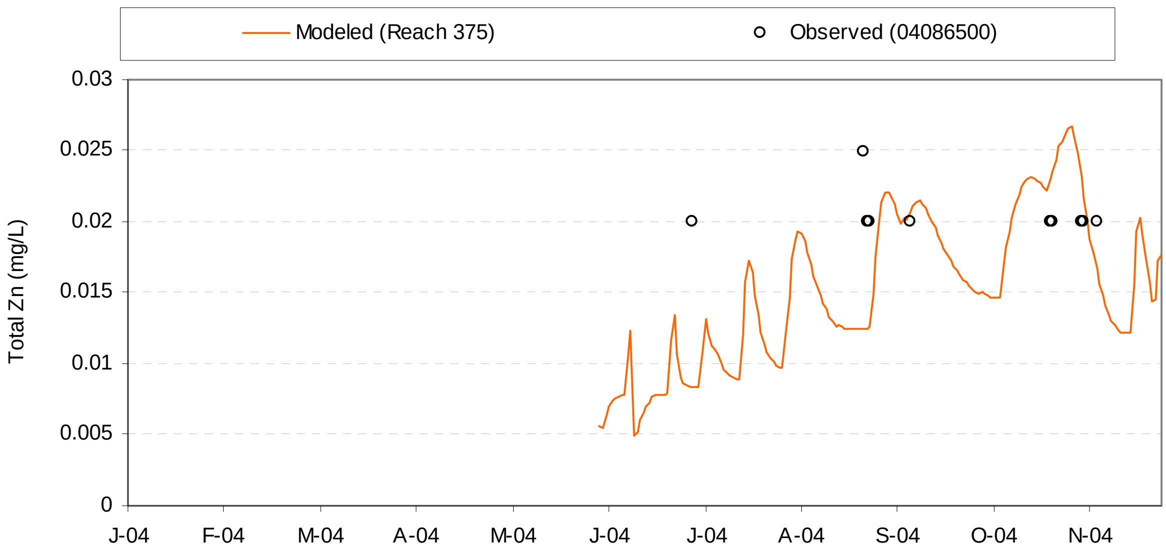

Modeled (Reach 92)
Observed (04086149)
Total Zn (mg/L)
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04


Modeled (Reach 439)
Observed (04086200)
Total Zn (mg/L)
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04

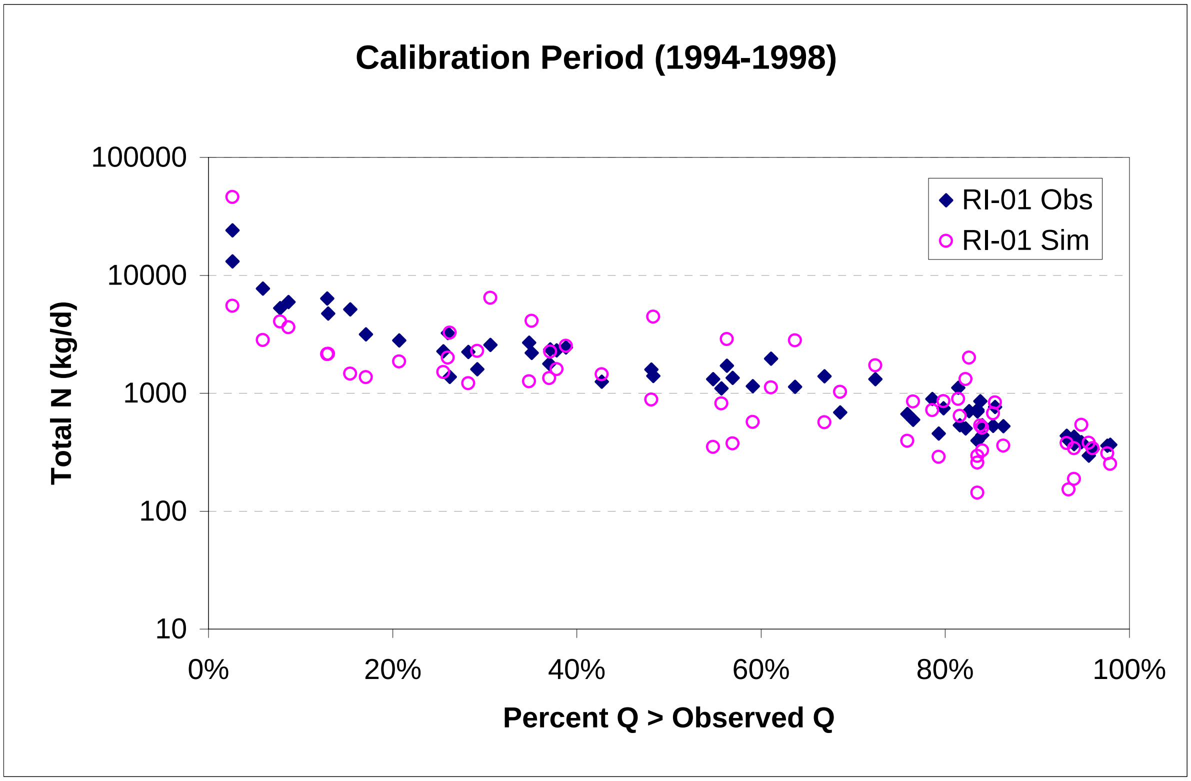

Modeled (Reach 480)
Observed (04086265)
Total Zn (mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04

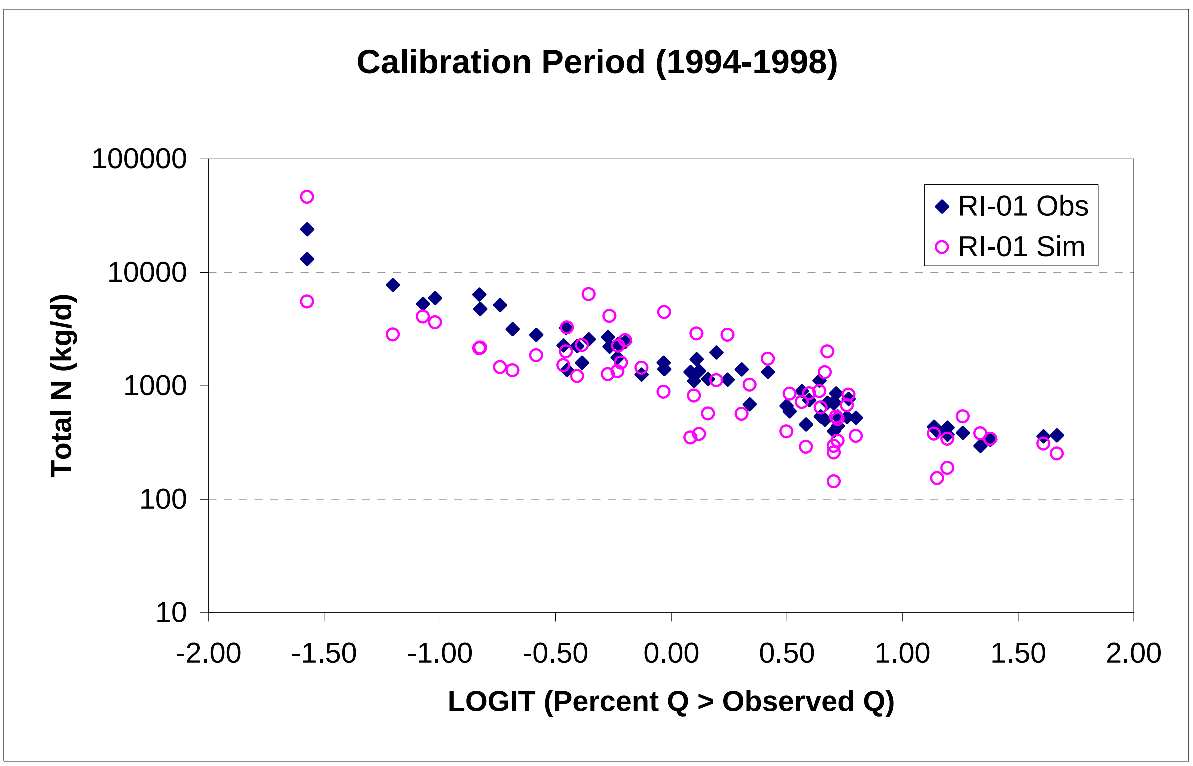

Modeled (Reach 290)
Observed (04086340)
Total Zn (mg/L)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04


Modeled (Reach 494)
Observed (04086360)
Total Zn (mg/L)
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04


Modeled (Reach 375)
Observed (04086500)
Total Zn (mg/L)
0.03
0.025
0.02
0.015
0.01
0.005
0
J-04
F-04
M-04
A-04
M-04
J-04
J-04
A-04
S-04
O-04
N-04

ATTACHMENT I – LOAD-DURATION ANALYSIS RESULTS


Calibration Period (1994-1998)
100000
10000
1000
100
10
Total N (kg/d)
RI-01 Obs
RI-01 Sim
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q


Calibration Period (1994-1998)
100000
10000
1000
100
10
Total N (kg/d)
RI-01 Obs
RI-01 Sim
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.64702	7.101845
0.275407	0.304179
0.836311	0.261331
35.76392	7
2.364624	
0.651235	
-2.29825	
-0.99578	

0-20% - Sim

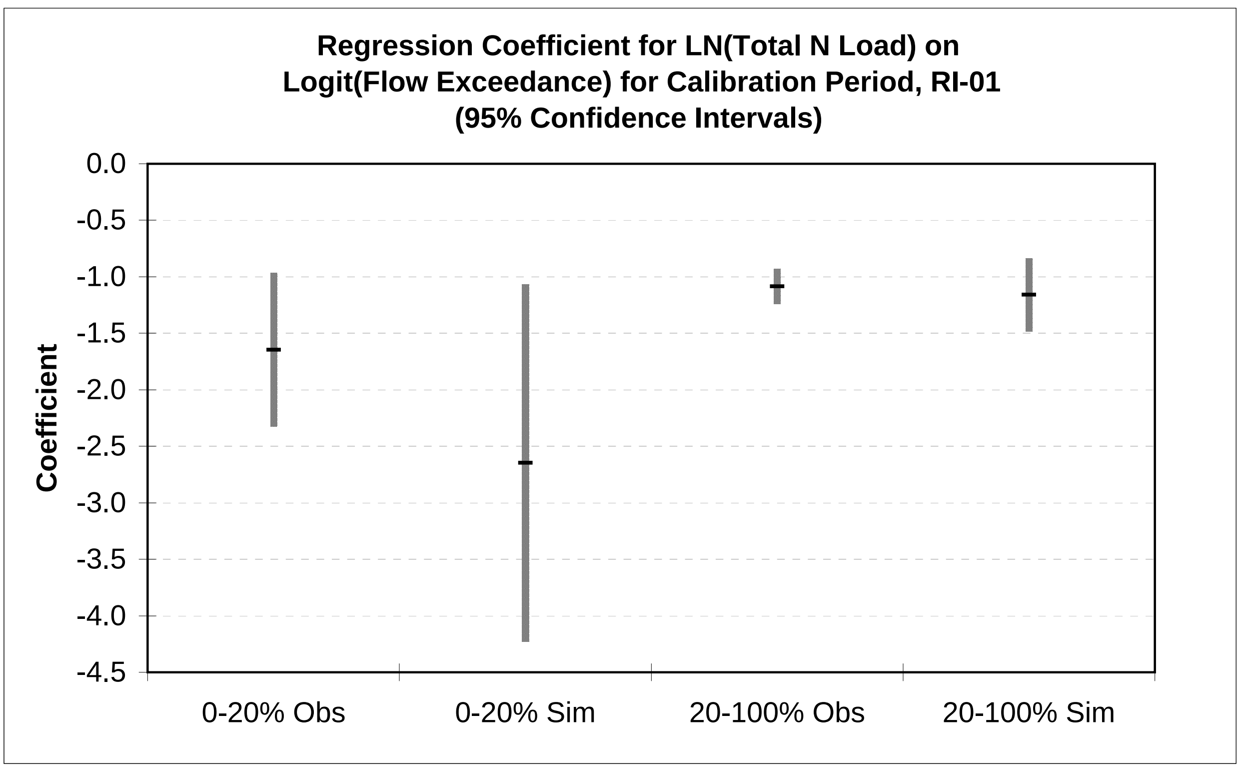
-2.64804	5.381231
0.656799	0.725415
0.698989	0.623229
16.25497	7
2.364624	
1.553082	
-4.20113	
-1.09496	

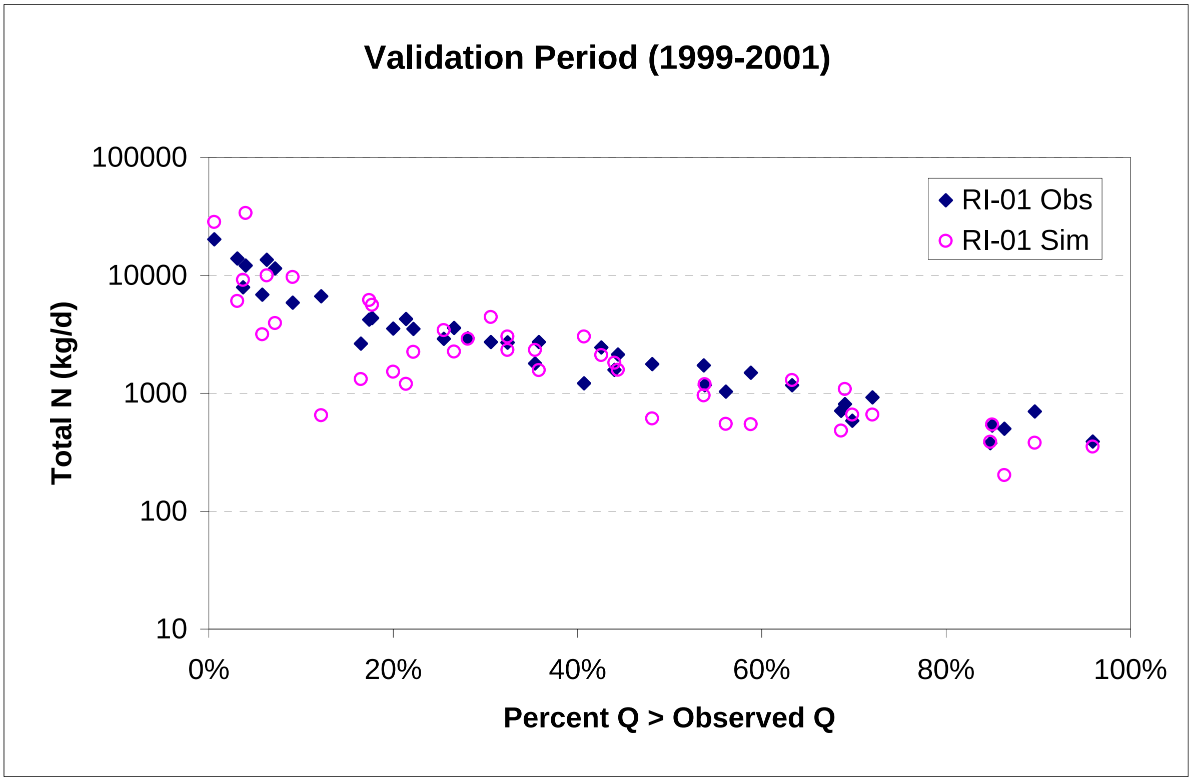
20-100% - Obs

-1.08443	7.278802
0.06203	0.043891
0.856993	0.263075
305.6271	51
2.007584	
0.124531	
-1.20896	
-0.95989	

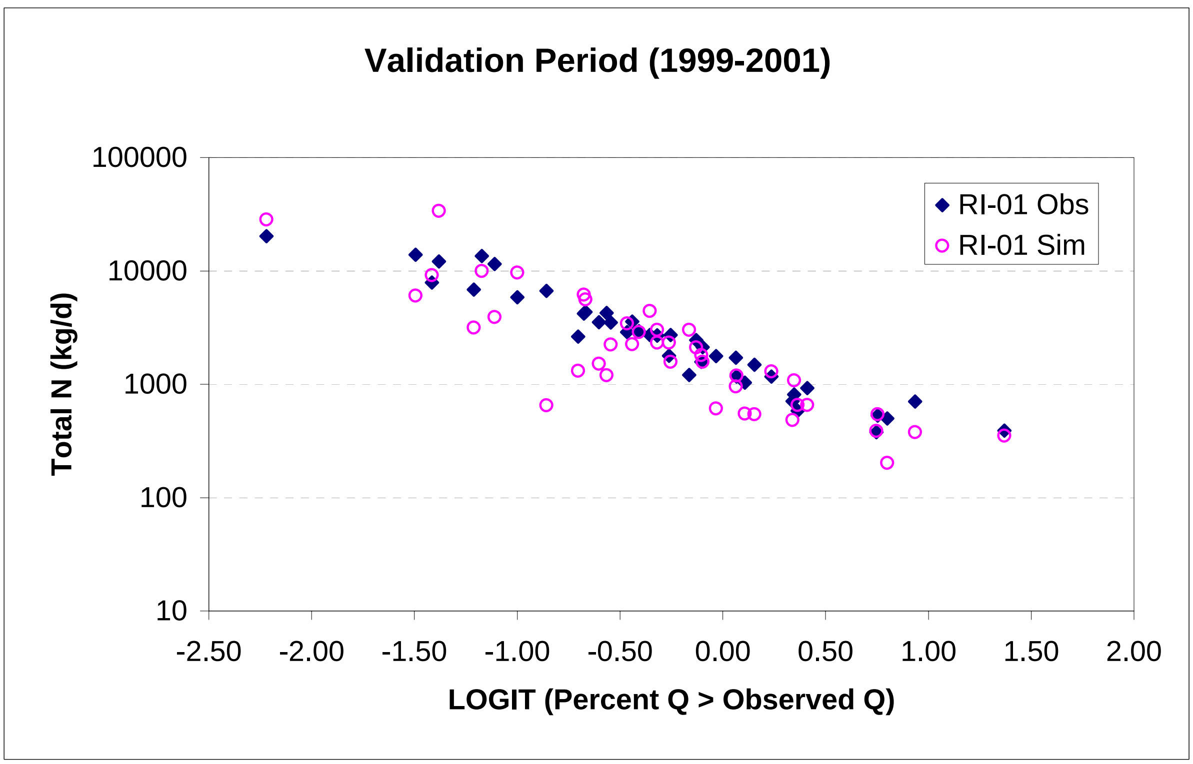
20-100% - Sim

-1.15861	7.171066
0.146864	0.103918
0.549614	0.622862
62.23631	51
2.007584	
0.294843	
-1.45346	
-0.86377	





Validation Period (1999-2001)
100000
10000
1000
100
10
Total N (kg/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-01 Obs
RI-01 Sim



Validation Period (1999-2001)
100000
10000
1000
100
10
Total N (kg/d)
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
RI-01 Obs
RI-01 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.17425	7.594137
0.205074	0.245536
0.748784	0.320407
32.78707	11
2.200985	
0.451364	
-1.62561	
-0.72289	

0-20% - Sim

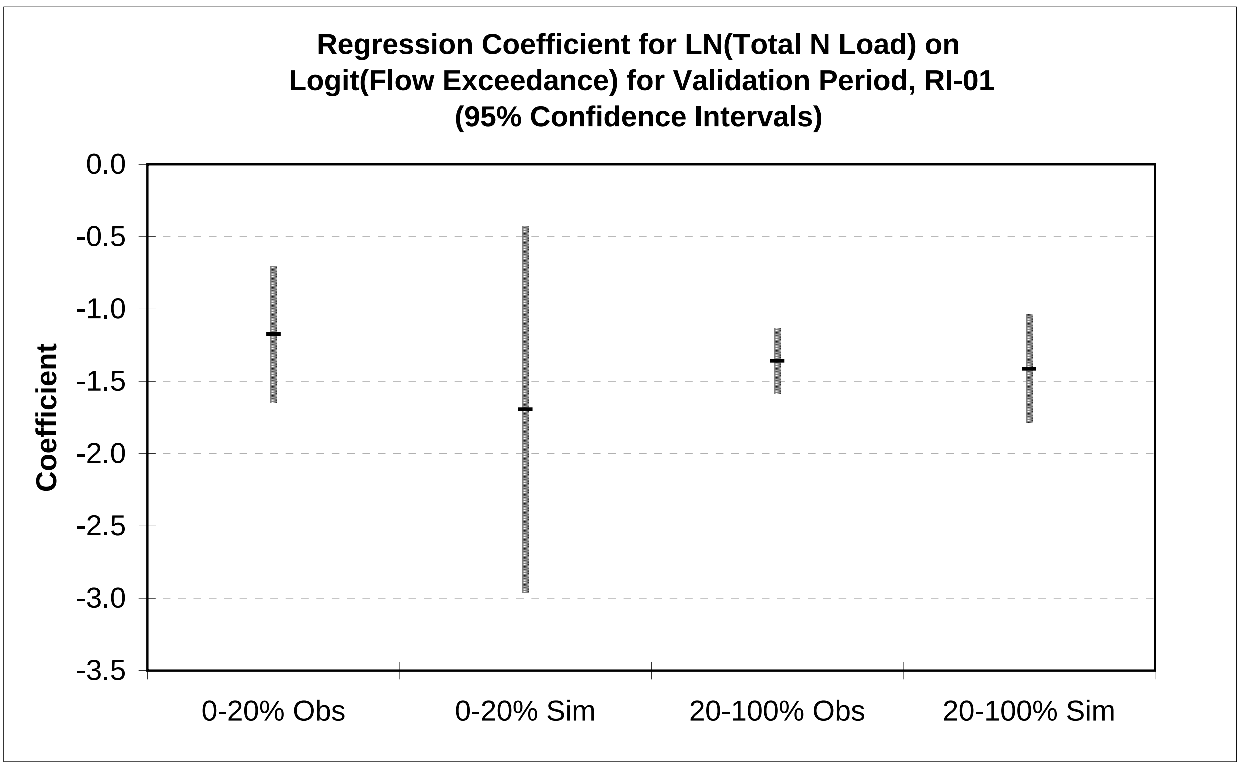
-1.69482	6.690066
0.56567	0.677282
0.449361	0.883803
8.97678	11
2.200985	
1.24503	
-2.93985	
-0.44979	

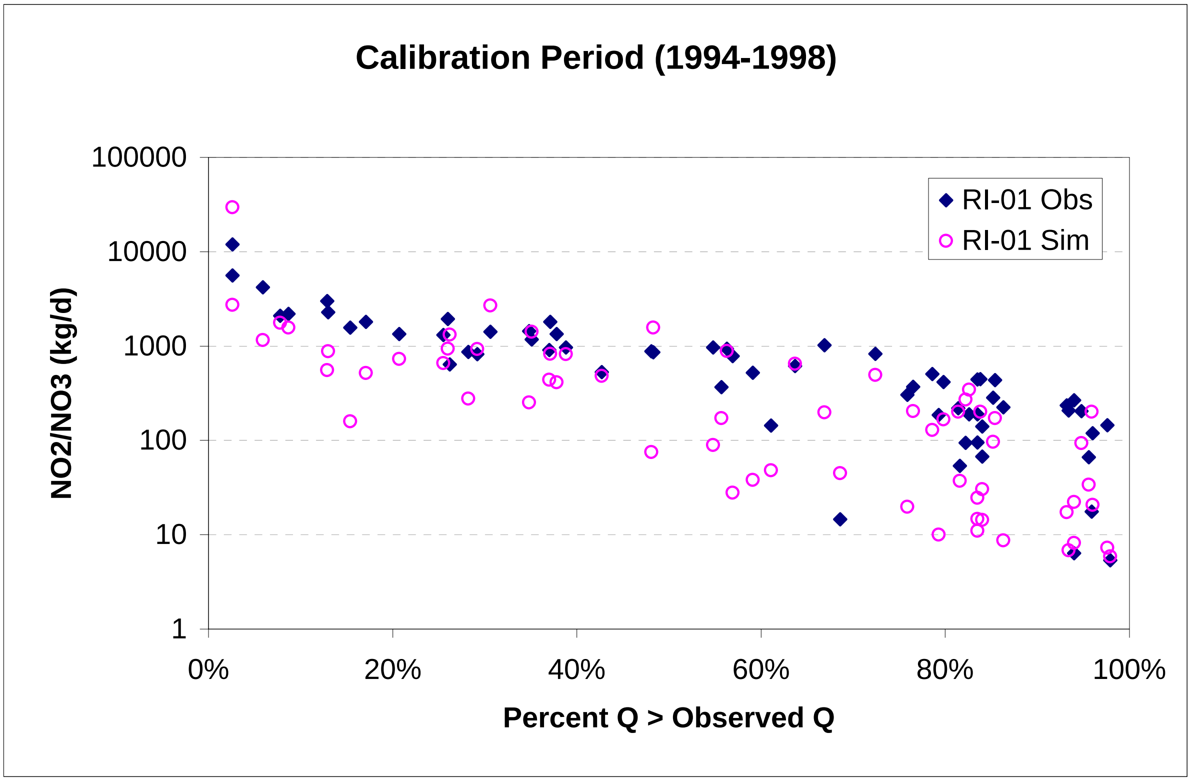
20-100% - Obs

-1.35882	7.35897
0.098924	0.04815
0.874814	0.256039
188.6783	27
2.05183	
0.202974	
-1.56179	
-1.15584	

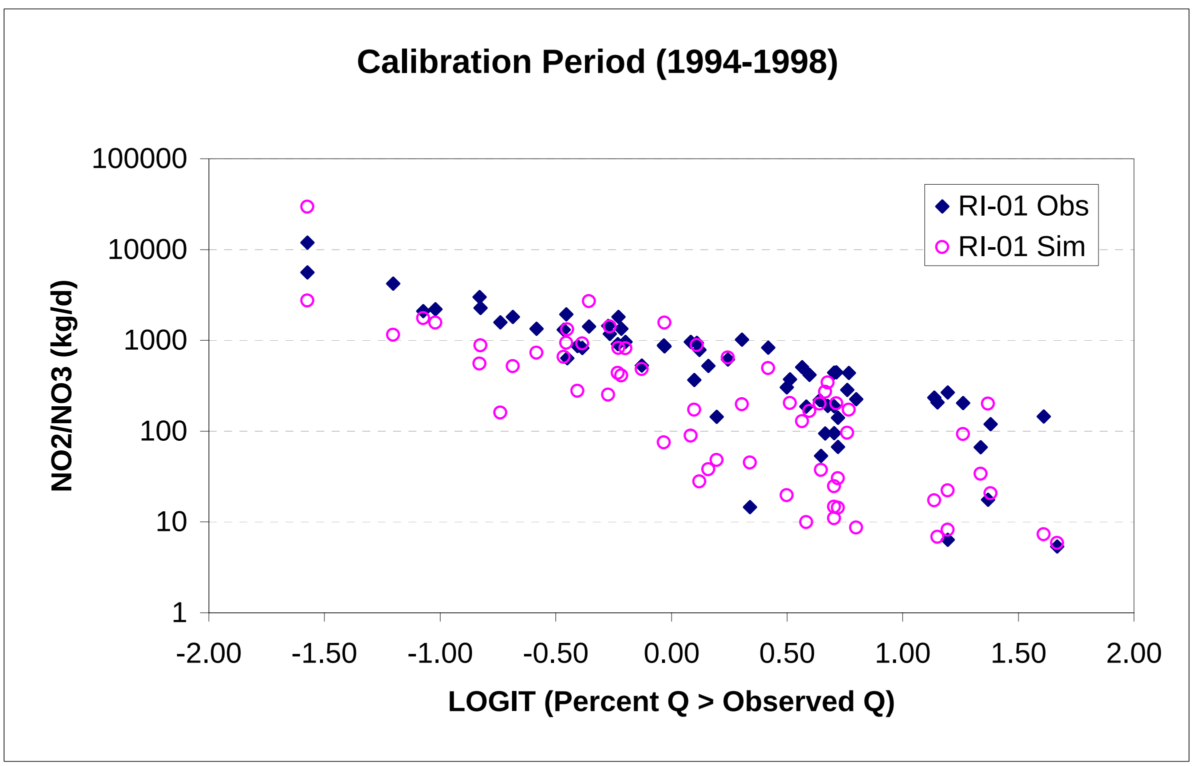
20-100% - Sim

-1.41368	7.145796
0.172067	0.083753
0.714287	0.445353
67.50033	27
2.05183	
0.353052	
-1.76673	
-1.06062	





Calibration Period (1994-1998)
100000
10000
1000
100
10
1
NO2/NO3 (kg/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-01 Obs
RI-01 Sim



Calibration Period (1994-1998)
100000
10000
1000
100
10
1
NO2/NO3 (kg/d)
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
RI-01 Obs
RI-01 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.71861	6.214715
0.337721	0.373003
0.787211	0.32046
25.8964	7
2.364624	
0.798583	
-2.51719	
-0.92003	

0-20% - Sim

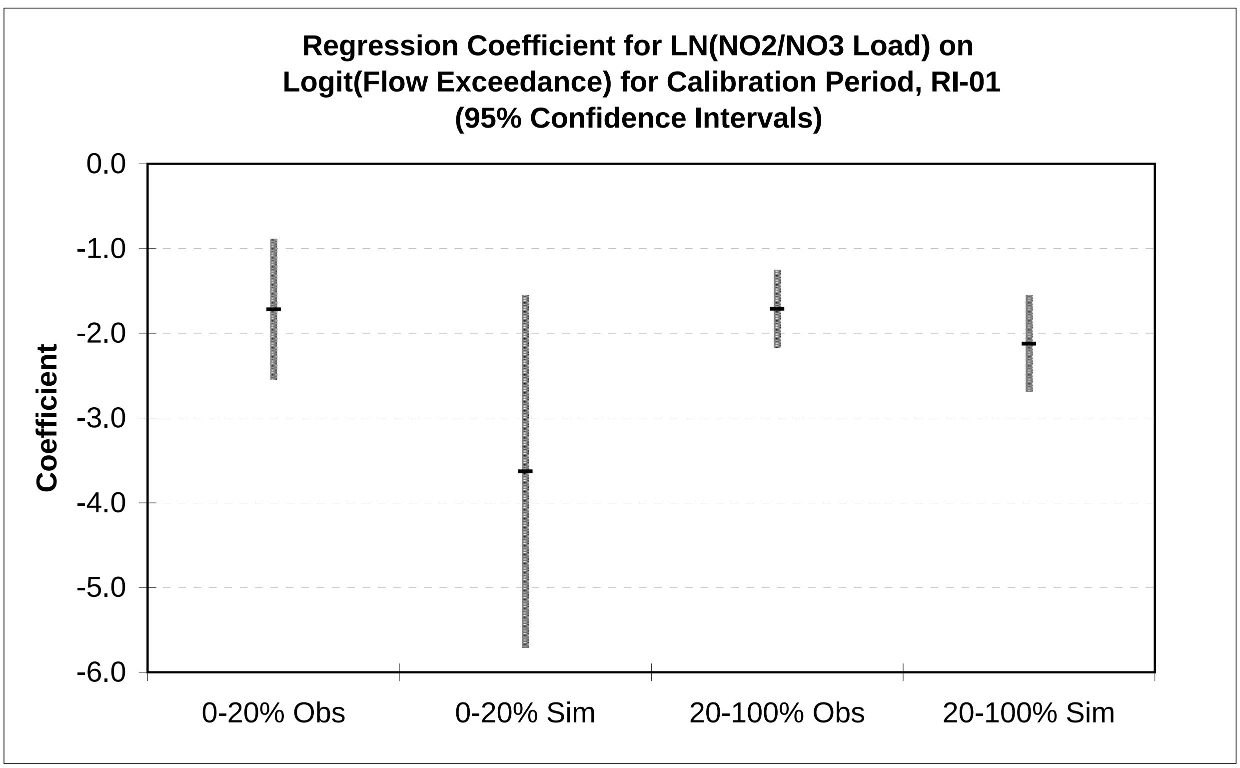
-3.63072	3.324674
0.863396	0.953596
0.716408	0.819267
17.68337	7
2.364624	
2.041608	
-5.67233	
-1.58911	

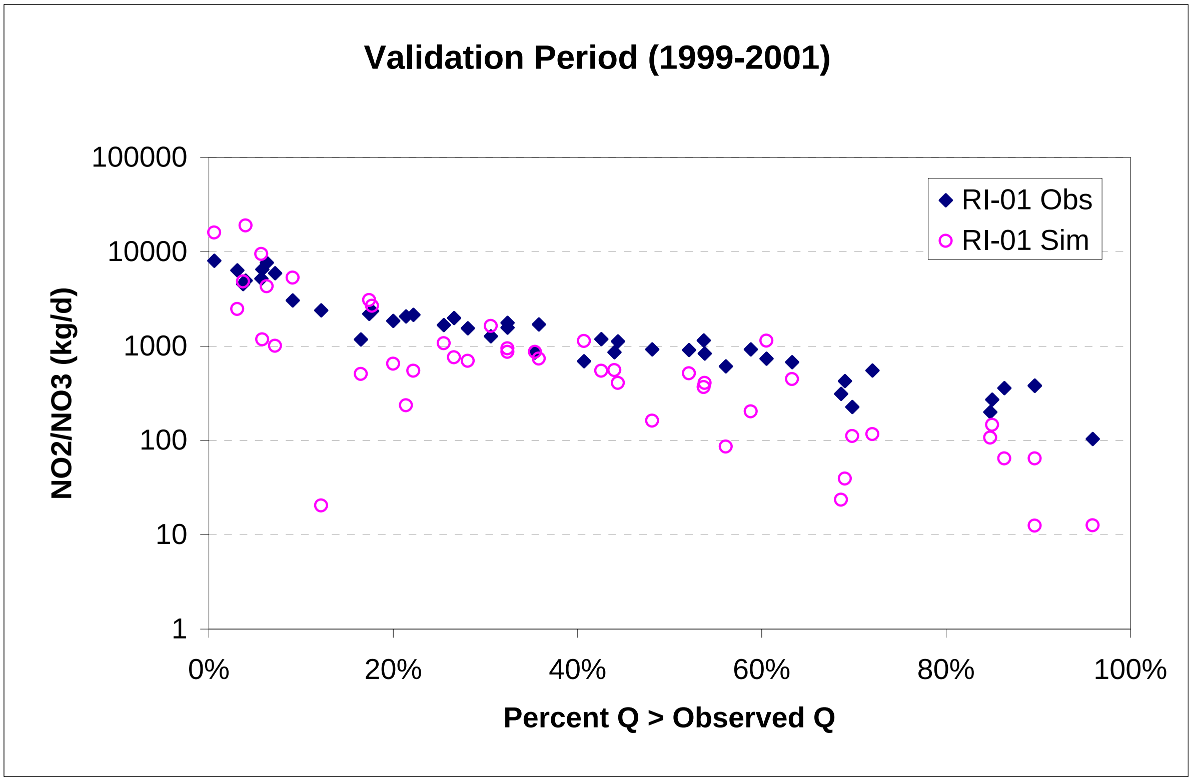
20-100% - Obs

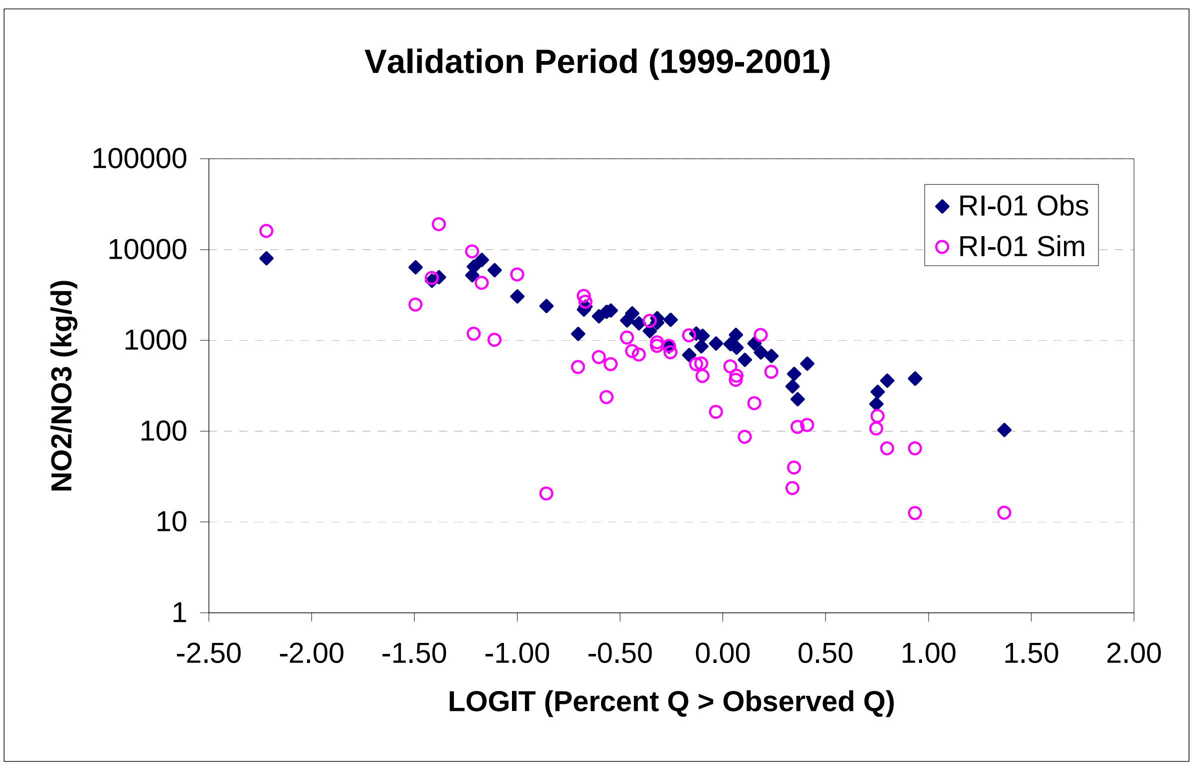
-1.71032	6.467833
0.207817	0.150736
0.565695	0.903592
67.7315	52
2.006647	
0.417016	
-2.12733	
-1.2933	

20-100% - Sim

-2.12275	5.617552
0.265845	0.192825
0.550791	1.155897
63.75895	52
2.006647	
0.533457	
-2.65621	
-1.58929	




Validation Period (1999-2001)
NO2/NO3 (kg/d)
Percent Q > Observed Q
RI-01 Obs
RI-01 Sim
100000
10000
1000
100
10
1
0%
20%
40%
60%
80%
100%


Validation Period (1999-2001)
NO2/NO3 (kg/d)
LOGIT (Percent Q > Observed Q)
RI-01 Obs
RI-01 Sim
100000
10000
1000
100
10
1
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.10806	7.004457
0.239261	0.286837
0.641231	0.374569
21.44773	12
2.178813	
0.521306	
-1.62937	
-0.58675	

0-20% - Sim

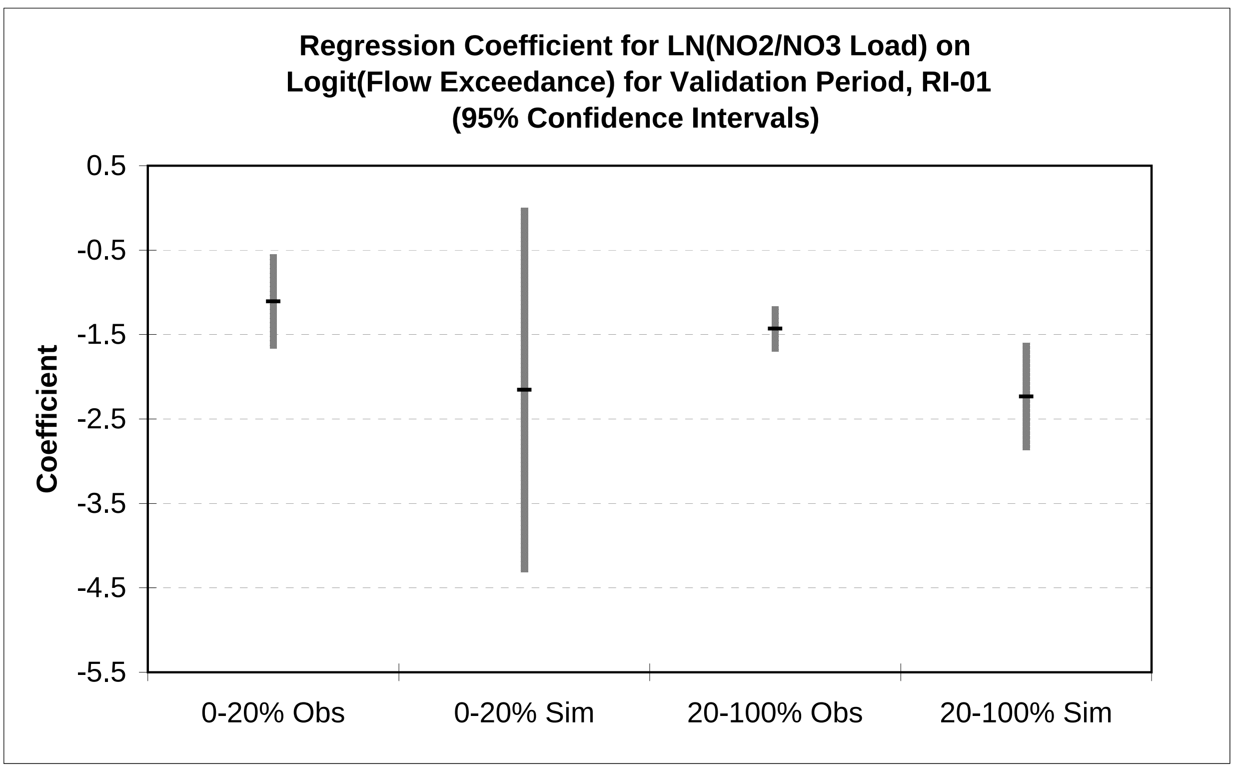
-2.15532	5.260387
0.973621	1.167221
0.289963	1.524223
4.900537	12
2.178813	
2.121337	
-4.27666	
-0.03398	

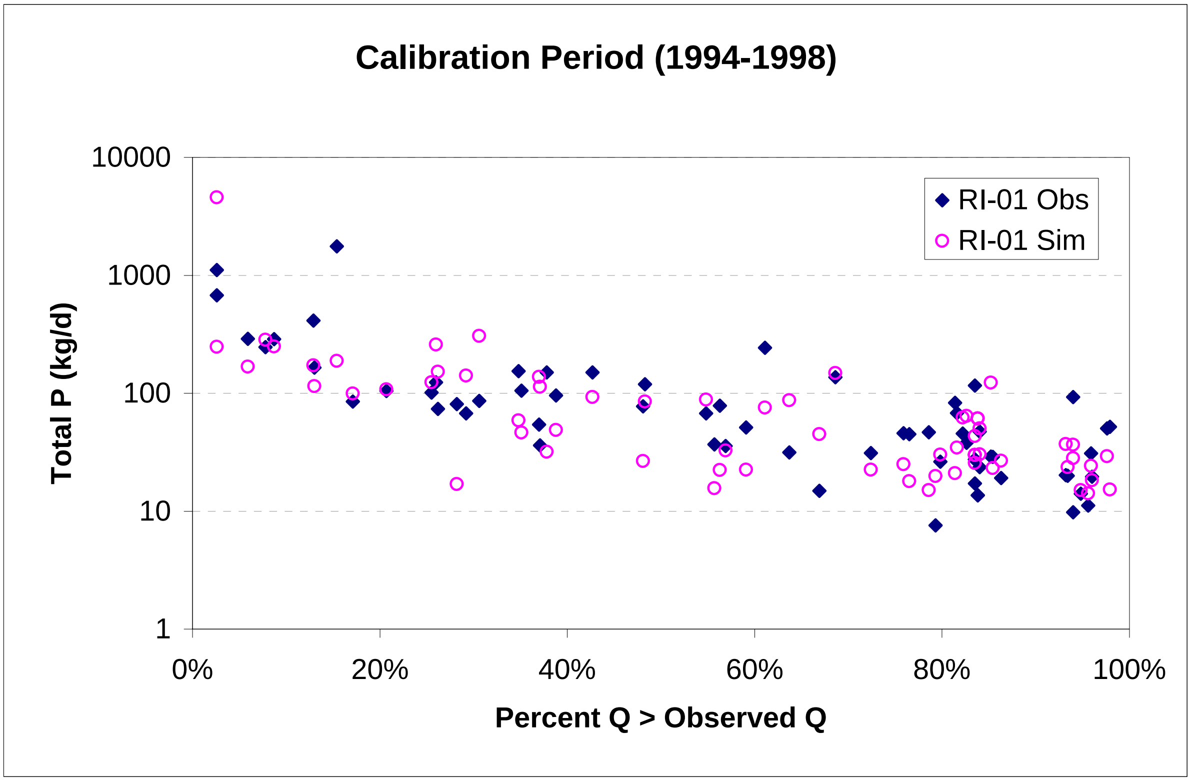
20-100% - Obs

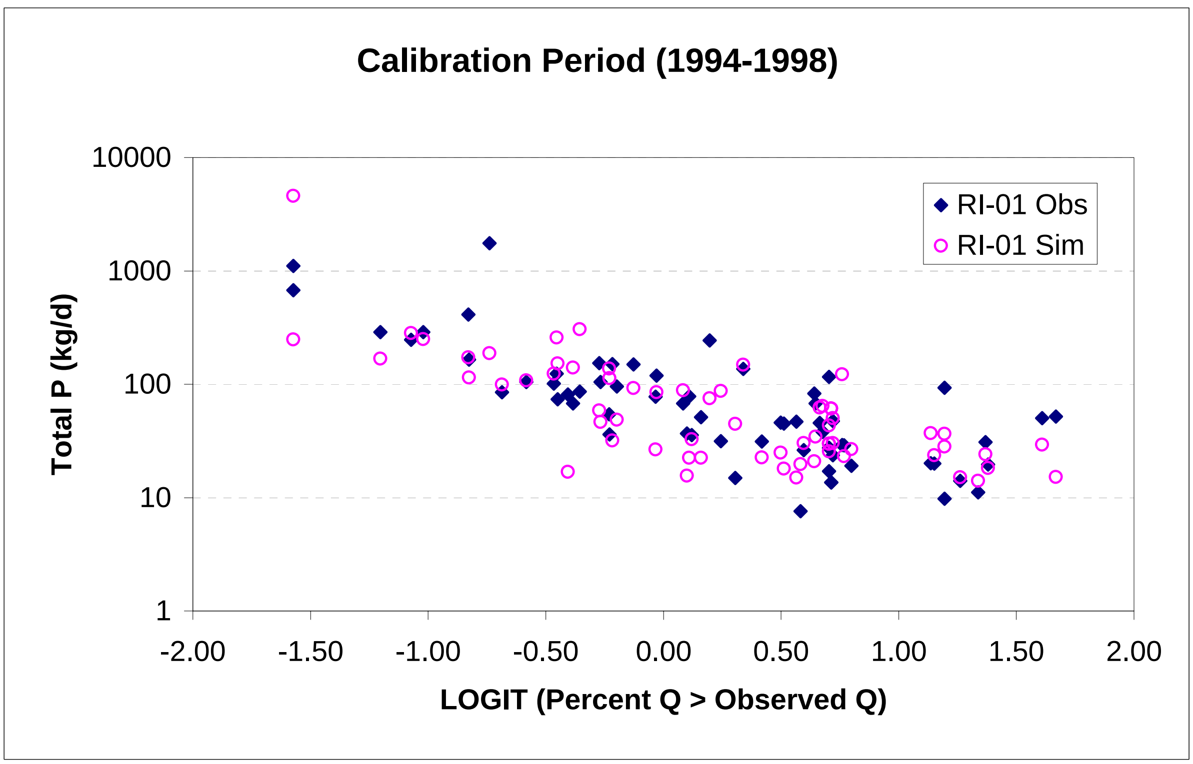
-1.4322	6.769895
0.111931	0.055194
0.845139	0.304944
163.7224	30
2.042272	
0.228593	
-1.66079	
-1.2036	

20-100% - Sim

-2.23528	5.781225
0.291955	0.143966
0.661469	0.795405
58.61813	30
2.042272	
0.596253	
-2.83154	
-1.63903	




Calibration Period (1994-1998)
Total P (kg/d)
10000
1000
100
10
1
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-01 Obs
RI-01 Sim


Calibration Period (1994-1998)
Total P (kg/d)
10000
1000
100
10
1
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
RI-01 Obs
RI-01 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.17514	4.689839
0.964442	1.065199
0.174982	0.915149
1.484667	7
2.364624	
2.280543	
-3.45569	
1.105401	

0-20% - Sim

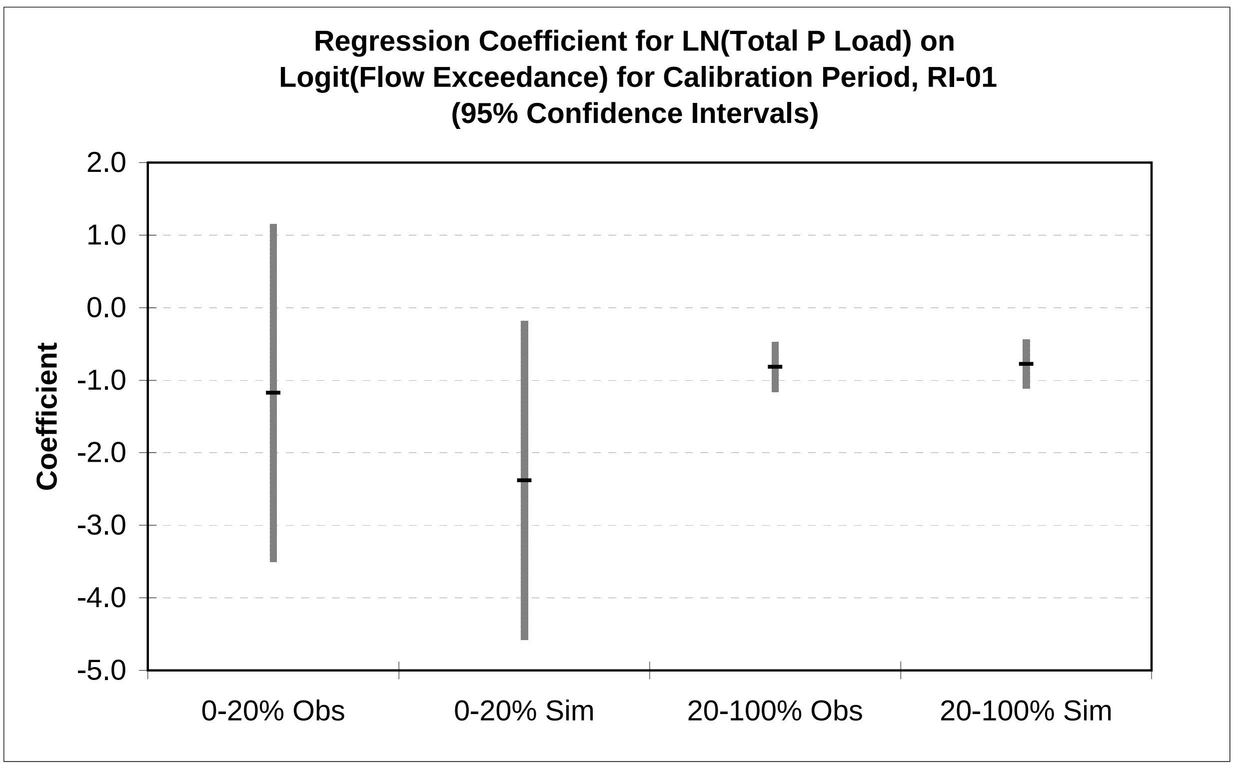
-2.38086	3.031689
0.909924	1.004985
0.494451	0.863417
6.846327	7
2.364624	
2.151628	
-4.53249	
-0.22923	

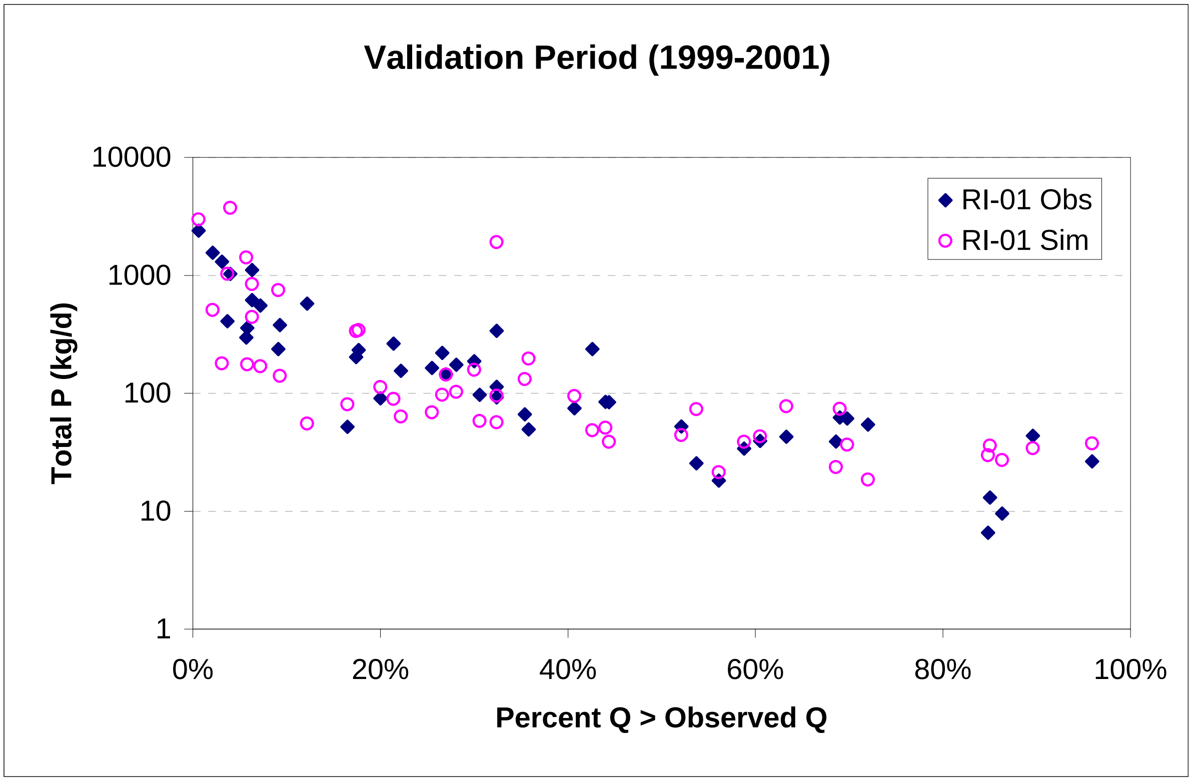
20-100% - Obs

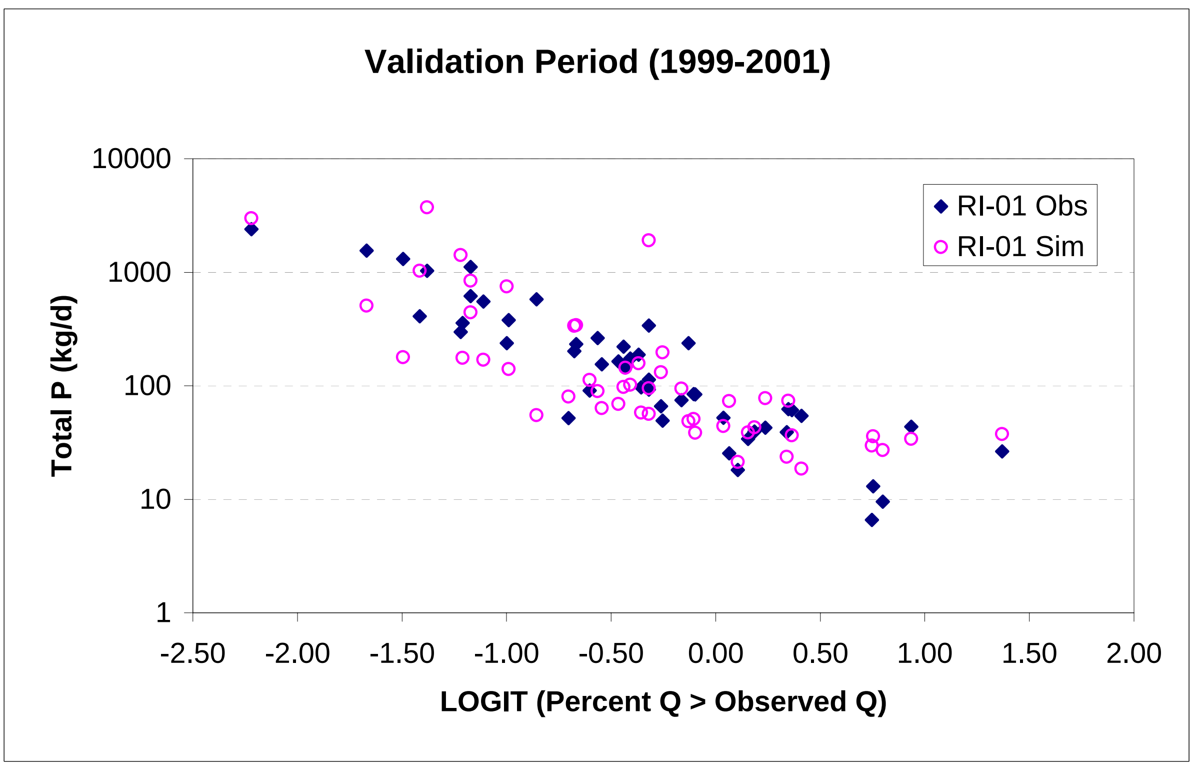
-0.81547	4.1583
0.149904	0.108643
0.354015	0.654565
29.59325	54
2.004879	
0.30054	
-1.11601	
-0.51493	

20-100% - Sim

-0.77827	4.090479
0.146084	0.105874
0.344522	0.637884
28.38257	54
2.004879	
0.292881	
-1.07115	
-0.48539	




Validation Period (1999-2001)
10000
1000
100
10
1
Total P (kg/d)
RI-01 Obs
RI-01 Sim
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q


Validation Period (1999-2001)
10000
1000
100
10
1
Total P (kg/d)
RI-01 Obs
RI-01 Sim
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.00663	3.782666
0.349454	0.425958
0.687322	0.580136
32.97263	15
2.13145	
0.744844	
-2.75147	
-1.26178	

0-20% - Sim

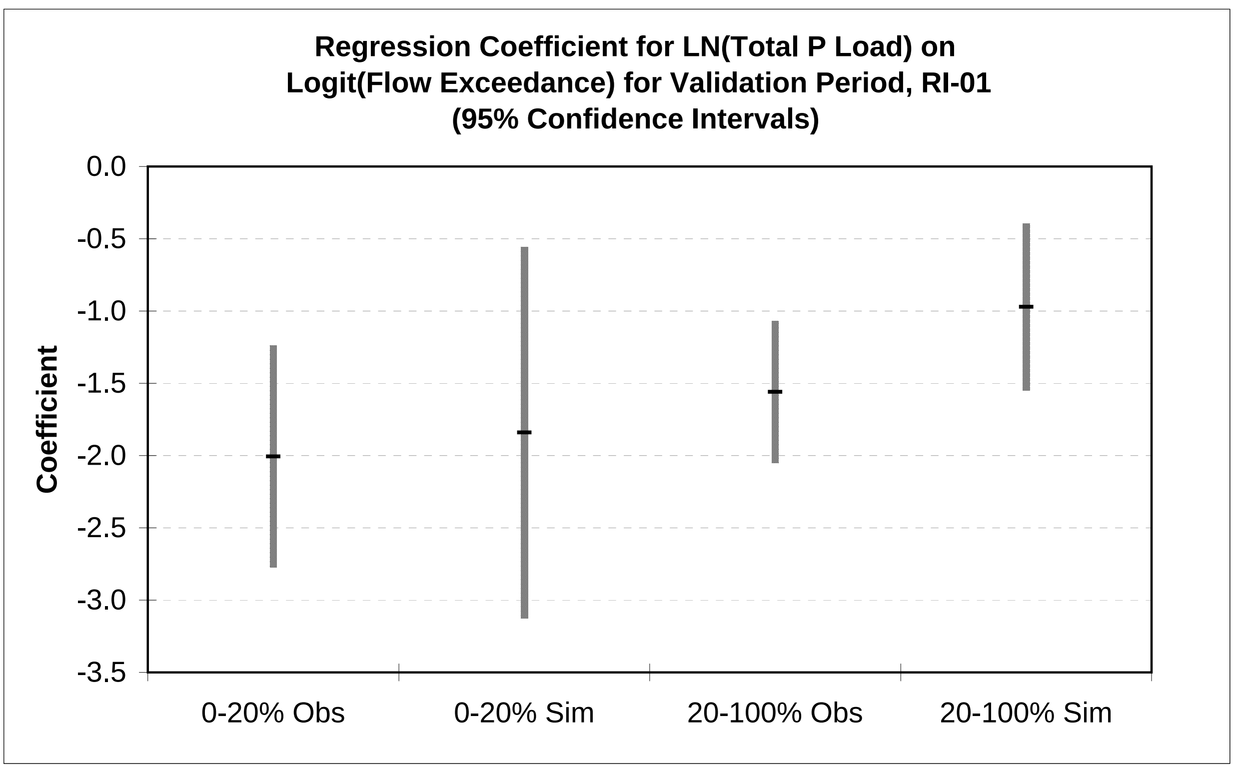
-1.84107	3.839856
0.592328	0.722003
0.391748	0.983335
9.66085	15
2.13145	
1.262516	
-3.10358	
-0.57855	

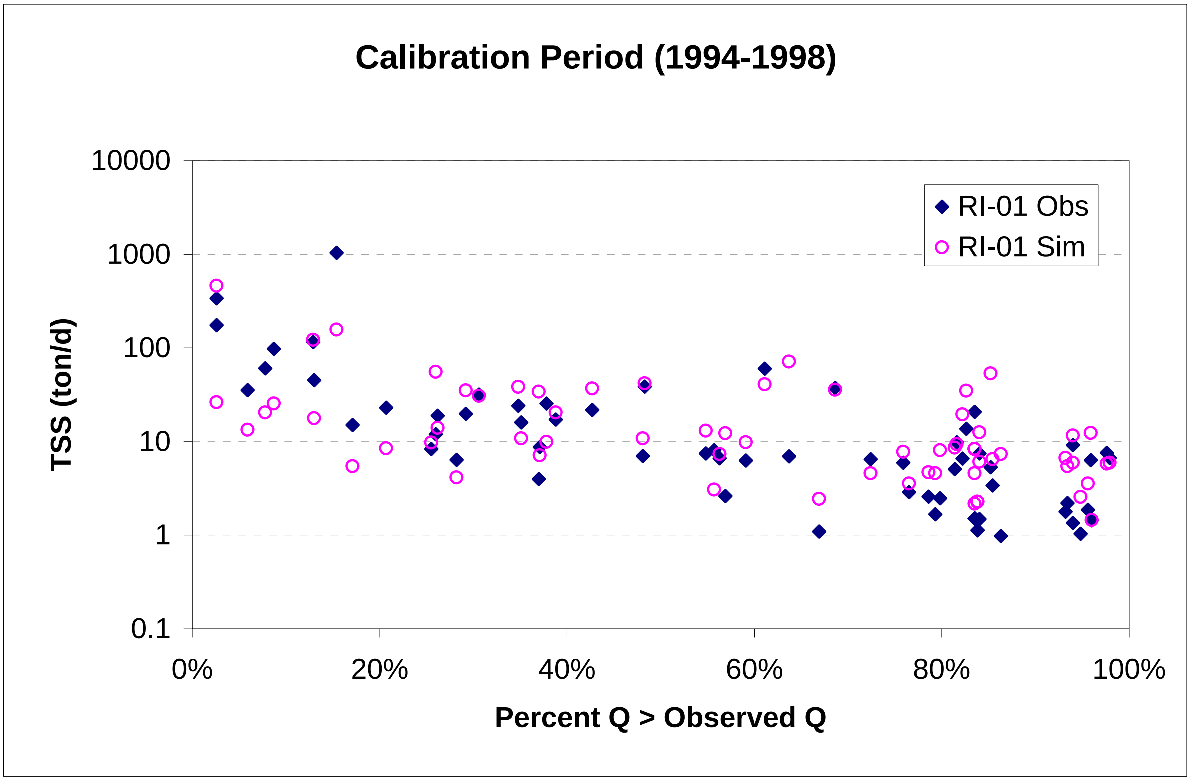
20-100% - Obs

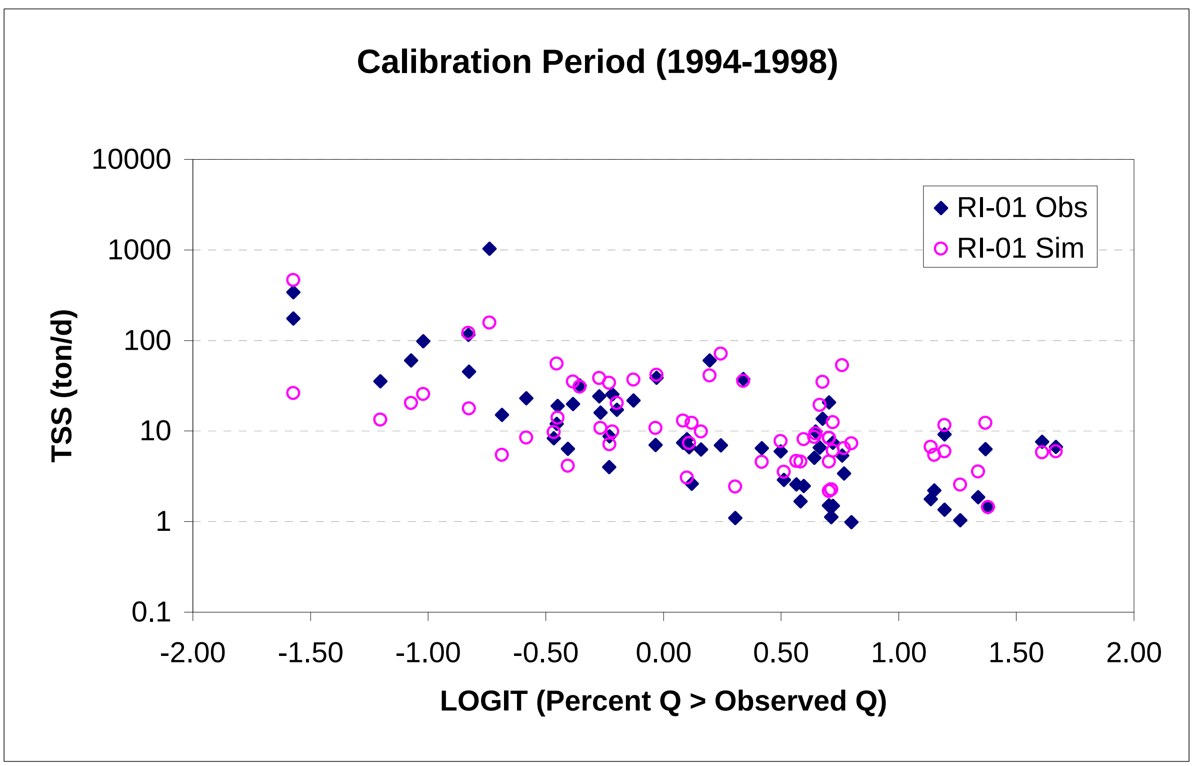
-1.56009	4.23691
0.229636	0.109866
0.606068	0.619253
46.15528	30
2.042272	
0.46898	
-2.02907	
-1.09112	

20-100% - Sim

-0.97225	4.189024
0.271756	0.130018
0.299057	0.732838
12.79949	30
2.042272	
0.555001	
-1.52725	
-0.41725	




Calibration Period (1994-1998)
10000
1000
100
10
1
0.1
TSS (ton/d)
RI-01 Obs
RI-01 Sim
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q


Calibration Period (1994-1998)
10000
1000
100
10
1
0.1
TSS (ton/d)
RI-01 Obs
RI-01 Sim
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-0.9747	3.575171
1.379187	1.523272
0.066599	1.308696
0.499458	7
2.364624	
3.26126	
-4.23596	
2.286556	

0-20% - Sim

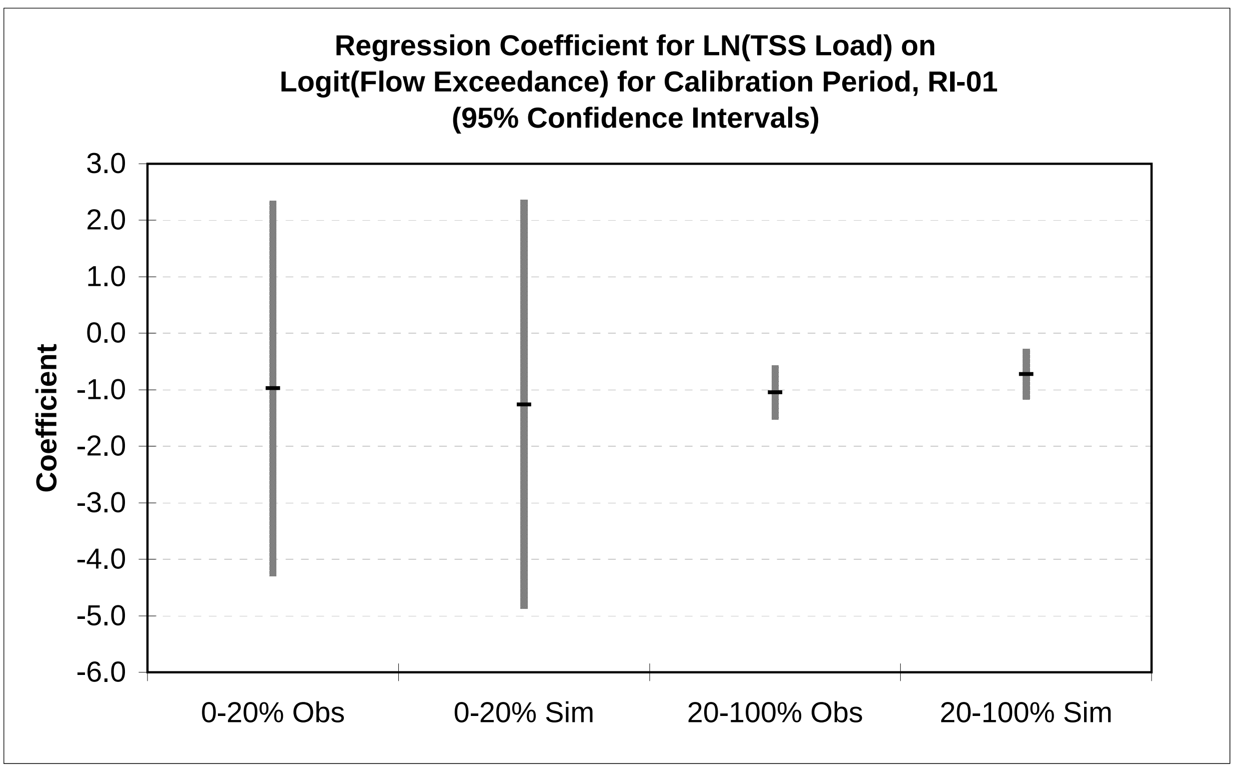
-1.26005	2.298067
1.506078	1.66342
0.090905	1.429101
0.699968	7
2.364624	
3.561309	
-4.82136	
2.301262	

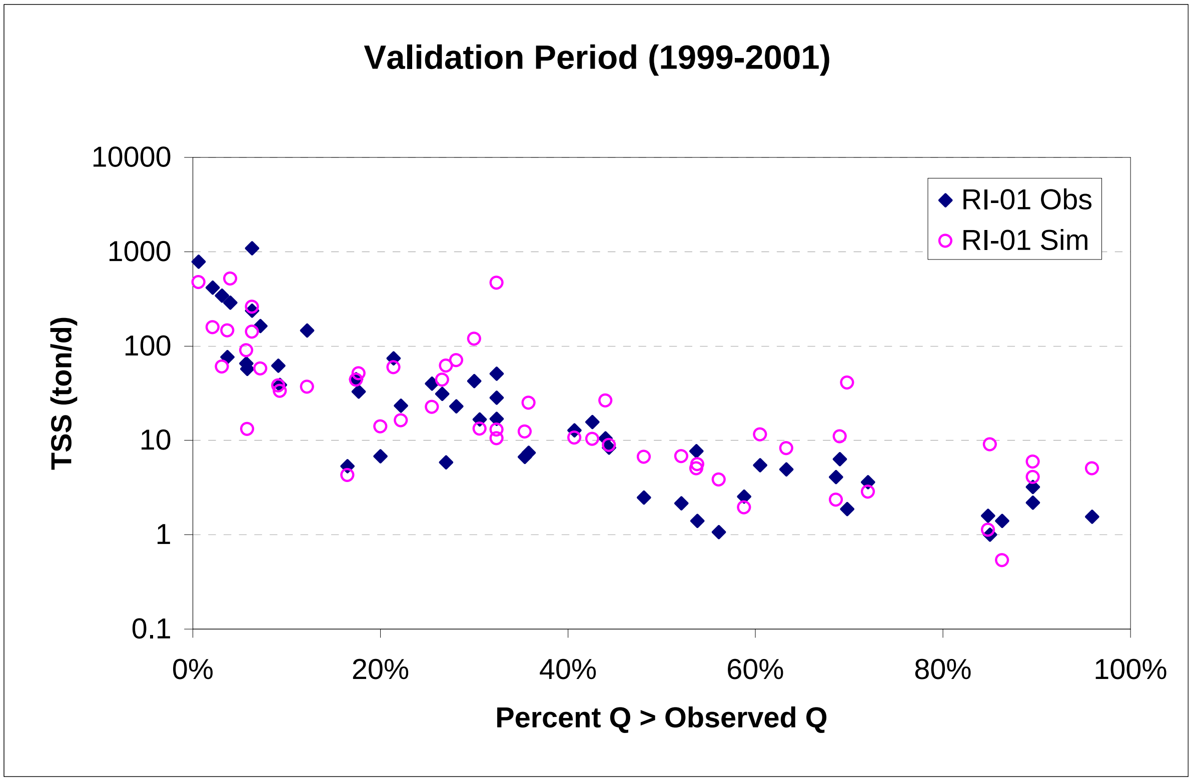
20-100% - Obs

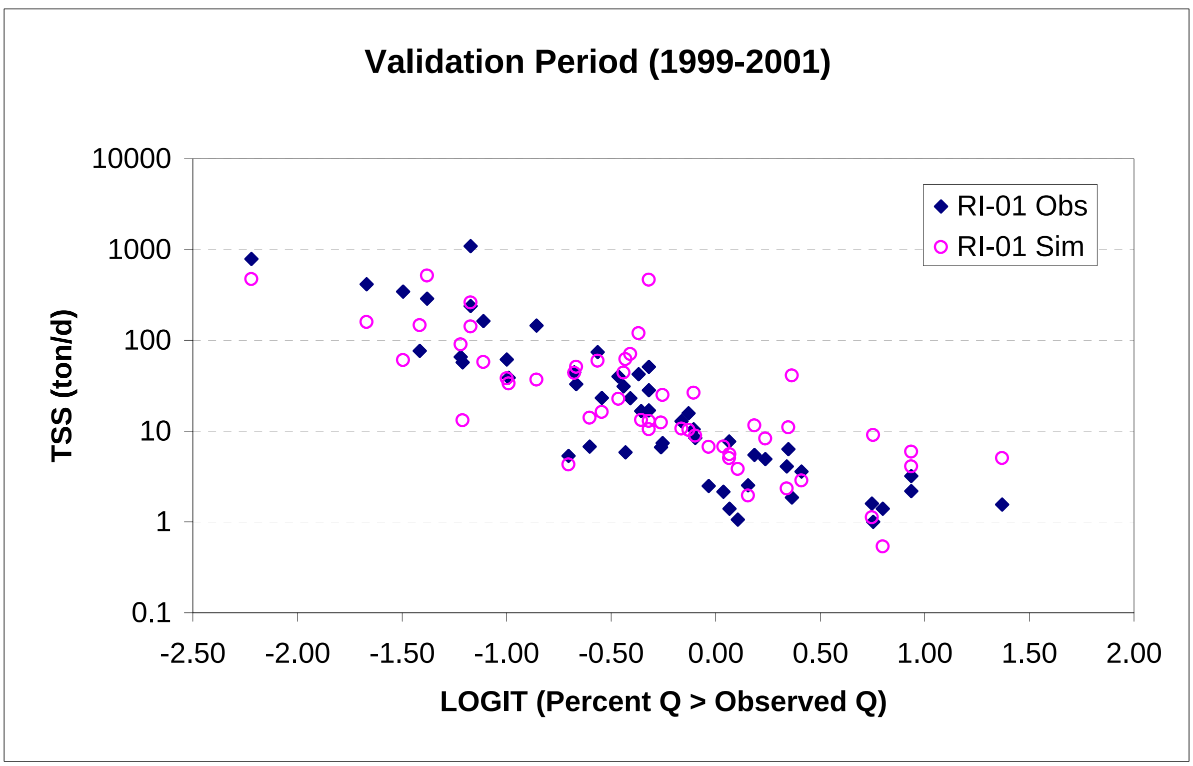
-1.04923	2.196326
0.209844	0.152085
0.316459	0.916296
25.00035	54
2.004879	
0.420712	
-1.46994	
-0.62852	

20-100% - Sim

-0.72535	2.573001
0.195196	0.141468
0.203641	0.852333
13.80859	54
2.004879	
0.391344	
-1.11669	
-0.334	




Validation Period (1999-2001)
TSS (ton/d)
10000
1000
100
10
1
0.1
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-01 Obs
RI-01 Sim


Validation Period (1999-2001)
TSS (ton/d)
10000
1000
100
10
1
0.1
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
RI-01 Obs
RI-01 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.66505	1.520726
0.613705	0.74806
0.55697	1.018824
18.85778	15
2.13145	
1.308081	
-3.97313	
-1.35697	

0-20% - Sim

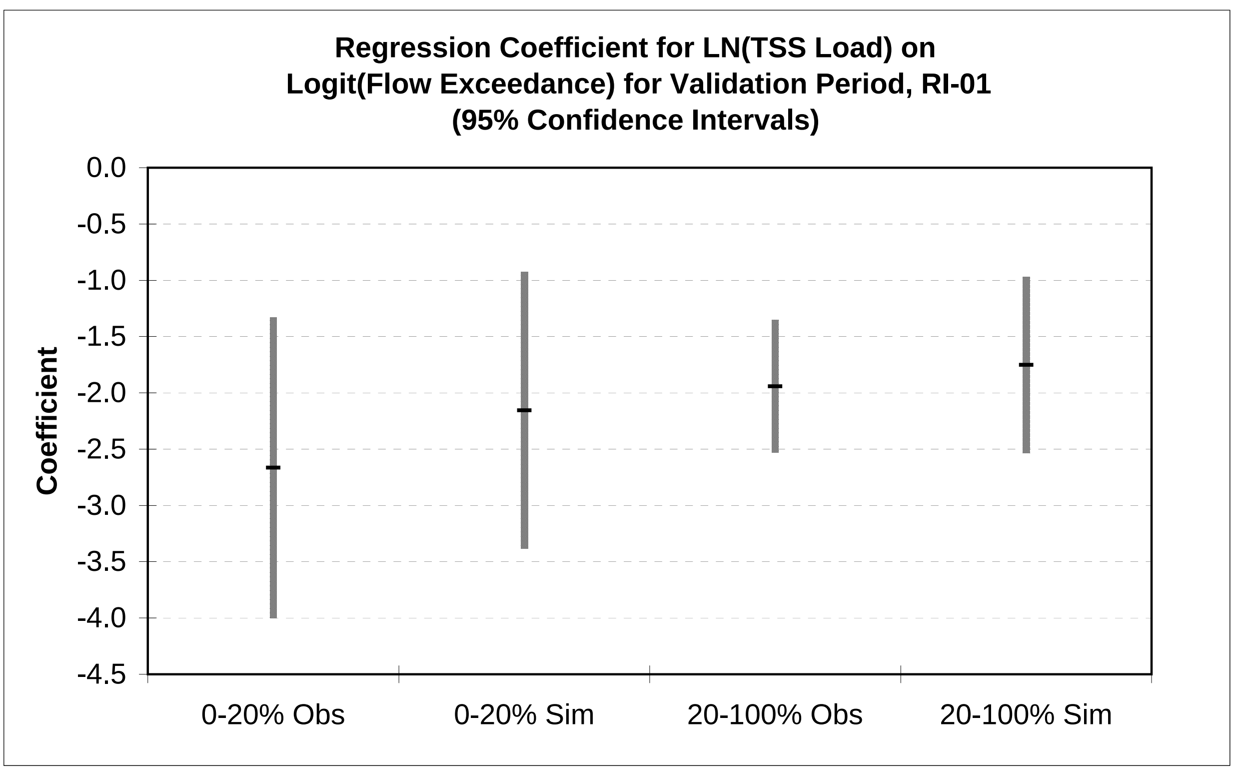
-2.15531	1.684262
0.563429	0.686777
0.493813	0.935359
14.63332	15
2.13145	
1.20092	
-3.35623	
-0.95439	

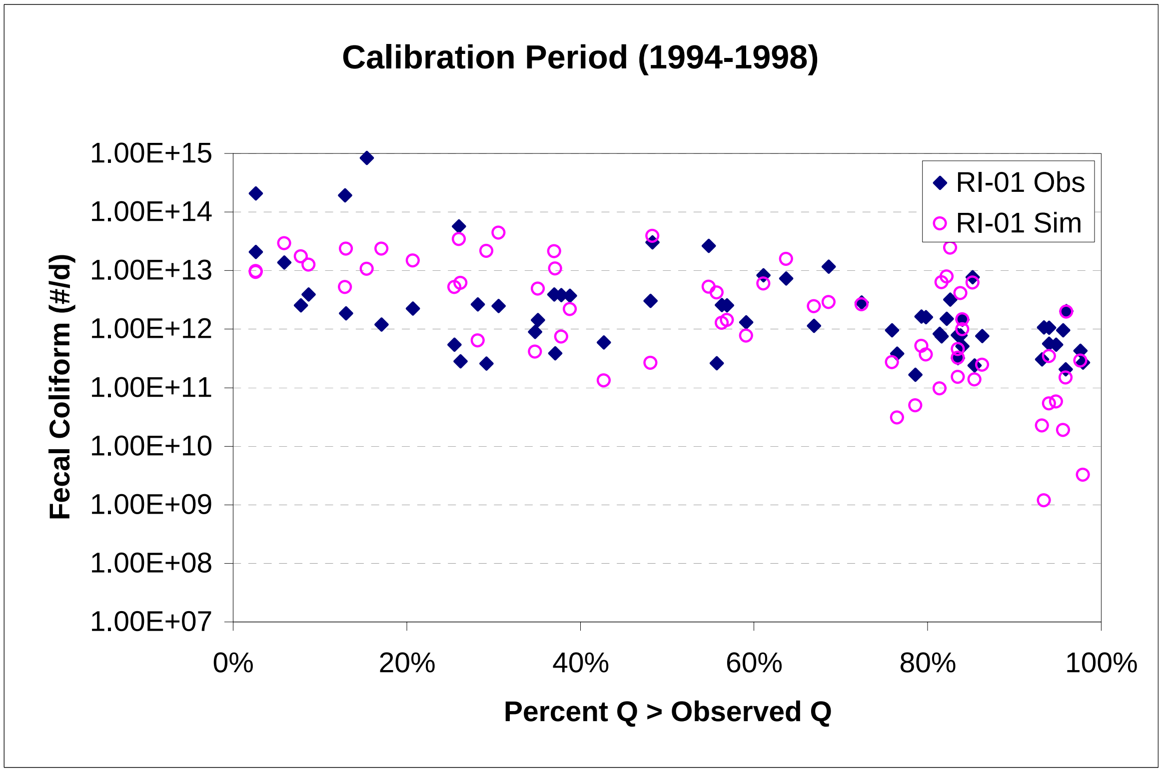
20-100% - Obs

-1.94338	2.026211
0.275662	0.13347
0.600969	0.782513
49.70037	33
2.034515	
0.560839	
-2.50422	
-1.38254	

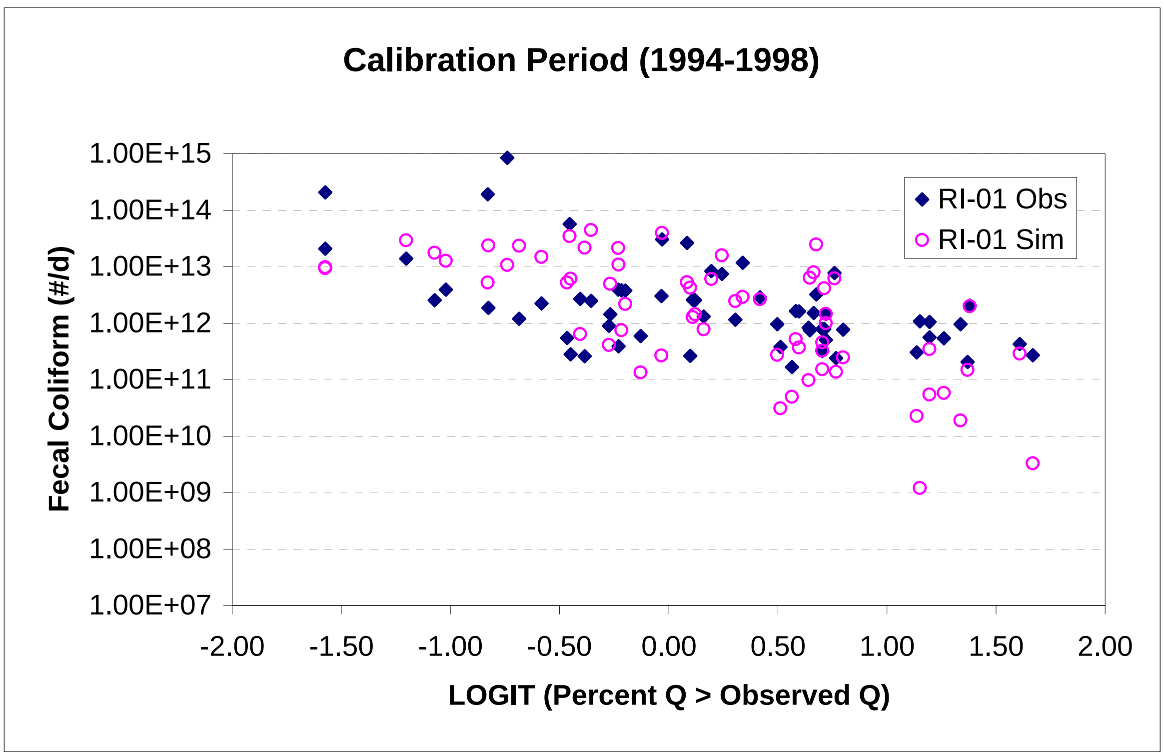
20-100% - Sim

-1.75164	2.534197
0.370325	0.179304
0.404041	1.051229
22.37295	33
2.034515	
0.753432	
-2.50507	
-0.99821	





Calibration Period (1994-1998)
1.00E+15
1.00E+14
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
Fecal Coliform (#/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-01 Obs
RI-01 Sim



Calibration Period (1994-1998)
1.00E+15
1.00E+14
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
Fecal Coliform (#/d)
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
RI-01 Obs
RI-01 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.218849	29.23839
2.636027	2.911416
0.029637	2.501298
0.213796	7
2.364624	
6.233214	
-7.452064	
5.014365	

0-20% - Sim

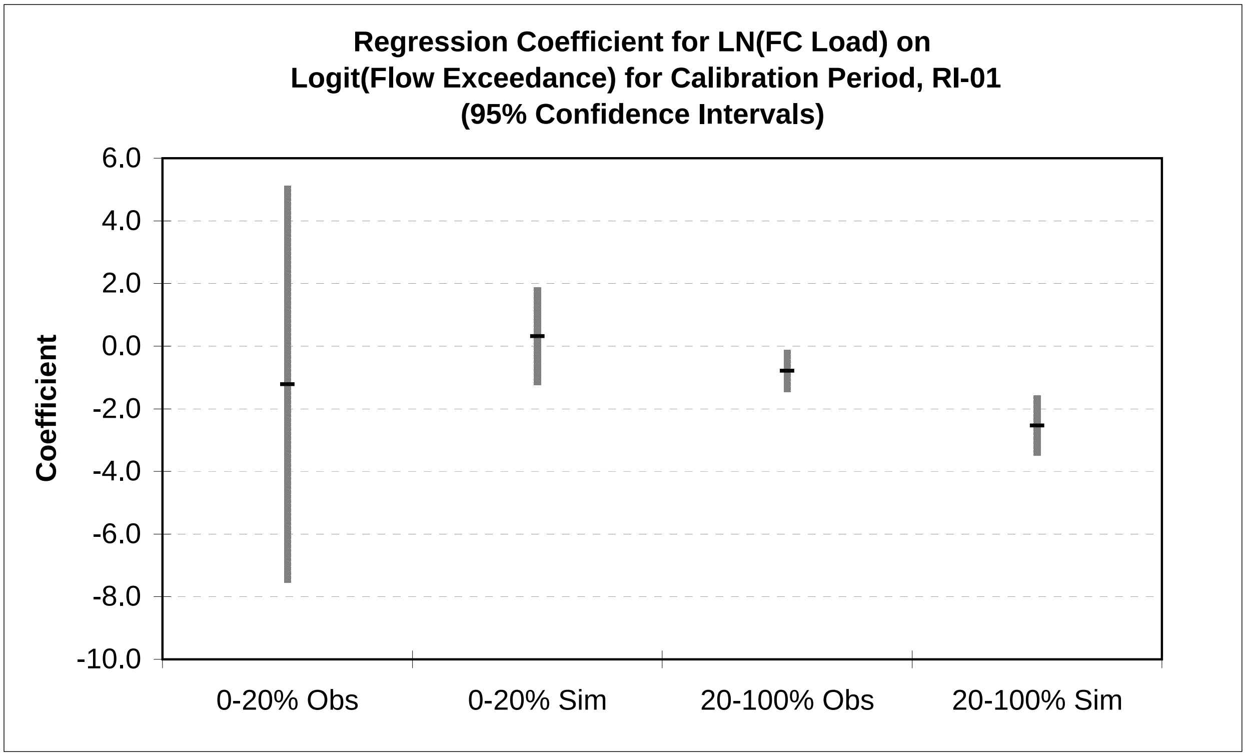
0.31473	30.58976
0.613383	0.677464
0.036248	0.582033
0.263276	7
2.364624	
1.450421	
-1.135691	
1.765151	

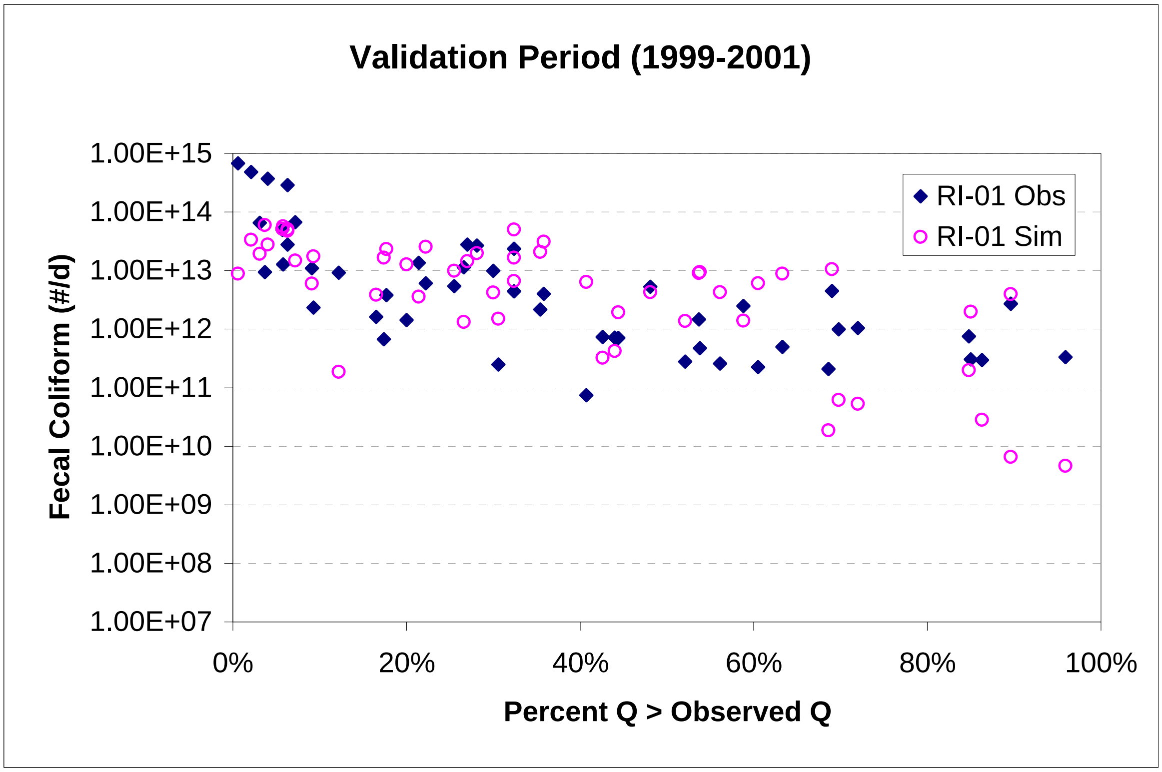
20-100% - Obs

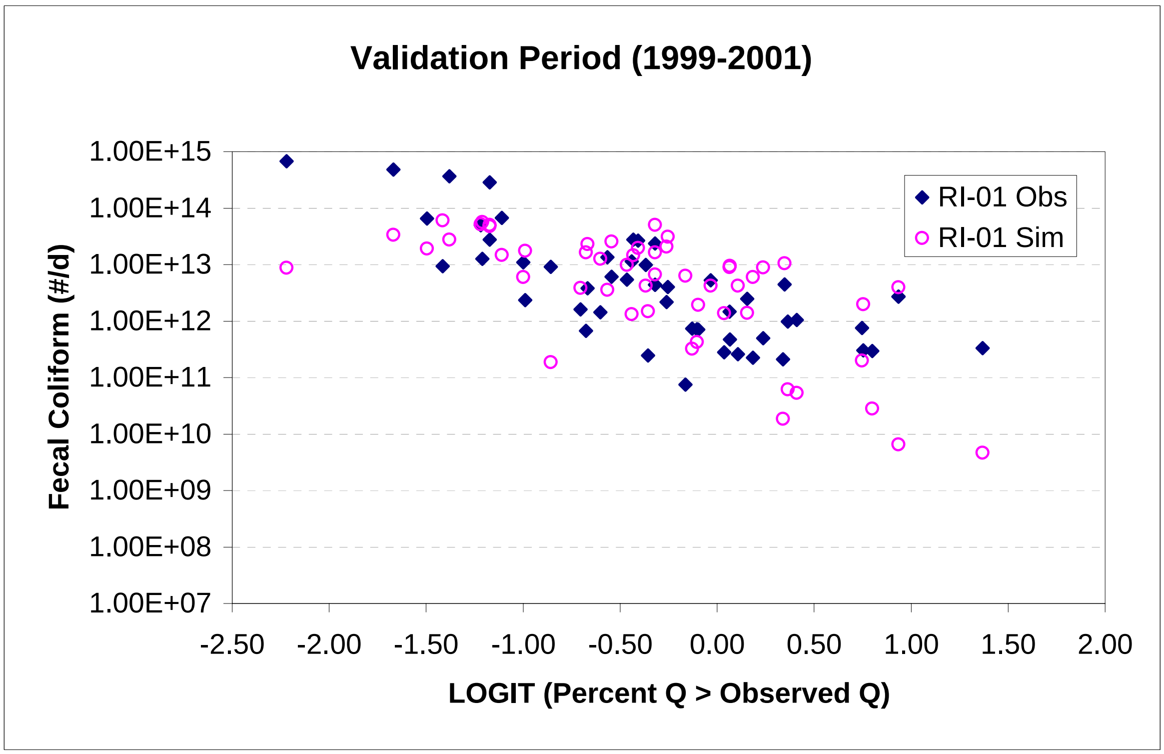
-0.793323	28.23672
0.282404	0.204835
0.131763	1.227895
7.891501	52
2.006647	
0.566685	
-1.360008	
-0.226639	

20-100% - Sim

-2.53603	28.62459
0.429196	0.311308
0.401706	1.866151
34.91377	52
2.006647	
0.861245	
-3.397275	
-1.674784	




Validation Period (1999-2001)
RI-01 Obs
RI-01 Sim
Fecal Coliform (#/d)
1.00E+15
1.00E+14
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q


Validation Period (1999-2001)
RI-01 Obs
RI-01 Sim
Fecal Coliform (#/d)
1.00E+15
1.00E+14
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-4.347426	25.6815
0.755808	0.921273
0.688057	1.254733
33.08576	15
2.13145	
1.610967	
-5.958393	
-2.736459	

0-20% - Sim

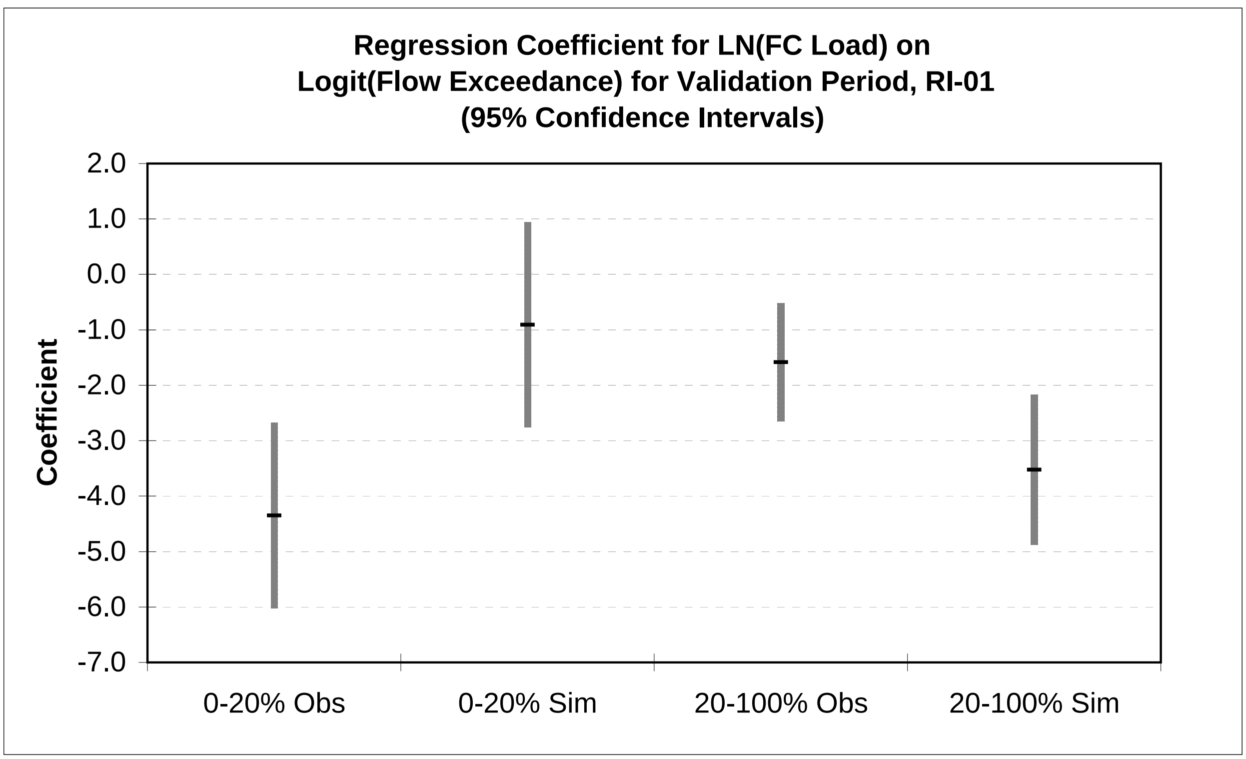
-0.907723	29.37172
0.840602	1.02463
0.072131	1.3955
1.166073	15
2.13145	
1.791701	
-2.699423	
0.883978	

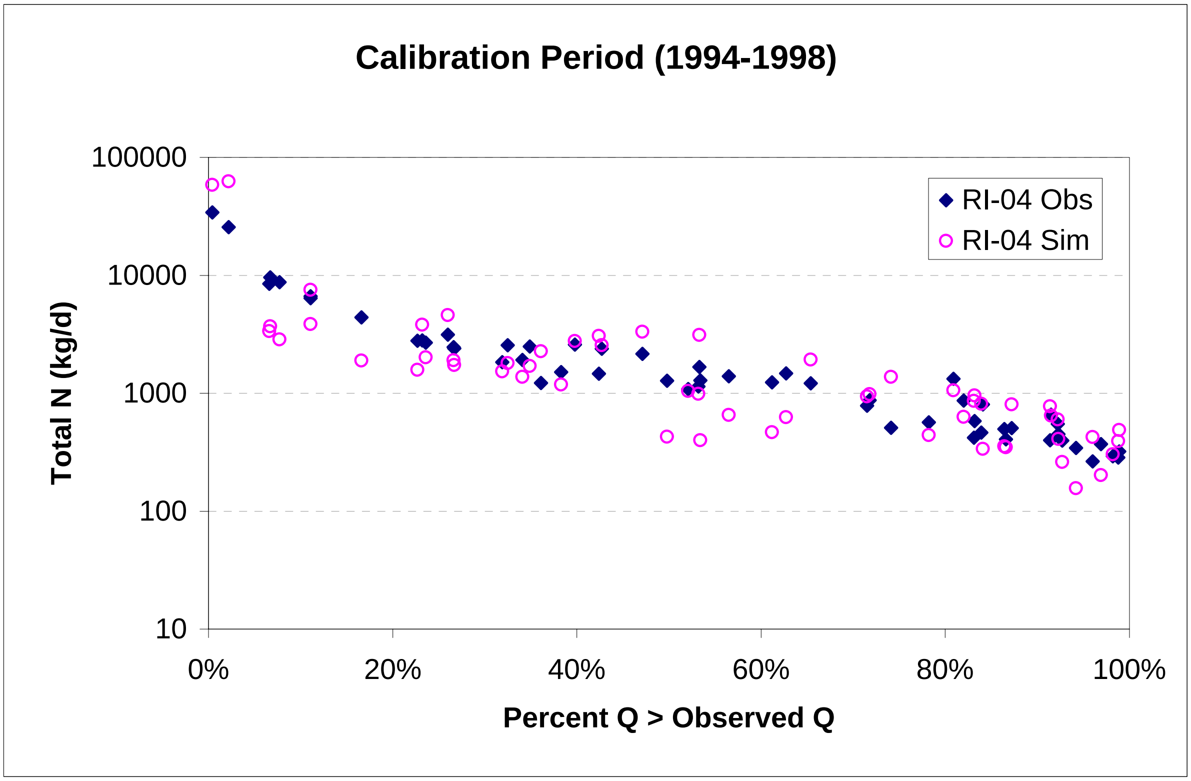
20-100% - Obs

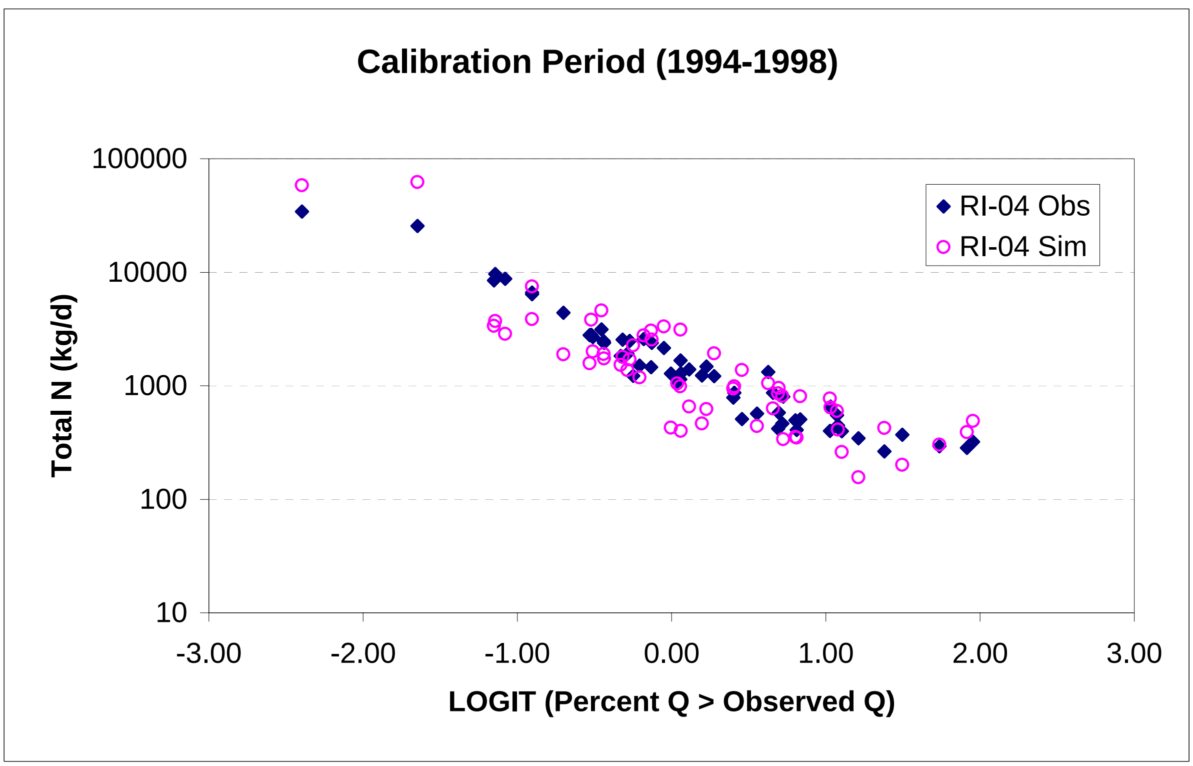
-1.586142	28.19908
0.495623	0.23997
0.236852	1.406908
10.24193	33
2.034515	
1.008352	
-2.594494	
-0.57779	

20-100% - Sim

-3.524442	28.468
0.638069	0.30894
0.480399	1.811265
30.51022	33
2.034515	
1.298161	
-4.822603	
-2.226281	




Calibration Period (1994-1998)
Total N (kg/d)
100000
10000
1000
100
10
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-04 Obs
RI-04 Sim


Calibration Period (1994-1998)
Total N (kg/d)
100000
10000
1000
100
10
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
RI-04 Obs
RI-04 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.24803	7.681214
0.146614	0.196553
0.923528	0.210596
72.45966	6
2.446912	
0.358752	
-1.60678	
-0.88927	

0-20% - Sim

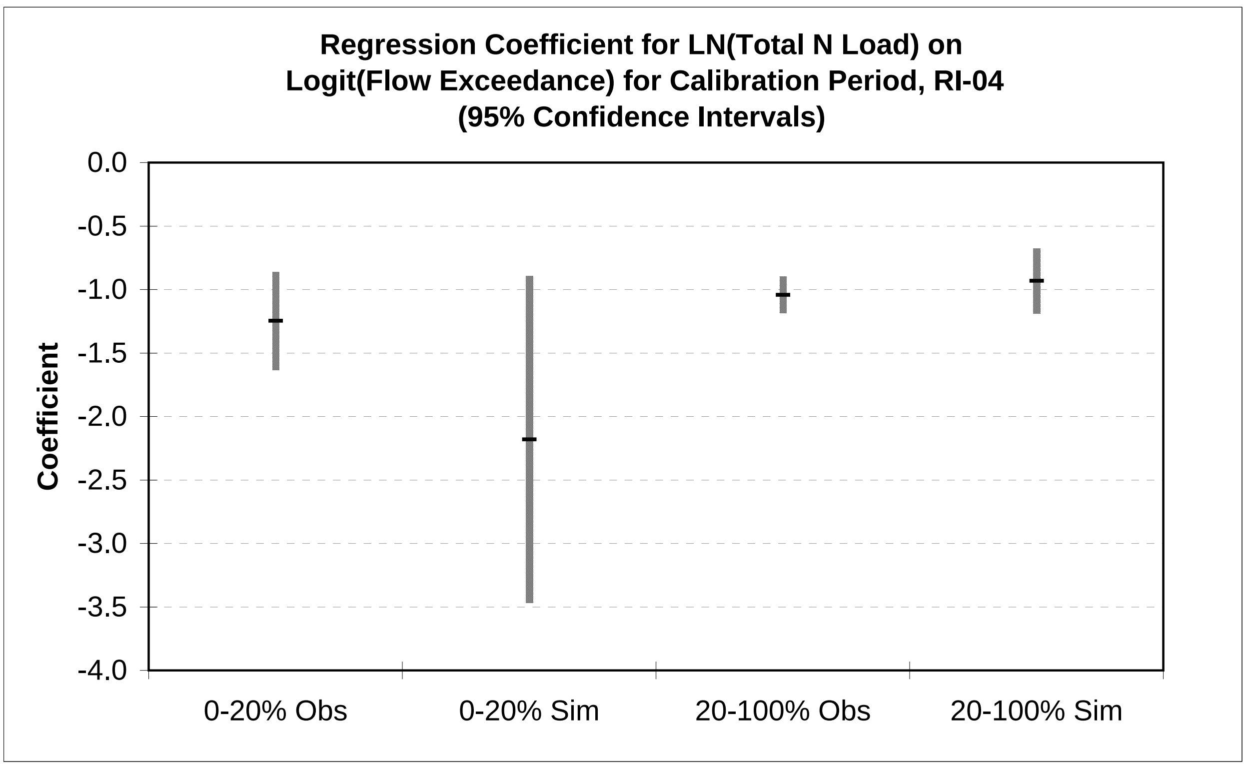
-2.18064	6.174288
0.515729	0.691395
0.748725	0.74079
17.87822	6
2.446912	
1.261943	
-3.44258	
-0.91869	

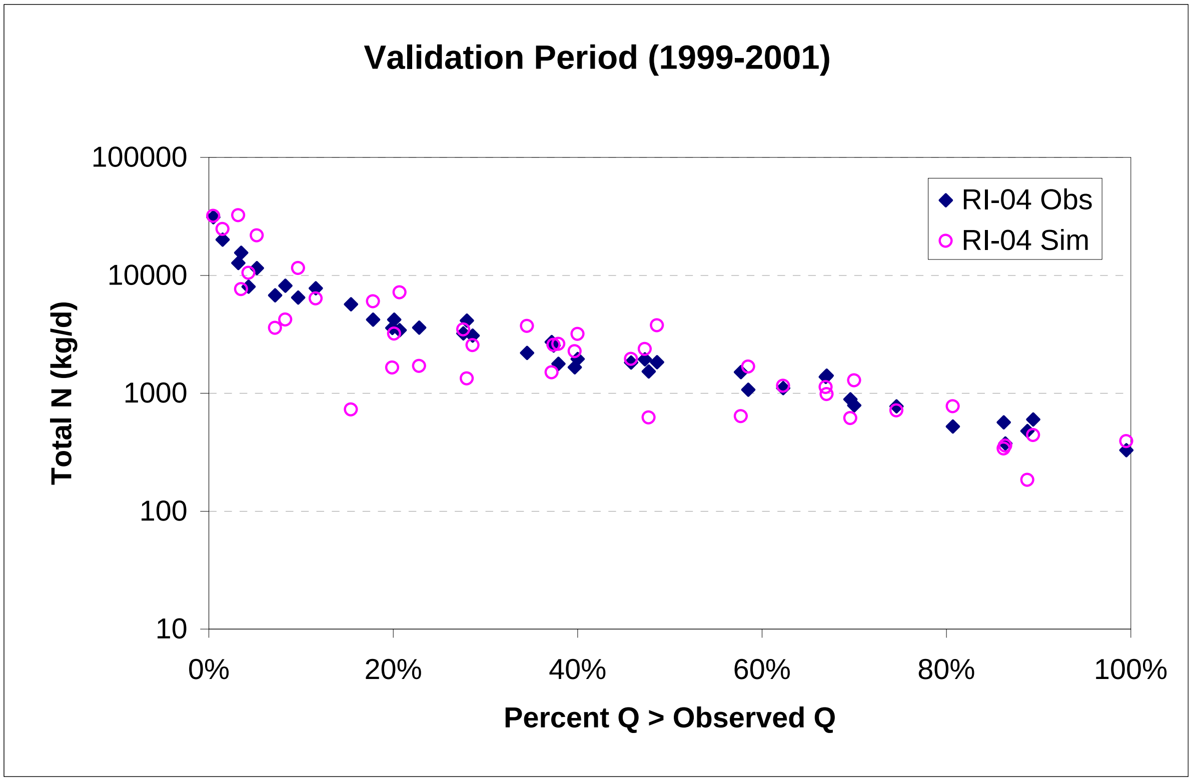
20-100% - Obs

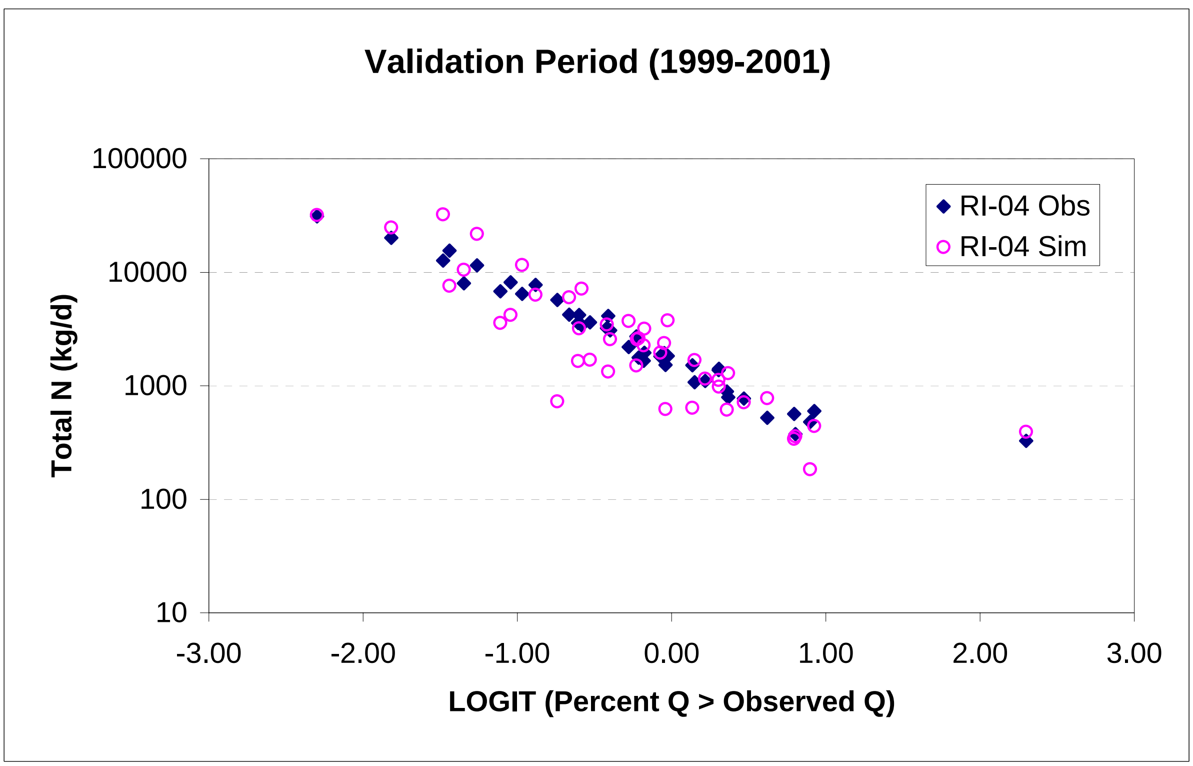
-1.042	7.281378
0.058331	0.045303
0.871623	0.273047
319.108	47
2.01174	
0.117346	
-1.15934	
-0.92465	

20-100% - Sim

-0.93305	7.181227
0.115087	0.089383
0.583073	0.538722
65.72945	47
2.01174	
0.231524	
-1.16457	
-0.70153	




Validation Period (1999-2001)
100000
10000
1000
100
10
0%
20%
40%
60%
80%
100%
Total N (kg/d)
Percent Q > Observed Q
RI-04 Obs
RI-04 Sim


Validation Period (1999-2001)
100000
10000
1000
100
10
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
Total N (kg/d)
LOGIT (Percent Q > Observed Q)
RI-04 Obs
RI-04 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.2227	7.63672
0.107046	0.138151
0.922243	0.178814
130.4669	11
2.200985	
0.235607	
-1.45831	
-0.9871	

0-20% - Sim

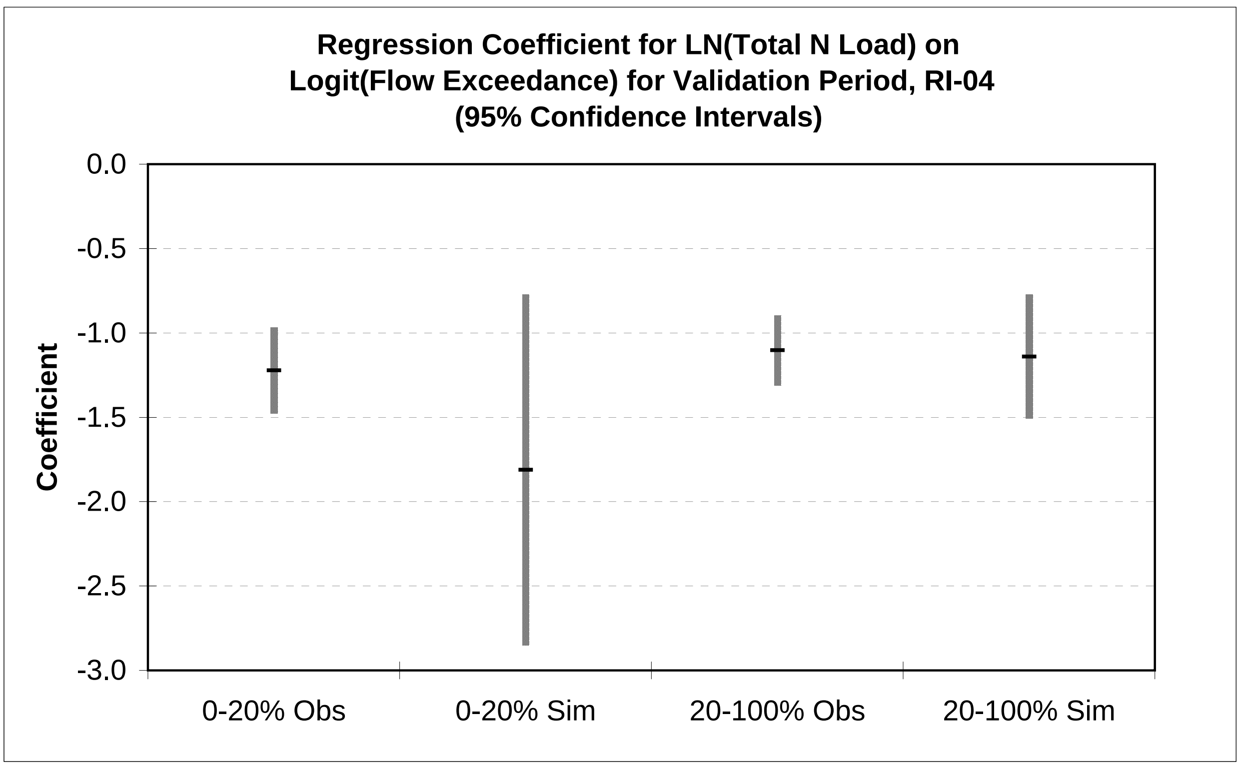
-1.81082	6.771201
0.46353	0.598219
0.581135	0.774299
15.26145	11
2.200985	
1.020222	
-2.83104	
-0.7906	

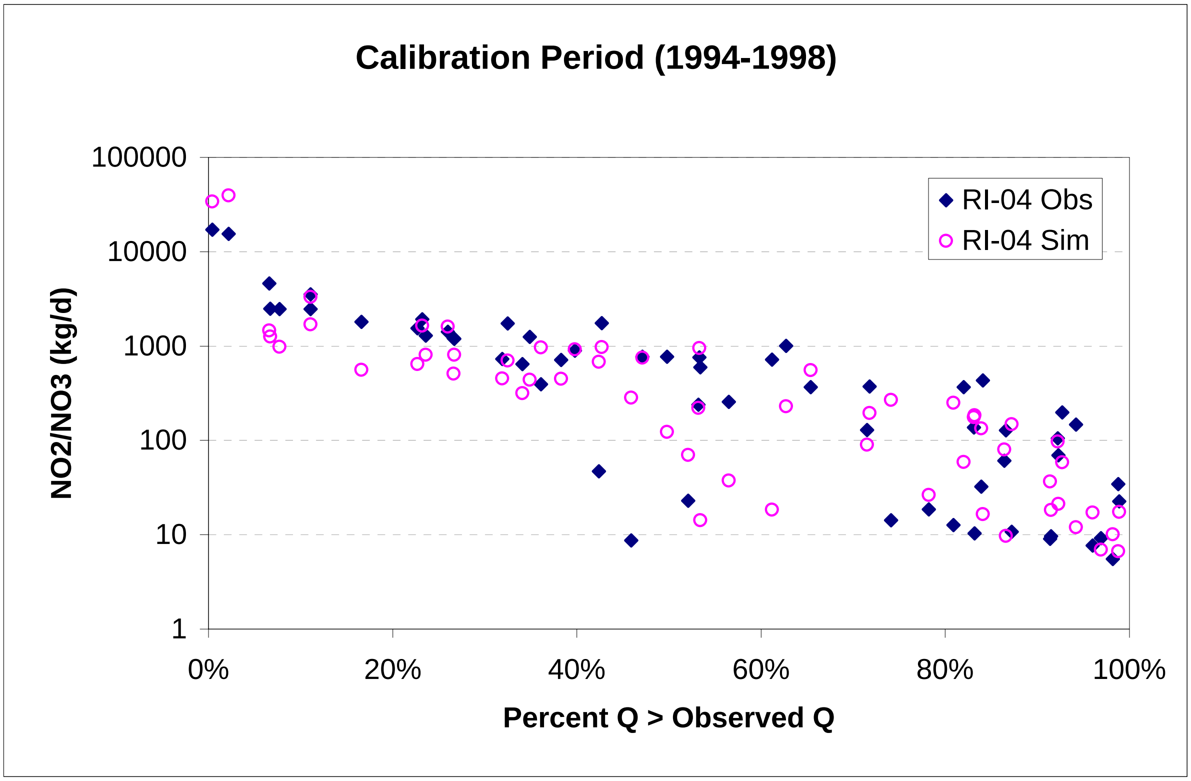
20-100% - Obs

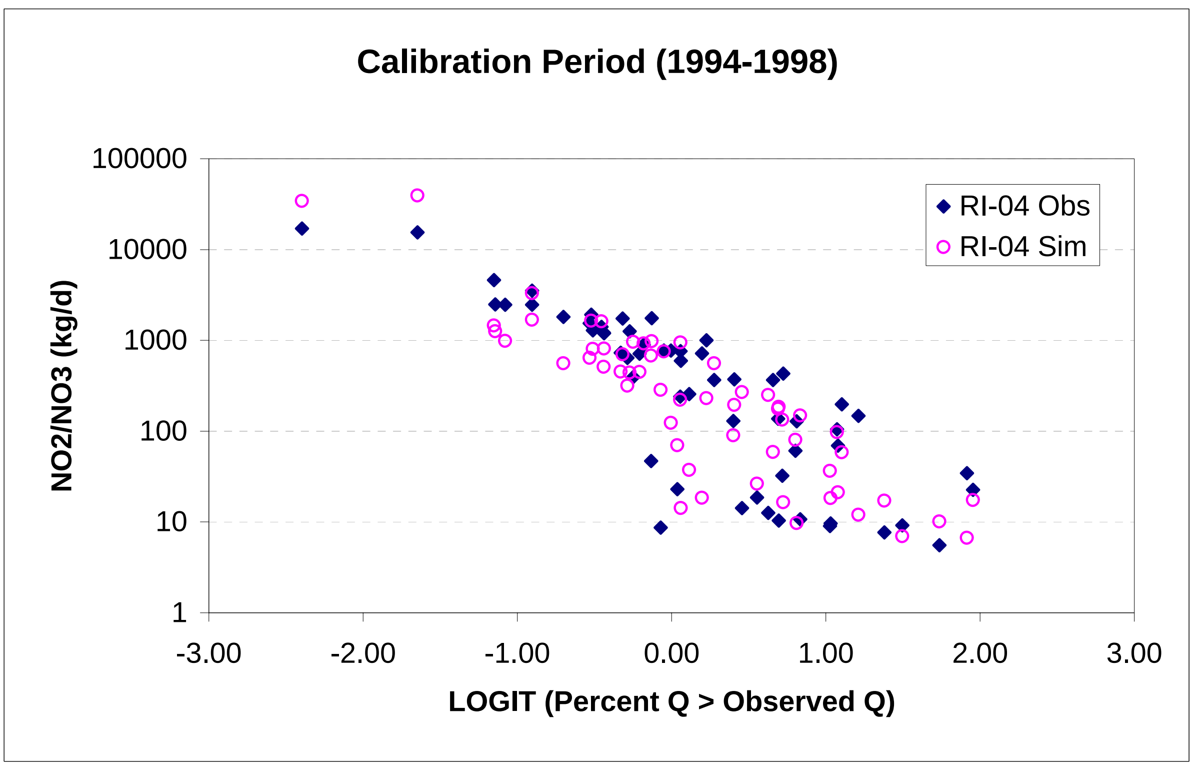
-1.10357	7.412632
0.091951	0.05607
0.837249	0.298782
144.0415	28
2.048407	
0.188352	
-1.29192	
-0.91521	

20-100% - Sim

-1.14014	7.336854
0.170978	0.104259
0.613614	0.555572
44.46633	28
2.048407	
0.350233	
-1.49037	
-0.7899	




Calibration Period (1994-1998)
100000
10000
1000
100
10
1
NO2/NO3 (kg/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-04 Obs
RI-04 Sim


Calibration Period (1994-1998)
100000
10000
1000
100
10
1
NO2/NO3 (kg/d)
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
RI-04 Obs
RI-04 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.44072	6.578939
0.27897	0.373992
0.816354	0.400711
26.67152	6
2.446912	
0.682614	
-2.12334	
-0.75811	

0-20% - Sim

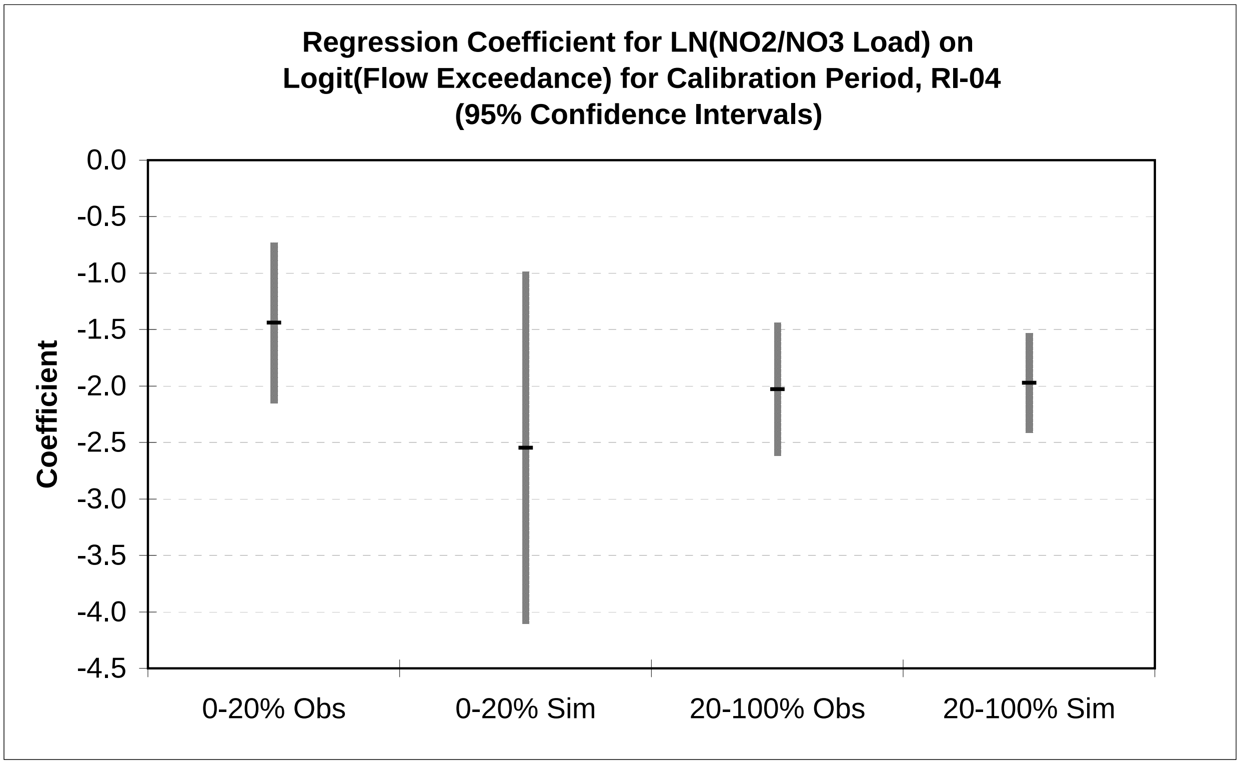
-2.54747	4.864283
0.625048	0.837951
0.73464	0.897816
16.61078	6
2.446912	
1.529437	
-4.0769	
-1.01803	

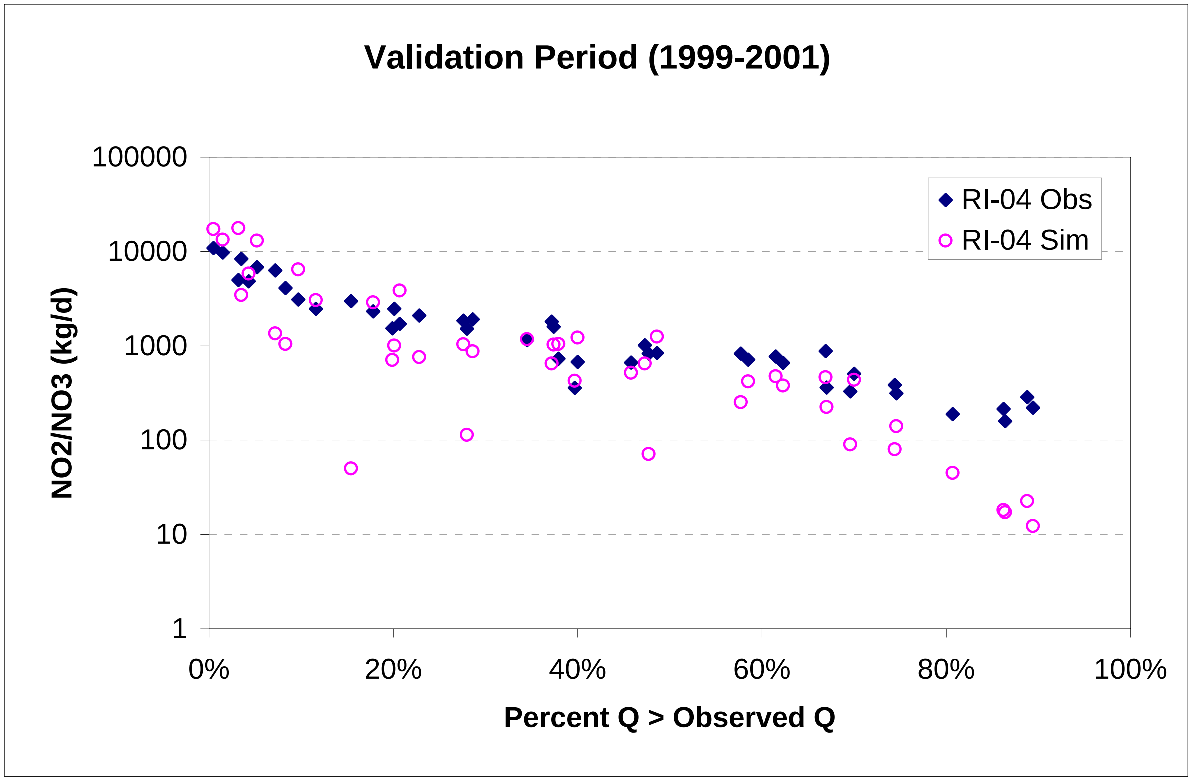
20-100% - Obs

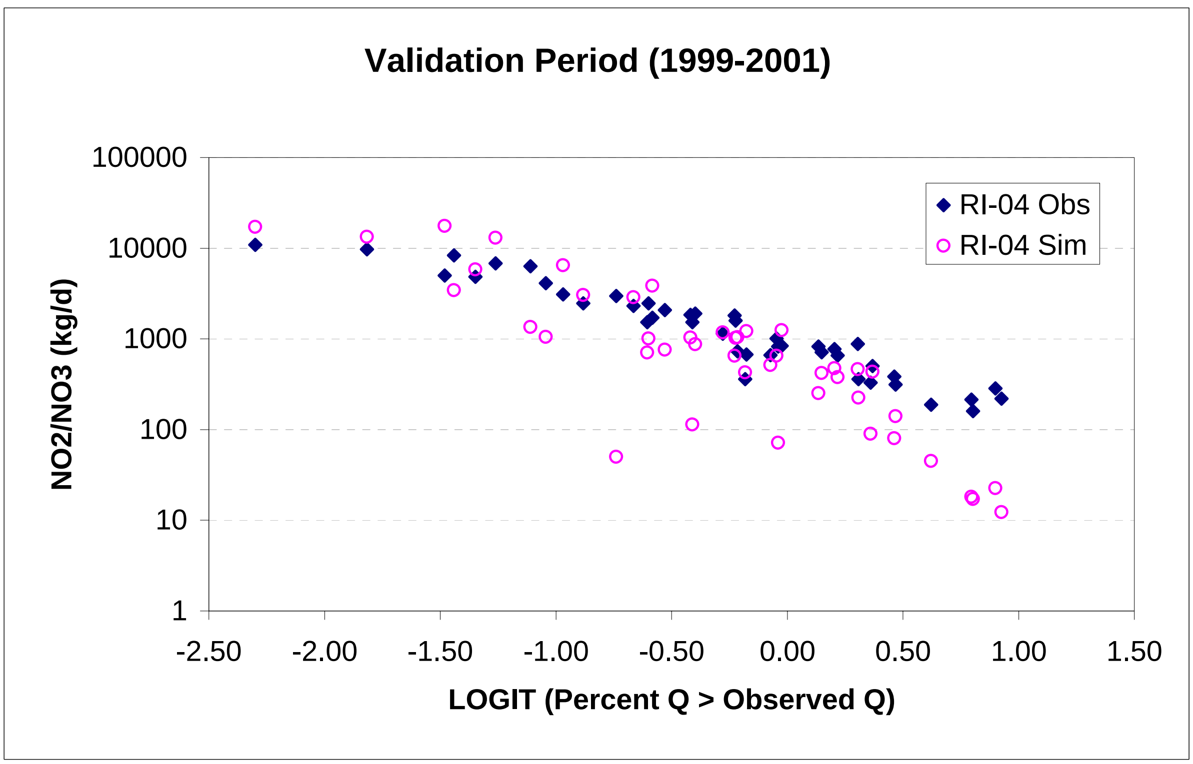
-2.02951	5.84339
0.278961	0.214498
0.524419	1.312155
52.92912	48
2.010635	
0.560888	
-2.59039	
-1.46862	

20-100% - Sim

-1.97362	5.634572
0.205178	0.157765
0.658426	0.965103
92.52591	48
2.010635	
0.412539	
-2.38616	
-1.56108	




Validation Period (1999-2001)
100000
10000
1000
100
10
1
NO2/NO3 (kg/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-04 Obs
RI-04 Sim


Validation Period (1999-2001)
100000
10000
1000
100
10
1
NO2/NO3 (kg/d)
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
LOGIT (Percent Q > Observed Q)
RI-04 Obs
RI-04 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.11445	7.067843
0.168816	0.217869
0.798463	0.281997
43.58051	11
2.200985	
0.371561	
-1.48601	
-0.74289	

0-20% - Sim

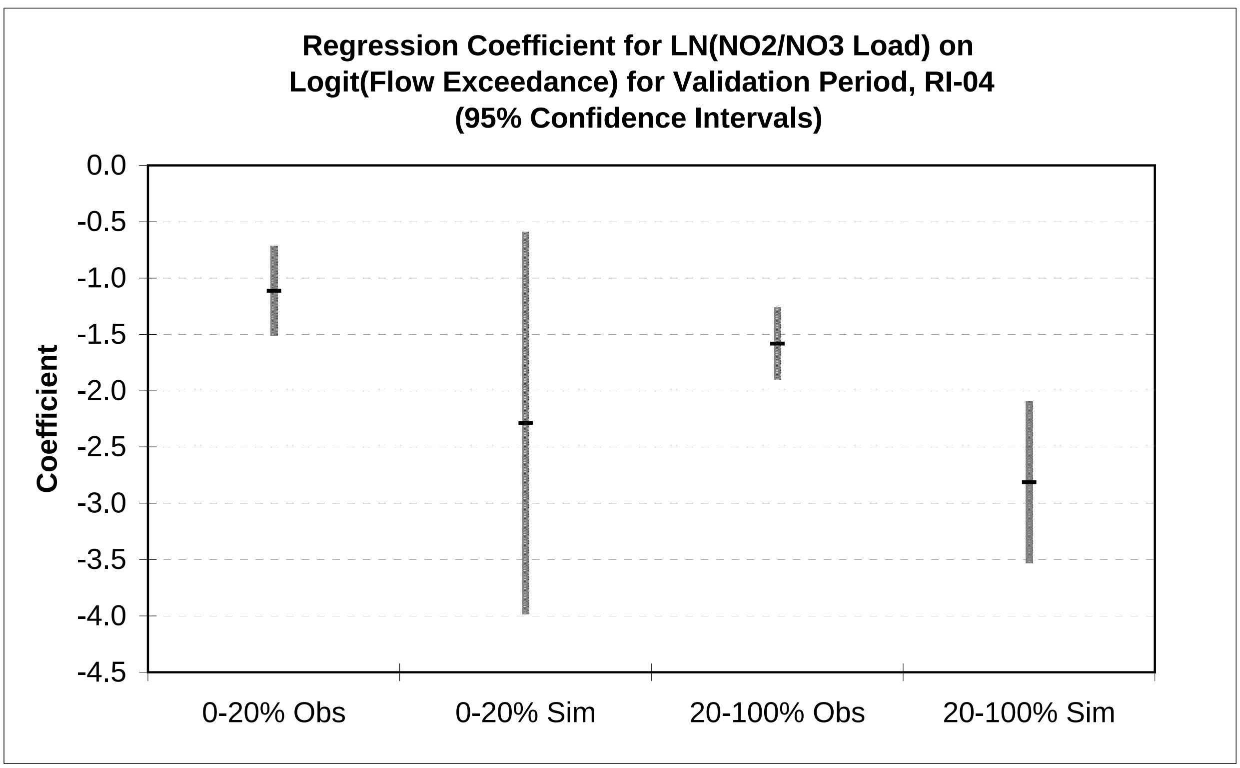
-2.28722	5.299357
0.757797	0.977993
0.453004	1.265855
9.109827	11
2.200985	
1.667899	
-3.95512	
-0.61932	

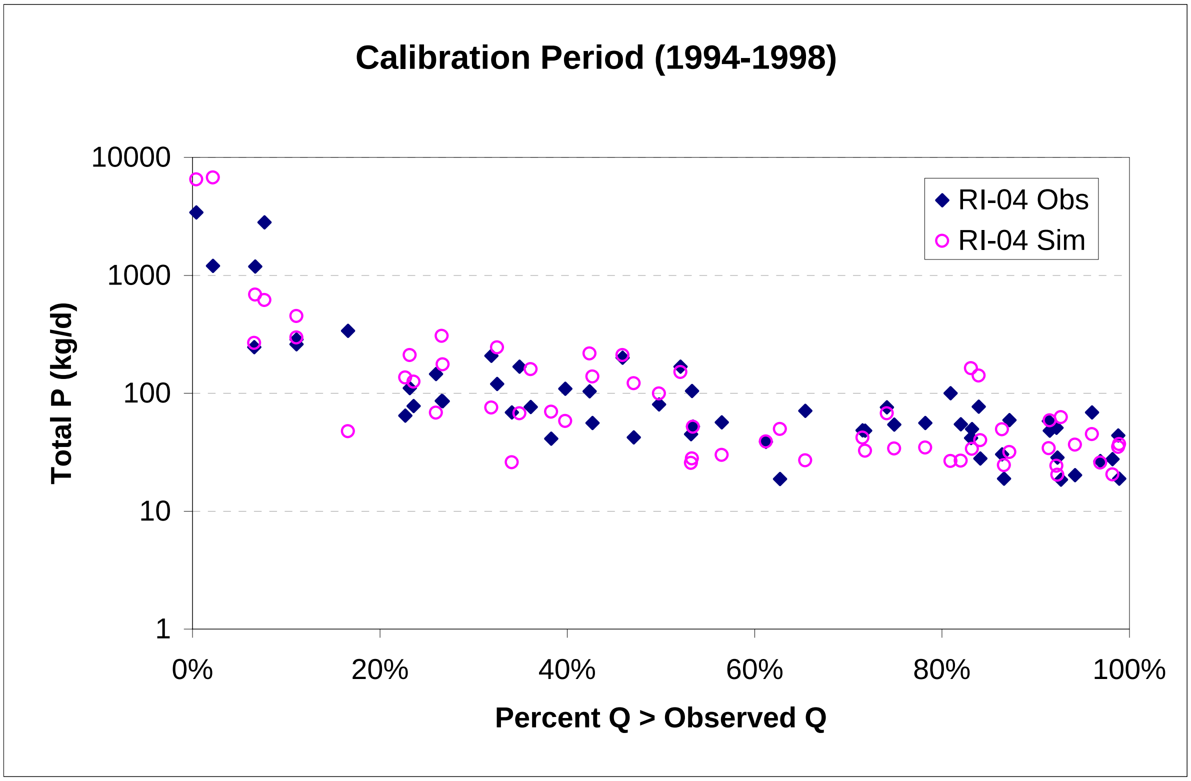
20-100% - Obs

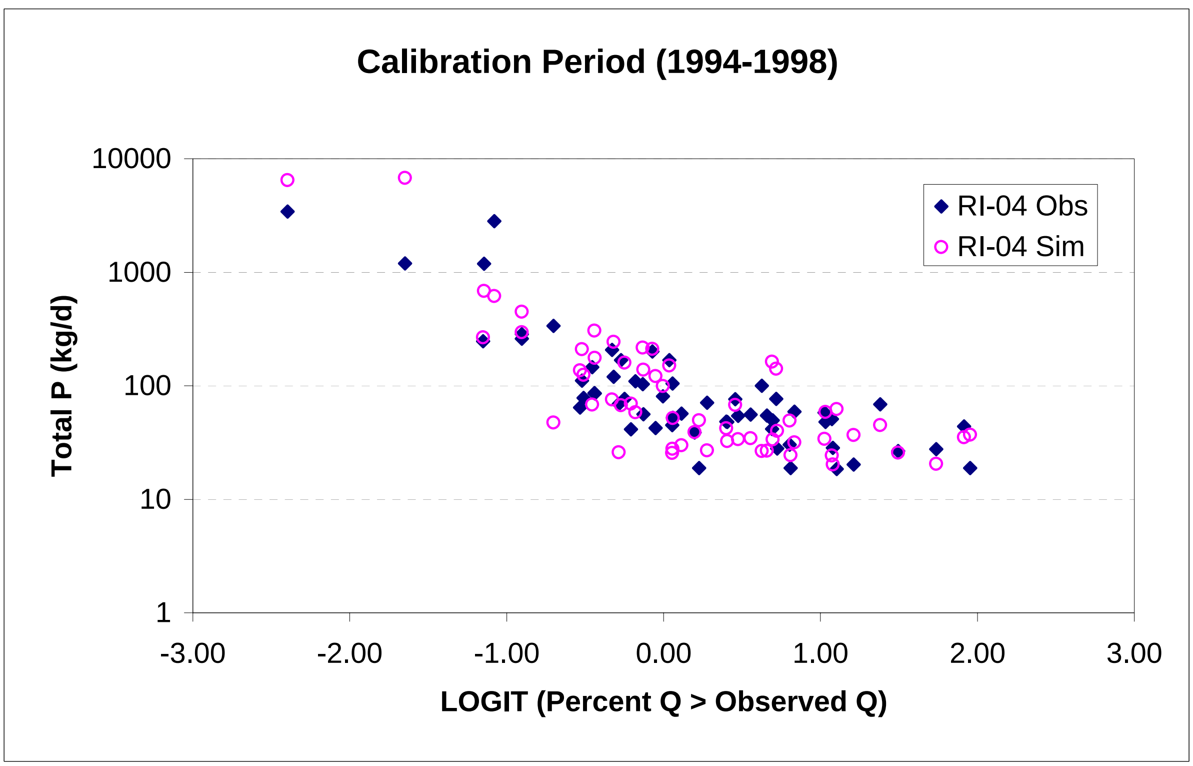
-1.58214	6.668044
0.141975	0.063115
0.810684	0.345105
124.1831	29
2.04523	
0.290372	
-1.87251	
-1.29177	

20-100% - Sim

-2.81377	5.889217
0.336048	0.149389
0.707393	0.816846
70.10915	29
2.04523	
0.687296	
-3.50107	
-2.12648	




Calibration Period (1994-1998)
10000
1000
100
10
1
Total P (kg/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-04 Obs
RI-04 Sim


Calibration Period (1994-1998)
10000
1000
100
10
1
Total P (kg/d)
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
RI-04 Obs
RI-04 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.40473	4.856276
0.592606	0.794459
0.483602	0.851216
5.618934	6
2.446912	
1.450055	
-2.85479	
0.045324	

0-20% - Sim

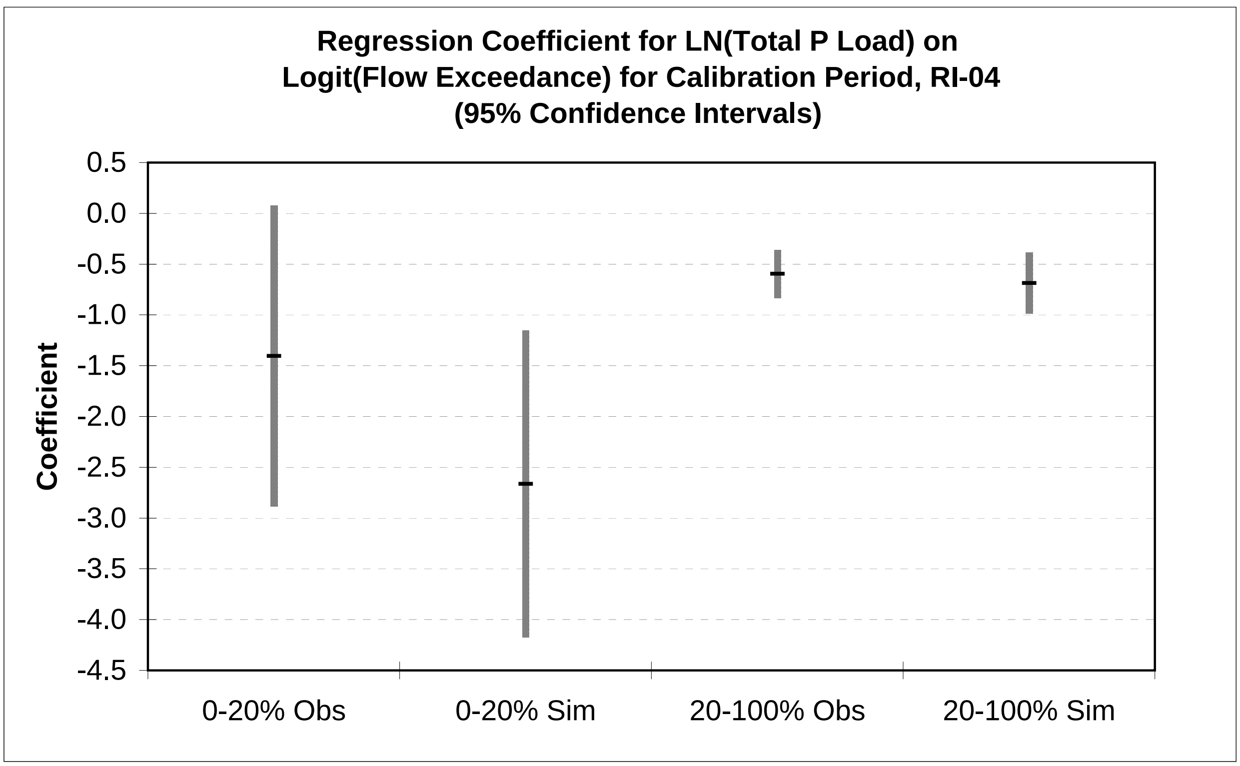
-2.66446	3.169169
0.604946	0.811002
0.763773	0.868942
19.39928	6
2.446912	
1.480251	
-4.14471	
-1.18421	

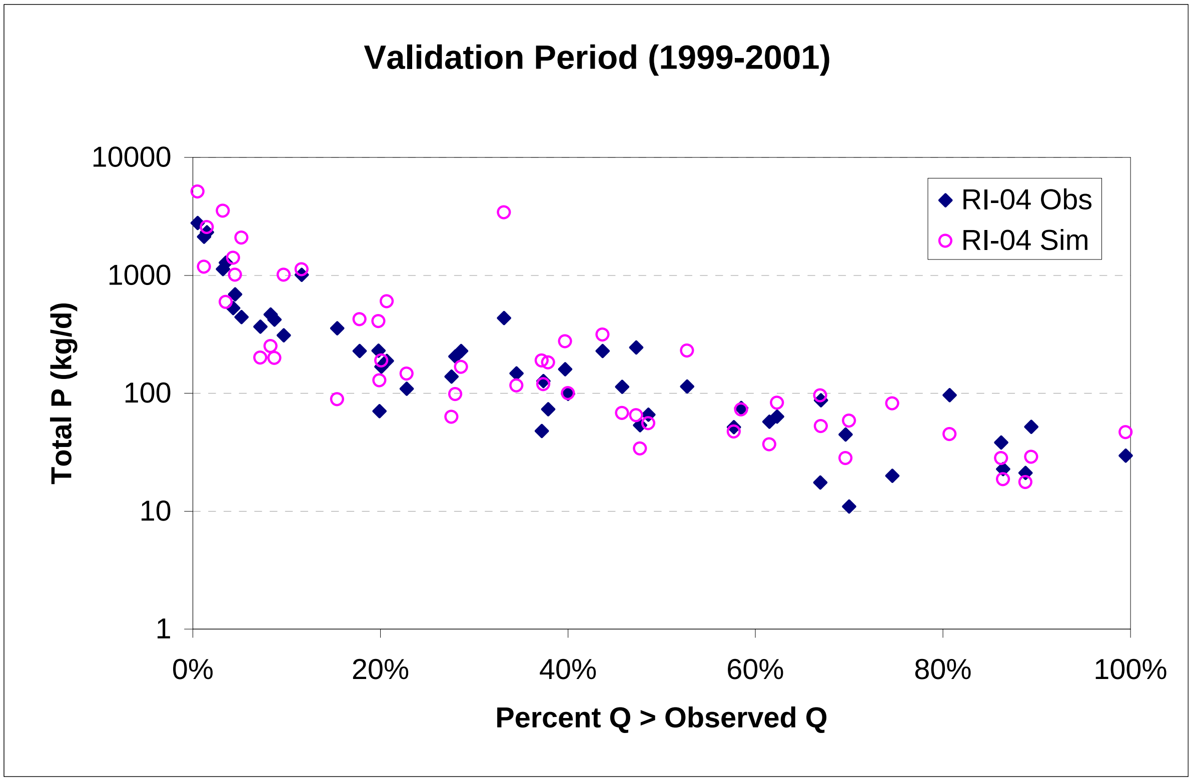
20-100% - Obs

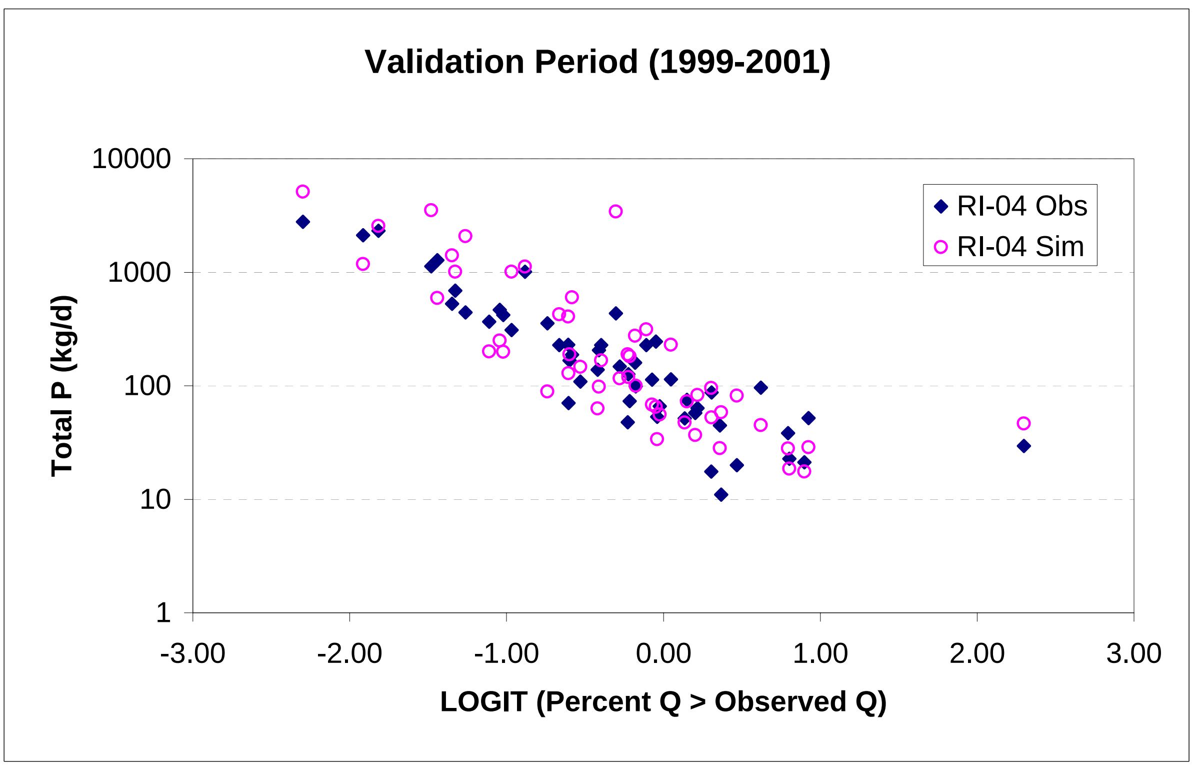
-0.59546	4.289114
0.101692	0.077717
0.411672	0.478416
34.28682	49
2.009575	
0.204358	
-0.79982	
-0.3911	

20-100% - Sim

-0.68681	4.332107
0.132577	0.10132
0.35388	0.623714
26.8373	49
2.009575	
0.266423	
-0.95323	
-0.42039	




Validation Period (1999-2001)
Total P (kg/d)
10000
1000
100
10
1
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-04 Obs
RI-04 Sim


Validation Period (1999-2001)
Total P (kg/d)
10000
1000
100
10
1
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
RI-04 Obs
RI-04 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.75709	4.23962
0.243028	0.314635
0.777027	0.467529
52.27267	15
2.13145	
0.518002	
-2.27509	
-1.23909	

0-20% - Sim

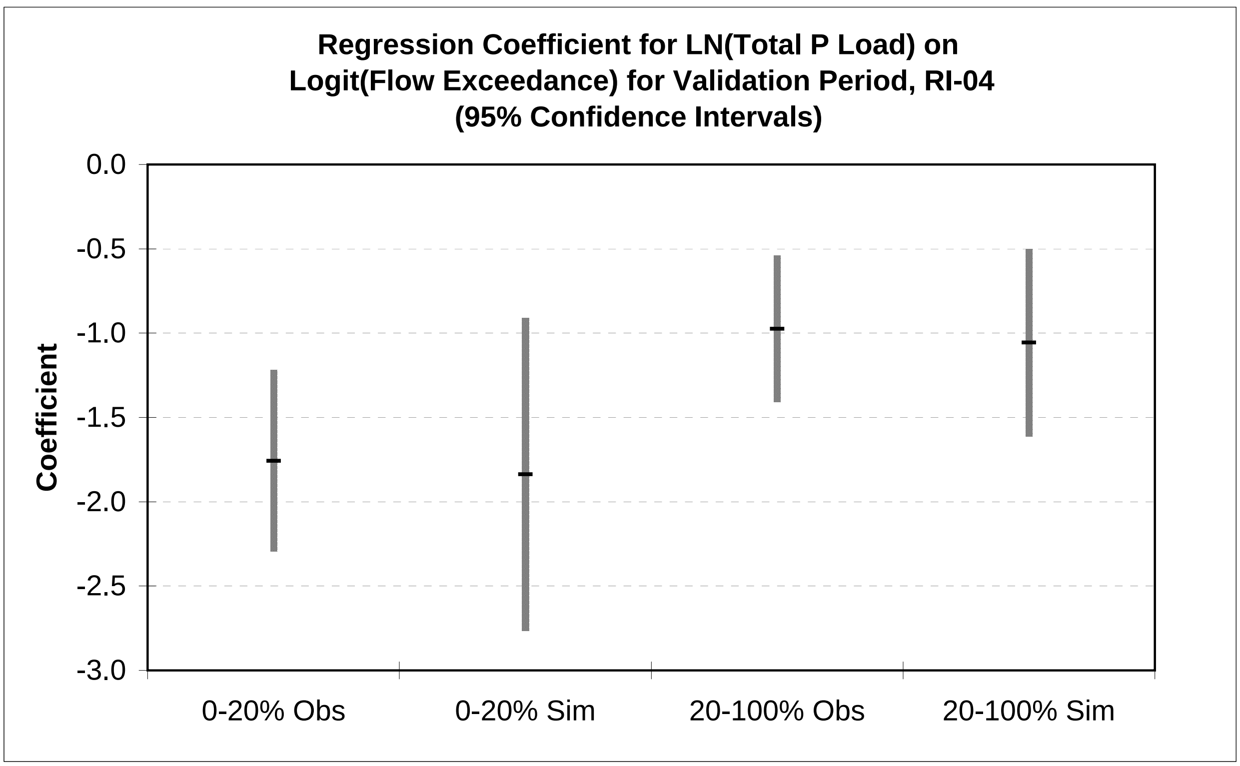
-1.83807	4.325588
0.426486	0.552148
0.553231	0.82046
18.57443	15
2.13145	
0.909034	
-2.74711	
-0.92904	

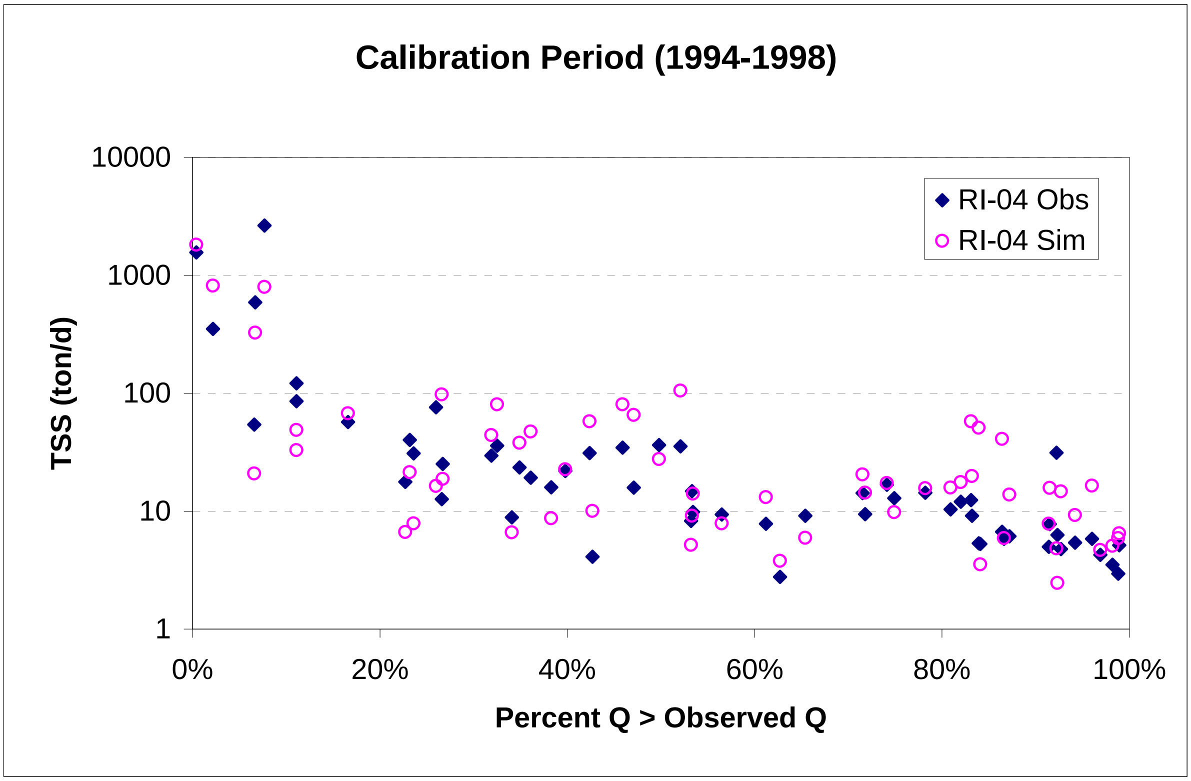
20-100% - Obs

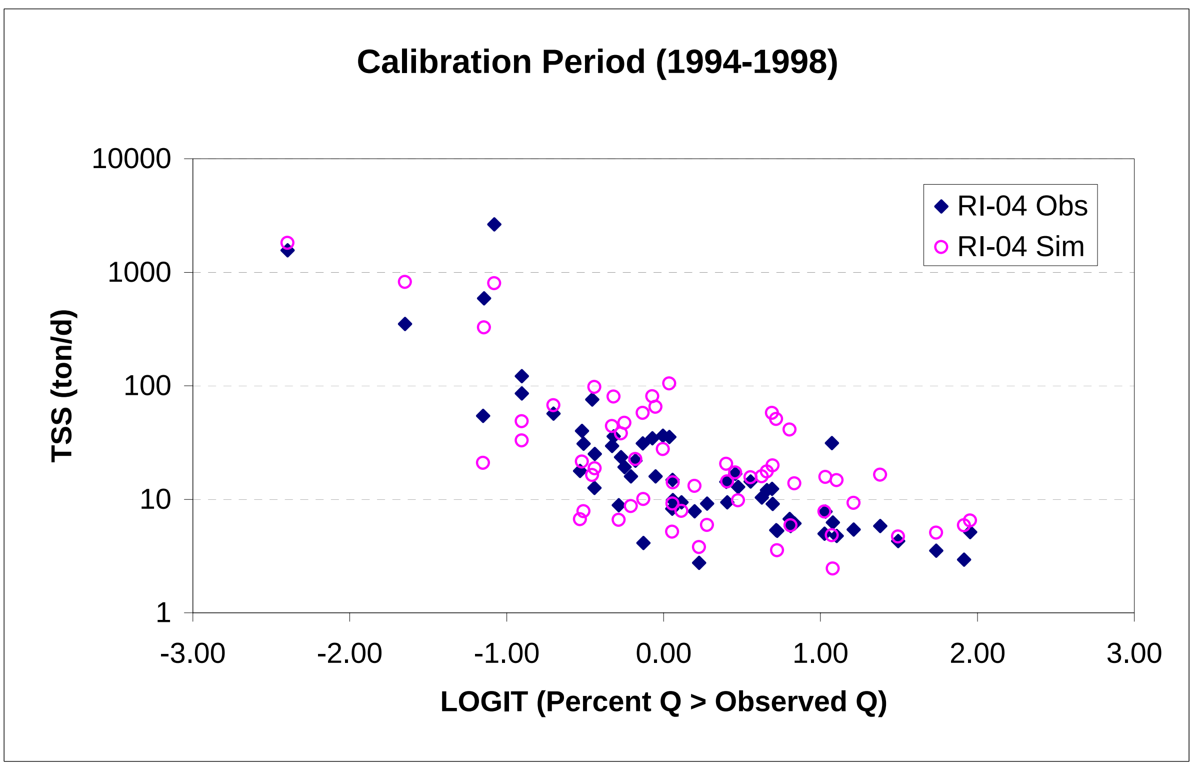
-0.97497	4.461549
0.203807	0.11751
0.416957	0.670286
22.88448	32
2.036933	
0.415142	
-1.39011	
-0.55983	

20-100% - Sim

-1.05692	4.613667
0.263999	0.152214
0.333722	0.868245
16.02803	32
2.036933	
0.537748	
-1.59467	
-0.51917	




Calibration Period (1994-1998)
10000
1000
100
10
1
TSS (ton/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-04 Obs
RI-04 Sim


Calibration Period (1994-1998)
10000
1000
100
10
1
TSS (ton/d)
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
RI-04 Obs
RI-04 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.61319	3.593044
0.922537	1.236769
0.337586	1.325127
3.057774	6
2.446912	
2.257366	
-3.87056	
0.644173	

0-20% - Sim

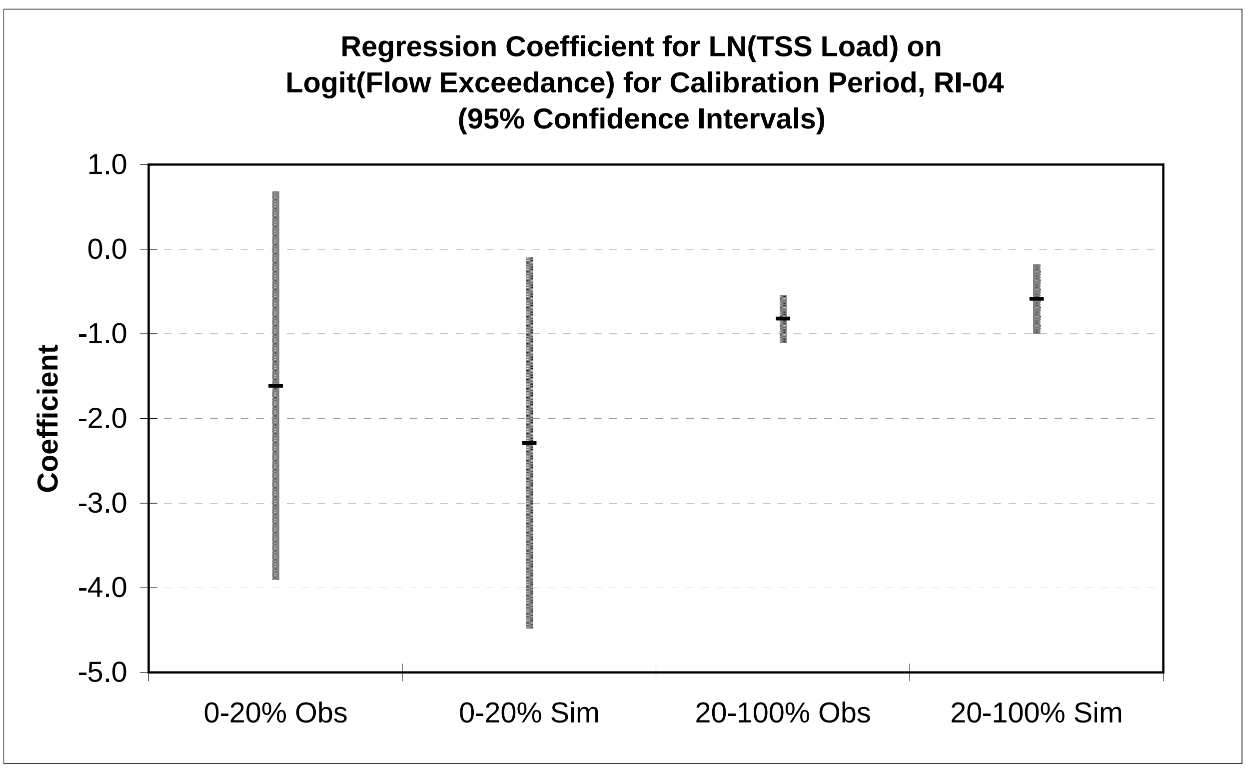
-2.29048	2.321106
0.879786	1.179456
0.530441	1.263719
6.777956	6
2.446912	
2.152758	
-4.44324	
-0.13772	

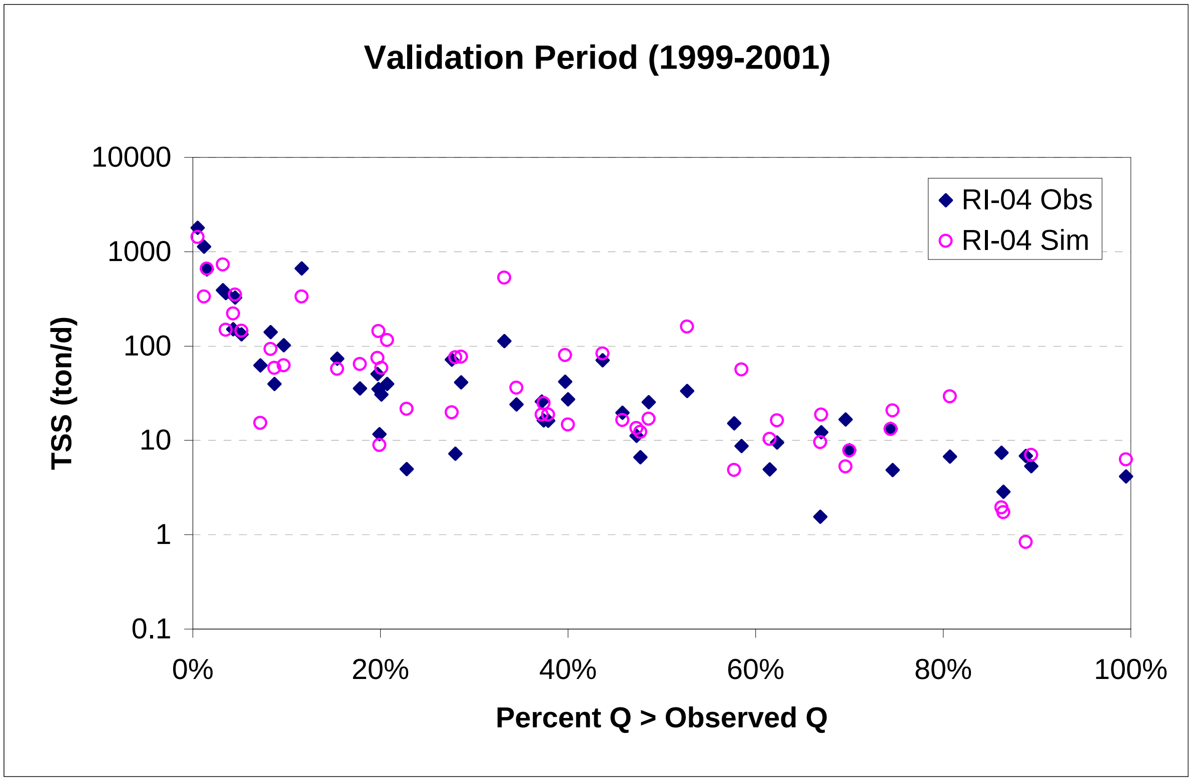
20-100% - Obs

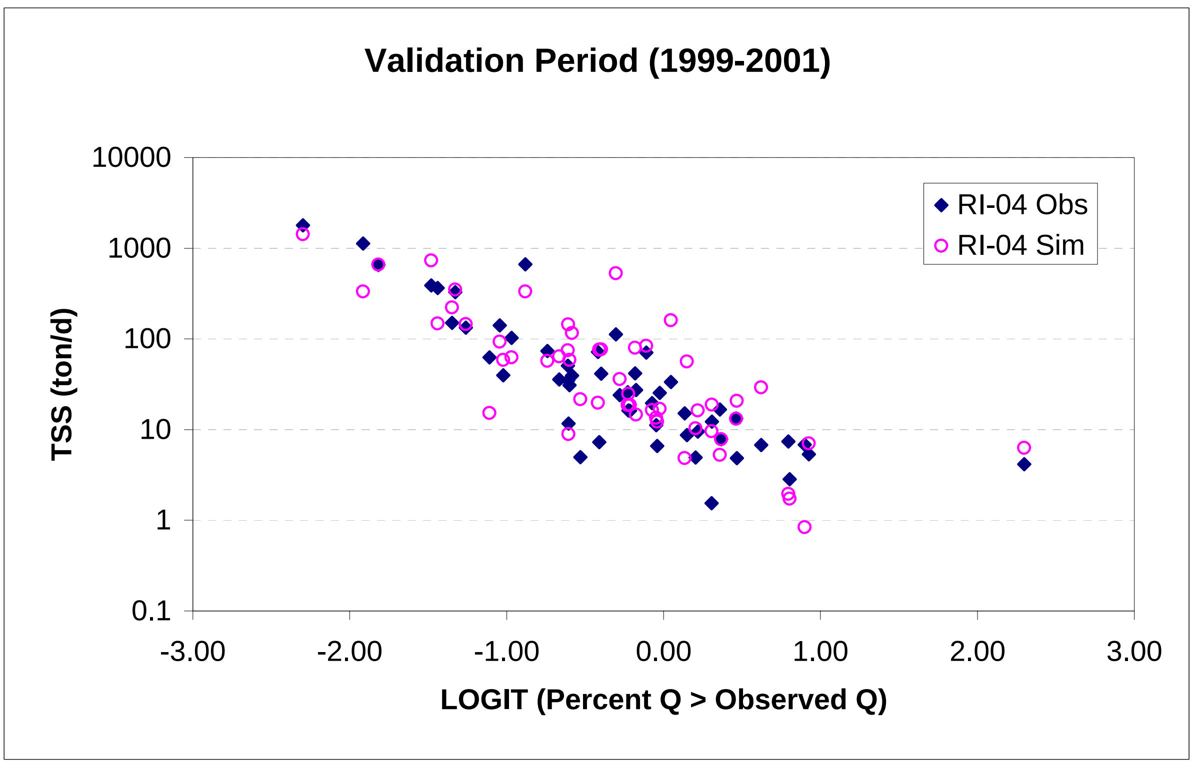
-0.82186	2.765569
0.11978	0.091541
0.490001	0.563511
47.07854	49
2.009575	
0.240707	
-1.06256	
-0.58115	

20-100% - Sim

-0.58739	2.94584
0.185061	0.141431
0.17054	0.870627
10.07461	49
2.009575	
0.371893	
-0.95929	
-0.2155	




Validation Period (1999-2001)
10000
1000
100
10
1
0.1
TSS (ton/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-04 Obs
RI-04 Sim


Validation Period (1999-2001)
10000
1000
100
10
1
0.1
TSS (ton/d)
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
RI-04 Obs
RI-04 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.40553	2.189213
0.365861	0.463312
0.729868	0.735182
43.23034	16
2.119905	
0.77559	
-3.18112	
-1.62994	

0-20% - Sim

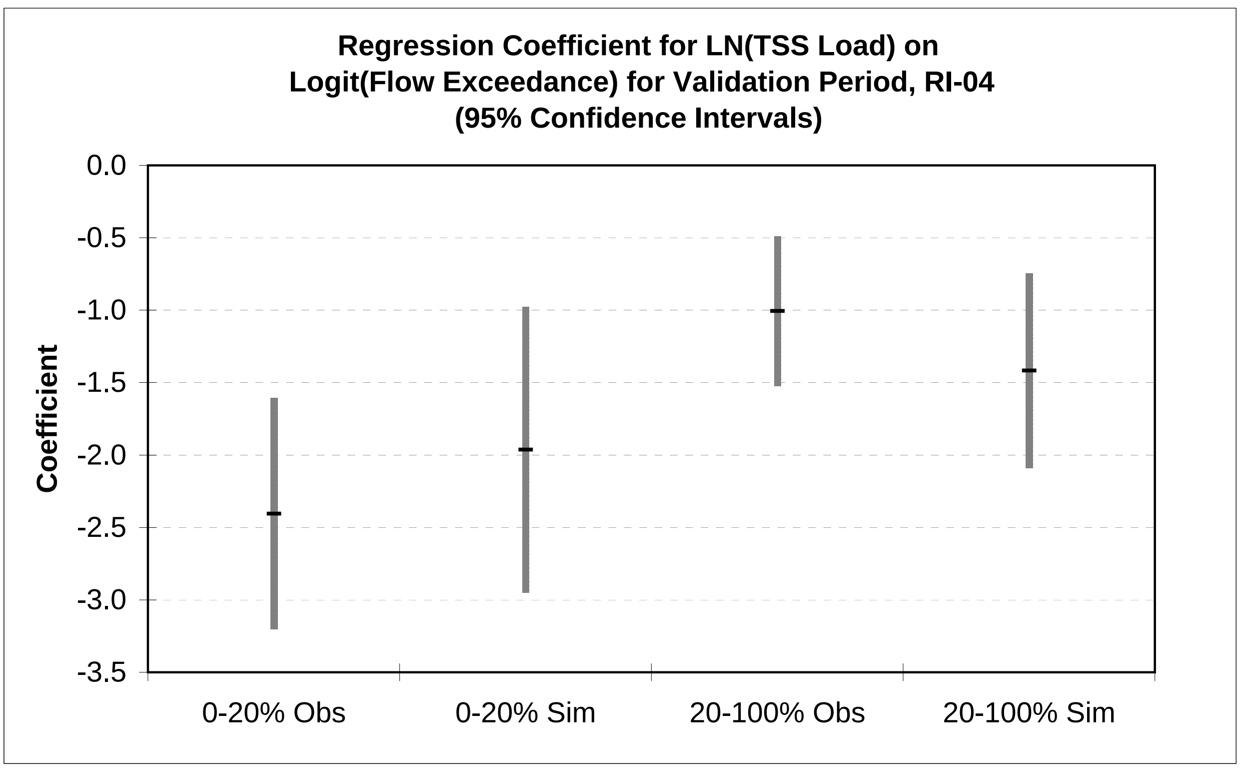
-1.96335	2.602983
0.454798	0.575939
0.538056	0.913898
18.63622	16
2.119905	
0.964129	
-2.92748	
-0.99922	

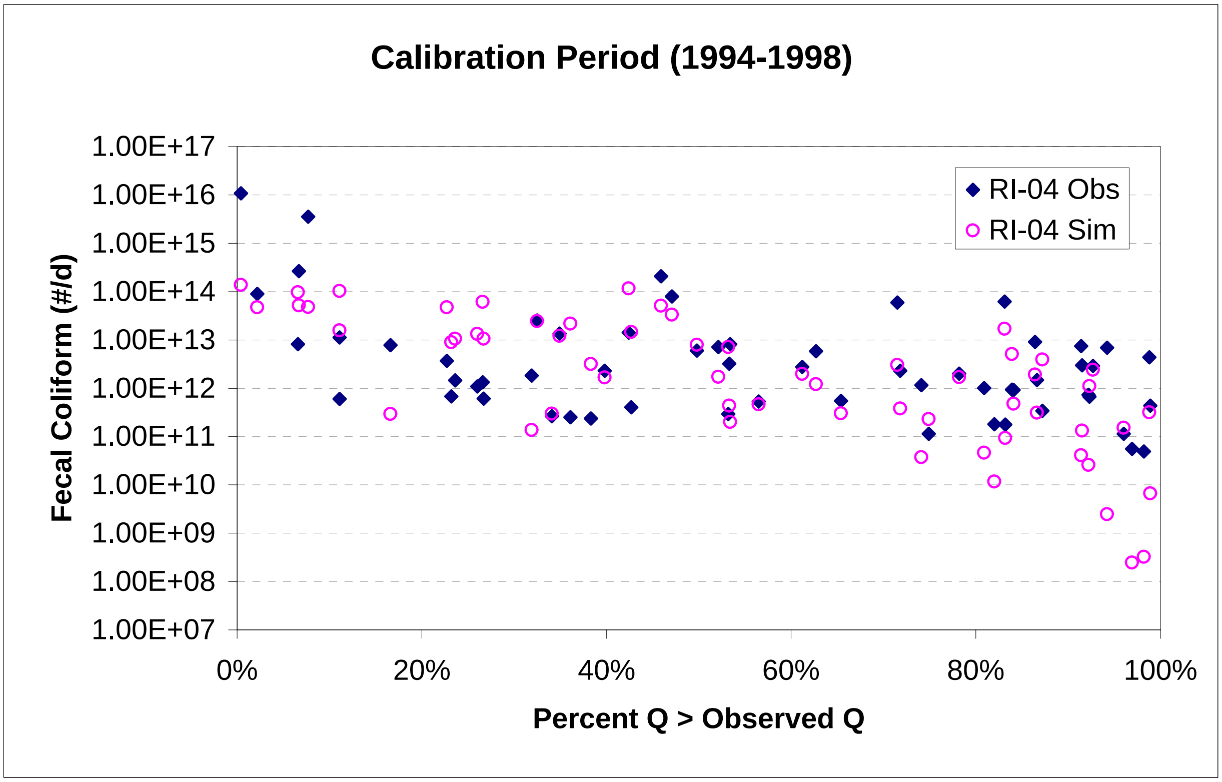
20-100% - Obs

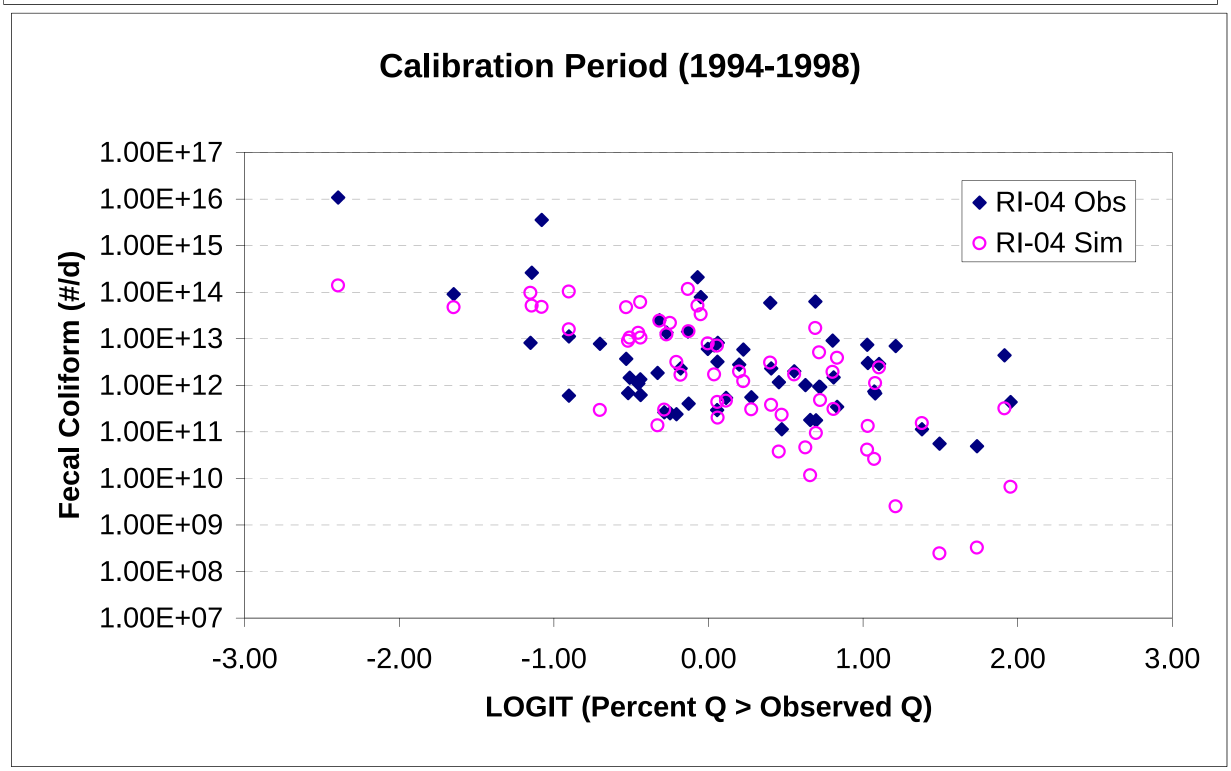
-1.00626	2.741522
0.243232	0.139529
0.341514	0.80418
17.115	33
2.034515	
0.49486	
-1.50112	
-0.5114	

20-100% - Sim

-1.41638	3.133111
0.319572	0.183321
0.373145	1.056575
19.64377	33
2.034515	
0.650174	
-2.06656	
-0.76621	




Calibration Period (1994-1998)
1.00E+17
1.00E+16
1.00E+15
1.00E+14
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
Fecal Coliform (#/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-04 Obs
RI-04 Sim


Calibration Period (1994-1998)
1.00E+17
1.00E+16
1.00E+15
1.00E+14
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
Fecal Coliform (#/d)
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
RI-04 Obs
RI-04 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-4.246778	26.55608
1.816381	2.435072
0.476734	2.609039
5.466451	6
2.446912	
4.444523	
-8.691301	
0.197745	

0-20% - Sim

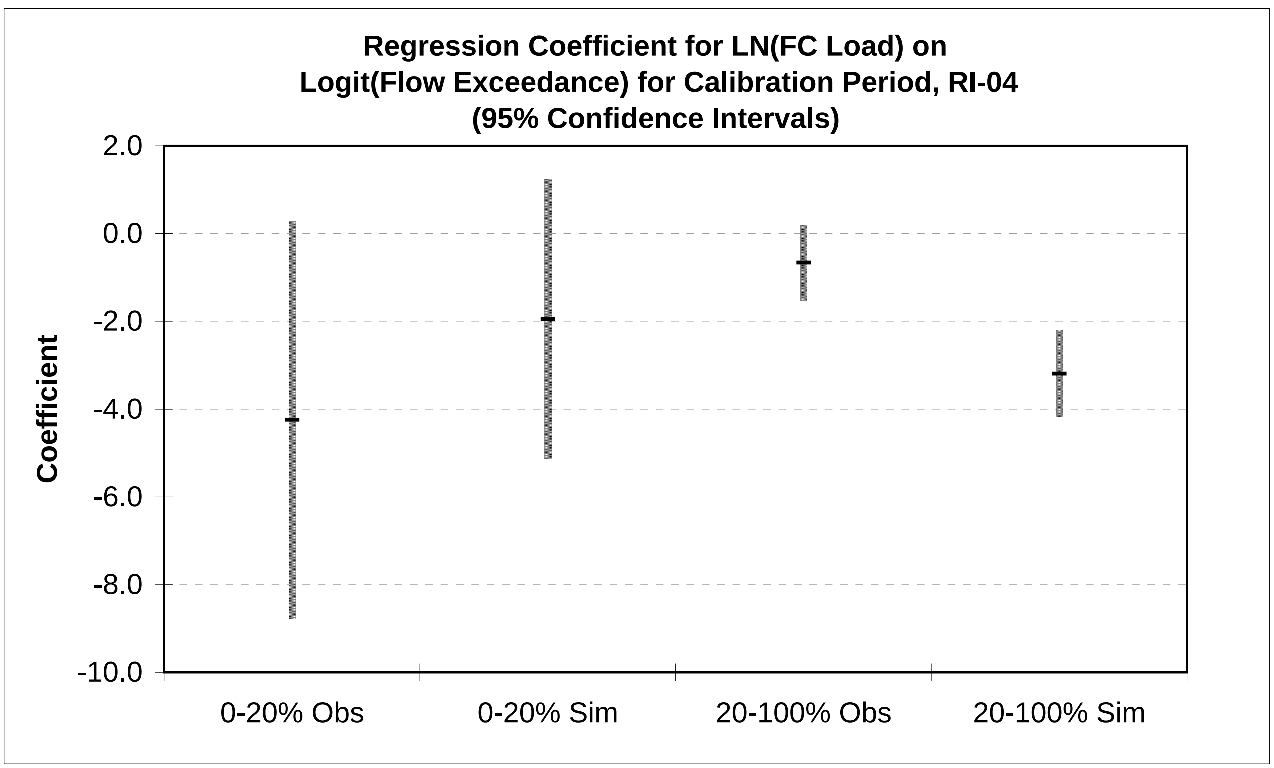
-1.947271	28.62901
1.269023	1.701275
0.281831	1.822817
2.354584	6
2.446912	
3.105187	
-5.052458	
1.157915	

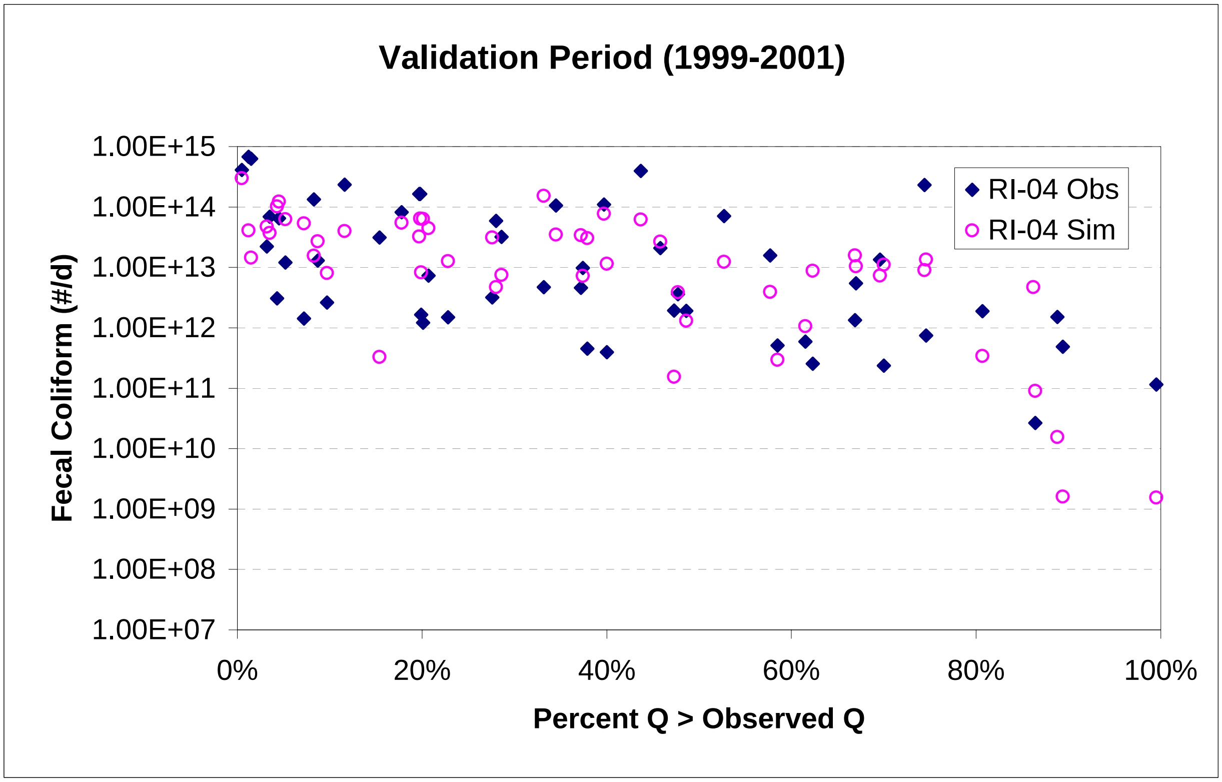
20-100% - Obs

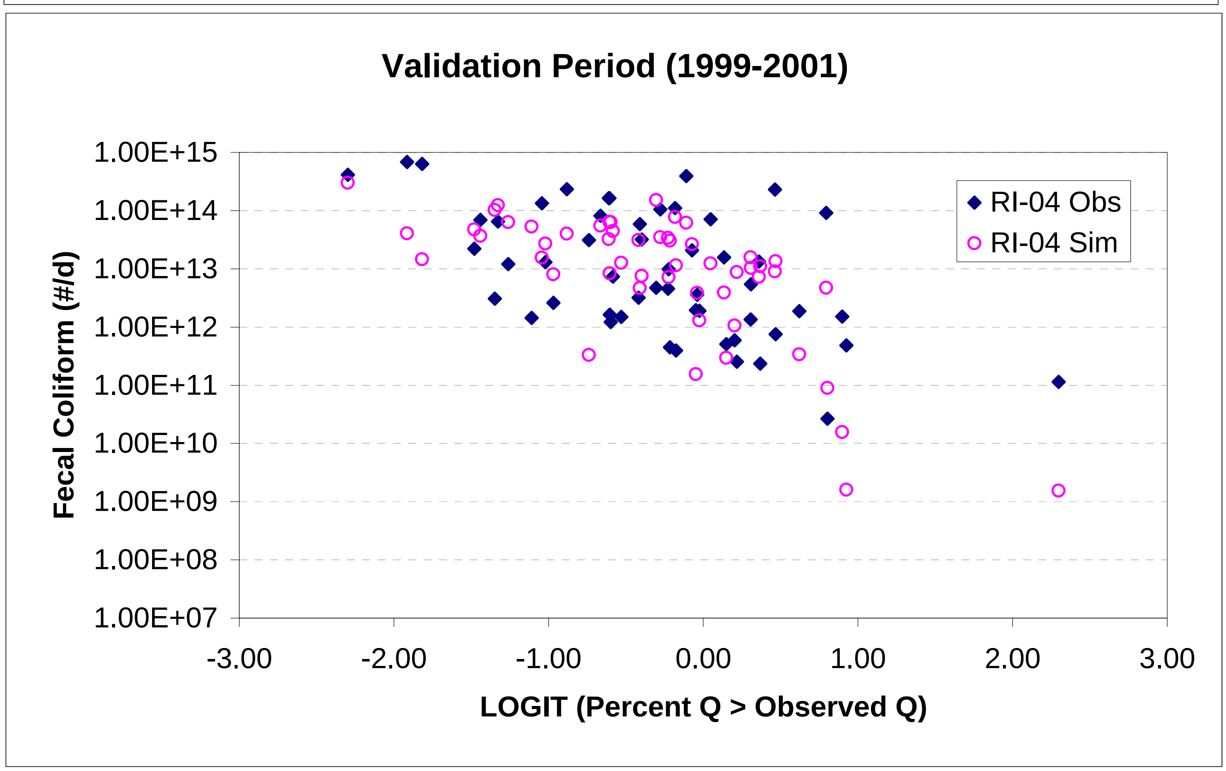
-0.666087	28.41149
0.389336	0.297546
0.056366	1.831651
2.926939	49
2.009575	
0.7824	
-1.448487	
0.116312	

20-100% - Sim

-3.190832	28.72779
0.456122	0.348587
0.499683	2.145852
48.9379	49
2.009575	
0.916612	
-4.107444	
-2.27422	




Validation Period (1999-2001)
1.00E+15
1.00E+14
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
Fecal Coliform (#/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RI-04 Obs
RI-04 Sim


Validation Period (1999-2001)
1.00E+15
1.00E+14
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
Fecal Coliform (#/d)
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
RI-04 Obs
RI-04 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.540477	29.53725
0.959922	1.21561
0.138644	1.928925
2.575362	16
2.119905	
2.034944	
-3.575421	
0.494467	

0-20% - Sim

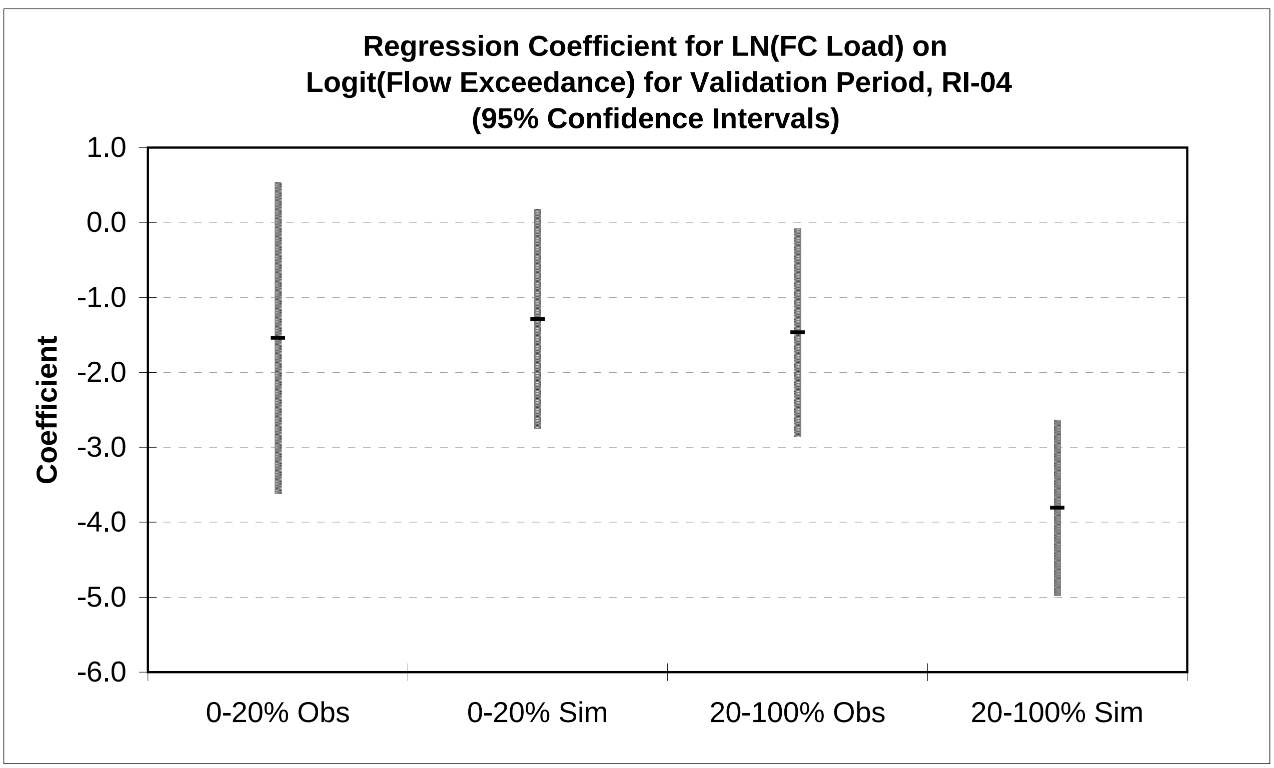
-1.287763	29.5394
0.670786	0.849459
0.187221	1.347918
3.685558	16
2.119905	
1.422003	
-2.709766	
0.134241	

20-100% - Obs

-1.468891	29.18269
0.660692	0.379004
0.130272	2.184394
4.942894	33
2.034515	
1.344188	
-2.813079	
-0.124703	

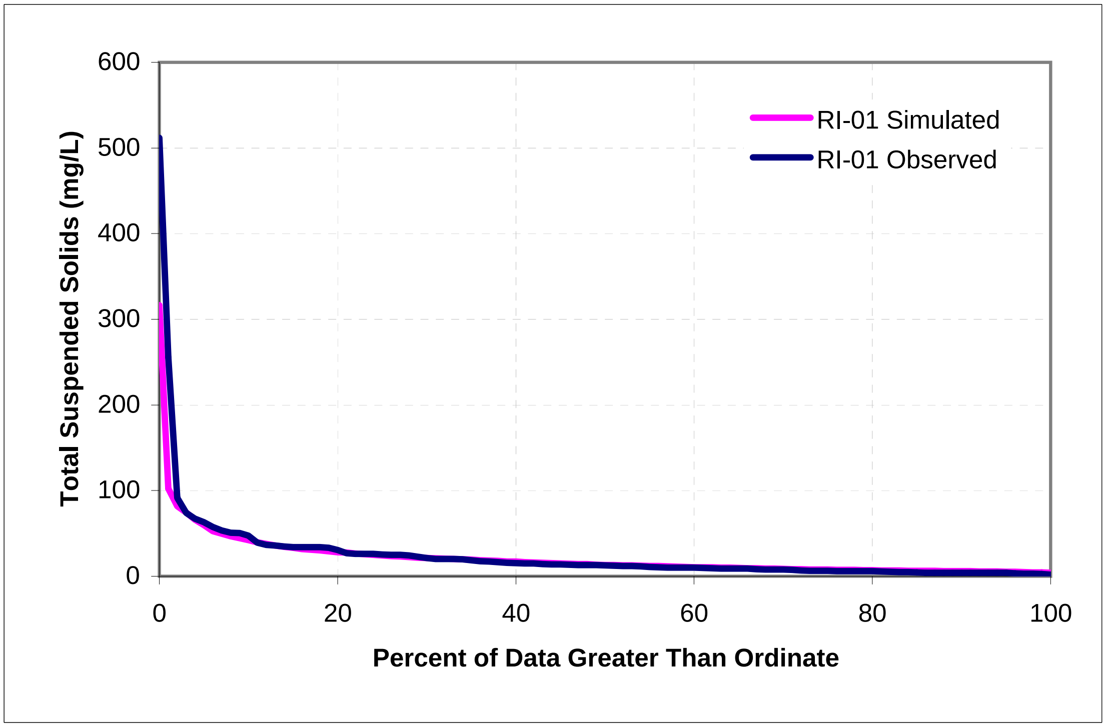
20-100% - Sim

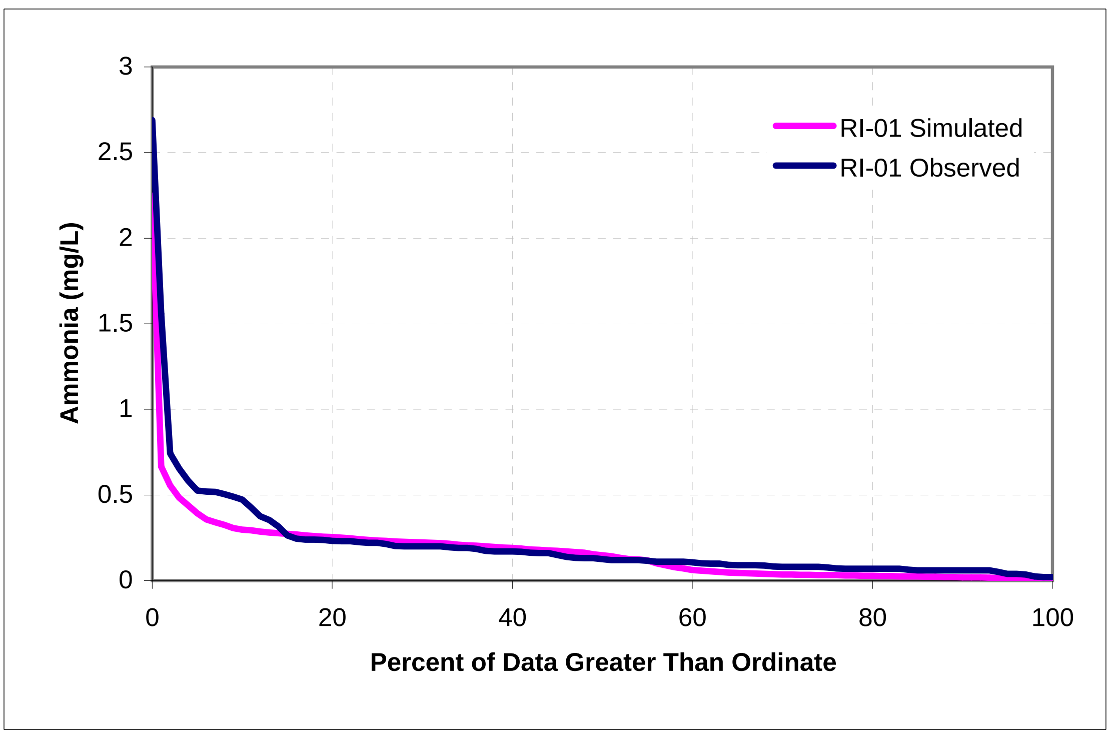
-3.805776	29.52572
0.556711	0.319355
0.586121	1.84061
46.73335	33
2.034515	
1.132637	
-4.938413	
-2.673139	



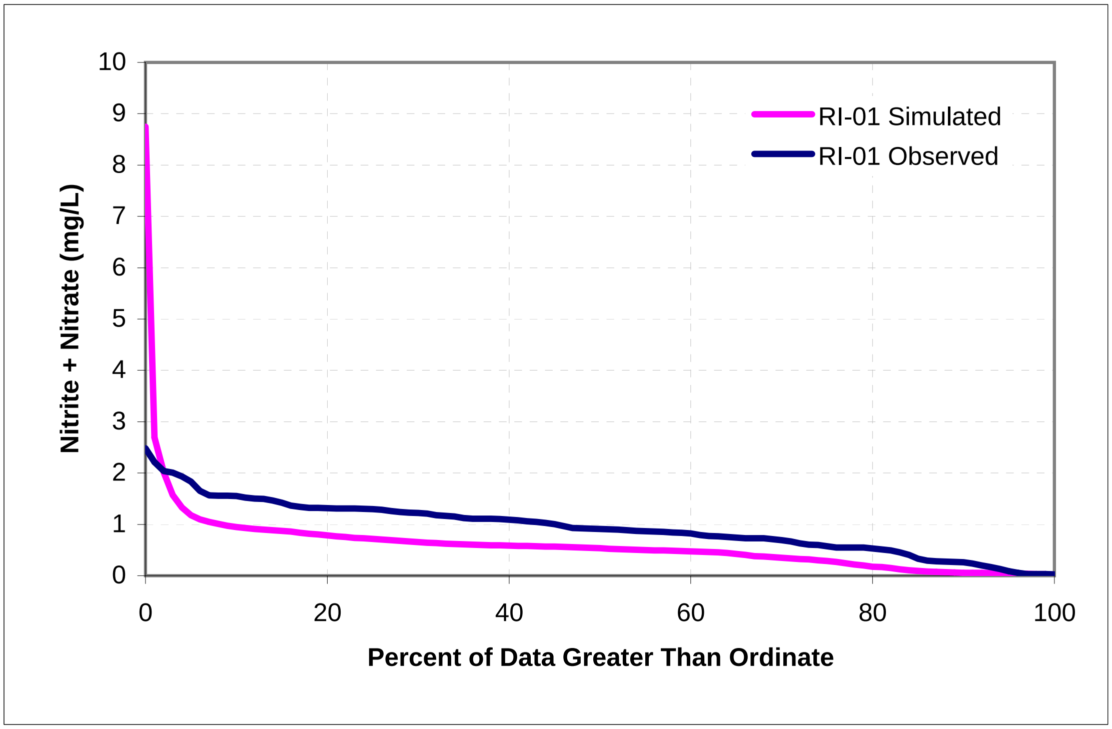
ATTACHMENT J – CONCENTRATION EXCEEDANCE CURVE PLOTS

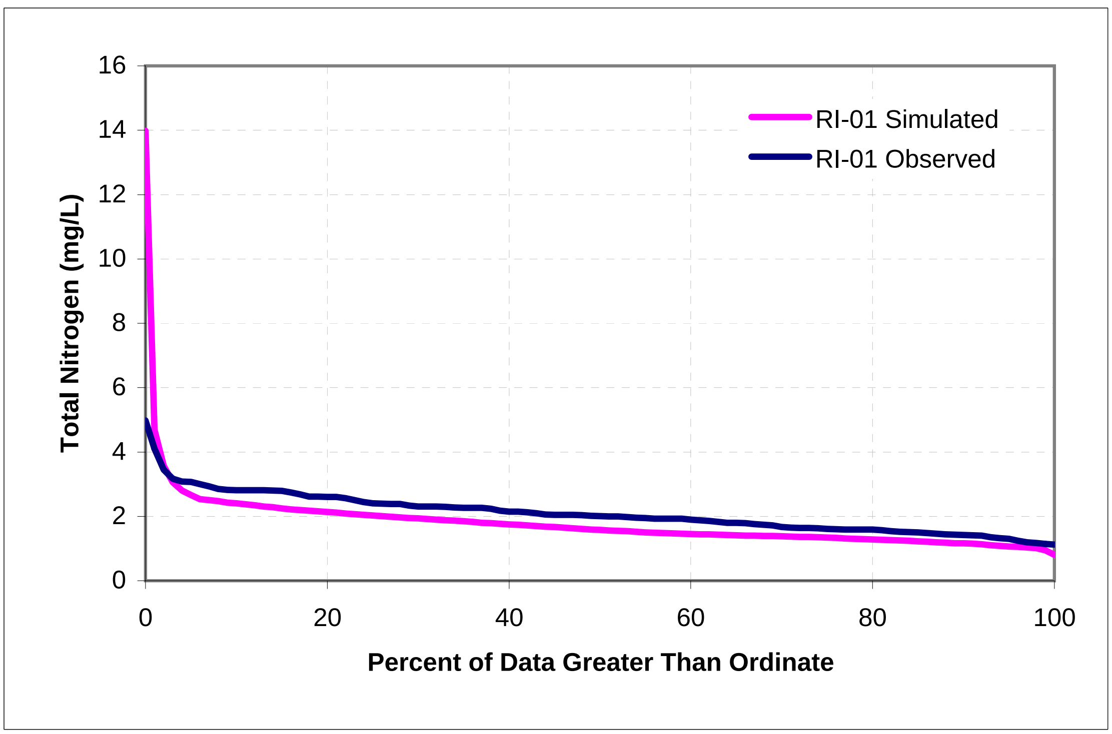
Milwaukee River, Station RI-01
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



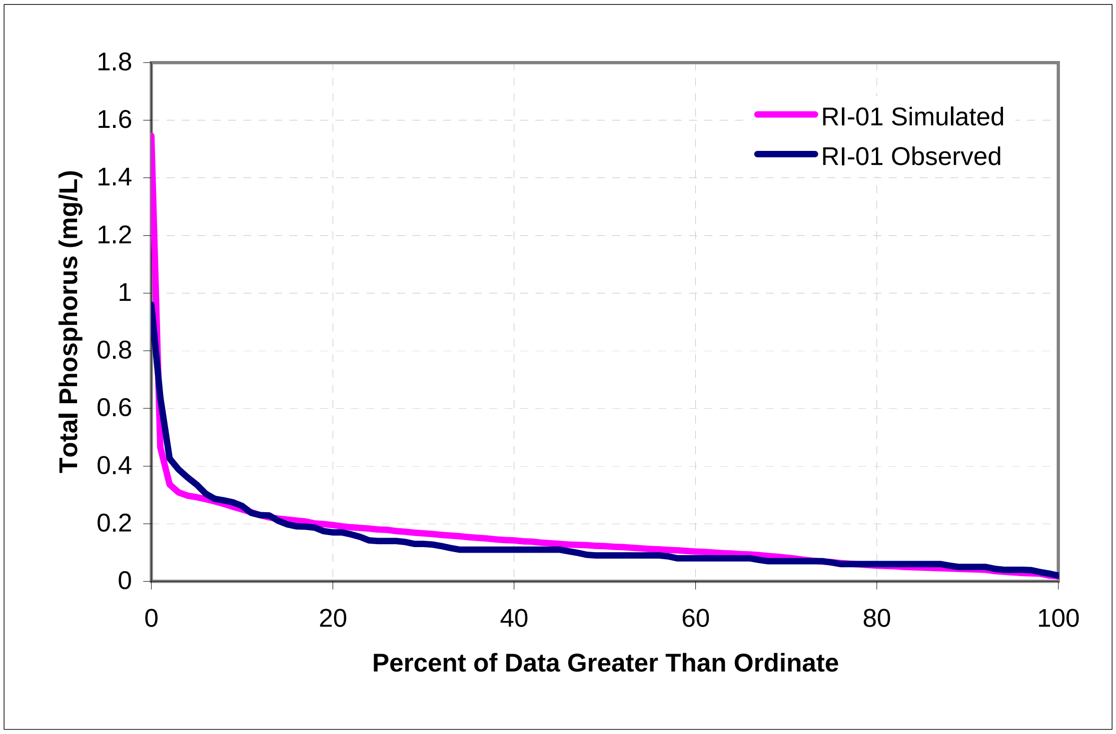


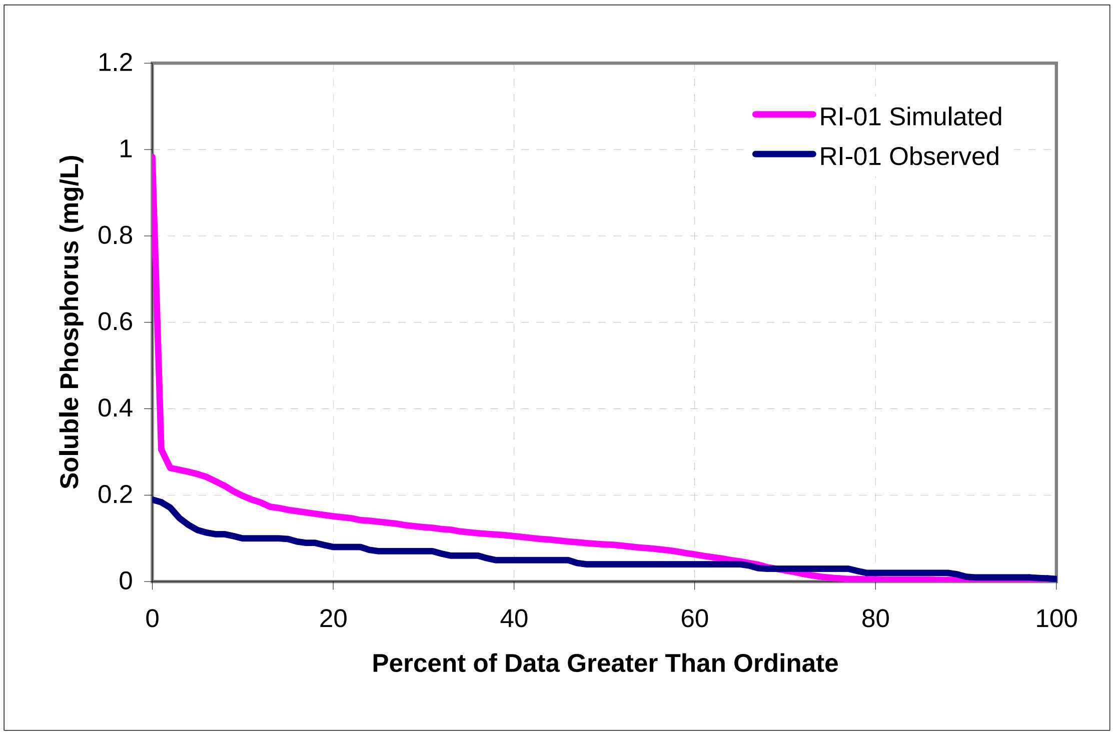
Milwaukee River, Station RI-01
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



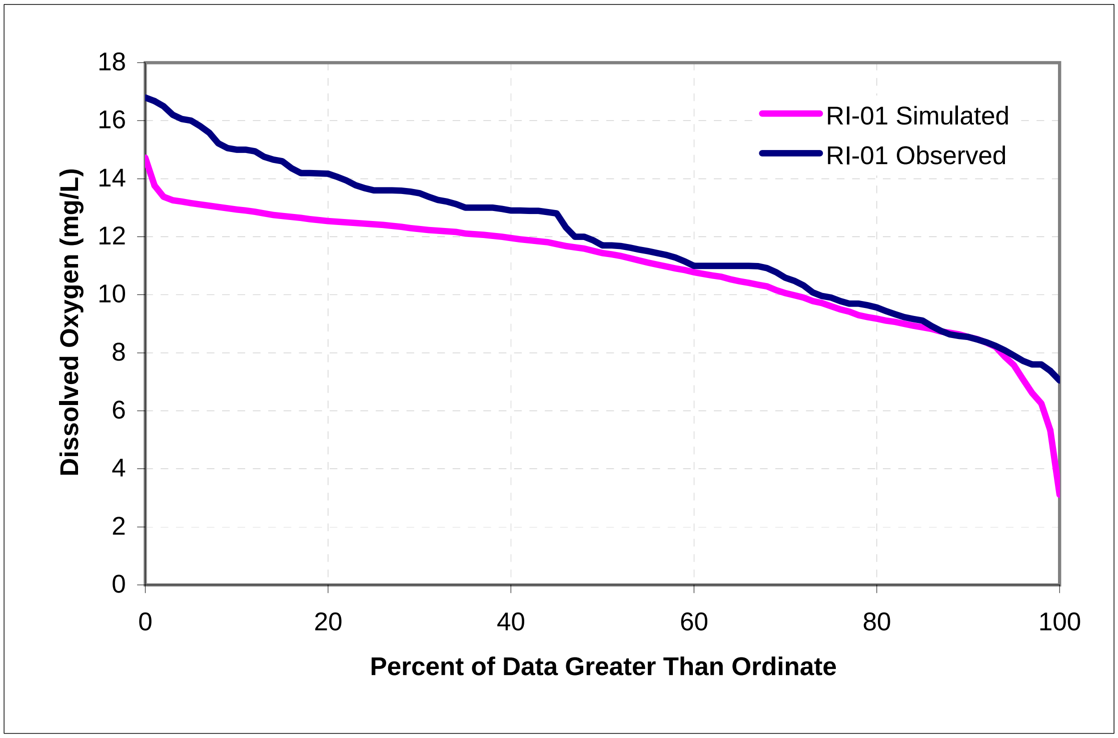


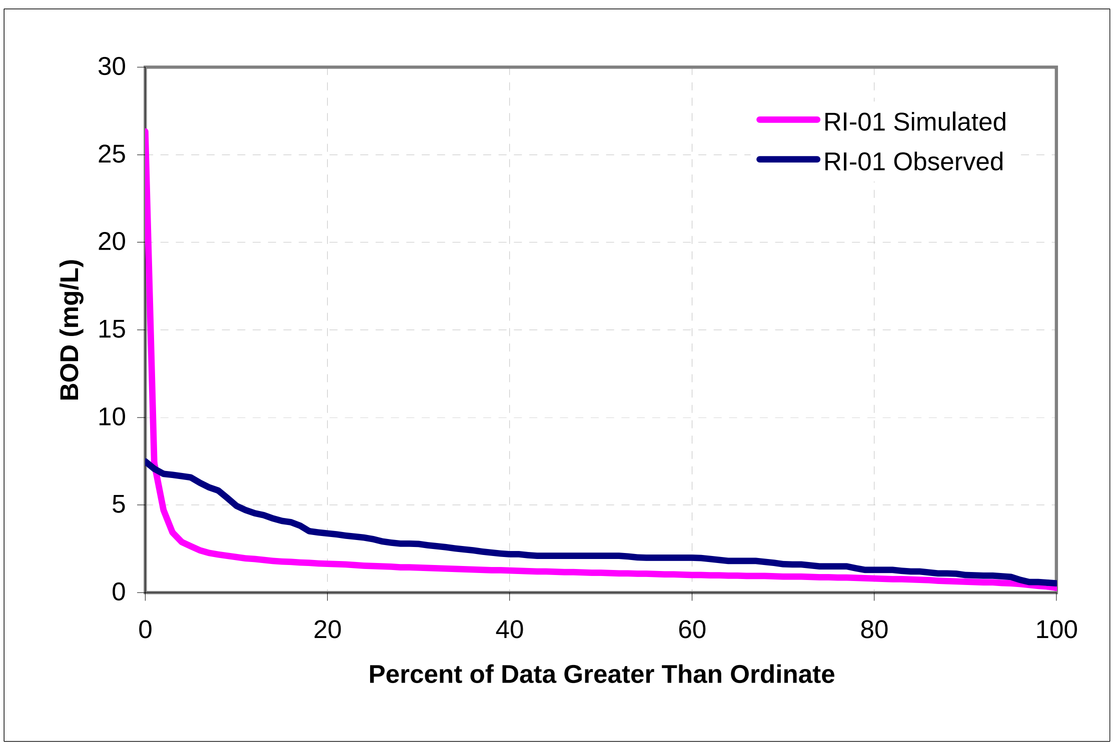
Milwaukee River, Station RI-01
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



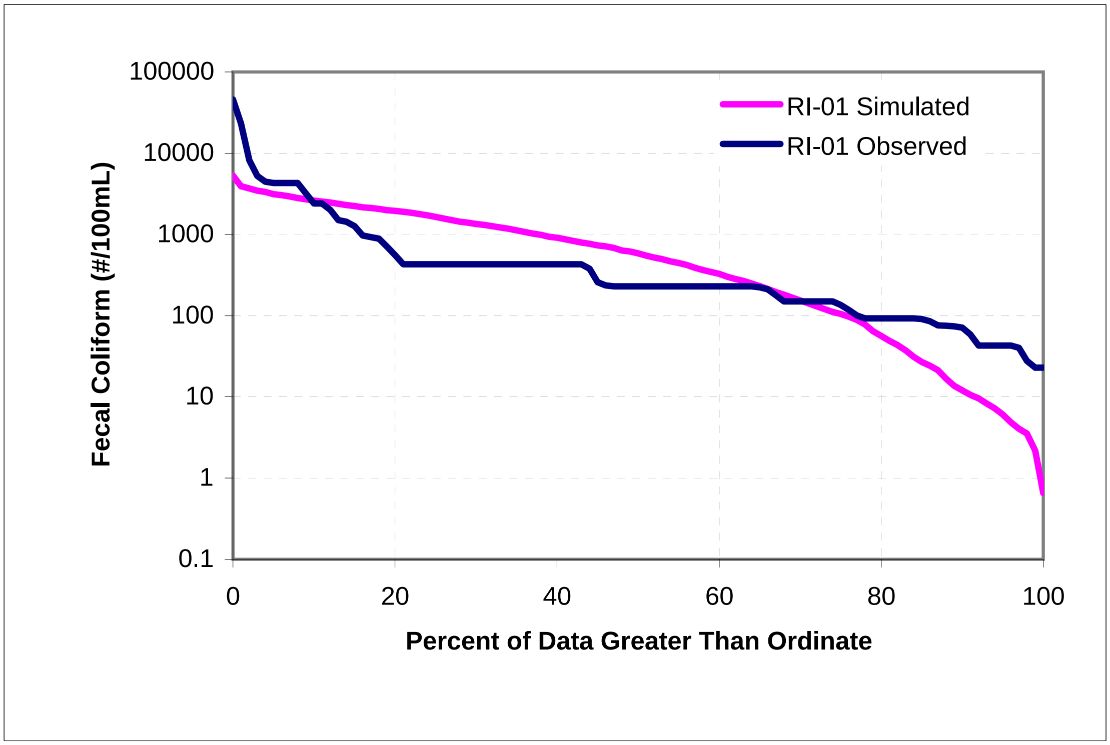


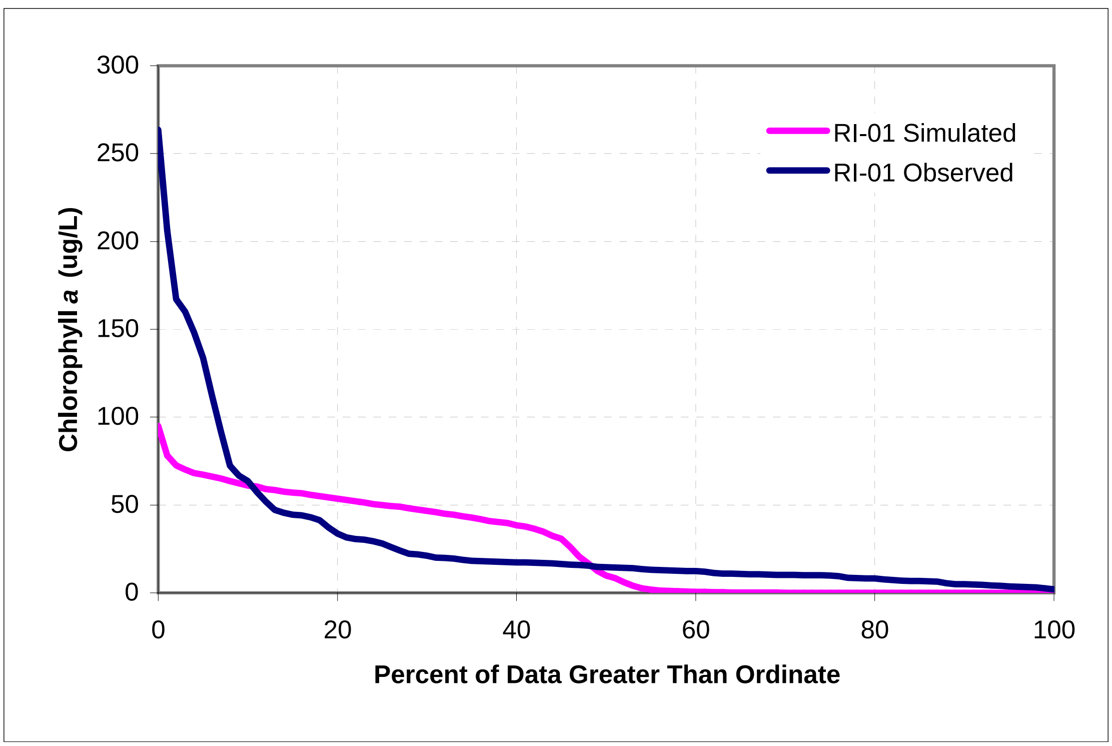
Milwaukee River, Station RI-01
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



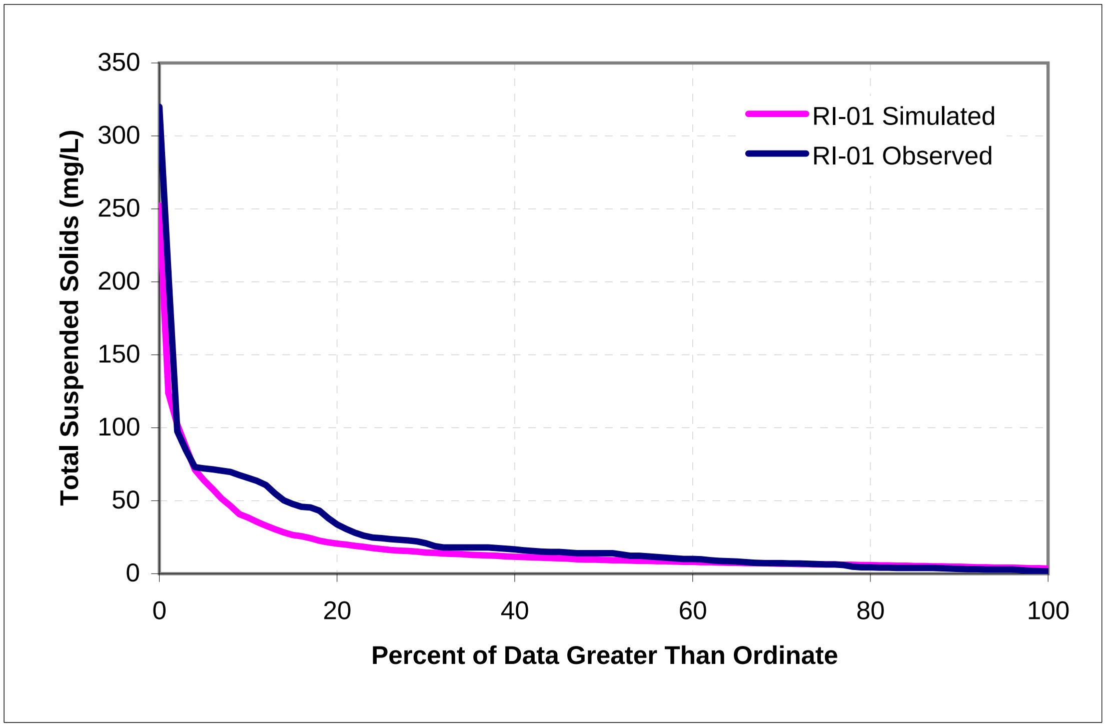


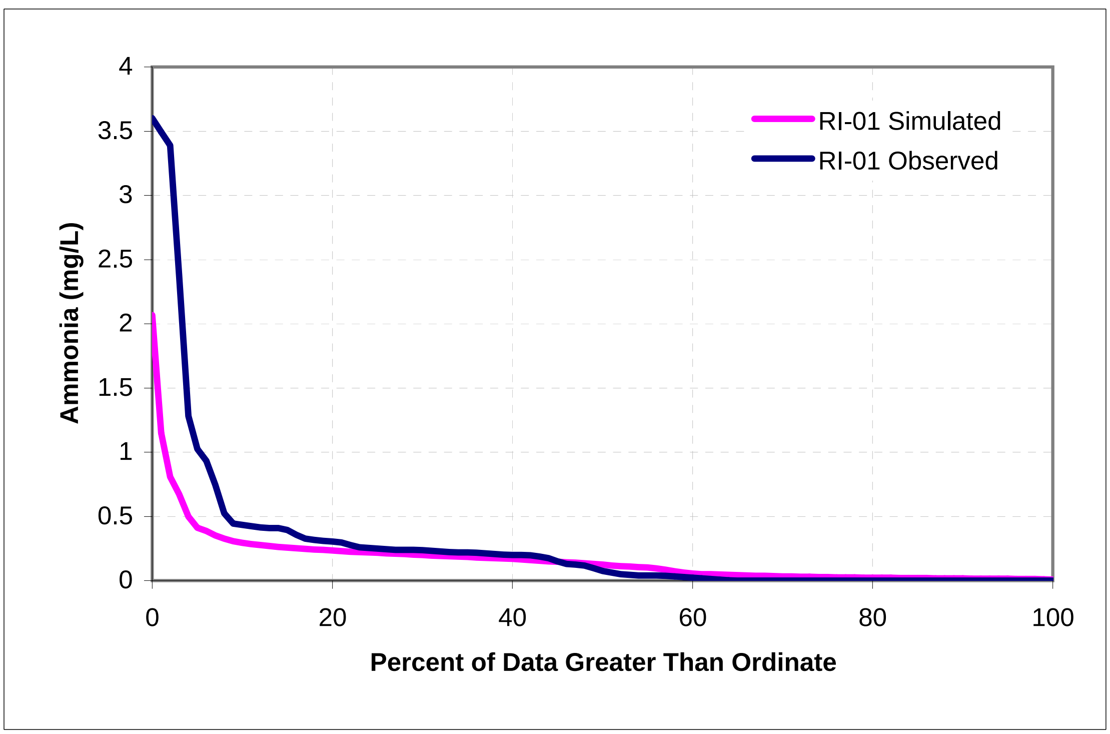
Milwaukee River, Station RI-01
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



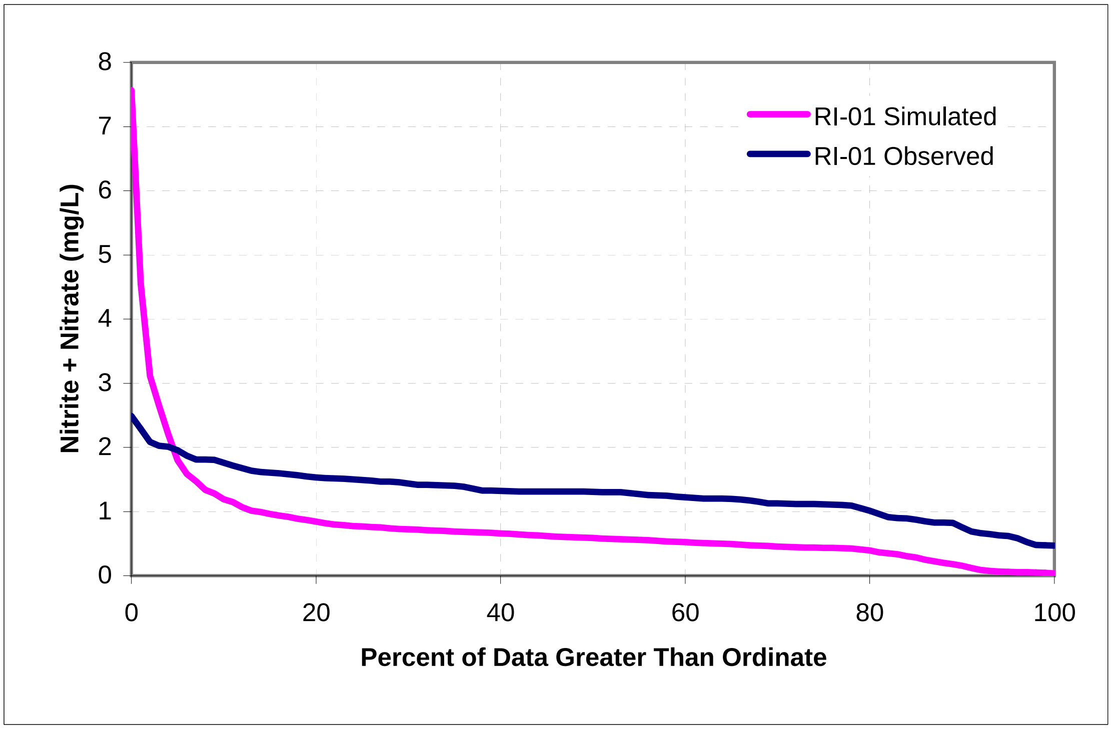


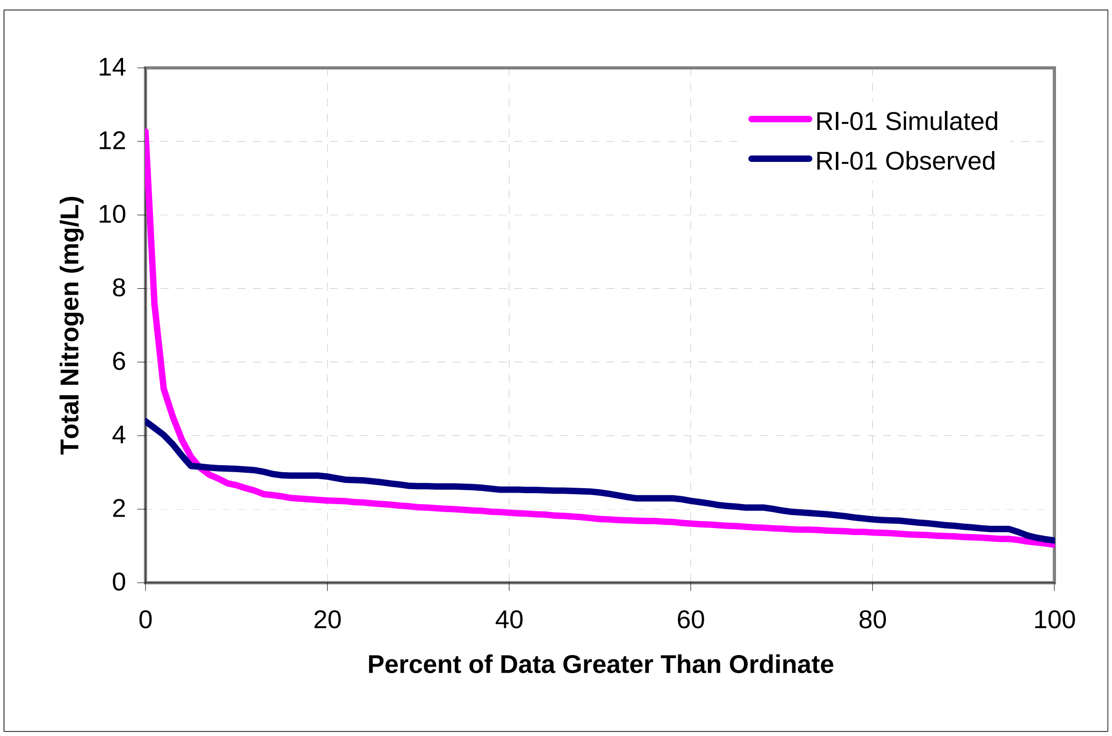
Milwaukee River, Station RI-01
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



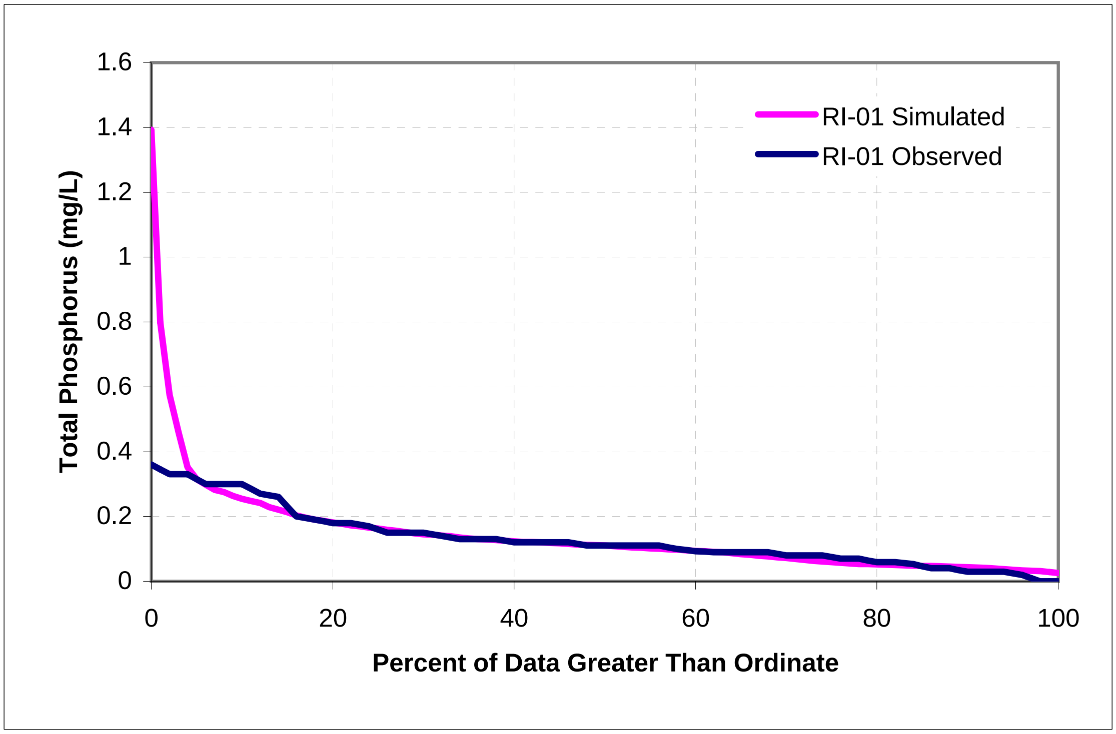


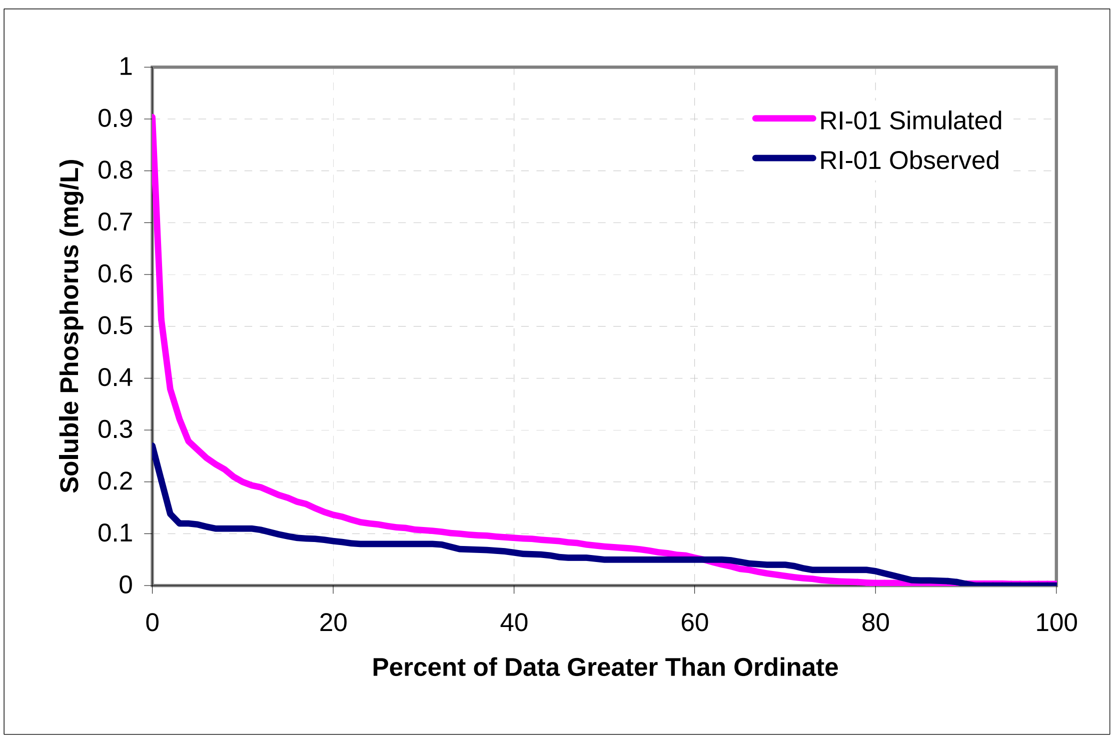
Milwaukee River, Station RI-01
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



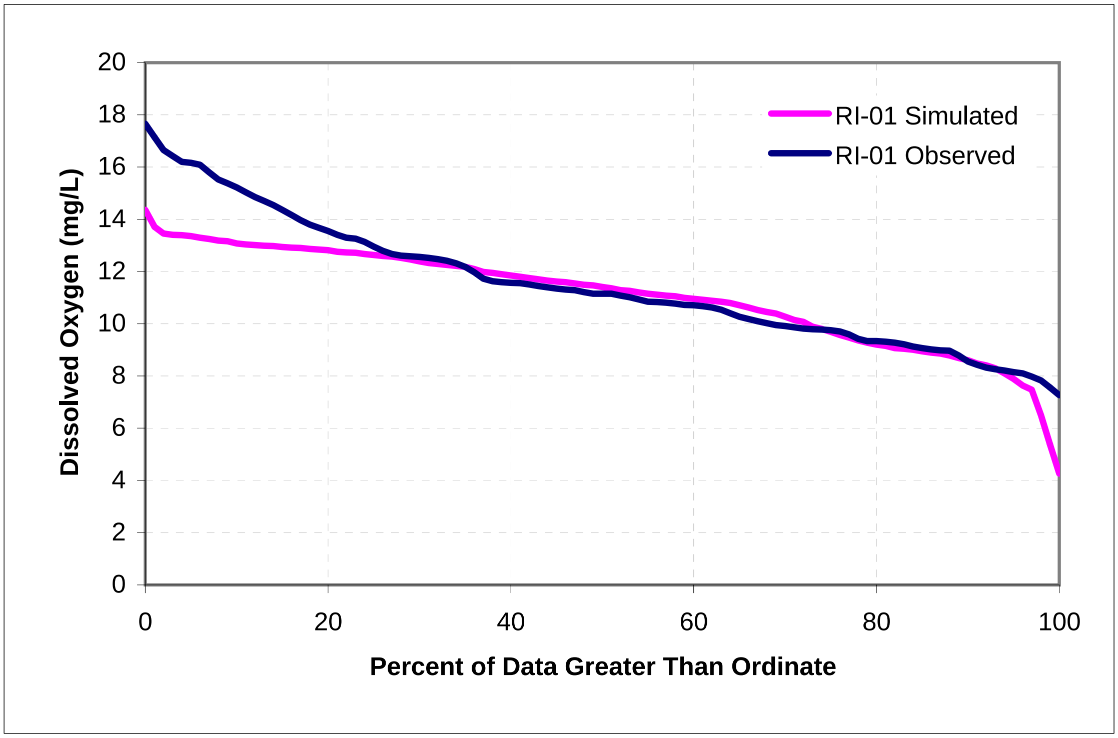


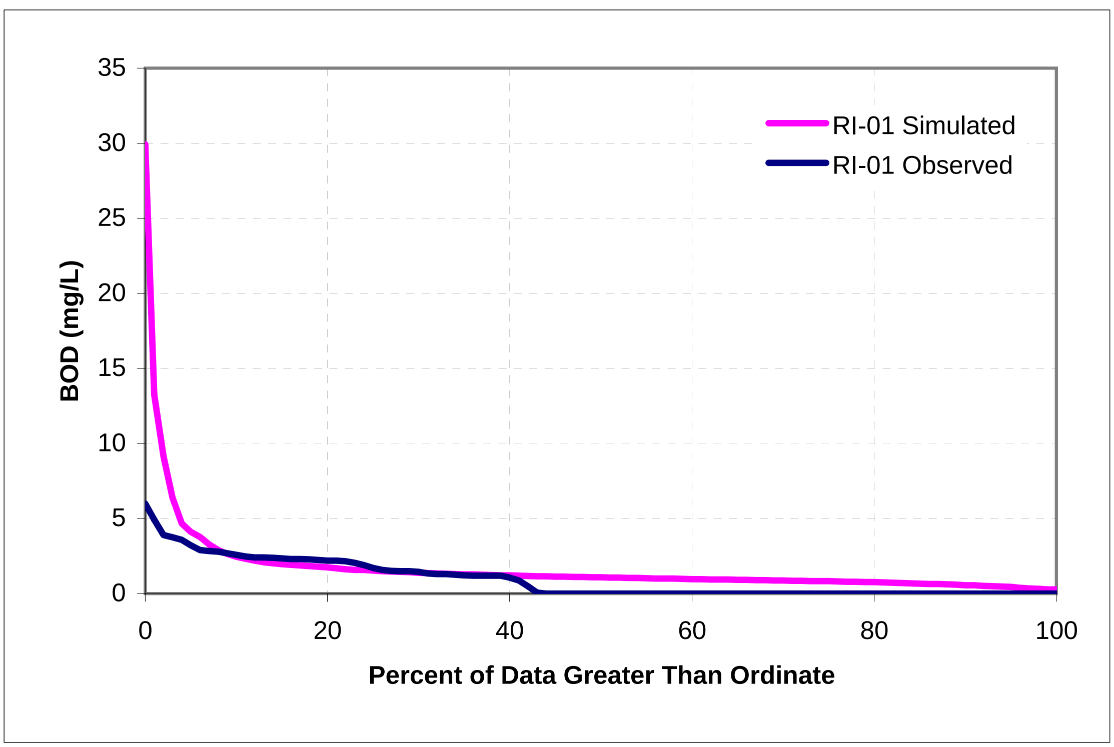
Milwaukee River, Station RI-01
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



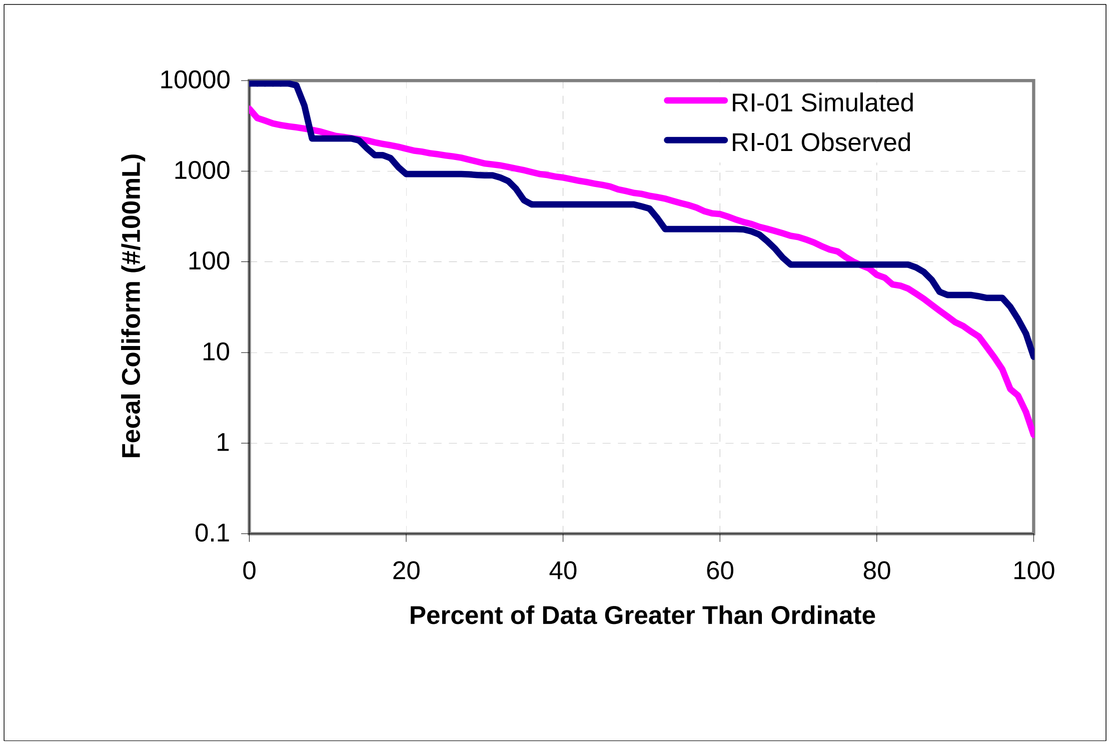


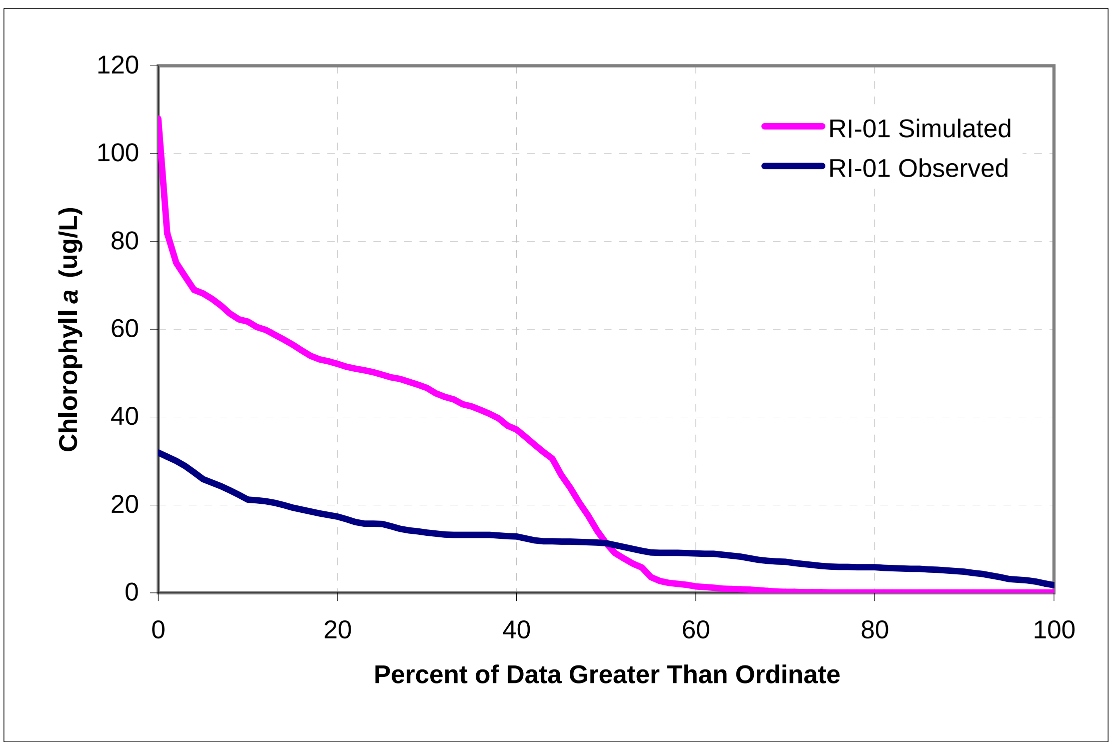
Milwaukee River, Station RI-01
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



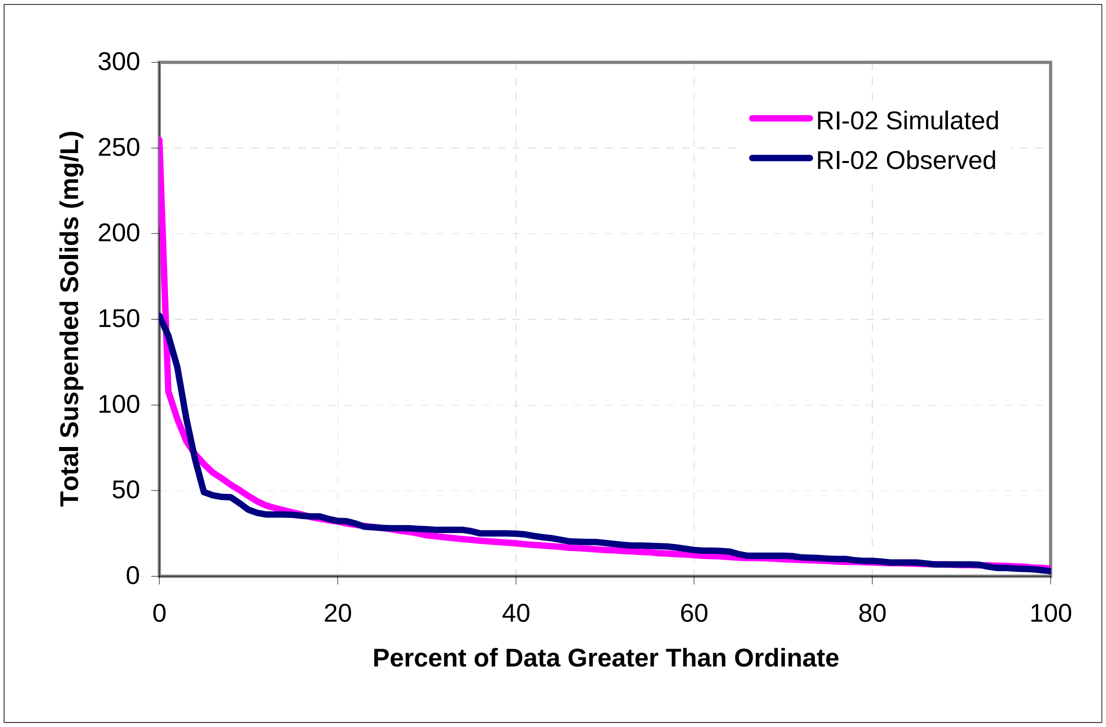


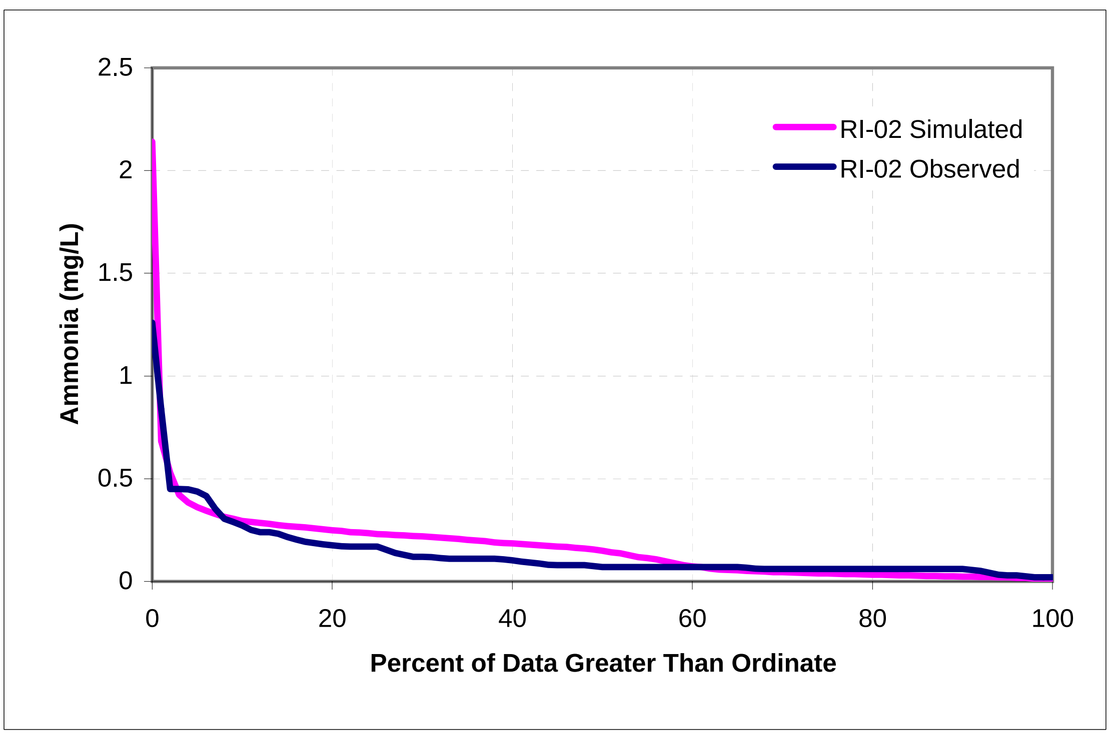
Milwaukee River, Station RI-01
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



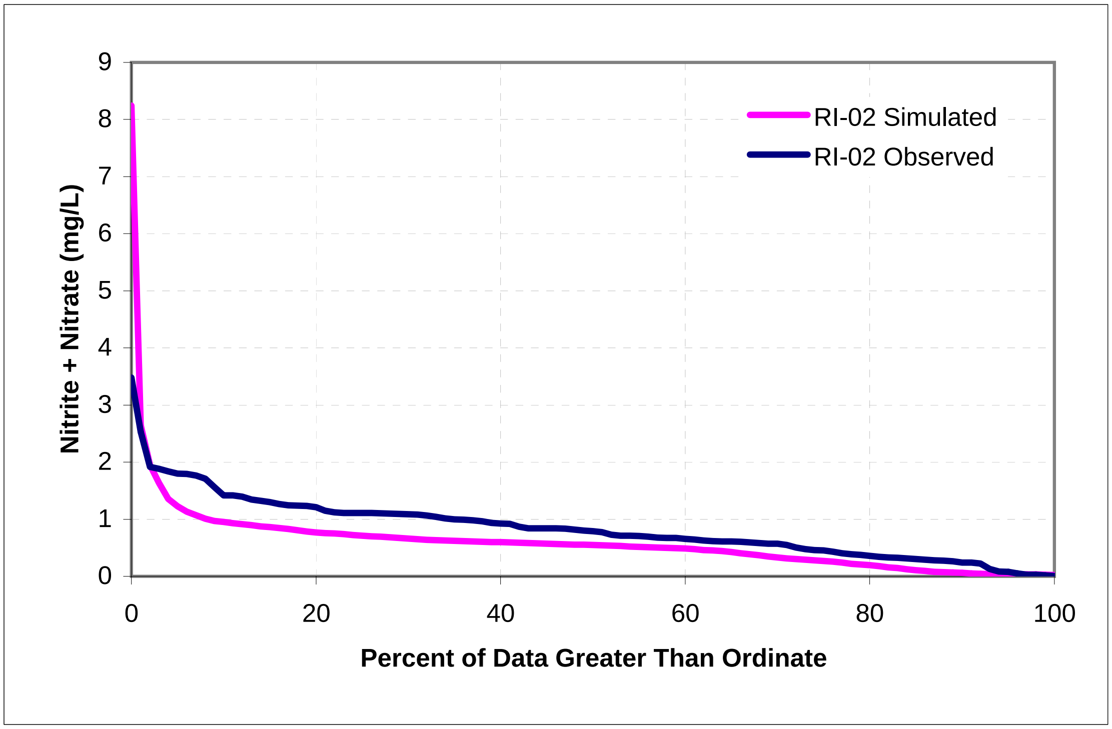


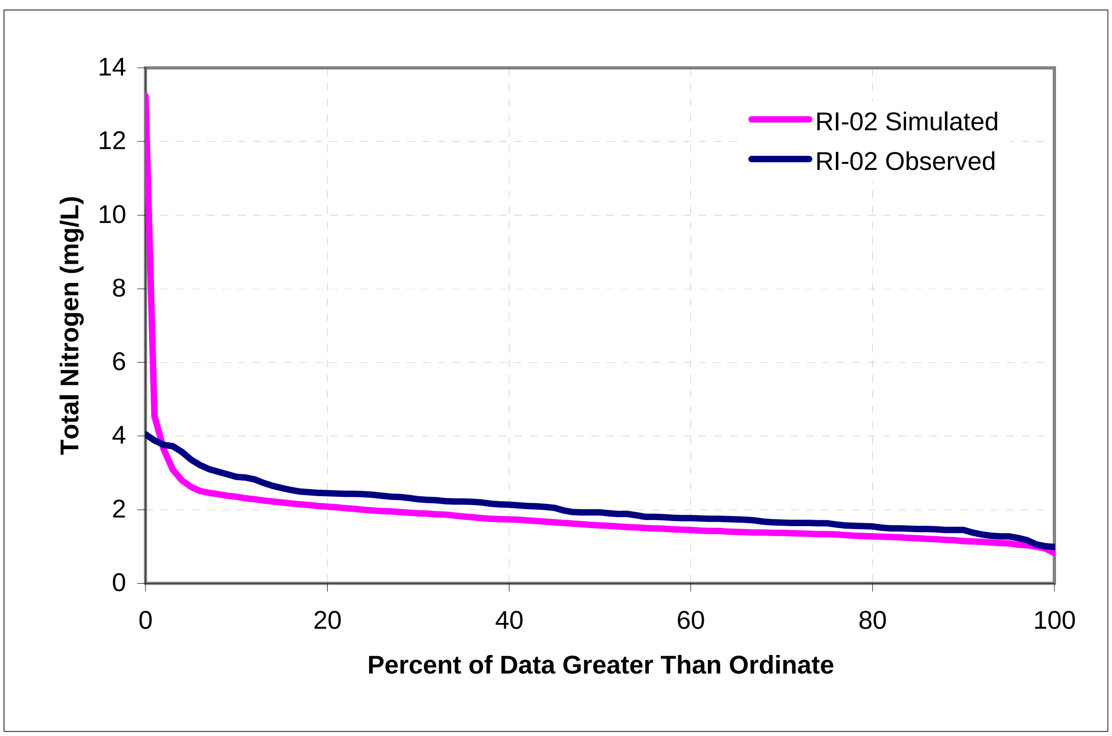
Milwaukee River, Station RI-02
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



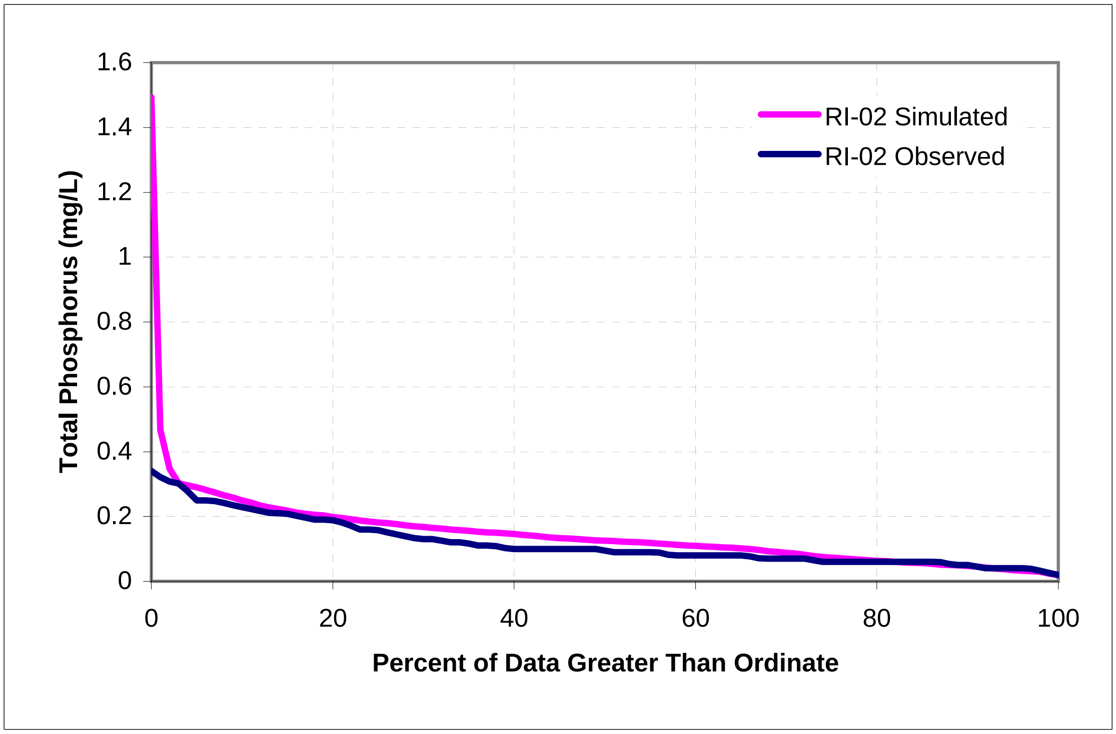


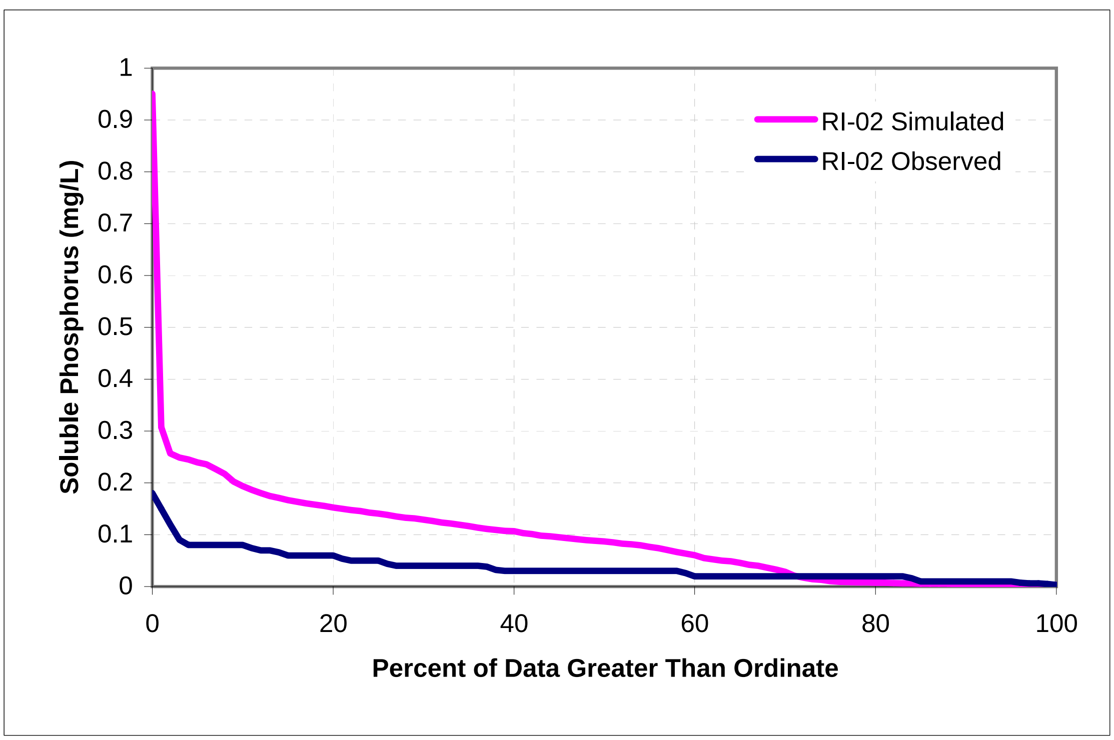
Milwaukee River, Station RI-02
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



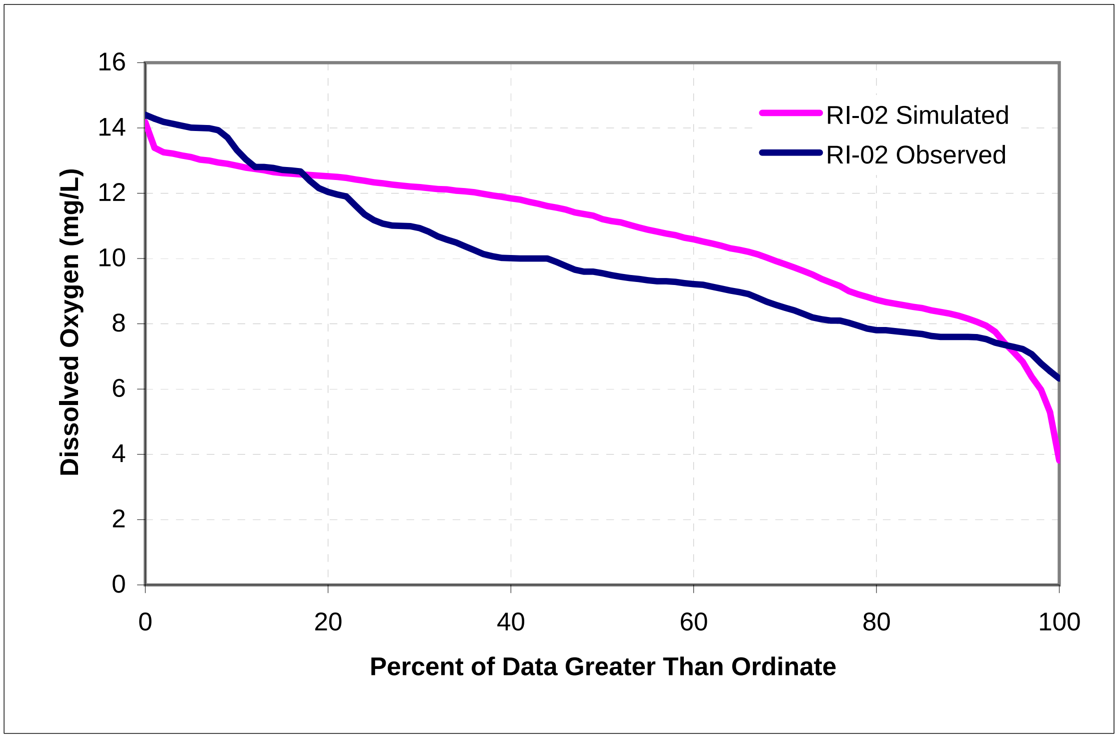


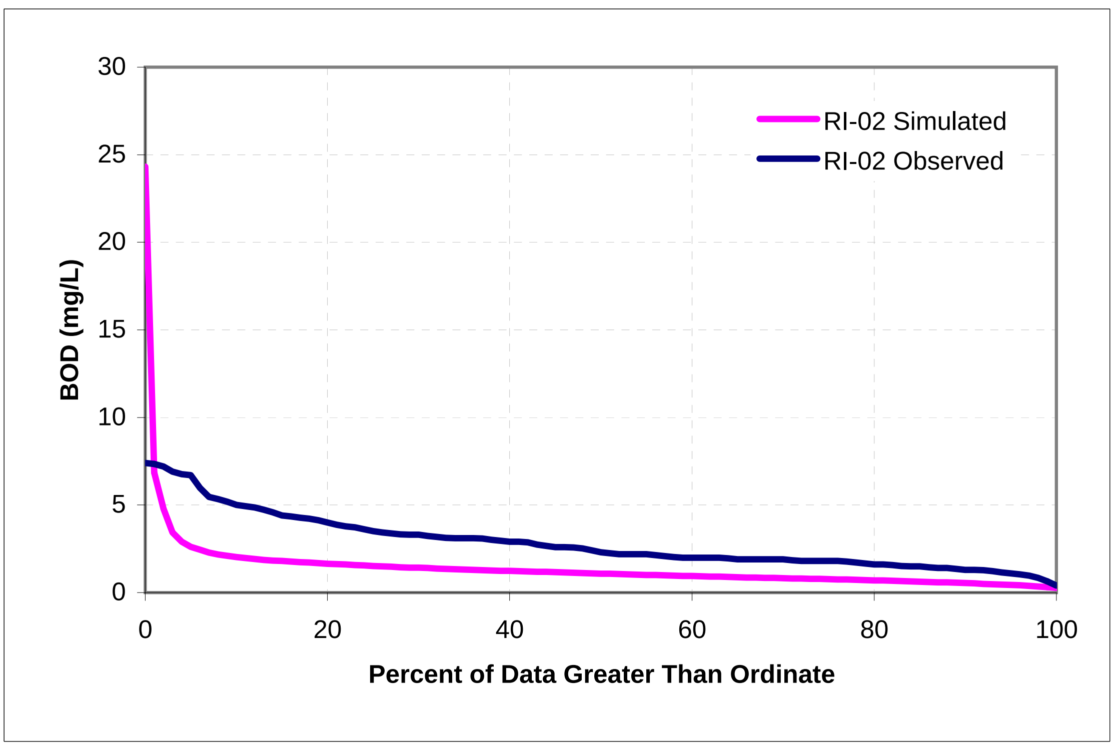
Milwaukee River, Station RI-02
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



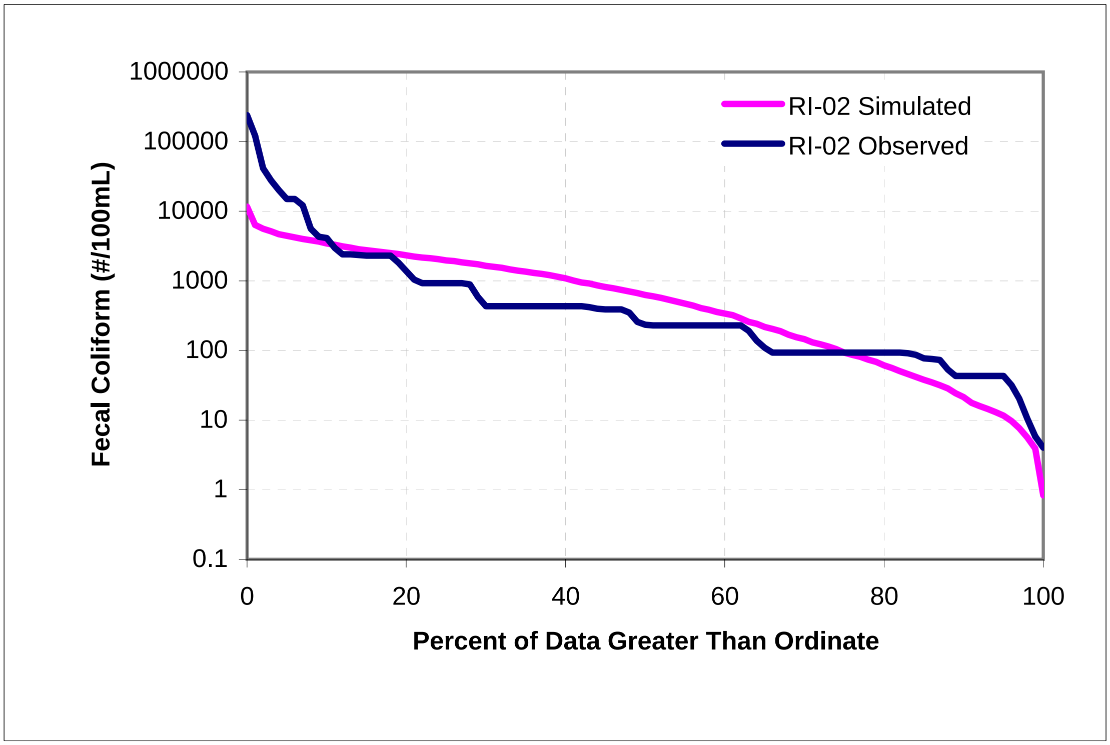


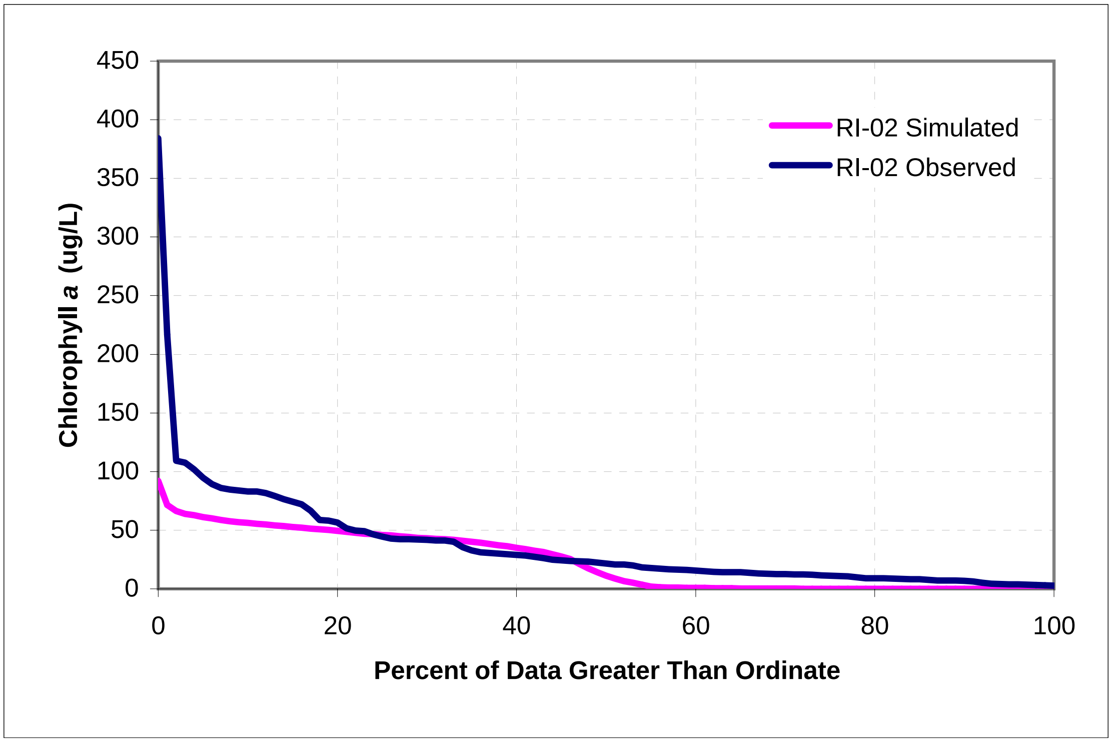
Milwaukee River, Station RI-02
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



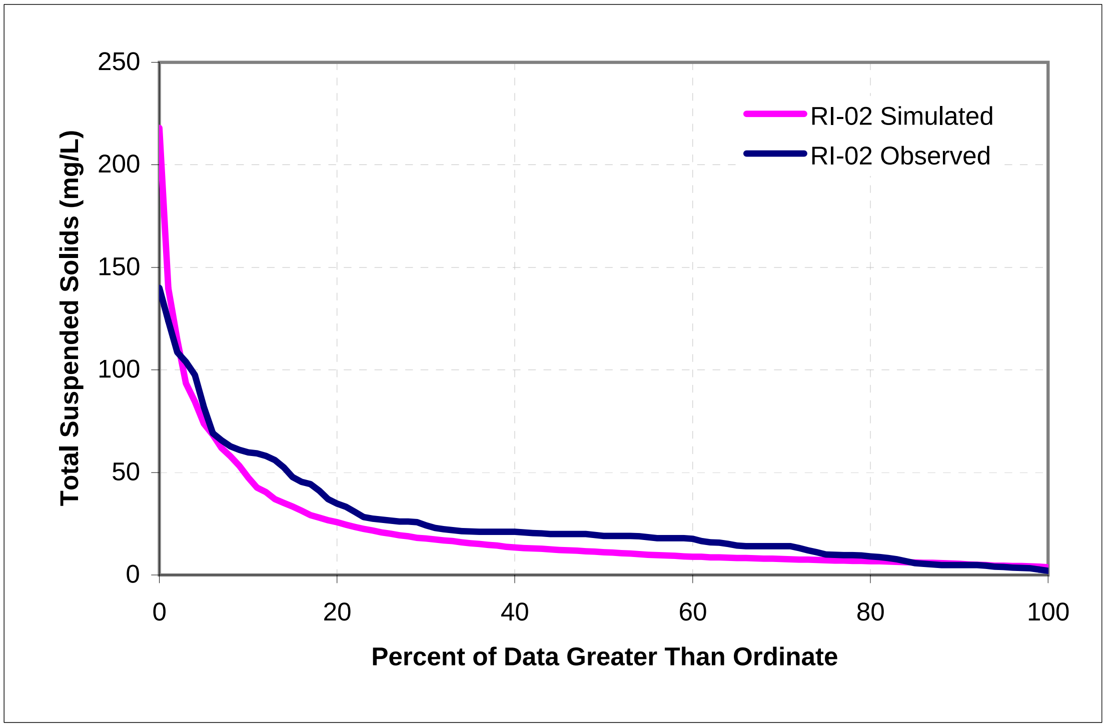


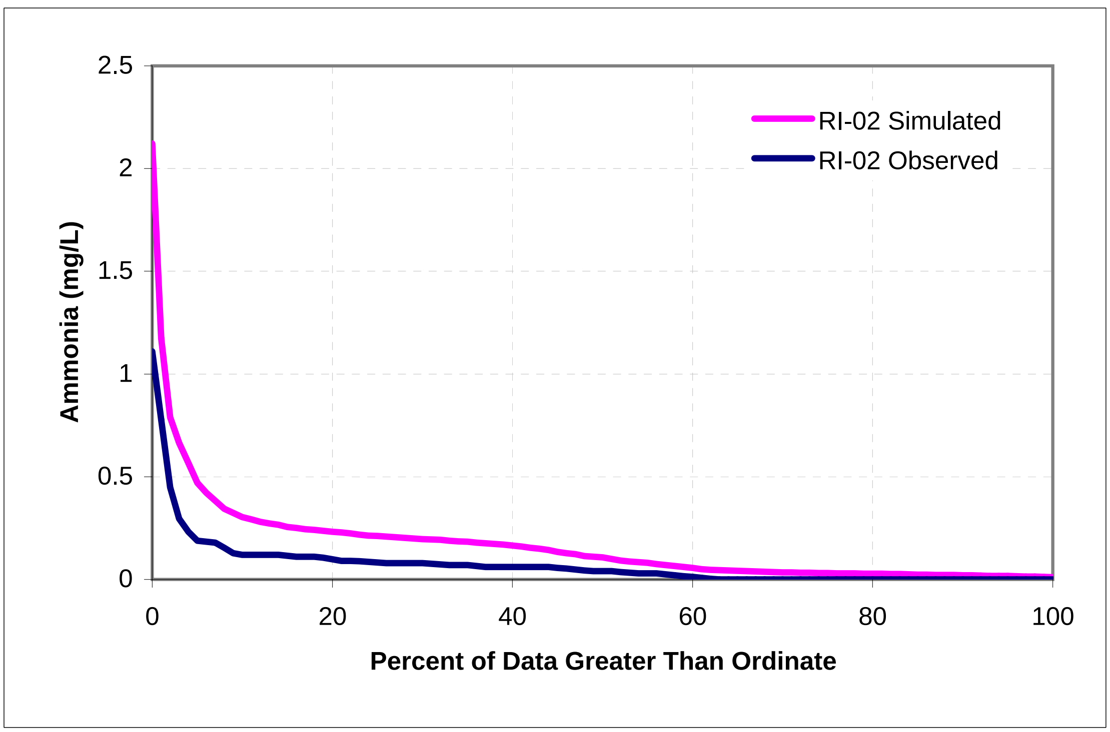
Milwaukee River, Station RI-02
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



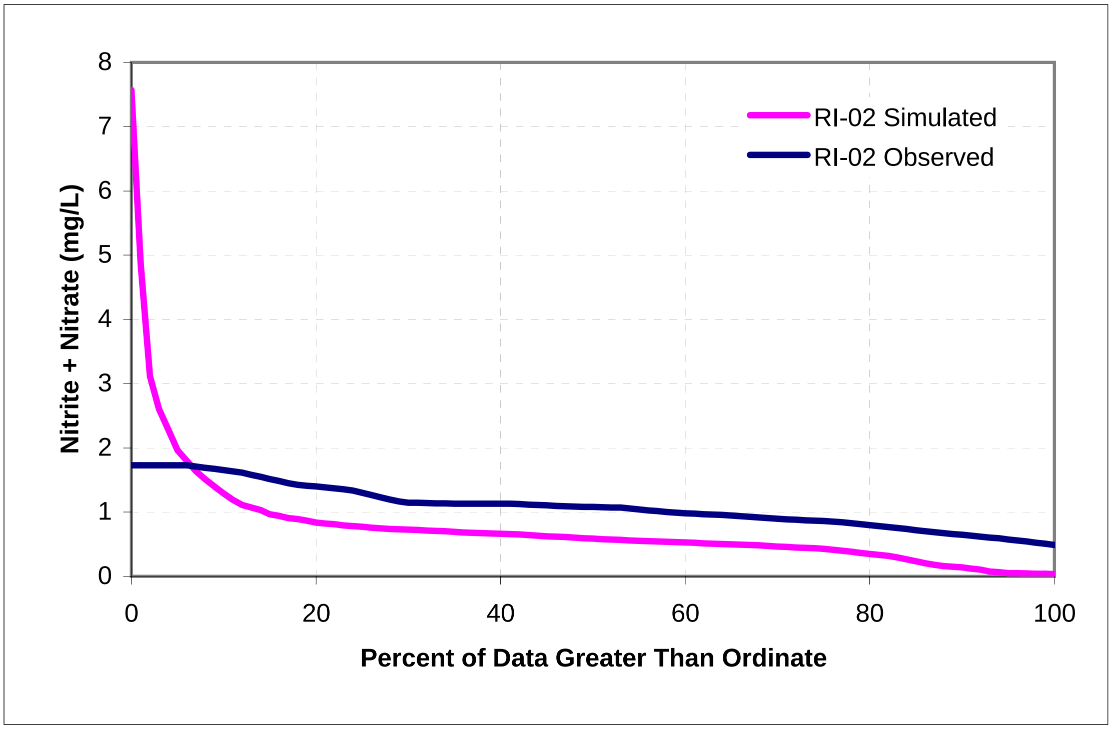


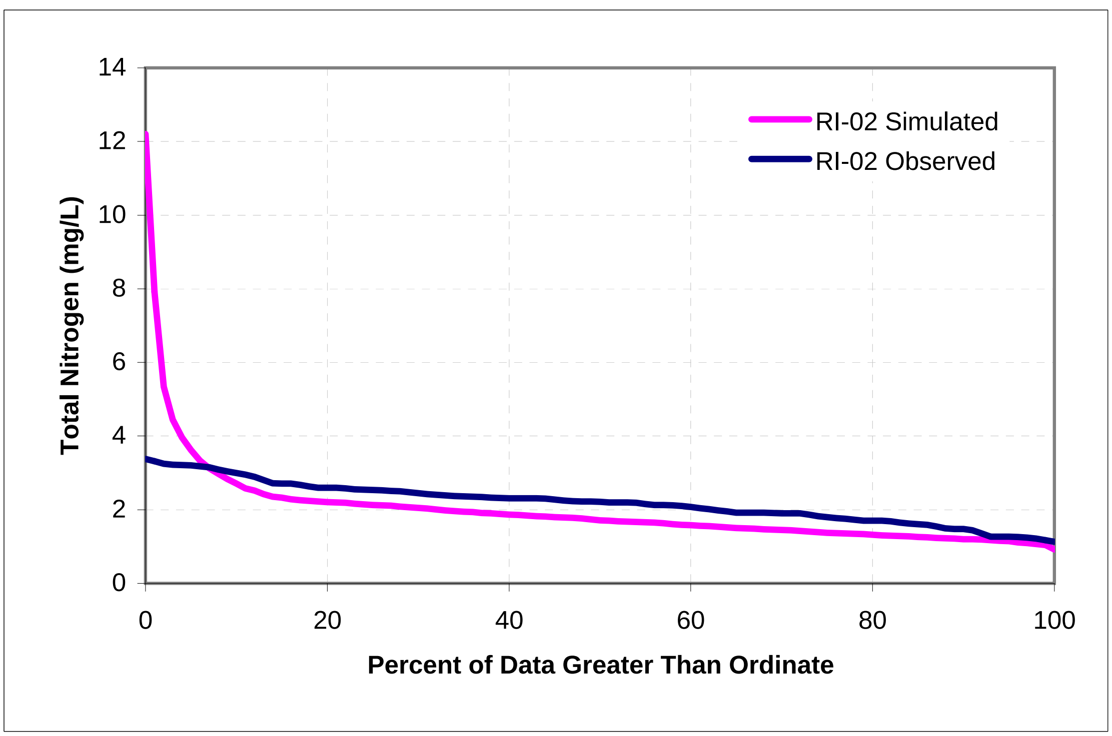
Milwaukee River, Station RI-02
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



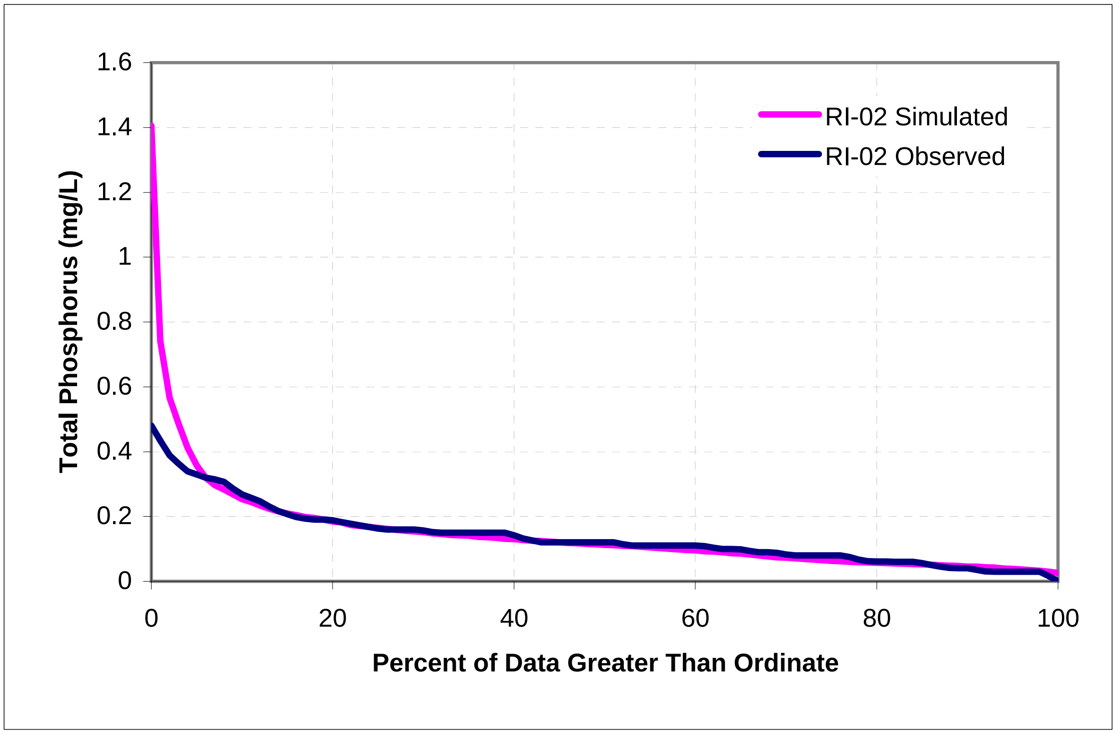


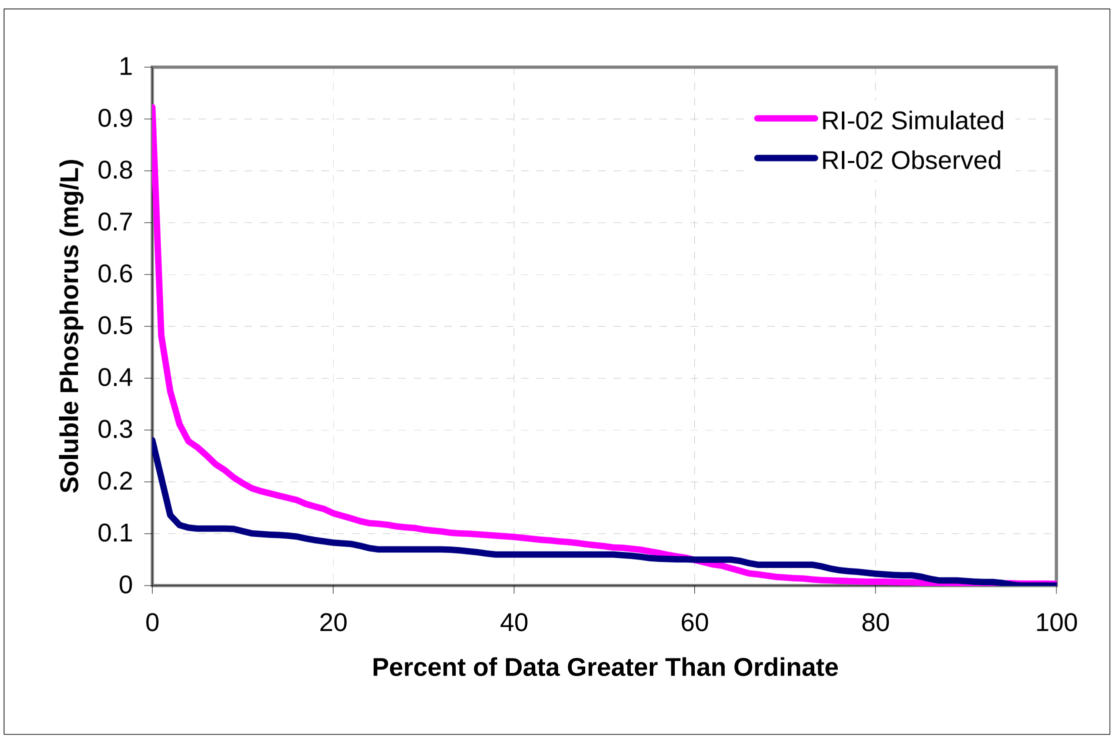
Milwaukee River, Station RI-02
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



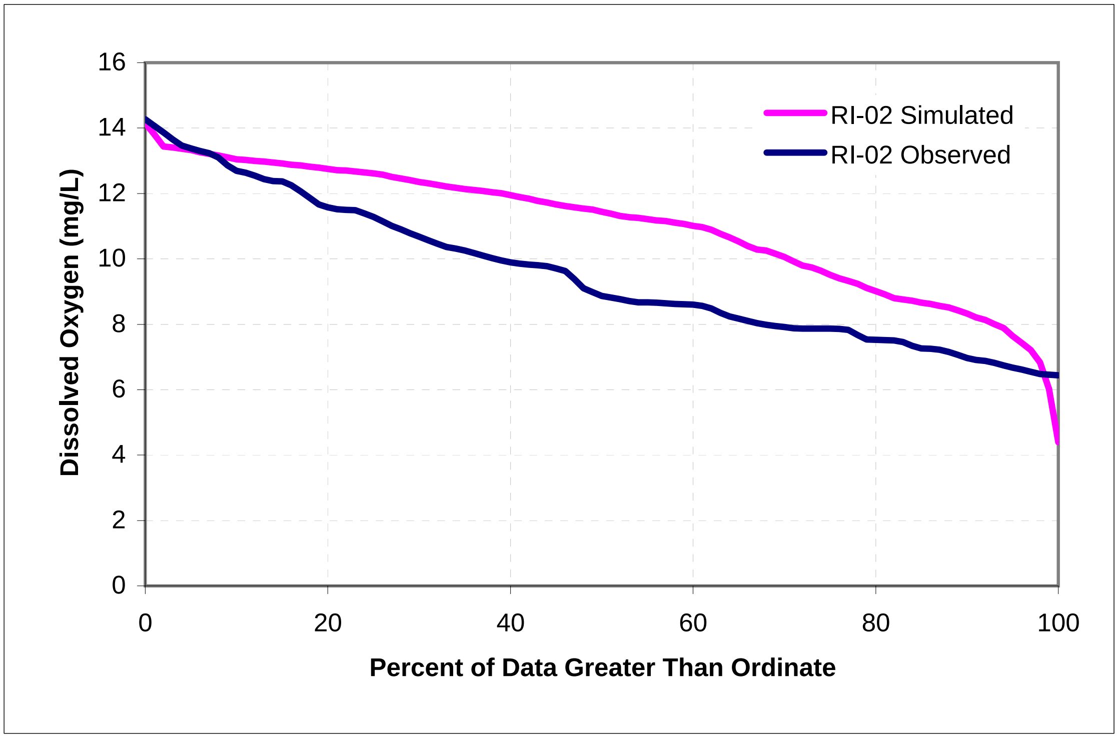


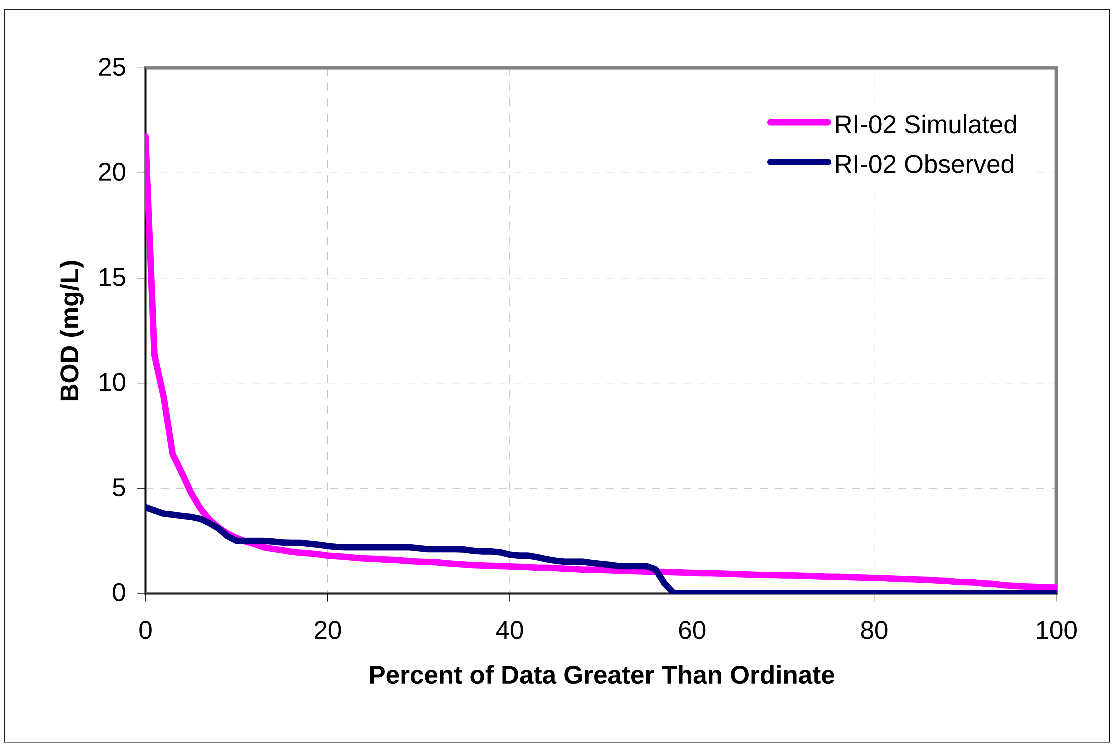
Milwaukee River, Station RI-02
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



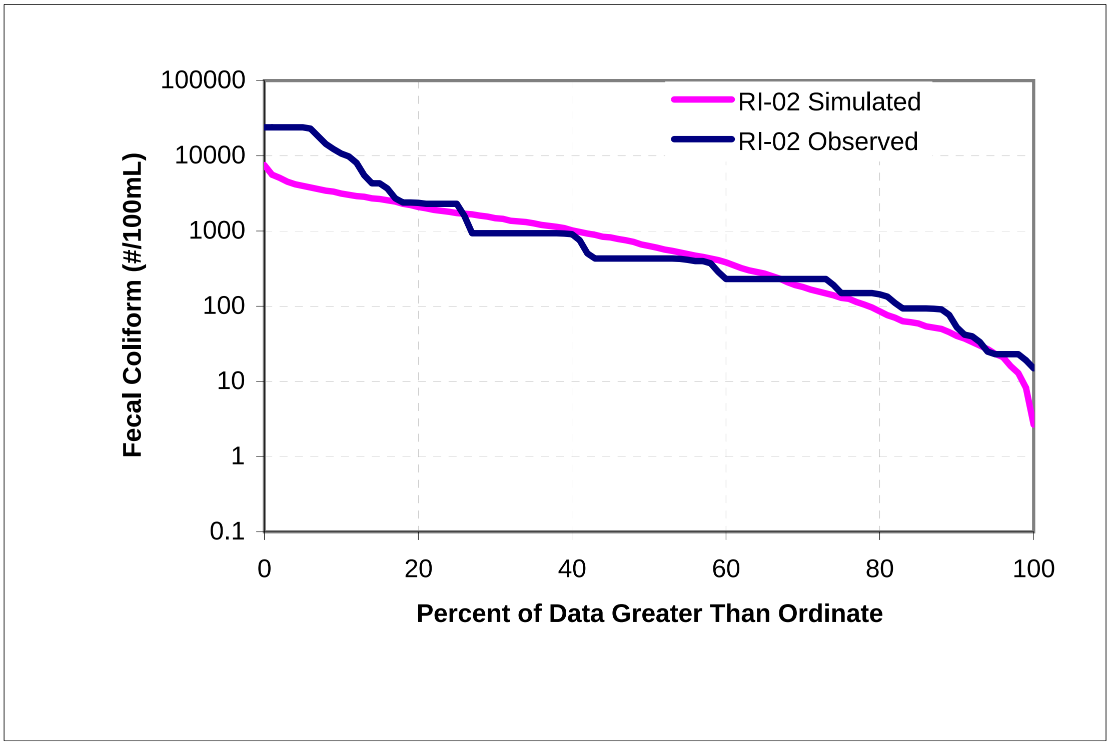


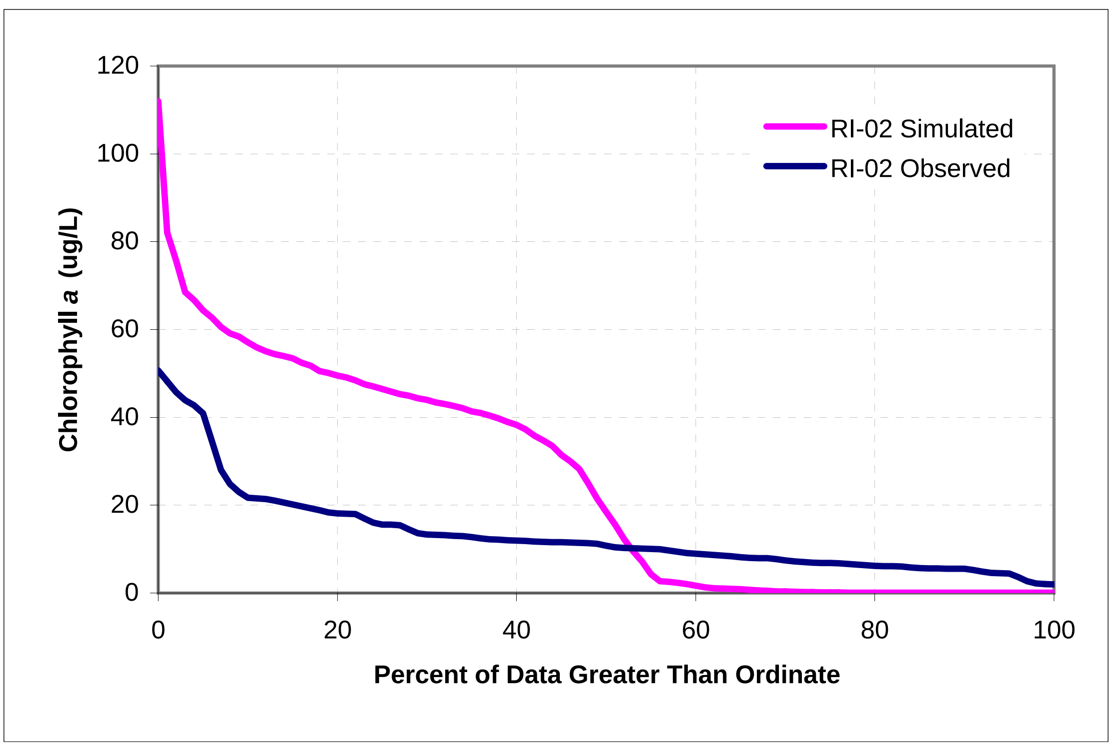
Milwaukee River, Station RI-02
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



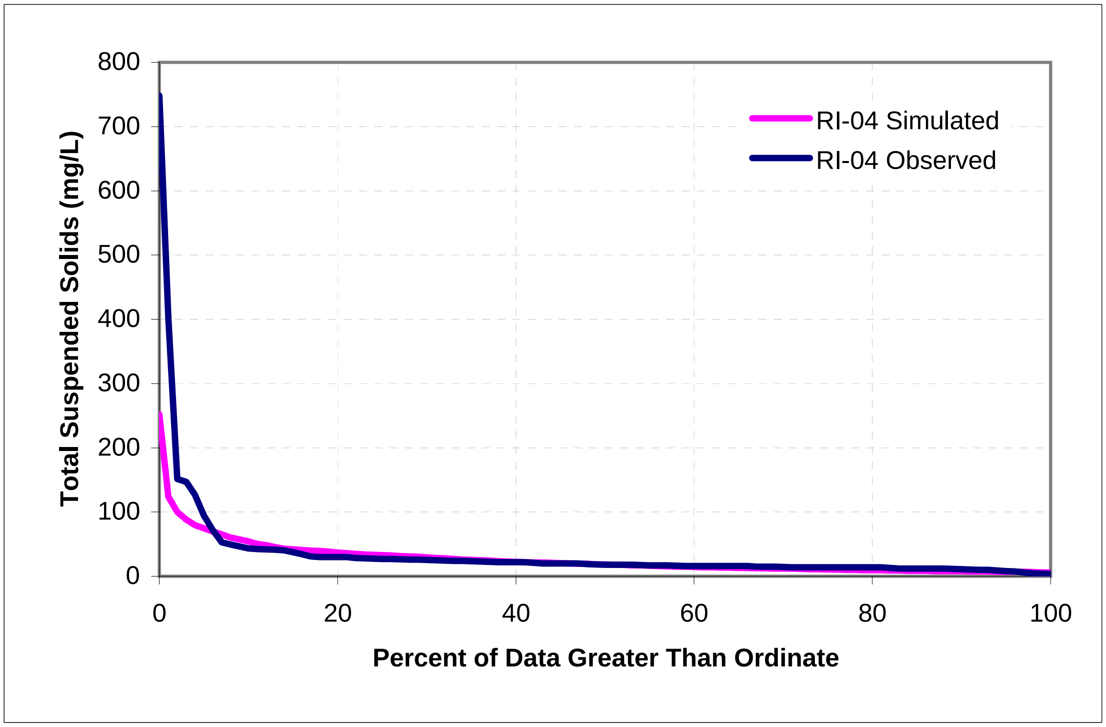


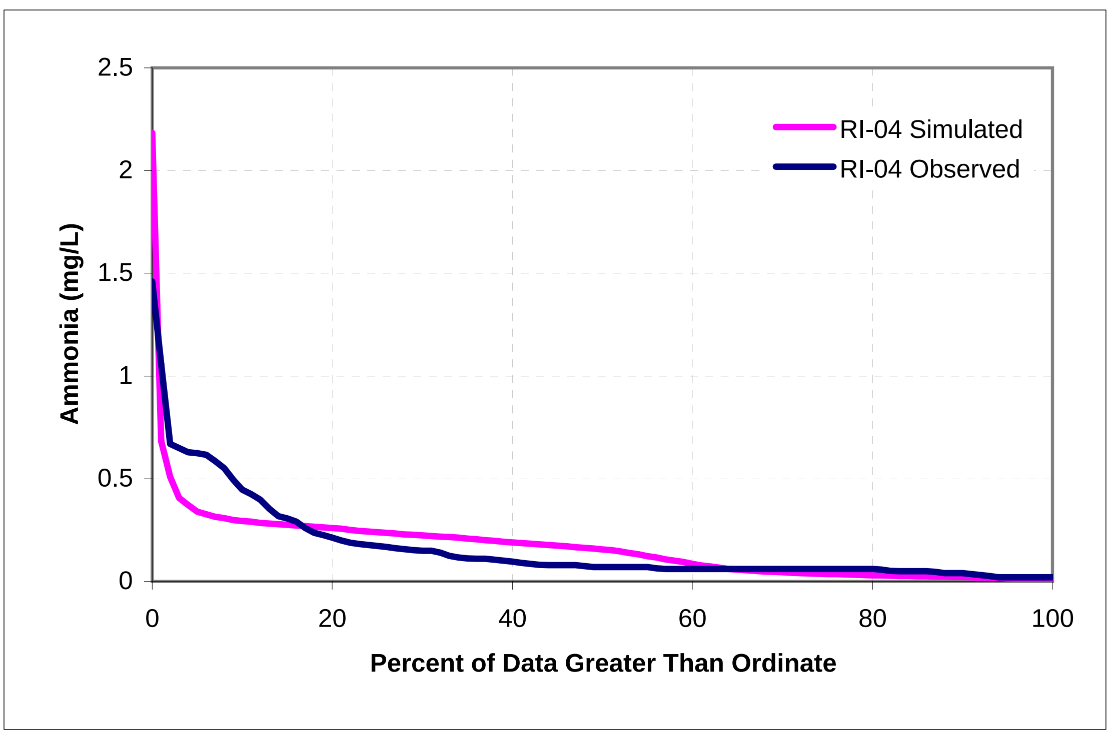
Milwaukee River, Station RI-02
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



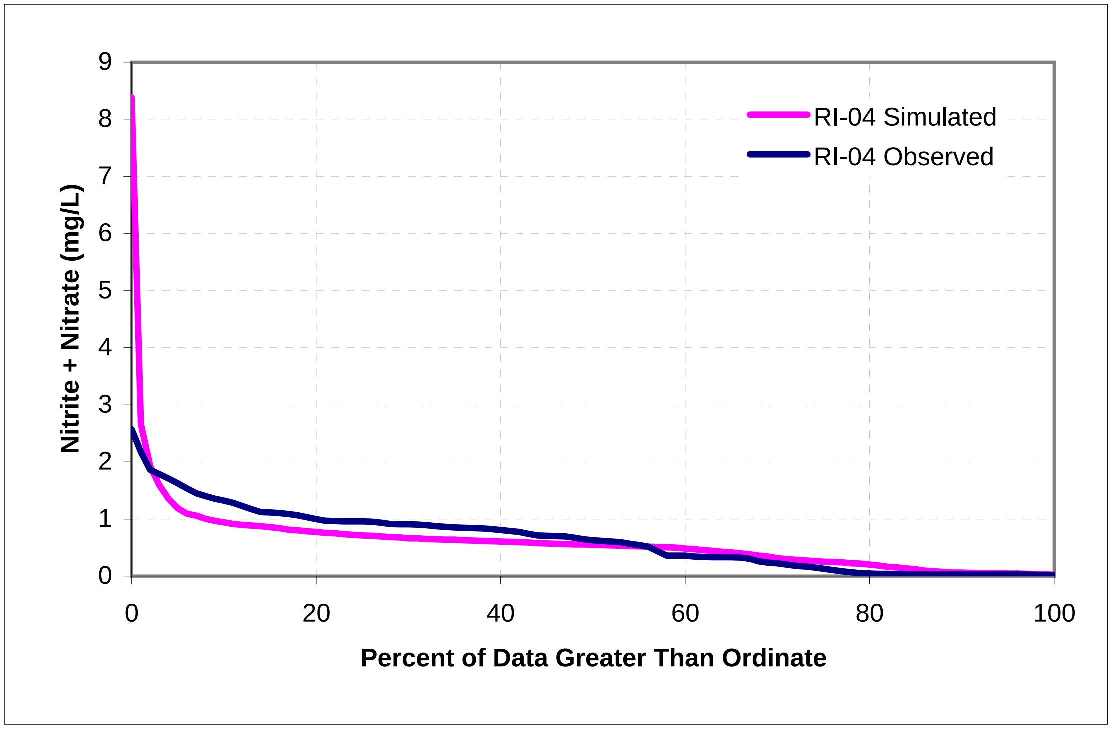


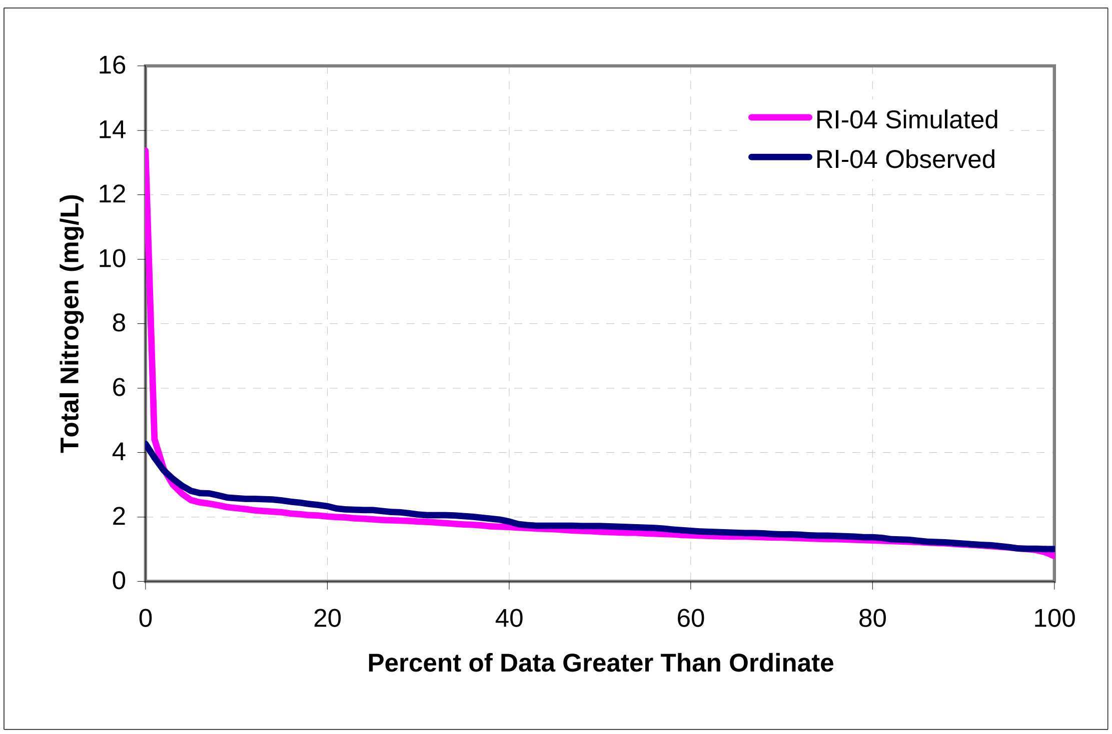
Milwaukee River, Station RI-04
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



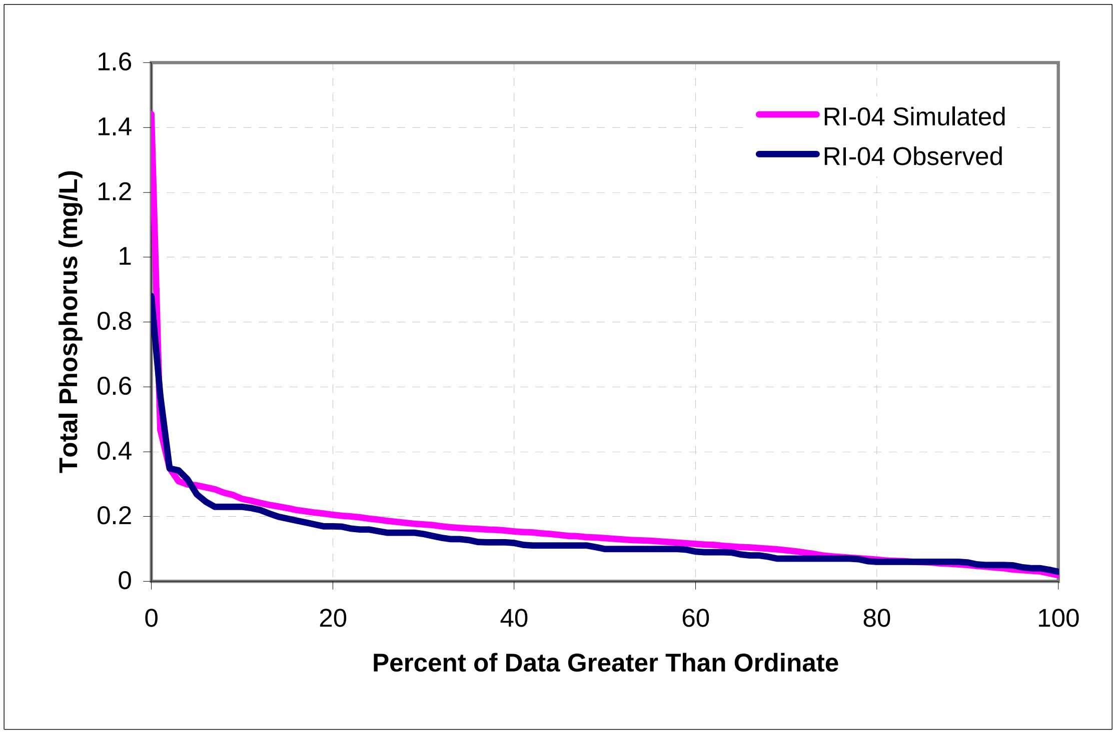


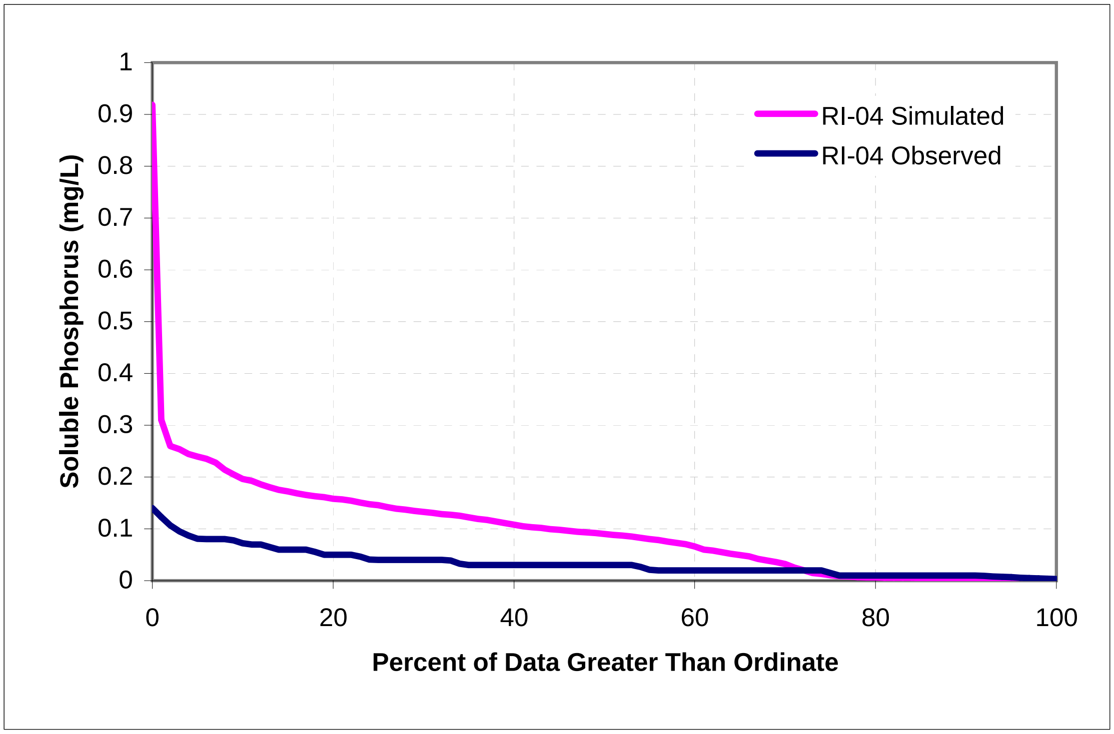
Milwaukee River, Station RI-04
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



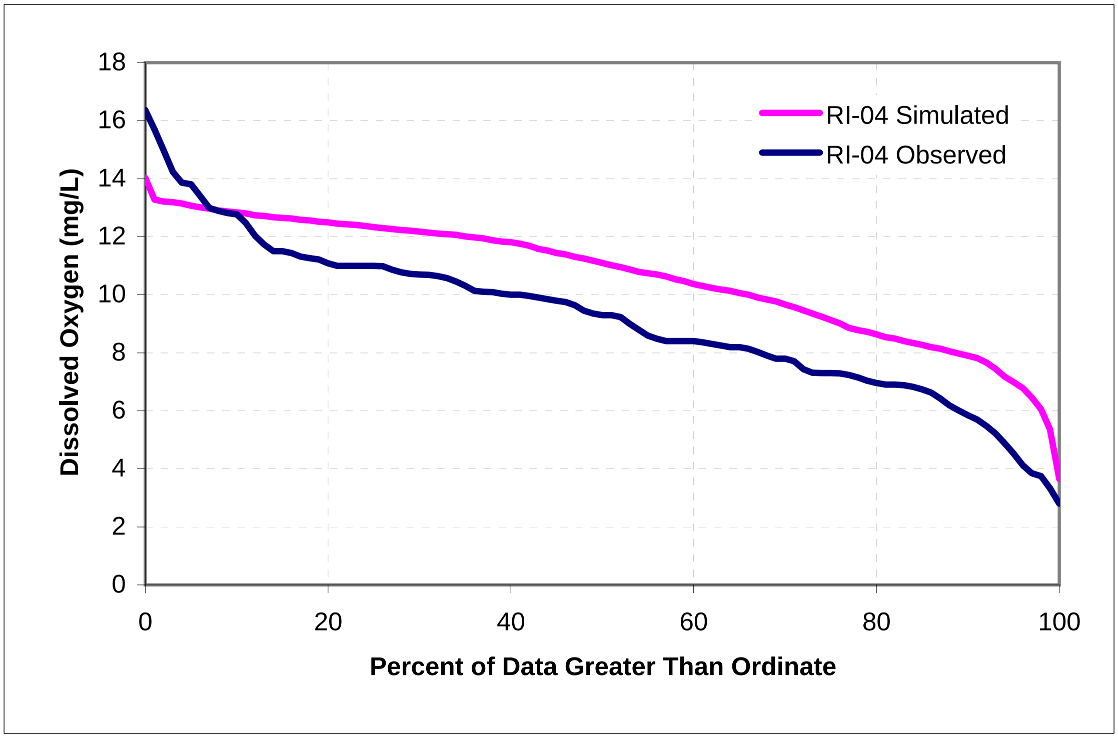


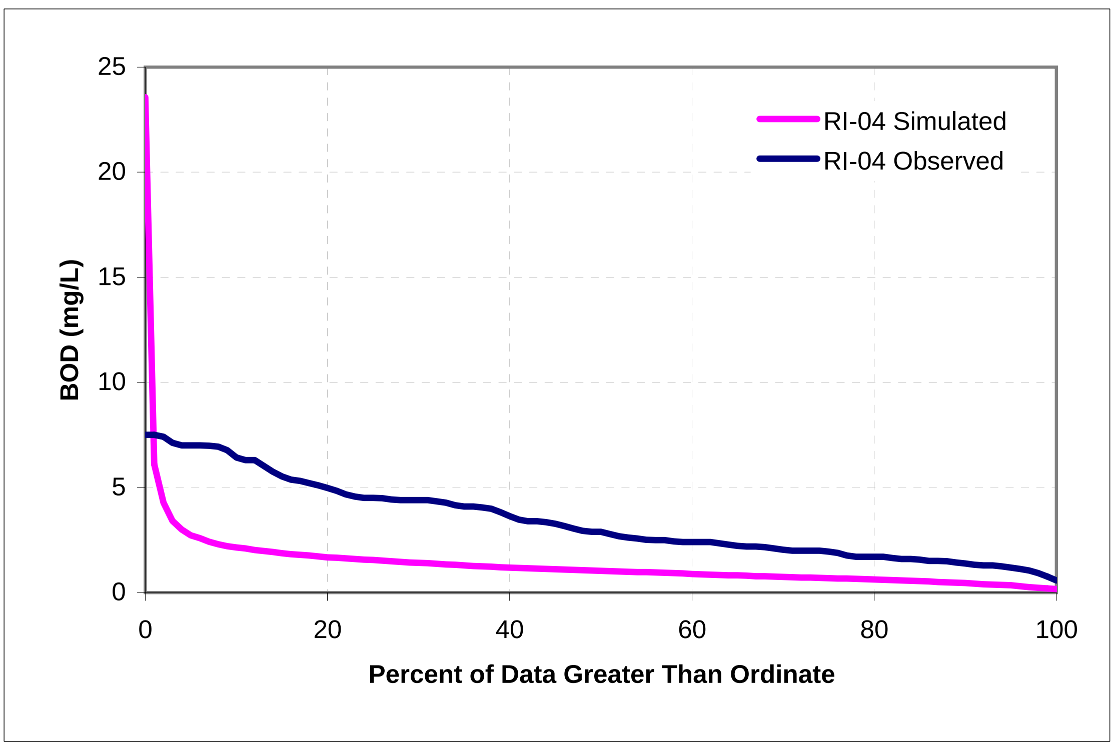
Milwaukee River, Station RI-04
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



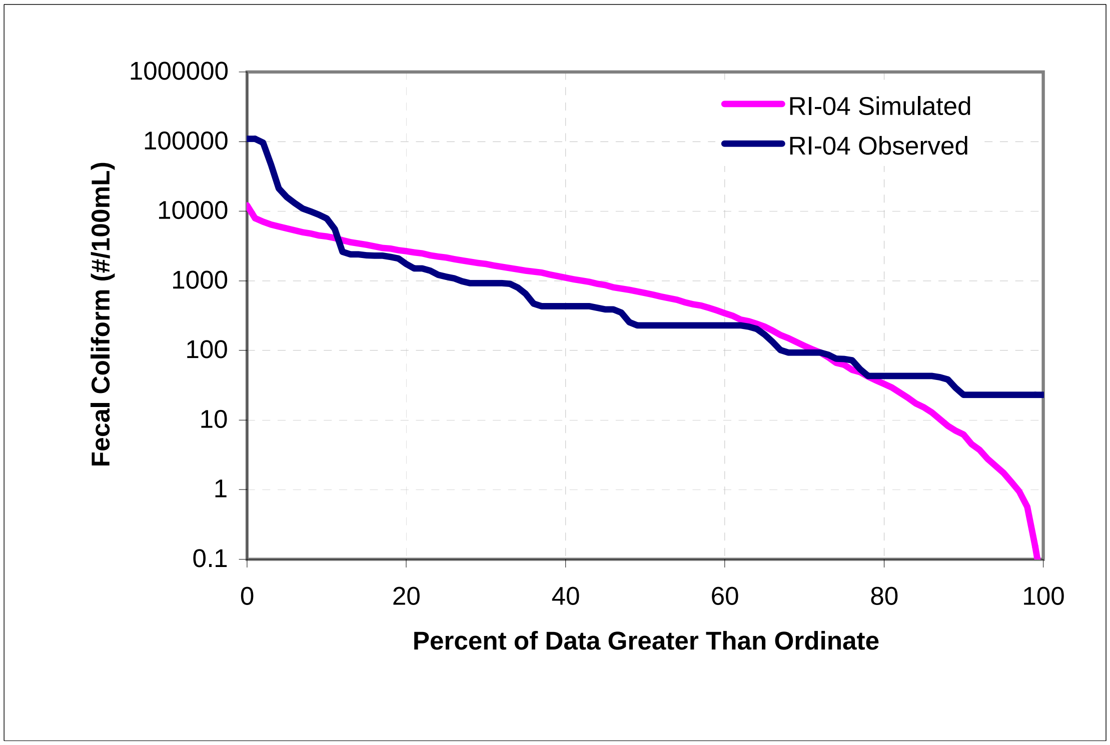


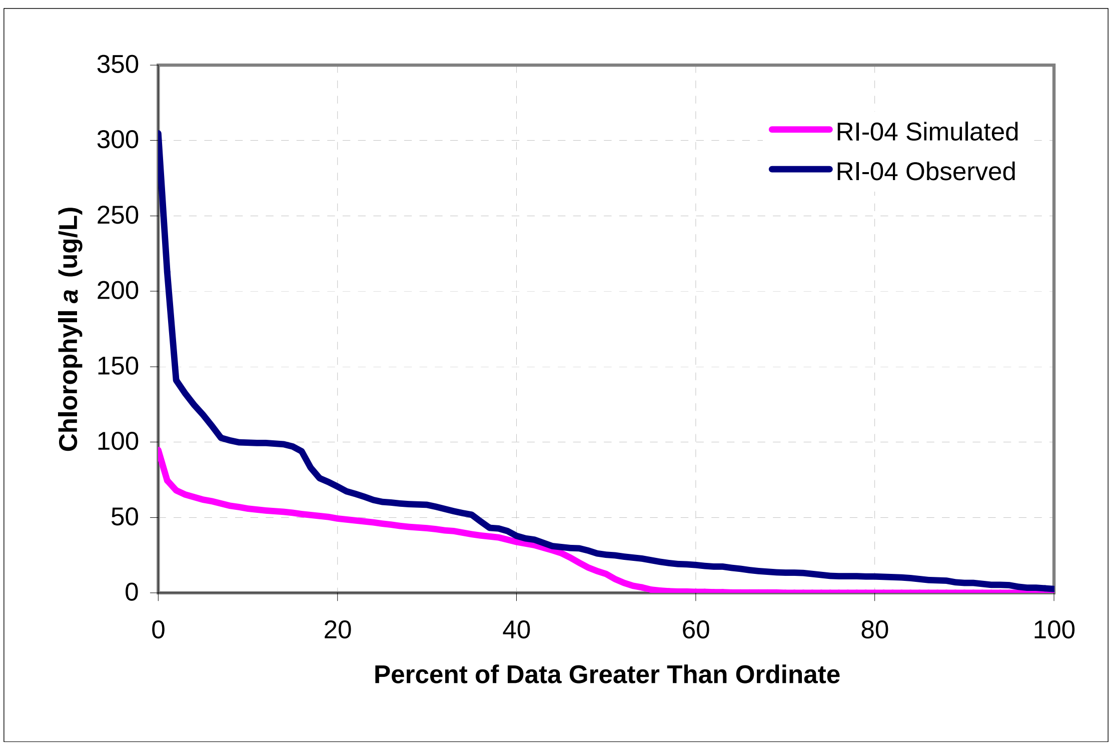
Milwaukee River, Station RI-04
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



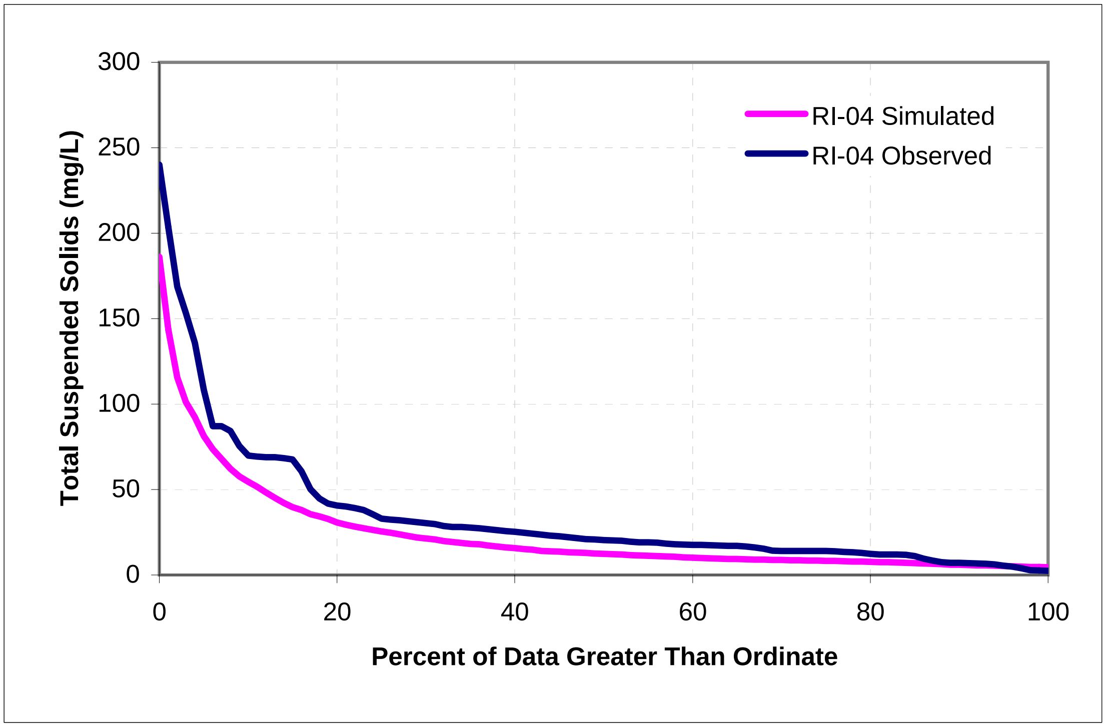


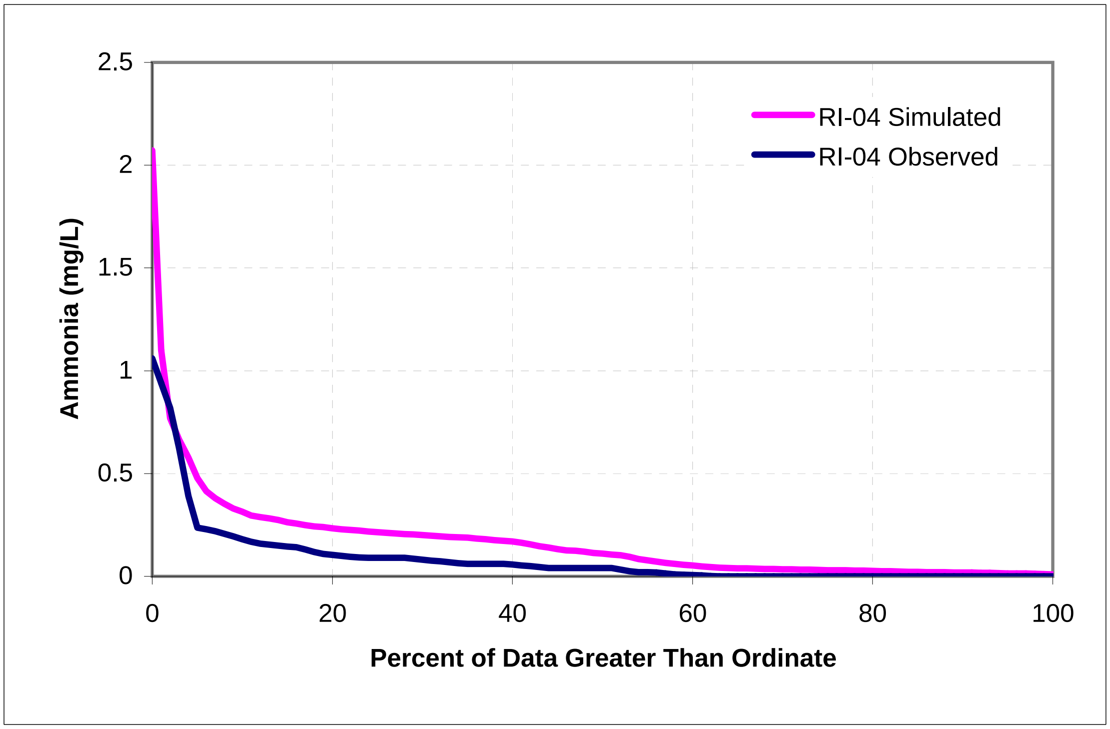
Milwaukee River, Station RI-04
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



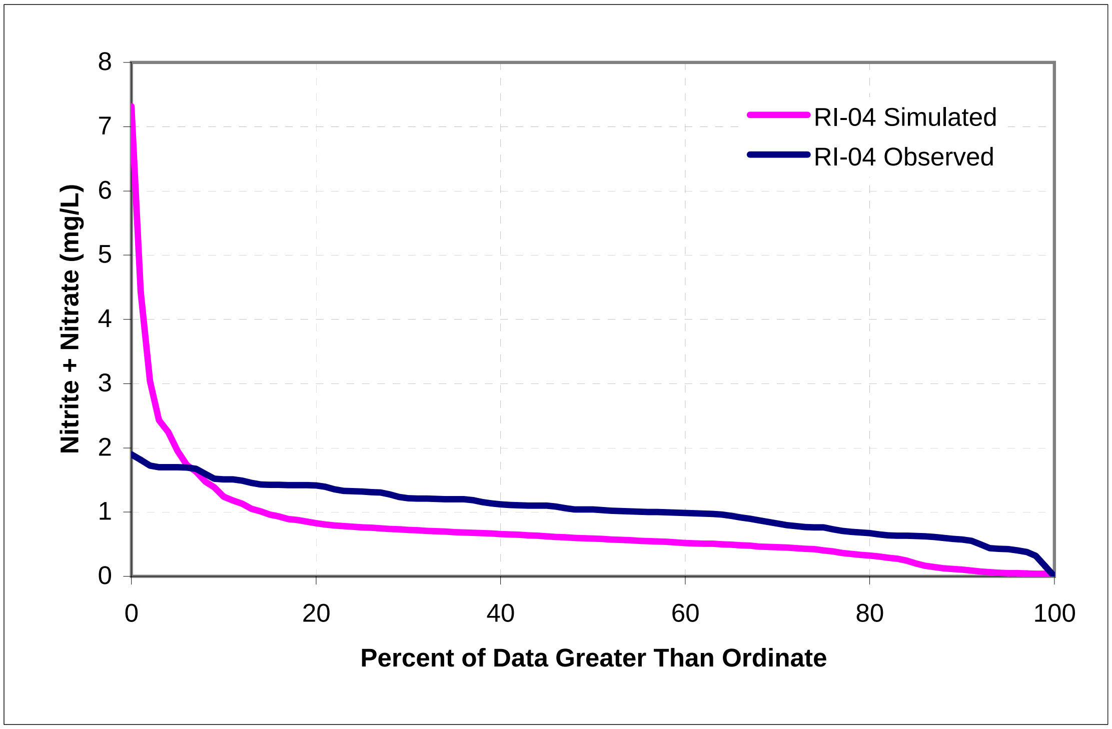


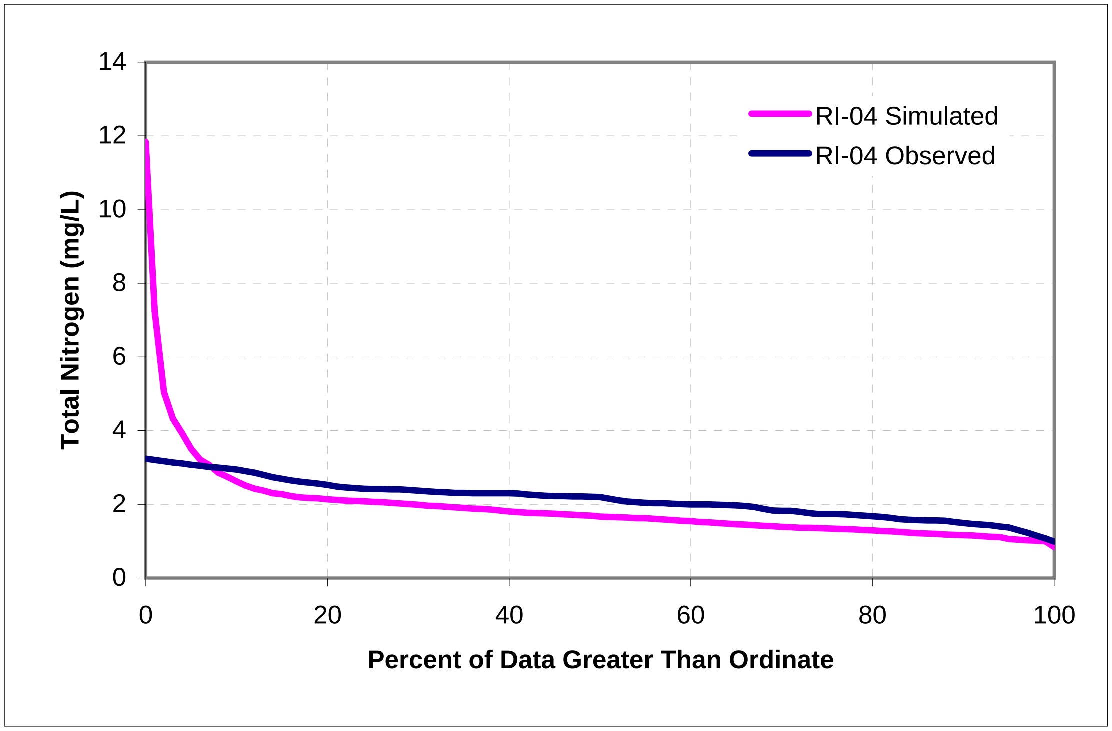
Milwaukee River, Station RI-04
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



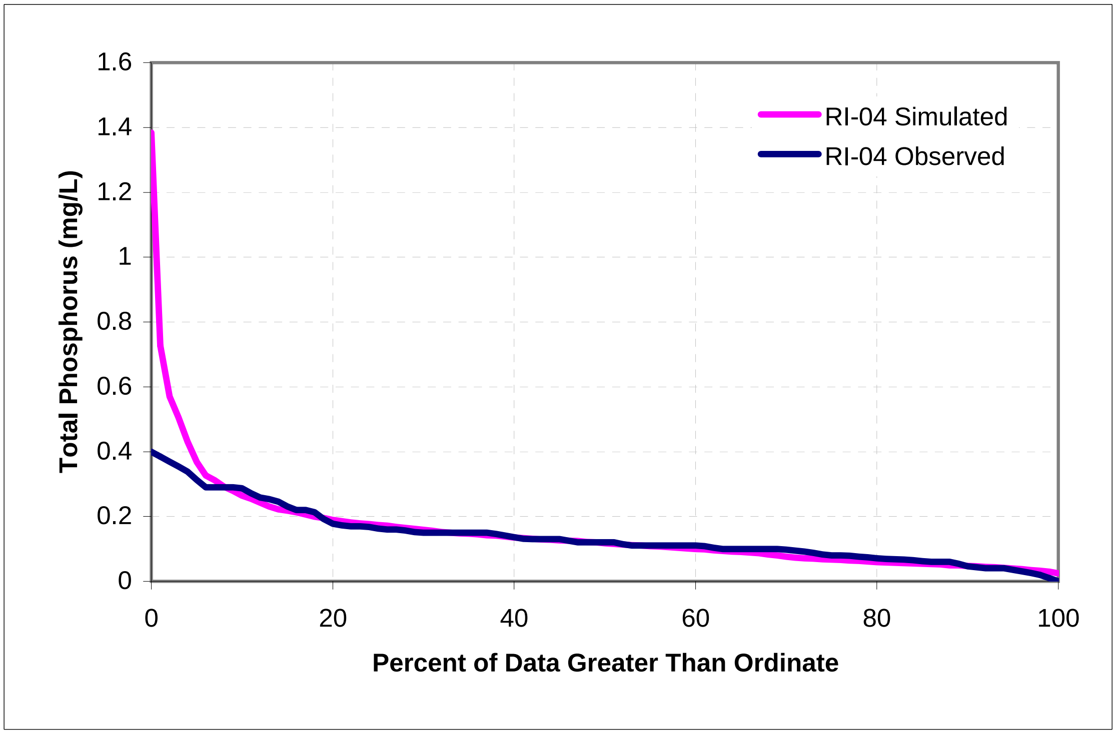


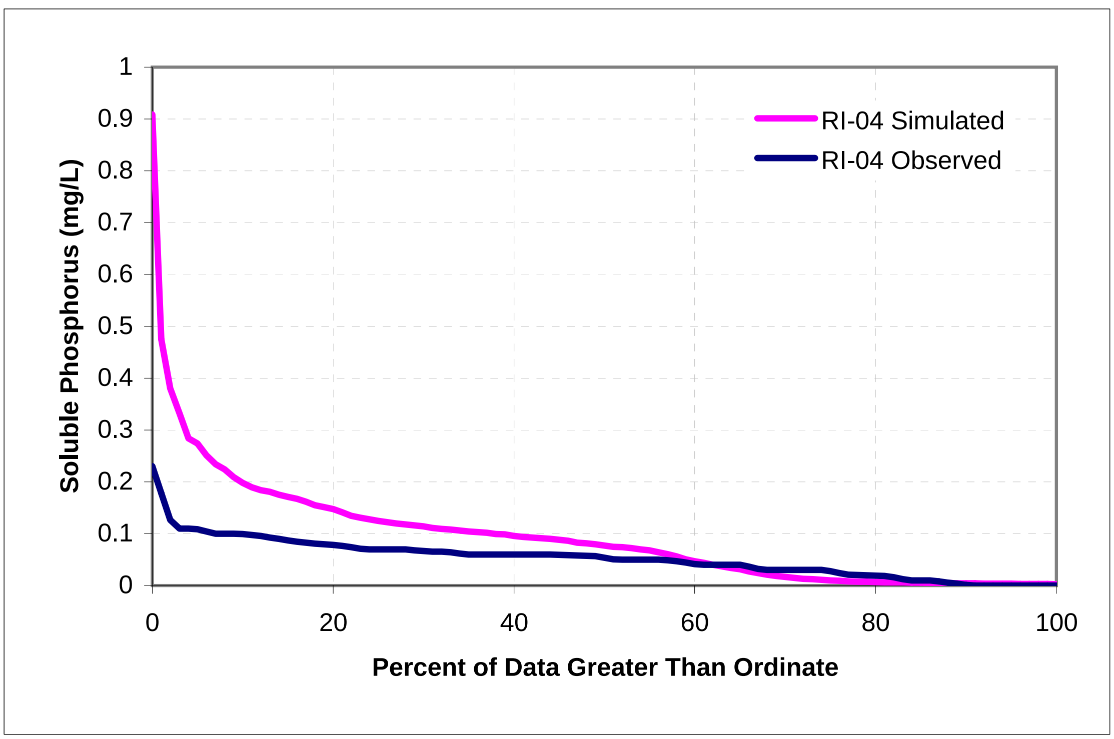
Milwaukee River, Station RI-04
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



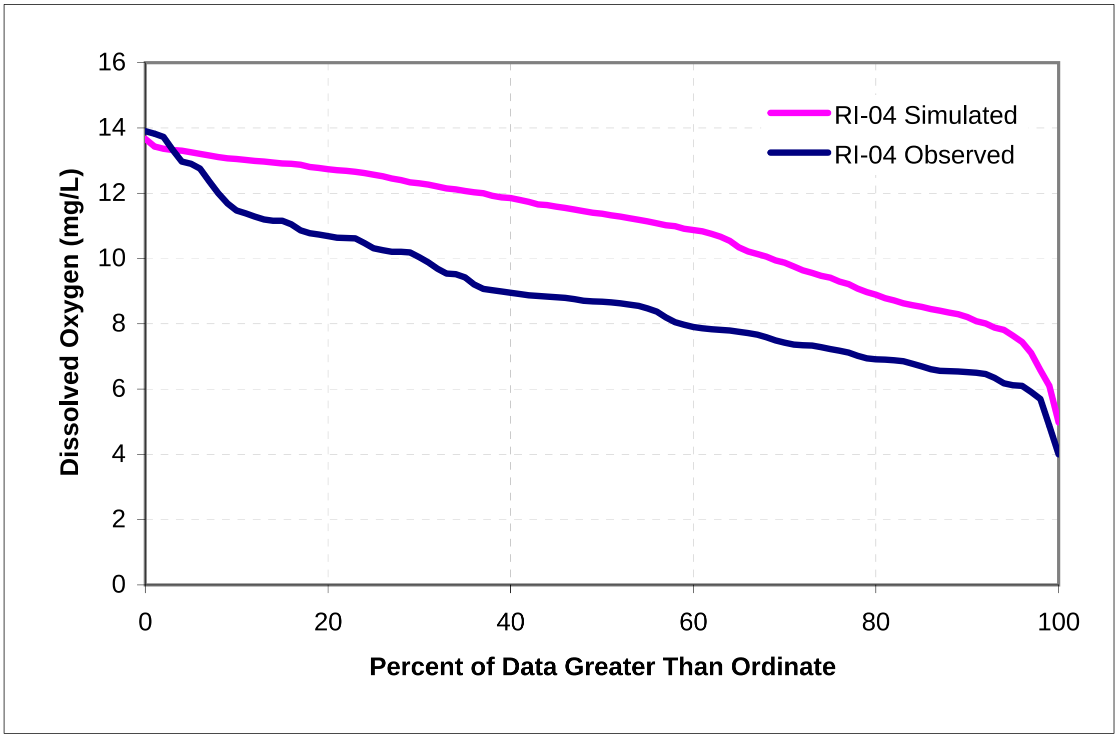


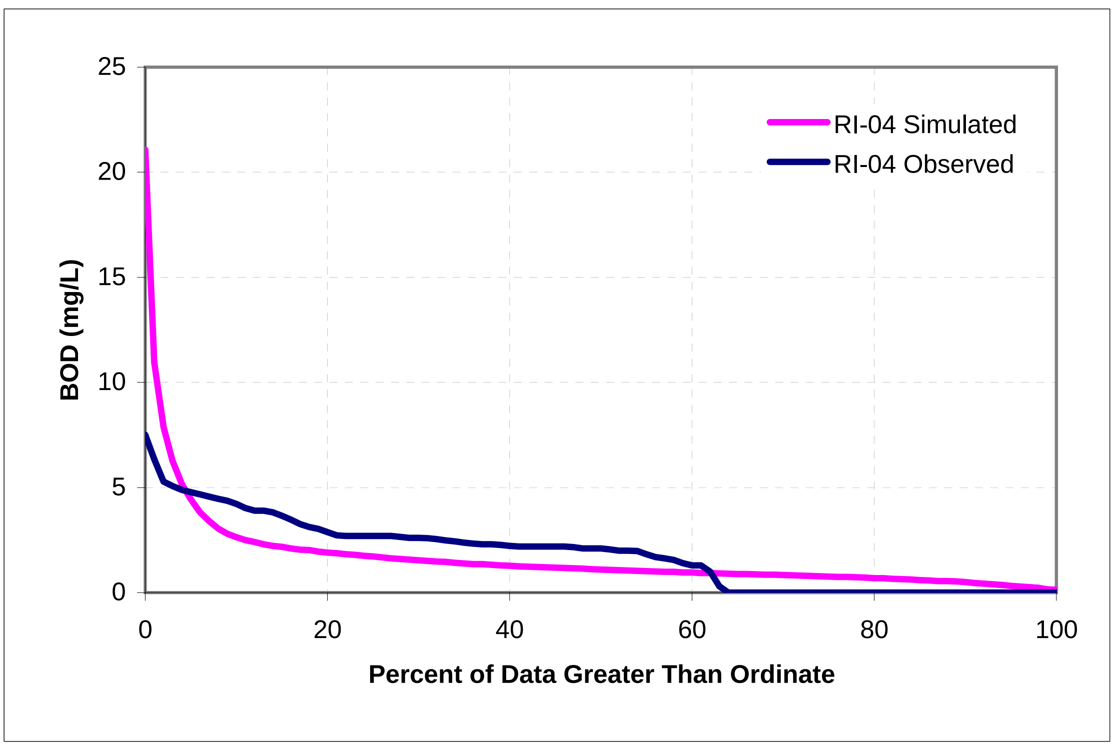
Milwaukee River, Station RI-04
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



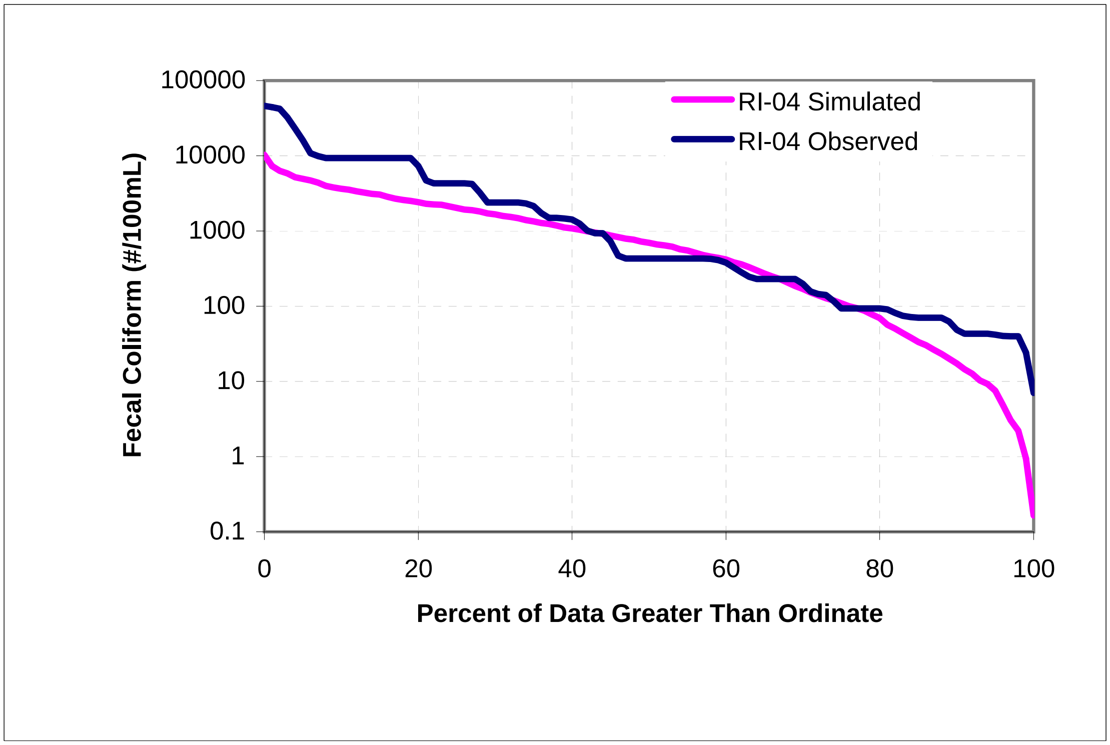


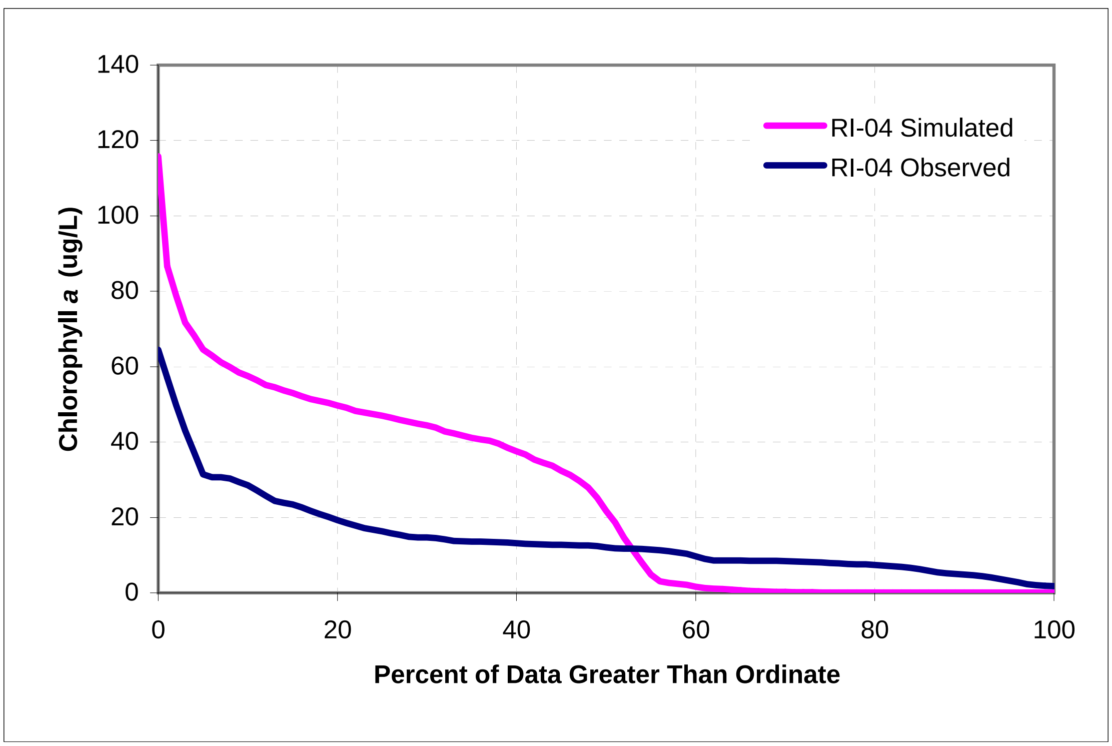
Milwaukee River, Station RI-04
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



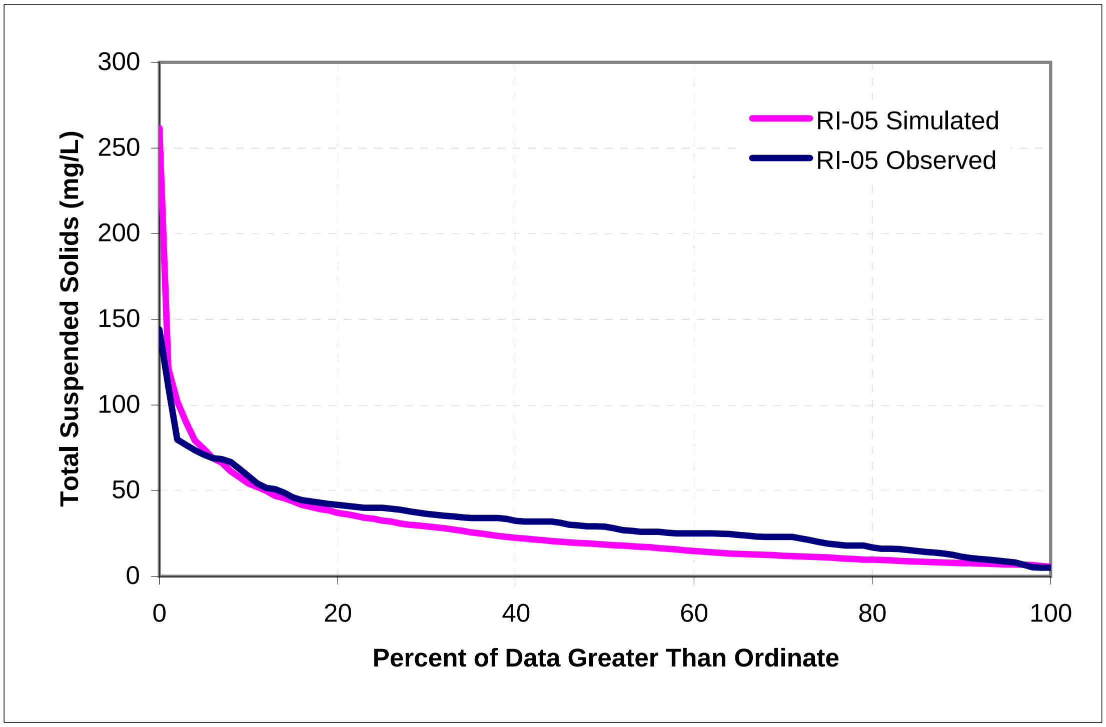


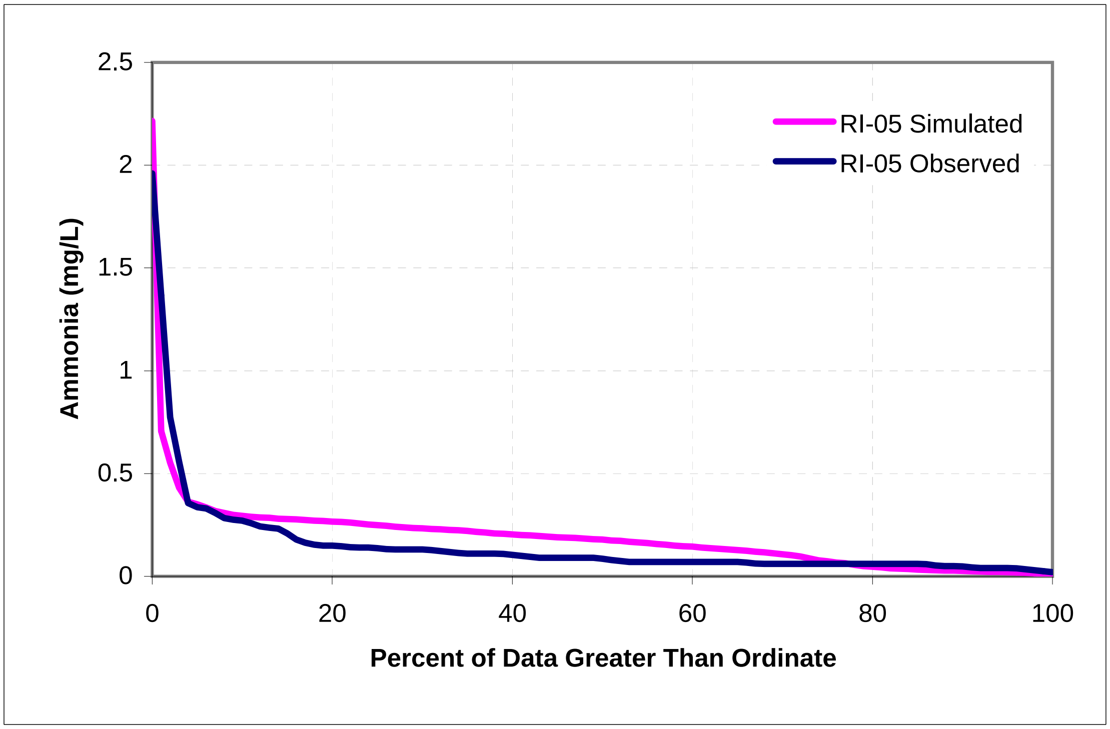
Milwaukee River, Station RI-04
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



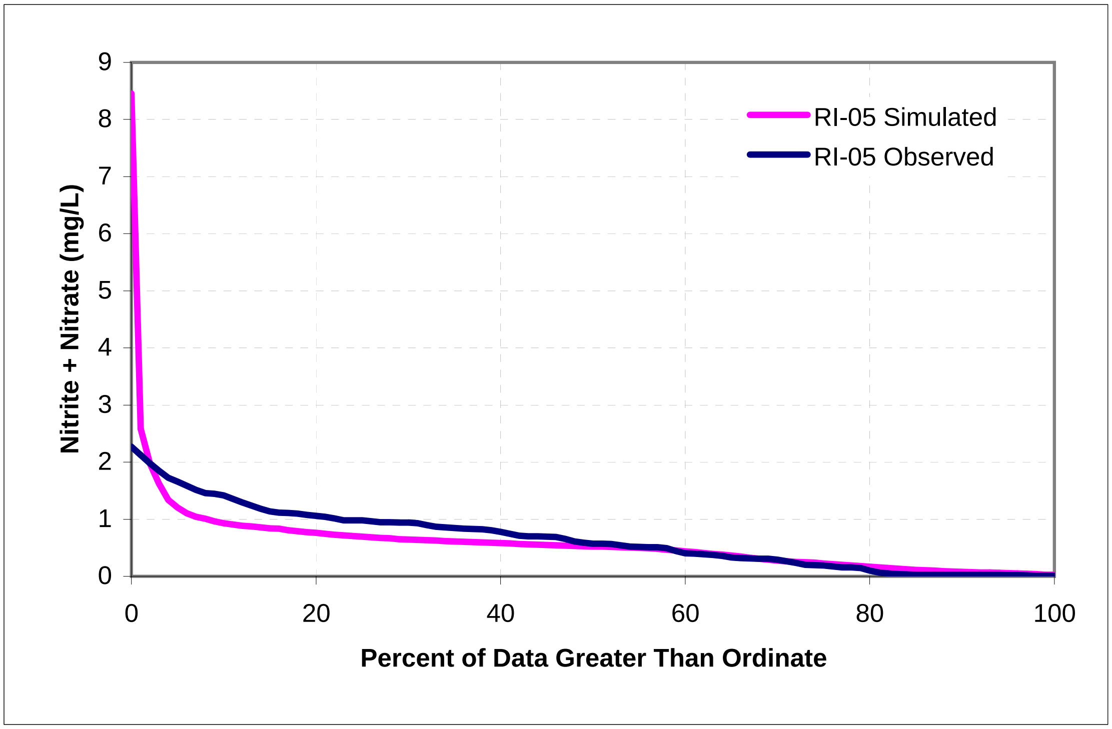


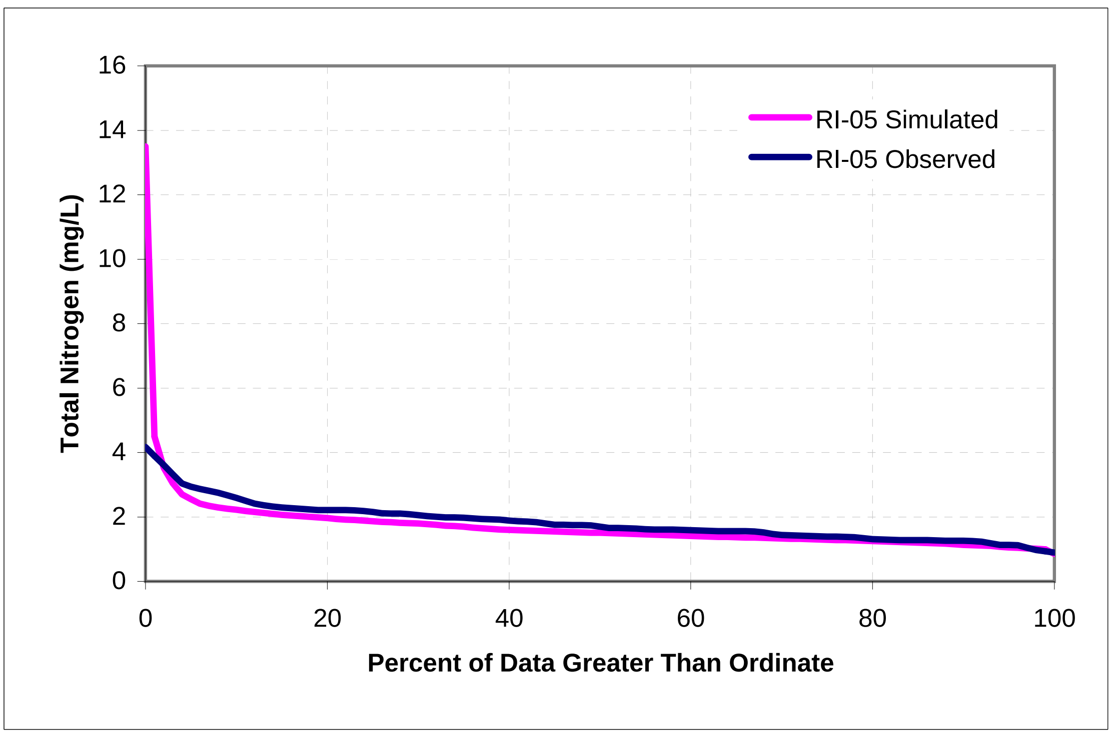
Milwaukee River, Station RI-05
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



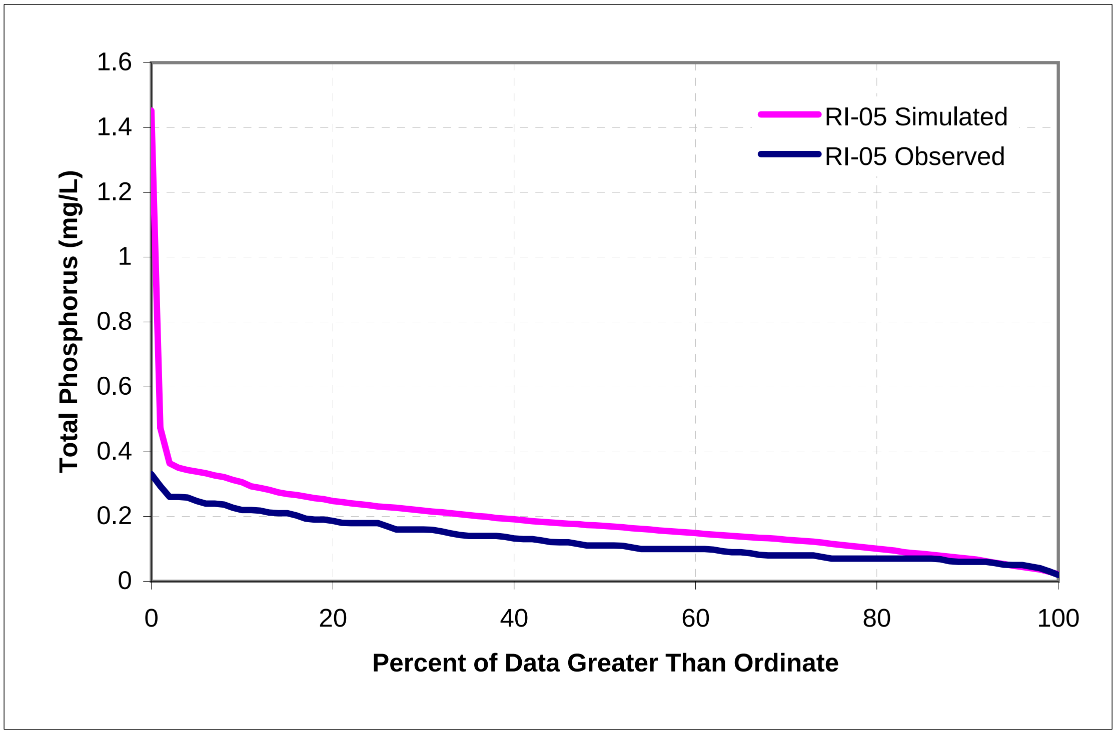


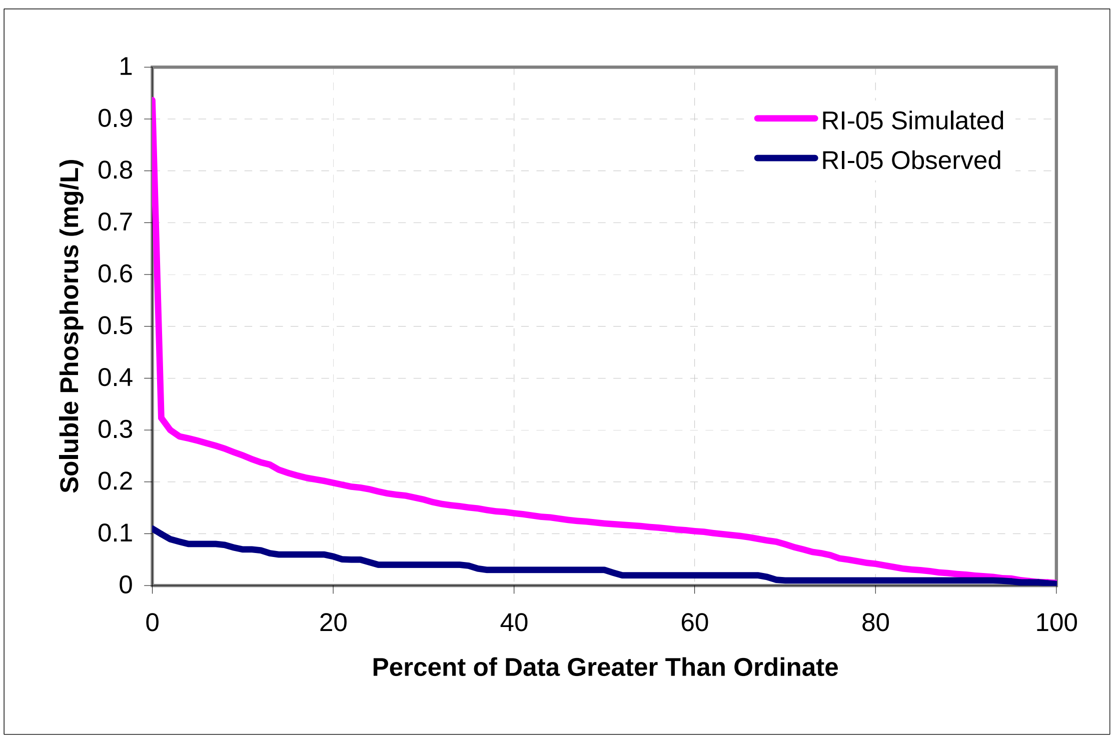
Milwaukee River, Station RI-05
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



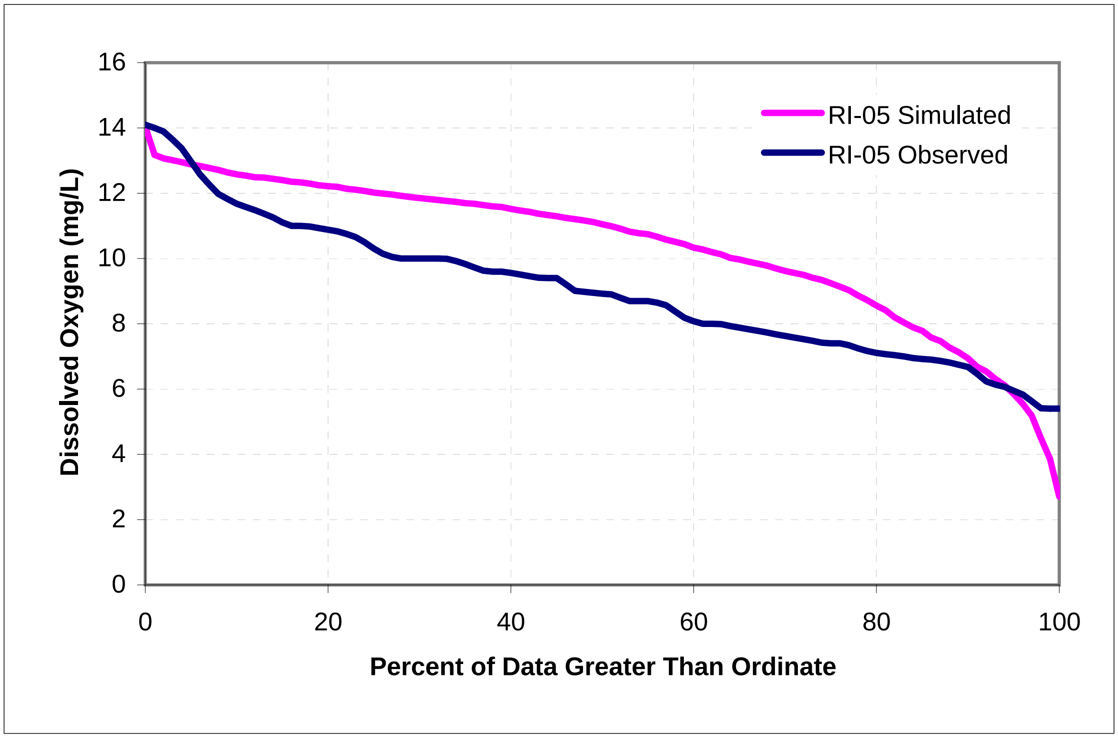


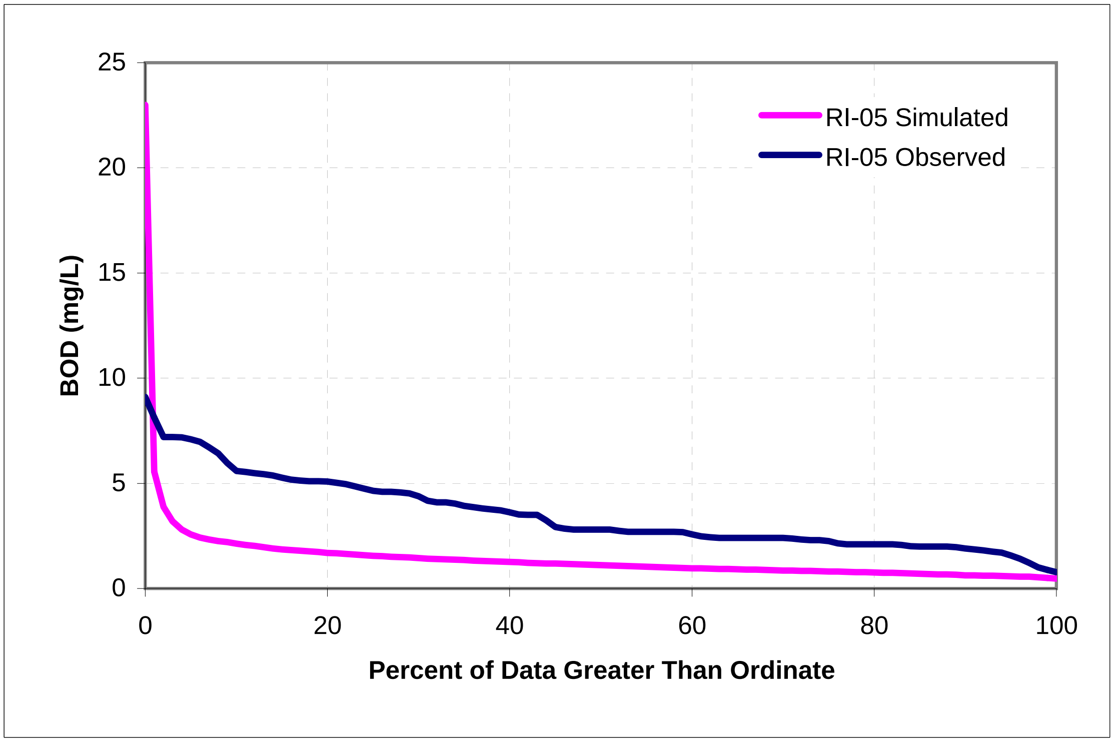
Milwaukee River, Station RI-05
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



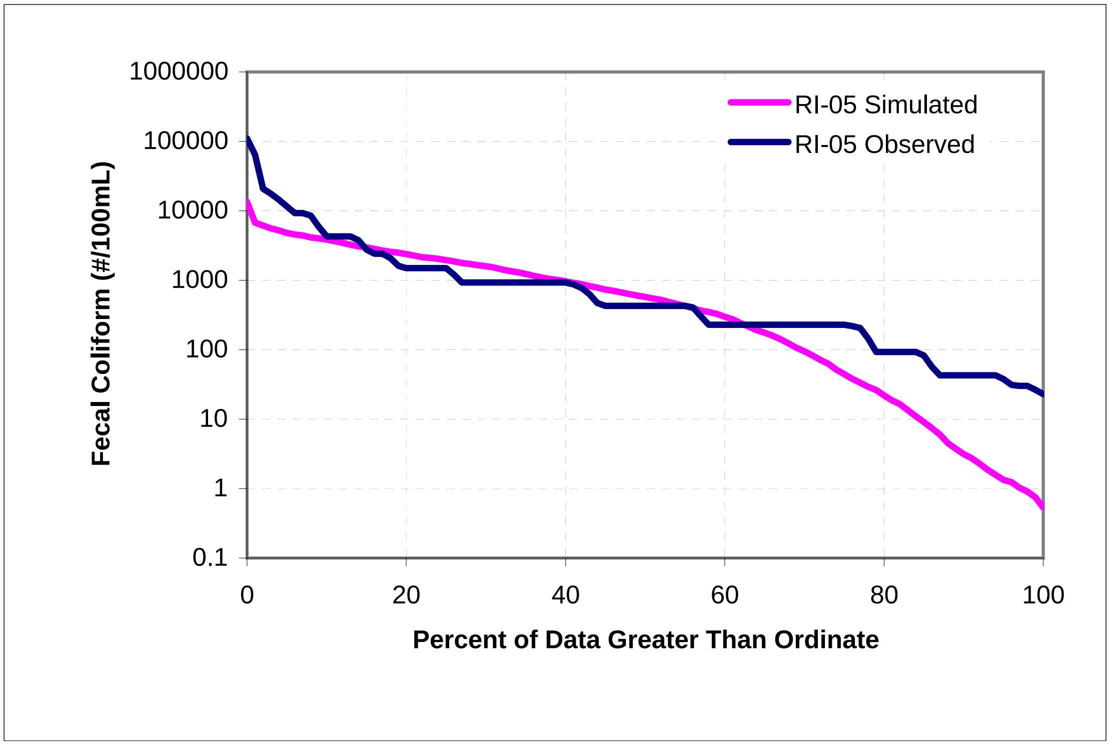


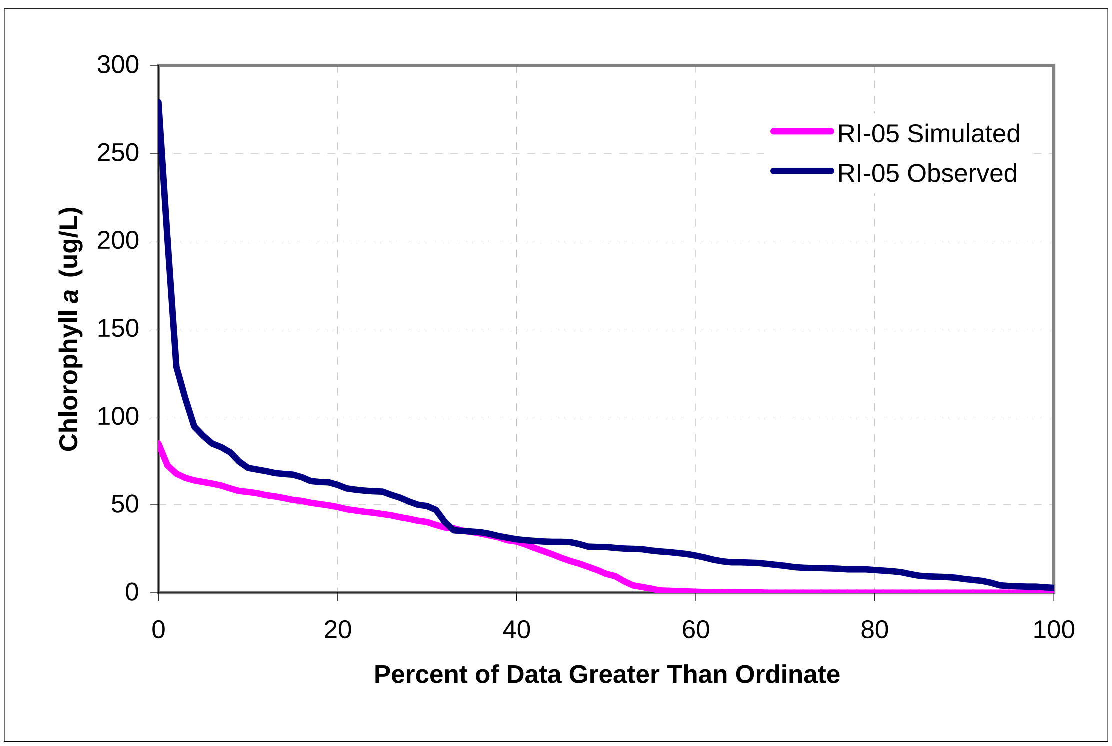
Milwaukee River, Station RI-05
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



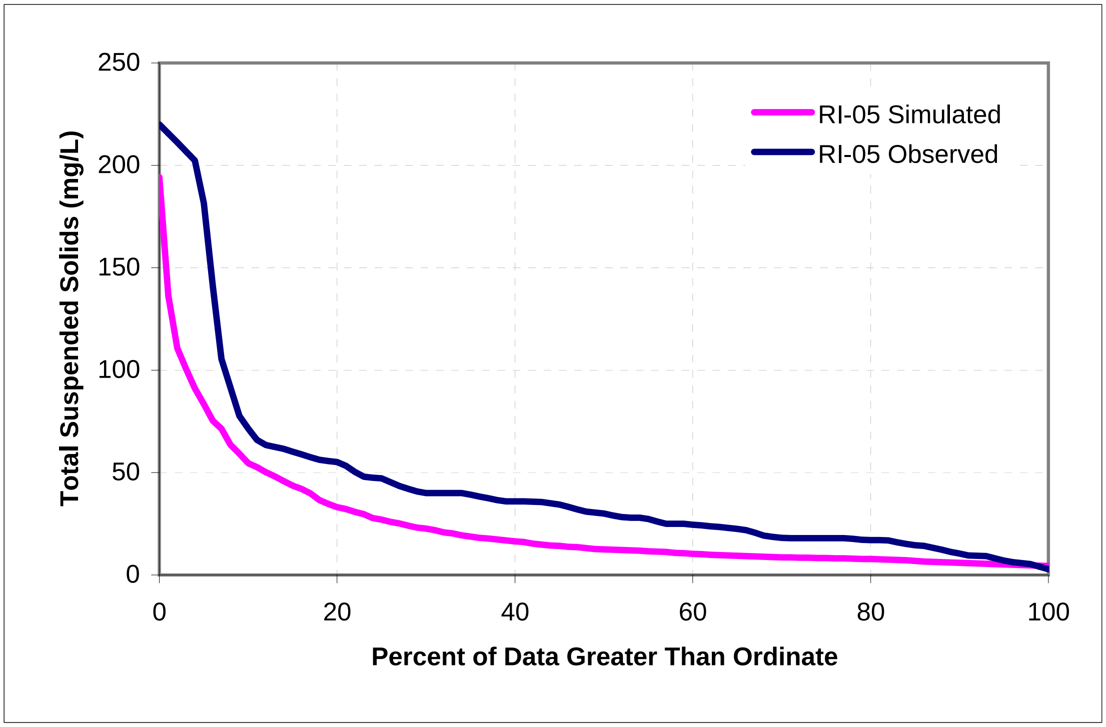


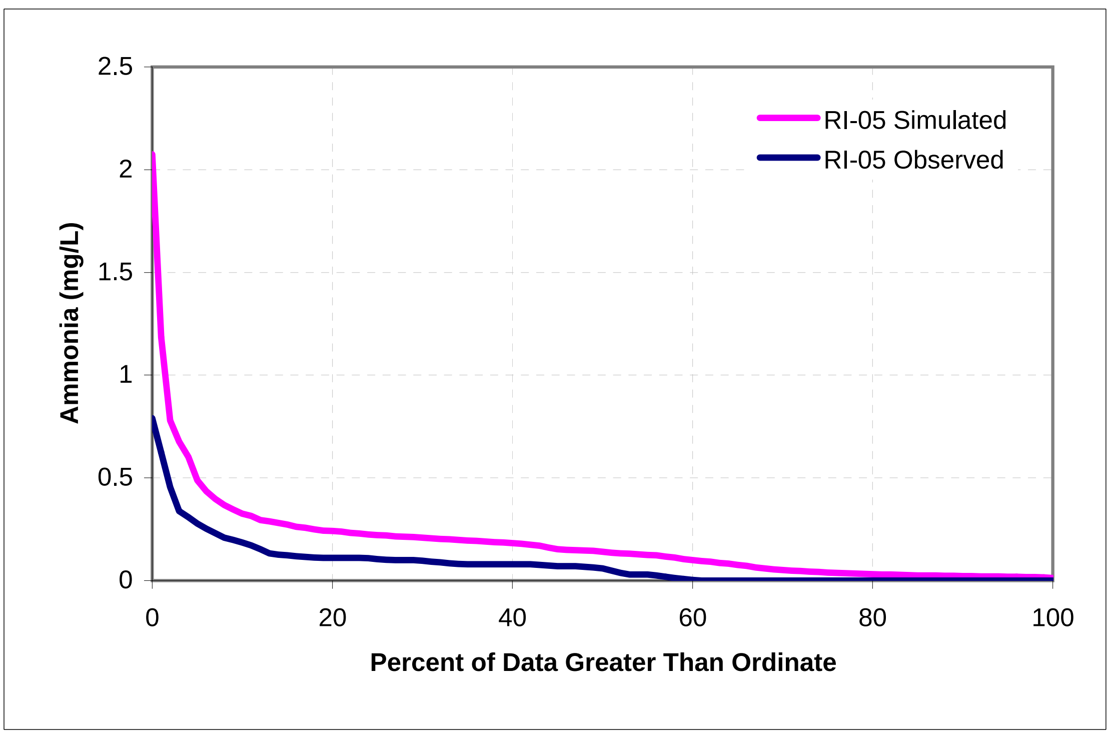
**Milwaukee River, Station RI-05
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998**



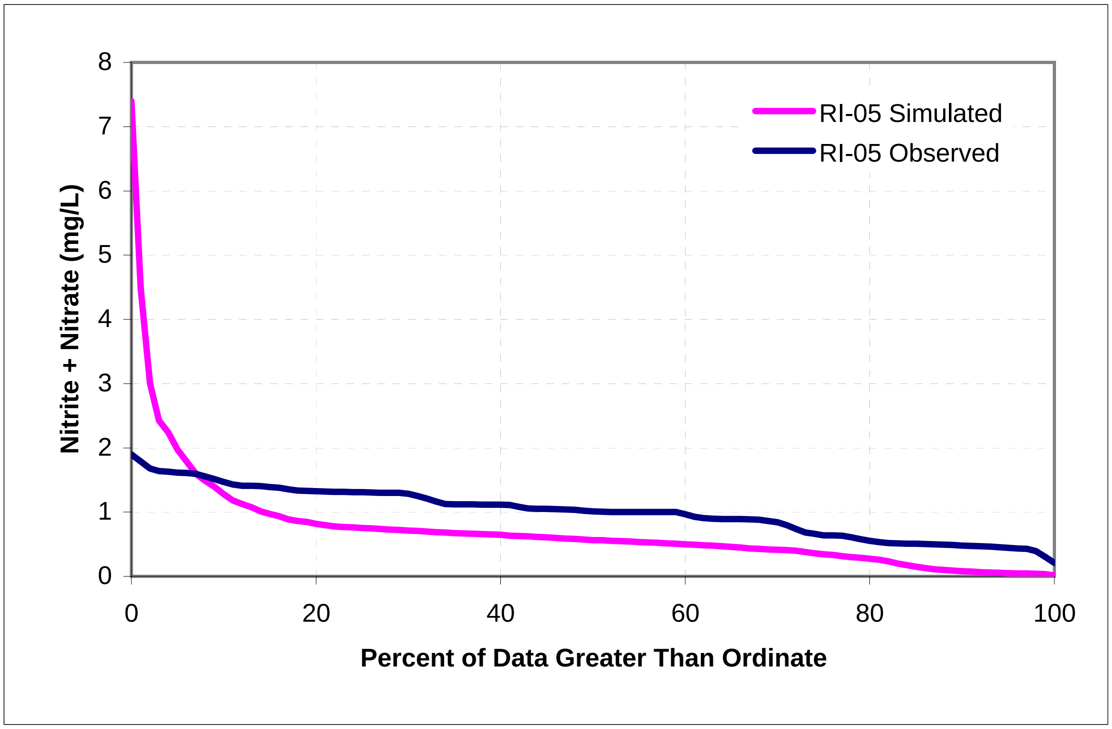


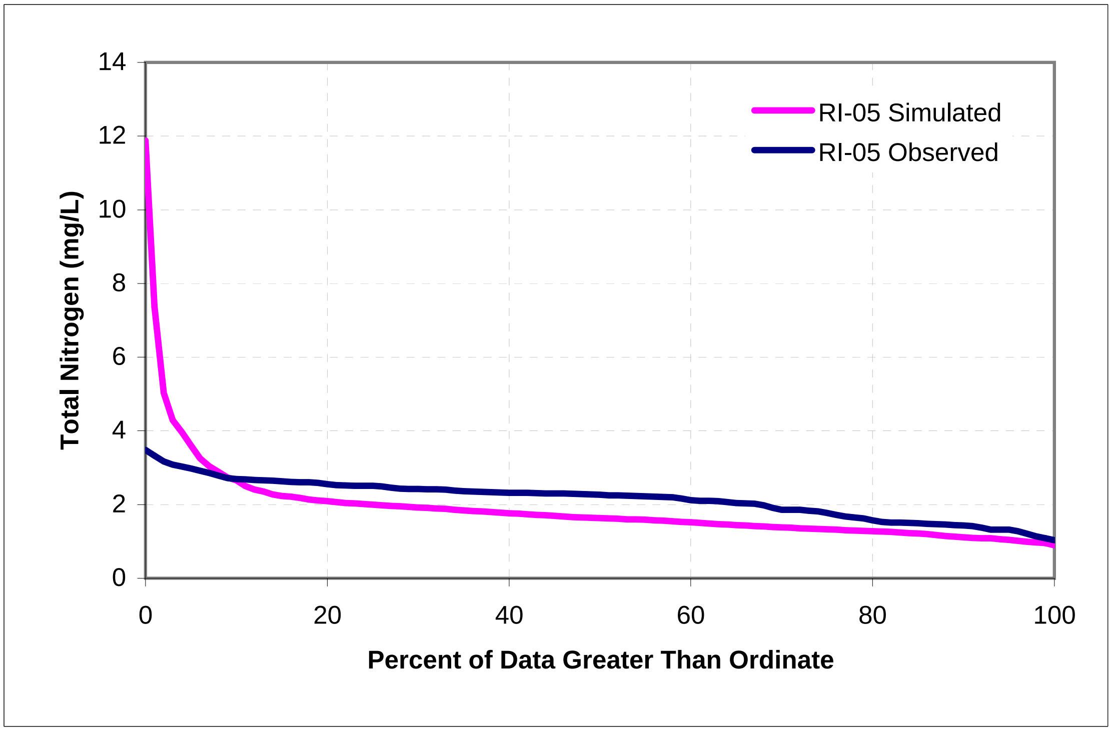
Milwaukee River, Station RI-05
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



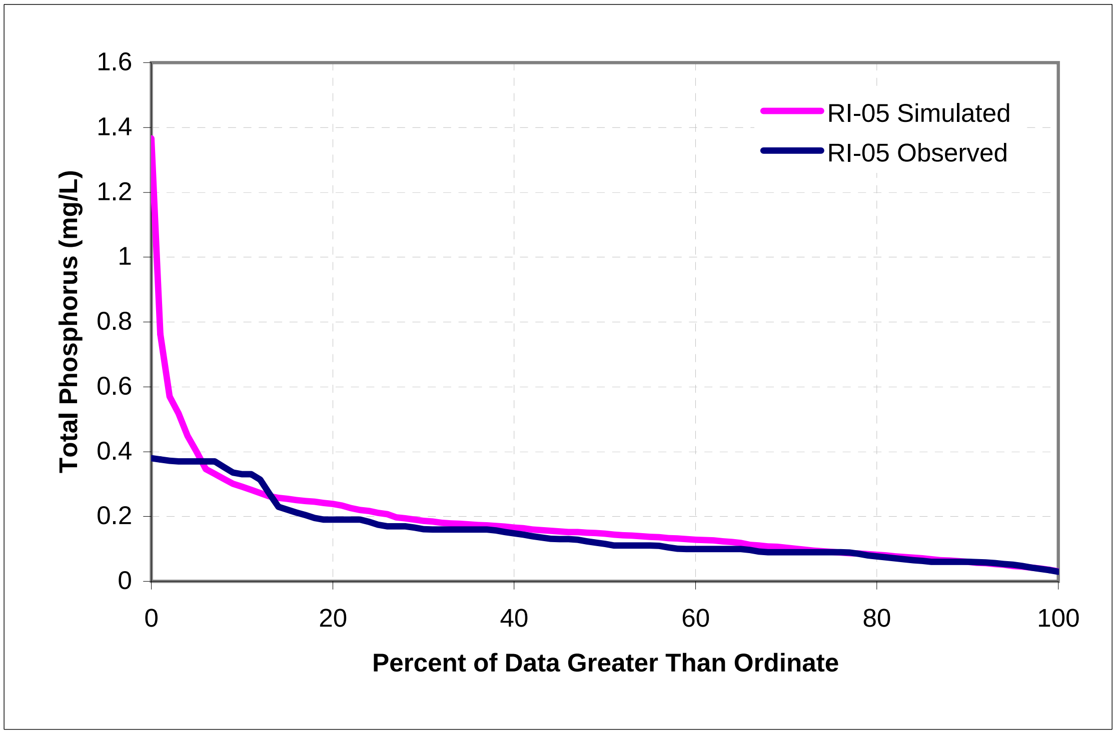


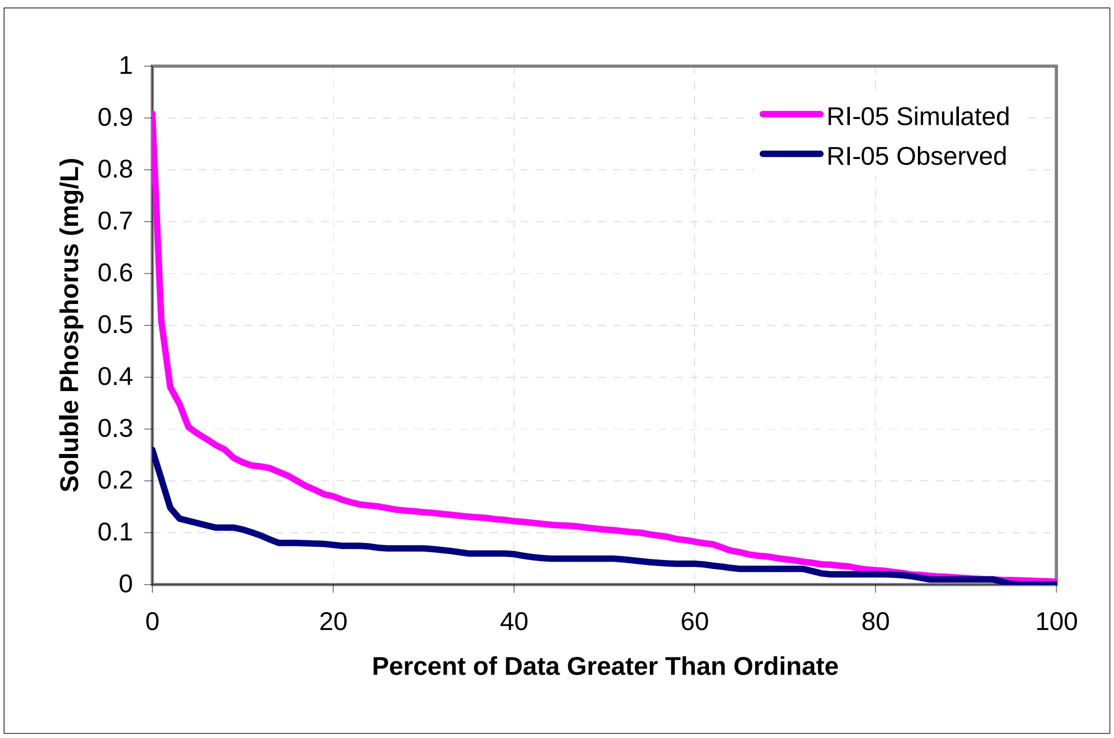
Milwaukee River, Station RI-05
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



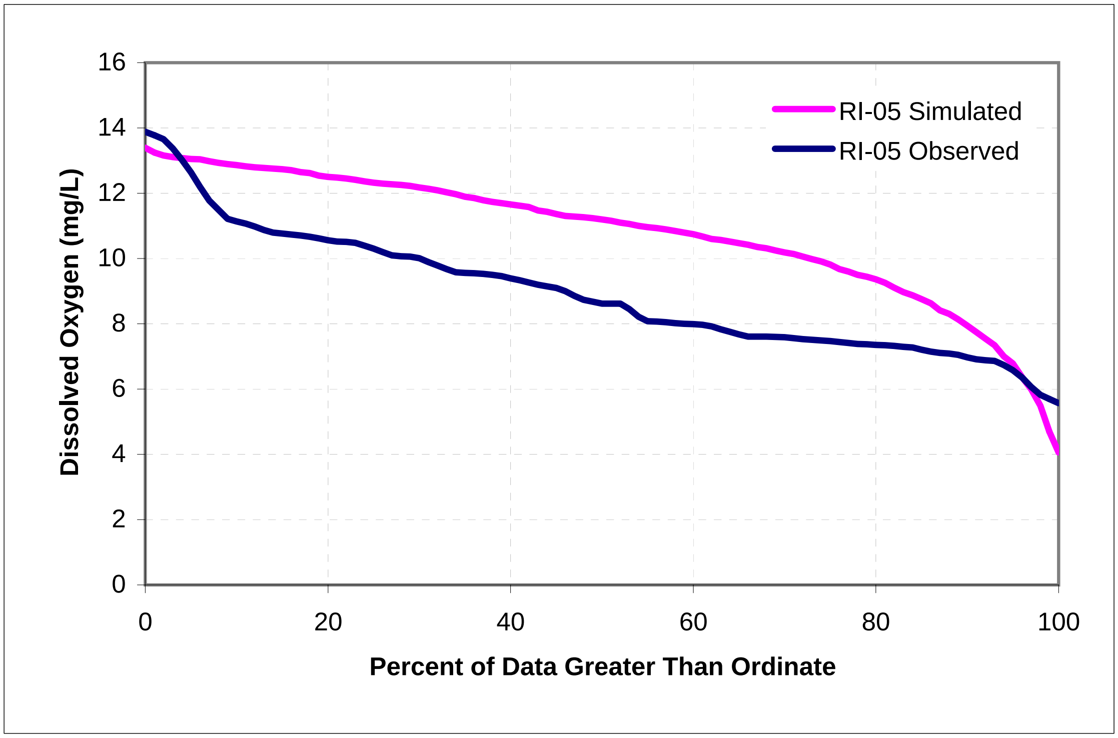


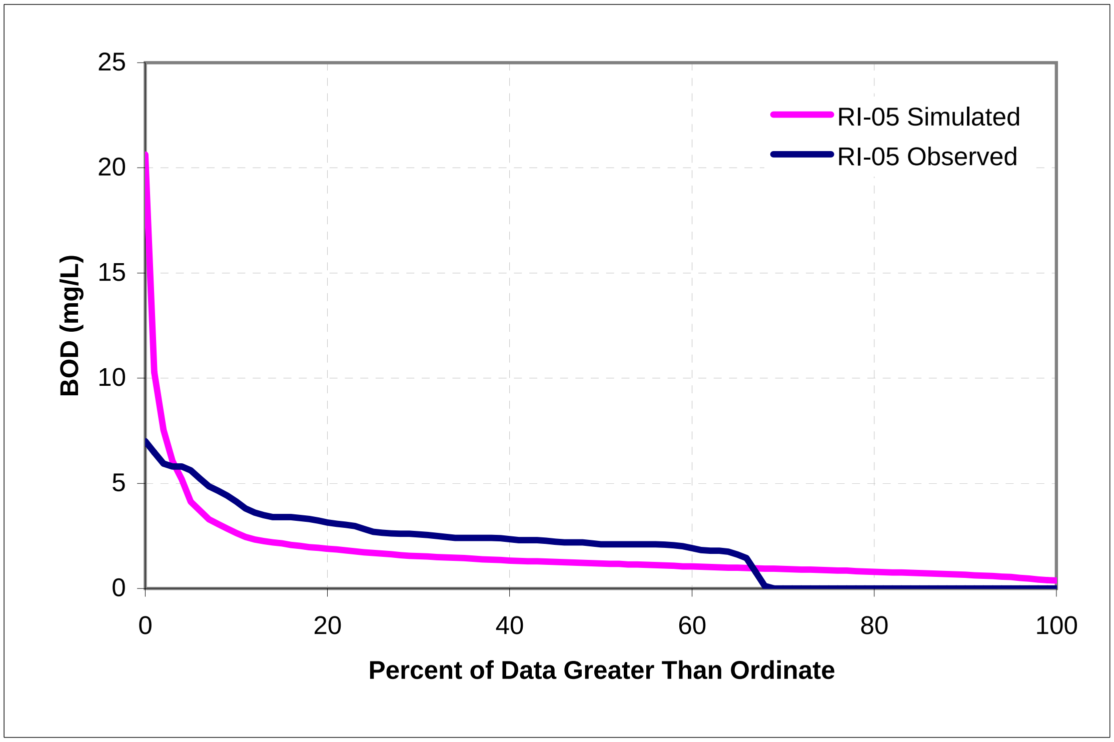
Milwaukee River, Station RI-05
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



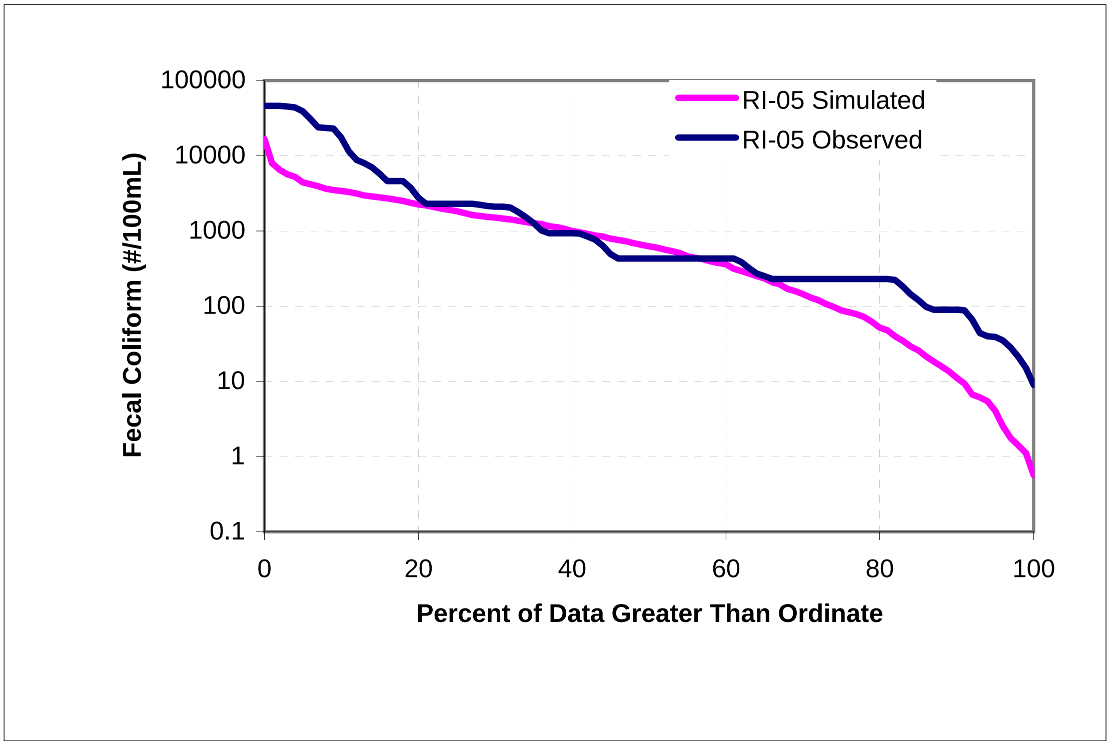


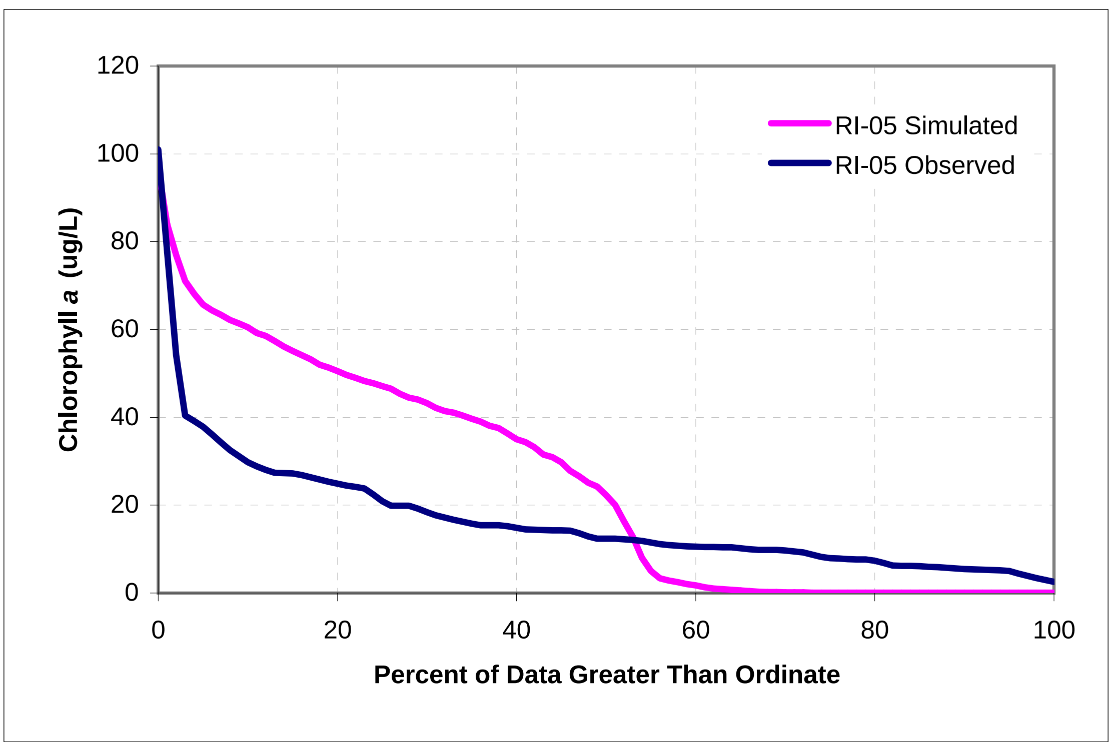
Milwaukee River, Station RI-05
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



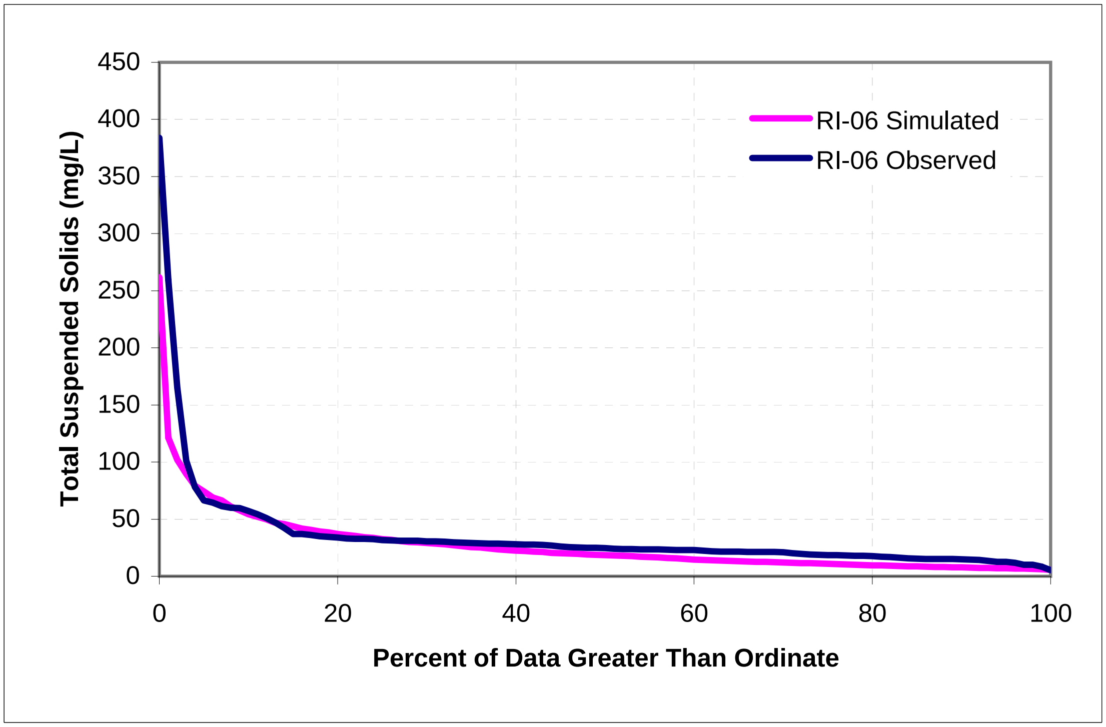


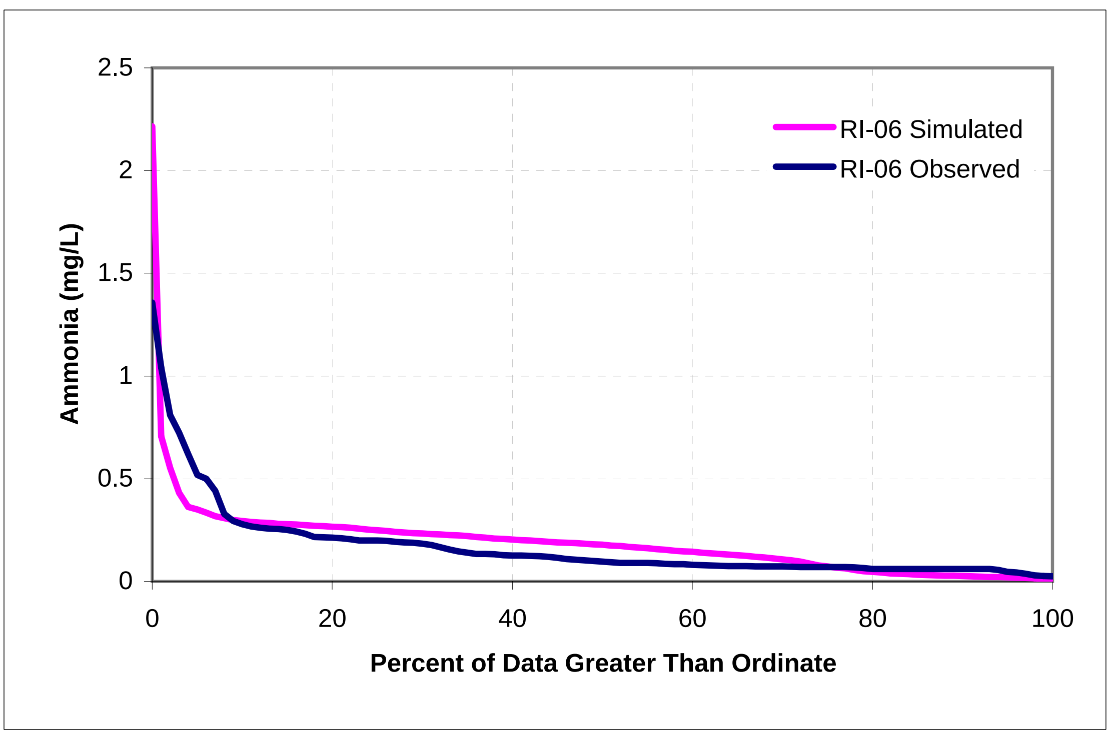
Milwaukee River, Station RI-05
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



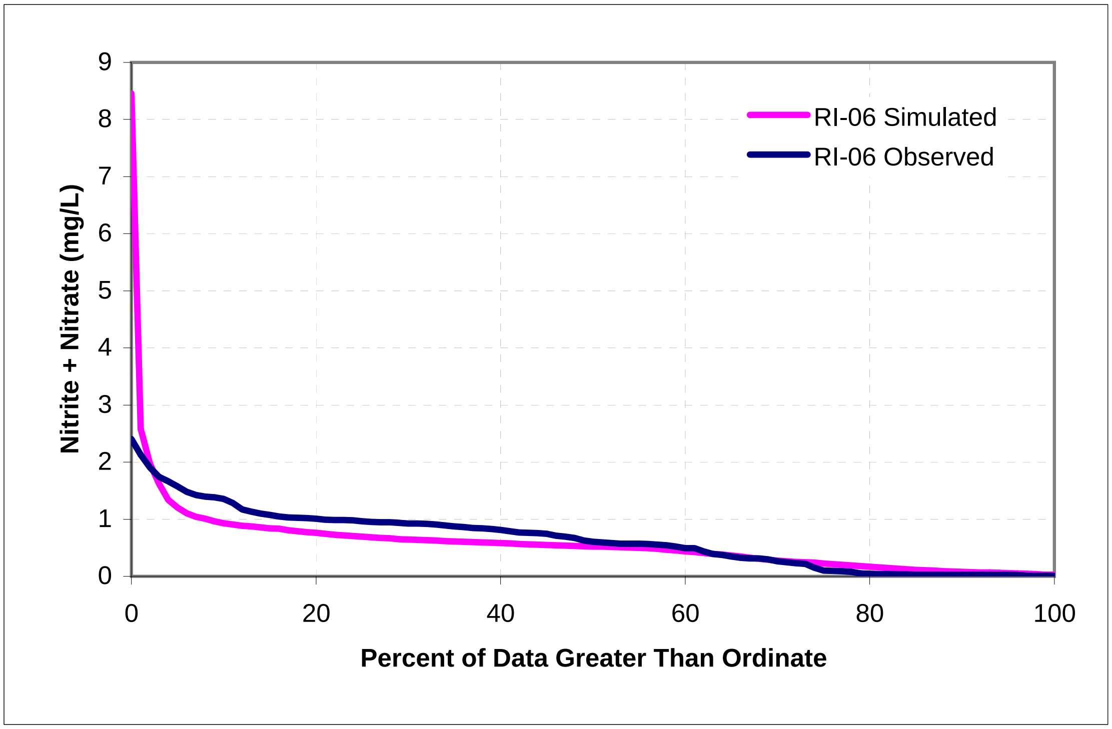


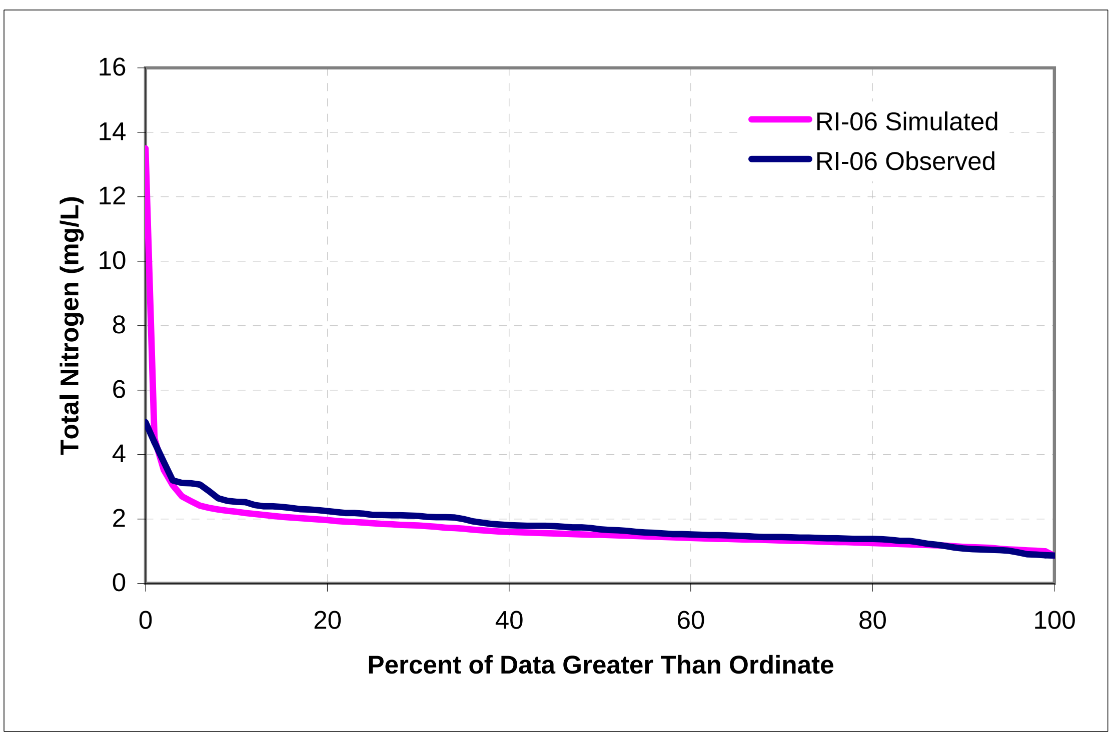
Milwaukee River, Station RI-06
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



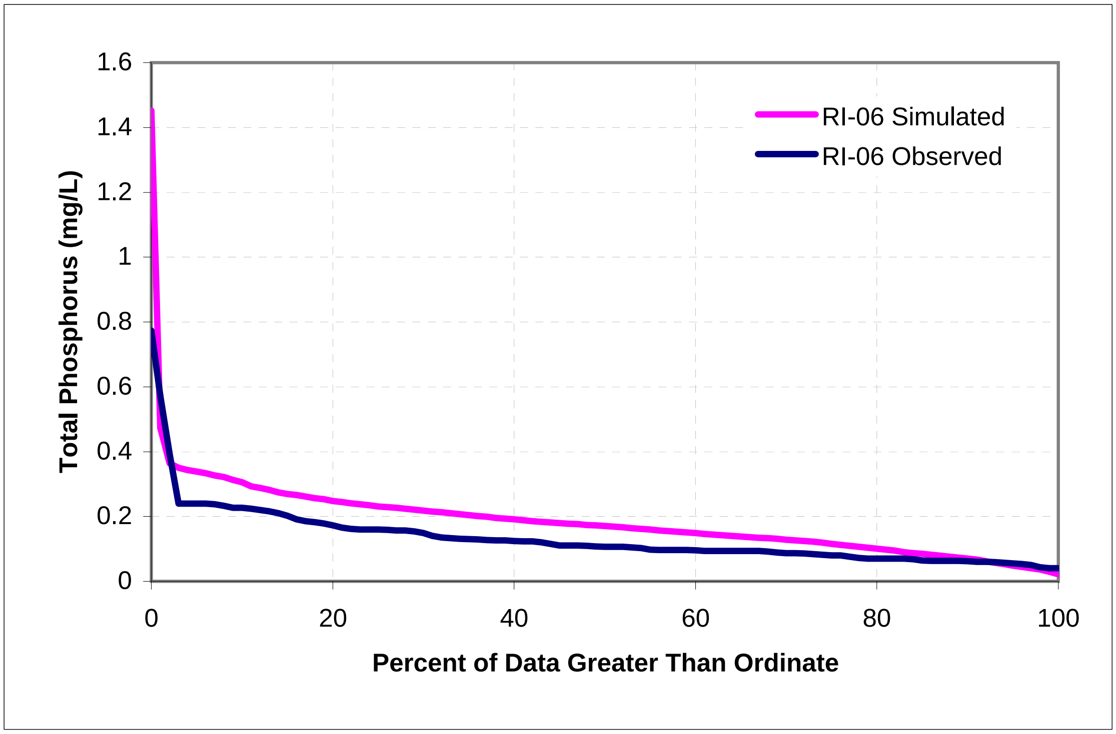


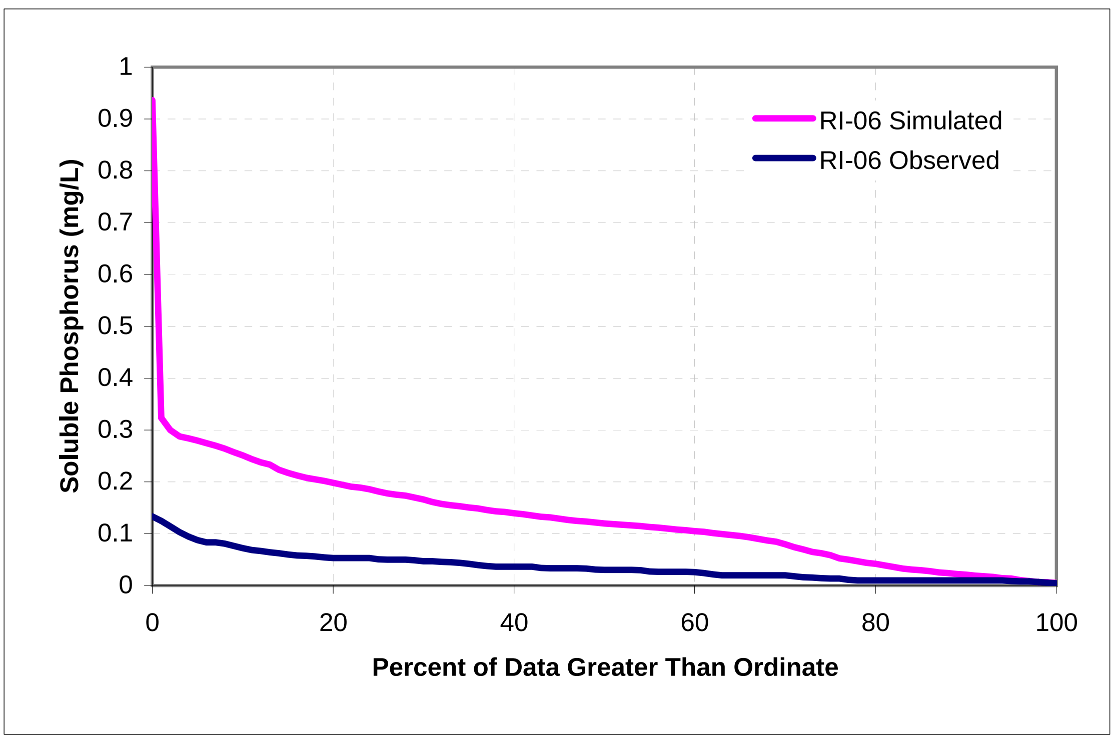
Milwaukee River, Station RI-06
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



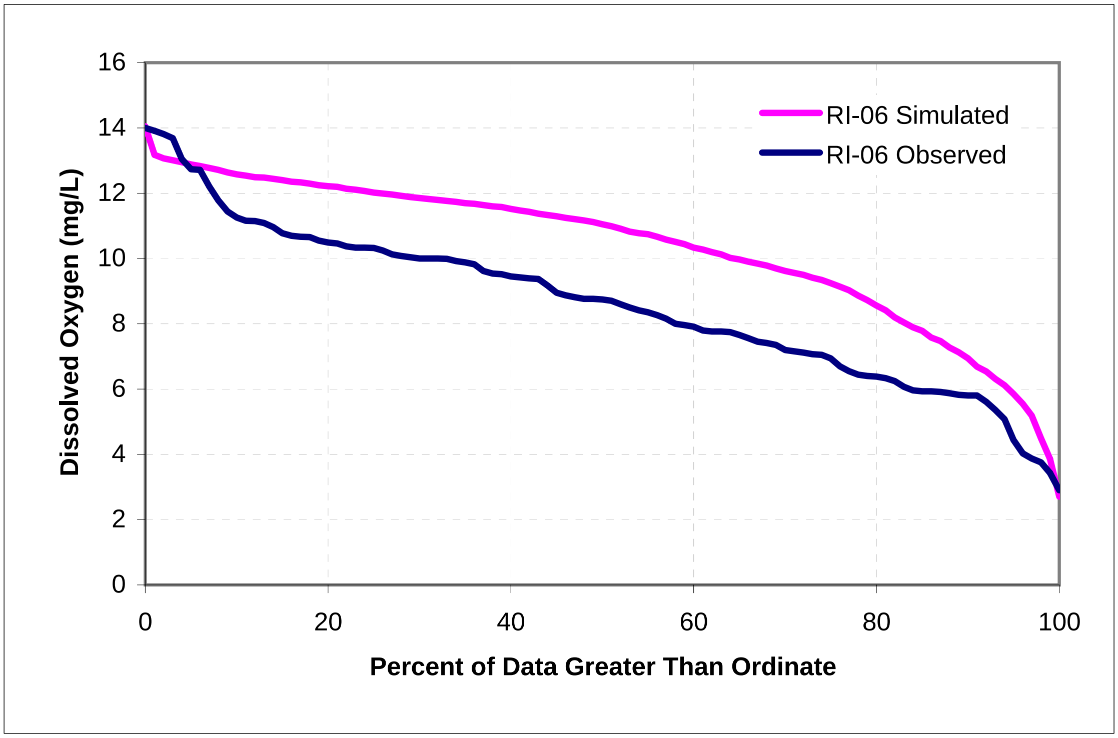


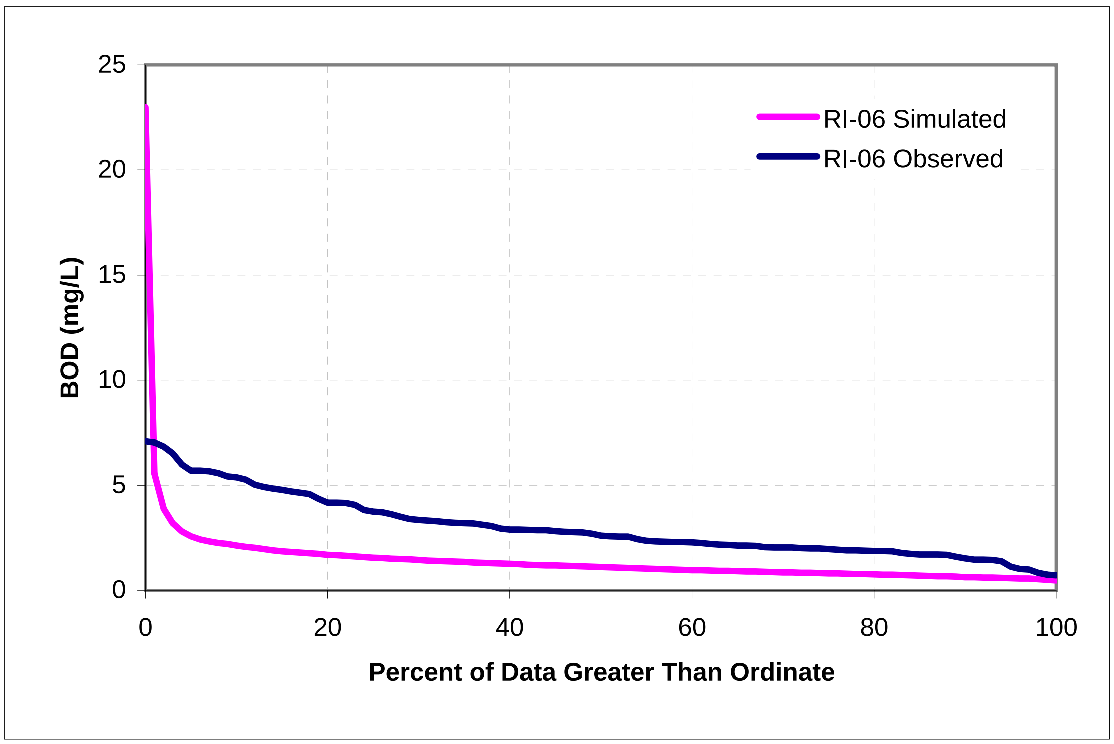
Milwaukee River, Station RI-06
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



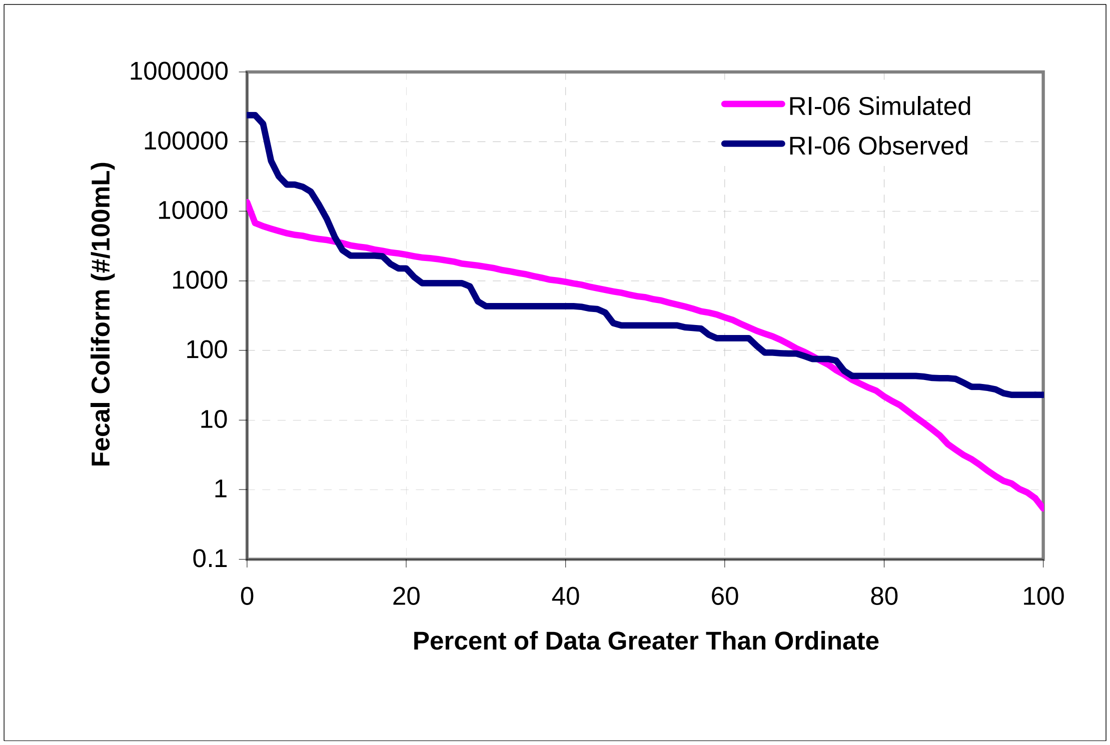


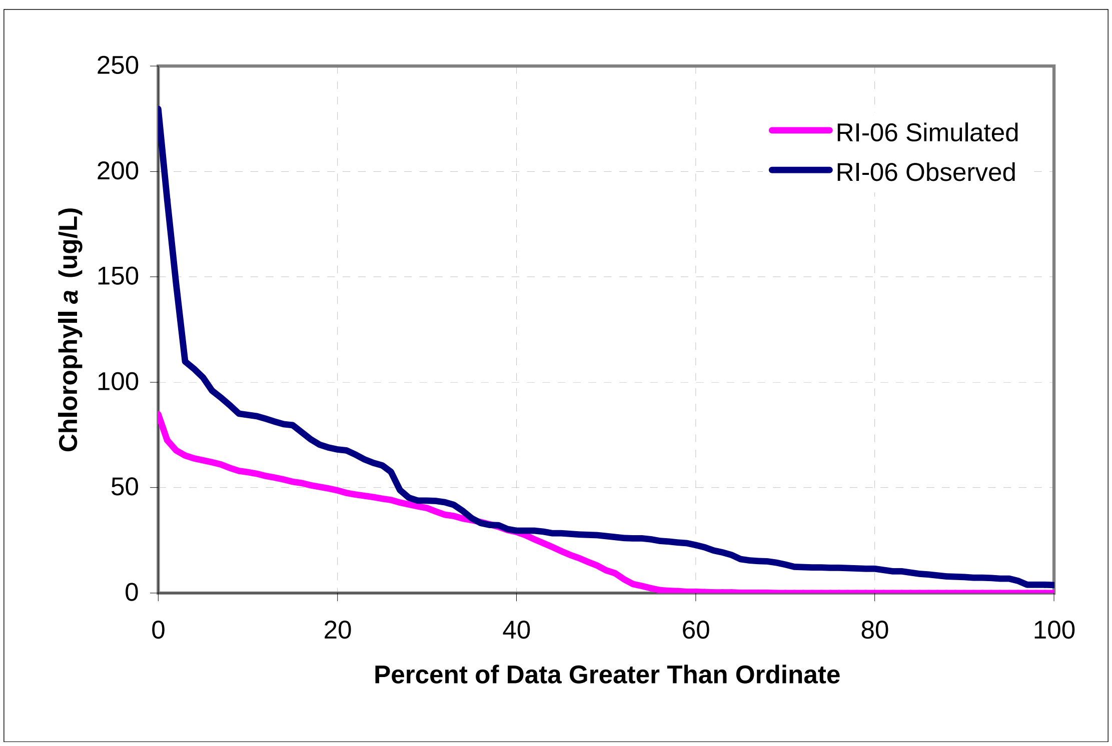
Milwaukee River, Station RI-06
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



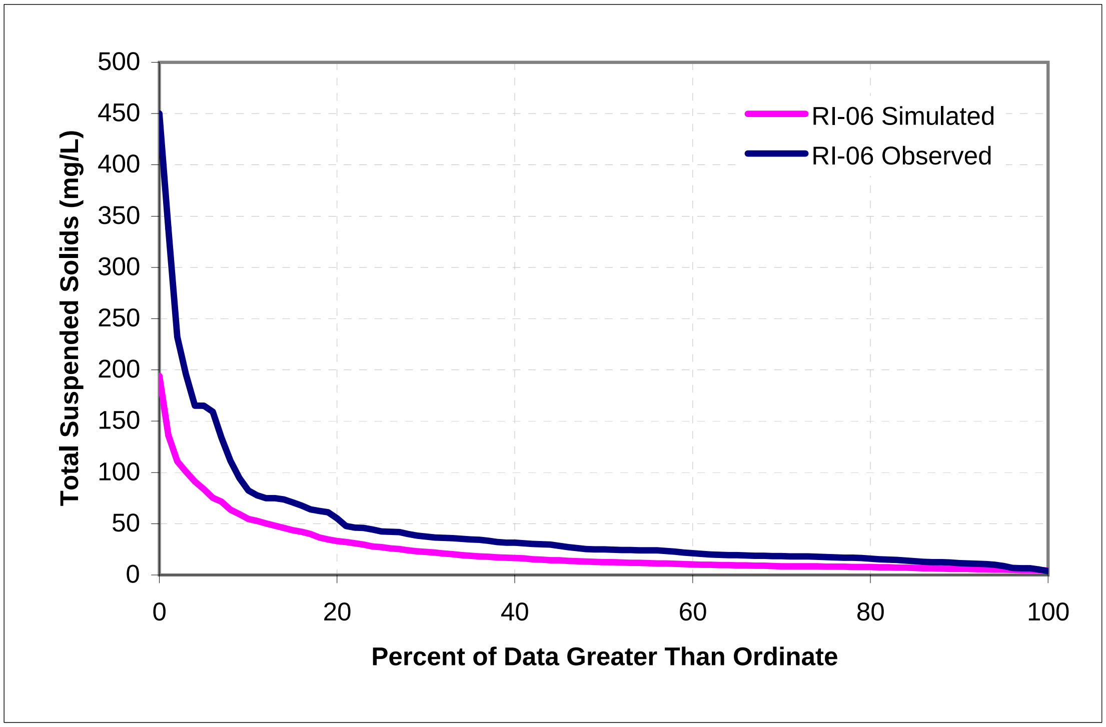


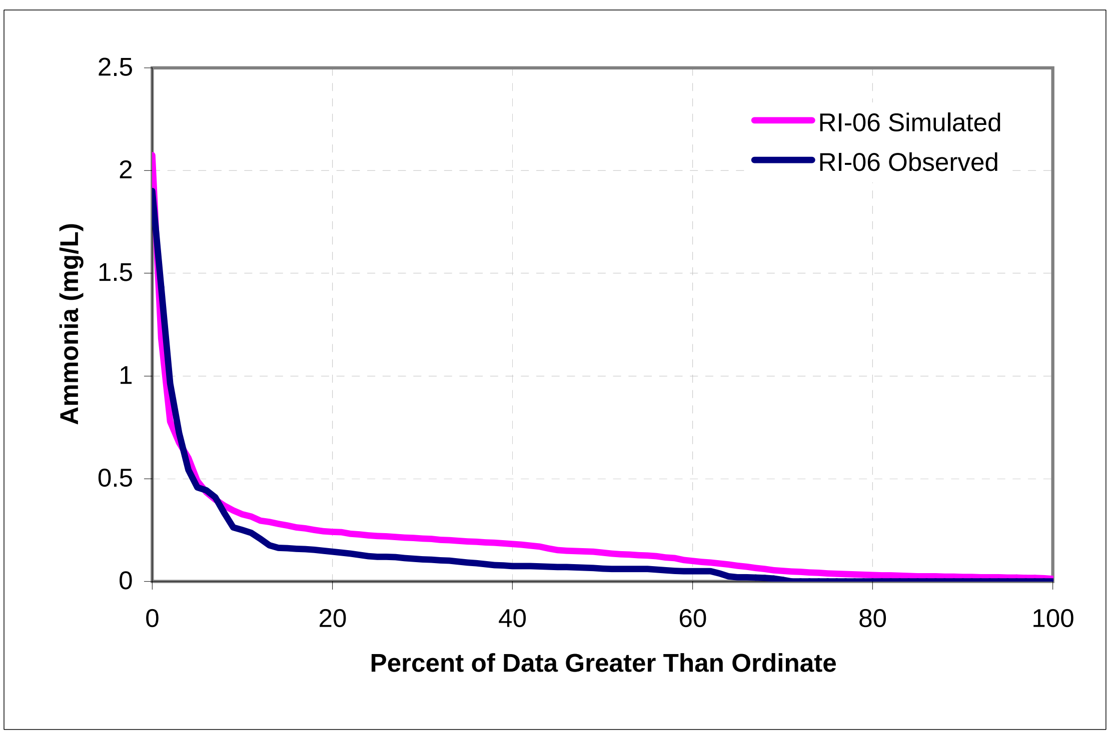
Milwaukee River, Station RI-06
Concentration Exceedance Curve Plots
Calibration Period, 1994-1998



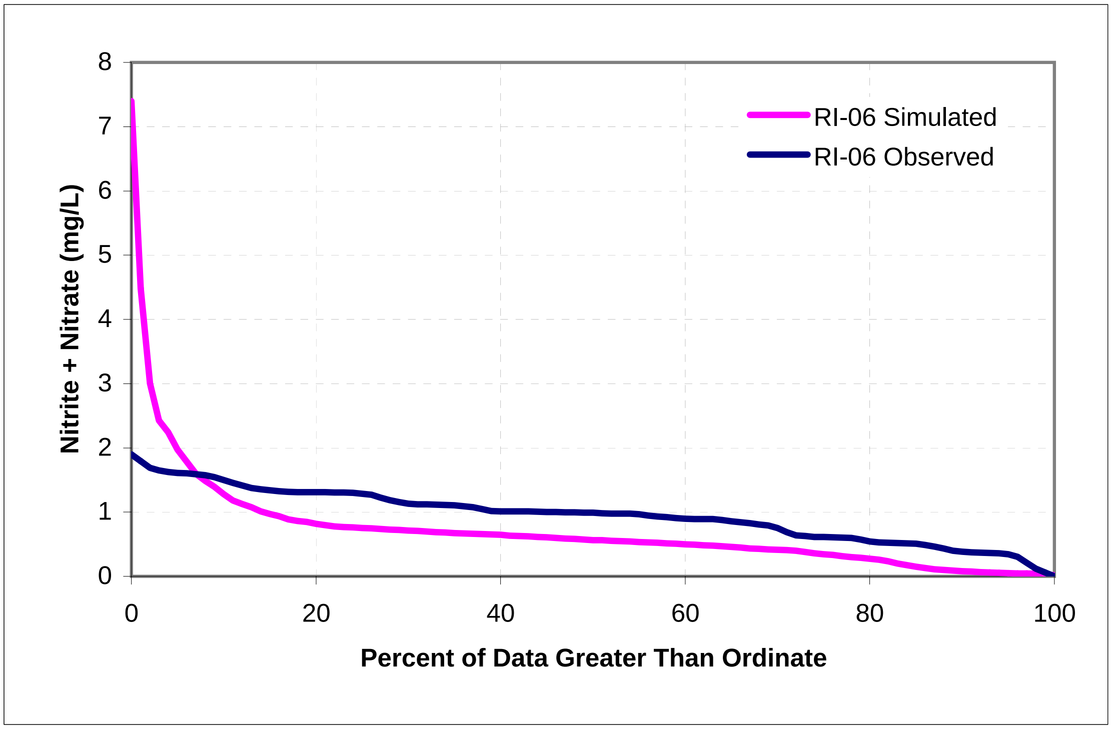


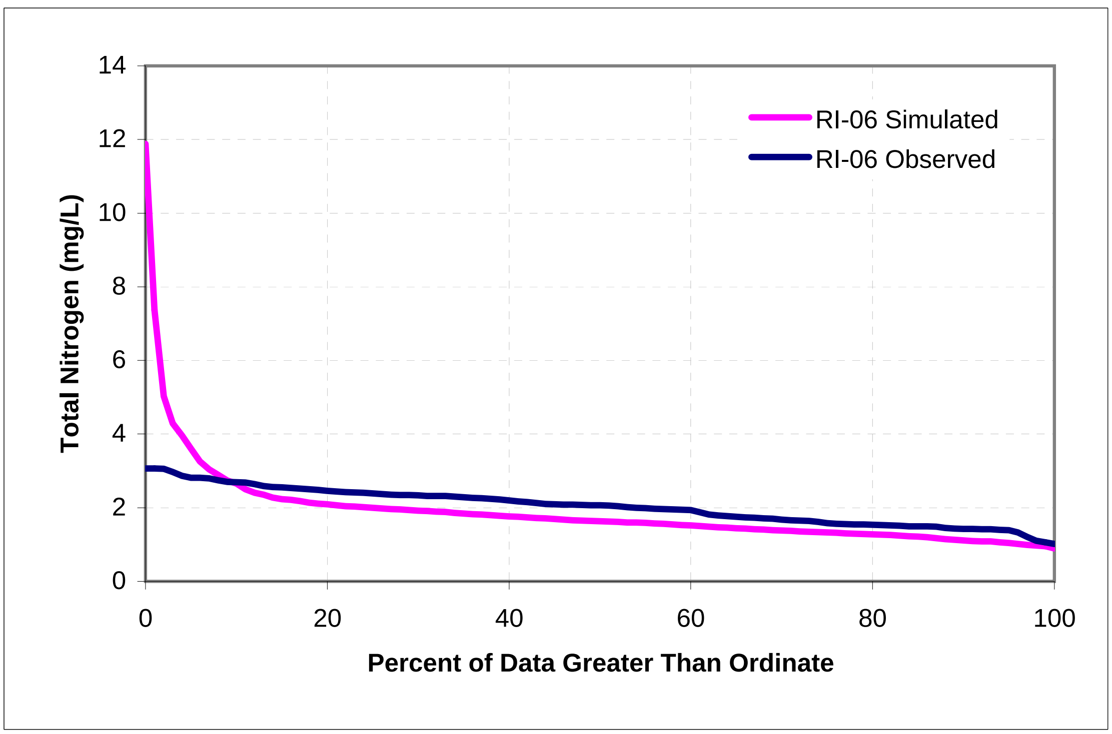
Milwaukee River, Station RI-06
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



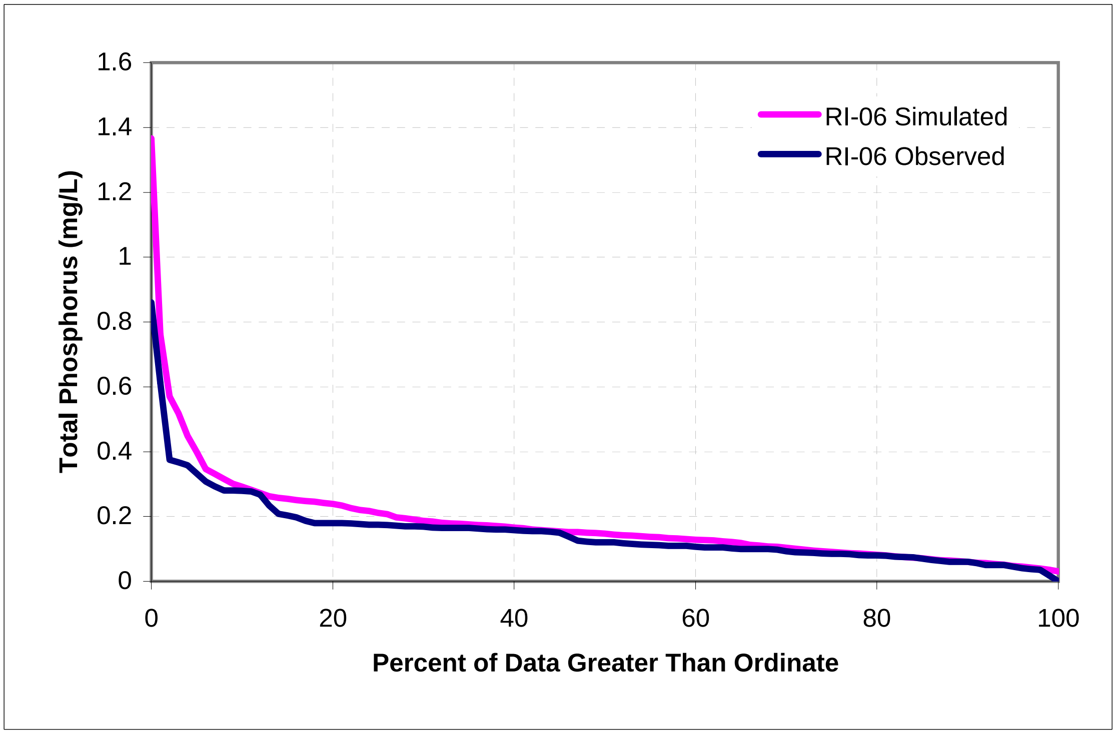


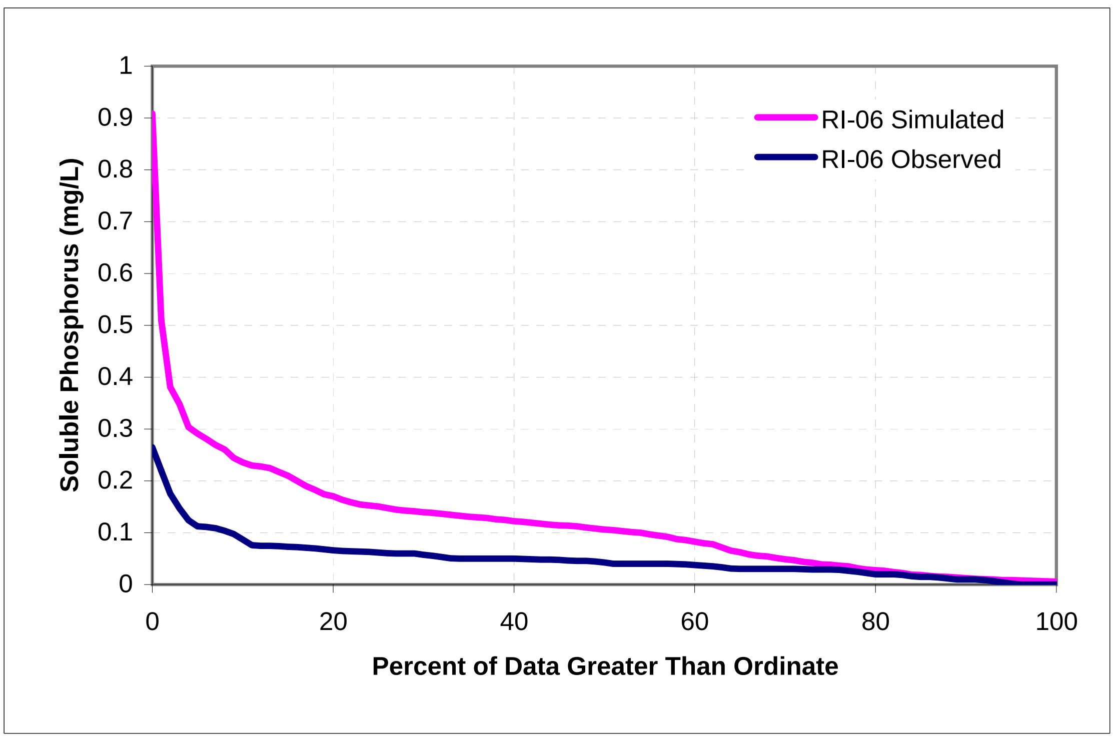
Milwaukee River, Station RI-06
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



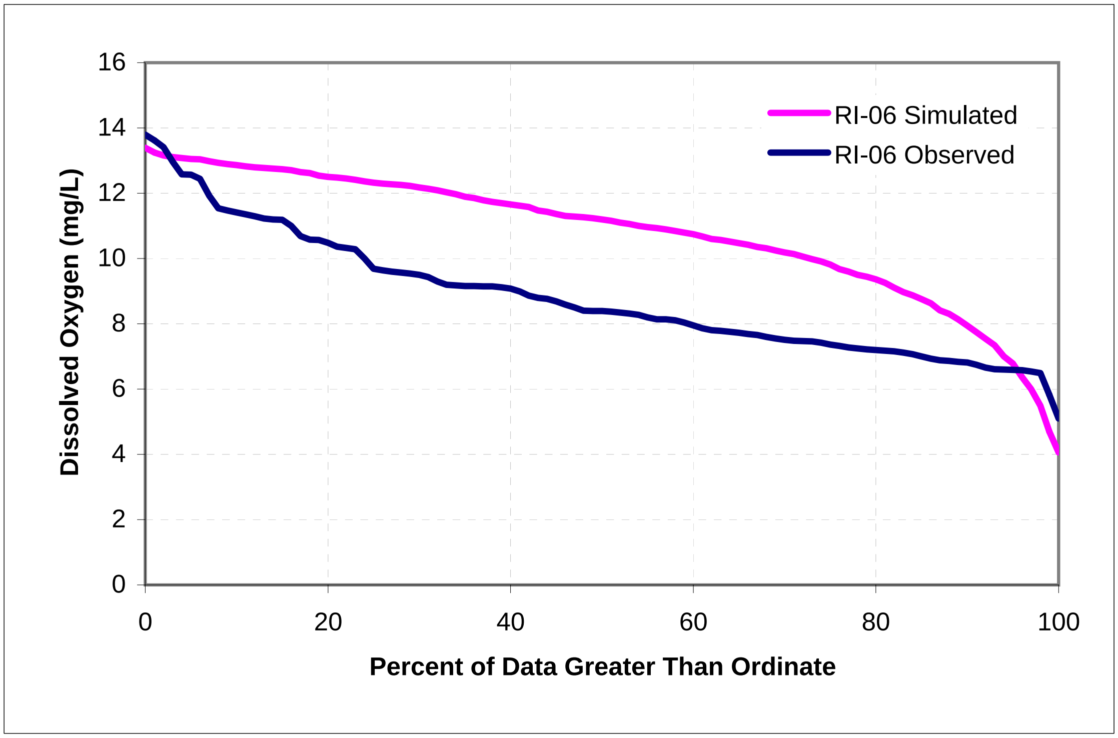


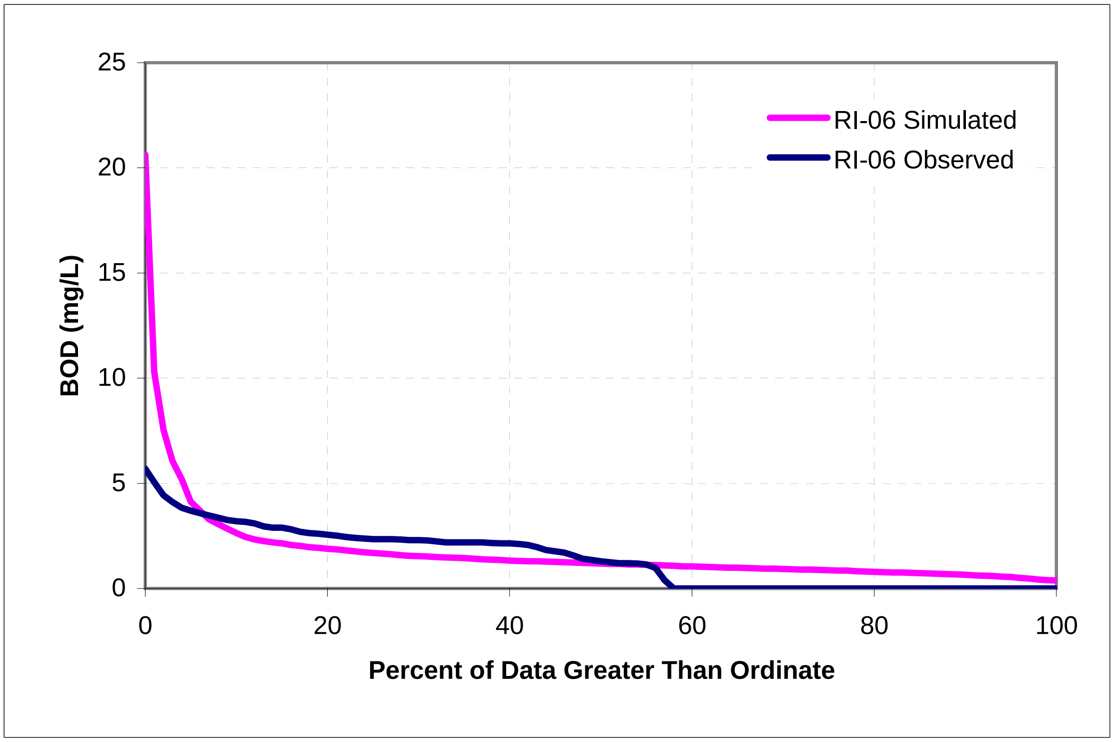
Milwaukee River, Station RI-06
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



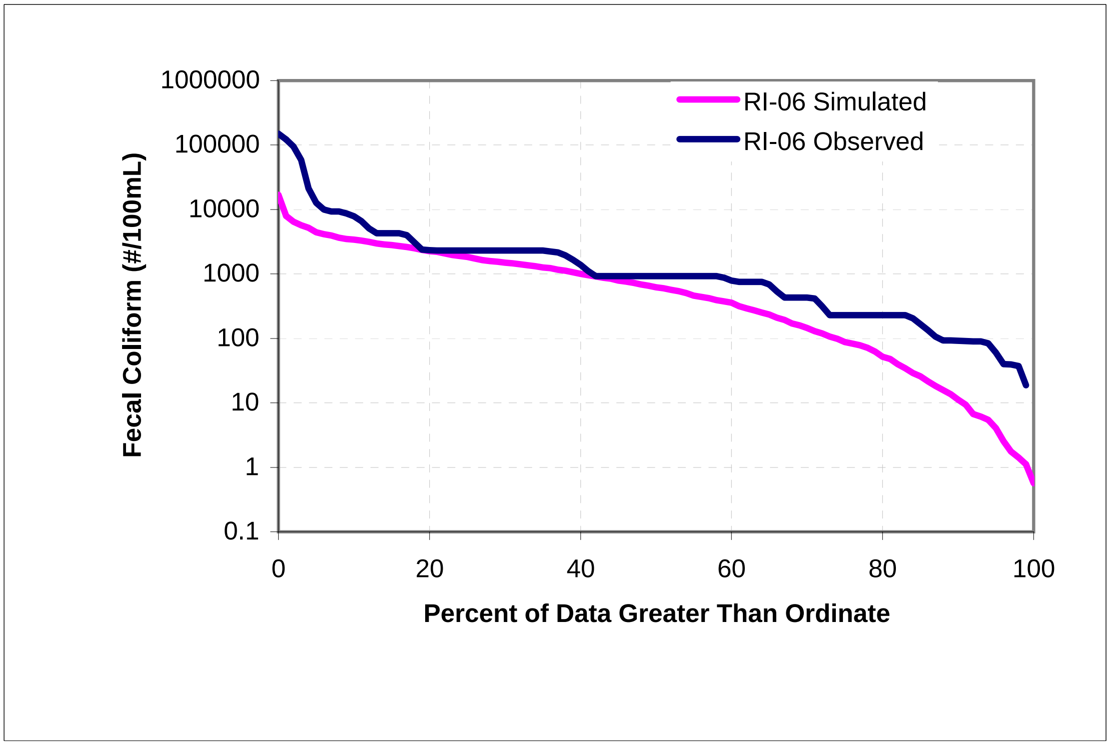


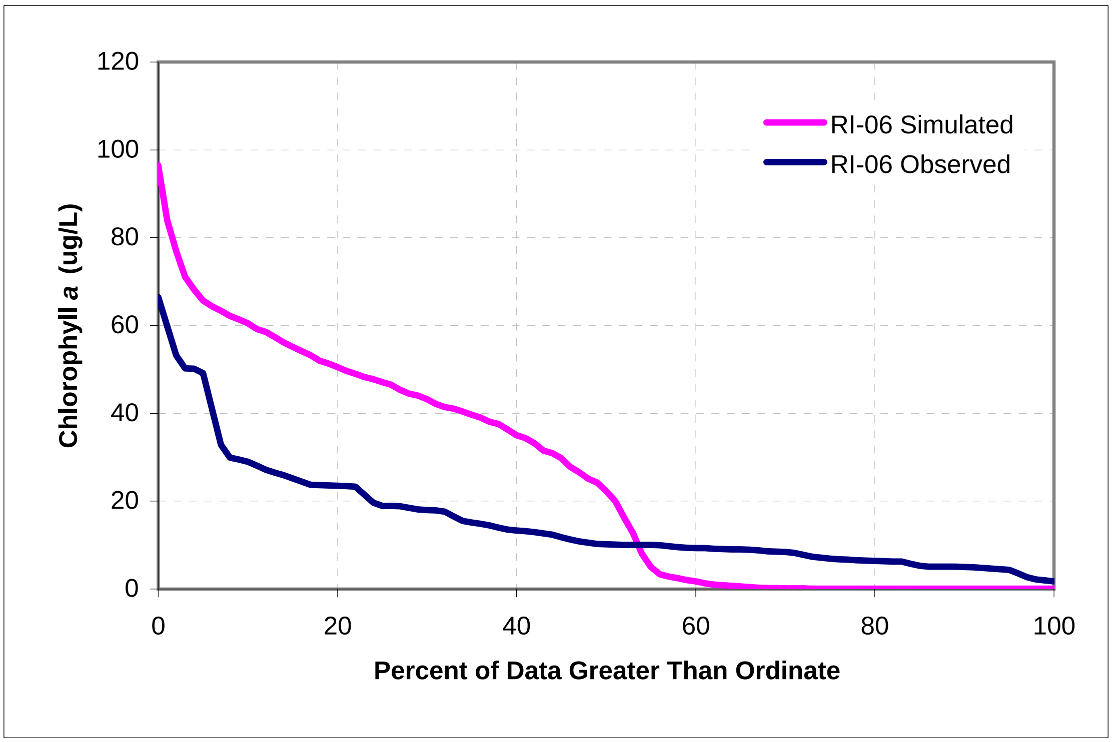
Milwaukee River, Station RI-06
Concentration Exceedance Curve Plots
Validation Period, 1999-2001



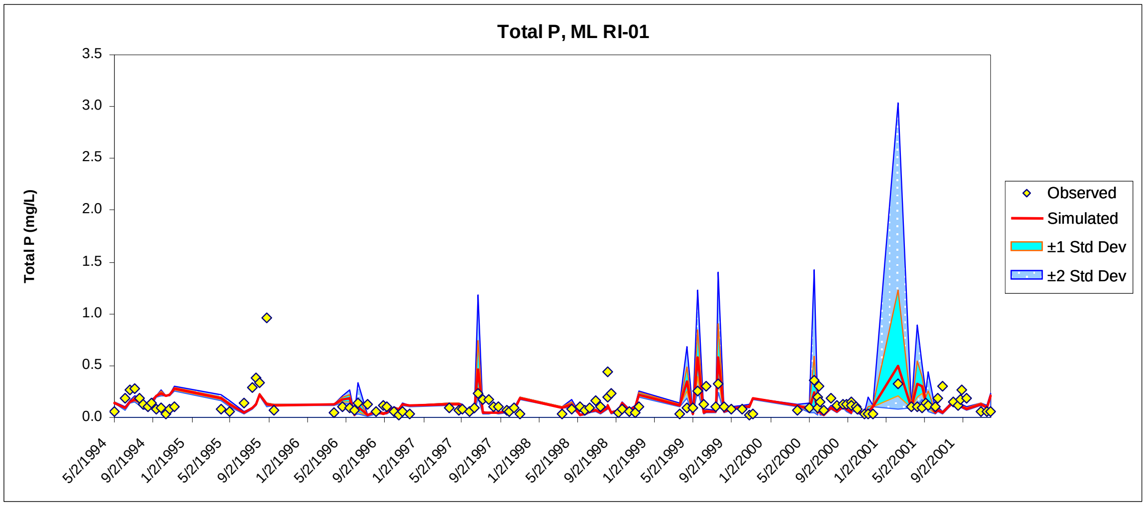


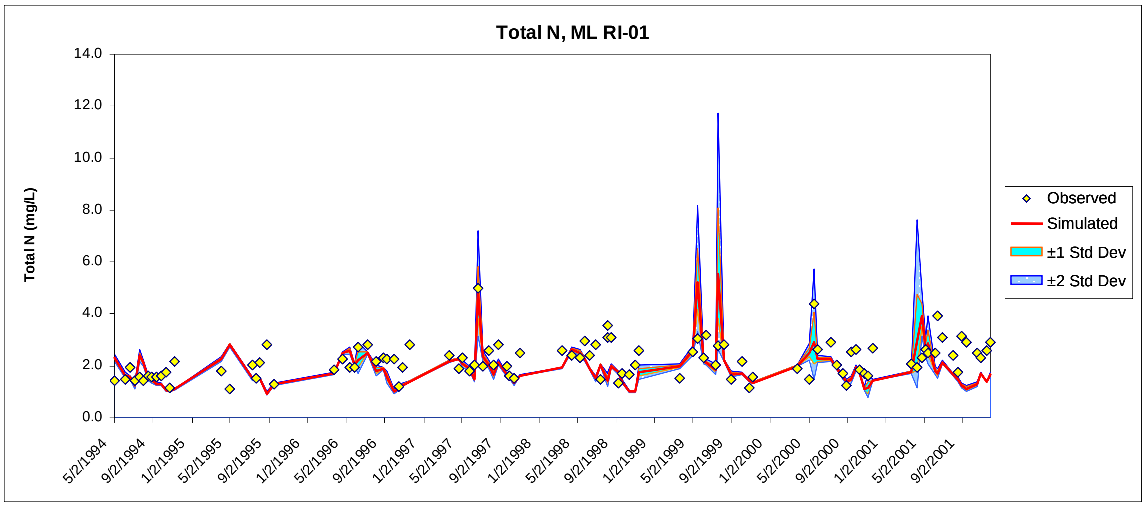
Milwaukee River, Station RI-06
Concentration Exceedance Curve Plots
Validation Period, 1999-2001

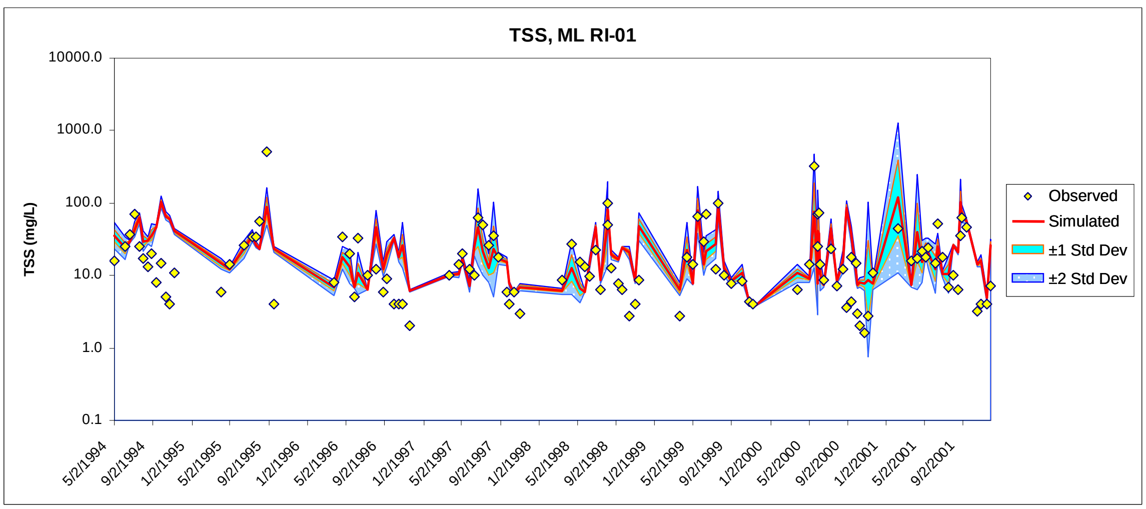


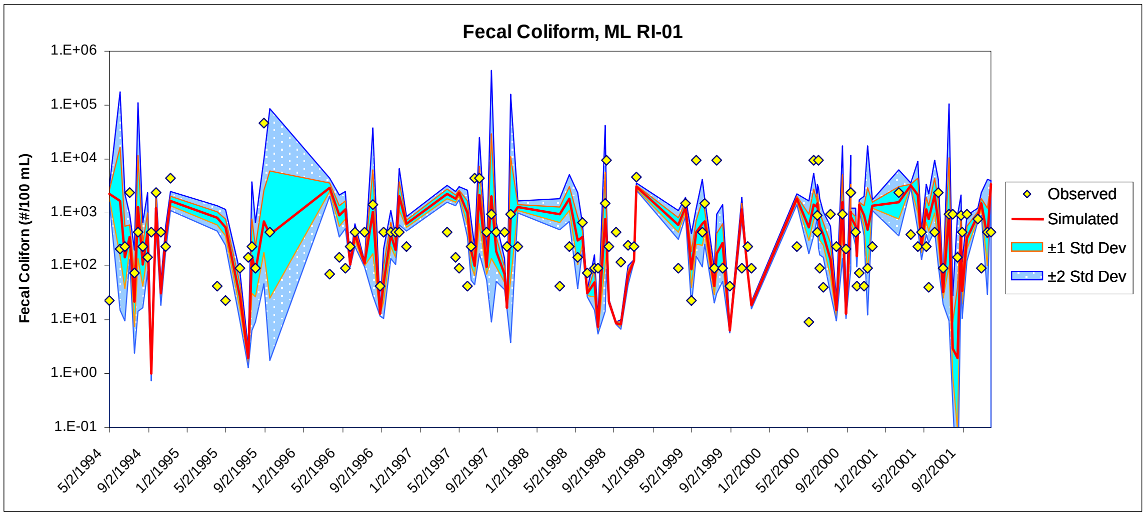


ATTACHMENT K – CONTROL CHARTS

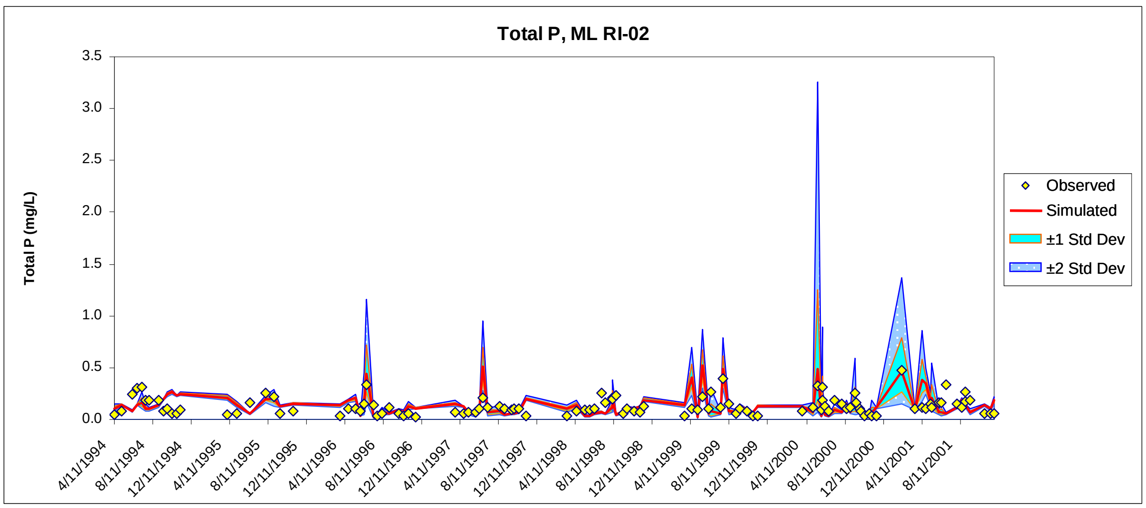

Total P, ML RI-01
Total P (mg/L)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5/2/1994
9/2/1994
1/2/1995
5/2/1995
9/2/1995
1/2/1996
5/2/1996
9/2/1996
1/2/1997
5/2/1997
9/2/1997
1/2/1998
5/2/1998
9/2/1998
1/2/1999
5/2/1999
9/2/1999
1/2/2000
5/2/2000
9/2/2000
1/2/2001
5/2/2001
9/2/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Total N, ML RI-01
Total N (mg/L)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
5/2/1994
9/2/1994
1/2/1995
5/2/1995
9/2/1995
1/2/1996
5/2/1996
9/2/1996
1/2/1997
5/2/1997
9/2/1997
1/2/1998
5/2/1998
9/2/1998
1/2/1999
5/2/1999
9/2/1999
1/2/2000
5/2/2000
9/2/2000
1/2/2001
5/2/2001
9/2/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

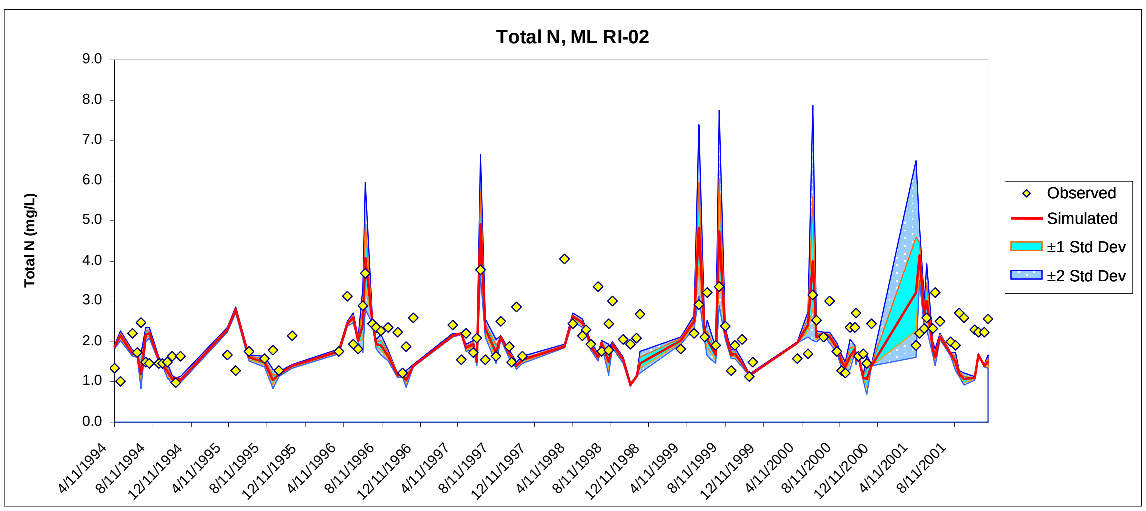

TSS, ML RI-01
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
5/2/1994
9/2/1994
1/2/1995
5/2/1995
9/2/1995
1/2/1996
5/2/1996
9/2/1996
1/2/1997
5/2/1997
9/2/1997
1/2/1998
5/2/1998
9/2/1998
1/2/1999
5/2/1999
9/2/1999
1/2/2000
5/2/2000
9/2/2000
1/2/2001
5/2/2001
9/2/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev



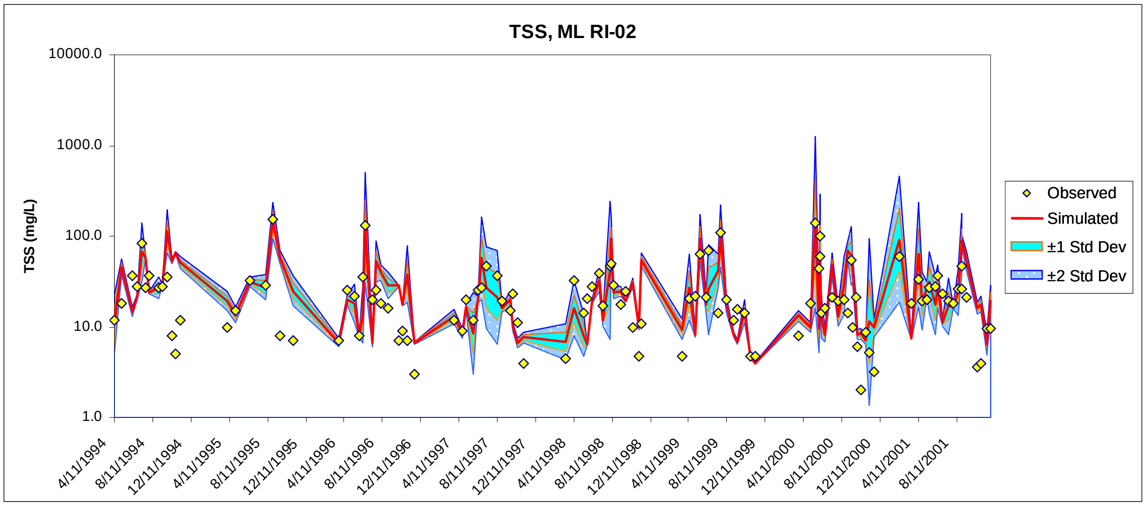
Fecal Coliform, ML RI-01
Fecal Coliforn (#/100 mL)
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
5/2/1994
9/2/1994
1/2/1995
5/2/1995
9/2/1995
1/2/1996
5/2/1996
9/2/1996
1/2/1997
5/2/1997
9/2/1997
1/2/1998
5/2/1998
9/2/1998
1/2/1999
5/2/1999
9/2/1999
1/2/2000
5/2/2000
9/2/2000
1/2/2001
5/2/2001
9/2/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev



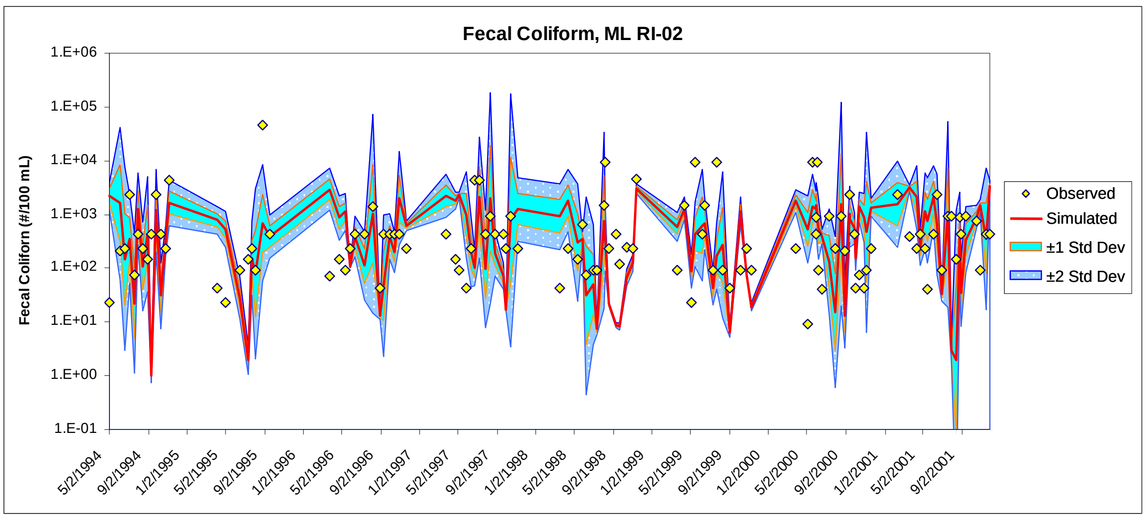
Total P, ML RI-02
Total P (mg/L)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4/11/1994
8/11/1994
12/11/1994
4/11/1995
8/11/1995
12/11/1995
4/11/1996
8/11/1996
12/11/1996
4/11/1997
8/11/1997
12/11/1997
4/11/1998
8/11/1998
12/11/1998
4/11/1999
8/11/1999
12/11/1999
4/11/2000
8/11/2000
12/11/2000
4/11/2001
8/11/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev



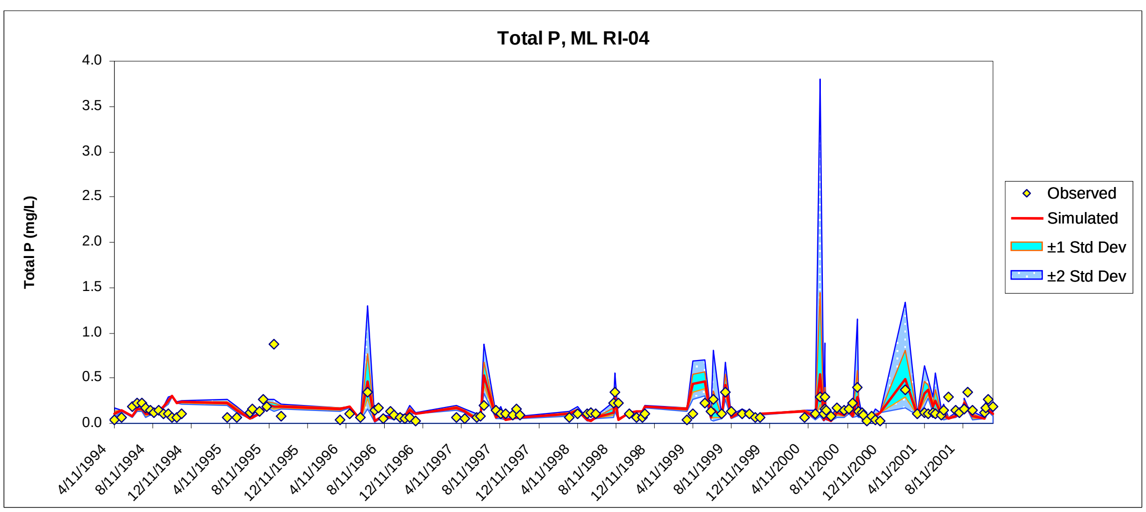
Total N, ML RI-02
Total N (mg/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4/11/1994
8/11/1994
12/11/1994
4/11/1995
8/11/1995
12/11/1995
4/11/1996
8/11/1996
12/11/1996
4/11/1997
8/11/1997
12/11/1997
4/11/1998
8/11/1998
12/11/1998
4/11/1999
8/11/1999
12/11/1999
4/11/2000
8/11/2000
12/11/2000
4/11/2001
8/11/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev



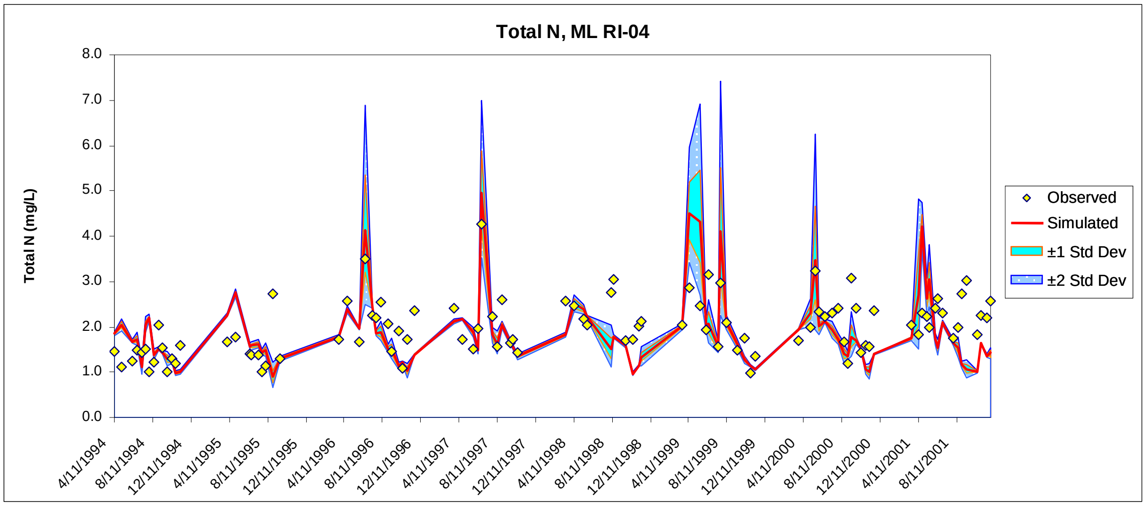
TSS, ML RI-02
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
4/11/1994
8/11/1994
12/11/1994
4/11/1995
8/11/1995
12/11/1995
4/11/1996
8/11/1996
12/11/1996
4/11/1997
8/11/1997
12/11/1997
4/11/1998
8/11/1998
12/11/1998
4/11/1999
8/11/1999
12/11/1999
4/11/2000
8/11/2000
12/11/2000
4/11/2001
8/11/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

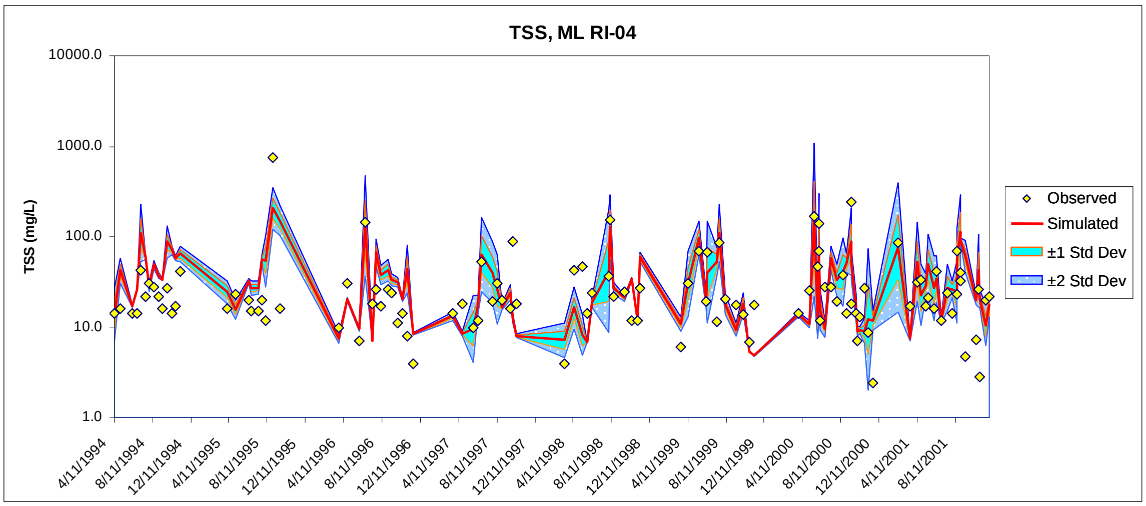


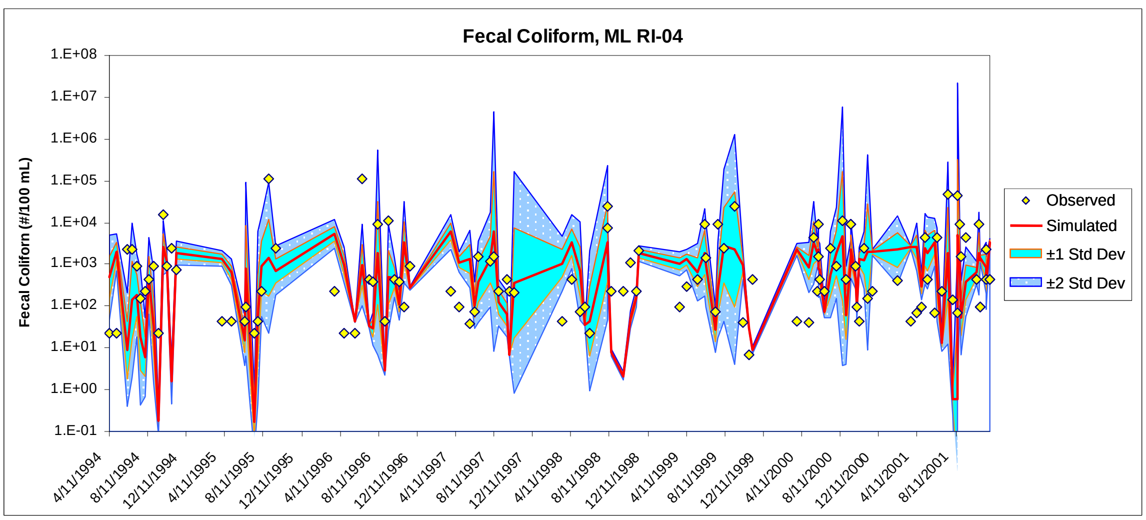
Fecal Coliform, ML RI-02
Fecal Coliform (#/100 mL)
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
5/2/1994
9/2/1994
1/2/1995
5/2/1995
9/2/1995
1/2/1996
5/2/1996
9/2/1996
1/2/1997
5/2/1997
9/2/1997
1/2/1998
5/2/1998
9/2/1998
1/2/1999
5/2/1999
9/2/1999
1/2/2000
5/2/2000
9/2/2000
1/2/2001
5/2/2001
9/2/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

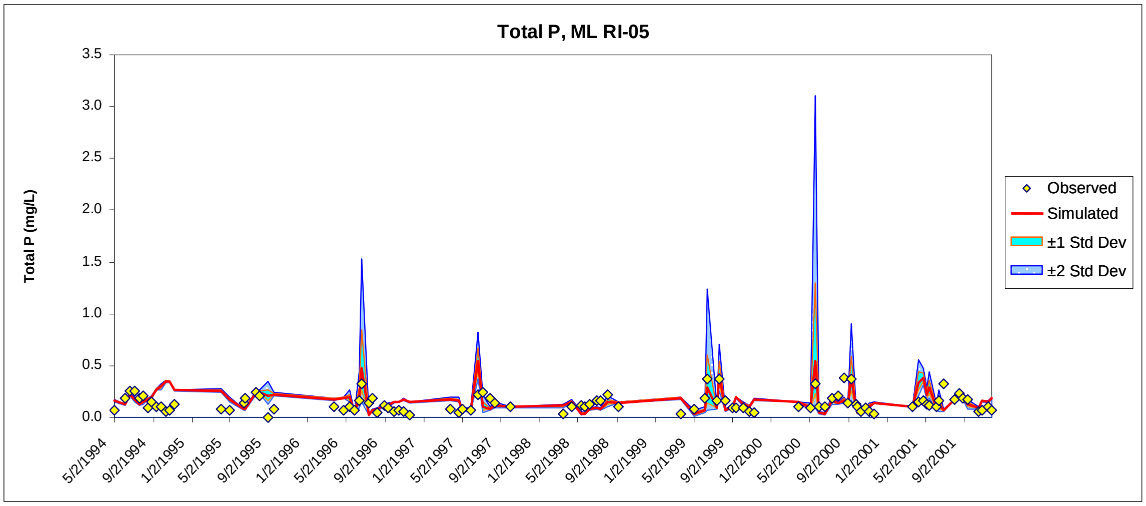


Total P, ML RI-04
Total P (mg/L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4/11/1994
8/11/1994
12/11/1994
4/11/1995
8/11/1995
12/11/1995
4/11/1996
8/11/1996
12/11/1996
4/11/1997
8/11/1997
12/11/1997
4/11/1998
8/11/1998
12/11/1998
4/11/1999
8/11/1999
12/11/1999
4/11/2000
8/11/2000
12/11/2000
4/11/2001
8/11/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

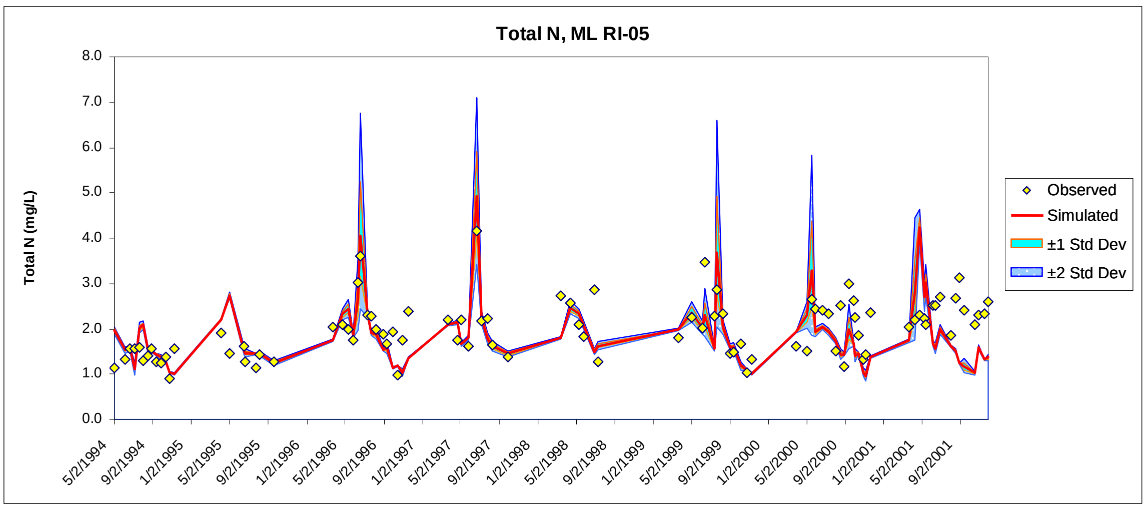

Total N, ML RI-04
Total N (mg/L)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4/11/1994
8/11/1994
12/11/1994
4/11/1995
8/11/1995
12/11/1995
4/11/1996
8/11/1996
12/11/1996
4/11/1997
8/11/1997
12/11/1997
4/11/1998
8/11/1998
12/11/1998
4/11/1999
8/11/1999
12/11/1999
4/11/2000
8/11/2000
12/11/2000
4/11/2001
8/11/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


TSS, ML RI-04
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
4/11/1994
8/11/1994
12/11/1994
4/11/1995
8/11/1995
12/11/1995
4/11/1996
8/11/1996
12/11/1996
4/11/1997
8/11/1997
12/11/1997
4/11/1998
8/11/1998
12/11/1998
4/11/1999
8/11/1999
12/11/1999
4/11/2000
8/11/2000
12/11/2000
4/11/2001
8/11/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

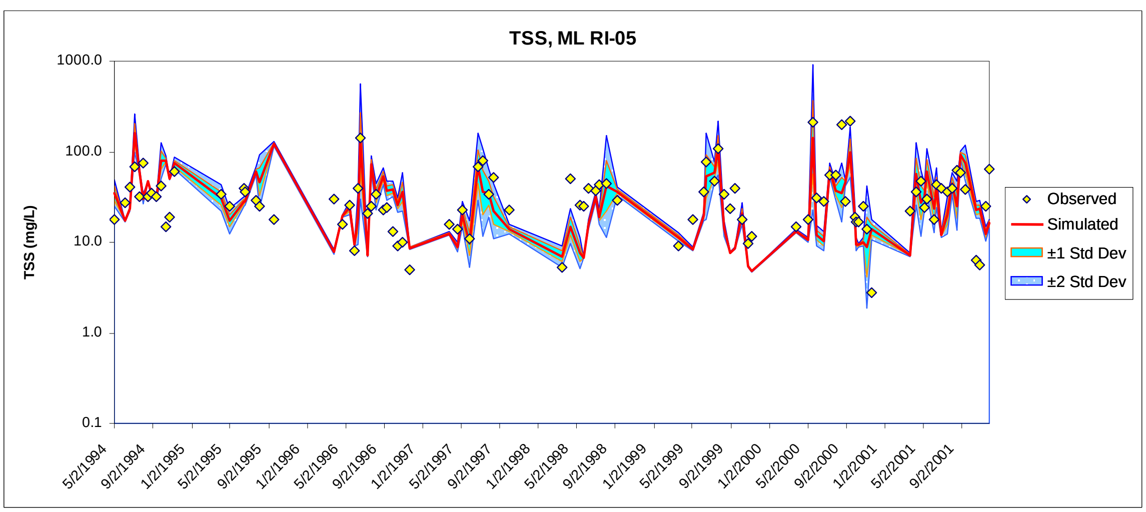

Fecal Coliform, ML RI-04
Fecal Coliform (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/11/1994
8/11/1994
12/11/1994
4/11/1995
8/11/1995
12/11/1995
4/11/1996
8/11/1996
12/11/1996
4/11/1997
8/11/1997
12/11/1997
4/11/1998
8/11/1998
12/11/1998
4/11/1999
8/11/1999
12/11/1999
4/11/2000
8/11/2000
12/11/2000
4/11/2001
8/11/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev



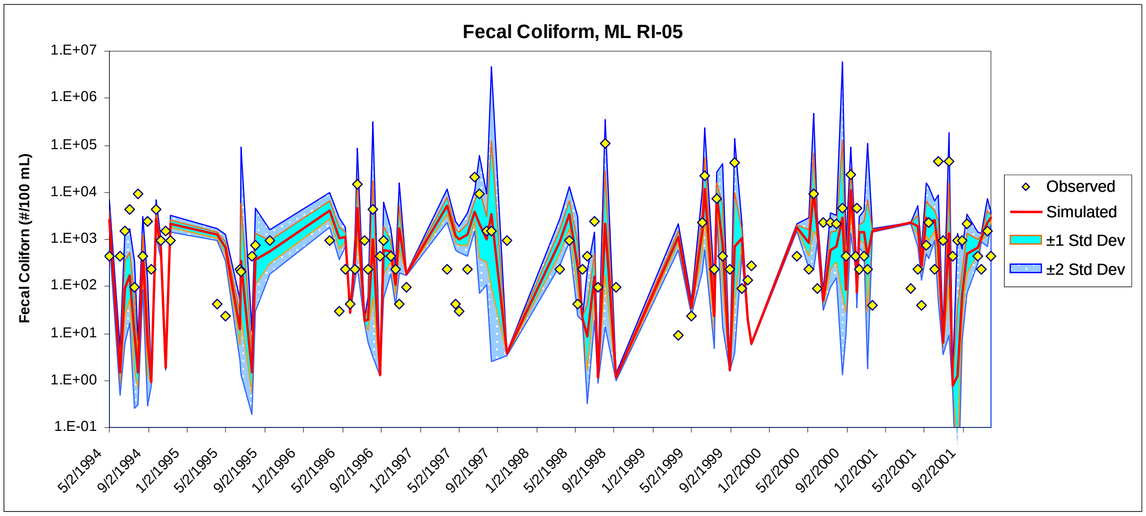
Total P, ML RI-05
Total P (mg/L)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5/2/1994
9/2/1994
1/2/1995
5/2/1995
9/2/1995
1/2/1996
5/2/1996
9/2/1996
1/2/1997
5/2/1997
9/2/1997
1/2/1998
5/2/1998
9/2/1998
1/2/1999
5/2/1999
9/2/1999
1/2/2000
5/2/2000
9/2/2000
1/2/2001
5/2/2001
9/2/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

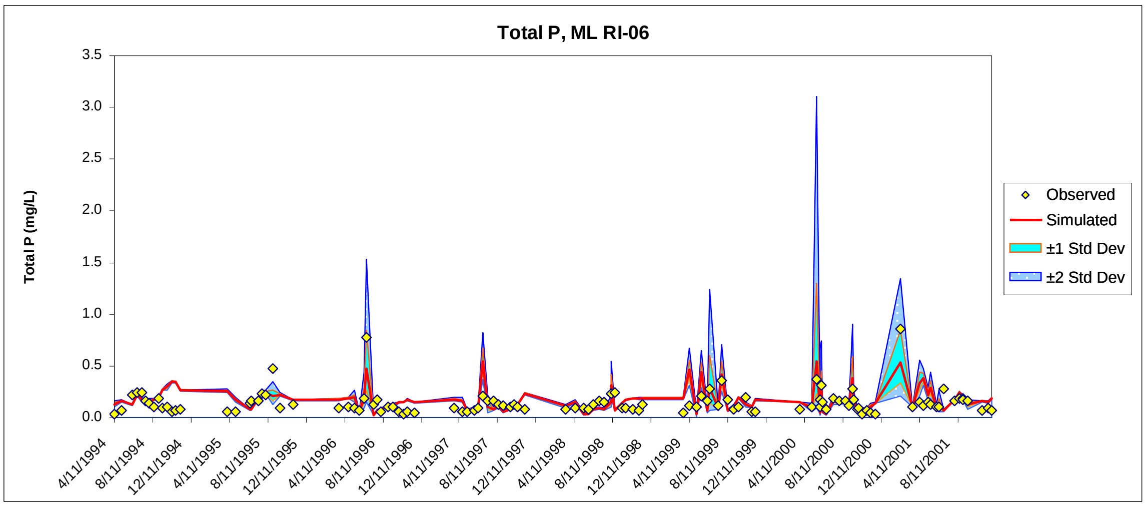


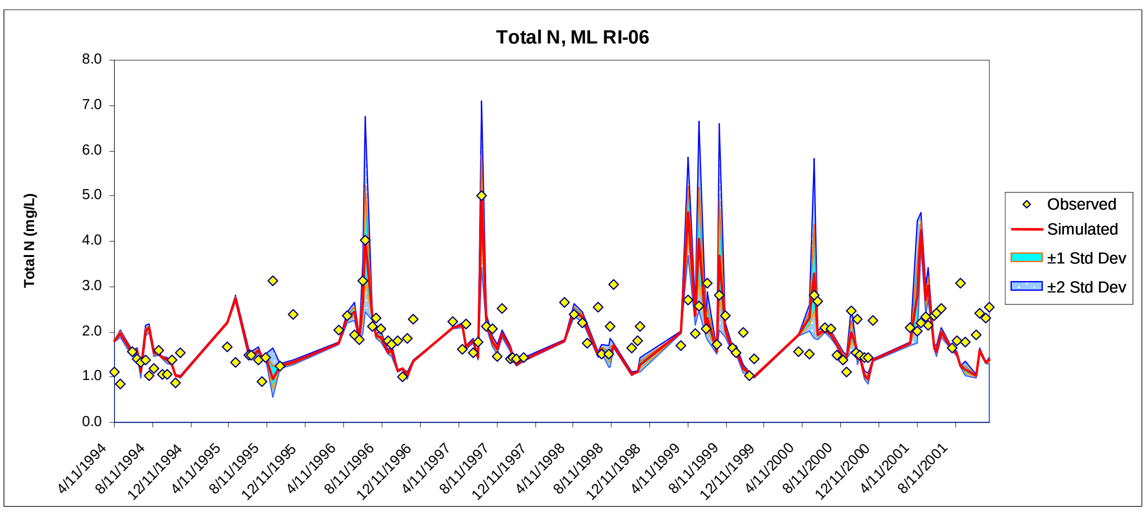
Total N, ML RI-05
Total N (mg/L)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5/2/1994
9/2/1994
1/2/1995
5/2/1995
9/2/1995
1/2/1996
5/2/1996
9/2/1996
1/2/1997
5/2/1997
9/2/1997
1/2/1998
5/2/1998
9/2/1998
1/2/1999
5/2/1999
9/2/1999
1/2/2000
5/2/2000
9/2/2000
1/2/2001
5/2/2001
9/2/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

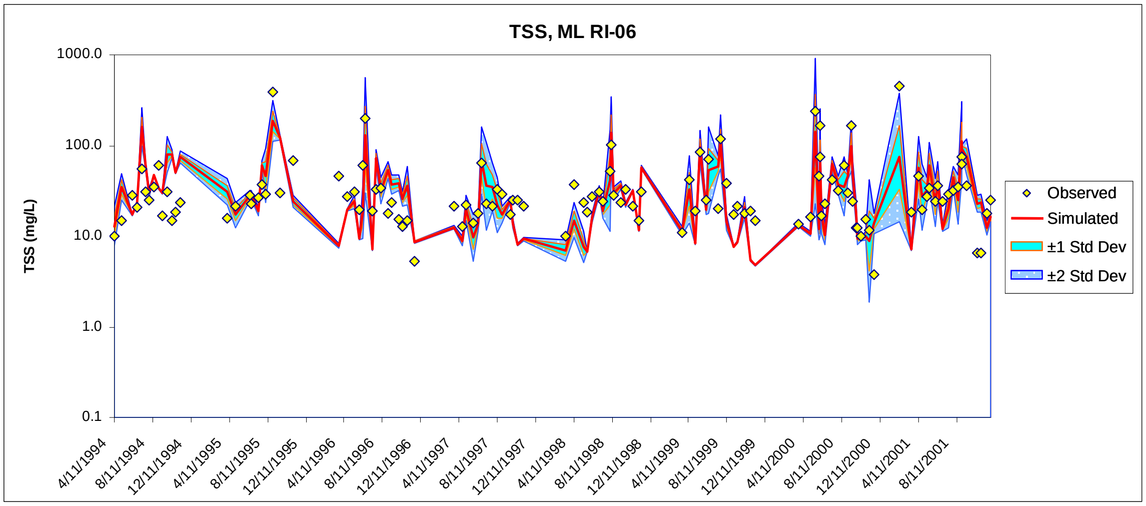


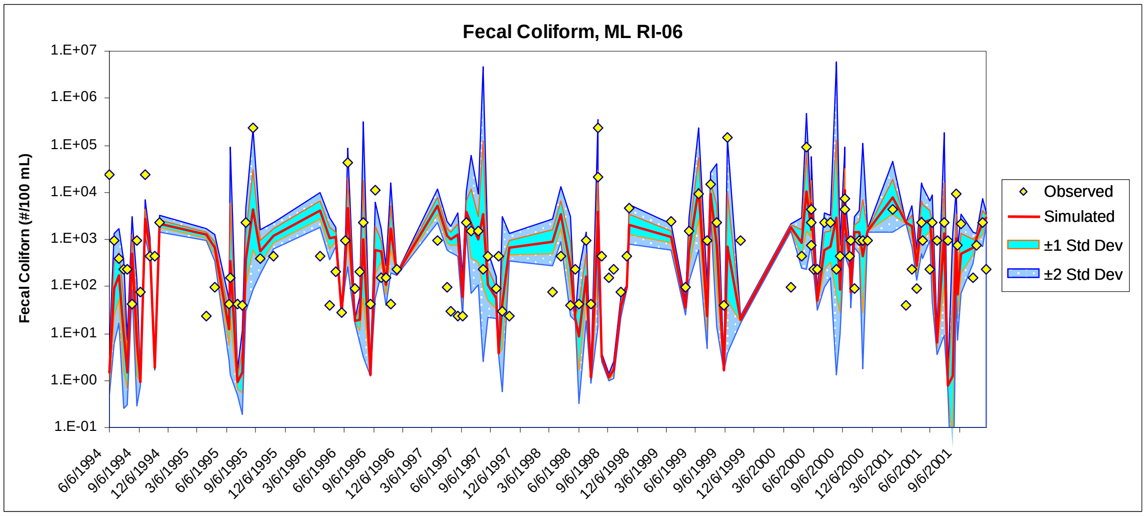
TSS, ML RI-05
TSS (mg/L)
1000.0
100.0
10.0
1.0
0.1
5/2/1994
9/2/1994
1/2/1995
5/2/1995
9/2/1995
1/2/1996
5/2/1996
9/2/1996
1/2/1997
5/2/1997
9/2/1997
1/2/1998
5/2/1998
9/2/1998
1/2/1999
5/2/1999
9/2/1999
1/2/2000
5/2/2000
9/2/2000
1/2/2001
5/2/2001
9/2/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Fecal Coliform, ML RI-05
Fecal Coliforn (#/100 mL)
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
5/2/1994
9/2/1994
1/2/1995
5/2/1995
9/2/1995
1/2/1996
5/2/1996
9/2/1996
1/2/1997
5/2/1997
9/2/1997
1/2/1998
5/2/1998
9/2/1998
1/2/1999
5/2/1999
9/2/1999
1/2/2000
5/2/2000
9/2/2000
1/2/2001
5/2/2001
9/2/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Total P, ML RI-06
Total P (mg/L)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4/11/1994
8/11/1994
12/11/1994
4/11/1995
8/11/1995
12/11/1995
4/11/1996
8/11/1996
12/11/1996
4/11/1997
8/11/1997
12/11/1997
4/11/1998
8/11/1998
12/11/1998
4/11/1999
8/11/1999
12/11/1999
4/11/2000
8/11/2000
12/11/2000
4/11/2001
8/11/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Total N, ML RI-06
Total N (mg/L)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4/11/1994
8/11/1994
12/11/1994
4/11/1995
8/11/1995
12/11/1995
4/11/1996
8/11/1996
12/11/1996
4/11/1997
8/11/1997
12/11/1997
4/11/1998
8/11/1998
12/11/1998
4/11/1999
8/11/1999
12/11/1999
4/11/2000
8/11/2000
12/11/2000
4/11/2001
8/11/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


TSS, ML RI-06
TSS (mg/L)
1000.0
100.0
10.0
1.0
0.1
4/11/1994
8/11/1994
12/11/1994
4/11/1995
8/11/1995
12/11/1995
4/11/1996
8/11/1996
12/11/1996
4/11/1997
8/11/1997
12/11/1997
4/11/1998
8/11/1998
12/11/1998
4/11/1999
8/11/1999
12/11/1999
4/11/2000
8/11/2000
12/11/2000
4/11/2001
8/11/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Fecal Coliform, ML RI-06
Fecal Coliform (#/100 mL)
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
6/6/1994
9/6/1994
12/6/1994
3/6/1995
6/6/1995
9/6/1995
12/6/1995
3/6/1996
6/6/1996
9/6/1996
12/6/1996
3/6/1997
6/6/1997
9/6/1997
12/6/1997
3/6/1998
6/6/1998
9/6/1998
12/6/1998
3/6/1999
6/6/1999
9/6/1999
12/6/1999
3/6/2000
6/6/2000
9/6/2000
12/6/2000
3/6/2001
6/6/2001
9/6/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

ATTACHMENT L – COMPARISON OF 2004 SIMULATED AND OBSERVED FLOWS

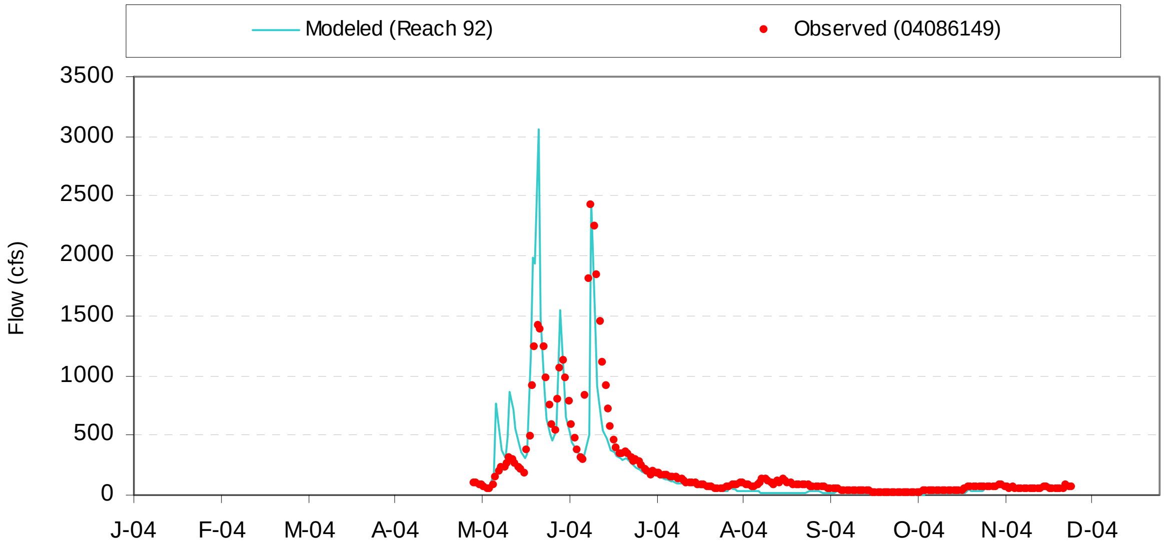


Table L-1. Time series hydrologic comparison for USGS gage 04086149 (2004).

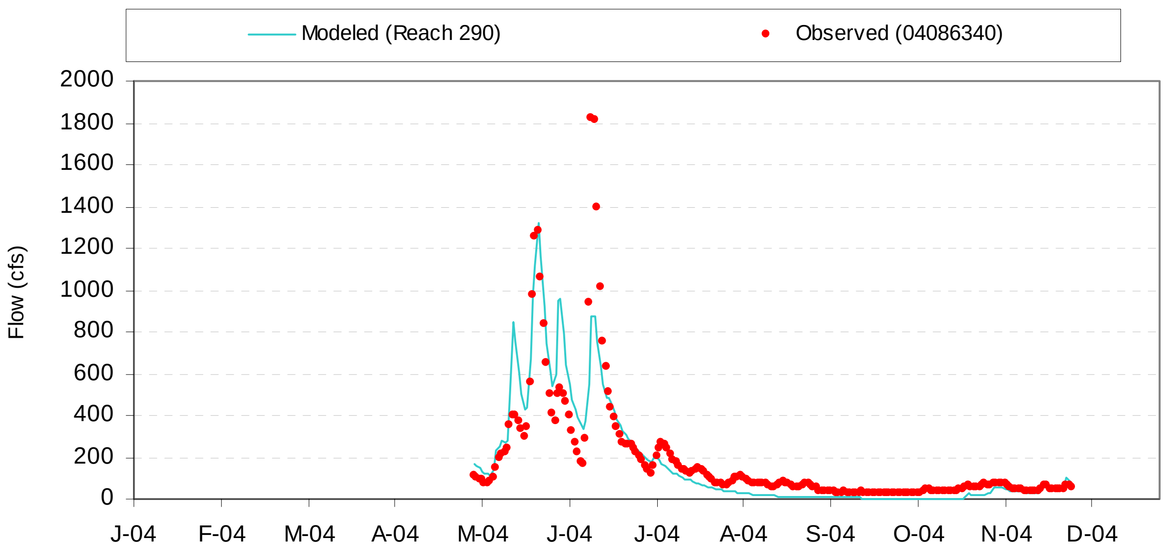


Table L-2. Time series hydrologic comparison for USGS gage 04086340 (2004).

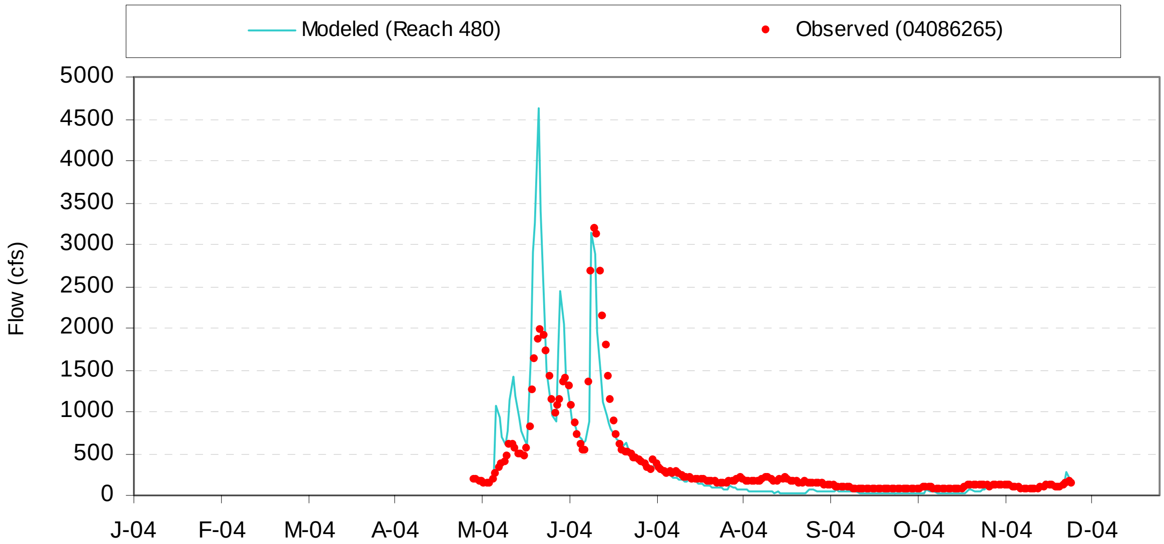


Table L-3. Time series hydrologic comparison for USGS gage 04086265 (2004).

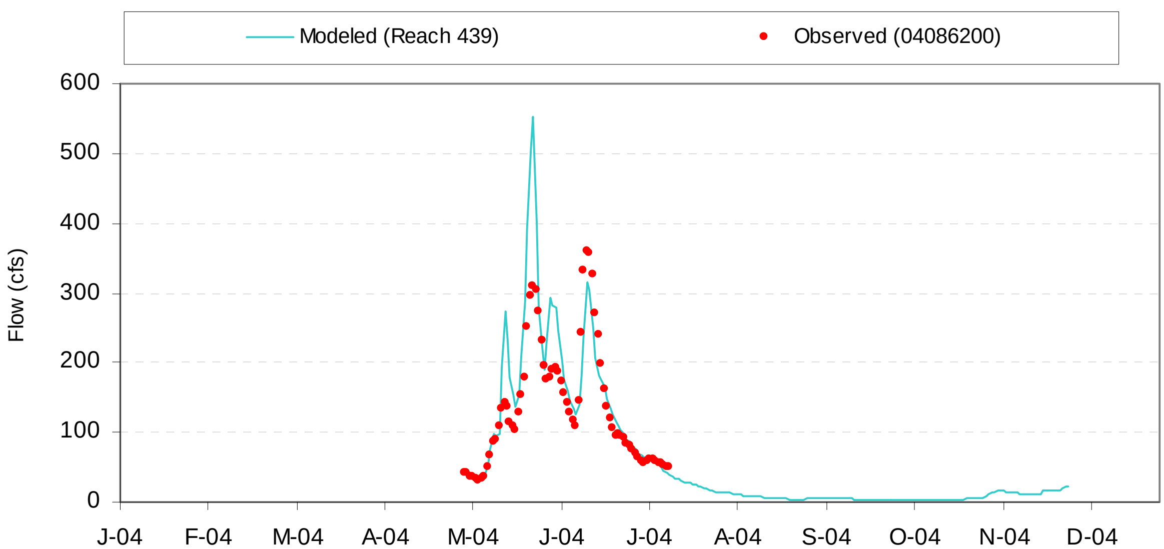


Table L-4. Time series hydrologic comparison for USGS gage 04086200 (2004).

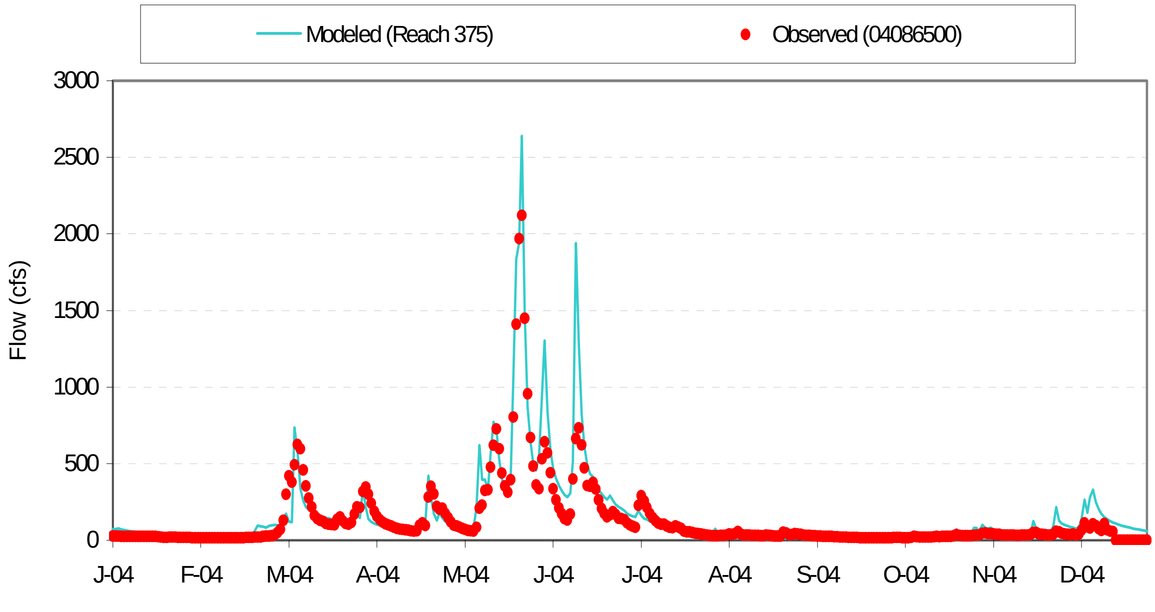


Table L-5. Time series hydrologic comparison for USGS gage 04086500 (2004).

2020 Facility Planning Project

Final Memorandum

Project Name:	MMSD – 2020 Facility Planning Project	MMSD Contract No:	M03002P01
DMS Folder Name:	Technology Analysis	MMSD File Code:	M009PE000.P7300-WQ1
Document Name:	Water Quality Calibration and Validation Results for the Oak Creek Model (Task 4)	HNTB Charge No:	34568-PL-400-115

Date: December 5, 2007
To: Michael Hahn, SEWRPC
Bill Krill, HNTB
From: Leslie Shoemaker, Tetra Tech, Inc.
Subject: Water Quality Calibration and Validation Results for the Oak Creek Model (Task 4)

1.0 EXECUTIVE SUMMARY

An important component of the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU) is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. The purpose of this memorandum is to describe the modeling process and provide final results of the water quality calibration and validation of the Oak Creek watershed model.

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for a variety of reasons, including that existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds. The Loading Simulation Program in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms but has the advantage of no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original Oak Creek HSPF model has been migrated to LSPC for the 2020 Facilities Planning Project.

Calibration of LSPC followed a sequential, hierarchical process that begins with hydrology, followed by sediment erosion and transport, and, finally, calibration of chemical water quality. The original hydrologic calibration for the Oak Creek watershed model is described in the memorandum entitled *Draft Hydrologic Calibration and Validation Results for the Oak Creek Model*. A final hydrologic calibration addressed various comments provided by SEWRPC. This memorandum provides final results of the water quality calibration that are consistent with the final hydrologic calibration and various other improvements that were made during re-calibration efforts.

2.0 CONCLUSIONS

Water quality calibration for Oak Creek relied on comparison of model predictions to observations and estimated loads at seven stations on the mainstem of the system. Achieving water quality calibration involves adjusting many parameters that interact with one another. The upland model represents expected loading associated with runoff events from specified land uses, but cannot represent unusual events that are outside the scope of events simulated in the model (for instance, discharge or breach of a waste lagoon). In addition, observed data – which consist of point in time and point in space measurements–may not be fully representative of conditions in the waterbody, and may also be subject to analytical uncertainty. The model provides an estimate of average conditions across the stream width and depth as a result of known upland sources. For this application, the long-term average loading from these upland sources has been constrained to be consistent with results from SWAT modeling of agriculture and SLAMM modeling of loading from urban land uses. Fit between model and observations is best judged graphically and statistically: the model should represent the central tendency and trends seen in observations, but may not replicate all individual observations. Model fit for water quality is thus evaluated in three ways: (1) through graphical comparison of simulated and observed data, (2) through statistical tests on the equivalence of means on paired observed and simulated concentration data, and (3) through evaluation of the ability of the model to represent apparent observed load delivery rates. A single set of parameter values (by land use) is specified throughout the watershed; thus, the ability of the model to replicate differences in concentrations between different sample points is as important as the ability to match concentrations at individual sites.

In general, the revised water quality calibration attains a good fit to observations, with some discrepancies for individual parameters at individual locations. The quality of fit is sufficiently good that the model is judged ready for application to management scenarios.

3.0 RECOMMENDATIONS

We recommend that the water quality calibration and validation of the Oak Creek model be considered complete.

4.0 INTRODUCTION

The Milwaukee Metropolitan Sewerage District (MMSD) is in the midst of a long-range planning effort to identify improvements needed for its facilities to accommodate growth and protect water quality through the year 2020. This effort is known as the MMSD 2020 Facility Plan. A related planning effort is being conducted by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) to update the regional water quality management plan for the Kinnickinnic River, Menomonee River, Milwaukee River, Root River, and Oak Creek watersheds, the Milwaukee Harbor estuary, and the adjacent nearshore Lake Michigan area. This effort is known as the Regional Water Quality Management Plan Update (RWQMPU). The two planning efforts are being coordinated and implemented in parallel.

One important component of both the 2020 Facility Plan and the RWQMPU is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. Watershed models are being developed for the following five watersheds:

- Kinnickinnic River
- Menomonee River
- Milwaukee River
- Oak Creek
- Root River

The Kinnickinnic, Menomonee, Milwaukee River, and Oak Creek models are linked to a model of the Lake Michigan estuary so that the benefits of upstream water quality improvements can be simulated by the Lake Michigan Harbor / Estuary Model. The following seven tasks have been identified for performing the system modeling:

1) Establish the model structure, including the delineation of subwatersheds, connectivity, and cross sections, etc.
2) Develop the model data sets using physical measurements, maps, and other appropriate information
3) Perform hydrologic and hydraulic calibration and validation
4) Perform watercourse water quality calibration and validation
5) Perform harbor/estuary and lake water quality calibration
6) Perform production runs as required for project planning
7) Document results.

The purpose of this report is to document the final watercourse water quality calibration and validation for the Oak Creek watershed model (Task 4). The modeling approach and results, by parameter, are presented below.

5.0 MODELING APPROACH AND RESULTS

The calibration process for LSPC is sequential, beginning with the calibration of flow. Sediment and dissolved pollutant transport depend directly on the representation of flow, while sorbed pollutant transport depends on the simulation of sediment. (In the model, sorption to sediment within stream reaches is currently simulated for phosphorus, ammonium, and bacteria.) The implementation of the model represents pollutant loading from the land surface by buildup-washoff formulations (independent of erosion); however, sorption to sediment and settling is simulated in the stream reaches and has an important effect on the downstream transport of particle-reactive pollutants including phosphorus, ammonium, and bacteria. Thus, any inaccuracies in the flow and sediment simulation will propagate forward into the water quality simulation, and the accuracy of the hydrologic simulation provides an inherent limitation on the potential accuracy of the water quality simulation.

Instream water quality kinetics are also highly linked with one another. For instance most kinetic rates depend on temperature, while nutrient balances and dissolved oxygen are strongly linked to the algal simulation. Accordingly, the water quality calibration uses the following sequential process:

1) Calibration of flow
2) Calibration of sediment
3) Calibration of water temperature
4) Initial calibration of gross nutrient transport
5) Initial calibration of BOD and DO
6) Calibration of algae
7) Final calibration of nutrient species and DO
8) Calibration of fecal coliform bacteria
9) Calibration of metals

SEWRPC and WDNR directed that loads from the land surface should be, to the extent compatible with achieving water quality calibration, consistent with the loads predicted by SWAT for agricultural land uses and by SLAMM for urban land uses. The SLAMM model in particular is preferred by the WDNR for use in assessing compliance with State urban nonpoint source pollutant regulations. Therefore, the loading rates produced by these models form the starting point for the water quality calibration.

The adequacy of the water quality calibration was assessed through comparison to observed water quality data. It should be noted that the observed water quality data are primarily point-in-time grab samples, which may exhibit significant temporal variability relative to the (unobserved) daily mean concentration. A key objective is to have the model replicate actual loads through the system. Unfortunately, loads are not directly observed, and can only be estimated from the point-in-time concentrations multiplied by daily average flow. While model adjustments are made to obtain general agreement between simulated loads and estimated observed loads, it should be recalled that the estimates of observed loads are highly uncertain.

Hydrologic calibration precedes sediment and water quality calibration because runoff is the transport mechanism by which nonpoint pollution occurs and the hydrologic calibration of the Oak Creek watershed model is described in a separate memorandum. The final calibration results for the Oak Creek model indicate acceptable agreement between observed and simulated streamflows and the successful hydrologic calibration provides a good basis for water quality calibration.

The approach that was used to calibrate the Oak Creek model for sediment and the other water quality parameters is described in detail in the memorandum entitled *Water Quality Calibration Results for the Menomonee River* (see discussion for urban areas). Simulation of water quality in Oak Creek uses the same parameters as the Menomonee model, with a limited number of exceptions to primarily address differences in the algal and nutrient simulations:

- The subbasins specified in the Oak Creek model are generally much smaller than those used in the Menomonee, and most of the first order streams are represented. Because of this, it is not necessary to specify an algal load associated with PERLND washoff. This was done in the Menomonee River model to account for algal growth that occurs in first-order streams and wetlands not explicitly simulated in the model.

- Because of the smaller sub-basin size, the value of OREF used in the Menomonee River model is not appropriate for Oak Creek. OREF is the flow breakpoint that determines the concentration of phytoplankton in a reach not subject to advection. Lower values are needed in Oak Creek to account for the smaller sub-basin size.

- Smaller sub-basin size also suggests a need to adjust trapping factors for sediment and sedimentassociated pollutants. These were instituted in the Menomonee River calibration to account for losses that occur in small first-order streams, riparian areas, and wetlands not explicitly included in the model reach network. Due to its finer resolution, trapping should be less in the Oak Creek model. During calibration the trapping of TSS from pervious land was reduced from 80 percent to 70 percent and from impervious land from 30 percent to 20 percent. Surface phosphorus trapping was reduced from 50 percent to 40 percent, with similar changes for zinc and total organic carbon.

- Observed water quality associated with scour events suggests that the bed sediment in portions of Oak Creek has higher ammonia and phosphorus concentrations than does the Menomonee. Accordingly, higher bed concentrations are assigned to the lower Oak Creek mainstem.

- Oxygen reaearation was modified in several ways from that used in the Menomonee. Much of Oak Creek is a channelized, trapezoidal ditch with incised banks and few riffles, resulting in relatively low reaeration. Accordingly, the empirical reaeration rate coefficients (option REAMFG=3) were adjusted downward in the areas around OC-1, OC-3, and OC-4 (but not OC-2, where riffles appear to be present). In addition, better results in the downstream end of Oak Creek were obtained by using the Covar approach (REAMFG=2). The most downstream station (OC-7) is below an old mill dam, which increases reaeration in that reach. The presence of numerous closely spaced observation stations in Oak Creek allows a more detailed site-specific calibration than was possible in the Menomonee River model.

- Benthic oxygen demand was adjusted to better fit observed dissolved oxygen concentrations. Some areas of the Oak Creek mainstem appear to have elevated benthic oxygen demand. For these areas, small benthic releases of ammonia and phosphate were also assigned, consistent with reducing conditions.

- Ground water and interflow dissolved oxygen concentrations appear to be lower in Oak Creek than in Menomonee River and were reduced accordingly. Ground water TOC (BOD) concentrations were also modified to better reflect observed conditions in Oak Creek.

- Simulation of fecal coliform bacteria was revised extensively from the initial parameter set used in the Menomonee River model.

Extensive water quality observations collected by MMSD were provided for 1994 through 2001 and were used to calibrate and validate the water quality model. Years 1994 through 1998 were used for calibration. The parameters were then applied to 1999 through 2001 observations as a validation check. Unless noted otherwise, the time series calibration and validation plots are based on the daily mean values of simulated output.

The calibration and validation periods used for water quality differ from those used in the hydrologic calibration due to constraints of data availability. Quality-controlled monitoring data were not available for 2002 at the initial time of the calibration, so this year was not included in the water quality analysis. In addition, the calibration period for water quality was started in 1994 (versus 1995 for the hydrology) to take full advantage of the available data. For both hydrology and water quality, simulations were started in January 1993 to minimize model spin-up effects. Hydrologic simulation for 1994 appears to be good (Figure 5-1).

Figure 5-2 displays the location of the water quality sampling stations that were used during the calibration process.

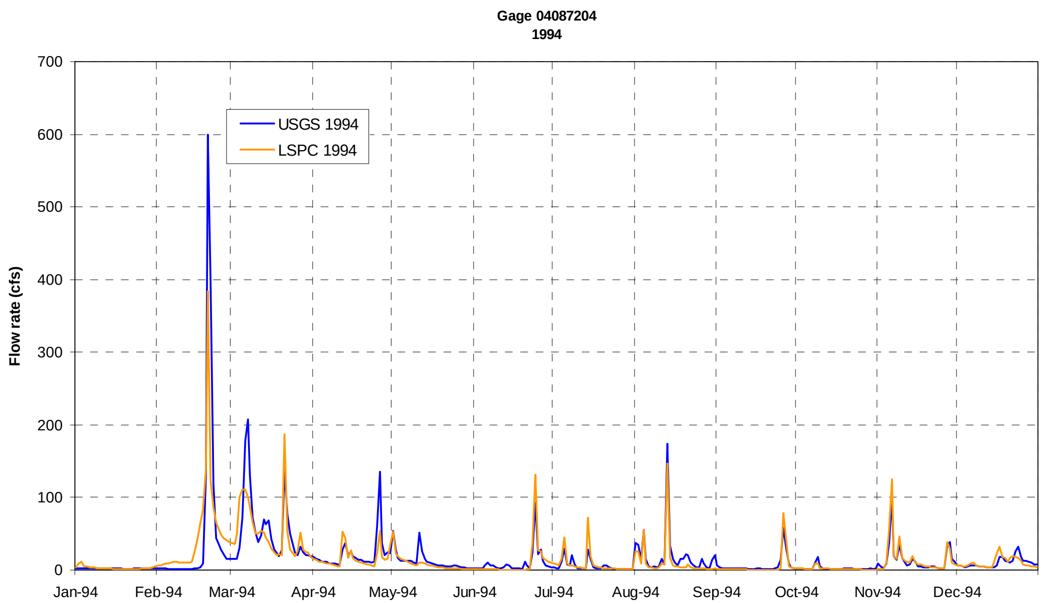


Figure 5-1. Time series hydrologic calibration results for Oak Creek at USGS gage 04087204 (1994).

5.1 Simulation of August/September 1996 Low Flow Period

The original modeling time series plots for sampling station OC-7 indicated that during the period from August 21, 1996 to September 25, 1996 all constituents except nitrate/nitrite, chlorophyll *a*, dissolved oxygen, and metals showed a steady rise in pollutant concentration, although the observed data never indicated such a trend. This was especially noticeable with a large spike in ammonia concentration. Conversely, nitrate/nitrite, chlorophyll *a*, dissolved oxygen and metals concentrations decreased to zero or nearly zero over this period. This was a period of very low and declining flow. The simulated flow at the gage declined from 0.94 cfs on August 21, 1996 to 0.28 cfs on September 25, 1996. In contrast, the measured flow at the gage remained a little above 1 cfs (possibly due to some dry-weather inputs (e.g., from lawn irrigation) that are not included in the model). However, the low simulated flows were likely also due in part to the FTables because the original FTables for the Lower Oak Creek mainstem were not defined below 540 cfs and thus have very little accuracy for the low flow regime.

During this period of very low flow, the model predicted that the lower reaches went anoxic. The anoxia caused increased release rates from the sediment of PO4, NH4, and BOD (which reinforced the anoxia). This caused smooth upward trending concentrations of constituent concentrations that were noted in the plots. On the other hand, reducing conditions prevented the creation of nitrate.

Fecal coliform declined to very low levels because of (1) lack of inflows and (2) long travel times and high temperatures that result in lots of decay.

During this period the simulated stream depth also declined to less than 1 inch - again a result of the original FTables. When average depth declines to less than 2 inches, LSPC turns off the algal simulation and therefore no algal growth was originally simulated in this period. The anoxia in this period therefore occurs simply because LSPC has turned off the algal growth (both plankton and periphyton), and thus no oxygen was being generated by photosynthesis. Based on these observations in the original calibration, SEWRPC re-evaluated the FTables in Lower Oak Creek and the model was updated. The FTable changes generally improved the fit to observed flow durations, bringing both the simulated 10 percent high and 50 percent low flows better in line with observations over the full simulation period. Seasonal fit improved for Fall, Winter, and Spring (although Summer was slightly worse).

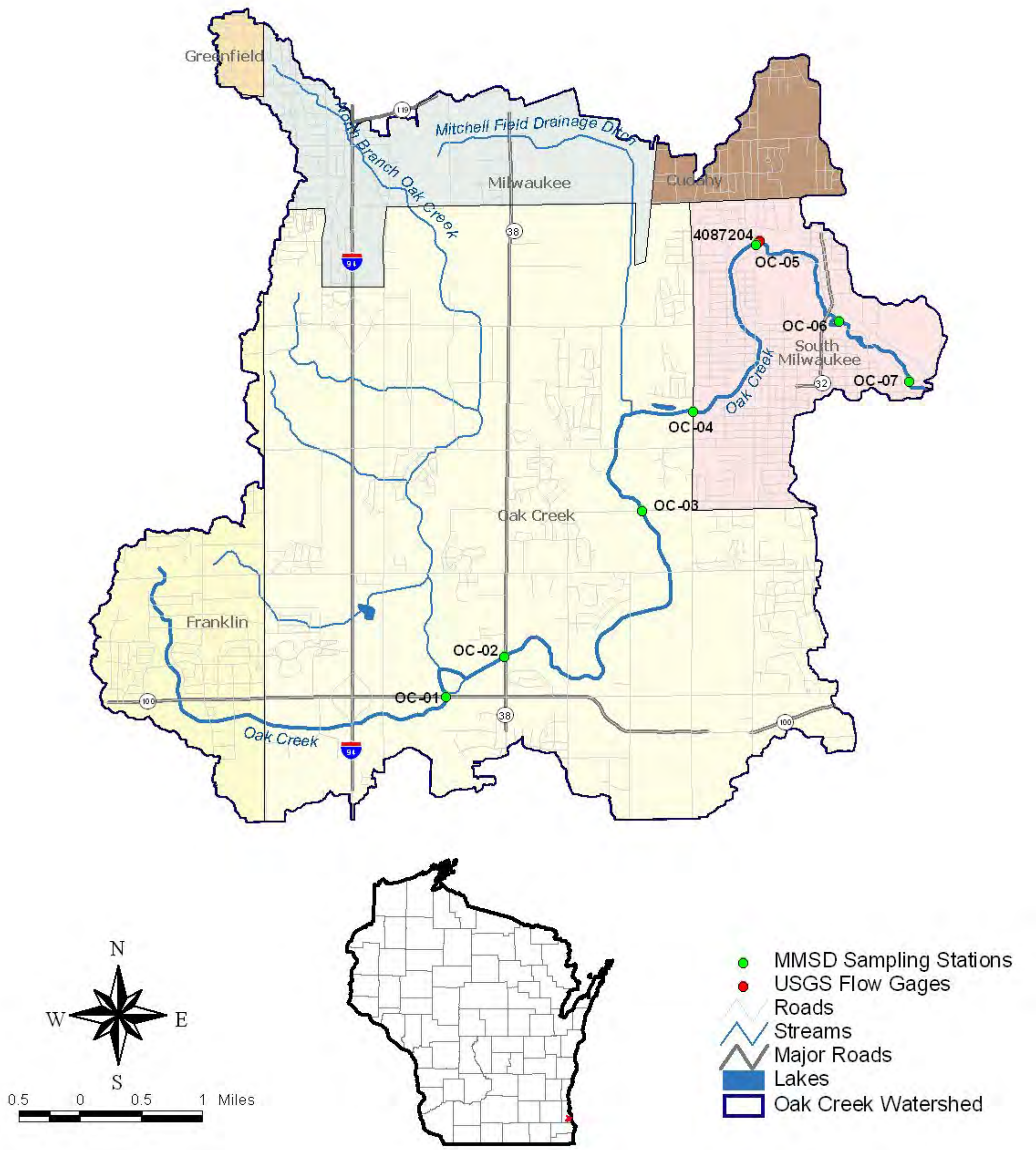


Figure 5-2. Location of MMSD sampling stations and USGS flow gages on Oak Creek.

5.2 Sediment Calibration

The general sequence for sediment calibration in LSPC (Donigian and Love, 2002; Donigian et al., 1984) is to (1) estimate target sediment loading rates from the landscape, (2) calibrate the model loading rates to the target rates, and (3) adjust scour, deposition, and transport parameters in the stream channel to mimic behavior of the streams/waterbodies.

Sediment loading from agricultural land uses in the Oak Creek watershed is derived from SWAT simulations and implemented by buildup/washoff coefficients (rather than LSPC sediment routines), as described in a separate memorandum (January 10, 2005 memorandum entitled *Revised and Expanded Discussion of SWAT Application*). The model uses three categories of cropland (by soil hydrologic group); however, the parameters for these groups are modified to reflect the mix of agricultural rotations present in each watershed. Other land covers are simulated using the sediment/solids routines. Parameters for impervious land covers were derived to match SLAMM output as described in the February 16, 2004 memorandum entitled *Urban Non-Point Source Unit Loading Rates*. For grass, forest, and wetlands, the sediment routines were used and parameters were developed based on theoretical relationship to USLE as described below[1].

LSPC parameters for pervious land uses were estimated based on a theoretical relationship between LSPC parameters and documented soil parameters, ensuring consistency in relative estimates of erosion based on soil type and cover. LSPC calculates the detachment rate of sediment by rainfall (in tons/acre) as

$$DET = (1 - COVER) \bullet SMPF \bullet KRER \bullet P^{JRER}$$

where P is precipitation in inches. Actual sediment storage available for transport (*DETS*) is a function of accumulation over time and the reincorporation rate, *AFFIX*. The equation for *DET* is formally similar to the USLE equation,

Sediment Yield = RE · K · LS · C · P.

USLE predicts sediment loss from one or a series of events at the field scale, and thus incorporates local transport as well as sediment detachment. For a large event with a significant antecedent dry period, it is reasonable to assume that *DET≈DETS* if *AFFIX* is greater than zero so that detached sediment storage from previous events is depleted. Further, during a large event, sediment yield at the field scale is assumed to be limited by supply, rather than transport capacity. Under those conditions, the USLE sediment yield from an event should approximate *DET* in LSPC.

With these assumptions, the LSPC variable *SMPF* may be taken as fully analogous to the USLE P factor. The complement of *COVER* is equivalent to the USLE C factor (i.e., (1 - *COVER*) = C). This leaves the following equivalence:

$$KRER \bullet P^{JRER} \quad = \quad RE \bullet K \bullet LS$$

The empirical equation of Richardson et al. (1983) as further tested by Haith and Merrill (1987) gives an expression for RE (in units of MJ-mm/ha-h) in terms of precipitation:

$$RE \quad = \quad 64.6 \bullet a_t \bullet R^{1.81}$$

where R is precipitation in cm and a_t is an empirical factor that varies by location and season. For southeast Wisconsin (USLE Region 14), a_t is estimated to average about 0.20 (Richardson et al., 1983). As LSPC does not implement *KRER* on a seasonal basis, the average value is most relevant.

As shown in Haith et al. (1992), the expression for RE can be re-expressed in units of tonnes/ha as:

$$RE \quad = \quad 0.132 \bullet 64.6 \bullet a_t \bullet R^{1.81}$$

This relationship suggests that the LSPC exponent on precipitation, *JRER*, should be set to 1.81.

The remainder of the terms in the calculation of *RE* must be subsumed into the *KRER* term of LSPC, with a units conversion. Writing *RE* in terms of tons/acre and using precipitation in inches:

---

[1] The discussion of the theoretical relationship between LSPC and USLE was modified to address comments on the *Draft Water Quality Calibration Results for the Menomonee River*.

$$RE(tons/ac) = [0.132 \bullet 64.6 \bullet a_t] \bullet R(in)^{1.81} \bullet (2.54\,cm/in)^{1.81} \bullet (1\,ton/ac)/(2.24\,tonnes/ha)$$

or, at the average value for a_t for this region, $4.115 \cdot R\ (in)^{1.81}$.

The power term for precipitation can then be eliminated from both sides of the equation, leaving the following expression for the *KRER* term in LSPC (English units) in terms of the USLE K factor:

$$KRER = 3.7032 \bullet K \bullet LS$$

The K factor is available directly from soil surveys, while the LS factor can be estimated from slope. This approach establishes initial values for *KRER* that are consistent with USLE information. Further calibration can then modify all *KRER* values by a single multiplicative factor (thus preserving the relationship among different land use:soil pairs) or by modifying the transport coefficient, *KSER.*

In addition to surface loads, a sediment concentration was associated with ground water discharge from pervious lands. This is necessary to match low-flow (non-scouring) total suspended solids (TSS) observations, and represents miscellaneous non-washoff sources of fine sediment load, including disturbances in the stream channel (by people, vehicles, farm animals, or wildlife) as well as fine sediment actually associated with ground water influx.

Input of these loads directly to the simulated stream reaches results in a consistent over-prediction of sediment concentration and load observed in-stream. This is largely because the first order and ephemeral streams are not simulated and, in these areas, as well as in riparian wetlands, substantial trapping may occur. In addition, the load estimates from the approved SLAMM and SWAT models could be too high. A sediment trapping rate for sediment and sediment-associated pollutants was taken as a general calibration parameter that effectively removes loads from the system. This approach simulates trapping losses as a fixed fraction of influent load, but is only applied to the surface washoff fraction of load. While this is a simplification of actual processes, monitoring of small tributaries is not available to support a more detailed representation of dependence on flow. In fact, the rate of trapping by settling within the stream channel is likely to be greater for smaller, less energetic flows; however, losses that are due to export in the flood plain are greater for higher flows. Actual trapping is also likely to vary by season, depending on vegetation condition. In essence, the trapping factors that are assumed are a simplified, empirical representation of the *net* difference between the estimated loading from the land surface and the event-associated load observed in streams.

Material that is trapped in the floodplain may eventually be eroded back into the stream. This is included as part of the general simulation of loading from the riparian area. Material that is “trapped” through deposition into bed sediments may also be re-entrained during high flow events. For small streams that are not simulated, the model can only represent this sediment source as part of the erosion of the bed material that is present at the start of the simulation in larger reaches. For sediment-associated pollutants, LSPC does not provide a complete sediment diagenesis model, so a mass balance of these constituents in sediment is not maintained in the model. Instead, the user must specify concentrations associated with resuspended sediment.

Smaller sub-basin size in the Oak Creek model compared to the Menomonee River model suggests a need to adjust trapping factors for sediment and sediment-associated pollutants. These were instituted in the Menomonee River calibration to account for losses that occur in small first-order streams, riparian areas, and wetlands not explicitly included in the model reach network. Due to its finer resolution, trapping should be less in the Oak Creek model. During calibration the trapping of TSS from pervious land was reduced from 80 percent to 70 percent and from impervious land from 30 percent to 20 percent. Similar reductions were made in trapping for sediment-associated phosphorus.

The instream parameters controlling scour and deposition mainly serve to modulate the movement of load derived from the uplands. Model simulation of scour and deposition depends on the simulation of shear stress, which in turn depends on the specification of F-tables. Given the simple one-dimensional representation of reaches in LSPC, values of critical shear stress are site-specific. We began with values successfully used for the Menomonee River smaller streams. The presence of numerous closely spaced sampling stations on Oak Creek allowed reach-by-reach adjustment in the main stem to better match observations.

Calibration of LSPC to observed instream suspended sediment concentrations is a difficult process, and an exact match cannot be expected for a number of reasons:

- Because suspended sediments often vary rapidly in time, point-in-time grab sample observations may not be representative of daily-average concentrations. Sediment load peaks are likely to be shifted slightly between the model and observations, resulting in larger apparent errors.

- Any errors in the hydrologic simulation of storm events also propagate into the sediment simulation. Both the washoff of sediment from the land surface and the scour of sediment within streams depend on the shape of the storm hydrograph at a fine temporal scale. But the spatial resolution of the rain gages representing broad geographic areas in the model limits the accuracy.

- Stream reaches are represented as relatively long segments, with average properties. The accuracy of scour/deposition simulation is limited by the relatively simplified representation of hydraulic conditions in the LSPC model.

- Because of the scale of the model, low-order streams are not explicitly simulated. As a result, sediment dynamics in the smaller streams are also not simulated.

- The timing of snowmelt peak flows are often not accurately captured by the models. These are often also peak sediment transport events.

- LSPC is a one-dimensional model, and thus simulates an average concentration for a crosssection. Samples that are not spatially integrated may not provide an accurate representation of the cross-sectional average concentration. This phenomenon can be particularly important at higher flows where there may be enhanced movement and higher concentrations of sediment near the sediment bed.

Calibration for sediment, as with any other water quality parameter, involves visual and statistical comparison of observed and predicted concentrations. However, the match on individual points is expected to be inexact, for the reasons cited above. For this reason, it is most important to reproduce observed transport curves (Donigian and Love, 2002; MPCA, 2001). That is, a log-log power plot of observed sediment load versus observed flow should match a similar plot of simulated sediment load and simulated flow.

Comparisons of observed and simulated TSS are shown at seven available monitoring stations within the LSPC modeling domain, arranged in upstream-to-downstream order (Figure 5-3 to Figure 5-16). Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment A.

A statistical comparison of paired sediment observations and simulated daily mean values are provided in Section 5.8 below. A statistical evaluation of observed and simulated sediment loads is provided in Section 5.9. These comparisons are fairly good, and, as noted above, much of the error in individual point predictions is anticipated to be due to temporal shifts. Observed and simulated sediment transport plots are presented in Section 5.10.

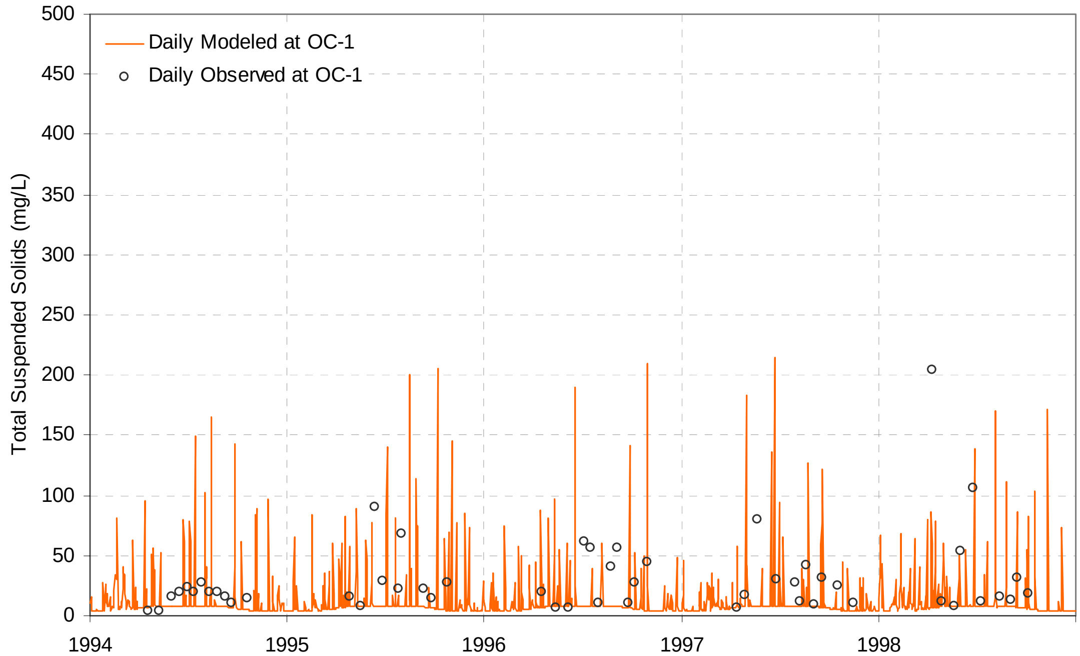


Figure 5-3. Total suspended solids time series calibration at Oak Creek Station OC-1.

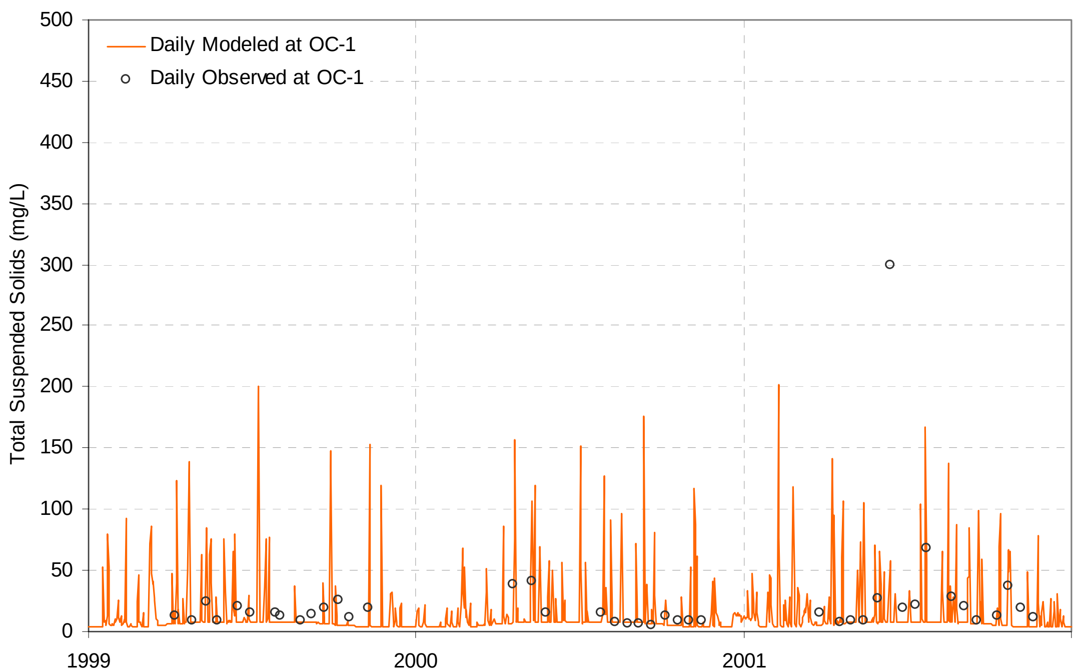


Figure 5-4. Total suspended solids time series validation at Oak Creek Station OC-1.

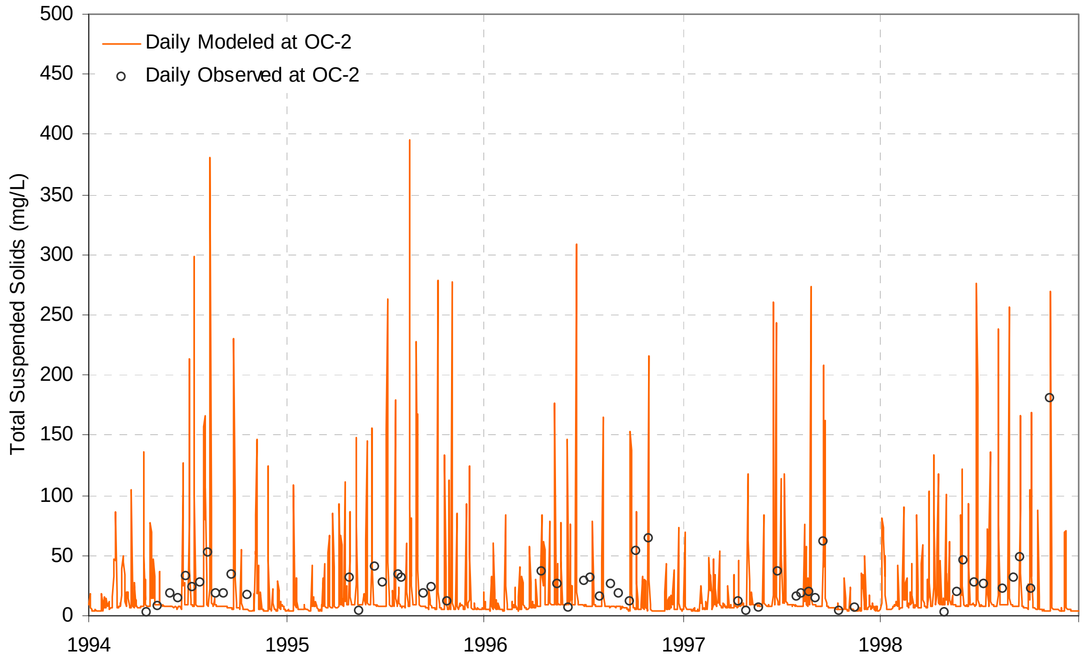


Figure 5-5. Total suspended solids time series calibration at Oak Creek Station OC-2.

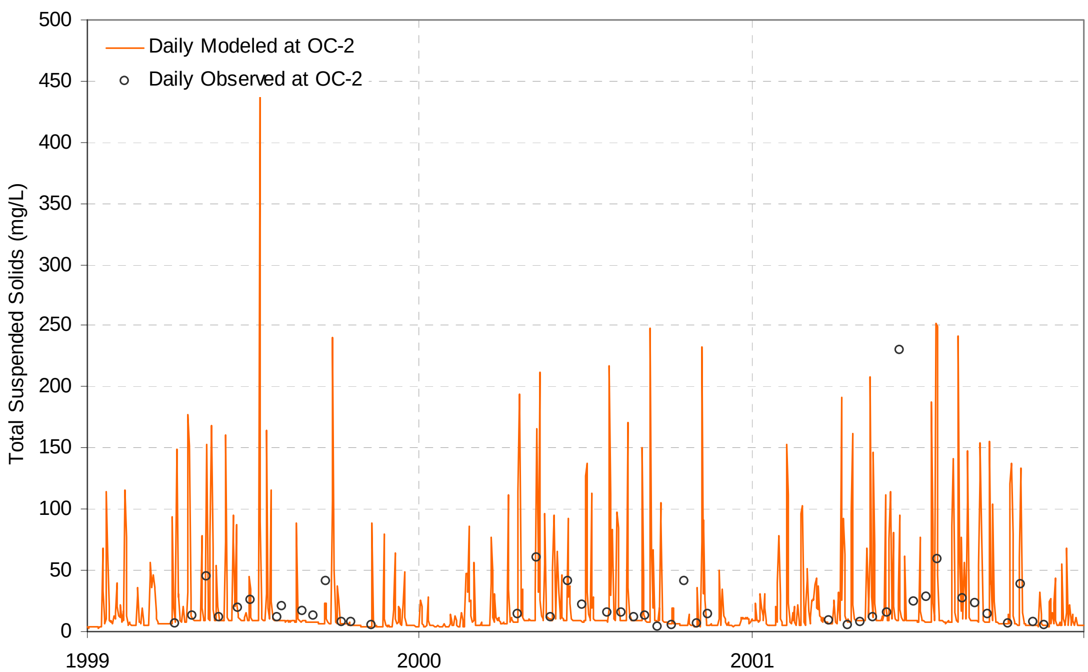


Figure 5-6. Total suspended solids time series validation at Oak Creek Station OC-2.

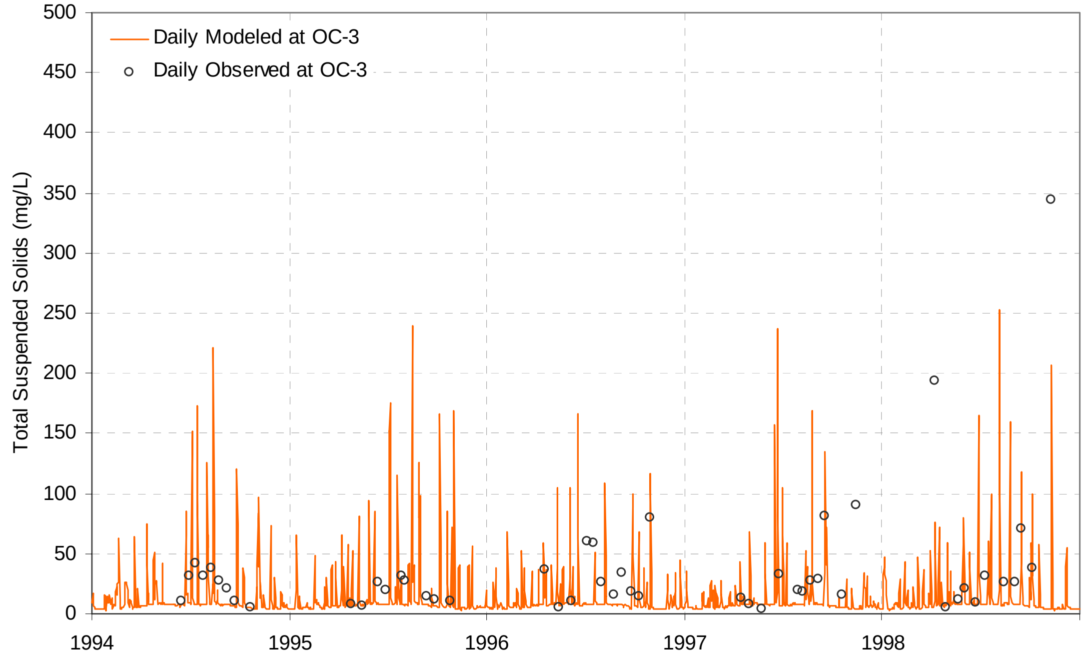


Figure 5-7. Total suspended solids time series calibration at Oak Creek Station OC-3.

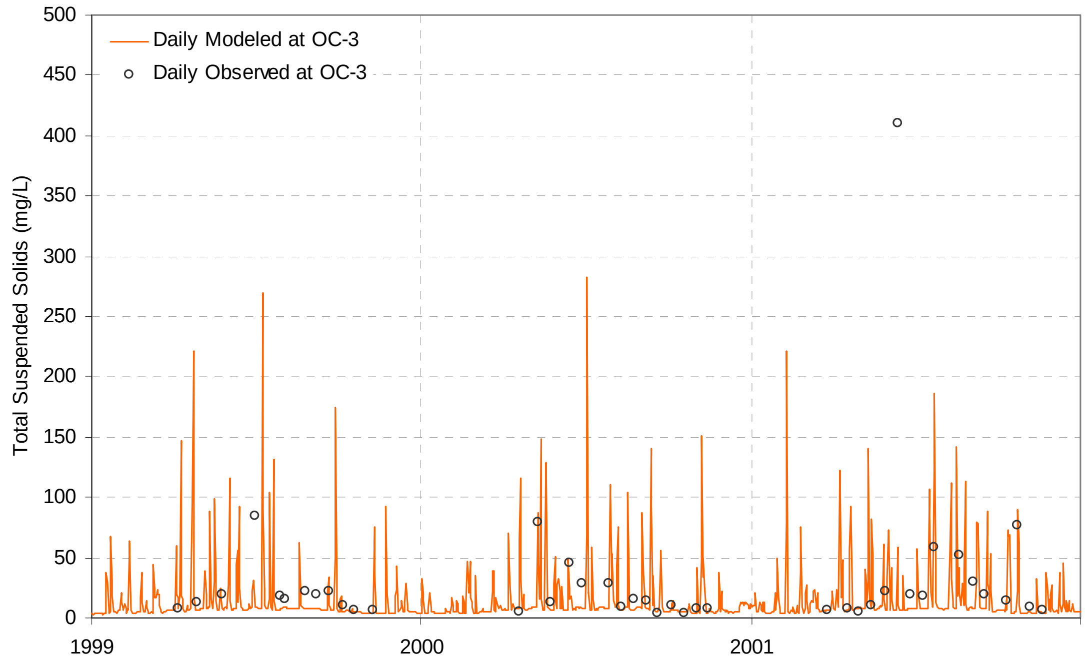


Figure 5-8. Total suspended solids time series validation at Oak Creek Station OC-3.

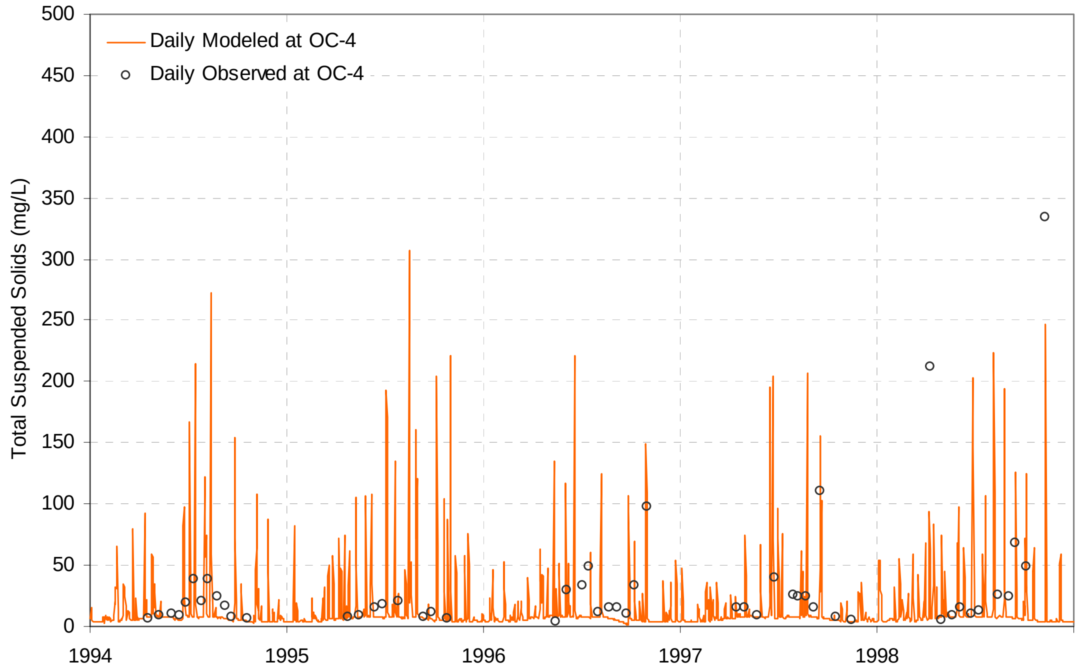


Figure 5-9. Total suspended solids time series calibration at Oak Creek Station OC-4.

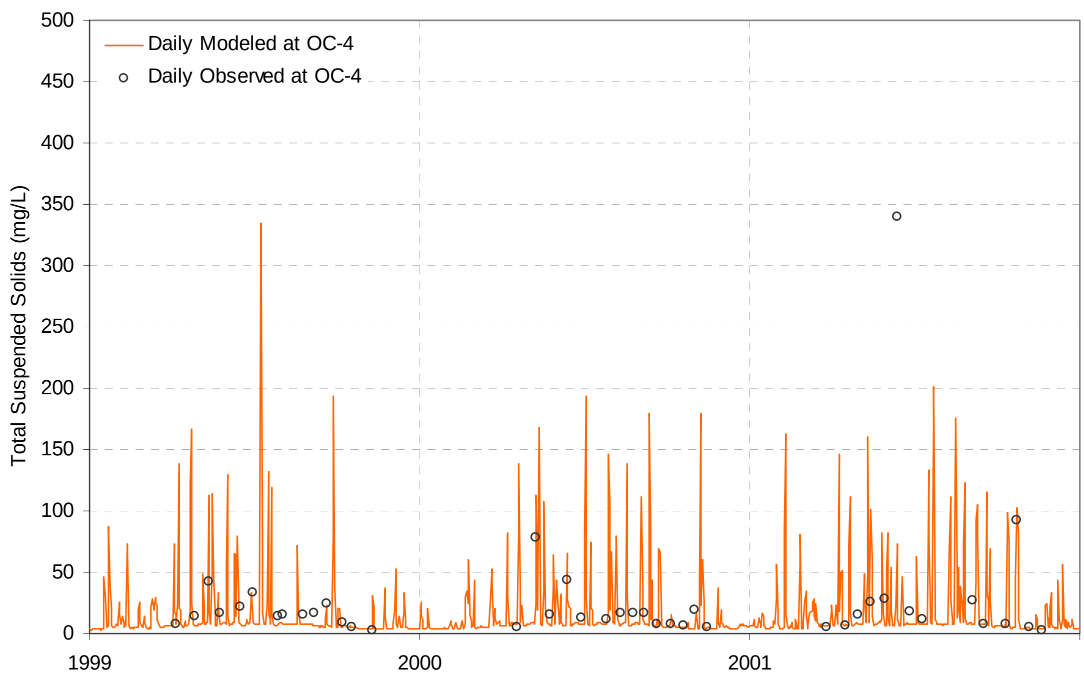


Figure 5-10. Total suspended solids time series validation at Oak Creek Station OC-4.

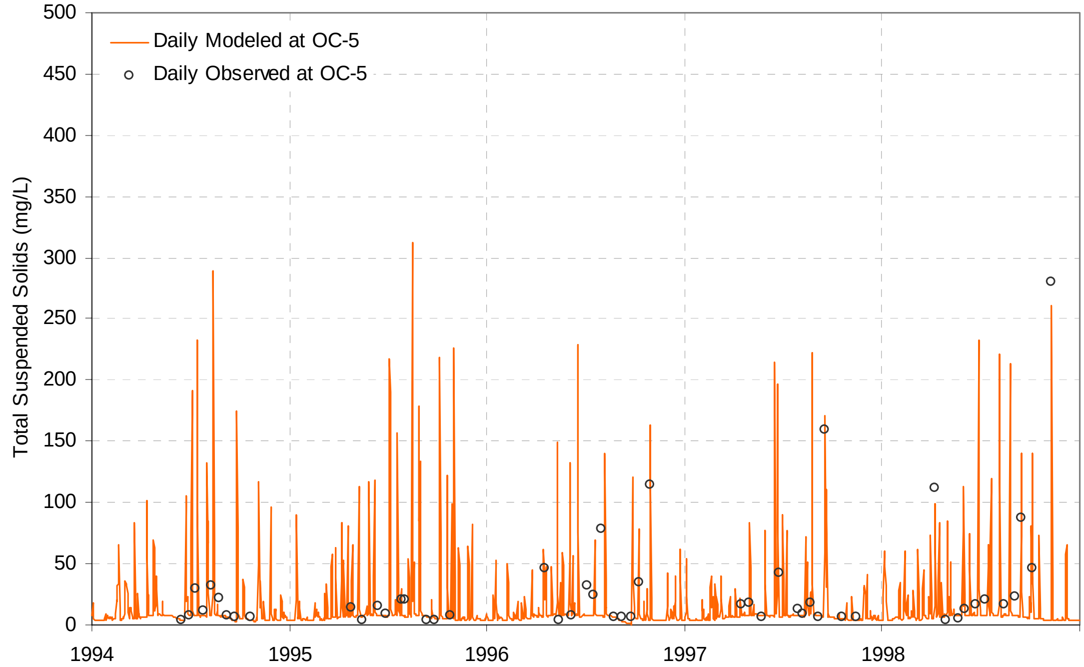


Figure 5-11. Total suspended solids time series calibration at Oak Creek Station OC-5.

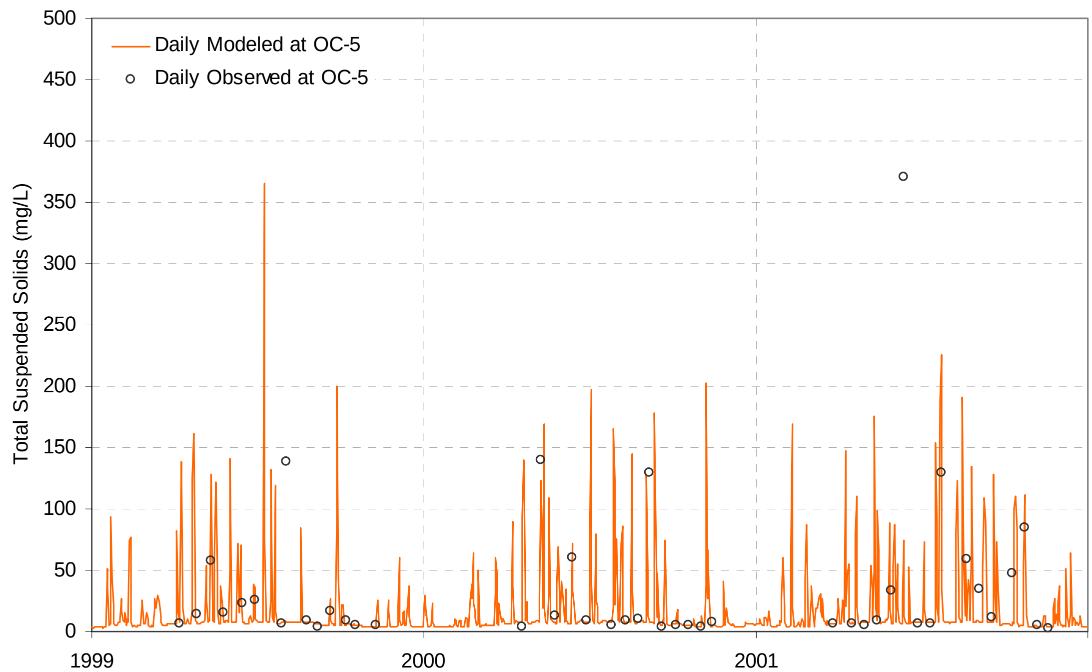


Figure 5-12. Total suspended solids time series validation at Oak Creek Station OC-5.

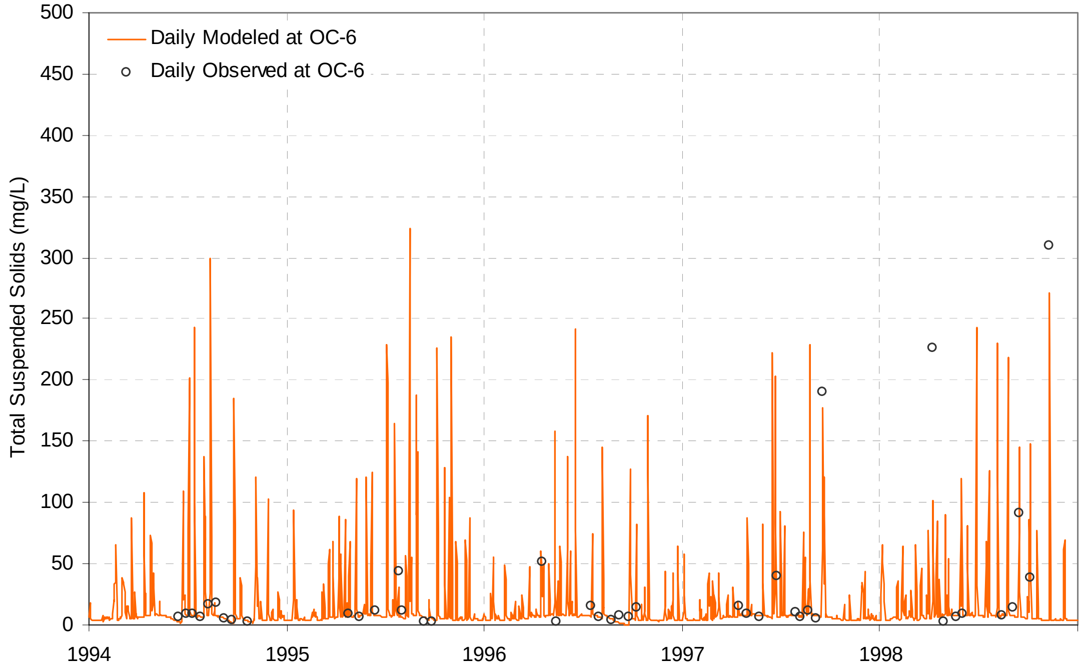


Figure 5-13. Total suspended solids time series calibration at Oak Creek Station OC-6.

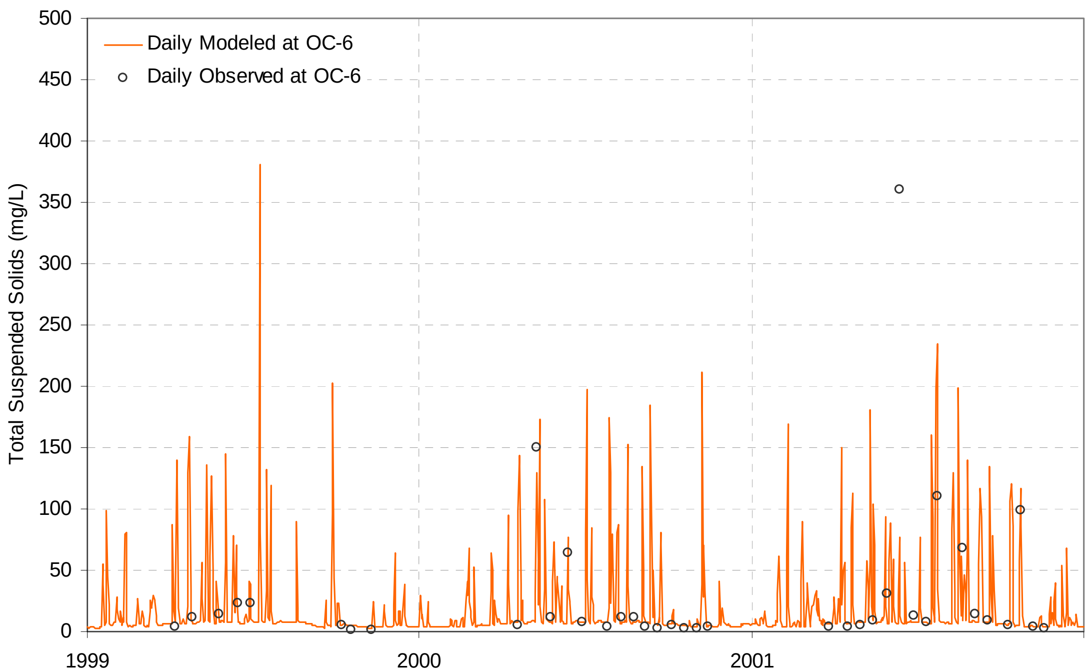


Figure 5-14. Total suspended solids time series validation at Oak Creek Station OC-6.

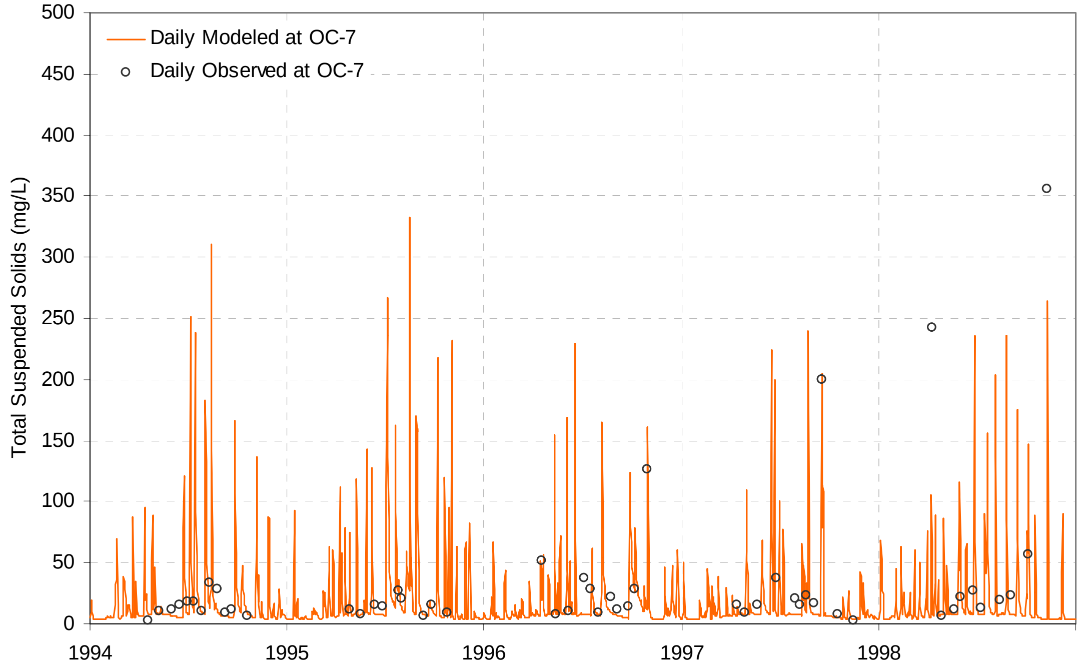


Figure 5-15. Total suspended solids time series calibration at Oak Creek Station OC-7.

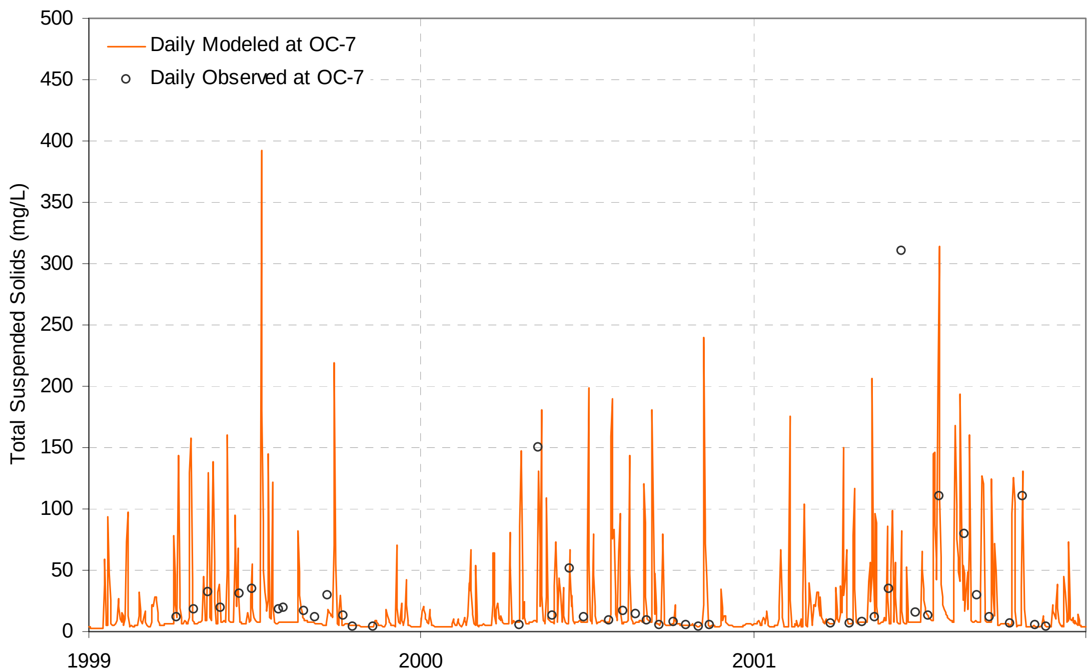


Figure 5-16. Total suspended solids time series validation at Oak Creek Station OC-7.

5.3 Water Temperature Calibration

Water temperature simulation is not an explicit goal of the water quality modeling. However, a reasonable simulation of water temperature is necessary because many kinetic reaction rates are temperature dependent. Temperature simulation was therefore checked visually for consistency with observations, but a full statistical analysis has not been provided at this time.

The Oak Creek temperature simulation relies on the same set of parameters as used for the Menomonee. PERLND soil temperature and reach water temperature parameters were adopted from successful Minnesota River model applications. IMPLND runoff temperature was revised to provide a slight increase above ambient air temperature, with constant AWTF = 35 and BWTF = 1.05.

Fit to observed water temperature appears generally good for both the calibration and validation time periods (comparison is shown to daily averages from the model as many of the observations do not report time of day) (Figure 5-17 to Figure 5-30). Summer temperatures appear to be over-predicted at station OC-1 (only). The reasons for this have not been fully explained, but may be a result of characteristics of the sample location, such as proximity to a groundwater discharge point.

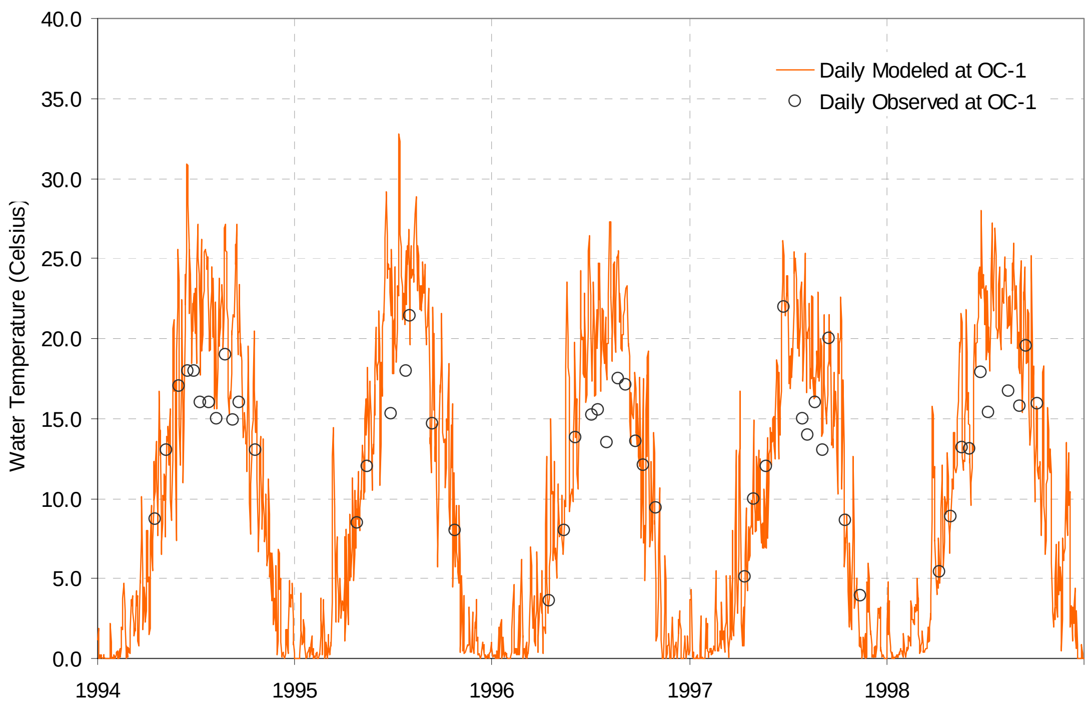


Figure 5-17. Temperature time series calibration at Oak Creek Station OC-1.

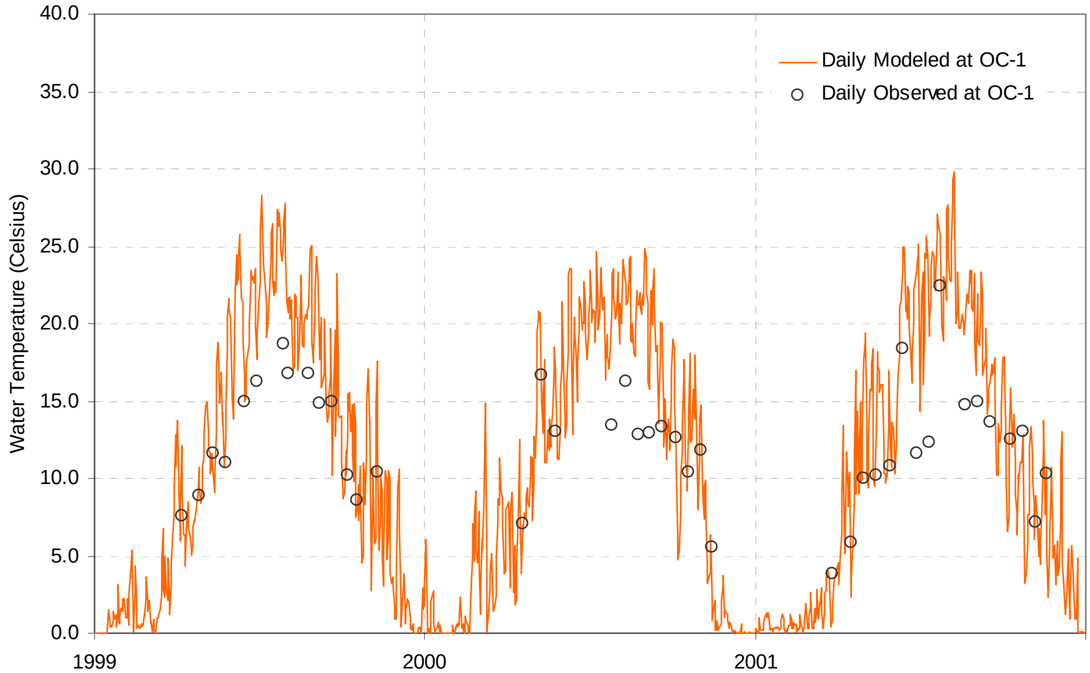


Figure 5-18. Temperature time series validation at Oak Creek Station OC-1.

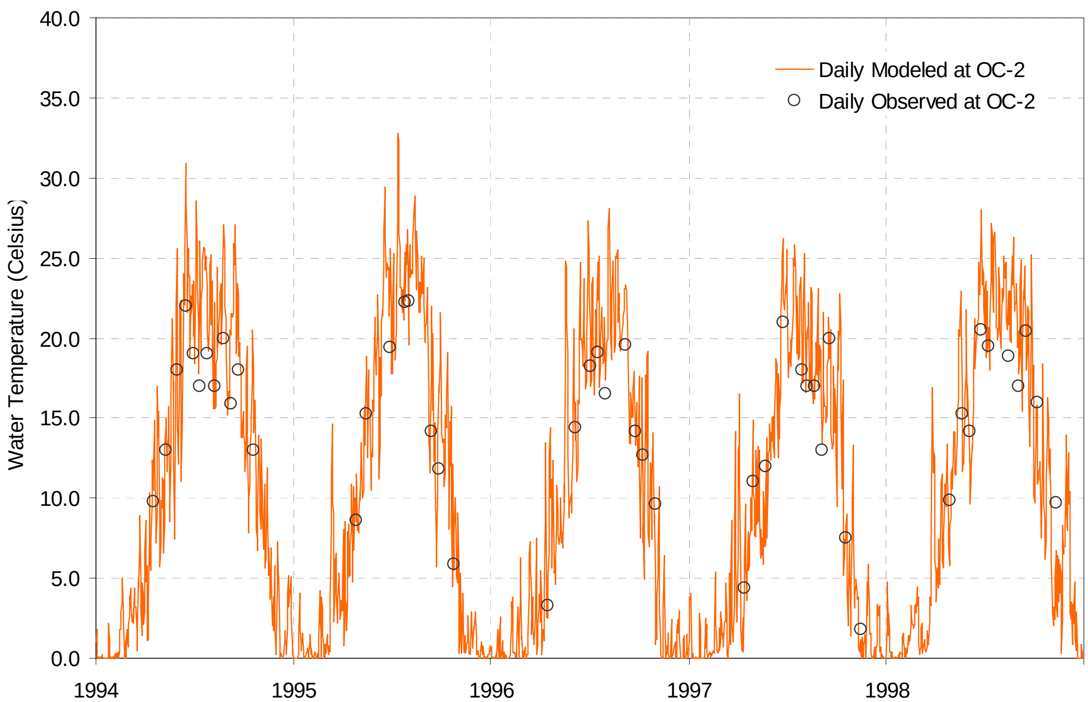


Figure 5-19. Temperature time series calibration at Oak Creek Station OC-2.

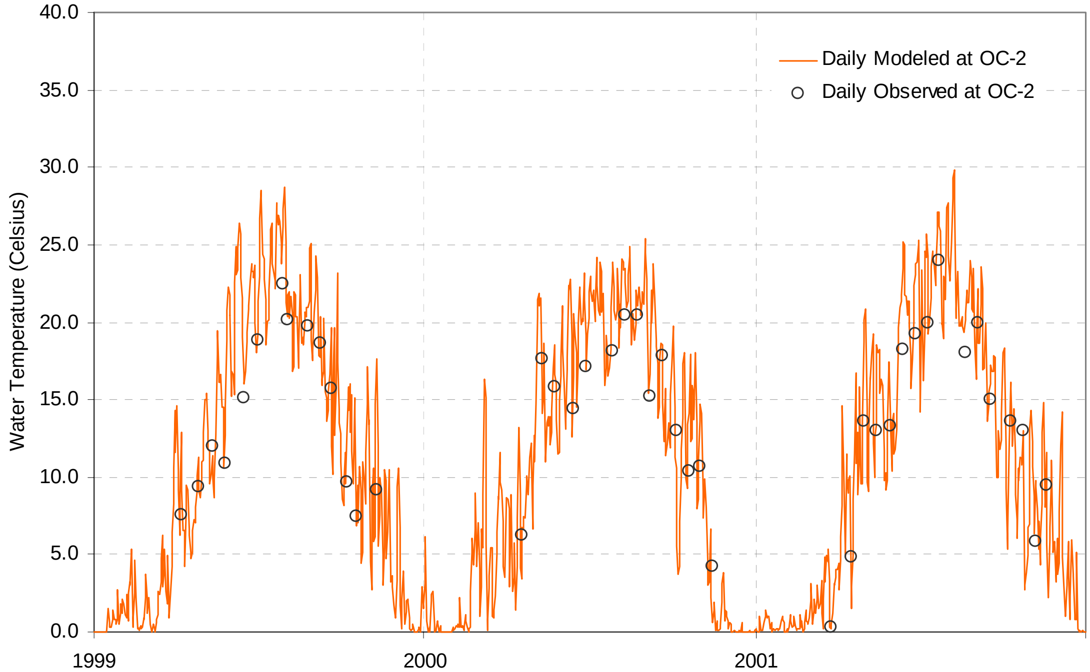


Figure 5-20. Temperature time series validation at Oak Creek Station OC-2.

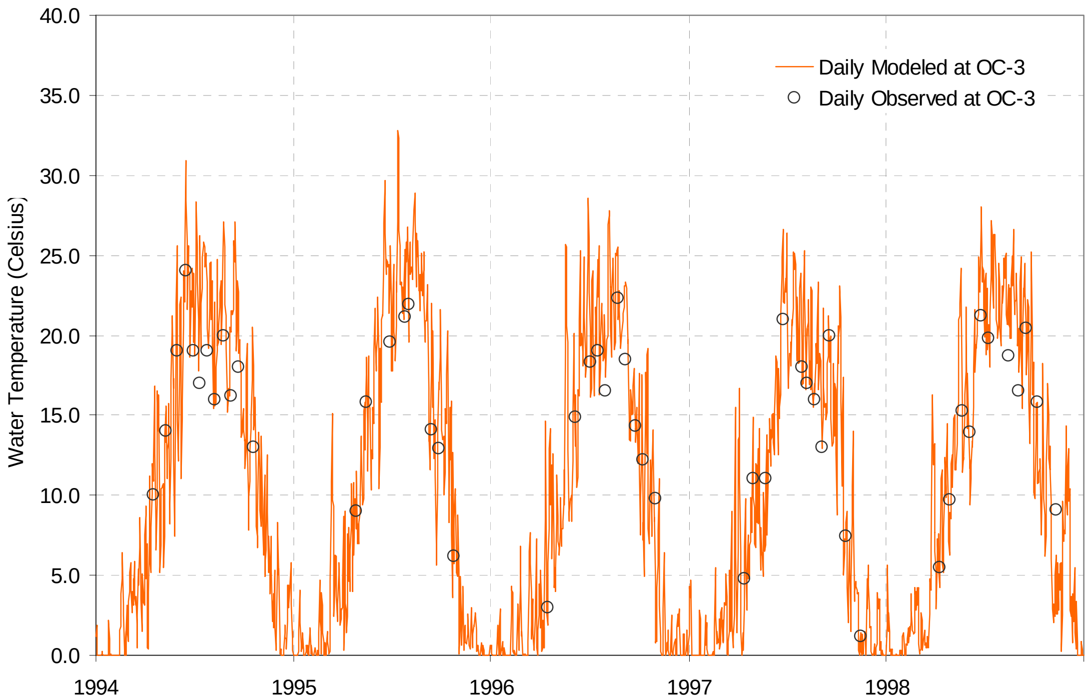


Figure 5-21. Temperature time series calibration at Oak Creek Station OC-3.

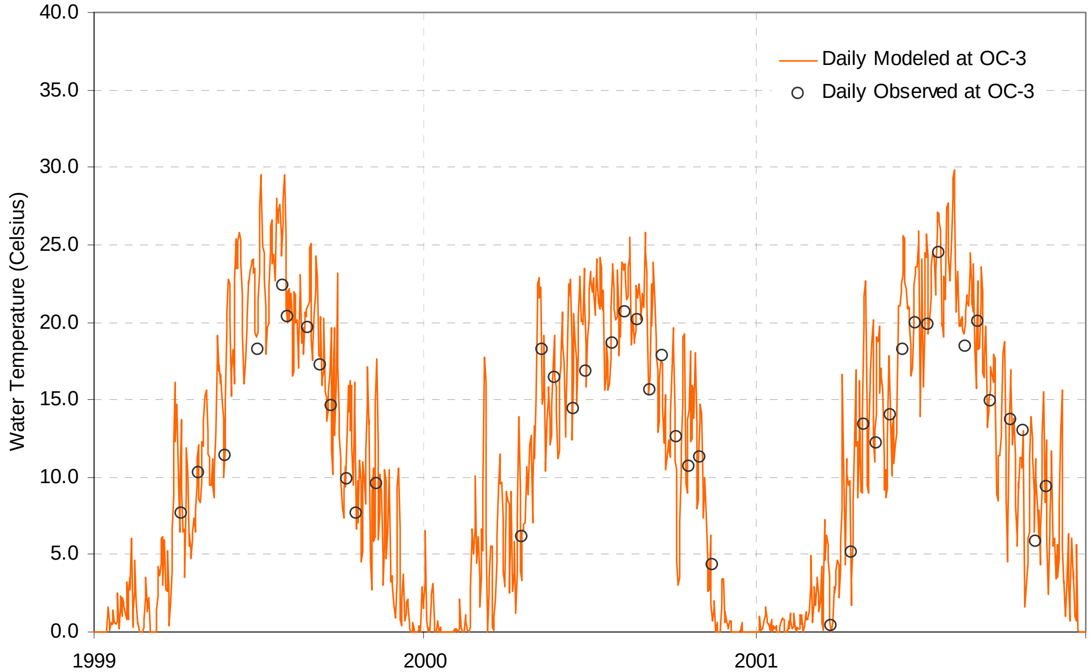


Figure 5-22. Temperature time series validation at Oak Creek Station OC-3.

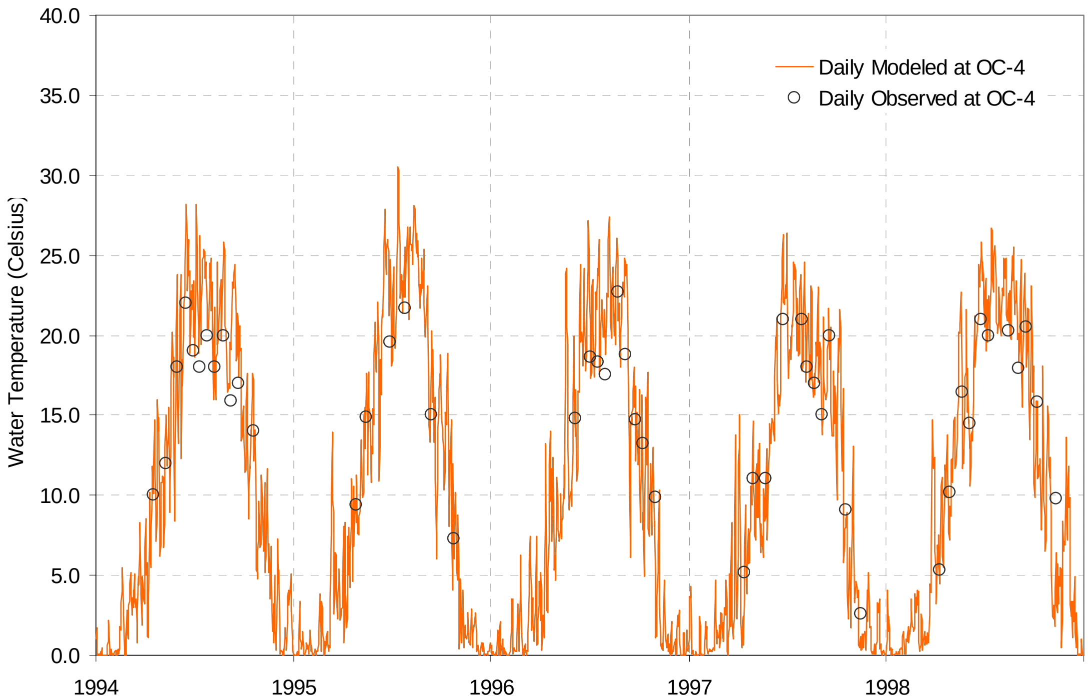


Figure 5-23. Temperature time series calibration at Oak Creek Station OC-4.

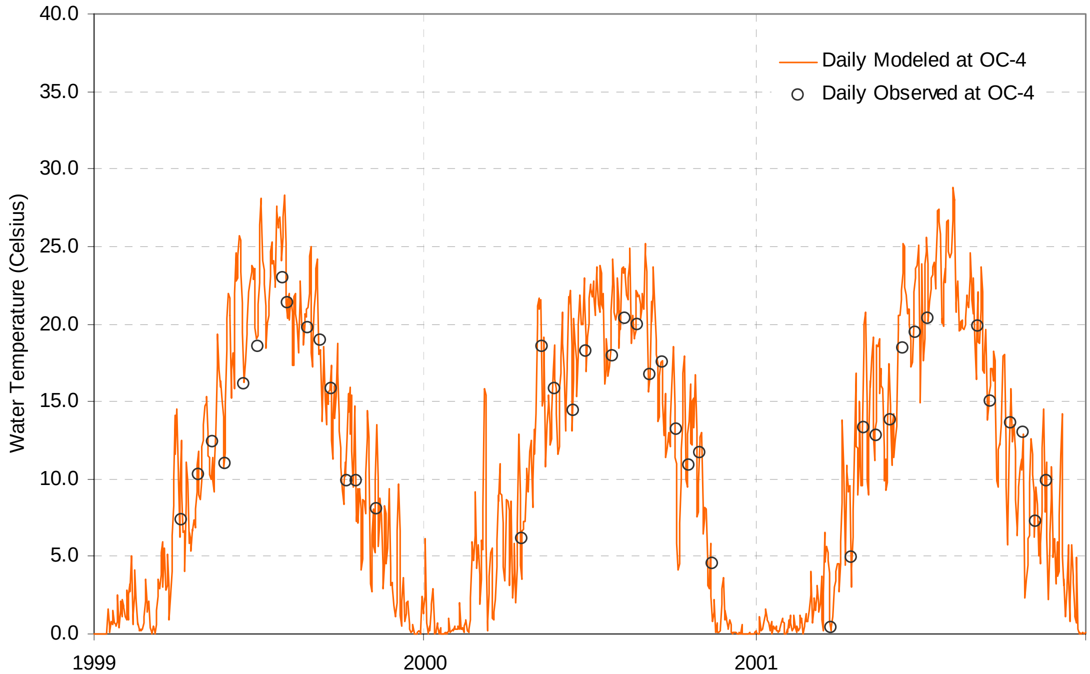


Figure 5-24. Temperature time series validation at Oak Creek Station OC-4.

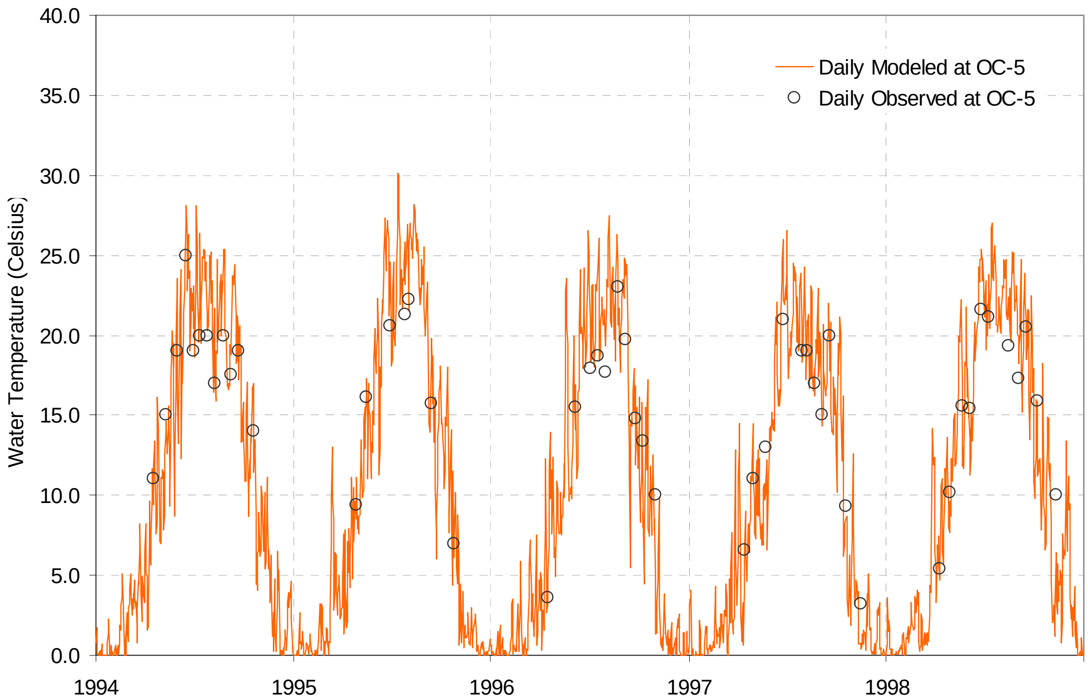


Figure 5-25. Temperature time series calibration at Oak Creek Station OC-5.

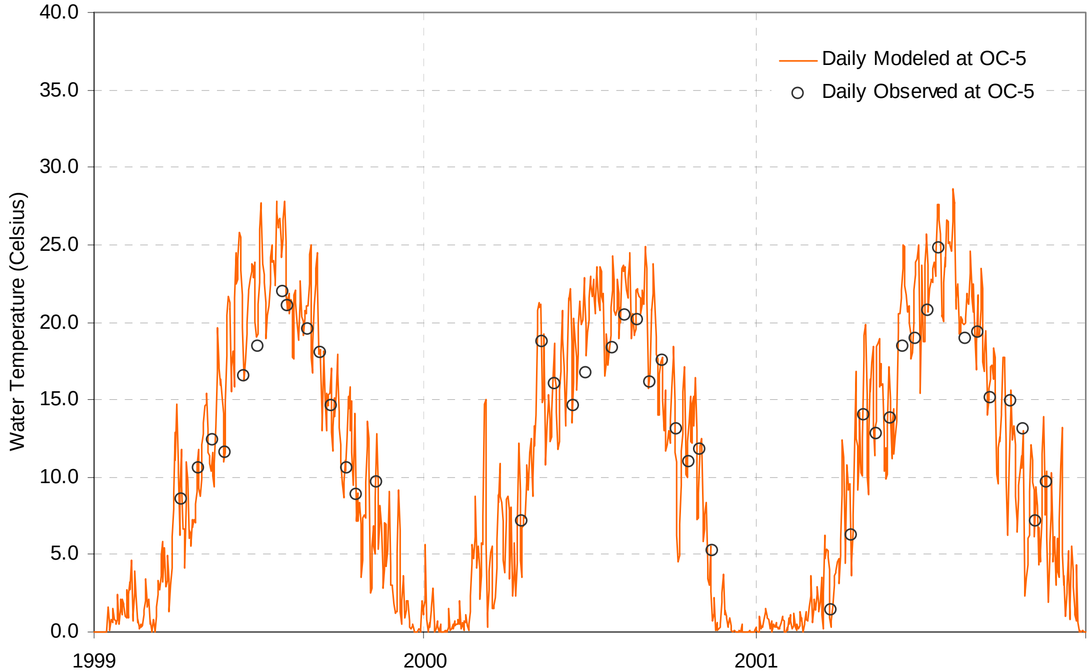


Figure 5-26. Temperature time series validation at Oak Creek Station OC-5.

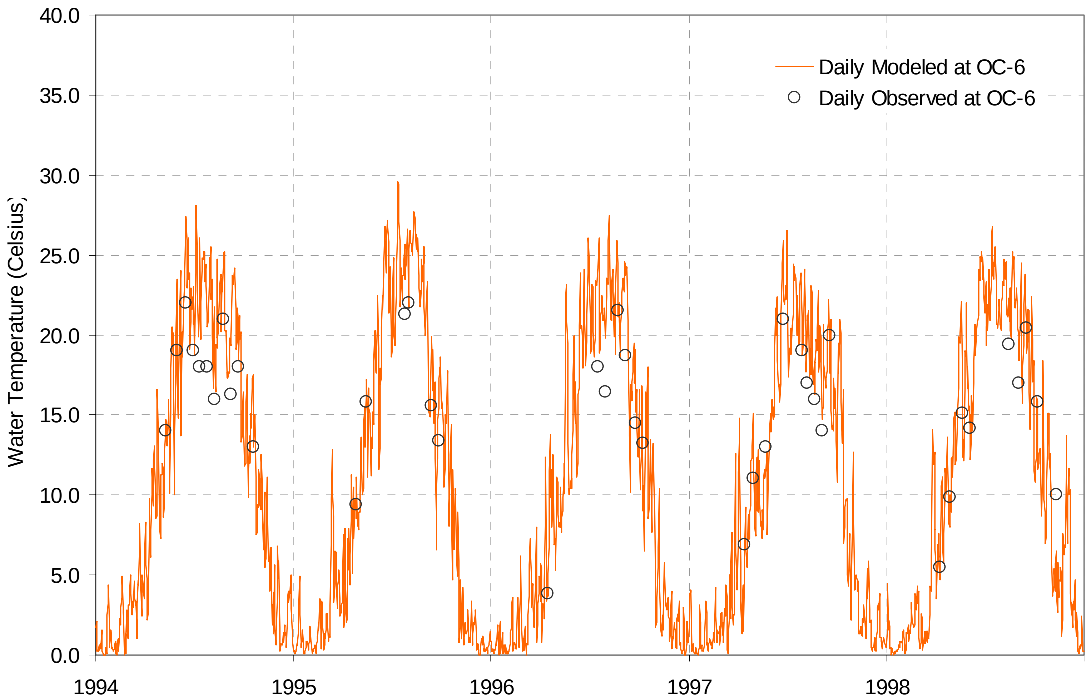


Figure 5-27. Temperature time series calibration at Oak Creek Station OC-6.

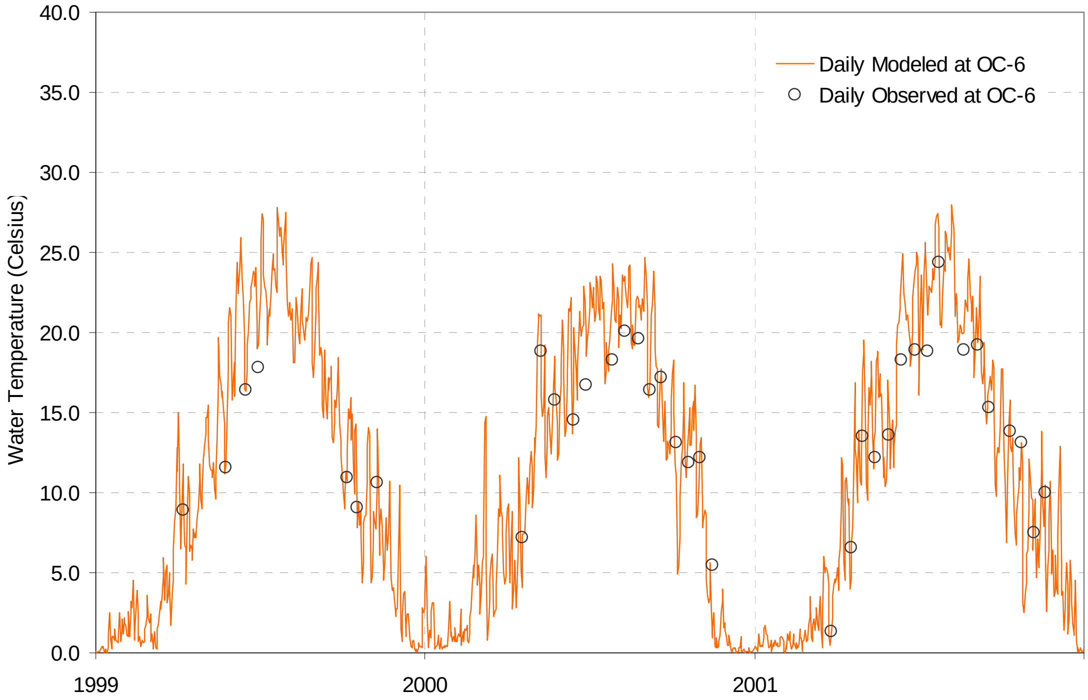


Figure 5-28. Temperature time series validation at Oak Creek Station OC-6.

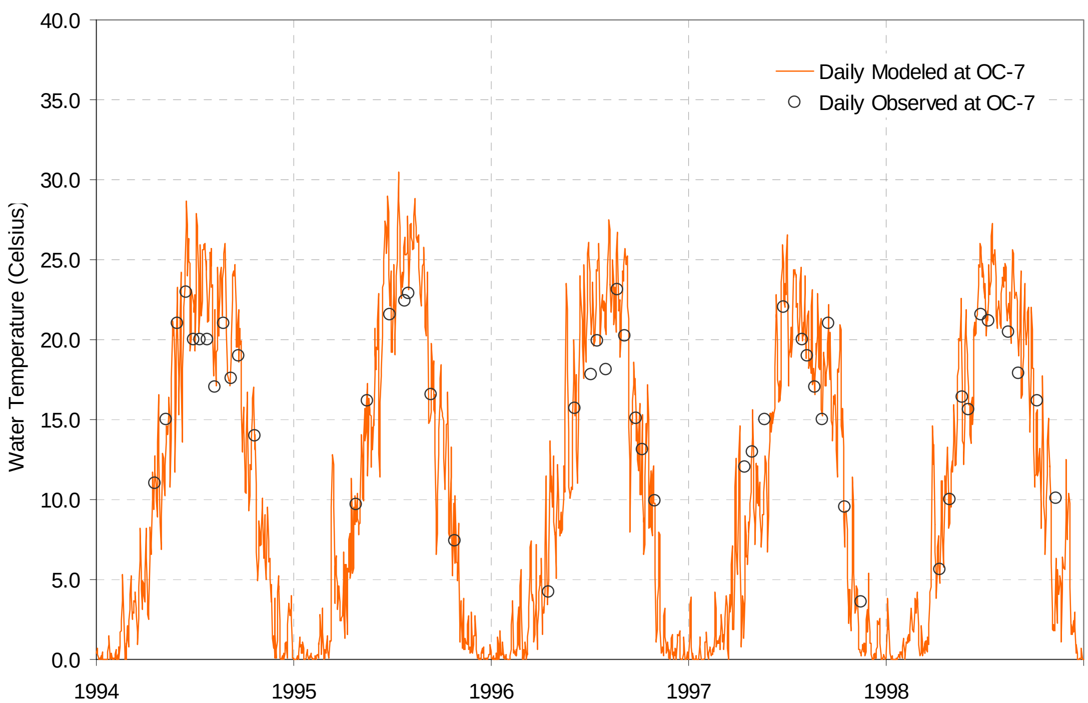


Figure 5-29. Temperature time series calibration at Oak Creek Station OC-7.

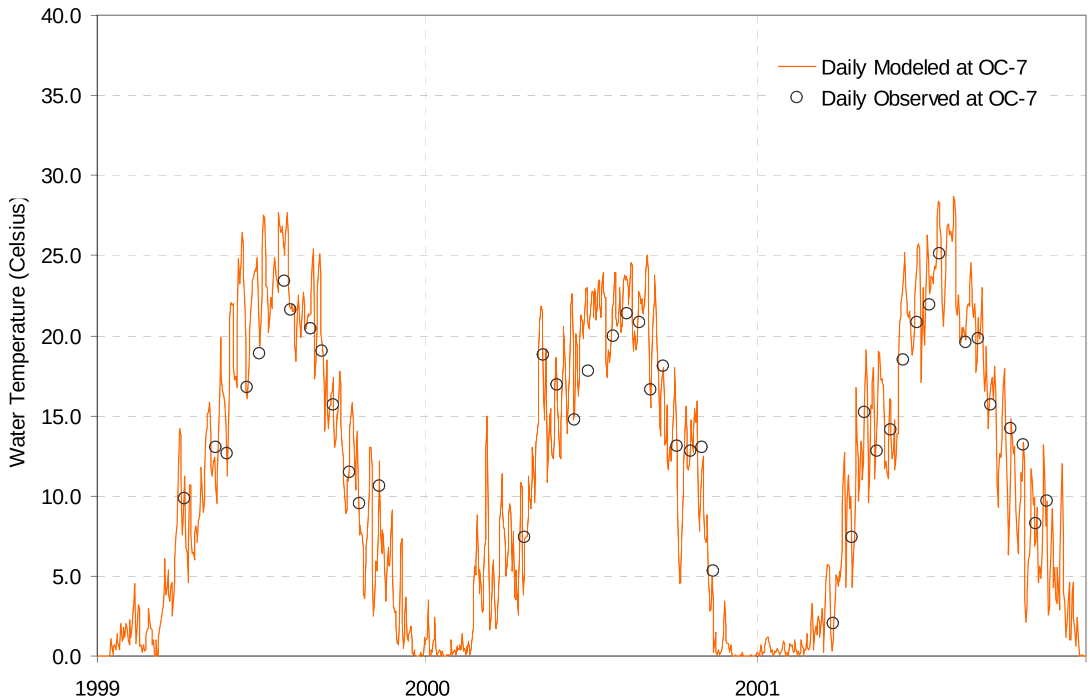


Figure 5-30. Temperature time series validation at Oak Creek Station OC-7.

5.4 Nutrient and Algal Calibration

As with sediment, the starting points for nutrient calibration in the model are the loading estimates for specific land uses derived from the SWAT application (for agricultural lands, 1993 to 1999) and the SLAMM application (for urban lands, 1995 to 1997). This ensures consistency with other tools endorsed by the Wisconsin Department of Natural Resources. A detailed discussion of the comparison of unit area loads estimated by SWAT, SLAMM and LSPC is provided in the memorandum *Water Quality Calibration Results for the Menomonee River.*

The model must be adjusted to achieve calibration to observed instream nutrient concentrations. In general, the mass of phosphorus observed instream is significantly less than the export from the land surface predicted by SWAT and SLAMM. This reflects trapping (of sediment-associated pollutants) and biological uptake (of labile forms), which primarily occurs in the small first-order and ephemeral streams. These small streams are not represented as reaches in the LSPC model, therefore the use of trapping factors is appropriate, and also enables calibration to be achieved while maintaining the relative loading magnitude for different land uses predicted by the SWAT and SLAMM models. Secondary adjustments to calibration are achieved by (1) adjusting the subsurface nutrient concentration components, and (2) adjusting instream nutrient kinetic parameters. A detailed discussion of the subsurface nutrient concentrations and instream nutrient kinetic parameters used in the Oak Creek model is provided in the memorandum *Water Quality Calibration Results for the Menomonee River.* Simulation of nutrient water quality in Oak Creek uses the same parameters as the Menomonee model with the following exceptions:

- Due to its finer resolution, net trapping prior to reaching the simulated stream reaches should be less in the Oak Creek model compared to the Menomonee River model. During calibration the surface phosphorus trapping was therefore reduced from 50 percent to 40 percent.

- Observed water quality associated with scour events suggests that the bed sediment in portions of Oak Creek has higher ammonia and phosphorus concentrations than does the Menomonee River. Accordingly, higher bed concentrations are assigned to the lower Oak mainstem. This effectively serves to re-introduce, over the long term, some of the phosphorus ultimately derived from the land surface that is assumed to be removed by trapping.

Calibration for nutrients addresses both total nutrient concentration and individual nutrient species. This calibration process is inherently somewhat inexact for a number of reasons. First, available samples represent individual points in time and space (grab samples) that may not be representative of average conditions throughout a stream reach. In addition, there is typically significant analytical uncertainty in reported results – which is clearly evidenced by the fact that reported orthophosphate is sometimes greater than total phosphorus. This is particularly problematic when concentrations are near detection limits. Another problem is often observed at high flows, where substantial amounts of nutrients may move either as parts of larger debris or associated with sediment bedload, both of which are likely to be omitted from surface grab samples.

Modeling results are presented graphically below, arranged by parameter from upstream to downstream (Figure 5-31 to Figure 5-100). A statistical assessment of concentrations is provided in Section 5.8, while a statistical assessment of loads is provided in Section 5.9. Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment A. While the model generally performs adequately, some higher-concentration events are missed. These may reflect localized events (such as timing of fertilizer application relative to storm events) that are beyond the spatial and temporal resolution of the model.

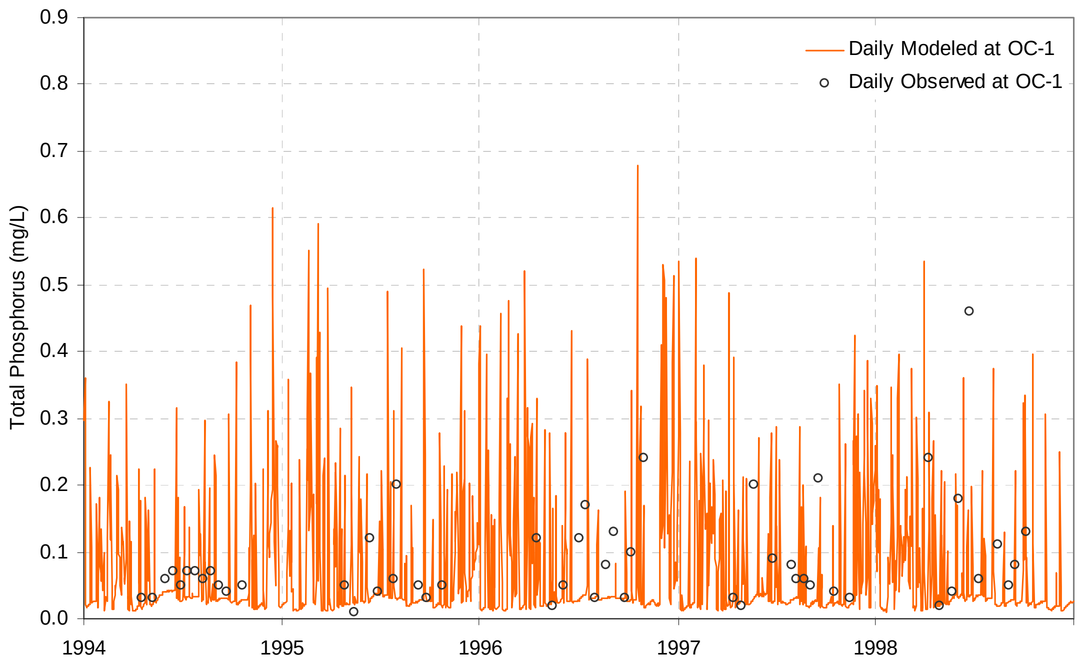


Figure 5-31. Total phosphorus time series calibration at Oak Creek Station OC-1.

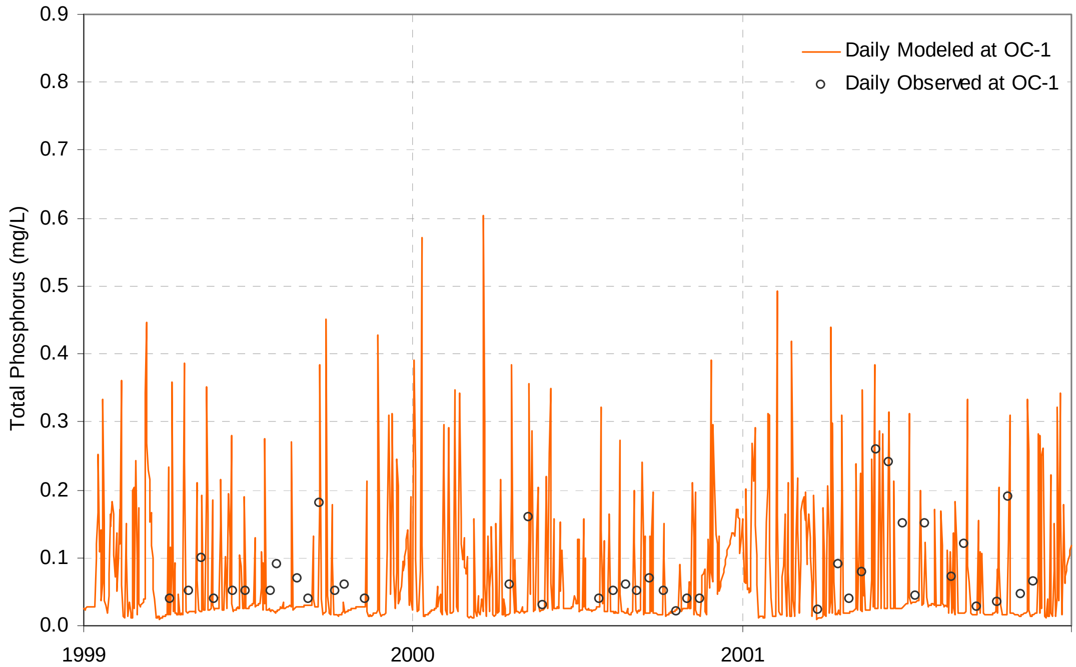


Figure 5-32. Total phosphorus time series validation at Oak Creek Station OC-1.

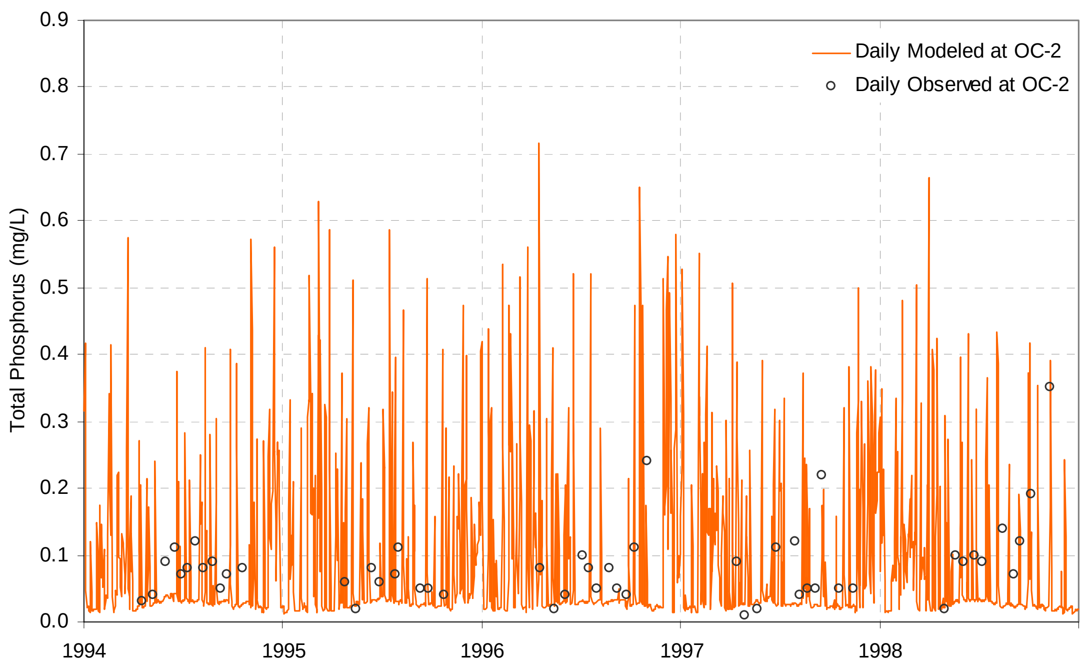


Figure 5-33. Total phosphorus time series calibration at Oak Creek Station OC-2.

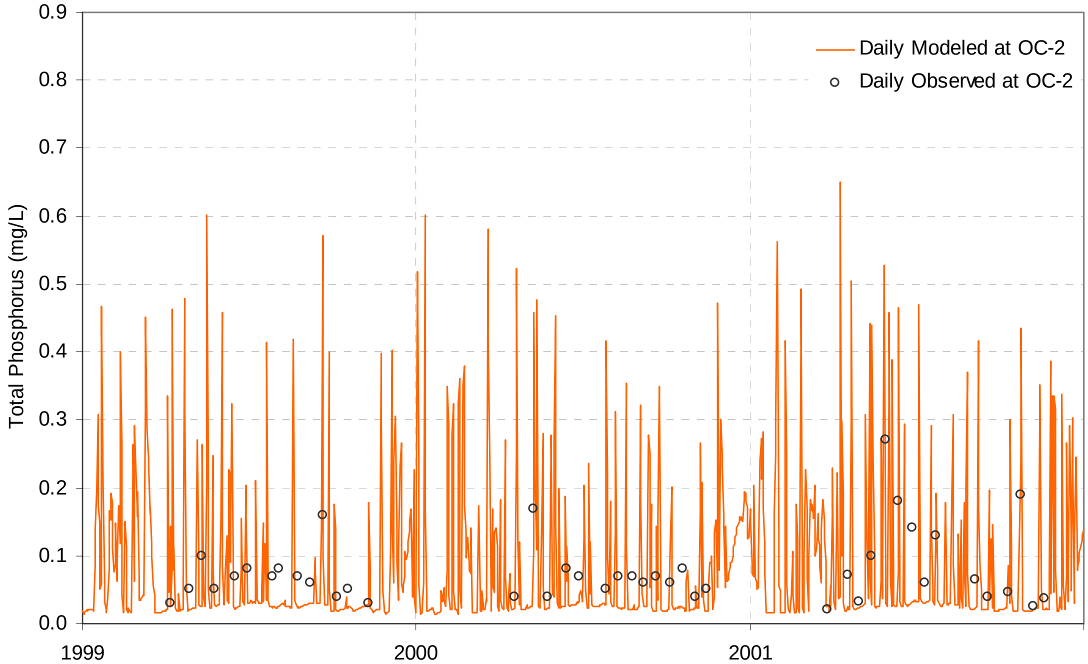


Figure 5-34. Total phosphorus time series validation at Oak Creek Station OC-2.

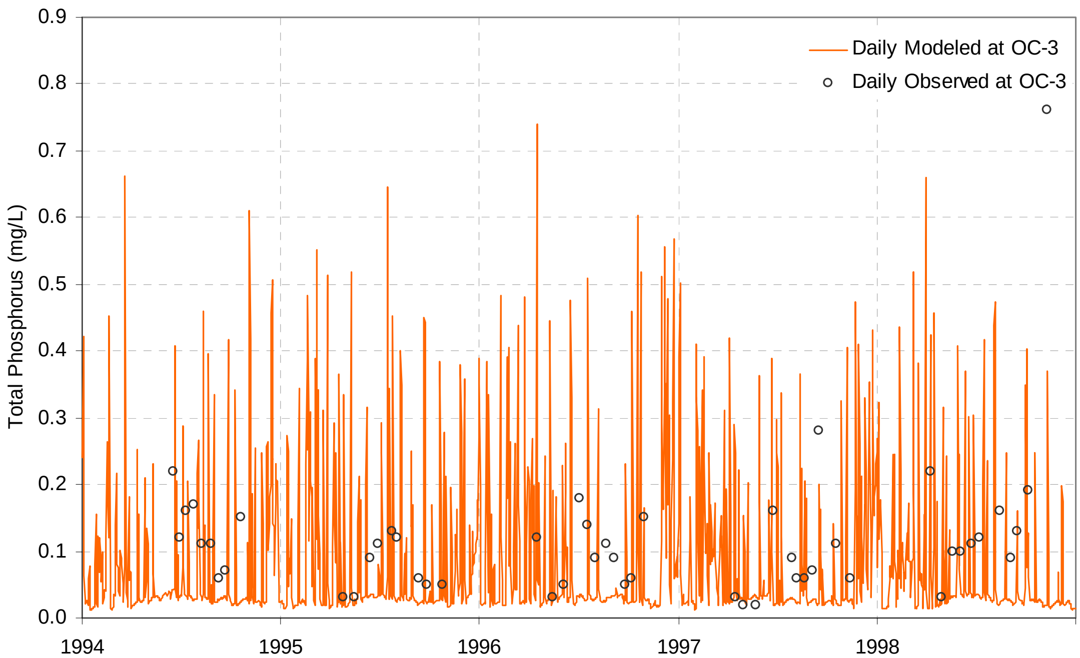


Figure 5-35. Total phosphorus time series calibration at Oak Creek Station OC-3.

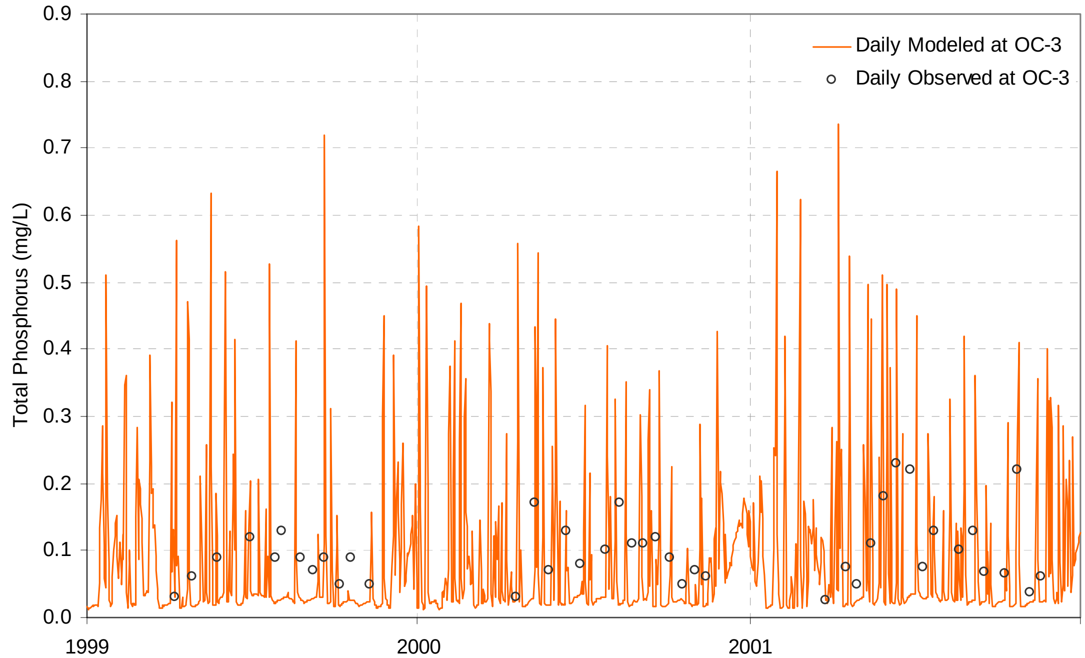


Figure 5-36. Total phosphorus time series validation at Oak Creek Station OC-3.

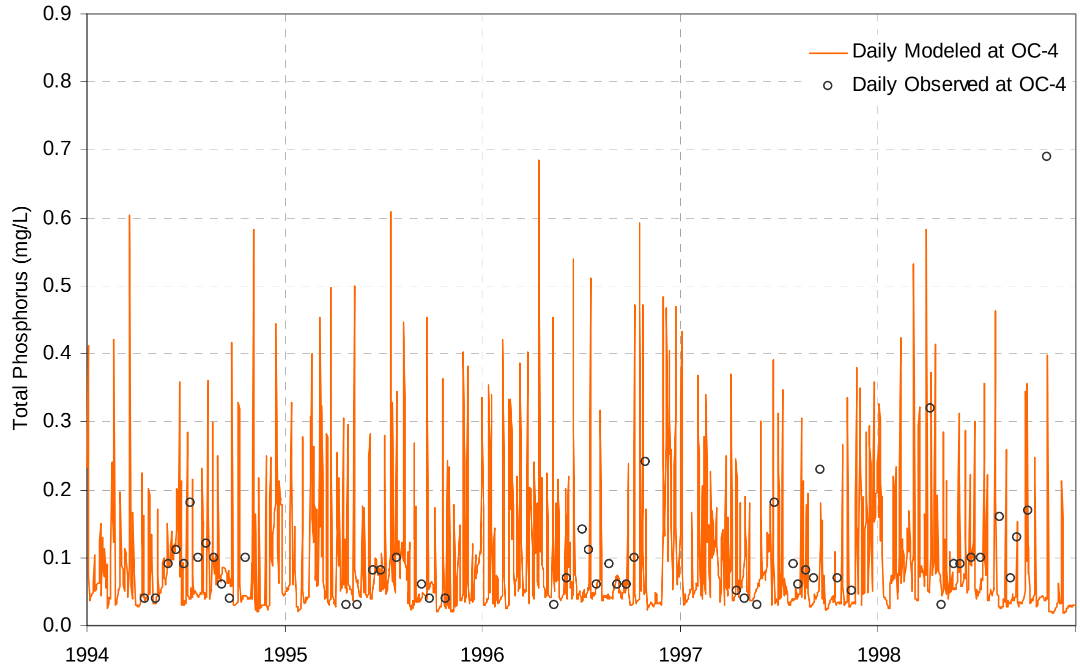


Figure 5-37. Total phosphorus time series calibration at Oak Creek Station OC-4.

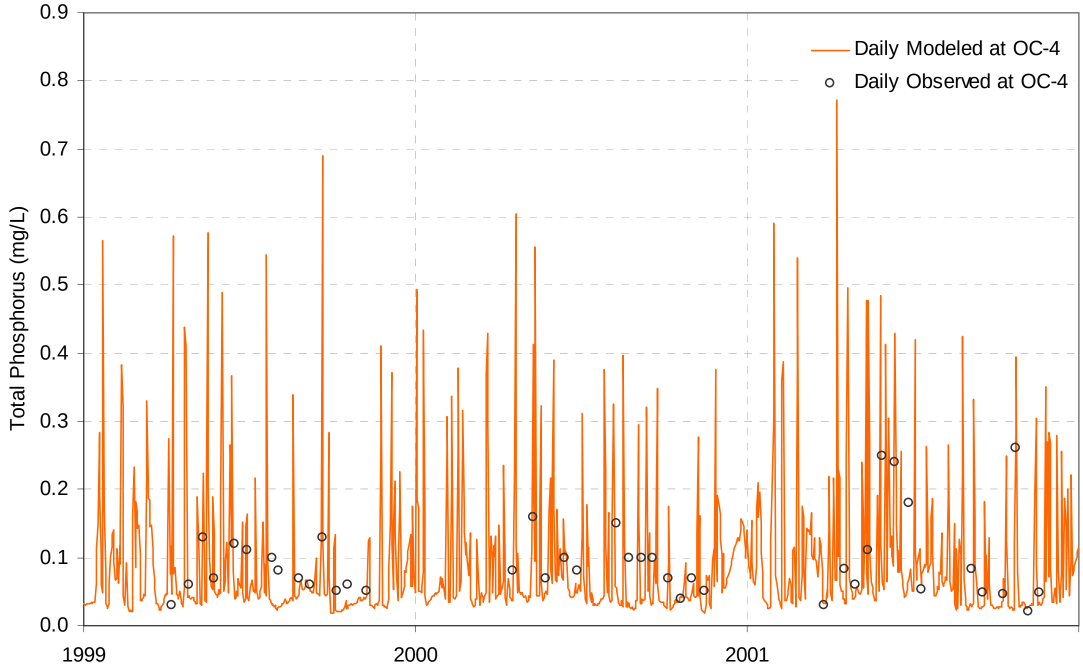


Figure 5-38. Total phosphorus time series validation at Oak Creek Station OC-4.

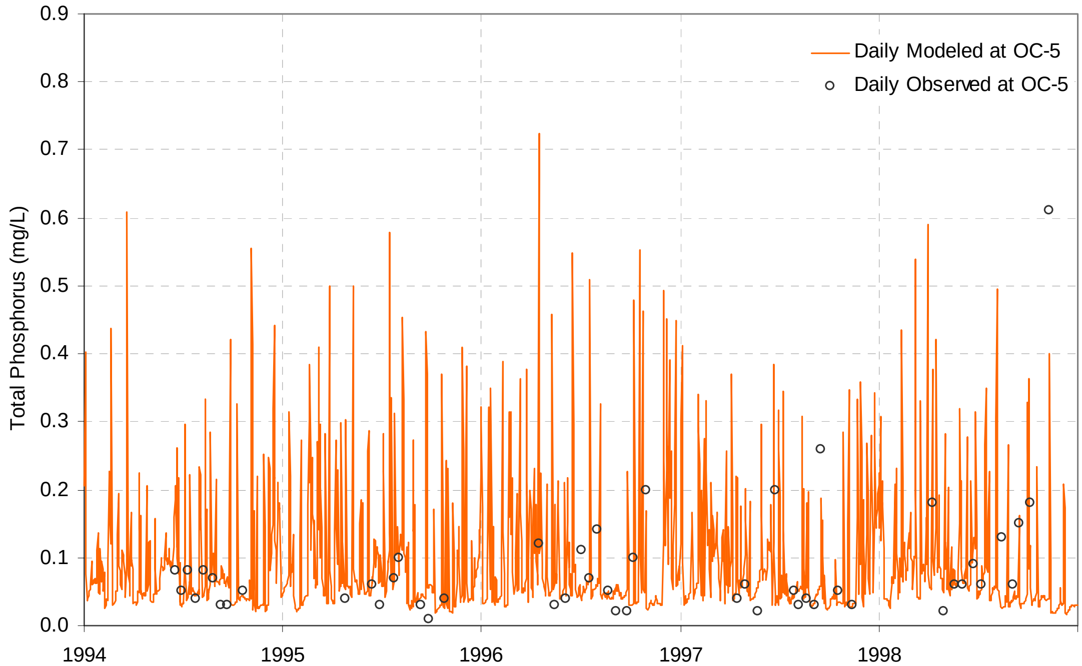


Figure 5-39. Total phosphorus time series calibration at Oak Creek Station OC-5.

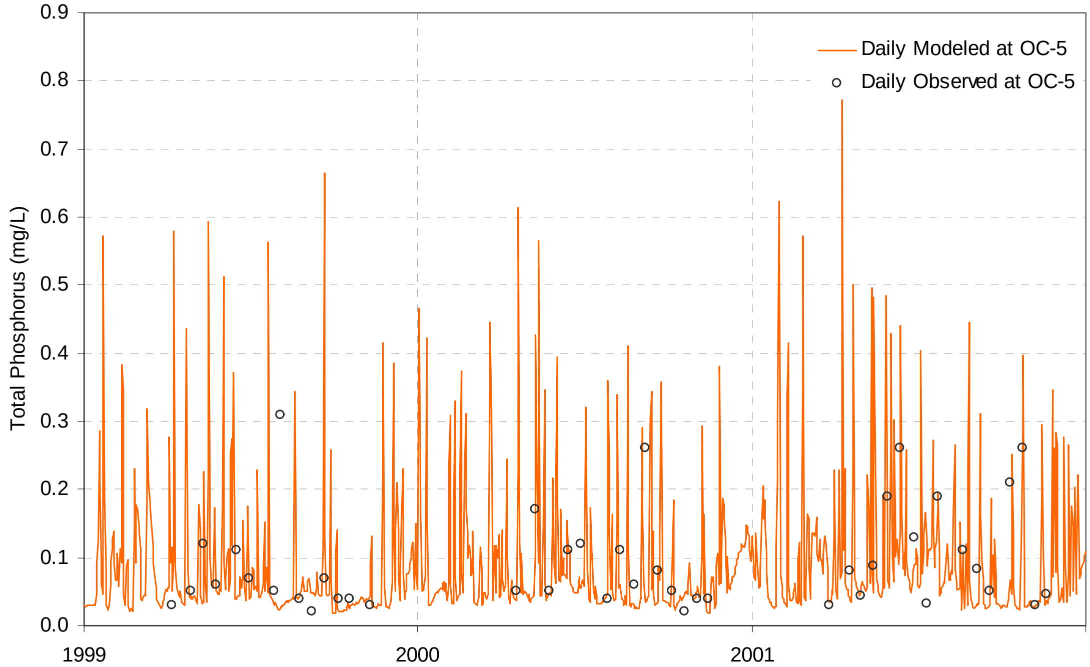


Figure 5-40. Total phosphorus time series validation at Oak Creek Station OC-5.

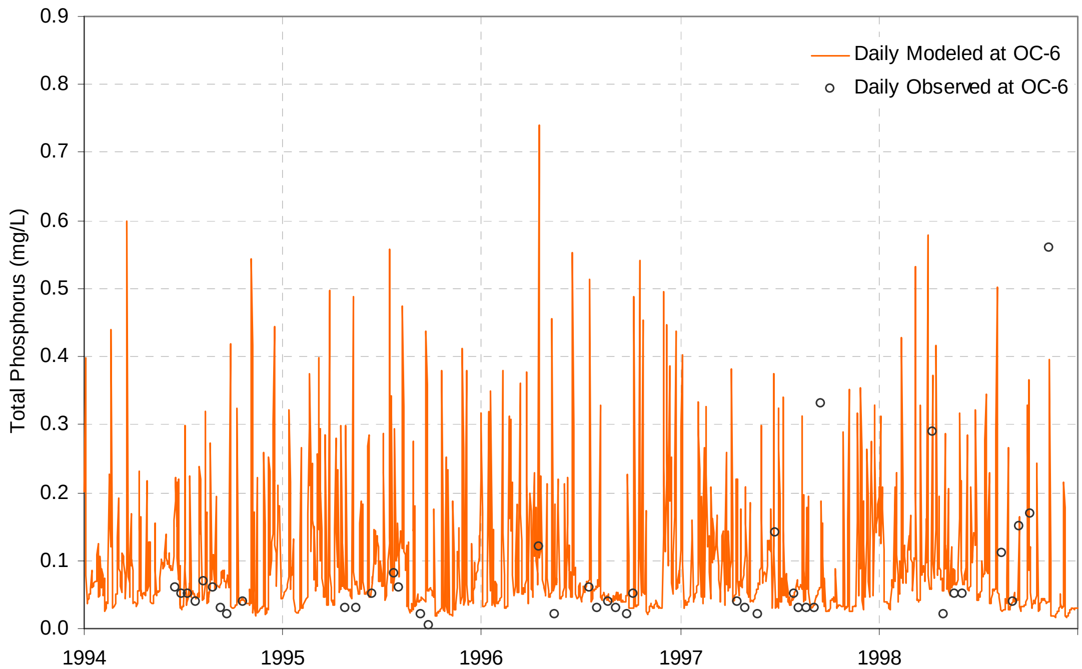


Figure 5-41. Total phosphorus time series calibration at Oak Creek Station OC-6.

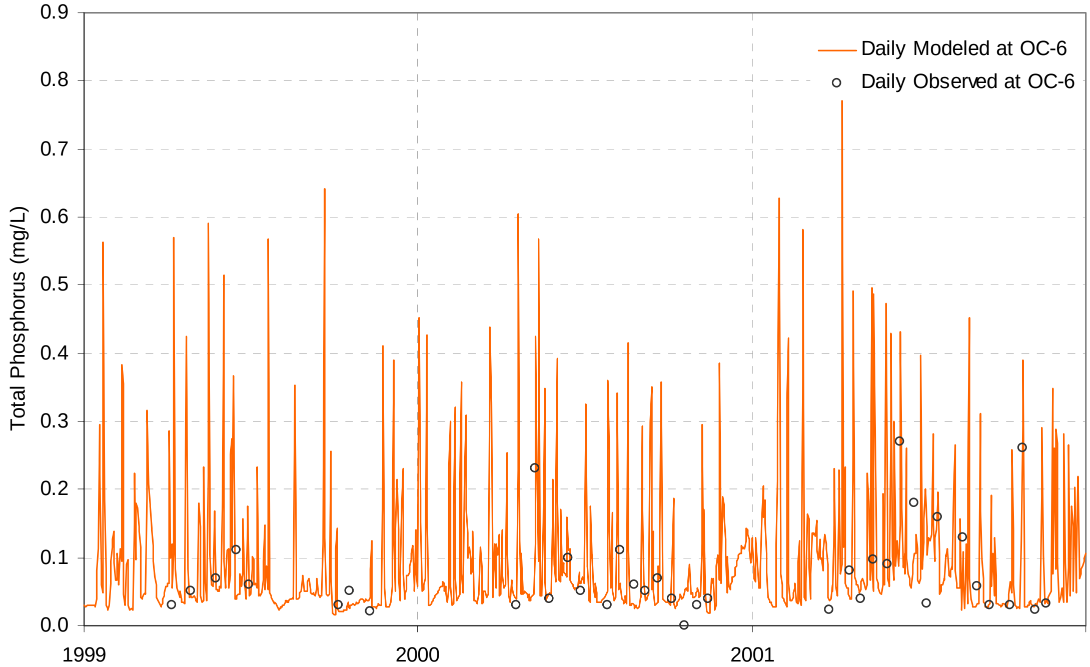


Figure 5-42. Total phosphorus time series validation at Oak Creek Station OC-6.

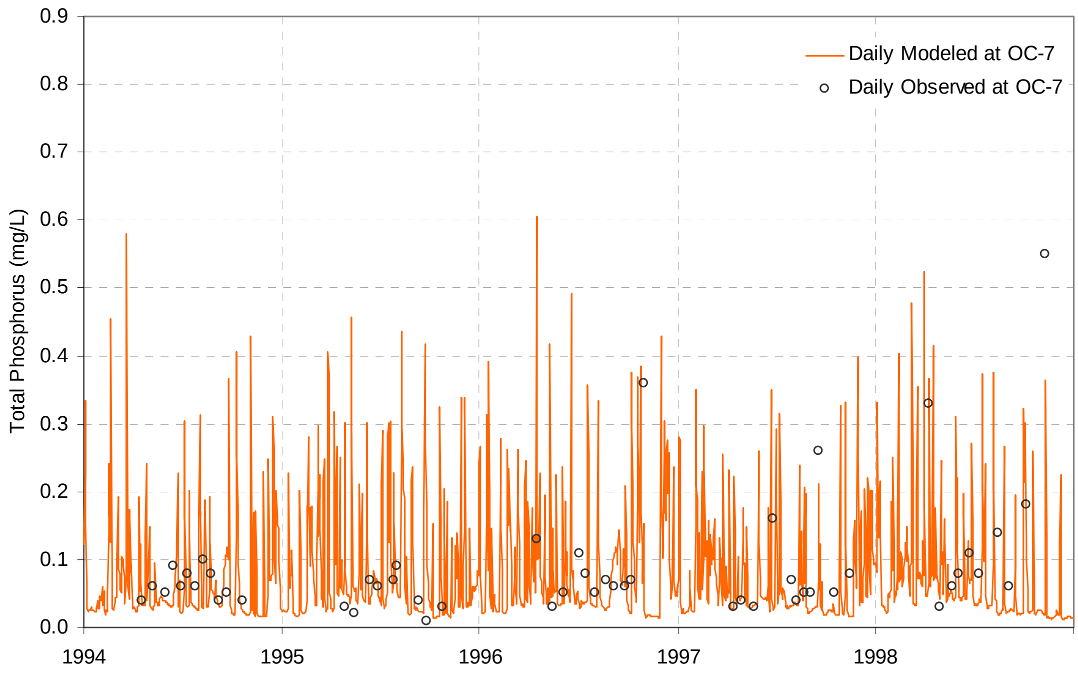


Figure 5-43. Total phosphorus time series calibration at Oak Creek Station OC-7.

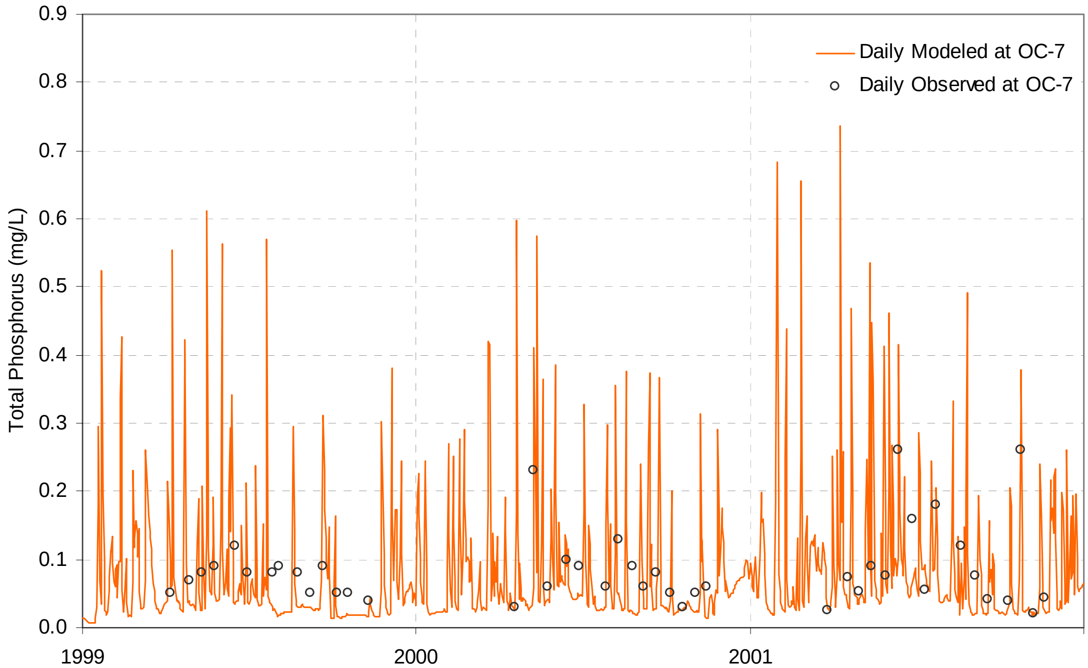


Figure 5-44. Total phosphorus time series validation at Oak Creek Station OC-7.

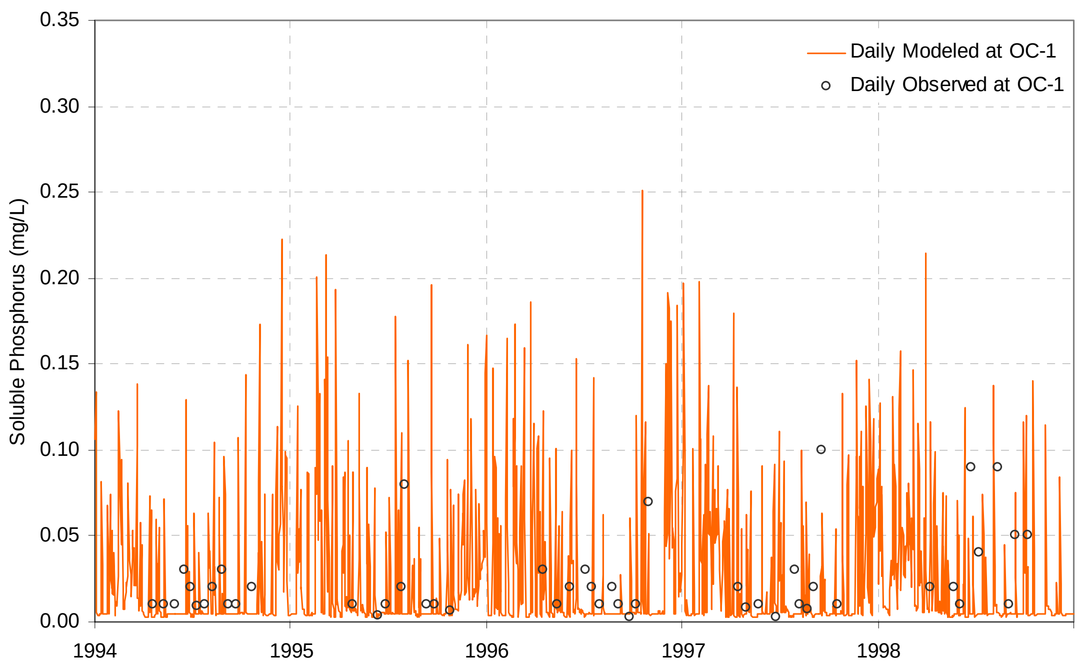


Figure 5-45. Soluble phosphorus time series calibration at Oak Creek Station OC-1.

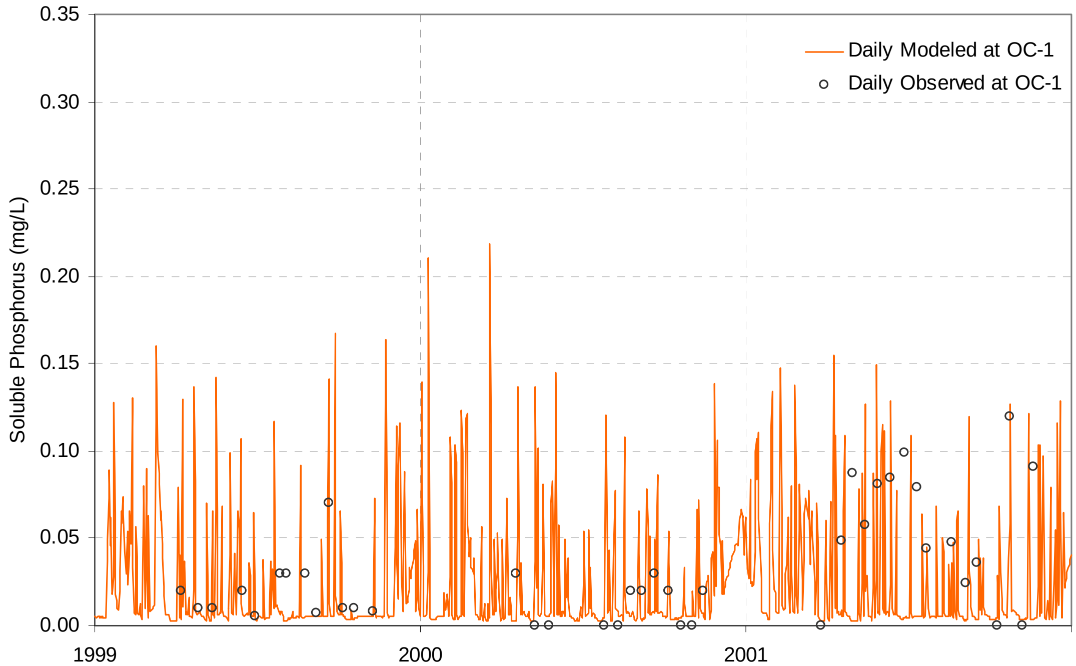


Figure 5-46. Soluble phosphorus time series validation at Oak Creek Station OC-1.

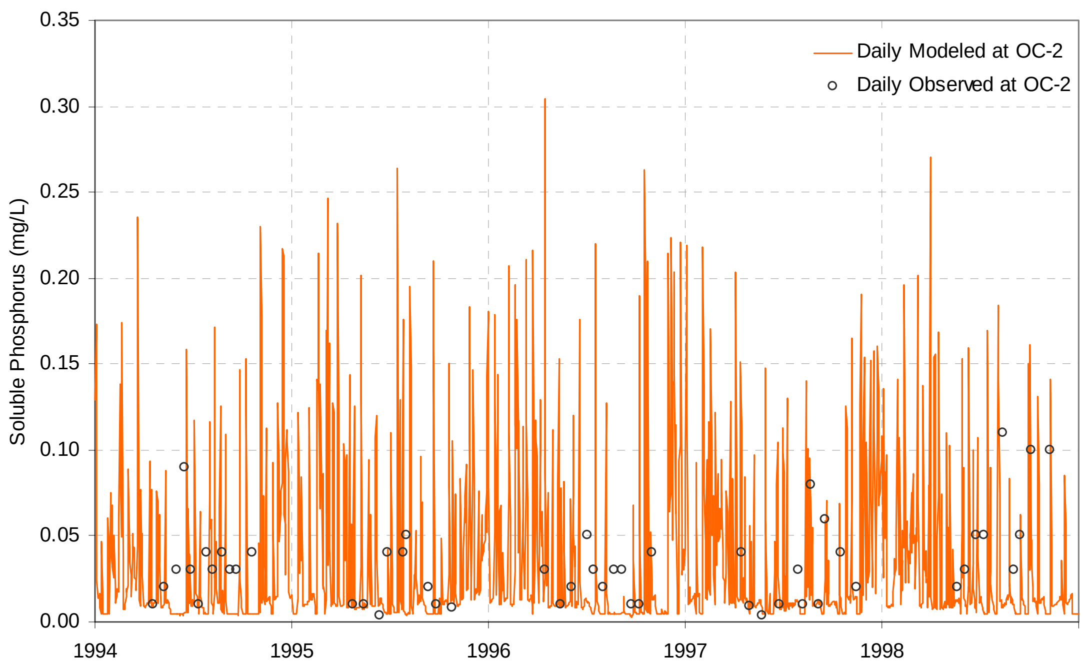


Figure 5-47. Soluble phosphorus time series calibration at Oak Creek Station OC-2.

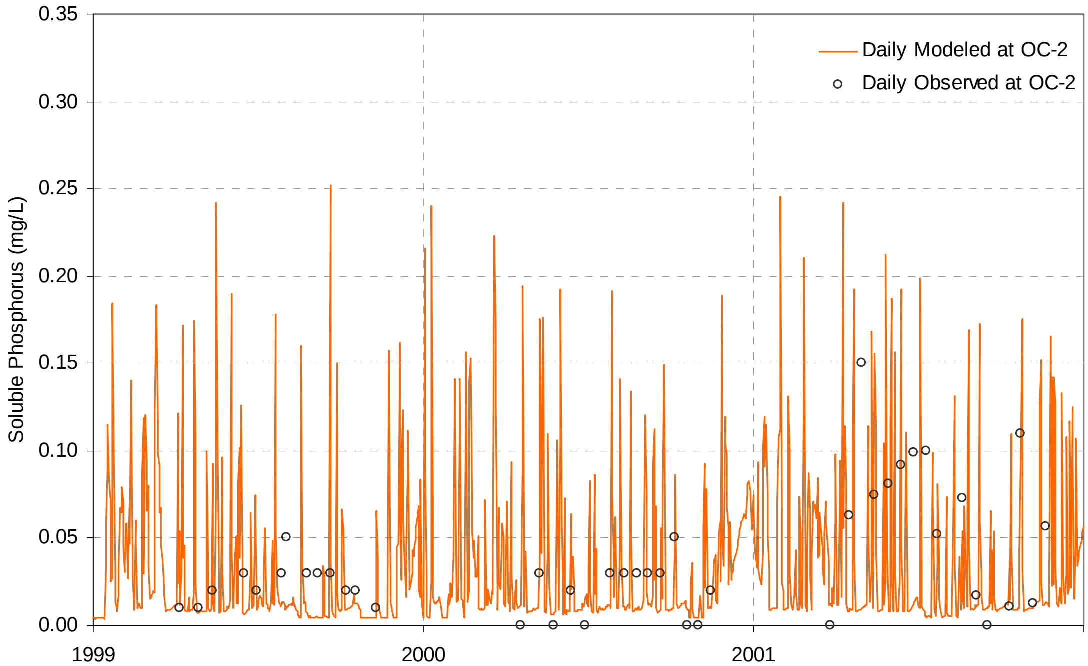


Figure 5-48. Soluble phosphorus time series validation at Oak Creek Station OC-2.

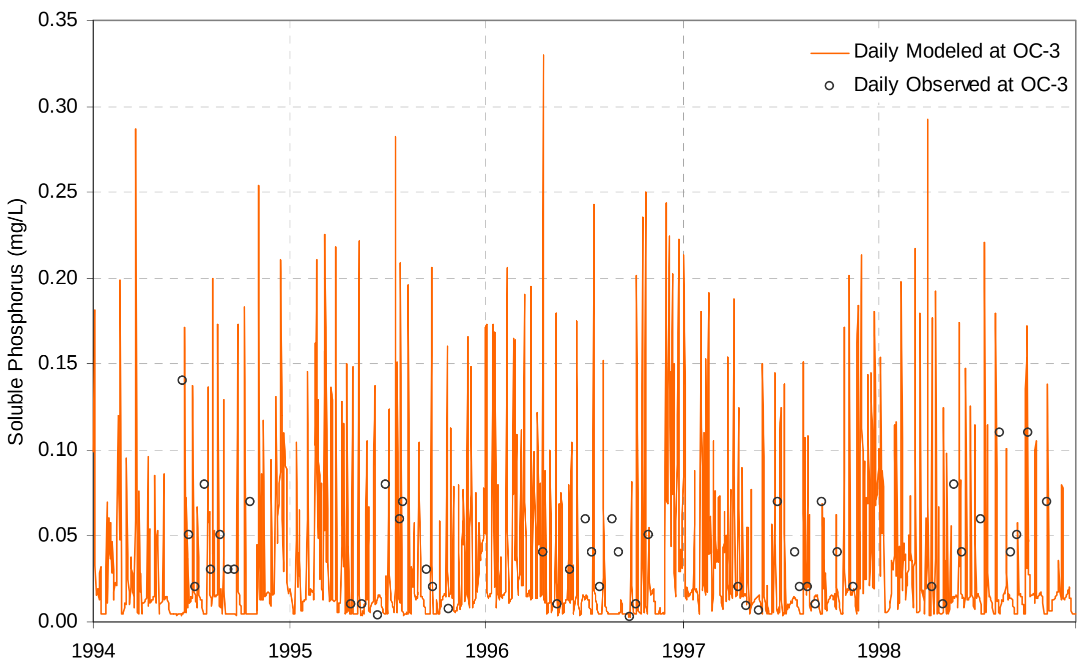


Figure 5-49. Soluble phosphorus time series calibration at Oak Creek Station OC-3.

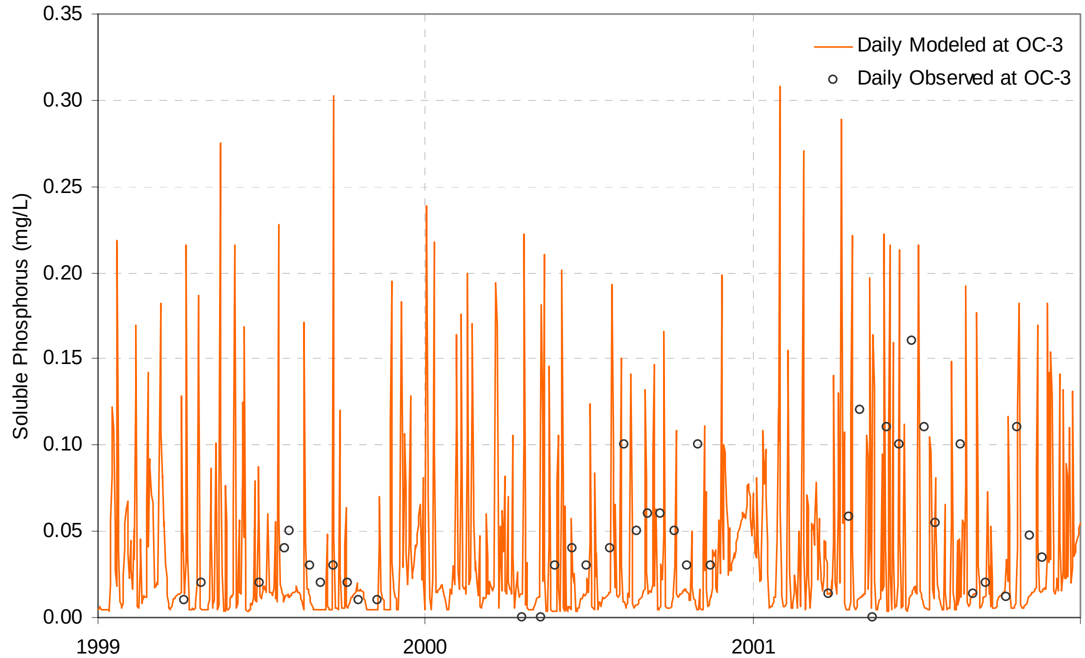


Figure 5-50. Soluble phosphorus time series validation at Oak Creek Station OC-3.

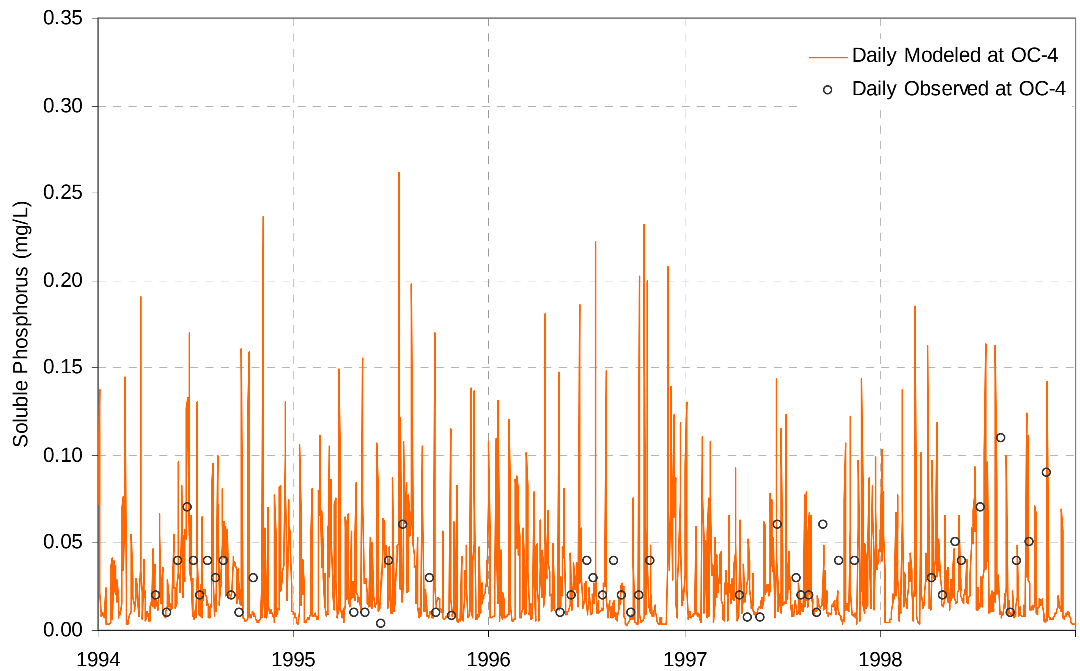


Figure 5-51. Soluble phosphorus time series calibration at Oak Creek Station OC-4.

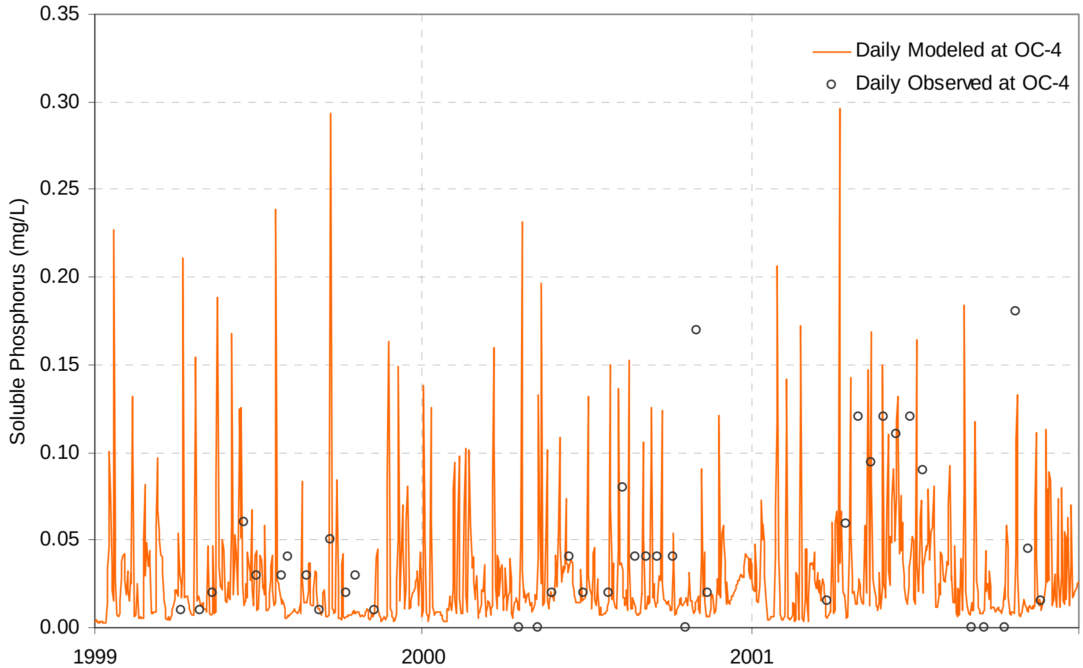


Figure 5-52. Soluble phosphorus time series validation at Oak Creek Station OC-4.

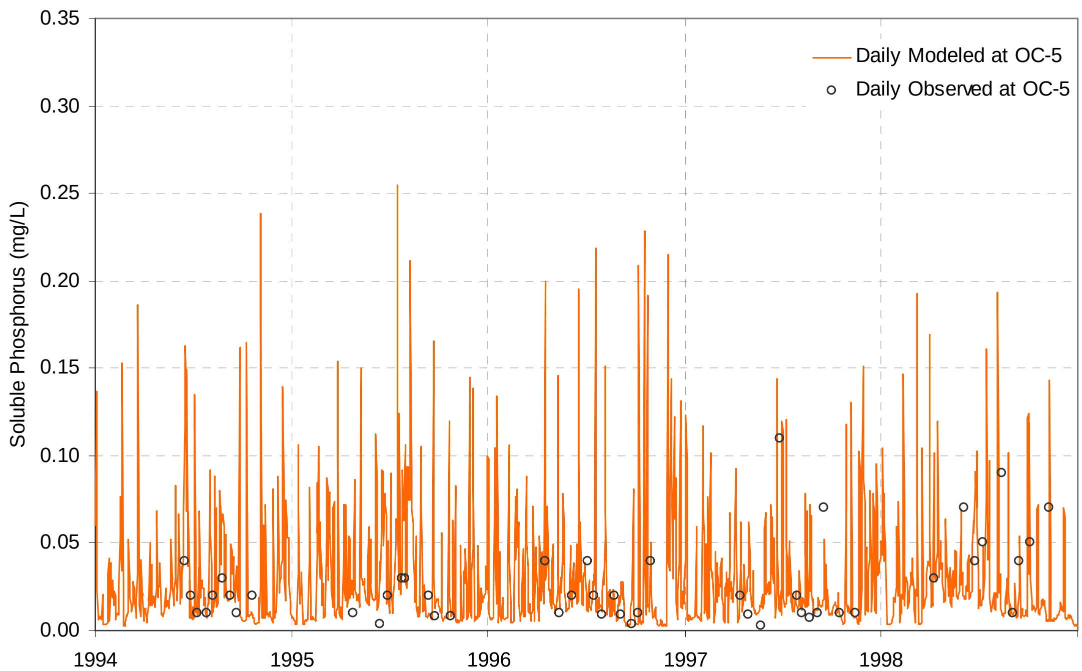


Figure 5-53. Soluble phosphorus time series calibration at Oak Creek Station OC-5.

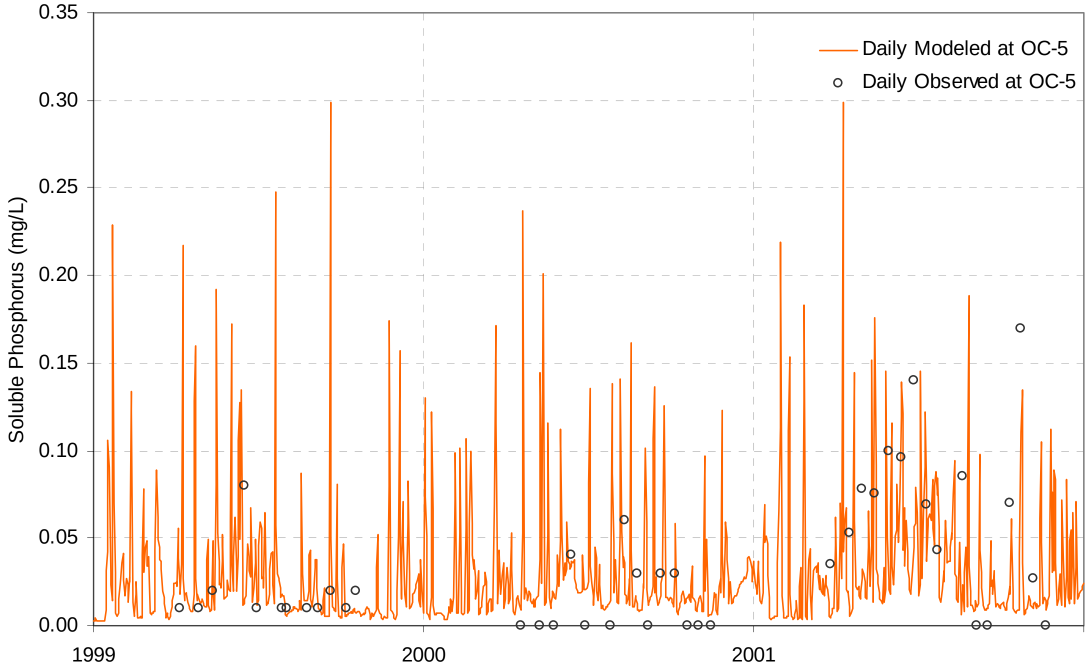


Figure 5-54. Soluble phosphorus time series validation at Oak Creek Station OC-5.

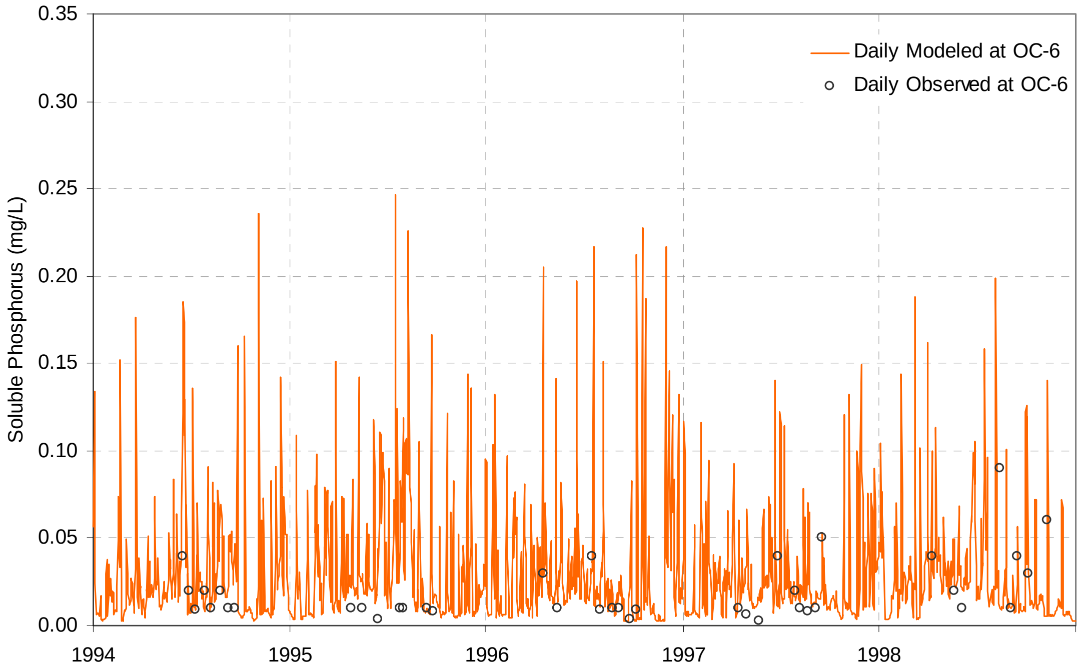


Figure 5-55. Soluble phosphorus time series calibration at Oak Creek Station OC-6.

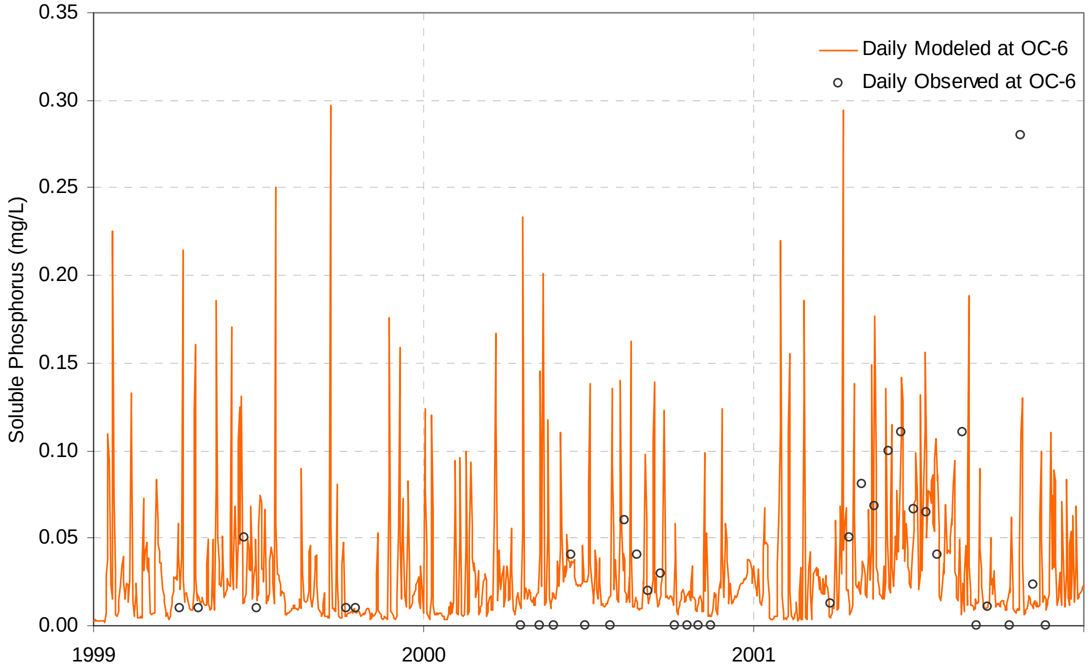


Figure 5-56. Soluble phosphorus time series validation at Oak Creek Station OC-6.

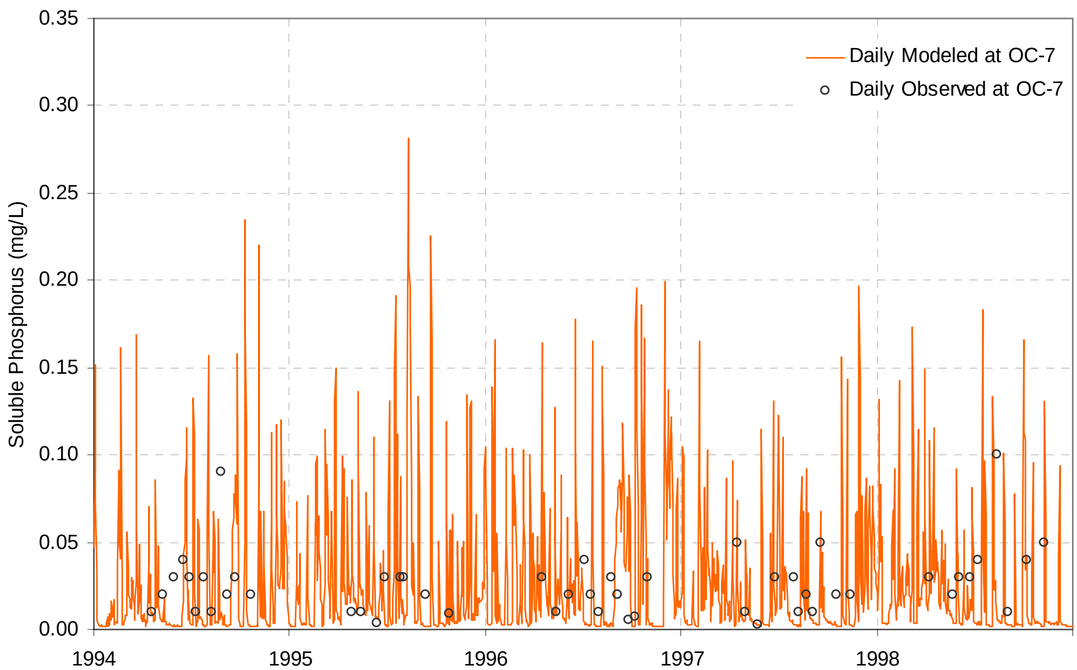


Figure 5-57. Soluble phosphorus time series calibration at Oak Creek Station OC-7.

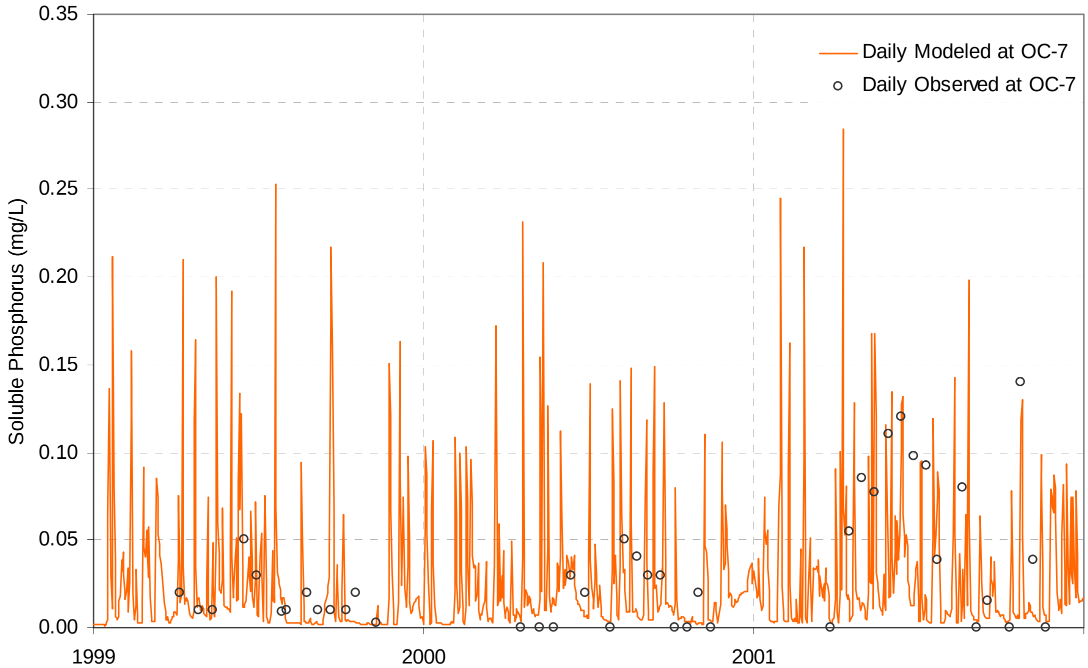


Figure 5-58. Soluble phosphorus time series validation at Oak Creek Station OC-7.

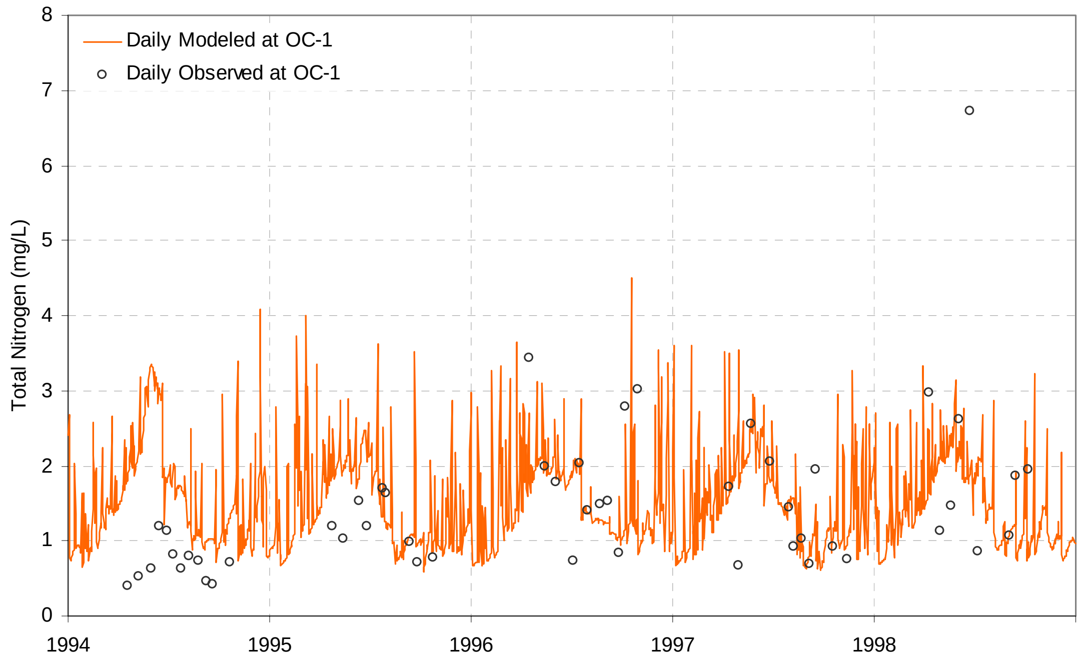


Figure 5-59. Total Nitrogen time series calibration at Oak Creek Station OC-1.

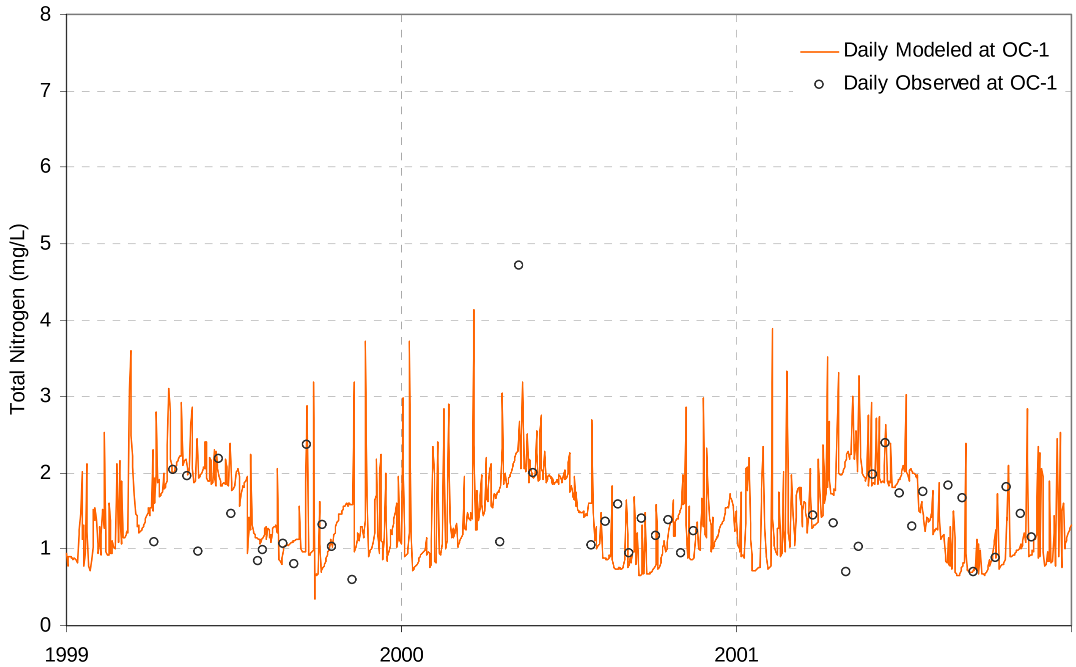


Figure 5-60. Total Nitrogen time series validation at Oak Creek Station OC-1.

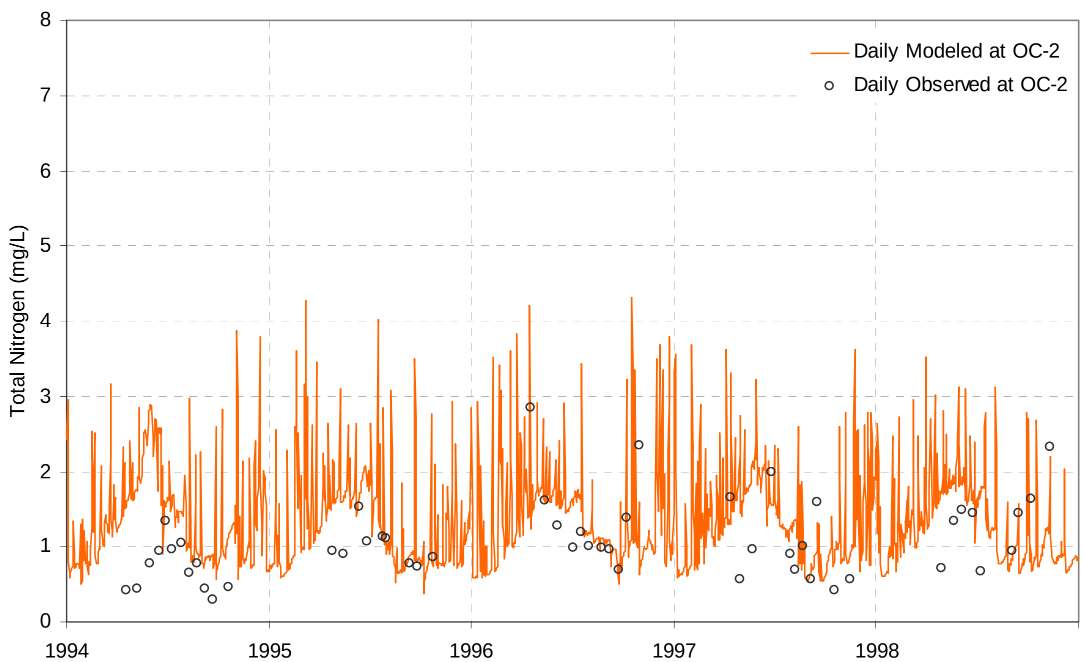


Figure 5-61. Total Nitrogen time series calibration at Oak Creek Station OC-2.

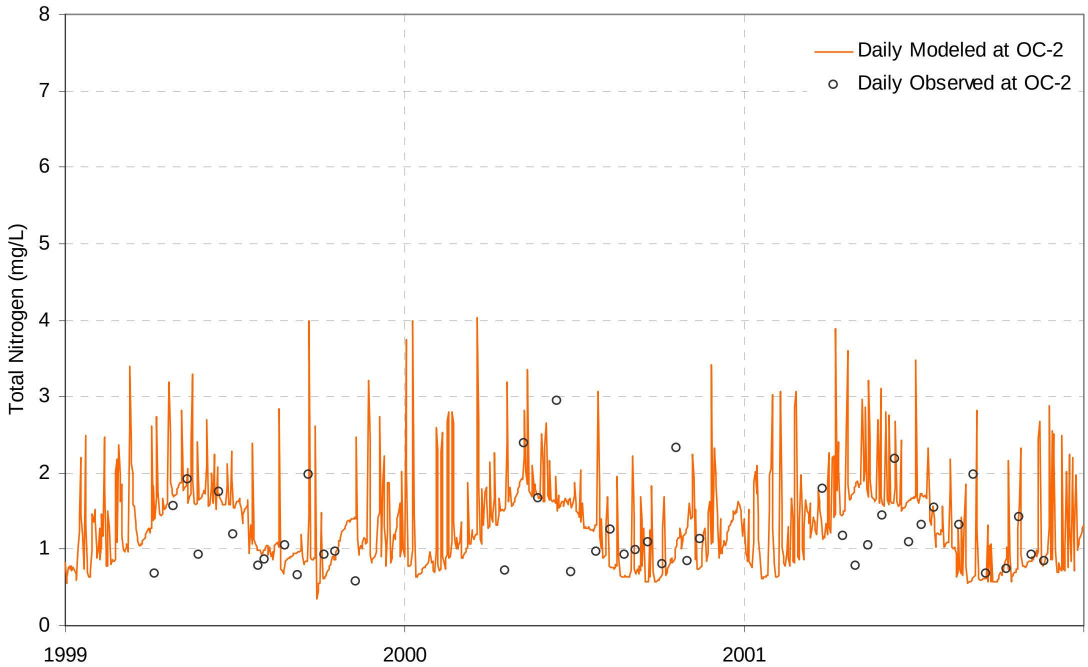


Figure 5-62. Total Nitrogen time series validation at Oak Creek Station OC-2.

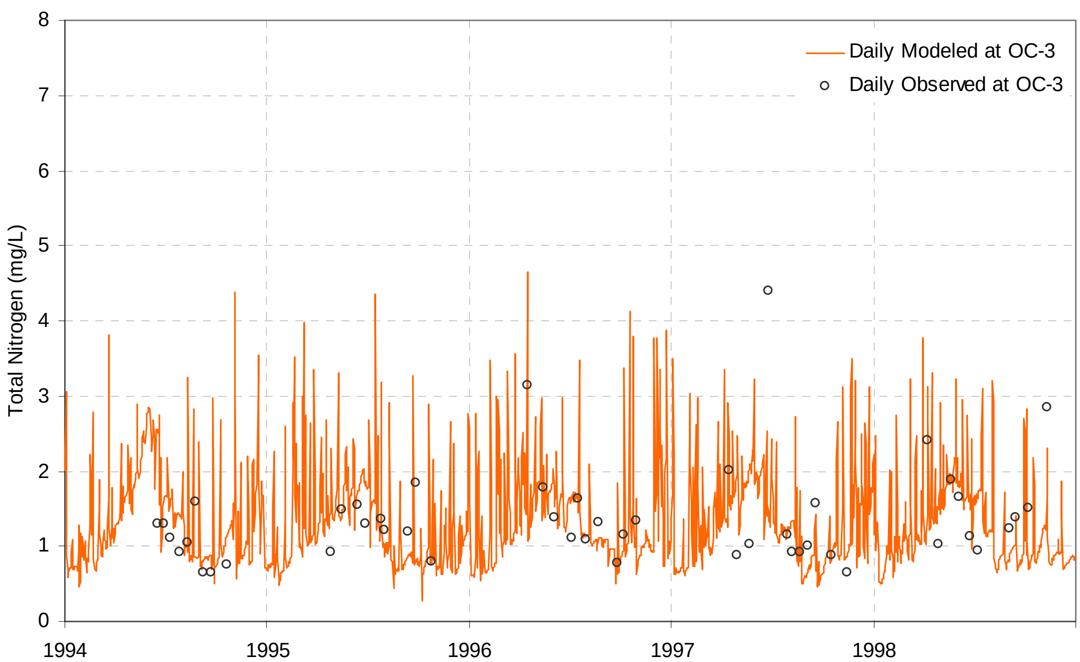


Figure 5-63. Total Nitrogen time series calibration at Oak Creek Station OC-3.

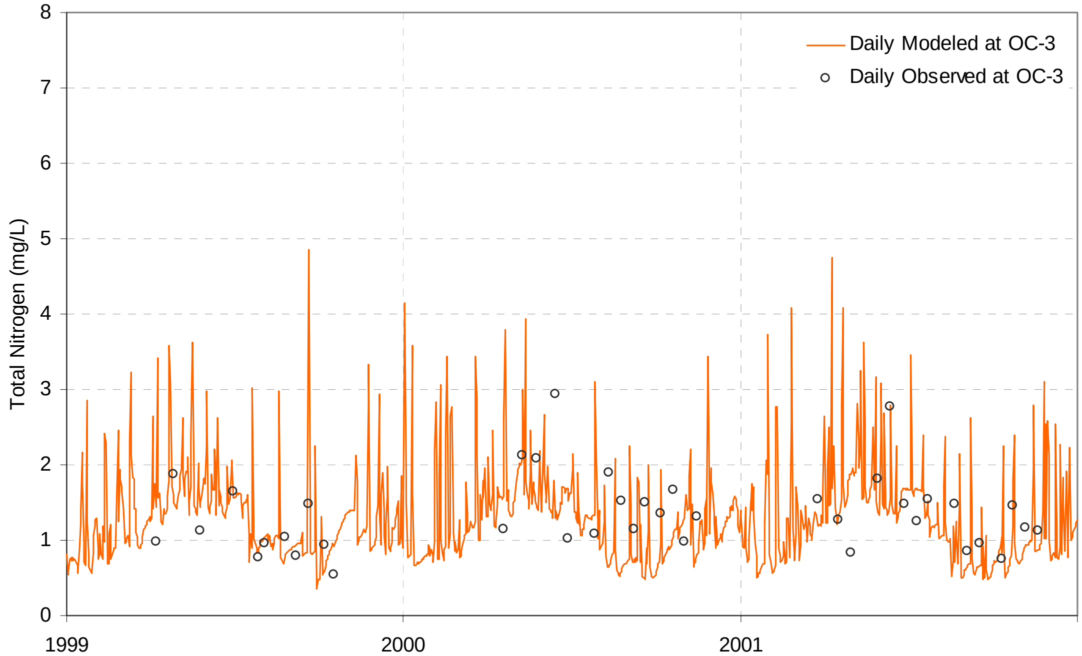


Figure 5-64. Total Nitrogen time series validation at Oak Creek Station OC-3.

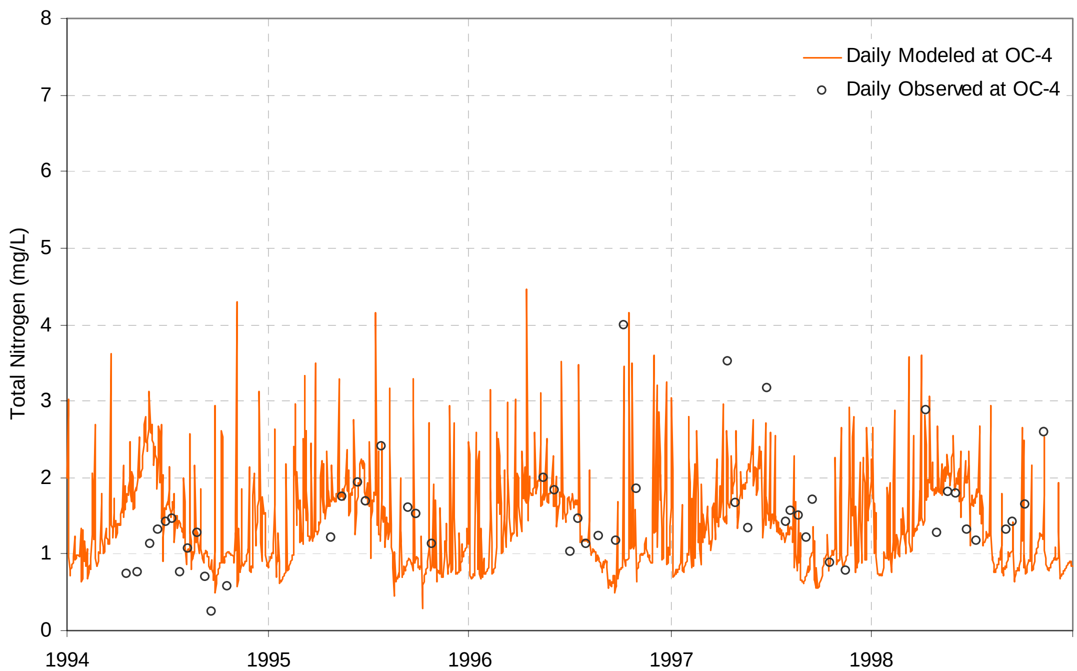


Figure 5-65. Total Nitrogen time series calibration at Oak Creek Station OC-4.

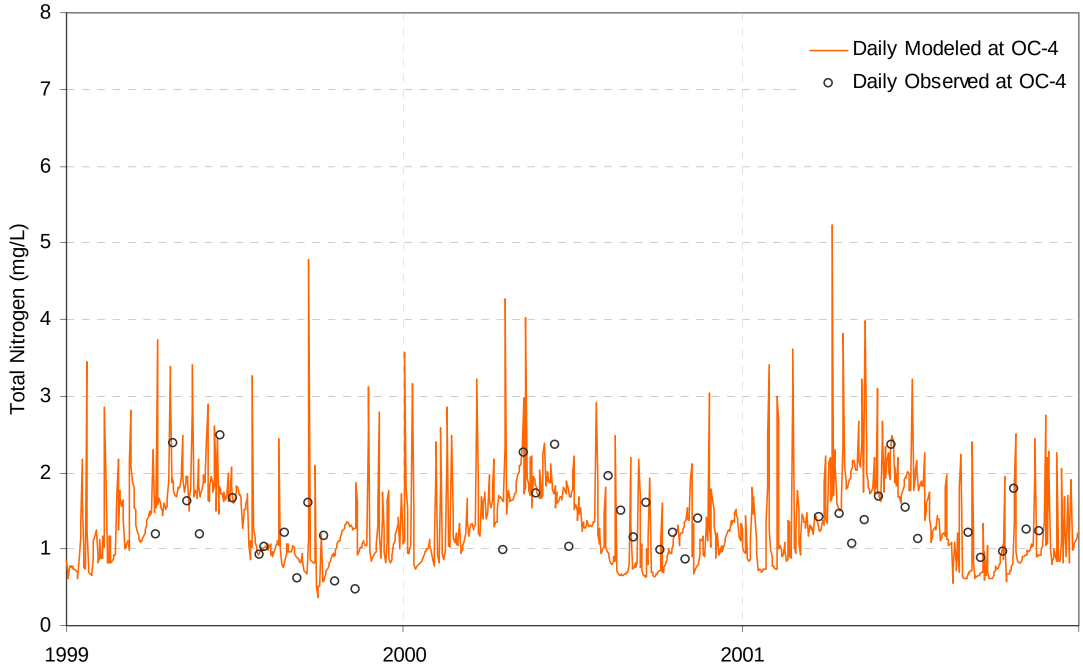


Figure 5-66. Total Nitrogen time series validation at Oak Creek Station OC-4.

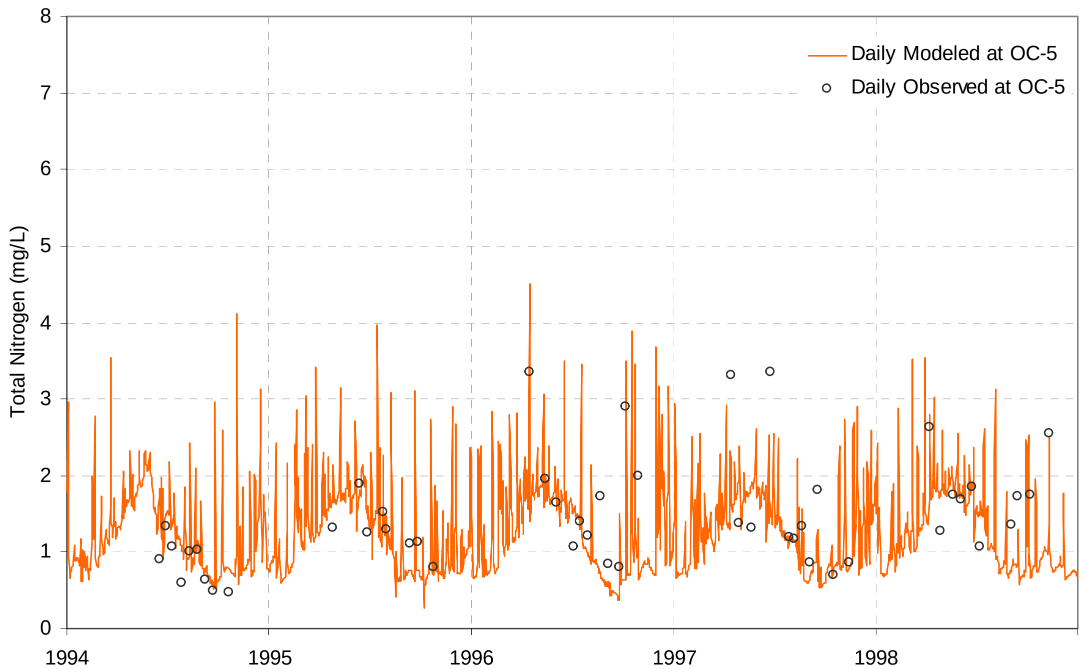


Figure 5-67. Total Nitrogen time series calibration at Oak Creek Station OC-5.

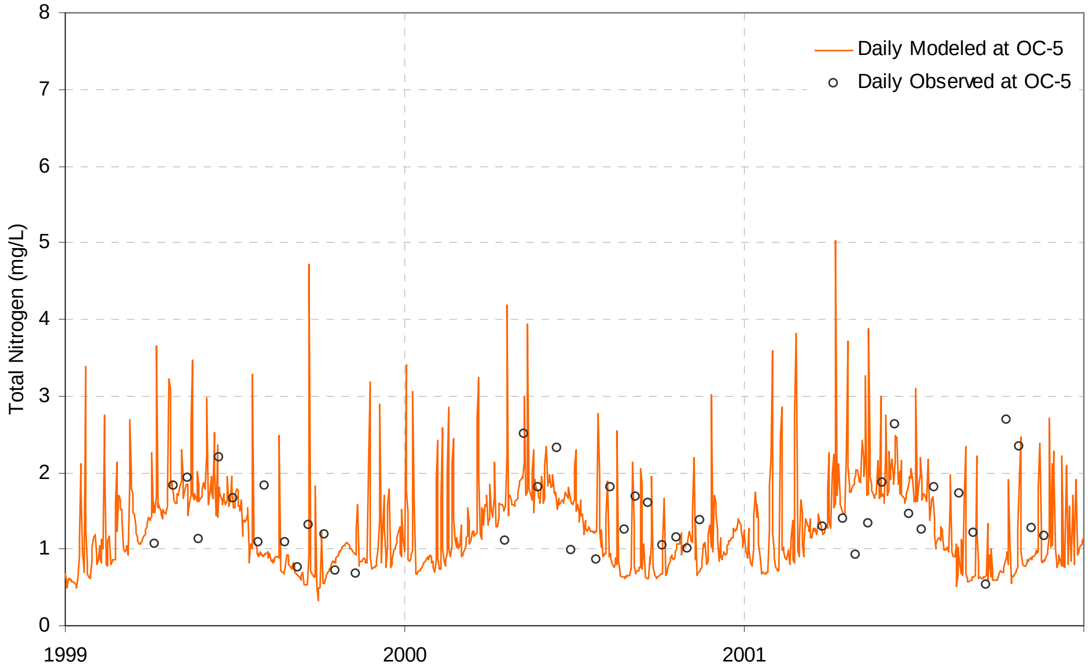


Figure 5-68. Total Nitrogen time series validation at Oak Creek Station OC-5.

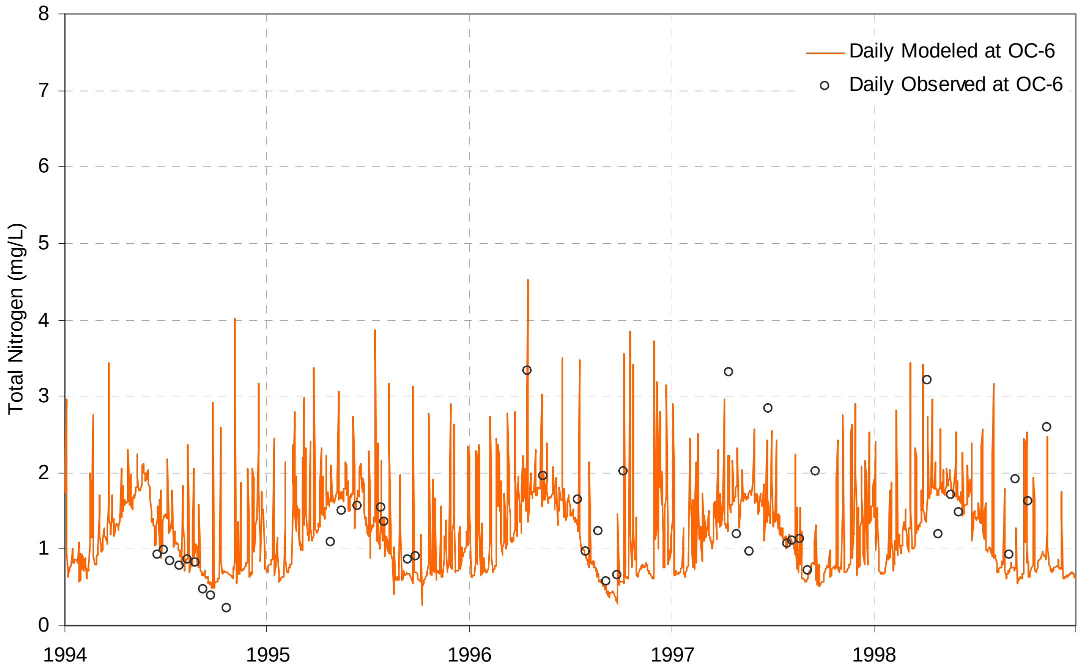


Figure 5-69. Total Nitrogen time series calibration at Oak Creek Station OC-6.

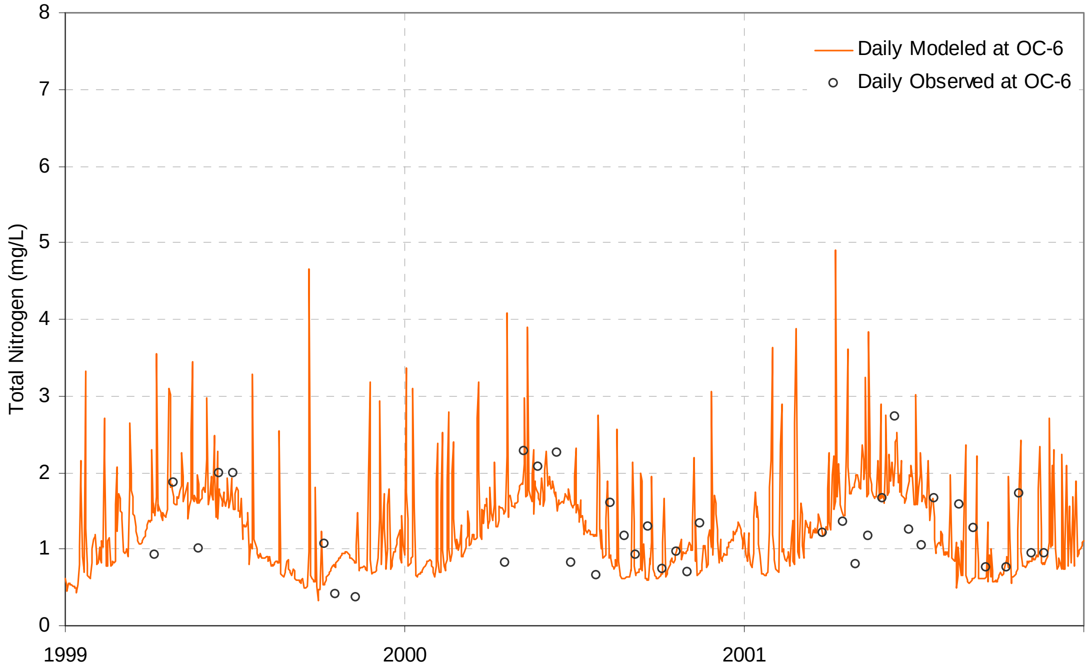


Figure 5-70. Total Nitrogen time series validation at Oak Creek Station OC-6.

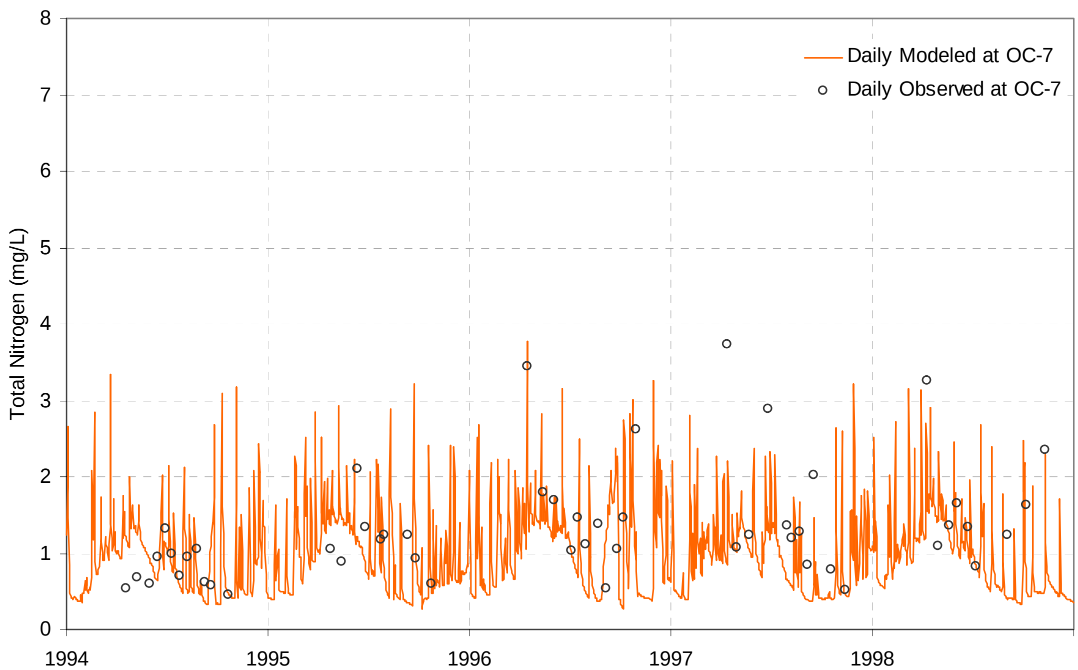


Figure 5-71. Total Nitrogen time series calibration at Oak Creek Station OC-7.

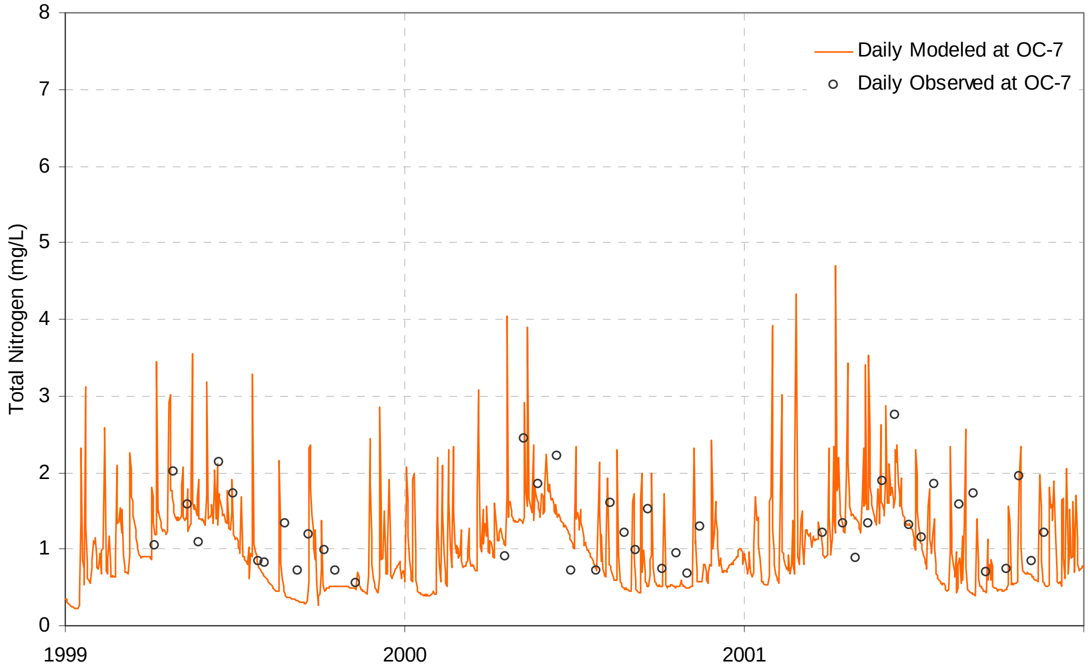


Figure 5-72. Total Nitrogen time series validation at Oak Creek Station OC-7.

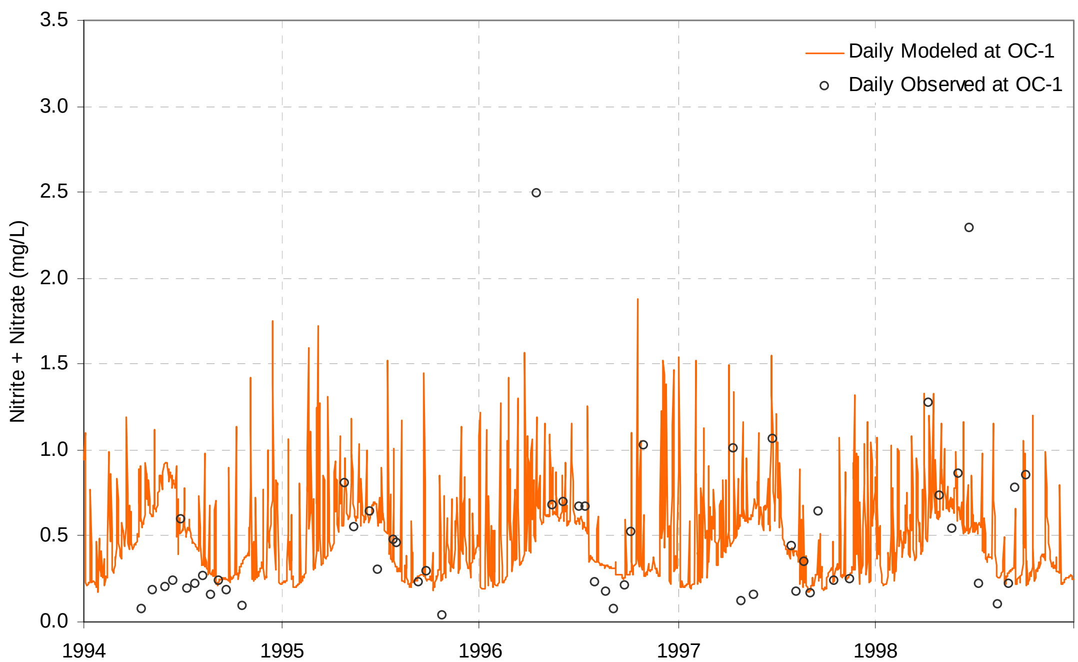


Figure 5-73. Nitrite+Nitrate time series calibration at Oak Creek Station OC-1.

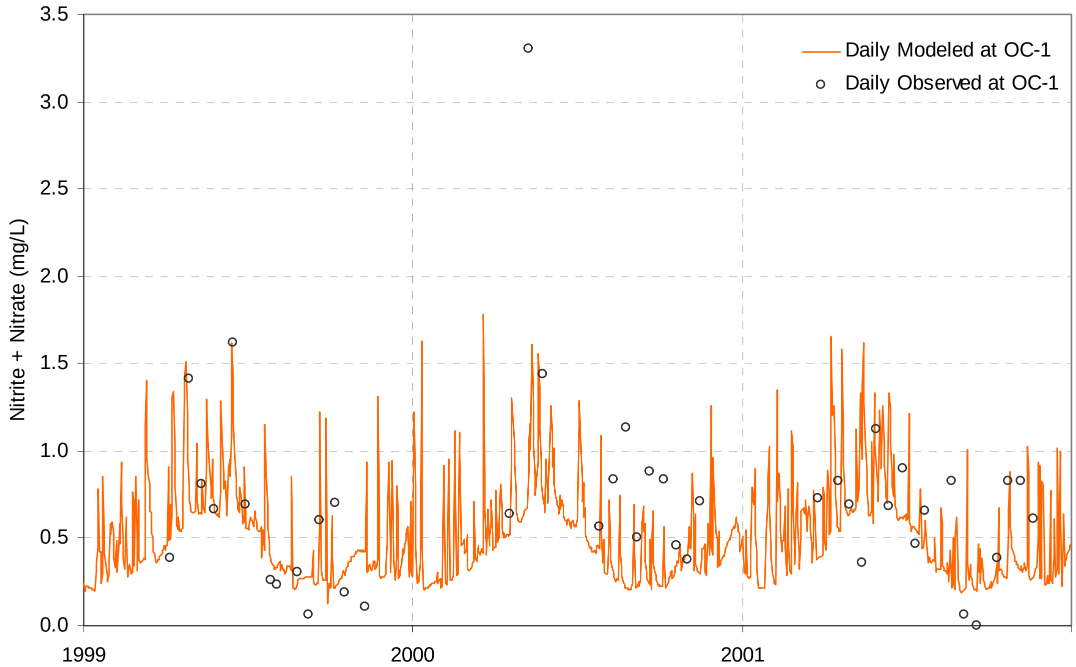


Figure 5-74. Nitrite+Nitrate time series validation at Oak Creek Station OC-1.

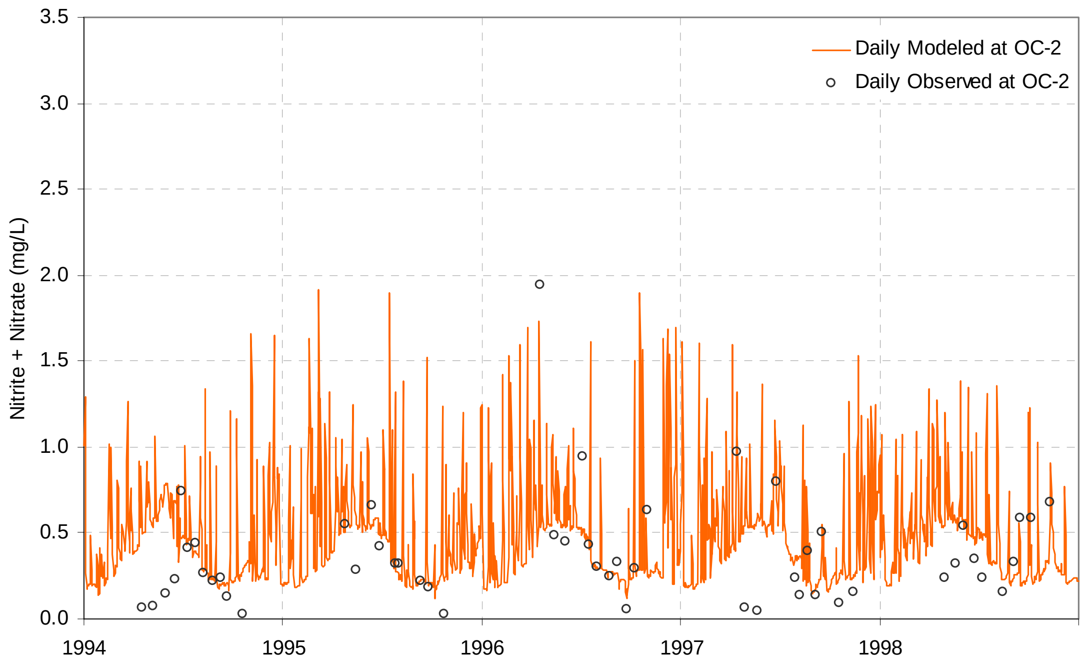


Figure 5-75. Nitrite+Nitrate time series calibration at Oak Creek Station OC-2.

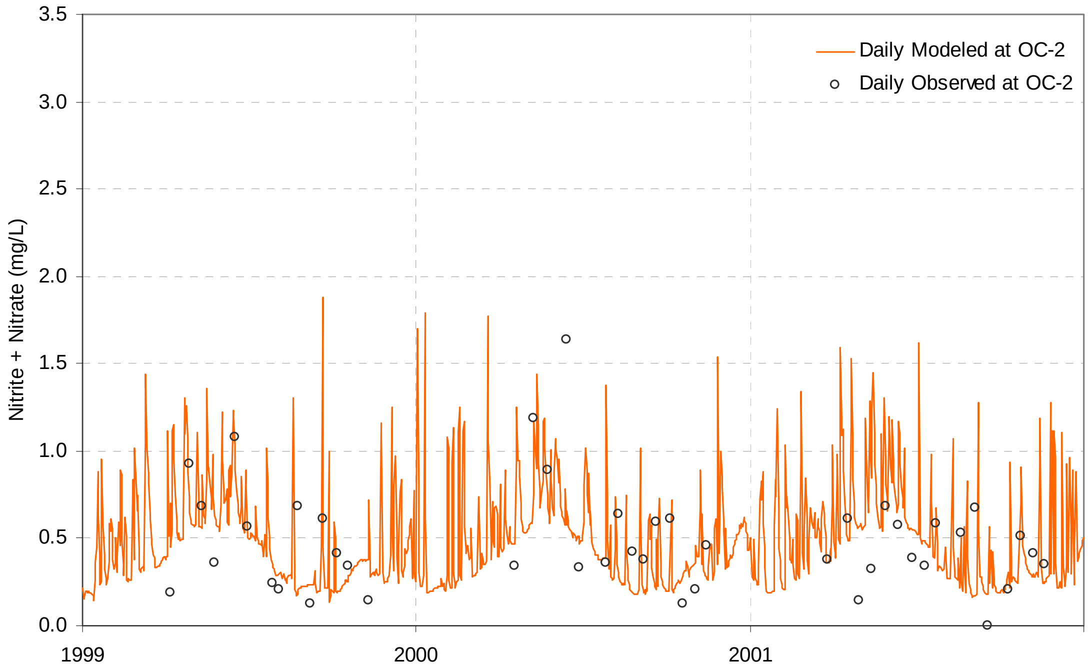


Figure 5-76. Nitrite+Nitrate time series validation at Oak Creek Station OC-2.

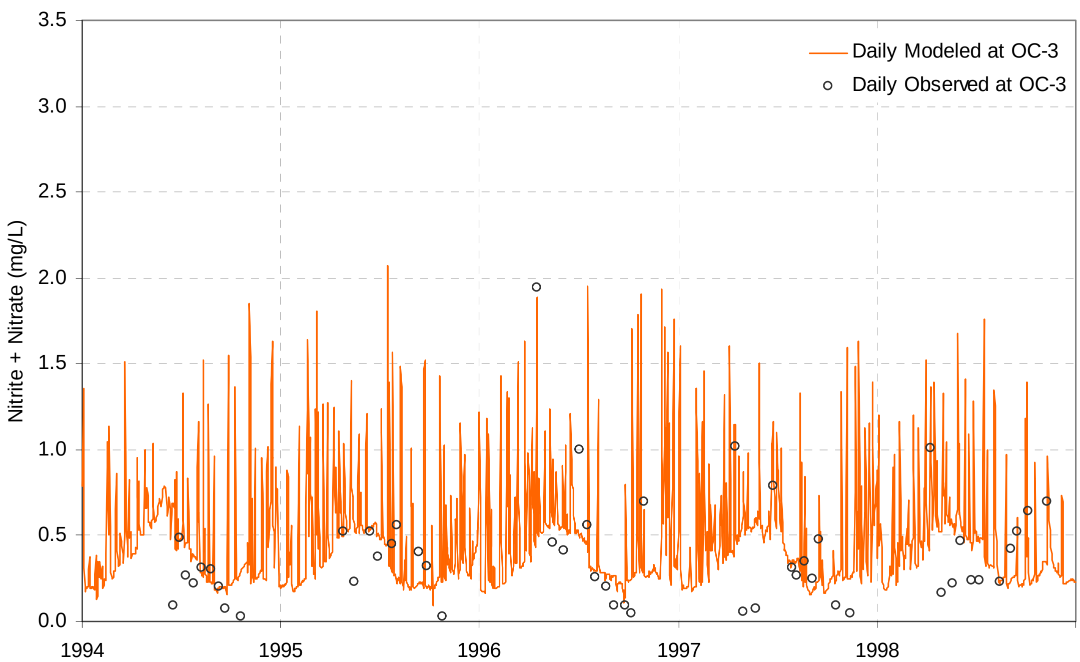


Figure 5-77. Nitrite+Nitrate time series calibration at Oak Creek Station OC-3.

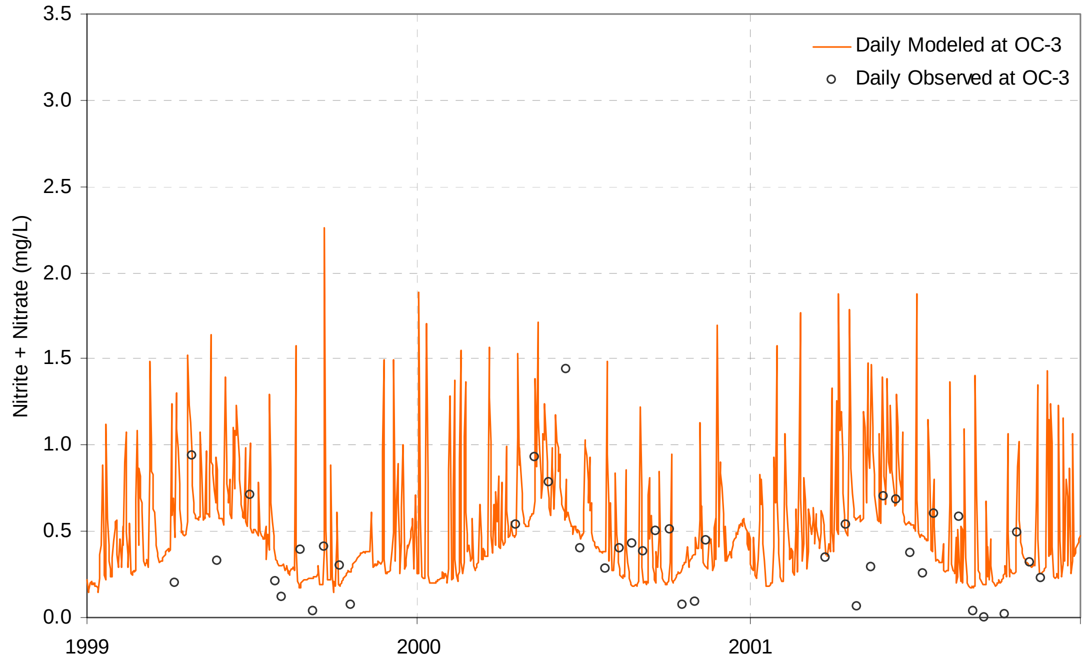


Figure 5-78. Nitrite+Nitrate time series validation at Oak Creek Station OC-3.

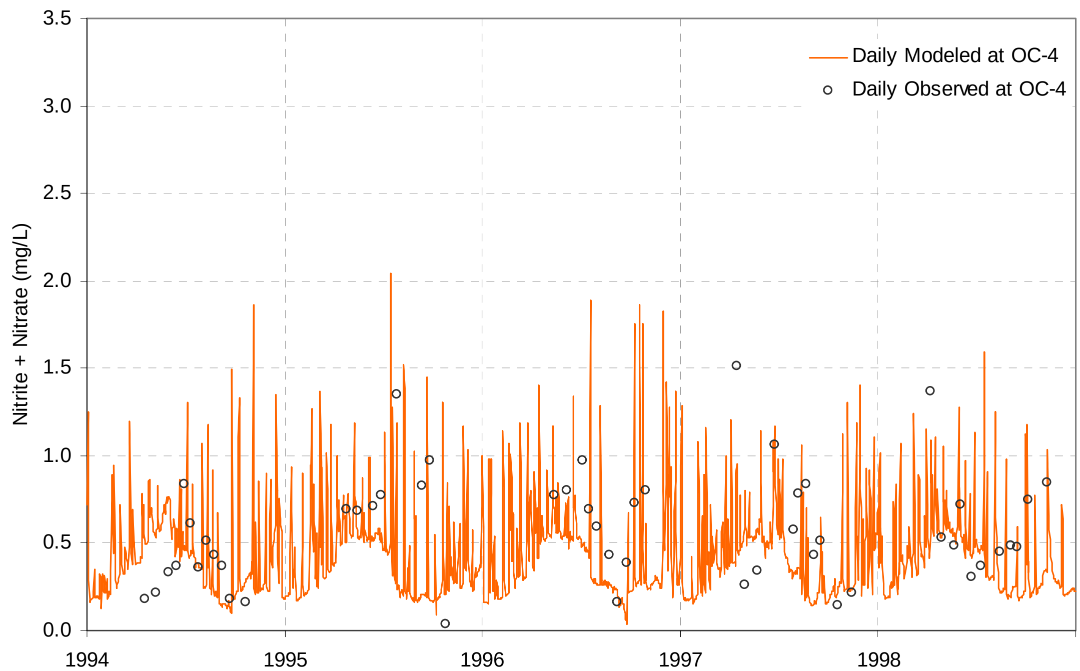


Figure 5-79. Nitrite+Nitrate time series calibration at Oak Creek Station OC-4.

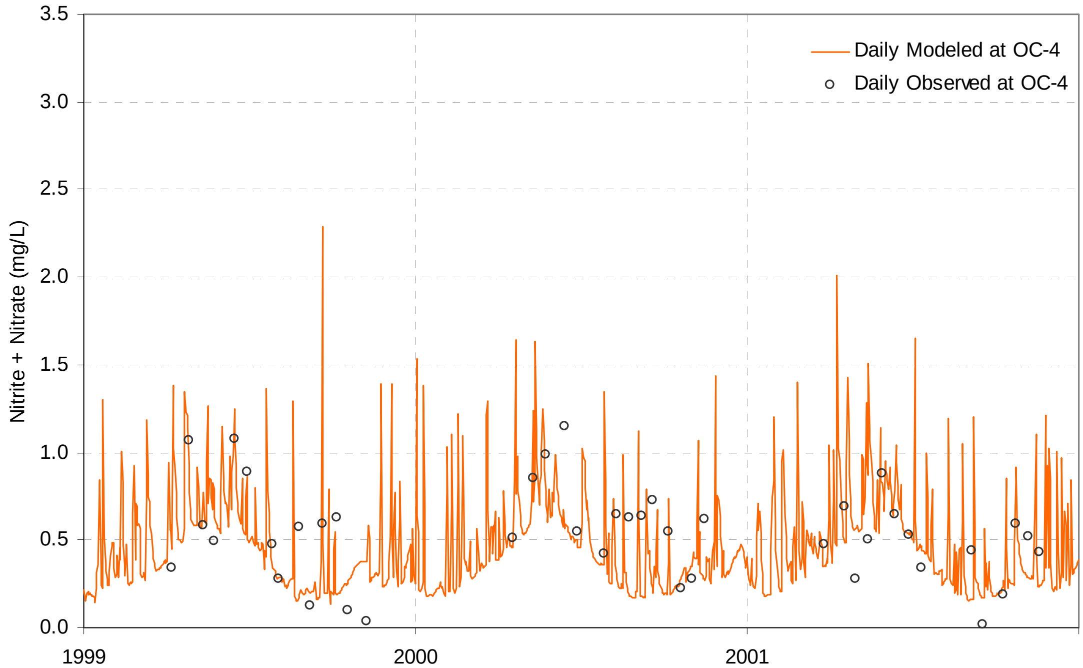


Figure 5-80. Nitrite+Nitrate time series validation at Oak Creek Station OC-4.

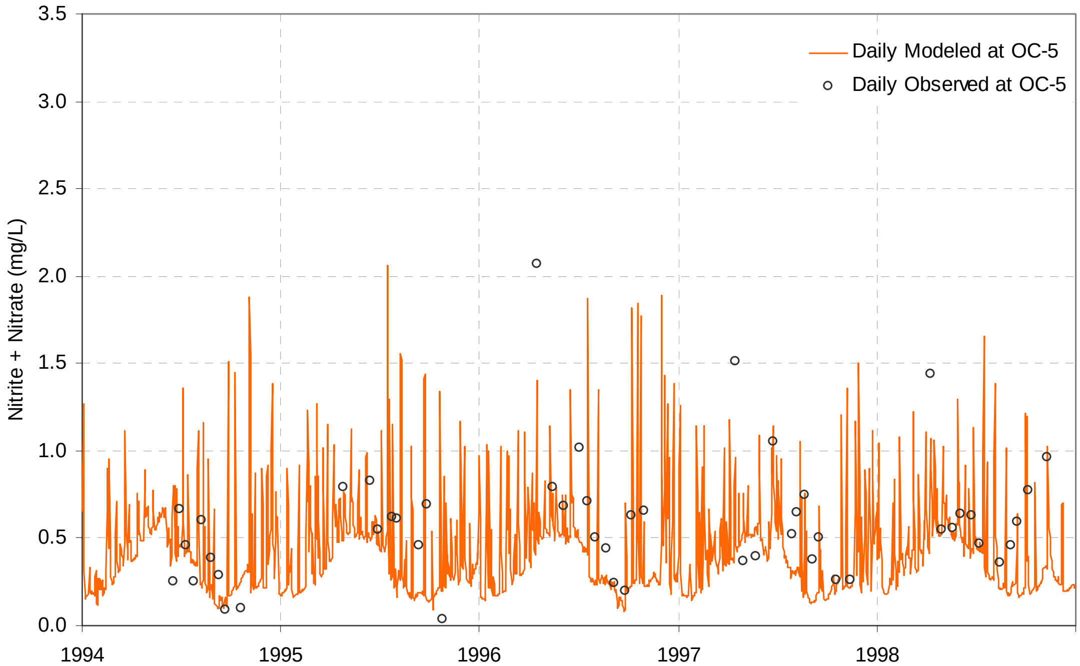


Figure 5-81. Nitrite+Nitrate time series calibration at Oak Creek Station OC-5.

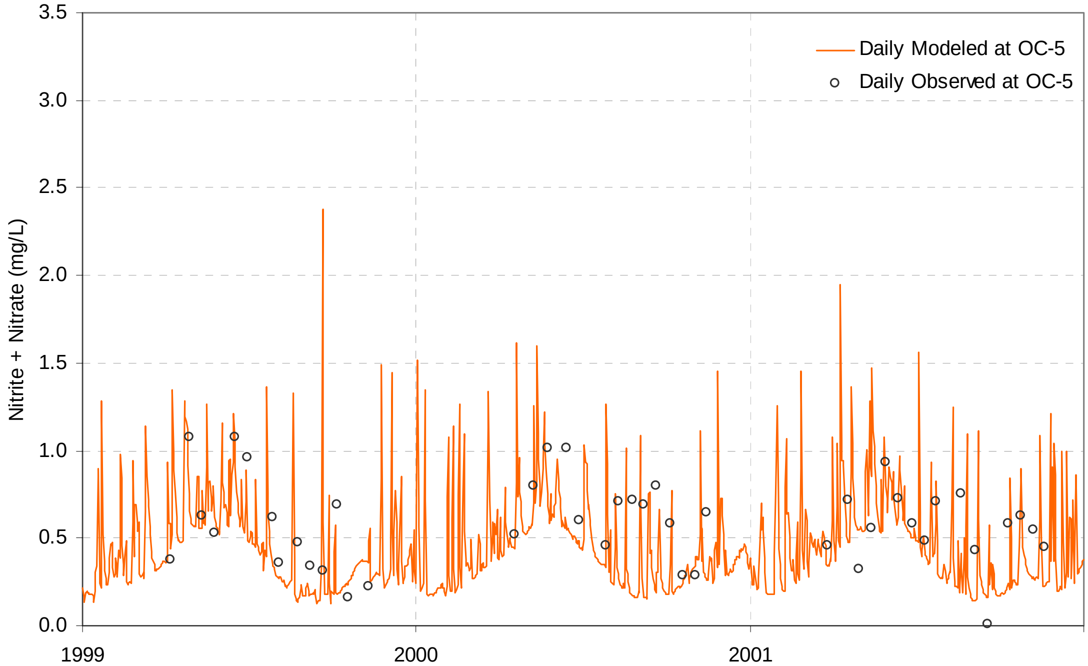


Figure 5-82. Nitrite+Nitrate time series validation at Oak Creek Station OC-5.

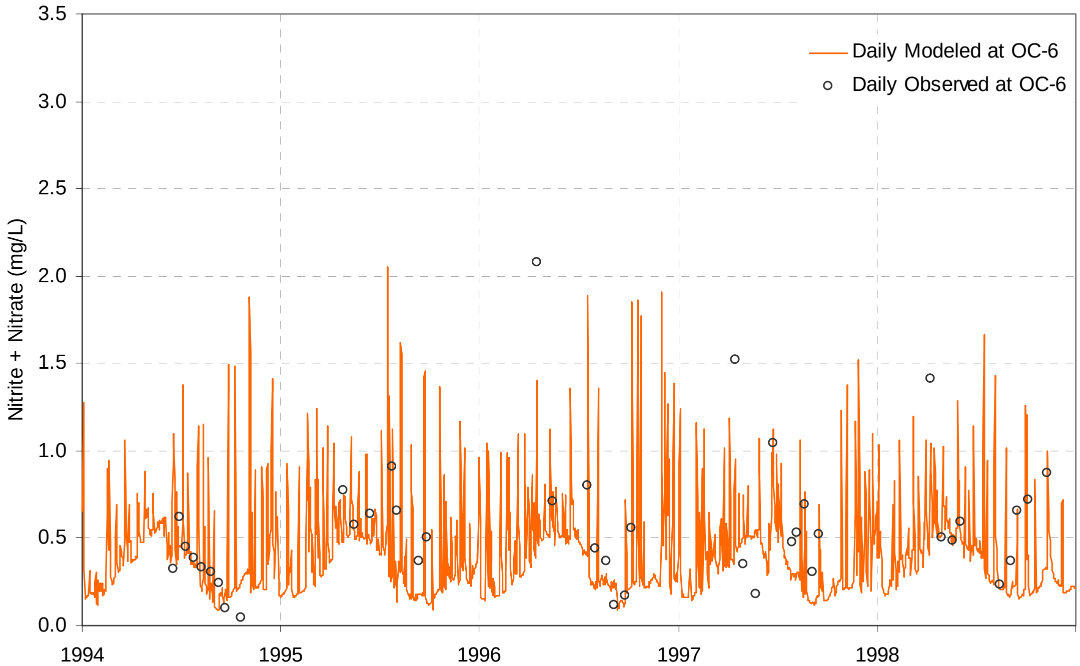


Figure 5-83. Nitrite+Nitrate time series calibration at Oak Creek Station OC-6.

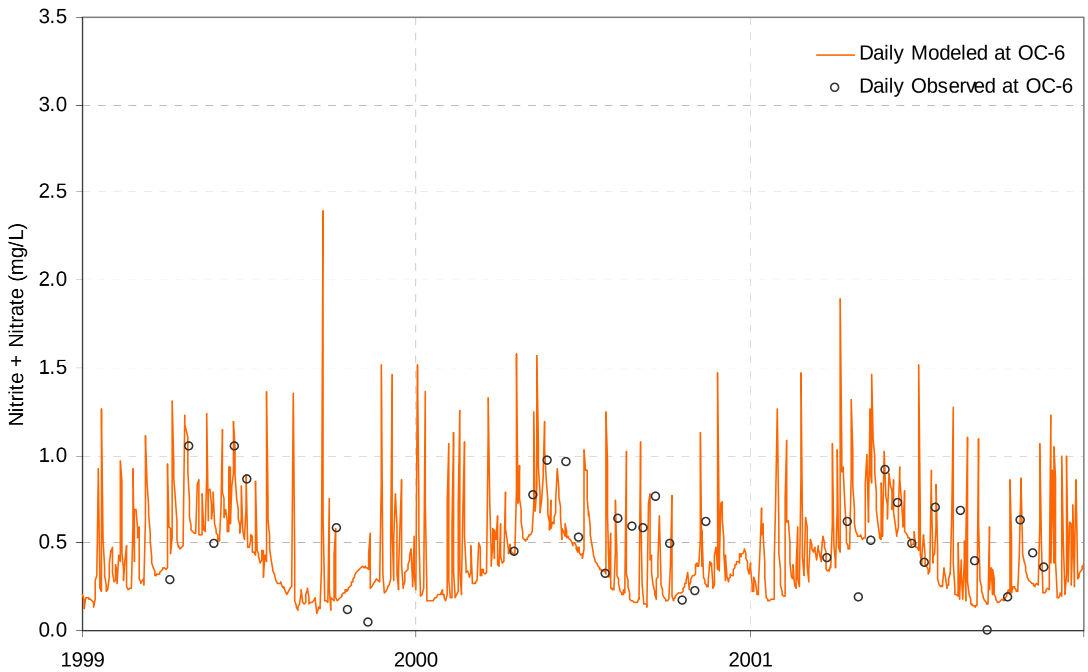


Figure 5-84. Nitrite+Nitrate time series validation at Oak Creek Station OC-6.

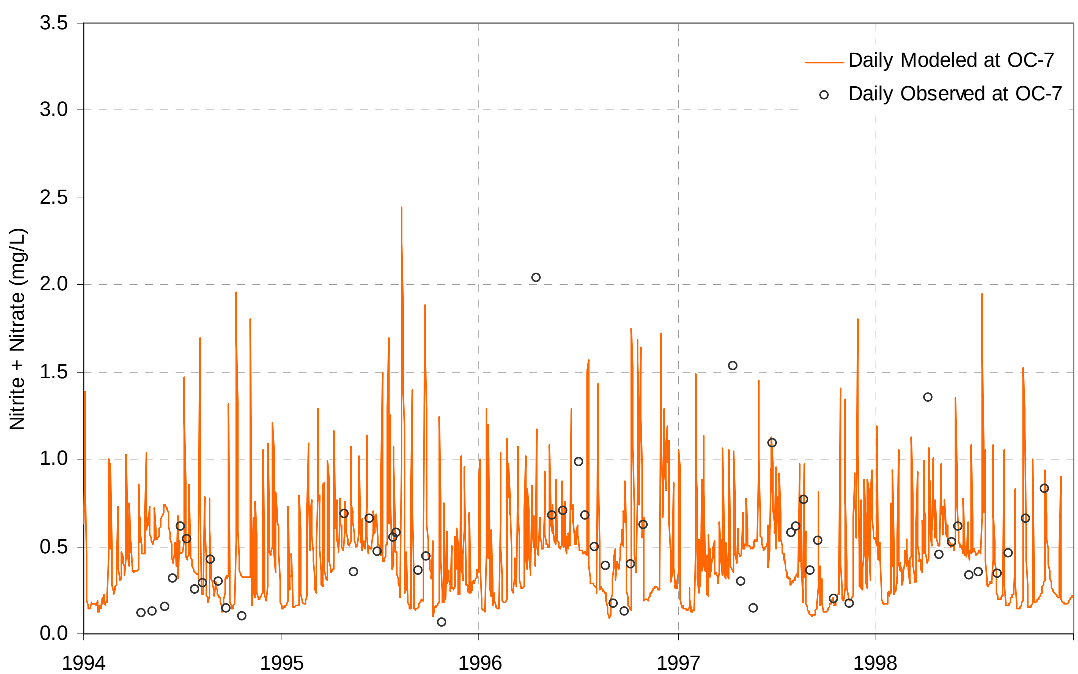


Figure 5-85. Nitrite+Nitrate time series calibration at Oak Creek Station OC-7.

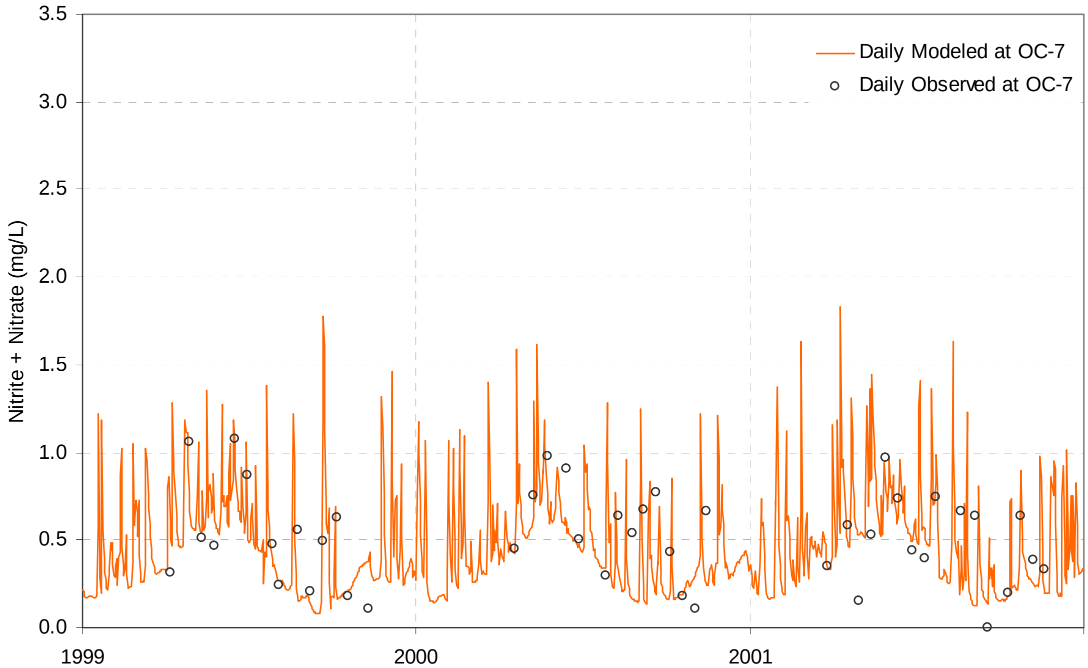


Figure 5-86. Nitrite+Nitrate time series validation at Oak Creek Station OC-7.

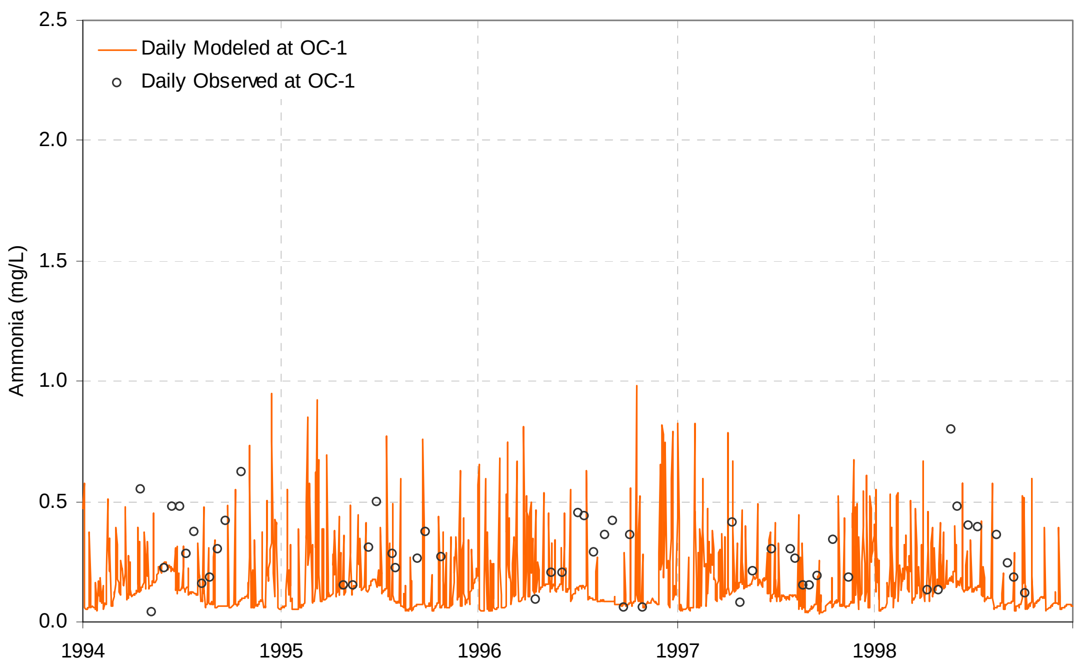


Figure 5-87. Ammonia time series calibration at Oak Creek Station OC-1.

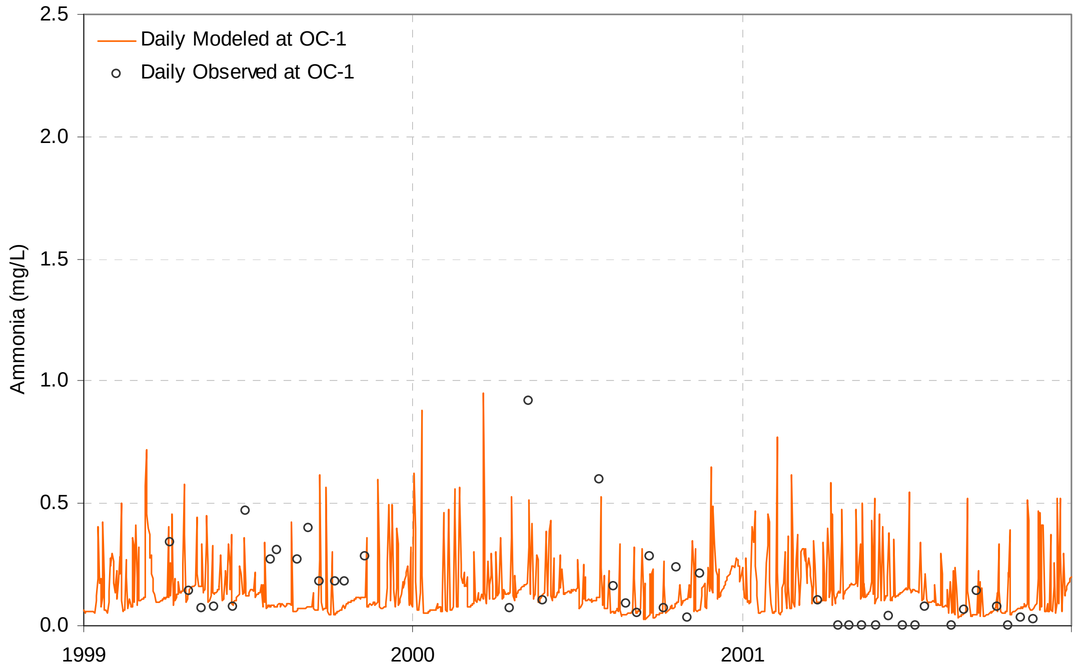


Figure 5-88. Ammonia time series validation at Oak Creek Station OC-1.

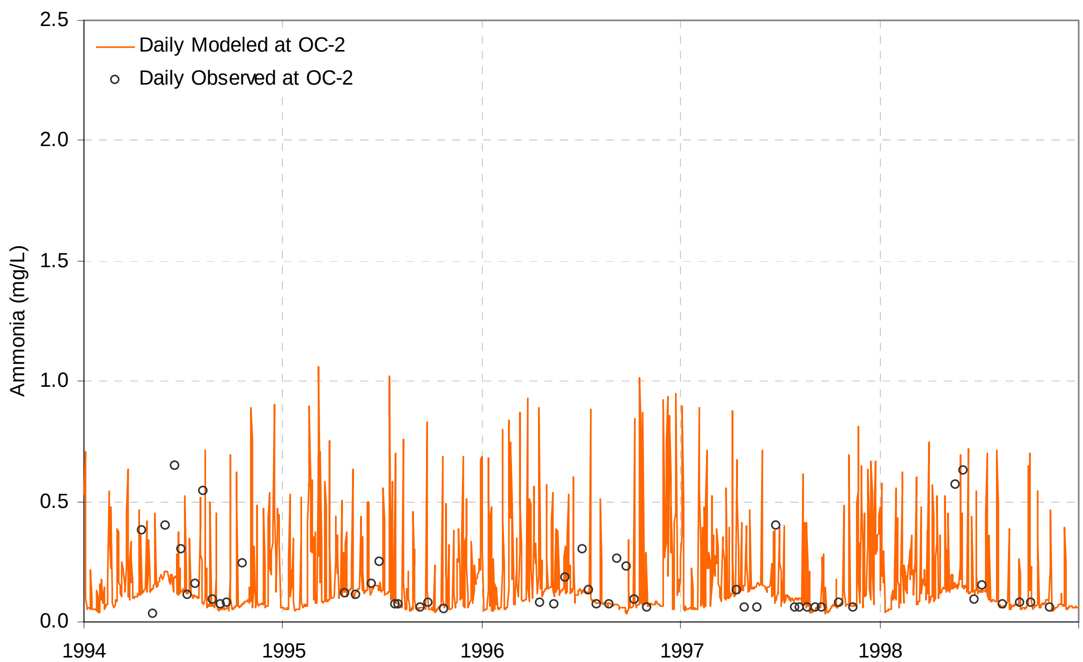


Figure 5-89. Ammonia time series calibration at Oak Creek Station OC-2.

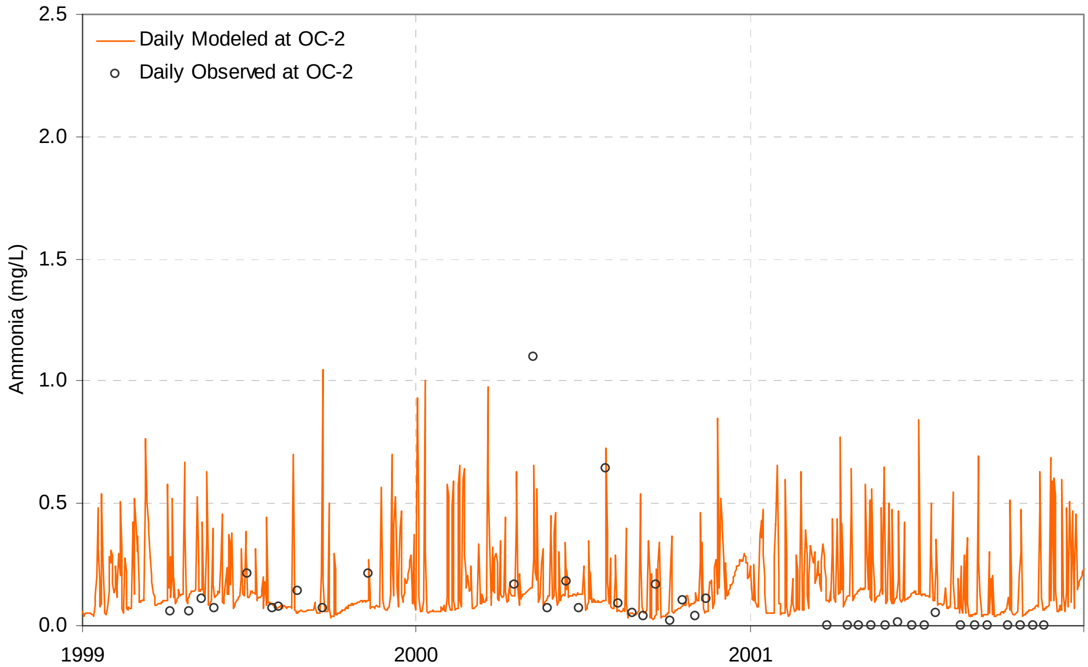


Figure 5-90. Ammonia time series validation at Oak Creek Station OC-2.

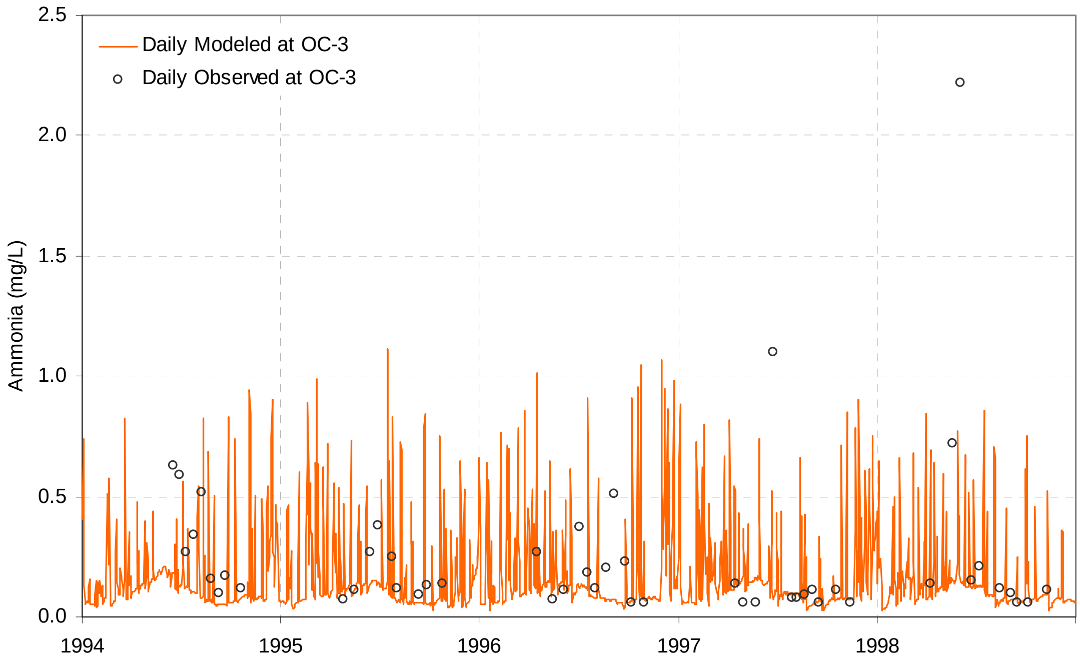


Figure 5-91. Ammonia time series calibration at Oak Creek Station OC-3.

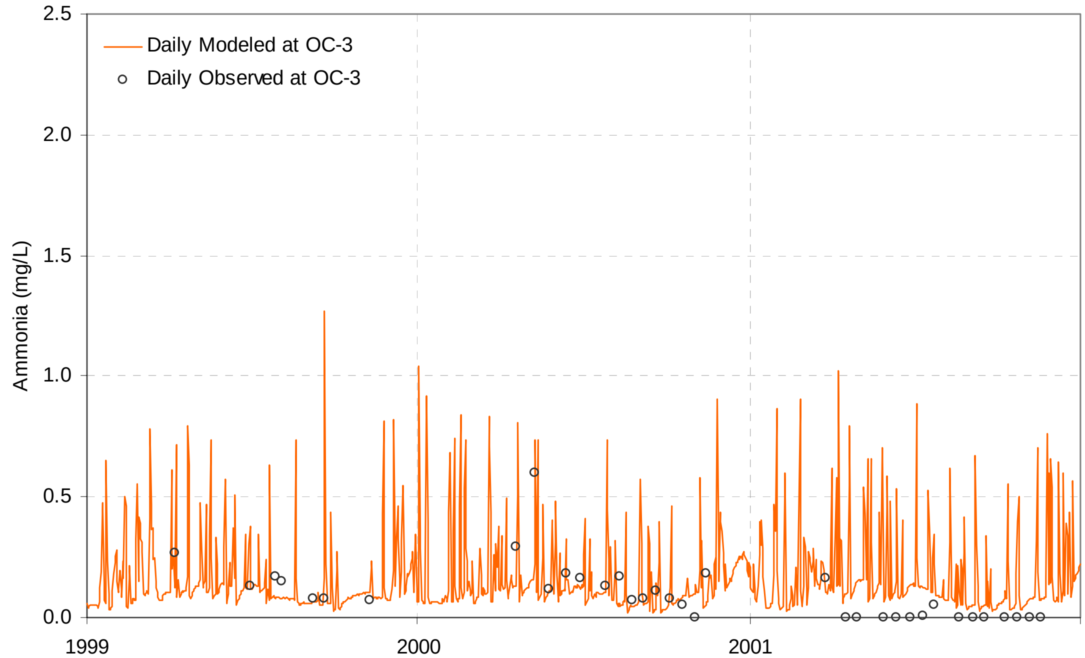


Figure 5-92. Ammonia time series validation at Oak Creek Station OC-3.

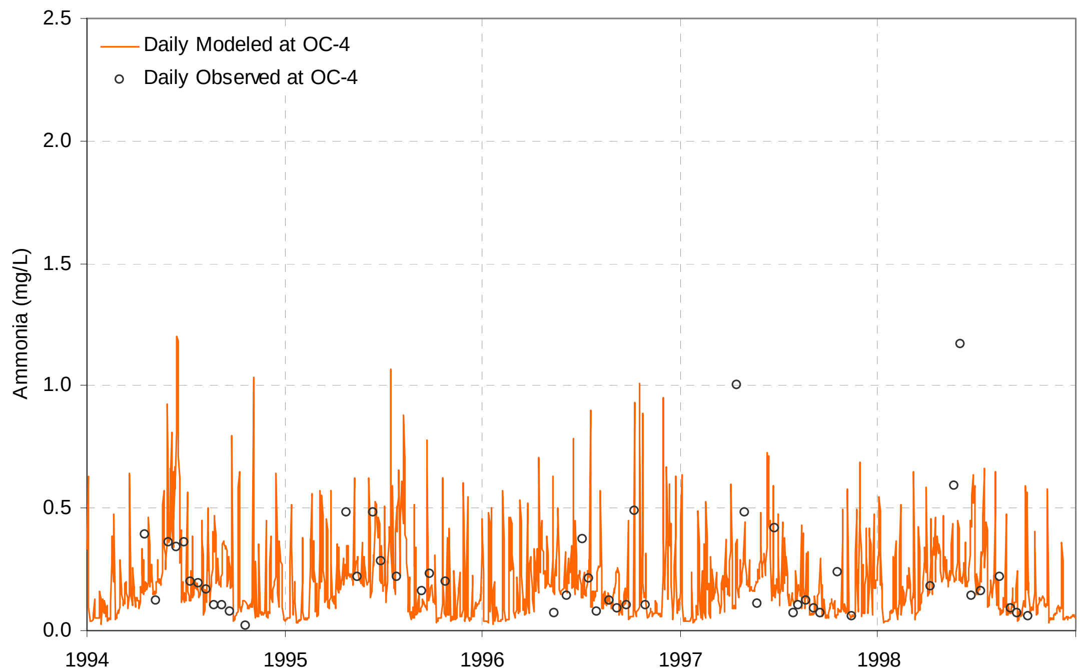


Figure 5-93. Ammonia time series calibration at Oak Creek Station OC-4.

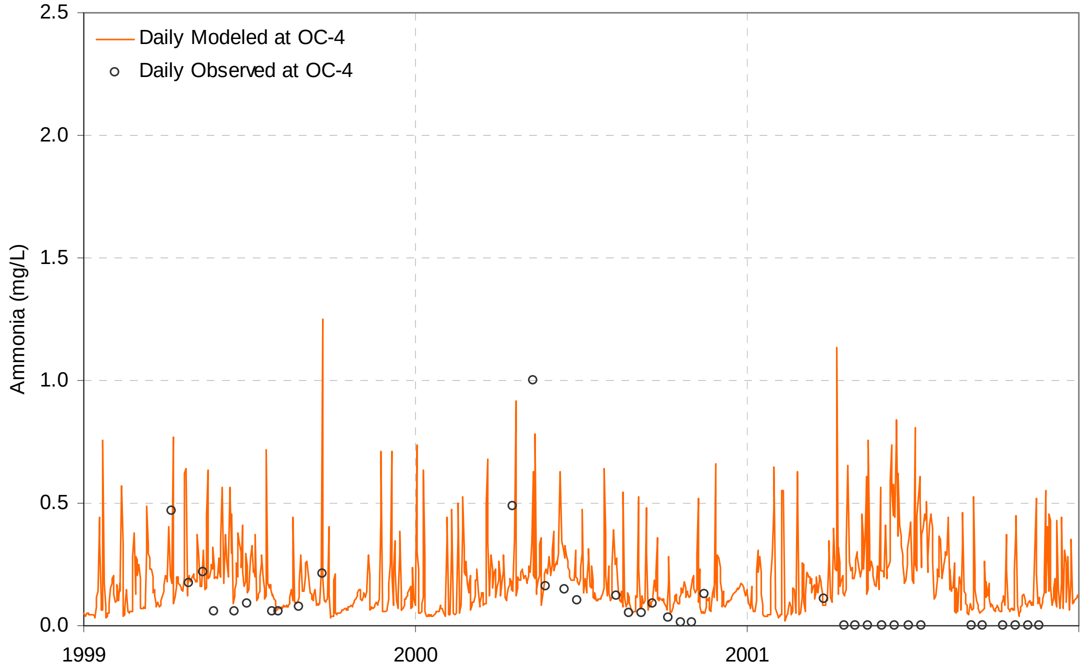


Figure 5-94. Ammonia time series validation at Oak Creek Station OC-4.

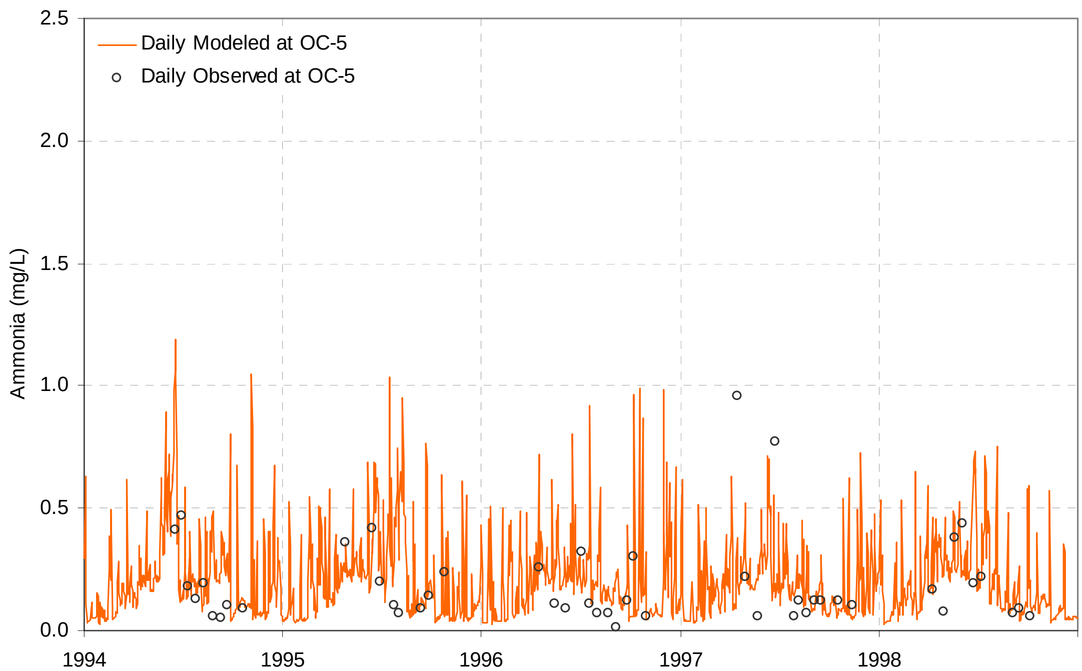


Figure 5-95. Ammonia time series calibration at Oak Creek Station OC-5.

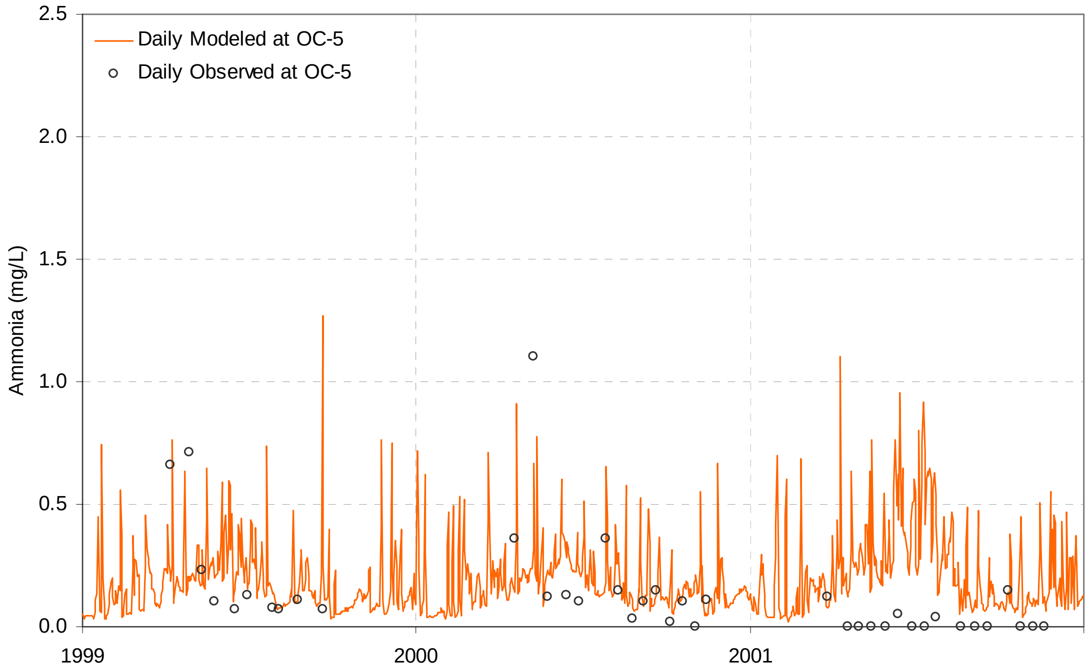


Figure 5-96. Ammonia time series validation at Oak Creek Station OC-5.

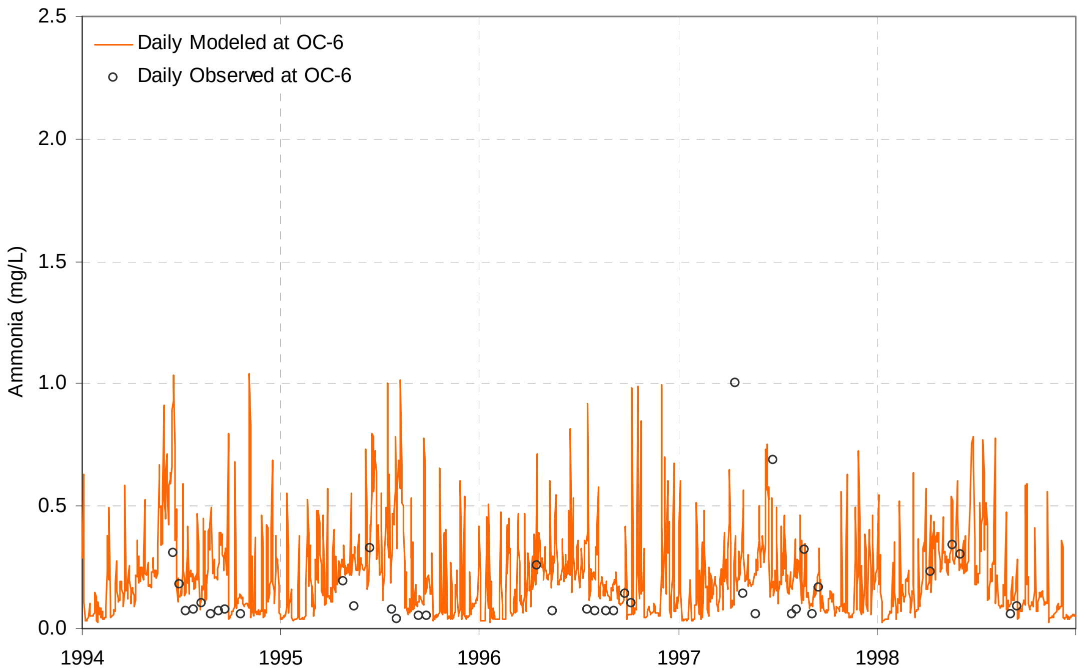


Figure 5-97. Ammonia time series calibration at Oak Creek Station OC-6.

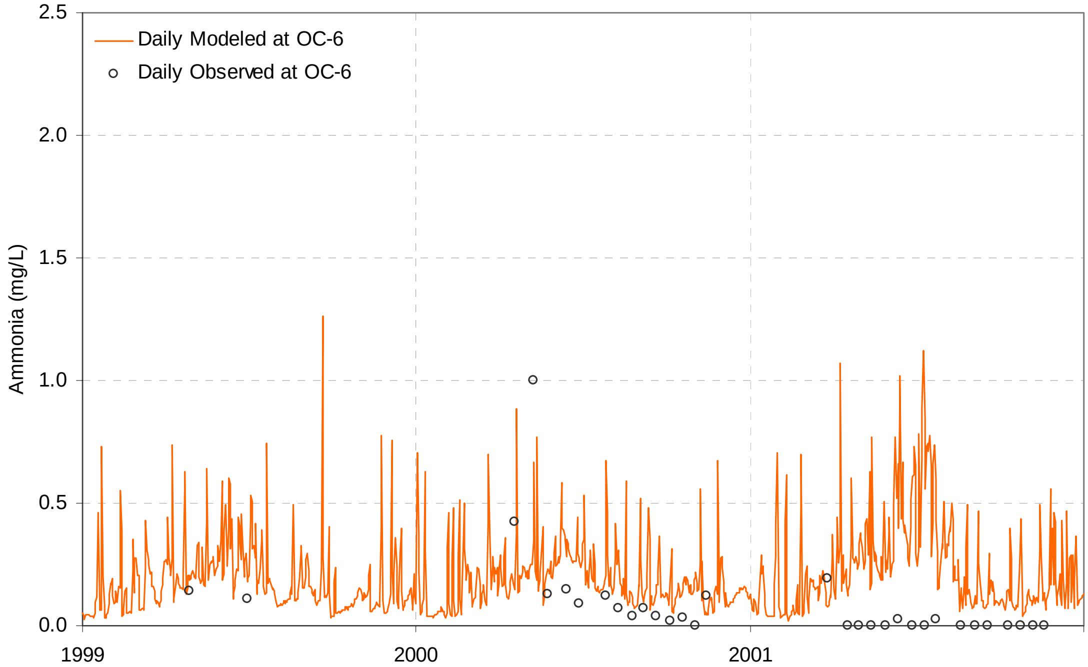


Figure 5-98. Ammonia time series validation at Oak Creek Station OC-6.

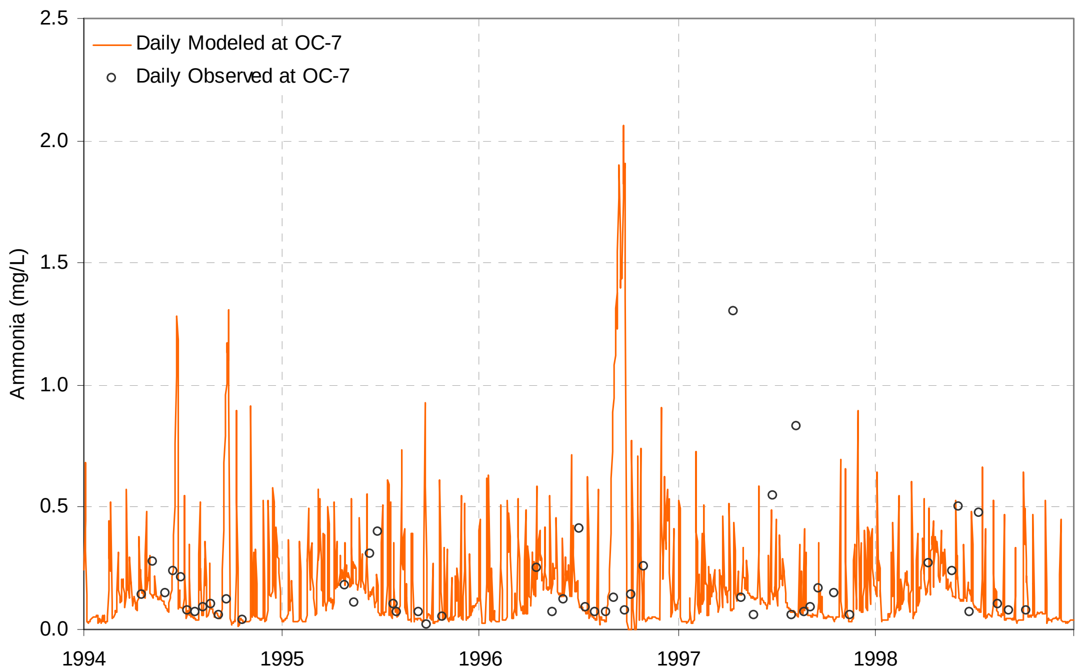


Figure 5-99. Ammonia time series calibration at Oak Creek Station OC-7.

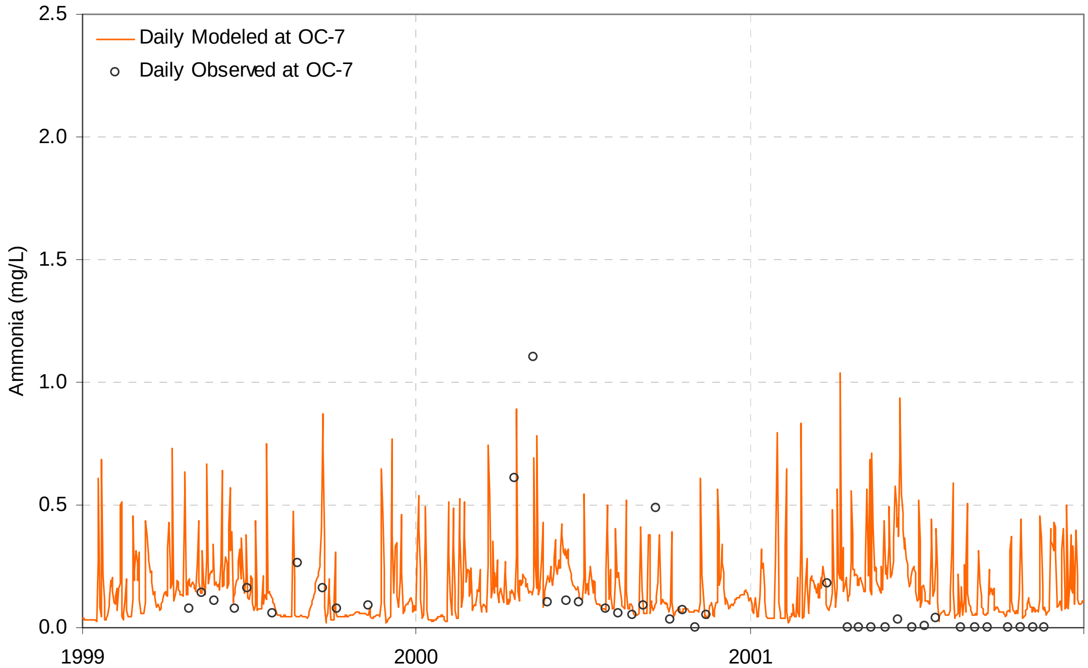


Figure 5-100. Ammonia time series validation at Oak Creek Station OC-7.

5.4.1 Algae and Chlorophyll a

Model calibration for chlorophyll *a* is challenging, because (1) algae respond in a complex way to a wide number of environmental factors, including self-shading, (2) chlorophyll *a* laboratory analyses are typically subject to a relatively high level of imprecision, and (3) algal response is naturally highly variable. Simulation of chlorophyll *a* in Oak Creek uses the same parameters as the Menomonee model with the following exceptions:

- The subbasins specified in the Oak Creek model are generally much smaller than those used in the Menomonee River model, and most of the first order streams are represented. Because of this, it is not necessary to specify an algal load associated with PERLND washoff. This was done in the Menomonee River model to account for algal growth that occurs in first-order streams and wetlands not explicitly simulated in the model.

- Because of the smaller sub-basin size, the value of OREF used in the Menomonee is not appropriate for Oak Creek. OREF is the flow breakpoint that determines the concentration of phytoplankton in a reach not subject to advection. Lower values are needed in Oak Creek to account for the smaller subbasin size.

The model also simulates benthic algae, which often constitute the major fraction of the algal biomass in shallow streams. Unfortunately, no reported data are available to calibrate the benthic algal concentration.

Model results for the calibration and validation time periods are provided below (Figure 5-101 to Figure 5-114). The model represents the general spatial and temporal trends in planktonic algal concentration, but does not predict a few isolated algal blooms that likely represent localized conditions in pooled backwaters during summer conditions or detachment of benthic algal biomass. Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment A.

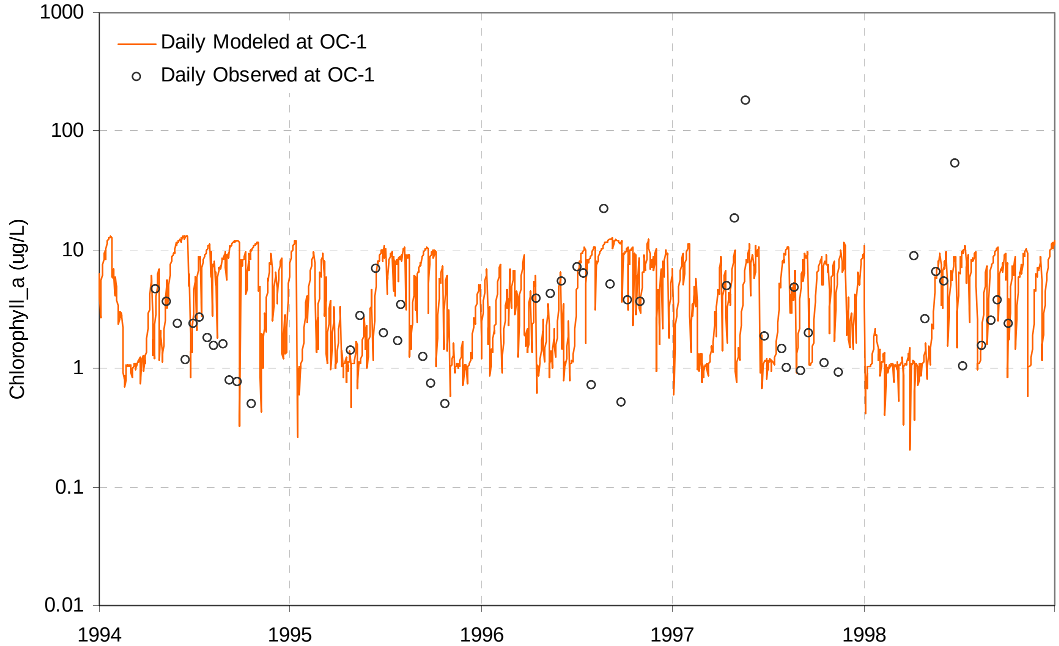


Figure 5-101. Chlorophyll *a* time series calibration at Oak Creek Station OC-1.

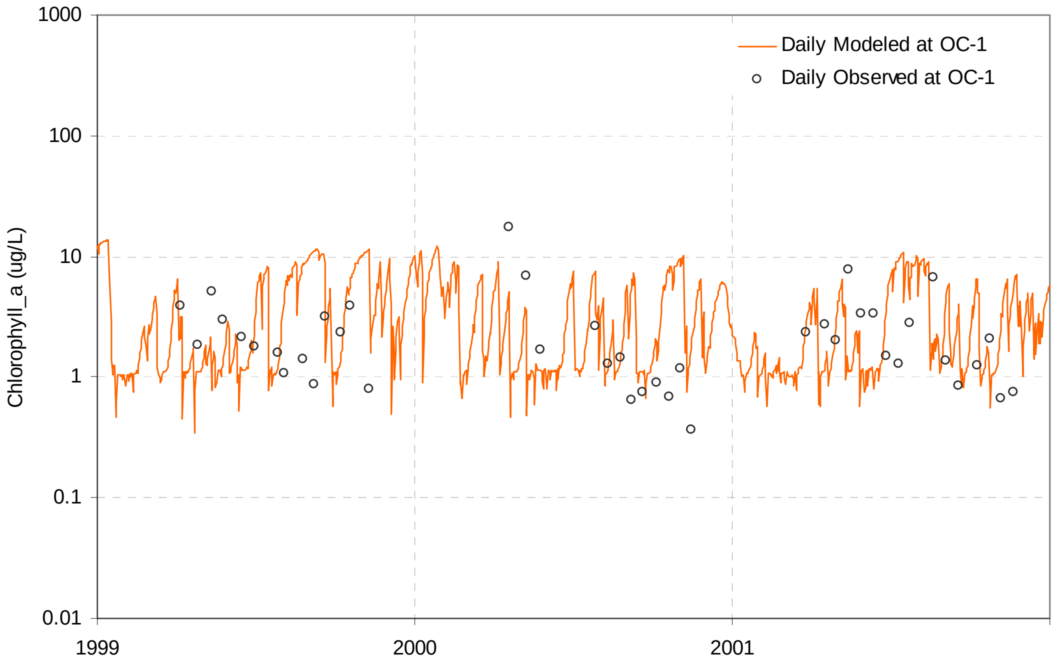


Figure 5-102. Chlorophyll *a* time series validation at Oak Creek Station OC-1.

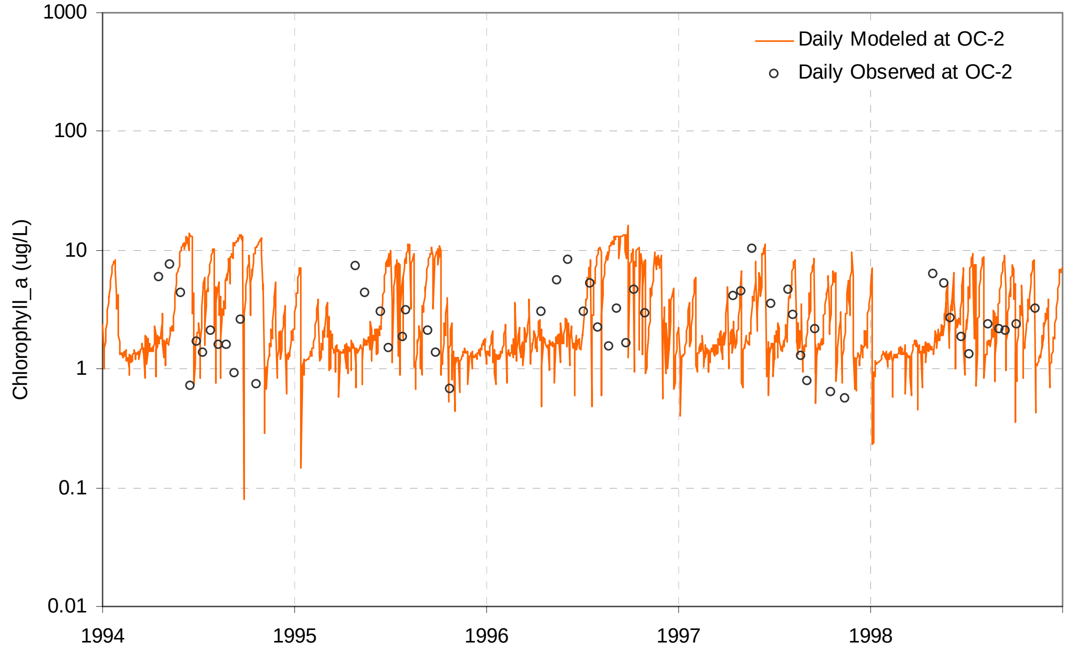


Figure 5-103. Chlorophyll *a* time series calibration at Oak Creek Station OC-2.

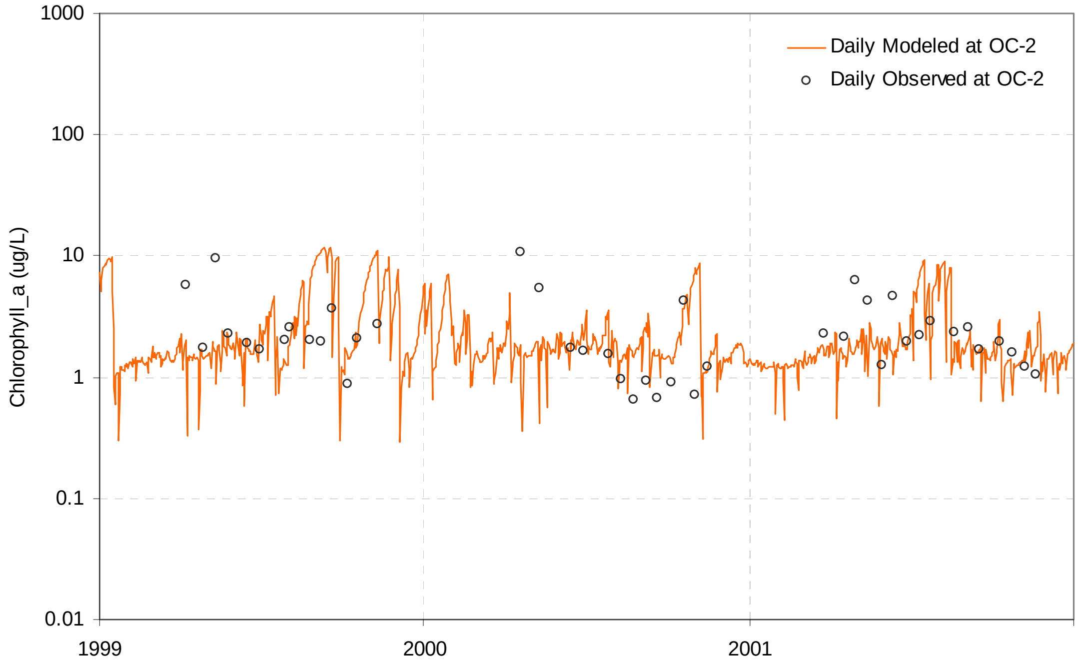


Figure 5-104. Chlorophyll *a* time series validation at Oak Creek Station OC-2.

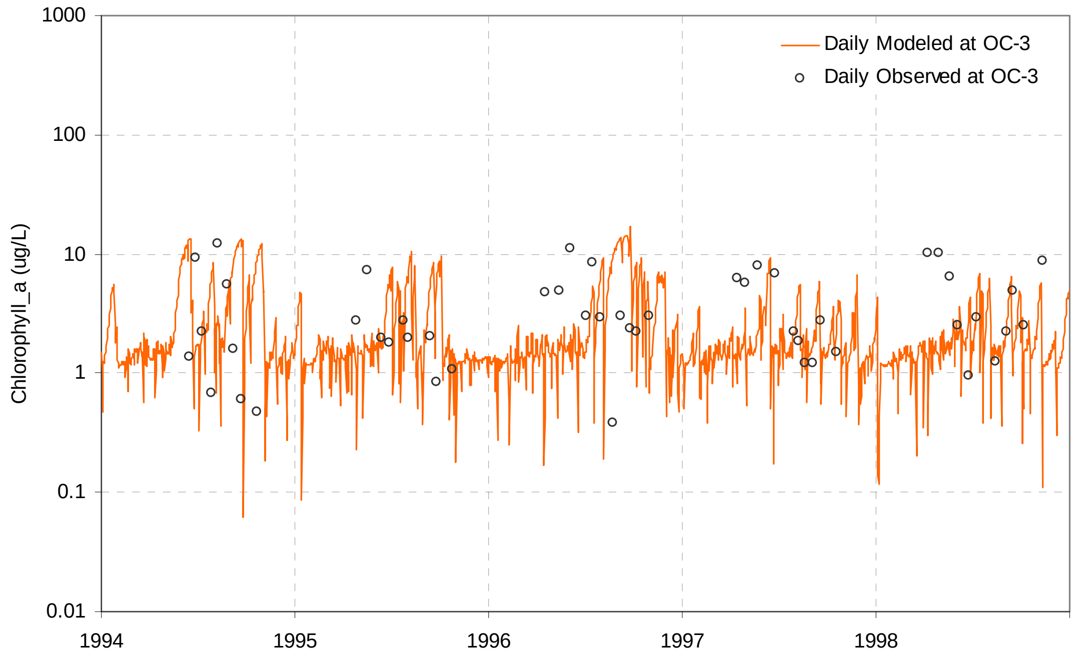


Figure 5-105. Chlorophyll *a* time series calibration at Oak Creek Station OC-3.

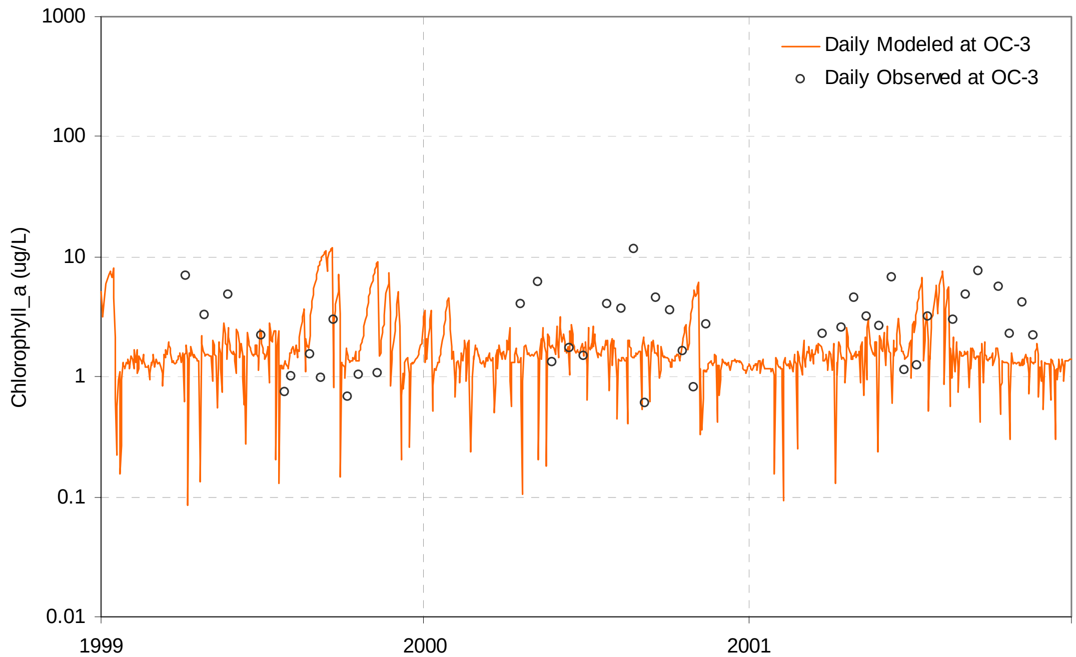


Figure 5-106. Chlorophyll *a* time series validation at Oak Creek Station OC-3.

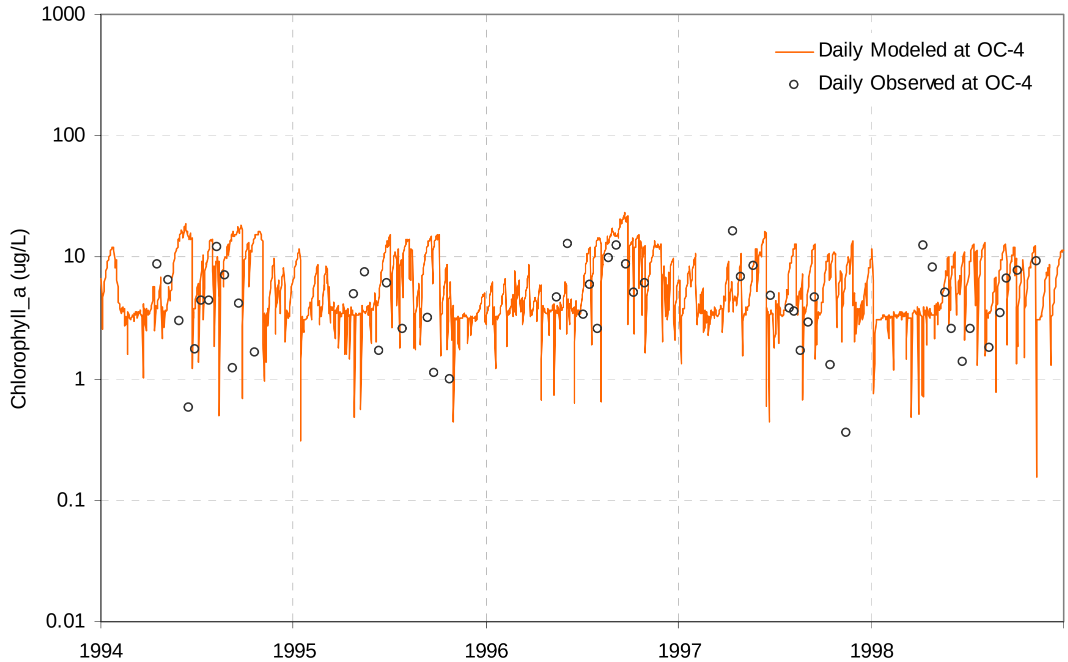


Figure 5-107. Chlorophyll *a* time series calibration at Oak Creek Station OC-4.

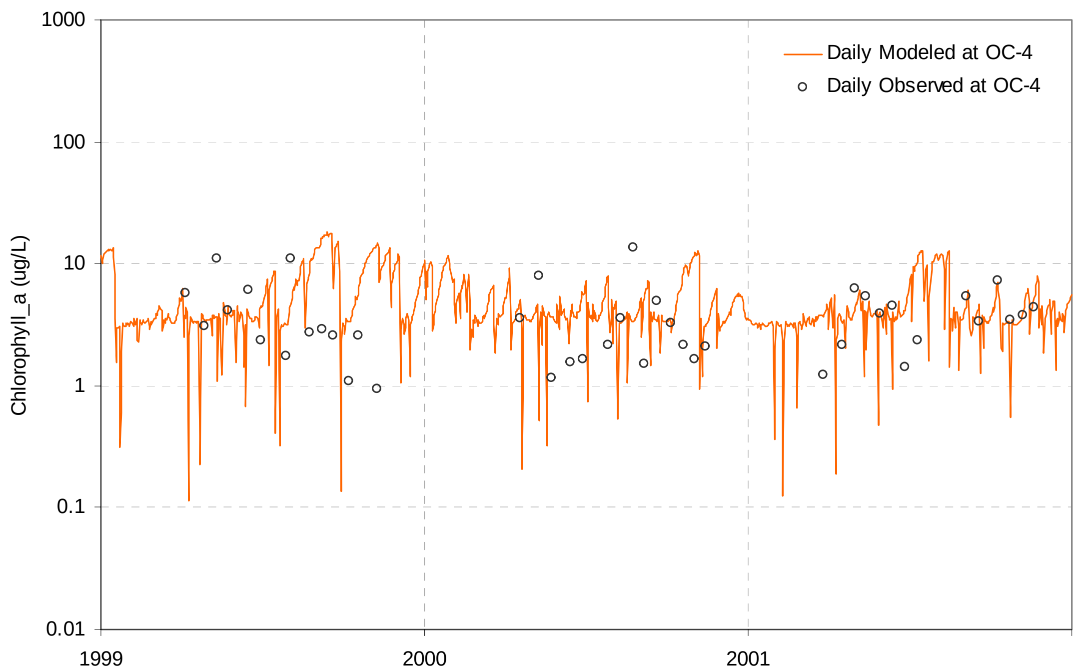


Figure 5-108. Chlorophyll *a* time series validation at Oak Creek Station OC-4.

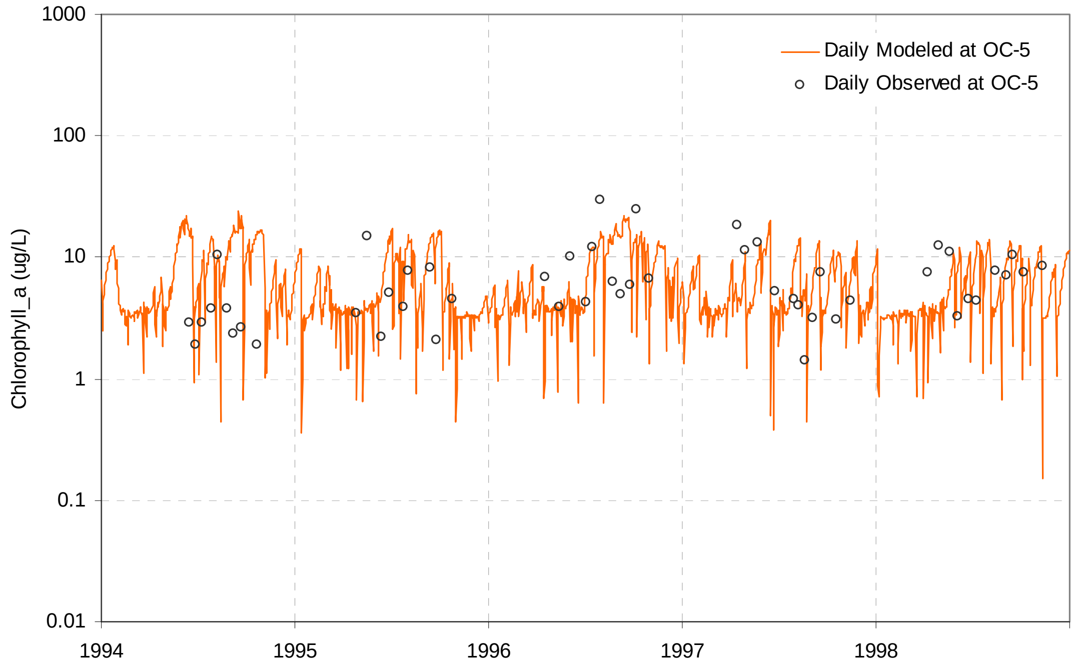


Figure 5-109. Chlorophyll *a* time series calibration at Oak Creek Station OC-5.

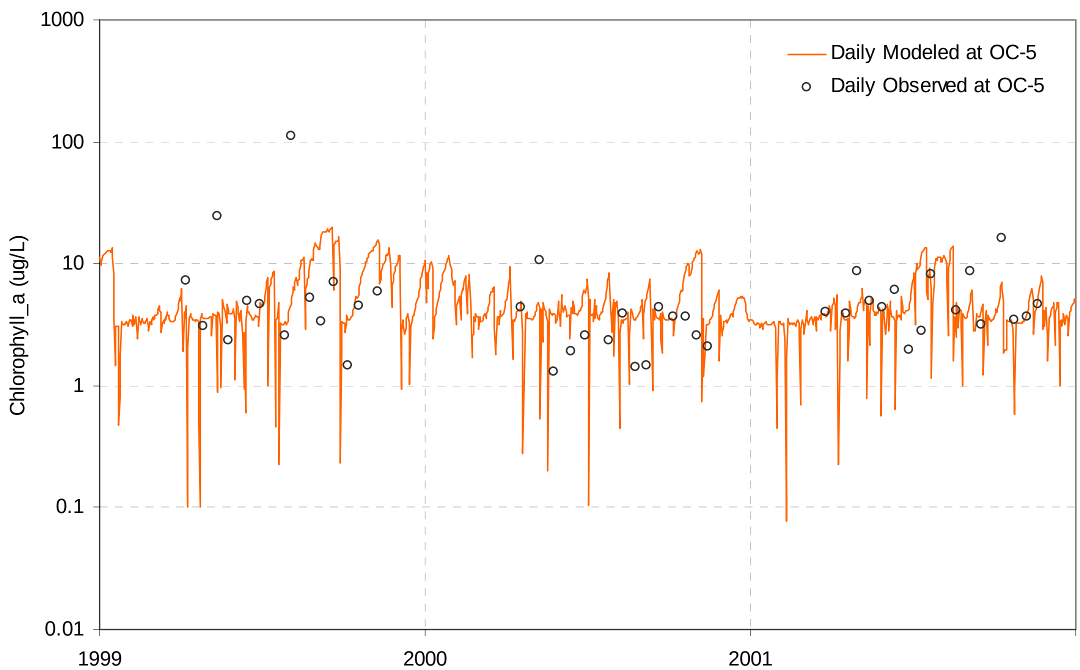


Figure 5-110. Chlorophyll *a* time series validation at Oak Creek Station OC-5.

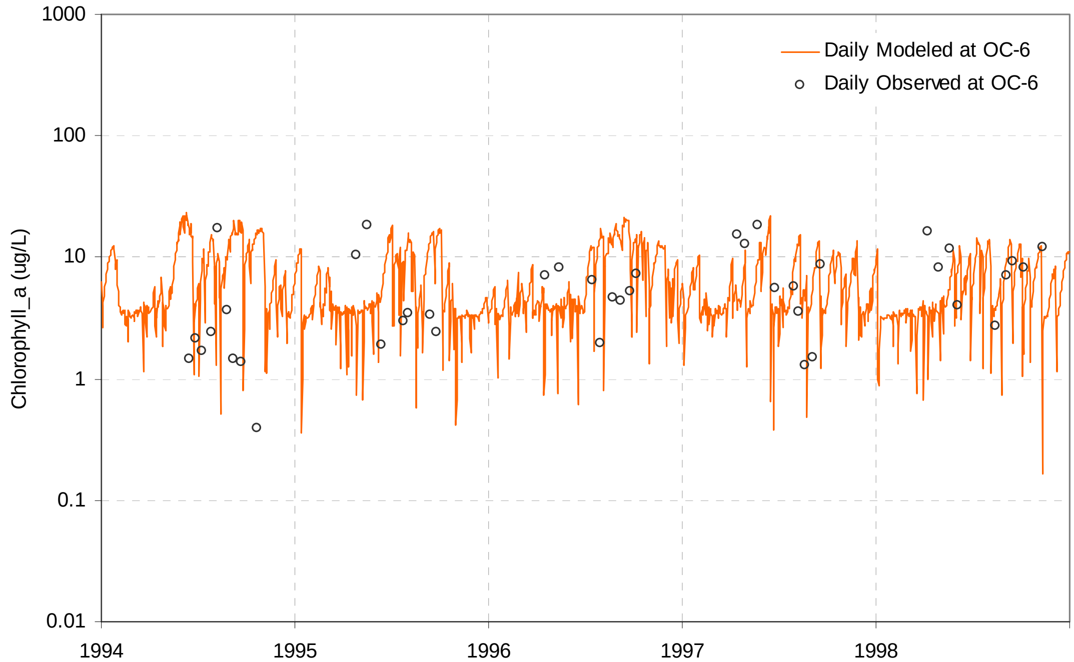


Figure 5-111. Chlorophyll *a* time series calibration at Oak Creek Station OC-6.

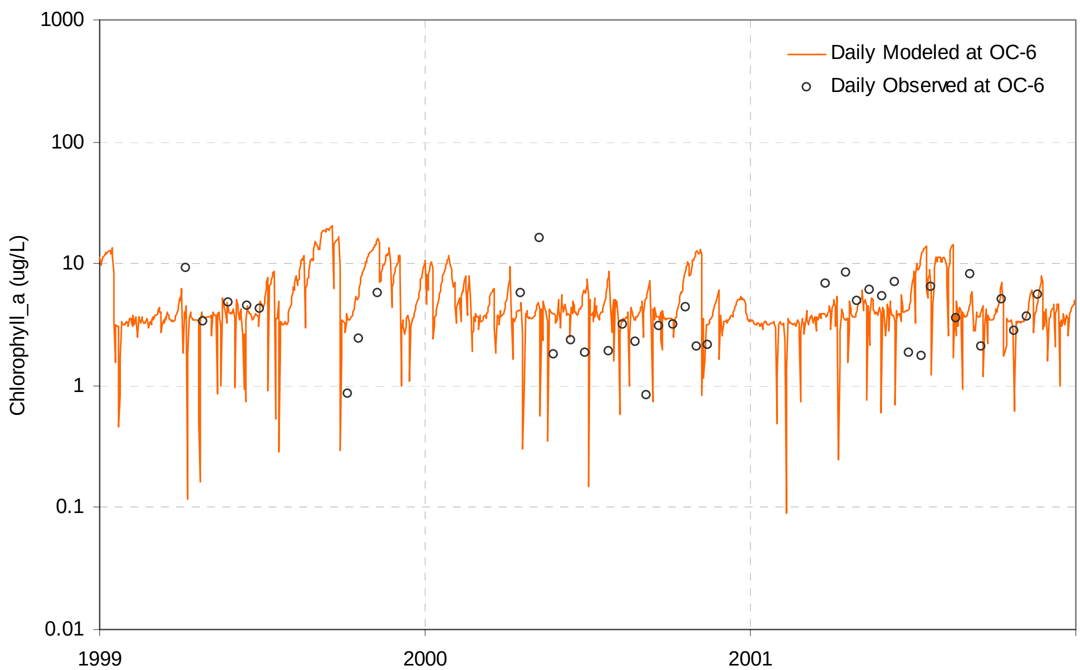


Figure 5-112. Chlorophyll *a* time series validation at Oak Creek Station OC-6.

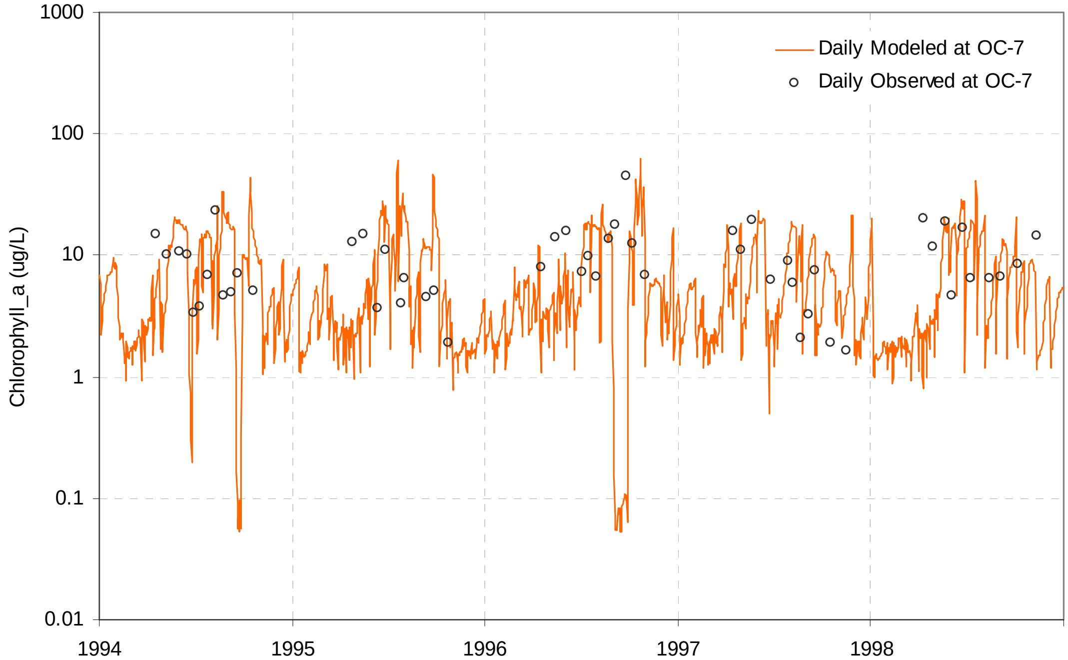


Figure 5-113. Chlorophyll *a* time series calibration at Oak Creek Station OC-7.

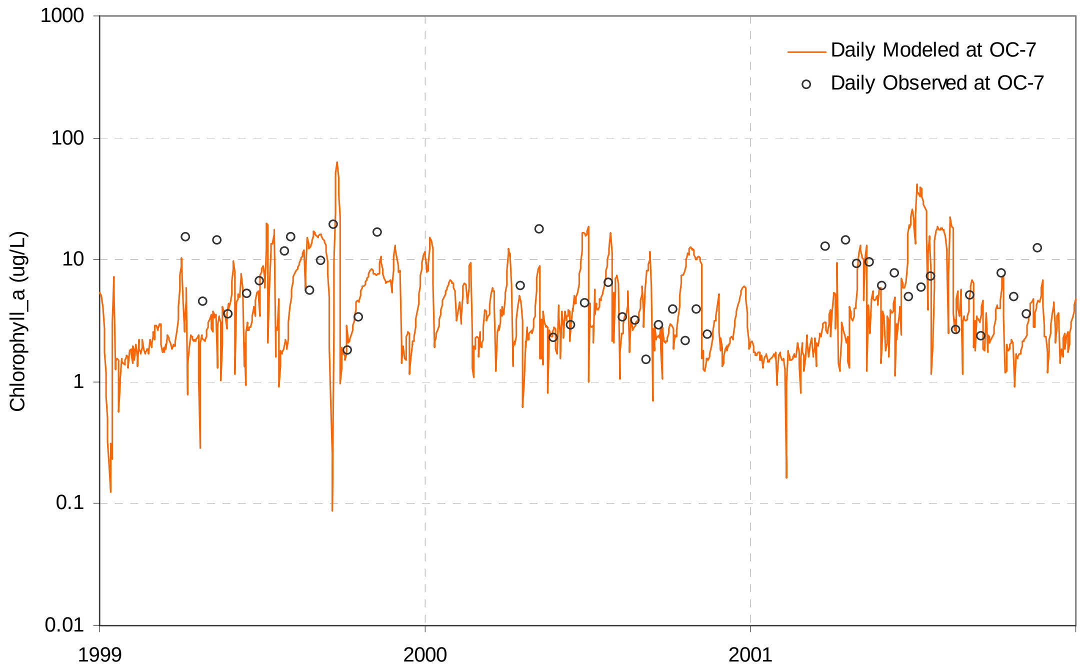


Figure 5-114. Chlorophyll *a* time series validation at Oak Creek Station OC-7.

5.5 BOD/DO Calibration

A rigorous calibration for biochemical oxygen demand (BOD) is problematic, because what is represented in the model is not fully equivalent to what is analyzed from ambient samples. BOD has been primarily monitored in Oak Creek using APHA (1998) Standard Method 5210B. This yields estimates of 5-day (short-term) BOD from whole-water samples, including both the carbonaceous and nitrogenous components. Detection limit in later samples is 0.2 mg/L; however, those samples obtained through 1995 appear to have had a detection limit of 2 mg/L. The DO supersaturation limit is set to the default value of 125 percent, which results in truncating the potential upper bound on DO concentration at around 18 mg/L at stations OC-4 through OC-6. Below OC-6, Oak Creek passes through a small dammed impoundment. Less periphyton growth occurs within the impoundment, and the dam causes enhanced reaeration, resulting in reduced variability in DO at station OC-7.

The LSPC model simulates a single dissolved CBOD component as a state variable. In fact, organic matter that exerts an oxygen demand via bacterial digestion is a complex mixture of chemicals with variable reaction rates. The LSPC variable is a summary compromise that, when combined with an average reaction rate, yields the observed rate of oxygen depletion. It is not necessarily equivalent to either a CBOD5 or an ultimate CBOD (CBODu), but rather an *ad hoc* hybrid. For flowing systems with relatively short residence times, an approximation in terms of CBOD5 is usually adequate, although the reaction rate may need to be modified from 5-day laboratory rates to compensate for the mixture of organic compounds actually exerting a demand.

A further complication is that the LSPC variable represents the non-living component of BOD. Method 5210B uses unfiltered samples, and these samples also include living algae. Algae are not allowed to grow during the BOD test, but may continue to exert a respiration demand or die and become part of the non-living BOD. This component of measured BOD is not included in the LSPC state variable. A correction can be calculated to account for the long-term CBODu represented by algal cells, but the effect on CBOD5 is more variable and less clear. Accordingly, if LSPC is set up to simulate BOD as an approximation of dissolved CBOD5, the model should generally provide a slight underestimation of CBOD5 measured by Method 5210B.

Simulation of BOD and DO in Oak Creek uses the same parameters as the Menomonee River model with a limited number of exceptions described below:

- Oxygen reaearation was modified in several ways from that used in the Menomonee River model. Much of Oak Creek is a channelized, trapezoidal ditch with incised banks and few riffles, resulting in relatively low reaeration. Accordingly, the empirical reaeration rate coefficients (option REAMFG=3) were adjusted downward in the areas around OC-1, OC-3, and OC-4 (but not OC-2, where riffles appear to be present). In addition, better results in the downstream end of Oak Creek were obtained by using the Covar approach (REAMFG=2). The most downstream station (OC-7) is below an old mill dam, which increases reaeration in that reach.

- Benthic oxygen demand was adjusted to better fit observed DO concentrations. Some areas of the Oak Creek mainstem appear to have elevated benthic oxygen demand. For these areas, small benthic releases of ammonia and phosphate were also assigned, consistent with reducing conditions.

- Ground water and interflow DO concentrations appear to be lower in Oak Creek than in Menomonee and were reduced accordingly. Ground water TOC (BOD) concentrations were also modified from Menomonee to better reflect observed conditions in Oak Creek.

Model results for the calibration and validation time periods are provided below for both BOD5 and dissolved oxygen (Figure 5-115 to Figure 5-142). It should be noted that many of the reported post-2000 BOD5 concentrations are zeroes whereas in earlier years it appears they were reported as constant values at the detection limit. The presence of these zeros in the database artificially increases the apparent discrepancy between the simulation model and observed data.

The fit for dissolved oxygen is in general good, with the exception of over-prediction of concentrations at OC-1 during 2000 and 2001 (which propagates to a lesser degree to the downstream stations). BOD5 in the water column remained low during this period. It is possible that unknown events resulted in a significant increase in the benthal oxygen demand in this reach during 2000.

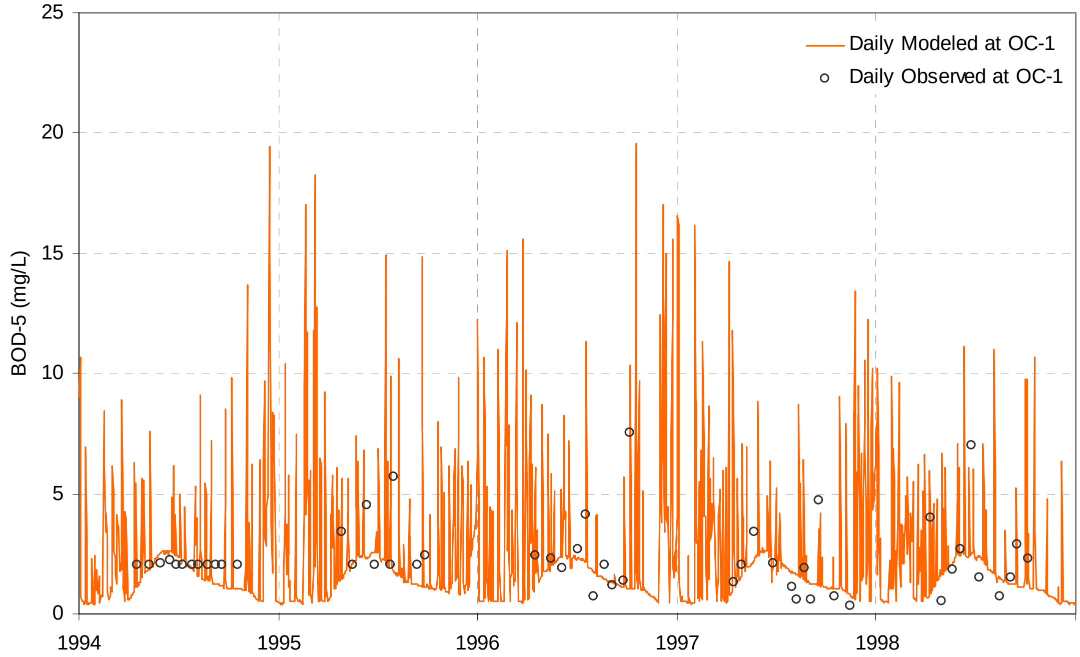


Figure 5-115. BOD5 time series calibration at Oak Creek Station OC-1.

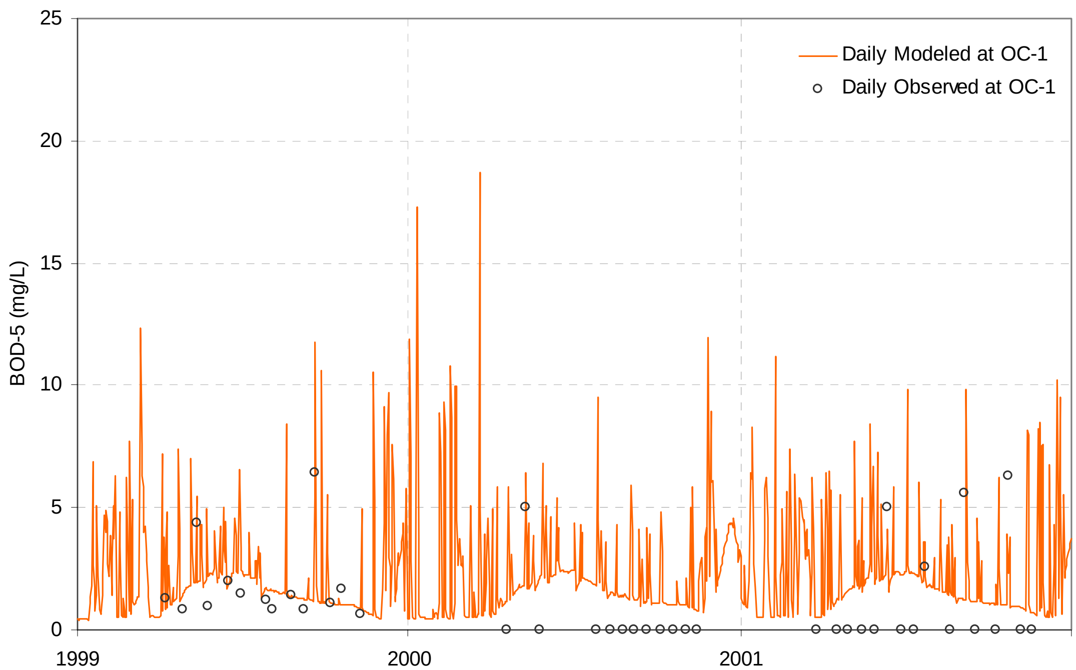


Figure 5-116. BOD5 time series validation at Oak Creek Station OC-1.

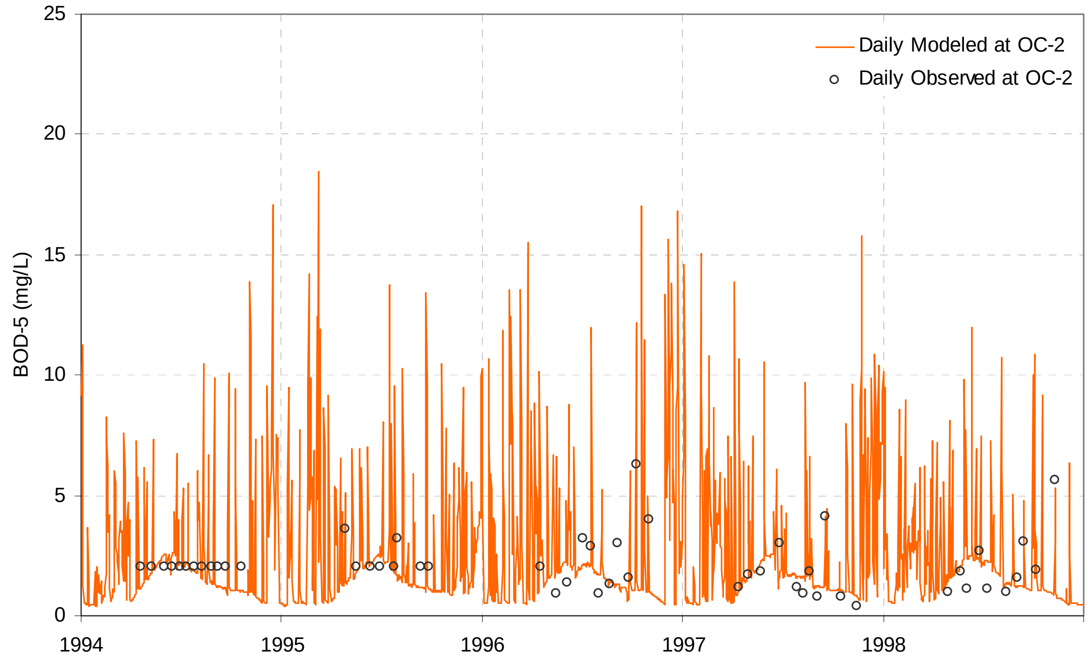


Figure 5-117. BOD5 time series calibration at Oak Creek Station OC-2.

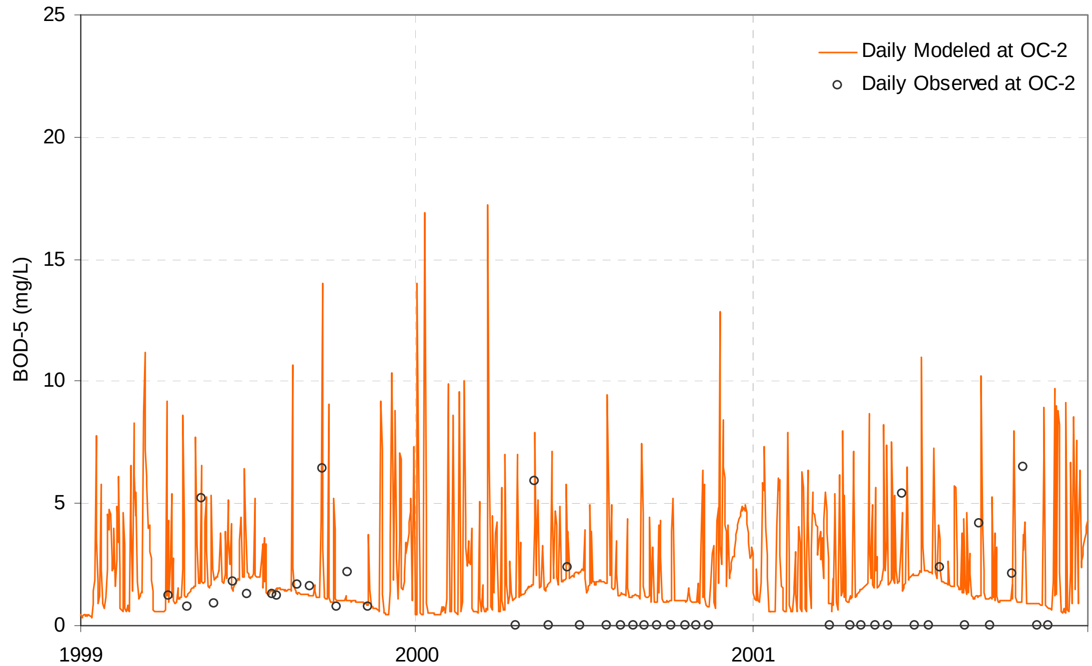


Figure 5-118. BOD5 time series validation at Oak Creek Station OC-2.

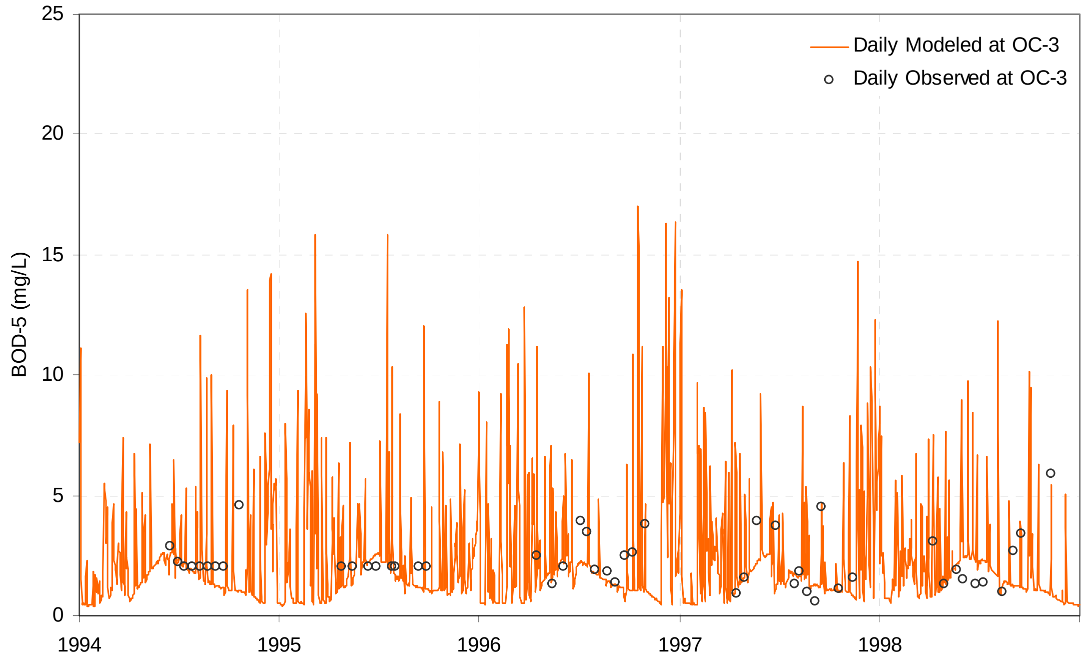


Figure 5-119. BOD5 time series calibration at Oak Creek Station OC-3.

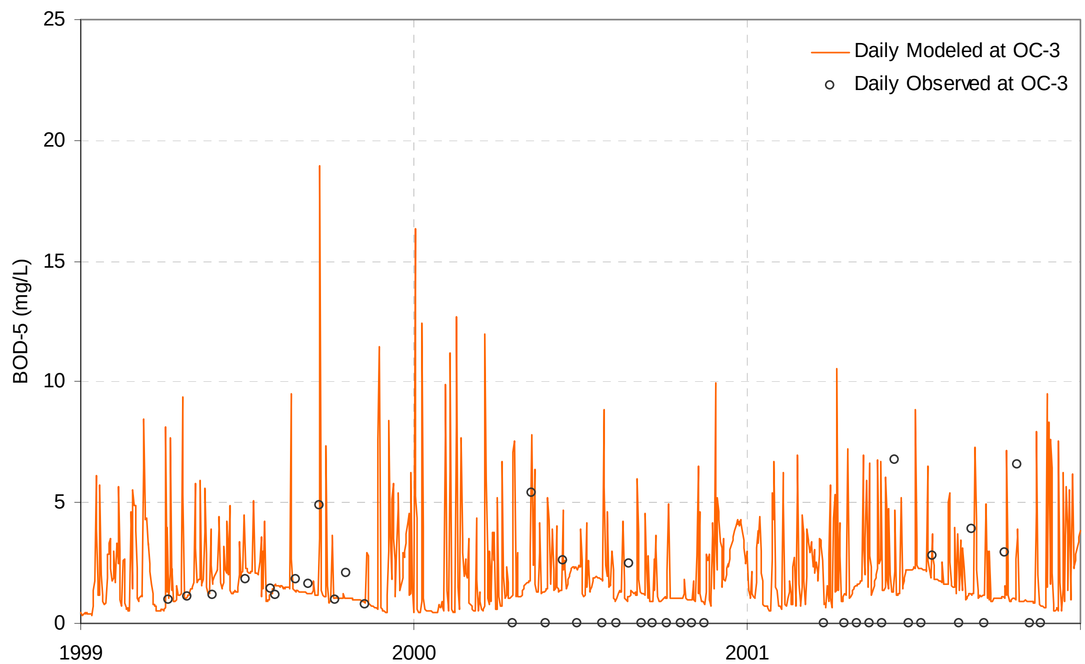


Figure 5-120. BOD5 time series validation at Oak Creek Station OC-3.

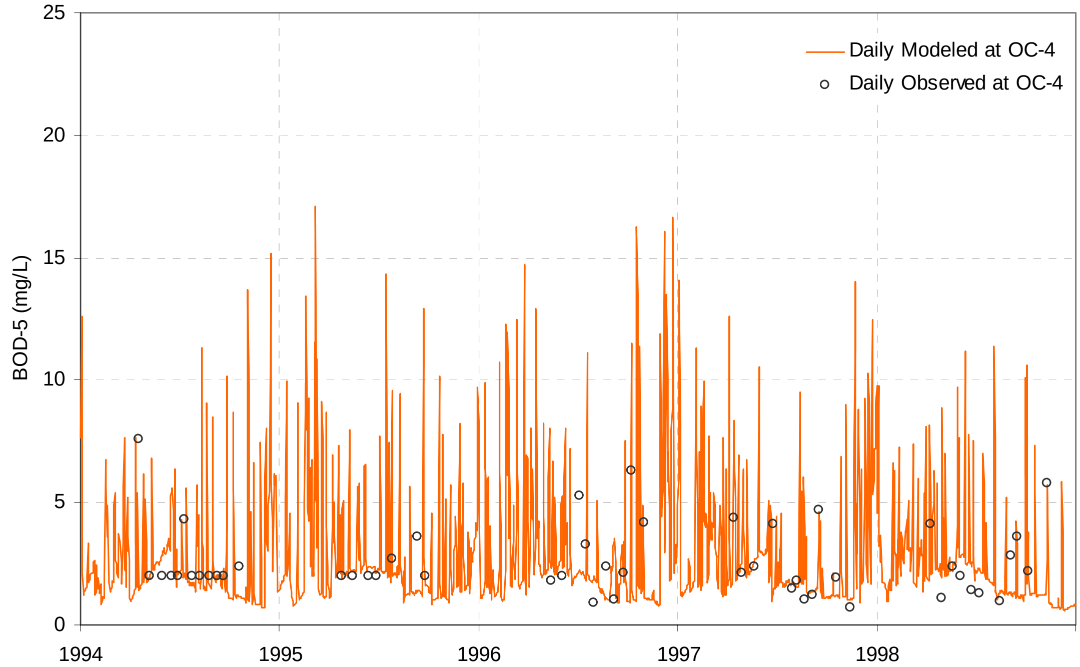


Figure 5-121. BOD5 time series calibration at Oak Creek Station OC-4.

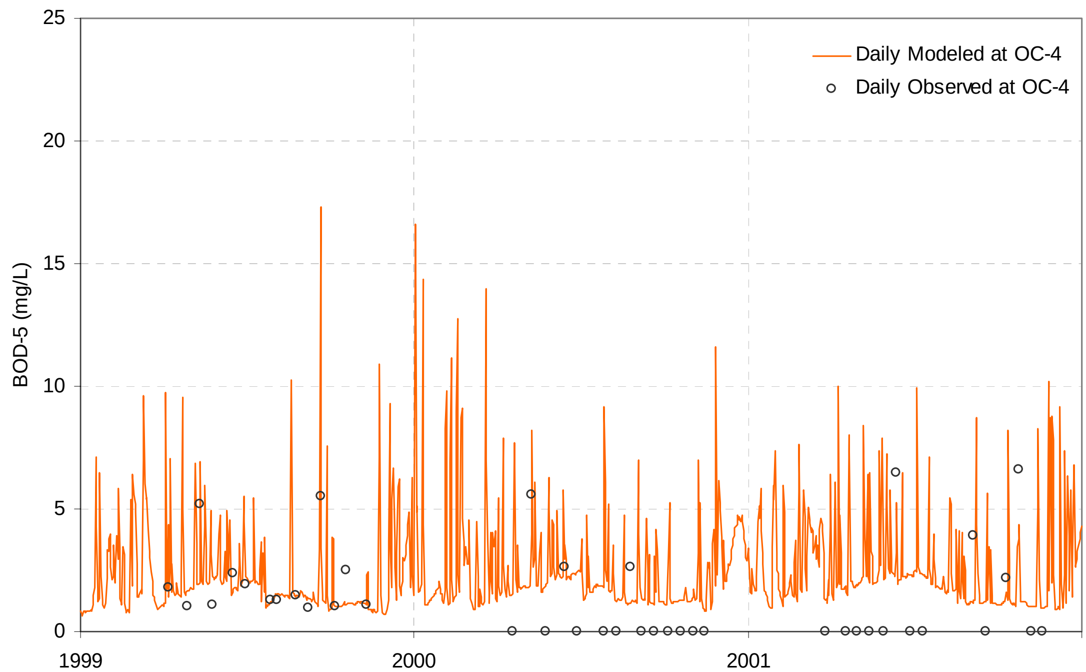


Figure 5-122. BOD5 time series validation at Oak Creek Station OC-4.

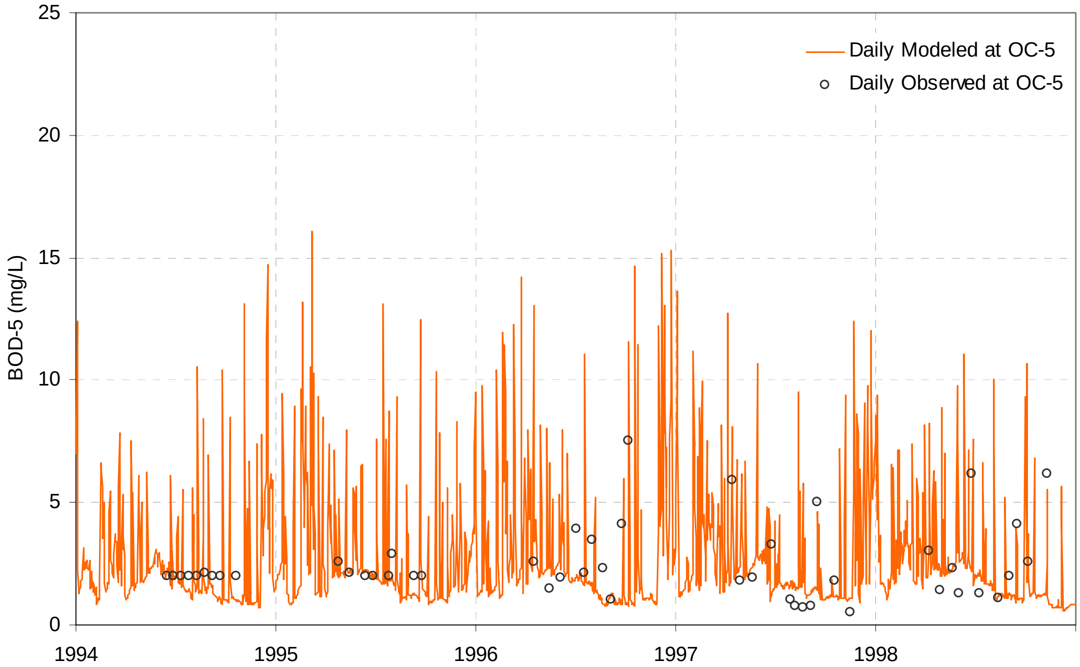


Figure 5-123. BOD5 time series calibration at Oak Creek Station OC-5.

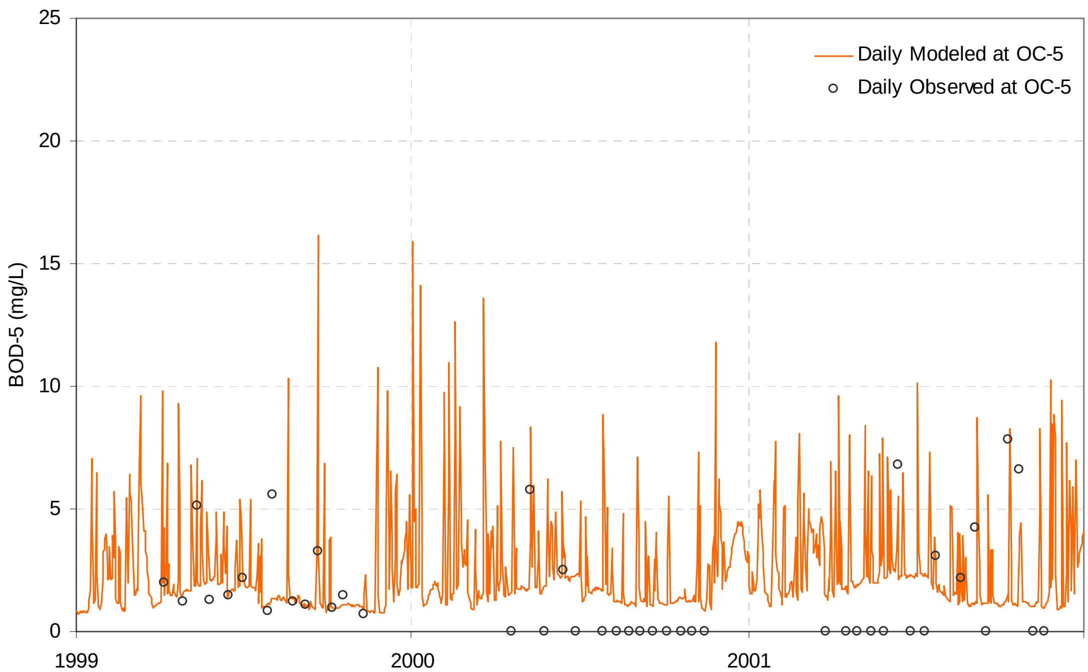


Figure 5-124. BOD5 time series validation at Oak Creek Station OC-5.

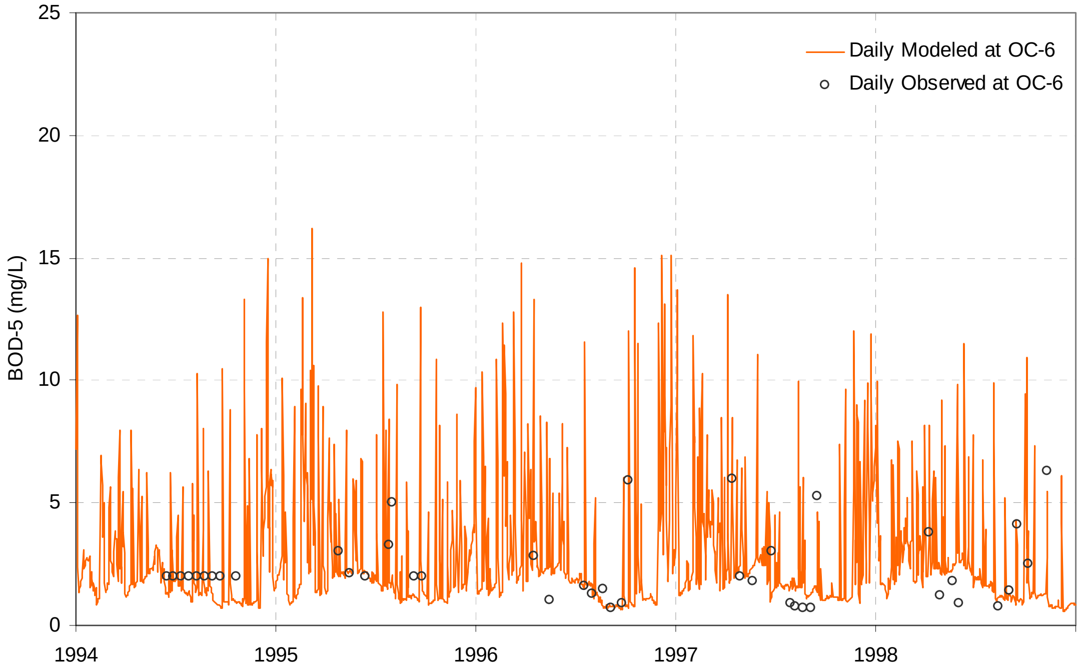


Figure 5-125. BOD5 time series calibration at Oak Creek Station OC-6.

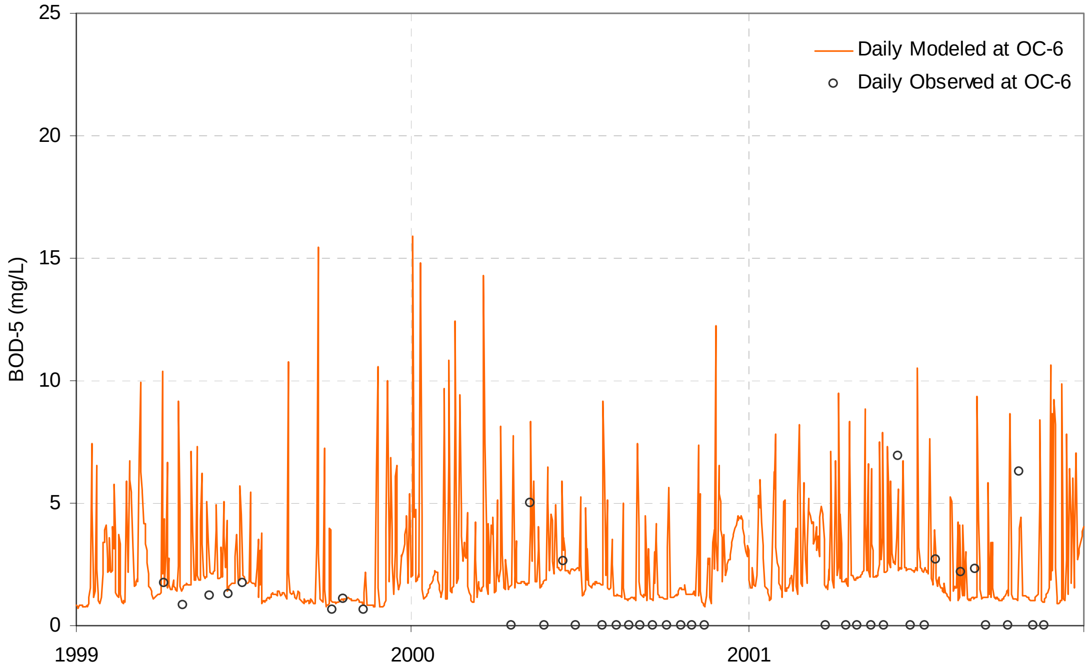


Figure 5-126. BOD5 time series validation at Oak Creek Station OC-6.

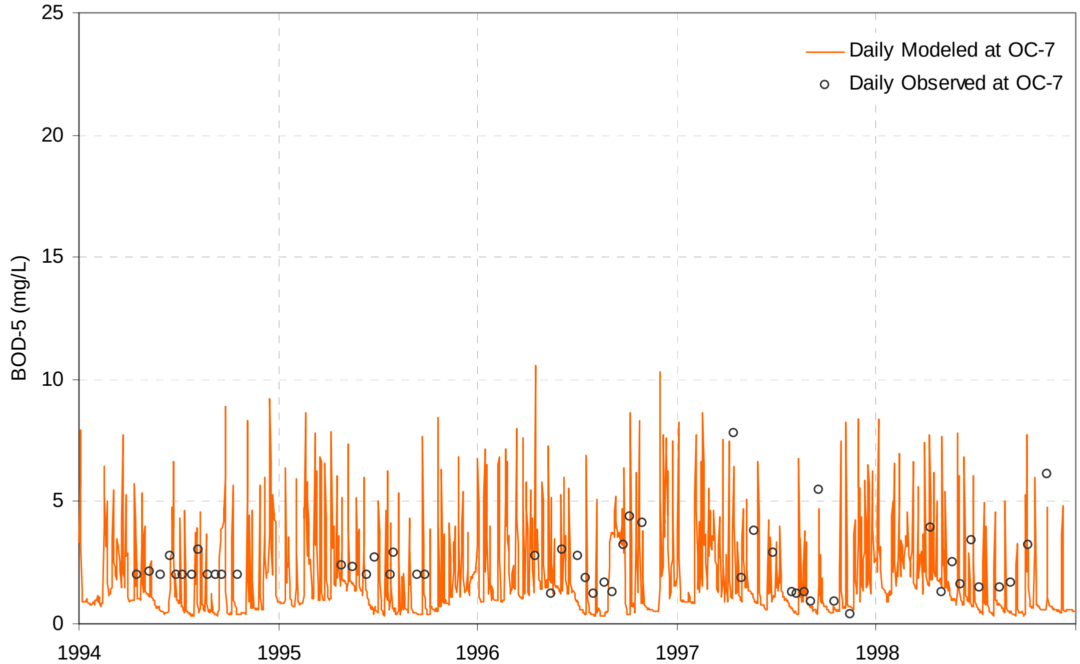


Figure 5-127. BOD5 time series calibration at Oak Creek Station OC-7.

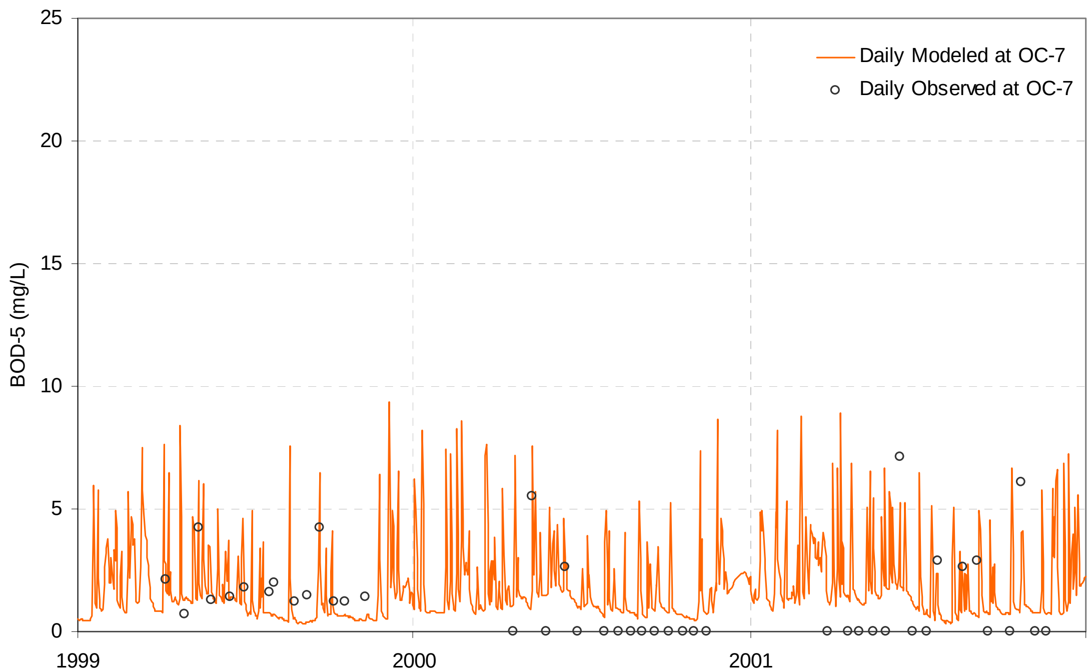


Figure 5-128. BOD5 time series validation at Oak Creek Station OC-7.

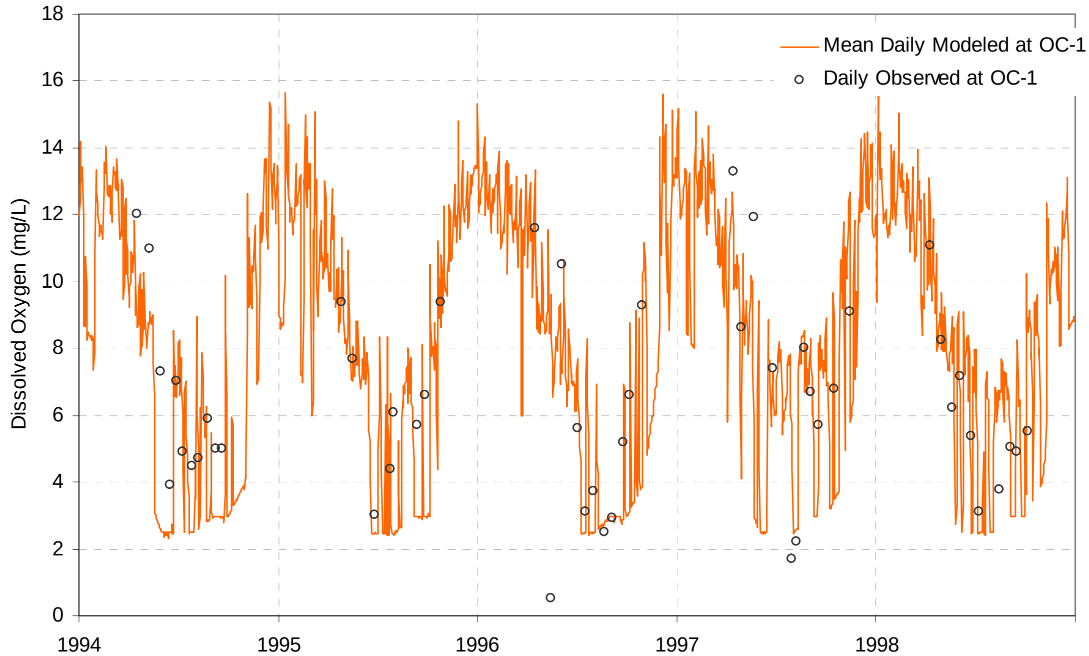


Figure 5-129. Dissolved oxygen time series calibration at Oak Creek Station OC-1.

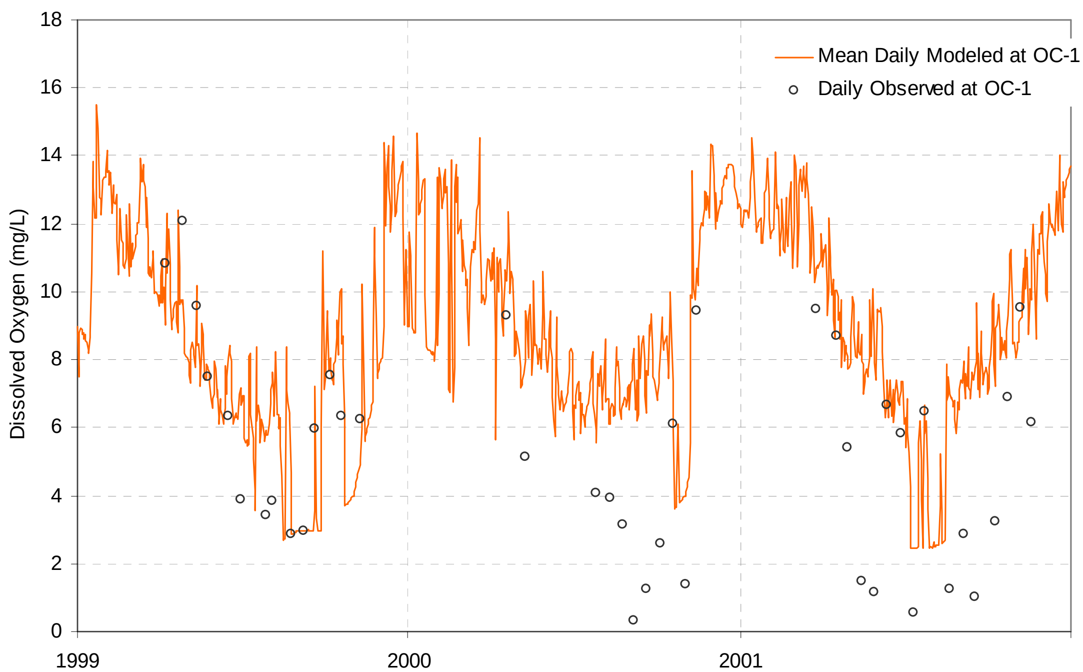


Figure 5-130. Dissolved oxygen time series validation at Oak Creek Station OC-1.

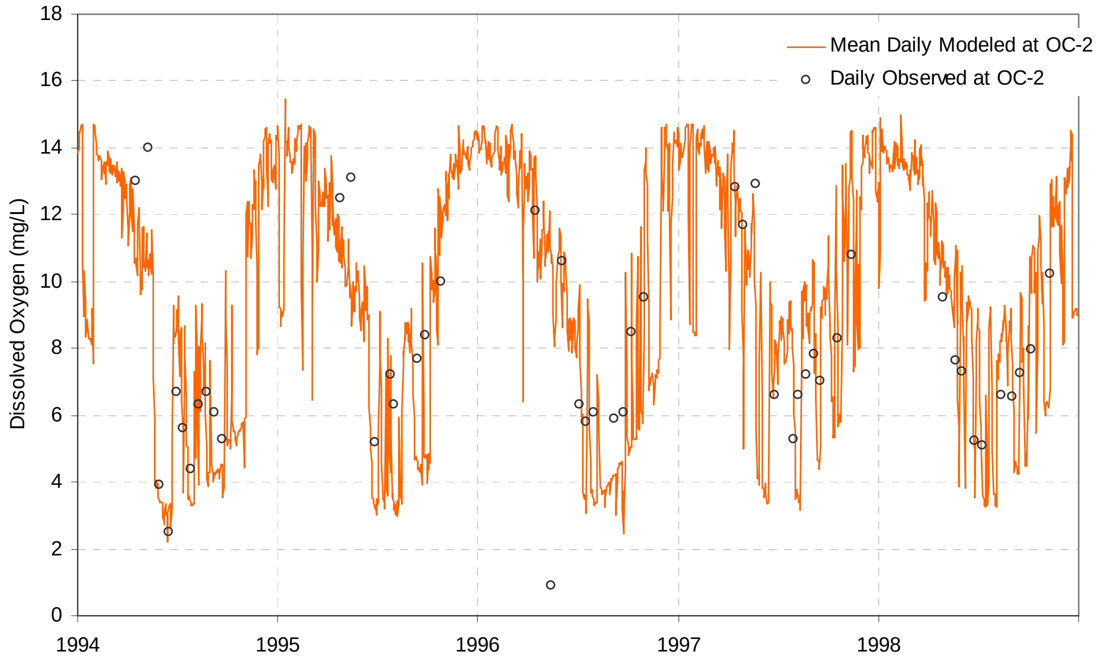


Figure 5-131. Dissolved oxygen time series calibration at Oak Creek Station OC-2.

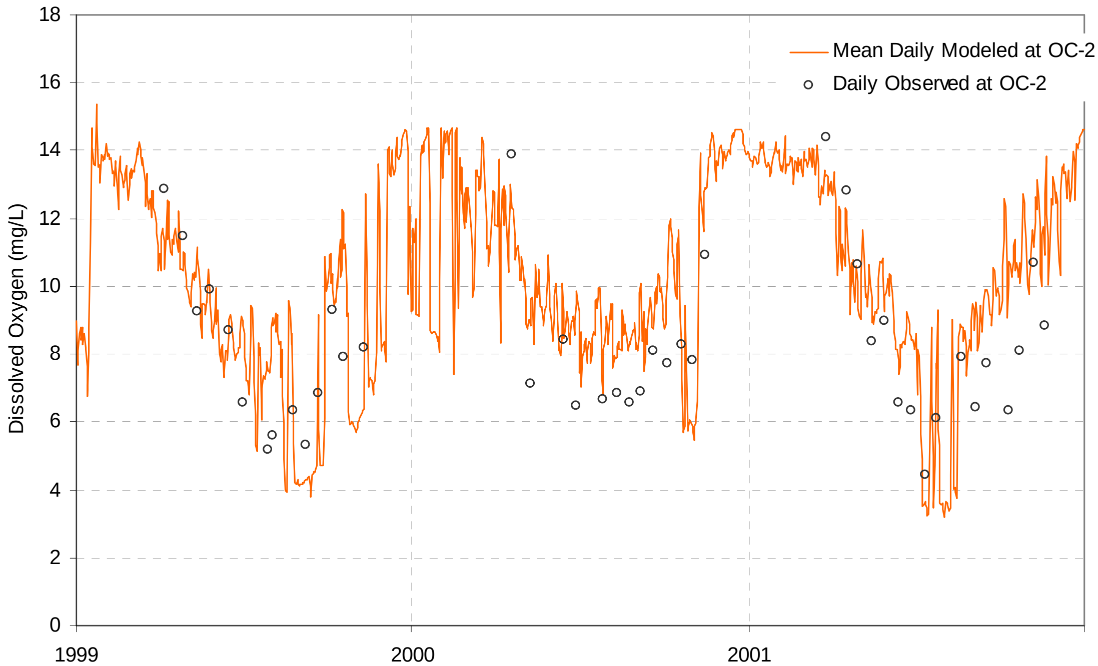


Figure 5-132. Dissolved oxygen time series validation at Oak Creek Station OC-2.

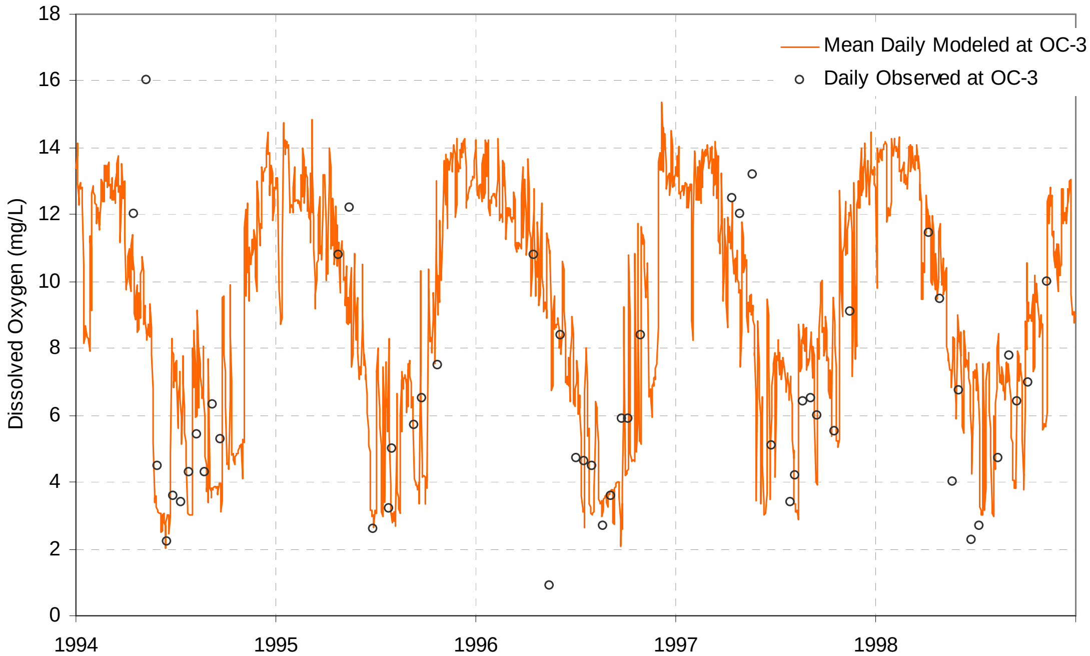


Figure 5-133. Dissolved oxygen time series calibration at Oak Creek Station OC-3.

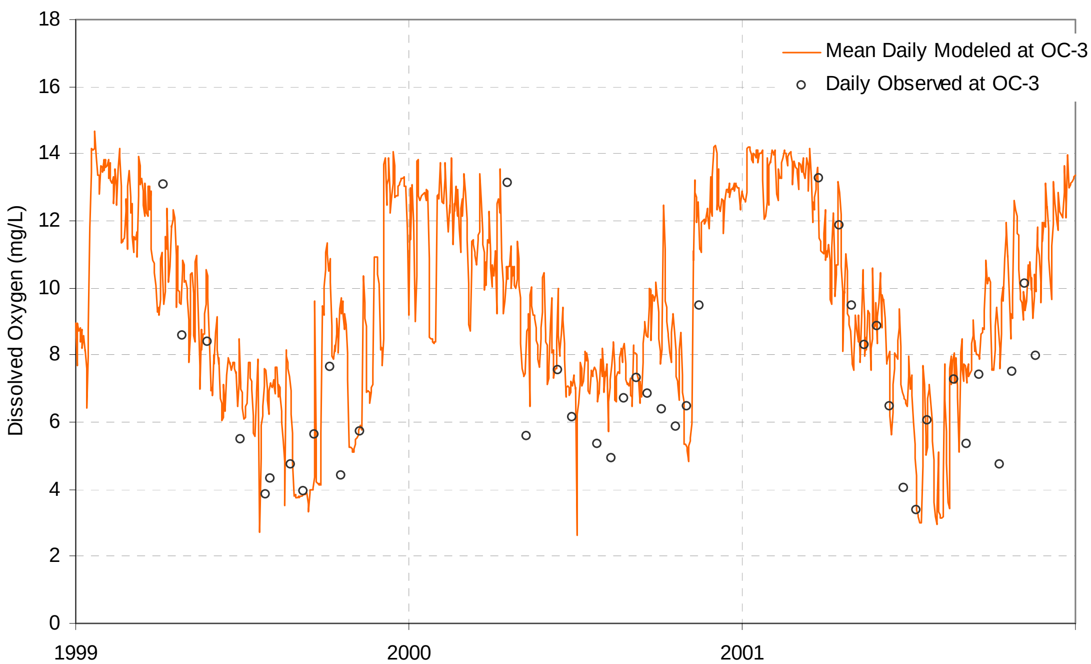


Figure 5-134. Dissolved oxygen time series validation at Oak Creek Station OC-3.

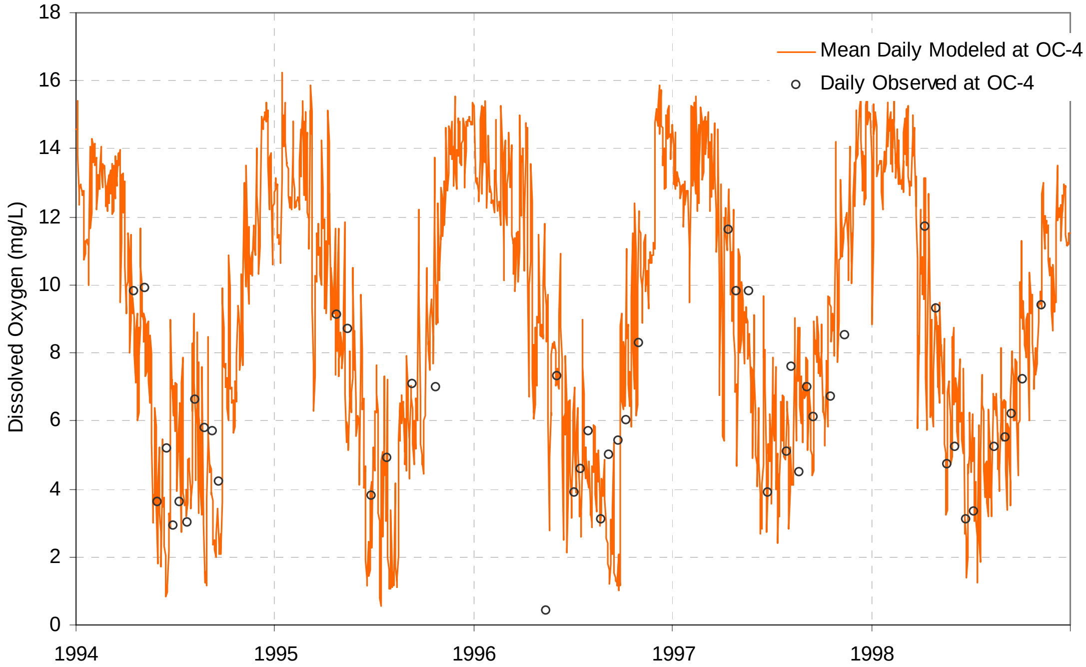


Figure 5-135. Dissolved oxygen time series calibration at Oak Creek Station OC-4.

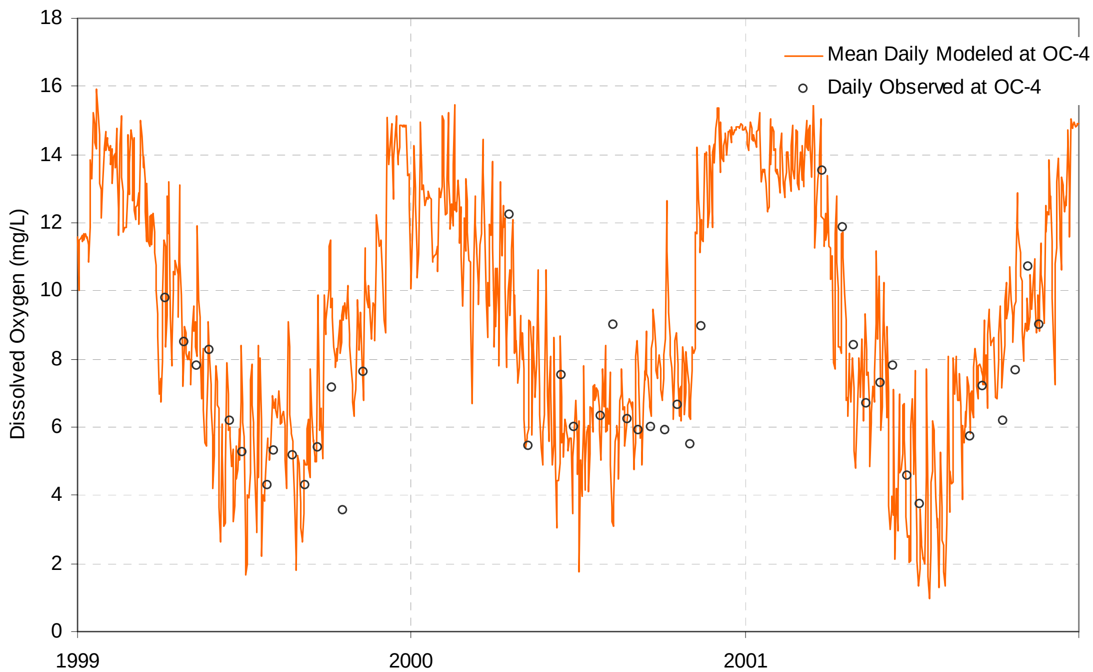


Figure 5-136. Dissolved oxygen time series validation at Oak Creek Station OC-4.

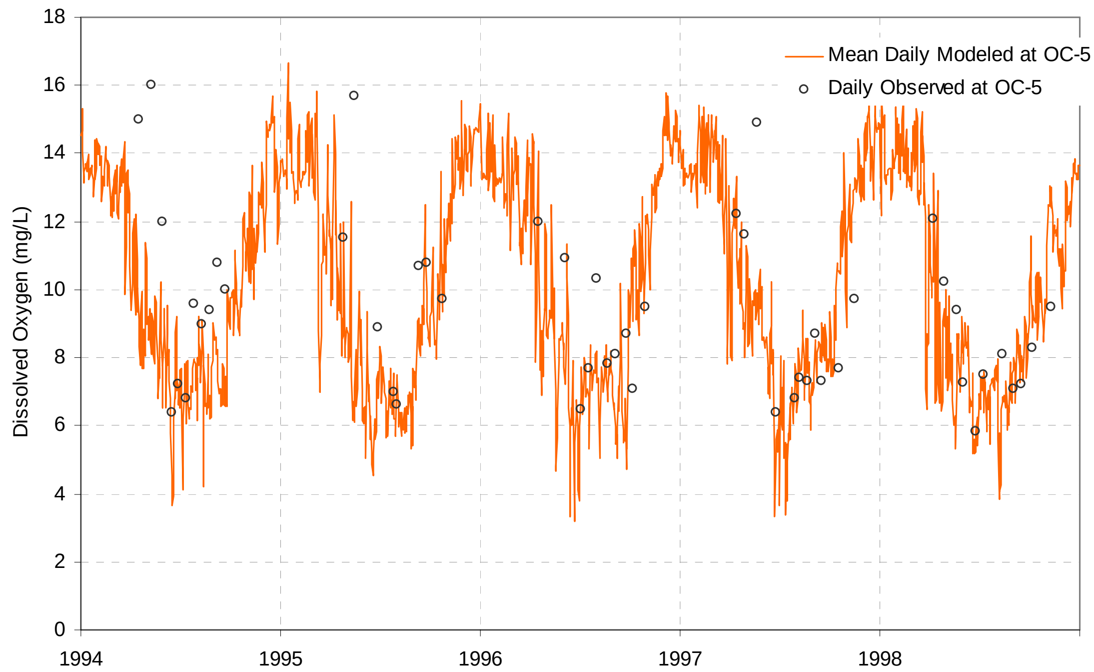


Figure 5-137. Dissolved oxygen time series calibration at Oak Creek Station OC-5.

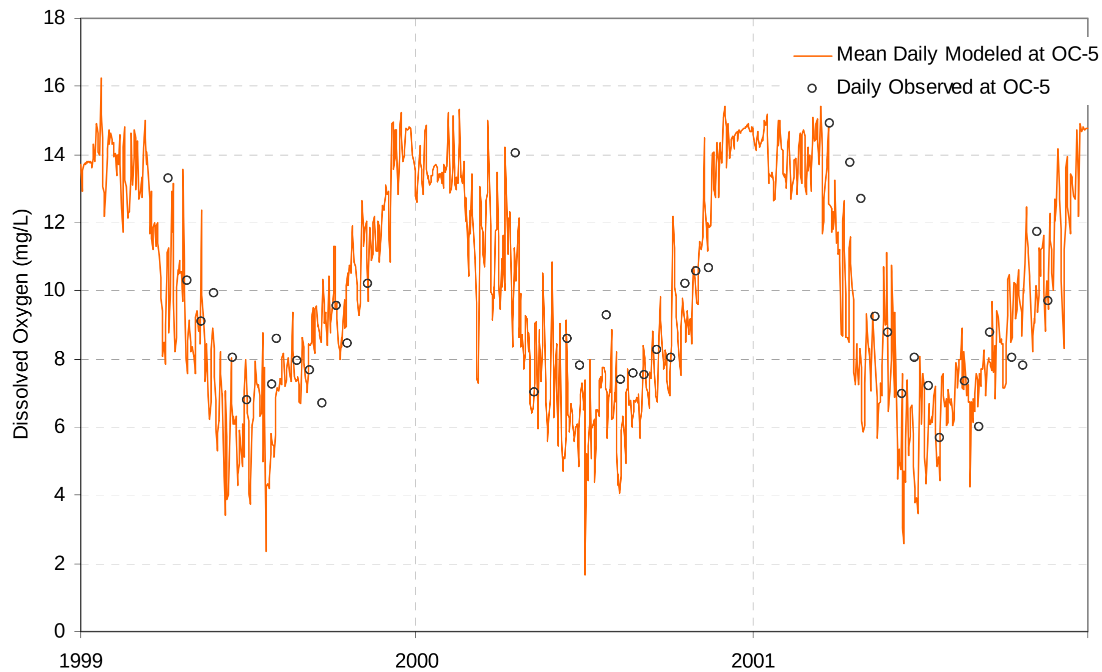


Figure 5-138. Dissolved oxygen time series validation at Oak Creek Station OC-5.

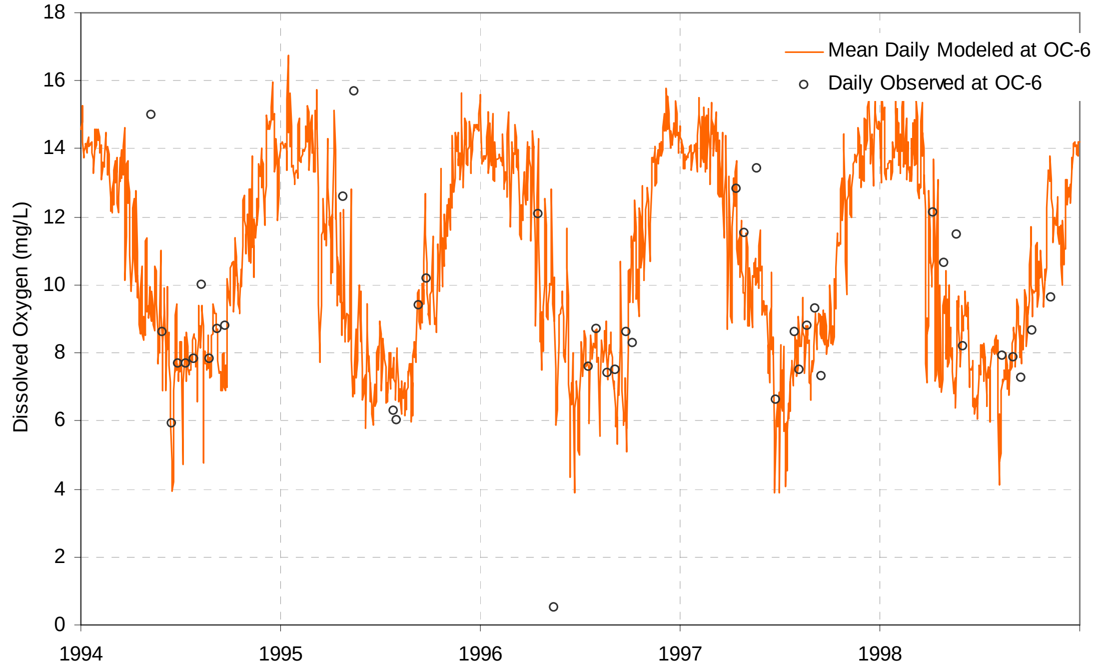


Figure 5-139. Dissolved oxygen time series calibration at Oak Creek Station OC-6.

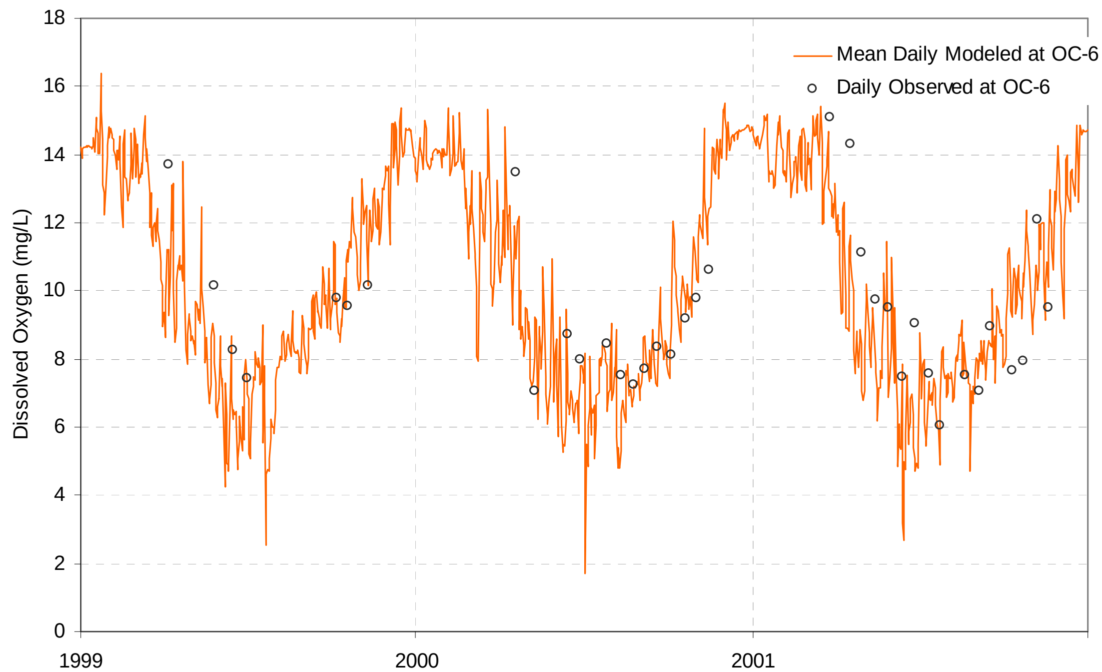


Figure 5-140. Dissolved oxygen time series validation at Oak Creek Station OC-6.

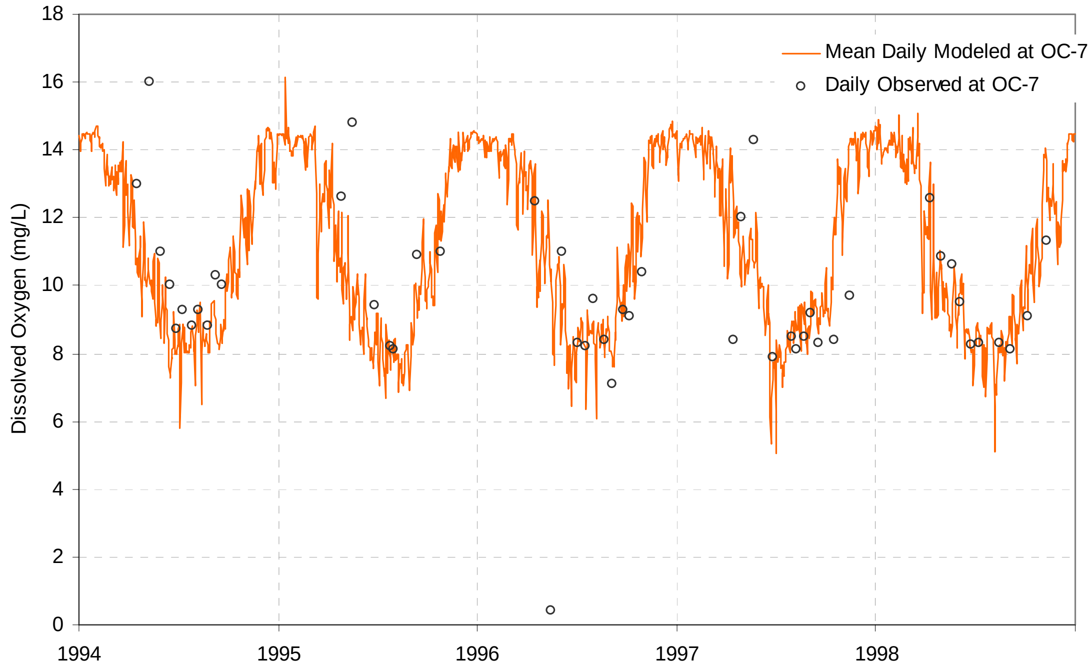


Figure 5-141. Dissolved oxygen time series calibration at Oak Creek Station OC-7.

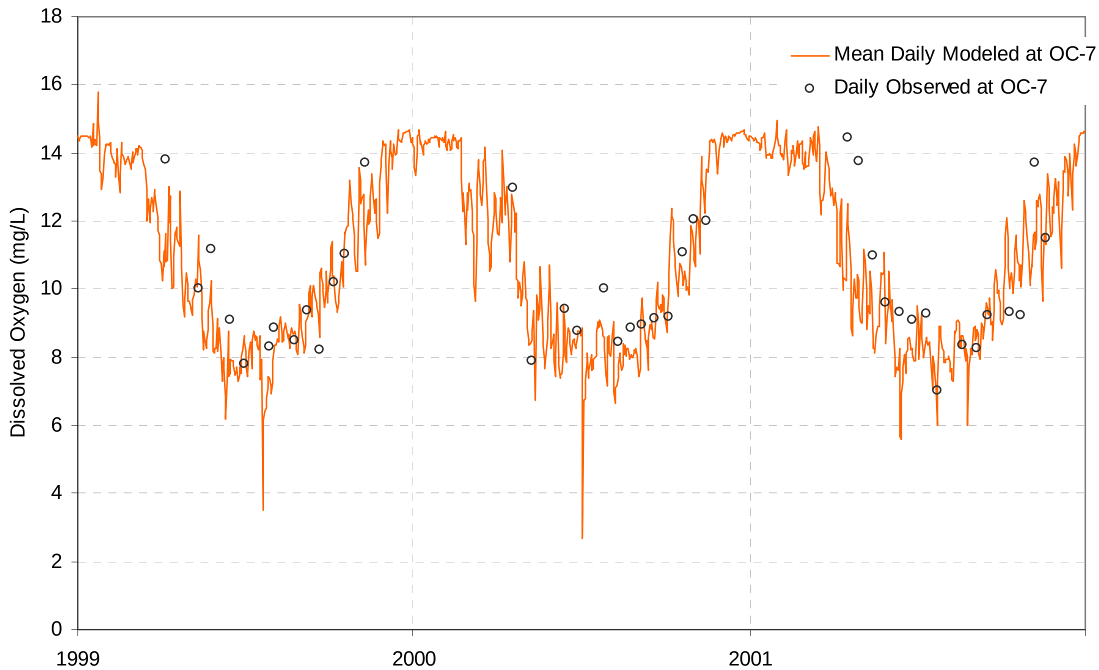


Figure 5-142. Dissolved oxygen time series validation at Oak Creek Station OC-7.

5.6 Fecal Coliform Bacteria

Simulation of fecal coliform bacteria concentrations often presents a challenge for watershed modeling. Observed concentrations tend to be highly variable in both space and time - due to both natural variability and analytical uncertainty. Further, instream concentrations may be elevated by sources which are not explicitly included in the model (e.g., water fowl, wildlife, illicit connections to storm sewers, or illegal dumping into storm drain systems), or which may be included in the model in a general way, but have large and unmonitored variability (e.g., occasional loads from wastewater pumping station spills or malfunctioning septic tanks). The watershed models represent average loads from the land surface as a washoff process. In addition, background loading is represented as a ground water concentration. In fact, the load attributed to ground water includes both true ground water load and other unmodeled sources of loading that are not flow-dependent.

The basis for setup of bacteria export from pervious land surfaces was the Fecal Coliform Loading Estimation spreadsheet. This tool was developed by Tetra Tech and NRCS for the purpose of compiling fecal coliform bacteria based on available local agency and national literature information. For agricultural lands, monthly estimates of fecal coliform loadings were estimated using agricultural census counts, literature values for manure production rates and bacteria counts, and estimates of manure application or deposition. Cattle waste is either applied as manure to cropland and pastureland or contributed directly to pastureland. Cattle are assumed to be either kept in feedlots or allowed to graze (depending on the season). Chicken waste is applied as manure to cropland and pasture. Swine manure is assumed to be collected and applied to cropland only.

Buildup and washoff rates for forest and wetland were not calculated in the spreadsheet, but were instead adopted from the successful application of the Minnesota River models (Tetra Tech, 2002). Loading rates for urban pervious surfaces are constant throughout the year and were derived primarily from estimates of domestic pet densities and pet waste characteristics. Loads from impervious surfaces were tuned to replicate loading predicted by SLAMM for 1995-1997 as described in *Draft Water Quality Calibration Results for the Menomonee River*.

Fecal coliform concentrations in streams during baseflow are simulated based on a combination of recycling from organic sediment and ground water loading. Ground water concentrations were varied on a seasonal basis to reproduce the general pattern of observed dry-weather baseflow concentrations and vary for rural versus urban land use. The baseflow concentration, which is simulated by assigning a ground water concentration, in part represents actual ground water loading, such as may occur from malfunctioning septic systems or leaky sewer lines, but also reflects direct non-washoff additions of bacteria into waterbodies from wildlife, waterfowl, and domestic animals. Ground water concentrations for non-urban pervious land ranged from 25 to 100 colonies per 100 ml, while higher rates were set for urban grass to reflect the potential for contributions from subsurface sewer leaks.

Observed concentrations of fecal coliform bacteria instream are strongly affected by the die off rate of fecal coliform bacteria. As these organisms reside in the mammalian gut, they do not prosper in surface waters. Die off rates are increased by a variety of factors including temperature, sunlight, salinity, settling, and predation. Mancini (1978) suggests a base loss rate of 0.8 per day, with increases above the base rate due to these factors and an Arrhenius temperature coefficient of 1.07. Based on trial and error, a loss rate of 1.15 per day appeared to provide a reasonable fit to observations.

Sorption to sediment may also play an important role in observed fecal coliform concentrations. It is well established (see Thomann and Mueller, 1987, Section 5.3.1) that coliform bacteria may be stored in stream sediment, where they experience a lower die off rate, and diffuse back into the water column, resulting in a slower recovery of stream concentrations to baseflow levels after washoff events. Accordingly, fecal coliform bacteria within stream reaches were simulated as weakly sediment-associated with the silt fraction, and with a lower decay rate (0.165 in reaches with cover, 0.180 in reaches without cover) while in storage in the stream bed.

For general quality constituents, LSPC uses both a sorption coefficient and a sorption rate. In the water column, a high sorption rate was specified, approximating equilibrium sorption. In the sediment, a low value of the sorption coefficient was used (so that all stored bacteria not removed by decay are available for reintroduction into the water column) coupled with a low rate coefficient of 1 percent per day. This allows the model to represent a gradual decline of water column concentrations following an event that loads bacterial contamination into the sediment bed.

Model results for the calibration and validation time periods are provided below (Figure 5-143 to Figure 5-156). Simulation results show a reasonable general agreement between observed and simulated fecal coliform concentrations. However, certain individual observations are under-estimated by the model. This type of phenomenon is commonly found in bacterial models, and may reflect a case in which there are strong local inputs (whether from leaky sewer lines, septic systems, or animals) that are not included in the model representation of diffuse upland sources. Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment A.

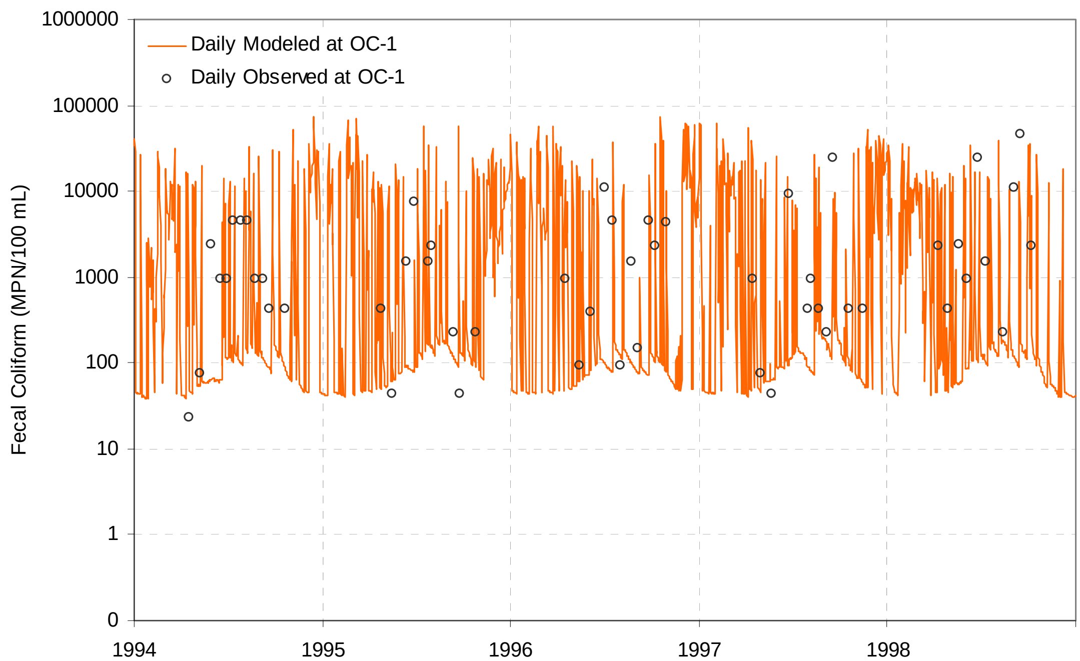


Figure 5-143. Fecal coliform time series calibration at Oak Creek Station OC-1.

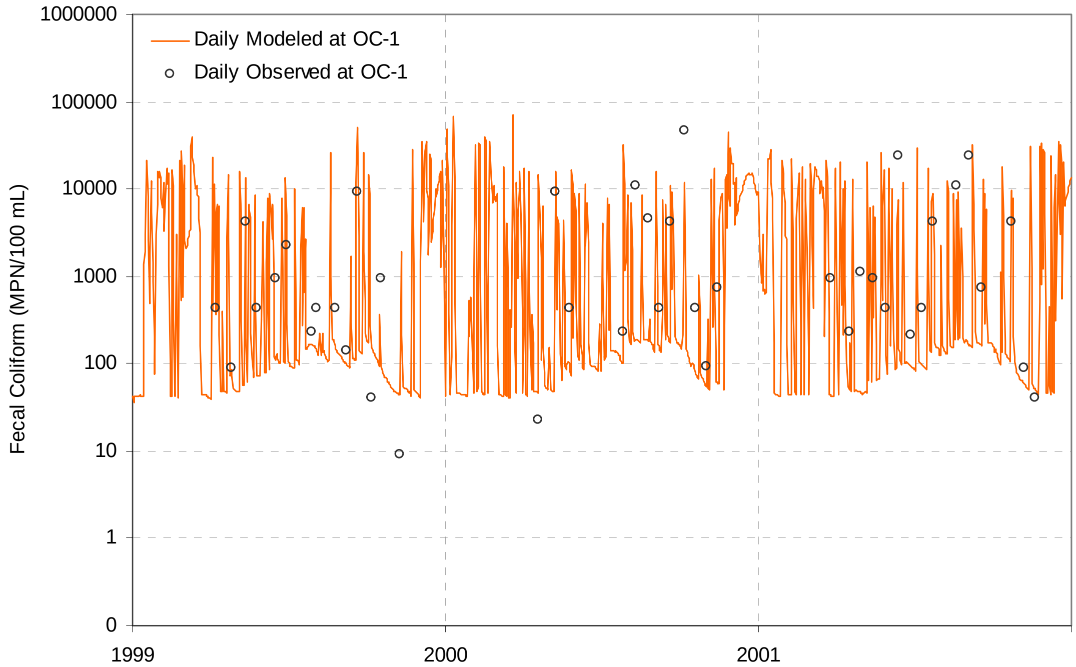


Figure 5-144. Fecal coliform time series validation at Oak Creek Station OC-1.

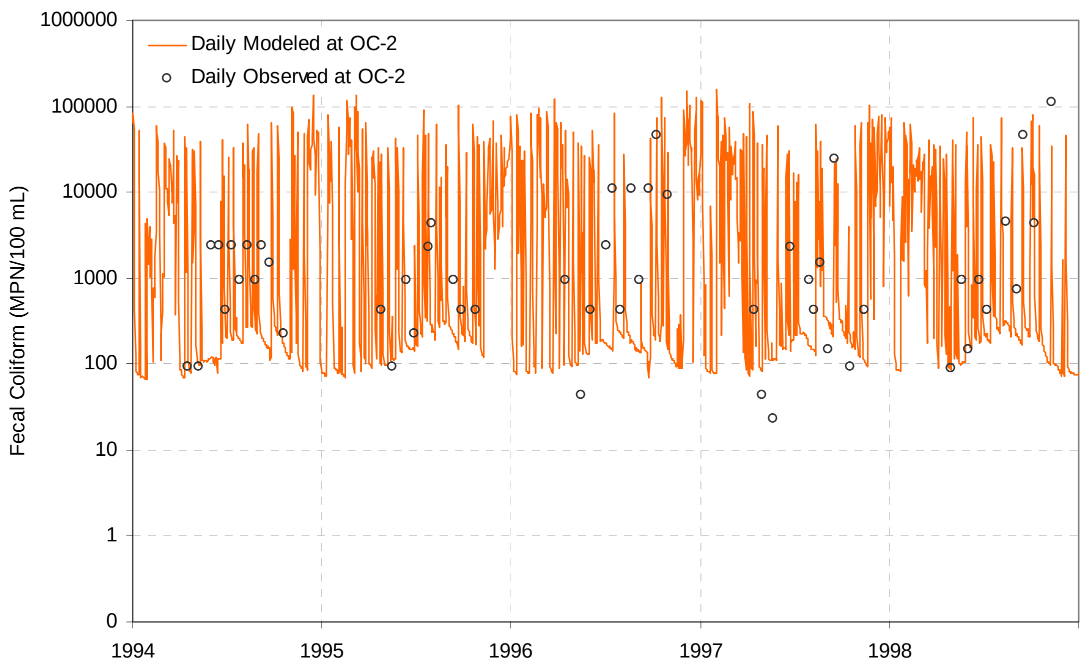


Figure 5-145. Fecal coliform time series calibration at Oak Creek Station OC-2.

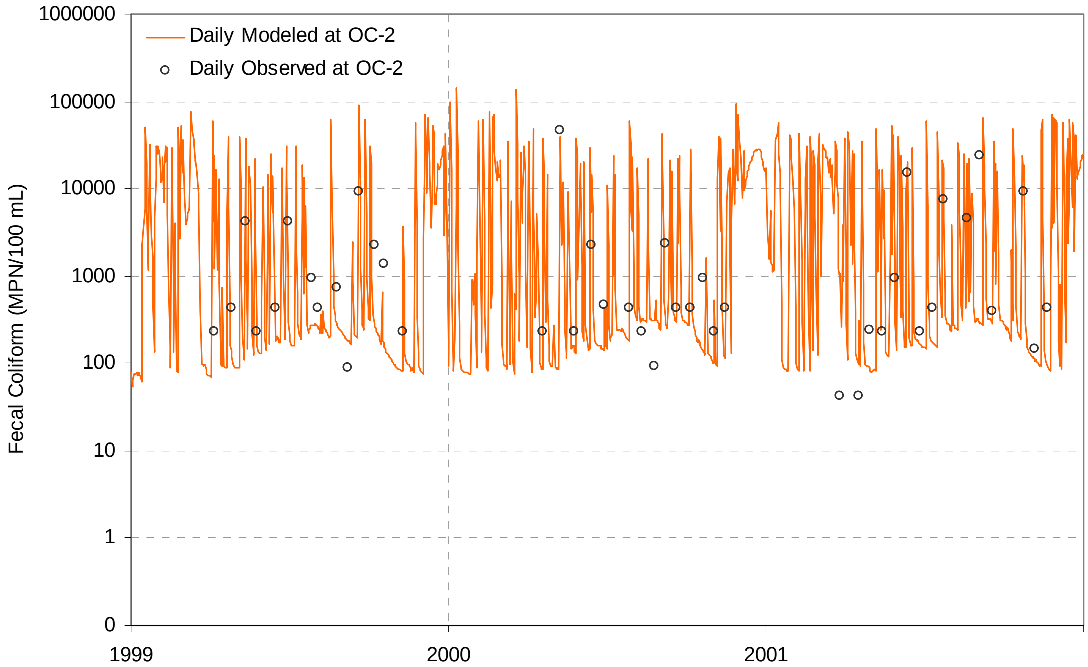


Figure 5-146. Fecal coliform time series validation at Oak Creek Station OC-2.

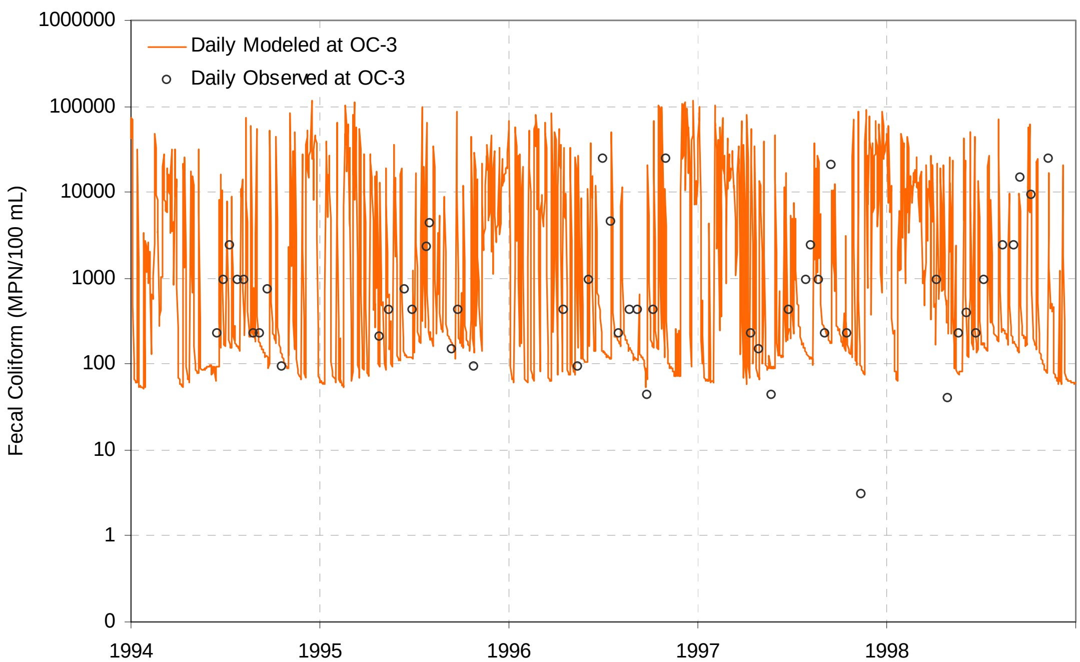


Figure 5-147. Fecal coliform time series calibration at Oak Creek Station OC-3.

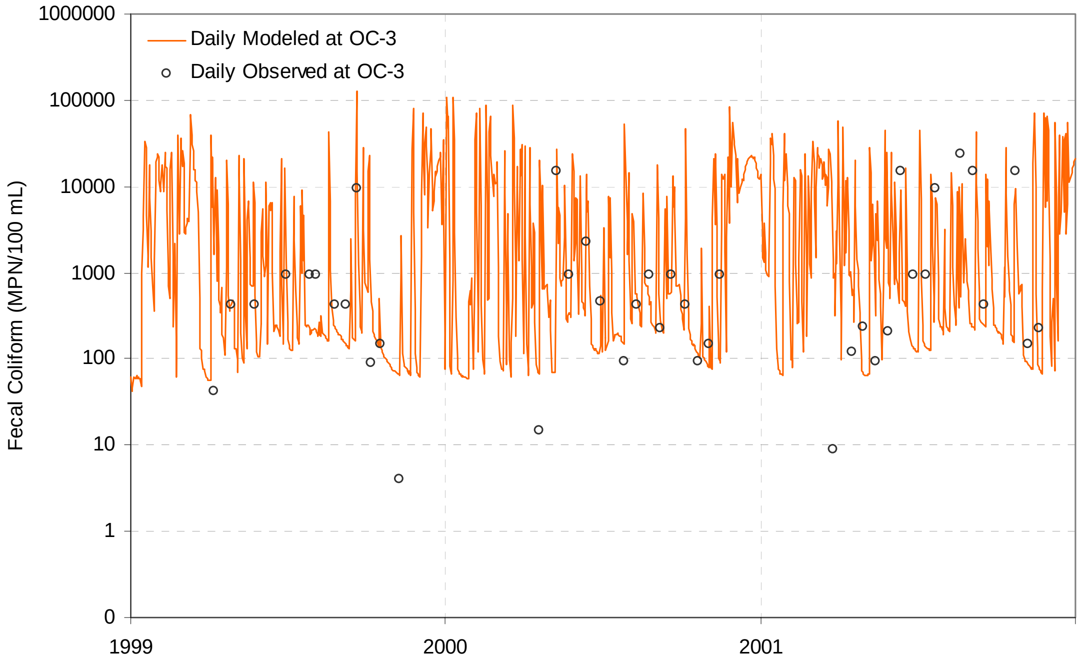


Figure 5-148. Fecal coliform time series validation at Oak Creek Station OC-3.

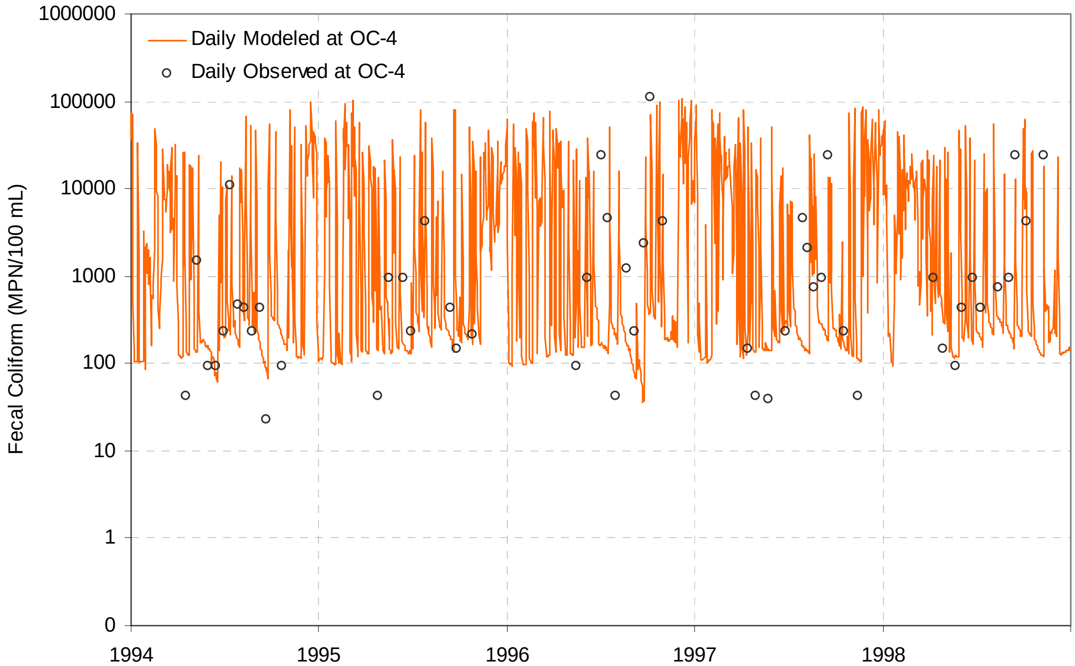


Figure 5-149. Fecal coliform time series calibration at Oak Creek Station OC-4.

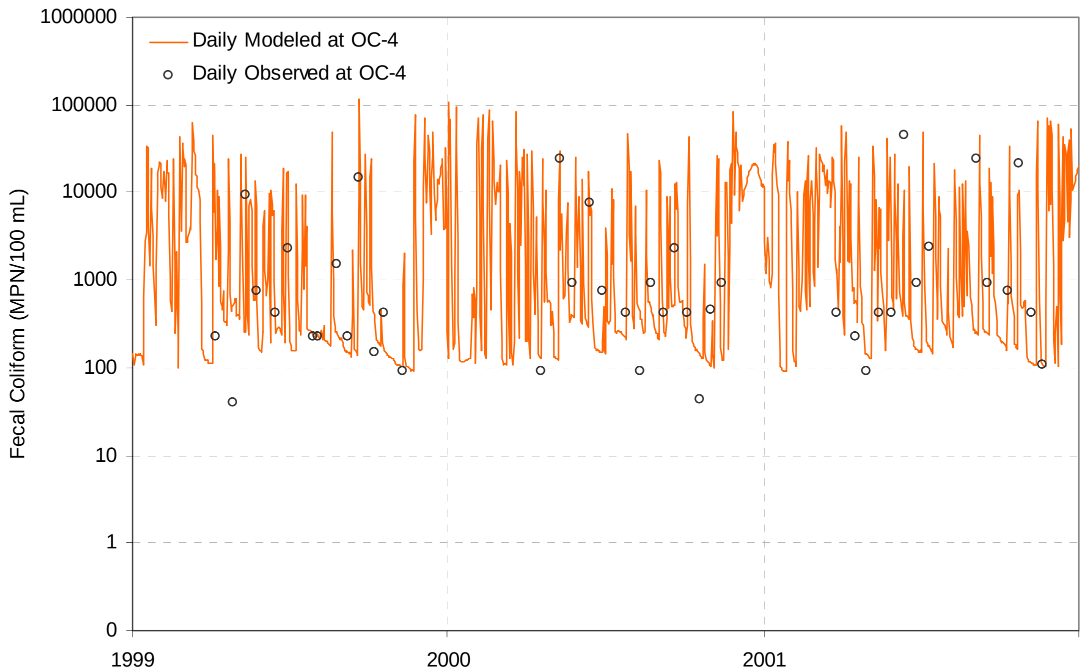


Figure 5-150. Fecal coliform time series validation at Oak Creek Station OC-4.

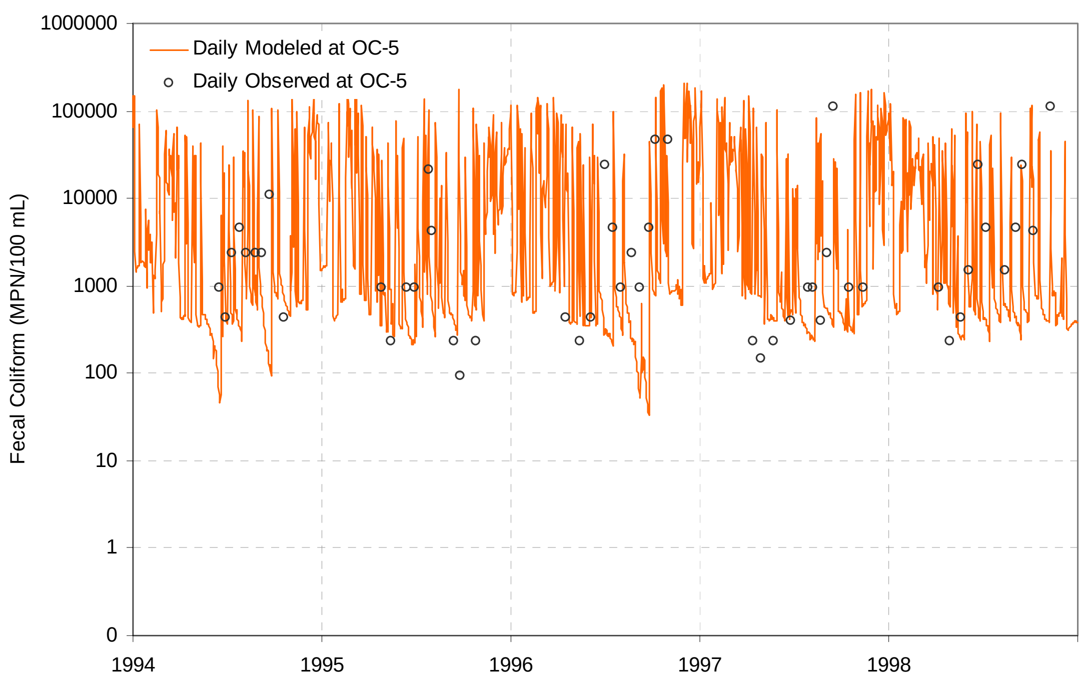


Figure 5-151. Fecal coliform time series calibration at Oak Creek Station OC-5.

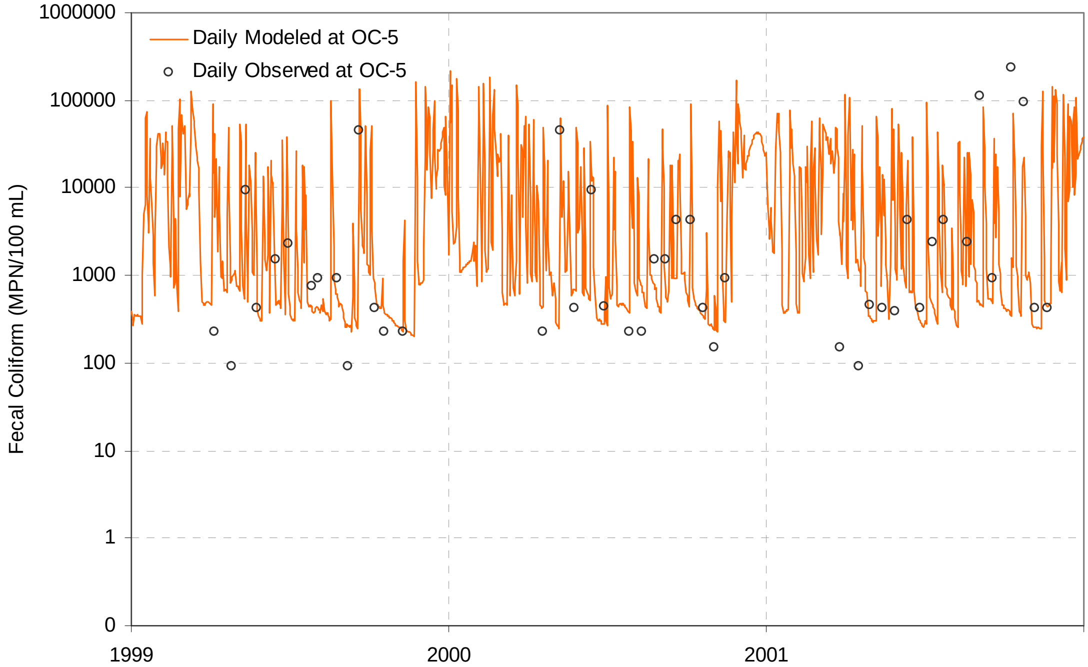


Figure 5-152. Fecal coliform time series validation at Oak Creek Station OC-5.

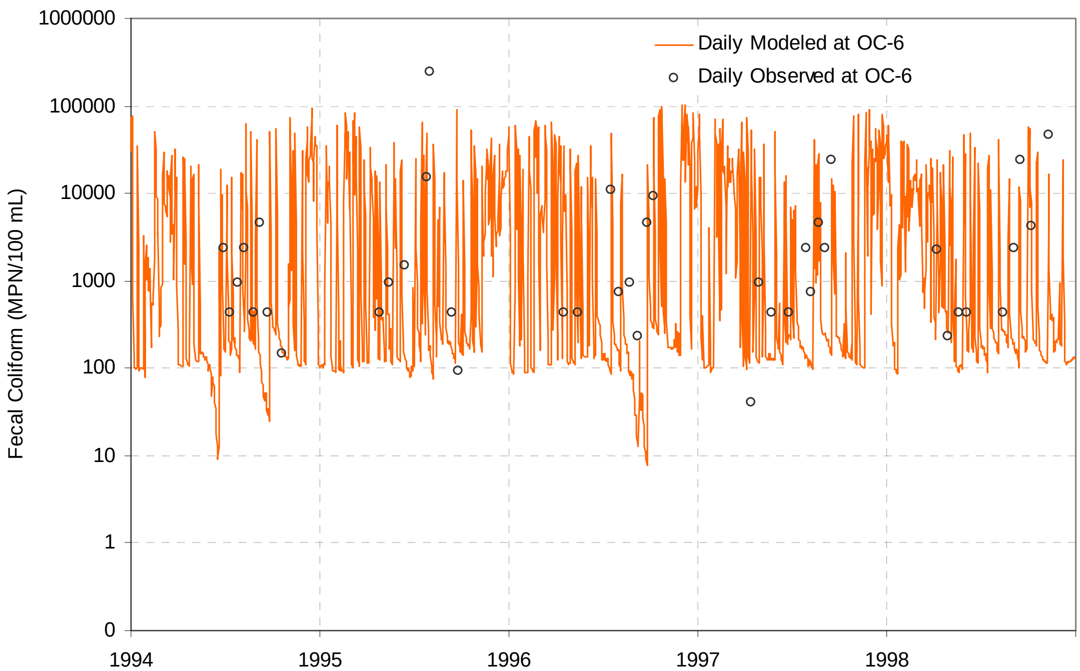


Figure 5-153. Fecal coliform time series calibration at Oak Creek Station OC-6.

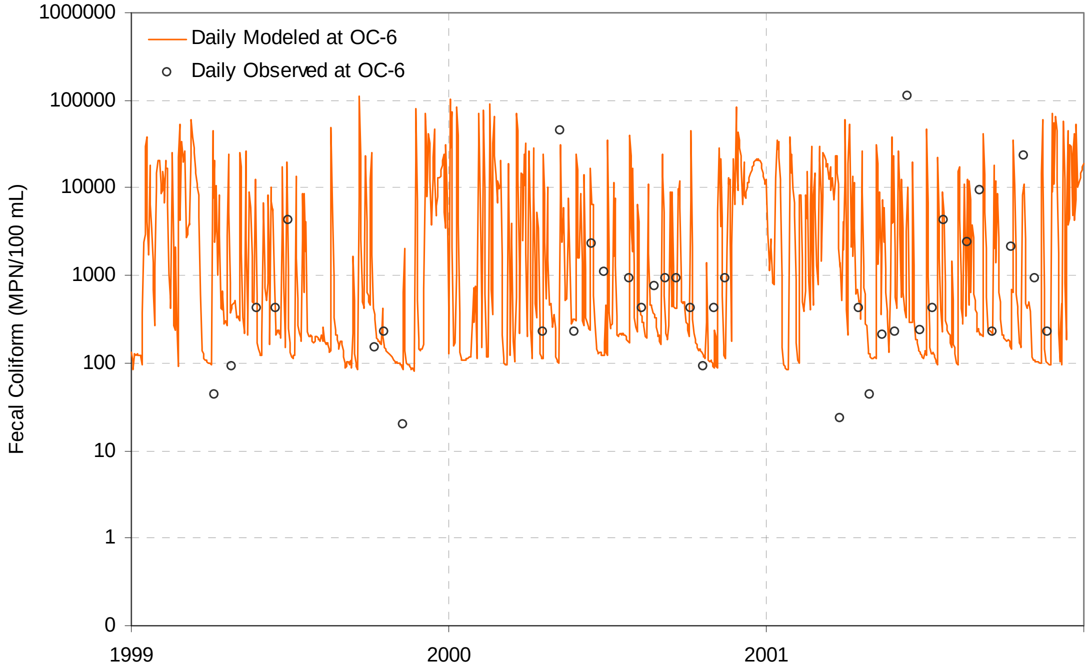


Figure 5-154. Fecal coliform time series validation at Oak Creek Station OC-6.

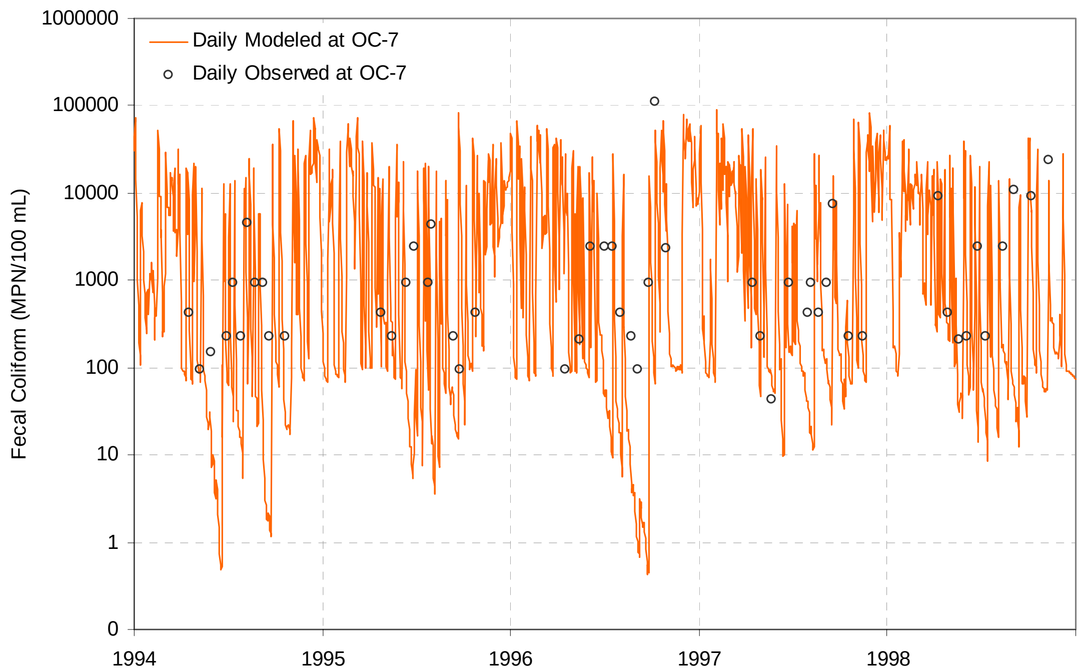


Figure 5-155. Fecal coliform time series calibration at Oak Creek Station OC-7.

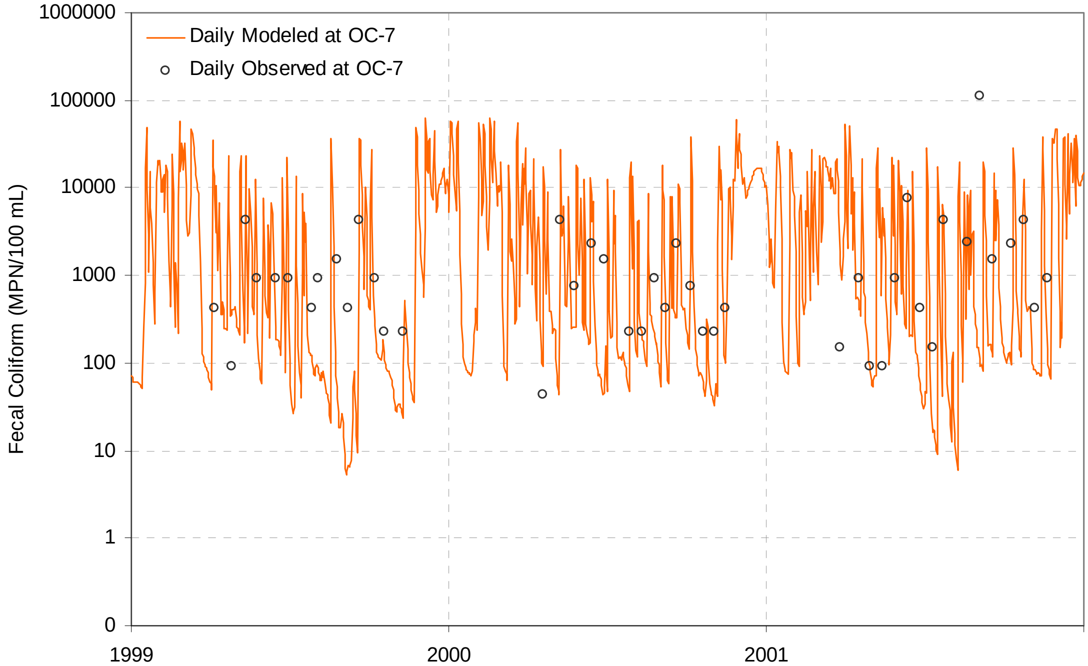


Figure 5-156. Fecal coliform time series validation at Oak Creek Station OC-7.

5.7 Metals

As requested by SEWRPC, the model includes simulations for copper and zinc, but at a highly simplified level. Both copper and zinc are simulated as total metals, and treated as conservative substances within stream reaches. This neglects the actual kinetics of these constituents, which sorb to particulate matter and exchange with the sediments. Such refinements may be added to the model at a future date.

Copper and zinc are also not rigorously calibrated. While there are observations for both total copper and total zinc, many of the observations (particularly for copper) are at or near method detection limits, and thus provide limited information on exact concentrations. Further, neglect of sorption kinetics means that the simulation will only be approximate. Therefore, the strategy was to base the metals simulation on independent loading estimates and adjust these only to the extent necessary to achieve approximate agreement with the range of concentrations reported instream.

For copper and zinc loading from impervious surfaces, the LSPC buildup and washoff rates developed from the SLAMM simulation are used (see February 16, 2004 memorandum entitled *Urban Non-Point Source Unit Loading Rates).* The SLAMM work did not provide estimates of copper loading from pervious surfaces, and use of the buildup/washoff coefficients provided for zinc on pervious surfaces yielded instream concentrations that were more than an order-of-magnitude greater than observed concentrations. Therefore, the starting point for the copper and zinc buildup and washoff coefficients on pervious lands were adopted from a similar model application conducted for Gwinnett County, GA (Tetra Tech and CH2M HILL, 1999).

Use of the Gwinnett County buildup rates for pervious lands and the SLAMM estimates for impervious surfaces directly yielded copper concentrations that are consistent with observations in the Oak Creek. Zinc predictions were still high, however, so a trapping factor of 40 percent (pass-through of 60 percent) was added in the mass-link block for pervious lands. Because zinc is particle reactive, trapping losses in small streams and wetlands is expected, and the factor is consistent with the trapping rate applied to phosphorus. No trapping was applied to copper.

Finally, concentrations in ground water were set at levels sufficient to replicate concentrations observed at baseflow in Milwaukee-area streams (1.3 µg/L total copper and 7.2 µg/L total zinc).

Results for the seven Oak Creek monitoring stations are shown in the following figures and indicate an approximate agreement in range between model predictions and observations. Note that many of the reported values appear to be quantitations at a detection limit of 0.01 mg/L.

As noted above, copper and zinc are simulated as conservative substances in the water column and not rigorously calibrated. For this reason, exceedance plots and load analysis of these constituents are not presented.

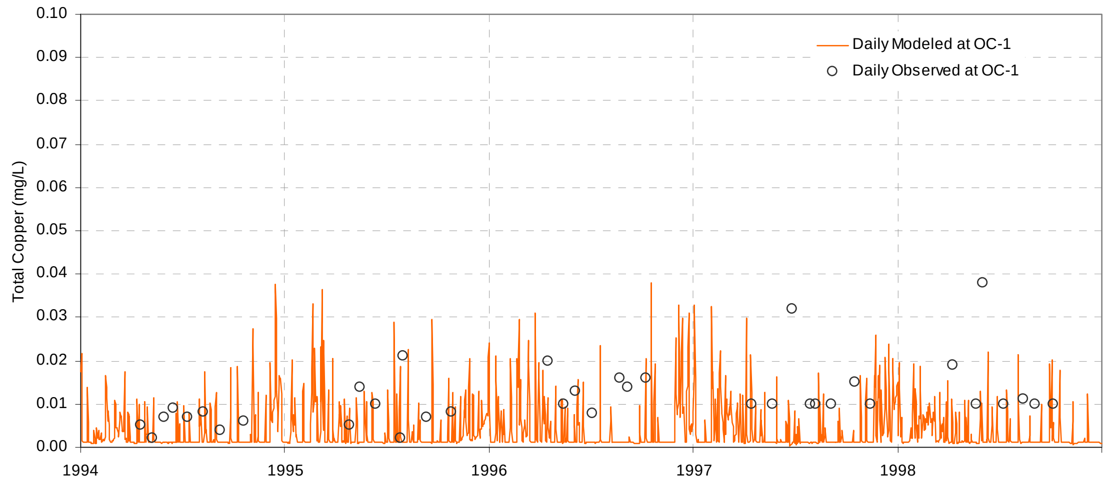


Figure 5-157. Total Copper simulation for calibration period at Oak Creek Station OC-1.

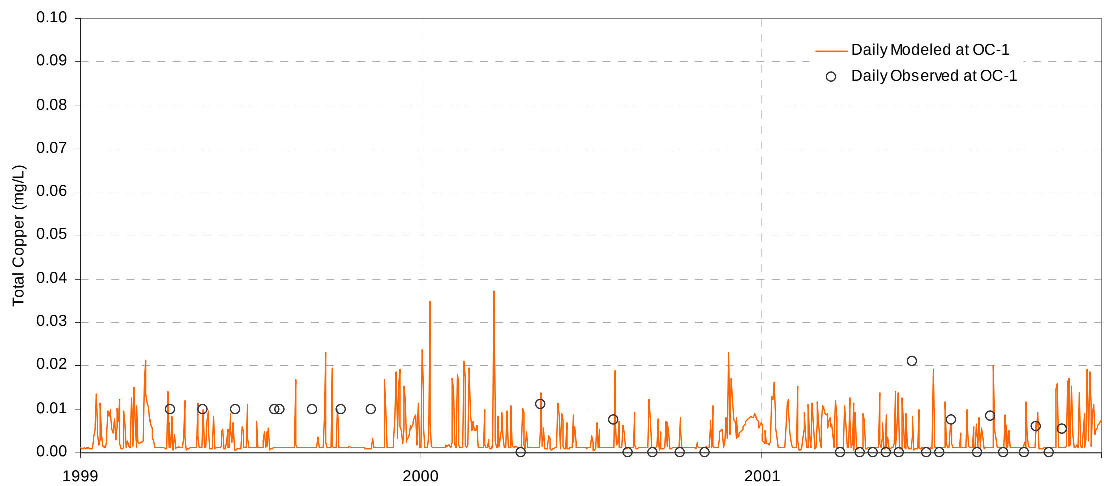


Figure 5-158. Total Copper simulation for validation period at Oak Creek Station OC-1.

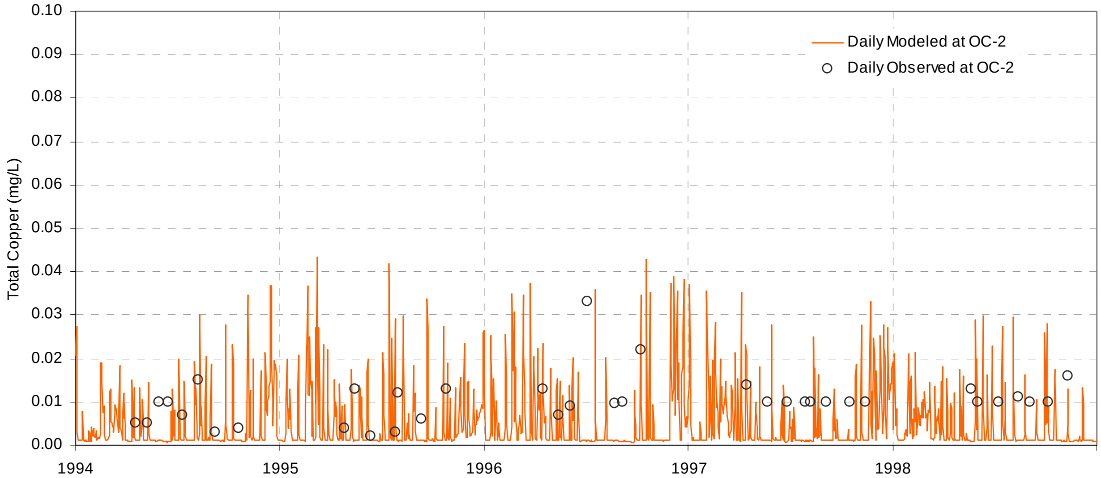


Figure 5-159. Total Copper simulation for calibration period at Oak Creek Station OC-2.

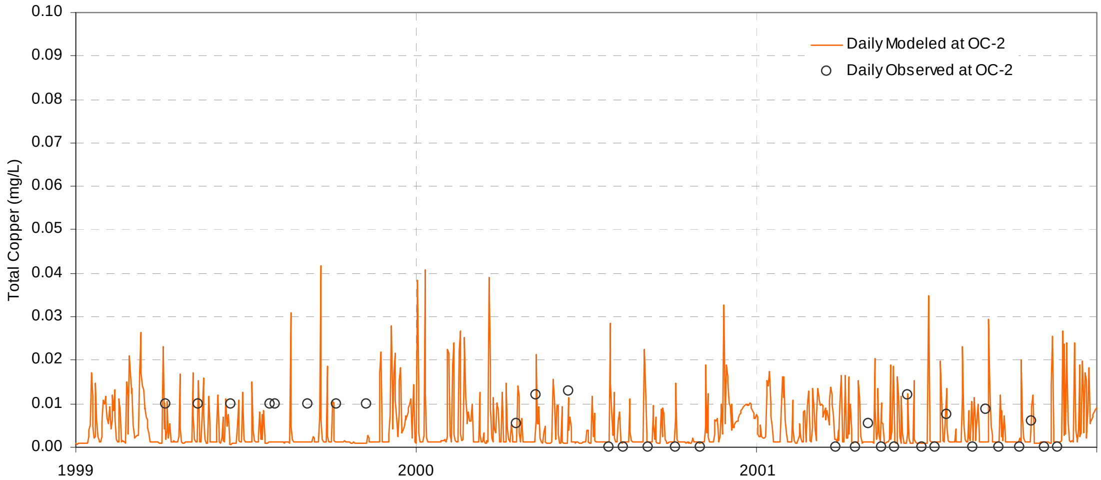


Figure 5-160. Total Copper simulation for validation period at Oak Creek Station OC-2.

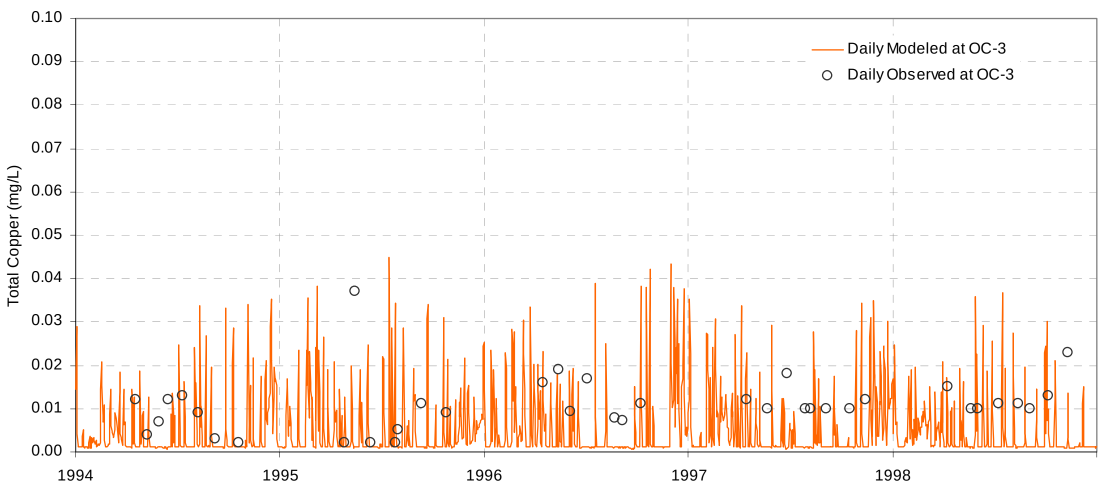


Figure 5-161. Total Copper simulation for calibration period at Oak Creek Station OC-3.

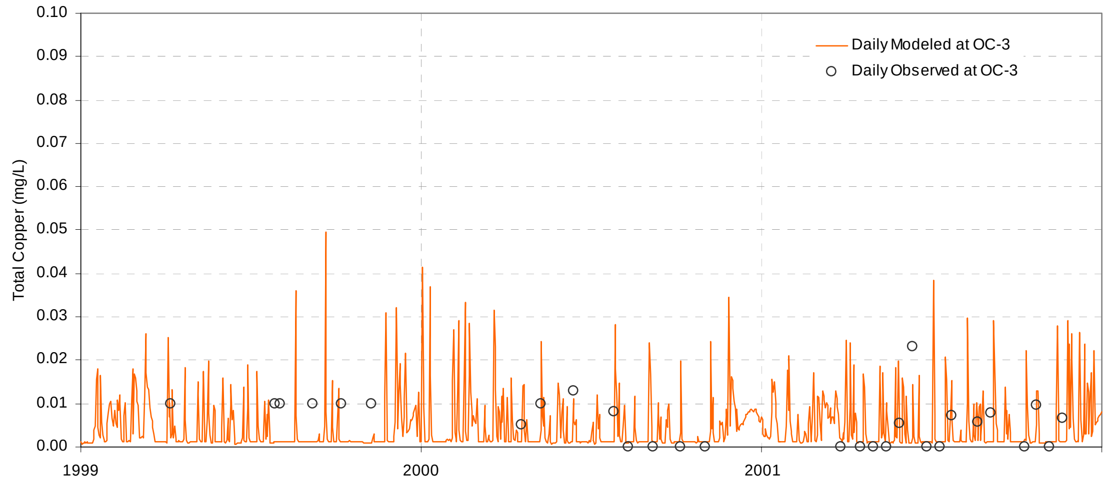


Figure 5-162. Total Copper simulation for validation period at Oak Creek Station OC-3.

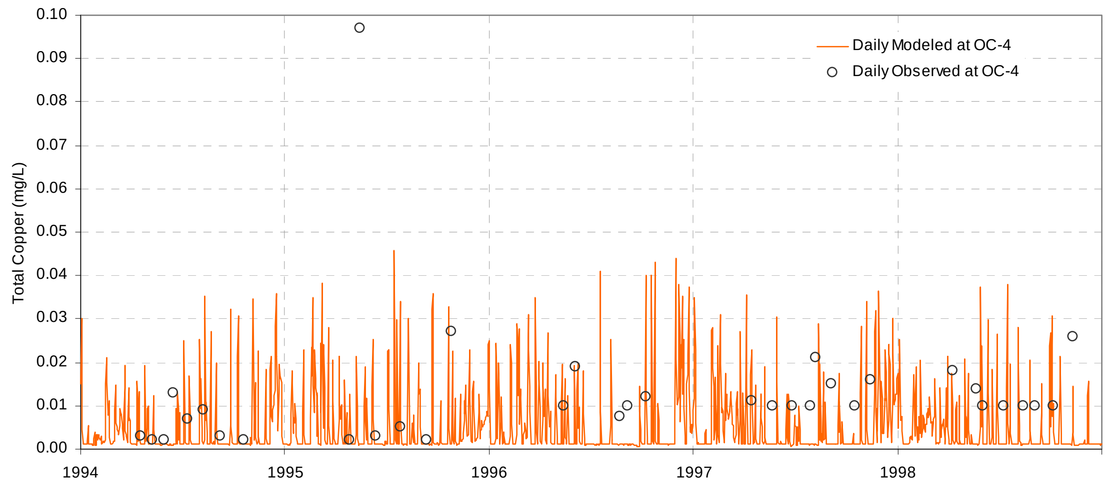


Figure 5-163. Total Copper simulation for calibration period at Oak Creek Station OC-4.

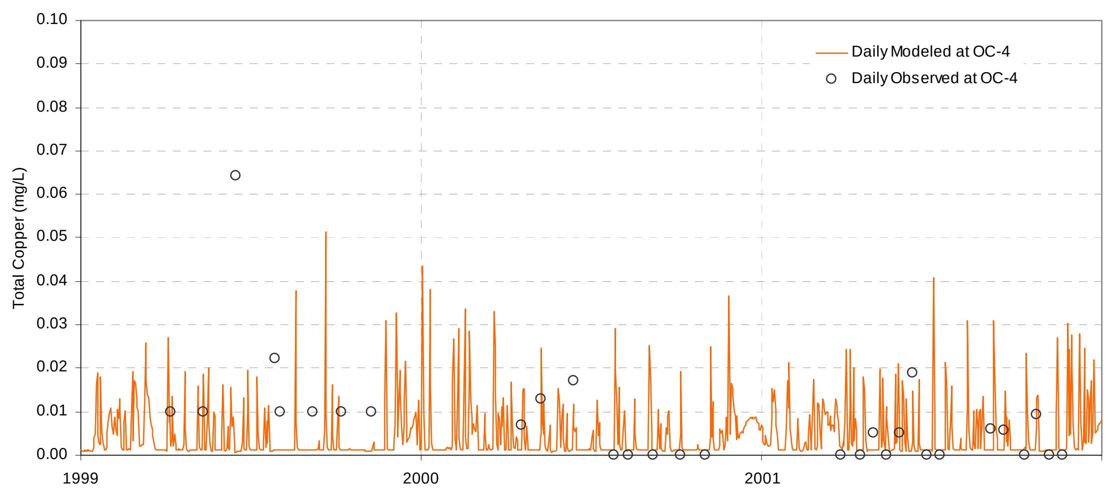


Figure 5-164. Total Copper simulation for validation period at Oak Creek Station OC-4.

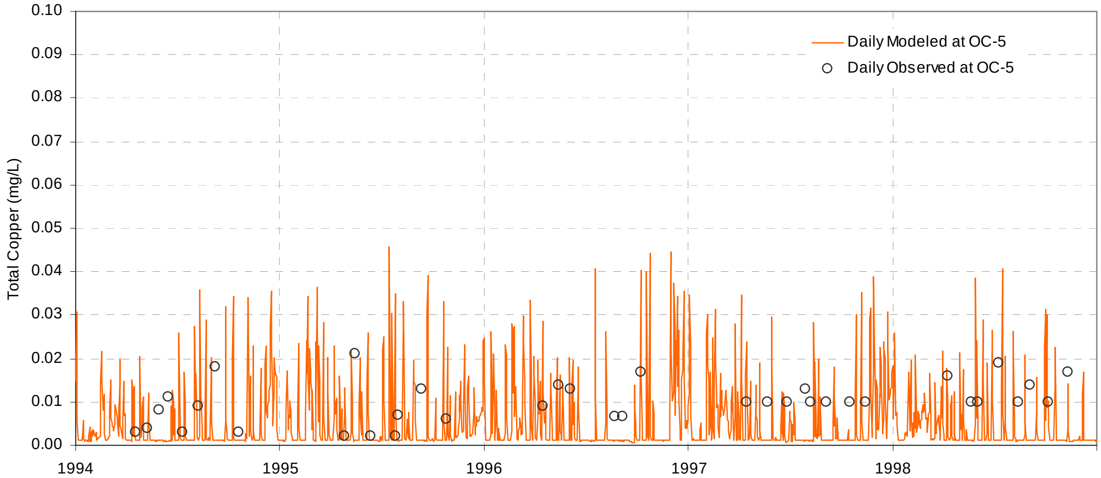


Figure 5-165. Total Copper simulation for calibration period at Oak Creek Station OC-5.

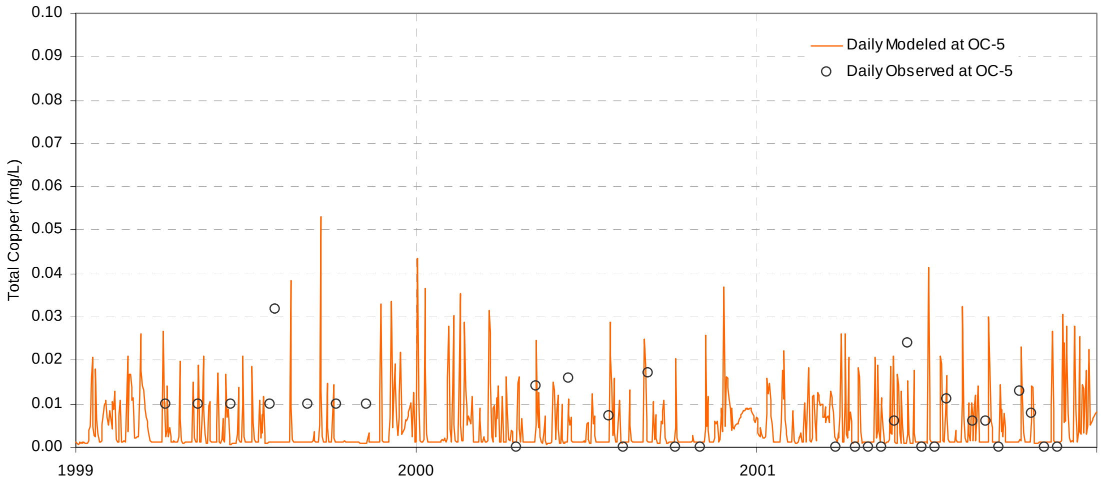


Figure 5-166. Total Copper simulation for validation period at Oak Creek Station OC-5.

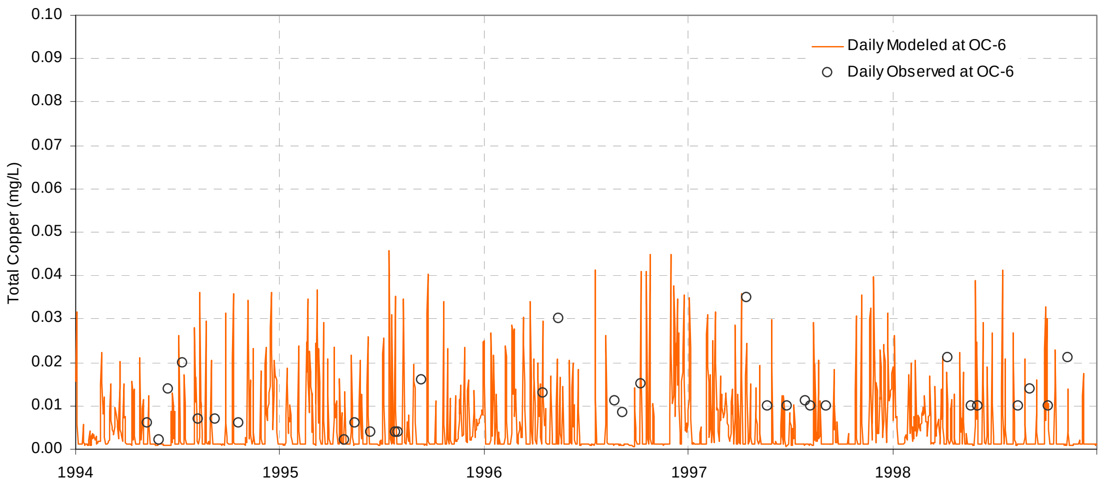


Figure 5-167. Total Copper simulation for calibration period at Oak Creek Station OC-6.

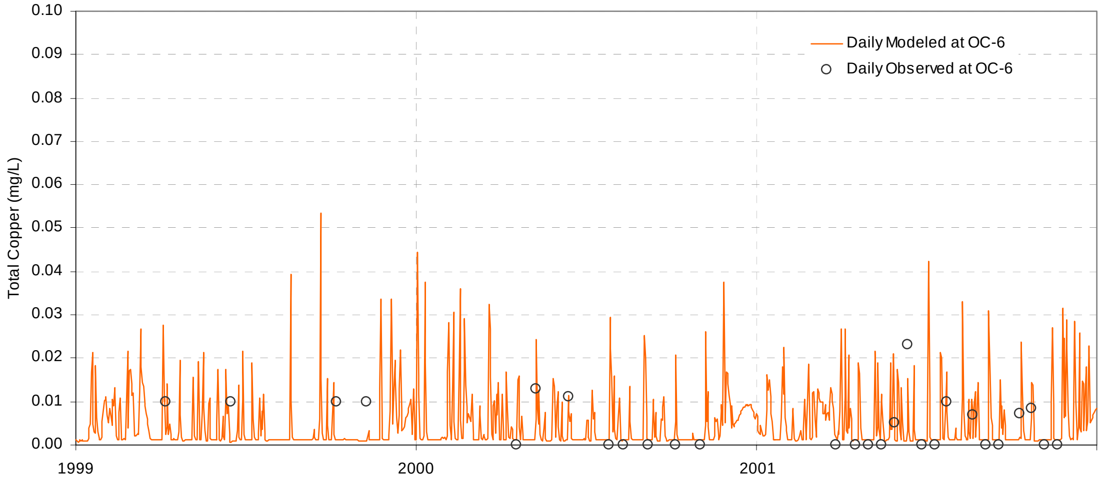


Figure 5-168. Total Copper simulation for validation period at Oak Creek Station OC-6.

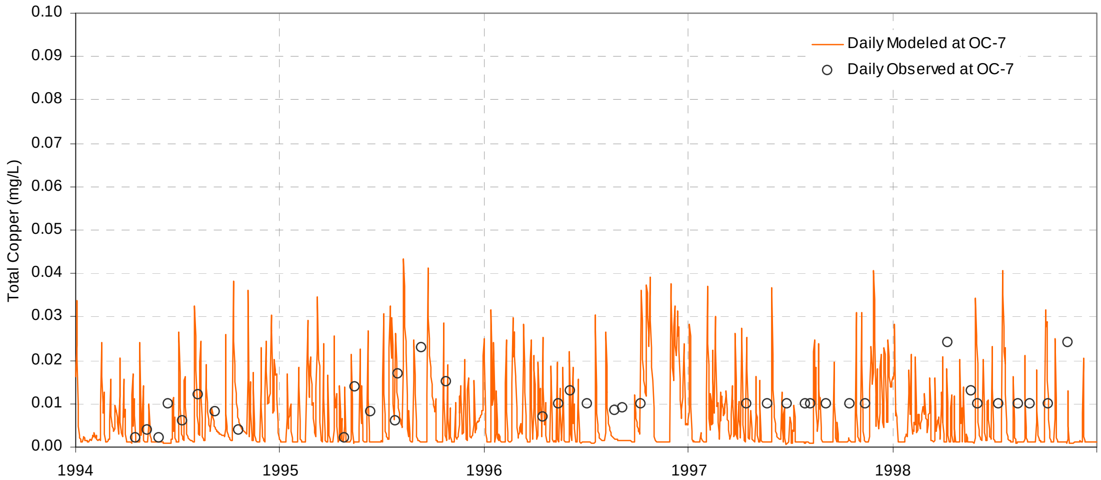


Figure 5-169. Total Copper simulation for calibration period at Oak Creek Station OC-7.

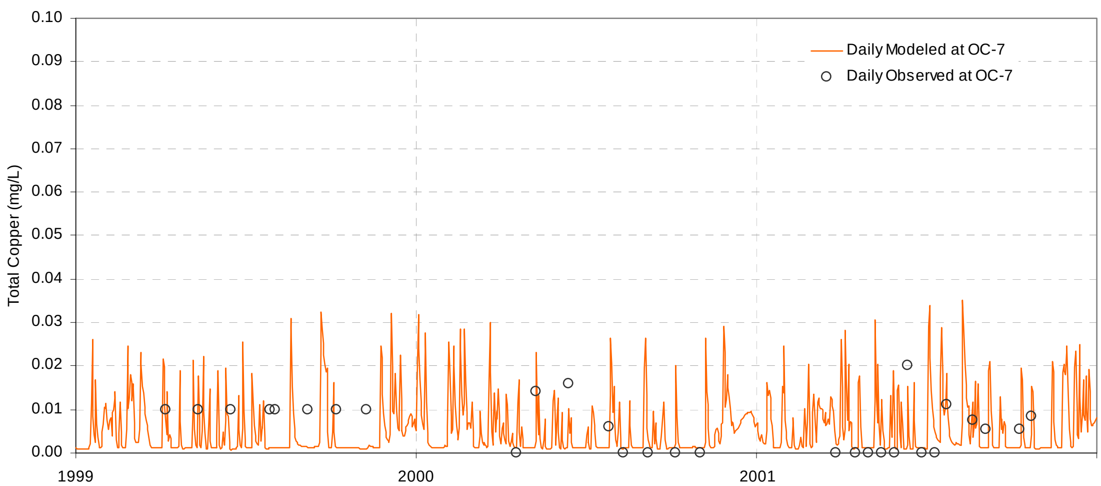


Figure 5-170. Total Copper simulation for validation period at Oak Creek Station OC-7.

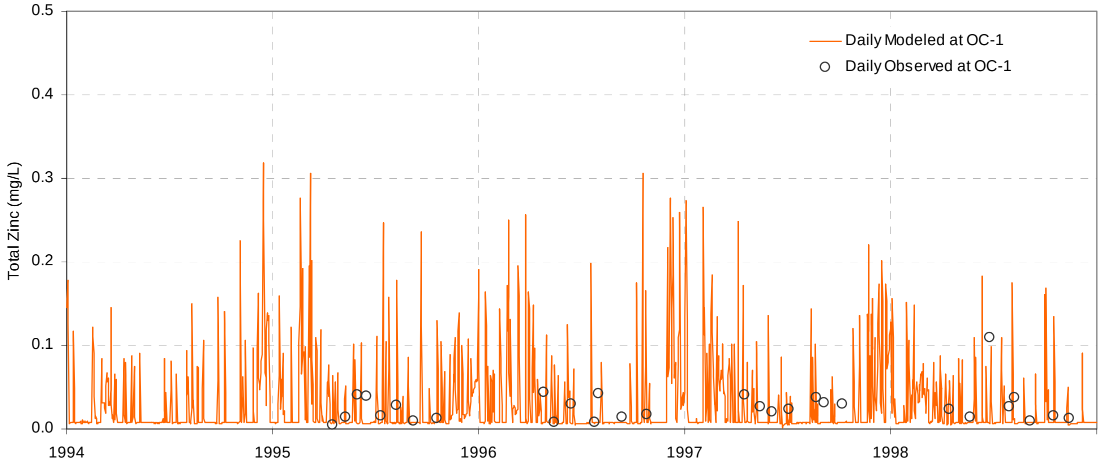


Figure 5-171. Total Zinc simulation for calibration period at Oak Creek Station OC-1.

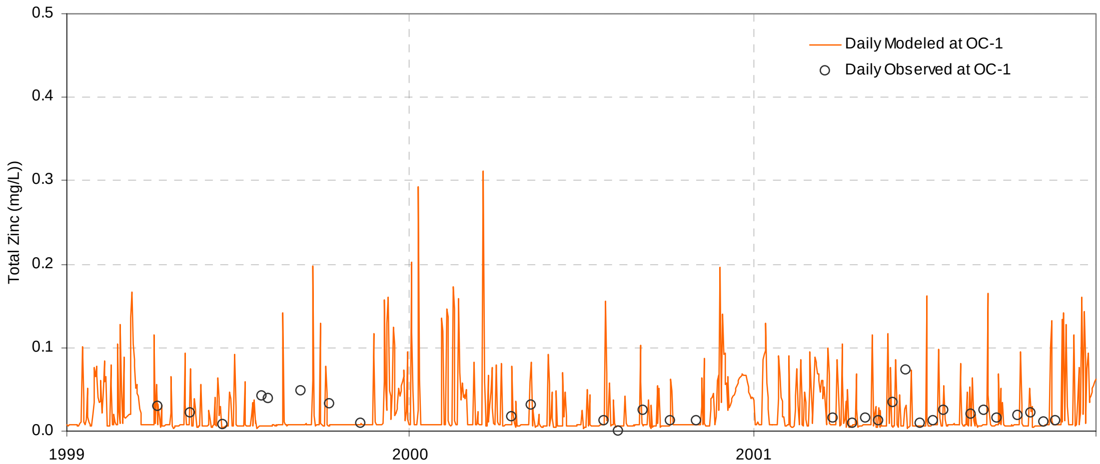


Figure 5-172. Total Zinc simulation for validation period at Oak Creek Station OC-1.

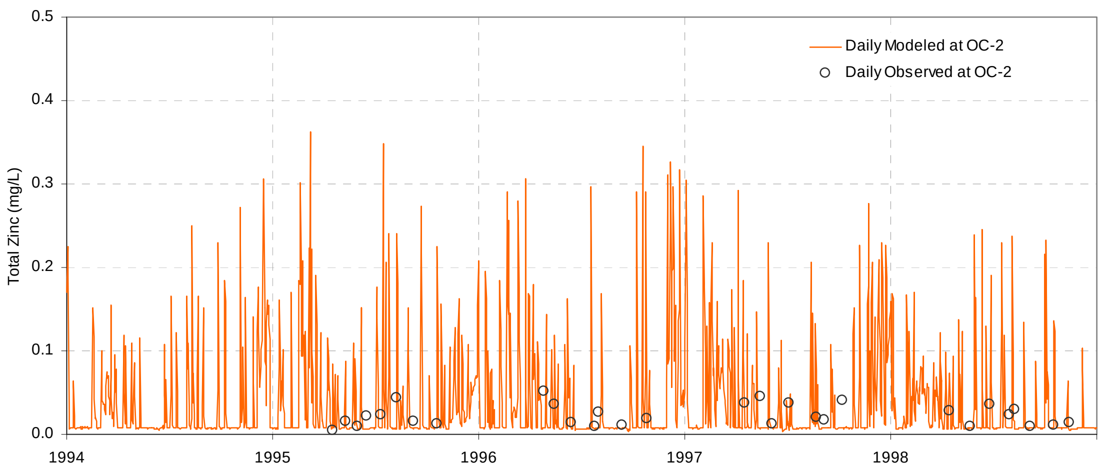


Figure 5-173. Total Zinc simulation for calibration period at Oak Creek Station OC-2.

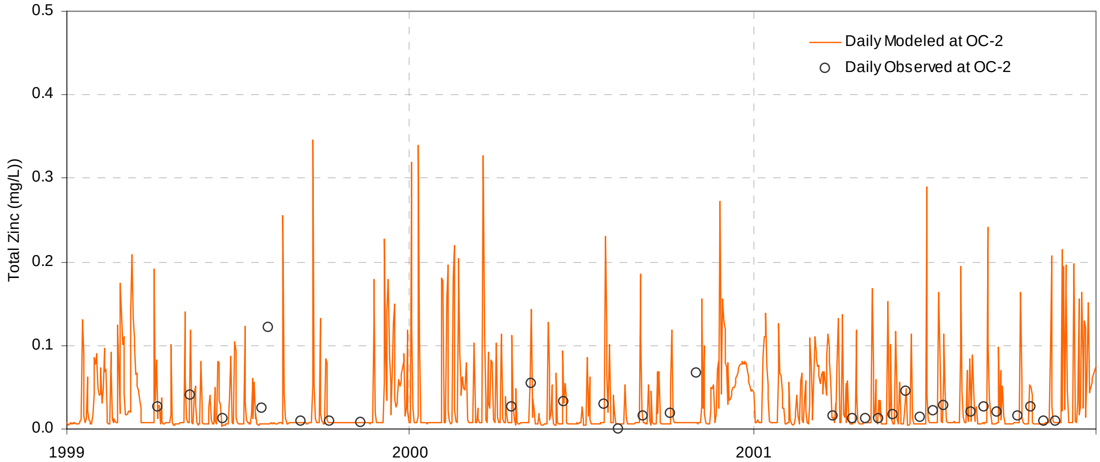


Figure 5-174. Total Zinc simulation for validation period at Oak Creek Station OC-2.

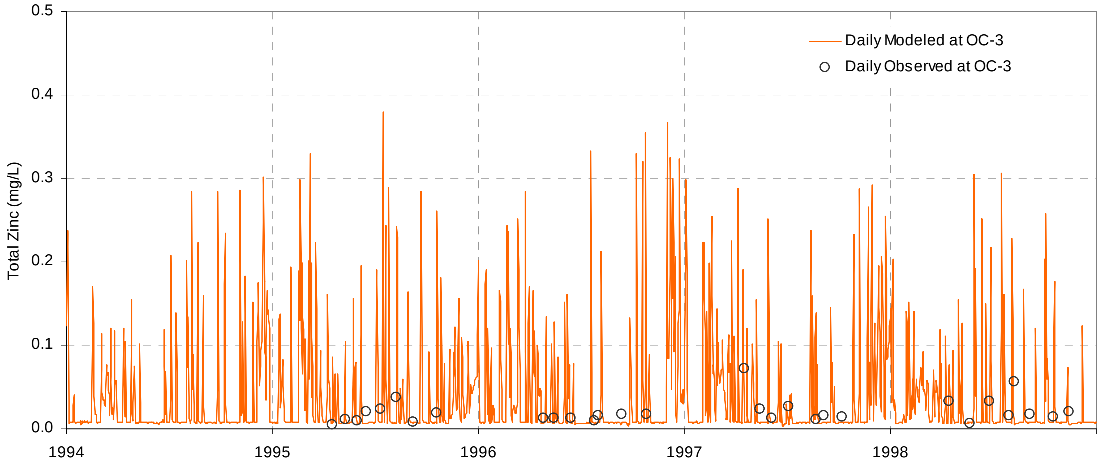


Figure 5-175. Total Zinc simulation for calibration period at Oak Creek Station OC-3.

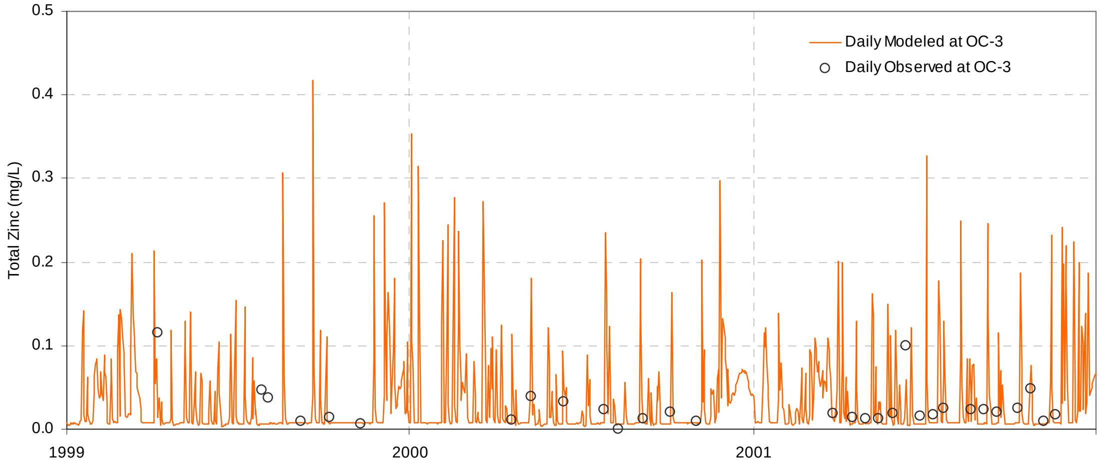


Figure 5-176. Total Zinc simulation for validation period at Oak Creek Station OC-3.

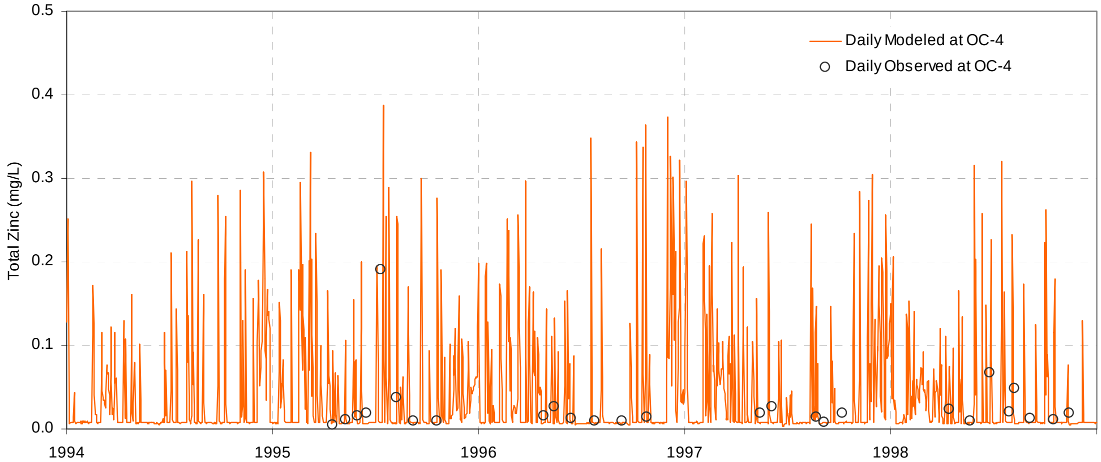


Figure 5-177. Total Zinc simulation for calibration period at Oak Creek Station OC-4.

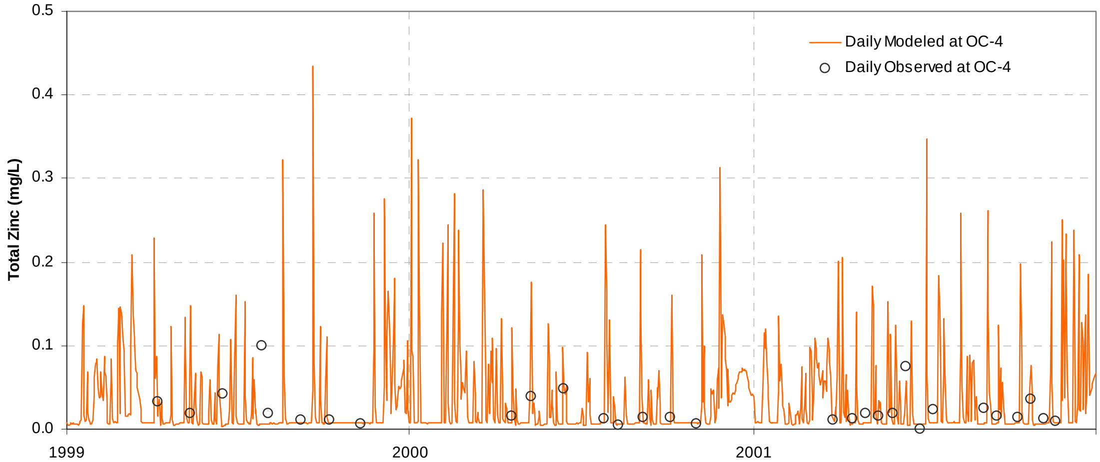


Figure 5-178. Total Zinc simulation for validation period at Oak Creek Station OC-4.

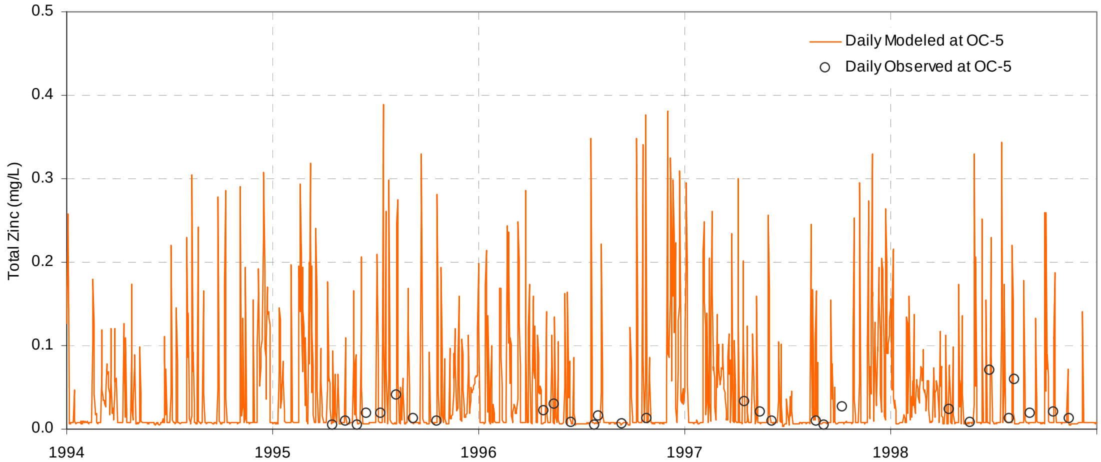


Figure 5-179. Total Zinc simulation for calibration period at Oak Creek Station OC-5.

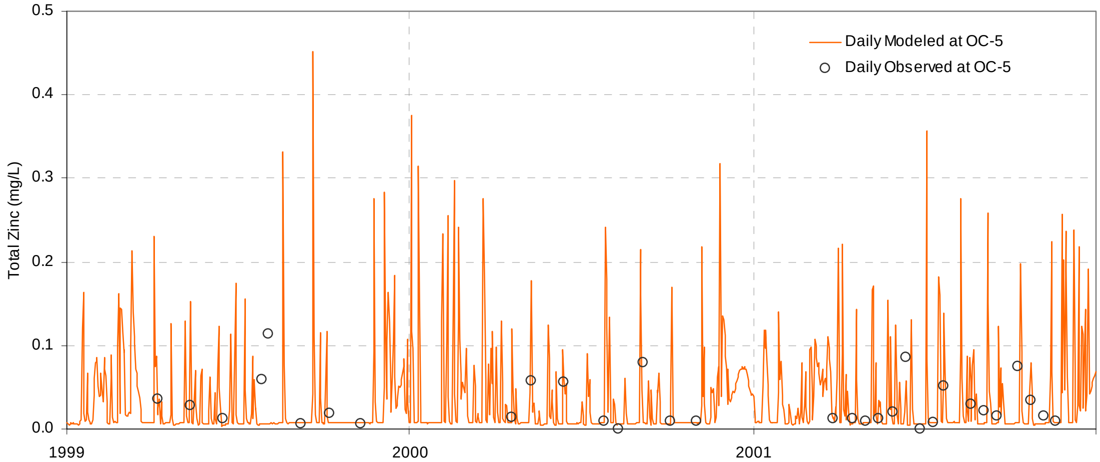


Figure 5-180. Total Zinc simulation for validation period at Oak Creek Station OC-5.

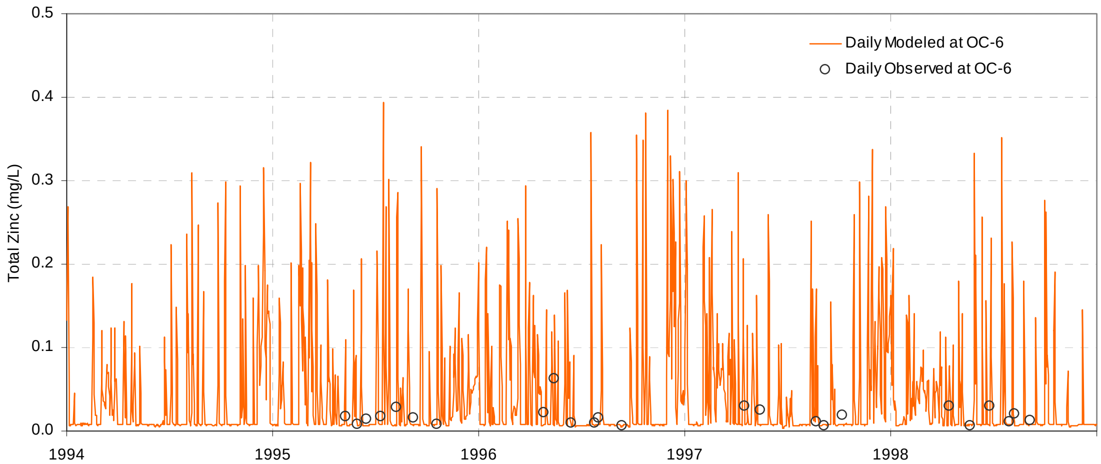


Figure 5-181. Total Zinc simulation for calibration period at Oak Creek Station OC-6.

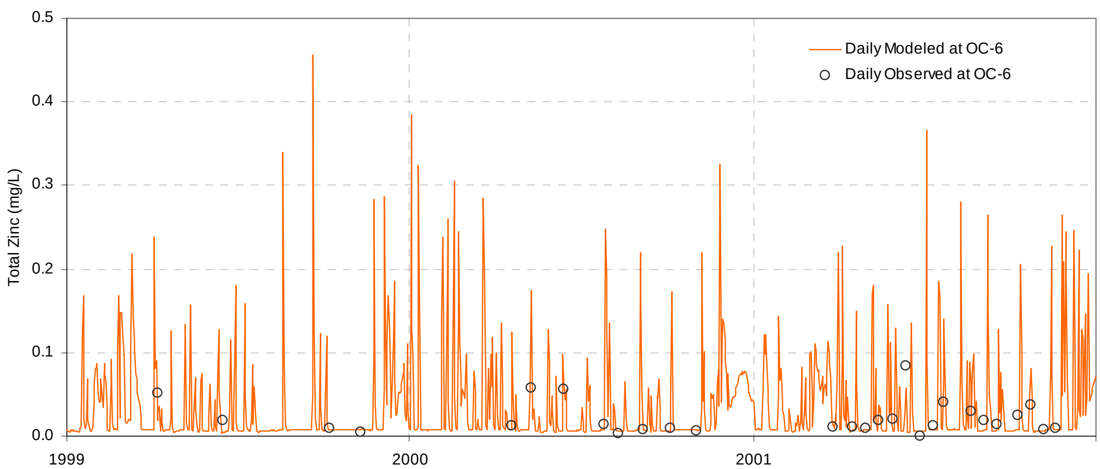


Figure 5-182. Total Zinc simulation for validation period at Oak Creek Station OC-6.

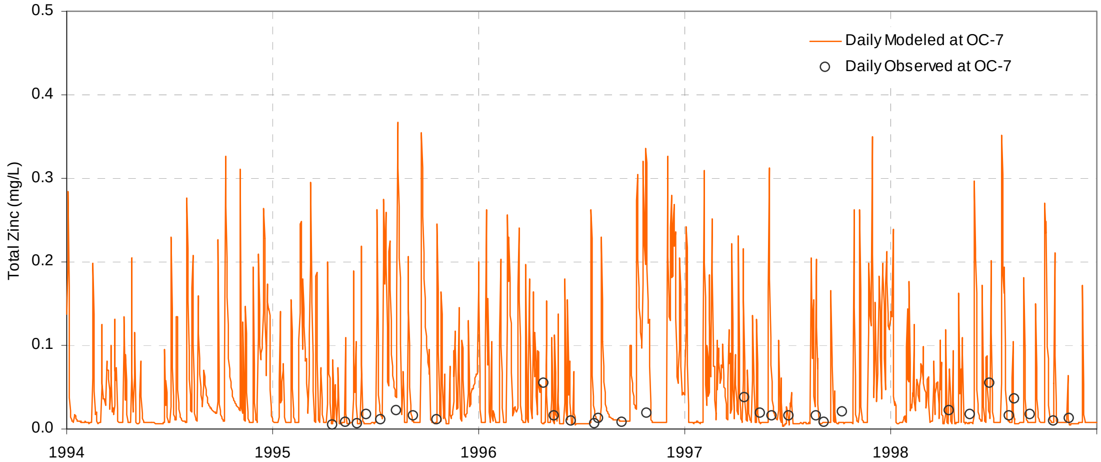


Figure 5-183. Total Zinc simulation for calibration period at Oak Creek Station OC-7.

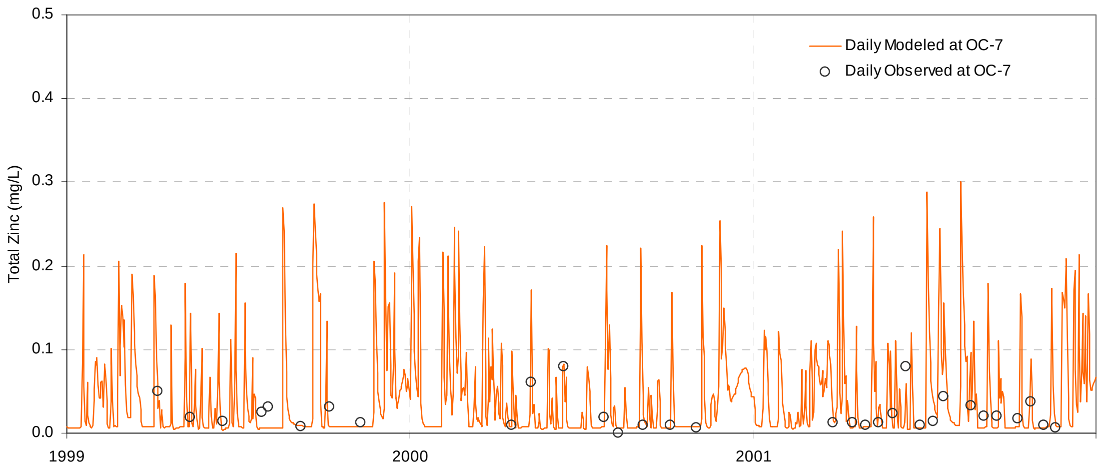


Figure 5-184. Total Zinc simulation for validation period at Oak Creek Station OC-7.

5.8 Statistical Assessment of Concentrations

An ideal simulation model would conclusively prove its credibility by matching exactly every observed data point. Unfortunately, this ideal cannot be achieved, for a variety of reasons. In the first place, any watershed model is a simplification of complex natural processes. Secondly, the model is capable of representing only those events that are specified to it in the forcing functions, which generally represent the response from the land surface of hydrologic events. Events that are unknown to the model, such as illicit discharges, cannot be replicated by the model. Water quality simulation in particular is constrained to be no better than the quality of the simulation of hydrology, which in turn is limited by the availability of representative meteorological data. For instance, a small error in the representation of the timing or magnitude of a surface washoff event can result in apparently large discrepancies between simulated and observed actual concentrations at a given location and point in time. Finally, the observed values also cannot be considered as fixed and certain.

First, there is the possibility of analytical uncertainty in any reported observation that derives from the inherent imprecision of analytical techniques, and, occasionally, from laboratory analysis and reporting errors. Perhaps more importantly, grab samples submitted for chemical analysis represent a specific location and point in time that is not entirely consistent with the spatial and temporal support of the model. LSPC represents waterbodies as discrete reaches, which are assumed to be fully mixed. Real waterbodies vary continuously in both longitudinal and lateral dimensions, as well as in time. A sample taken from a specific location may not be representative of the average concentration across the stream cross section, and even less representative of the average across an entire model reach. Further, a sample taken at a discrete point in time may not be representative of the average concentration that would be observed across a modeling time step – particularly when the sample is taken near a source of discharge or during the course of a runoff event.

Several additional explanations as to why the quality of model fit may differ between simulated and observed data include the following:

- Point sources included in the model generally do not account for temporal changes and may differ between the calibration and validation periods.

- As pointed out in section 5.4.1 in the case of chlorophyll-a concentrations, there may be some inherent physiological processes not accounted for in the model that may be causing the discrepancy between actual versus calibrated and calibrated versus validated comparisons.

For these reasons, it is important to evaluate model performance based on statistical criteria. In essence, the model and observations may differ on individual points, but should be in general agreement over larger spans of time and space. This testing is accomplished using a weight of evidence approach. It is first important to realize that the model uses a single set of parameters, by land use, across the entire watershed, with minimal local adjustments. Thus, achieving an acceptable fit across multiple stations (with one set of parameters) is a better indication of the validity of the model than any discrepancies at individual stations. Second, the model is developed using a calibration/validation approach, in which the model was developed on one set of observations (1994 to 1998), then tested on a subsequent set of observations (1999 to 2001). Where the quality of model fit differs between the calibration and validation periods this may indicate either that the apparent discrepancy is due to random variability or that the discrepancy arises from temporal changes in land use and discharges, which are not included in the model.

Statistical tests are applied to both concentrations and estimated loads. Both comparisons are important, and reveal different features of the model. For instance, a simulation that is problematic with regard to concentrations but provides a good estimate of loads can be judged as providing a good representation of pollutant source loading that is corrupted by a sub-optimal representation of the timing of their delivery.

The primary test for model performance on concentrations is a Student's *t*-test of equality of means over the entire calibration or validation period. (There are not sufficient data to adequately evaluate performance on individual seasons or years, particularly given the presence of analytical and sampling uncertainty.) In these tests, the equality of observed and sample means on paired daily average data is taken as the null hypothesis or a rebuttable proposition. That is, model performance is judged acceptable unless the statistical analysis proves otherwise.

The *t*-test is developed on assumptions that samples are drawn from a normal distribution and the variances are equal across distributions. Both of these assumptions are not met for various observed and simulated parameters in Oak Creek. However, the tests presented here are on means, not individual observations, and the distribution of means converges to a normal distribution under the Central Limit Theorem. Further, Box et al. (1978) have shown that the *t*-test is somewhat robust against violations of the assumptions of normality and equality of variances.

Tests for equality of means, at each station, for the calibration and validation periods are presented in Tables 5-1 and 5-2. A probability value less than 5 percent is judged to represent proof of a discrepancy between the model and data – although it does not reveal to what extent the discrepancy is the result of the model and to what extent it is a result of the data. Also note that this test does not address whether the difference, even if statistically significant, is meaningful in terms of environmental impact.

Across multiple parameters and stations, the model meets the *t*-test criteria in a majority of cases for both the calibration and validation periods. The quality of model fit is further buttressed by a good agreement between simulated and estimated loads (Section 5.9). An additional evaluation of the model quality of fit for individual observations was conducted by plotting observations against simulated results with confidence bounds that represent one and two standard deviations for the day. The standard deviations are calculated on a daily basis from the sub-daily model output. The confidence limits are assumed to be either normally or lognormally distributed based on the distribution which most reduces skew (in most cases, log transformation reduces skew as is common for environmental data that are constrained to be greater than or equal to zero and contain sporadic high values associated with washoff events). Comparison can be made both visually and by tabulating the number of observations that fall within one and two-standard deviation confidence limits. These results are provided in Attachment C and summarized in Table 5-15.

There are parameter-location contrasts for which the model-data comparison does not pass the statistical criterion. Where both the inequality and the direction of deviation is consistently shown in both the calibration and validation tests, there may be a need for additional investigation and potential model improvement (unless the unrepresentativeness is due to the sampling location not being a good indicator of conditions in the model reach as a whole). On sum, however, the model is believed to provide a reasonable representation of water quality processes in Oak Creek that is suitable for the evaluation and comparison of management scenarios.

Table 5-1. Oak Creek Station OC-1 Concentration Calibration Statistics (1994-1998).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	30.151	0.497	0.289	1.453	0.023	0.087	6.408	2.316	7.740	3640.151
	Paired Simulated	12.983	0.519	0.150	1.696	0.016	0.056	5.866	2.400	6.563	2739.602
	Full Simulated	12.723	0.496	0.161	1.520	0.024	0.073	8.294	2.516	5.090	4974.261
Median	Observed	20.000	0.290	0.280	1.165	0.010	0.060	5.900	2.000	2.400	930.000
	Paired Simulated	7.930	0.520	0.131	1.781	0.005	0.032	6.470	1.987	7.627	103.518
	Full Simulated	7.712	0.426	0.115	1.379	0.005	0.030	8.505	1.704	4.530	138.293
Standard Deviation	Observed	32.976	0.484	0.155	1.044	0.024	0.078	2.922	1.476	25.209	7752.471
	Paired Simulated	15.331	0.252	0.150	0.650	0.028	0.071	3.035	1.890	3.782	7474.261
Count		53	53	53	52	50	53	51	51	53	53
Mean Error		17.168	0.022	0.140	0.244	0.007	0.031	0.542	0.083	1.177	900.549
Mean Absolute Error		22.383	0.281	0.190	0.794	0.024	0.064	1.995	1.117	8.877	5328.662
Mean Squared Error		1,266.907	0.201	0.053	1.331	0.001	0.011	7.280	3.408	623.792	112417250.422
RMSE		35.594	0.448	0.231	1.154	0.037	0.103	2.698	1.846	5.265	10602.700
pval, paired t-test		0.0002	0.727	0.000	0.129	0.180	0.299	0.153	0.751	0.735	0.541
Alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		True	False	True	False	False	False	False	False	False	False
Pass t-test?		No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 5-2. Oak Creek Station OC-2 Concentration Calibration Statistics (1994-1998).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	27.094	0.371	0.164	1.074	0.033	0.083	7.741	2.093	3.070	6004.736
	Paired Simulated	26.455	0.485	0.164	1.505	0.025	0.070	7.575	2.470	4.914	6064.481
	Full Simulated	18.538	0.477	0.173	1.376	0.033	0.085	9.751	2.569	3.473	10311.443
Median	Observed	22.400	0.300	0.080	0.966	0.030	0.080	7.100	2.000	2.390	930.000
	Paired Simulated	8.463	0.464	0.122	1.544	0.009	0.031	8.150	1.839	3.254	199.573
	Full Simulated	8.271	0.409	0.113	1.225	0.012	0.031	10.219	1.652	1.904	298.131
Standard Deviation	Observed	26.098	0.317	0.159	0.526	0.025	0.059	2.888	1.127	2.136	17300.873
	Paired Simulated	52.870	0.281	0.158	0.624	0.042	0.101	3.313	2.149	3.874	14669.164
Count		53	53	51	52	52	53	50	52	53	53
Mean Error		0.640	0.114	0.001	0.431	0.008	0.013	0.166	0.377	1.845	59.745
Mean Absolute Error		21.288	0.228	0.152	0.634	0.030	0.063	2.267	1.088	4.230	7004.462
Mean Squared Error		1,209.288	0.123	0.054	0.694	0.002	0.009	7.892	3.488	27.720	258048486.846
RMSE		34.775	0.351	0.233	0.833	0.045	0.093	2.809	1.868	5.265	16063.888
pval, paired t-test		0.895	0.016	0.988	0.000	0.212	0.315	0.680	0.148	0.009	0.979
Alpha		0.05	0.050	0.050	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		False	True	False	True	False	False	False	False	True	False
Pass t-test?		Yes	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes

Table 5-3. Oak Creek Station OC-3 Concentration Calibration Statistics (1994-1998).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	36.243	0.387	0.250	1.371	0.041	0.115	6.496	2.253	3.577	2849.222
	Paired Simulated	21.897	0.513	0.177	1.494	0.032	0.079	7.177	2.498	3.724	5354.229
	Full Simulated	13.951	0.484	0.171	1.343	0.034	0.081	9.227	2.369	2.666	8274.564
Median	Observed	26.000	0.310	0.125	1.220	0.040	0.100	5.800	2.000	2.420	430.000
	Paired Simulated	8.115	0.457	0.116	1.473	0.011	0.030	7.496	1.737	1.925	168.626
	Full Simulated	7.719	0.400	0.108	1.164	0.015	0.031	9.486	1.606	1.600	310.066
Standard Deviation	Observed	53.774	0.336	0.351	0.675	0.031	0.108	3.346	1.074	3.196	6325.102
	Paired Simulated	38.689	0.339	0.189	0.646	0.034	0.114	3.096	2.065	3.550	14400.445
Count		51	51	50	49	50	51	52	49	54	54
Mean Error		14.346	0.126	0.072	0.123	0.010	0.036	0.684	0.246	0.146	2505.006
Mean Absolute Error		22.271	0.257	0.237	0.553	0.044	0.094	2.394	1.220	4.224	6057.394
Mean Squared Error		1,345.571	0.154	0.173	0.646	0.004	0.016	8.967	4.578	29.946	237313676.358
RMSE		36.682	0.392	0.416	0.804	0.062	0.126	2.995	2.140	5.472	15404.989
pval, paired t-test		0.004	0.021	0.222	0.291	0.280	0.041	0.100	0.427	0.846	0.236
Alpha		0.05	0.05	0.050	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		True	True	False	False	False	True	False	False	False	False
Pass t-test?		No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes

Table 5-4. Oak Creek Station OC-4 Concentration Calibration Statistics (1994-1998).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	32.073	0.585	0.238	1.527	0.032	0.104	6.166	2.576	5.201	4994.269
	Paired Simulated	22.646	0.481	0.253	1.582	0.033	0.095	6.544	2.783	8.081	5414.954
	Full Simulated	14.397	0.443	0.197	1.393	0.029	0.093	9.112	2.816	6.599	8146.632
Median	Observed	16.000	0.520	0.165	1.410	0.030	0.085	5.700	2.000	4.510	430.000
	Paired Simulated	7.727	0.464	0.199	1.608	0.016	0.059	6.605	2.115	7.511	205.085
	Full Simulated	7.241	0.385	0.156	1.260	0.017	0.056	9.024	2.024	4.840	361.435
Standard Deviation	Observed	54.400	0.321	0.224	0.714	0.022	0.101	2.483	1.466	3.657	16178.191
	Paired Simulated	44.365	0.304	0.208	0.641	0.039	0.098	3.240	2.046	5.037	14353.548
Count		52	52	50	50	51	52	49	51	52	52
Mean Error		9.428	0.104	0.014	0.055	0.001	0.009	0.378	0.208	2.881	420.684
Mean Absolute Error		16.615	0.262	0.176	0.488	0.026	0.063	2.260	1.266	6.081	5368.280
Mean Squared Error		884.664	0.108	0.070	0.420	0.002	0.009	7.565	3.939	53.016	165295075.832
RMSE		29.743	0.329	0.264	0.648	0.040	0.097	2.750	1.985	7.281	12856.713
pval, paired t-test		0.021	0.021	0.705	0.557	0.832	0.510	0.341	0.461	0.003	0.816
Alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		True	True	False	False	False	False	False	False	True	False
Pass t-test?		No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes

Table 5-5. Oak Creek Station OC-5 Concentration Calibration Statistics (1994-1998).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	29.780	0.594	0.193	1.463	0.026	0.084	9.289	2.471	6.684	9412.020
	Paired Simulated	25.066	0.469	0.271	1.374	0.038	0.101	8.365	2.602	8.206	11818.612
	Full Simulated	15.310	0.432	0.208	1.281	0.030	0.219	10.294	2.698	6.689	16287.696
Median	Observed	14.000	0.555	0.120	1.310	0.020	0.060	8.900	2.000	4.770	930.000
	Paired Simulated	7.744	0.431	0.231	1.386	0.020	0.061	8.011	1.978	7.413	552.602
	Full Simulated	7.232	0.373	0.171	1.174	0.018	0.057	10.012	1.894	4.722	1065.207
Standard Deviation	Observed	47.870	0.364	0.185	0.712	0.023	0.094	2.506	1.890	5.645	22976.985
	Paired Simulated	48.550	0.322	0.202	0.632	0.042	0.100	2.162	2.103	5.228	29427.727
Count		51	50	48	49	48	50	51	49	54	51
Mean Error		4.715	0.125	0.079	0.089	0.012	0.017	0.934	0.131	1.522	2406.592
Mean Absolute Error		11.537	0.261	0.185	0.419	0.028	0.061	2.120	1.146	6.609	14327.104
Mean Squared Error		351.388	0.133	0.064	0.344	0.002	0.009	8.140	2.937	68.064	935339473.156
RMSE		18.745	0.364	0.253	0.587	0.046	0.096	2.853	1.714	8.250	30583.320
pval, paired t-test		0.072	0.014	0.029	0.292	0.073	0.219	0.179	0.599	0.177	0.579
Alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		False	True	True	False	False	False	False	False	False	False
Pass t-test?		Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 5-6. Oak Creek Station OC-6 Concentration Calibration Statistics (1994-1998).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	30.348	0.570	0.166	1.380	0.019	0.076	9.011	2.312	6.206	9416.432
	Paired Simulated	26.864	0.491	0.293	1.353	0.042	0.110	8.745	2.680	8.456	6584.637
	Full Simulated	15.638	0.427	0.215	1.238	0.030	0.094	10.747	2.720	6.819	7908.801
Median	Observed	9.000	0.500	0.080	1.140	0.010	0.045	8.600	2.000	4.540	840.000
	Paired Simulated	7.650	0.429	0.262	1.294	0.027	0.065	8.679	1.805	8.189	174.434
	Full Simulated	6.902	0.370	0.177	1.135	0.018	0.060	10.743	1.878	4.662	323.006
Standard Deviation	Observed	63.155	0.390	0.189	0.775	0.018	0.101	2.682	1.501	5.190	36575.598
	Paired Simulated	53.021	0.348	0.189	0.666	0.043	0.105	1.961	2.320	5.549	15547.254
Count		42	42	38	41	40	42	42	42	44	44
Mean Error		3.484	0.079	0.127	0.027	0.023	0.034	0.266	0.368	2.250	2831.759
Mean Absolute Error		12.868	0.248	0.197	0.469	0.030	0.064	1.587	1.121	7.948	12360.093
Mean Squared Error		913.297	0.140	0.077	0.374	0.002	0.010	6.405	2.812	87.084	1541896215.934
RMSE		30.221	0.374	0.277	0.612	0.048	0.102	2.531	1.677	9.332	39266.986
pval, paired t-test		0.462	0.174	0.003	0.777	0.002	0.030	0.502	0.157	0.111	0.638
Alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		False	False	True	False	True	True	False	False	False	False
Pass t-test?		Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes

Table 5-7. Oak Creek Station OC-7 Concentration Calibration Statistics (1994-1998).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	33.713	0.509	0.194	1.331	0.026	0.089	9.696	2.431	9.924	4014.245
	Paired Simulated	25.707	0.498	0.221	1.069	0.026	0.080	9.592	1.763	10.189	4447.216
	Full Simulated	18.649	0.460	0.178	0.994	0.026	0.078	11.265	1.867	7.050	7123.158
Median	Observed	16.000	0.450	0.110	1.185	0.020	0.060	9.300	2.000	7.410	430.000
	Paired Simulated	7.905	0.474	0.120	1.019	0.005	0.041	9.039	0.972	9.396	72.291
	Full Simulated	7.762	0.414	0.114	0.907	0.009	0.044	11.160	1.172	4.318	448.769
Standard Deviation	Observed	62.386	0.368	0.222	0.748	0.019	0.094	2.350	1.337	7.287	15356.284
	Paired Simulated	49.410	0.272	0.325	0.583	0.039	0.090	1.696	1.860	9.396	11268.250
Count		53	53	51	52	51	53	50	52	53	53
Mean Error		8.006	0.011	0.028	0.262	0.000	0.010	0.105	0.667	0.265	432.971
Mean Absolute Error		14.201	0.251	0.207	0.565	0.028	0.058	1.502	1.414	9.381	4826.594
Mean Squared Error		915.173	0.114	0.151	0.498	0.002	0.007	5.615	2.600	14.339	149641642.993
RMSE		30.252	0.338	0.389	0.706	0.041	0.086	2.370	1.613	12.179	12232.810
pval, paired t-test		0.053	0.817	0.616	0.006	0.976	0.427	0.758	0.002	0.876	0.799
Alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		False	False	False	True	False	False	False	True	False	False
Pass t-test?		Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes

Table 5-8. Oak Creek Station OC-1 Concentration Validation Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	24.024	0.707	0.158	1.445	0.032	0.077	5.191	1.182	2.612	4055.119
	Paired Simulated	17.677	0.538	0.149	1.519	0.023	0.067	7.603	2.193	3.584	2986.618
	Full Simulated	14.820	0.522	0.151	1.466	0.024	0.069	8.854	2.283	3.549	4070.491
Median	Observed	14.600	0.675	0.085	1.327	0.020	0.050	5.420	-	1.730	430.000
	Paired Simulated	7.788	0.436	0.112	1.490	0.005	0.023	7.735	1.506	2.406	154.521
	Full Simulated	7.614	0.445	0.114	1.357	0.007	0.026	8.529	1.622	2.162	174.284
Standard Deviation	Observed	45.185	0.548	0.185	0.692	0.033	0.058	3.102	1.902	2.937	8696.021
	Paired Simulated	26.330	0.319	0.133	0.630	0.040	0.102	2.141	2.048	3.043	8510.309
Count		42	42	42	42	41	42	41	42	42	42
Mean Error		6.346	0.170	0.009	0.074	0.009	0.010	2.411	1.011	0.972	1068.501
Mean Absolute Error		18.685	0.348	0.162	0.507	0.032	0.057	2.695	1.509	3.369	4353.788
Mean Squared Error		1917.575	0.271	0.044	0.497	0.002	0.007	12.169	4.079	21.298	98603769.990
RMSE		43.790	0.520	0.209	0.705	0.045	0.084	3.488	2.020	4.615	9929.943
pval, paired t-test		0.354	0.033	0.782	0.502	0.221	0.468	0.000	0.001	0.175	0.492
Alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		False	True	False	False	False	False	True	True	False	False
Pass t-test?		Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes

Table 5-9. Oak Creek Station OC-2 Concentration Validation Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	23.400	0.488	0.100	1.246	0.037	0.077	8.232	1.273	2.555	3265.659
	Paired Simulated	29.796	0.511	0.175	1.390	0.034	0.087	9.262	2.250	2.474	6318.884
	Full Simulated	21.482	0.497	0.163	1.333	0.034	0.085	10.314	2.327	2.474	8710.675
Median	Observed	14.000	0.410	0.056	1.065	0.030	0.064	7.890	-	1.965	430.000
	Paired Simulated	8.786	0.418	0.116	1.365	0.011	0.026	9.497	1.455	1.745	300.170
	Full Simulated	8.771	0.429	0.109	1.254	0.012	0.030	10.122	1.543	1.655	377.313
Standard Deviation	Observed	34.906	0.310	0.197	0.547	0.035	0.051	2.326	1.922	2.166	8010.447
	Paired Simulated	54.312	0.352	0.201	0.712	0.057	0.141	2.158	2.385	2.381	16.132.478
Count		44	44	40	44	43	43	43	44	44	44
Mean Error		6.396	0.024	0.076	0.144	0.002	0.010	1.030	0.976	0.080	3053.225
Mean Absolute Error		24.007	0.252	0.154	0.516	0.037	0.069	1.691	1.429	2.107	5163.674
Mean Squared Error		2467.465	0.132	0.062	0.505	0.003	0.014	4.029	4.064	11.330	211953951.864
RMSE		49.674	0.363	0.248	0.711	0.059	0.118	2.007	2.016	3.366	14558.638
pval, paired t-test		0.399	0.672	0.053	0.182	0.819	0.580	0.000	0.001	0.876	0.167
Alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.050	0.05
Fail t-test?		False	False	False	False	False	False	True	True	False	False
Pass t-test?		Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes

Table 5-10. Oak Creek Station OC-3 Concentration Validation Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	30.586	0.401	0.094	1.355	0.047	0.098	7.061	1.271	3.141	2825.238
	Paired Simulated	19.727	0.524	0.172	1.319	0.037	0.086	8.251	2.229	2.032	4991.198
	Full Simulated	15.606	0.510	0.163	1.302	0.035	0.081	9.617	2.138	1.972	6750.875
Median	Observed	15.000	0.380	0.075	1.262	0.035	0.090	6.490	-	2.670	430.000
	Paired Simulated	7.727	0.368	0.102	1.232	0.013	0.026	8.126	1.300	1.480	376.224
	Full Simulated	7.472	0.419	0.103	1.208	0.015	0.030	9.458	1.439	1.507	629.383
Standard Deviation	Observed	63.388	0.294	0.119	0.514	0.039	0.051	2.538	1.859	2.276	5692.620
	Paired Simulated	34.240	0.420	0.236	0.788	0.065	0.155	1.951	3.012	1.918	19856.201
Count		42	41	36	40	41	42	41	42	42	42
Mean Error		10.859	0.123	0.078	0.036	0.011	0.012	1.189	0.959	1.110	2165.960
Mean Absolute Error		22.364	0.279	0.133	0.521	0.051	0.088	1.777	1.571	2.604	4825.428
Mean Squared Error		3680.884	0.185	0.061	0.599	0.006	0.020	4.522	7.536	12.641	353060039.363
RMSE		60.670	0.431	0.246	0.774	0.077	0.141	2.126	2.745	3.555	18789.892
pval, paired t-test		0.251	0.67	0.057	0.773	0.374	0.592	0.000	0.022	0.042	0.462
Alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.050
Fail t-test?		False	False	False	False	False	False	True	True	True	False
Pass t-test?		Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes

Table 5-11. Oak Creek Station OC-4 Concentration Validation Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	26.019	0.538	0.108	1.378	0.045	0.093	7.087	1.395	3.883	4009.405
	Paired Simulated	18.963	0.517	0.233	1.501	0.035	0.099	7.495	2.518	5.094	5370.155
	Full Simulated	16.556	0.474	0.185	1.370	0.029	0.090	9.275	2.505	5.099	6770.672
Median	Observed	14.900	0.541	0.060	1.228	0.030	0.080	6.630	0.495	3.150	430.000
	Paired Simulated	7.415	0.370	0.175	1.381	0.015	0.046	7.290	1.612	4.135	348.252
	Full Simulated	7.350	0.387	0.143	1.245	0.017	0.052	8.960	1.795	3.784	566.188
Standard Deviation	Observed	52.755	0.273	0.190	0.495	0.046	0.057	2.252	1.952	2.820	9144.359
	Paired Simulated	31.066	0.412	0.229	0.851	0.055	0.147	2.256	2.862	3.437	18572.895
Count		42	42	37	41	41	41	41	42	42	42
Mean Error		7.056	0.021	0.125	0.123	0.010	0.007	0.408	1.123	1.211	1360.750
Mean Absolute Error		16.740	0.271	0.185	0.538	0.038	0.070	1.510	1.666	3.729	5359.078
Mean Squared Error		2056.155	0.160	0.078	0.663	0.004	0.016	4.369	6.553	27.066	298083762.276
RMSE		45.345	0.400	0.279	0.814	0.062	0.127	2.090	2.560	5.203	17265.102
pval, paired t-test		0.319	0.738	0.004	0.341	0.292	0.741	0.221	0.003	0.133	0.615
Alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		False	False	True	False	False	False	False	True	False	False
Pass t-test?		Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes

Table 5-12. Oak Creek Station OC-5 Concentration Validation Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	35.466	0.588	0.135	1.450	0.035	0.093	9.004	1.534	7.338	13489.841
	Paired Simulated	24.728	0.508	0.252	1.409	0.038	0.102	8.215	2.454	5.131	10748.275
	Full Simulated	17.450	0.461	0.197	1.294	0.030	0.092	9.993	2.465	5.147	13687.345
Median	Observed	9.400	0.583	0.075	1.300	0.020	0.060	8.430	0.360	3.955	605.000
	Paired Simulated	7.538	0.355	0.179	1.203	0.017	0.047	7.925	1.595	4.255	727.466
	Full Simulated	7.402	0.378	0.151	1.144	0.018	0.054	9.630	1.756	3.894	1268.245
Standard Deviation	Observed	64.612	0.245	0.224	0.532	0.041	0.075	2.179	2.202	16.451	41721.951
	Paired Simulated	45.048	0.417	0.230	0.839	0.057	0.142	2.039	2.681	3.620	36087.374
Count		44	44	40	44	42	44	43	44	44	44
Mean Error		10.738	0.081	0.117	0.041	0.004	0.010	0.789	0.920	2.207	2741.566
Mean Absolute Error		25.220	0.295	0.213	0.559	0.035	0.072	1.723	1.803	6.142	16799.047
Mean Squared Error		3361.568	0.196	0.101	0.720	0.004	0.019	4.618	8.026	289.754	2511329097.785
RMSE		57.979	0.442	0.318	0.848	0.060	0.137	2.149	2.833	17.022	50113.163
pval, paired t-test		0.223	0.231	0.018	0.752	0.691	0.648	0.014	0.029	0.396	0.721
Alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		False	False	True	False	False	False	True	True	False	False
Pass t-test?		Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes

Table 5-13. Oak Creek Station OC-6 Concentration Validation Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	29.447	0.532	0.087	1.265	0.036	0.075	9.278	0.977	4.358	5671.105
	Paired Simulated	24.557	0.471	0.254	1.344	0.035	0.093	8.684	2.131	4.854	2460.398
	Full Simulated	17.957	0.454	0.205	1.264	0.031	0.093	10.395	2.508	5.156	6716.698
Median	Observed	7.600	0.520	0.025	1.165	0.012	0.050	8.840	-	3.585	430.000
	Paired Simulated	7.290	0.365	0.197	1.290	0.018	0.051	8.498	1.626	4.200	350.555
	Full Simulated	7.267	0.373	0.157	1.115	0.019	0.056	10.107	1.764	3.920	506.770
Standard Deviation	Observed	64.413	0.273	0.188	0.552	0.054	0.066	2.170	1.739	2.900	19221.082
	Paired Simulated	47.213	0.308	0.183	0.690	0.041	0.117	1.994	1.578	3.171	5517.399
Count		38	38	32	38	36	38	36	38	38	38
Mean Error		4.891	0.061	0.167	0.079	0.001	0.018	0.594	1.155	0.495	3210.707
Mean Absolute Error		19.625	0.228	0.215	0.488	0.031	0.046	1.510	1.446	3.316	4532.311
Mean Squared Error		2877.877	0.090	0.077	0.435	0.002	0.007	3.550	3.415	22.945	278847290.465
RMSE		53.646	0.299	0.277	0.660	0.050	0.083	1.884	1.848	4.790	16698.721
pval, paired t-test		0.581	0.217	0.000	0.469	0.881	0.171	0.058	0.000	0.531	0.241
Alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fail t-test?		False	False	True	False	False	False	False	True	False	False
Pass t-test?		Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes

Table 5-14. Oak Creek Station OC-7 Concentration Validation Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	30.241	0.519	0.111	1.295	0.032	0.084	10.195	1.262	7.083	3810.886
	Paired Simulated	28.573	0.483	0.193	1.091	0.028	0.085	9.616	1.727	5.951	3527.078
	Full Simulated	20.067	0.472	0.163	1.043	0.027	0.080	11.026	1.824	5.245	6244.636
Median	Observed	12.900	0.505	0.060	1.210	0.020	0.075	9.320	-	5.405	930.000
	Paired Simulated	7.913	0.401	0.114	0.900	0.008	0.033	9.010	1.028	3.955	221.709
	Full Simulated	7.713	0.393	0.119	0.899	0.013	0.044	10.680	1.275	3.244	610.372
Standard Deviation	Observed	53.185	0.268	0.203	0.533	0.037	0.056	2.111	1.807	4.866	16459.017
	Paired Simulated	56.390	0.334	0.193	0.712	0.046	0.116	1.709	1.777	6.651	7725.913
Count		44	44	40	44	43	44	42	44	44	44
Mean Error		1.668	0.036	0.082	0.204	0.004	0.000	0.579	0.466	1.133	283.808
Mean Absolute Error		20.518	0.242	0.170	0.456	0.031	0.053	1.083	1.103	5.961	5454.614
Mean Squared Error		2621.825	0.100	0.061	0.372	0.002	0.007	1.955	1.954	74.315	323908568.842
RMSE		51.204	0.316	0.246	0.610	0.049	0.084	1.398	1.398	8.621	17997.460
pval, paired t-test		0.832	0.451	0.033	0.025	0.626	0.973	0.006	0.025	0.390	0.918
Alpha		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.050	0.05
Fail t-test?		False	False	True	True	False	False	True	True	False	False
Pass t-test?		Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes

Table 5-15. Confidence limit results for Oak Creek water quality calibration and validation.

Station	Parameter	Within 1 Standard Deviation	Within 2 Standard Deviations
OC-1	Total Phosphorus	26%	41%
	Total Nitrogen	27%	47%
	Total Suspended Solids	21%	32%
	Fecal Coliform	19%	36%
OC-2	Total Phosphorus	23%	39%
	Total Nitrogen	23%	43%
	Total Suspended Solids	26%	35%
	Fecal Coliform	28%	42%
OC-3	Total Phosphorus	24%	33%
	Total Nitrogen	22%	36%
	Total Suspended Solids	26%	33%
	Fecal Coliform	26%	44%
OC-4	Total Phosphorus	38%	71%
	Total Nitrogen	31%	44%
	Total Suspended Solids	24%	32%
	Fecal Coliform	30%	43%
OC-5	Total Phosphorus	42%	72%
	Total Nitrogen	35%	57%
	Total Suspended Solids	31%	40%
	Fecal Coliform	26%	37%
OC-6	Total Phosphorus	50%	71%
	Total Nitrogen	34%	59%
	Total Suspended Solids	29%	53%
	Fecal Coliform	27%	40%
OC-7	Total Phosphorus	23%	39%
	Total Nitrogen	20%	34%
	Total Suspended Solids	31%	40%
	Fecal Coliform	28%	35%

5.9 Statistical Assessment of Loads

For the evaluation of impacts on downstream receiving waters, correct model representation of total loads is as important as the representation of concentration. Unfortunately, load is not observed directly. Estimates of observed load on those days with observations can be formed by multiplying concentration by daily average flow. However, because the concentrations represent point-in-time grab samples, these represent highly uncertain estimates of daily load.

Load estimates require both concentration and flow. For the Oak Creek, flow is gaged only at the USGS gage at Oak Creek at South Milwaukee (04087204) (approximately corresponding to water quality station OC-5). Observed load estimates can be calculated for only this station.

Because loads depend on both flow and concentration, it is unreasonable to expect that all observed and simulated data points will match closely. That is, apparent discrepancies will arise due to any errors in the timing or magnitude of flows, in addition to the uncertainty introduced by point-in-time concentration observations. However, the mean loads on paired observations should be in general agreement between the model and predictions. In addition, the relationship between load and flow should be similar.

Equality of observed and simulated mean concentrations is evaluated using a paired *t*-test. Results, with probability values (pvals) are shown in Table 5-16 and Table 5-17. As shown in the tables, the agreement between the model and estimated observed loads is in general good, with no contrasts failing the *t*-test – and this agreement is achieved while also preserving the relationship to SWAT and SLAMM loading rates from the uplands.

Table 5-16. Oak Creek Station OC-05 Load Calibration Statistics (1994-1998).

		TSS	NO2+NO3	TN	TP
		(mg/L)	(mg/L)	(mg/L)	(mg/L)
Mean	Observed	17867.598	165.672	367.550	37.415
	Paired Simulated	18501.739	124.795	316.205	41.220
	Full Simulated	6212.877	70.657	181.356	19.548
Median	Observed	450.915	16.071	38.306	1.640
	Paired Simulated	143.805	6.350	23.486	0.998
	Full Simulated	275.555	13.402	45.336	2.140
Standard Deviation	Observed	72148.781	500.317	1004.774	151.309
	Paired simulated	81019.427	383.548	1005.069	153.392
Count		51	50	49	50
Mean Error		634.141	40.877	51.345	3.805
Mean Absolute Error		5991.685	88.106	131.708	16.367
Mean Squared Error		432897821.263	67367.135	96930.096	2697.486
RMSE		20806.197	259.552	311.336	51.937
pval, paired t-test		0.830	0.270	0.252	0.609
Alpha		0.05	0.05	0.05	0.05
Fail t-test?		False	False	False	False
Pass t-test?		Yes	Yes	Yes	Yes

Table 5-17. Oak Creek Station OC-05 Load Validation Statistics (1999-2001).

		TSS	NO2+NO3	TN	TP
		(mg/L)	(mg/L)	(mg/L)	(mg/L)
Mean	Observed	27385.677	140.704	408.208	32.956
	Paired Simulated	13735.195	164.800	429.303	52.892
	Full Simulated	11635.670	141.793	353.516	40.839
Median	Observed	512.404	31.553	70.442	4.161
	Paired Simulated	491.927	23.116	78.911	3.074
	Full Simulated	556.983	26.461	84.190	3.529
Standard Deviation	Observed	125879.338	292.654	1019.903	99.127
	Paired simulated	34566.983	356.183	994.127	158.228
Count		44	44	44	44
Mean Error		13650.481	24.096	21.095	19.936
Mean Absolute Error		21054.293	66.539	171.084	27.072
Mean Squared Error		10752943061.777	35388.471	275105.211	7201.630
RMSE		103696.398	188.118	524.505	84.862
pval, paired t-test		0.389	0.402	0.793	0.120
Alpha		0.05	0.05	0.05	0.05
Fail t-test?		False	False	False	False
Pass t-test?		Yes	Yes	Yes	Yes

5.10 Load-Flow Relationships

An additional test of the pollutant load calibration is provided by developing log-log transport plots. These can be estimated only at OC-5, where flow gaging is available, and are shown in the following figures. The observed load:flow relationship overlies the simulated load:flow relationship very closely, indicating that the model is correctly representing the long-term sediment transport in the system.

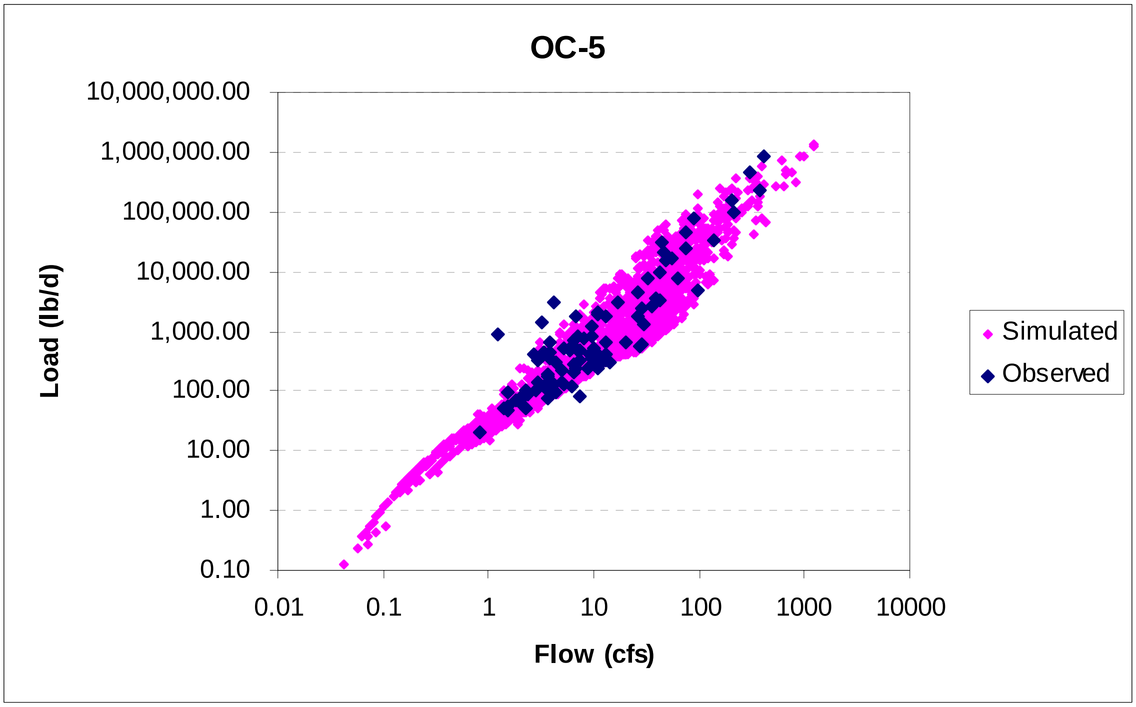


Figure 5-185. Log-log transport plot of sediment load at Oak Creek Station OC-5, 1994-2001.

As with the sediment results discussed above, the nutrient load simulation can also be evaluated in a qualitative graphical manner by log-log plots of load versus flow. In general, the observed load points should fall within the cloud defined by the simulation output and also follow a similar slope. This is indeed the case, as shown in Figure 5-186 through Figure 5-188. Some discrepancy is seen at the lower flow end of the spectrum, where the model predicts occasional flows lower than those that are observed.

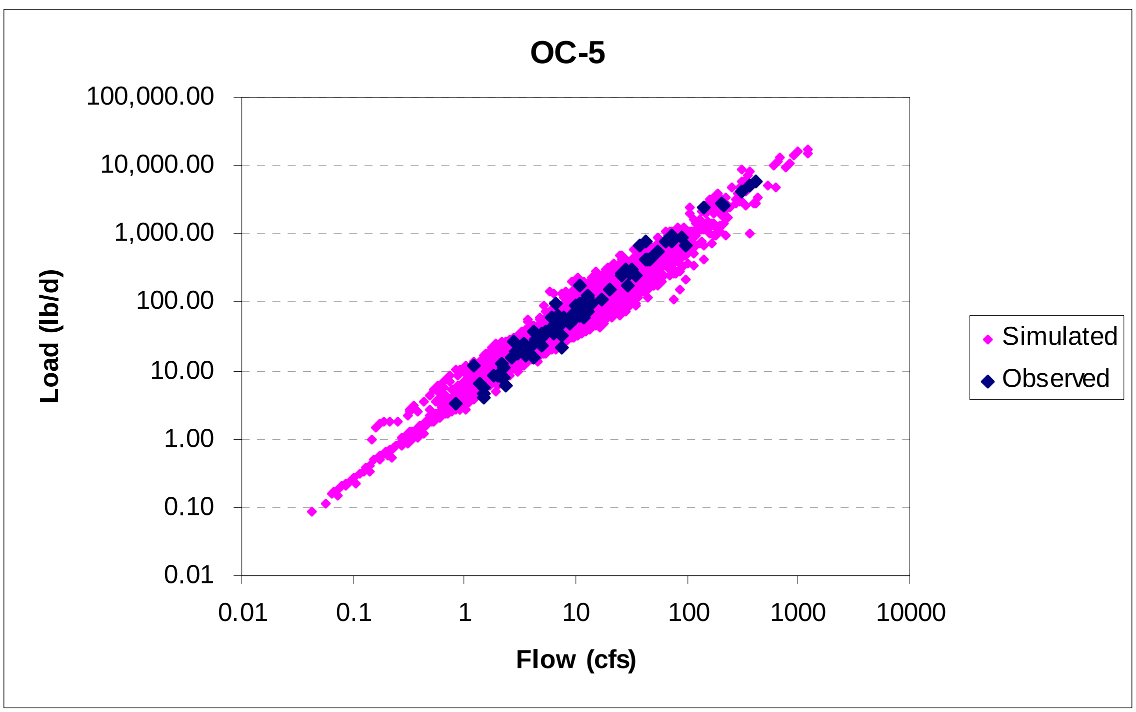


Figure 5-186. Transport Plots for Total Nitrogen, 1994-2001.

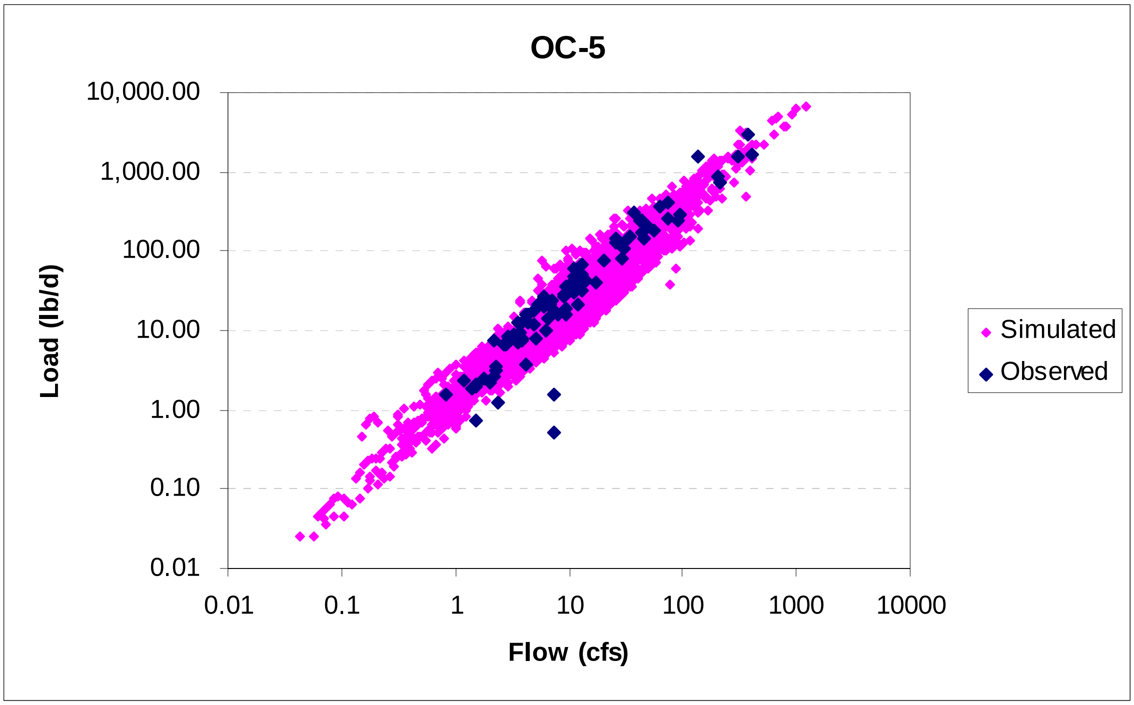


Figure 5-187. Transport Plots for Nitrite + Nitrate Nitrogen, 1994-2001.

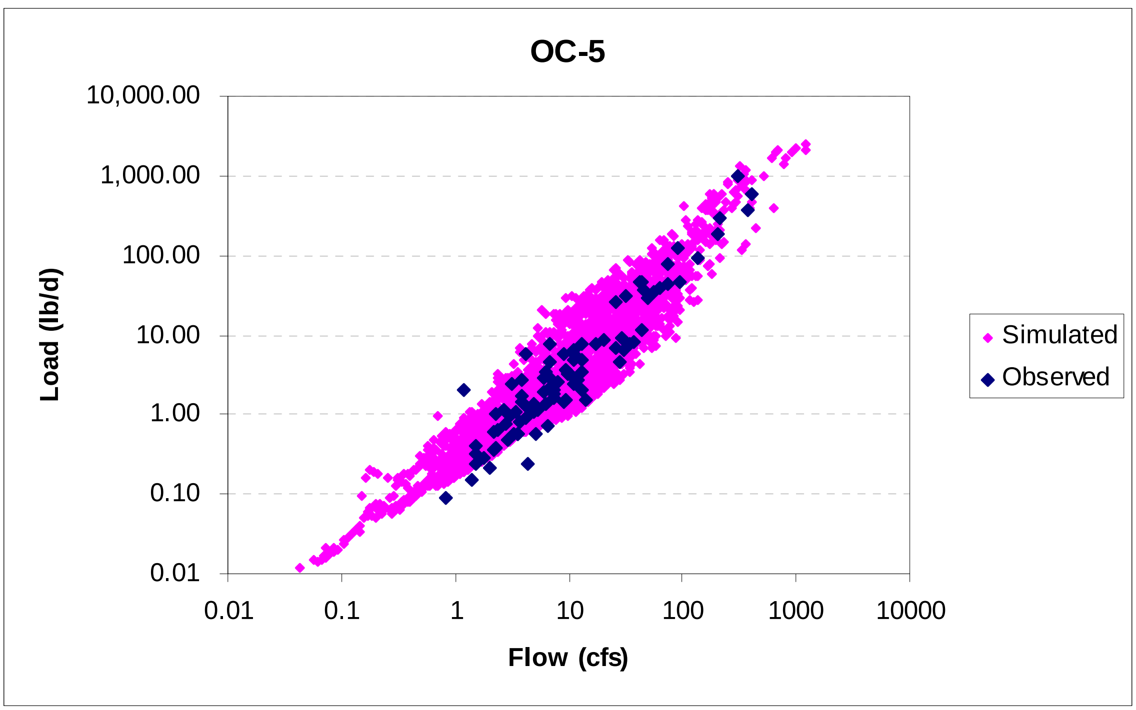


Figure 5-188. Transport Plots for Total Phosphorus, 1994-2001

Another useful test of representation of the load-flow relationships is obtained by plotting simulated and observed loads against the probability of exceedance of a given flow value, based on the period of record at the gage. These are known as load-duration curves. As a general rule, the portion of this relationship corresponding to flows that are exceeded less than 20 percent of the time can be assumed to represent high-flow, washoff events, while the remainder of the relationship corresponds to moderate and low flows.

The untransformed load-duration curve relationship is highly nonlinear. These plots can be linearized by plotting the natural logarithm of load versus the logit of flow, where the logit is defined as the natural log of (P/(1-P)), given P is the flow exceedance probability (Pindyck and Rubinfeld, 1981). After the loglogit transformation, separate linear regressions can be performed on the natural logarithms of observed and simulated loads versus logit of flow for the 0-20 percent and 20-100 percent flow ranges. (The breakpoint between these ranges corresponds to a logit of –1.386.) When the model is simulating accurately, the slope coefficients of the observed and simulated regressions should be in agreement within each of the two flow ranges. The analysis shows that this test is generally met in the Oak Creek model. Full results are provided in Attachment B.

REFERENCES

APHA. 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed. American Public Health Association (APHA), 1015 15th Street, NW, Washington, DC.

Bicknell, B.R., J.C. Imhoff, J. Kittle, A.S. Donigian, and R.C. Johansen. 1996. *Hydrological Simulation Program !FORTRAN, User's Manual for Release H*. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Bowie, G.L., et al. 1985. Rates, Constants, and Kinetic Formulations in Surface Water Quality Modeling, 2d. ed. EPA/600/3-85/040. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Box, G.E.P., J.S. Hunter and W.G. Hunter. 1978. *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building.* John Wiley and Sons, New York.

Chapra, S. and G. Pelletier. 2003. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

Donigian, A.S., Jr., and J.T. Love. 2002. Sediment Calibration Procedures and Guidelines for Watershed Modeling. Aqua Terra Consultants, Mountain View, CA.

Donigian, A.S., Jr., J.C. Imhoff, B.R. Bicknell, and J.L. Kittle, Jr. 1984. Application Guide for Hydrological Simulation Program – FORTRAN (HSPF). EPA-600/3-84-065. Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Haith, D.A. and D.E. Merrill. 1987. Evaluation of a daily rainfall erosivity model. *Trans. Amer. Soc. Agric. Eng.*, 28(6): 1916-1920.

Haith, D.A., R. Mandel, and R.S. Wu. 1992. *GWLF - Generalized watershed loading functions, Version 2.0 - User's manual*. Department of Agricultural Engineering, Cornell University, Ithaca, NY.

Hartigan, J.P., T.F. Quasebarth, and E. Southerland. 1983. Calibration of NPS model loading factors. *Journal of Environmental Engineering*, 109(6): 1259-1272.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. *Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage*, 89(IR4): 15-41.

Jensen, M.E., D.C.N. Rob, and C.E. Franzoy. 1969. Scheduling irrigations using climate-crop-soil data. Proceedings, National Conference on Water Resources Engineering of the American Society of Civil Engineers, New Orleans, LA.

Mancini, J.L. 1978. Numerical estimates of coliform mortality rates under various conditions. *J. Water Poll. Contr. Fed.*, 50(11): 2477-2484. MPCA. 2001. Status of a Model Simulation of Nonpoint-Source Contamination in the Minnesota River Basin, April 1999. Final report submitted by the USGS to Minnesota Pollution Control Agency.

Pindyck, R.S. and D.L. Rubinfeld. 1981. *Econometric Models and Economic Forecasts, Second Edition.* McGraw-Hill, New York.

Richardson, C.W., G.R. Foster, and D.A. Wright. 1983. Estimation of erosion index from daily rainfall amount. *Trans. Am. Soc. Agric. Eng.*, 26(1): 153-157, 160.

Tetra Tech, Inc. and CH2M HILL. 1999. Gwinnett County Watershed Assessment and Modeling Study, Watershed Model Calibration Technical Memorandum. Prepared for Gwinnett County, GA by Tetra Tech, Inc., Research Triangle Park, NC.

Tetra Tech. 2002. Minnesota River Basin Model, Model Calibration and Validation Report. Prepared for Minnesota Pollution Control Agency, St. Paul, MN by Tetra Tech, Inc., Research Triangle Park, NC.

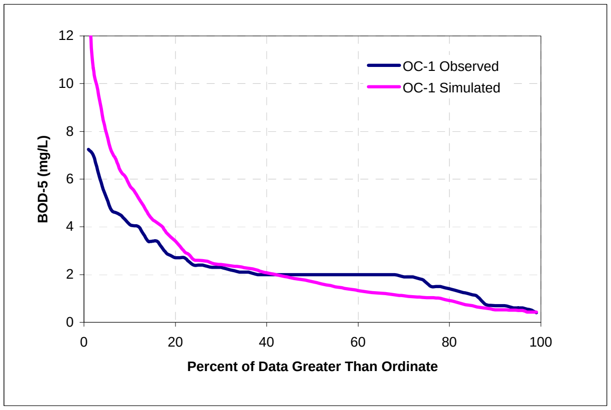
Thomann*n,* R.V. and J.A. Mueller. 1987*.* Principles of Surface Water Quality Modeling and Control. Harper & Row, New York.

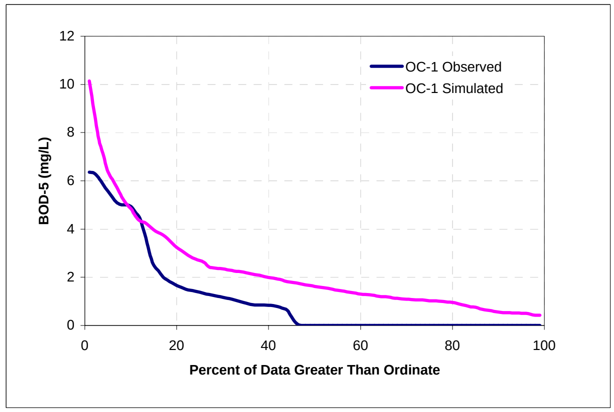
U.S. Environmental Protection Agency (USEPA). 2000. *BASINS Technical Note 6. Estimating Hydrology and Hydraulic Parameters for HSPF*. EPA-823-R00-012. U.S. Environmental Protection Agency. Office of Water. July 2000.

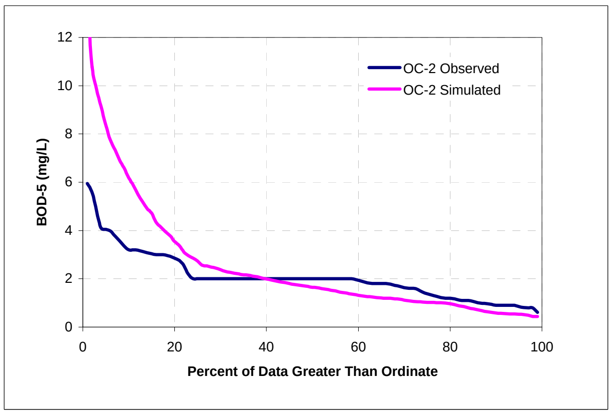
ATTACHMENT A – CONCENTRATION EXCEEDANCE CURVE PLOTS

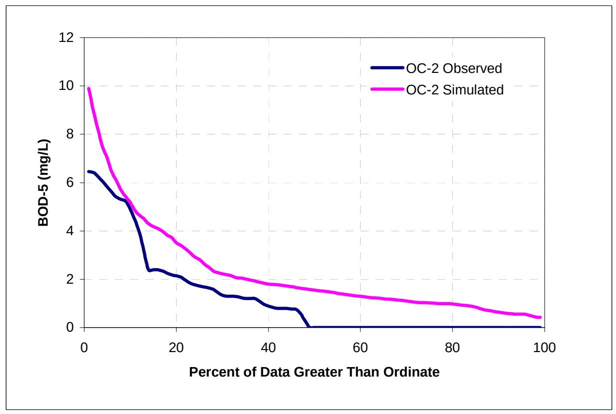
BOD5 Calibration Exceedance Plots

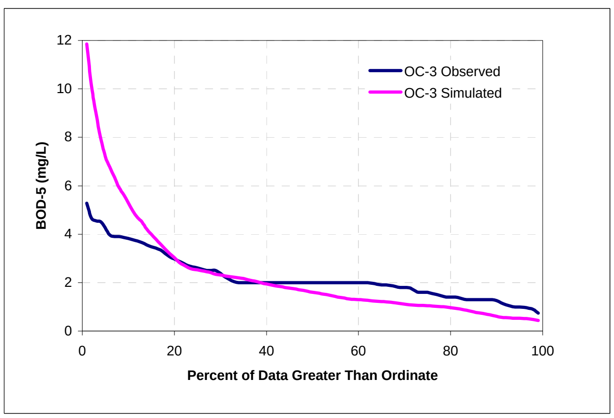
BOD5 Validation Exceedance Plots

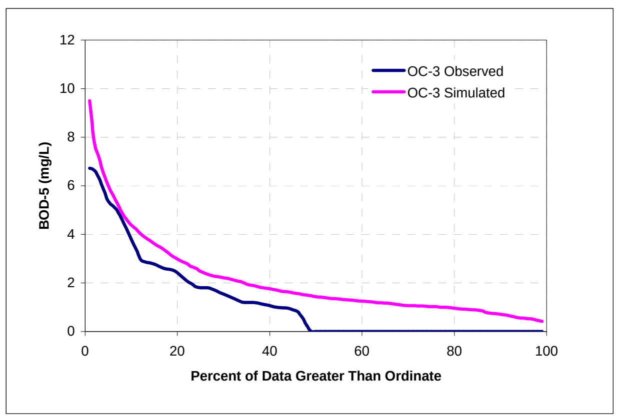






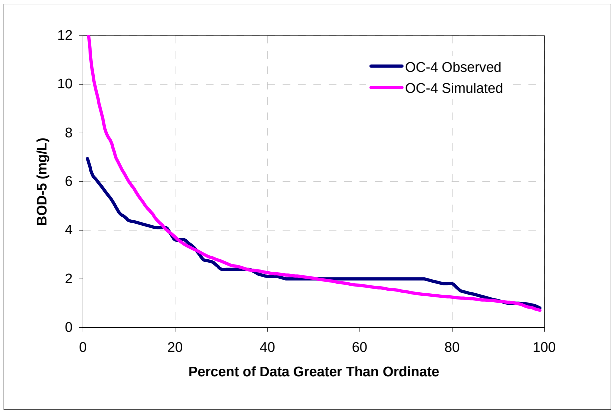


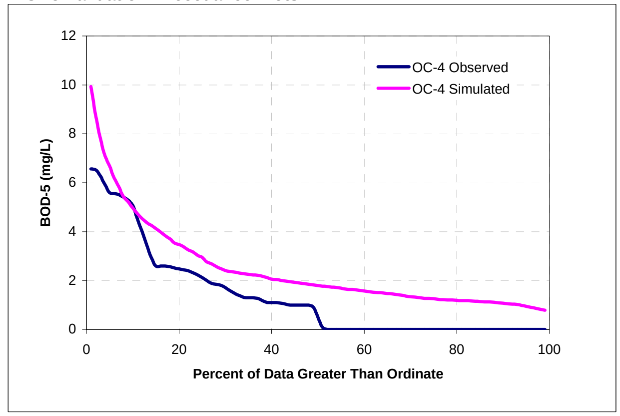


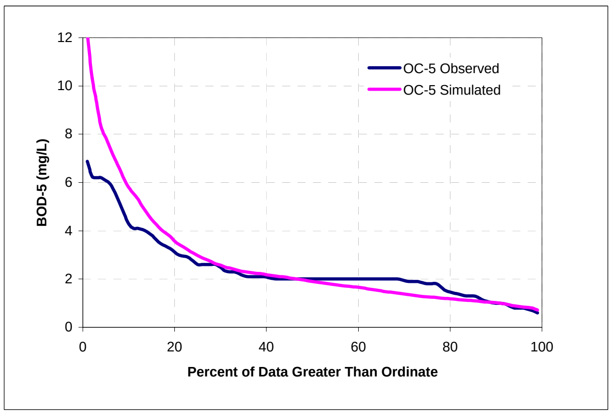


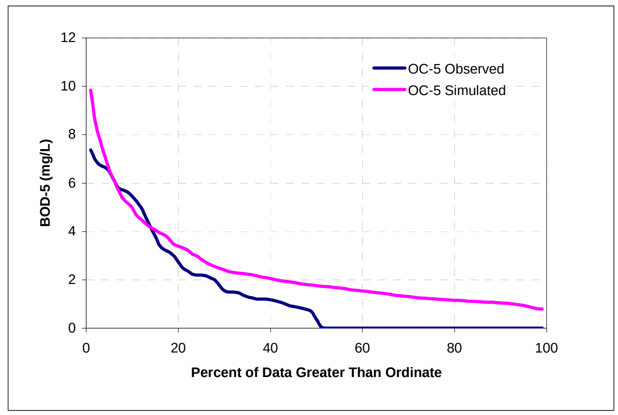
BOD5 Calibration Exceedance Plots

BOD5 Validation Exceedance Plots

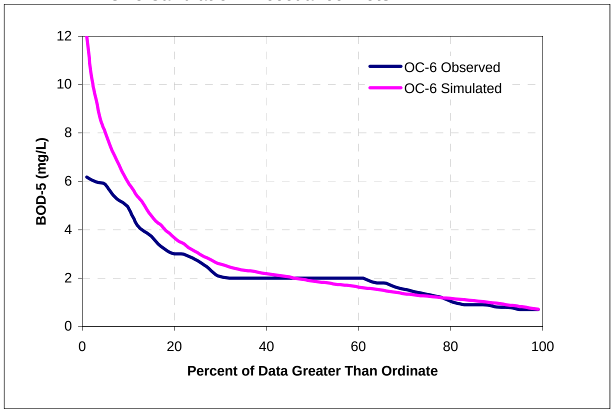


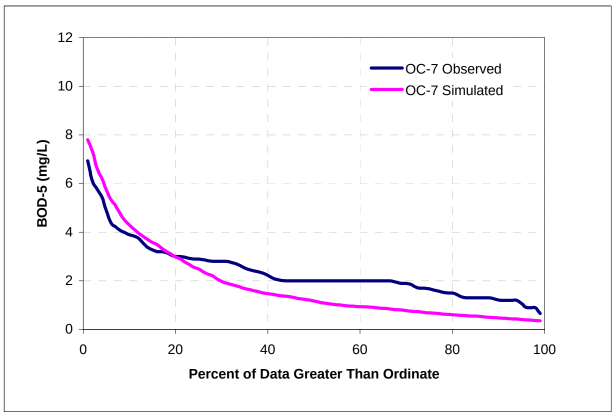




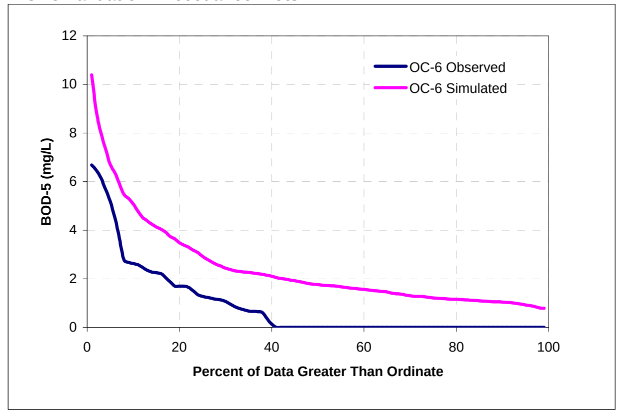


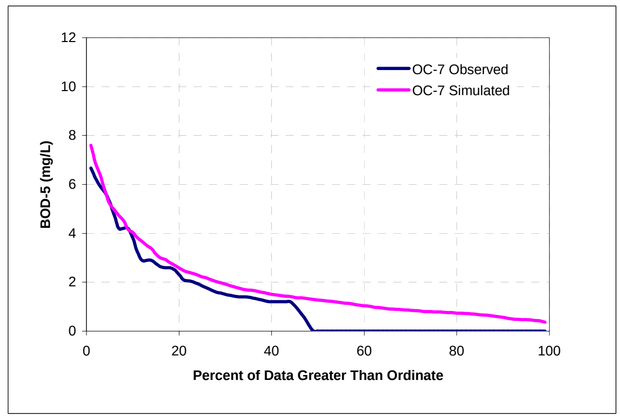
BOD5 Calibration Exceedance Plots



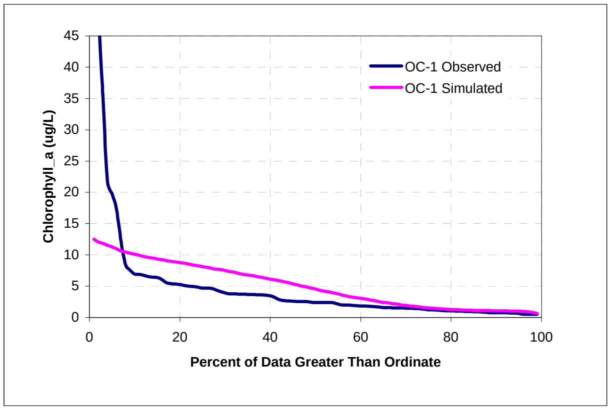


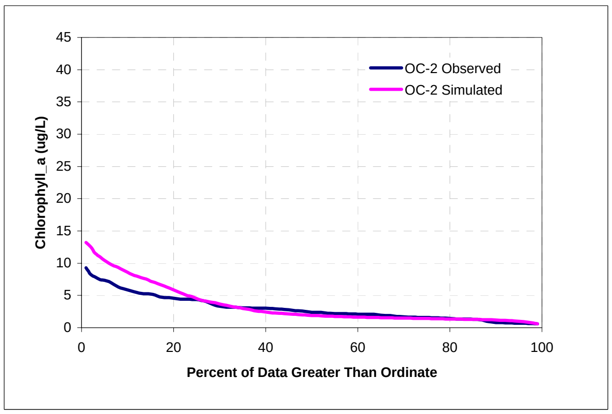
BOD5 Validation Exceedance Plots

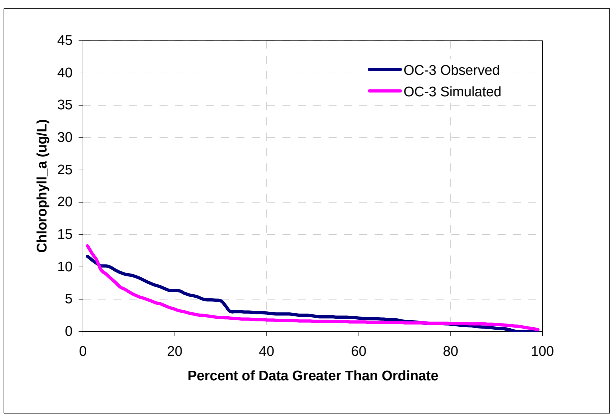




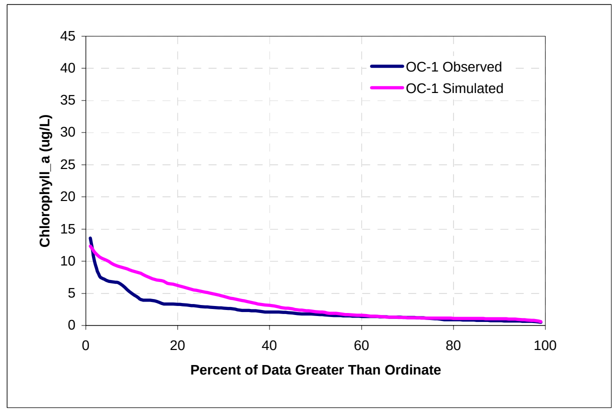
CHLA Calibration Exceedance Plots

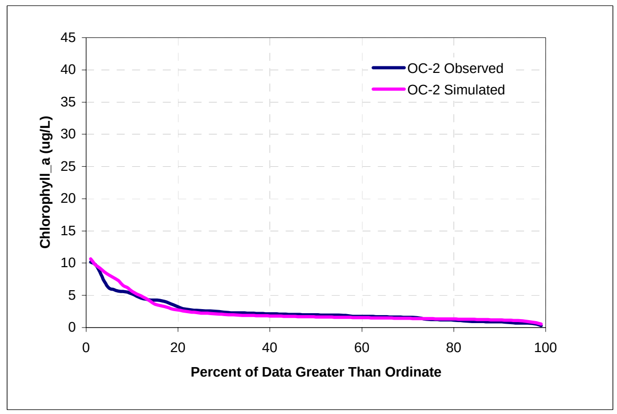


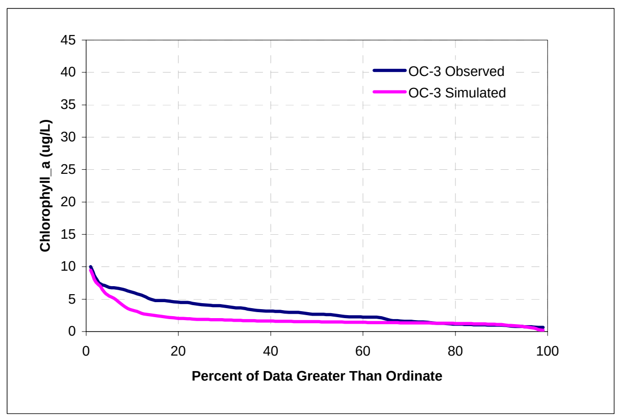




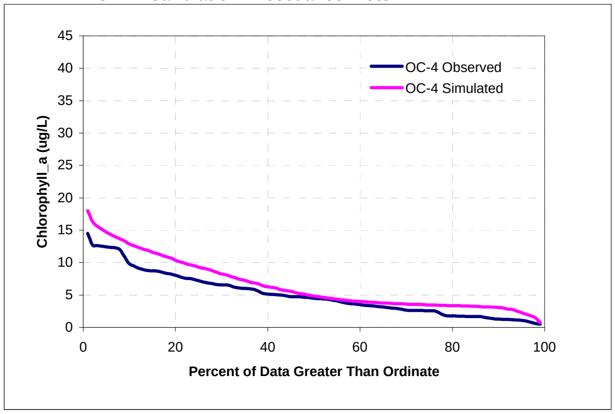
CHLA Validation Exceedance Plots

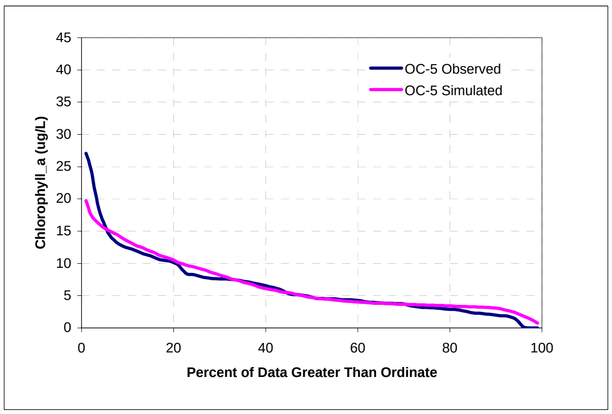




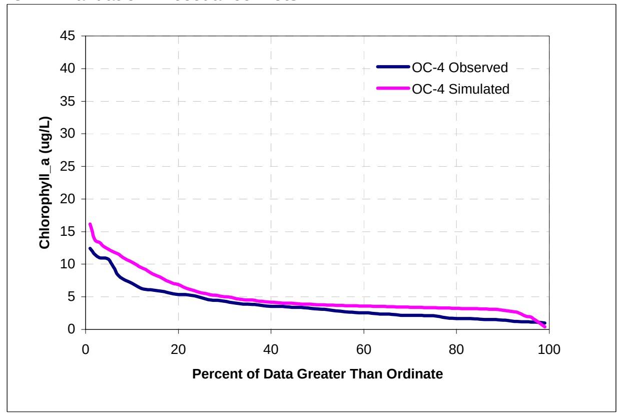


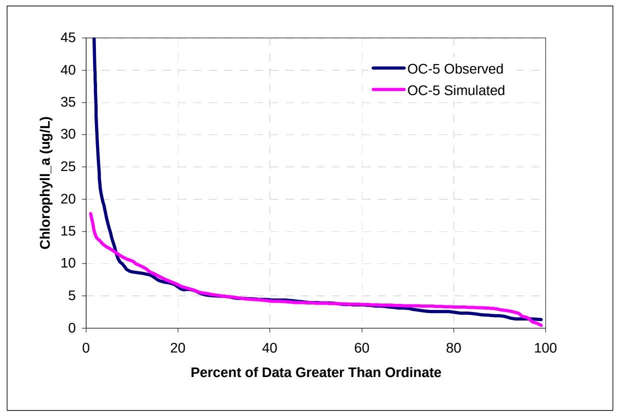
CHLA Calibration Exceedance Plots



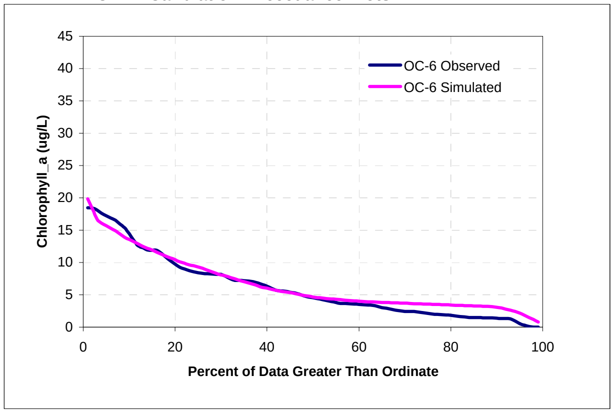


CHLA Validation Exceedance Plots

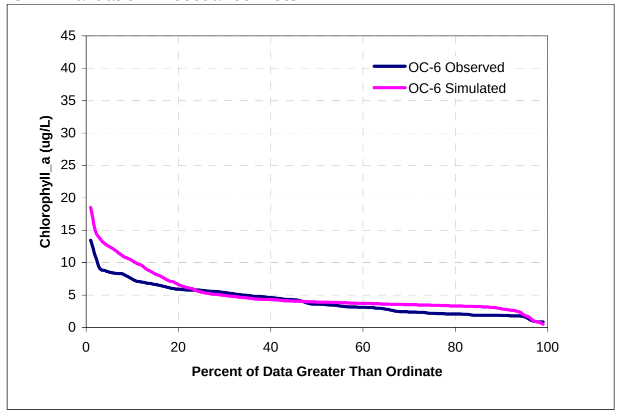


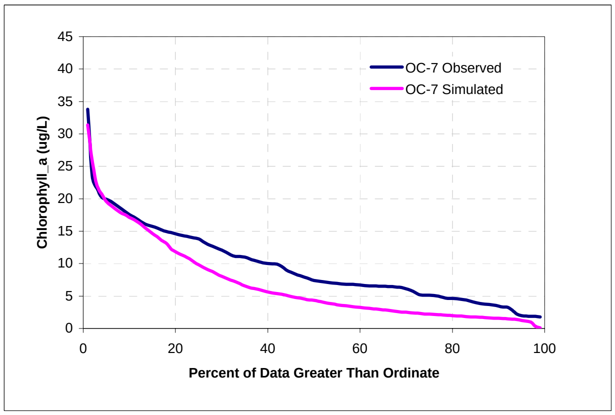


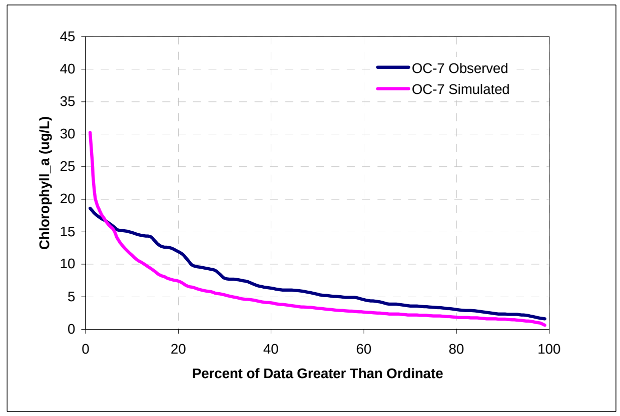
CHLA Calibration Exceedance Plots



CHLA Validation Exceedance Plots

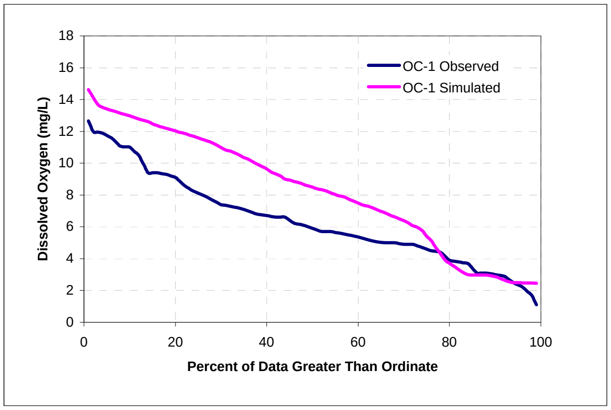


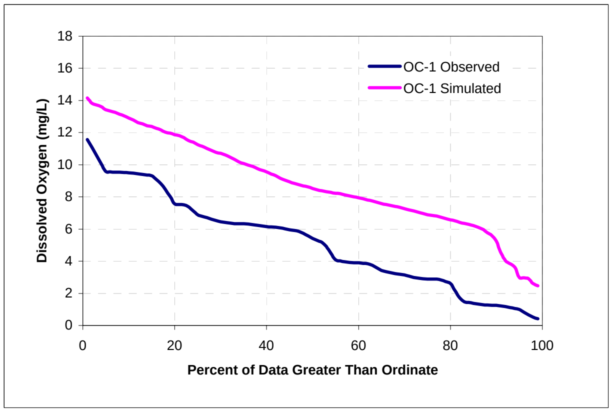


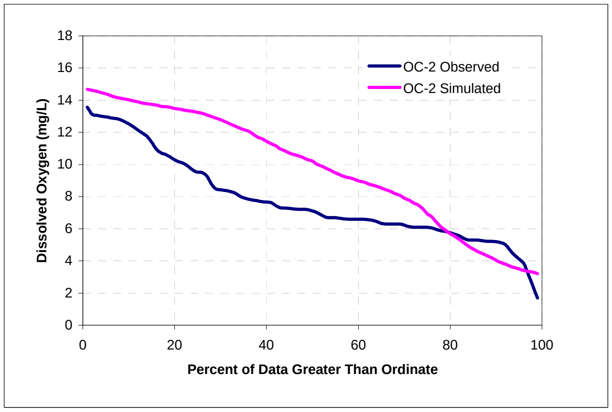


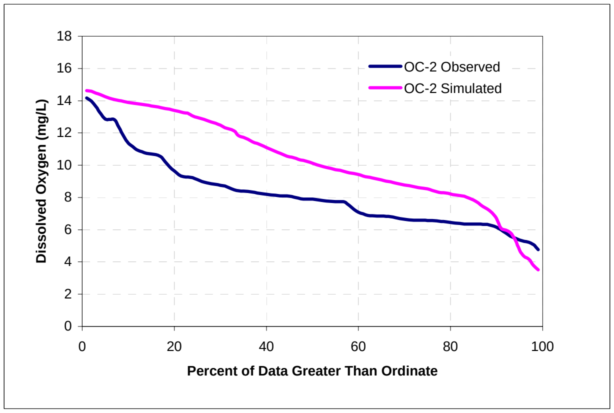
DOX Calibration Exceedance Plots

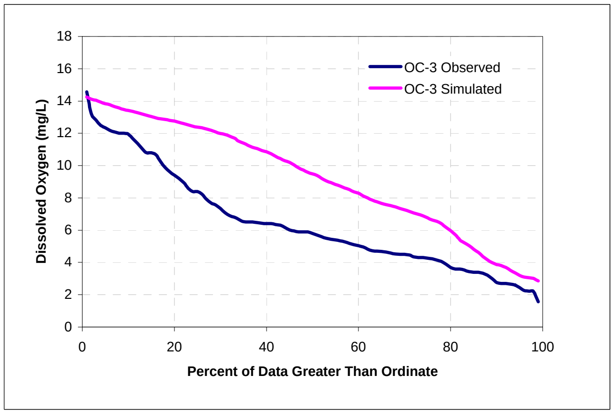
DOX Validation Exceedance Plots

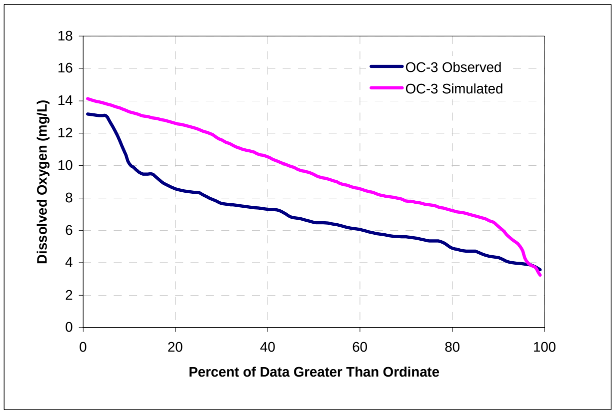




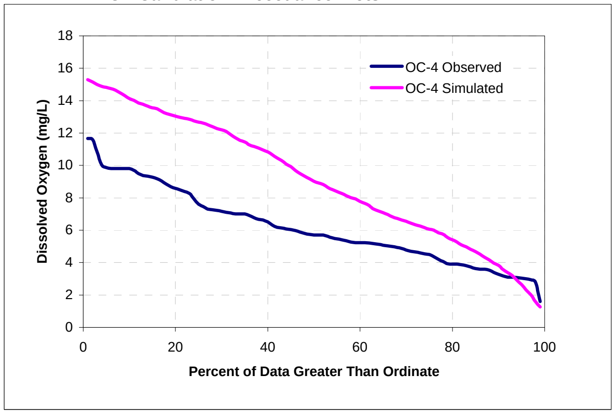




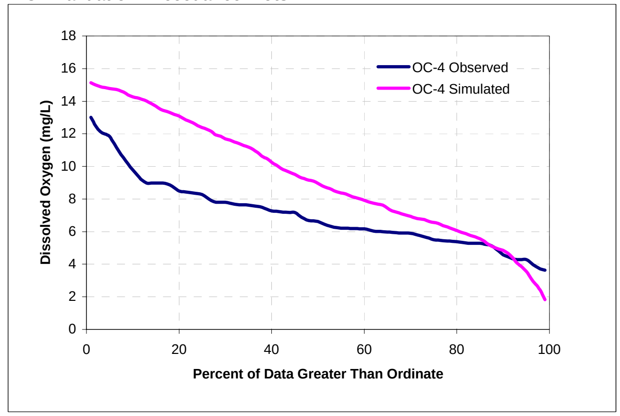


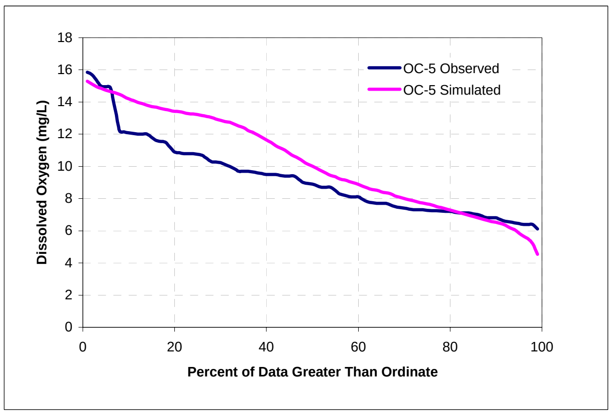


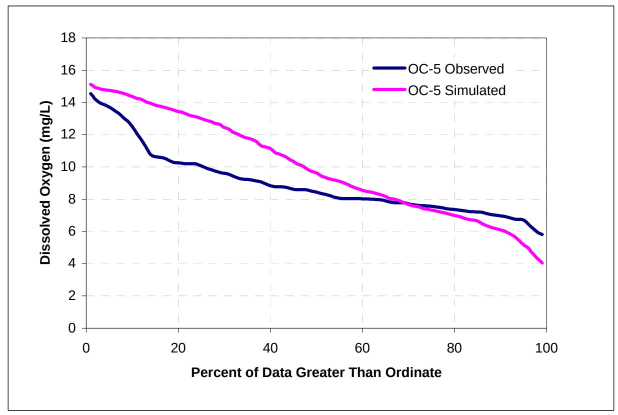
DOX Calibration Exceedance Plots



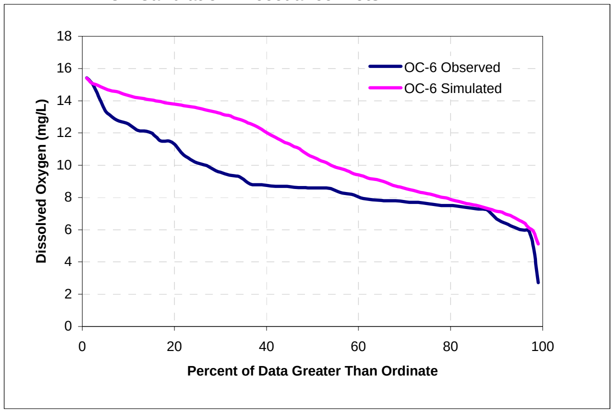
DOX Validation Exceedance Plots

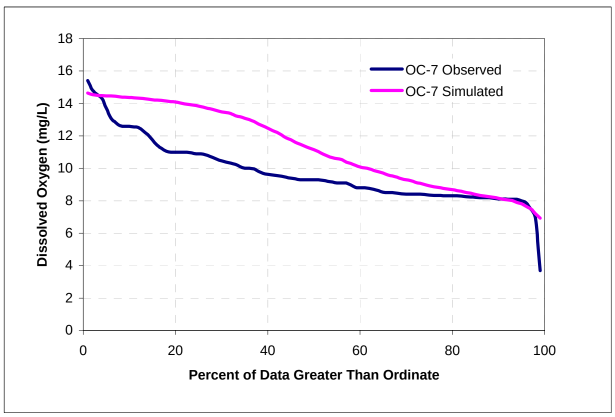




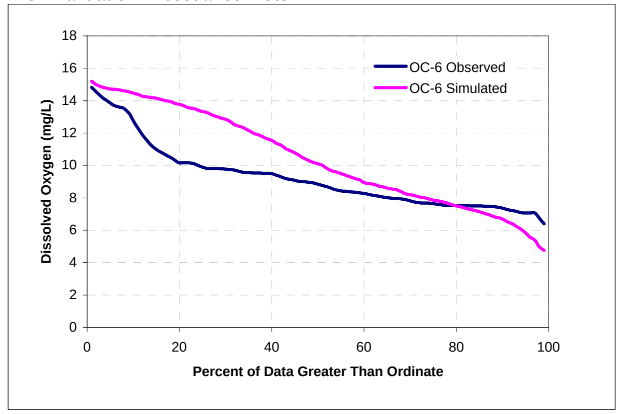


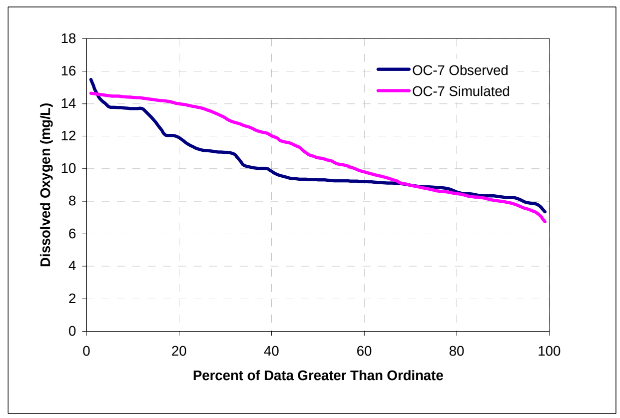
DOX Calibration Exceedance Plots





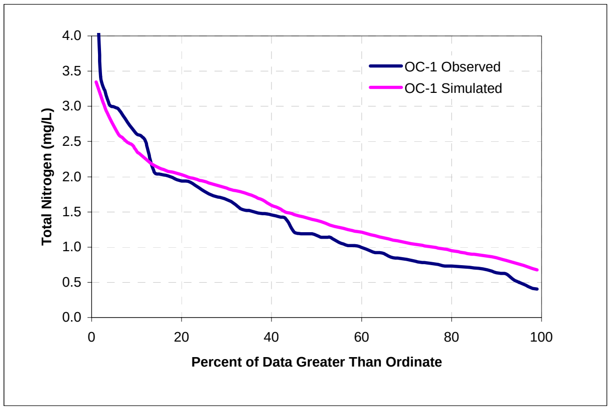
DOX Validation Exceedance Plots

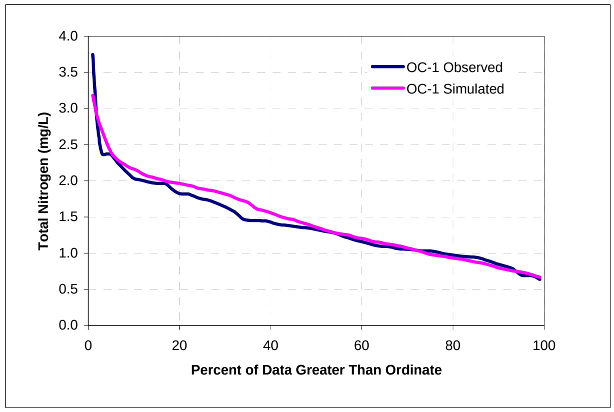


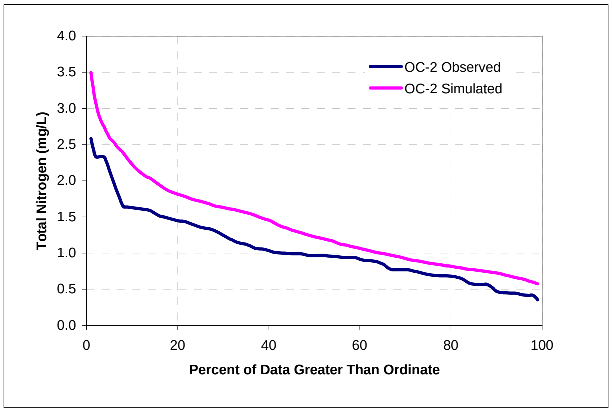


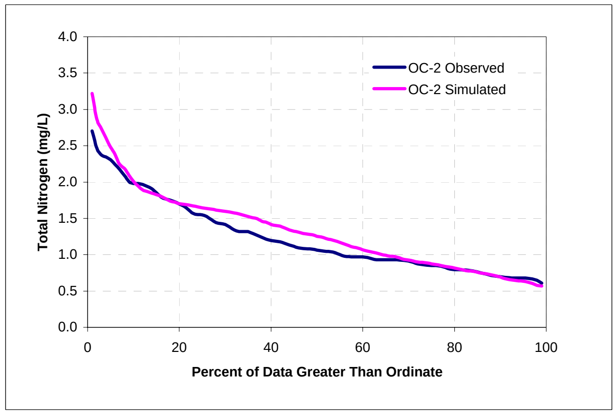
TOTN Calibration Exceedance Plots

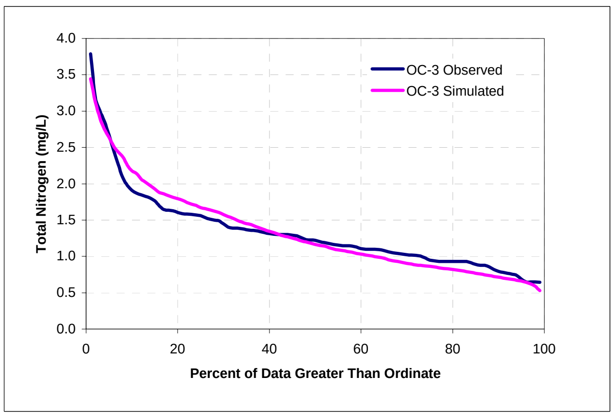
TOTN Validation Exceedance Plots

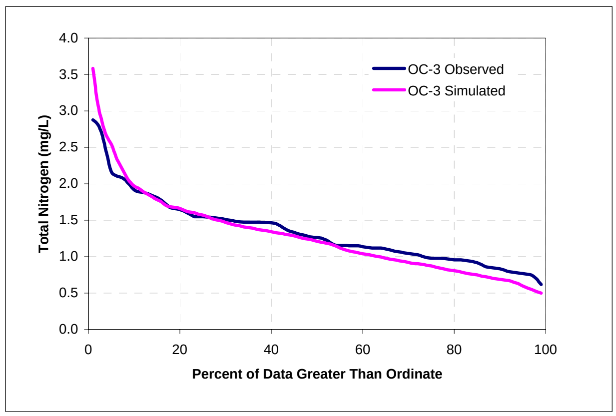




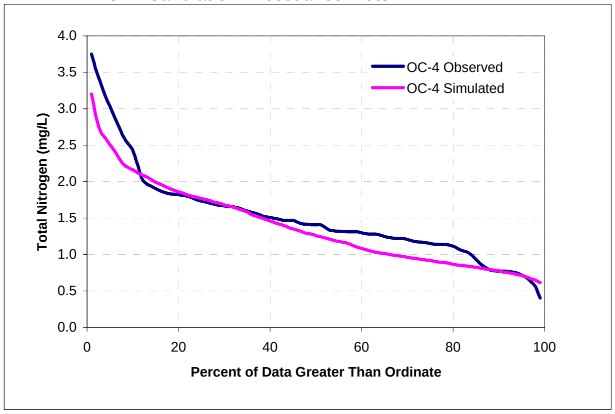




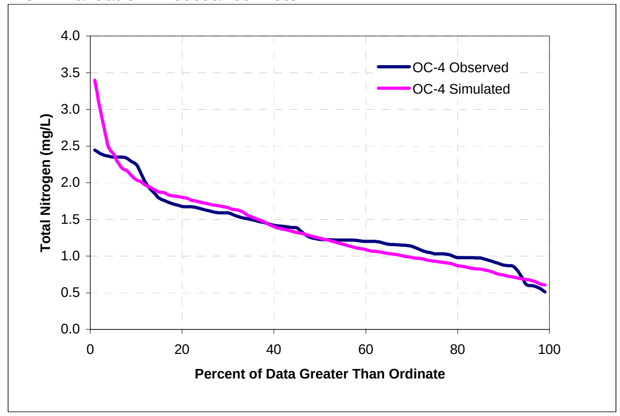


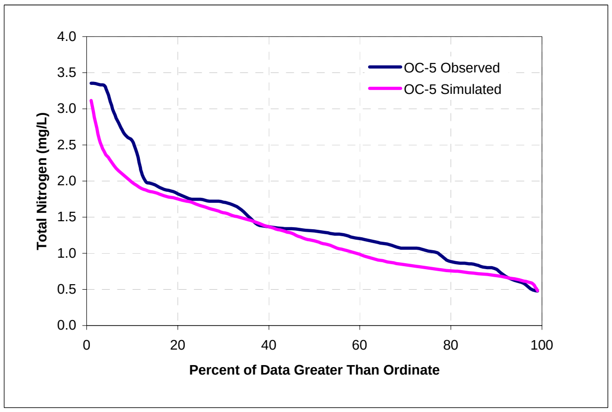


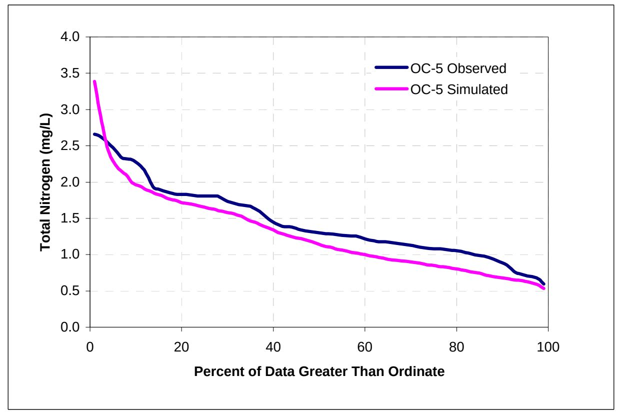
TOTN Calibration Exceedance Plots



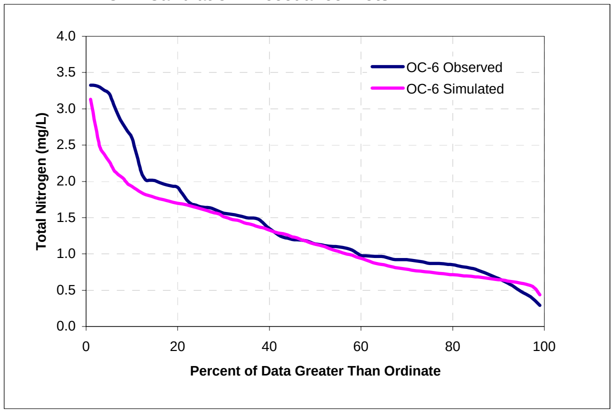
TOTN Validation Exceedance Plots

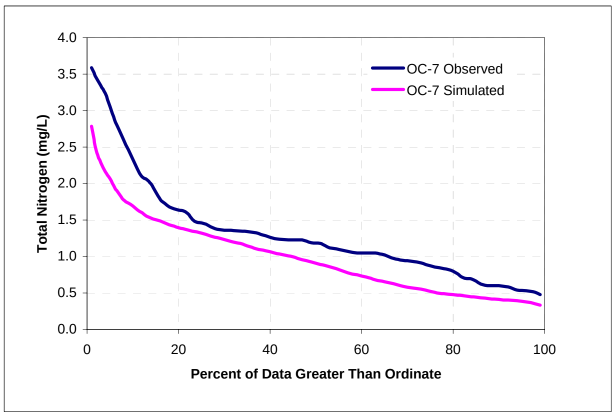




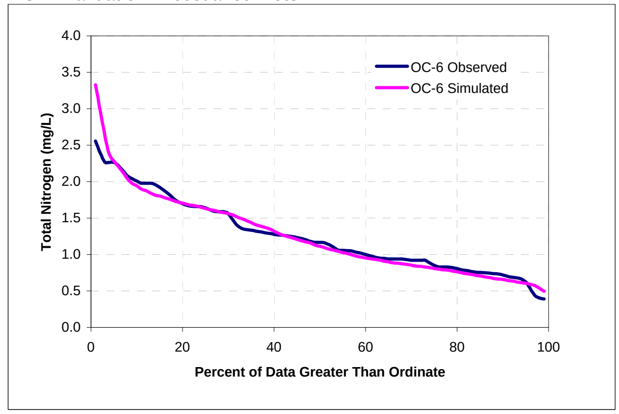


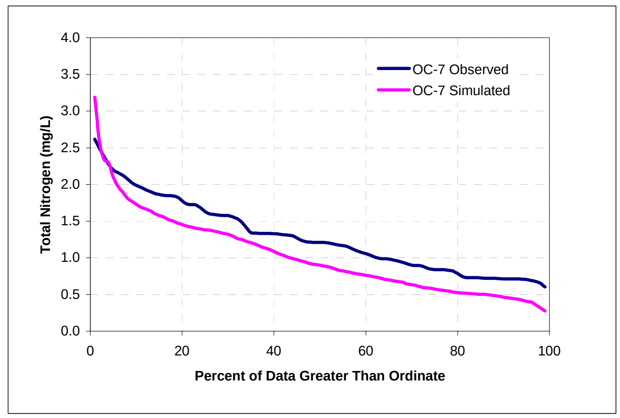
TOTN Calibration Exceedance Plots





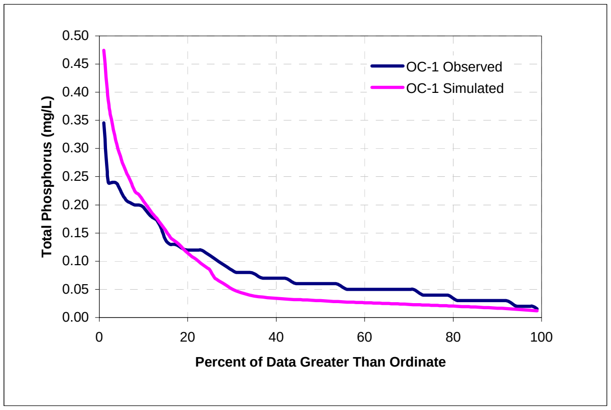
TOTN Validation Exceedance Plots

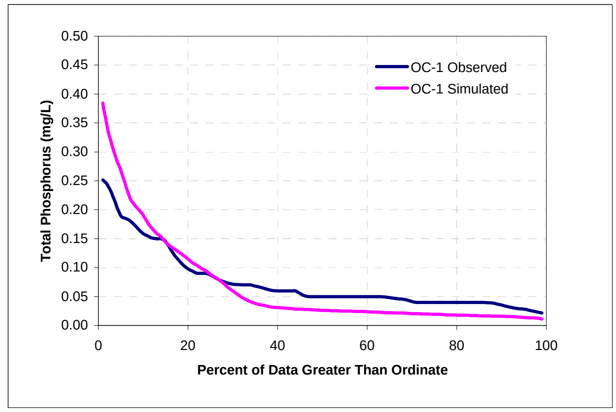


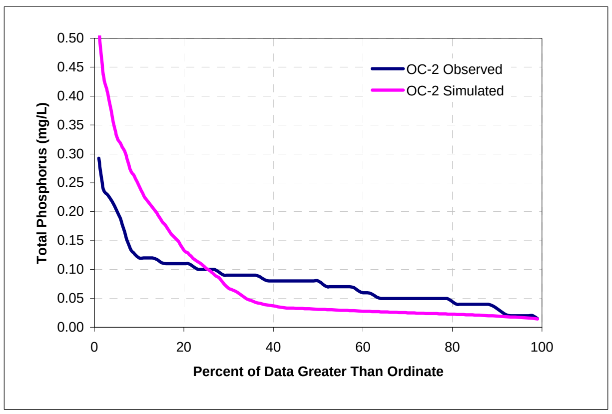


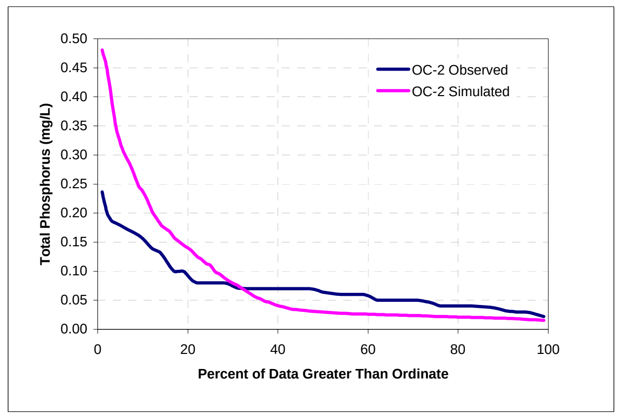
TOTP Calibration Exceedance Plots

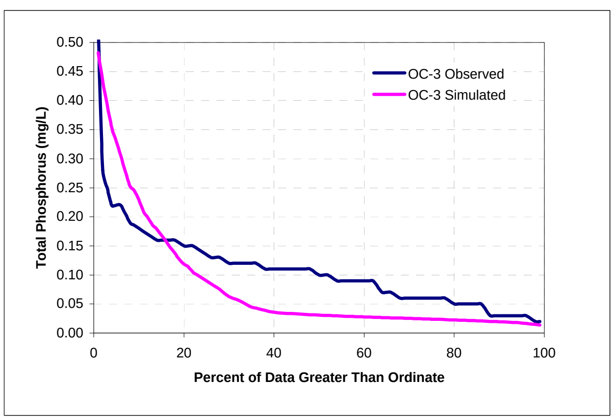
TOTP Validation Exceedance Plots

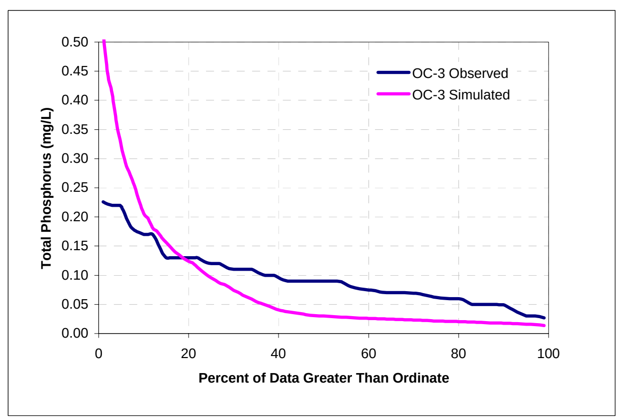




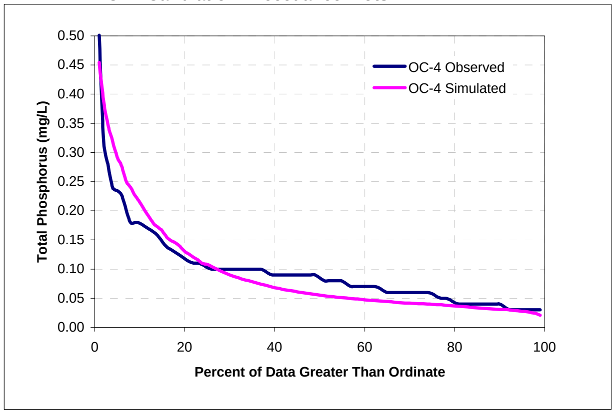




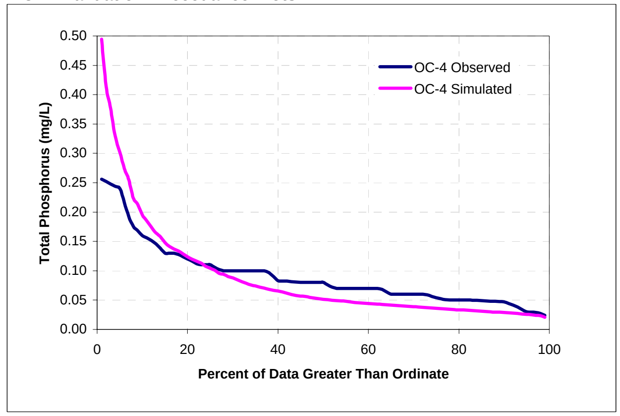


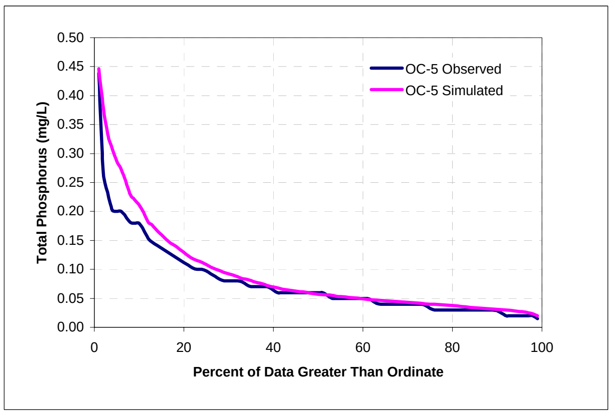


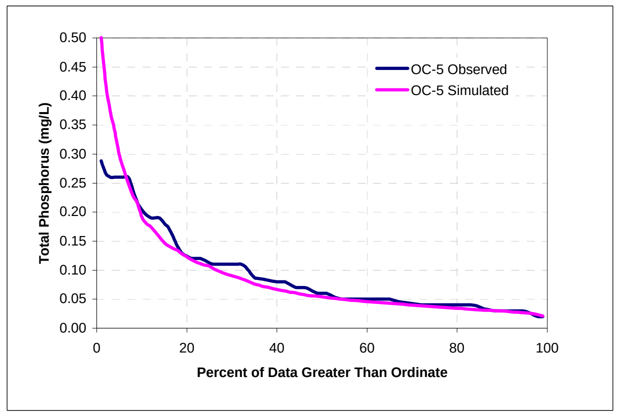
TOTP Calibration Exceedance Plots



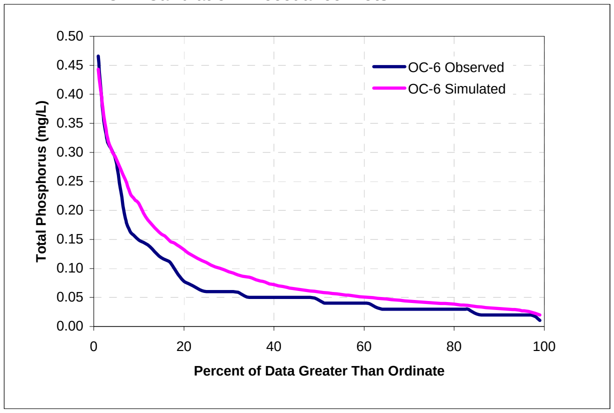
TOTP Validation Exceedance Plots

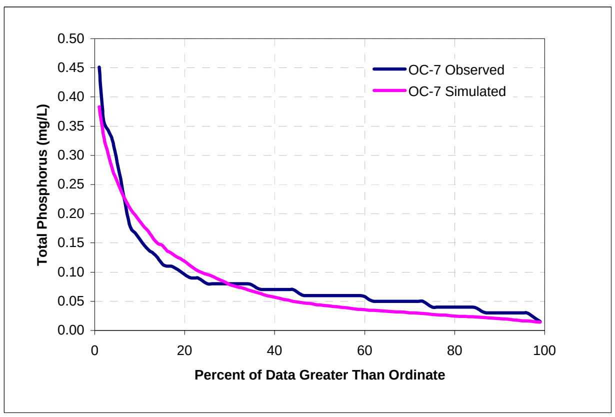




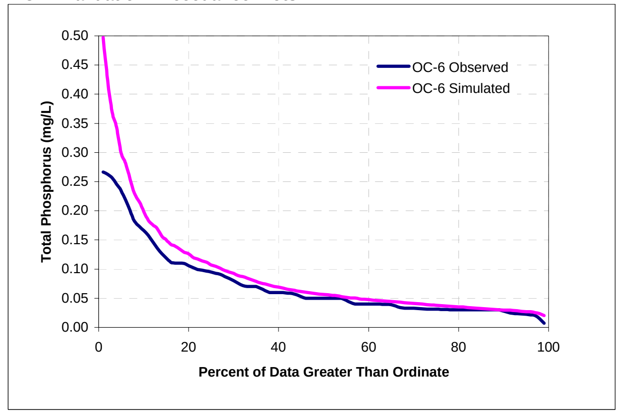


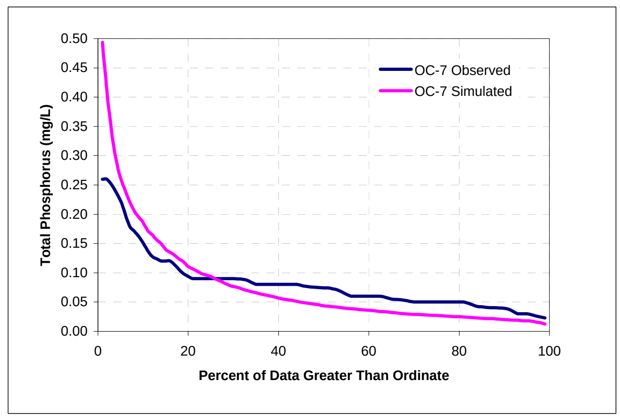
TOTP Calibration Exceedance Plots



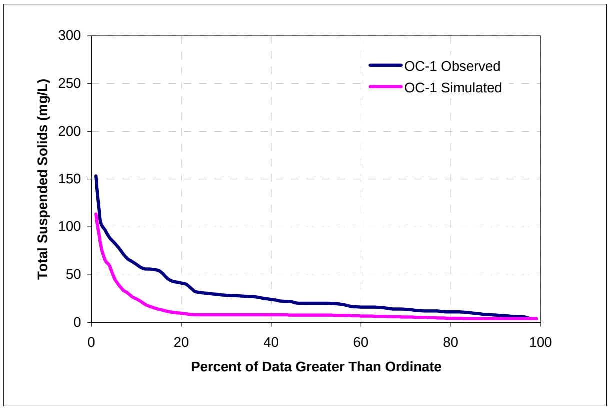


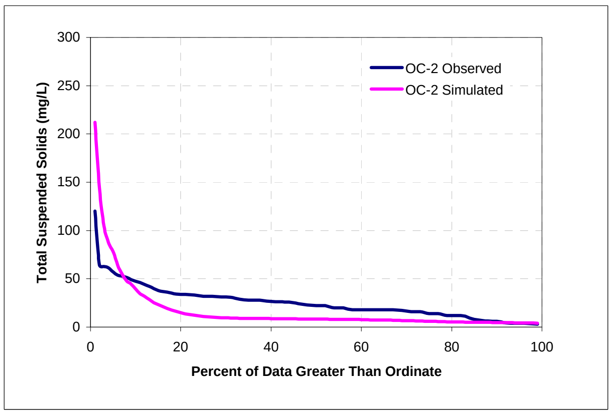
TOTP Validation Exceedance Plots

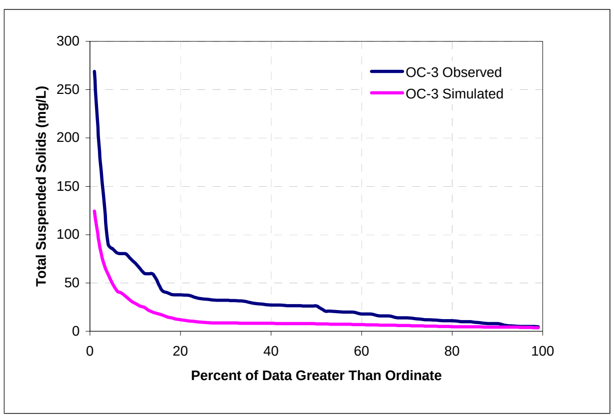




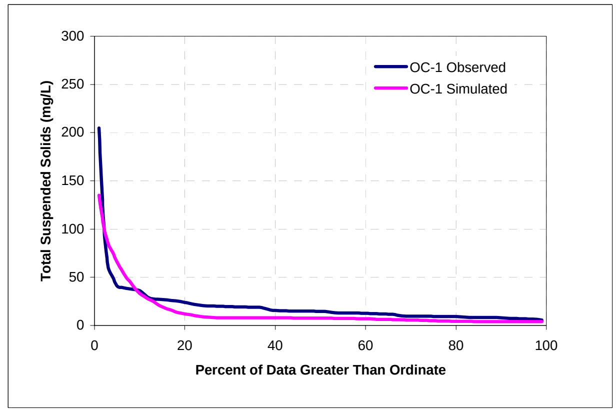
TSS Calibration Exceedance Plots

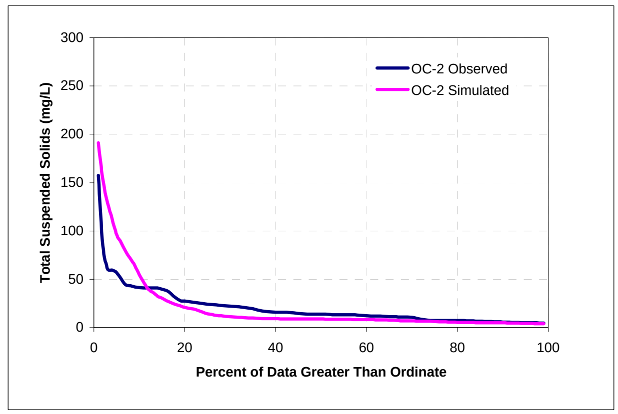


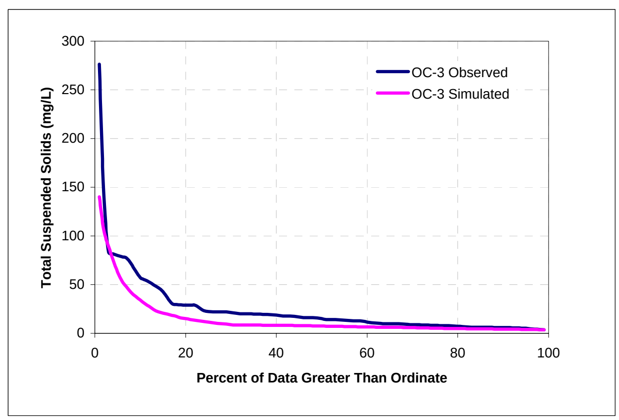




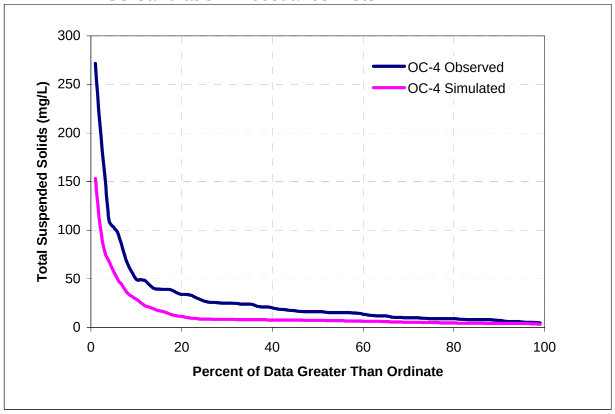
TSS Validation Exceedance Plots

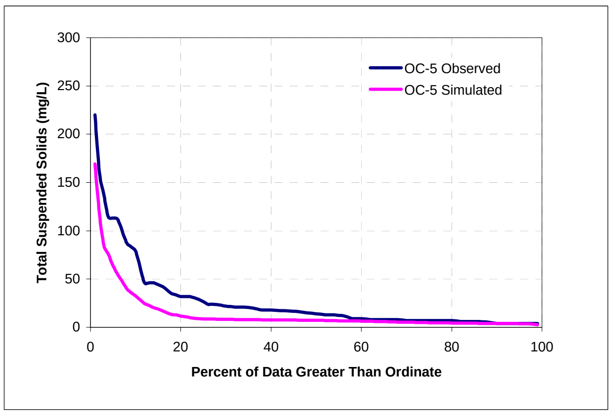




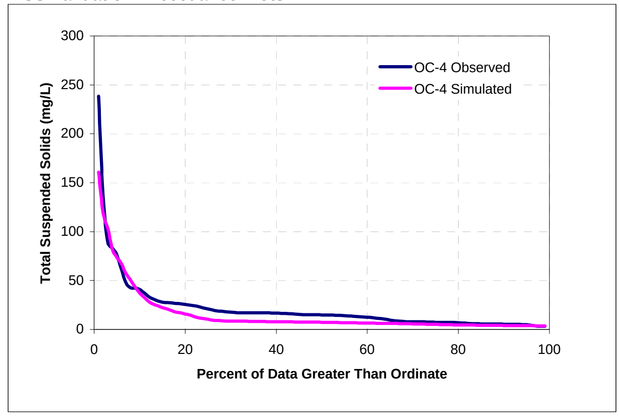


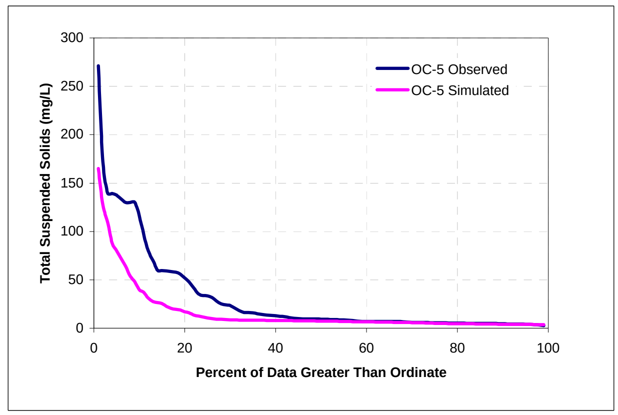
TSS Calibration Exceedance Plots



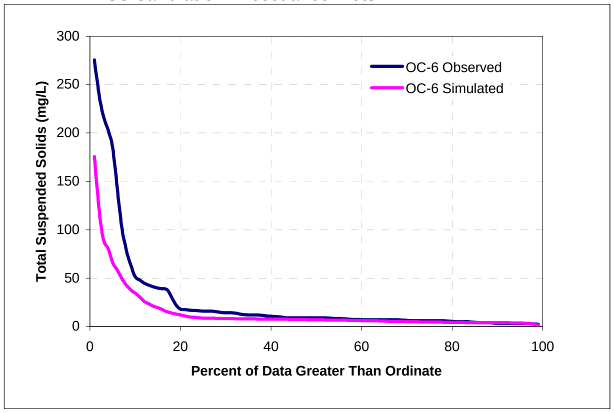


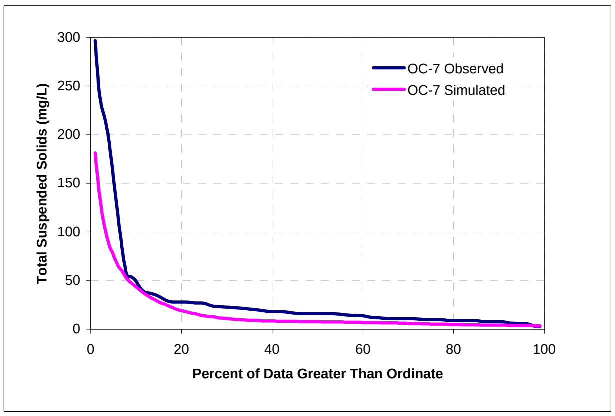
TSS Validation Exceedance Plots



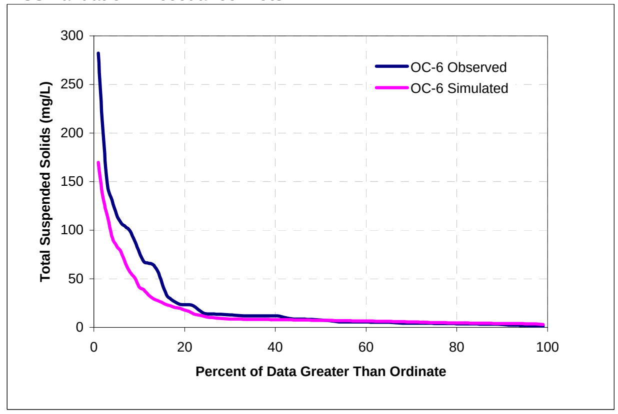


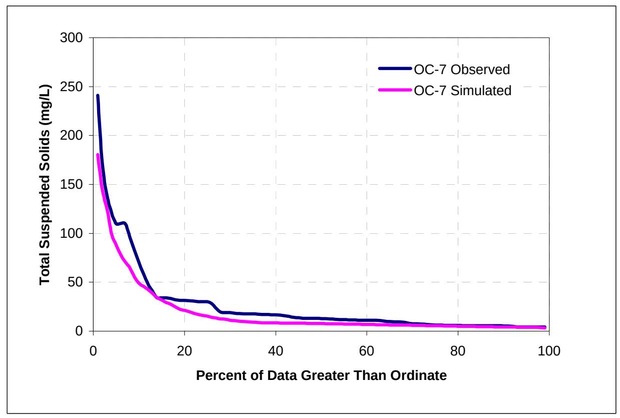
TSS Calibration Exceedance Plots





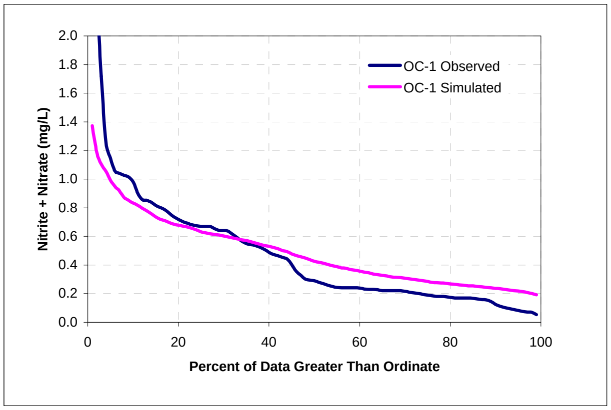
TSS Validation Exceedance Plots

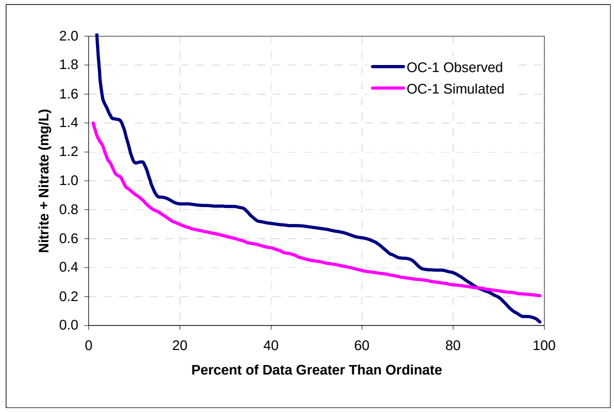


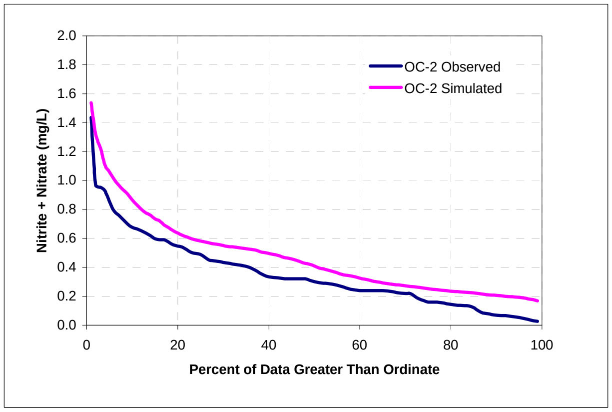


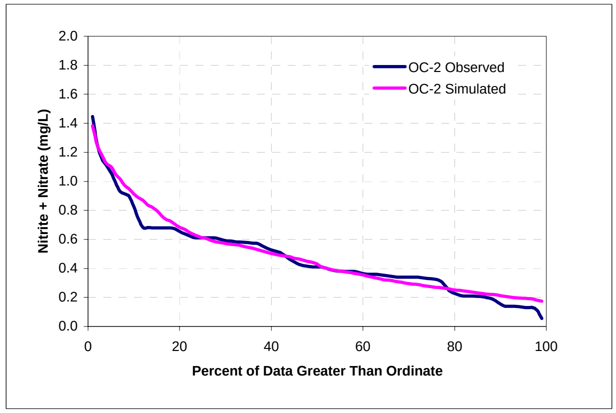
NO23 Calibration Exceedance Plots

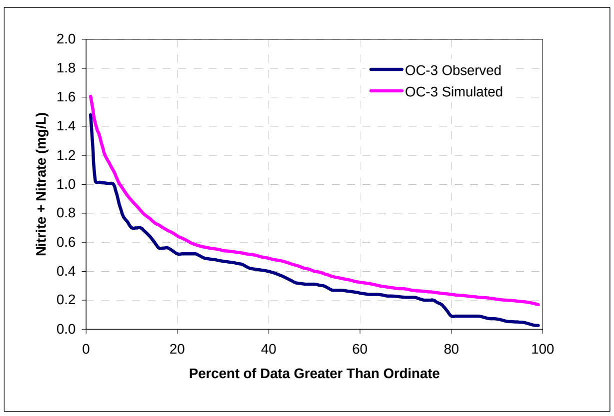
NO23 Validation Exceedance Plots

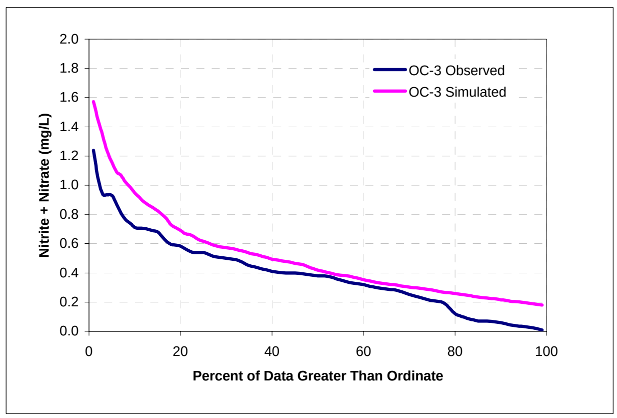




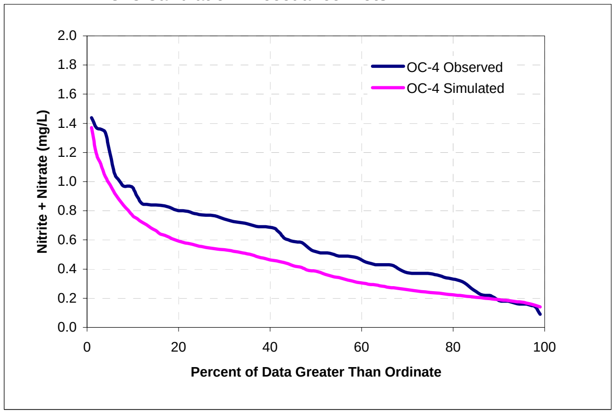




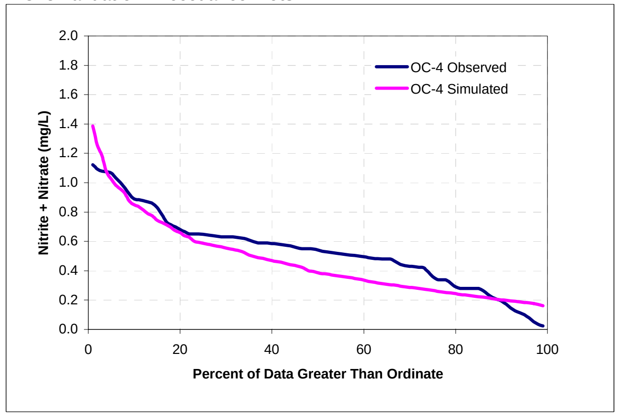


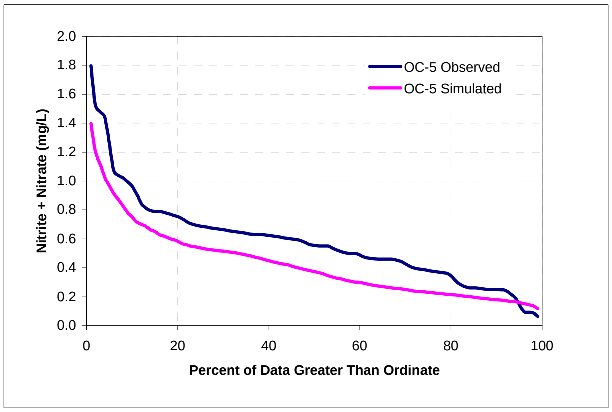


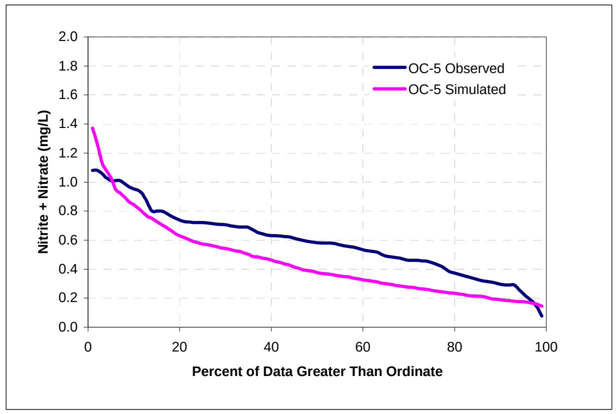
NO23 Calibration Exceedance Plots



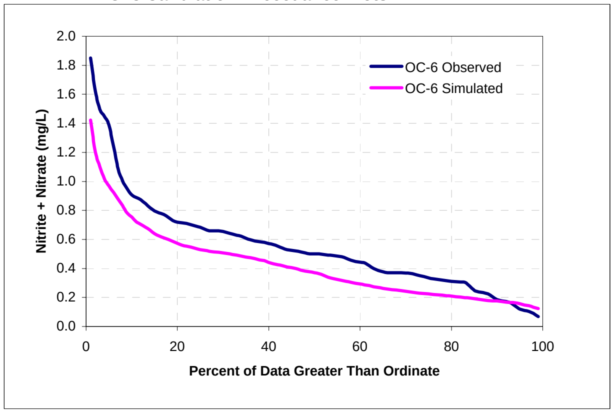
NO23 Validation Exceedance Plots



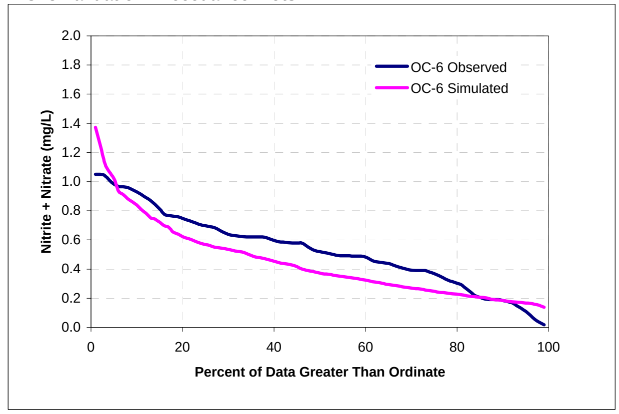


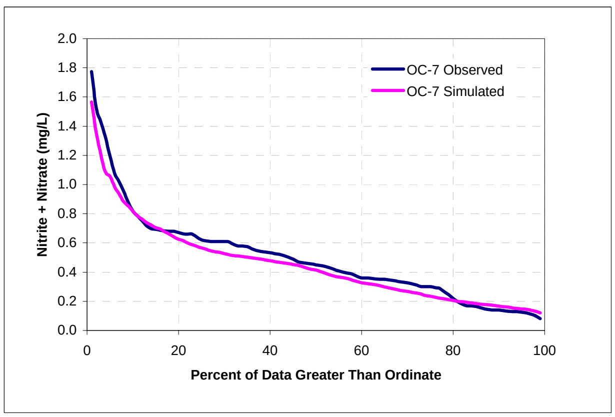


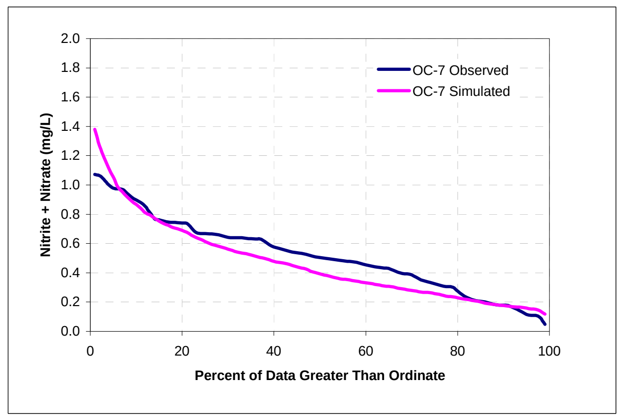
NO23 Calibration Exceedance Plots



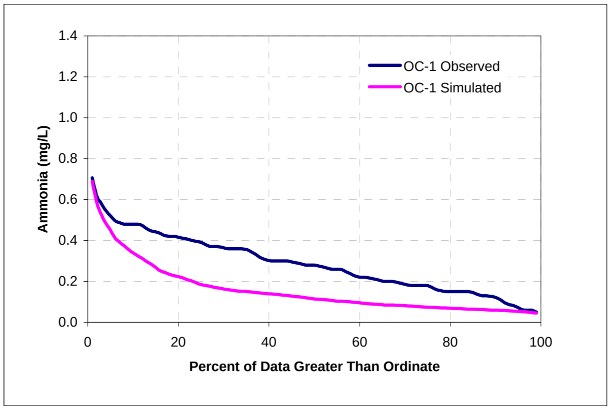
NO23 Validation Exceedance Plots

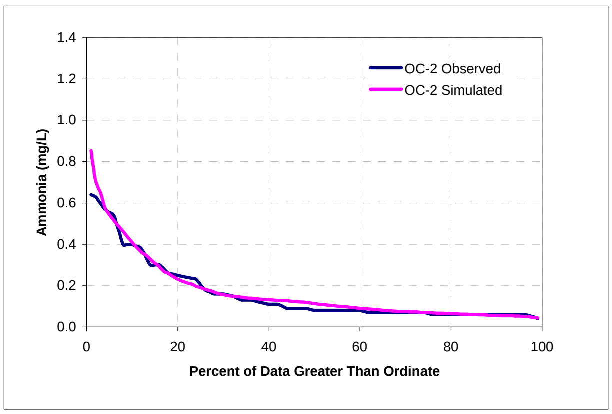


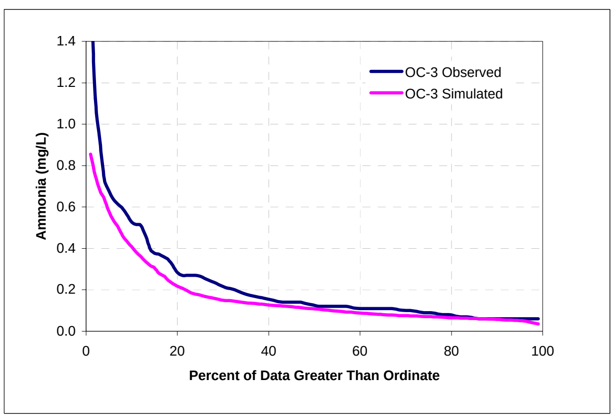




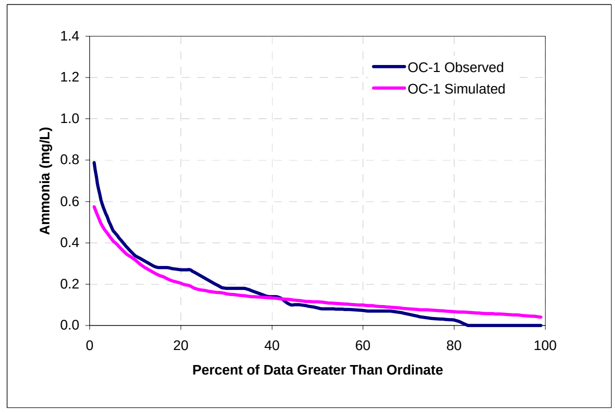
NH3 Calibration Exceedance Plots

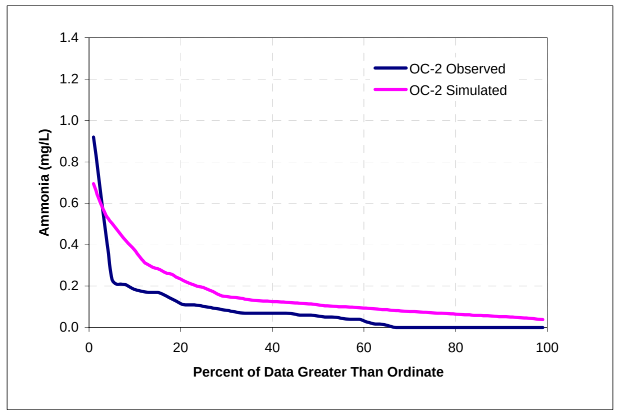


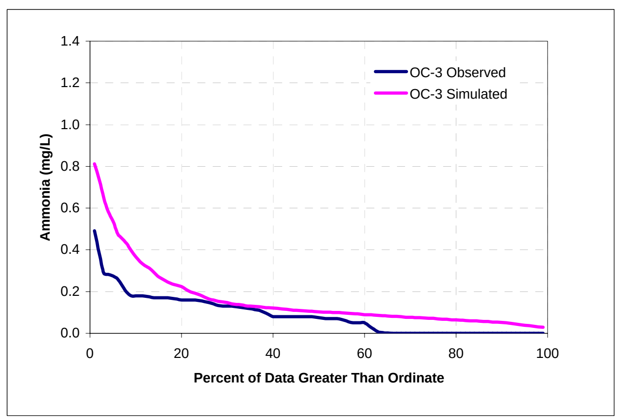




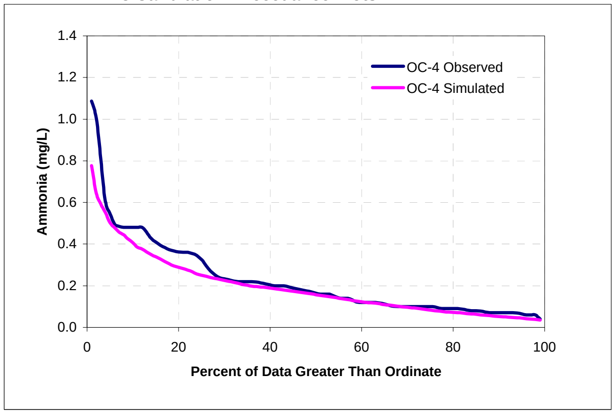
NH3 Validation Exceedance Plots



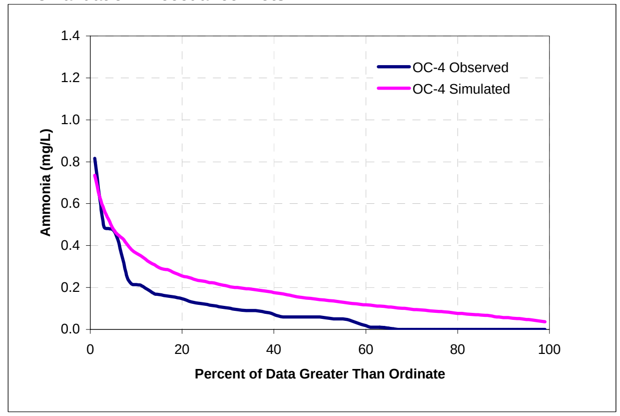


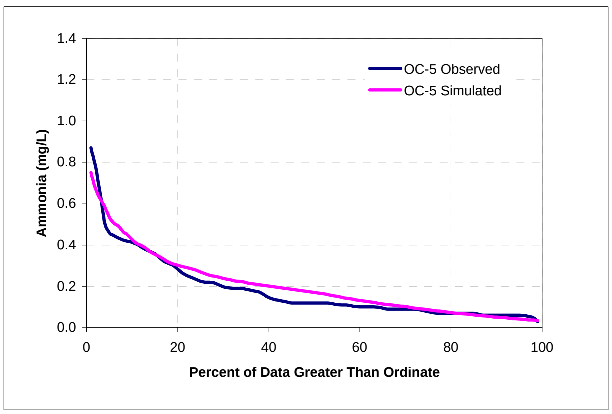


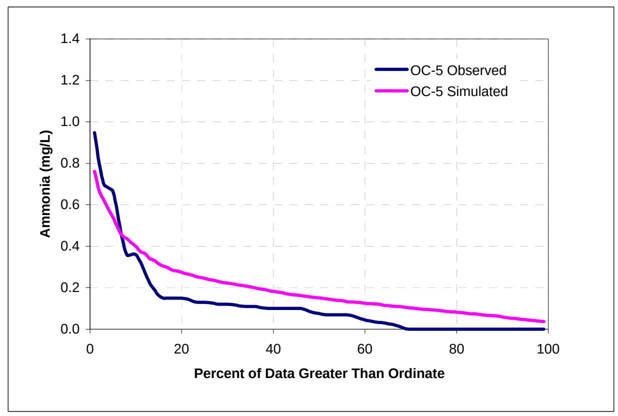
NH3 Calibration Exceedance Plots



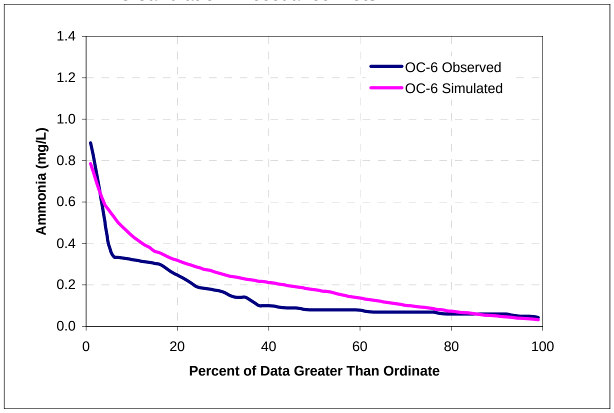
NH3 Validation Exceedance Plots

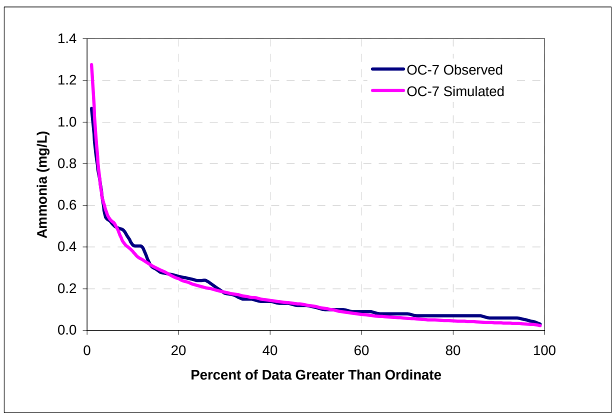




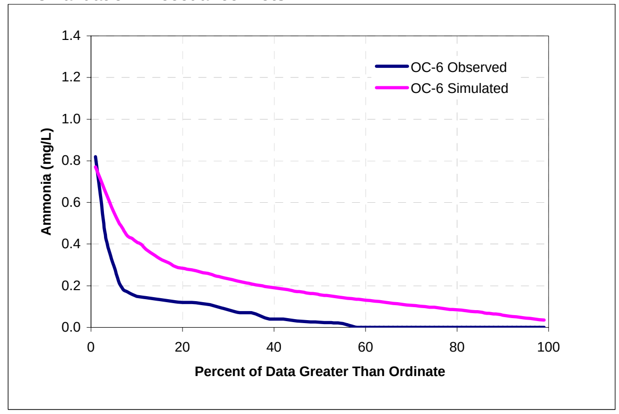


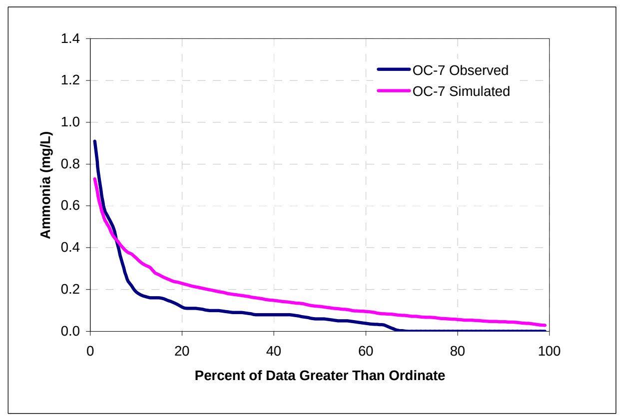
NH3 Calibration Exceedance Plots





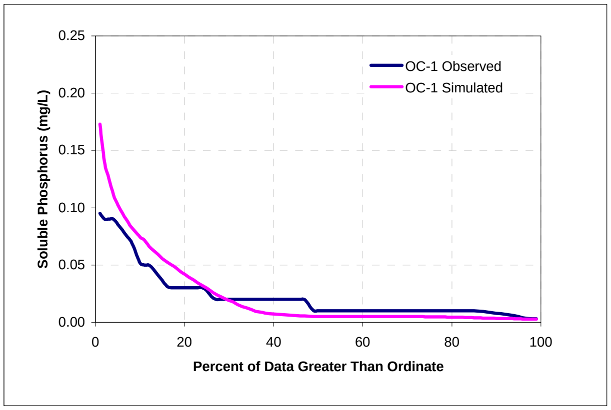
NH3 Validation Exceedance Plots

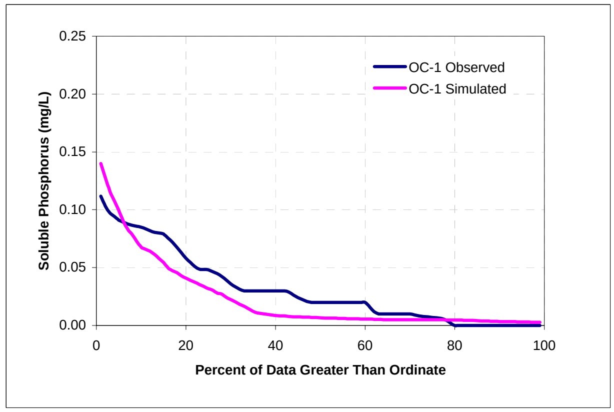


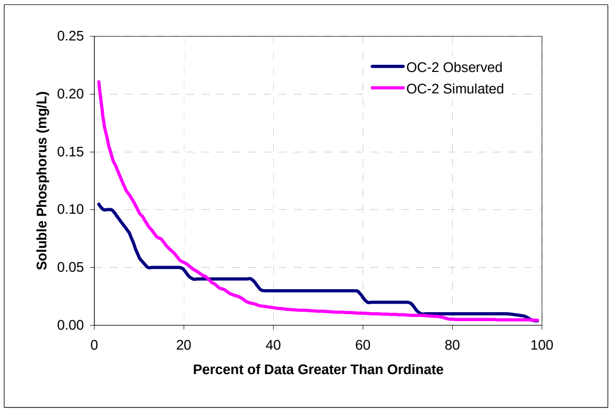


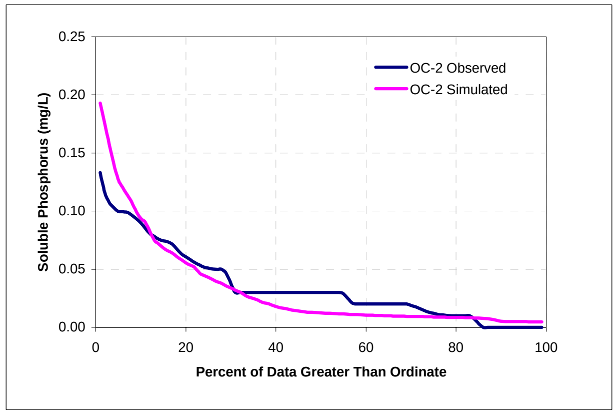
PORTH Calibration Exceedance Plots

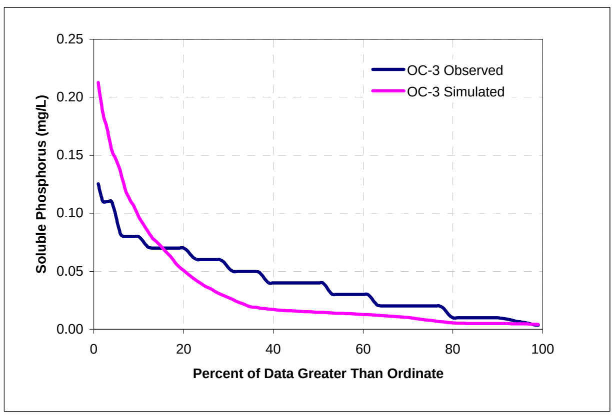
PORTH Validation Exceedance Plots

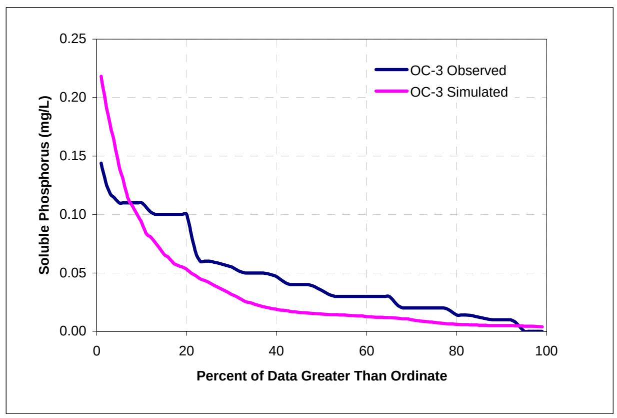






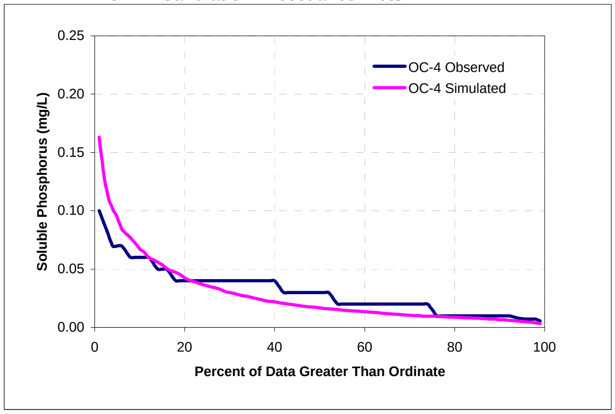


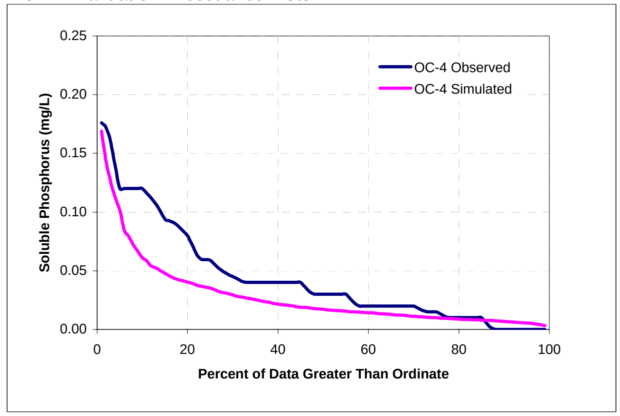


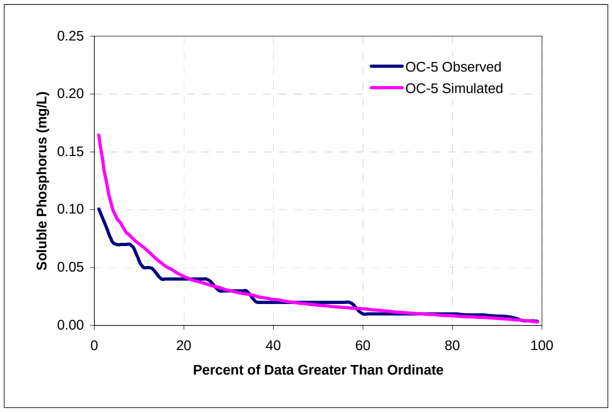


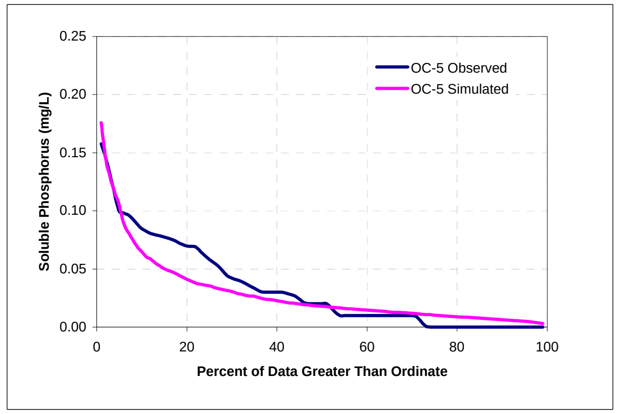
PORTH Calibration Exceedance Plots

PORTH Validation Exceedance Plots

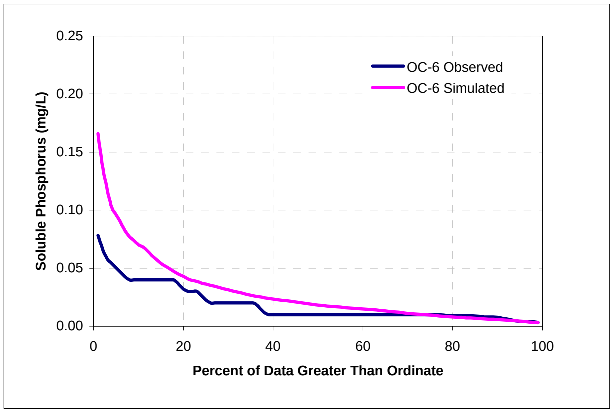


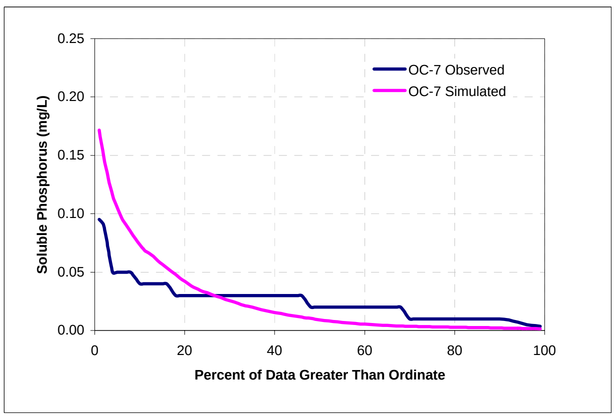




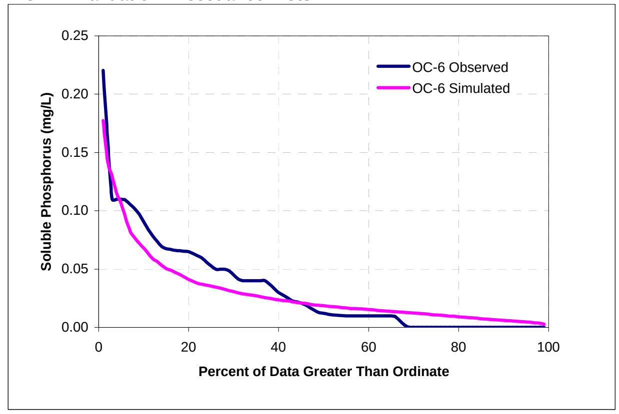


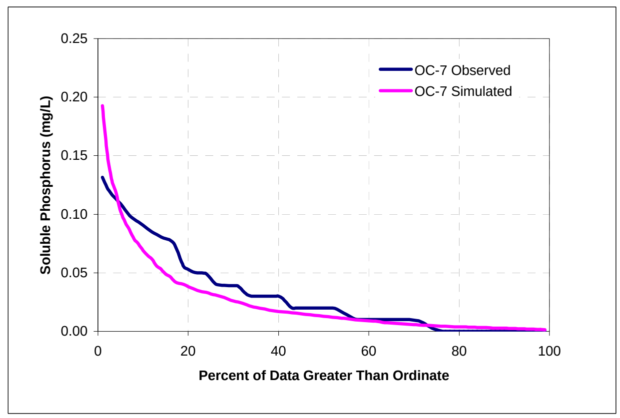
PORTH Calibration Exceedance Plots





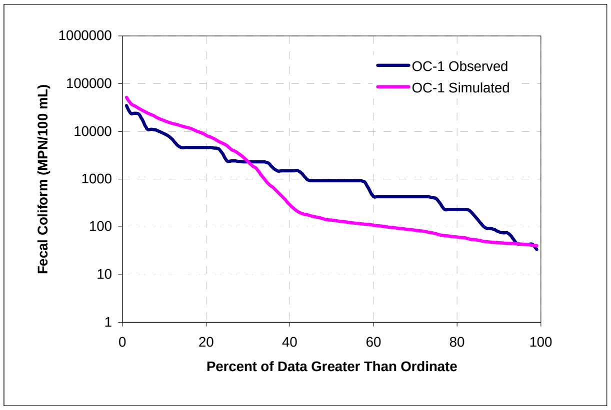
PORTH Validation Exceedance Plots

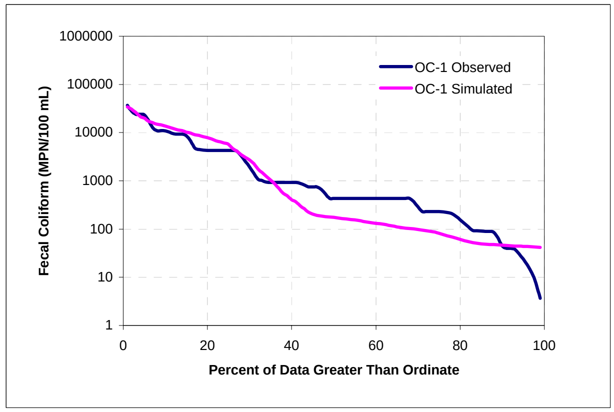


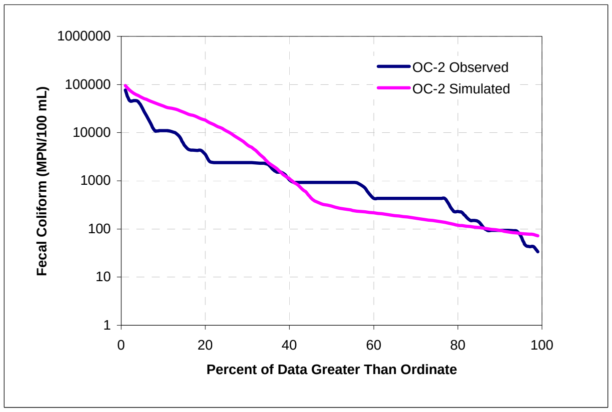


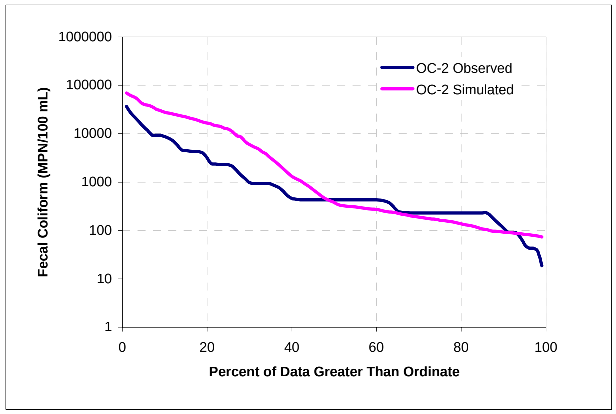
FCOL Calibration Exceedance Plots

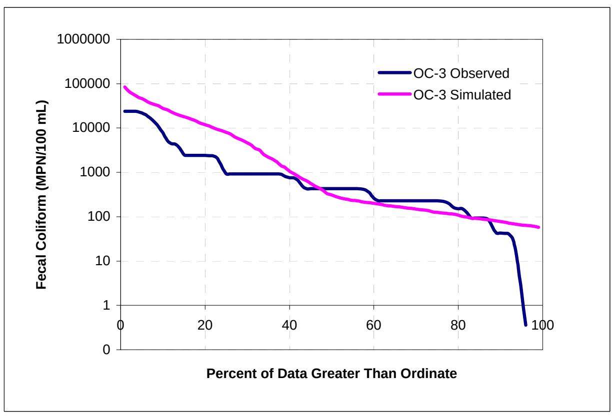
FCOL Validation Exceedance Plots

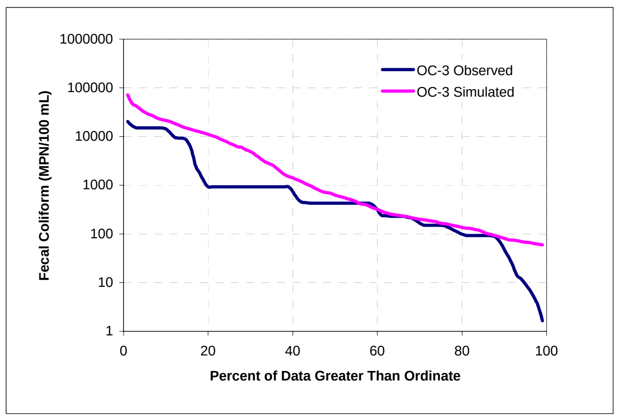




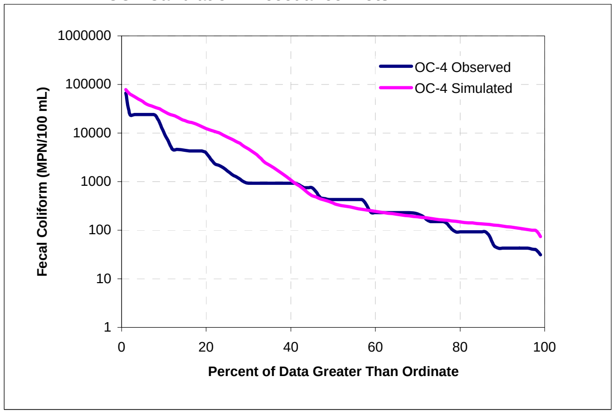




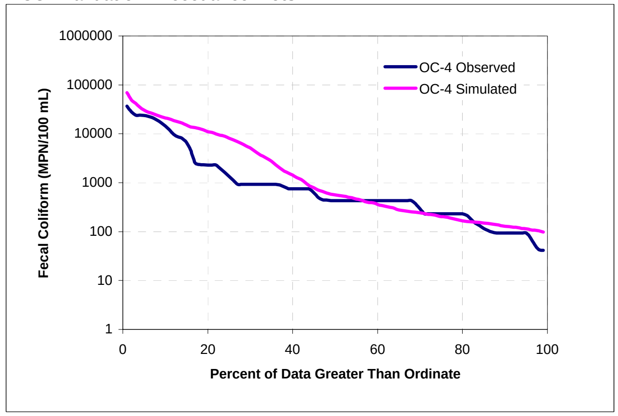


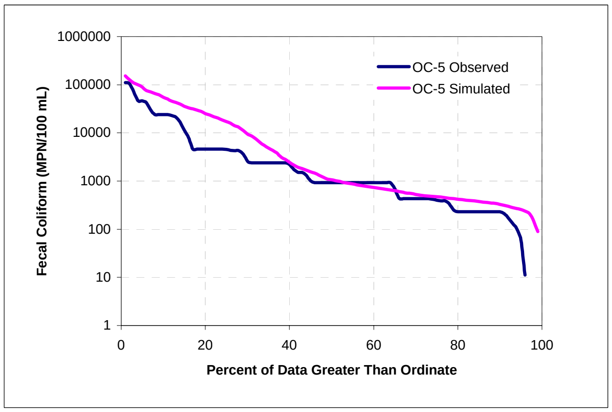


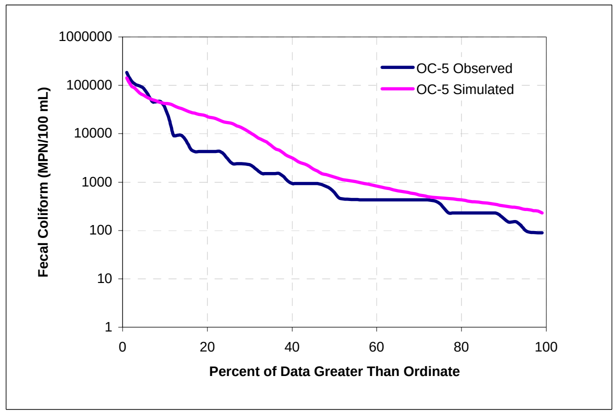
FCOL Calibration Exceedance Plots



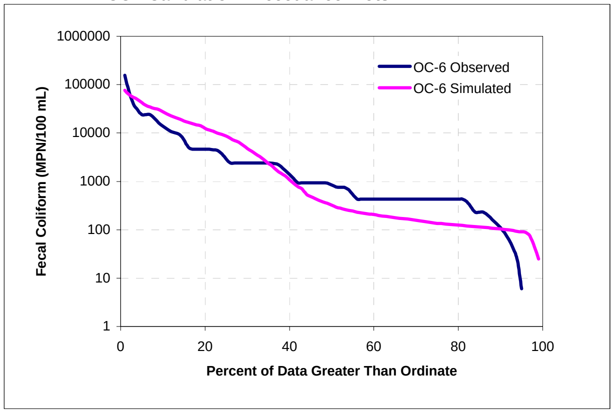
FCOL Validation Exceedance Plots

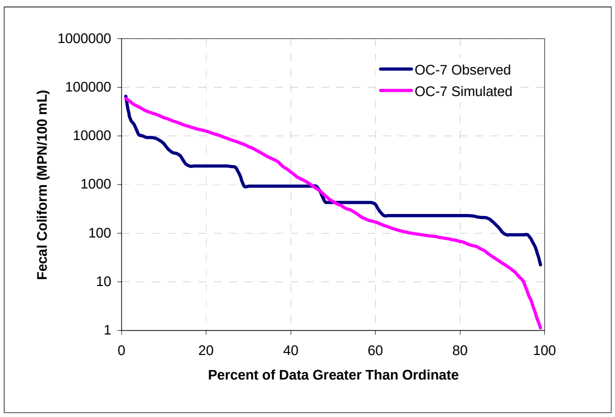




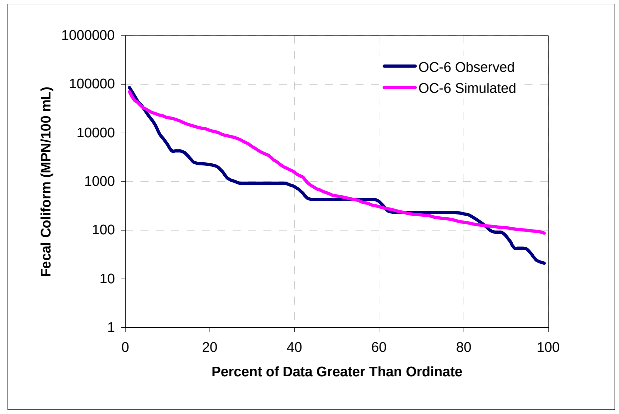


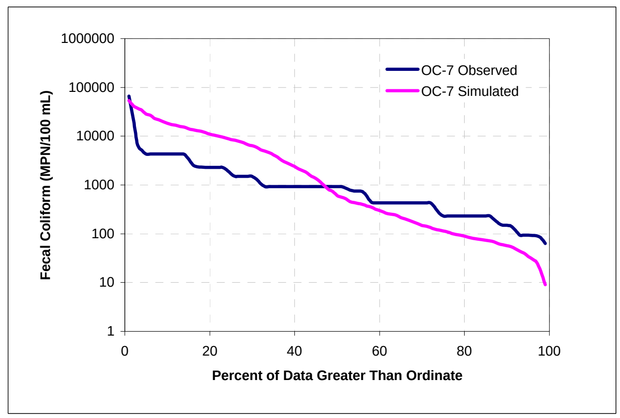
FCOL Calibration Exceedance Plots



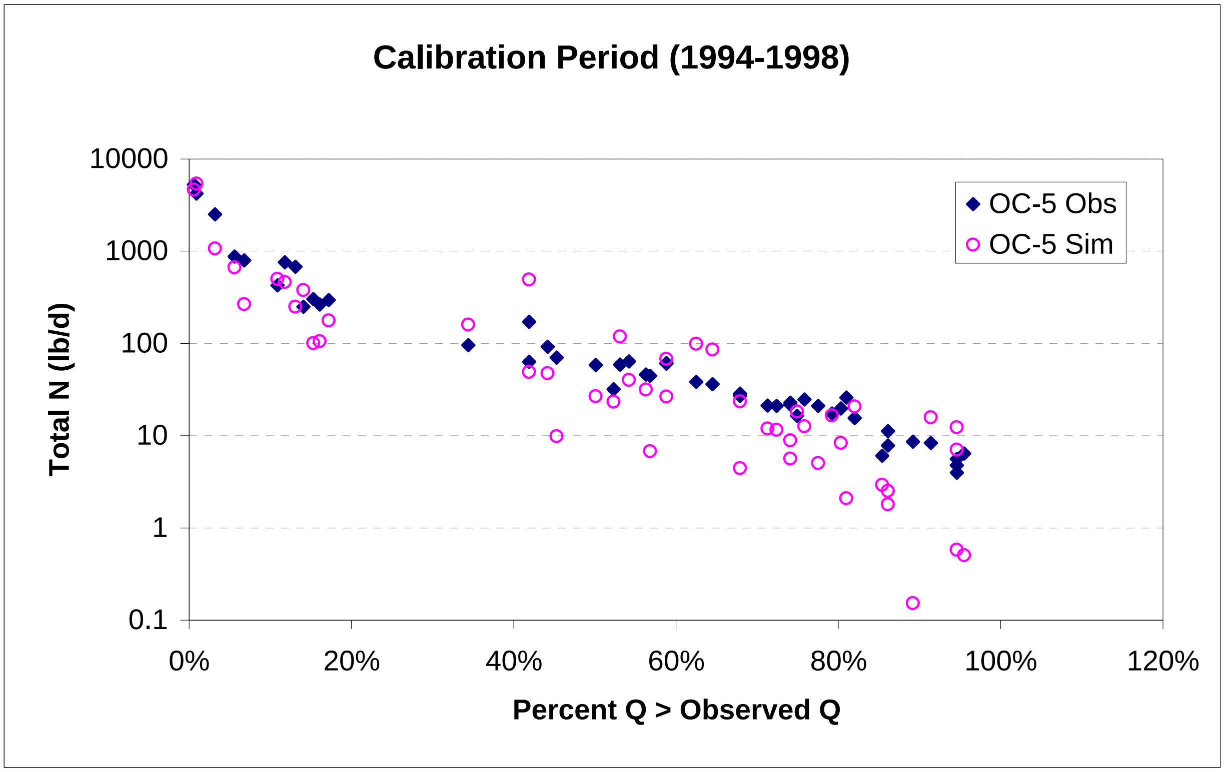


FCOL Validation Exceedance Plots

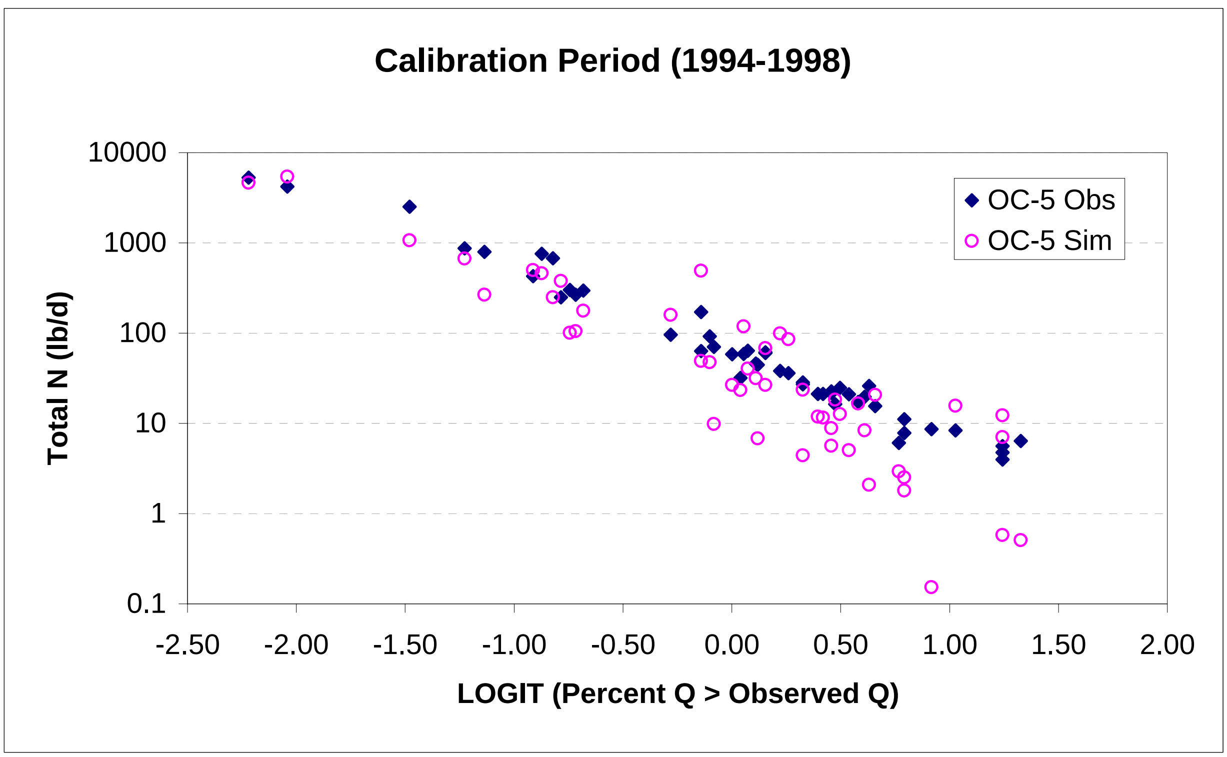




ATTACHMENT B – LOAD-DURATION ANALYSIS RESULTS



Calibration Period (1994-1998)
Total N (lb/d)
10000
1000
100
10
1
0.1
0%
20%
40%
60%
80%
100%
120%
Percent Q > Observed Q
OC-5 Obs
OC-5 Sim



Calibration Period (1994-1998)
Total N (lb/d)
10000
1000
100
10
1
0.1
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
OC-5 Obs
OC-5 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.95707	4.434921
0.191874	0.238258
0.912308	0.332197
104.0357	10
2.228139	
0.427521	
-2.384591	
-1.529549	

0-20% - Sim

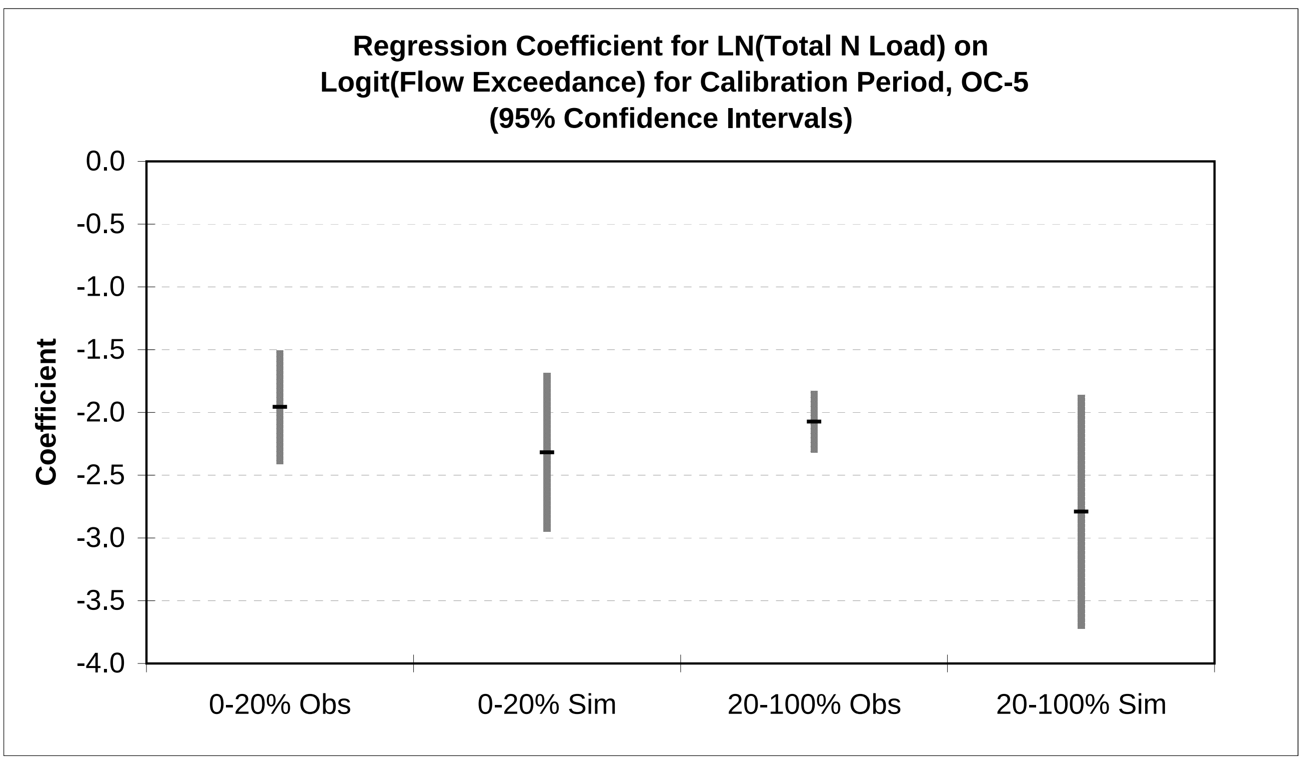
-2.318056	3.56079
0.271725	0.337413
0.879193	0.470446
72.77634	10
2.228139	
0.60544	
-2.923496	
-1.712616	

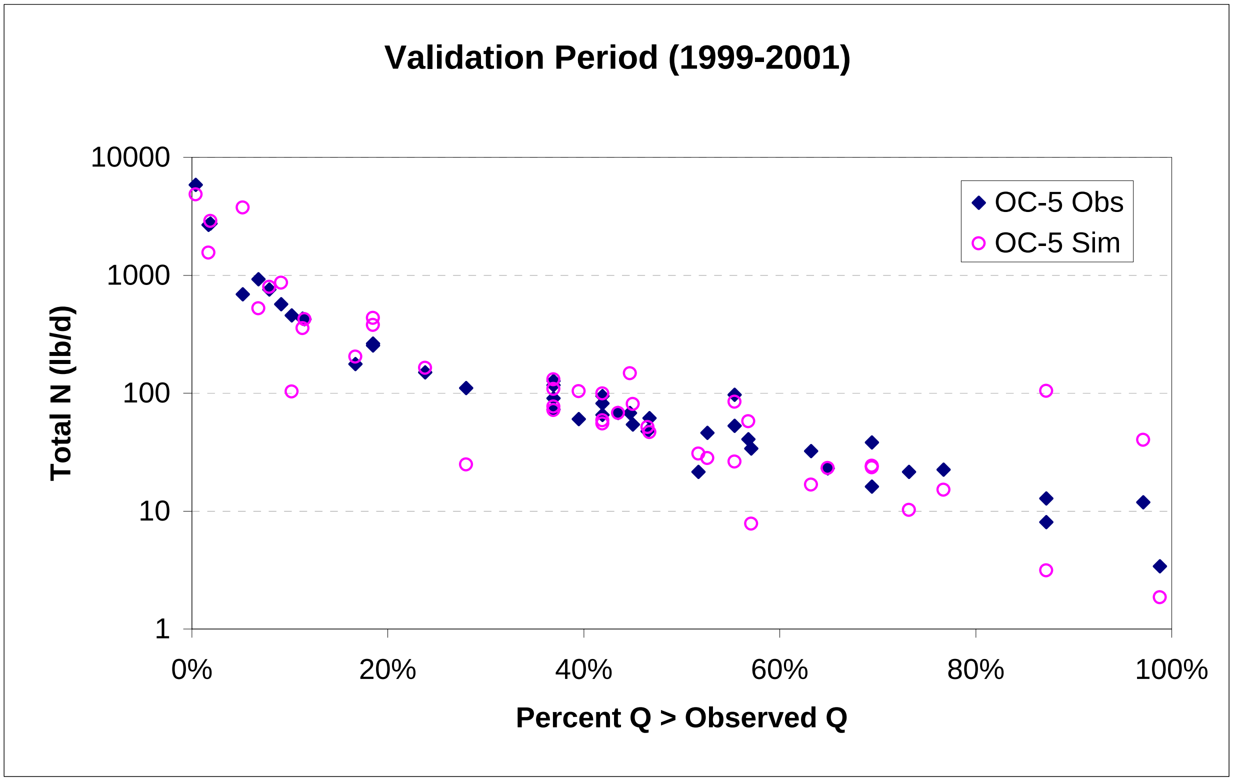
20-100% - Obs

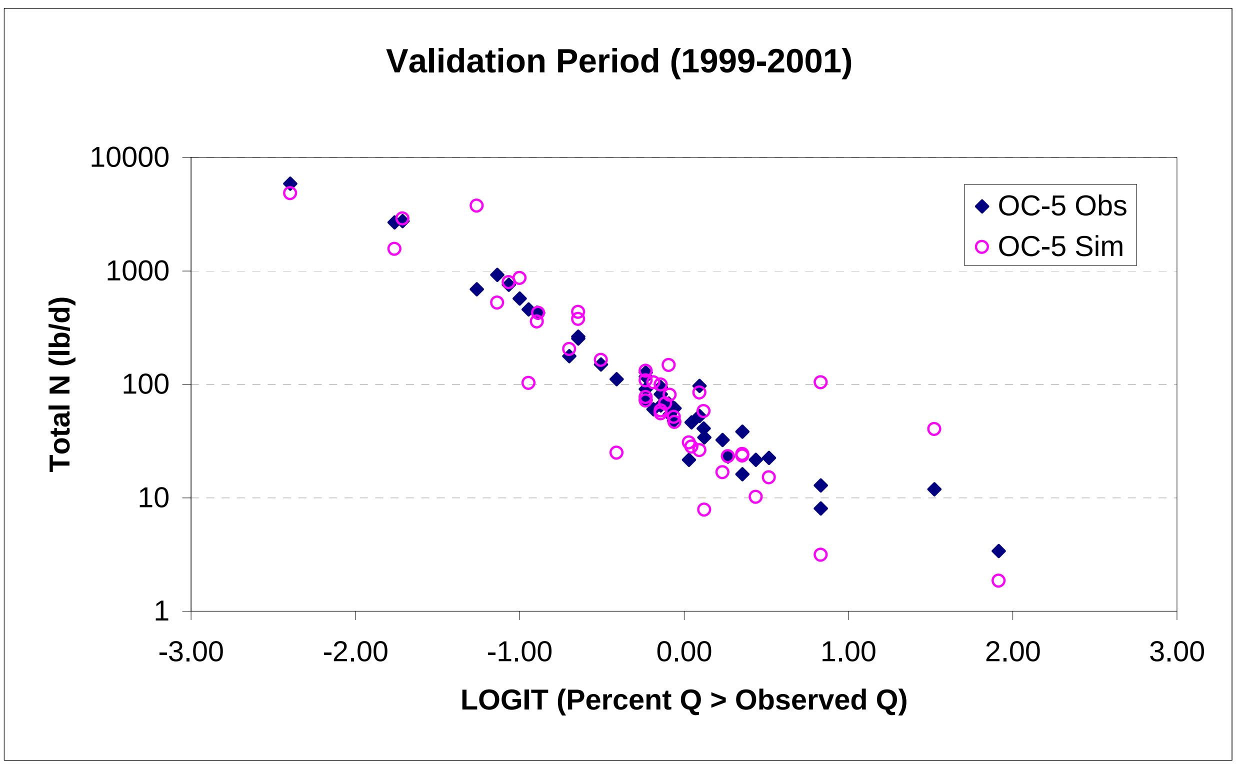
-2.074203	4.105286
0.108416	0.066049
0.912725	0.280148
366.0303	35
2.030108	
0.220096	
-2.294298	
-1.854107	

20-100% - Sim

-2.791375	3.761713
0.446673	0.272122
0.527367	1.154209
39.0532	35
2.030108	
0.906795	
-3.698169	
-1.88458	




Validation Period (1999-2001)
10000
1000
100
10
1
0%
20%
40%
60%
80%
100%
Total N (lb/d)
Percent Q > Observed Q
OC-5 Obs
OC-5 Sim


Validation Period (1999-2001)
10000
1000
100
10
1
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
Total N (lb/d)
LOGIT (Percent Q > Observed Q)
OC-5 Obs
OC-5 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.95968	4.295933
0.135509	0.170559
0.950032	0.241615
209.1404	11
2.200985	
0.298253	
-2.25794	
-1.66143	

0-20% - Sim

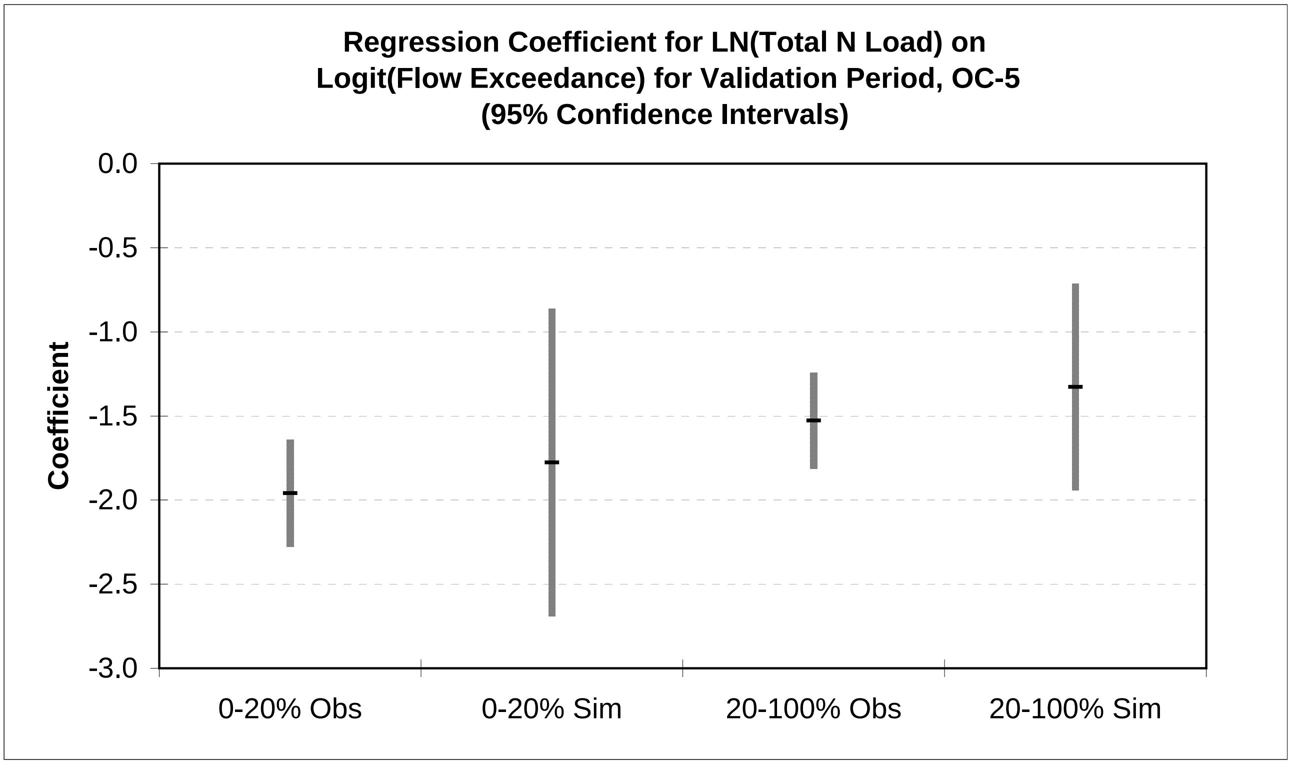
-1.77623	4.530423
0.407143	0.512455
0.633733	0.725947
19.03275	11
2.200985	
0.896117	
-2.67234	
-0.88011	

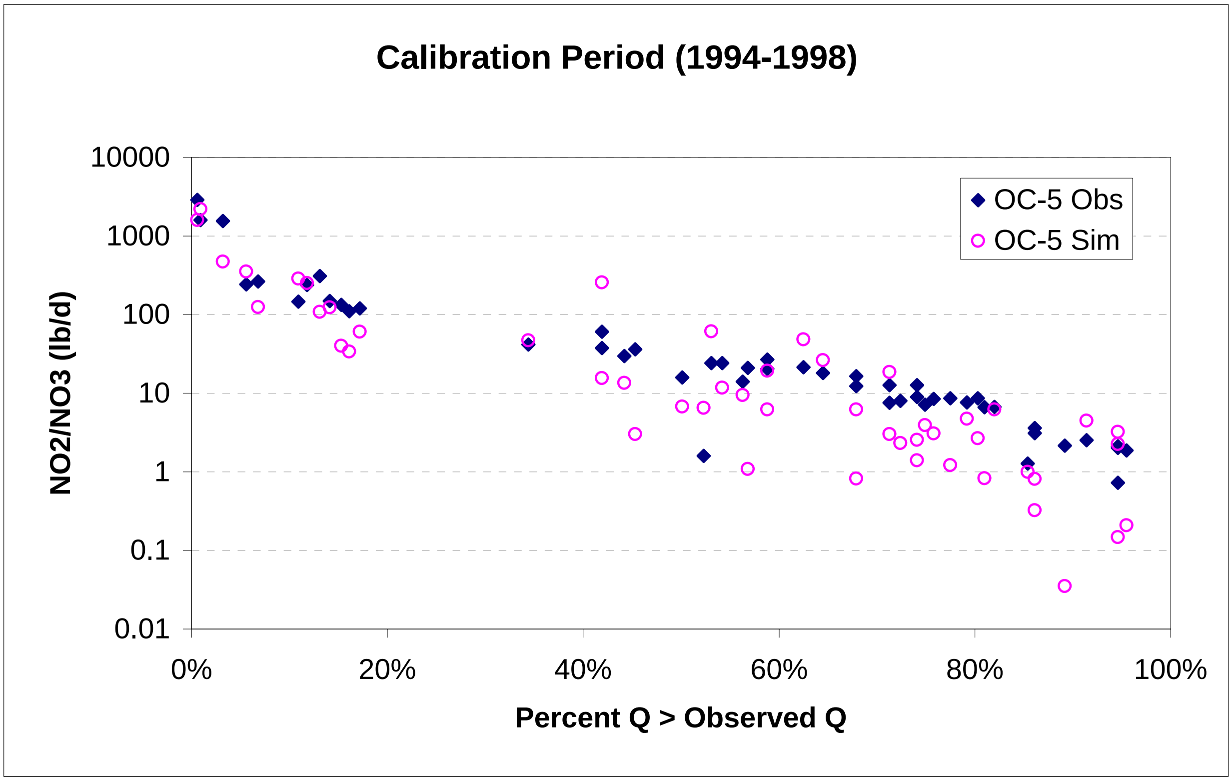
20-100% - Obs

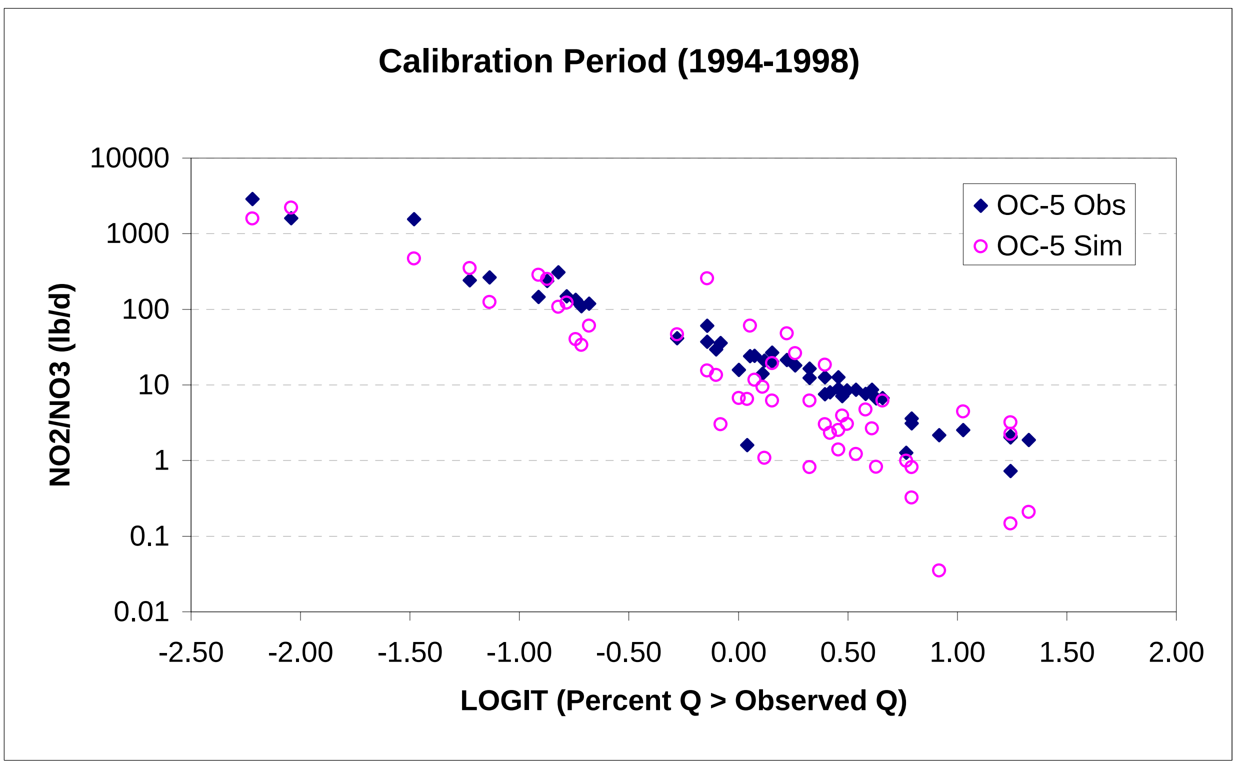
-1.52704	3.983105
0.1304	0.070428
0.825442	0.374886
137.1343	29
2.04523	
0.266698	
-1.79374	
-1.26034	

20-100% - Sim

-1.3281	3.862954
0.290924	0.157126
0.418141	0.836374
20.84023	29
2.04523	
0.595007	
-1.92311	
-0.73309	




Calibration Period (1994-1998)
NO2/NO3 (lb/d)
10000
1000
100
10
1
0.1
0.01
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
OC-5 Obs
OC-5 Sim


Calibration Period (1994-1998)
NO2/NO3 (lb/d)
10000
1000
100
10
1
0.1
0.01
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
OC-5 Obs
OC-5 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.04364	3.453895
0.235765	0.29276
0.882542	0.408188
75.1365	10
2.228139	
0.525317	
-2.56896	
-1.51832	

0-20% - Sim

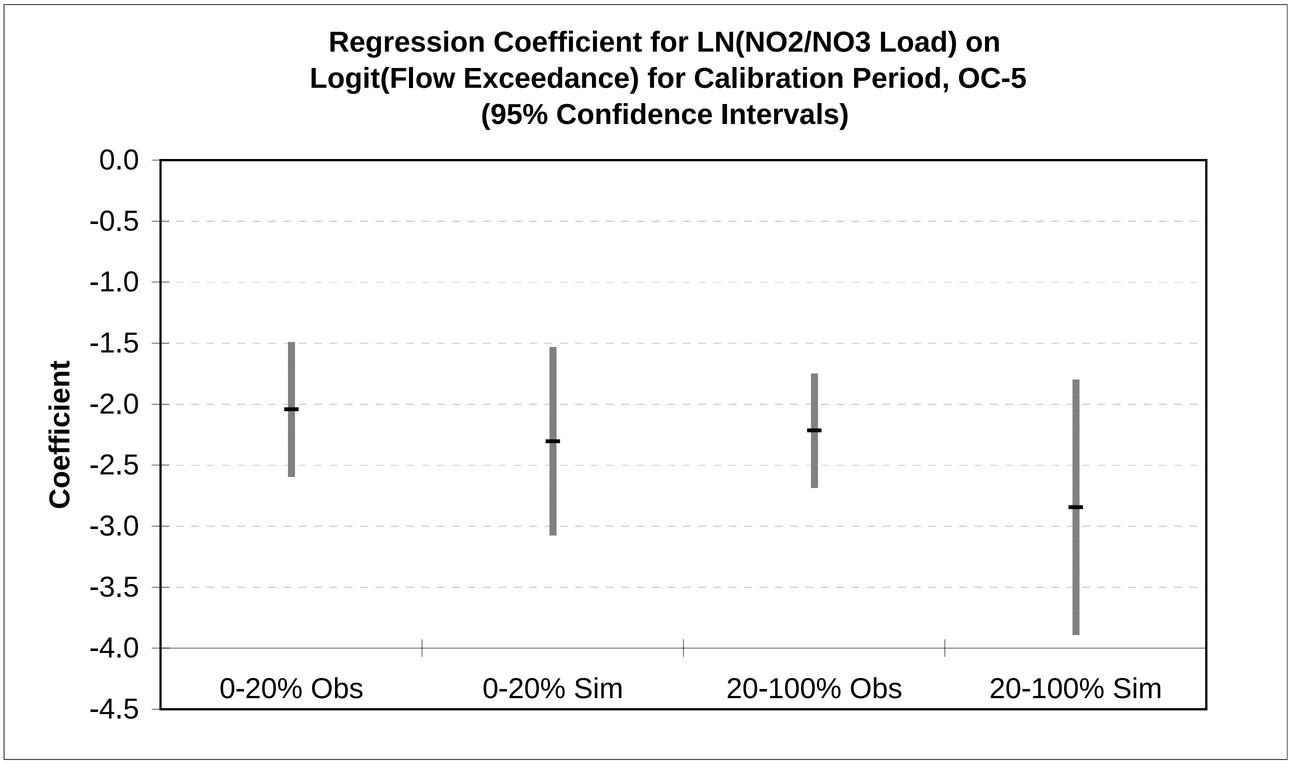
-2.30419	2.705637
0.33513	0.416147
0.825396	0.580223
47.27258	10
2.228139	
0.746717	
-3.05091	
-1.55747	

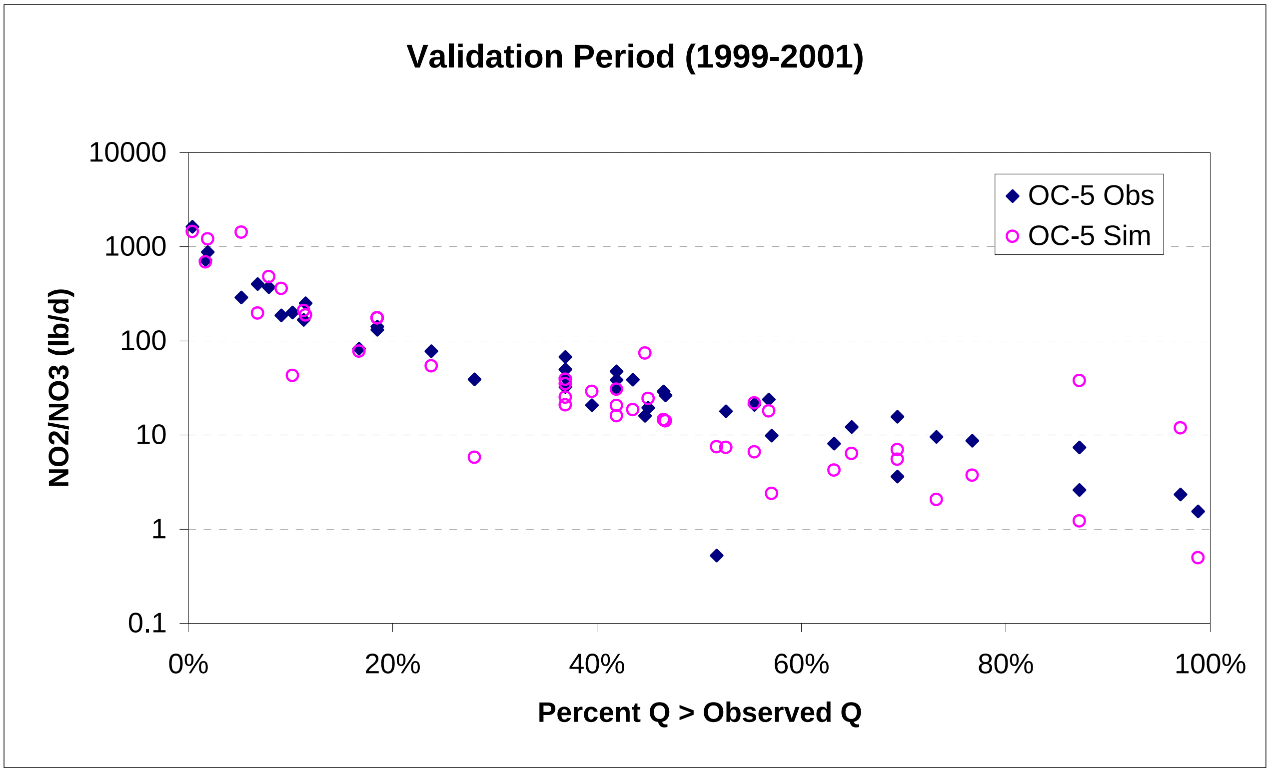
20-100% - Obs

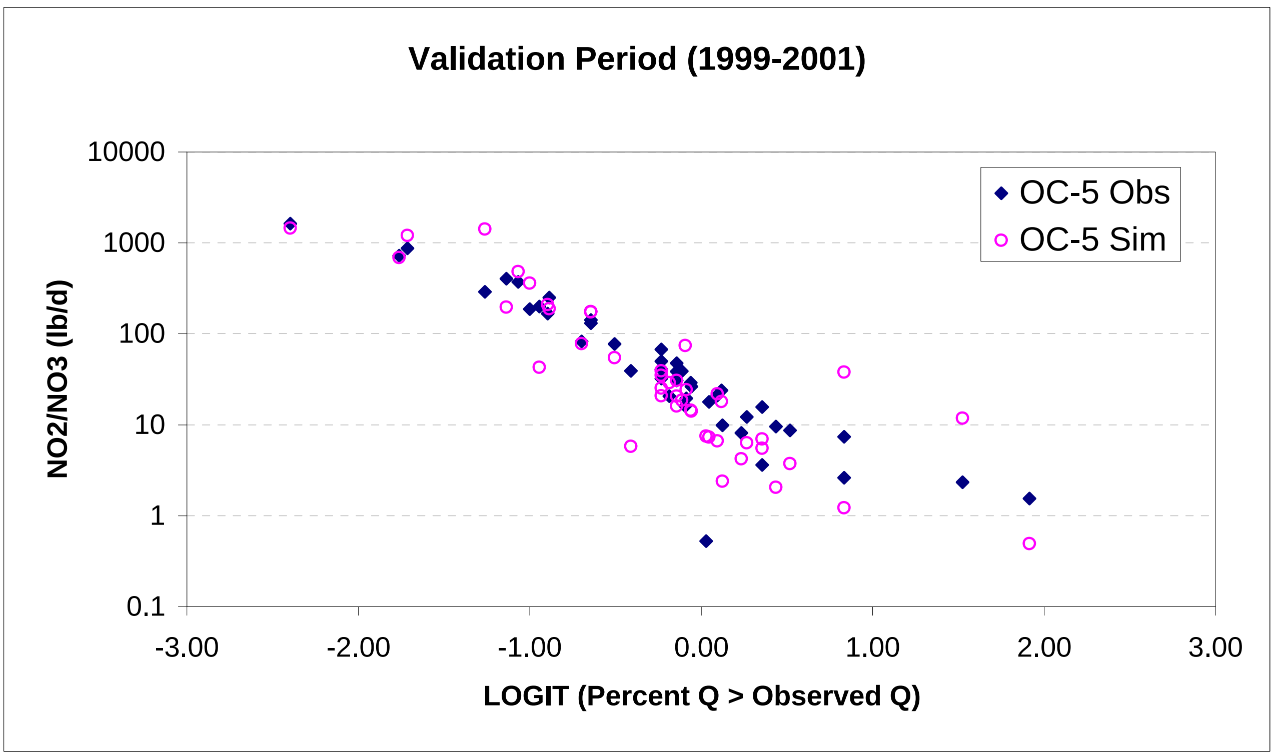
-2.21722	3.14907
0.217565	0.131531
0.742595	0.562261
103.8575	36
2.028094	
0.441242	
-2.65846	
-1.77597	

20-100% - Sim

-2.84612	2.564661
0.502574	0.303835
0.471137	1.298821
32.07051	36
2.028094	
1.019268	
-3.86539	
-1.82685	




Validation Period (1999-2001)
10000
1000
100
10
1
0.1
NO2/NO3 (lb/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
OC-5 Obs
OC-5 Sim


Validation Period (1999-2001)
10000
1000
100
10
1
0.1
NO2/NO3 (lb/d)
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
OC-5 Obs
OC-5 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.558952	3.869624
0.155118	0.195241
0.901789	0.27658
101.004	11
2.200985	
0.341413	
-1.900365	
-1.217538	

0-20% - Sim

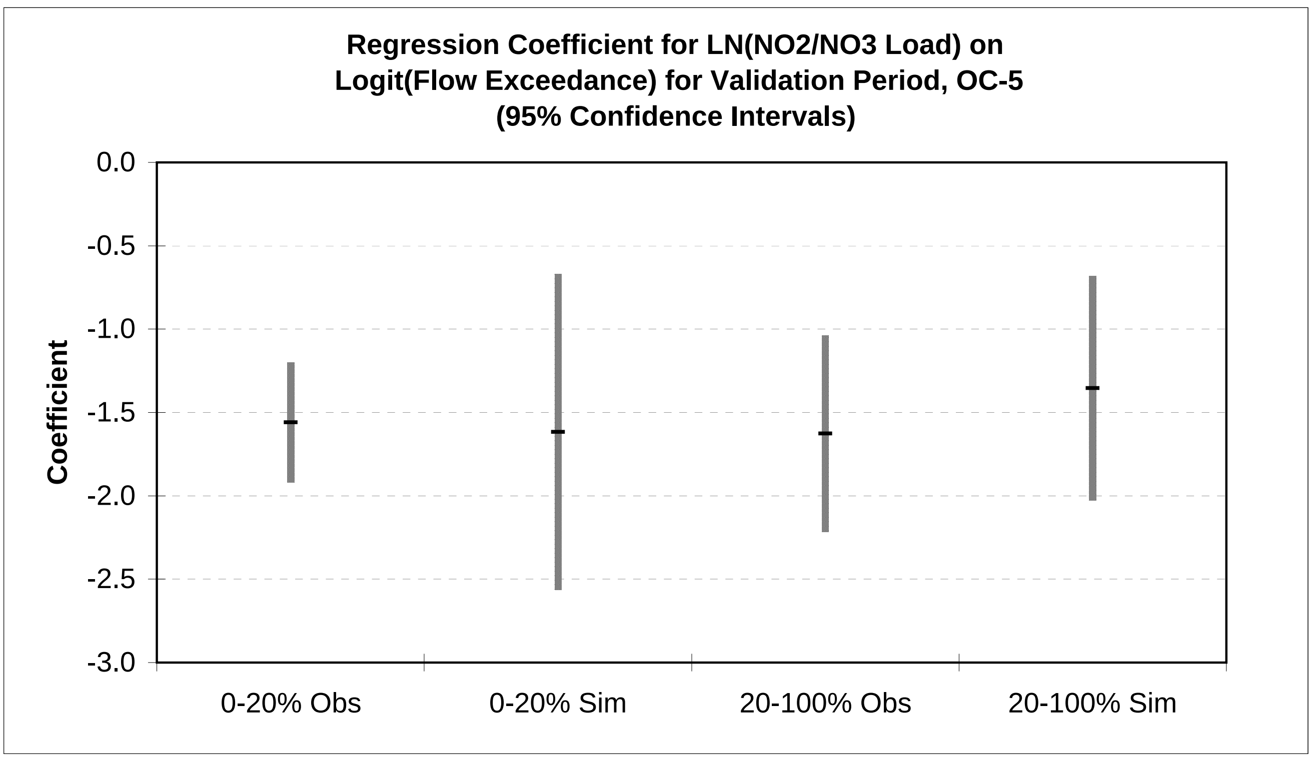
-1.616188	3.863564
0.421416	0.530419
0.572122	0.751395
14.70828	11
2.200985	
0.92753	
-2.543717	
-0.688658	

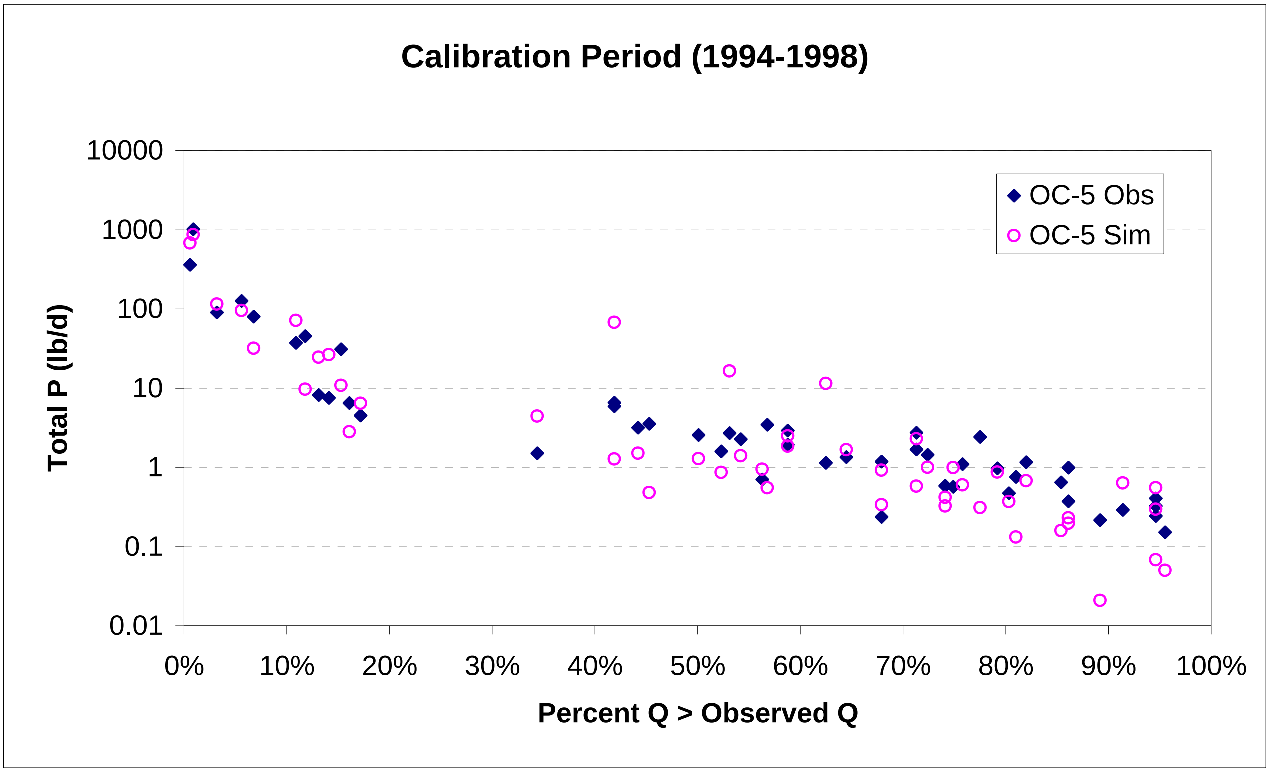
20-100% - Obs

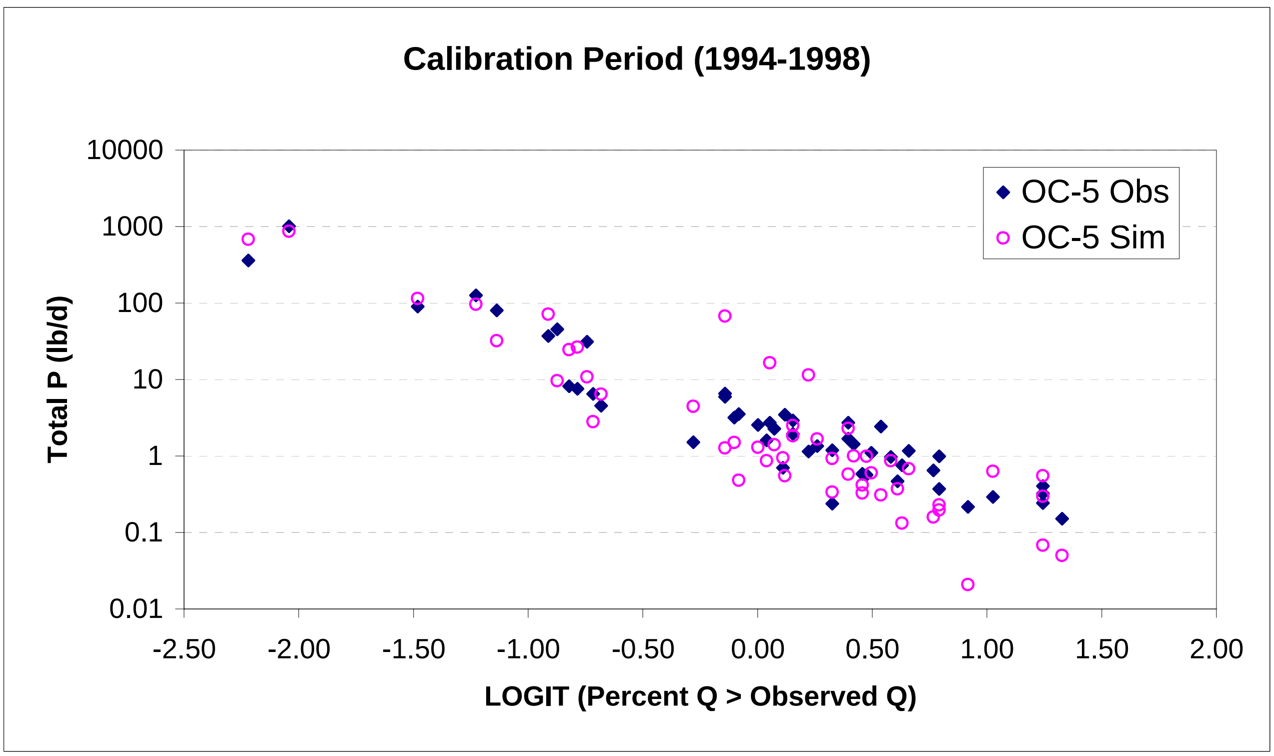
-1.627468	2.980794
0.278632	0.150487
0.54053	0.801037
34.11625	29
2.04523	
0.569867	
-2.197335	
-1.0576	

20-100% - Sim

-1.354204	2.63156
0.320135	0.172902
0.381581	0.920352
17.89374	29
2.04523	
0.65475	
-2.008954	
-0.699454	




Calibration Period (1994-1998)
10000
1000
100
10
1
0.1
0.01
Total P (lb/d)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent Q > Observed Q
OC-5 Obs
OC-5 Sim


Calibration Period (1994-1998)
10000
1000
100
10
1
0.1
0.01
Total P (lb/d)
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
OC-5 Obs
OC-5 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.872266	0.4763176
0.462309	0.5740701
0.7942376	0.8004119
38.599755	10
2.2281388	
1.0300886	
-3.902354	
-1.842177	

0-20% - Sim

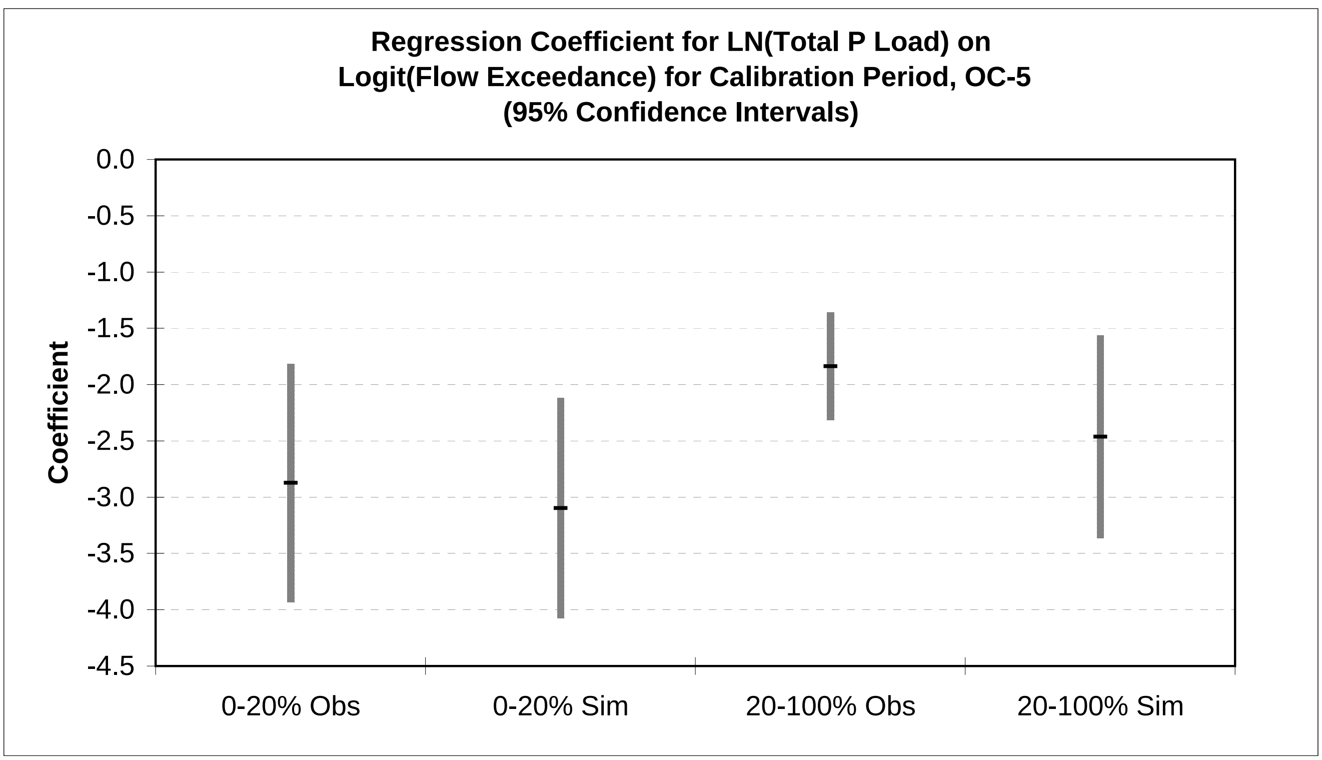
-3.09772	0.1739054
0.4268673	0.5300605
0.8404141	0.7390504
52.662172	10
2.2281388	
0.9511195	
-4.04884	
-2.146601	

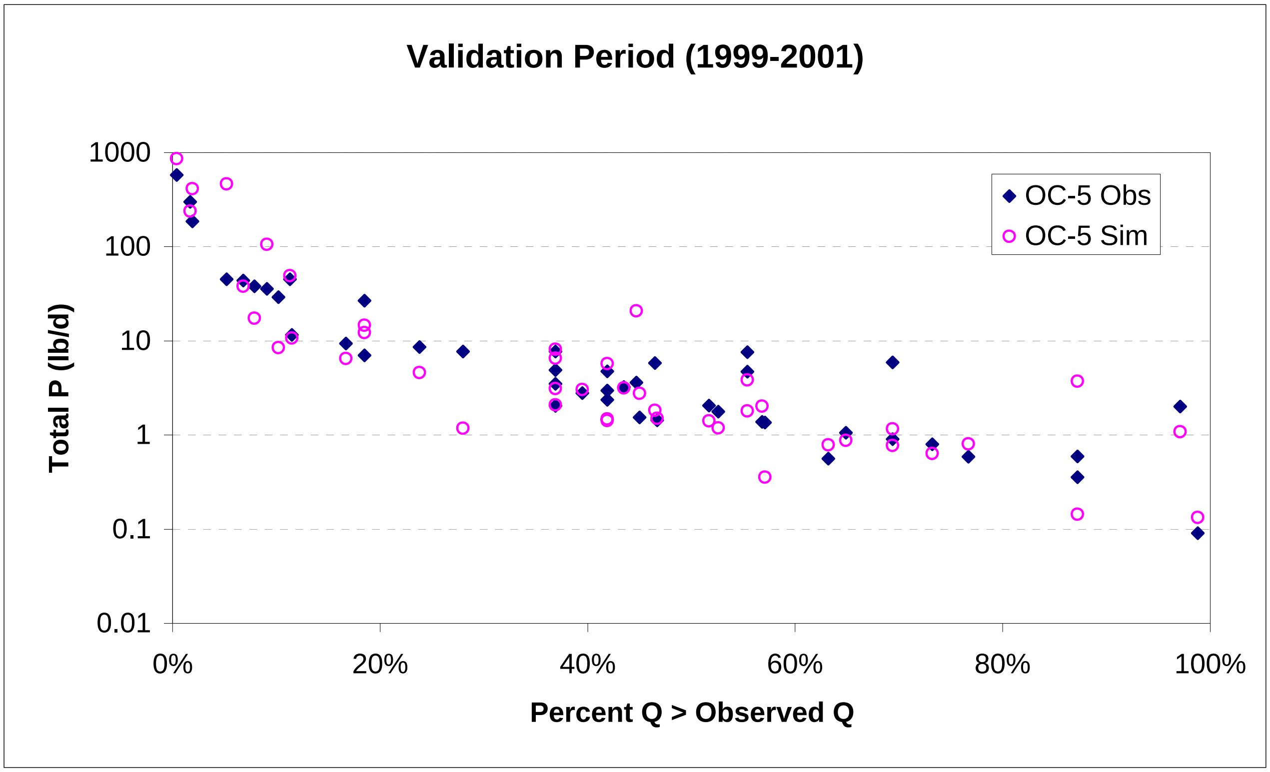
20-100% - Obs

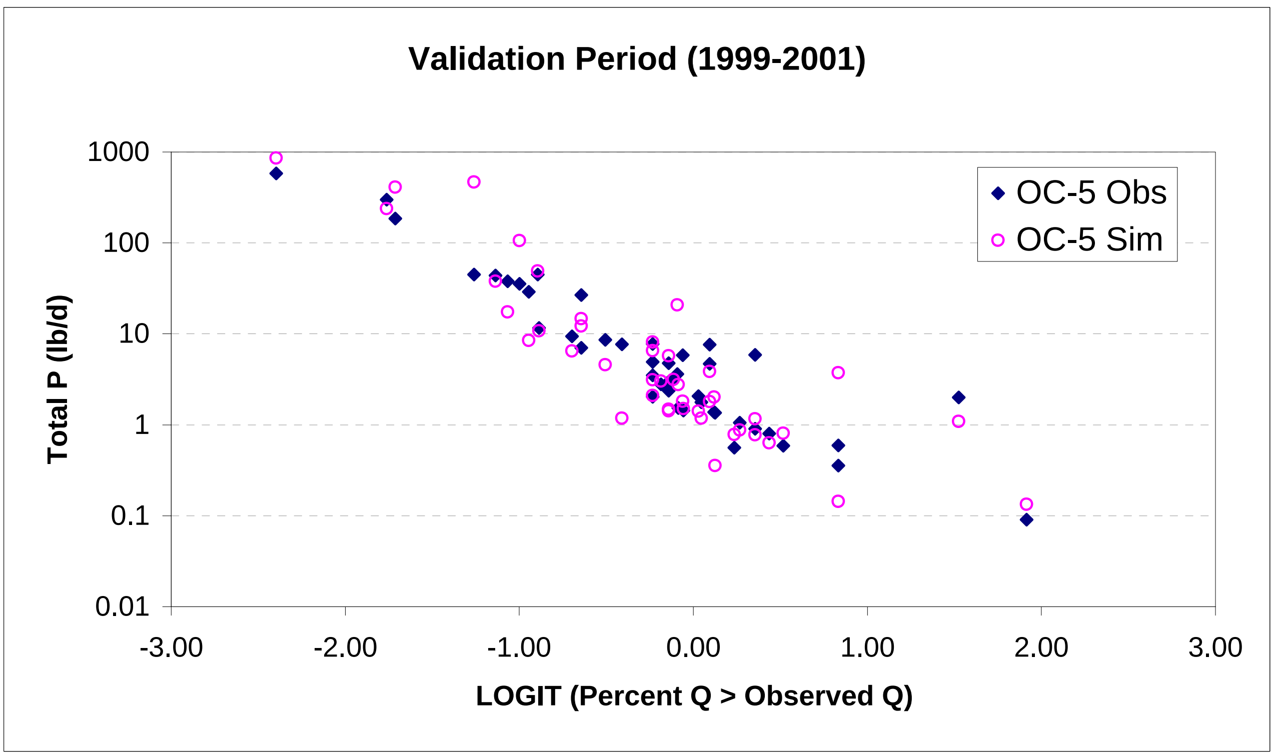
-1.83709	0.8596896
0.2218427	0.1341168
0.6557521	0.5733163
68.575801	36
2.028094	
0.4499177	
-2.287008	
-1.387173	

20-100% - Sim

-2.464617	0.7519824
0.4305756	0.260308
0.4764722	1.1127526
32.764252	36
2.028094	
0.8732477	
-3.337865	
-1.59137	




Validation Period (1999-2001)
OC-5 Obs
OC-5 Sim
Total P (lb/d)
1000
100
10
1
0.1
0.01
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q


Validation Period (1999-2001)
OC-5 Obs
OC-5 Sim
Total P (lb/d)
1000
100
10
1
0.1
0.01
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.376484	1.032814
0.265555	0.334244
0.879236	0.473492
80.08666	11
2.200985	
0.584483	
-2.960968	
-1.792001	

0-20% - Sim

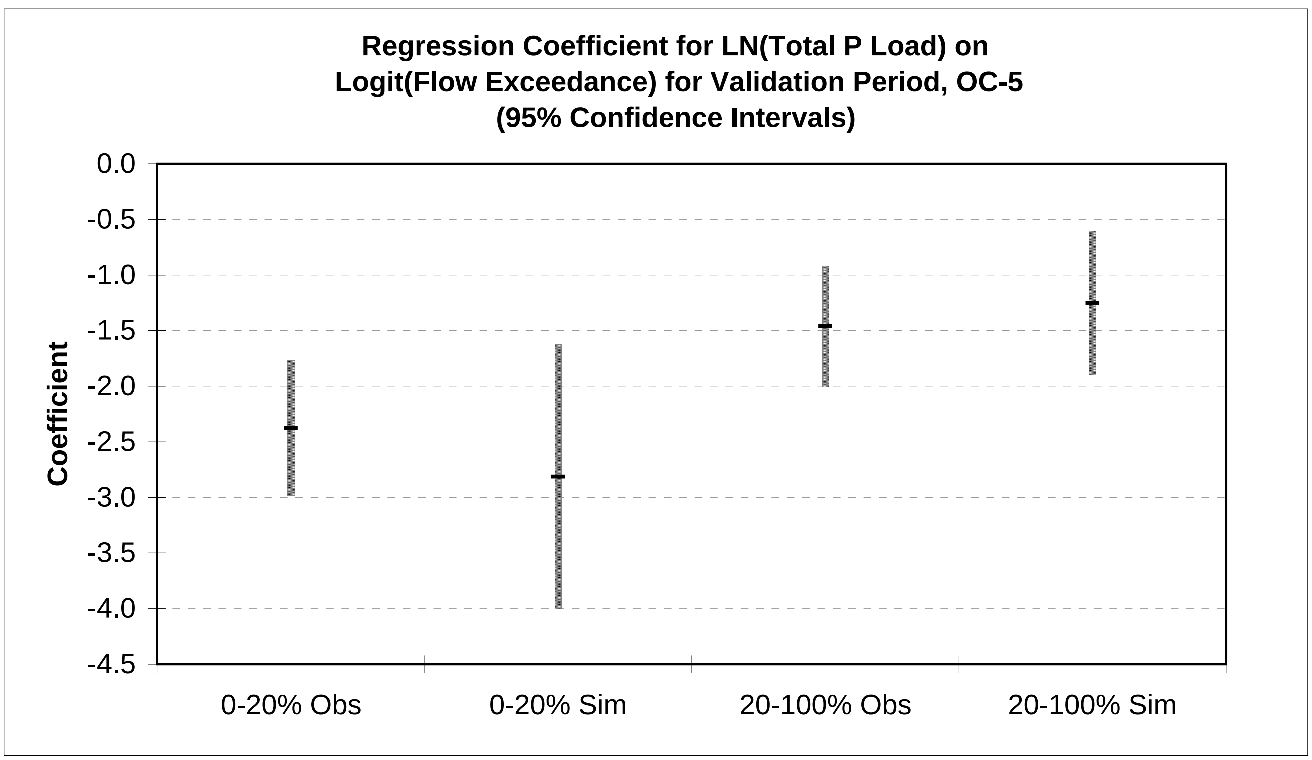
-2.812732	0.669218
0.527033	0.663355
0.721397	0.939712
28.48273	11
2.200985	
1.159991	
-3.972723	
-1.652741	

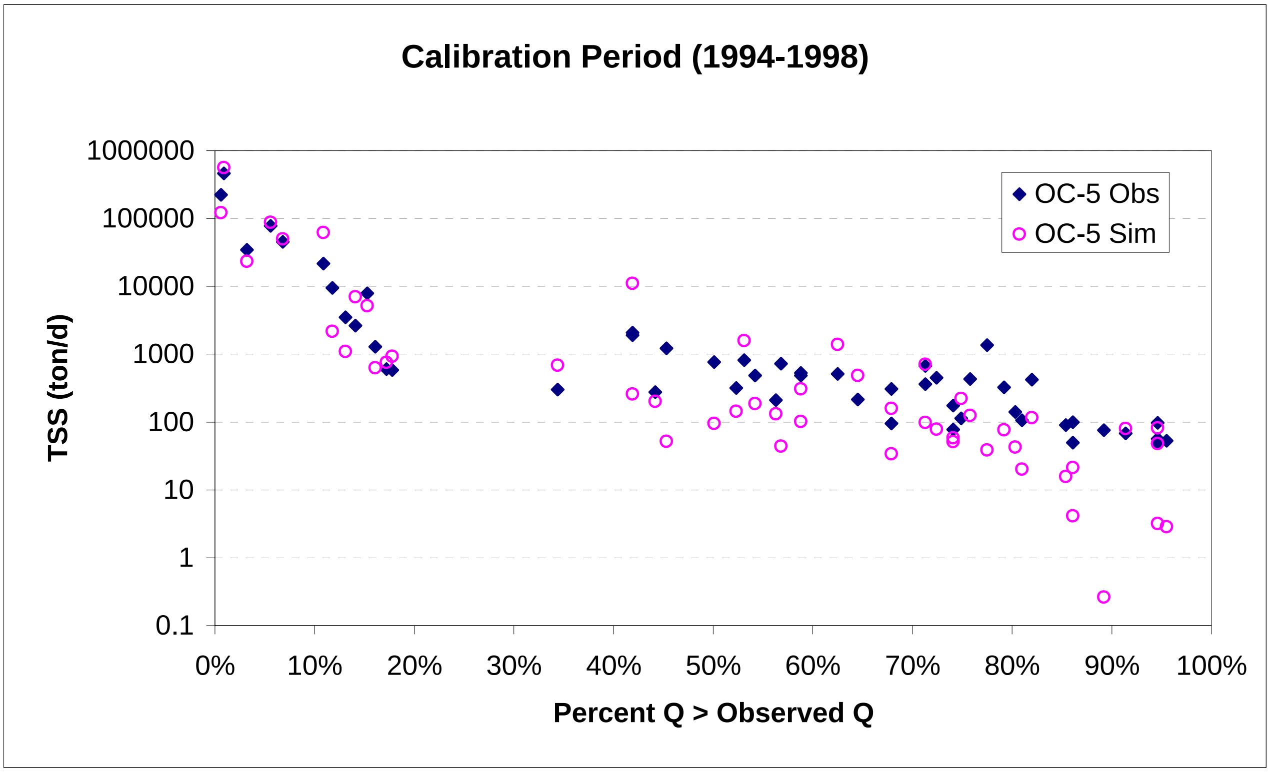
20-100% - Obs

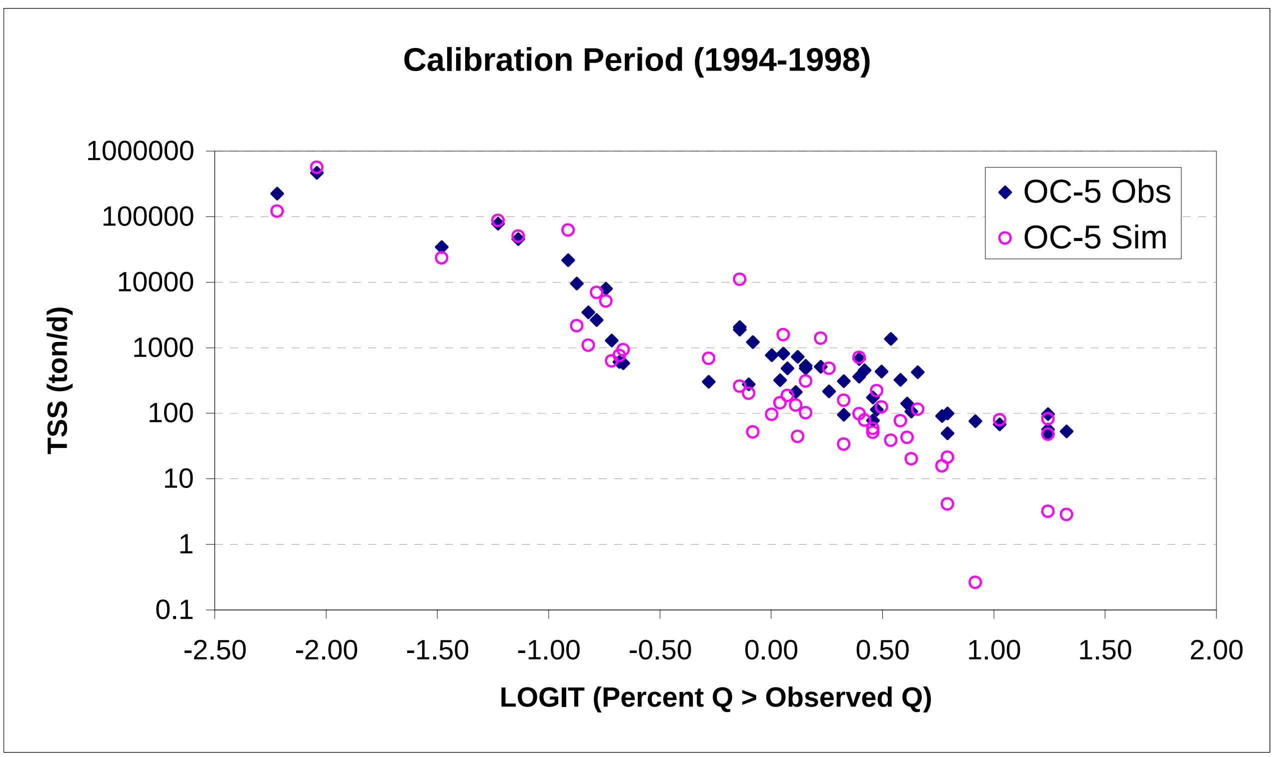
-1.462851	0.940766
0.251425	0.135793
0.538597	0.722819
33.85177	29
2.04523	
0.514223	
-1.977073	
-0.948628	

20-100% - Sim

-1.25299	0.707146
0.300536	0.162317
0.374759	0.864007
17.38209	29
2.04523	
0.614665	
-1.867655	
-0.638324	




Calibration Period (1994-1998)
TSS (ton/d)
1000000
100000
10000
1000
100
10
1
0.1
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent Q > Observed Q
OC-5 Obs
OC-5 Sim


Calibration Period (1994-1998)
TSS (ton/d)
1000000
100000
10000
1000
100
10
1
0.1
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
OC-5 Obs
OC-5 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-3.663942	5.345421
0.6017127	0.726375
0.7712062	1.076949
37.078218	11
2.2009852	
1.3243608	
-4.988303	
-2.339581	

0-20% - Sim

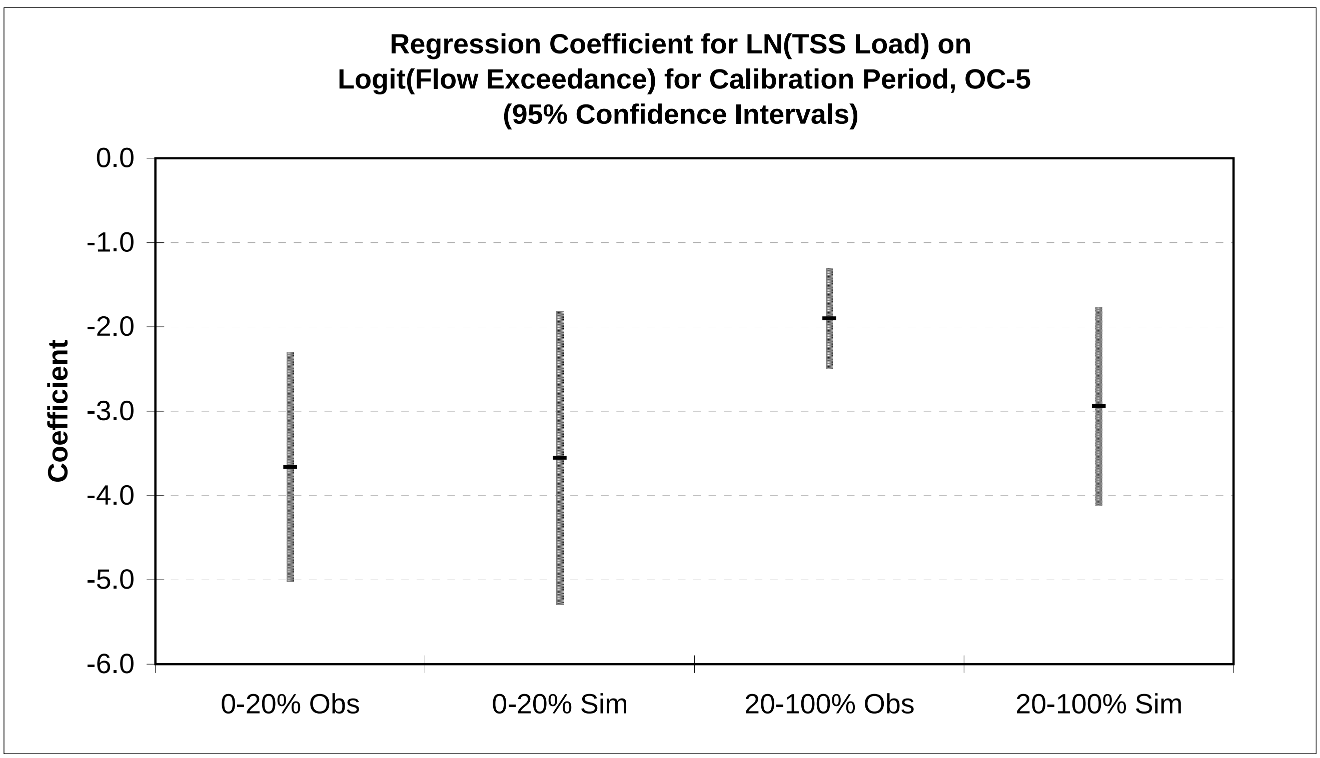
-3.554659	5.33743
0.773933	0.934276
0.6572725	1.38519
21.095468	11
2.2009852	
1.703415	
-5.258074	
-1.851244	

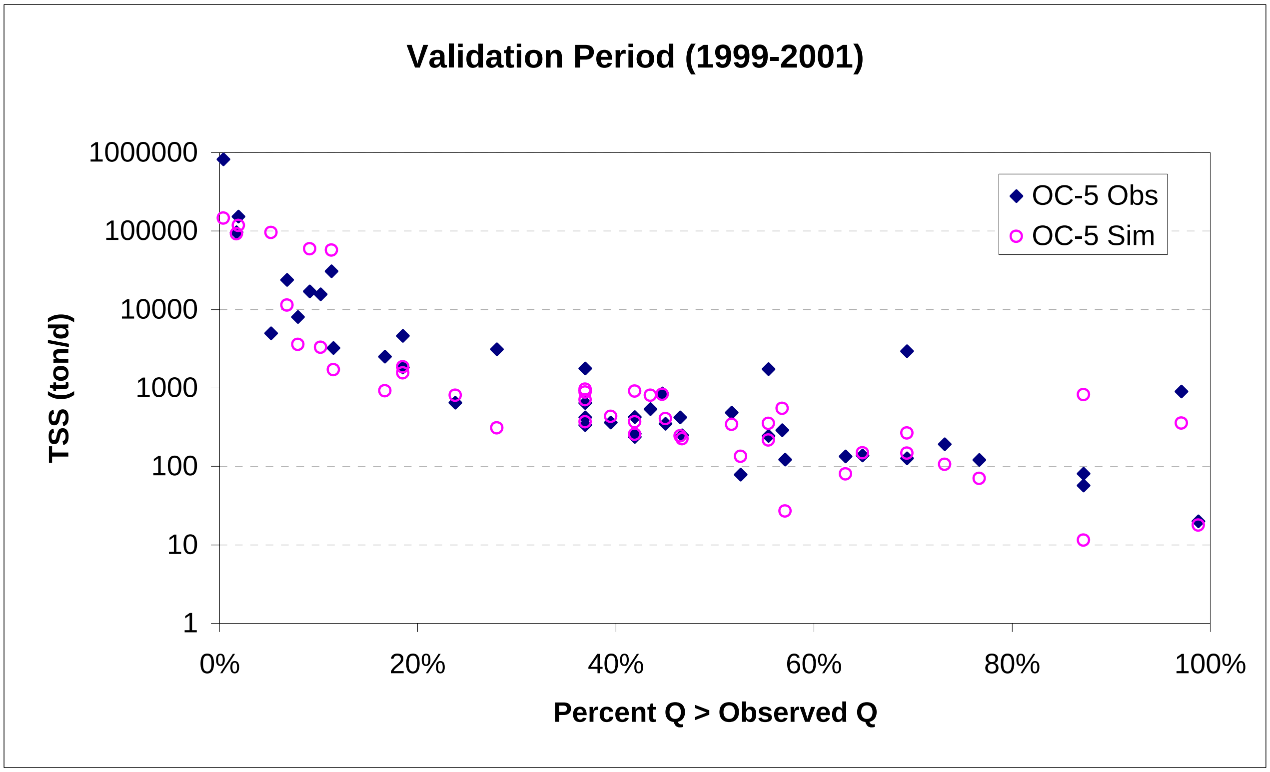
20-100% - Obs

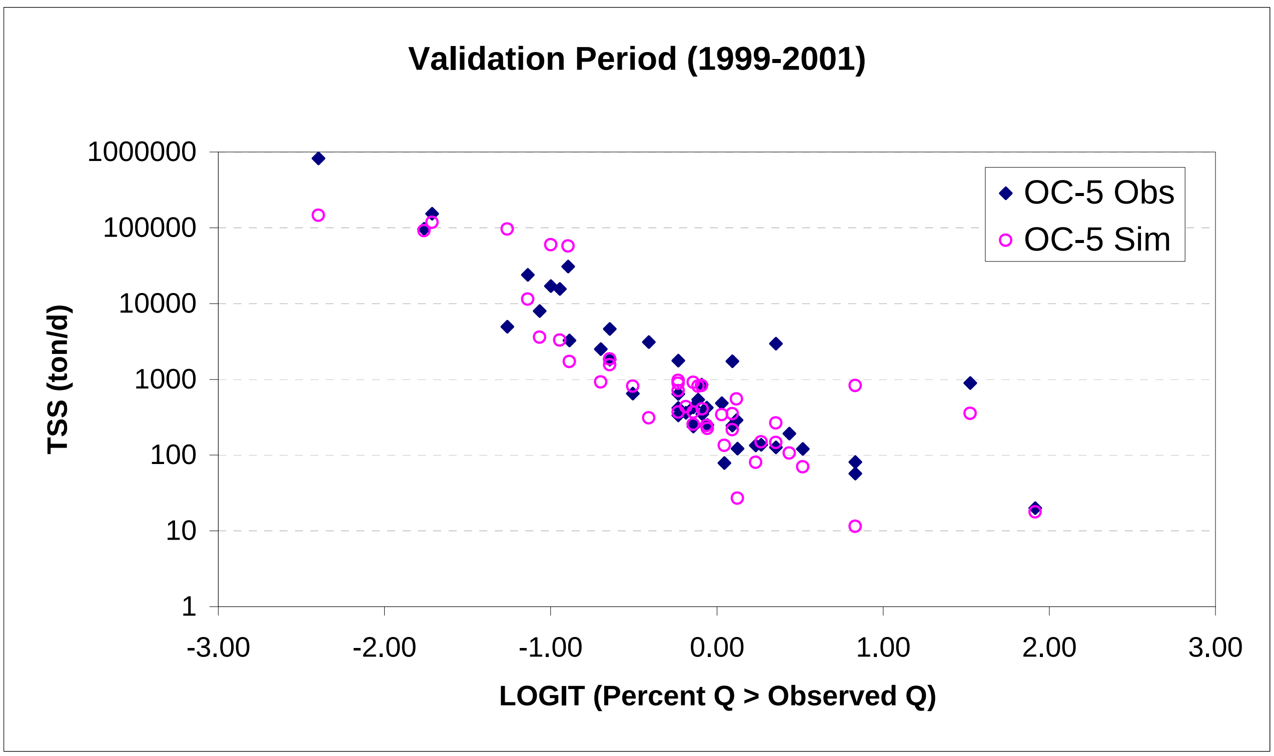
-1.900381	6.372598
0.2724755	0.164727
0.5746878	0.704169
48.643696	36
2.028094	
0.5526059	
-2.452987	
-1.347775	

20-100% - Sim

-2.939518	5.697055
0.5608574	0.339071
0.4327966	1.449445
27.46929	36
2.028094	
1.1374715	
-4.07699	
-1.802047	




Validation Period (1999-2001)
1000000
100000
10000
1000
100
10
1
0%
20%
40%
60%
80%
100%
TSS (ton/d)
Percent Q > Observed Q
OC-5 Obs
OC-5 Sim


Validation Period (1999-2001)
1000000
100000
10000
1000
100
10
1
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
TSS (ton/d)
LOGIT (Percent Q > Observed Q)
OC-5 Obs
OC-5 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-3.151259	6.061772
0.446719	0.562268
0.818966	0.796511
49.76216	11
2.200985	
0.983222	
-4.134481	
-2.168037	

0-20% - Sim

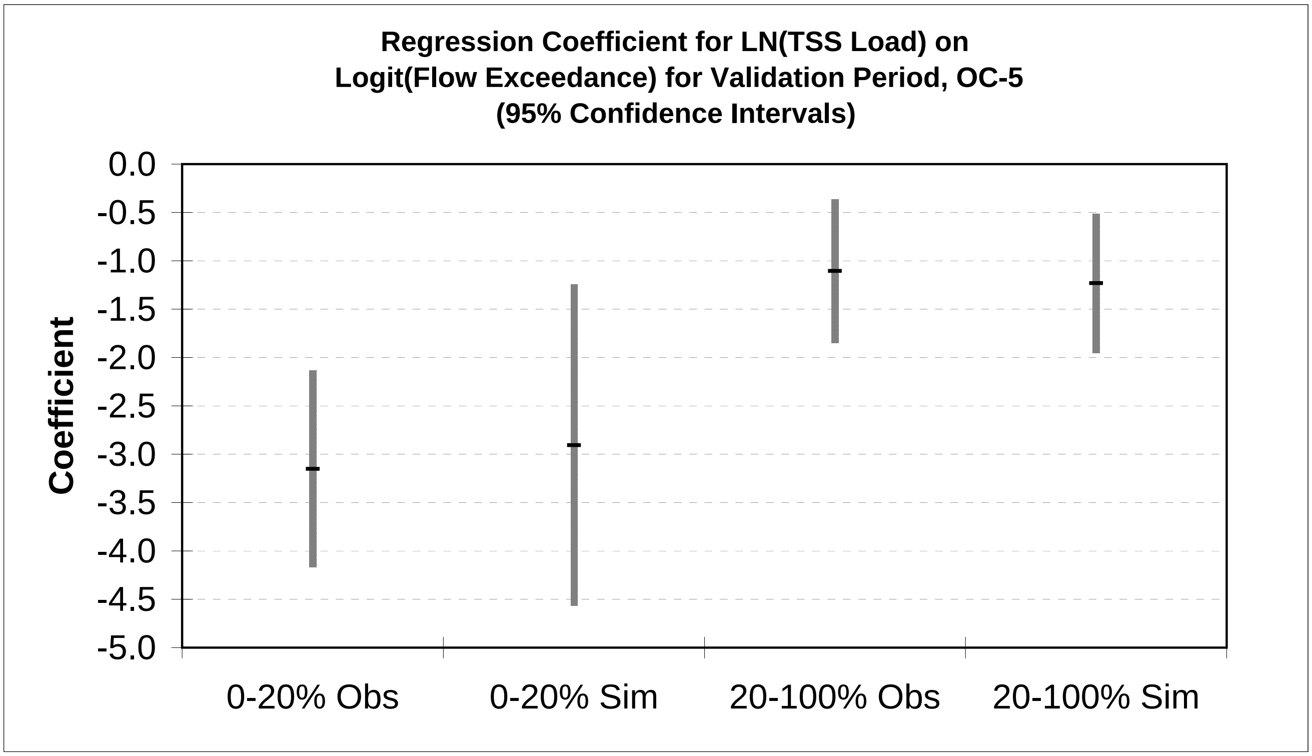
-2.906687	6.111776
0.739328	0.930563
0.584229	1.318241
15.45688	11
2.200985	
1.62725	
-4.533937	
-1.279436	

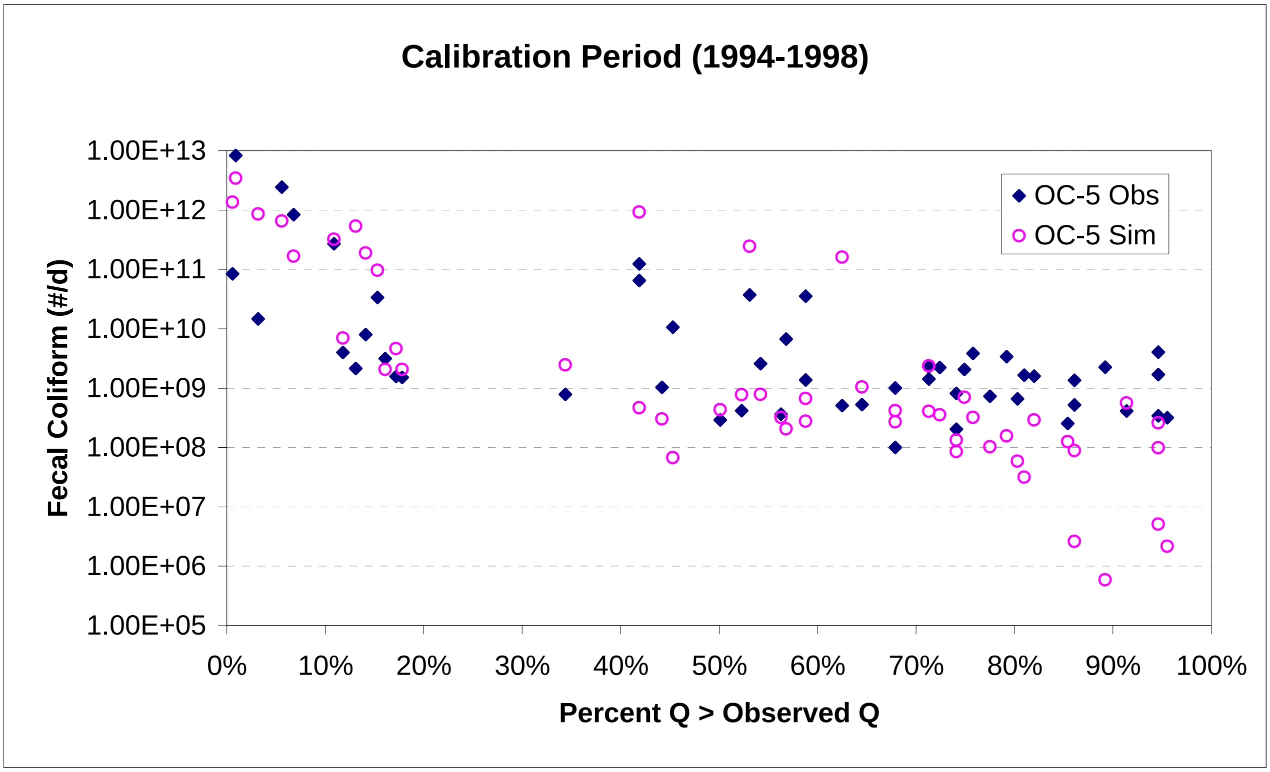
20-100% - Obs

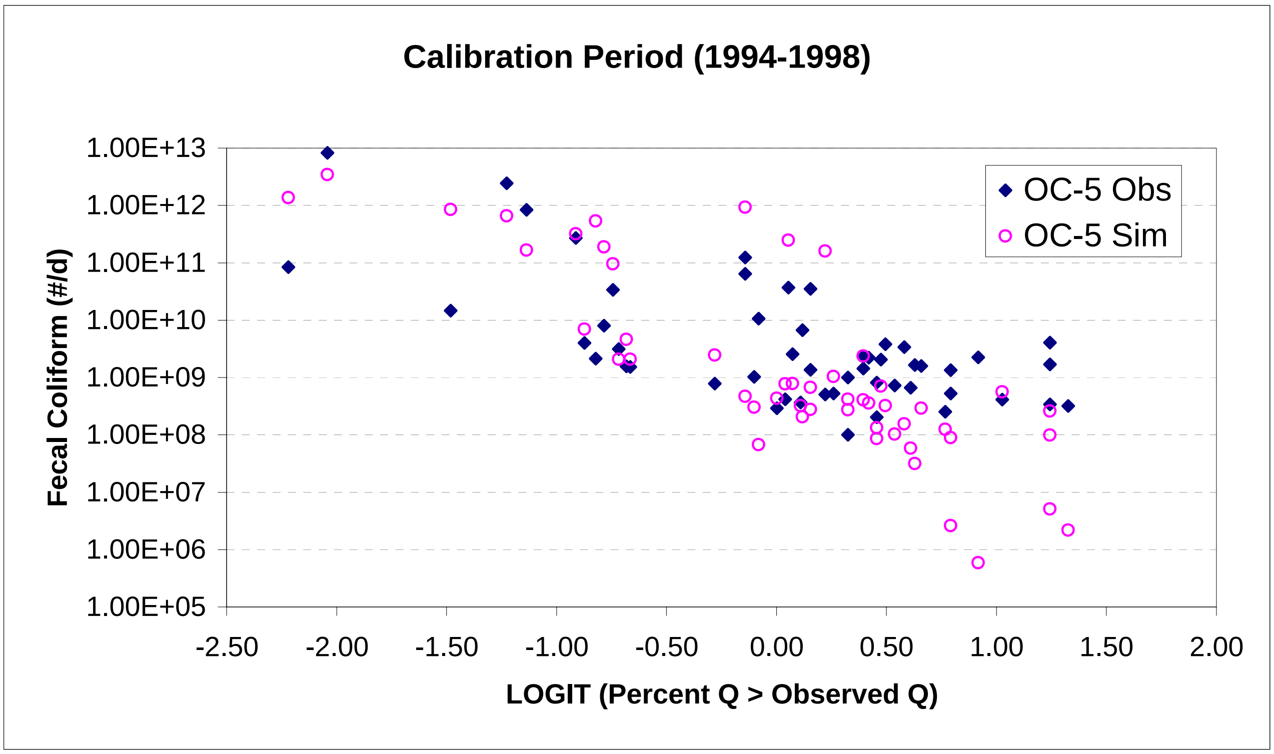
-1.104843	5.939104
0.346529	0.187157
0.25955	0.99623
10.16537	29
2.04523	
0.70873	
-1.813574	
-0.396113	

20-100% - Sim

-1.233232	5.730895
0.335968	0.181453
0.317229	0.965868
13.47395	29
2.04523	
0.687131	
-1.920363	
-0.546101	




Calibration Period (1994-1998)
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
Fecal Coliform (#/d)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent Q > Observed Q
OC-5 Obs
OC-5 Sim


Calibration Period (1994-1998)
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
Fecal Coliform (#/d)
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
LOGIT (Percent Q > Observed Q)
OC-5 Obs
OC-5 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-3.56027	20.34547
1.336506	1.613403
0.3921366	2.392086
7.0961704	11
2.2009852	
2.9416299	
-6.5019	
-0.61864	

0-20% - Sim

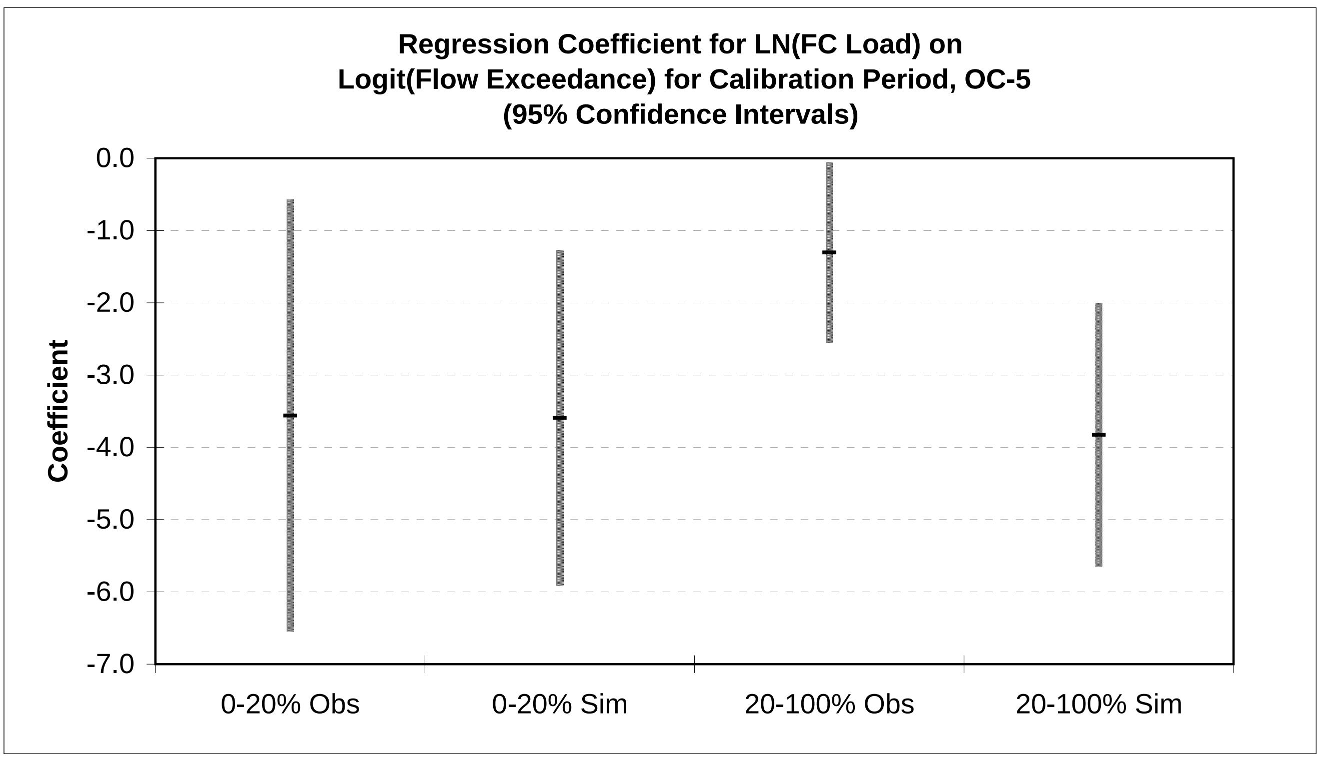
-3.591897	21.42499
1.031289	1.244951
0.5244422	1.845807
12.130732	11
2.2009852	
2.2698517	
-5.861749	
-1.322045	

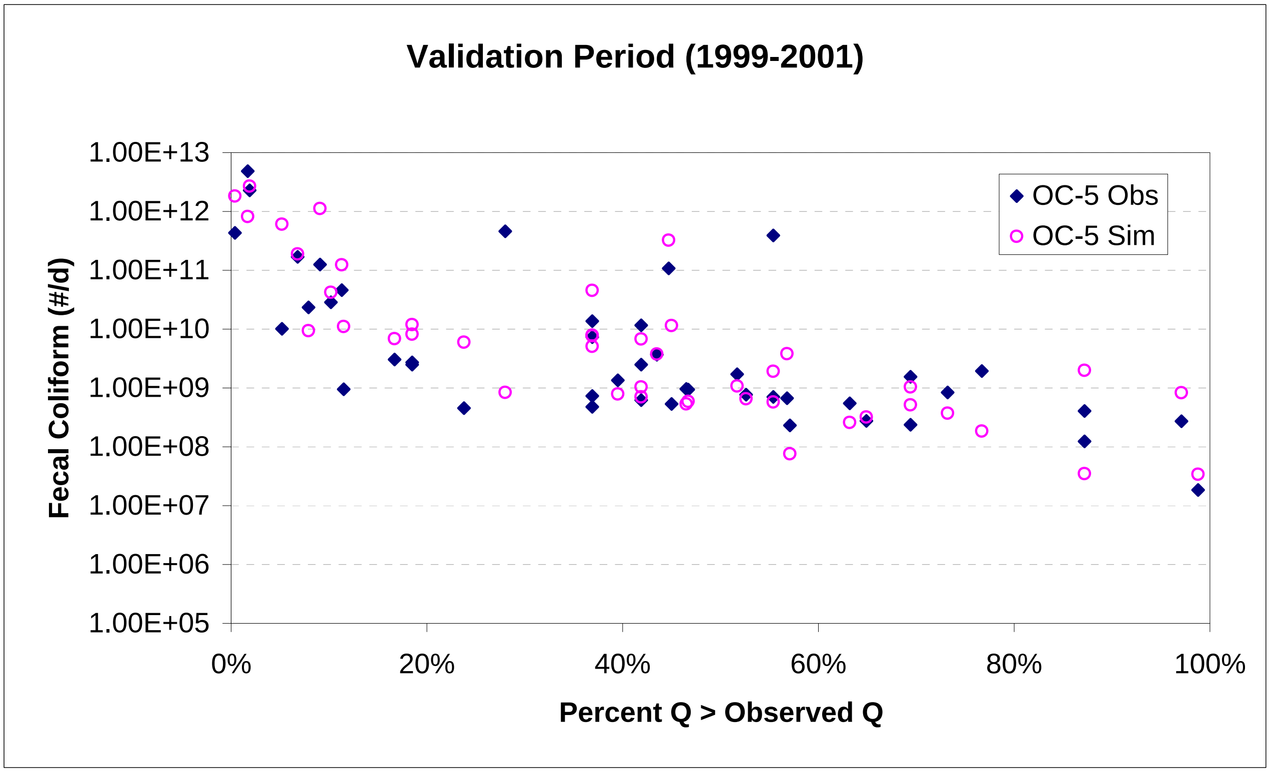
20-100% - Obs

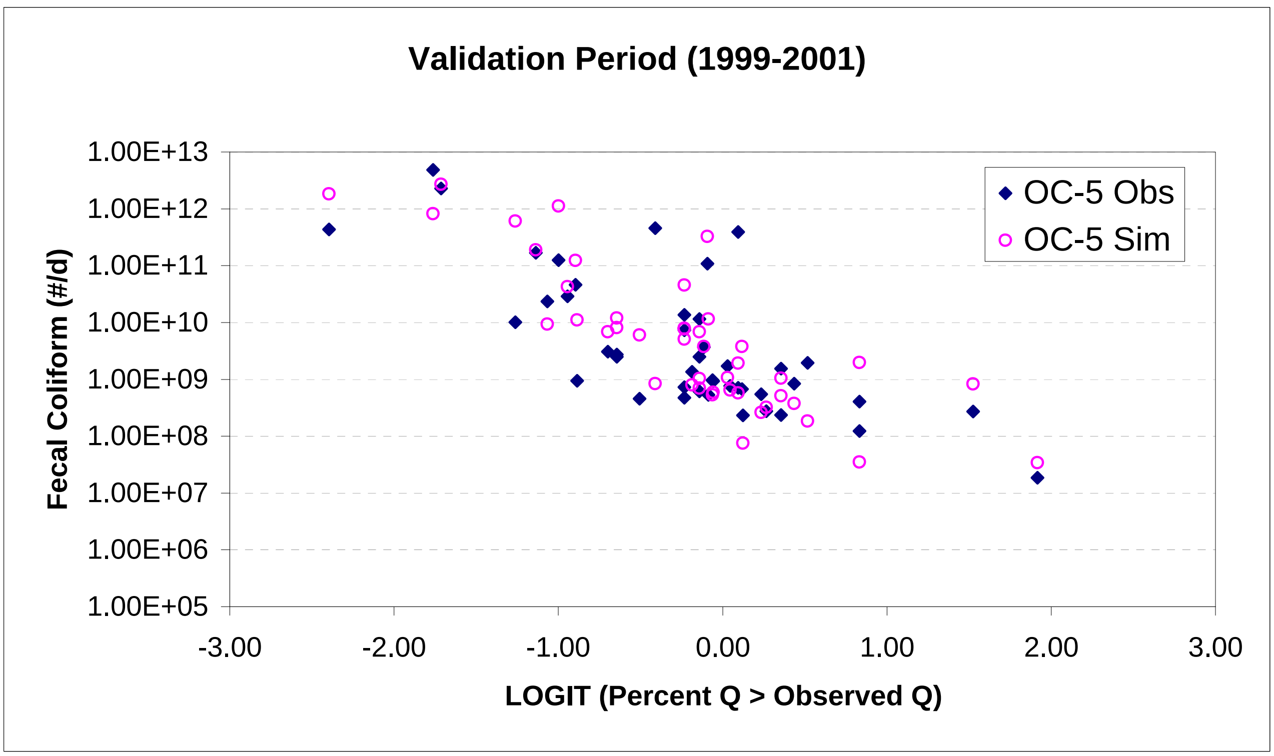
-1.305475	21.72139
0.593821	0.358999
0.1183624	1.534634
4.8331052	36
2.028094	
1.2043247	
-2.5098	
-0.101151	

20-100% - Sim

-3.826327	21.16819
0.8780262	0.530818
0.3453481	2.269116
18.991056	36
2.028094	
1.7807196	
-5.607046	
-2.045607	




Validation Period (1999-2001)
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
Fecal Coliform (#/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
OC-5 Obs
OC-5 Sim


Validation Period (1999-2001)
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
Fecal Coliform (#/d)
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
LOGIT (Percent Q > Observed Q)
OC-5 Obs
OC-5 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-4.036673	19.73479
0.993216	1.250122
0.600263	1.770929
16.51808	11
2.200985	
2.186054	
-6.222727	
-1.850619	

0-20% - Sim

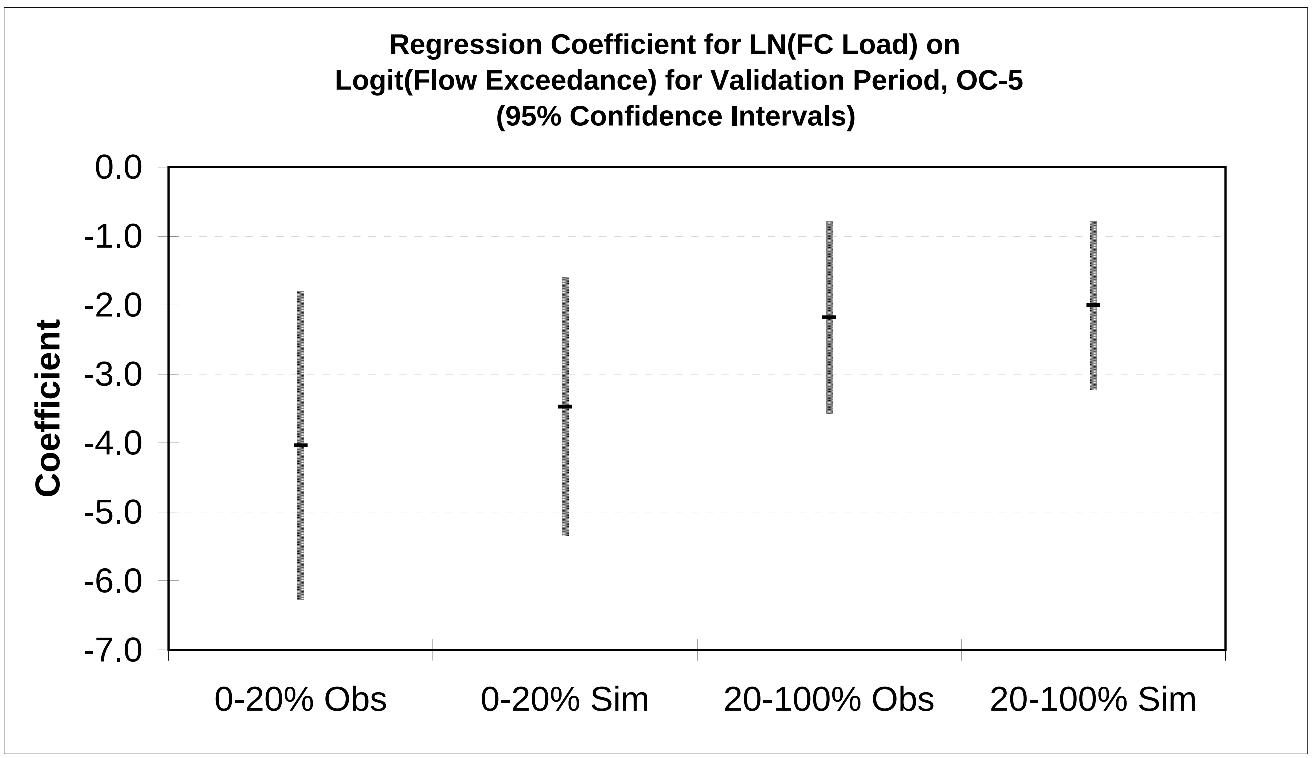
-3.473335	21.35639
0.829417	1.043954
0.614531	1.478871
17.5367	11
2.200985	
1.825533	
-5.298868	
-1.647801	

20-100% - Obs

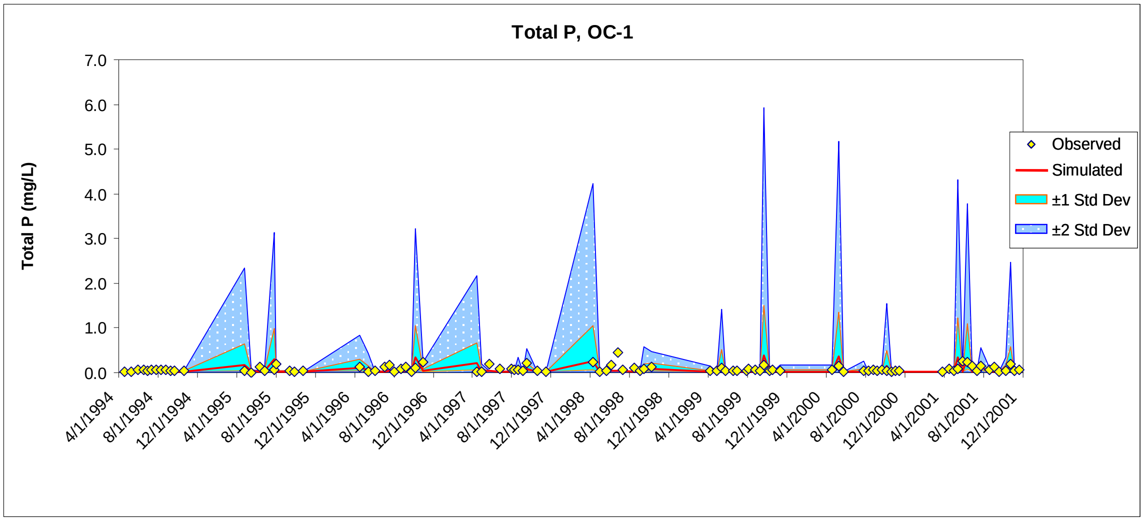
-2.179273	21.41283
0.658289	0.355536
0.274265	1.892504
10.9595	29
2.04523	
1.346351	
-3.525624	
-0.832922	

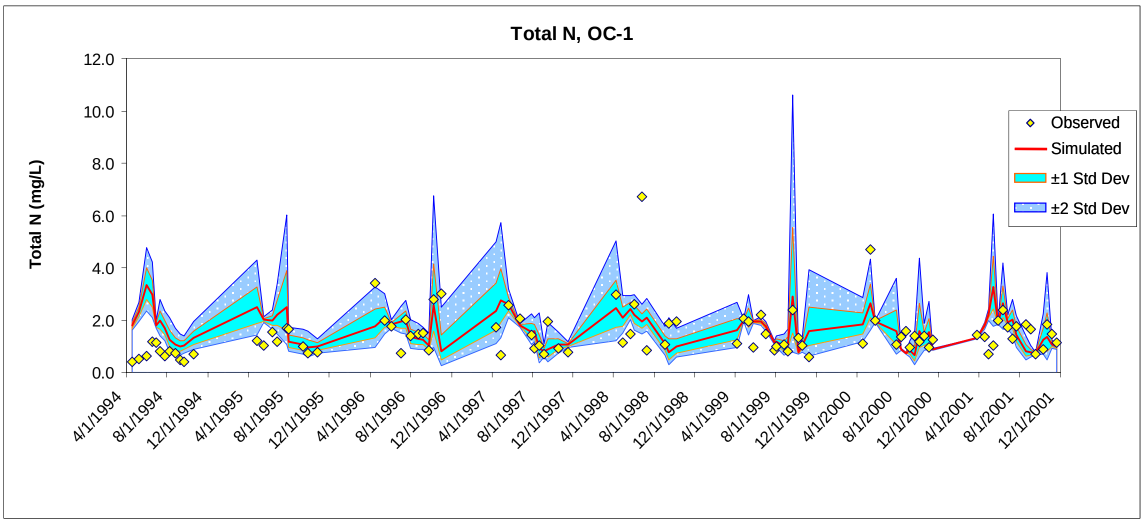
20-100% - Sim

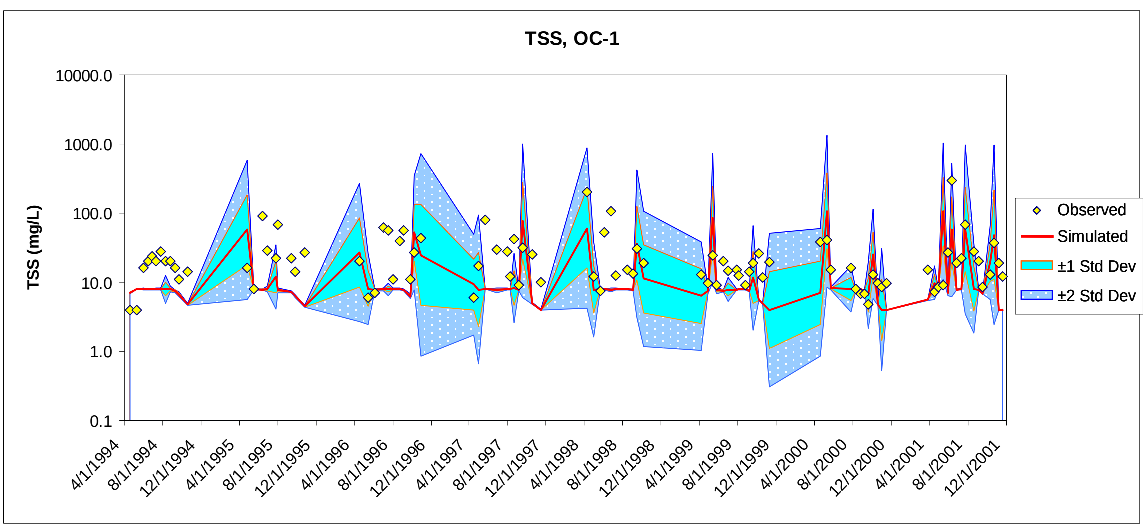
-2.00355	21.27919
0.576413	0.311316
0.294092	1.657122
12.08182	29
2.04523	
1.178898	
-3.182448	
-0.824653	

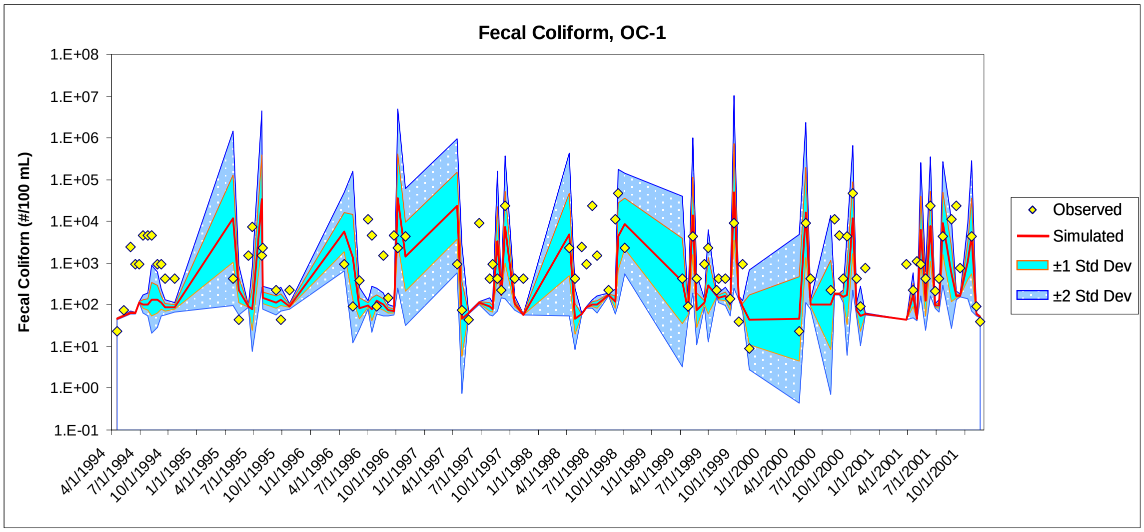


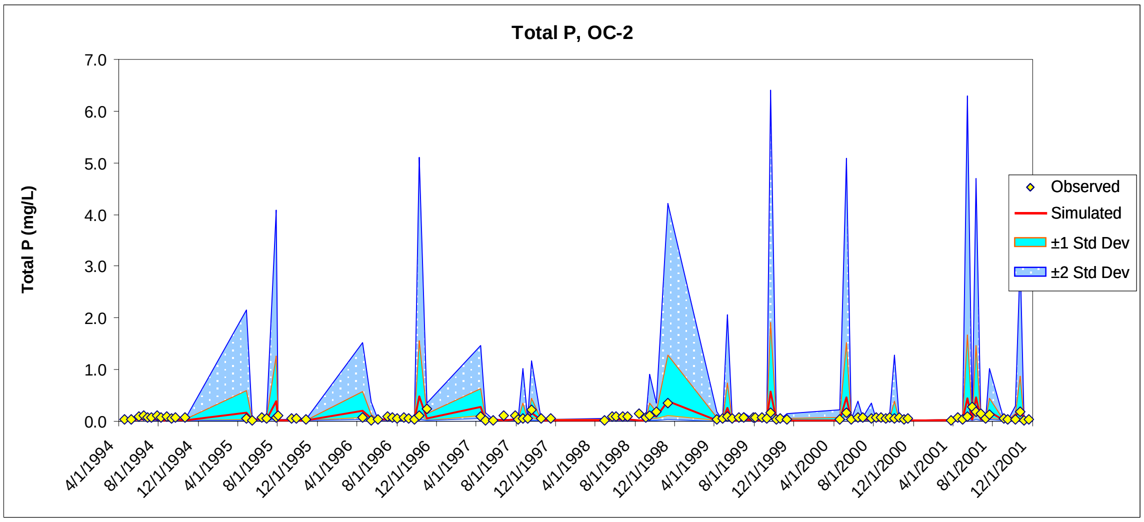
ATTACHMENT C – CONTROL CHARTS

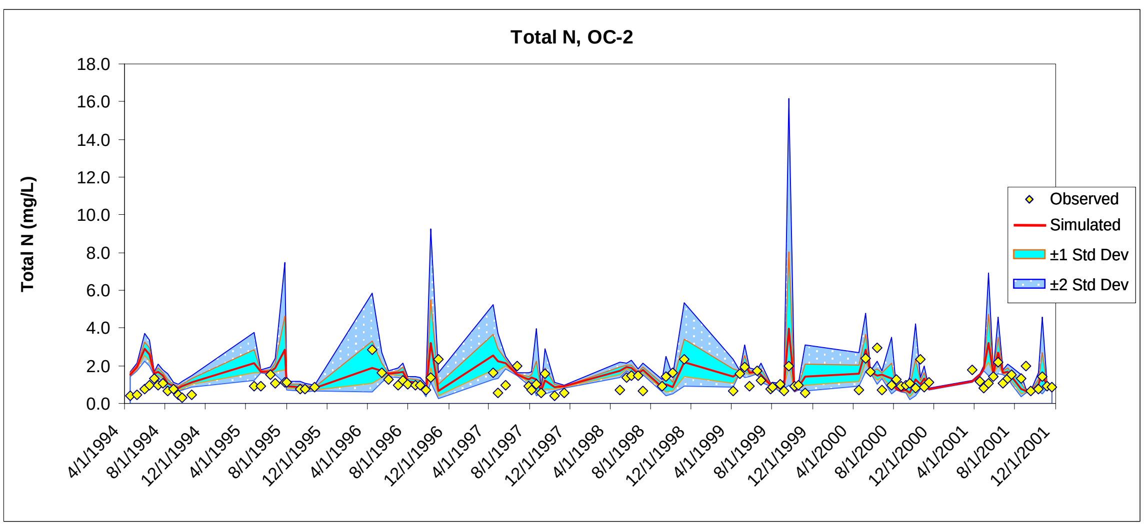

Total P, OC-1
Total P (mg/L)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

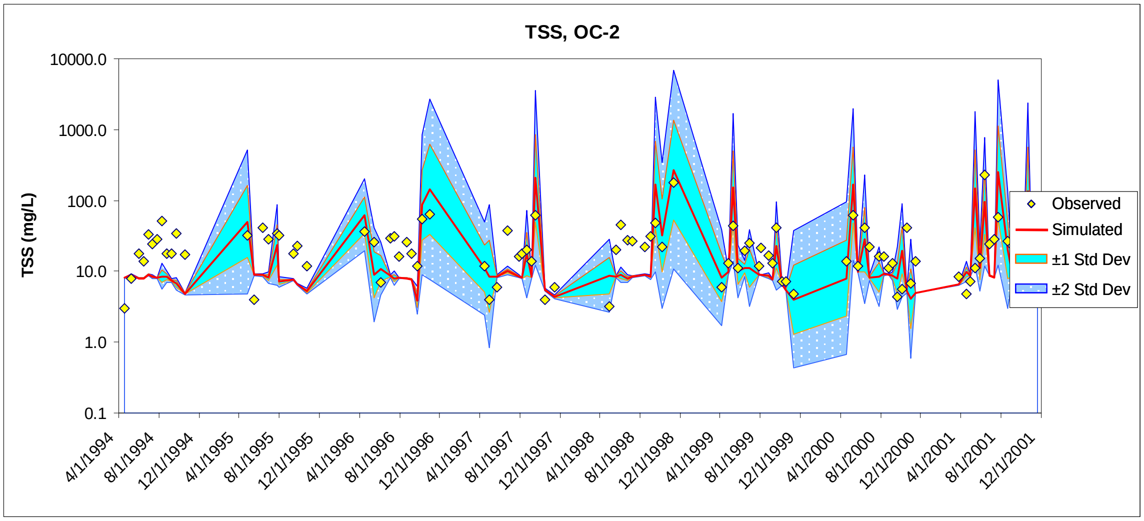

Total N, OC-1
Total N (mg/L)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

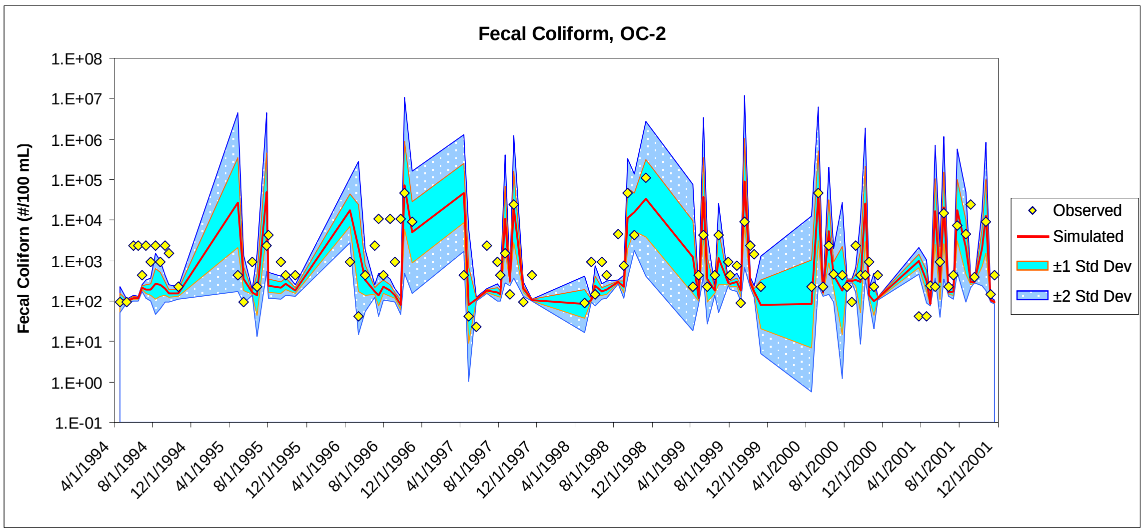

TSS, OC-1
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

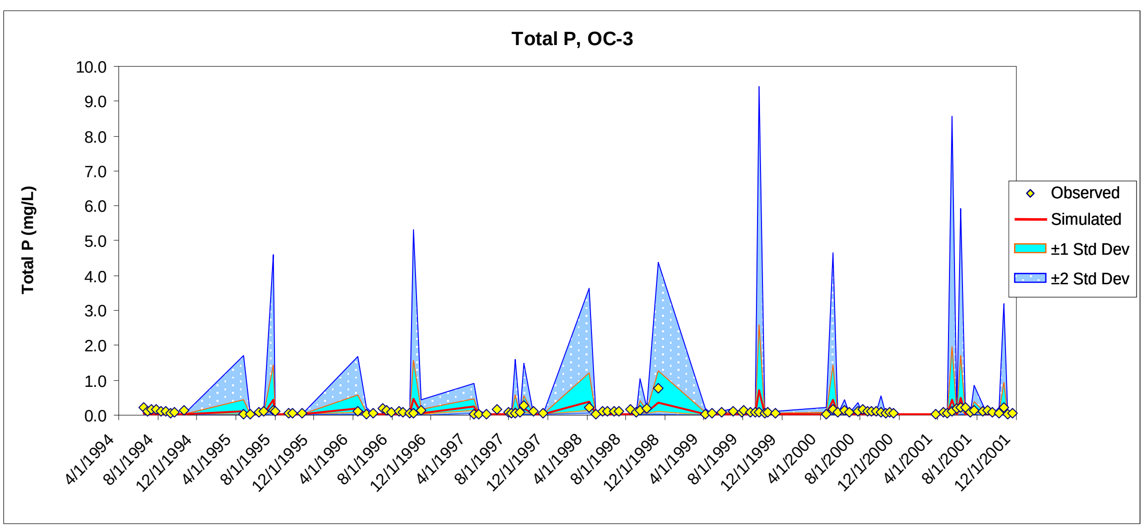

Fecal Coliform, OC-1
Fecal Coliform (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
7/1/1994
10/1/1994
1/1/1995
4/1/1995
7/1/1995
10/1/1995
1/1/1996
4/1/1996
7/1/1996
10/1/1996
1/1/1997
4/1/1997
7/1/1997
10/1/1997
1/1/1998
4/1/1998
7/1/1998
10/1/1998
1/1/1999
4/1/1999
7/1/1999
10/1/1999
1/1/2000
4/1/2000
7/1/2000
10/1/2000
1/1/2001
4/1/2001
7/1/2001
10/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

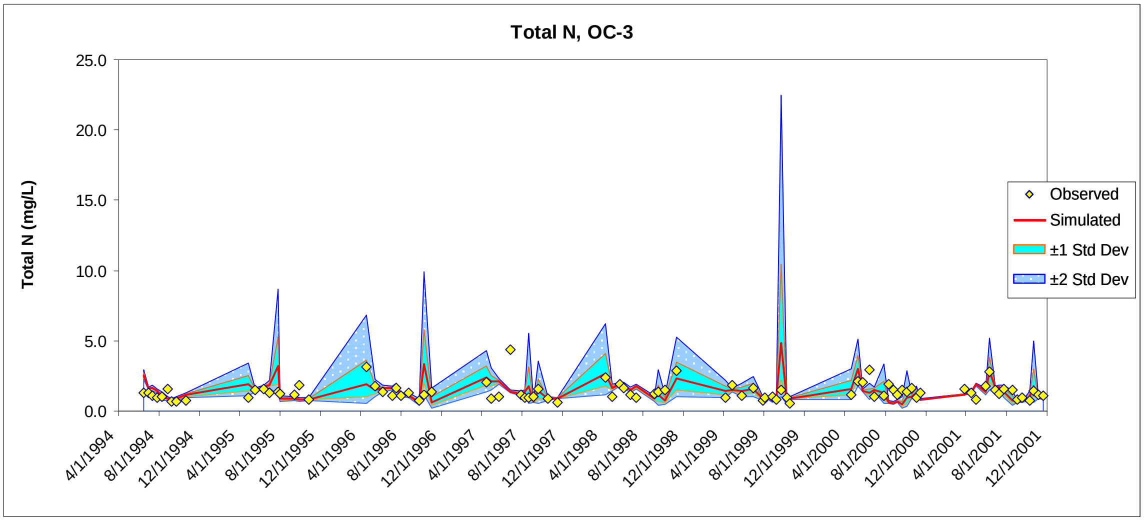

Total P, OC-2
Total P (mg/L)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

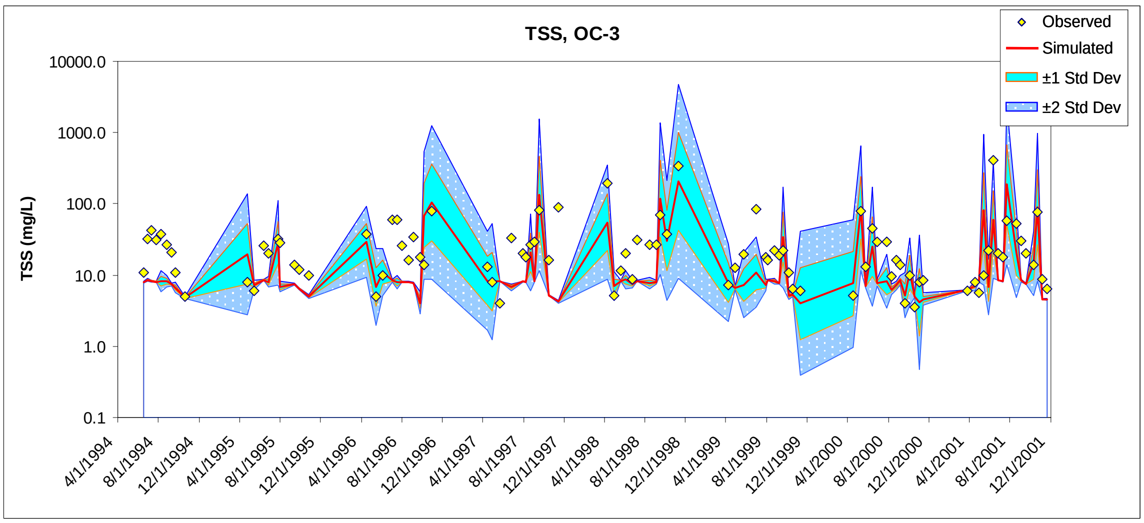

Total N, OC-2
Total N (mg/L)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

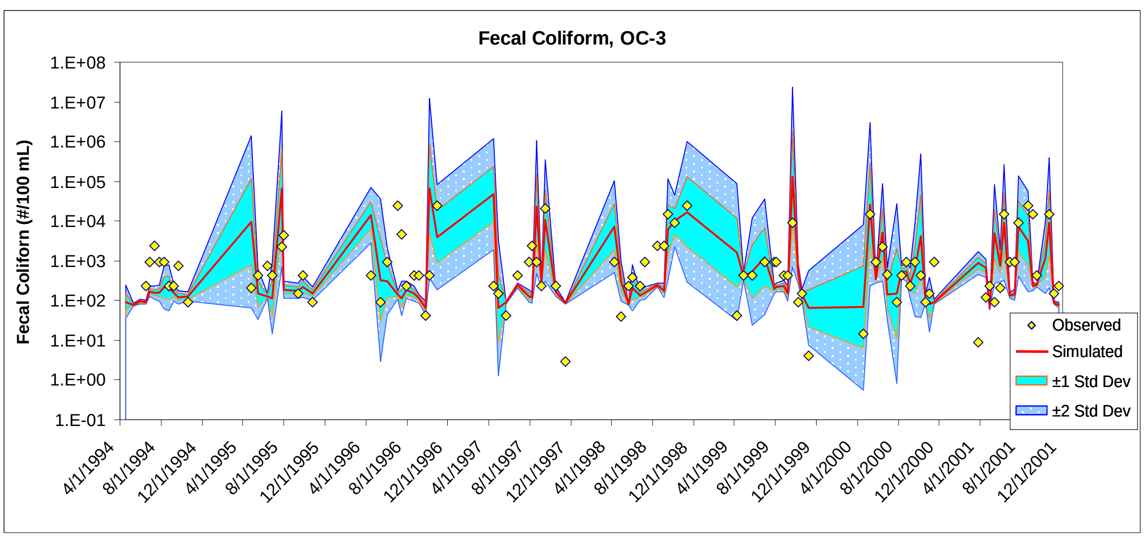

TSS, OC-2
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

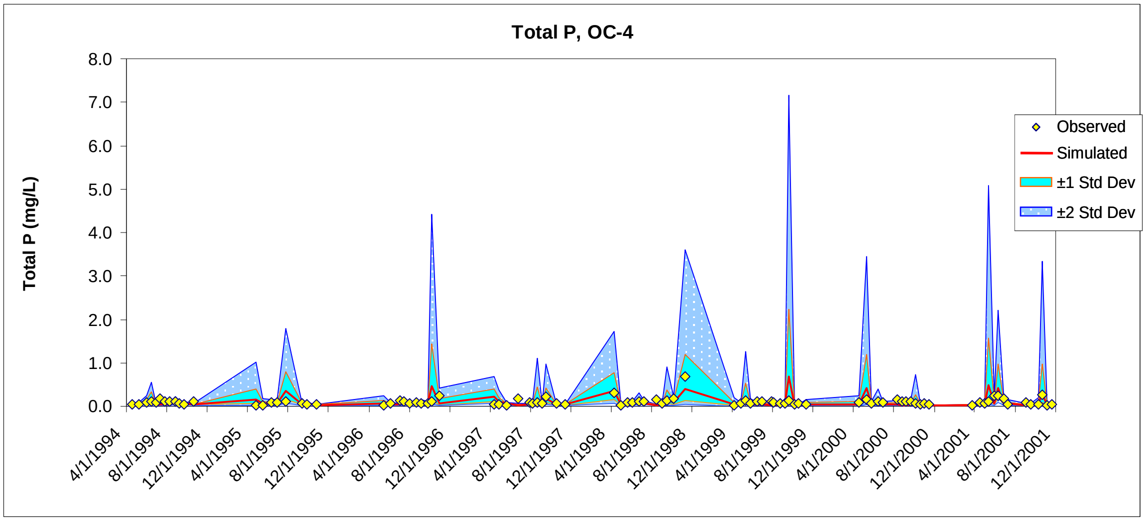

Fecal Coliform, OC-2
Fecal Coliform (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

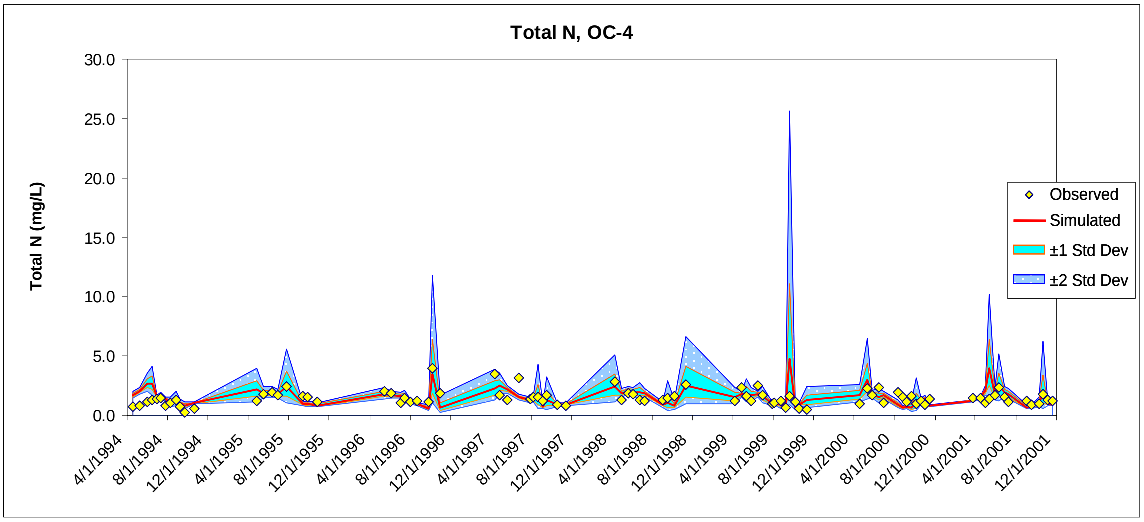

Total P, OC-3
Total P (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

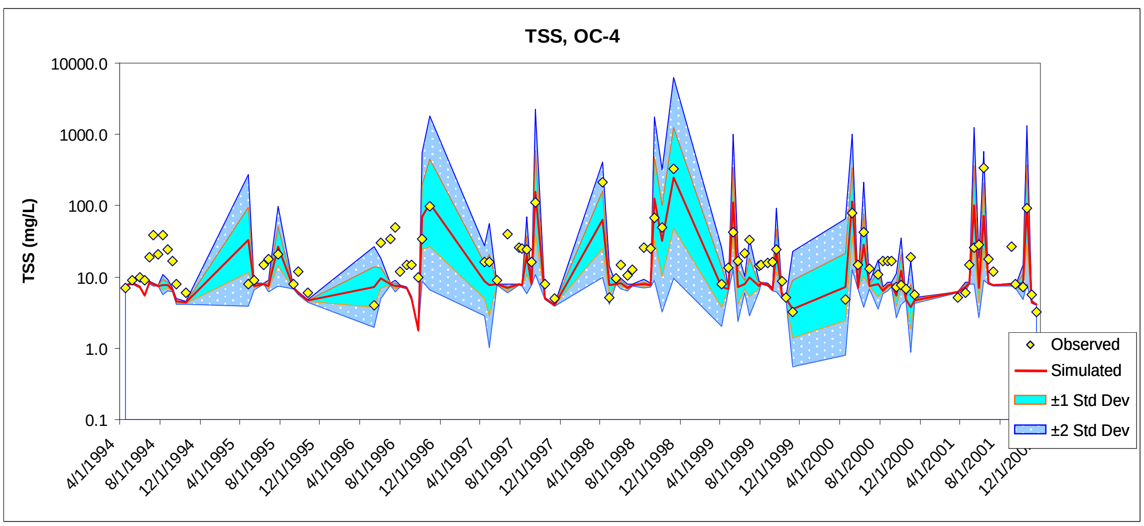

Total N, OC-3
Total N (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

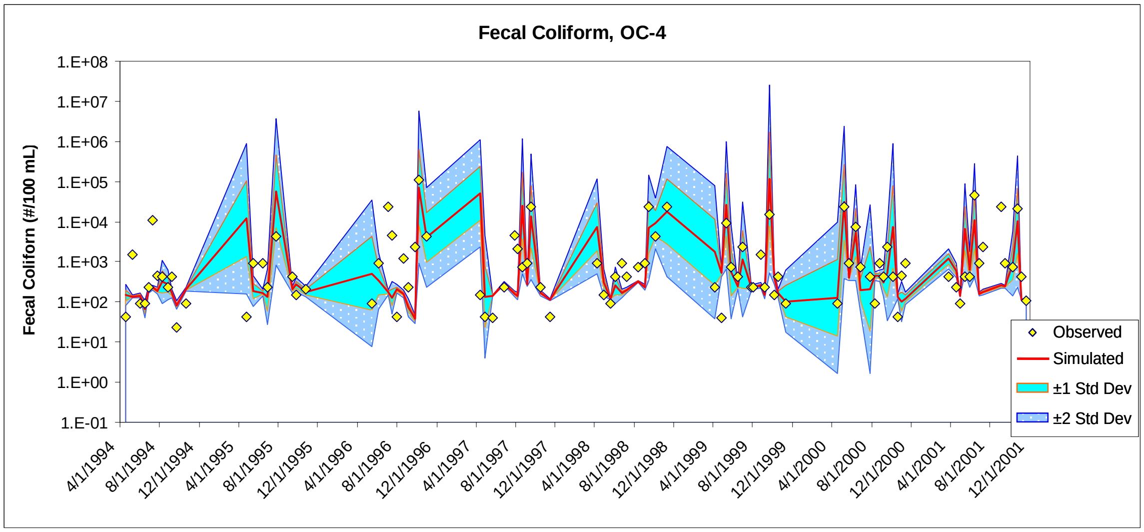

TSS, OC-3
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

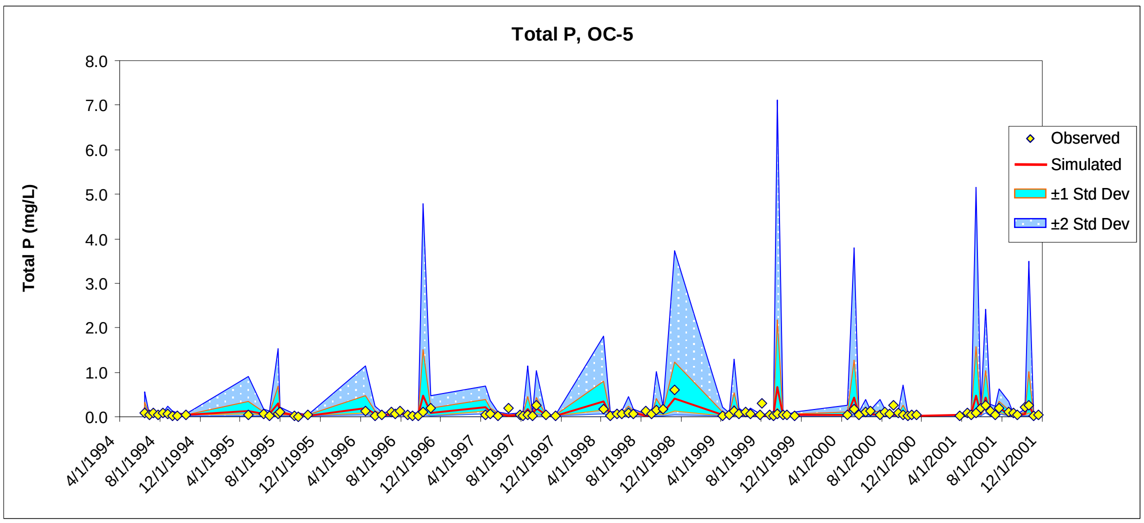

Fecal Coliform, OC-3
Fecal Coliform (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

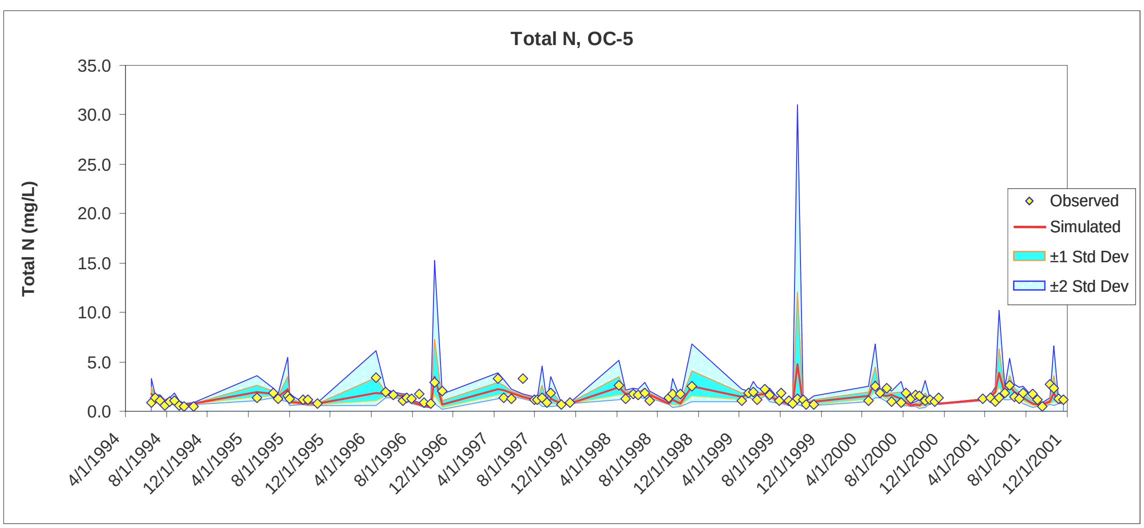

Total P, OC-4
Total P (mg/L)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

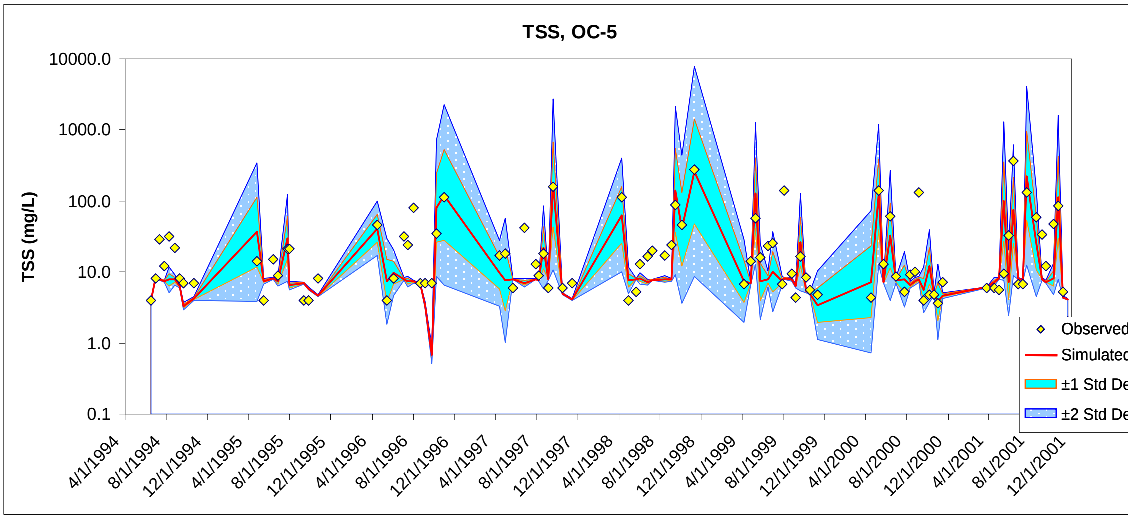

Total N, OC-4
Total N (mg/L)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

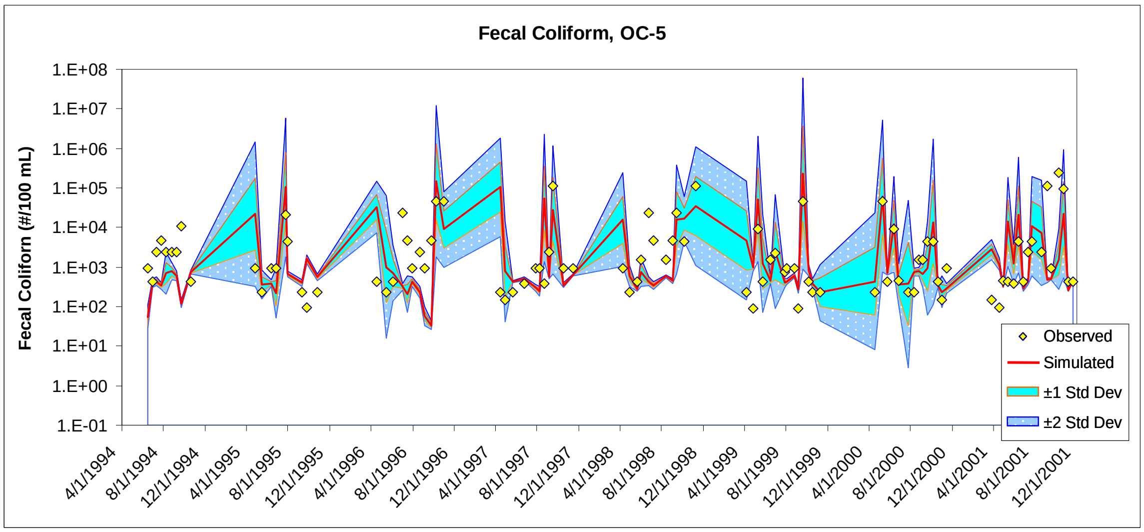

TSS, OC-4
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

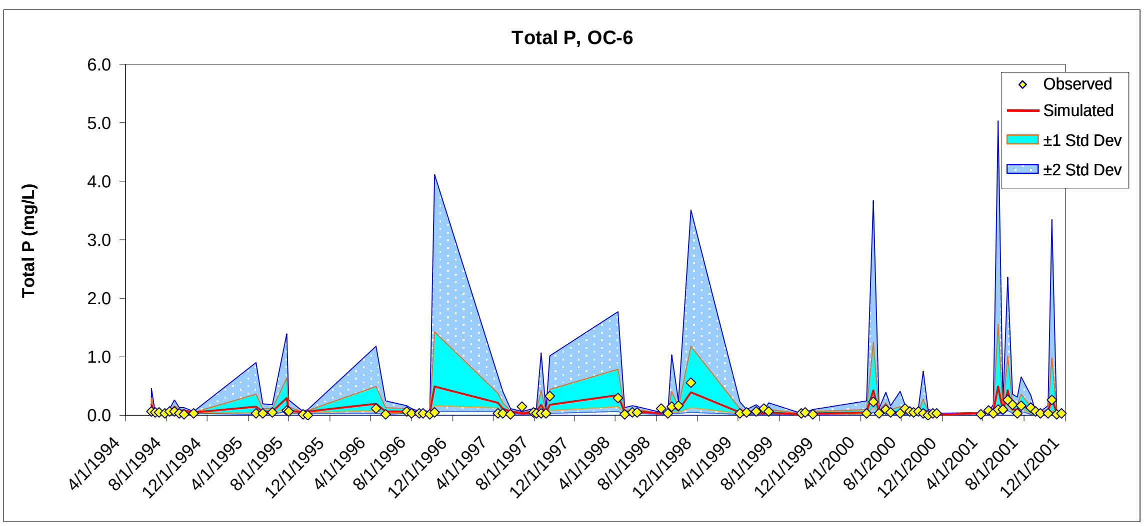

Fecal Coliform, OC-4
Fecal Coliform (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

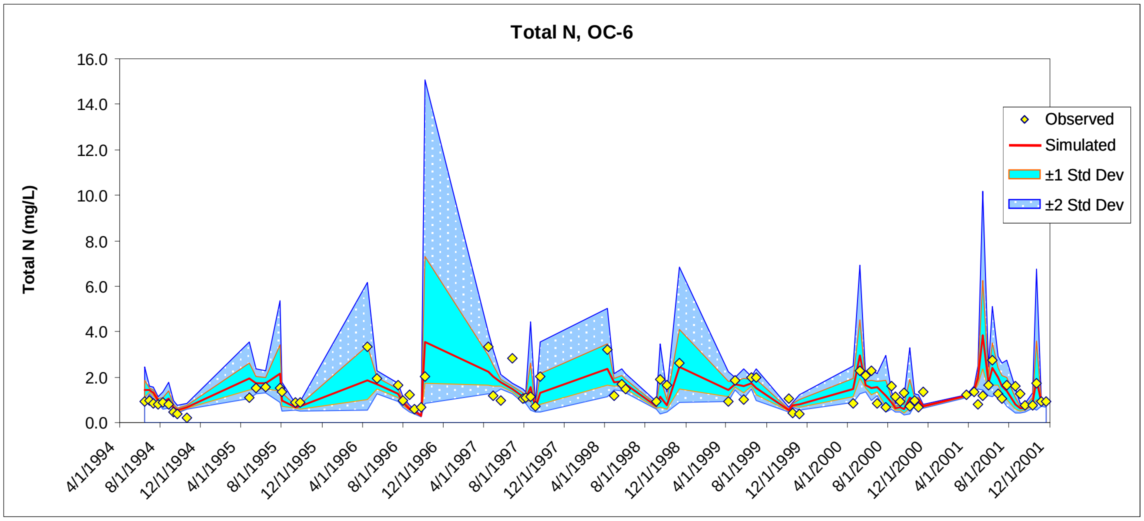

Total P, OC-5
Total P (mg/L)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

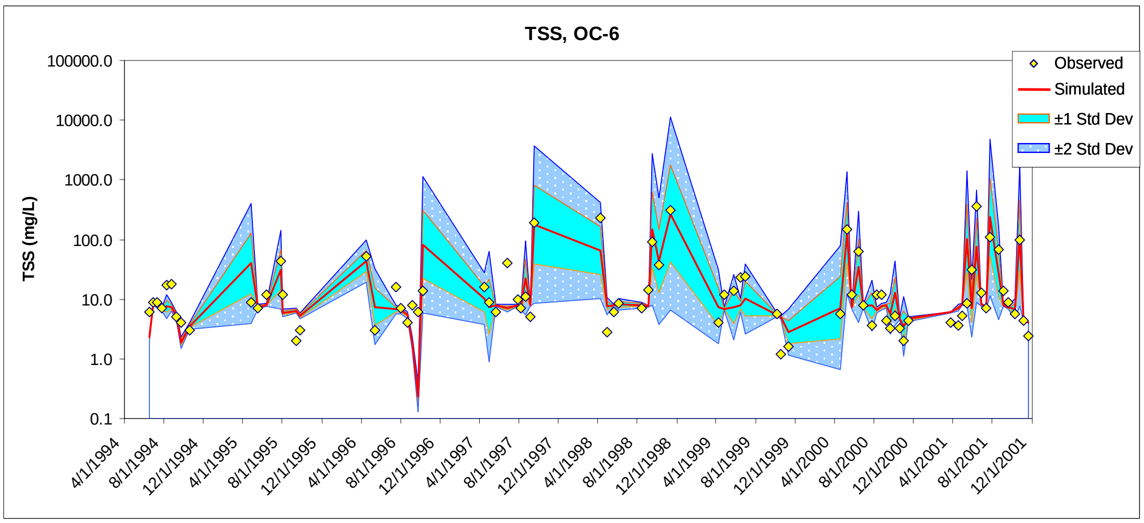

Total N, OC-5
Total N (mg/L)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

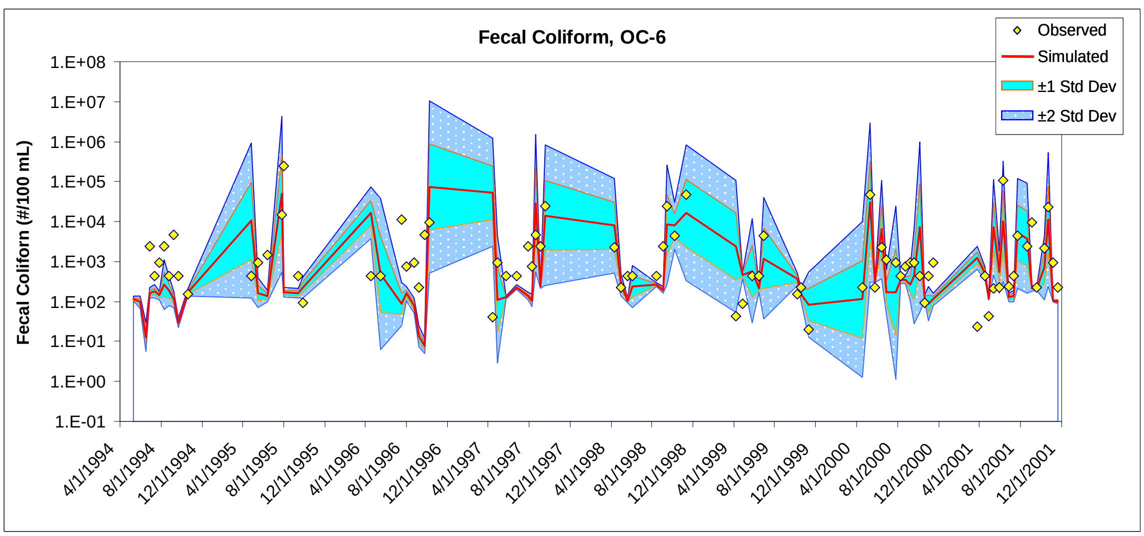

TSS, OC-5
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

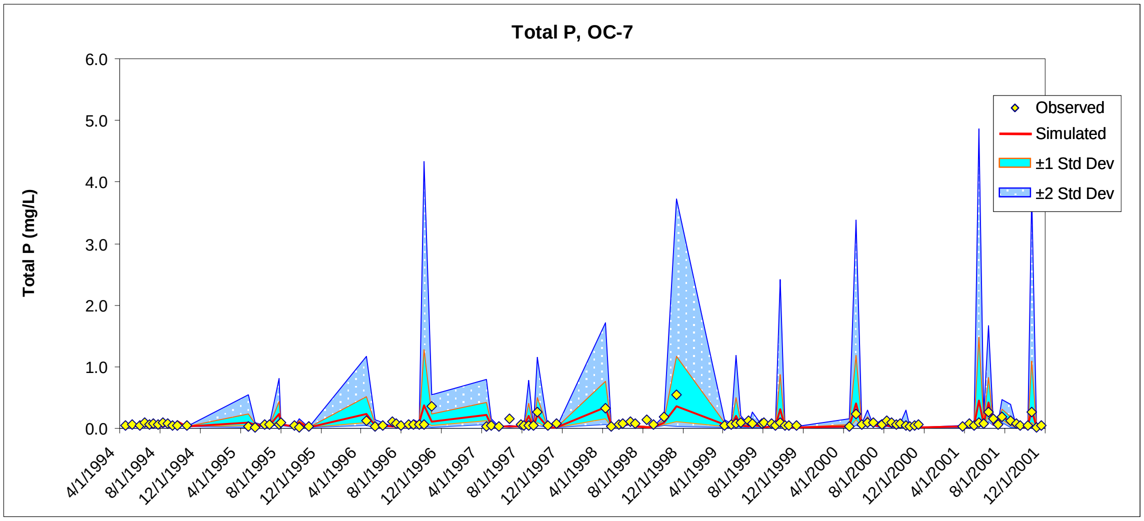

Fecal Coliform, OC-5
Fecal Coliform (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

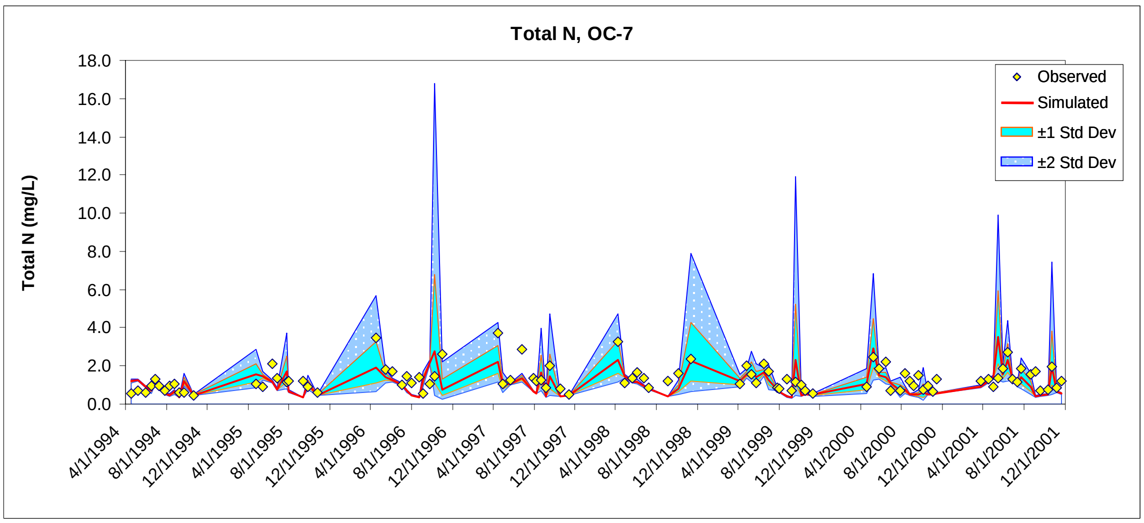

Total P, OC-6
Total P (mg/L)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

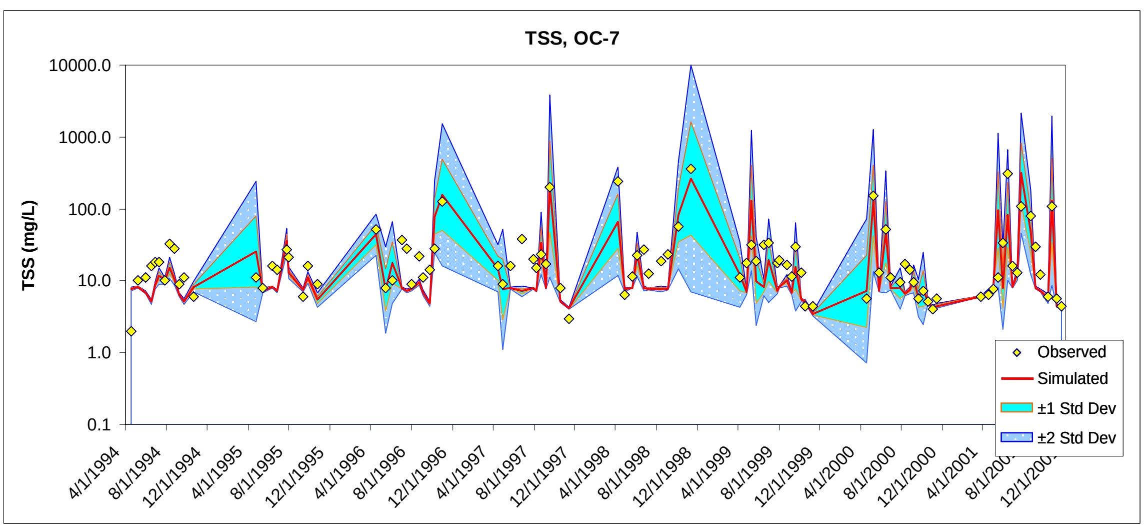

Total N, OC-6
Total N (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

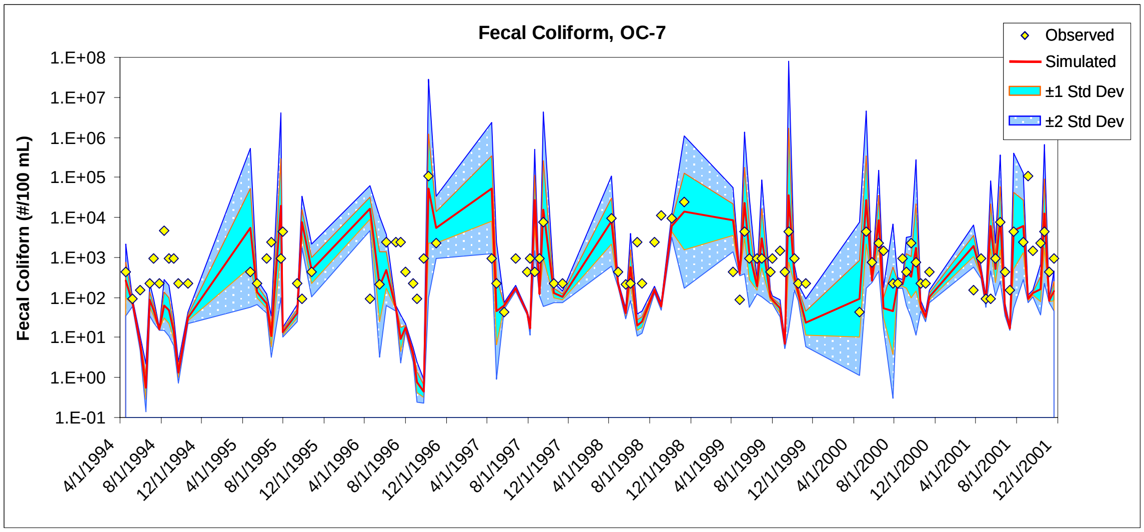

TSS, OC-6
TSS (mg/L)
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Fecal Coliform, OC-6
Fecal Coliform (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Total P, OC-7
Total P (mg/L)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Total N, OC-7
Total N (mg/L)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


TSS, OC-7
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev



Fecal Coliform, OC-7
Observed
Simulated
±1 Std Dev
±2 Std Dev
Fecal Coliforn (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1994
8/1/1994
12/1/1994
4/1/1995
8/1/1995
12/1/1995
4/1/1996
8/1/1996
12/1/1996
4/1/1997
8/1/1997
12/1/1997
4/1/1998
8/1/1998
12/1/1998
4/1/1999
8/1/1999
12/1/1999
4/1/2000
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001

Final Memorandum

2020 Facility Planning Project

Project Name:	MMSD – 2020 Facility Planning Project	MMSD Contract No:	M03002P01
DMS Folder Name:	Technology Analysis	MMSD File Code:	M009PE000.P2000
Document Name:	Water Quality Calibration and Validation Results for the Root River Model (Task 4)	HNTB Charge No:	34568-PL-400-115

Date: December 21, 2007
To: Michael Hahn, SEWRPC
Bill Krill, HNTB
From: Leslie Shoemaker, Tetra Tech, Inc.
Subject: Water Quality Calibration and Validation Results for the Root River Model (Task 4)

1 EXECUTIVE SUMMARY

An important component of the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU) is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. The purpose of this memorandum is to describe the modeling process and provide results of the water quality calibration of the Root River watershed model.

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. The Hydrologic Simulation Program in Fortran (HSPF) was originally chosen for the 2020 Facility Planning Project for a variety of reasons, including that existing HSPF models were available for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds. The Loading Simulation Program in C++ (LSPC) is a watershed modeling system that includes HSPF algorithms but has the advantage of no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. For these reasons, the original HSPF models for the Oak Creek, Kinnickinnic River, Upper Root River, and Menomonee River watersheds have been migrated to LSPC and the Root River model has been developed within LSPC for the 2020 Facilities Planning Project.

Calibration of LSPC followed a sequential, hierarchical process that begins with hydrology, followed by sediment erosion and transport, and, finally, calibration of chemical water quality. The hydrologic calibration for the Root River watershed model is described in the memorandum entitled *Hydrologic Calibration and Validation Results for the Root River Model*. This memorandum provides the results of the water quality calibration that are consistent with the hydrologic calibration.

2 CONCLUSIONS

Water quality calibration for the Root River relied on comparison of model predictions to observed concentrations at six water quality sampling sites located along the Root River and several tributaries. Predicted loads were compared at one modeling reach where both flow and concentration data were available. Achieving water quality calibration involves adjusting many parameters that interact with one another. The upland model represents expected loading associated with runoff events from specified land uses, but cannot represent unusual events that are outside the scope of events simulated in the model (for instance, discharge or breach of a waste lagoon). Any errors present in the simulation of hydrology (whether due to model formulation or the inherent uncertainty of predicting watershed-scale response from point rain gage monitoring) will propagate into the water quality simulation. In addition, observed data – which consist of point in time and point in space measurements – may not be fully representative of conditions in the waterbody, and may also be subject to analytical uncertainty. The model provides an estimate of average conditions across the stream width and depth as a result of known upland sources. For this application, the long-term average loading from these upland sources has been constrained to be consistent with results from SWAT modeling of agriculture and SLAMM modeling of loading from urban land uses. Fit between model and observations is best judged graphically and statistically; the model should represent the central tendency and trends seen in observations, but may not replicate all individual observations. Model fit for water quality is thus evaluated in three ways: (1) through graphical comparison of simulated and observed data, (2) through statistical tests on the equivalence of means on paired observed and simulated concentration data, and (3) through evaluation of the ability of the model to represent apparent observed load delivery rates. A single set of parameter values (by land cover) is specified throughout the watershed; thus, the ability of the model to replicate differences in concentrations between different sample points is as important as the ability to match concentrations at individual sites.

In general, the water quality calibration attains a reasonable fit to observations, with some discrepancies for individual parameters (most significantly dissolved oxygen) and at individual locations. A significant part of the inaccuracy may be tied to limited stream channel representation and hydrologic timing issues. The quality of fit is sufficiently good that the model is judged ready for application to management scenarios.

3 RECOMMENDATIONS

We recommend that the water quality calibration of the Root River model be considered complete.

4 INTRODUCTION

The Milwaukee Metropolitan Sewerage District (MMSD) is in the midst of a long-range planning effort to identify improvements needed for its facilities to accommodate growth and protect water quality through the year 2020. This effort is known as the MMSD 2020 Facility Plan. A related planning effort is being conducted by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) to update the regional water quality management plan for the Kinnickinnic River, Menomonee River, Milwaukee River, Root River, and Oak Creek watersheds, the Milwaukee Harbor estuary, and the adjacent nearshore Lake Michigan area. This effort is known as the Regional Water Quality Management Plan Update (RWQMPU). The two planning efforts are being coordinated and implemented in parallel.

One important component of both the 2020 Facility Plan and the RWQMPU is the development and application of a suite of watershed and receiving water models. These models will allow planners to evaluate the potential water quality benefits of a range of implementation measures, including facility improvements and urban, suburban, and rural stormwater best management practices. Watershed models are being developed for the following five watersheds:

- Kinnickinnic River
- Menomonee River
- Milwaukee River
- Oak Creek
- Root River

The Kinnickinnic, Menomonee, Milwaukee River and Oak Creek models are linked to a model of the Lake Michigan estuary so that the benefits of upstream water quality improvements can be simulated by the Lake Michigan Harbor / Estuary Model. The Root River model is a stand-alone model and does not provide input to the Lake Michigan Harbor / Estuary Model.

The following seven tasks have been identified for performing the system modeling:

1) Establish the model structure, including the delineation of subwatersheds, connectivity, and cross sections, etc.
2) Develop the model data sets using physical measurements, maps, and other appropriate information
3) Perform hydrologic and hydraulic calibration and validation
4) Perform watercourse water quality calibration and validation
5) Perform harbor/estuary and lake water quality calibration
6) Perform production runs as required for project planning
7) Document results.

The purpose of this report is to document the watercourse water quality calibration for the Root River watershed model (Task 4). Observed data are available for 1999 through 2001 and were used to perform the calibration. No formal validation was performed as insufficient data were available for a separate validation period, although limited data from 2004 were also used to evaluate model results. The modeling approach and results, by parameter, are presented below.

5 MODELING APPROACH AND RESULTS

The calibration process for LSPC is sequential, beginning with the calibration of flow (refer to the *Final Hydrologic Calibration and Validation Results for the Root River Model*). Sediment and dissolved pollutant transport depend directly on the representation of flow, while sorbed pollutant transport depends on the simulation of sediment. (In the model, sorption to sediment within stream reaches is currently simulated for phosphorus, ammonium, and bacteria.) The implementation of the model represents pollutant loading from the land surface by buildup-washoff formulations (independent of erosion); however, sorption to sediment and settling is simulated in the stream reaches and has an important effect on the downstream transport of particle-reactive pollutants including phosphorus, ammonium, and bacteria. Thus, any inaccuracies in the flow and sediment simulation will propagate forward into the water quality simulation, and the accuracy of the hydrologic simulation provides an inherent limitation on the potential accuracy of the water quality simulation. The representation of the stream geometry for the Root River watershed is not as fine as for the other watersheds and therefore is likely to lead to poor individual storm response and timing. In addition, many of the stream segments lack a representation of a low flow channel, forcing the channel to be very wide and shallow. This is likely to greatly impact the algal kinetics, nutrient species balance, and dissolved oxygen concentrations.

Instream water quality kinetics are also highly linked with one another. For instance most kinetic rates depend on temperature, while nutrient balances and dissolved oxygen are strongly linked to the algal simulation. Accordingly, the water quality calibration uses the following sequential process:

1. Calibration of flow
2. Calibration of sediment
3. Calibration of water temperature
4. Initial calibration of gross nutrient transport
5. Initial calibration of BOD and DO
6. Calibration of algae
7. Final calibration of nutrient species and DO
8. Calibration of fecal coliform bacteria
9. Calibration of metals

Steps 1 through 4 were performed to correctly quantify loading. SEWRPC and WDNR directed that loads from the land surface should be, to the extent compatible with achieving water quality calibration, consistent with the loads predicted by SWAT for agricultural land uses and by SLAMM for urban land uses. The SLAMM model in particular is preferred by the WDNR for use in assessing compliance with State urban nonpoint source pollutant regulations. Therefore, the loading rates produced by these models form the starting point for the water quality calibration.

The adequacy of the water quality calibration was assessed through comparison to observed water quality data. It should be noted that the observed water quality data are primarily point-in-time grab samples, which may exhibit significant temporal variability relative to the (unobserved) daily mean concentration. A key objective is to have the model replicate actual loads through the system. Unfortunately, loads are not directly observed, and can only be estimated from the point-in-time concentrations multiplied by daily average flow. While model adjustments are made to obtain general agreement between simulated loads and estimated observed loads, it should be recalled that the estimates of observed loads are highly uncertain.

Hydrologic calibration precedes sediment and water quality calibration because runoff is the transport mechanism by which nonpoint pollution occurs and the hydrologic calibration of the Root River watershed model is described in a separate memorandum (*Final Hydrologic Calibration and Validation Results for the Root River Model*). The revised calibration results for the Root River model indicate acceptable agreement between observed and simulated streamflows. The successful hydrologic calibration provides a good basis for water quality calibration.

The approach that was used to calibrate the Root River model for sediment and the other water quality parameters is based on the Menomonee model and is described in detail in previous memorandums (e.g., *Revised Draft Water Quality Calibration Results for the Menomonee River)*. Simulation of water quality in the Root River uses parameters from the revised upper Menomonee River model with adjustments to the loading rates based on cropping patterns. Kinetic rates for BOD, nutrients, and algae are site-specific, which depend on a variety factors such as hydraulic characteristics and local chemical-biological factors. Adjustments were not made to these parameters since, in many cases; the flow representation is currently controlling algal kinetics. It is recommended that the kinetic rates be reviewed after better channel representations can be implemented.

Water quality observations collected by MMSD were provided for 1999 through 2001 and were used to calibrate the water quality model. Due to the limited monitoring period, a separate validation check was not performed although some USGS data collected in 2004 were used to evaluate model results. They indicated that the simulated concentrations for most locations for most parameters covered the range of the observed data (see Attachment L for results). Unless noted otherwise, all time series calibration plots are based on the daily mean values of simulated output.

The calibration period used for water quality differ from those used in the hydrologic calibration due to constraints of data availability. The calibration period for water quality was started in 1999 (versus 1995 for the hydrology) and extended to 2001 (versus 2002 for hydrology) to take full advantage of the available data. For both hydrology and water quality, simulations were started in January 1993 to minimize the effects of the initial conditions. Figure 1 displays the location of the water quality sampling stations that were used during the calibration process.

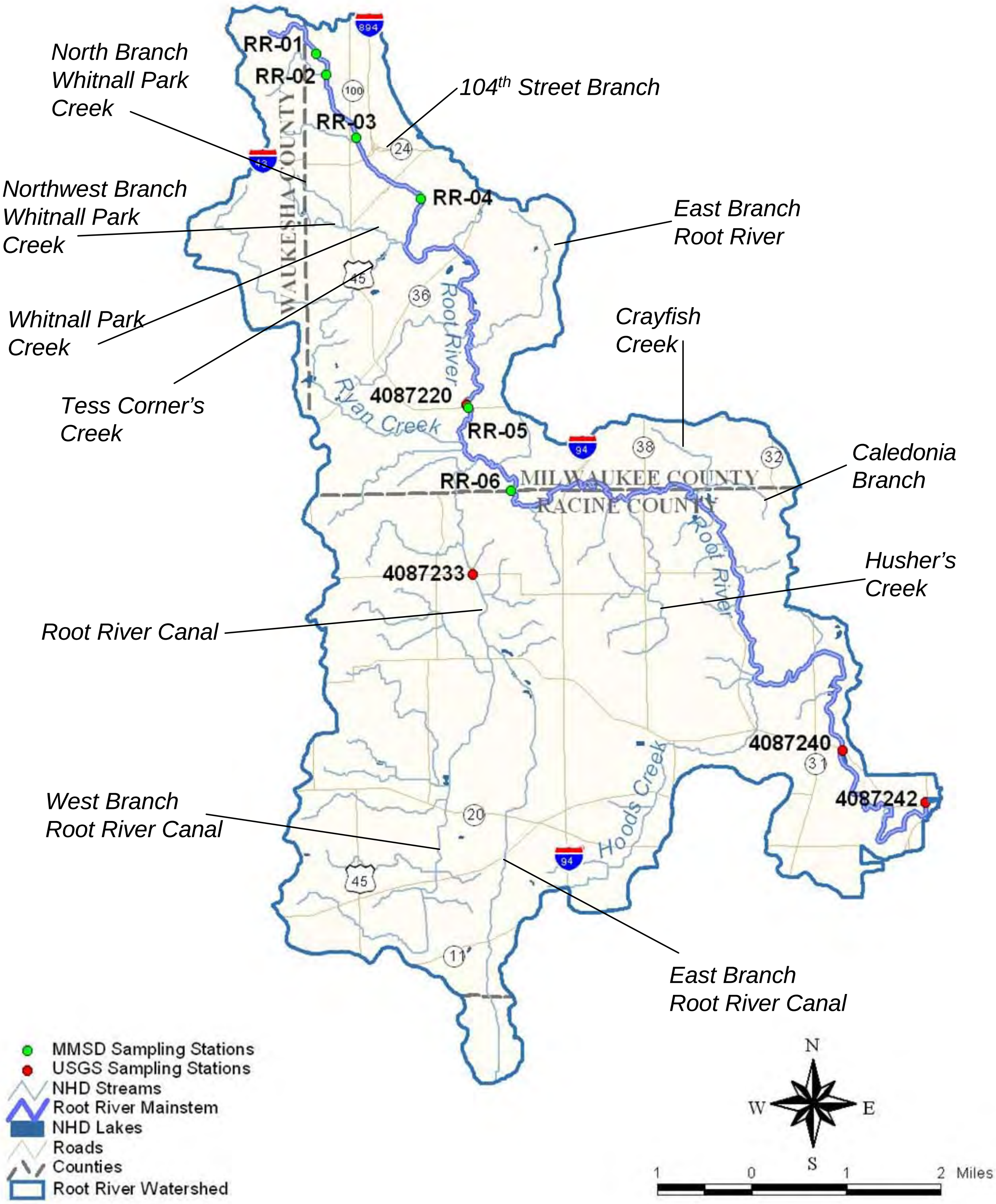


Figure 1. Location of MMSD sampling stations and USGS flow gages on the Root River.

5.1 Sediment Calibration

The general sequence for sediment calibration in LSPC (Donigian and Love, 2002; Donigian et al., 1984) is to (1) estimate target sediment loading rates from the landscape, (2) calibrate the model loading rates to the target rates, and (3) adjust scour, deposition, and transport parameters in the stream channel to mimic behavior of the streams/waterbodies.

Sediment loading from agricultural land uses in the Root River watershed is derived from SWAT simulations and implemented by buildup/washoff coefficients (rather than LSPC sediment routines), as described in a separate memorandum (January 10, 2005 memorandum entitled *Revised and Expanded Discussion of SWAT Application*). The model uses three categories of cropland (by soil hydrologic group); however, the parameters for these groups are modified to reflect the mix of agricultural rotations present in each watershed. Other land uses are simulated using the sediment/solids routines. Parameters for impervious land uses were derived to match SLAMM output as described in the February 16, 2004 memorandum entitled *Urban Non-Point Source Unit Loading Rates*. For grass, forest, and wetlands, the sediment routines were used and parameters were developed based on theoretical relationship to USLE – as discussed below.

Figure 4 displays a comparison of surface washoff loads from PERLNDs with predictions from SWAT for the period 1993 to 1999. Slight differences are expected due to the different simulation of hydrology, but the general agreement is good.

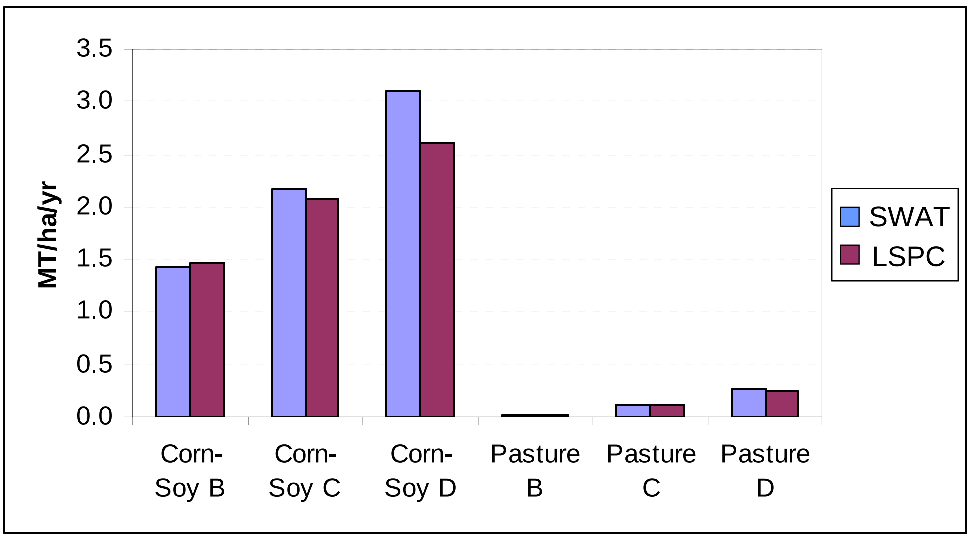


Figure 2. Correspondence of SWAT and LSPC Sediment Loading Rates for 1993-1999, Upper Menomonee.

For urban land uses (and forest), loads were initially set to approximately reproduce estimates produced by SLAMM model applications for 1995 to 1997, as reported in the February 16, 2004 memorandum *Urban Non-Point Source Unit Loading Rates*. The sediment/solids routines in LSPC are used for these land uses. The memorandum reports LSPC parameter values designed to match SLAMM loads. However, significant changes have been made to the parameters controlling flow response from pervious lands since those calculations were done. Therefore, it was necessary to re-estimate the pervious land parameters.

LSPC parameters for pervious land uses were estimated based on a theoretical relationship between LSPC algorithms and documented soil parameters, ensuring consistency in relative estimates of erosion based on soil type and cover. LSPC calculates the detachment rate of sediment by rainfall (in tons/acre) as

$$DETS = (1 - COVER) \bullet SMPF \bullet KRER \bullet P^{JRER} \bullet \frac{1}{1 - AFFIX}$$

where P is precipitation in inches. Actual sediment storage available for transport (*DETS*) is a function of accumulation over time and the reincorporation rate, *AFFIX*. The equation for *DET* is formally similar to the USLE equation,

$$Sediment\ yield = RE \cdot K \cdot LS \cdot C \cdot P.$$

USLE predicts sediment loss from one or a series of events at the field scale, and thus incorporates local transport as well as sediment detachment. For a large event with a significant antecedent dry period, it is reasonable to assume that *DET≈DETS* if *AFFIX* is greater than zero. Further, during a large event, sediment yield at the field scale is assumed to be limited by supply, rather than transport capacity. Under those conditions, the USLE yield from an event should approximate *DET* in LSPC.

With these assumptions, the LSPC variable *SMPF* may be taken as fully analogous to the USLE P factor.
The complement of *COVER* is equivalent to the USLE C factor (i.e., (1 - *COVER*) = C). This leaves the following equivalence:

$$\frac{KRER}{1 - AFFIX} \bullet P^{JRER} \quad = \quad RE \bullet K \bullet LS$$

The empirical equation of Richardson et al. (1983) as further tested by Haith and Merrill (1987) gives an expression for RE (in units of MJ-mm/ha-h) in terms of precipitation:

$$RE \quad = \quad 64.6 \bullet a_t \bullet R^{1.81}$$

where R is precipitation in cm and a_t is an empirical factor that varies by location and season. For southeast Wisconsin (USLE Region 14), a_t is estimated to average about 0.20 (Richardson et al., 1983). As LSPC does not implement *KRER* on a seasonal basis, the average value is most relevant.

As shown in Haith et al. (1992), the expression for RE can be re-expressed in units of tonnes/ha as:

$$RE \quad = \quad 0.132 \bullet 64.6 \bullet a_t \bullet R^{1.81}$$

This relationship suggests that the LSPC exponent on precipitation, *JRER*, should be set to 1.81.

The remainder of the terms in the calculation of *RE* must be subsumed into the *KRER* term of LSPC, with a units conversion. Writing *RE* in terms of tons/acre and using precipitation in inches:

$$RE\,(tons/ac) \quad = \quad [0.132 \bullet 64.6 \bullet a_t] \bullet R\,(in)^{1.81} \bullet (2.54\,cm/in)^{1.81} \bullet (1\,ton/ac)/(2.24\,tonnes/ha)$$

or, at the average value for a_t for this region, 4.115 · R (in)1.81.

The power term for precipitation can then be eliminated from both sides of the equation, leaving the following expression for the *KRER* term in LSPC (English units) in terms of the USLE K factor:

$$KRER \quad = \quad 3.7032 \bullet K \bullet LS \bullet (1 - AFFIX)$$

The K factor is available directly from soil surveys, while the LS factor can be estimated from slope. This approach establishes initial values for *KRER* that are consistent with USLE information. Further calibration can then modify all *KRER* values by a single multiplicative factor (thus preserving the relationship among different land use:soil pairs) or by modifying the transport coefficient, *KSER.*

Because SLAMM is a simple model, and was only run for a three-year period, the SLAMM loads were considered to be appropriate as approximate “soft” targets only. The resulting comparison is shown below. Note that SLAMM produces a single loading estimate for B and C soils; however, LSPC simulates very different hydrology, and thus should show different loading rates for these soils. In the case of forest, the solids loading estimate in the February 16, 2004 memorandum was not developed from modeling, but rather is taken from a nonpoint source control plan for the Root River priority watershed project. Undisturbed forest has very low sediment loading rates. However, the major sources of sediment load in areas identified as forest are roads, trails, and other clearings – not the intact forest itself. Most forest land use in the Milwaukee area will have these types of disturbances present. Therefore, it seems appropriate to use a net forest sediment loading rate, based on theoretical parameters, that is significantly greater than the loading of 1.8 lb/ac/yr (0.003 MT/ha/yr) cited in the February 16, 2004 memorandum.

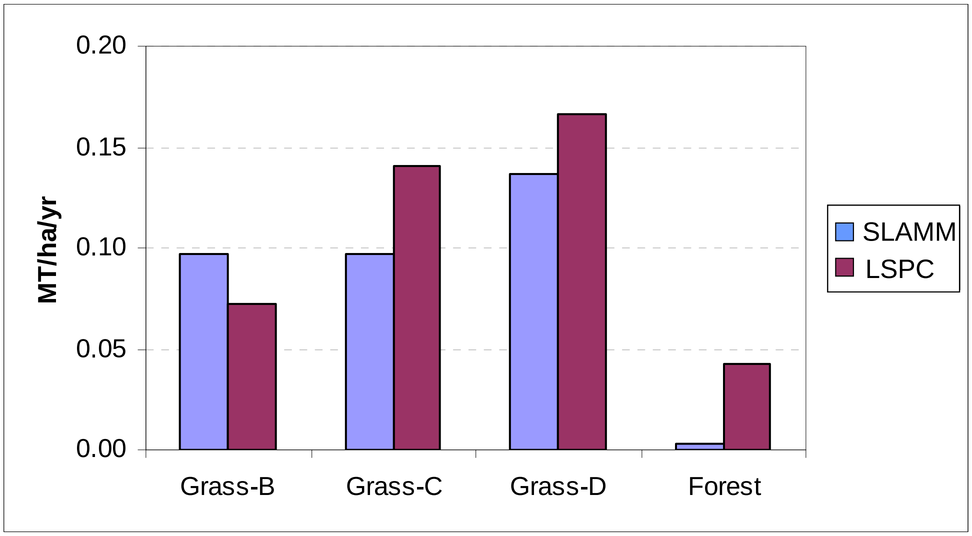


Figure 3. Correspondence of SLAMM and LSPC Sediment Loading Rates for 1995 to 1997.

In addition to surface loads, a fine sediment concentration was associated with ground water discharge from pervious lands. This is necessary to match low-flow (non-scouring) total suspended solids (TSS) observations, and represents miscellaneous non-washoff sources of fine sediment load, including disturbances in the stream channel (by people, vehicles, farm animals, or wildlife) as well as fine sediment actually associated with ground water influx.

Input of these loads directly to the simulated stream reaches results in a consistent over-prediction of sediment concentration and load observed in-stream. This is largely because the first order and ephemeral streams are not simulated and, in these areas as well as in riparian wetlands, substantial trapping may occur. A sediment trapping rate for sediment and sediment-associated pollutants (implemented in the MASS-LINK block) was taken as a general calibration parameter that effectively removes loads from the system. This approach simulates trapping losses as a fixed fraction of influent load, but is only applied to the surface washoff fraction of load. While this is a simplification of actual processes, monitoring of small tributaries is not available to support a more detailed representation of dependence on flow. In fact, the rate of trapping by settling within the stream channel is likely to be greater for smaller, less energetic flows; however, losses that are due to export in the flood plain are greater for higher flows. Actual trapping is also likely to vary by season, depending on vegetation condition. In essence, the trapping factors that are assumed are a simplified, empirical representation of the *net* difference between the estimated loading from the land surface and the event-associated load observed in streams.

Material that is trapped in the floodplain may eventually be eroded back into the stream. This is included as part of the general simulation of loading from the riparian area. Material that is “trapped” through deposition into bed sediments may also be re-entrained during high flow events. For small streams that are not simulated, the model can only represent this sediment source as part of the erosion of the bed material that is present at the start of the simulation in larger reaches. For sediment-associated pollutants, LSPC does not provide a complete sediment diagenesis model, so a mass balance of these constituents in sediment is not maintained in the model. Instead, the user must specify concentrations associated with resuspended sediment.

Setting a trapping rate of 80 percent for sediment loads from pervious surfaces and 30 percent for solids loads from impervious surfaces brings simulated and observed loads approximately into line. In further refinements during calibration, a slightly higher trapping rate was determined to be appropriate for the upstream (Washington County) portion of the basin, probably due to the presence of more extensive riparian wetlands in this area, while a somewhat lower trapping rate for loads from impervious surfaces was used in the downstream, urban portions of the watershed, where direct conveyance to the stream through lined drainage ways is more likely to occur. (Alternatively, the need to employ trapping rates to achieve agreement between the model and data may indicate that the load estimates obtained from SLAMM and SWAT are simply too high.)

The instream parameters controlling scour and deposition mainly serve to modulate the movement of load derived from the uplands. Model simulation of scour and deposition depends on the simulation of shear stress, which in turn depends on the specification of F-tables. Given the simple one-dimensional representation of reaches in LSPC, values of critical shear stress are site-specific. We began with values successfully used in the Minnesota River watershed (Tetra Tech, 2002) and modified them to achieve a reasonable fit. Two sets of parameters were fit: one for the smaller streams, and one for the main channel from Pilgrim Road downstream.

Calibration of LSPC to observed instream suspended sediment concentrations is a difficult process, and an exact match cannot be expected for a number of reasons:

- Because suspended sediments often vary rapidly in time, point-in-time grab sample observations may not be representative of daily-average concentrations. Sediment load peaks are likely to be shifted slightly between the model and observations, resulting in larger apparent errors.
- Any errors in the hydrologic simulation of storm events also propagate into the sediment simulation. Both the washoff of sediment from the land surface and the scour of sediment within streams depend on the shape of the storm hydrograph at a fine temporal scale. But the spatial resolution of the rain gages representing broad geographic areas in the model limits the accuracy.
- Stream reaches are represented as relatively long segments, with average properties. The accuracy of the scour/deposition simulation is limited by the relatively simplified representation of hydraulic conditions in the LSPC model.
- Because of the scale of the model, low-order streams are not explicitly simulated. As a result, sediment dynamics in the smaller streams are also not simulated.
- The timing of snowmelt peak flows is often not accurately captured by the models. These are often also peak sediment transport events.
- LSPC is a one-dimensional model, and thus simulates an average concentration for a crosssection. Samples that are not spatially integrated may not provide an accurate representation of the cross-sectional average concentration. This phenomenon can be particularly important at higher flows where there may be enhanced movement and higher concentrations of sediment near the sediment bed.

Calibration for sediment, as with any other water quality parameter, involves visual and statistical comparison of observed and predicted concentrations. However, the match on individual points is expected to be inexact, for the reasons cited above. For this reason, it is most important to reproduce observed transport curves (Donigian and Love, 2002; MPCA, 2001). That is, a log-log power plot of observed sediment load versus observed flow should match a similar plot of simulated sediment load and simulated flow.

Comparisons of observed and simulated TSS are shown at four available monitoring stations within the LSPC modeling domain, arranged in upstream-to-downstream order (Attachment A). Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment J.

A statistical comparison of paired sediment observations and simulated daily mean values are provided in Section 5.6 (concentrations) and Section 5.7 (loads) below. These comparisons are fairly good, and, as noted above, much of the error in individual point predictions is anticipated to be due to temporal shifts. Observed and simulated sediment transport plots are presented in Section 5.7.

5.2 Water Temperature Calibration

Water temperature simulation is not an explicit goal of the water quality modeling. However, a reasonable simulation of water temperature is necessary because many kinetic reaction rates are temperature dependent. Temperature simulation was therefore checked visually for consistency with observations, but a full statistical analysis has not been provided at this time.

The Root River temperature simulation relies on the same set of parameters as used for the Menomonee River. PERLND soil temperature and reach water temperature parameters were adopted from successful Minnesota River model applications. Fit to observed water temperature at the MMSD monitoring stations appears generally good for the calibration time period (comparison is shown to daily averages from the model as many of the observations do not report time of day) (Attachment B). The main discrepancies seen are over estimation of summer temperatures at the upper monitoring locations. This may be due in part to the inaccurate representation of the low flow channel resulting in a wide shallow stream with a large potential for heating due to solar radiation.

5.3 Nutrient and Algal Calibration

As with sediment, the starting points for nutrient calibration in the model are the loading estimates for specific land uses derived from the SWAT application (for agricultural lands, 1993 to 1999) and the SLAMM application (for urban lands, 1995 to 1997). This ensures consistency with other tools endorsed by WDNR. A detailed discussion of the comparison of unit area loads estimated by SWAT, SLAMM and HSPF is provided in the memorandum *Draft Water Quality Calibration Results for the Menomonee River.*

The general strategy for nutrient calibration is as follows: Nutrient loads from the land surface are represented by buildup/washoff formulations, and adjusted to approximately match loads from SWAT and SLAMM. In the case of SWAT, these formulations are implemented on a monthly pattern; in the case of SLAMM, an annual average is used. (This approach is reasonable, as the greatest monthly variability is expected for agricultural lands, due to annual patterns of tillage and fertilization). Because SWAT and SLAMM represent nutrient species in different ways, the buildup/washoff formulations are specified for total nitrogen and total phosphorus. These are then partitioned at the land/water interface into inorganic and organic nutrient species. Phosphorus is not simulated as sediment-associated in washoff from the land surface in this model. Within the stream, equilibrium partitioning assumptions are used to spit inorganic phosphorus into sorbed and dissolved fractions, ensuring that the sediment-sorbed fraction is consistent with the available sediment supply in stream.

For agricultural croplands, the loads predicted by SWAT differ significantly by crop and management type. Information on the distribution of crop types in the Root River watershed is provided in the 2003 NASS cropland data layer. This information was used to infer the distribution of cropland into corn (grain)-soybean, dairy silage, alfalfa, and straight corn rotations. Loading rates and associated parameters for each sub-watershed were then adjusted to reflect the crop distribution in that subwatershed.

The model must be adjusted to achieve calibration to observed instream nutrient concentrations. In general, the mass of phosphorus observed instream is significantly less than the export from the land surface predicted by SWAT and SLAMM. This reflects trapping (of sediment-associated pollutants) and biological uptake (of labile forms), which primarily occurs in the small first-order and ephemeral streams. These small streams are not represented as reaches in the LSPC model, therefore the use of trapping factors is appropriate, and also enables calibration to be achieved while maintaining the relative loading magnitude for different land uses predicted by the SWAT and SLAMM models. Secondary adjustments to calibration are achieved by (1) adjusting the subsurface nutrient concentration components, and (2) adjusting instream nutrient kinetic parameters. A detailed discussion of the subsurface nutrient concentrations and instream nutrient kinetic parameters used in the Root River model is provided in the memorandum *Draft Water Quality Calibration Results for the Menomonee River.* Simulation of nutrient water quality in the Root River was based on parameters from the Menomonee River model.

Calibration for nutrients addresses both total nutrient concentration and individual nutrient species. This calibration process is inherently somewhat inexact for a number of reasons. First, available samples represent individual points in time and space (grab samples) that may not be representative of average conditions throughout a stream reach. In addition, there is typically significant analytical uncertainty in reported results – which is clearly evidenced by the fact that reported orthophosphate is sometimes greater than total phosphorus. This is particularly problematic when concentrations are near detection limits. Another problem is often observed at high flows, where substantial amounts of nutrients may move either as parts of larger debris or associated with sediment bedload, both of which are likely to be omitted from surface grab samples.

Modeling results are presented graphically in Attachments C (total phosphorus and dissolved phosphorus) and Attachment D (total nitrogen, nitrite and nitrate, and ammonia). A statistical assessment of concentrations and loads is provided below. Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment J. While the model generally performs adequately, higher-concentration events are frequently shown at RR-06. These may reflect a greater sensitivity to agricultural inputs than is seen in the other Greater Milwaukee watershed models.

5.3.1 Algae and Chlorophyll *a*

Model calibration for chlorophyll *a* is challenging, because (1) algae respond in a complex way to a wide number of environmental factors, including self-shading, (2) chlorophyll *a* laboratory analyses are typically subject to a relatively high level of imprecision, and (3) algal response is naturally highly variable. Simulation of chlorophyll *a* in the Root River initially was based on parameters from the Menomonee River model.

The model also simulates benthic algae, which often constitute the major fraction of the algal biomass in shallow streams. Unfortunately, no reported data are available to calibrate the benthic algal concentration.

Model results for the calibration time period are provided in Attachment E. The model represents the general spatial and temporal trends in planktonic algal concentration, but does not predict a few isolated algal blooms that likely represent localized conditions in pooled backwaters during summer conditions or detachment of benthic algal biomass. Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment J. As with water temperature, the main discrepancies seen are over estimation of dissolved oxygen at the upper monitoring locations. This may be due in part to the inaccurate representation of the low flow channel resulting in a wide shallow stream with a large potential for algal growth due to solar radiation.

5.3.2 BOD/DO Calibration

A rigorous calibration for biochemical oxygen demand (BOD) is problematic, because what is represented in the model is not fully equivalent to what is analyzed from ambient samples. BOD has been primarily monitored in the Root River using APHA (1998) Standard Method 5210B. This yields estimates of 5-day (short-term) BOD from whole-water samples, including both the carbonaceous and nitrogenous components.

The LSPC model simulates a single dissolved CBOD component as a state variable. In fact, organic matter that exerts an oxygen demand via bacterial digestion is a complex mixture of chemicals with variable reaction rates. The LSPC variable is a summary compromise that, when combined with an average reaction rate, yields the observed rate of oxygen depletion. It is not necessarily equivalent to either a CBOD5 or an ultimate CBOD (CBODu), but rather an *ad hoc* hybrid. For flowing systems with relatively short residence times, an approximation in terms of CBOD5 is usually adequate, although the reaction rate may need to be modified from 5-day laboratory rates to compensate for the mixture of organic compounds actually exerting a demand.

A further complication is that the LSPC variable represents the non-living component of BOD. Method 5210B uses unfiltered samples, and these samples also include living algae. Algae are not allowed to grow during the BOD test, but may continue to exert a respiration demand or die and become part of the non-living BOD. This component of measured BOD is not included in the LSPC state variable. A correction can be calculated to account for the long-term CBODu represented by algal cells, but the effect on BOD5 is more variable and less clear. The lack of filtration and analysis for total rather than carbonaceous BOD both tend to cause reported BOD5 to overestimate CBOD5; however, use of only a 5-day test underestimates the effective CBOD needed by the model to achieve approximate mass balance in the DO simulation. As a result of all these factors, there is no direct correspondence between model simulated CBOD and observed BOD5; rather, only a general qualitative agreement can be shown.

Model results for the calibration time period are provided in Attachment F for both BOD5 and dissolved oxygen. The fit for BOD is in general fair. It should be noted that many of the reported post-2000 BOD5 concentrations are zeroes . The presence of these zeros in the database artificially increases the apparent discrepancy between the simulation model and observed data. Dissolved oxygen concentrations are frequently overestimated. This is due in part to excessive simulation of algal growth and the potential for reaeration in the headwater tributaries during low flow periods where the flow is spread over a very wide channel. Improvement of the low flow channel resolution would likely improve the simulation of dissolved oxygen.

5.4 Fecal Coliform Bacteria

Simulation of fecal coliform bacteria concentrations often presents a challenge for watershed modeling. Observed concentrations tend to be highly variable in both space and time - due to both natural variability and analytical uncertainty. Further, instream concentrations may be elevated by sources which are not explicitly included in the model (e.g., water fowl, wildlife, illicit connections to storm sewers, or illegal dumping into storm drain systems), or which may be included in the model in a general way, but have large and unmonitored variability (e.g., occasional loads from wastewater pumping station spills or malfunctioning septic tanks). The watershed models represent average loads from the land surface as a washoff process. In addition, background loading is represented as a ground water concentration. In fact, the load attributed to ground water includes both true ground water load and other unmodeled sources of loading that are not flow-dependent.

The basis for setup of bacteria export from pervious land surfaces was the Fecal Coliform Loading Estimation spreadsheet. This tool was developed by Tetra Tech and EPA for the purpose of compiling fecal coliform bacteria based on available local agency and national literature information. For agricultural lands, monthly estimates of fecal coliform loadings were estimated using agricultural census counts, literature values for manure production rates and bacteria counts, and estimates of manure application or deposition. Cattle waste is either applied as manure to cropland and pastureland or contributed directly to pastureland. Cattle are assumed to be either kept in feedlots or allowed to graze (depending on the season). Chicken waste is applied as manure to cropland and pasture. Swine manure is assumed to be collected and applied to cropland only.

Buildup and washoff rates for forest and wetland were not calculated in the spreadsheet, but were instead adopted from the successful application of the Minnesota River models (Tetra Tech, 2002). Loading rates for urban pervious surfaces are constant throughout the year and were derived primarily from estimates of domestic pet densities and pet waste characteristics. Loads from impervious surfaces were tuned to replicate loading predicted by SLAMM for 1995-1997 as described in *Draft Water Quality Calibration Results for the Menomonee River*.

Fecal coliform concentrations in streams during baseflow are simulated based on a combination of recycling from organic sediment and ground water loading. Ground water concentrations were varied on a seasonal basis to reproduce the general pattern of observed dry-weather baseflow concentrations and vary for rural versus urban land use. The baseflow concentration, which is simulated by assigning a ground water concentration, in part represents actual ground water loading, such as may occur from malfunctioning septic systems or leaky sewer lines, but also reflects direct non-washoff additions of bacteria into waterbodies from wildlife, waterfowl, and domestic animals. Ground water concentrations for non-urban pervious land ranged from 25 to 50 colonies per 100 ml, while higher rates were set for urban grass to reflect the potential for contributions from subsurface sewer leaks.

Observed concentrations of fecal coliform bacteria instream are strongly affected by the die off rate of fecal coliform bacteria. As these organisms reside in the mammalian gut, they do not prosper in surface waters. Die off rates are increased by a variety of factors including temperature, sunlight, salinity, settling, and predation. Mancini (1978) suggests a base loss rate of 0.8 per day, with increases above the base rate due to these factors and an Arrhenius temperature coefficient of 1.07. Based on trial and error, a loss rate of 1.10 per day appeared to provide a reasonable fit to observations.

Model results for the calibration time period is provided in Attachment G. Exceedance curve plots that compare the observed data to the modeling results are presented in Attachment J.

5.5 Metals

As requested by SEWRPC, the model includes simulations for copper and zinc, but at a highly simplified level. Both copper and zinc are simulated as total metals, and treated as conservative substances within stream reaches. This neglects the actual kinetics of these constituents, which sorb to particulate matter and exchange with the sediments. Such refinements may be added to the model at a future date.

Copper and zinc are also not rigorously calibrated. While there are observations for both total copper and total zinc, many of the observations (particularly) for copper are at or near method detection limits, and thus provide limited information on exact concentrations. Further, neglect of sorption kinetics means that the simulation will only be approximate. Therefore, the strategy was to base the metals simulation on independent loading estimates and adjust these only to the extent necessary to achieve approximate agreement with the range of concentrations reported instream.

For copper and zinc loading from impervious surfaces, the LSPC buildup and washoff rates developed from the SLAMM simulation are used. The SLAMM work did not provide estimates of copper loading from pervious surfaces, and use of the buildup/washoff coefficients provided for zinc on pervious surfaces yielded instream concentrations that were more than an order-of-magnitude greater than observed concentrations. Therefore, the starting point for the copper and zinc buildup and washoff coefficients on pervious lands were adopted from a similar model application conducted for Gwinnett County, GA (Tetra Tech and CH2M HILL, 1999).

Use of the Gwinnett County buildup rates for pervious lands and the SLAMM estimates for impervious surfaces directly yielded copper concentrations that are consistent with observations in the Root River. Zinc predictions were high so a trapping factor of 40 percent (pass-through of 60 percent) was added for pervious lands. Because zinc is particle reactive, trapping losses in small streams and wetlands is expected, and the factor is consistent with the trapping rate applied to phosphorus. No trapping was applied to copper. As noted above, copper and zinc are simulated as conservative substances in the water column and not rigorously calibrated. The validation plots for copper and zinc are provided in Attachment H.

5.6 Statistical Assessment of Concentrations

An ideal simulation model would conclusively prove its credibility by matching exactly every observed data point. Unfortunately, this ideal cannot be achieved, for a variety of reasons. In the first place, any watershed model is a simplification of complex natural processes. Secondly, the model is capable of representing only those events that are specified to it in the forcing functions, which generally represent the response from the land surface of hydrologic events. Events that are unknown to the model, such as illicit discharges, cannot be replicated by the model. Water quality simulation in particular is constrained to be no better than the quality of the simulation of hydrology, which in turn is limited by the availability of representative meteorological data. For instance, a small error in the representation of the timing or magnitude of a surface washoff event can result in apparently large discrepancies between simulated and observed actual concentrations at a given location and point in time. Finally, the observed values also cannot be considered as fixed and certain.

First, there is the possibility of analytical uncertainty in any reported observation that derives from the inherent imprecision of analytical techniques, and, occasionally, from laboratory analysis and reporting errors. Perhaps more importantly, grab samples submitted for chemical analysis represent a specific location and point in time that is not entirely consistent with the spatial and temporal support of the model. LSPC represents waterbodies as discrete reaches, which are assumed to be fully mixed. Real waterbodies vary continuously in both longitudinal and lateral dimensions, as well as in time. A sample taken from a specific location may not be representative of the average concentration across the stream cross section, and even less representative of the average across an entire model reach. Further, a sample taken at a discrete point in time may not be representative of the average concentration that would be observed across a modeling time step – particularly when the sample is taken near a source of discharge or during the course of a runoff event.

Several additional explanations as to why the quality of model fit may differ between simulated and observed data include the following:

- Point sources included in the model generally do not account for temporal changes.
- As pointed out previously, poor resolution of stream geometry under low to moderate flows may cause a discrepancy between actual versus calibrated comparisons. The model currently represents these flows as being spread across a very wide channel bed, likely causing an excess of temperature and light penetration. This will, in turn, enhance algal growth, nutrient uptake, and DO fluctuations.

For these reasons, it is important to evaluate model performance based on statistical criteria. In essence, the model and observations may differ on individual points, but should be in general agreement over larger spans of time and space. This testing is accomplished using a weight of evidence approach. It is first important to realize that the model uses a single set of parameters, by land use, across the entire watershed, with minimal local adjustments. Thus, achieving an acceptable fit across multiple stations (with one set of parameters) is a better indication of the validity of the model than any discrepancies at individual stations.

Statistical tests are applied to both concentrations and estimated loads. Both comparisons are important, and reveal different features of the model. For instance, a simulation that is problematic with regard to concentrations but provides a good estimate of loads can be judged as providing a good representation of pollutant source loading that is corrupted by a sub-optimal representation of the timing of their delivery. This is generally the case for the Root River simulations.

The primary test for model performance on concentrations is a Student's *t*-test of equality of means over the entire calibration period. (There are not sufficient data to adequately evaluate performance on individual seasons or years, particularly given the presence of analytical and sampling uncertainty.) In these tests, the equality of observed and sample means on paired daily average data is taken as the null hypothesis or a rebuttable proposition. That is, model performance is judged acceptable unless the statistical analysis proves otherwise.

The *t*-test is developed on assumptions that samples are drawn from a normal distribution and the variances are equal across distributions. Both of these assumptions are not met for various observed and simulated parameters in the Root River. However, the tests presented here are on means, not individual observations, and the distribution of means converges to a normal distribution under the Central Limit Theorem. Further, Box et al. (1978) have shown that the *t*-test is somewhat robust against violations of the assumptions of normality and equality of variances.

Tests for equality of means, at each station, for the calibration period are presented in Table 1 through Table 6. A probability value ("pval") for each contrast is presented, with higher probability values indicating a better quality of fit. A probability value less than 5 percent is judged to represent proof of a discrepancy between the model and data – although it does not reveal to what extent the discrepancy is the result of the model and to what extent it is a result of the data. Also note that this test does not address whether the difference, even if statistically significant, is meaningful in terms of environmental impact.

Across multiple parameters and stations, the model meets the *t*-test criteria in a majority of cases for the validation period. The quality of model fit is further buttressed by a good agreement between simulated and estimated loads. An additional evaluation of the model quality of fit for individual observations was conducted by plotting observations against simulated results with confidence bounds that represent one and two standard deviations for the day. The standard deviations are calculated on a daily basis from the sub-daily model output. The confidence limits are assumed to be either normally or lognormally distributed based on the distribution which most reduces skew (in most cases, log transformation reduces skew as is common for environmental data that are constrained to be greater than or equal to zero and contain sporadic high values associated with washoff events). Comparison can be made both visually and by tabulating the number of observations that fall within one and two-standard deviation confidence limits. These results are provided in Attachment K and summarized in Table 7.

There are parameter-location contrasts for which the model-data comparison does not pass the statistical criterion. Where both the inequality and the direction of deviation is consistently shown in the validation tests, there may be a need for additional investigation and potential model improvement (unless the unrepresentativeness is due to the sampling location not being a good indicator of conditions in the model reach as a whole). On sum, however, the model is believed to provide a reasonable representation of water quality processes in the Root River that is suitable for the evaluation and comparison of management scenarios.

Table 1. Root River Station RR-01 Concentration Calibration Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	14.3000	0.3991	0.2263	1.2657	0.0392	0.0972	5.0550	1.9143	4.1107	12841.0
	Paired Simulated	5.2970	0.3647	0.1229	1.1519	0.0250	0.0722	9.7434	2.3001	3.8653	4848.5
	Full Simulated	4.9507	0.3271	0.1131	0.9982	0.0221	0.0616	10.8649	2.1023	3.0451	4768.1
Median	Observed	7.4000	0.2845	0.1000	1.1450	0.0300	0.0785	4.7650	0.0000	0.9850	840.0
	Paired Simulated	4.9152	0.3112	0.0777	1.1013	0.0053	0.0241	9.3543	1.4986	3.5598	191.2
	Full Simulated	4.5853	0.2963	0.0778	1.0347	0.0057	0.0238	10.8054	1.6058	2.6148	191.1
Standard Deviation	Observed	27.5405	0.4145	0.2996	0.6493	0.0354	0.0761	2.6569	2.5543	10.9522	45673.1985
	Paired Simulated	3.8388	0.2582	0.1433	0.5704	0.0438	0.1122	1.5375	2.6986	2.1162	14518.4455
Count		28	26	28	24	28	28	28	28	28	28
Mean Error		-9.0030	-0.0344	-0.1034	-0.1138	-0.0141	-0.0250	4.6884	0.3858	-0.2454	-7992.5
Mean Absolute Error		10.5005	0.3215	0.2231	0.5173	0.0327	0.0812	4.8085	2.0056	4.6909	14764.7
Mean Squared Error		682.8426	0.2165	0.1223	0.5439	0.0021	0.0132	27.5400	6.3440	99.6287	2.1E+09
RMSE		26.1313	0.4653	0.3497	0.7375	0.0454	0.1151	5.2479	2.5187	9.9814	45325.3
pval, paired t-test		0.0672	0.7137	0.1193	0.4614	0.1000	0.2577	0.0000	0.4276	0.8992	0.3602
Alpha		0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Fail t-test?		FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Pass t-test?		yes	yes	yes	yes	yes	yes	no	yes	yes	yes

Table 2. Root River Station RR-02 Concentration Calibration Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	15.6074	0.6275	0.2959	1.7782	0.0728	0.1682	4.4785	3.0074	2.6326	19423.9
	Paired Simulated	5.5252	0.4471	0.1698	1.3398	0.0424	0.1033	7.3618	3.1068	2.2558	9436.7
	Full Simulated	5.3412	0.3829	0.1565	1.1536	0.0381	0.0921	7.8947	2.9661	1.9722	9812.8
Median	Observed	8.8000	0.5835	0.1600	1.6960	0.0400	0.1200	4.2000	2.7000	1.3300	1500.0
	Paired Simulated	4.9993	0.3333	0.0890	1.1875	0.0100	0.0283	7.4906	1.9212	1.8386	1872.1
	Full Simulated	4.9445	0.3080	0.0850	1.0875	0.0117	0.0295	7.9282	1.9315	1.5854	2136.0
Standard Deviation	Observed	25.9727	0.3601	0.3653	0.6263	0.0849	0.1512	2.9310	2.6427	3.6295	50014.2833
	Paired Simulated	3.3970	0.3856	0.2176	0.8122	0.0636	0.1495	1.2521	3.9501	1.2485	19898.2706
Count		27	24	27	22	27	27	27	27	27	27
Mean Error		-10.0822	-0.1804	-0.1261	-0.4384	-0.0304	-0.0649	2.8833	0.0994	-0.3768	-9987.3
Mean Absolute Error		11.9594	0.3932	0.2719	0.6664	0.0576	0.1019	3.4618	2.0682	2.5255	16762.4
Mean Squared Error		729.4125	0.2697	0.1648	0.5940	0.0077	0.0188	18.1187	10.9243	14.5102	2.1E+09
RMSE		27.0076	0.5193	0.4060	0.7707	0.0878	0.1372	4.2566	3.3052	3.8092	45934.2
pval, paired t-test		0.0504	0.0889	0.1076	0.0046	0.0714	0.0110	0.0001	0.8793	0.6166	0.2664
Alpha		0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Fail t-test?		FALSE	FALSE	FALSE	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
Pass t-test?		yes	yes	yes	no	yes	no	no	yes	yes	yes

Table 3. Root River Station RR-03 Concentration Calibration Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	14.1571	0.4548	0.1588	1.3012	0.0381	0.0974	5.2614	1.8500	1.8554	15263.1
	Paired Simulated	6.1684	0.4832	0.1855	1.3262	0.0448	0.1060	8.1895	3.0172	1.4050	7431.7
	Full Simulated	5.3412	0.3829	0.1565	1.1536	0.0381	0.0921	7.8947	2.9661	1.9722	9812.8
Median	Observed	8.0000	0.4200	0.0900	1.2400	0.0300	0.0820	5.1000	0.0000	0.9950	430.0
	Paired Simulated	4.8840	0.3319	0.0921	1.1038	0.0088	0.0341	7.7913	1.8438	1.2730	1145.7
	Full Simulated	4.9445	0.3080	0.0850	1.0875	0.0117	0.0295	7.9282	1.9315	1.5854	2136.0
Standard Deviation	Observed	34.5816	0.3002	0.2513	0.4390	0.0384	0.0562	3.2973	2.5762	1.9861	49273.5774
	Paired Simulated	6.8953	0.4187	0.2390	0.8019	0.0721	0.1626	2.4286	3.1371	0.7133	17936.1416
Count		28	25	28	24	28	28	28	28	28	28
Mean Error		-7.9887	0.0284	0.0268	0.0250	0.0068	0.0086	2.9281	1.1672	-0.4504	-7831.4
Mean Absolute Error		10.0485	0.3633	0.1746	0.4894	0.0485	0.0876	3.3771	2.2012	1.6102	17766.8
Mean Squared Error		944.2278	0.2921	0.0979	0.5927	0.0048	0.0170	19.9676	10.5846	5.4153	2.3E+09
RMSE		30.7283	0.5405	0.3129	0.7699	0.0694	0.1304	4.4685	3.2534	2.3271	47632.4
pval, paired t-test		0.1732	0.7987	0.6593	0.8776	0.6155	0.7345	0.0001	0.0560	0.3145	0.3941
Alpha		0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Fail t-test?		FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Pass t-test?		yes	yes	yes	yes	yes	yes	no	yes	yes	yes

Table 4. Root River Station RR-04 Concentration Calibration Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	15.7929	0.4859	0.1307	1.2584	0.0343	0.0802	6.3096	1.7393	2.7843	12735.6
	Paired Simulated	11.1361	0.5235	0.2270	1.3107	0.0633	0.1356	8.9287	3.2922	2.7739	10868.3
	Full Simulated	5.3412	0.3829	0.1565	1.1536	0.0381	0.0921	7.8947	2.9661	1.9722	9812.8
Median	Observed	9.2000	0.5000	0.0715	1.2160	0.0300	0.0700	6.0950	0.5000	2.1200	590.0
	Paired Simulated	4.2393	0.3462	0.1269	1.1651	0.0219	0.0554	8.8442	3.1497	1.9781	3459.9
	Full Simulated	4.9445	0.3080	0.0850	1.0875	0.0117	0.0295	7.9282	1.9315	1.5854	2136.0
Standard Deviation	Observed	26.9569	0.3310	0.2048	0.5117	0.0419	0.0411	3.0827	2.4272	2.4452	45610.7374
	Paired Simulated	23.9284	0.4441	0.2466	0.8147	0.0774	0.1668	2.1560	2.7156	2.3920	18362.1698
Count		0	28	28	28	28	28	28	28	28	28
Mean Error		-4.6568	0.0376	0.0963	0.0523	0.0290	0.0554	2.6191	1.5529	-0.0104	-1867.3
Mean Absolute Error		10.7735	0.3690	0.1896	0.5532	0.0645	0.0947	3.1416	2.3280	2.7642	18328.7
Mean Squared Error		346.4334	0.2543	0.0809	0.6192	0.0088	0.0249	14.1642	10.0219	13.8000	2.0E+09
RMSE		18.6127	0.5043	0.2843	0.7869	0.0936	0.1577	3.7635	3.1657	3.7148	44514.9
pval, paired t-test		0.1905	0.7006	0.0722	0.7320	0.1020	0.0615	0.0000	0.0069	0.9885	0.8289
Alpha		0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Fail t-test?		FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE
Pass t-test?		yes	yes	yes	yes	yes	yes	no	no	yes	Yes

Table 5. Root River Station RR-05 Concentration Calibration Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100mL)
Mean	Observed	32.4714	0.5642	0.0731	1.2760	0.0315	0.0731	7.9496	1.0750	7.0696	2164.0
	Paired Simulated	15.7471	0.3141	0.2456	1.1497	0.0324	0.1139	10.3802	2.7147	2.5109	8844.0
	Full Simulated	5.3412	0.3829	0.1565	1.1536	0.0381	0.0921	7.8947	2.9661	1.9722	9812.8
Median	Observed	15.8000	0.5450	0.0000	1.1950	0.0160	0.0630	7.4850	0.0000	7.1500	230.0
	Paired Simulated	4.5387	0.2833	0.2163	0.9888	0.0219	0.0630	10.1305	1.8125	1.5748	3474.3
	Full Simulated	4.9445	0.3080	0.0850	1.0875	0.0117	0.0295	7.9282	1.9315	1.5854	2136.0
Standard Deviation	Observed	53.3278	0.4091	0.2075	0.6218	0.0391	0.0428	2.6139	1.6646	3.9073	5350.1520
	Paired Simulated	31.5025	0.2397	0.1343	0.5456	0.0290	0.1196	1.7932	2.4026	1.9516	15904.9472
Count		0	28	28	28	28	28	28	28	28	28
Mean Error		-16.7243	-0.2501	0.1725	-0.1263	0.0009	0.0408	2.4305	1.6397	-4.5587	6680.0
Mean Absolute Error		24.2230	0.3738	0.2329	0.5059	0.0310	0.0619	2.6405	1.9778	5.2782	9214.5
Mean Squared Error		1844.9148	0.2579	0.0777	0.4443	0.0017	0.0118	12.6113	8.6889	41.7103	3.3E+08
RMSE		42.9525	0.5078	0.2787	0.6665	0.0418	0.1084	3.5512	2.9477	6.4583	18055.3
pval, paired t-test		0.0368	0.0067	0.0003	0.3248	0.9124	0.0444	0.0000	0.0017	0.0000	0.0482
Alpha		0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Fail t-test?		TRUE	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
Pass t-test?		no	no	no	yes	yes	no	no	no	no	No

Table 6. Root River Station RR-06 Concentration Calibration Statistics (1999-2001).

		TSS	NO2+NO3	NH3	TN	PO4	TP	DO	BOD	Chlor a	FC
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(#/100Ml)
Mean	Observed	45.4000	1.9862	0.0792	3.2217	0.0734	0.1481	7.6508	1.3000	8.3542	2077.8
	Paired Simulated	61.8040	0.8103	0.5811	2.6108	0.0520	0.1912	9.5704	4.2876	6.3093	5489.8
	Full Simulated	5.3412	0.3829	0.1565	1.1536	0.0381	0.0921	7.8947	2.9661	1.9722	9812.8
Median	Observed	24.6000	2.0350	0.0400	3.3200	0.0550	0.1400	7.1100	1.1000	5.0250	430.0
	Paired Simulated	3.7716	0.2541	0.2418	1.1022	0.0184	0.0673	9.6544	1.6972	4.6733	1138.7
	Full Simulated	4.9445	0.3080	0.0850	1.0875	0.0117	0.0295	7.9282	1.9315	1.5854	2136.0
Standard Deviation	Observed	75.6462	1.0303	0.1495	1.3577	0.0554	0.0628	2.7516	1.5618	10.8920	5371.1190
	Paired Simulated	165.2273	1.5230	1.0510	4.3628	0.0779	0.3193	2.7895	7.9729	4.6099	9832.4364
Count		26	26	26	25	26	26	26	26	26	26
Mean Error		16.4040	-1.1759	0.5018	-0.6109	-0.0214	0.0432	1.9197	2.9876	-2.0449	3412.0
Mean Absolute Error		65.9500	1.6037	0.5018	2.5909	0.0582	0.1437	2.9410	3.2469	7.0911	6588.3
Mean Squared Error		24001.08	3.5304	1.1247	15.8778	0.0074	0.0847	13.3761	68.1424	130.5952	1.5E+08
RMSE		154.9228	1.8789	1.0605	3.9847	0.0859	0.2911	3.6573	8.2548	11.4278	12161.8
pval, paired t-test		0.5991	0.0005	0.0127	0.4547	0.2104	0.4604	0.0049	0.0636	0.3718	0.1563
Alpha		0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Fail t-test?		FALSE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Pass t-test?		yes	no	no	yes	yes	yes	no	yes	yes	yes

Table 7. Confidence limit results for Root River water quality calibration and validation.

Station	Parameter	Within 1 Standard Deviation	Within 2 Standard Deviations
RR-01	Total Phosphorus	14%	39%
	Total Nitrogen	17%	42%
	Total Suspended Solids	18%	46%
	Fecal Coliform	21%	54%
RR-02	Total Phosphorus	30%	44%
	Total Nitrogen	36%	41%
	Total Suspended Solids	18%	37%
	Fecal Coliform	41%	52%
RR-03	Total Phosphorus	39%	50%
	Total Nitrogen	38%	54%
	Total Suspended Solids	14%	29%
	Fecal Coliform	21%	50%
RR-04	Total Phosphorus	39%	54%
	Total Nitrogen	25%	54%
	Total Suspended Solids	14%	29%
	Fecal Coliform	25%	39%
RR-05	Total Phosphorus	61%	93%
	Total Nitrogen	32%	64%
	Total Suspended Solids	32%	39%
	Fecal Coliform	32%	61%
RR-06	Total Phosphorus	31%	69%
	Total Nitrogen	12%	24%
	Total Suspended Solids	15%	35%
	Fecal Coliform	23%	35%

5.7 Statistical Assessment of Loads

For the evaluation of impacts on downstream receiving waters, correct model representation of total loads is as important as the representation of concentration. Unfortunately, load is not observed directly. Estimates of observed load on those days with observations can be formed by multiplying concentration by daily average flow. However, because the concentrations represent point-in-time grab samples, these represent highly uncertain estimates of daily load.

Load estimates require both concentration and flow. For the Root River watershed, flow and water quality are both monitored at USGS 04087220 (RR-05) and only for the period from 1999 to 2001. Because loads depend on both flow and concentration, it is unreasonable to expect that all observed and simulated data points will match closely. That is, apparent discrepancies will arise due to any errors in the timing or magnitude of flows, in addition to the uncertainty introduced by point-in-time concentration observations. However, the mean loads on paired observations should be in general agreement between the model and predictions. In addition, the relationship between load and flow should be similar.

Equality of observed and simulated mean loads is evaluated using a paired *t*-test. Results, with probability values (pvals) are shown in Table 8. As shown in the table, the agreement between the model and estimated observed loads is good, with no contrasts failing the *t*-test – and this agreement is achieved while also preserving the relationship to SWAT and SLAMM loading rates from the uplands. Log-log transport plots for sediment, total nitrogen, nitrite+nitrate, and total phosphorus are shown in Figure 4.

Table 8. Root River Station RR-05 Load Calibration Statistics (1999-2001).

		TSS	NO2+NO3	TN	TP
		(mg/L)	(mg/L)	(mg/L)	(mg/L)
Mean	Observed	31327.05	199.52	502.02	30.57
	Paired Simulated	32241.88	178.25	741.85	133.08
	Full Simulated	17104.8551	158.8553	525.2150	75.7235
Median	Observed	938.0760	47.8315	71.5100	3.5032
	Paired Simulated	706.1870	40.5534	141.0474	8.5187
	Full Simulated	734.9220	48.3489	169.1345	10.9069
Count		28	28	28	28
Mean Error		914.8270	-21.2757	239.8348	102.5174
Mean Absolute Error		1.19E+04	1.20E+02	2.84E+02	1.05E+02
Mean Squared Error		1.58E+09	6.99E+04	5.26E+05	1.45E+05
RMSE		3.97E+04	2.64E+02	7.26E+02	3.81E+02
pval, paired t-test		0.9056	0.6782	0.0799	0.1578
Alpha		0.050	0.050	0.050	0.050
Fail t-test?		FALSE	FALSE	FALSE	FALSE
Pass t-test?		yes	yes	yes	yes

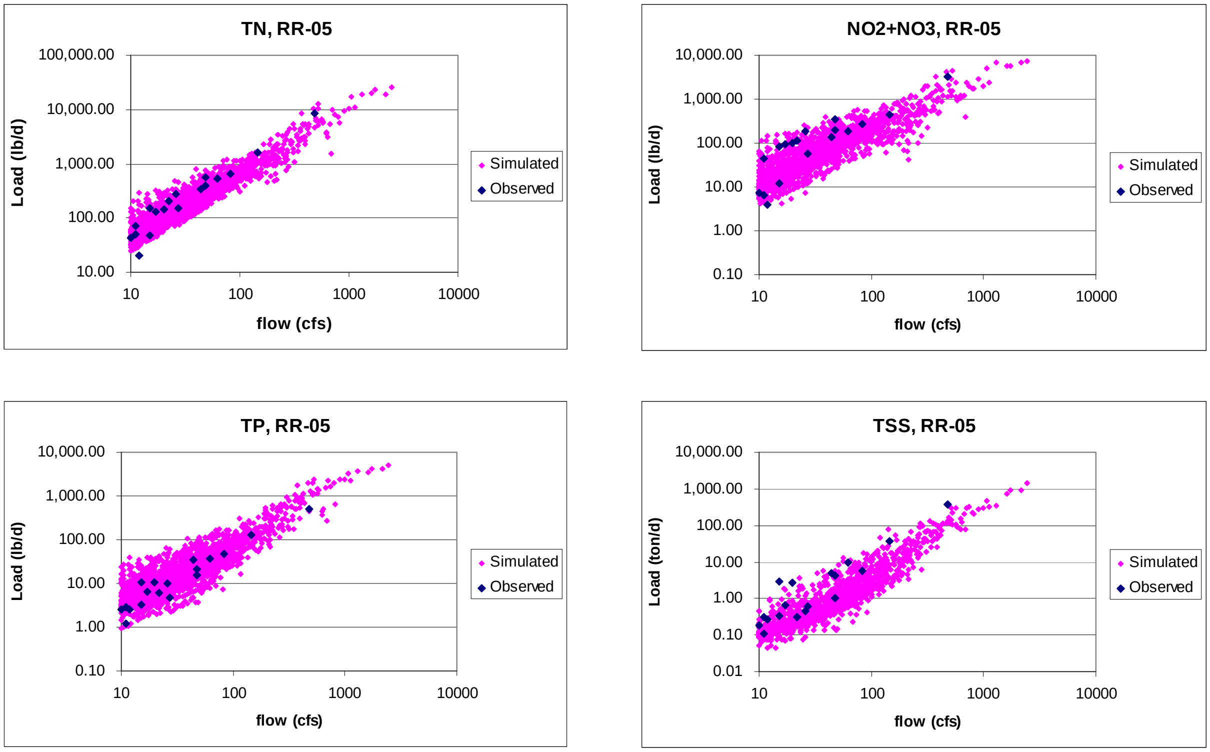


Figure 4. Log-log transport plot for nutrient and sediment loads at RR-05, 1999-2001.

Another useful test of representation of the load-flow relationships is obtained by plotting simulated and observed loads against the probability of exceedance of a given flow value, based on the period of record at the gage. These are known as load-duration curves. As a general rule, the portion of this relationship corresponding to flows that are exceeded less than 20 percent of the time can be assumed to represent high-flow, washoff events, while the remainder of the relationship corresponds to moderate and low flows.

The untransformed load-duration curve relationship is highly nonlinear. These plots can be linearized by plotting the natural logarithm of load versus the logit of flow, where the logit is defined as the natural log of (P/(1-P)), given P is the flow exceedance probability (Pindyck and Rubinfeld, 1981). After the log-logit transformation, separate linear regressions can be performed on the natural logarithms of observed and simulated loads versus logit of flow for the 0-20 percent and 20-100 percent flow ranges. (The breakpoint between these ranges corresponds to a logit of –1.386.) When the model is simulating accurately, the slope coefficients of the observed and simulated regressions should be in agreement within each of the two flow ranges. The analysis shows that this test is generally met in the Root River model. Full results are provided in Attachment I.

6 REFERENCES

APHA. 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed. American Public Health Association (APHA), 1015 15th Street, NW, Washington, DC.

Bicknell, B.R., J.C. Imhoff, J. Kittle, A.S. Donigian, and R.C. Johansen. 1996. *Hydrological Simulation Program –FORTRAN, User's Manual for Release H*. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Bowie, G.L., et al. 1985. Rates, Constants, and Kinetic Formulations in Surface Water Quality Modeling, 2d. ed. EPA/600/3-85/040. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Box, G.E.P., J.S. Hunter and W.G. Hunter. 1978. *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building.* John Wiley and Sons, New York.

Chapra, S. and G. Pelletier. 2003. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

Donigian, A.S., Jr., and J.T. Love. 2002. Sediment Calibration Procedures and Guidelines for Watershed Modeling. Aqua Terra Consultants, Mountain View, CA.

Donigian, A.S., Jr., J.C. Imhoff, B.R. Bicknell, and J.L. Kittle, Jr. 1984. Application Guide for Hydrological Simulation Program – FORTRAN (HSPF). EPA-600/3-84-065. Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Haith, D.A. and D.E. Merrill. 1987. Evaluation of a daily rainfall erosivity model. *Trans. Amer. Soc. Agric. Eng.*, 28(6): 1916-1920.

Haith, D.A., R. Mandel, and R.S. Wu. 1992. *GWLF - Generalized watershed loading functions, Version 2.0 - User's manual*. Department of Agricultural Engineering, Cornell University, Ithaca, NY.

Hartigan, J.P., T.F. Quasebarth, and E. Southerland. 1983. Calibration of NPS model loading factors. *Journal of Environmental Engineering*, 109(6): 1259-1272.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. *Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage*, 89(IR4): 15-41.

Jensen, M.E., D.C.N. Rob, and C.E. Franzoy. 1969. Scheduling irrigations using climate-crop-soil data. Proceedings, National Conference on Water Resources Engineering of the American Society of Civil Engineers, New Orleans, LA.

Mancini, J.L. 1978. Numerical estimates of coliform mortality rates under various conditions. *J. Water Poll. Contr. Fed.*, 50(11): 2477-2484.

MPCA. 2001. Status of a Model Simulation of Nonpoint-Source Contamination in the Minnesota River Basin, April 1999. Final report submitted by the USGS to Minnesota Pollution Control Agency.

Pindyck, R.S. and D.L. Rubinfeld. 1981. *Econometric Models and Economic Forecasts, Second Edition.* McGraw-Hill, New York.

Richardson, C.W., G.R. Foster, and D.A. Wright. 1983. Estimation of erosion index from daily rainfall amount. *Trans. Am. Soc. Agric. Eng*., 26(1): 153-157, 160.

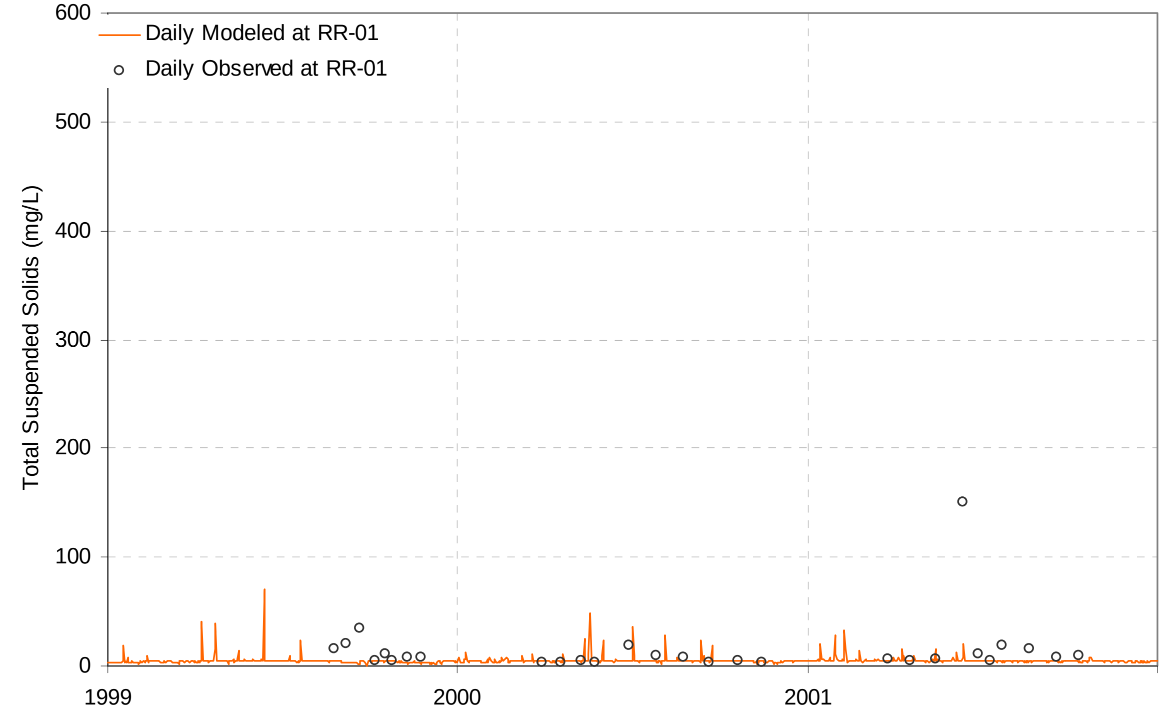
Tetra Tech, Inc. and CH2M HILL. 1999. Gwinnett County Watershed Assessment and Modeling Study, Watershed Model Calibration Technical Memorandum. Prepared for Gwinnett County, GA by Tetra Tech, Inc., Research Triangle Park, NC.

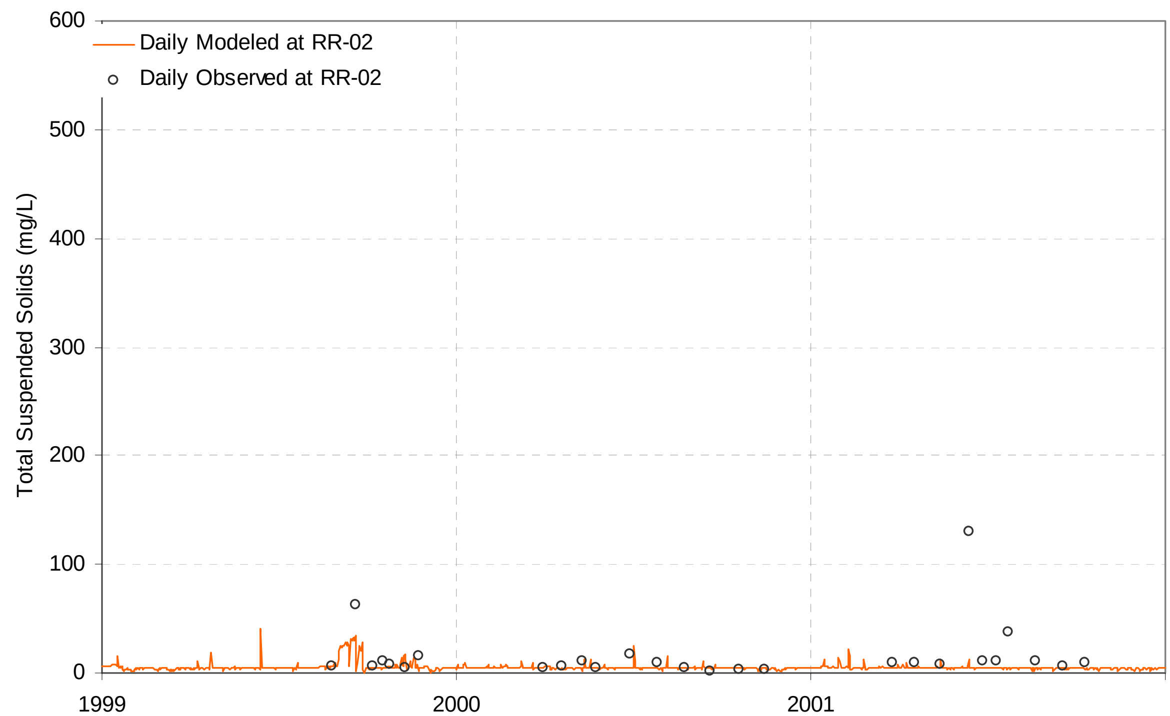
Tetra Tech. 2002. Minnesota River Basin Model, Model Calibration and Validation Report. Prepared for Minnesota Pollution Control Agency, St. Paul, MN by Tetra Tech, Inc., Research Triangle Park, NC.

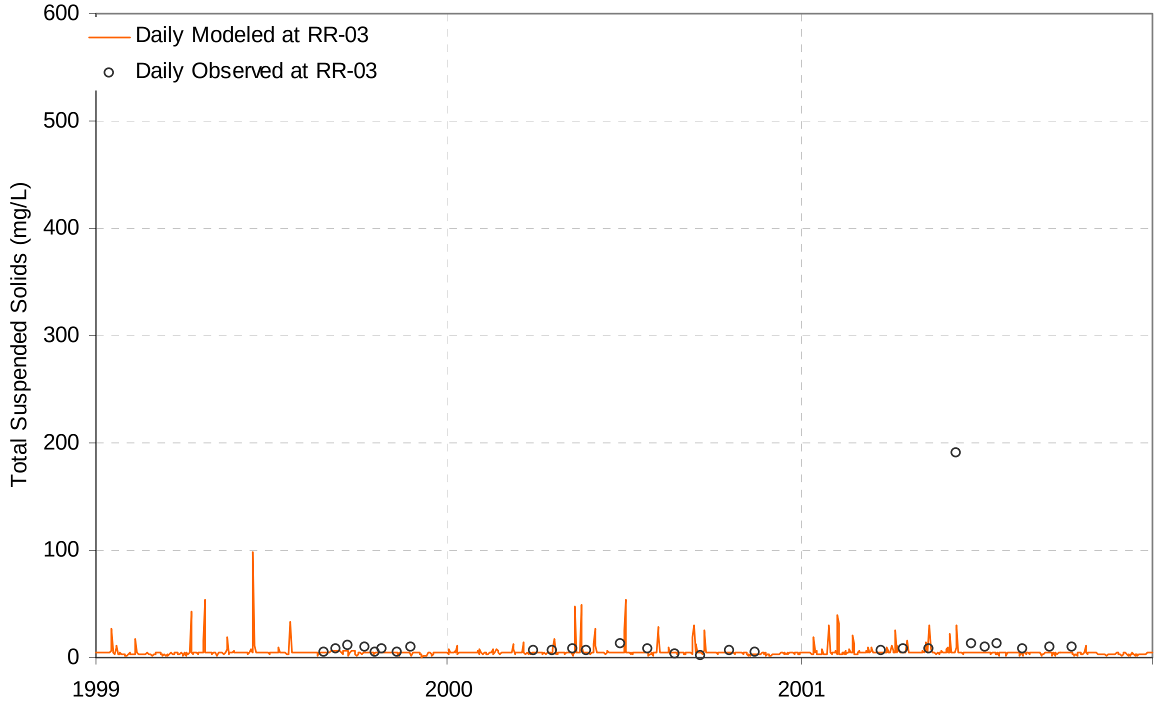
Thomann, R.V. and J.A. Mueller. 1987. Principles of Surface Water Quality Modeling and Control. Harper & Row, New York.

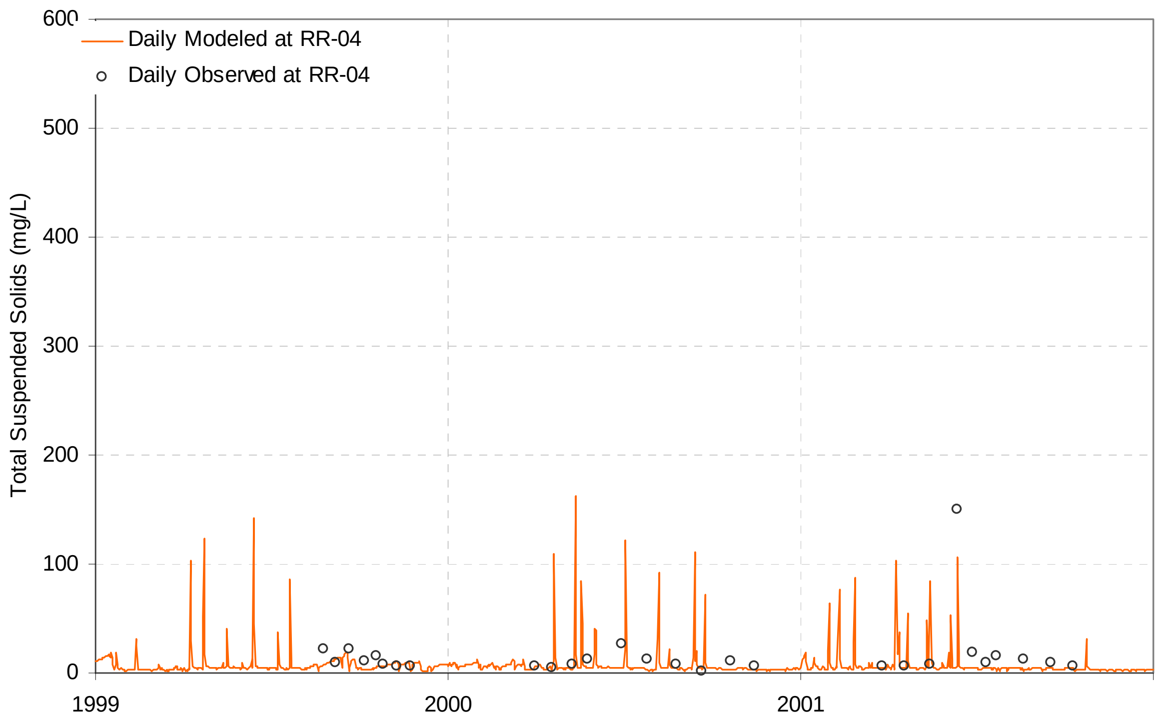
U.S. Environmental Protection Agency (USEPA). 2000. *BASINS Technical Note 6. Estimating Hydrology and Hydraulic Parameters for HSPF*. EPA-823-R00-012. U.S. Environmental Protection Agency. Office of Water. July 2000.

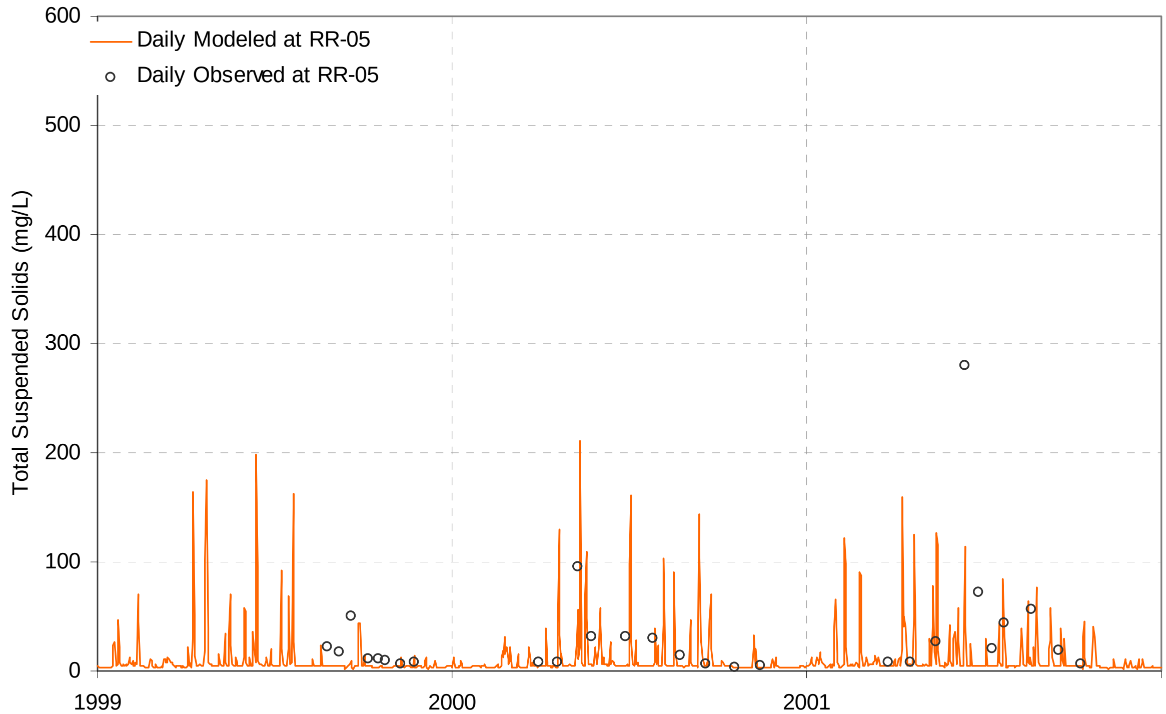
ATTACHMENT A – CALIBRATION PLOTS FOR TOTAL SUSPENDED SOLIDS

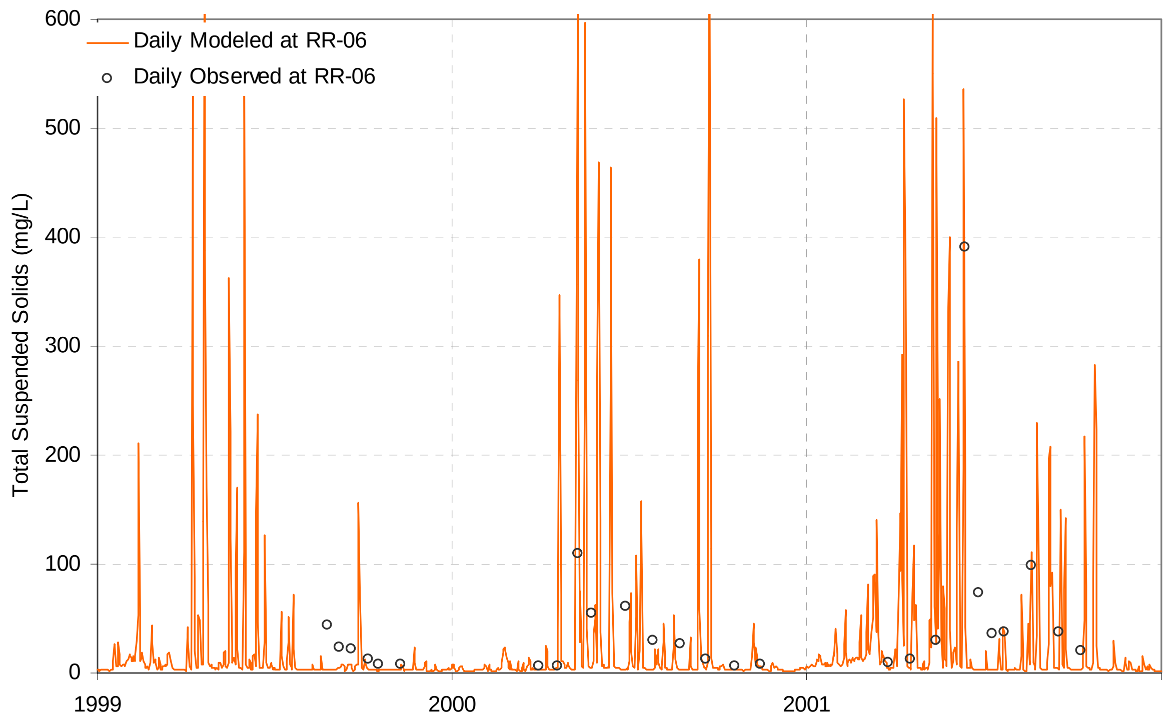

Daily Modeled at RR-01
Daily Observed at RR-01
Total Suspended Solids (mg/L)
0
100
200
300
400
500
600
1999
2000
2001

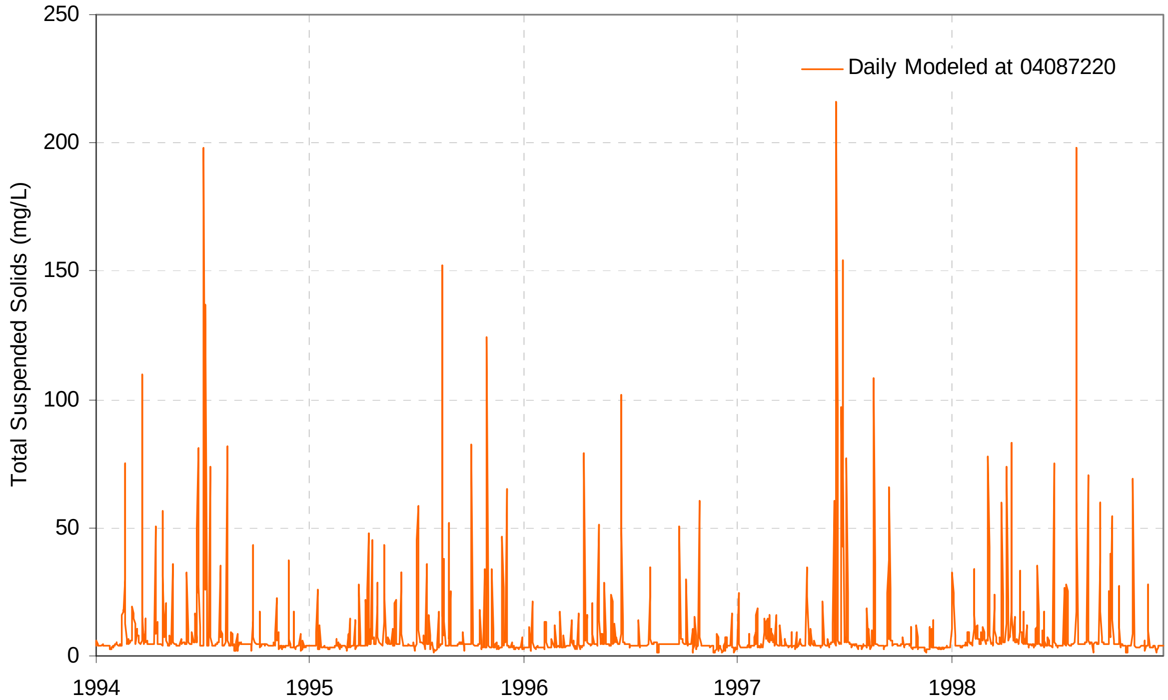

Daily Modeled at RR-02
Daily Observed at RR-02
Total Suspended Solids (mg/L)
0
100
200
300
400
500
600
1999
2000
2001


Daily Modeled at RR-03
Daily Observed at RR-03
Total Suspended Solids (mg/L)
600
500
400
300
200
100
0
1999
2000
2001

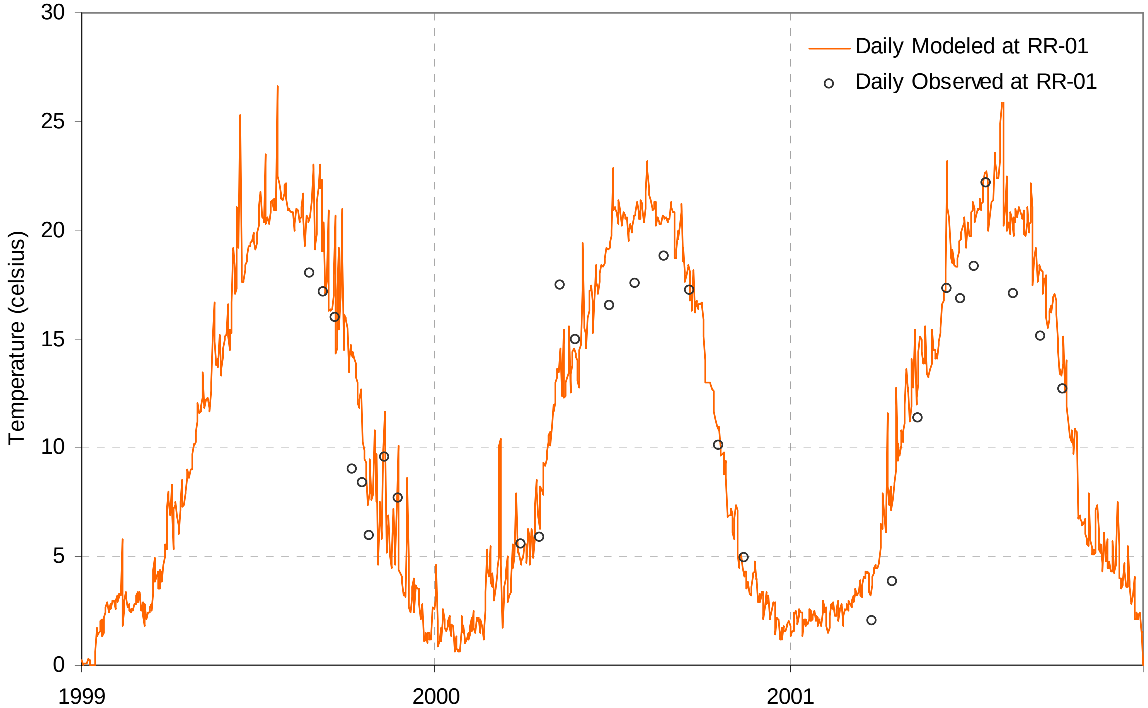

Daily Modeled at RR-04
Daily Observed at RR-04
Total Suspended Solids (mg/L)
600
500
400
300
200
100
0
1999
2000
2001

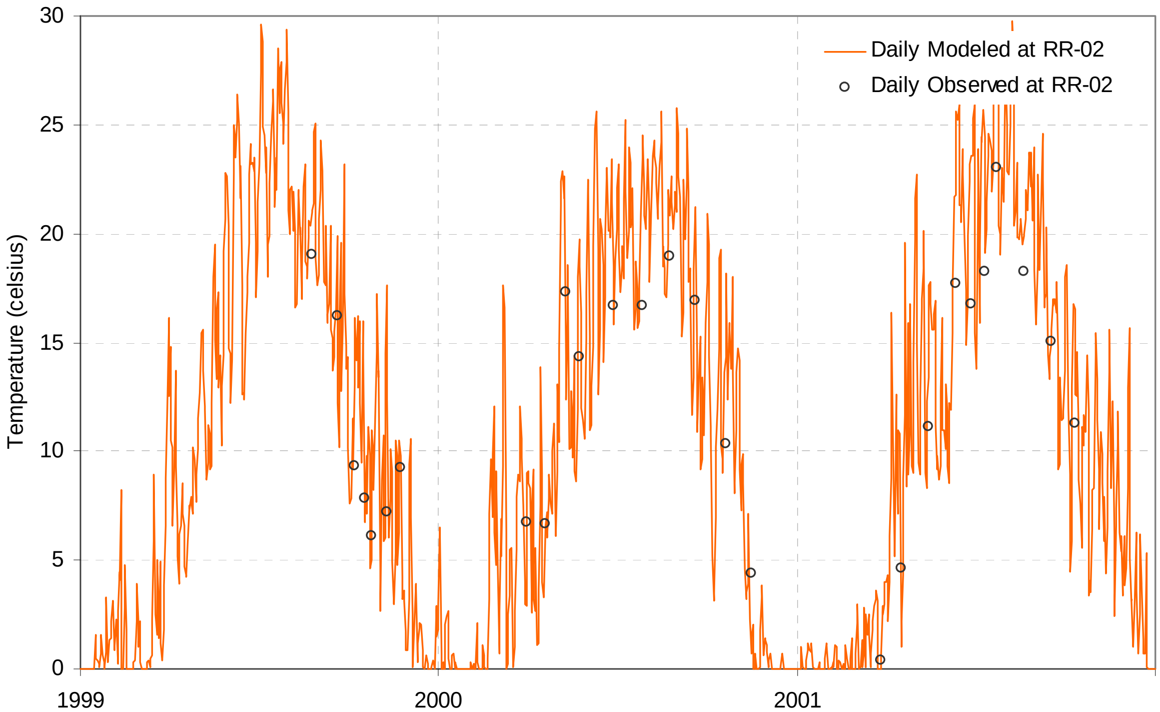

Daily Modeled at RR-05
Daily Observed at RR-05
Total Suspended Solids (mg/L)
0
100
200
300
400
500
600
1999
2000
2001

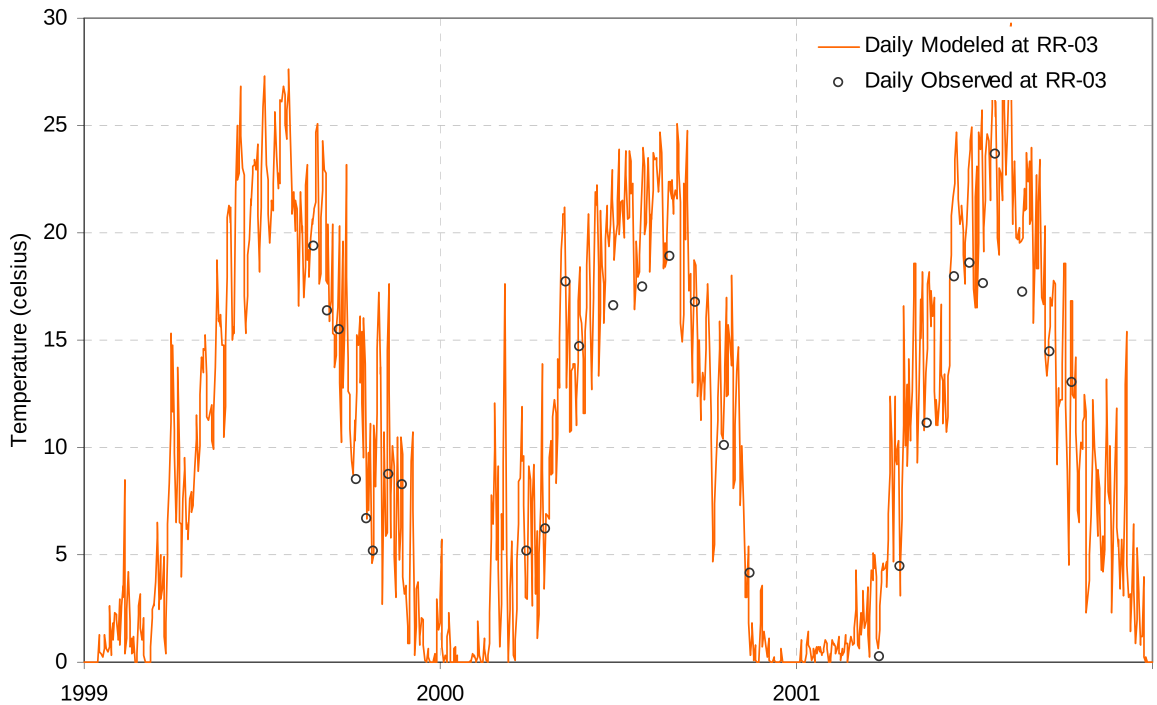

Daily Modeled at RR-06
Daily Observed at RR-06
Total Suspended Solids (mg/L)
0
100
200
300
400
500
600
1999
2000
2001

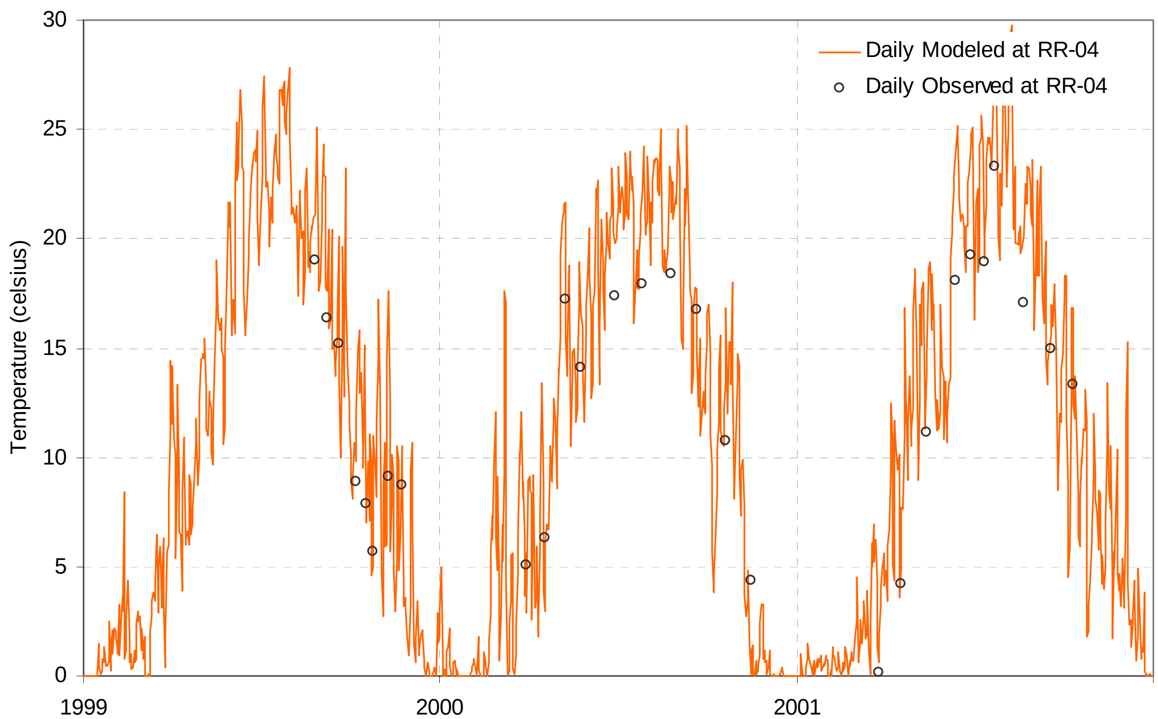

Daily Modeled at 04087220
Total Suspended Solids (mg/L)
250
200
150
100
50
0
1994
1995
1996
1997
1998

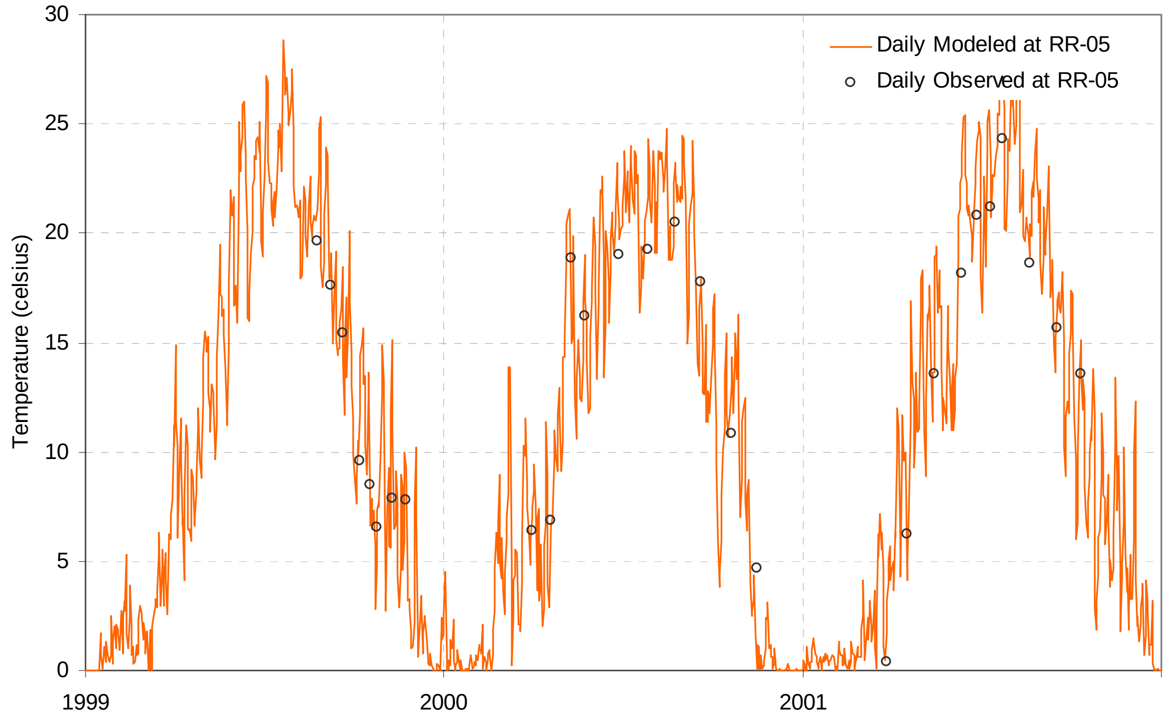
ATTACHMENT B – CALIBRATION PLOTS FOR TEMPERATURE

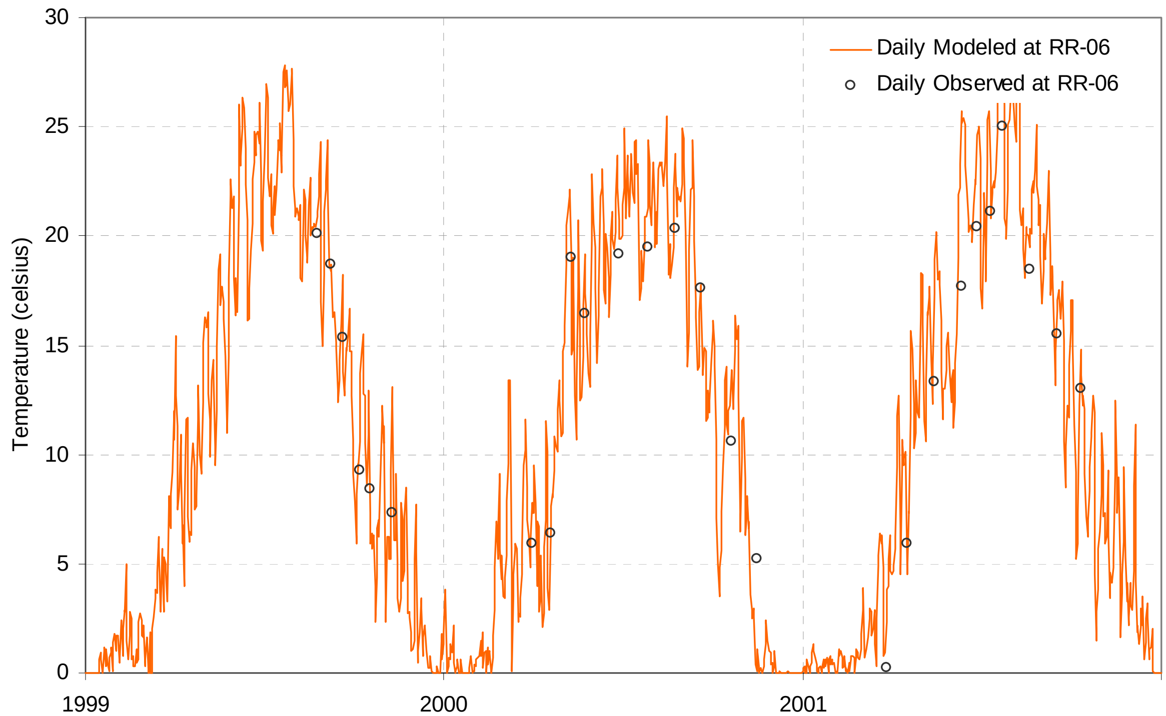

Daily Modeled at RR-01
Daily Observed at RR-01
Temperature (celsius)
30
25
20
15
10
5
0
1999
2000
2001


Daily Modeled at RR-02
Daily Observed at RR-02
Temperature (celsius)
30
25
20
15
10
5
0
1999
2000
2001

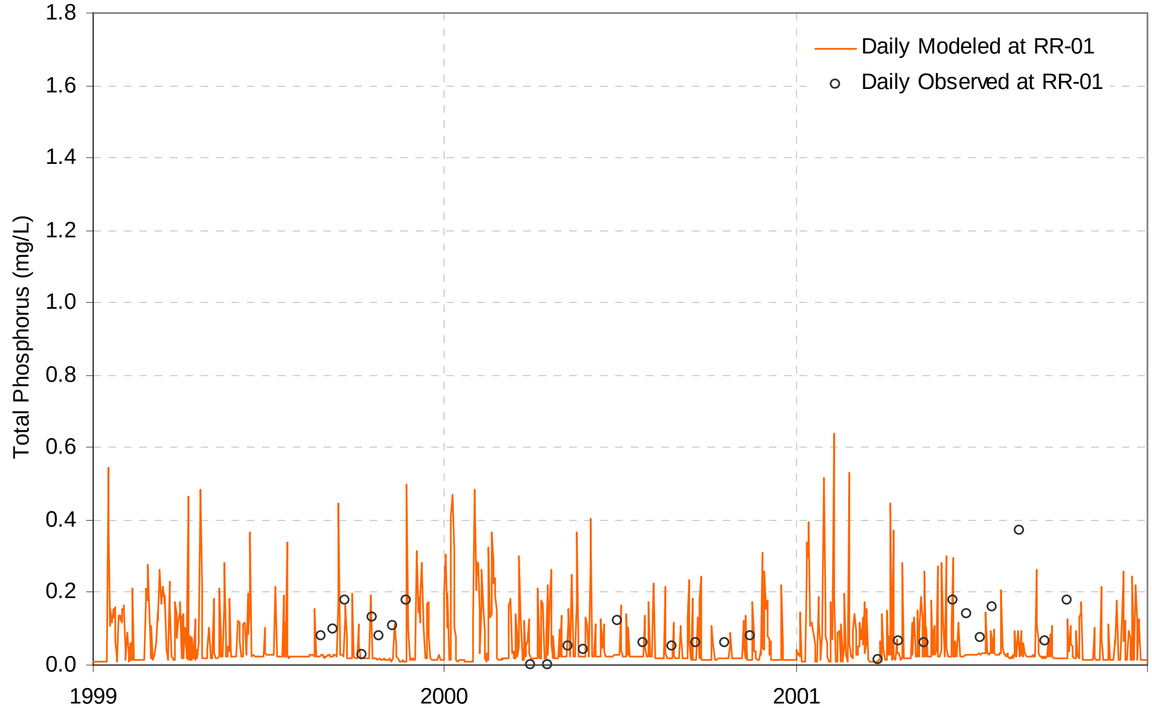

Daily Modeled at RR-03
Daily Observed at RR-03
Temperature (celsius)
30
25
20
15
10
5
0
1999
2000
2001

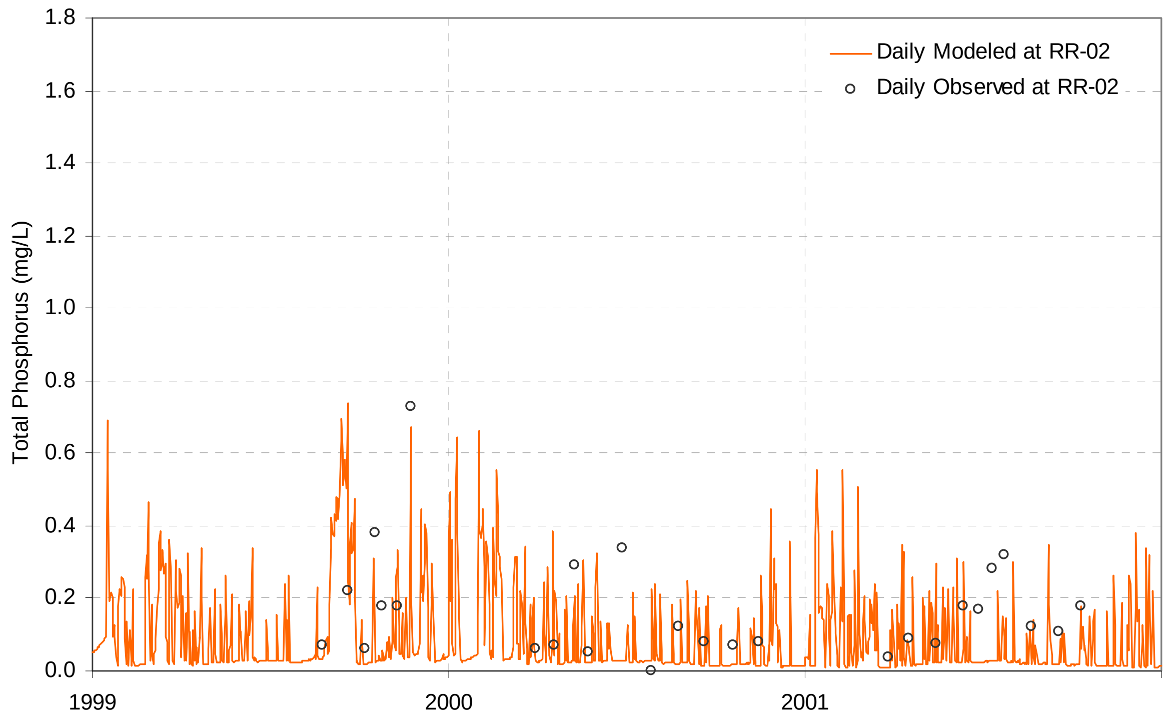

Daily Modeled at RR-04
Daily Observed at RR-04
Temperature (celsius)
30
25
20
15
10
5
0
1999
2000
2001

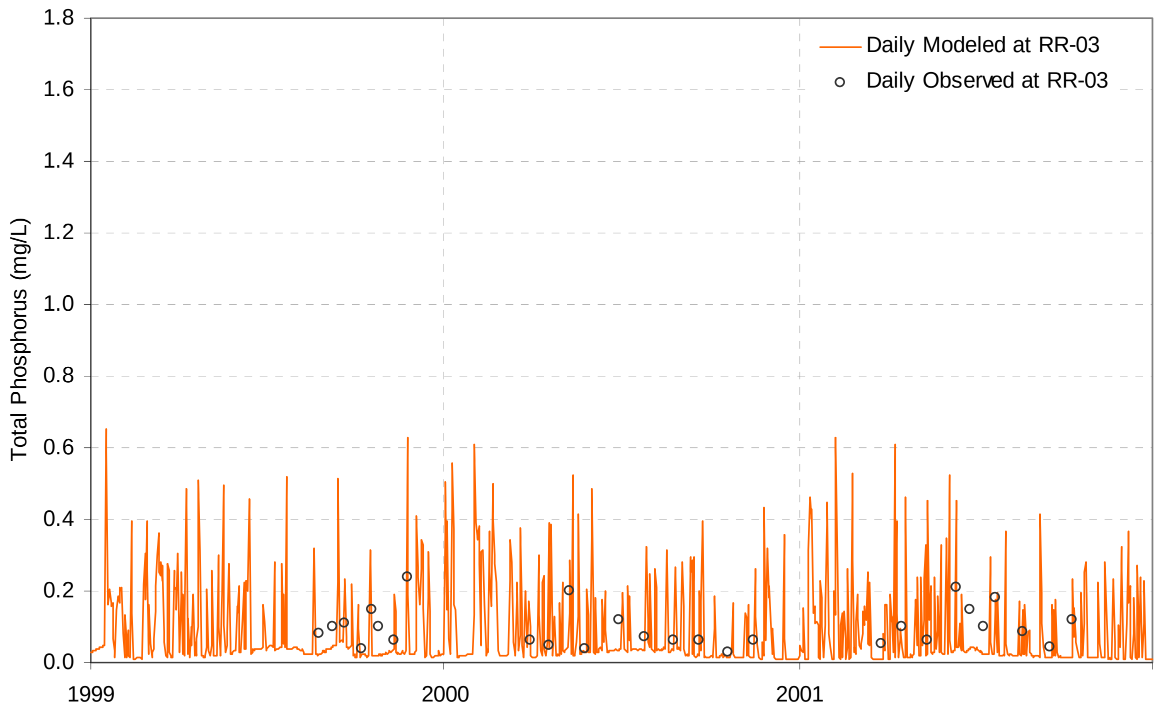

Daily Modeled at RR-05
Daily Observed at RR-05
Temperature (celsius)
30
25
20
15
10
5
0
1999
2000
2001


Daily Modeled at RR-06
Daily Observed at RR-06
Temperature (celsius)
30
25
20
15
10
5
0
1999
2000
2001

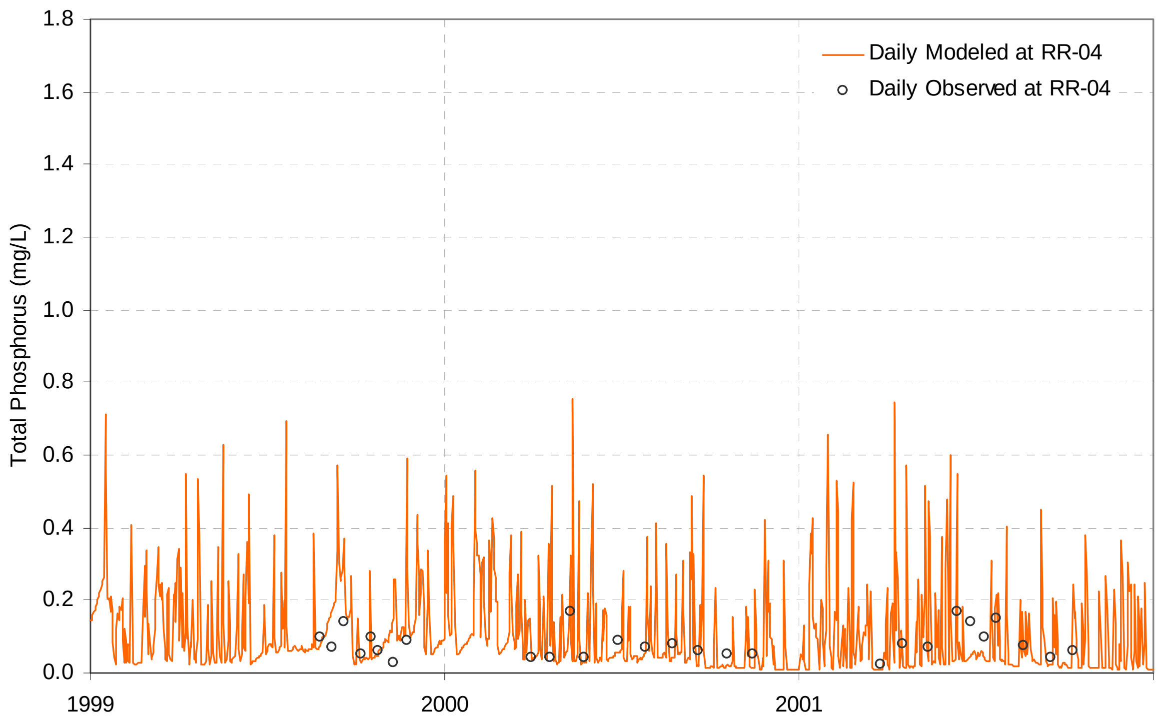
ATTACHMENT C – CALIBRATION PLOTS FOR TOTAL PHOSPHORUS AND SOLUBLE PHOSPHORUS


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Total Phosphorus (mg/L)
1999
2000
2001
Daily Modeled at RR-01
Daily Observed at RR-01

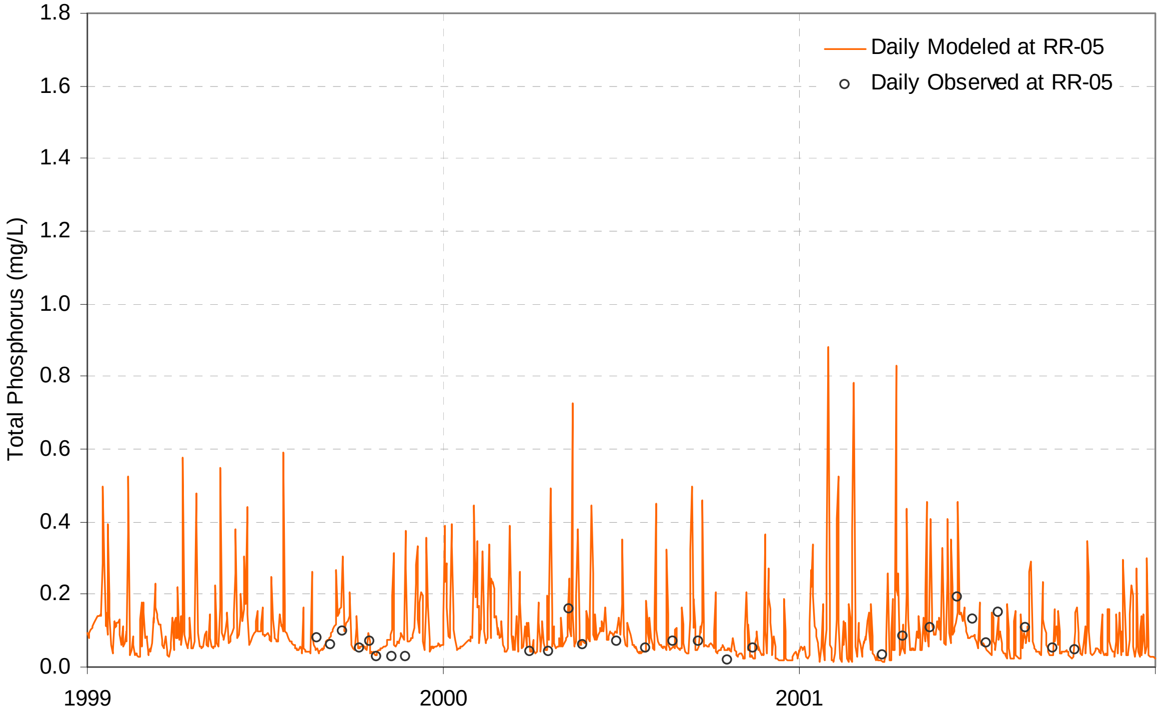

1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Total Phosphorus (mg/L)
1999
2000
2001
Daily Modeled at RR-02
Daily Observed at RR-02

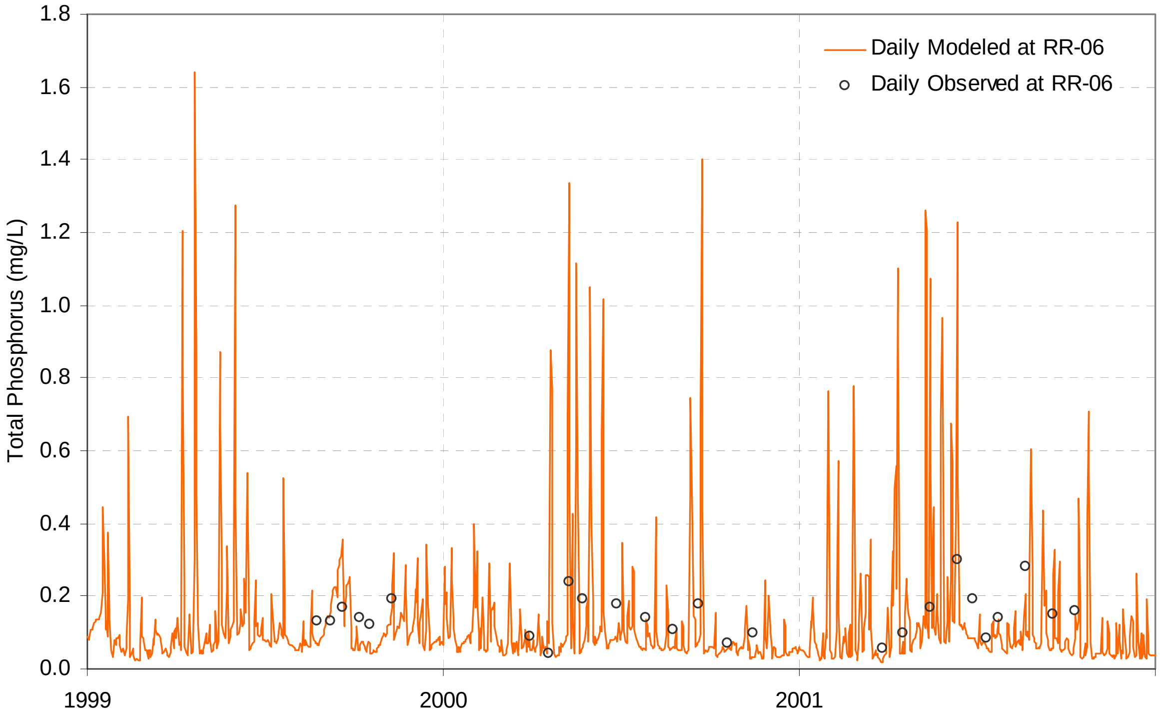


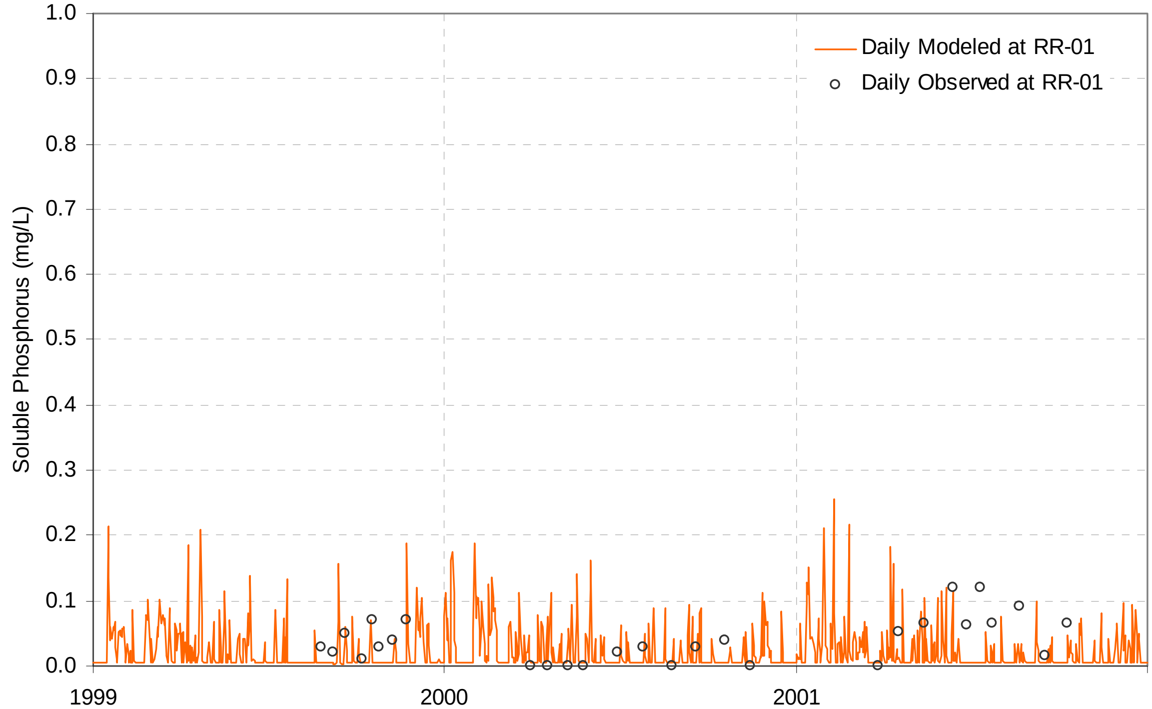
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1999
2000
2001
Daily Modeled at RR-03
Daily Observed at RR-03

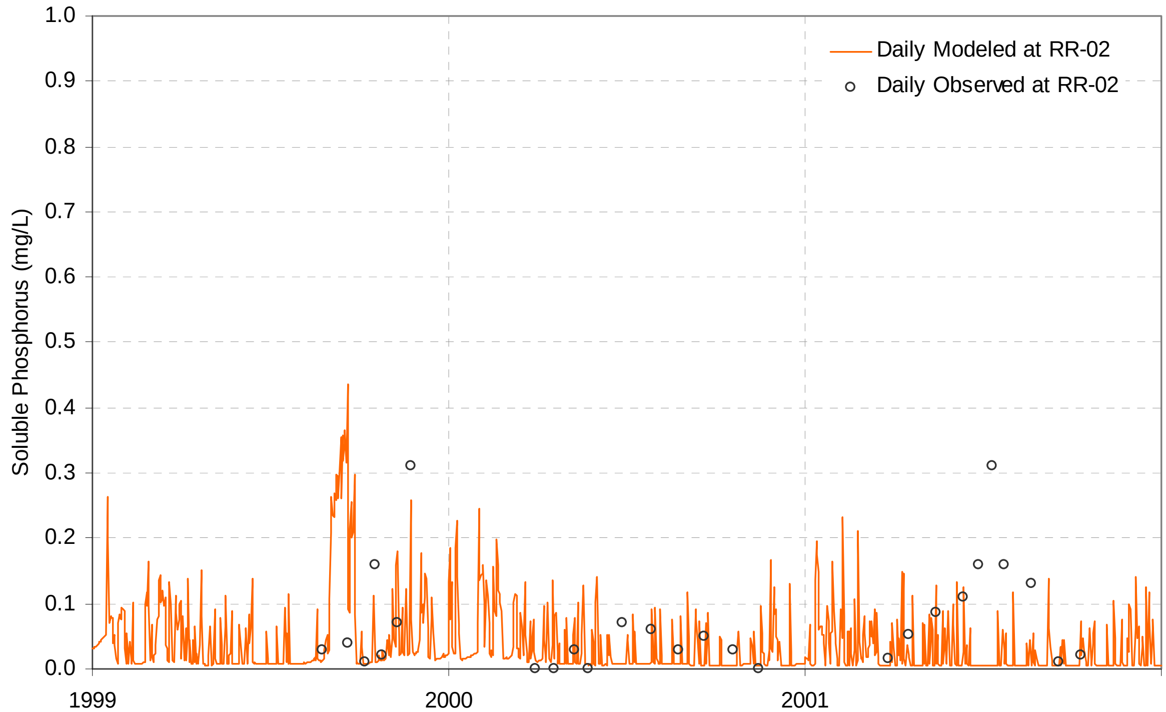


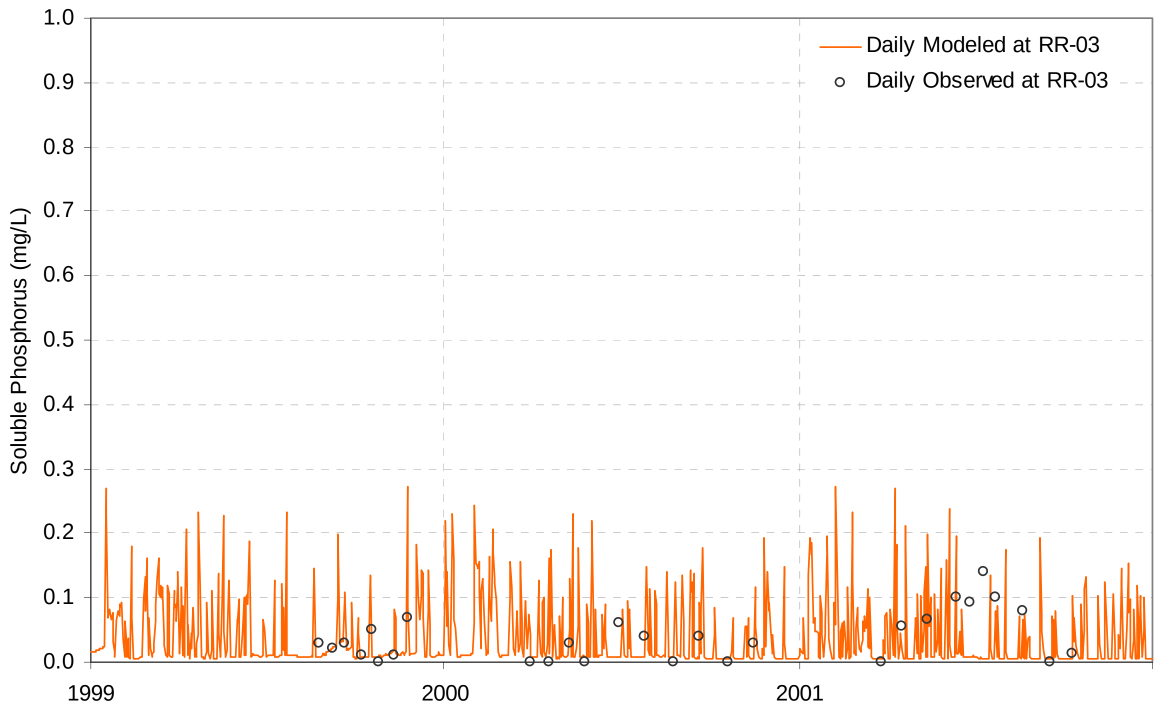
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1999
2000
2001
Daily Modeled at RR-04
Daily Observed at RR-04


Total Phosphorus (mg/L)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
1999
2000
2001
Daily Modeled at RR-05
Daily Observed at RR-05

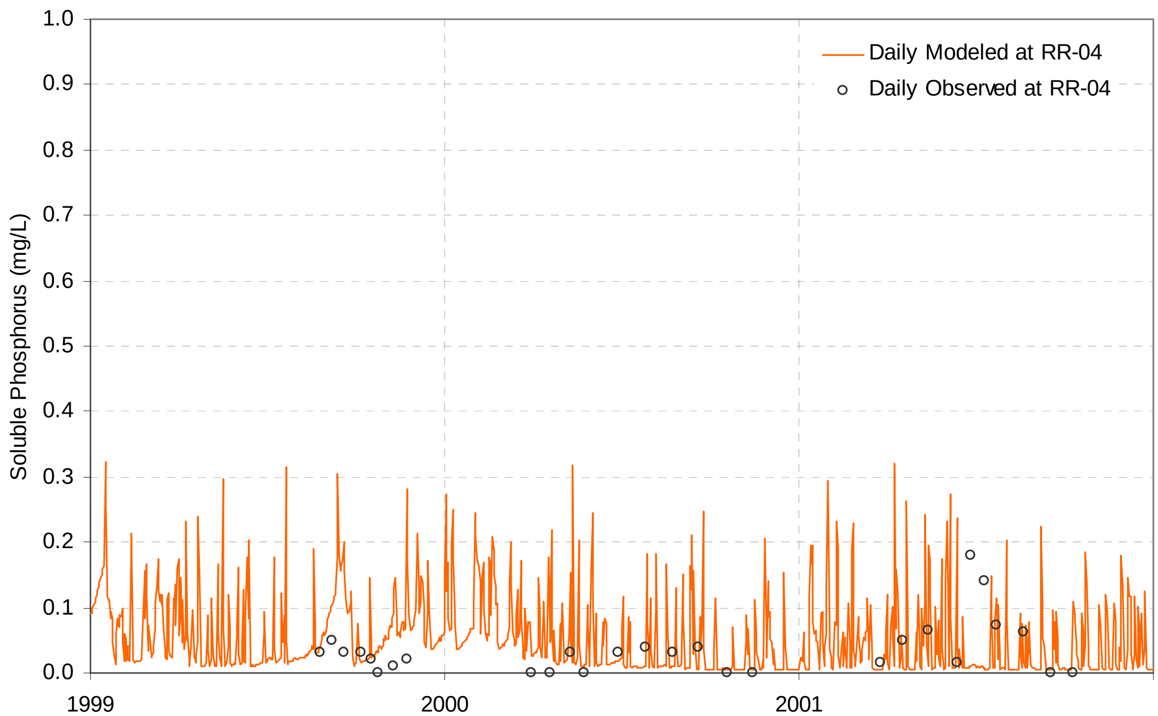

Total Phosphorus (mg/L)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
1999
2000
2001
Daily Modeled at RR-06
Daily Observed at RR-06


Daily Modeled at RR-01
Daily Observed at RR-01
Soluble Phosphorus (mg/L)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001

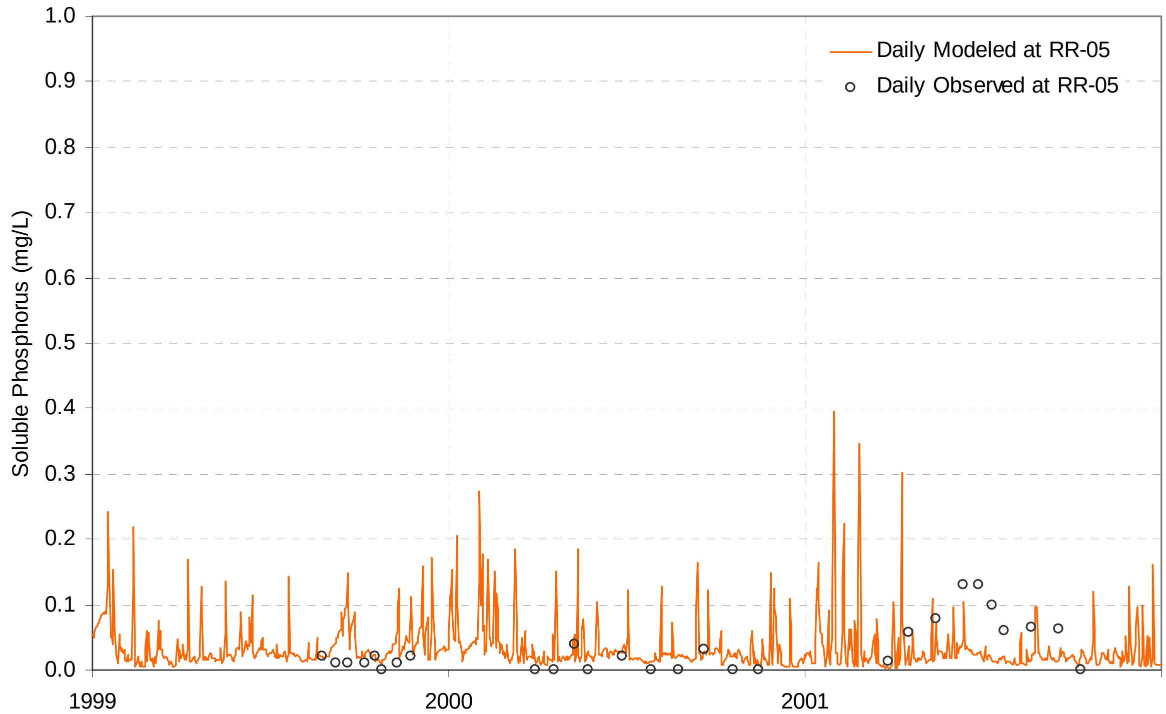

Daily Modeled at RR-02
Daily Observed at RR-02
Soluble Phosphorus (mg/L)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001

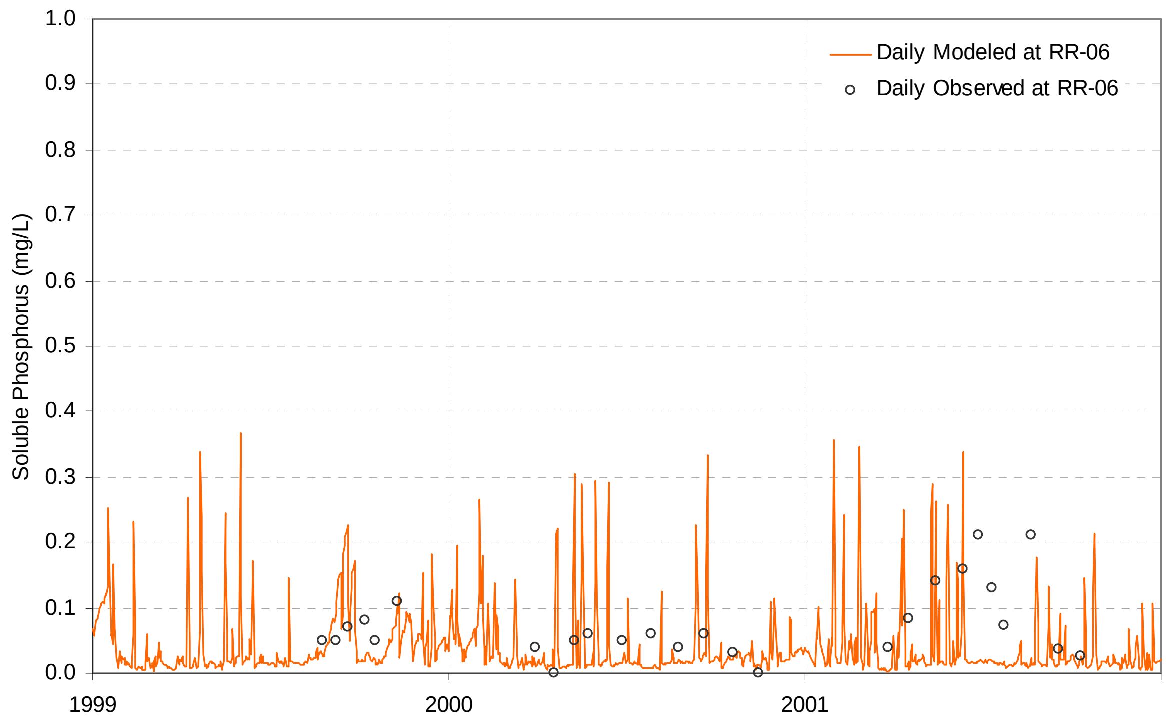


Daily Modeled at RR-03
Daily Observed at RR-03
Soluble Phosphorus (mg/L)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001

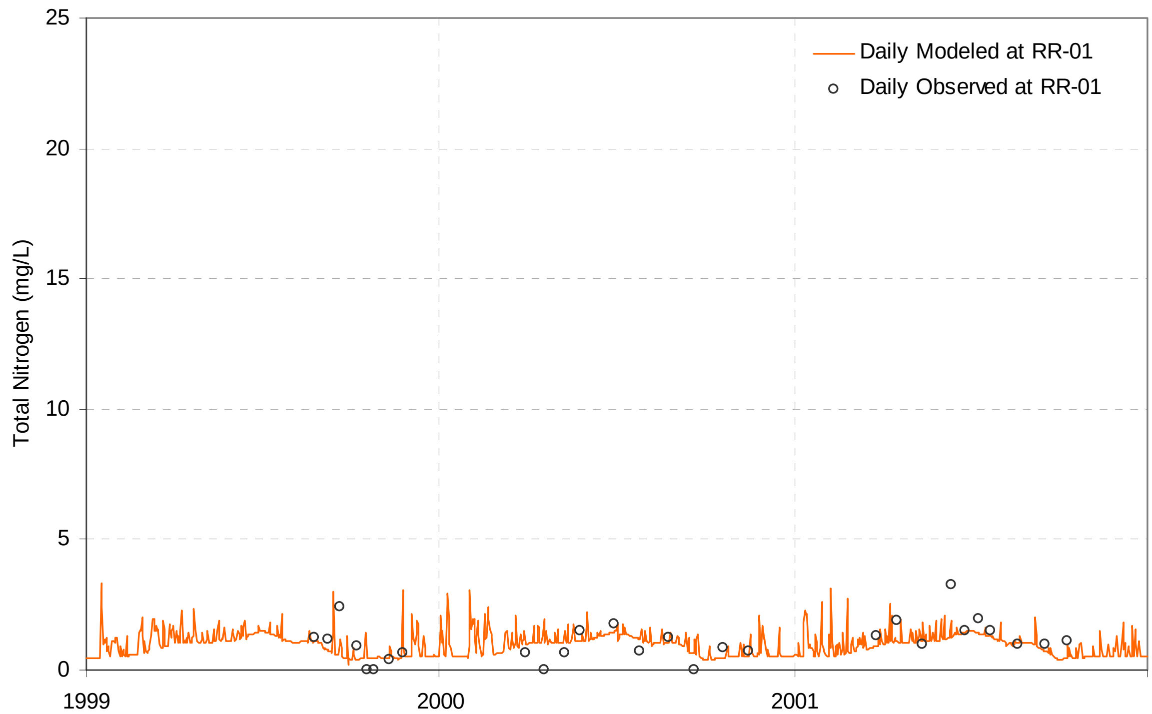


Daily Modeled at RR-04
Daily Observed at RR-04
Soluble Phosphorus (mg/L)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001

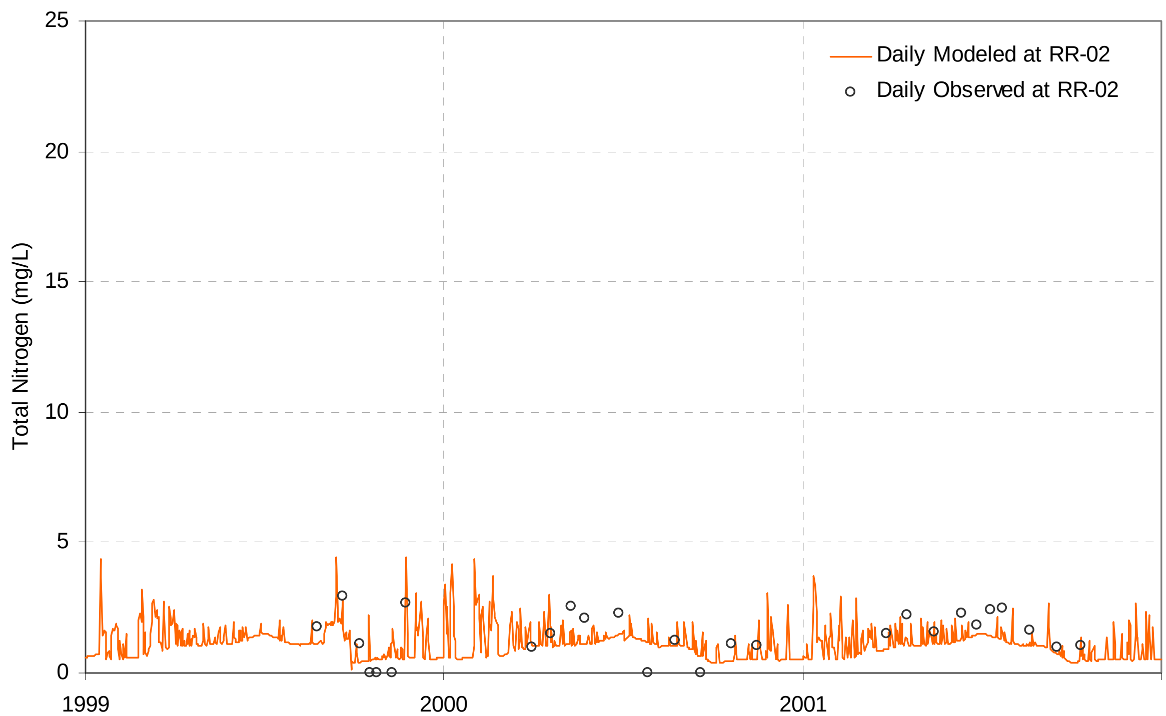

Daily Modeled at RR-05
Daily Observed at RR-05
Soluble Phosphorus (mg/L)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001


Daily Modeled at RR-06
Daily Observed at RR-06
Soluble Phosphorus (mg/L)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001

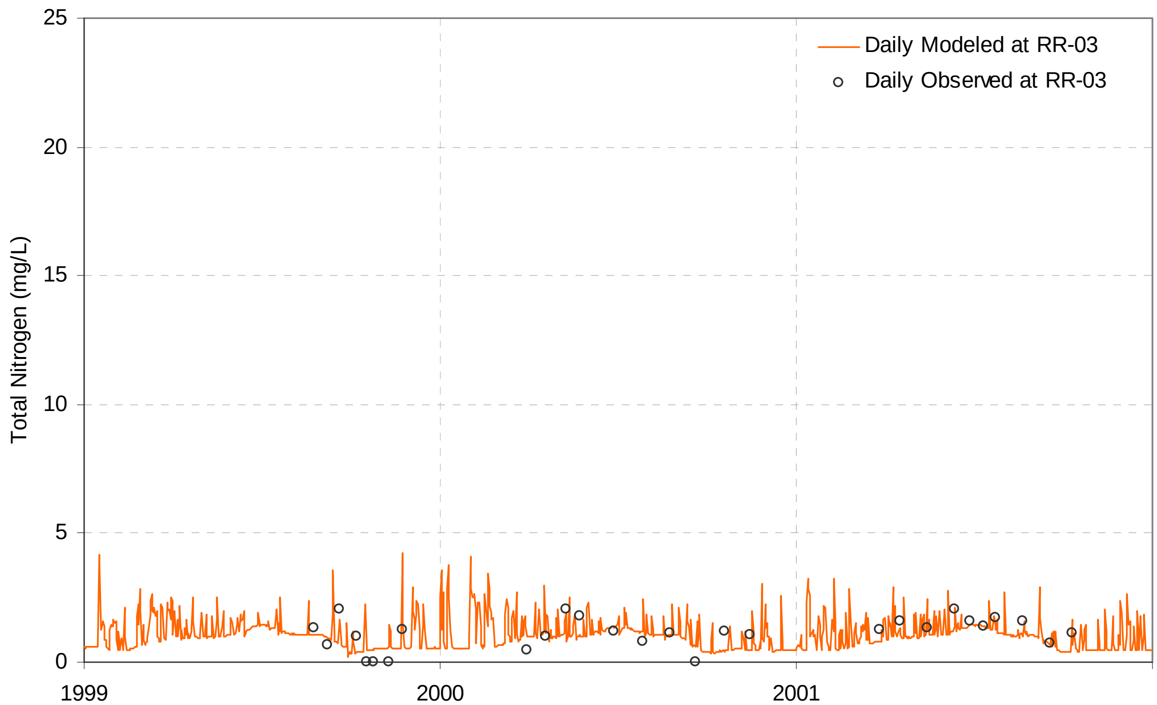
ATTACHMENT D – CALIBRATION PLOTS FOR TOTAL NITROGEN, NITRITE+NITRATE, AND AMMONIA

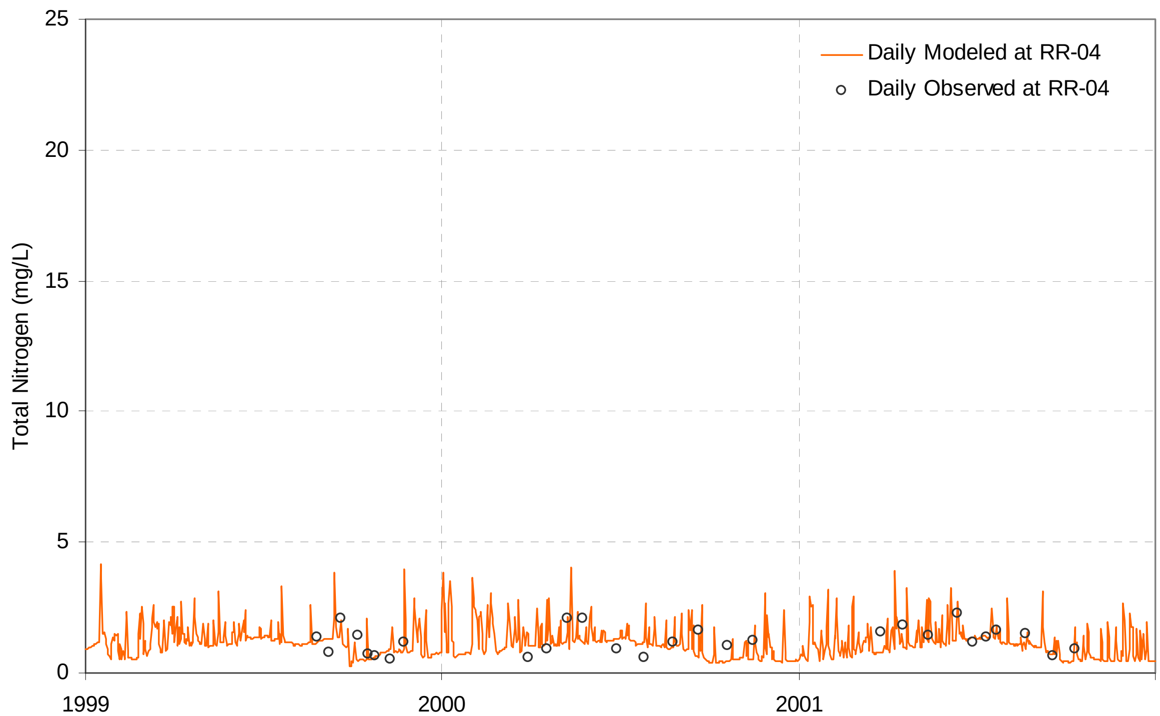


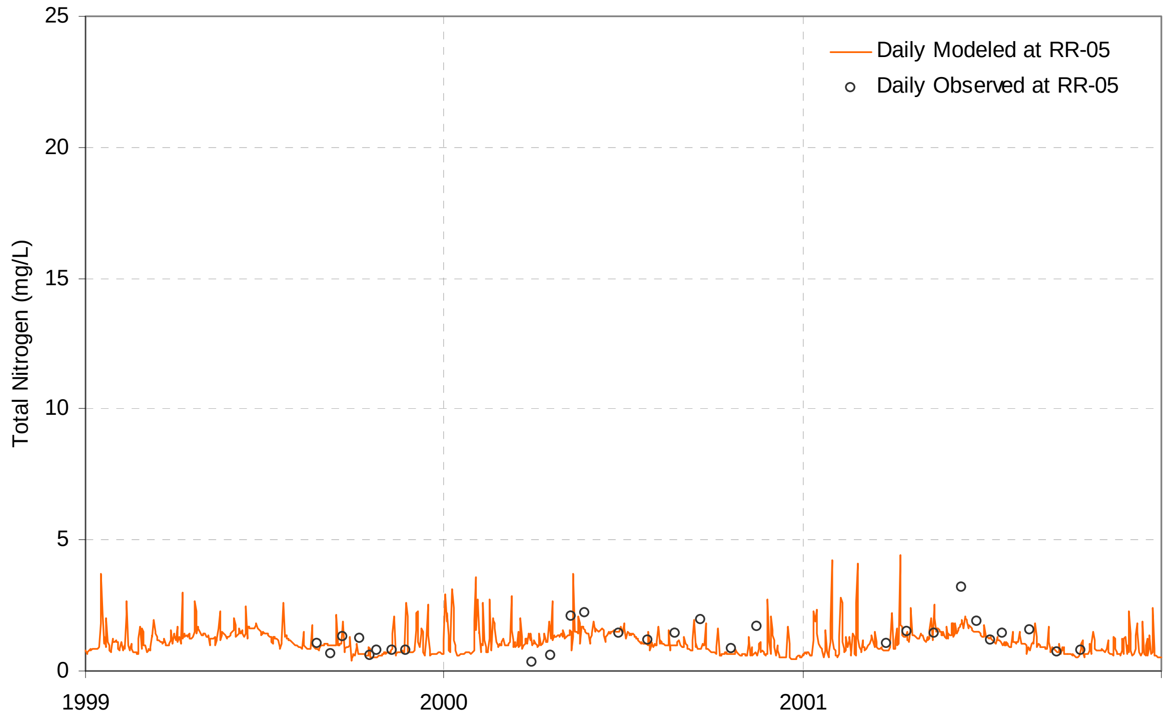
Daily Modeled at RR-01
Daily Observed at RR-01
Total Nitrogen (mg/L)
25
20
15
10
5
0
1999
2000
2001

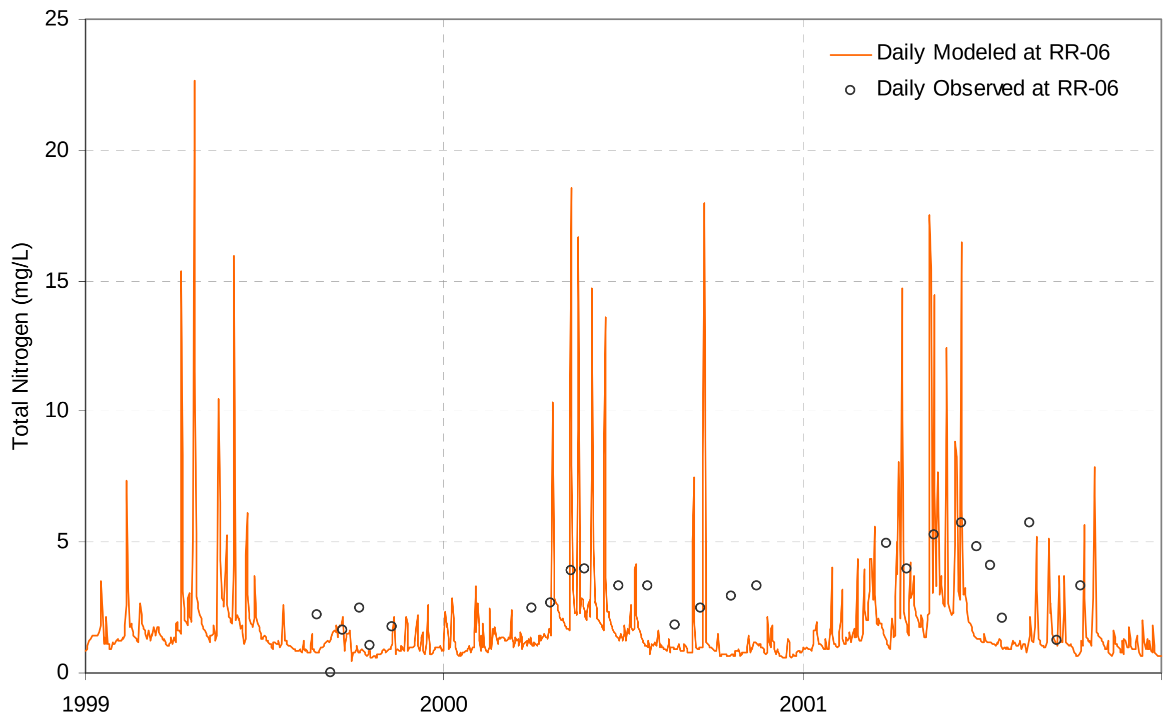


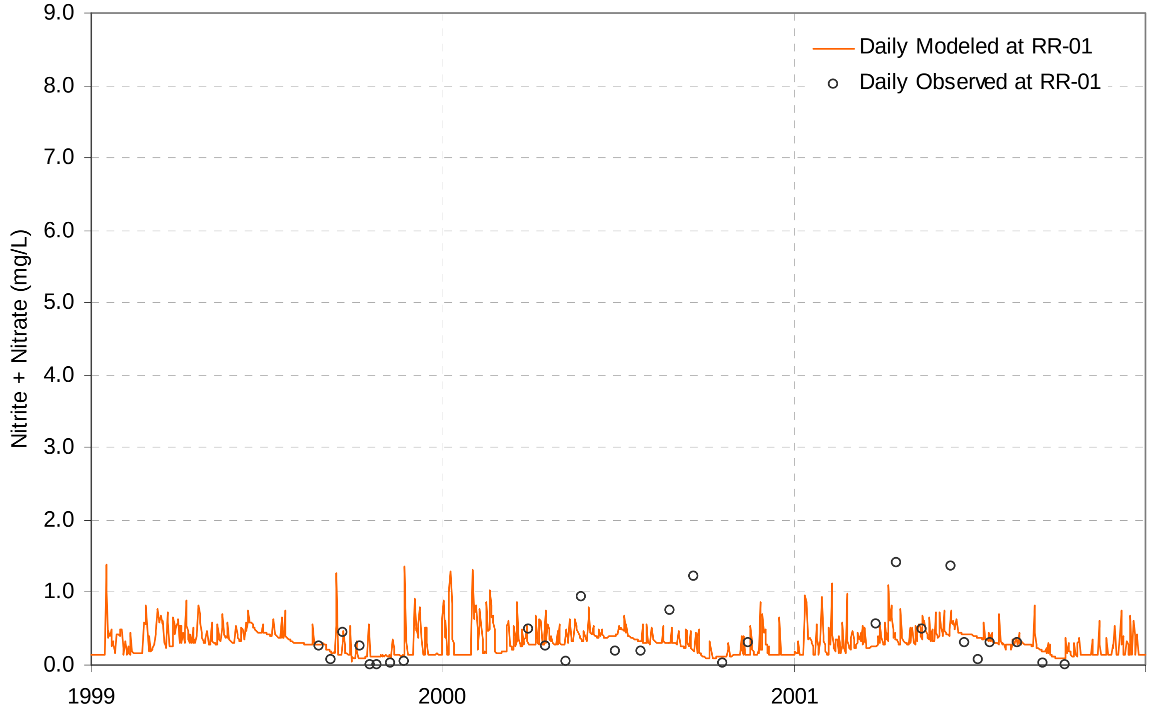
Daily Modeled at RR-02
Daily Observed at RR-02
Total Nitrogen (mg/L)
25
20
15
10
5
0
1999
2000
2001

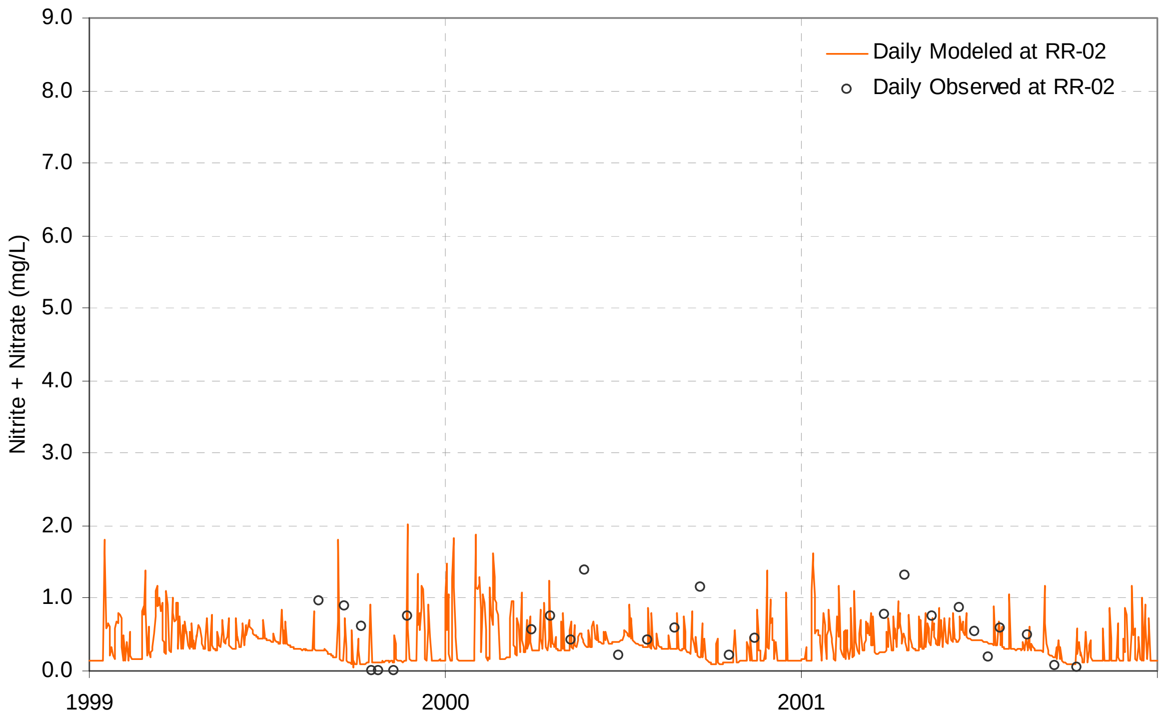

25
20
15
10
5
0
Total Nitrogen (mg/L)
1999
2000
2001
Daily Modeled at RR-03
Daily Observed at RR-03

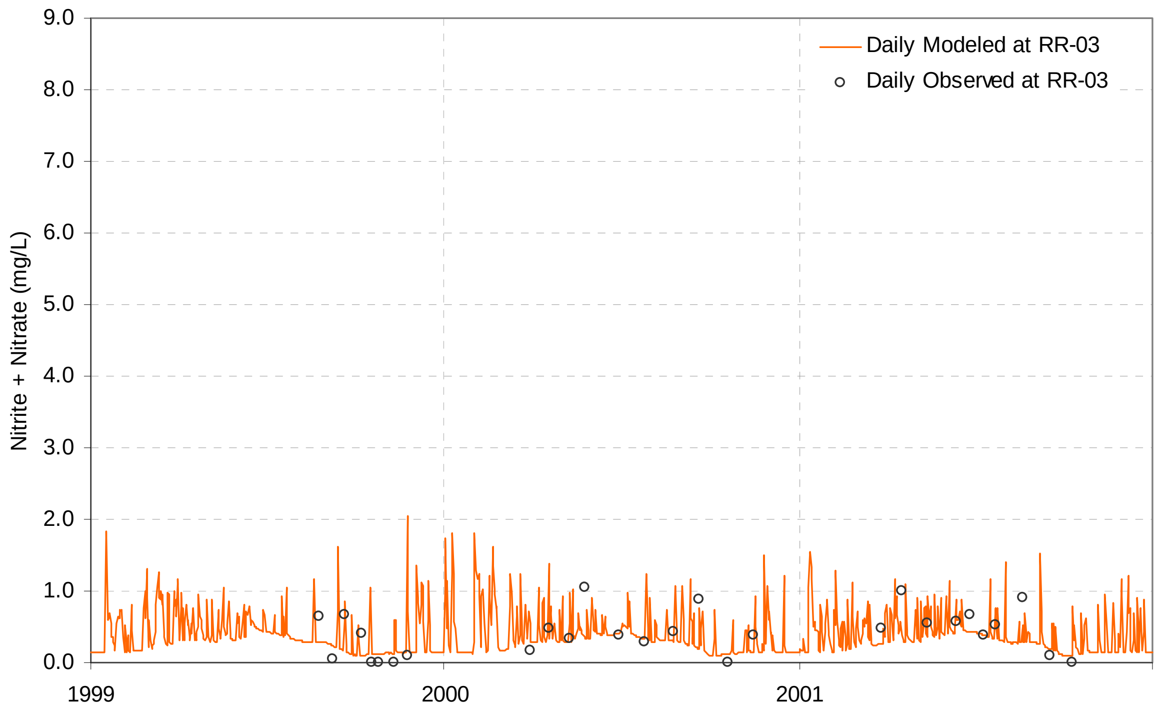

25
20
15
10
5
0
Total Nitrogen (mg/L)
1999
2000
2001
Daily Modeled at RR-04
Daily Observed at RR-04

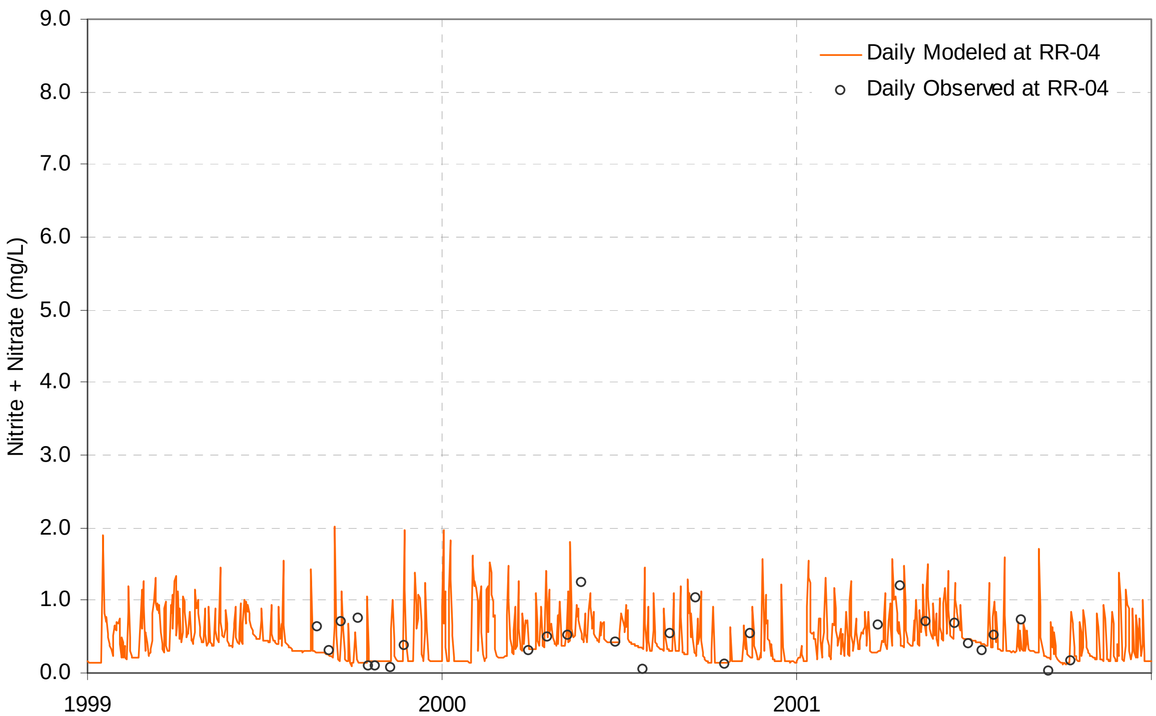

25
20
15
10
5
0
Total Nitrogen (mg/L)
1999
2000
2001
Daily Modeled at RR-05
Daily Observed at RR-05

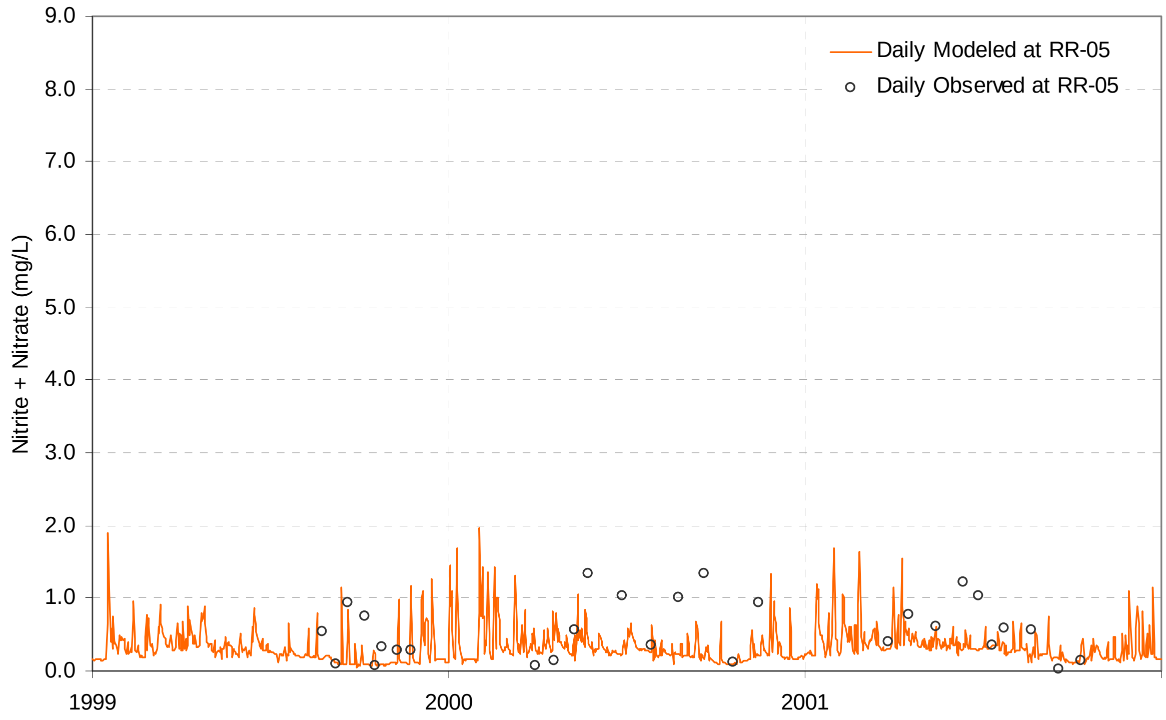

25
20
15
10
5
0
Total Nitrogen (mg/L)
1999
2000
2001
Daily Modeled at RR-06
Daily Observed at RR-06


9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Nitrite + Nitrate (mg/L)
1999
2000
2001
Daily Modeled at RR-01
Daily Observed at RR-01

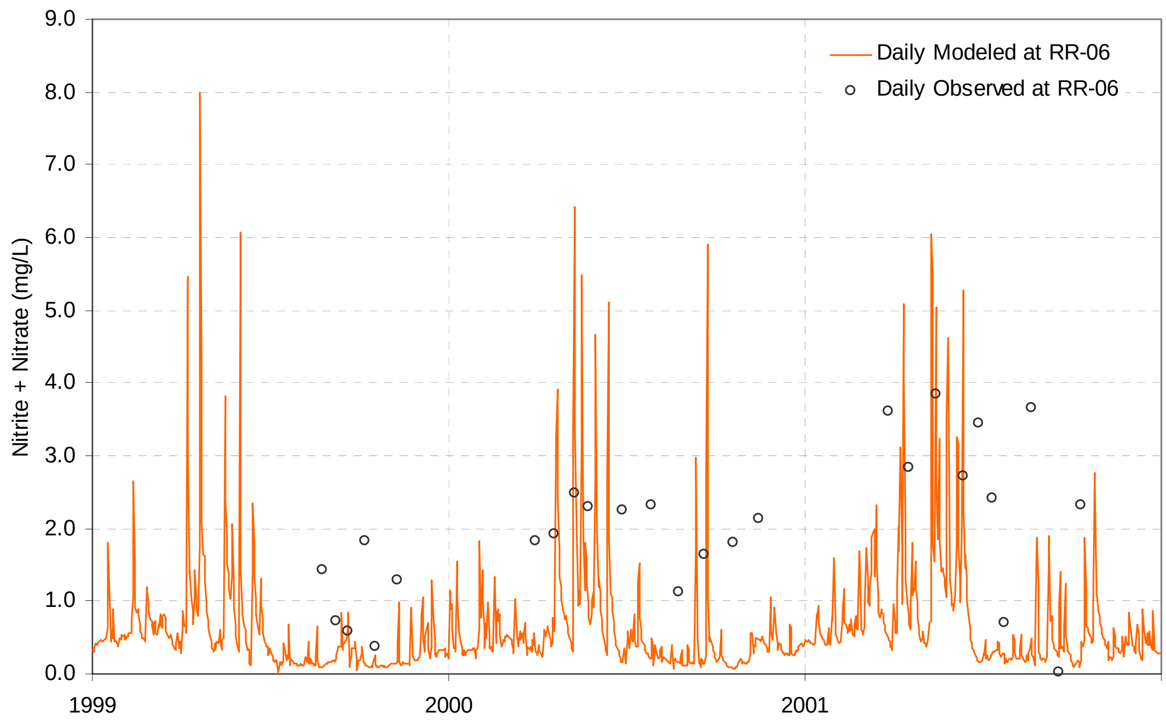

9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Nitrite + Nitrate (mg/L)
1999
2000
2001
Daily Modeled at RR-02
Daily Observed at RR-02


Daily Modeled at RR-03
Daily Observed at RR-03
Nitrite + Nitrate (mg/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1999
2000
2001

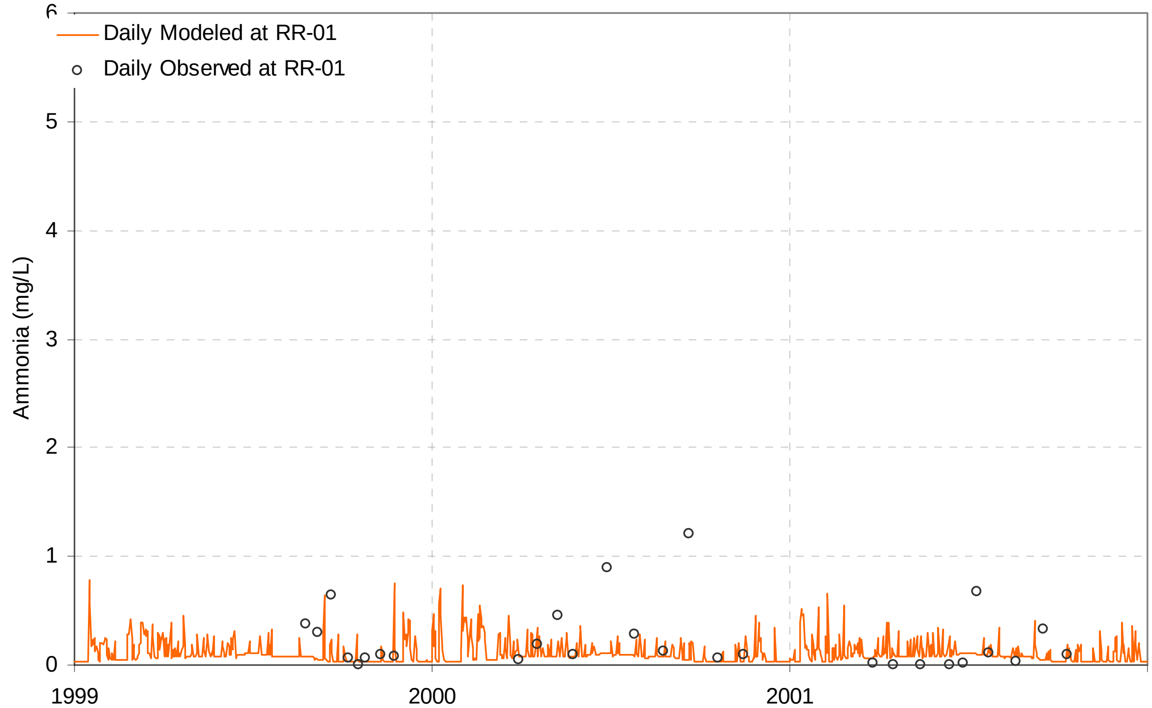

Daily Modeled at RR-04
Daily Observed at RR-04
Nitrite + Nitrate (mg/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1999
2000
2001

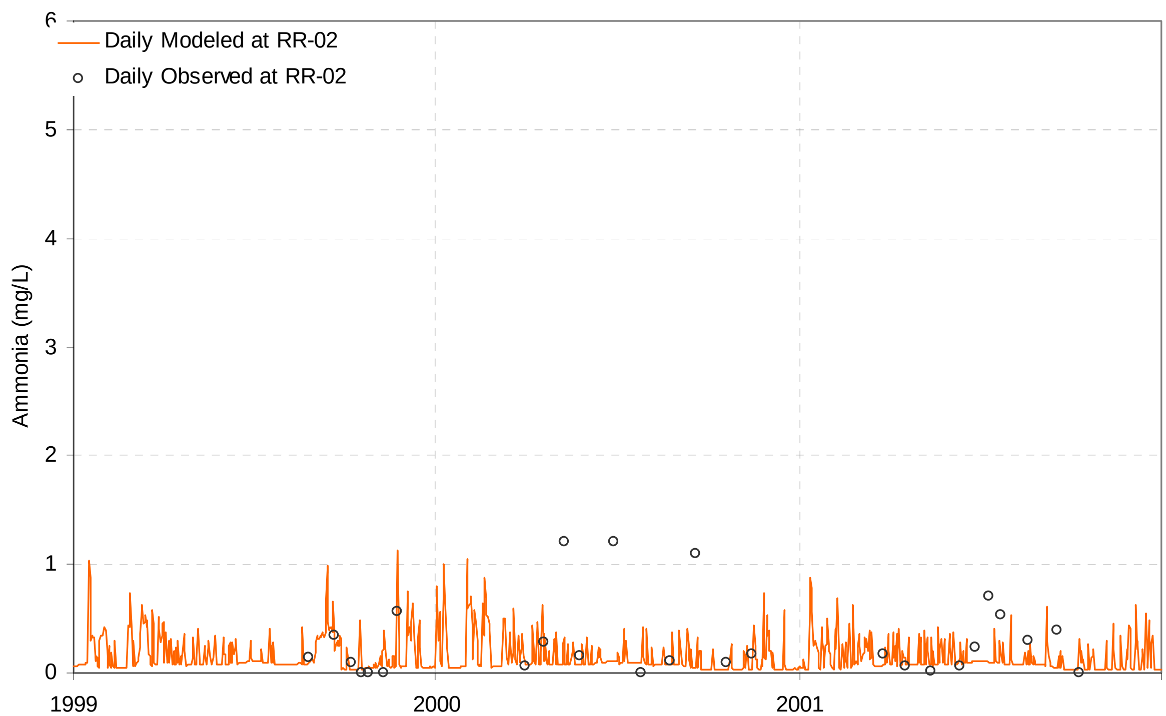


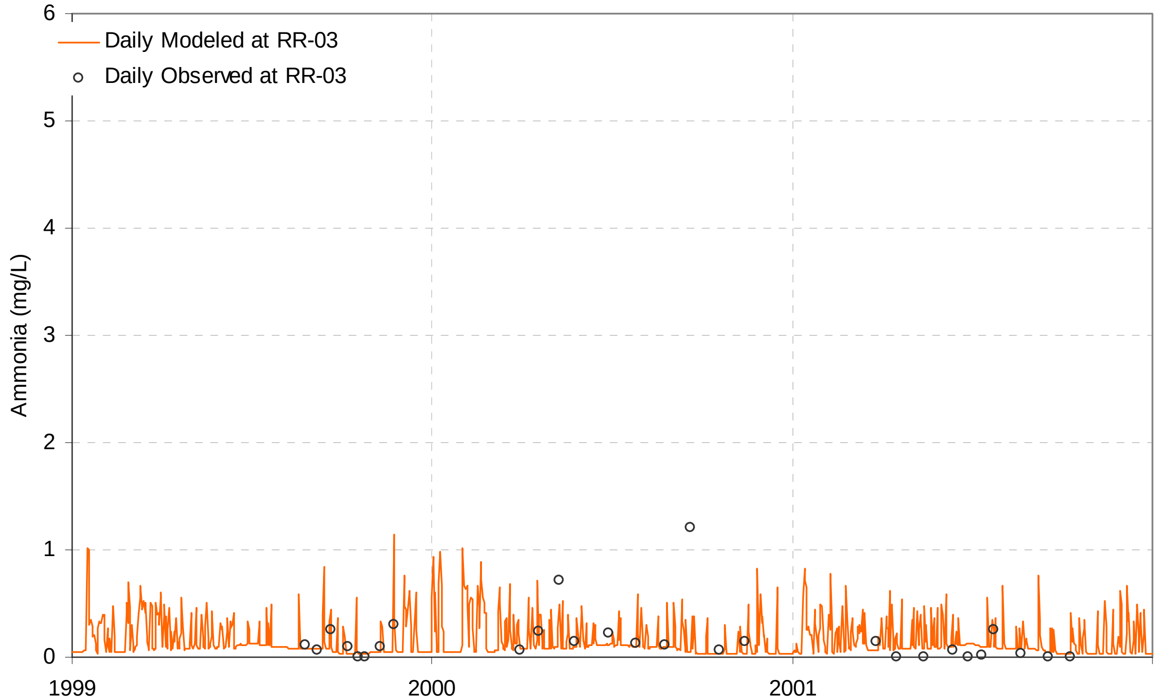
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Nitrite + Nitrate (mg/L)
1999
2000
2001
Daily Modeled at RR-05
Daily Observed at RR-05



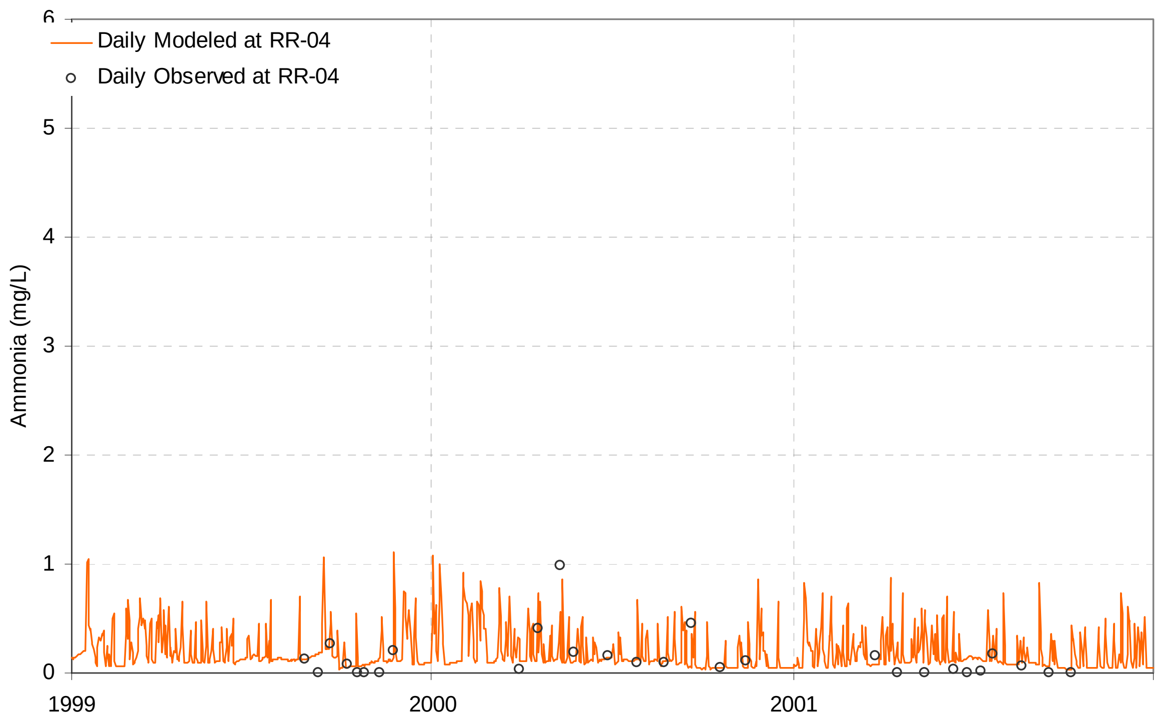
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Nitrite + Nitrate (mg/L)
1999
2000
2001
Daily Modeled at RR-06
Daily Observed at RR-06


Daily Modeled at RR-01
Daily Observed at RR-01
Ammonia (mg/L)
6
5
4
3
2
1
0
1999
2000
2001

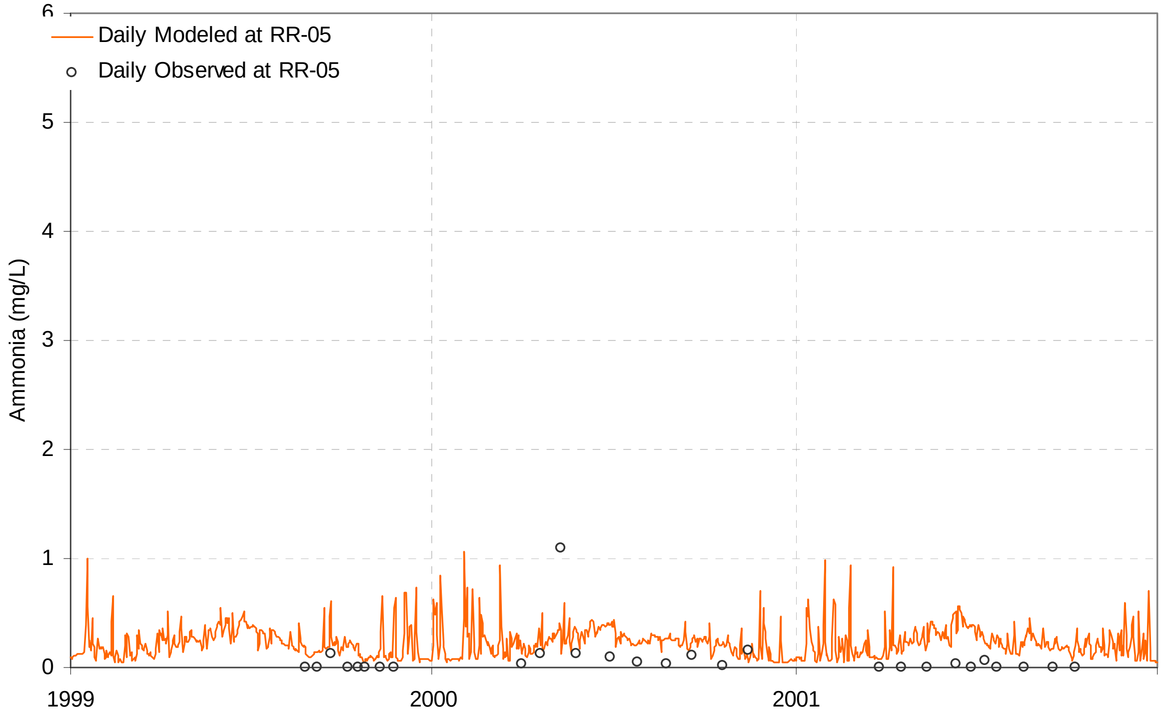

Daily Modeled at RR-02
Daily Observed at RR-02
Ammonia (mg/L)
6
5
4
3
2
1
0
1999
2000
2001



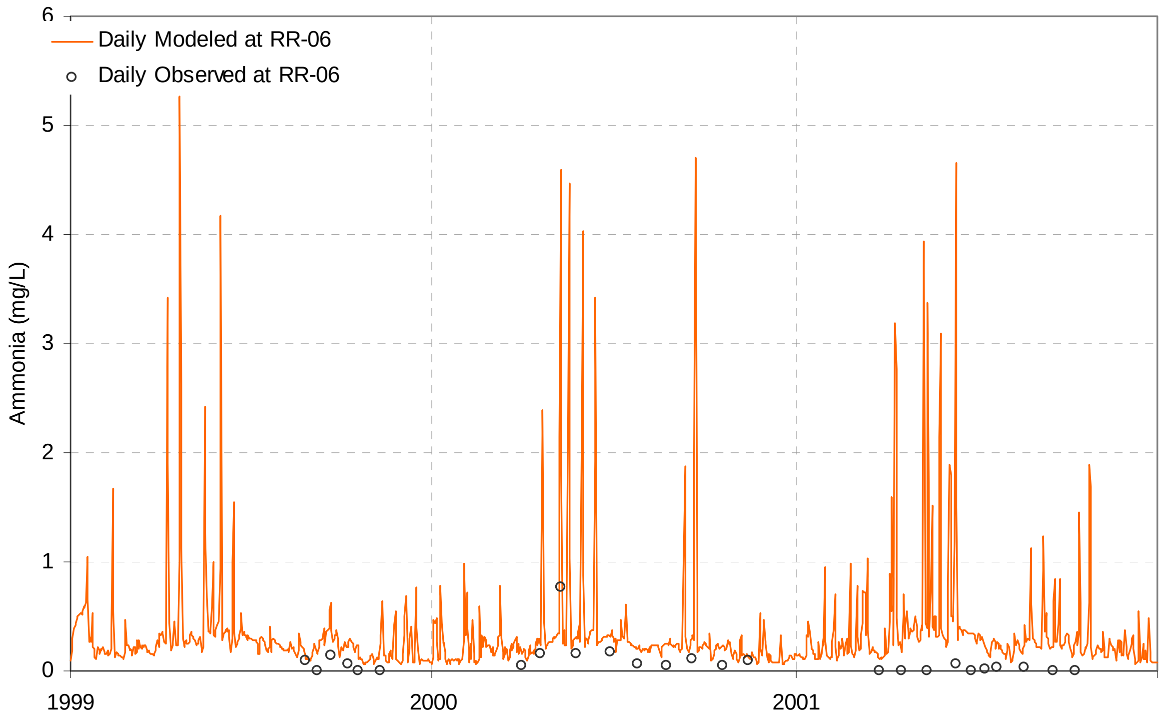
Daily Modeled at RR-03
Daily Observed at RR-03
Ammonia (mg/L)
6
5
4
3
2
1
0
1999
2000
2001



Daily Modeled at RR-04
Daily Observed at RR-04
Ammonia (mg/L)
6
5
4
3
2
1
0
1999
2000
2001

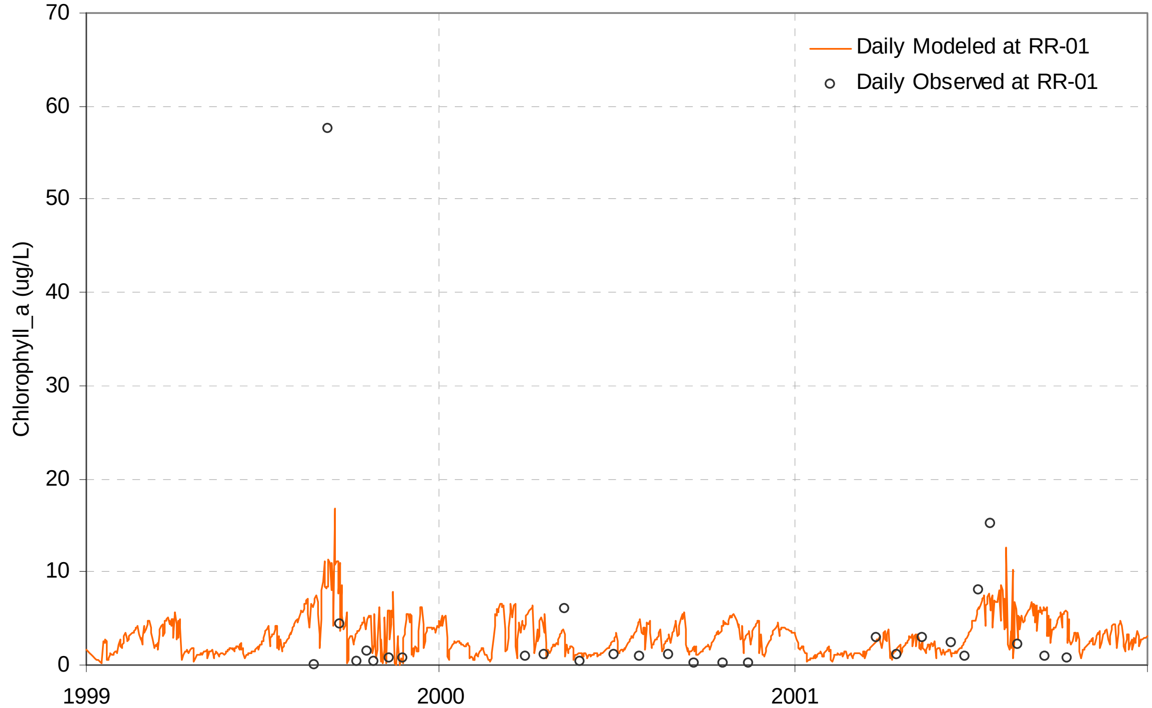


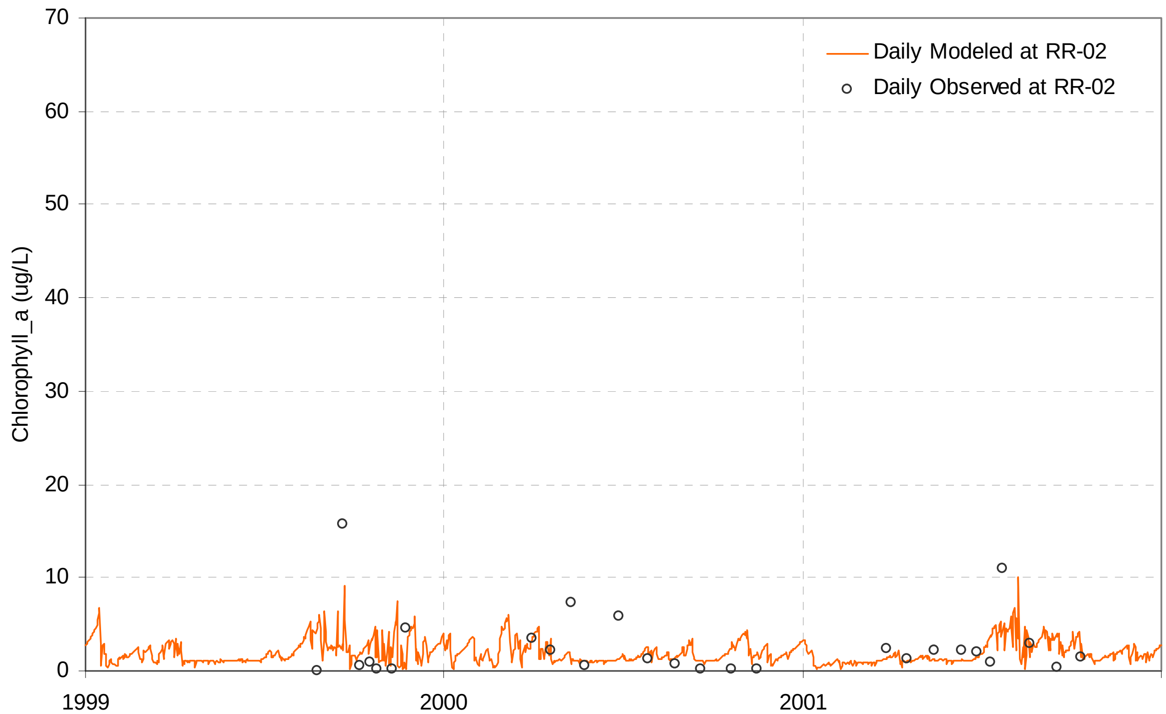
Daily Modeled at RR-05
Daily Observed at RR-05
Ammonia (mg/L)
0
1
2
3
4
5
6
1999
2000
2001

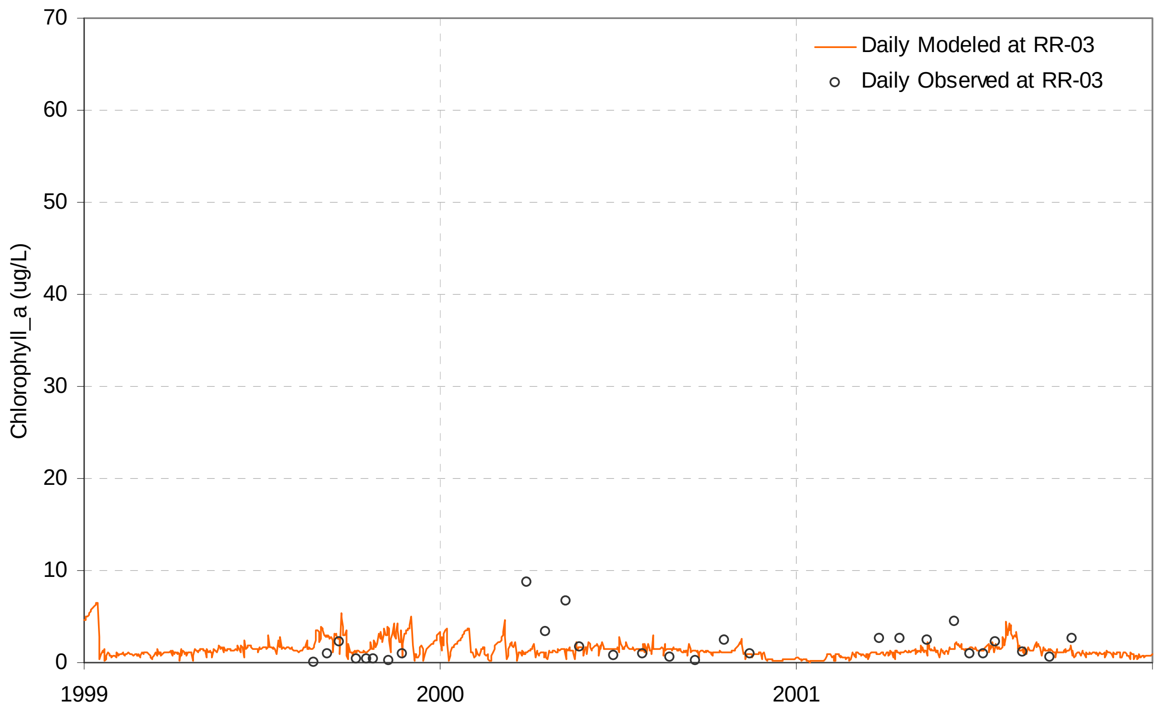


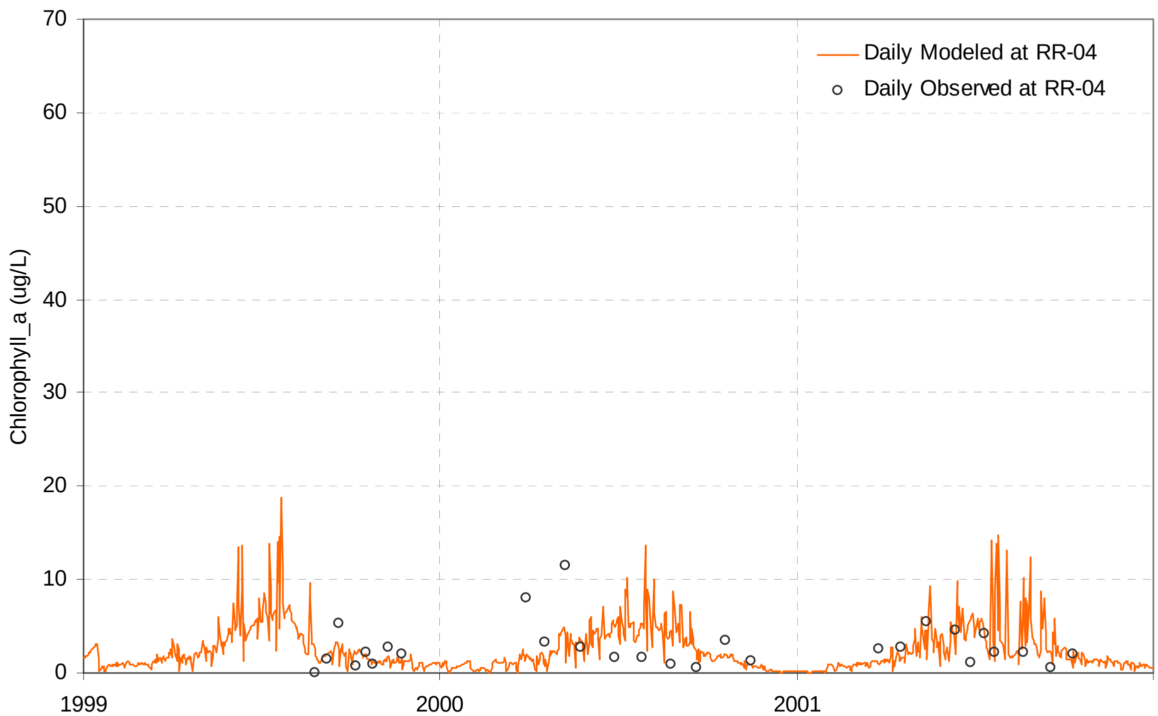
Daily Modeled at RR-06
Daily Observed at RR-06
Ammonia (mg/L)
0
1
2
3
4
5
6
1999
2000
2001

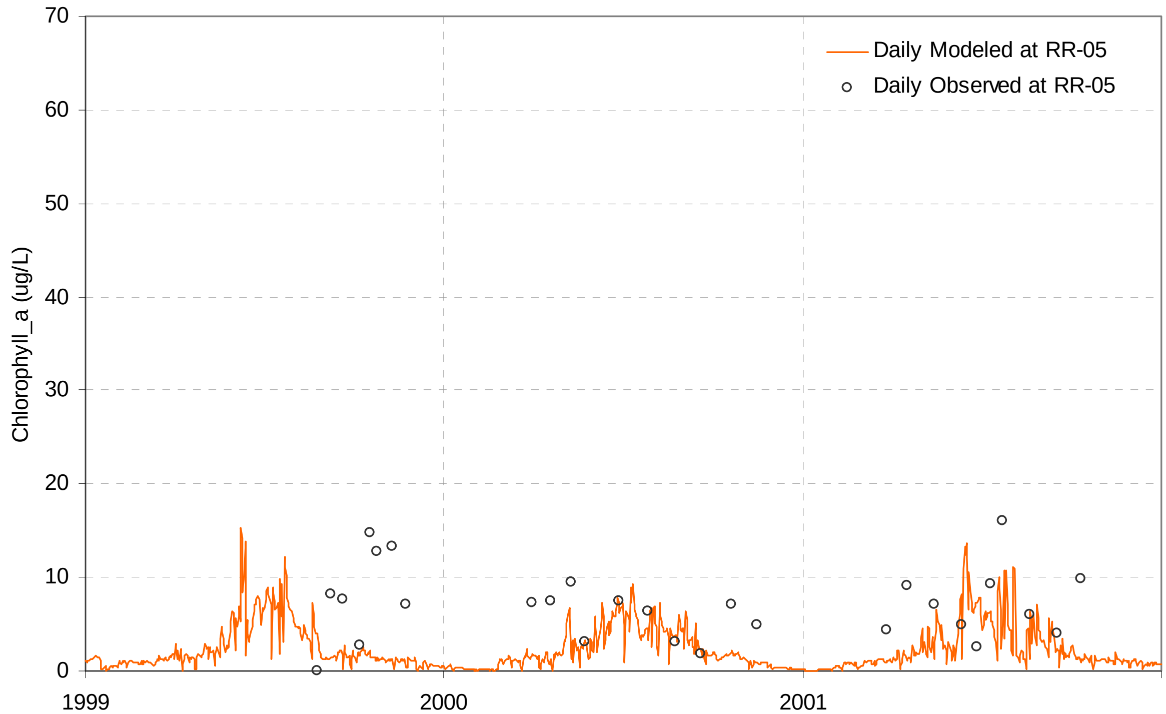
ATTACHMENT E – CALIBRATION PLOTS FOR CHLOROPHYLL *A*


Daily Modeled at RR-01
Daily Observed at RR-01
Chlorophyll_a (ug/L)
70
60
50
40
30
20
10
0
1999
2000
2001

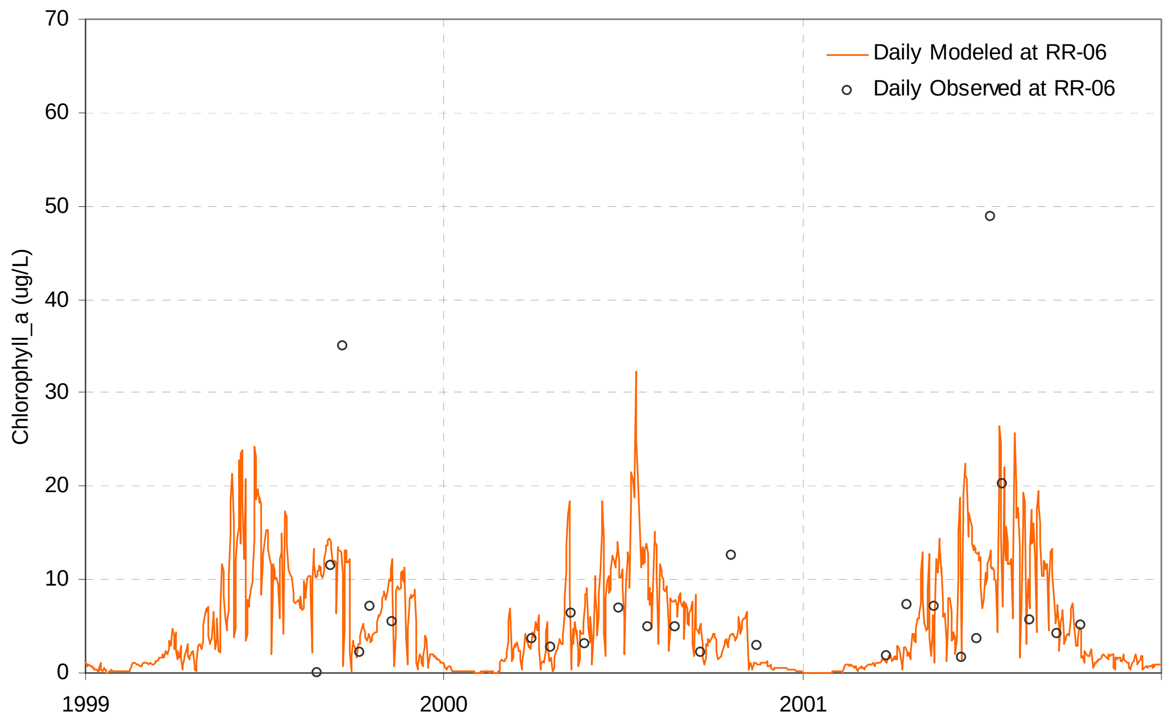

Daily Modeled at RR-02
Daily Observed at RR-02
Chlorophyll_a (ug/L)
70
60
50
40
30
20
10
0
1999
2000
2001


70
60
50
40
30
20
10
0
Chlorophyll_a (ug/L)
1999
2000
2001
Daily Modeled at RR-03
Daily Observed at RR-03


70
60
50
40
30
20
10
0
Chlorophyll_a (ug/L)
1999
2000
2001
Daily Modeled at RR-04
Daily Observed at RR-04

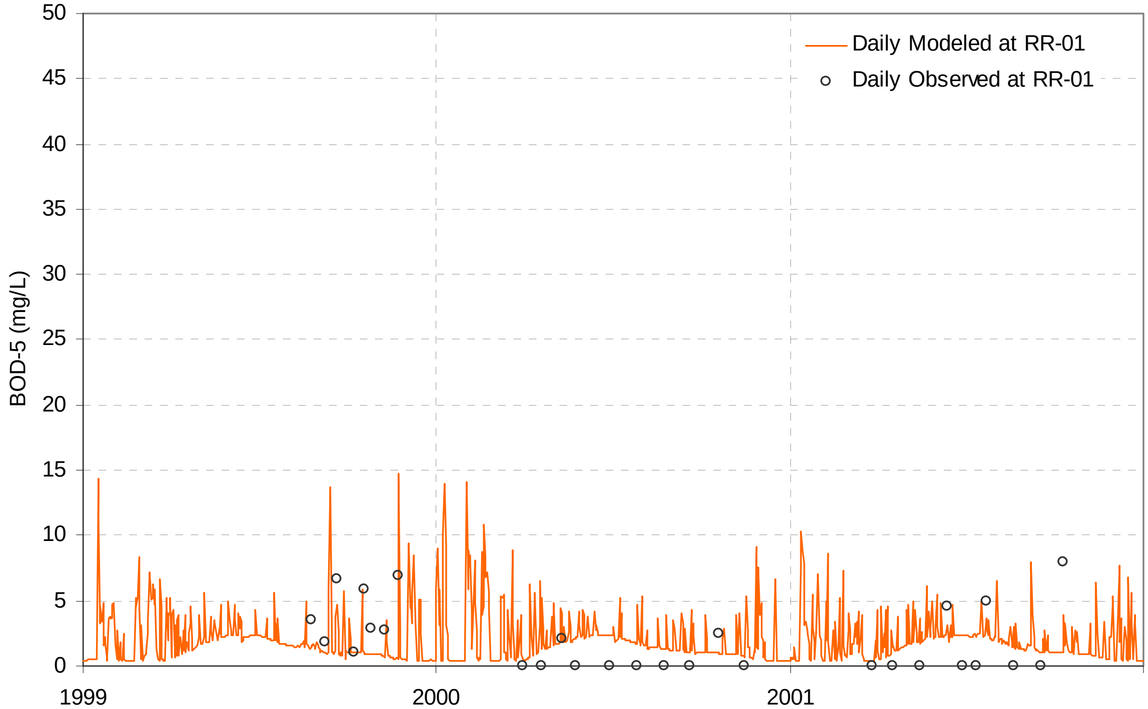


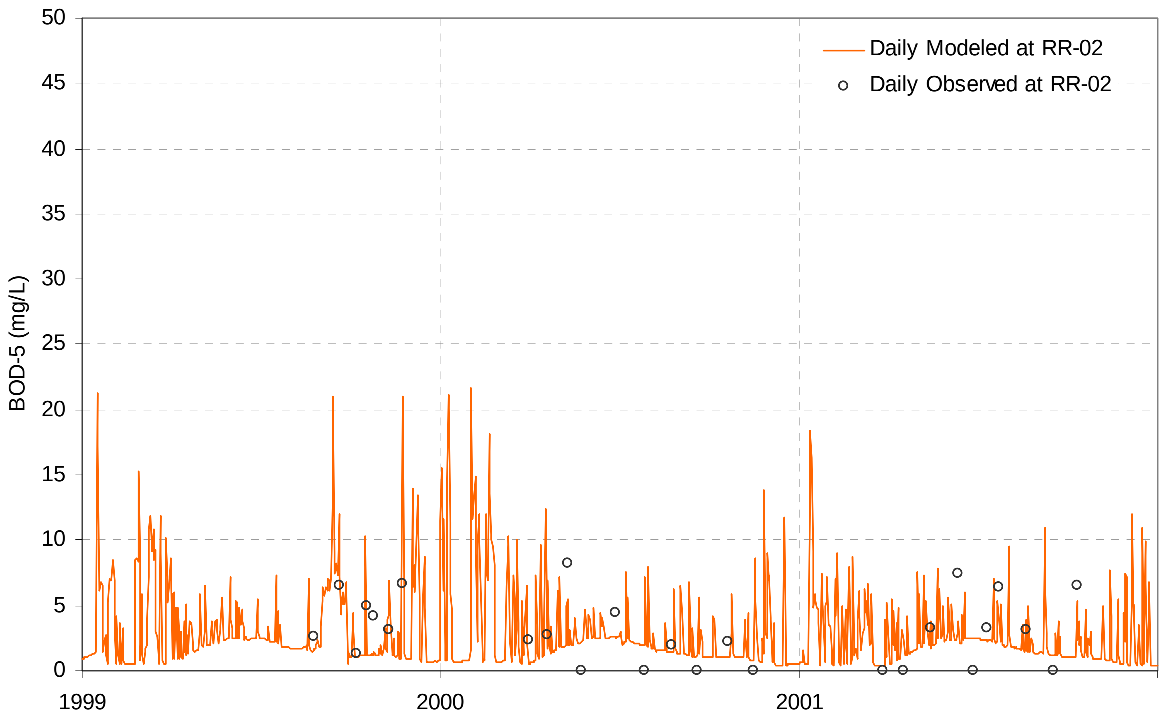
Chlorophyll_a (ug/L)
0
10
20
30
40
50
60
70
1999
2000
2001
Daily Modeled at RR-05
Daily Observed at RR-05

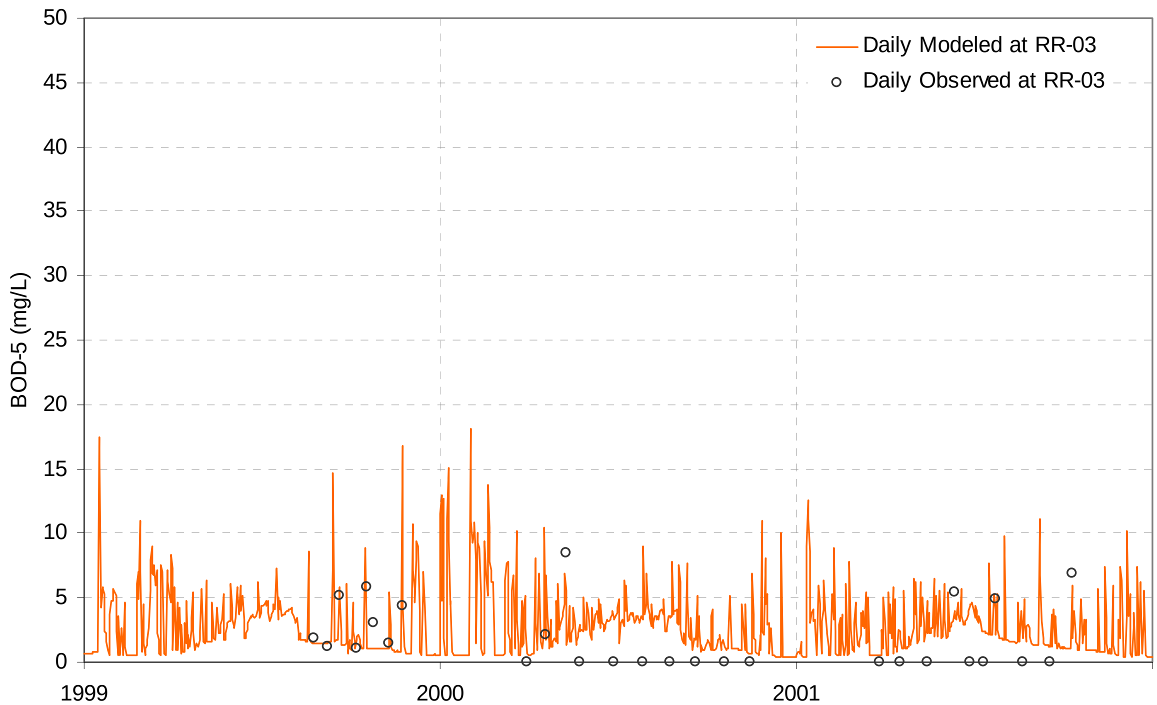


Chlorophyll_a (ug/L)
0
10
20
30
40
50
60
70
1999
2000
2001
Daily Modeled at RR-06
Daily Observed at RR-06

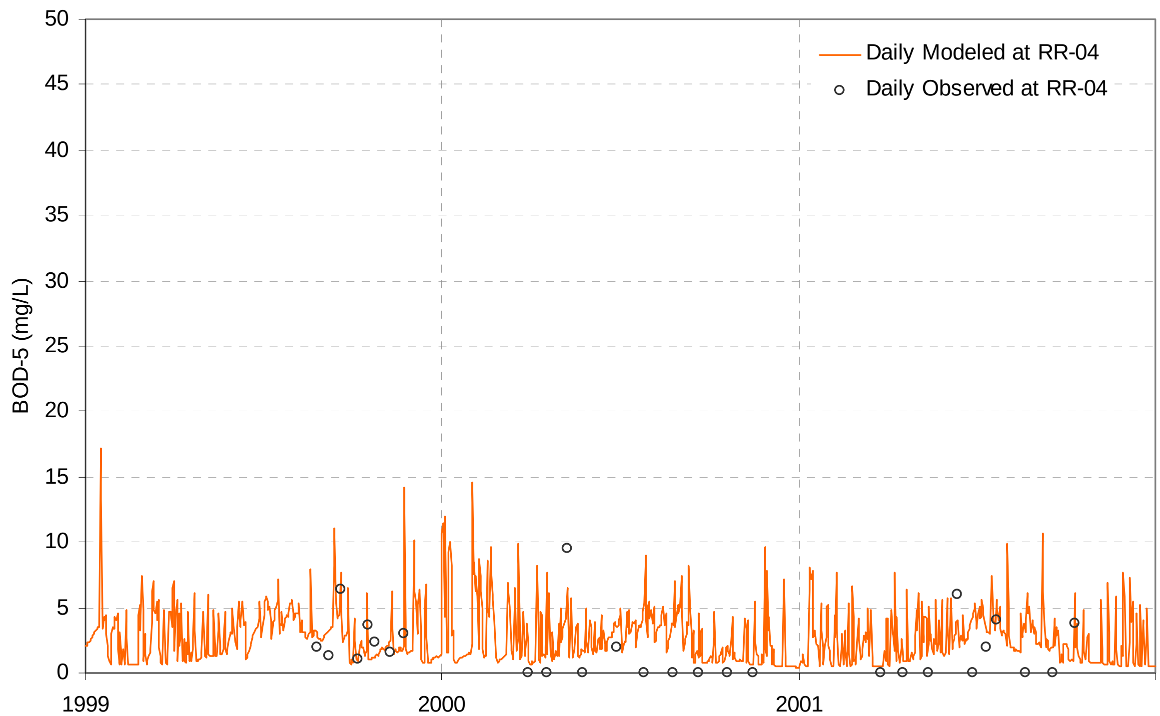
ATTACHMENT F – CALIBRATION PLOTS FOR BOD AND DISSOLVED OXYGEN


Daily Modeled at RR-01
Daily Observed at RR-01
BOD-5 (mg/L)
50
45
40
35
30
25
20
15
10
5
0
1999
2000
2001

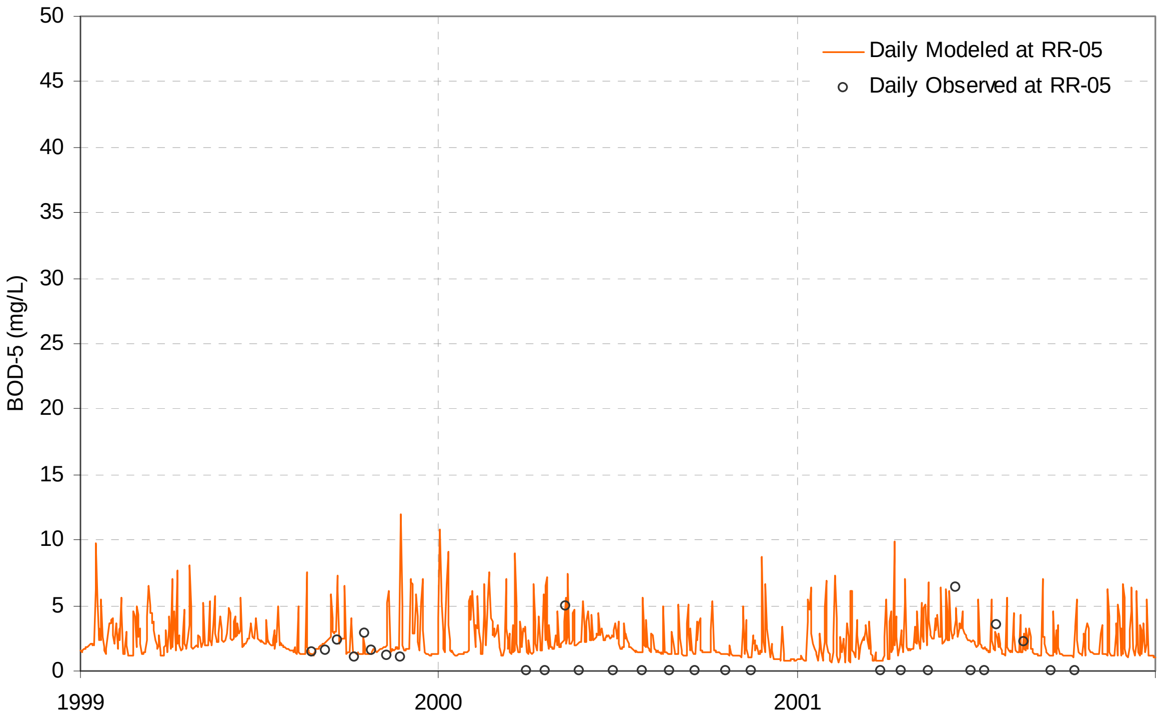

Daily Modeled at RR-02
Daily Observed at RR-02
BOD-5 (mg/L)
50
45
40
35
30
25
20
15
10
5
0
1999
2000
2001



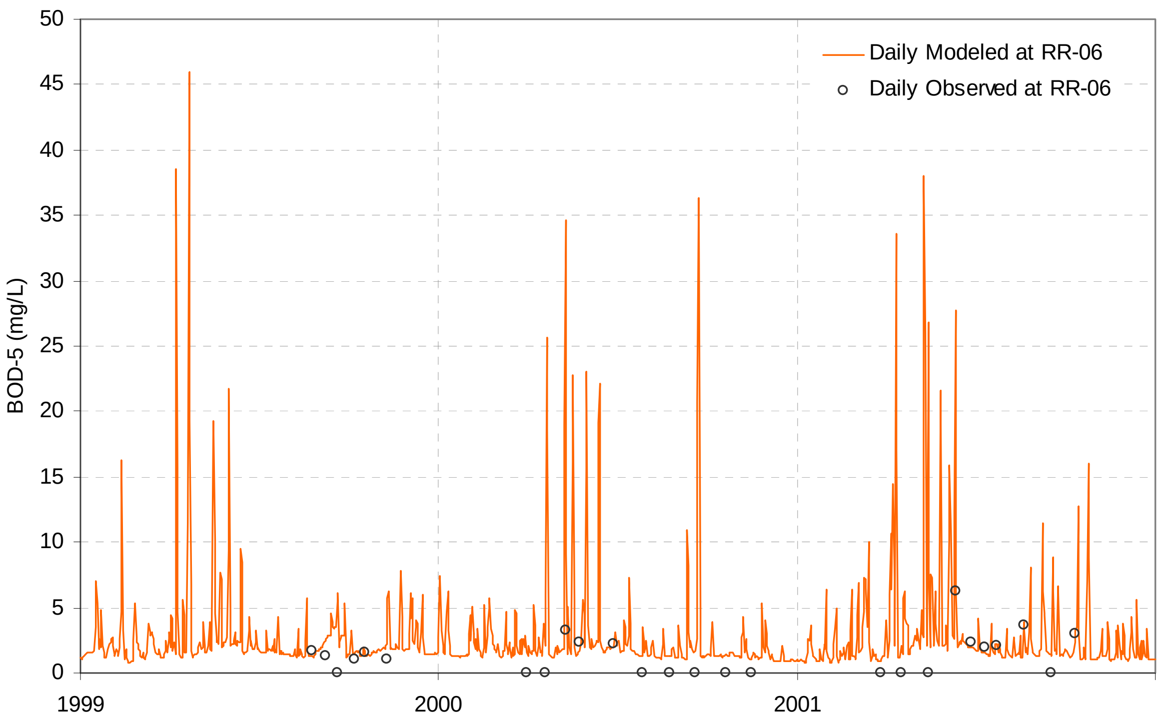
50
45
40
35
30
25
20
15
10
5
0
BOD-5 (mg/L)
1999
2000
2001
Daily Modeled at RR-03
Daily Observed at RR-03



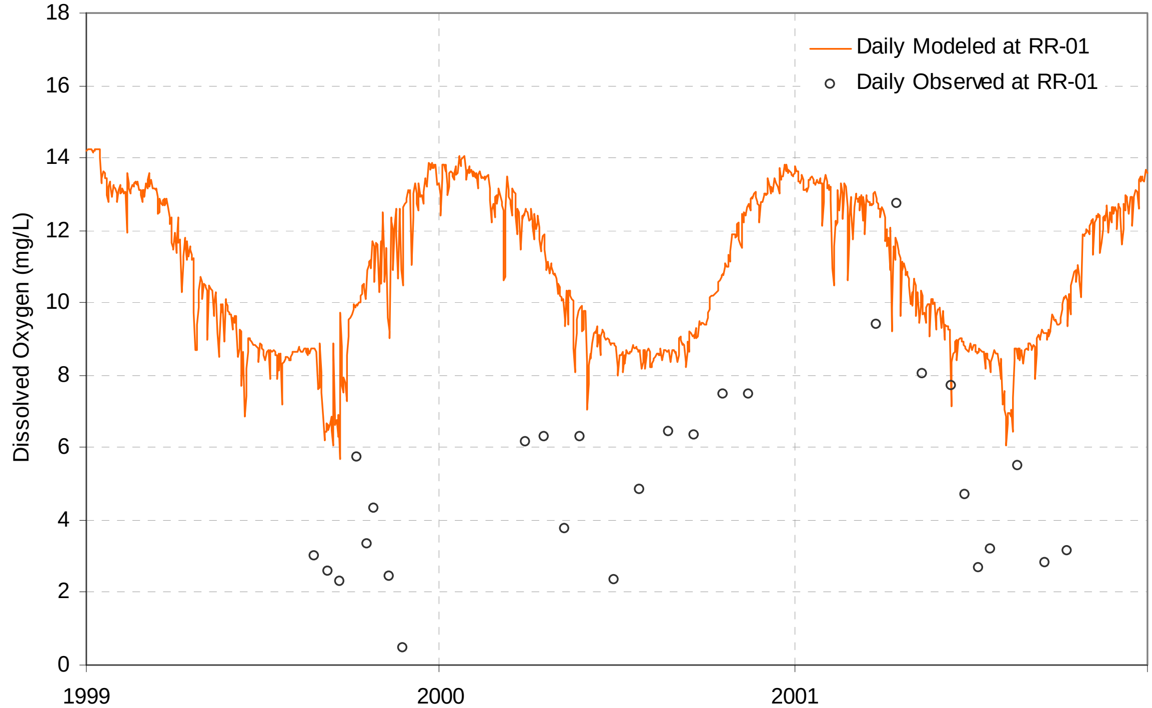
50
45
40
35
30
25
20
15
10
5
0
BOD-5 (mg/L)
1999
2000
2001
Daily Modeled at RR-04
Daily Observed at RR-04



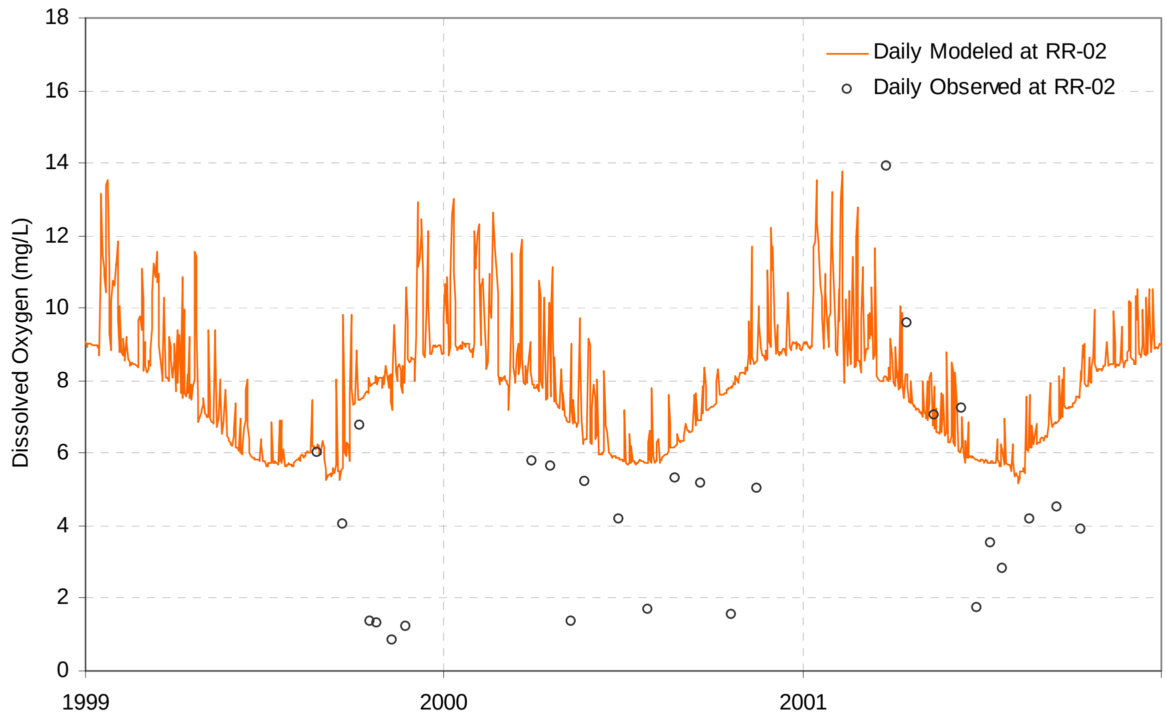
Daily Modeled at RR-05
Daily Observed at RR-05
BOD-5 (mg/L)
50
45
40
35
30
25
20
15
10
5
0
1999
2000
2001



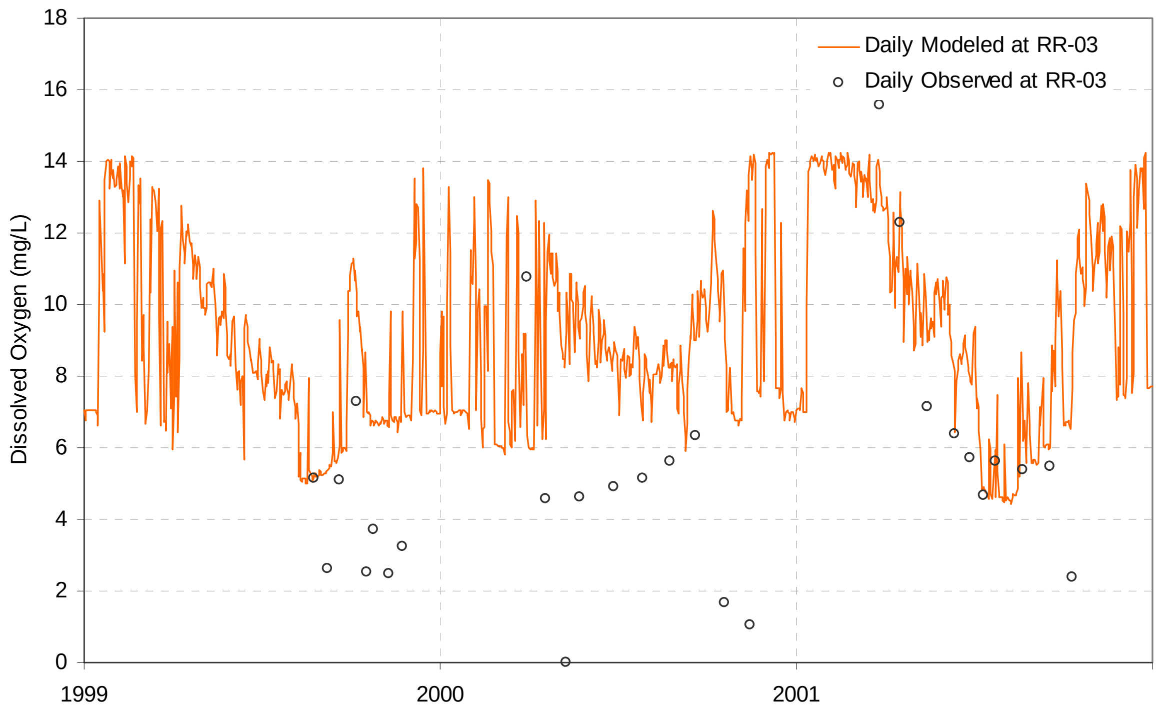
Daily Modeled at RR-06
Daily Observed at RR-06
BOD-5 (mg/L)
50
45
40
35
30
25
20
15
10
5
0
1999
2000
2001

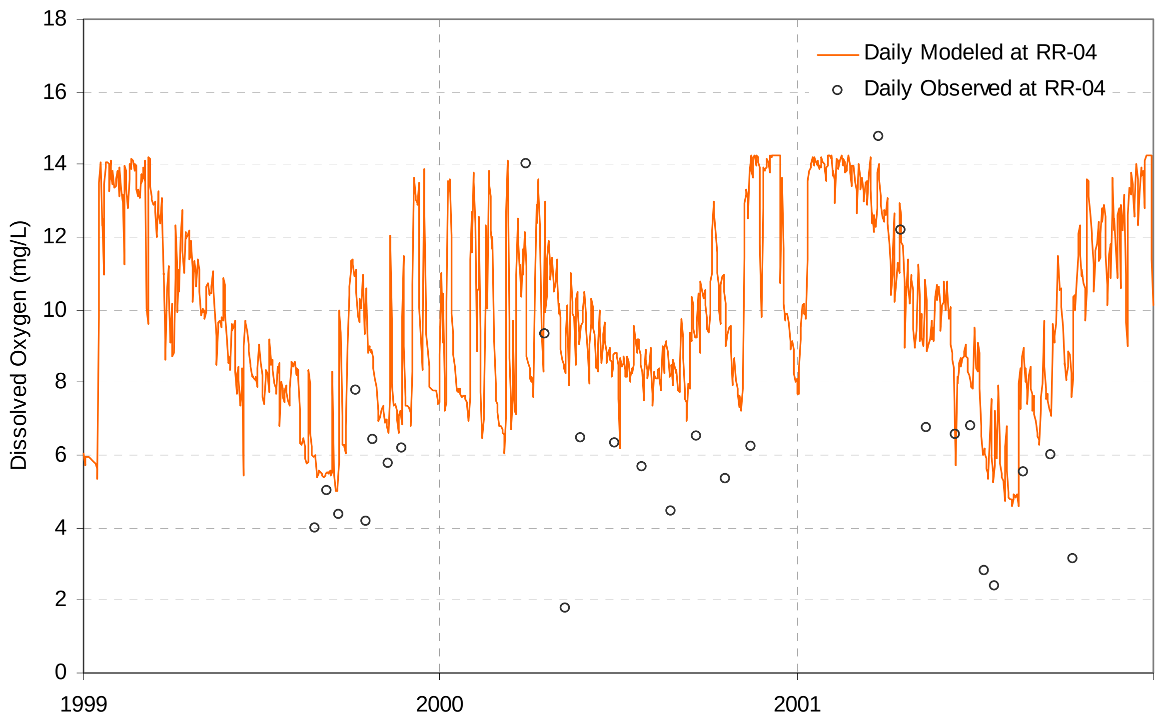


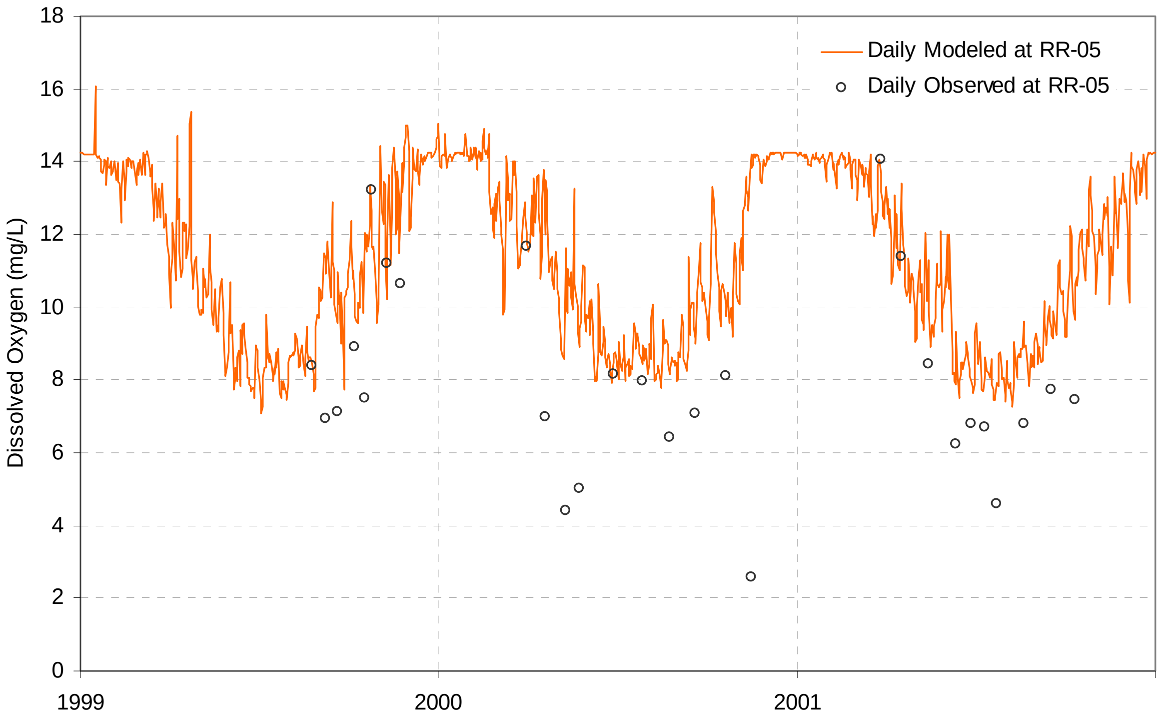
Daily Modeled at RR-01
Daily Observed at RR-01
Dissolved Oxygen (mg/L)
0
2
4
6
8
10
12
14
16
18
1999
2000
2001

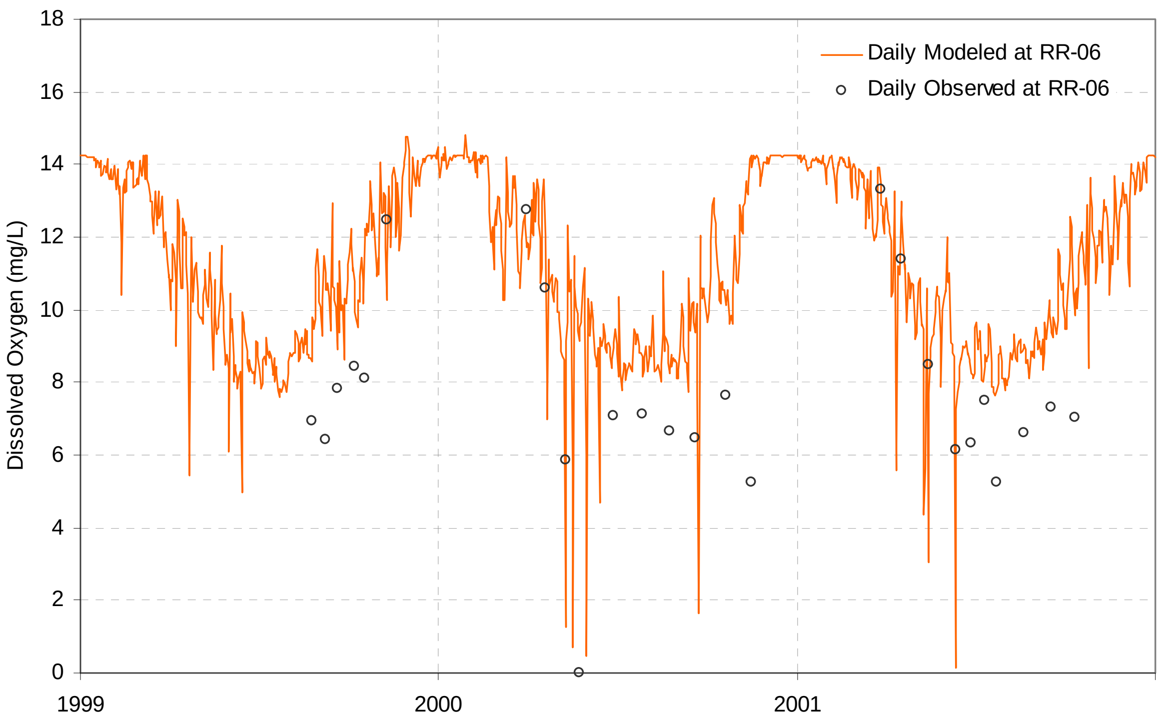


Daily Modeled at RR-02
Daily Observed at RR-02
Dissolved Oxygen (mg/L)
0
2
4
6
8
10
12
14
16
18
1999
2000
2001

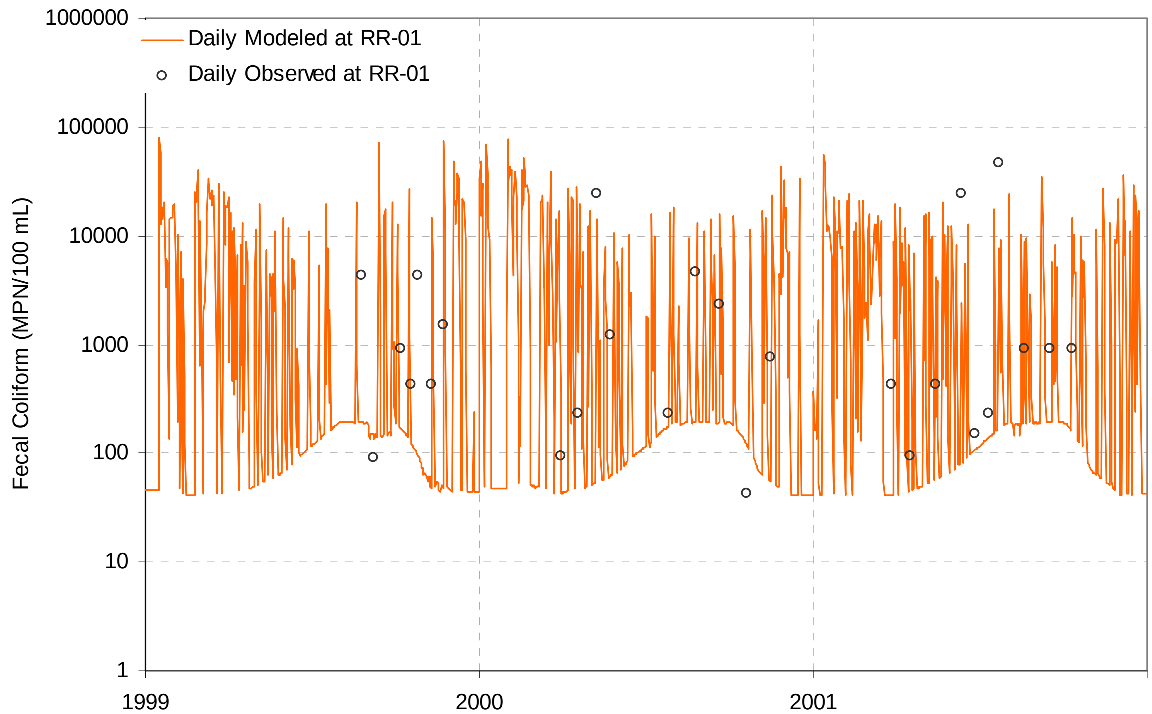

Daily Modeled at RR-03
Daily Observed at RR-03
Dissolved Oxygen (mg/L)
18
16
14
12
10
8
6
4
2
0
1999
2000
2001


Daily Modeled at RR-04
Daily Observed at RR-04
Dissolved Oxygen (mg/L)
18
16
14
12
10
8
6
4
2
0
1999
2000
2001

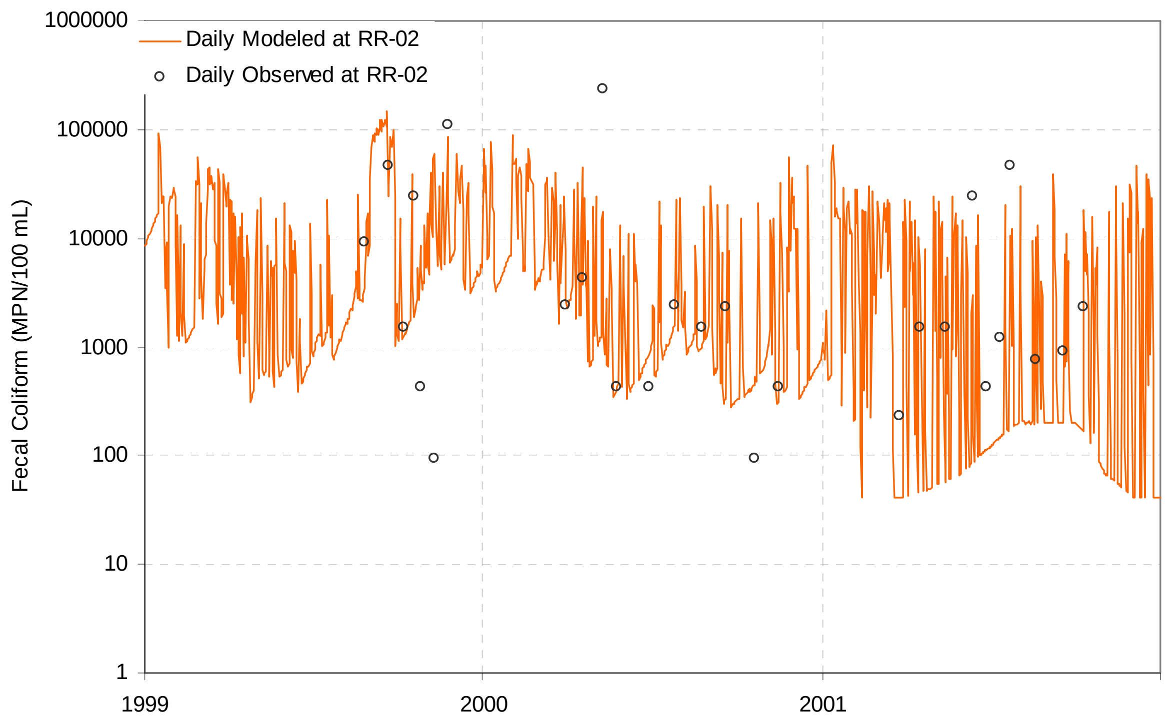

Daily Modeled at RR-05
Daily Observed at RR-05
Dissolved Oxygen (mg/L)
18
16
14
12
10
8
6
4
2
0
1999
2000
2001


Daily Modeled at RR-06
Daily Observed at RR-06
Dissolved Oxygen (mg/L)
18
16
14
12
10
8
6
4
2
0
1999
2000
2001

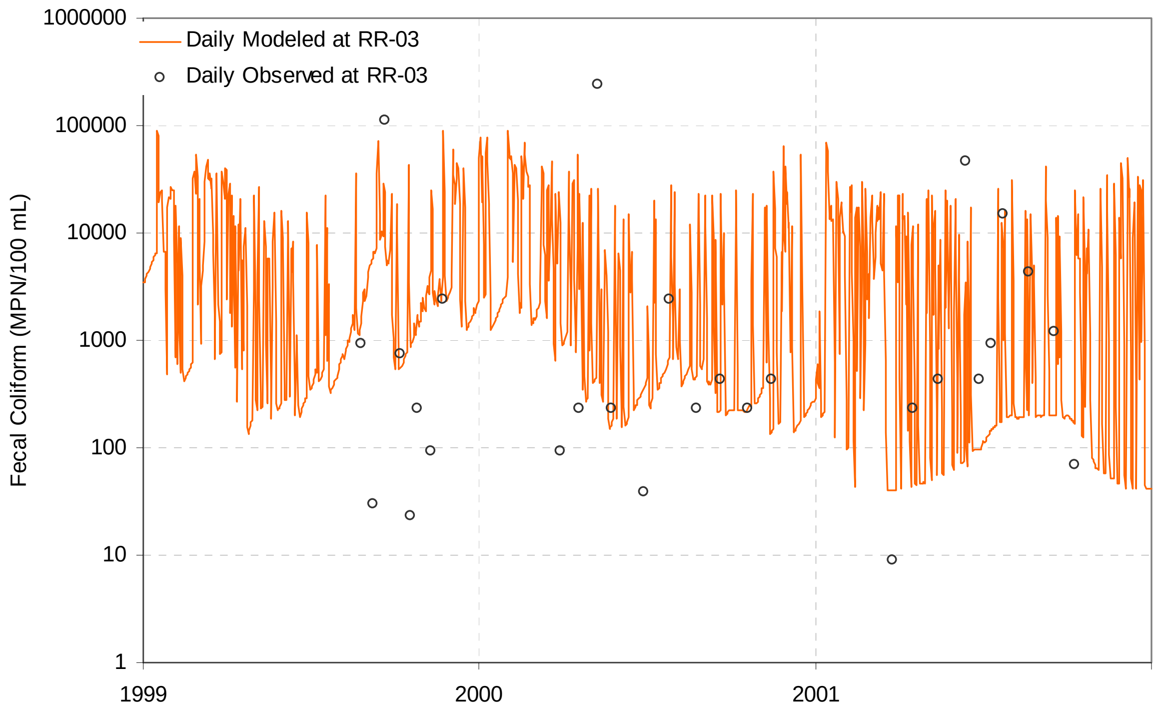
ATTACHMENT G – CALIBRATION PLOTS FOR FECAL COLIFORM

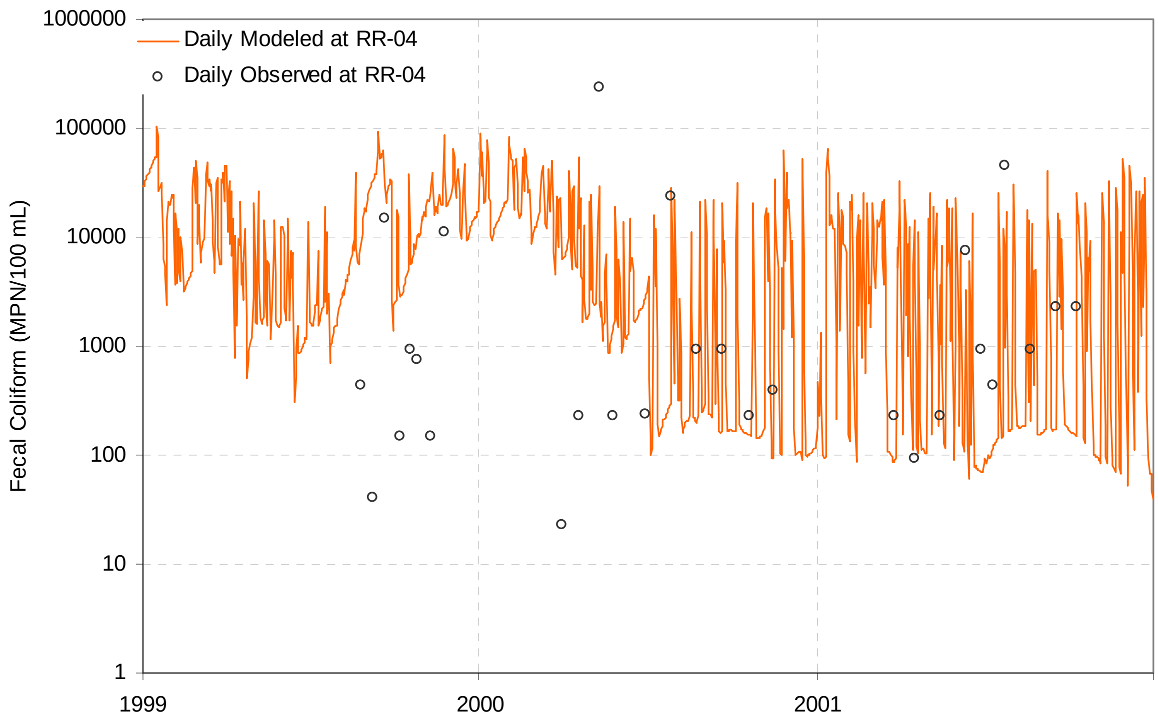


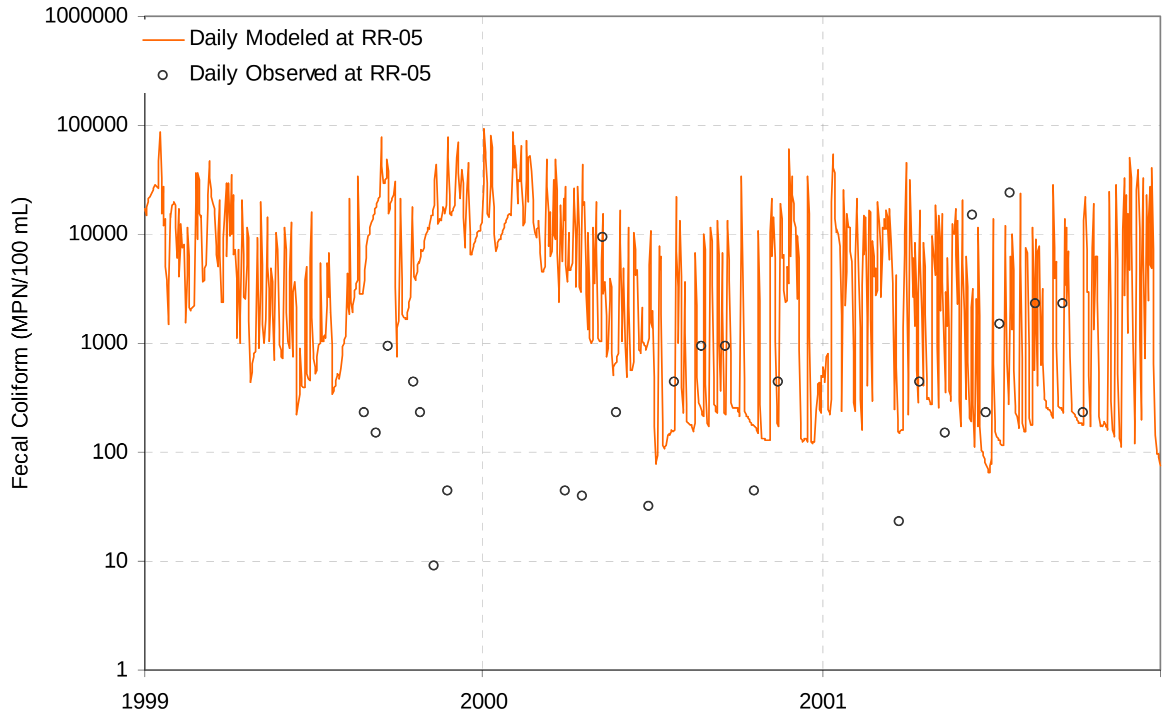
Daily Modeled at RR-01
Daily Observed at RR-01
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
1999
2000
2001

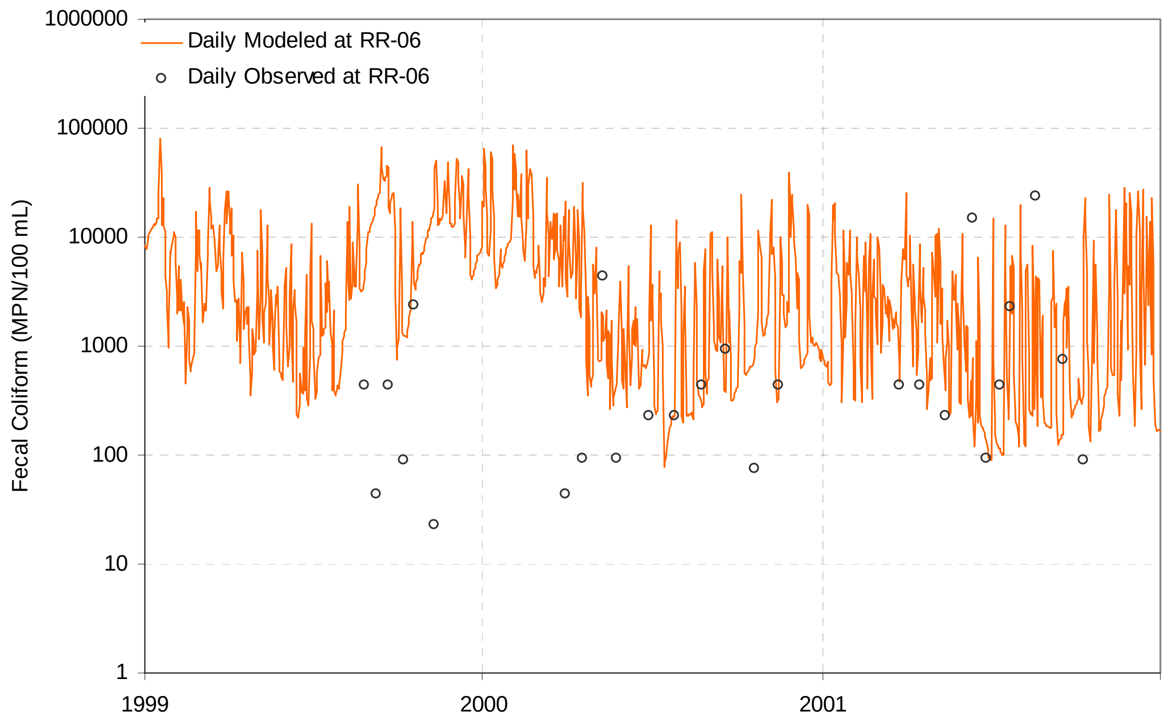


Daily Modeled at RR-02
Daily Observed at RR-02
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
1999
2000
2001

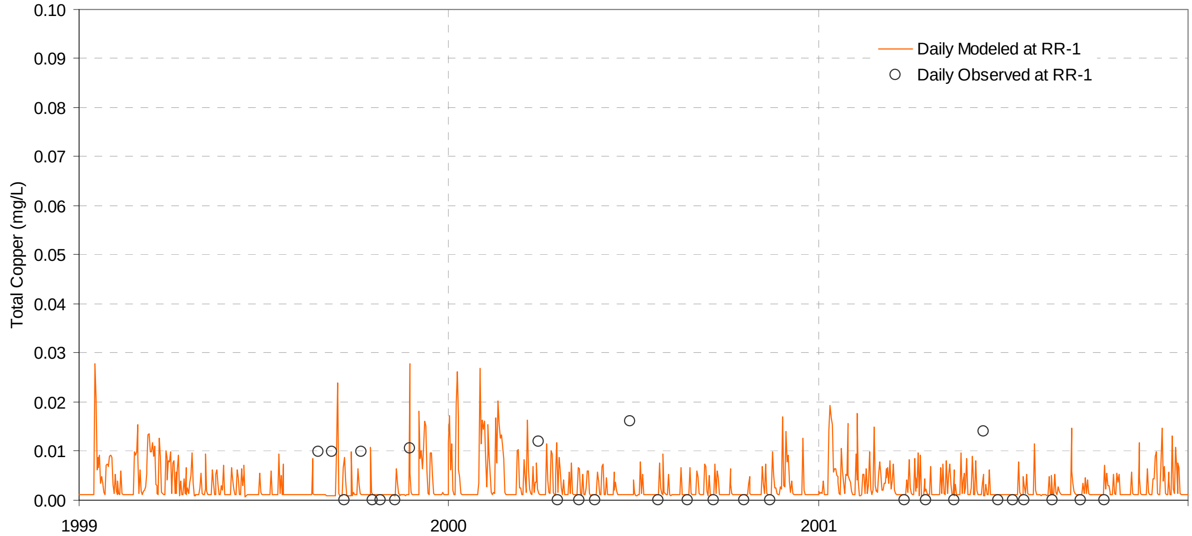

Daily Modeled at RR-03
Daily Observed at RR-03
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
1999
2000
2001


Daily Modeled at RR-04
Daily Observed at RR-04
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
1999
2000
2001

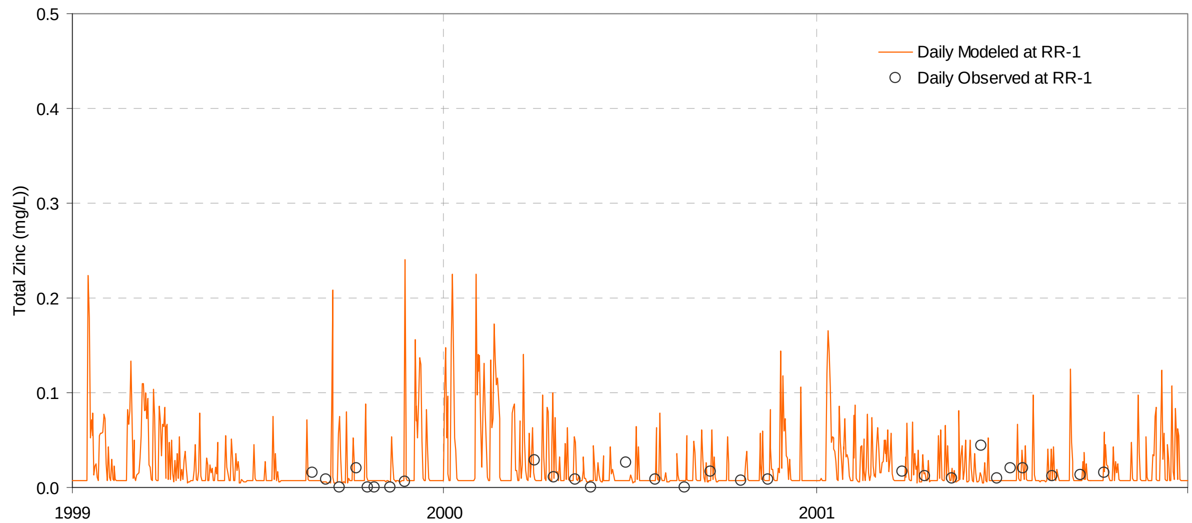

Daily Modeled at RR-05
Daily Observed at RR-05
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
1999
2000
2001


Daily Modeled at RR-06
Daily Observed at RR-06
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
1999
2000
2001

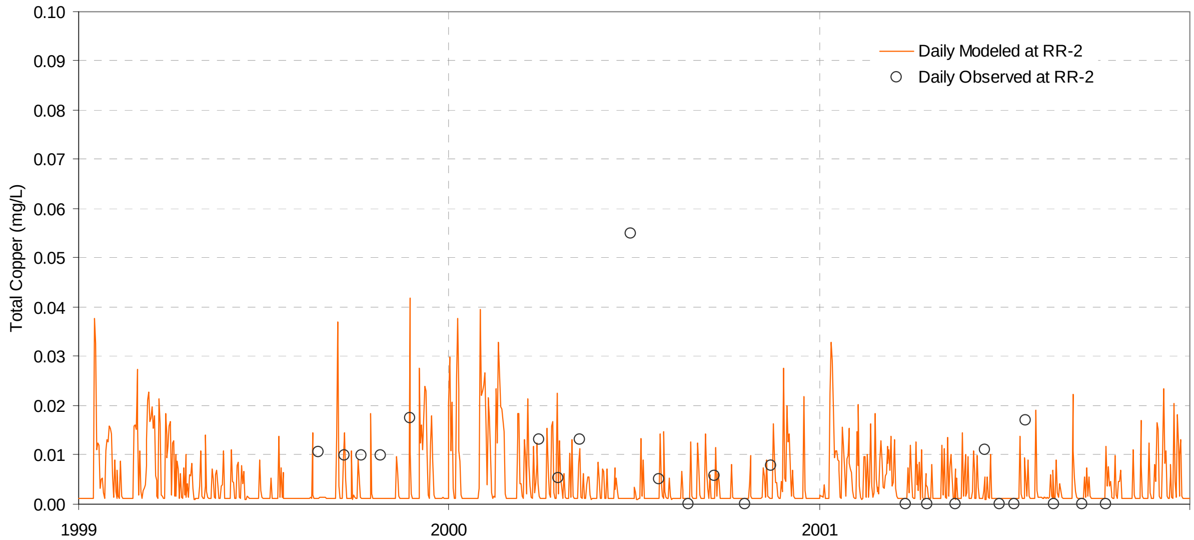
ATTACHMENT H – CALIBRATION PLOTS FOR COPPER AND ZINC



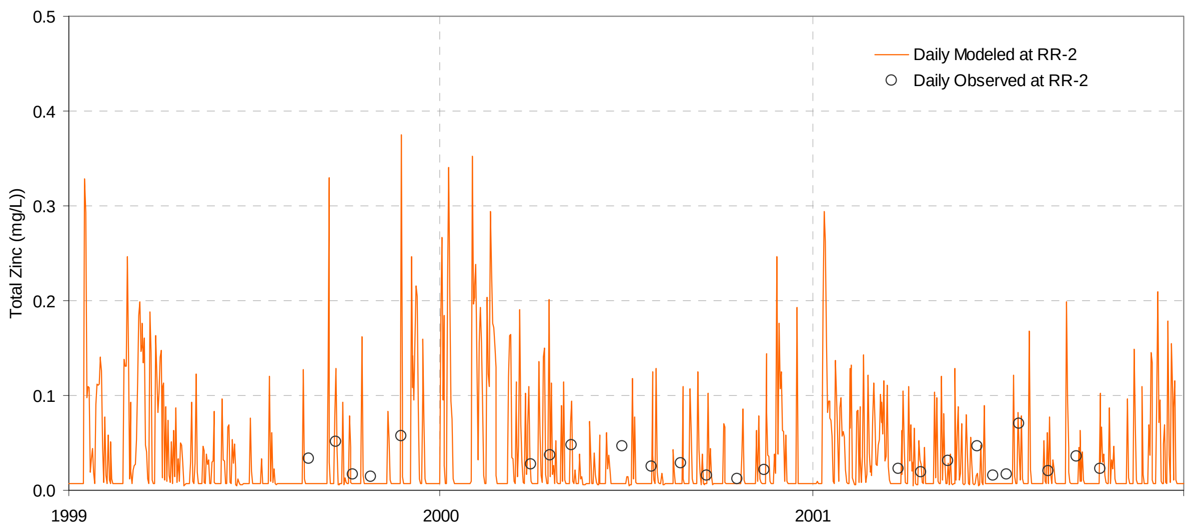
Total Copper (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1999
2000
2001
Daily Modeled at RR-1
Daily Observed at RR-1



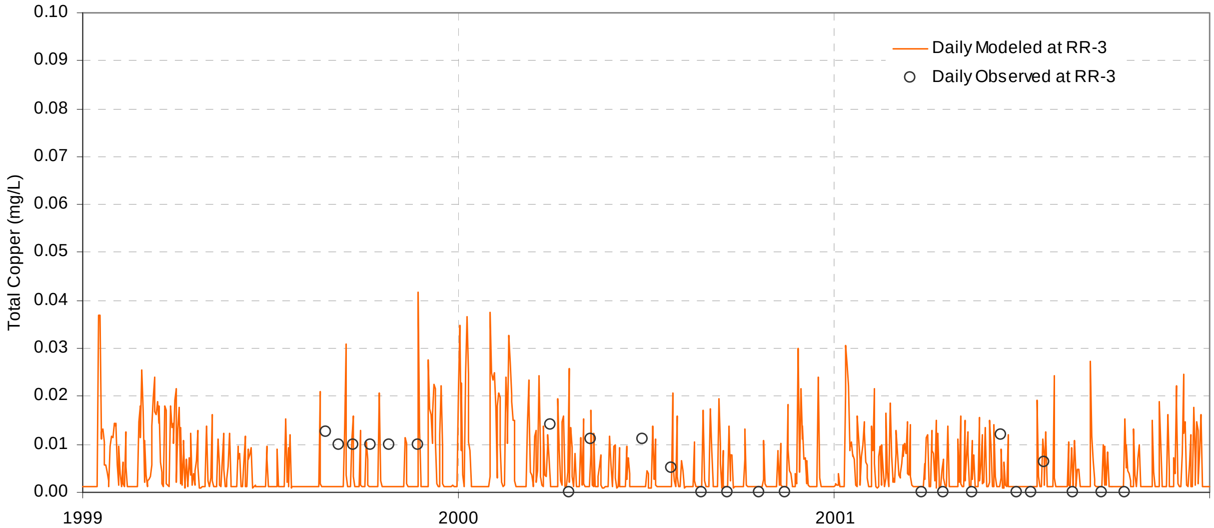
Total Zinc (mg/L))
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001
Daily Modeled at RR-1
Daily Observed at RR-1



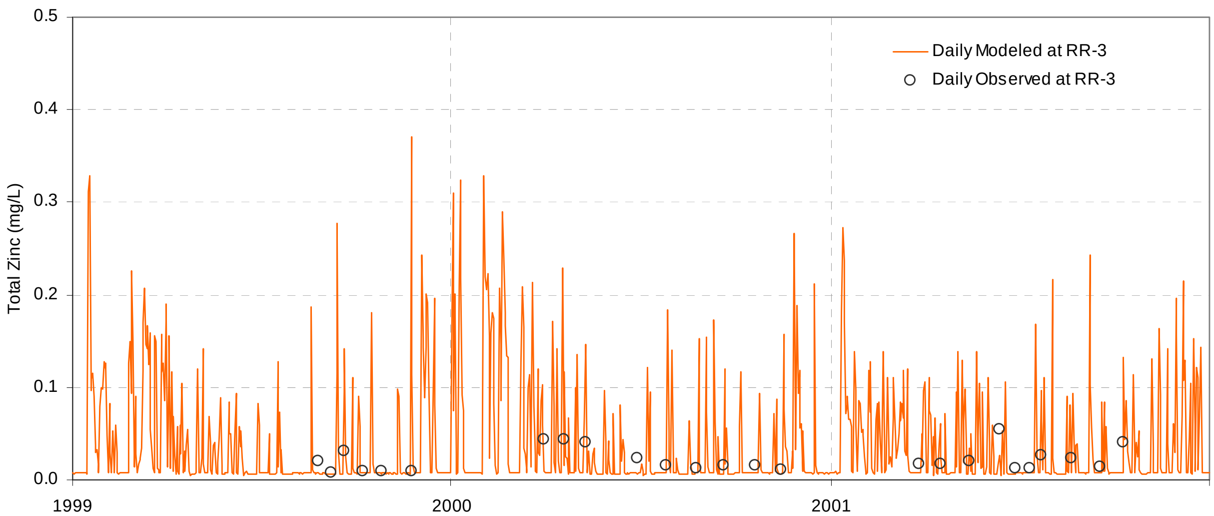
Daily Modeled at RR-2
Daily Observed at RR-2
Total Copper (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1999
2000
2001



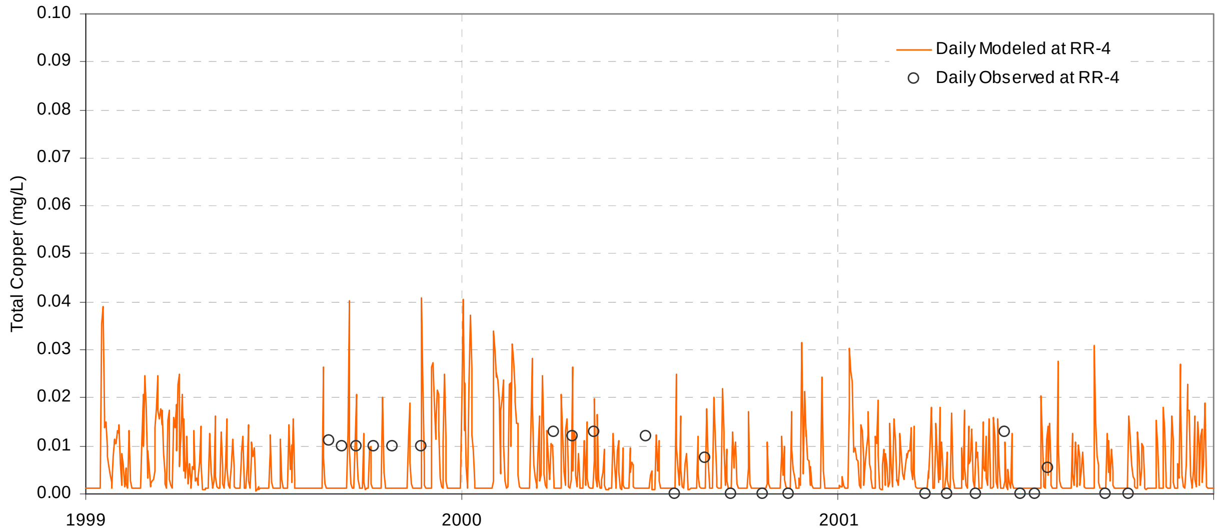
Daily Modeled at RR-2
Daily Observed at RR-2
Total Zinc (mg/L))
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001



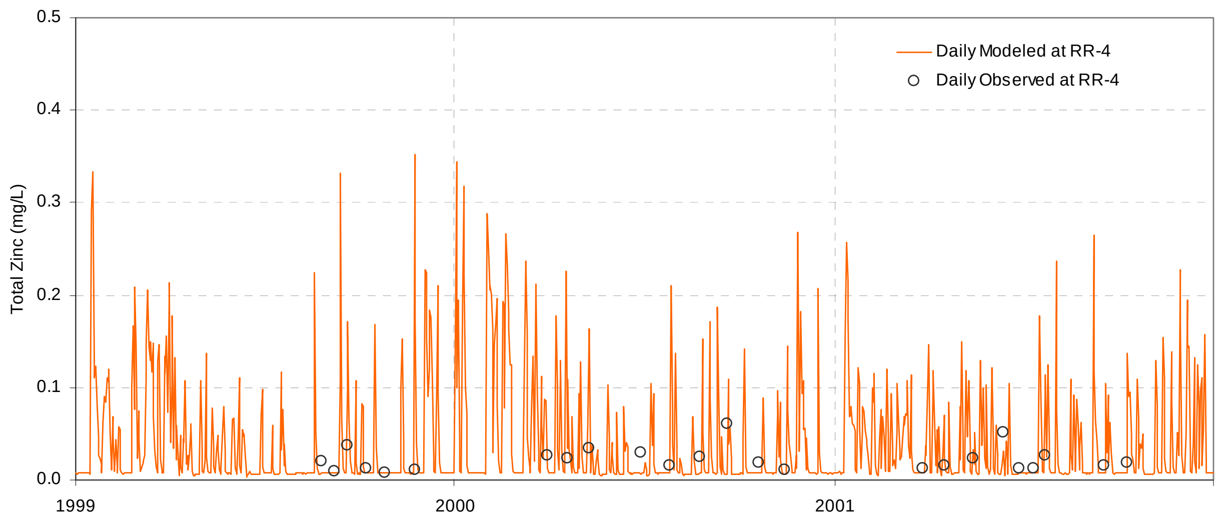
Daily Modeled at RR-3
Daily Observed at RR-3
Total Copper (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1999
2000
2001



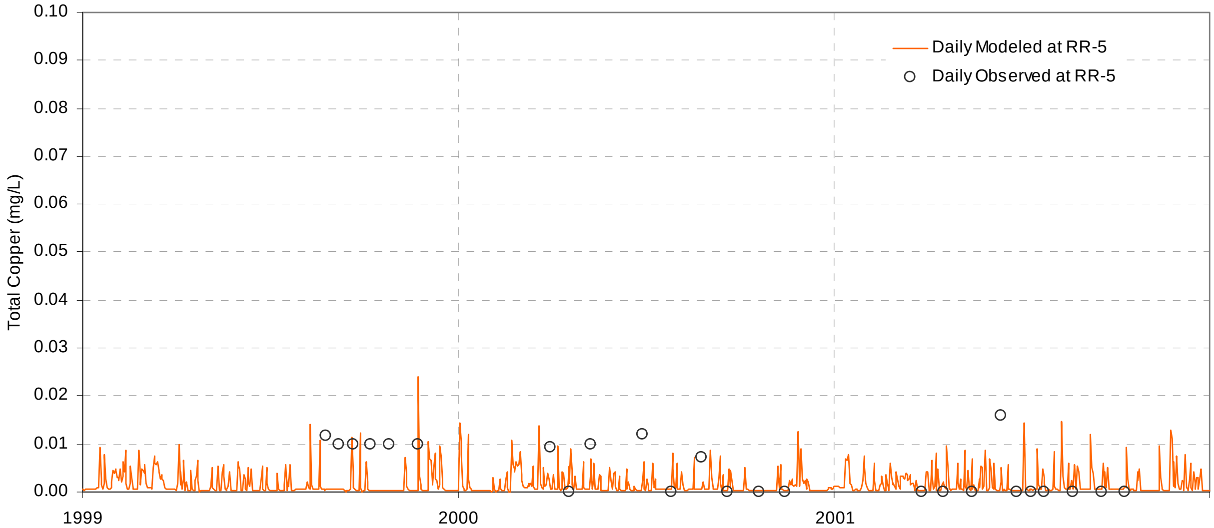
Daily Modeled at RR-3
Daily Observed at RR-3
Total Zinc (mg/L)
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001

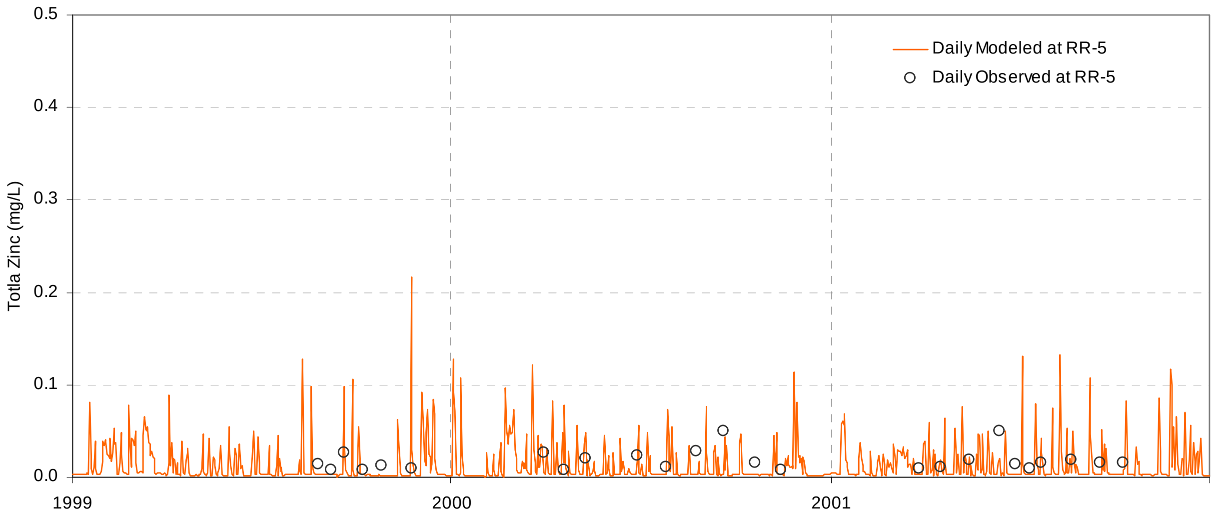


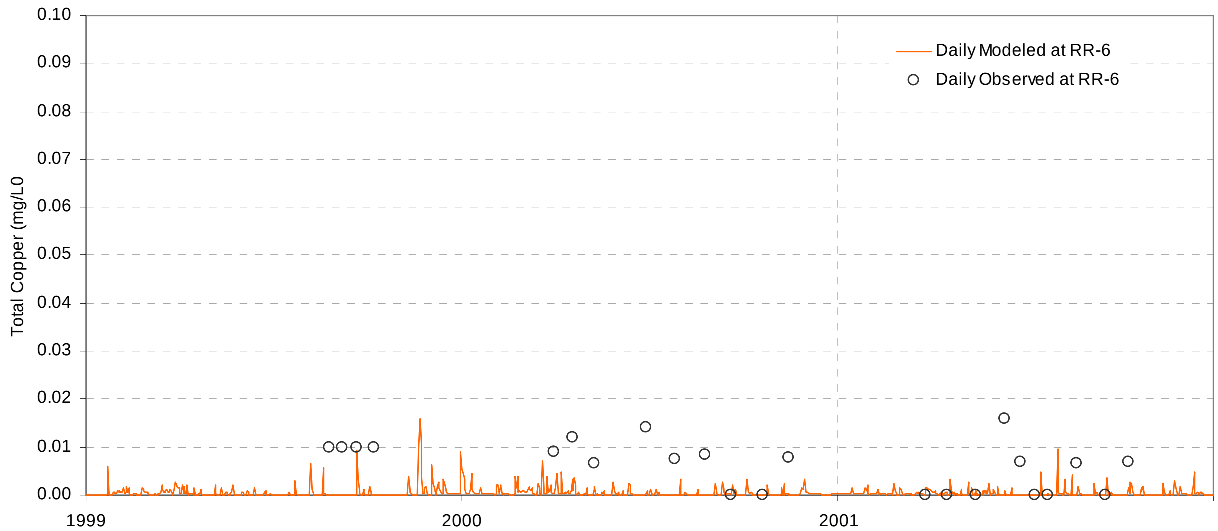
Daily Modeled at RR-4
Daily Observed at RR-4
Total Copper (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1999
2000
2001

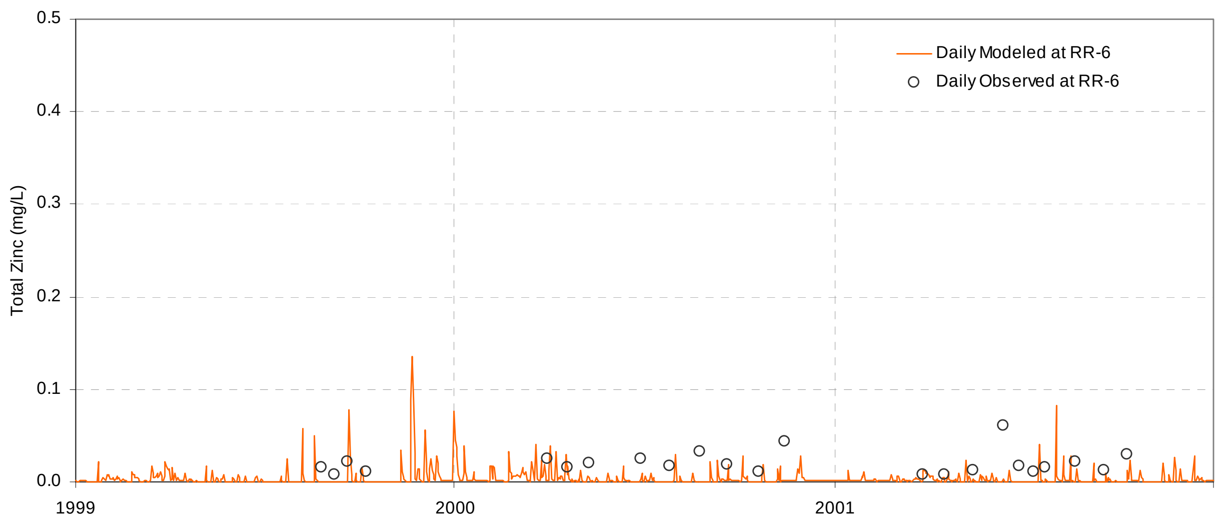


Daily Modeled at RR-4
Daily Observed at RR-4
Total Zinc (mg/L)
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001

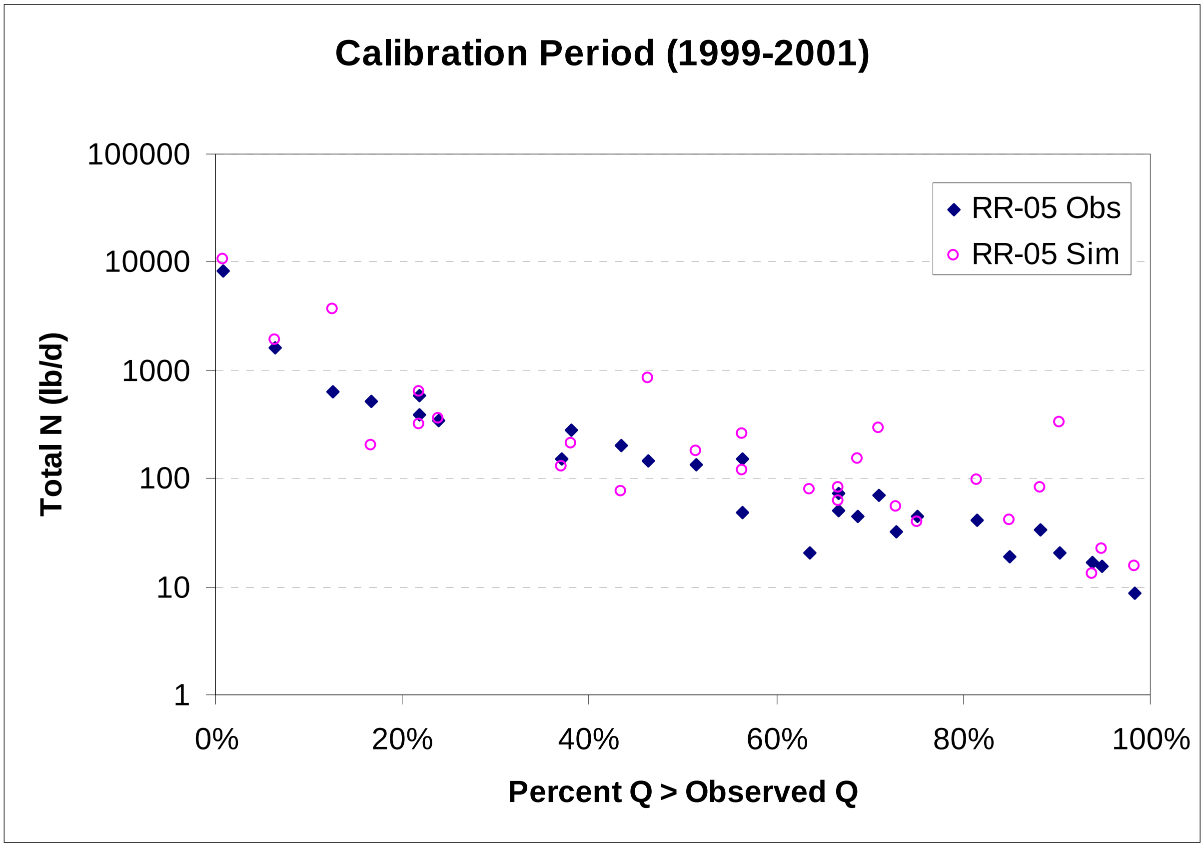

Total Copper (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1999
2000
2001
Daily Modeled at RR-5
Daily Observed at RR-5

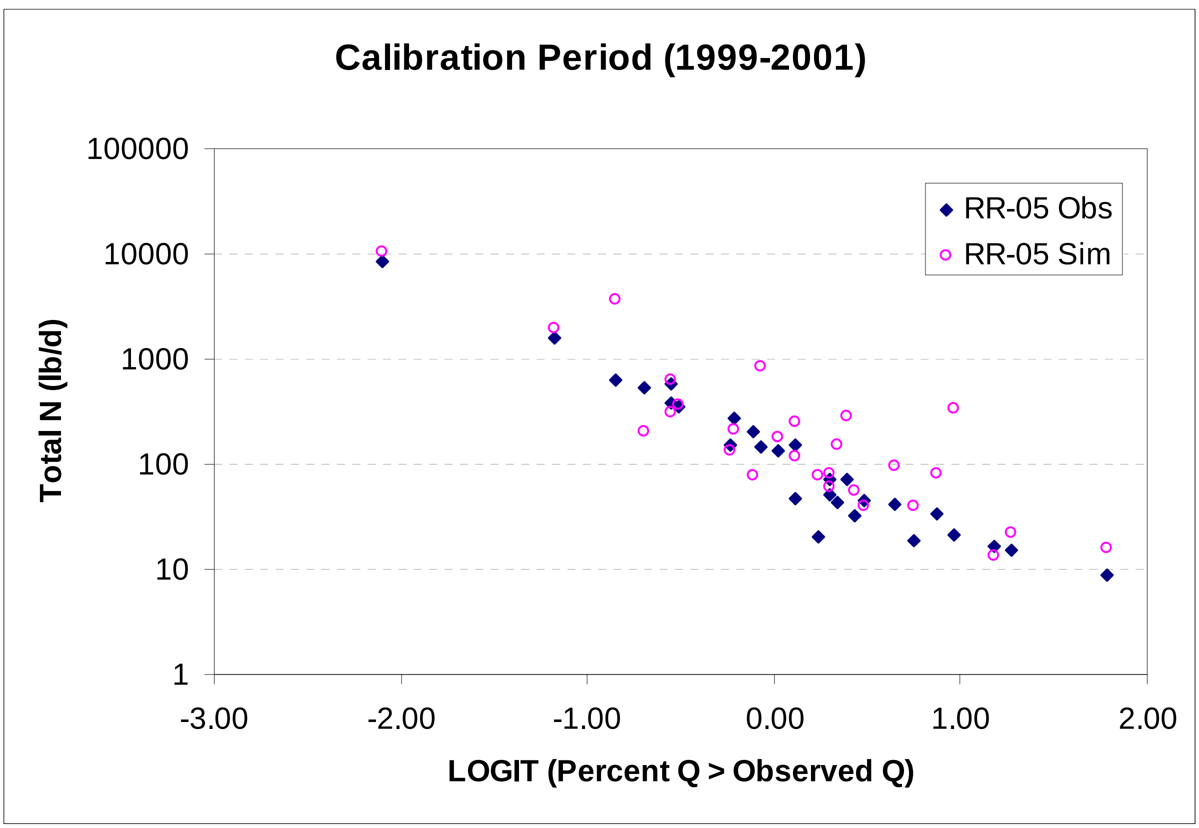

Totla Zinc (mg/L)
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001
Daily Modeled at RR-5
Daily Observed at RR-5


Total Copper (mg/L0
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1999
2000
2001
Daily Modeled at RR-6
Daily Observed at RR-6


Total Zinc (mg/L)
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001
Daily Modeled at RR-6
Daily Observed at RR-6

ATTACHMENT I – LOAD-DURATION ANALYSIS RESULTS


Calibration Period (1999-2001)
Total N (lb/d)
100000
10000
1000
100
10
1
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RR-05 Obs
RR-05 Sim


Calibration Period (1999-2001)
Total N (lb/d)
100000
10000
1000
100
10
1
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RR-05 Obs
RR-05 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.0074	4.872893
0.127352	0.167967
0.992015	0.138162
248.4619	2
4.302653	
0.54795	
-2.55535	
-1.45945	

0-20% - Sim

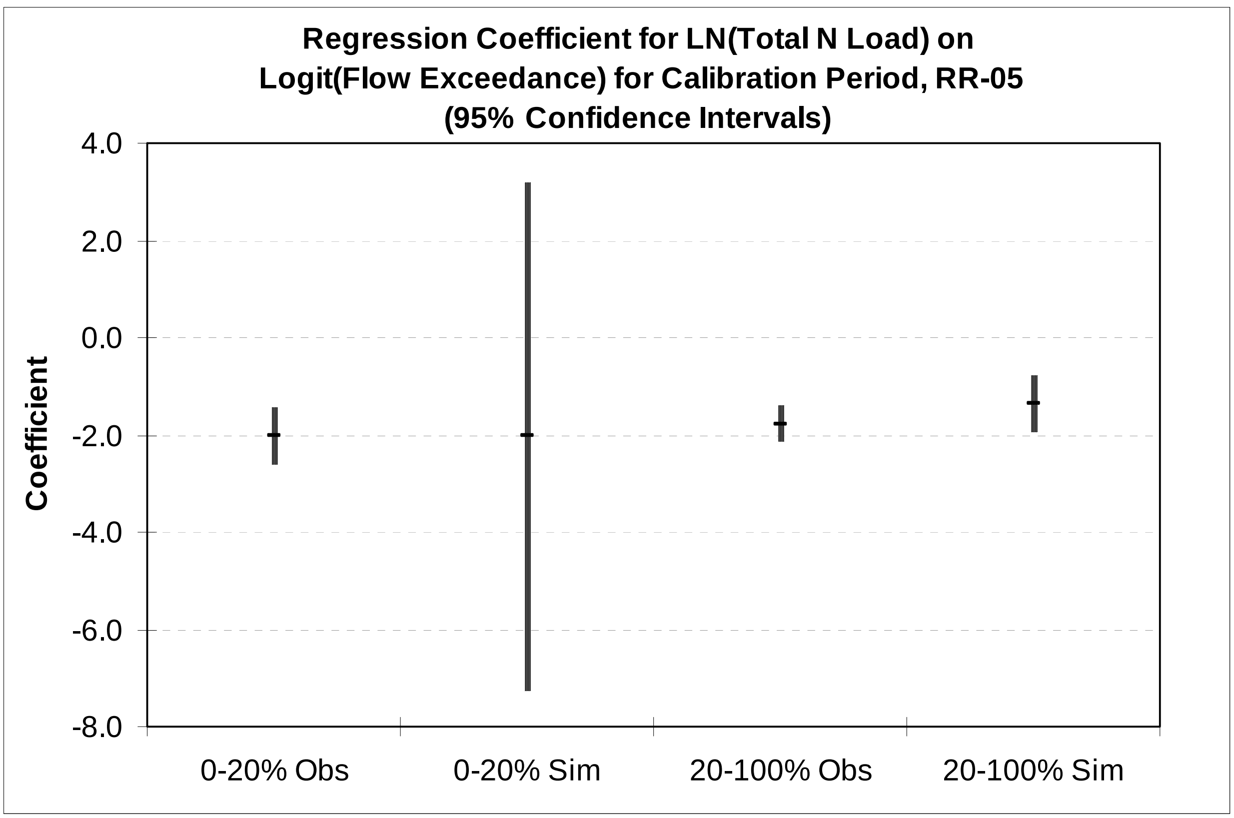
-2.03819	5.141096
1.202292	1.58573
0.589651	1.304349
2.873897	2
4.302653	
5.173045	
-7.21124	
3.134851	

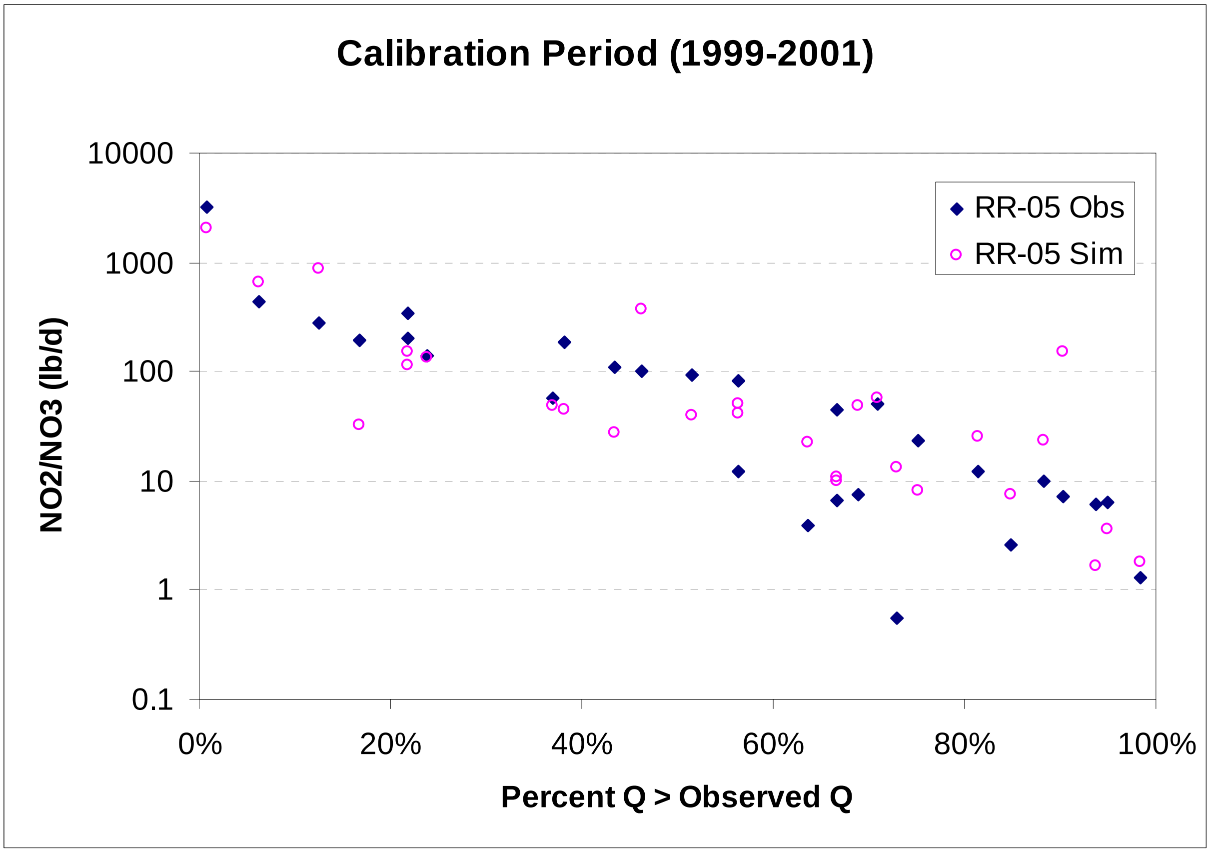
20-100% - Obs

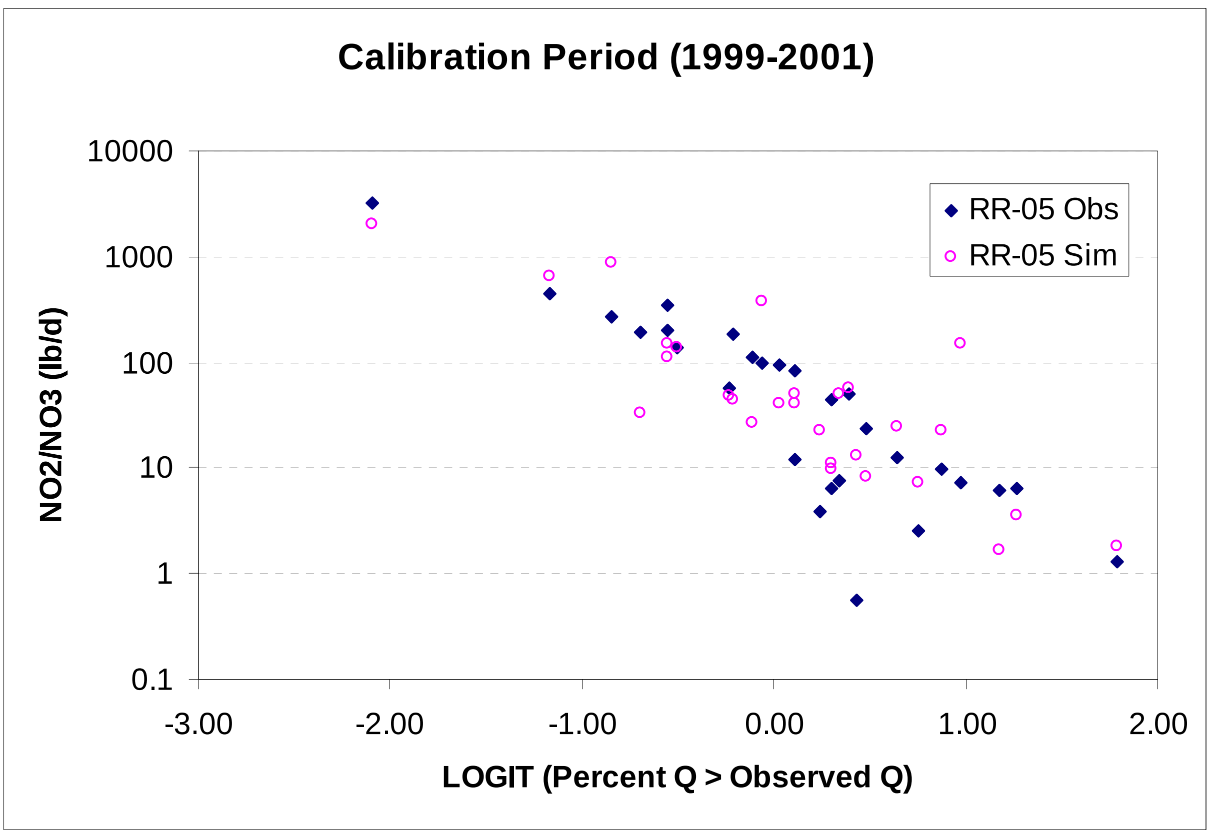
-1.77539	4.772662
0.15915	0.106898
0.849772	0.455064
124.4444	22
2.073873	
0.330056	
-2.10545	
-1.44533	

20-100% - Sim

-1.35403	5.161518
0.262827	0.176536
0.546773	0.751513
26.5408	22
2.073873	
0.545071	
-1.8991	
-0.80896	




Calibration Period (1999-2001)
10000
1000
100
10
1
0.1
0%
20%
40%
60%
80%
100%
NO2/NO3 (lb/d)
Percent Q > Observed Q
RR-05 Obs
RR-05 Sim


Calibration Period (1999-2001)
10000
1000
100
10
1
0.1
-3.00
-2.00
-1.00
0.00
1.00
2.00
NO2/NO3 (lb/d)
LOGIT (Percent Q > Observed Q)
RR-05 Obs
RR-05 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.99692	3.851811
0.089299	0.117778
0.996016	0.096879
500.0693	2
4.302653	
0.384222	
-2.38114	
-1.6127	

0-20% - Sim

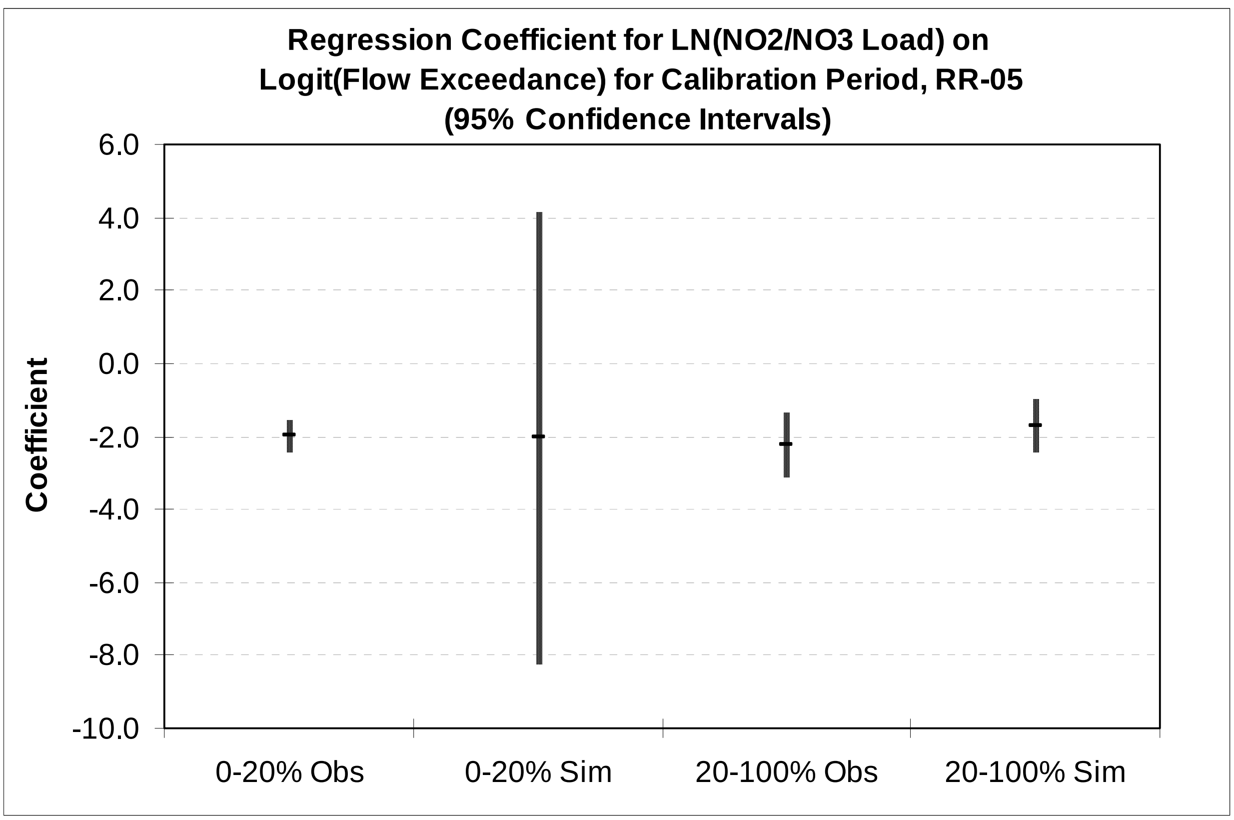
-2.04482	3.630546
1.429753	1.885734
0.505617	1.551118
2.045448	2
4.302653	
6.151732	
-8.19655	
4.106911	

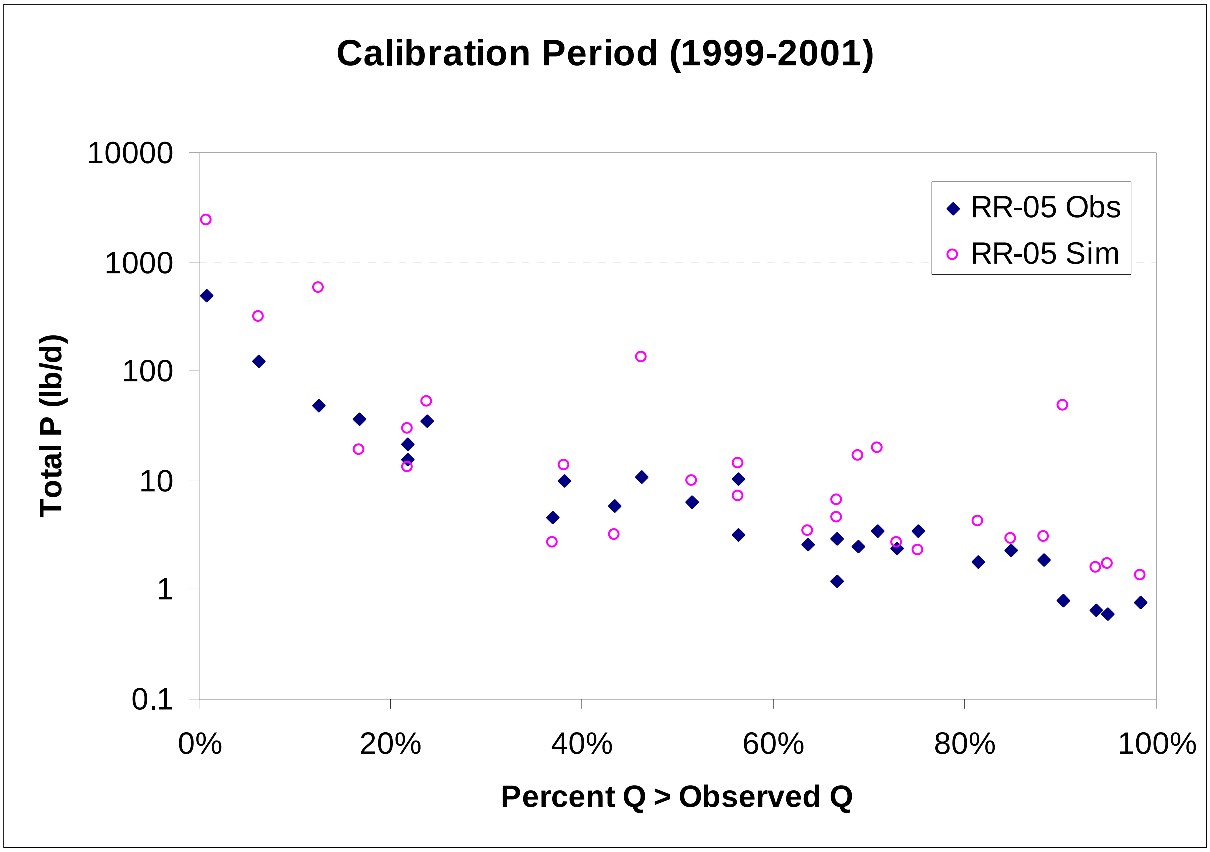
20-100% - Obs

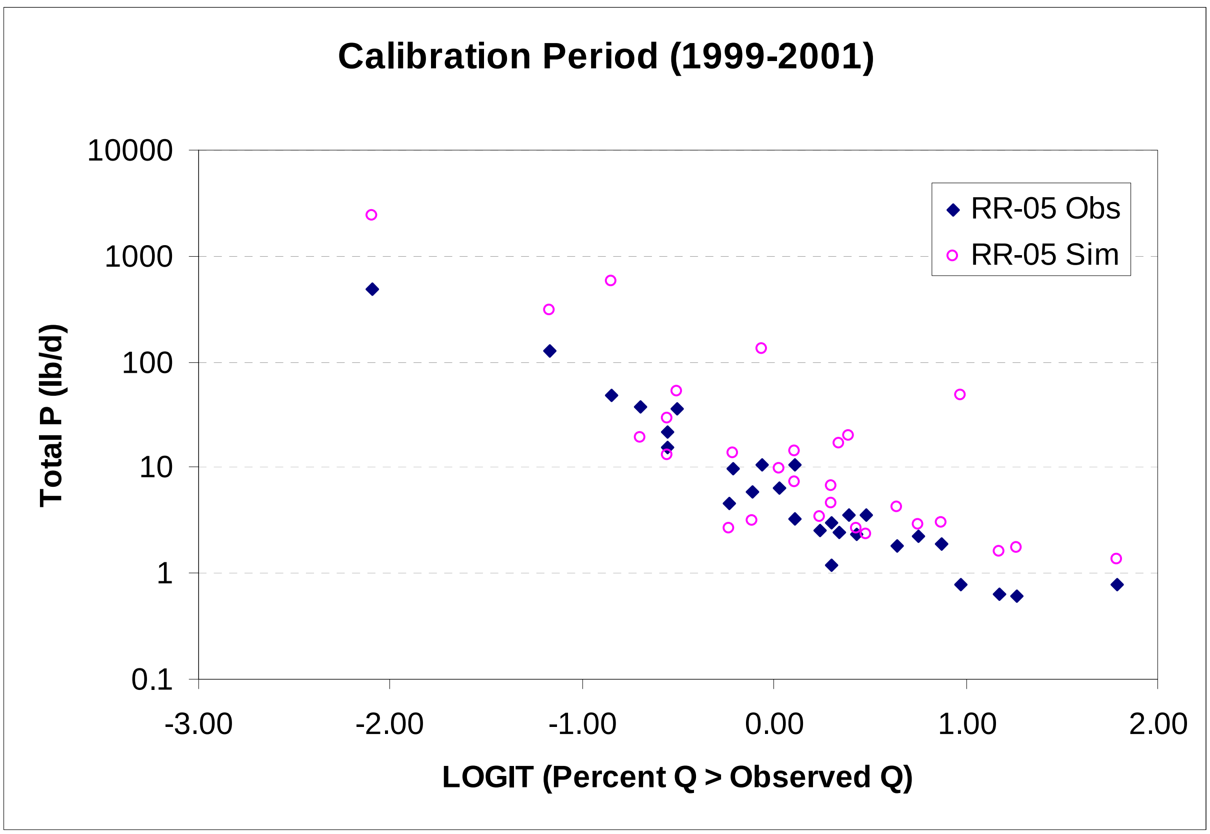
-2.24336	3.799105
0.392042	0.263328
0.598129	1.120983
32.74397	22
2.073873	
0.813046	
-3.05641	
-1.43031	

20-100% - Sim

-1.71458	3.860567
0.336692	0.226149
0.541026	0.962716
25.93298	22
2.073873	
0.698256	
-2.41284	
-1.01633	




Calibration Period (1999-2001)
Total P (lb/d)
10000
1000
100
10
1
0.1
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RR-05 Obs
RR-05 Sim


Calibration Period (1999-2001)
Total P (lb/d)
10000
1000
100
10
1
0.1
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RR-05 Obs
RR-05 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-1.85088	2.405259
0.191403	0.252446
0.97906	0.207651
93.51004	2
4.302653	
0.823543	
-2.67443	
-1.02734	

0-20% - Sim

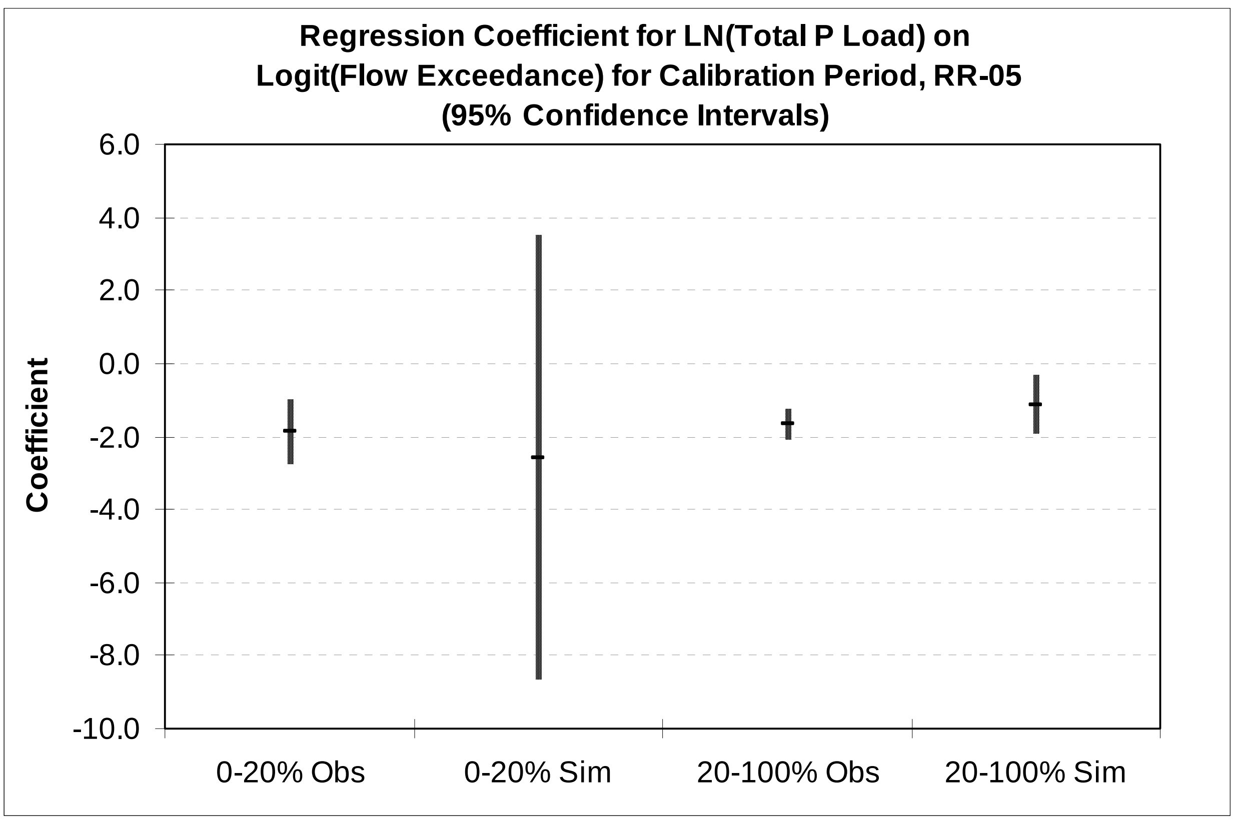
-2.5703	2.615701
1.401166	1.84803
0.627214	1.520104
3.365014	2
4.302653	
6.028732	
-8.59903	
3.458436	

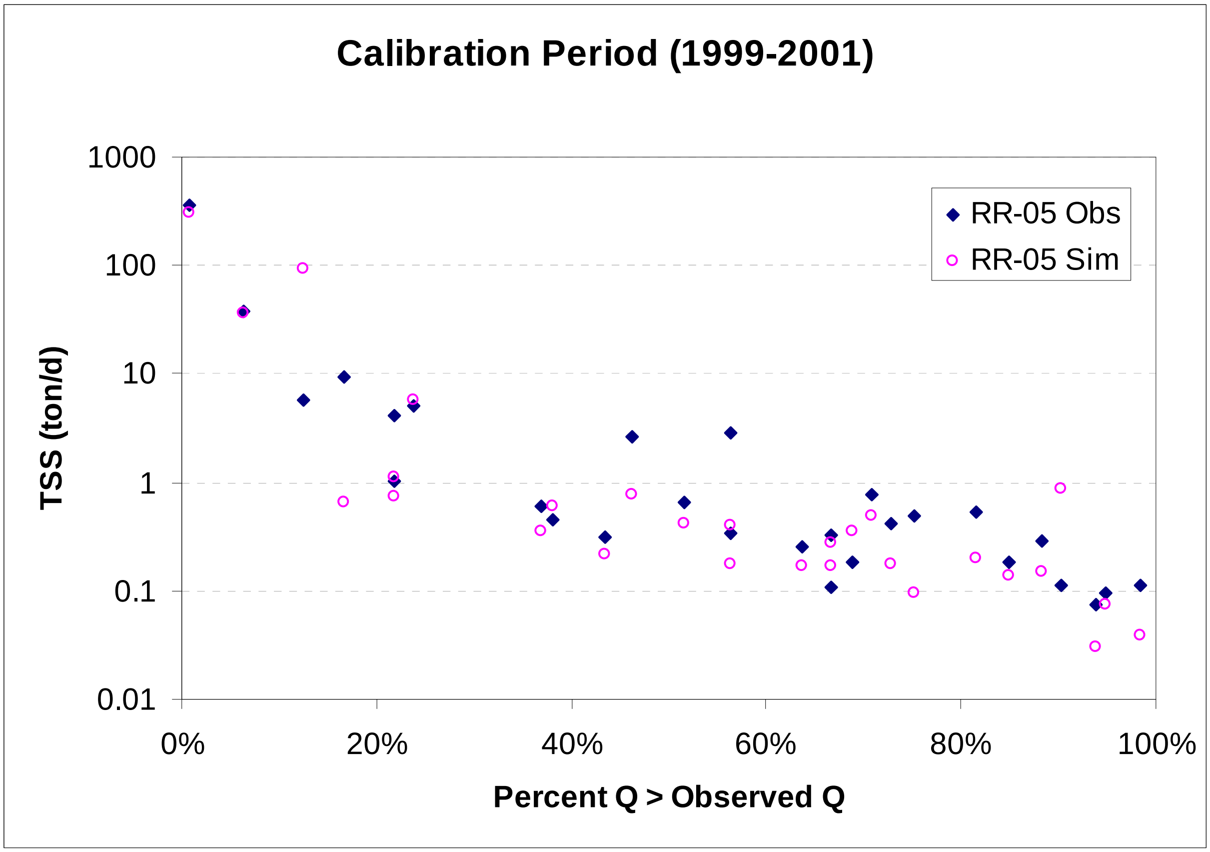
20-100% - Obs

-1.66564	1.797084
0.174832	0.117432
0.804904	0.499905
90.76503	22
2.073873	
0.36258	
-2.02822	
-1.30306	

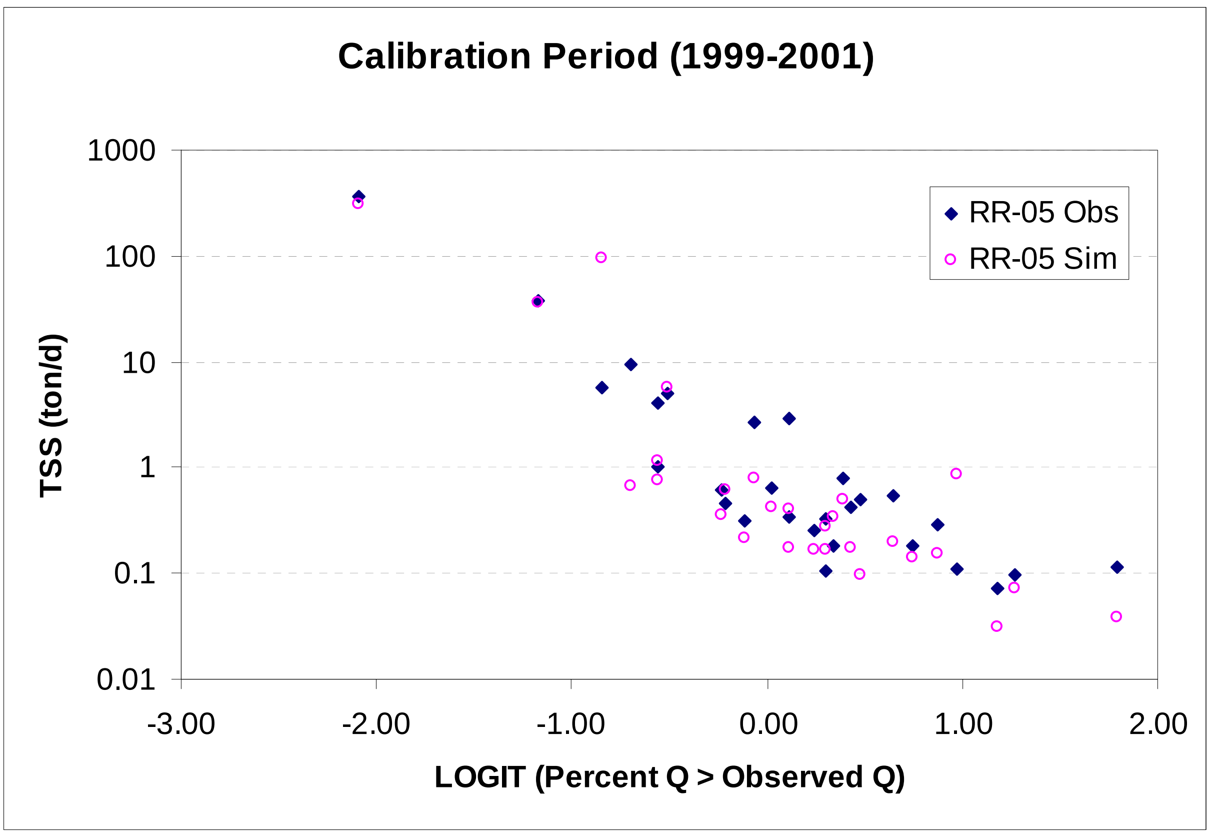
20-100% - Sim

-1.13306	2.363599
0.367969	0.247158
0.301179	1.05215
9.481603	22
2.073873	
0.763122	
-1.89618	
-0.36994	





Calibration Period (1999-2001)
1000
100
10
1
0.1
0.01
TSS (ton/d)
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RR-05 Obs
RR-05 Sim



Calibration Period (1999-2001)
1000
100
10
1
0.1
0.01
TSS (ton/d)
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RR-05 Obs
RR-05 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-2.87703	-0.07987
0.494253	0.651882
0.944264	0.536208
33.88355	2
4.302653	
2.1266	
-5.00363	
-0.75043	

0-20% - Sim

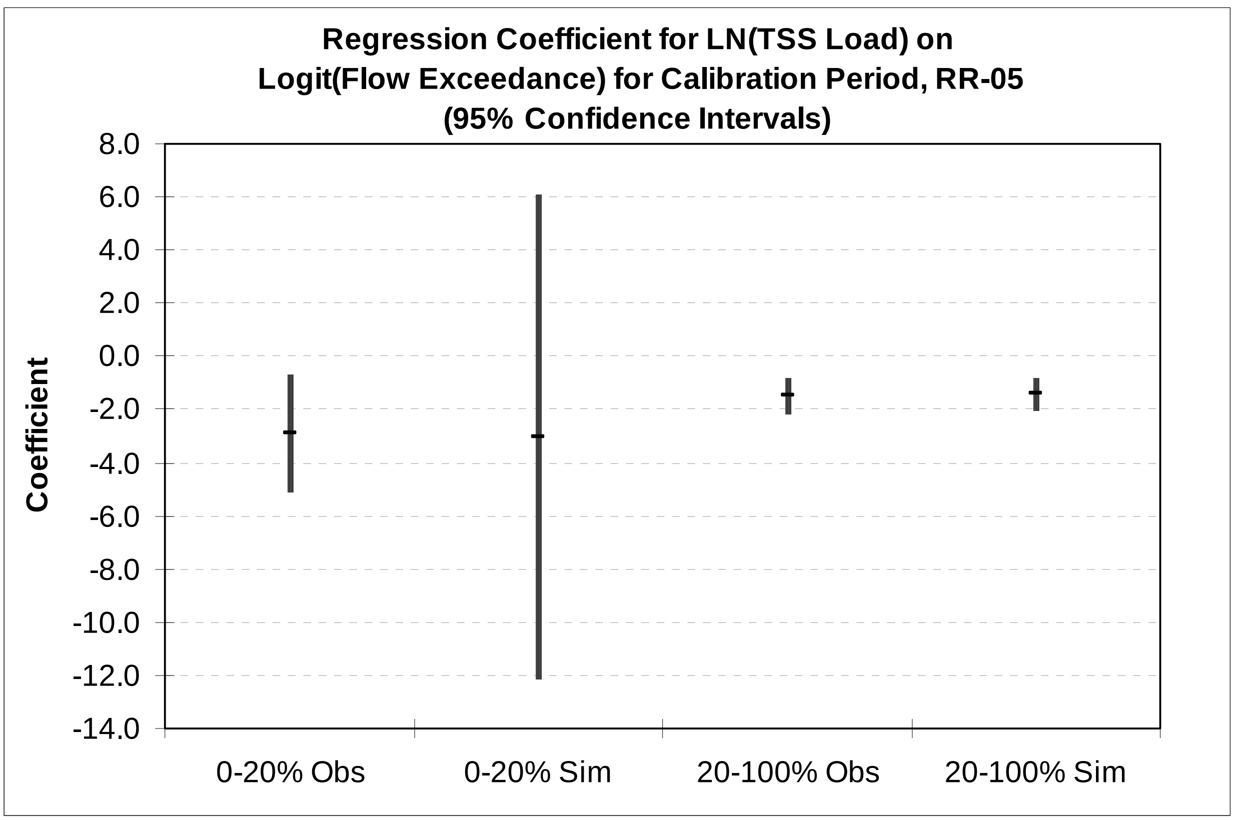
-3.04857	-0.30556
2.101554	2.771788
0.512708	2.279945
2.104318	2
4.302653	
9.042258	
-12.0908	
5.993687	

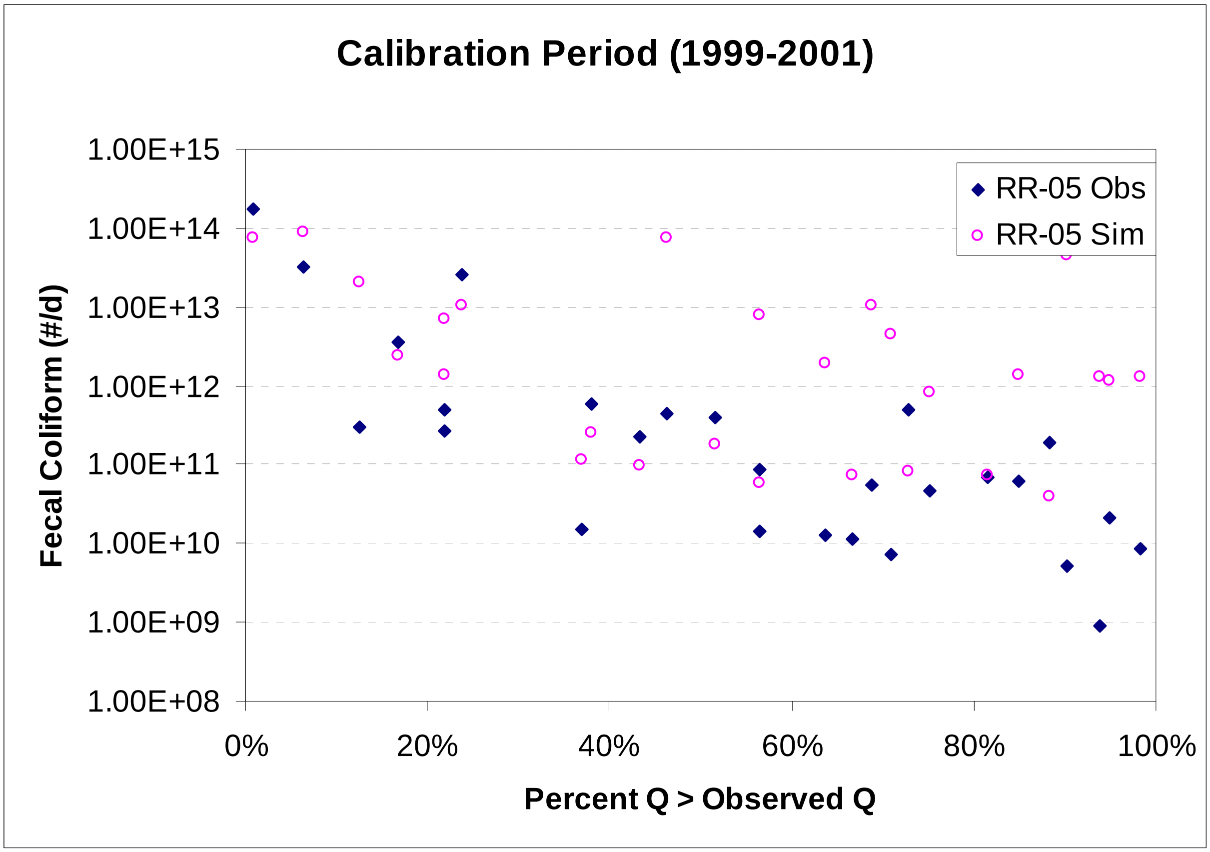
20-100% - Obs

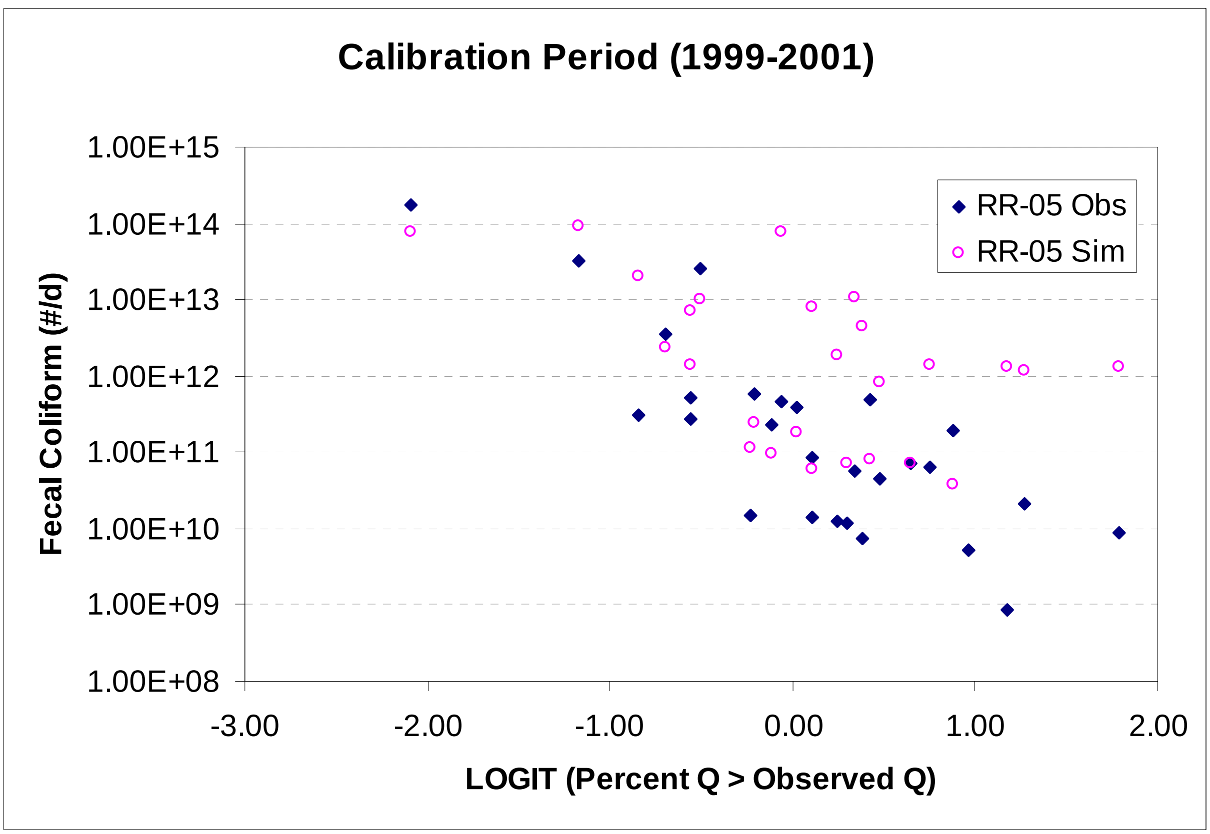
-1.49616	-0.33618
0.283906	0.190695
0.557984	0.811785
27.77201	22
2.073873	
0.588786	
-2.08495	
-0.90738	

20-100% - Sim

-1.43217	-0.8137
0.264793	0.177856
0.570761	0.757133
29.25353	22
2.073873	
0.549147	
-1.98132	
-0.88303	




Calibration Period (1999-2001)
Fecal Coliform (#/d)
1.00E+15
1.00E+14
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
0%
20%
40%
60%
80%
100%
Percent Q > Observed Q
RR-05 Obs
RR-05 Sim


Calibration Period (1999-2001)
Fecal Coliform (#/d)
1.00E+15
1.00E+14
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
-3.00
-2.00
-1.00
0.00
1.00
2.00
LOGIT (Percent Q > Observed Q)
RR-05 Obs
RR-05 Sim

Stats Key

X coeff	Intercept
SE X coeff	SE Int
R sq	SE reg
F reg	Resid df
t stat X	
Interval X	
Lower X	
Upper X	

0-20% - Obs

-3.659339	25.41184
1.753899	2.313257
0.685192	1.902779
4.353075	2
4.302653	
7.546418	
-11.20576	
3.887079	

0-20% - Sim

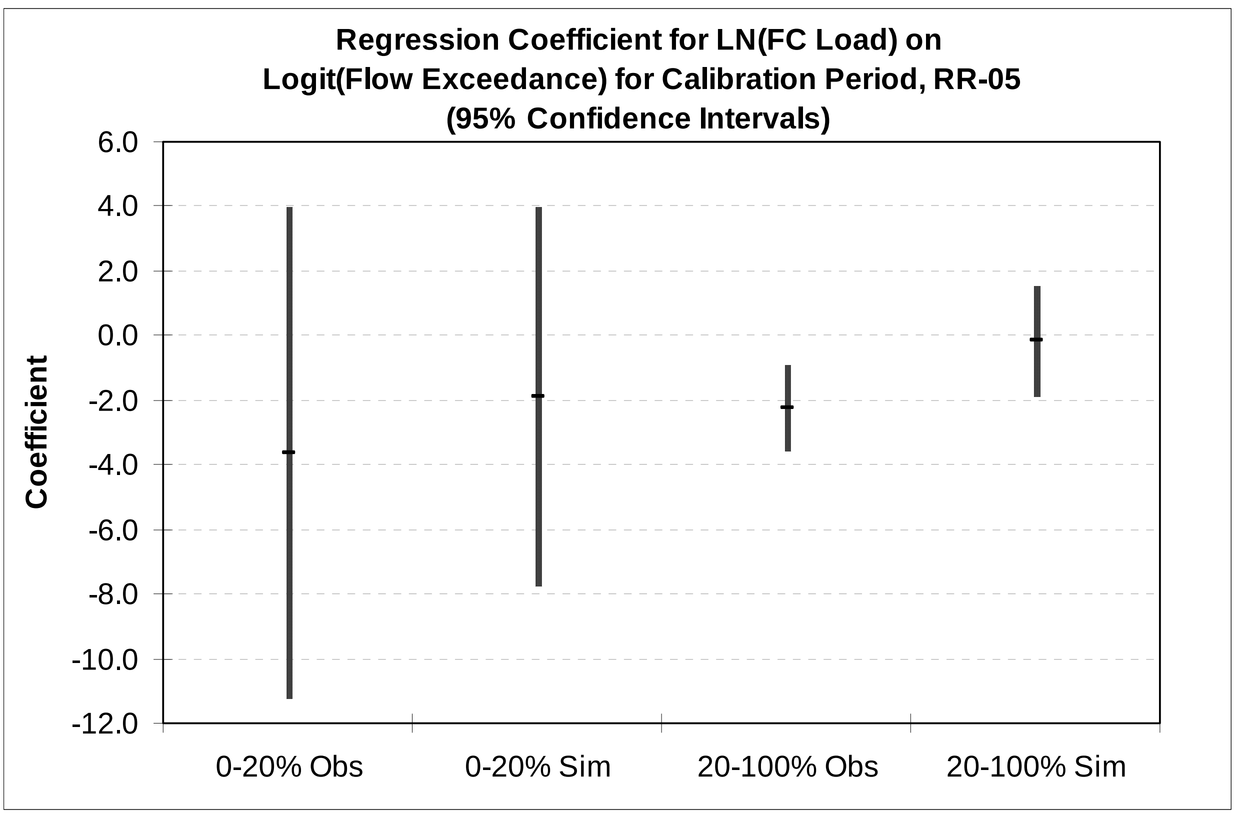
-1.882811	28.54583
1.3466	1.776062
0.494305	1.460907
1.954952	2
4.302653	
5.793954	
-7.676765	
3.911143	

20-100% - Obs

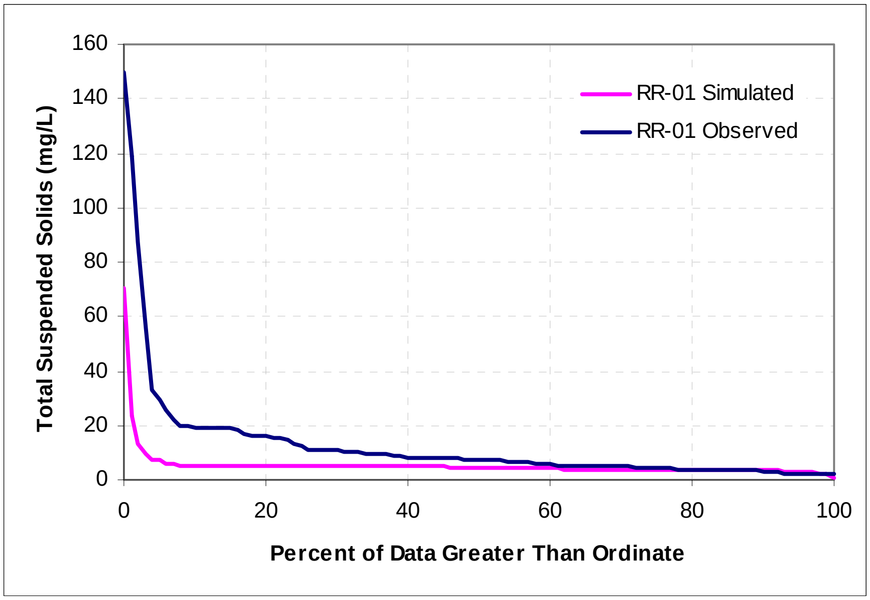
-2.262425	25.70069
0.611487	0.417791
0.394622	1.748343
13.68909	21
2.079614	
1.271656	
-3.534081	
-0.990769	

20-100% - Sim

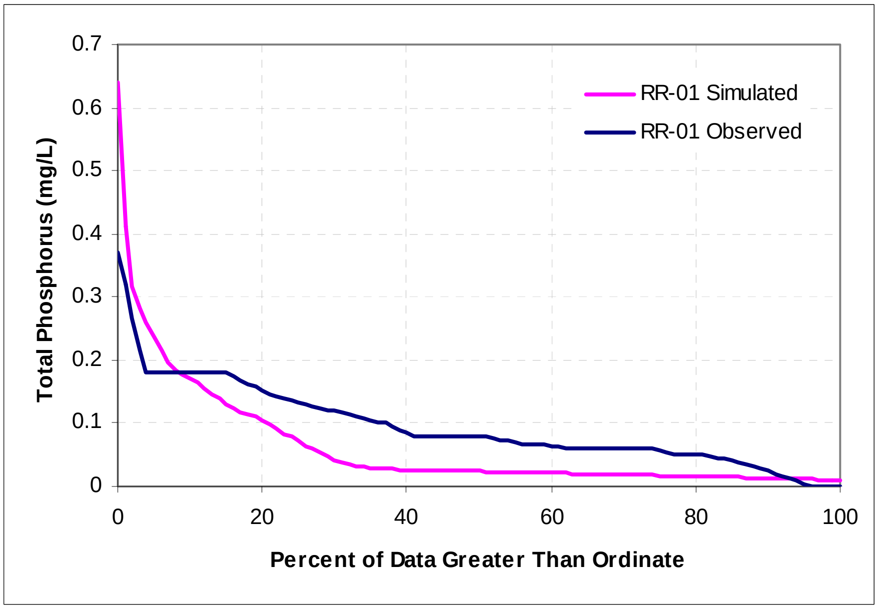
-0.168711	27.6324
0.796829	0.544424
0.00213	2.278269
0.044829	21
2.079614	
1.657097	
-1.825808	
1.488386	



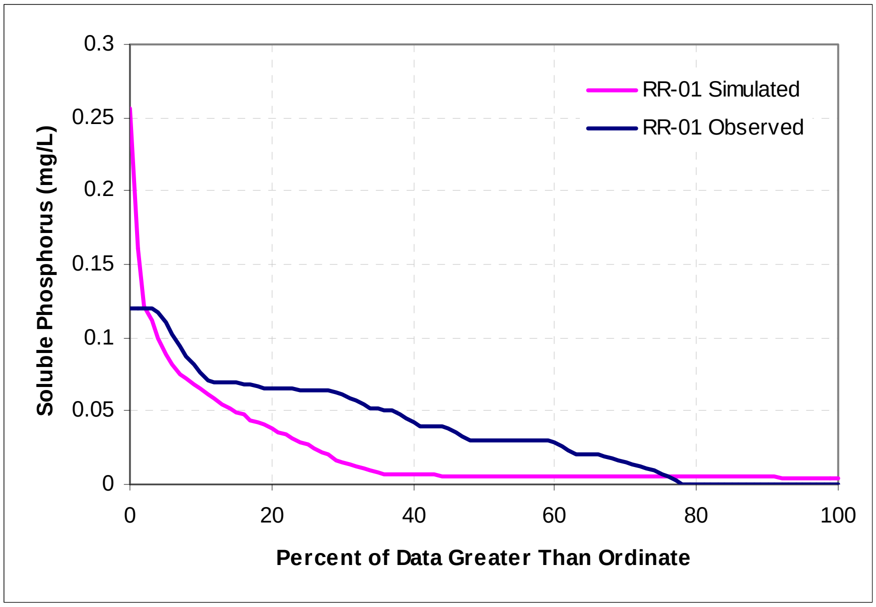
ATTACHMENT J – CONCENTRATION EXCEEDANCE CURVE PLOTS



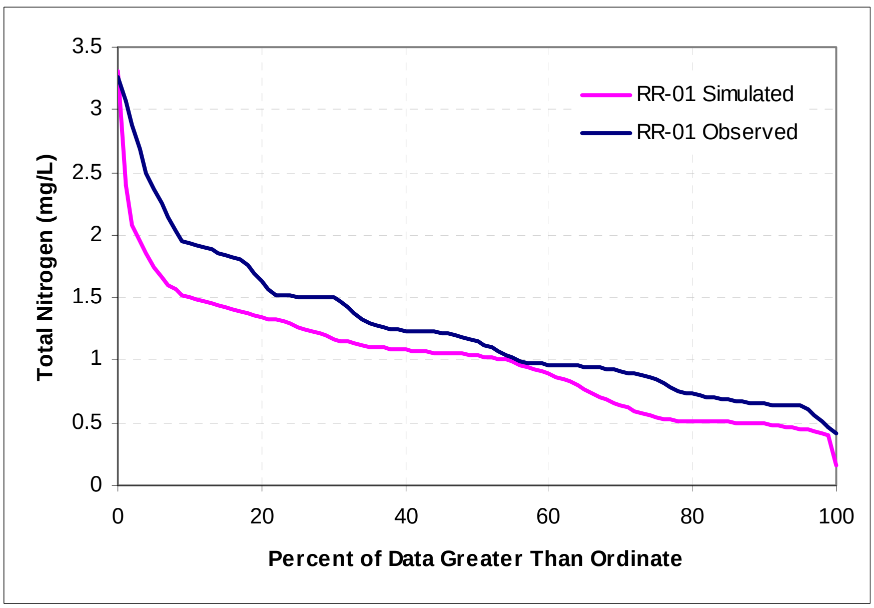
160
140
120
100
80
60
40
20
0
Total Suspended Solids (mg/L)
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-01 Simulated
RR-01 Observed



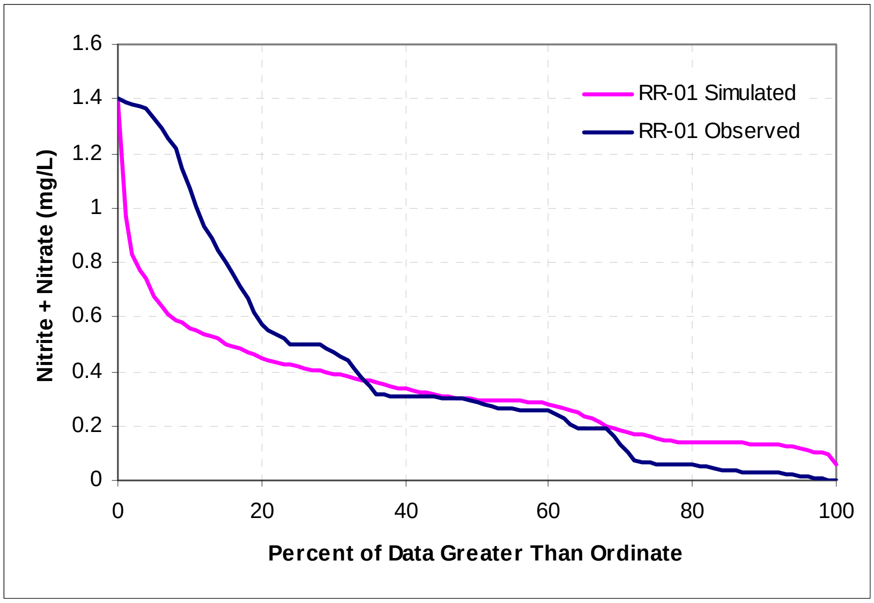
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Total Phosphorus (mg/L)
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-01 Simulated
RR-01 Observed

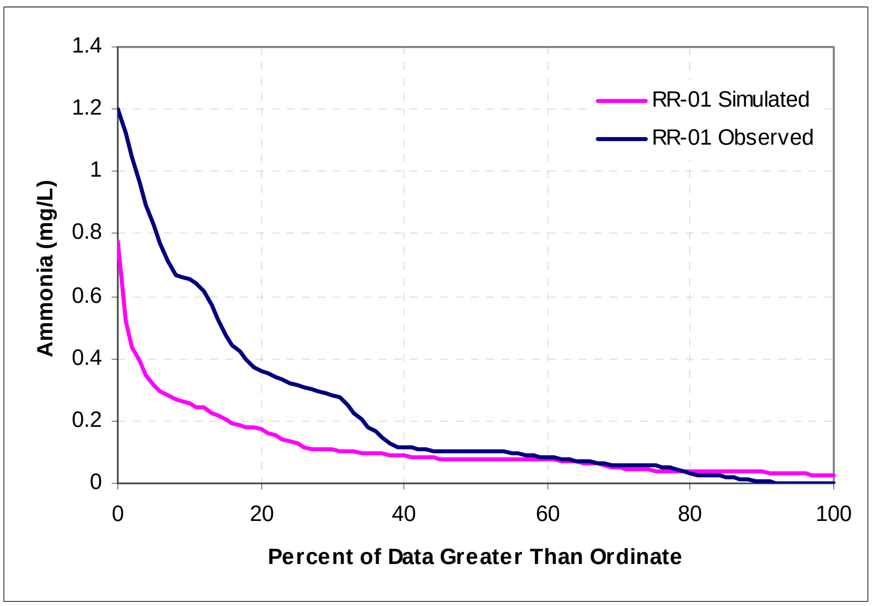


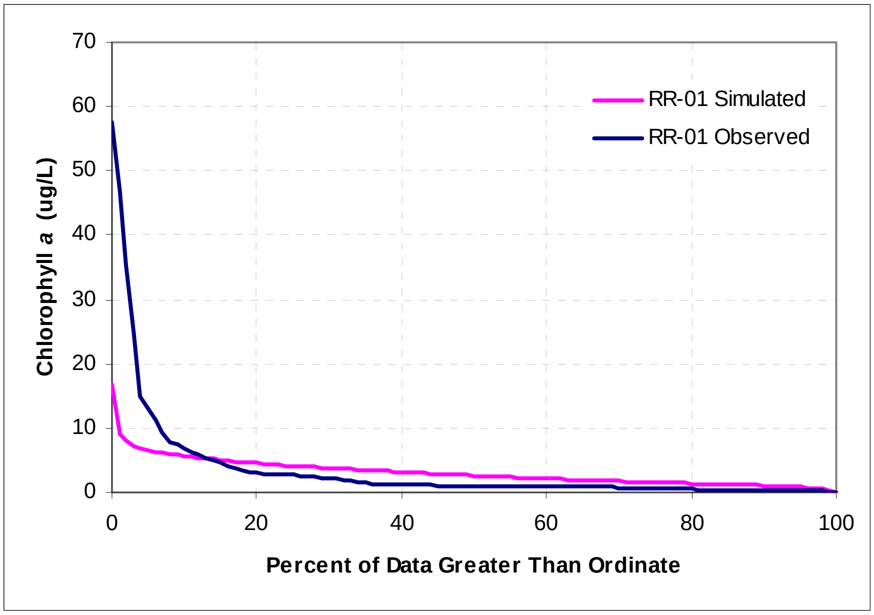
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
Soluble Phosphorus (mg/L)
Percent of Data Greater Than Ordinate
RR-01 Simulated
RR-01 Observed



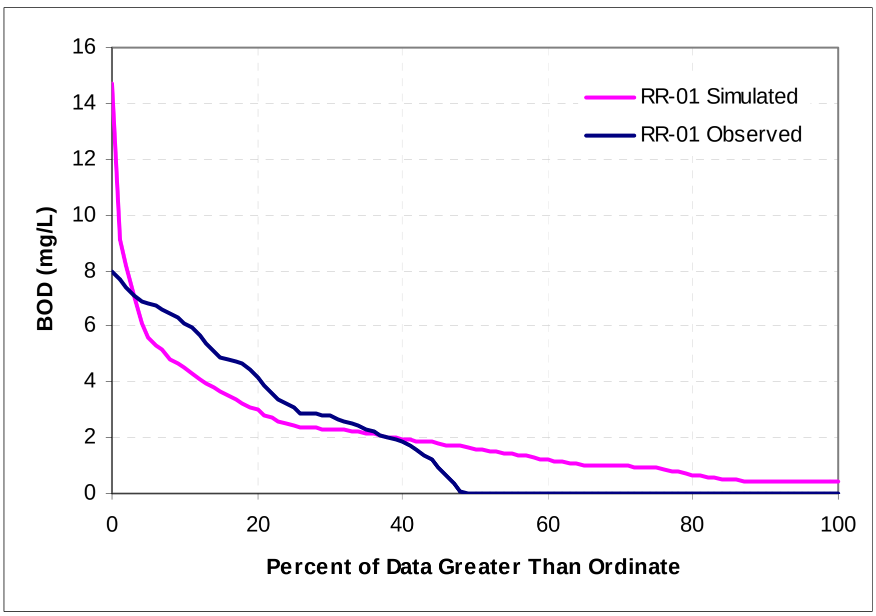
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
Total Nitrogen (mg/L)
Percent of Data Greater Than Ordinate
RR-01 Simulated
RR-01 Observed


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Nitrite + Nitrate (mg/L)
Percent of Data Greater Than Ordinate
RR-01 Simulated
RR-01 Observed

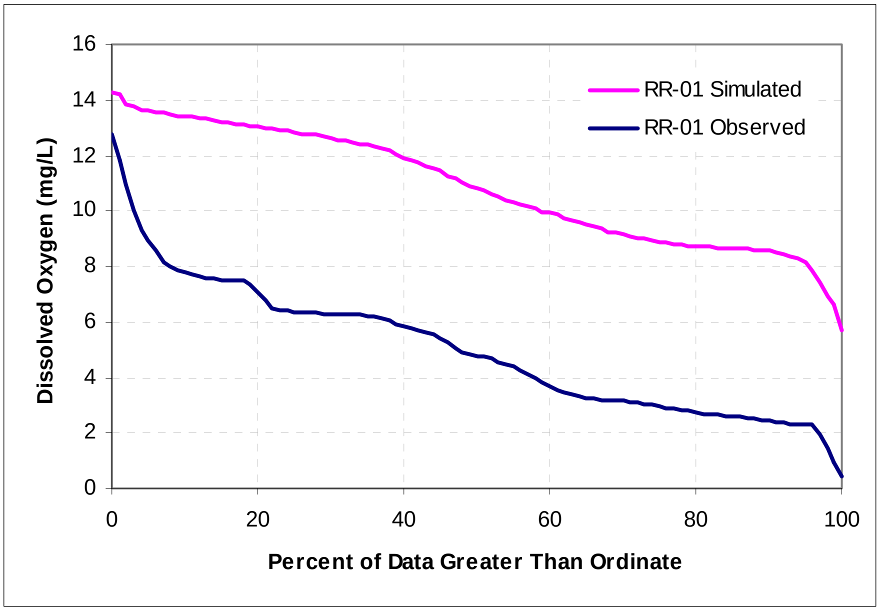

1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Ammonia (mg/L)
Percent of Data Greater Than Ordinate
RR-01 Simulated
RR-01 Observed



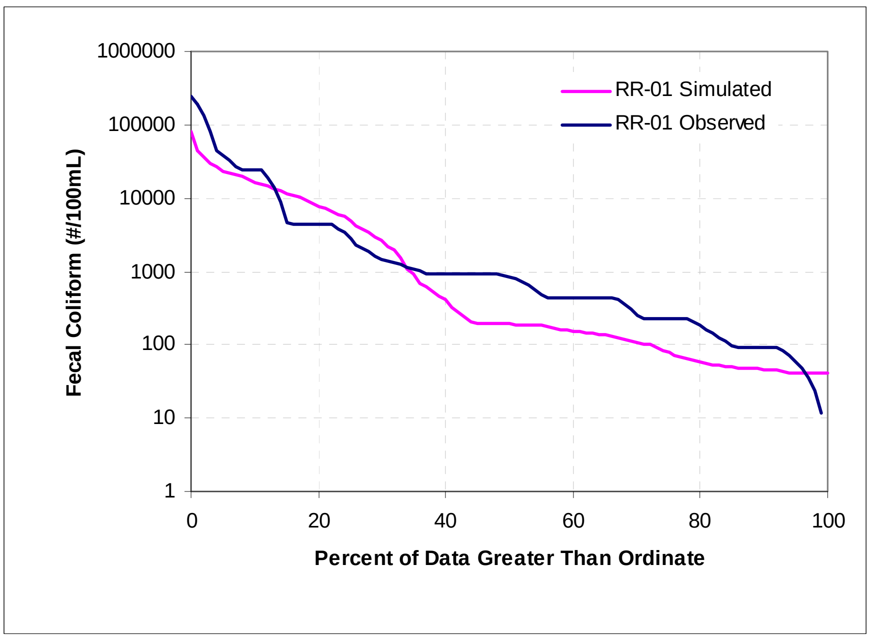
70
60
50
40
30
20
10
0
Chlorophyll a (ug/L)
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-01 Simulated
RR-01 Observed



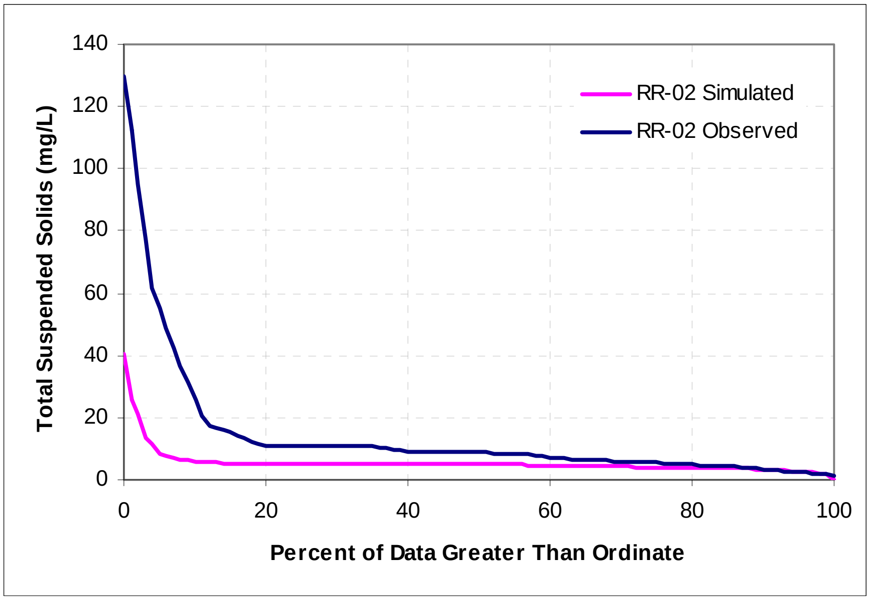
16
14
12
10
8
6
4
2
0
BOD (mg/L)
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-01 Simulated
RR-01 Observed



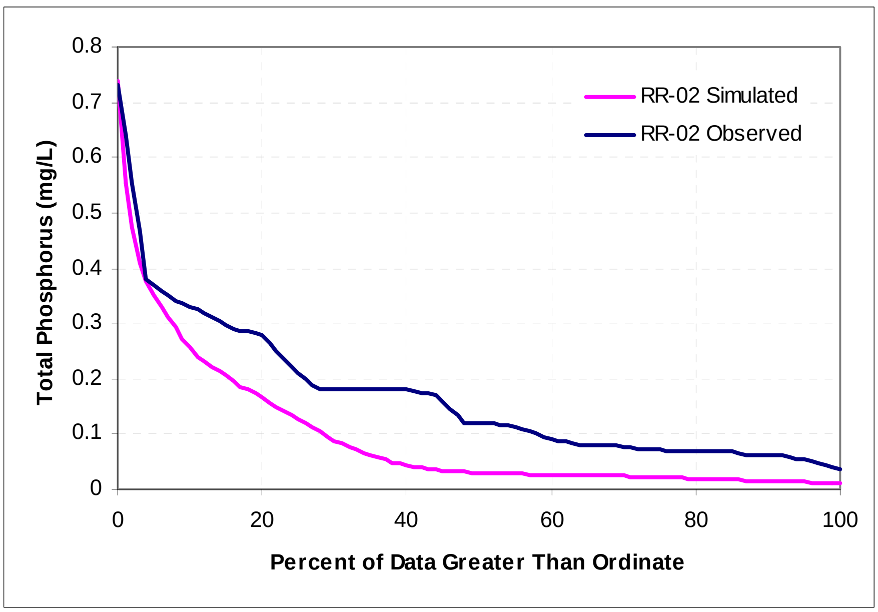
RR-01 Simulated
RR-01 Observed
Dissolved Oxygen (mg/L)
Percent of Data Greater Than Ordinate
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100



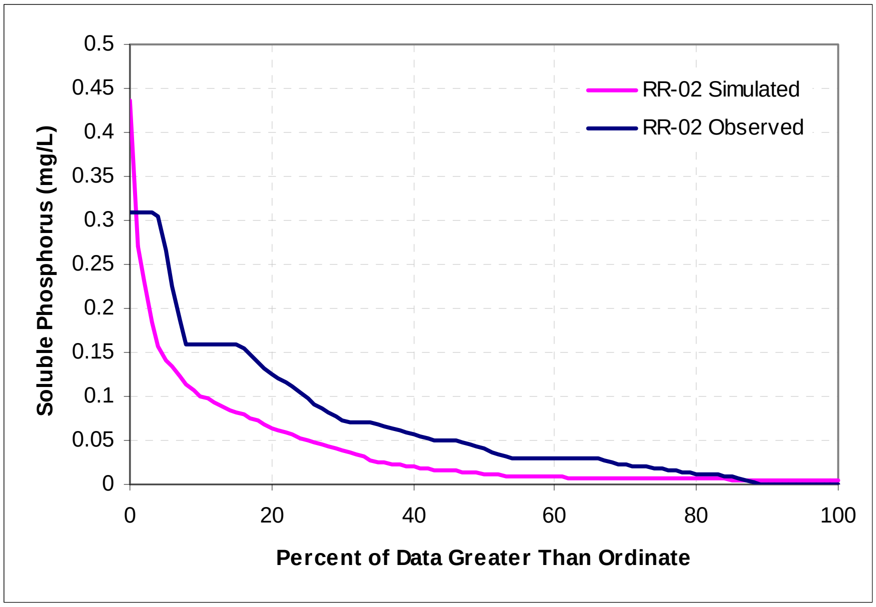
RR-01 Simulated
RR-01 Observed
Fecal Coliform (#/100mL)
Percent of Data Greater Than Ordinate
1000000
100000
10000
1000
100
10
1
0
20
40
60
80
100



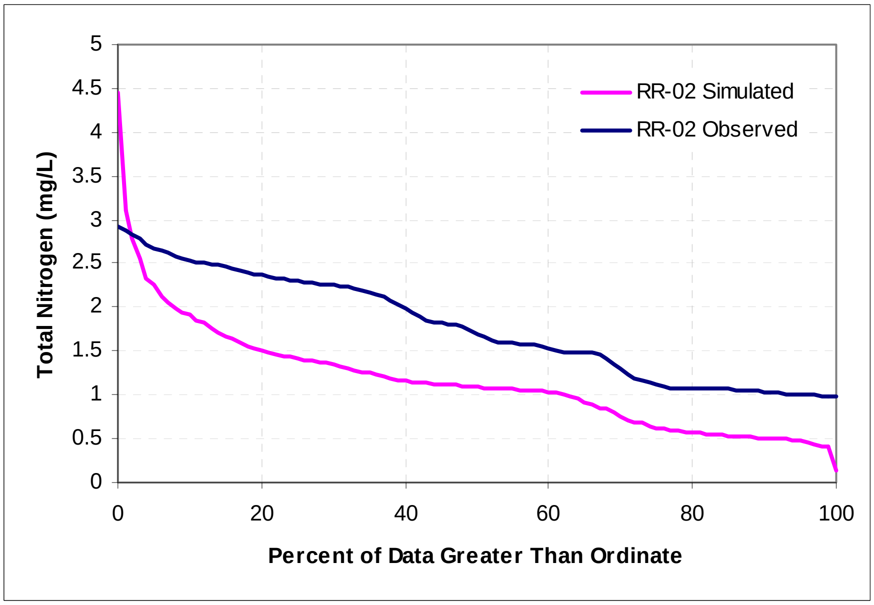
RR-02 Simulated
RR-02 Observed
Total Suspended Solids (mg/L)
Percent of Data Greater Than Ordinate
0
20
40
60
80
100
120
140
0
20
40
60
80
100



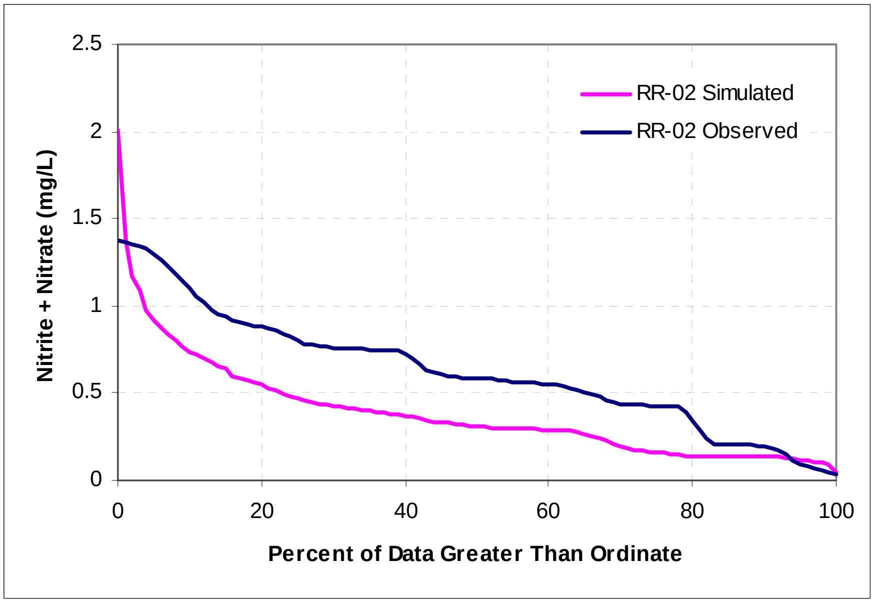
RR-02 Simulated
RR-02 Observed
Total Phosphorus (mg/L)
Percent of Data Greater Than Ordinate
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
20
40
60
80
100

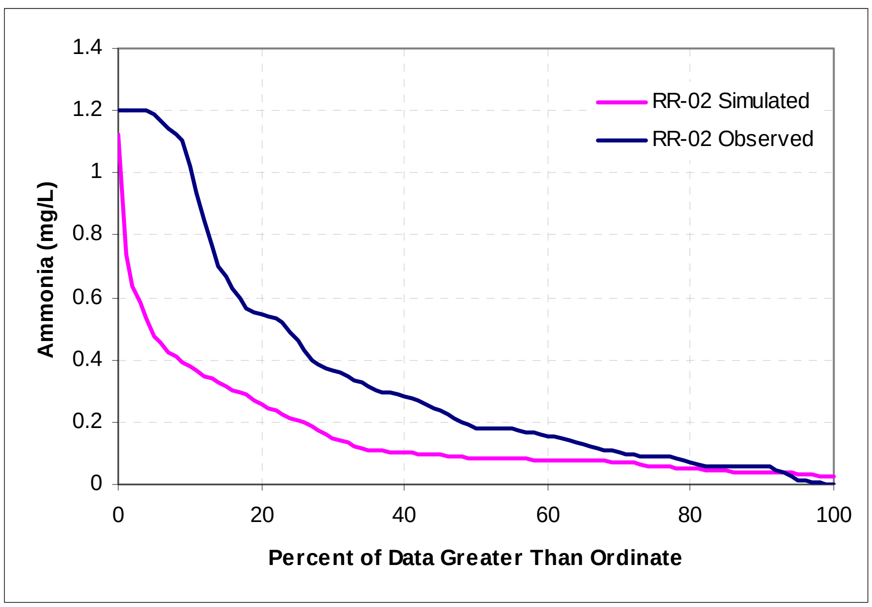


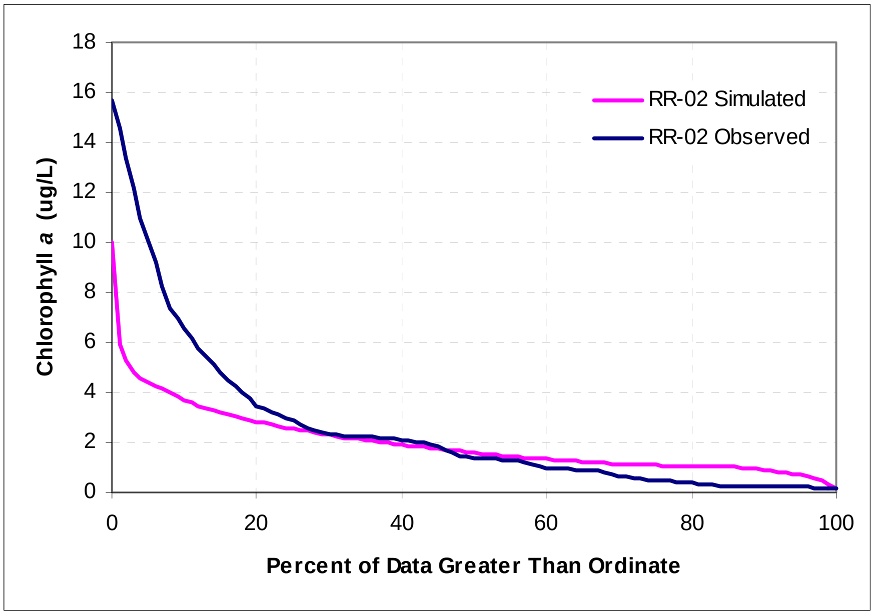
Soluble Phosphorus (mg/L)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-02 Simulated
RR-02 Observed

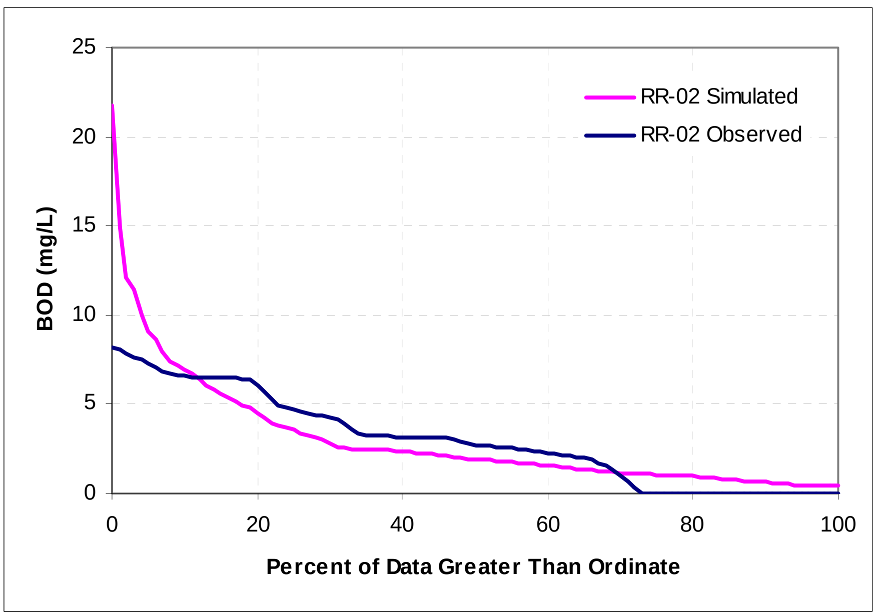


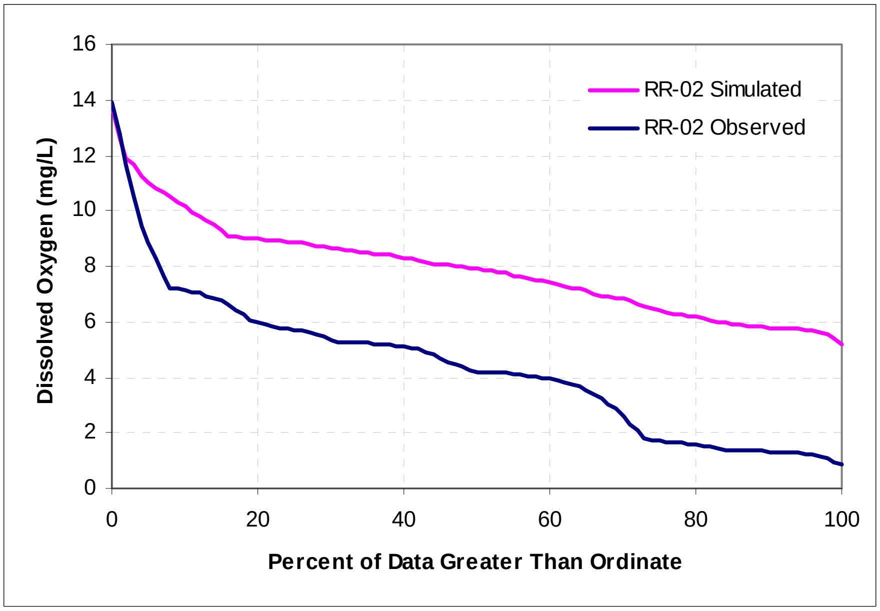
Total Nitrogen (mg/L)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-02 Simulated
RR-02 Observed

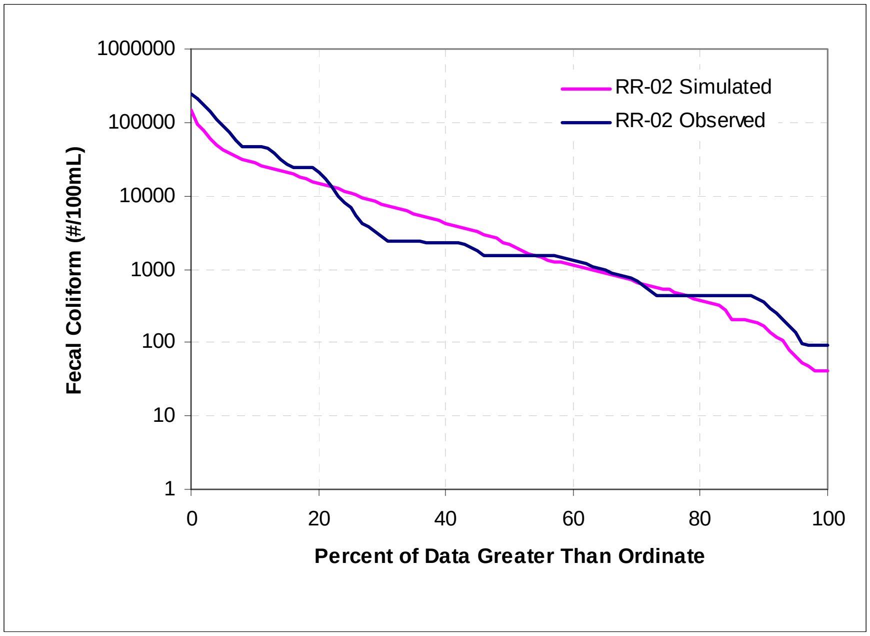

2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
Nitrite + Nitrate (mg/L)
Percent of Data Greater Than Ordinate
RR-02 Simulated
RR-02 Observed

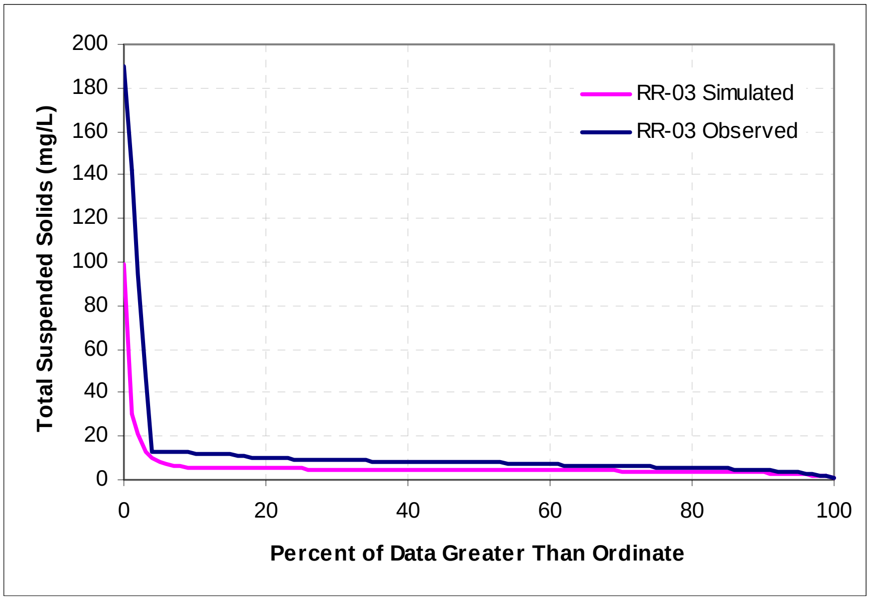

1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Ammonia (mg/L)
Percent of Data Greater Than Ordinate
RR-02 Simulated
RR-02 Observed


18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
Chlorophyll a (ug/L)
Percent of Data Greater Than Ordinate
RR-02 Simulated
RR-02 Observed

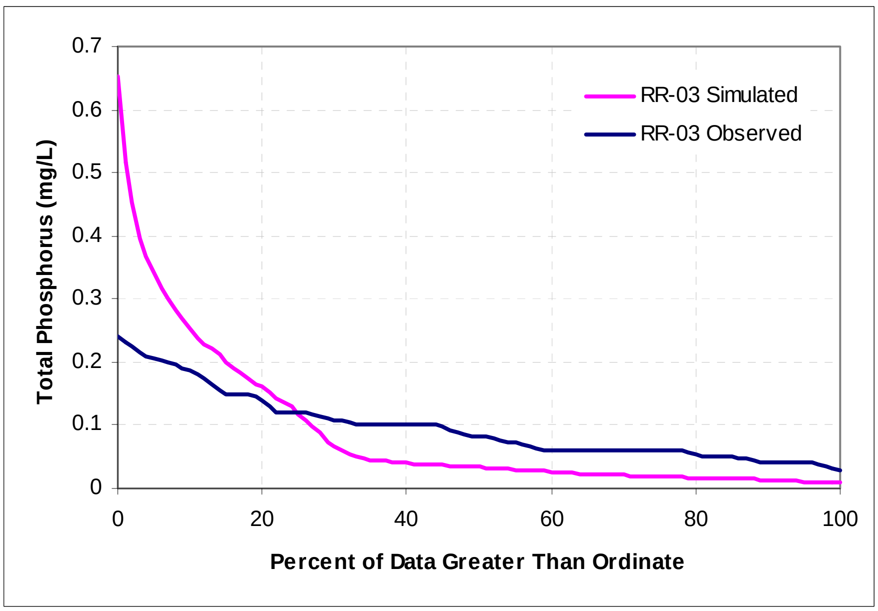

25
20
15
10
5
0
0
20
40
60
80
100
BOD (mg/L)
Percent of Data Greater Than Ordinate
RR-02 Simulated
RR-02 Observed


RR-02 Simulated
RR-02 Observed
Dissolved Oxygen (mg/L)
Percent of Data Greater Than Ordinate
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100

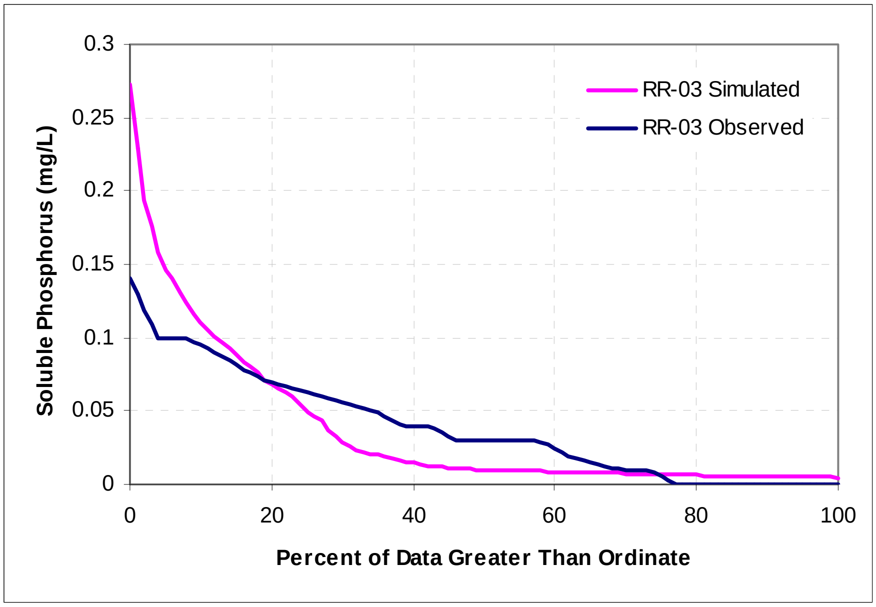

RR-02 Simulated
RR-02 Observed
Fecal Coliform (#/100mL)
Percent of Data Greater Than Ordinate
1000000
100000
10000
1000
100
10
1
0
20
40
60
80
100

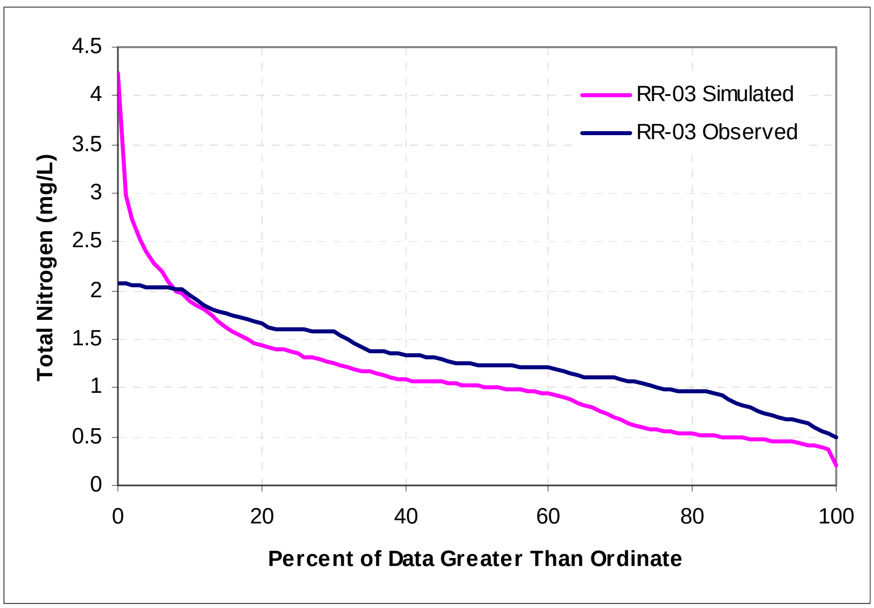


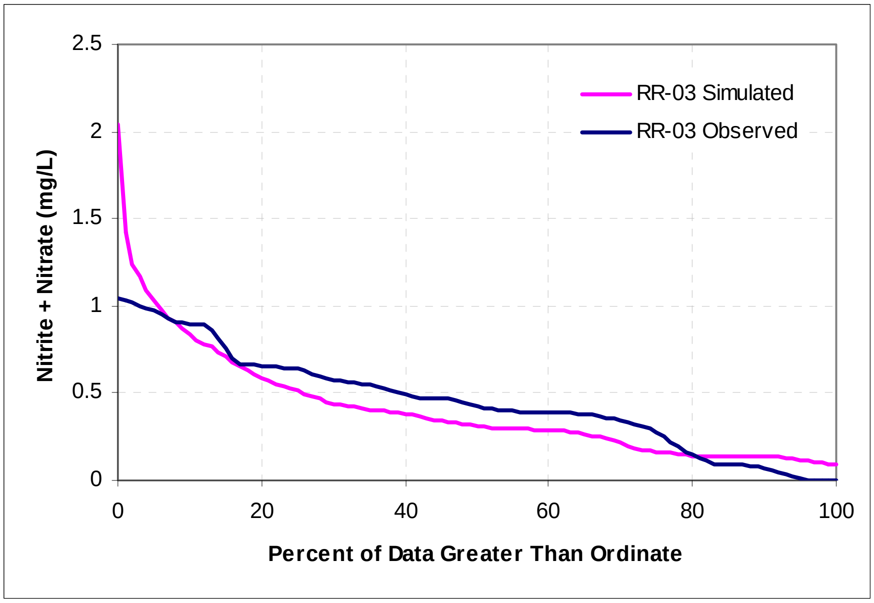
Total Suspended Solids (mg/L)
200
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-03 Simulated
RR-03 Observed



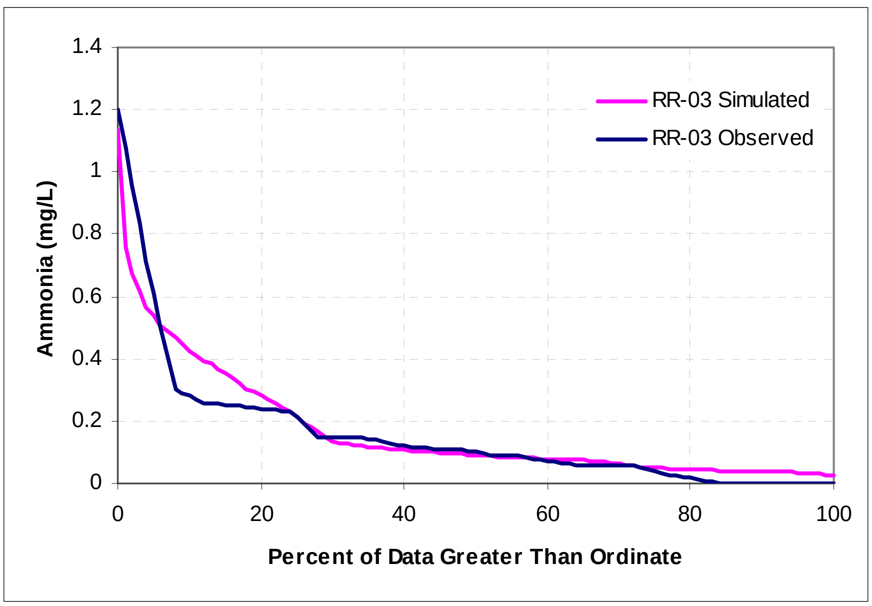
Total Phosphorus (mg/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-03 Simulated
RR-03 Observed


RR-03 Simulated
RR-03 Observed
Soluble Phosphorus (mg/L)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate

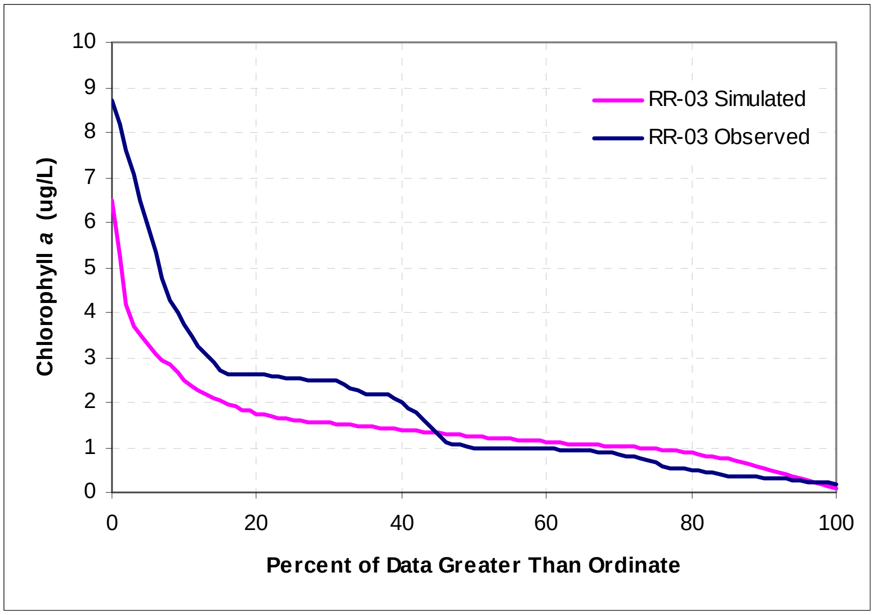

RR-03 Simulated
RR-03 Observed
Total Nitrogen (mg/L)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate



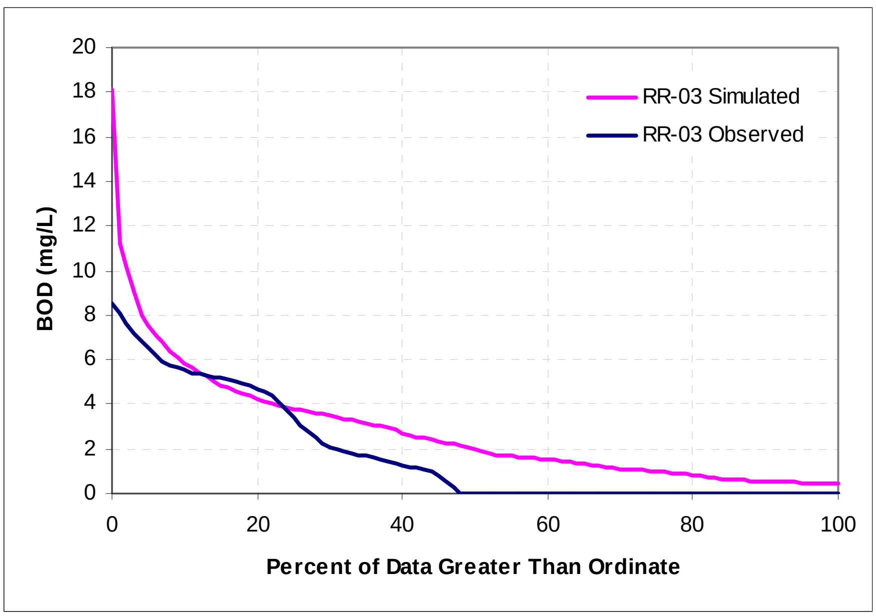
RR-03 Simulated
RR-03 Observed
Nitrite + Nitrate (mg/L)
Percent of Data Greater Than Ordinate
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100



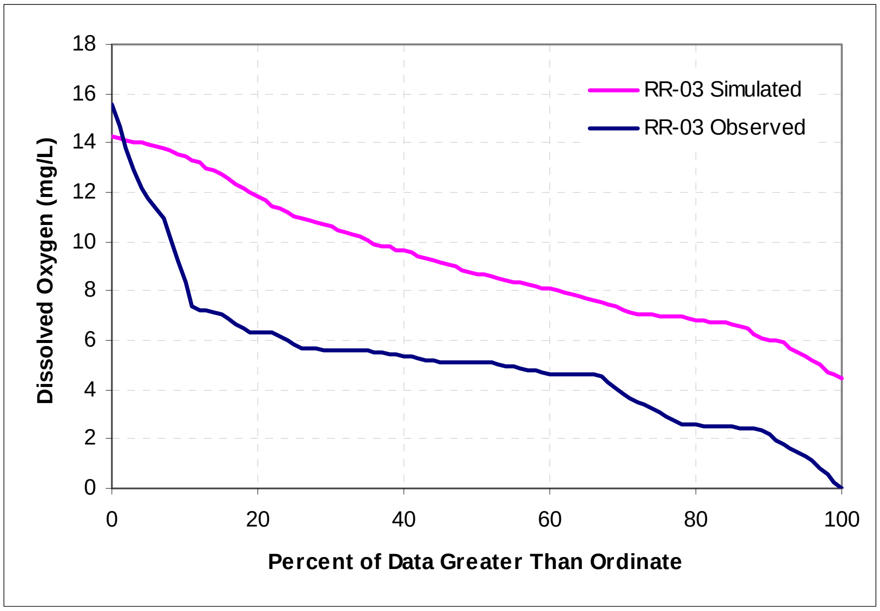
RR-03 Simulated
RR-03 Observed
Ammonia (mg/L)
Percent of Data Greater Than Ordinate
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100



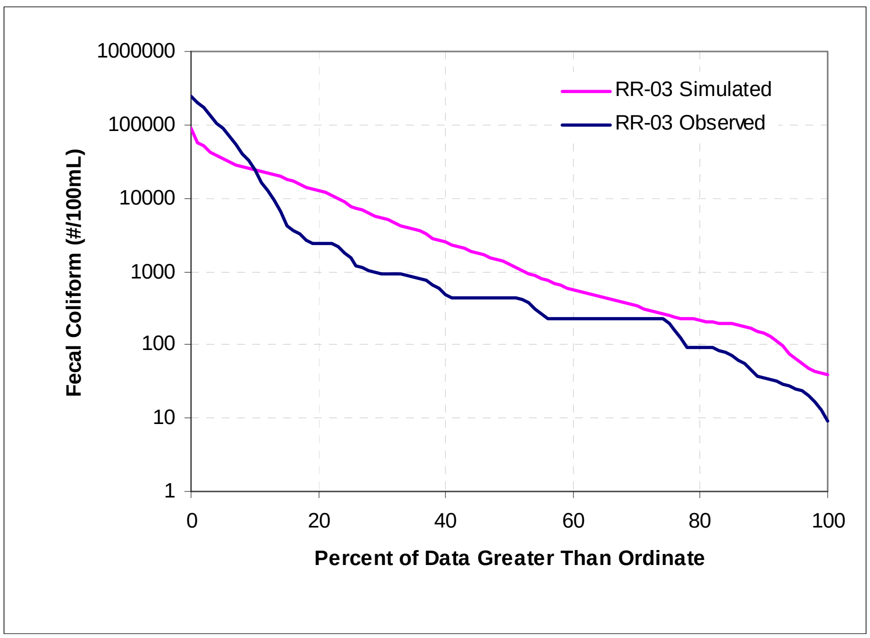
Chlorophyll *a* (ug/L)
10
9
8
7
6
5
4
3
2
1
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-03 Simulated
RR-03 Observed



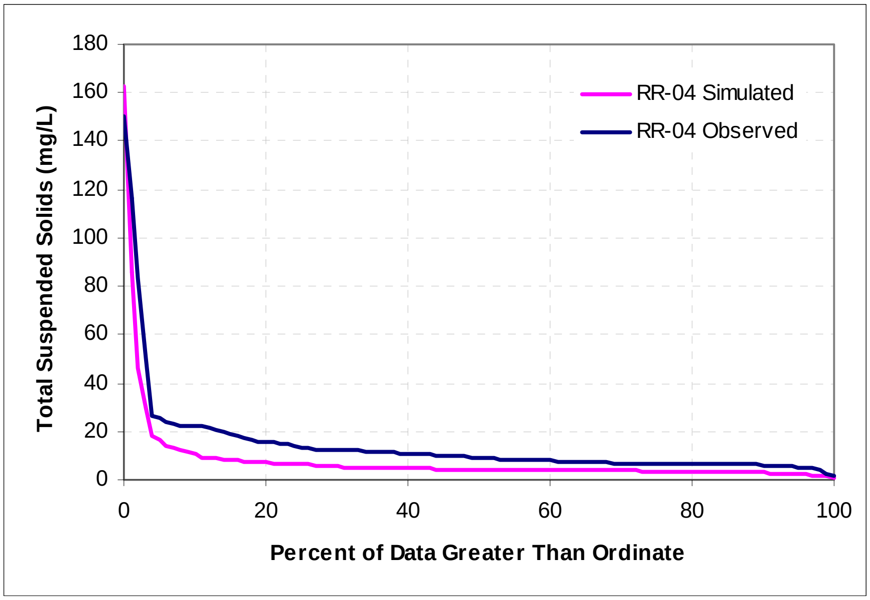
BOD (mg/L)
20
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-03 Simulated
RR-03 Observed



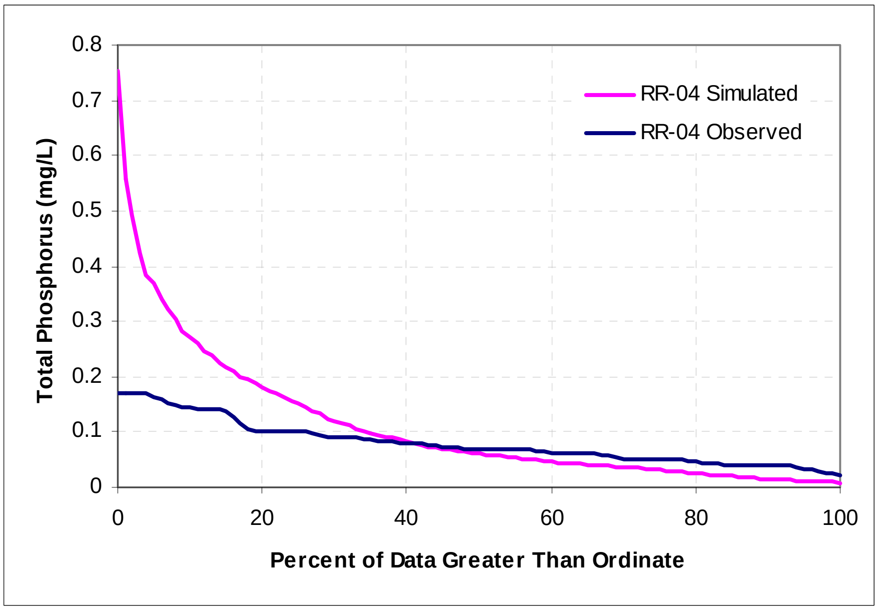
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
Dissolved Oxygen (mg/L)
Percent of Data Greater Than Ordinate
RR-03 Simulated
RR-03 Observed



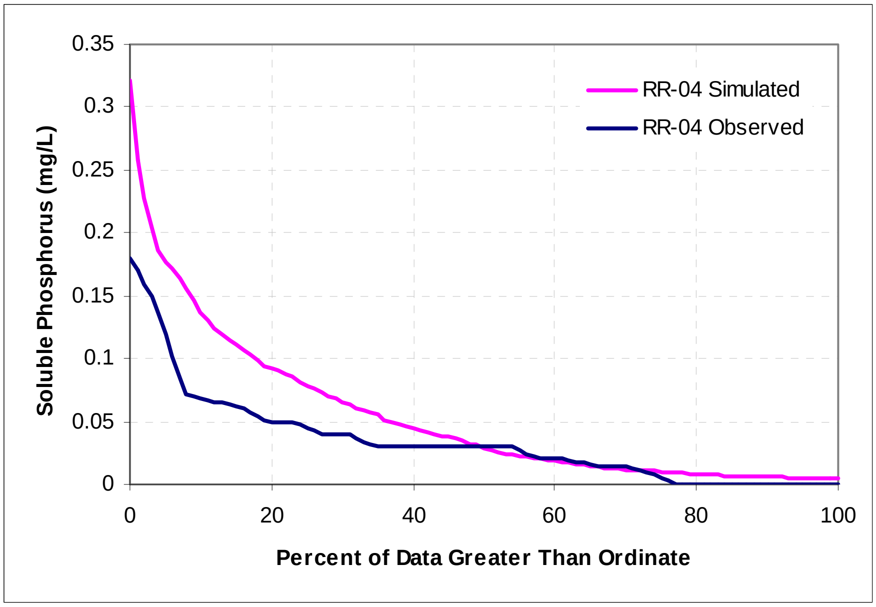
1000000
100000
10000
1000
100
10
1
0
20
40
60
80
100
Fecal Coliform (#/100mL)
Percent of Data Greater Than Ordinate
RR-03 Simulated
RR-03 Observed



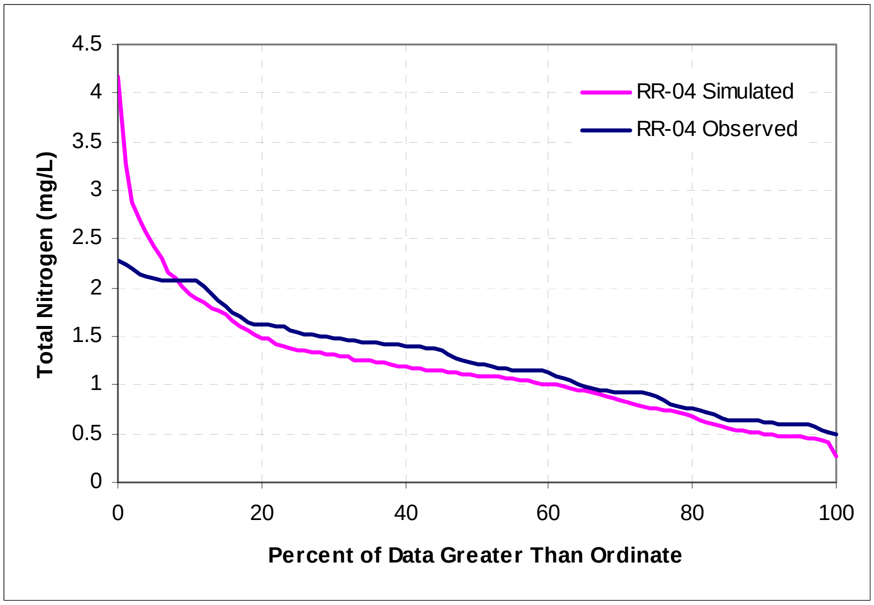
RR-04 Simulated
RR-04 Observed
Total Suspended Solids (mg/L)
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate



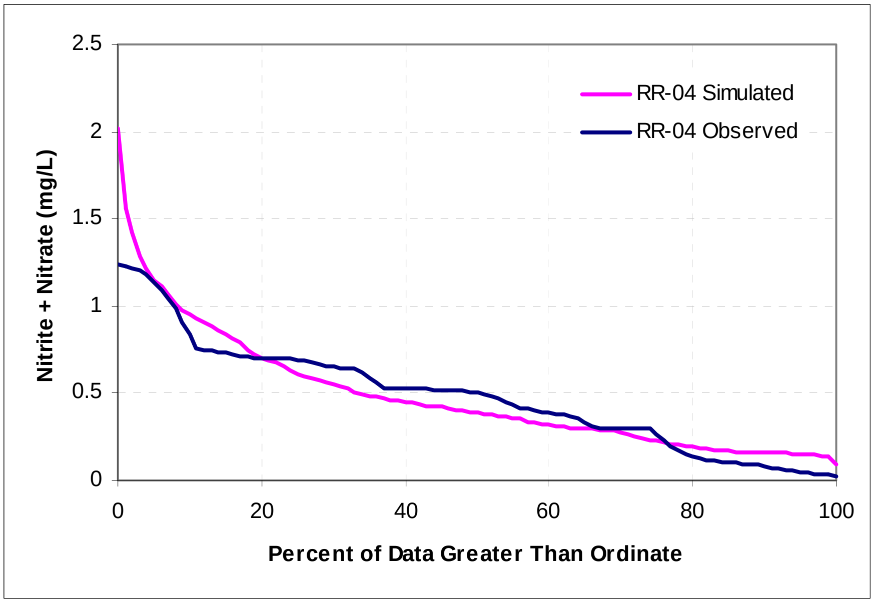
RR-04 Simulated
RR-04 Observed
Total Phosphorus (mg/L)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate

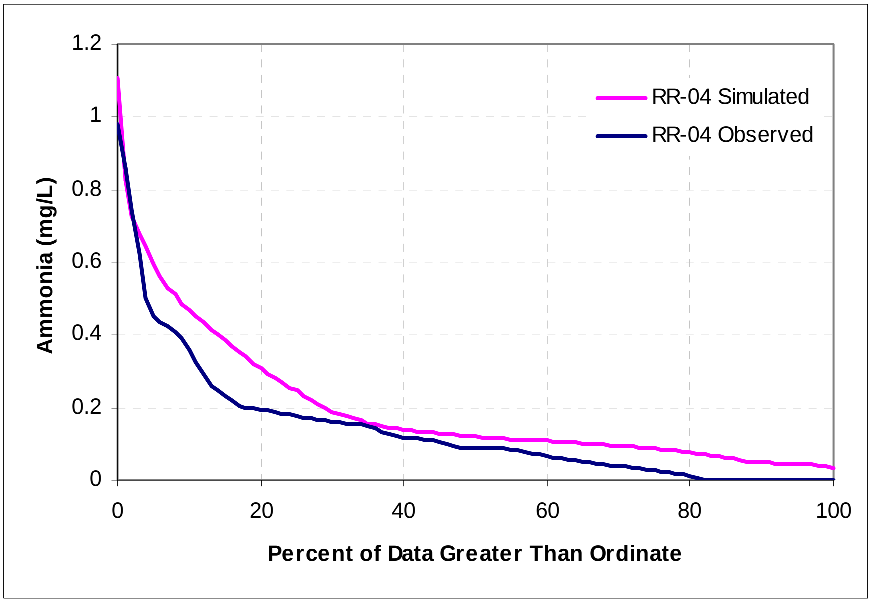


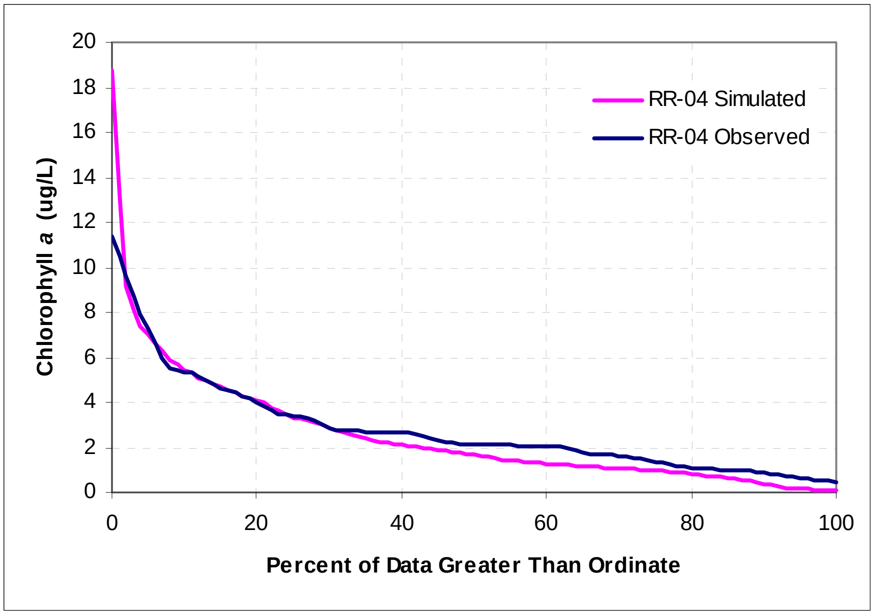
Soluble Phosphorus (mg/L)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-04 Simulated
RR-04 Observed

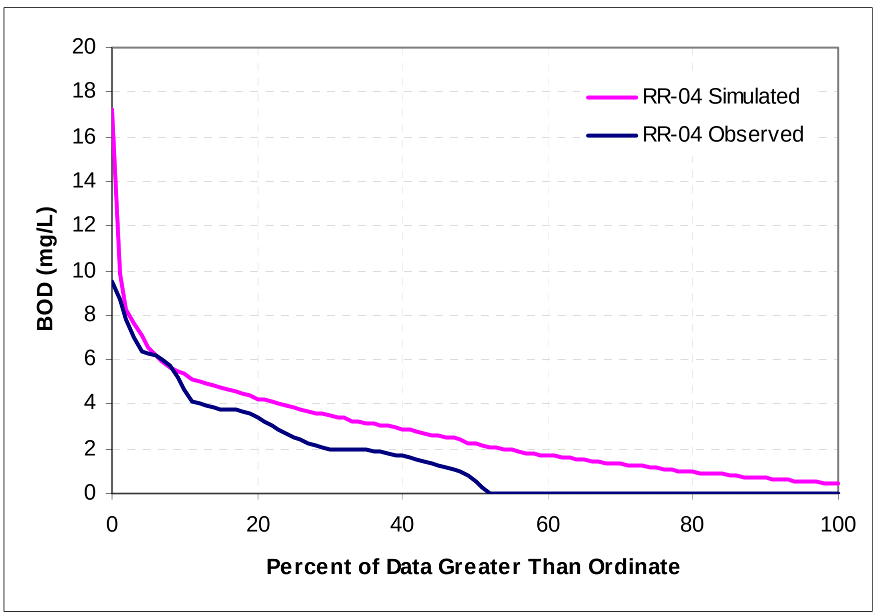


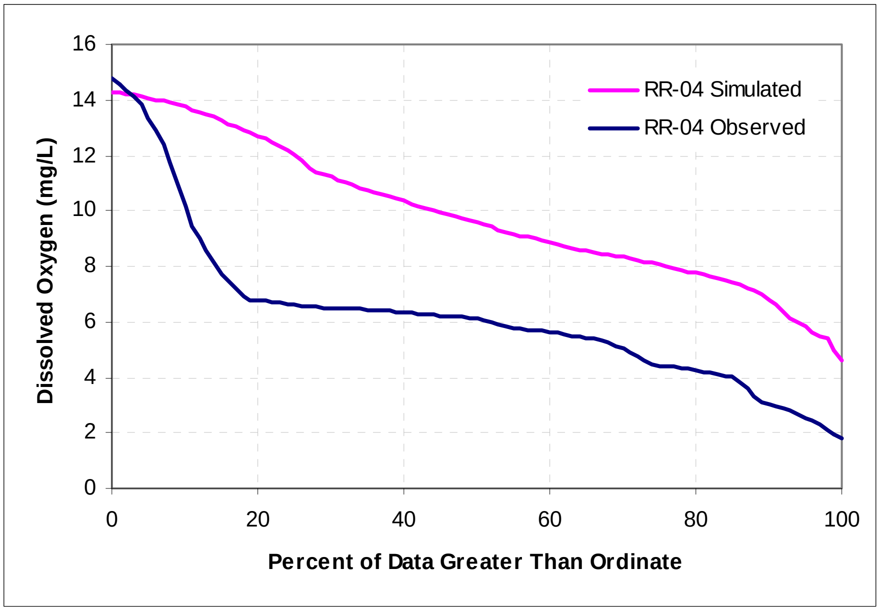
Total Nitrogen (mg/L)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-04 Simulated
RR-04 Observed

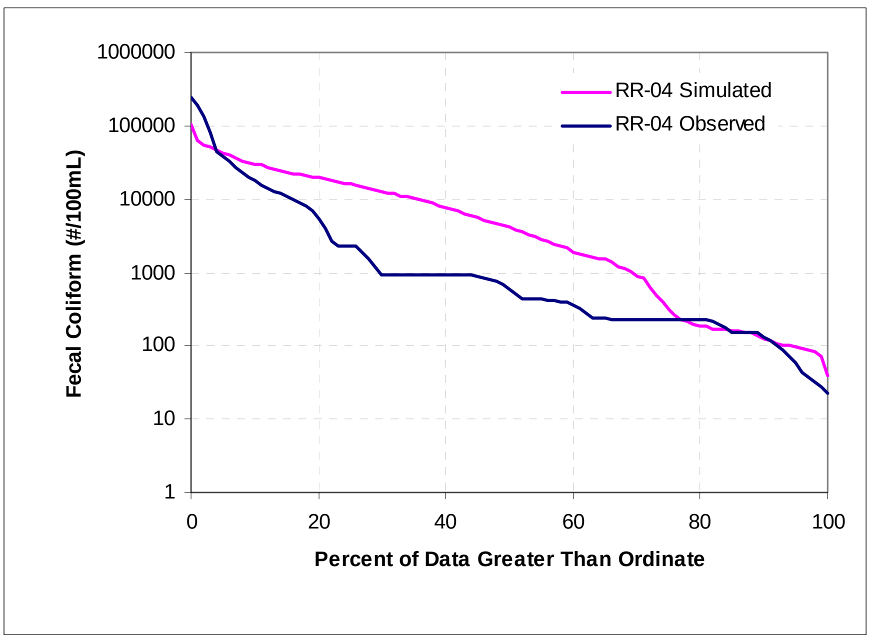

2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
Nitrite + Nitrate (mg/L)
Percent of Data Greater Than Ordinate
RR-04 Simulated
RR-04 Observed

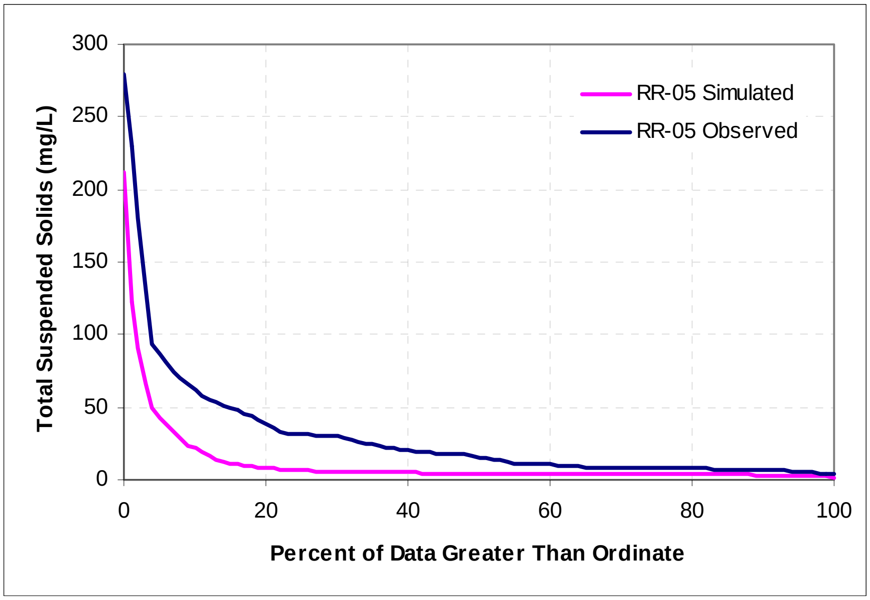

1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Ammonia (mg/L)
Percent of Data Greater Than Ordinate
RR-04 Simulated
RR-04 Observed


Chlorophyll a (ug/L)
Percent of Data Greater Than Ordinate
RR-04 Simulated
RR-04 Observed
0
2
4
6
8
10
12
14
16
18
20
0
20
40
60
80
100

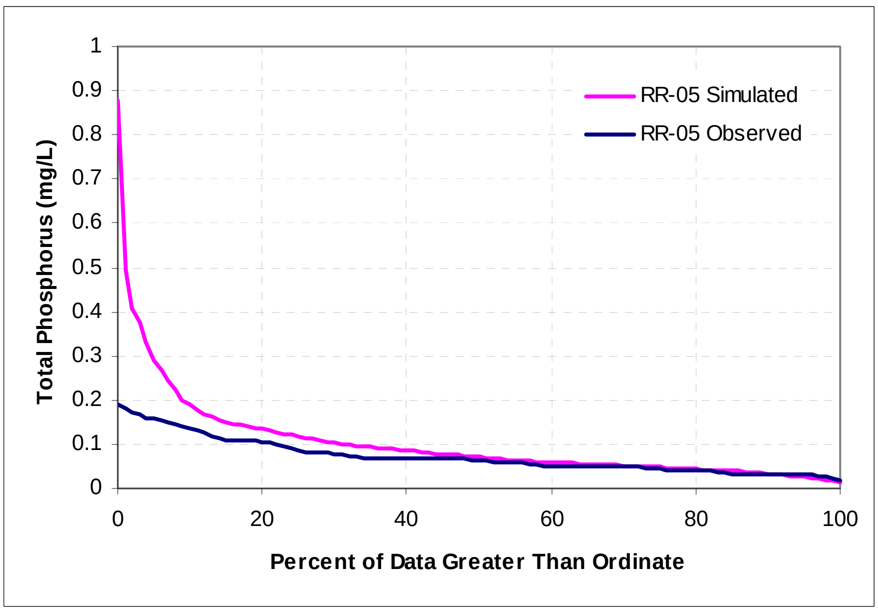

BOD (mg/L)
Percent of Data Greater Than Ordinate
RR-04 Simulated
RR-04 Observed
0
2
4
6
8
10
12
14
16
18
20
0
20
40
60
80
100


RR-04 Simulated
RR-04 Observed
Dissolved Oxygen (mg/L)
0
2
4
6
8
10
12
14
16
0
20
40
60
80
100
Percent of Data Greater Than Ordinate

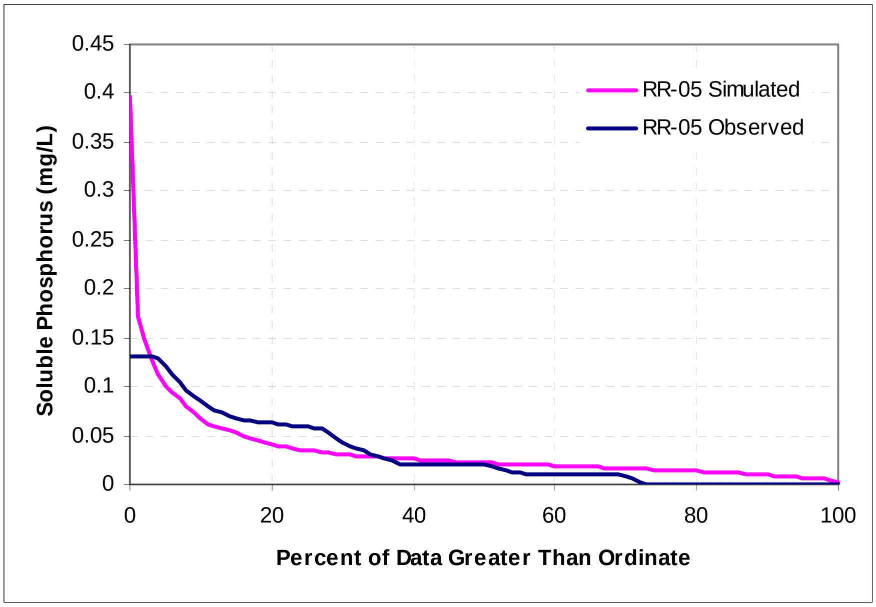

RR-04 Simulated
RR-04 Observed
Fecal Coliform (#/100mL)
1
10
100
1000
10000
100000
1000000
0
20
40
60
80
100
Percent of Data Greater Than Ordinate



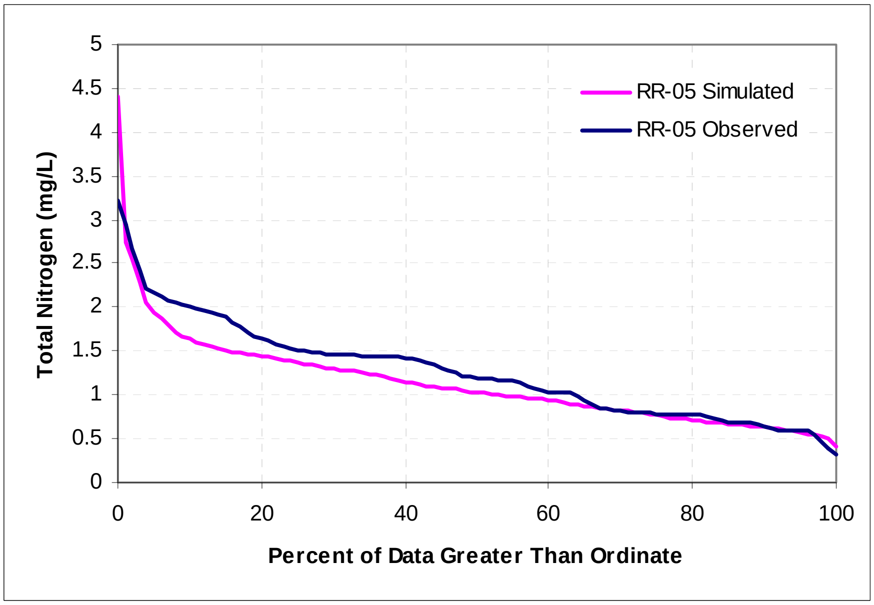
Total Suspended Solids (mg/L)
300
250
200
150
100
50
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-05 Simulated
RR-05 Observed



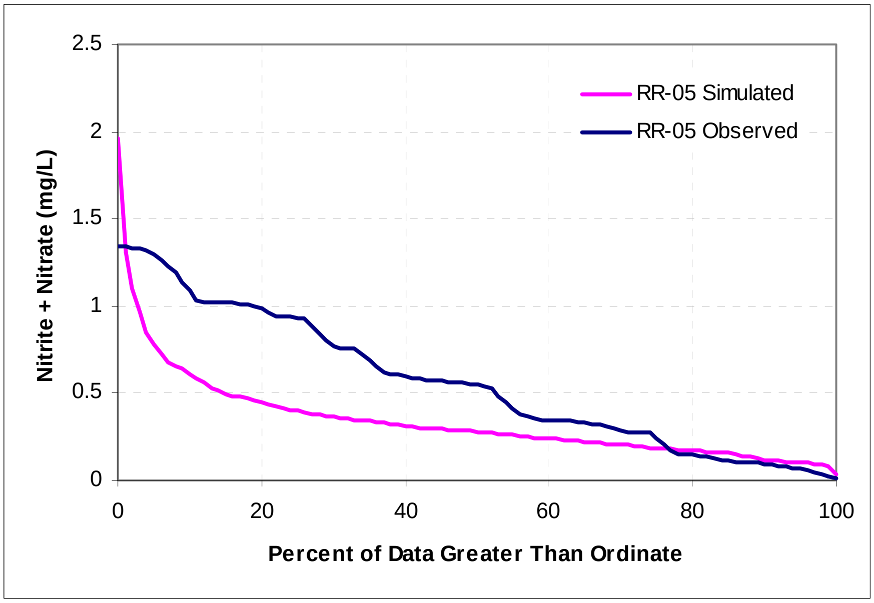
Total Phosphorus (mg/L)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-05 Simulated
RR-05 Observed



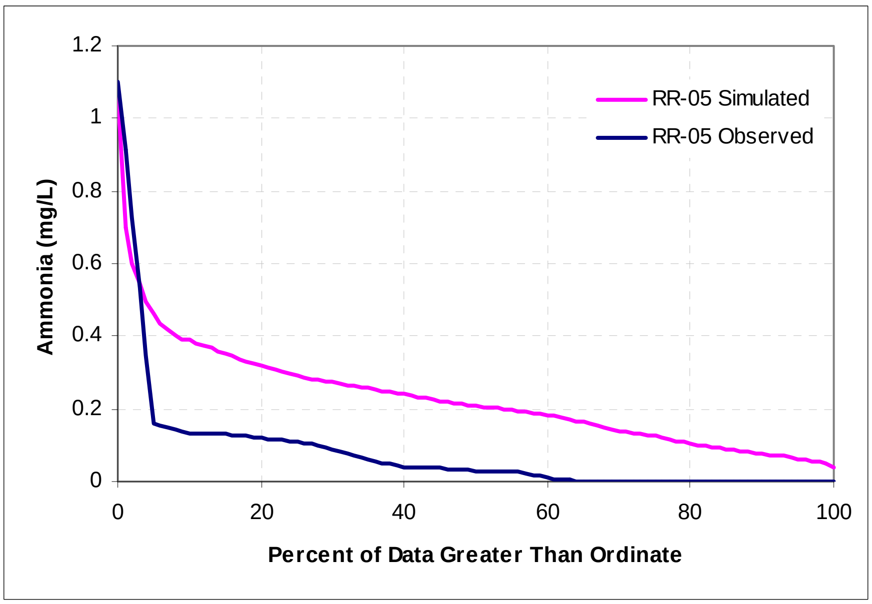
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Soluble Phosphorus (mg/L)
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-05 Simulated
RR-05 Observed



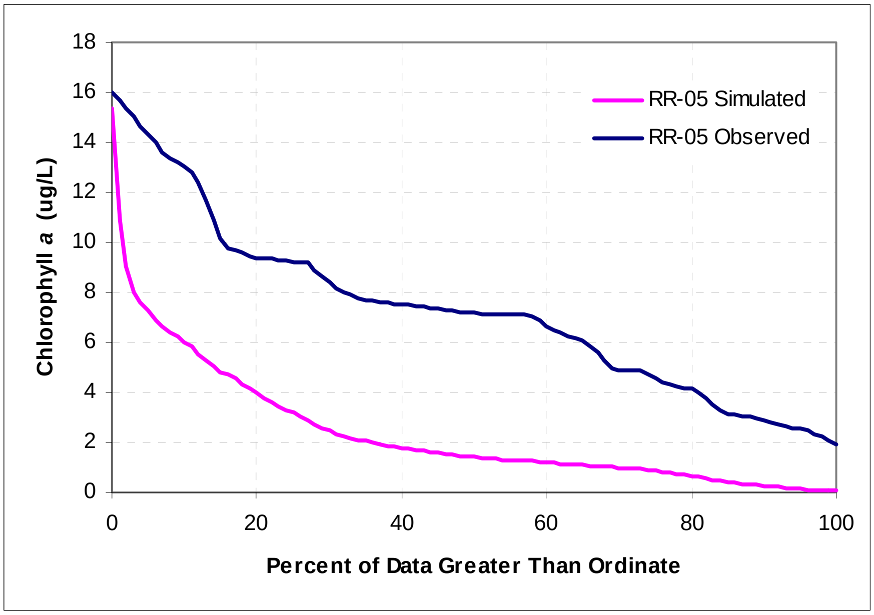
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Total Nitrogen (mg/L)
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-05 Simulated
RR-05 Observed



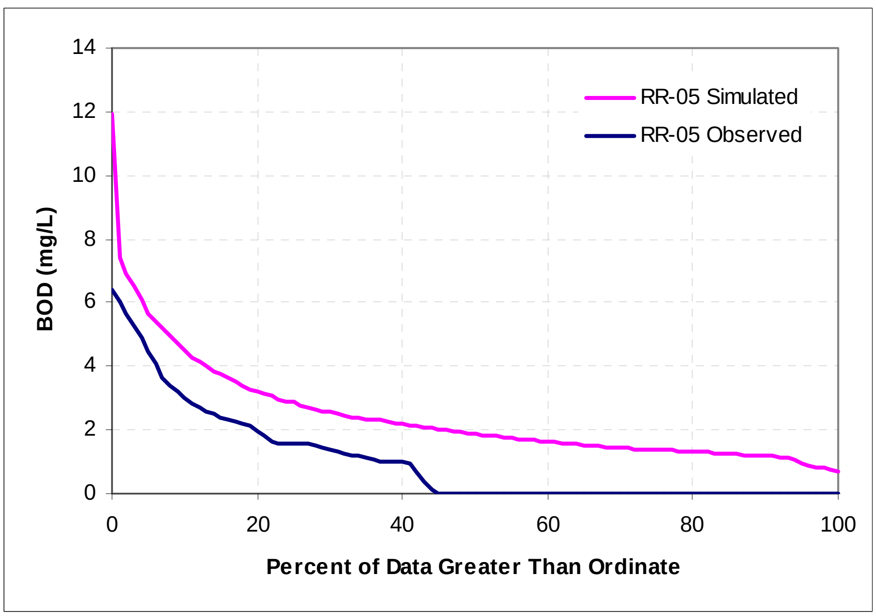
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
Nitrite + Nitrate (mg/L)
Percent of Data Greater Than Ordinate
RR-05 Simulated
RR-05 Observed



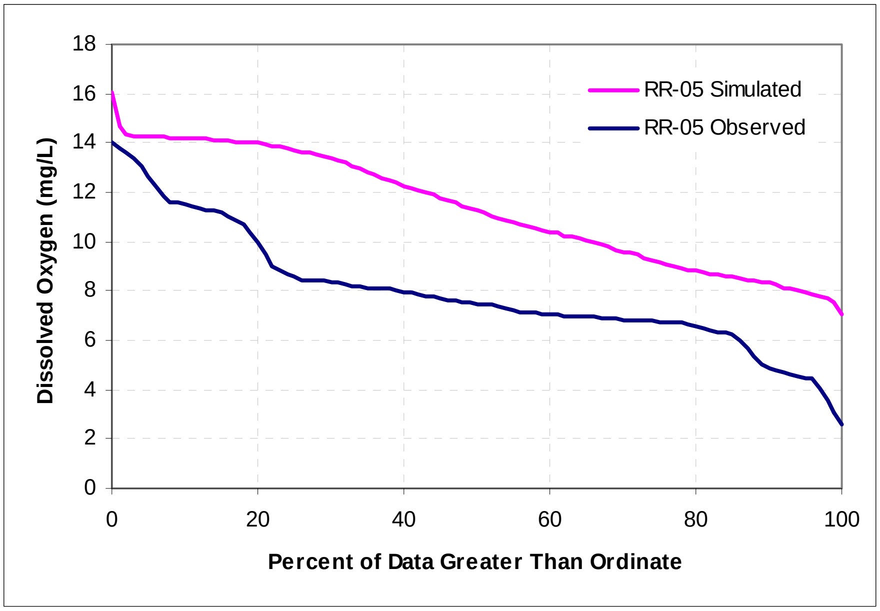
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Ammonia (mg/L)
Percent of Data Greater Than Ordinate
RR-05 Simulated
RR-05 Observed



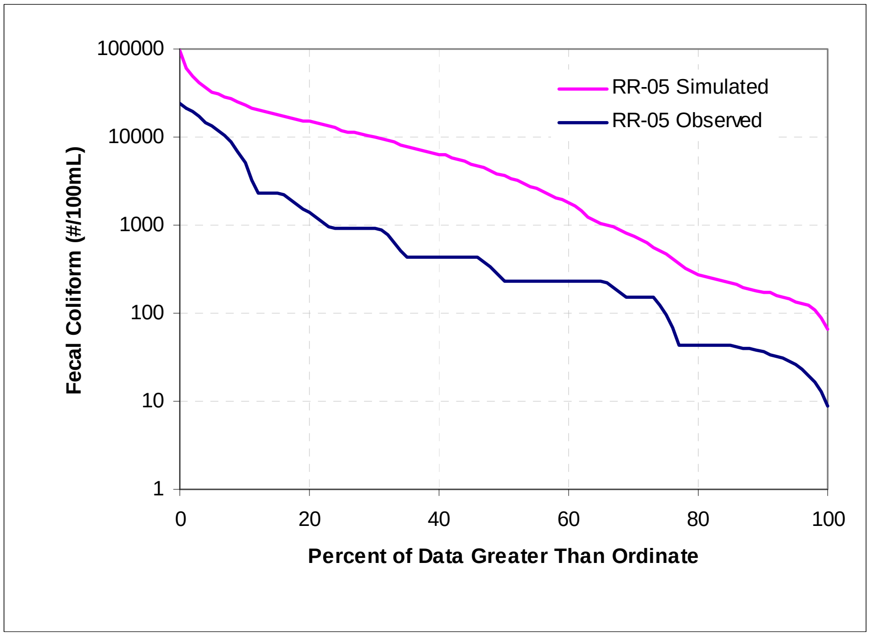
RR-05 Simulated
RR-05 Observed
Chlorophyll a (ug/L)
Percent of Data Greater Than Ordinate
0
2
4
6
8
10
12
14
16
18
0
20
40
60
80
100



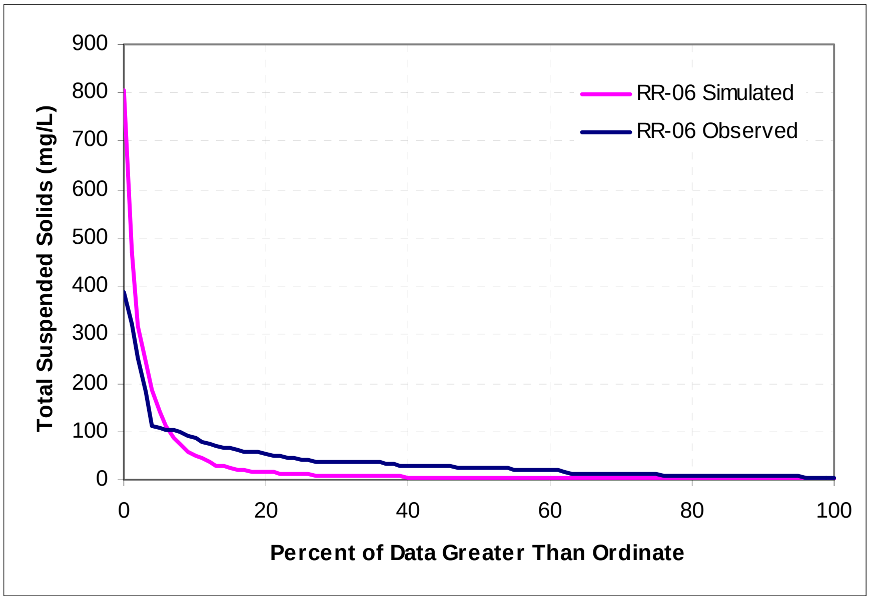
RR-05 Simulated
RR-05 Observed
BOD (mg/L)
Percent of Data Greater Than Ordinate
0
2
4
6
8
10
12
14
0
20
40
60
80
100



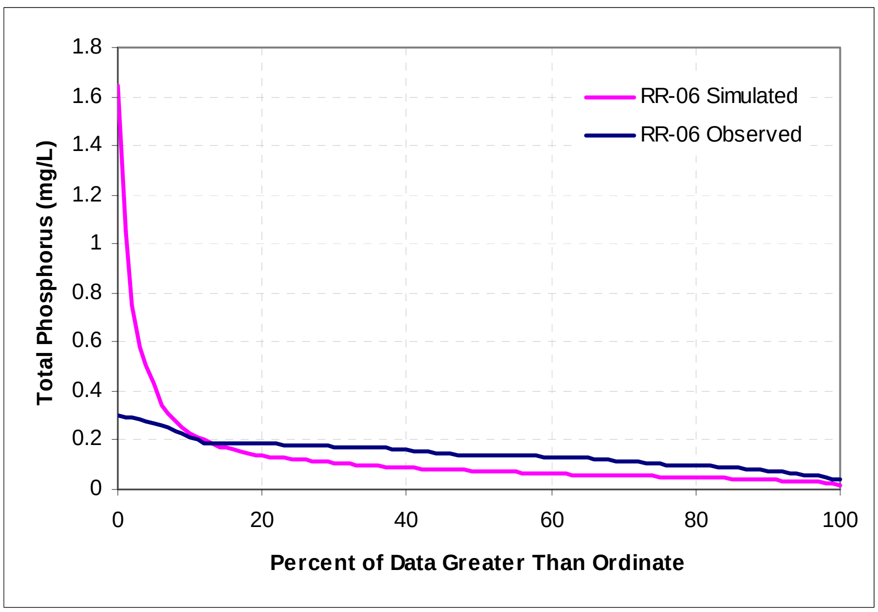
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
Dissolved Oxygen (mg/L)
Percent of Data Greater Than Ordinate
RR-05 Simulated
RR-05 Observed



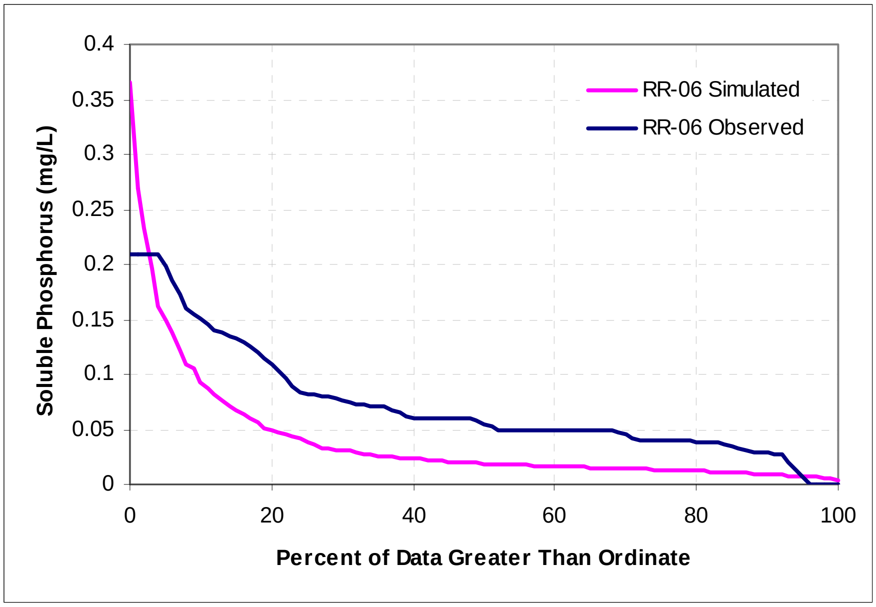
100000
10000
1000
100
10
1
0
20
40
60
80
100
Fecal Coliform (#/100mL)
Percent of Data Greater Than Ordinate
RR-05 Simulated
RR-05 Observed

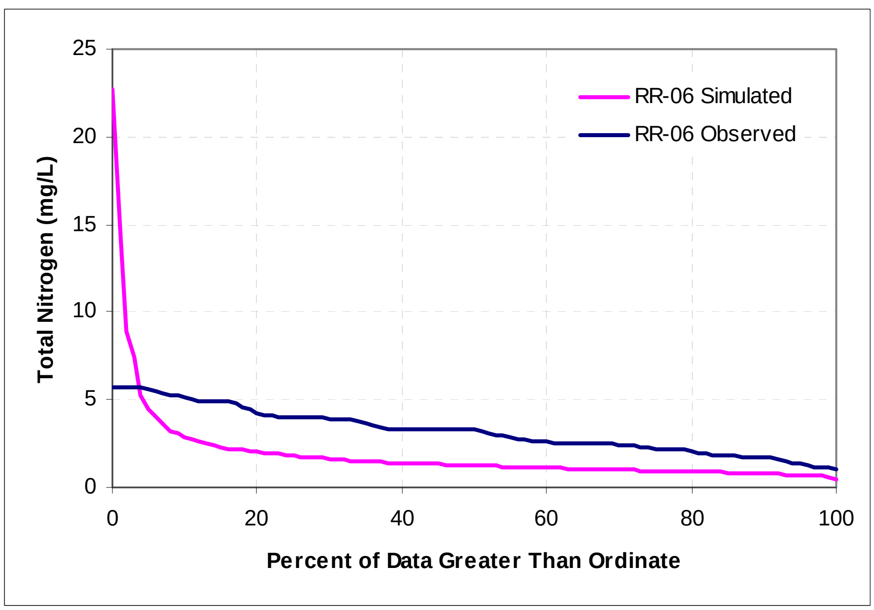


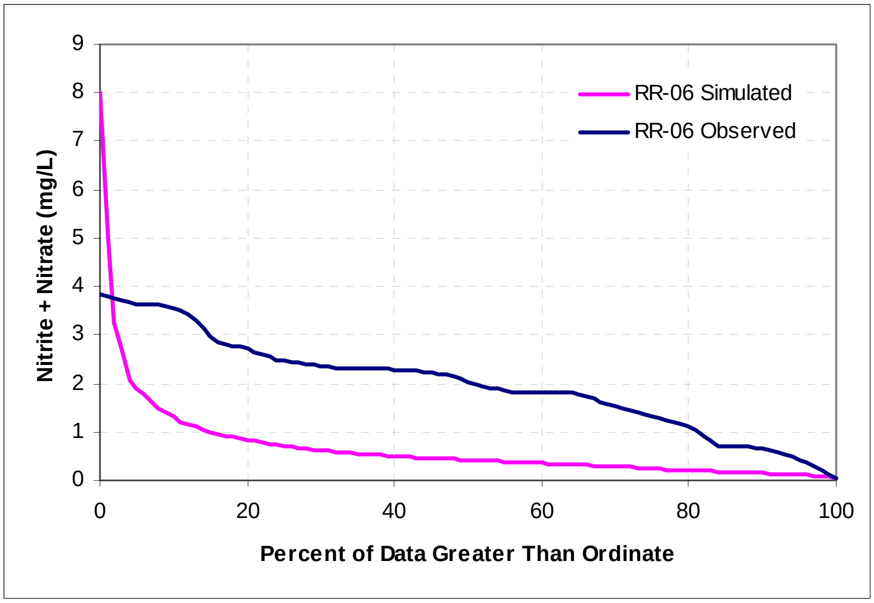
900
800
700
600
500
400
300
200
100
0
Total Suspended Solids (mg/L)
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-06 Simulated
RR-06 Observed



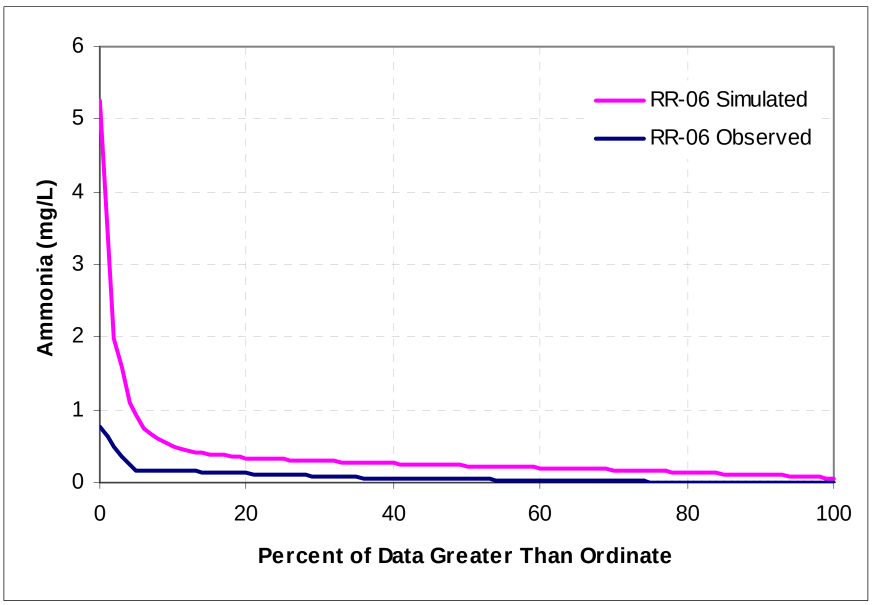
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Total Phosphorus (mg/L)
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-06 Simulated
RR-06 Observed


RR-06 Simulated
RR-06 Observed
Soluble Phosphorus (mg/L)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate

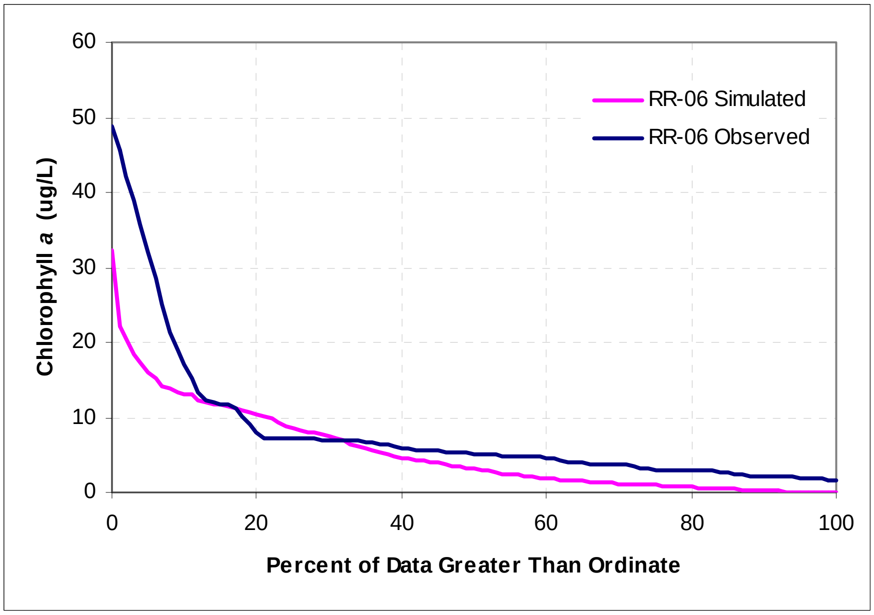

RR-06 Simulated
RR-06 Observed
Total Nitrogen (mg/L)
25
20
15
10
5
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate



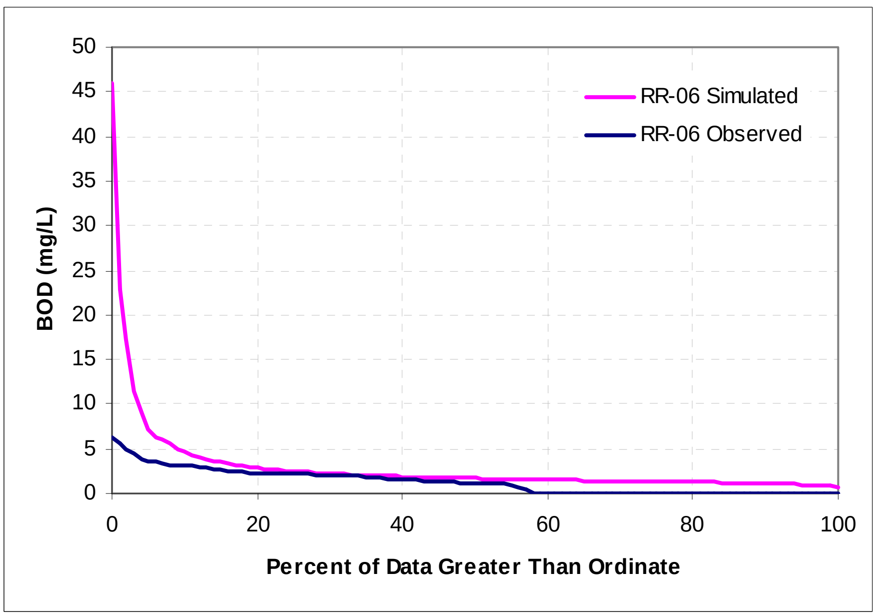
RR-06 Simulated
RR-06 Observed
Nitrite + Nitrate (mg/L)
0
1
2
3
4
5
6
7
8
9
0
20
40
60
80
100
Percent of Data Greater Than Ordinate



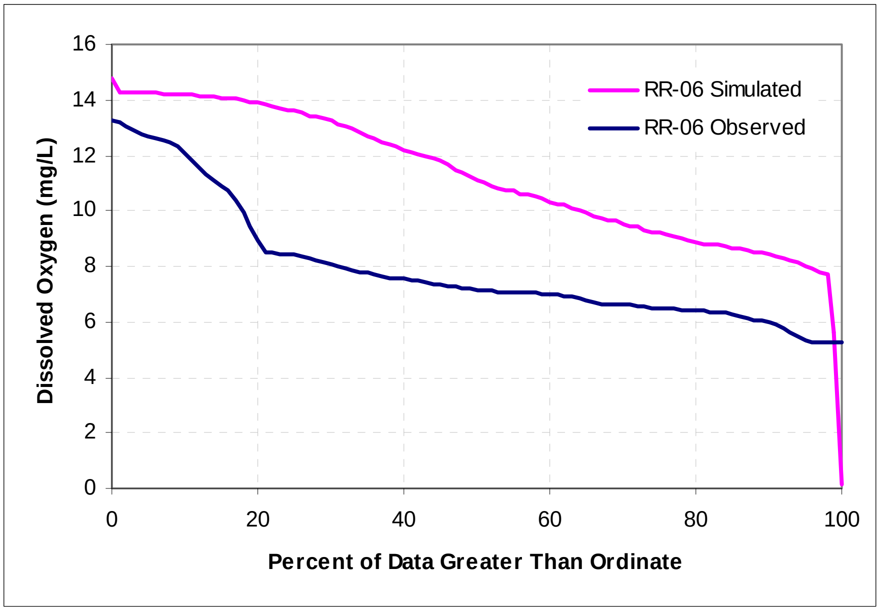
RR-06 Simulated
RR-06 Observed
Ammonia (mg/L)
0
1
2
3
4
5
6
0
20
40
60
80
100
Percent of Data Greater Than Ordinate



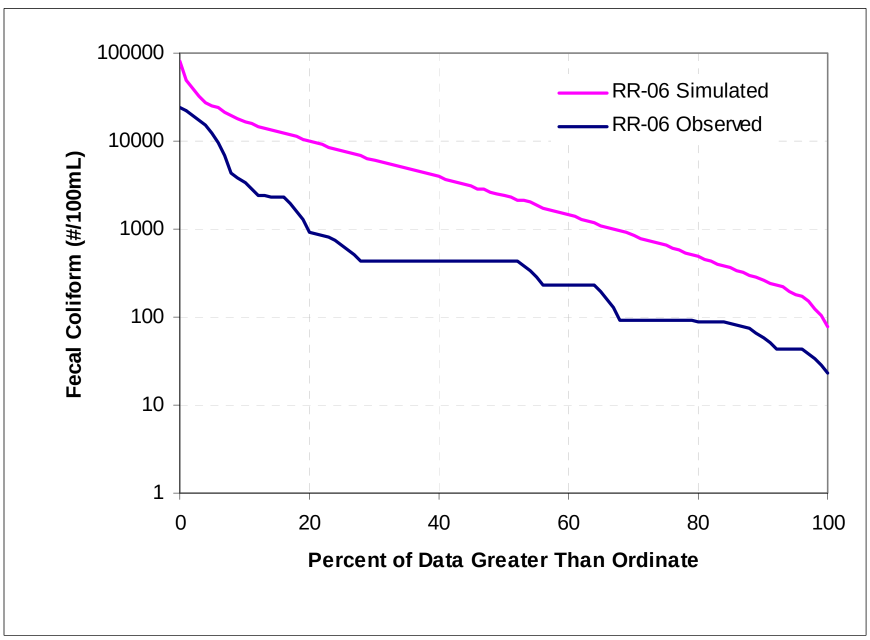
60
50
40
30
20
10
0
0
20
40
60
80
100
Chlorophyll a (ug/L)
Percent of Data Greater Than Ordinate
RR-06 Simulated
RR-06 Observed



50
45
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100
BOD (mg/L)
Percent of Data Greater Than Ordinate
RR-06 Simulated
RR-06 Observed

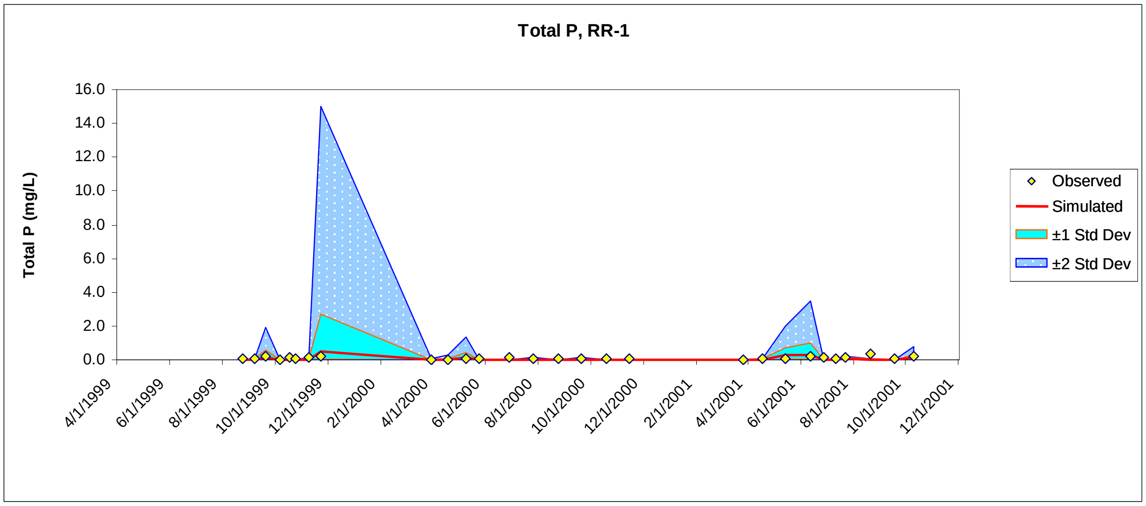


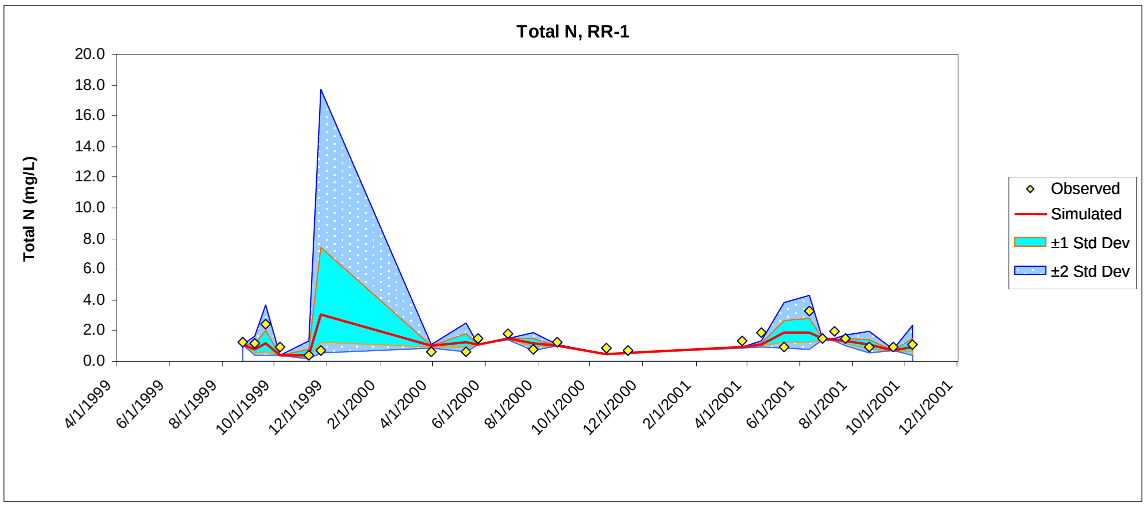
Dissolved Oxygen (mg/L)
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-06 Simulated
RR-06 Observed

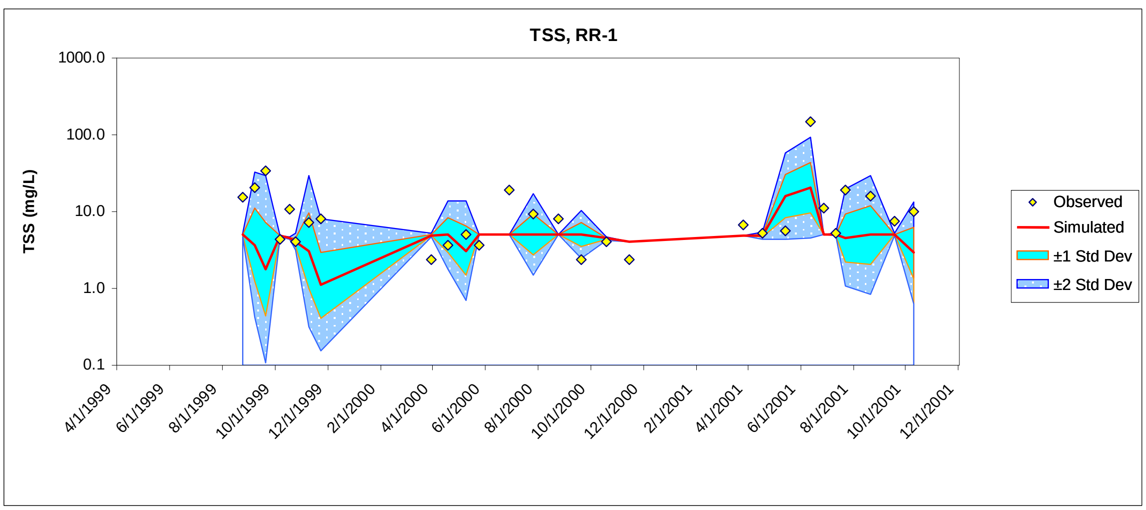


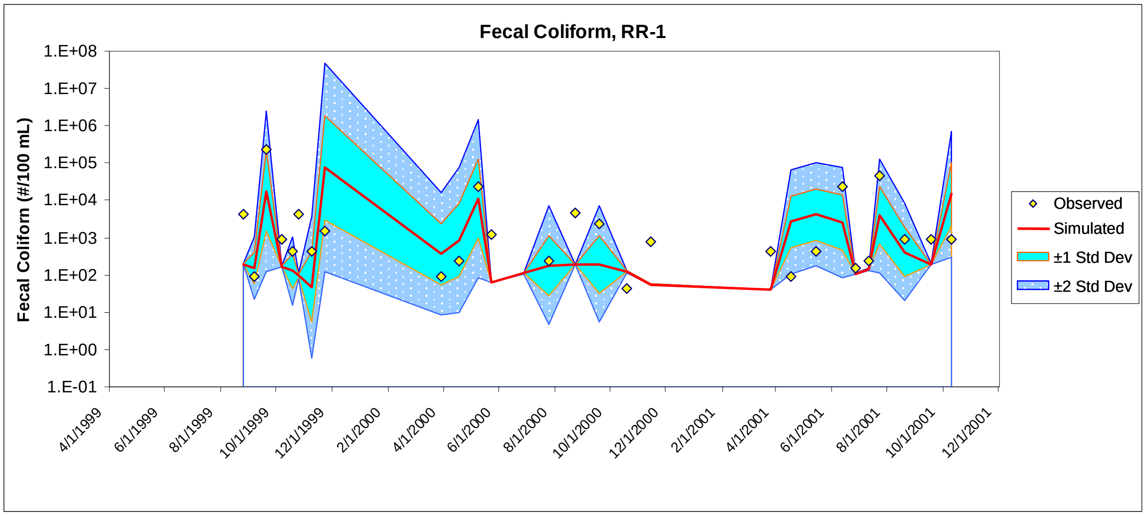
Fecal Coliform (#/100mL)
100000
10000
1000
100
10
1
0
20
40
60
80
100
Percent of Data Greater Than Ordinate
RR-06 Simulated
RR-06 Observed

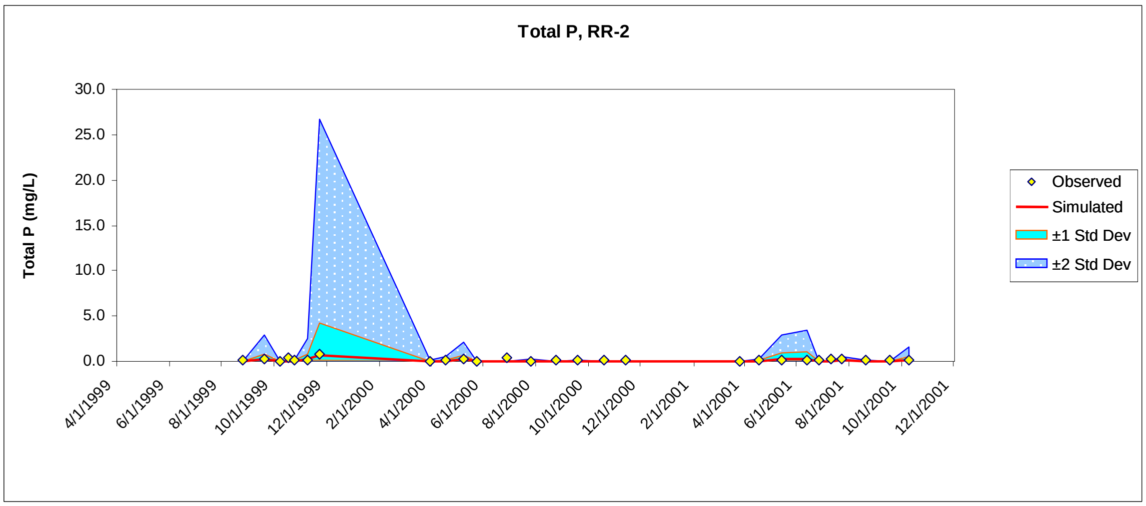
ATTACHMENT K – CONTROL CHARTS

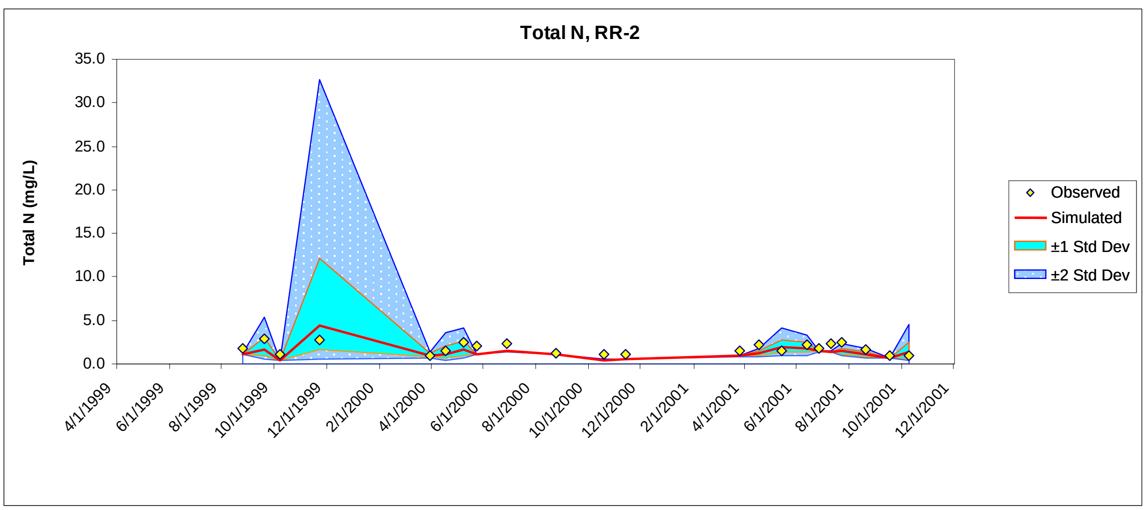

Total P, RR-1
Total P (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

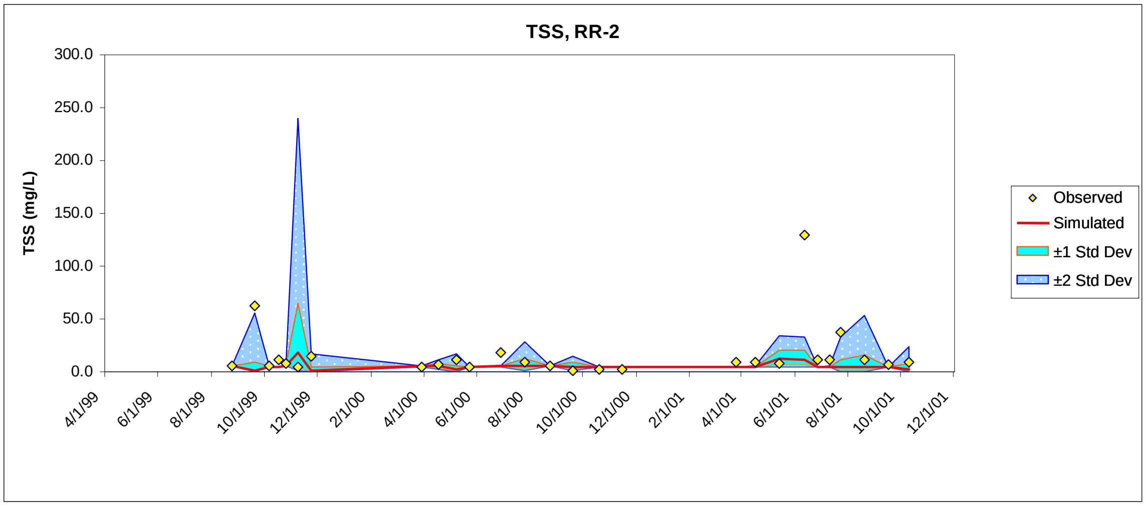

Total N, RR-1
Total N (mg/L)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

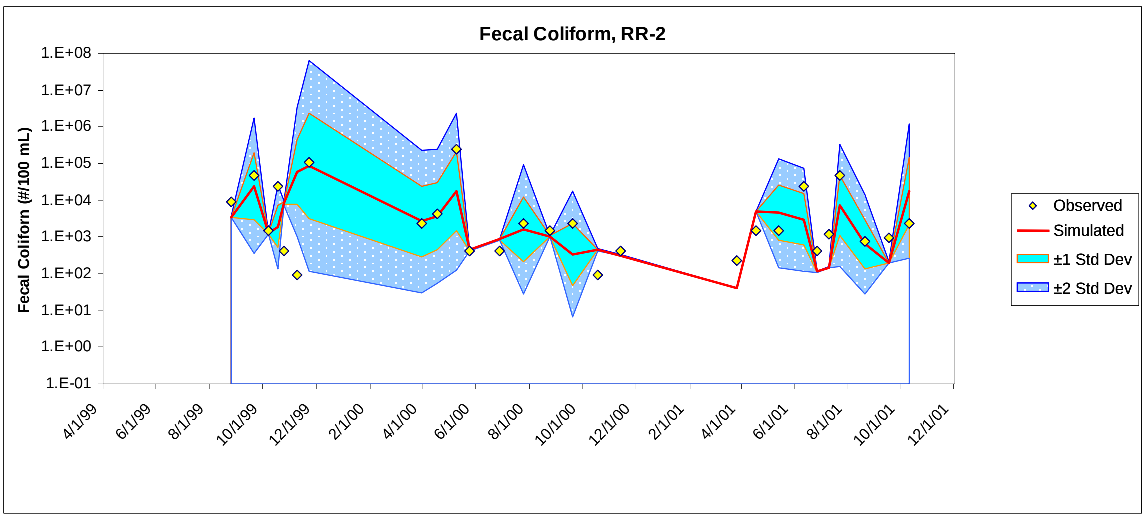

TSS, RR-1
TSS (mg/L)
1000.0
100.0
10.0
1.0
0.1
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

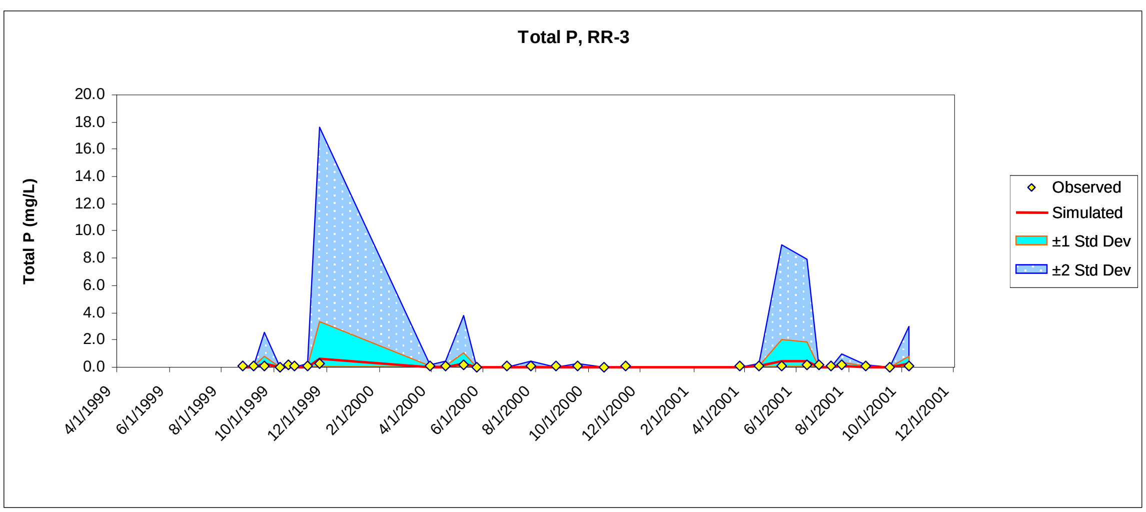

Fecal Coliform, RR-1
Fecal Coliform (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

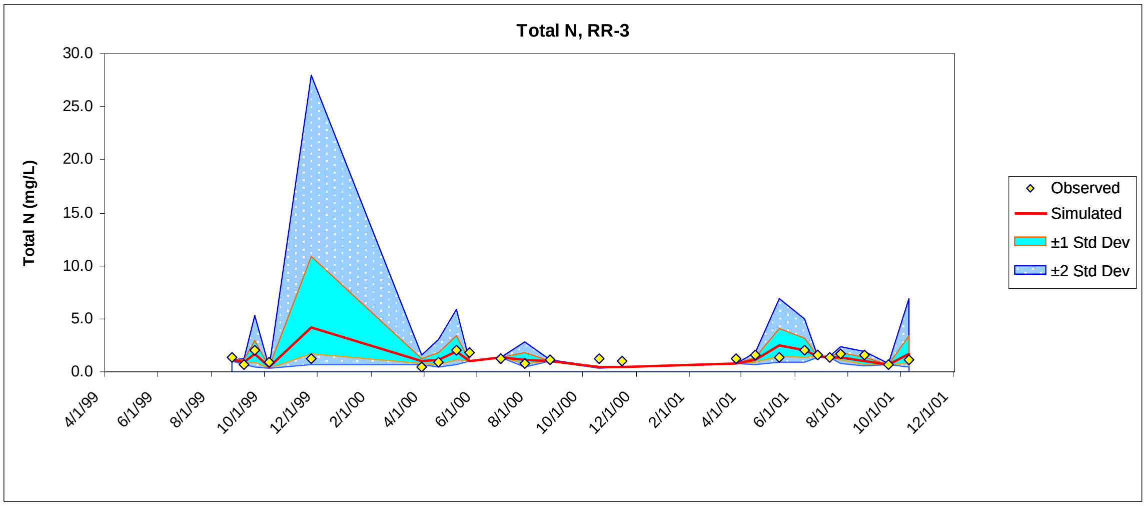

Total P, RR-2
Total P (mg/L)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

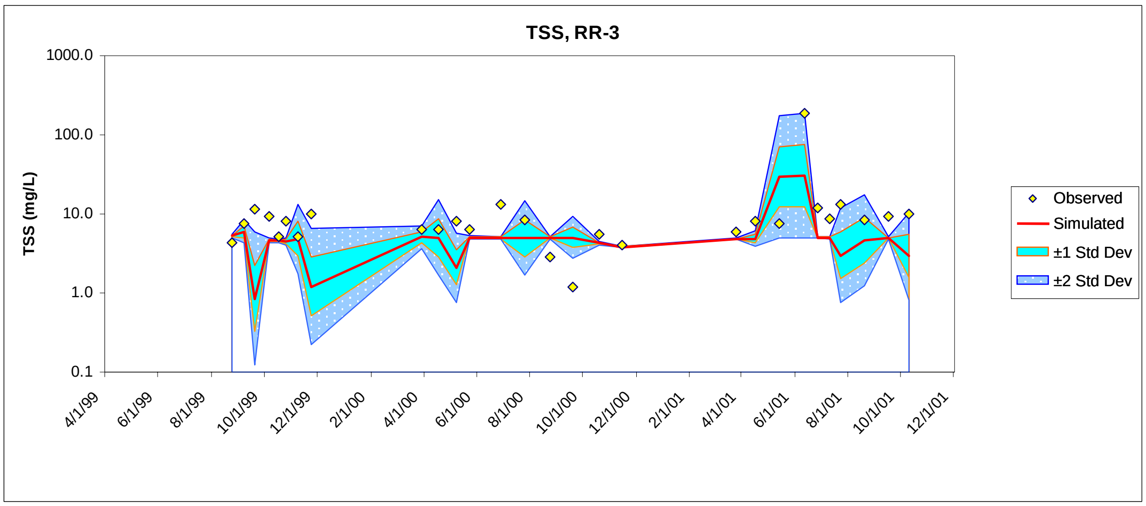

Total N, RR-2
Total N (mg/L)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

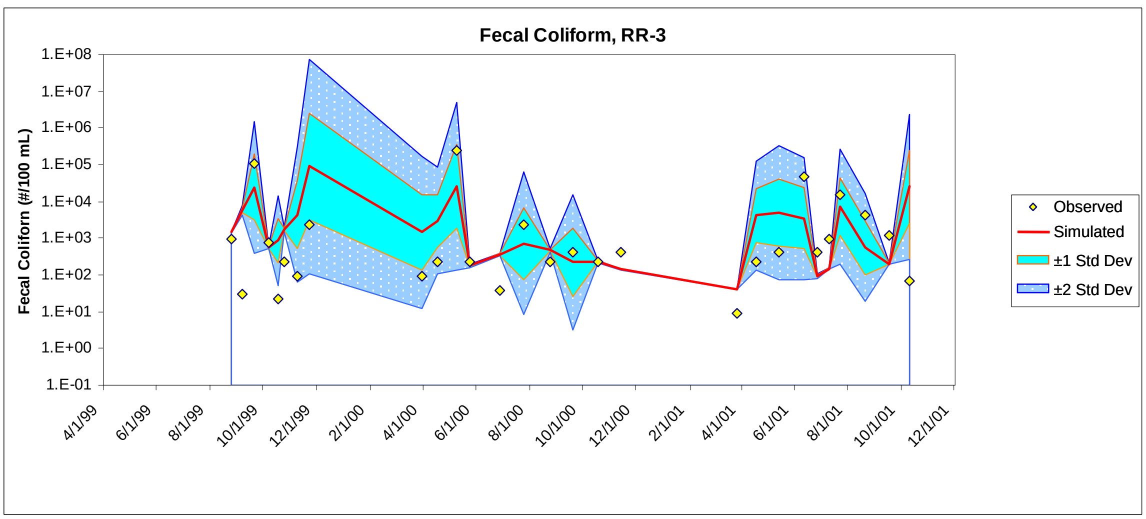

TSS, RR-2
TSS (mg/L)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
4/1/99
6/1/99
8/1/99
10/1/99
12/1/99
2/1/00
4/1/00
6/1/00
8/1/00
10/1/00
12/1/00
2/1/01
4/1/01
6/1/01
8/1/01
10/1/01
12/1/01
Observed
Simulated
±1 Std Dev
±2 Std Dev

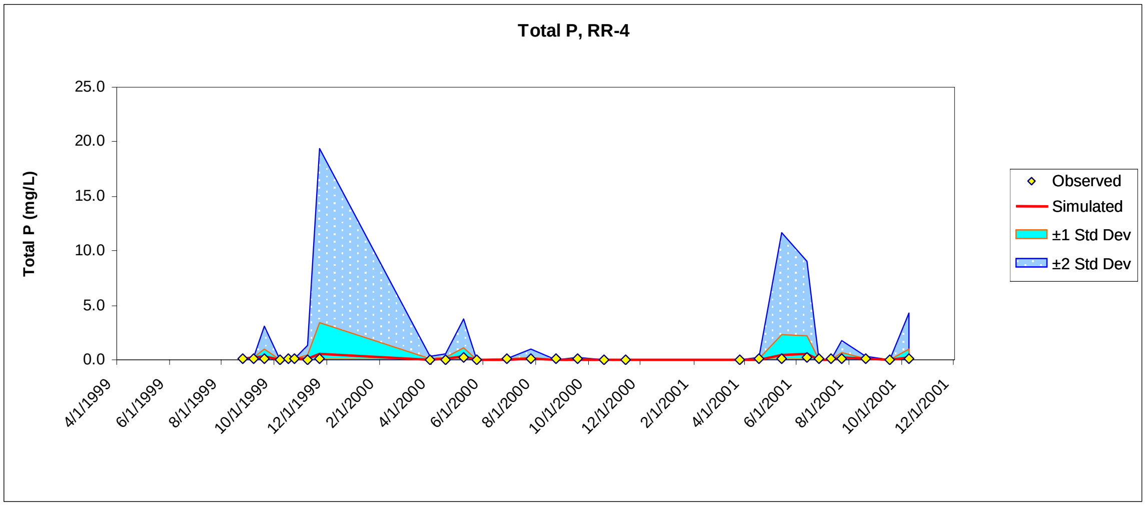

Fecal Coliform, RR-2
Fecal Coliforn (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/99
6/1/99
8/1/99
10/1/99
12/1/99
2/1/00
4/1/00
6/1/00
8/1/00
10/1/00
12/1/00
2/1/01
4/1/01
6/1/01
8/1/01
10/1/01
12/1/01
Observed
Simulated
±1 Std Dev
±2 Std Dev

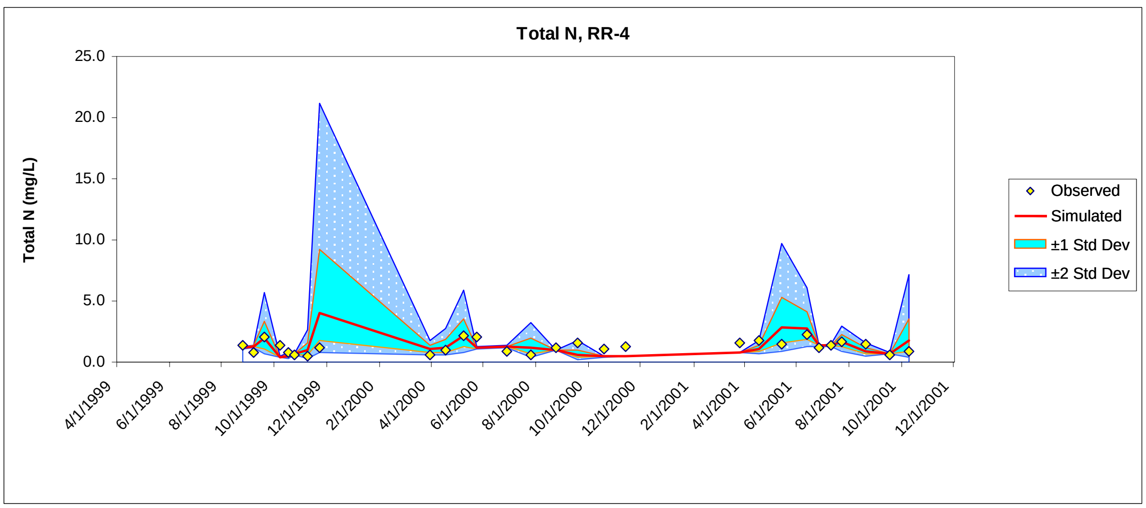

Total P, RR-3
Total P (mg/L)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

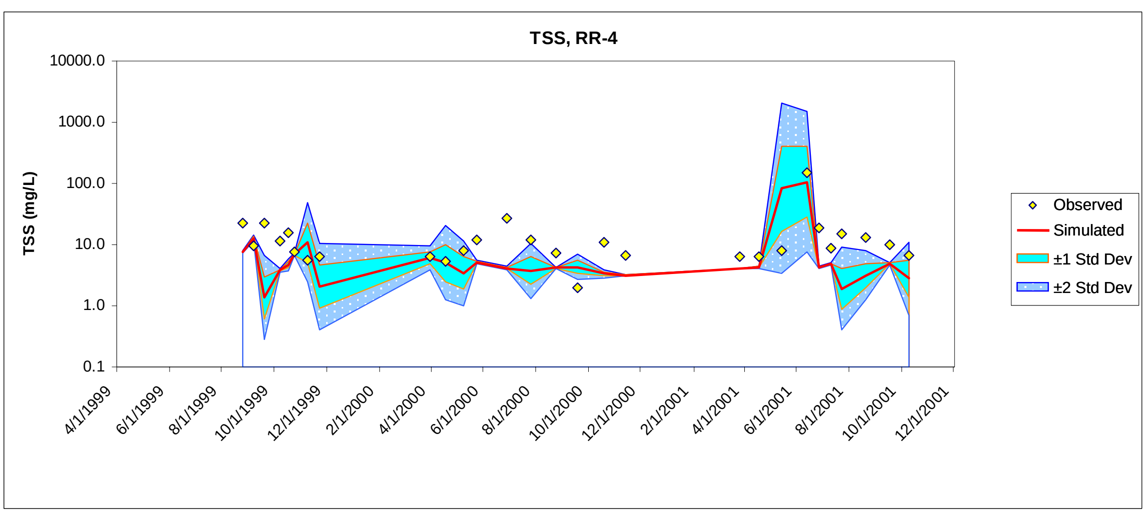

Total N, RR-3
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Total N (mg/L)
4/1/99
6/1/99
8/1/99
10/1/99
12/1/99
2/1/00
4/1/00
6/1/00
8/1/00
10/1/00
12/1/00
2/1/01
4/1/01
6/1/01
8/1/01
10/1/01
12/1/01
Observed
Simulated
±1 Std Dev
±2 Std Dev

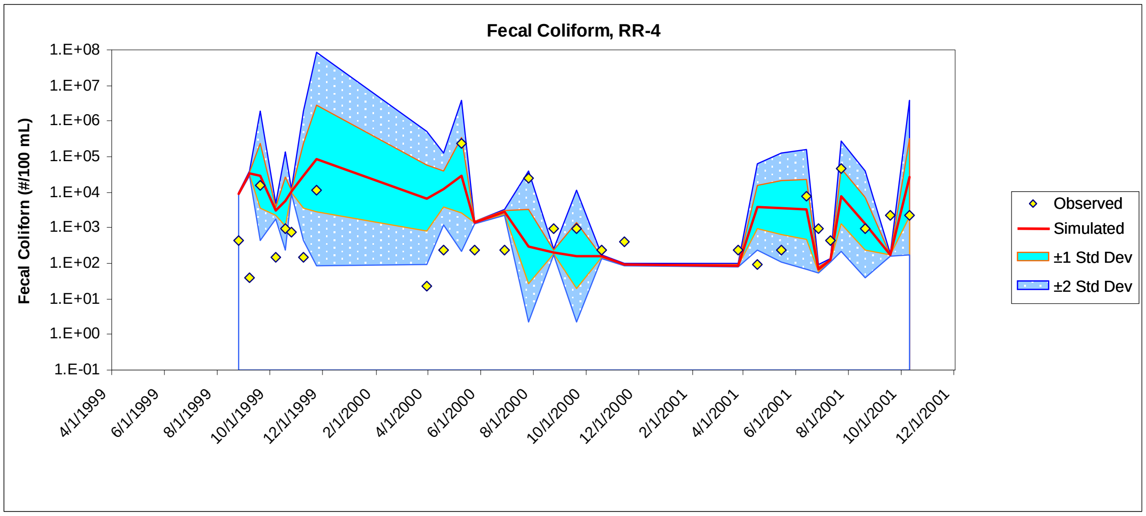

TSS, RR-3
1000.0
100.0
10.0
1.0
0.1
TSS (mg/L)
4/1/99
6/1/99
8/1/99
10/1/99
12/1/99
2/1/00
4/1/00
6/1/00
8/1/00
10/1/00
12/1/00
2/1/01
4/1/01
6/1/01
8/1/01
10/1/01
12/1/01
Observed
Simulated
±1 Std Dev
±2 Std Dev

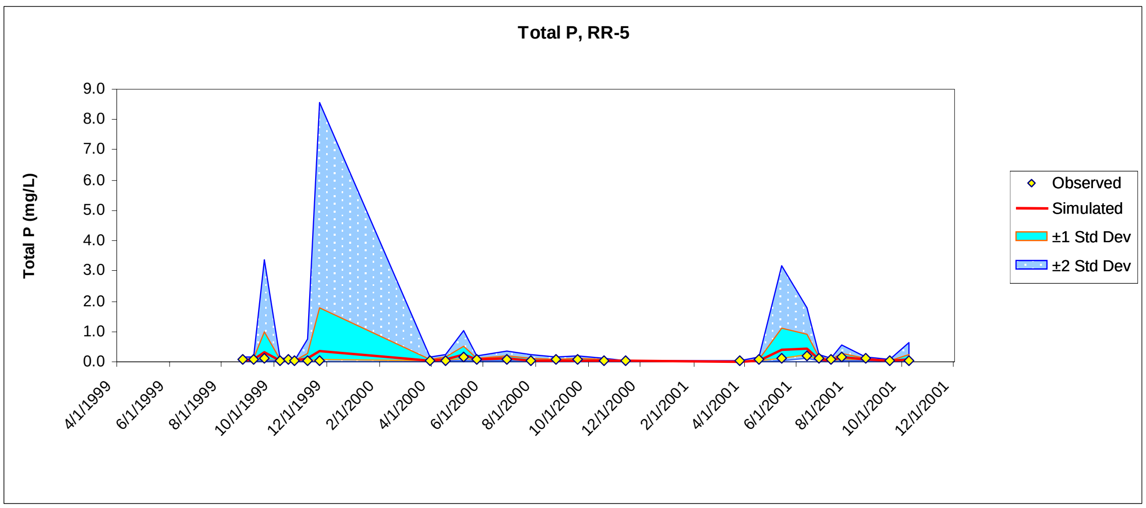

Fecal Coliform, RR-3
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
Fecal Coliforn (#/100 mL)
4/1/99
6/1/99
8/1/99
10/1/99
12/1/99
2/1/00
4/1/00
6/1/00
8/1/00
10/1/00
12/1/00
2/1/01
4/1/01
6/1/01
8/1/01
10/1/01
12/1/01
Observed
Simulated
±1 Std Dev
±2 Std Dev

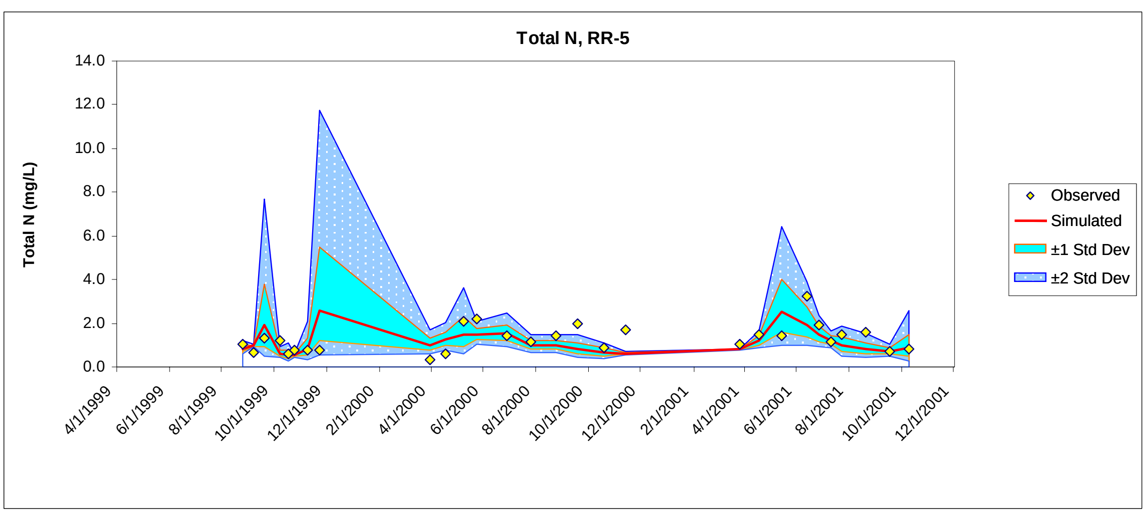

Total P, RR-4
Total P (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

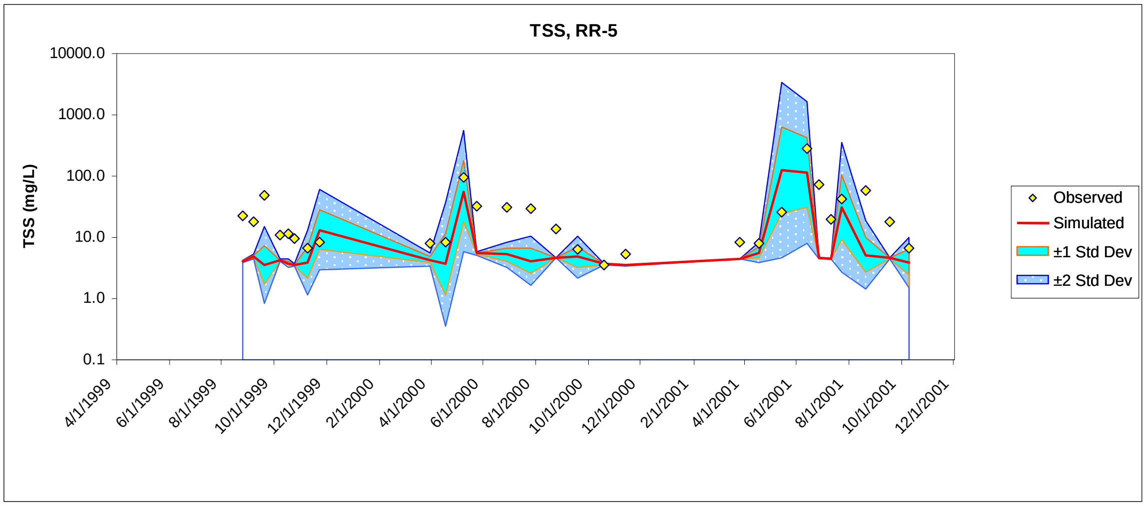

Total N, RR-4
Total N (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

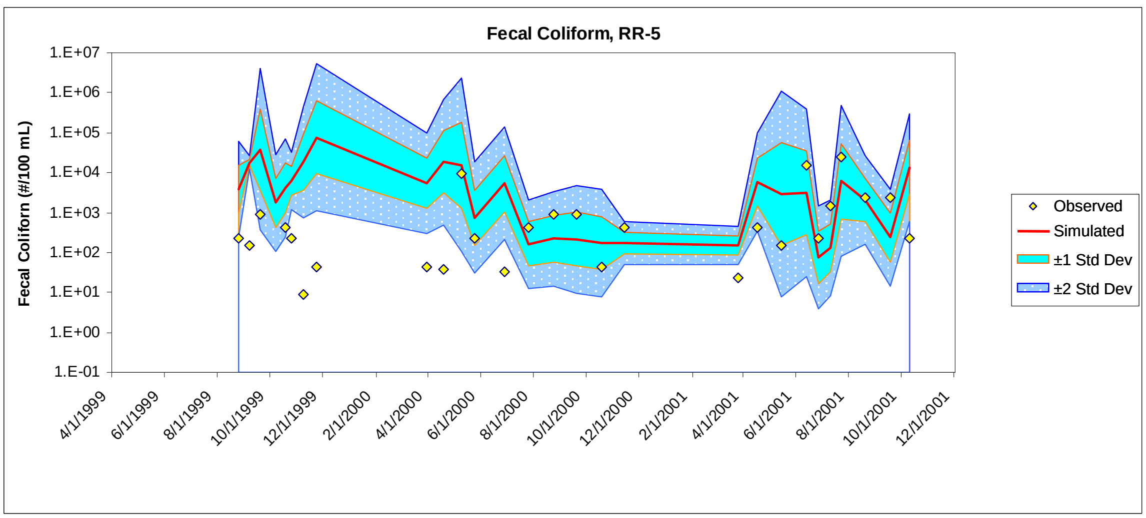

TSS, RR-4
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

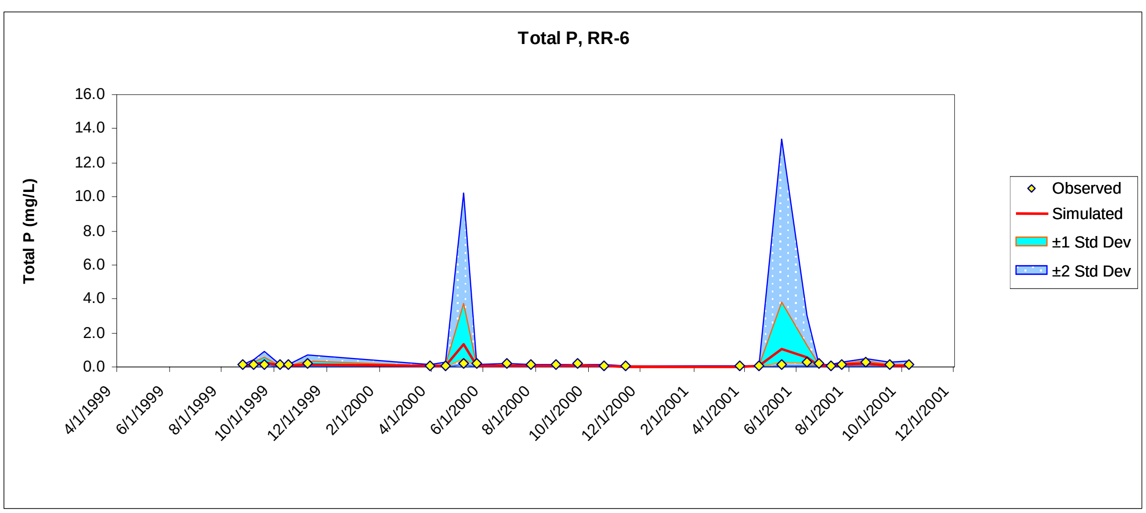

Fecal Coliform, RR-4
Fecal Coliforn (#/100 mL)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

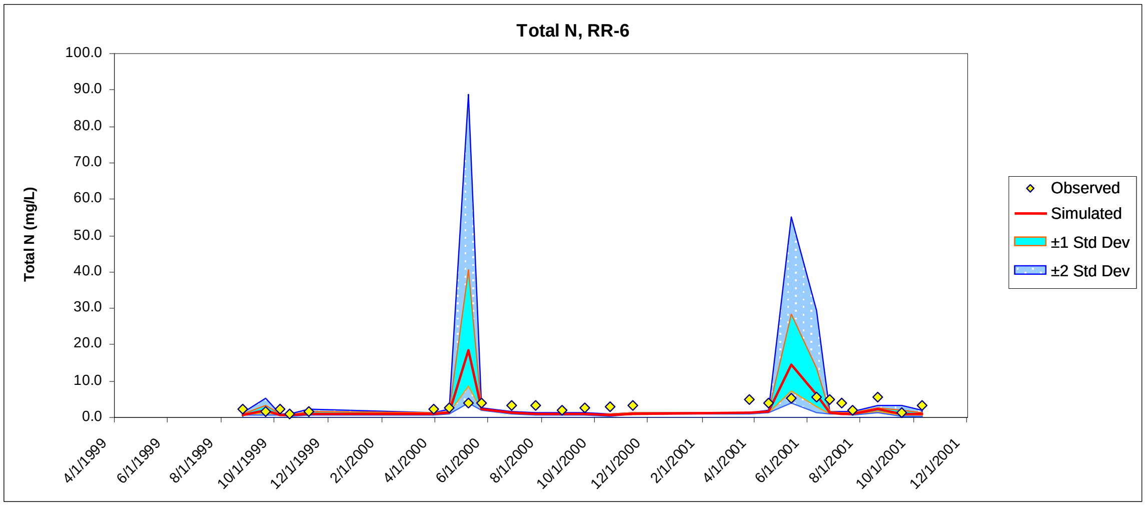

Total P, RR-5
Total P (mg/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

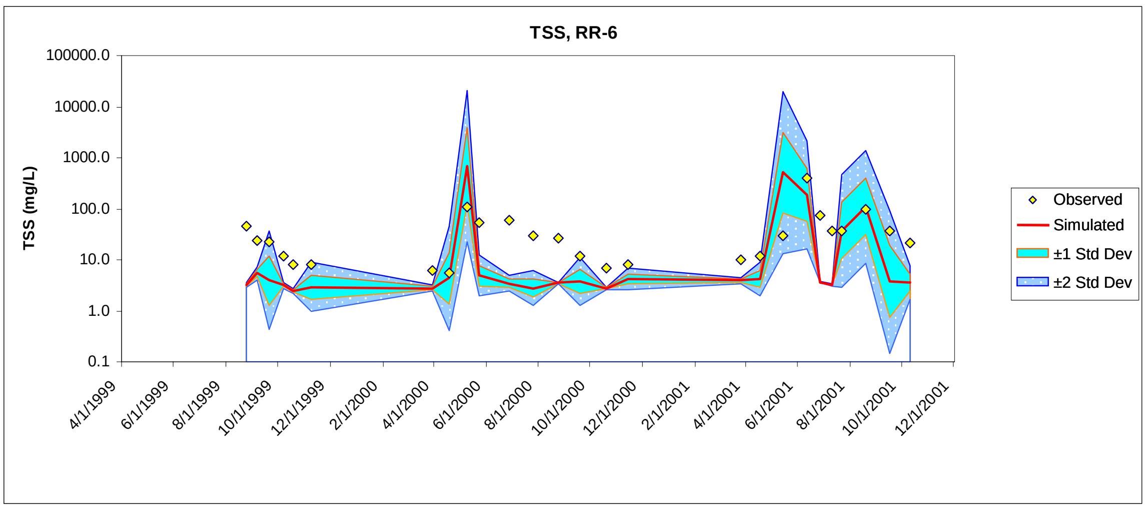

Total N, RR-5
Total N (mg/L)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

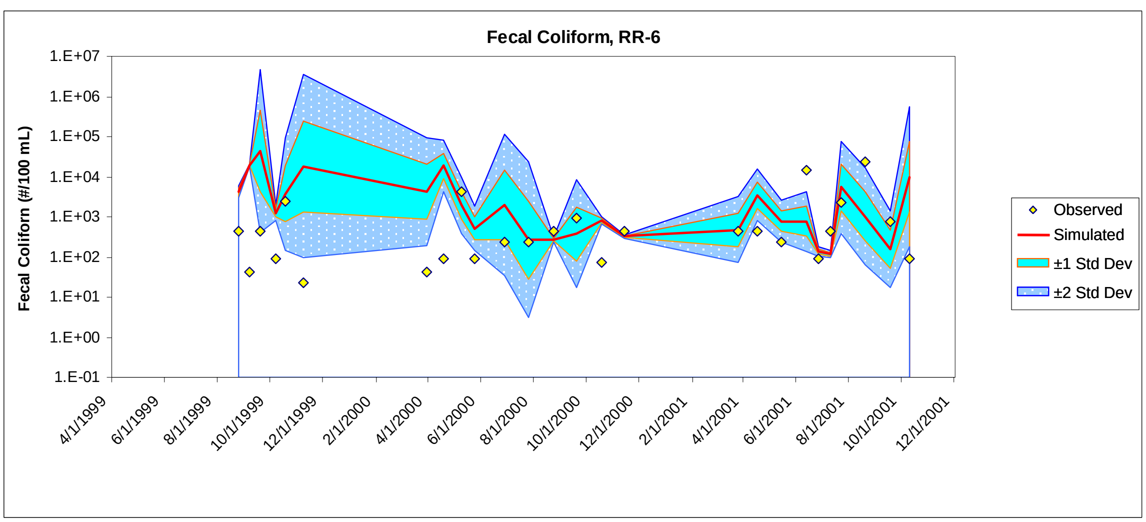

TSS, RR-5
TSS (mg/L)
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Fecal Coliform, RR-5
Fecal Coliform (#/100 mL)
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

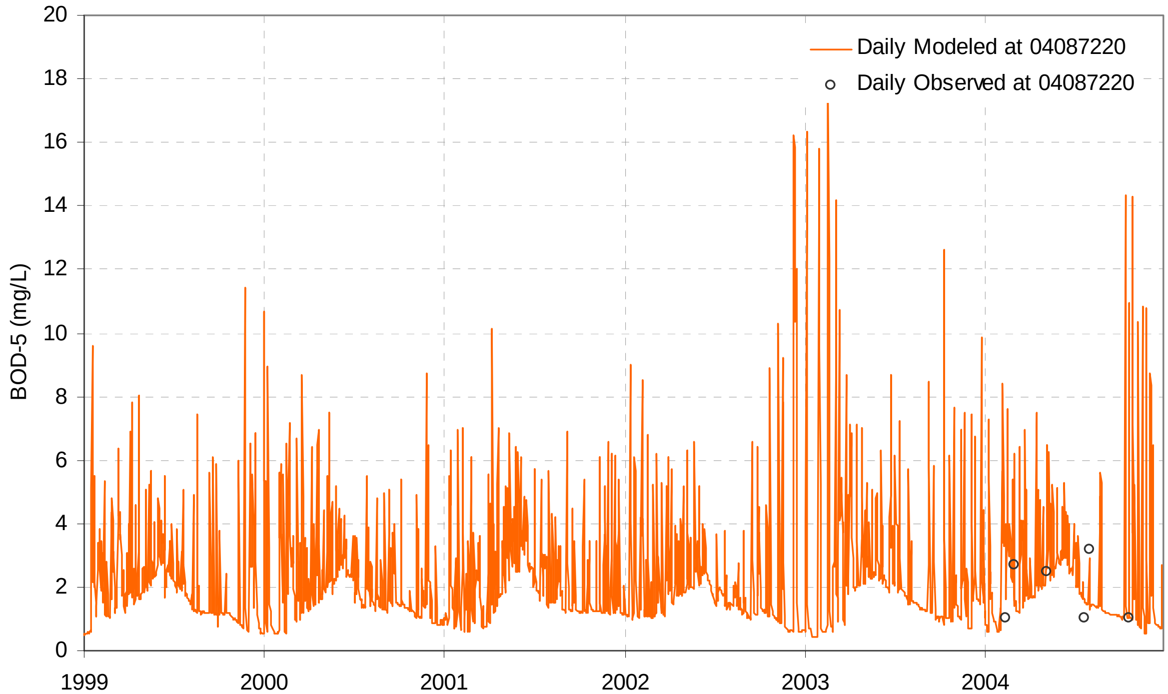

Total P, RR-6
Total P (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Total N, RR-6
Total N (mg/L)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

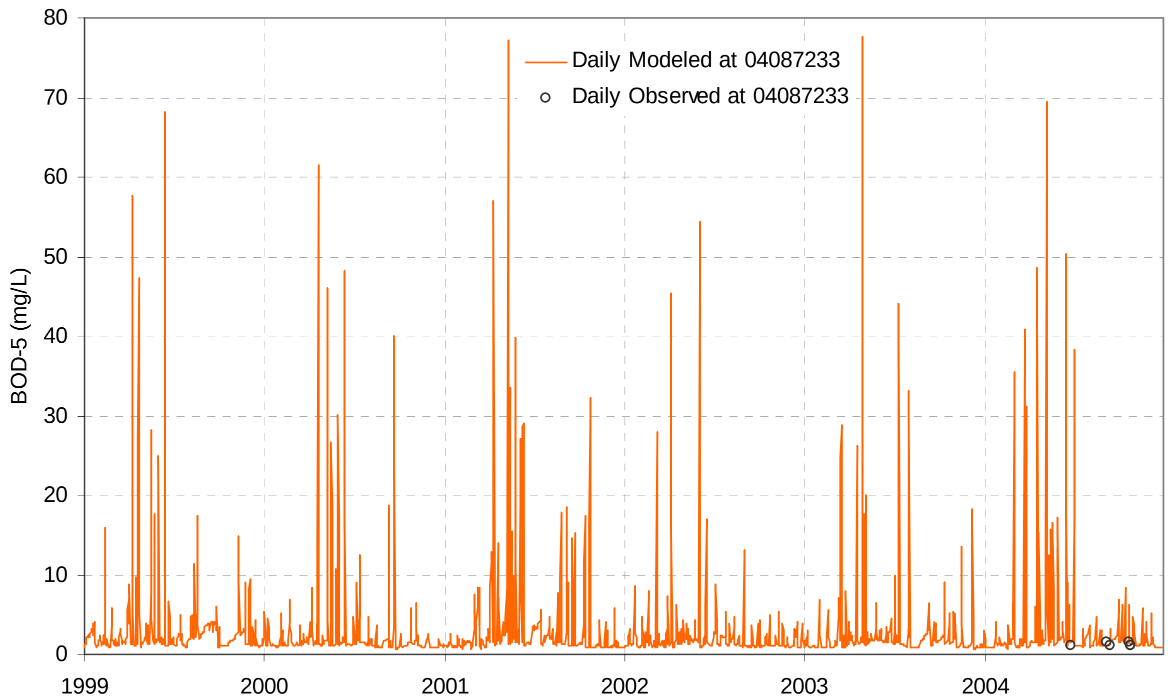

TSS, RR-6
TSS (mg/L)
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev


Fecal Coliform, RR-6
Fecal Coliforn (#/100 mL)
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
4/1/1999
6/1/1999
8/1/1999
10/1/1999
12/1/1999
2/1/2000
4/1/2000
6/1/2000
8/1/2000
10/1/2000
12/1/2000
2/1/2001
4/1/2001
6/1/2001
8/1/2001
10/1/2001
12/1/2001
Observed
Simulated
±1 Std Dev
±2 Std Dev

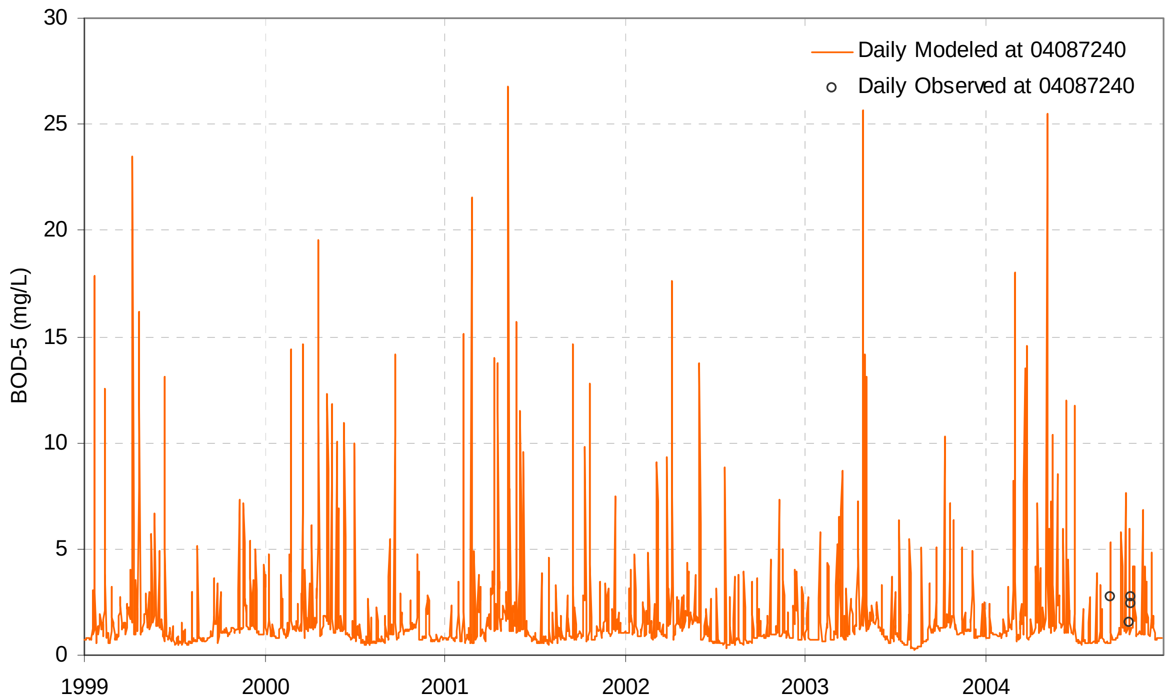
ATTACHMENT L – VALIDATION PLOTS FOR THE USGS GAGE STATIONS

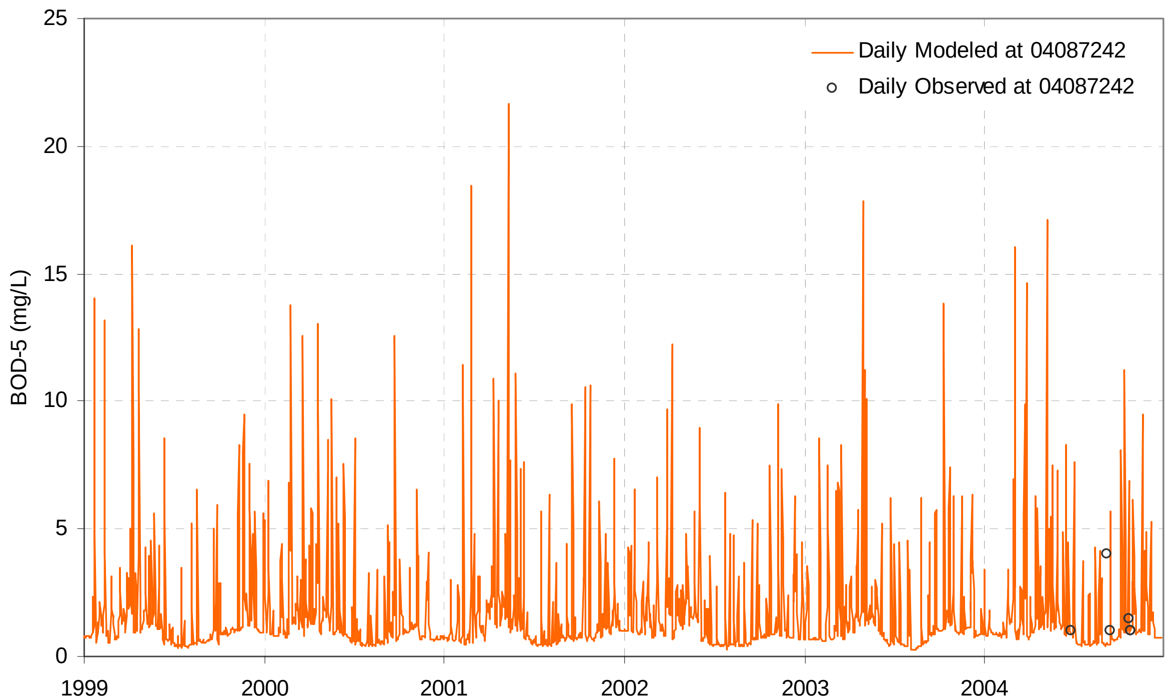


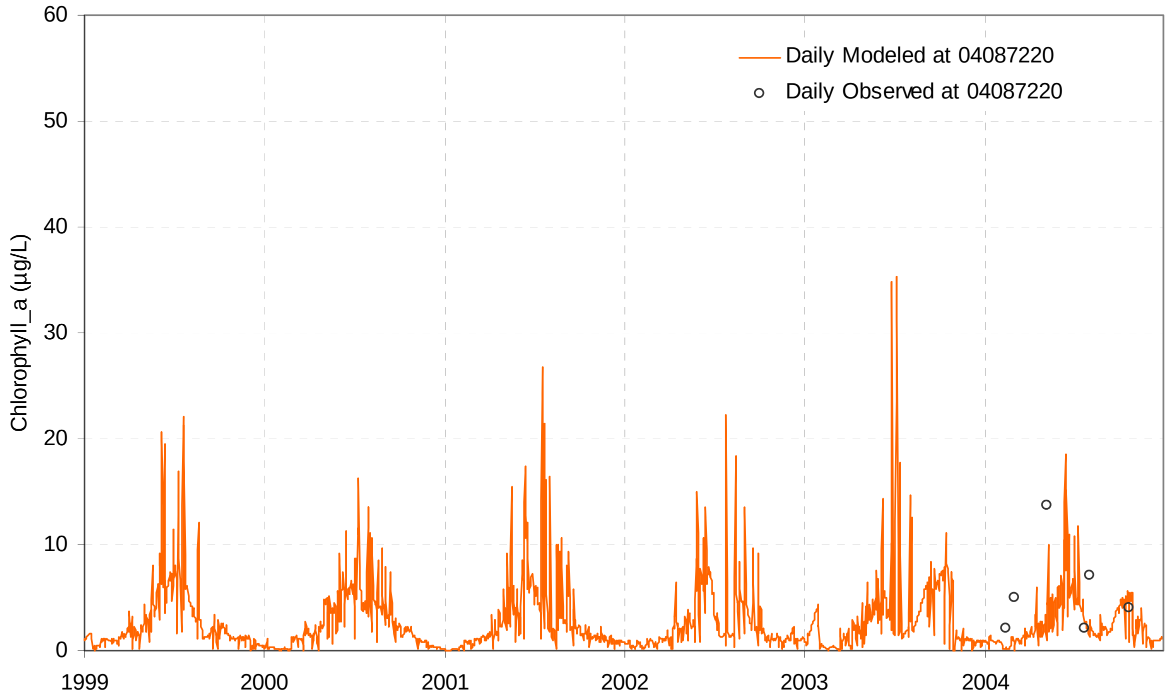
BOD-5 (mg/L)
0
2
4
6
8
10
12
14
16
18
20
1999
2000
2001
2002
2003
2004
Daily Modeled at 04087220
Daily Observed at 04087220



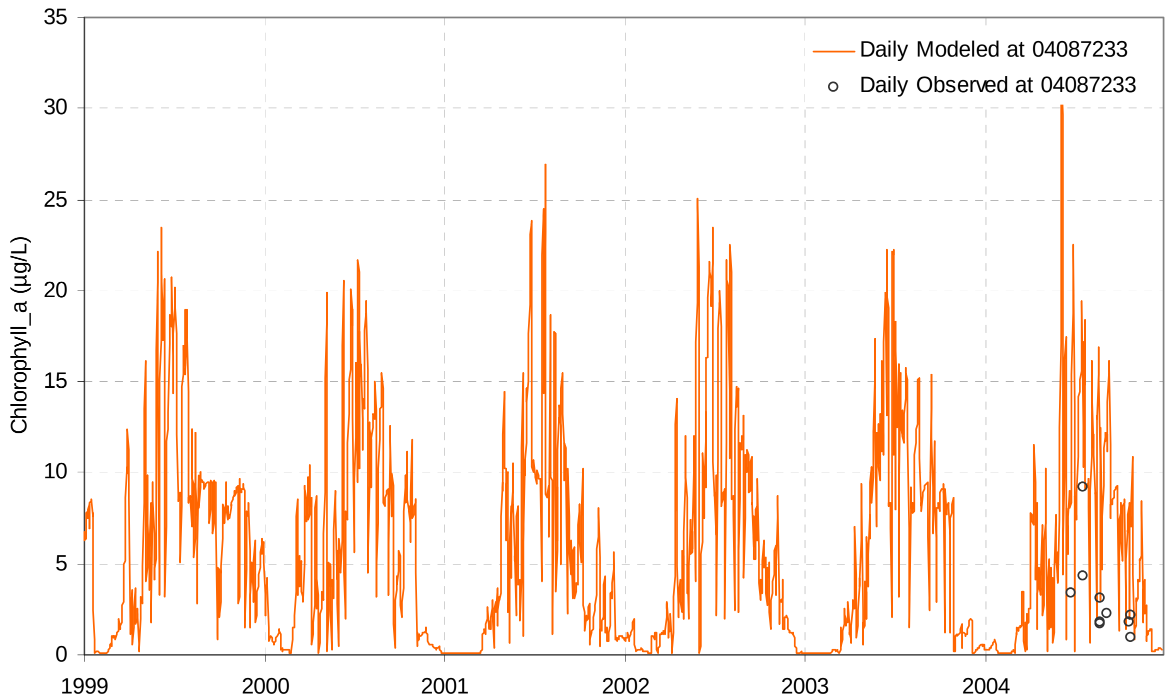
BOD-5 (mg/L)
0
10
20
30
40
50
60
70
80
1999
2000
2001
2002
2003
2004
Daily Modeled at 04087233
Daily Observed at 04087233


30
25
20
15
10
5
0
BOD-5 (mg/L)
1999
2000
2001
2002
2003
2004
Daily Modeled at 04087240
Daily Observed at 04087240

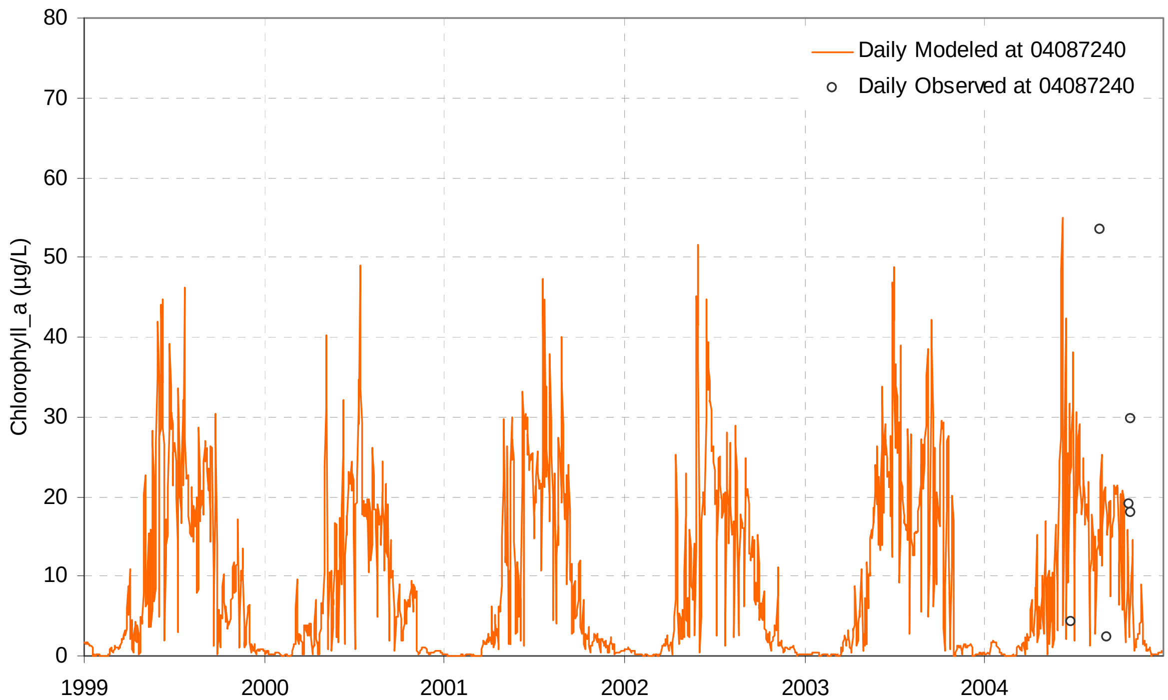

25
20
15
10
5
0
BOD-5 (mg/L)
1999
2000
2001
2002
2003
2004
Daily Modeled at 04087242
Daily Observed at 04087242



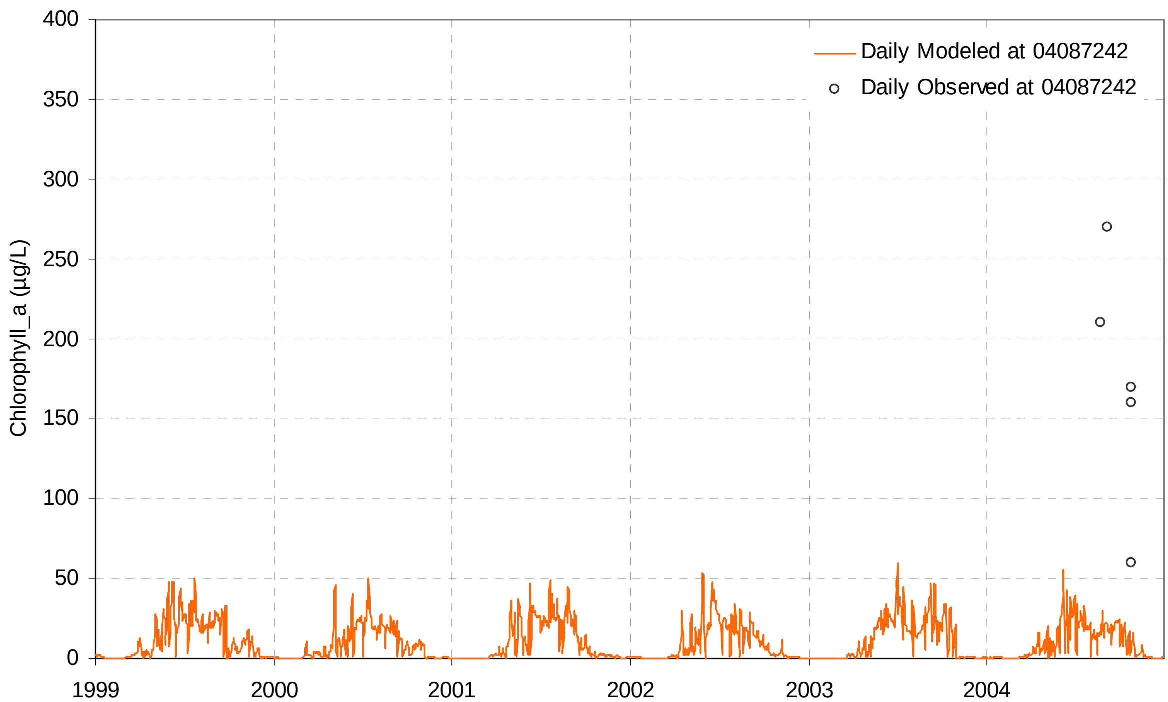
Daily Modeled at 04087220
Daily Observed at 04087220
Chlorophyll_a (µg/L)
60
50
40
30
20
10
0
1999
2000
2001
2002
2003
2004



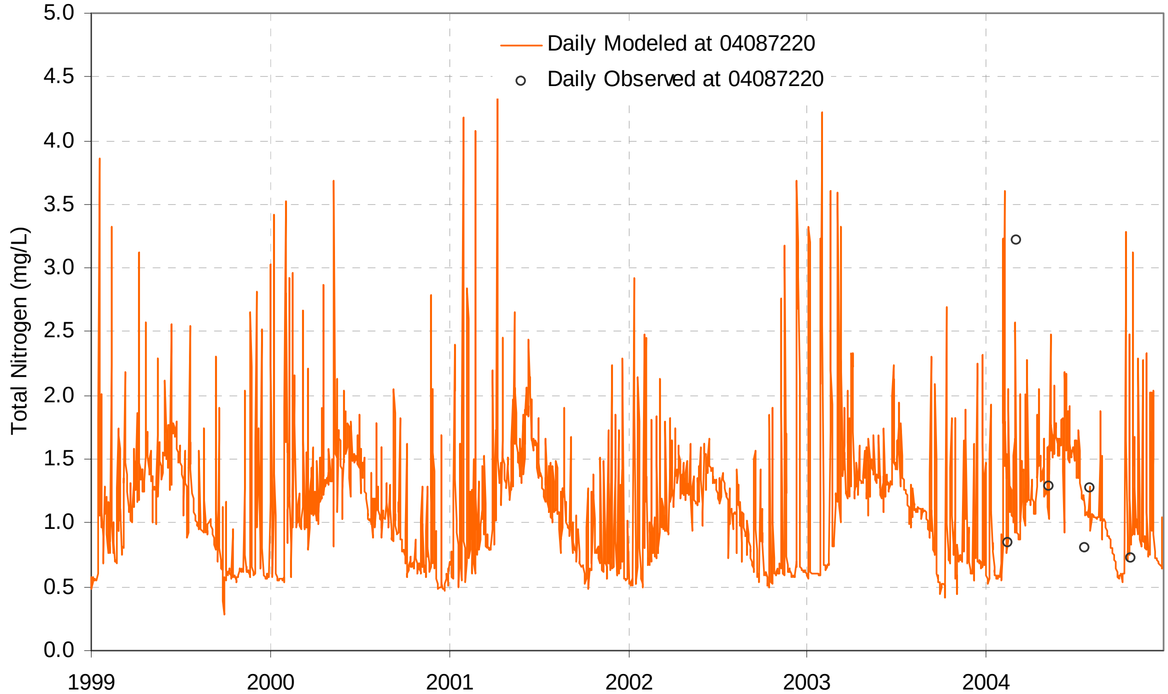
Daily Modeled at 04087233
Daily Observed at 04087233
Chlorophyll_a (µg/L)
35
30
25
20
15
10
5
0
1999
2000
2001
2002
2003
2004

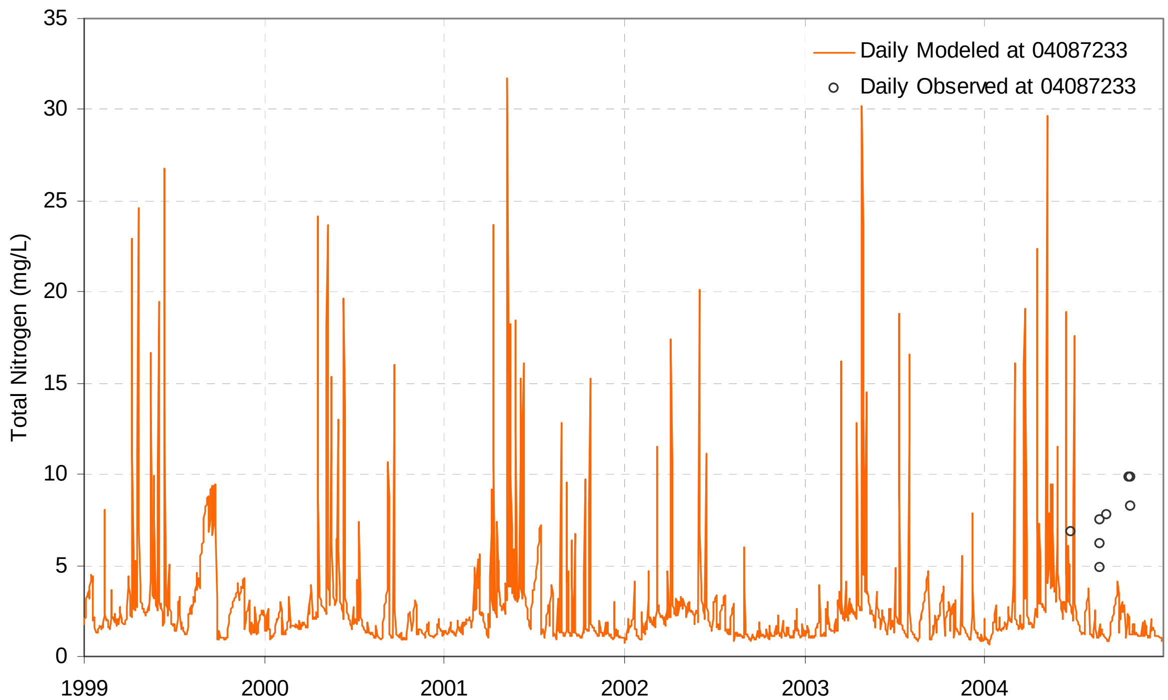


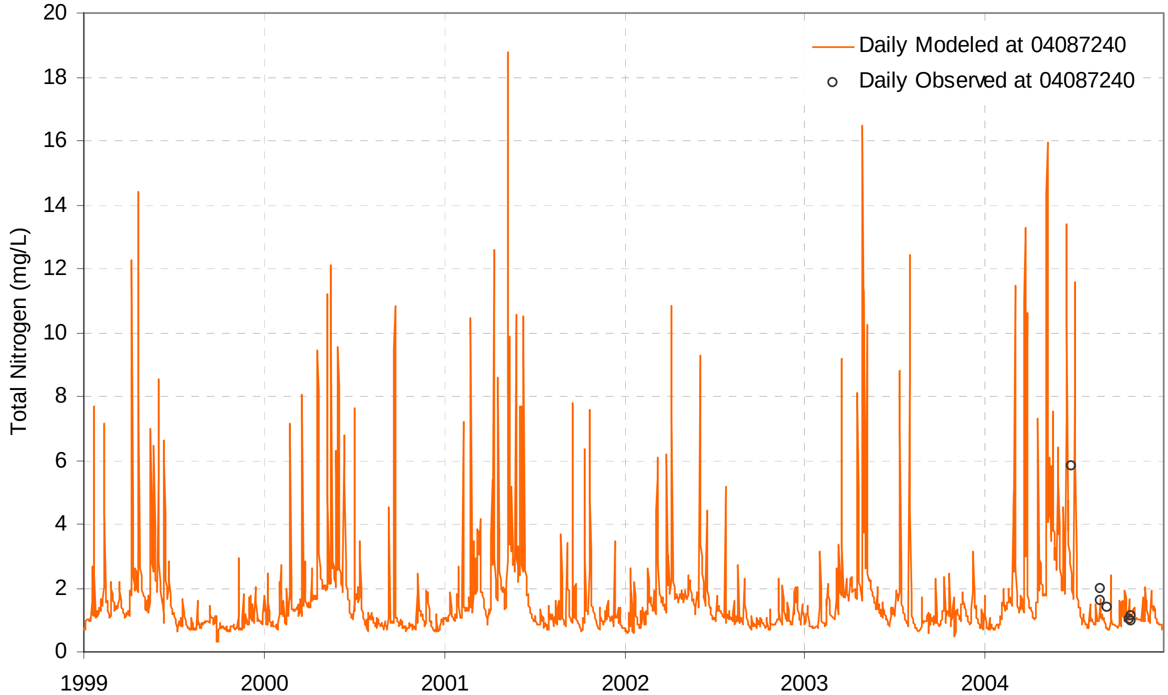
Daily Modeled at 04087240
Daily Observed at 04087240
Chlorophyll_a (µg/L)
0
10
20
30
40
50
60
70
80
1999
2000
2001
2002
2003
2004



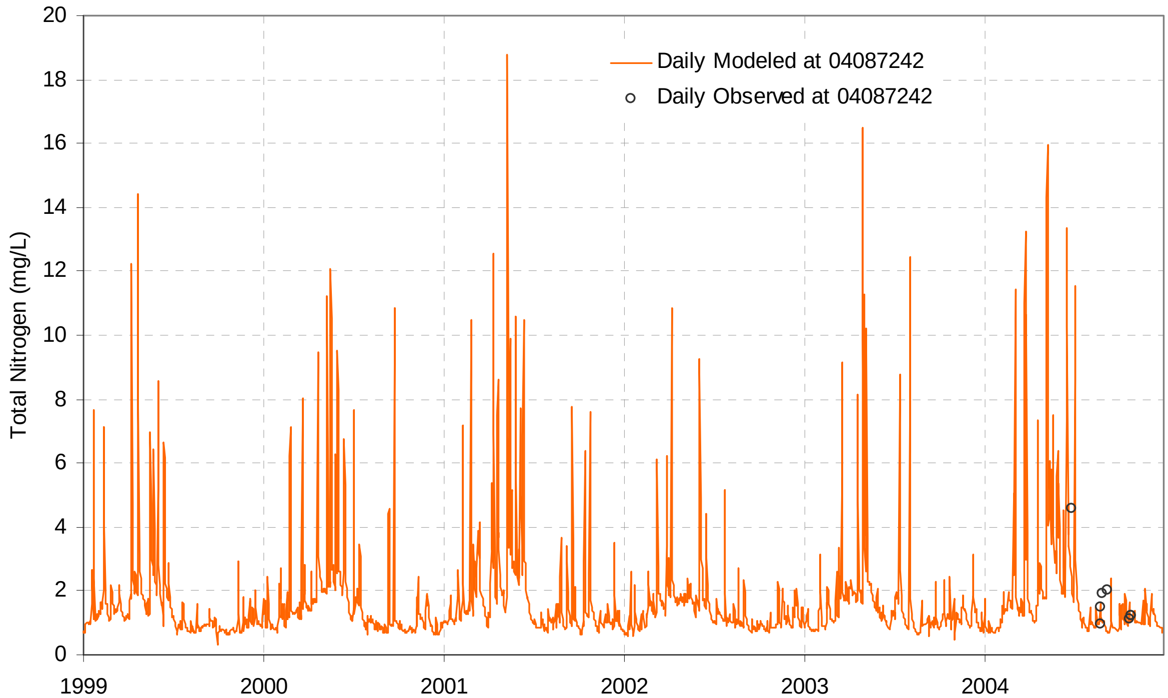
Daily Modeled at 04087242
Daily Observed at 04087242
Chlorophyll_a (µg/L)
0
50
100
150
200
250
300
350
400
1999
2000
2001
2002
2003
2004


Daily Modeled at 04087220
Daily Observed at 04087220
Total Nitrogen (mg/L)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
2004

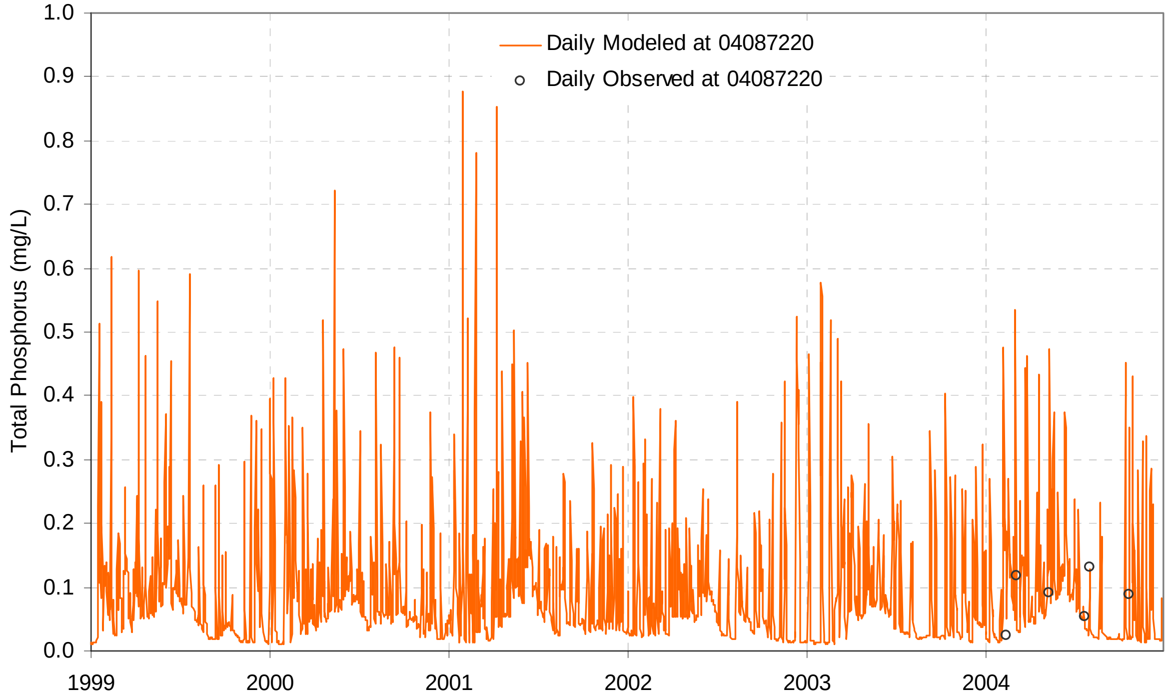

Daily Modeled at 04087233
Daily Observed at 04087233
Total Nitrogen (mg/L)
35
30
25
20
15
10
5
0
1999
2000
2001
2002
2003
2004

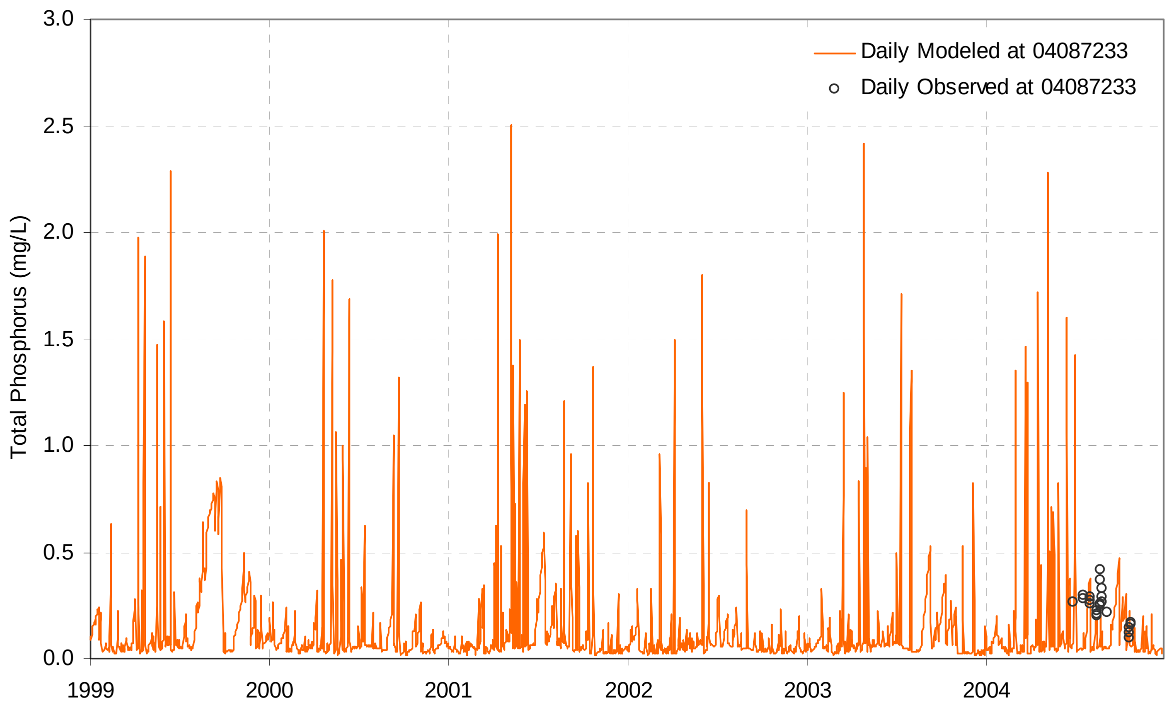


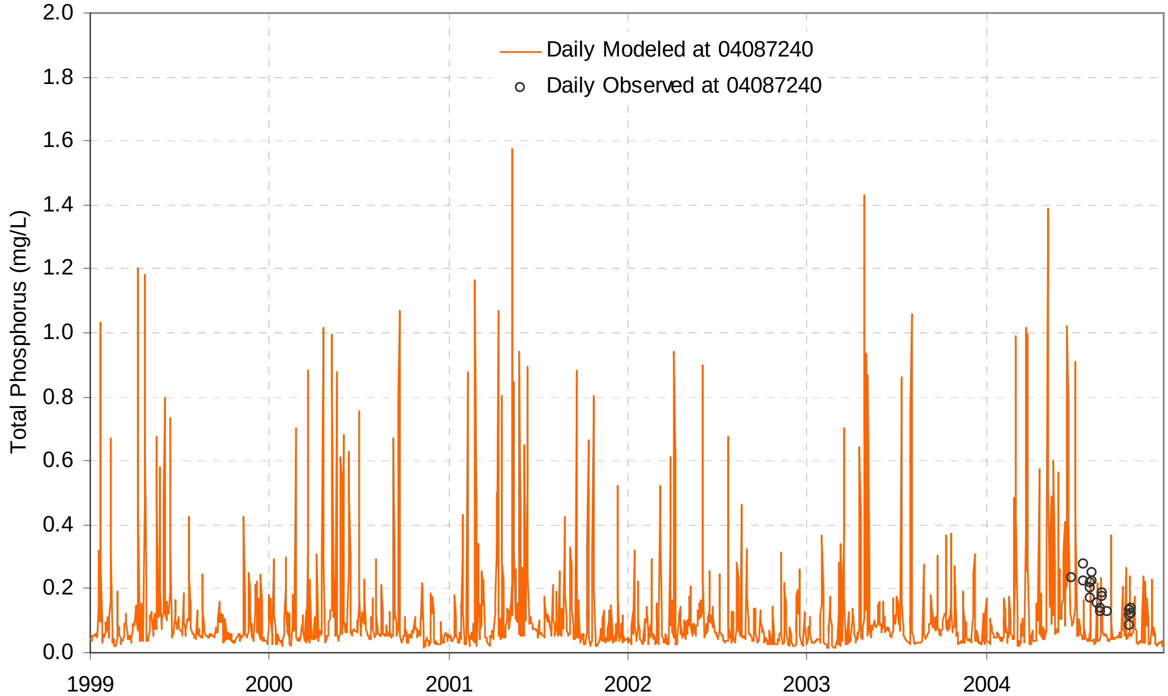
Daily Modeled at 04087240
Daily Observed at 04087240
Total Nitrogen (mg/L)
0
2
4
6
8
10
12
14
16
18
20
1999
2000
2001
2002
2003
2004

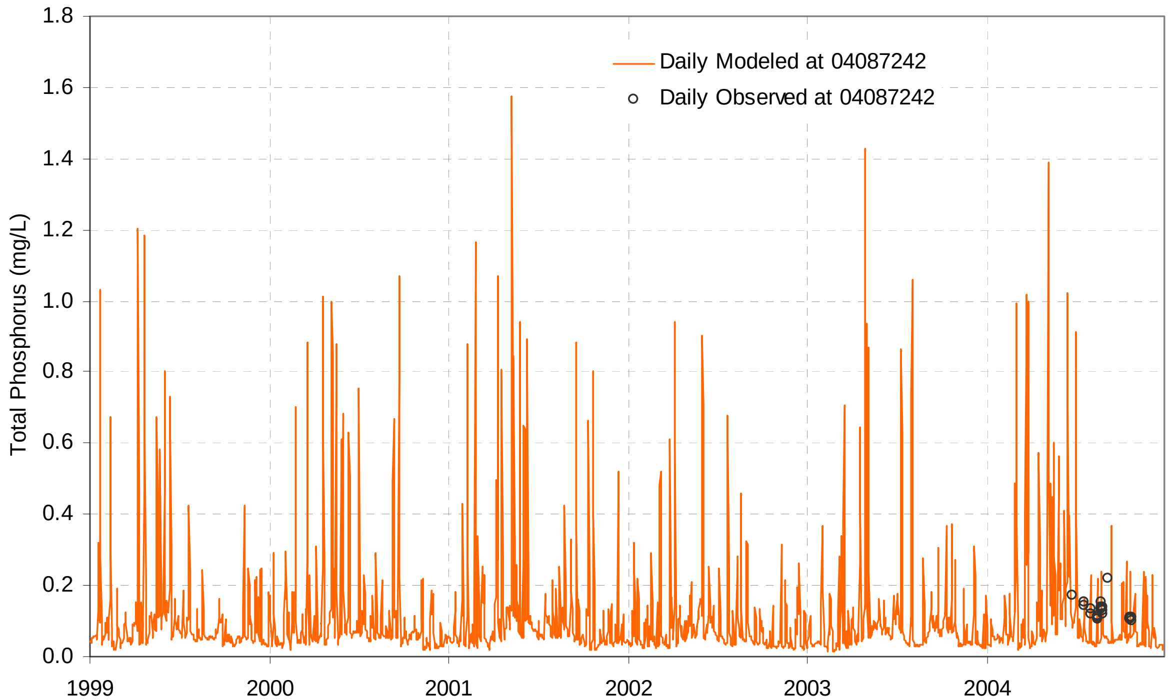


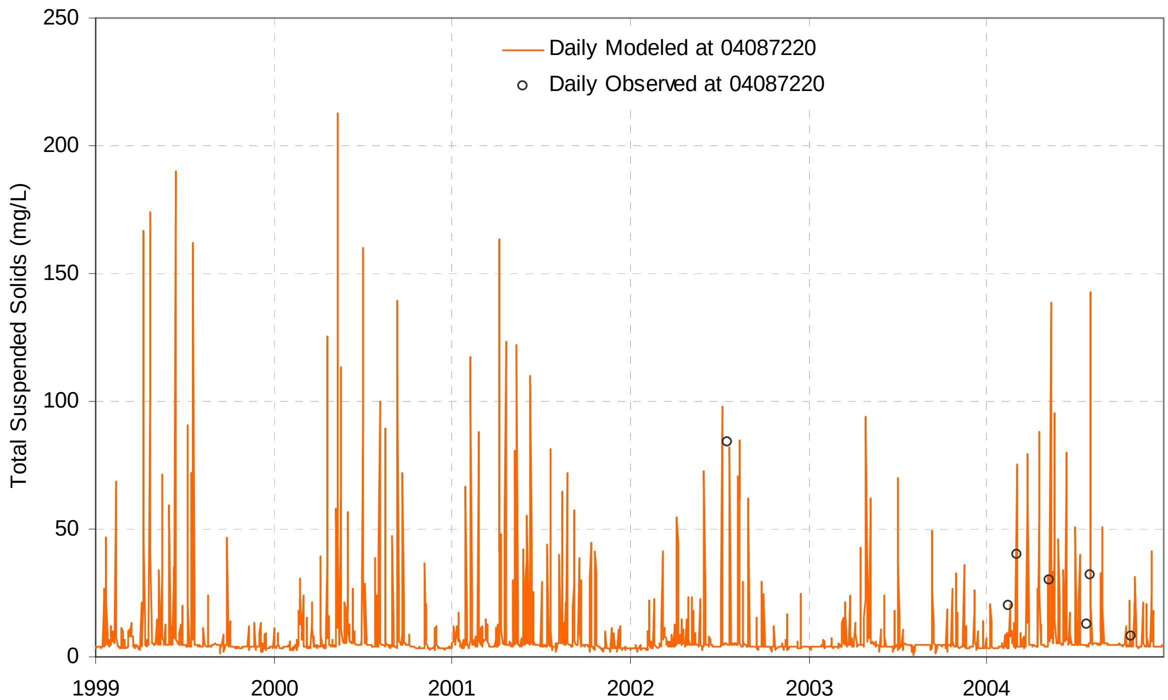
Daily Modeled at 04087242
Daily Observed at 04087242
Total Nitrogen (mg/L)
0
2
4
6
8
10
12
14
16
18
20
1999
2000
2001
2002
2003
2004


Daily Modeled at 04087220
Daily Observed at 04087220
Total Phosphorus (mg/L)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001
2002
2003
2004

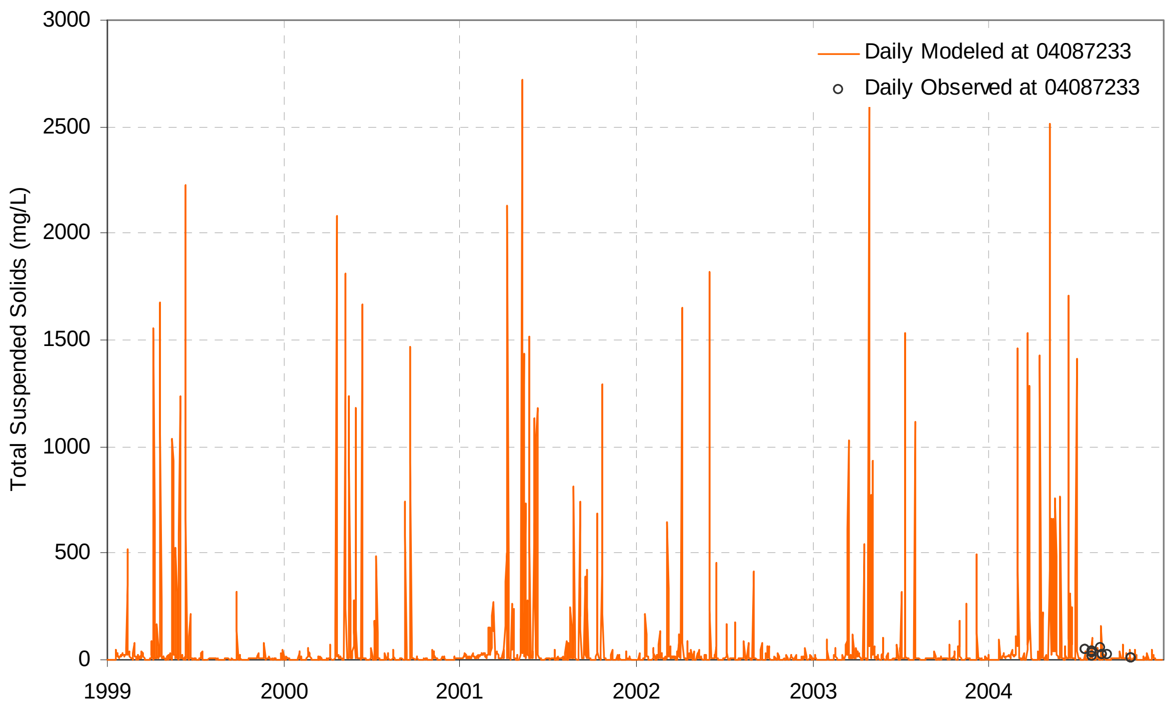

Daily Modeled at 04087233
Daily Observed at 04087233
Total Phosphorus (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
2004


Daily Modeled at 04087240
Daily Observed at 04087240
Total Phosphorus (mg/L)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1999
2000
2001
2002
2003
2004

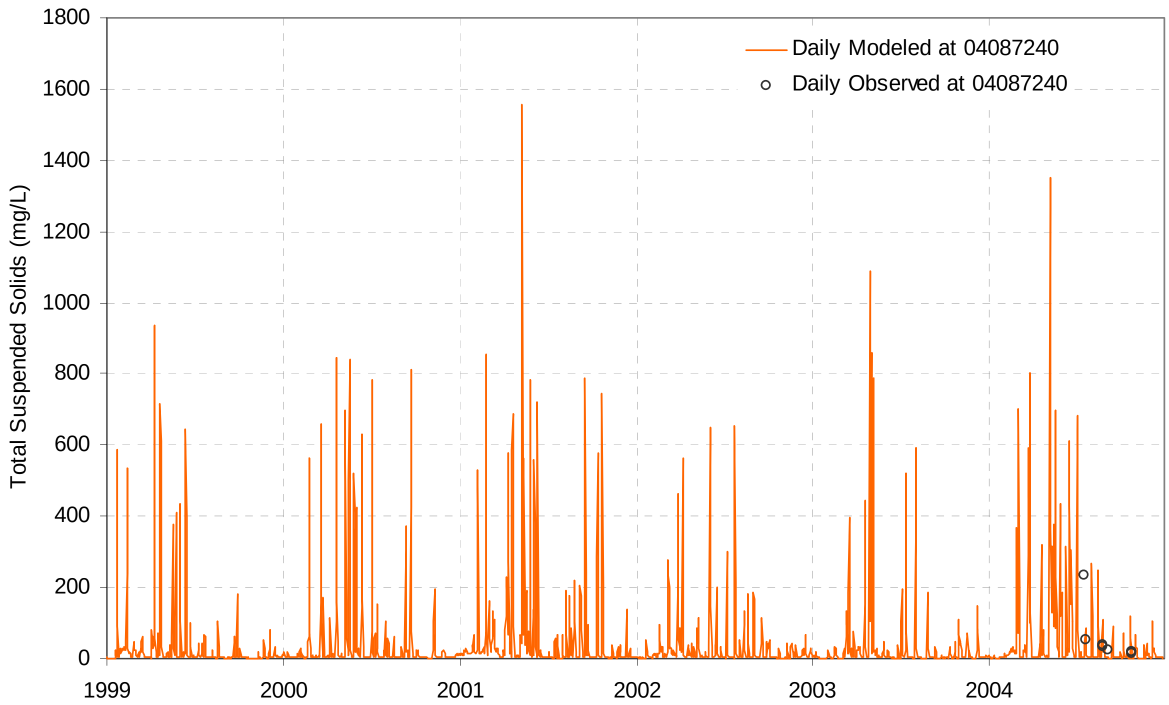

Daily Modeled at 04087242
Daily Observed at 04087242
Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1999
2000
2001
2002
2003
2004

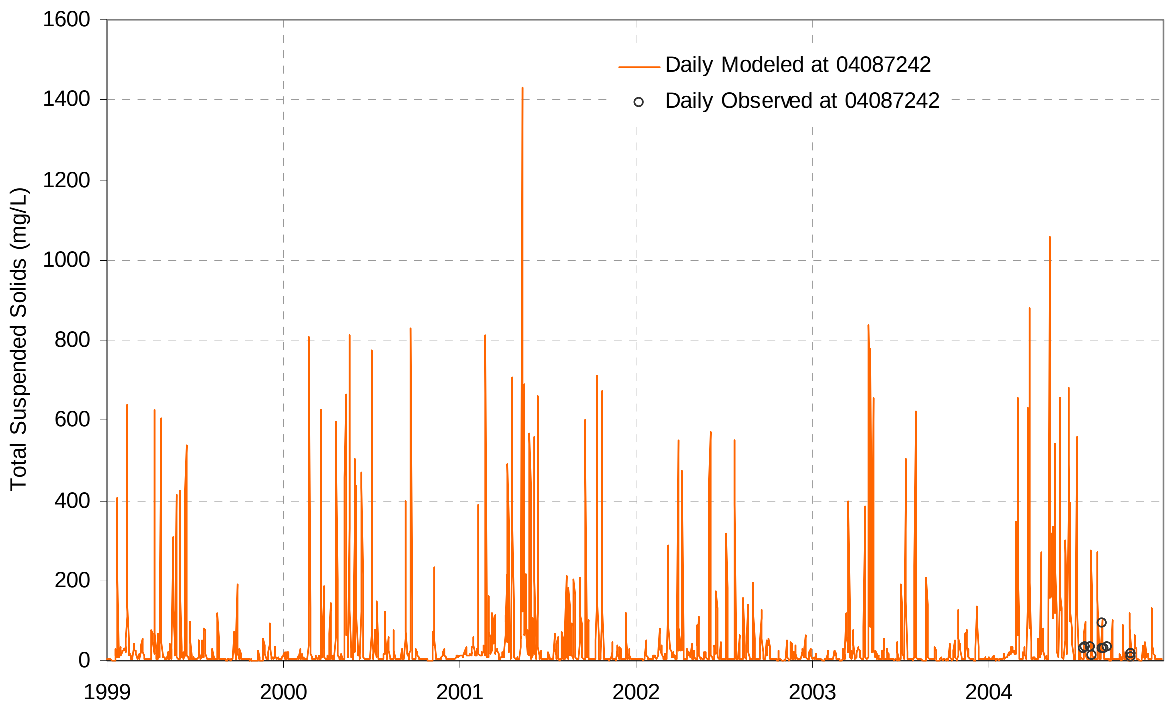


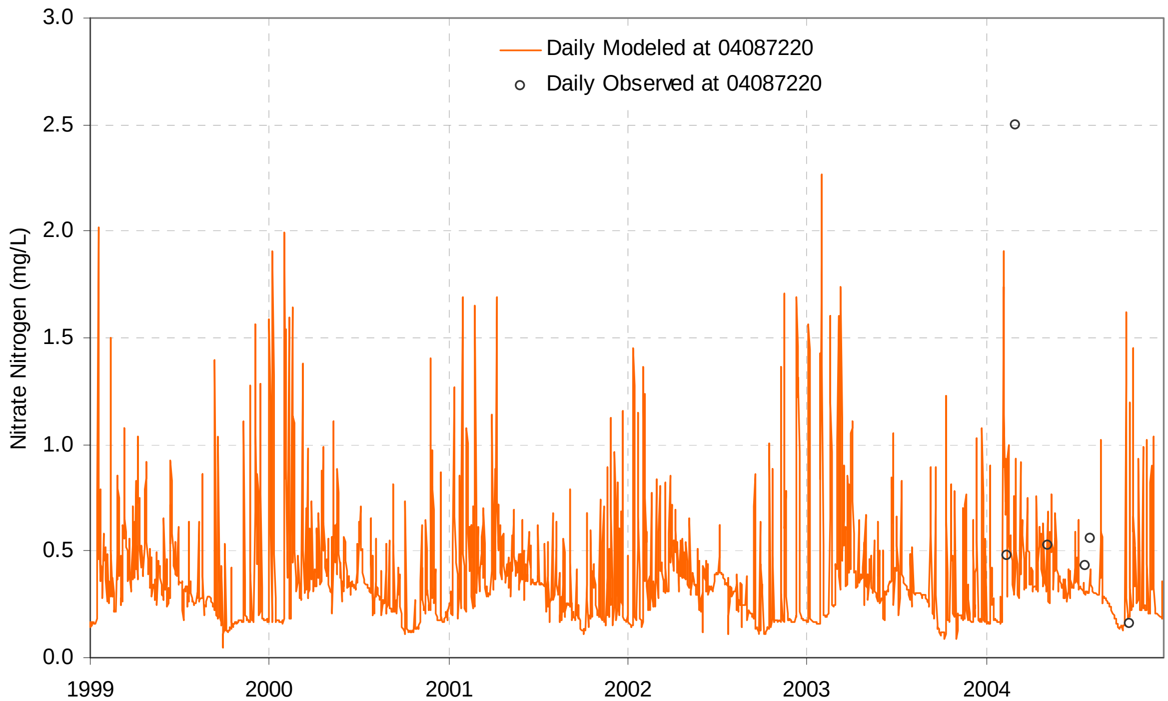
Daily Modeled at 04087220
Daily Observed at 04087220
Total Suspended Solids (mg/L)
250
200
150
100
50
0
1999
2000
2001
2002
2003
2004

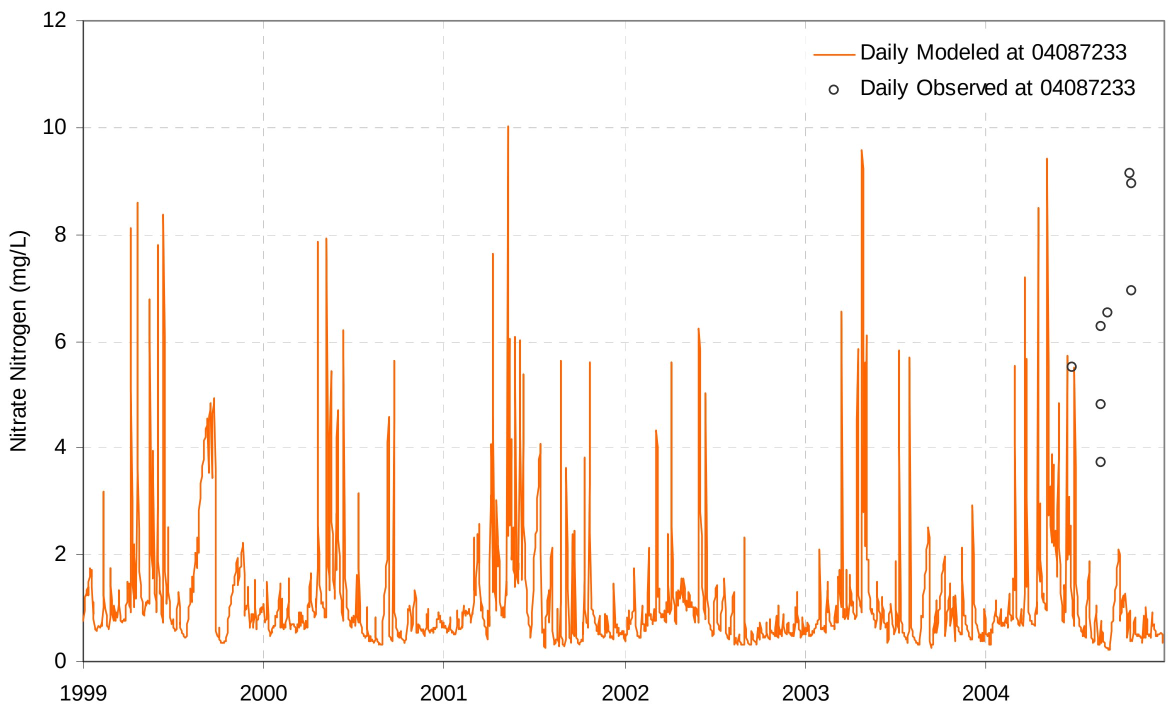


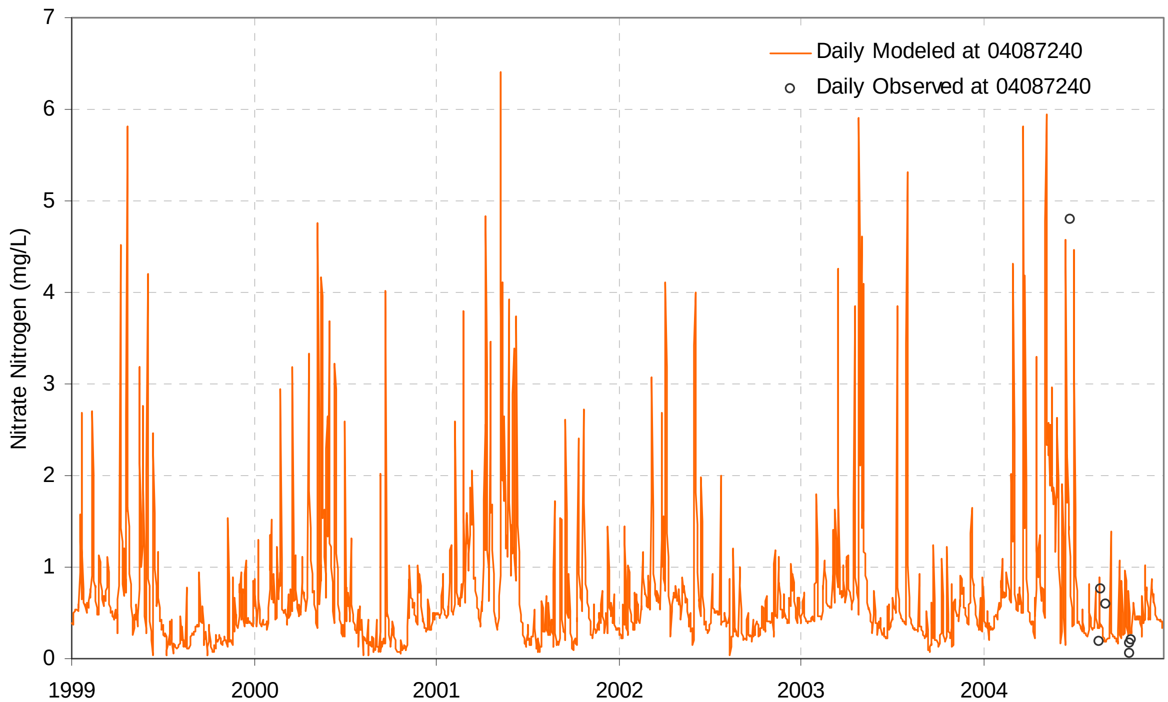
Daily Modeled at 04087233
Daily Observed at 04087233
Total Suspended Solids (mg/L)
3000
2500
2000
1500
1000
500
0
1999
2000
2001
2002
2003
2004

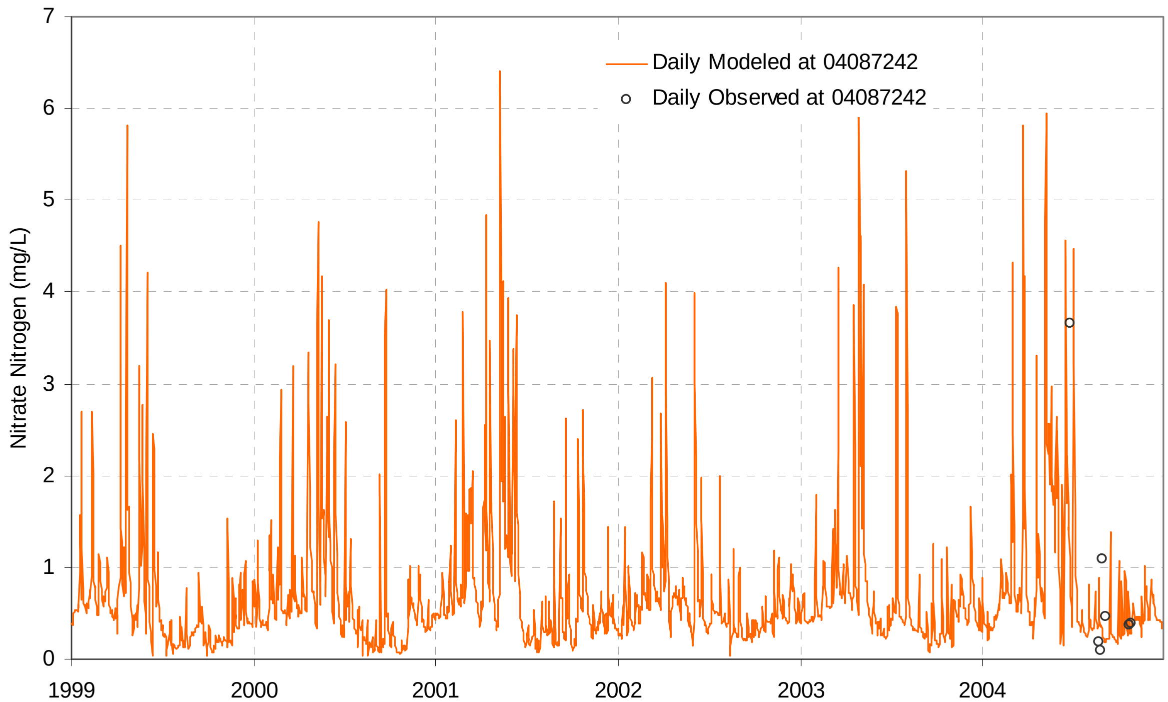

Daily Modeled at 04087240
Daily Observed at 04087240
Total Suspended Solids (mg/L)
0
200
400
600
800
1000
1200
1400
1600
1800
1999
2000
2001
2002
2003
2004

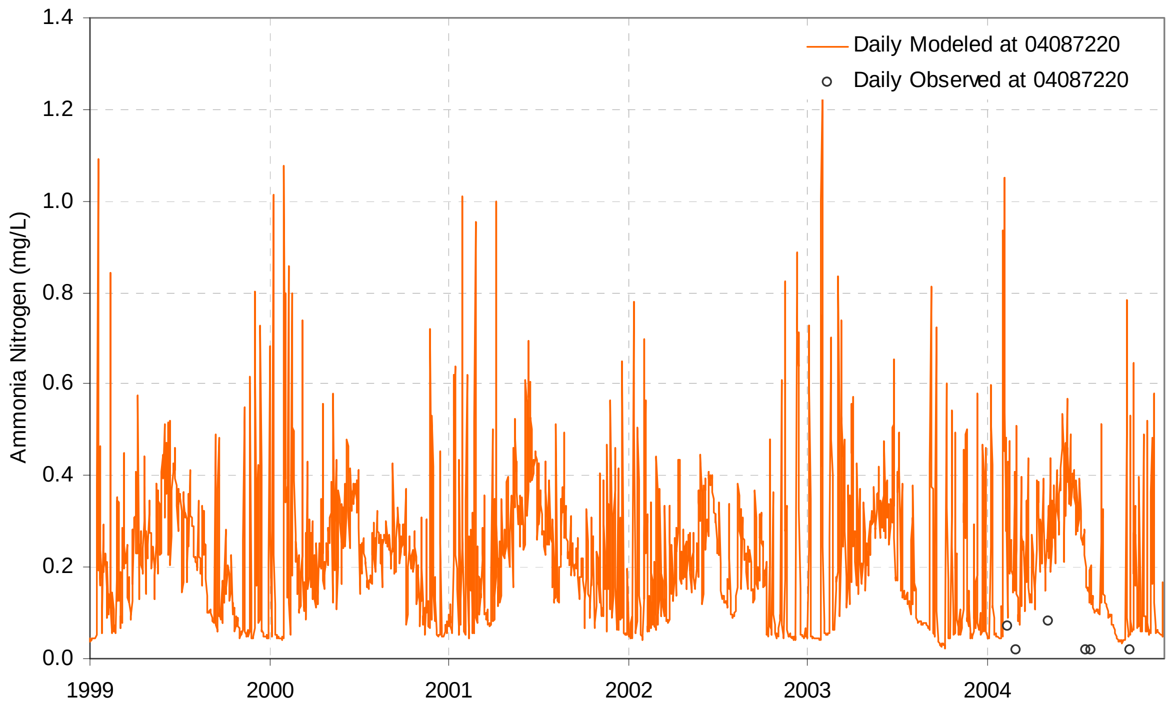

Daily Modeled at 04087242
Daily Observed at 04087242
Total Suspended Solids (mg/L)
0
200
400
600
800
1000
1200
1400
1600
1999
2000
2001
2002
2003
2004


Daily Modeled at 04087220
Daily Observed at 04087220
Nitrate Nitrogen (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
2004

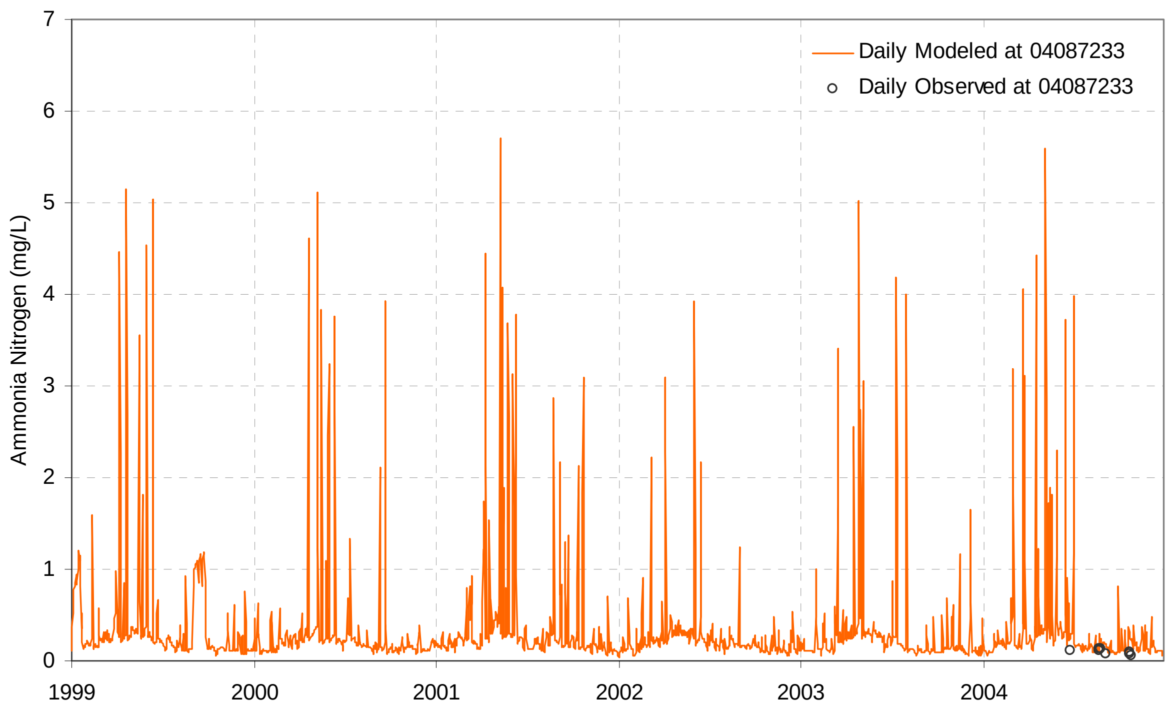

Daily Modeled at 04087233
Daily Observed at 04087233
Nitrate Nitrogen (mg/L)
12
10
8
6
4
2
0
1999
2000
2001
2002
2003
2004


Daily Modeled at 04087240
Daily Observed at 04087240
Nitrate Nitrogen (mg/L)
0
1
2
3
4
5
6
7
1999
2000
2001
2002
2003
2004

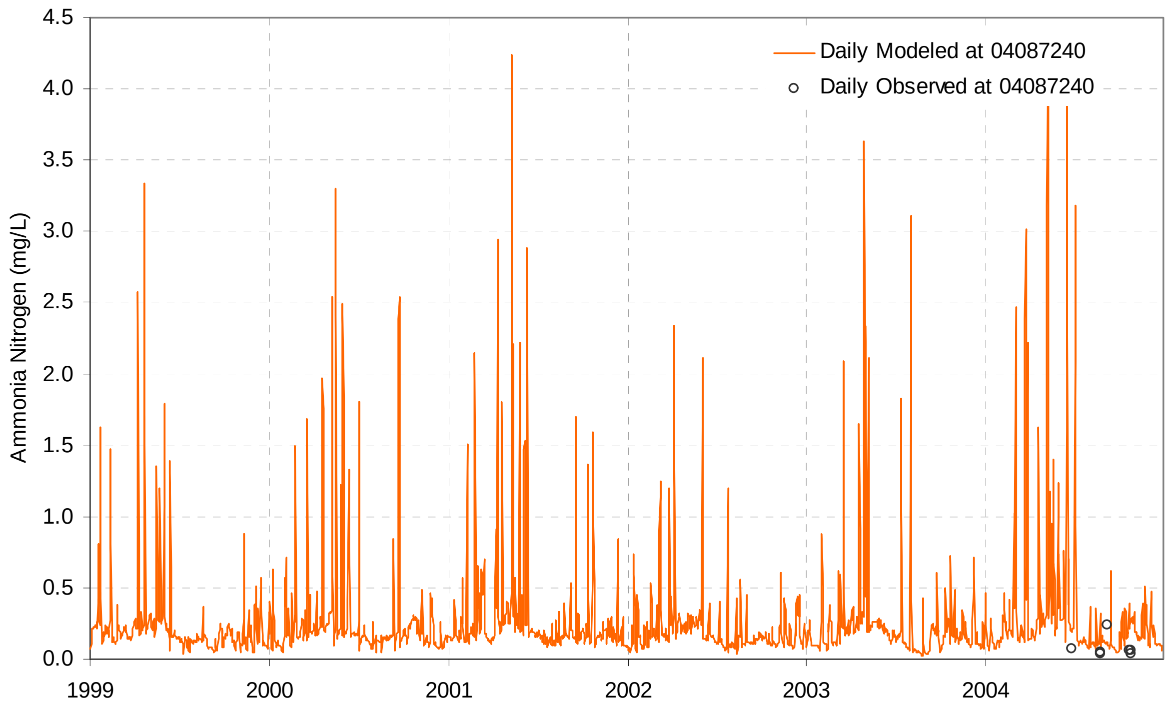

Daily Modeled at 04087242
Daily Observed at 04087242
Nitrate Nitrogen (mg/L)
0
1
2
3
4
5
6
7
1999
2000
2001
2002
2003
2004



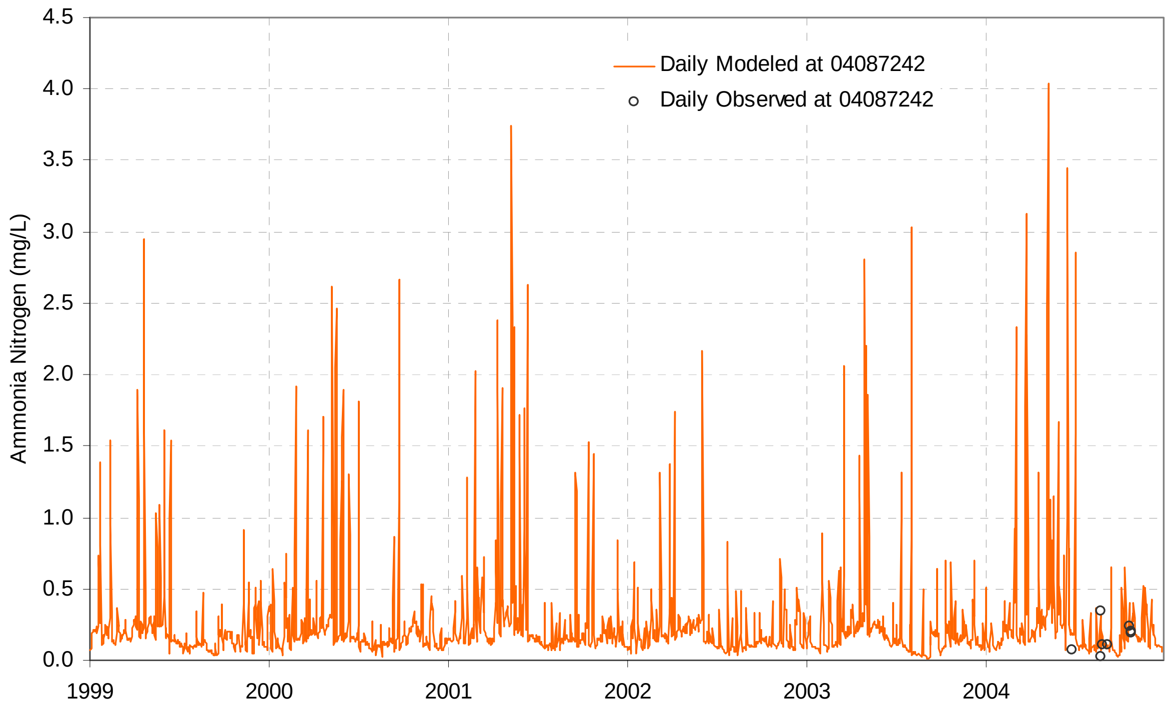
Daily Modeled at 04087220
Daily Observed at 04087220
Ammonia Nitrogen (mg/L)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1999
2000
2001
2002
2003
2004



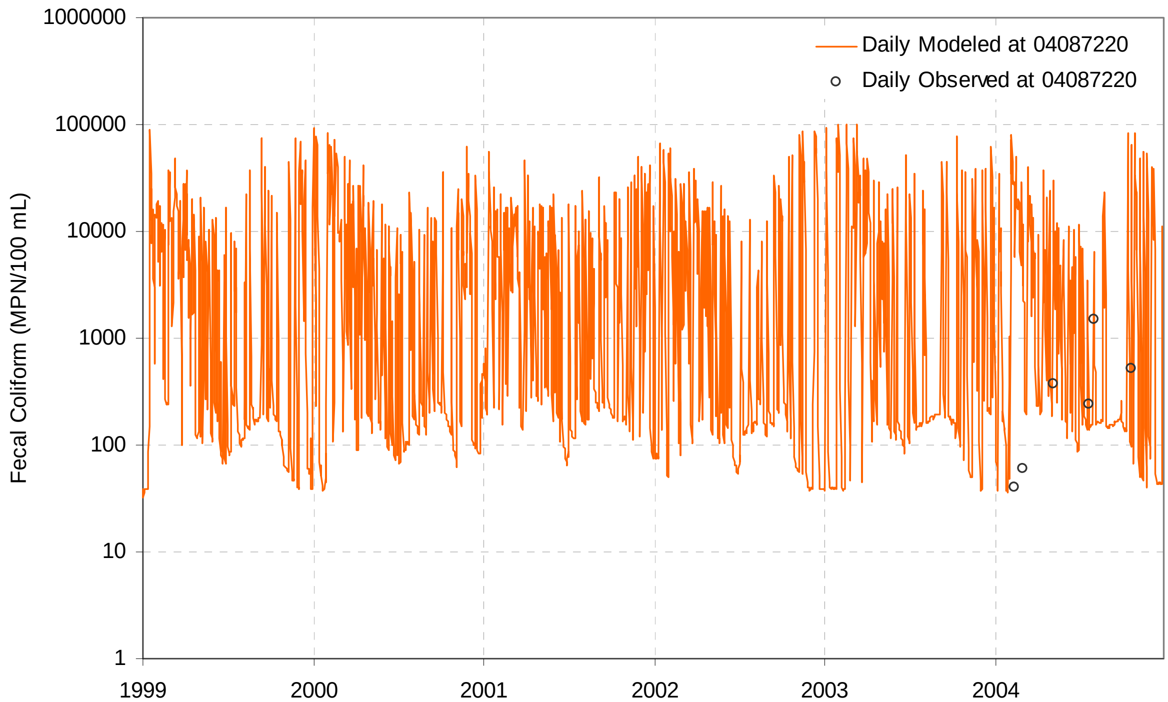
Daily Modeled at 04087233
Daily Observed at 04087233
Ammonia Nitrogen (mg/L)
7
6
5
4
3
2
1
0
1999
2000
2001
2002
2003
2004

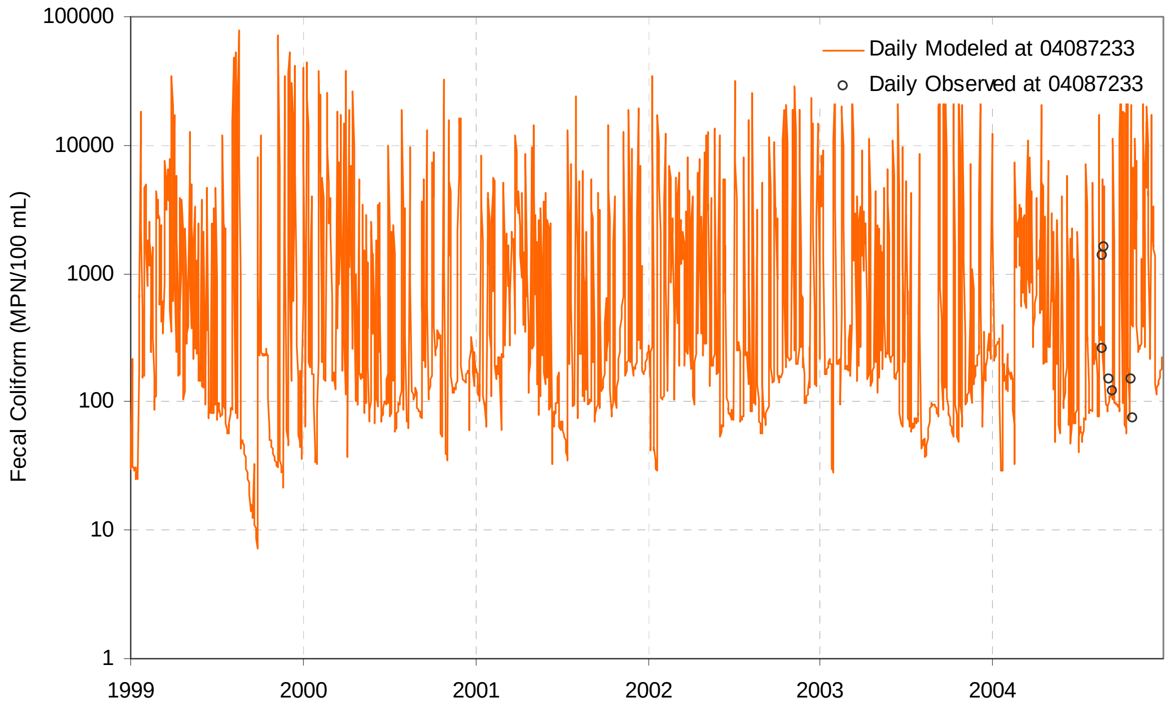


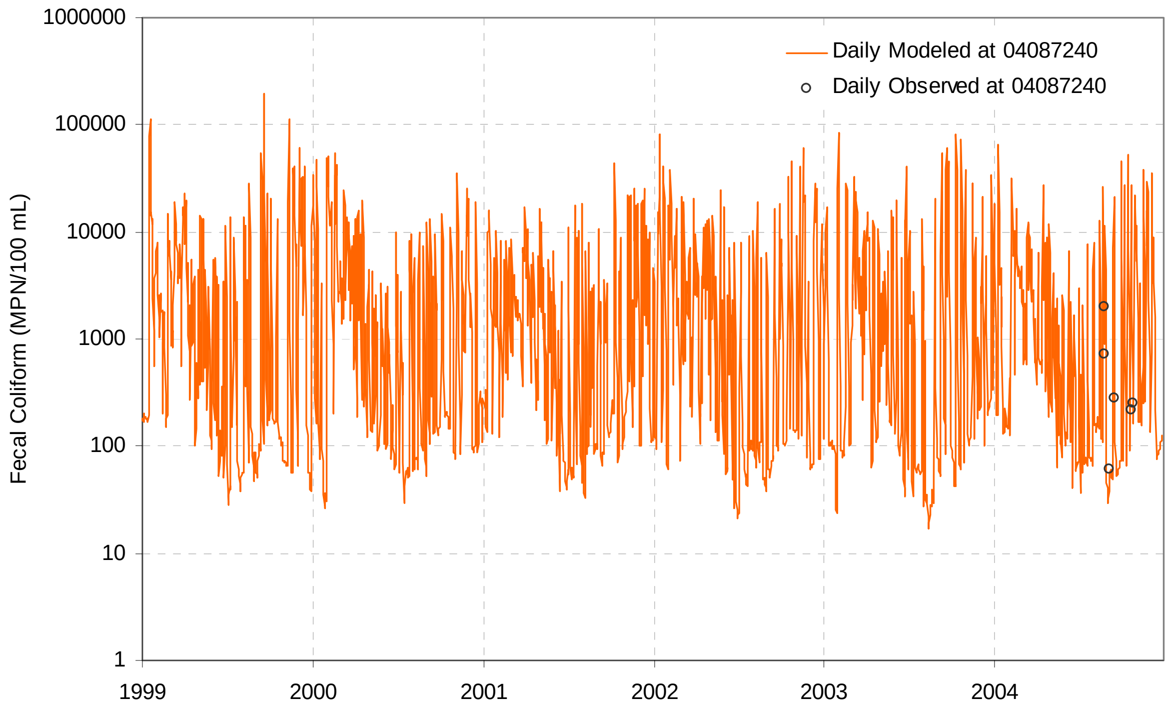
Daily Modeled at 04087240
Daily Observed at 04087240
Ammonia Nitrogen (mg/L)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
2004



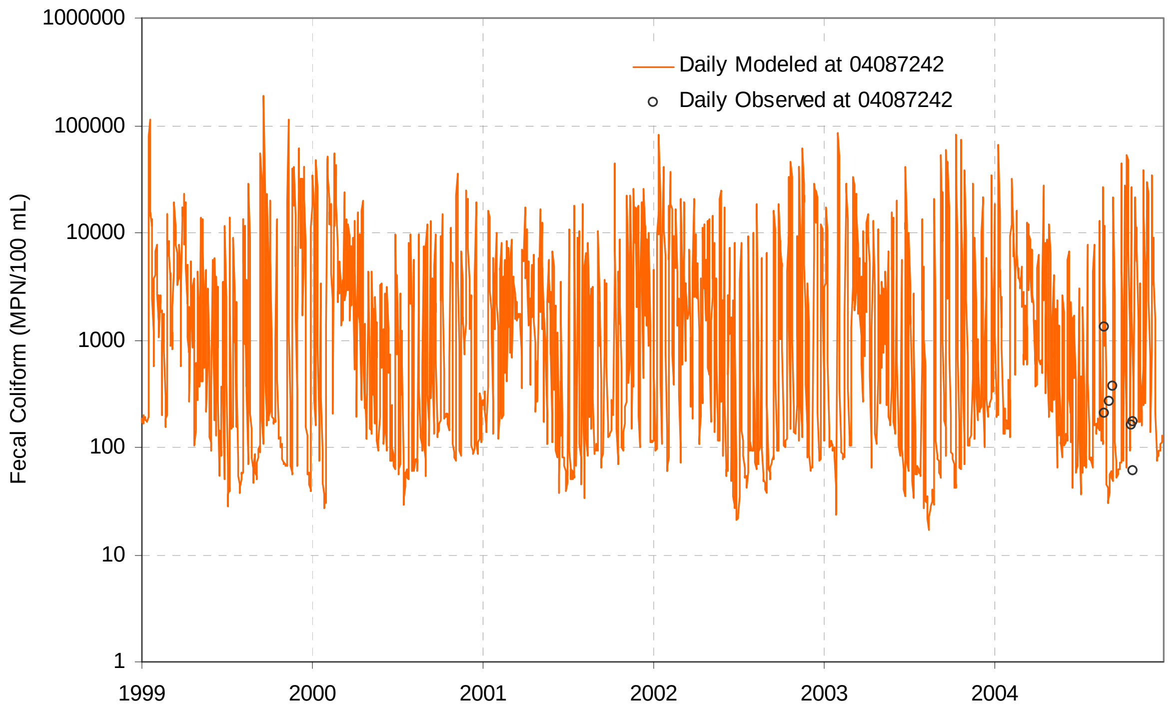
Daily Modeled at 04087242
Daily Observed at 04087242
Ammonia Nitrogen (mg/L)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
2004


Daily Modeled at 04087220
Daily Observed at 04087220
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
1999
2000
2001
2002
2003
2004


Daily Modeled at 04087233
Daily Observed at 04087233
Fecal Coliform (MPN/100 mL)
100000
10000
1000
100
10
1
1999
2000
2001
2002
2003
2004



Daily Modeled at 04087240
Daily Observed at 04087240
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
1999
2000
2001
2002
2003
2004



Daily Modeled at 04087242
Daily Observed at 04087242
Fecal Coliform (MPN/100 mL)
1000000
100000
10000
1000
100
10
1
1999
2000
2001
2002
2003
2004

2020 Facility Planning Project

Technical Memorandum

MMSD Contract #: M03002P01
MMSD File Code #: M009PE000.7300

Project Name: 2020 Facilities Planning Project

To: Ronald Prince, SEWRPC
Michael Hahn, SEWRPC
William Krill, HNTB
cc: Troy Deibert, HNTB

From: Andrew Thuman, HydroQual
Honghai Li, HydroQual

Date: September 25, 2007

Subject: Estuary Model Hydrodynamic Calibration/Validation

1.0 EXECUTIVE SUMMARY

The time-variable, three-dimensional hydrodynamic model, ECOMSED, has been developed and configured to the Milwaukee, Menomonee, and Kinnickinnic Rivers, Milwaukee harbor and Lake Michigan. The near shore Lake Michigan part of the model extends from Fox Point (WI) in the north to Wind Point (WI) in the south and extends approximately 4-6 miles offshore to the east. The break wall, located in the outer harbor extending from the Milwaukee Yacht Club in the north and to just south of the South Shore beach area, was uniquely represented in the hydrodynamic model through the use of "thin wall dams" in the model framework. This model representation of the break wall allows for the effective and realistic calculation of water transport and circulation between the harbor and Lake Michigan.

Extensive data measurements that have been collected throughout the study area were used to drive the hydrodynamic model for the period of 1995 through 2002. These data sets include:

- Water surface elevation at the NOAA gage station (#9087057) near the Milwaukee Coast Guard Station in the harbor;
- Water temperature near the open boundaries (near shore Lake Michigan);
- Milwaukee River (#04087000), Menomonee River (#04087120), Kinnickinnic River (#04087159), and Oak Creek (#04087204) flows and temperatures;
- Jones Island, South Shore and South Milwaukee wastewater treatment plant (WWTP) effluent flows and temperatures;

- Combined sewer overflows (CSOs)/sanitary sewer overflows (SSOs)/combined area stormwater (CSSWs) discharges;
- Discharges from the Milwaukee and Kinnickinnic River flushing tunnels;
- WE Energies Menomonee Valley and Oak Creek Power Plant cooling water flows and temperatures; and
- Meteorological parameters from the General Mitchell Airport in Milwaukee (wind speed and direction, air temperature, relative humidity, atmospheric pressure and solar radiation).

The hydrodynamic model calibration and validation effort has been completed with the water surface elevation measured at the NOAA gage in the harbor, flow measured at the Jones Island USGS gage and the water temperature profiles at 34 MMSD water quality sampling stations located in the Milwaukee, Menomonee, and Kinnickinnic Rivers, Milwaukee Harbor and near shore Lake Michigan. The calibration and validation periods are from 1995 through 1998 and from 1999 through 2002, respectively, that encompasses a range of river flows and also includes various sized CSO/SSO/CSSW overflow events. Statistical parameters of the root mean square error (RMSE) and the relative RMSE were calculated to compare the computed water temperature, water surface elevation and flow against observed data and to evaluate the model performance during the calibration/validation periods.

2.0 CONCLUSIONS

The hydrodynamic model reasonably reproduces observed water surface elevations, river flows and water temperature measurements and, therefore, overall circulation and mixing characteristics in the model domain are well represented. The calibrated and validated hydrodynamic model is capable of reproducing the lacustrine conditions of the Milwaukee, Menomonee and Kinnickinnic Rivers, Milwaukee Harbor, and near shore Lake Michigan and is suitable for the water quality modeling as part of the 2020 Facilities Planning process in this river-lake system.

3.0 RECOMMENDATIONS

The current hydrodynamic model calibration/validation was based on assigning measured river flows from the USGS and measured temperature from the MMSD at the three river boundaries. When the upstream watershed models are completed, the watershed model calculated flow and temperature will be assigned at the river boundaries. For temperature, this will fill in the periods between the dates when MMSD sampling is completed (roughly bi-weekly from April to October). This process will be completed later in the 2020 Facilities Planning modeling.

4.0 INTRODUCTION

In order to provide an integrated modeling framework for the 2020 Facilities Planning process, the Loading Simulation Program C++ (LSPC) upstream river watershed models (Milwaukee, Menomonee and Kinnickinnic) will be coupled to the downstream Milwaukee Harbor estuary model. As part of this process, HydroQual is calibrating and validating the

Milwaukee Harbor estuary model (hydrodynamic and water quality models) for the years 1995-1998 and 1999-2002, respectively. This memorandum describes the hydrodynamic model development (inputs, calibration, validation) for the 2020 Facilities Planning process.

5.0 HYDRODYNAMIC MODEL INPUTS

5.1 MODEL CONFIGURATION

A practical, numerically efficient and accurate approach has been taken in order to discretize the study area, including the Milwaukee River (upstream to the old North Avenue Dam), Menomonee River (upstream to the old Falk Corporation Dam) and Kinnickinnic River (upstream to 11th Street), Milwaukee Harbor and the near-shore Lake Michigan, within a single modeling grid framework. The model lake boundary extends east to approximately the 30-60 meter bathymetric contour in Lake Michigan, to Fox Point in the north and to Wind Point in the south. An orthogonal, curvilinear grid system used in the present study is shown in Attachment 1. The system consists of a 96×42 segment grid in the horizontal plane with 11 equally spaced σ-levels in the vertical plane. The transformed σ-coordinate system in the vertical plane allows the model to have an equal number of vertical segments in all of the computational grid boxes independent of water depth. In the horizontal, the curvilinear grid system allows for much finer grid resolution near areas of interest, such as in the river/harbor areas, where the grid size is as small as 90×50 meters. A coarser grid system was adopted in the Lake Michigan areas, where the maximum size of the grid is as large as 1500×1000 meters. Using this technique, an efficient and computationally time-effective modeling framework was designed.

There is a break wall located in the outer harbor extending from the Milwaukee Yacht Club in the north and to just south of the South Shore beach area (Attachment 1). This break wall protects the harbor from rough water conditions in Lake Michigan and has a number of openings or gaps along its length for passage from the harbor to the lake. The break wall tends to trap flow and constituent loads (e.g., solids, bacteria) within the harbor area and causes distinct river plumes to emanate from the openings in the break wall during high river flow events. The break wall was uniquely represented in the hydrodynamic model through the use of "thin wall dams" in the model framework. This model representation of the break wall allows for the effective and realistic calculation of water transport and circulation between the harbor and Lake Michigan.

5.2 MODEL FORCING FUNCTIONS

The following types of data were used to drive the hydrodynamic model: water level, river flow, water temperature and meteorological conditions. Water level measurements were available at the NOAA gage station (#9087057) near the Milwaukee Coast Guard Station in the harbor and are presented in Attachment 2 for both 4-year calibration and validation periods. The NOAA gage water elevation data were used as the water elevation boundary conditions in Lake Michigan for the

Milwaukee Harbor model. MMSD temperature data collected at water quality stations in Milwaukee Harbor and Lake Michigan were also available during the period of 1988-2002. In addition to the water surface elevation, the model was forced with the MMSD temperature observations at the lake boundaries (Attachment 3).

Daily average river flow and temperature from the Milwaukee, Menomonee, Kinnickinnic Rivers and Oak Creek during the calibration/validation period are also driving forcings for the model. The flow information at the model river boundaries was obtained from four USGS flow gages located on the Milwaukee River at Milwaukee (#04087000), on the Menomonee River at Wauwatosa (#04087120), on the Kinnickinnic River at Milwaukee (#04087159) and on Oak Creek at South Milwaukee (#04087204). Attachment 4 presents the river flow boundary conditions for the Milwaukee, Menomonee, Kinnickinnic Rivers and Oak Creek for the calibration and validation periods. Annual average flows and the flow ranges during the period are presented in Table 5-1 for the four rivers.

Table 5-1. Annual Average River Flows and Annual River Flow Ranges.

Year	Milwaukee River		Menomonee River		Kinnickinnic River		Oak Creek	
	Annual Average (cfs)	Flow Range (cfs)	Annual Average (cfs)	Flow Range (cfs)	Annual Average (cfs)	Flow Range (cfs)	Annual Average (cfs)	Flow Range (cfs)
1995	347	77-1310	94	13-994	21	4-366	24	2-324
1996	550	113-5840	119	10-2770	18	4-480	20	1-446
1997	497	23-8970	137	13-7520	23	5-1170	19	1-660
1998	474	53-3650	119	11-3250	25	3-564	26	1-412
1999	549	102-3670	124	5-2690	33	3-1210	28	1-778
2000	425	120-3910	131	16-3530	34	4-871	35	2-827
2001	526	67-2880	130	12-1730	30	4-550	32	3-642
2002	421	97-2030	94	12-1170	20	3-509	16	1-398

The river temperature boundary condition data were obtained from MMSD river monitoring stations RI-05 on the Milwaukee River, RI-20 on the Menomonee River, RI-13 on the Kinnickinnic River and OC-7 on Oak Creek. Attachment 5 presents the river temperature boundary conditions assigned for the calibration and validation periods. Generally, the temperature boundary conditions were based on bi-weekly temperature measurements at the above-mentioned four water quality monitoring stations.

Volumes and durations of CSO/SSO events were also assigned in the hydrodynamic model. Using the conveyance system model (mini-MOUSE), the 2020 Team (Brown & Caldwell) generated 15-minute CSO/SSO discharges for the period of 1988-2002. There were 20 CSO and 20 SSO locations within the MMSD service area. Each simulated CSO/SSO discharge "represents the flow from several real overflow locations" (Brown & Caldwell, 2004). 13 CSO and 3 SSO locations were within the estuarine model domain in the inner/outer harbor and along the rivers. There were also seven Combined Sewer Storm Water (CSSW) sewersheds. Six of these CSSW sewersheds were located in the model domain. Since the locations of the CSSW sewersheds are very close to some of the CSO locations, the CSSW discharges were specified in those CSO model cells. From 1988 through 2002, 92 overflow events occurred. Attachments 6 and 7 present the locations of CSO/SSO/CSSWs in the MMSD service area. The assigned temperatures to the CSO/SSO/CSSWs were estimated from measured river temperatures at MMSD monitoring stations. The annual average temperatures and the temperature ranges for the period of 1995 through 2002 are shown in Table 5-2.

The WWTP inputs were accounted for in the hydrodynamic model with flow and temperature from the Jones Island, the South Shore and the South Milwaukee WWTPs based on effluent Discharge Monitoring Report (DMR) records. Since effluent temperatures were only available for the Jones Island WWTP, they were also assigned to the other two WWTPs. Attachment 8 and Table 5-3 indicate that the Jones Island WWTP effluent flow ranged from approximately 27-354 MGD (average flow of 110 MGD), the South Shore WWTP effluent flow ranged from approximately 30-323 MGD (average flow of 105 MGD) and the South Milwaukee WWTP effluent flow ranged from approximately 2-13 MGD (average flow of 3 MGD) during the period of 1995-2002. Effluent temperature at the Jones Island WWTP has a multiyear average of 61°F (16°C) and a range of 45-76°F (7-24°C) (Attachment 9 and Table 5-3).

There are also point source inputs from the two MMSD flushing tunnels on the Milwaukee River and Kinnickinnic River and from the WE Energies Menomonee Valley and Oak Creek Power Plants. These point sources have both intake and discharge locations in the study area. The Milwaukee River flushing tunnel pulls water from the outer harbor near the Milwaukee Yacht Club and discharges water to the Milwaukee River just downstream from the old North Avenue Dam. The Kinnickinnic River flushing tunnel pulls water from the outer harbor near the South Shore Park and discharges water to the Kinnickinnic River. The WE Energies Menomonee Valley power plant pulls water from the Menomonee River and discharges water to the South Menomonee Canal and the Oak Creek power plant pulls and discharges water from Lake Michigan just south of Oak Creek. Daily intake and discharge temperatures were measured at the WE Energies Menomonee Valley and Oak Creek Power Plants and the temperature rise through the plants cooling water systems were assigned in the model. Attachments 10 and 11 present the two flushing tunnel discharges and WE Energies Menomonee Valley and Oak Creek Power Plant discharges during the calibration and validation periods. There were no flow data available from the two flushing tunnels during the periods of January 1995 through May 1997 and July 1997 through August 1997, and from the Kinnickinnic River flushing tunnel during the periods of November 1997 through April 1998 (Attachment 10). For those periods, zero flushing tunnel flows were assumed in the model. The intake/discharge temperature information from the WE Energies Menomonee Valley and Oak Creek Power Plant is presented in Attachment 11 and Table 5-4. The 8-year average discharge temperature at the two Menomonee

Valley outfalls was about 76°F (24°C) and the discharge temperature ranged from 43-115°F (6-46°C) during the period of 1995 through 2002. For the Oak Creek plant, the 8-year average discharge temperature at the five outfalls was about 60°F (15°C) and ranged from 32-94°F (0-34°C) during the period of 1995 through 2002.

Finally, the hydrodynamic model requires the input of wind speed and direction, air temperature, relative humidity, atmospheric pressure and solar radiation. These meteorological data were obtained from the General Mitchell Airport in Milwaukee on an hourly basis for the calibration and validation periods of 1995-2002 and are presented in Attachment 12 on a monthly basis. The hourly solar radiation data were the same as those used in the upstream LSPC model by Tetra Tech and calculated from cloud cover observations from General Mitchell Airport.

Table 5.2. Annual Average Temperatures and Annual Ranges Assigned to the CSO/SSO/CSSW Inflows Based on River Temperature Measurements.

Year	1995		1996		1997		1998	
CSO/SSO Station	Annual Average Temperature (℉)	Annual Average Temperature Range (°F)	Annual Average Temperature (℉)	Annual Average Temperature Range (°F)	Annual Average Temperature (℉)	Annual Average Temperature Range (°F)	Annual Average Temperature (℉)	Annual Average Temperature Range (°F)
CT-56	52.5	34.3~73.8	54.1	39.0~80.8	57.0	39.0~80.6	56.7	34.6~83.0
CT-07	52.5	34.3~73.8	54.1	39.0~80.8	57.0	39.0~80.6	56.7	34.6~83.0
CT-08	54.0	34.3~78.7	54.3	38.4~78.1	56.3	38.4~80.5	56.6	36.2~81.0
KK-01	56.5	34.3~87.4	57.6	39.0~85.1	57.7	39.0~84.2	58.7	39.2~87.5
KK-02	56.5	34.3~87.4	57.6	39.0~85.1	57.7	39.0~84.2	58.7	39.2~87.5
KK-03	56.5	34.3~87.4	57.6	39.0~85.1	57.7	39.0~84.2	58.7	39.2~87.5
KK-04	56.5	34.3~87.4	57.6	39.0~85.1	57.7	39.0~84.2	58.7	39.2~87.5
LM-N	56.5	34.3~87.4	57.6	39.0~85.1	57.7	39.0~84.2	58.7	39.2~87.5
LM-S	56.5	34.3~87.4	57.6	39.0~85.1	57.7	39.0~84.2	58.7	39.2~87.5
NS-07	52.9	34.3~79.7	51.0	33.3~75.9	54.2	34.9~77.0	54.5	33.8~76.6
NS-08	52.9	34.3~79.7	51.0	33.3~75.9	54.2	34.9~77.0	54.5	33.8~76.6
NS-09	52.9	34.3~79.7	51.0	33.3~75.9	54.2	34.9~77.0	54.5	33.8~76.6
NS-10	54.0	34.3~78.7	54.3	38.4~78.1	56.3	38.4~80.5	56.6	36.2~81.0
BS-6-2	56.5	34.3~87.4	57.6	39.0~85.1	57.7	39.0~84.2	58.7	39.2~87.5
BS-7-1	54.0	34.3~78.7	54.3	38.4~78.1	56.3	38.4~80.5	56.6	36.2~81.0
DC63-DC13	56.5	34.3~87.4	57.6	39.0~85.1	57.7	39.0~84.2	58.7	39.2~87.5
	1999		2000		2001		2002	
CT-56	55.1	38.7~76.8	53.9	36.1~73.1	53.2	33.2~84.5	52.6	33.3~81.6
CT-07	55.1	38.7~76.8	53.9	36.1~73.1	53.2	33.2~84.5	52.6	33.3~81.6
CT-08	55.7	38.4~77.2	54.2	33.1~75.5	55.0	37.0~83.6	53.3	34.5~79.9
KK-01	58.9	39.0~82.3	55.5	32.0~77.7	58.0	39.0~89.2	55.8	32.0~83.7
KK-02	58.9	39.0~82.3	55.5	32.0~77.7	58.0	39.0~89.2	55.8	32.0~83.7
KK-03	58.9	39.0~82.3	55.5	32.0~77.7	58.0	39.0~89.2	55.8	32.0~83.7
KK-04	58.9	39.0~82.3	55.5	32.0~77.7	58.0	39.0~89.2	55.8	32.0~83.7
LM-N	58.9	39.0~82.3	55.5	32.0~77.7	58.0	39.0~89.2	55.8	32.0~83.7
LM-S	58.9	39.0~82.3	55.5	32.0~77.7	58.0	39.0~89.2	55.8	32.0~83.7
NS-07	53.2	37.2~73.6	53.2	32.0~77.5	53.7	35.4~78.8	51.6	32.0~79.8
NS-08	53.2	37.2~73.6	53.2	32.0~77.5	53.7	35.4~78.8	51.6	32.0~79.8
NS-09	53.2	37.2~73.6	53.2	32.0~77.5	53.7	35.4~78.8	51.6	32.0~79.8
NS-10	55.7	38.4~77.2	54.2	33.1~75.5	55.0	37.0~83.6	53.3	34.5~79.9
BS-6-2	58.9	39.0~82.3	55.5	32.0~77.7	58.0	39.0~89.2	55.8	32.0~83.7
BS-7-1	55.7	38.4~77.2	54.2	33.1~75.5	55.0	37.0~83.6	53.3	34.5~79.9
DC63-DC13	58.9	39.0~82.3	55.5	32.0~77.7	58.0	39.0~89.2	55.8	32.0~83.7

Table 5-3. Annual Average WWTP Flows and Annual WWTP Flow Rranges. Annual Average Effluent Temperatures and Annual Temperature Ranges at the Jones Island WWTP.

Year	Jones Island				South Shore		South Milwaukee	
	Annual Average (MGD)	Flow Range (MGD)	Annual Average Temp (°F)	Annual Avg Temp Range (°F)	Annual Average (MGD)	Flow Range (MGD)	Annual Average (MGD)	Flow Range (MGD)
1995	121	78-260	60	51-73	101	69-287	3	2-9
1996	113	77-279	60	50-72	101	65-305	4	3-11
1997	113	71-320	61	46-71	99	67-323	3	2-10
1998	107	59-263	62	48-73	115	67-302	3	2-11
1999	109	57-350	62	45-74	111	65-307	3	2-12
2000	109	27-354	61	52-73	107	30-304	3	2-13
2001	110	52-321	61	45-76	106	65-231	3	2-6
2002	97	54-297	61	47-73	96	37-208	3	2-7

Table 5-4a. Annual Average Discharge Temperatures and Ranges at the WE Energies Menomonee Valley Power Plant.

Year	Outfall 1		Outfall 2	
	Annual Average Temp (°F)	Annual Average Temp Range (°F)	Annual Average Temp (°F)	Annual Average Temp Range (°F)
1995	70	48-107	72	47-106
1996	70	47-111	71	44-100
1997	76	50-111	77	48-106
1998	77	48-114	79	54-110
1999	76	46-114	78	49-112
2000	78	54-108	78	56-113
2001	77	43-115	79	44-113
2002	78	47-110	80	45-111

Table 5-4b. Annual Average Discharge Temperatures and Ranges at the WE Energies Oak Creek Power Plant.

Year	Outfalls 301, 303, 304, 305, 306	
	Annual Average Temp (°F)	Annual Average Temp Range (°F)
1995	58.1	37.2-84.7
1996	55.4	38.1-80.3
1997	59.1	39.6-78.5
1998	65.4	42.4-85.6
1999	61.1	40.3-79.7
2000	60.6	36.1-80.0
2001	59.7	38.7-82.5
2002	59.3	36.9-80.4

6.0 MODEL CALIBRATION AND VALIDATION

The hydrodynamic model was calibrated with available water quality data from 1995 through 1998 and validated from 1999 through 2002 using the model inputs previously described. The hydrodynamic model was calibrated/validated with measured NOAA water levels in the harbor, measured USGS flow at mouth of the rivers (near Jones Island) and measured MMSD temperature data at various stations in the three rivers, harbor area and Lake Michigan. The calibration/validation periods encompassed a range of river flows and also included various sized CSO/SSO/CSSW overflow events. The following section presents the hydrodynamic model calibration/validation in more detail.

6.1 HYDRODYNAMIC MODEL

The ability of the hydrodynamic model to simulate advective and dispersive processes in the Milwaukee, Menomonee and Kinnickinnic Rivers, Milwaukee Harbor and Lake Michigan was assessed by comparing model output with observed data. Model calibration and validation were completed using water elevation data at the NOAA gage in the harbor and flow data at the Jones Island USGS gage at the mouth of the rivers. In addition, vertical temperature data collected at 34 water quality stations in the rivers, Milwaukee Harbor and Lake Michigan during the calibration/validation periods were also used. These temperature observations are from the MMSD surface water quality monitoring program and include stations in the Outer Harbor (OH), Near Shore Lake Michigan (NS) and the three rivers (RI).

All of the water motions induced by small-scale processes not directly resolved by the model grid (sub-grid scale) are parameterized in terms of horizontal and vertical mixing processes and can be adjusted during the calibration process. The resolution of the current grid in the Milwaukee, Menomonee and Kinnickinnic Rivers is not fine enough to resolve the detailed coastline and bathymetric features of the rivers, which are important to producing horizontal diffusion and vertical mixing. Therefore, horizontal and vertical mixing coefficients were adjusted to properly represent the mixing processes based on reproducing the observed vertical temperature profiles in the rivers and harbor. The horizontal mixing coefficients used in the calibration/validation were adjusted using a non-dimensional parameter (HORCON), which ranged from 0.05 in the lake to 0.2 in the rivers and harbor. For the vertical mixing coefficients, the background mixing values (UMOL) used in the calibration/validation ranged from 10^{-3} m^2/s in the rivers and harbor to 10^{-6} m^2/s in the lake. A minimum bottom friction coefficient (BFRIC) of 0.0025 (non-dimensional) and bottom roughness coefficient (Z0B) of 0.003 meters were used throughout the model domain for the calibration/validation.

6.2 MODEL PERFORMANCE

Statistical analyses were conducted to evaluate the model performance, in which the model-computed results were compared against the measurements for water surface elevation, flow and water temperature. Statistical parameters include the root mean square error (RMSE) and the relative RMSE. The RMSE is a measure of the error between the model and observed data (variability unaccounted for by the model) as expressed by the following equation:

$$\mathrm{RMSE} = \sqrt{\frac{\sum (C_{OBS_i} - C_{MODEL_i})^2}{n}},$$

where C_{OBS} is the observed variable, $C_{MODE}L$ is the model calculated variable, and n is the number of paired variables. The relative RMSE (%) is defined as RMSE/(data range).

The first part of the calibration/validation was to demonstrate the model's capability for reproducing the time variable water elevations in the harbor. Water level calibration/validation is fundamentally important because it demonstrates that the model bathymetry, geometry and hydraulics are configured correctly. The depth-averaged currents are generally consistent with the water surface elevation. Attachments 13 and 14 present the model-computed water elevations against the measurements at the NOAA gage station near the Milwaukee Coast Guard Station. Attachment 13 presents the hourly model output and observed data and Attachment 14 presents the 34-hour low-pass filtered model output and data. Filtering of the model output and data removes high frequency (small time-scale) oscillations and allows low frequency signals (large time scale) to be observed in the model output and data.

The model output and observed water elevations are in excellent agreement at the harbor gage for both the calibration and validation periods. The annual root mean square errors (RMSE) between model results and data are less than 3.0 cm on an hourly basis from 1995 to 2002 (Table 6.1). The relative RMSE ranges from 1.8 to 3.8%. The eight-year average of the RMSE and the relative RMSE are 2.3 cm and 2.8%, respectively.

Table 6.1. Root Mean Square Errors (RMSE) and Relative RMSE for Computed and Measured Water Surface Elevations.

YEAR	NOAA Gage	
	RMSE (cm)	Relative RMSE (%)
1995	2.1	2.6
1996	2.1	2.6
1997	2.8	3.8
1998	2.4	2.0
1999	1.8	1.8
2000	2.5	3.6
2001	2.8	3.8
2002	2.2	2.5
Average	2.3	2.8

The purpose of the hydrodynamic modeling was to reproduce the transport characteristics of the rivers and harbor, which is important in determining the distribution of water quality constituents. For this purpose, the model computed flow was compared against observed data available at the Jones Island USGS gage (Attachment 15). Since current meter data was not available in the harbor during the calibration/validation period, the comparison to river flow was used to generally assess transport at the river/harbor confluence. Calibration/validation of the water quality model will further test the transport calculated in the hydrodynamic model.

Daily flow data were collected at the Jones Island USGS gage (#04087170) at the mouth of the three rivers in Milwaukee for the periods of January-October 1995, October-December 2001, and 2002. The overall comparison is good with an average RMSE of 3.7 m^3/s and average relative RMSE of 5.1% through these periods (Table 6.2). The consistency between the model and the observations further demonstrates correct computation of transport in this estuarine system. Attachment 15 shows that the model under- and over-predicts some of the peak flows for the periods, which may be related to the assignment of daily average inflows in the model where some of the variability may be due to hourly inflows to the system.

Table 6.2. Root Mean Square Errors (RMSE) and Relative RMSE for Computed and Measured Flows at USGS Gage #04087170.

PERIOD	USGS Gage	
	RMSE (m^3/s)	Relative RMSE (%)
Jan-Oct 1995	3.9	4.7
Oct-Dec 2001	2.4	5.8
2002	4.9	4.9
Average	3.7	5.1

The three-dimensional circulation dynamics is also represented by the vertical temperature structure in the system since water temperature is not only determined by air-water heat exchange, but also by heat transfer carried by currents and turbulent motion of water bodies. Attachment 16 displays the comparison of model calculated vertical temperature profiles and observations at four river and five harbor stations for both the calibration and validation periods. The attachment presents the observed data as filled circles and the daily average model output on the day of the sample as a solid line with the daily model output range as the horizontal bars in each of the ten layers in the model. Appendix 1 contains these same results at all 34 sampling stations in the model domain from March through December when data were available for the 1995-1998 calibration and 1999-2002 validation periods. In addition, time series of the computed surface and bottom temperatures were compared against the observed data at the sampling stations and presented in Appendix 2. As can be seen from these figures, there is reasonable agreement between the model calculated and observed temperature profiles. The model reproduces the observed temperature data well at the MMSD monitoring stations both temporally and spatially. The overall model-data comparison is quite good with an eight-year average RMSE and relative RMSE of 1.64ºC and 7.6%, respectively. Table 6.3 shows the annual RMSEs and relative RMSEs at the Near Shore Lake Michigan (NS), the Outer Harbor (OH), and the River (RI) regions for the calibration and validation periods. The largest multi-year average RMSE of 1.75ºC occurs in the RI region. But since the largest annual temperature variability also occurs in the rivers, the smallest relative RMSE of 6.0% is presented in this same region in Table 6.3. From the temperature comparisons during the calibration and validation periods, the year 2000 has the best calibration/validation result (RMSE = 1.30ºC and relative RMSE = 5.8%) and the year 2002 has the worst (RMSE = 2.05ºC and relative RMSE = 8.6%), although both are within acceptable ranges.

The comparison results between the computed and the observed temperatures by using the RMSE and the relative RMSE can be justified by some previous modeling studies. Beletsky and Schwab (2001) applied the Princeton Ocean Model (POM, the original version of ECOM) to study the circulation and thermal structure in Lake Michigan. A four-year simulation was conducted and the computed surface temperature was compared against the observed temperature data collected from the observation network in Lake Michigan. The RMSE estimated from the comparison is 1.4ºC. Jin et al. (2002) modeled the winter circulation in Lake Okeechobee, Florida. A modified version of EFDC (also originated from POM) was used for the study. A similar statistical analysis was employed to compare the computed lake surface elevation and lake temperature with observations at the surface, mid-depth and bottom layers at 4 stations in the lake. Their error analysis showed an average RMSE of 1.8 cm and relative RMSE of 6.9% for the lake surface elevation and an average RMSE of 0.88ºC and a relative RMSE of 8.0% for the lake temperature.

Although the modeled temperature structure shows good quantitative agreement with the observed temperature from the MMSD sampling stations, occasionally the model could not capture the vertical structure of the observed temperature data at some stations. Attachment 16 shows that the model underestimated temperature at some OH stations on May 4, 1995, May 22, 1996, May 29, 1997 and May 13, 1998. The discrepancies became smaller when approaching the open lake (OH-07) from the river mouth (OH-01) and the outer harbor (OH-03, OH-04 and OH-11). The meteorological conditions were carefully checked for those periods (Attachment 12) and no significant warm events were identified. Therefore, some heat sources in the rivers may be under-estimated in the model forcing functions. Improperly specified (i.e., assigned bi-weekly but actually varies daily) or missed local heat inputs (heat discharges from the WE Energies Menomonee Valley power plant, CSO/SSO/CSSW and river temperature specifications) could attribute to the model-data discrepancies shown at those OH and some RI stations (Attachment 16).

Table 6.3. Root Mean Square Errors (RMSE) and Relative RMSE for Computed and Measured Water Temperatures.

YEAR	SURVEY					
	NS		OH		RI	
	RMSE (ºC)	Relative RMSE (%)	RMSE (ºC)	Relative RMSE (%)	RMSE (ºC)	Relative RMSE (%)
1995	1.24	9.9	1.55	7.5	1.67	7.0
1996	1.77	12.1	1.64	7.3	1.57	5.7
1997	1.72	10.7	1.37	6.1	1.80	6.1
1998	1.32	7.4	1.39	6.5	1.78	5.5
1999	1.57	10.2	1.86	8.2	1.82	7.1
2000	0.99	5.8	1.37	6.9	1.53	4.8
2001	1.84	11.1	1.64	6.2	1.72	5.2
2002	1.95	10.1	2.05	9.2	2.14	6.6
Average	1.55	9.7	1.61	7.2	1.75	6.0

7.0 SUMMARY

The time variable, three-dimensional hydrodynamic model, ECOMSED, has been developed and configured for the Milwaukee, Menomonee, and Kinnickinnic Rivers, Milwaukee Harbor and near shore Lake Michigan.

The extensive data measurements available from MMSD, USGS and NOAA sources were used to drive the hydrodynamic model for the period of 1995 through 2002 (calibration and validation periods). These data sets include water surface elevation, water temperature, river flow, WWTP and CSO/SSO/CSSW discharges, intake and discharge from the river flushing tunnels and WE Energies Menomonee Valley and Oak Creek Power Plants, and meteorological parameters.

The hydrodynamic model calibration and validation effort was completed against water surface elevation measured at the NOAA gage, flow measured at the Jones Island USGS gage and water temperature profiles and time-series at the 34 MMSD water quality sampling stations located in the Milwaukee, Menomonee, and Kinnickinnic Rivers, Milwaukee Harbor and near shore Lake Michigan. The model reasonably reproduces observed water surface elevations, river-harbor flows and water temperature measurements and, therefore, overall circulation and mixing characteristics in the model domain are well represented. The calibrated and validated hydrodynamic model is capable of reproducing the lacustrine conditions of Milwaukee Harbor and is suitable for the water quality modeling component of the 2020 Facilities Planning process.

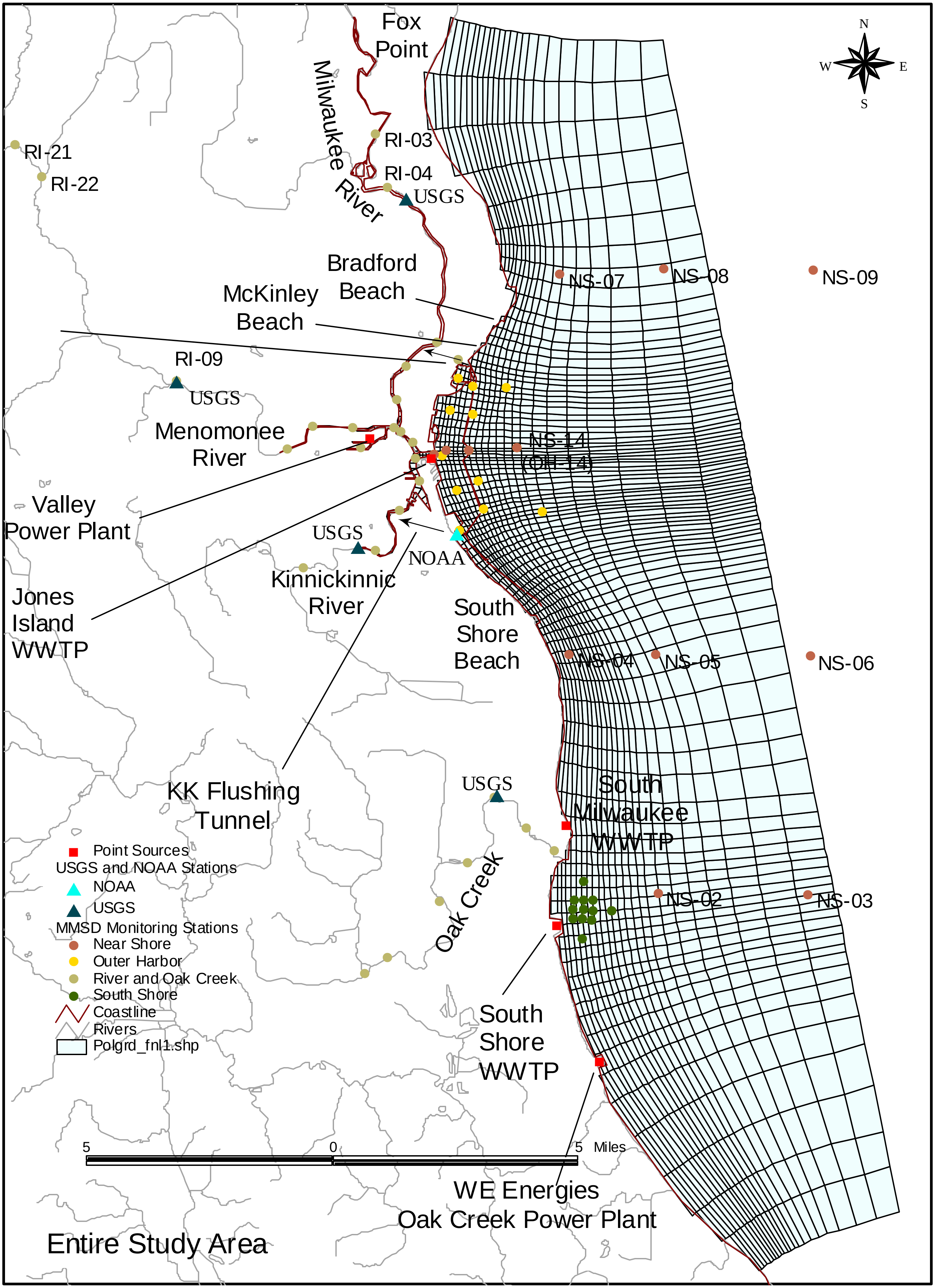
8.0 REFERENCES

Beletsky, D. and D. J. Schwab, 2001. Modeling Circulation and Thermal Structure in Lake Michigan: Annual Cycle and Interannual Variability. Journal of Geophysical Research, 106: 19,745-19,771.

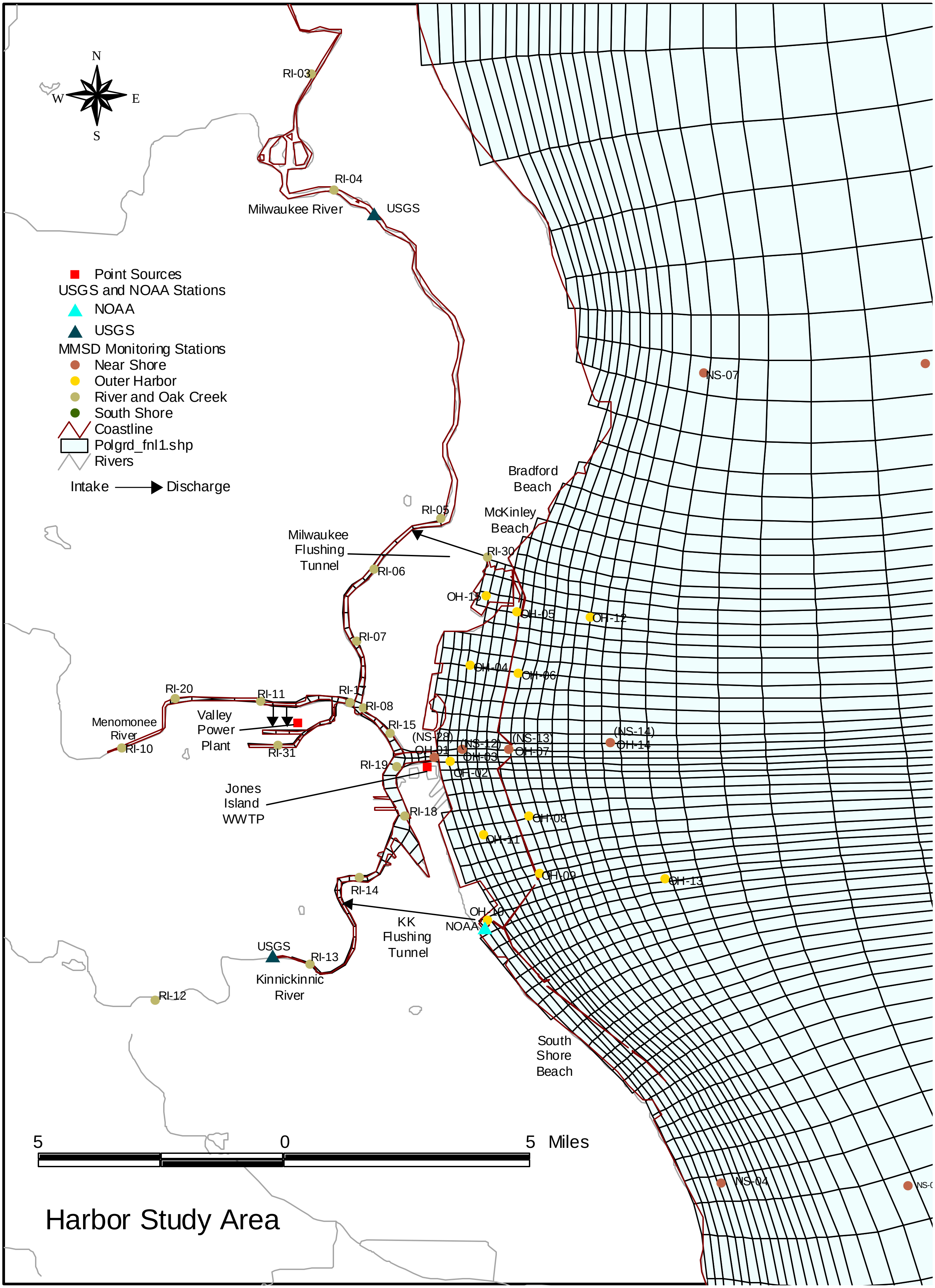
Brown & Caldwell, 2004. Draft Memo of CSO and SSO Hydrographs 1988-2002. December 2004. From MMSD-2020 Facility Planning Project (MMSD Contract No: M03002 P01).

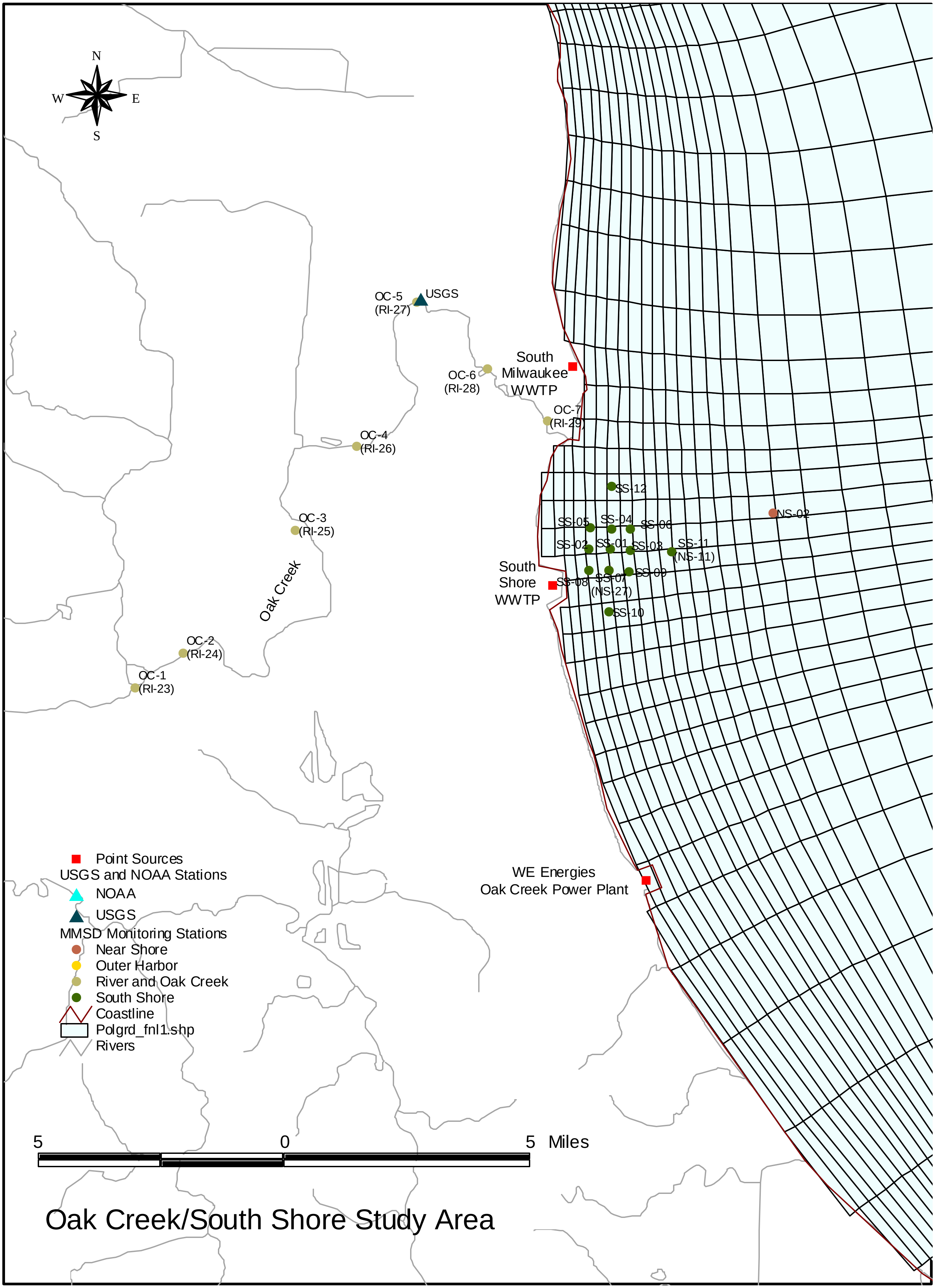
Jin, K.R., Z. G. Ji, and J. H. Hamrick, 2002. Modeling Winter Circulation in Lake Okeechobee, Florida. Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 128, No. 3, 114-125.

ATTACHMENT 1
STUDY AREA AND MODEL GRID



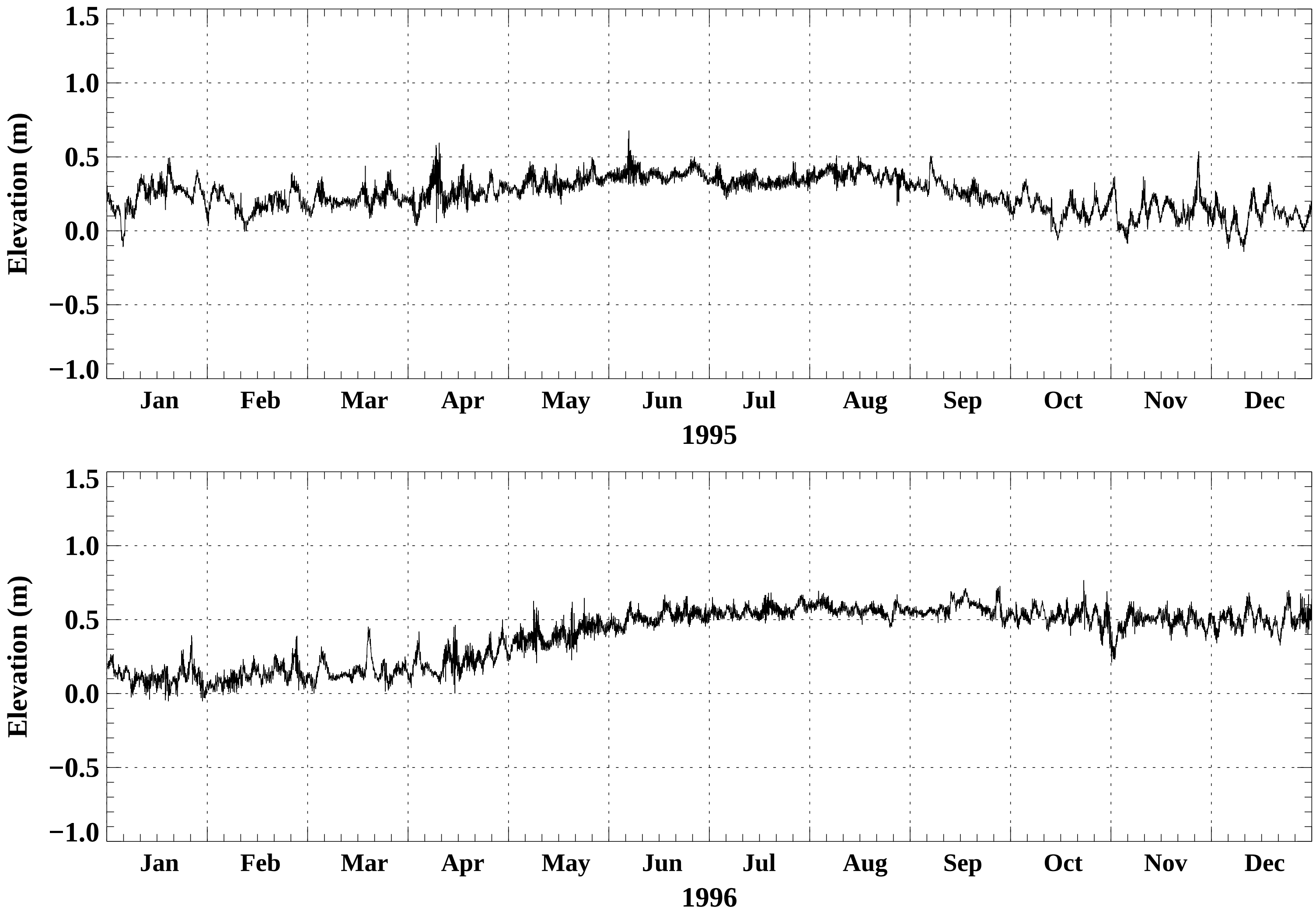
Fox Point
Milwaukee River
RI-03
RI-04
USGS
RI-21
RI-22
N
W
E
S
Bradford Beach
McKinley Beach
NS-07
NS-08
NS-09
RI-09
USGS
Menomonee River
NS-14 (OH-14)
Valley Power Plant
USGS
NOAA
Jones Island WWTP
Kinnickinnic River
South Shore Beach
NS-04
NS-05
NS-06
KK Flushing Tunnel
USGS
South Milwaukee WWTP
Oak Creek
NS-02
NS-03
Point Sources
USGS and NOAA Stations
NOAA
USGS
MMSD Monitoring Stations
Near Shore
Outer Harbor
River and Oak Creek
South Shore
Coastline
Rivers
Polgrd_fnl1.shp
South Shore WWTP
5
0
5 Miles
WE Energies Oak Creek Power Plant
Entire Study Area

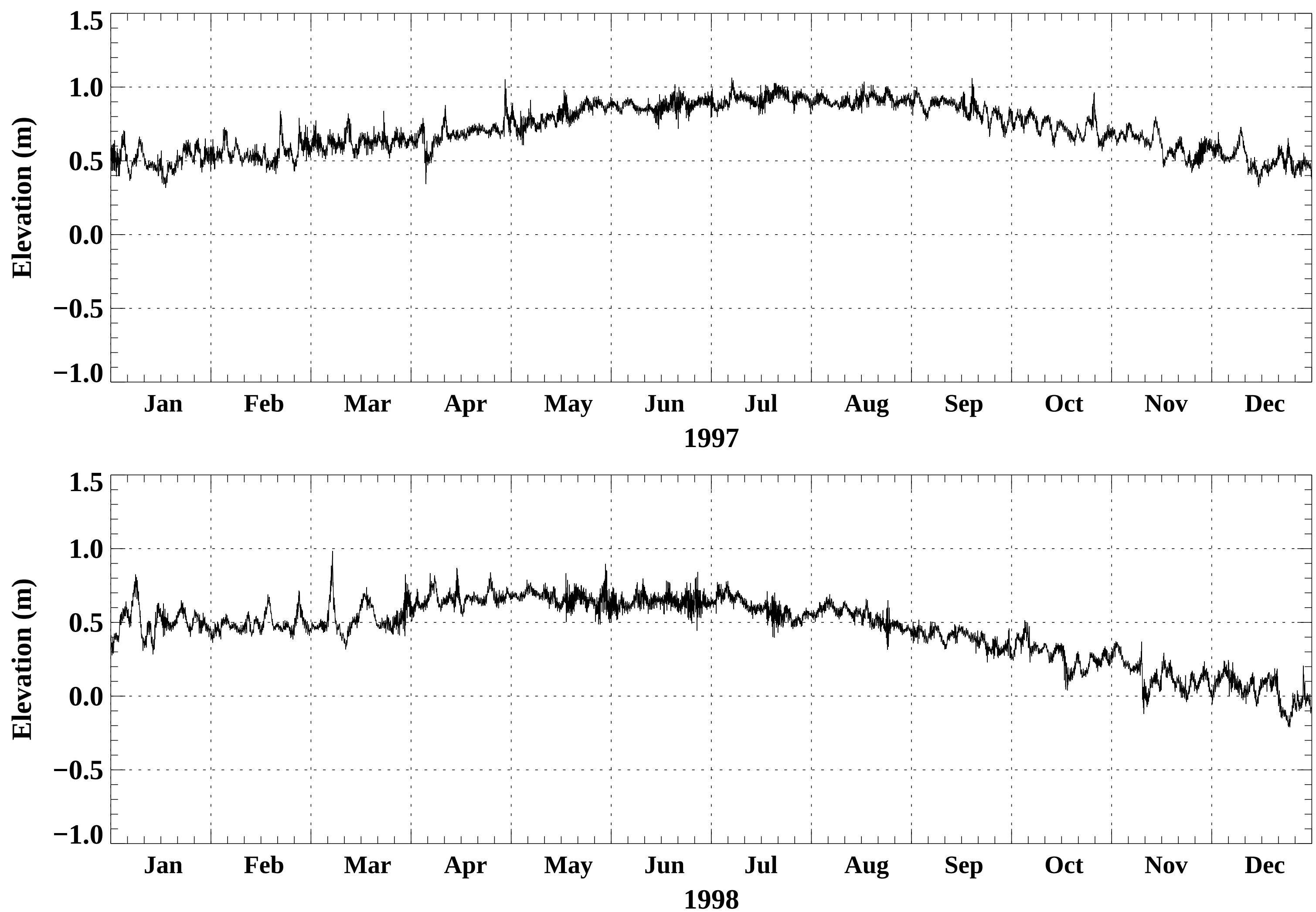

N
E
S
W
Point Sources
USGS and NOAA Stations
NOAA
USGS
MMSD Monitoring Stations
Near Shore
Outer Harbor
River and Oak Creek
South Shore
Coastline
Polgrd_fnl1.shp
Rivers
Intake
Discharge
RI-03
RI-04
Milwaukee River
USGS
NS-07
Bradford Beach
McKinley Beach
RI-05
Milwaukee Flushing Tunnel
RI-30
RI-06
OH-15
OH-05
OH-12
RI-07
OH-04
OH-06
RI-20
RI-11
RI-17
RI-08
Menomonee River
RI-10
Valley Power Plant
RI-31
RI-15
(NS-28)
OH-01
(NS-12)
OH-03
(NS-13)
OH-07
(NS-14)
OH-14
RI-19
OH-02
Jones Island WWTP
RI-18
OH-08
OH-11
OH-09
OH-13
RI-14
OH-10
NOAA
KK Flushing Tunnel
USGS
RI-13
Kinnickinnic River
RI-12
South Shore Beach
5
0
5 Miles
NS-04
Harbor Study Area

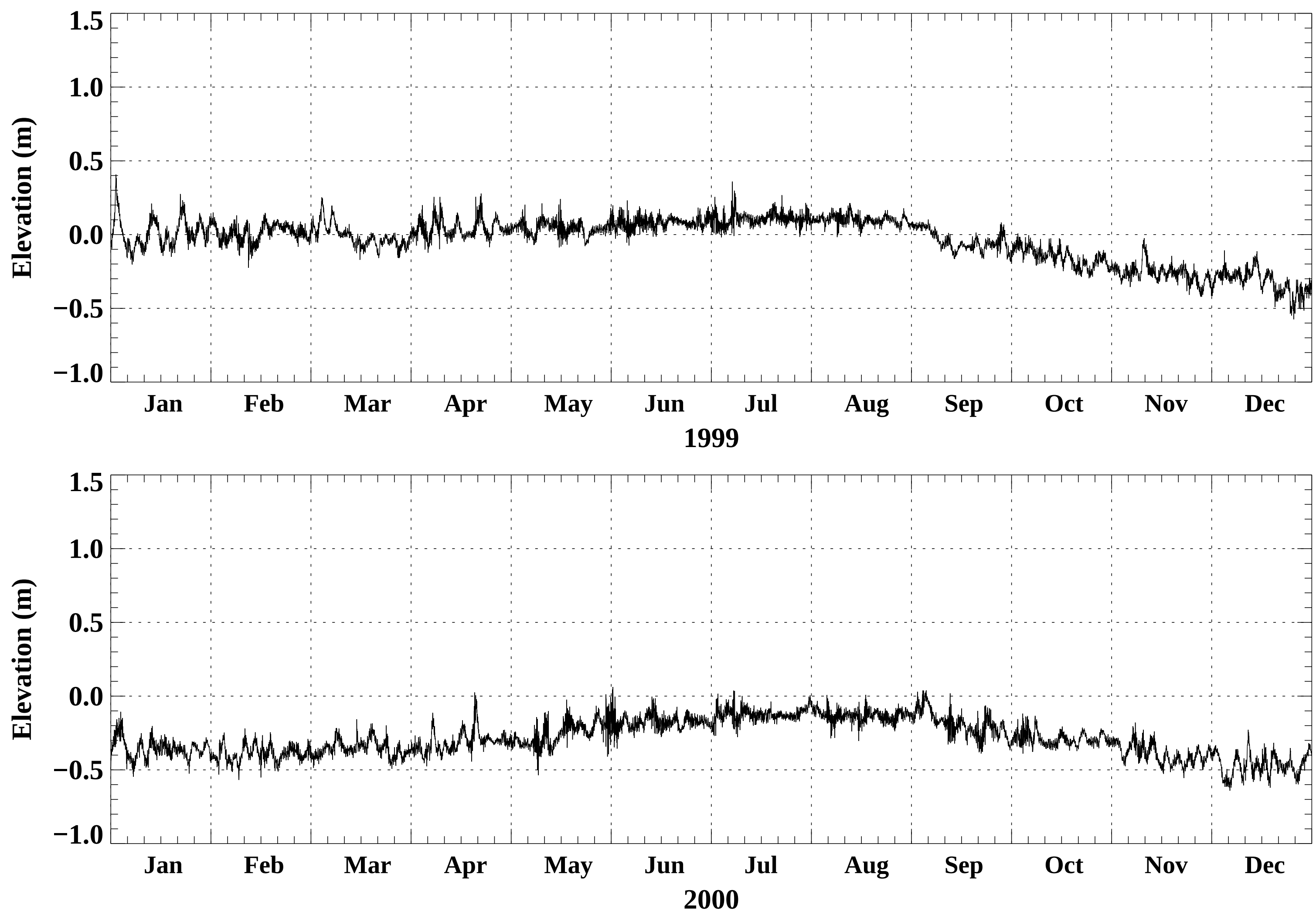


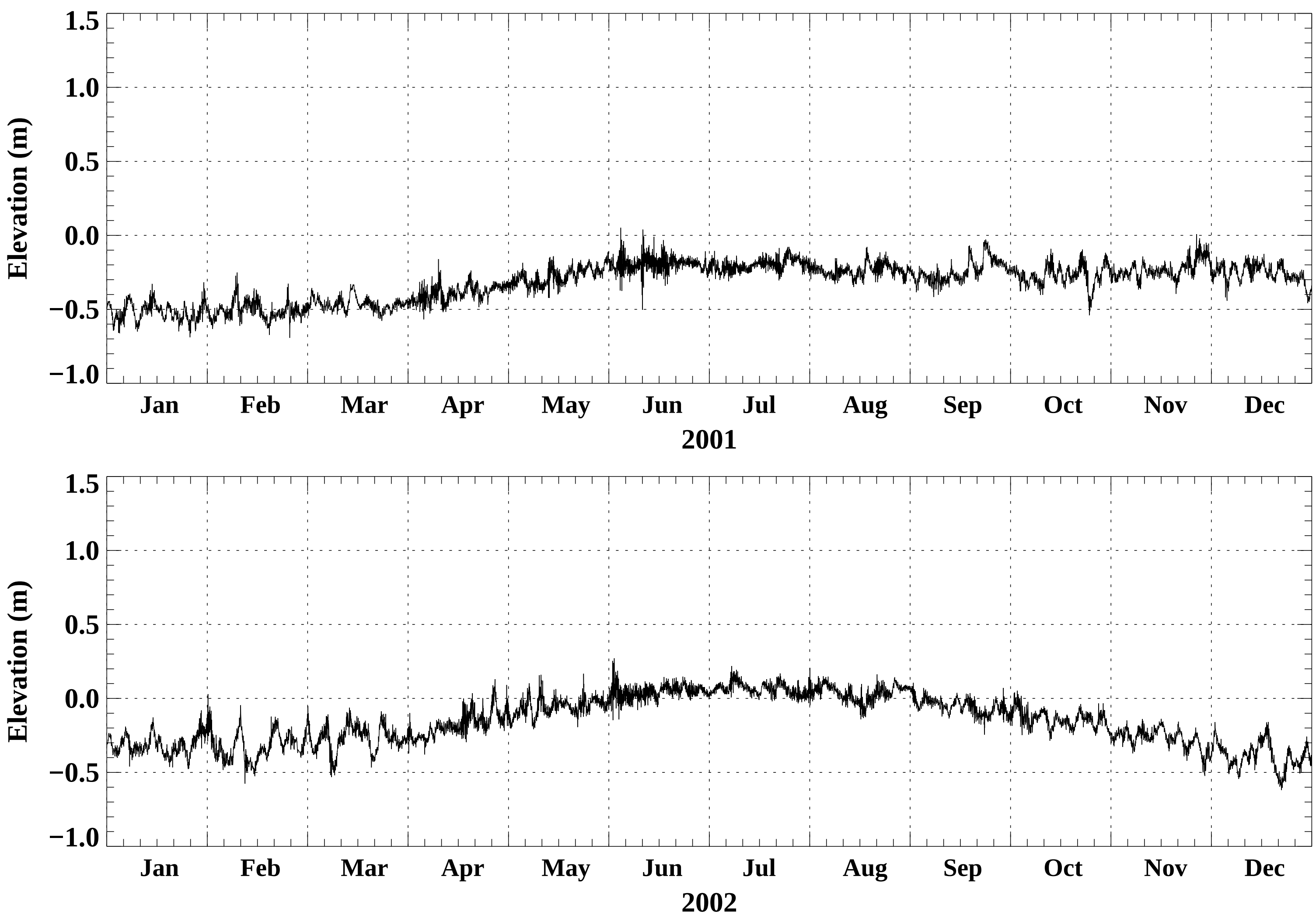
Oak Creek/South Shore Study Area

ATTACHMENT 2
WATER SURFACE ELEVATION BOUNDARY CONDITION

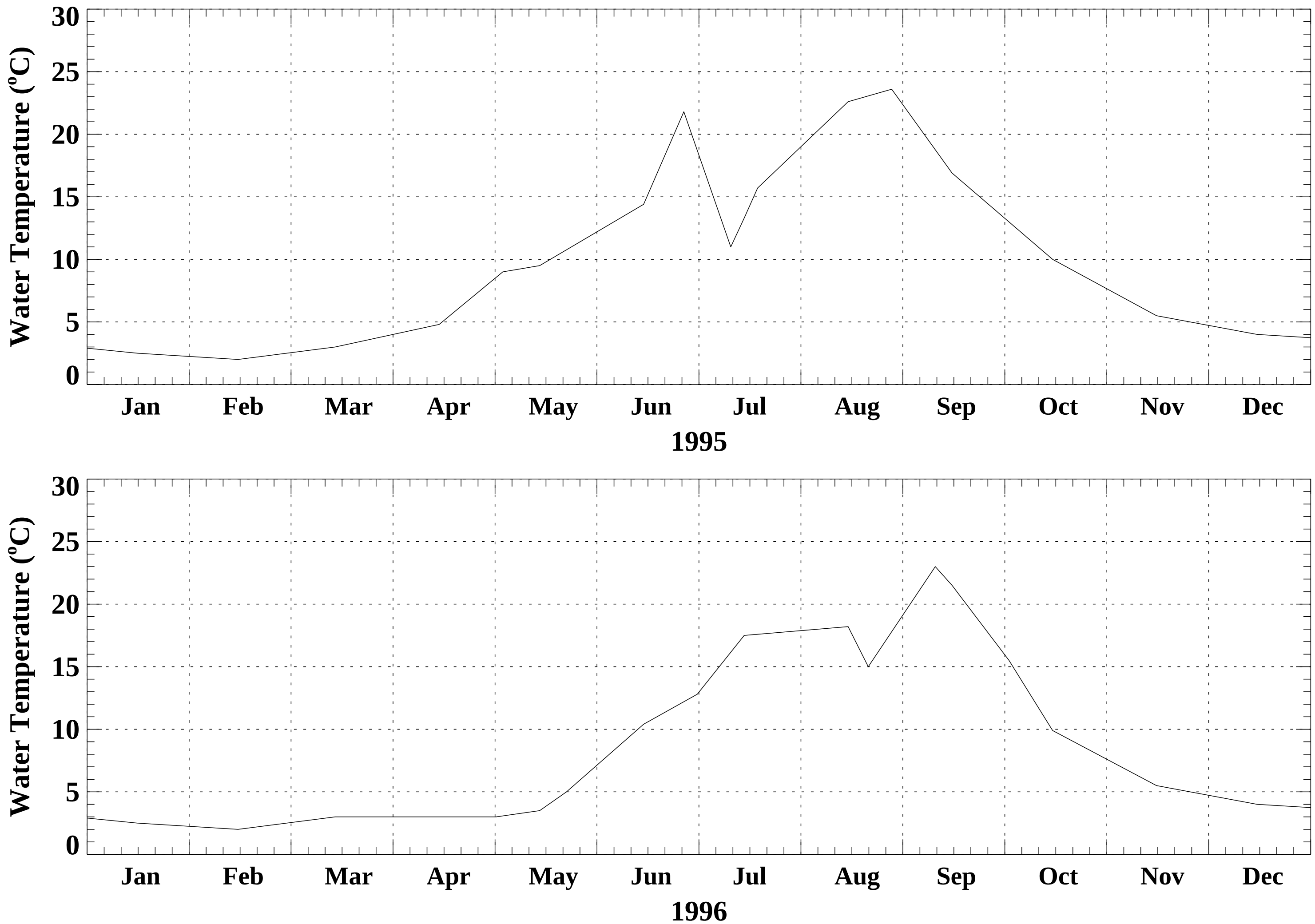

1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995
1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996


1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997
1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998

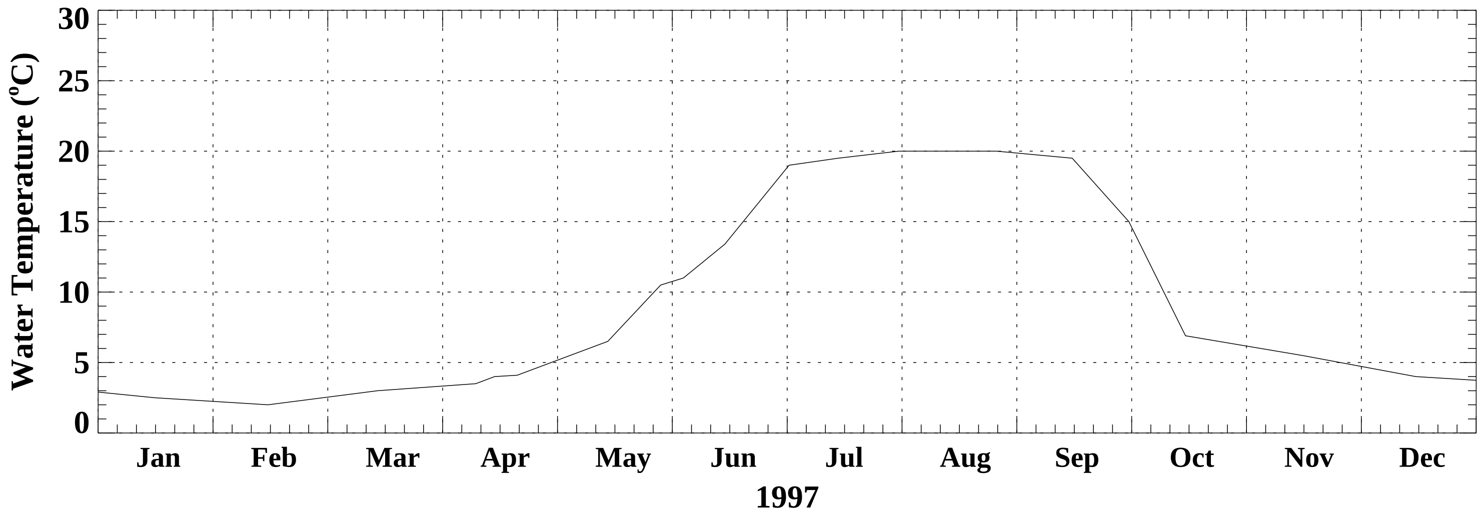

1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999
1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000

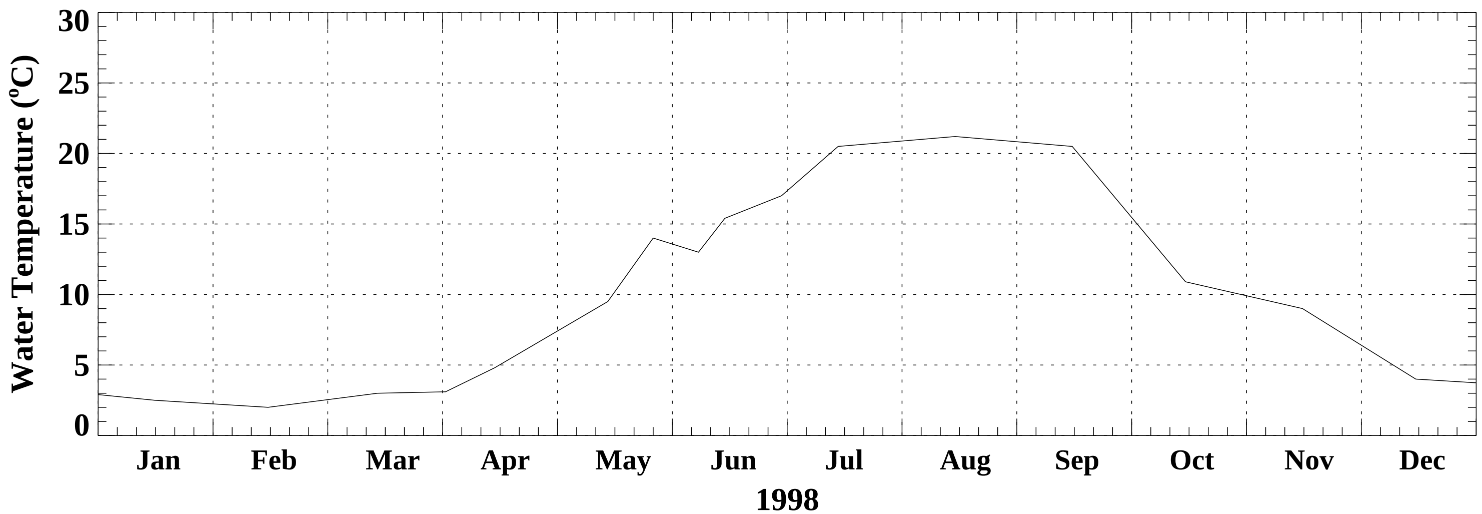

1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001
1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002

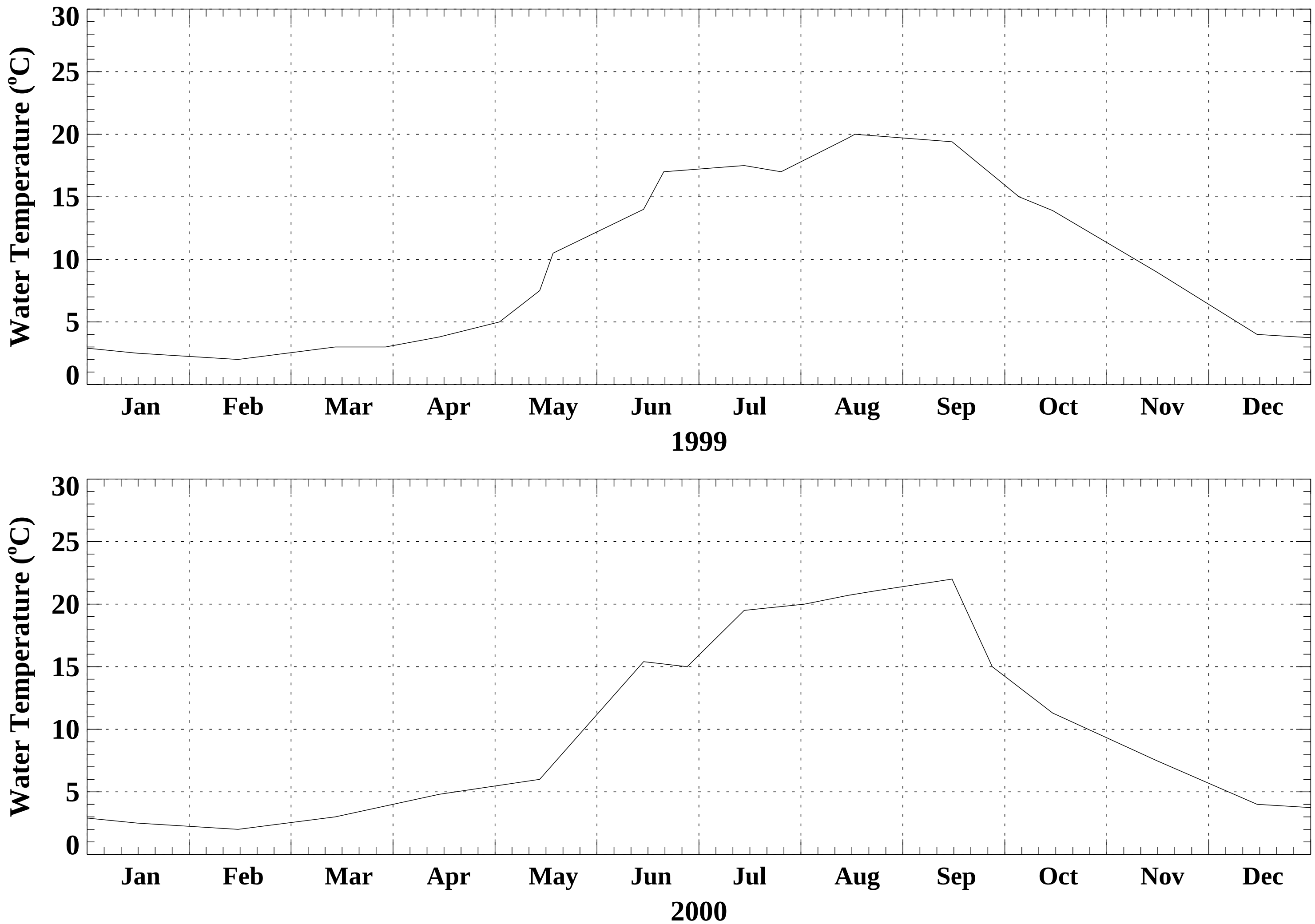
ATTACHMENT 3
WATER SURFACE TEMPERATURE BOUNDARY CONDITION

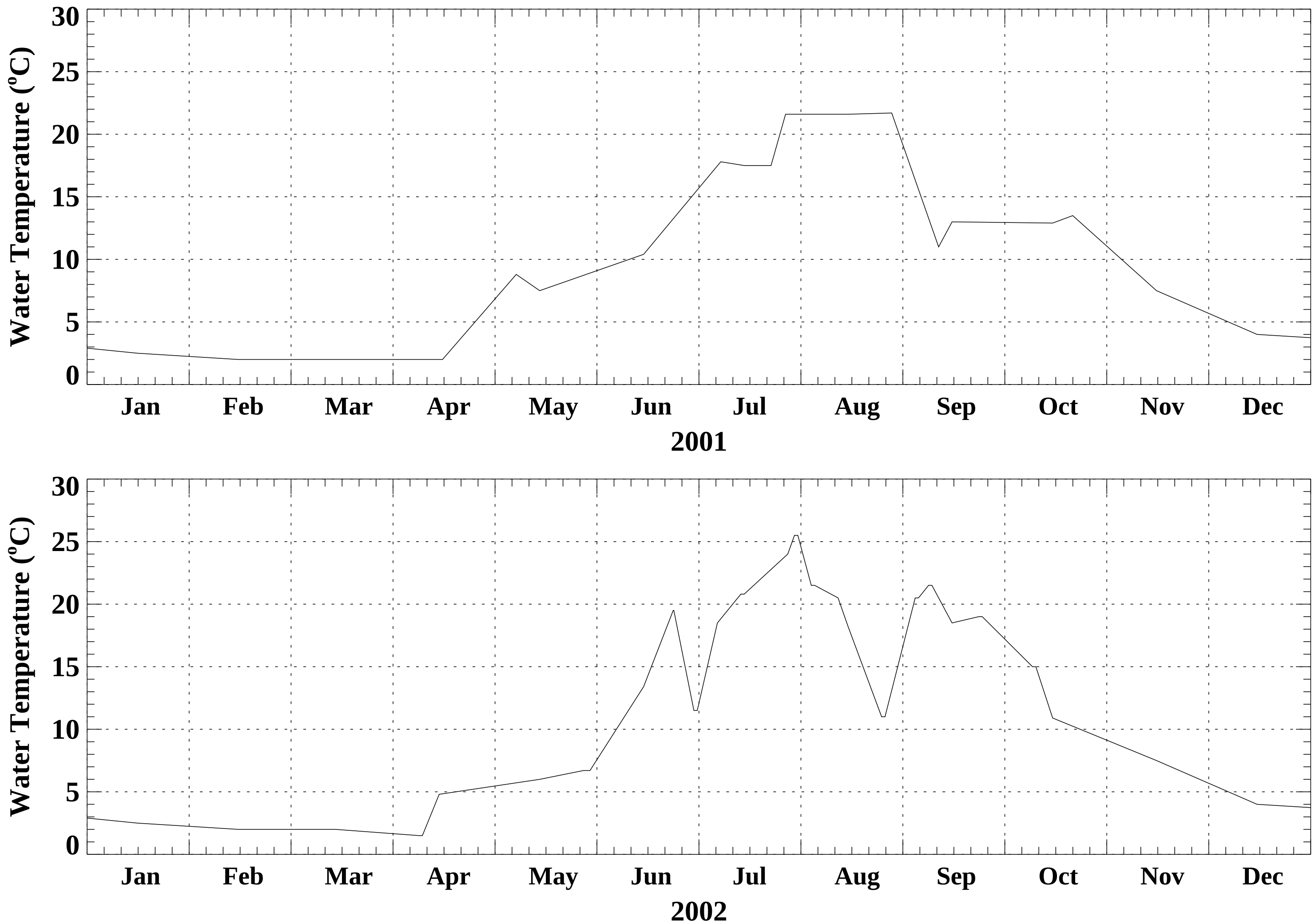


Water Temperature (°C)
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995
Water Temperature (°C)
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996


Water Temperature (°C)
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997

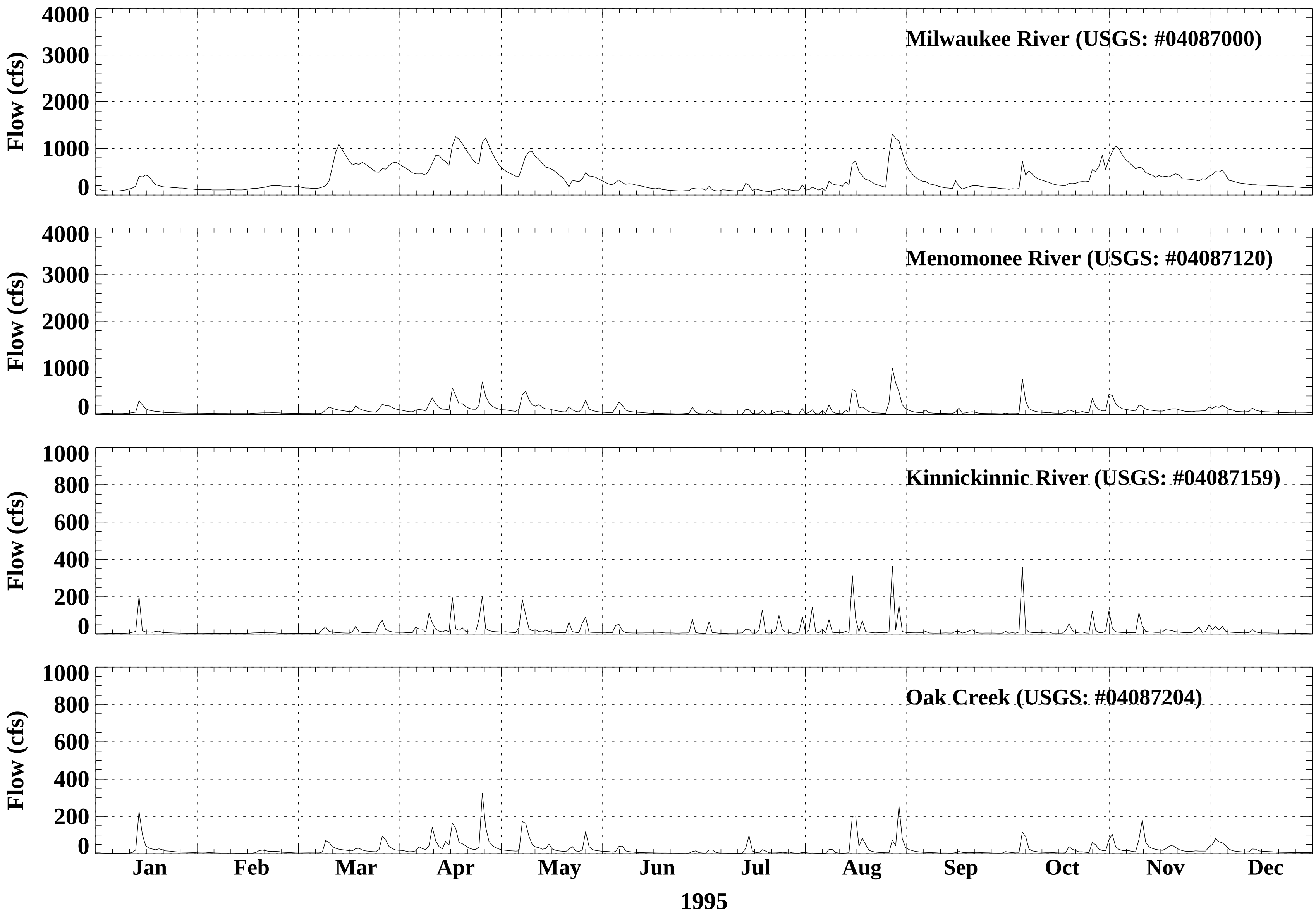

Water Temperature (°C)
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998

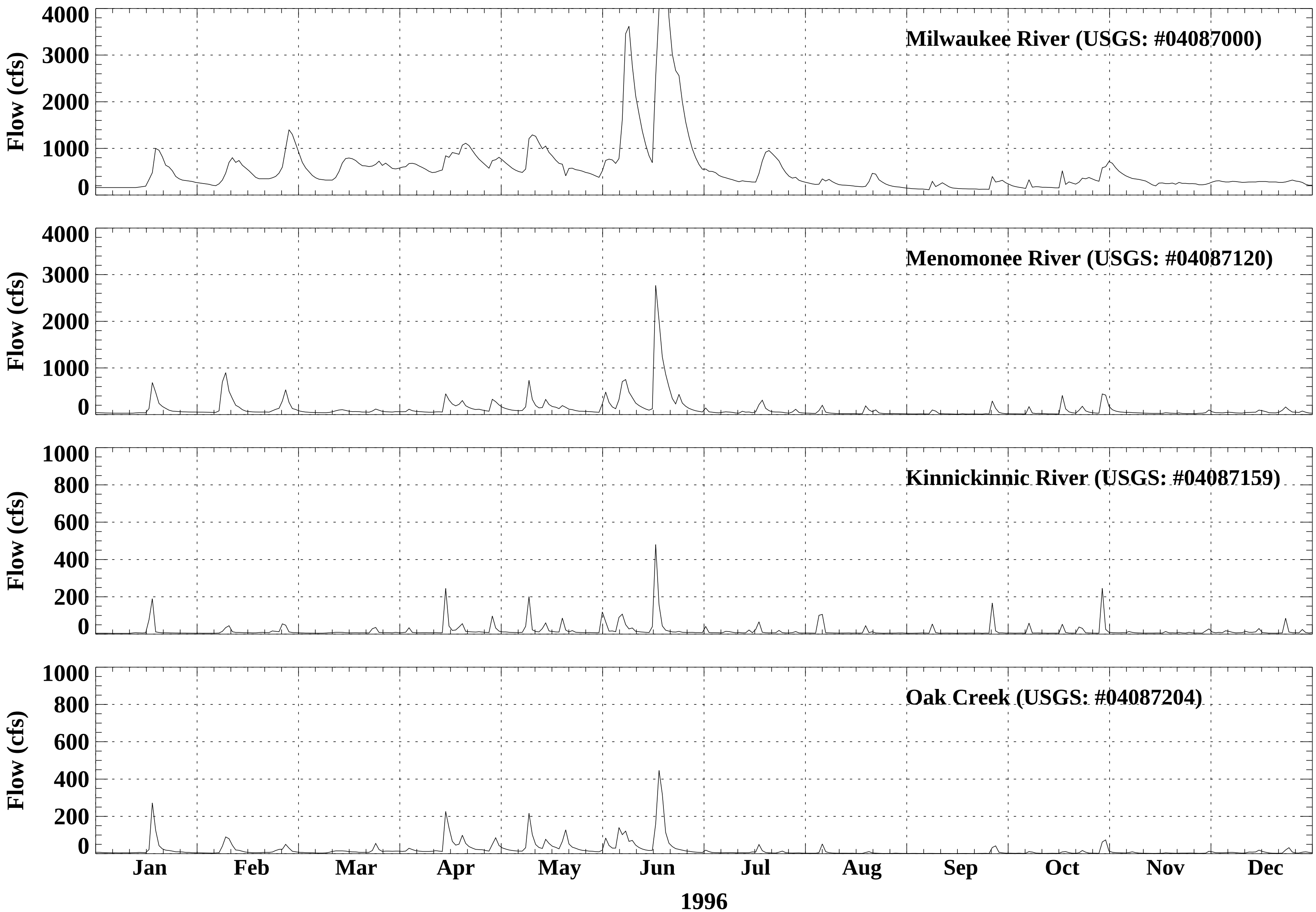

30
25
20
15
10
5
0
Water Temperature (°C)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999
30
25
20
15
10
5
0
Water Temperature (°C)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000



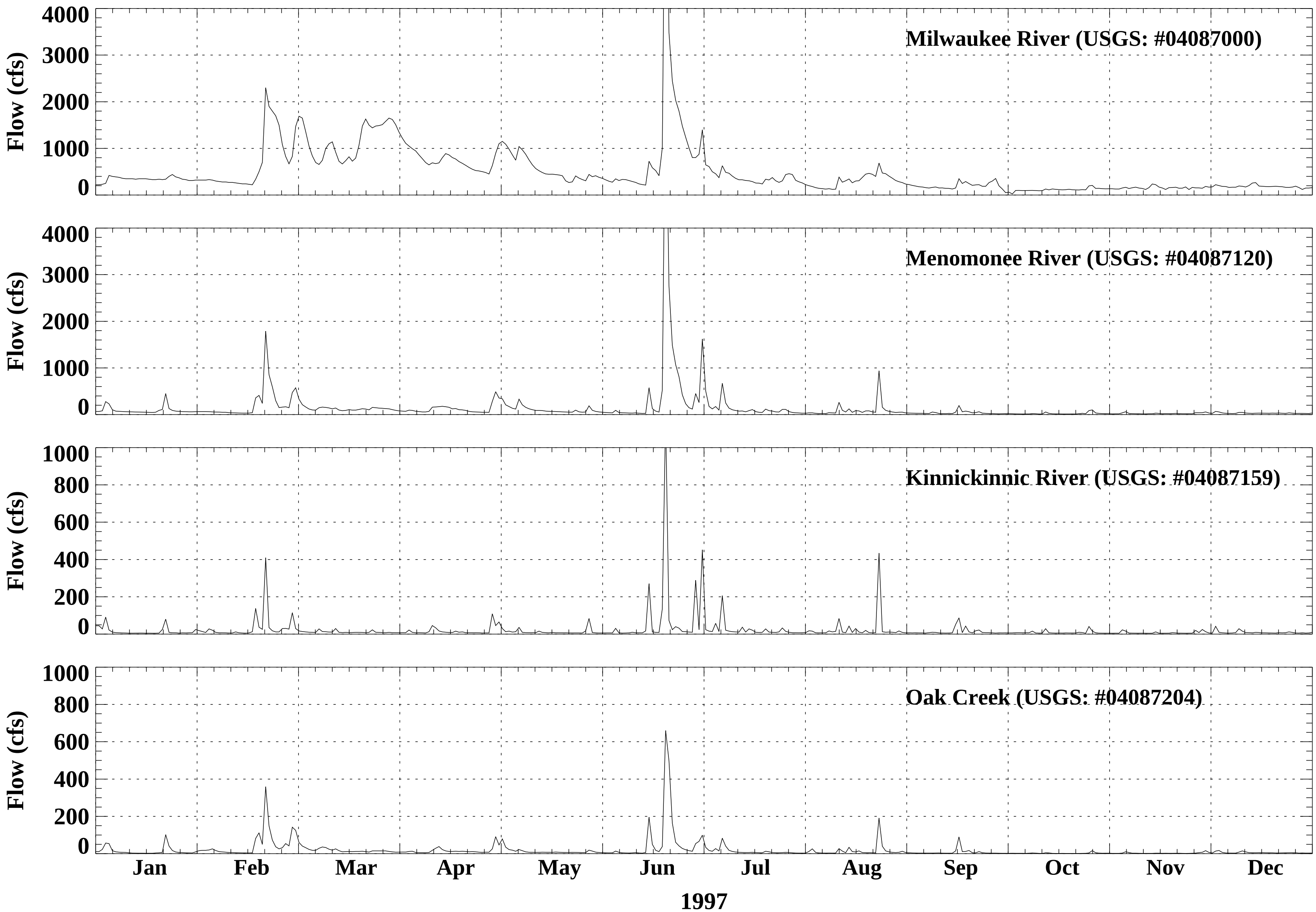
Water Temperature (oC)
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001
Water Temperature (oC)
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002

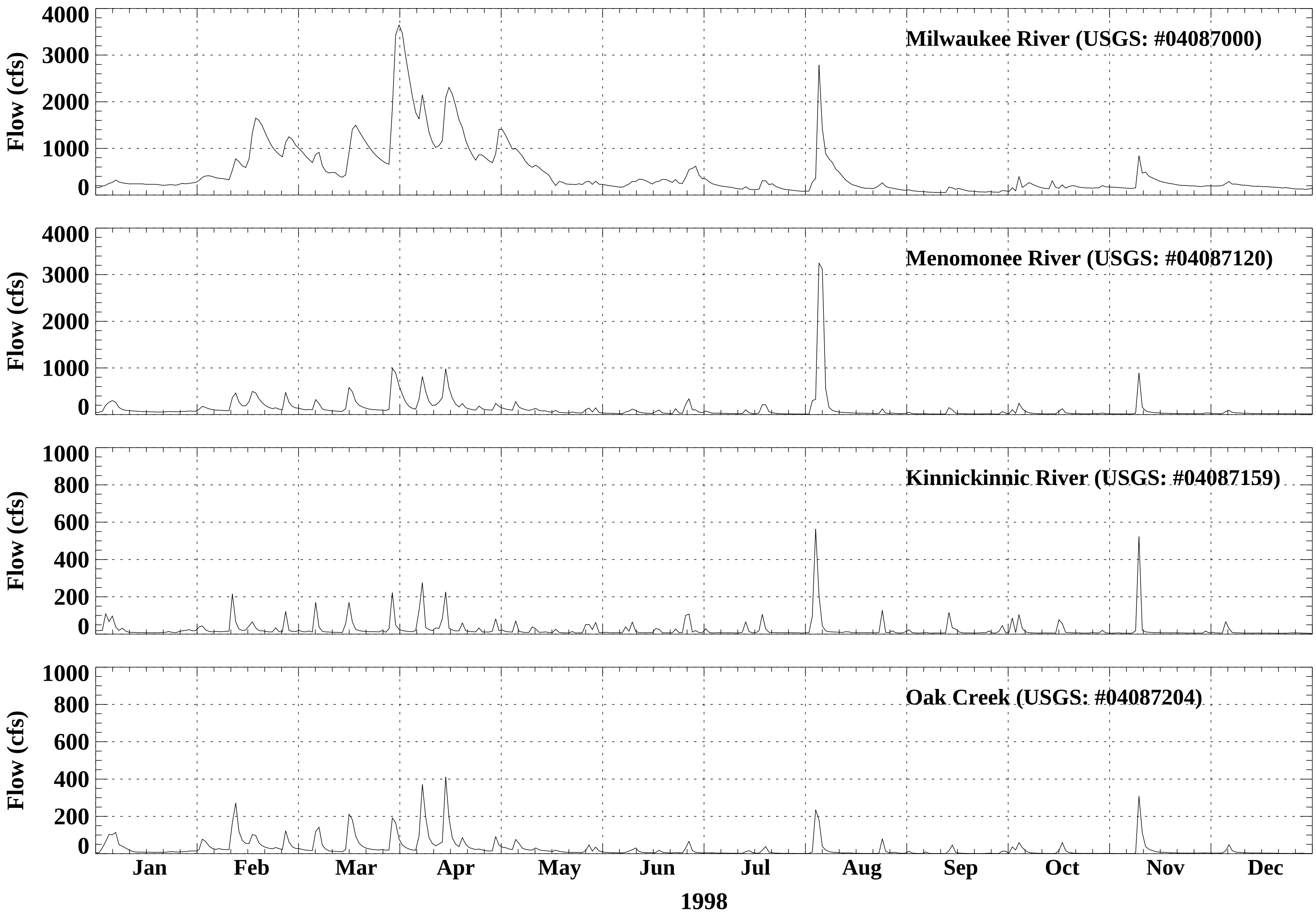
ATTACHMENT 4
RIVER FLOW BOUNDARY CONDITIONS

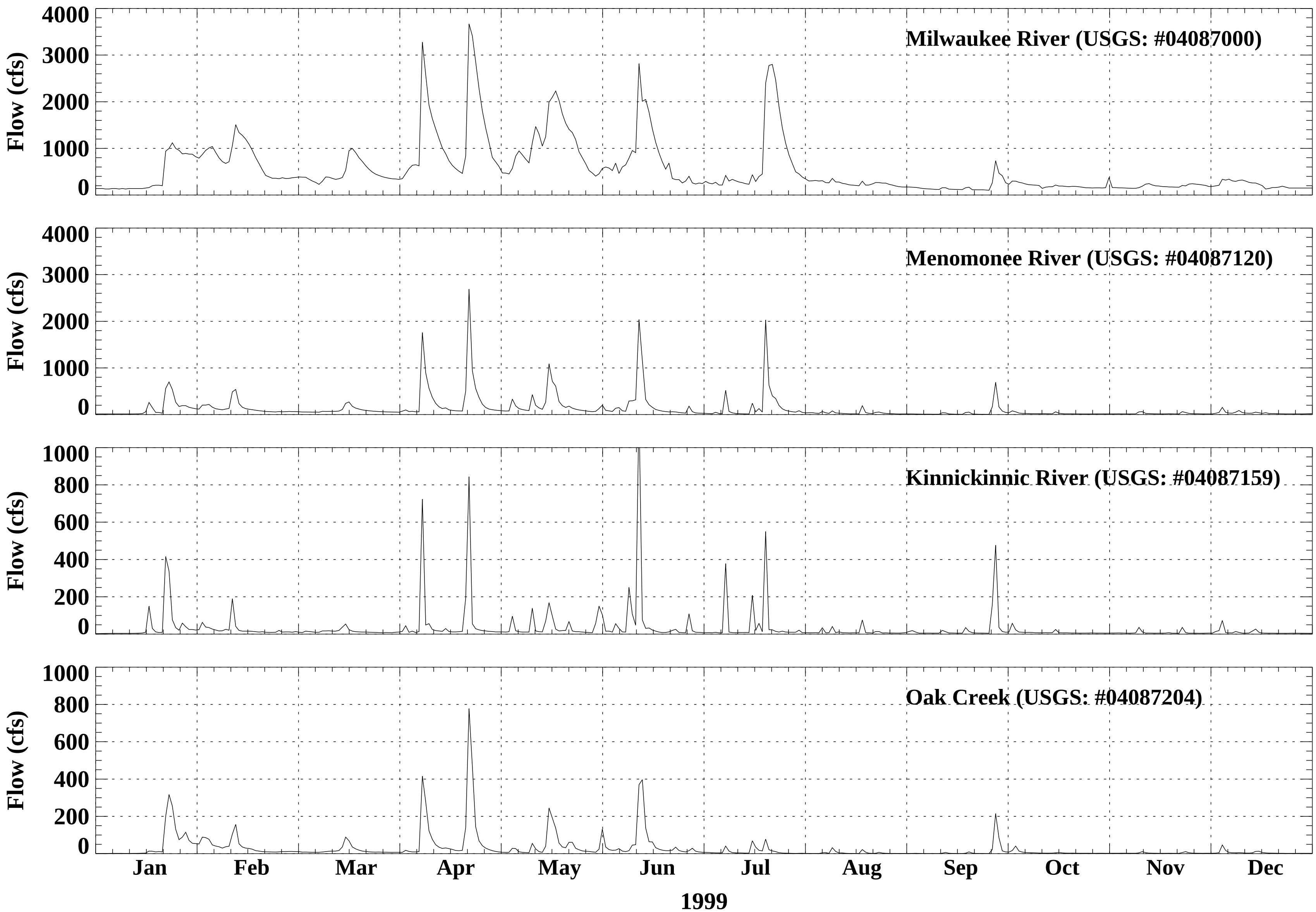

Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Flow (cfs)
4000
3000
2000
1000
0
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995



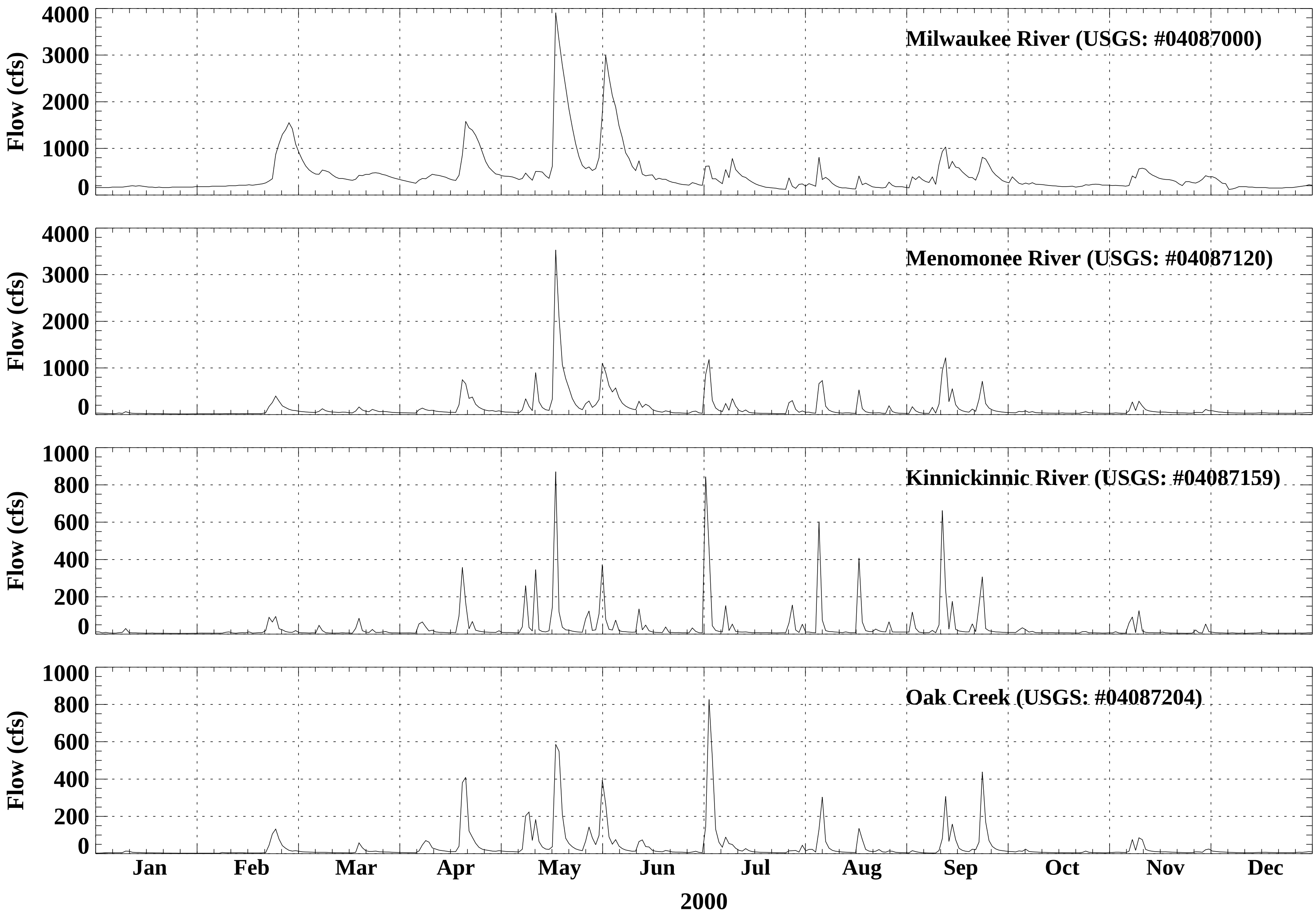
Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Flow (cfs)
4000
3000
2000
1000
0
800
600
400
200
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996


Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Flow (cfs)
4000
3000
2000
1000
0
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997

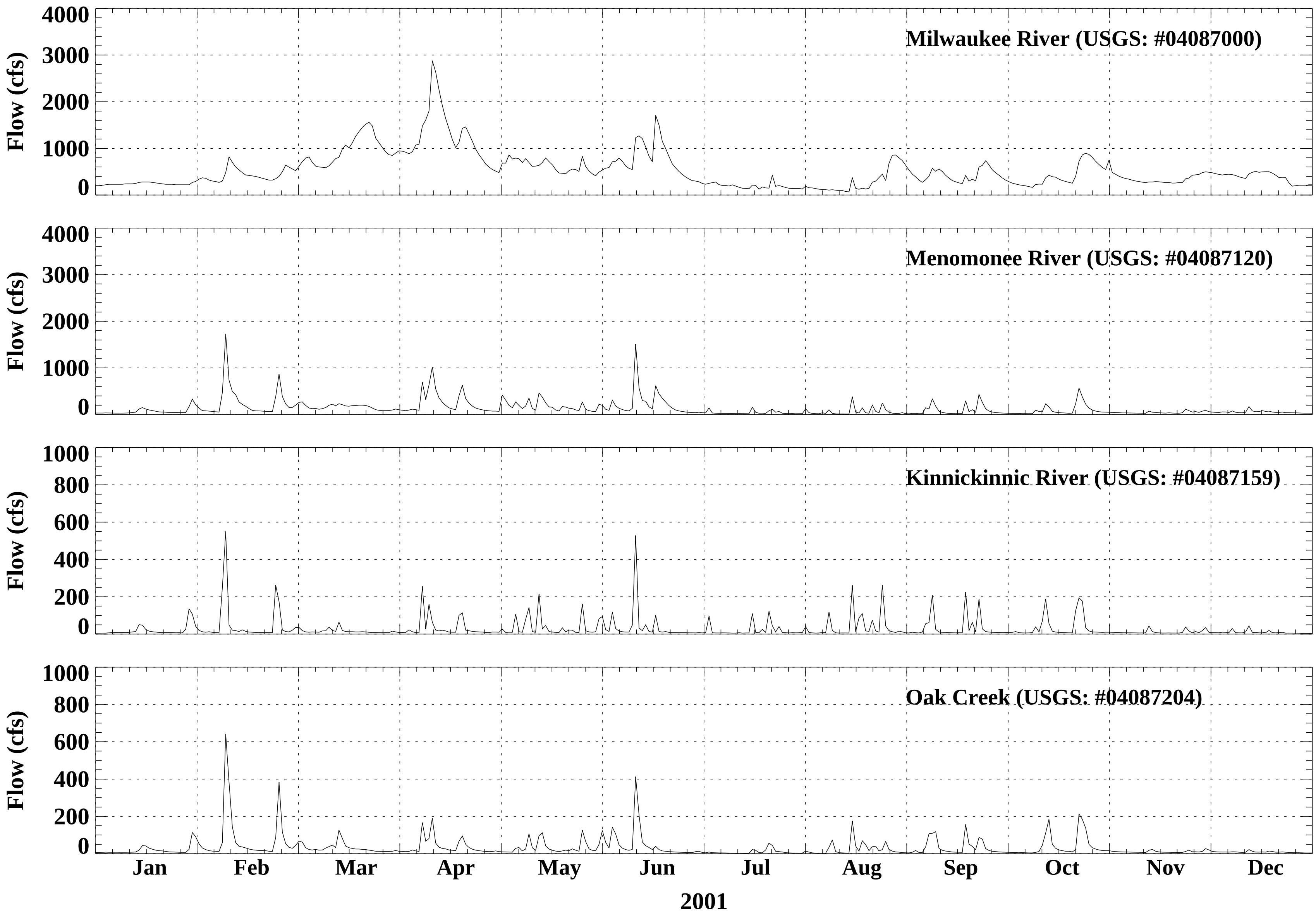

Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Flow (cfs)
4000
3000
2000
1000
0
800
600
400
200
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998

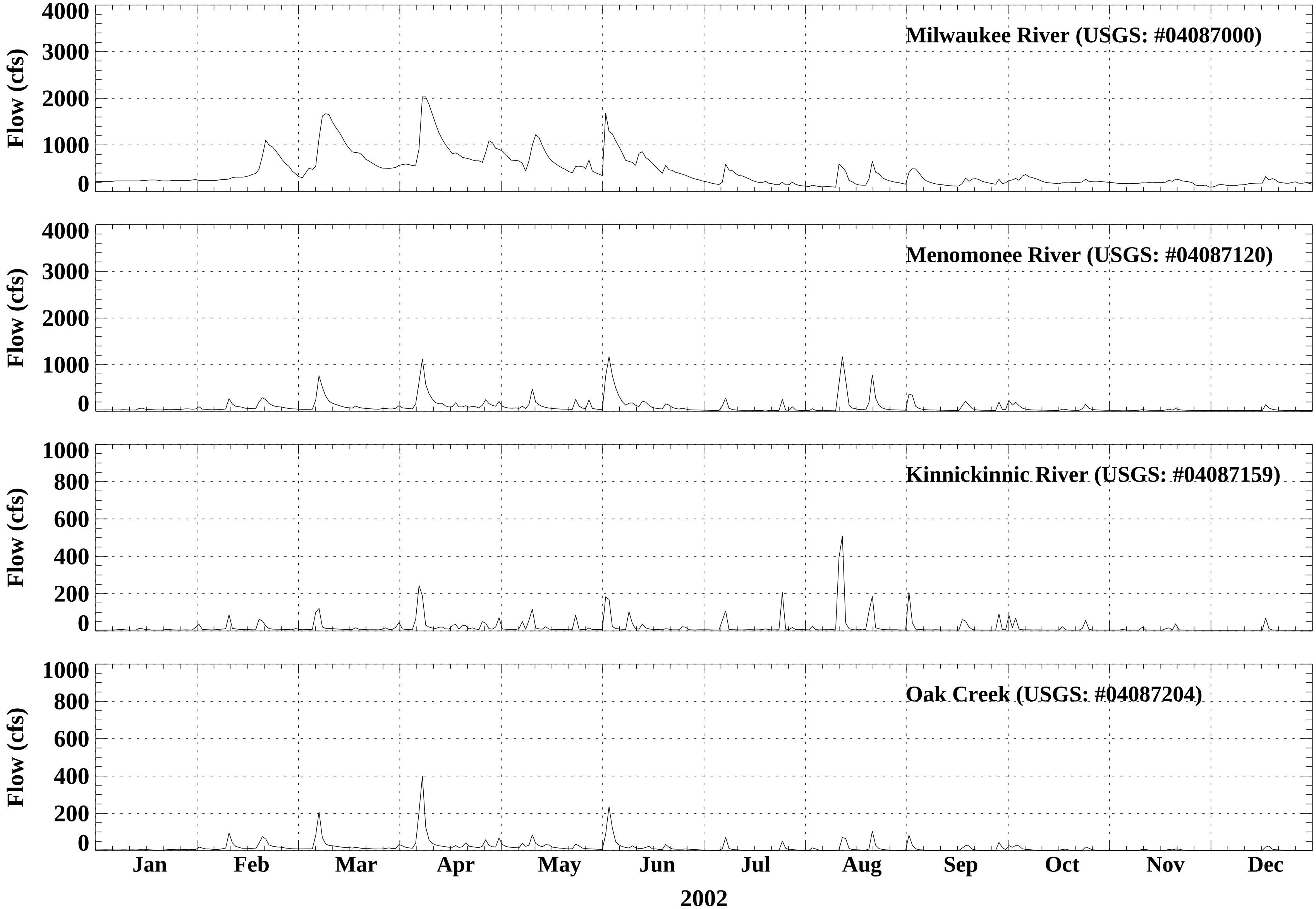


Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Flow (cfs)
4000
3000
2000
1000
0
1000
800
600
400
200
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999



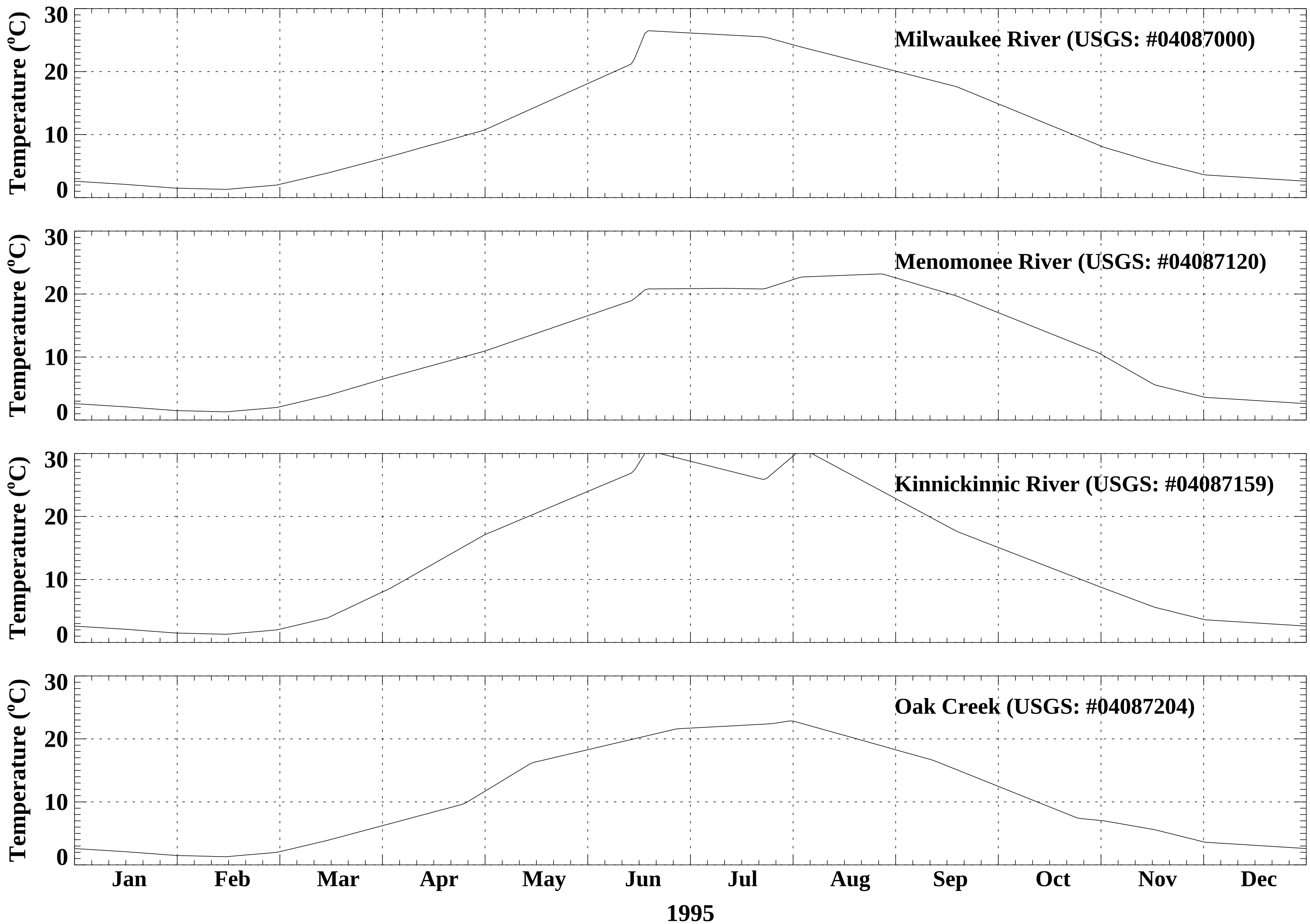
Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Flow (cfs)
0
1000
2000
3000
4000
200
400
600
800
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000

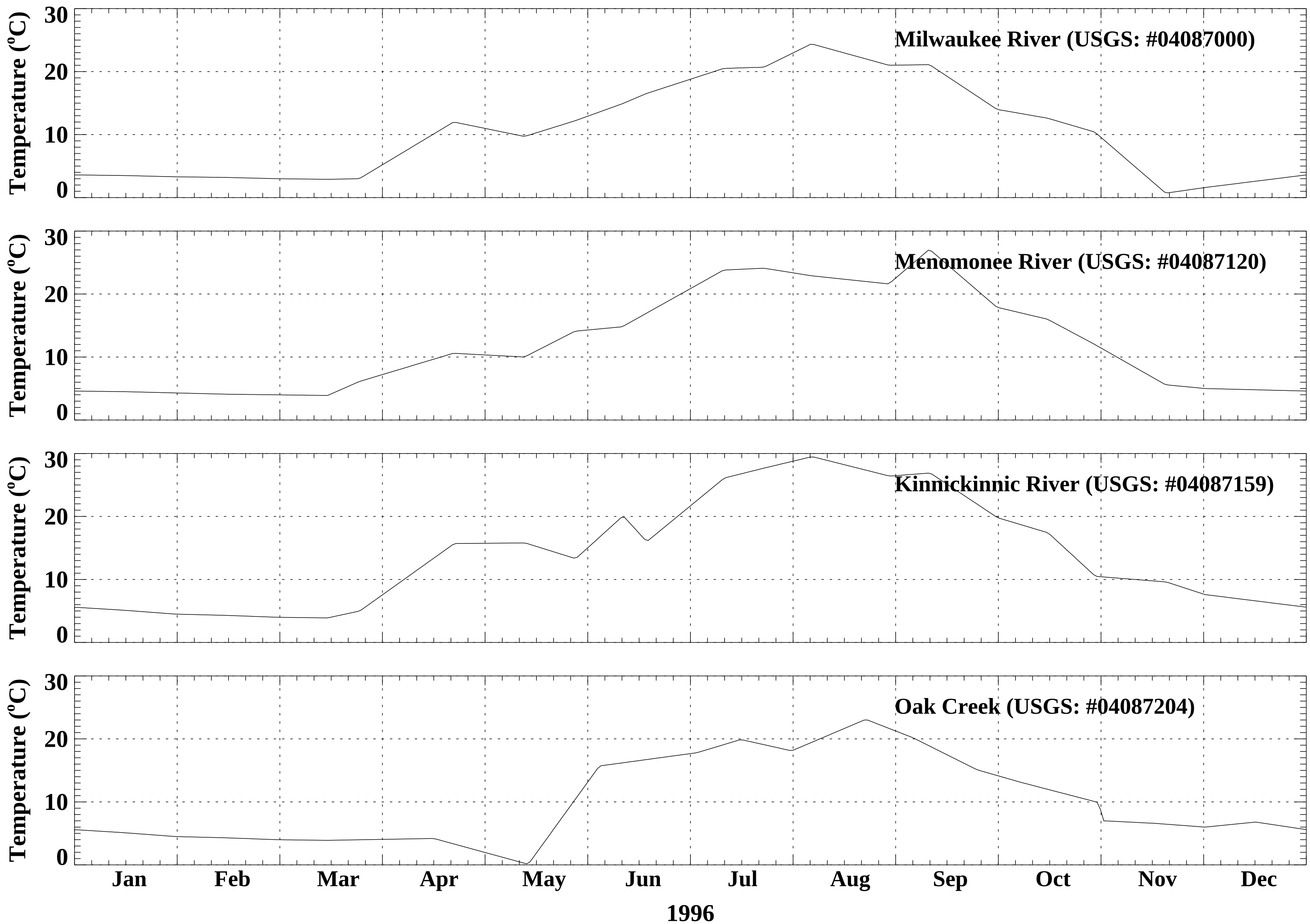

Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Flow (cfs)
4000
3000
2000
1000
0
800
600
400
200
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001



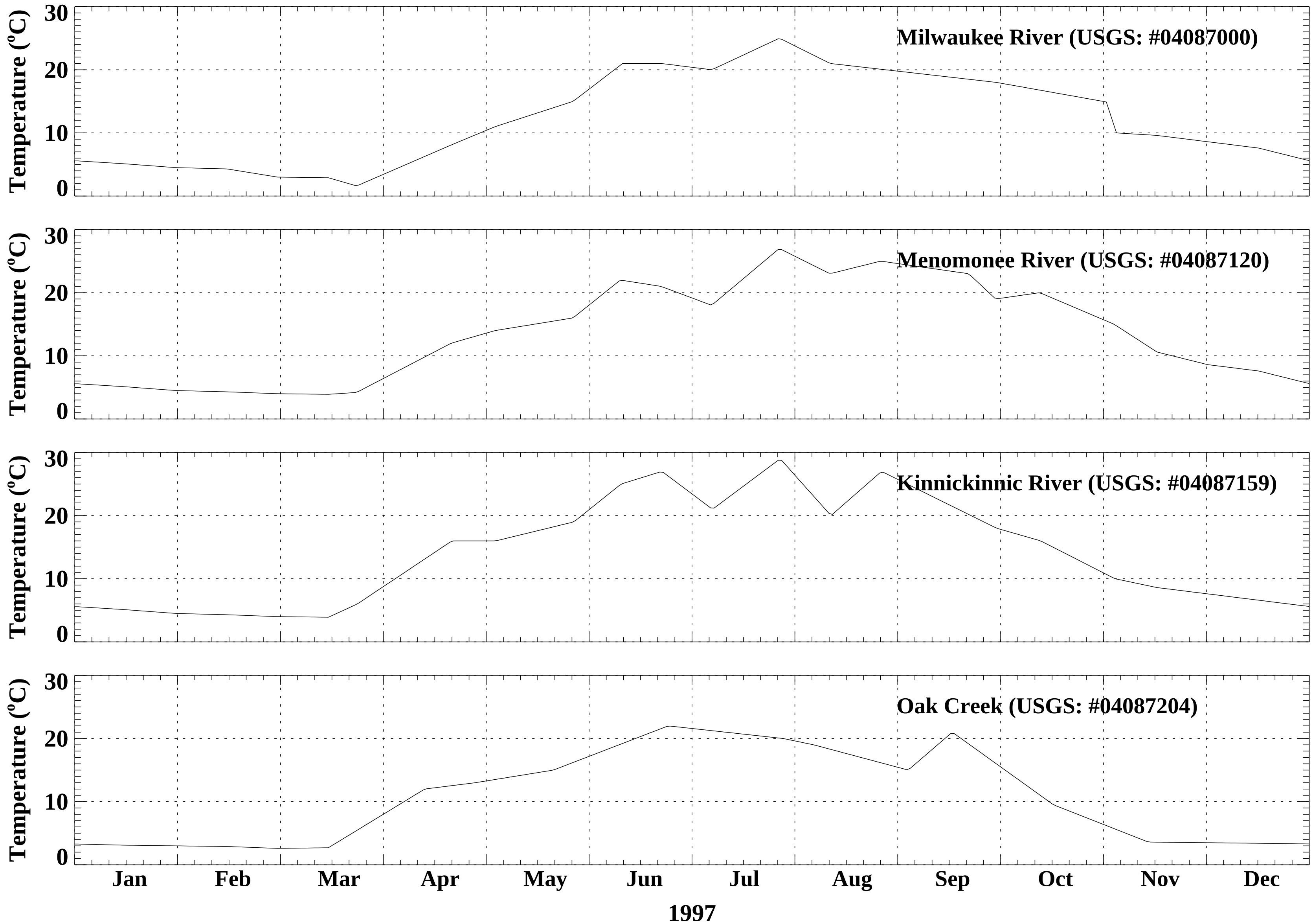
Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Flow (cfs)
0
1000
2000
3000
4000
0
200
400
600
800
1000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002

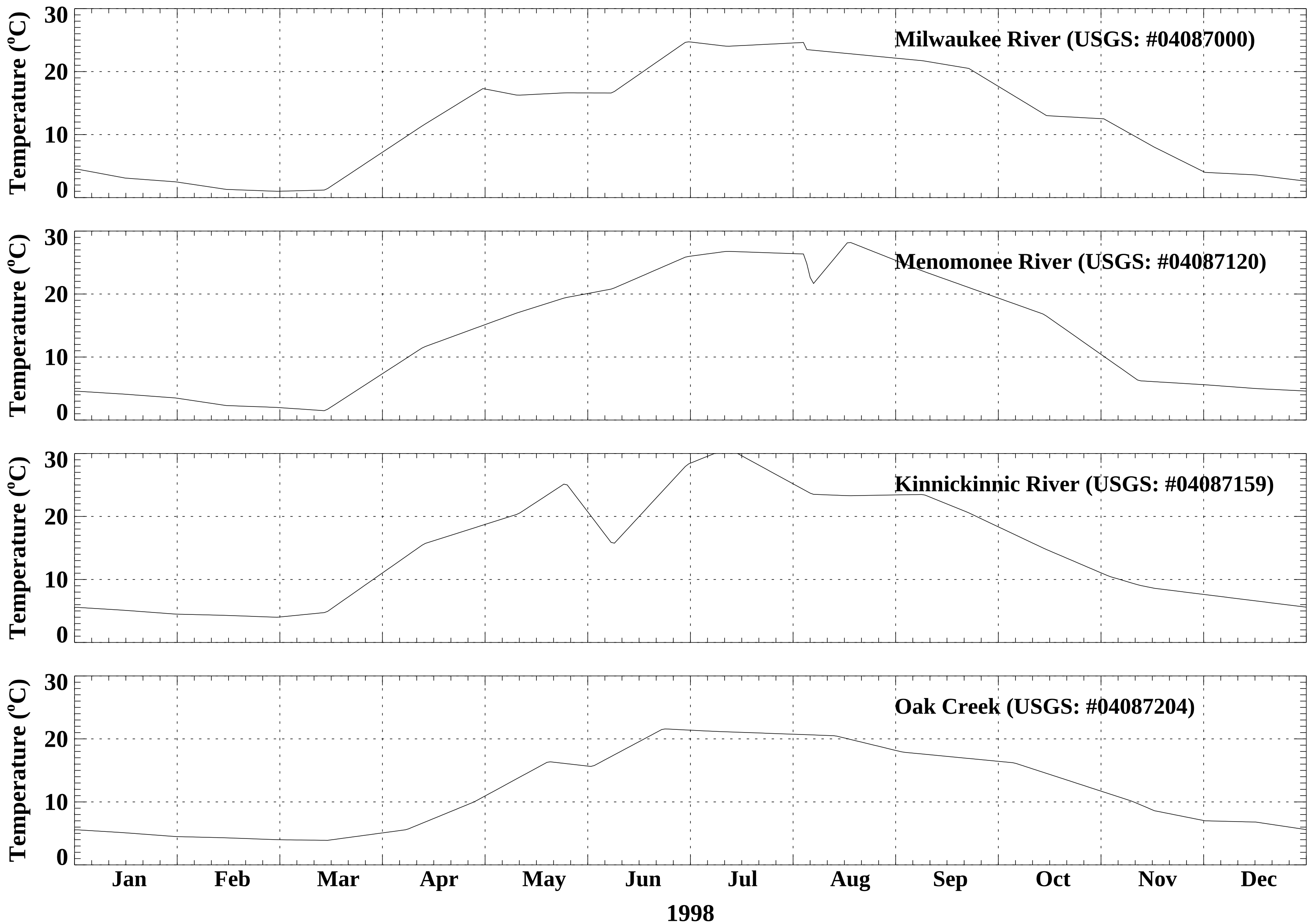
ATTACHMENT 5
RIVER TEMPERATURE BOUNDARY CONDITIONS


Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Temperature (°C)
0
10
20
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995

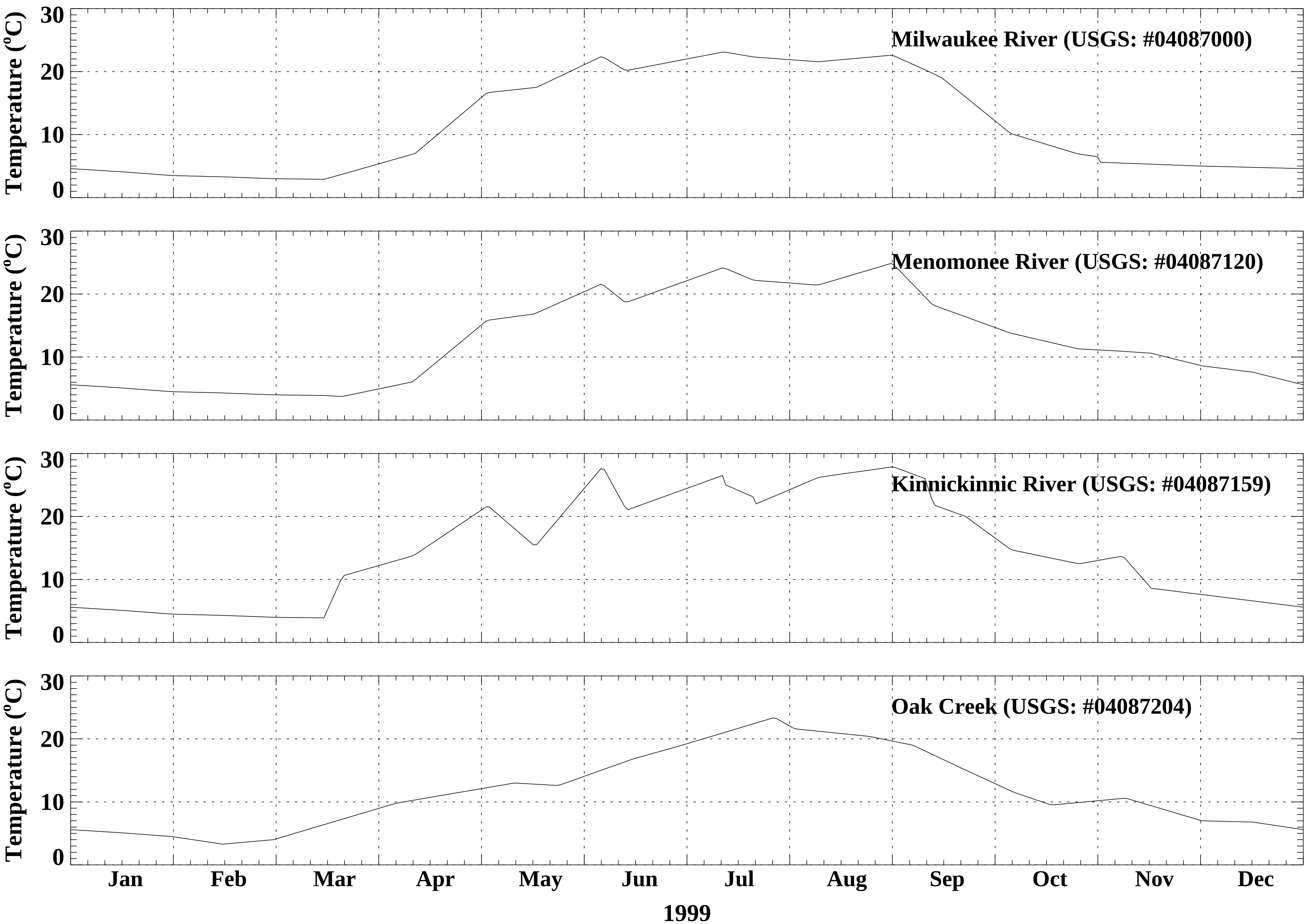


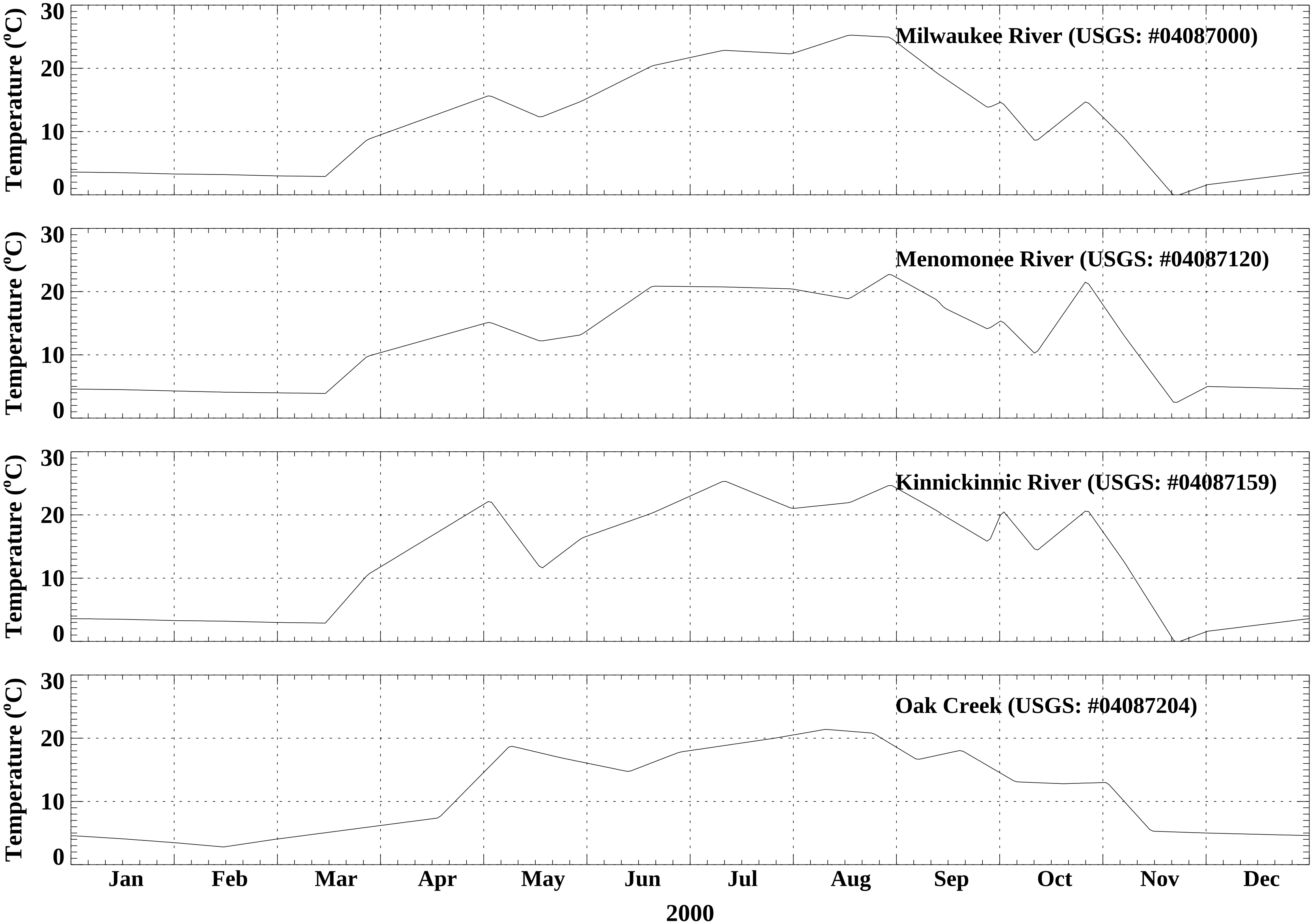
Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Temperature (ºC)
0
10
20
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996


Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Temperature (°C)
0
10
20
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997

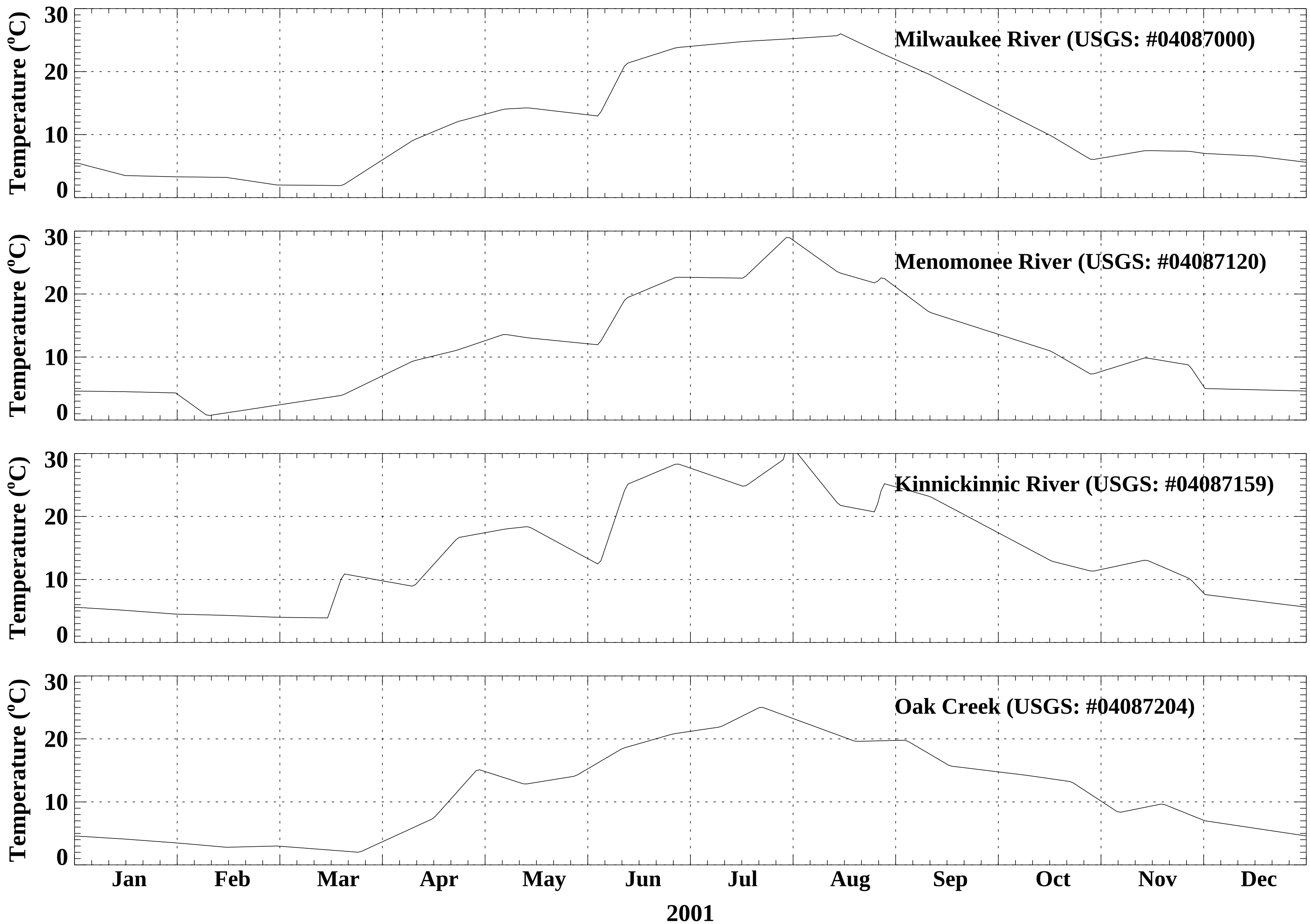


Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Temperature (°C)
0
10
20
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998

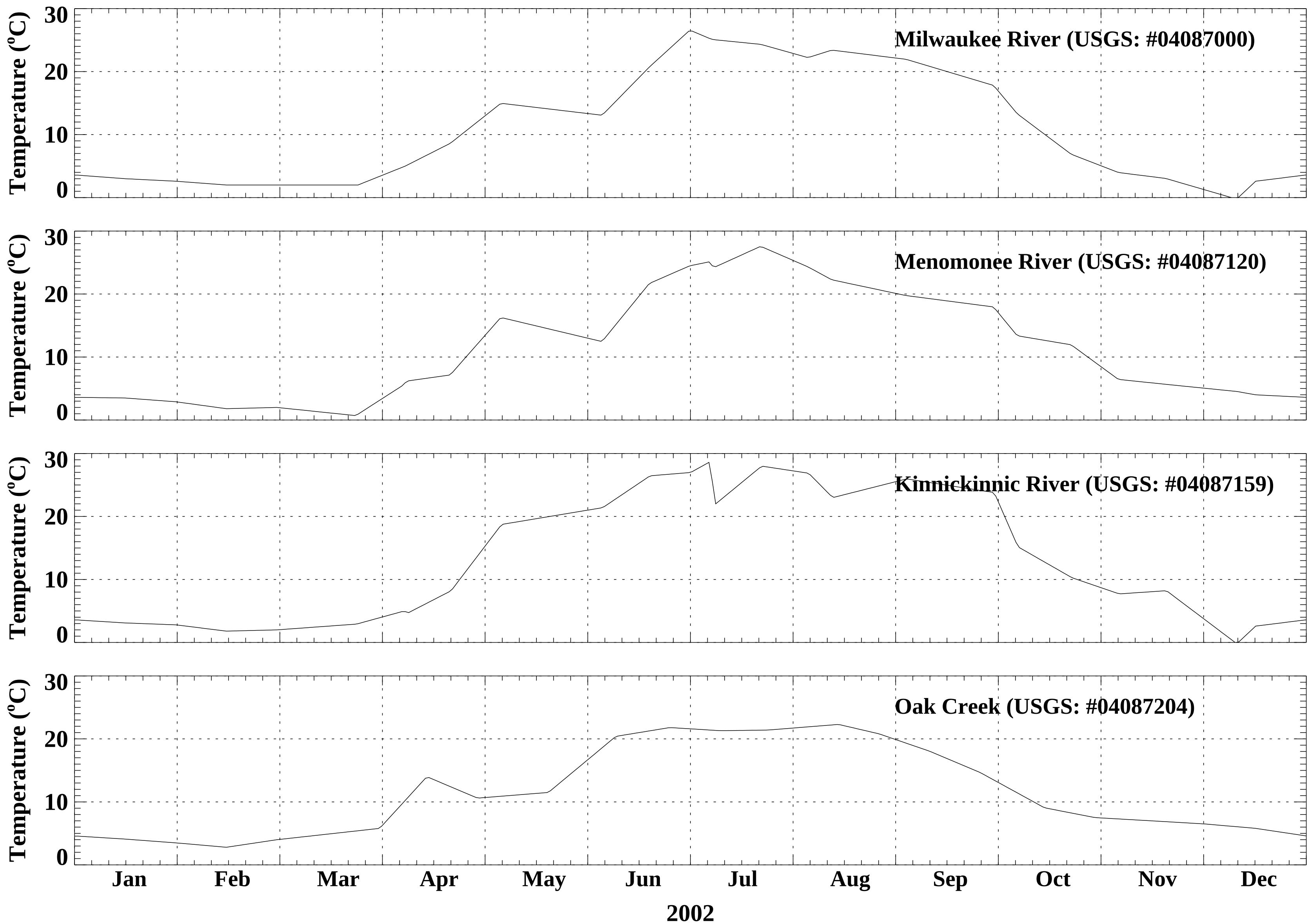

Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Temperature (°C)
0
10
20
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999



Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Temperature (°C)
0
10
20
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000

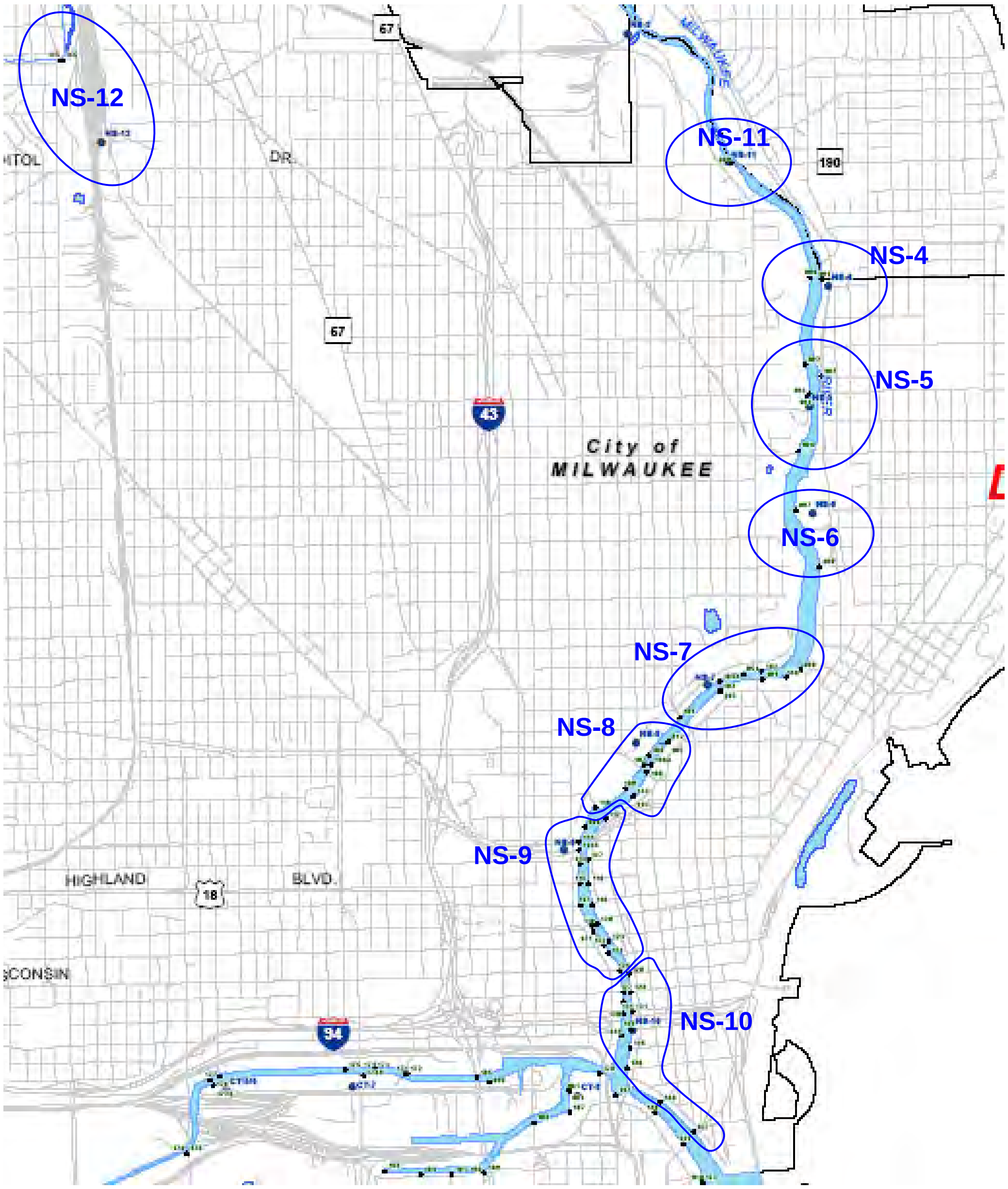


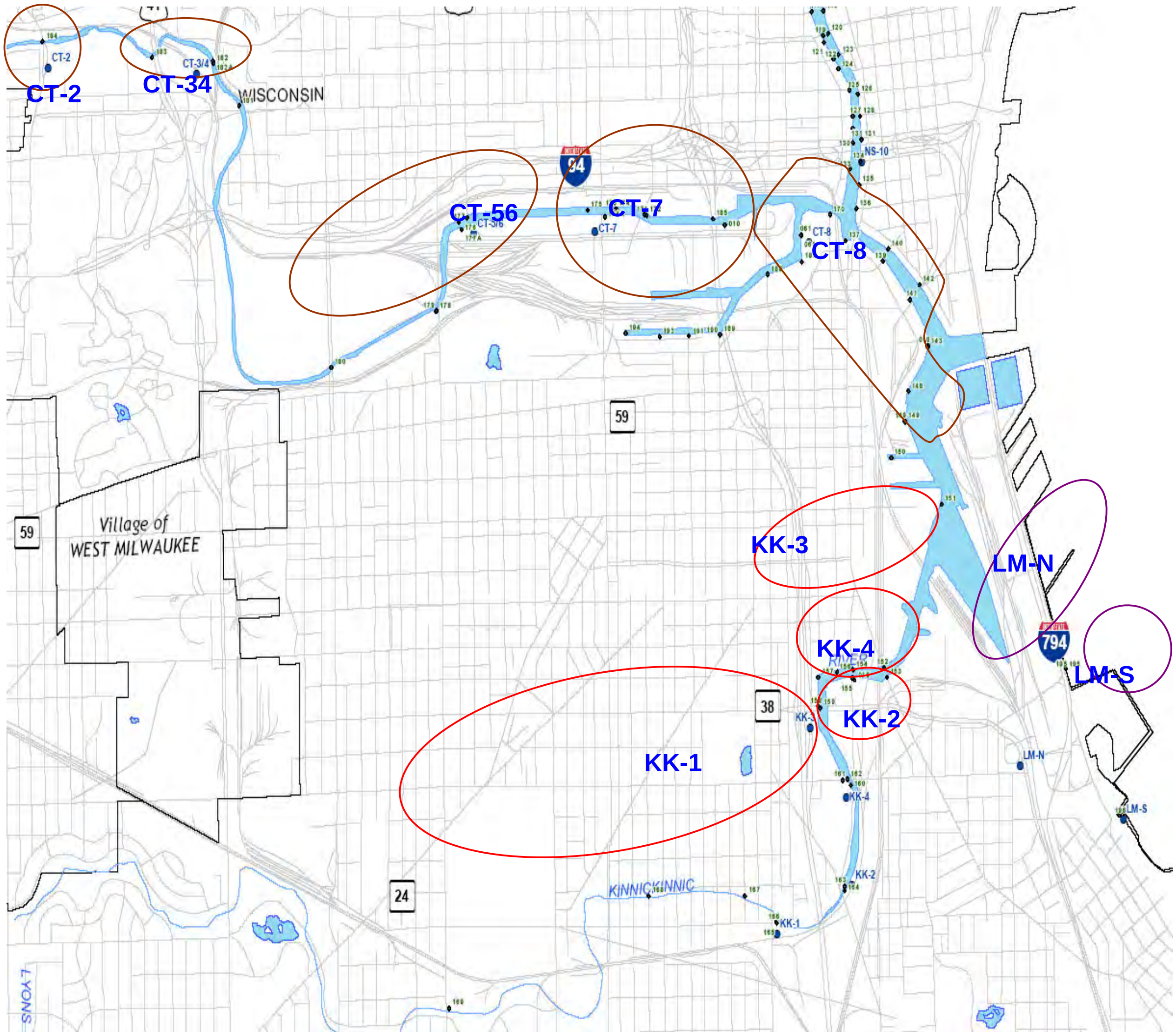
Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Temperature (°C)
0
10
20
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001



Milwaukee River (USGS: #04087000)
Menomonee River (USGS: #04087120)
Kinnickinnic River (USGS: #04087159)
Oak Creek (USGS: #04087204)
Temperature (°C)
0
10
20
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002

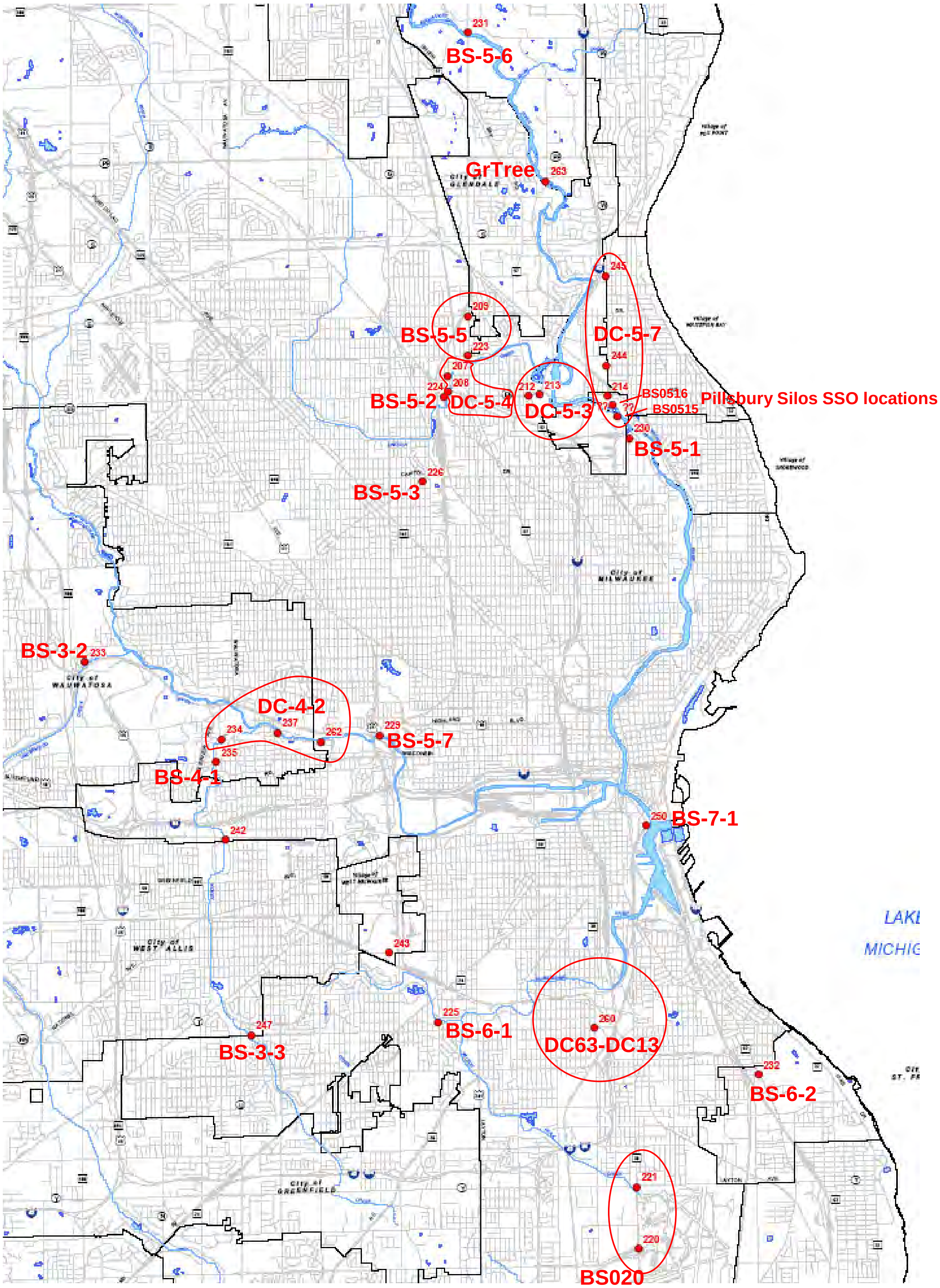
ATTACHMENT 6
CSO LOCATION MAPS (BROWN & CALDWELL)


NS-12
NS-11
NS-4
NS-5
NS-6
NS-7
NS-8
NS-9
NS-10
City of
MILWAUKEE
HIGHLAND
BLVD.
DR.
SCONSIN
67
190
43
18
94

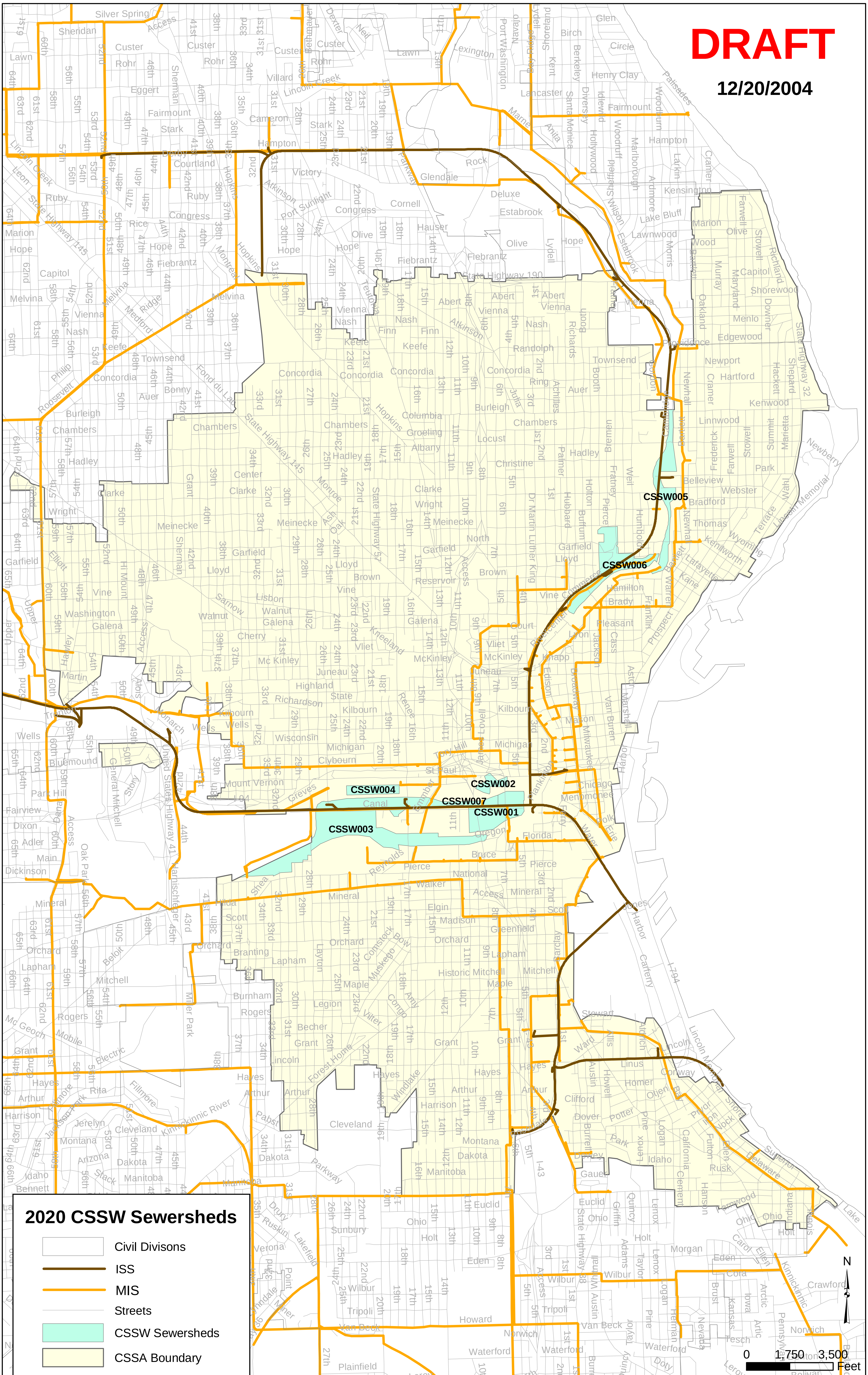

CT-2
CT-34
WISCONSIN
CT-56
CT-7
CT-8
NS-10
94
59
Village of
WEST MILWAUKEE
KK-3
LM-N
794
KK-4
LM-S
38
KK-2
KK-1
24
KINNICKINNIC
LYONS

ATTACHMENT 7
SSO/CSSW LOCATION MAPS (BROWN & CALDWELL)

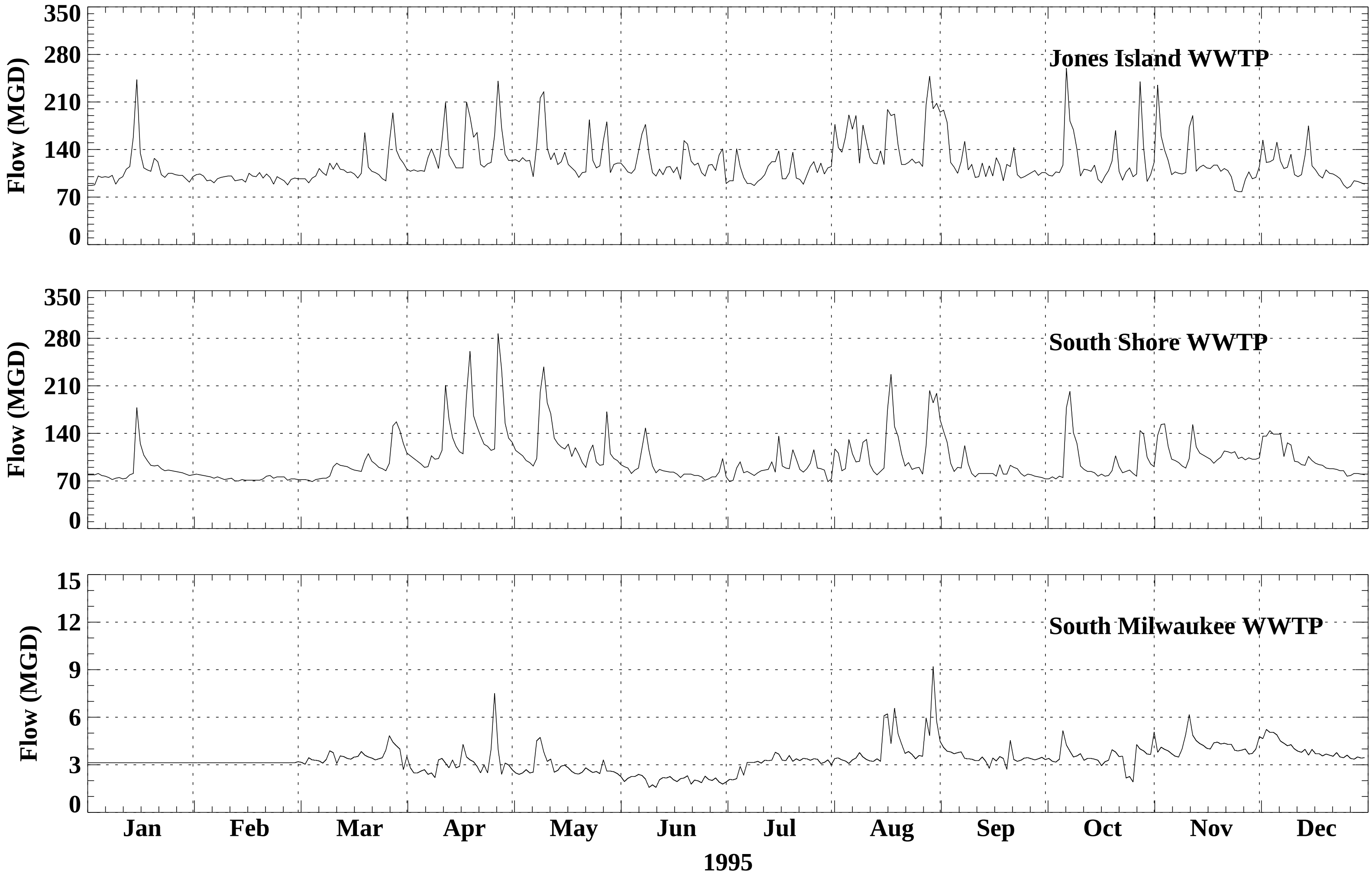
DRAFT

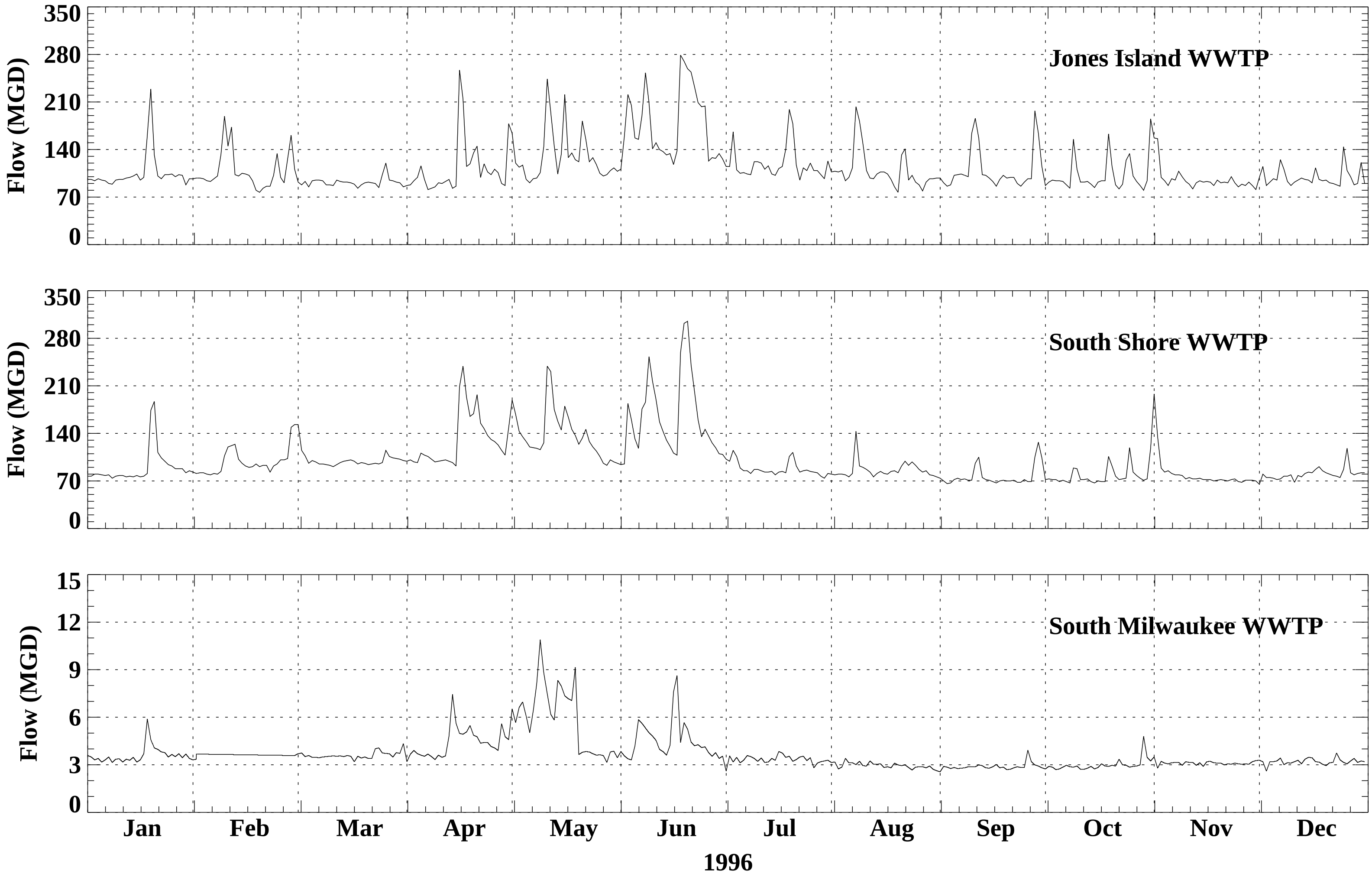


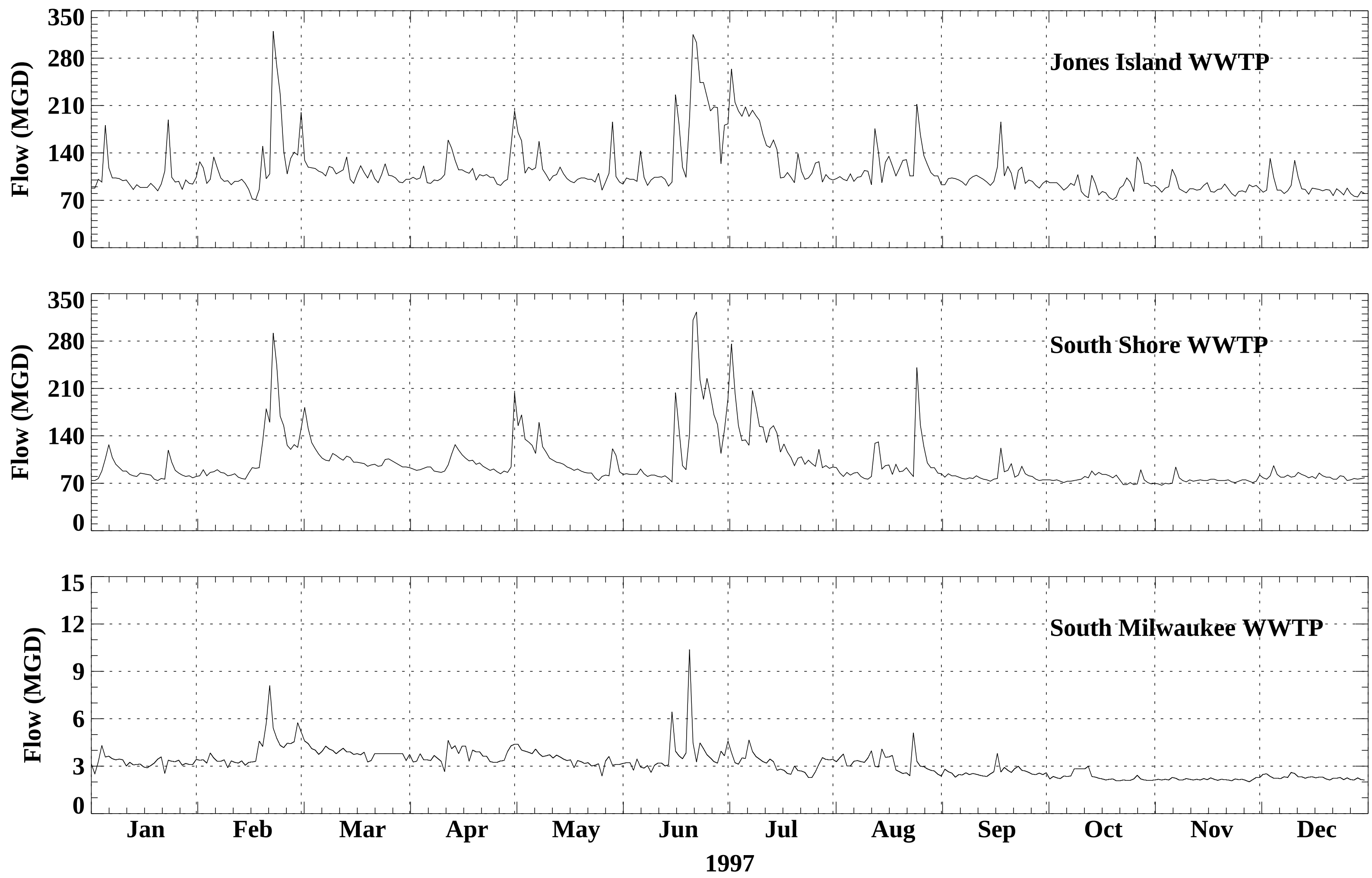
BS-5-6
231
GrTree
263
DC-5-7
245
244
214
BS-5-5
209
223
207
208
224
BS-5-2
DC-5-4
212
213
DC-5-3
BS0516
BS0515
Pillsbury Silos SSO locations
230
BS-5-1
226
BS-5-3
City of MILWAUKEE
BS-3-2
233
City of WAUWATOSA
DC-4-2
234
237
262
235
BS-4-1
229
BS-5-7
250
BS-7-1
242
243
City of WEST ALLIS
LAKE
MICHIG
225
BS-6-1
260
DC63-DC13
247
BS-3-3
232
BS-6-2
City of GREENFIELD
221
220
BS020

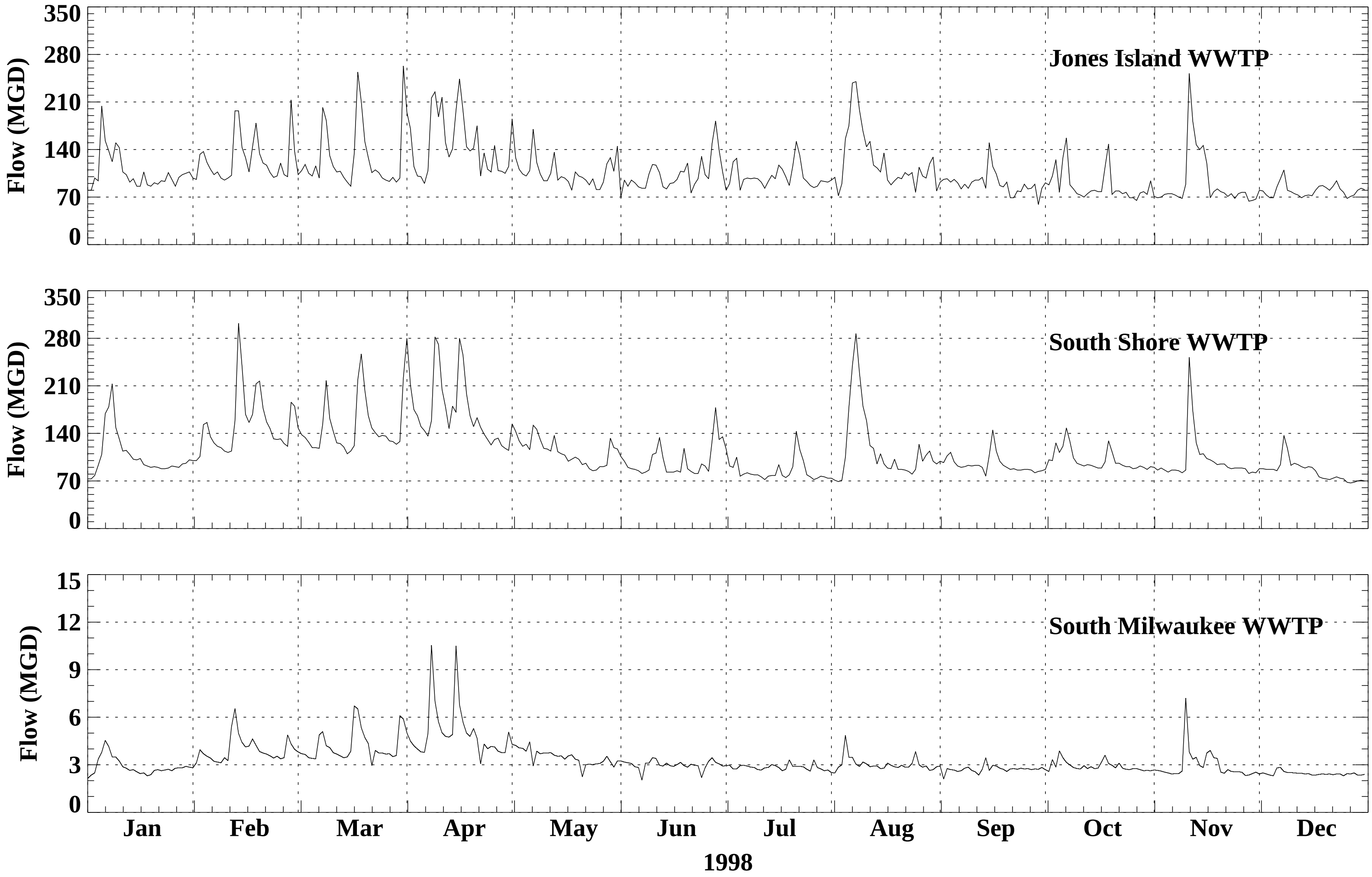

DRAFT
12/20/2004
2020 CSSW Sewersheds
Civil Divisons
ISS
MIS
Streets
CSSW Sewersheds
CSSA Boundary
CSSW001
CSSW002
CSSW003
CSSW004
CSSW005
CSSW006
CSSW007
N
0
1,750
3,500
Feet

ATTACHMENT 8
WWTP DISCHARGES

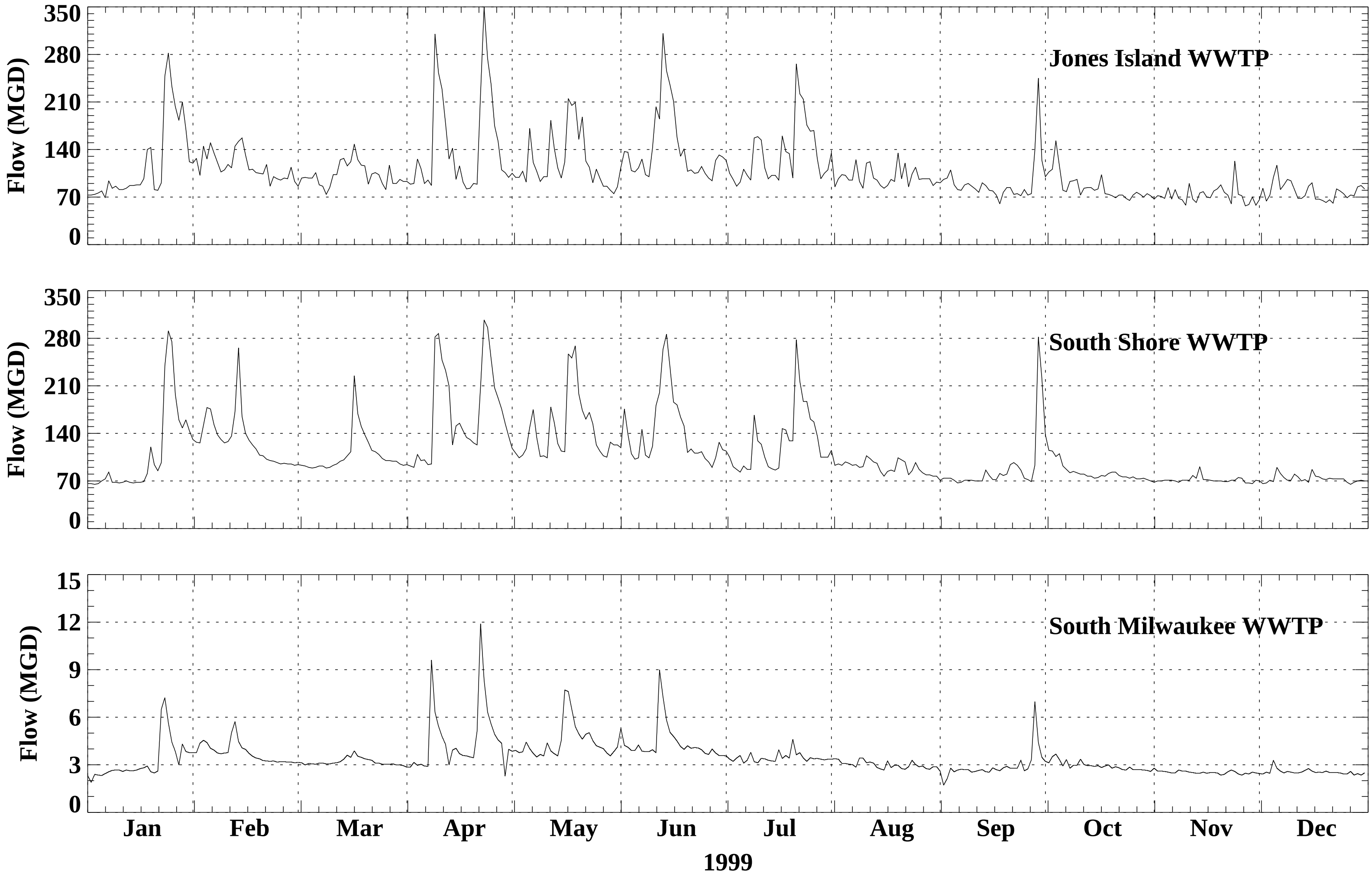

Jones Island WWTP
South Shore WWTP
South Milwaukee WWTP
Flow (MGD)
350
280
210
140
70
0
15
12
9
6
3
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995

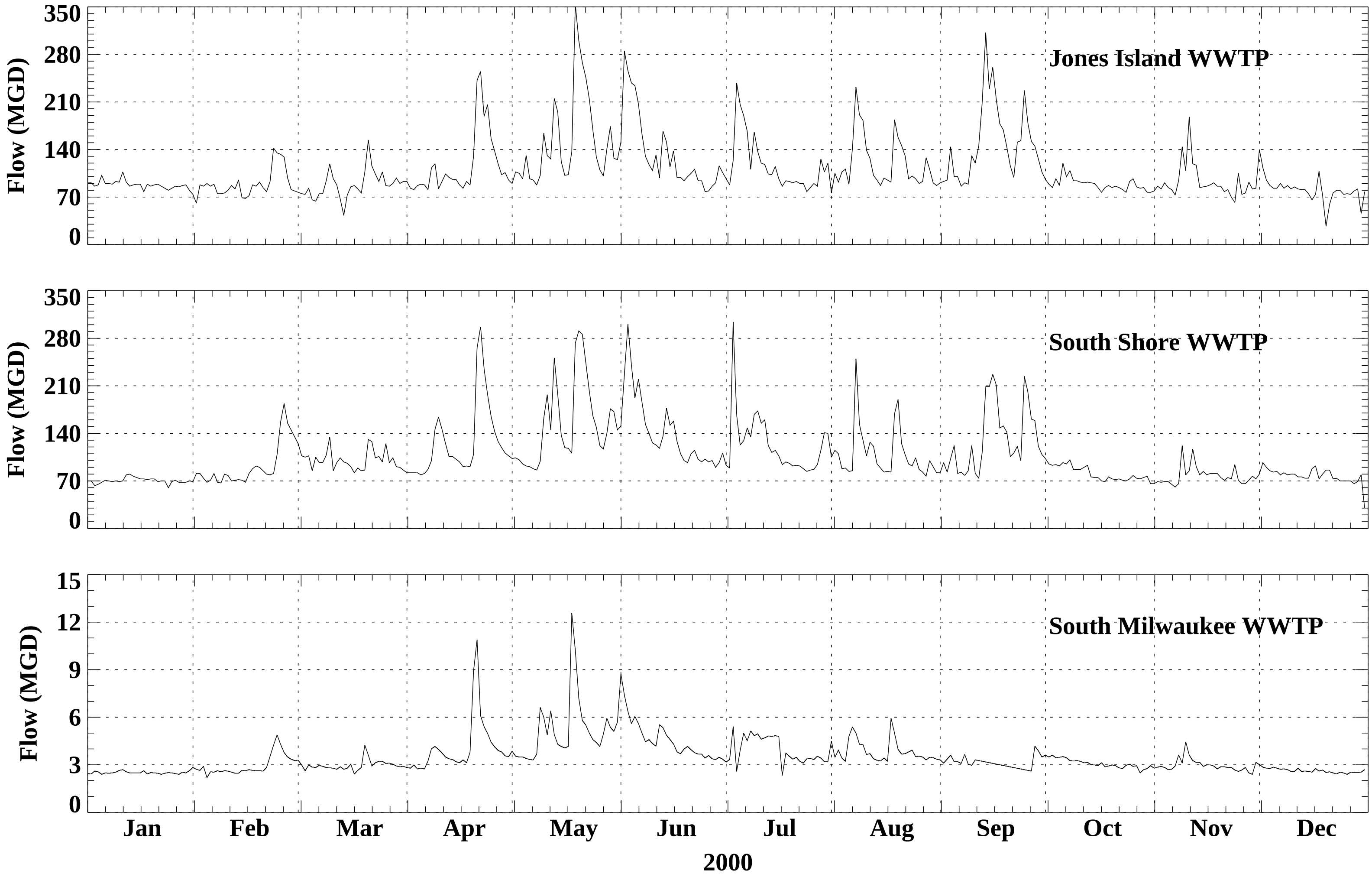

Jones Island WWTP
South Shore WWTP
South Milwaukee WWTP
Flow (MGD)
350
280
210
140
70
0
15
12
9
6
3
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996

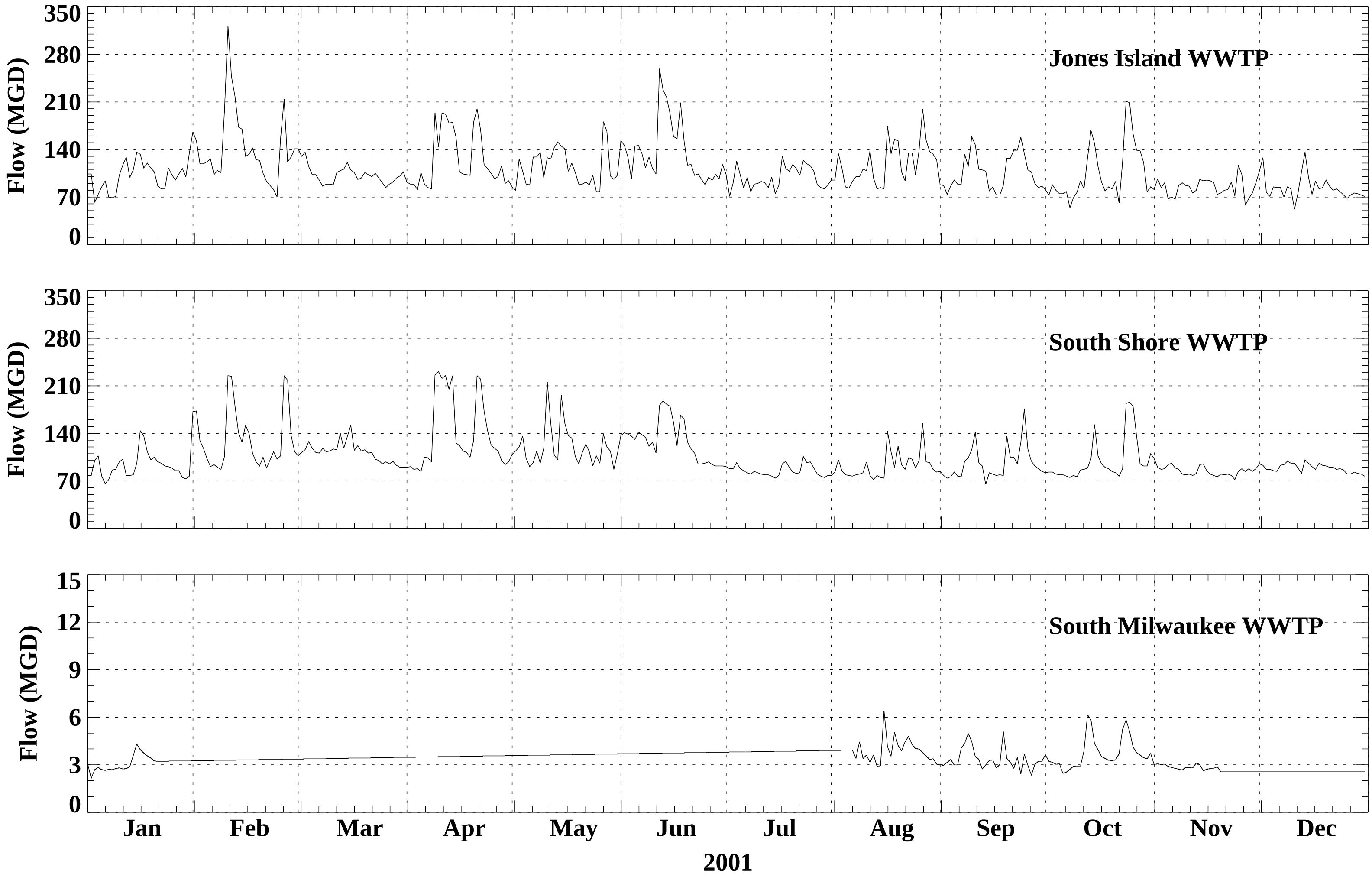

Jones Island WWTP
South Shore WWTP
South Milwaukee WWTP
Flow (MGD)
350
280
210
140
70
0
15
12
9
6
3
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997

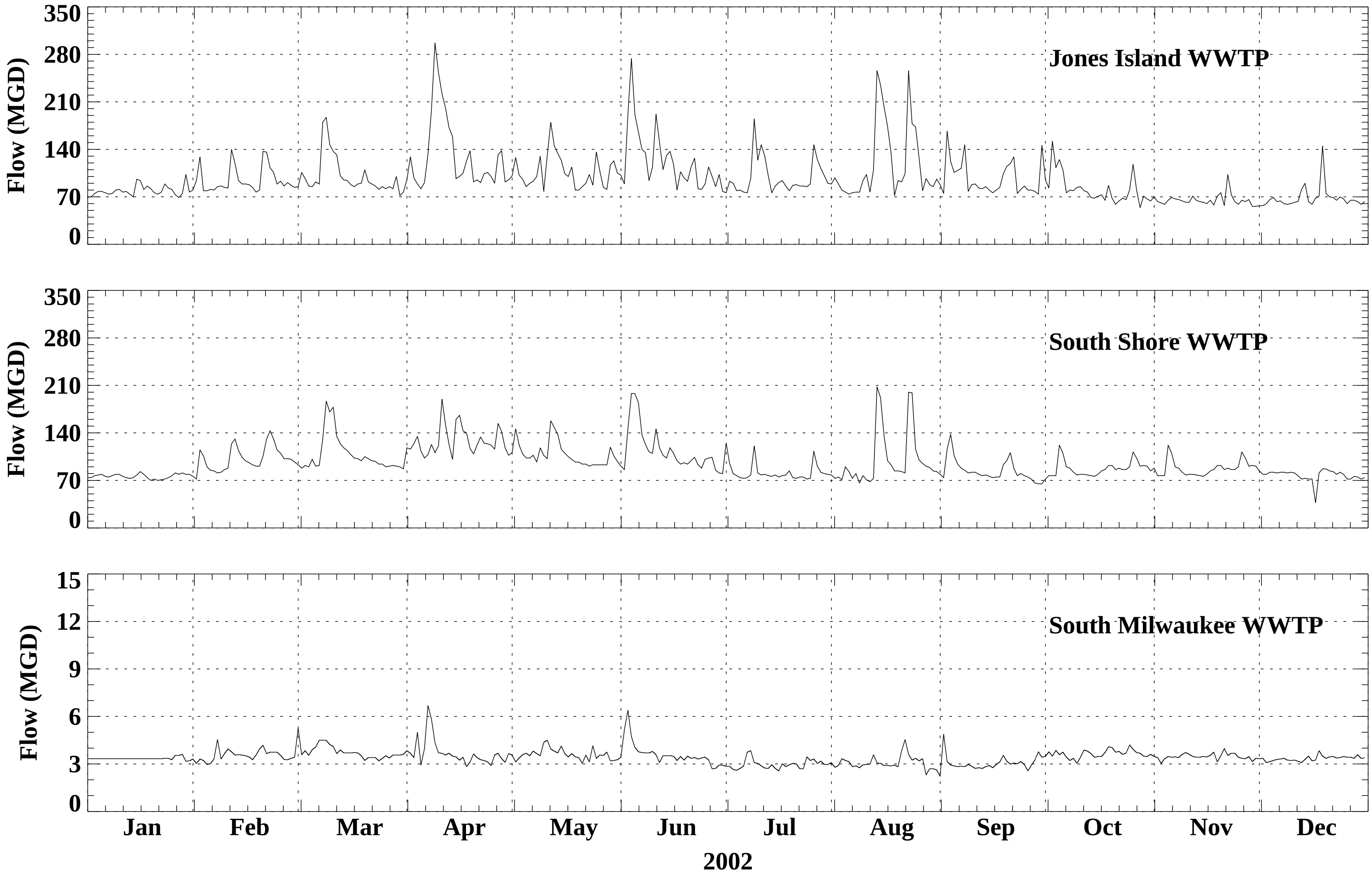


Jones Island WWTP
South Shore WWTP
South Milwaukee WWTP
Flow (MGD)
350
280
210
140
70
0
15
12
9
6
3
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998

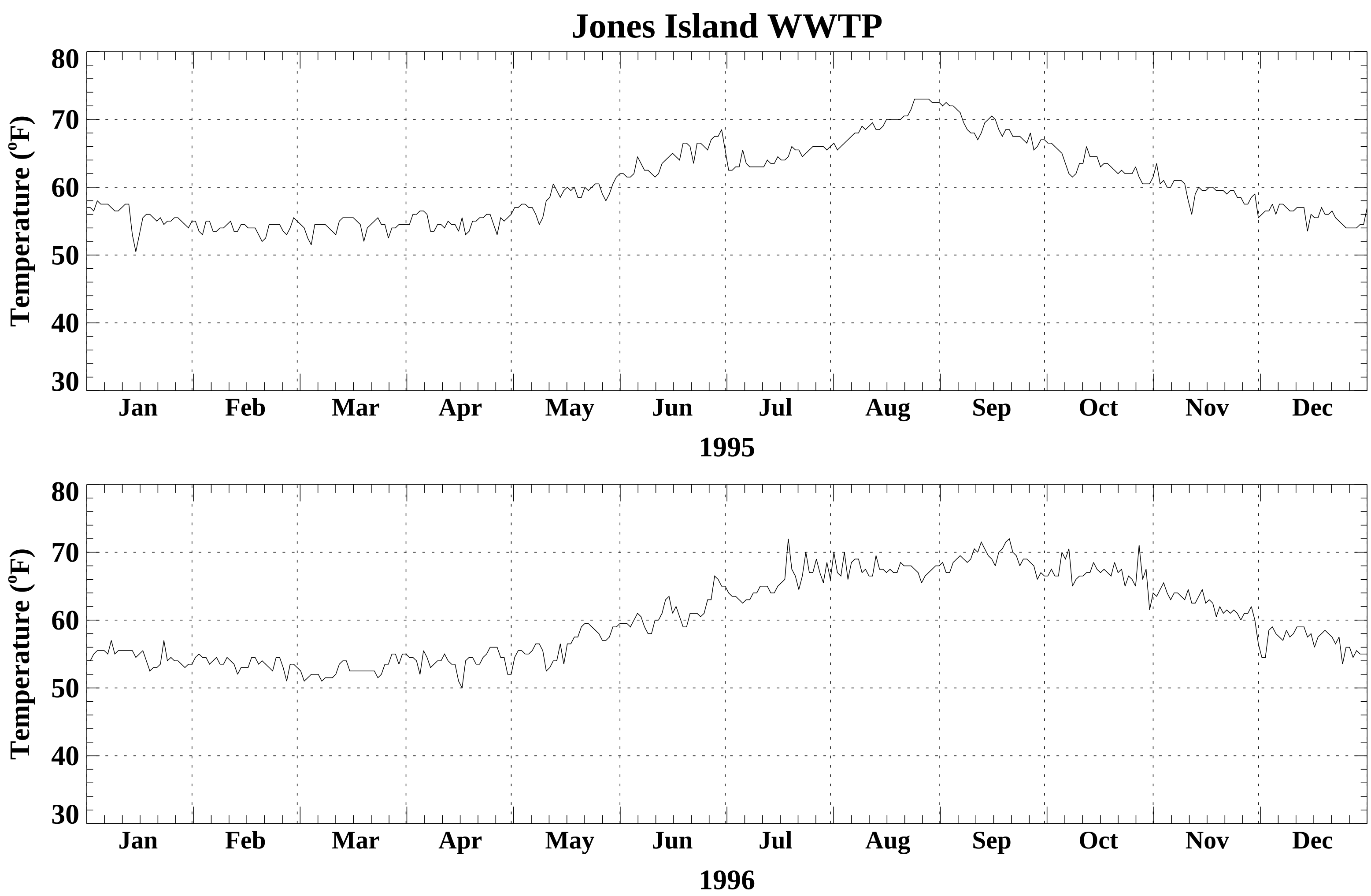

Jones Island WWTP
South Shore WWTP
South Milwaukee WWTP
Flow (MGD)
Flow (MGD)
Flow (MGD)
350
280
210
140
70
0
15
12
9
6
3
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999


Jones Island WWTP
South Shore WWTP
South Milwaukee WWTP
Flow (MGD)
350
280
210
140
70
0
15
12
9
6
3
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000

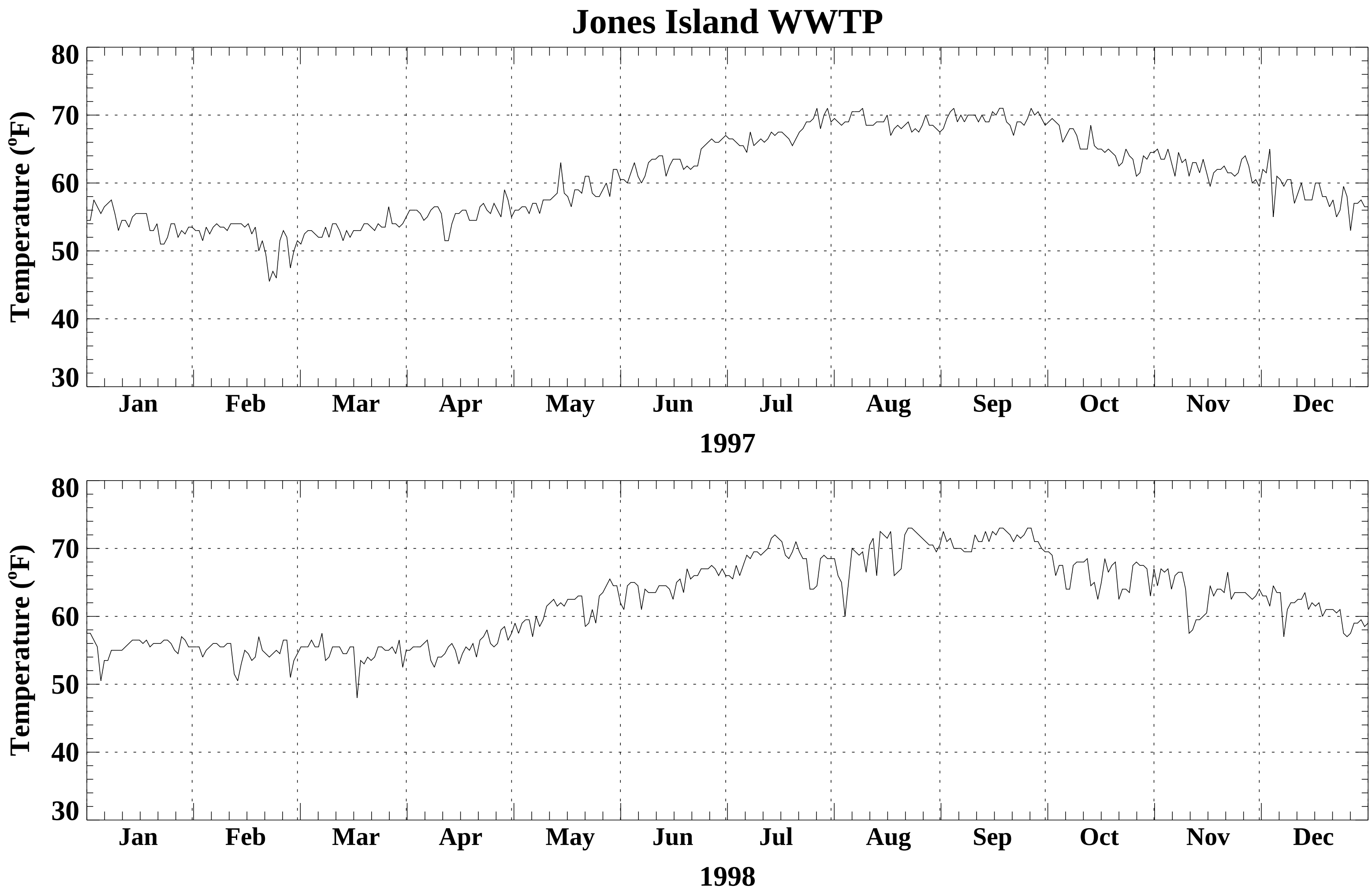

Jones Island WWTP
South Shore WWTP
South Milwaukee WWTP
Flow (MGD)
350
280
210
140
70
0
15
12
9
6
3
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001


Jones Island WWTP
South Shore WWTP
South Milwaukee WWTP
Flow (MGD)
Flow (MGD)
Flow (MGD)
350
280
210
140
70
0
350
280
210
140
70
0
15
12
9
6
3
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002

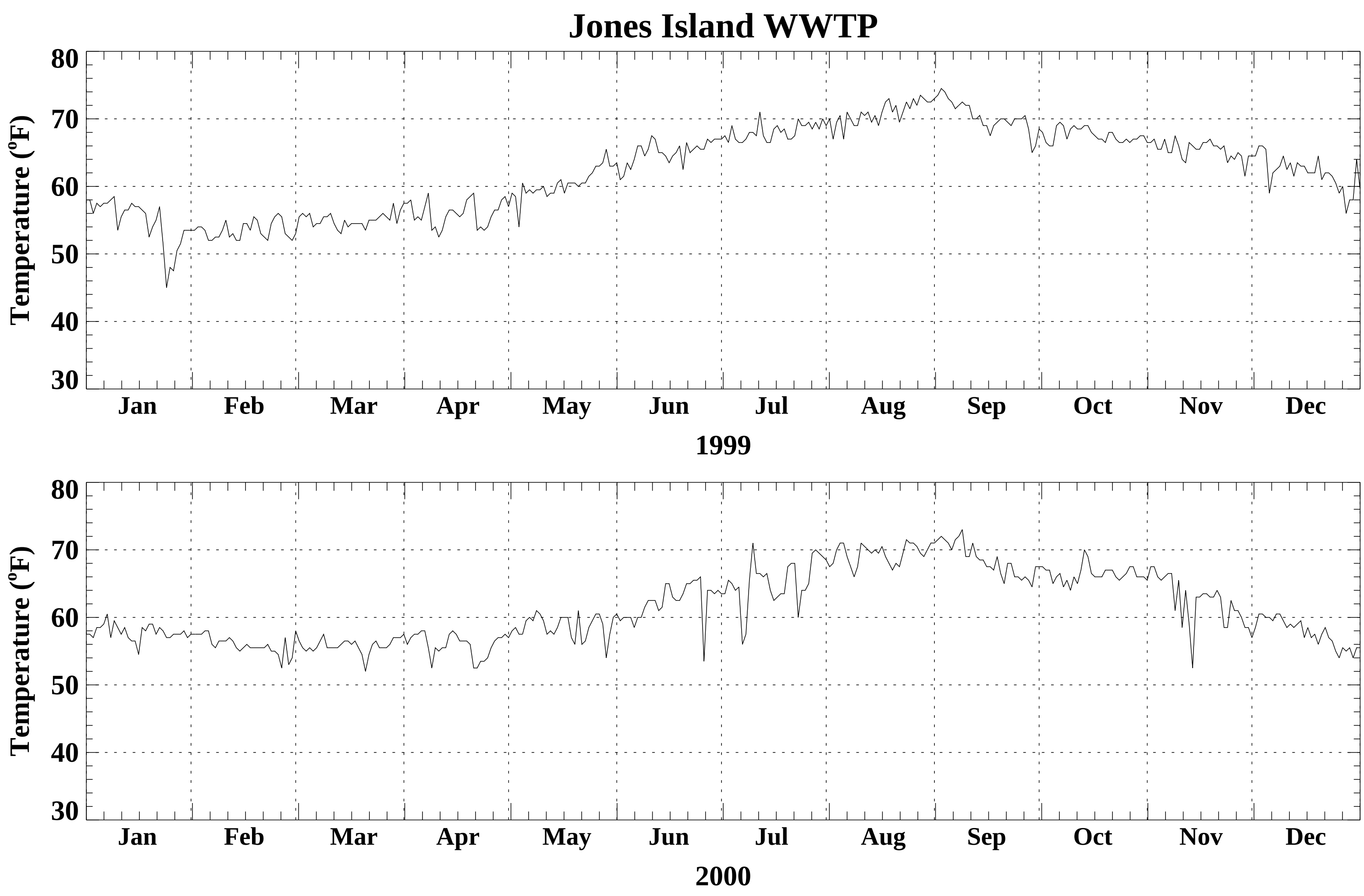
ATTACHMENT 9
JONES ISLAND WWTP TEMPERATURE



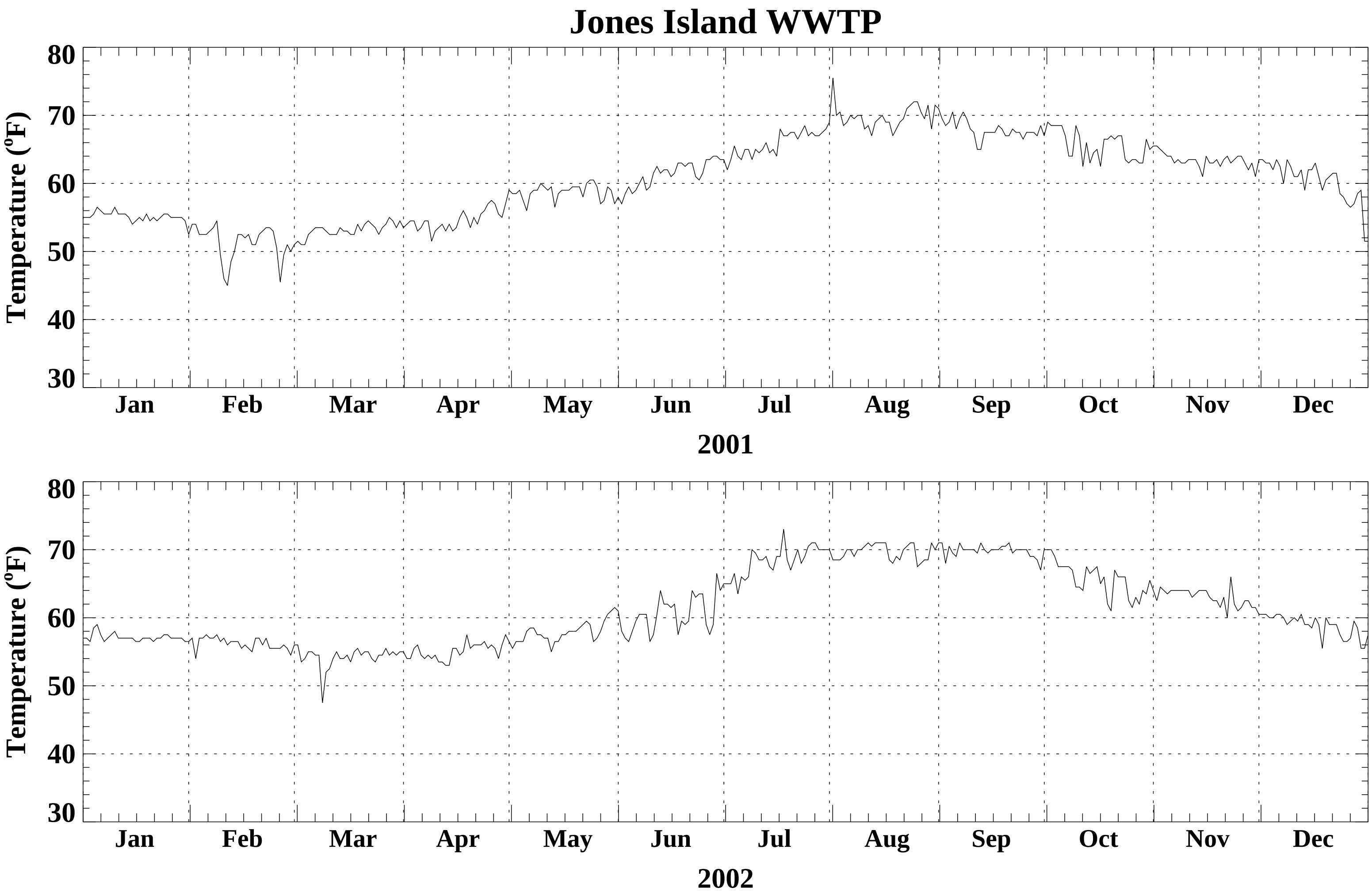
Jones Island WWTP
Temperature (°F)
80
70
60
50
40
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995
Temperature (°F)
80
70
60
50
40
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996



Jones Island WWTP
Temperature (°F)
80
70
60
50
40
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997
Temperature (°F)
80
70
60
50
40
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998

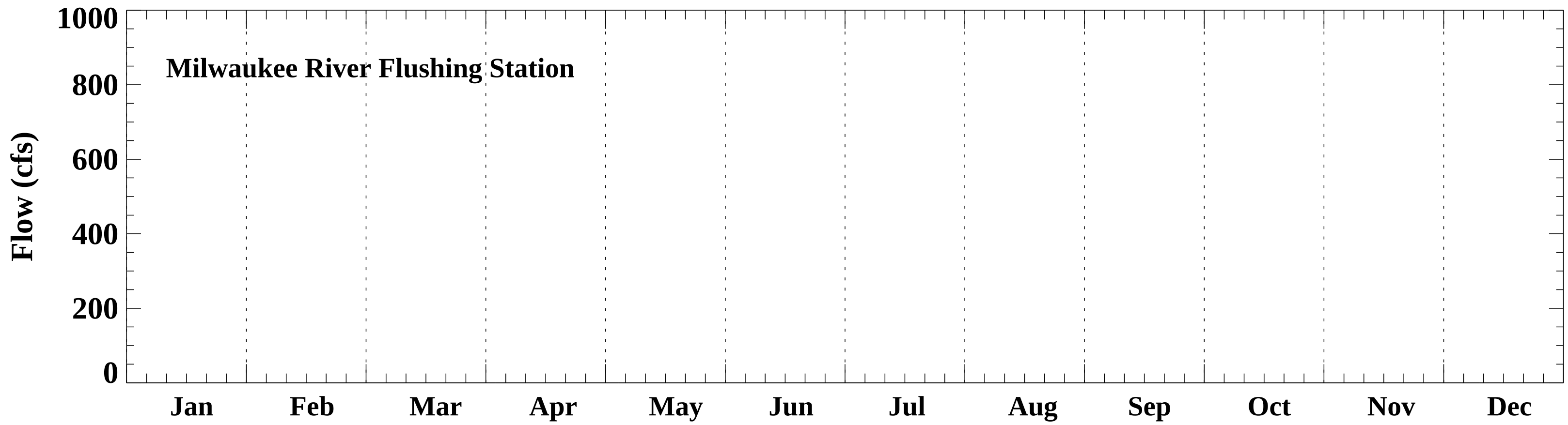


Jones Island WWTP
Temperature (°F)
80
70
60
50
40
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999
Temperature (°F)
80
70
60
50
40
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000

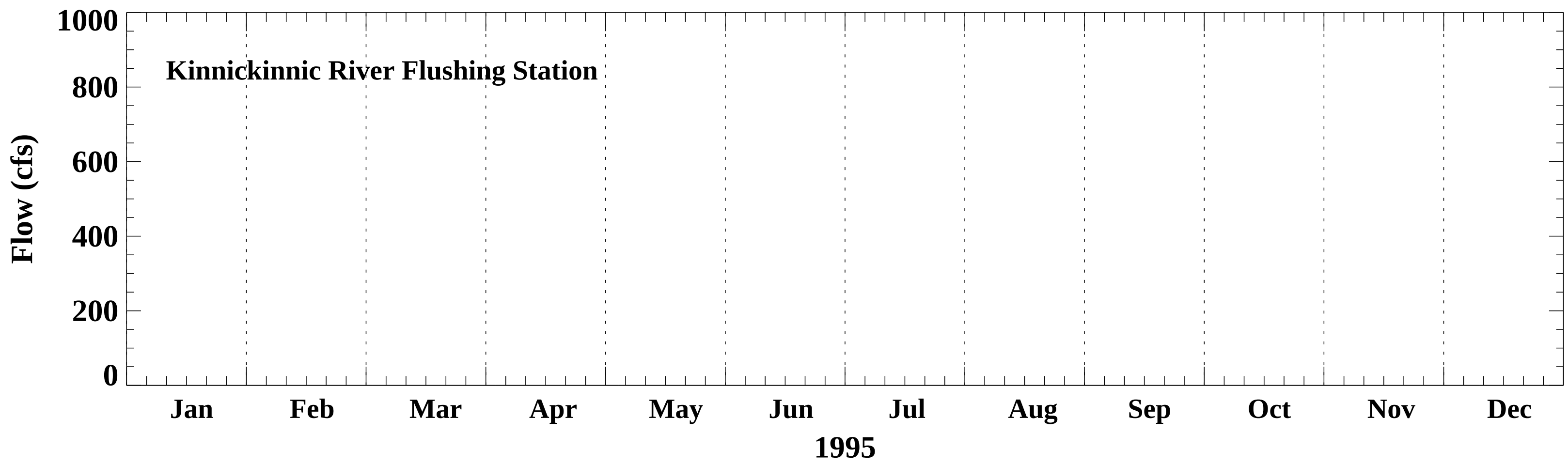


Jones Island WWTP
Temperature (ºF)
80
70
60
50
40
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001
Temperature (ºF)
80
70
60
50
40
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002

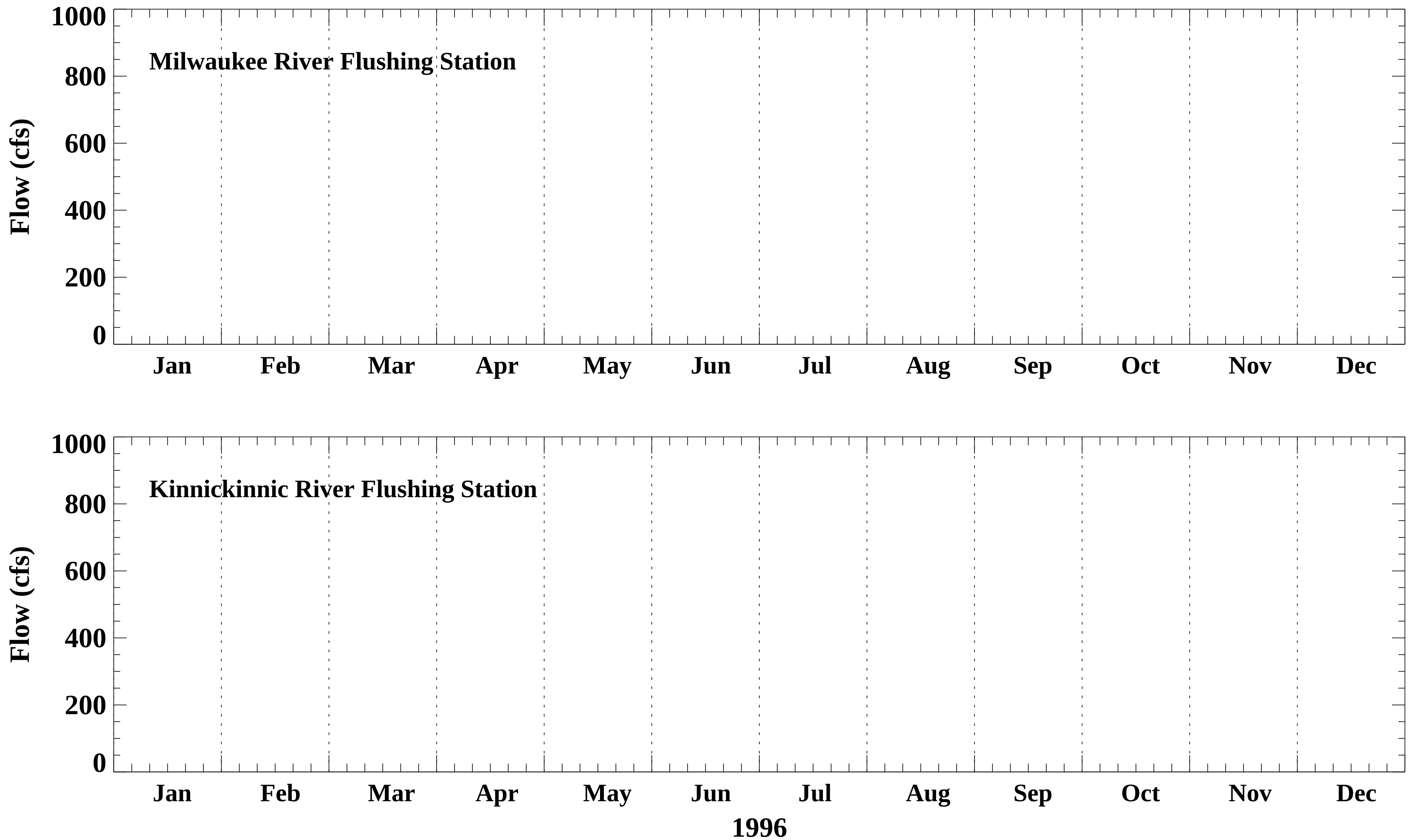
ATTACHMENT 10
FLUSHING TUNNEL DISCHARGES

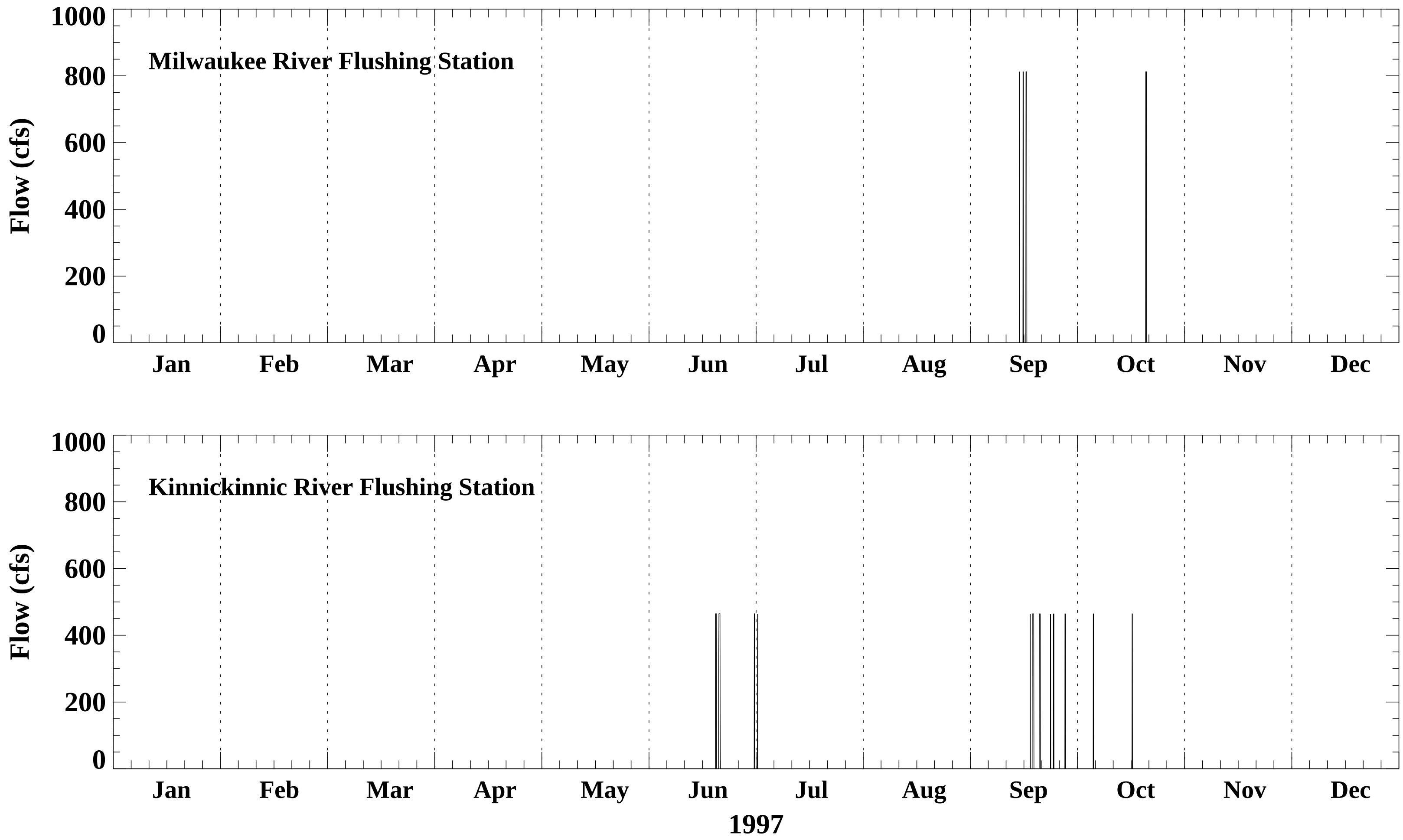


Milwaukee River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

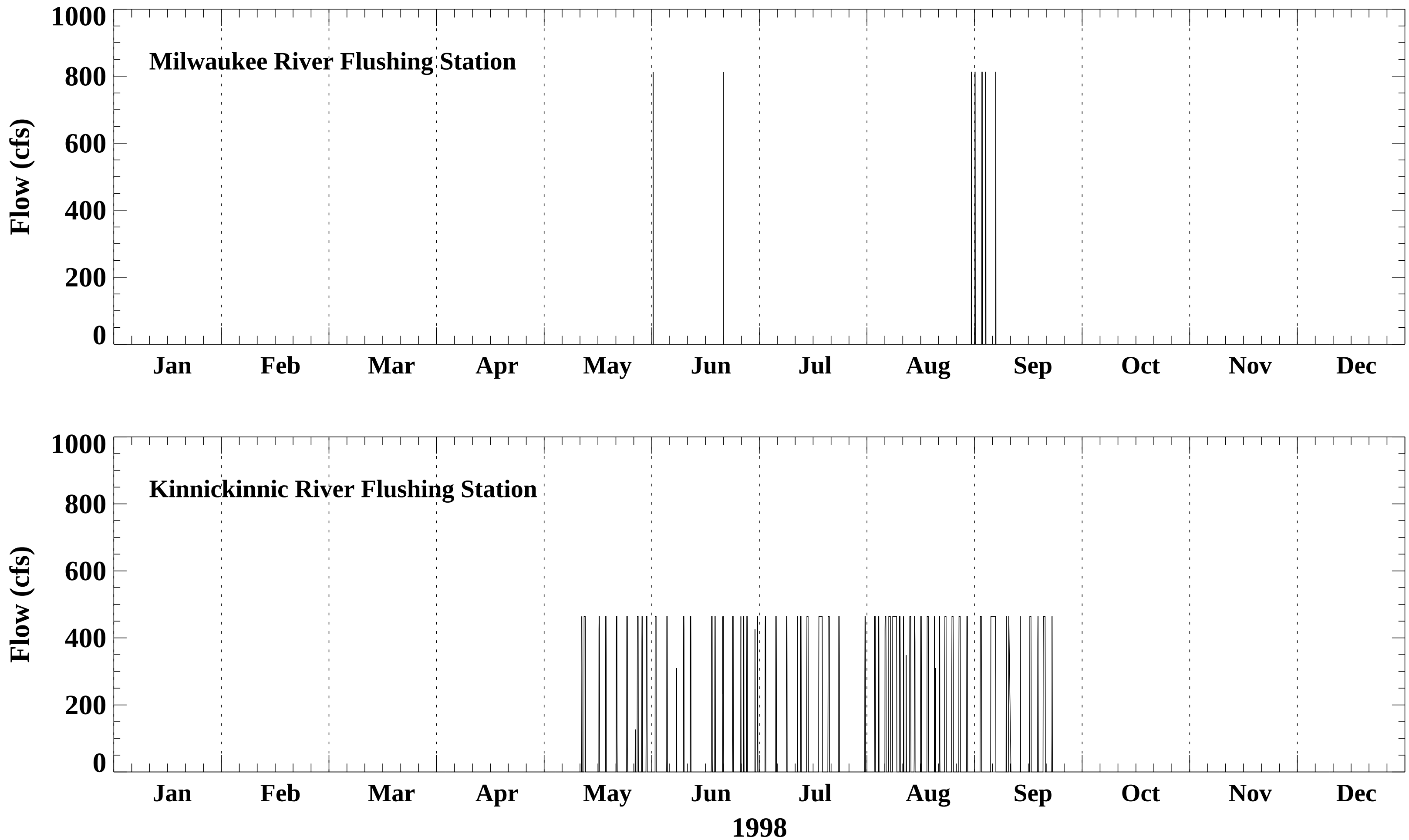


Kinnickinnic River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995

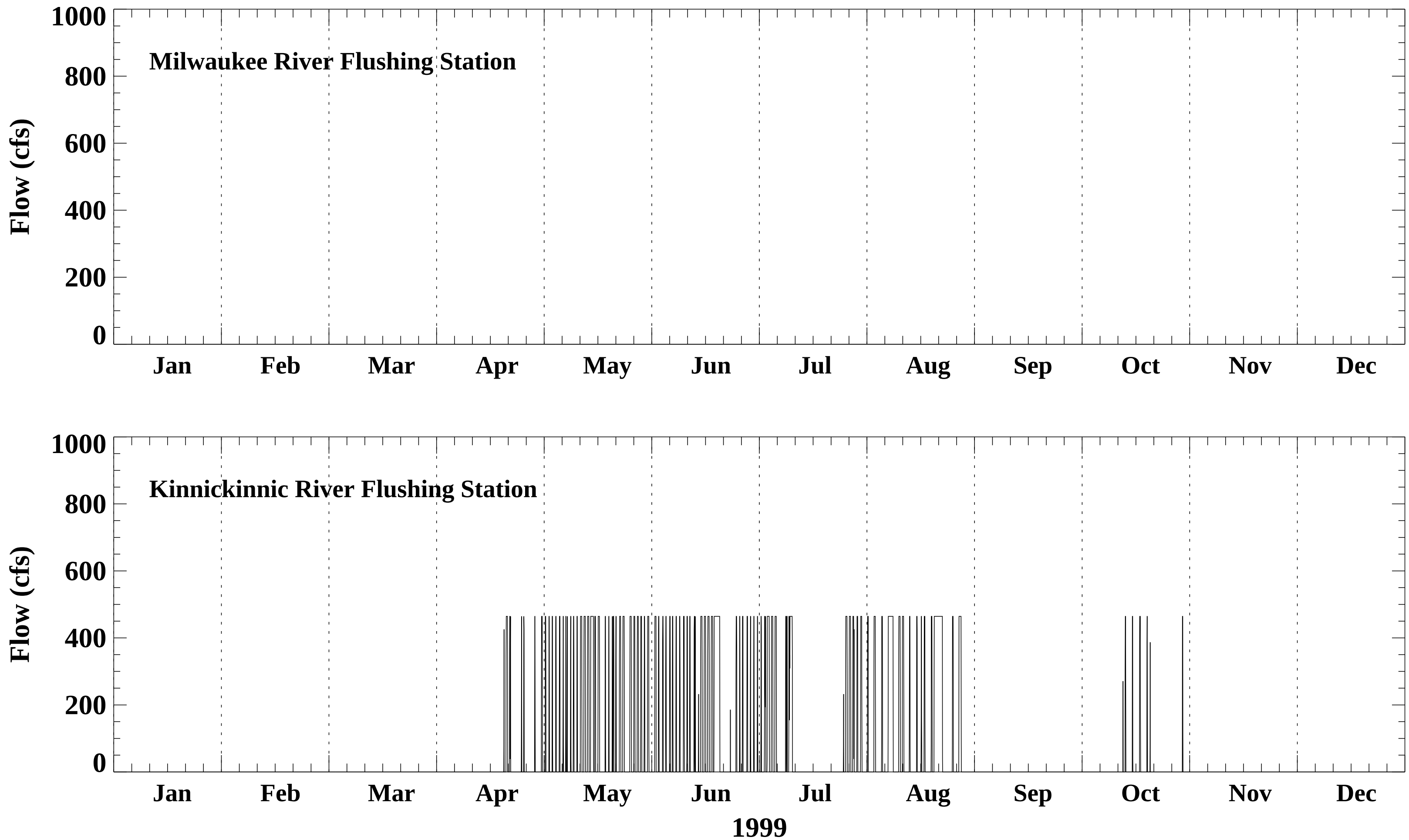

Milwaukee River Flushing Station
Kinnickinnic River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996

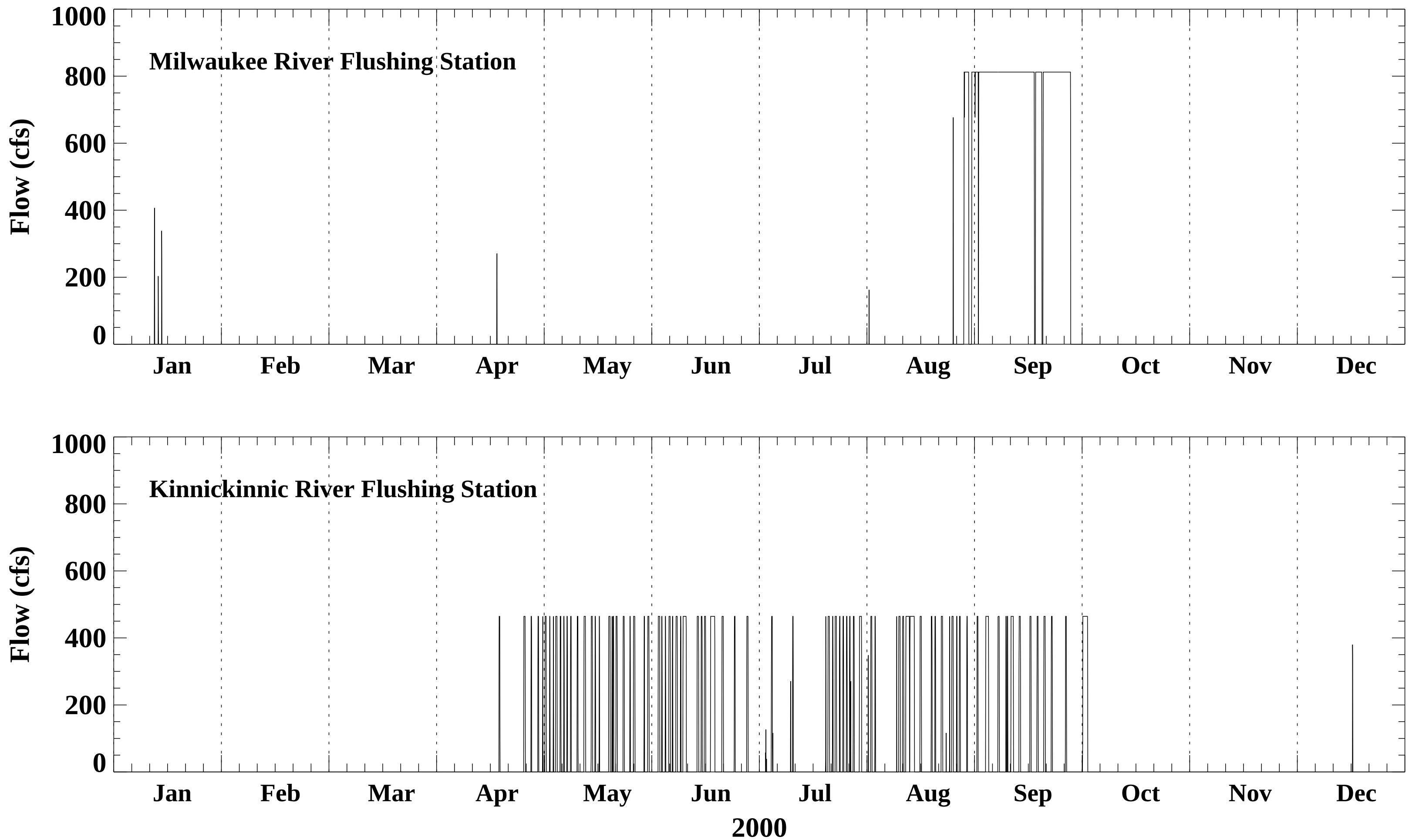


Milwaukee River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Kinnickinnic River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997

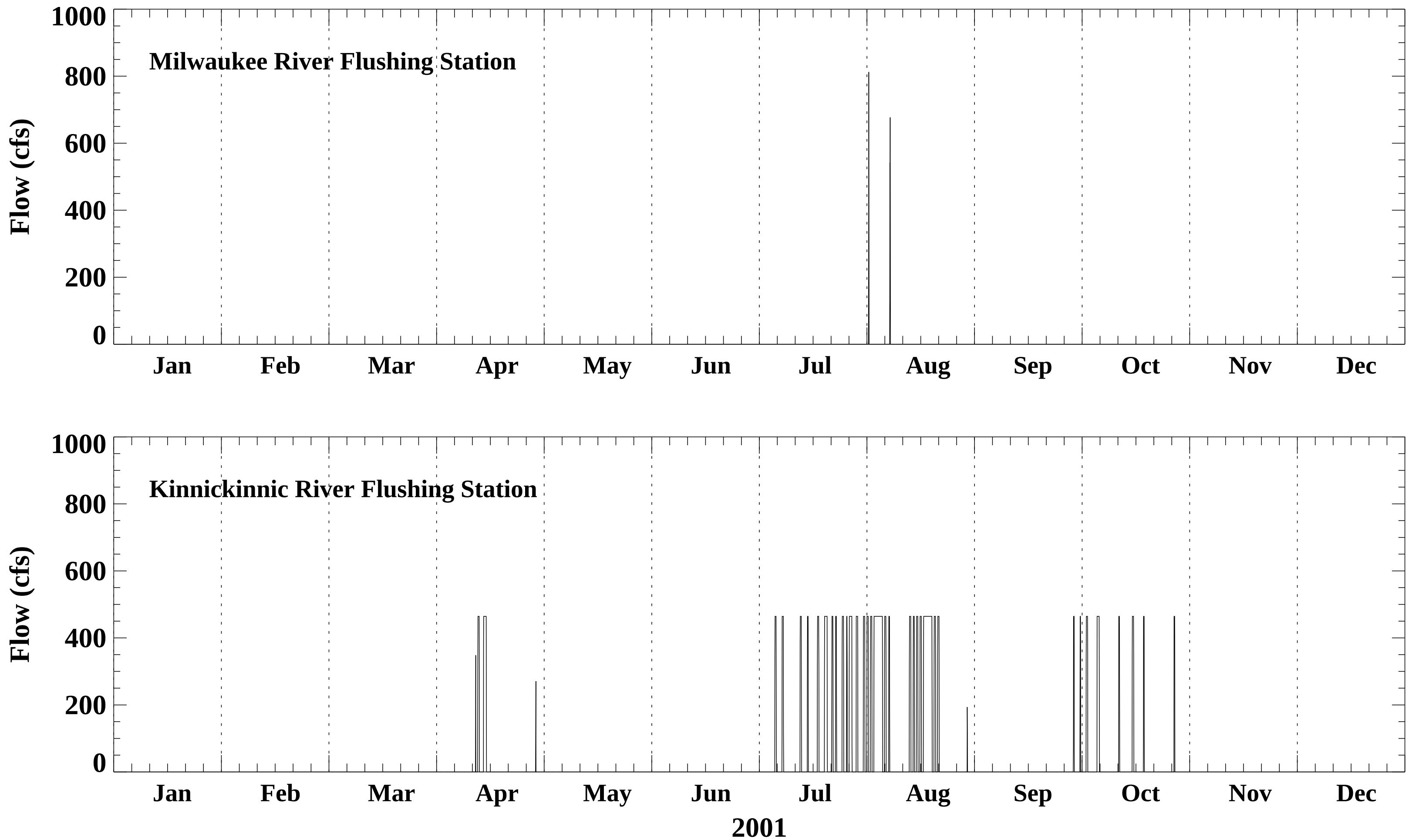


Milwaukee River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Kinnickinnic River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998

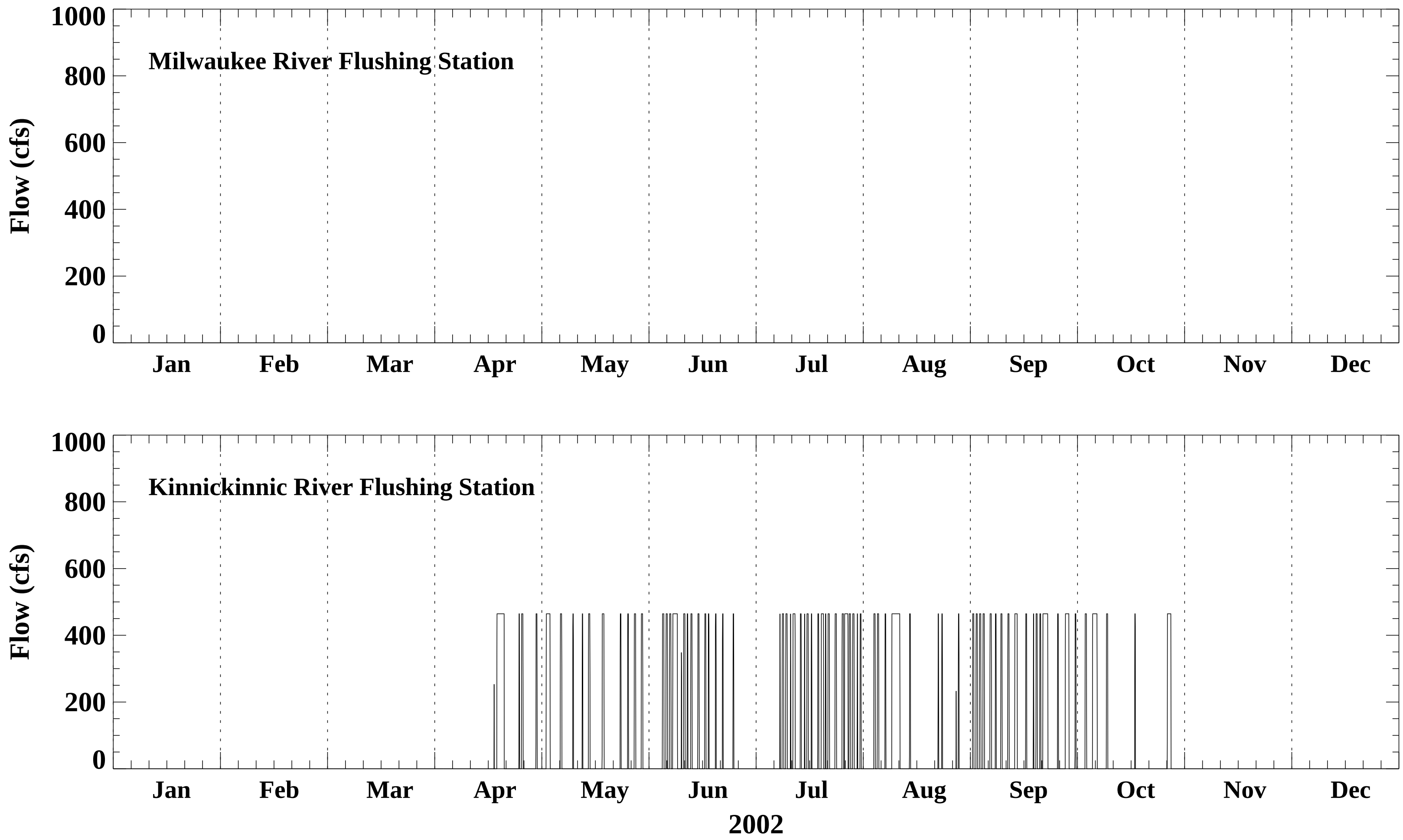

Milwaukee River Flushing Station
Kinnickinnic River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999



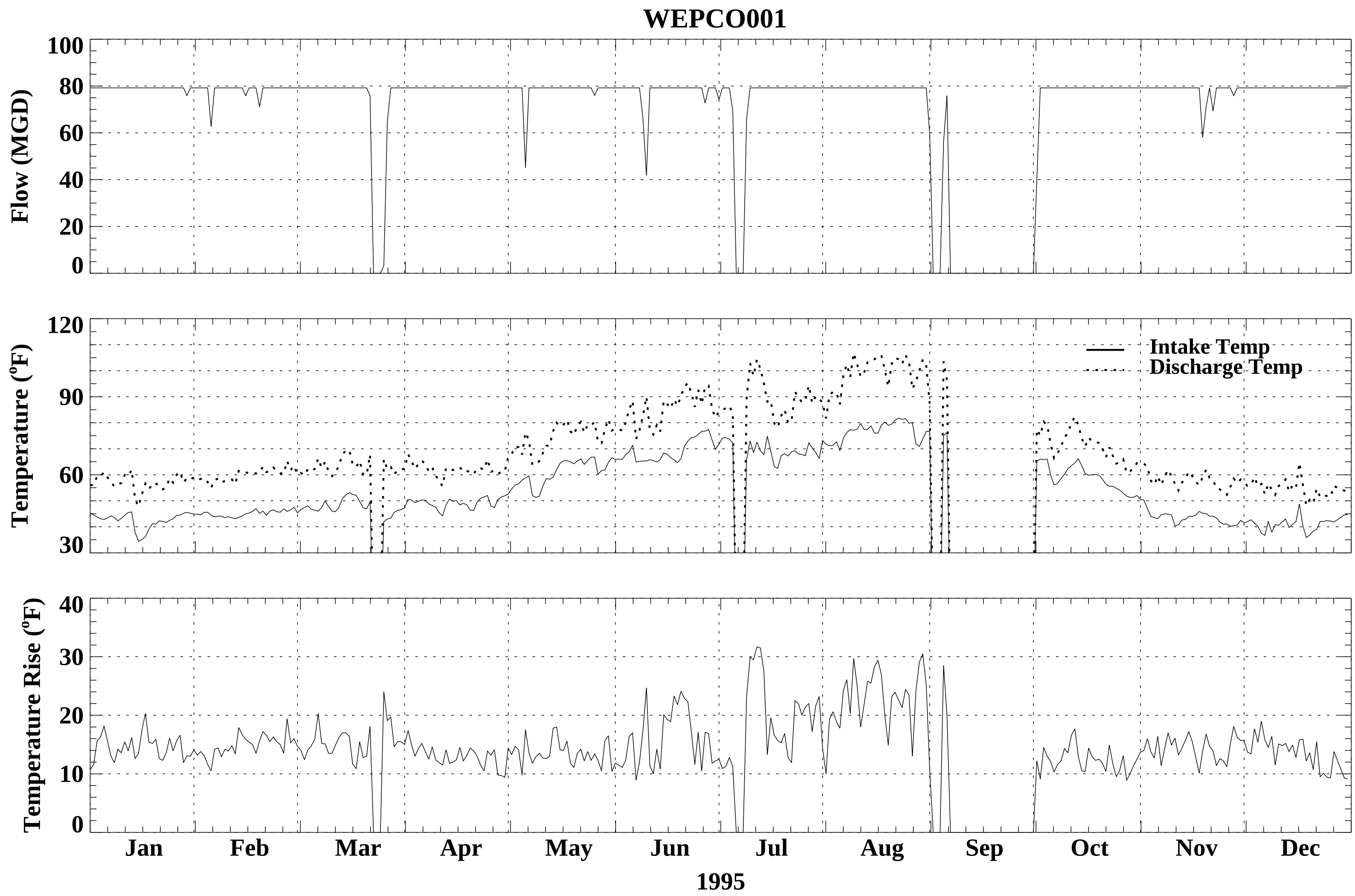
Milwaukee River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Kinnickinnic River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000



Milwaukee River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Kinnickinnic River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001

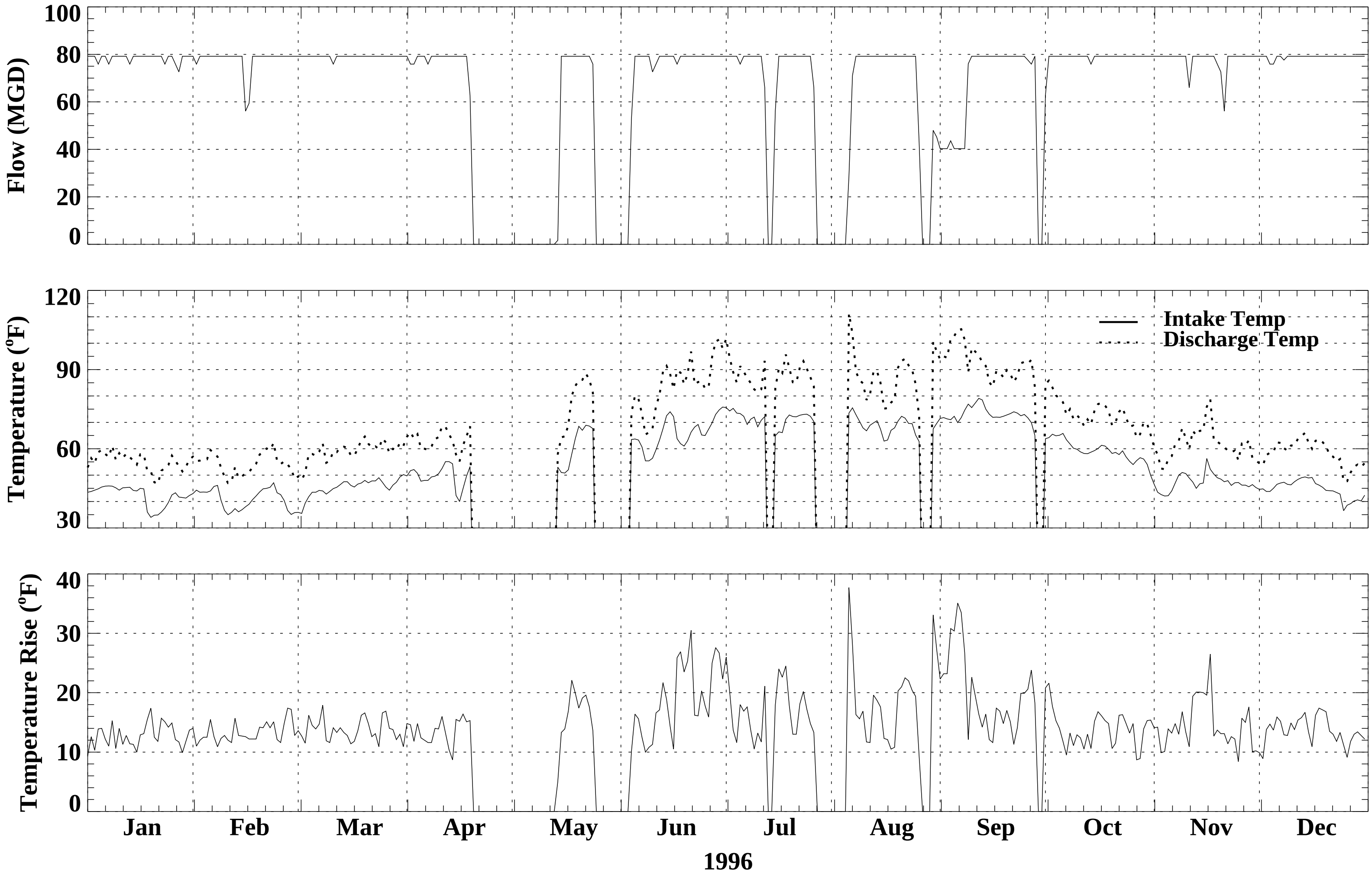

Milwaukee River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Kinnickinnic River Flushing Station
Flow (cfs)
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002

ATTACHMENT 11
DISCHARGE AND TEMPERATURE OF WE ENERGIES MENOMONEE VALLEY AND OAK CREEK POWER PLANTS

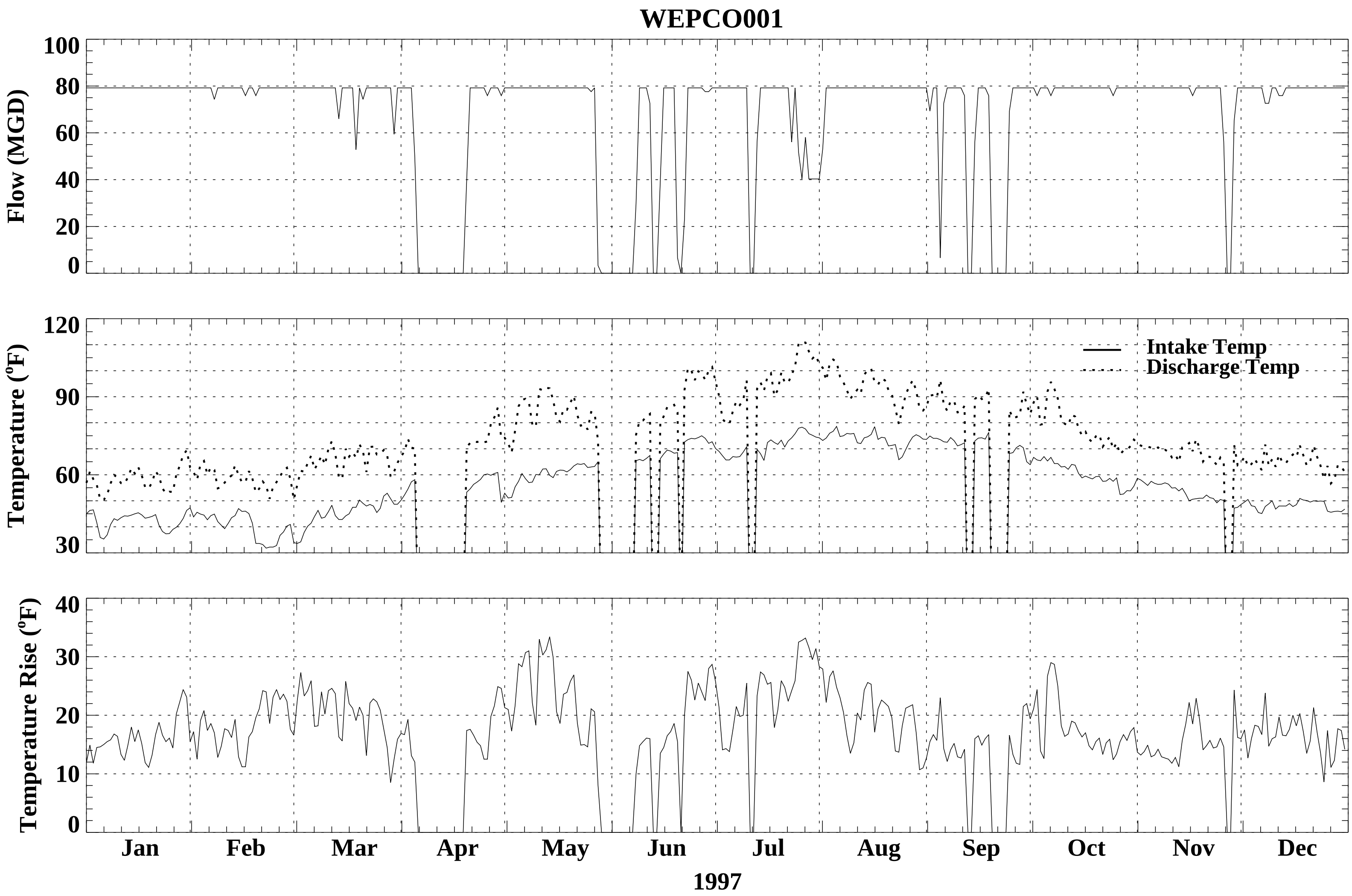


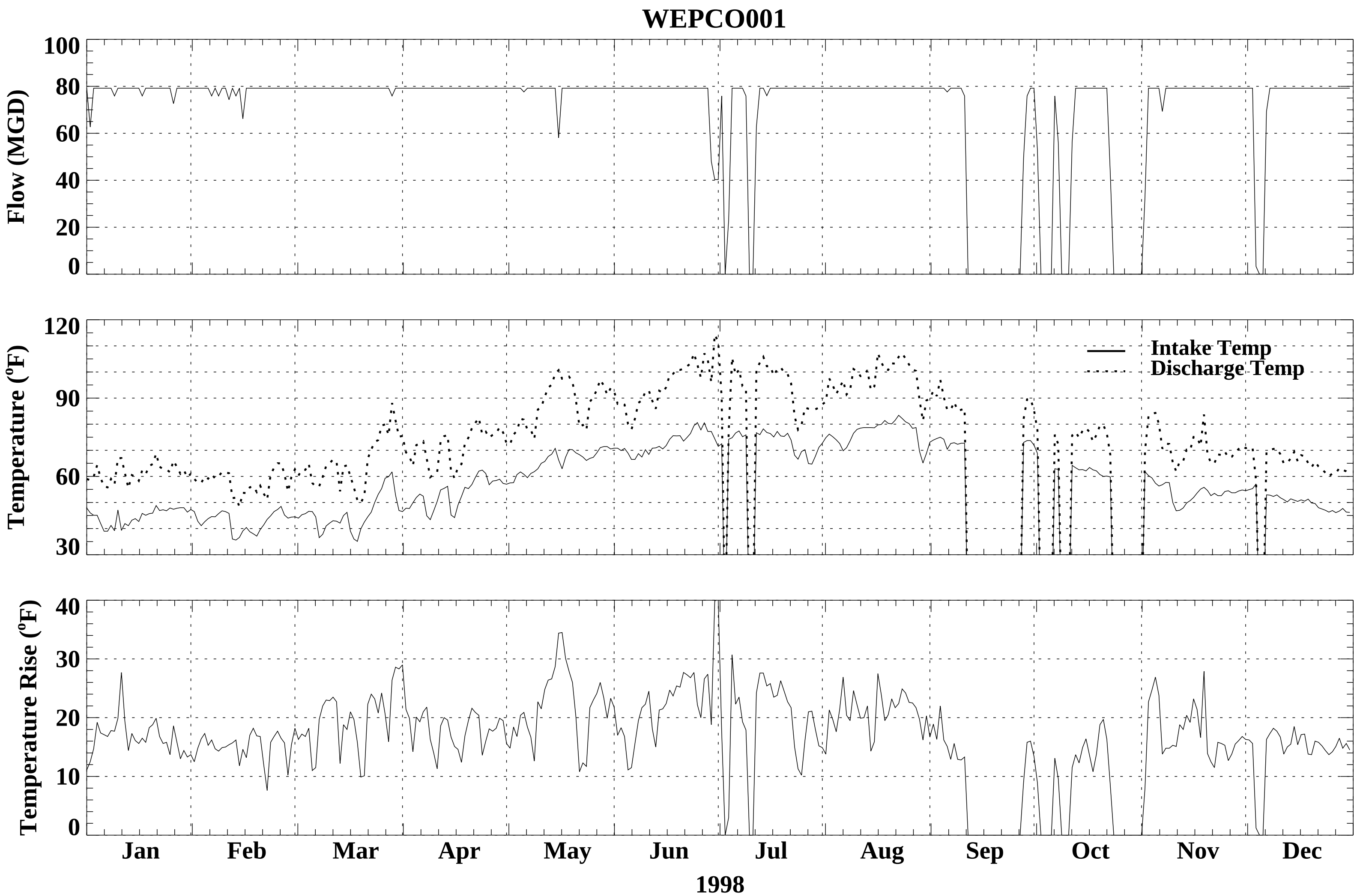
WEPCO001
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995

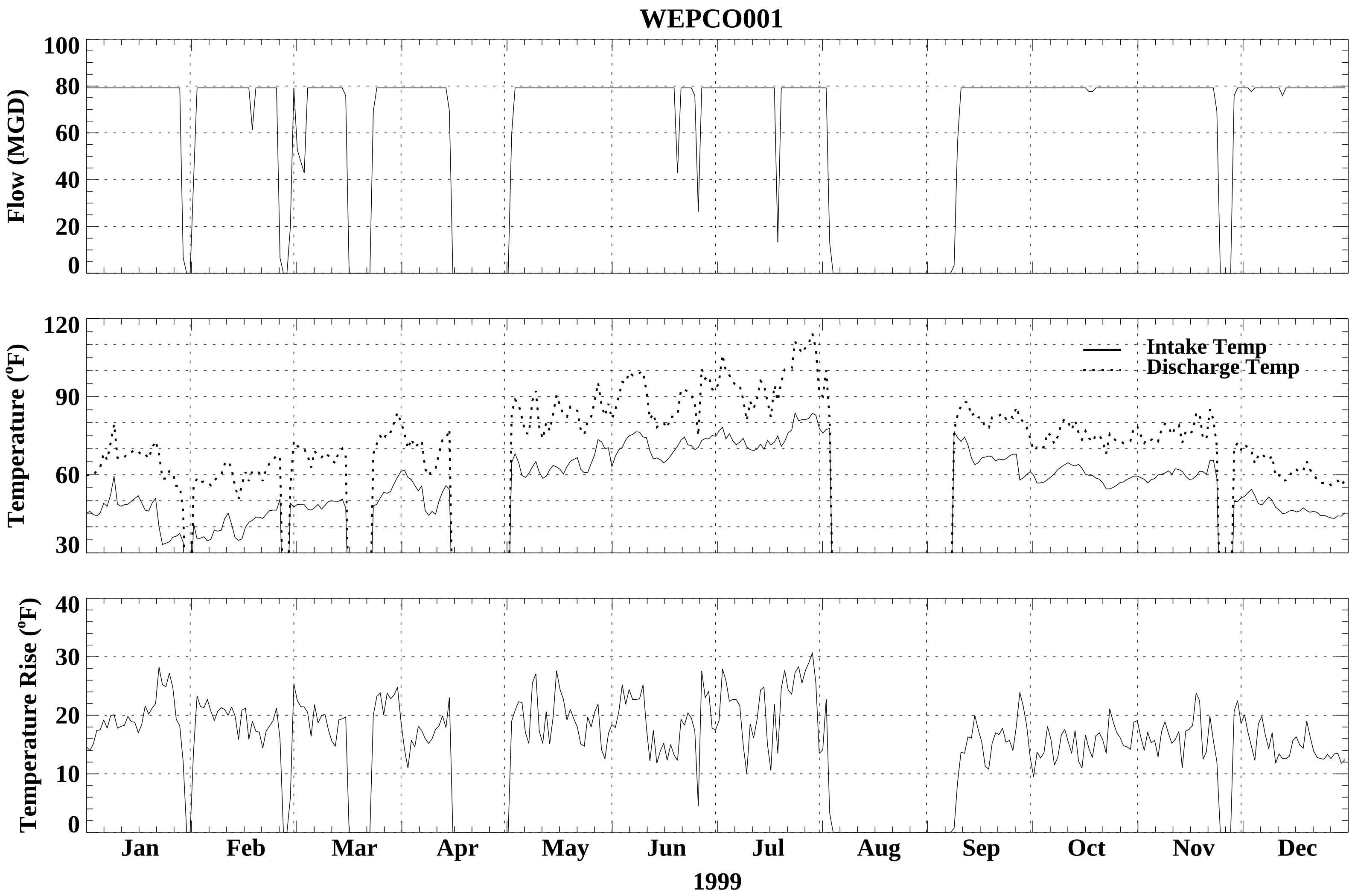
WEPCO001



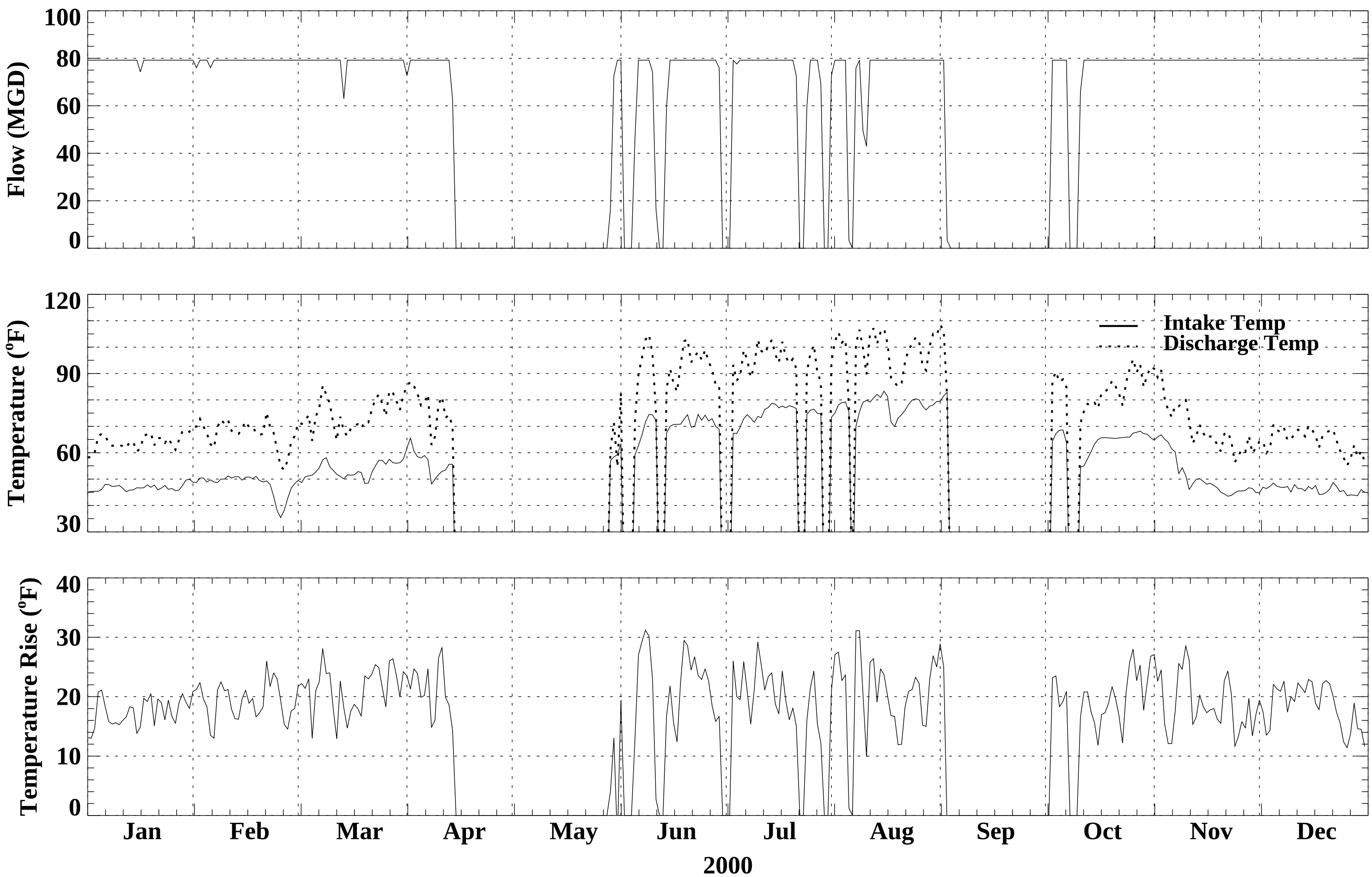
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996


WEPCO001
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997

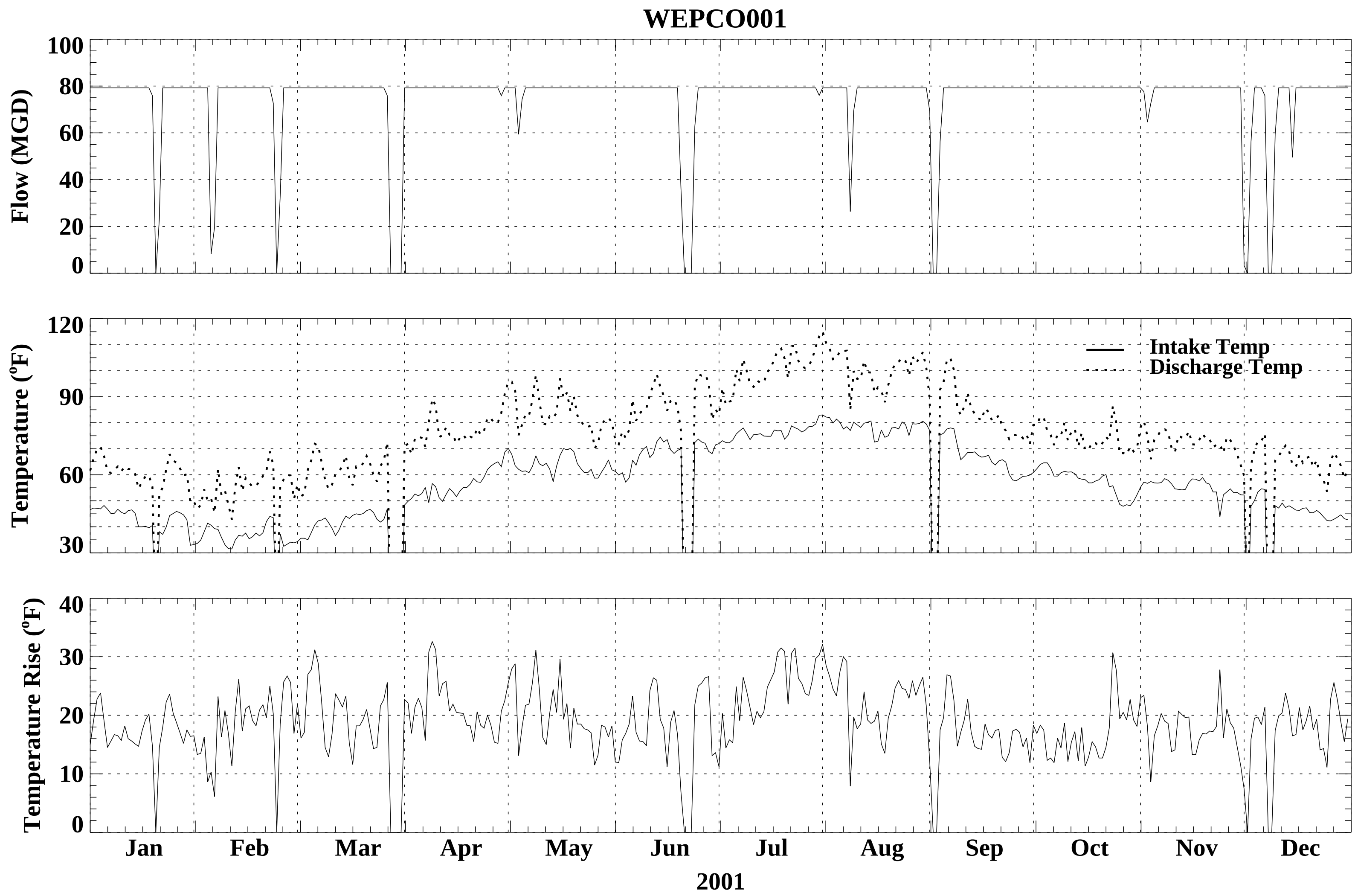

WEPCO001
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998

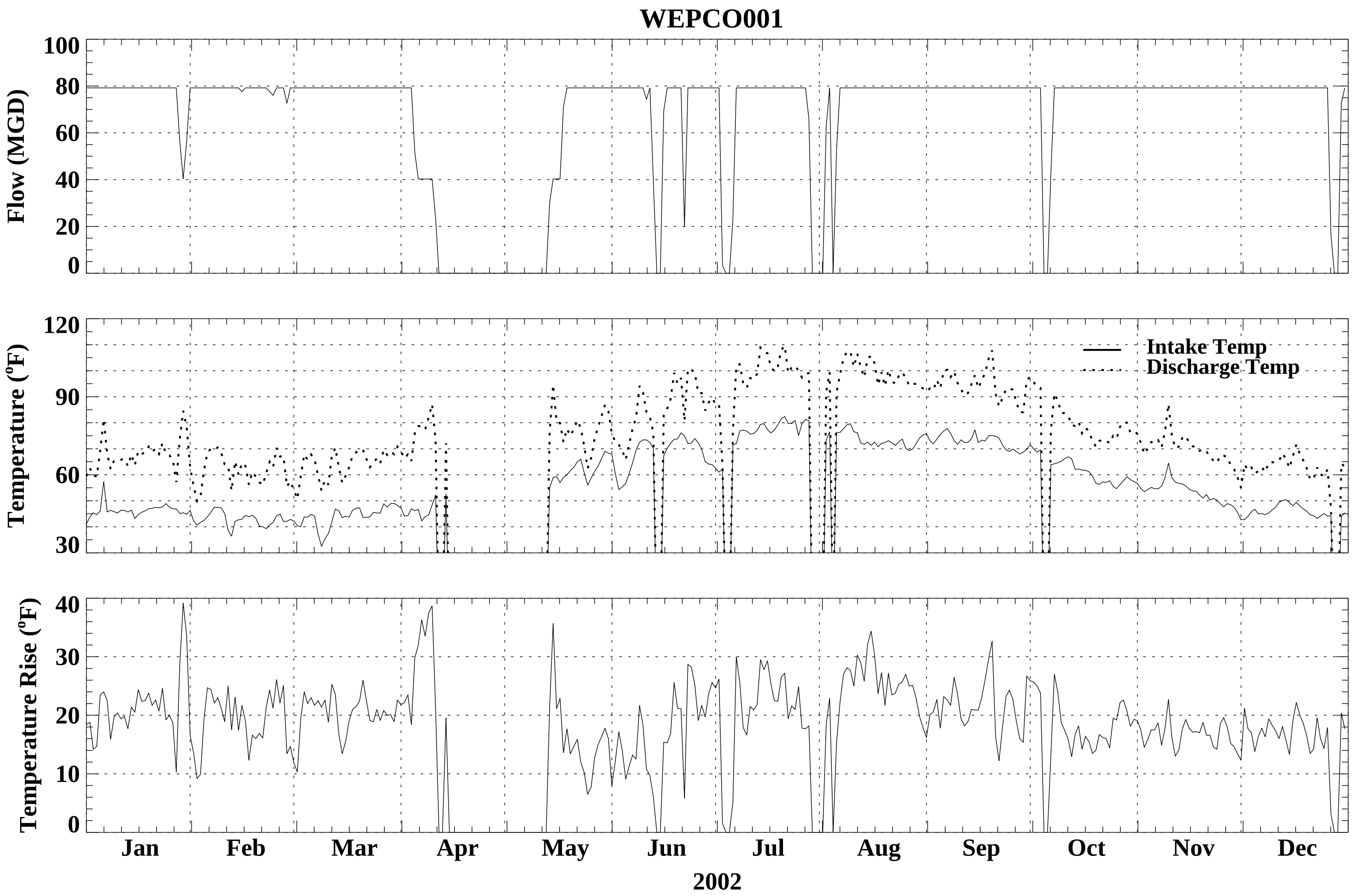

WEPCO001
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999

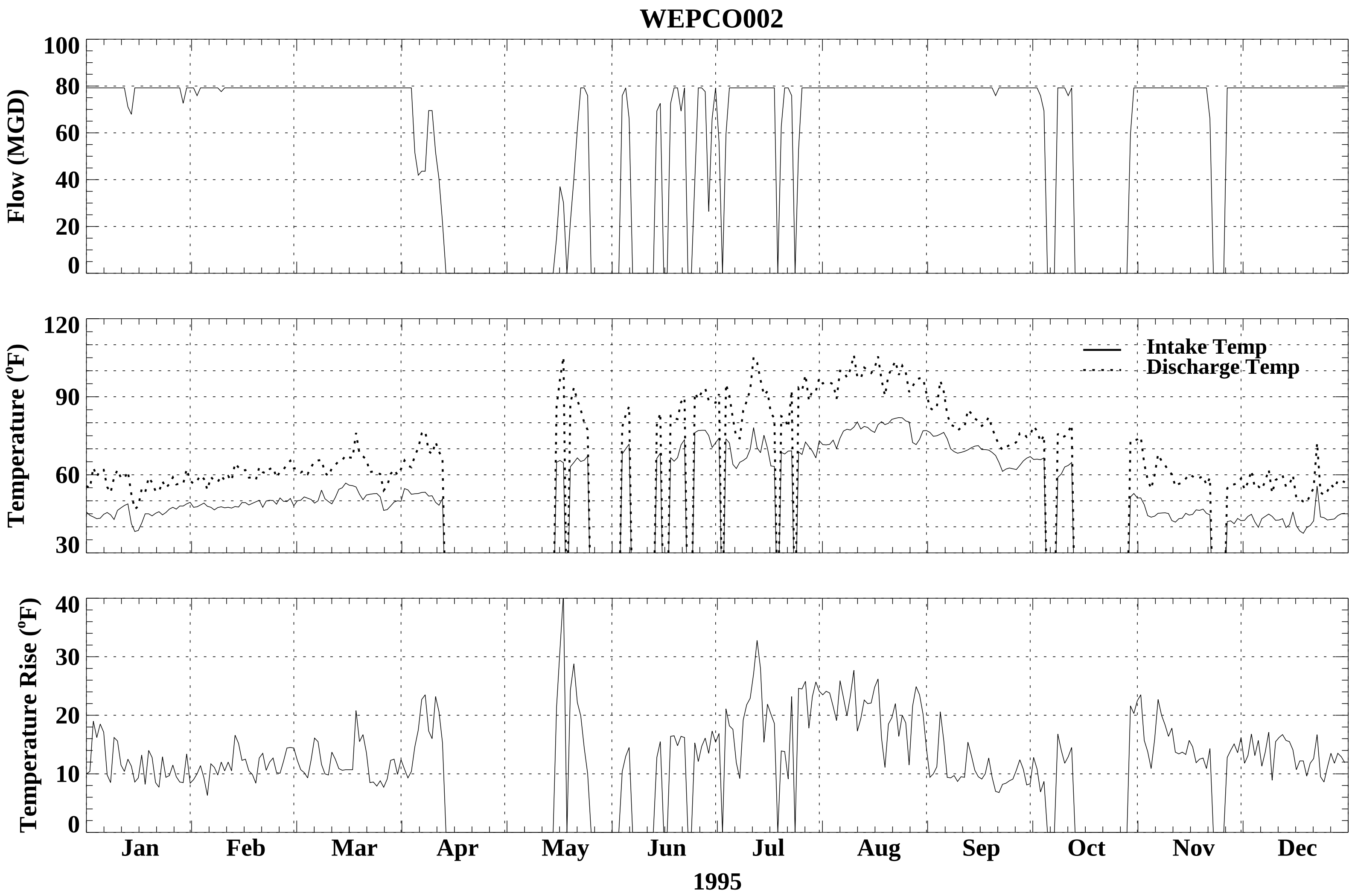
WEPCO001



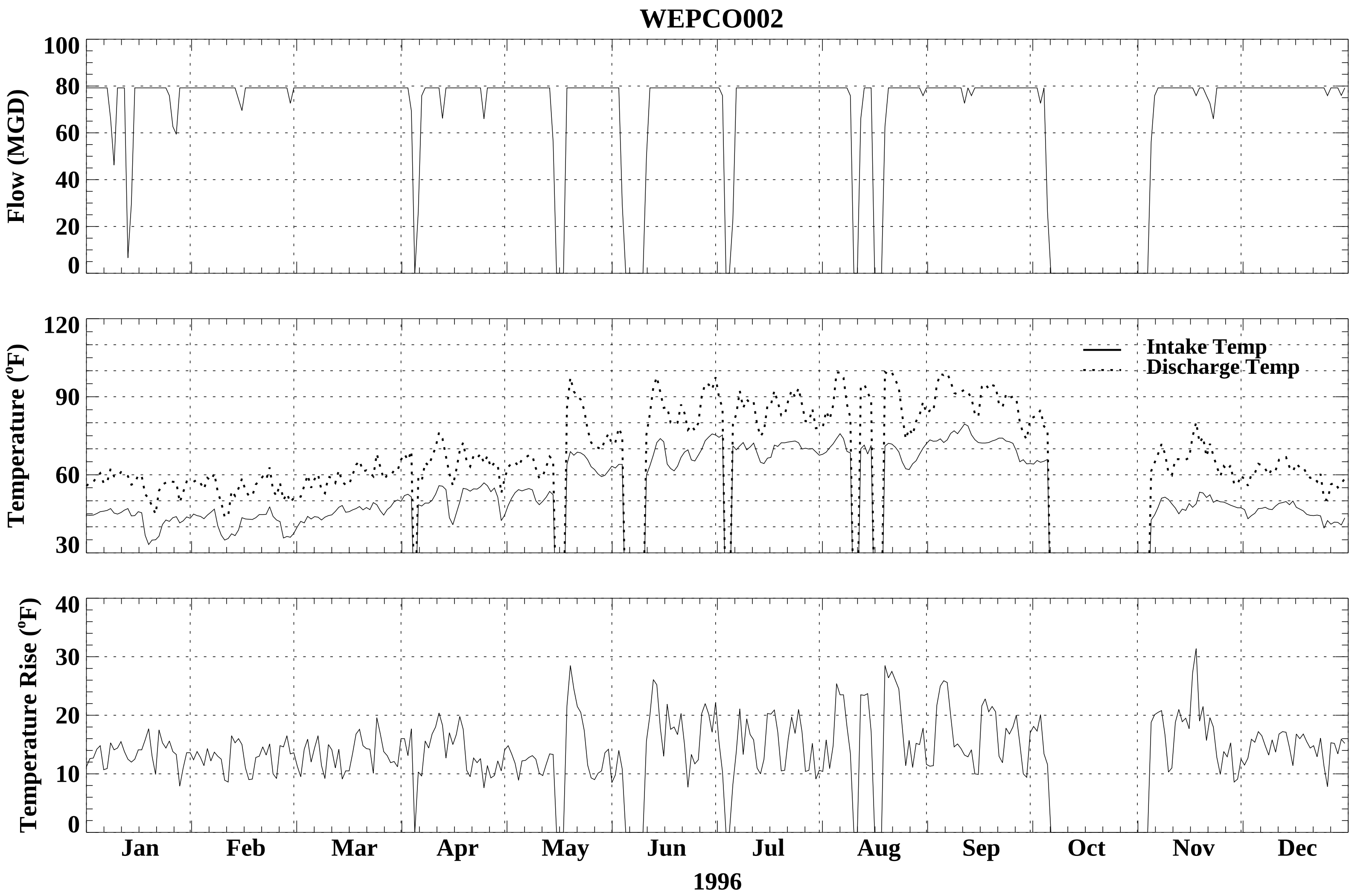
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000

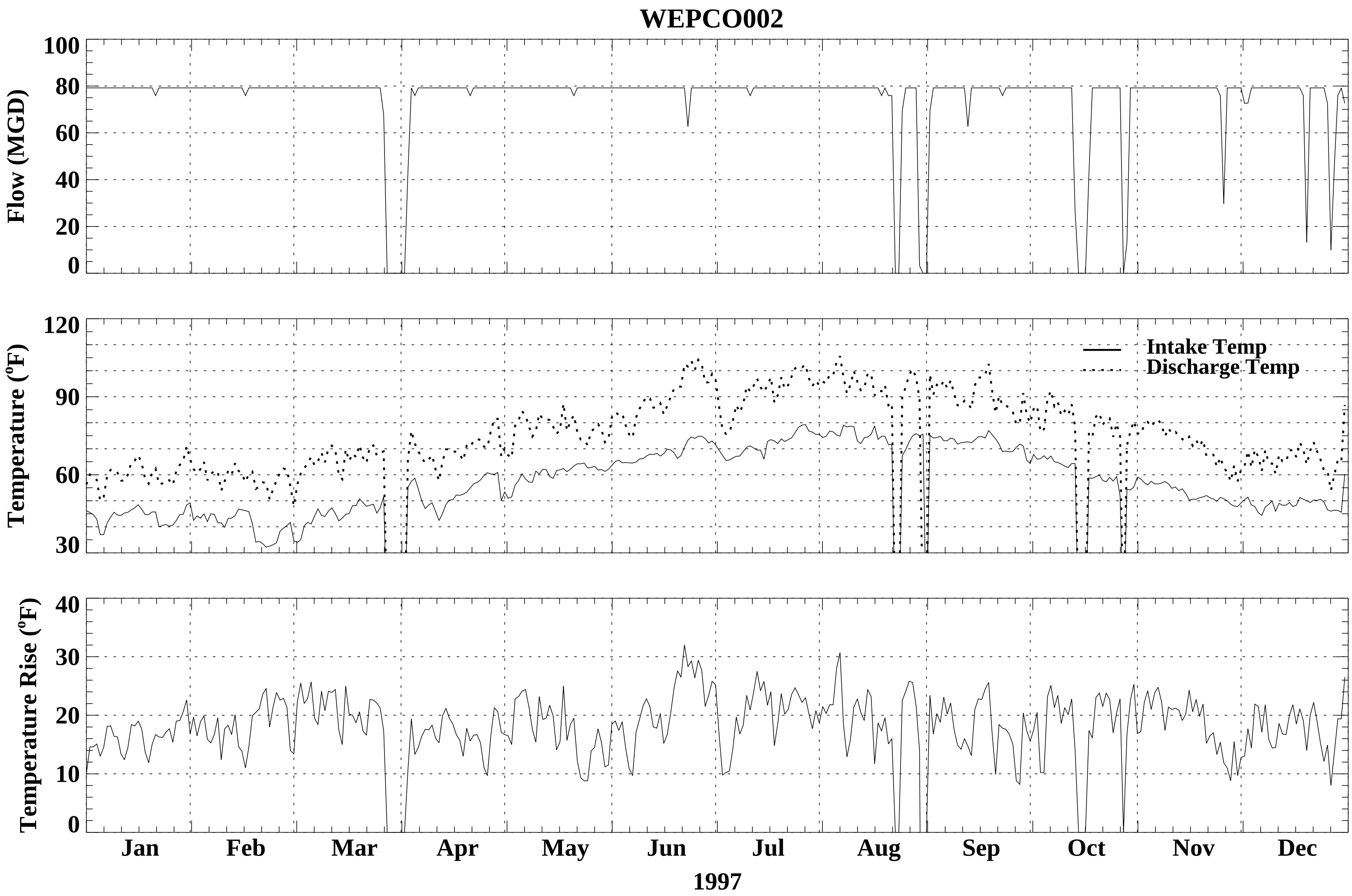

WEPCO001
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001


WEPCO001
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002

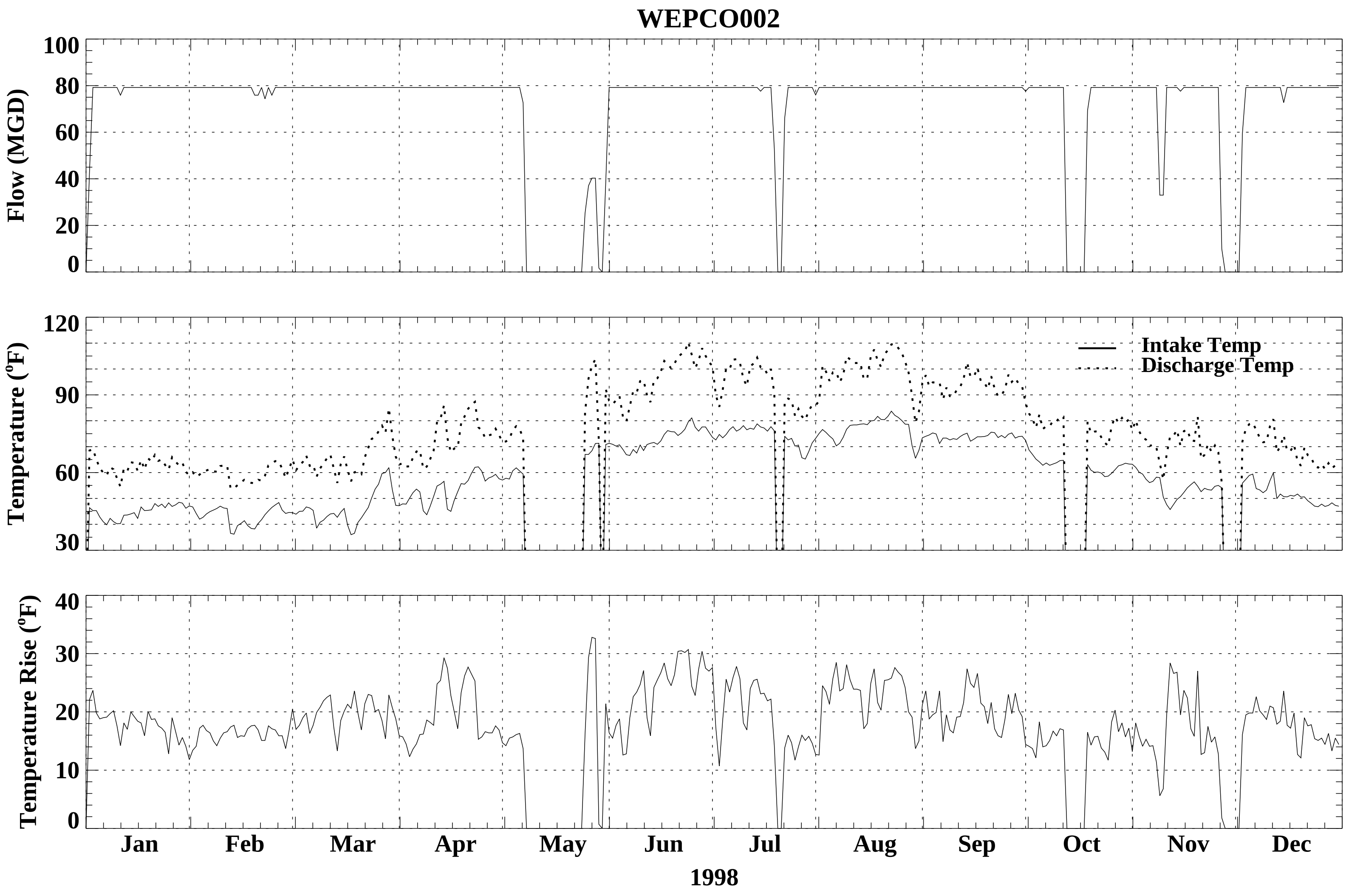


WEPCO002
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995

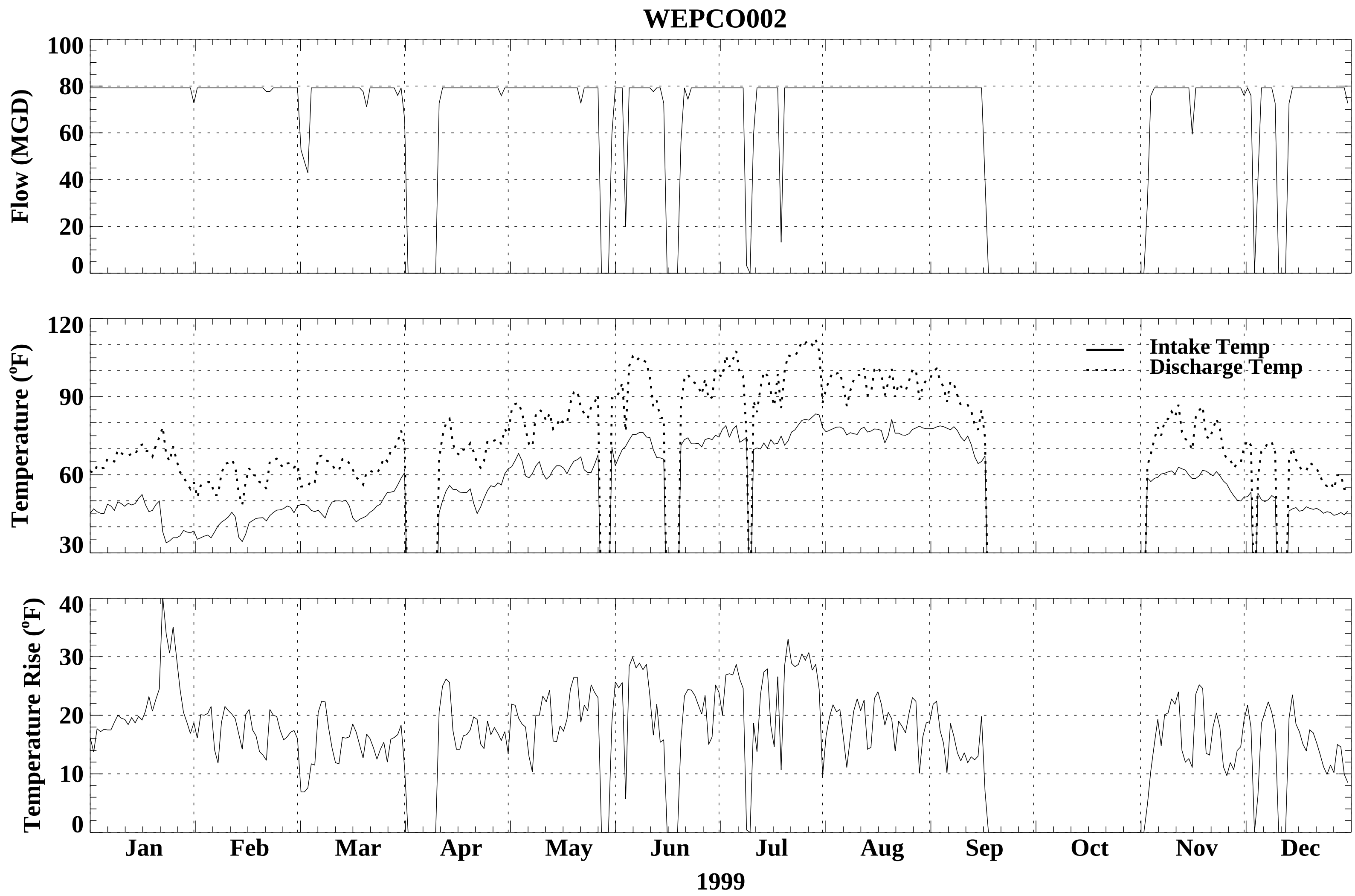

WEPCO002
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996



WEPCO002
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997

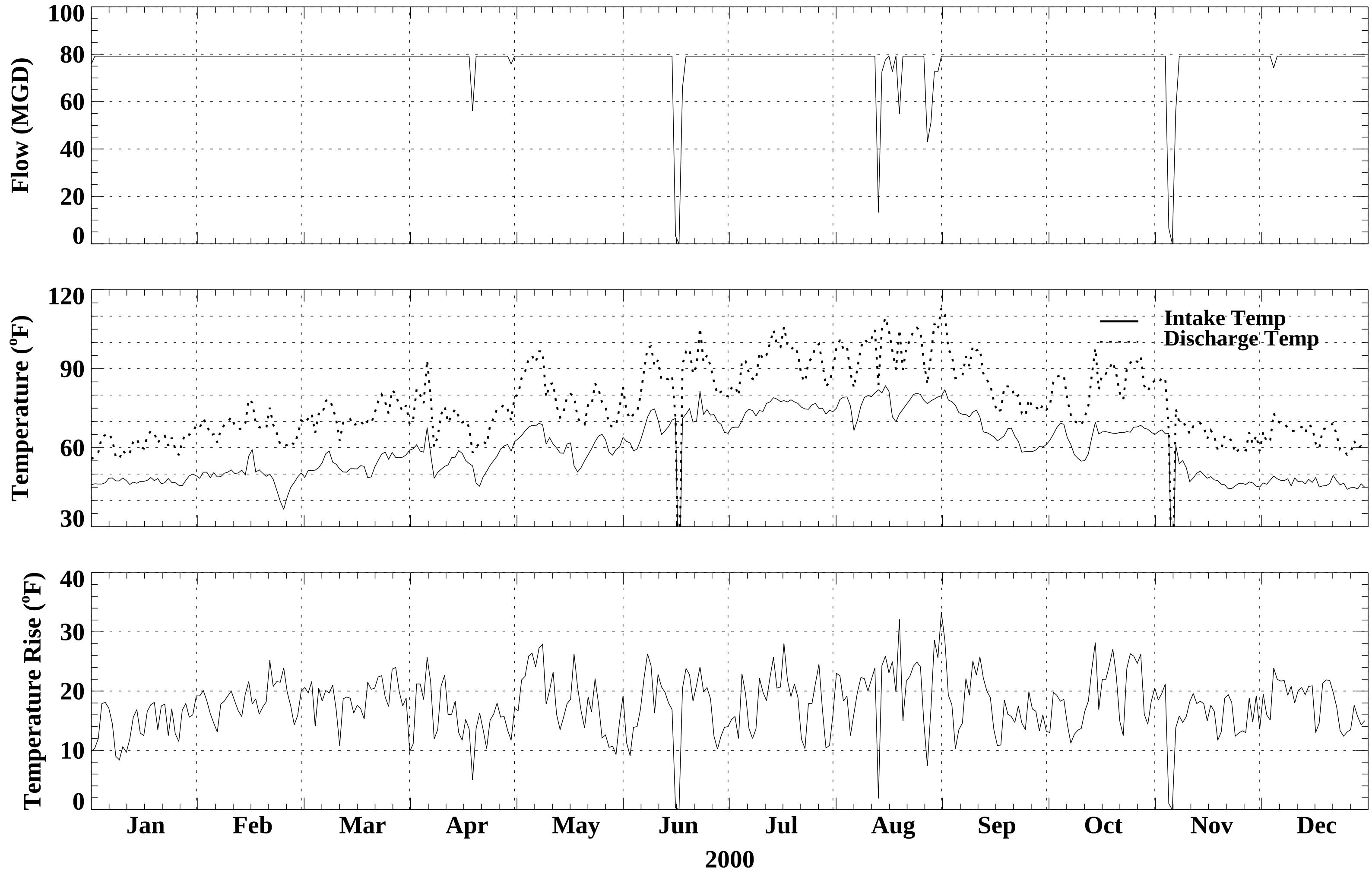


WEPCO002
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998



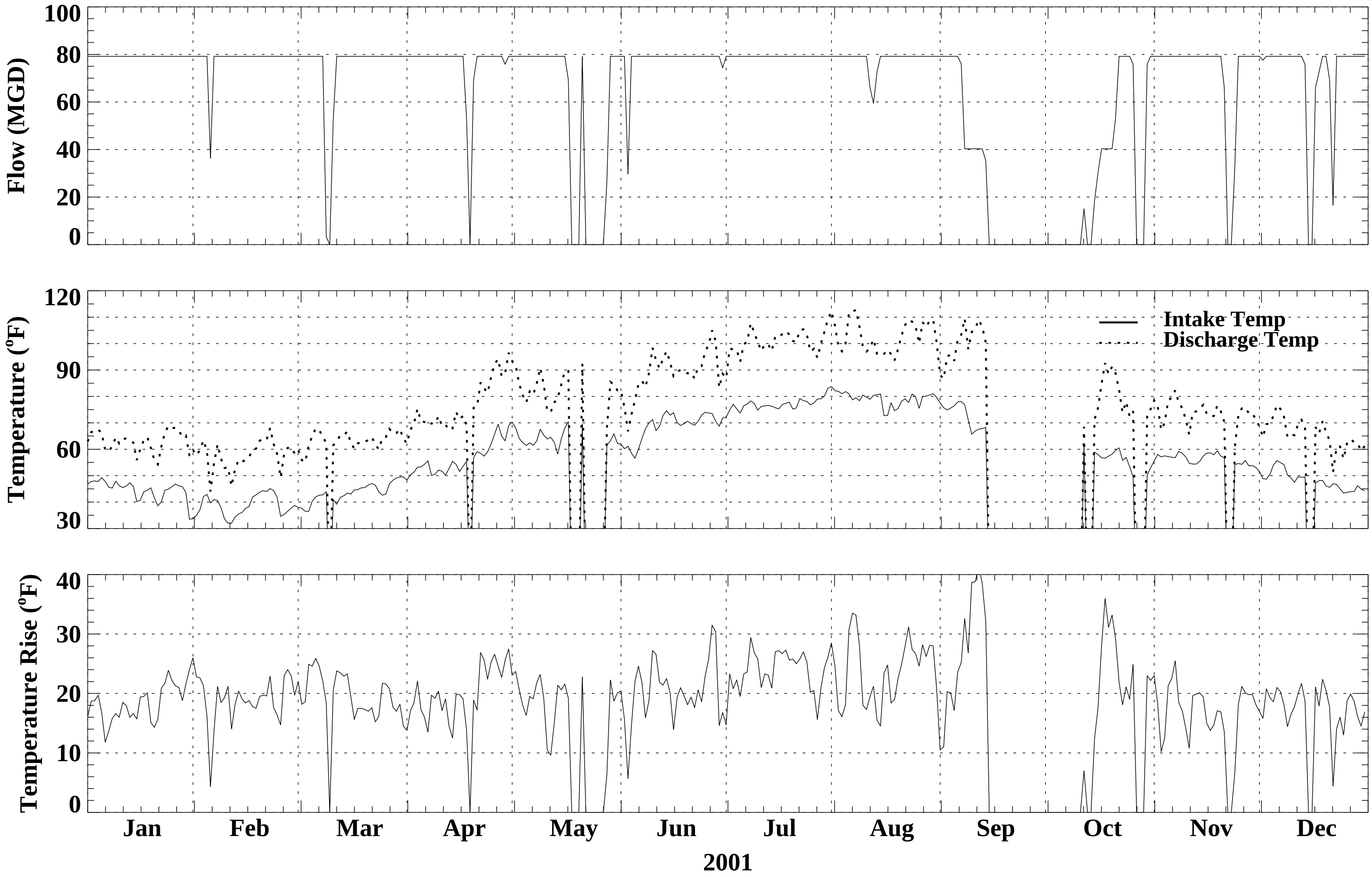
WEPCO002
Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999

WEPCO002

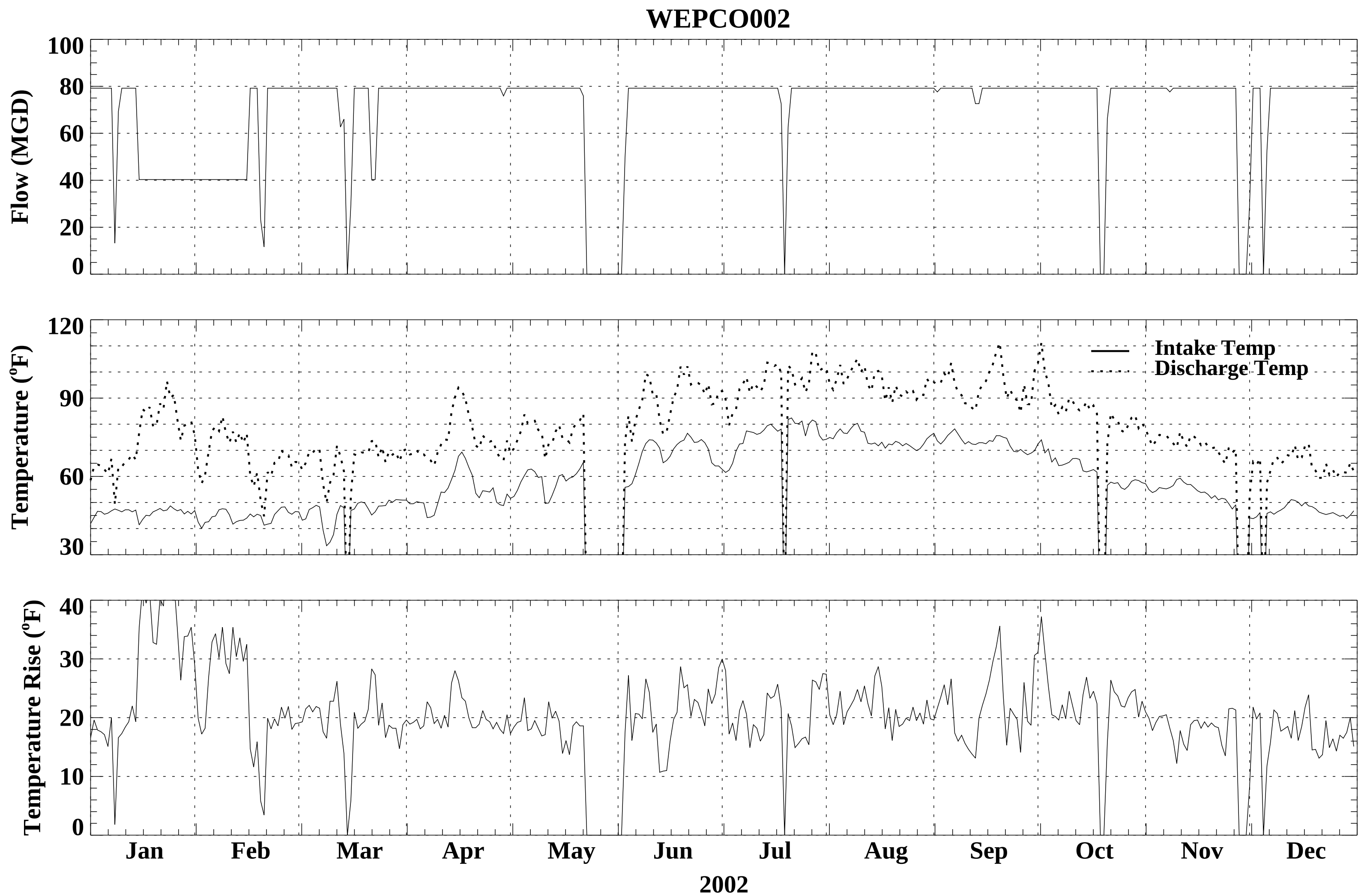


100
80
60
40
20
0
Flow (MGD)
120
90
60
30
Temperature (°F)
Intake Temp
Discharge Temp
40
30
20
10
0
Temperature Rise (°F)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000

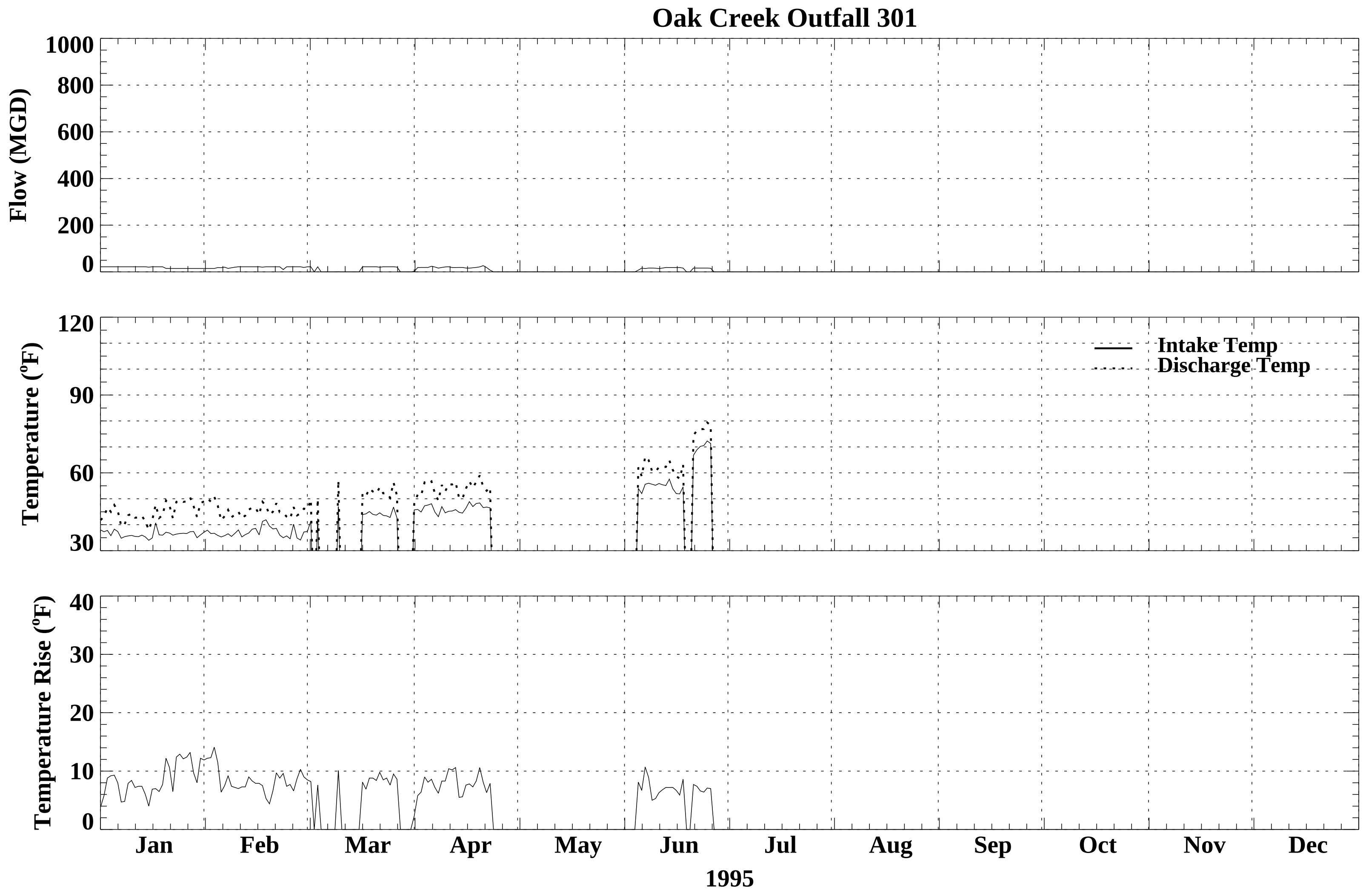
WEPCO002

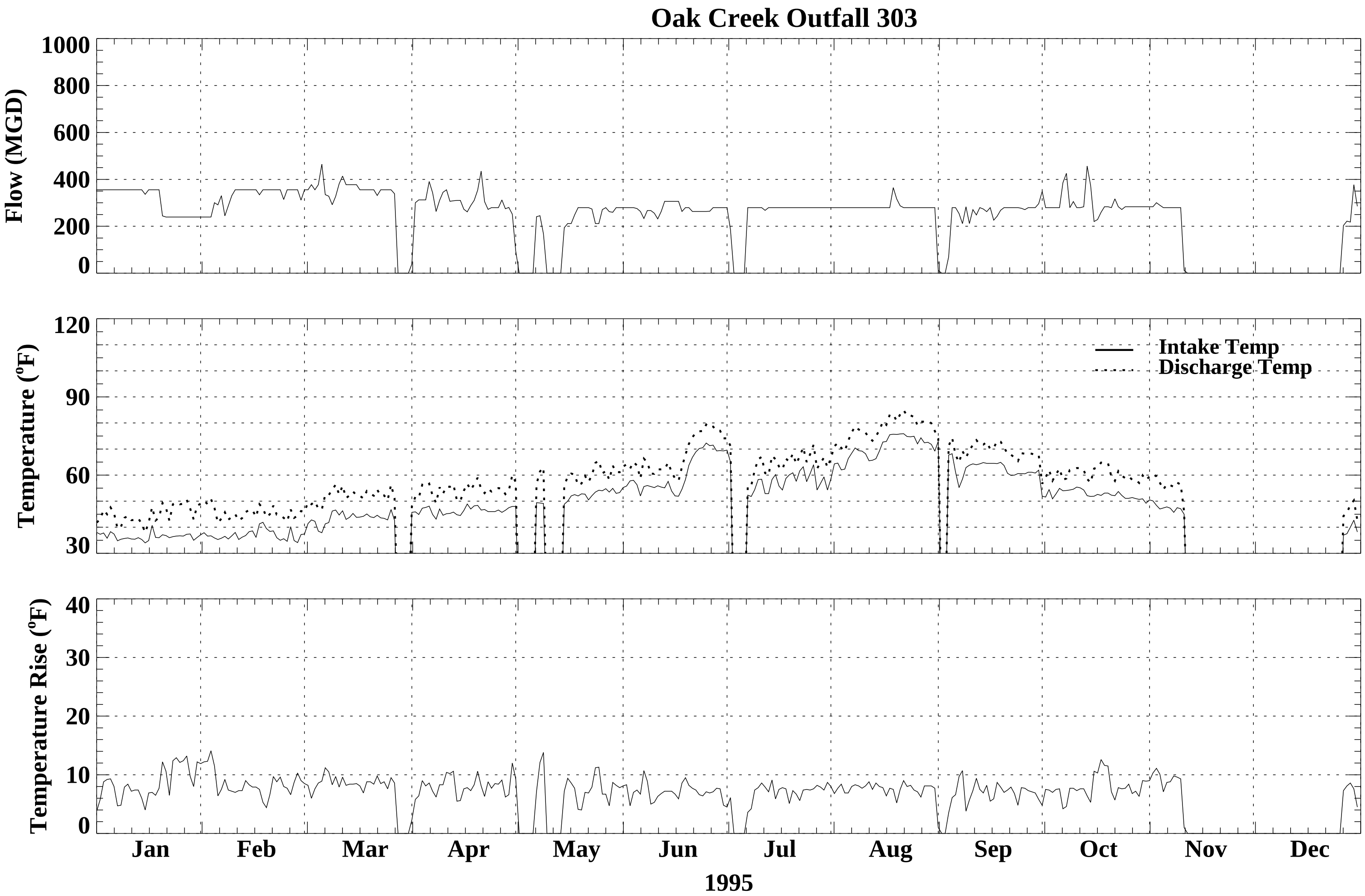


Flow (MGD)
100
80
60
40
20
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001

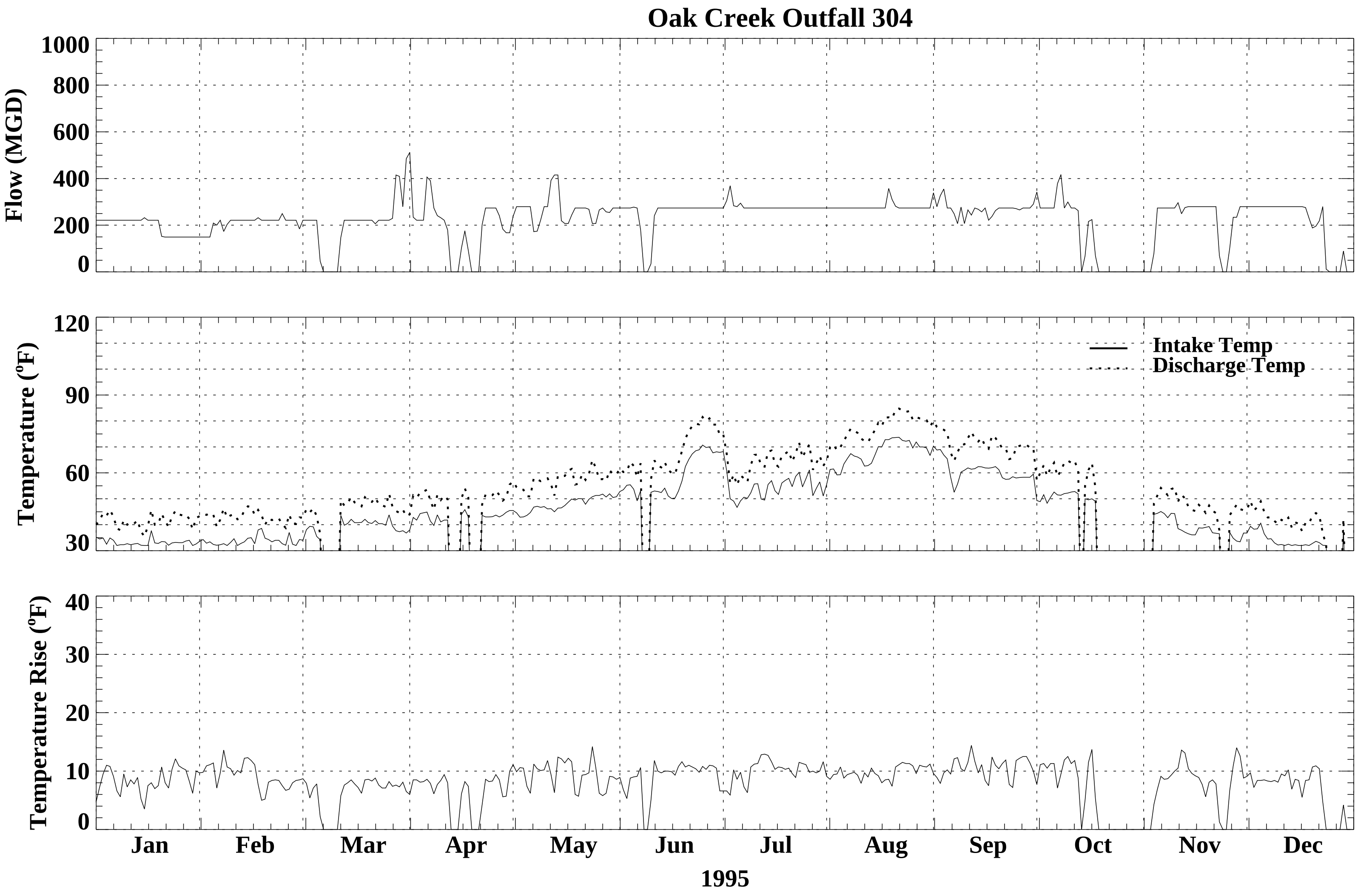


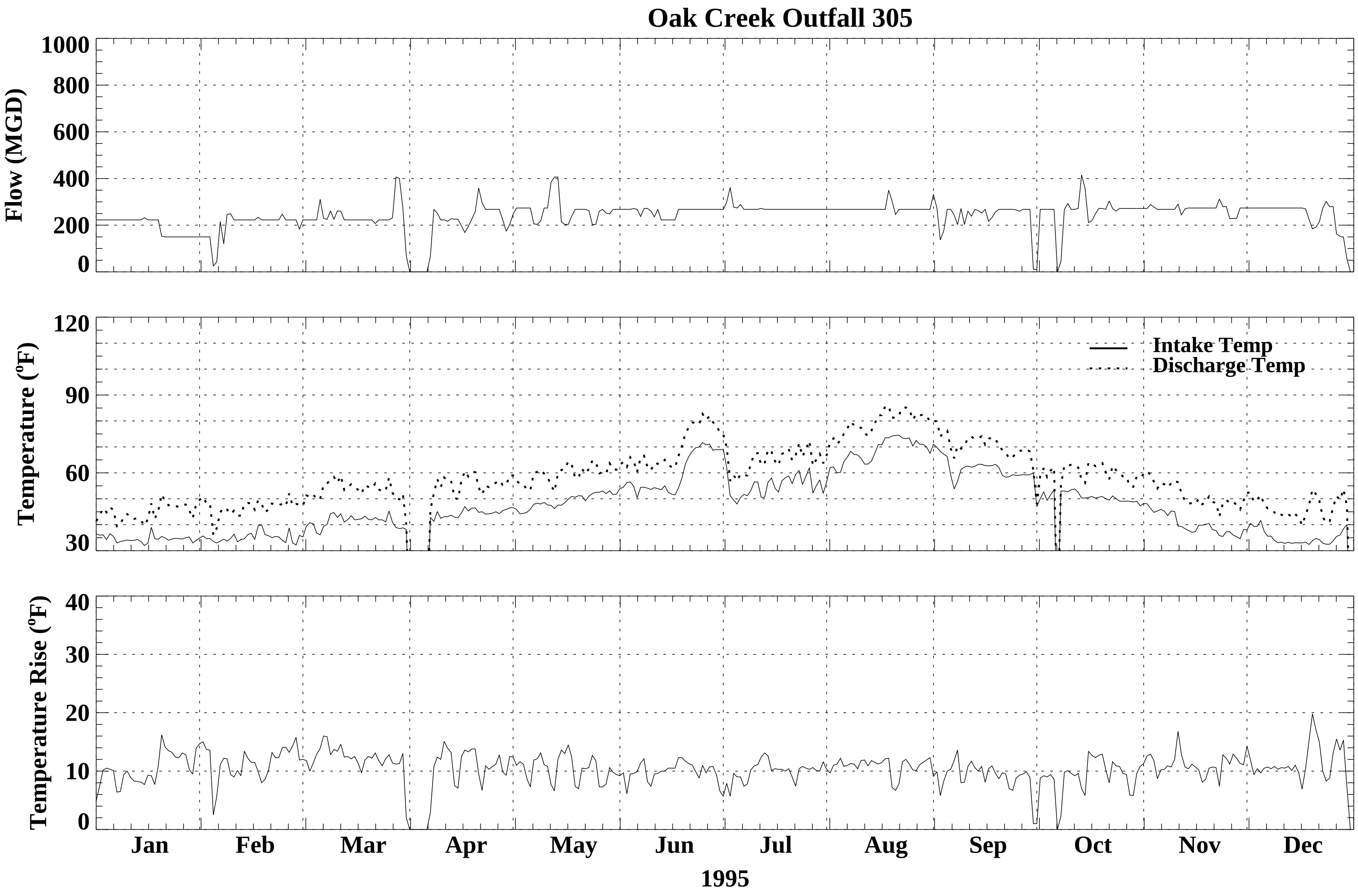
WEPCO002
Flow (MGD)
100
80
60
40
20
0
Temperature (oF)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (oF)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002


Oak Creek Outfall 301
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995

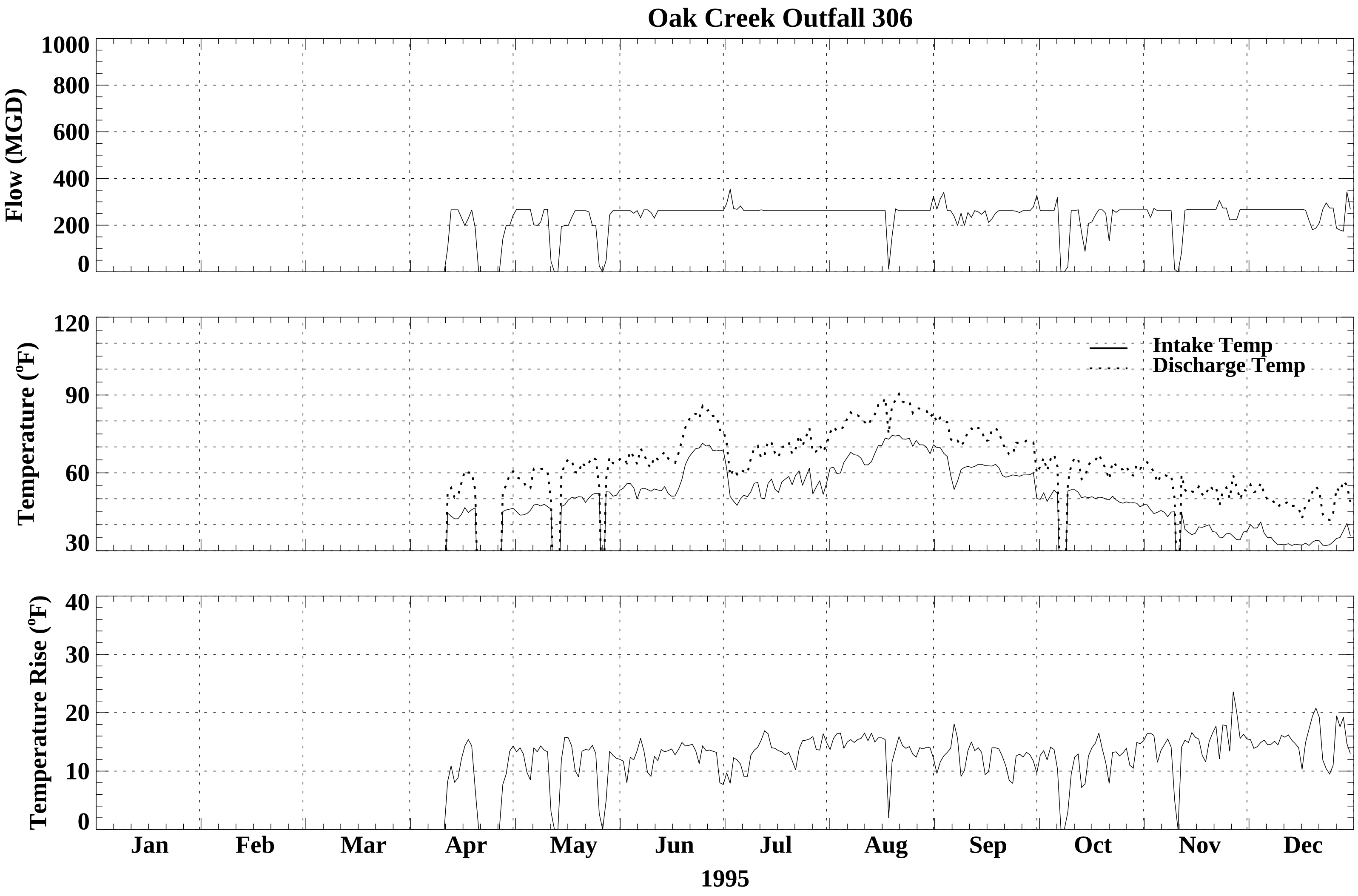


Oak Creek Outfall 303
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995

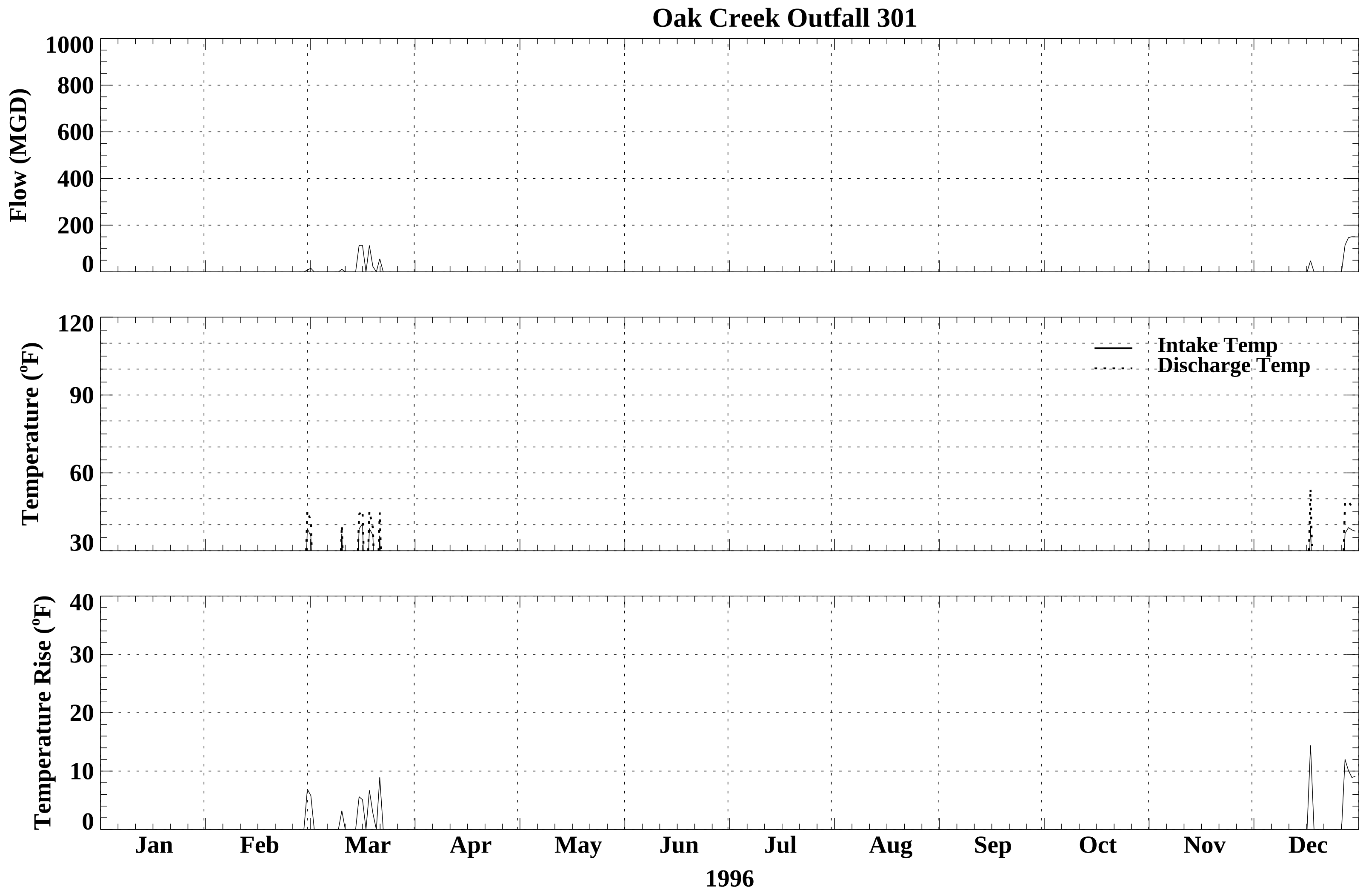

Oak Creek Outfall 304
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995



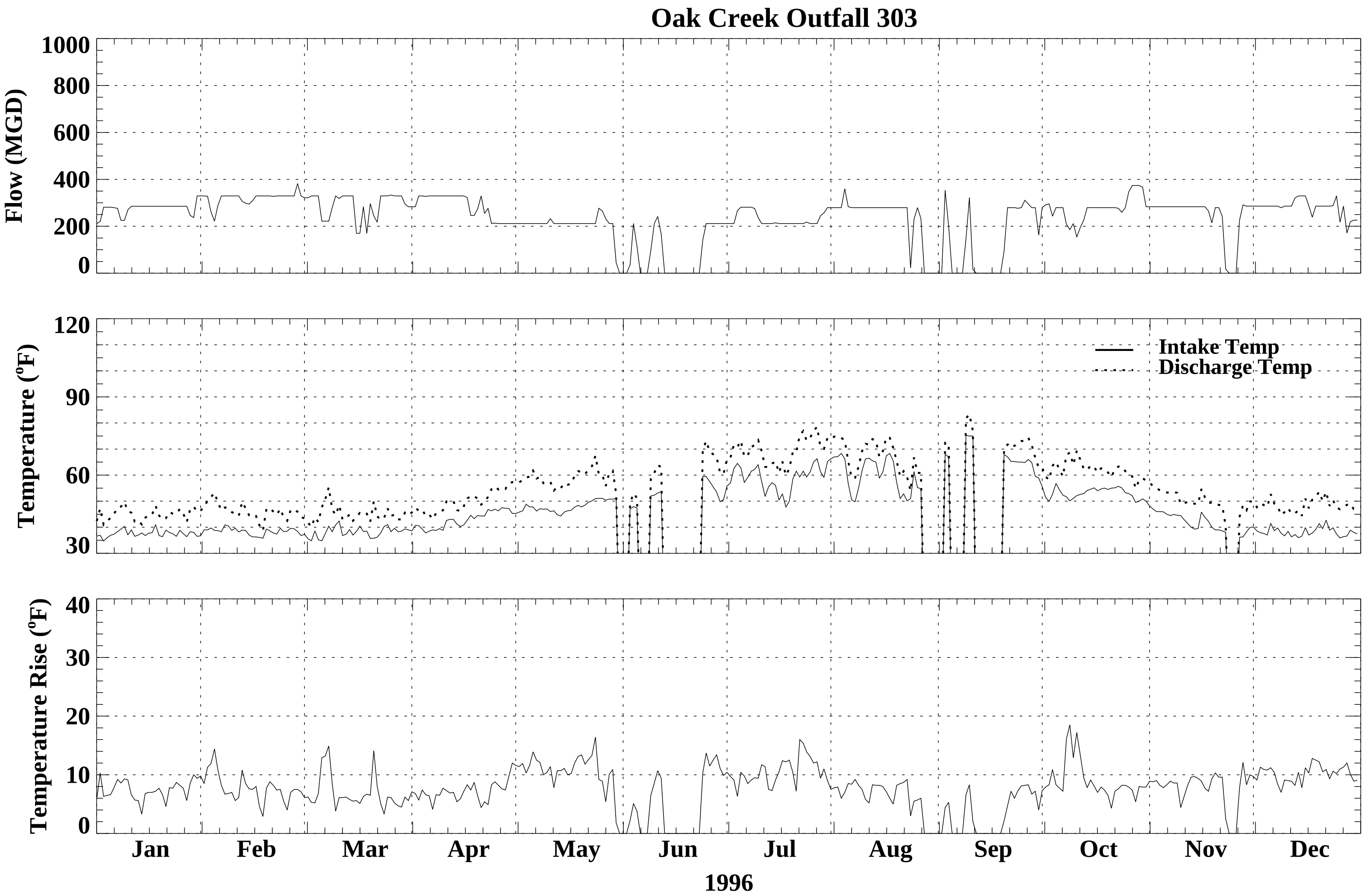
Oak Creek Outfall 305
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995



Oak Creek Outfall 306
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995

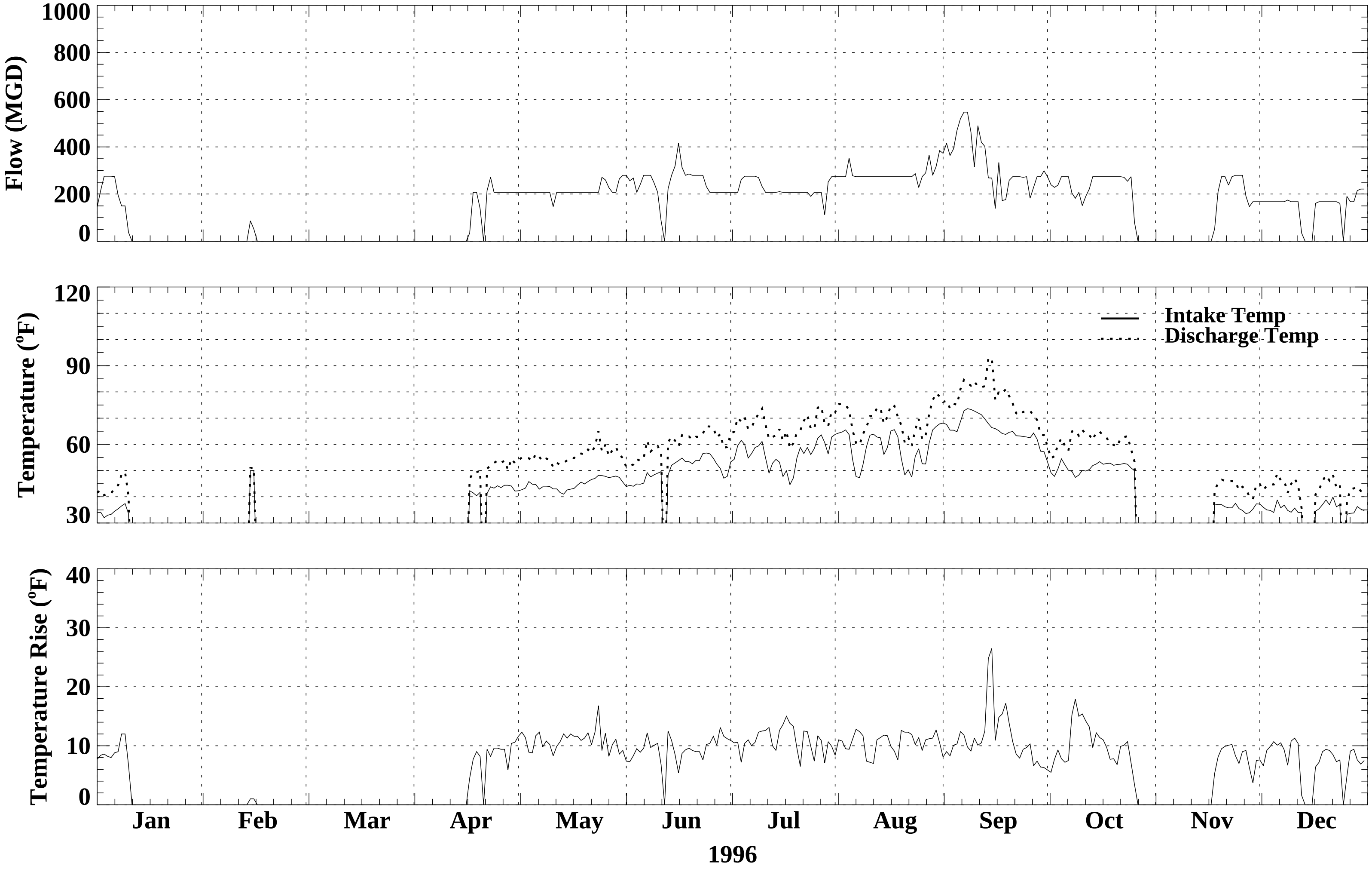


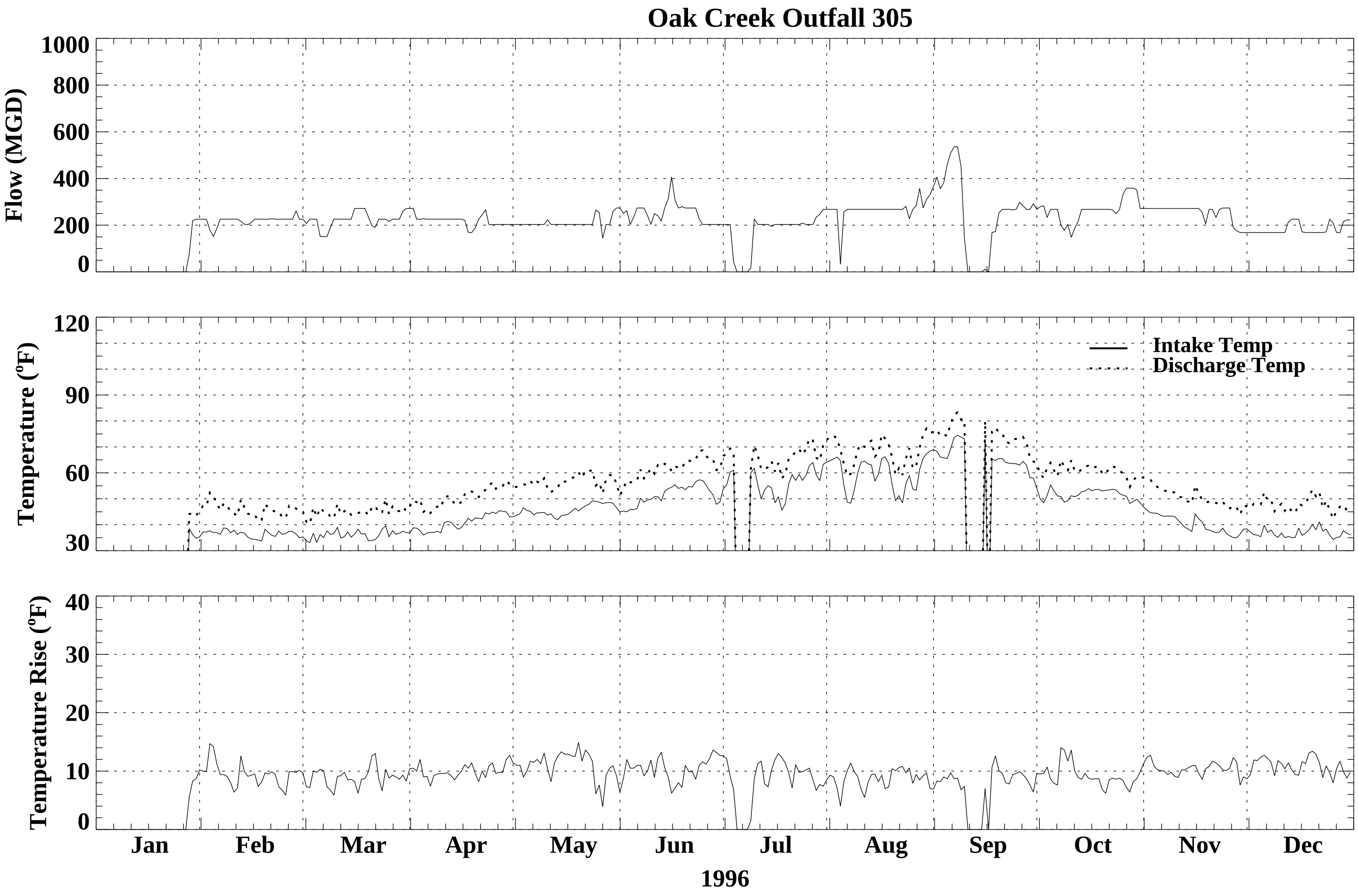
Oak Creek Outfall 301
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996

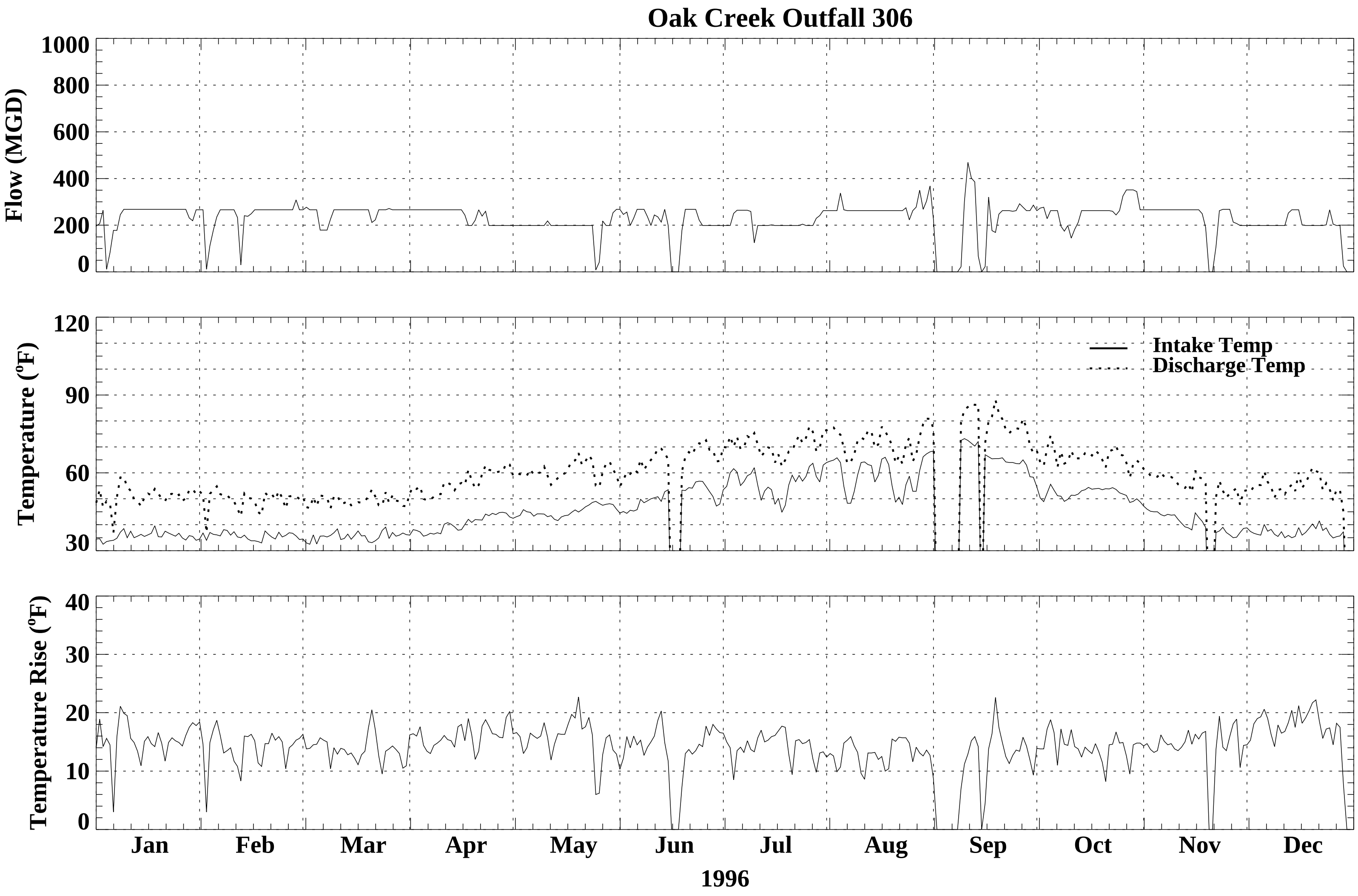


Oak Creek Outfall 303
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996

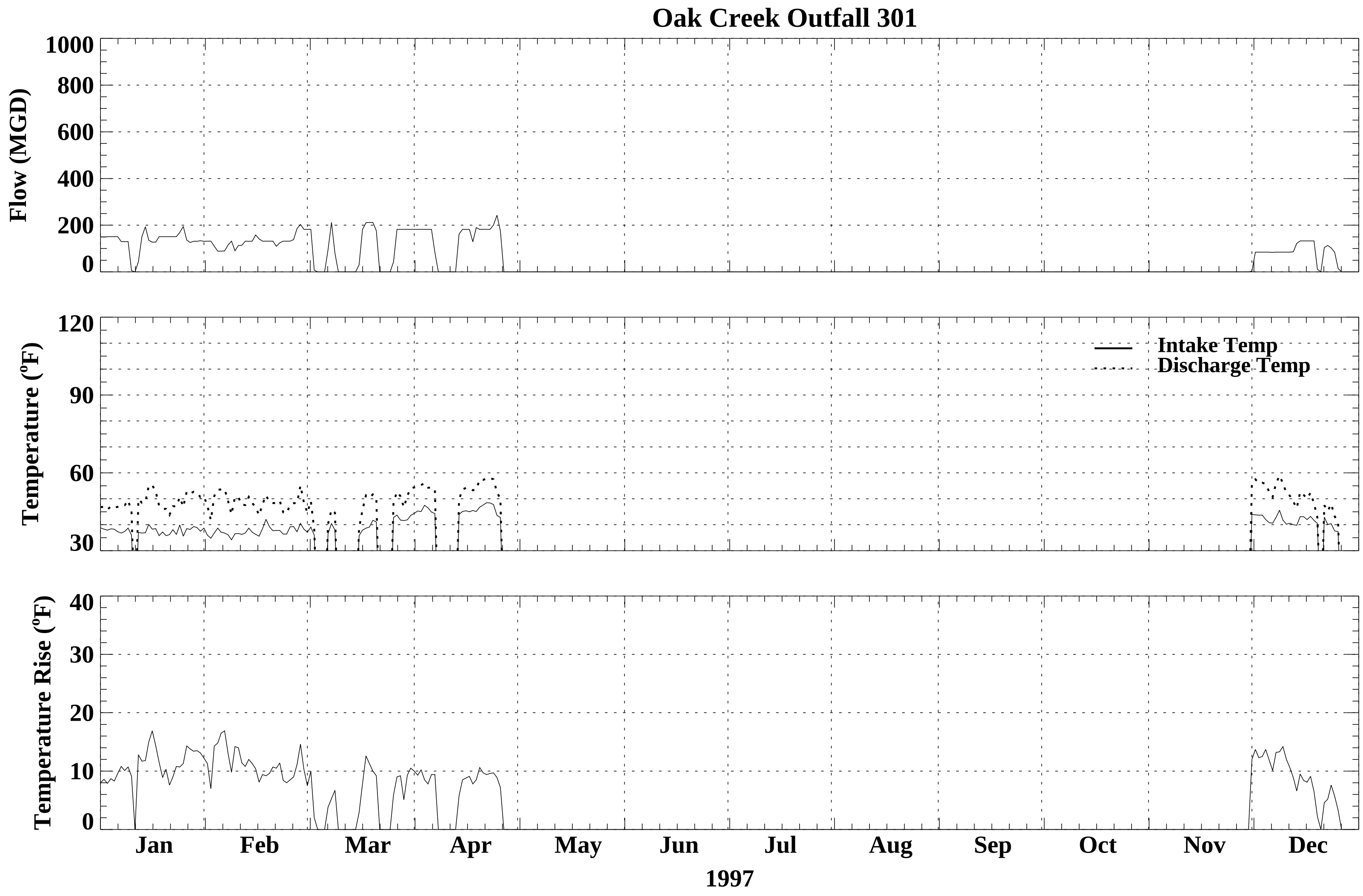
Oak Creek Outfall 304

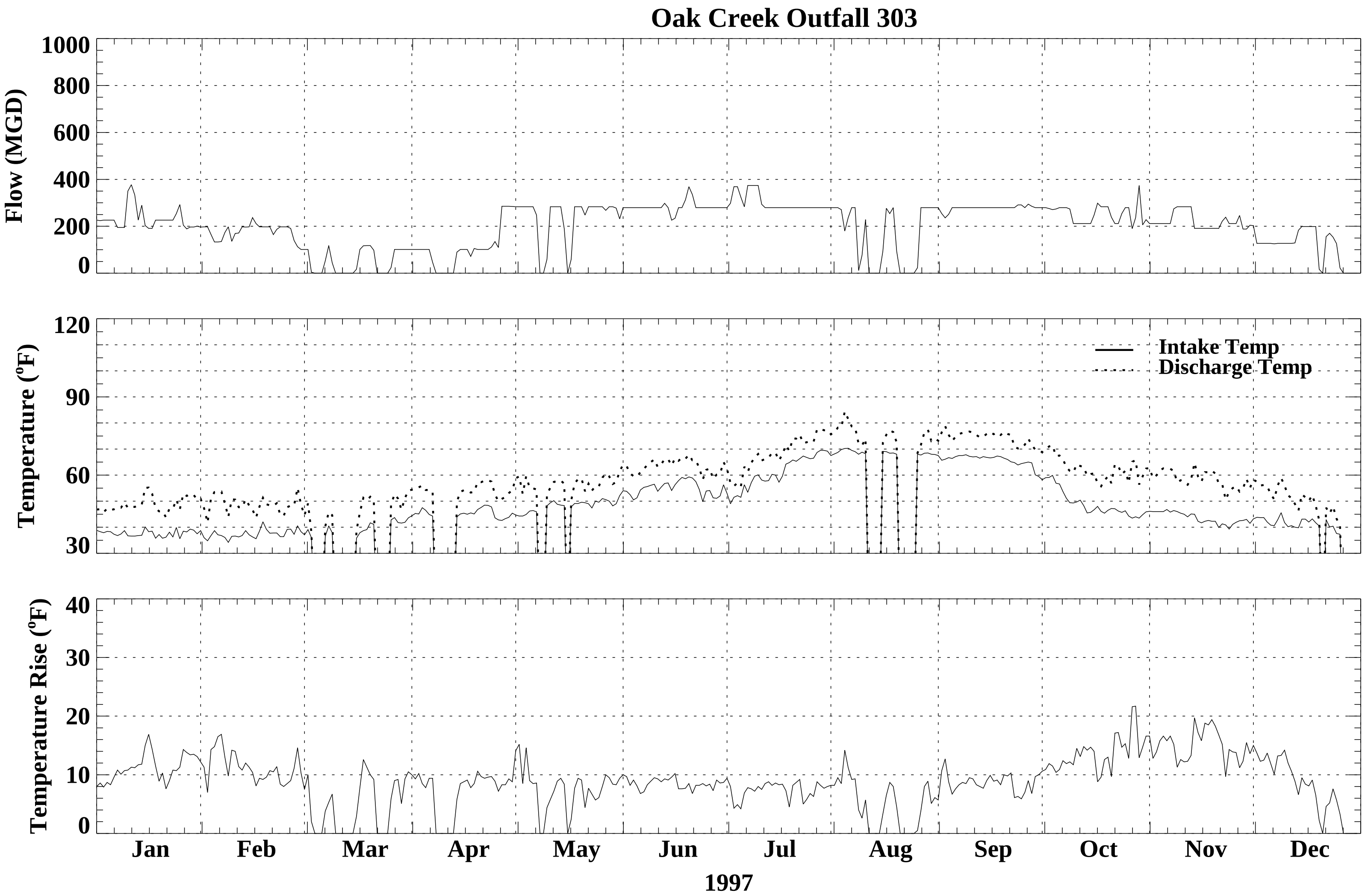



Oak Creek Outfall 305
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996

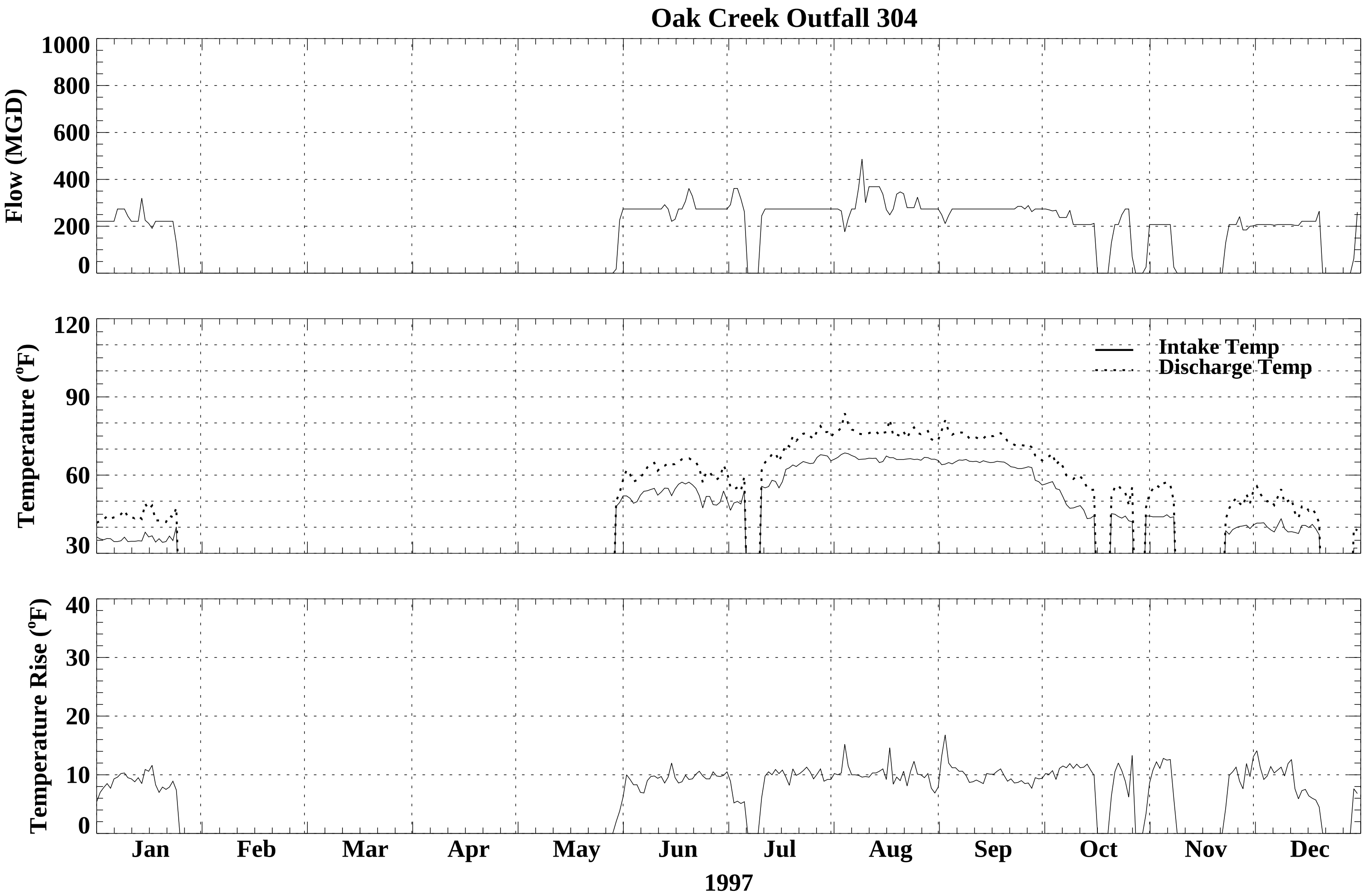


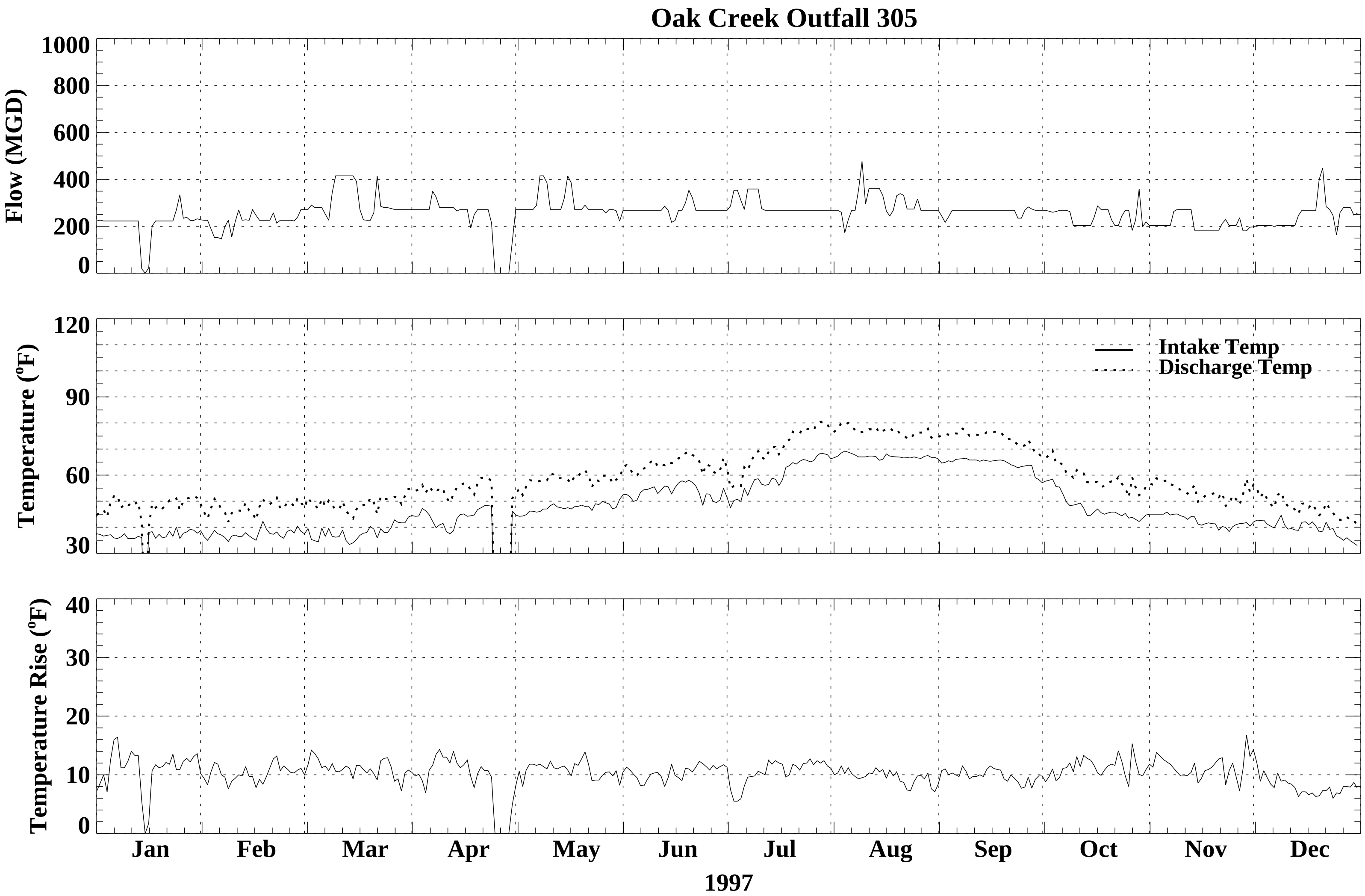
Oak Creek Outfall 306
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996


Oak Creek Outfall 301
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997

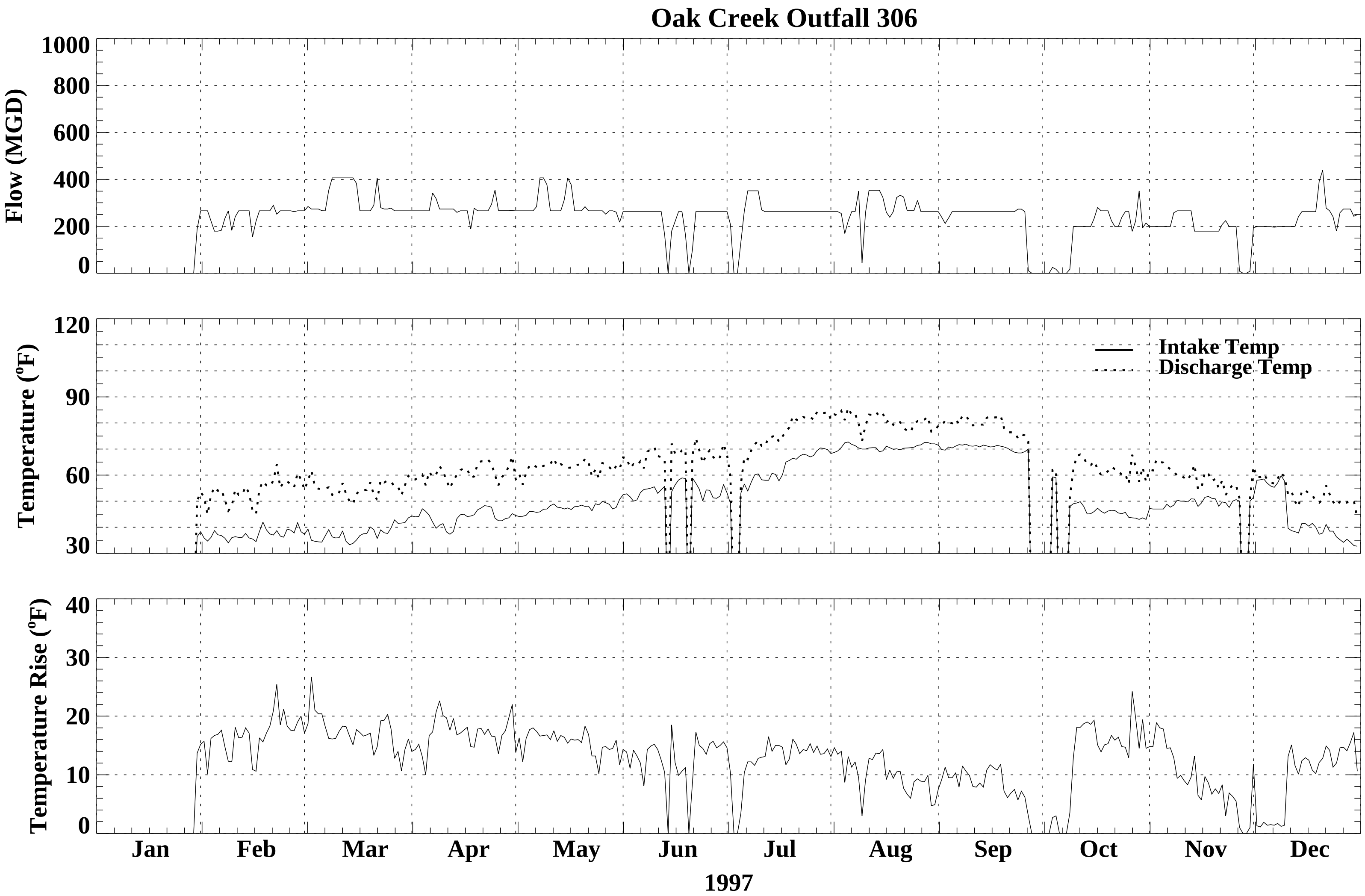


Oak Creek Outfall 303
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997

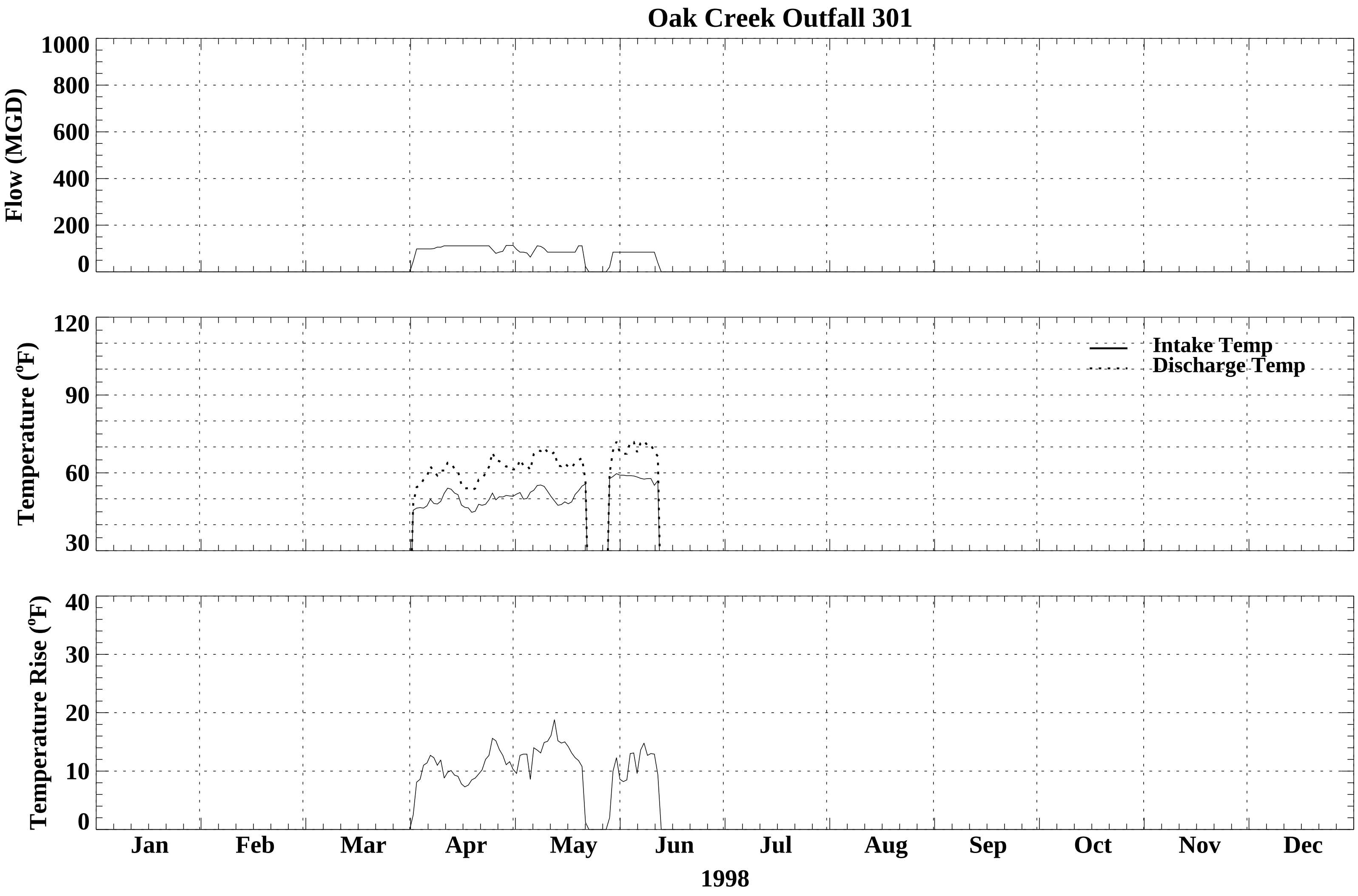

Oak Creek Outfall 304
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997



Oak Creek Outfall 305
Flow (MGD)
1000
800
600
400
200
0
Temperature (ºF)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (ºF)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997

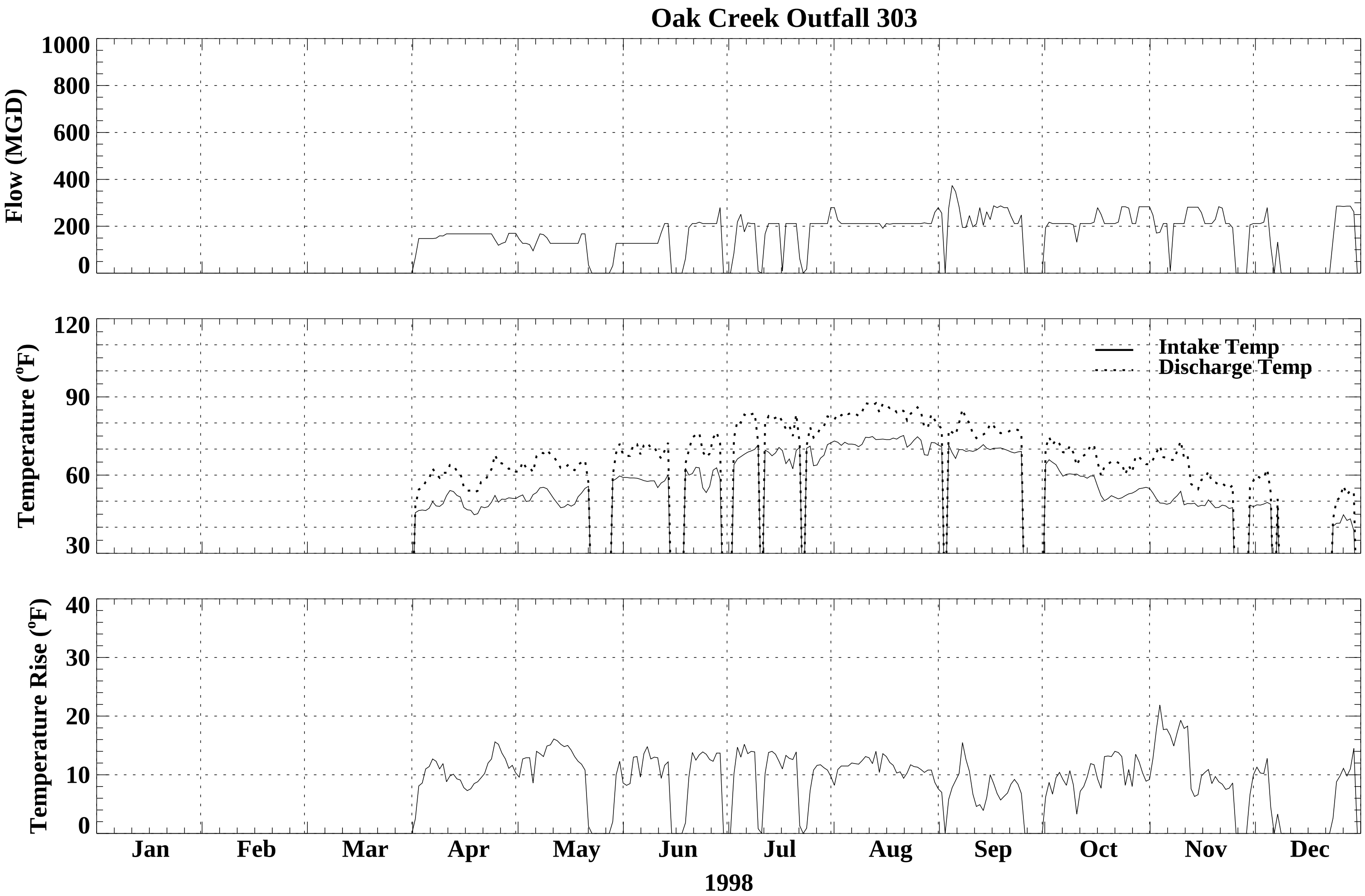


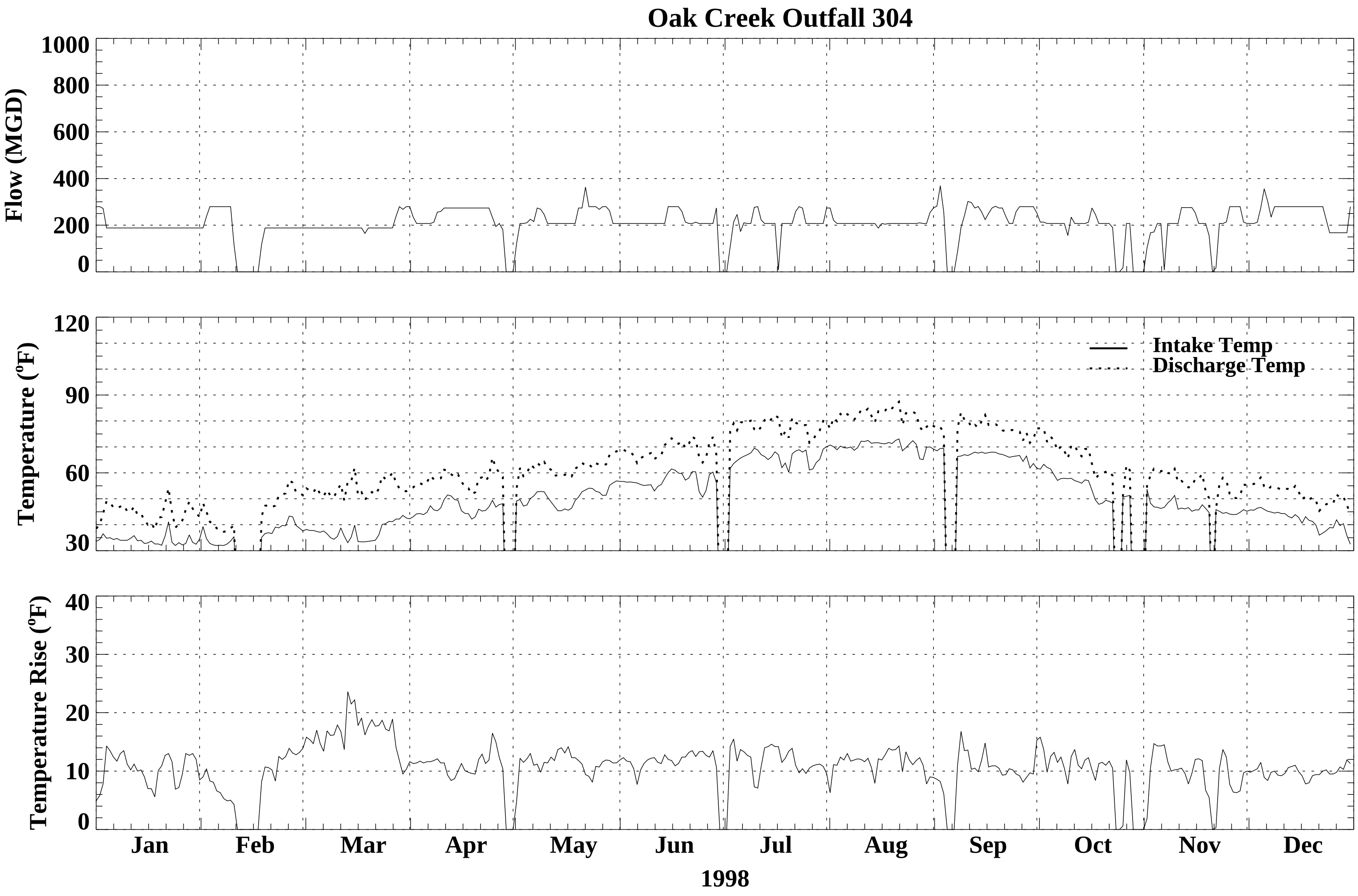
Oak Creek Outfall 306
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997



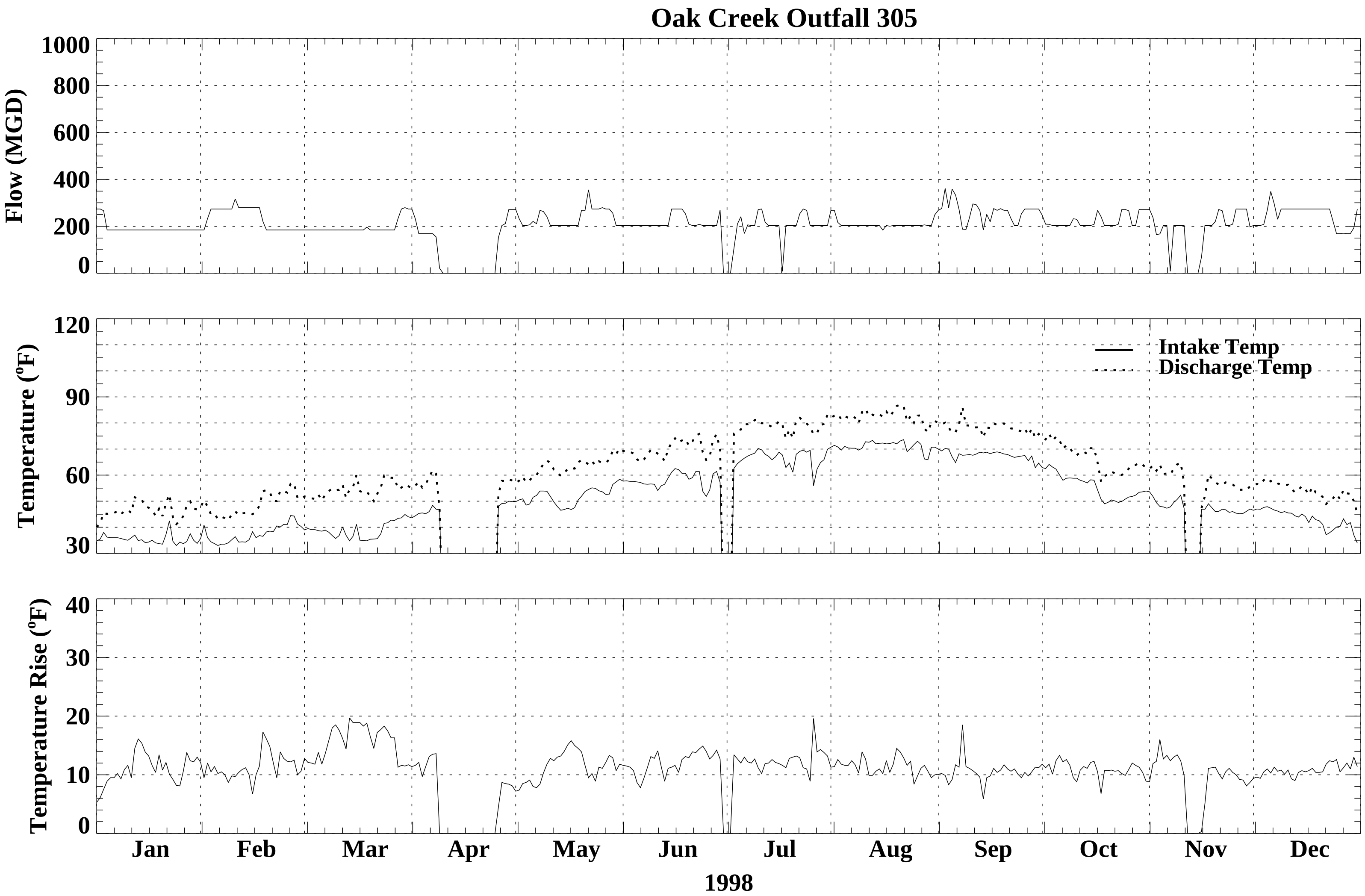
Oak Creek Outfall 301
Flow (MGD)
1000
800
600
400
200
0
Temperature (ºF)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (ºF)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998

Oak Creek Outfall 303

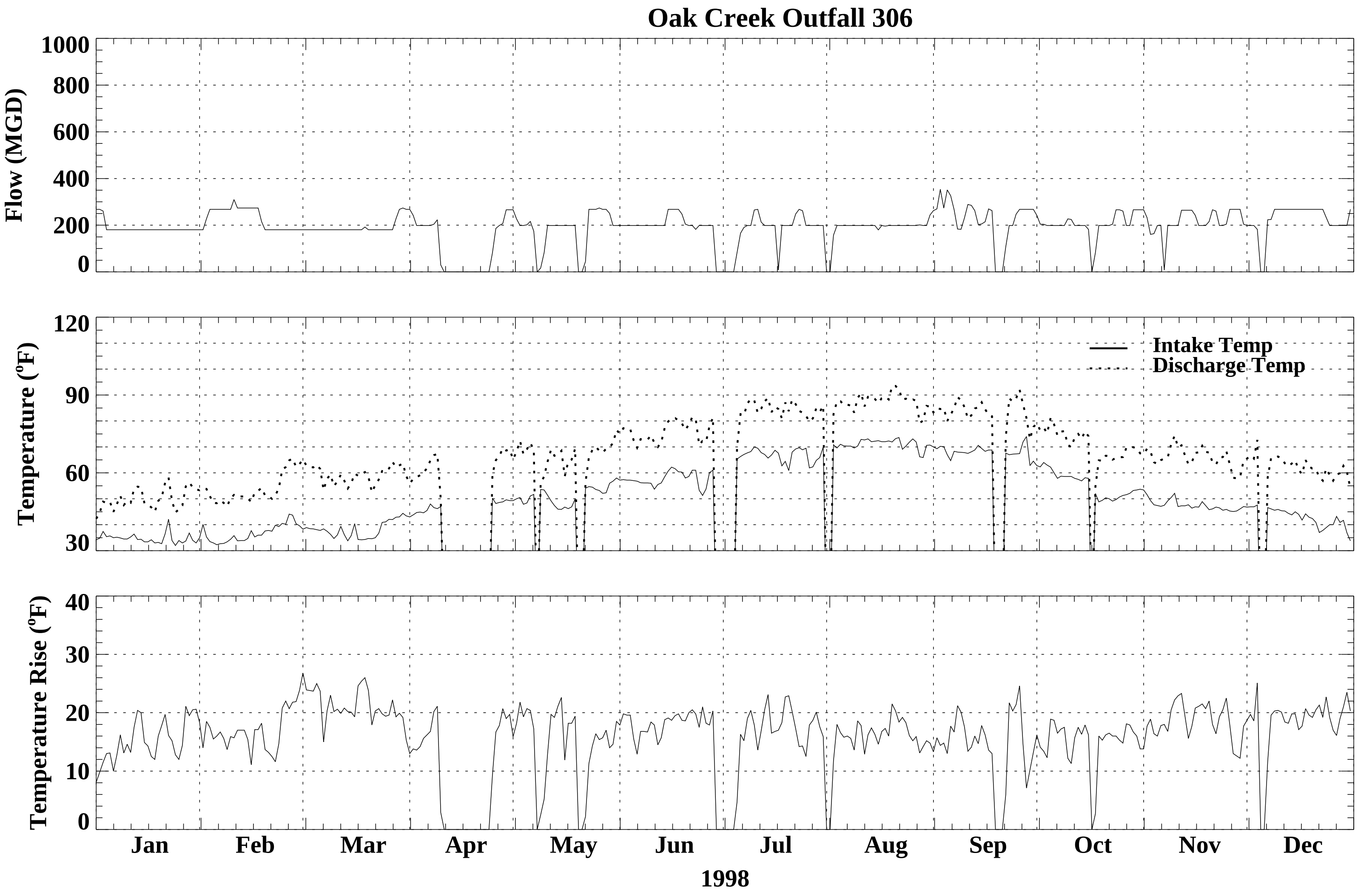




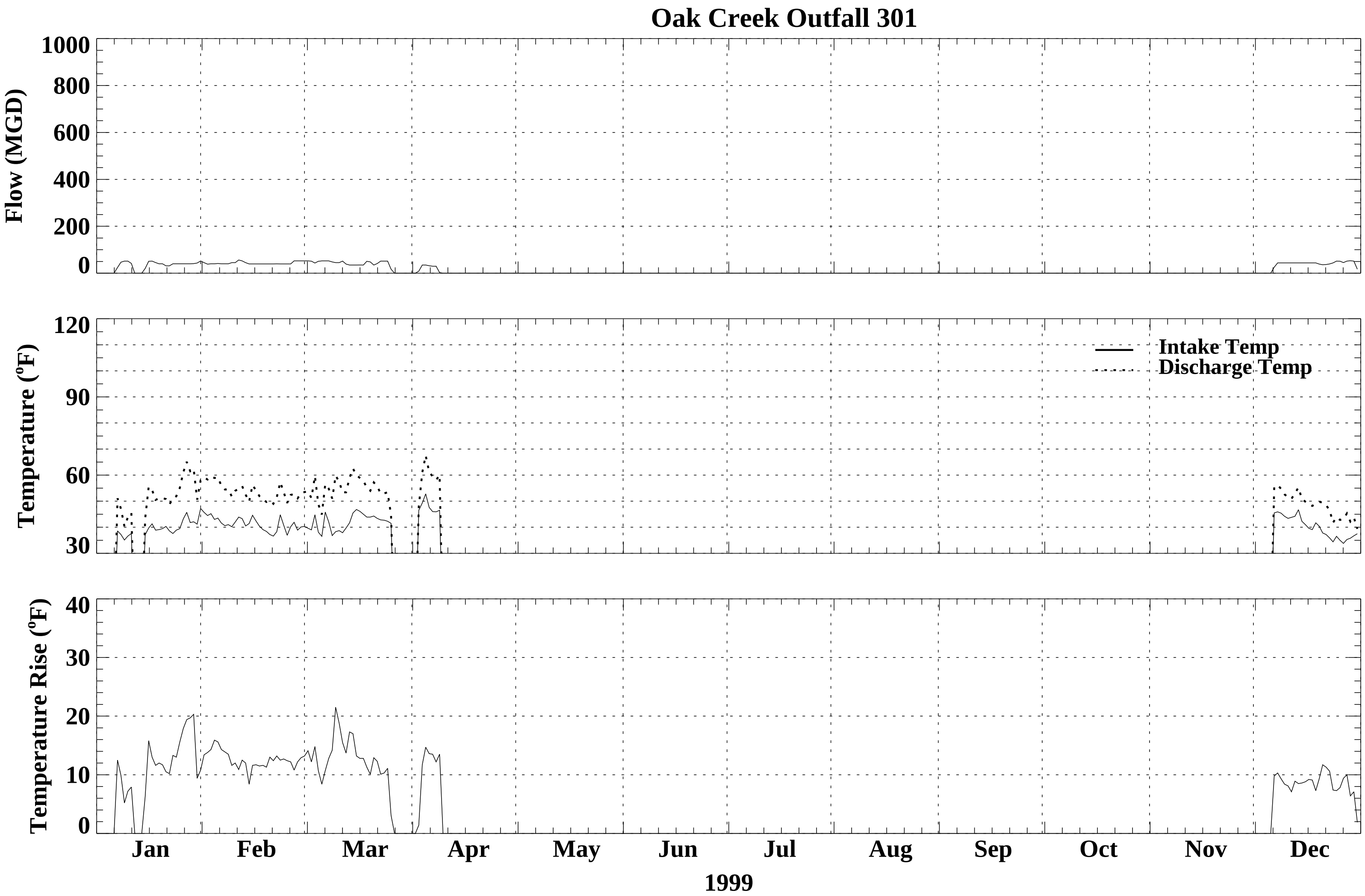
Oak Creek Outfall 304
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998



Oak Creek Outfall 305
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998

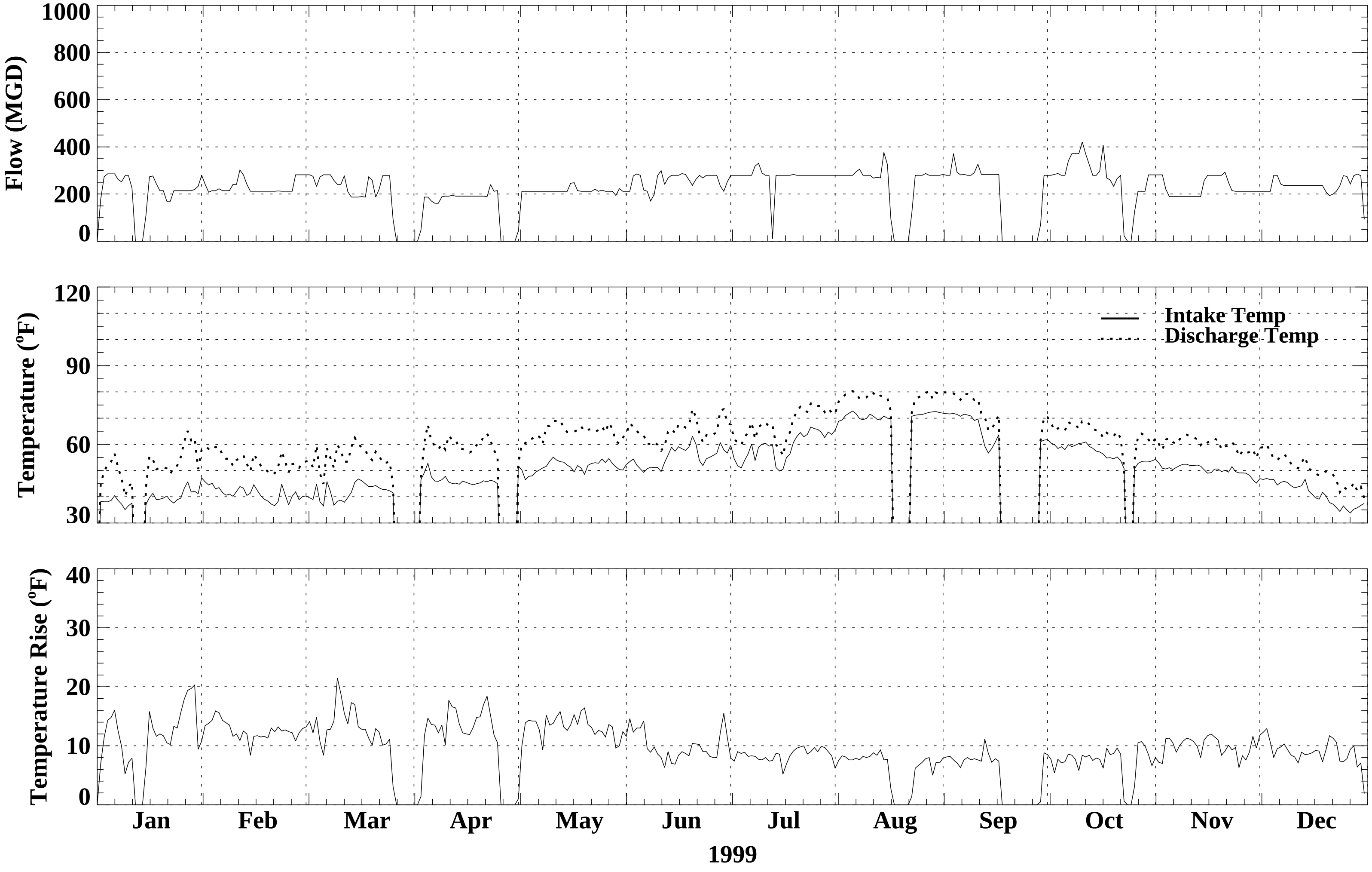


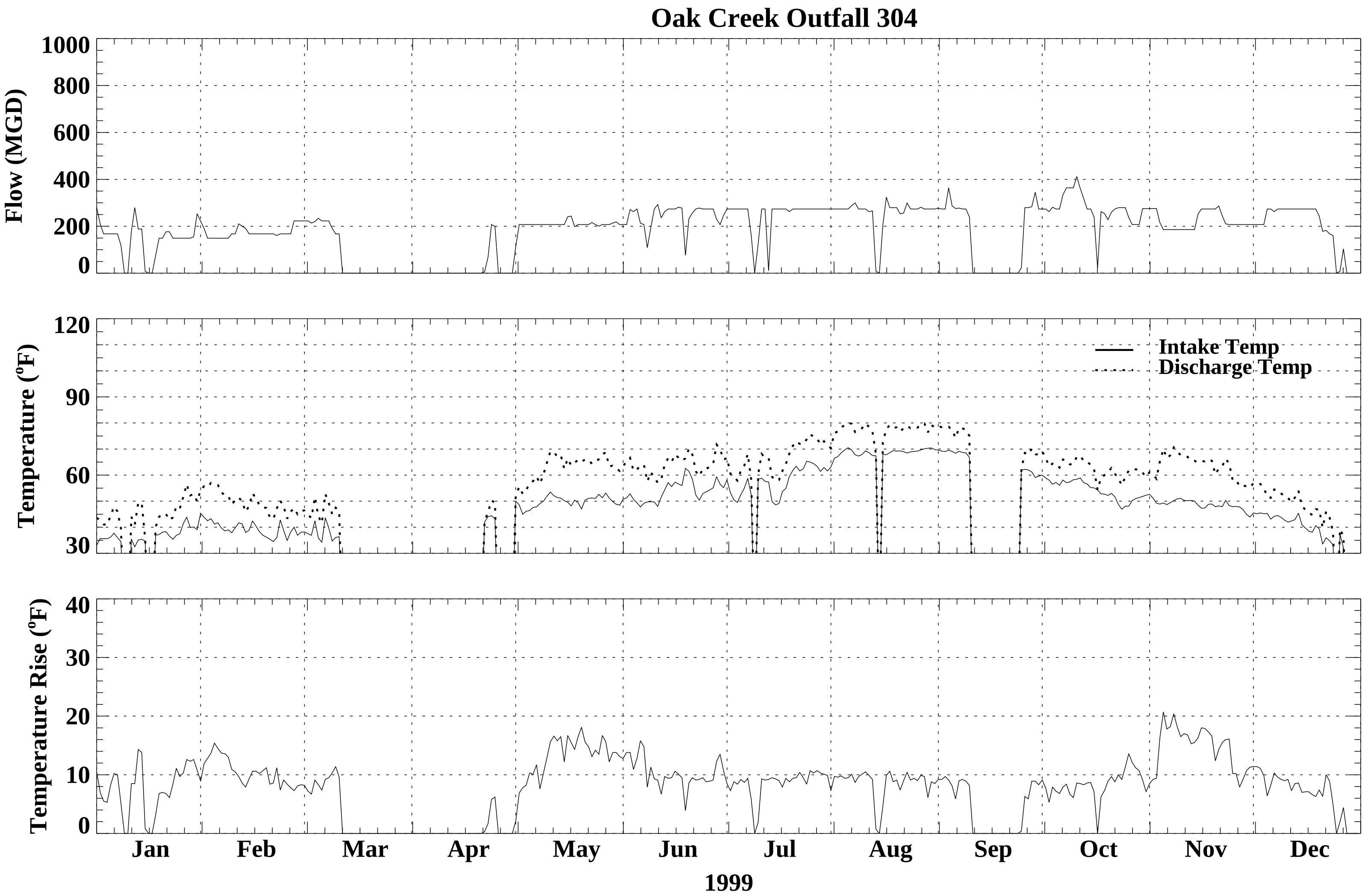
Oak Creek Outfall 306
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998

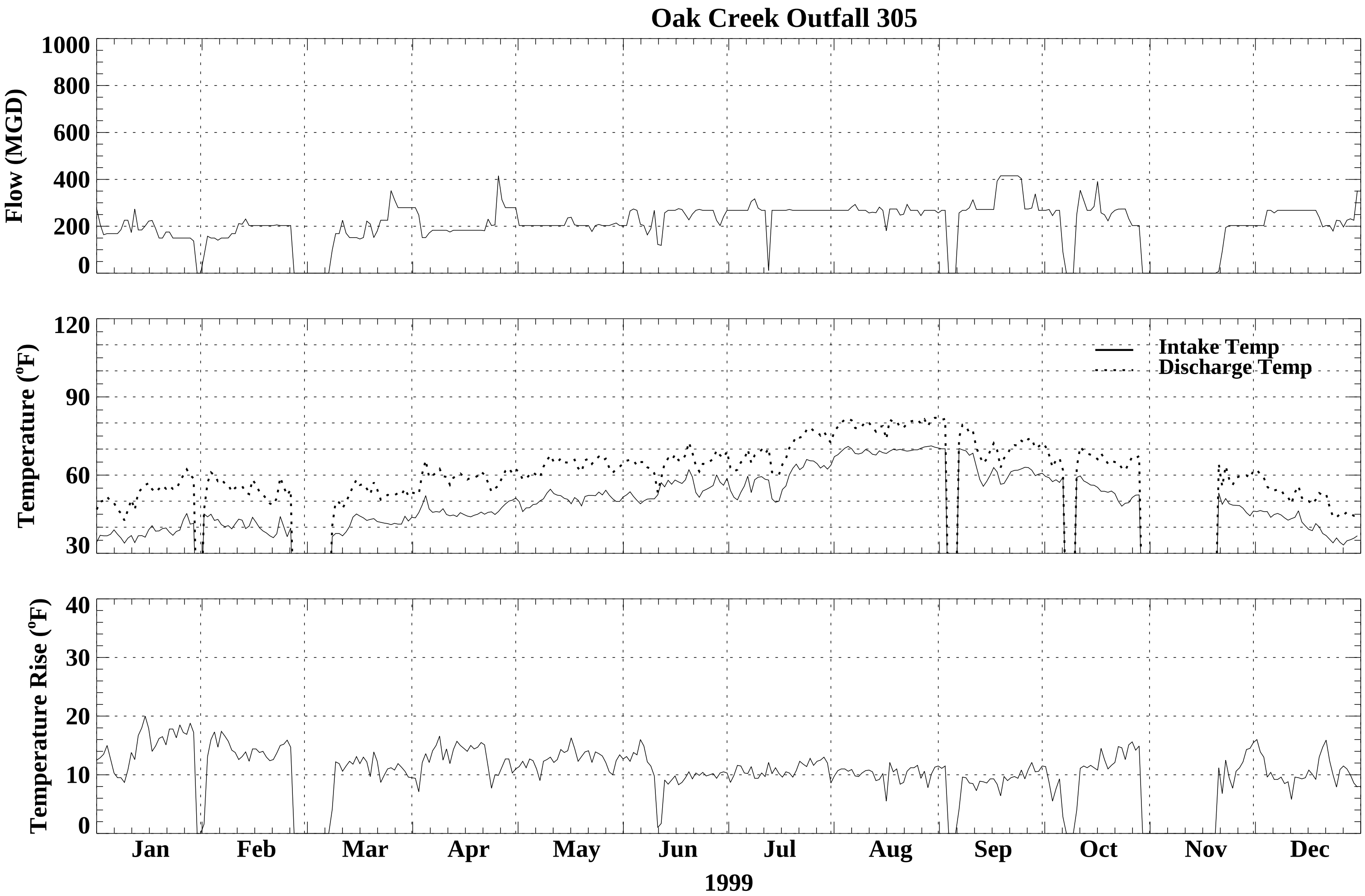


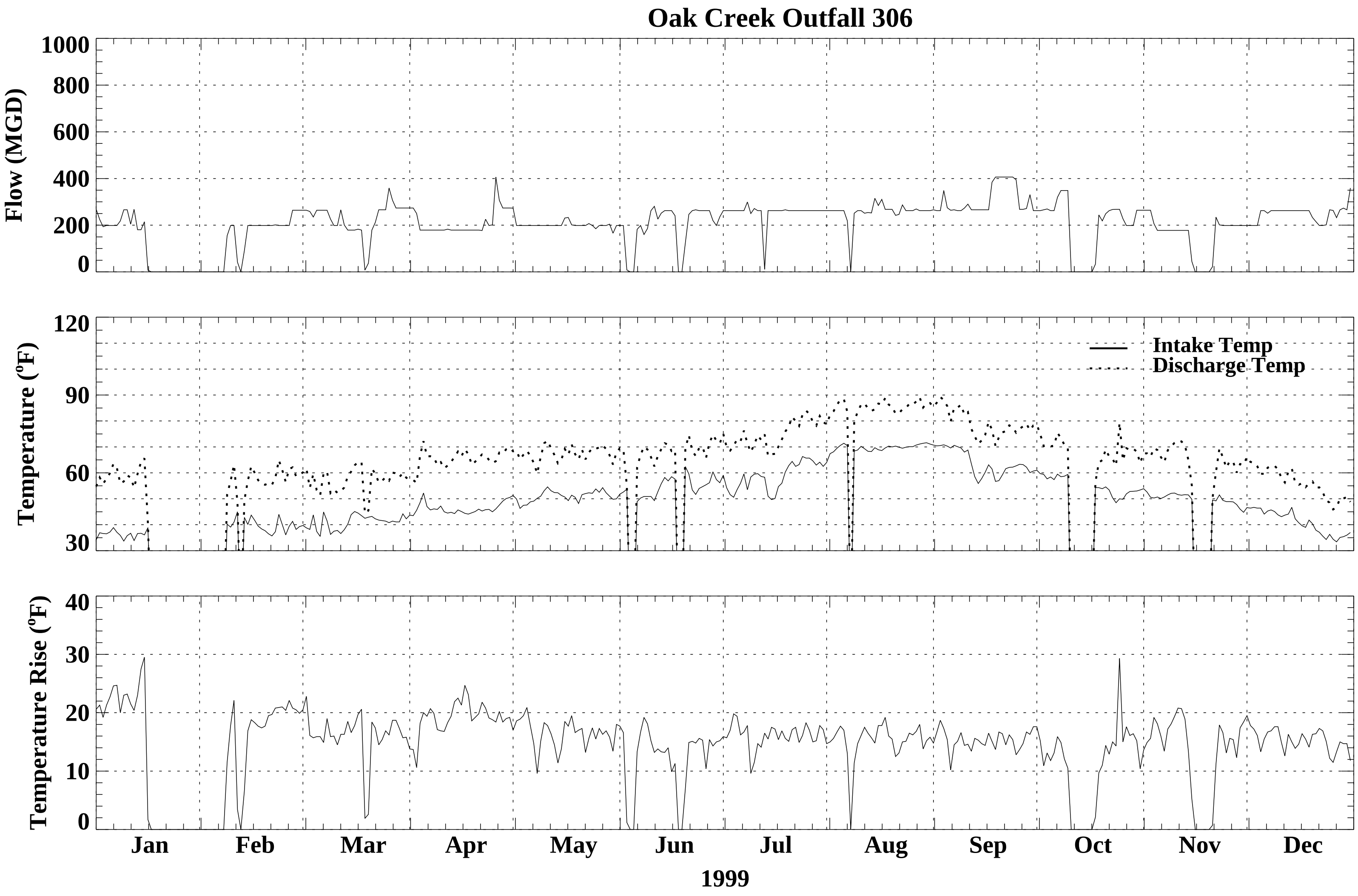
Oak Creek Outfall 301
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999

Oak Creek Outfall 303

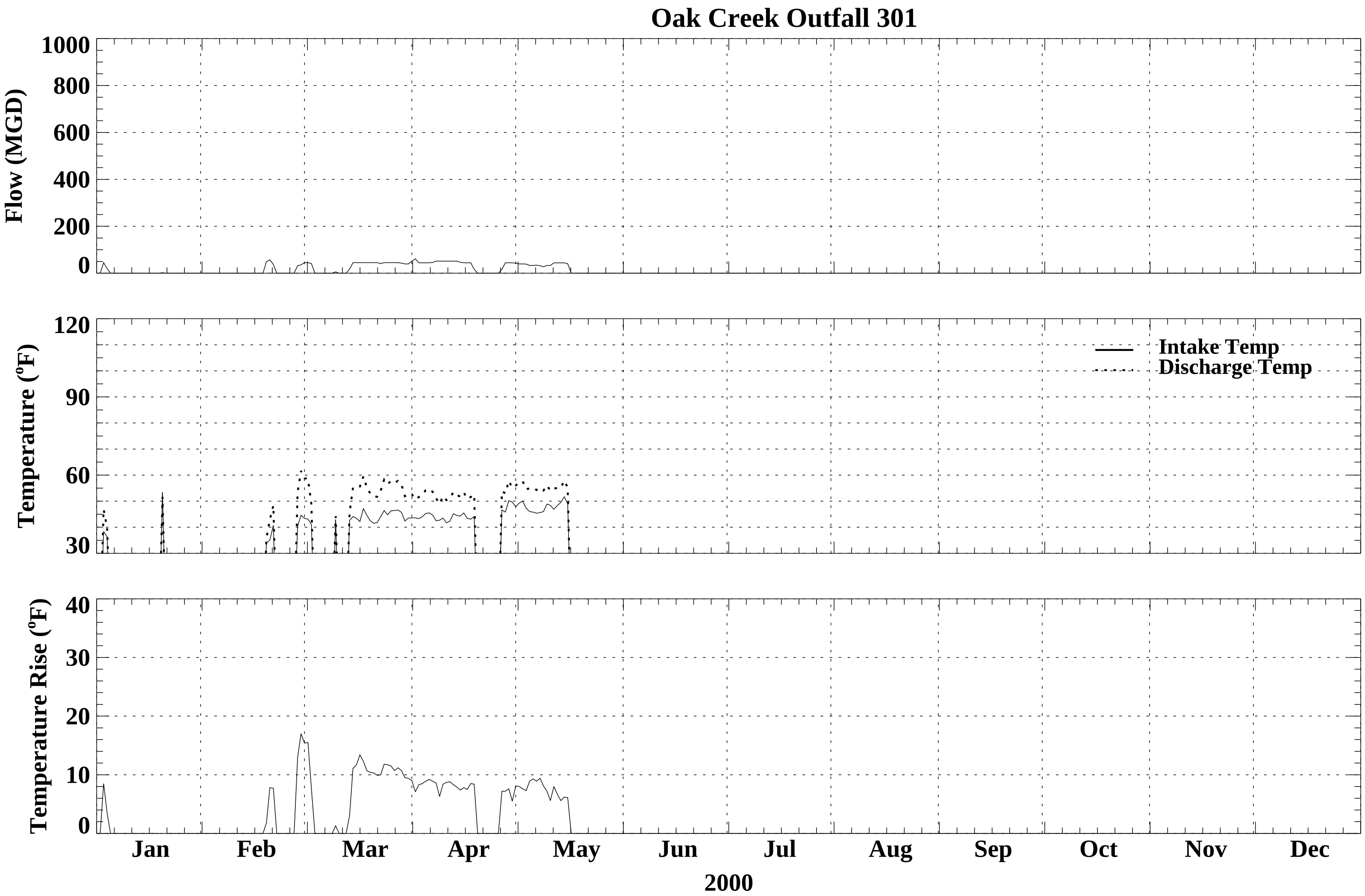


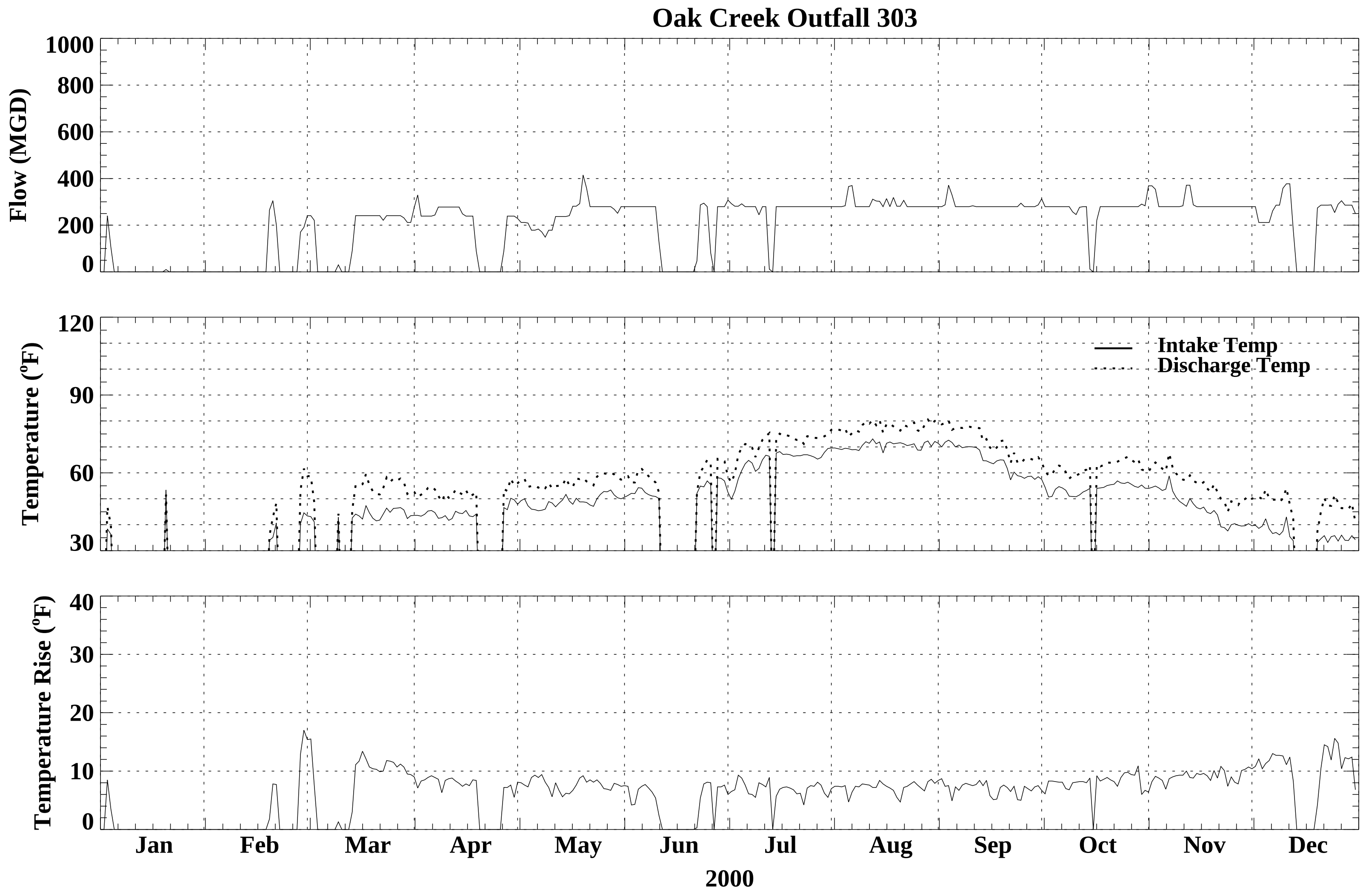

Oak Creek Outfall 304
Flow (MGD)
1000
800
600
400
200
0
Temperature (ºF)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (ºF)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999


Oak Creek Outfall 305
Flow (MGD)
1000
800
600
400
200
0
Temperature (ºF)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (ºF)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999

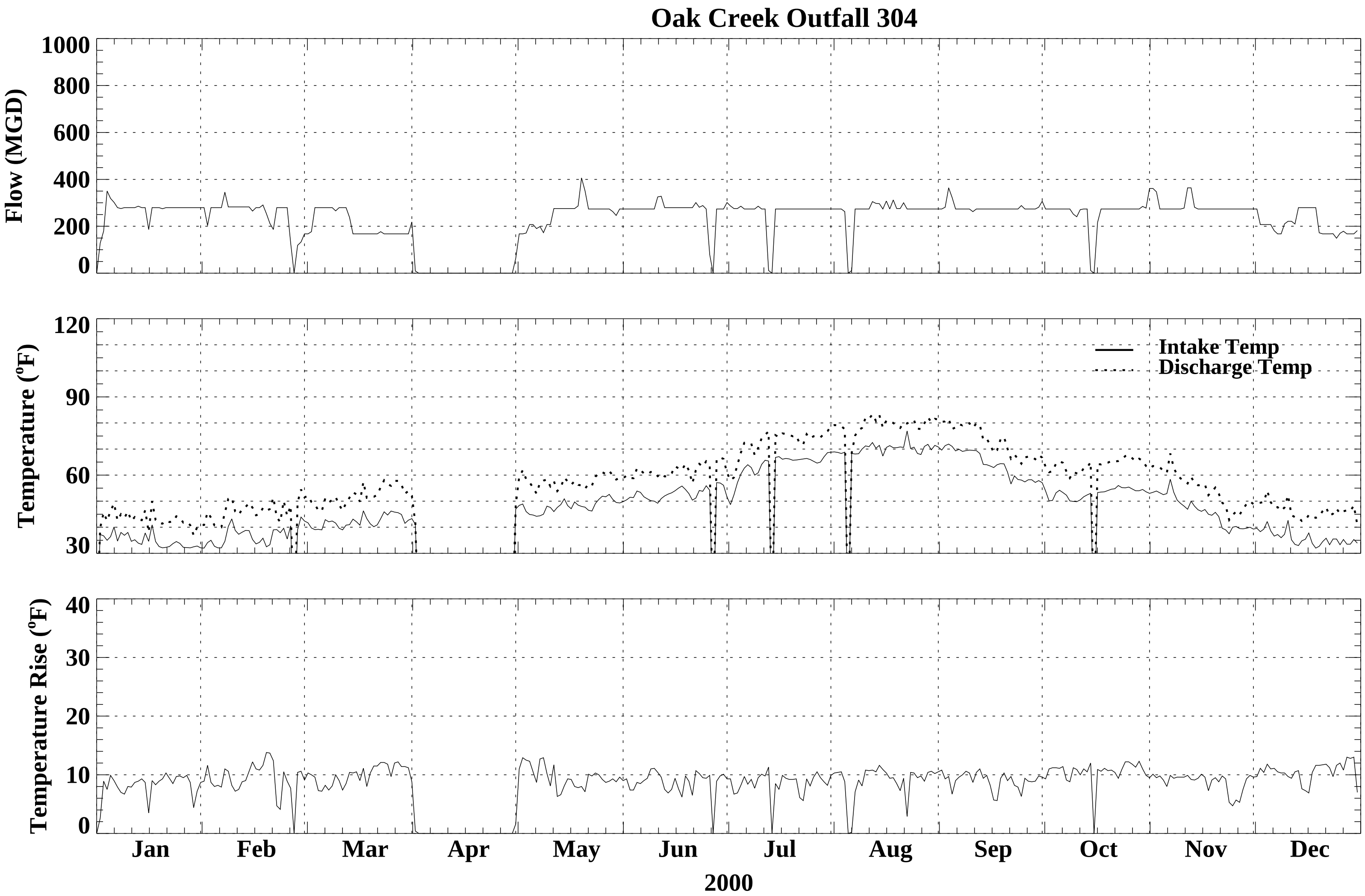


Oak Creek Outfall 306
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999

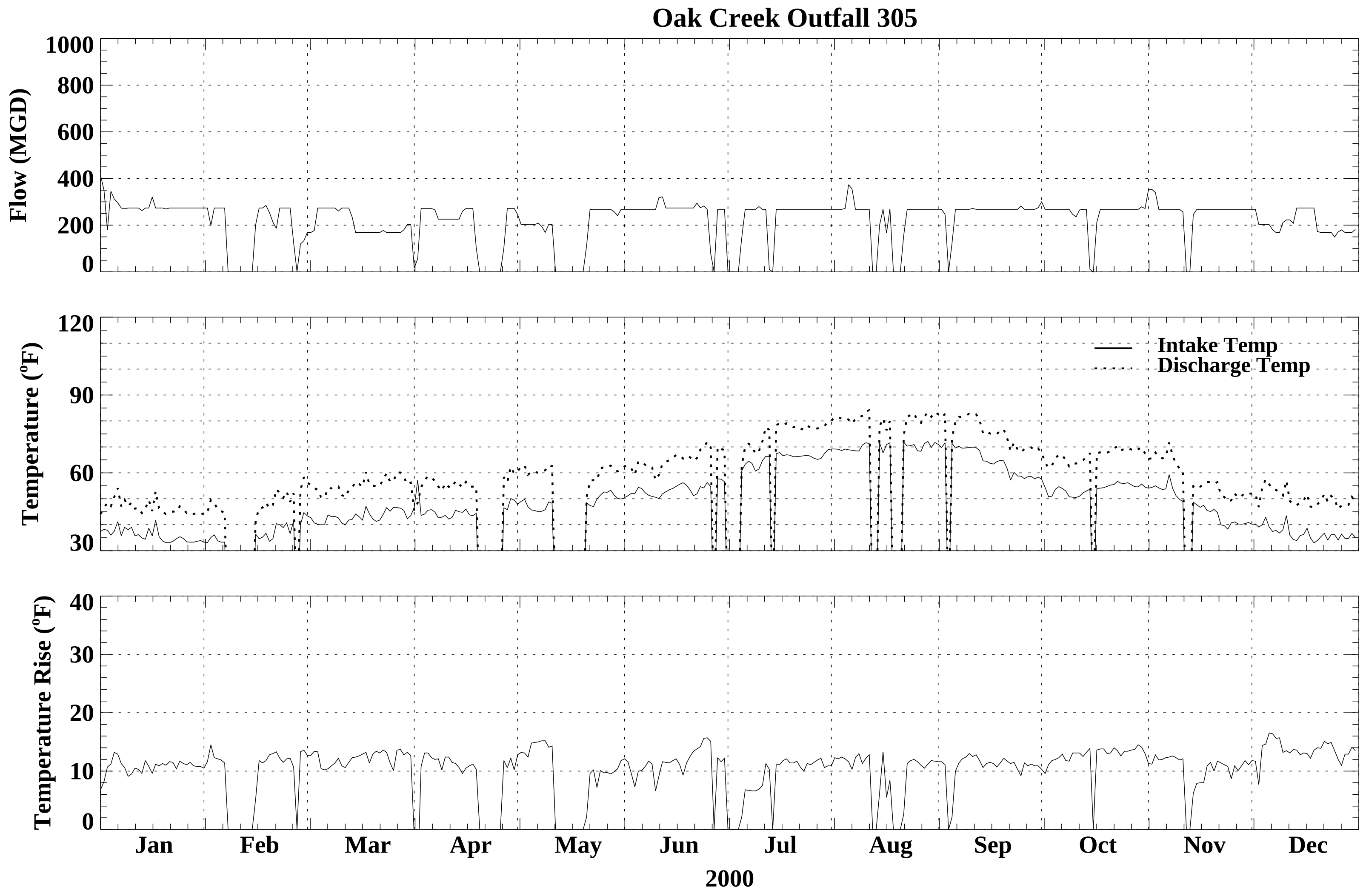

Oak Creek Outfall 301
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000



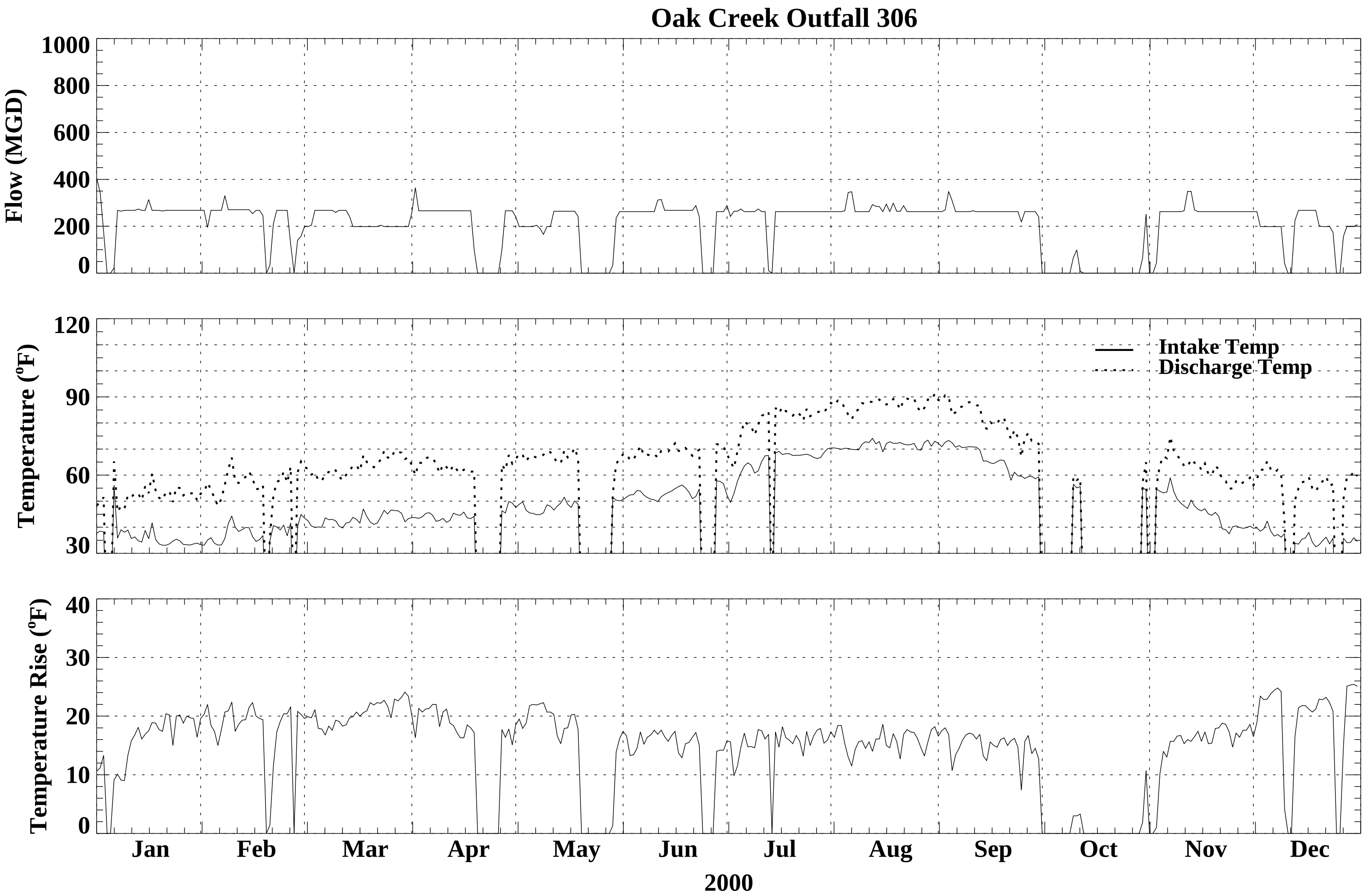
Oak Creek Outfall 303
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000

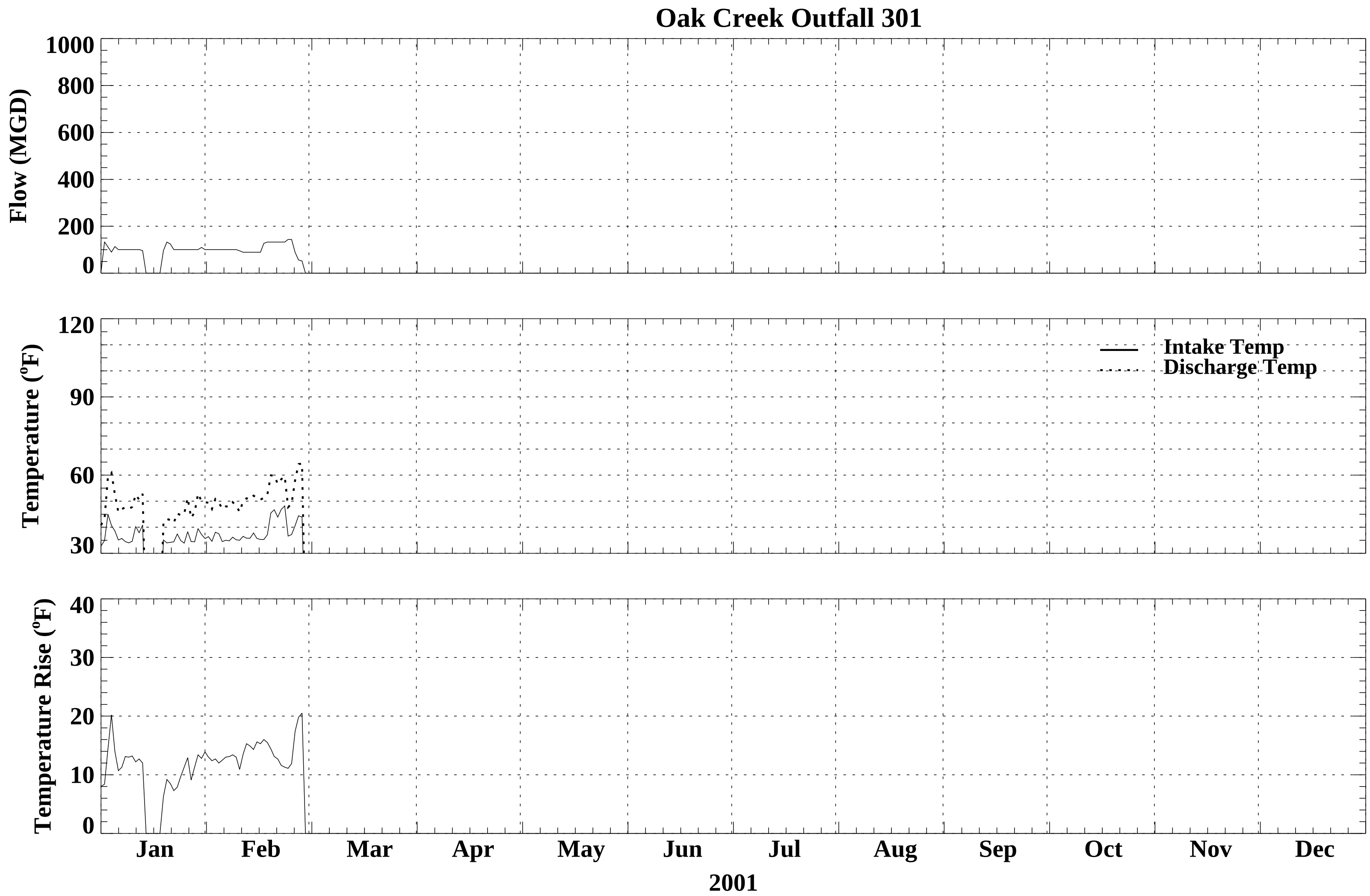


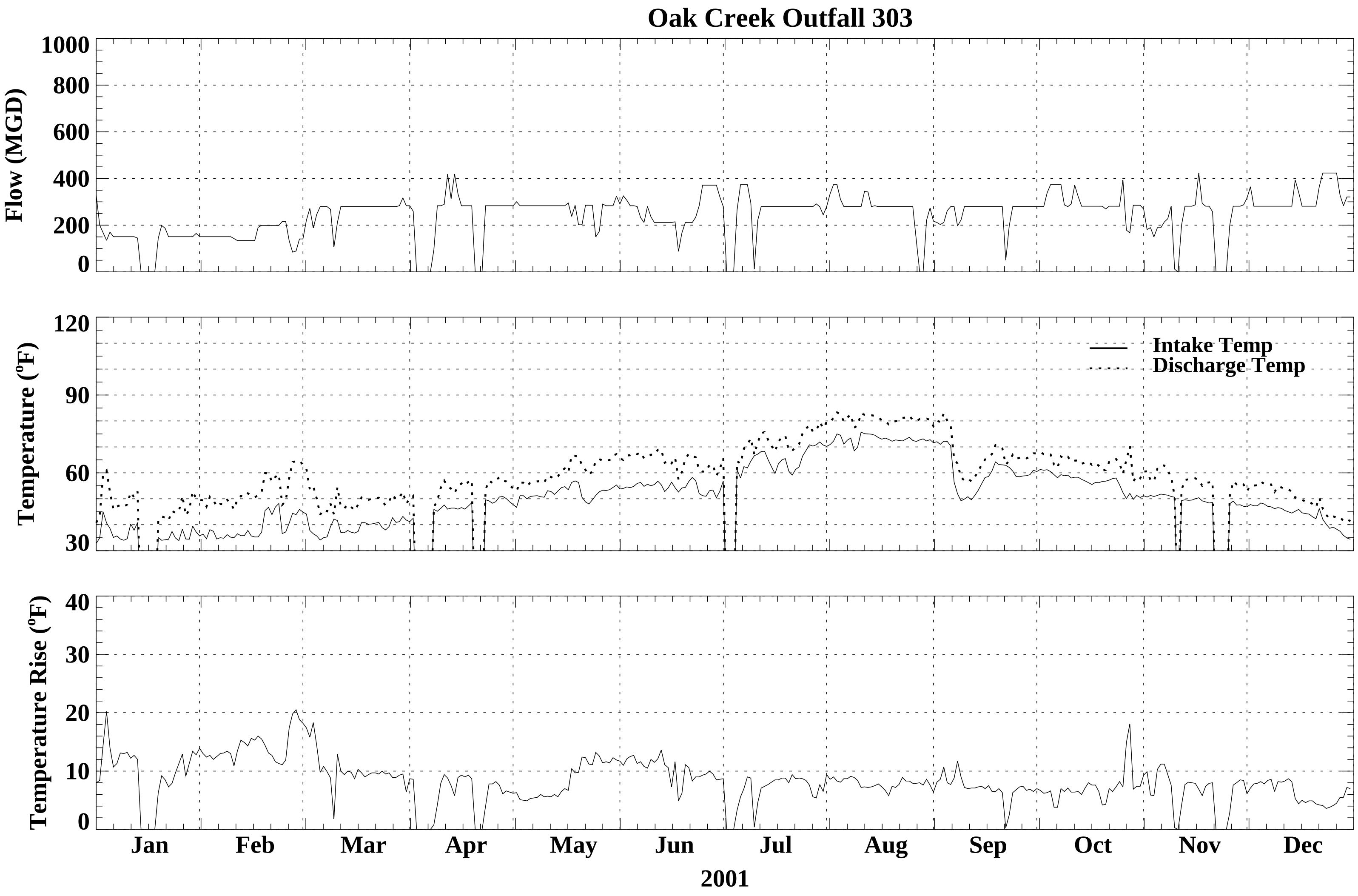
Oak Creek Outfall 304
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000

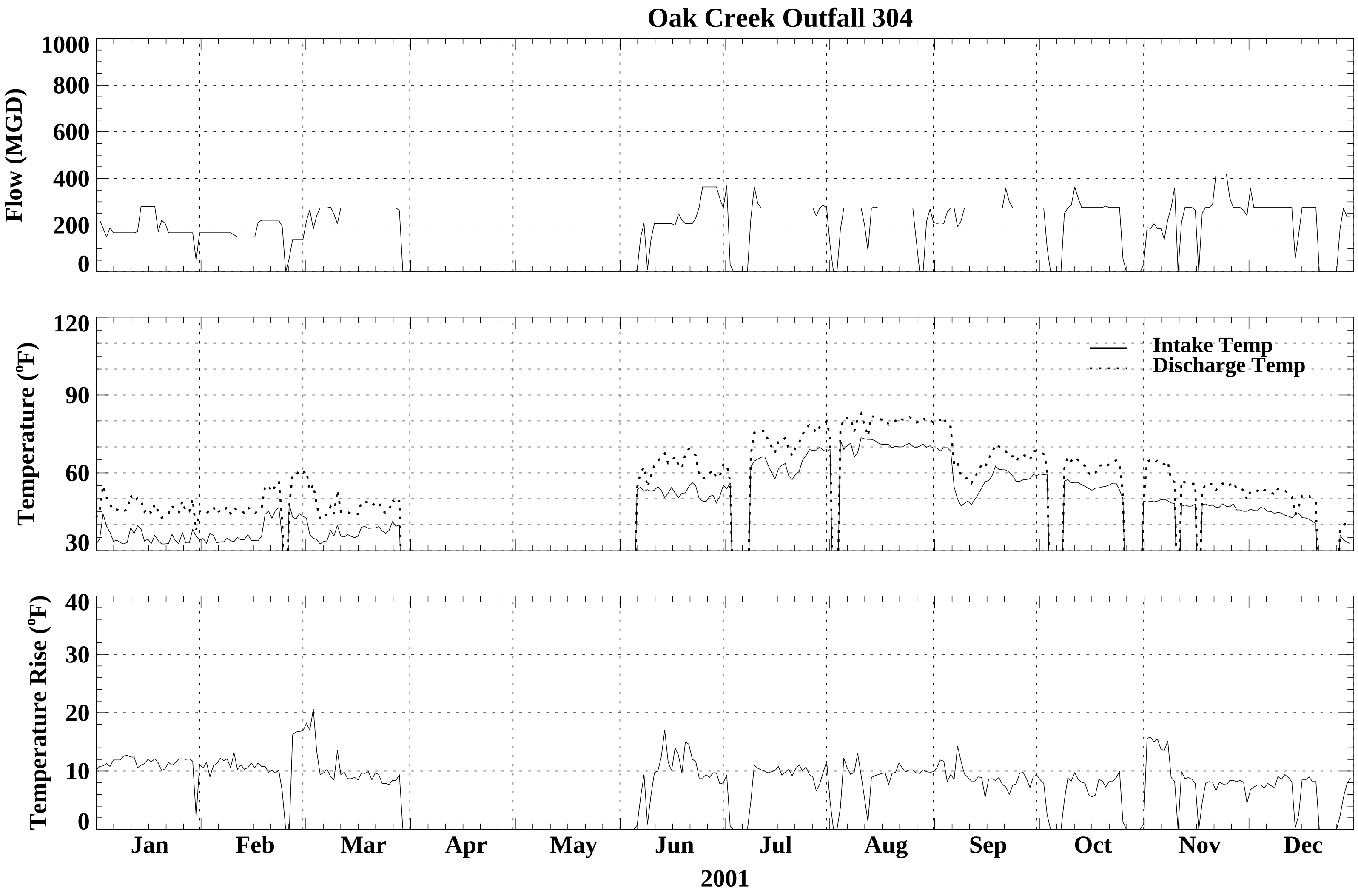

Oak Creek Outfall 305
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000

Oak Creek Outfall 306

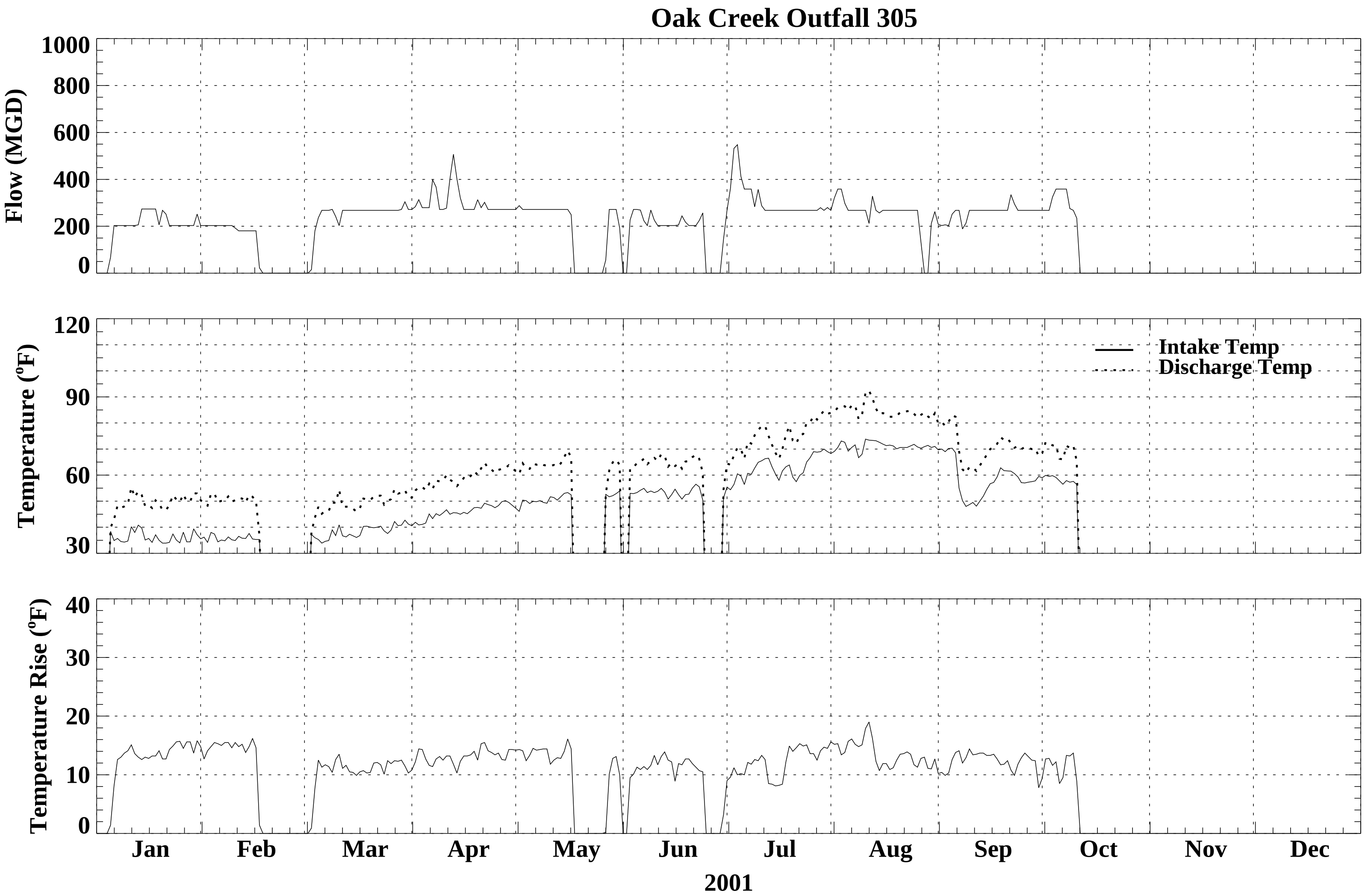



Oak Creek Outfall 301
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001

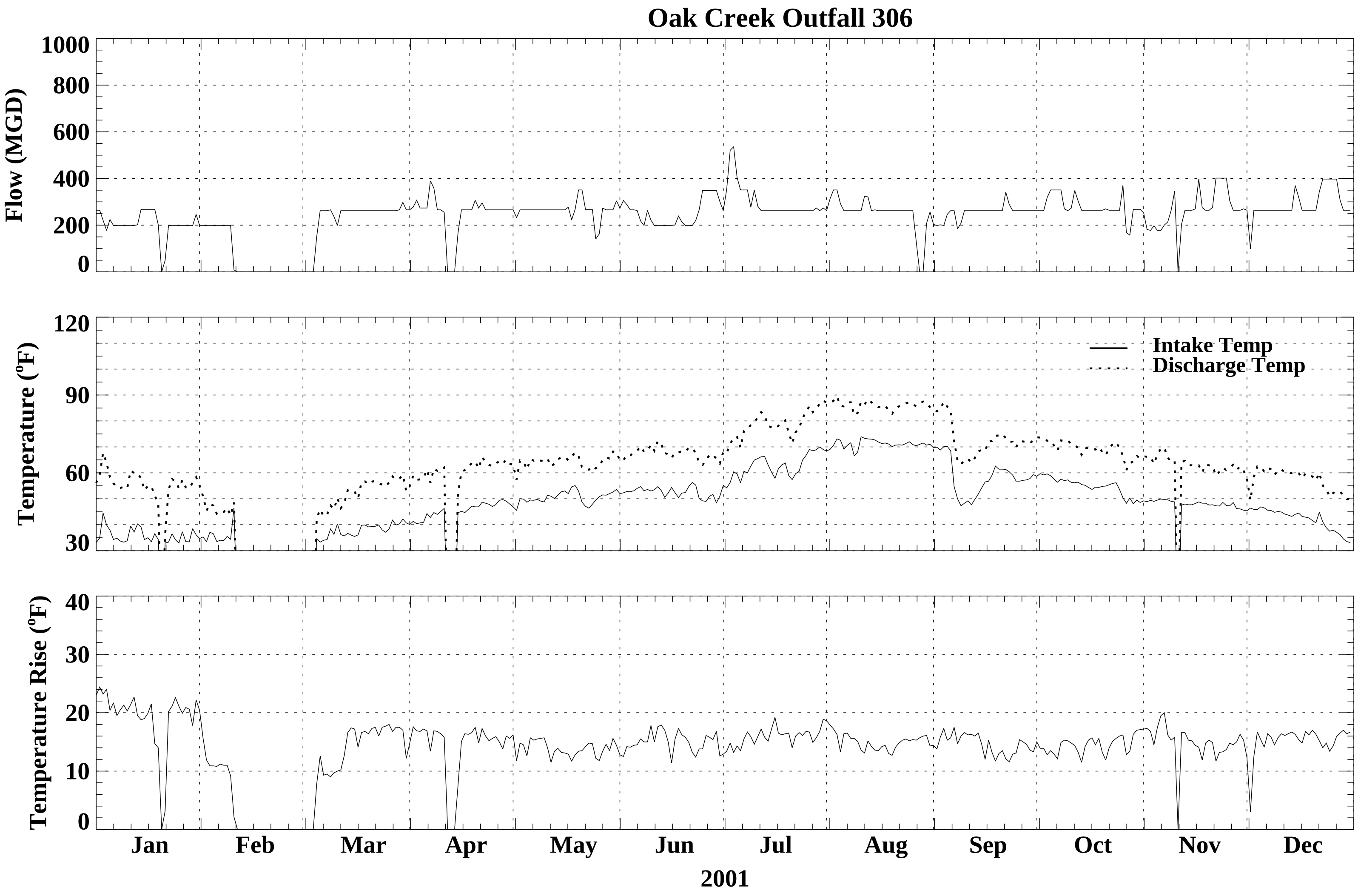

Oak Creek Outfall 303
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001



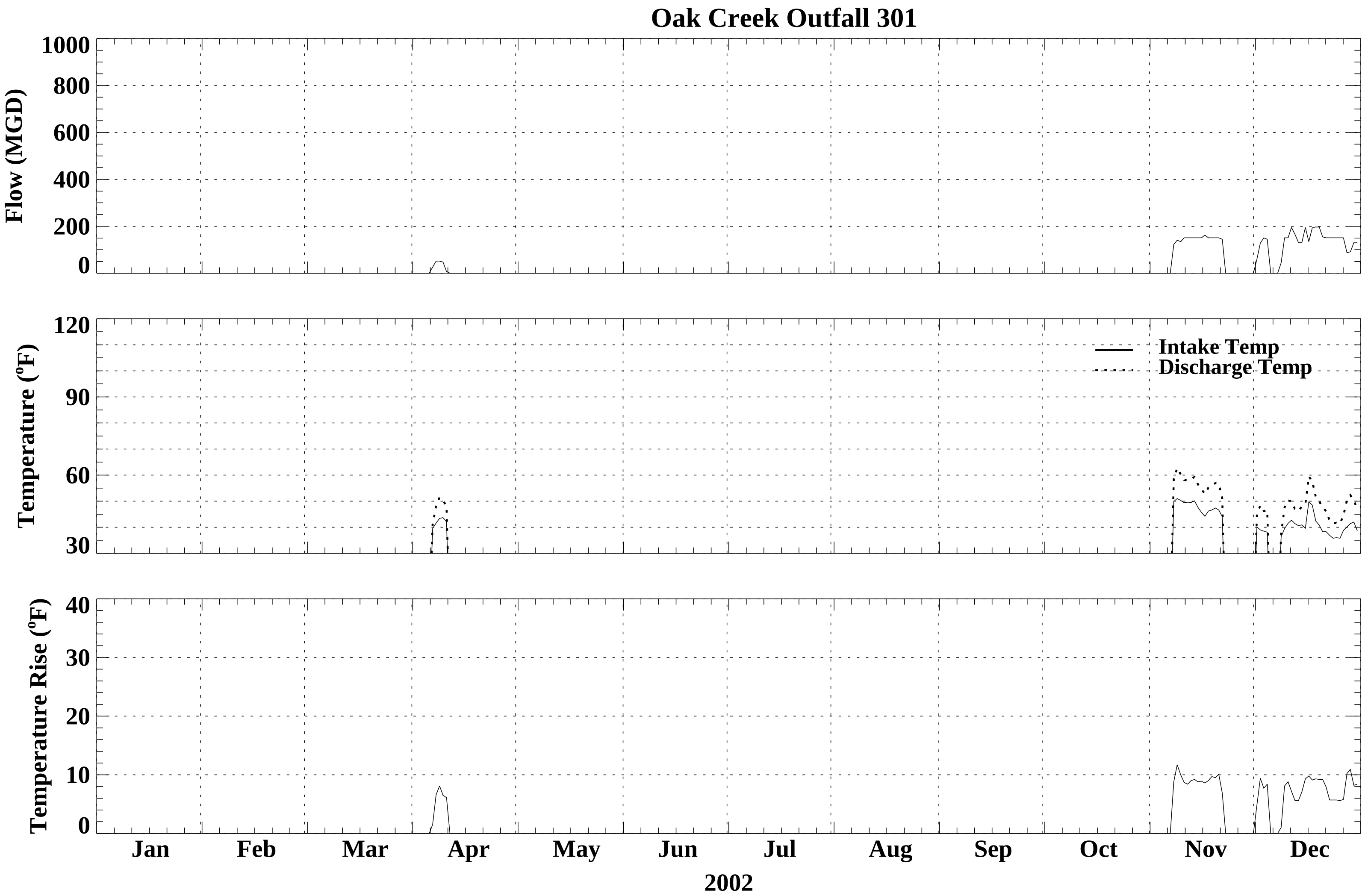
Oak Creek Outfall 304
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001



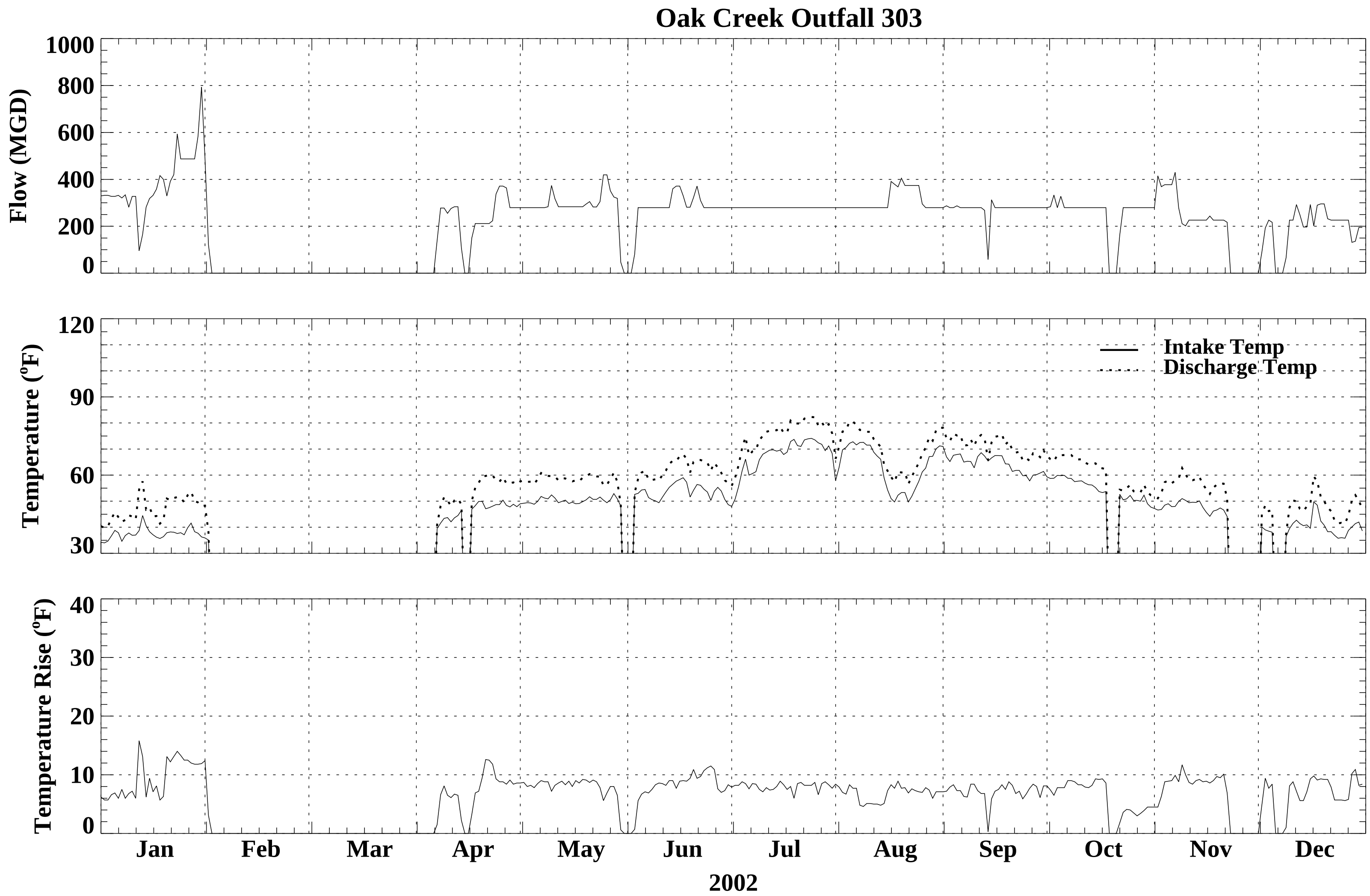
Oak Creek Outfall 305
Flow (MGD)
1000
800
600
400
200
0
Temperature (ºF)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (ºF)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001



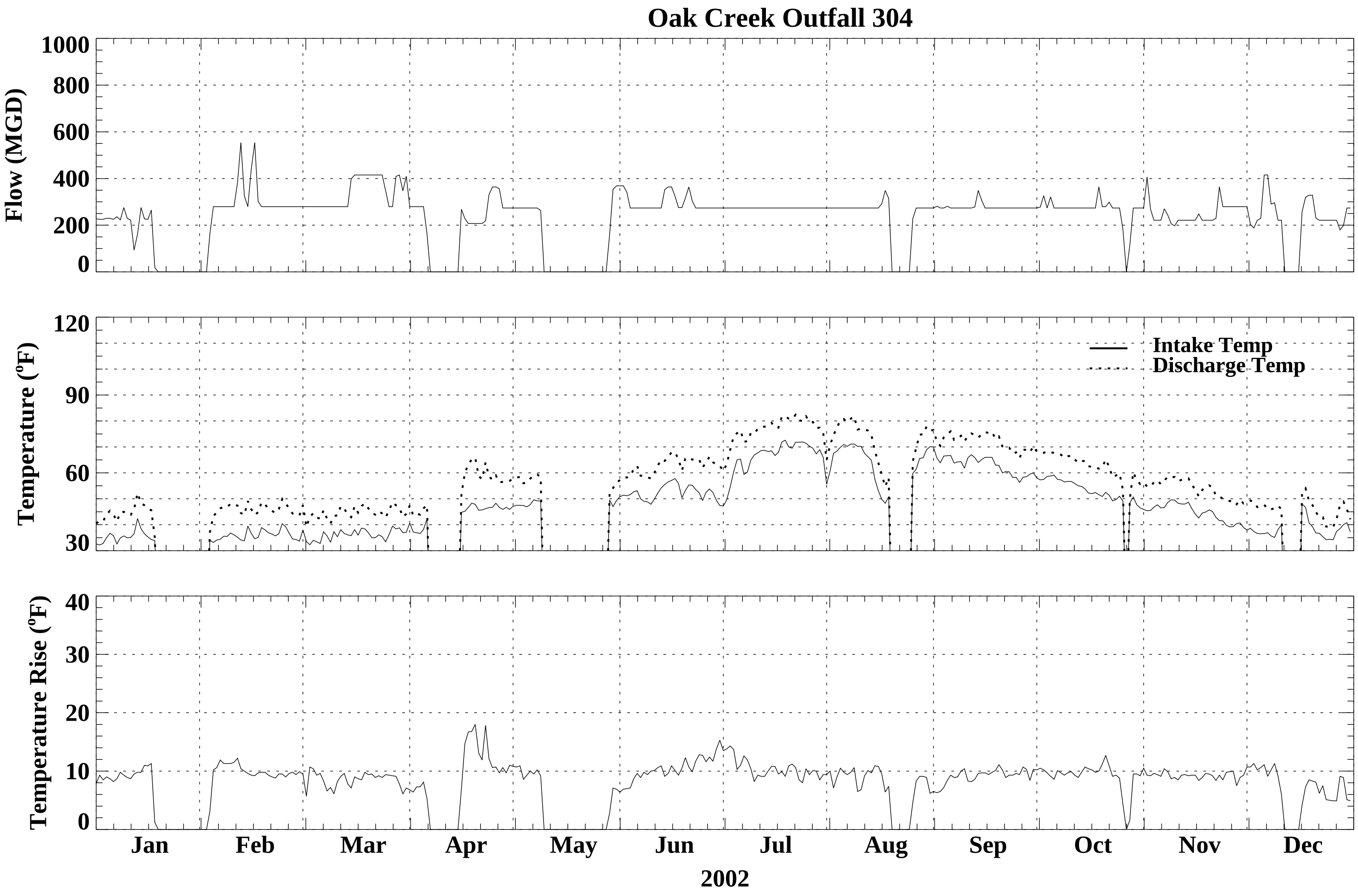
Oak Creek Outfall 306
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001



Oak Creek Outfall 301
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002

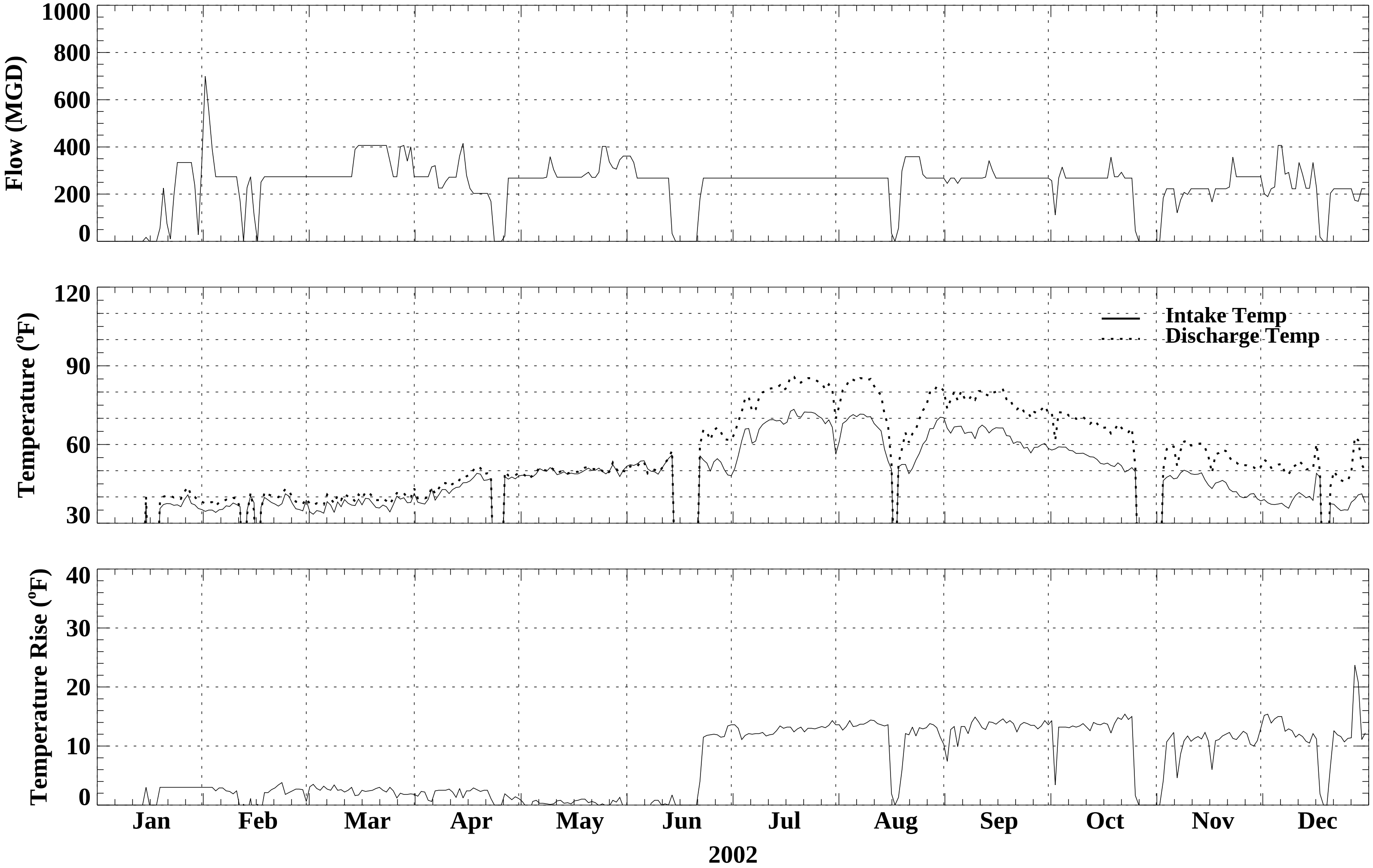


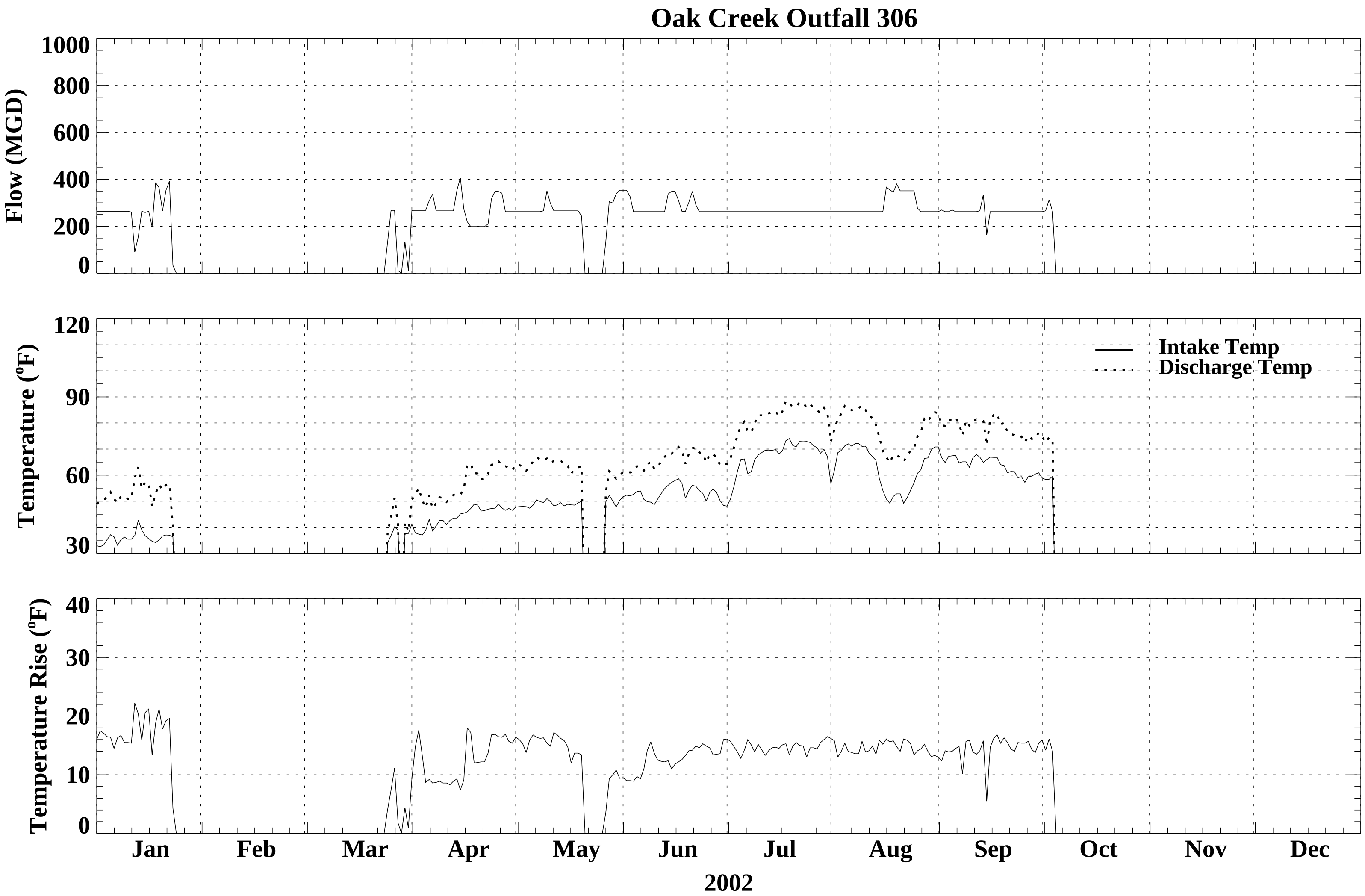
Oak Creek Outfall 303
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002



Oak Creek Outfall 304
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002

Oak Creek Outfall 305

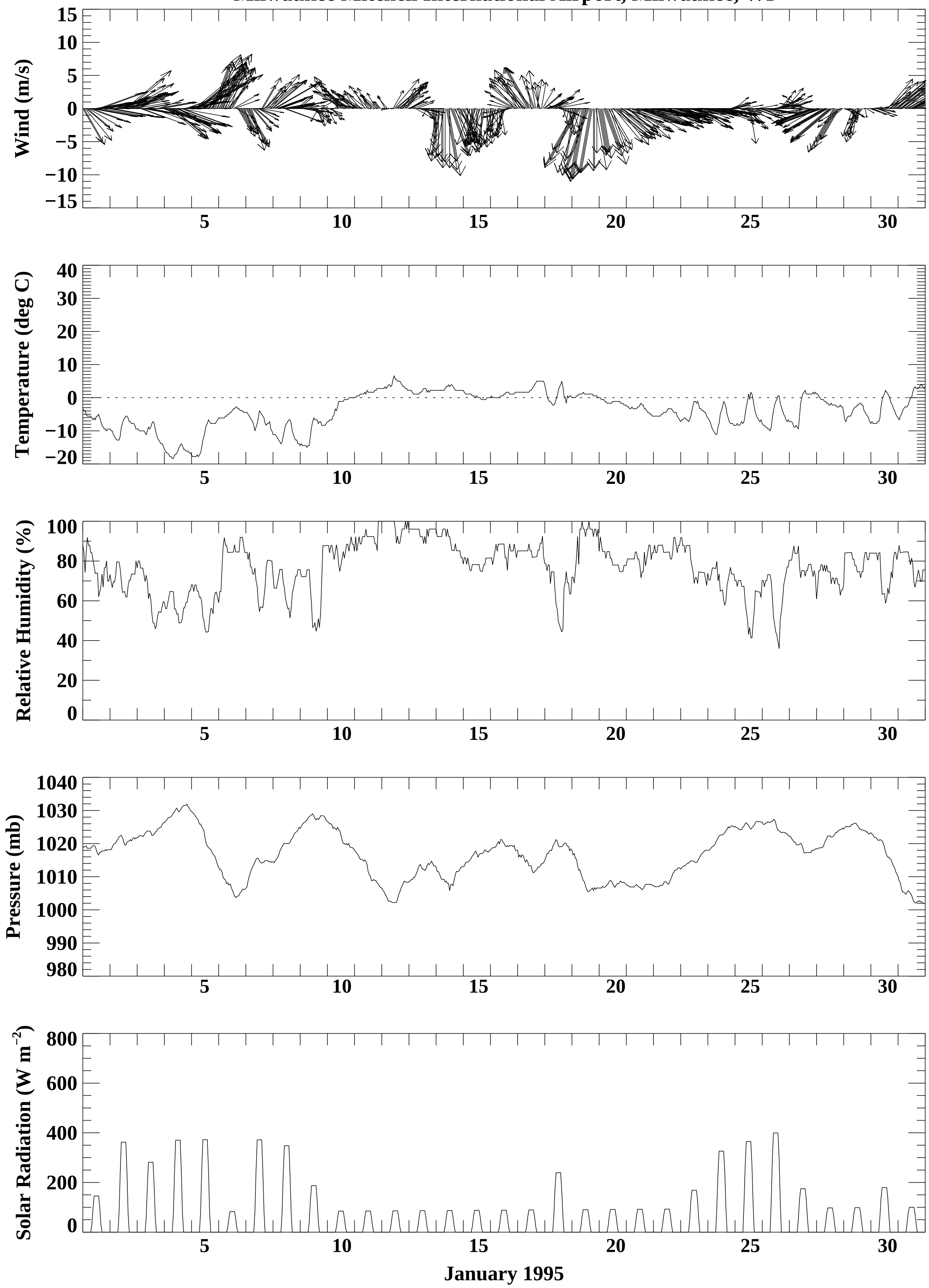


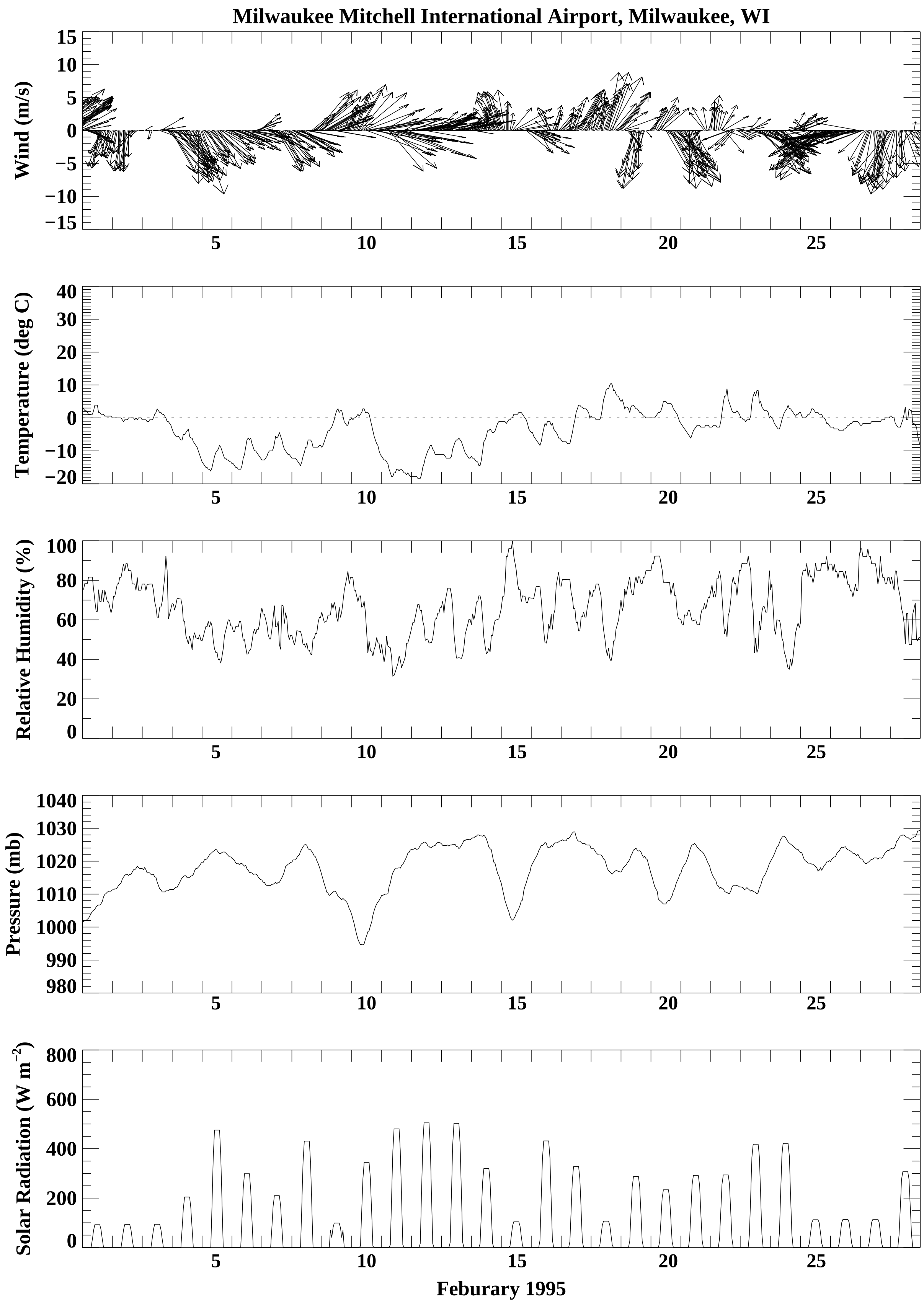


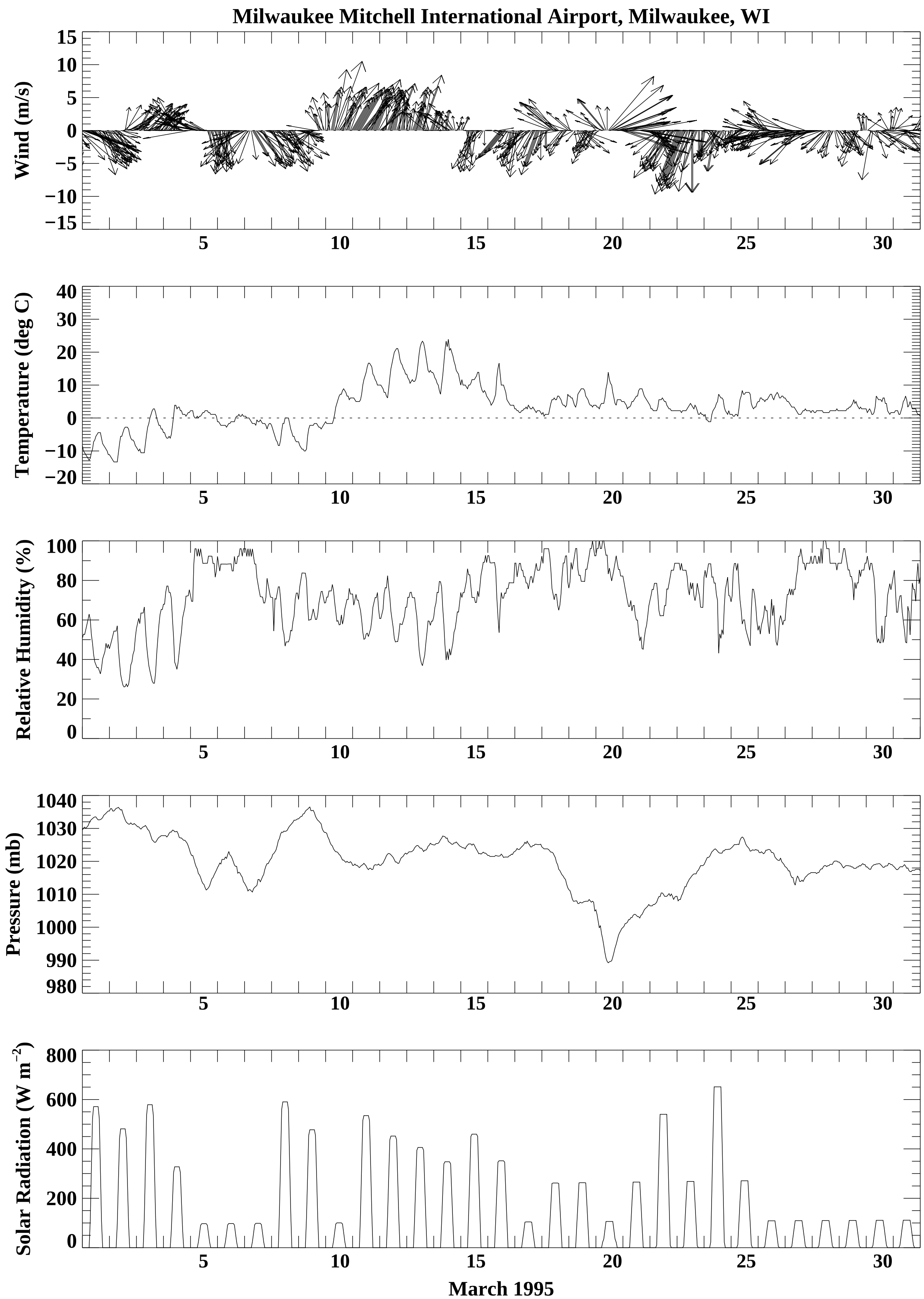
Oak Creek Outfall 306
Flow (MGD)
1000
800
600
400
200
0
Temperature (°F)
120
90
60
30
Intake Temp
Discharge Temp
Temperature Rise (°F)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002

ATTACHMENT 12
METEOROLOGICAL PARAMETERS

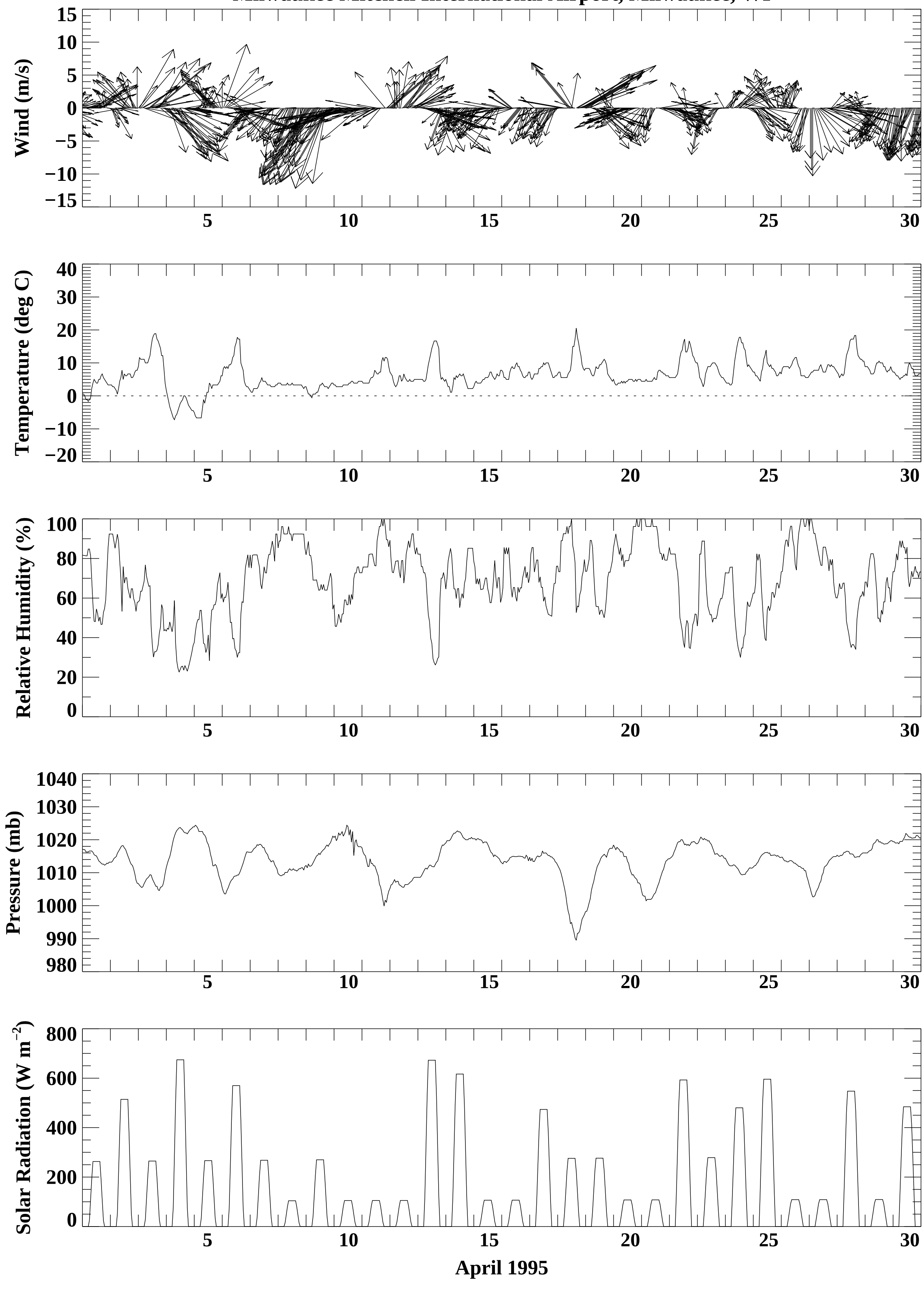
Milwaukee Mitchell International Airport, Milwaukee, WI

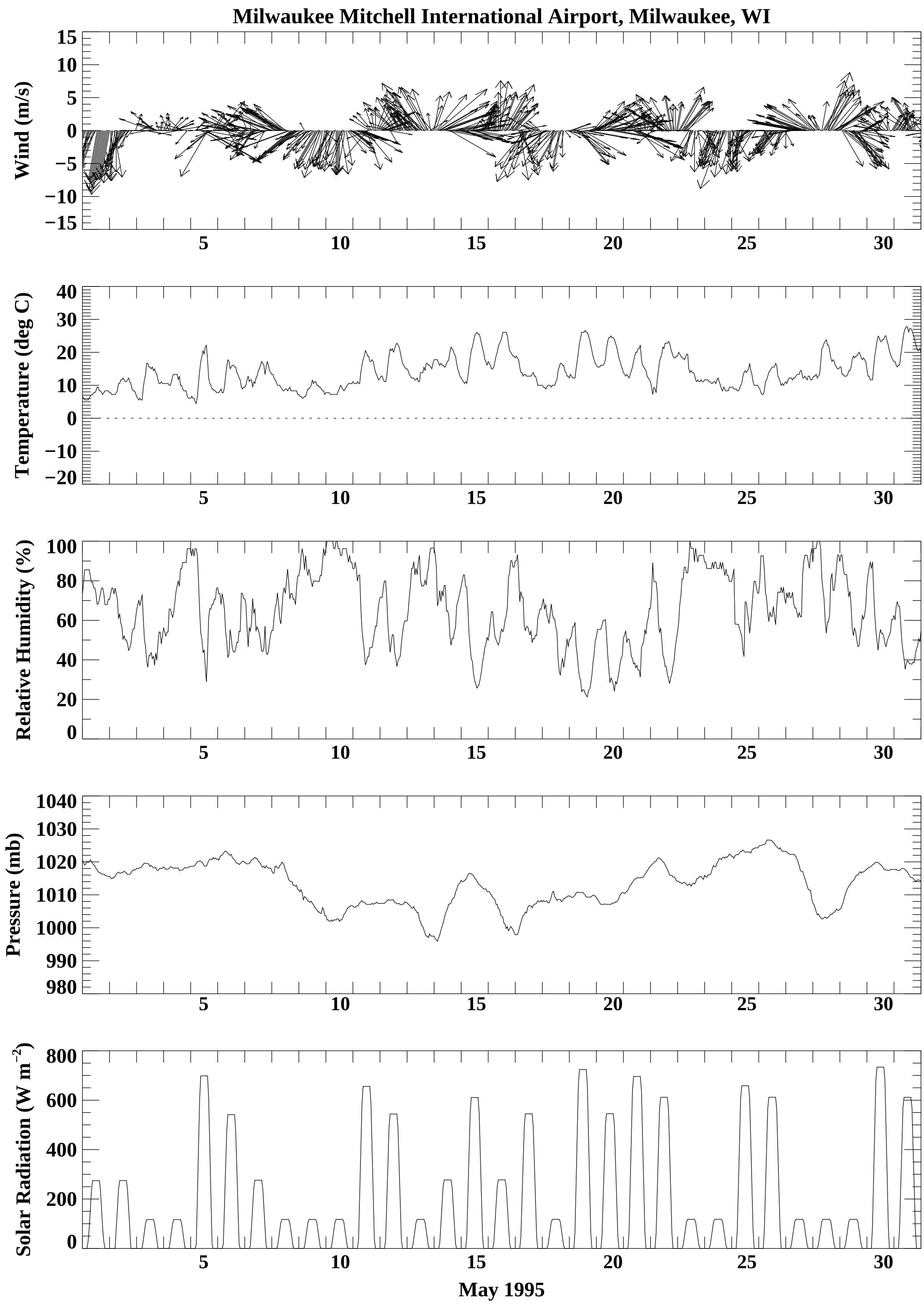


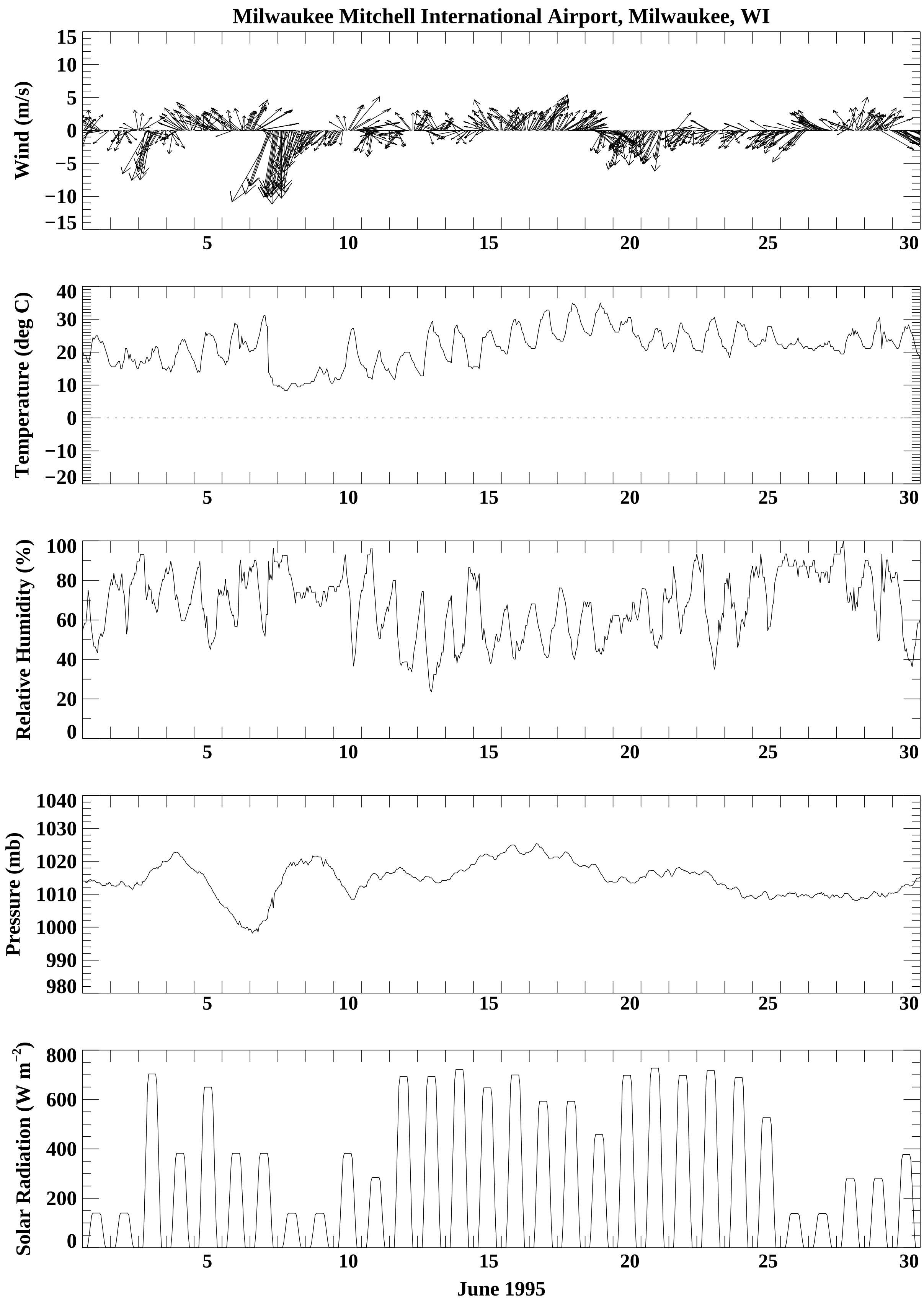

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
Feburary 1995


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m⁻²)
March 1995

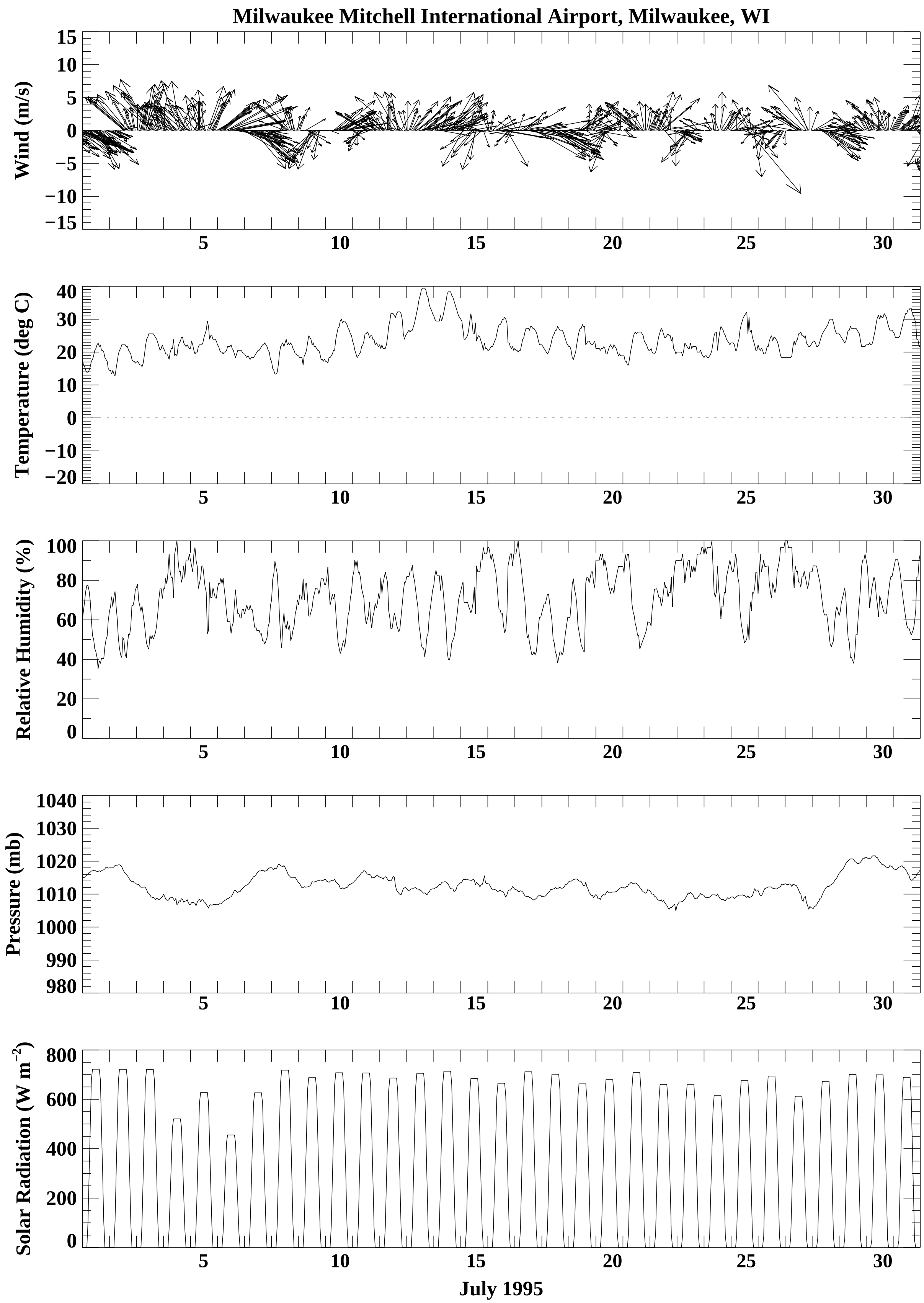
Milwaukee Mitchell International Airport, Milwaukee, WI



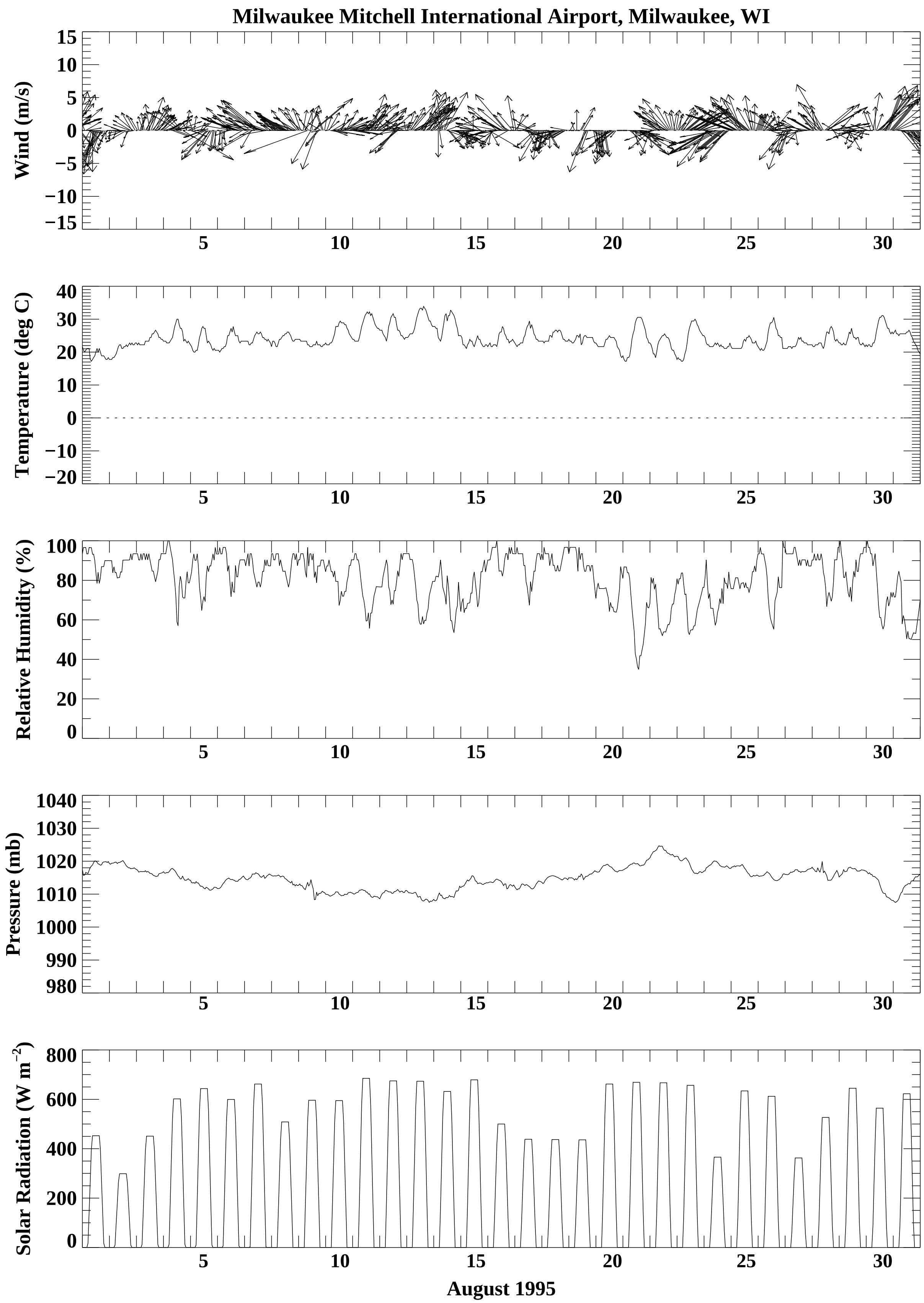

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
5
10
15
20
25
30
May 1995

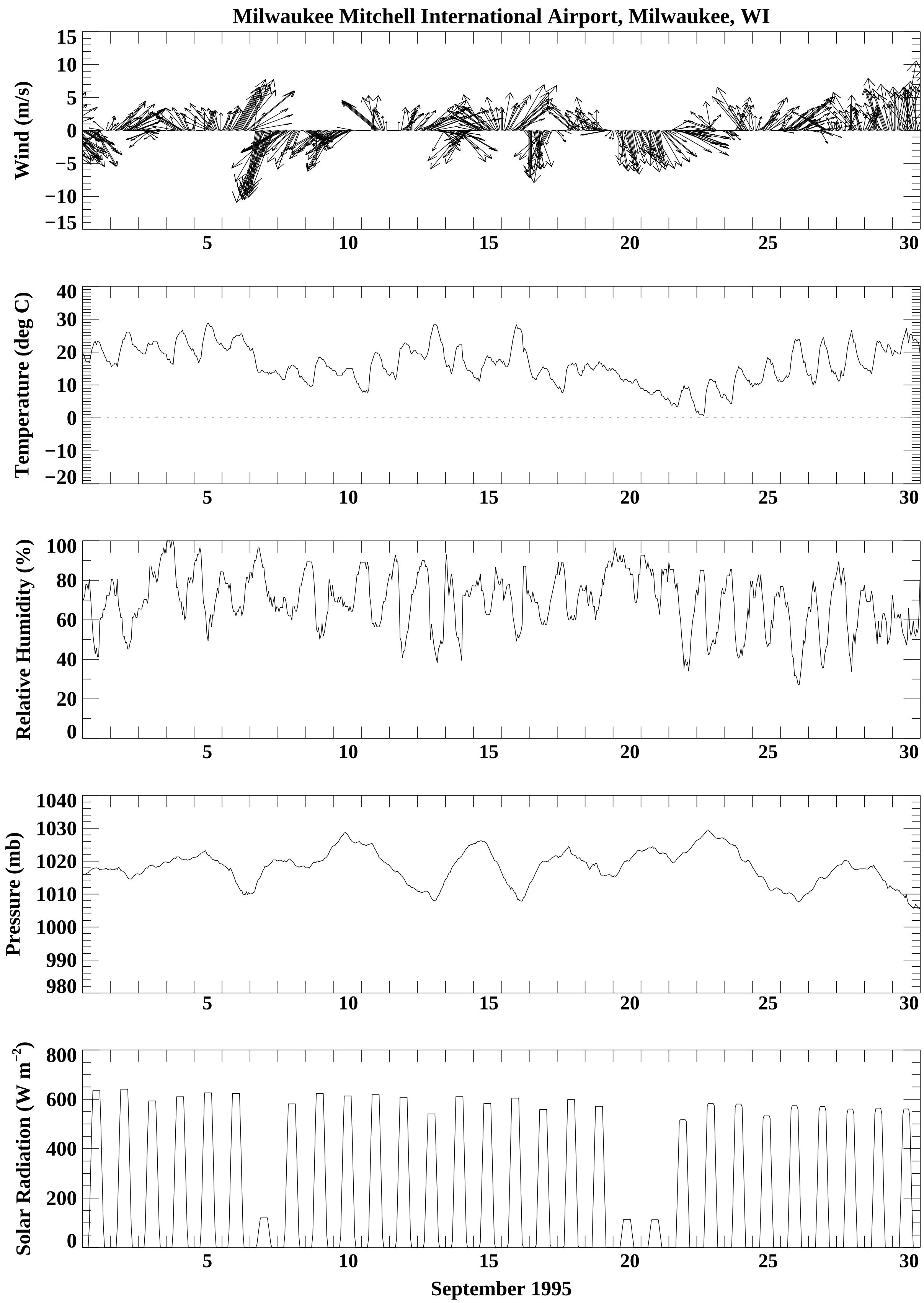


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
June 1995

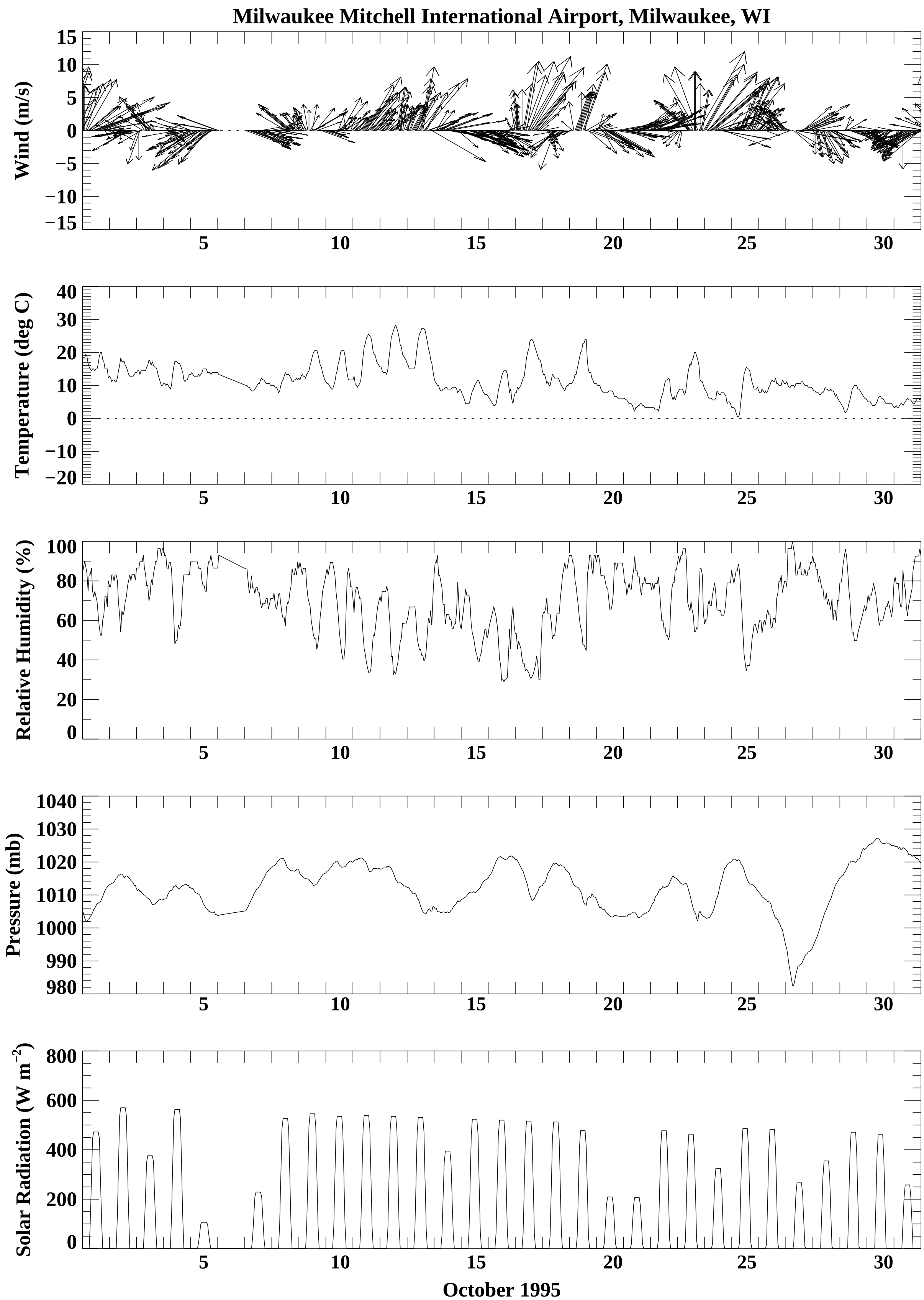


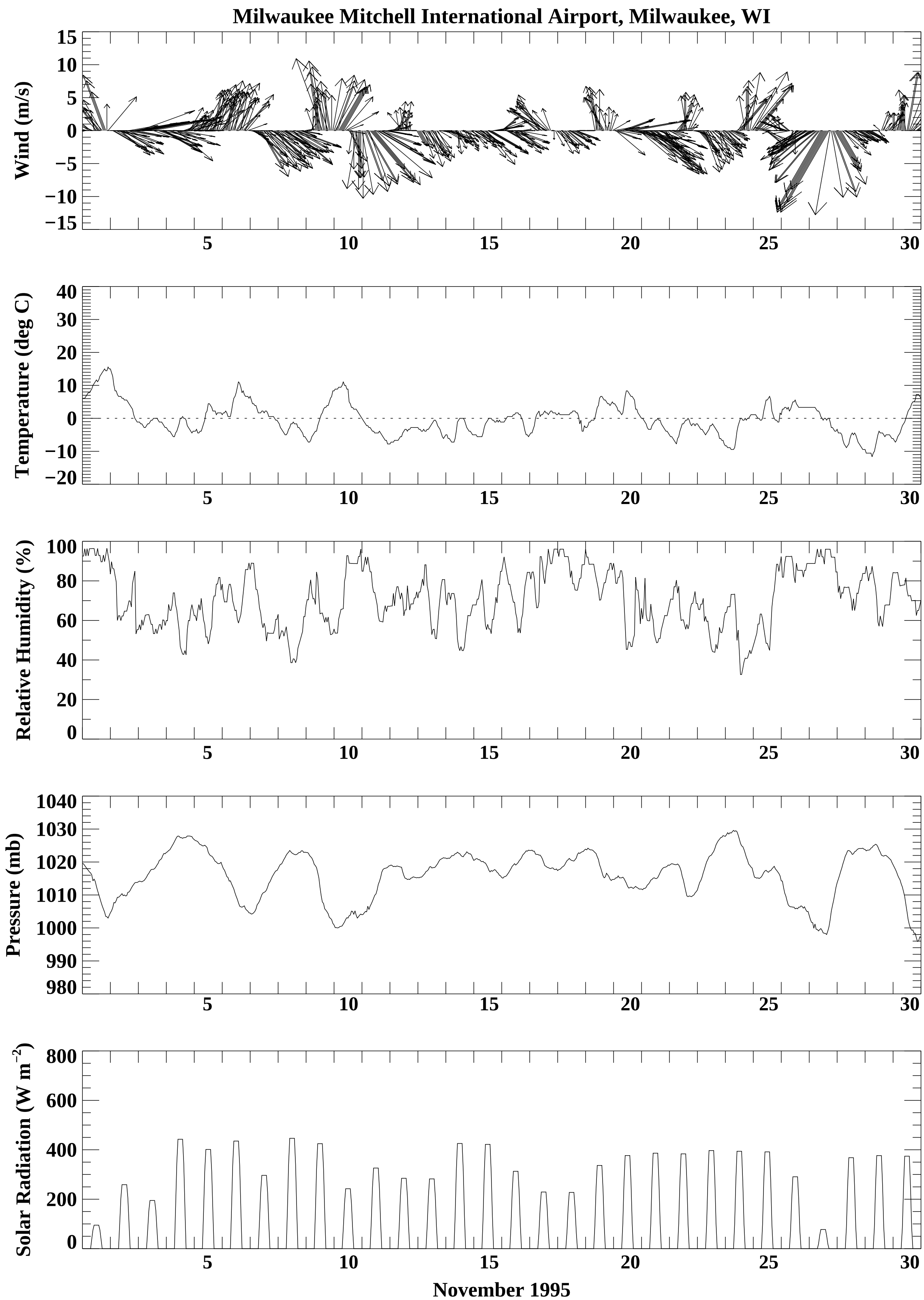
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
July 1995


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
August 1995

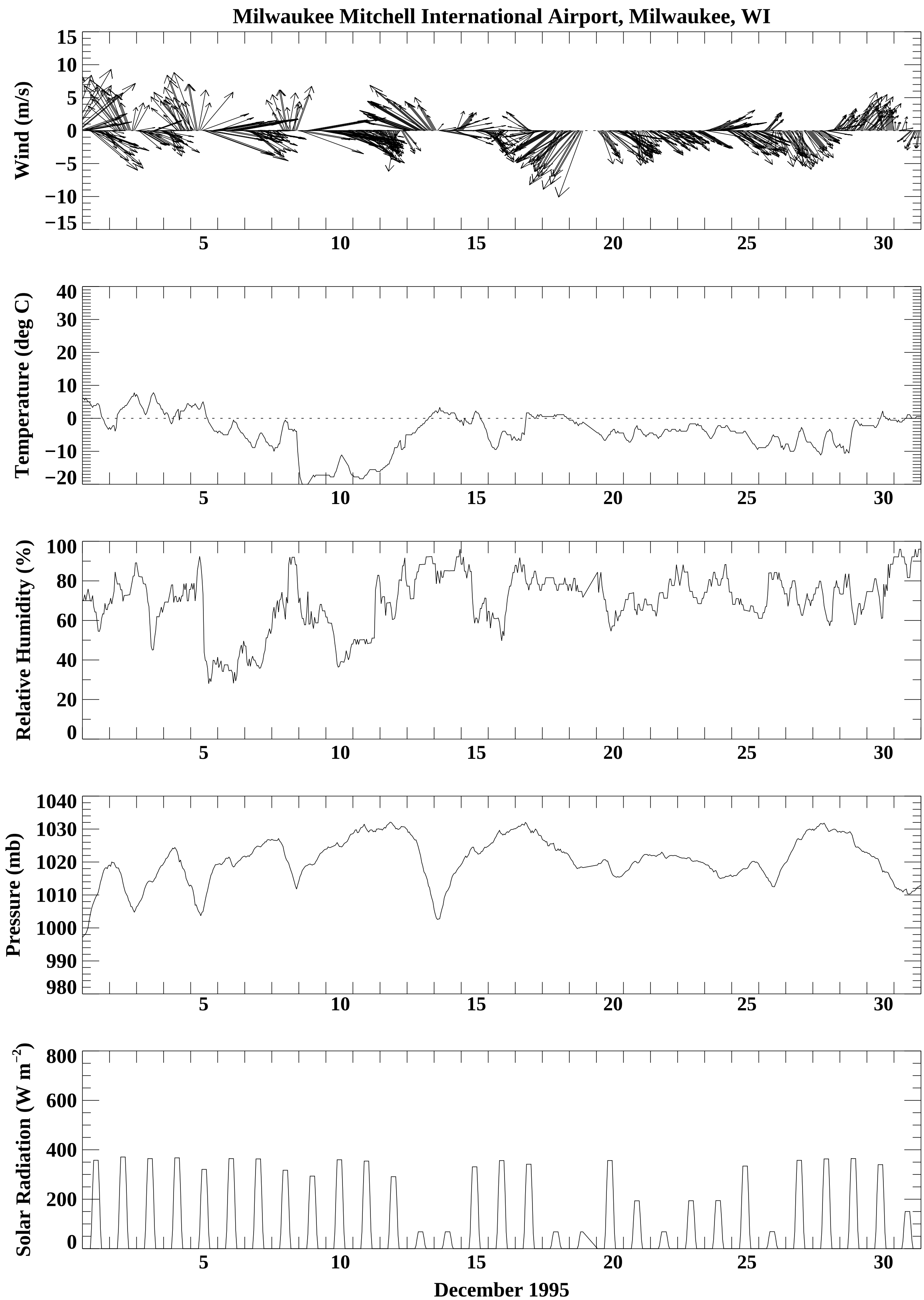


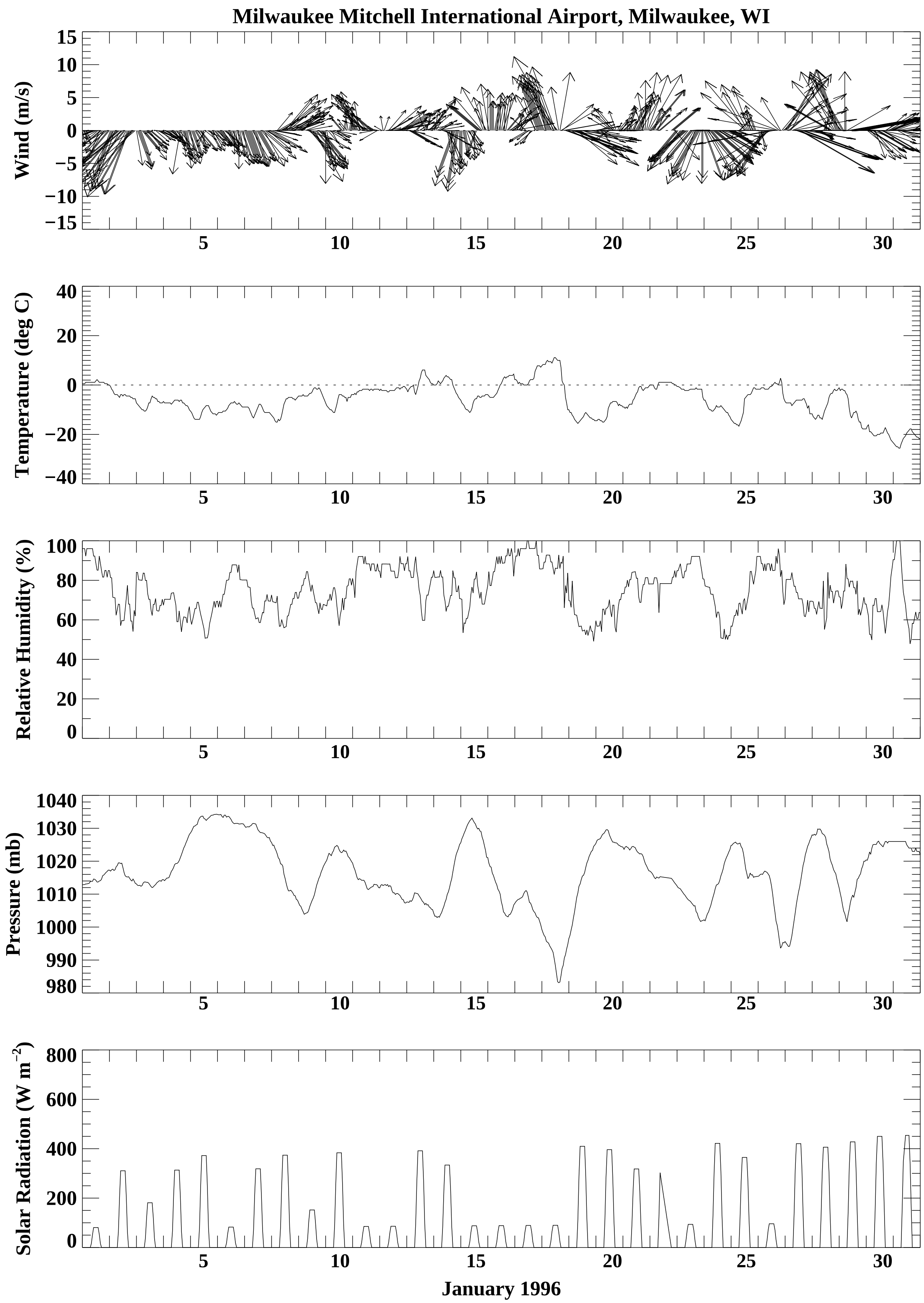
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
September 1995

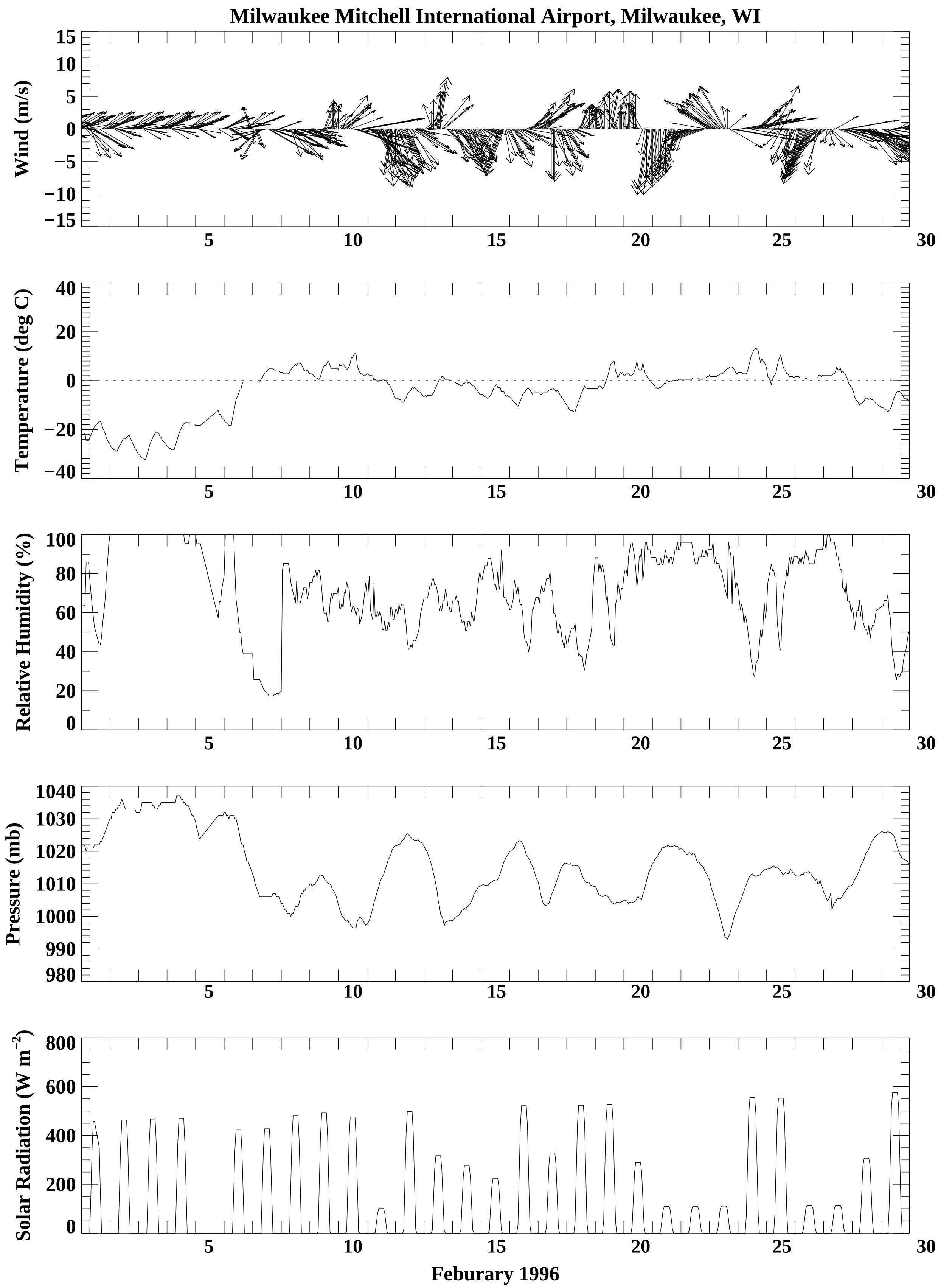

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
October 1995

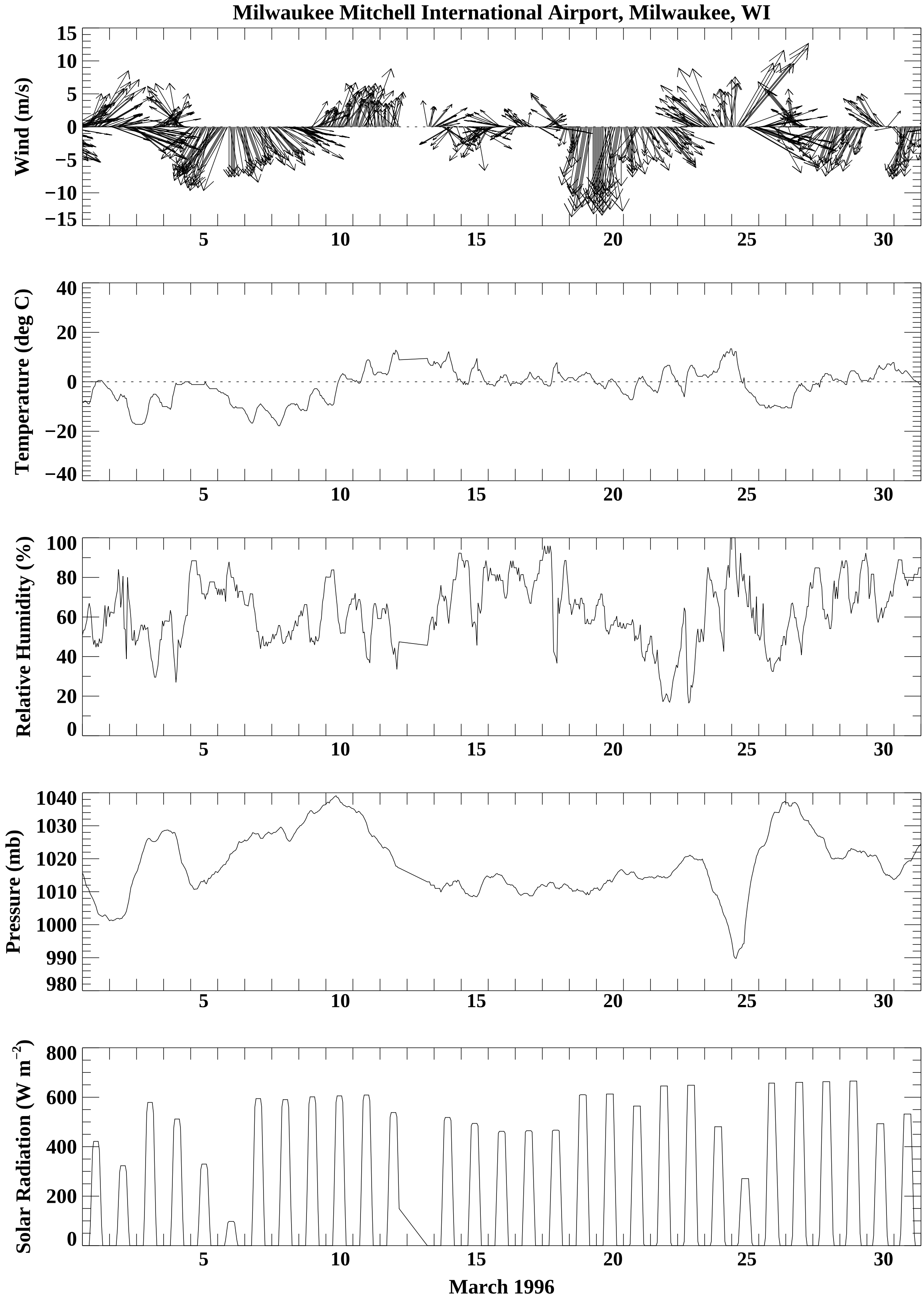


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
November 1995

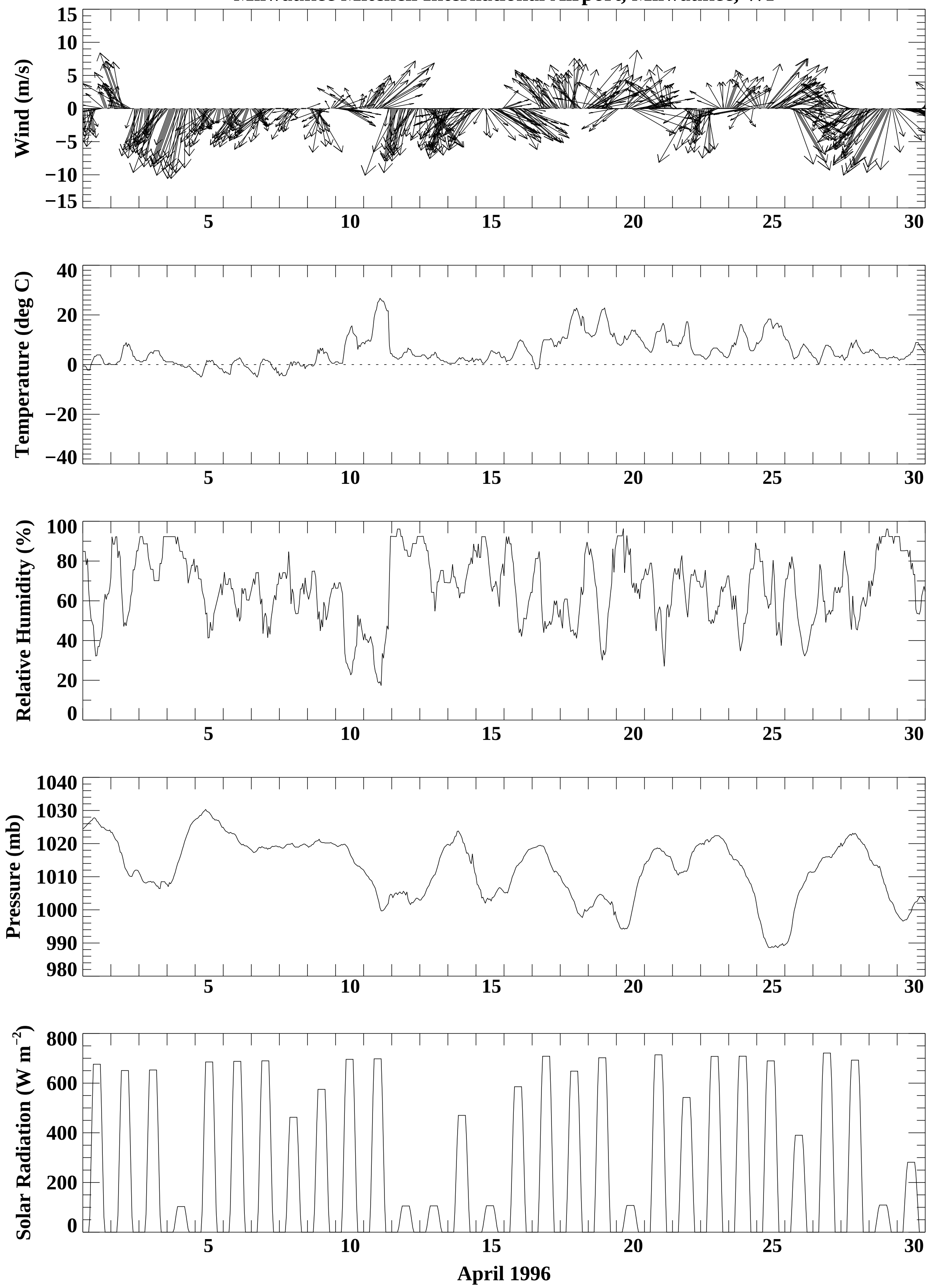

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m⁻²)
December 1995

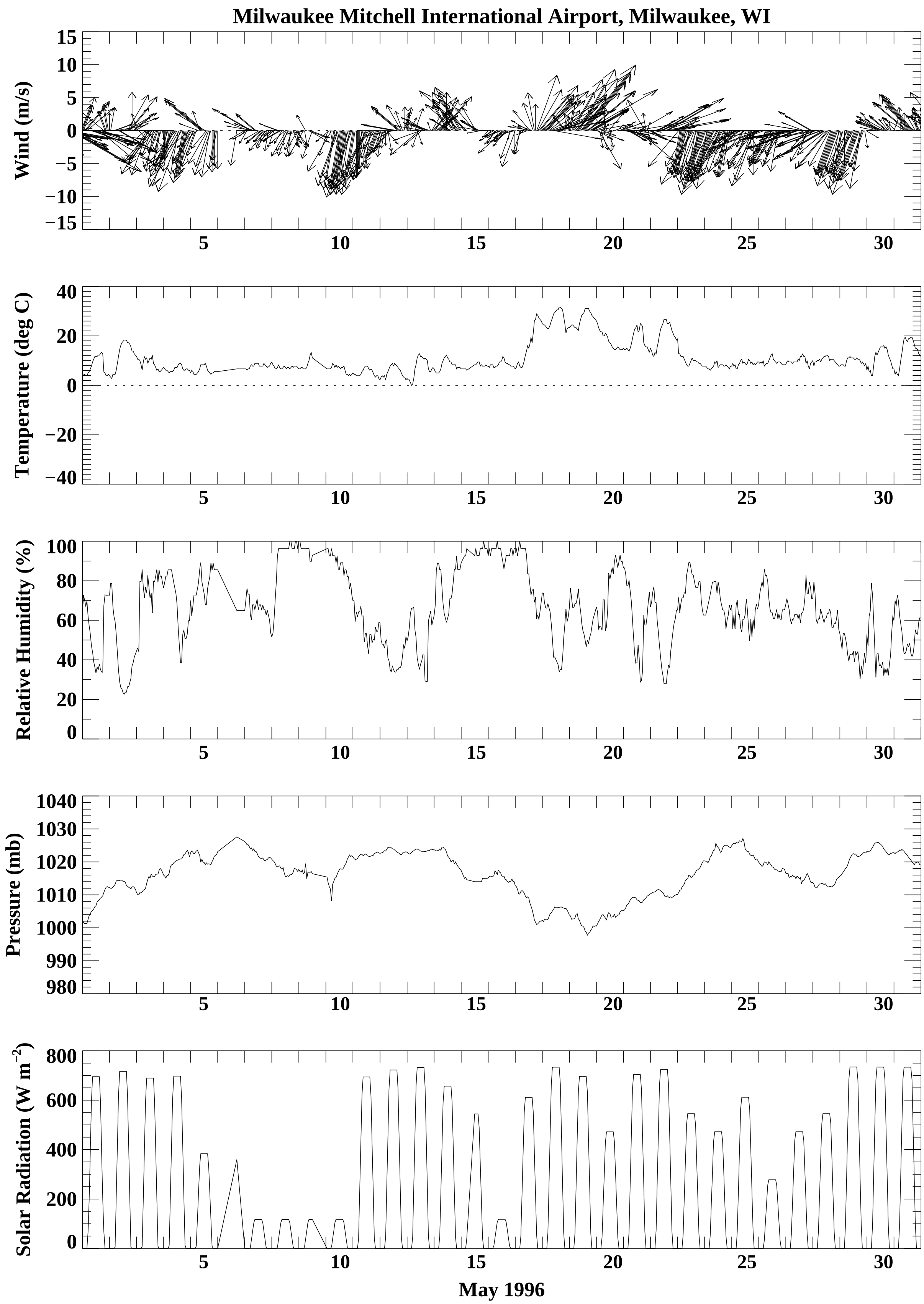

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
January 1996

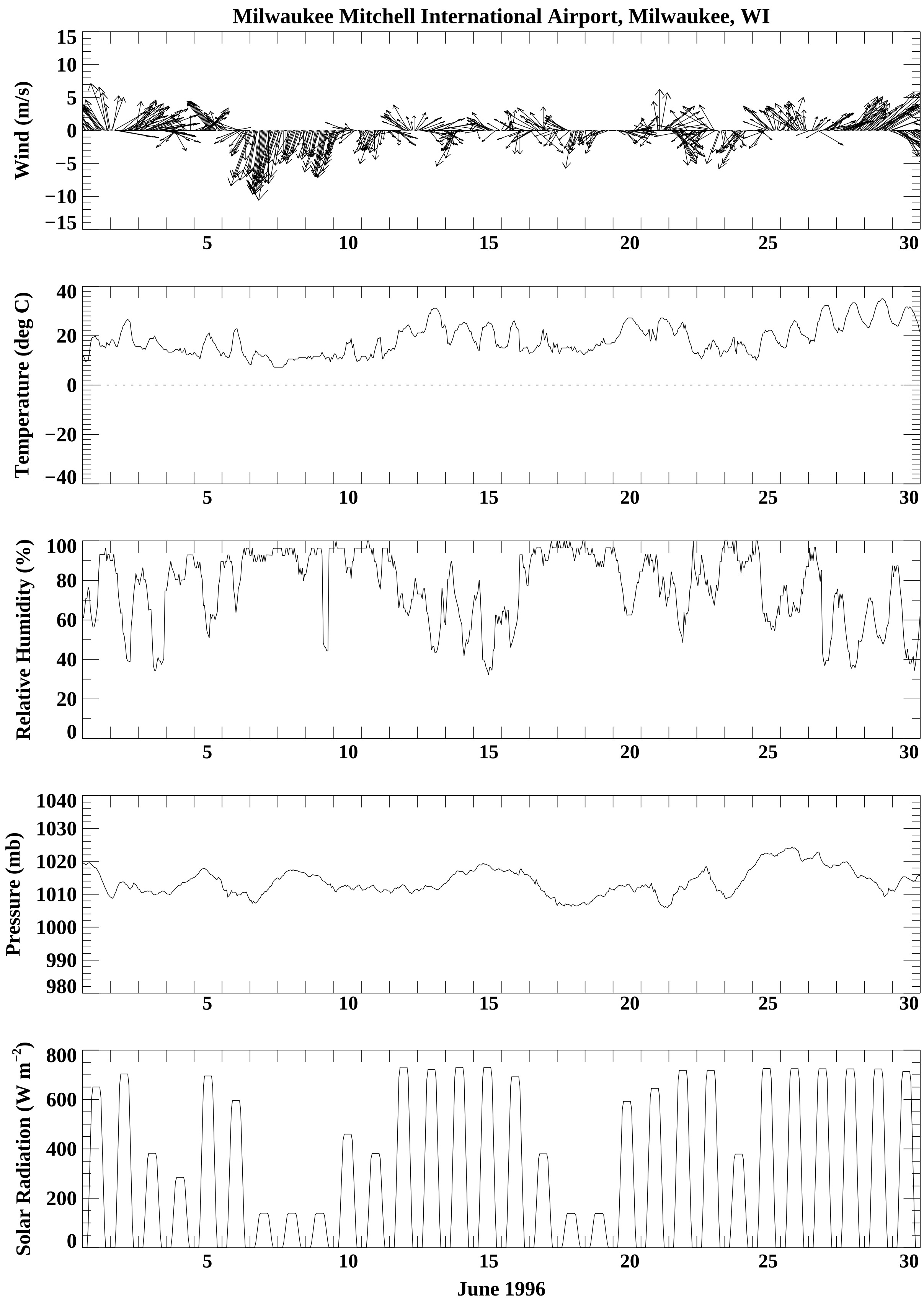

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m⁻²)
Feburary 1996


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m⁻²)
March 1996

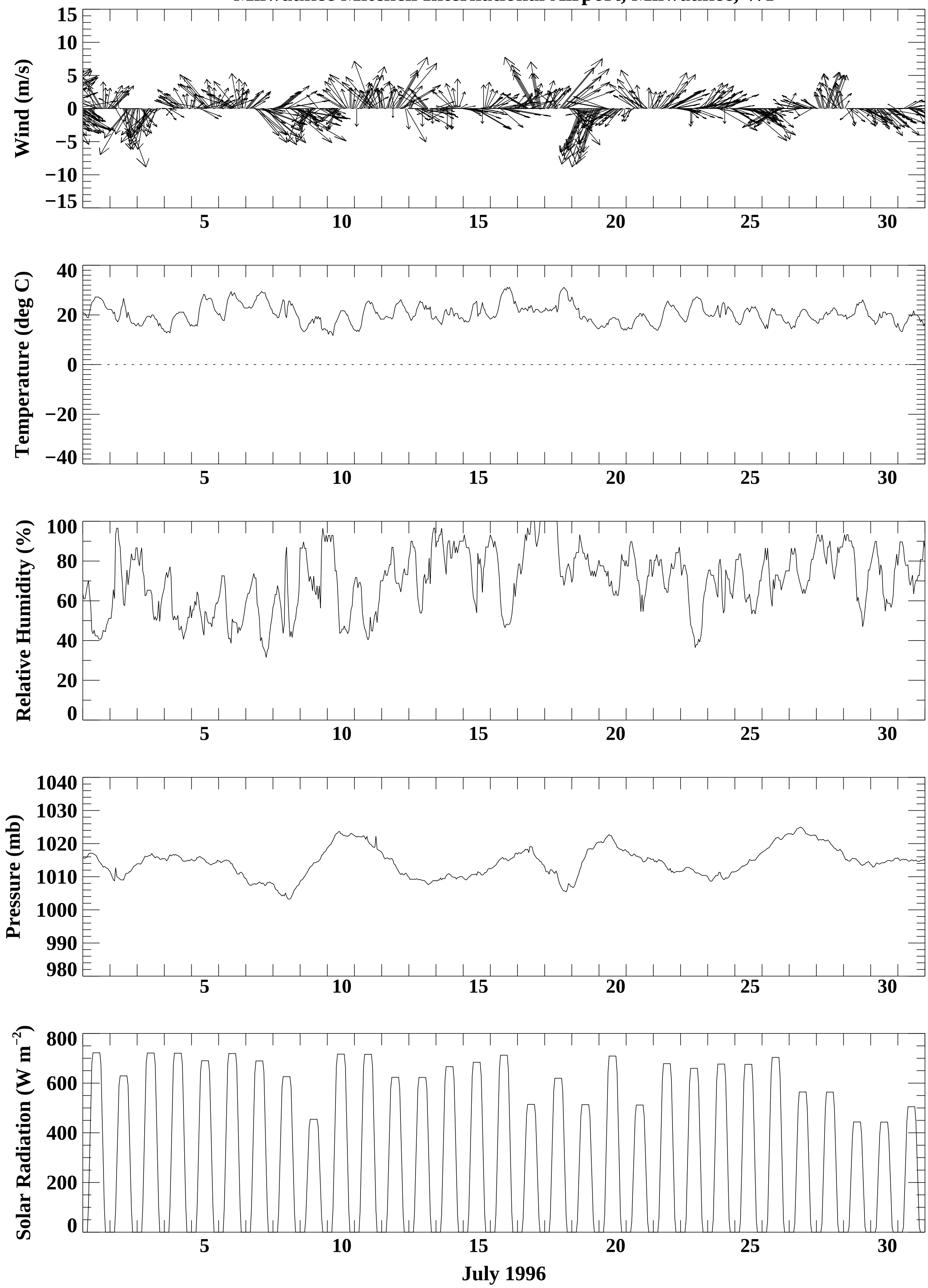
Milwaukee Mitchell International Airport, Milwaukee, WI

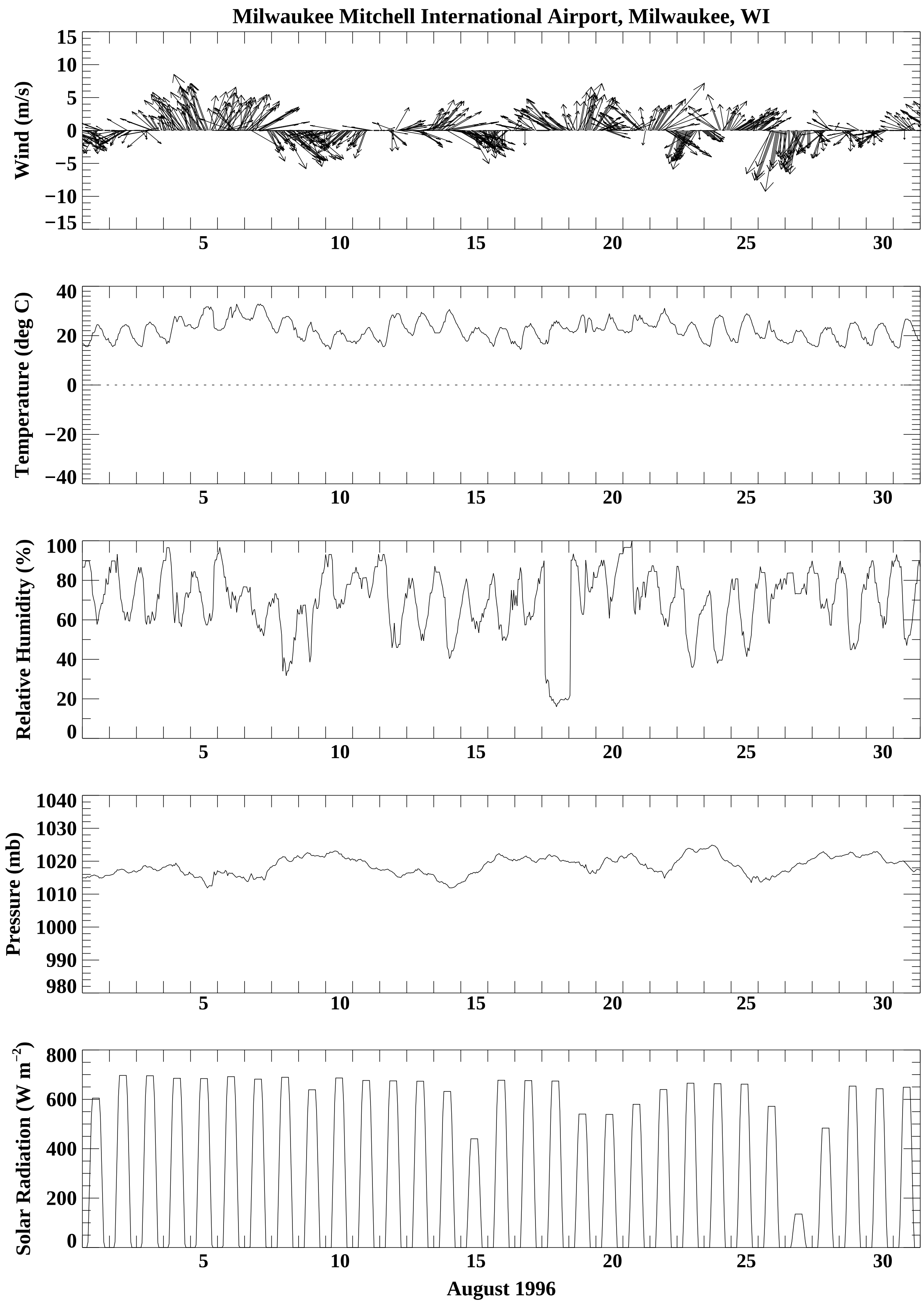



Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
May 1996

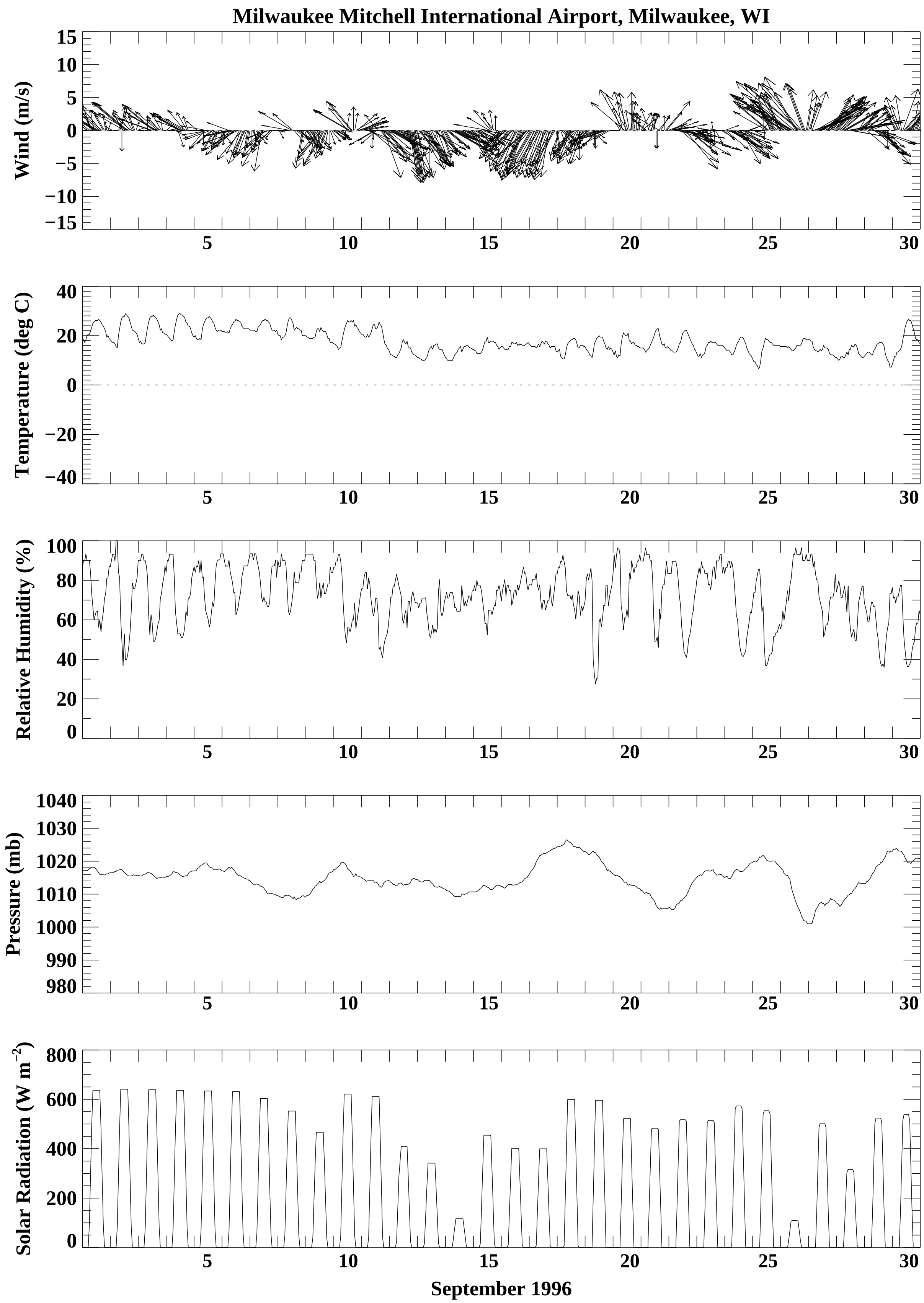

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m⁻²)
June 1996

Milwaukee Mitchell International Airport, Milwaukee, WI

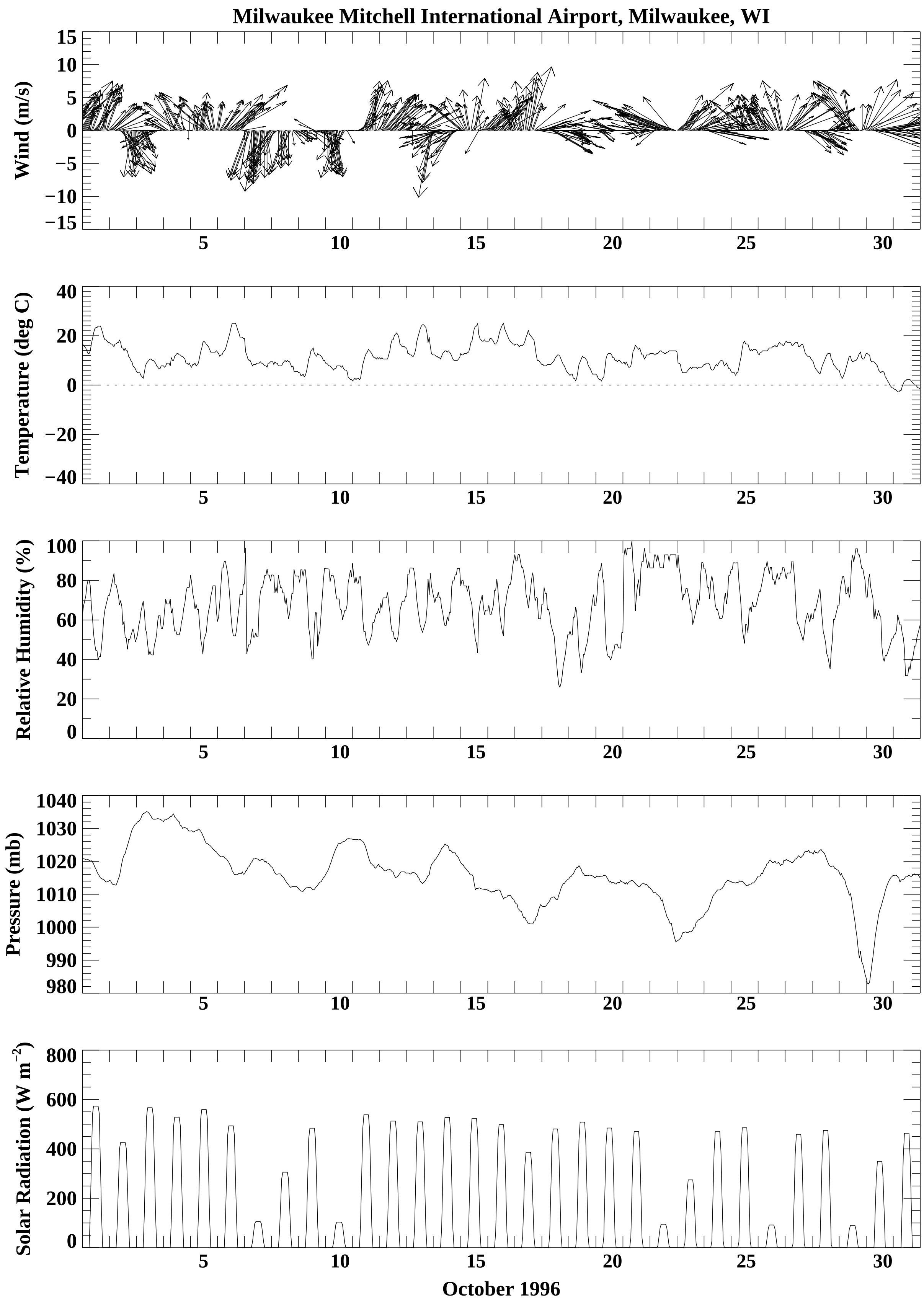


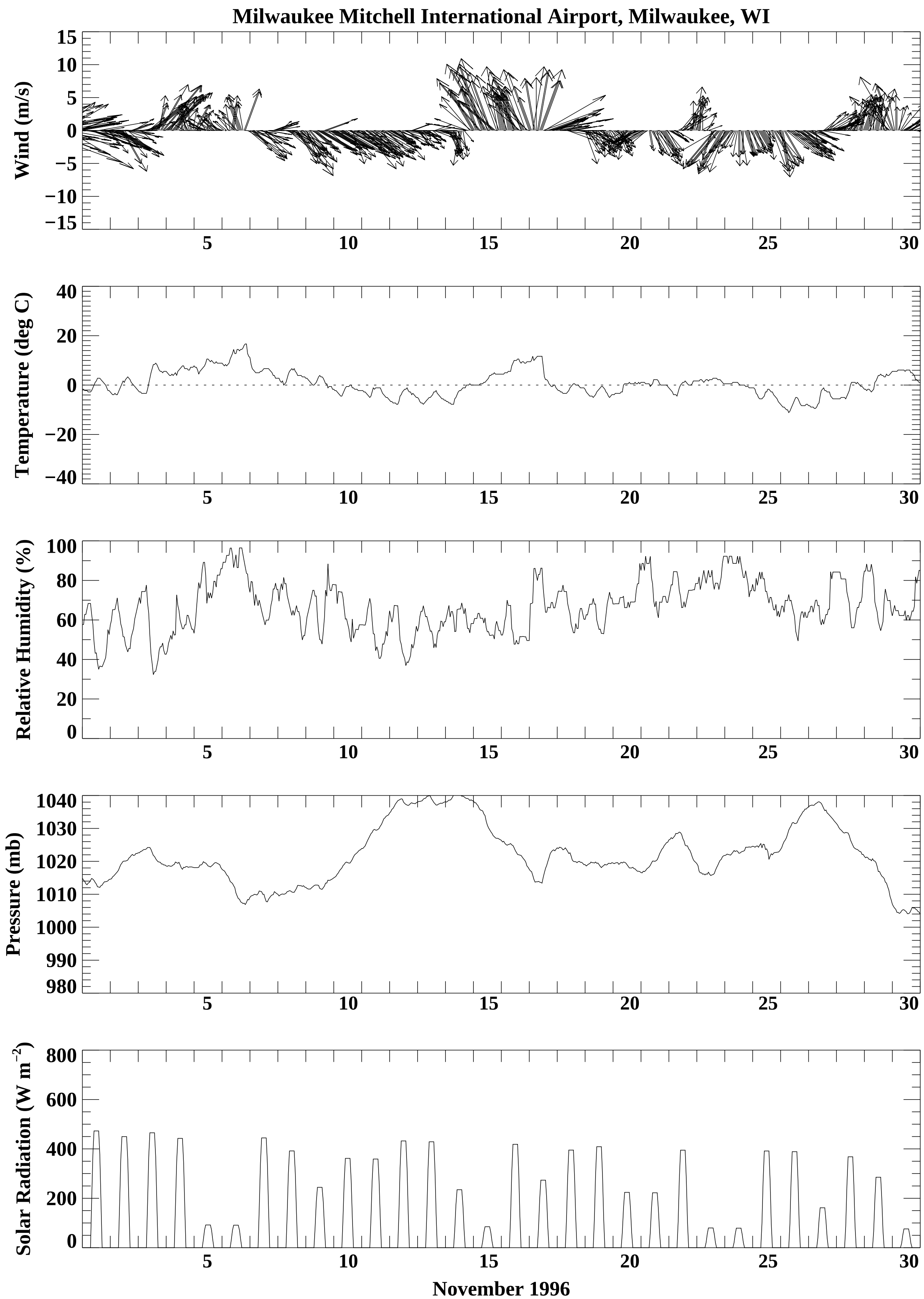


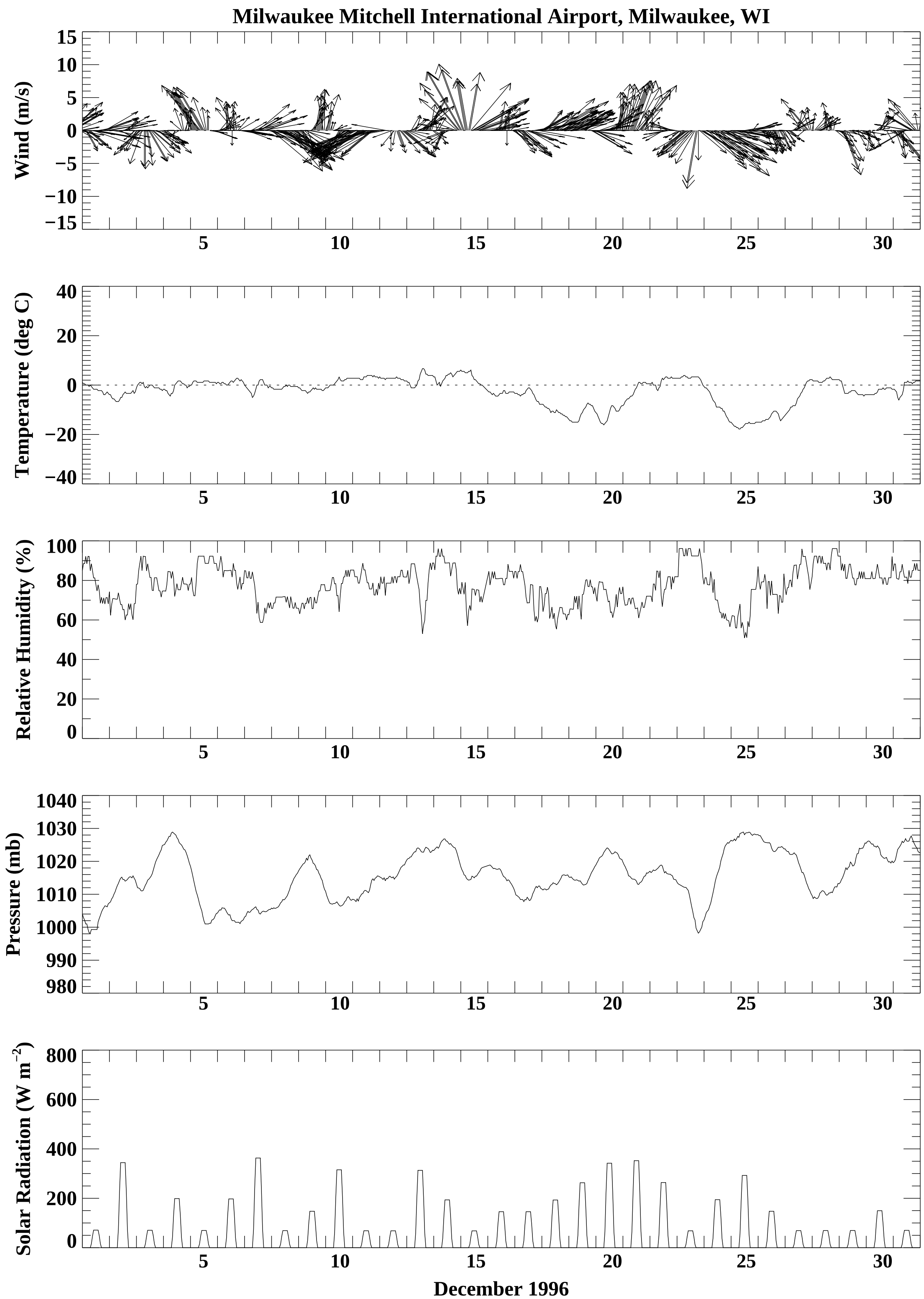
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
August 1996

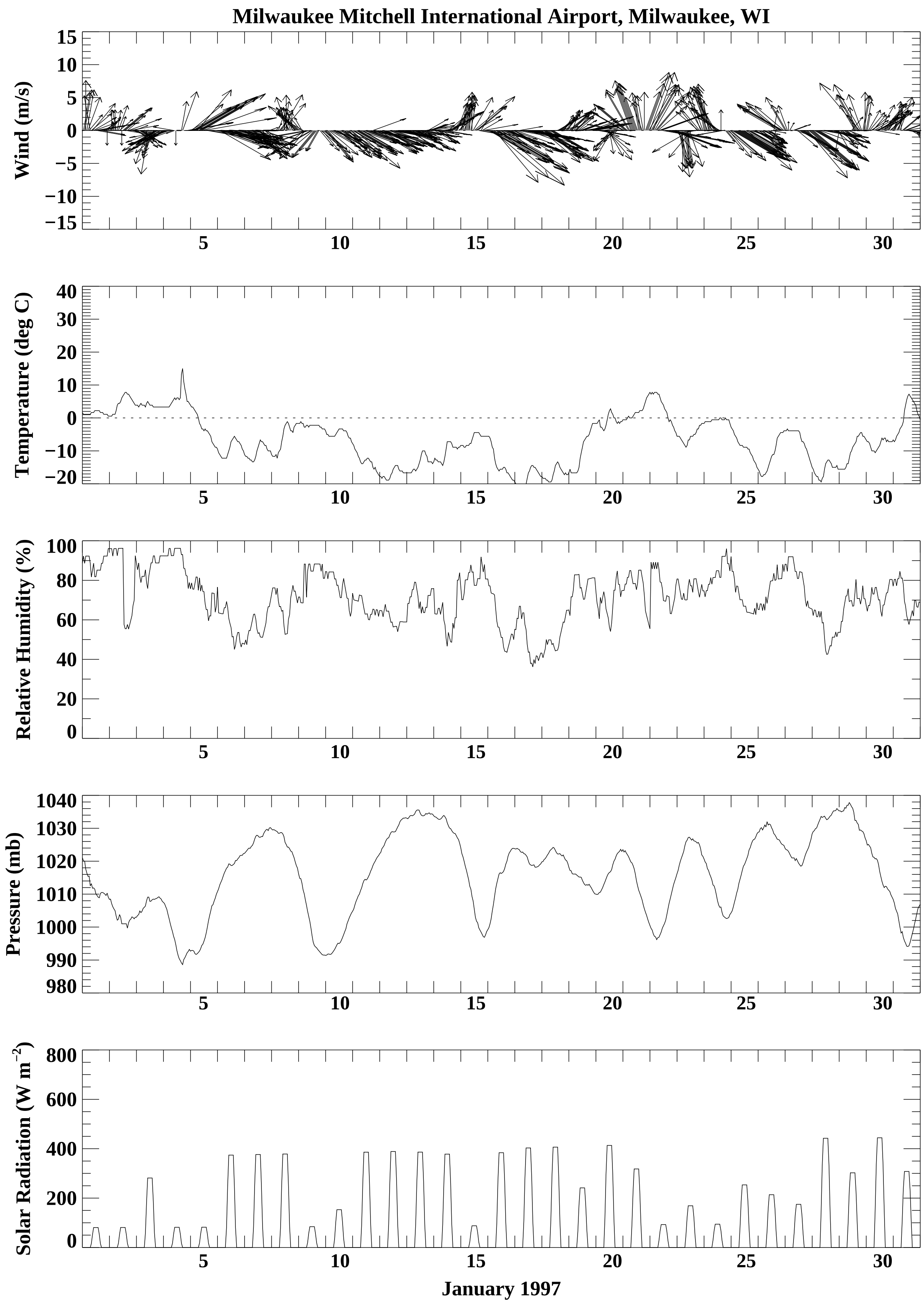


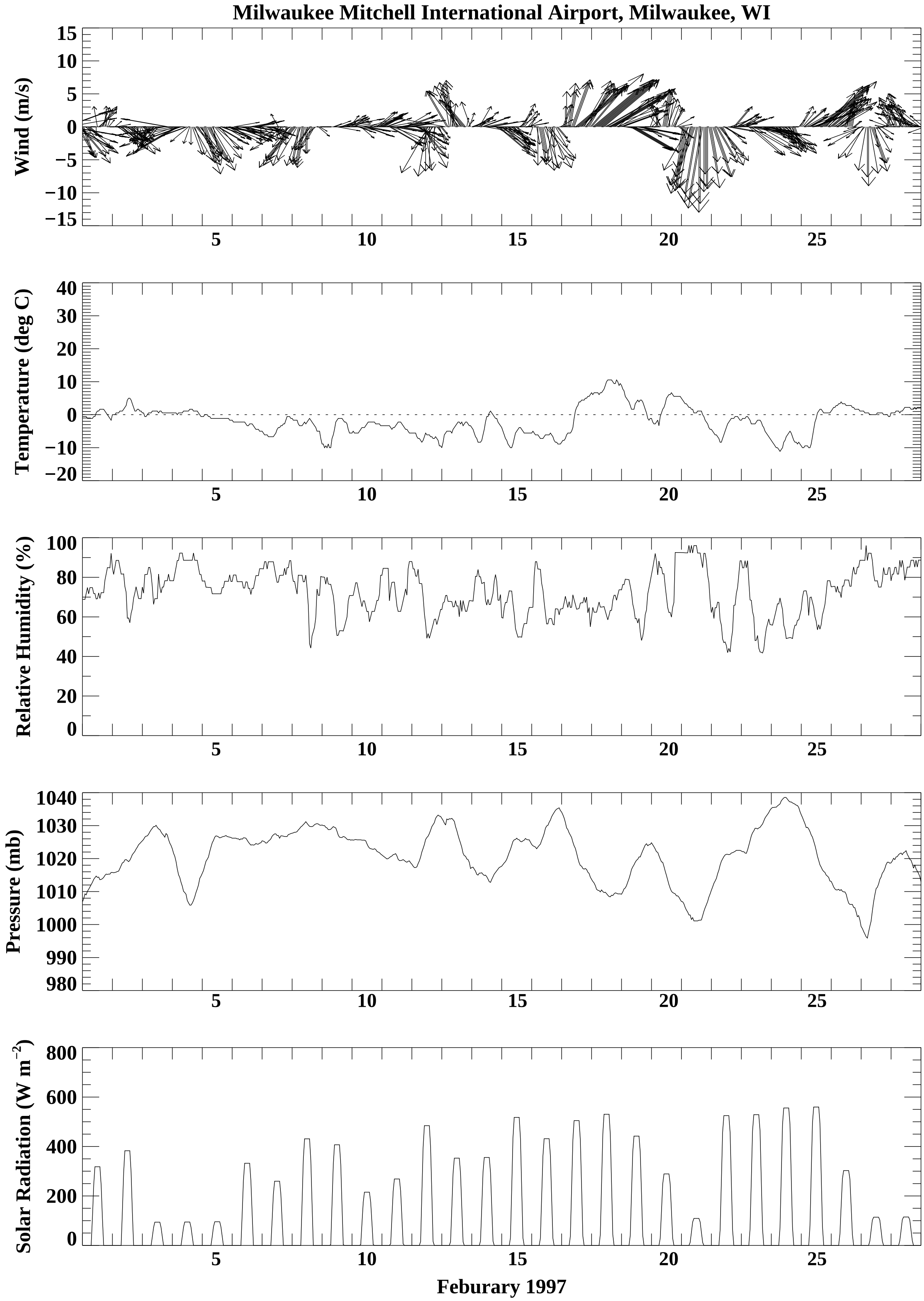
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
15
10
5
0
−5
−10
−15
Temperature (deg C)
40
20
0
−20
−40
Relative Humidity (%)
100
80
60
40
20
0
Pressure (mb)
1040
1030
1020
1010
1000
990
980
Solar Radiation (W m^{-2})
800
600
400
200
0
5
10
15
20
25
30
September 1996


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
15
10
5
0
−5
−10
−15
Temperature (deg C)
40
20
0
−20
−40
Relative Humidity (%)
100
80
60
40
20
0
Pressure (mb)
1040
1030
1020
1010
1000
990
980
Solar Radiation (W m^{-2})
800
600
400
200
0
5
10
15
20
25
30
October 1996

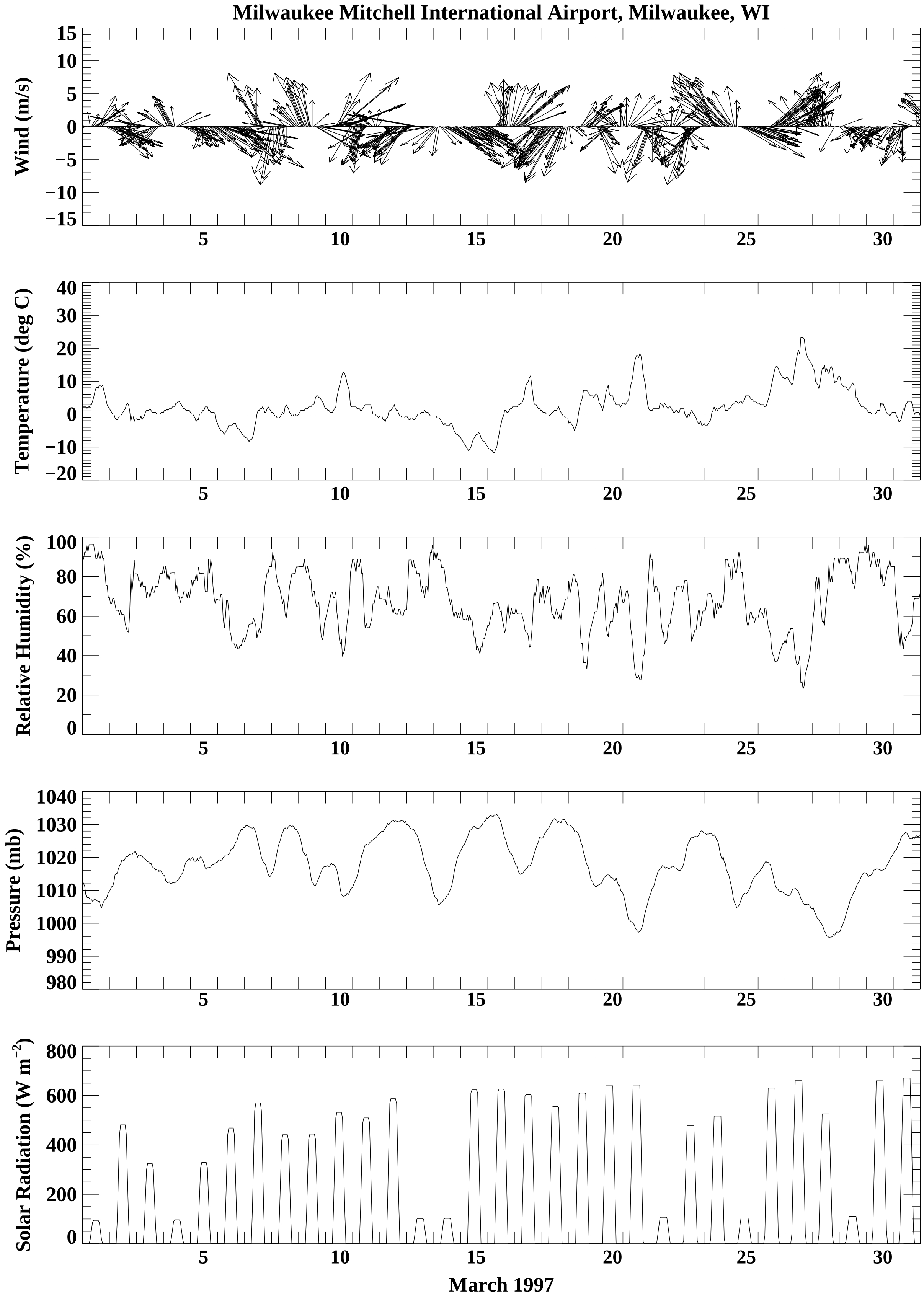

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
November 1996

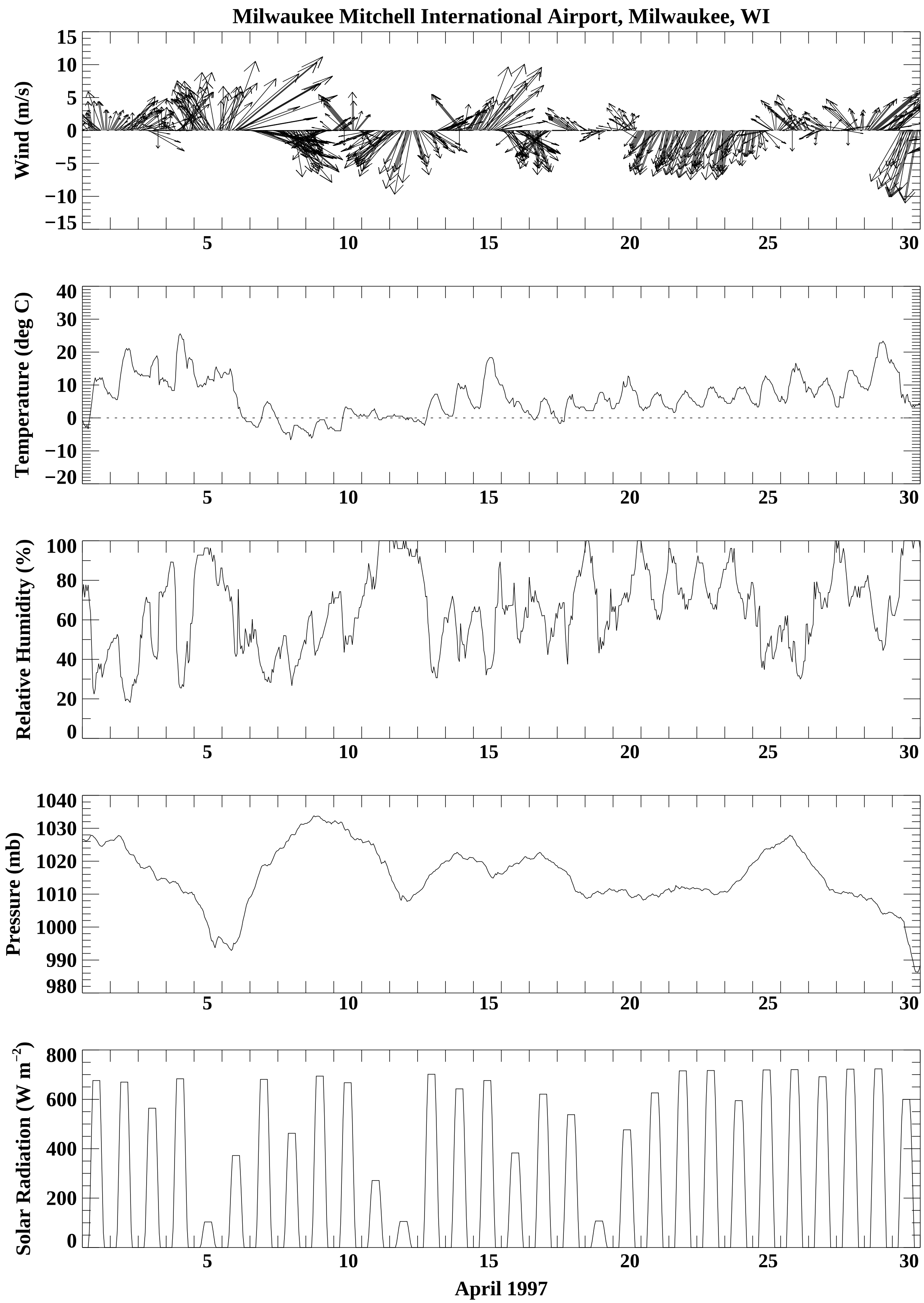

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
December 1996

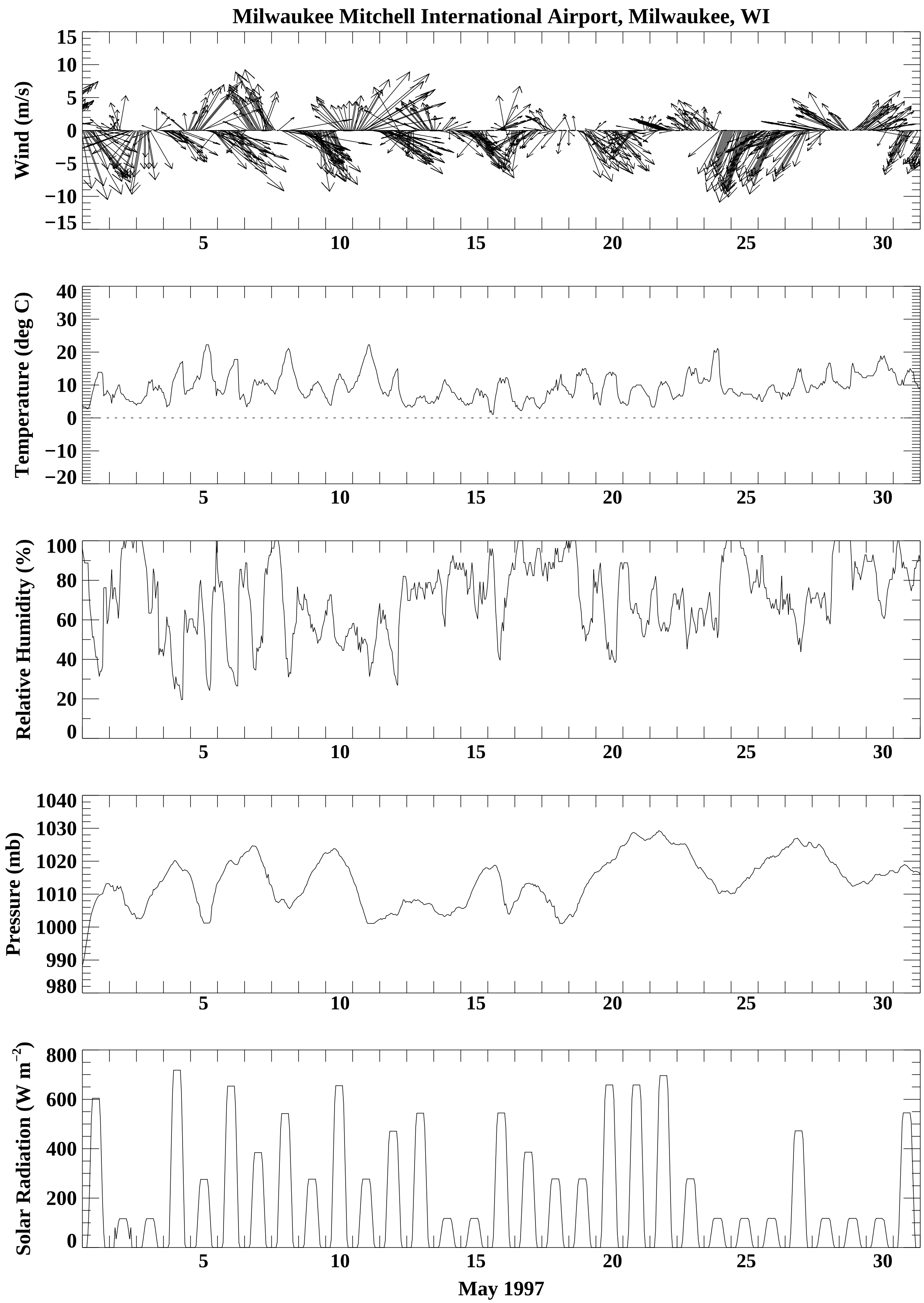

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
January 1997

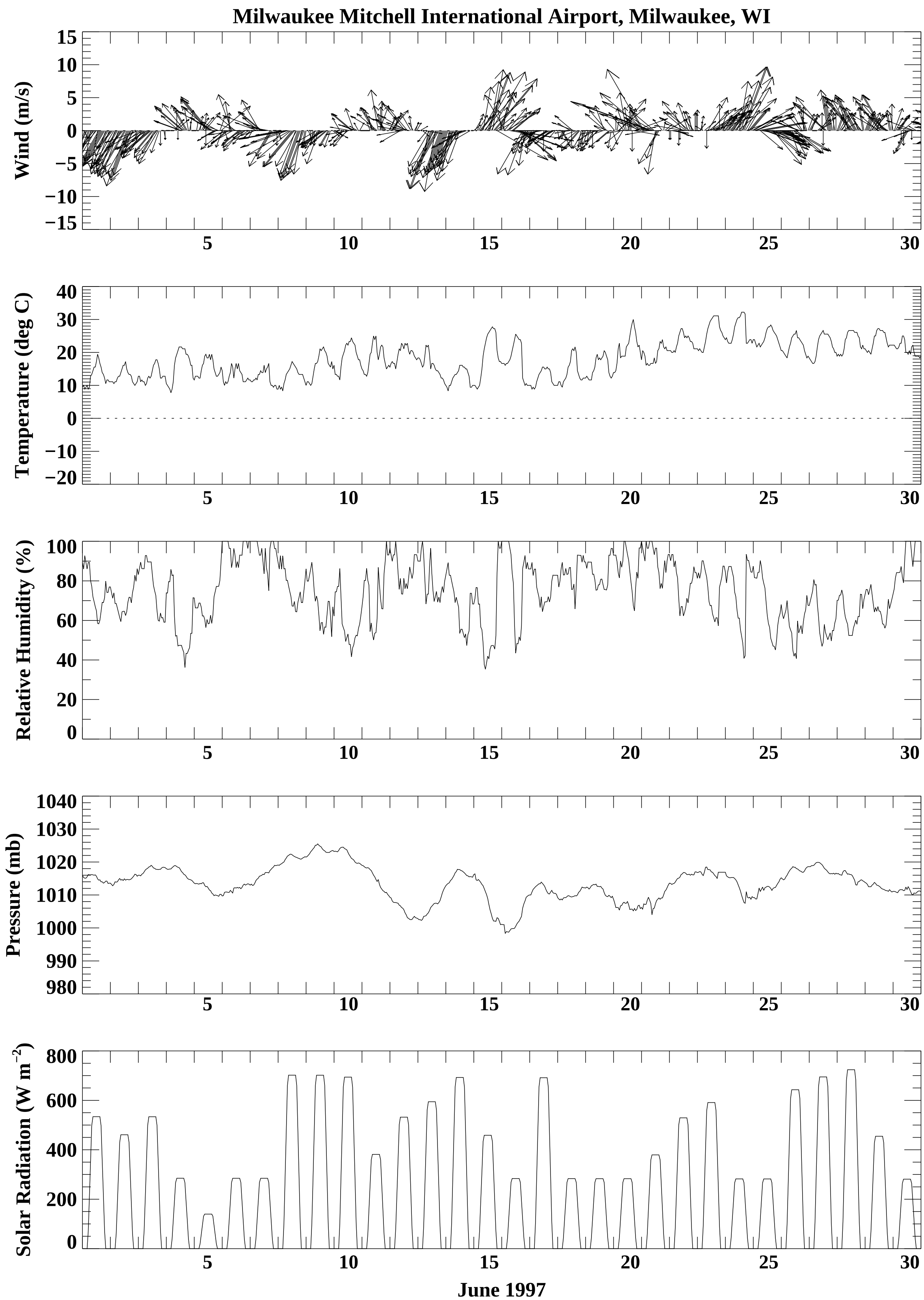


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
15
10
5
0
−5
−10
−15
5
10
15
20
25
Temperature (deg C)
40
30
20
10
0
−10
−20
Relative Humidity (%)
100
80
60
40
20
0
Pressure (mb)
1040
1030
1020
1010
1000
990
980
Solar Radiation (W m⁻²)
800
600
400
200
0
Feburary 1997

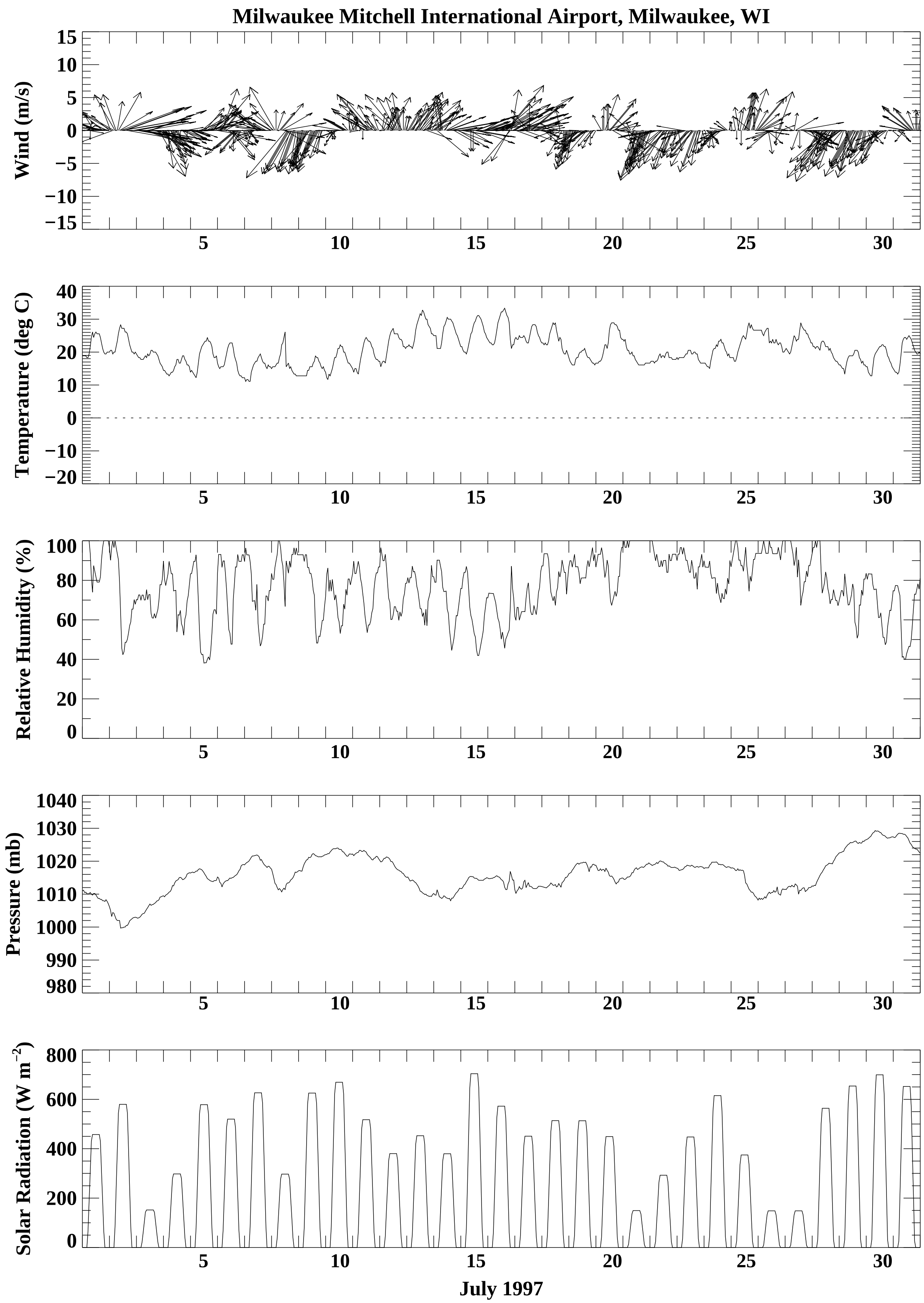

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
March 1997


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
April 1997

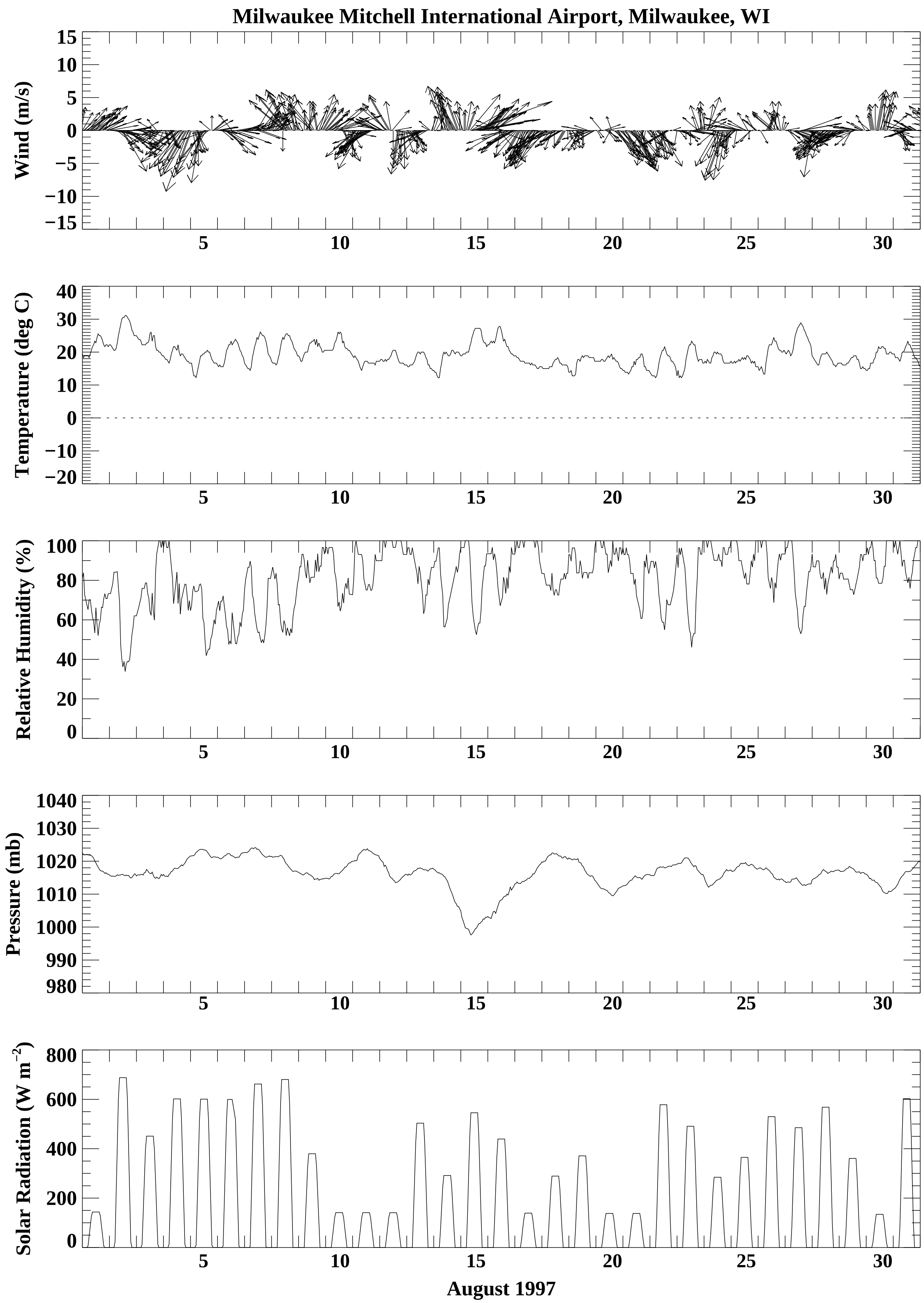

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
May 1997



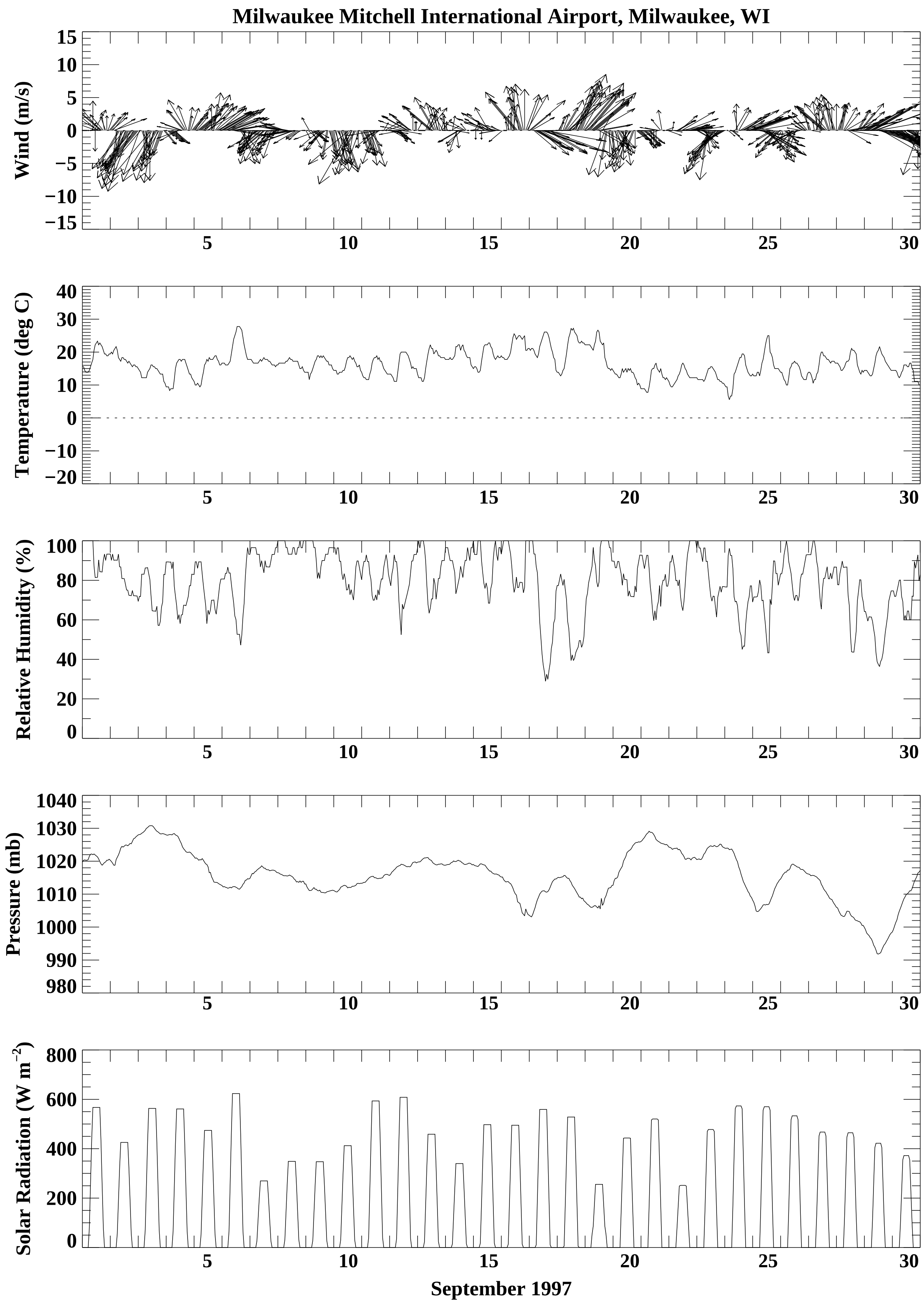
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
June 1997

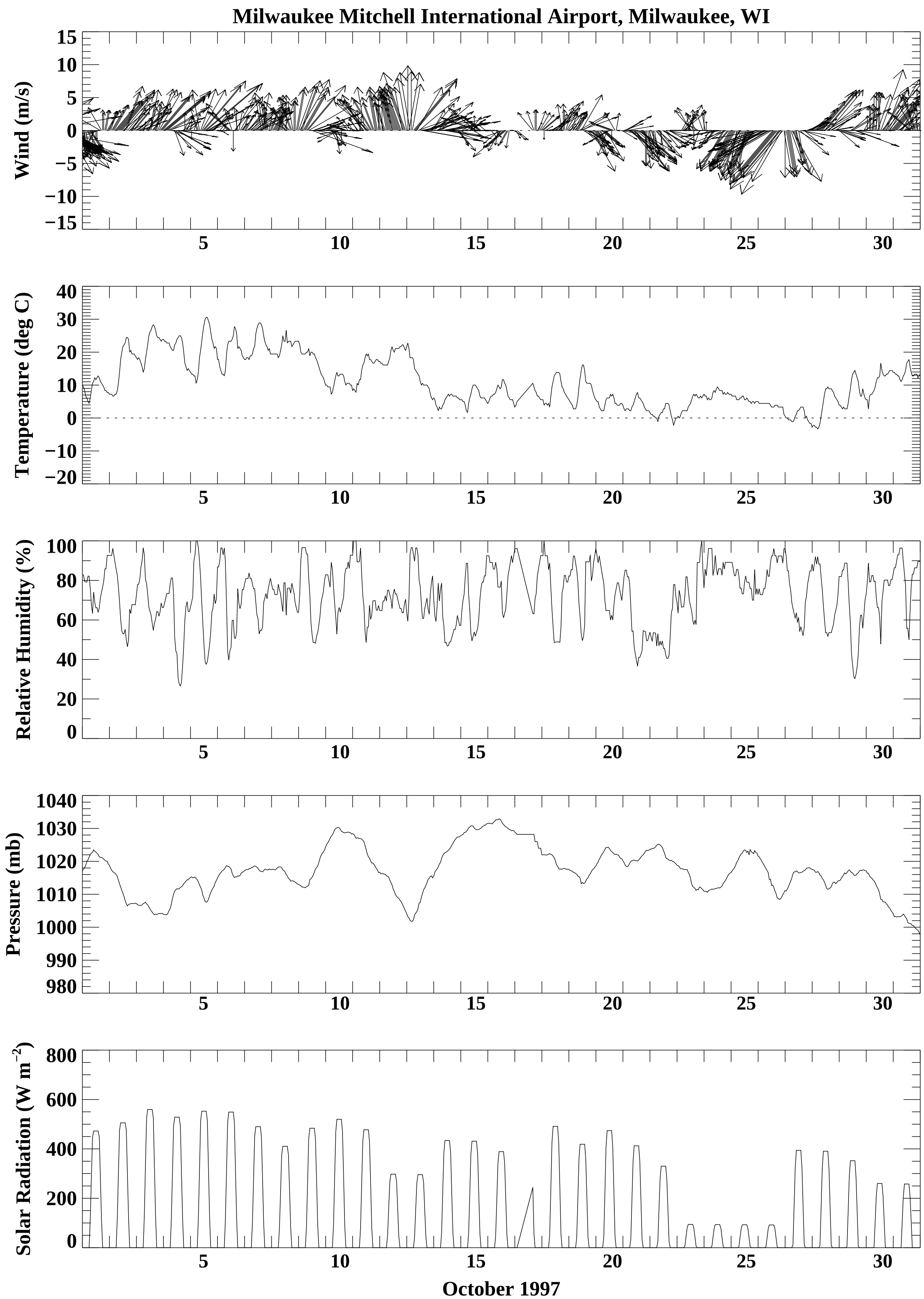


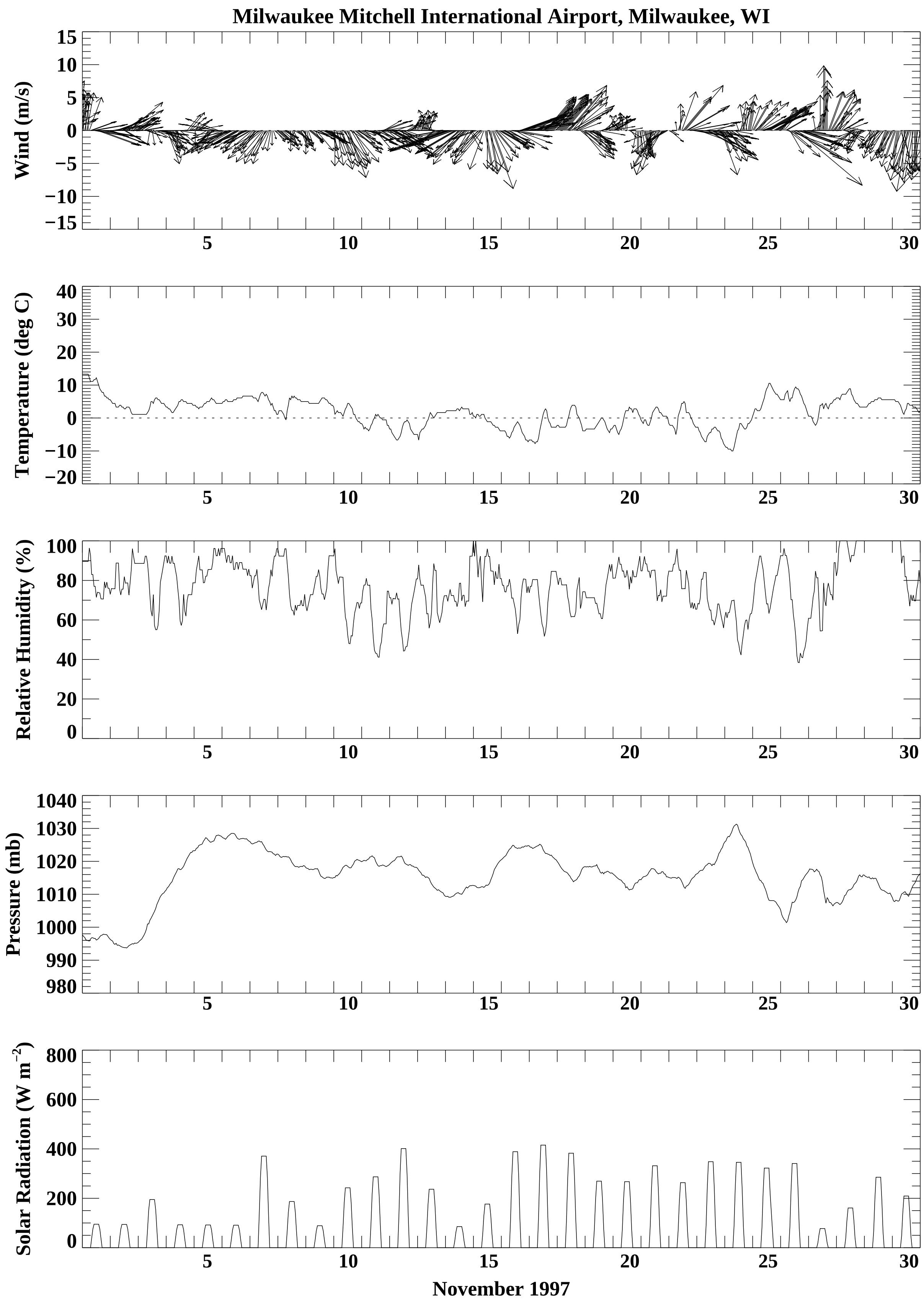
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
15
10
5
0
−5
−10
−15
Temperature (deg C)
40
30
20
10
0
−10
−20
Relative Humidity (%)
100
80
60
40
20
0
Pressure (mb)
1040
1030
1020
1010
1000
990
980
Solar Radiation (W m^{-2})
800
600
400
200
0
5
10
15
20
25
30
July 1997



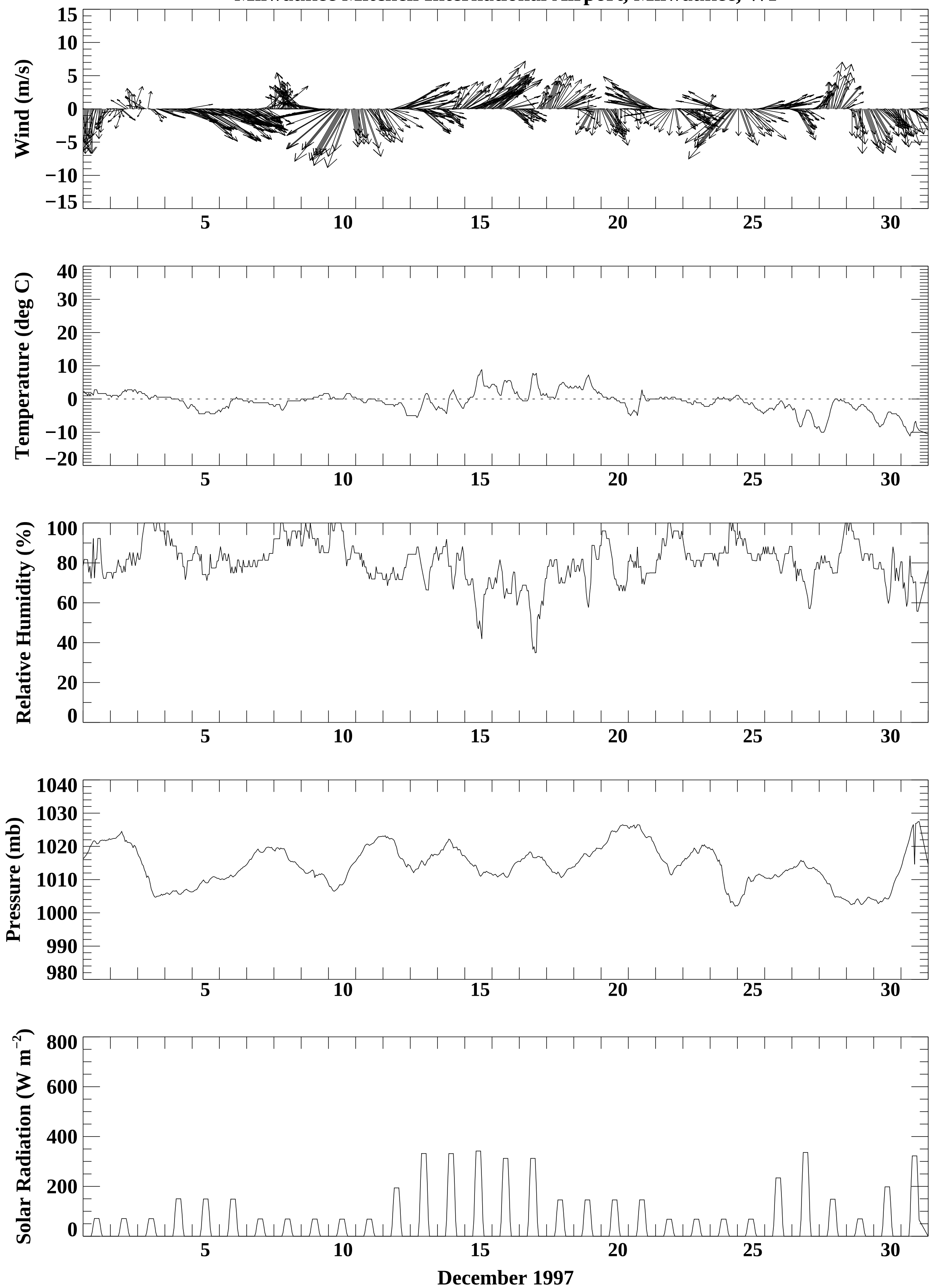
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
August 1997

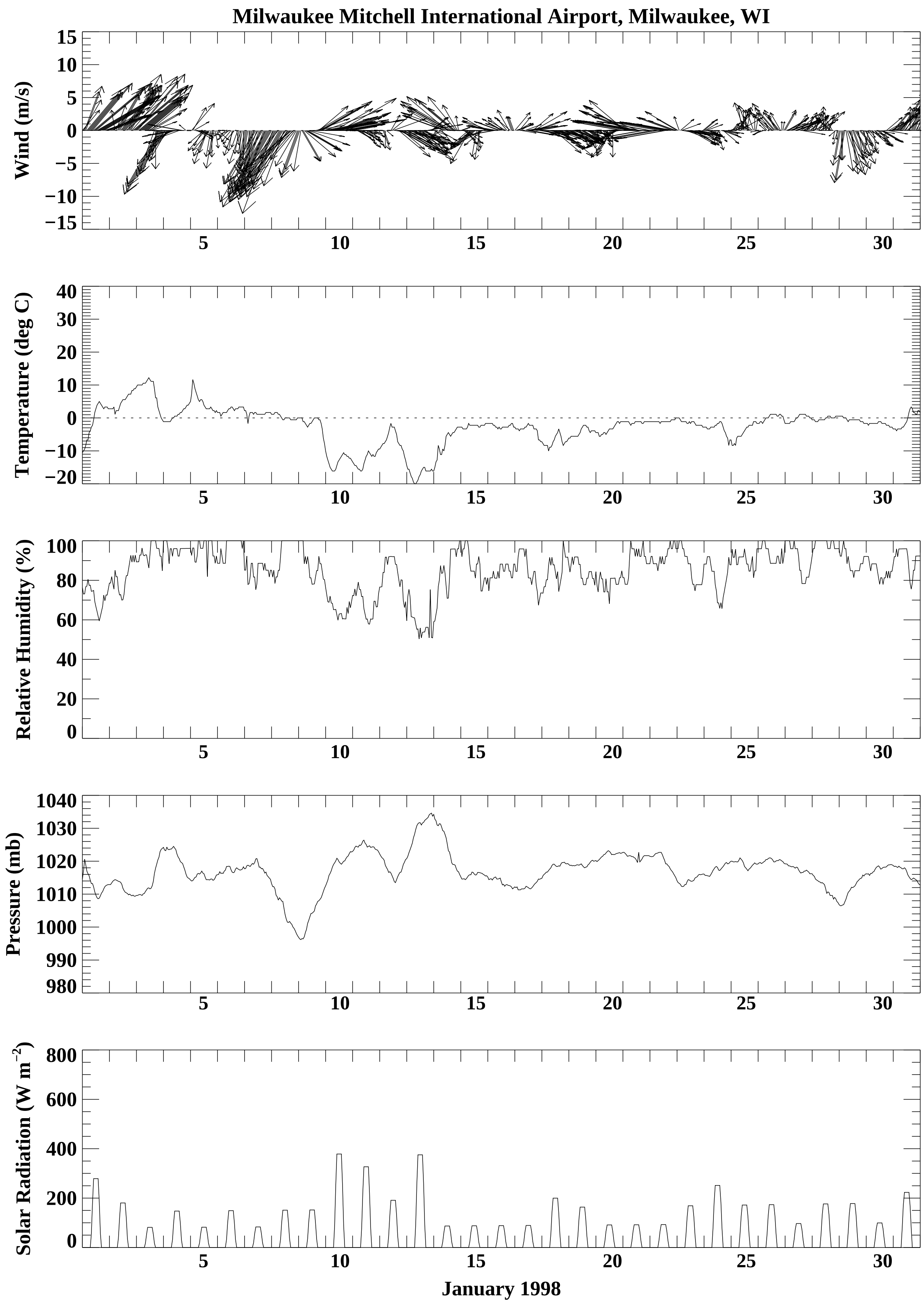

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
September 1997

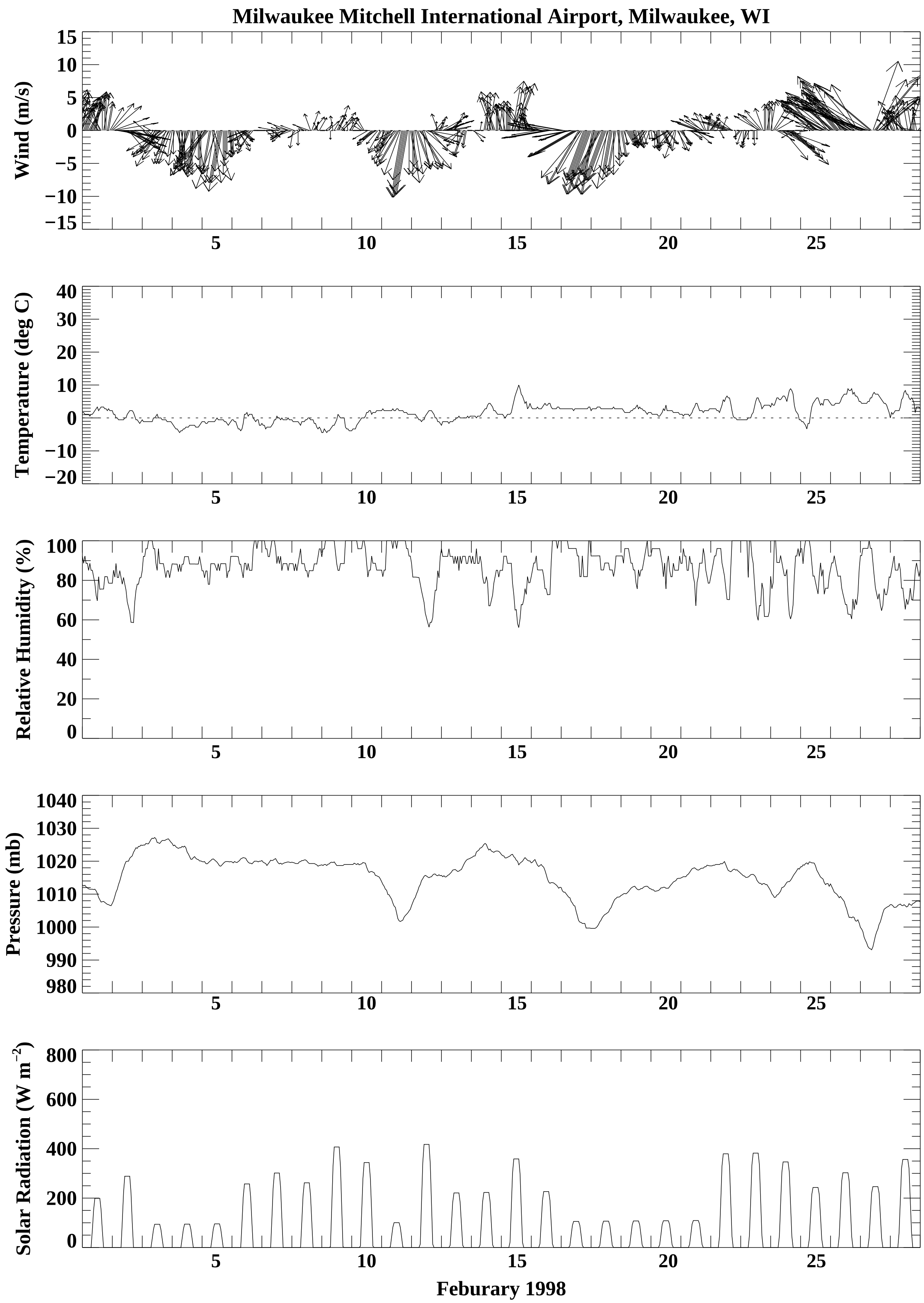

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
October 1997

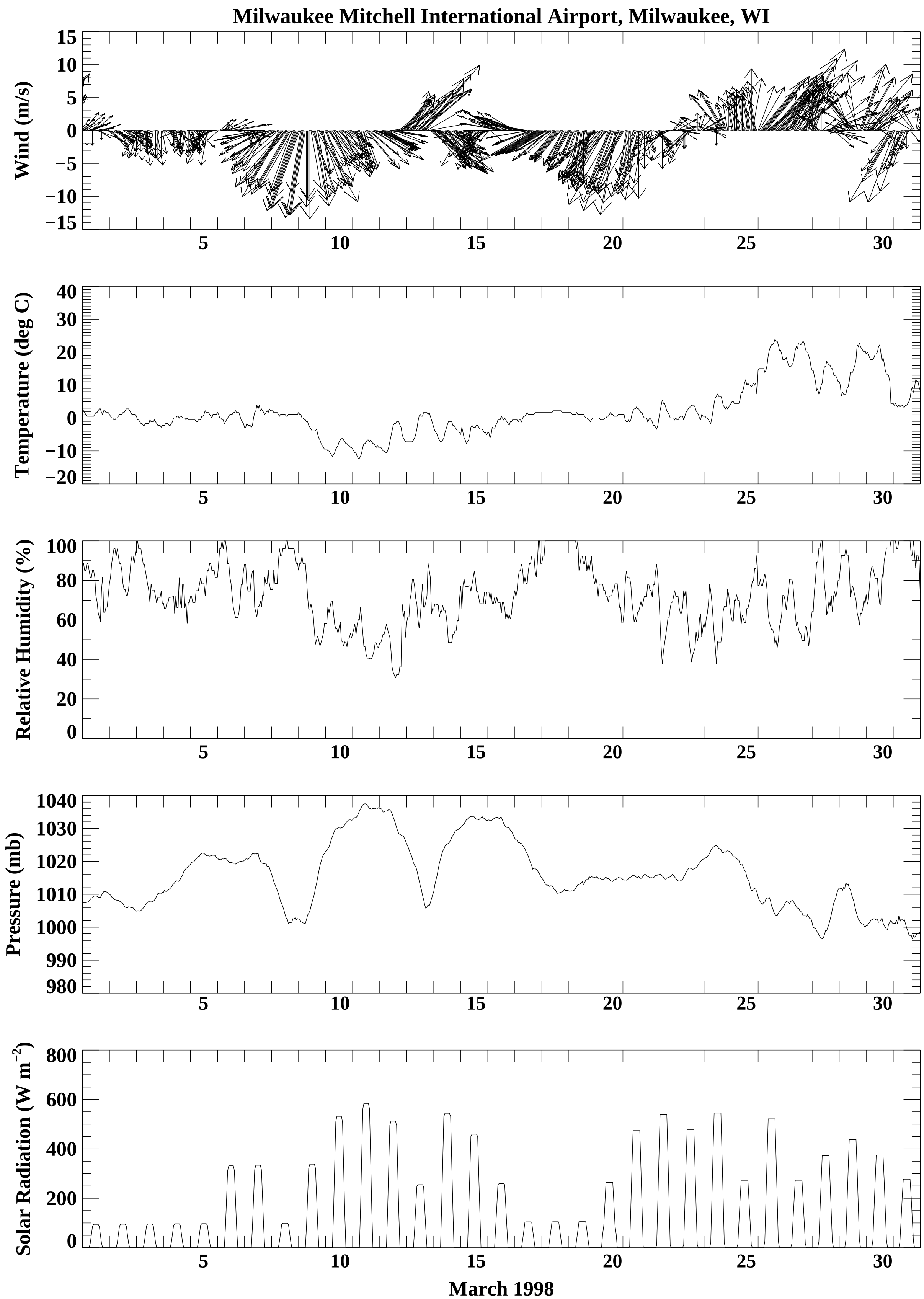

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
November 1997

Milwaukee Mitchell International Airport, Milwaukee, WI



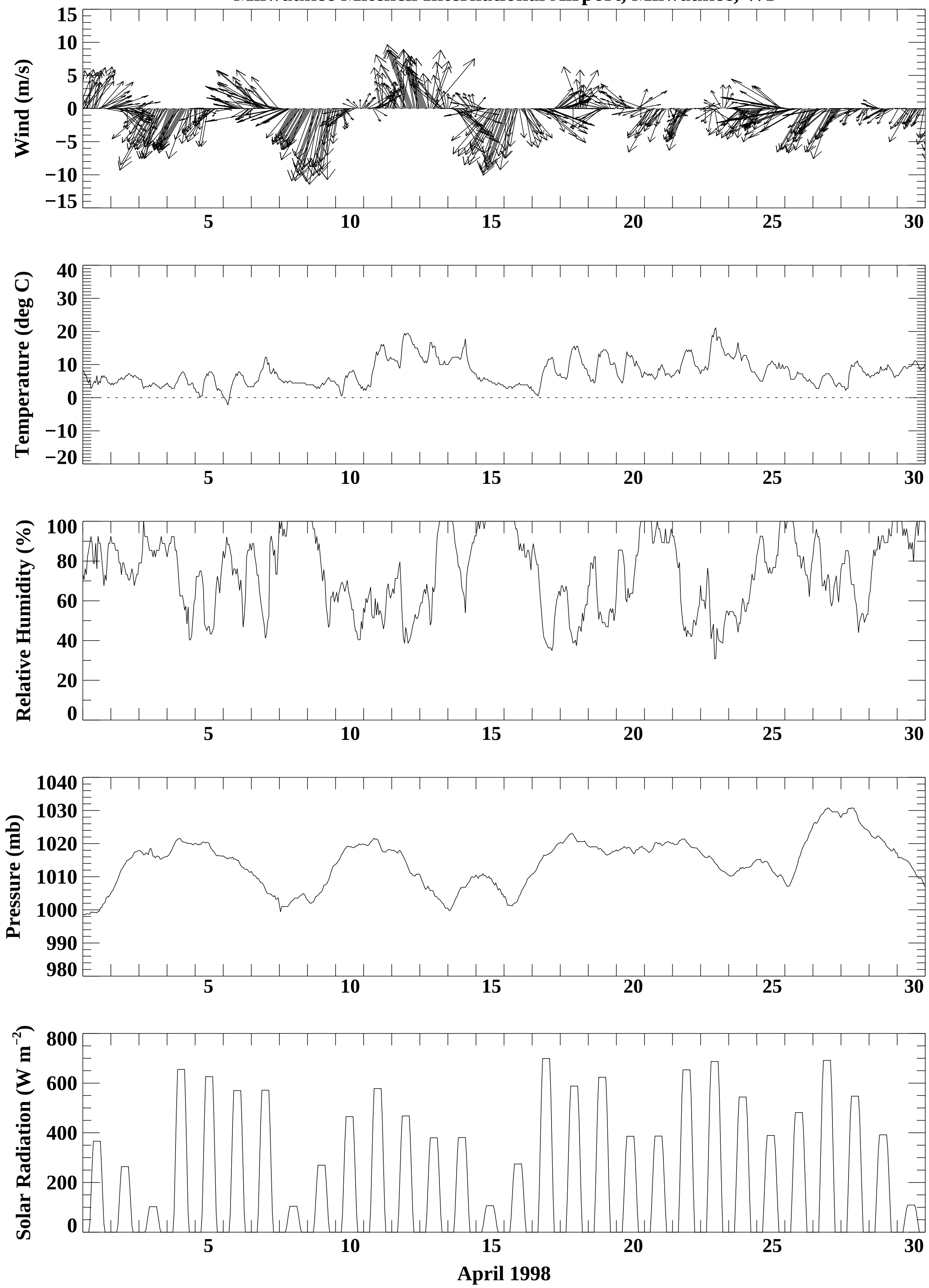

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
January 1998


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
Feburary 1998

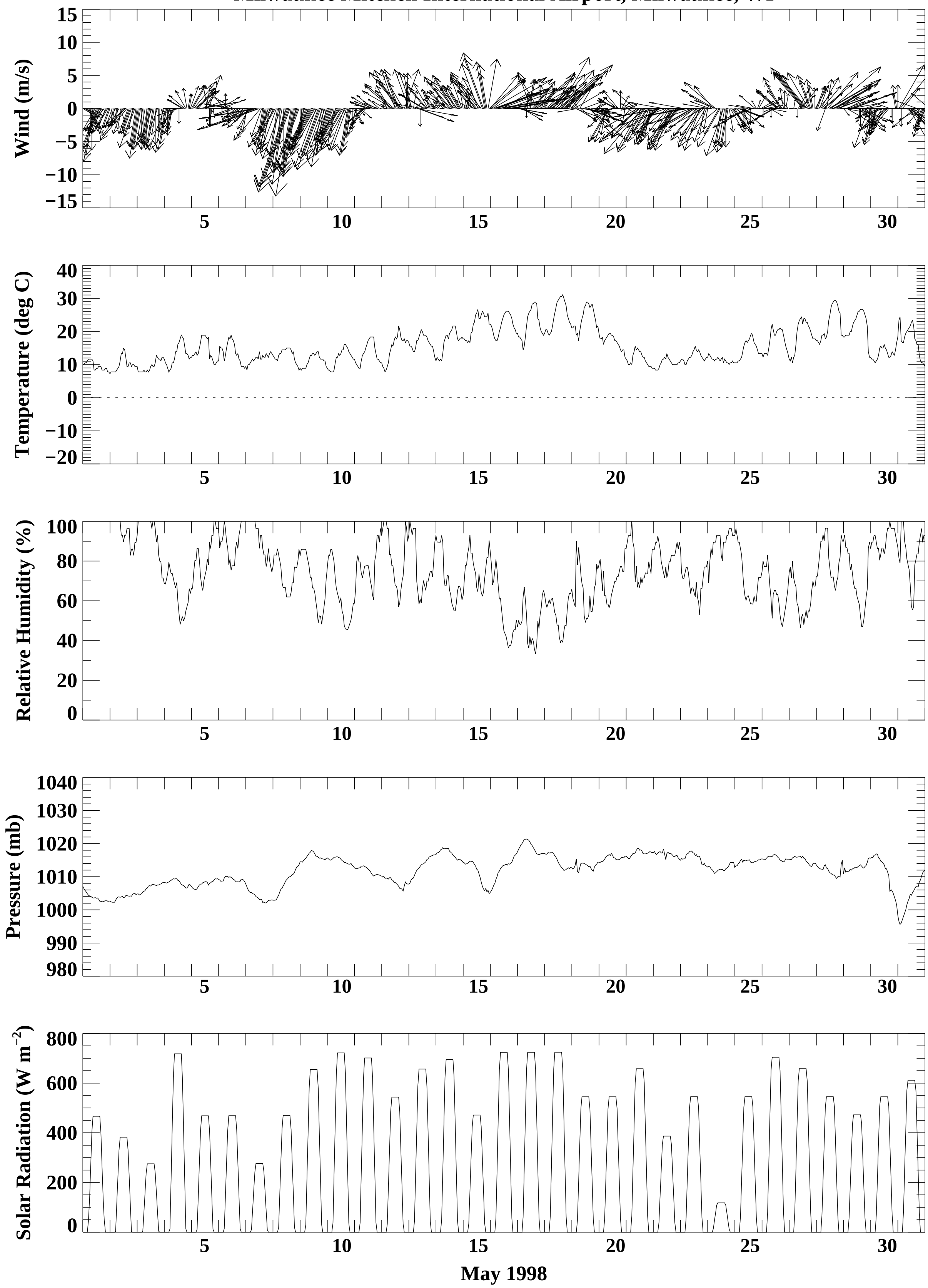


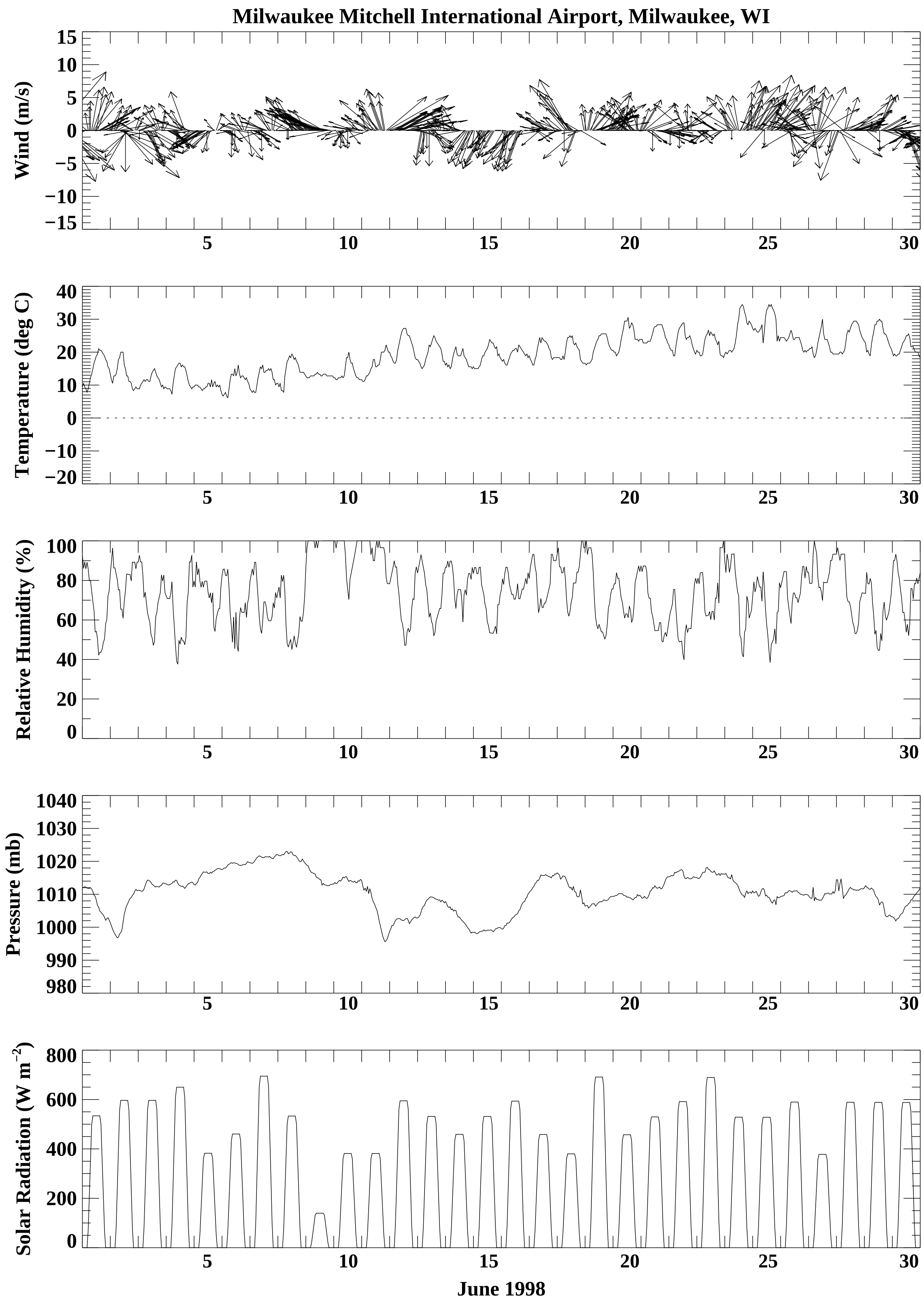
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
15
10
5
0
−5
−10
−15
5
10
15
20
25
30
Temperature (deg C)
40
30
20
10
0
−10
−20
Relative Humidity (%)
100
80
60
40
20
0
Pressure (mb)
1040
1030
1020
1010
1000
990
980
Solar Radiation (W m−2)
800
600
400
200
0
March 1998

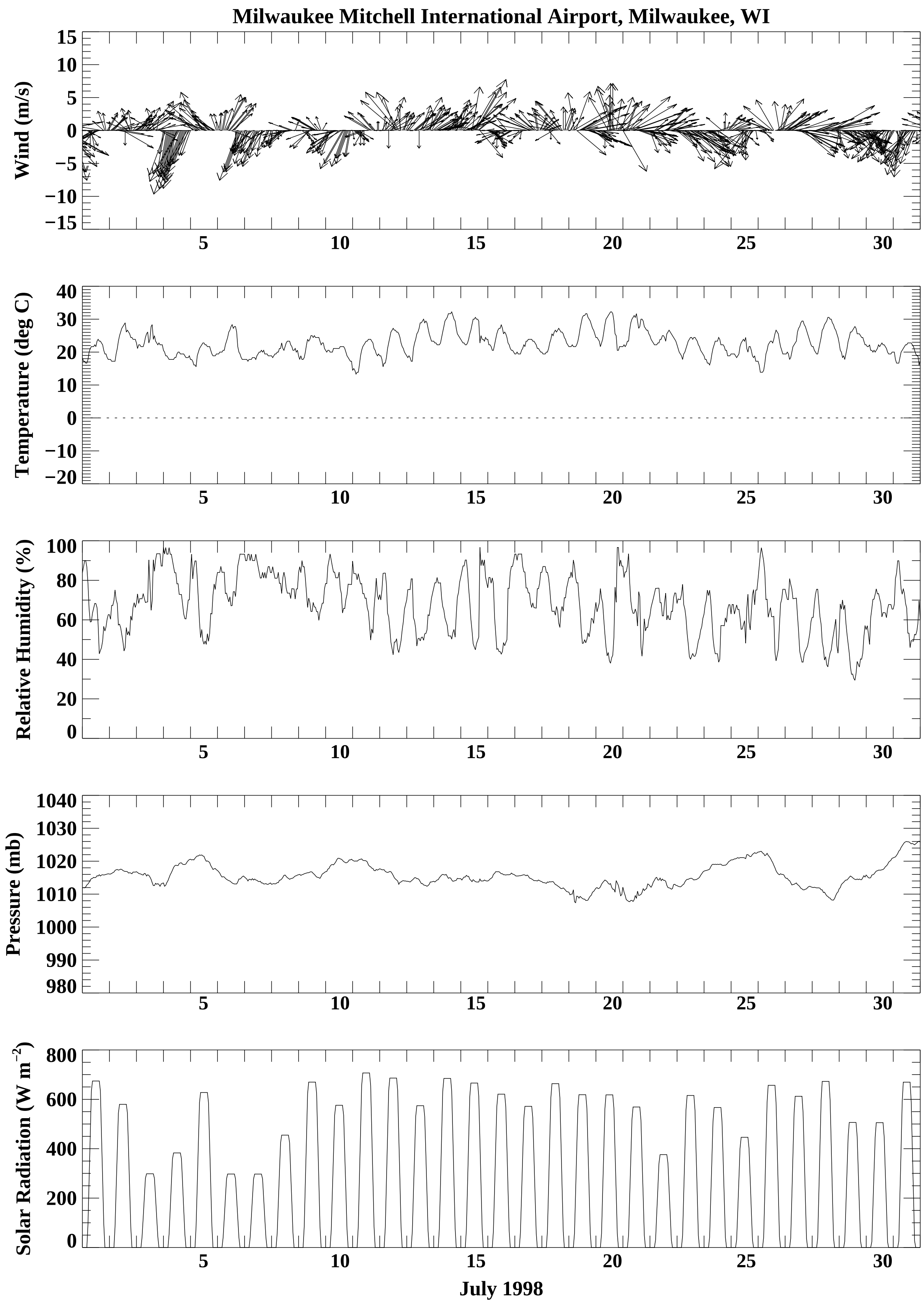
Milwaukee Mitchell International Airport, Milwaukee, WI

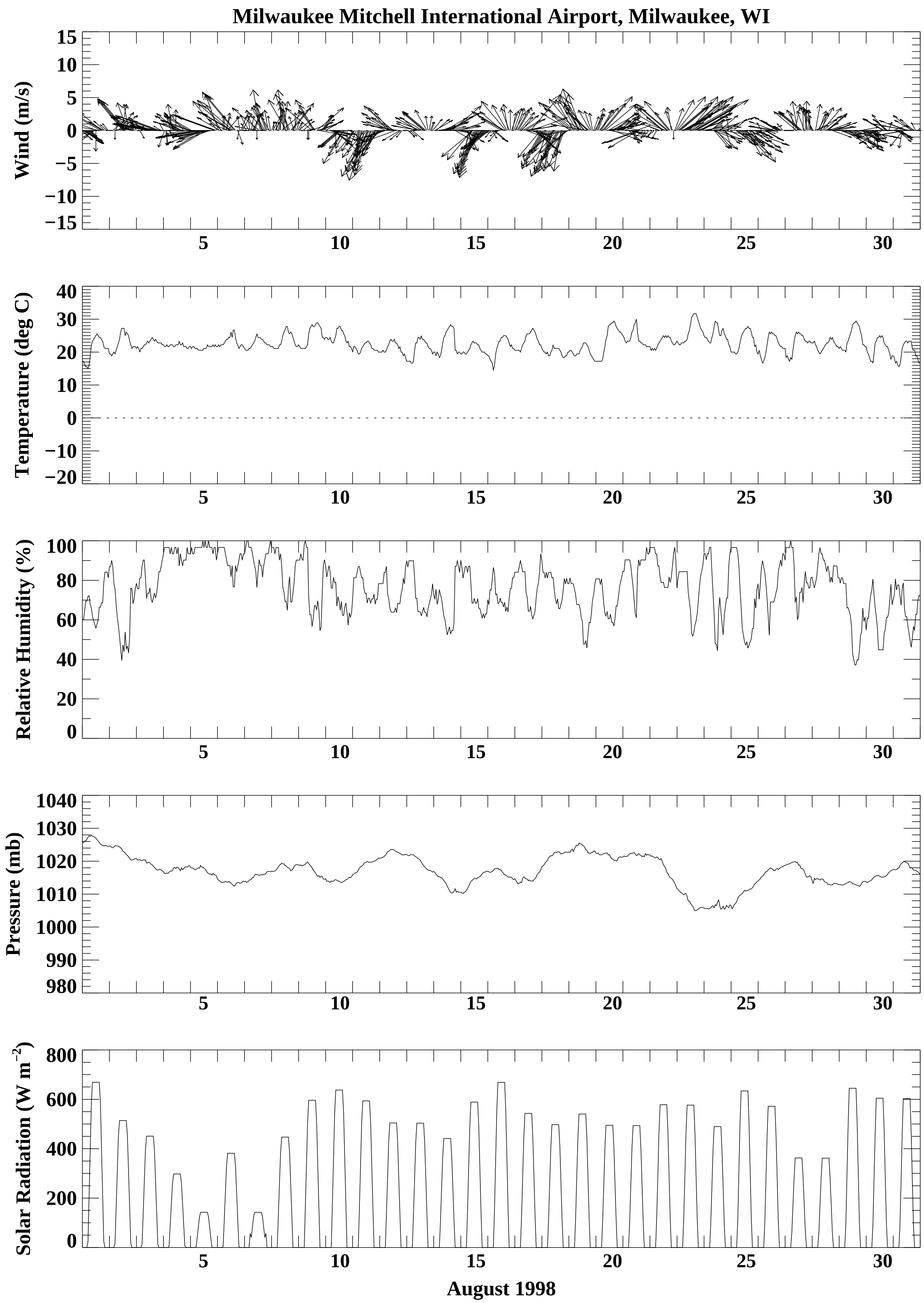


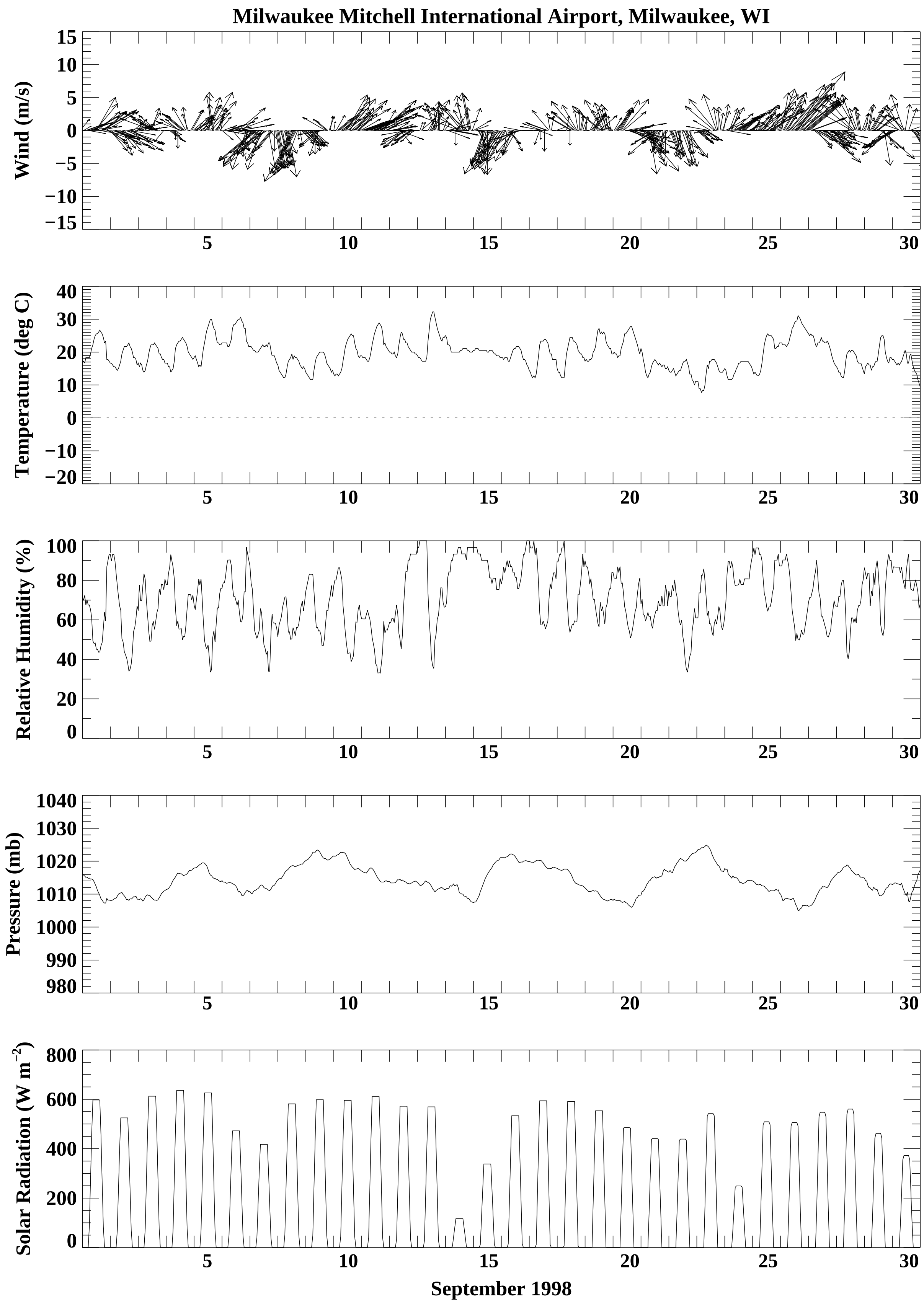
Milwaukee Mitchell International Airport, Milwaukee, WI

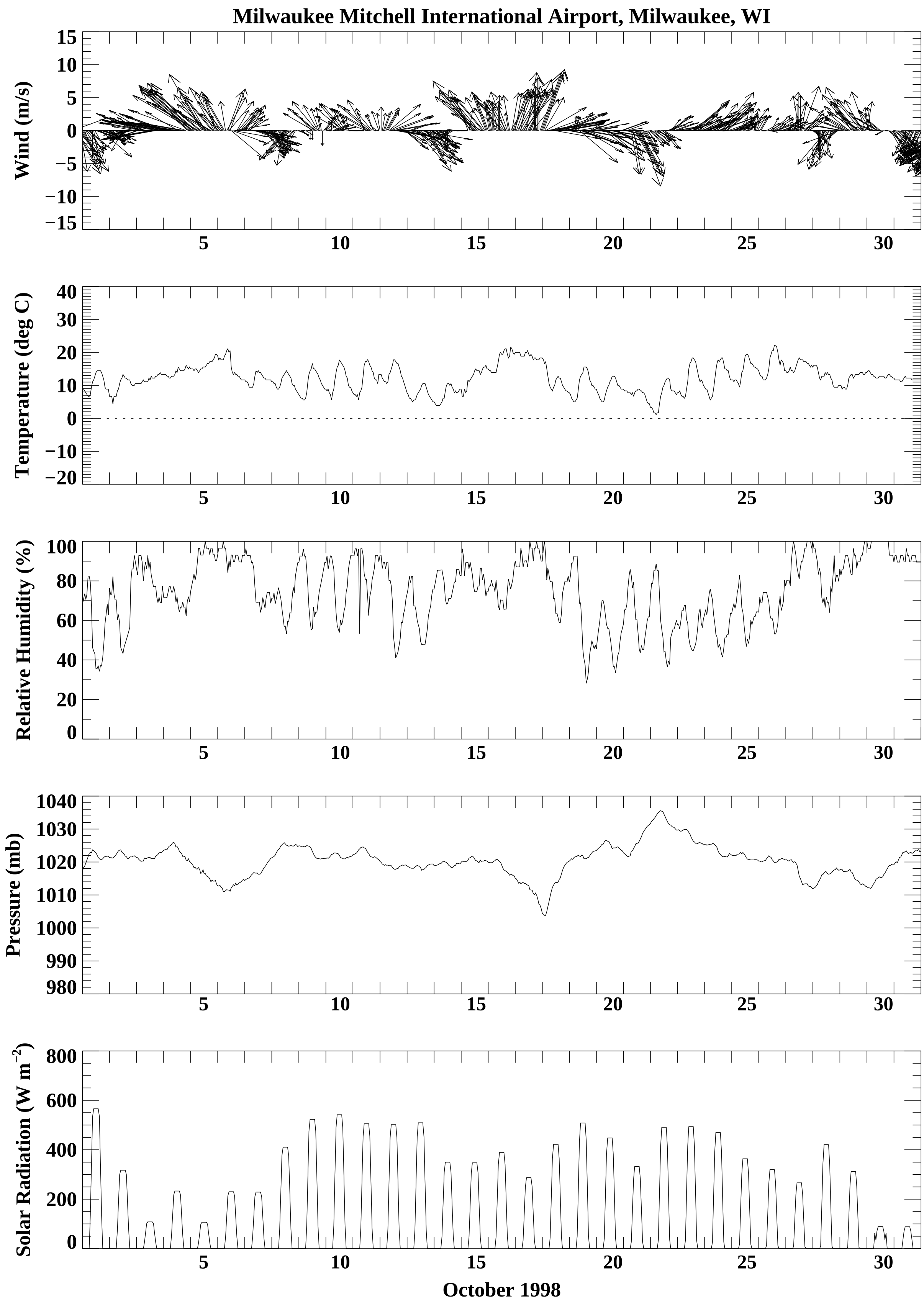


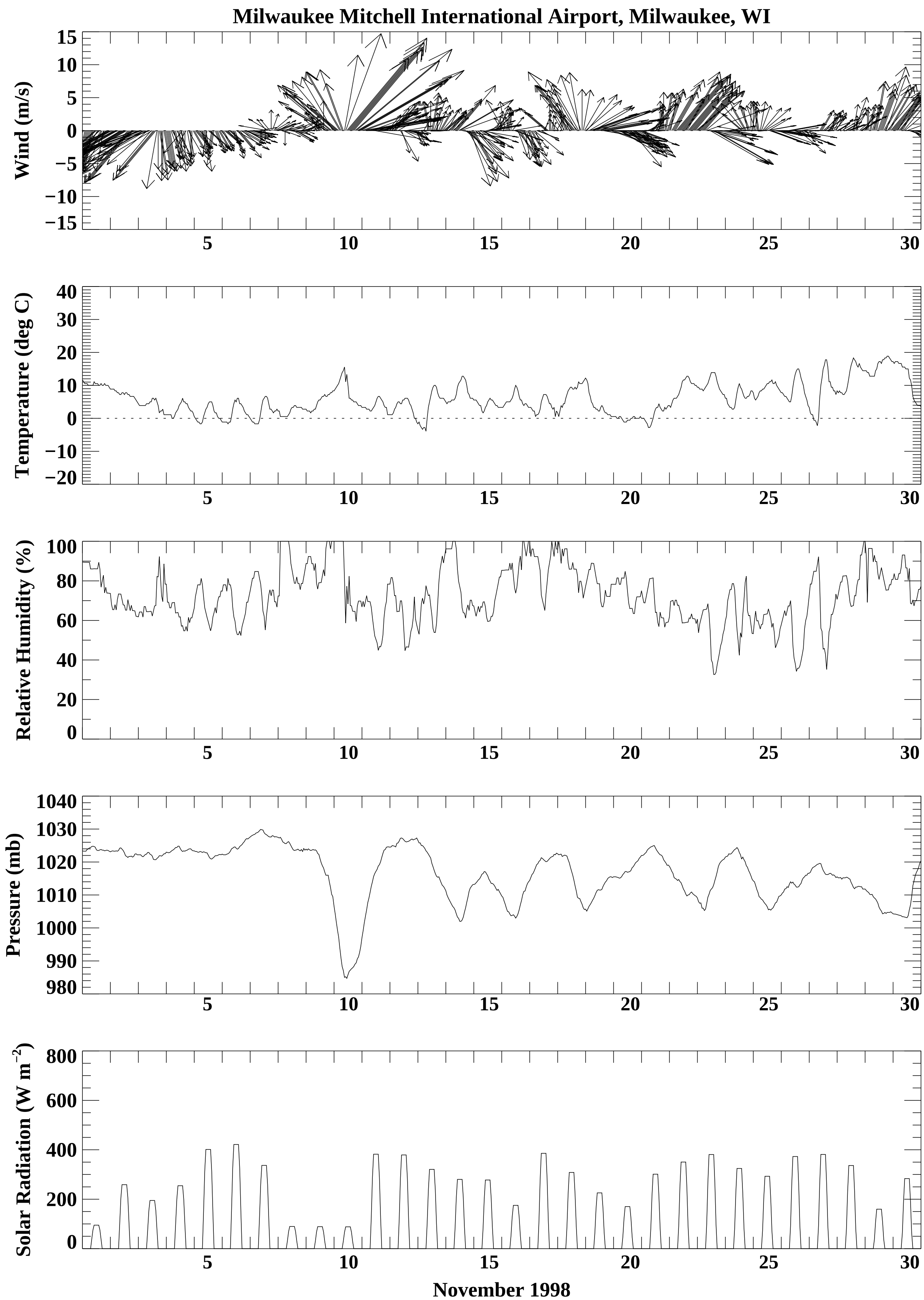

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
15
10
5
0
−5
−10
−15
Temperature (deg C)
40
30
20
10
0
−10
−20
Relative Humidity (%)
100
80
60
40
20
0
Pressure (mb)
1040
1030
1020
1010
1000
990
980
Solar Radiation (W m−2)
800
600
400
200
0
5
10
15
20
25
30
June 1998

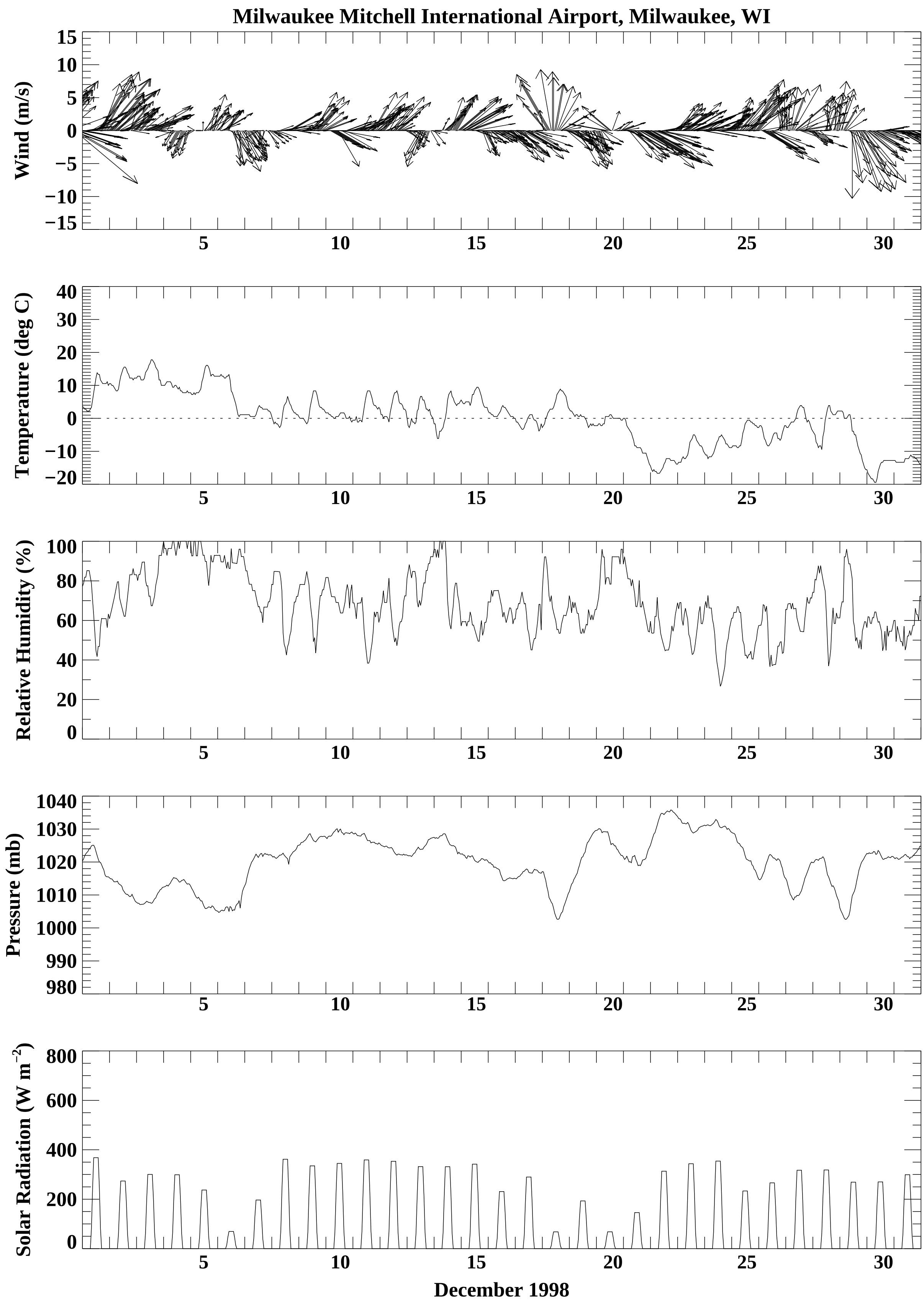

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
July 1998


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m−2)
August 1998

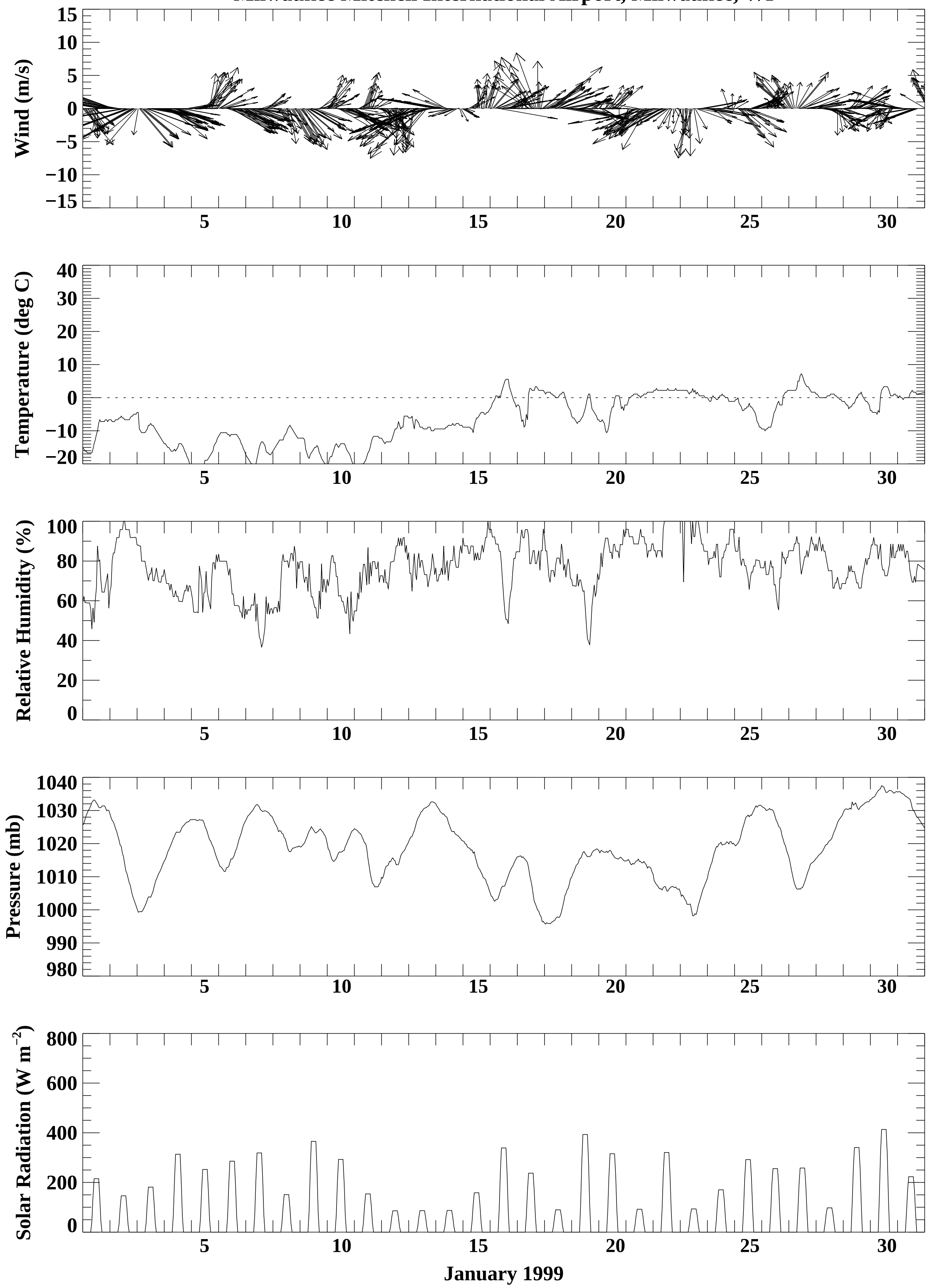

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
September 1998

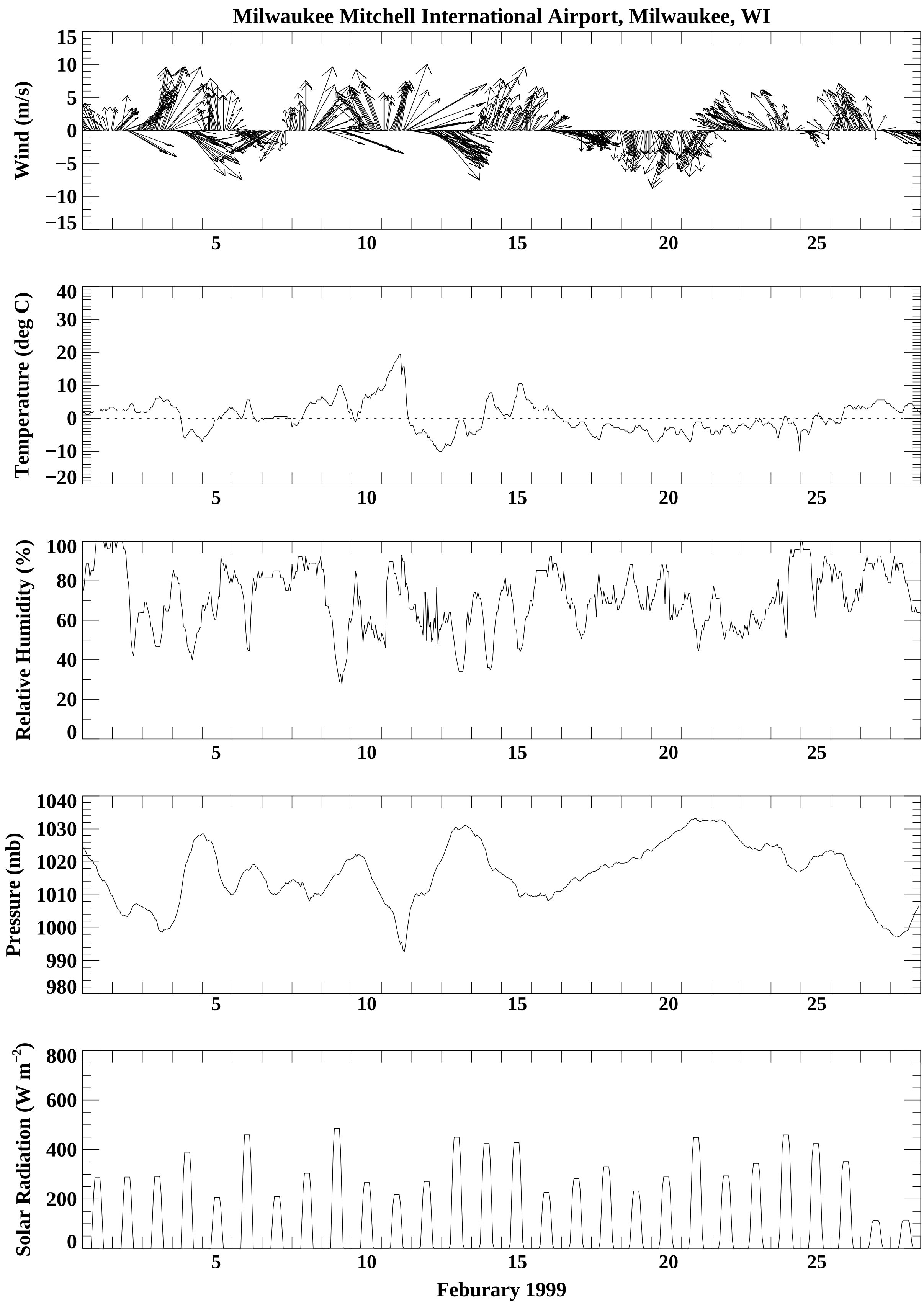

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
October 1998

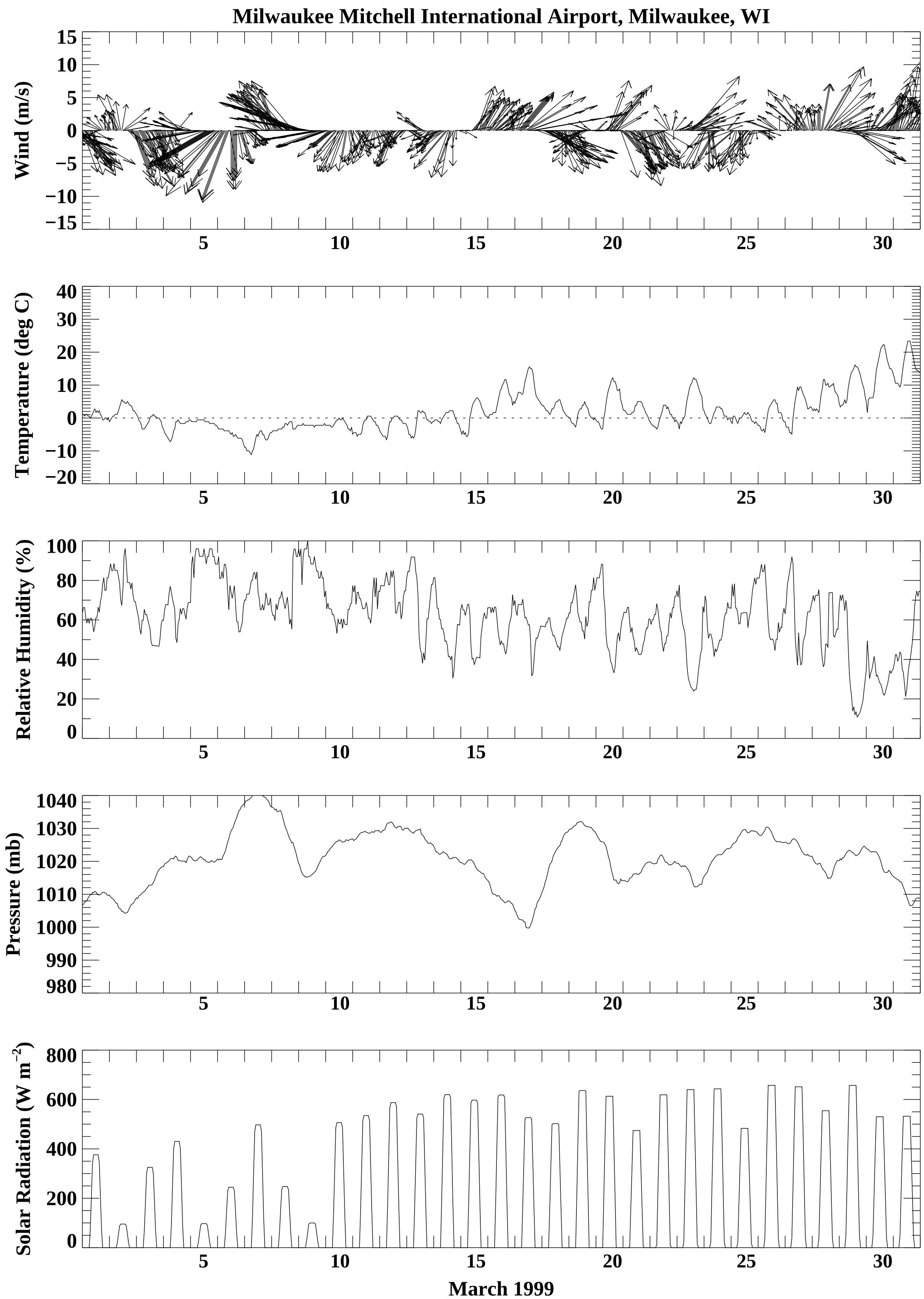

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
November 1998


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
December 1998

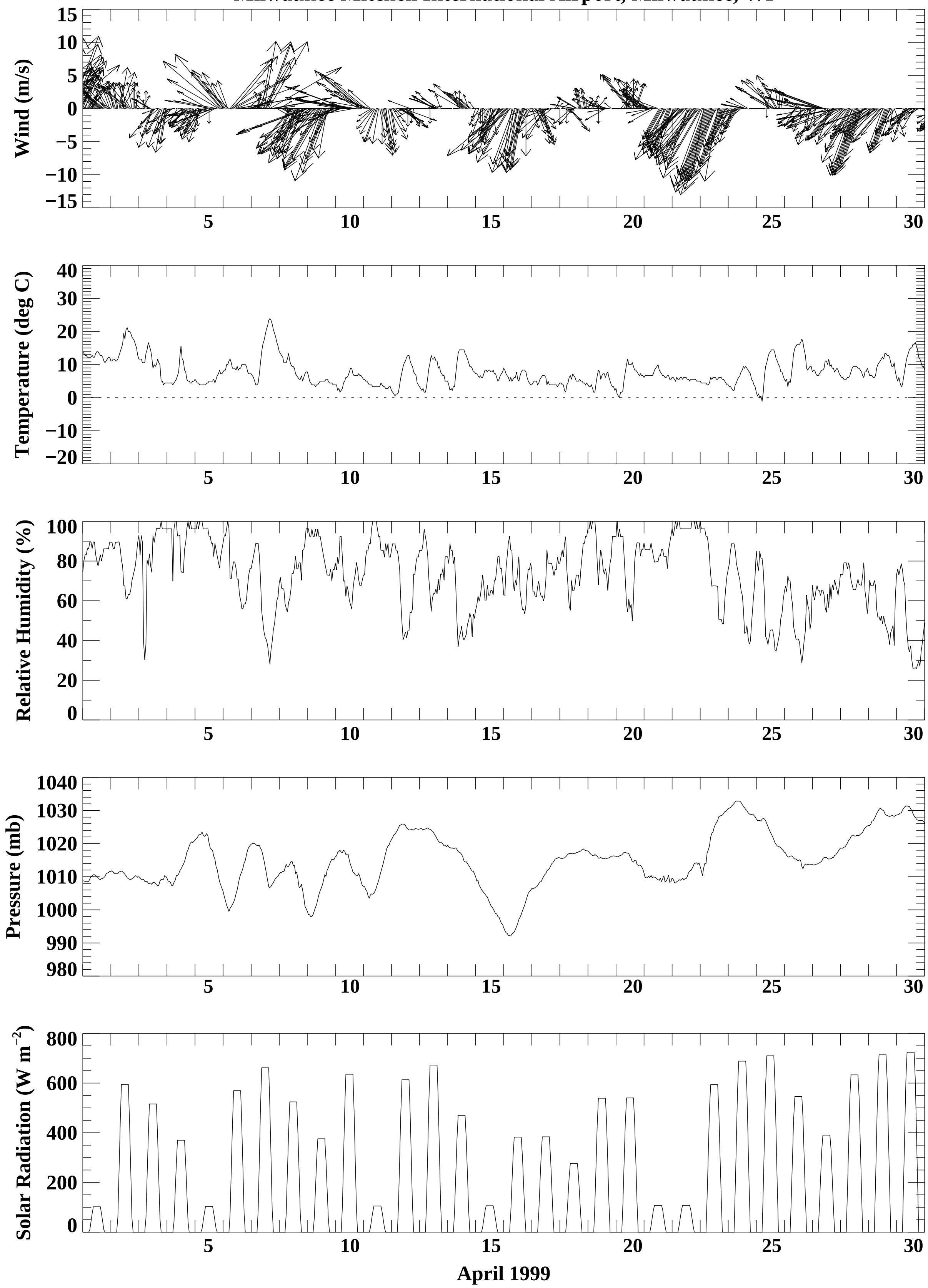
Milwaukee Mitchell International Airport, Milwaukee, WI

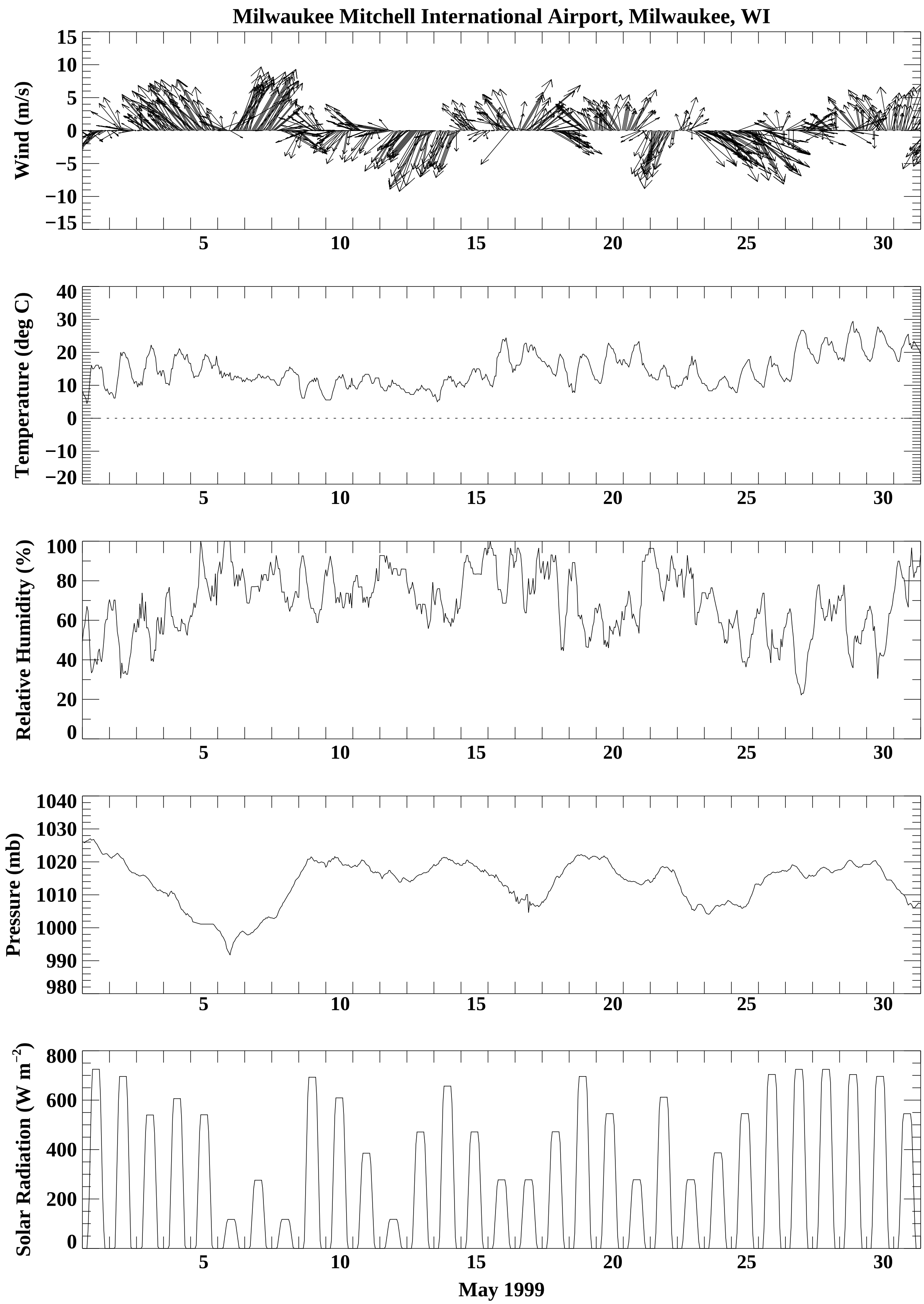



Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
Feburary 1999

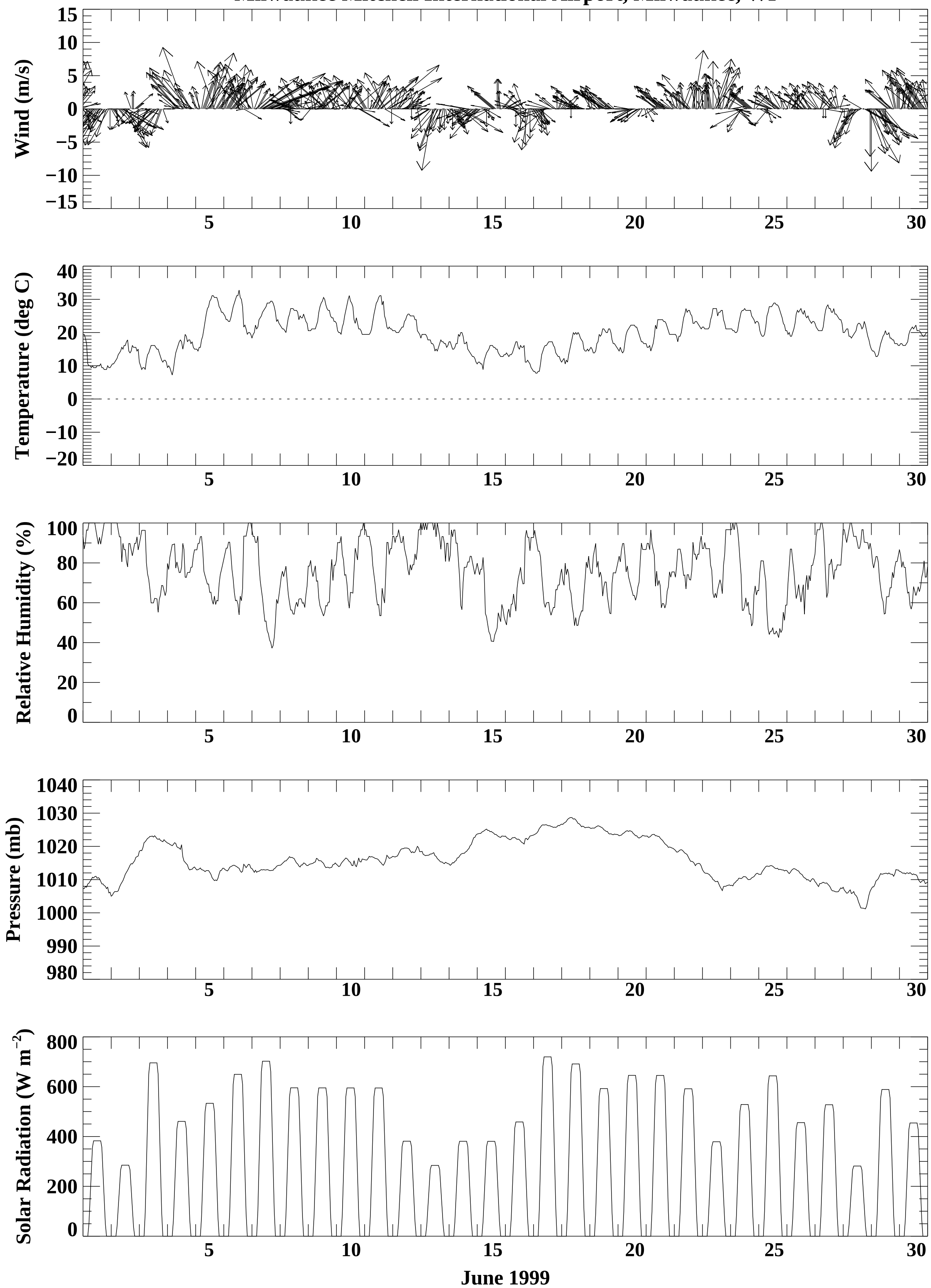

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
March 1999

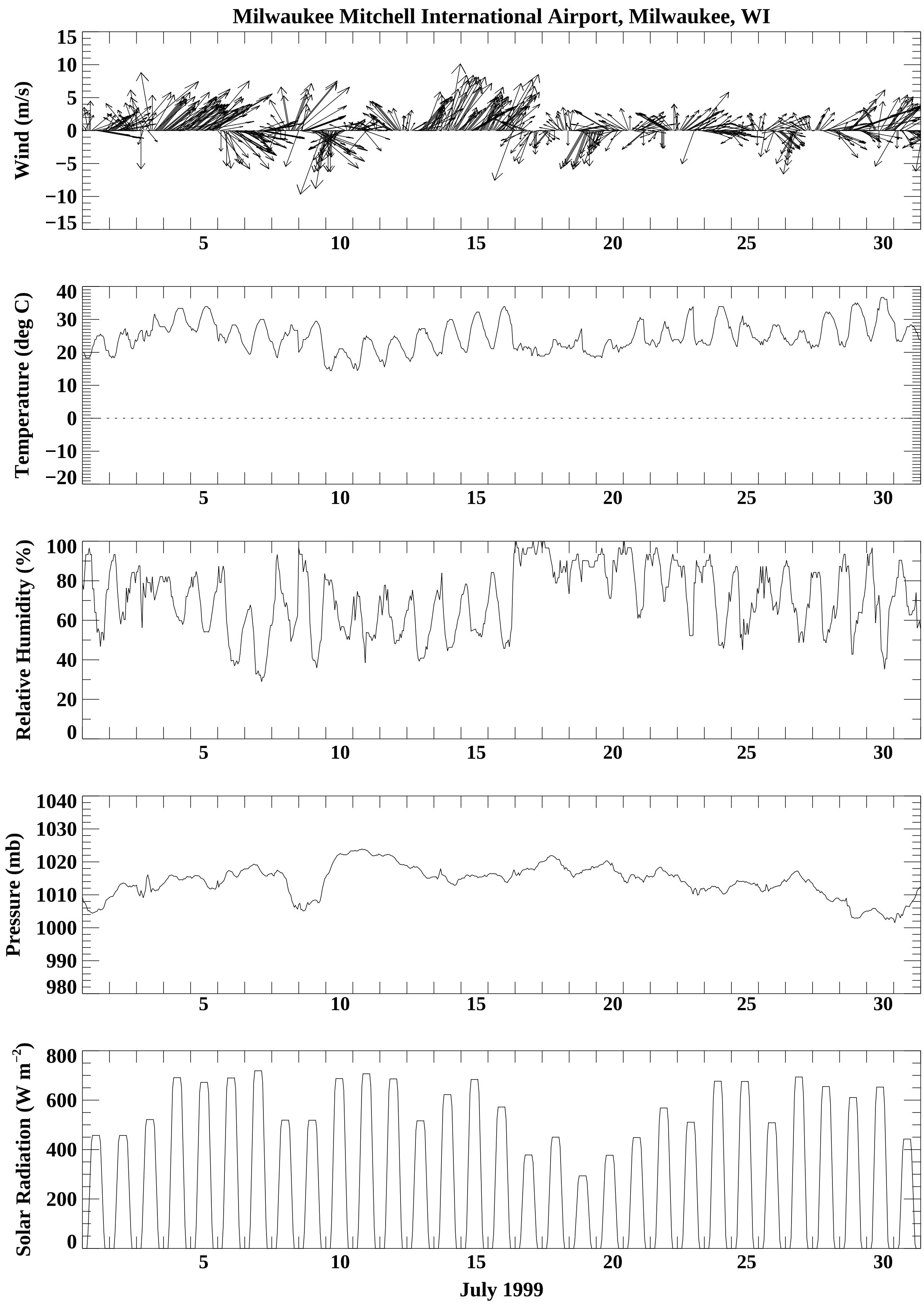
Milwaukee Mitchell International Airport, Milwaukee, WI



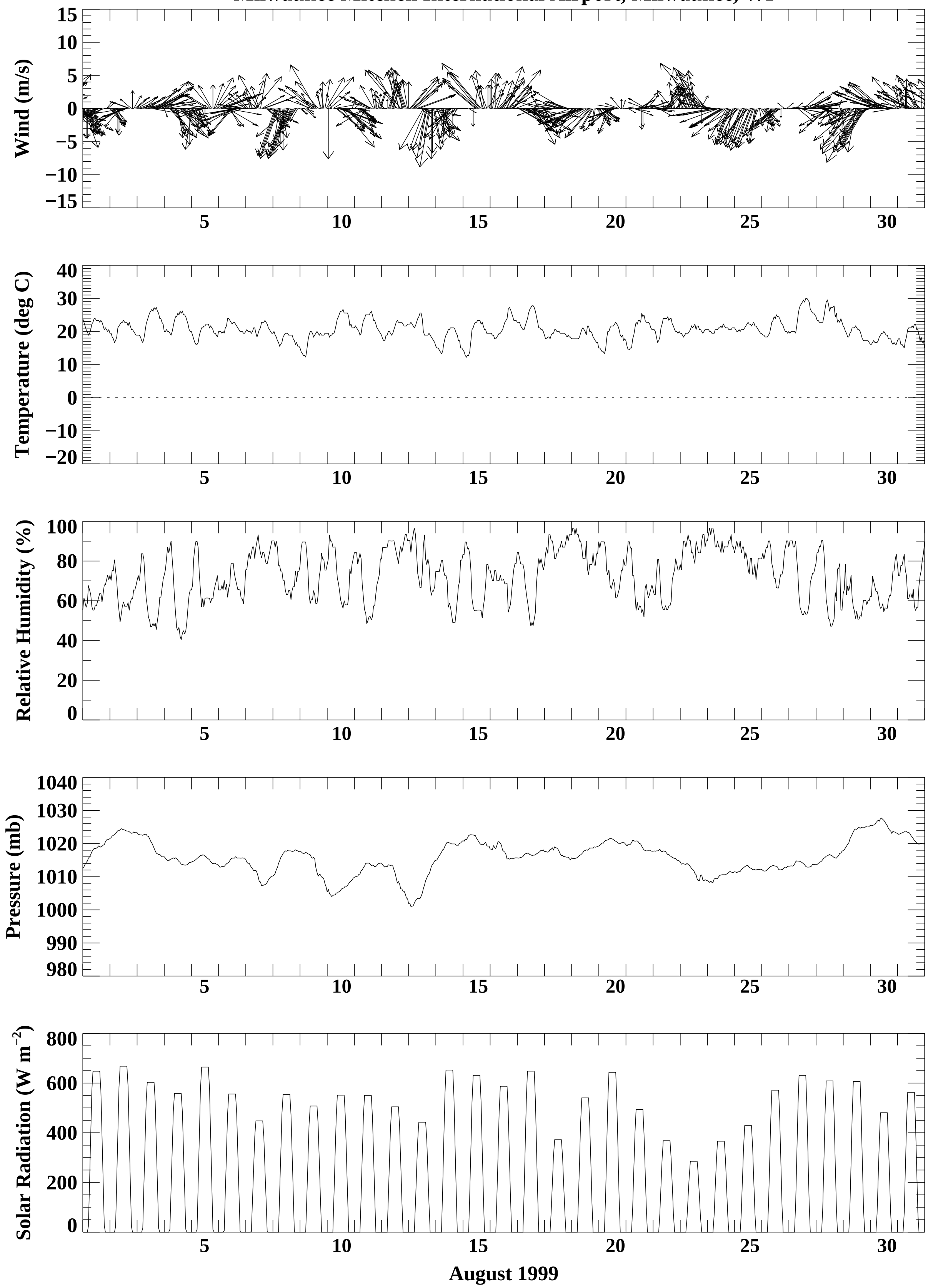

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
May 1999

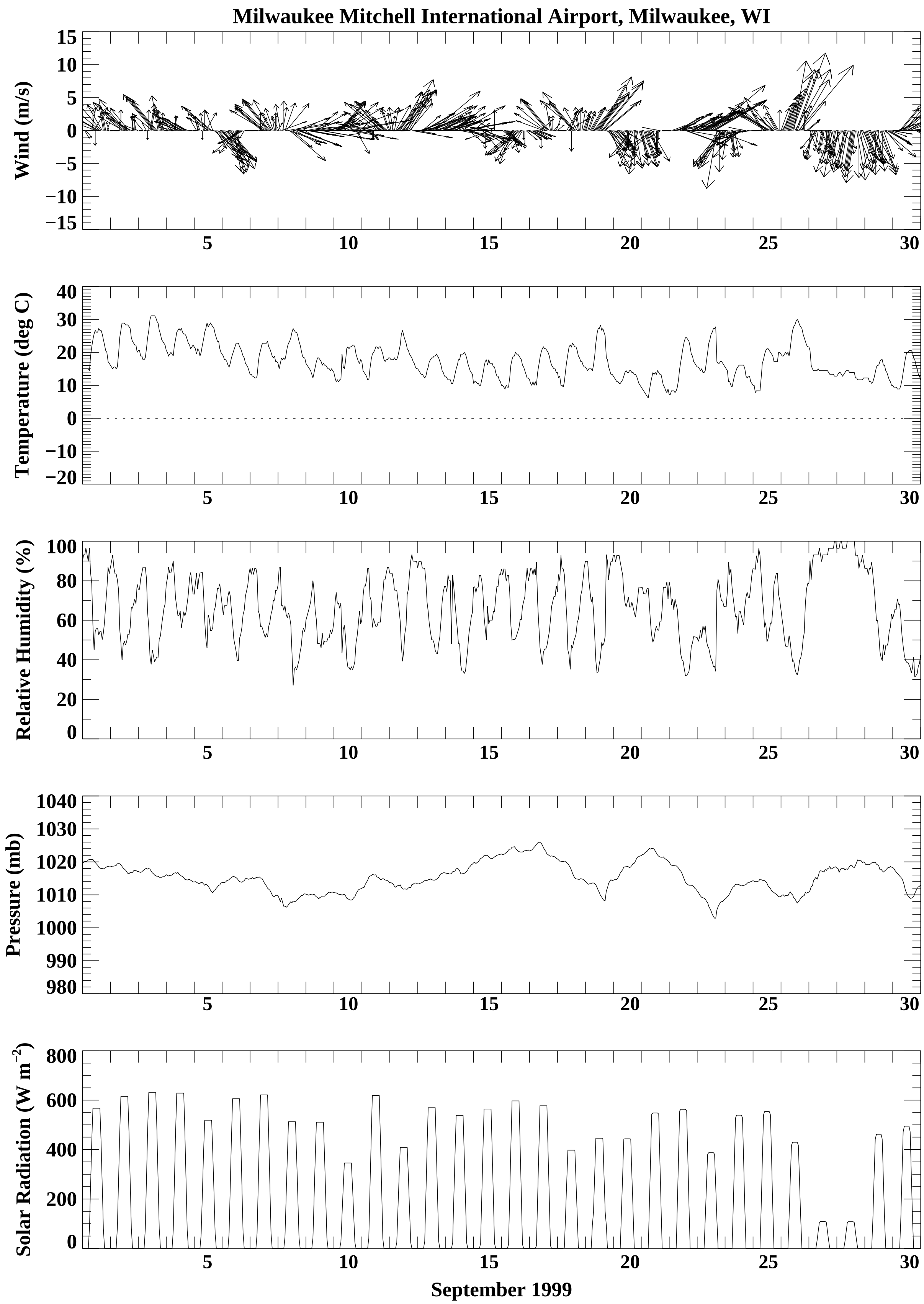
Milwaukee Mitchell International Airport, Milwaukee, WI



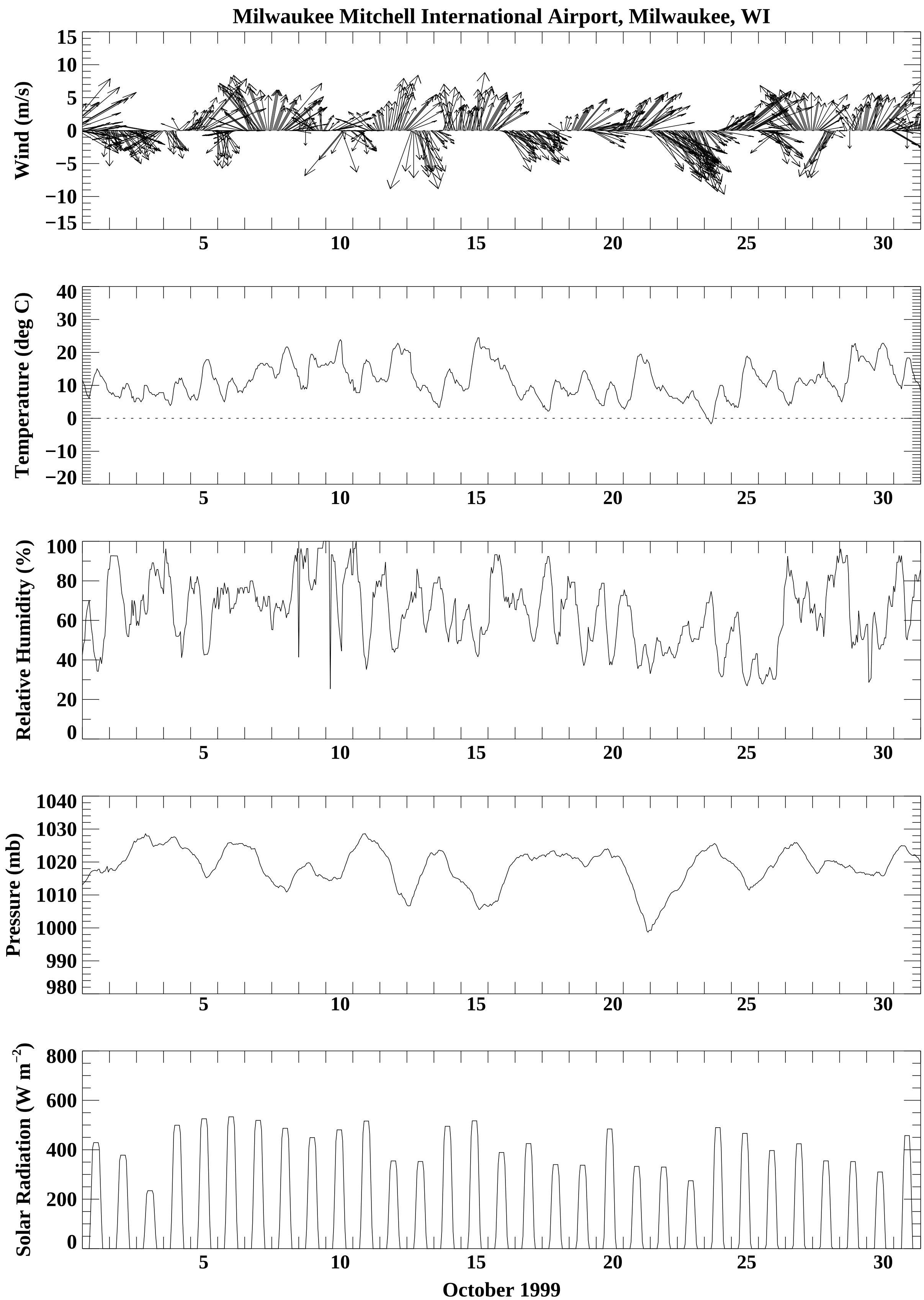

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
July 1999

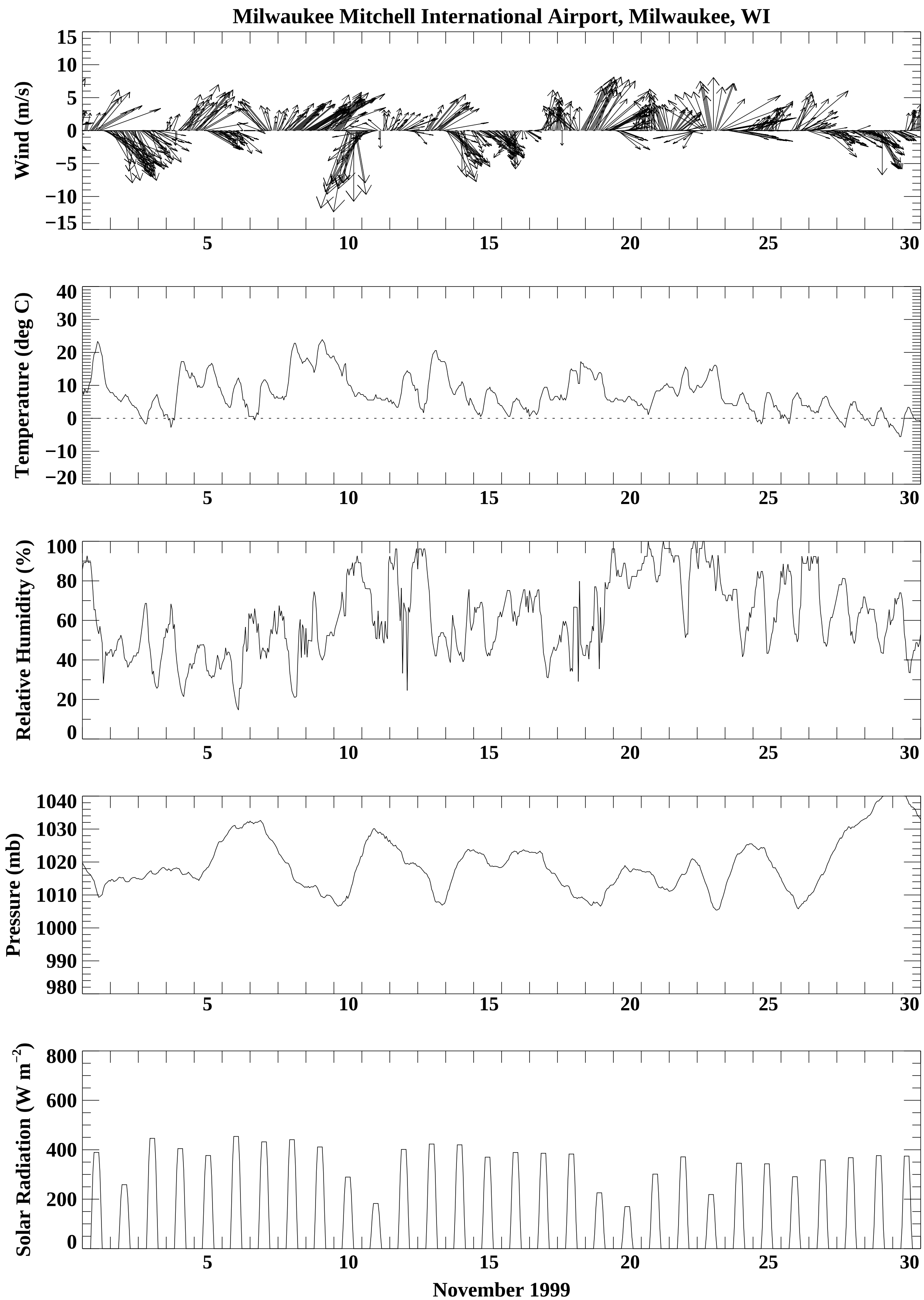
Milwaukee Mitchell International Airport, Milwaukee, WI



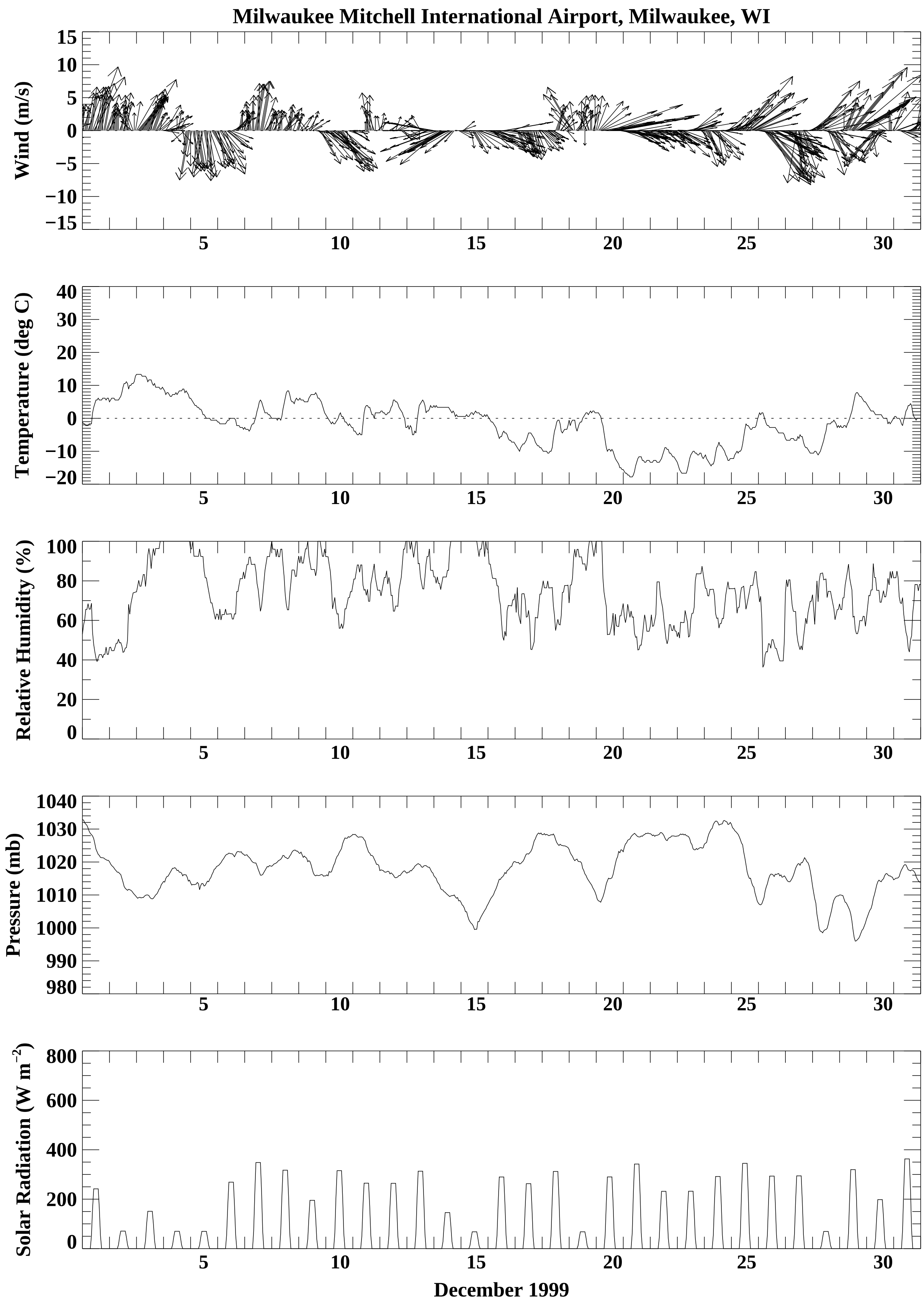


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
September 1999

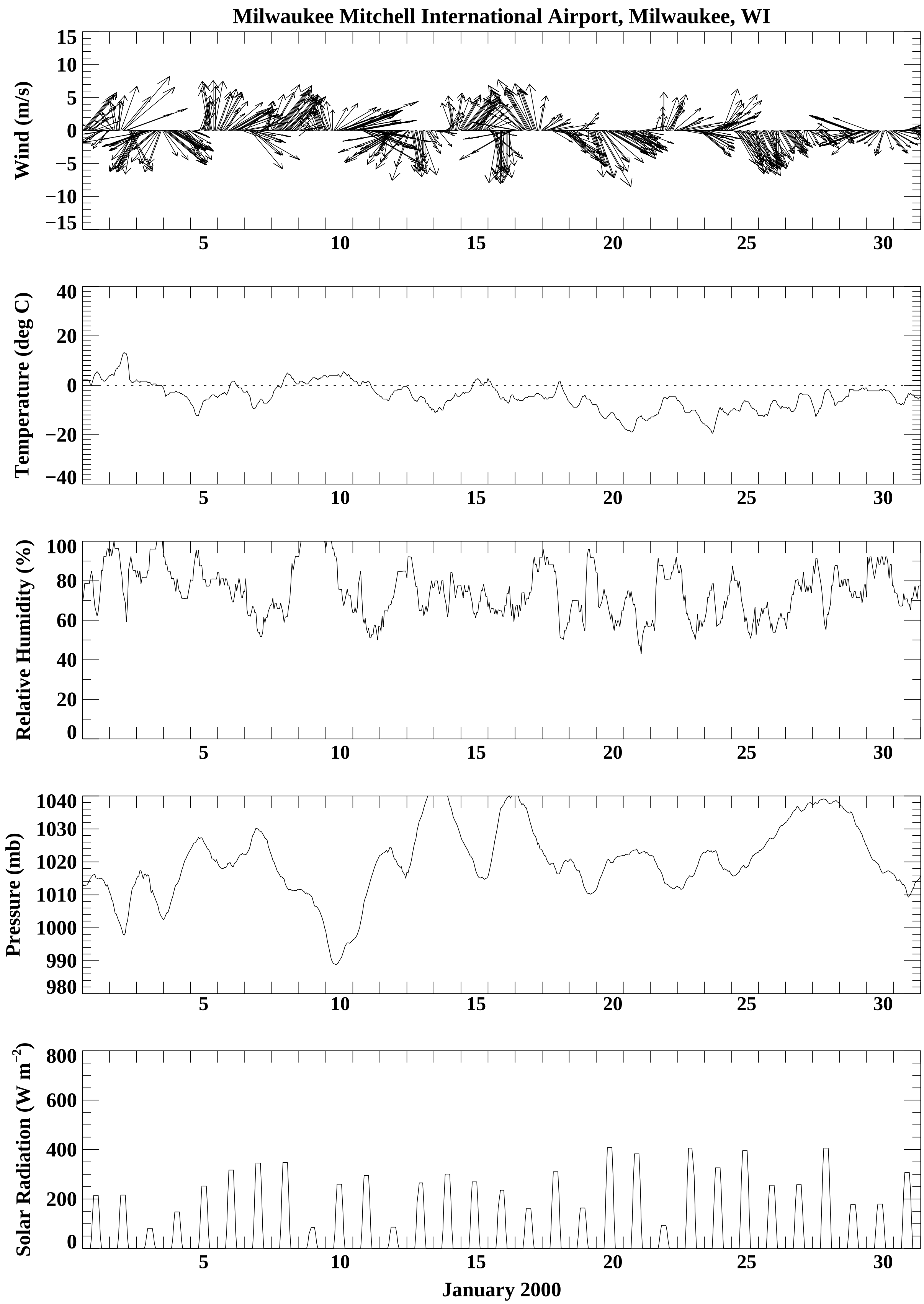

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m⁻²)
October 1999



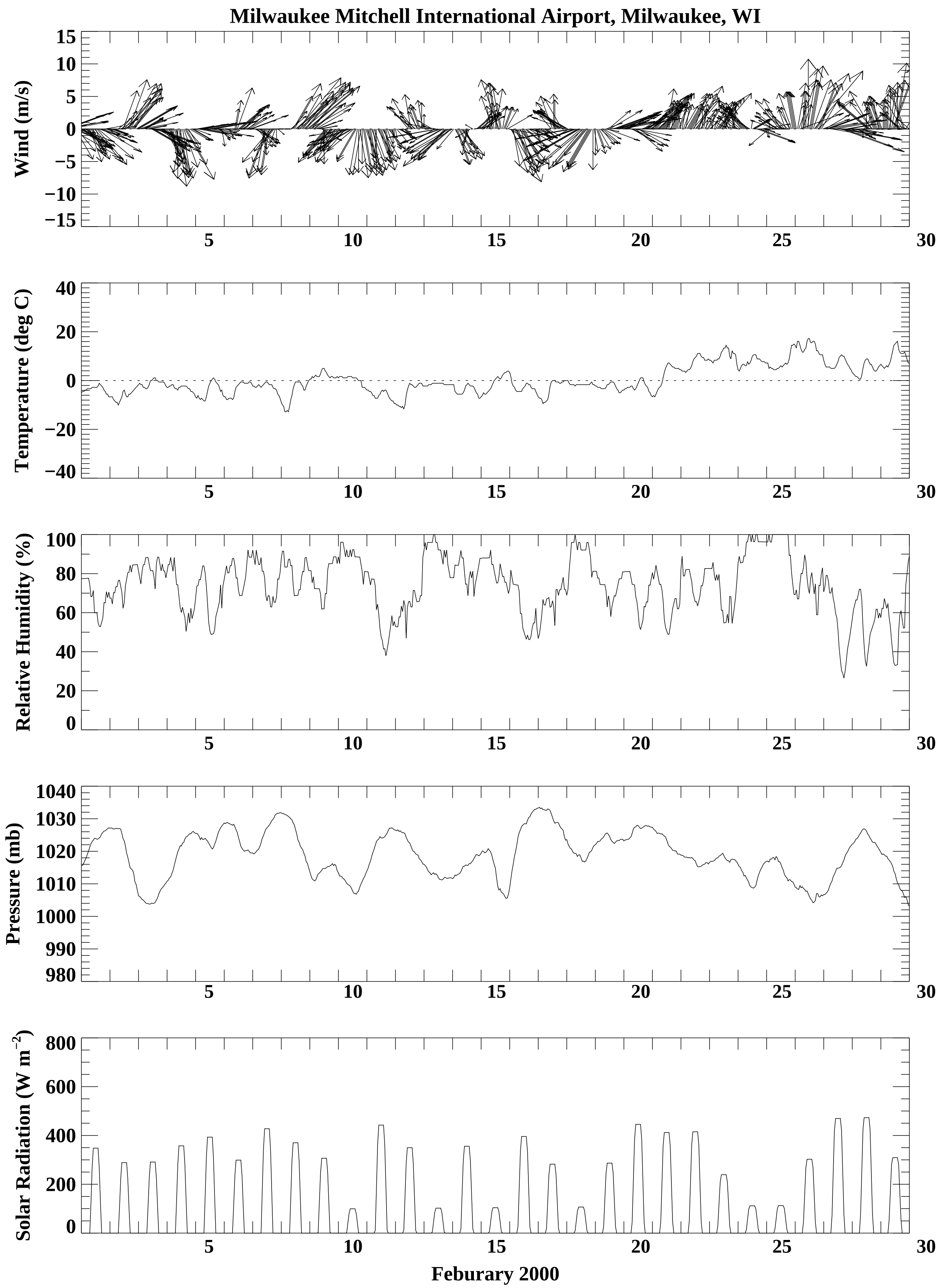
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
November 1999



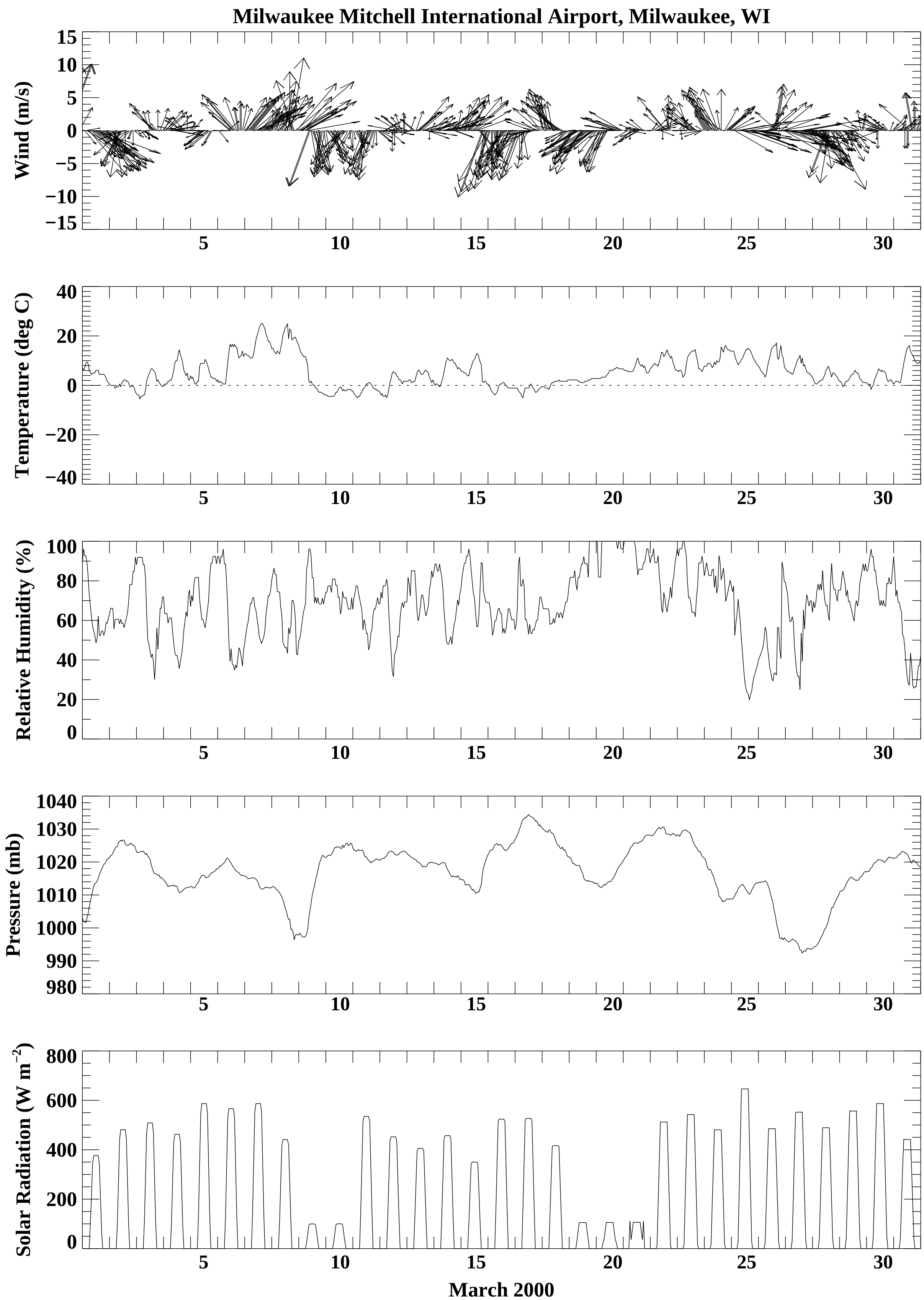
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
December 1999

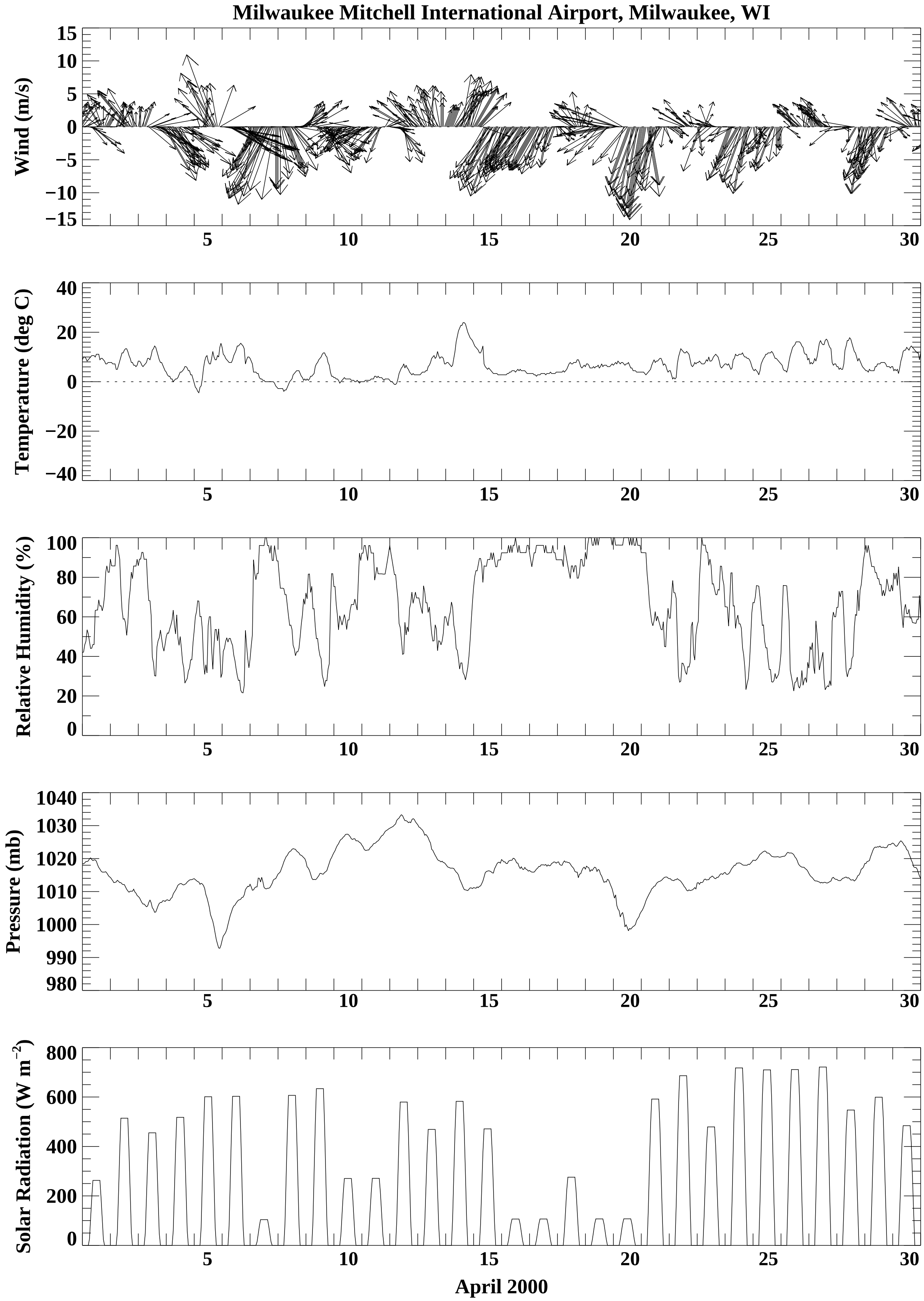


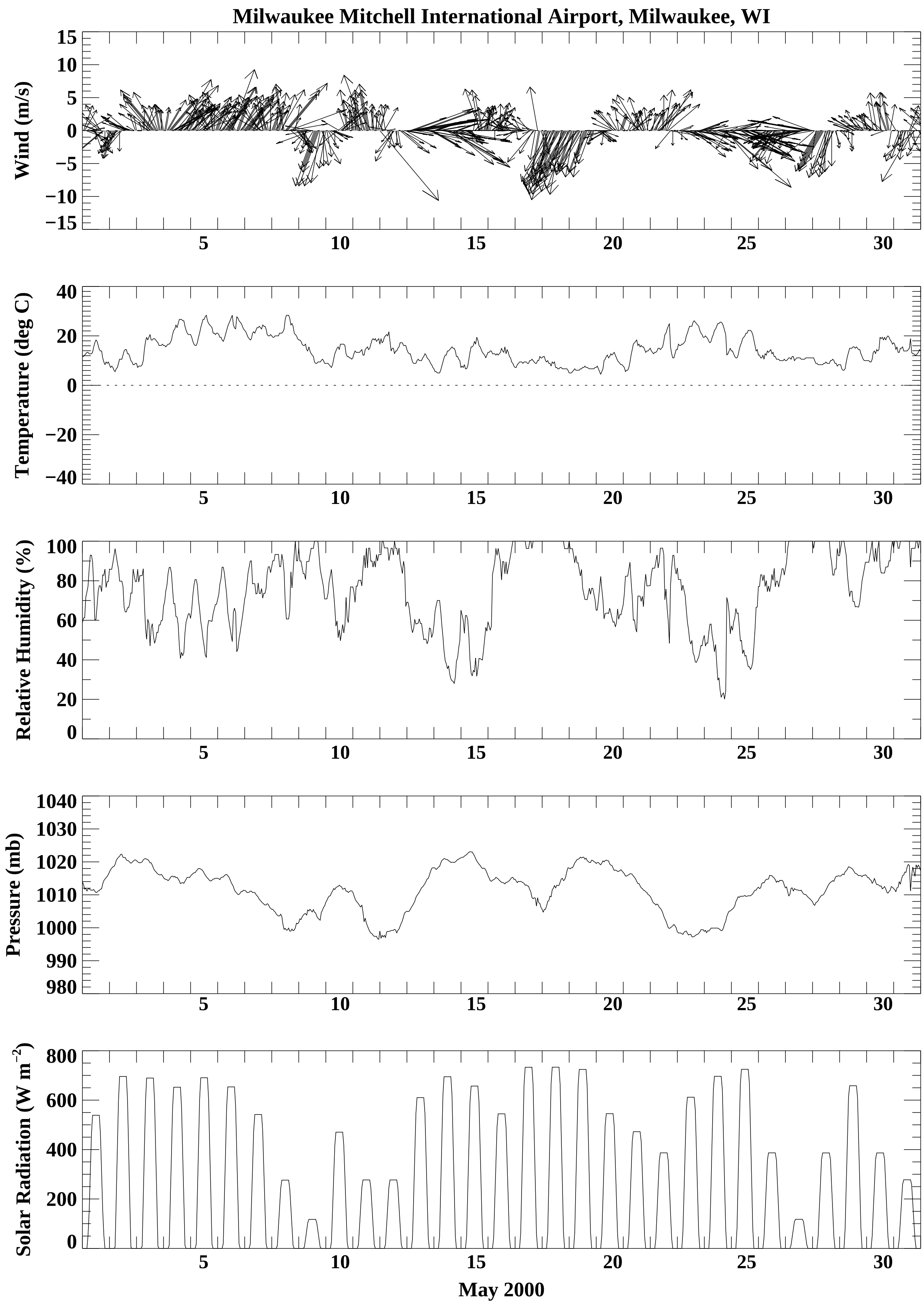
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
January 2000

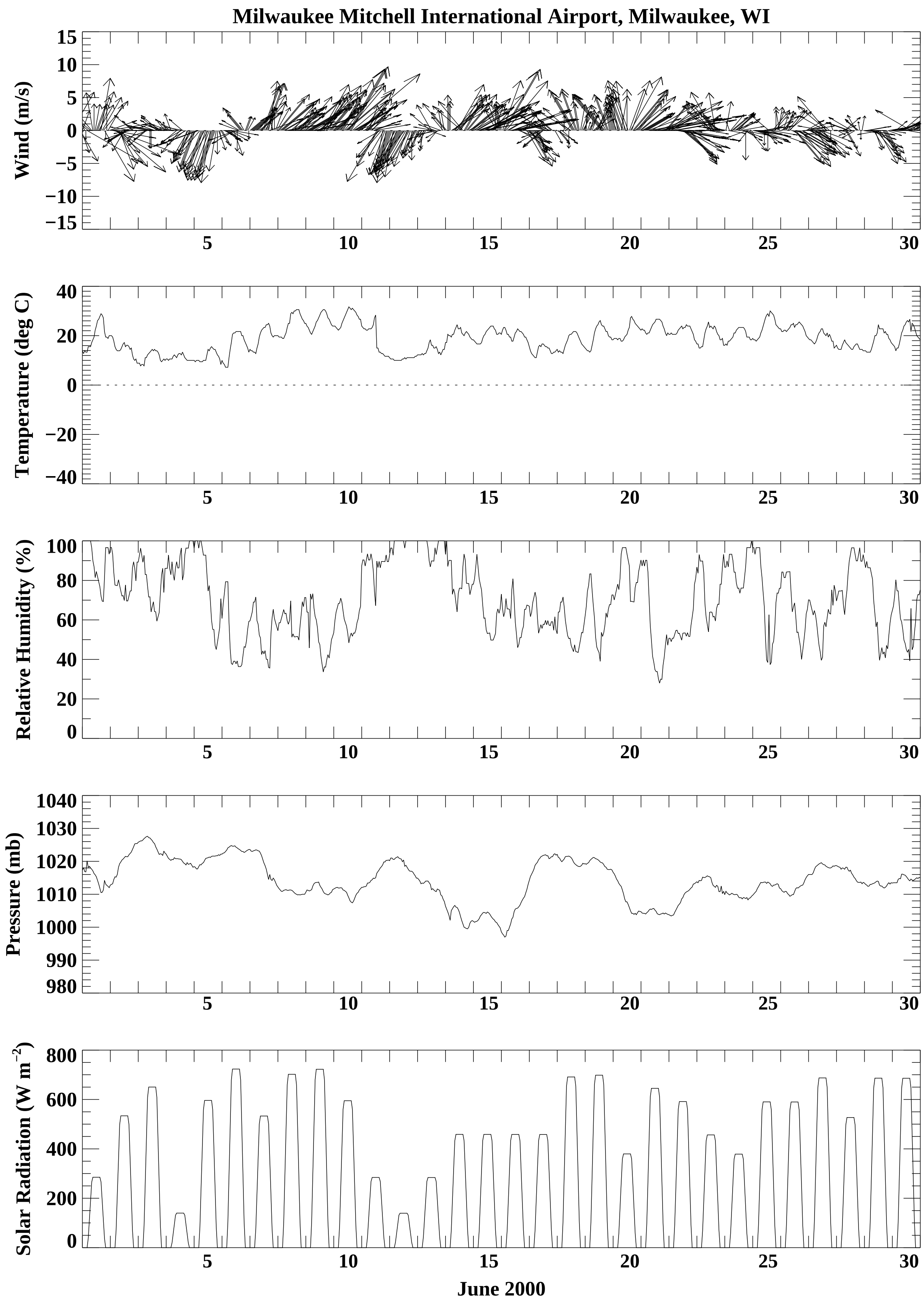


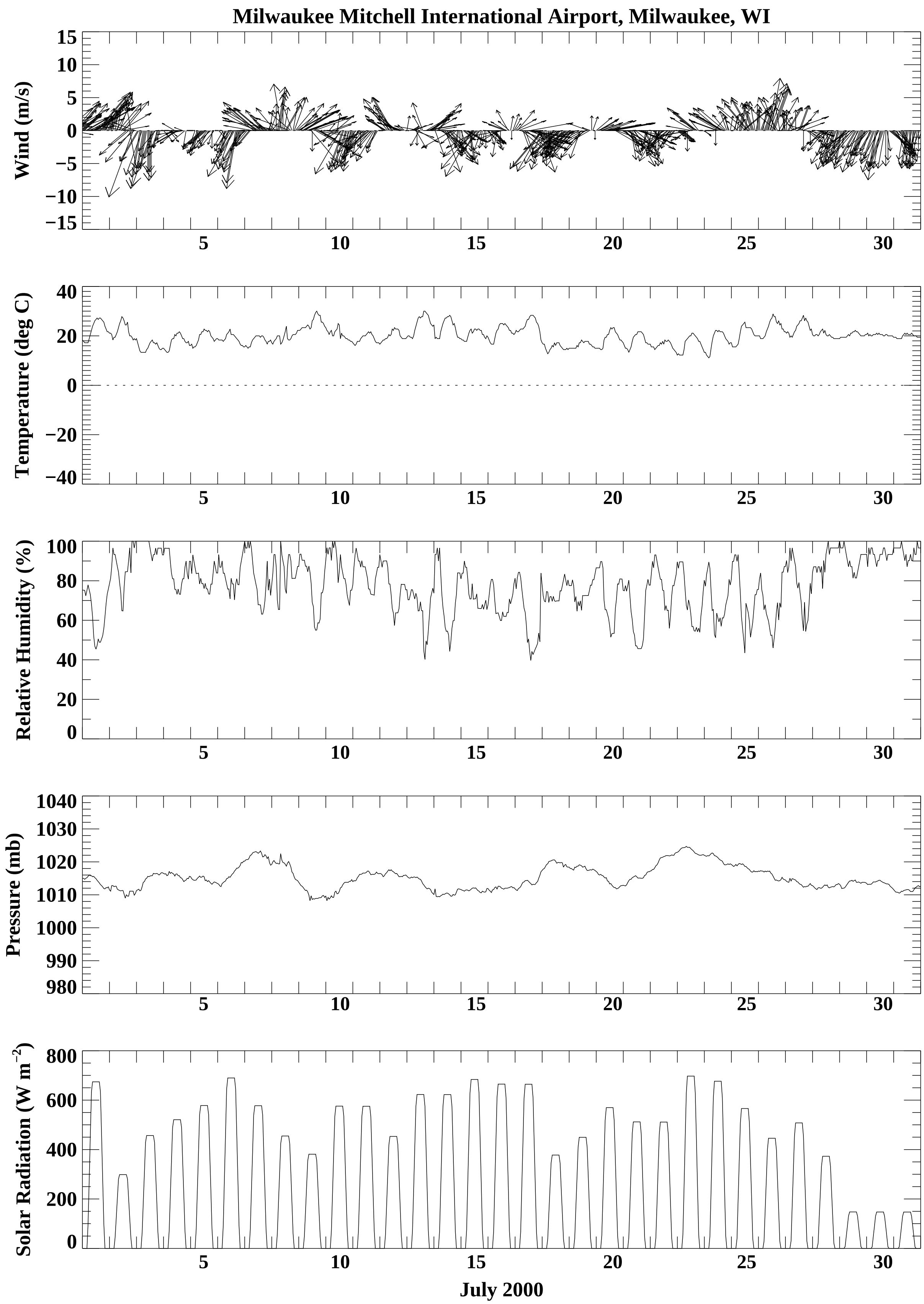
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
15
10
5
0
−5
−10
−15
Temperature (deg C)
40
20
0
−20
−40
Relative Humidity (%)
100
80
60
40
20
0
Pressure (mb)
1040
1030
1020
1010
1000
990
980
Solar Radiation (W m−2)
800
600
400
200
0
5
10
15
20
25
30
Feburary 2000

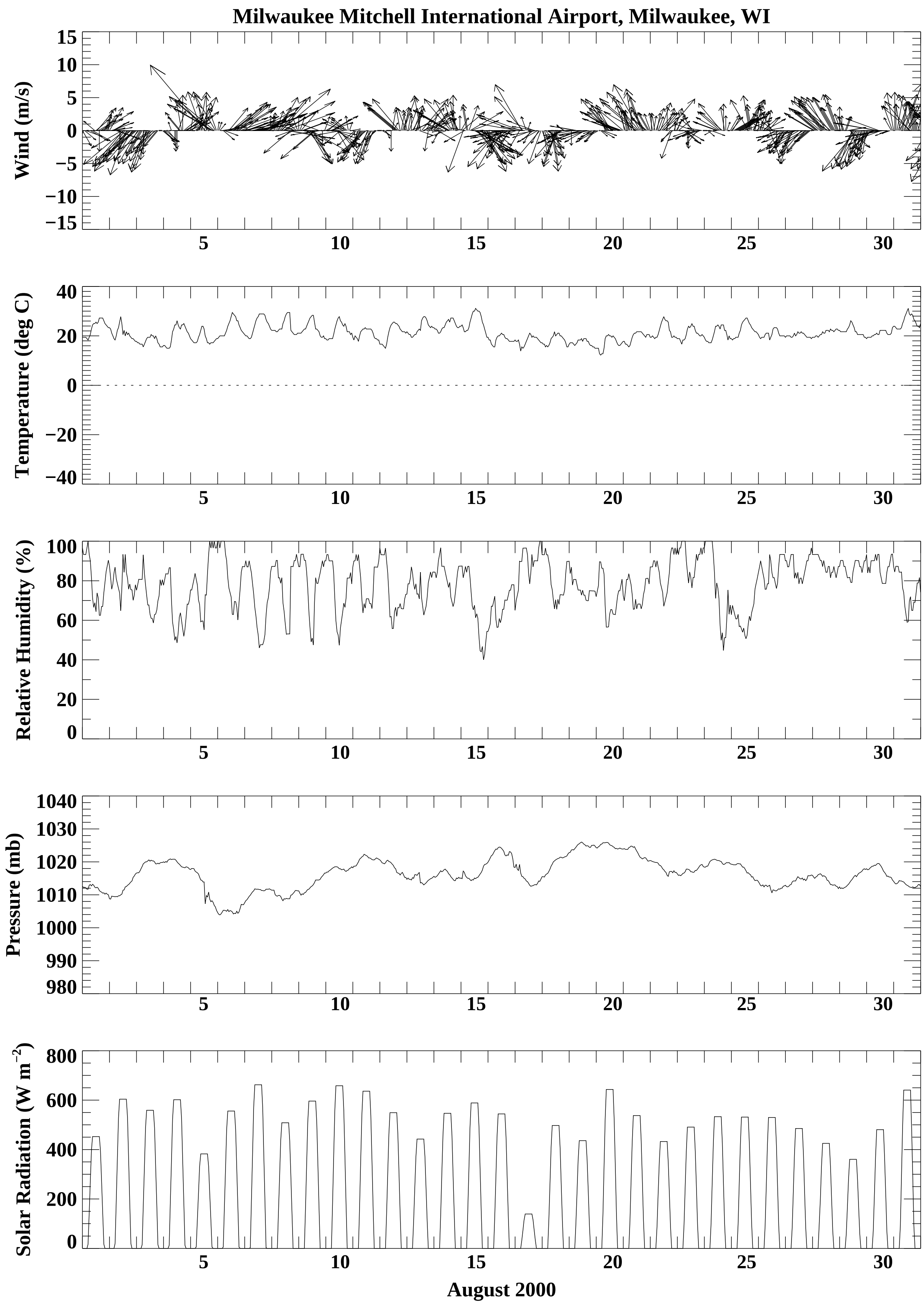

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
March 2000


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m−2)
April 2000

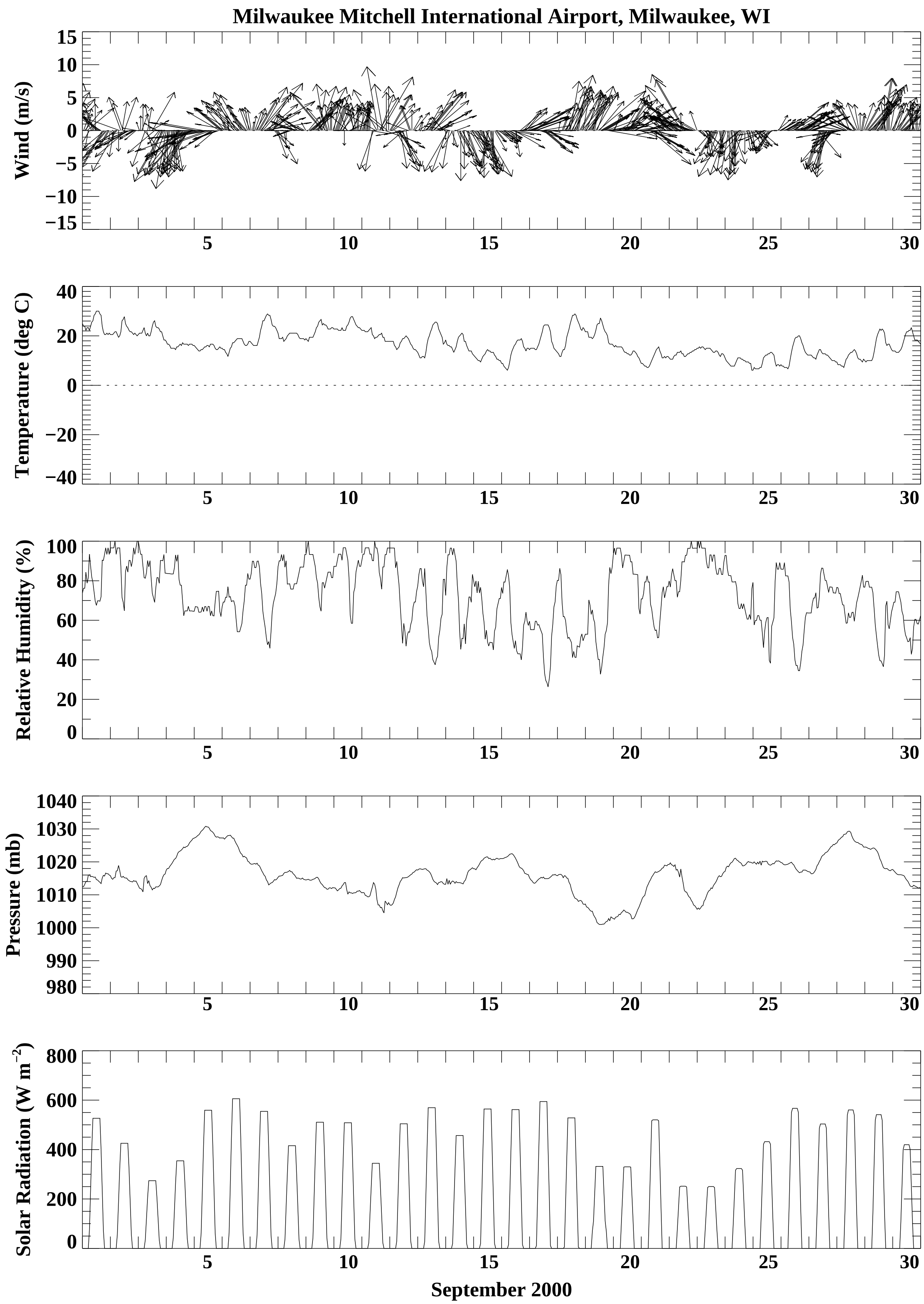

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
May 2000

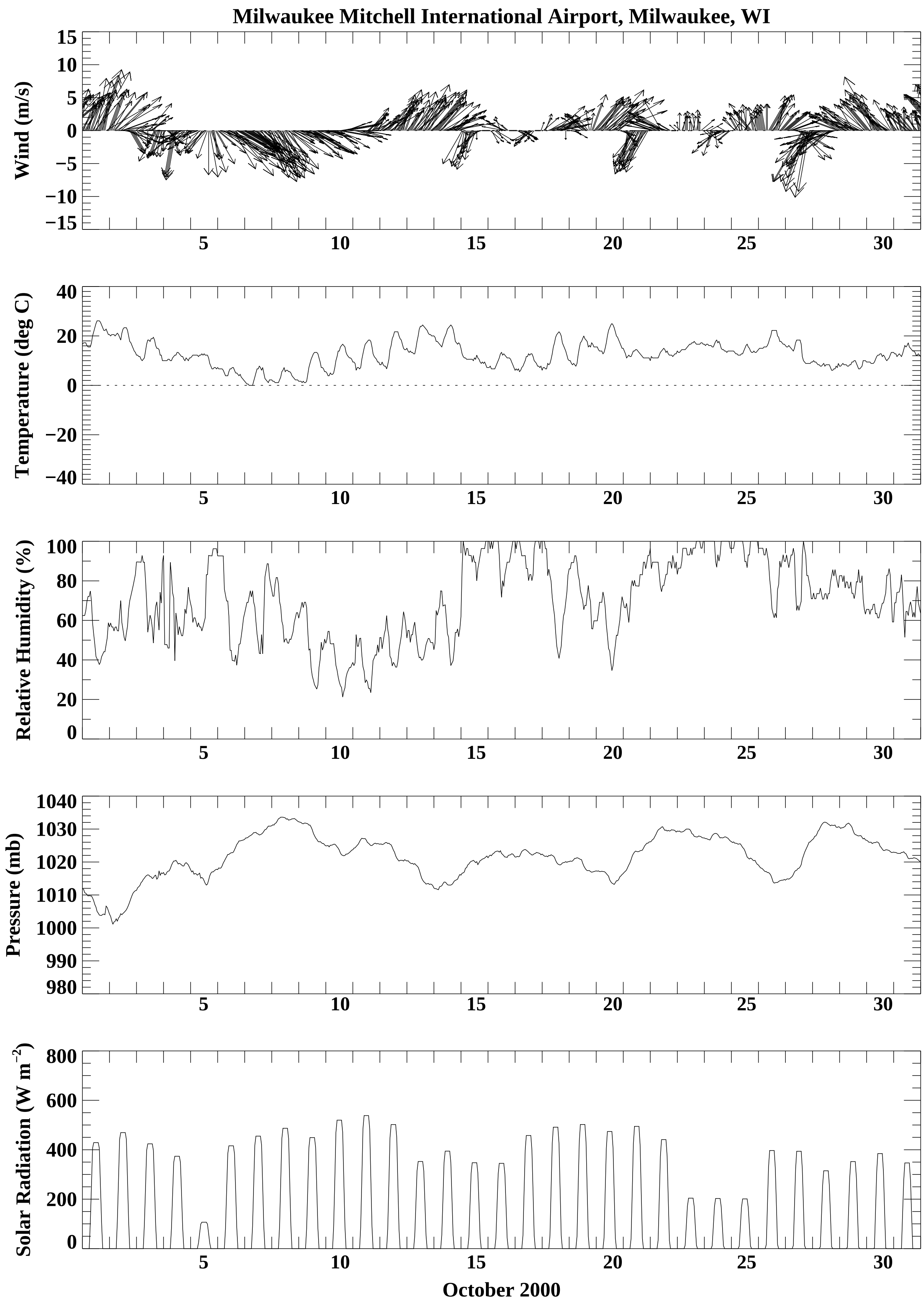

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m⁻²)
June 2000


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
July 2000

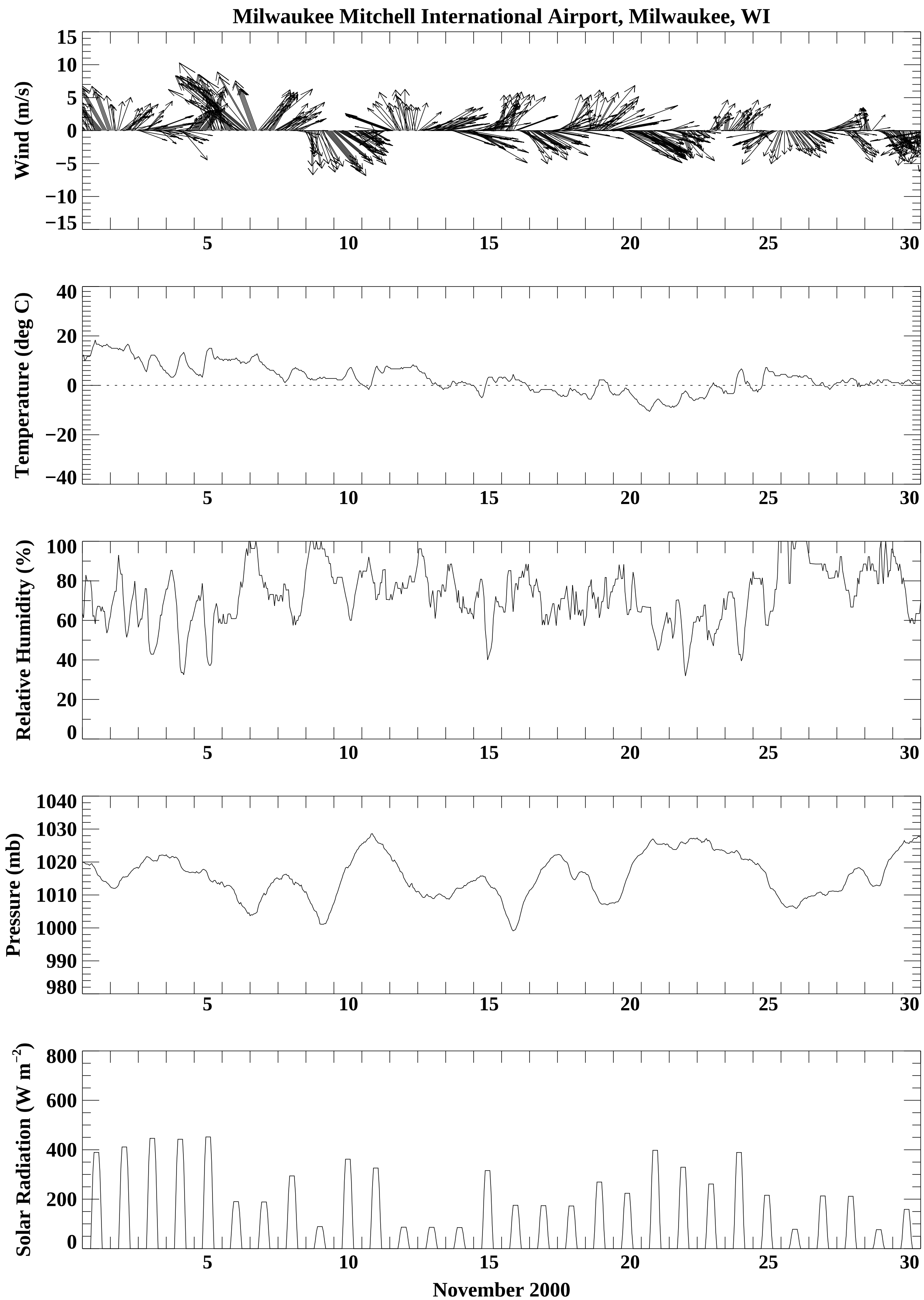


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
August 2000


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
15
10
5
0
−5
−10
−15
Temperature (deg C)
40
20
0
−20
−40
Relative Humidity (%)
100
80
60
40
20
0
Pressure (mb)
1040
1030
1020
1010
1000
990
980
Solar Radiation (W m^{-2})
800
600
400
200
0
5
10
15
20
25
30
September 2000

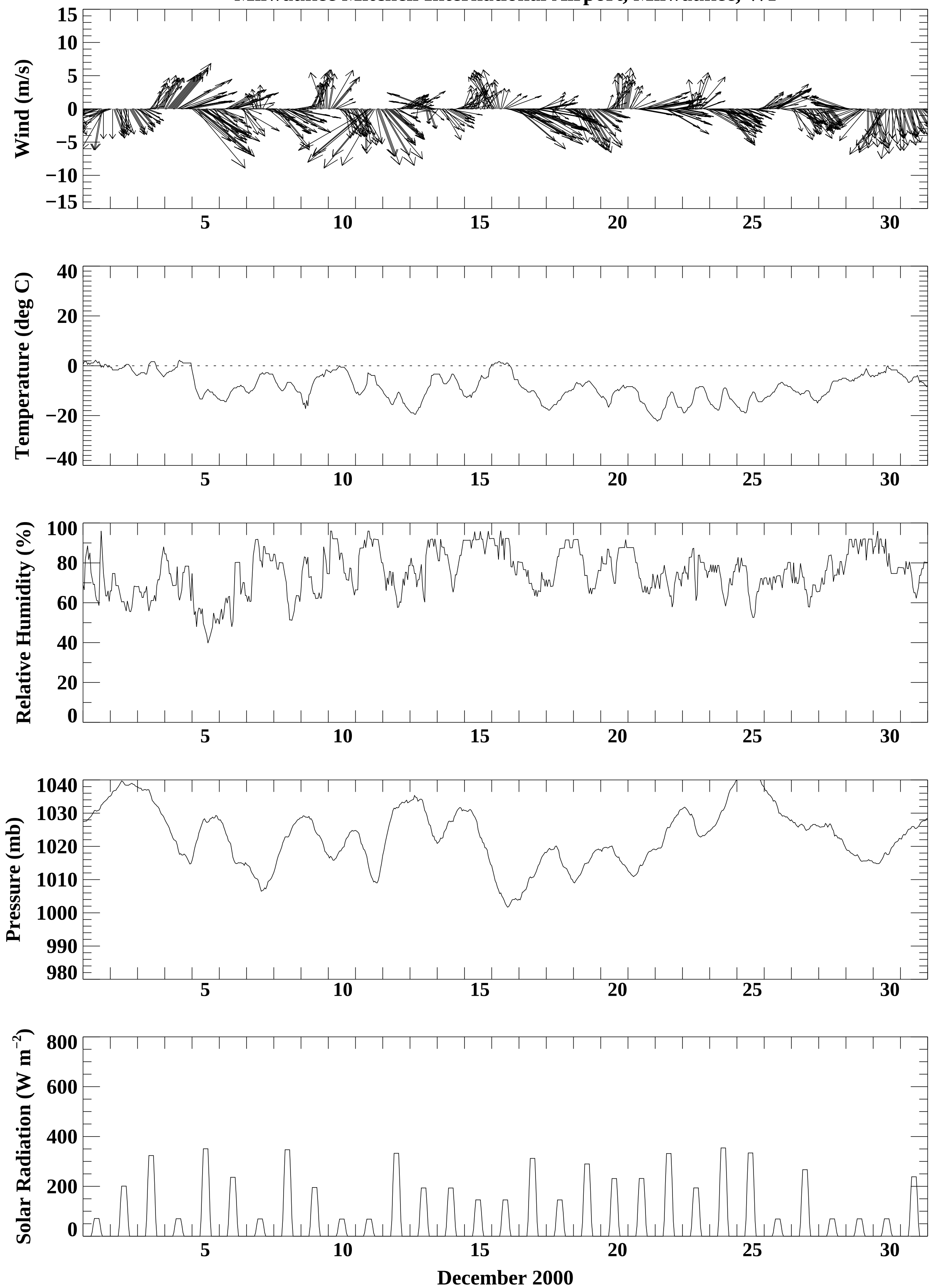


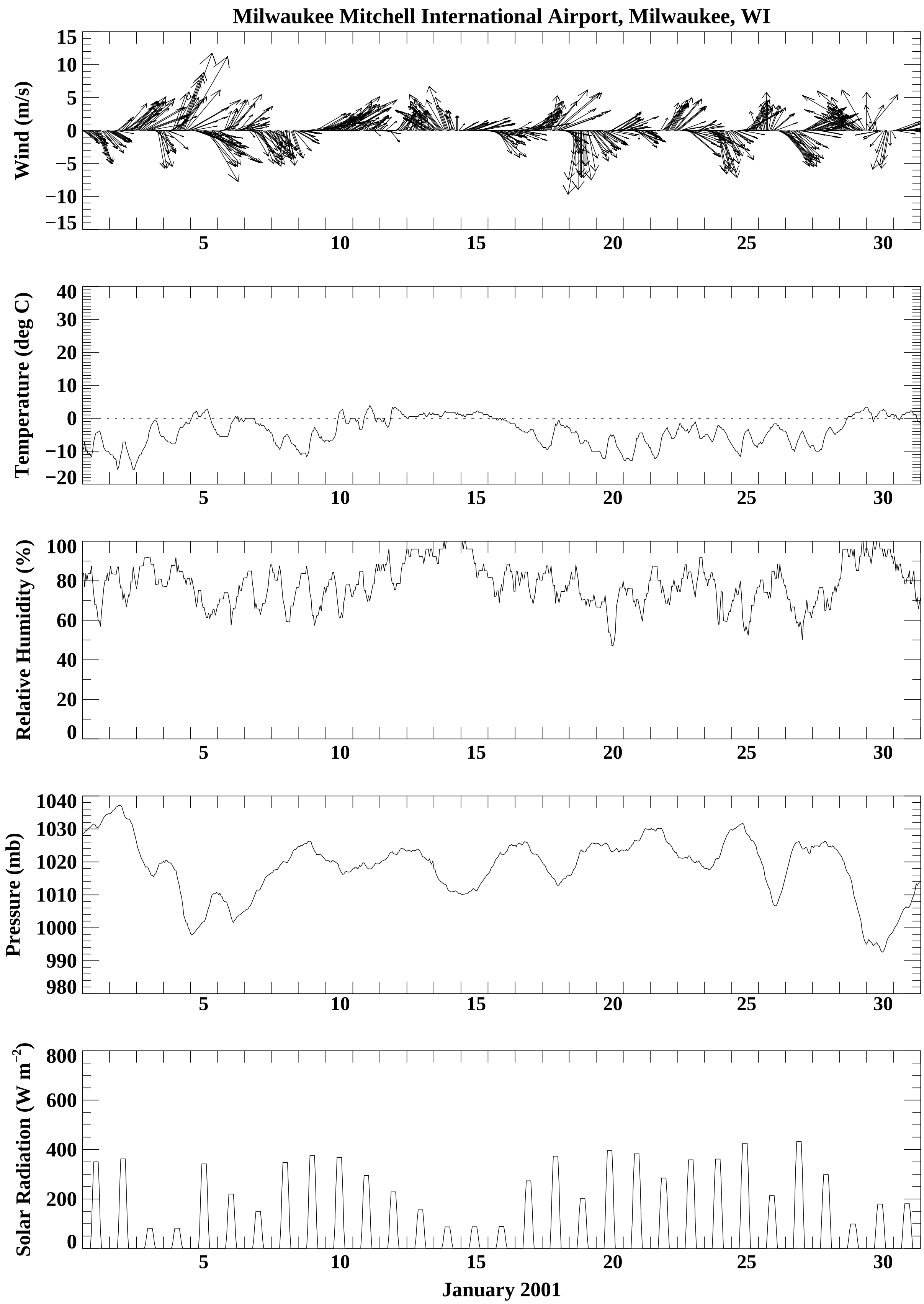
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
October 2000



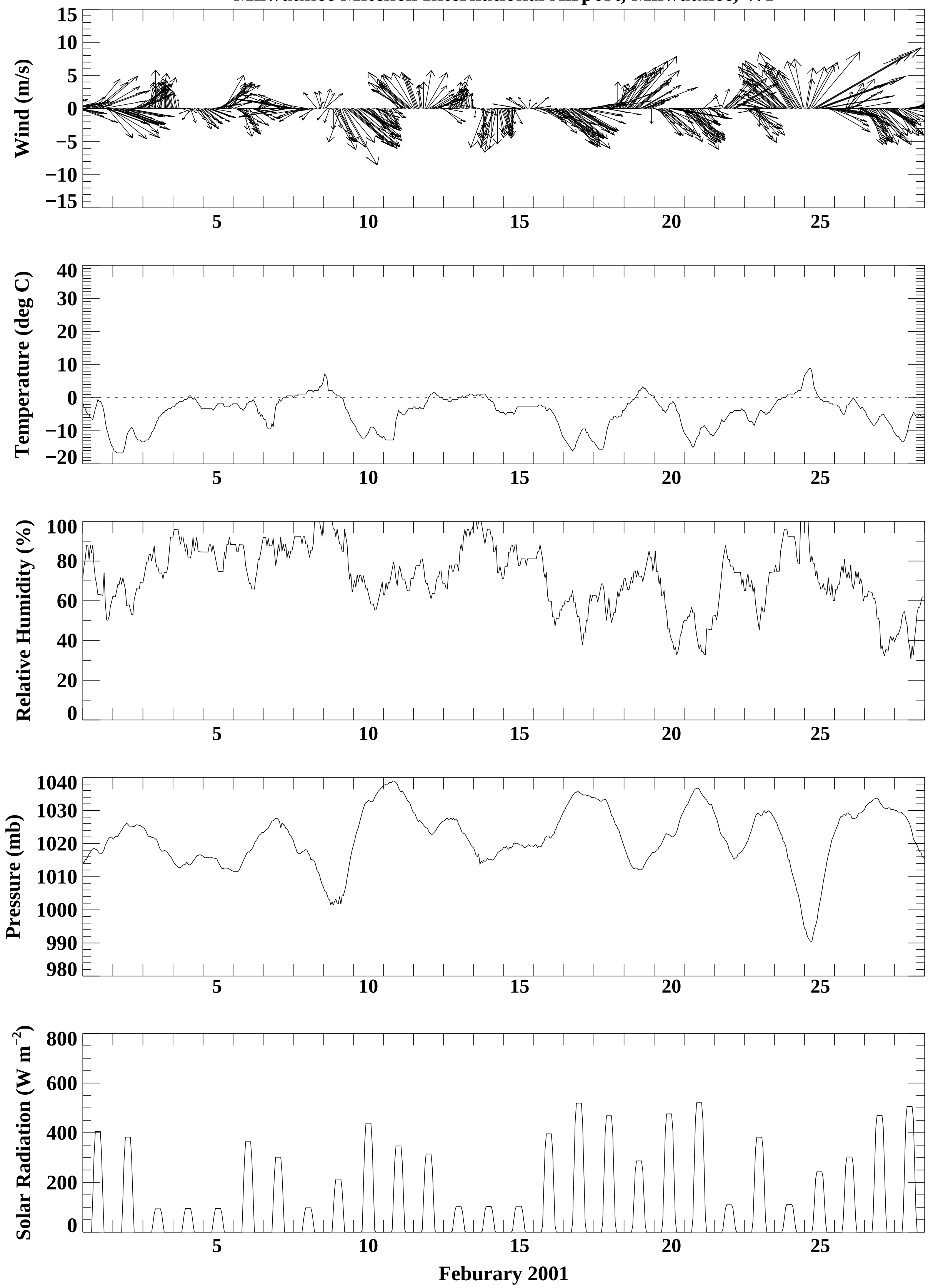
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
November 2000

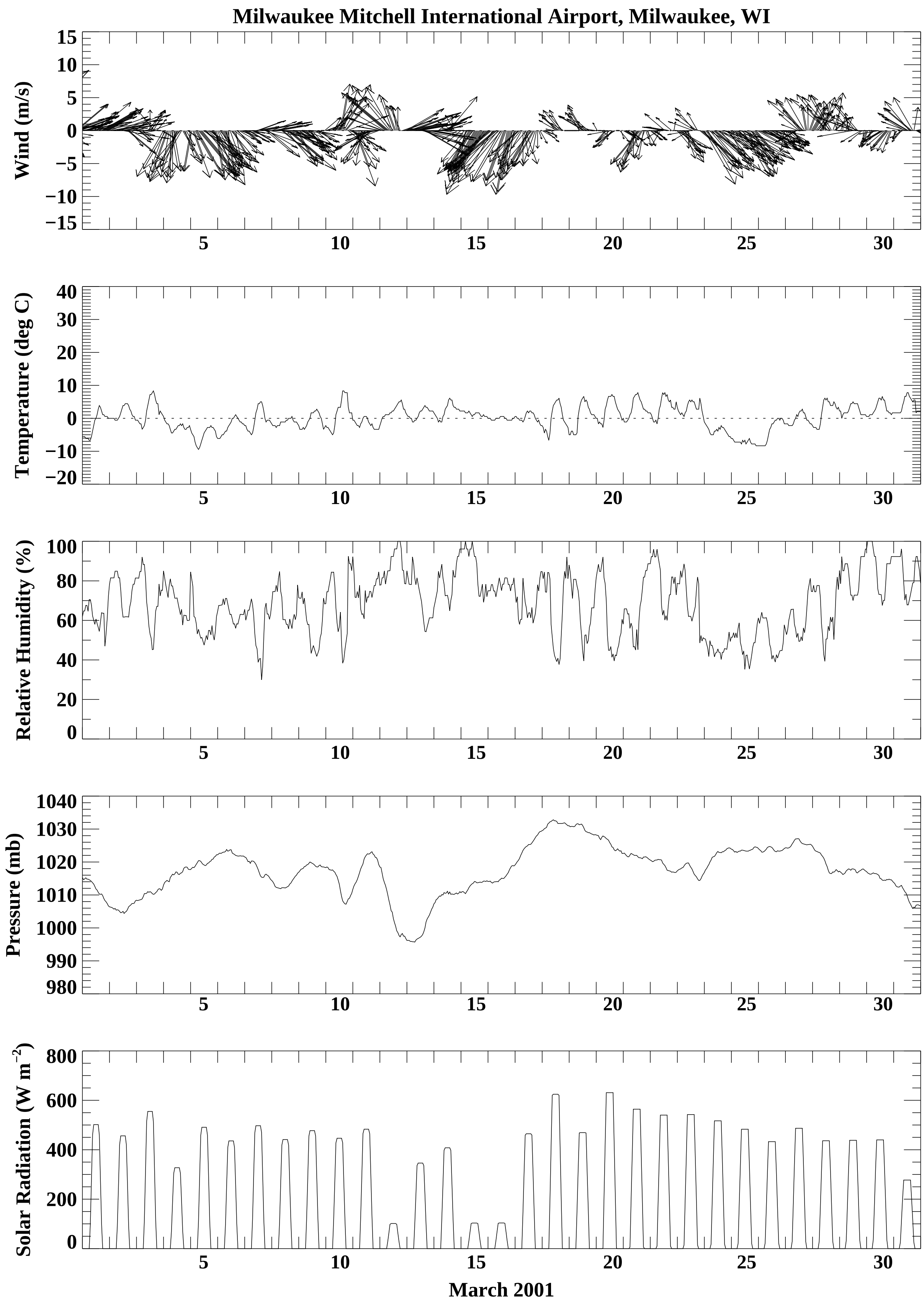
Milwaukee Mitchell International Airport, Milwaukee, WI



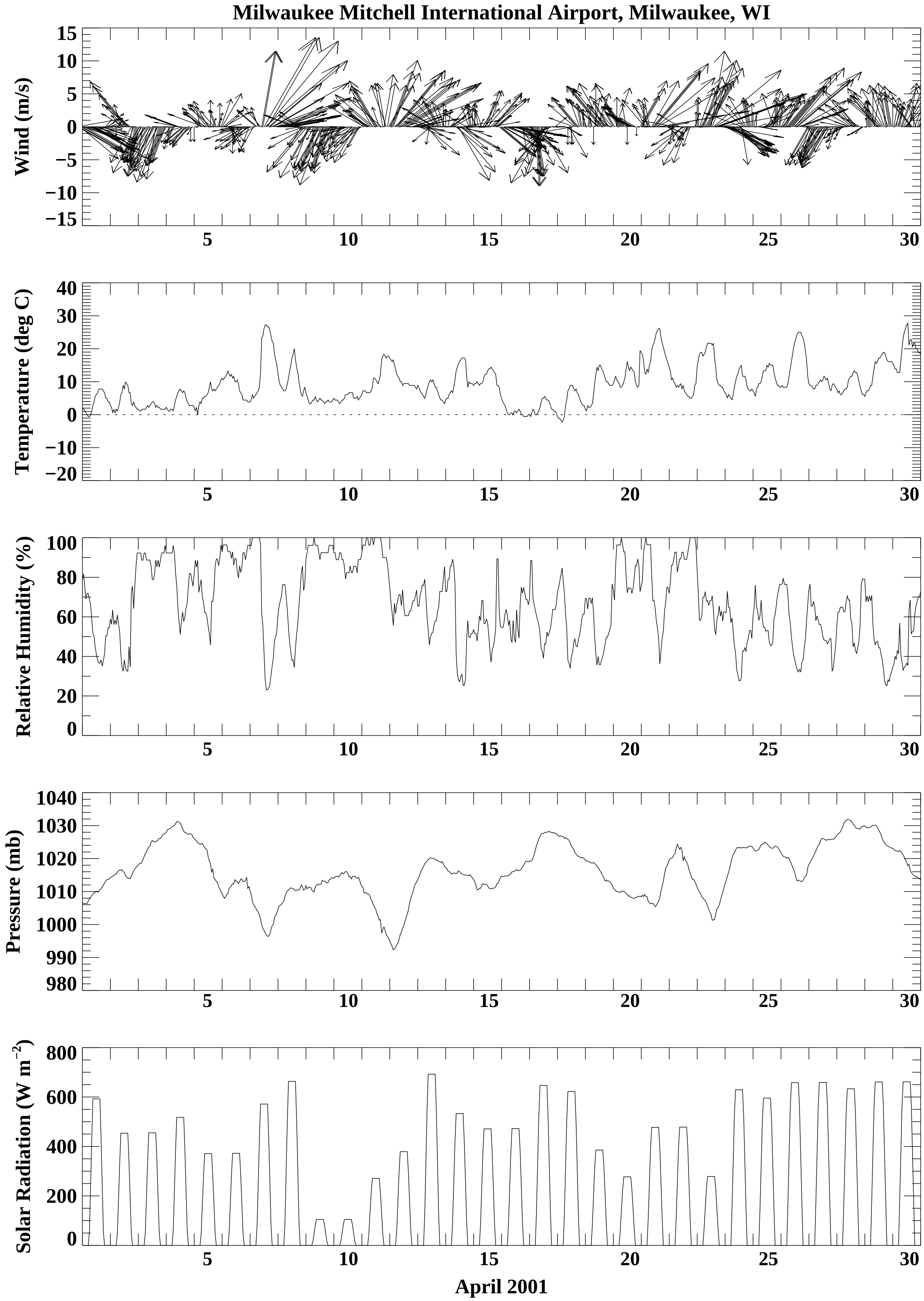

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
January 2001

Milwaukee Mitchell International Airport, Milwaukee, WI

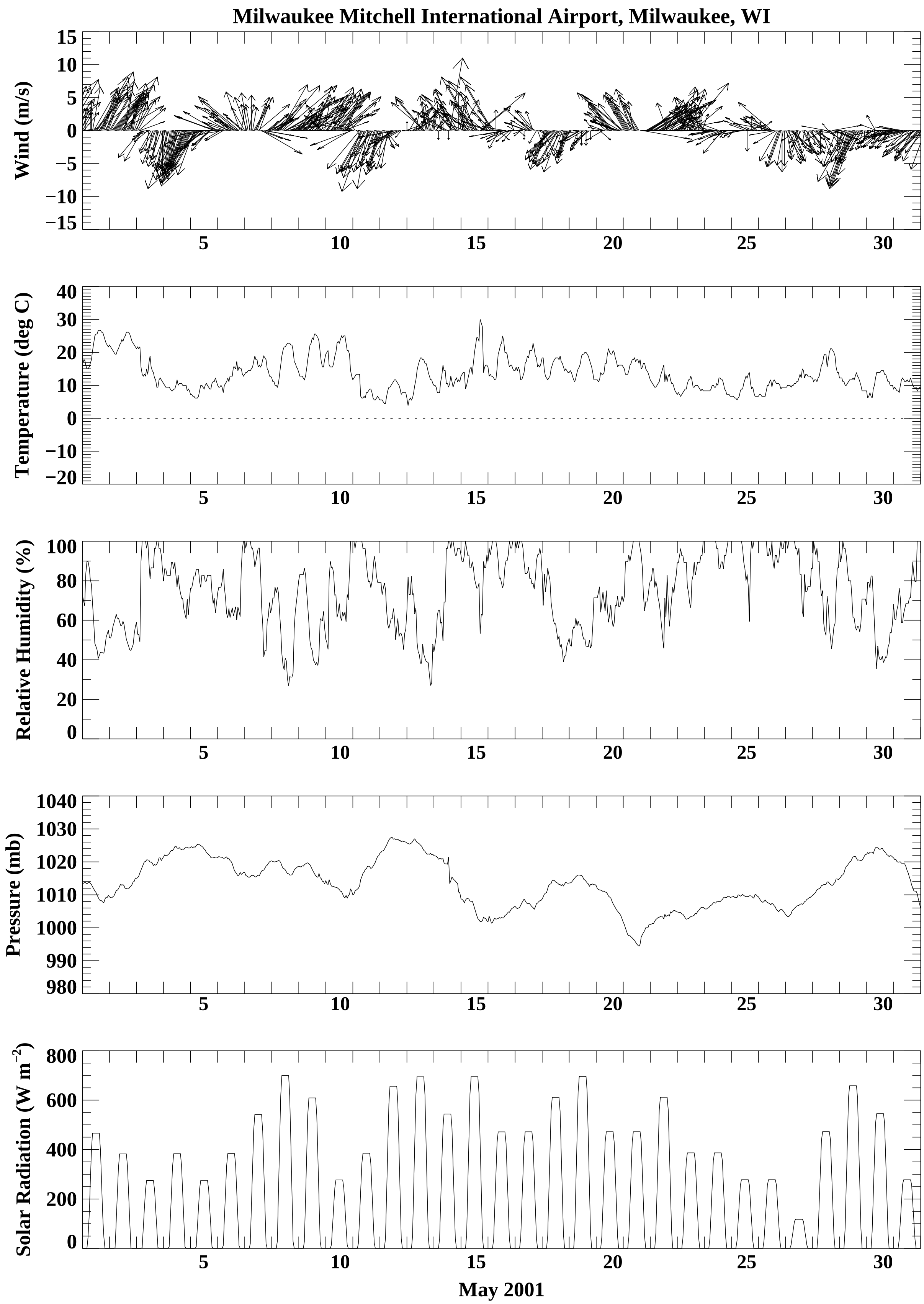


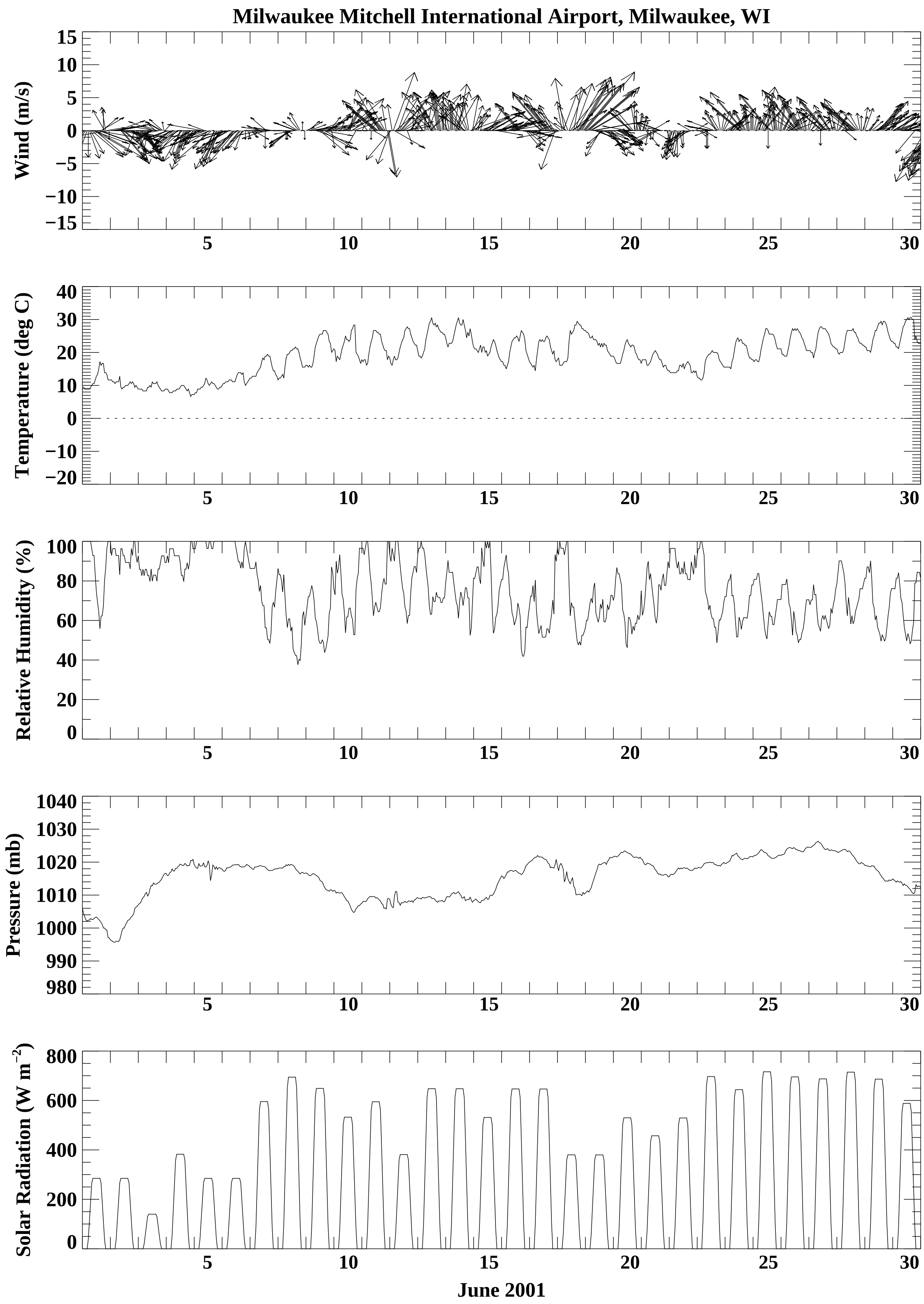


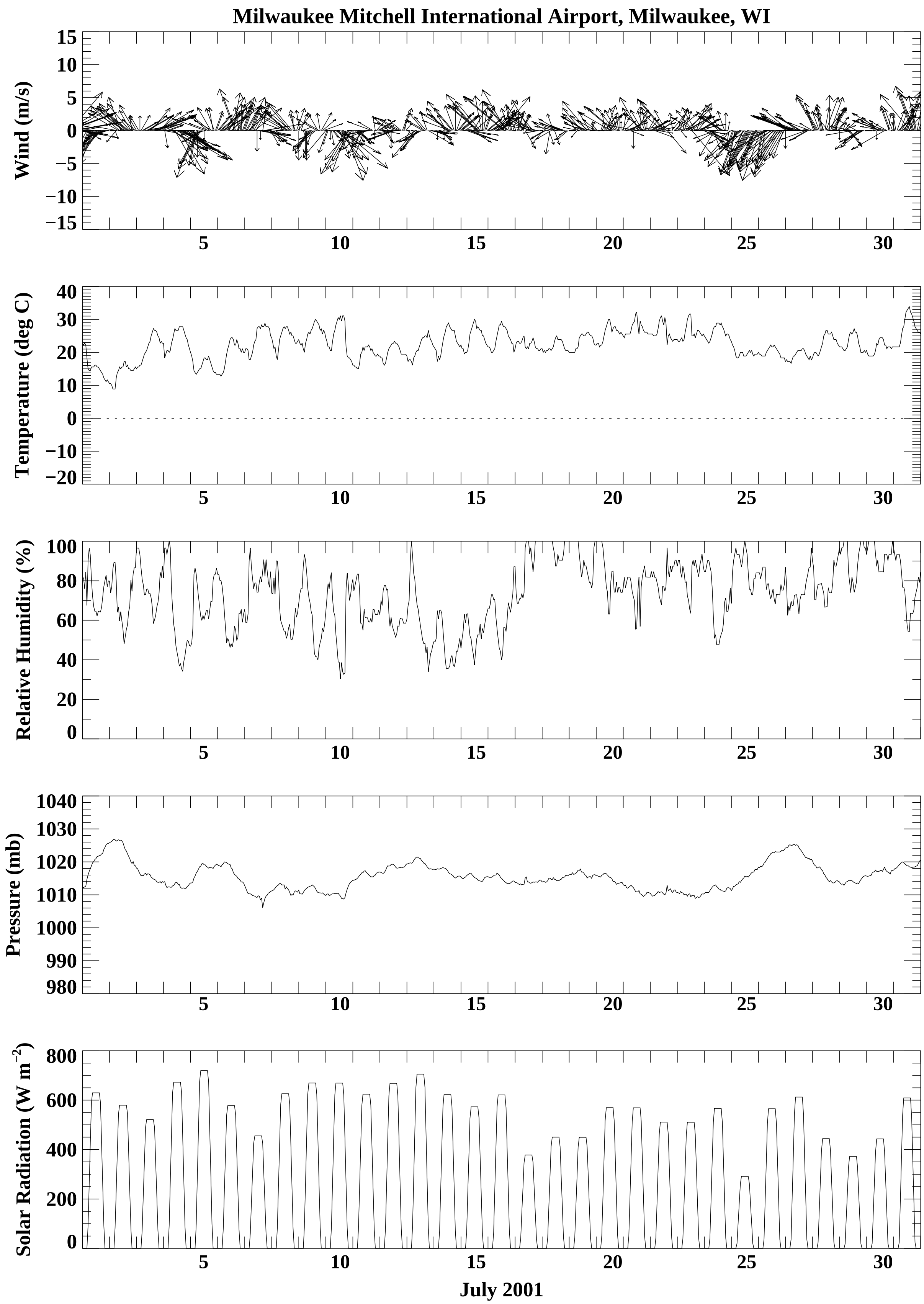
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m⁻²)
March 2001

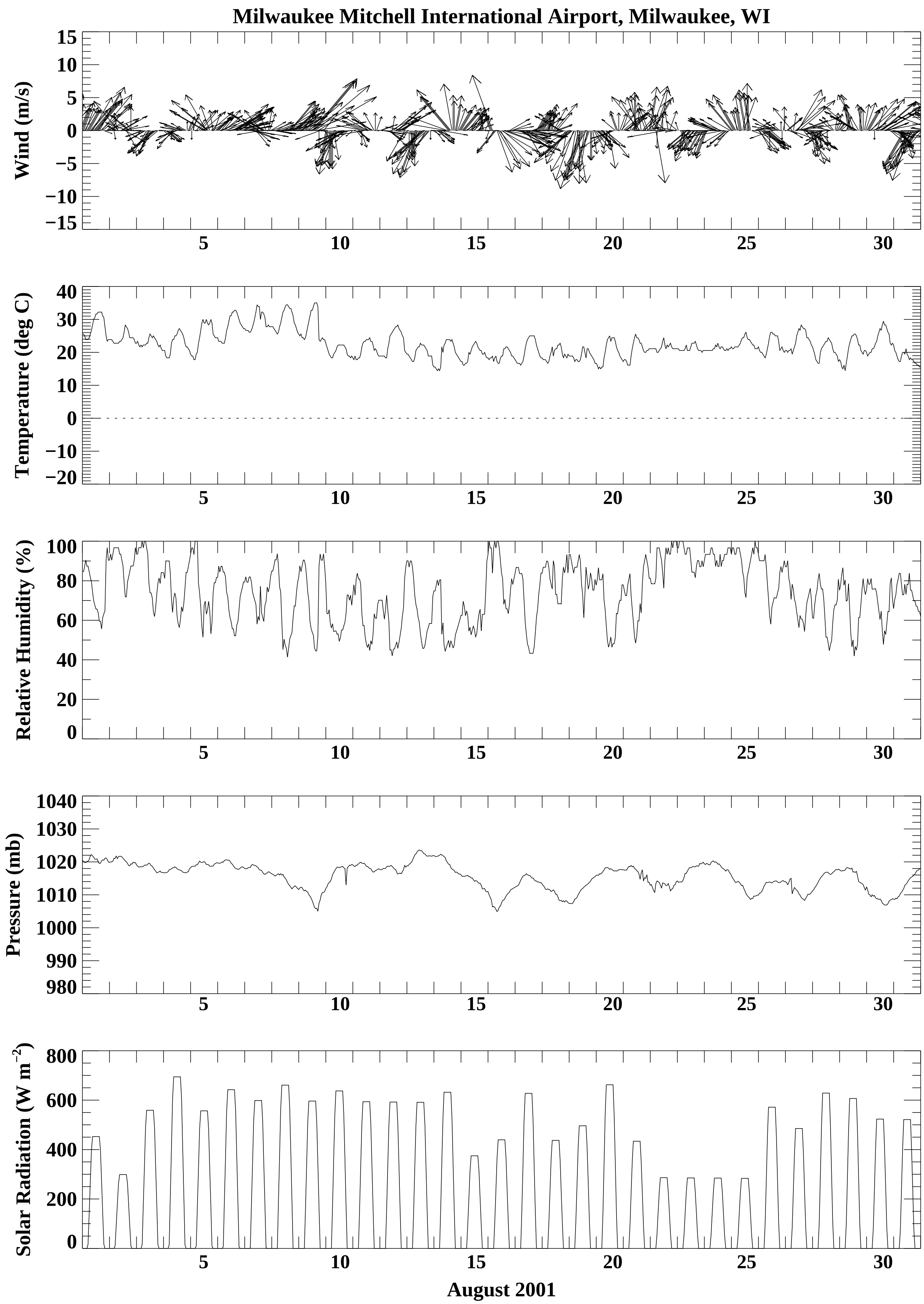


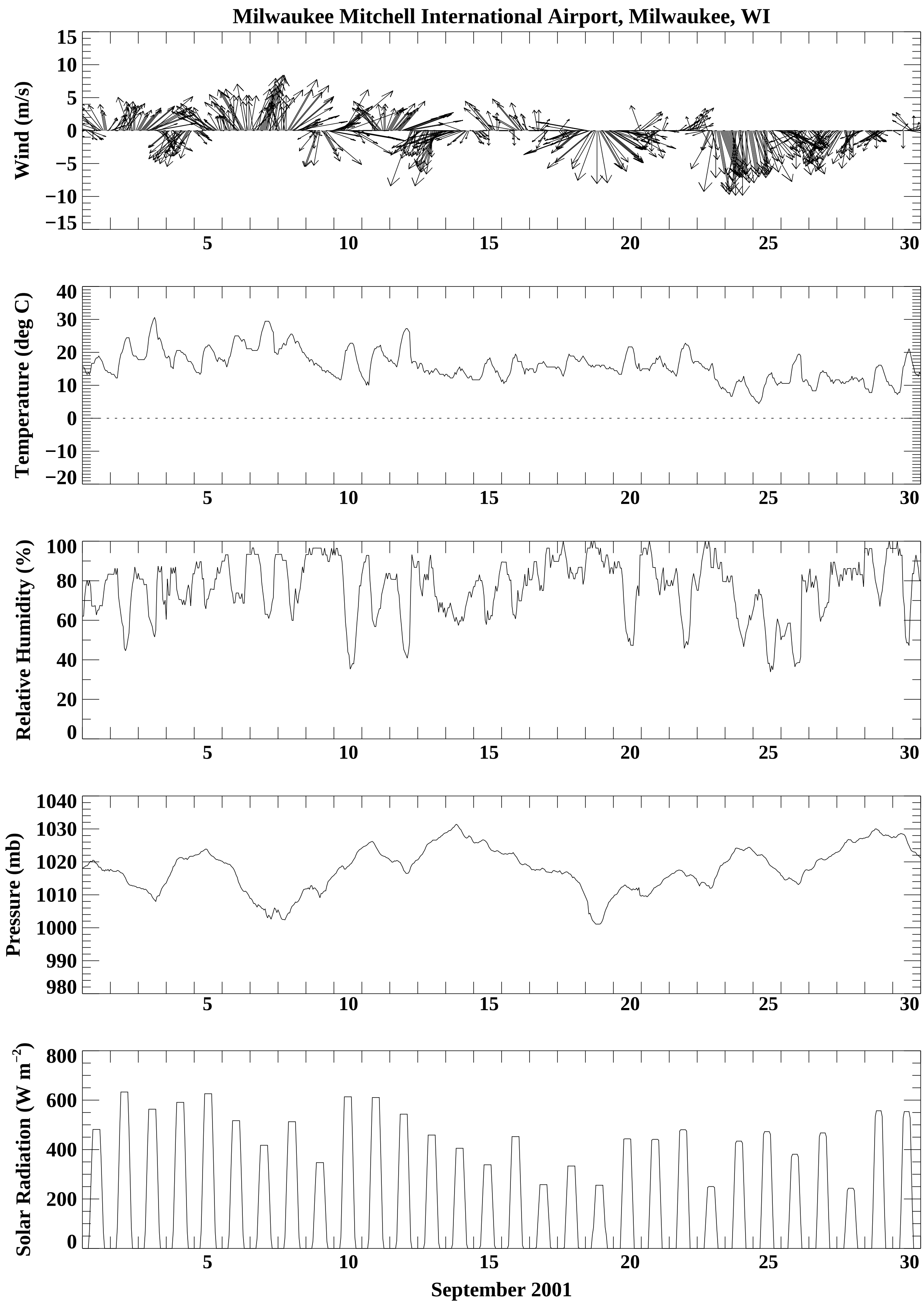
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
April 2001


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
May 2001

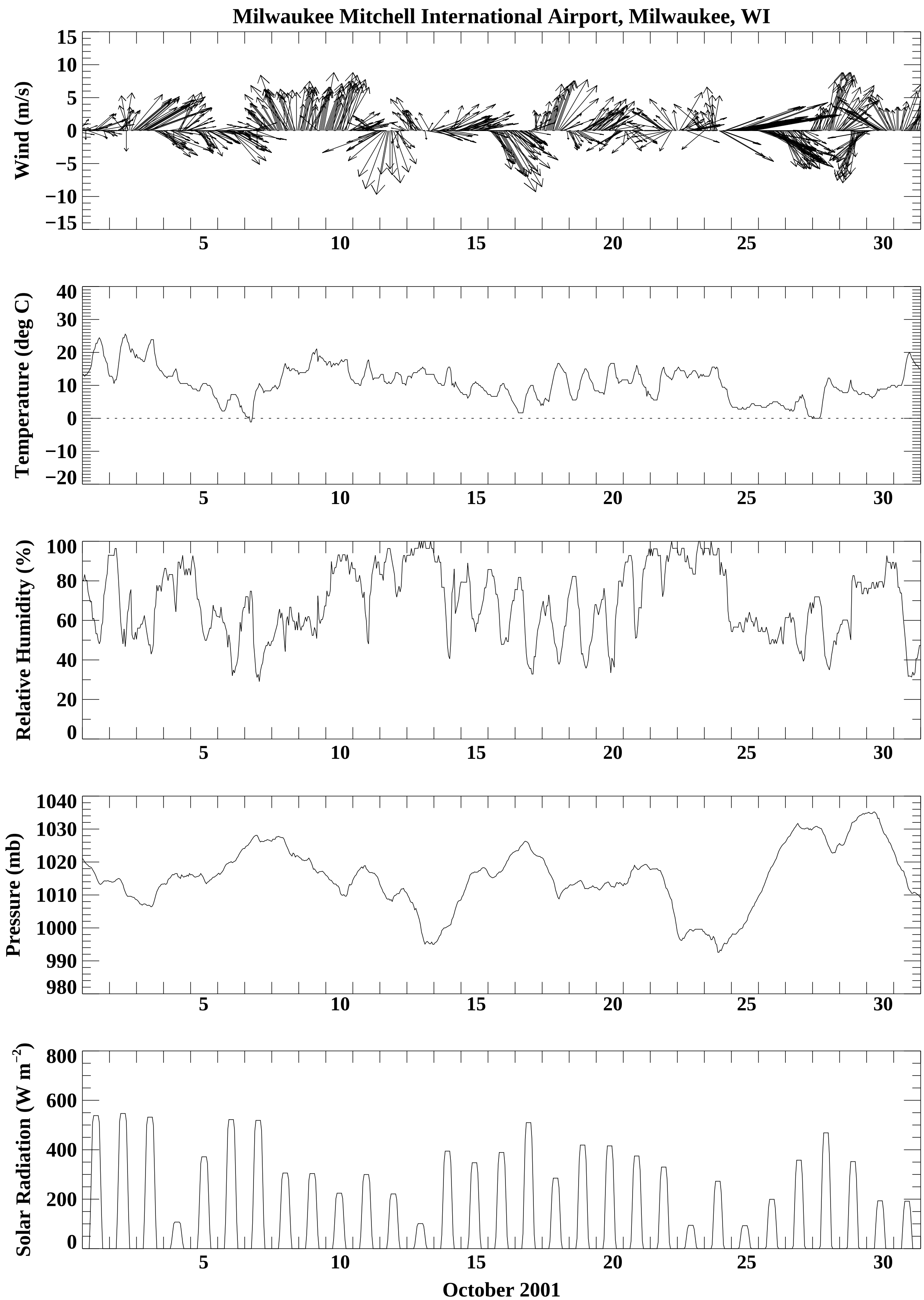

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
June 2001


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m−2)
July 2001

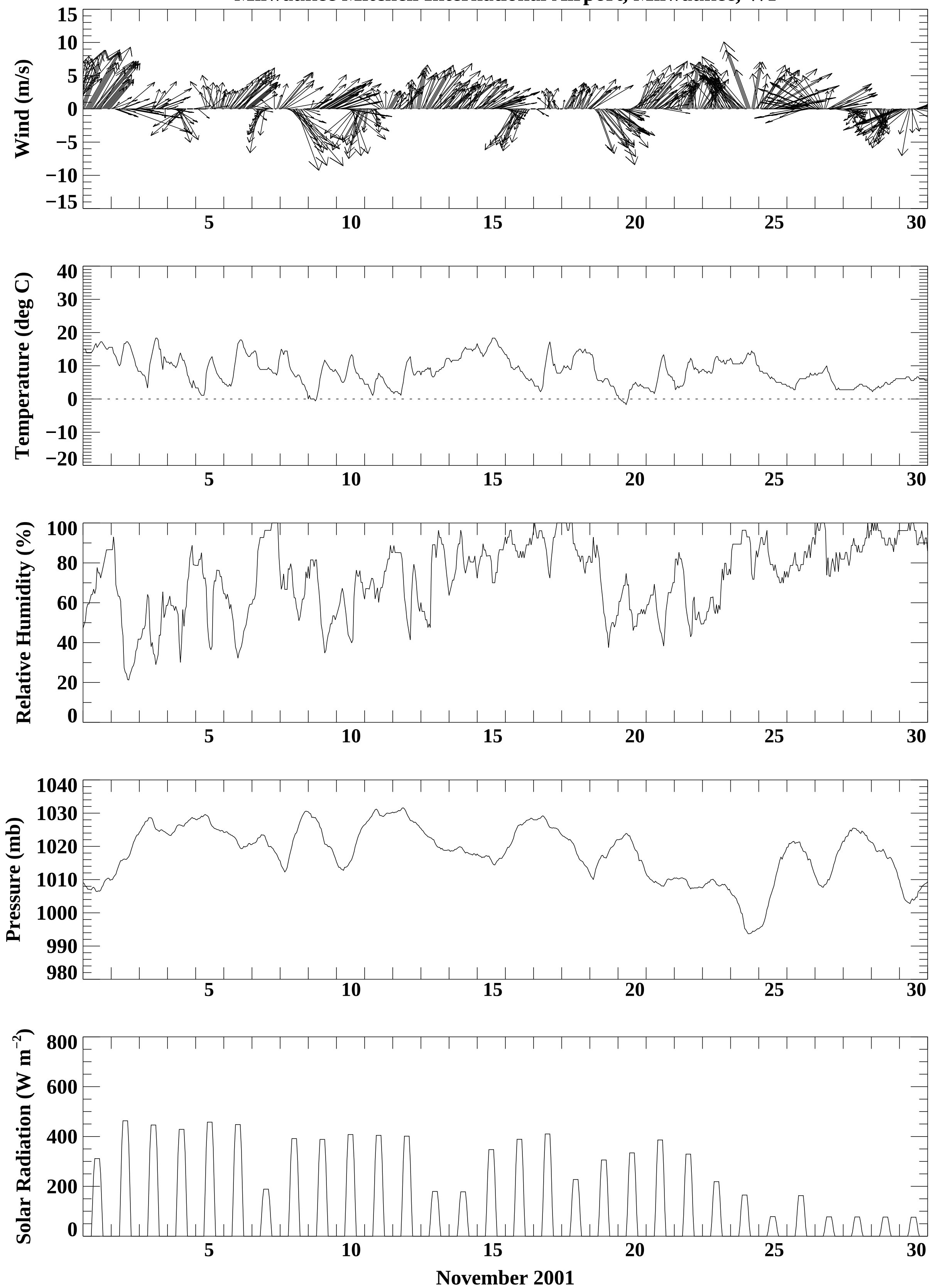

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
15
10
5
0
−5
−10
−15
Temperature (deg C)
40
30
20
10
0
−10
−20
Relative Humidity (%)
100
80
60
40
20
0
Pressure (mb)
1040
1030
1020
1010
1000
990
980
Solar Radiation (W m−2)
800
600
400
200
0
5
10
15
20
25
30
August 2001

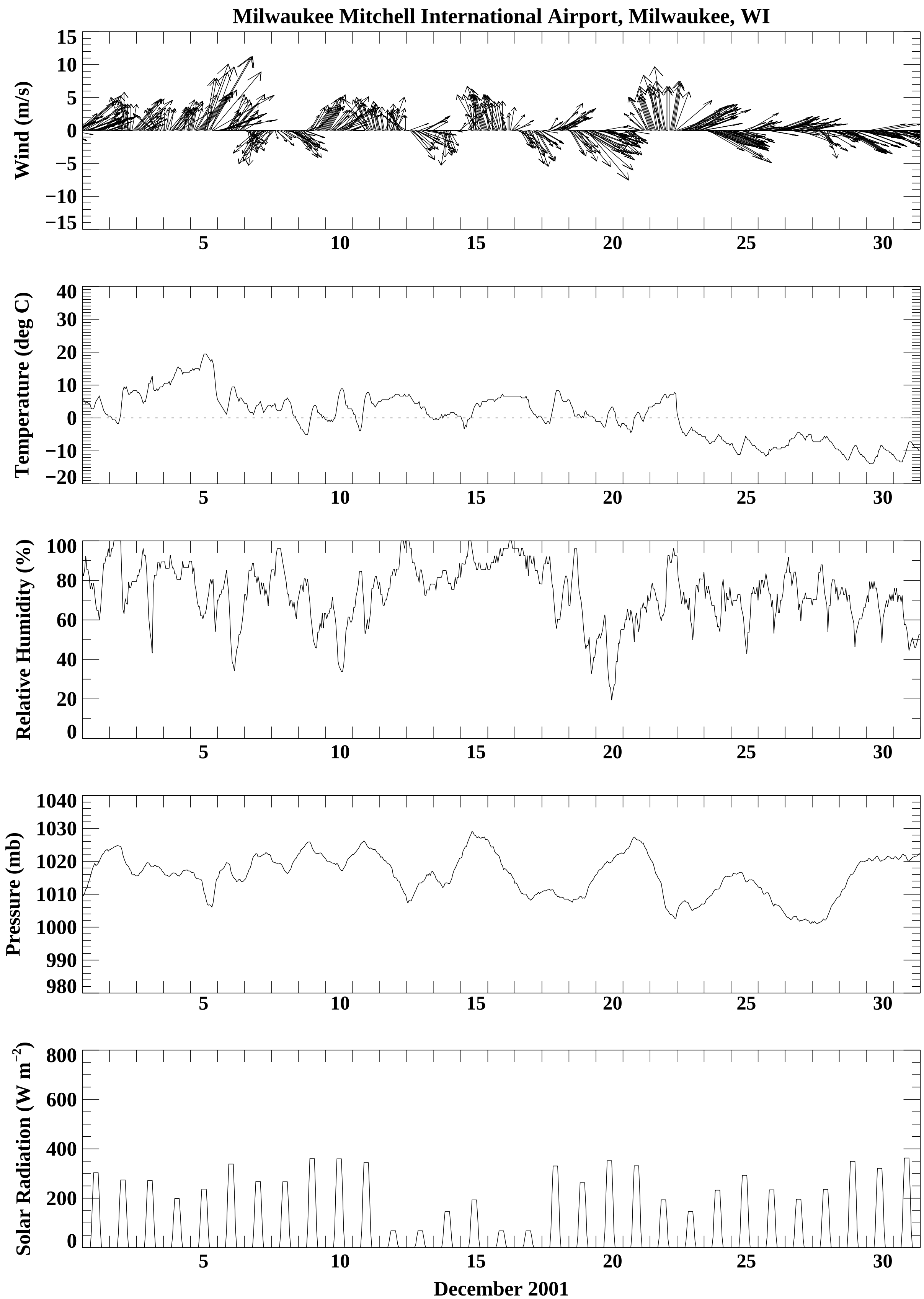


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
September 2001

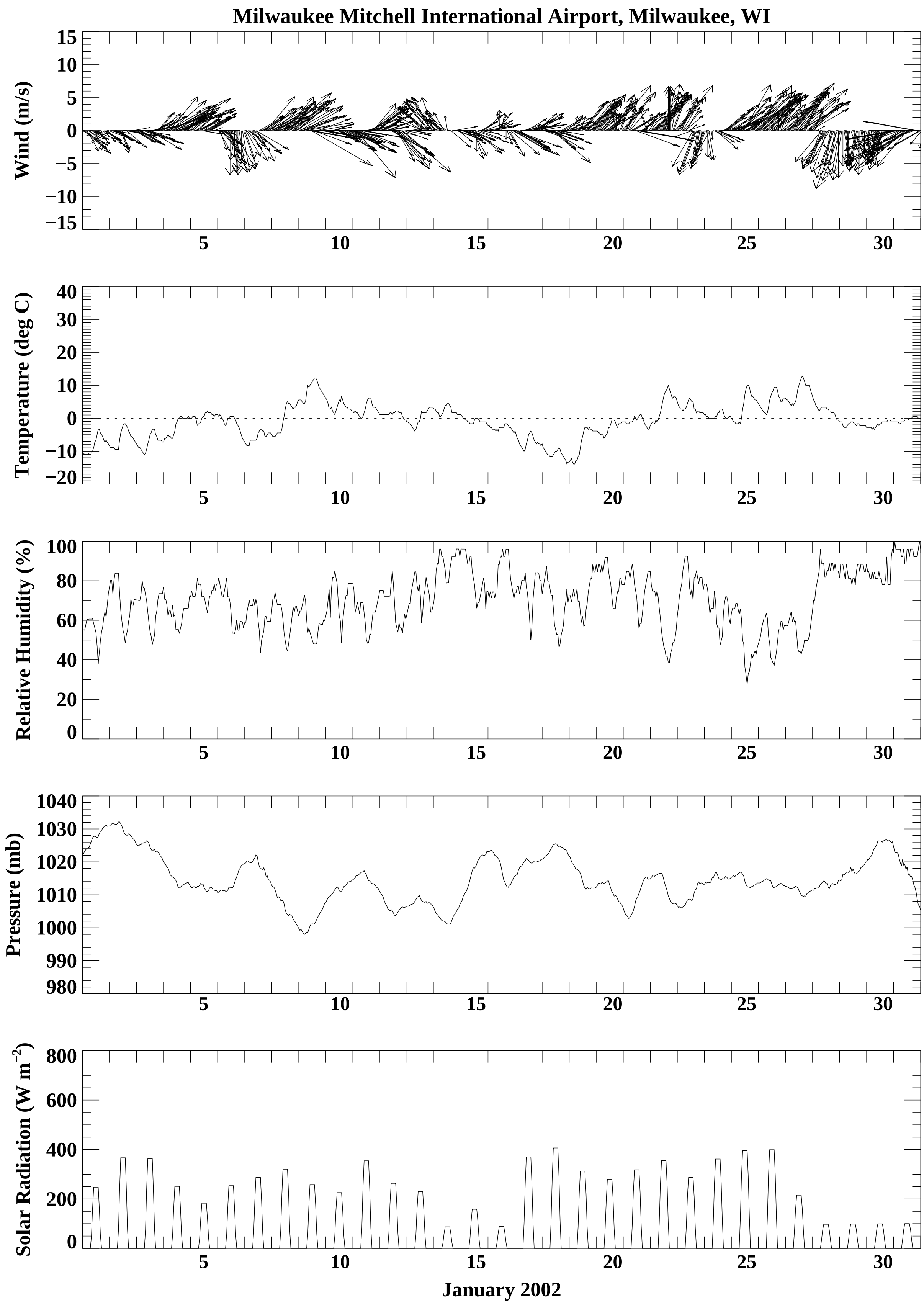

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
October 2001

Milwaukee Mitchell International Airport, Milwaukee, WI

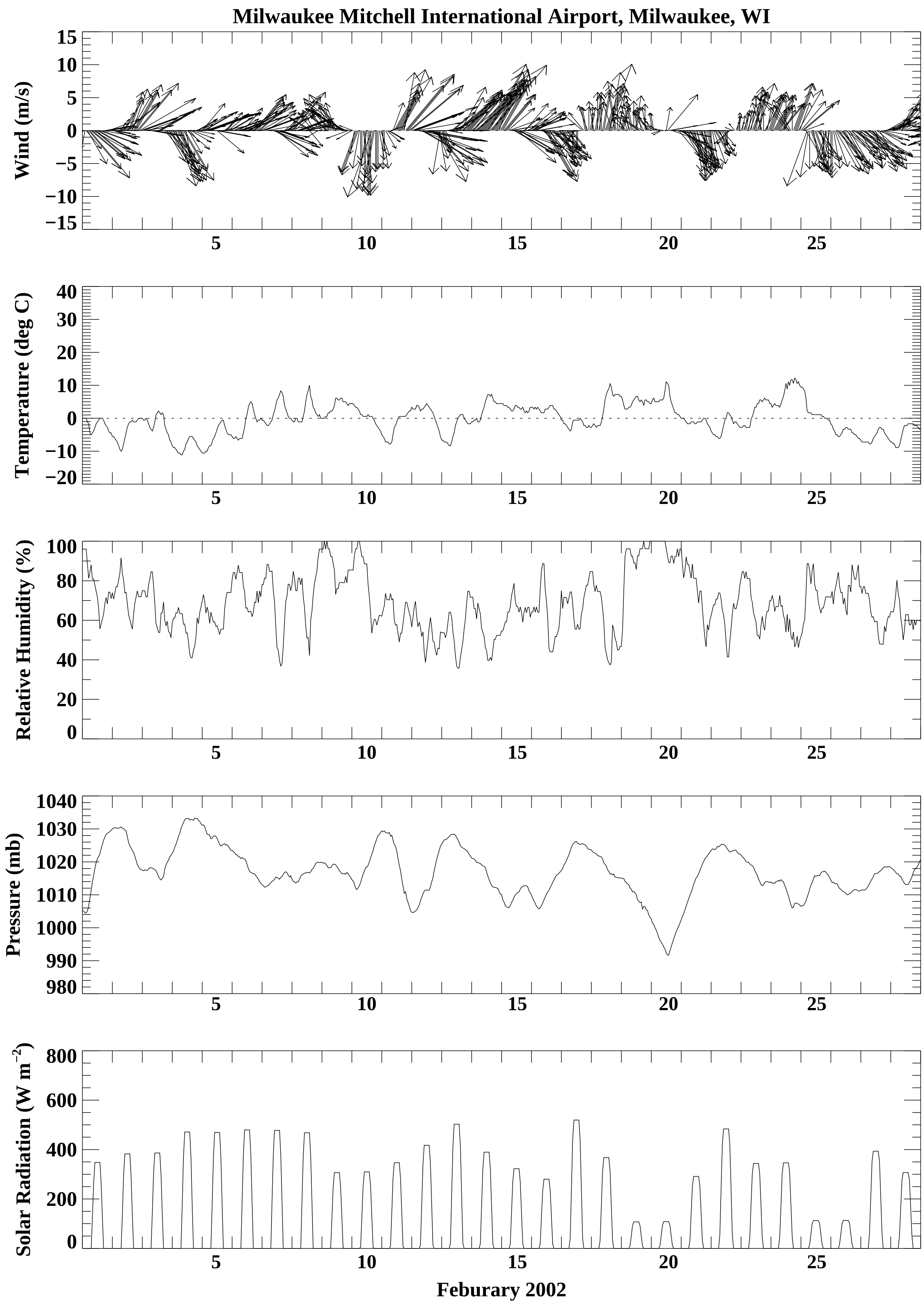


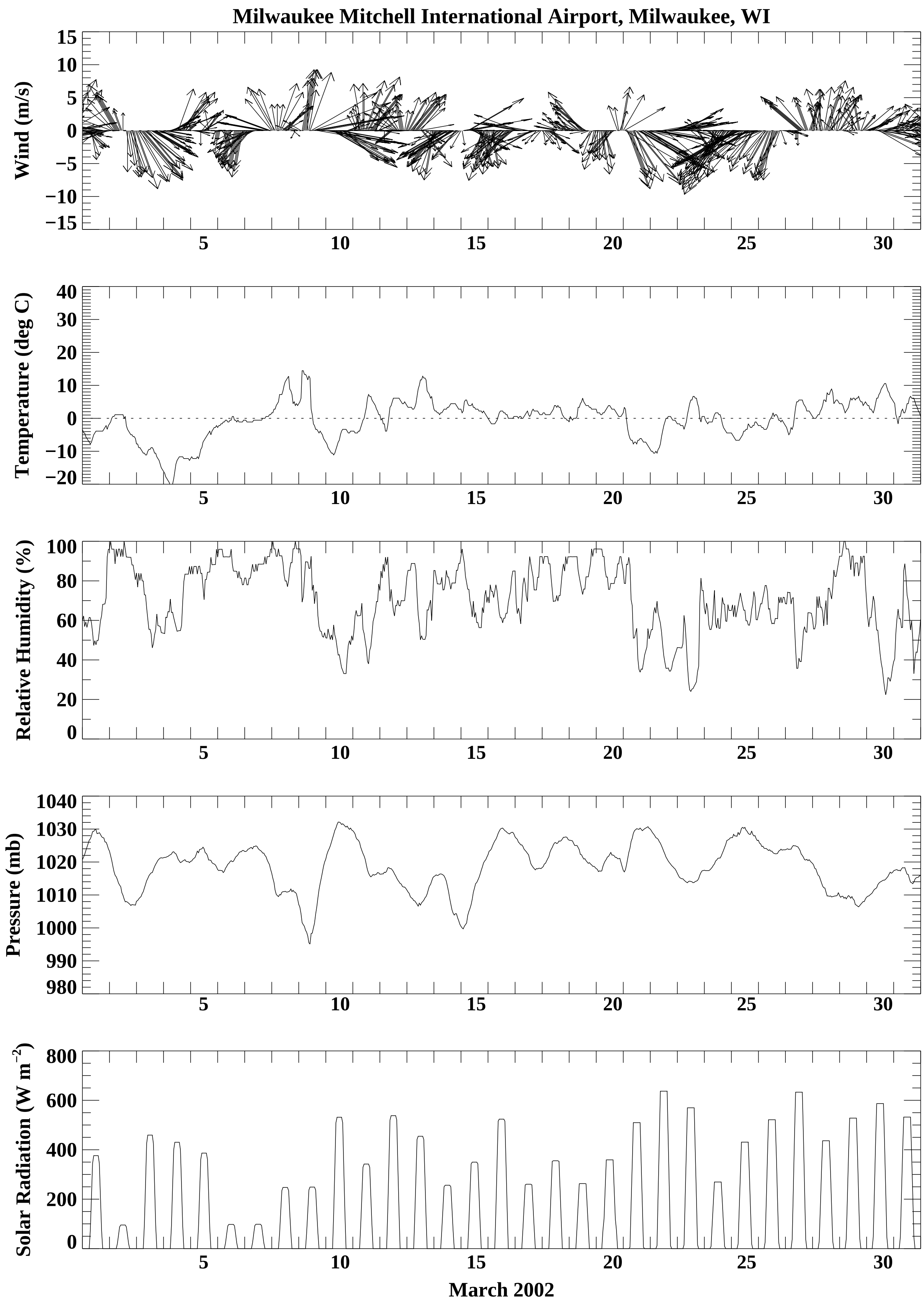


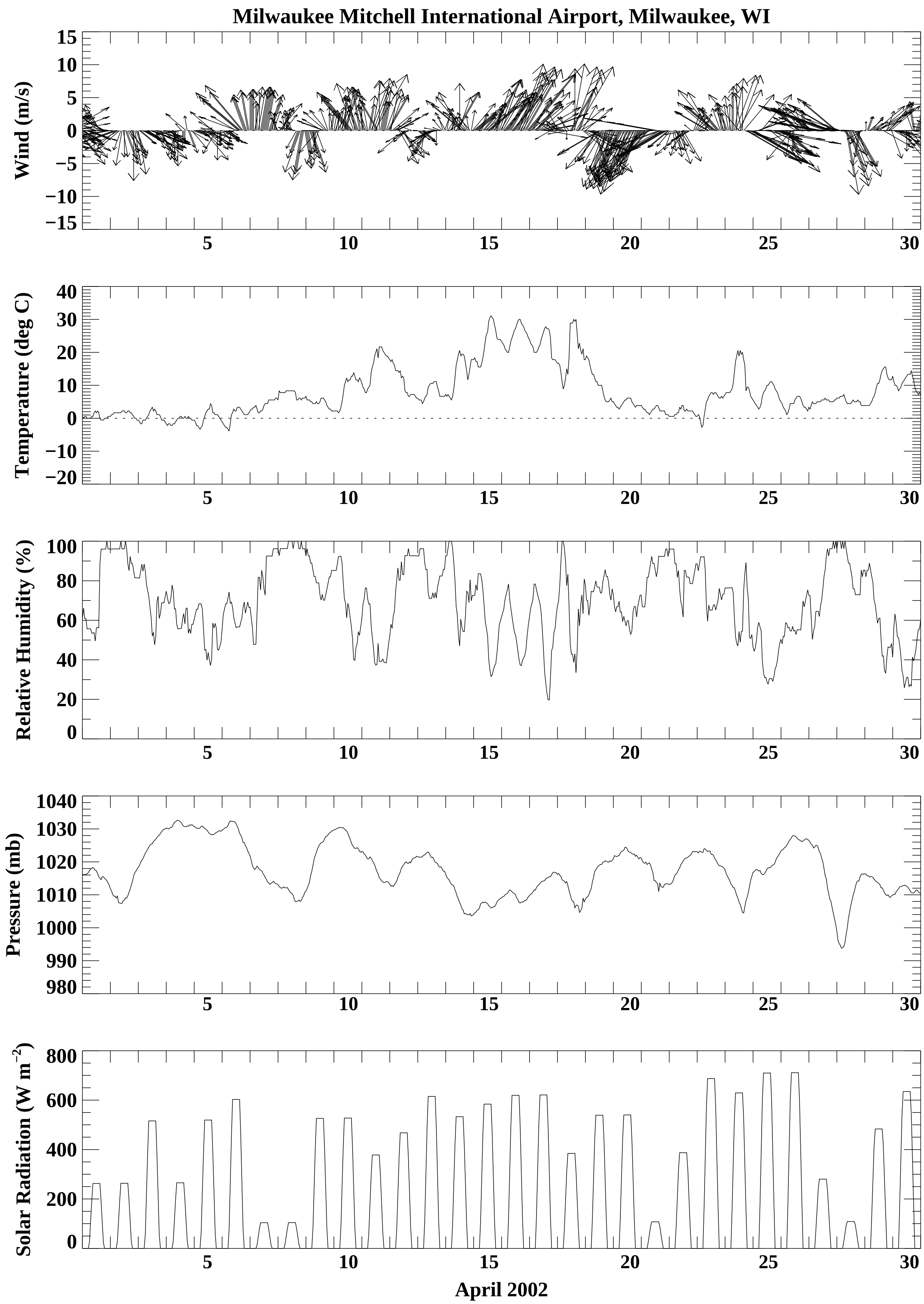
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
December 2001

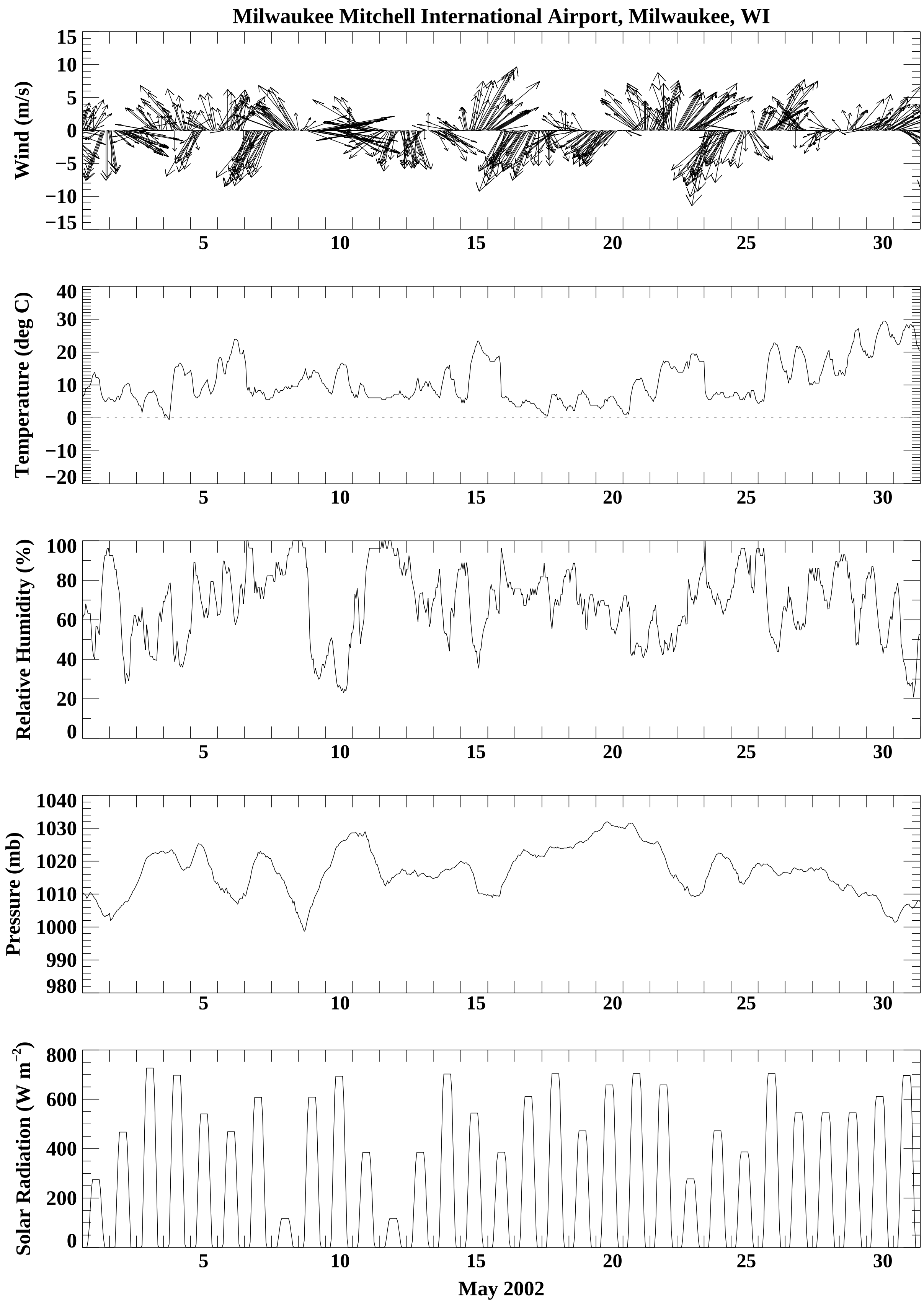


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
January 2002

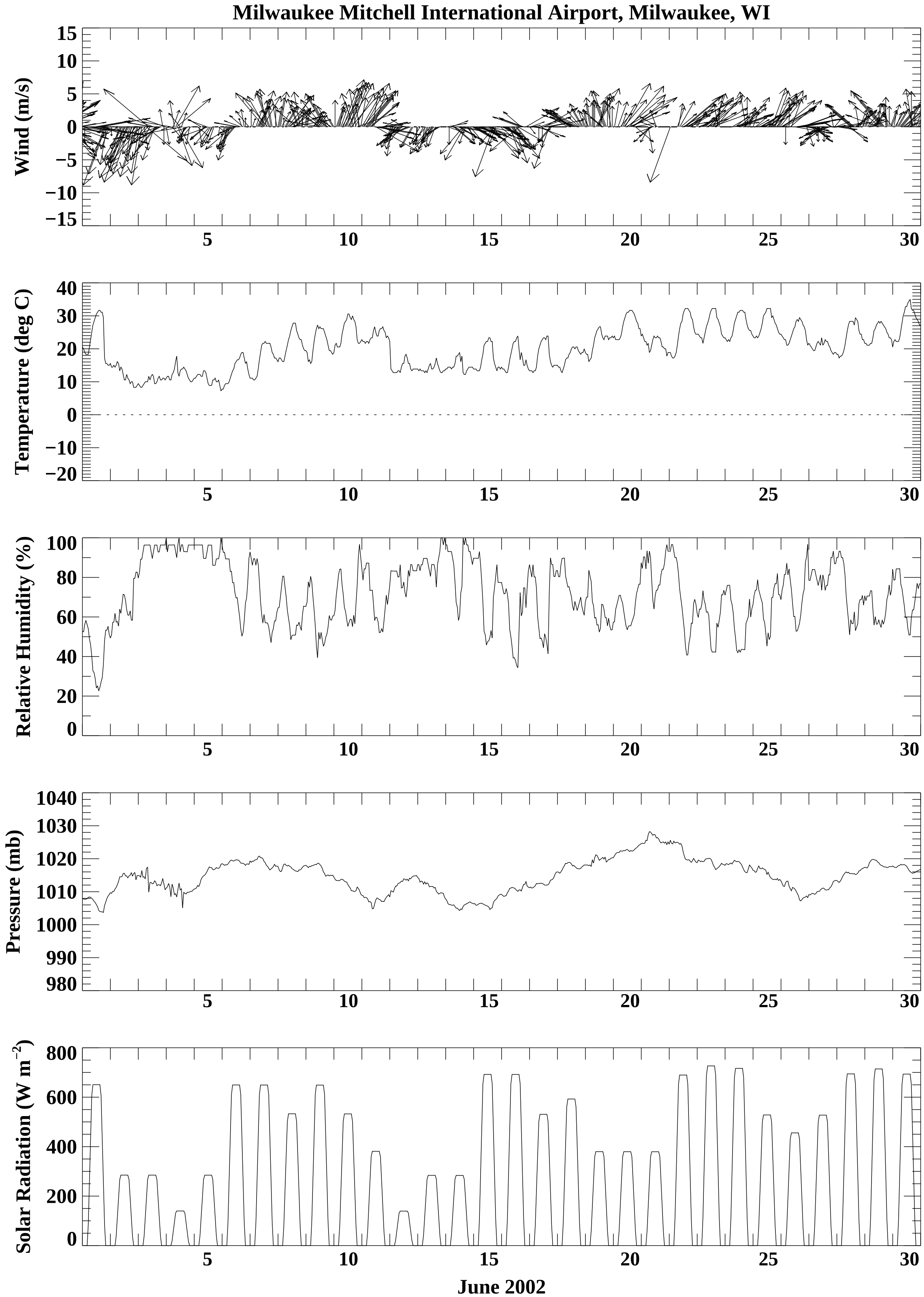

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
15
10
5
0
−5
−10
−15
Temperature (deg C)
40
30
20
10
0
−10
−20
Relative Humidity (%)
100
80
60
40
20
0
Pressure (mb)
1040
1030
1020
1010
1000
990
980
Solar Radiation (W m^{-2})
800
600
400
200
0
5
10
15
20
25
Feburary 2002


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
March 2002

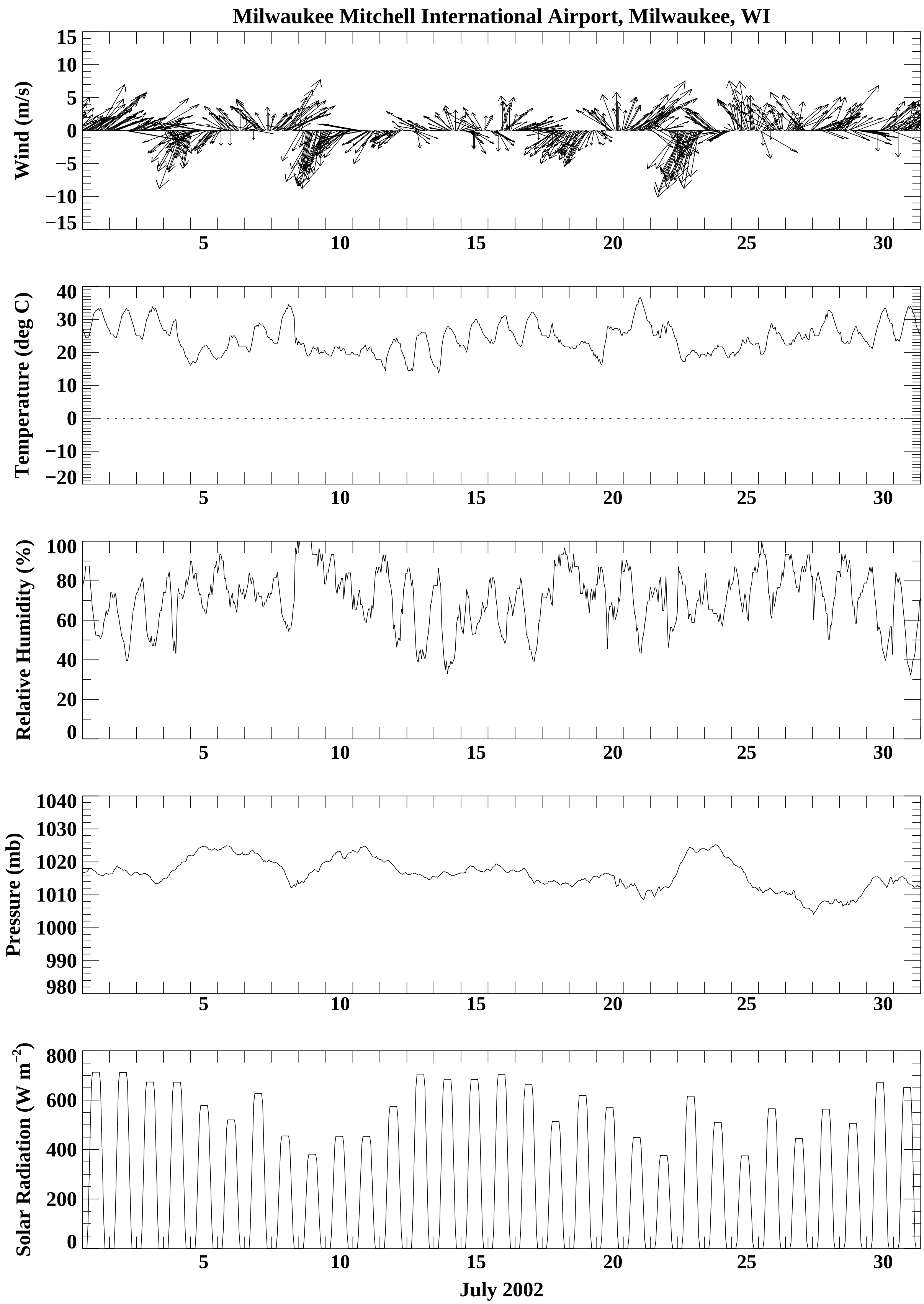

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
April 2002

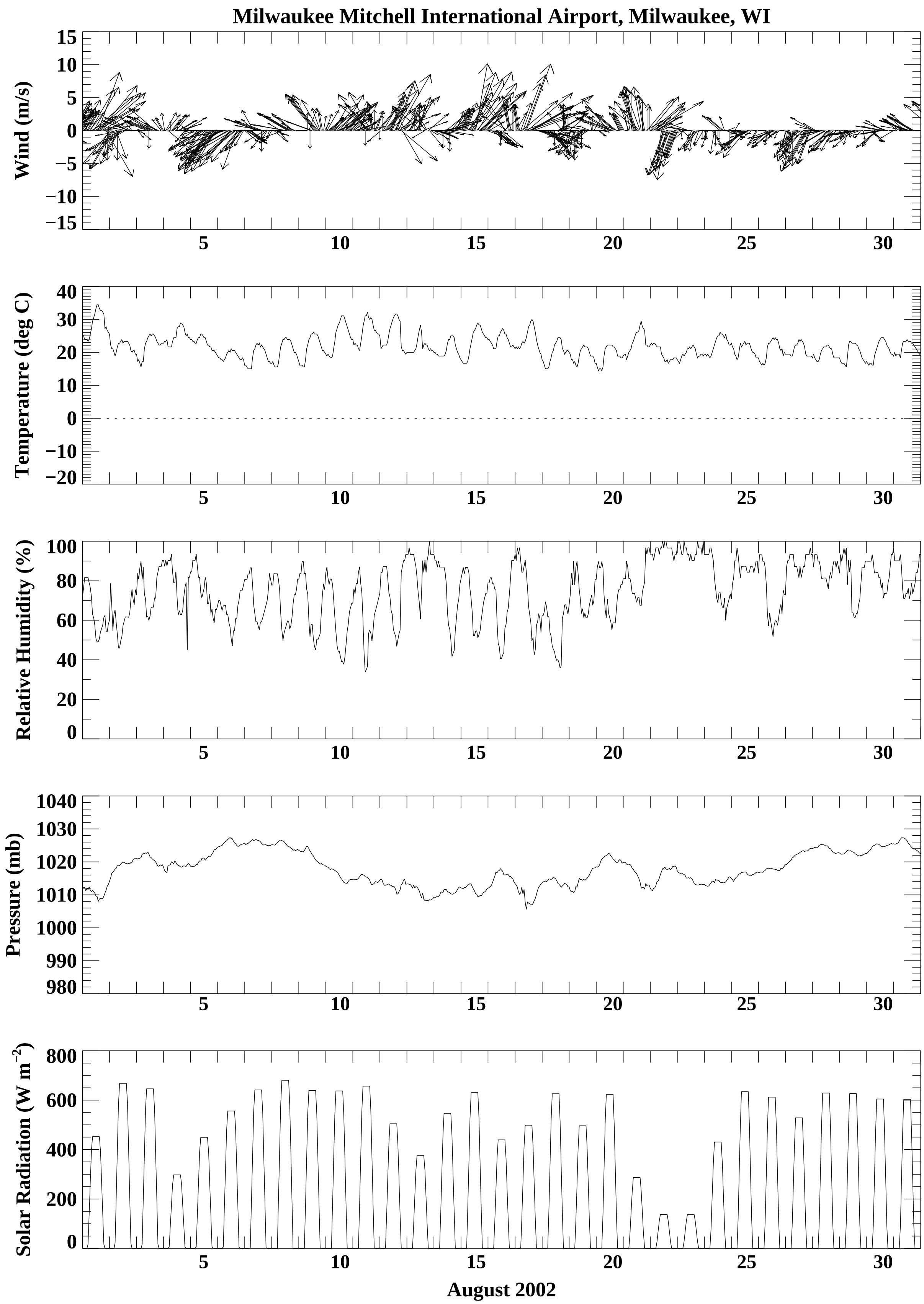


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
15
10
5
0
−5
−10
−15
Temperature (deg C)
40
30
20
10
0
−10
−20
Relative Humidity (%)
100
80
60
40
20
0
Pressure (mb)
1040
1030
1020
1010
1000
990
980
Solar Radiation (W m^{-2})
800
600
400
200
0
5
10
15
20
25
30
May 2002

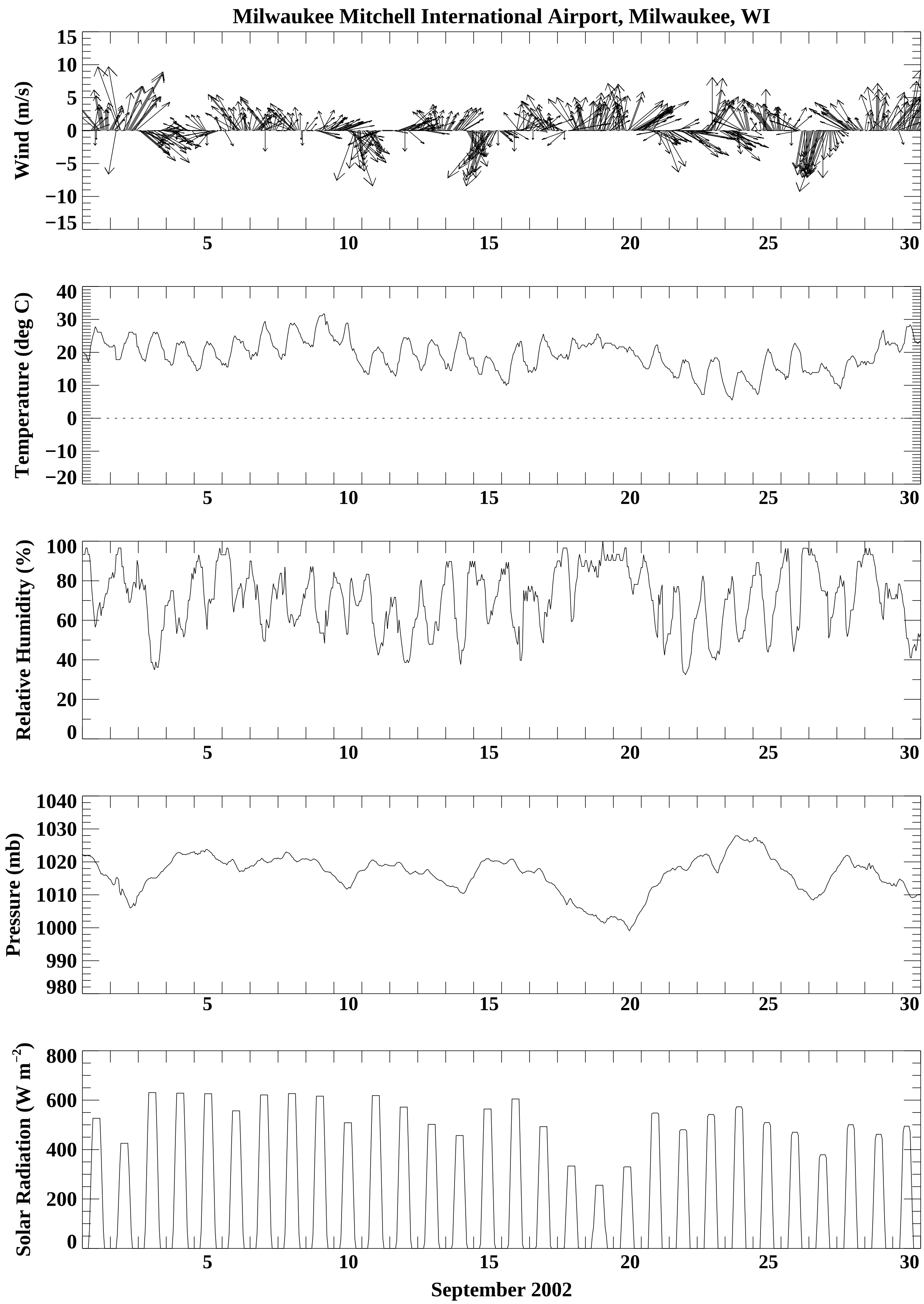


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
June 2002

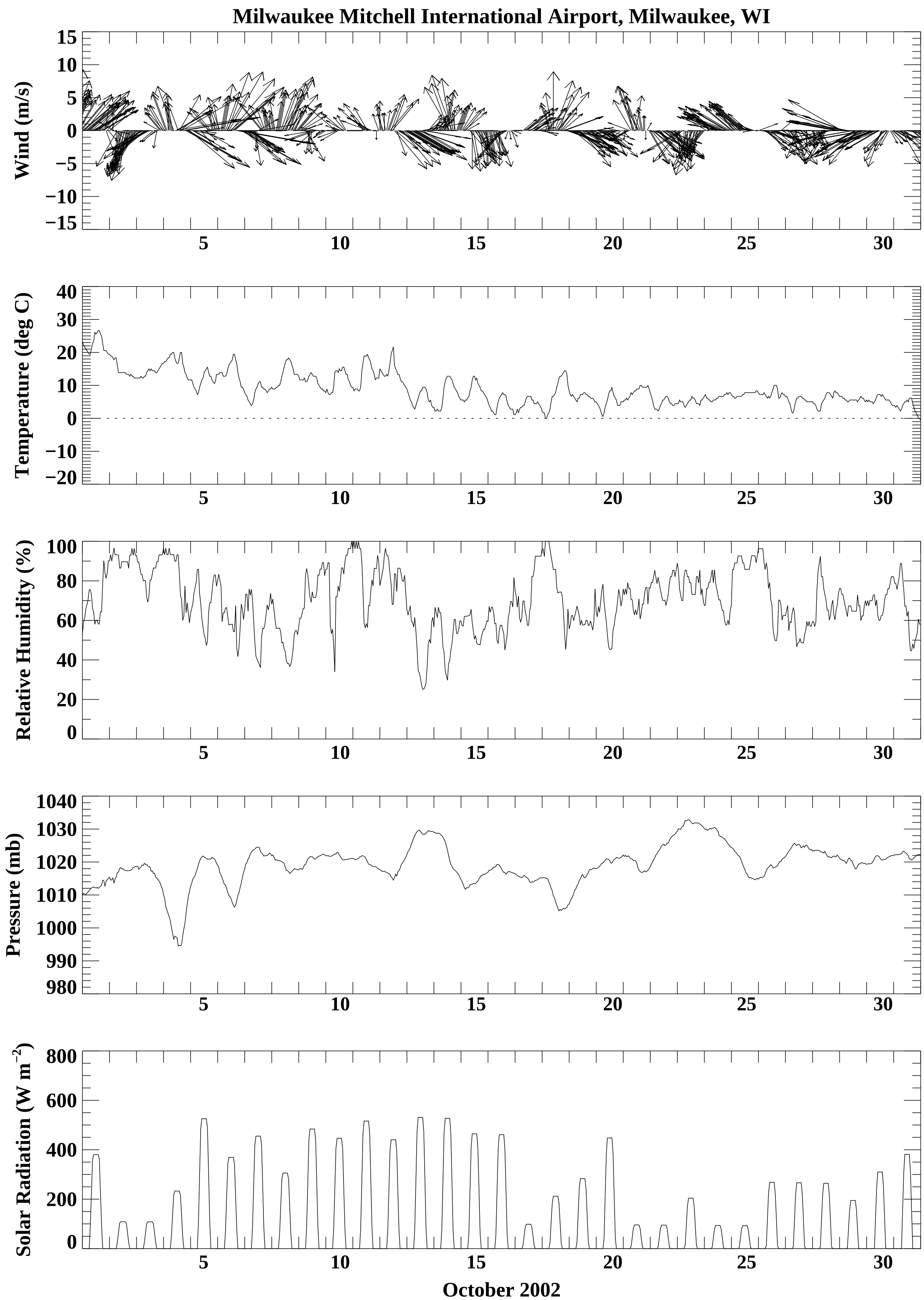

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
July 2002



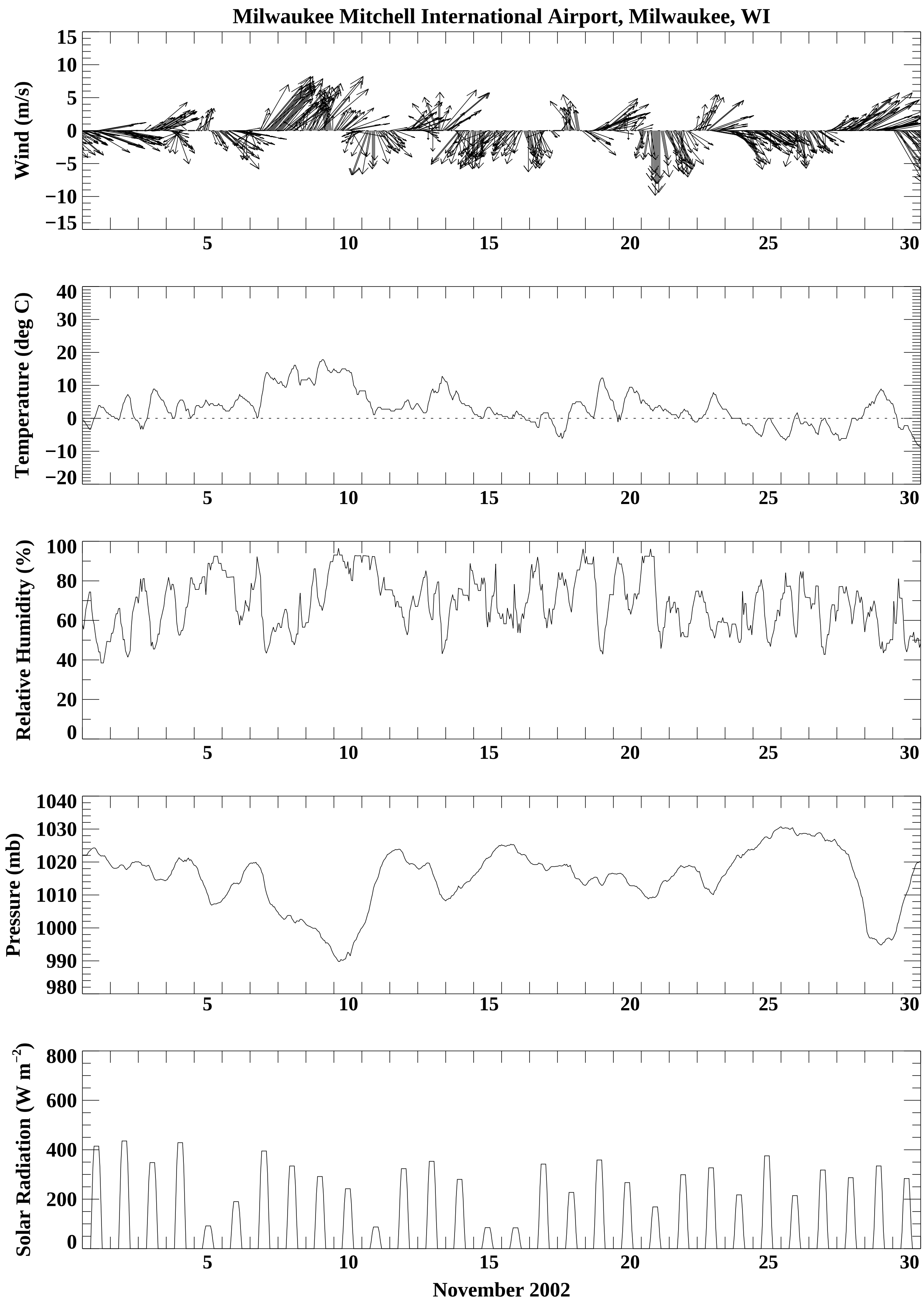
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
August 2002

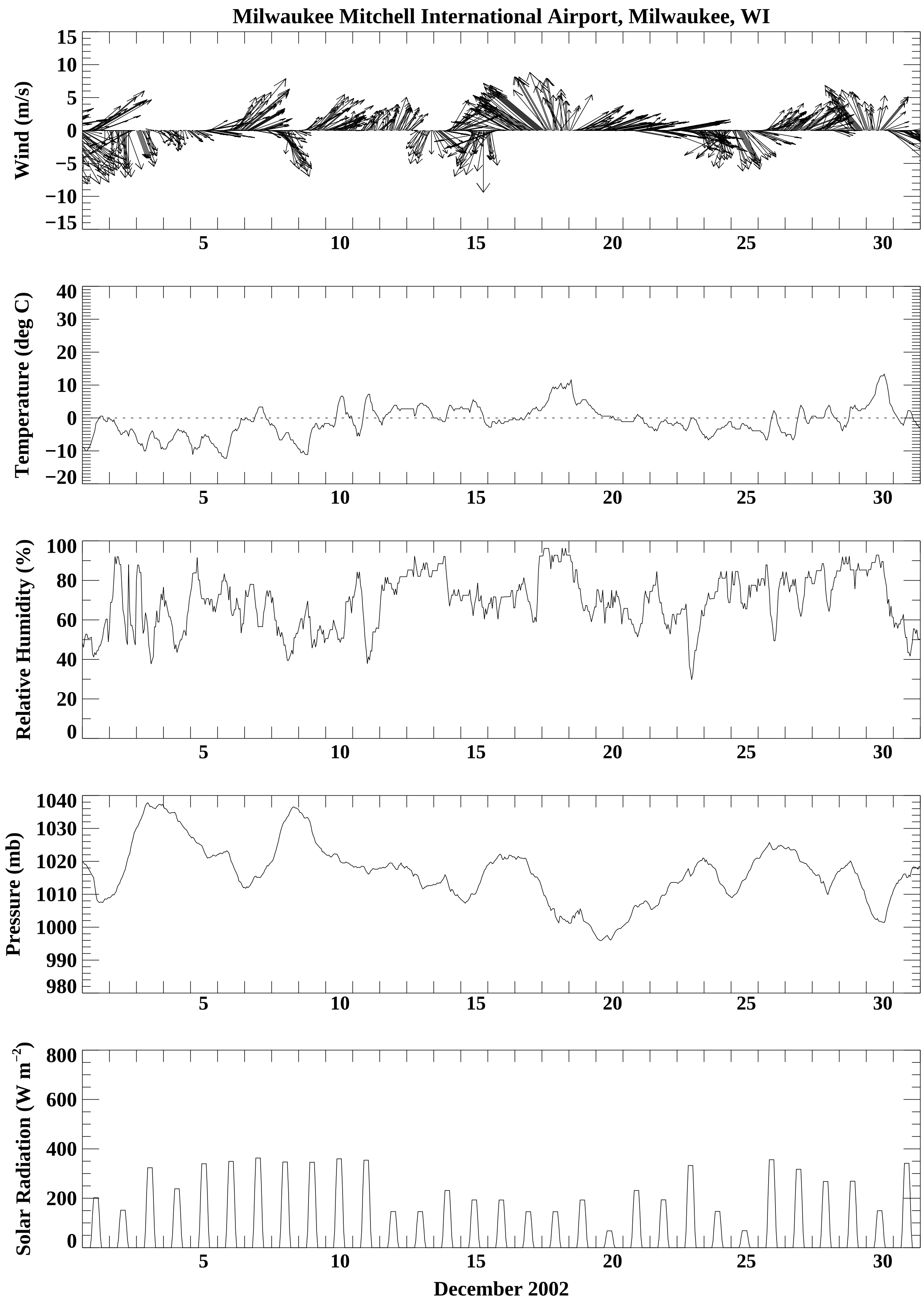


Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
September 2002



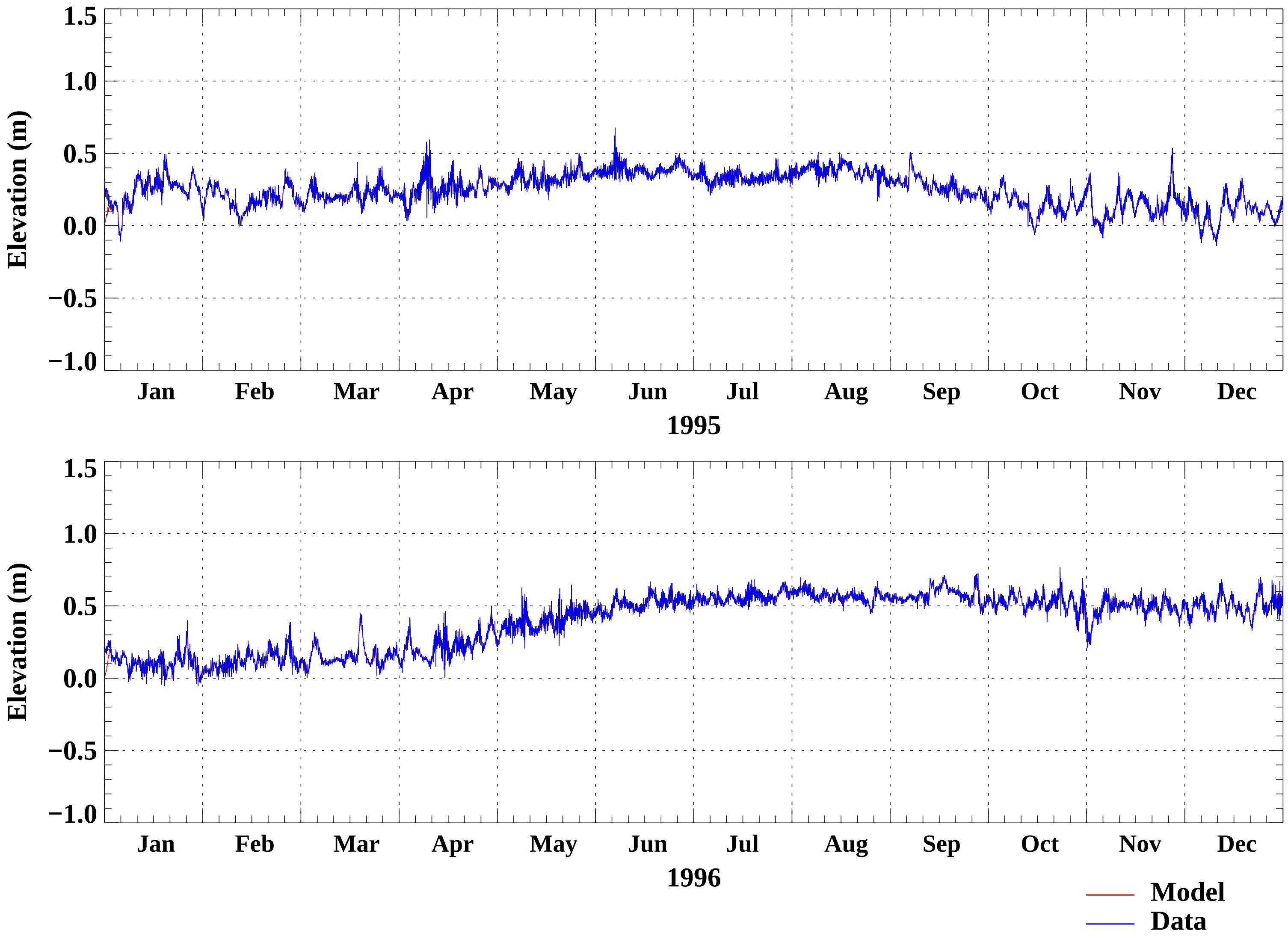
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
October 2002

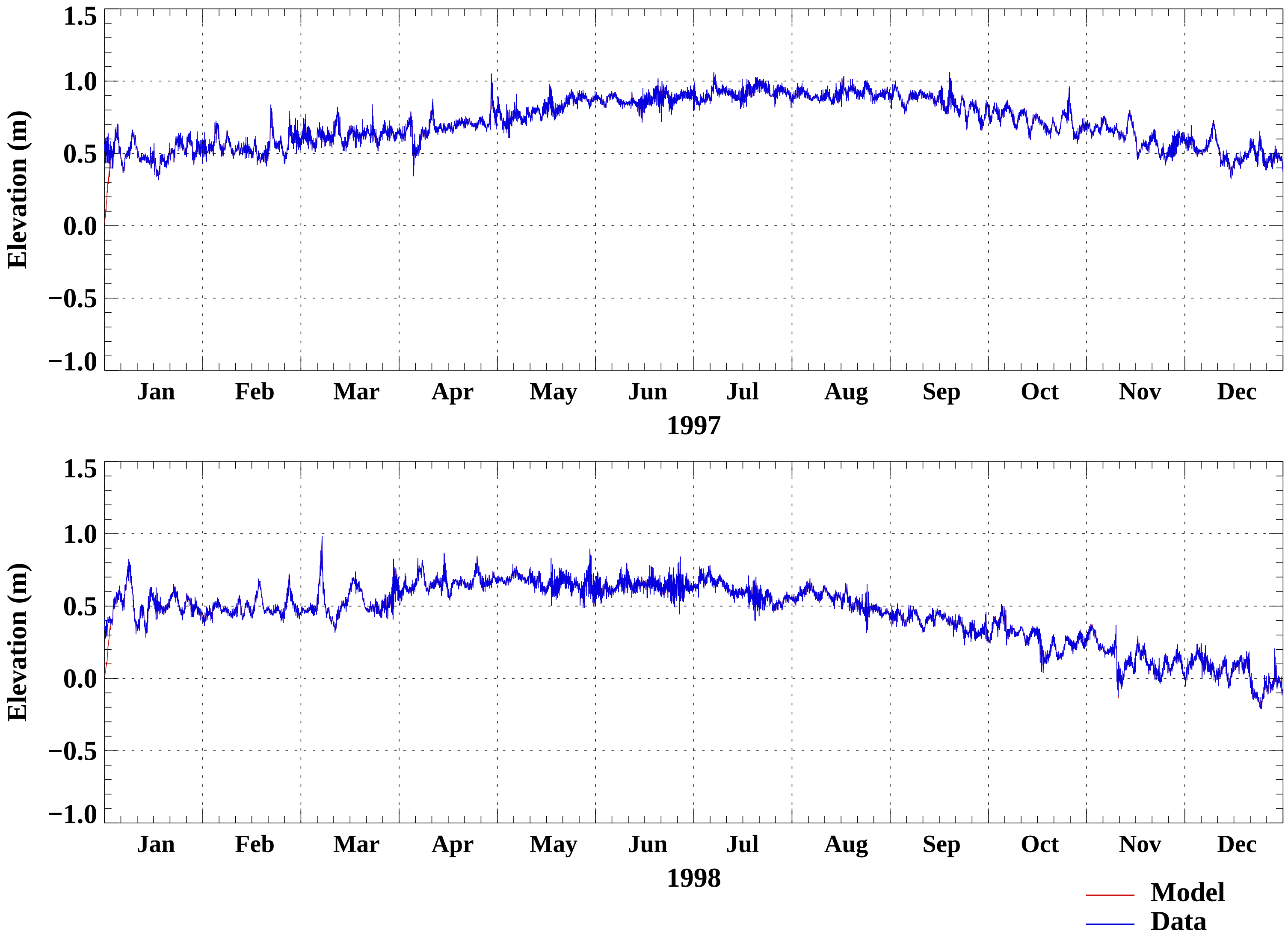

Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
November 2002



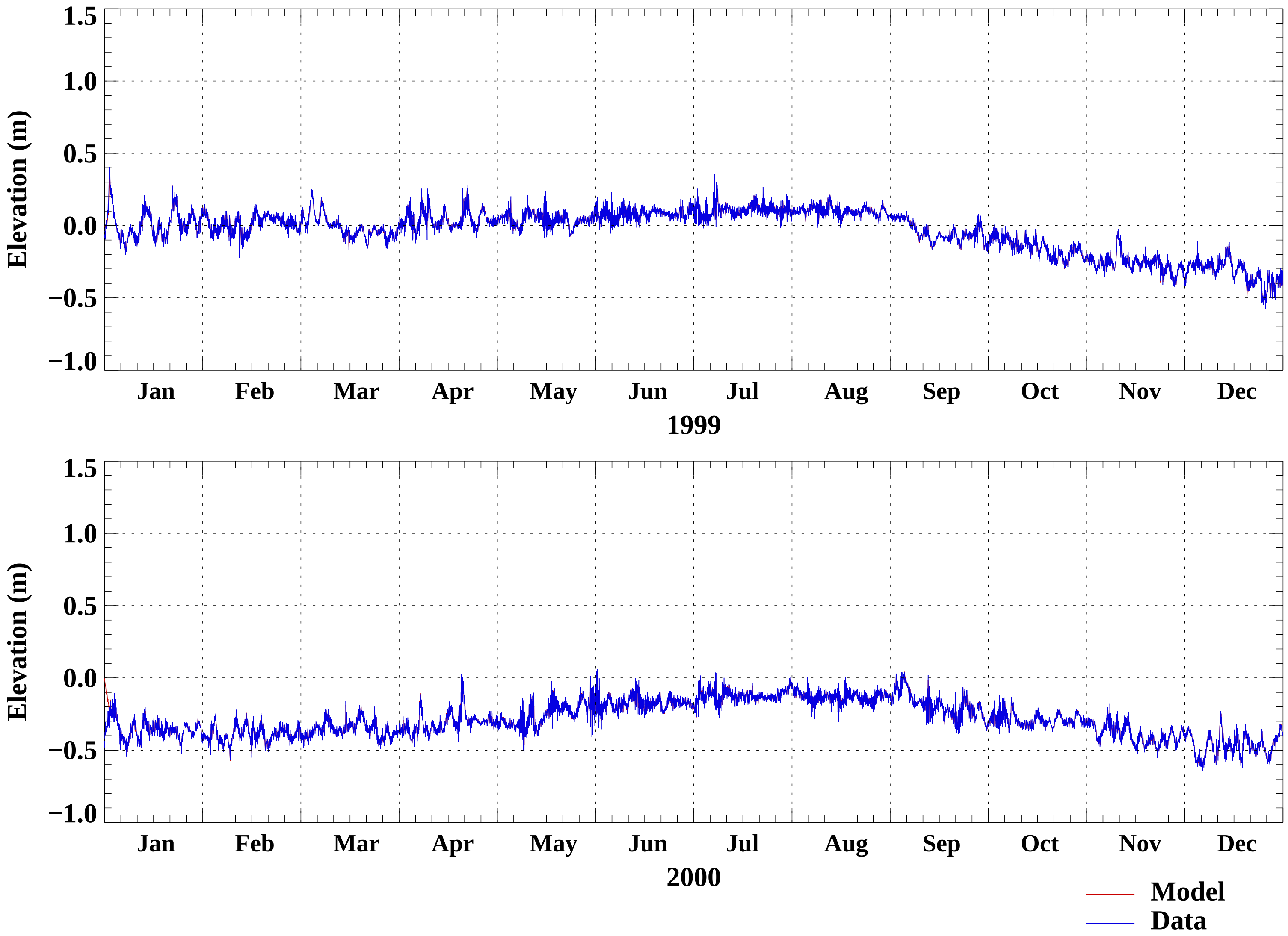
Milwaukee Mitchell International Airport, Milwaukee, WI
Wind (m/s)
Temperature (deg C)
Relative Humidity (%)
Pressure (mb)
Solar Radiation (W m^{-2})
December 2002

ATTACHMENT 13
CALIBRATION/VALIDATION OF WATER SURFACE ELEVATION

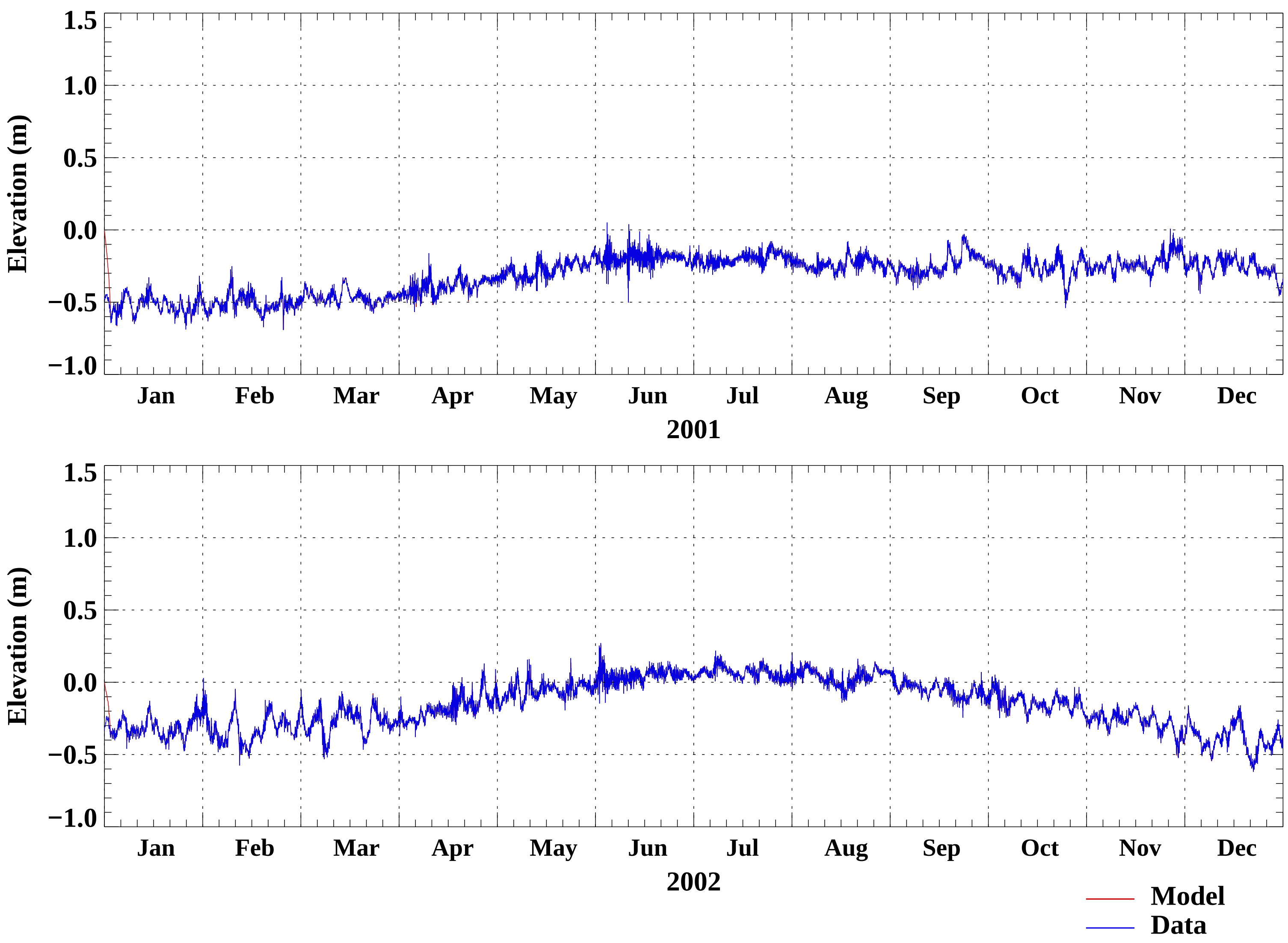

1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995
1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996
Model
Data



1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997
1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998
Model
Data

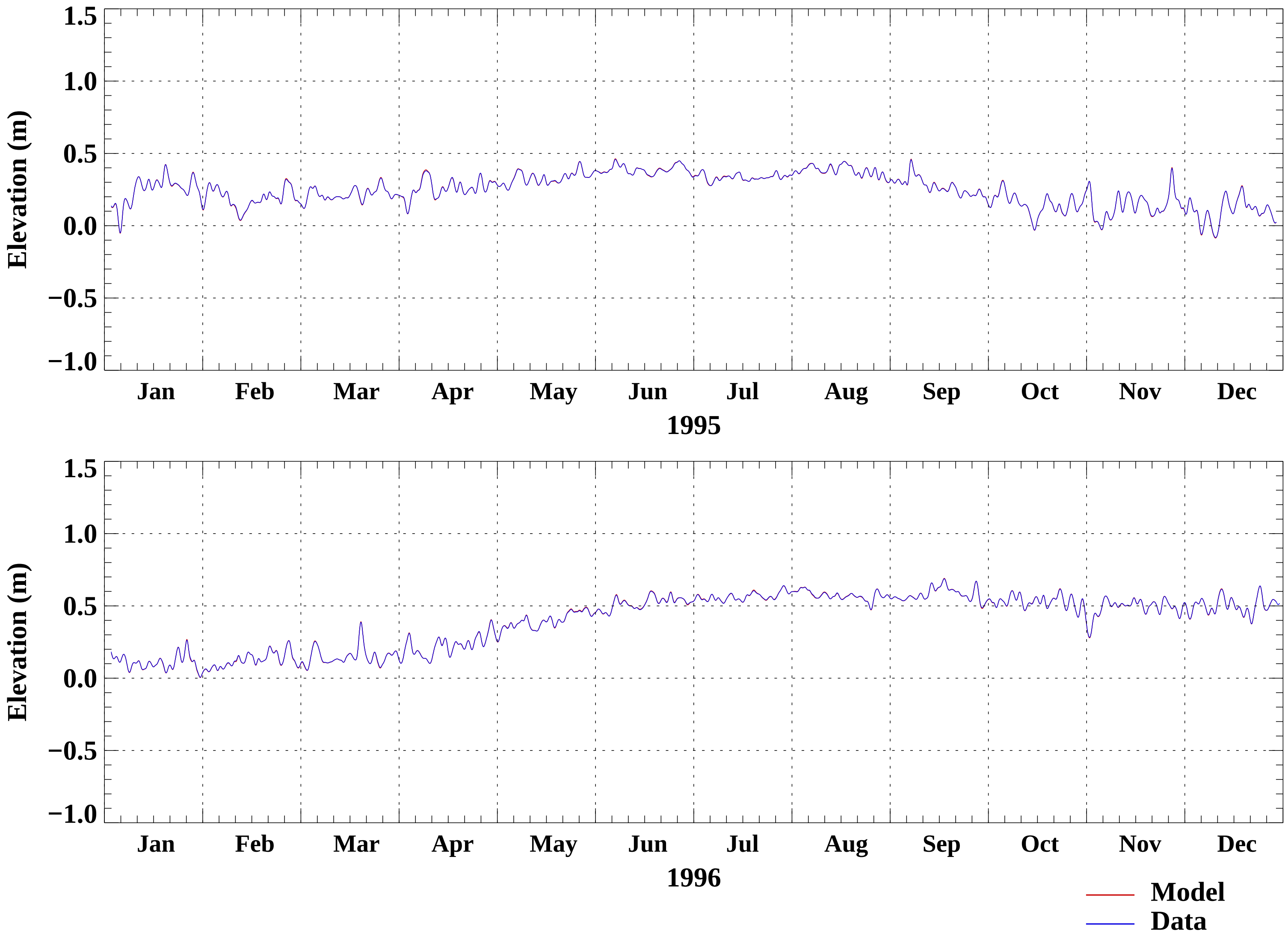


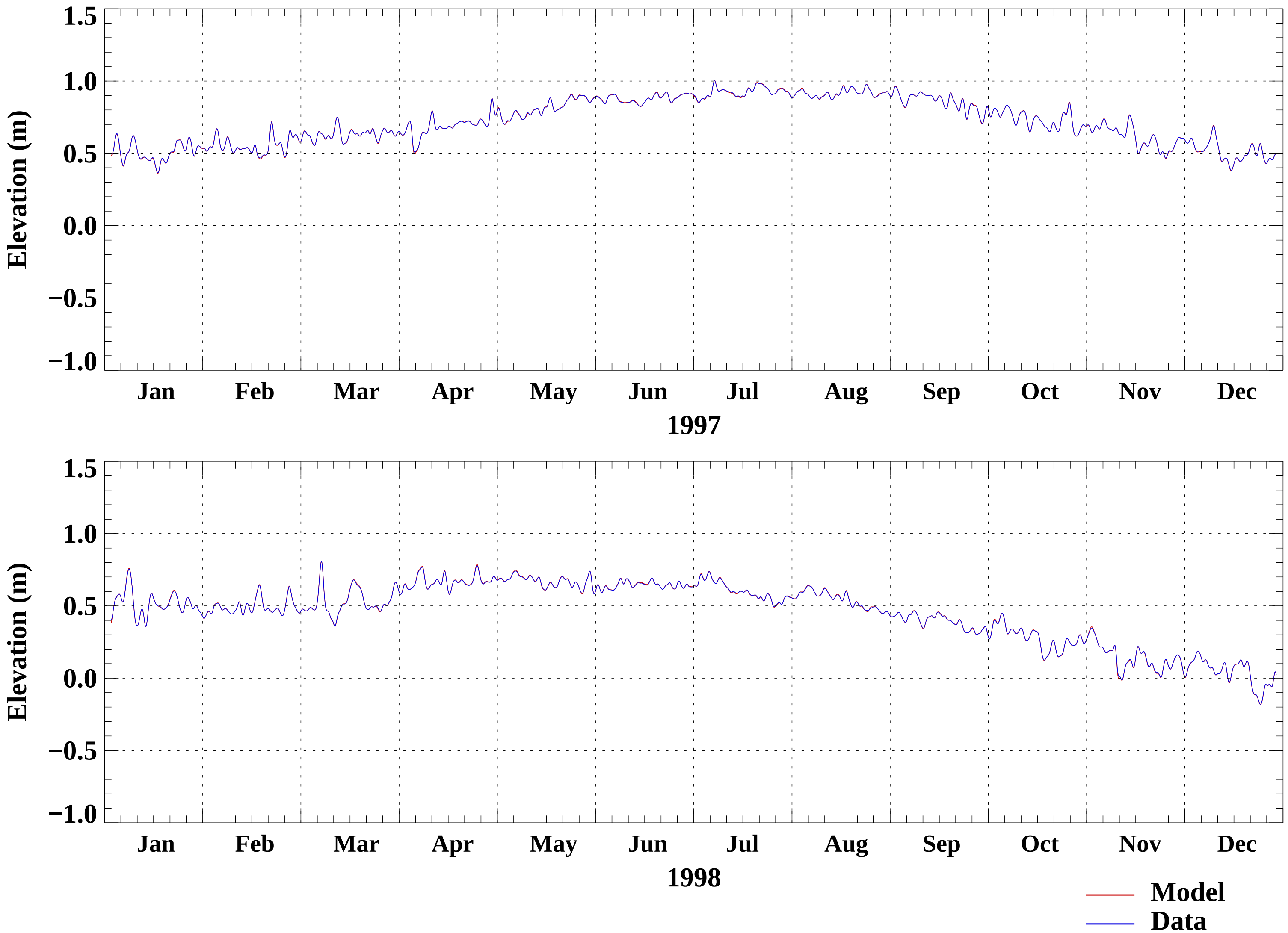
Elevation (m)
1.5
1.0
0.5
0.0
−0.5
−1.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999
Elevation (m)
1.5
1.0
0.5
0.0
−0.5
−1.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000
Model
Data



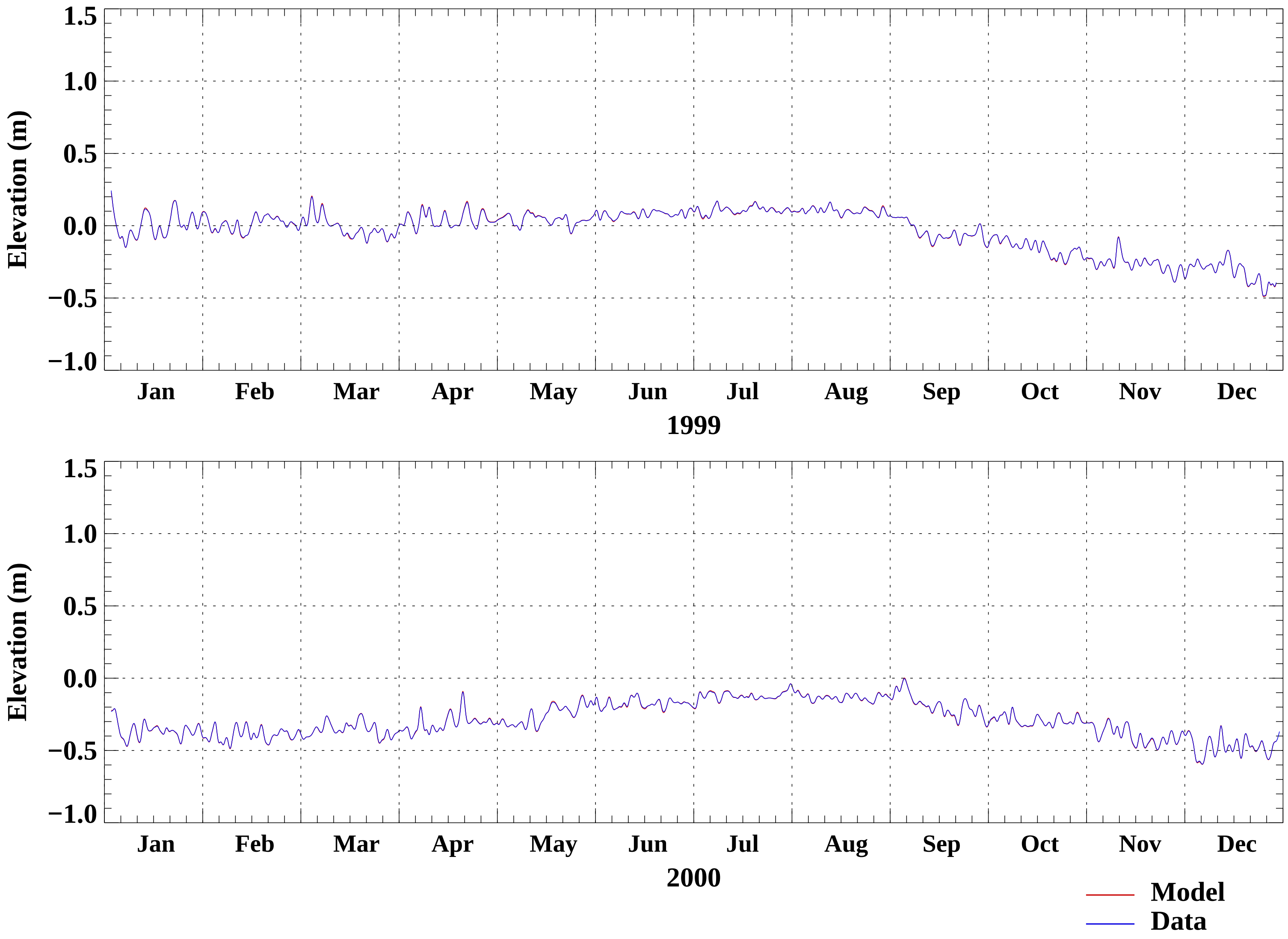
1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001
1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002
Model
Data

ATTACHMENT 14
CALIBRATION/VALIDATION OF WATER SURFACE ELEVATION
(34-HOUR LOW-PASS FILTERED)

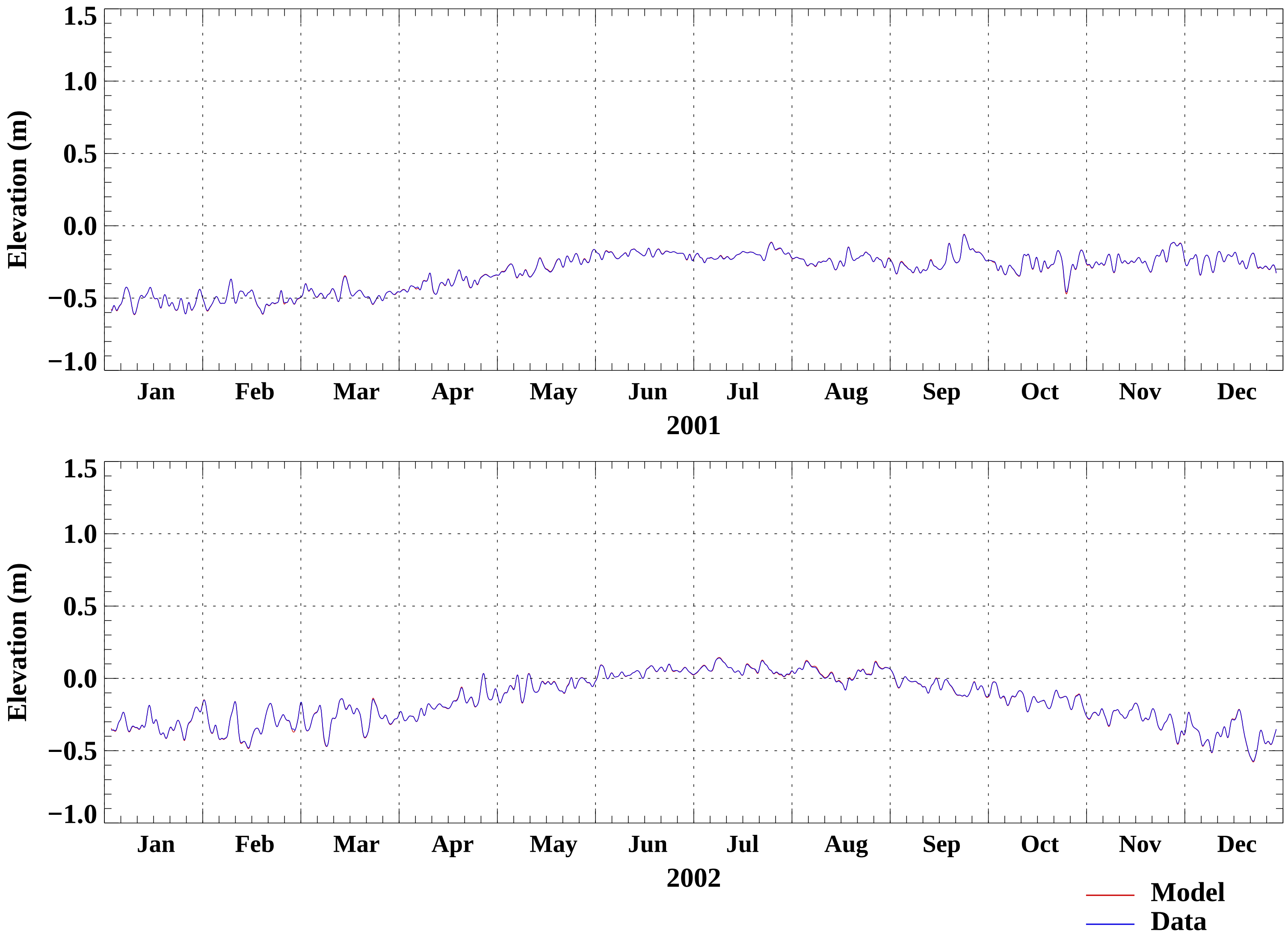

1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995
1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996
Model
Data



1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1997
1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1998
Model
Data

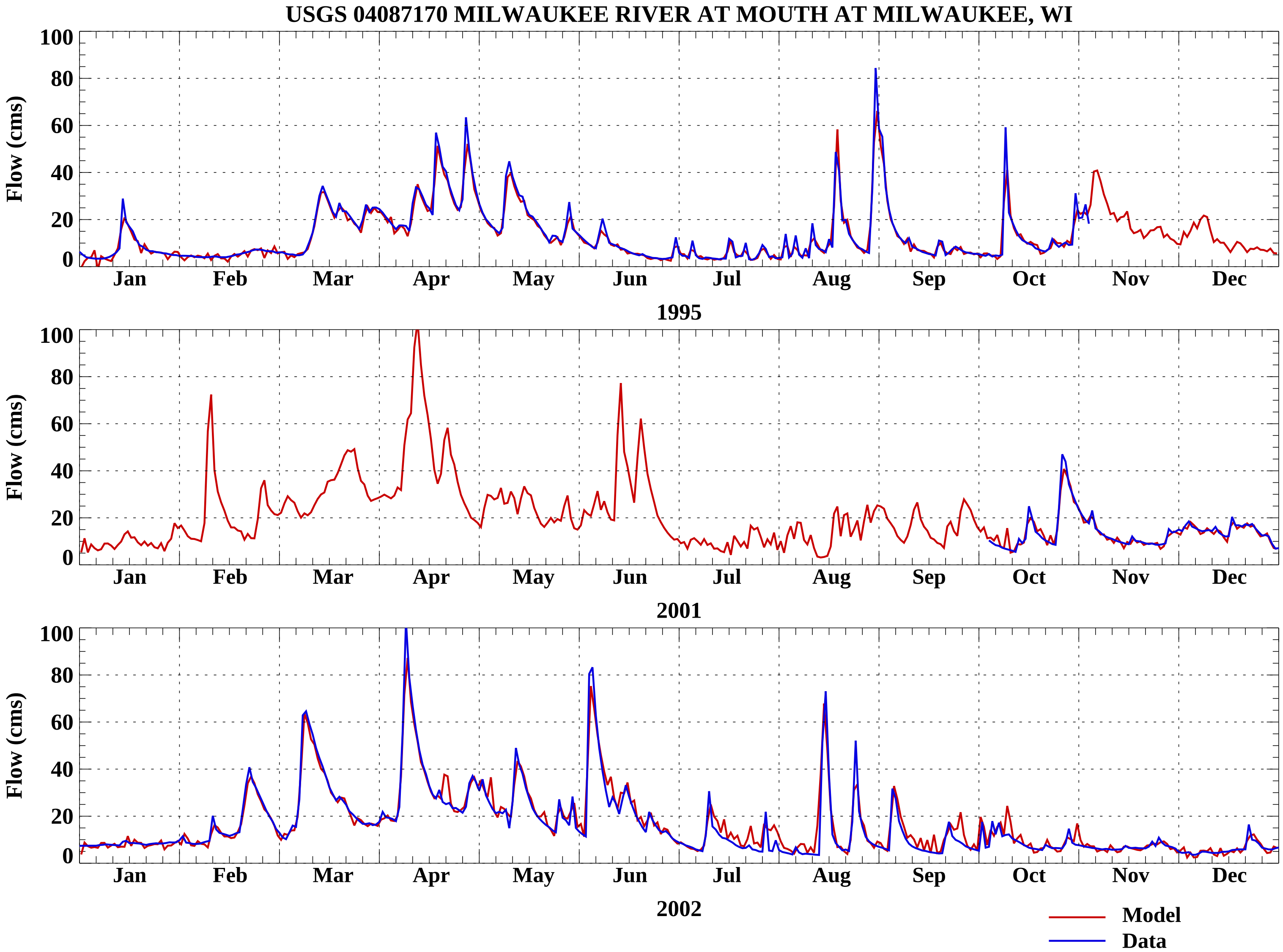


Elevation (m)
1.5
1.0
0.5
0.0
−0.5
−1.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999
Elevation (m)
1.5
1.0
0.5
0.0
−0.5
−1.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2000
Model
Data



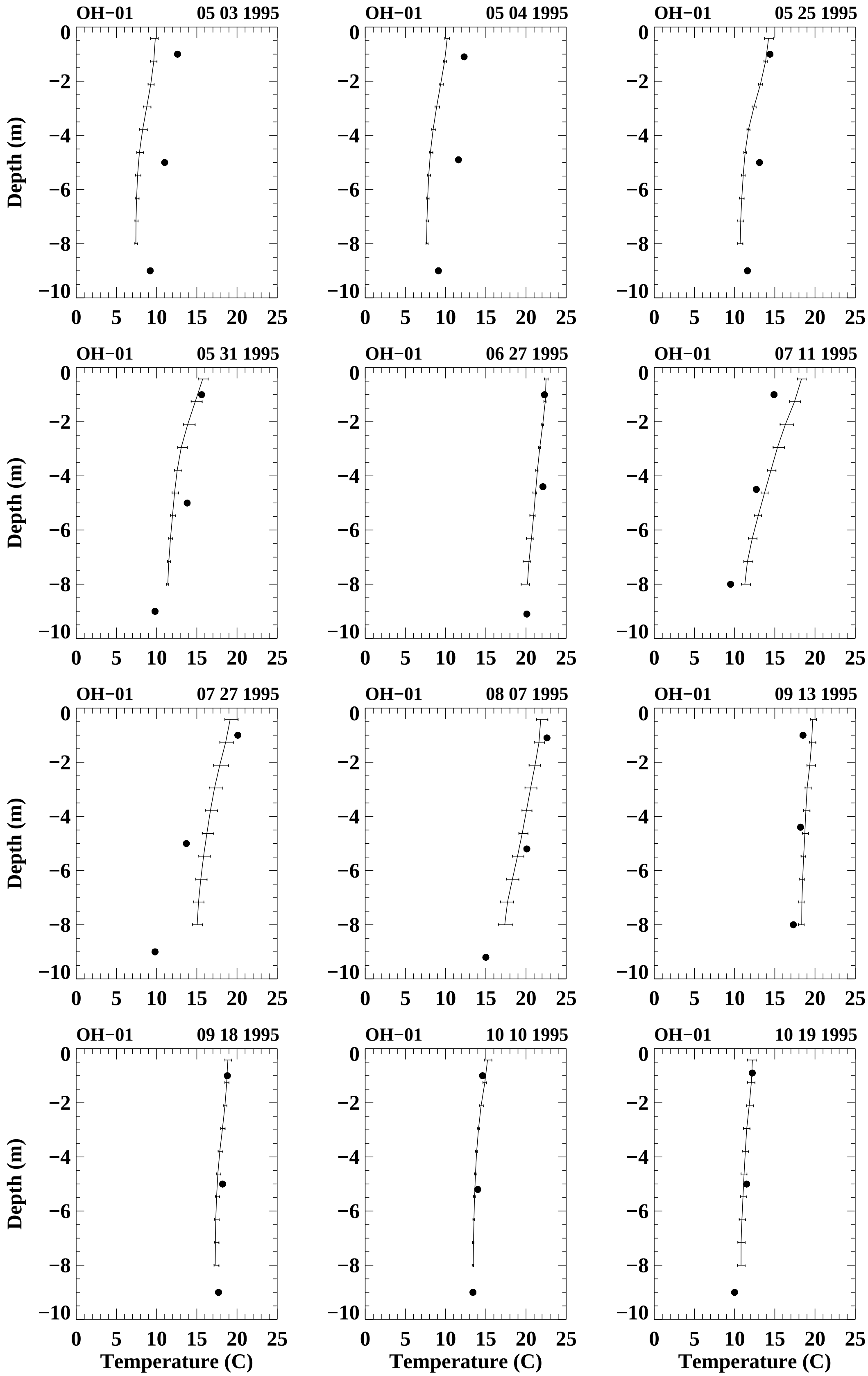
1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2001
1.5
1.0
0.5
0.0
−0.5
−1.0
Elevation (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002
Model
Data

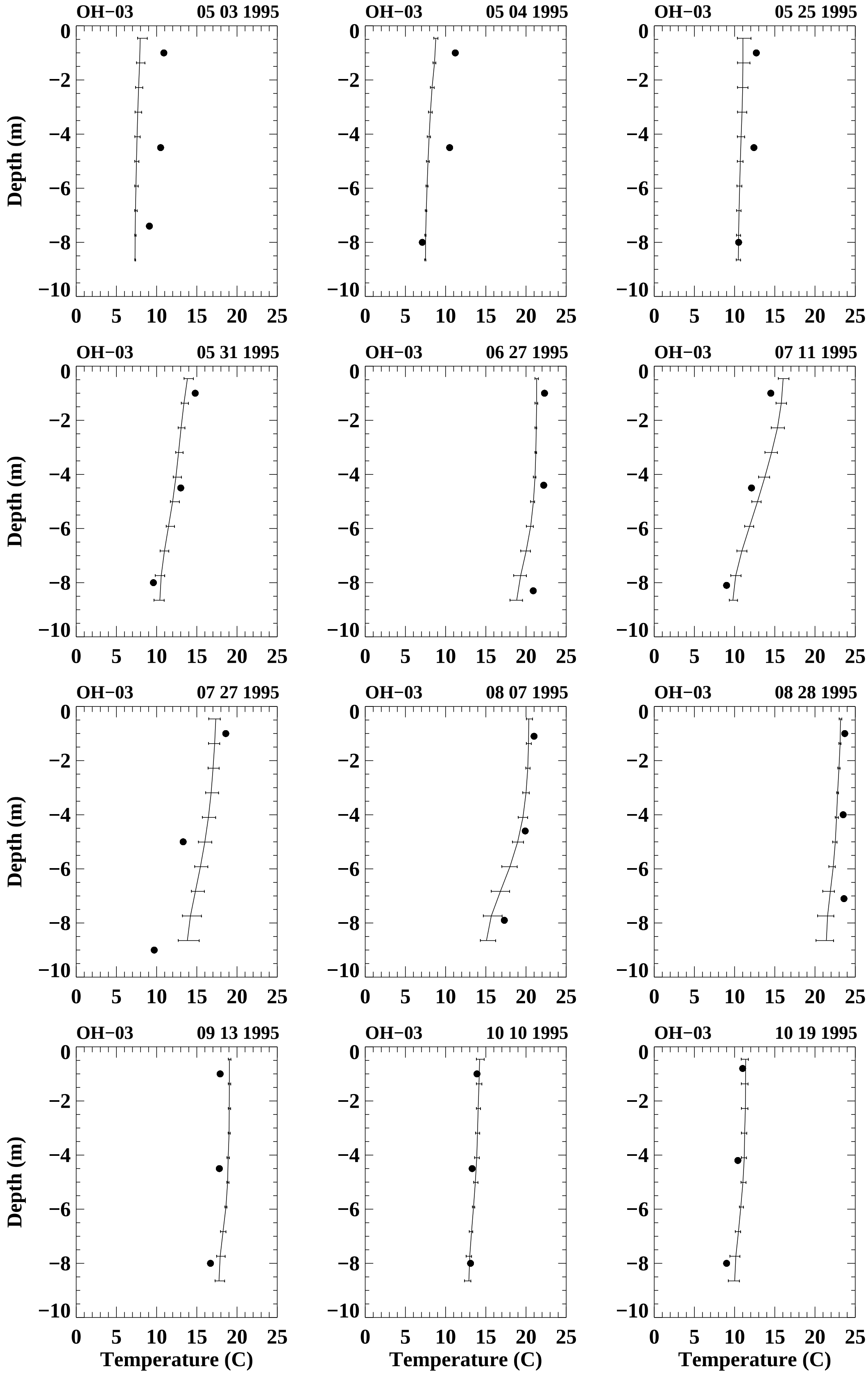
ATTACHMENT 15
CALIBRATION/VALIDATION OF RIVER FLOW



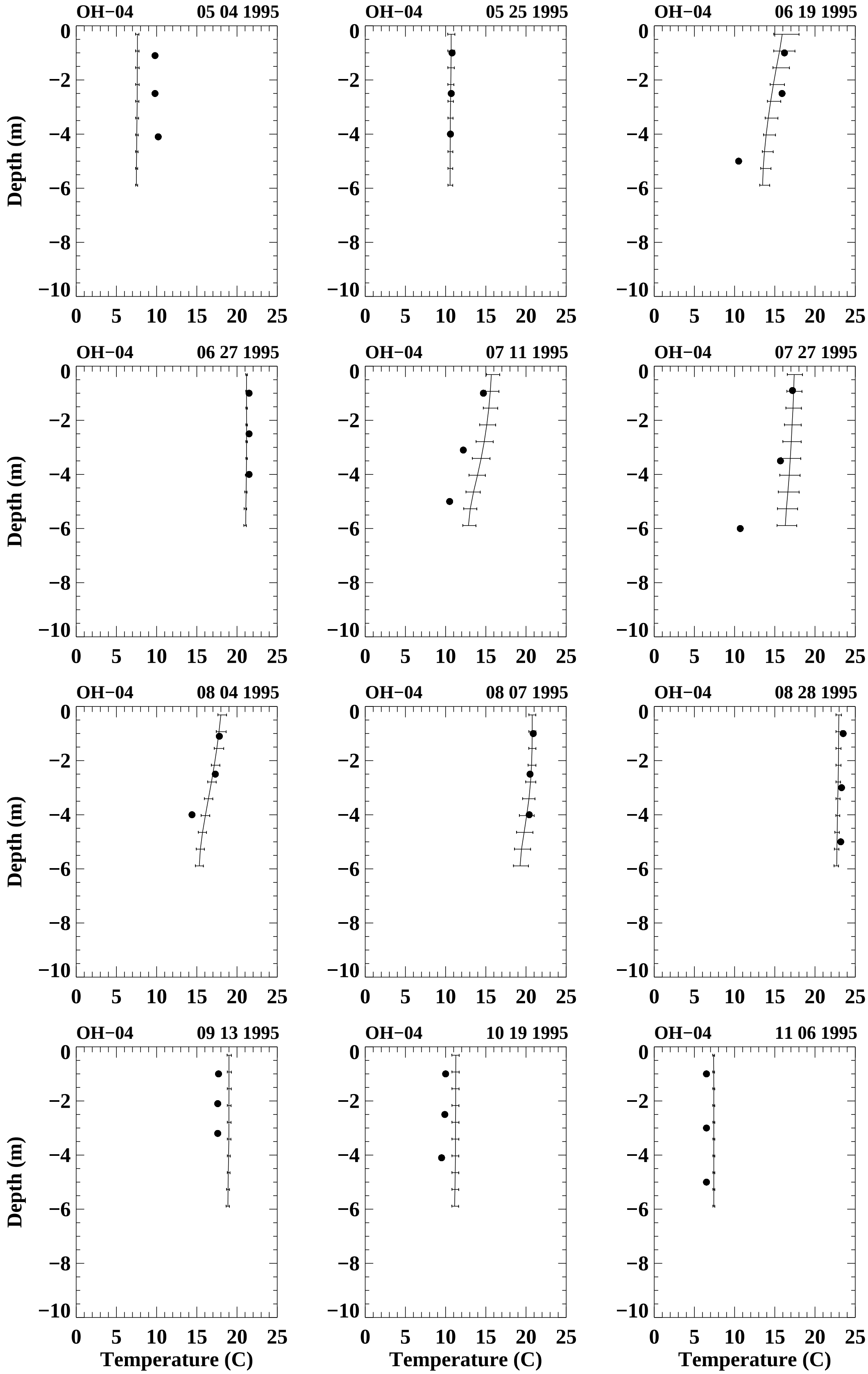
USGS 04087170 MILWAUKEE RIVER AT MOUTH AT MILWAUKEE, WI
Flow (cms)
0
20
40
60
80
100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1995
2001
2002
Model
Data

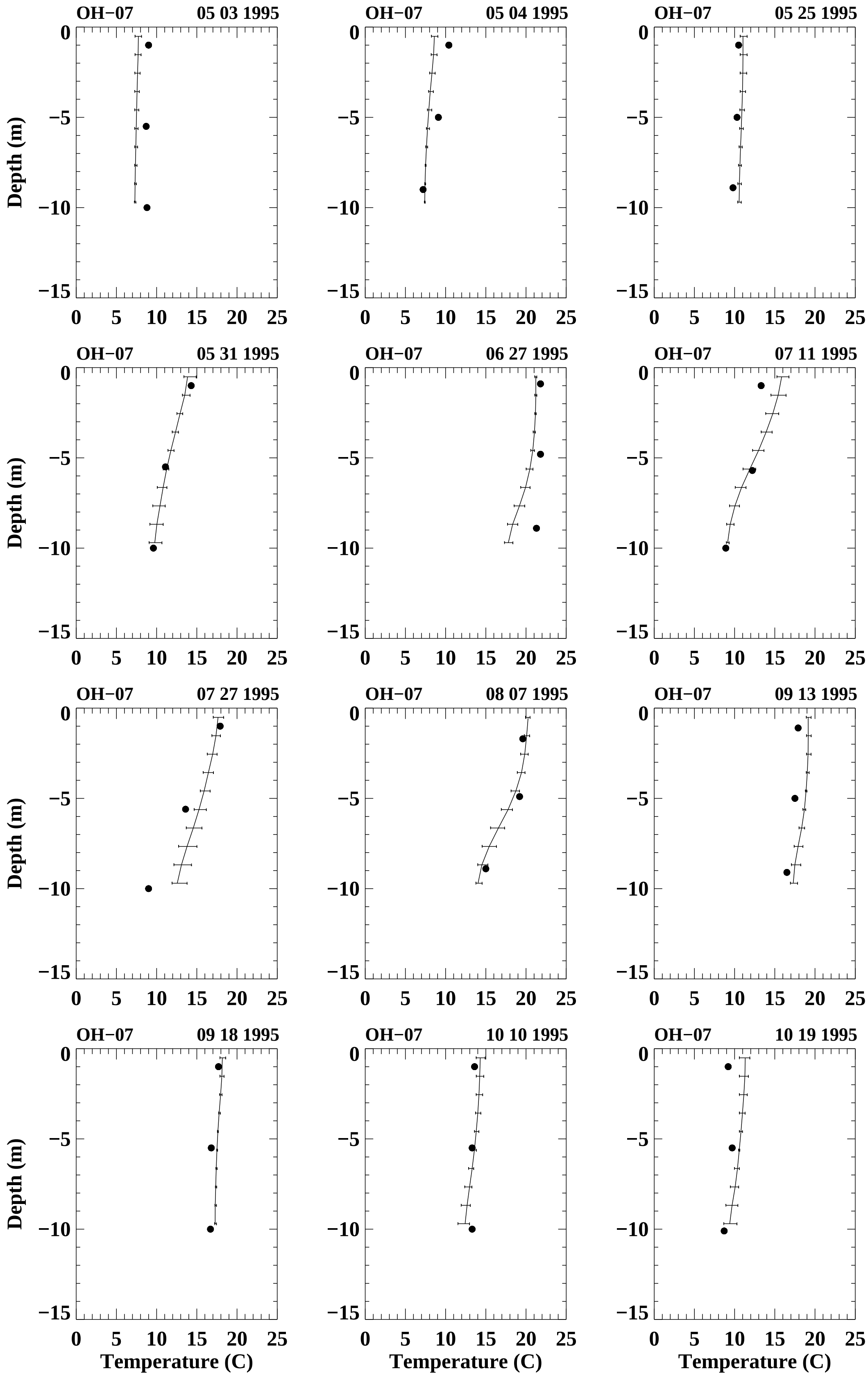
ATTACHMENT 16
CALIBRATION/VALIDATION OF WATER TEMPERATURE


OH−01 05 03 1995
OH−01 05 04 1995
OH−01 05 25 1995
OH−01 05 31 1995
OH−01 06 27 1995
OH−01 07 11 1995
OH−01 07 27 1995
OH−01 08 07 1995
OH−01 09 13 1995
OH−01 09 18 1995
OH−01 10 10 1995
OH−01 10 19 1995
Depth (m)
0 −2 −4 −6 −8 −10
0 5 10 15 20 25
Temperature (C)

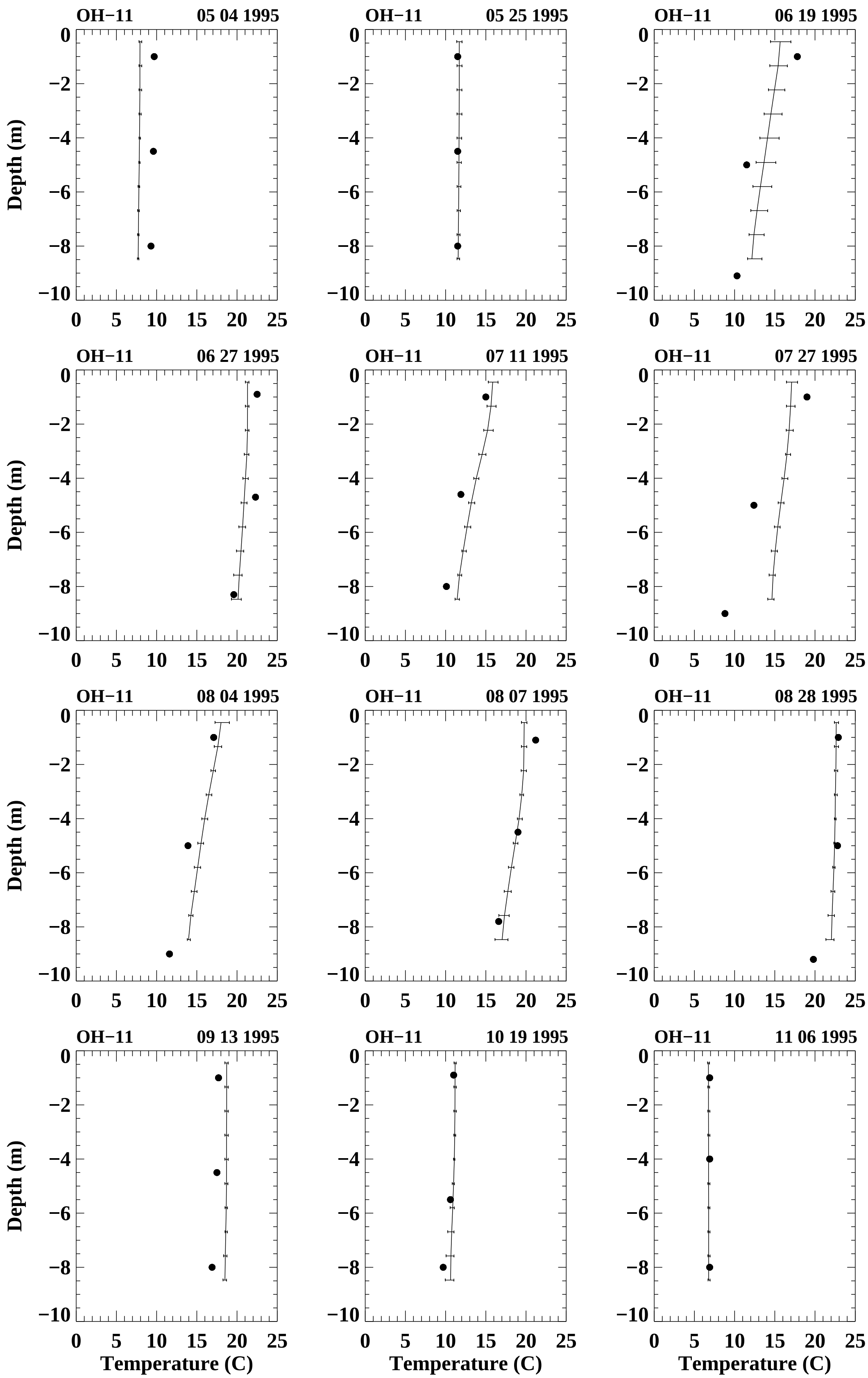


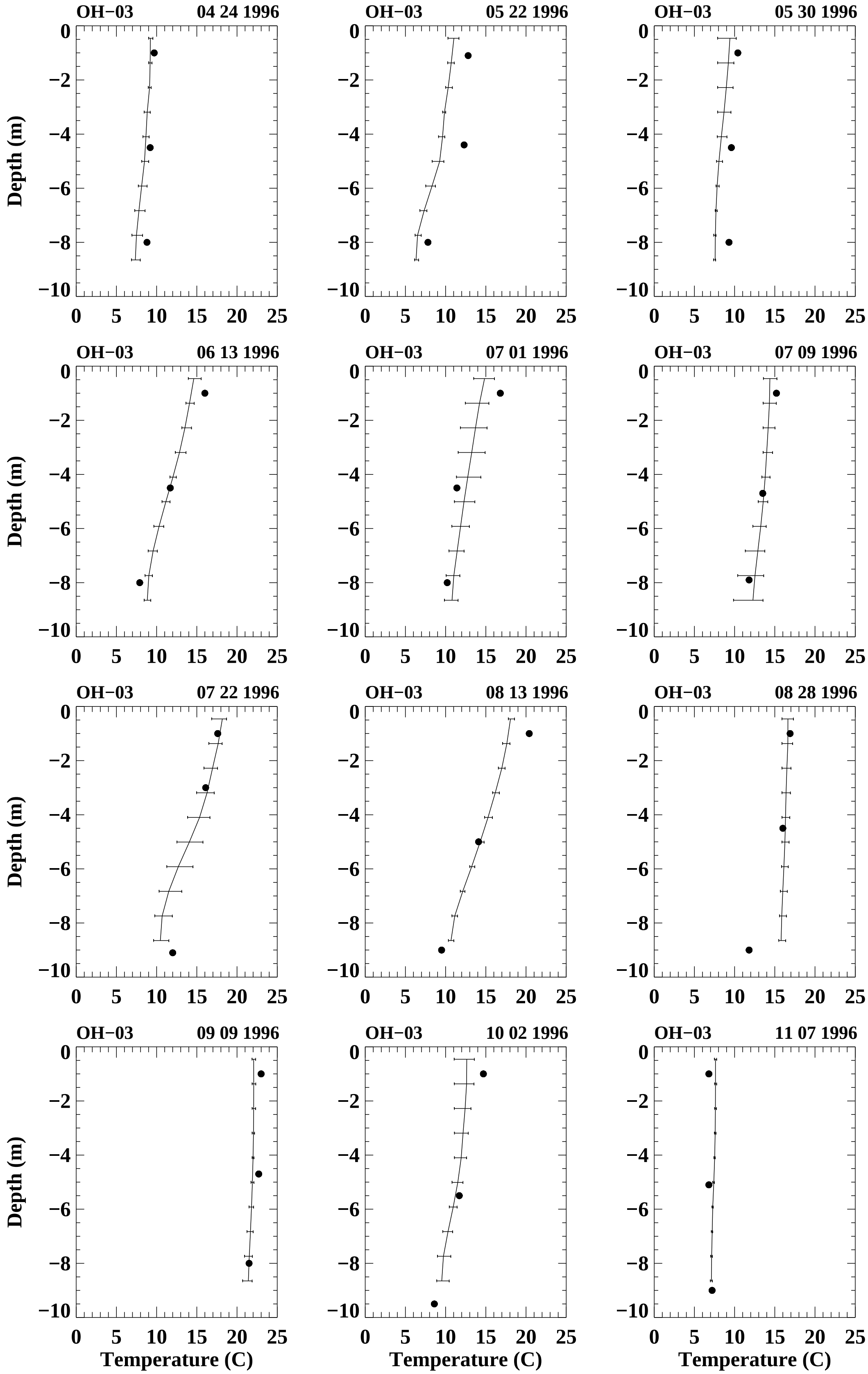
OH−03 05 03 1995
OH−03 05 04 1995
OH−03 05 25 1995
OH−03 05 31 1995
OH−03 06 27 1995
OH−03 07 11 1995
OH−03 07 27 1995
OH−03 08 07 1995
OH−03 08 28 1995
OH−03 09 13 1995
OH−03 10 10 1995
OH−03 10 19 1995
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25

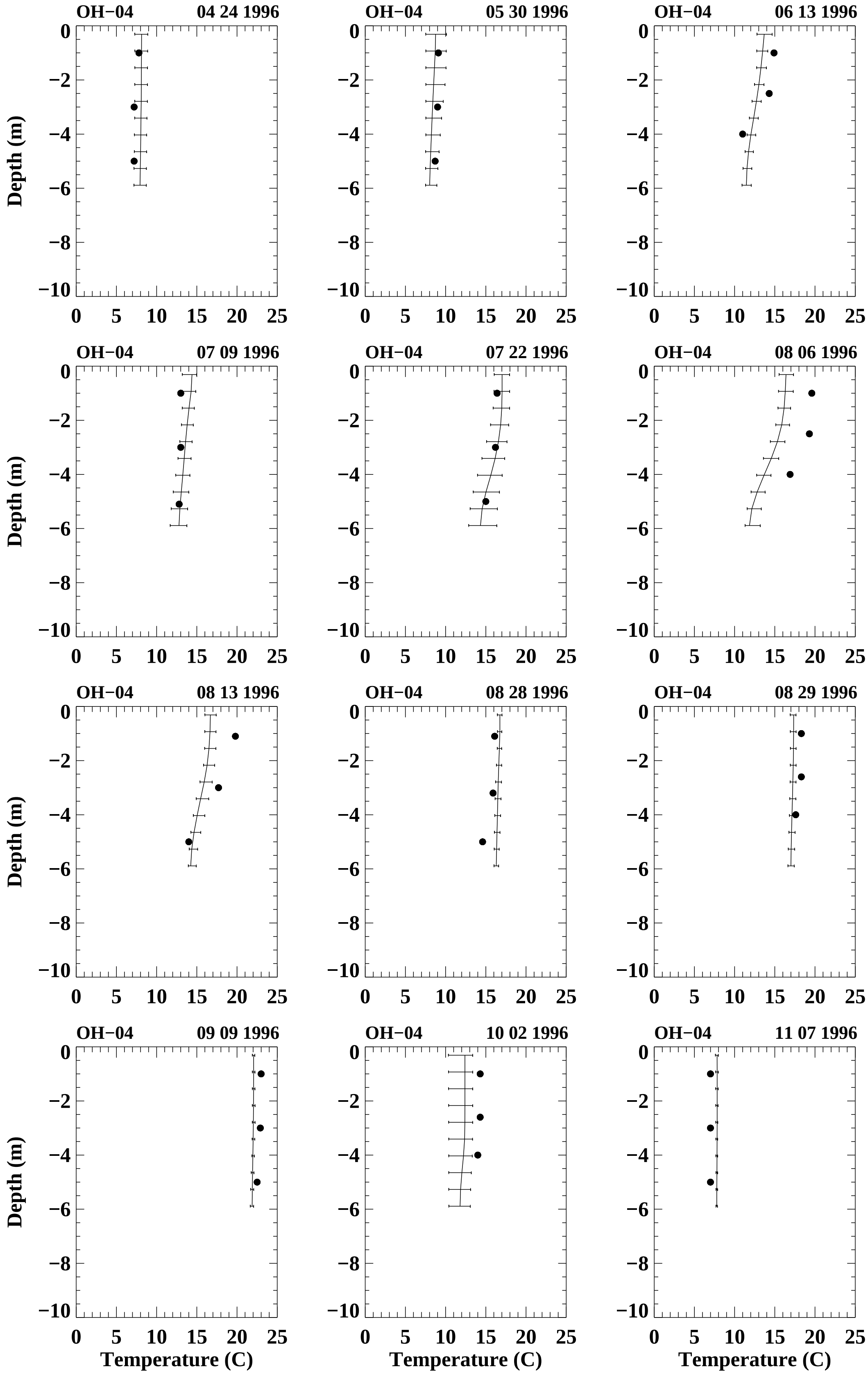

OH−04 05 04 1995
OH−04 05 25 1995
OH−04 06 19 1995
OH−04 06 27 1995
OH−04 07 11 1995
OH−04 07 27 1995
OH−04 08 04 1995
OH−04 08 07 1995
OH−04 08 28 1995
OH−04 09 13 1995
OH−04 10 19 1995
OH−04 11 06 1995
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)

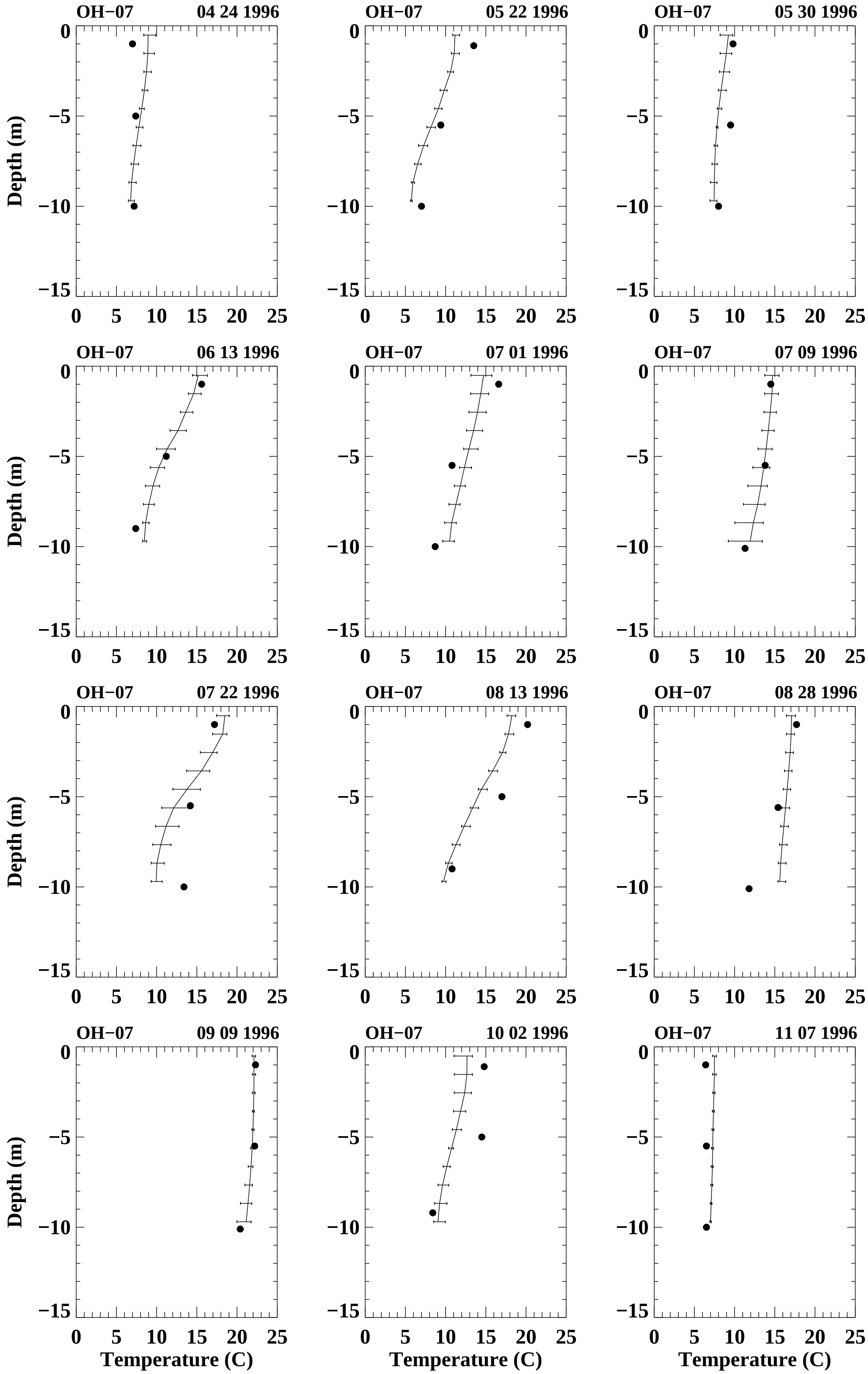


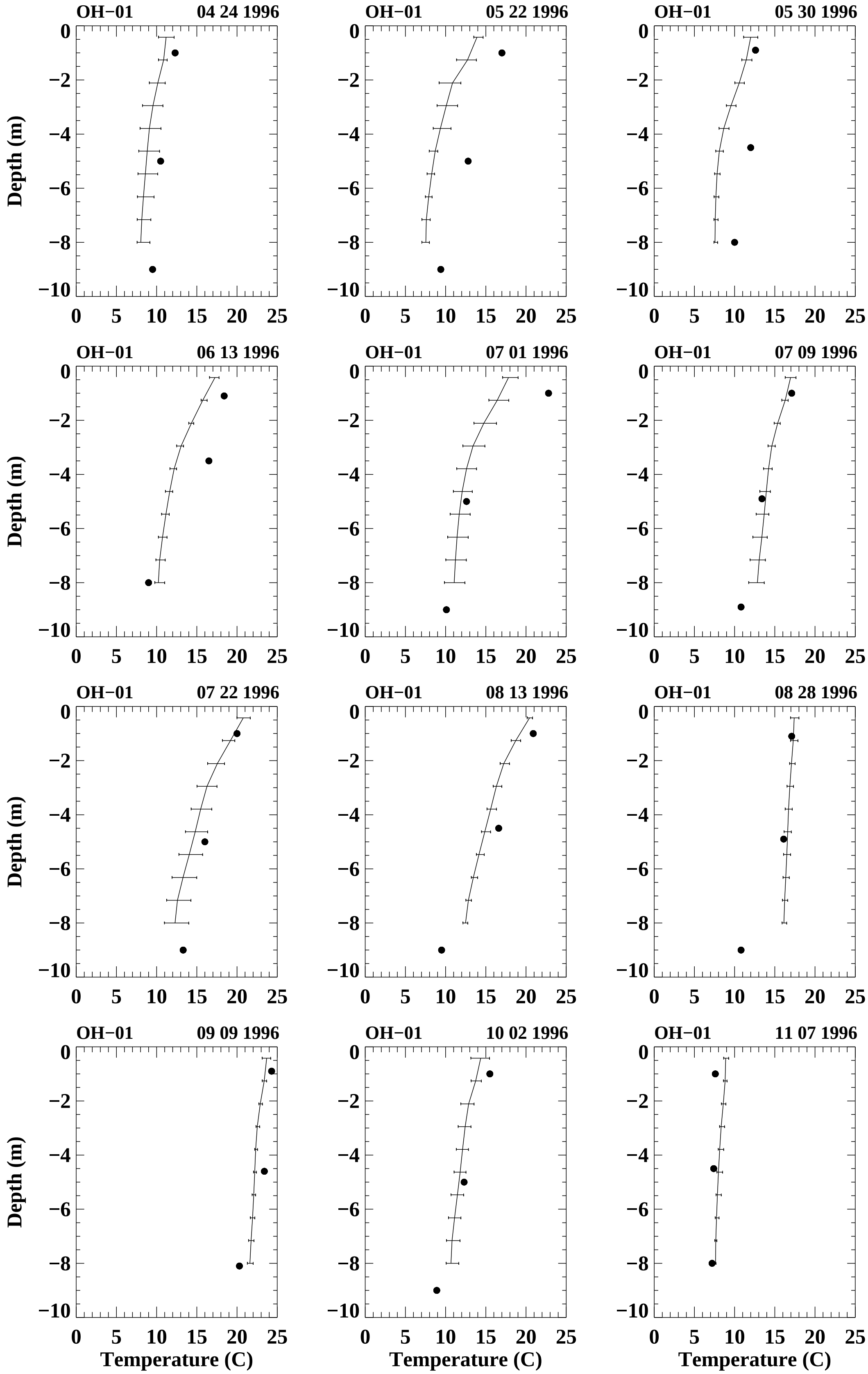
OH−07
05 03 1995
OH−07
05 04 1995
OH−07
05 25 1995
OH−07
05 31 1995
OH−07
06 27 1995
OH−07
07 11 1995
OH−07
07 27 1995
OH−07
08 07 1995
OH−07
09 13 1995
OH−07
09 18 1995
OH−07
10 10 1995
OH−07
10 19 1995
Depth (m)
0
−5
−10
−15
0
5
10
15
20
25
Temperature (C)


OH−11
05 04 1995
OH−11
05 25 1995
OH−11
06 19 1995
OH−11
06 27 1995
OH−11
07 11 1995
OH−11
07 27 1995
OH−11
08 04 1995
OH−11
08 07 1995
OH−11
08 28 1995
OH−11
09 13 1995
OH−11
10 19 1995
OH−11
11 06 1995
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)

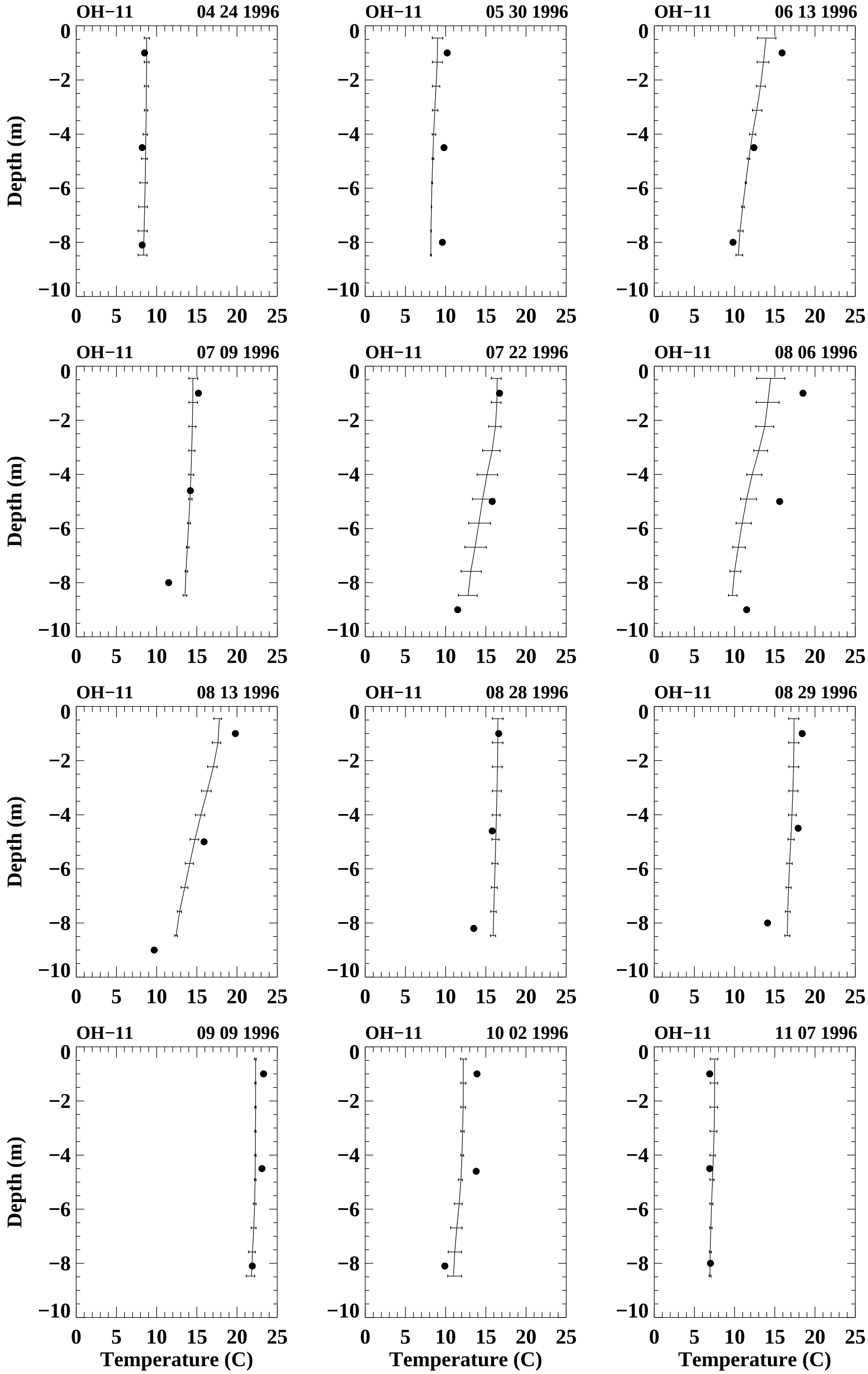

OH−03
04 24 1996
05 22 1996
05 30 1996
06 13 1996
07 01 1996
07 09 1996
07 22 1996
08 13 1996
08 28 1996
09 09 1996
10 02 1996
11 07 1996
Depth (m)
Temperature (C)


OH−04 04 24 1996
OH−04 05 30 1996
OH−04 06 13 1996
OH−04 07 09 1996
OH−04 07 22 1996
OH−04 08 06 1996
OH−04 08 13 1996
OH−04 08 28 1996
OH−04 08 29 1996
OH−04 09 09 1996
OH−04 10 02 1996
OH−04 11 07 1996
Depth (m)
0 −2 −4 −6 −8 −10
0 5 10 15 20 25
Temperature (C)

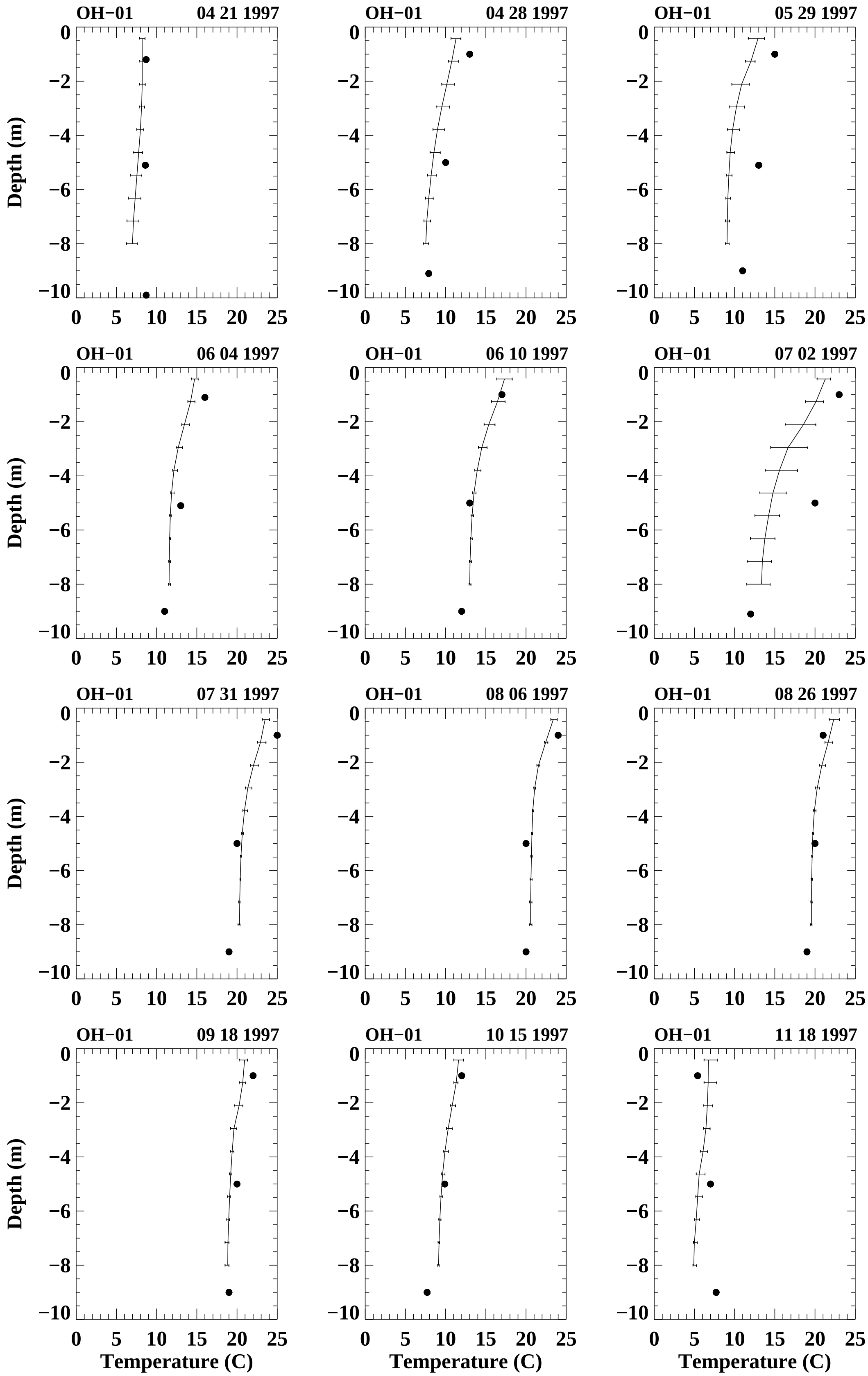

OH−07
04 24 1996
05 22 1996
05 30 1996
06 13 1996
07 01 1996
07 09 1996
07 22 1996
08 13 1996
08 28 1996
09 09 1996
10 02 1996
11 07 1996
Depth (m)
Temperature (C)

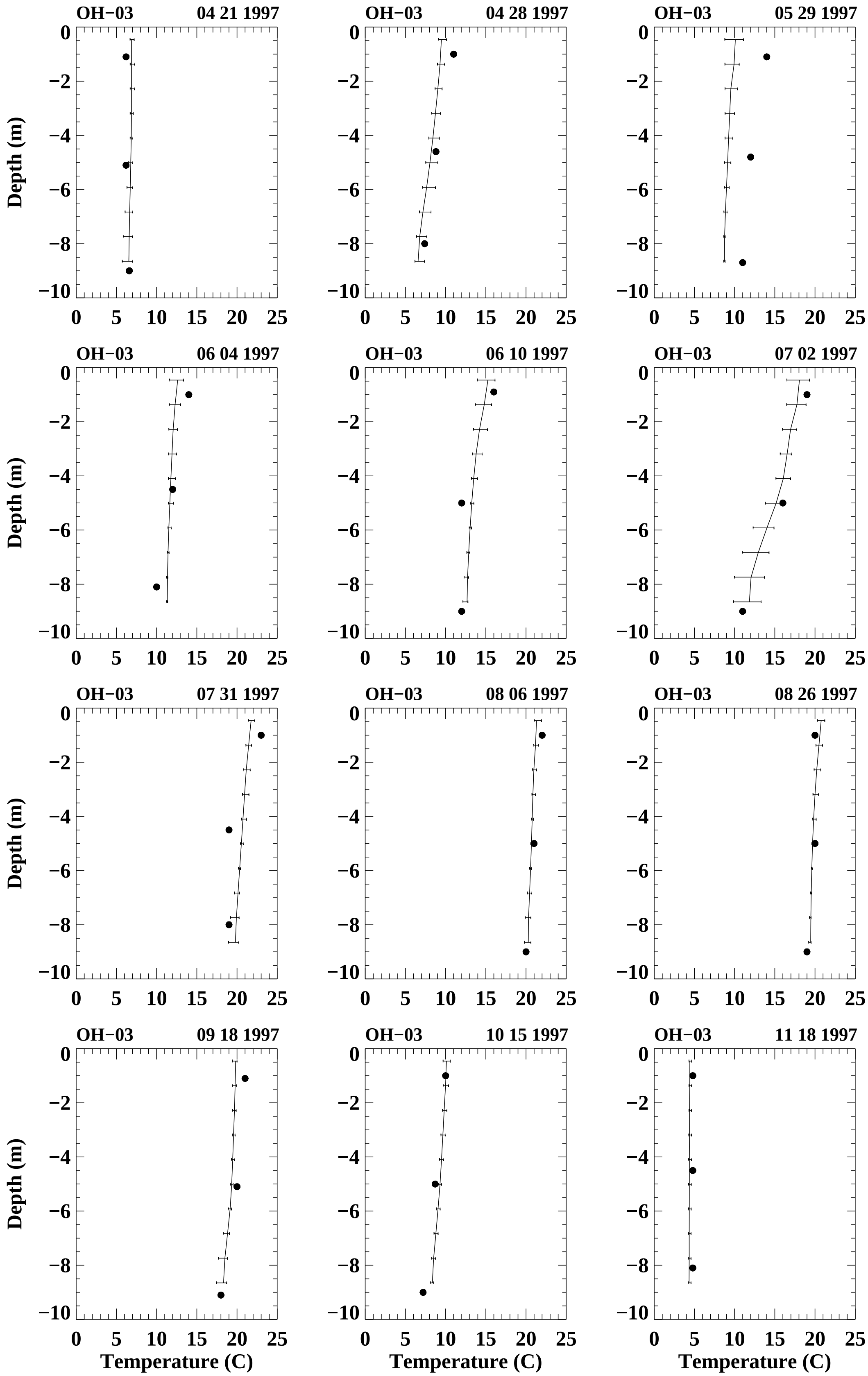


OH−01 04 24 1996
OH−01 05 22 1996
OH−01 05 30 1996
OH−01 06 13 1996
OH−01 07 01 1996
OH−01 07 09 1996
OH−01 07 22 1996
OH−01 08 13 1996
OH−01 08 28 1996
OH−01 09 09 1996
OH−01 10 02 1996
OH−01 11 07 1996
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25

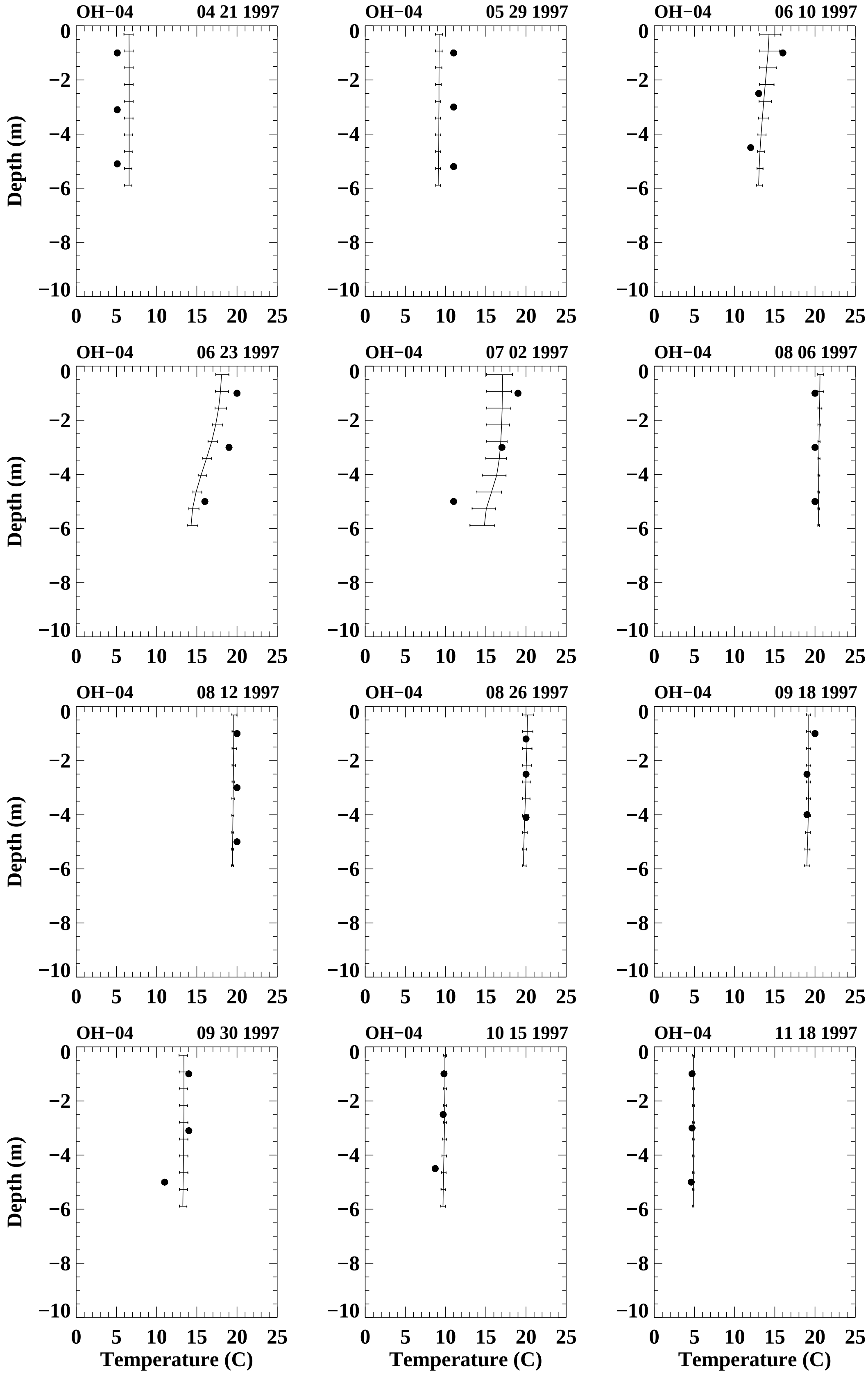


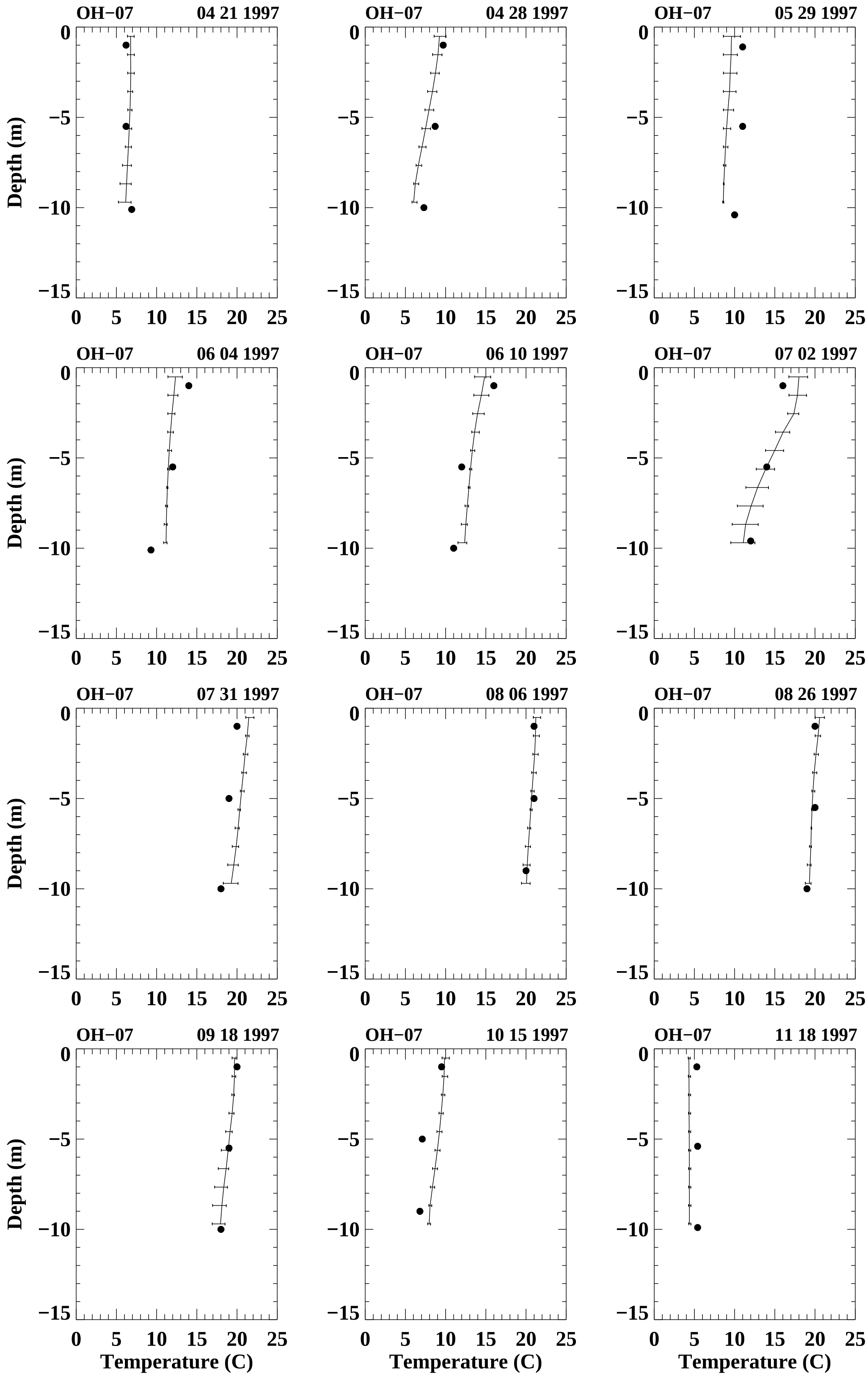
OH−11 04 24 1996
OH−11 05 30 1996
OH−11 06 13 1996
OH−11 07 09 1996
OH−11 07 22 1996
OH−11 08 06 1996
OH−11 08 13 1996
OH−11 08 28 1996
OH−11 08 29 1996
OH−11 09 09 1996
OH−11 10 02 1996
OH−11 11 07 1996
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25

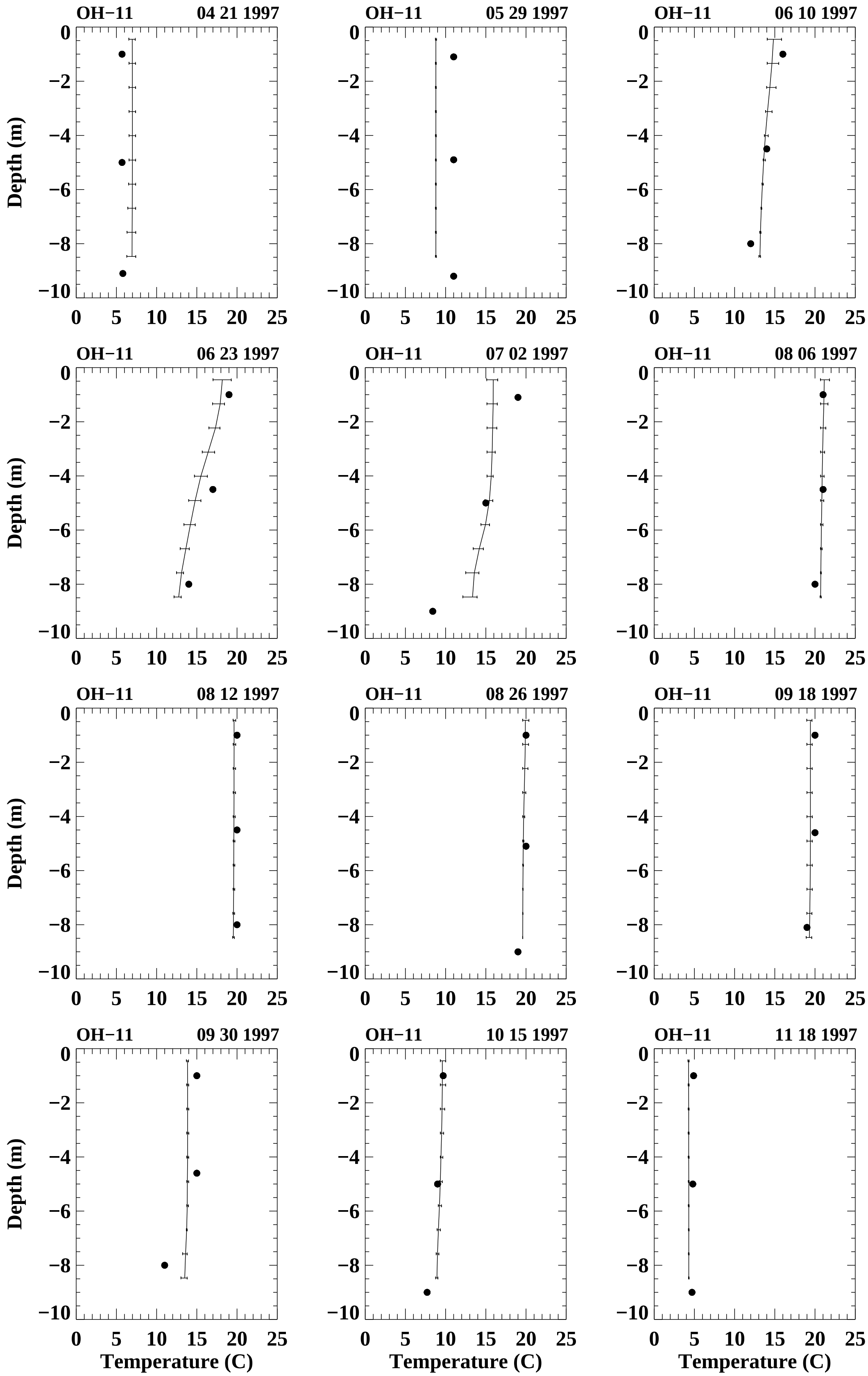

OH−01 04 21 1997
OH−01 04 28 1997
OH−01 05 29 1997
OH−01 06 04 1997
OH−01 06 10 1997
OH−01 07 02 1997
OH−01 07 31 1997
OH−01 08 06 1997
OH−01 08 26 1997
OH−01 09 18 1997
OH−01 10 15 1997
OH−01 11 18 1997
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25

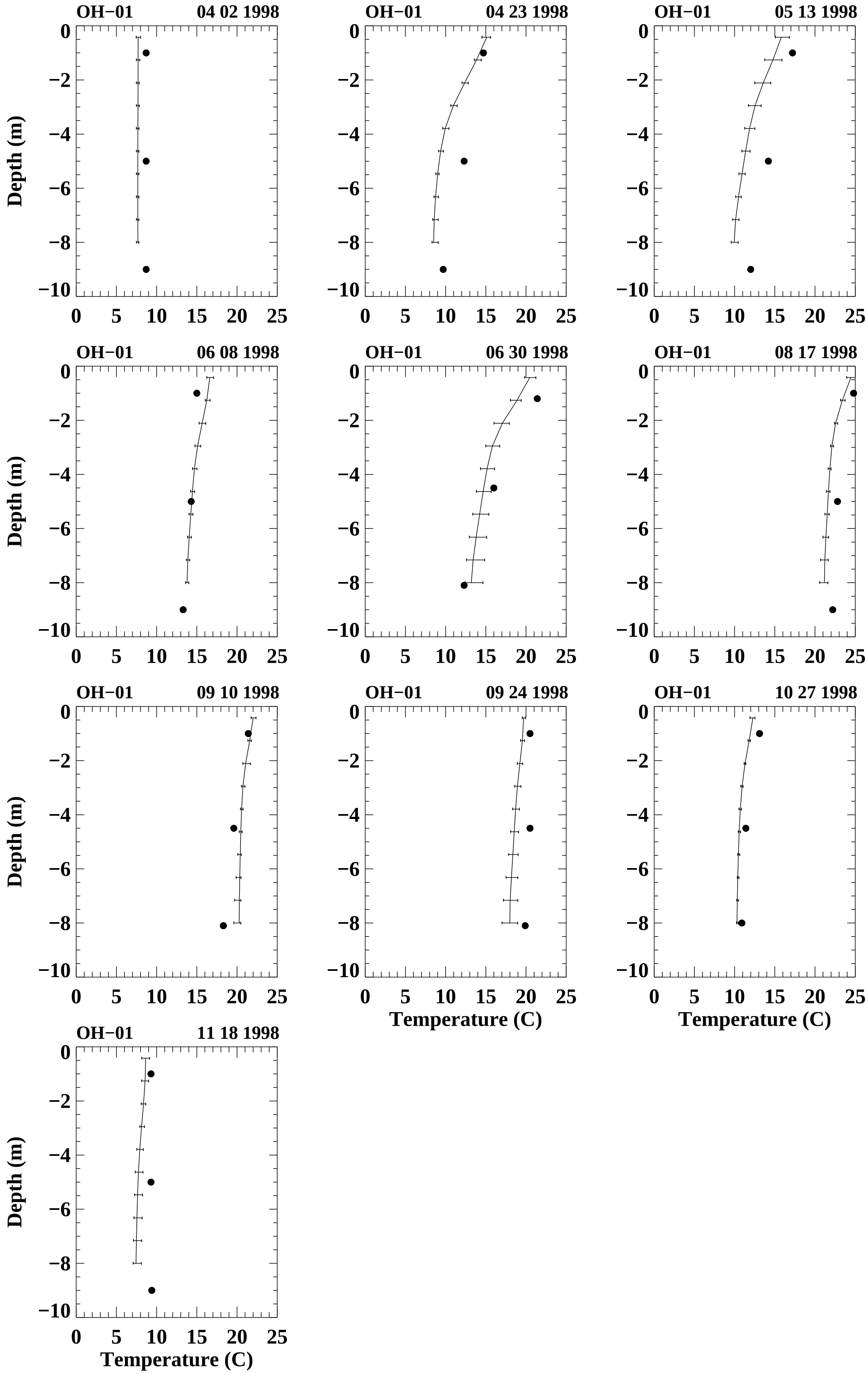


OH−03
04 21 1997
OH−03
04 28 1997
OH−03
05 29 1997
OH−03
06 04 1997
OH−03
06 10 1997
OH−03
07 02 1997
OH−03
07 31 1997
OH−03
08 06 1997
OH−03
08 26 1997
OH−03
09 18 1997
OH−03
10 15 1997
OH−03
11 18 1997
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)

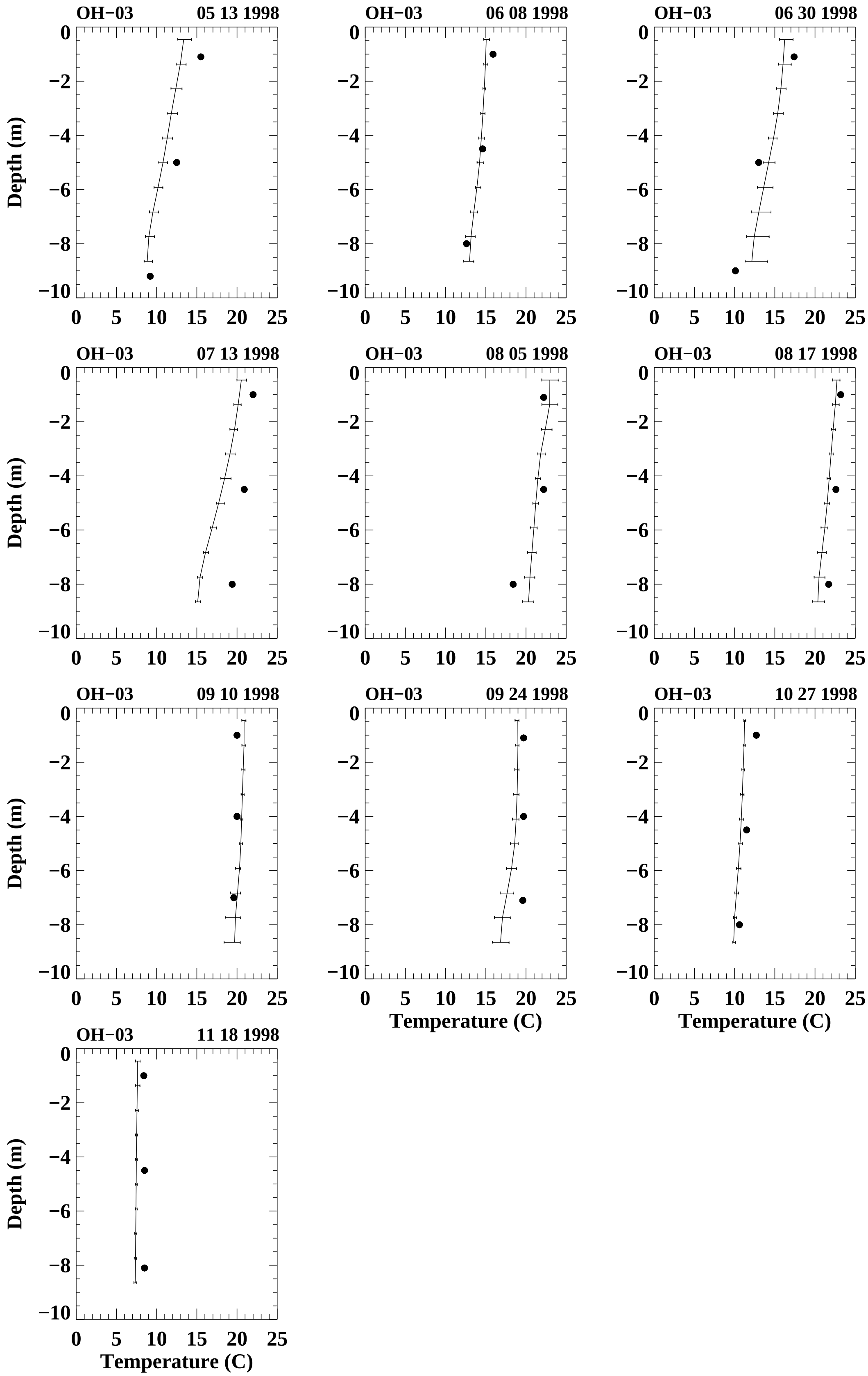

OH−04 04 21 1997
OH−04 05 29 1997
OH−04 06 10 1997
OH−04 06 23 1997
OH−04 07 02 1997
OH−04 08 06 1997
OH−04 08 12 1997
OH−04 08 26 1997
OH−04 09 18 1997
OH−04 09 30 1997
OH−04 10 15 1997
OH−04 11 18 1997
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)


OH−07
04 21 1997
OH−07
04 28 1997
OH−07
05 29 1997
OH−07
06 04 1997
OH−07
06 10 1997
OH−07
07 02 1997
OH−07
07 31 1997
OH−07
08 06 1997
OH−07
08 26 1997
OH−07
09 18 1997
OH−07
10 15 1997
OH−07
11 18 1997
Depth (m)
Temperature (C)
0
−5
−10
−15
0
5
10
15
20
25

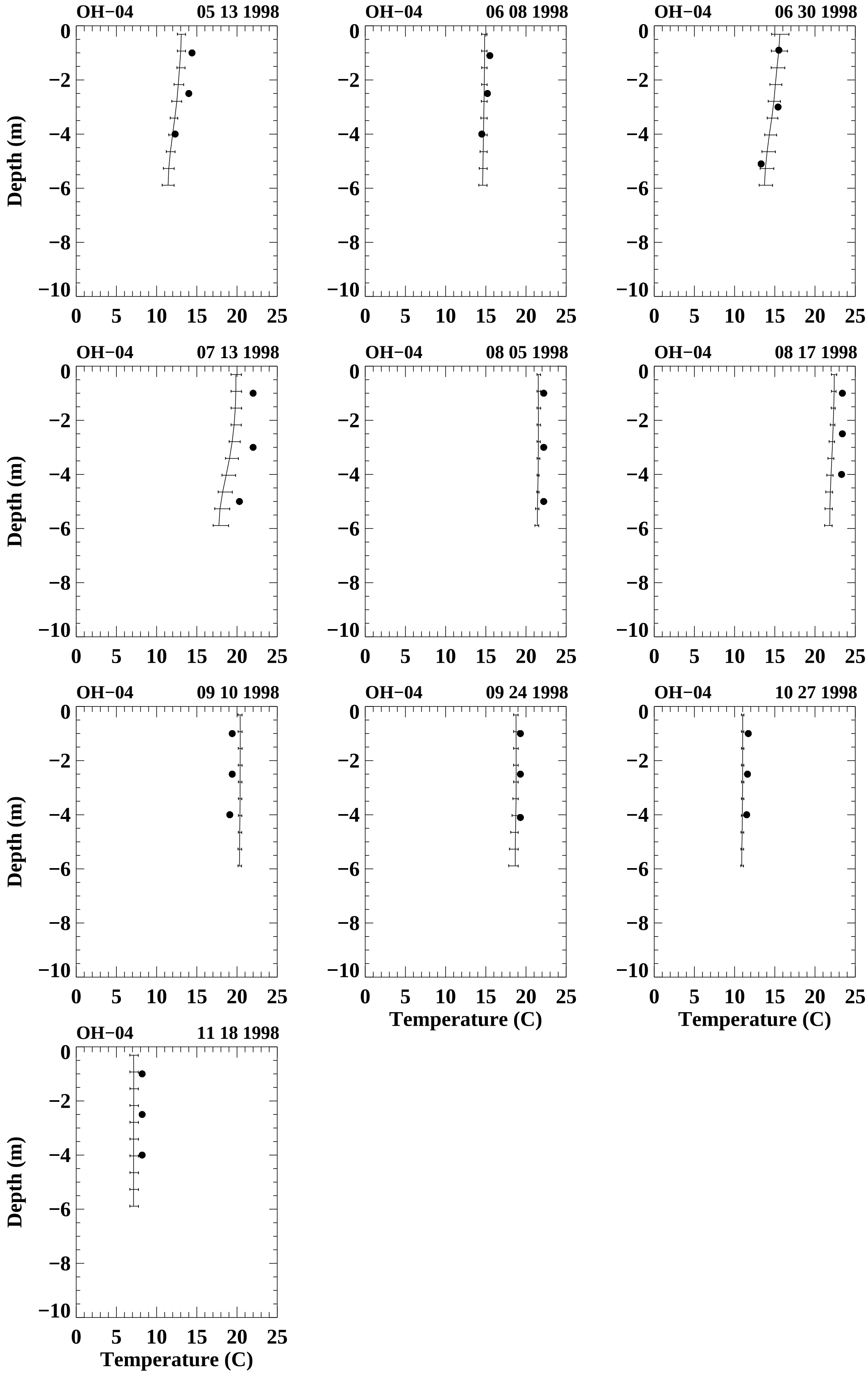

OH−11 04 21 1997
OH−11 05 29 1997
OH−11 06 10 1997
OH−11 06 23 1997
OH−11 07 02 1997
OH−11 08 06 1997
OH−11 08 12 1997
OH−11 08 26 1997
OH−11 09 18 1997
OH−11 09 30 1997
OH−11 10 15 1997
OH−11 11 18 1997
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)

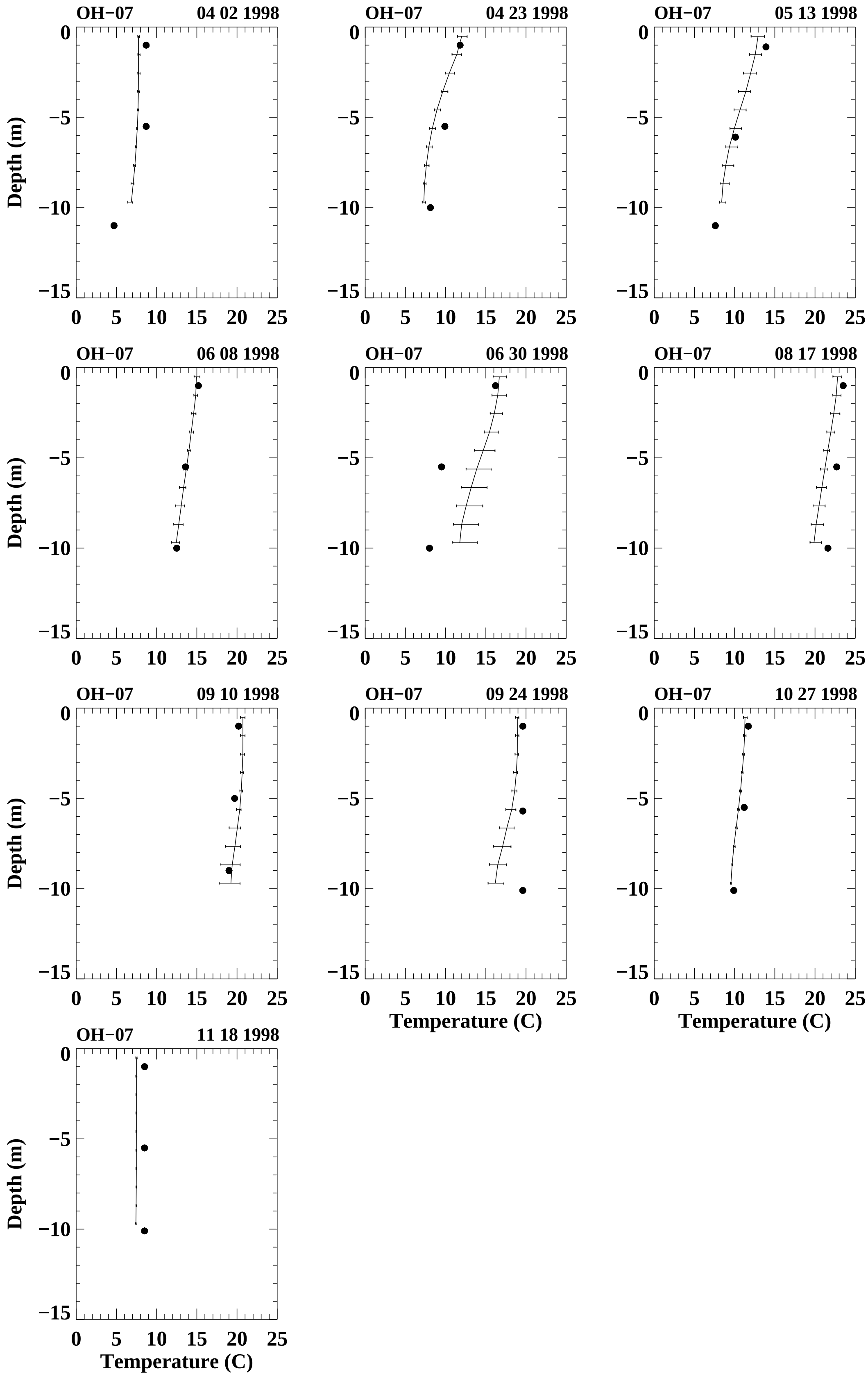


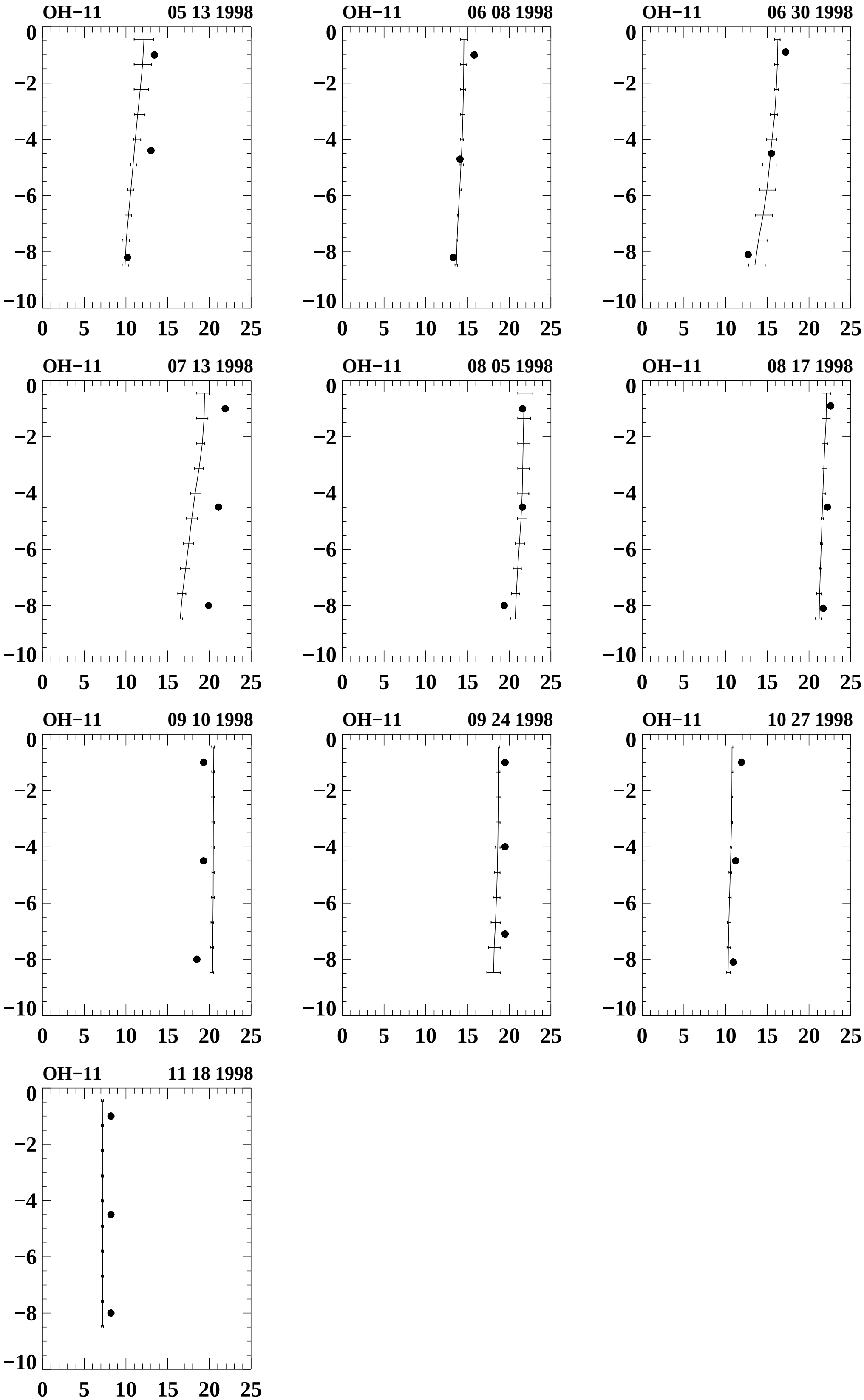
OH−01 04 02 1998
OH−01 04 23 1998
OH−01 05 13 1998
OH−01 06 08 1998
OH−01 06 30 1998
OH−01 08 17 1998
OH−01 09 10 1998
OH−01 09 24 1998
OH−01 10 27 1998
OH−01 11 18 1998
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25

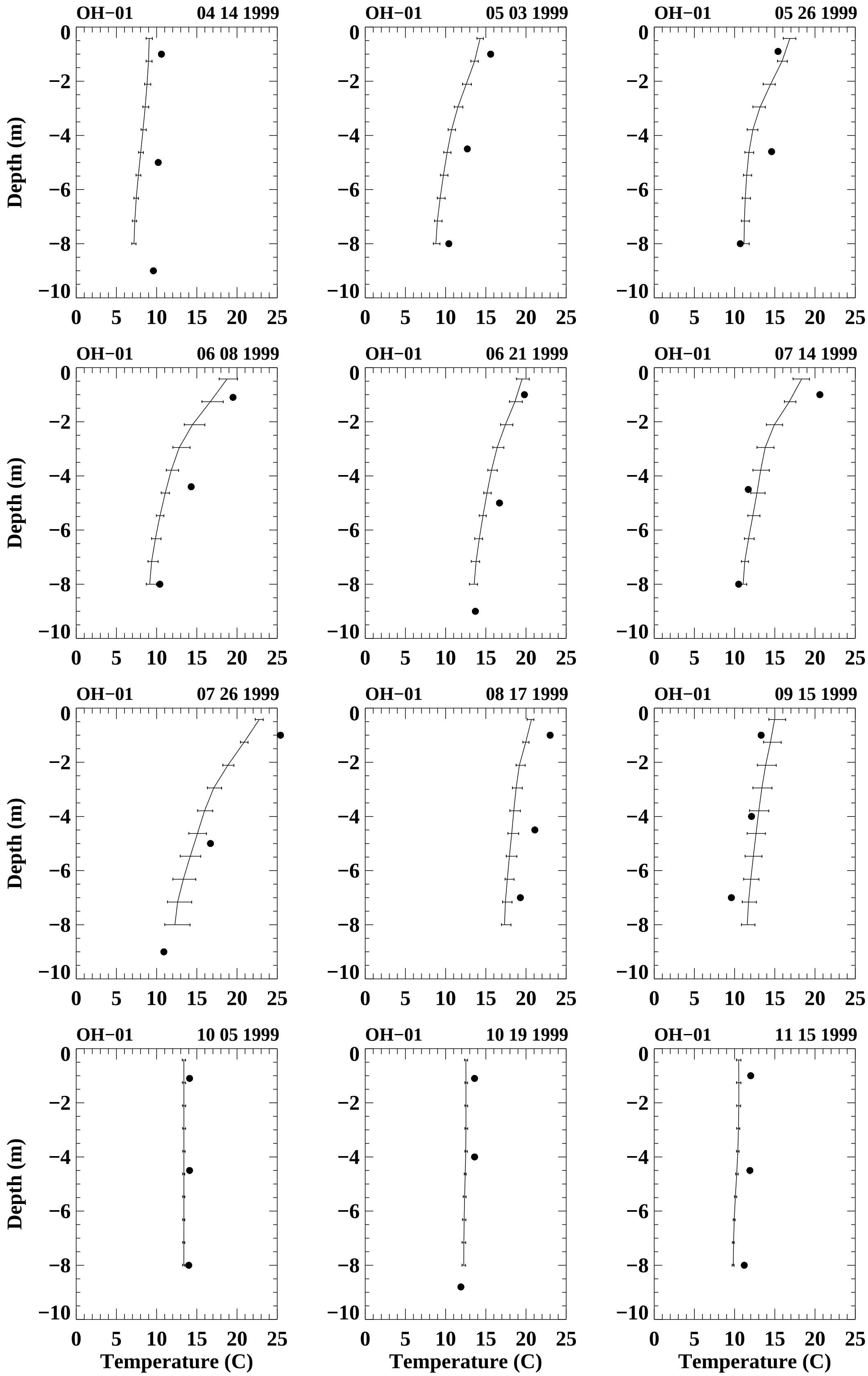


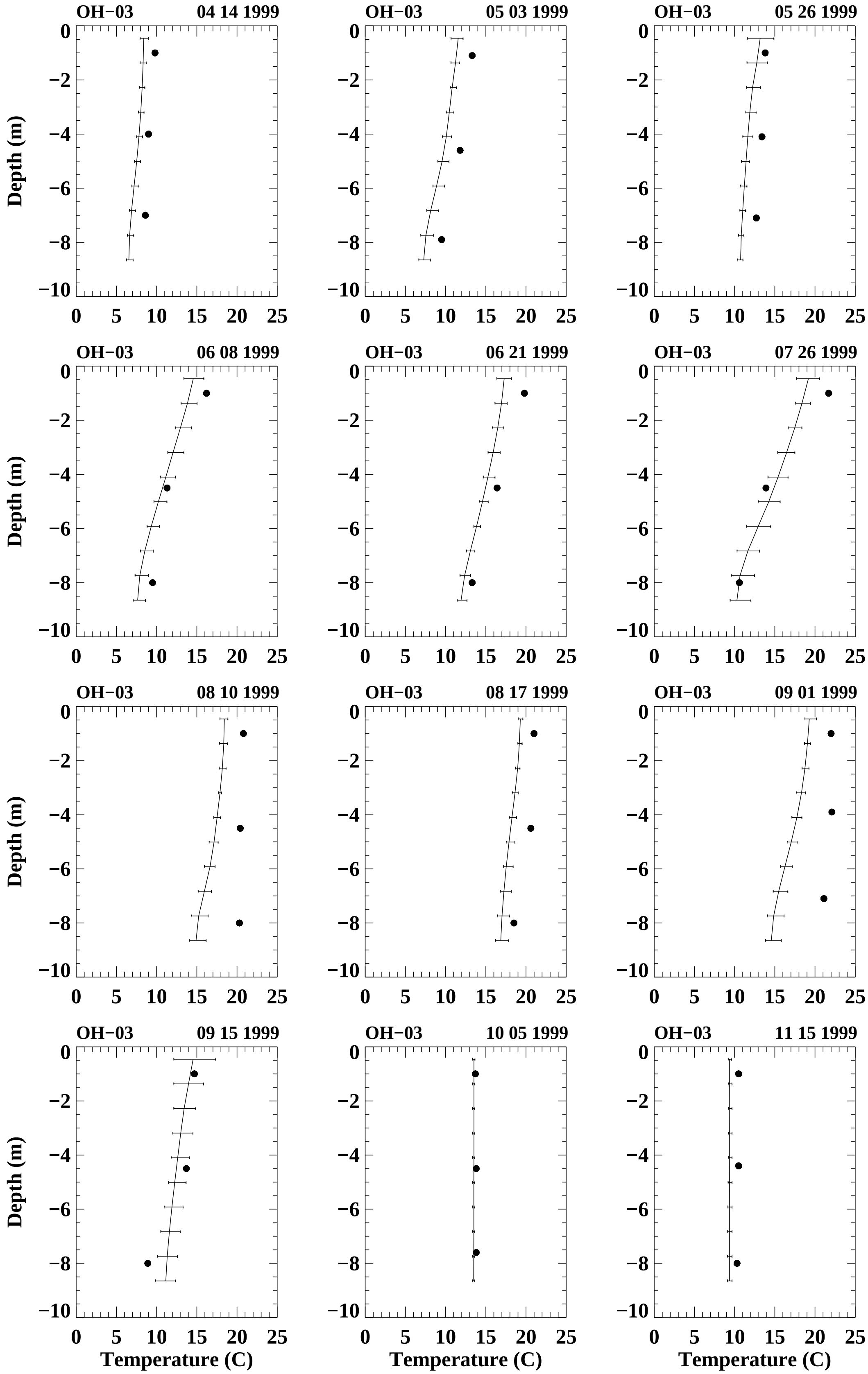
OH−03 05 13 1998
OH−03 06 08 1998
OH−03 06 30 1998
OH−03 07 13 1998
OH−03 08 05 1998
OH−03 08 17 1998
OH−03 09 10 1998
OH−03 09 24 1998
OH−03 10 27 1998
OH−03 11 18 1998
Depth (m)
Temperature (C)

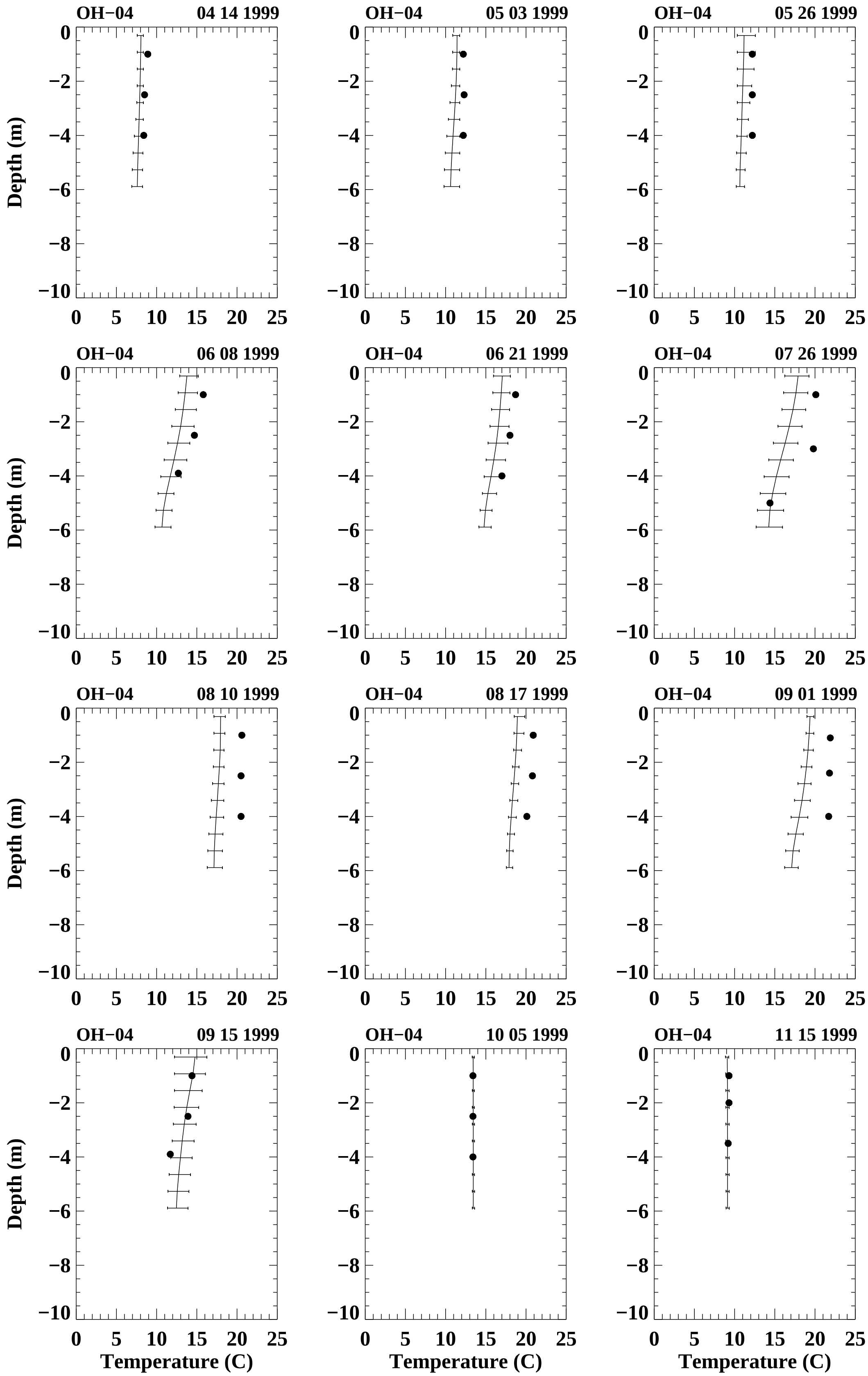

OH−04 05 13 1998
OH−04 06 08 1998
OH−04 06 30 1998
OH−04 07 13 1998
OH−04 08 05 1998
OH−04 08 17 1998
OH−04 09 10 1998
OH−04 09 24 1998
OH−04 10 27 1998
OH−04 11 18 1998
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)


OH−07 04 02 1998
OH−07 04 23 1998
OH−07 05 13 1998
OH−07 06 08 1998
OH−07 06 30 1998
OH−07 08 17 1998
OH−07 09 10 1998
OH−07 09 24 1998
OH−07 10 27 1998
OH−07 11 18 1998
Depth (m)
0
−5
−10
−15
0 5 10 15 20 25
Temperature (C)

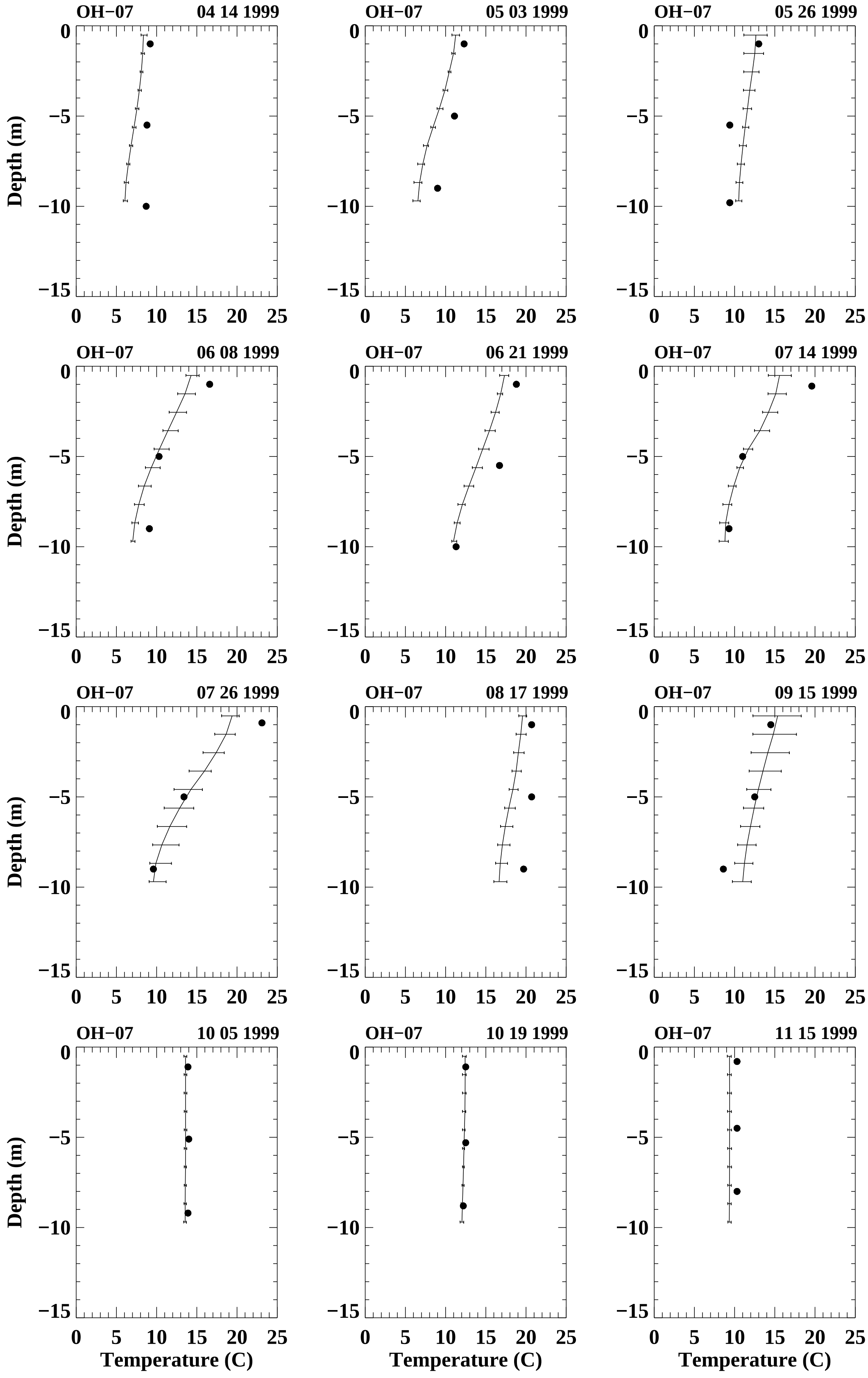

OH−11 05 13 1998
OH−11 06 08 1998
OH−11 06 30 1998
OH−11 07 13 1998
OH−11 08 05 1998
OH−11 08 17 1998
OH−11 09 10 1998
OH−11 09 24 1998
OH−11 10 27 1998
OH−11 11 18 1998
0 −2 −4 −6 −8 −10
0 5 10 15 20 25


OH−01 04 14 1999
OH−01 05 03 1999
OH−01 05 26 1999
OH−01 06 08 1999
OH−01 06 21 1999
OH−01 07 14 1999
OH−01 07 26 1999
OH−01 08 17 1999
OH−01 09 15 1999
OH−01 10 05 1999
OH−01 10 19 1999
OH−01 11 15 1999
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)

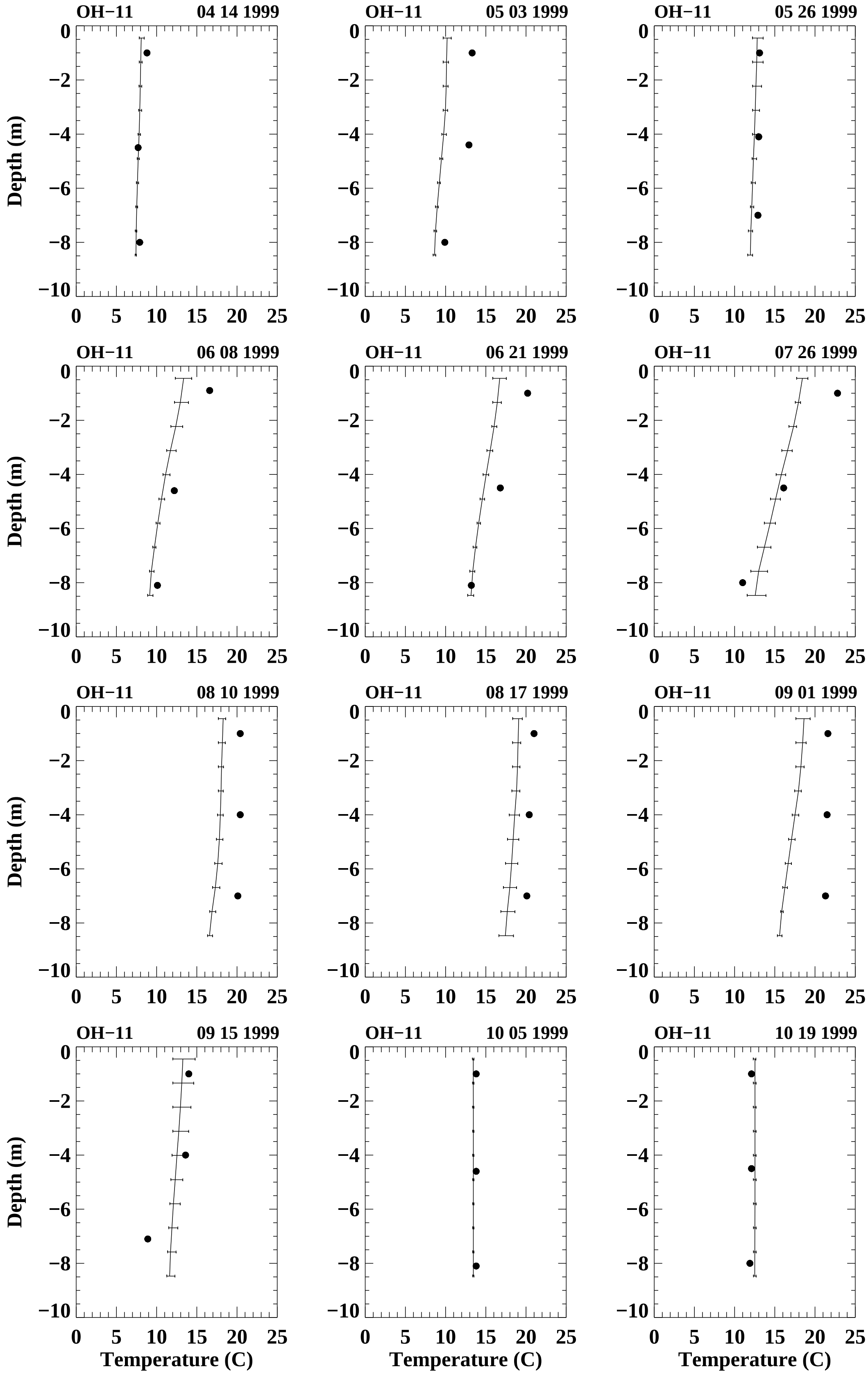

OH−03 04 14 1999
OH−03 05 03 1999
OH−03 05 26 1999
OH−03 06 08 1999
OH−03 06 21 1999
OH−03 07 26 1999
OH−03 08 10 1999
OH−03 08 17 1999
OH−03 09 01 1999
OH−03 09 15 1999
OH−03 10 05 1999
OH−03 11 15 1999
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)



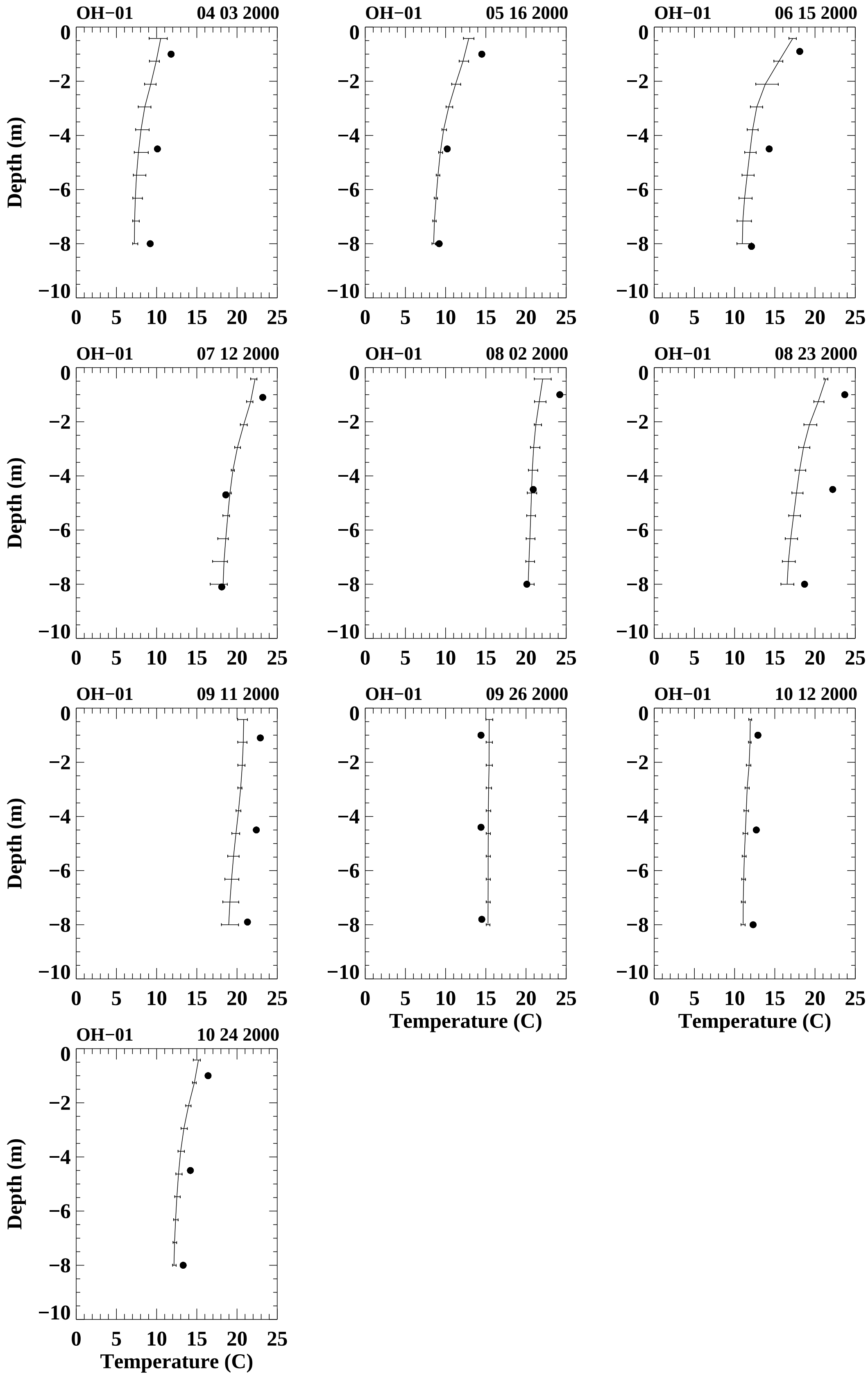
OH−04 04 14 1999
OH−04 05 03 1999
OH−04 05 26 1999
OH−04 06 08 1999
OH−04 06 21 1999
OH−04 07 26 1999
OH−04 08 10 1999
OH−04 08 17 1999
OH−04 09 01 1999
OH−04 09 15 1999
OH−04 10 05 1999
OH−04 11 15 1999
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)

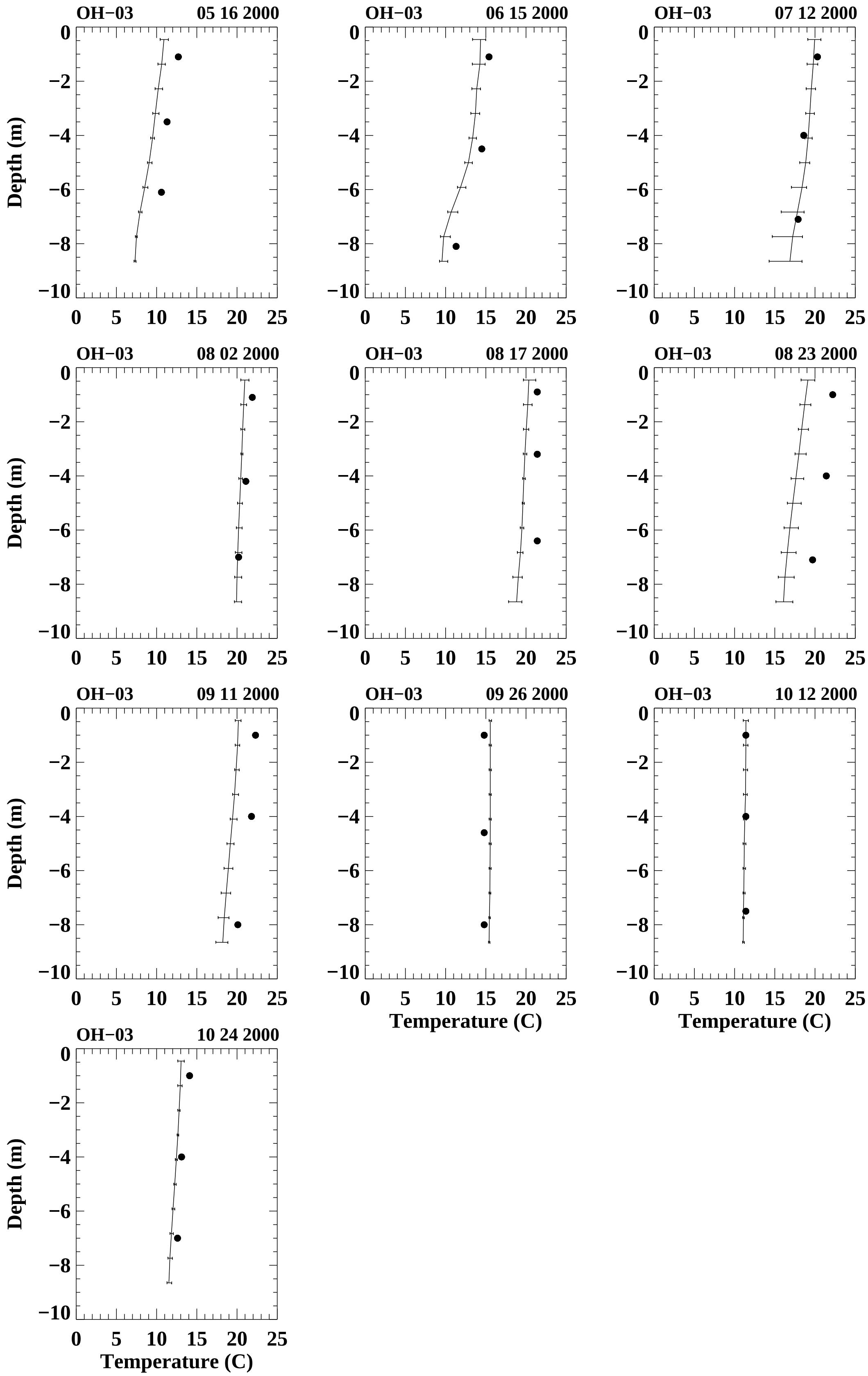


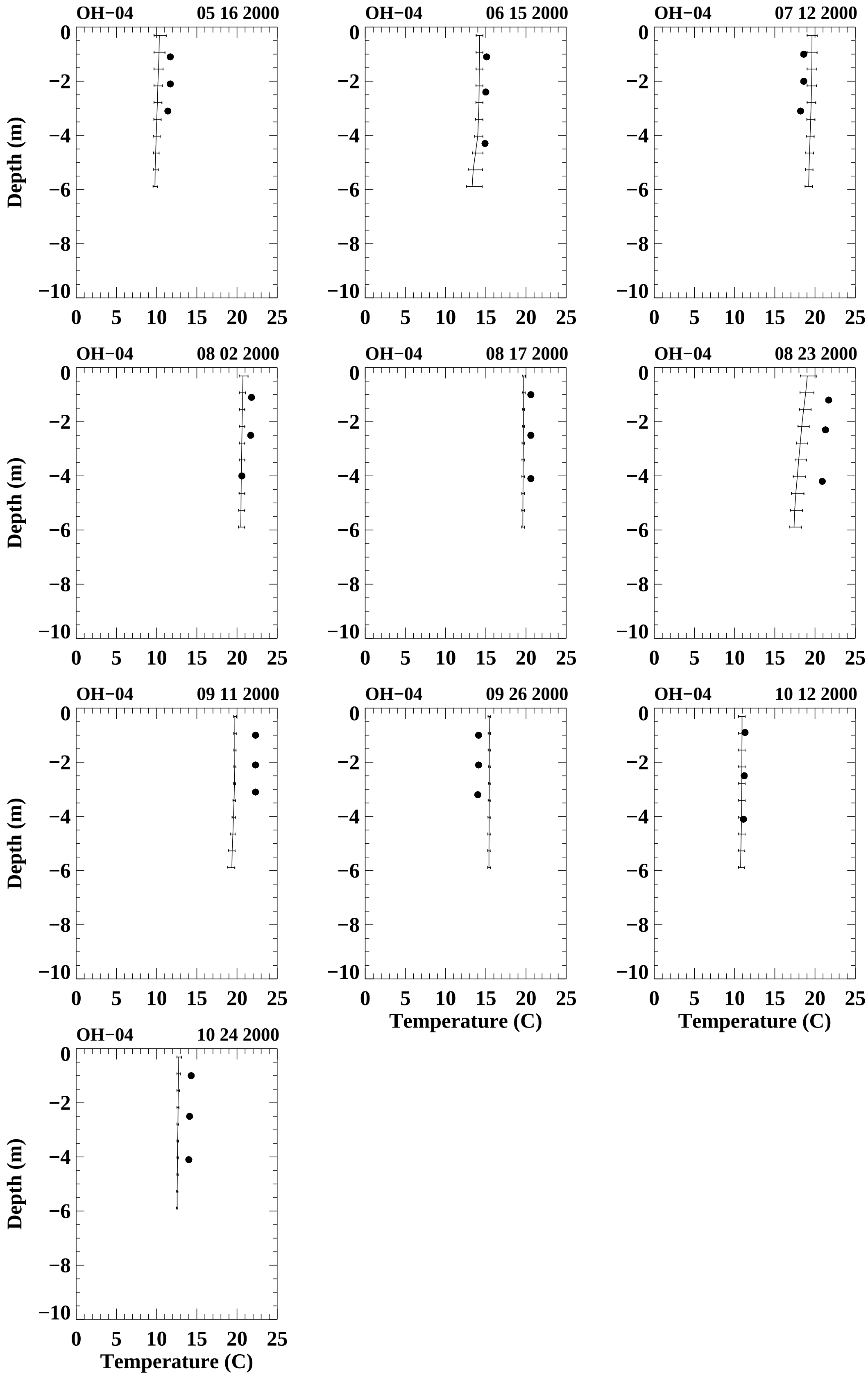
OH−07
04 14 1999
OH−07
05 03 1999
OH−07
05 26 1999
OH−07
06 08 1999
OH−07
06 21 1999
OH−07
07 14 1999
OH−07
07 26 1999
OH−07
08 17 1999
OH−07
09 15 1999
OH−07
10 05 1999
OH−07
10 19 1999
OH−07
11 15 1999
Depth (m)
0
−5
−10
−15
0
5
10
15
20
25
Temperature (C)

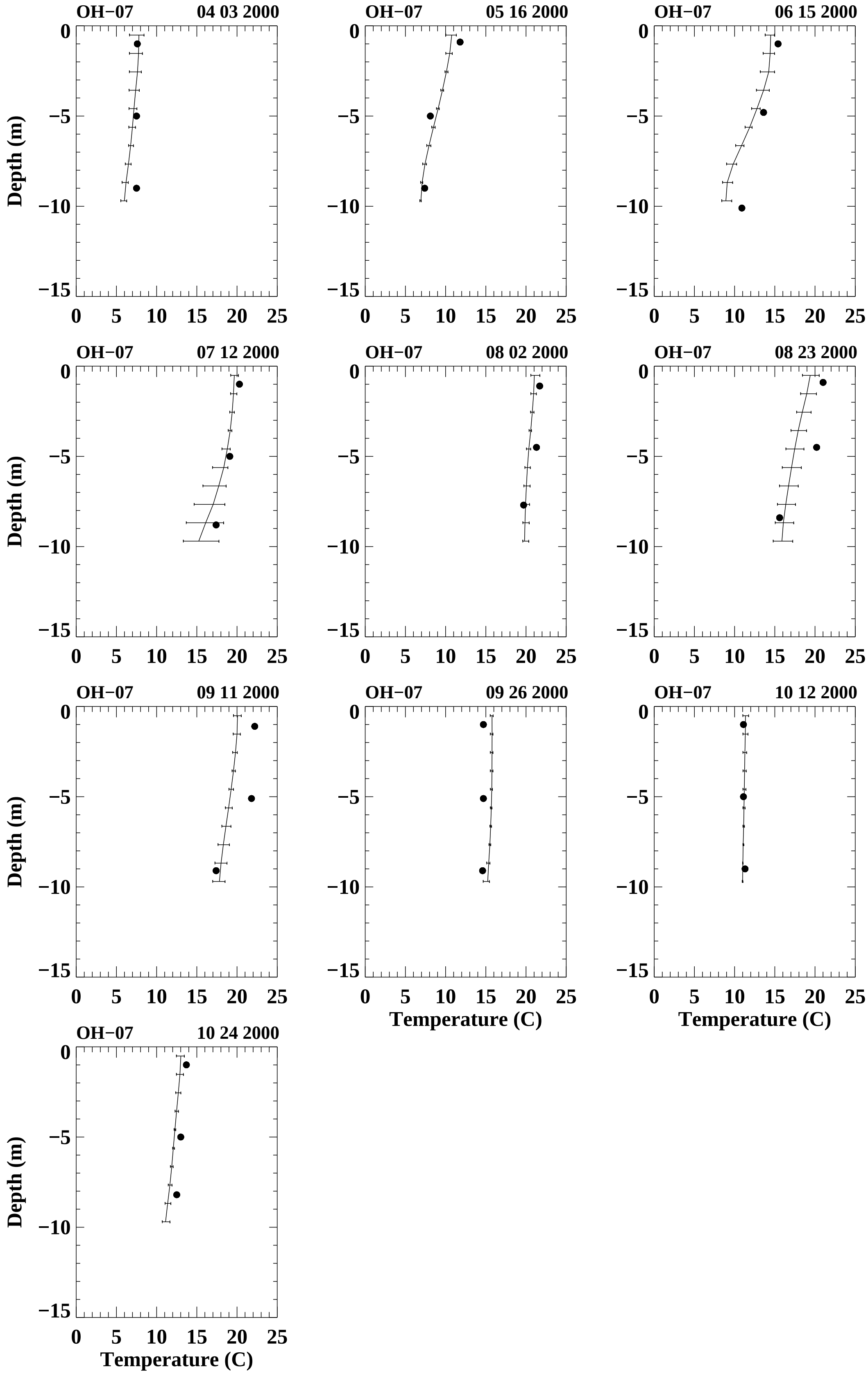


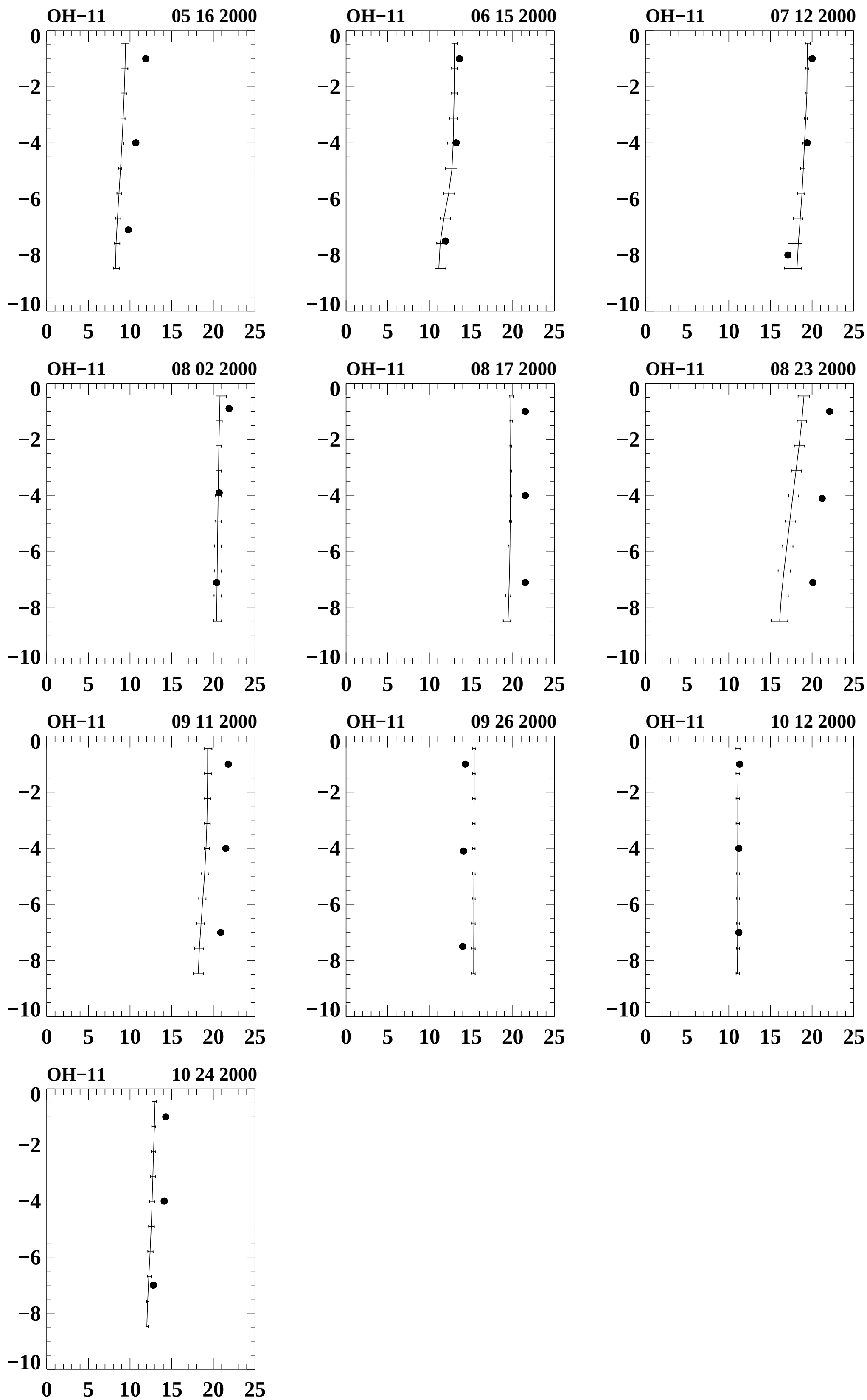
OH−11 04 14 1999
OH−11 05 03 1999
OH−11 05 26 1999
OH−11 06 08 1999
OH−11 06 21 1999
OH−11 07 26 1999
OH−11 08 10 1999
OH−11 08 17 1999
OH−11 09 01 1999
OH−11 09 15 1999
OH−11 10 05 1999
OH−11 10 19 1999
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25

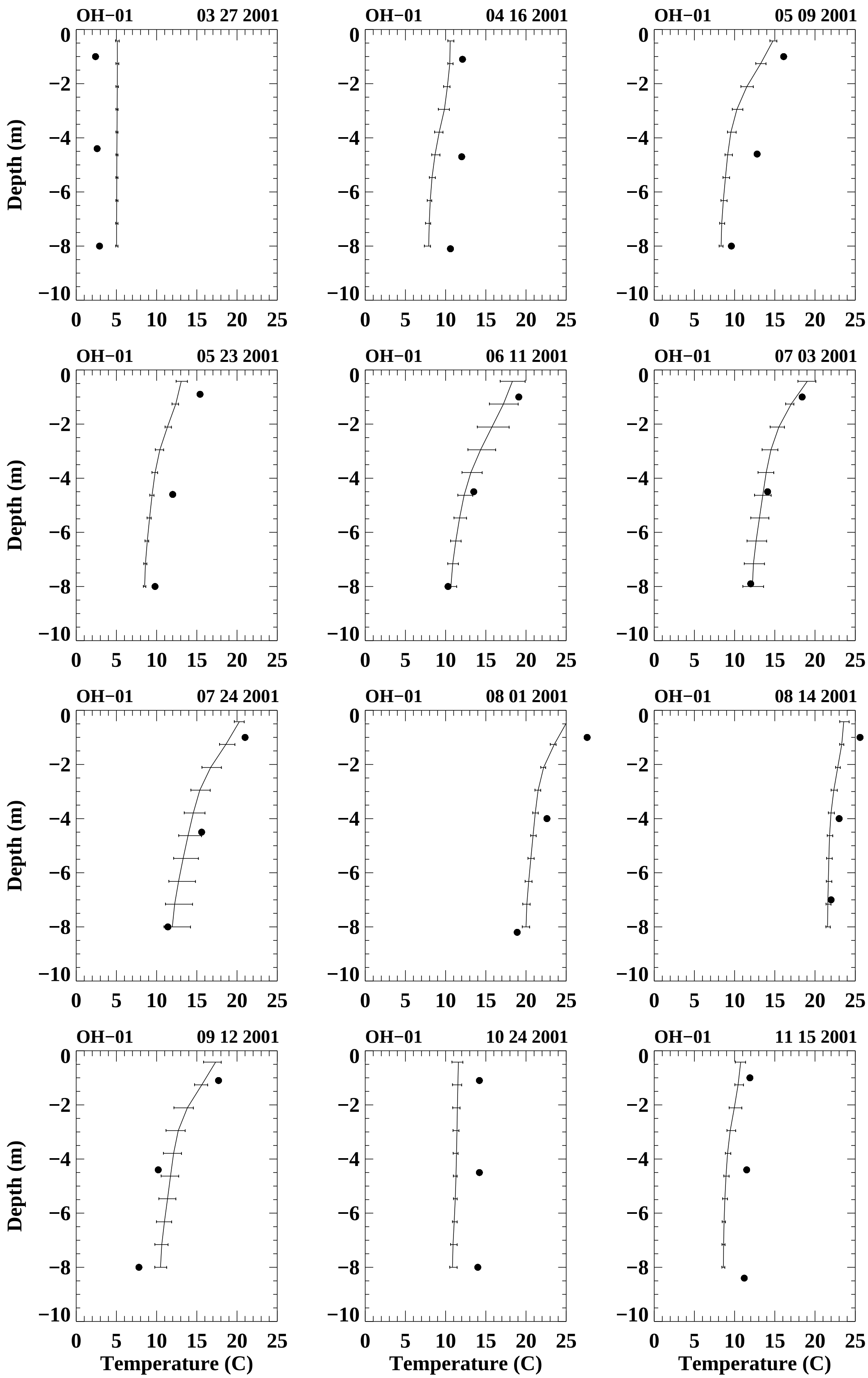

OH−01 04 03 2000
OH−01 05 16 2000
OH−01 06 15 2000
OH−01 07 12 2000
OH−01 08 02 2000
OH−01 08 23 2000
OH−01 09 11 2000
OH−01 09 26 2000
OH−01 10 12 2000
OH−01 10 24 2000
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)

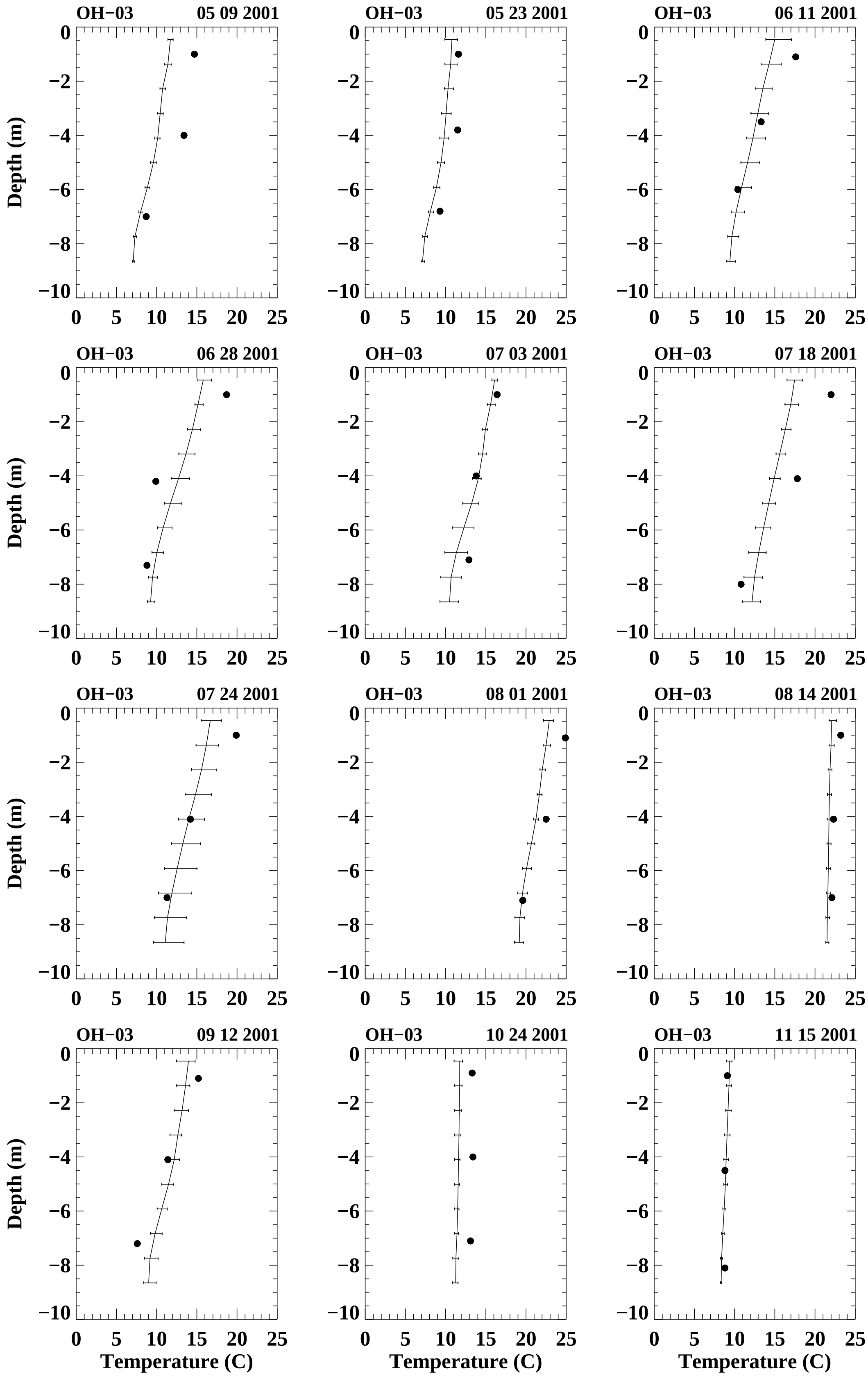

OH−03 05 16 2000
OH−03 06 15 2000
OH−03 07 12 2000
OH−03 08 02 2000
OH−03 08 17 2000
OH−03 08 23 2000
OH−03 09 11 2000
OH−03 09 26 2000
OH−03 10 12 2000
OH−03 10 24 2000
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)

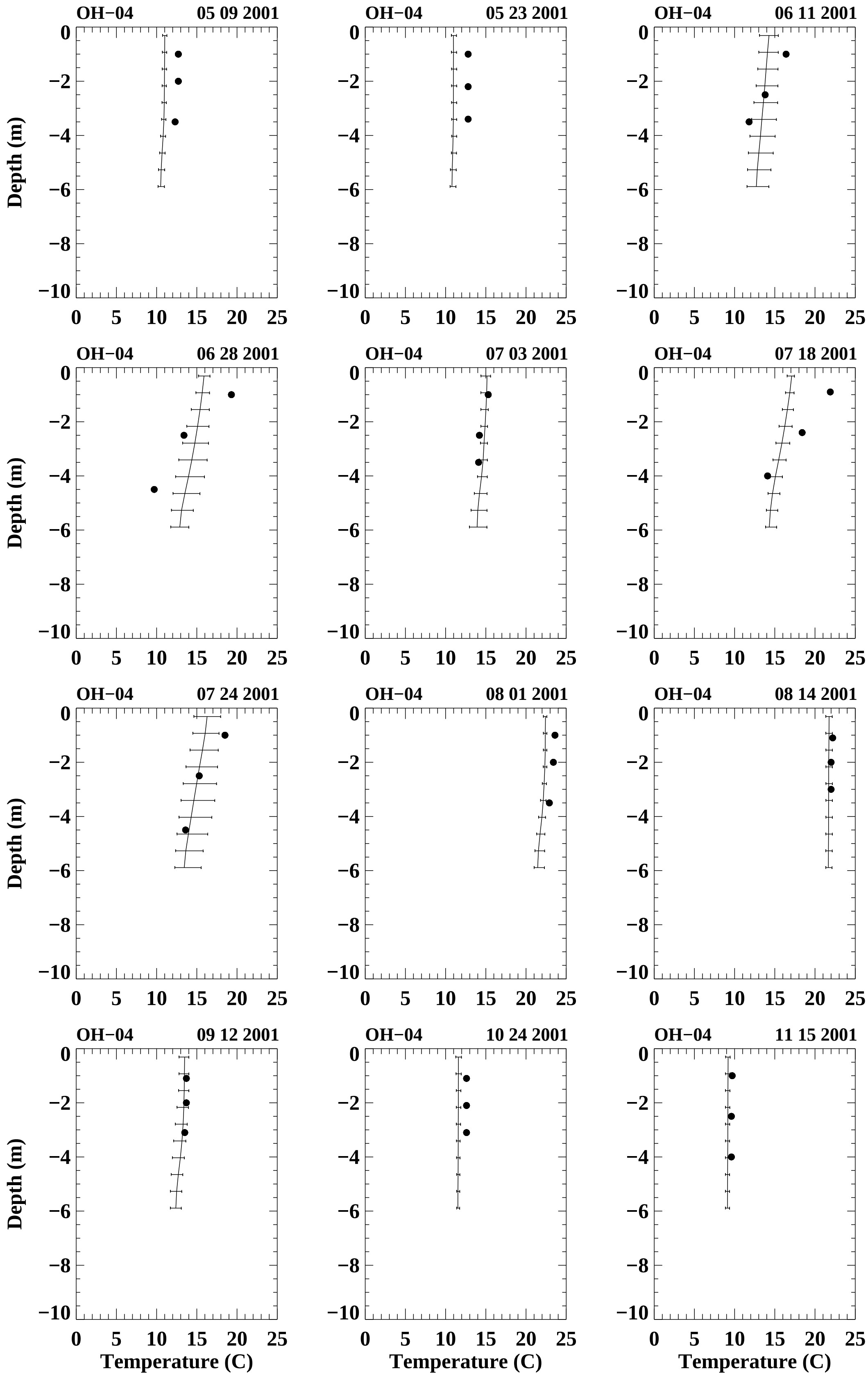

OH−04
05 16 2000
06 15 2000
07 12 2000
08 02 2000
08 17 2000
08 23 2000
09 11 2000
09 26 2000
10 12 2000
10 24 2000
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
0
5
10
15
20
25

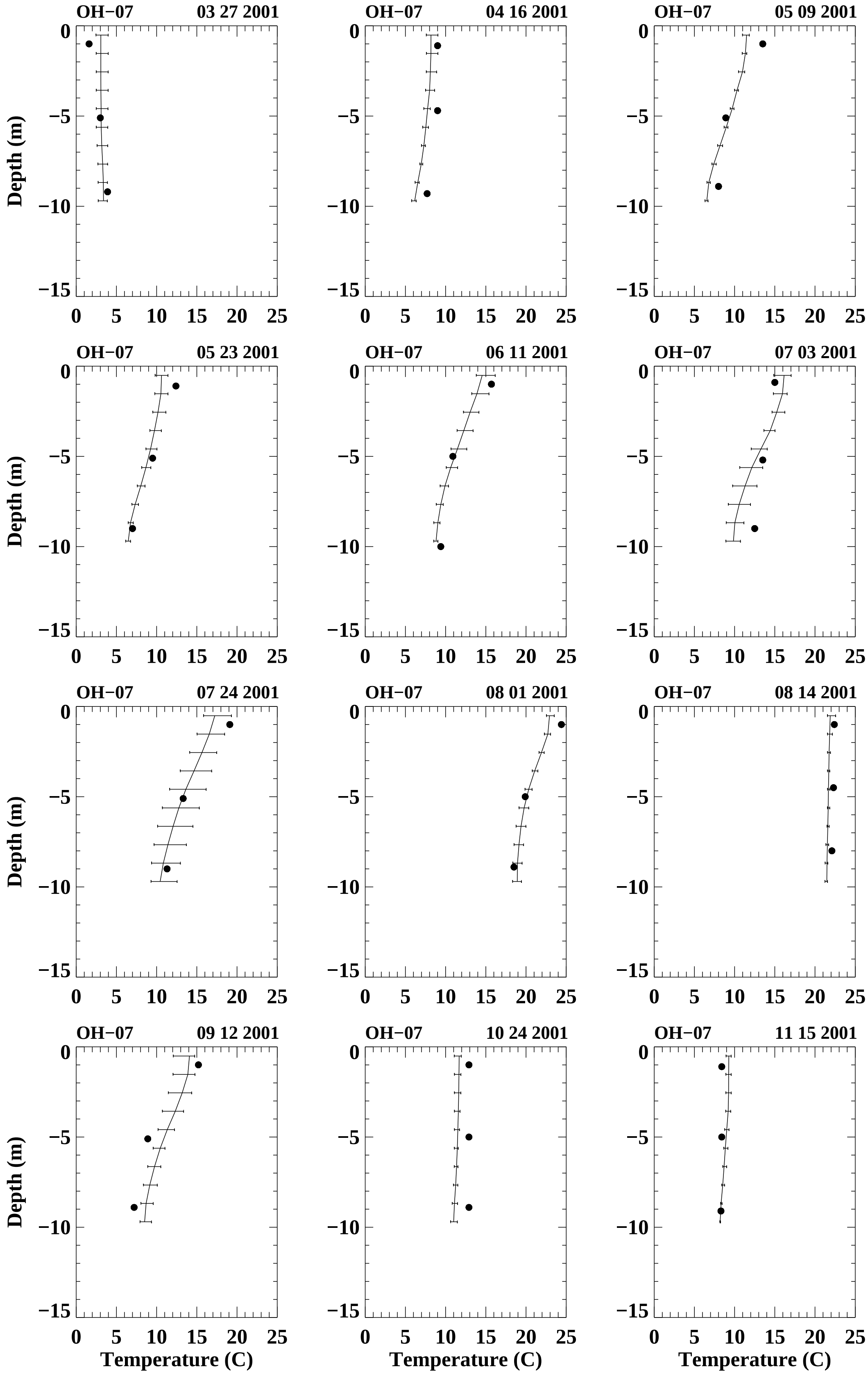

OH−07 04 03 2000
OH−07 05 16 2000
OH−07 06 15 2000
OH−07 07 12 2000
OH−07 08 02 2000
OH−07 08 23 2000
OH−07 09 11 2000
OH−07 09 26 2000
OH−07 10 12 2000
OH−07 10 24 2000
Depth (m)
0
−5
−10
−15
0 5 10 15 20 25
Temperature (C)


OH−11 05 16 2000
OH−11 06 15 2000
OH−11 07 12 2000
OH−11 08 02 2000
OH−11 08 17 2000
OH−11 08 23 2000
OH−11 09 11 2000
OH−11 09 26 2000
OH−11 10 12 2000
OH−11 10 24 2000
0 −2 −4 −6 −8 −10
0 5 10 15 20 25

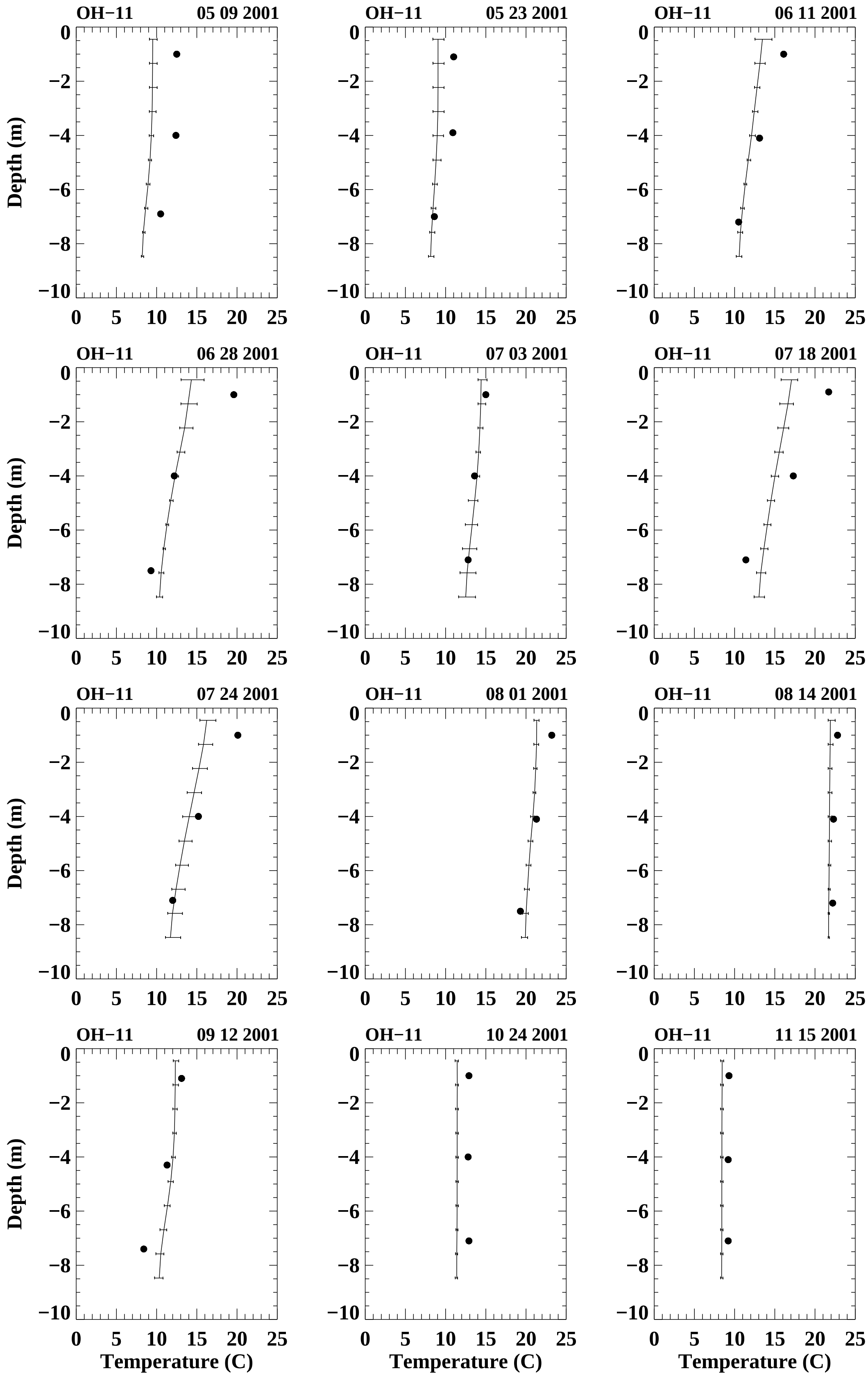

OH−01 03 27 2001
OH−01 04 16 2001
OH−01 05 09 2001
OH−01 05 23 2001
OH−01 06 11 2001
OH−01 07 03 2001
OH−01 07 24 2001
OH−01 08 01 2001
OH−01 08 14 2001
OH−01 09 12 2001
OH−01 10 24 2001
OH−01 11 15 2001
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)

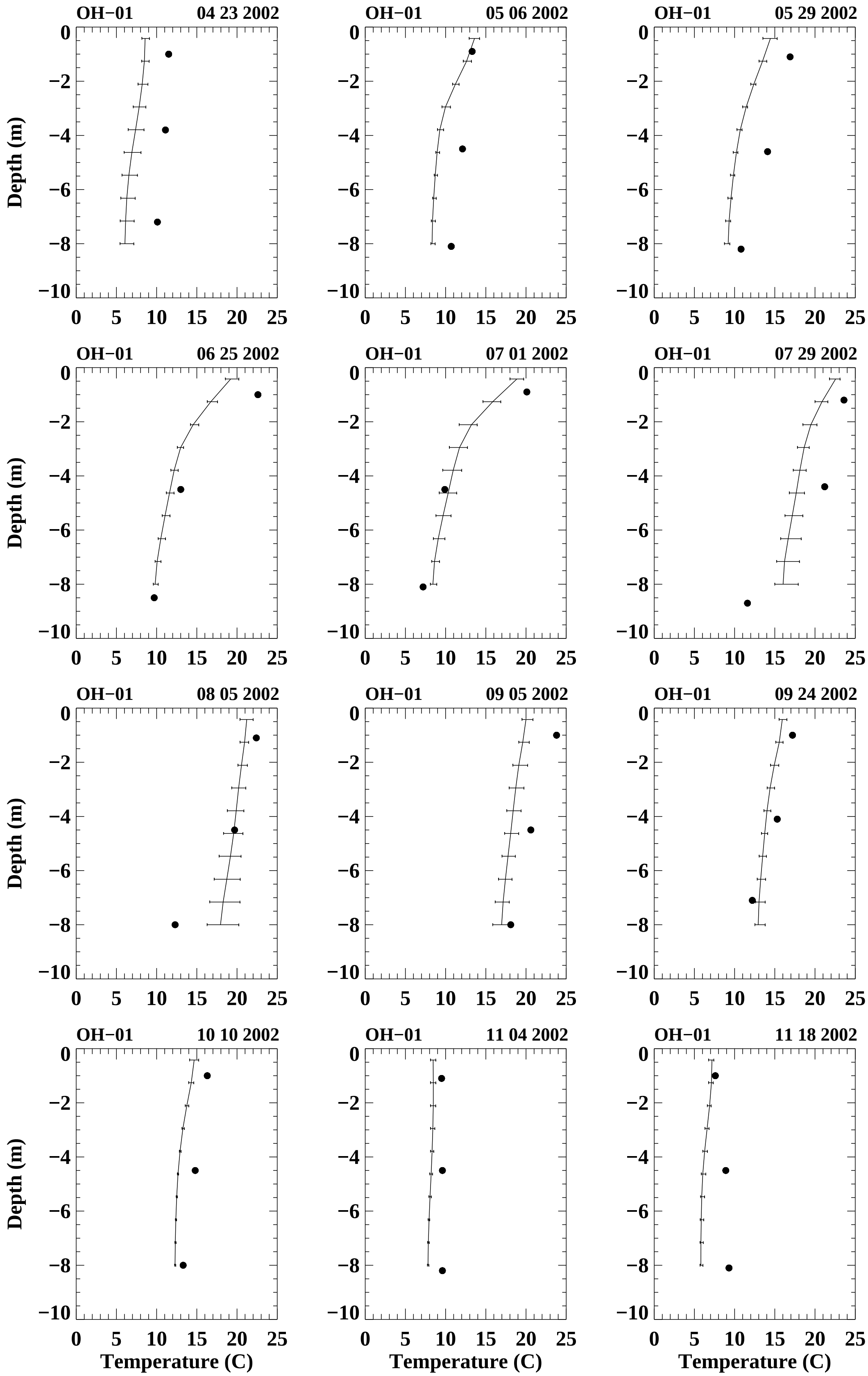

OH−03
05 09 2001
OH−03
05 23 2001
OH−03
06 11 2001
OH−03
06 28 2001
OH−03
07 03 2001
OH−03
07 18 2001
OH−03
07 24 2001
OH−03
08 01 2001
OH−03
08 14 2001
OH−03
09 12 2001
OH−03
10 24 2001
OH−03
11 15 2001
Depth (m)
0
−2
−4
−6
−8
−10
0
5
10
15
20
25
Temperature (C)

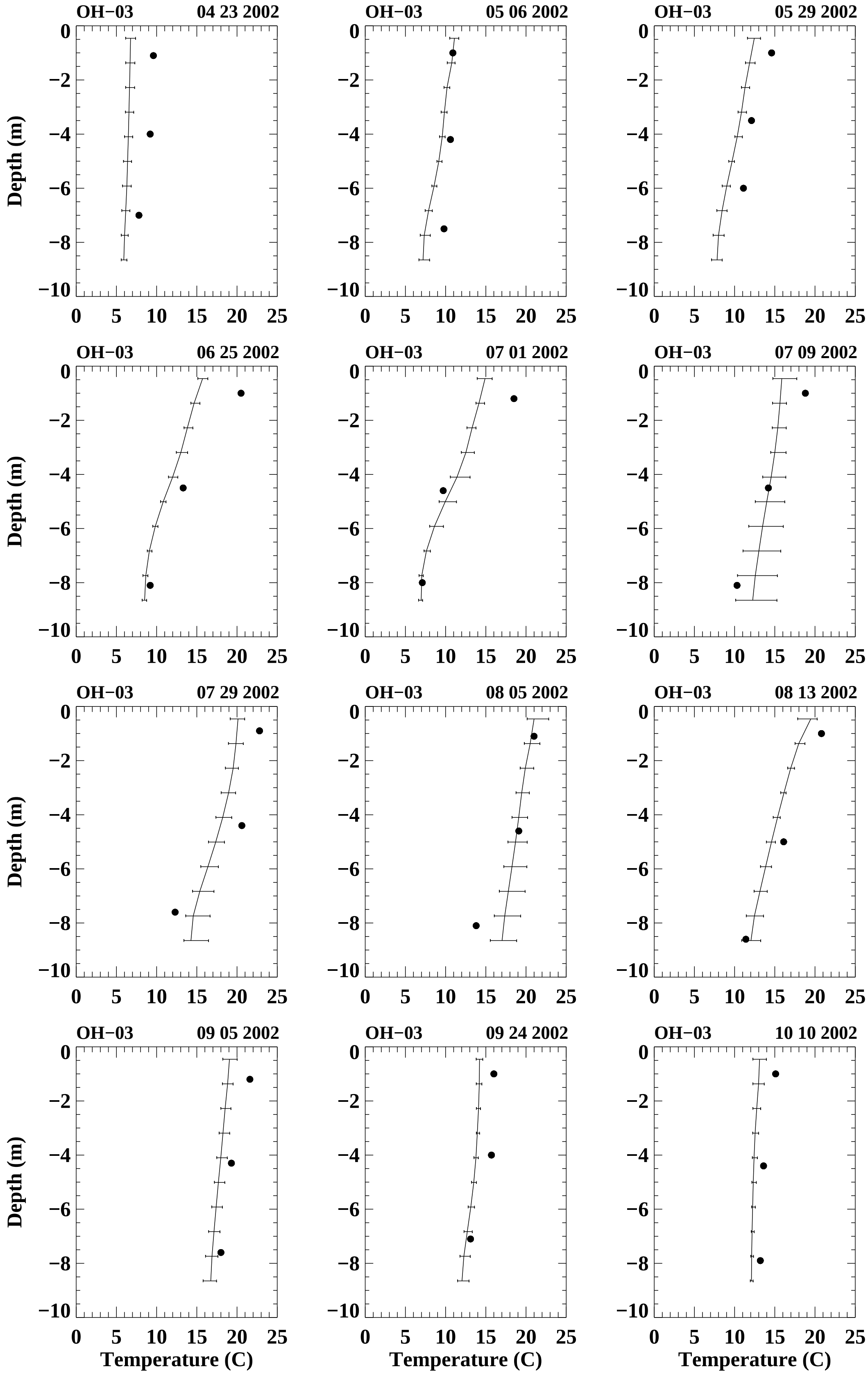

OH−04 05 09 2001
OH−04 05 23 2001
OH−04 06 11 2001
OH−04 06 28 2001
OH−04 07 03 2001
OH−04 07 18 2001
OH−04 07 24 2001
OH−04 08 01 2001
OH−04 08 14 2001
OH−04 09 12 2001
OH−04 10 24 2001
OH−04 11 15 2001
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)

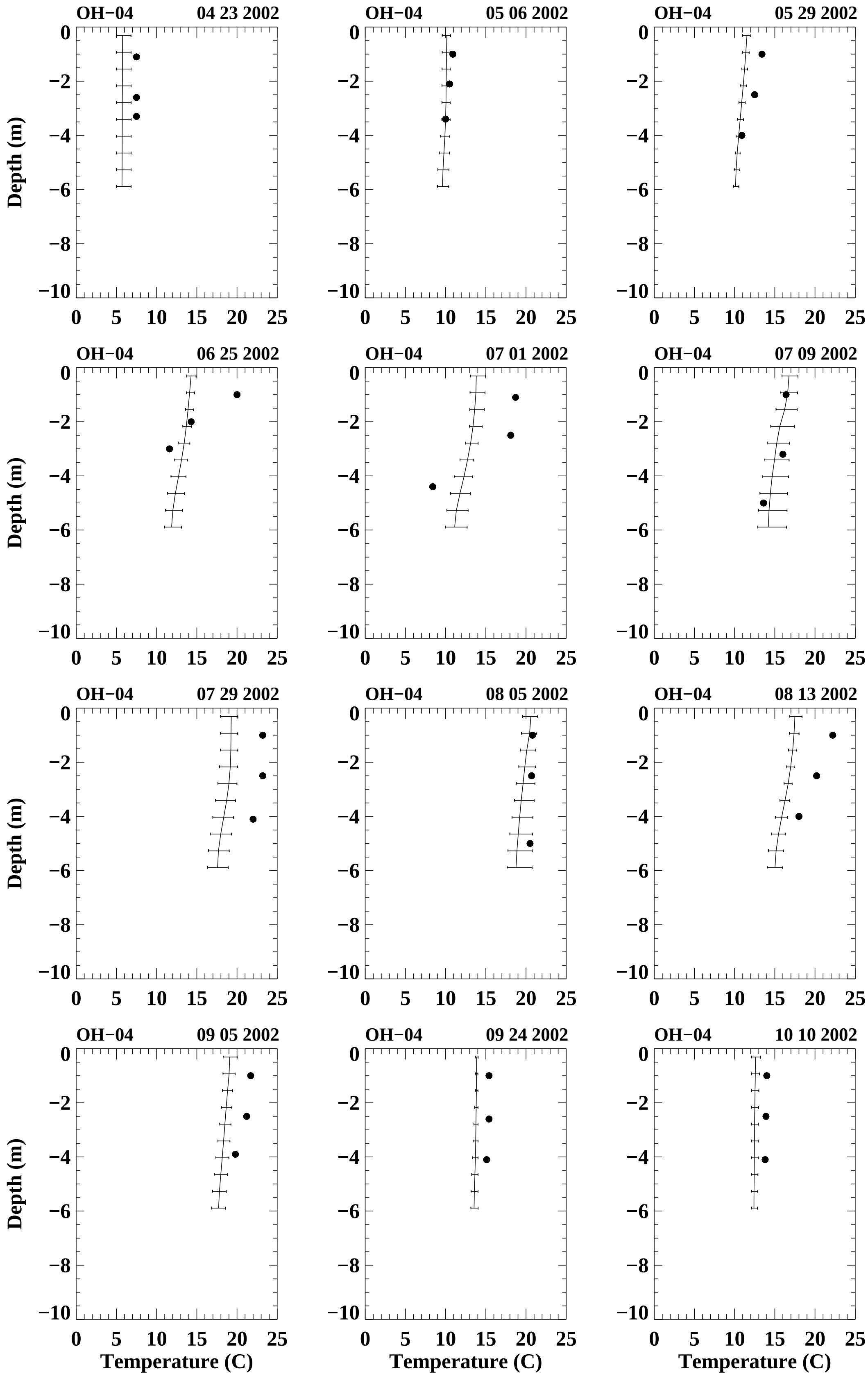


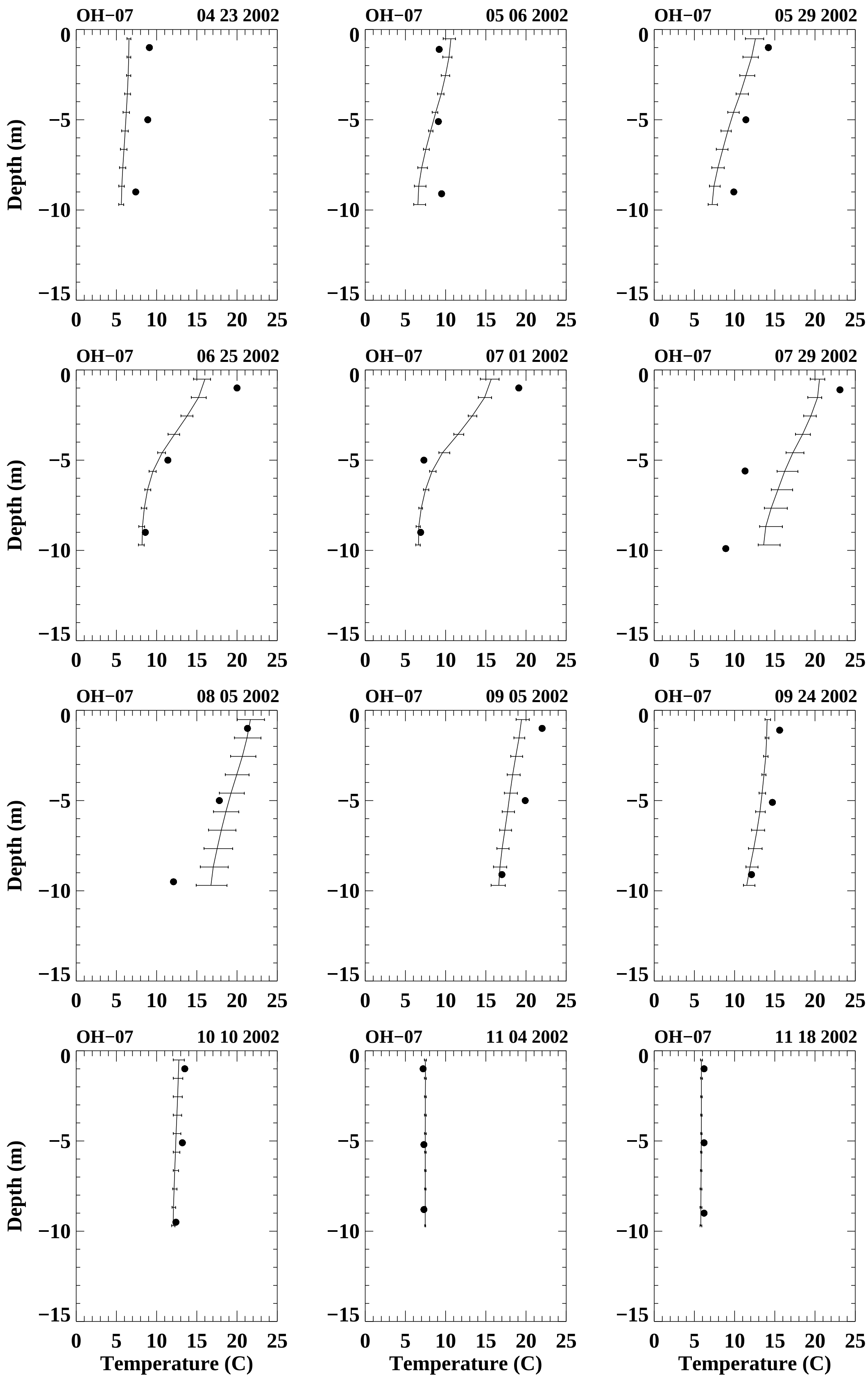
OH−07 03 27 2001
OH−07 04 16 2001
OH−07 05 09 2001
OH−07 05 23 2001
OH−07 06 11 2001
OH−07 07 03 2001
OH−07 07 24 2001
OH−07 08 01 2001
OH−07 08 14 2001
OH−07 09 12 2001
OH−07 10 24 2001
OH−07 11 15 2001
Depth (m)
Temperature (C)
0
−5
−10
−15
0 5 10 15 20 25

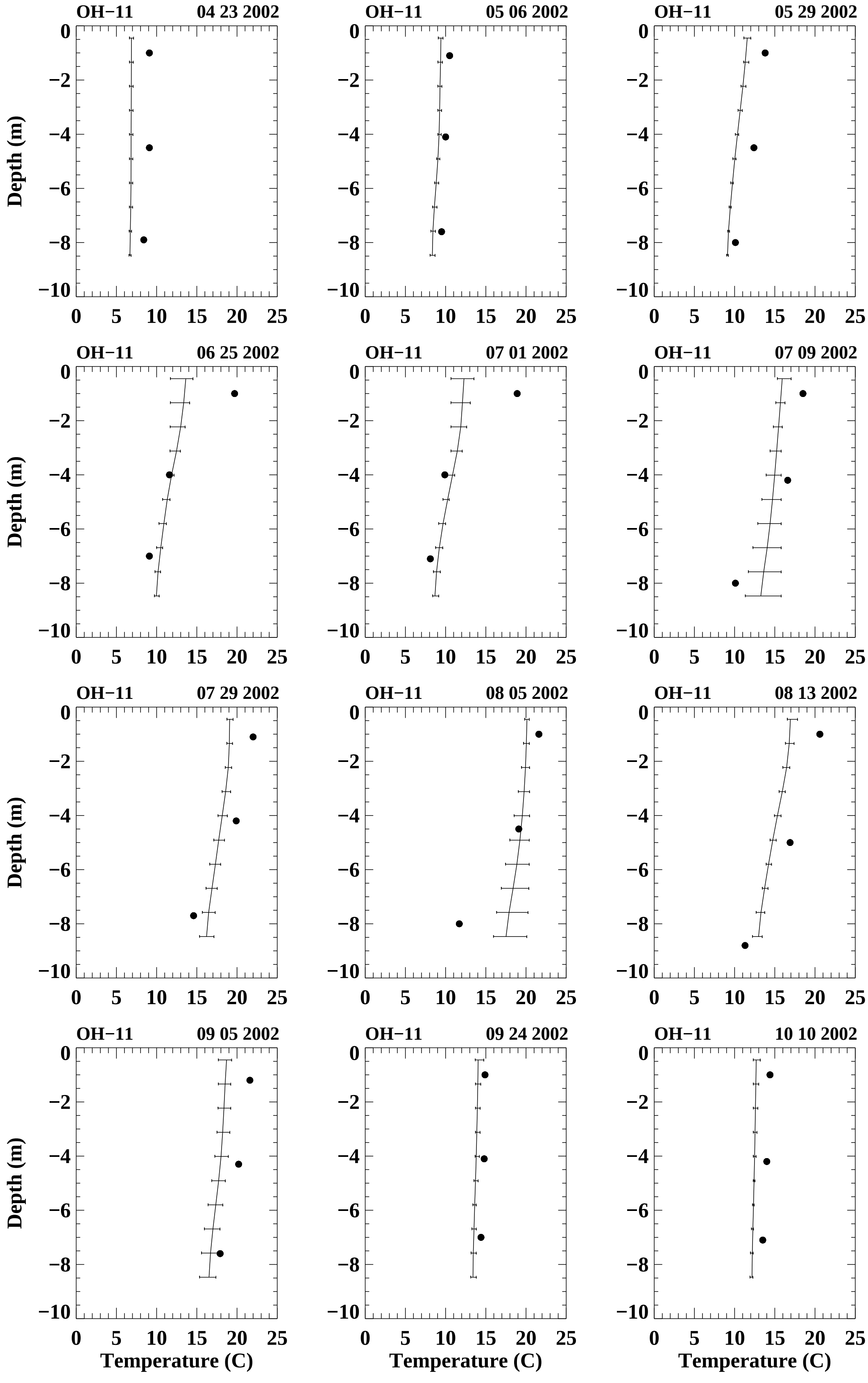

OH−11
05 09 2001
05 23 2001
06 11 2001
06 28 2001
07 03 2001
07 18 2001
07 24 2001
08 01 2001
08 14 2001
09 12 2001
10 24 2001
11 15 2001
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25

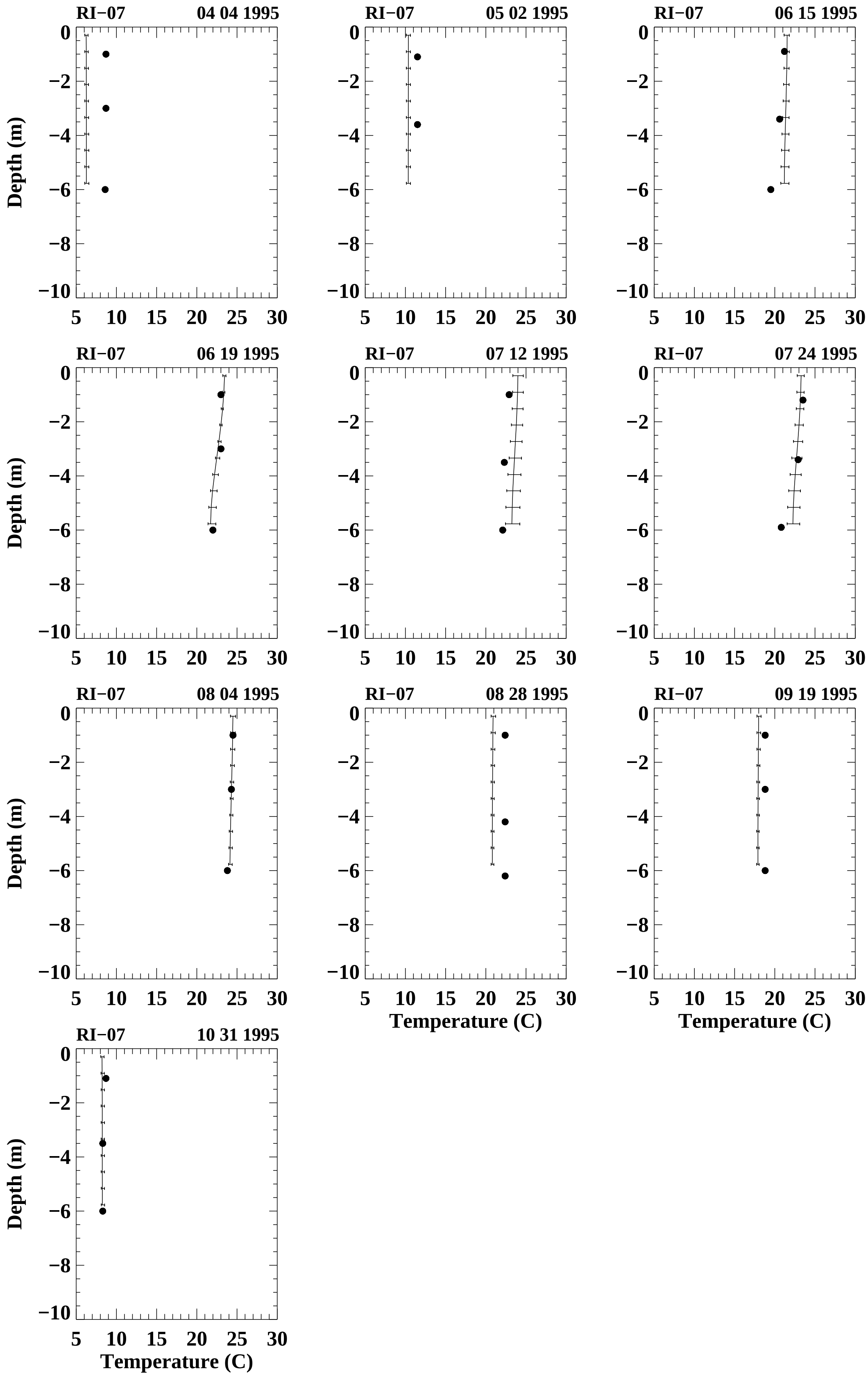

OH−01 04 23 2002
OH−01 05 06 2002
OH−01 05 29 2002
OH−01 06 25 2002
OH−01 07 01 2002
OH−01 07 29 2002
OH−01 08 05 2002
OH−01 09 05 2002
OH−01 09 24 2002
OH−01 10 10 2002
OH−01 11 04 2002
OH−01 11 18 2002
Depth (m)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25
Temperature (C)

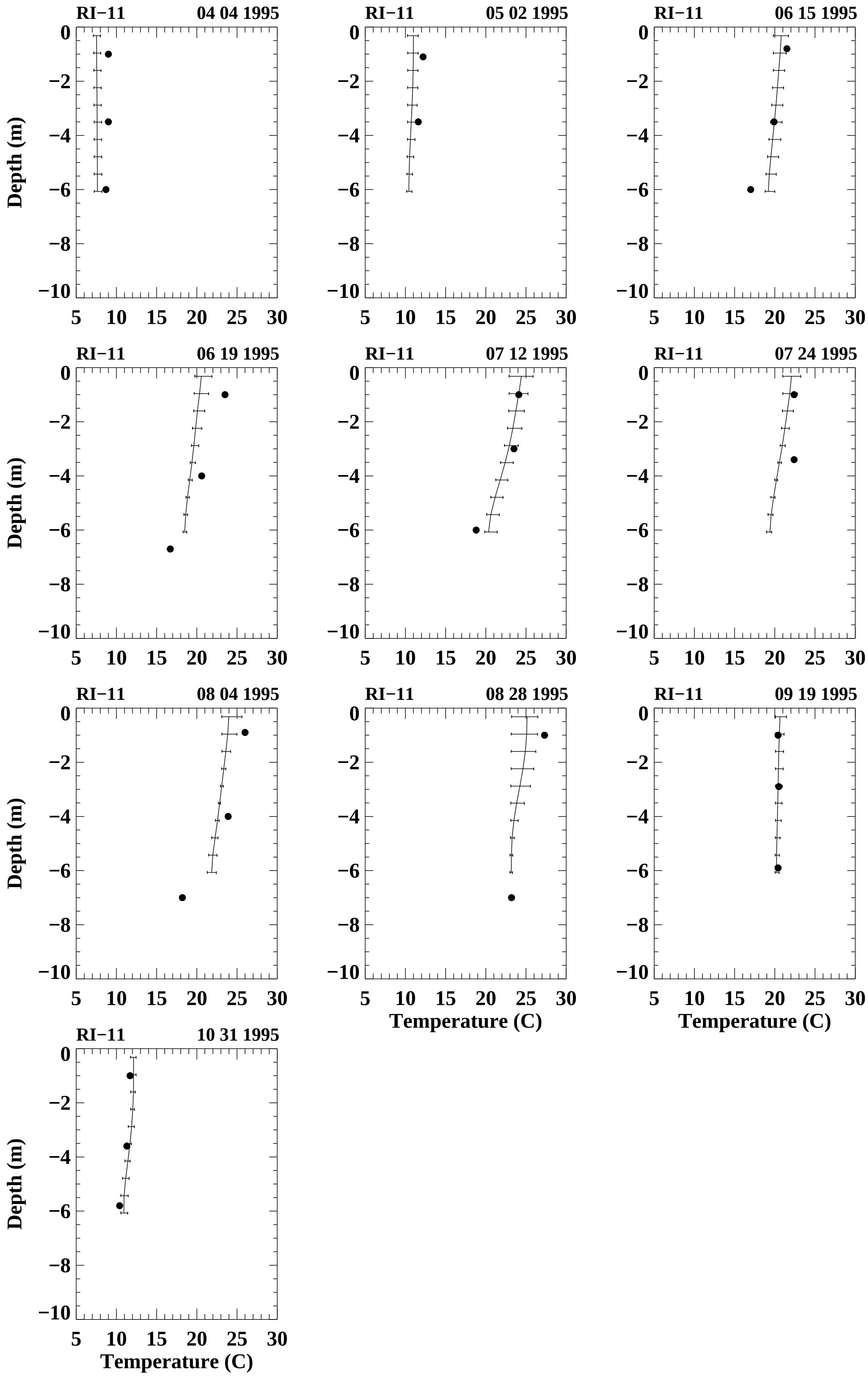

OH−03 04 23 2002
OH−03 05 06 2002
OH−03 05 29 2002
OH−03 06 25 2002
OH−03 07 01 2002
OH−03 07 09 2002
OH−03 07 29 2002
OH−03 08 05 2002
OH−03 08 13 2002
OH−03 09 05 2002
OH−03 09 24 2002
OH−03 10 10 2002
Depth (m)
Temperature (C)


OH−04
04 23 2002
05 06 2002
05 29 2002
06 25 2002
07 01 2002
07 09 2002
07 29 2002
08 05 2002
08 13 2002
09 05 2002
09 24 2002
10 10 2002
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
0 5 10 15 20 25

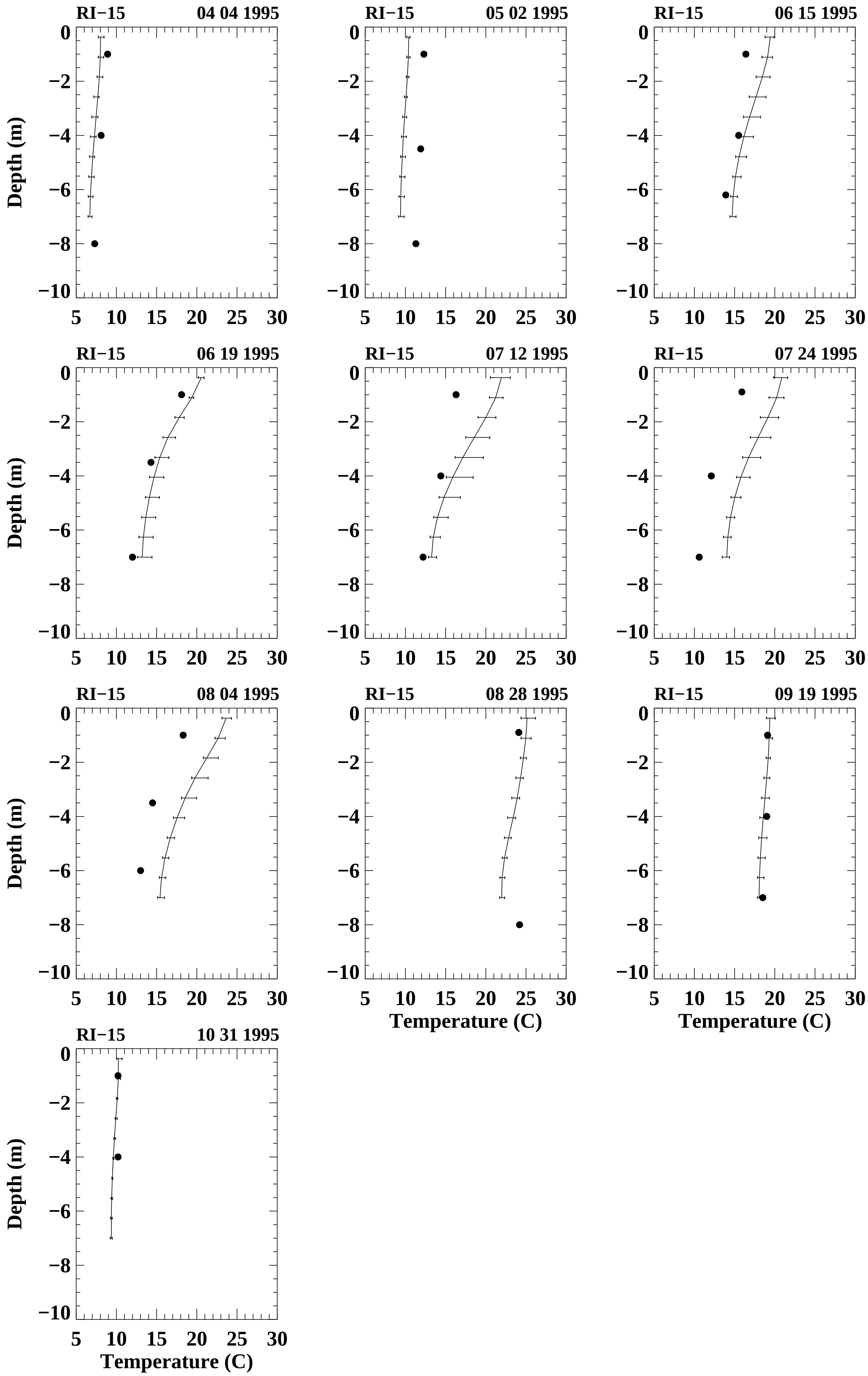

OH−07
04 23 2002
05 06 2002
05 29 2002
06 25 2002
07 01 2002
07 29 2002
08 05 2002
09 05 2002
09 24 2002
10 10 2002
11 04 2002
11 18 2002
Depth (m)
Temperature (C)
0
−5
−10
−15
0 5 10 15 20 25

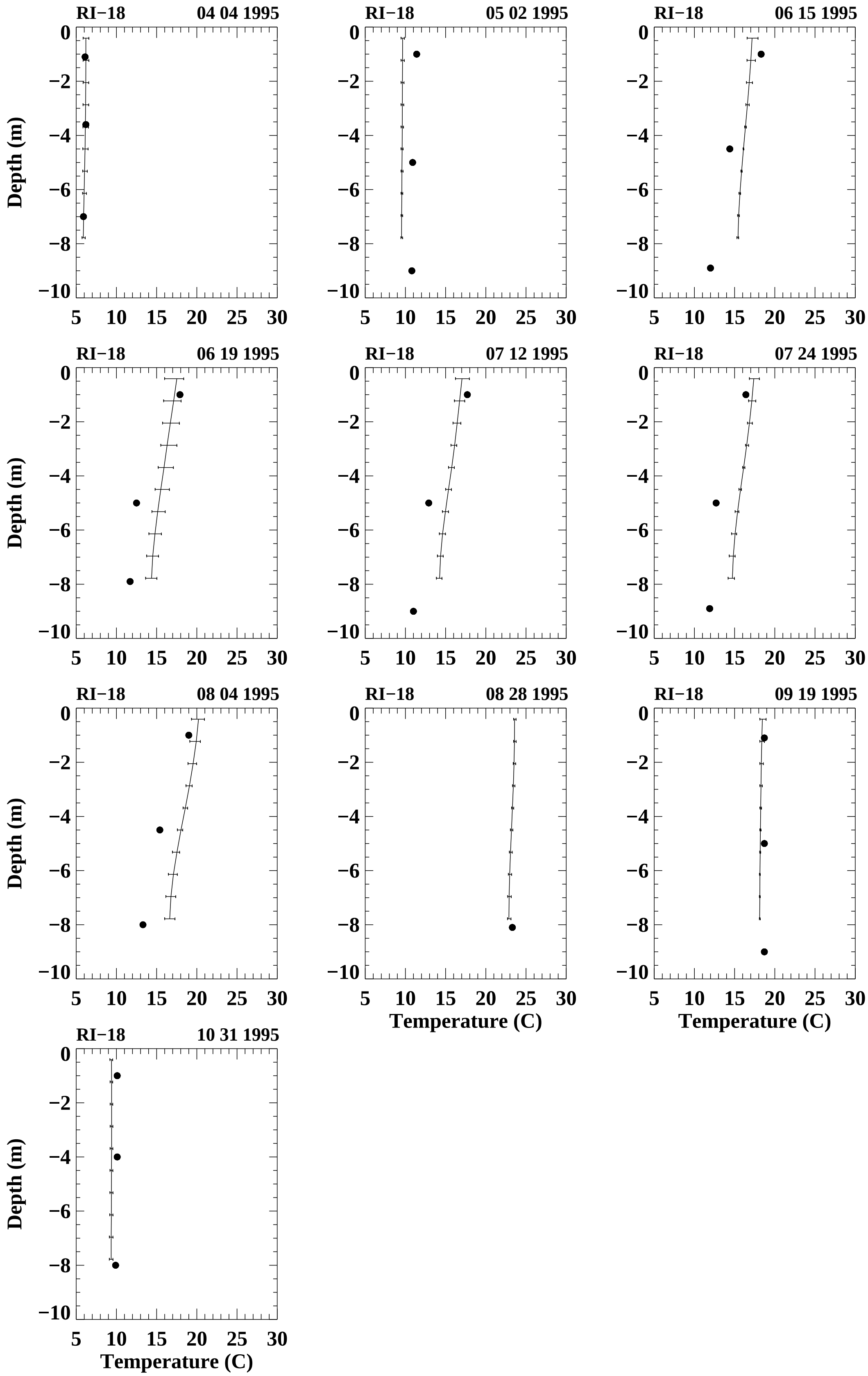

OH−11
04 23 2002
OH−11
05 06 2002
OH−11
05 29 2002
OH−11
06 25 2002
OH−11
07 01 2002
OH−11
07 09 2002
OH−11
07 29 2002
OH−11
08 05 2002
OH−11
08 13 2002
OH−11
09 05 2002
OH−11
09 24 2002
OH−11
10 10 2002
Depth (m)
0
−2
−4
−6
−8
−10
0
5
10
15
20
25
Temperature (C)

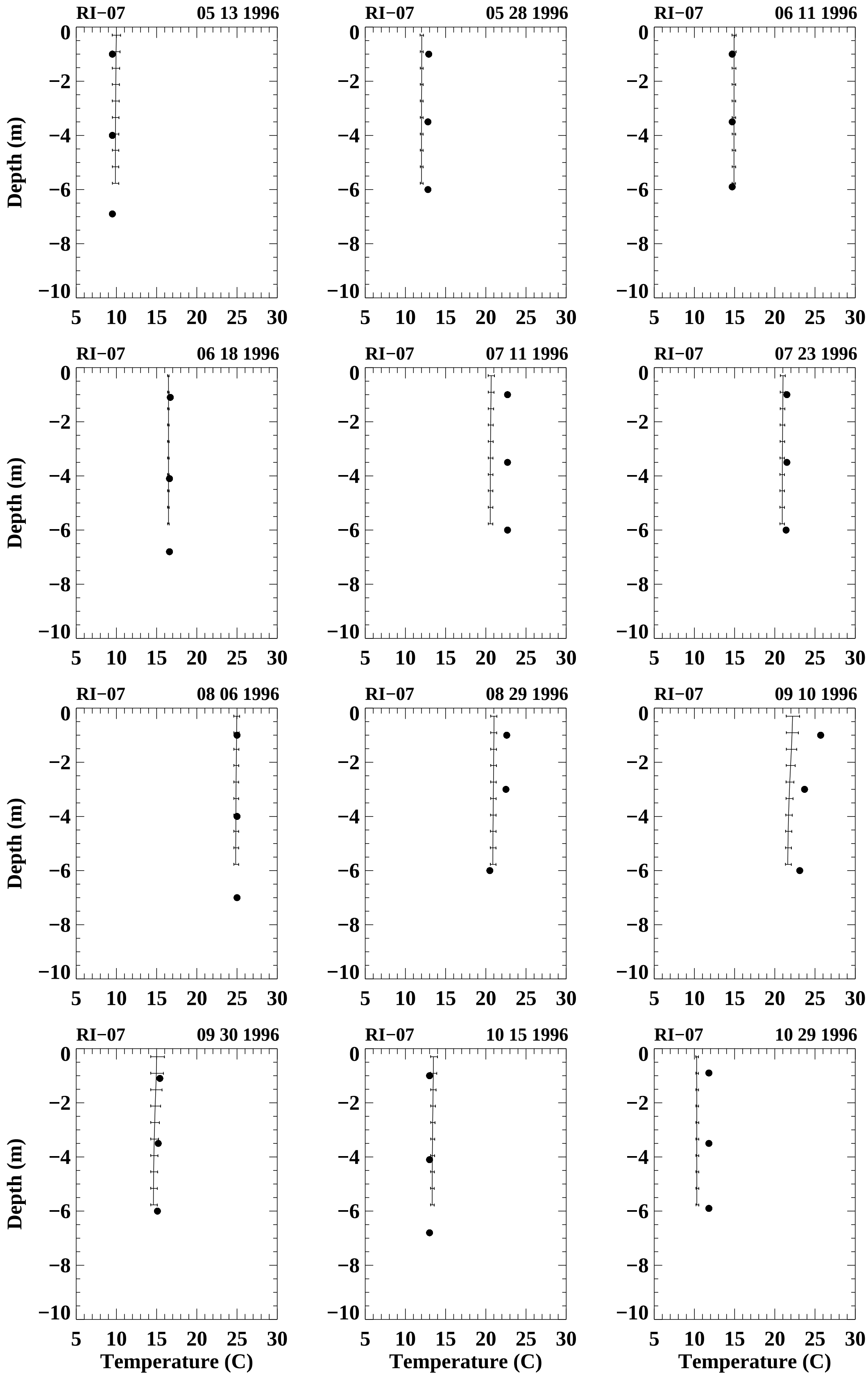

RI−07 04 04 1995
RI−07 05 02 1995
RI−07 06 15 1995
RI−07 06 19 1995
RI−07 07 12 1995
RI−07 07 24 1995
RI−07 08 04 1995
RI−07 08 28 1995
RI−07 09 19 1995
RI−07 10 31 1995
Depth (m)
0
−2
−4
−6
−8
−10
5 10 15 20 25 30
Temperature (C)



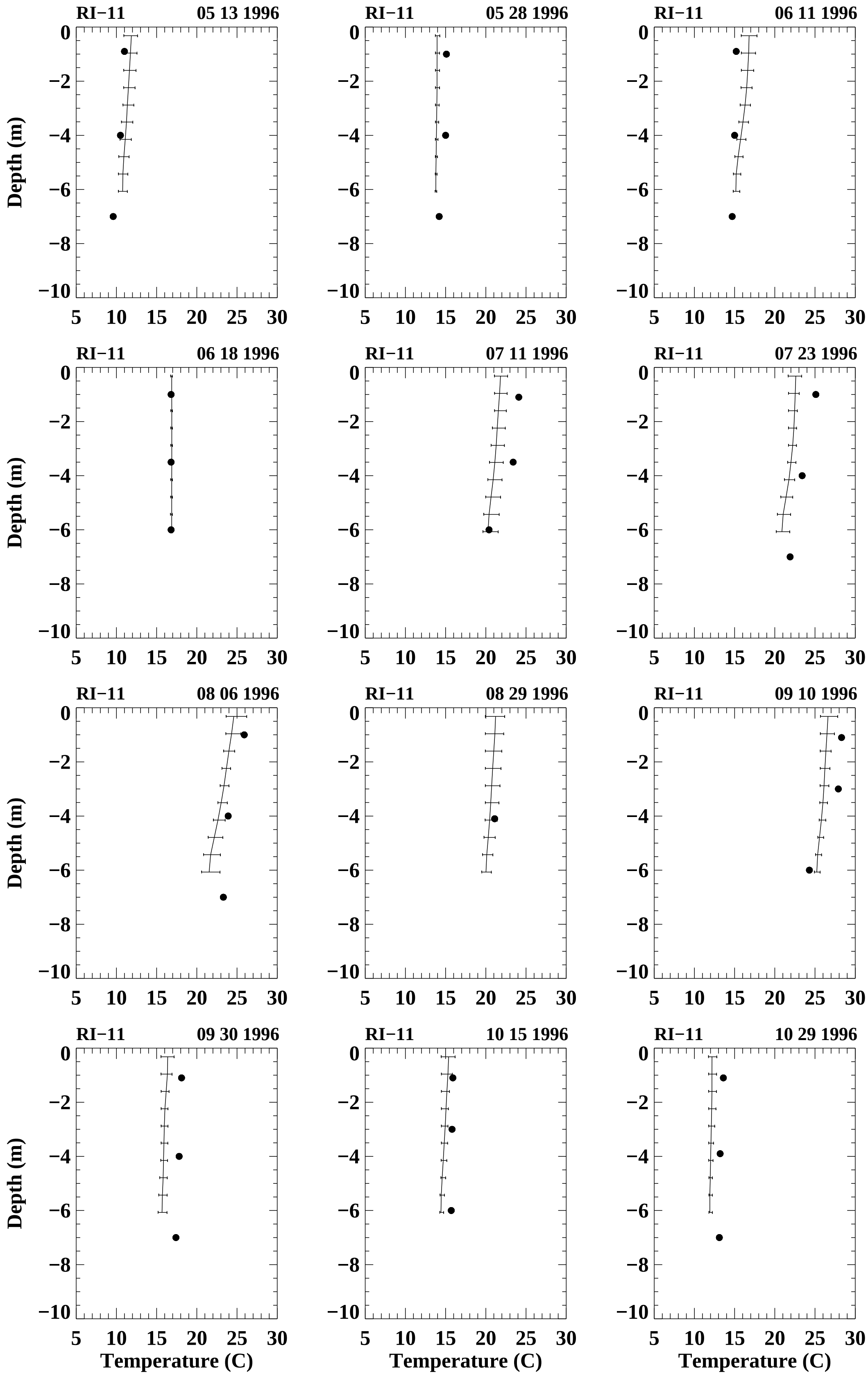
RI−11 04 04 1995
RI−11 05 02 1995
RI−11 06 15 1995
RI−11 06 19 1995
RI−11 07 12 1995
RI−11 07 24 1995
RI−11 08 04 1995
RI−11 08 28 1995
RI−11 09 19 1995
RI−11 10 31 1995
Depth (m)
0 −2 −4 −6 −8 −10
5 10 15 20 25 30
Temperature (C)

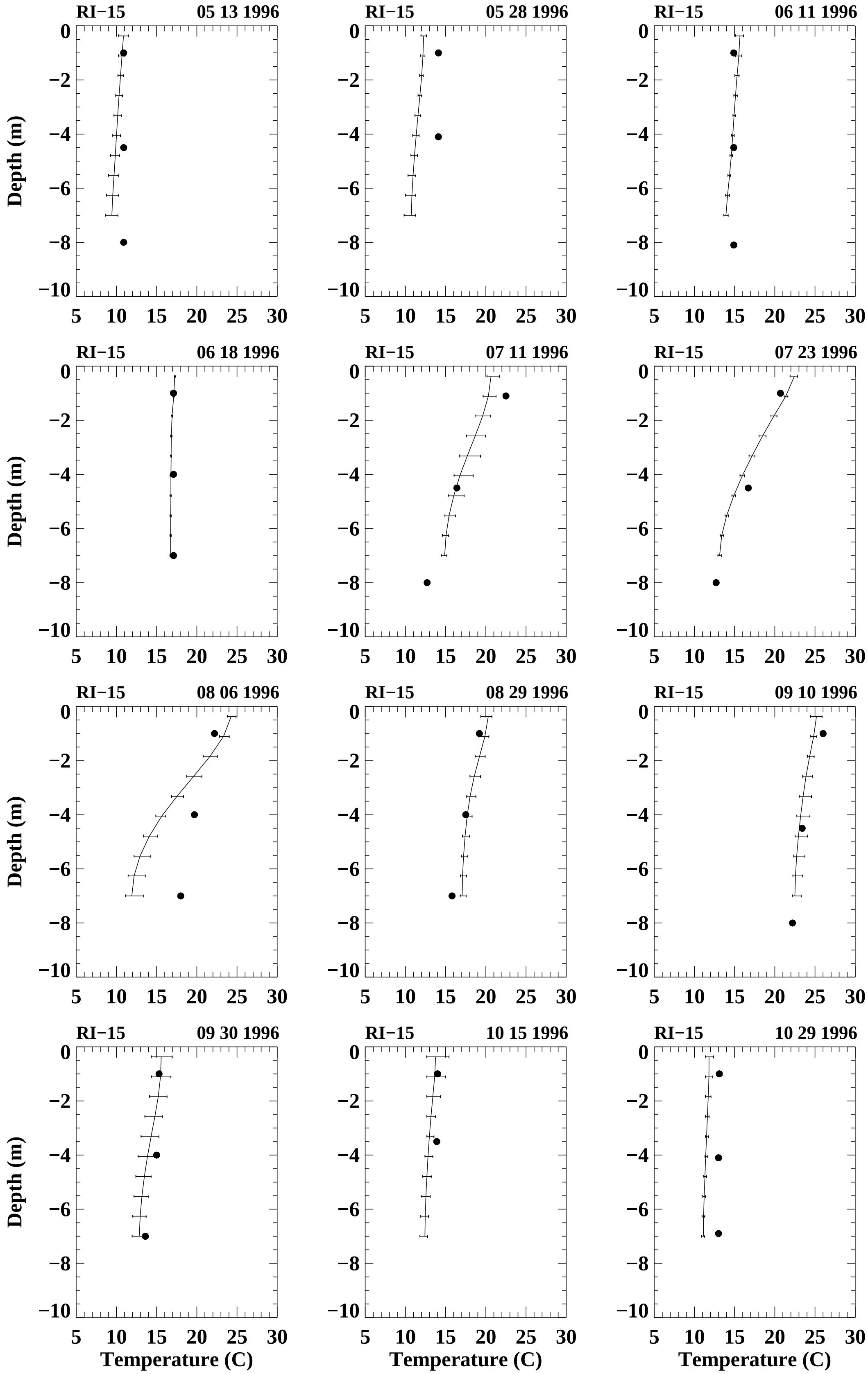

RI−15 04 04 1995
RI−15 05 02 1995
RI−15 06 15 1995
RI−15 06 19 1995
RI−15 07 12 1995
RI−15 07 24 1995
RI−15 08 04 1995
RI−15 08 28 1995
RI−15 09 19 1995
RI−15 10 31 1995
Depth (m)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30
Temperature (C)


RI−18 04 04 1995
RI−18 05 02 1995
RI−18 06 15 1995
RI−18 06 19 1995
RI−18 07 12 1995
RI−18 07 24 1995
RI−18 08 04 1995
RI−18 08 28 1995
RI−18 09 19 1995
RI−18 10 31 1995
Depth (m)
0
−2
−4
−6
−8
−10
5 10 15 20 25 30
Temperature (C)

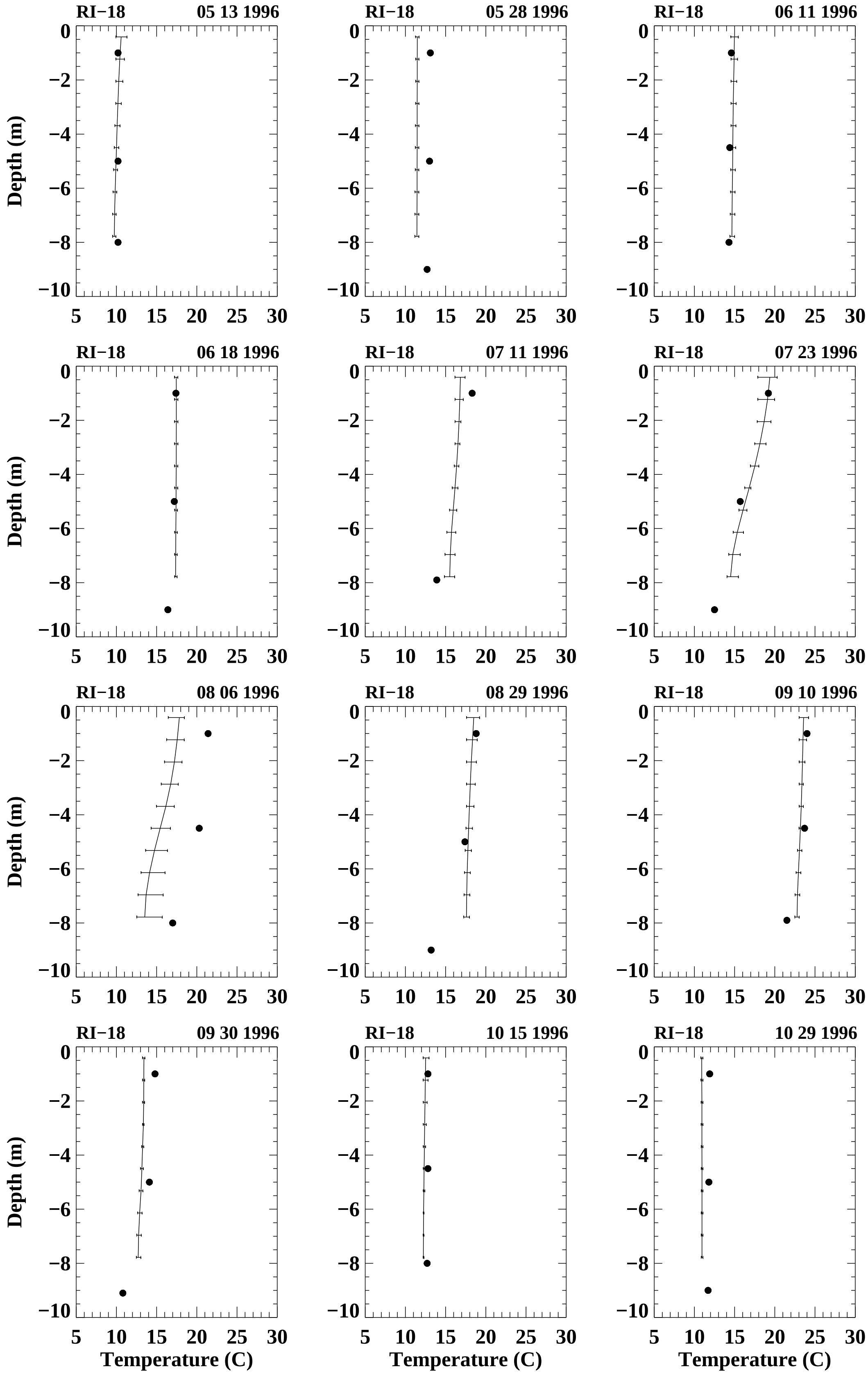


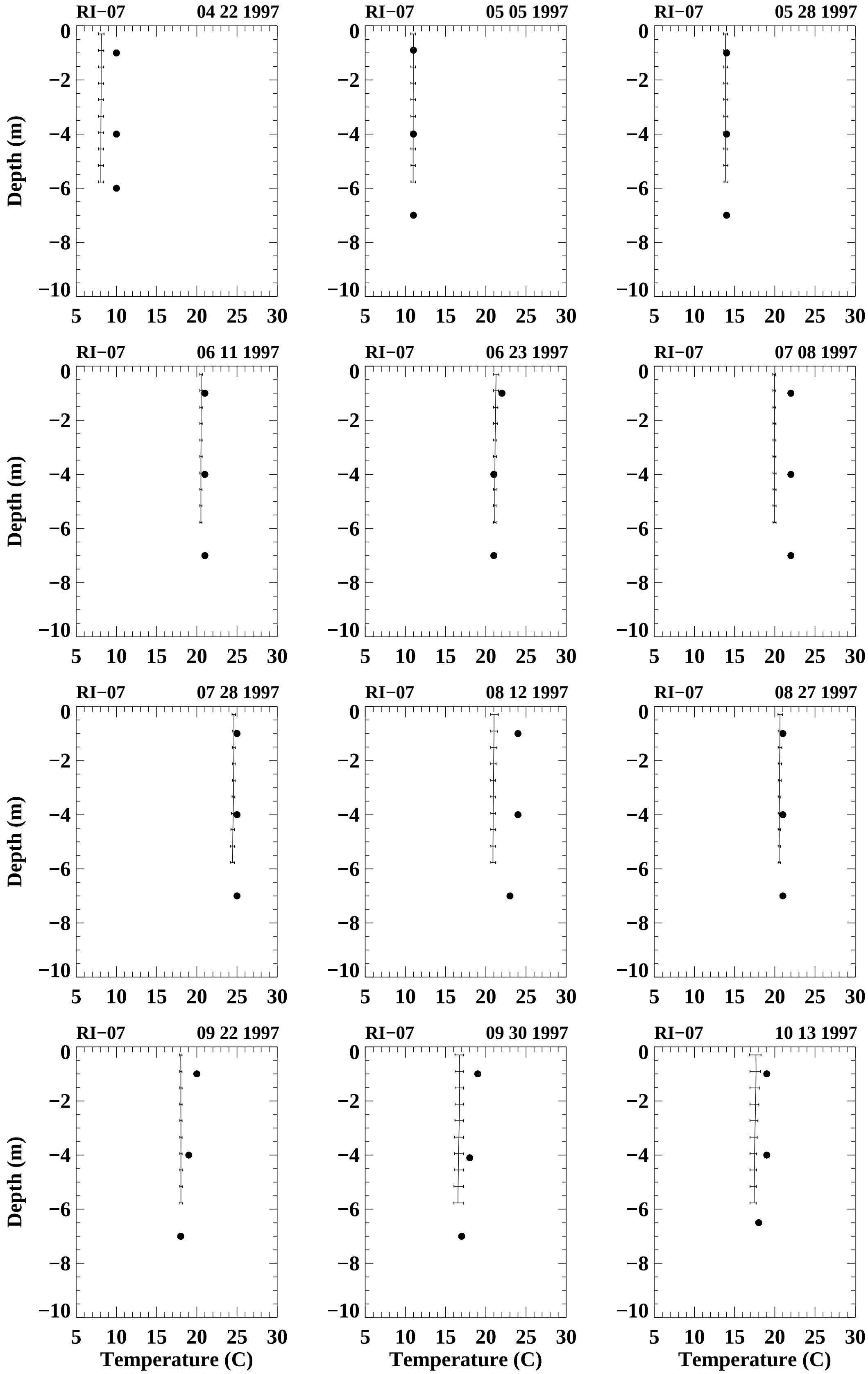
RI−07 05 13 1996
RI−07 05 28 1996
RI−07 06 11 1996
RI−07 06 18 1996
RI−07 07 11 1996
RI−07 07 23 1996
RI−07 08 06 1996
RI−07 08 29 1996
RI−07 09 10 1996
RI−07 09 30 1996
RI−07 10 15 1996
RI−07 10 29 1996
Depth (m)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30
Temperature (C)

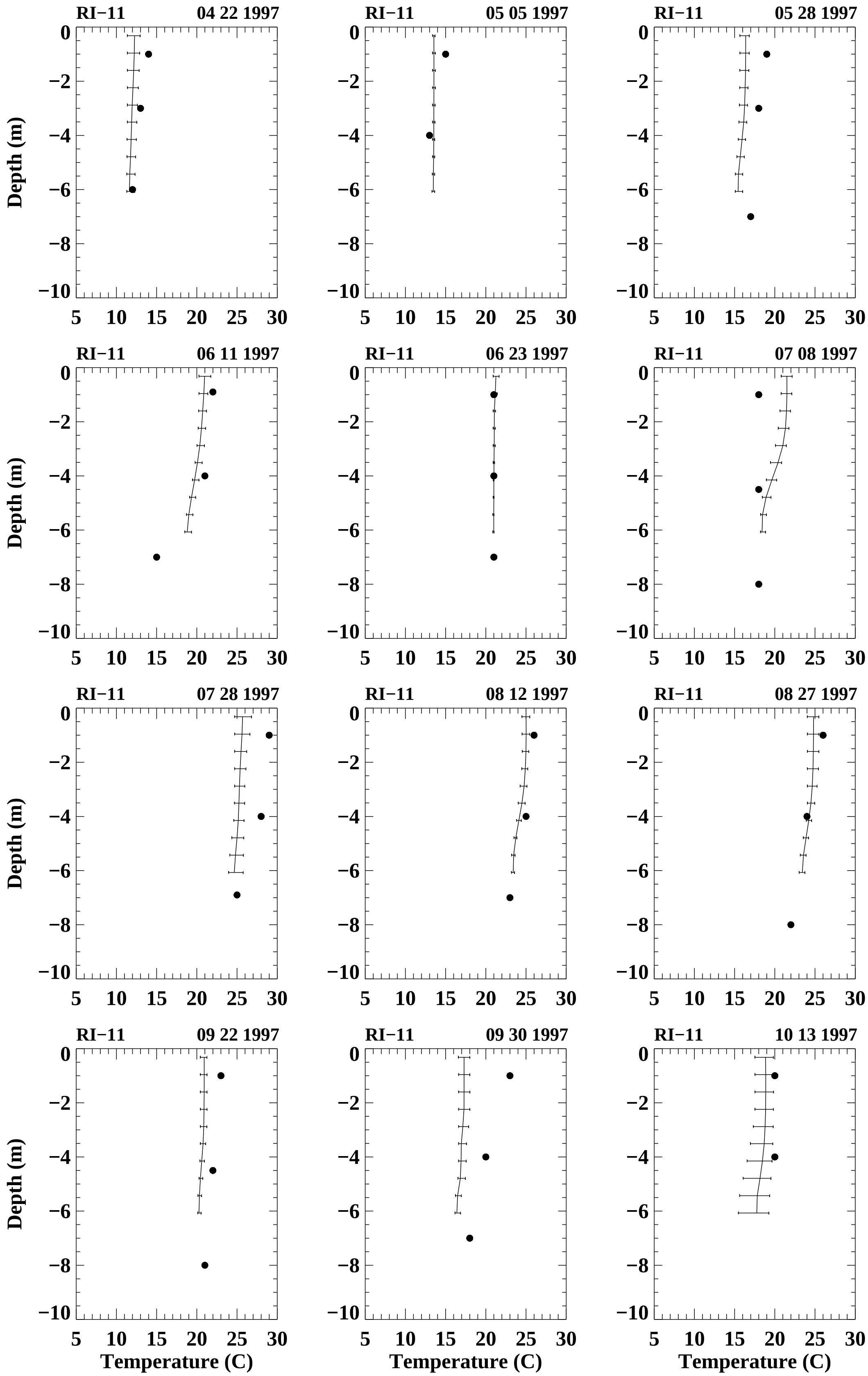

RI−11 05 13 1996
RI−11 05 28 1996
RI−11 06 11 1996
RI−11 06 18 1996
RI−11 07 11 1996
RI−11 07 23 1996
RI−11 08 06 1996
RI−11 08 29 1996
RI−11 09 10 1996
RI−11 09 30 1996
RI−11 10 15 1996
RI−11 10 29 1996
Depth (m)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30
Temperature (C)

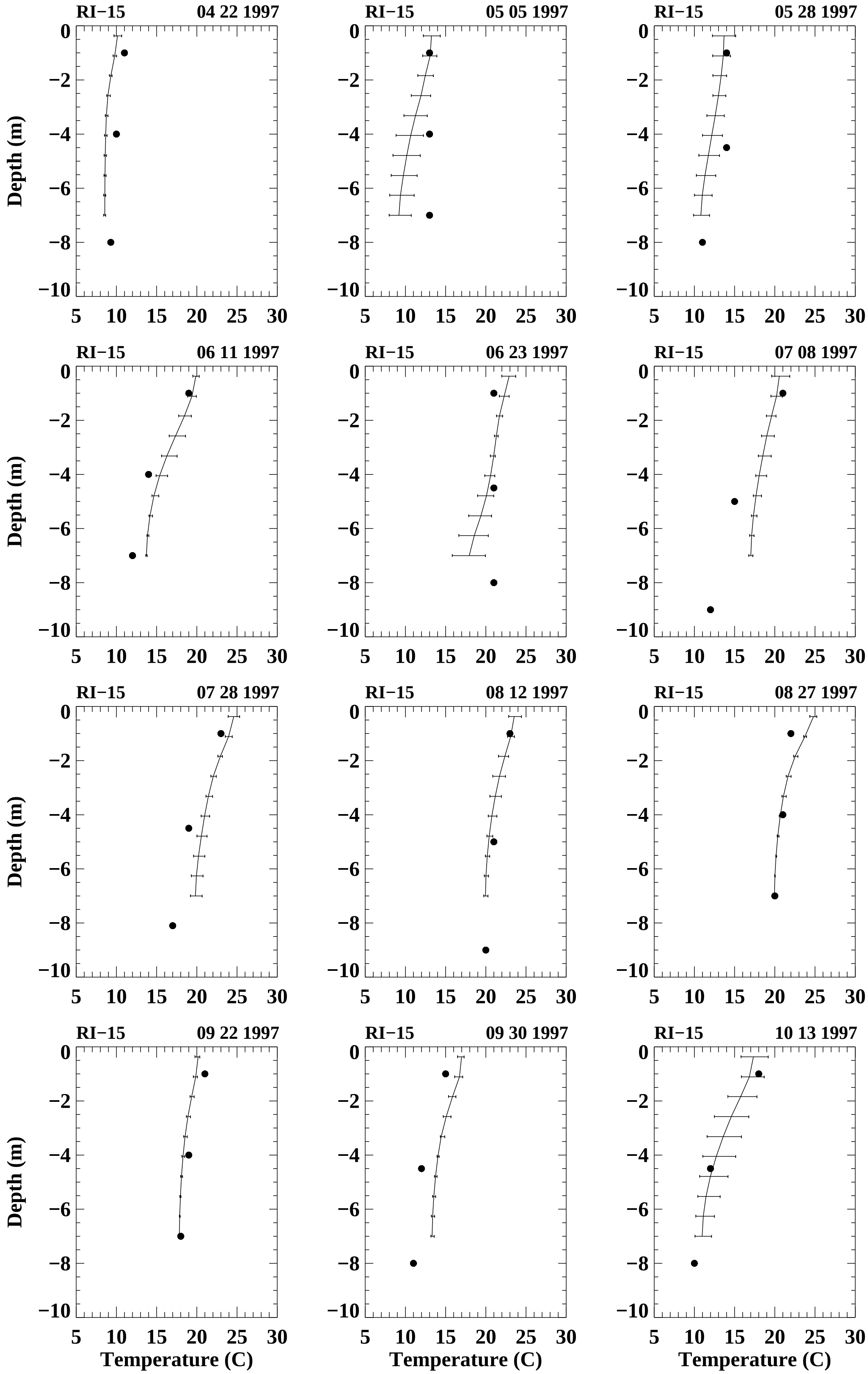


RI−15
05 13 1996
05 28 1996
06 11 1996
06 18 1996
07 11 1996
07 23 1996
08 06 1996
08 29 1996
09 10 1996
09 30 1996
10 15 1996
10 29 1996
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30

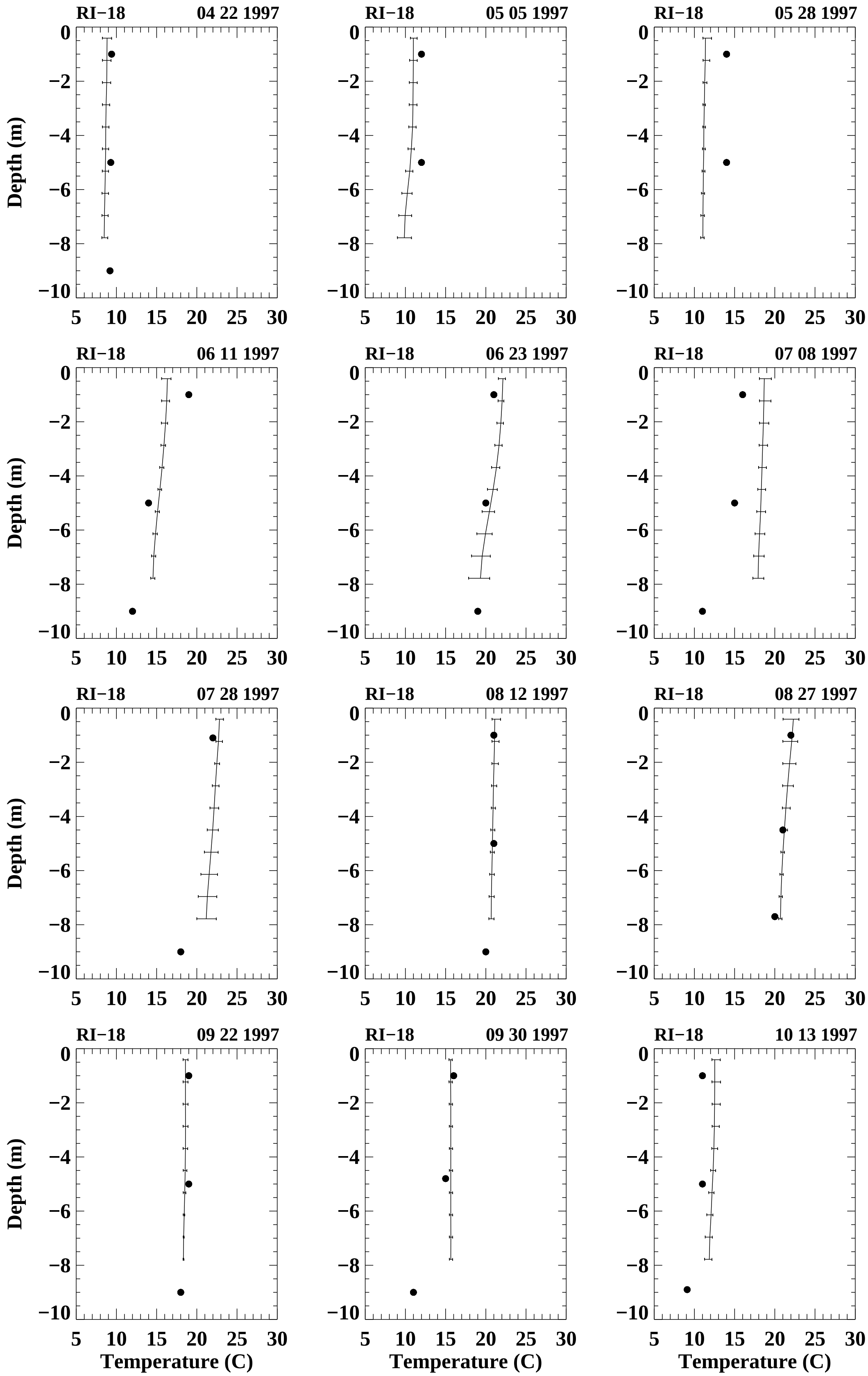

RI−18
05 13 1996
RI−18
05 28 1996
RI−18
06 11 1996
RI−18
06 18 1996
RI−18
07 11 1996
RI−18
07 23 1996
RI−18
08 06 1996
RI−18
08 29 1996
RI−18
09 10 1996
RI−18
09 30 1996
RI−18
10 15 1996
RI−18
10 29 1996
Depth (m)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30
Temperature (C)

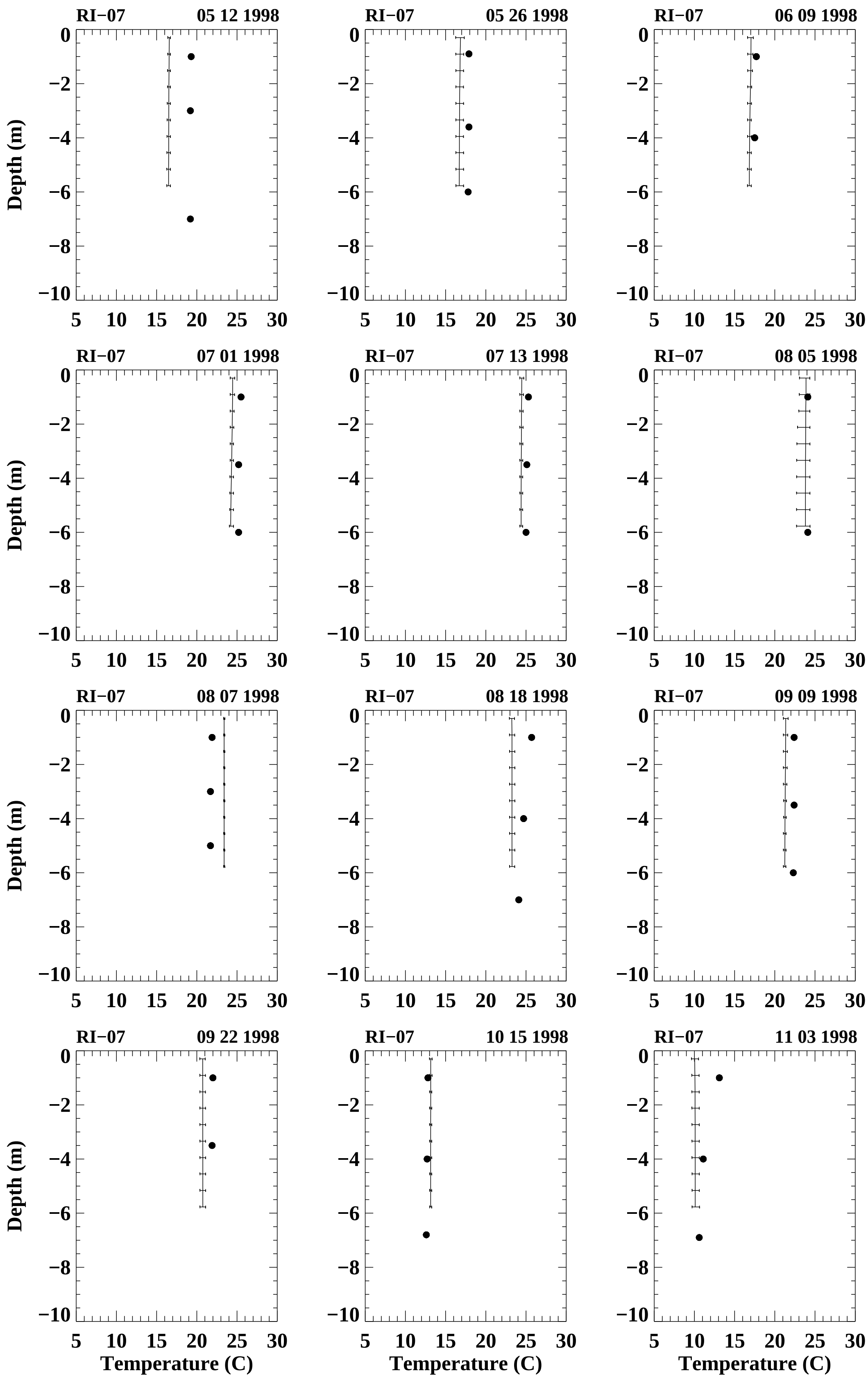

RI−07 04 22 1997
RI−07 05 05 1997
RI−07 05 28 1997
RI−07 06 11 1997
RI−07 06 23 1997
RI−07 07 08 1997
RI−07 07 28 1997
RI−07 08 12 1997
RI−07 08 27 1997
RI−07 09 22 1997
RI−07 09 30 1997
RI−07 10 13 1997
Depth (m)
0
−2
−4
−6
−8
−10
5 10 15 20 25 30
Temperature (C)

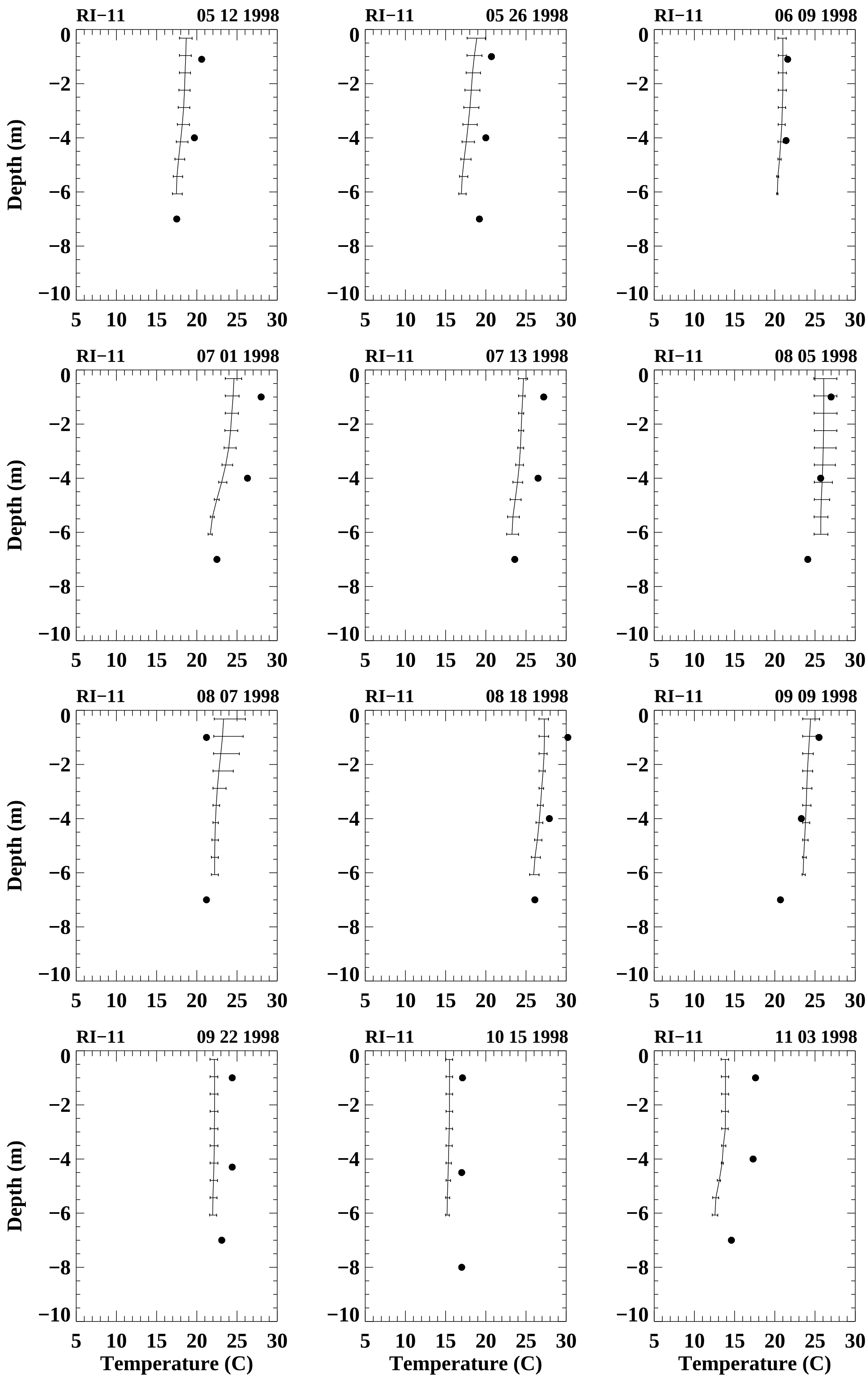

RI−11
04 22 1997
RI−11
05 05 1997
RI−11
05 28 1997
RI−11
06 11 1997
RI−11
06 23 1997
RI−11
07 08 1997
RI−11
07 28 1997
RI−11
08 12 1997
RI−11
08 27 1997
RI−11
09 22 1997
RI−11
09 30 1997
RI−11
10 13 1997
Depth (m)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30
Temperature (C)

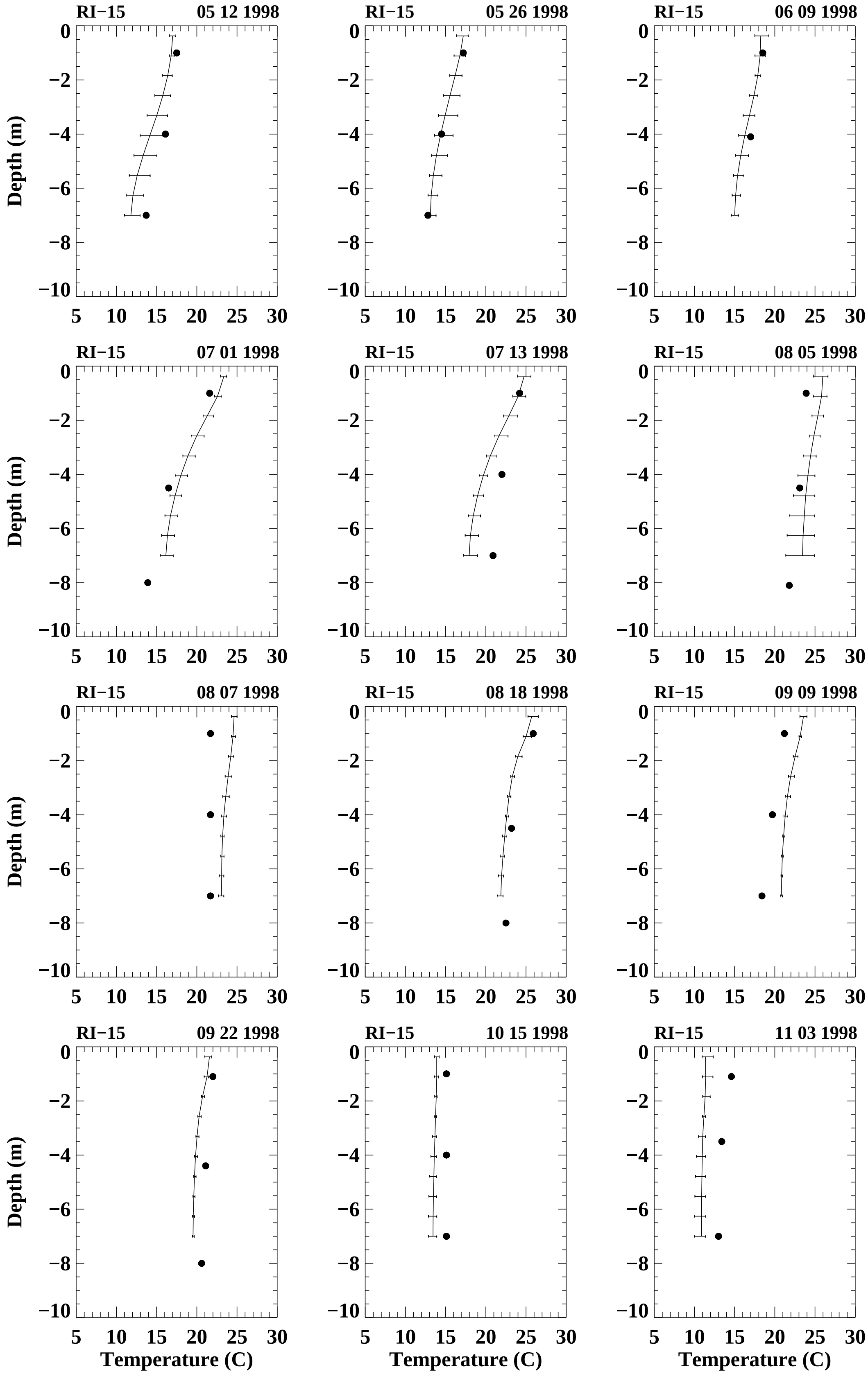


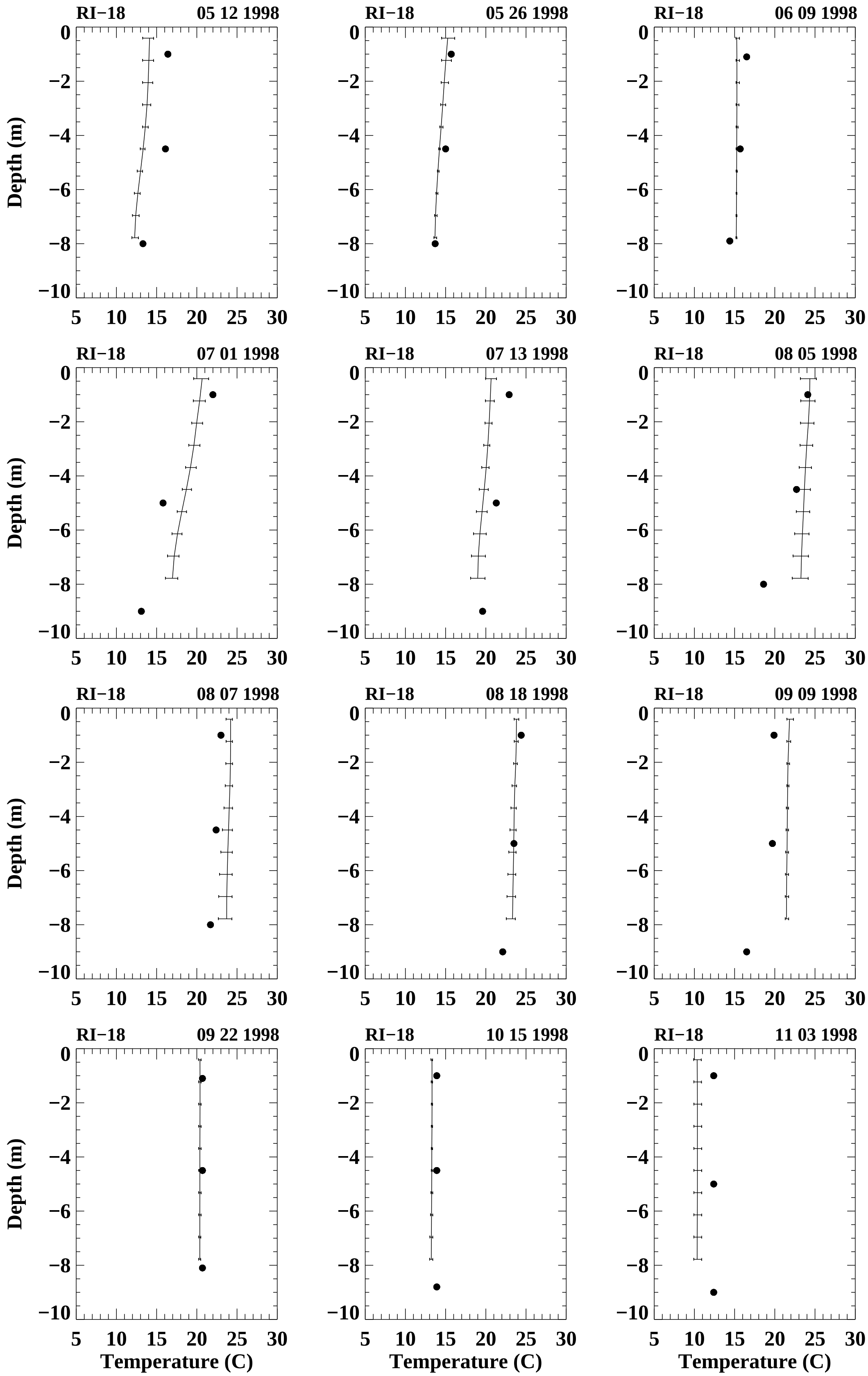
RI−15
04 22 1997
RI−15
05 05 1997
RI−15
05 28 1997
RI−15
06 11 1997
RI−15
06 23 1997
RI−15
07 08 1997
RI−15
07 28 1997
RI−15
08 12 1997
RI−15
08 27 1997
RI−15
09 22 1997
RI−15
09 30 1997
RI−15
10 13 1997
Depth (m)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30
Temperature (C)

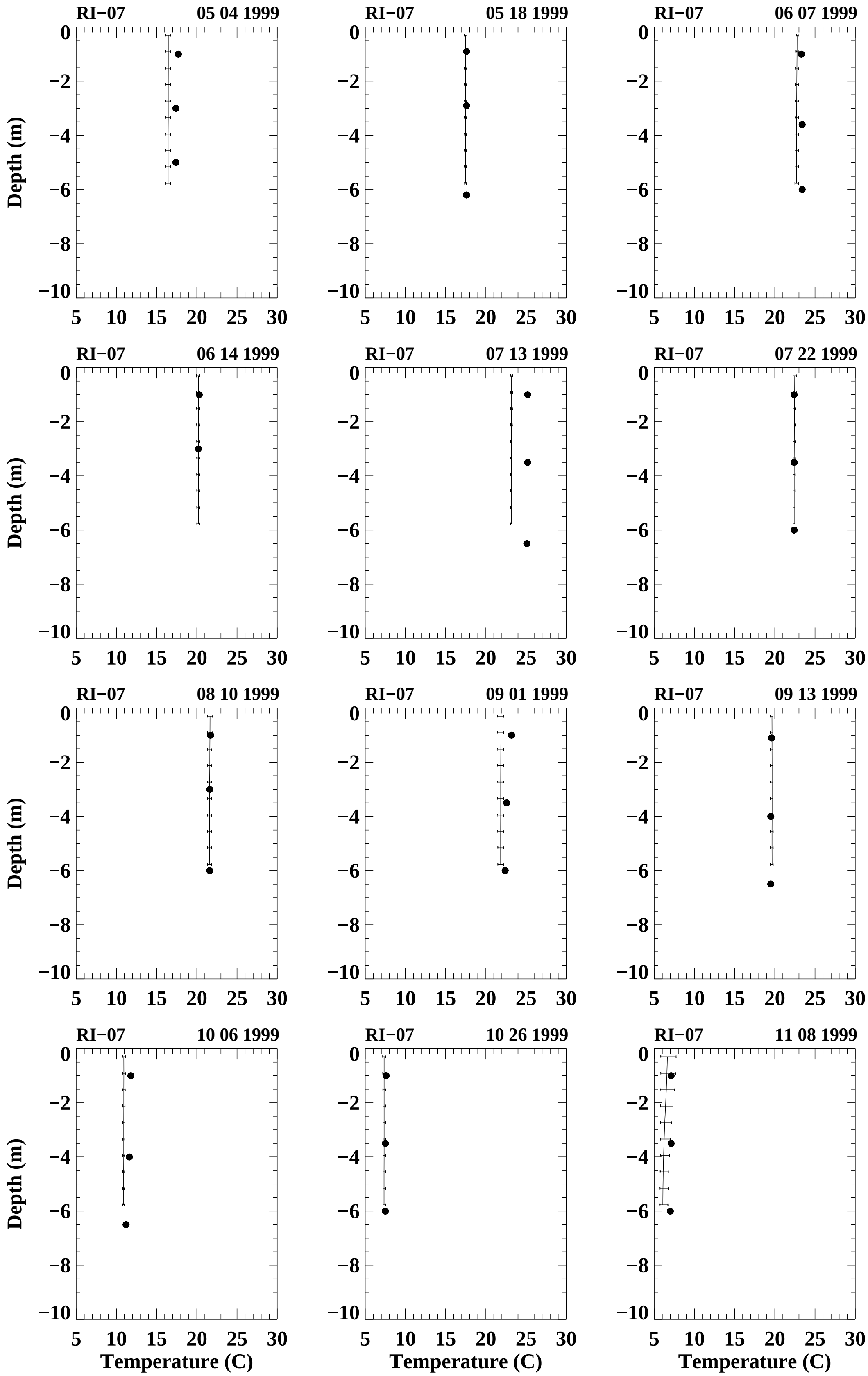

RI−18
04 22 1997
RI−18
05 05 1997
RI−18
05 28 1997
RI−18
06 11 1997
RI−18
06 23 1997
RI−18
07 08 1997
RI−18
07 28 1997
RI−18
08 12 1997
RI−18
08 27 1997
RI−18
09 22 1997
RI−18
09 30 1997
RI−18
10 13 1997
Depth (m)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30
Temperature (C)

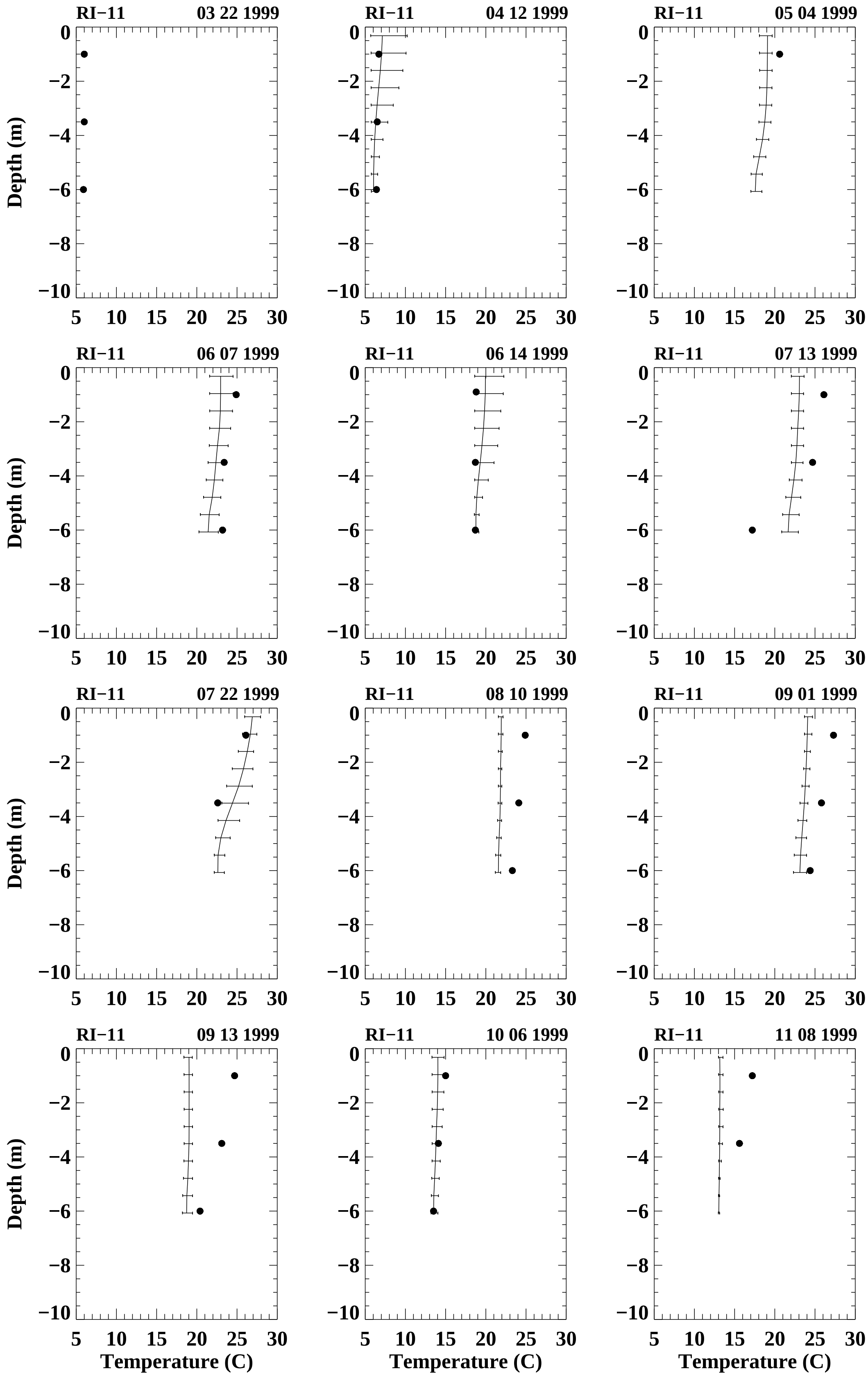

RI−07 05 12 1998
RI−07 05 26 1998
RI−07 06 09 1998
RI−07 07 01 1998
RI−07 07 13 1998
RI−07 08 05 1998
RI−07 08 07 1998
RI−07 08 18 1998
RI−07 09 09 1998
RI−07 09 22 1998
RI−07 10 15 1998
RI−07 11 03 1998
Depth (m)
0
−2
−4
−6
−8
−10
5 10 15 20 25 30
Temperature (C)


RI−11 05 12 1998
RI−11 05 26 1998
RI−11 06 09 1998
RI−11 07 01 1998
RI−11 07 13 1998
RI−11 08 05 1998
RI−11 08 07 1998
RI−11 08 18 1998
RI−11 09 09 1998
RI−11 09 22 1998
RI−11 10 15 1998
RI−11 11 03 1998
Depth (m)
0
−2
−4
−6
−8
−10
5 10 15 20 25 30
Temperature (C)

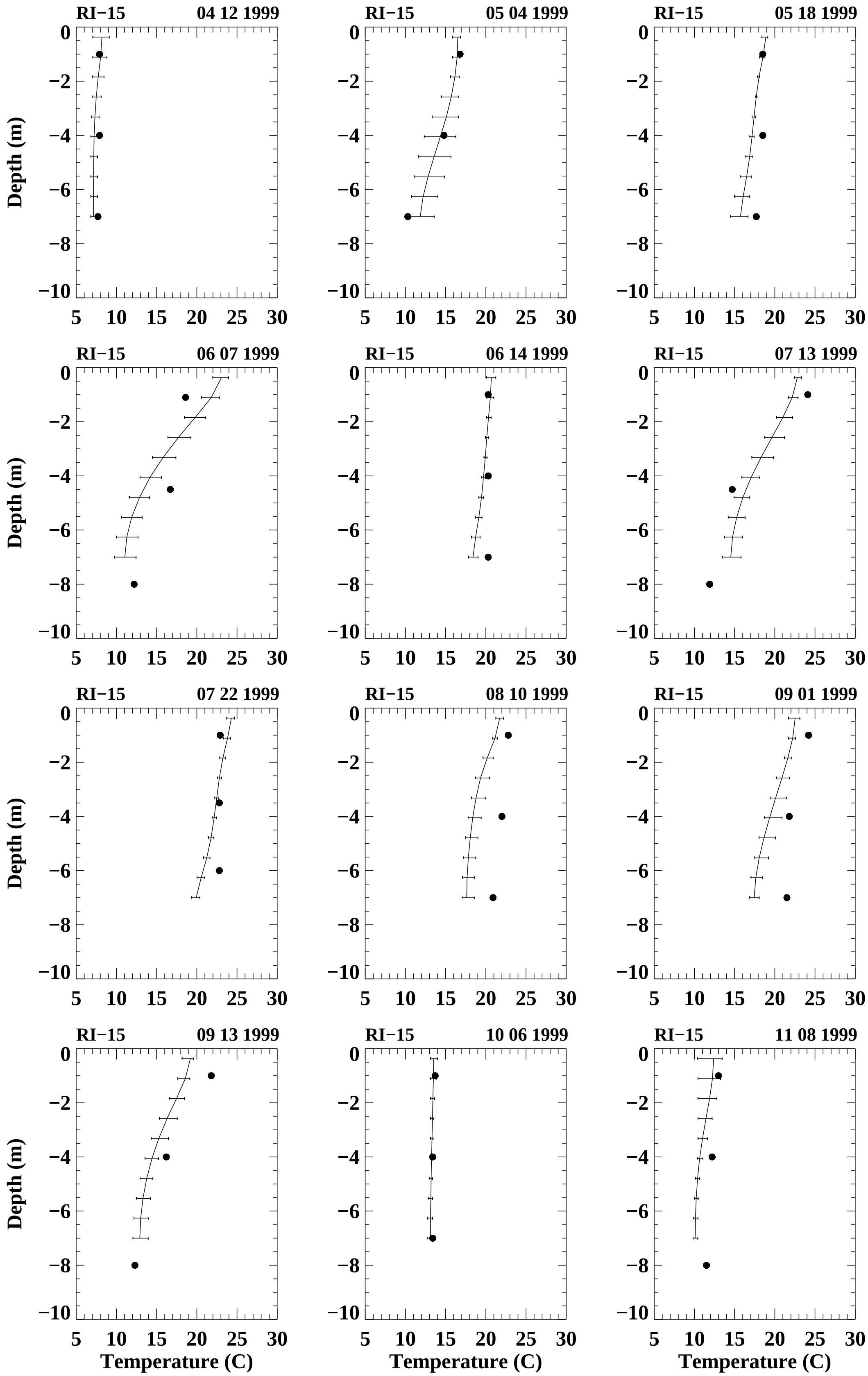

RI−15
05 12 1998
05 26 1998
06 09 1998
07 01 1998
07 13 1998
08 05 1998
08 07 1998
08 18 1998
09 09 1998
09 22 1998
10 15 1998
11 03 1998
Depth (m)
Temperature (C)

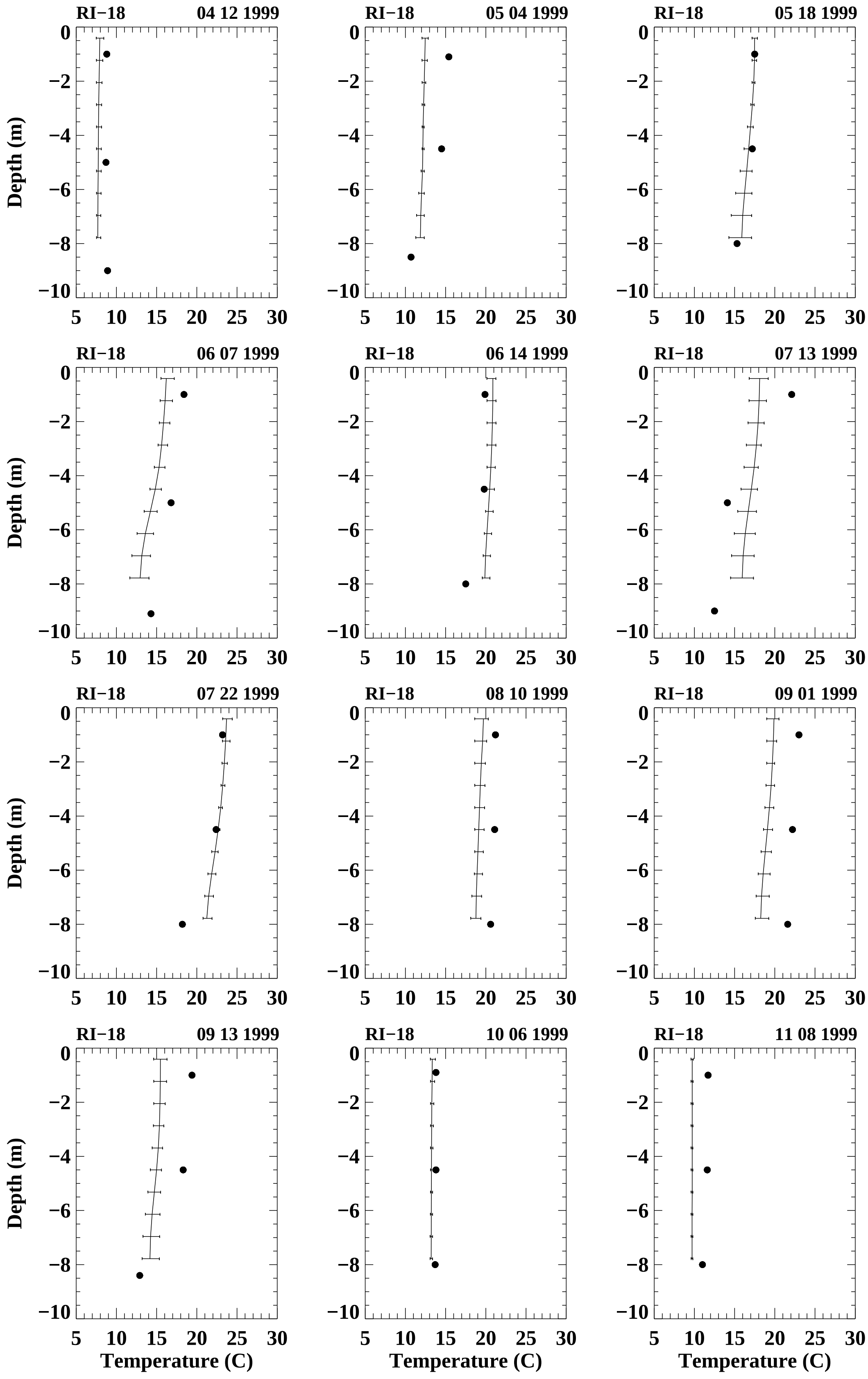

RI−18
05 12 1998
05 26 1998
06 09 1998
07 01 1998
07 13 1998
08 05 1998
08 07 1998
08 18 1998
09 09 1998
09 22 1998
10 15 1998
11 03 1998
Depth (m)
Temperature (C)

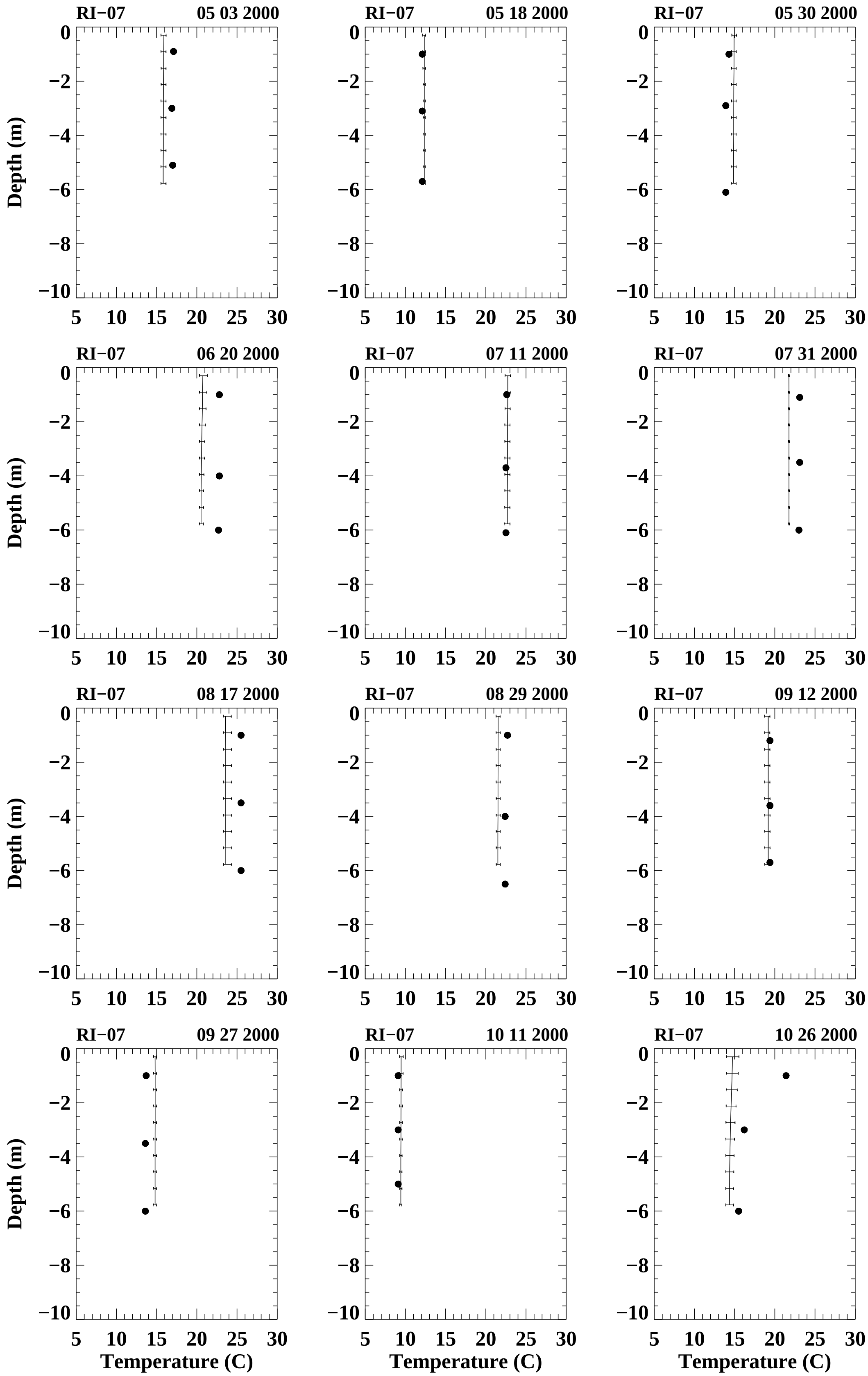

RI−07 05 04 1999
RI−07 05 18 1999
RI−07 06 07 1999
RI−07 06 14 1999
RI−07 07 13 1999
RI−07 07 22 1999
RI−07 08 10 1999
RI−07 09 01 1999
RI−07 09 13 1999
RI−07 10 06 1999
RI−07 10 26 1999
RI−07 11 08 1999
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
5 10 15 20 25 30

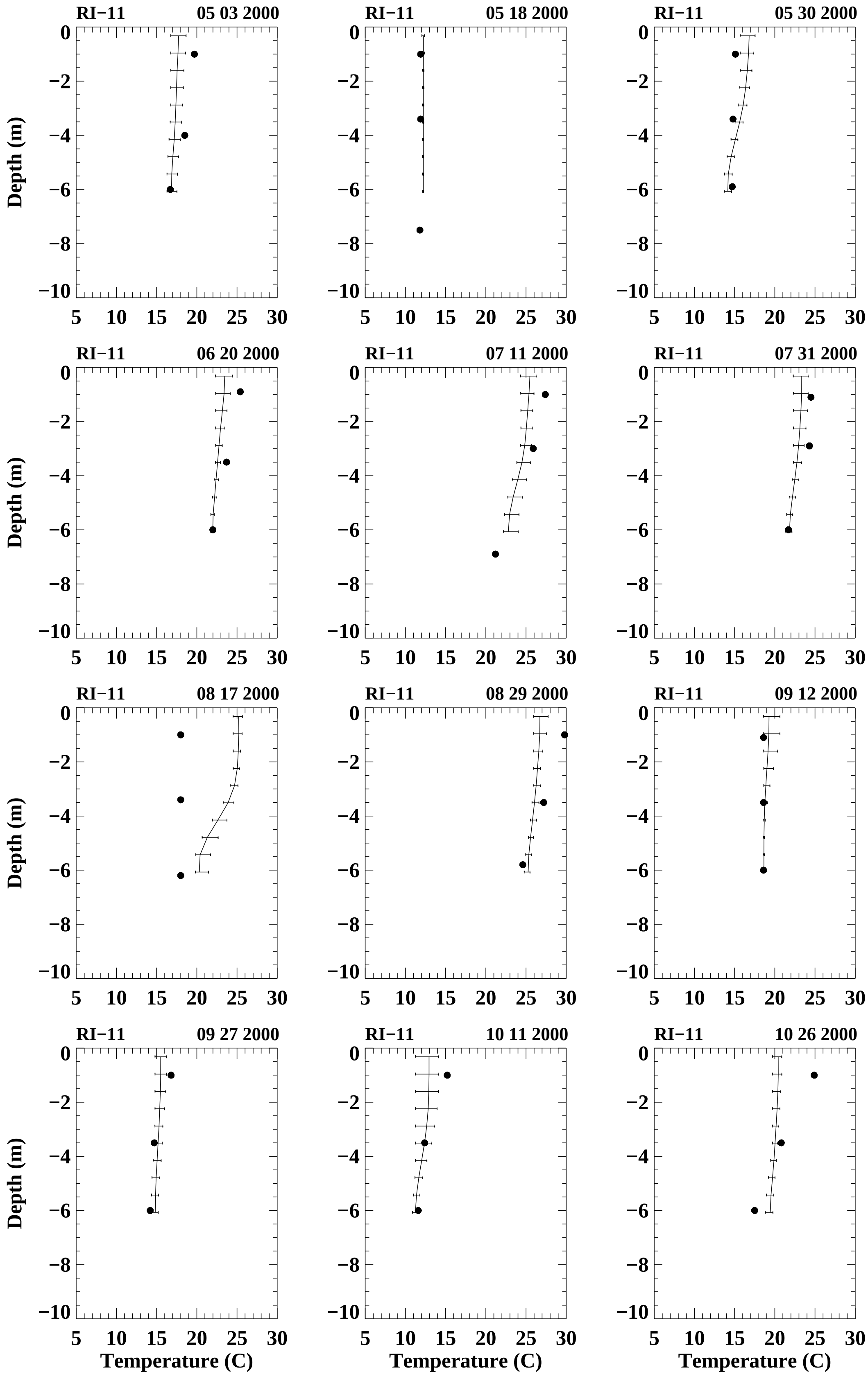


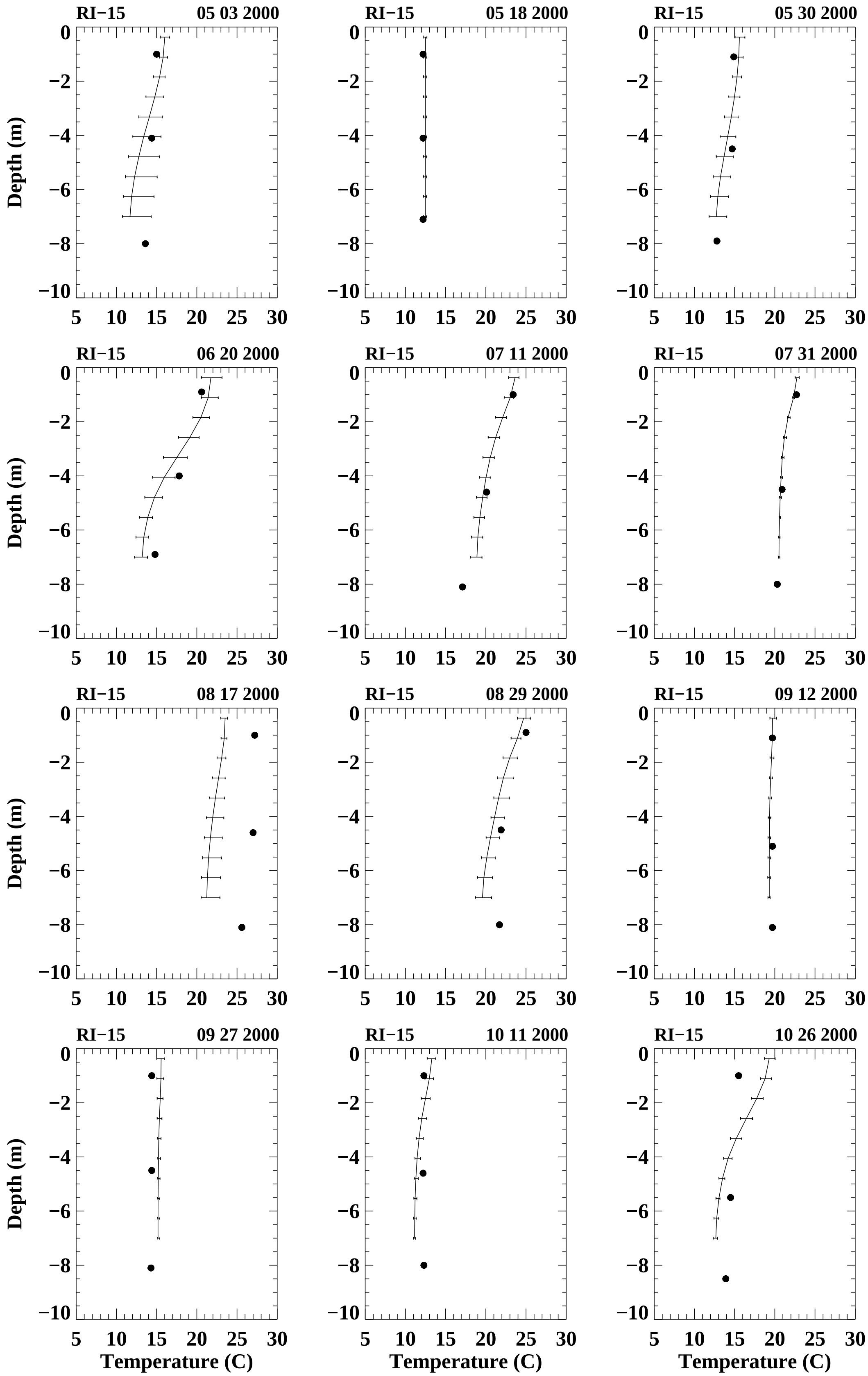
RI−11 03 22 1999
RI−11 04 12 1999
RI−11 05 04 1999
RI−11 06 07 1999
RI−11 06 14 1999
RI−11 07 13 1999
RI−11 07 22 1999
RI−11 08 10 1999
RI−11 09 01 1999
RI−11 09 13 1999
RI−11 10 06 1999
RI−11 11 08 1999
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
5 10 15 20 25 30


RI−15
04 12 1999
RI−15
05 04 1999
RI−15
05 18 1999
RI−15
06 07 1999
RI−15
06 14 1999
RI−15
07 13 1999
RI−15
07 22 1999
RI−15
08 10 1999
RI−15
09 01 1999
RI−15
09 13 1999
RI−15
10 06 1999
RI−15
11 08 1999
Depth (m)
0
−2
−4
−6
−8
−10
5 10 15 20 25 30
Temperature (C)

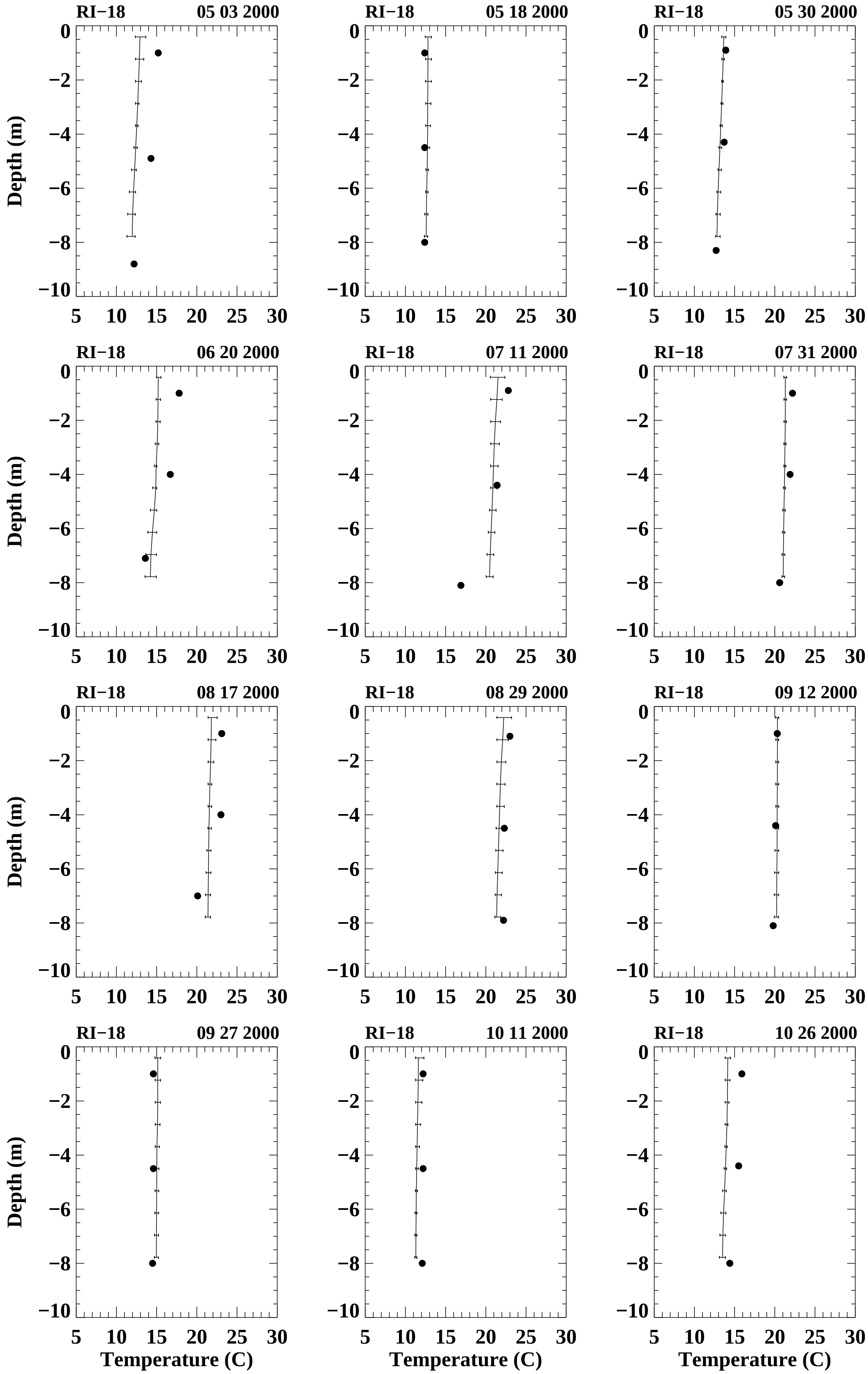

RI−18
04 12 1999
05 04 1999
05 18 1999
06 07 1999
06 14 1999
07 13 1999
07 22 1999
08 10 1999
09 01 1999
09 13 1999
10 06 1999
11 08 1999
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30

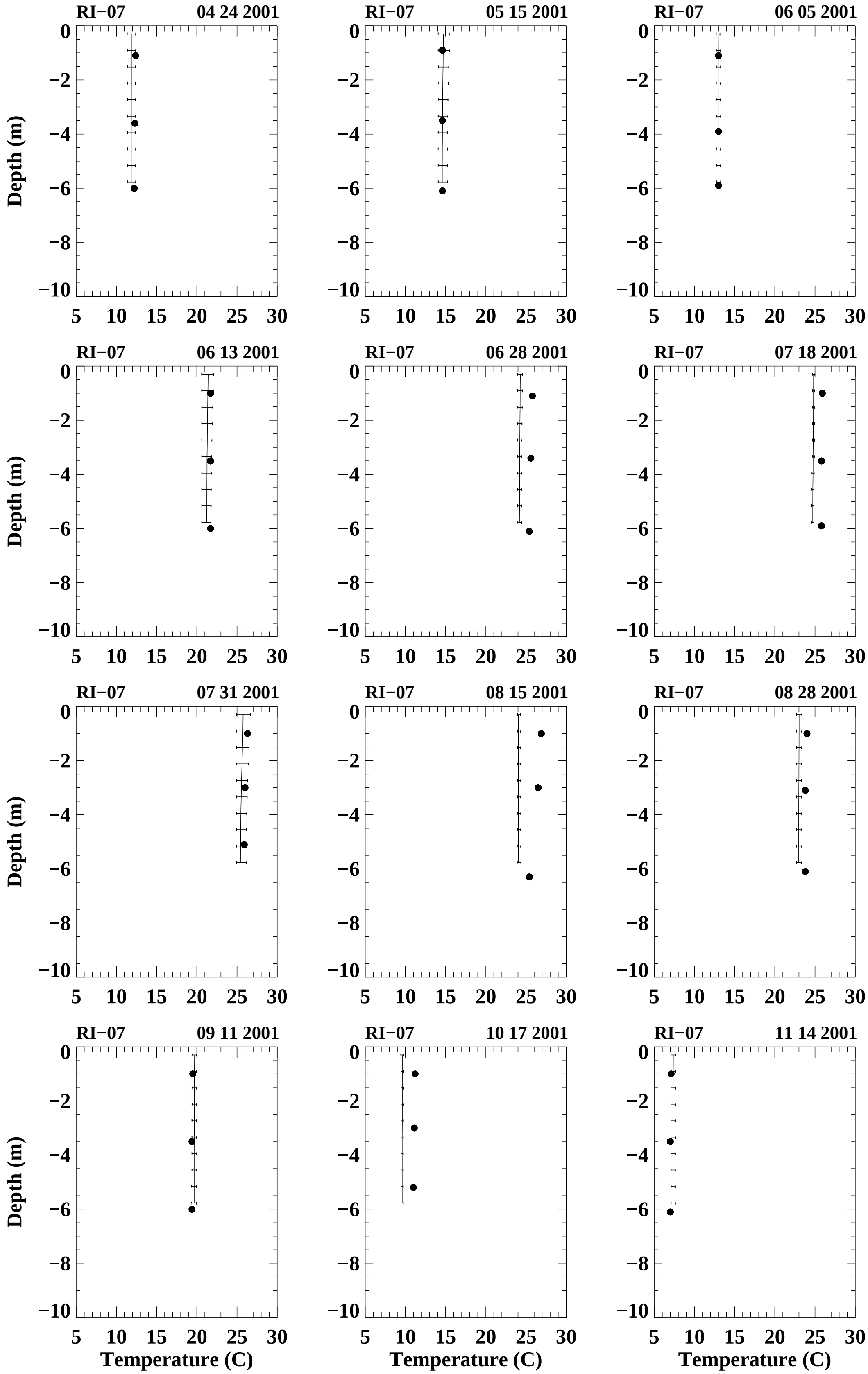

RI−07
05 03 2000
05 18 2000
05 30 2000
06 20 2000
07 11 2000
07 31 2000
08 17 2000
08 29 2000
09 12 2000
09 27 2000
10 11 2000
10 26 2000
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30

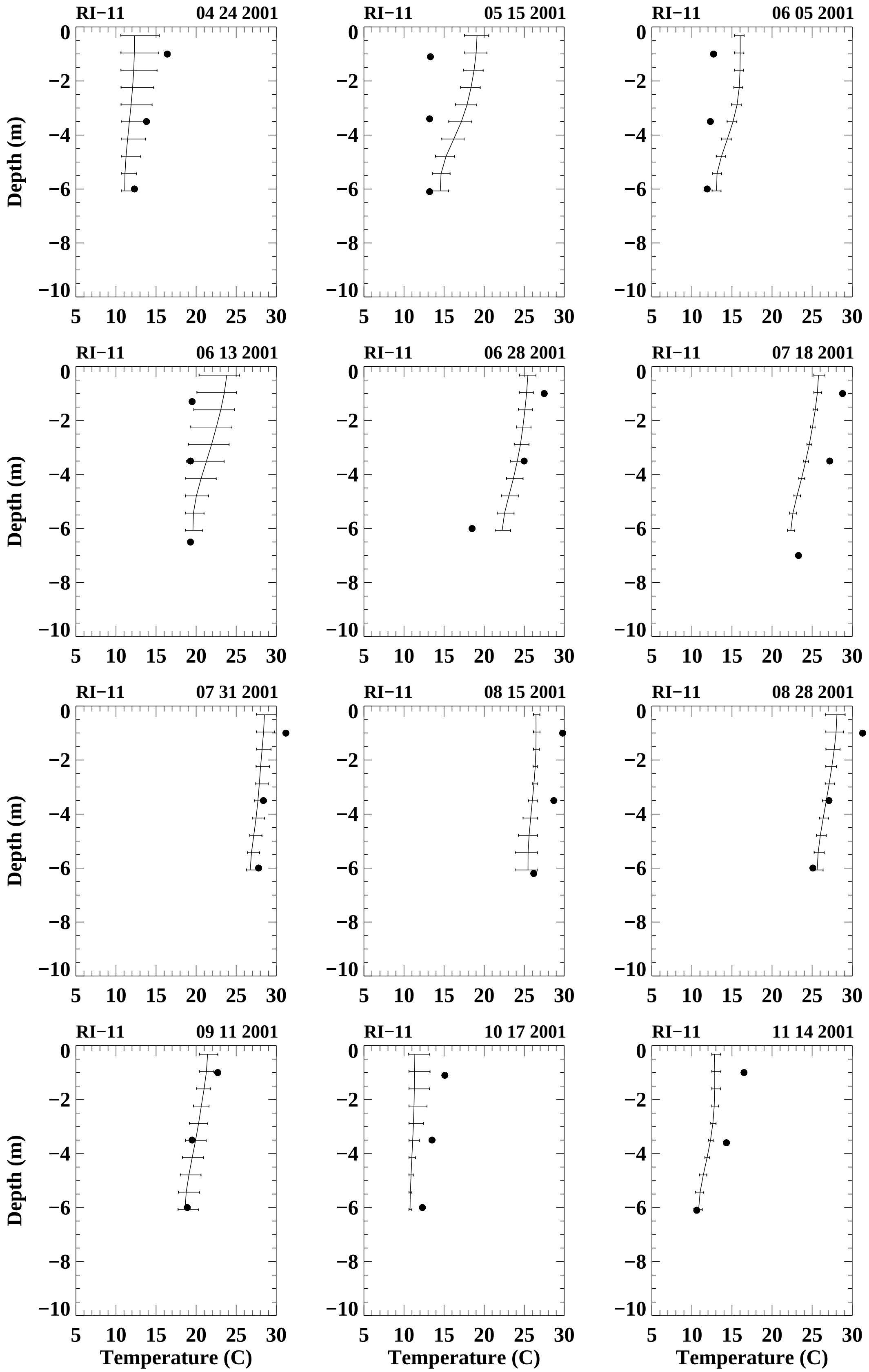

RI−11
05 03 2000
05 18 2000
05 30 2000
06 20 2000
07 11 2000
07 31 2000
08 17 2000
08 29 2000
09 12 2000
09 27 2000
10 11 2000
10 26 2000
Depth (m)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30
Temperature (C)

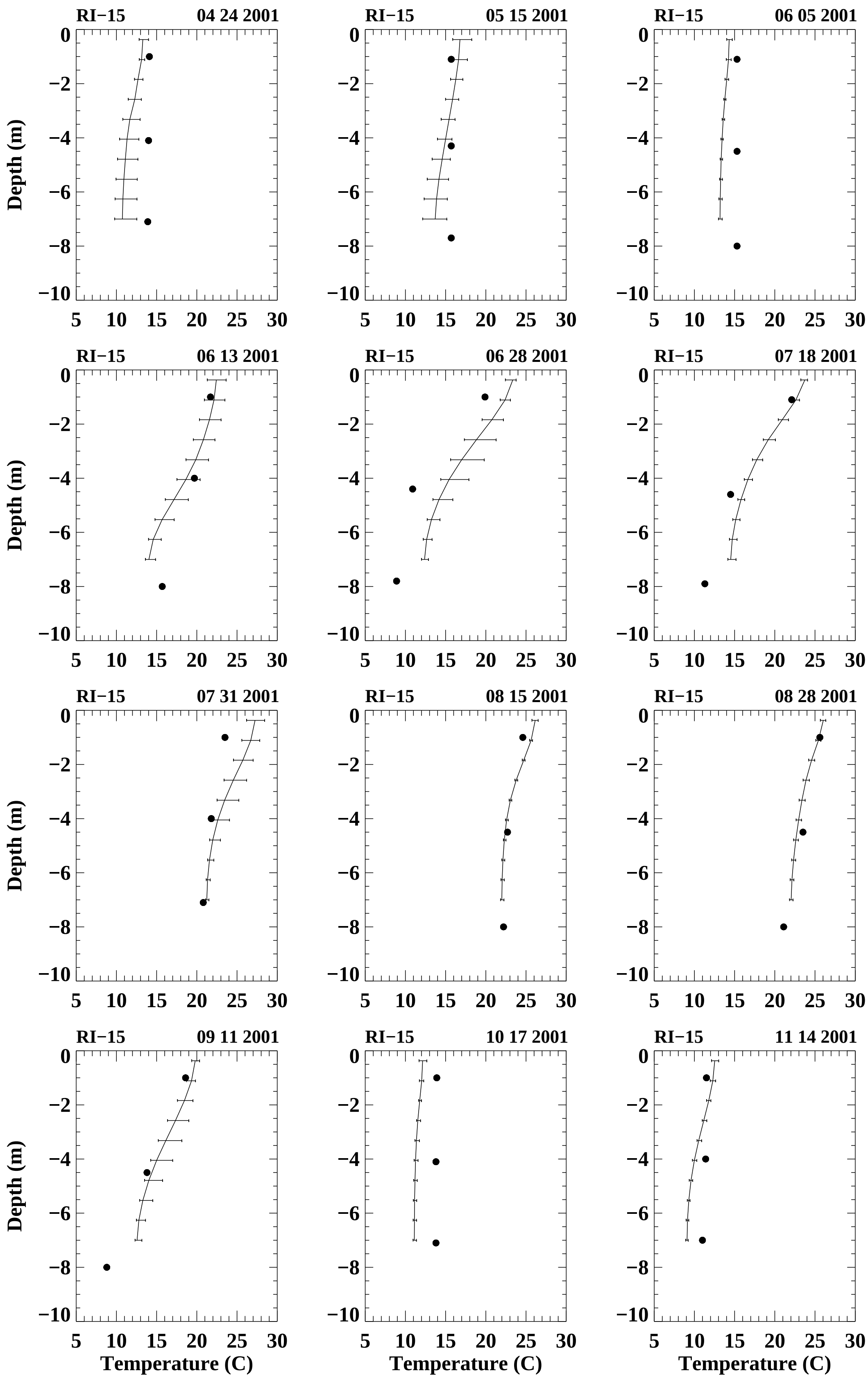


RI−15
05 03 2000
05 18 2000
05 30 2000
06 20 2000
07 11 2000
07 31 2000
08 17 2000
08 29 2000
09 12 2000
09 27 2000
10 11 2000
10 26 2000
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30

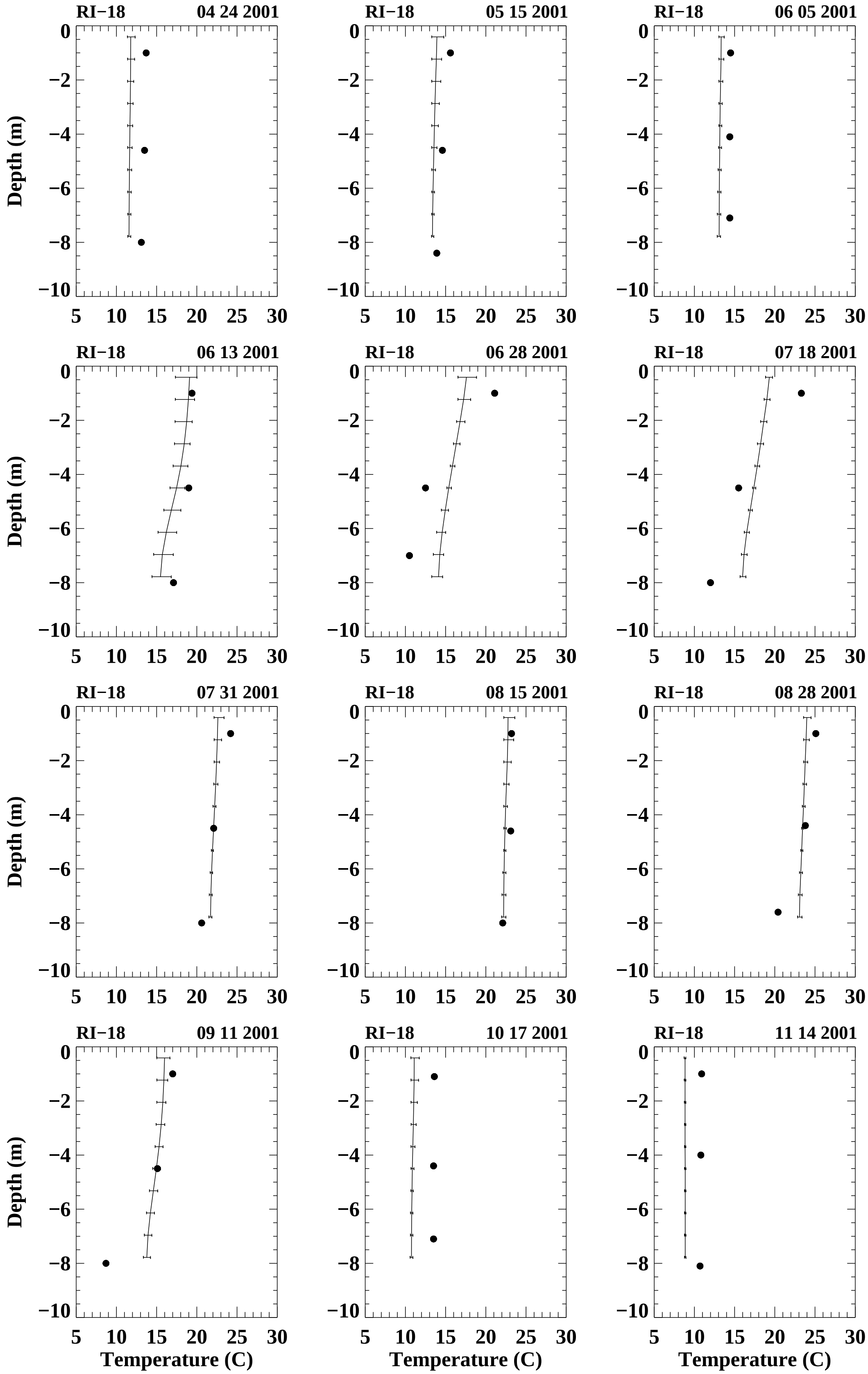

RI−18 05 03 2000
RI−18 05 18 2000
RI−18 05 30 2000
RI−18 06 20 2000
RI−18 07 11 2000
RI−18 07 31 2000
RI−18 08 17 2000
RI−18 08 29 2000
RI−18 09 12 2000
RI−18 09 27 2000
RI−18 10 11 2000
RI−18 10 26 2000
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30

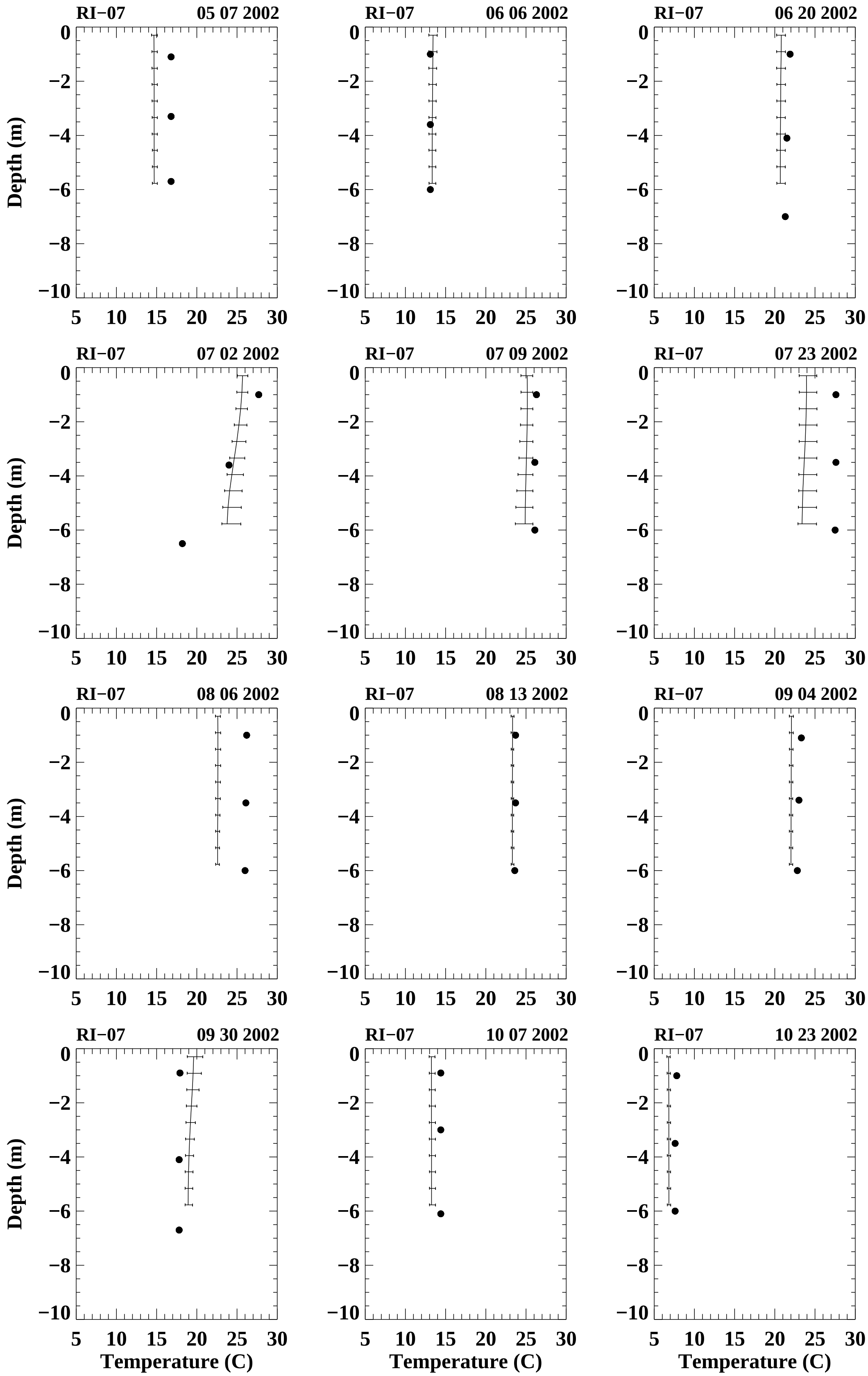

RI−07 04 24 2001
RI−07 05 15 2001
RI−07 06 05 2001
RI−07 06 13 2001
RI−07 06 28 2001
RI−07 07 18 2001
RI−07 07 31 2001
RI−07 08 15 2001
RI−07 08 28 2001
RI−07 09 11 2001
RI−07 10 17 2001
RI−07 11 14 2001
Depth (m)
0
−2
−4
−6
−8
−10
5 10 15 20 25 30
Temperature (C)

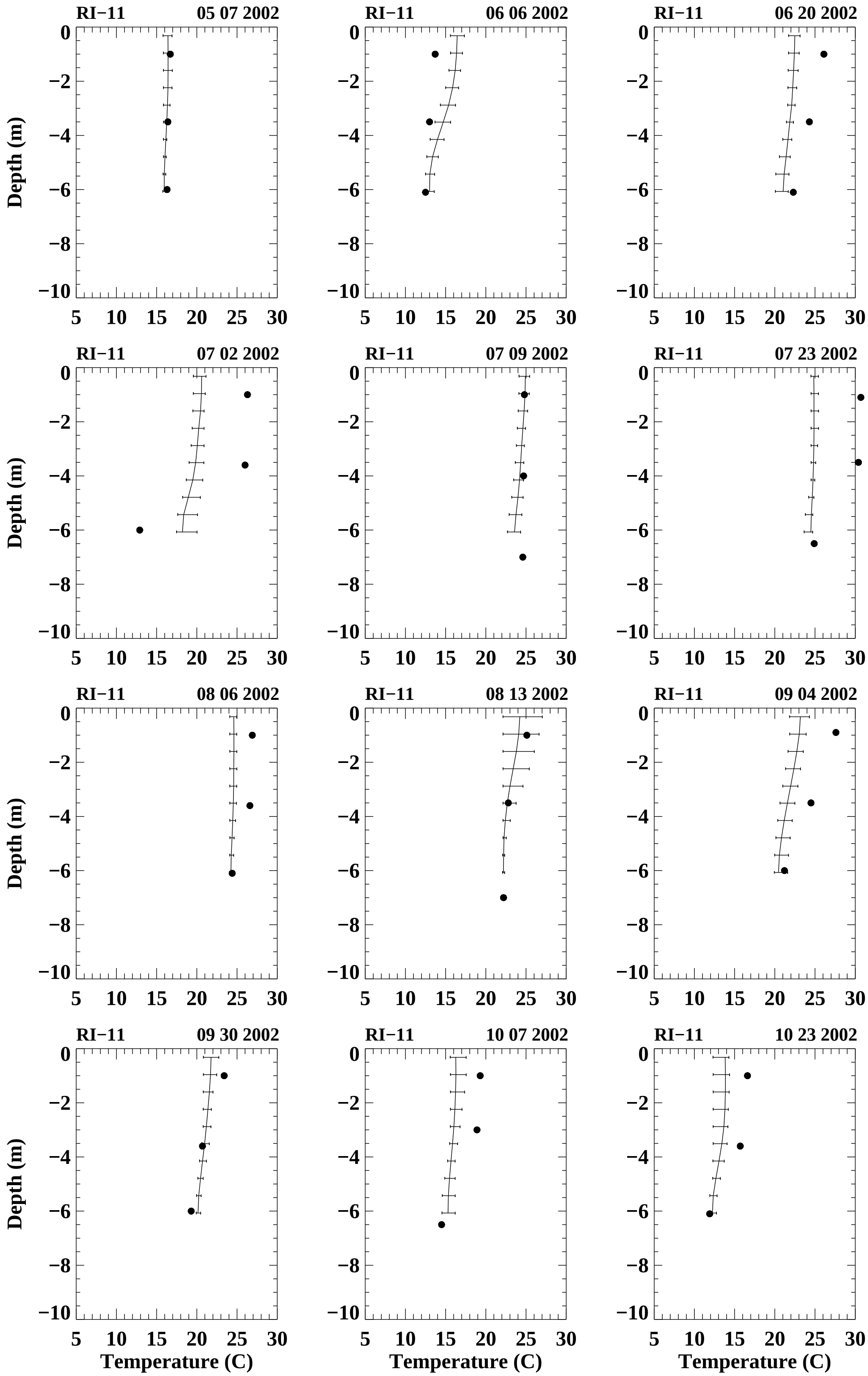

RI−11
04 24 2001
RI−11
05 15 2001
RI−11
06 05 2001
RI−11
06 13 2001
RI−11
06 28 2001
RI−11
07 18 2001
RI−11
07 31 2001
RI−11
08 15 2001
RI−11
08 28 2001
RI−11
09 11 2001
RI−11
10 17 2001
RI−11
11 14 2001
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30

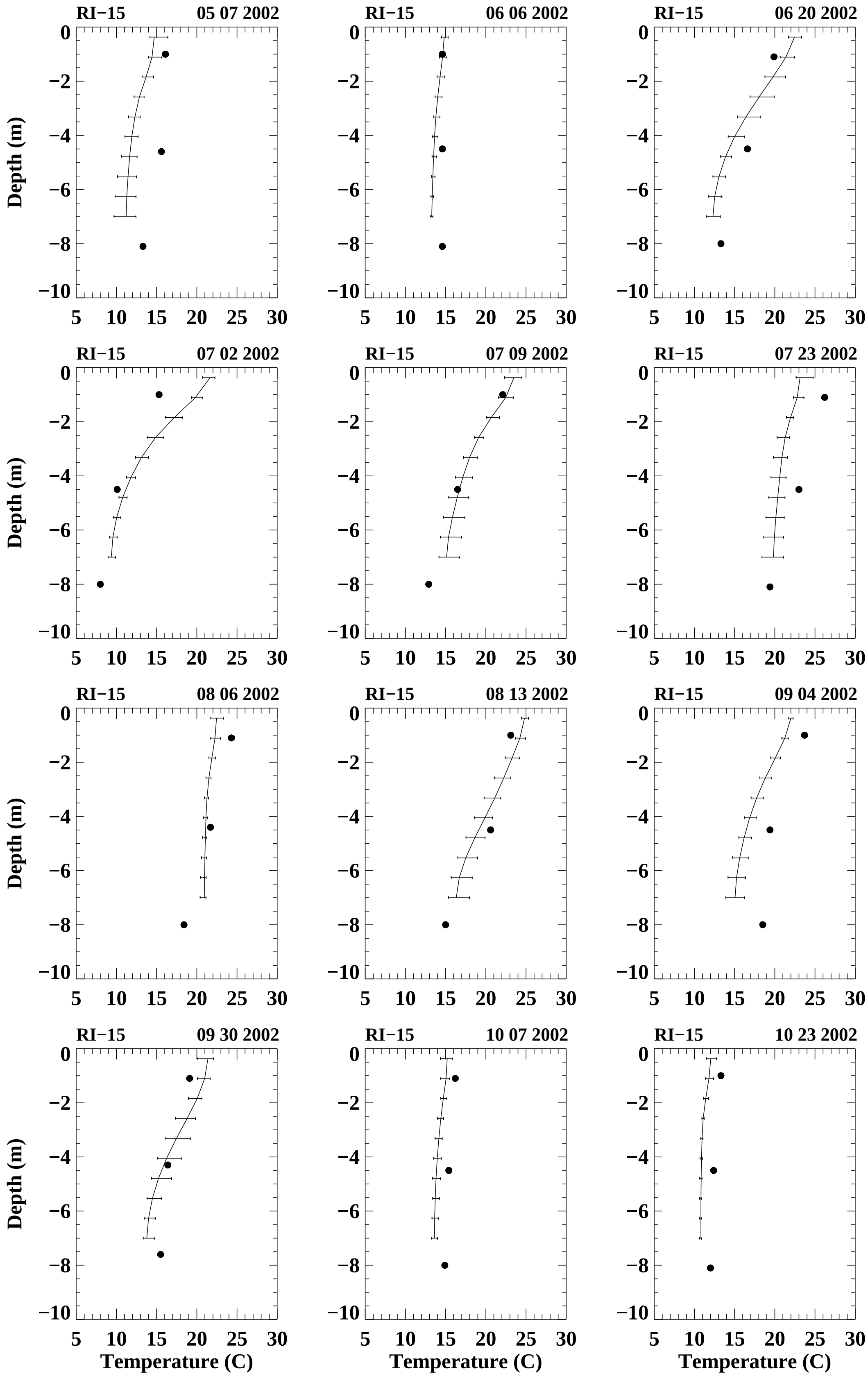


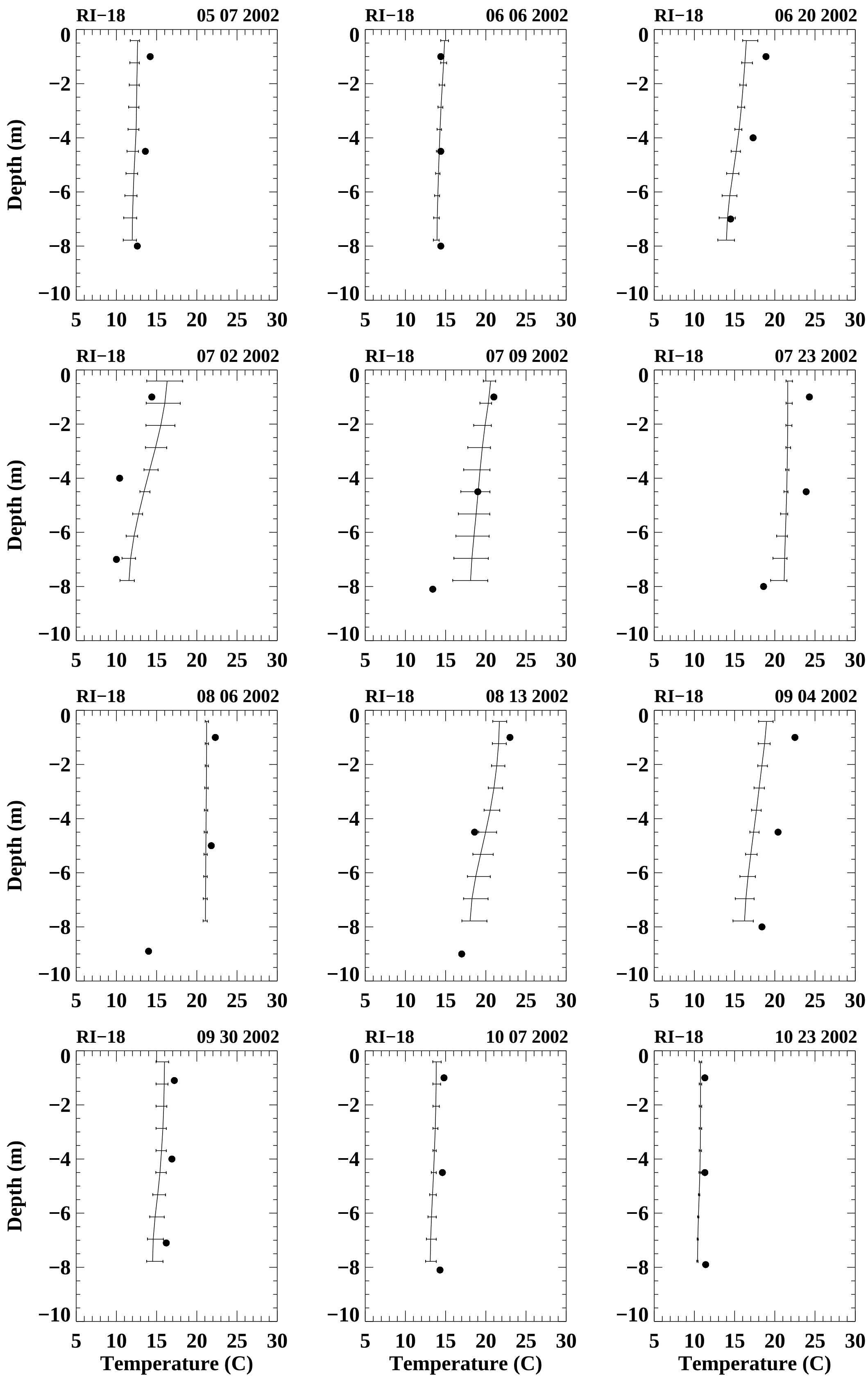
RI−15
04 24 2001
05 15 2001
06 05 2001
06 13 2001
06 28 2001
07 18 2001
07 31 2001
08 15 2001
08 28 2001
09 11 2001
10 17 2001
11 14 2001
Depth (m)
Temperature (C)


RI−18
04 24 2001
05 15 2001
06 05 2001
06 13 2001
06 28 2001
07 18 2001
07 31 2001
08 15 2001
08 28 2001
09 11 2001
10 17 2001
11 14 2001
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30


RI−07 05 07 2002
RI−07 06 06 2002
RI−07 06 20 2002
RI−07 07 02 2002
RI−07 07 09 2002
RI−07 07 23 2002
RI−07 08 06 2002
RI−07 08 13 2002
RI−07 09 04 2002
RI−07 09 30 2002
RI−07 10 07 2002
RI−07 10 23 2002
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
5 10 15 20 25 30


RI−11
05 07 2002
RI−11
06 06 2002
RI−11
06 20 2002
RI−11
07 02 2002
RI−11
07 09 2002
RI−11
07 23 2002
RI−11
08 06 2002
RI−11
08 13 2002
RI−11
09 04 2002
RI−11
09 30 2002
RI−11
10 07 2002
RI−11
10 23 2002
Depth (m)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30
Temperature (C)


RI−15 05 07 2002
RI−15 06 06 2002
RI−15 06 20 2002
RI−15 07 02 2002
RI−15 07 09 2002
RI−15 07 23 2002
RI−15 08 06 2002
RI−15 08 13 2002
RI−15 09 04 2002
RI−15 09 30 2002
RI−15 10 07 2002
RI−15 10 23 2002
Depth (m)
0
−2
−4
−6
−8
−10
5 10 15 20 25 30
Temperature (C)


RI−18
05 07 2002
06 06 2002
06 20 2002
07 02 2002
07 09 2002
07 23 2002
08 06 2002
08 13 2002
09 04 2002
09 30 2002
10 07 2002
10 23 2002
Depth (m)
Temperature (C)
0
−2
−4
−6
−8
−10
5
10
15
20
25
30

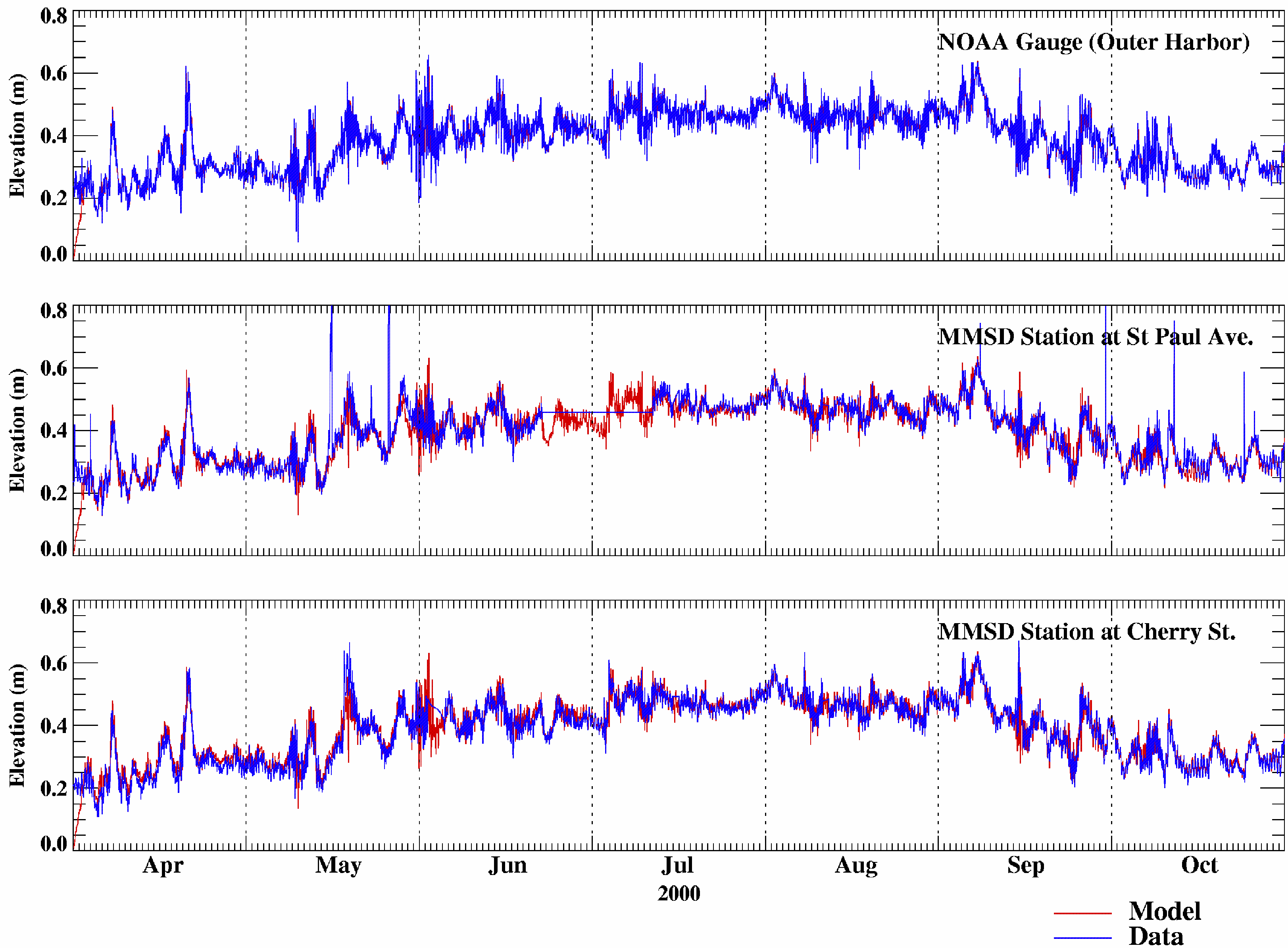


Figure 28. Water Level Model Calibration (Hourly)

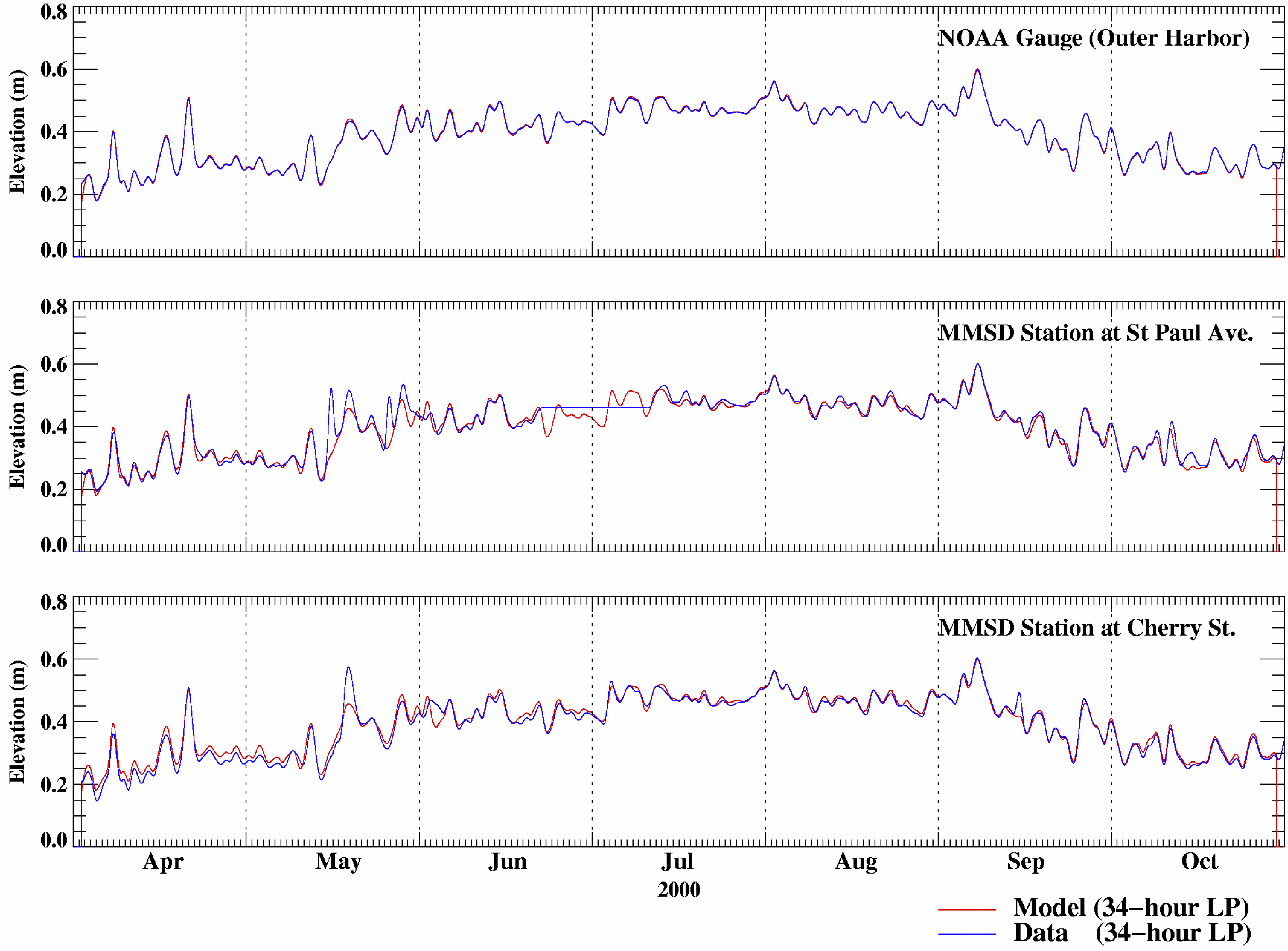
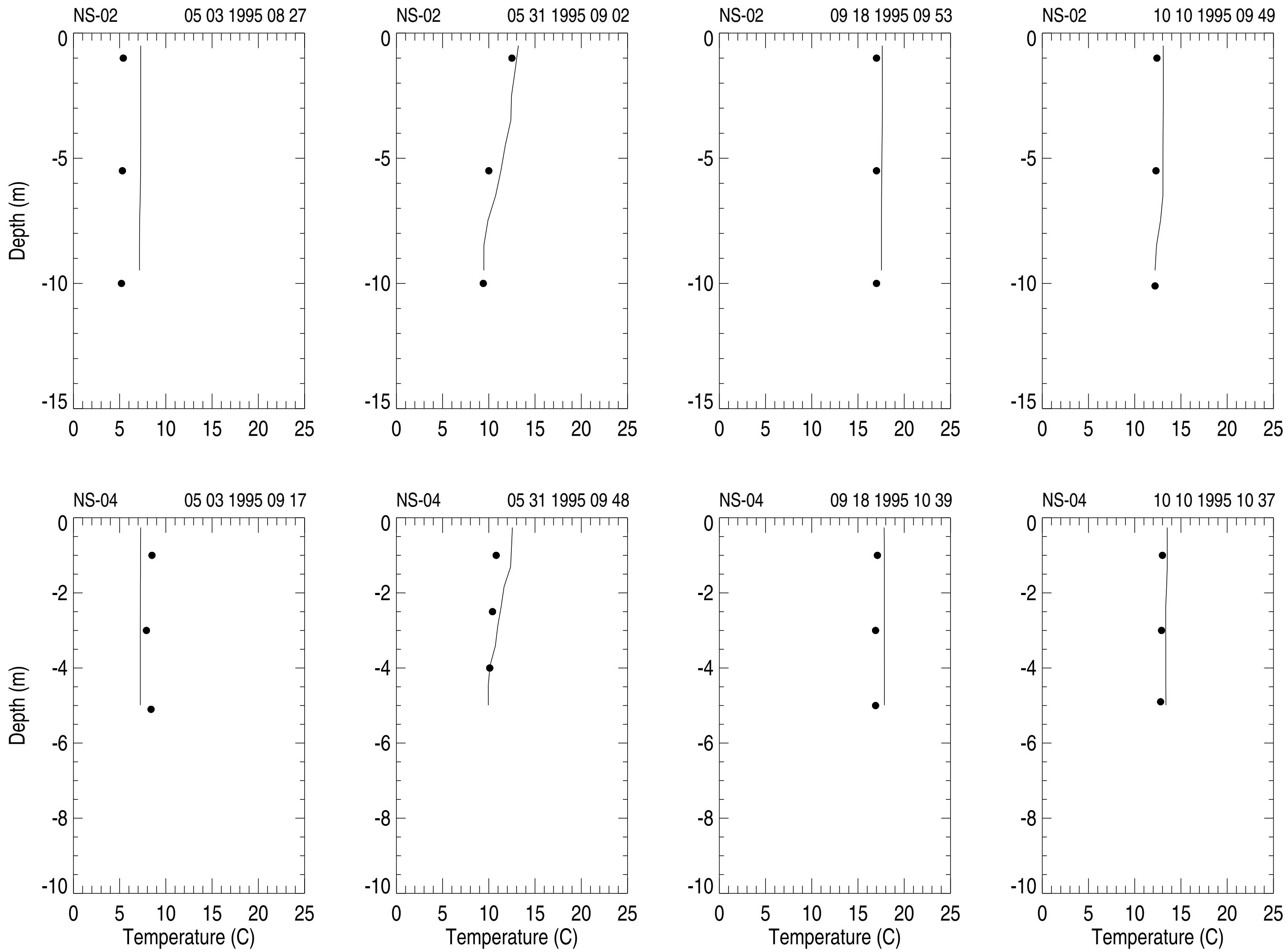
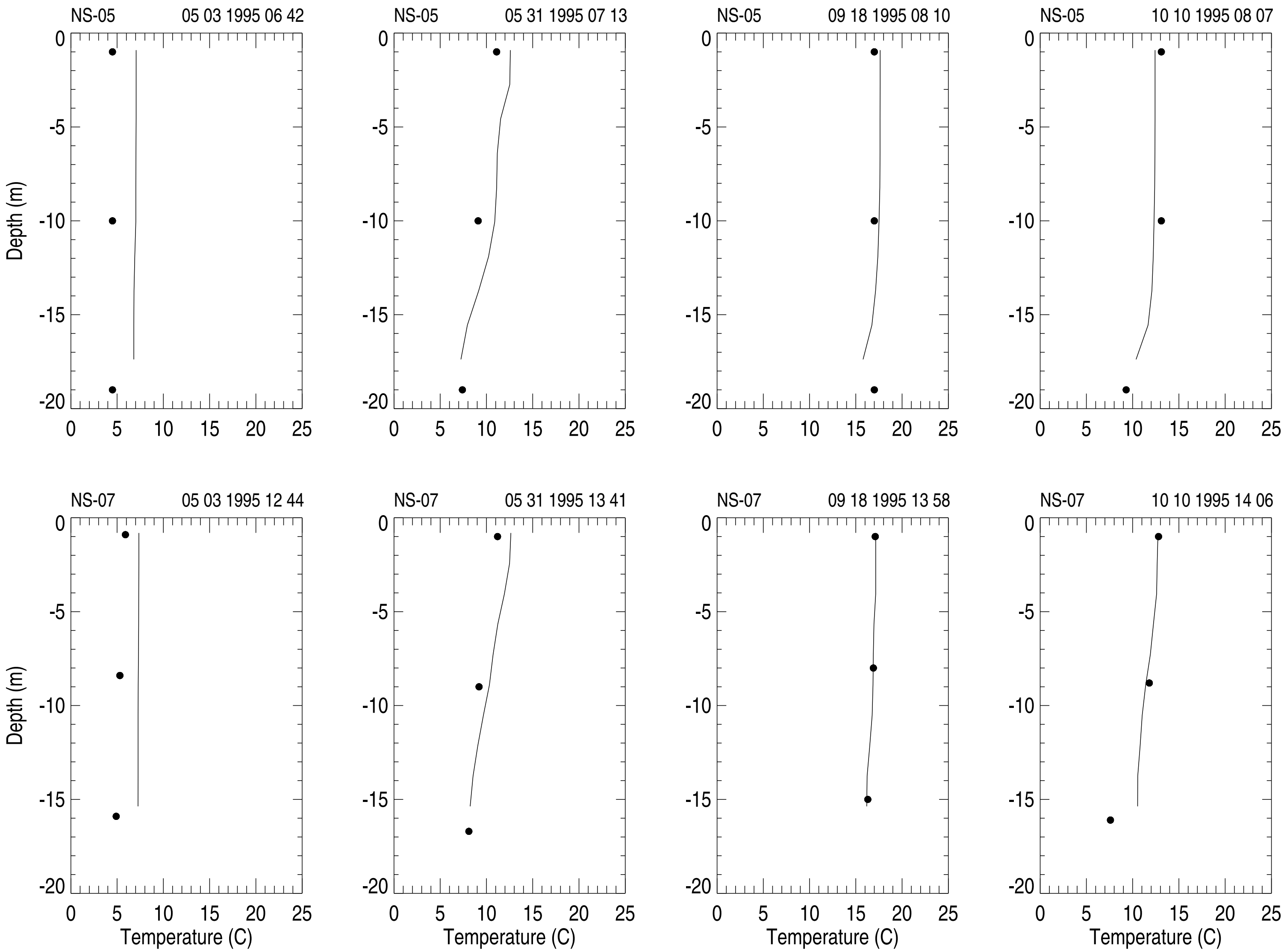
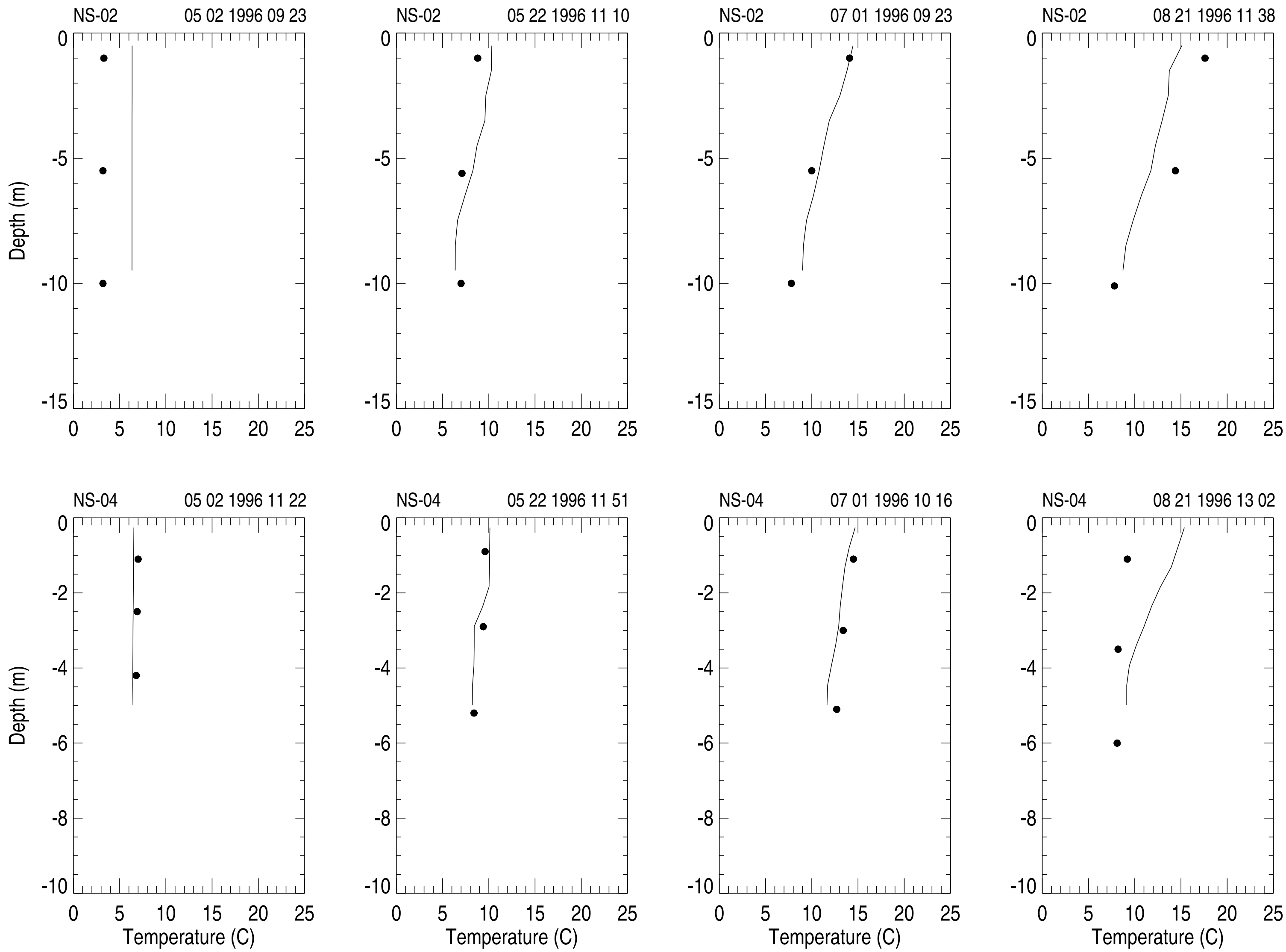


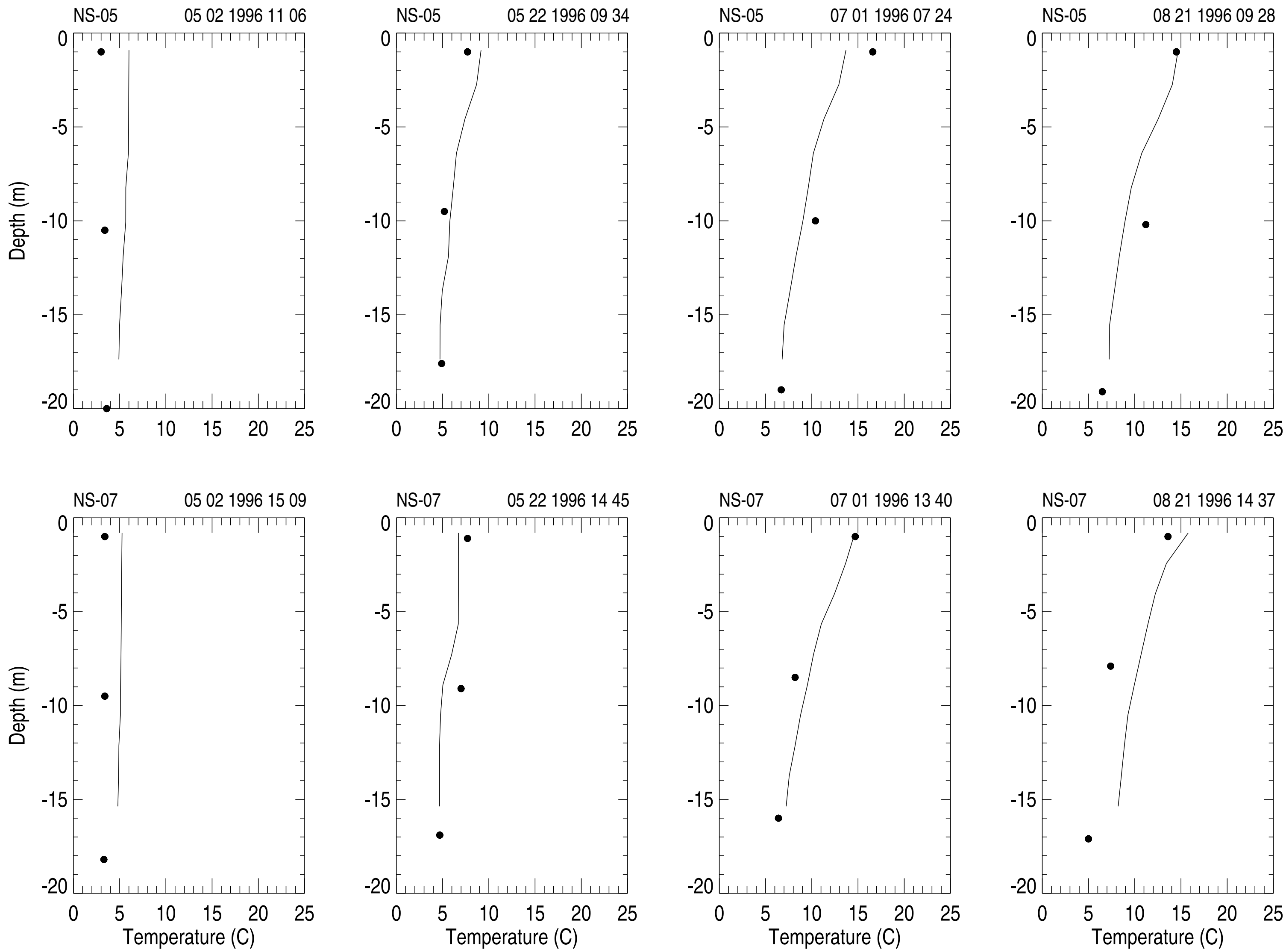
Figure 29. Water Level Model Calibration (34-hour Low-pass Filtered)

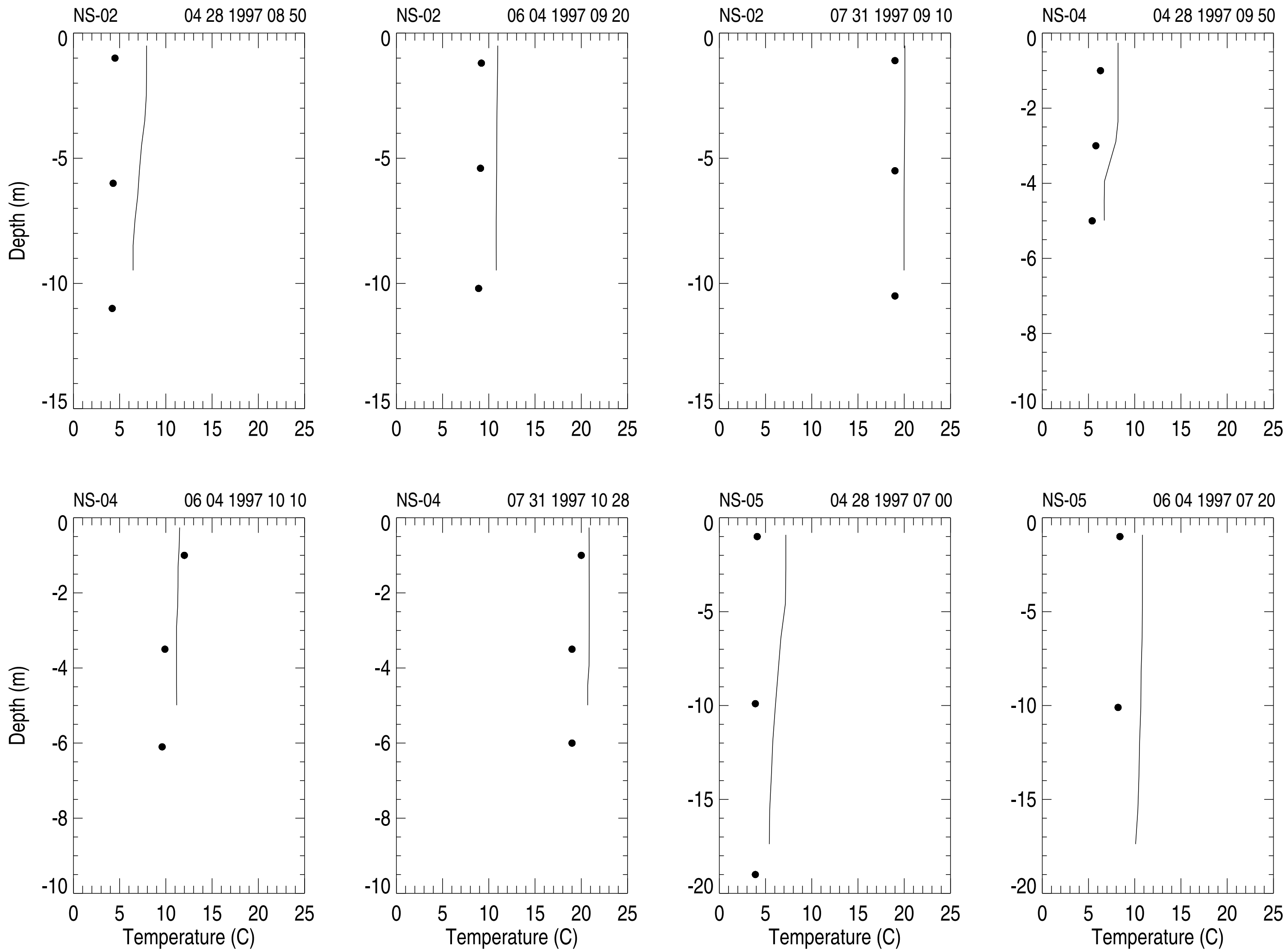
APPENDIX 1
COMPARISON OF THE COMPUTED AND OBSERVED TEMPERATURE PROFILES AT 34 MMSD SAMPLING STATIONS

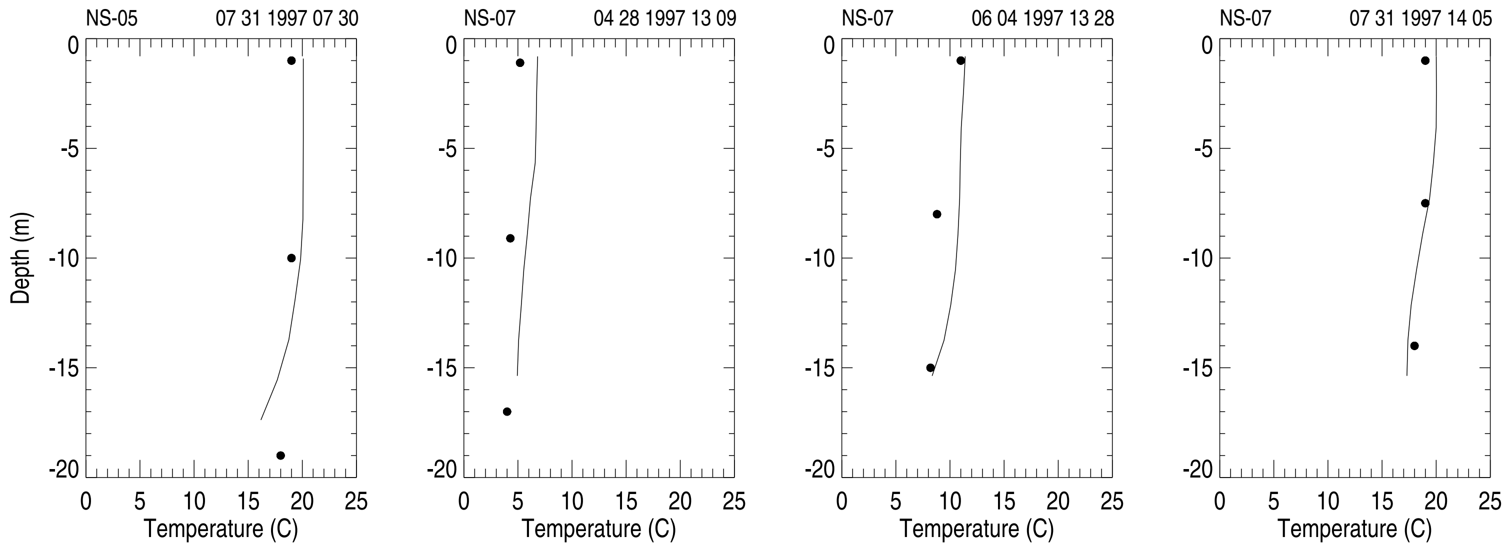

NS-02
05 03 1995 08 27
NS-02
05 31 1995 09 02
NS-02
09 18 1995 09 53
NS-02
10 10 1995 09 49
Depth (m)
NS-04
05 03 1995 09 17
NS-04
05 31 1995 09 48
NS-04
09 18 1995 10 39
NS-04
10 10 1995 10 37
Depth (m)
Temperature (C)


NS-05 05 03 1995 06 42
NS-05 05 31 1995 07 13
NS-05 09 18 1995 08 10
NS-05 10 10 1995 08 07
NS-07 05 03 1995 12 44
NS-07 05 31 1995 13 41
NS-07 09 18 1995 13 58
NS-07 10 10 1995 14 06
Depth (m)
0
-5
-10
-15
-20
0 5 10 15 20 25
Temperature (C)

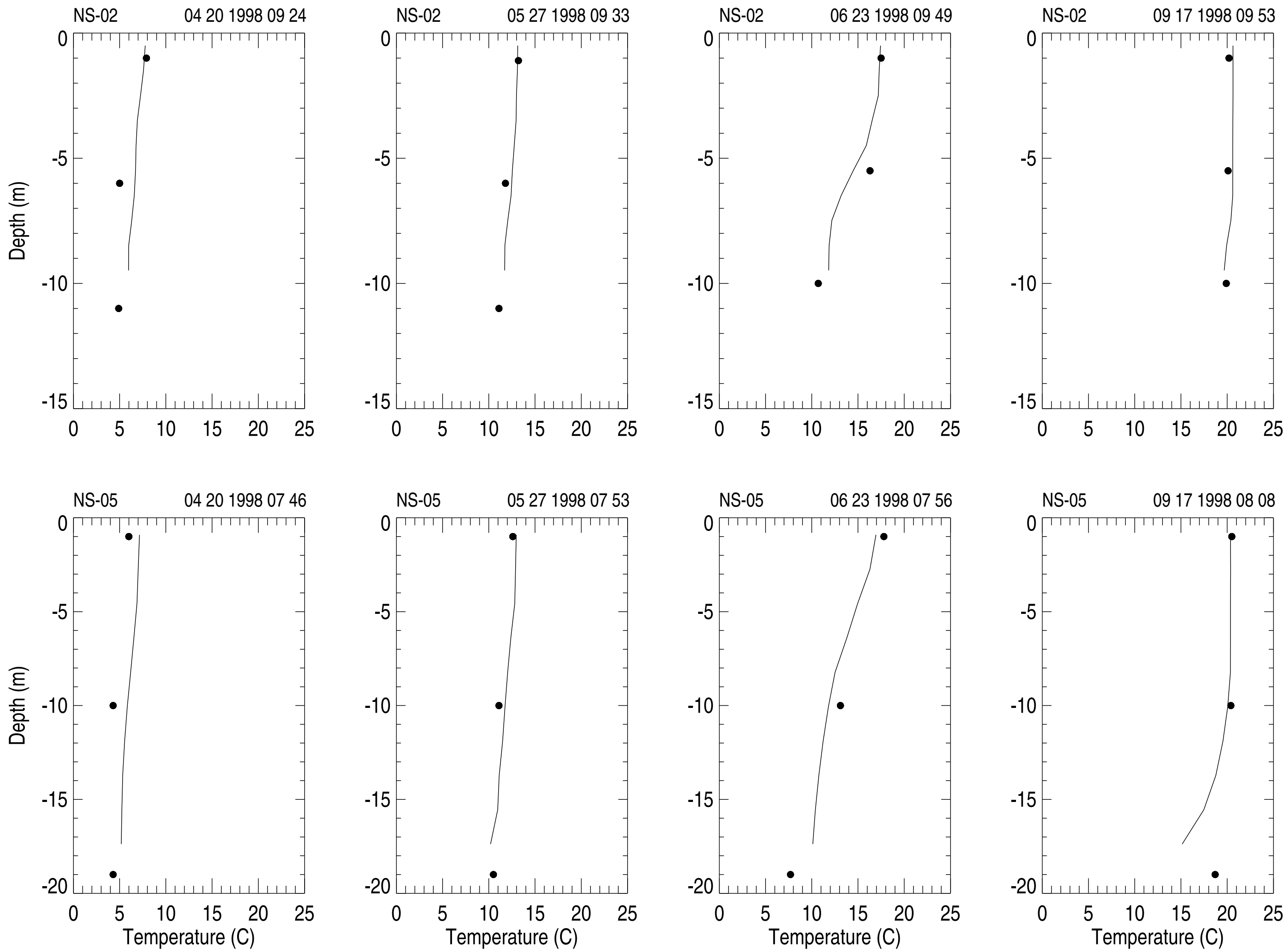

NS-02
05 02 1996 09 23
NS-02
05 22 1996 11 10
NS-02
07 01 1996 09 23
NS-02
08 21 1996 11 38
NS-04
05 02 1996 11 22
NS-04
05 22 1996 11 51
NS-04
07 01 1996 10 16
NS-04
08 21 1996 13 02
Depth (m)
Temperature (C)
0
-5
-10
-15
-2
-4
-6
-8
5
10
15
20
25

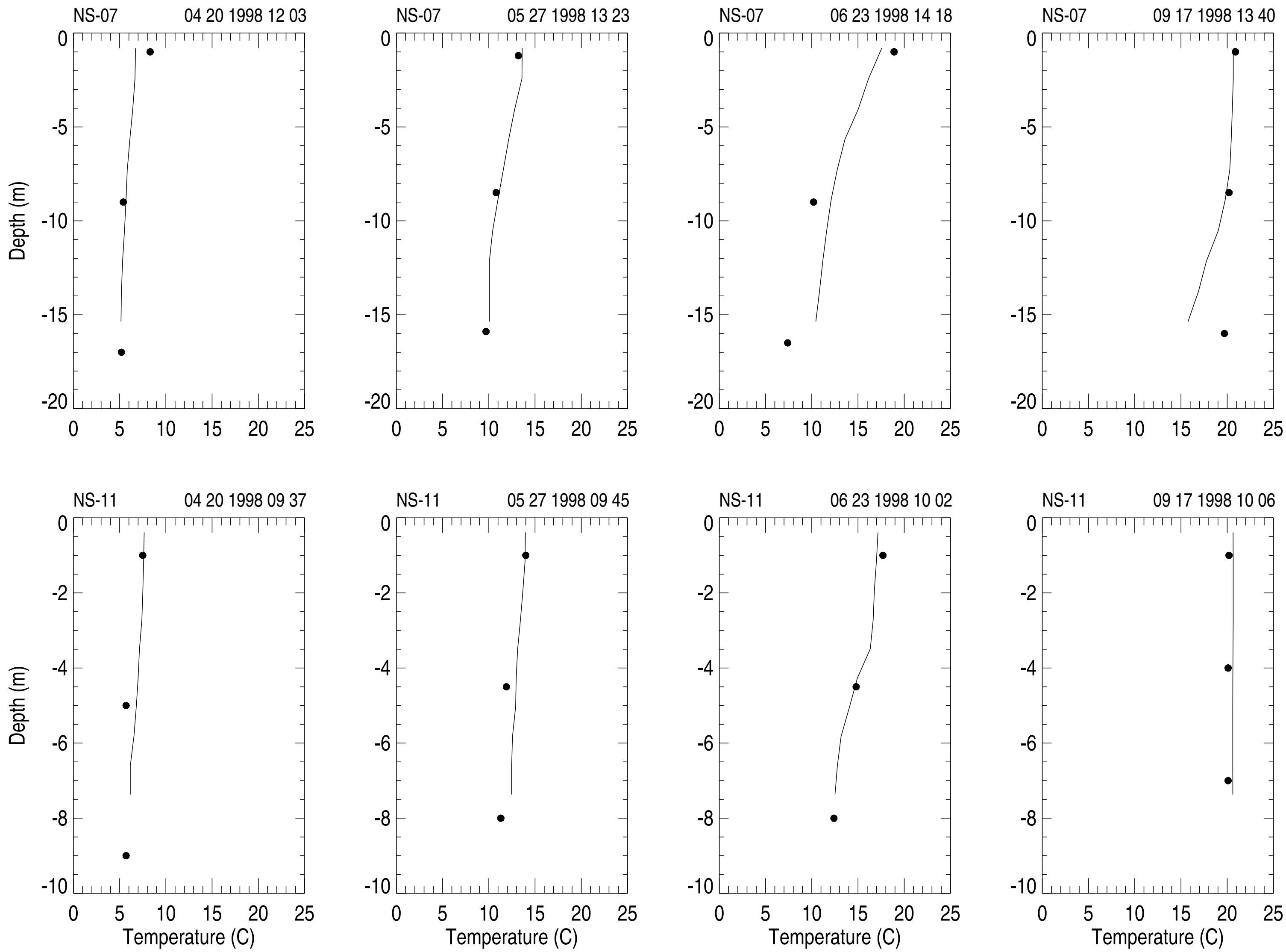

NS-05
05 02 1996 11 06
05 22 1996 09 34
07 01 1996 07 24
08 21 1996 09 28
NS-07
05 02 1996 15 09
05 22 1996 14 45
07 01 1996 13 40
08 21 1996 14 37
Depth (m)
Temperature (C)

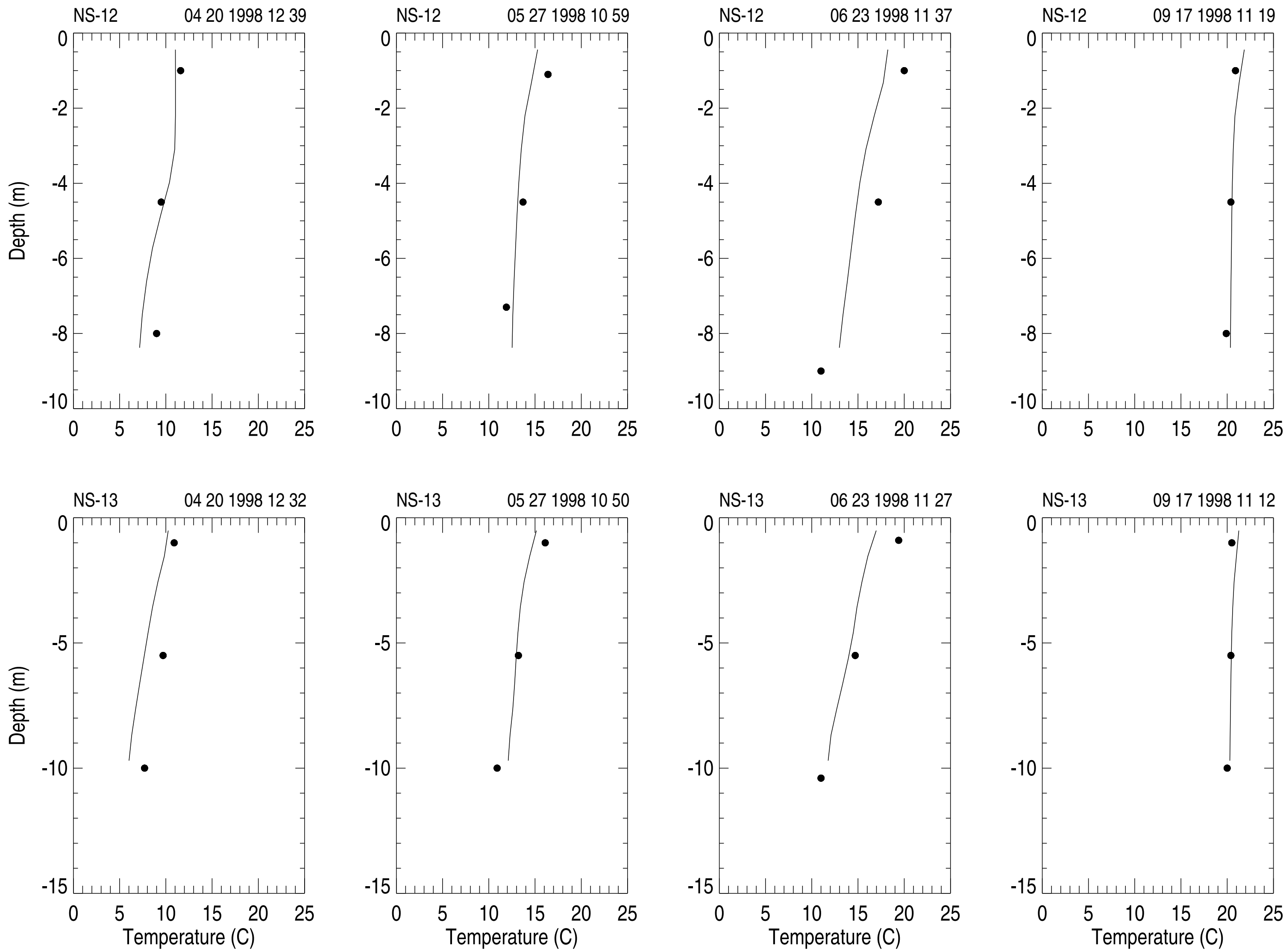

NS-02 04 28 1997 08 50
NS-02 06 04 1997 09 20
NS-02 07 31 1997 09 10
NS-04 04 28 1997 09 50
NS-04 06 04 1997 10 10
NS-04 07 31 1997 10 28
NS-05 04 28 1997 07 00
NS-05 06 04 1997 07 20
Depth (m)
Temperature (C)

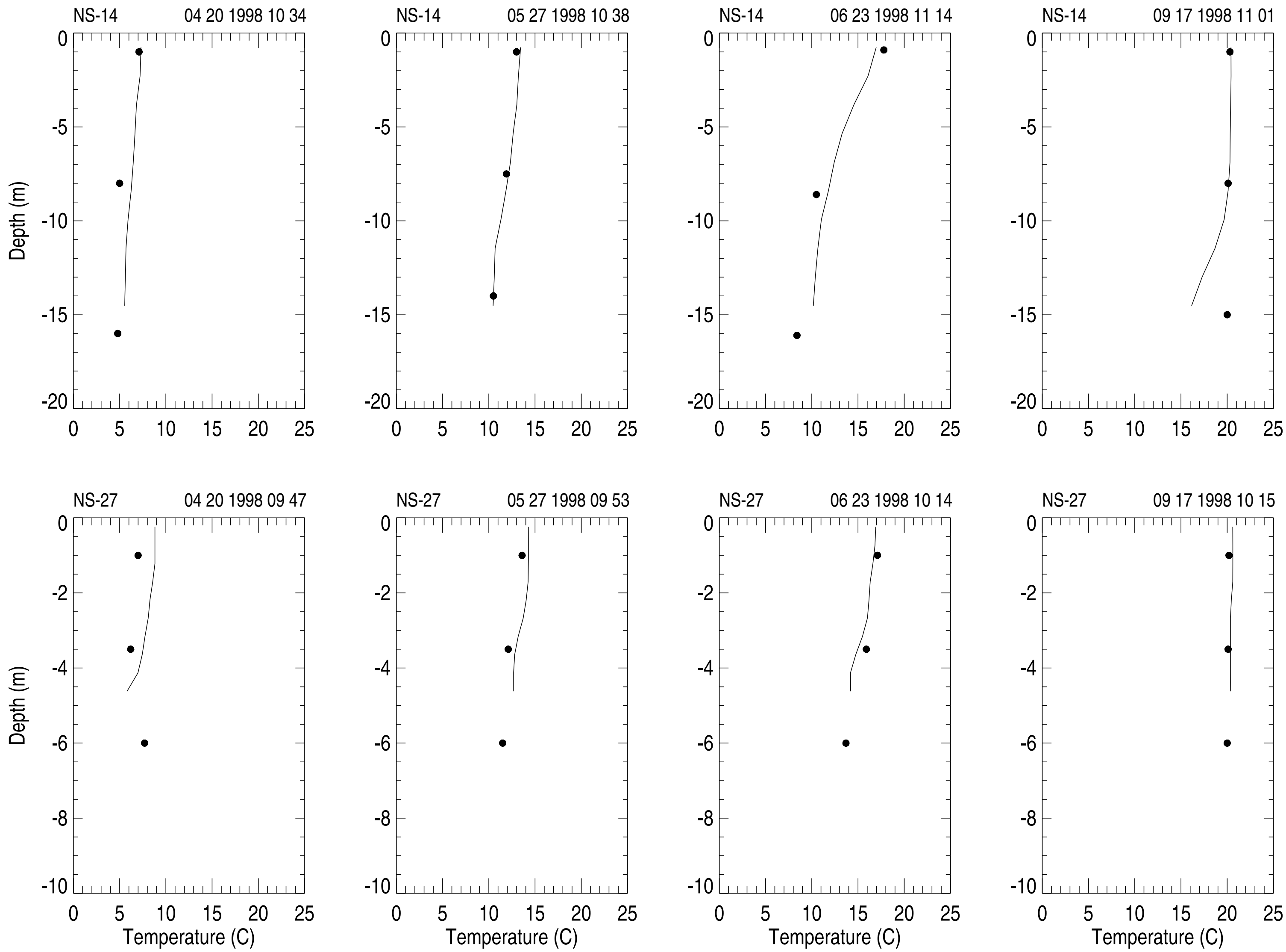


NS-05
07 31 1997 07 30
NS-07
04 28 1997 13 09
NS-07
06 04 1997 13 28
NS-07
07 31 1997 14 05
Depth (m)
Temperature (C)
0
-5
-10
-15
-20
0 5 10 15 20 25

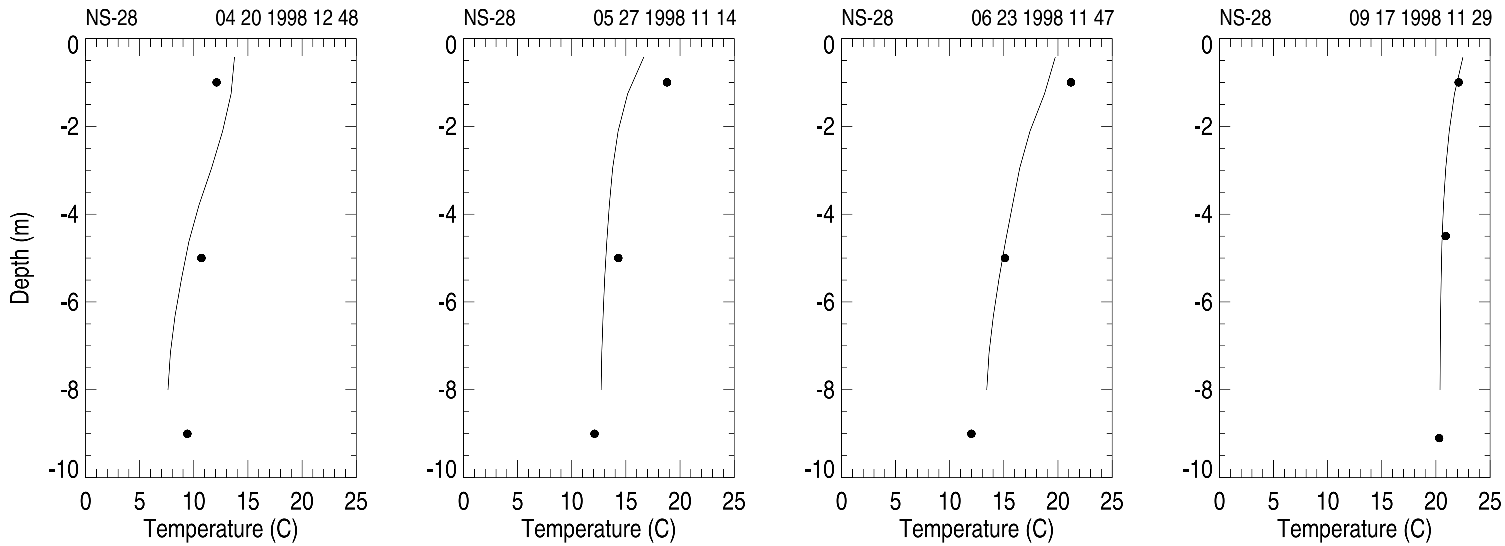

NS-02 04 20 1998 09 24
NS-02 05 27 1998 09 33
NS-02 06 23 1998 09 49
NS-02 09 17 1998 09 53
NS-05 04 20 1998 07 46
NS-05 05 27 1998 07 53
NS-05 06 23 1998 07 56
NS-05 09 17 1998 08 08
Depth (m)
0
-5
-10
-15
-20
0 5 10 15 20 25
Temperature (C)

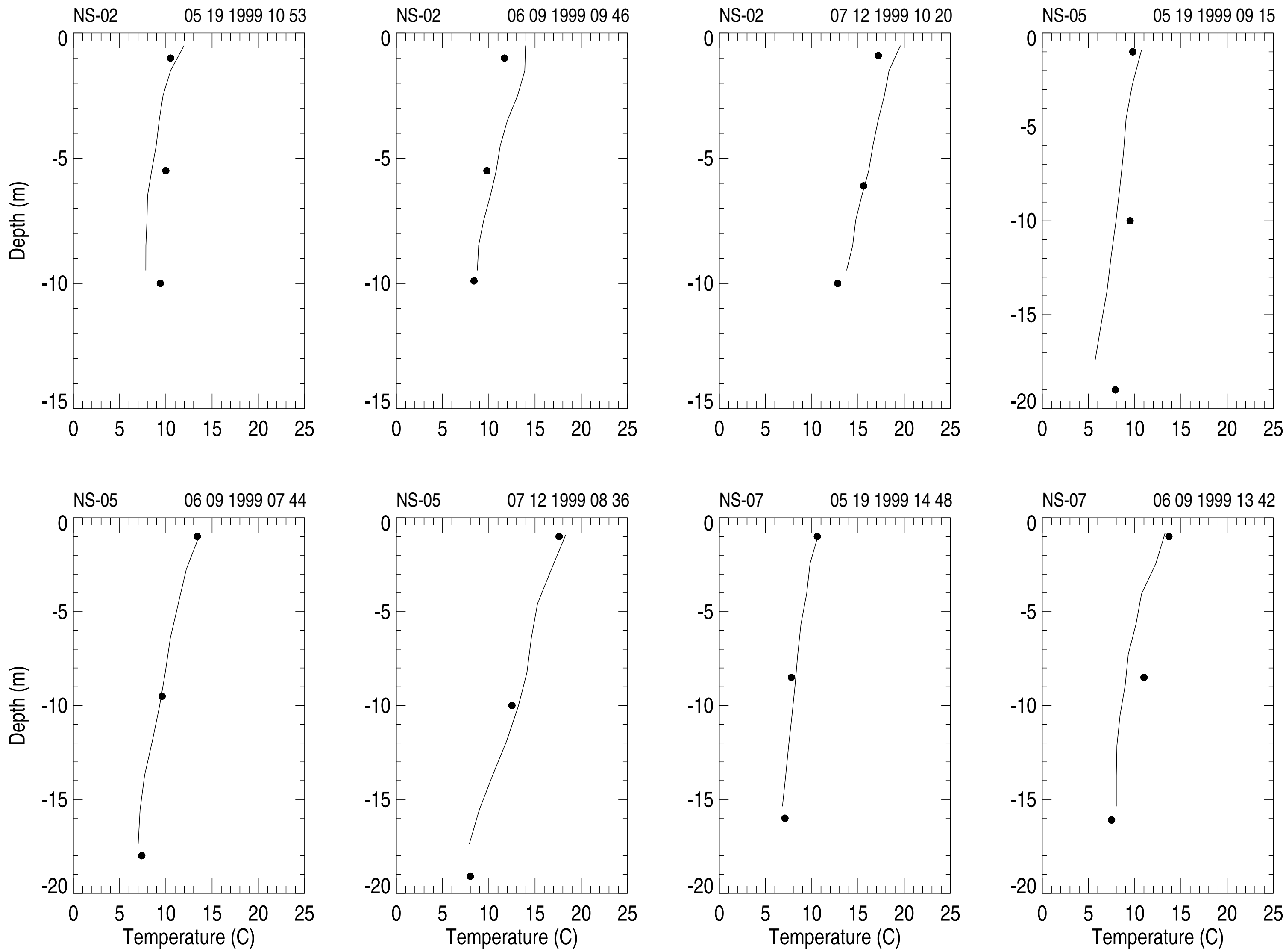

NS-07 04 20 1998 12 03
NS-07 05 27 1998 13 23
NS-07 06 23 1998 14 18
NS-07 09 17 1998 13 40
NS-11 04 20 1998 09 37
NS-11 05 27 1998 09 45
NS-11 06 23 1998 10 02
NS-11 09 17 1998 10 06
Depth (m)
Depth (m)
Temperature (C)
Temperature (C)
Temperature (C)
Temperature (C)

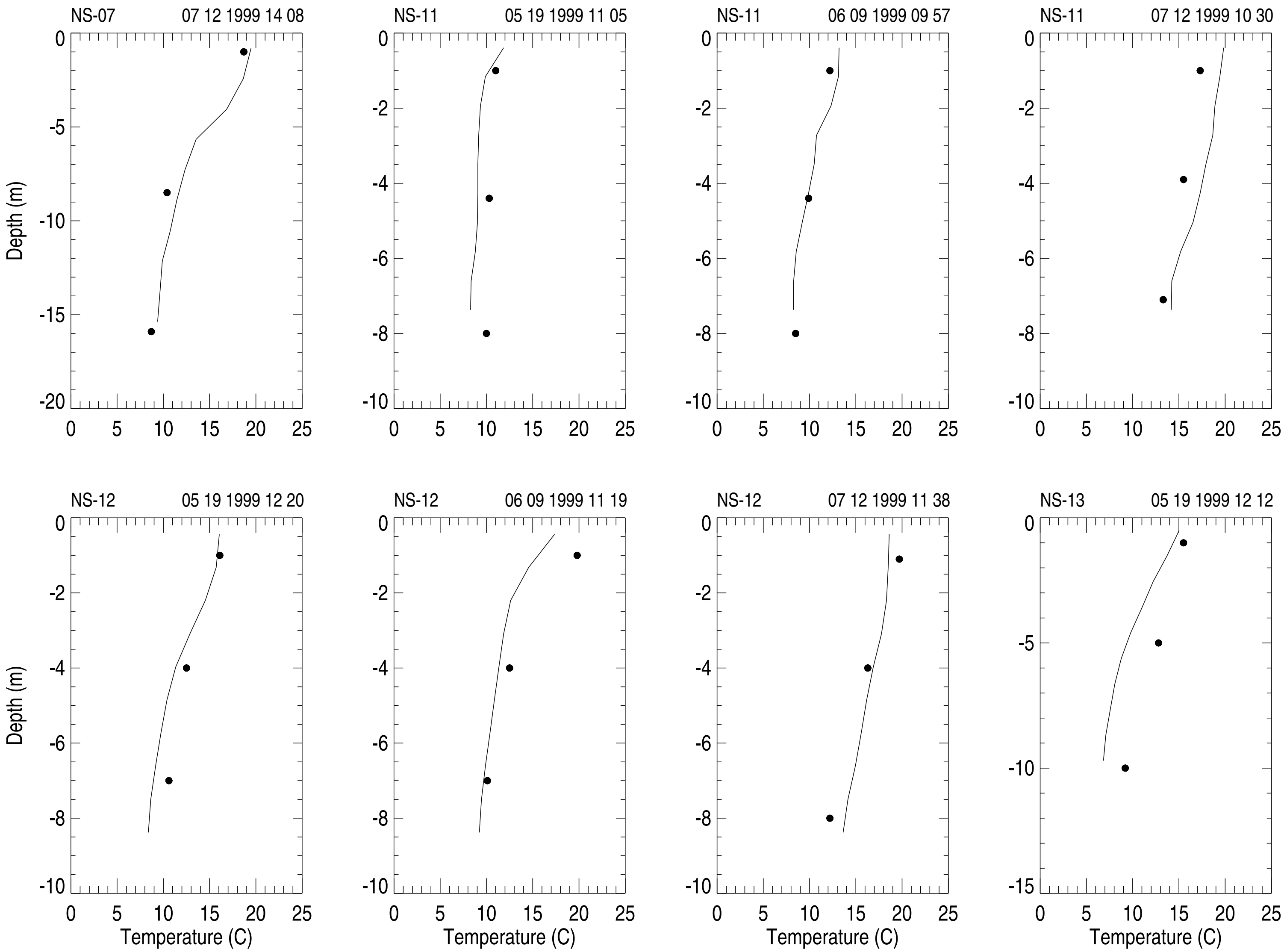

NS-12 04 20 1998 12 39
NS-12 05 27 1998 10 59
NS-12 06 23 1998 11 37
NS-12 09 17 1998 11 19
NS-13 04 20 1998 12 32
NS-13 05 27 1998 10 50
NS-13 06 23 1998 11 27
NS-13 09 17 1998 11 12
Depth (m)
Temperature (C)

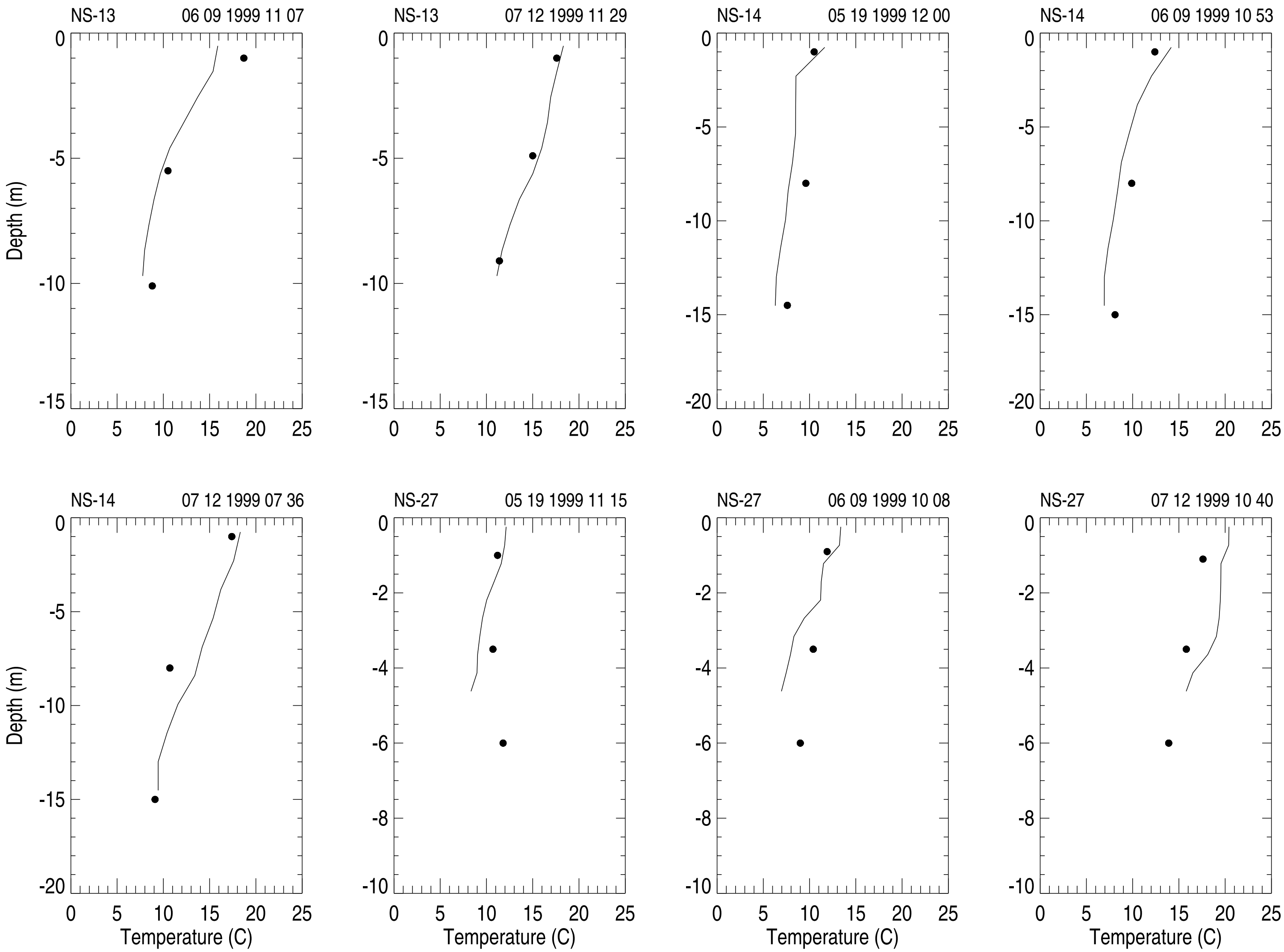


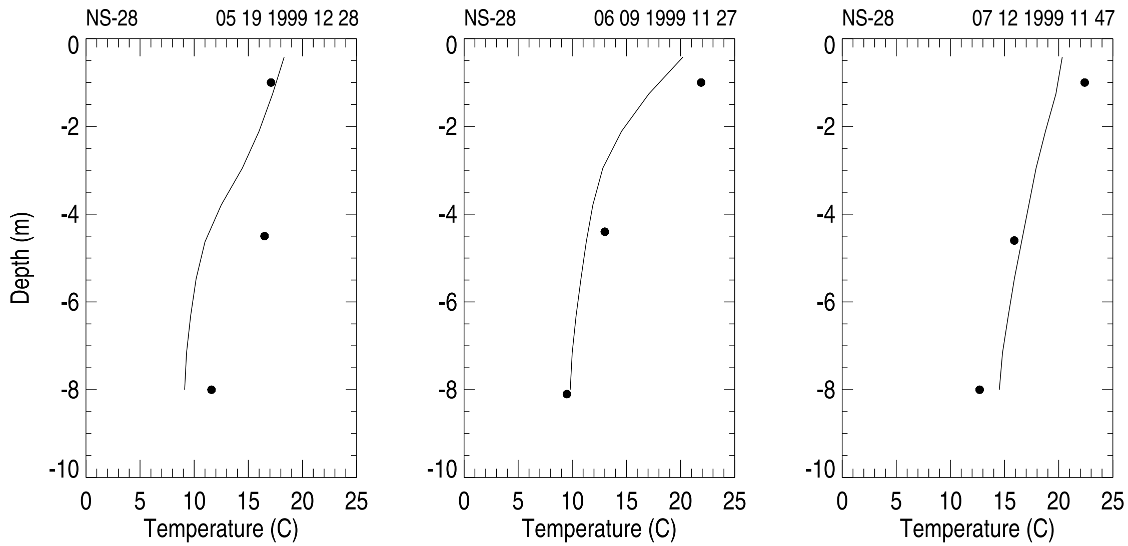
NS-14 04 20 1998 10 34
NS-14 05 27 1998 10 38
NS-14 06 23 1998 11 14
NS-14 09 17 1998 11 01
NS-27 04 20 1998 09 47
NS-27 05 27 1998 09 53
NS-27 06 23 1998 10 14
NS-27 09 17 1998 10 15
Depth (m)
Temperature (C)


NS-28
04 20 1998 12 48
NS-28
05 27 1998 11 14
NS-28
06 23 1998 11 47
NS-28
09 17 1998 11 29
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

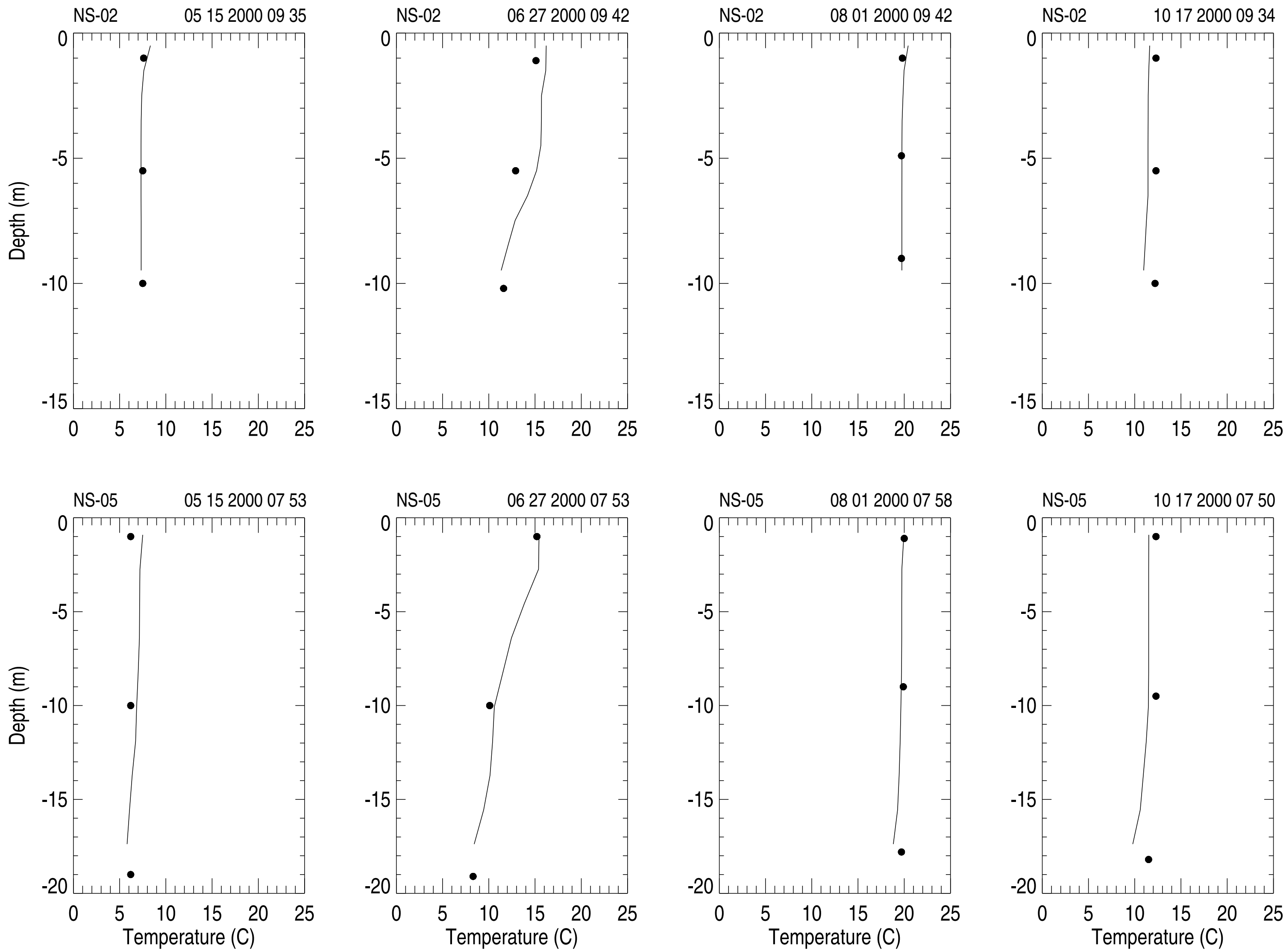

NS-02 05 19 1999 10 53
NS-02 06 09 1999 09 46
NS-02 07 12 1999 10 20
NS-05 05 19 1999 09 15
NS-05 06 09 1999 07 44
NS-05 07 12 1999 08 36
NS-07 05 19 1999 14 48
NS-07 06 09 1999 13 42
Depth (m)
Temperature (C)

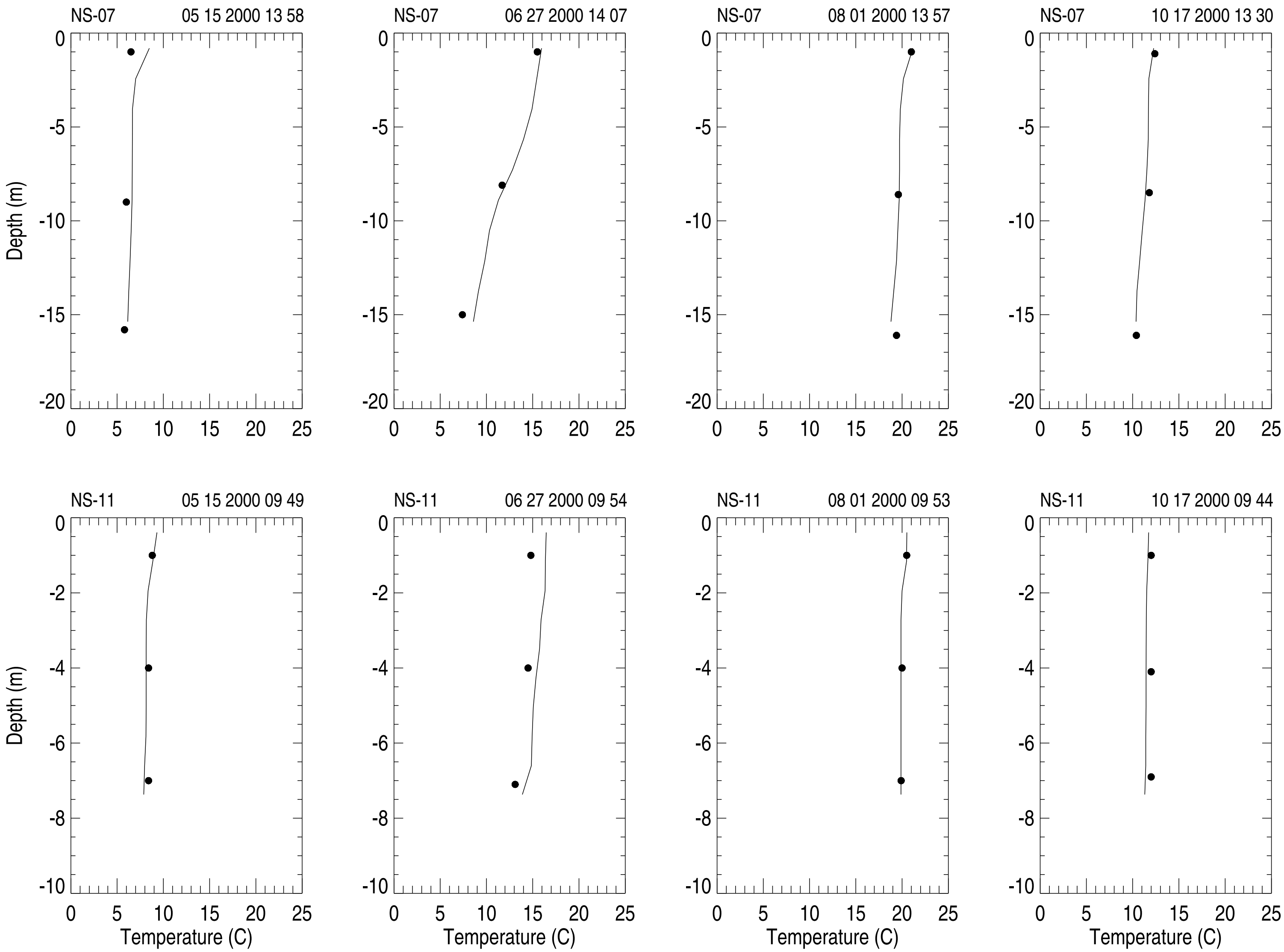

NS-07 07 12 1999 14 08
NS-11 05 19 1999 11 05
NS-11 06 09 1999 09 57
NS-11 07 12 1999 10 30
NS-12 05 19 1999 12 20
NS-12 06 09 1999 11 19
NS-12 07 12 1999 11 38
NS-13 05 19 1999 12 12
Depth (m)
Temperature (C)

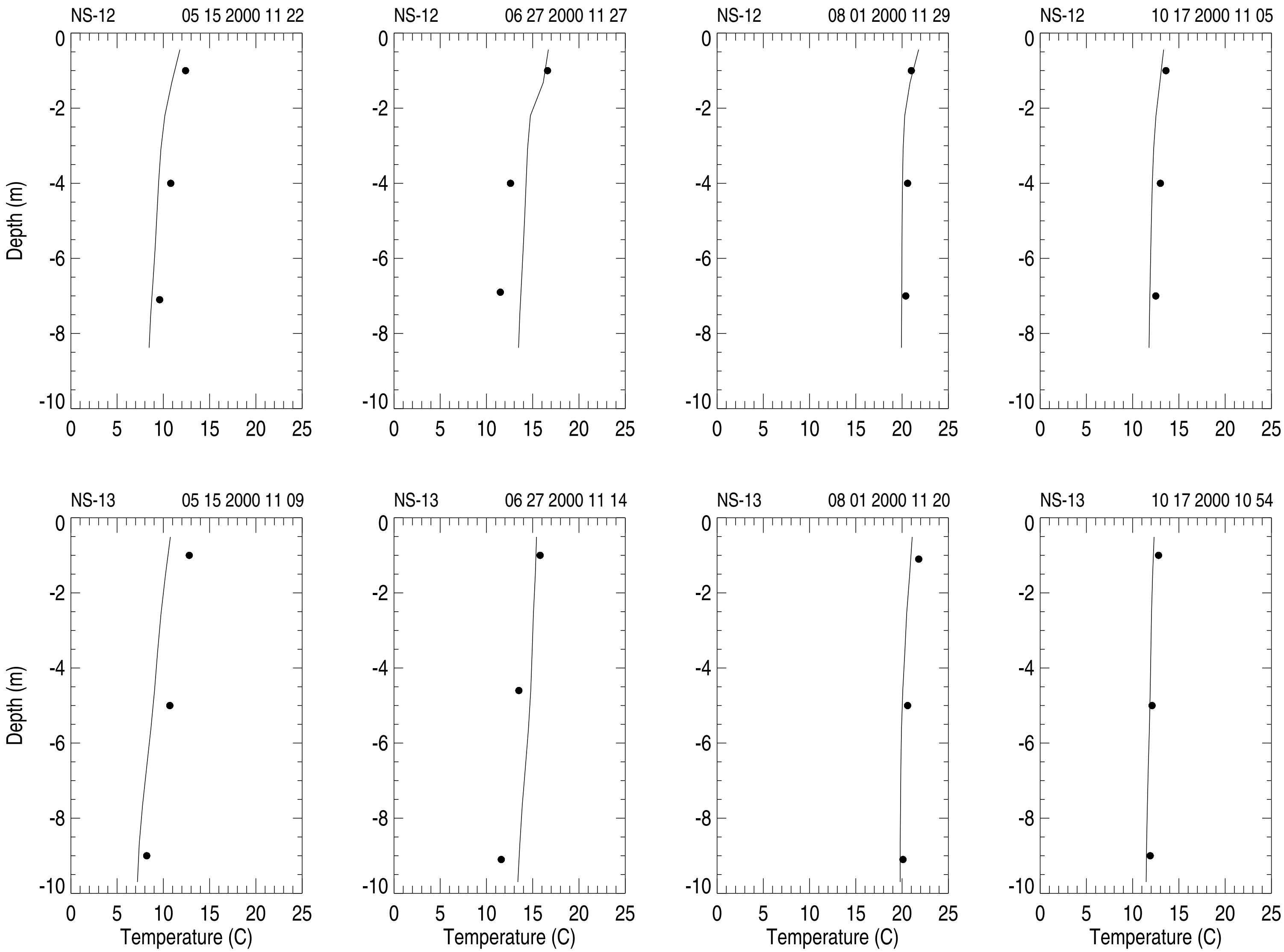

NS-13 06 09 1999 11 07
NS-13 07 12 1999 11 29
NS-14 05 19 1999 12 00
NS-14 06 09 1999 10 53
NS-14 07 12 1999 07 36
NS-27 05 19 1999 11 15
NS-27 06 09 1999 10 08
NS-27 07 12 1999 10 40
Depth (m)
Depth (m)
Temperature (C)
Temperature (C)
Temperature (C)
Temperature (C)

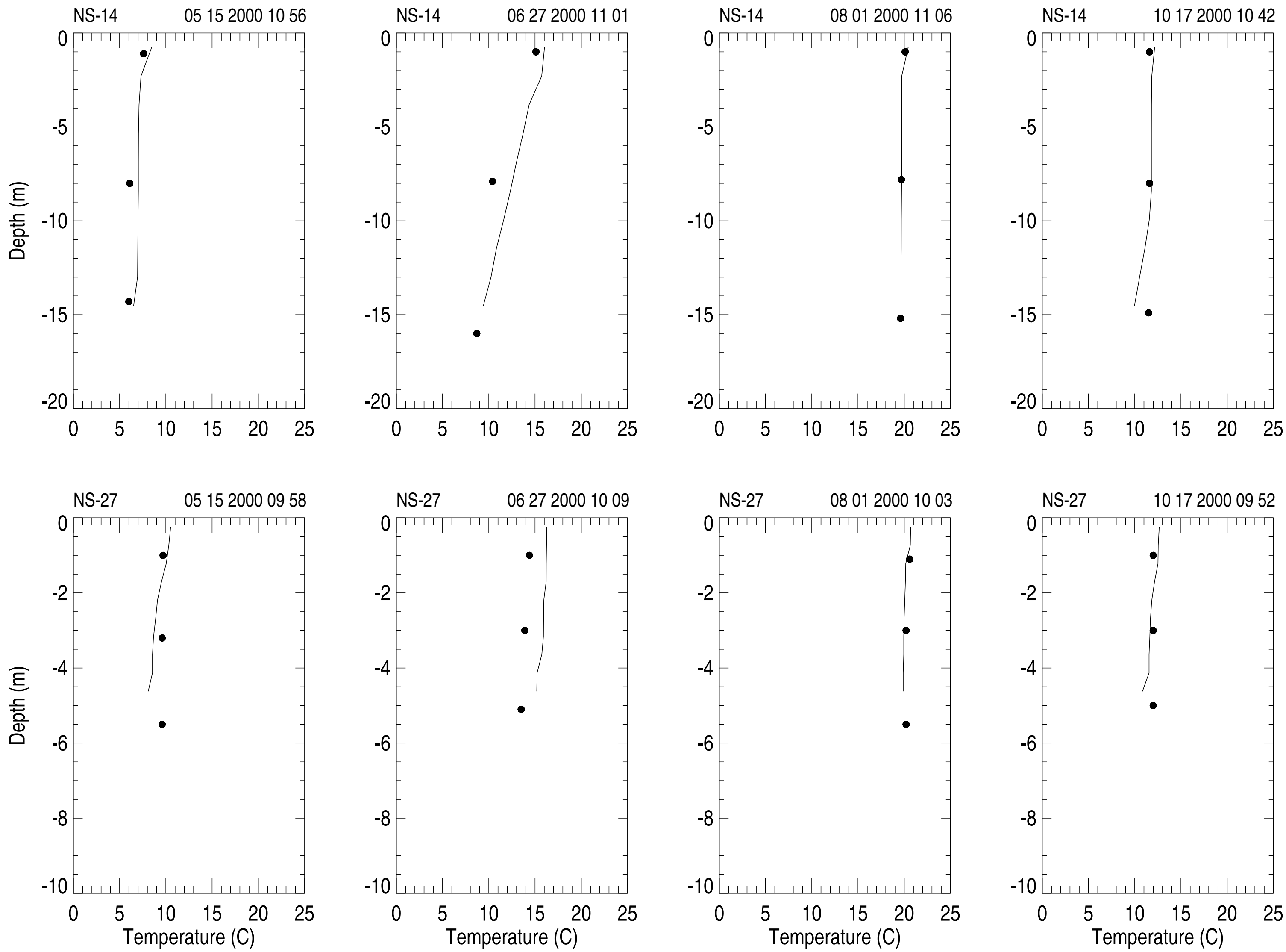


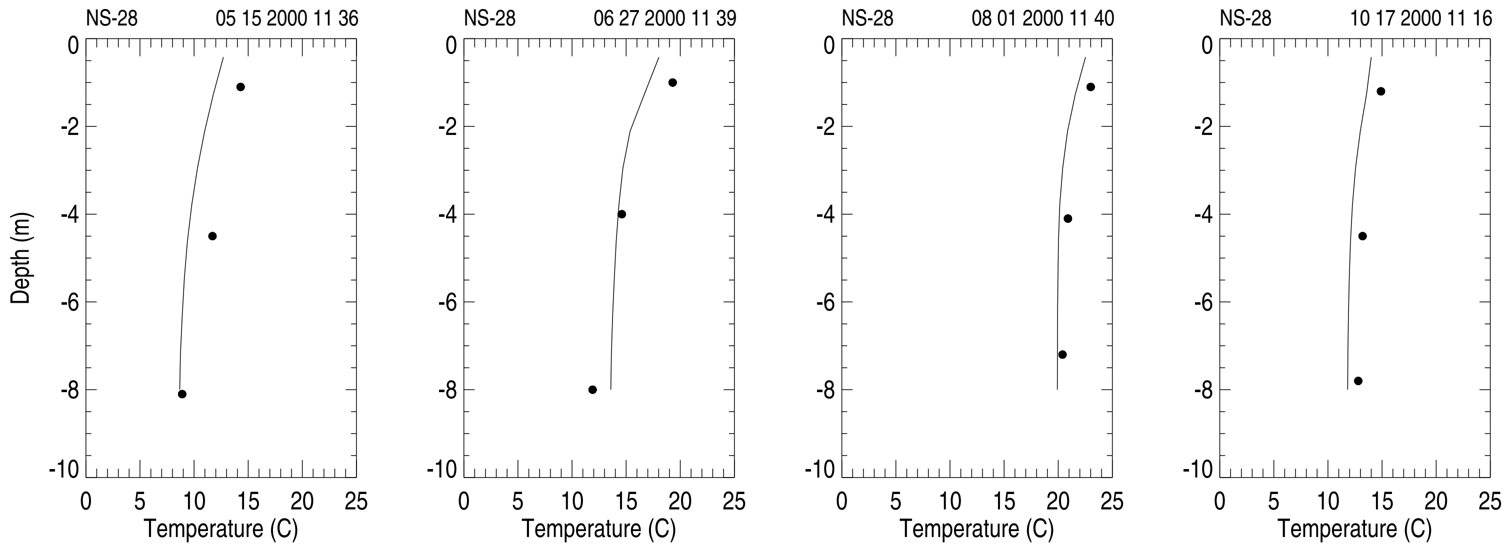
NS-28
05 19 1999 12 28
NS-28
06 09 1999 11 27
NS-28
07 12 1999 11 47
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)


NS-02 05 15 2000 09 35
NS-02 06 27 2000 09 42
NS-02 08 01 2000 09 42
NS-02 10 17 2000 09 34
NS-05 05 15 2000 07 53
NS-05 06 27 2000 07 53
NS-05 08 01 2000 07 58
NS-05 10 17 2000 07 50
Depth (m)
Temperature (C)
0
-5
-10
-15
-20
0 5 10 15 20 25

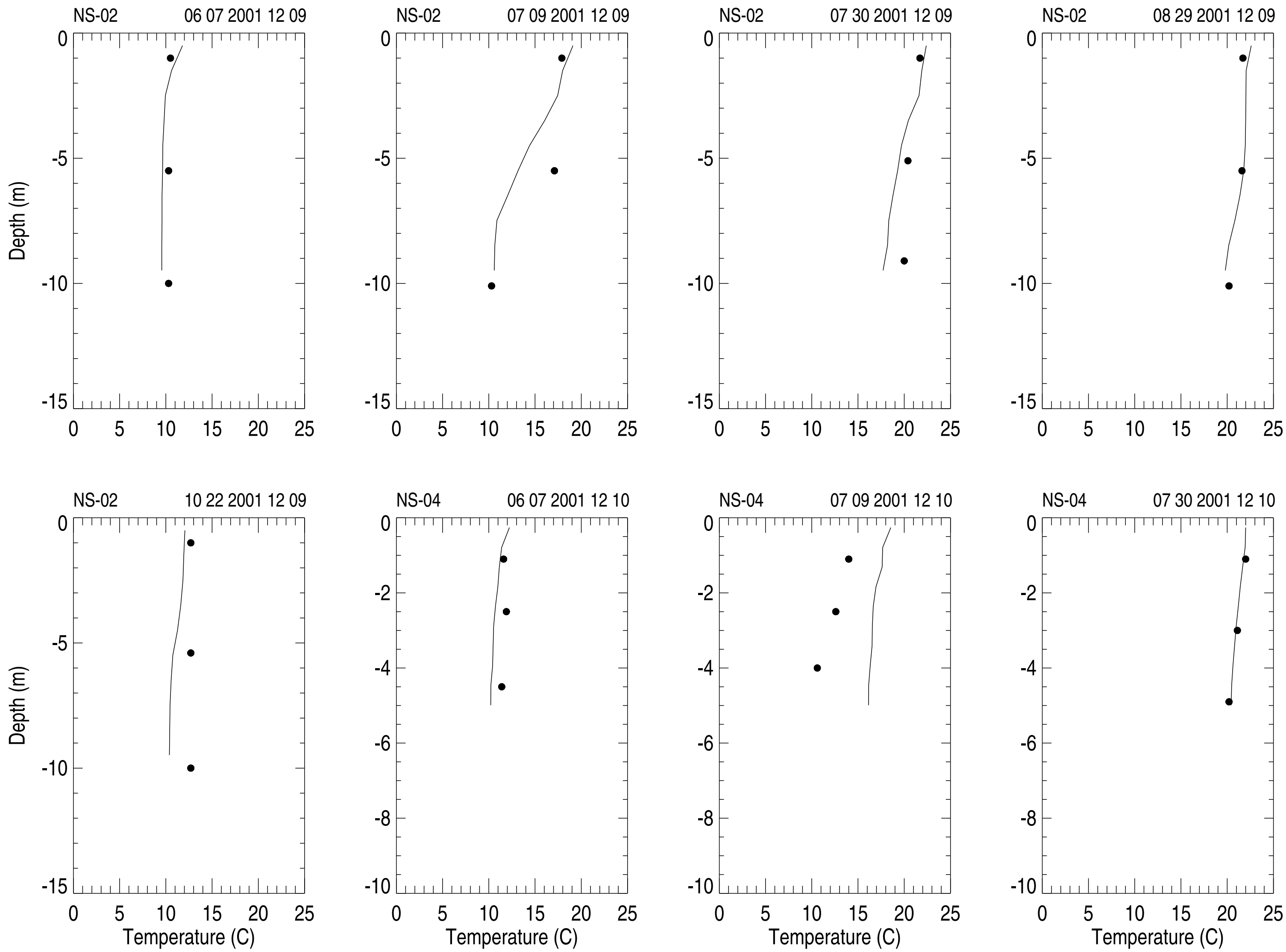

NS-07 05 15 2000 13 58
NS-07 06 27 2000 14 07
NS-07 08 01 2000 13 57
NS-07 10 17 2000 13 30
NS-11 05 15 2000 09 49
NS-11 06 27 2000 09 54
NS-11 08 01 2000 09 53
NS-11 10 17 2000 09 44
Depth (m)
Temperature (C)
0
-5
-10
-15
-20
-2
-4
-6
-8
5
10
15
20
25

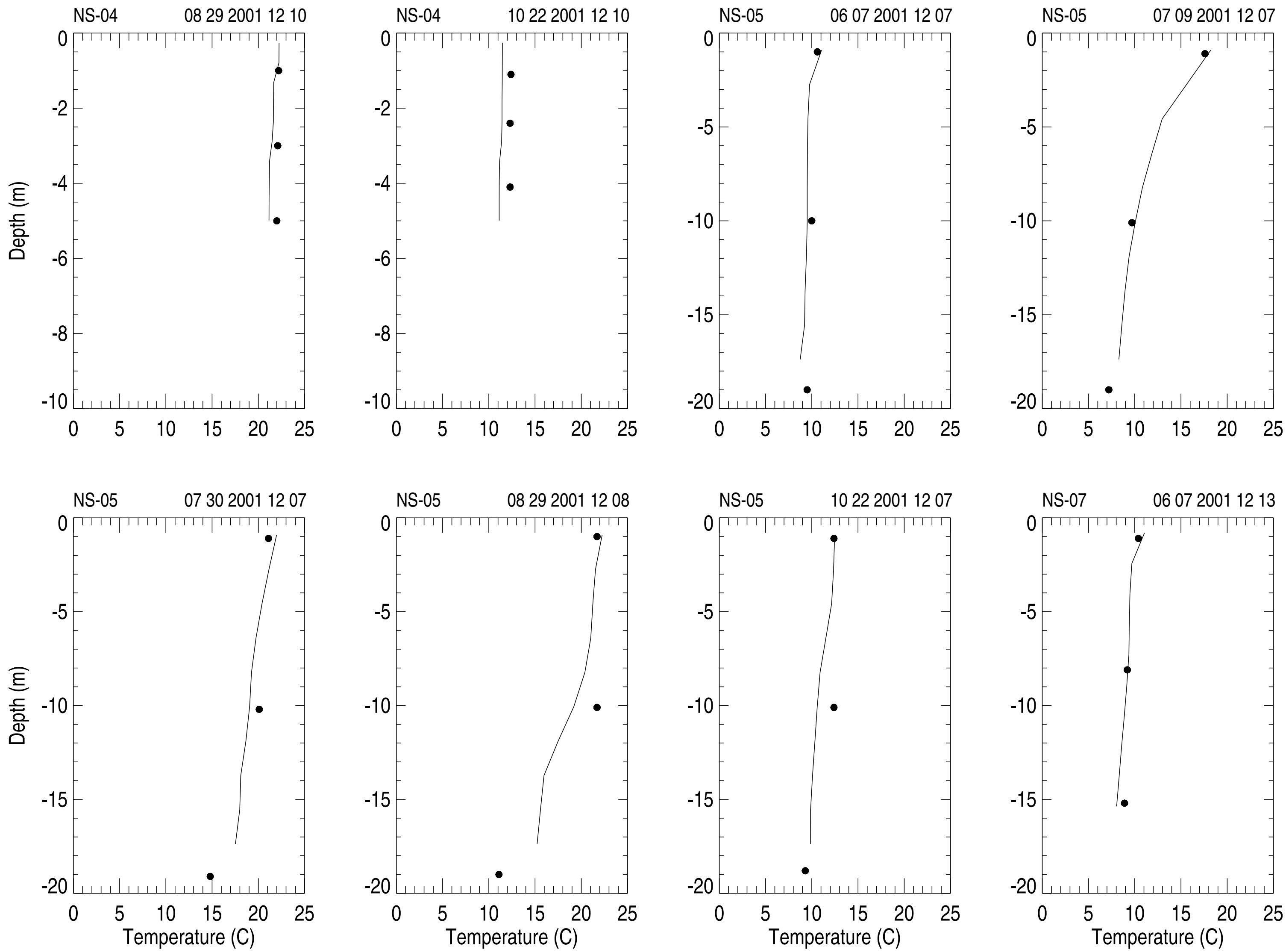

NS-12 05 15 2000 11 22
NS-12 06 27 2000 11 27
NS-12 08 01 2000 11 29
NS-12 10 17 2000 11 05
NS-13 05 15 2000 11 09
NS-13 06 27 2000 11 14
NS-13 08 01 2000 11 20
NS-13 10 17 2000 10 54
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

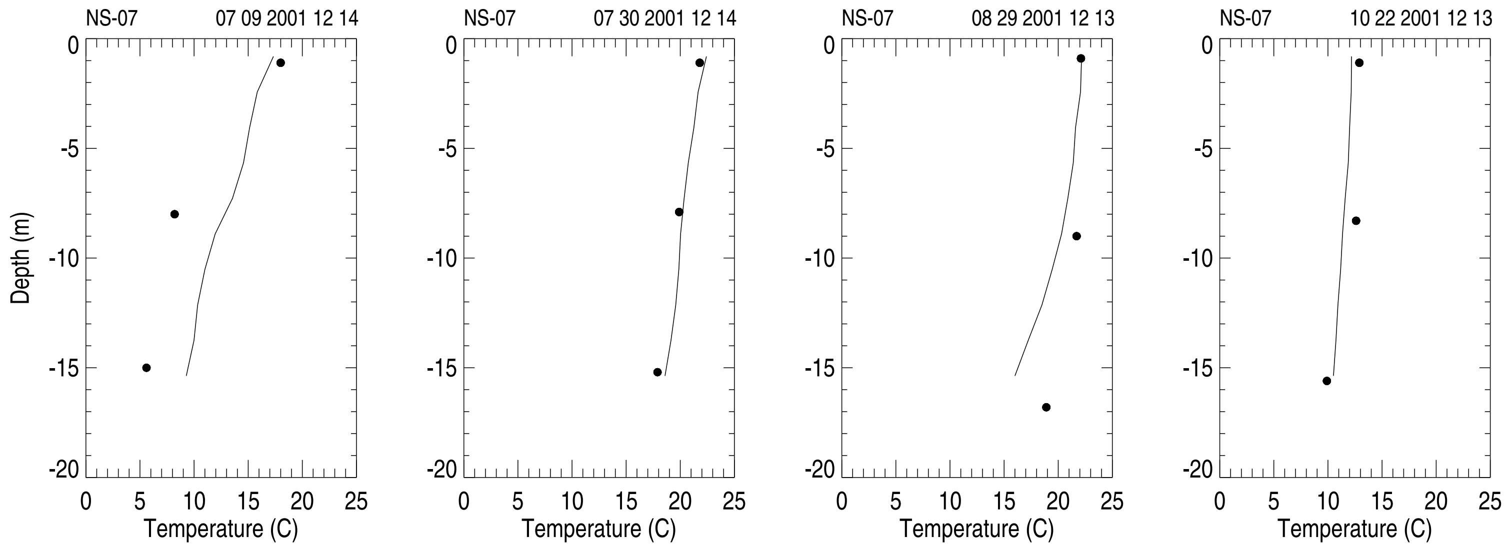

NS-14
05 15 2000 10 56
NS-14
06 27 2000 11 01
NS-14
08 01 2000 11 06
NS-14
10 17 2000 10 42
NS-27
05 15 2000 09 58
NS-27
06 27 2000 10 09
NS-27
08 01 2000 10 03
NS-27
10 17 2000 09 52
Depth (m)
Temperature (C)

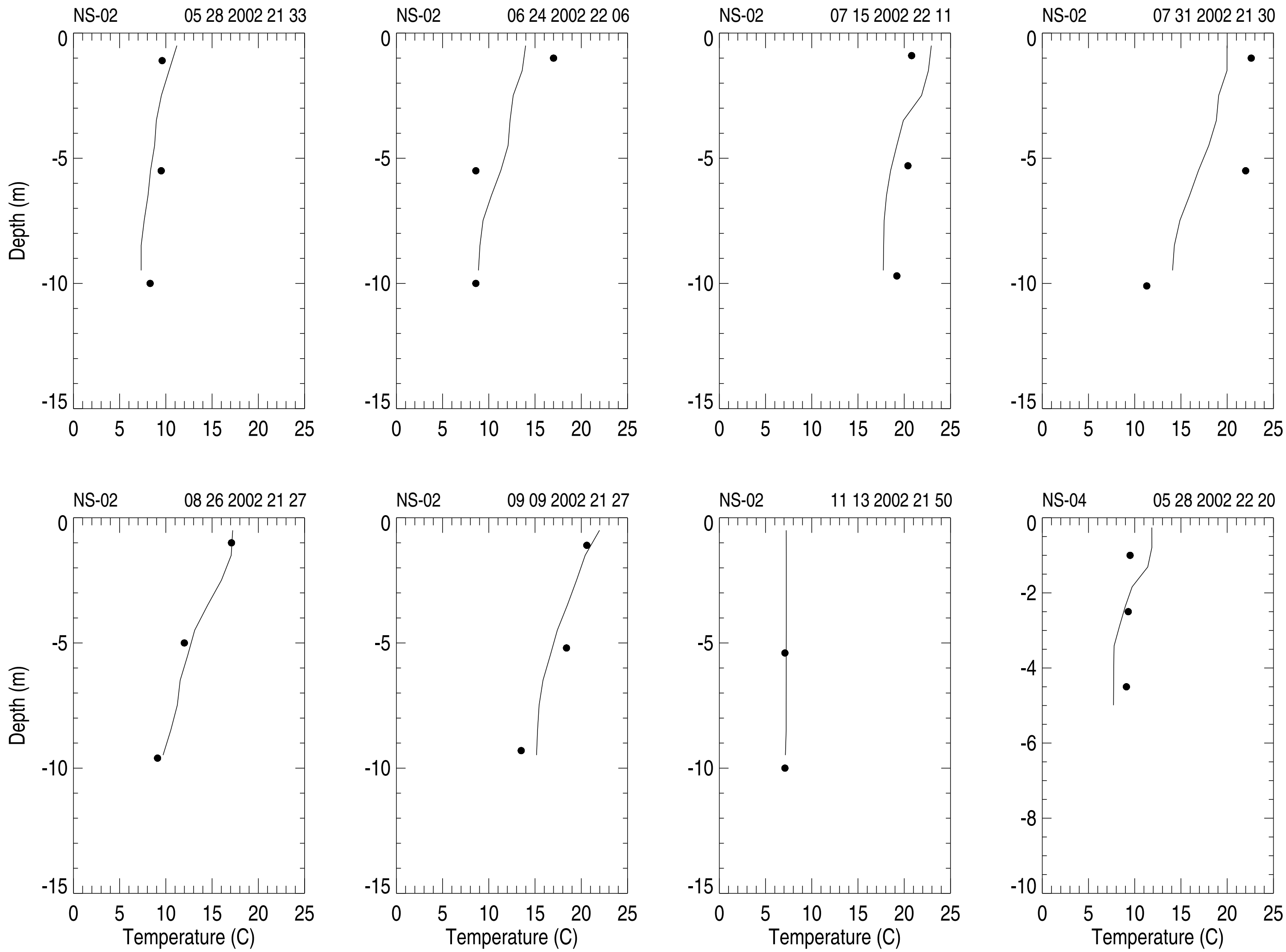


NS-28
05 15 2000 11 36
NS-28
06 27 2000 11 39
NS-28
08 01 2000 11 40
NS-28
10 17 2000 11 16
Depth (m)
Temperature (C)

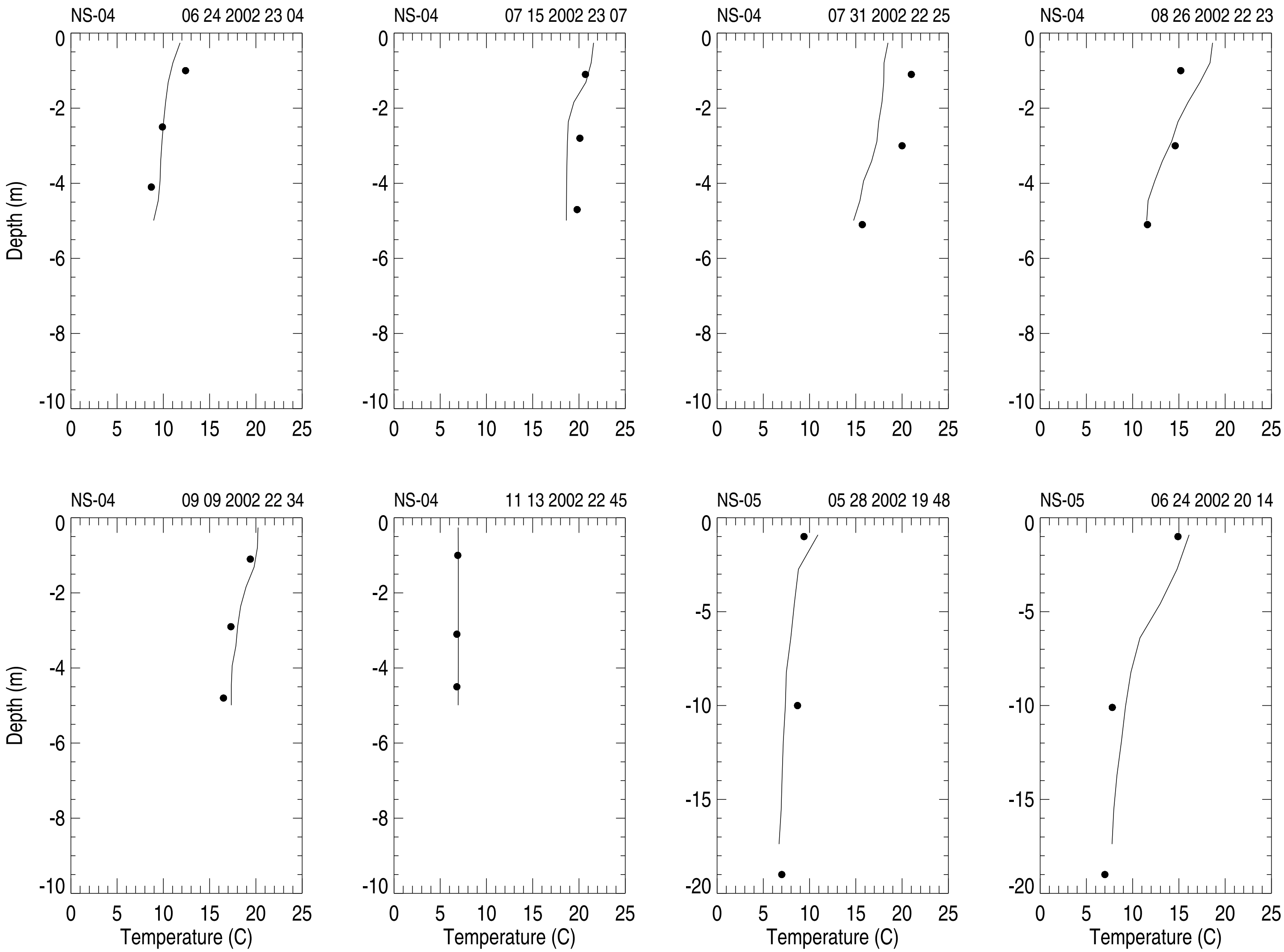

NS-02
06 07 2001 12 09
NS-02
07 09 2001 12 09
NS-02
07 30 2001 12 09
NS-02
08 29 2001 12 09
NS-02
10 22 2001 12 09
NS-04
06 07 2001 12 10
NS-04
07 09 2001 12 10
NS-04
07 30 2001 12 10
Depth (m)
Temperature (C)
0
-5
-10
-15
-2
-4
-6
-8
5
10
15
20
25


NS-04 08 29 2001 12 10
NS-04 10 22 2001 12 10
NS-05 06 07 2001 12 07
NS-05 07 09 2001 12 07
NS-05 07 30 2001 12 07
NS-05 08 29 2001 12 08
NS-05 10 22 2001 12 07
NS-07 06 07 2001 12 13
Depth (m)
Temperature (C)

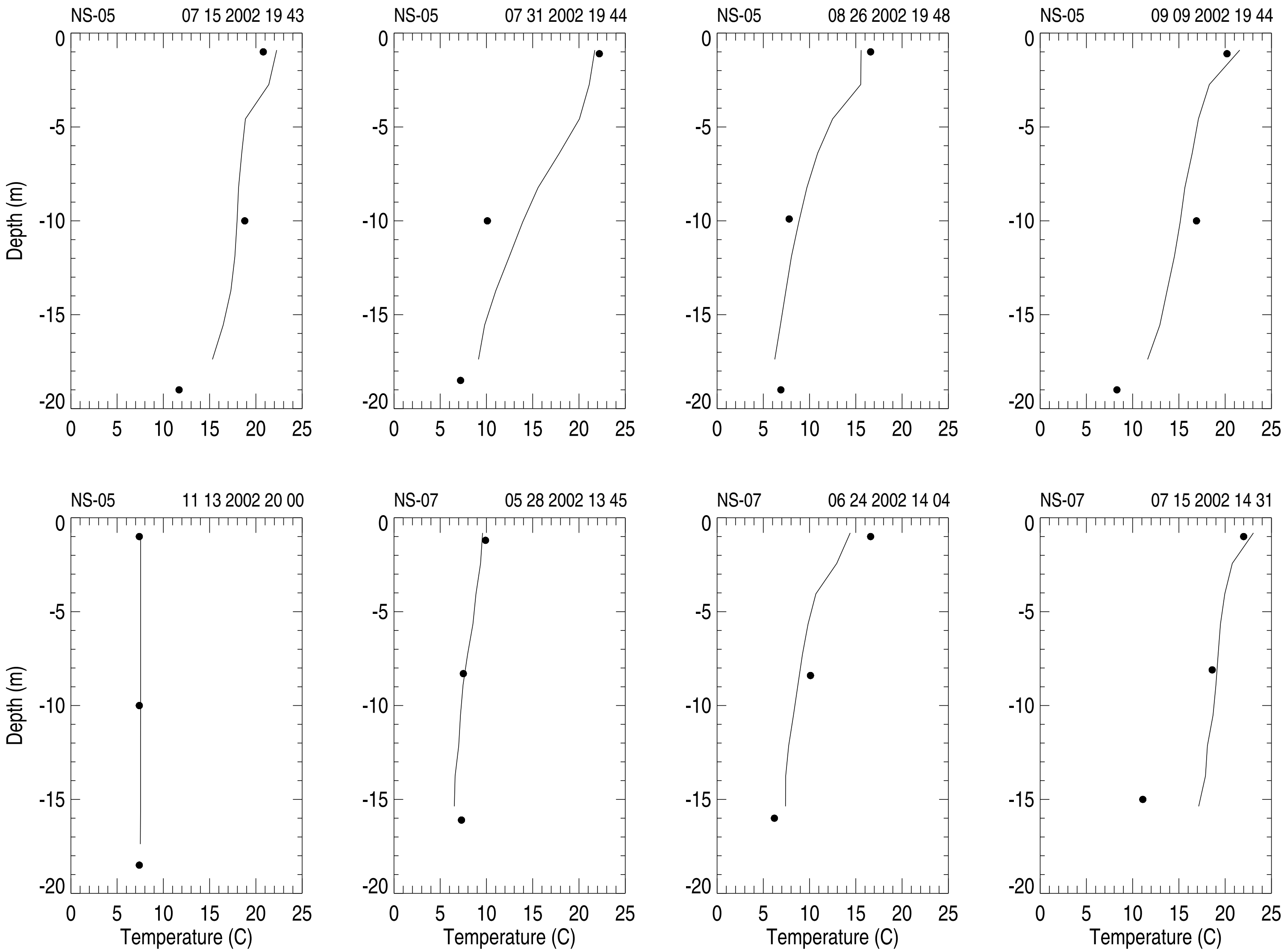

NS-07
07 09 2001 12 14
NS-07
07 30 2001 12 14
NS-07
08 29 2001 12 13
NS-07
10 22 2001 12 13
Depth (m)
Temperature (C)



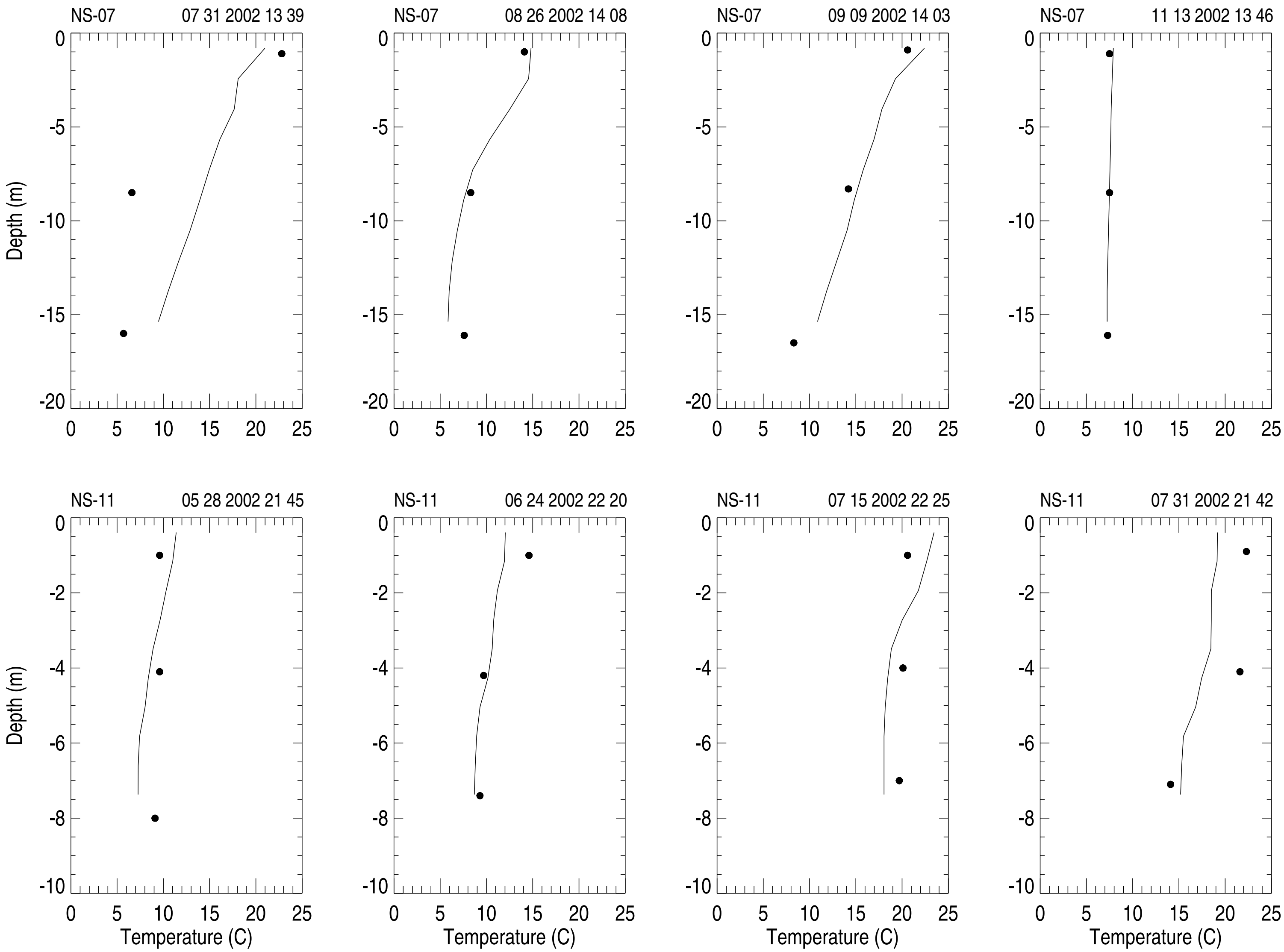
17:35:26 Mon Mar 28, 2005
/hamp2/hntb0020/HYDRO/ANLYS/c_t_s_NS_2002.pro

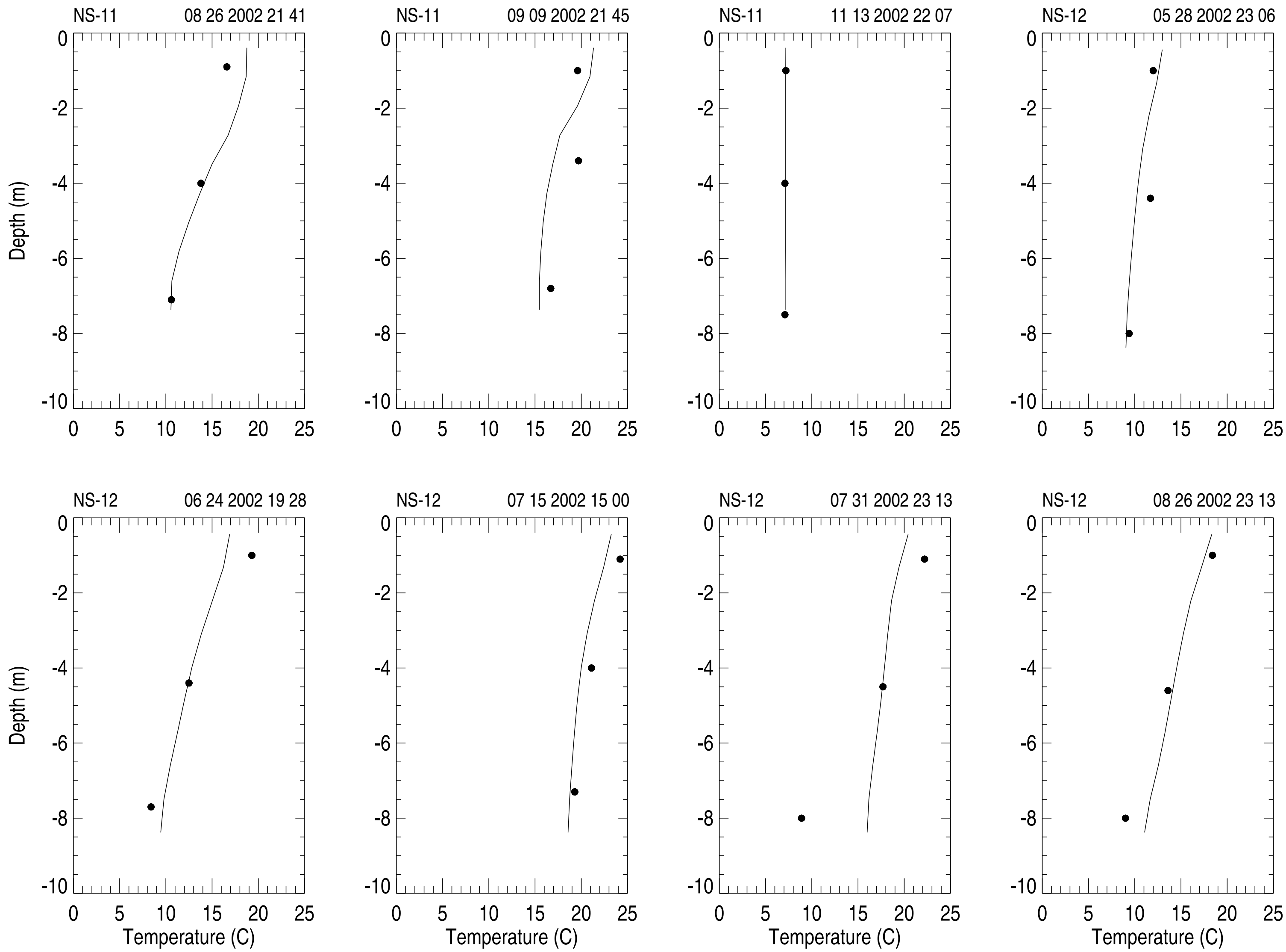


17:35:26 Mon Mar 28, 2005
/hamp2/hntb0020/HYDRO/ANLYS/c_t_s_NS_2002.pro

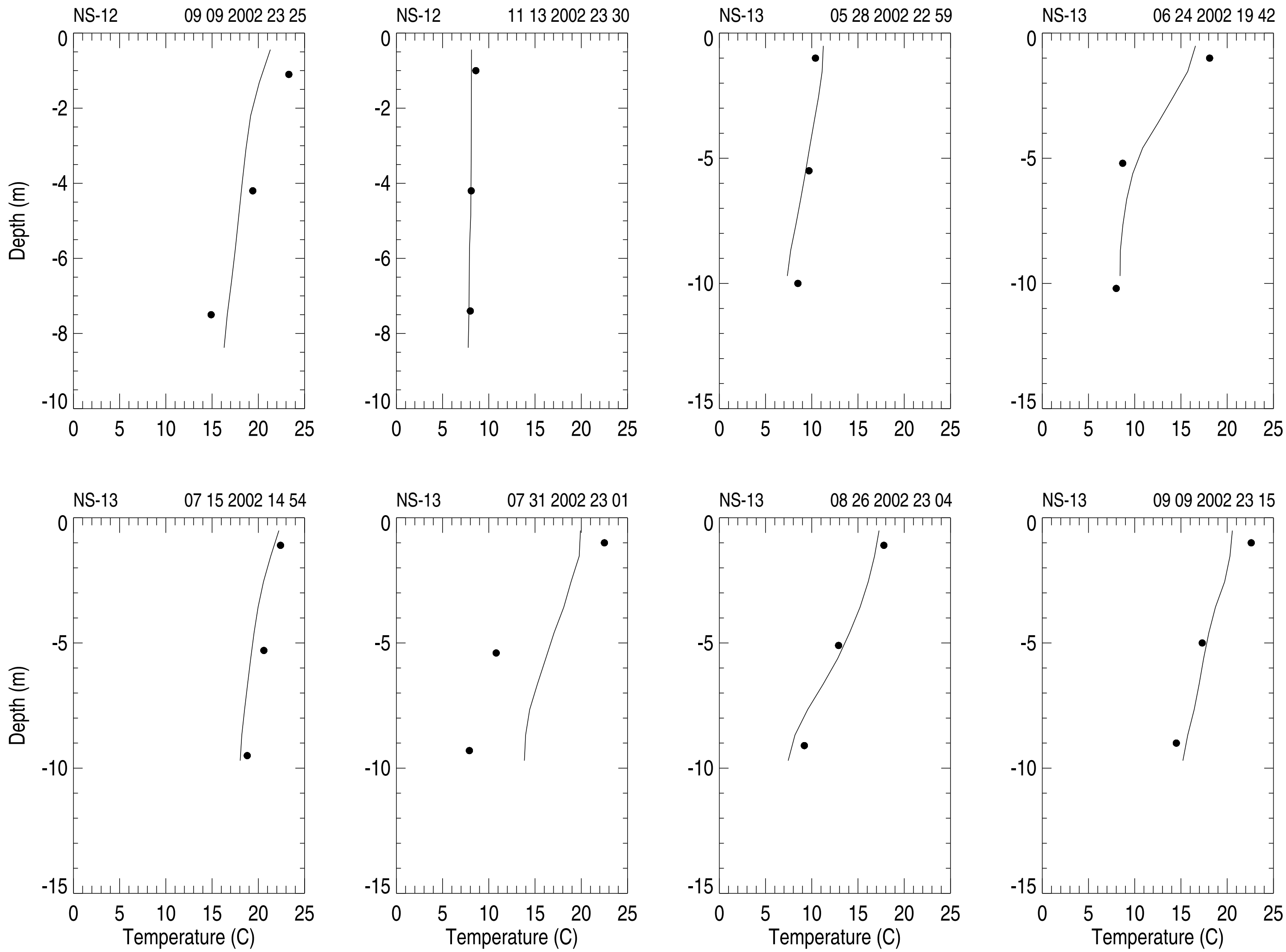


17:35:26 Mon Mar 28, 2005
/hamp2/hntb0020/HYDRO/ANLYS/c_t_s_NS_2002.pro

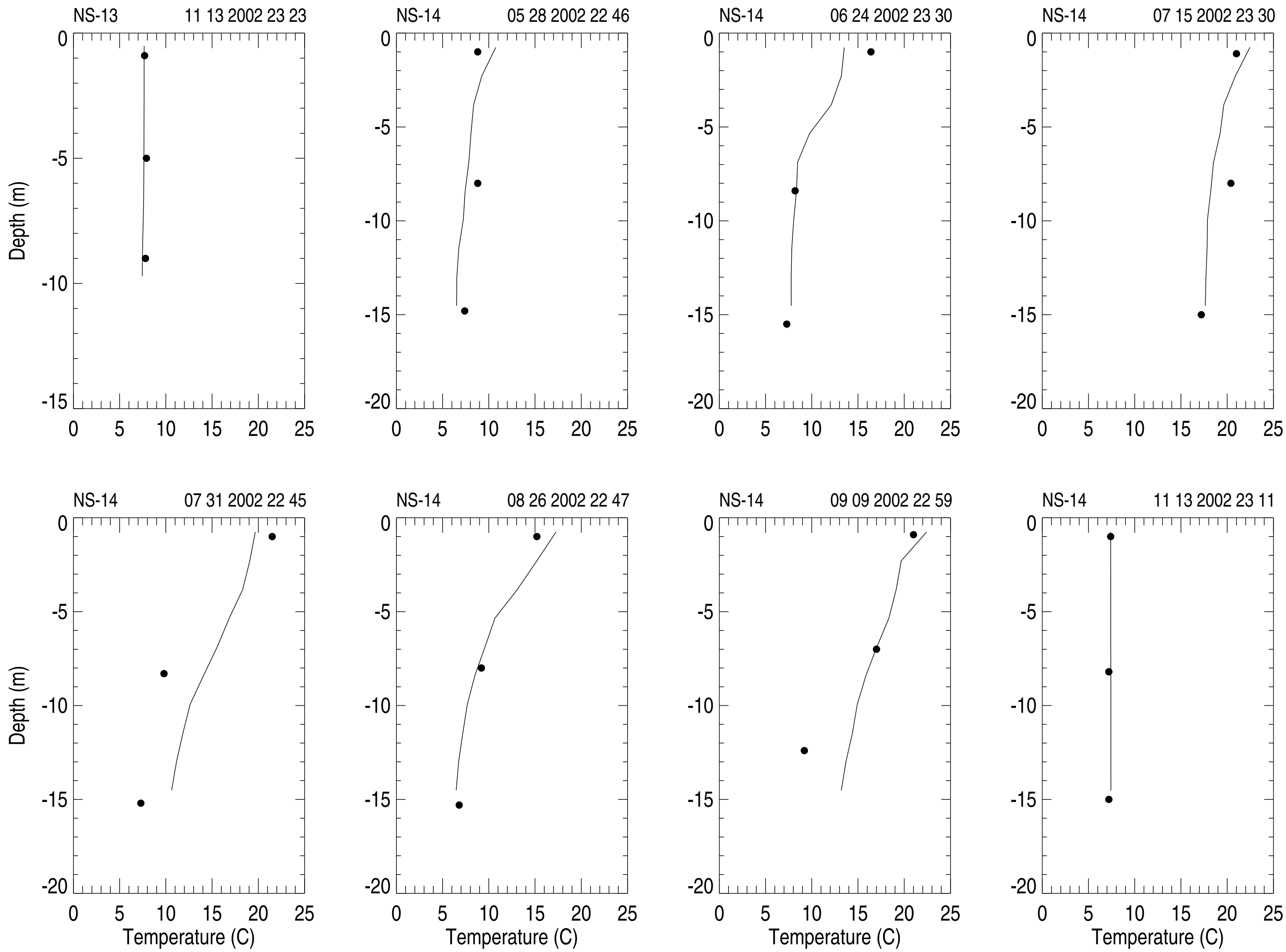

NS-07 07 31 2002 13 39
NS-07 08 26 2002 14 08
NS-07 09 09 2002 14 03
NS-07 11 13 2002 13 46
NS-11 05 28 2002 21 45
NS-11 06 24 2002 22 20
NS-11 07 15 2002 22 25
NS-11 07 31 2002 21 42
Depth (m)
Temperature (C)
0
-5
-10
-15
-20
-2
-4
-6
-8
5
10
15
20
25



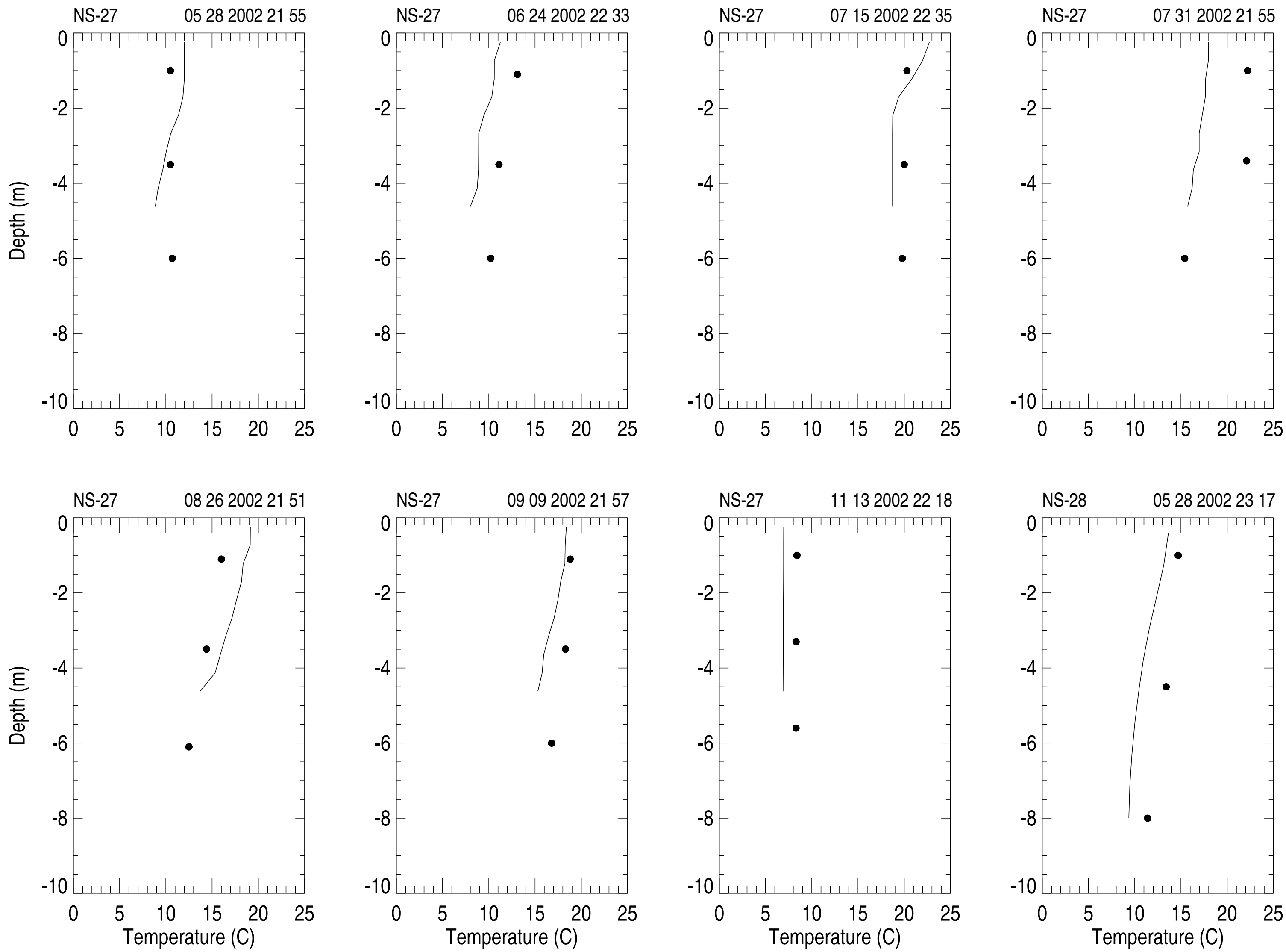
17:35:26 Mon Mar 28, 2005
/hamp2/hntb0020/HYDRO/ANLYS/c_t_s_NS_2002.pro



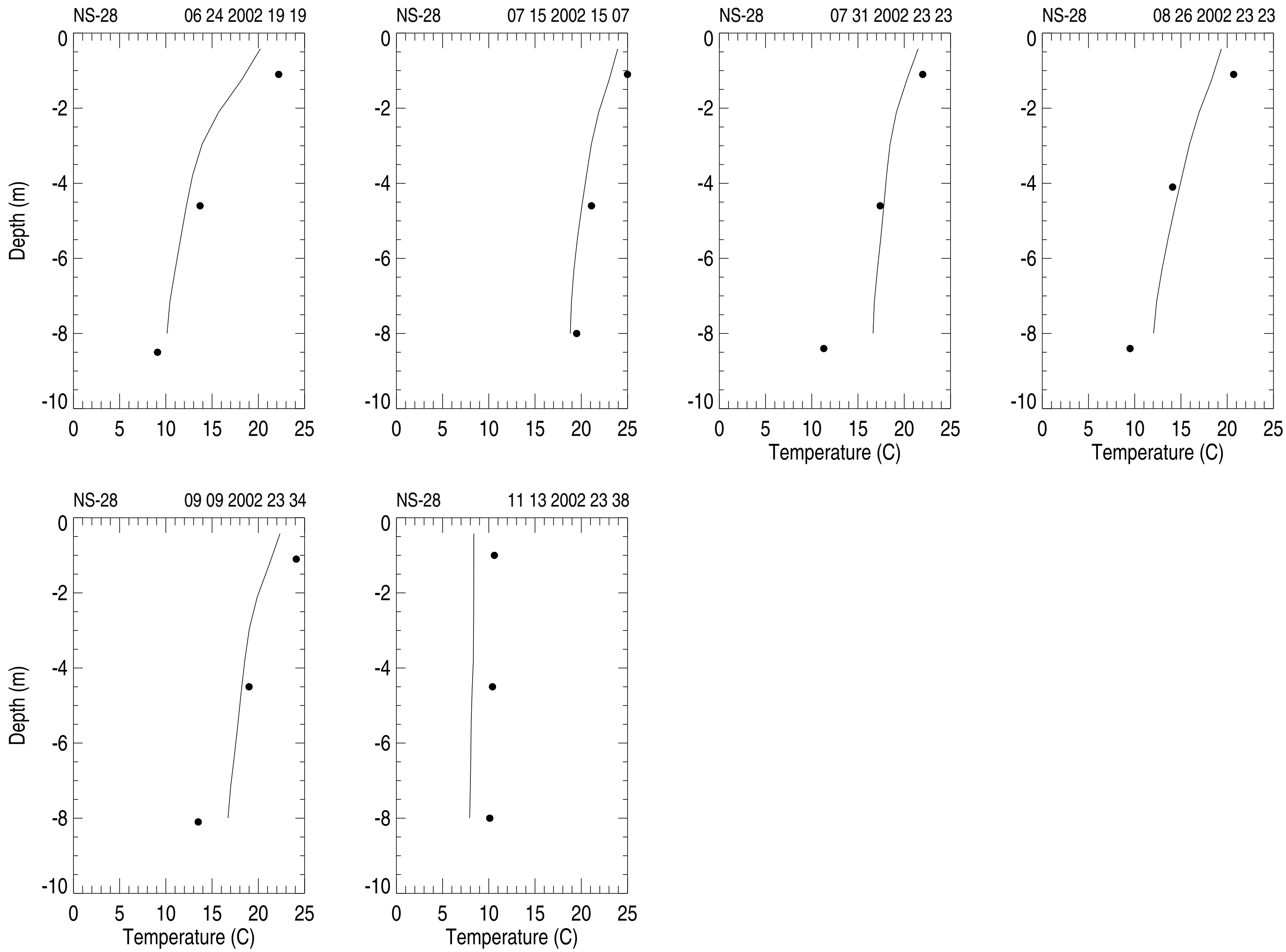
17:35:26 Mon Mar 28, 2005
/hamp2/hntb0020/HYDRO/ANLYS/c_t_s_NS_2002.pro

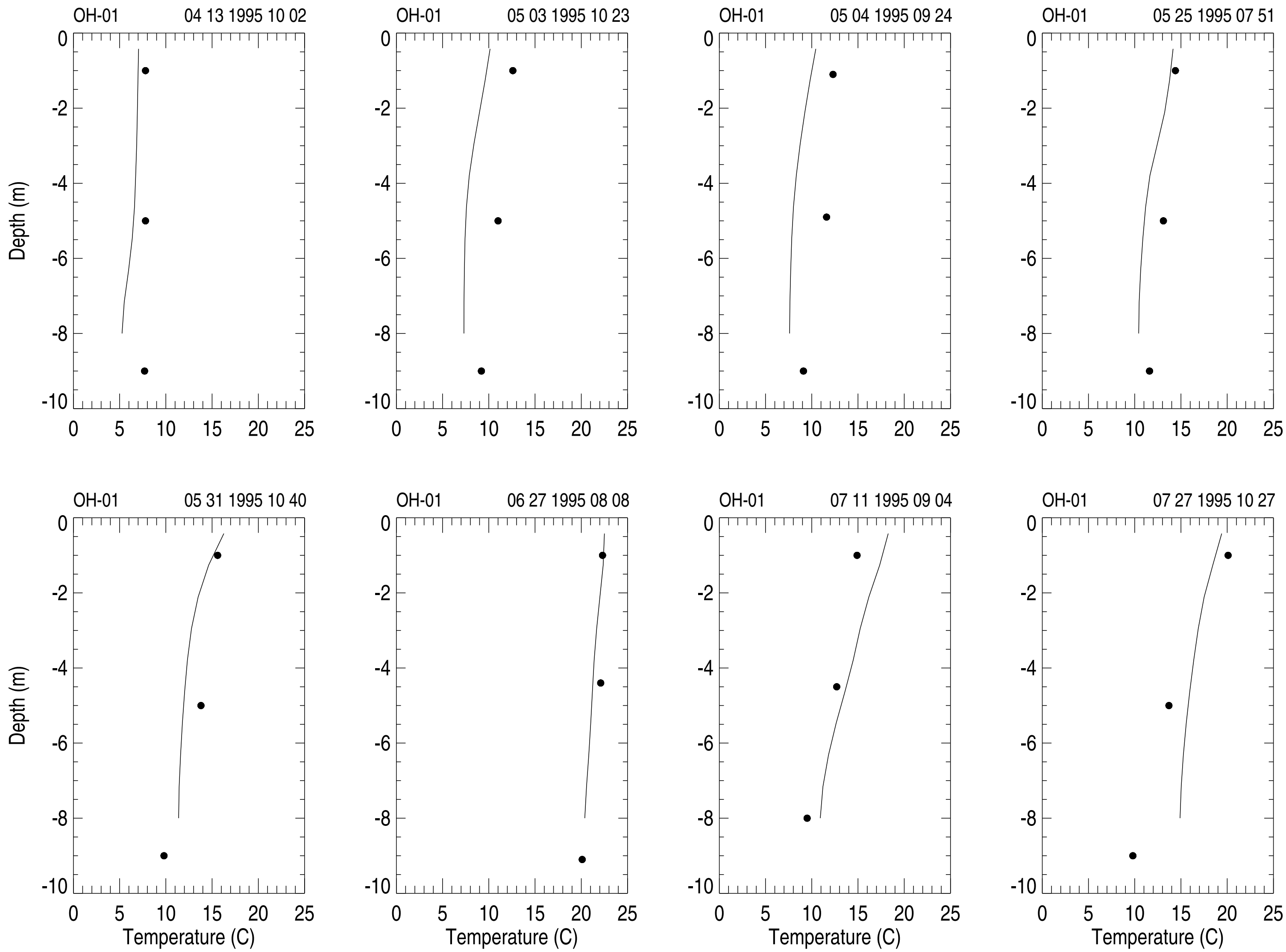


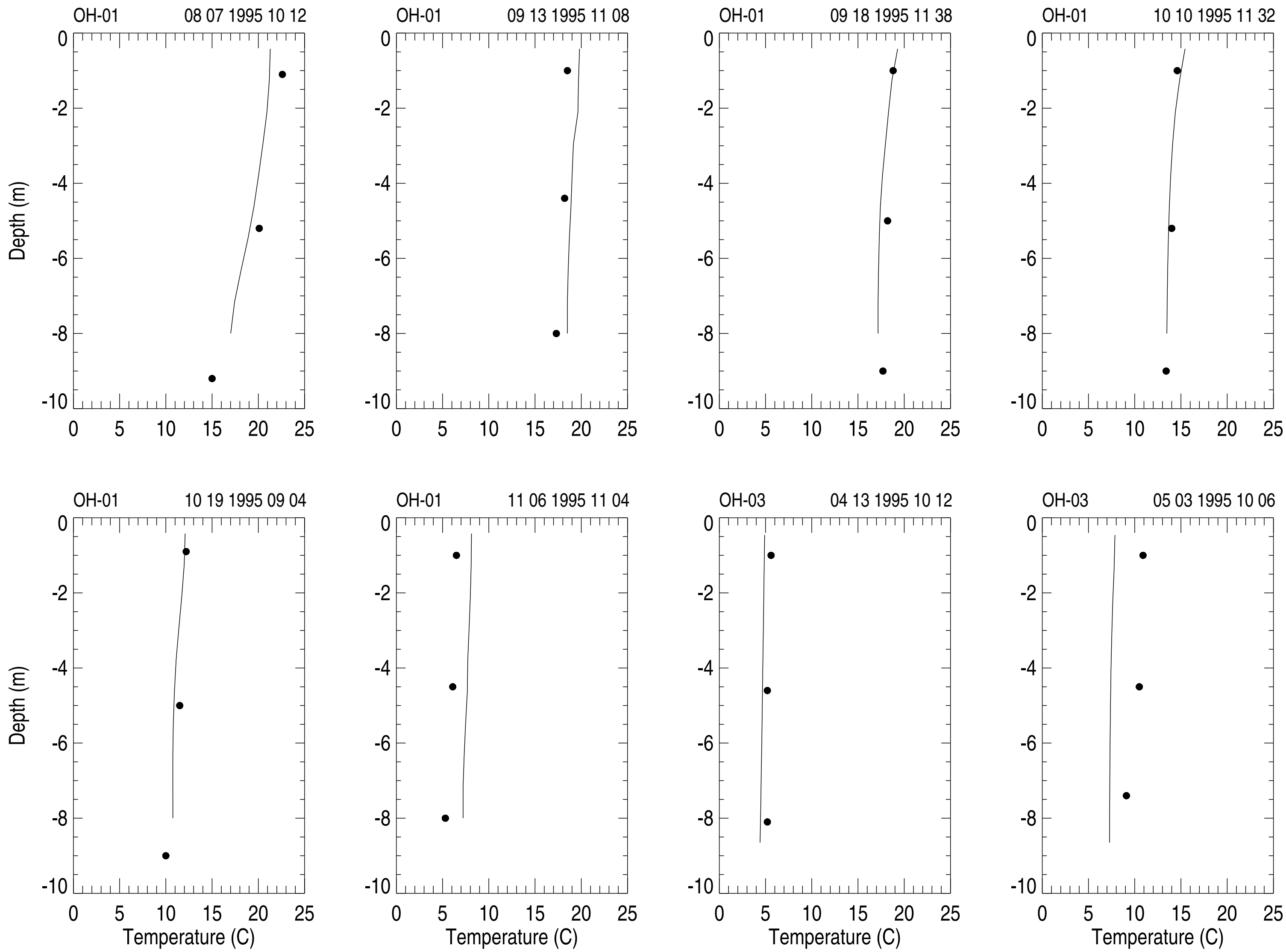
17:35:26 Mon Mar 28, 2005
/hamp2/hntb0020/HYDRO/ANLYS/c_t_s_NS_2002.pro

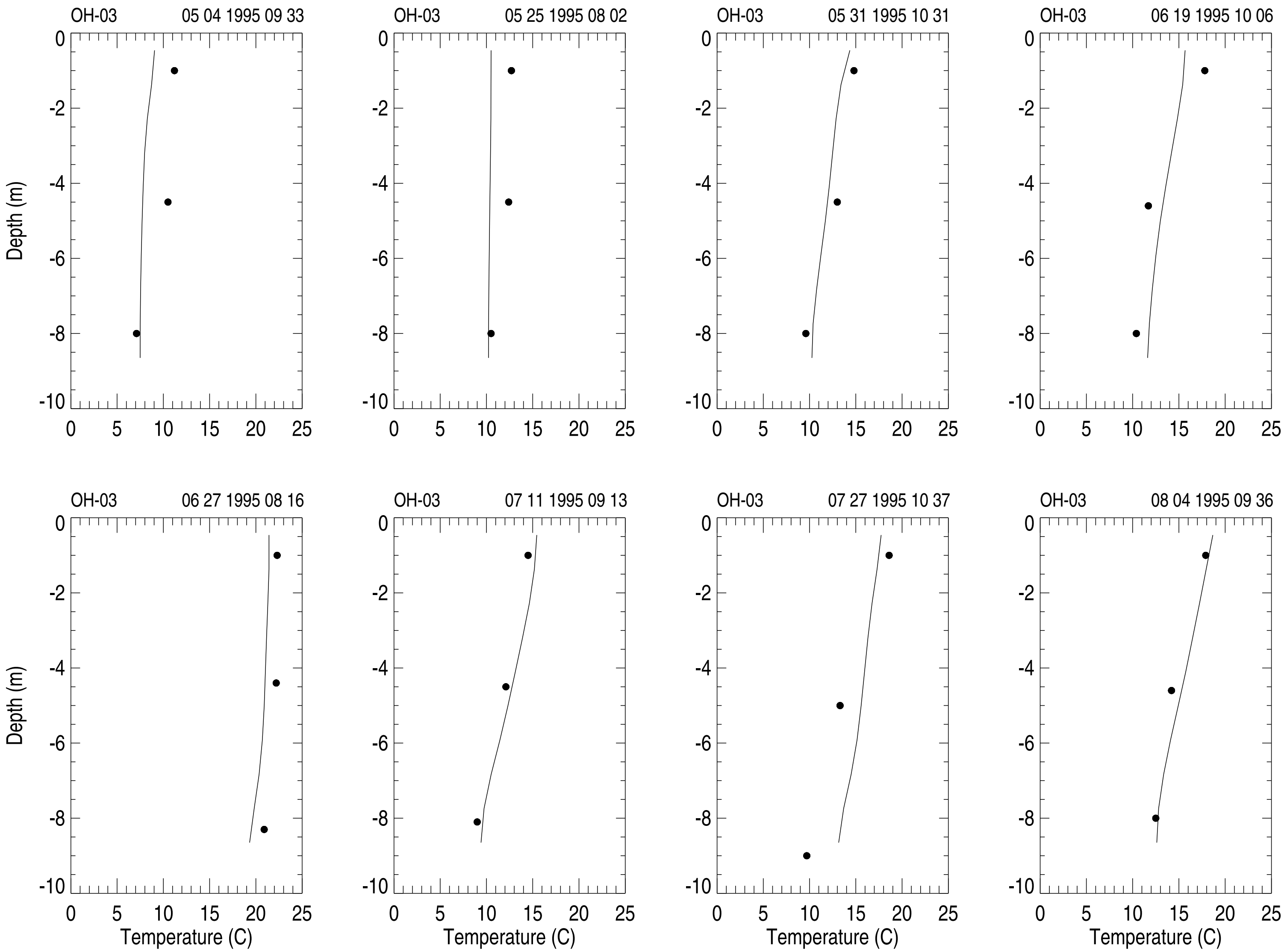


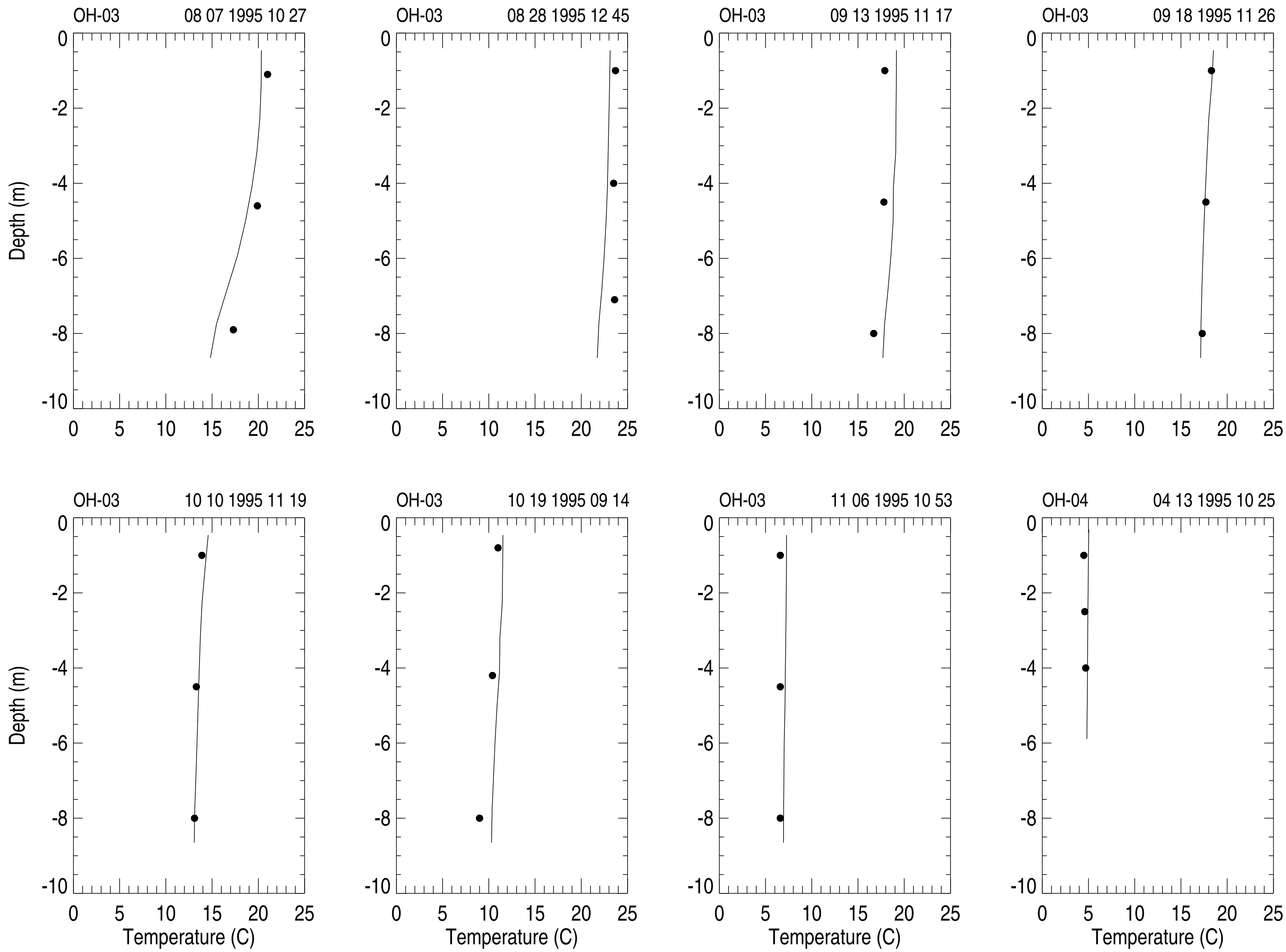
17:35:26 Mon Mar 28, 2005
/hamp2/hntb0020/HYDRO/ANLYS/c_t_s_NS_2002.pro

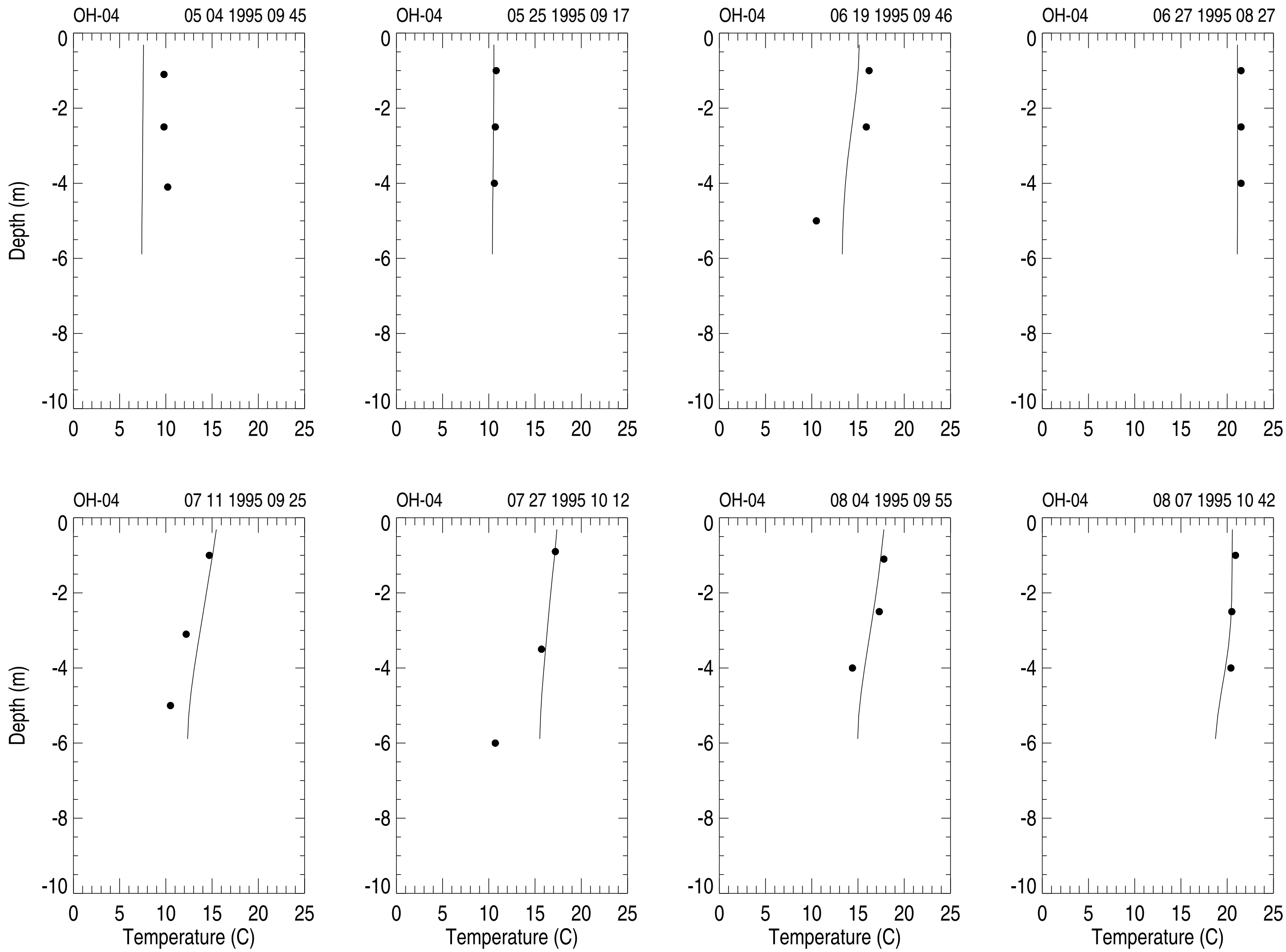

NS-28
06 24 2002 19 19
NS-28
07 15 2002 15 07
NS-28
07 31 2002 23 23
NS-28
08 26 2002 23 23
NS-28
09 09 2002 23 34
NS-28
11 13 2002 23 38
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25


OH-01
04 13 1995 10 02
OH-01
05 03 1995 10 23
OH-01
05 04 1995 09 24
OH-01
05 25 1995 07 51
OH-01
05 31 1995 10 40
OH-01
06 27 1995 08 08
OH-01
07 11 1995 09 04
OH-01
07 27 1995 10 27
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

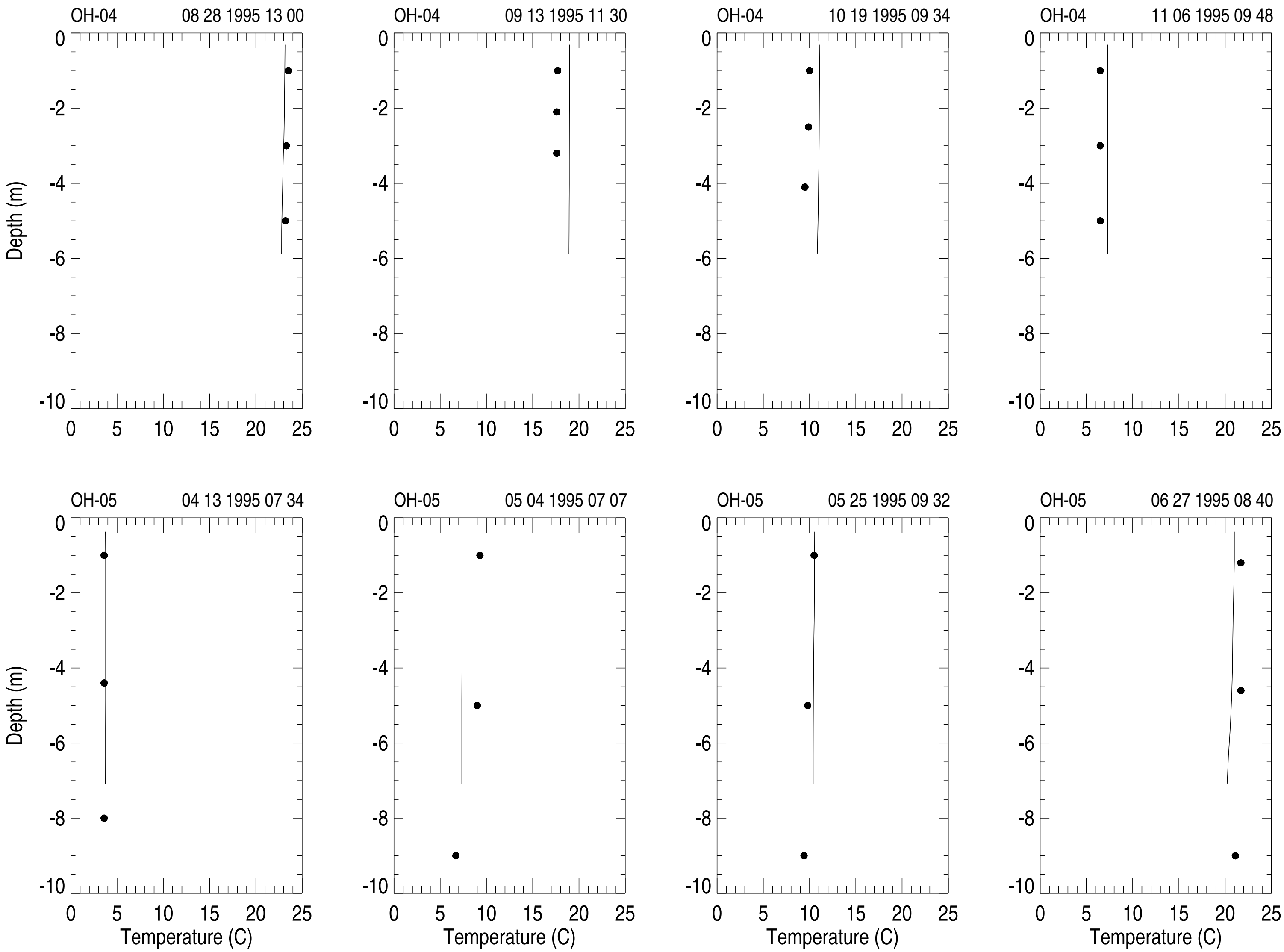

OH-01 08 07 1995 10 12
OH-01 09 13 1995 11 08
OH-01 09 18 1995 11 38
OH-01 10 10 1995 11 32
OH-01 10 19 1995 09 04
OH-01 11 06 1995 11 04
OH-03 04 13 1995 10 12
OH-03 05 03 1995 10 06
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

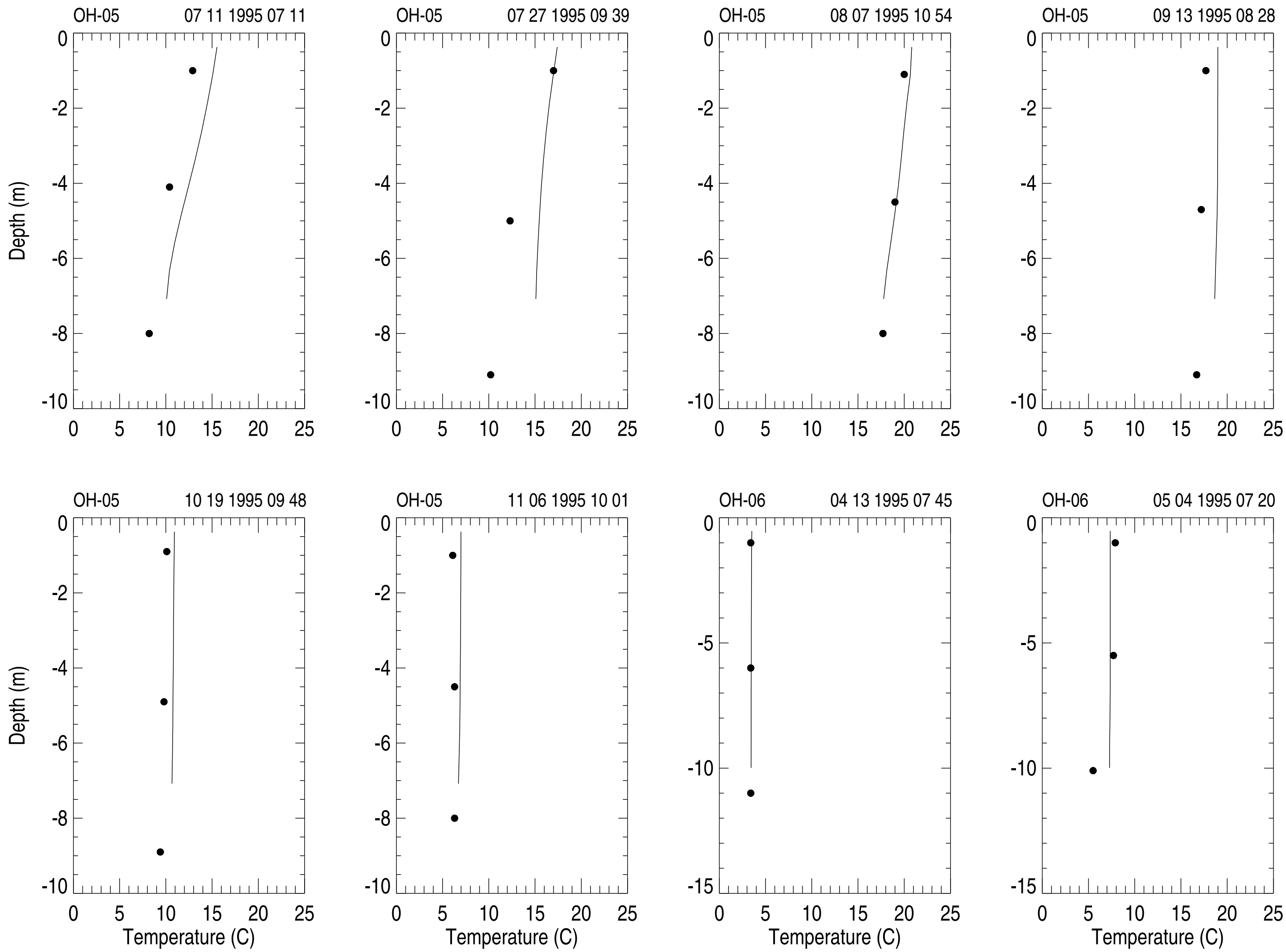

OH-03
05 04 1995 09 33
OH-03
05 25 1995 08 02
OH-03
05 31 1995 10 31
OH-03
06 19 1995 10 06
OH-03
06 27 1995 08 16
OH-03
07 11 1995 09 13
OH-03
07 27 1995 10 37
OH-03
08 04 1995 09 36
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)


OH-03
08 07 1995 10 27
OH-03
08 28 1995 12 45
OH-03
09 13 1995 11 17
OH-03
09 18 1995 11 26
OH-03
10 10 1995 11 19
OH-03
10 19 1995 09 14
OH-03
11 06 1995 10 53
OH-04
04 13 1995 10 25
Depth (m)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
Temperature (C)

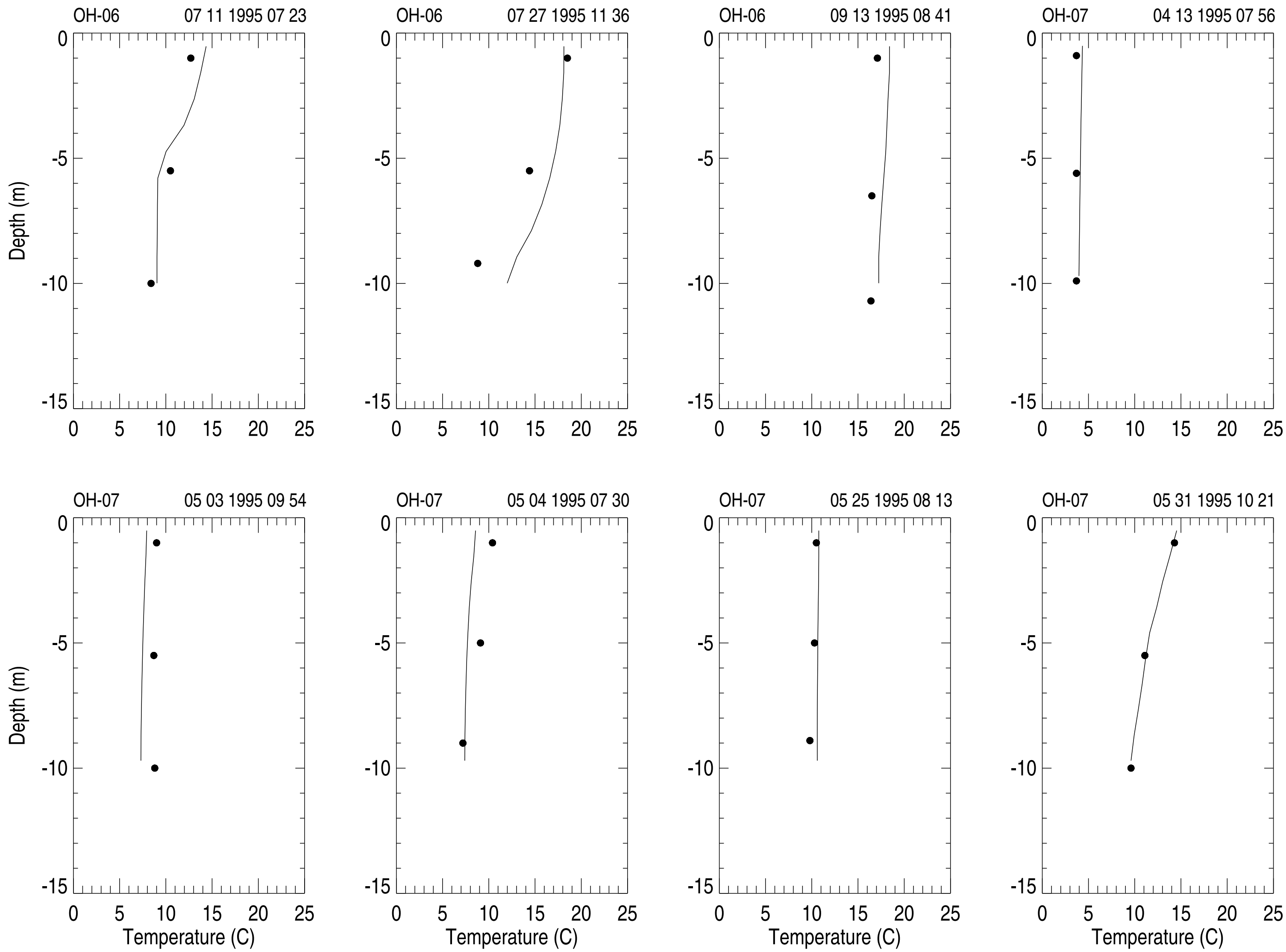


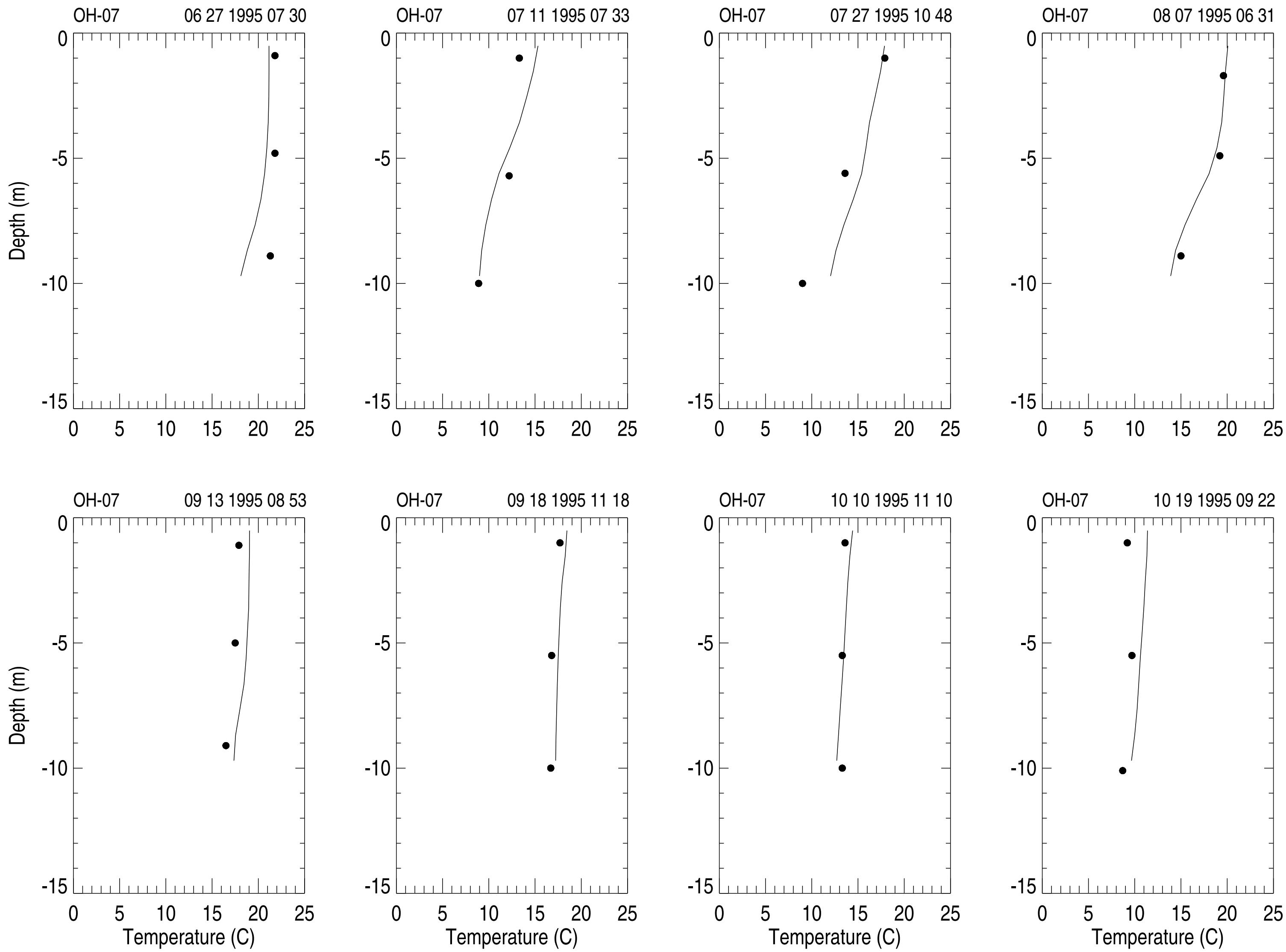
OH-04
05 04 1995 09 45
OH-04
05 25 1995 09 17
OH-04
06 19 1995 09 46
OH-04
06 27 1995 08 27
OH-04
07 11 1995 09 25
OH-04
07 27 1995 10 12
OH-04
08 04 1995 09 55
OH-04
08 07 1995 10 42
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)


OH-04
08 28 1995 13 00
OH-04
09 13 1995 11 30
OH-04
10 19 1995 09 34
OH-04
11 06 1995 09 48
OH-05
04 13 1995 07 34
OH-05
05 04 1995 07 07
OH-05
05 25 1995 09 32
OH-05
06 27 1995 08 40
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25

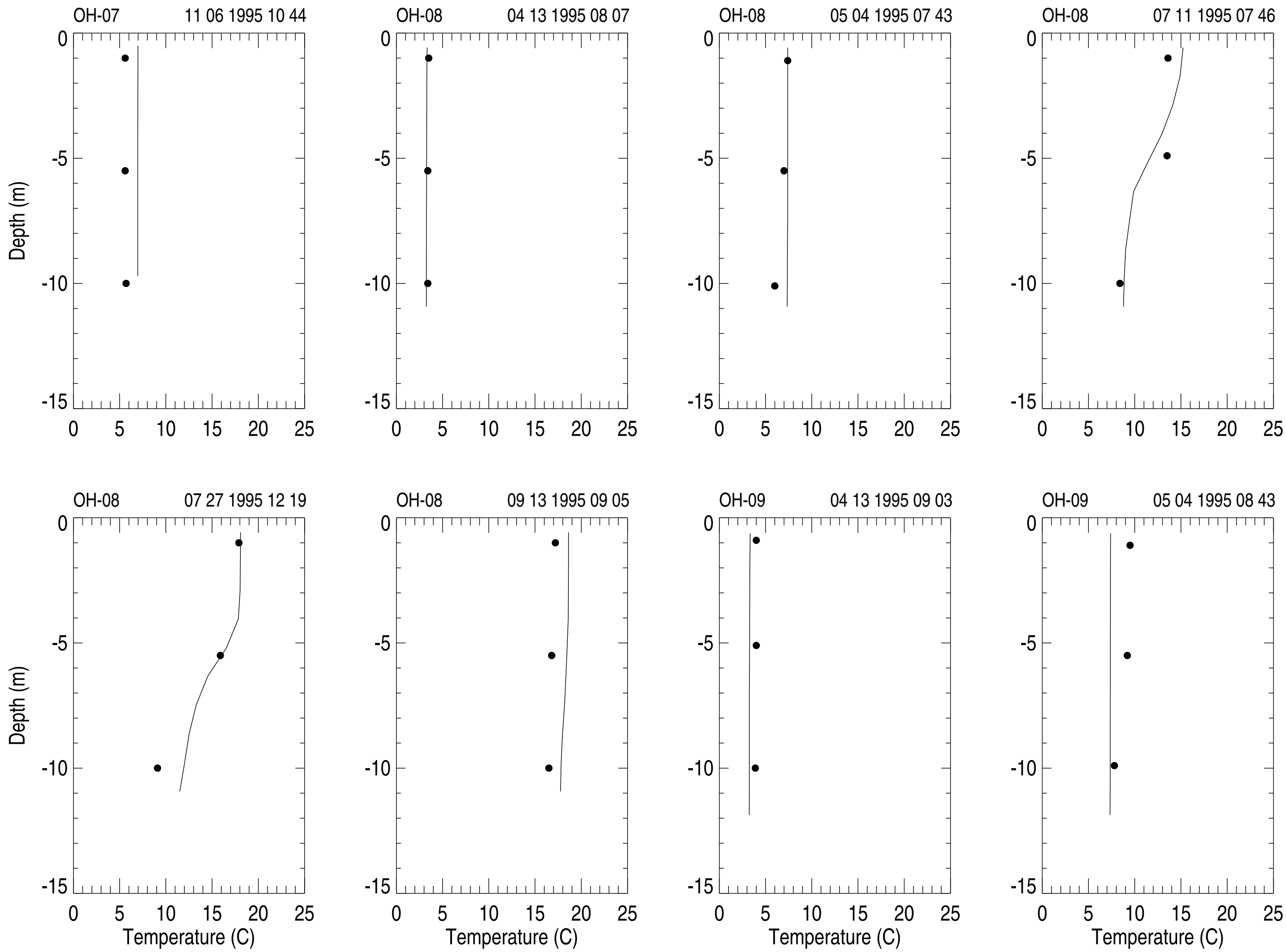


OH-05 07 11 1995 07 11
OH-05 07 27 1995 09 39
OH-05 08 07 1995 10 54
OH-05 09 13 1995 08 28
OH-05 10 19 1995 09 48
OH-05 11 06 1995 10 01
OH-06 04 13 1995 07 45
OH-06 05 04 1995 07 20
Depth (m)
Temperature (C)

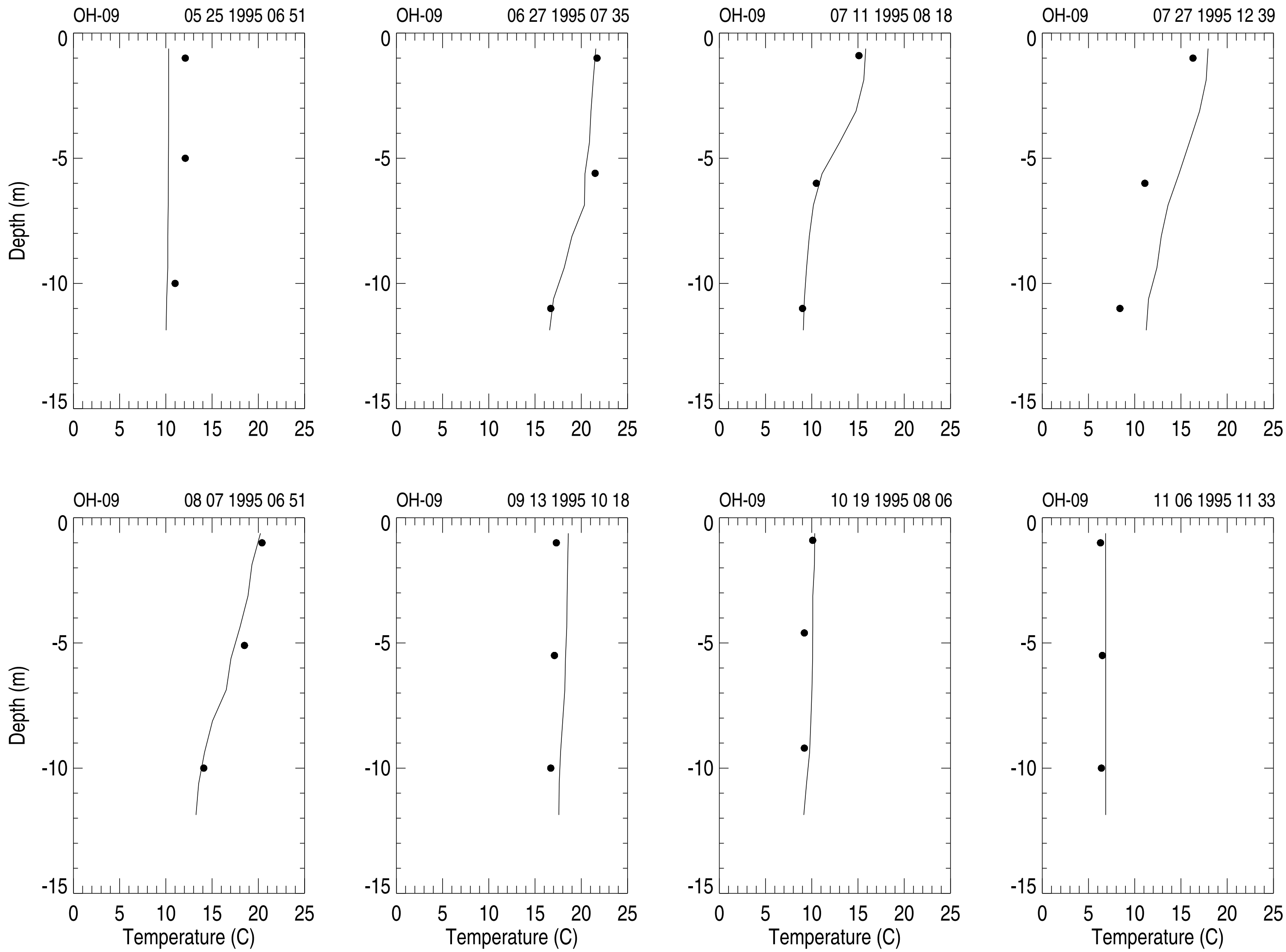

OH-06
07 11 1995 07 23
OH-06
07 27 1995 11 36
OH-06
09 13 1995 08 41
OH-07
04 13 1995 07 56
OH-07
05 03 1995 09 54
OH-07
05 04 1995 07 30
OH-07
05 25 1995 08 13
OH-07
05 31 1995 10 21
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25
Temperature (C)

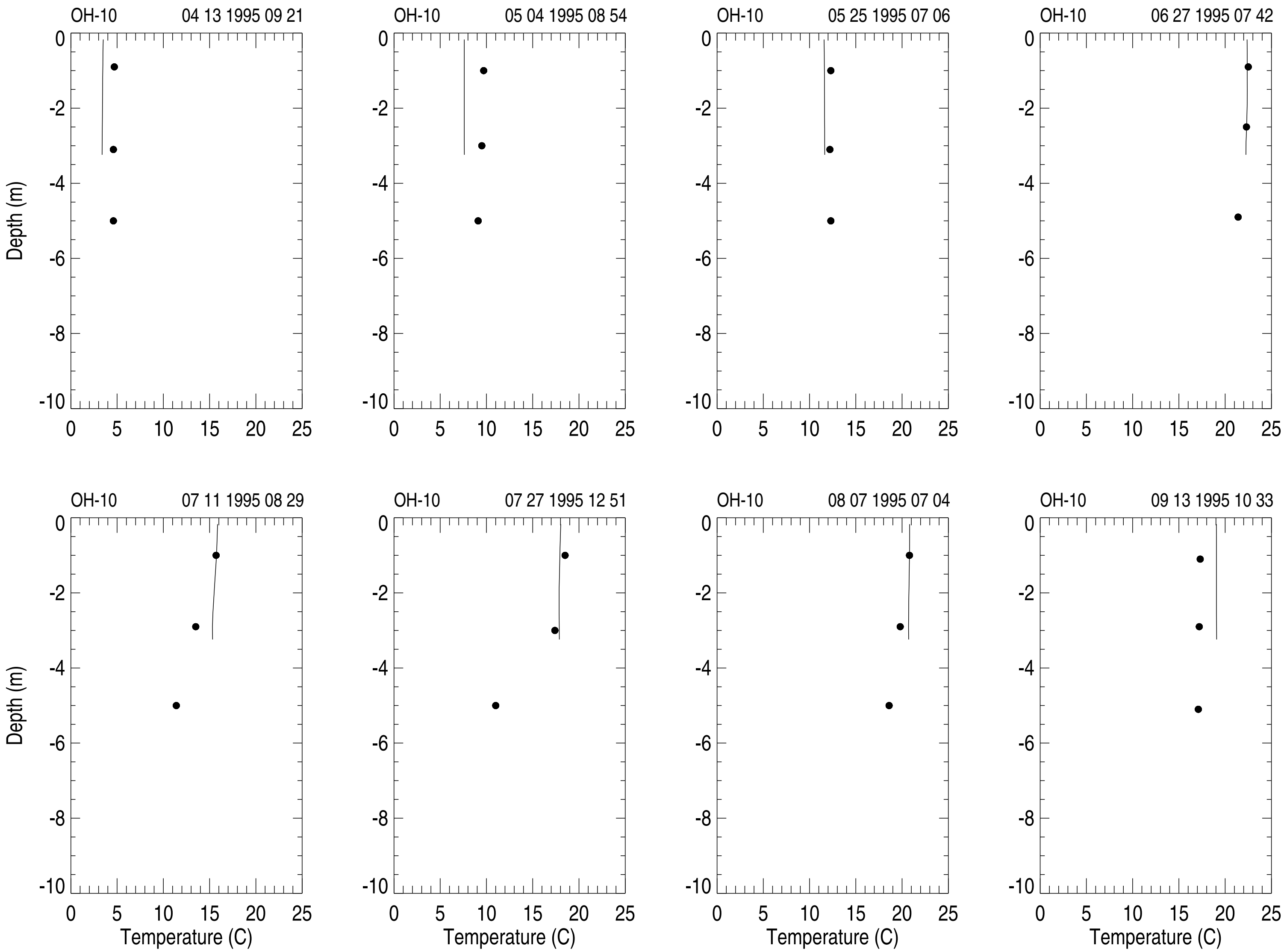


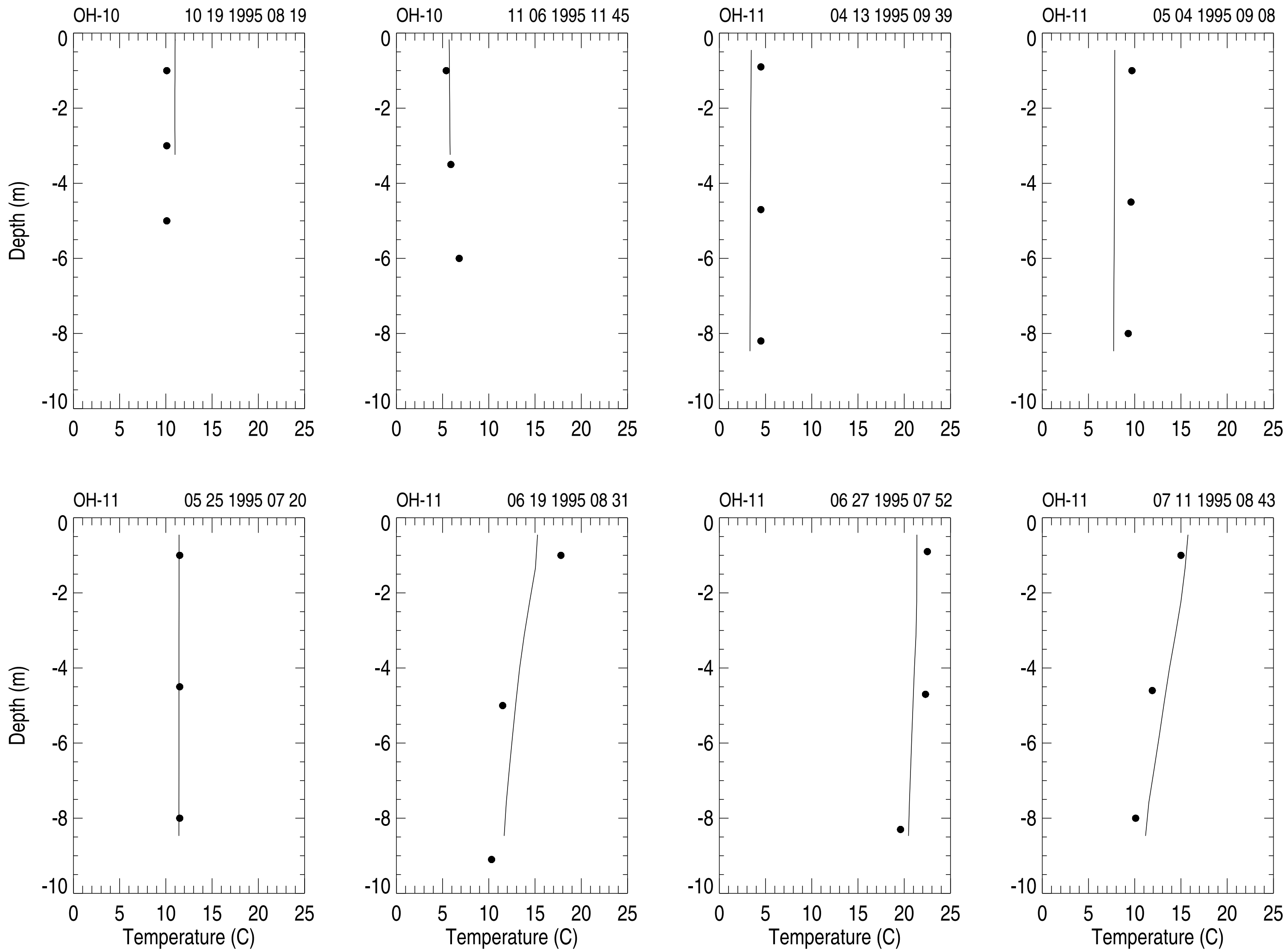
OH-07
06 27 1995 07 30
OH-07
07 11 1995 07 33
OH-07
07 27 1995 10 48
OH-07
08 07 1995 06 31
OH-07
09 13 1995 08 53
OH-07
09 18 1995 11 18
OH-07
10 10 1995 11 10
OH-07
10 19 1995 09 22
Depth (m)
Temperature (C)
0
-5
-10
-15
0 5 10 15 20 25

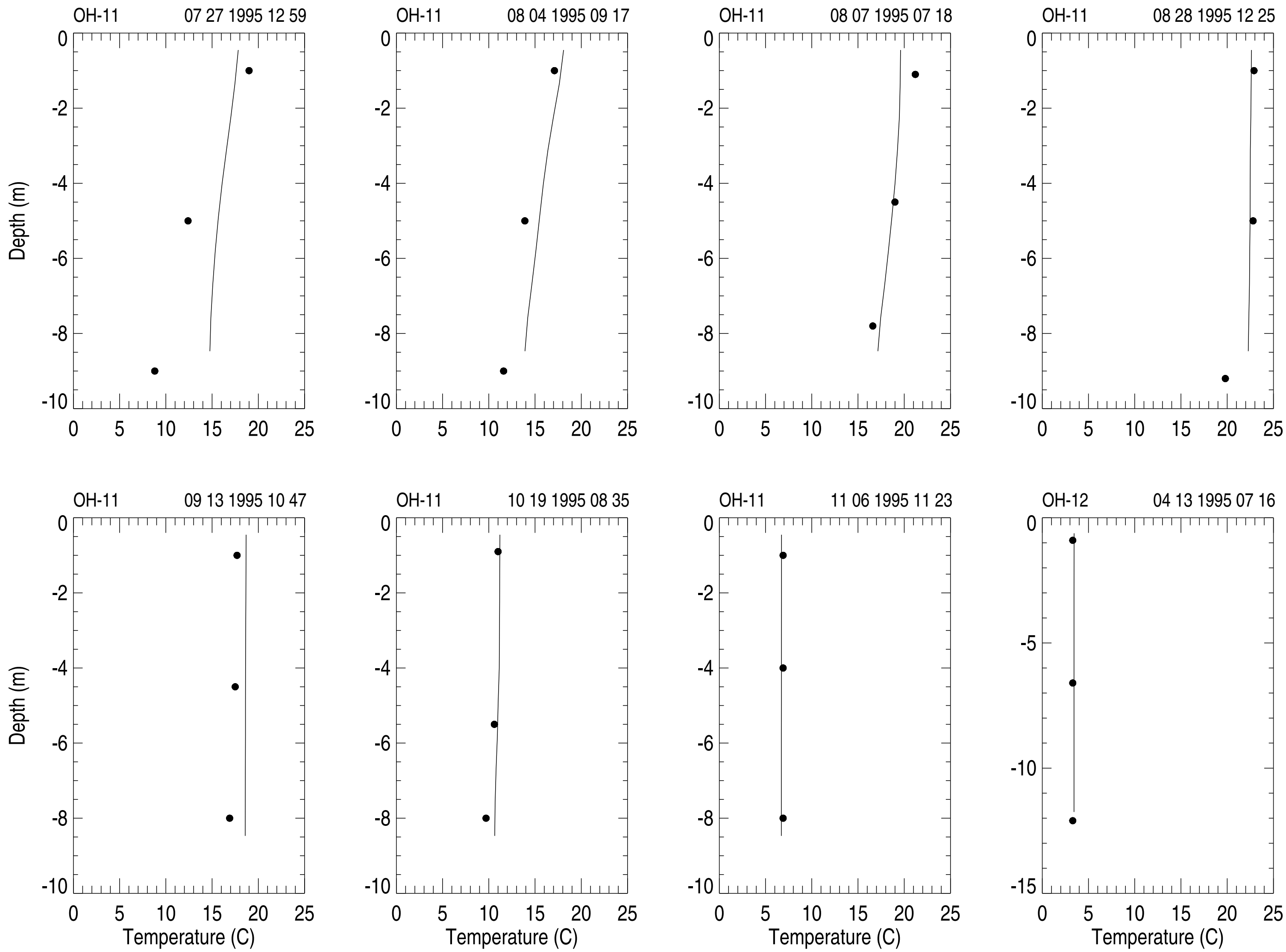


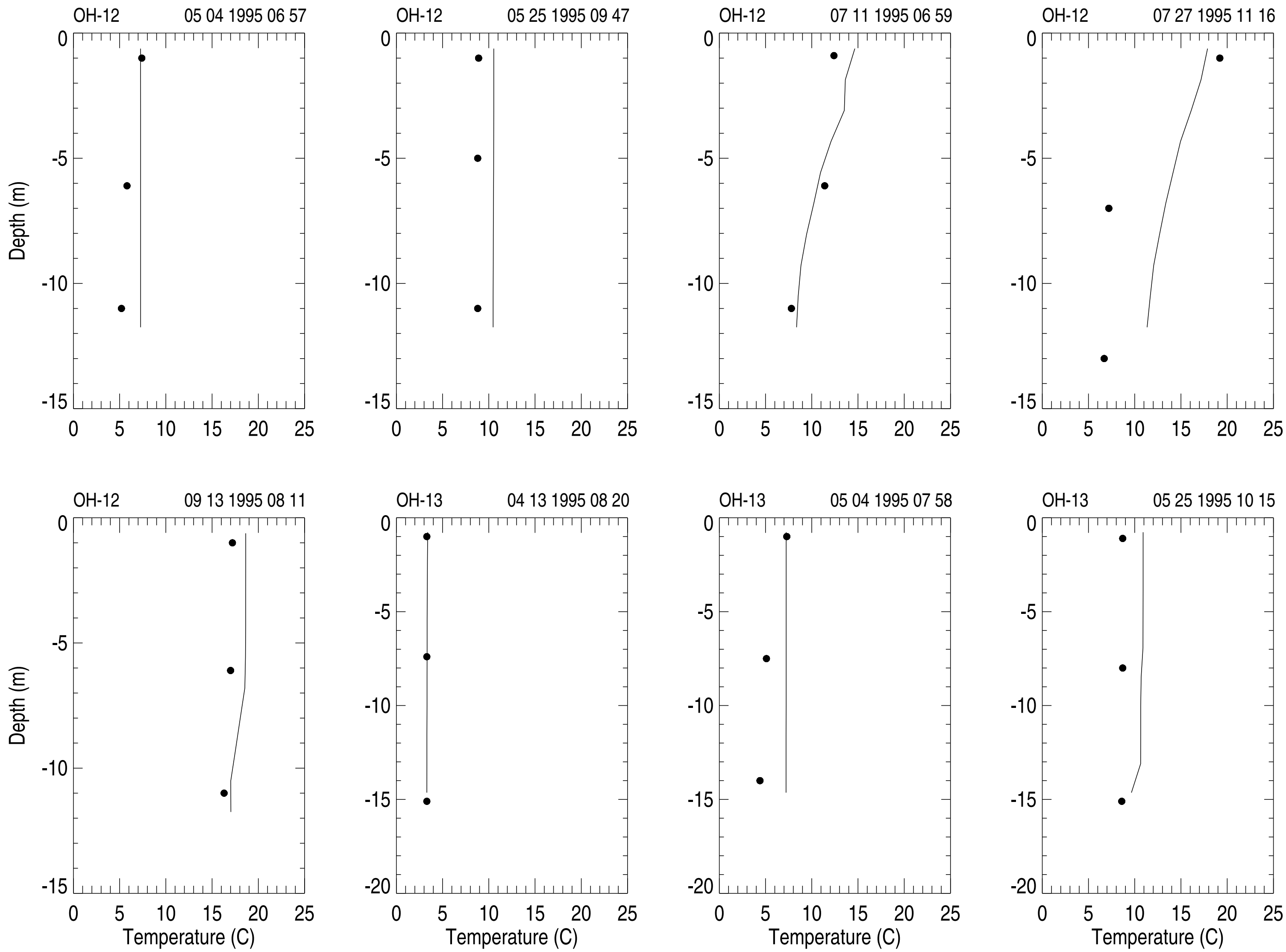
OH-07
11 06 1995 10 44
OH-08
04 13 1995 08 07
OH-08
05 04 1995 07 43
OH-08
07 11 1995 07 46
OH-08
07 27 1995 12 19
OH-08
09 13 1995 09 05
OH-09
04 13 1995 09 03
OH-09
05 04 1995 08 43
Depth (m)
Temperature (C)
0
-5
-10
-15
0
5
10
15
20
25

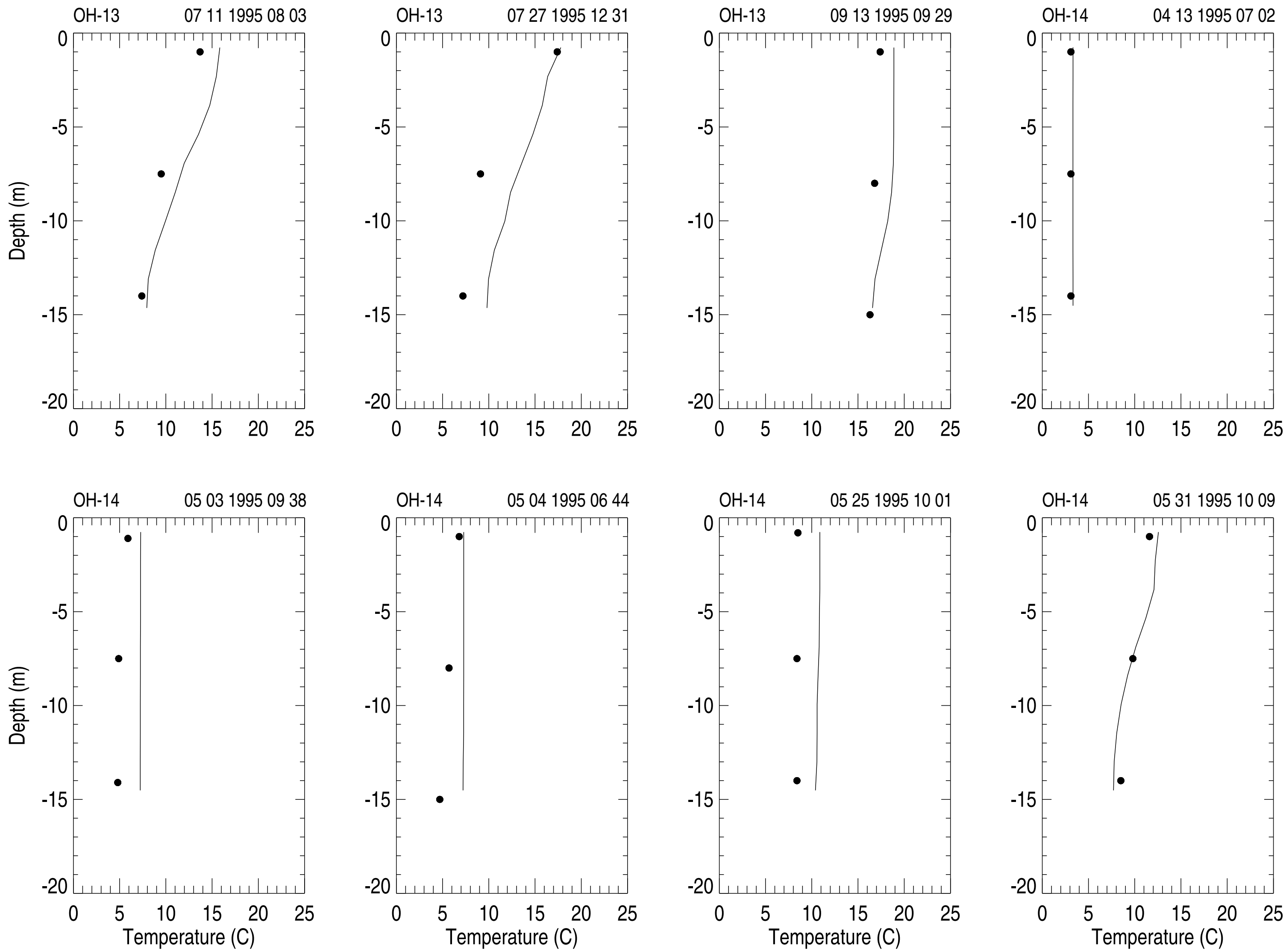

OH-09
05 25 1995 06 51
OH-09
06 27 1995 07 35
OH-09
07 11 1995 08 18
OH-09
07 27 1995 12 39
OH-09
08 07 1995 06 51
OH-09
09 13 1995 10 18
OH-09
10 19 1995 08 06
OH-09
11 06 1995 11 33
Depth (m)
Temperature (C)
0
-5
-10
-15
0 5 10 15 20 25

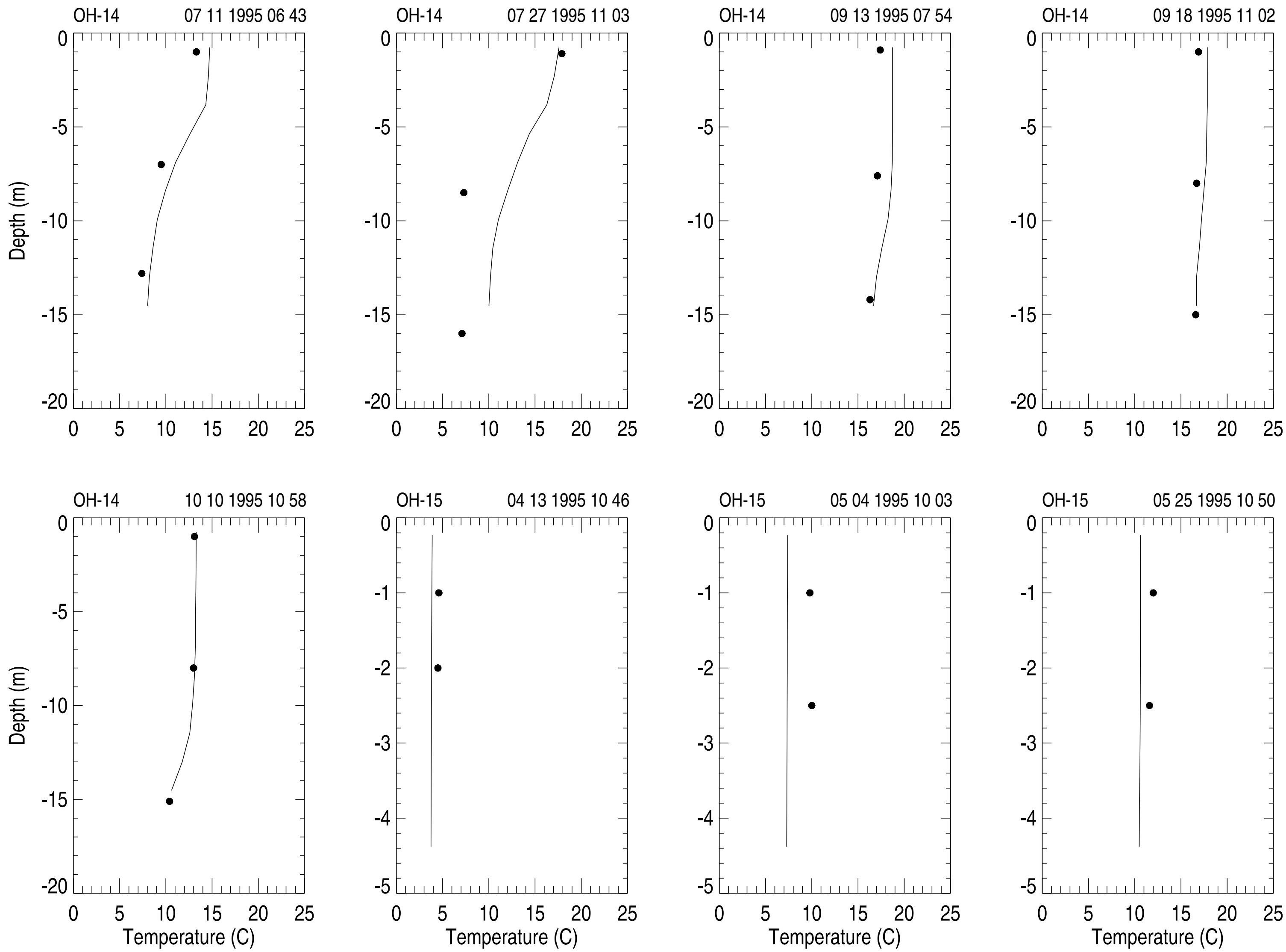

OH-10
04 13 1995 09 21
OH-10
05 04 1995 08 54
OH-10
05 25 1995 07 06
OH-10
06 27 1995 07 42
OH-10
07 11 1995 08 29
OH-10
07 27 1995 12 51
OH-10
08 07 1995 07 04
OH-10
09 13 1995 10 33
Depth (m)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
Temperature (C)

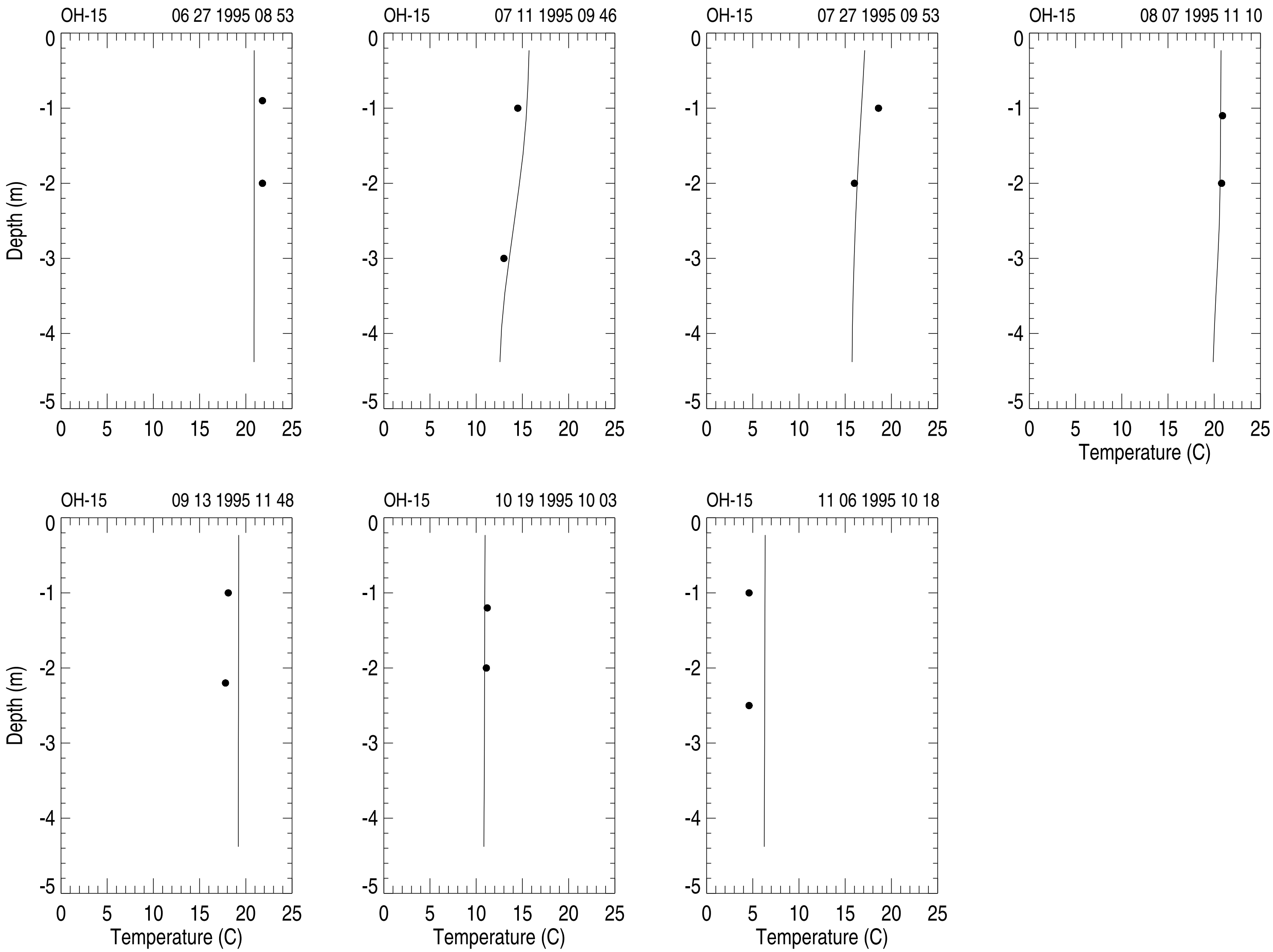

OH-10 10 19 1995 08 19
OH-10 11 06 1995 11 45
OH-11 04 13 1995 09 39
OH-11 05 04 1995 09 08
OH-11 05 25 1995 07 20
OH-11 06 19 1995 08 31
OH-11 06 27 1995 07 52
OH-11 07 11 1995 08 43
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

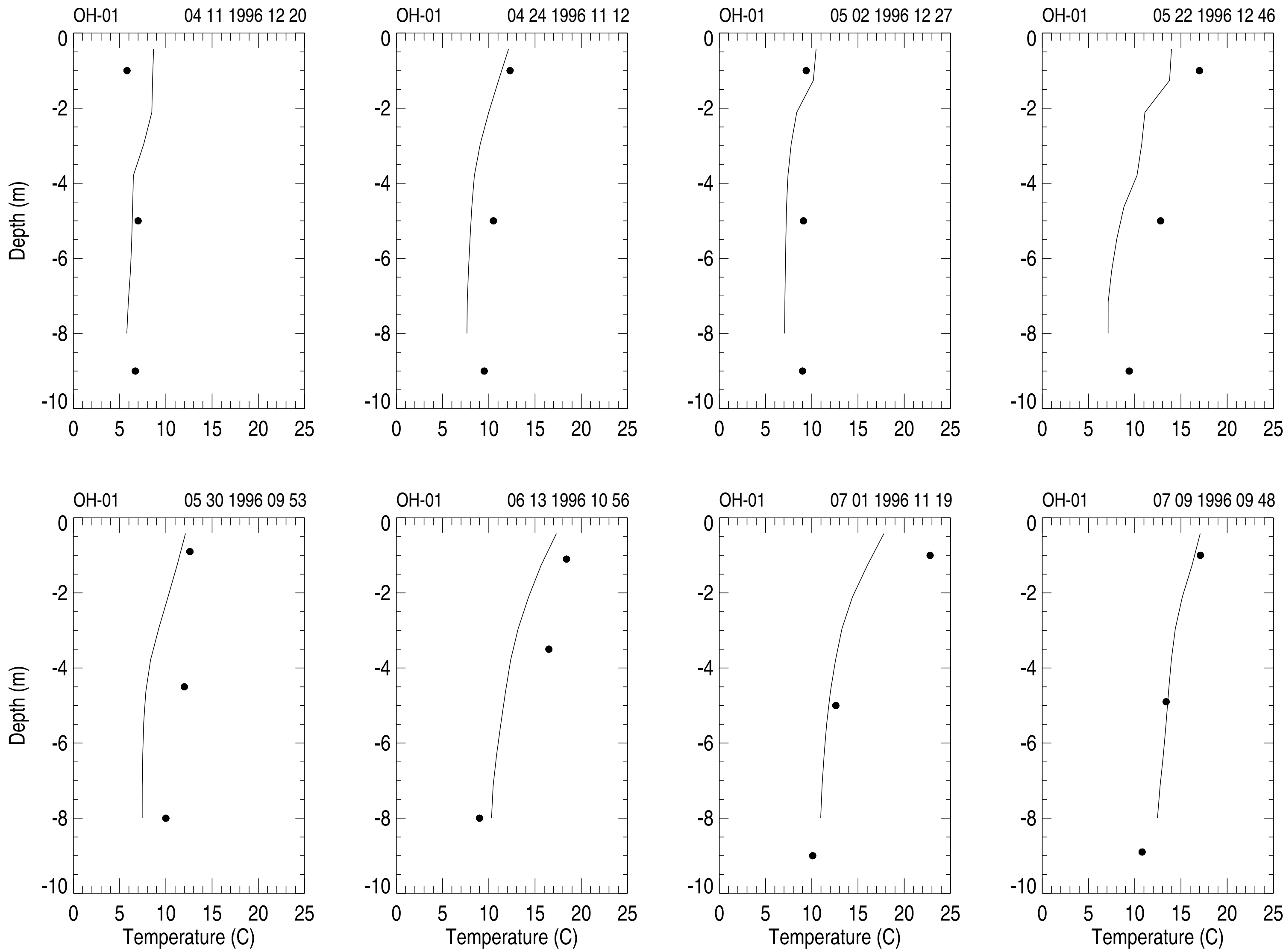

OH-11 07 27 1995 12 59
OH-11 08 04 1995 09 17
OH-11 08 07 1995 07 18
OH-11 08 28 1995 12 25
OH-11 09 13 1995 10 47
OH-11 10 19 1995 08 35
OH-11 11 06 1995 11 23
OH-12 04 13 1995 07 16
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
-5
-15
0 5 10 15 20 25


OH-12 05 04 1995 06 57
OH-12 05 25 1995 09 47
OH-12 07 11 1995 06 59
OH-12 07 27 1995 11 16
OH-12 09 13 1995 08 11
OH-13 04 13 1995 08 20
OH-13 05 04 1995 07 58
OH-13 05 25 1995 10 15
Depth (m)
Temperature (C)

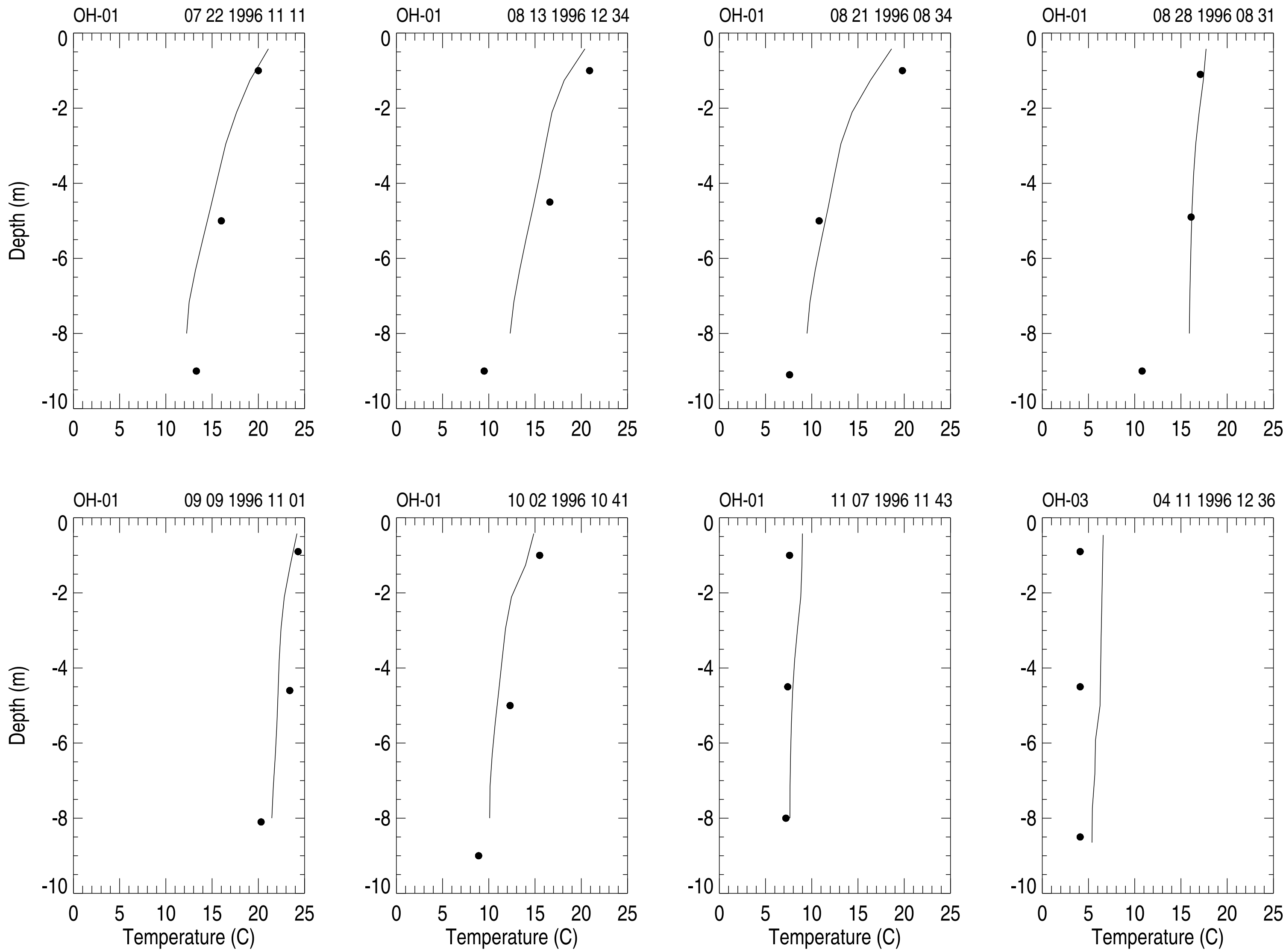

OH-13 07 11 1995 08 03
OH-13 07 27 1995 12 31
OH-13 09 13 1995 09 29
OH-14 04 13 1995 07 02
OH-14 05 03 1995 09 38
OH-14 05 04 1995 06 44
OH-14 05 25 1995 10 01
OH-14 05 31 1995 10 09
Depth (m)
0
-5
-10
-15
-20
0 5 10 15 20 25
Temperature (C)


OH-14 07 11 1995 06 43
OH-14 07 27 1995 11 03
OH-14 09 13 1995 07 54
OH-14 09 18 1995 11 02
OH-14 10 10 1995 10 58
OH-15 04 13 1995 10 46
OH-15 05 04 1995 10 03
OH-15 05 25 1995 10 50
Depth (m)
Temperature (C)
0
-5
-10
-15
-20
-1
-2
-3
-4
0 5 10 15 20 25

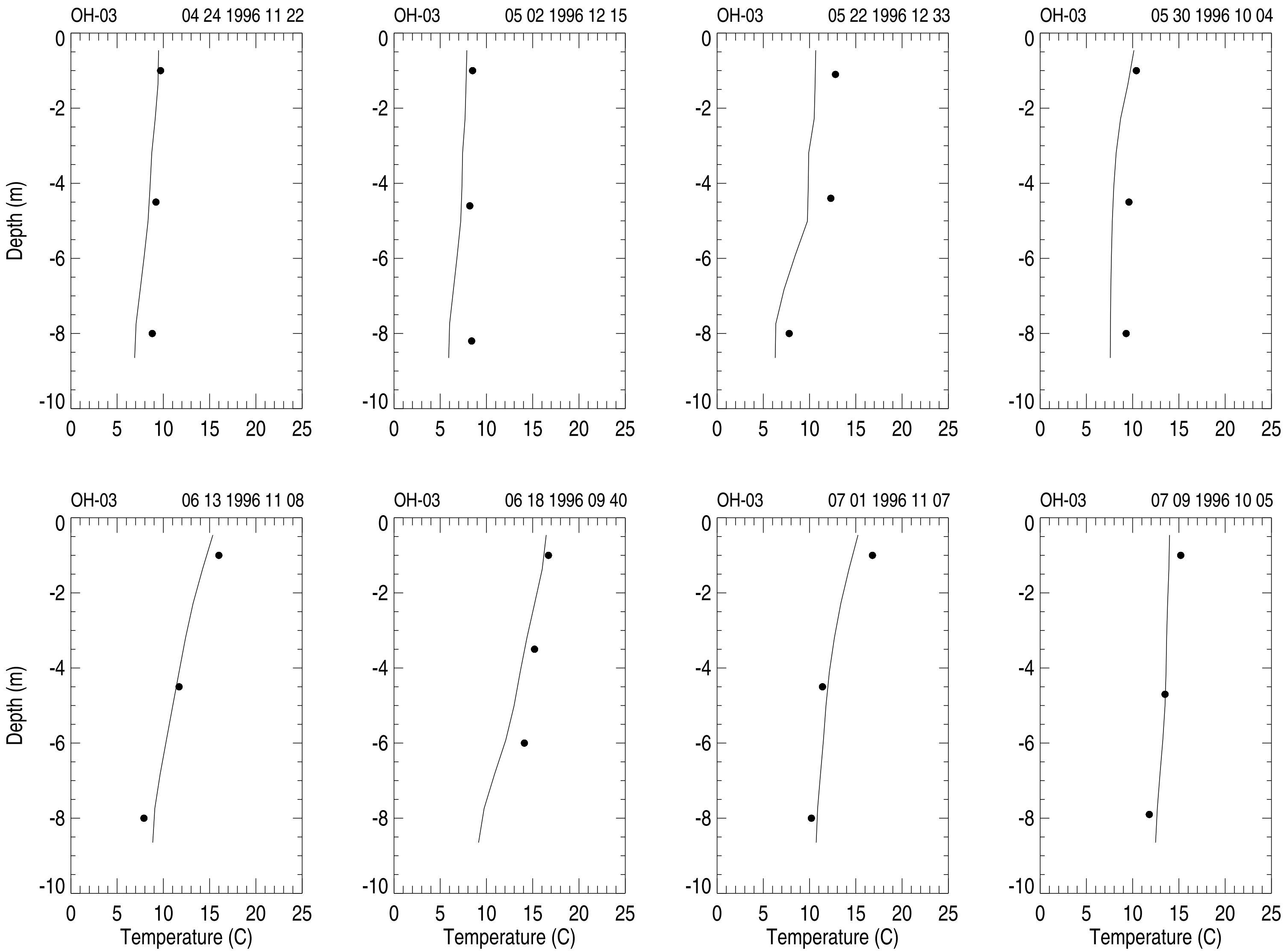

OH-15 06 27 1995 08 53
OH-15 07 11 1995 09 46
OH-15 07 27 1995 09 53
OH-15 08 07 1995 11 10
OH-15 09 13 1995 11 48
OH-15 10 19 1995 10 03
OH-15 11 06 1995 10 18
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25

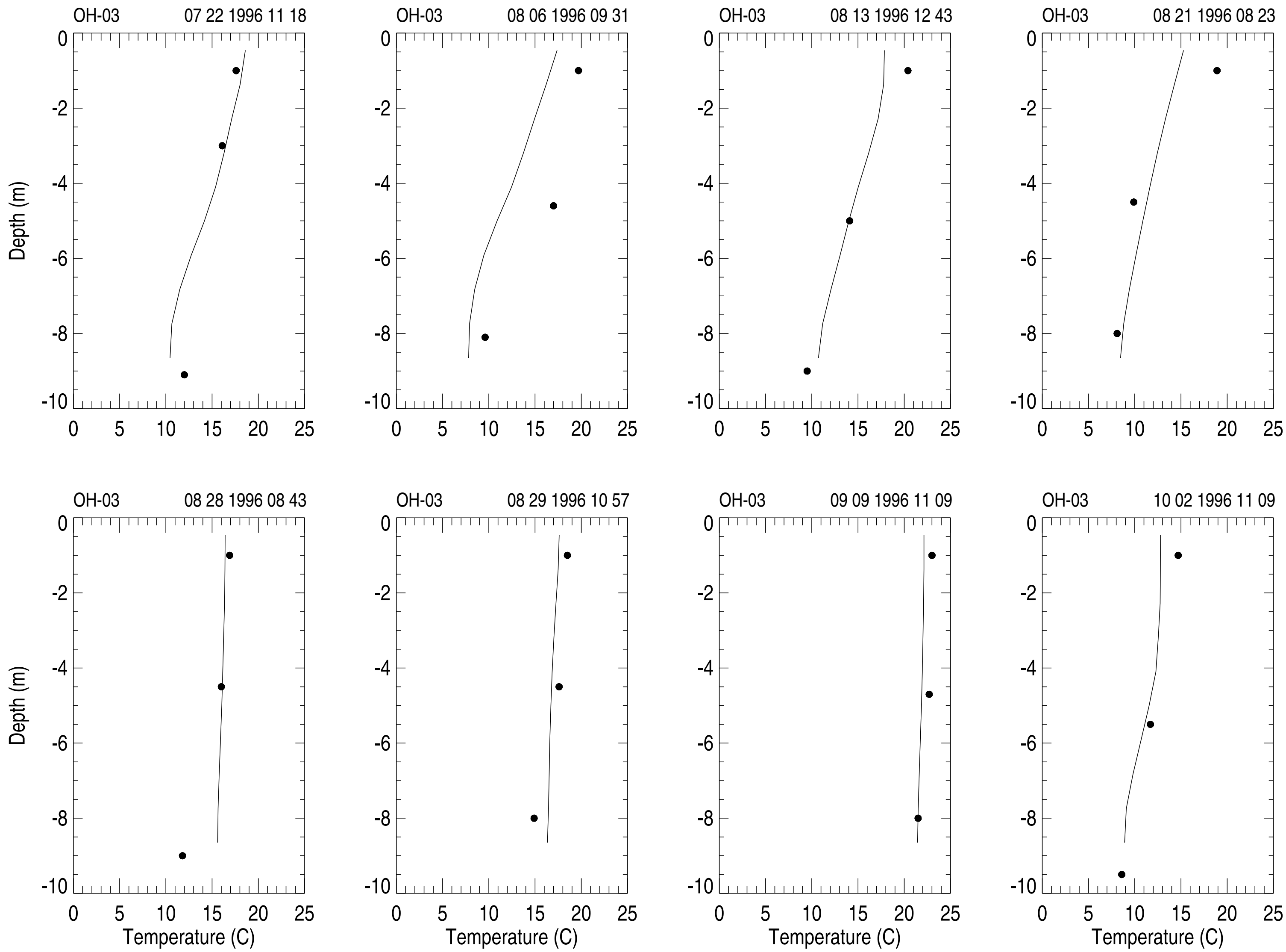


OH-01
04 11 1996 12 20
OH-01
04 24 1996 11 12
OH-01
05 02 1996 12 27
OH-01
05 22 1996 12 46
OH-01
05 30 1996 09 53
OH-01
06 13 1996 10 56
OH-01
07 01 1996 11 19
OH-01
07 09 1996 09 48
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25

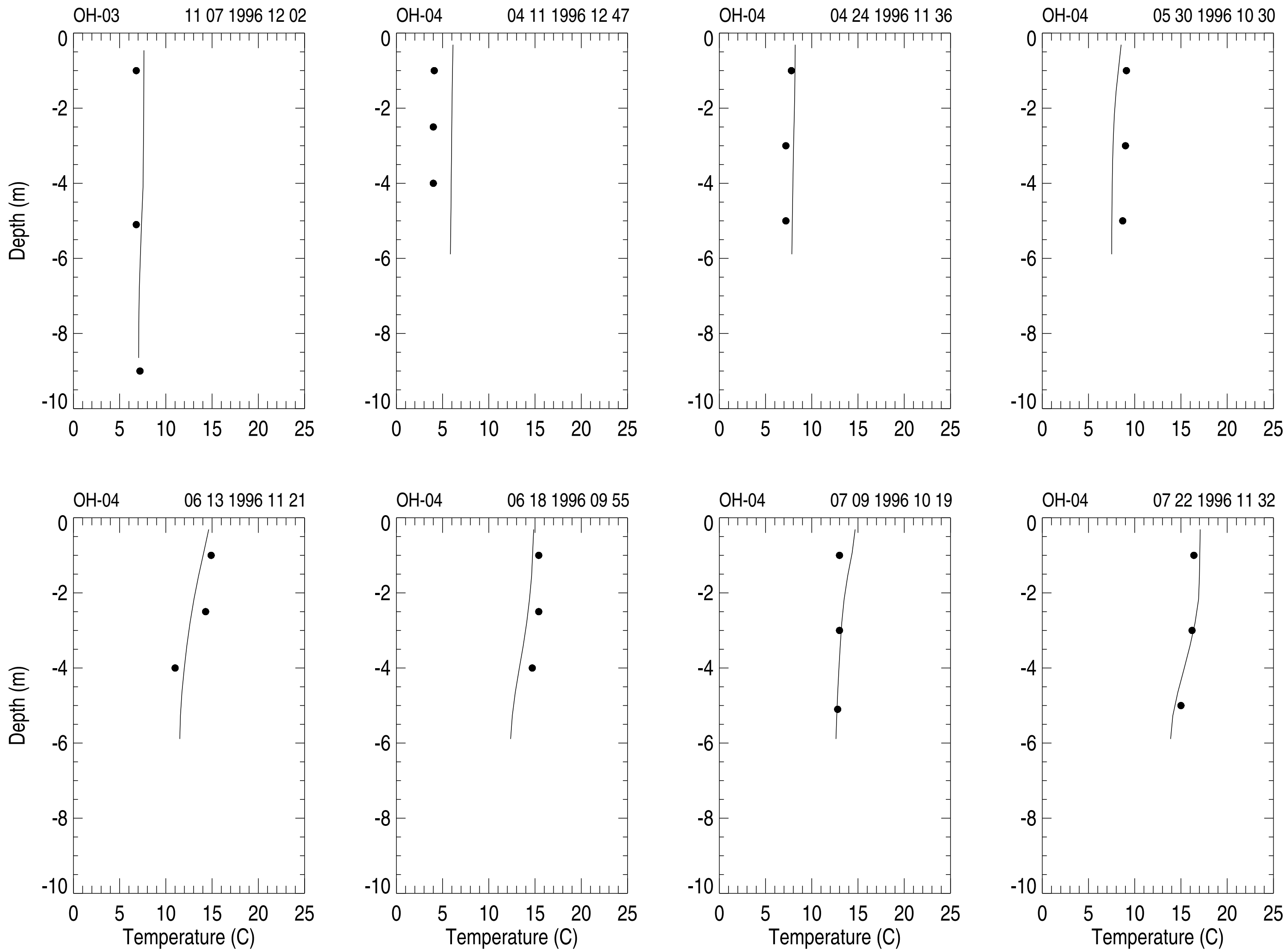


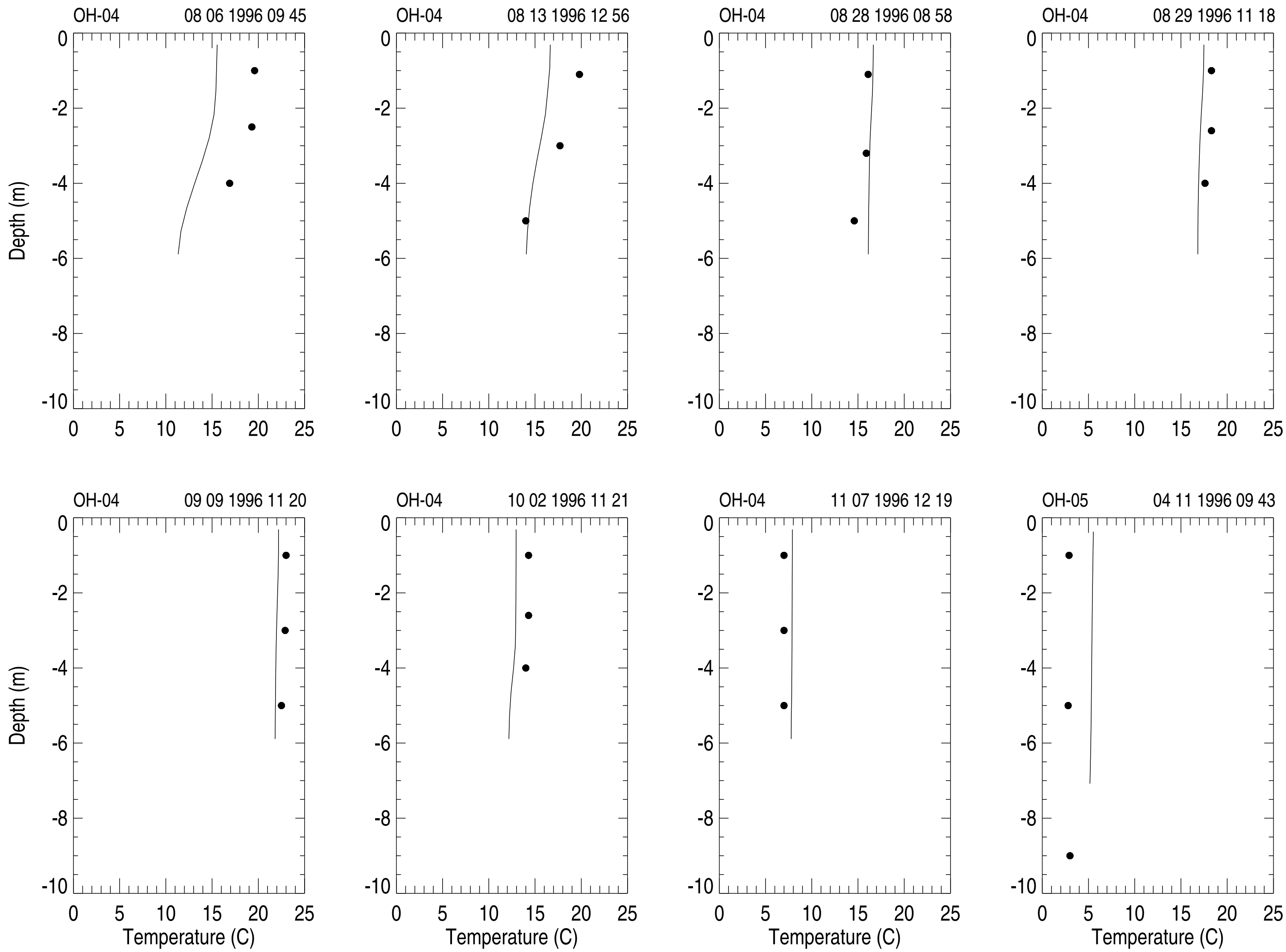
OH-01 07 22 1996 11 11
OH-01 08 13 1996 12 34
OH-01 08 21 1996 08 34
OH-01 08 28 1996 08 31
OH-01 09 09 1996 11 01
OH-01 10 02 1996 10 41
OH-01 11 07 1996 11 43
OH-03 04 11 1996 12 36
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

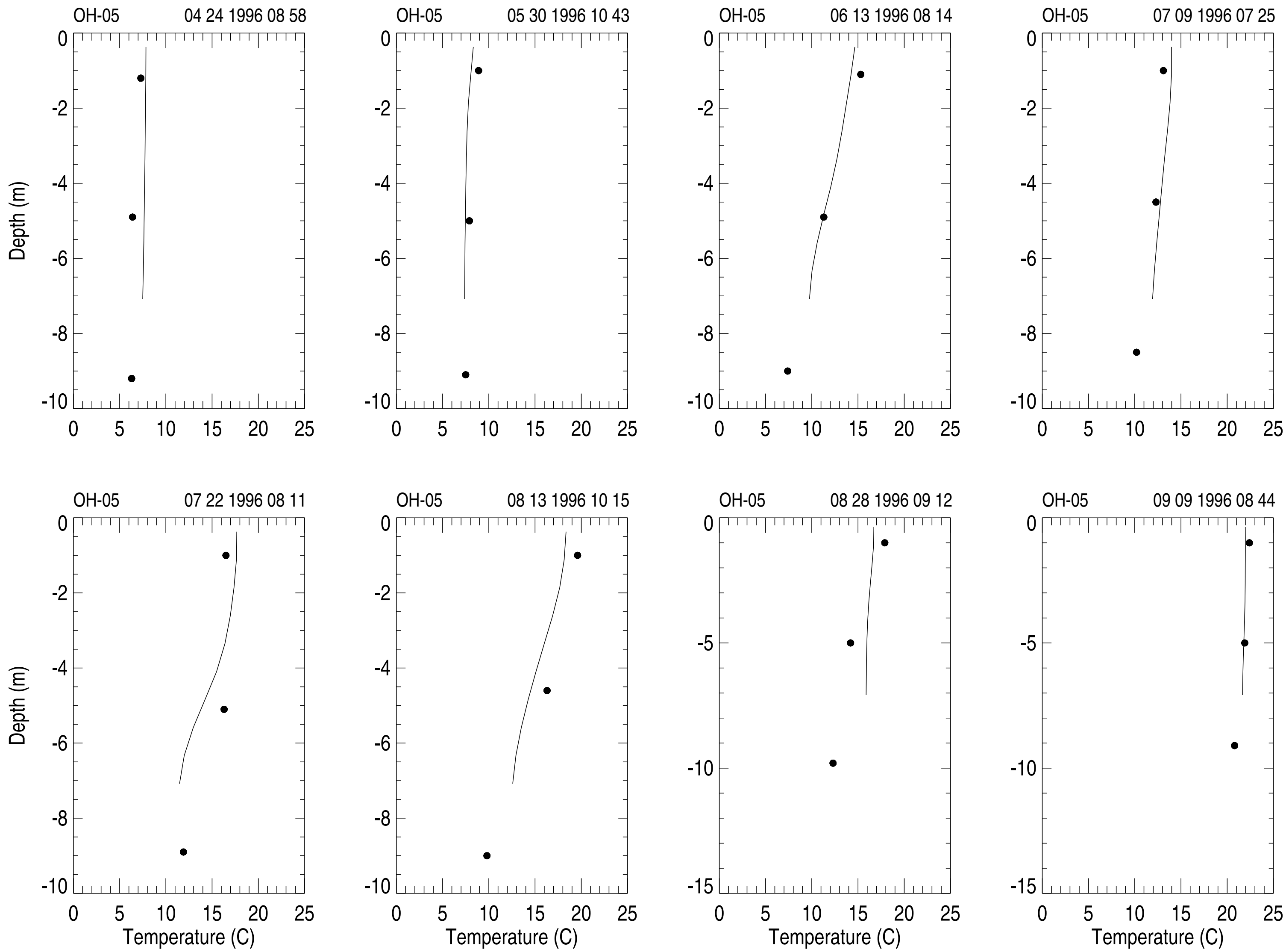

OH-03
04 24 1996 11 22
OH-03
05 02 1996 12 15
OH-03
05 22 1996 12 33
OH-03
05 30 1996 10 04
OH-03
06 13 1996 11 08
OH-03
06 18 1996 09 40
OH-03
07 01 1996 11 07
OH-03
07 09 1996 10 05
Depth (m)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
Temperature (C)

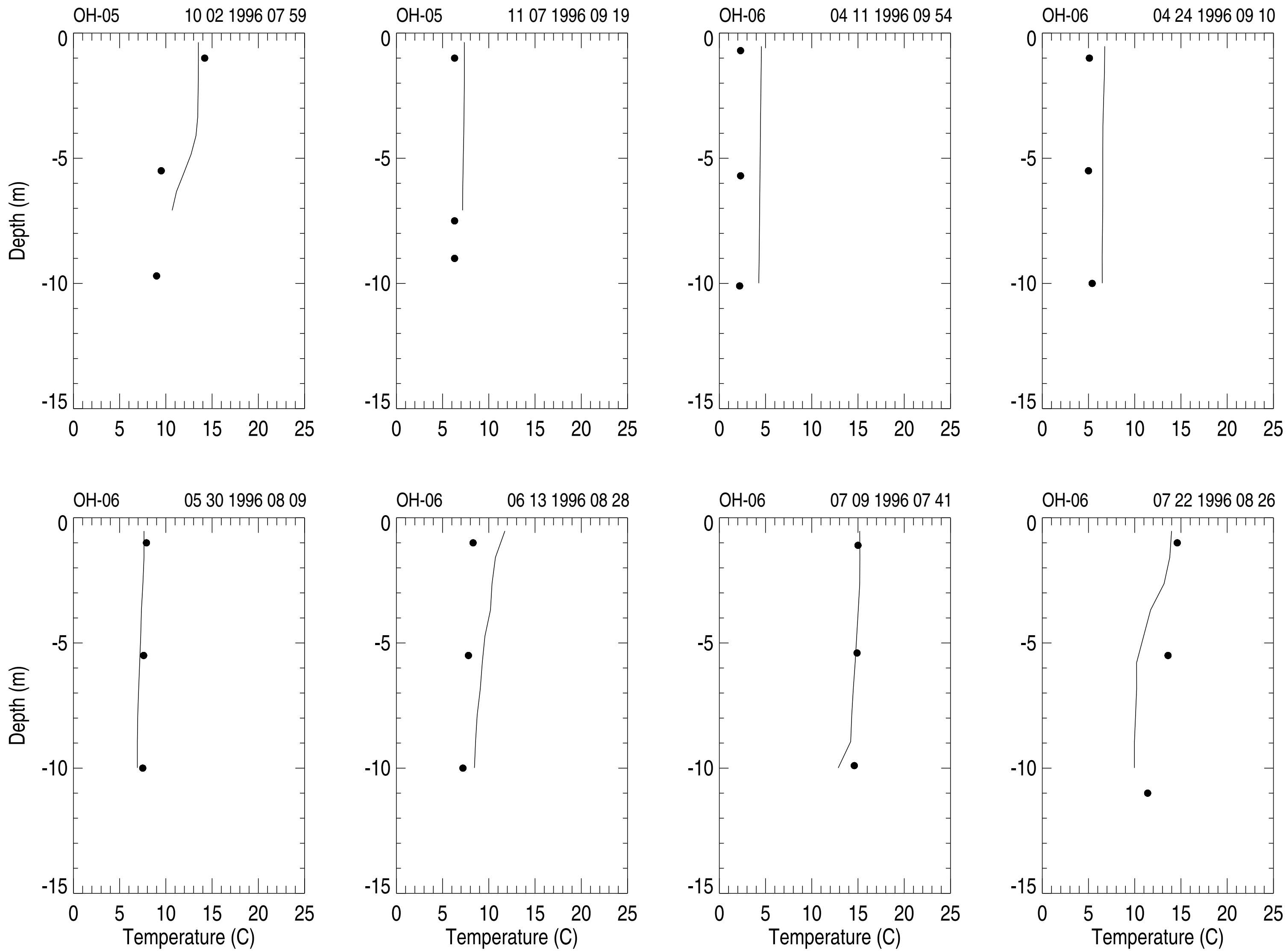


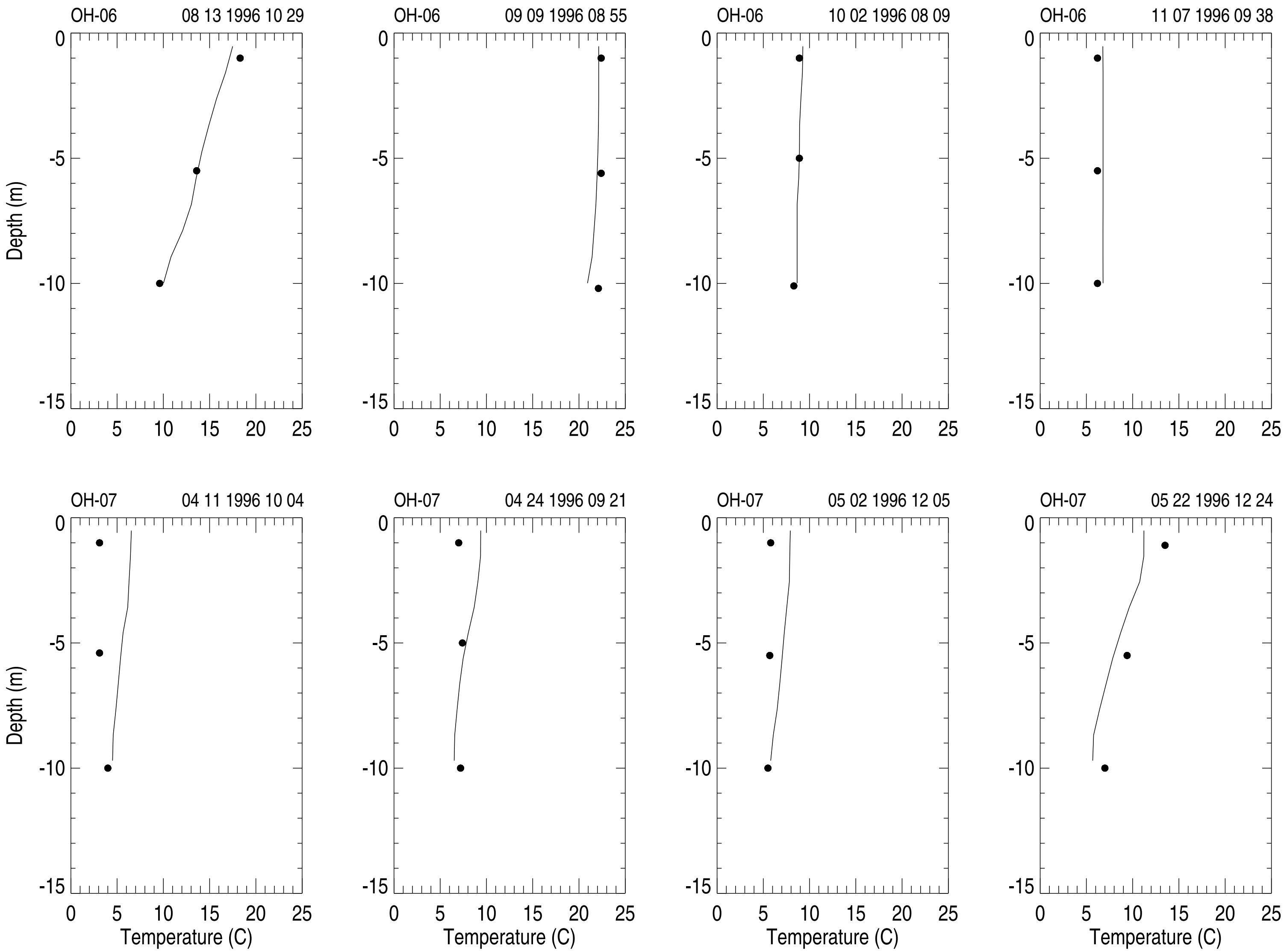
OH-03
07 22 1996 11 18
OH-03
08 06 1996 09 31
OH-03
08 13 1996 12 43
OH-03
08 21 1996 08 23
OH-03
08 28 1996 08 43
OH-03
08 29 1996 10 57
OH-03
09 09 1996 11 09
OH-03
10 02 1996 11 09
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25


OH-03 11 07 1996 12 02
OH-04 04 11 1996 12 47
OH-04 04 24 1996 11 36
OH-04 05 30 1996 10 30
OH-04 06 13 1996 11 21
OH-04 06 18 1996 09 55
OH-04 07 09 1996 10 19
OH-04 07 22 1996 11 32
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

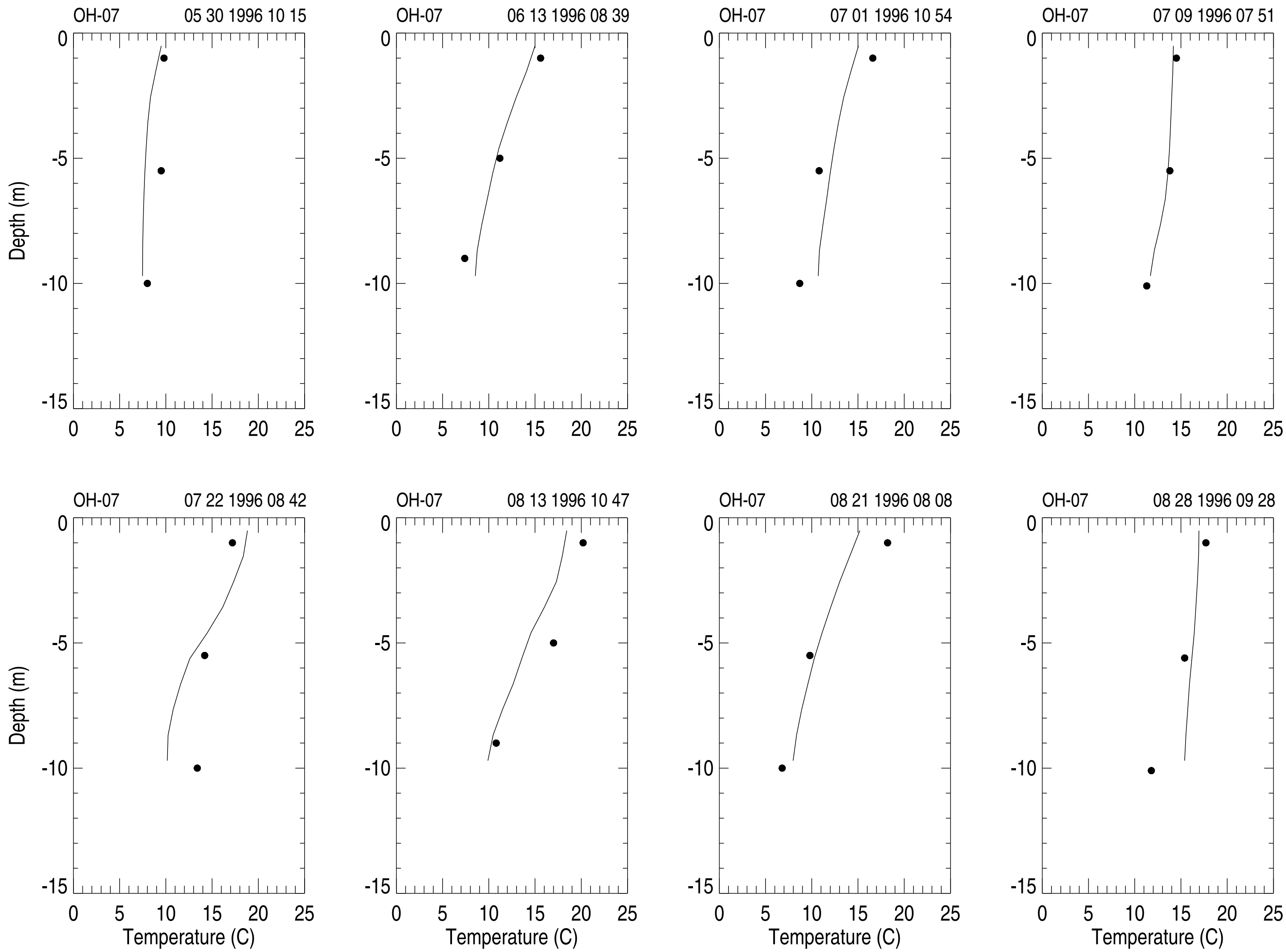

OH-04
08 06 1996 09 45
OH-04
08 13 1996 12 56
OH-04
08 28 1996 08 58
OH-04
08 29 1996 11 18
OH-04
09 09 1996 11 20
OH-04
10 02 1996 11 21
OH-04
11 07 1996 12 19
OH-05
04 11 1996 09 43
Depth (m)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
Temperature (C)

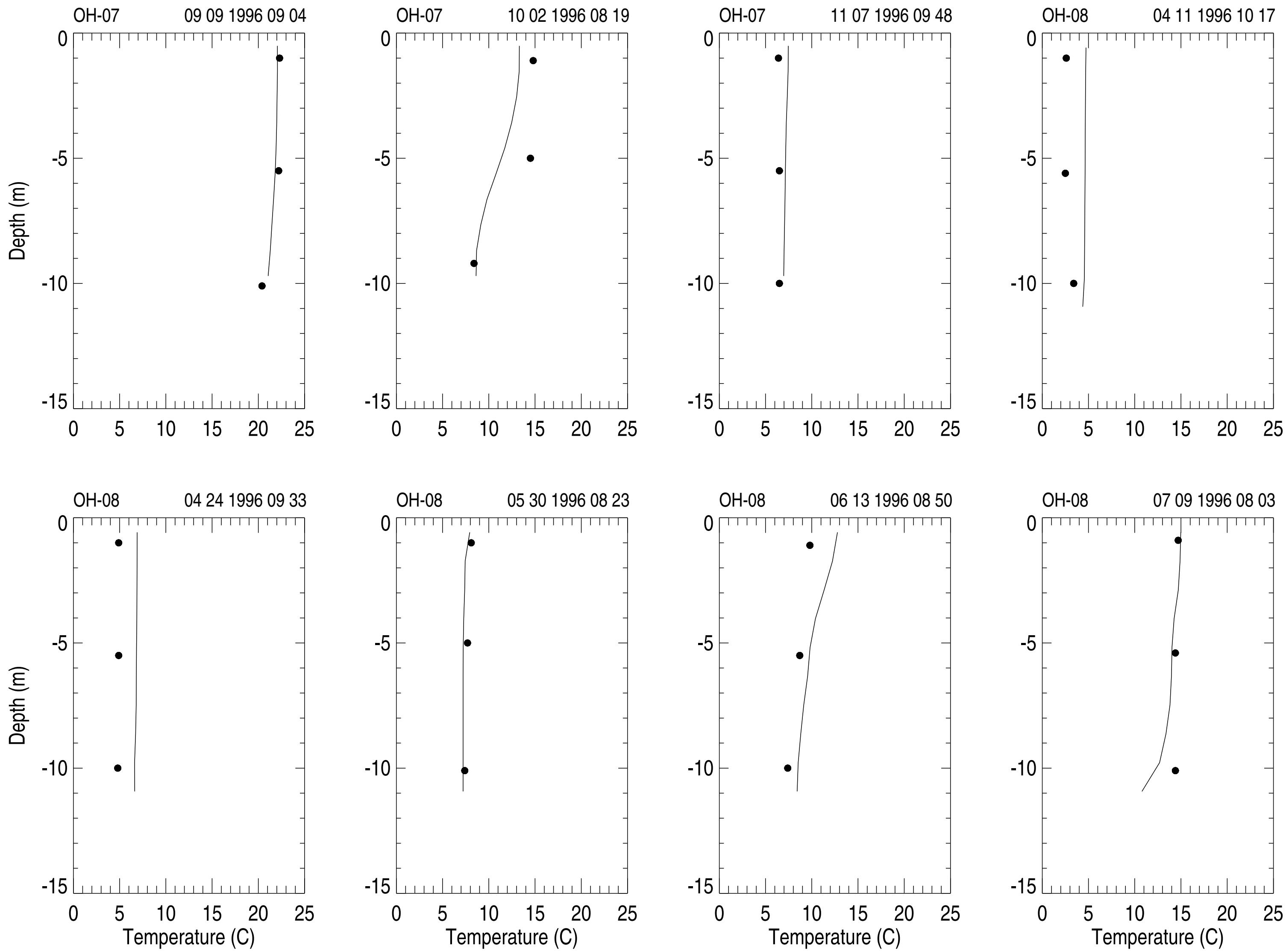

OH-05
04 24 1996 08 58
OH-05
05 30 1996 10 43
OH-05
06 13 1996 08 14
OH-05
07 09 1996 07 25
OH-05
07 22 1996 08 11
OH-05
08 13 1996 10 15
OH-05
08 28 1996 09 12
OH-05
09 09 1996 08 44
Depth (m)
Temperature (C)


OH-05
10 02 1996 07 59
OH-05
11 07 1996 09 19
OH-06
04 11 1996 09 54
OH-06
04 24 1996 09 10
OH-06
05 30 1996 08 09
OH-06
06 13 1996 08 28
OH-06
07 09 1996 07 41
OH-06
07 22 1996 08 26
Depth (m)
0
-5
-10
-15
0
5
10
15
20
25
Temperature (C)

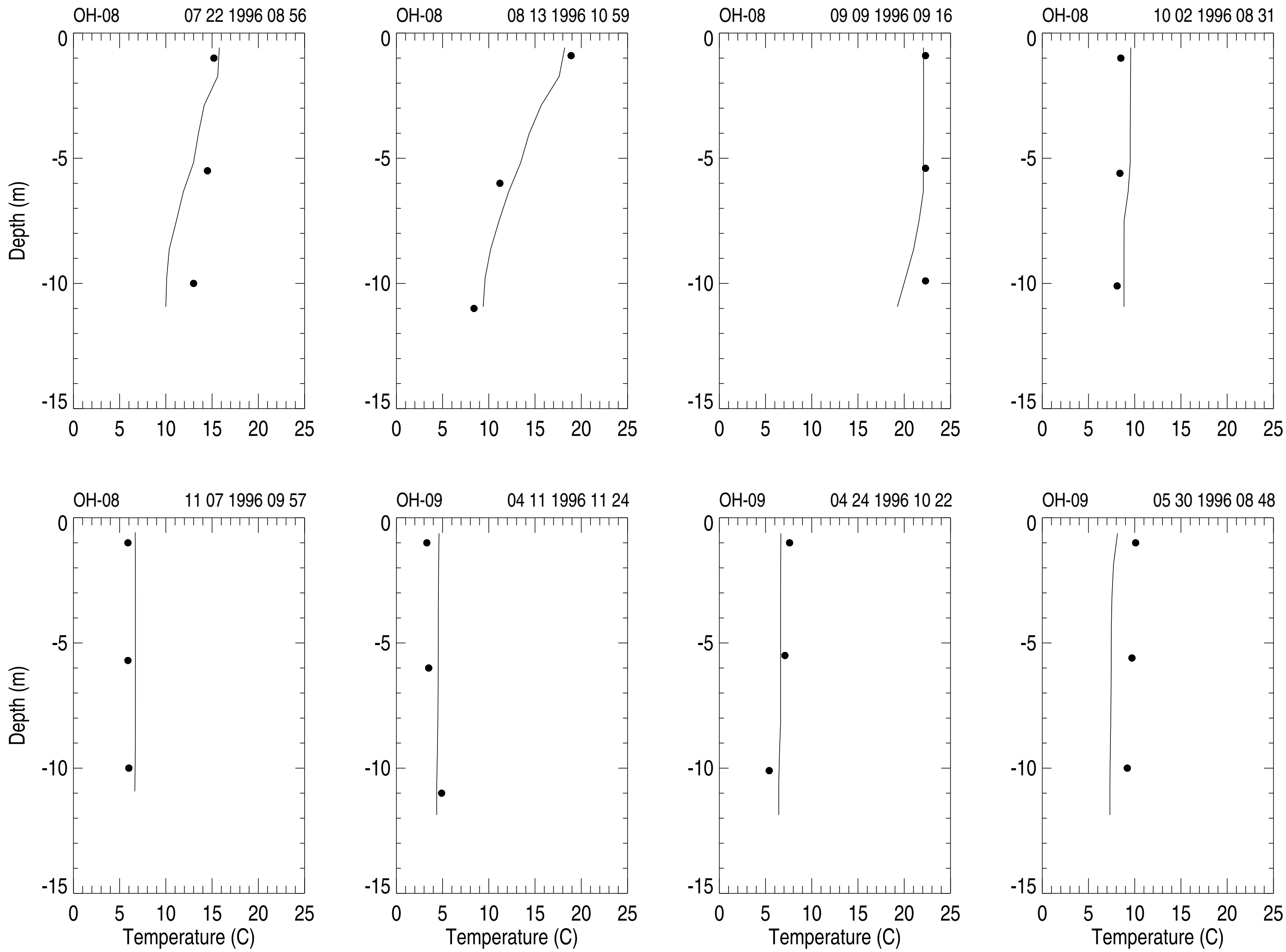


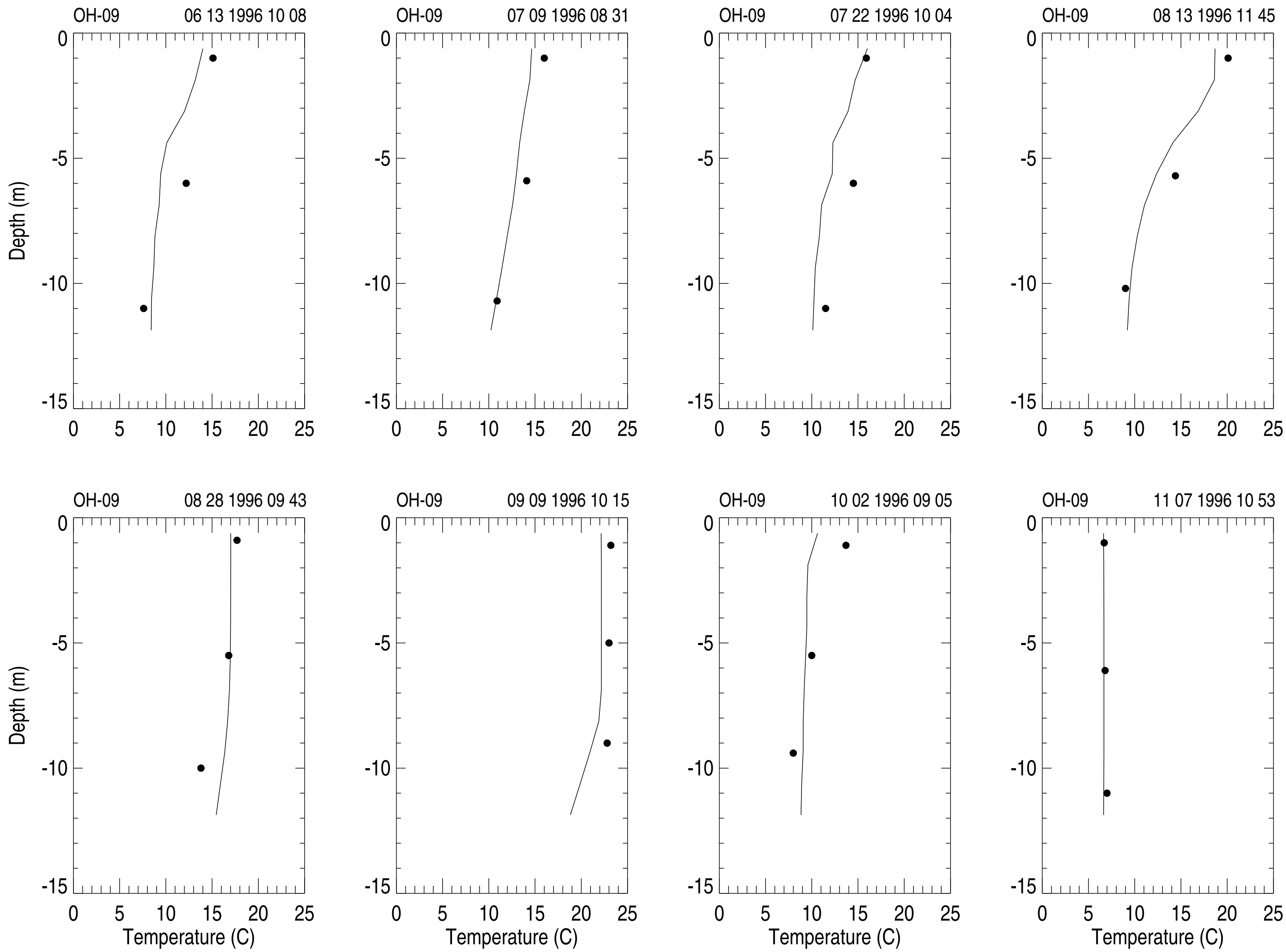
OH-06 08 13 1996 10 29
OH-06 09 09 1996 08 55
OH-06 10 02 1996 08 09
OH-06 11 07 1996 09 38
OH-07 04 11 1996 10 04
OH-07 04 24 1996 09 21
OH-07 05 02 1996 12 05
OH-07 05 22 1996 12 24
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25
Temperature (C)


OH-07
05 30 1996 10 15
06 13 1996 08 39
07 01 1996 10 54
07 09 1996 07 51
07 22 1996 08 42
08 13 1996 10 47
08 21 1996 08 08
08 28 1996 09 28
Depth (m)
Temperature (C)
0
-5
-10
-15
0
5
10
15
20
25

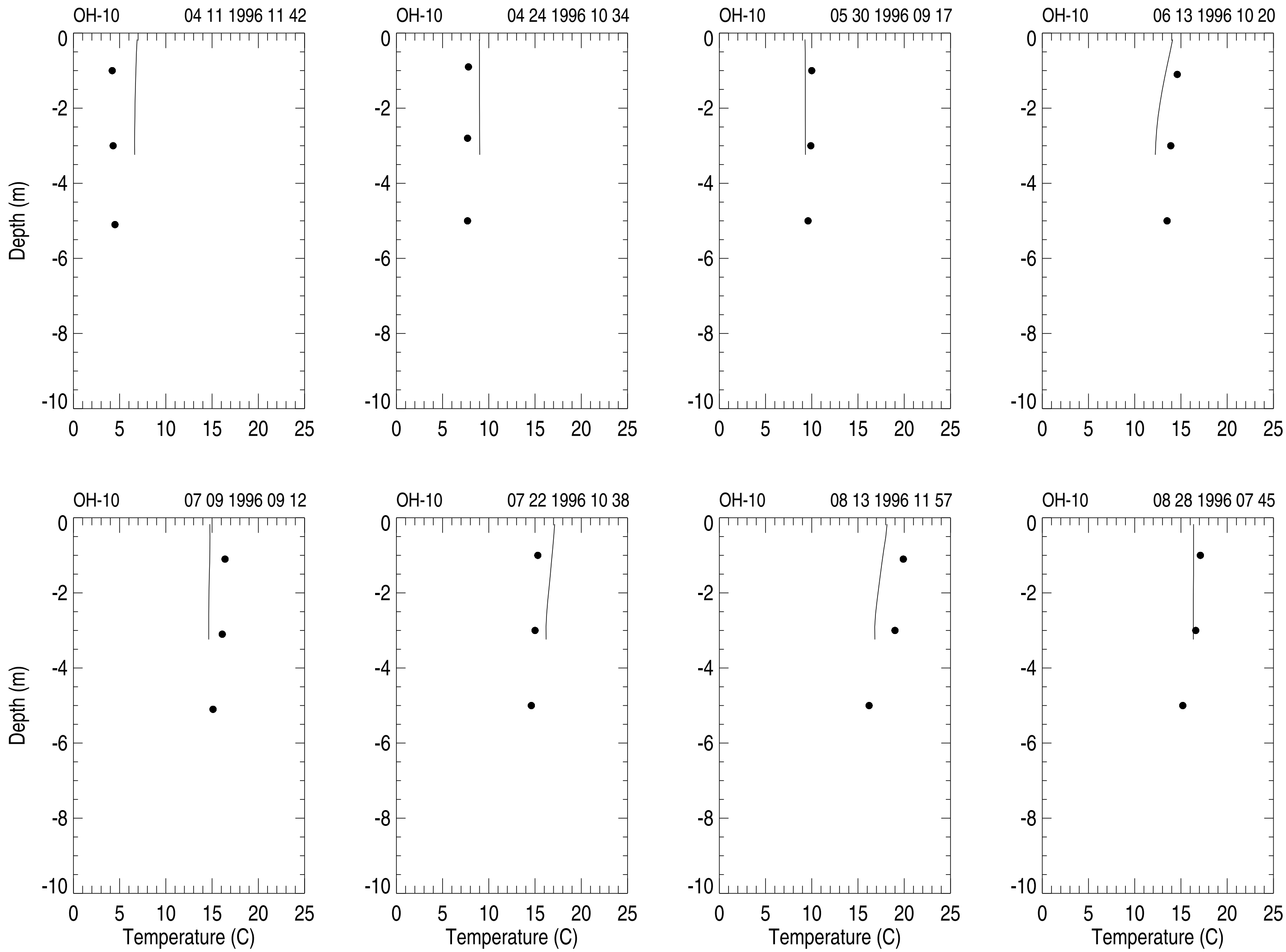


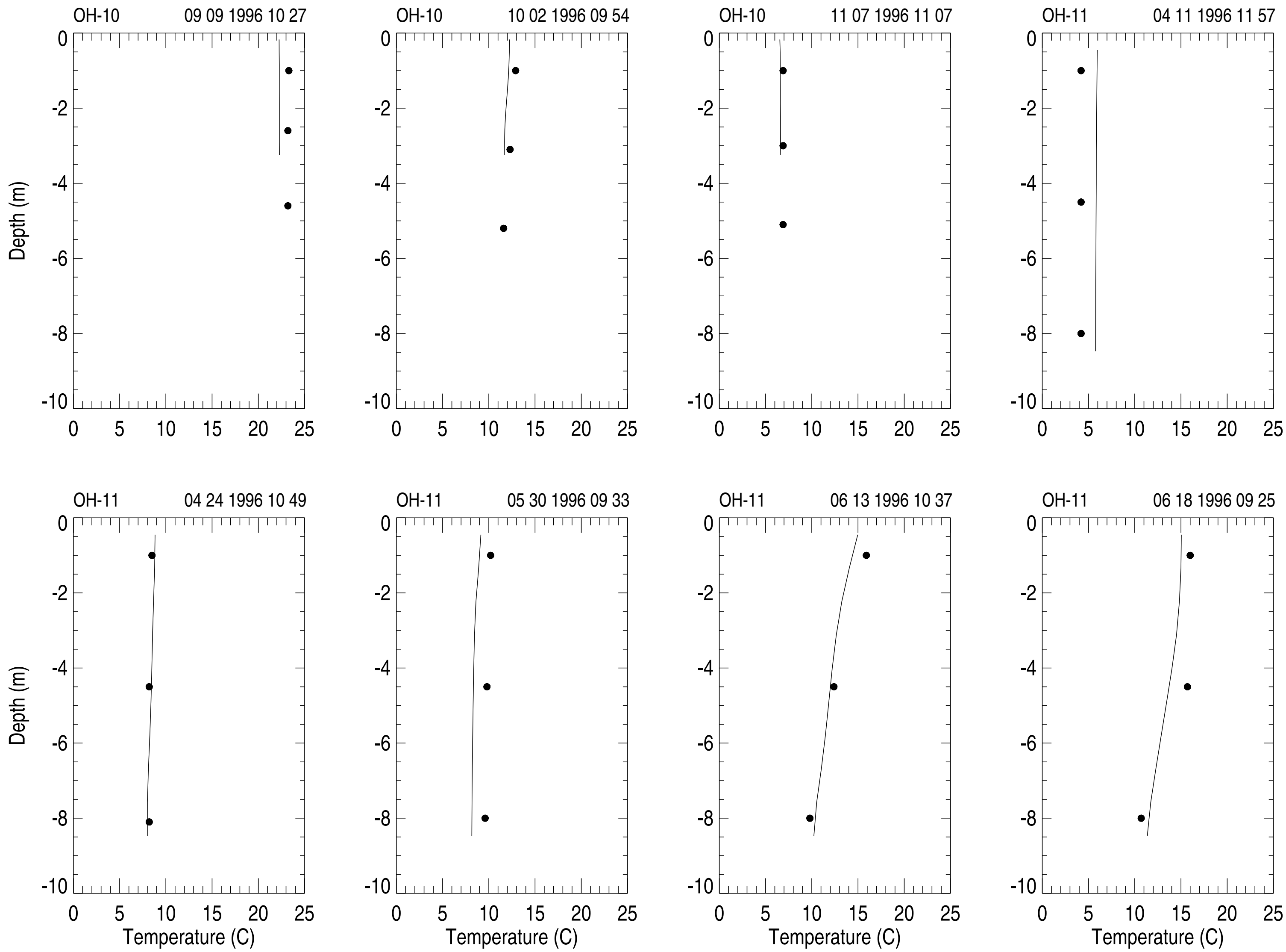
OH-07 09 09 1996 09 04
OH-07 10 02 1996 08 19
OH-07 11 07 1996 09 48
OH-08 04 11 1996 10 17
OH-08 04 24 1996 09 33
OH-08 05 30 1996 08 23
OH-08 06 13 1996 08 50
OH-08 07 09 1996 08 03
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25
Temperature (C)


OH-08
07 22 1996 08 56
OH-08
08 13 1996 10 59
OH-08
09 09 1996 09 16
OH-08
10 02 1996 08 31
OH-08
11 07 1996 09 57
OH-09
04 11 1996 11 24
OH-09
04 24 1996 10 22
OH-09
05 30 1996 08 48
Depth (m)
Temperature (C)
0
-5
-10
-15
0
5
10
15
20
25

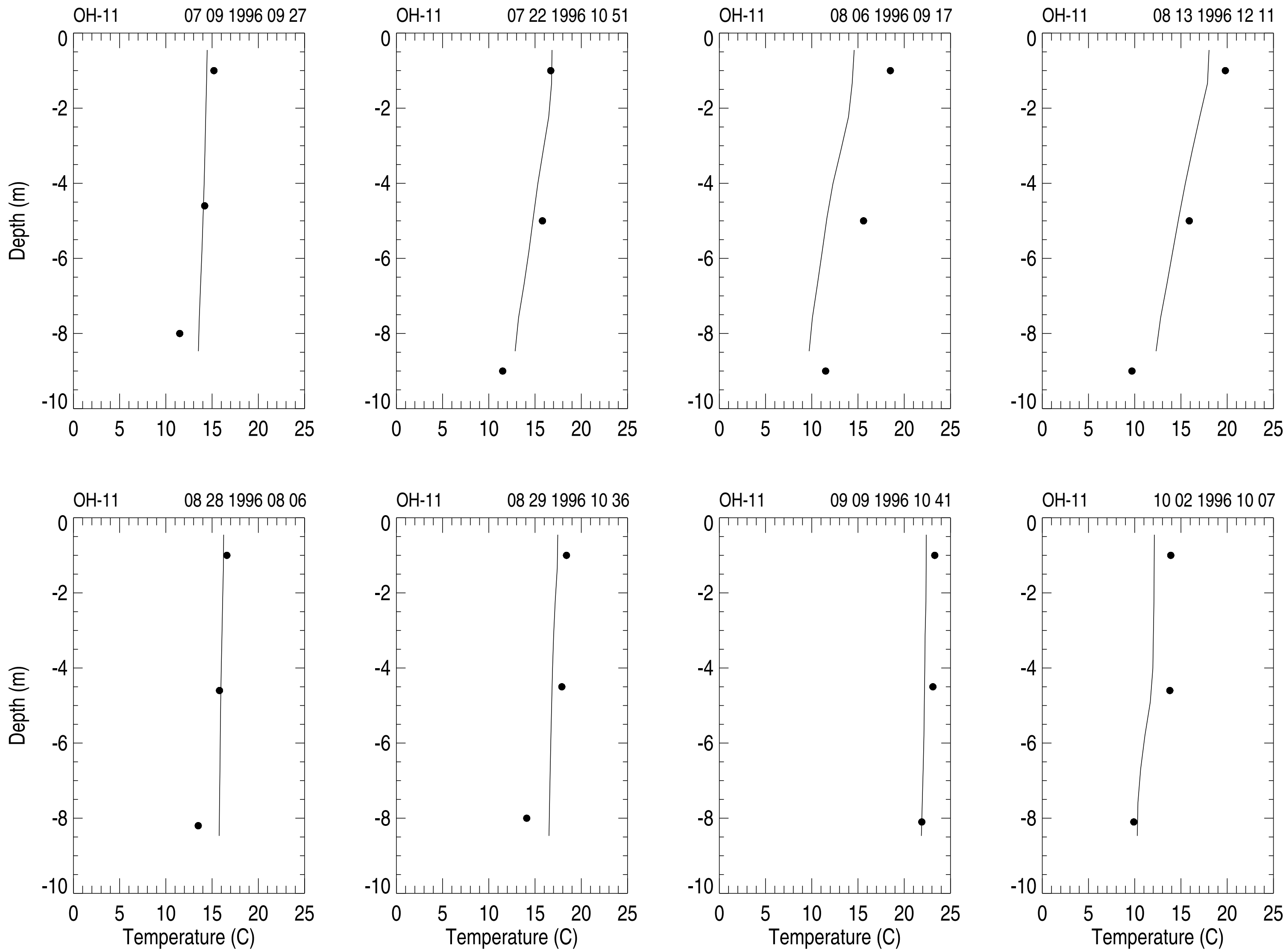


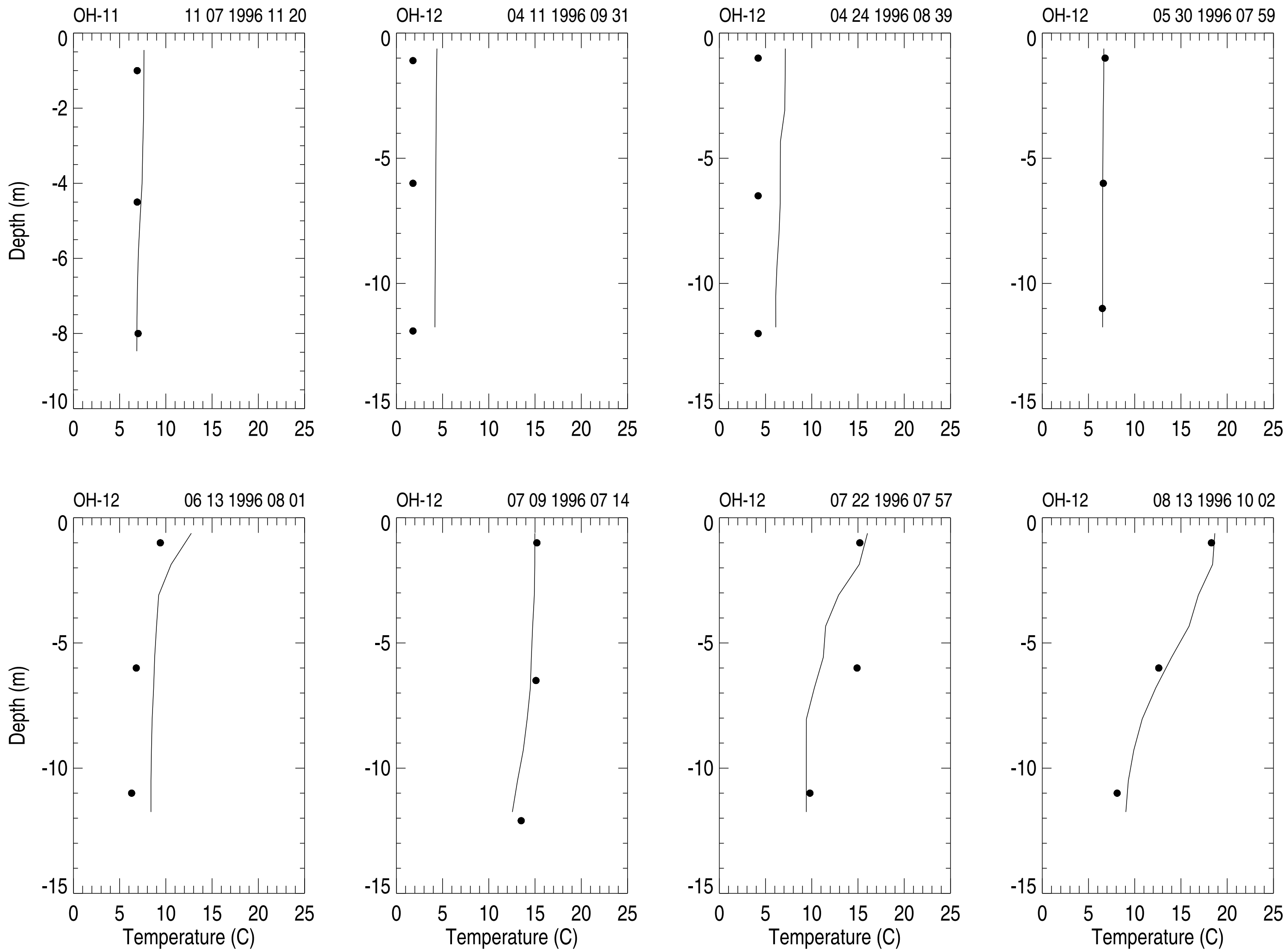
OH-09
06 13 1996 10 08
OH-09
07 09 1996 08 31
OH-09
07 22 1996 10 04
OH-09
08 13 1996 11 45
OH-09
08 28 1996 09 43
OH-09
09 09 1996 10 15
OH-09
10 02 1996 09 05
OH-09
11 07 1996 10 53
Depth (m)
Temperature (C)


OH-10
04 11 1996 11 42
OH-10
04 24 1996 10 34
OH-10
05 30 1996 09 17
OH-10
06 13 1996 10 20
OH-10
07 09 1996 09 12
OH-10
07 22 1996 10 38
OH-10
08 13 1996 11 57
OH-10
08 28 1996 07 45
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

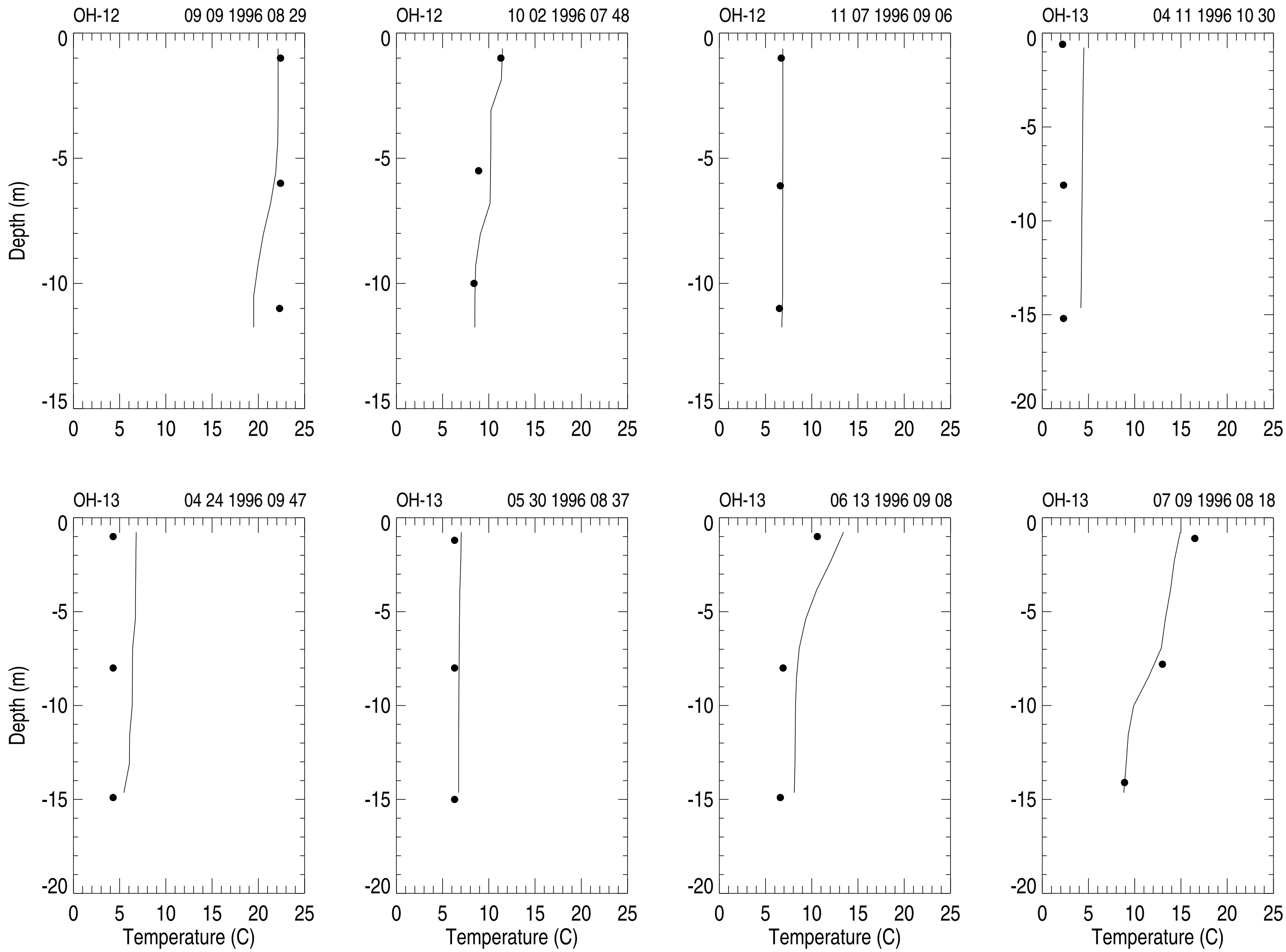


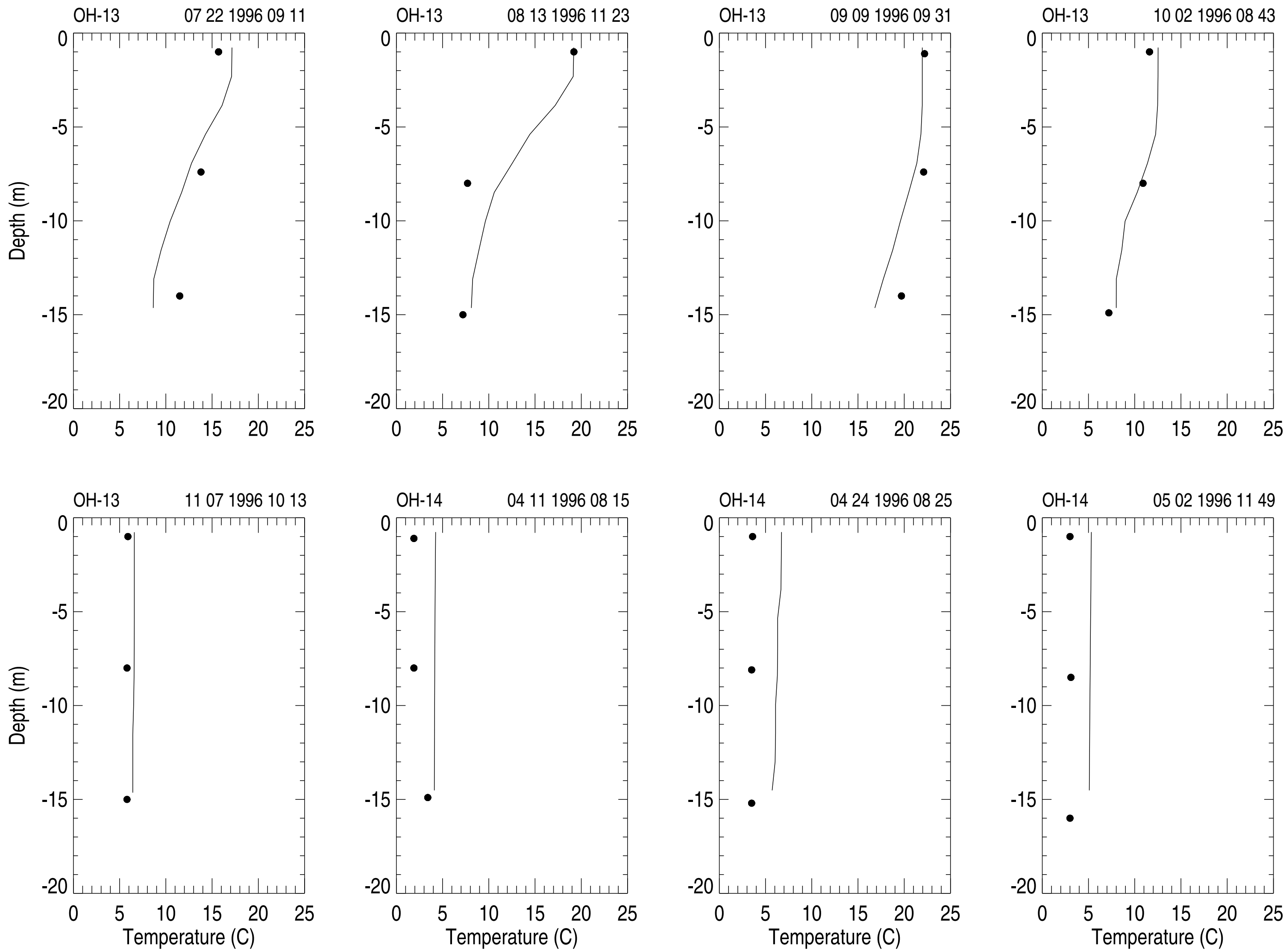
OH-10 09 09 1996 10 27
OH-10 10 02 1996 09 54
OH-10 11 07 1996 11 07
OH-11 04 11 1996 11 57
OH-11 04 24 1996 10 49
OH-11 05 30 1996 09 33
OH-11 06 13 1996 10 37
OH-11 06 18 1996 09 25
Depth (m)
Temperature (C)

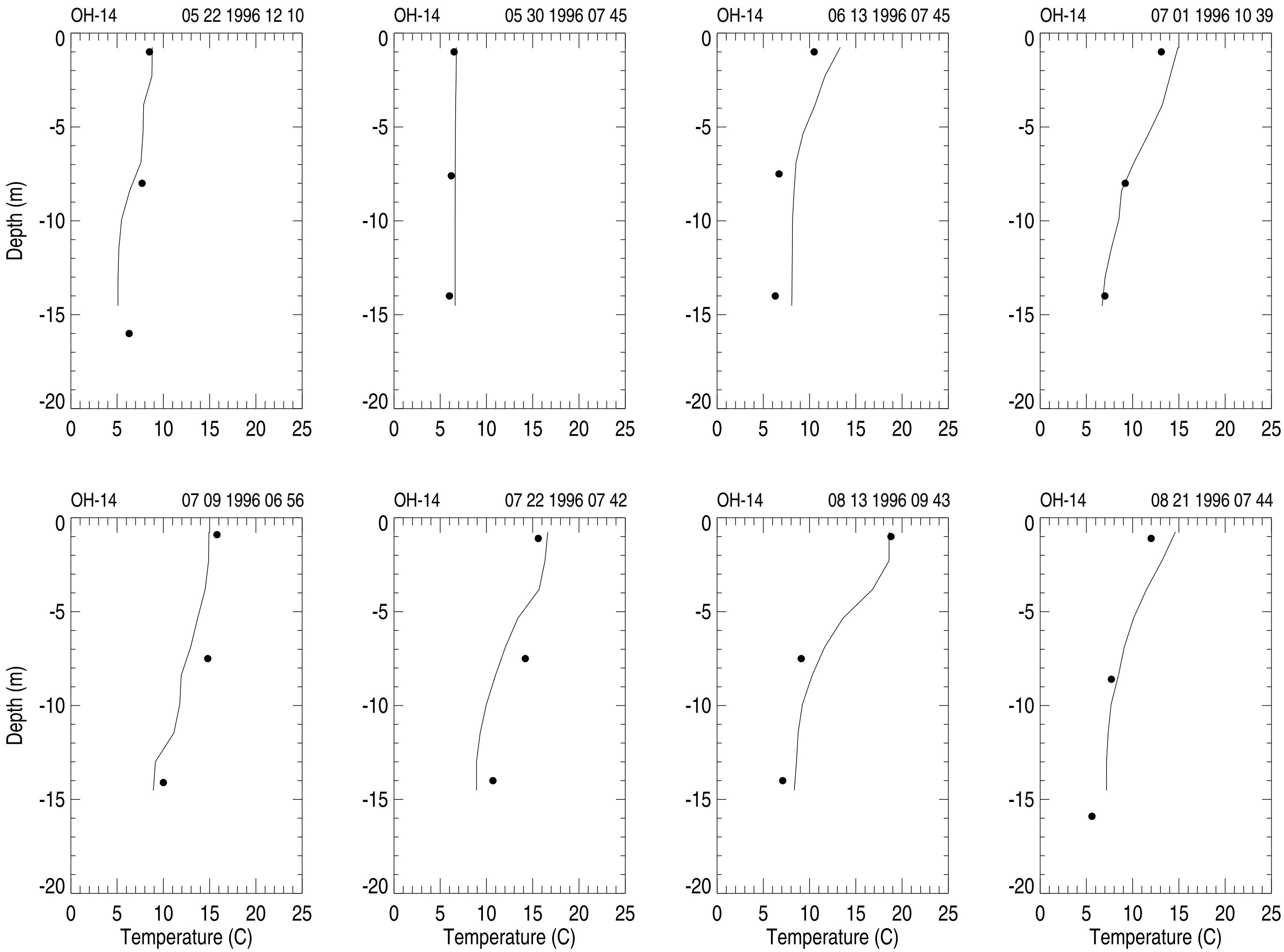

OH-11 07 09 1996 09 27
OH-11 07 22 1996 10 51
OH-11 08 06 1996 09 17
OH-11 08 13 1996 12 11
OH-11 08 28 1996 08 06
OH-11 08 29 1996 10 36
OH-11 09 09 1996 10 41
OH-11 10 02 1996 10 07
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

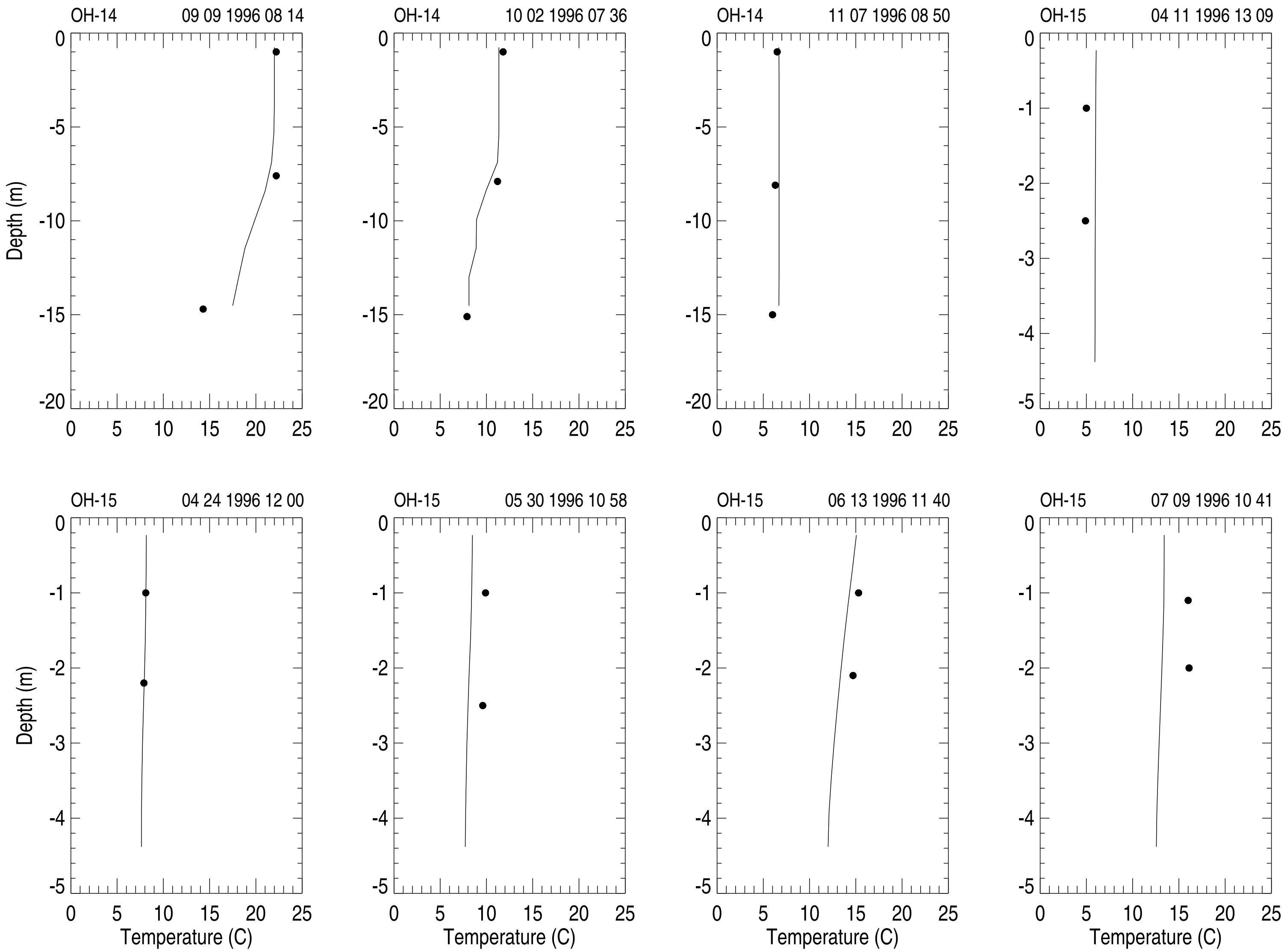


OH-11 11 07 1996 11 20
OH-12 04 11 1996 09 31
OH-12 04 24 1996 08 39
OH-12 05 30 1996 07 59
OH-12 06 13 1996 08 01
OH-12 07 09 1996 07 14
OH-12 07 22 1996 07 57
OH-12 08 13 1996 10 02
Depth (m)
Temperature (C)

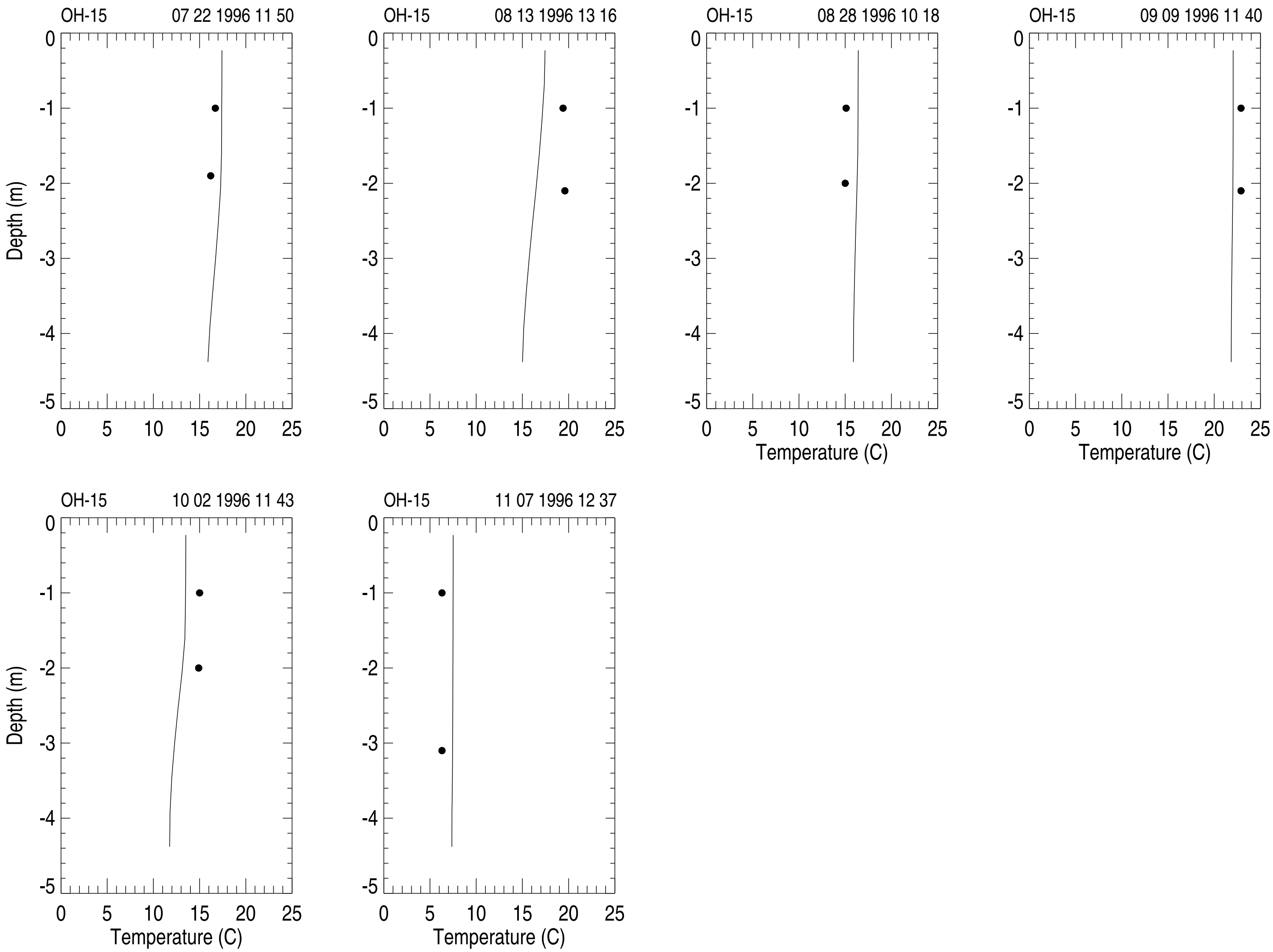

OH-12 09 09 1996 08 29
OH-12 10 02 1996 07 48
OH-12 11 07 1996 09 06
OH-13 04 11 1996 10 30
OH-13 04 24 1996 09 47
OH-13 05 30 1996 08 37
OH-13 06 13 1996 09 08
OH-13 07 09 1996 08 18
Depth (m)
Temperature (C)

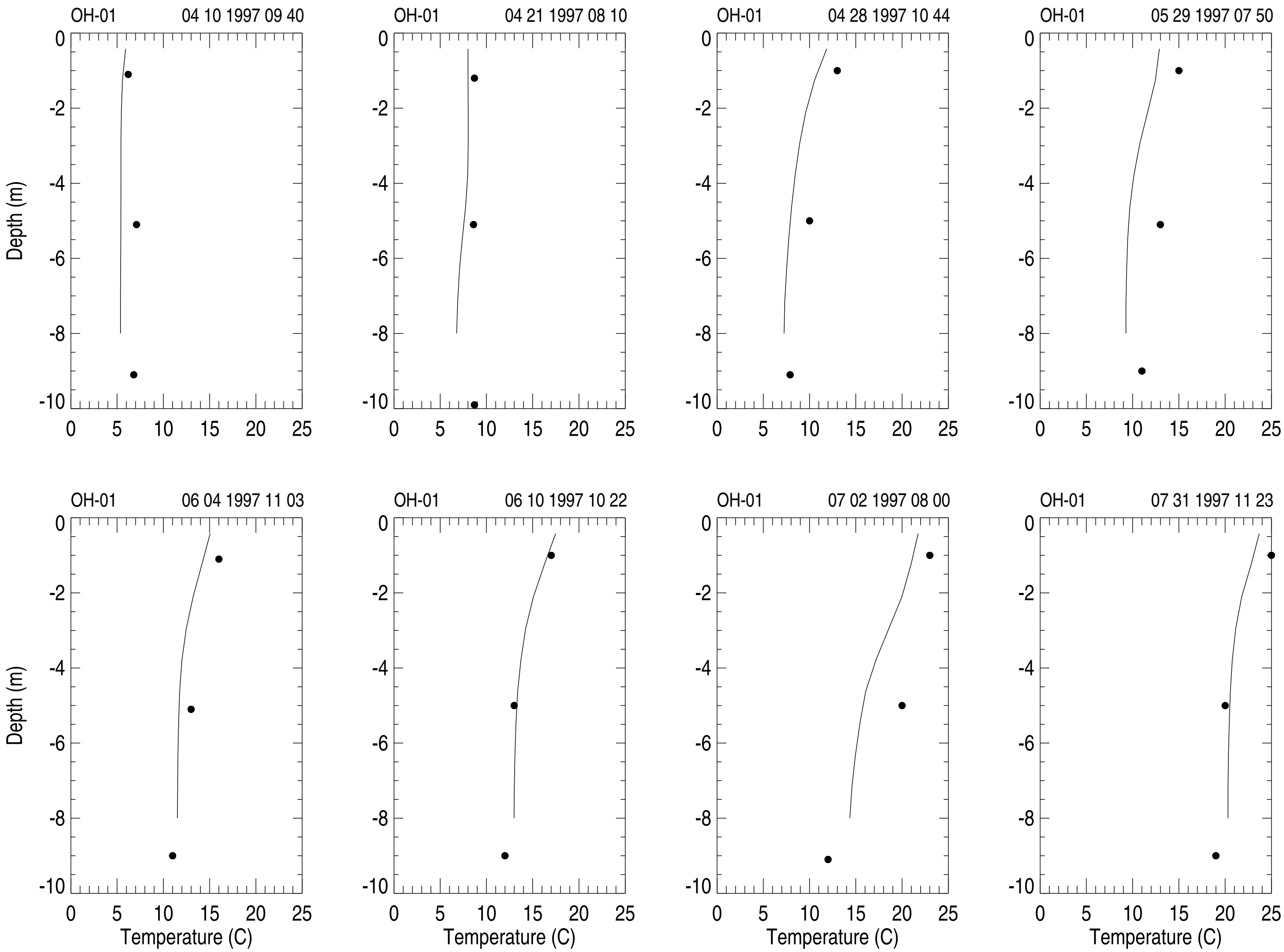

OH-13
07 22 1996 09 11
OH-13
08 13 1996 11 23
OH-13
09 09 1996 09 31
OH-13
10 02 1996 08 43
OH-13
11 07 1996 10 13
OH-14
04 11 1996 08 15
OH-14
04 24 1996 08 25
OH-14
05 02 1996 11 49
Depth (m)
0
-5
-10
-15
-20
0
5
10
15
20
25
Temperature (C)

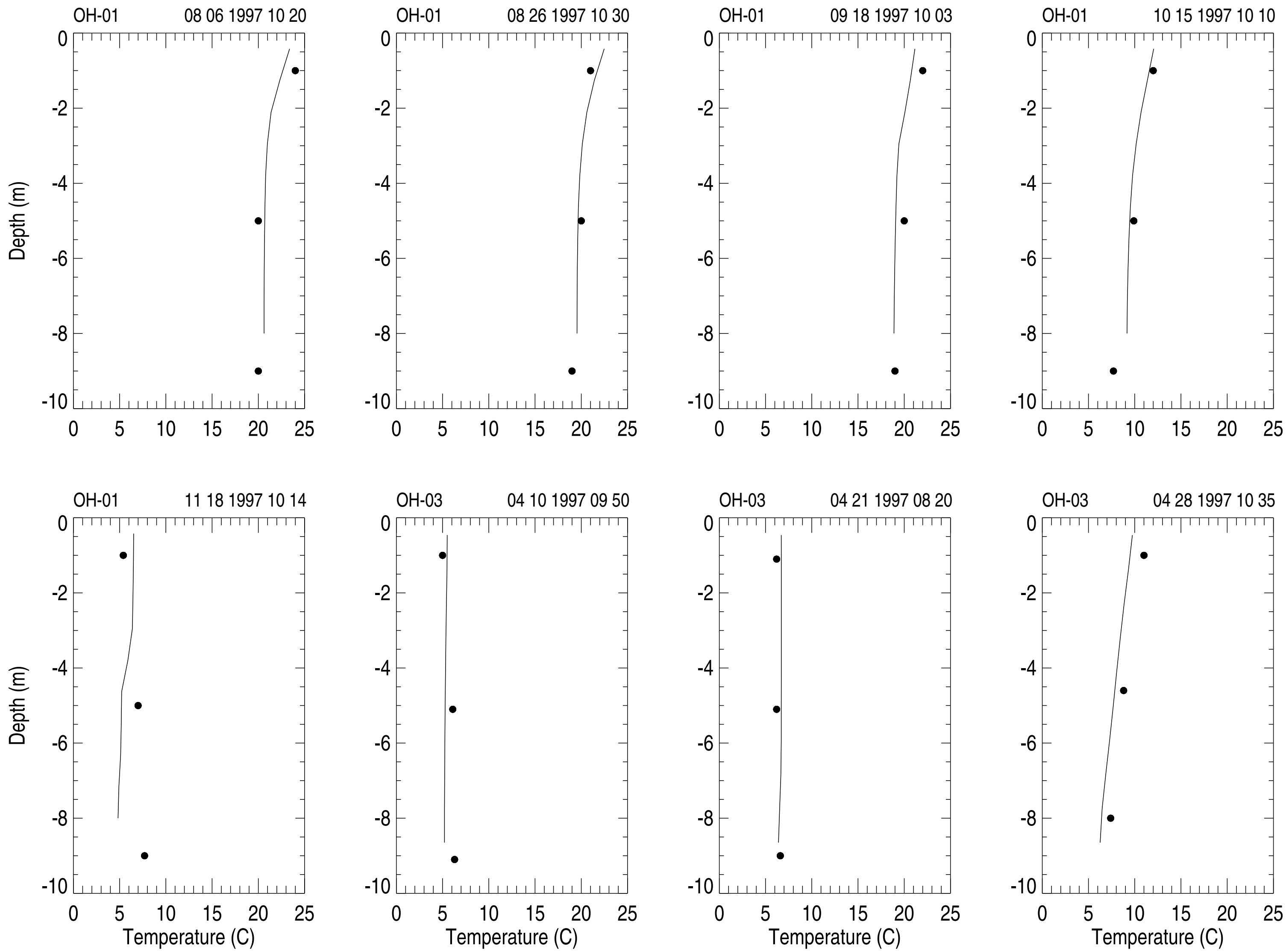

OH-14
05 22 1996 12 10
05 30 1996 07 45
06 13 1996 07 45
07 01 1996 10 39
07 09 1996 06 56
07 22 1996 07 42
08 13 1996 09 43
08 21 1996 07 44
Depth (m)
0
-5
-10
-15
-20
0 5 10 15 20 25
Temperature (C)

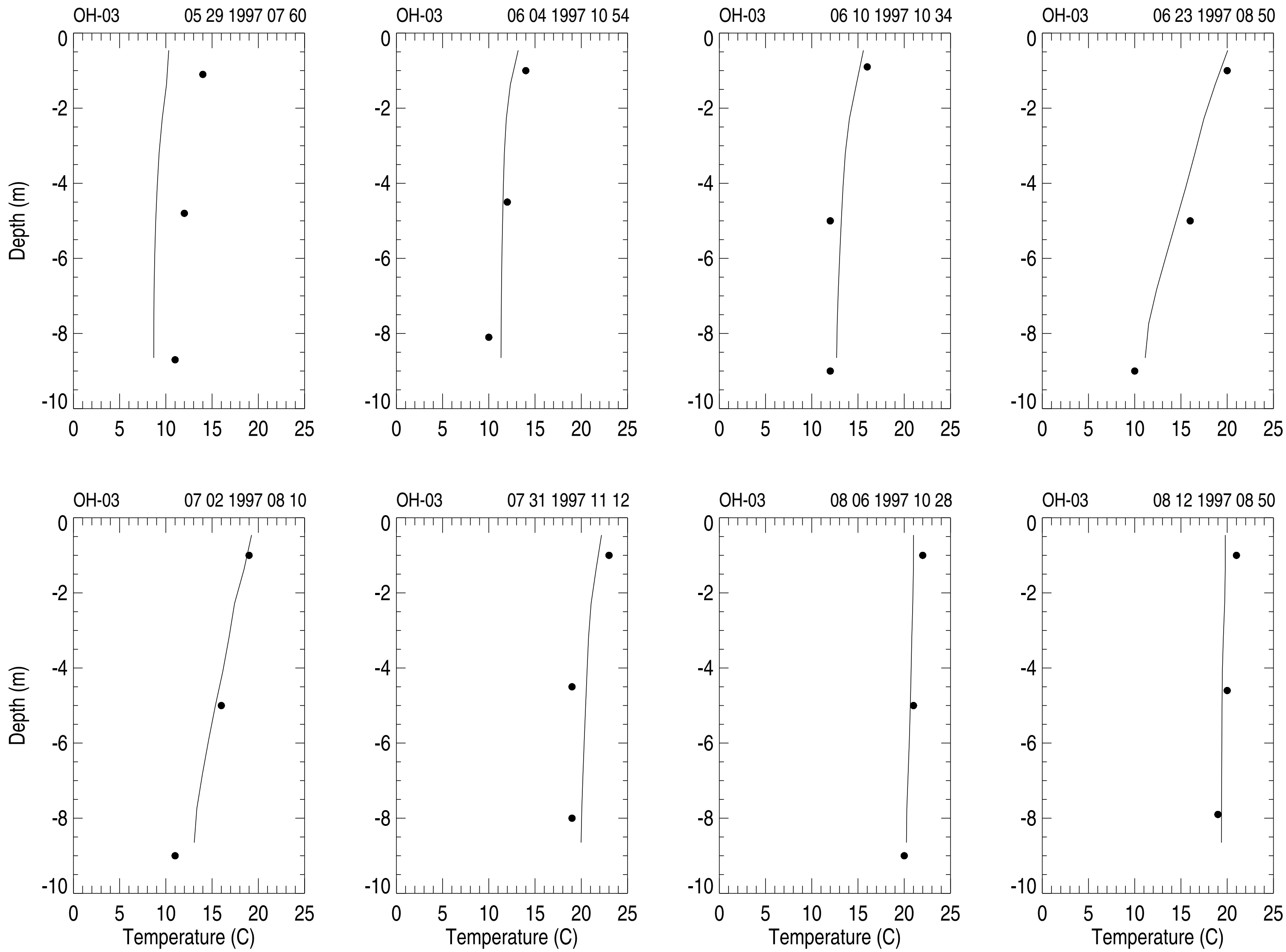


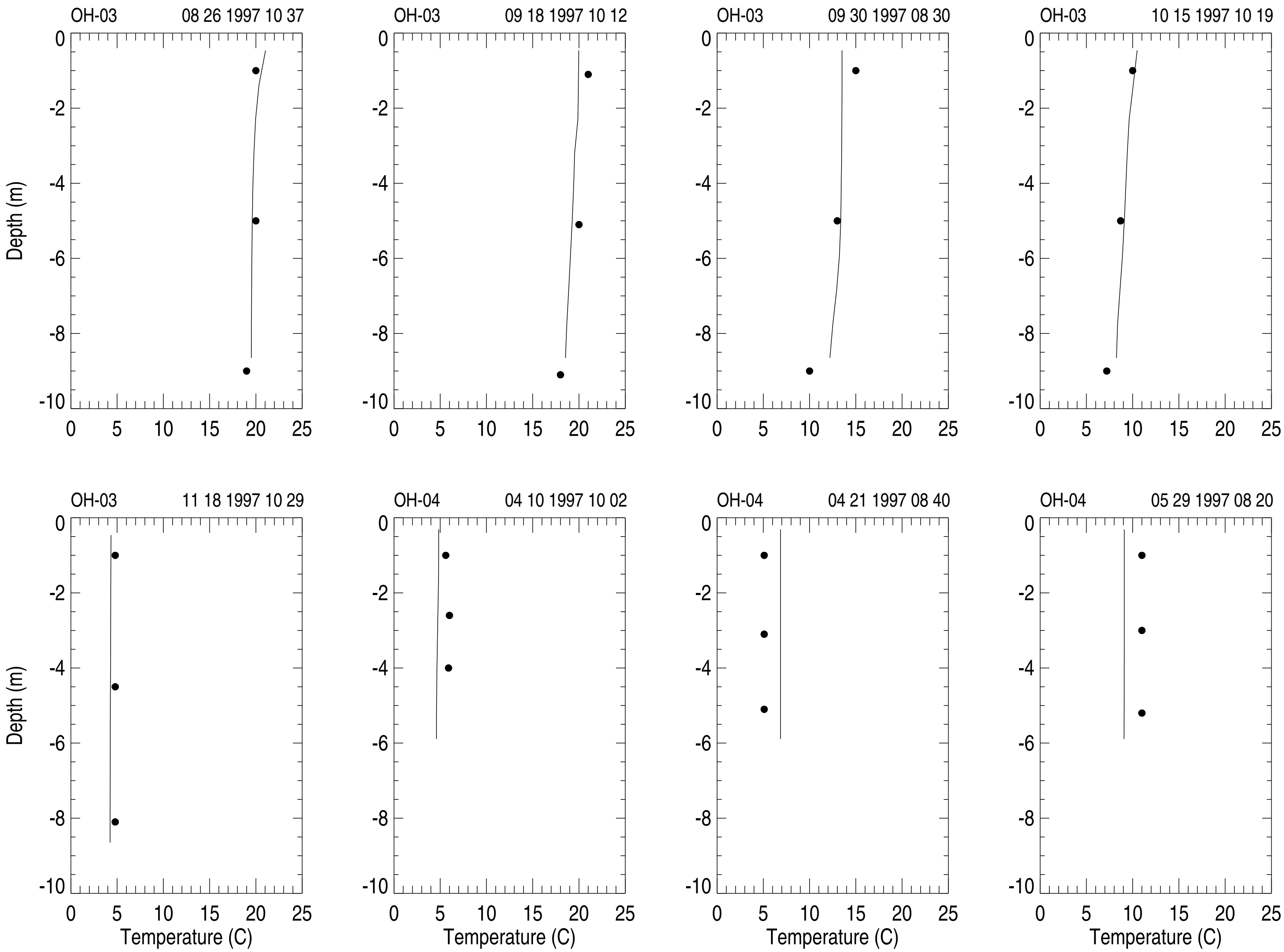
OH-14 09 09 1996 08 14
OH-14 10 02 1996 07 36
OH-14 11 07 1996 08 50
OH-15 04 11 1996 13 09
OH-15 04 24 1996 12 00
OH-15 05 30 1996 10 58
OH-15 06 13 1996 11 40
OH-15 07 09 1996 10 41
Depth (m)
Temperature (C)

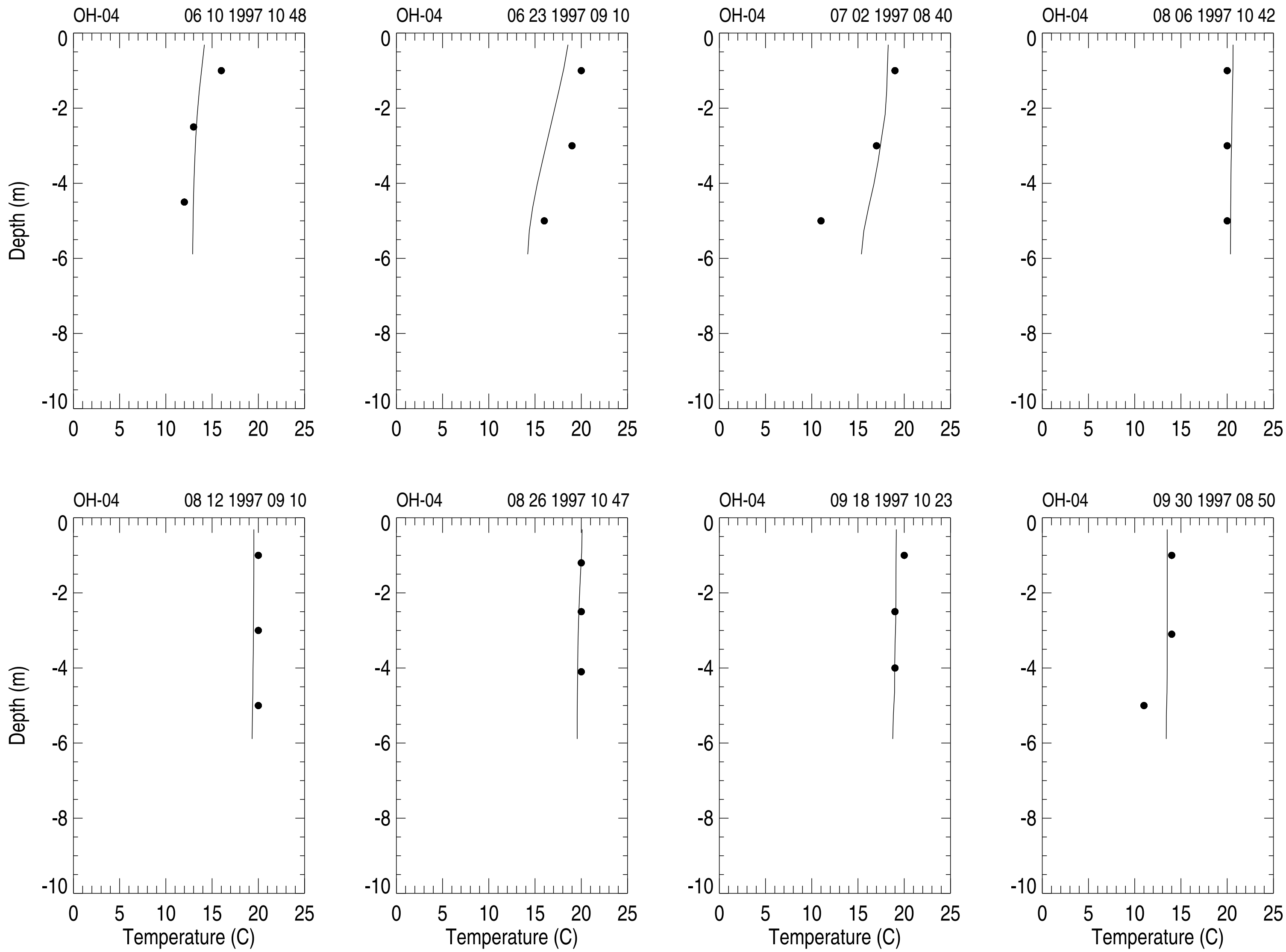

OH-15
07 22 1996 11 50
08 13 1996 13 16
08 28 1996 10 18
09 09 1996 11 40
10 02 1996 11 43
11 07 1996 12 37
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25

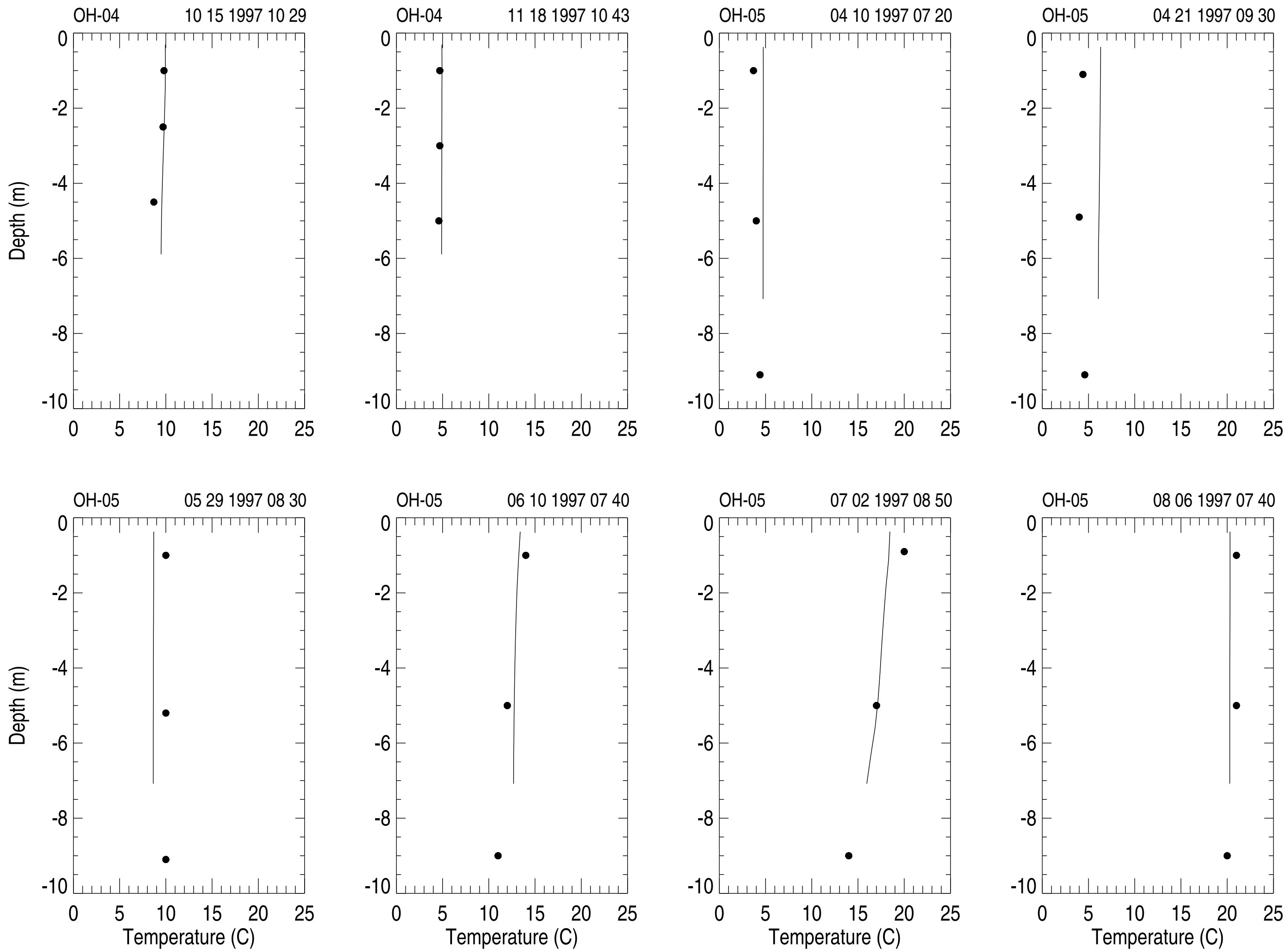

OH-01 04 10 1997 09 40
OH-01 04 21 1997 08 10
OH-01 04 28 1997 10 44
OH-01 05 29 1997 07 50
OH-01 06 04 1997 11 03
OH-01 06 10 1997 10 22
OH-01 07 02 1997 08 00
OH-01 07 31 1997 11 23
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

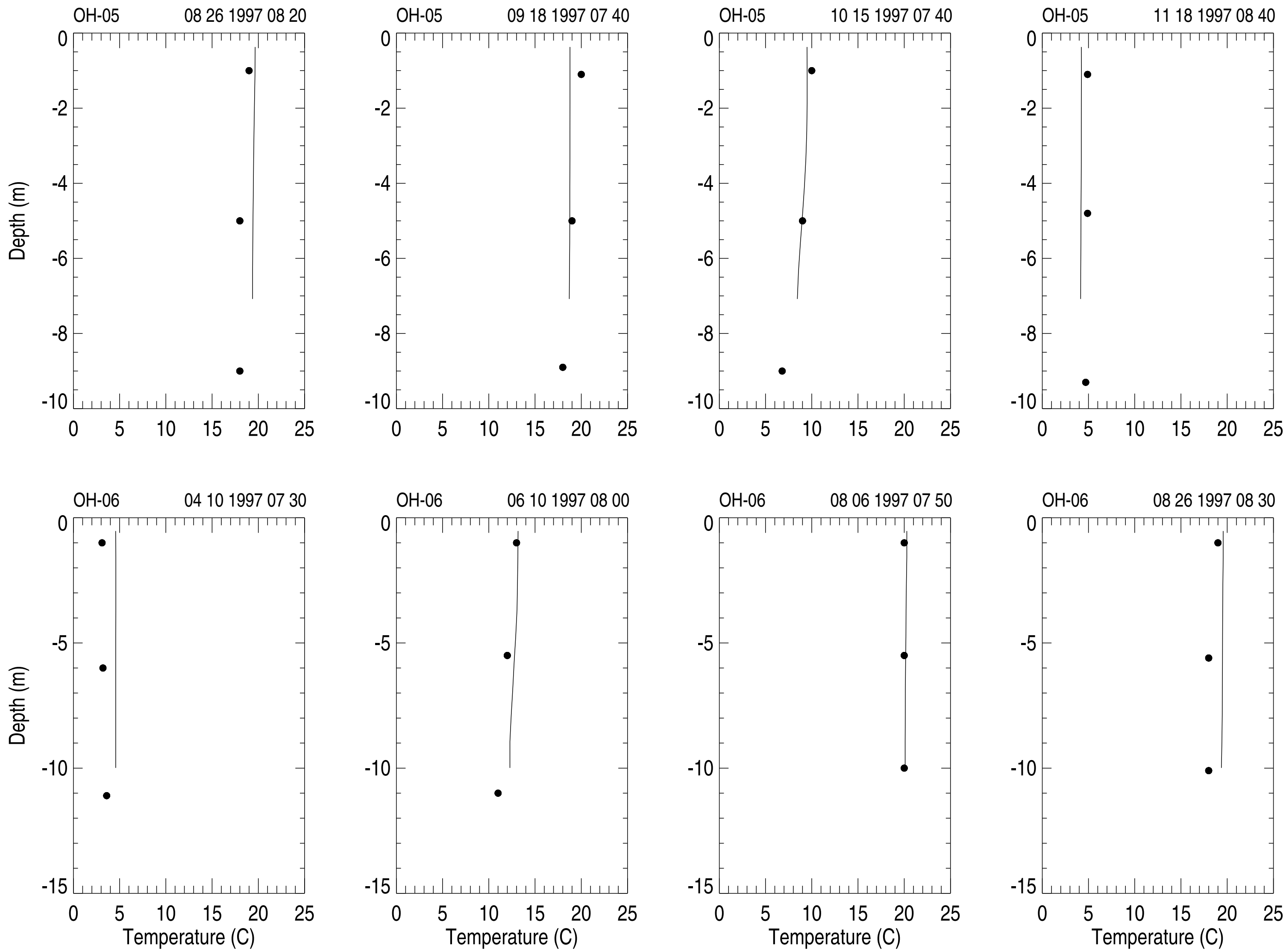

OH-01
08 06 1997 10 20
OH-01
08 26 1997 10 30
OH-01
09 18 1997 10 03
OH-01
10 15 1997 10 10
OH-01
11 18 1997 10 14
OH-03
04 10 1997 09 50
OH-03
04 21 1997 08 20
OH-03
04 28 1997 10 35
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

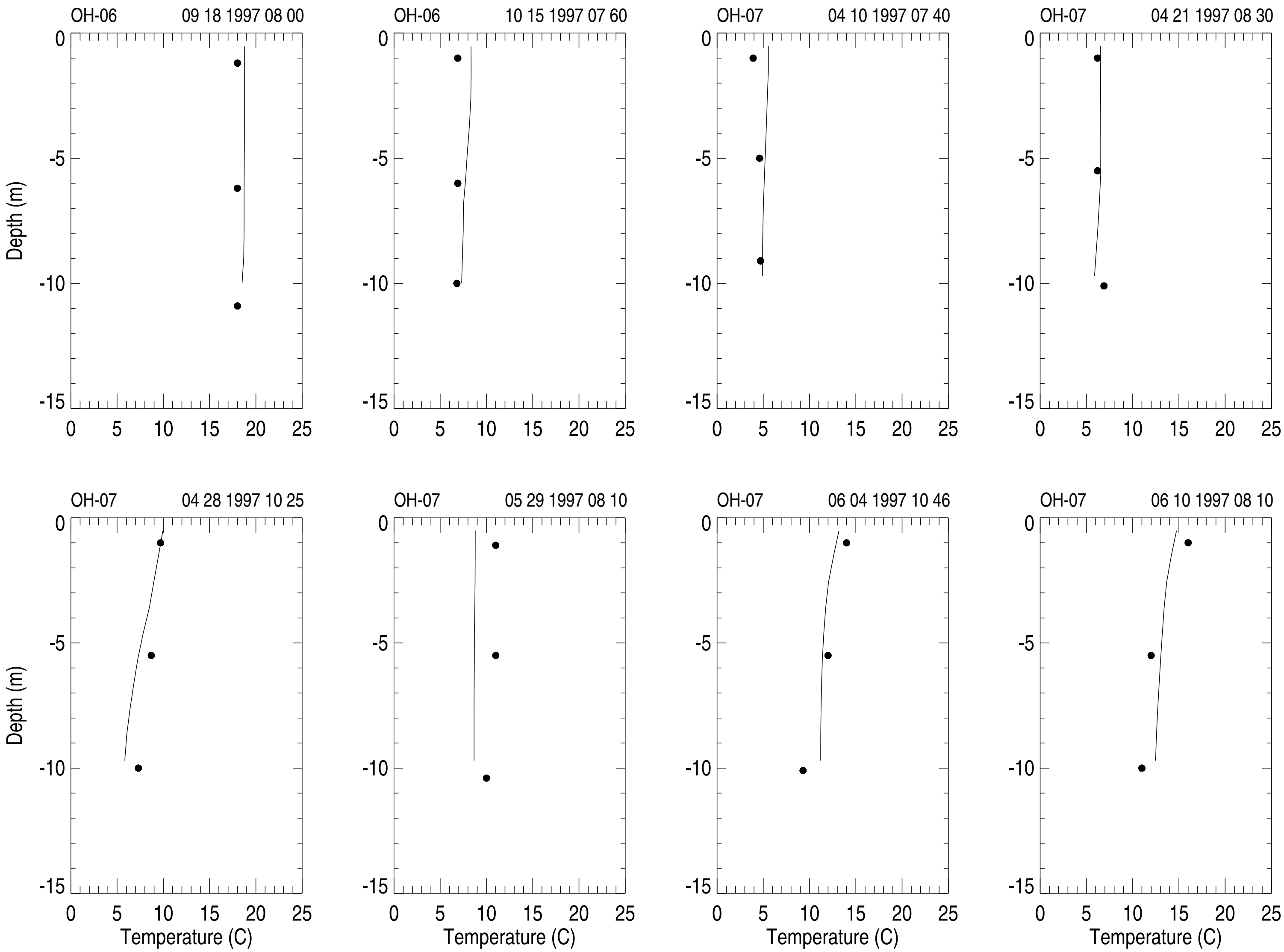

OH-03
05 29 1997 07 60
06 04 1997 10 54
06 10 1997 10 34
06 23 1997 08 50
07 02 1997 08 10
07 31 1997 11 12
08 06 1997 10 28
08 12 1997 08 50
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

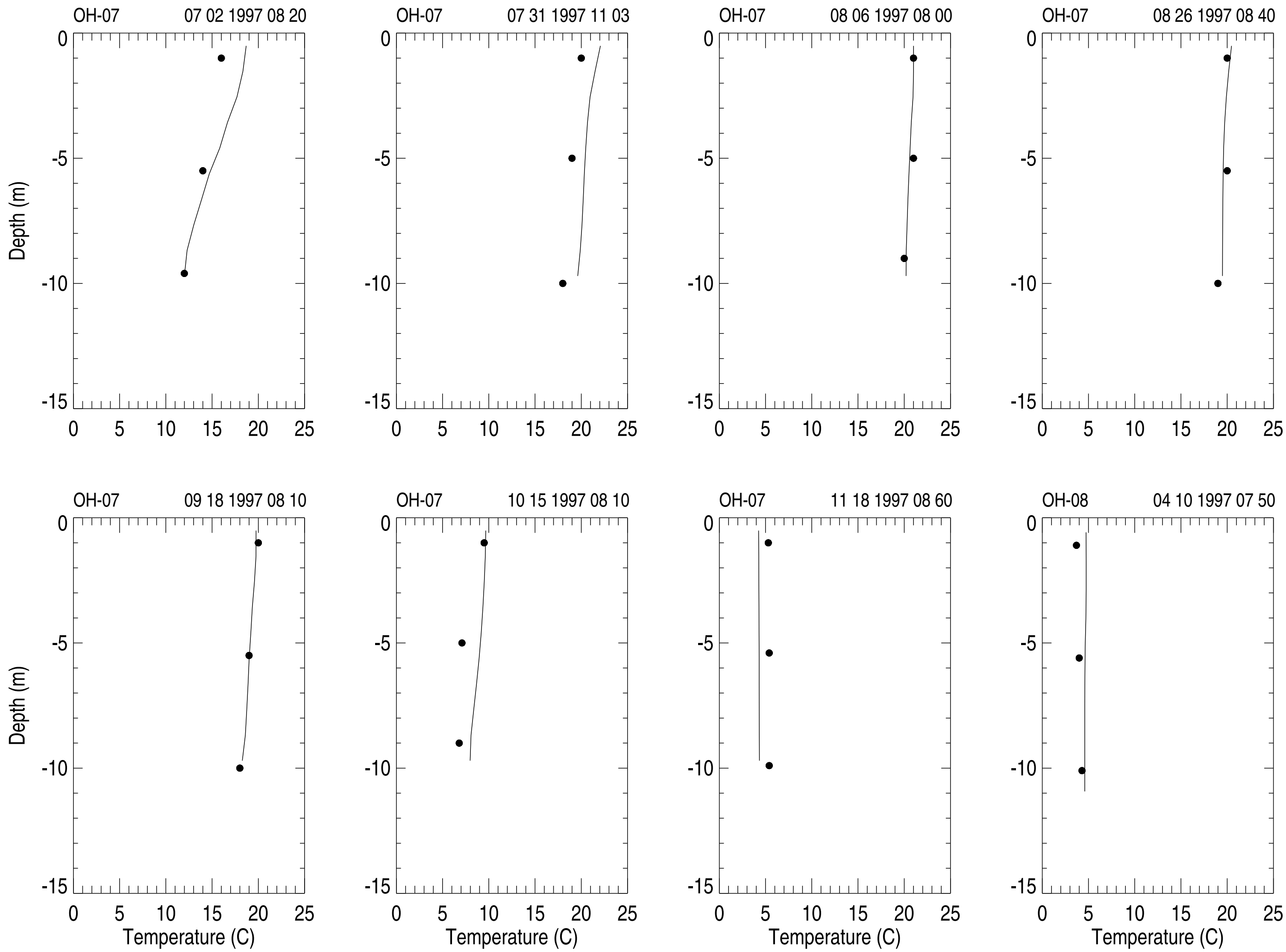

OH-03 08 26 1997 10 37
OH-03 09 18 1997 10 12
OH-03 09 30 1997 08 30
OH-03 10 15 1997 10 19
OH-03 11 18 1997 10 29
OH-04 04 10 1997 10 02
OH-04 04 21 1997 08 40
OH-04 05 29 1997 08 20
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

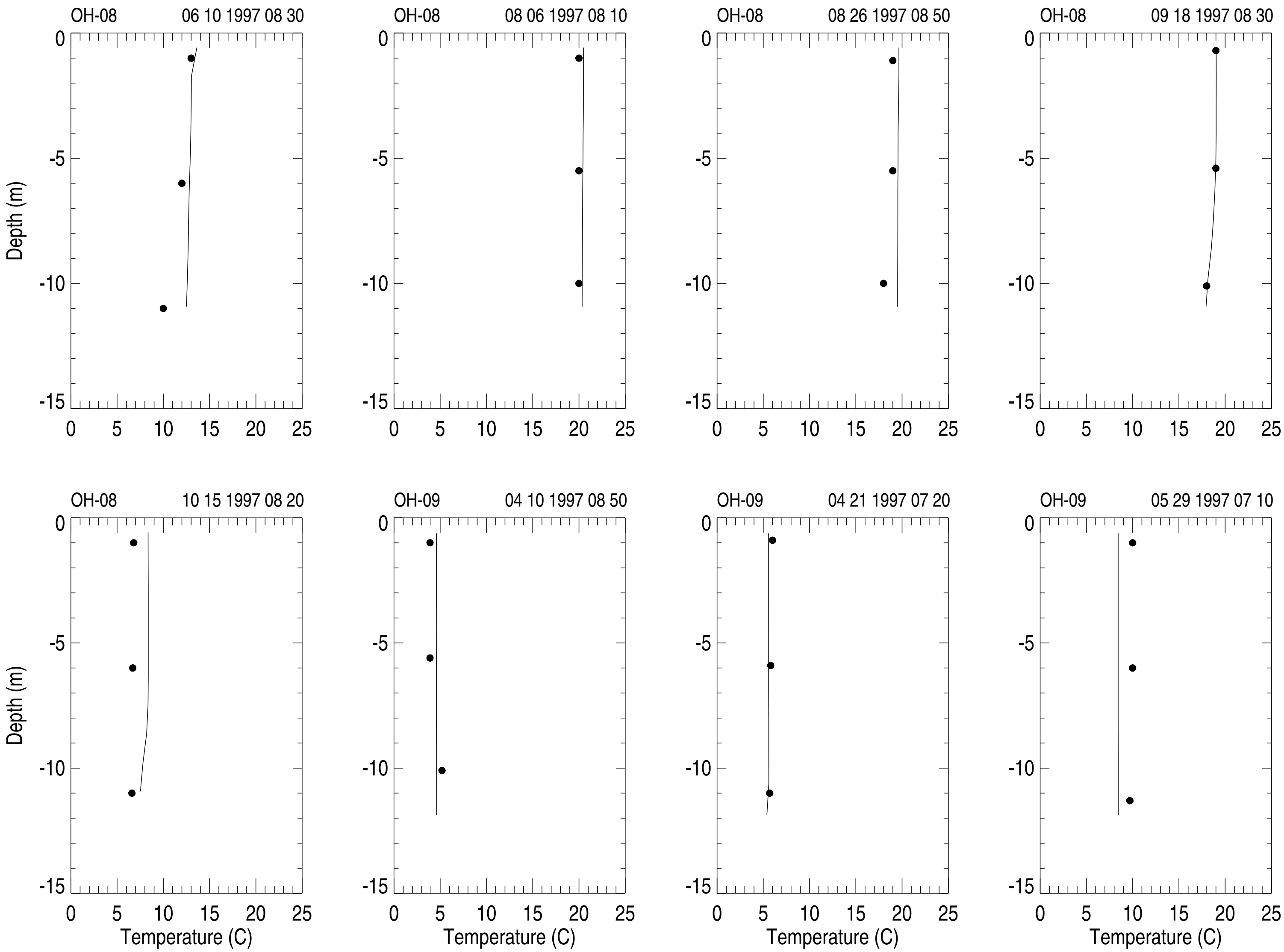

OH-04
06 10 1997 10 48
OH-04
06 23 1997 09 10
OH-04
07 02 1997 08 40
OH-04
08 06 1997 10 42
OH-04
08 12 1997 09 10
OH-04
08 26 1997 10 47
OH-04
09 18 1997 10 23
OH-04
09 30 1997 08 50
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25


OH-04 10 15 1997 10 29
OH-04 11 18 1997 10 43
OH-05 04 10 1997 07 20
OH-05 04 21 1997 09 30
OH-05 05 29 1997 08 30
OH-05 06 10 1997 07 40
OH-05 07 02 1997 08 50
OH-05 08 06 1997 07 40
Depth (m)
Temperature (C)

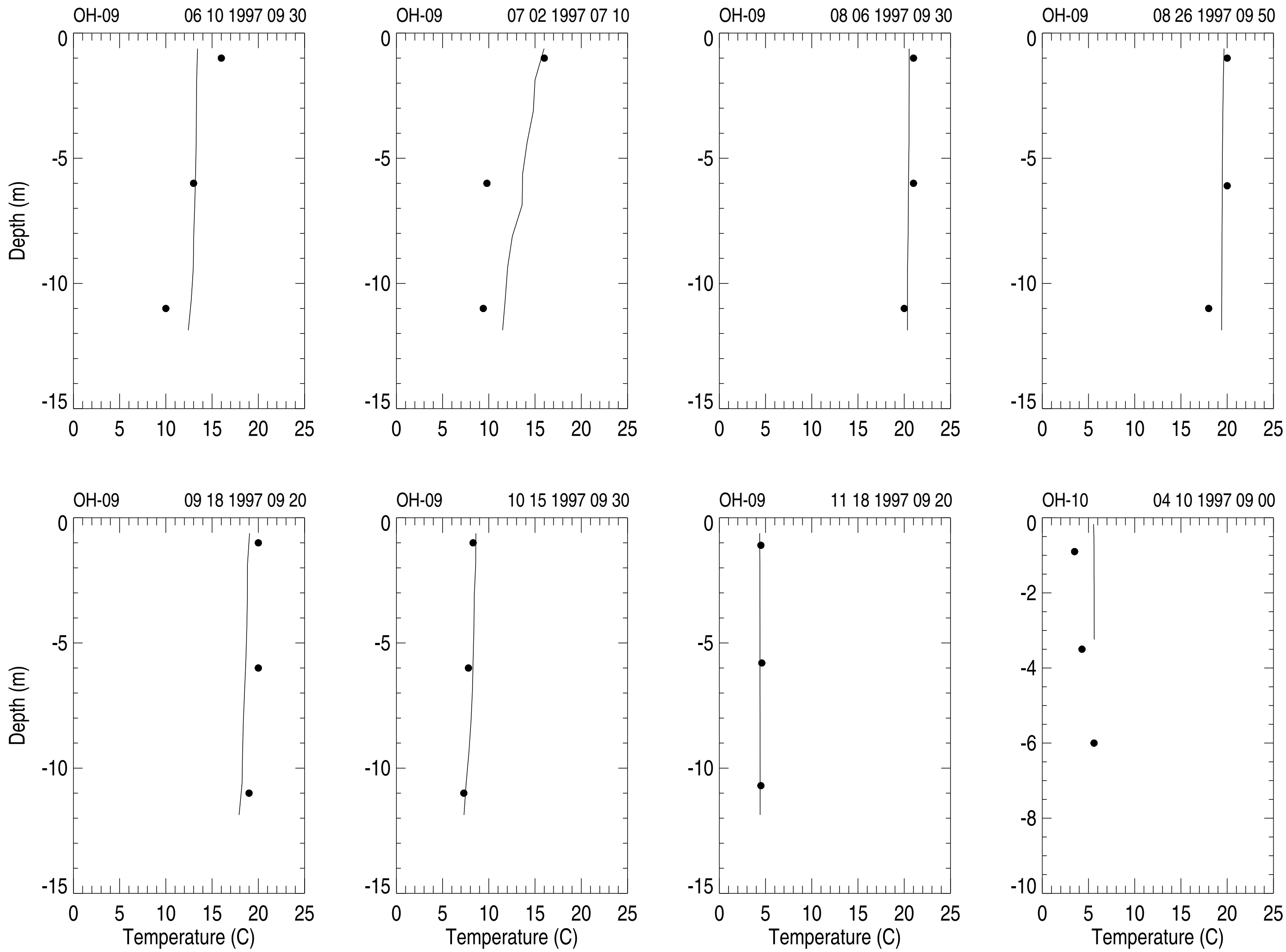

OH-05
08 26 1997 08 20
OH-05
09 18 1997 07 40
OH-05
10 15 1997 07 40
OH-05
11 18 1997 08 40
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
OH-06
04 10 1997 07 30
OH-06
06 10 1997 08 00
OH-06
08 06 1997 07 50
OH-06
08 26 1997 08 30
Depth (m)
0
-5
-10
-15
Temperature (C)

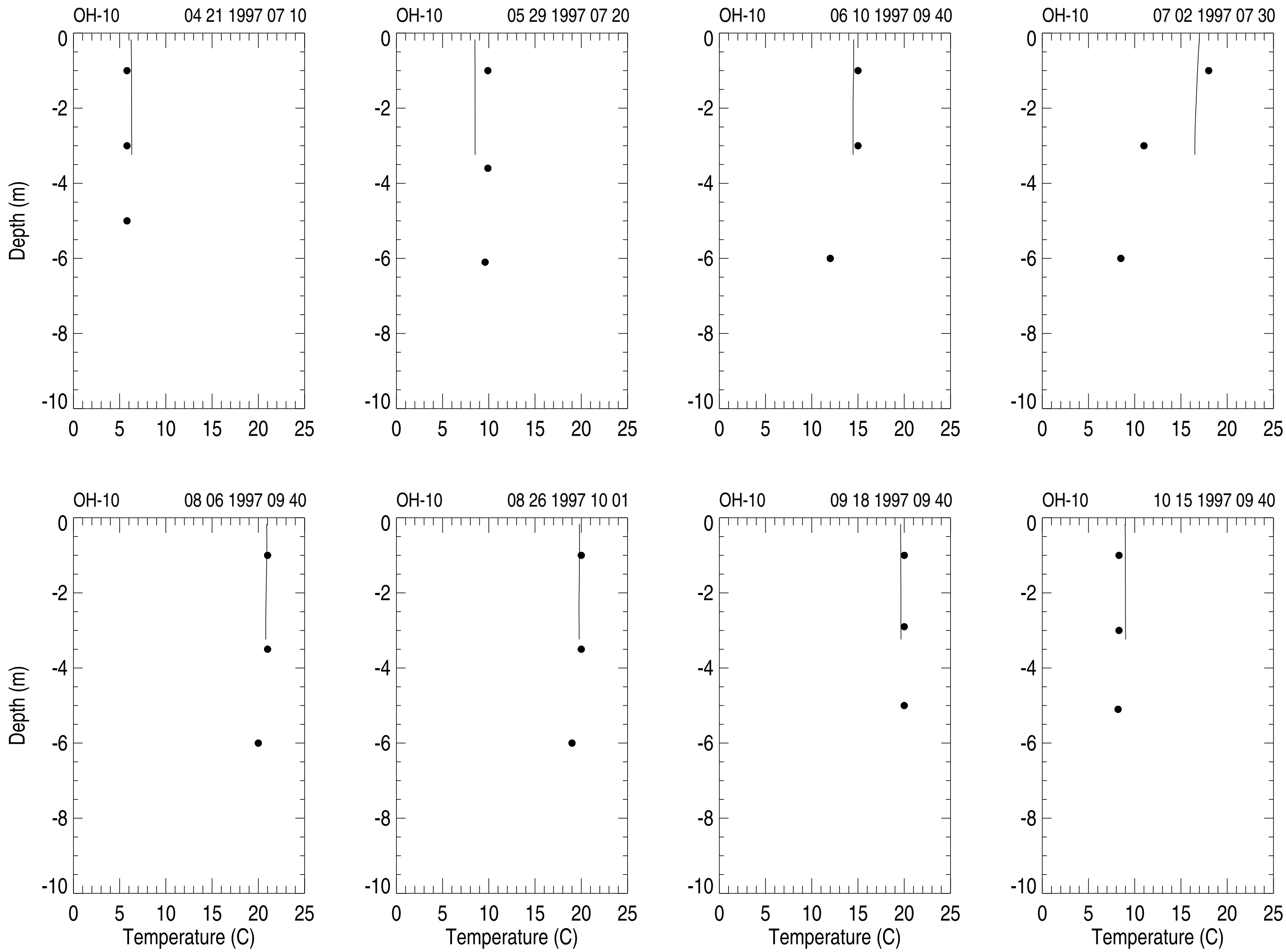

OH-06 09 18 1997 08 00
OH-06 10 15 1997 07 60
OH-07 04 10 1997 07 40
OH-07 04 21 1997 08 30
OH-07 04 28 1997 10 25
OH-07 05 29 1997 08 10
OH-07 06 04 1997 10 46
OH-07 06 10 1997 08 10
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25
Temperature (C)


OH-07 07 02 1997 08 20
OH-07 07 31 1997 11 03
OH-07 08 06 1997 08 00
OH-07 08 26 1997 08 40
OH-07 09 18 1997 08 10
OH-07 10 15 1997 08 10
OH-07 11 18 1997 08 60
OH-08 04 10 1997 07 50
Depth (m)
Temperature (C)
0
-5
-10
-15
0 5 10 15 20 25

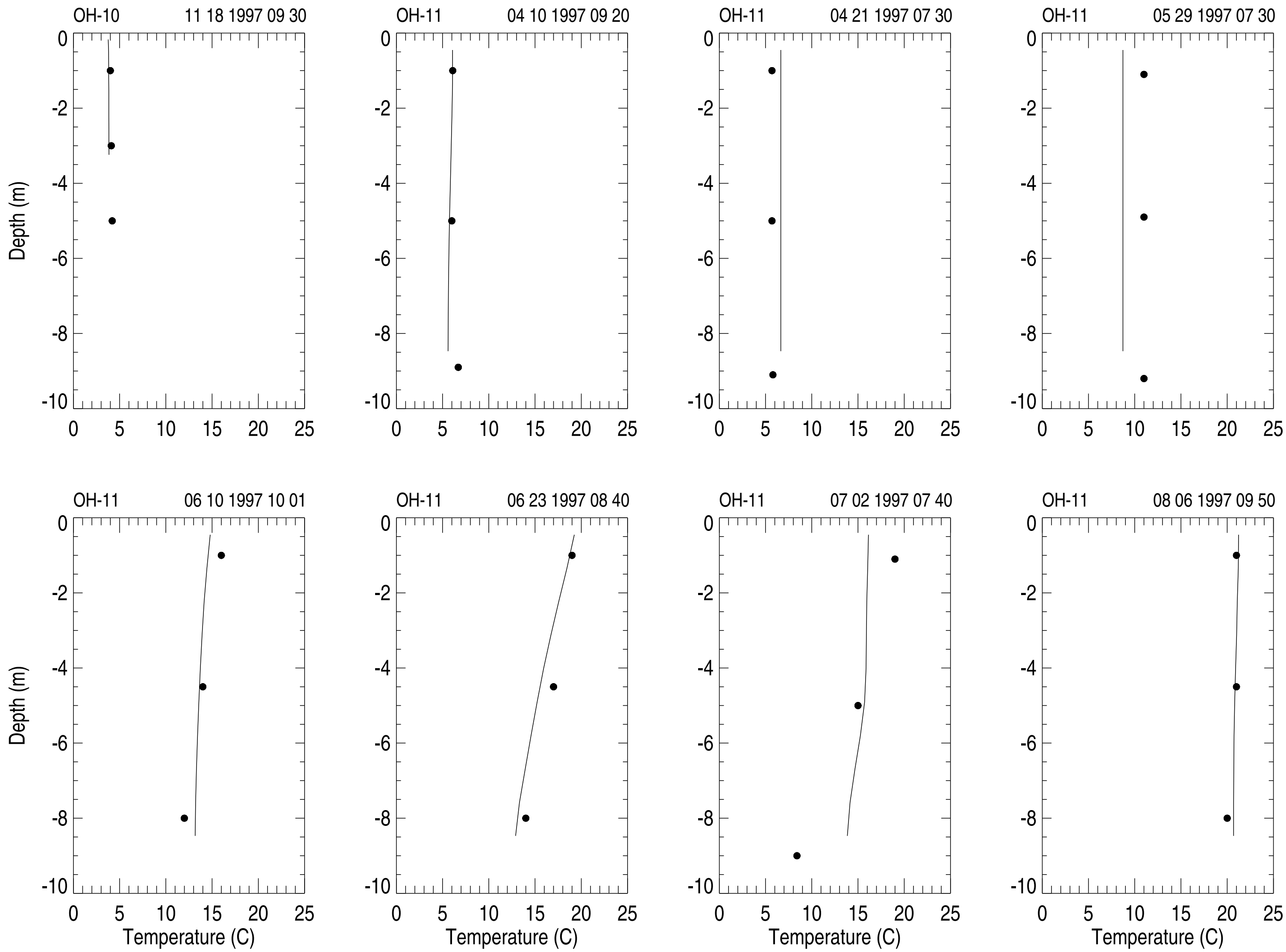


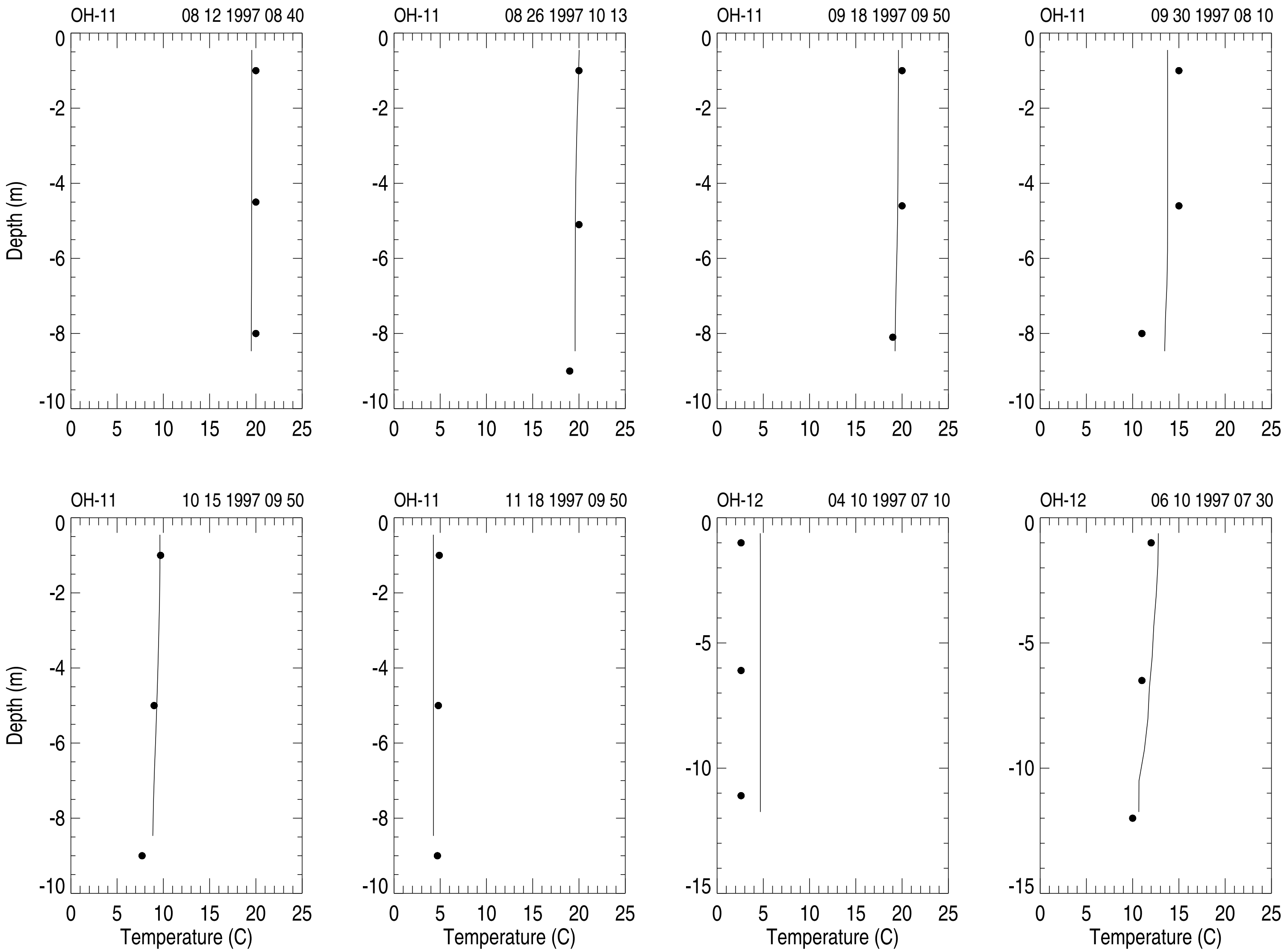
OH-08
06 10 1997 08 30
OH-08
08 06 1997 08 10
OH-08
08 26 1997 08 50
OH-08
09 18 1997 08 30
OH-08
10 15 1997 08 20
OH-09
04 10 1997 08 50
OH-09
04 21 1997 07 20
OH-09
05 29 1997 07 10
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25
Temperature (C)

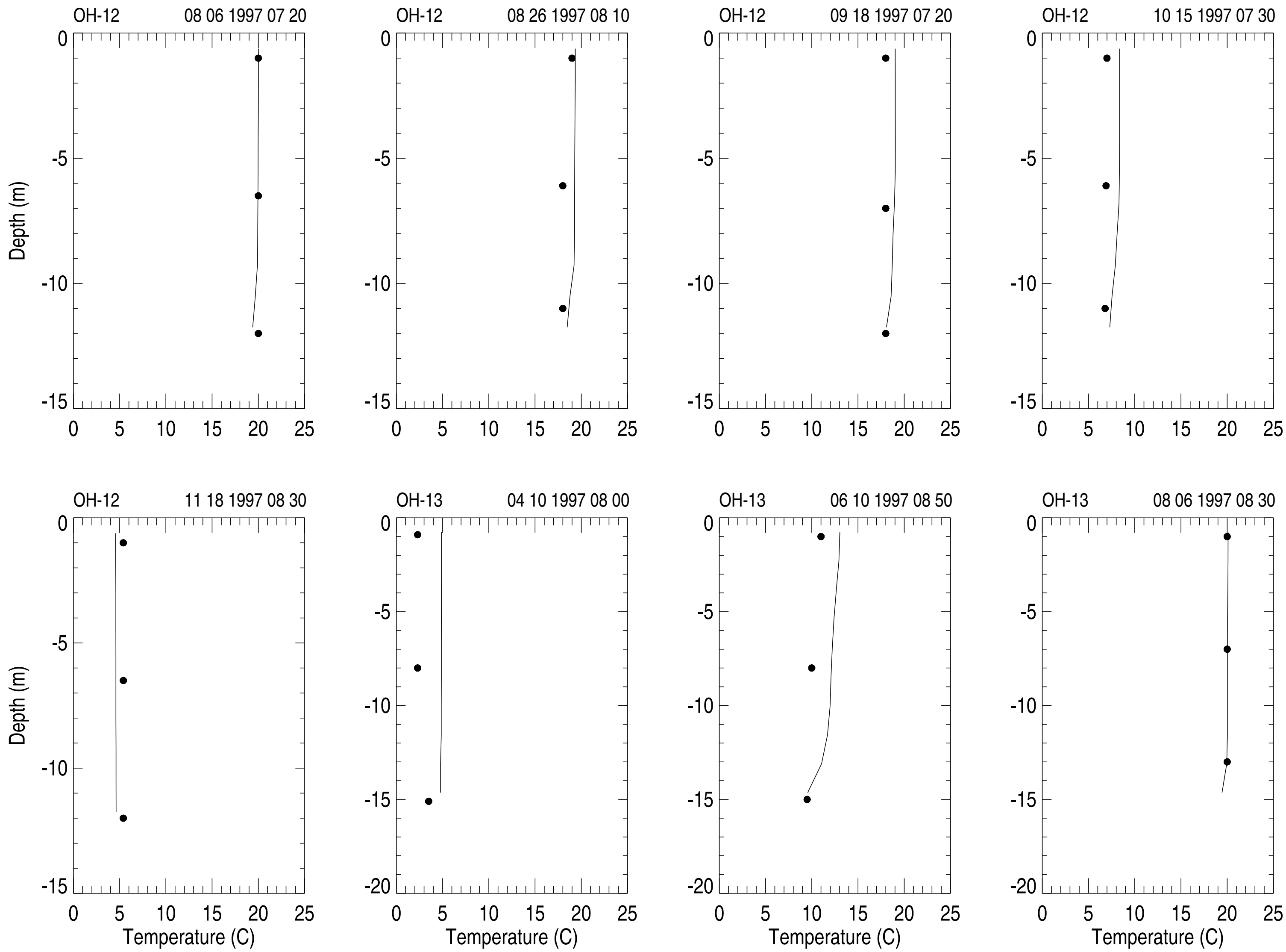

OH-09
06 10 1997 09 30
OH-09
07 02 1997 07 10
OH-09
08 06 1997 09 30
OH-09
08 26 1997 09 50
OH-09
09 18 1997 09 20
OH-09
10 15 1997 09 30
OH-09
11 18 1997 09 20
OH-10
04 10 1997 09 00
Depth (m)
Temperature (C)



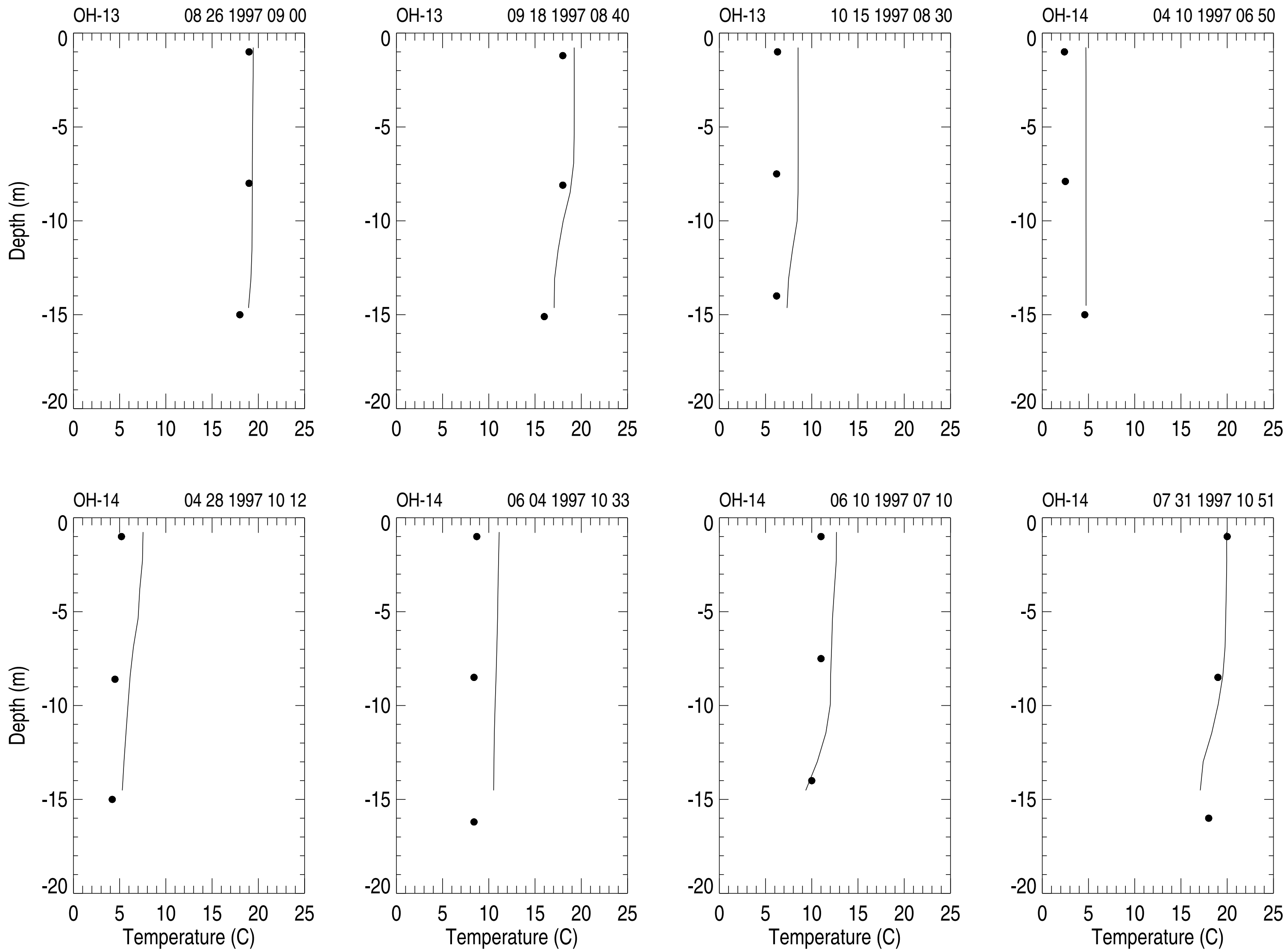
OH-10
04 21 1997 07 10
OH-10
05 29 1997 07 20
OH-10
06 10 1997 09 40
OH-10
07 02 1997 07 30
OH-10
08 06 1997 09 40
OH-10
08 26 1997 10 01
OH-10
09 18 1997 09 40
OH-10
10 15 1997 09 40
Depth (m)
Temperature (C)

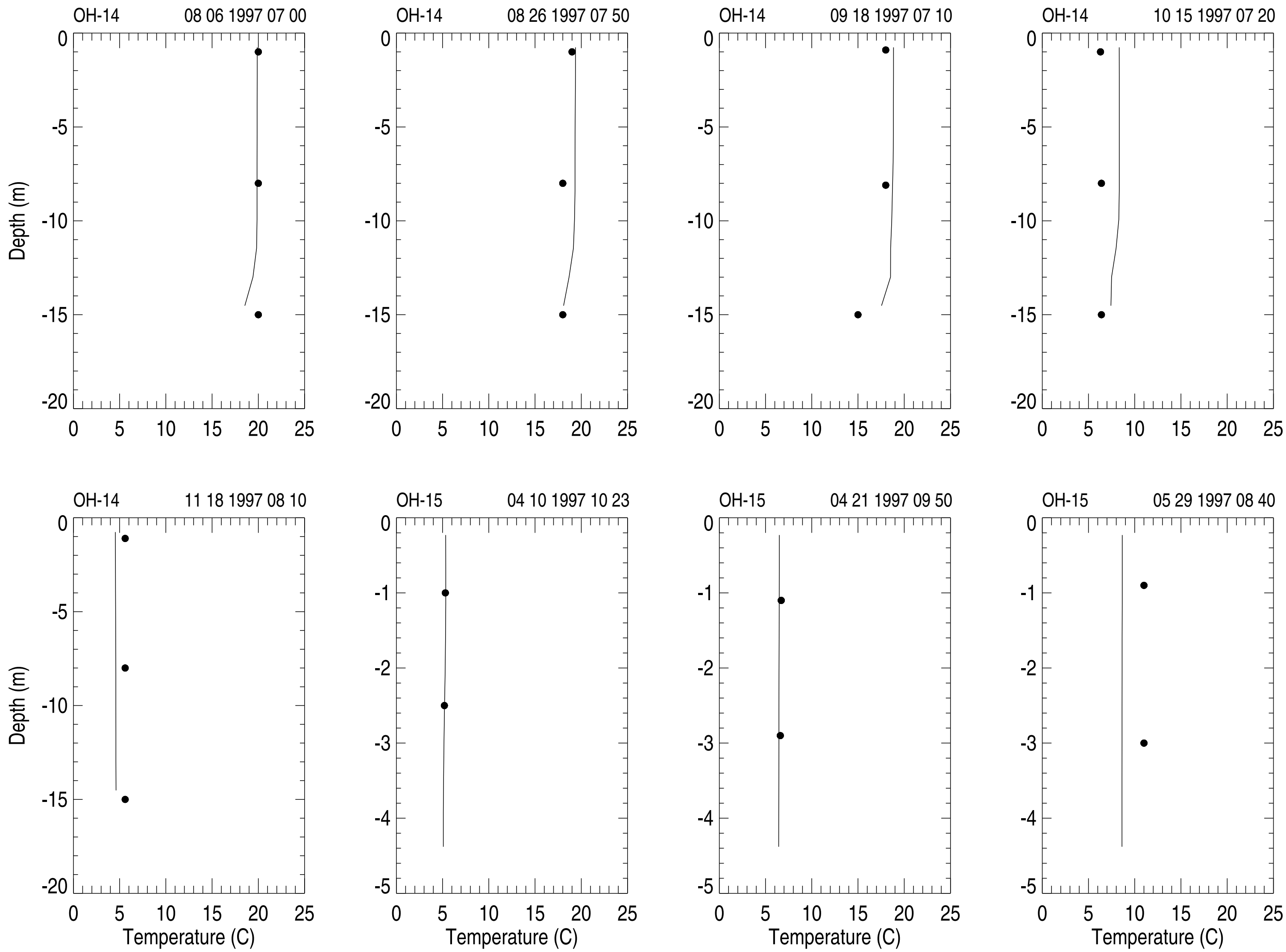

OH-10
11 18 1997 09 30
OH-11
04 10 1997 09 20
OH-11
04 21 1997 07 30
OH-11
05 29 1997 07 30
OH-11
06 10 1997 10 01
OH-11
06 23 1997 08 40
OH-11
07 02 1997 07 40
OH-11
08 06 1997 09 50
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

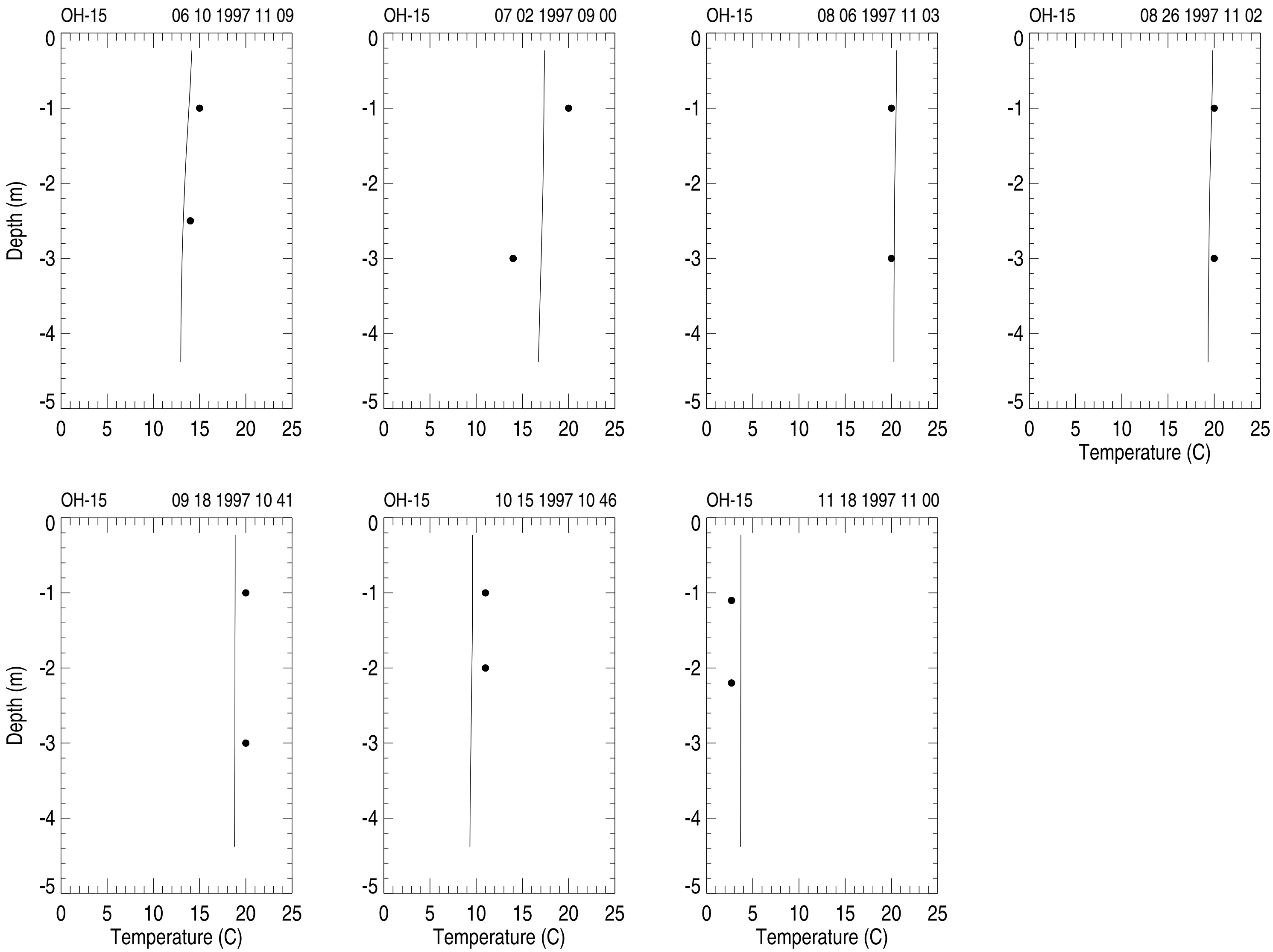

OH-11 08 12 1997 08 40
OH-11 08 26 1997 10 13
OH-11 09 18 1997 09 50
OH-11 09 30 1997 08 10
OH-11 10 15 1997 09 50
OH-11 11 18 1997 09 50
OH-12 04 10 1997 07 10
OH-12 06 10 1997 07 30
Depth (m)
0
-2
-4
-6
-8
-10
-5
-15
Temperature (C)
0 5 10 15 20 25

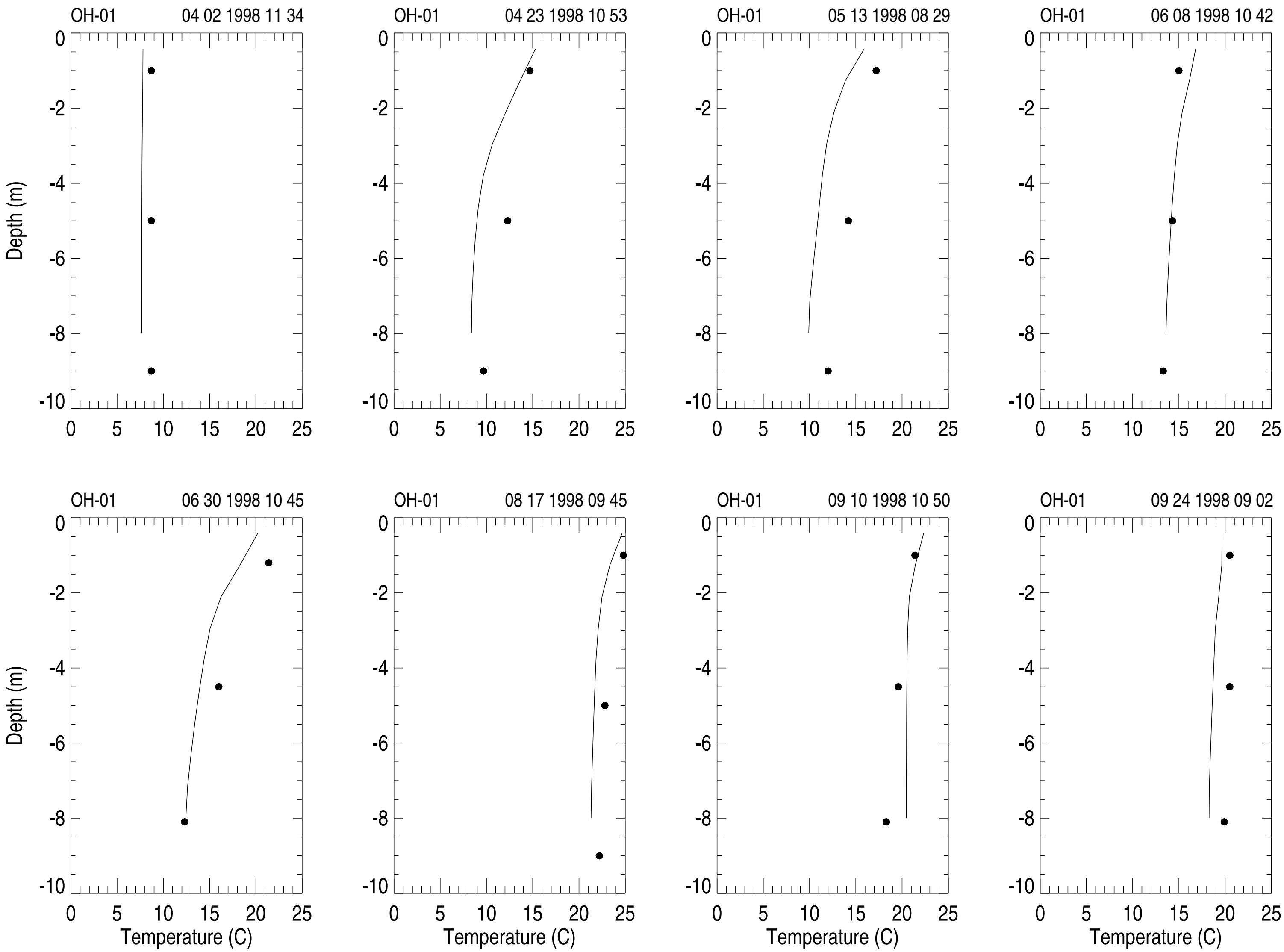


OH-12 08 06 1997 07 20
OH-12 08 26 1997 08 10
OH-12 09 18 1997 07 20
OH-12 10 15 1997 07 30
OH-12 11 18 1997 08 30
OH-13 04 10 1997 08 00
OH-13 06 10 1997 08 50
OH-13 08 06 1997 08 30
Depth (m)
Temperature (C)
0
-5
-10
-15
-20
0 5 10 15 20 25

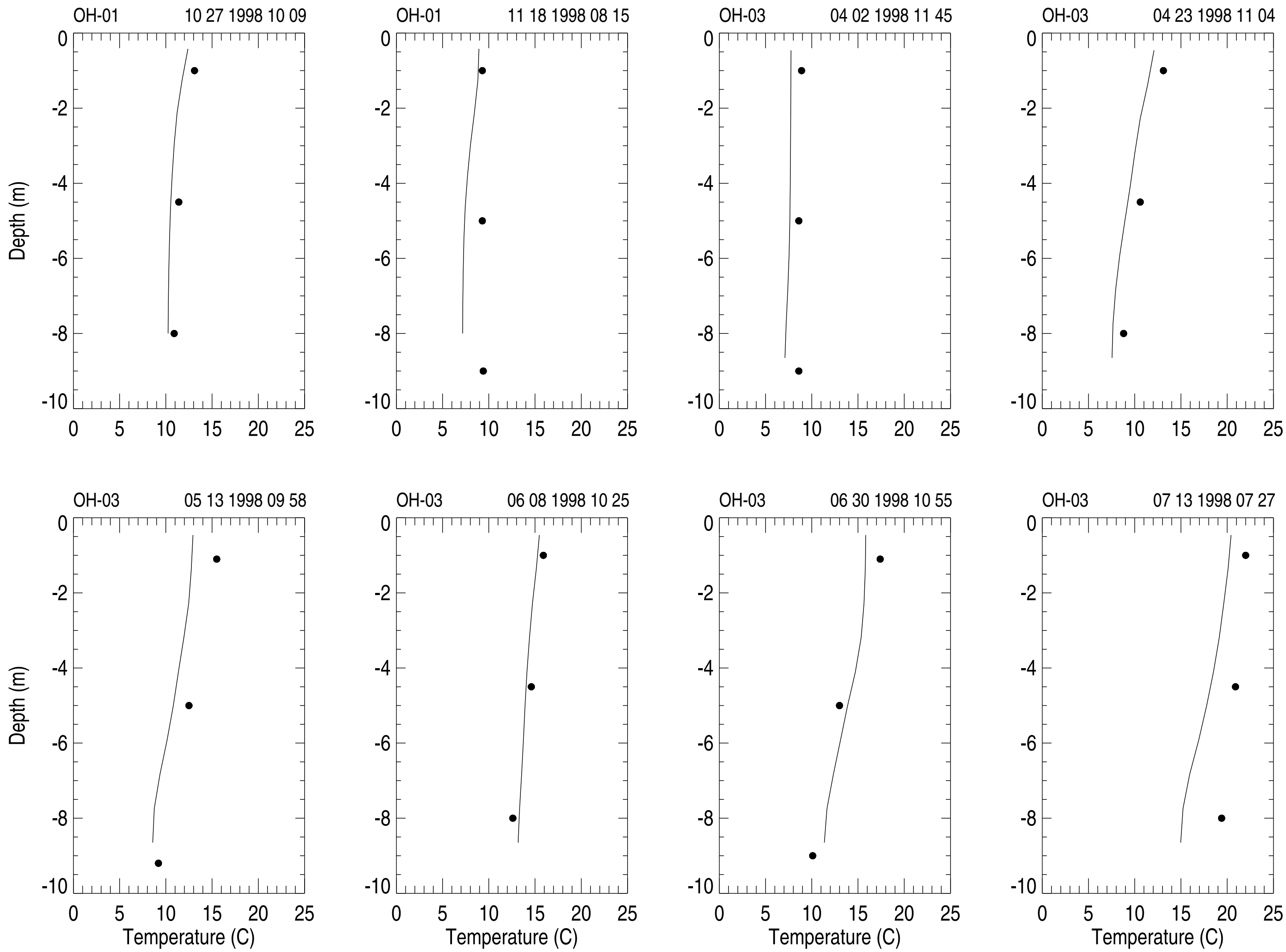

OH-13 08 26 1997 09 00
OH-13 09 18 1997 08 40
OH-13 10 15 1997 08 30
OH-14 04 10 1997 06 50
OH-14 04 28 1997 10 12
OH-14 06 04 1997 10 33
OH-14 06 10 1997 07 10
OH-14 07 31 1997 10 51
Depth (m)
Temperature (C)

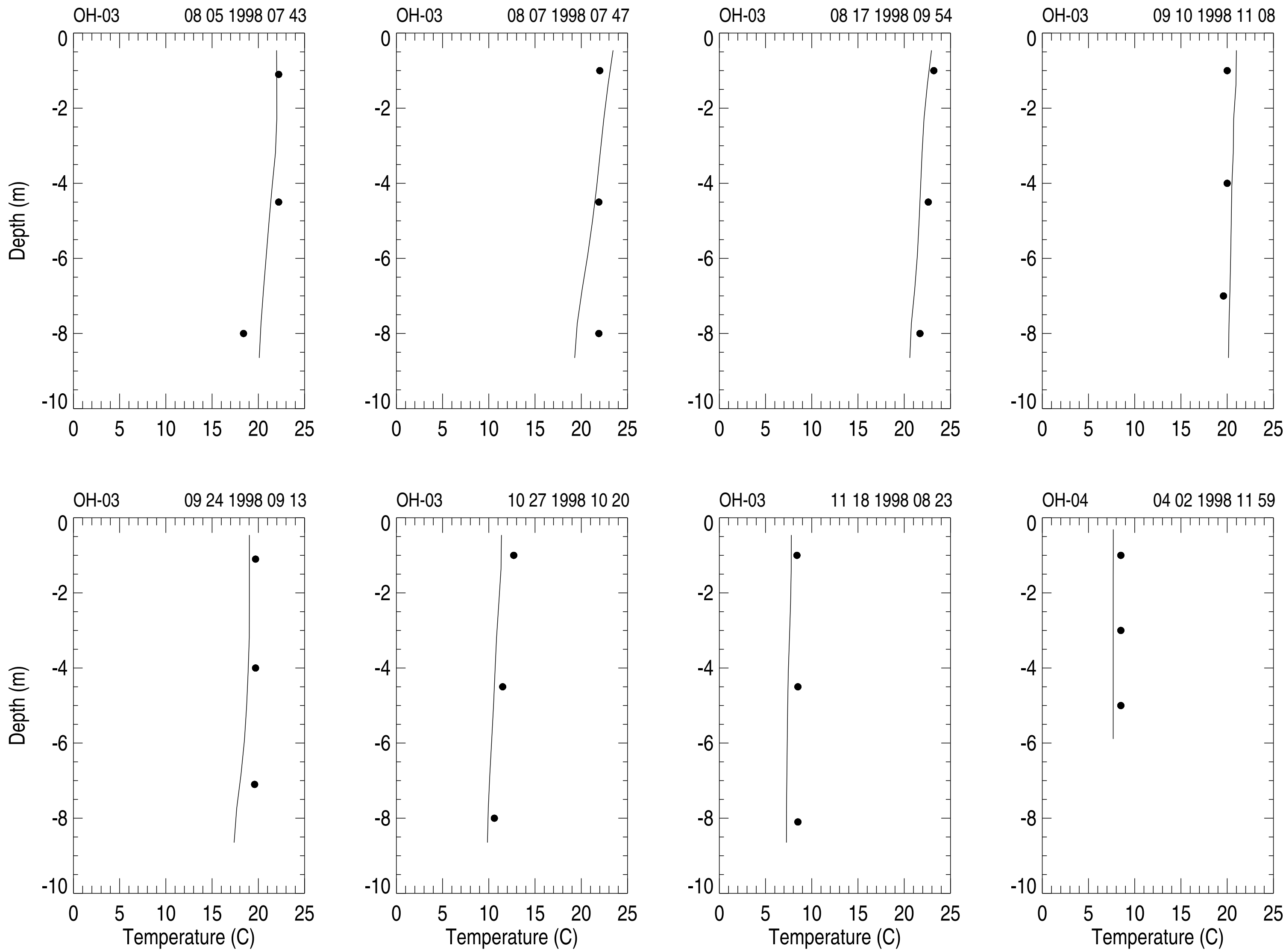

OH-14 08 06 1997 07 00
OH-14 08 26 1997 07 50
OH-14 09 18 1997 07 10
OH-14 10 15 1997 07 20
OH-14 11 18 1997 08 10
OH-15 04 10 1997 10 23
OH-15 04 21 1997 09 50
OH-15 05 29 1997 08 40
Depth (m)
Temperature (C)

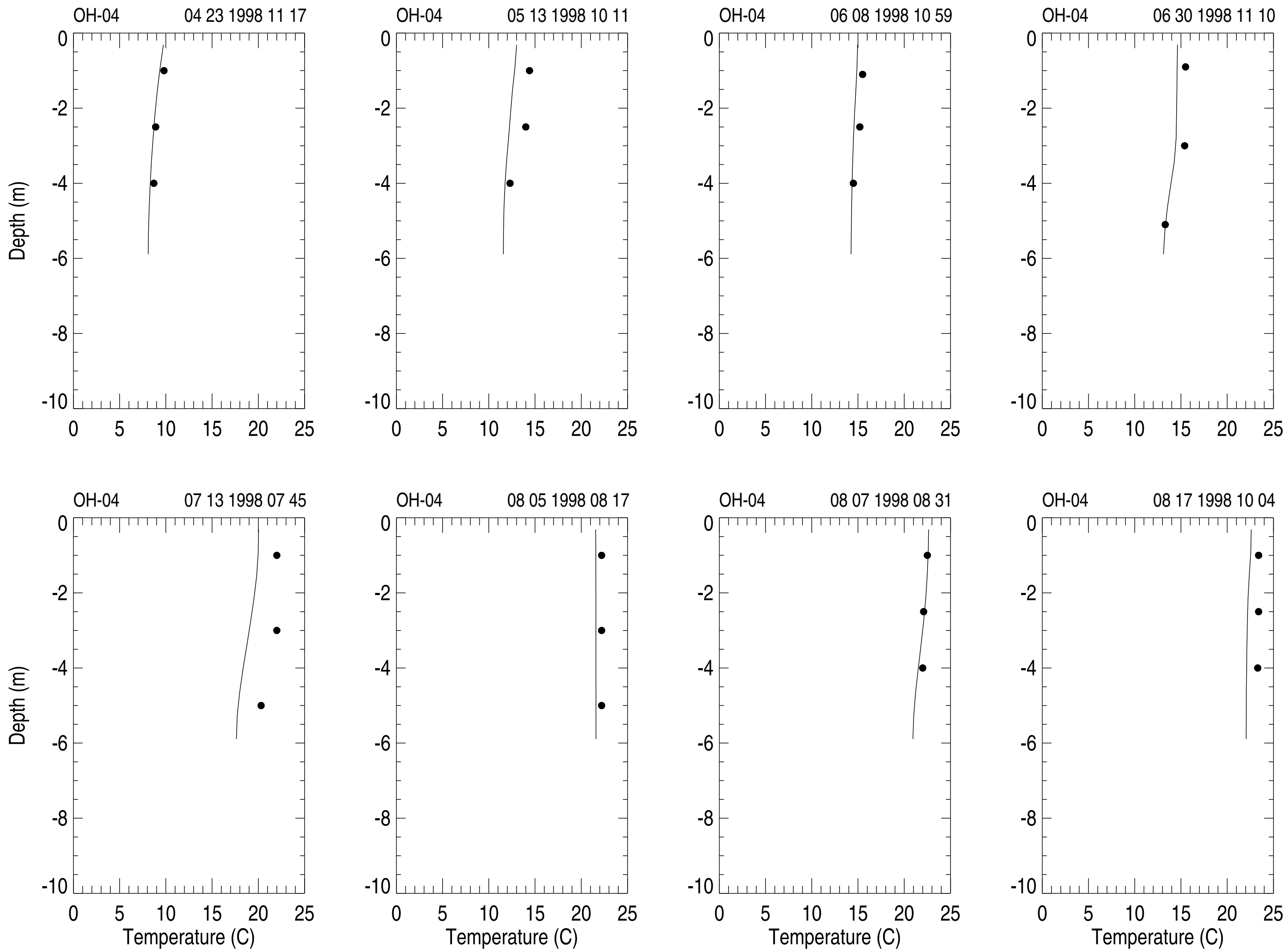

OH-15
06 10 1997 11 09
OH-15
07 02 1997 09 00
OH-15
08 06 1997 11 03
OH-15
08 26 1997 11 02
OH-15
09 18 1997 10 41
OH-15
10 15 1997 10 46
OH-15
11 18 1997 11 00
Depth (m)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25
Temperature (C)

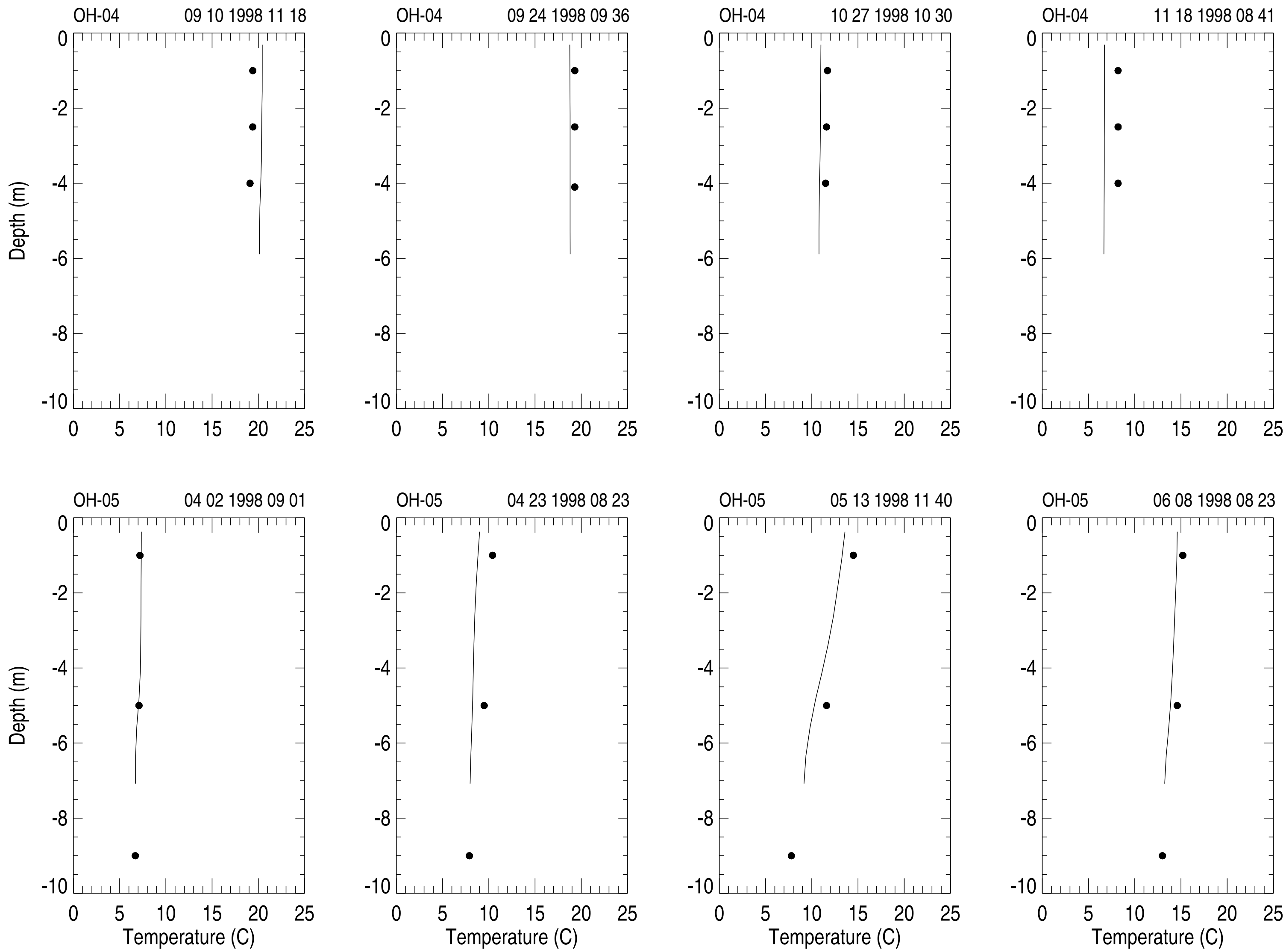


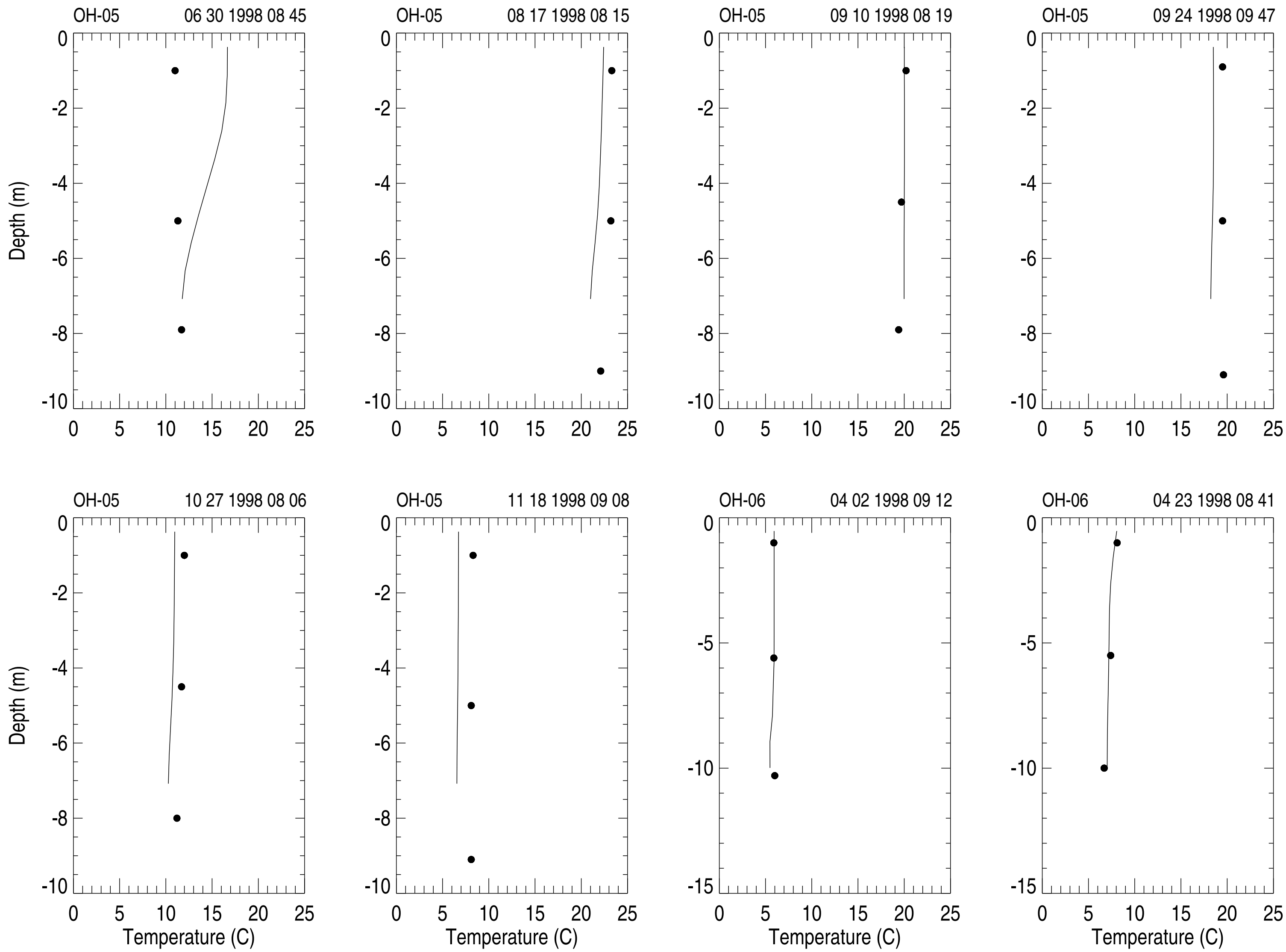
OH-01
04 02 1998 11 34
OH-01
04 23 1998 10 53
OH-01
05 13 1998 08 29
OH-01
06 08 1998 10 42
OH-01
06 30 1998 10 45
OH-01
08 17 1998 09 45
OH-01
09 10 1998 10 50
OH-01
09 24 1998 09 02
Depth (m)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
Temperature (C)


OH-01 10 27 1998 10 09
OH-01 11 18 1998 08 15
OH-03 04 02 1998 11 45
OH-03 04 23 1998 11 04
OH-03 05 13 1998 09 58
OH-03 06 08 1998 10 25
OH-03 06 30 1998 10 55
OH-03 07 13 1998 07 27
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

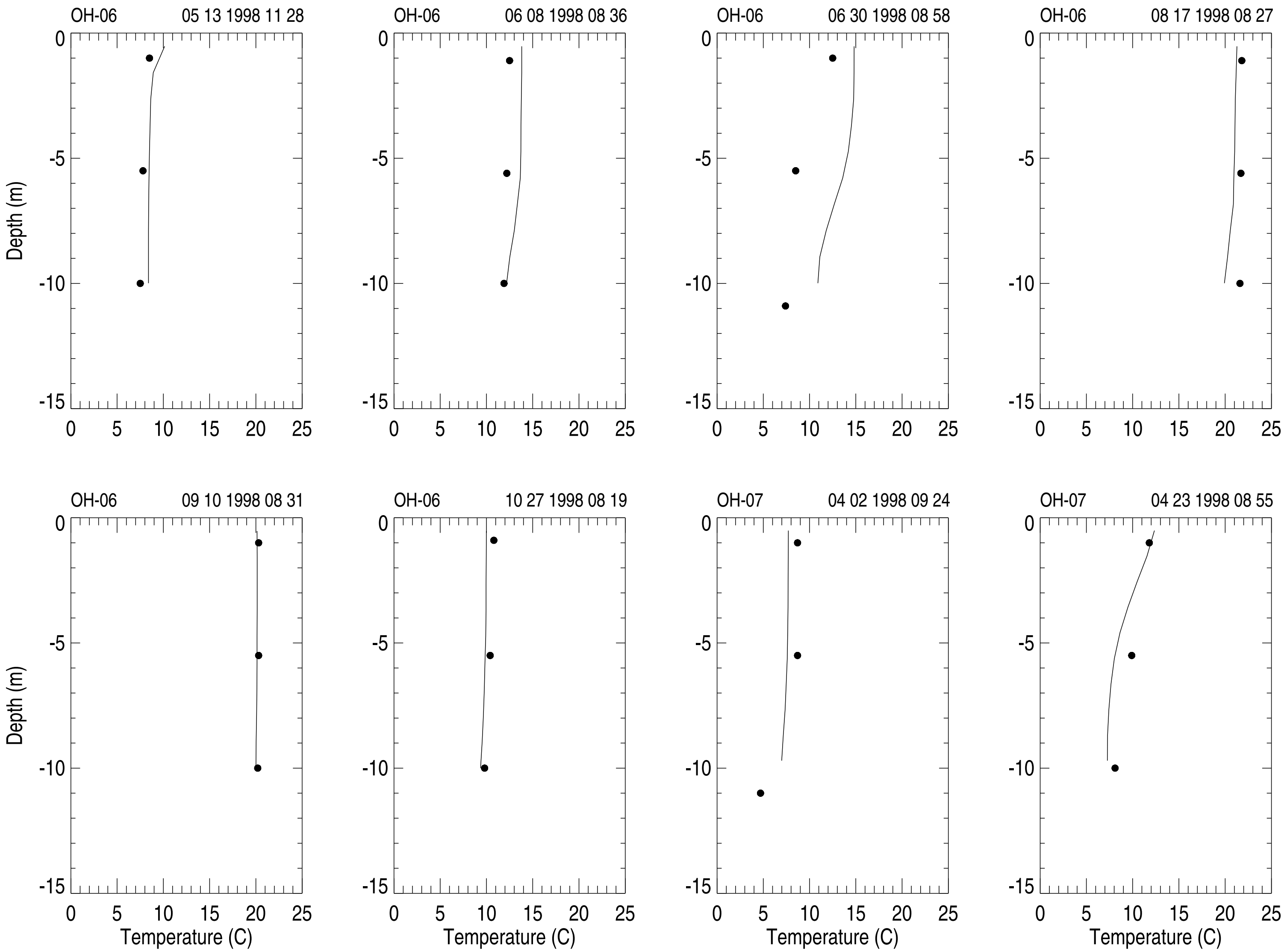

OH-03 08 05 1998 07 43
OH-03 08 07 1998 07 47
OH-03 08 17 1998 09 54
OH-03 09 10 1998 11 08
OH-03 09 24 1998 09 13
OH-03 10 27 1998 10 20
OH-03 11 18 1998 08 23
OH-04 04 02 1998 11 59
Depth (m)
0
-2
-4
-6
-8
-10
Temperature (C)
0 5 10 15 20 25

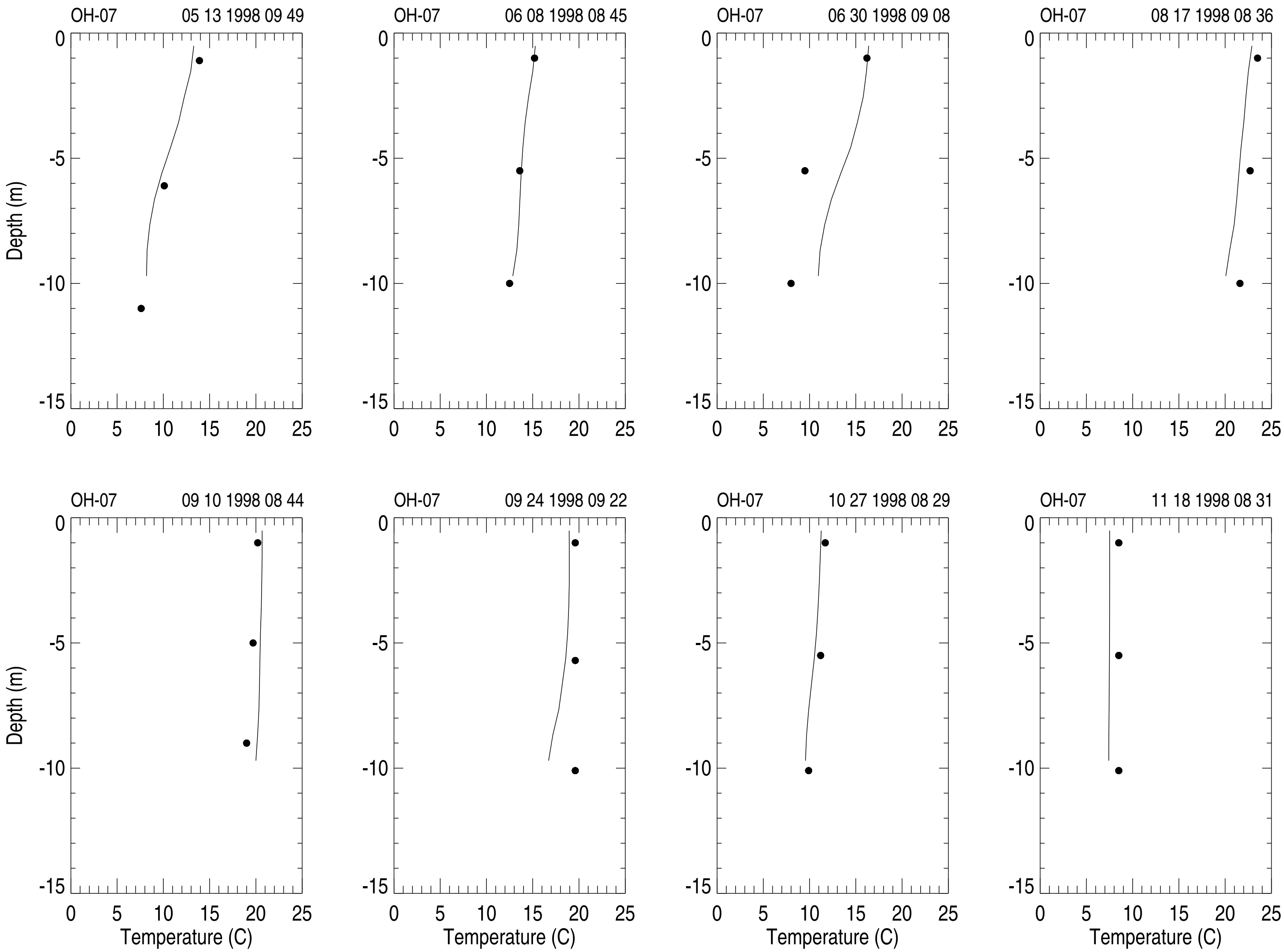

OH-04
04 23 1998 11 17
OH-04
05 13 1998 10 11
OH-04
06 08 1998 10 59
OH-04
06 30 1998 11 10
OH-04
07 13 1998 07 45
OH-04
08 05 1998 08 17
OH-04
08 07 1998 08 31
OH-04
08 17 1998 10 04
Depth (m)
Temperature (C)

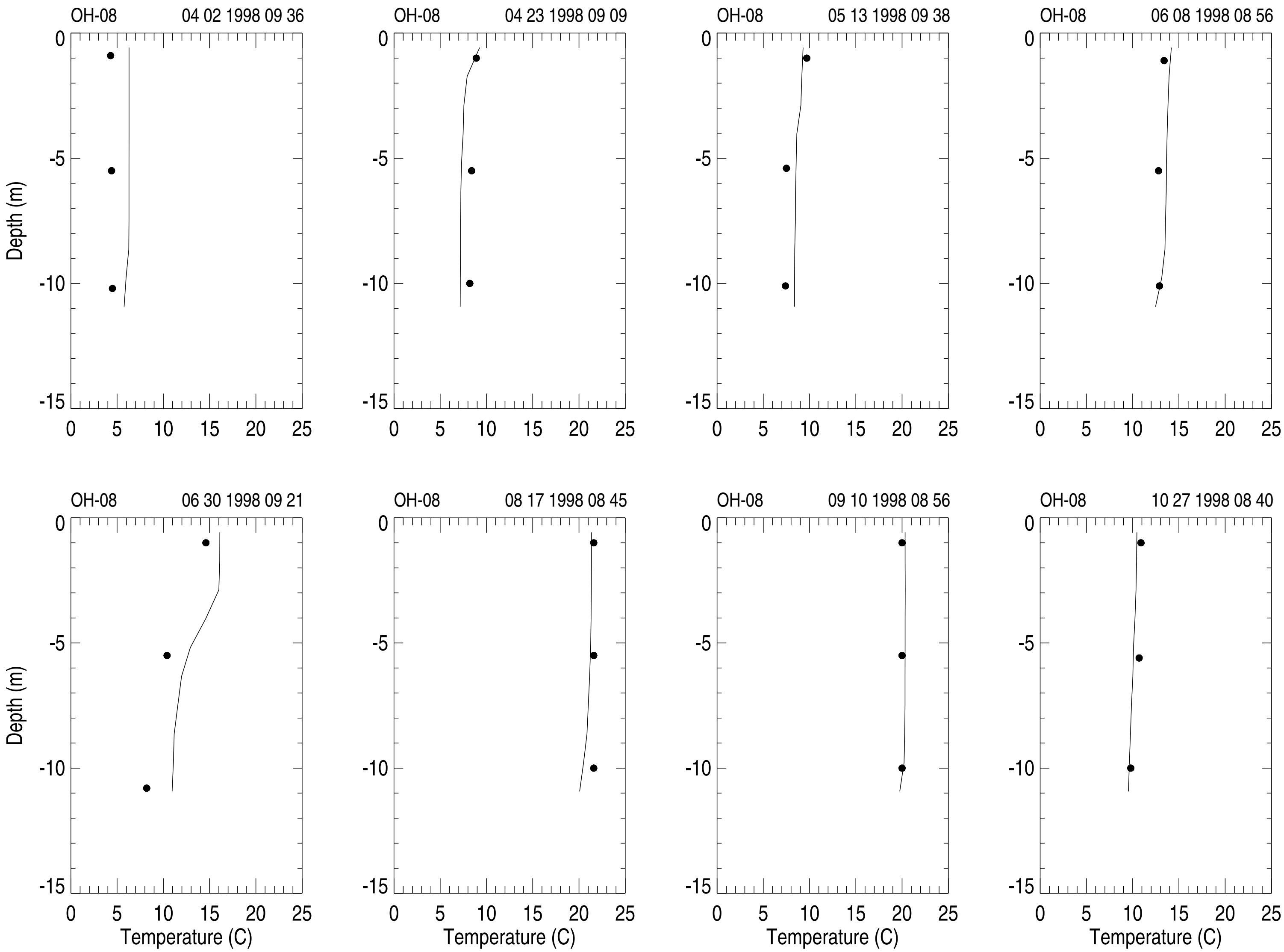

OH-04 09 10 1998 11 18
OH-04 09 24 1998 09 36
OH-04 10 27 1998 10 30
OH-04 11 18 1998 08 41
OH-05 04 02 1998 09 01
OH-05 04 23 1998 08 23
OH-05 05 13 1998 11 40
OH-05 06 08 1998 08 23
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25



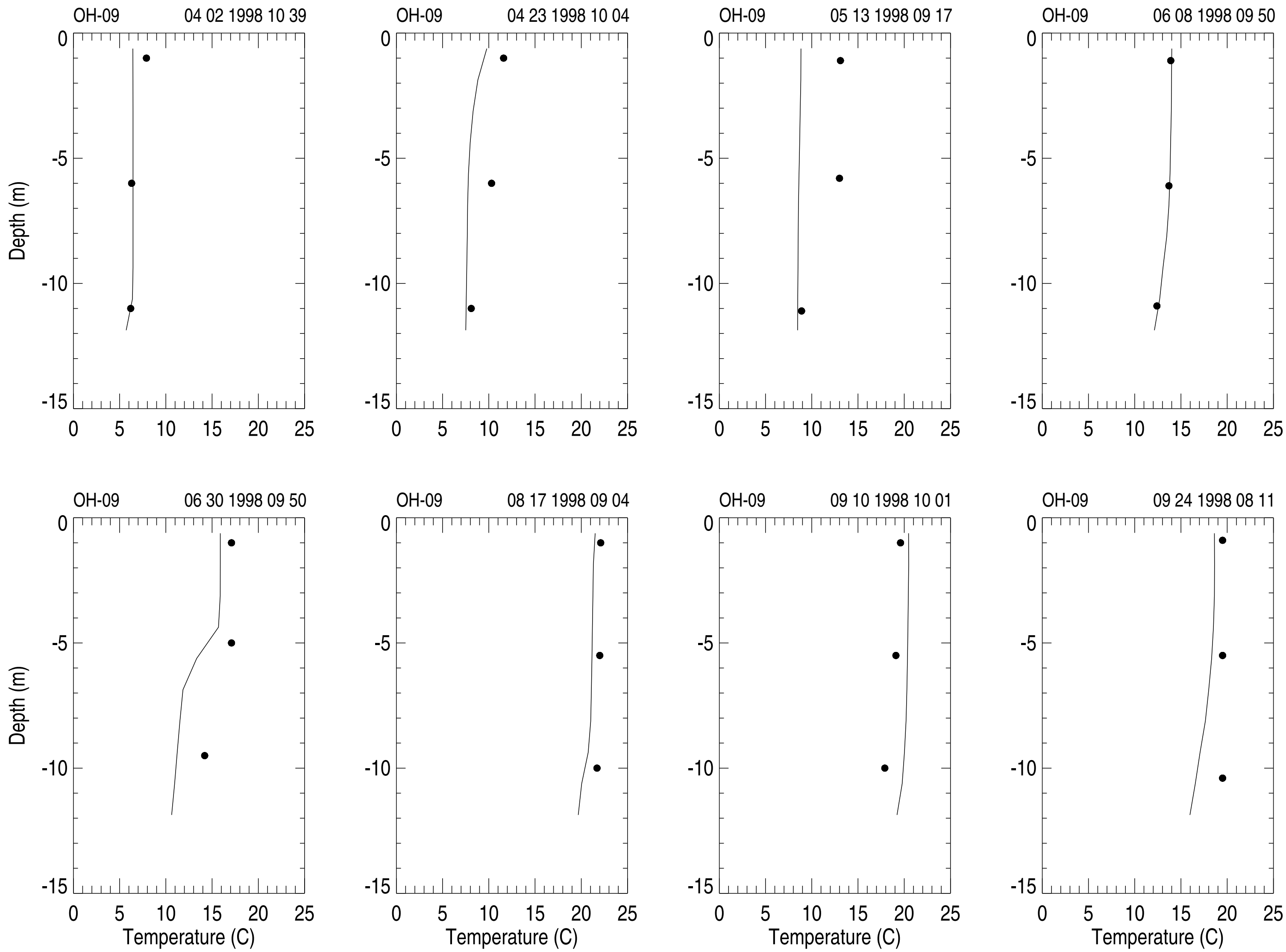
OH-05 06 30 1998 08 45
OH-05 08 17 1998 08 15
OH-05 09 10 1998 08 19
OH-05 09 24 1998 09 47
OH-05 10 27 1998 08 06
OH-05 11 18 1998 09 08
OH-06 04 02 1998 09 12
OH-06 04 23 1998 08 41
Depth (m)
Temperature (C)

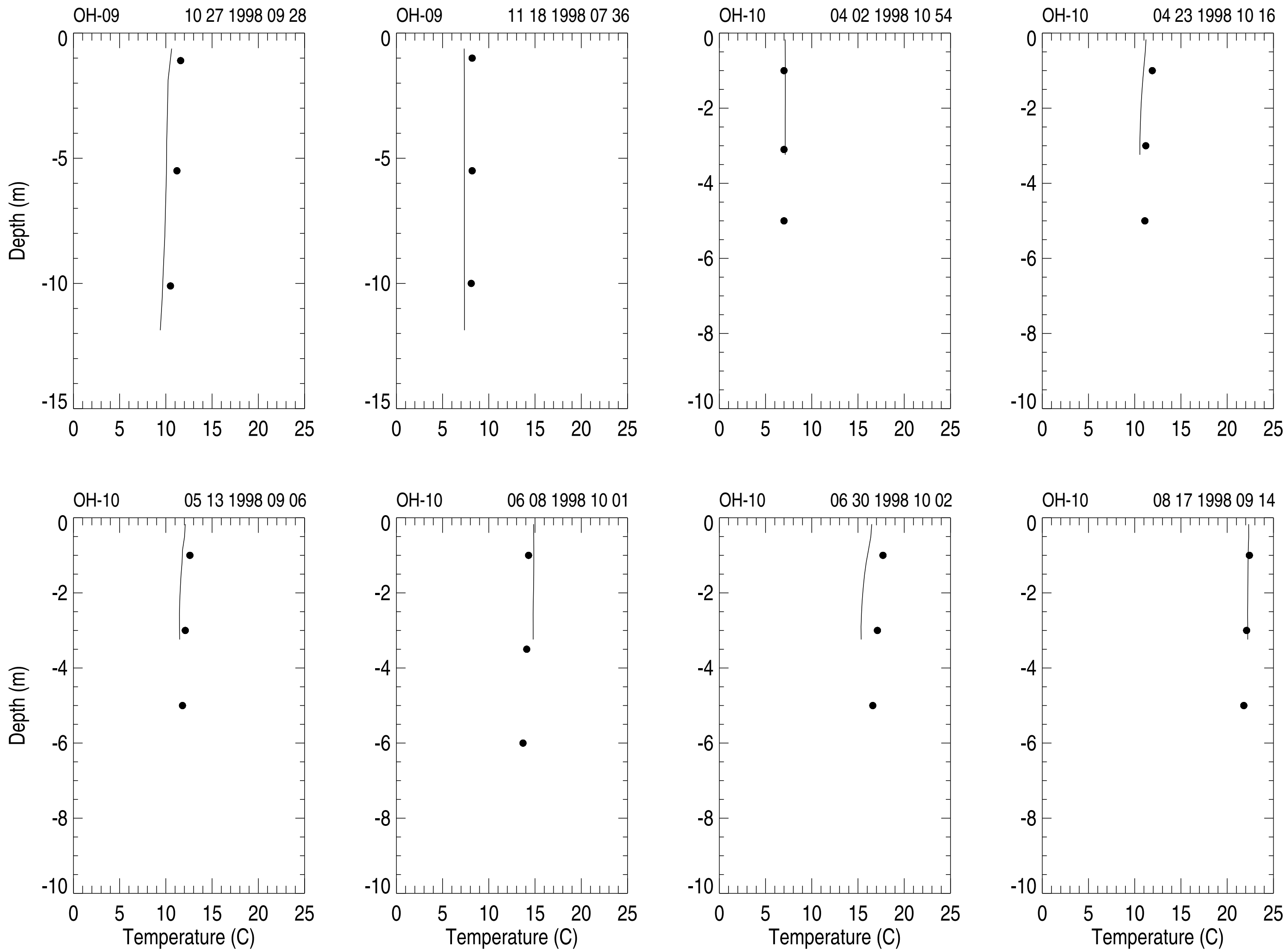

OH-06 05 13 1998 11 28
OH-06 06 08 1998 08 36
OH-06 06 30 1998 08 58
OH-06 08 17 1998 08 27
OH-06 09 10 1998 08 31
OH-06 10 27 1998 08 19
OH-07 04 02 1998 09 24
OH-07 04 23 1998 08 55
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25
Temperature (C)

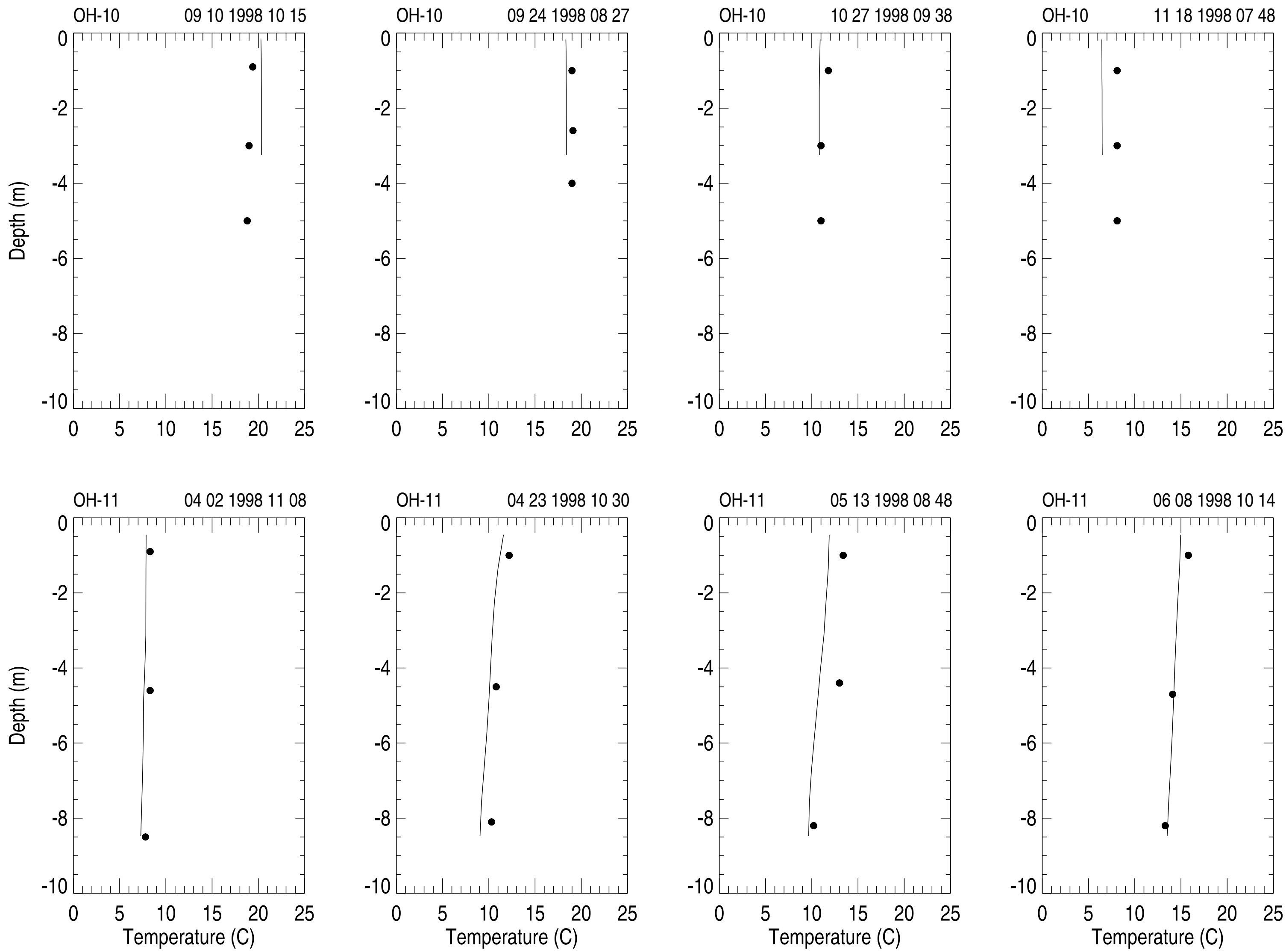

OH-07
05 13 1998 09 49
OH-07
06 08 1998 08 45
OH-07
06 30 1998 09 08
OH-07
08 17 1998 08 36
OH-07
09 10 1998 08 44
OH-07
09 24 1998 09 22
OH-07
10 27 1998 08 29
OH-07
11 18 1998 08 31
Depth (m)
Temperature (C)
0
-5
-10
-15
0
5
10
15
20
25



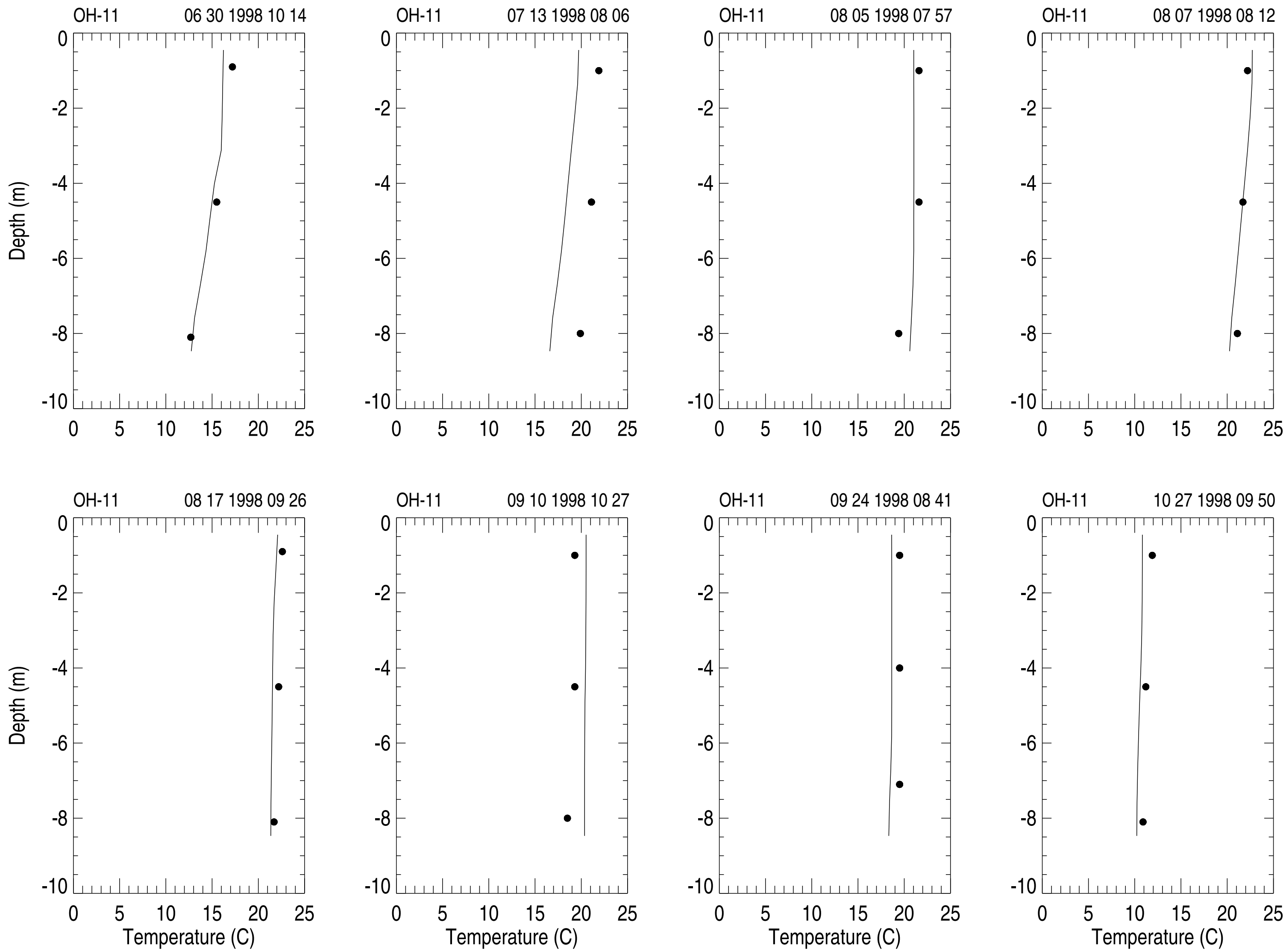
OH-08
04 02 1998 09 36
OH-08
04 23 1998 09 09
OH-08
05 13 1998 09 38
OH-08
06 08 1998 08 56
OH-08
06 30 1998 09 21
OH-08
08 17 1998 08 45
OH-08
09 10 1998 08 56
OH-08
10 27 1998 08 40
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25
Temperature (C)

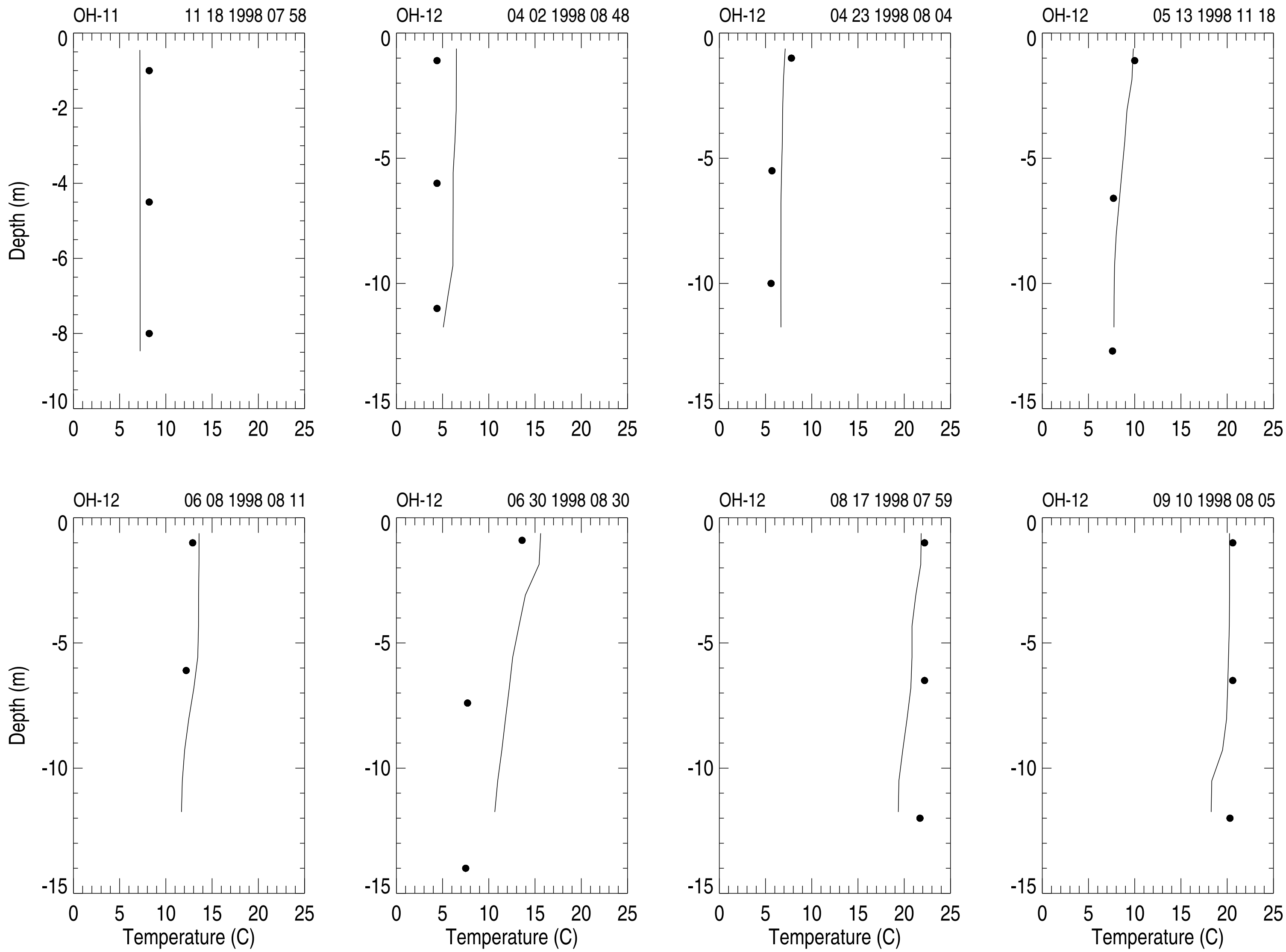

OH-09
04 02 1998 10 39
OH-09
04 23 1998 10 04
OH-09
05 13 1998 09 17
OH-09
06 08 1998 09 50
OH-09
06 30 1998 09 50
OH-09
08 17 1998 09 04
OH-09
09 10 1998 10 01
OH-09
09 24 1998 08 11
Depth (m)
Temperature (C)
0
-5
-10
-15
0
5
10
15
20
25


OH-09 10 27 1998 09 28
OH-09 11 18 1998 07 36
OH-10 04 02 1998 10 54
OH-10 04 23 1998 10 16
OH-10 05 13 1998 09 06
OH-10 06 08 1998 10 01
OH-10 06 30 1998 10 02
OH-10 08 17 1998 09 14
Depth (m)
Temperature (C)

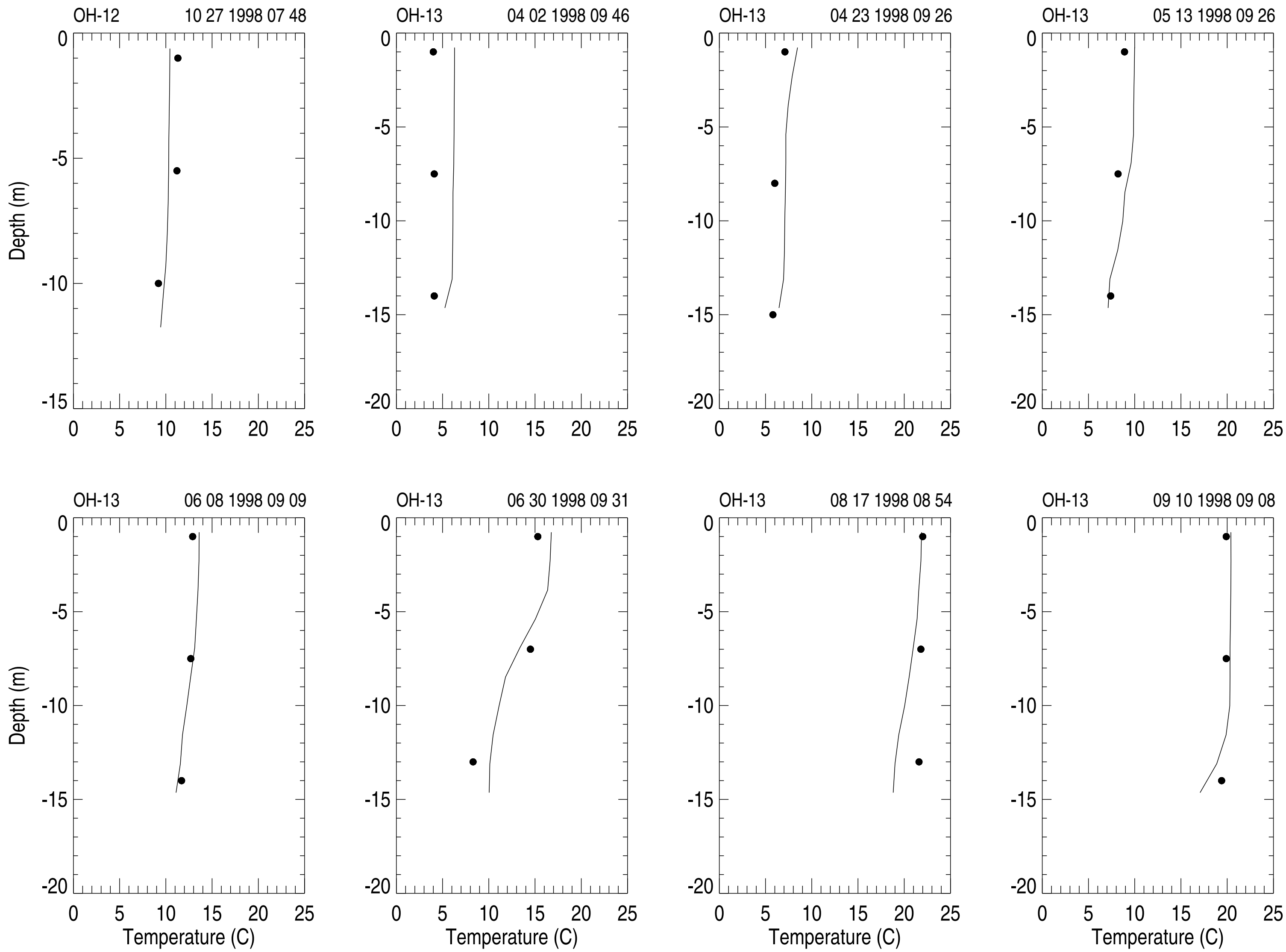


OH-10 09 10 1998 10 15
OH-10 09 24 1998 08 27
OH-10 10 27 1998 09 38
OH-10 11 18 1998 07 48
OH-11 04 02 1998 11 08
OH-11 04 23 1998 10 30
OH-11 05 13 1998 08 48
OH-11 06 08 1998 10 14
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

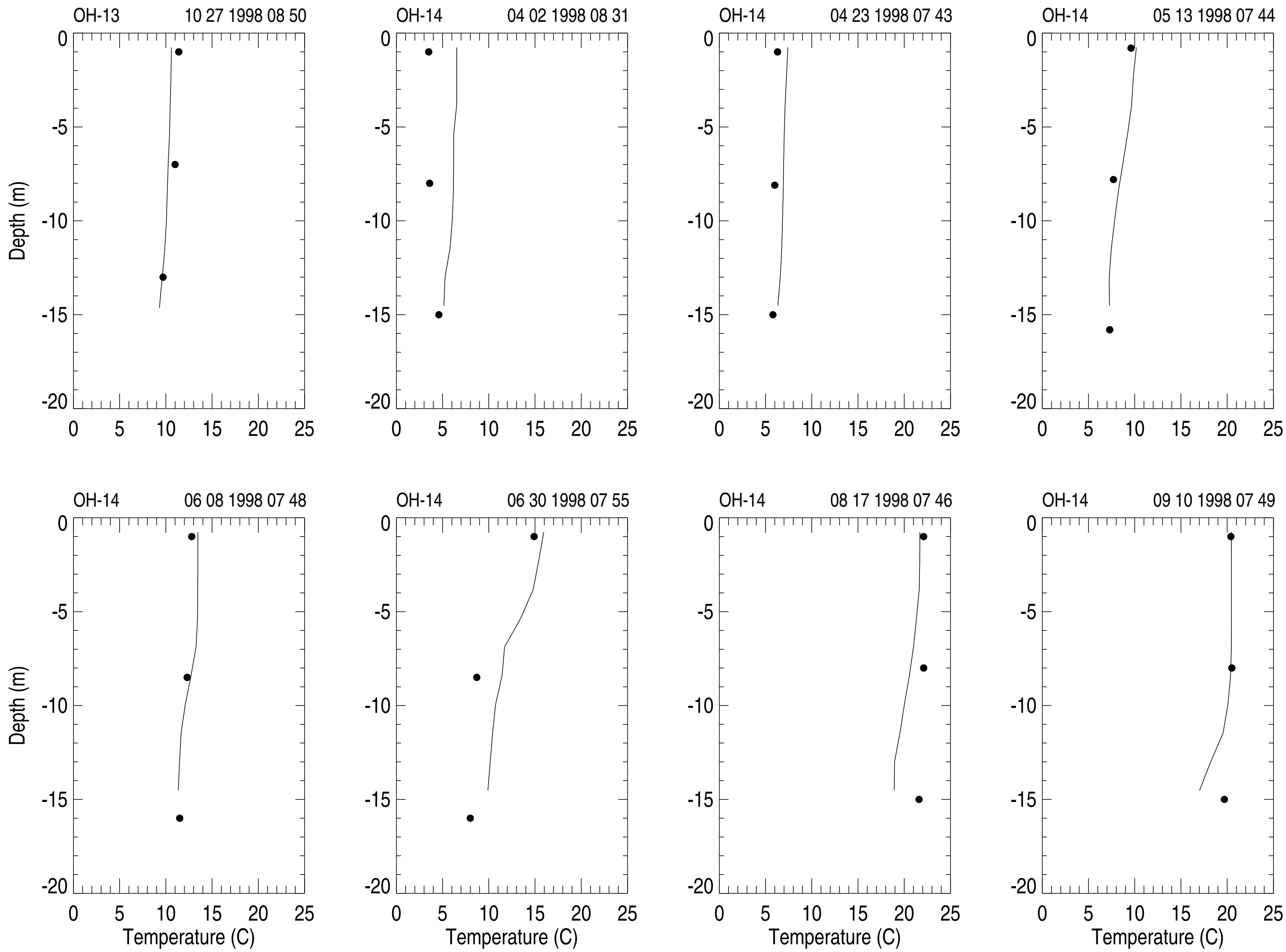

OH-11
06 30 1998 10 14
OH-11
07 13 1998 08 06
OH-11
08 05 1998 07 57
OH-11
08 07 1998 08 12
OH-11
08 17 1998 09 26
OH-11
09 10 1998 10 27
OH-11
09 24 1998 08 41
OH-11
10 27 1998 09 50
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25

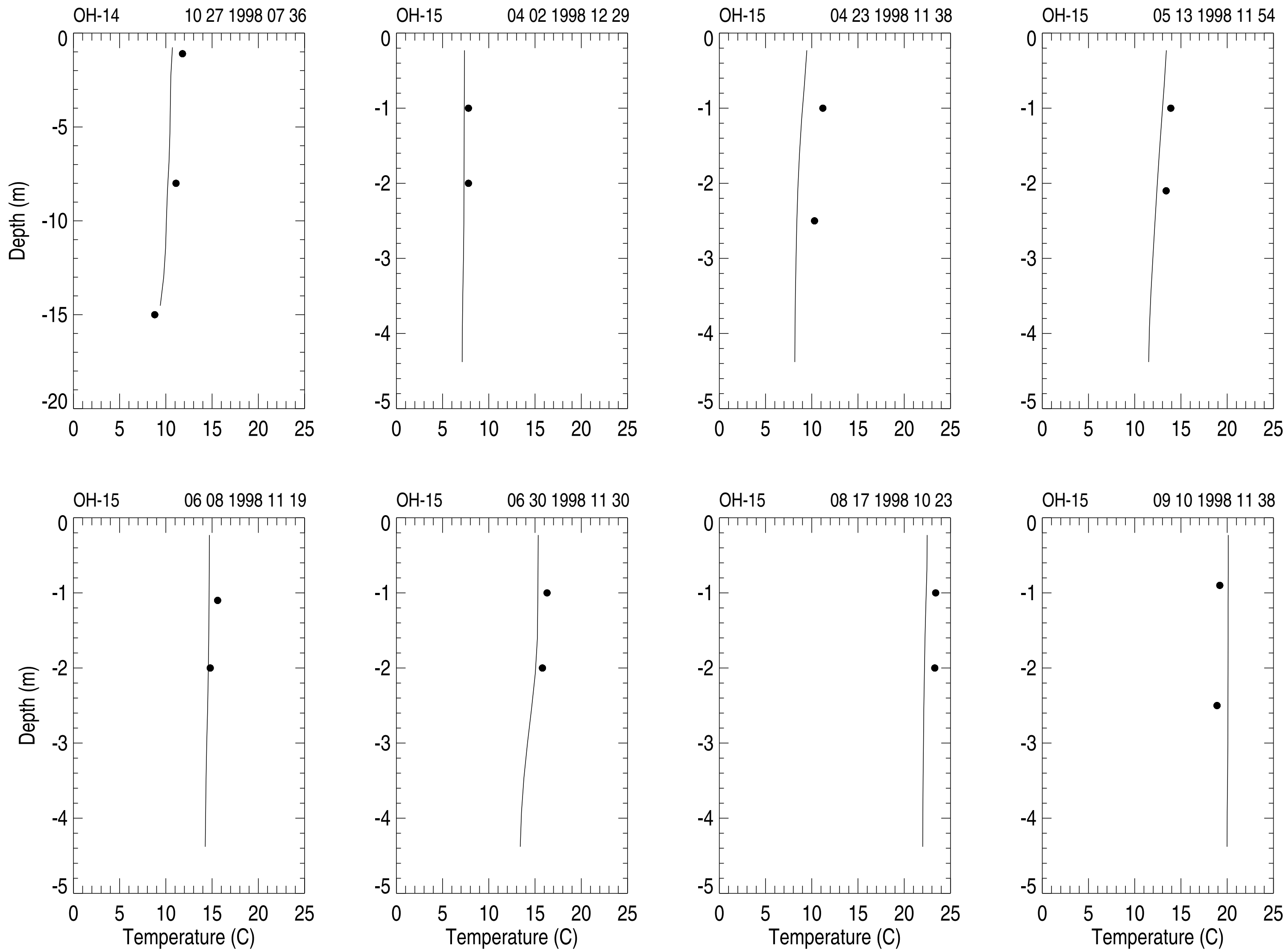


OH-11 11 18 1998 07 58
OH-12 04 02 1998 08 48
OH-12 04 23 1998 08 04
OH-12 05 13 1998 11 18
OH-12 06 08 1998 08 11
OH-12 06 30 1998 08 30
OH-12 08 17 1998 07 59
OH-12 09 10 1998 08 05
Depth (m)
Temperature (C)

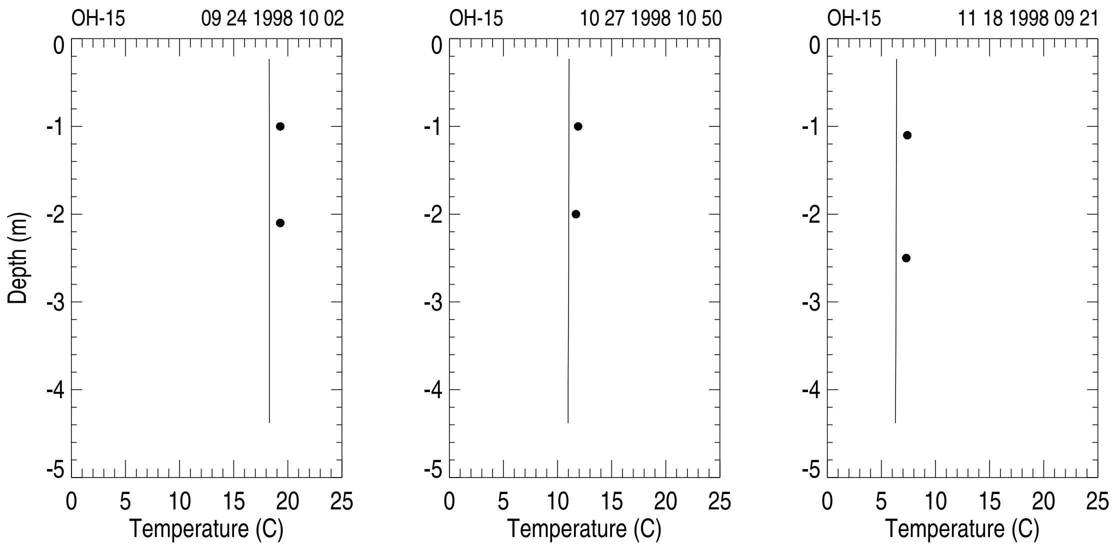


OH-12 10 27 1998 07 48
OH-13 04 02 1998 09 46
OH-13 04 23 1998 09 26
OH-13 05 13 1998 09 26
OH-13 06 08 1998 09 09
OH-13 06 30 1998 09 31
OH-13 08 17 1998 08 54
OH-13 09 10 1998 09 08
Depth (m)
Temperature (C)

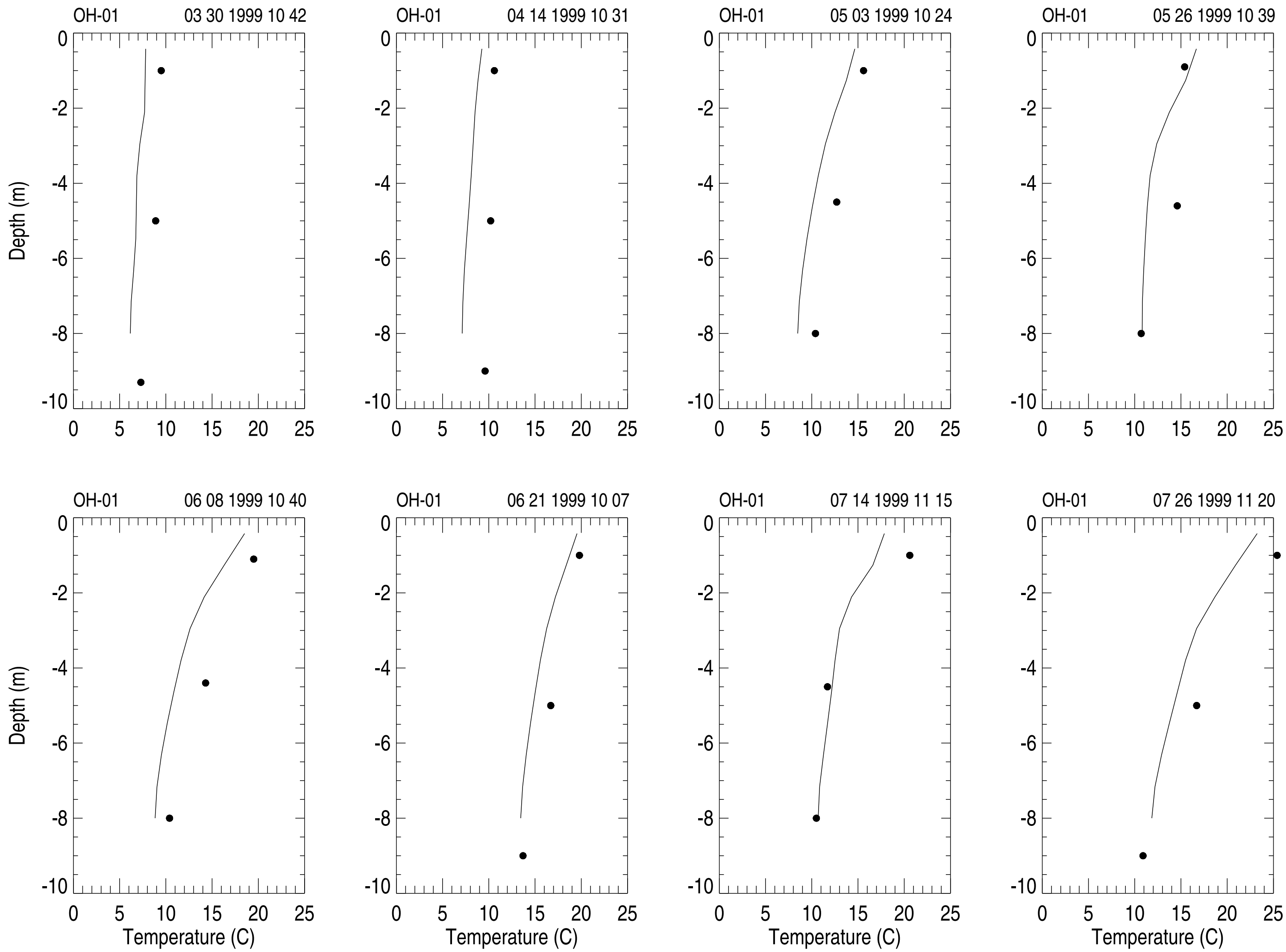

OH-13
10 27 1998 08 50
OH-14
04 02 1998 08 31
OH-14
04 23 1998 07 43
OH-14
05 13 1998 07 44
OH-14
06 08 1998 07 48
OH-14
06 30 1998 07 55
OH-14
08 17 1998 07 46
OH-14
09 10 1998 07 49
Depth (m)
Temperature (C)
0
-5
-10
-15
-20
0 5 10 15 20 25

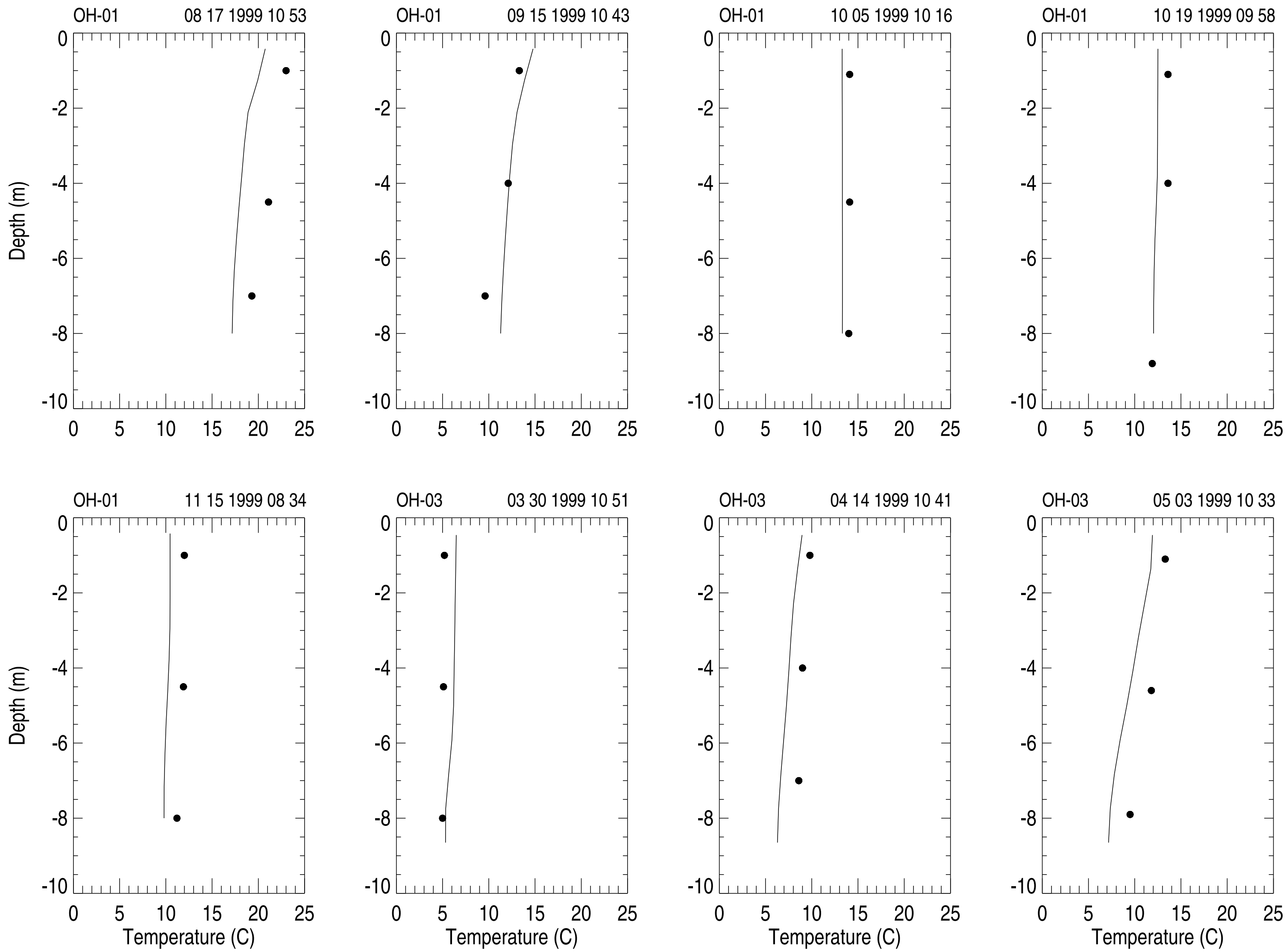


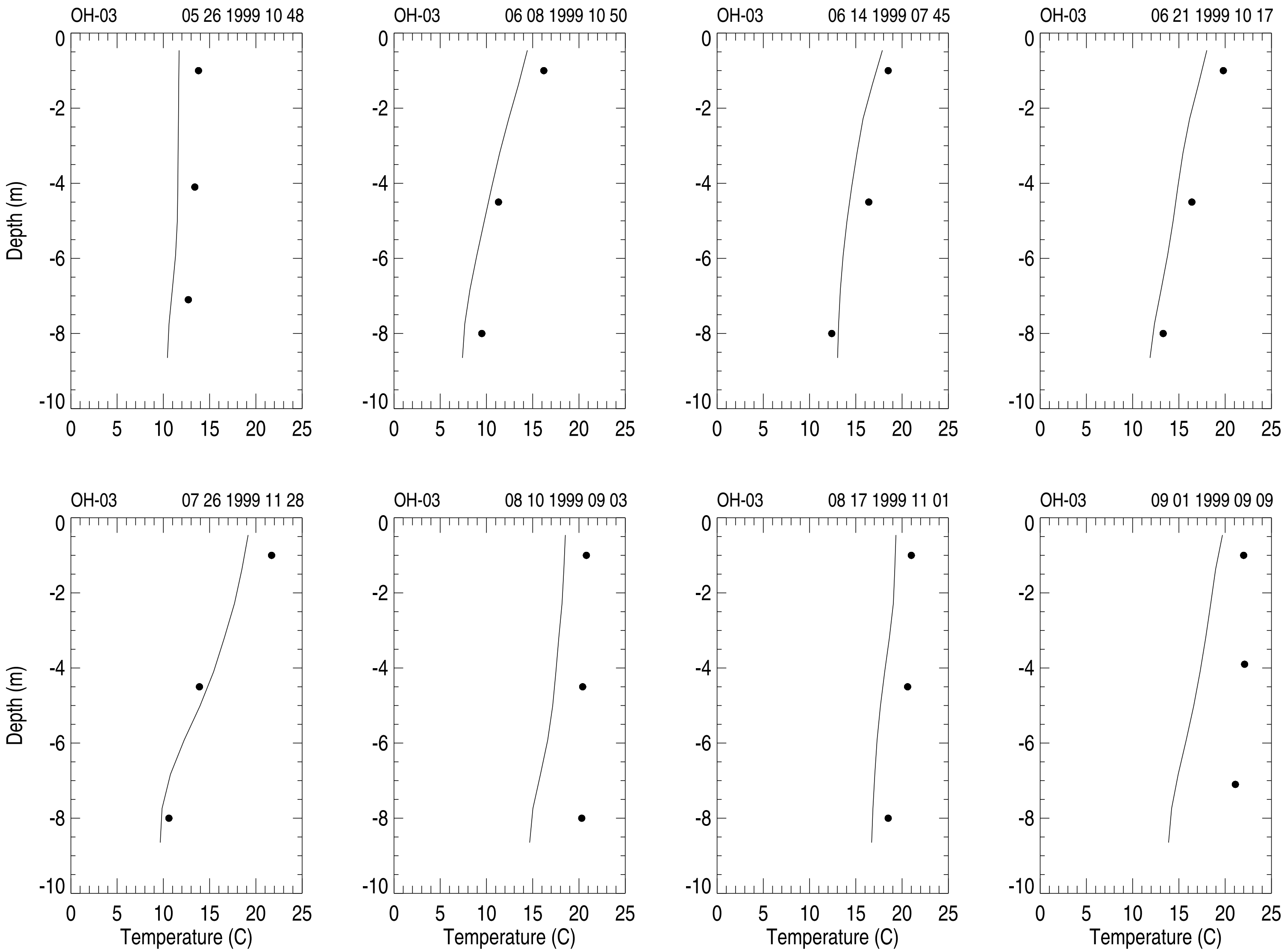
OH-14 10 27 1998 07 36
OH-15 04 02 1998 12 29
OH-15 04 23 1998 11 38
OH-15 05 13 1998 11 54
OH-15 06 08 1998 11 19
OH-15 06 30 1998 11 30
OH-15 08 17 1998 10 23
OH-15 09 10 1998 11 38
Depth (m)
Temperature (C)

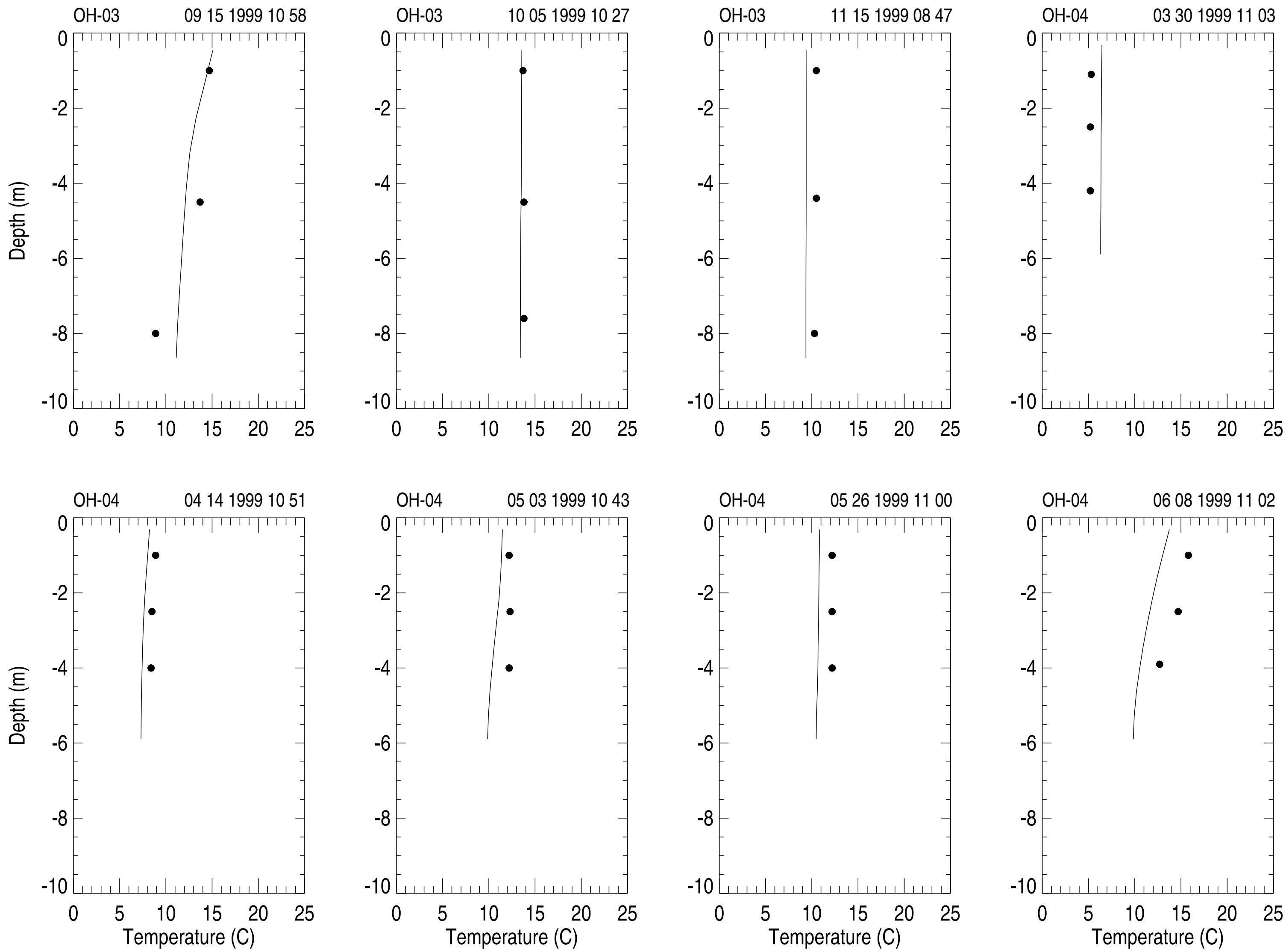


OH-15
09 24 1998 10 02
Depth (m)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25
Temperature (C)
OH-15
10 27 1998 10 50
Temperature (C)
OH-15
11 18 1998 09 21
Temperature (C)

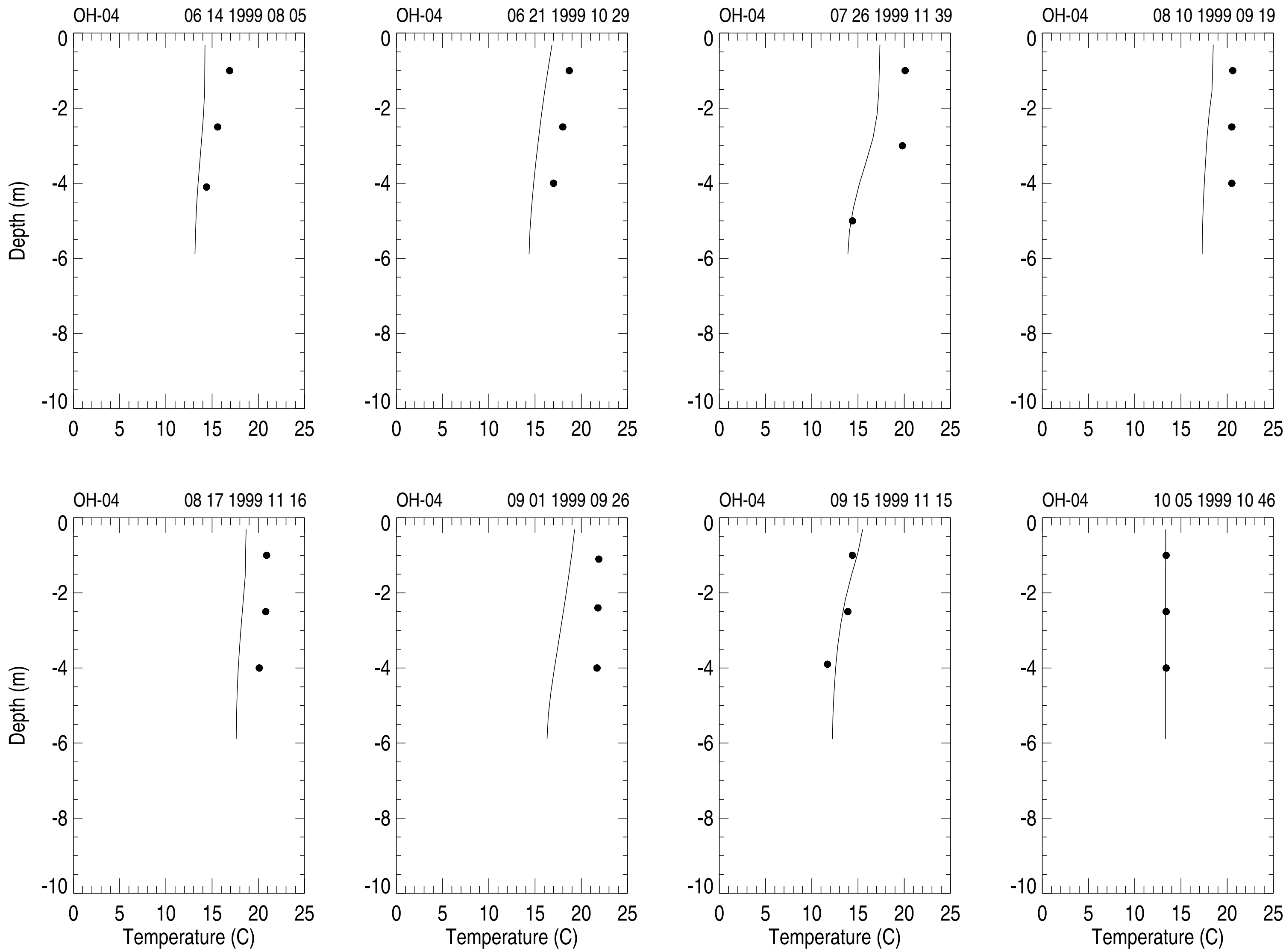

OH-01 03 30 1999 10 42
OH-01 04 14 1999 10 31
OH-01 05 03 1999 10 24
OH-01 05 26 1999 10 39
OH-01 06 08 1999 10 40
OH-01 06 21 1999 10 07
OH-01 07 14 1999 11 15
OH-01 07 26 1999 11 20
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

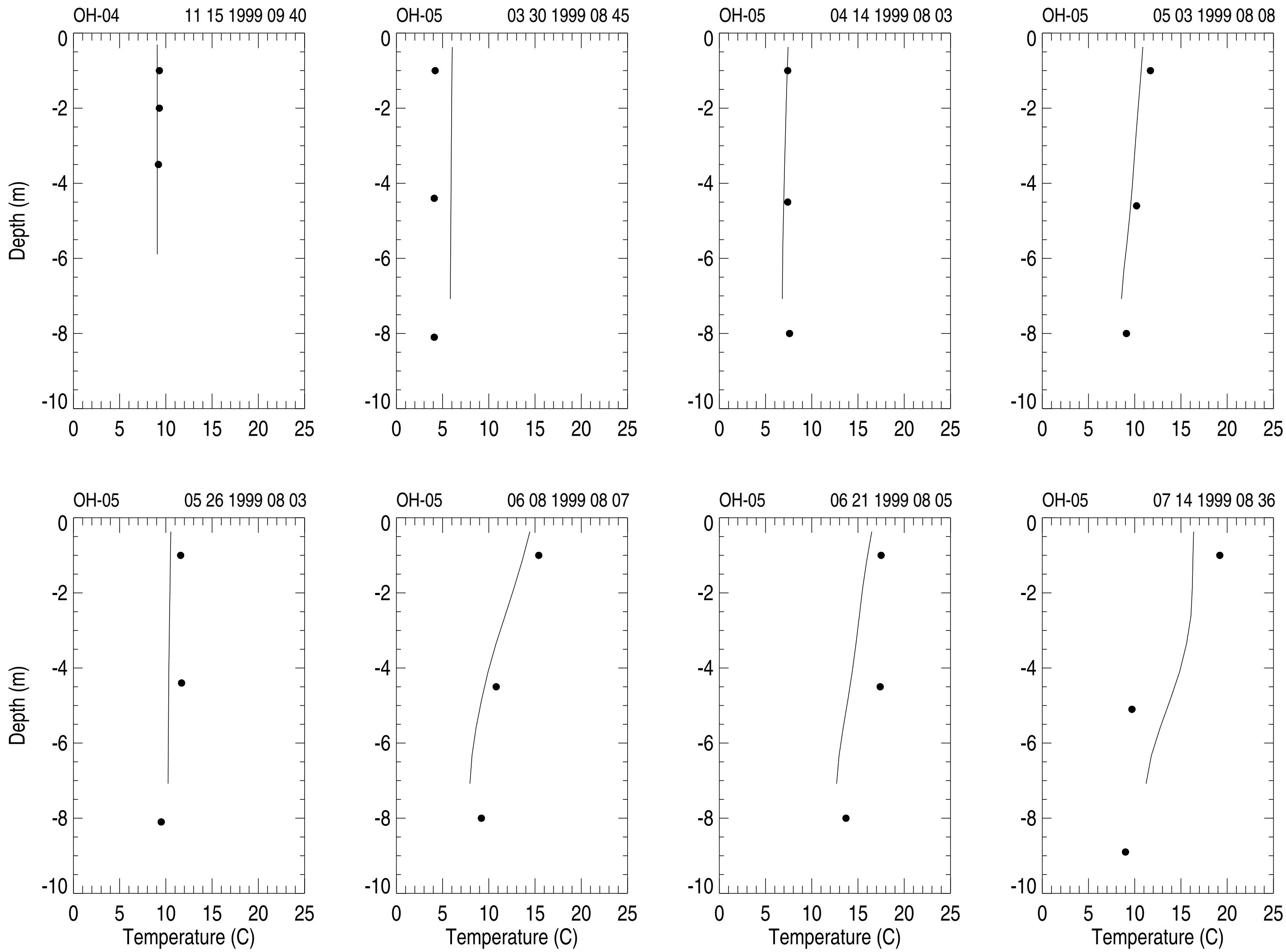

OH-01 08 17 1999 10 53
OH-01 09 15 1999 10 43
OH-01 10 05 1999 10 16
OH-01 10 19 1999 09 58
OH-01 11 15 1999 08 34
OH-03 03 30 1999 10 51
OH-03 04 14 1999 10 41
OH-03 05 03 1999 10 33
Depth (m)
Temperature (C)

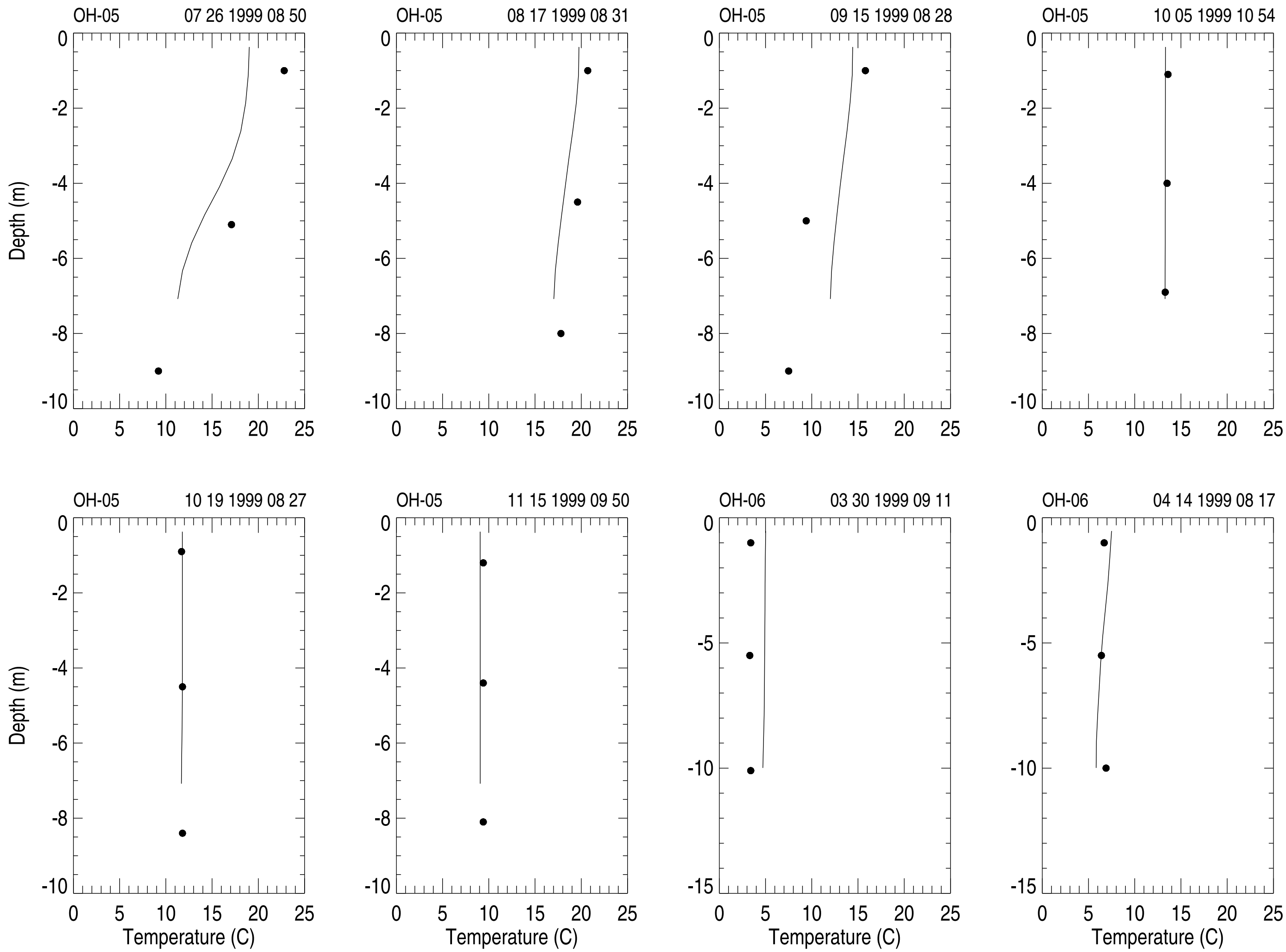

OH-03 05 26 1999 10 48
OH-03 06 08 1999 10 50
OH-03 06 14 1999 07 45
OH-03 06 21 1999 10 17
OH-03 07 26 1999 11 28
OH-03 08 10 1999 09 03
OH-03 08 17 1999 11 01
OH-03 09 01 1999 09 09
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25



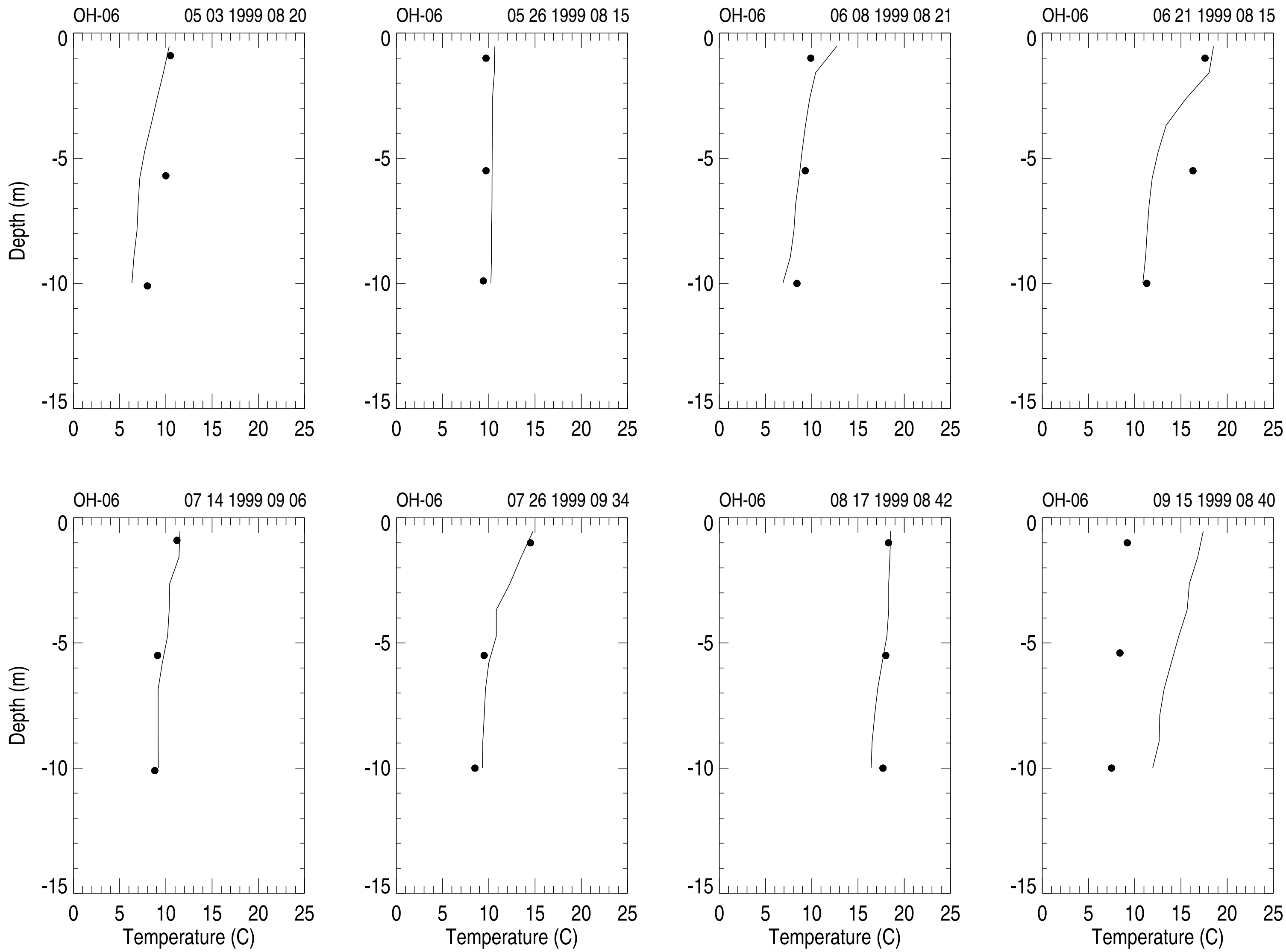
OH-03 09 15 1999 10 58
OH-03 10 05 1999 10 27
OH-03 11 15 1999 08 47
OH-04 03 30 1999 11 03
OH-04 04 14 1999 10 51
OH-04 05 03 1999 10 43
OH-04 05 26 1999 11 00
OH-04 06 08 1999 11 02
Depth (m)
Temperature (C)


OH-04
06 14 1999 08 05
OH-04
06 21 1999 10 29
OH-04
07 26 1999 11 39
OH-04
08 10 1999 09 19
OH-04
08 17 1999 11 16
OH-04
09 01 1999 09 26
OH-04
09 15 1999 11 15
OH-04
10 05 1999 10 46
Depth (m)
Temperature (C)

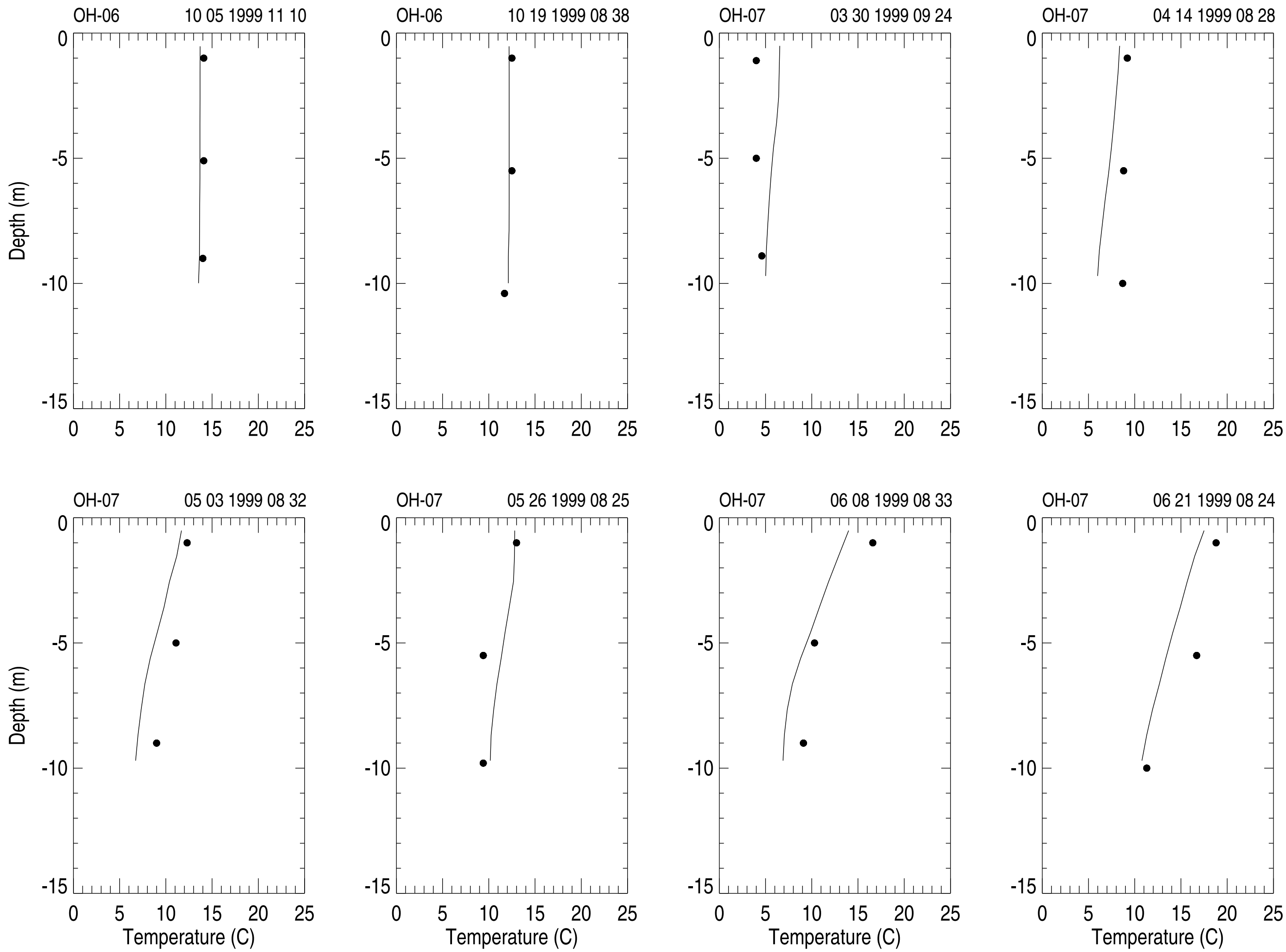

OH-04
11 15 1999 09 40
OH-05
03 30 1999 08 45
OH-05
04 14 1999 08 03
OH-05
05 03 1999 08 08
OH-05
05 26 1999 08 03
OH-05
06 08 1999 08 07
OH-05
06 21 1999 08 05
OH-05
07 14 1999 08 36
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25



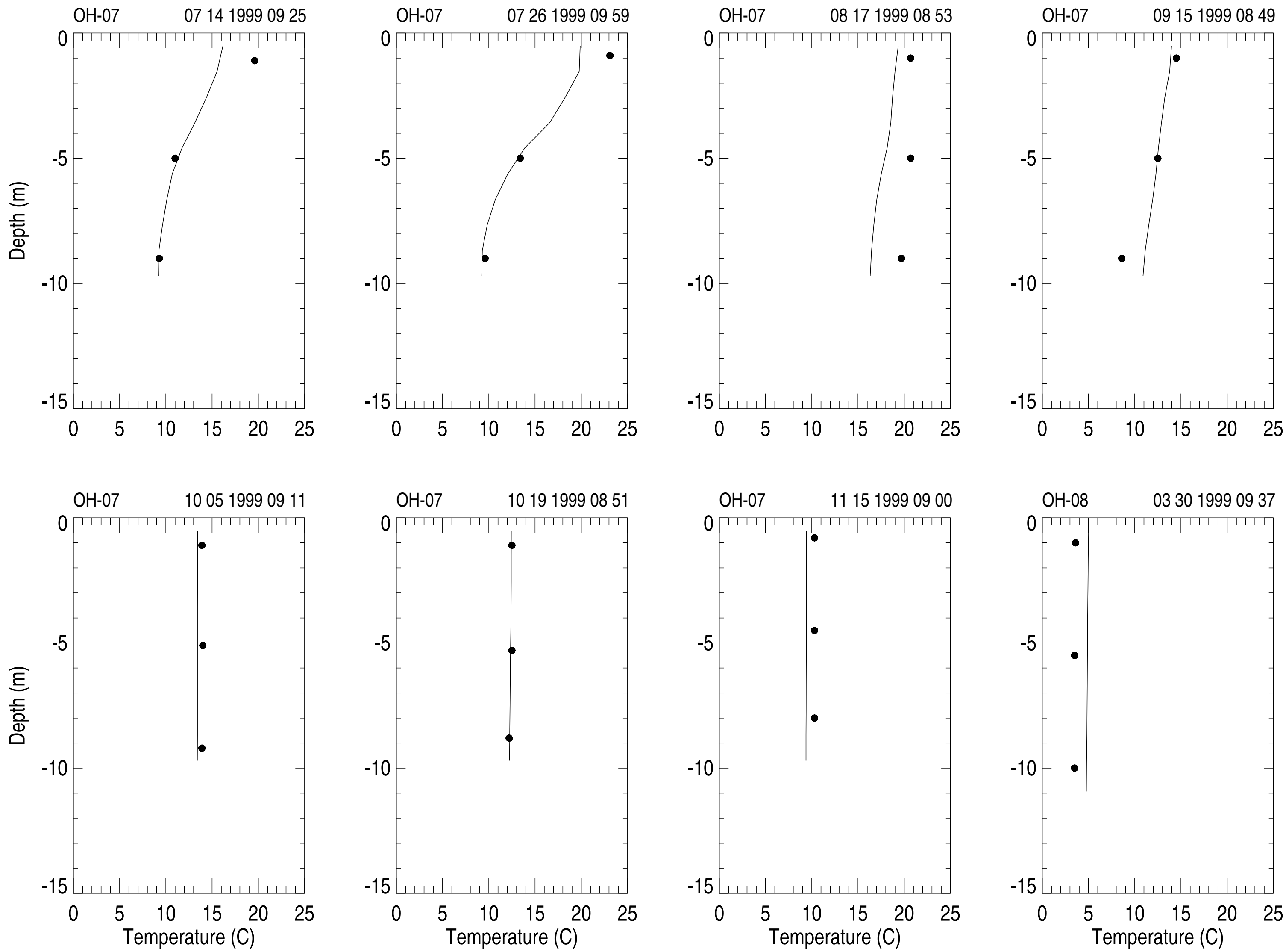
OH-05 07 26 1999 08 50
OH-05 08 17 1999 08 31
OH-05 09 15 1999 08 28
OH-05 10 05 1999 10 54
OH-05 10 19 1999 08 27
OH-05 11 15 1999 09 50
OH-06 03 30 1999 09 11
OH-06 04 14 1999 08 17
Depth (m)
Temperature (C)

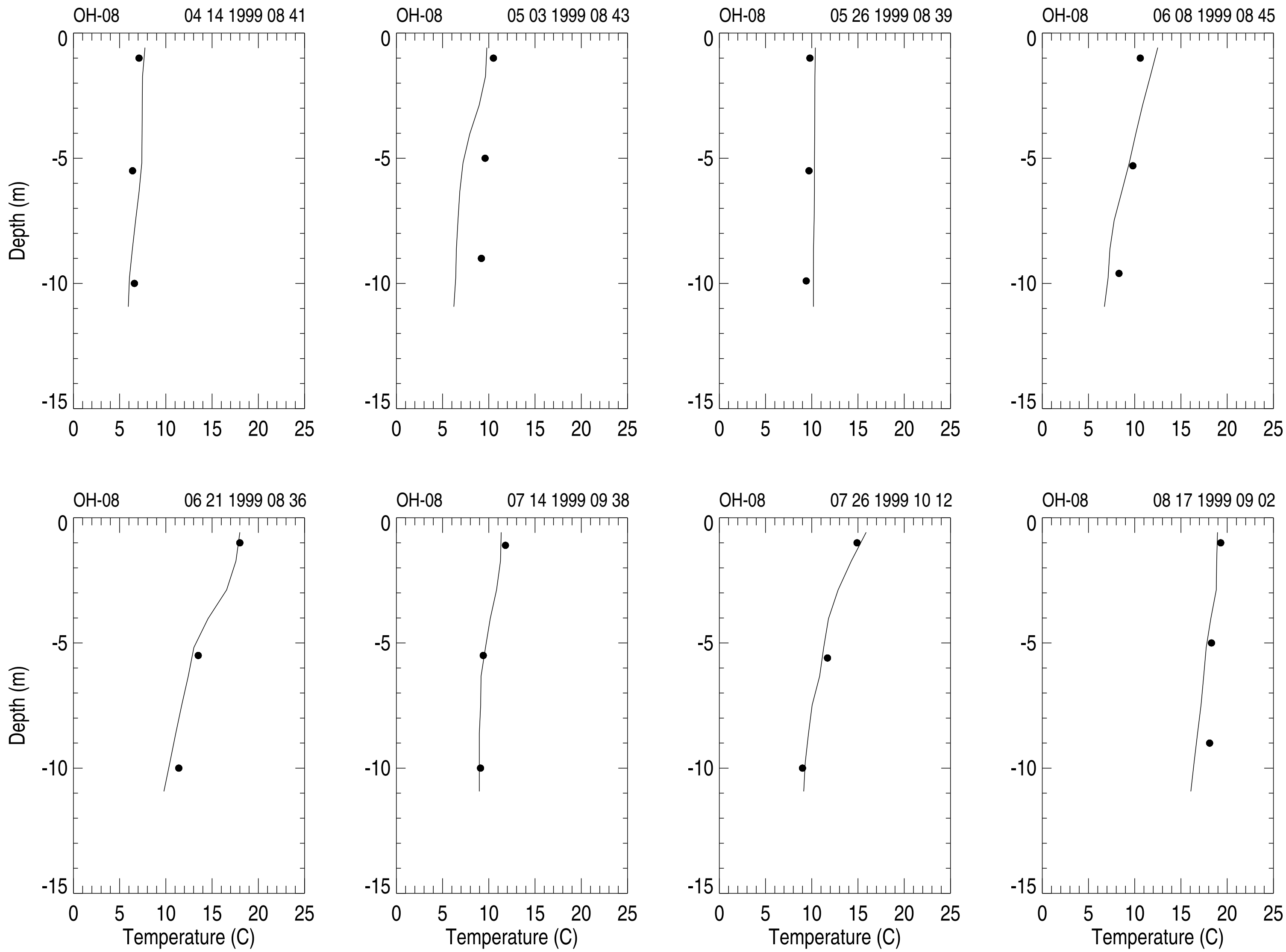


OH-06
05 03 1999 08 20
OH-06
05 26 1999 08 15
OH-06
06 08 1999 08 21
OH-06
06 21 1999 08 15
OH-06
07 14 1999 09 06
OH-06
07 26 1999 09 34
OH-06
08 17 1999 08 42
OH-06
09 15 1999 08 40
Depth (m)
Temperature (C)
0
-5
-10
-15
0 5 10 15 20 25

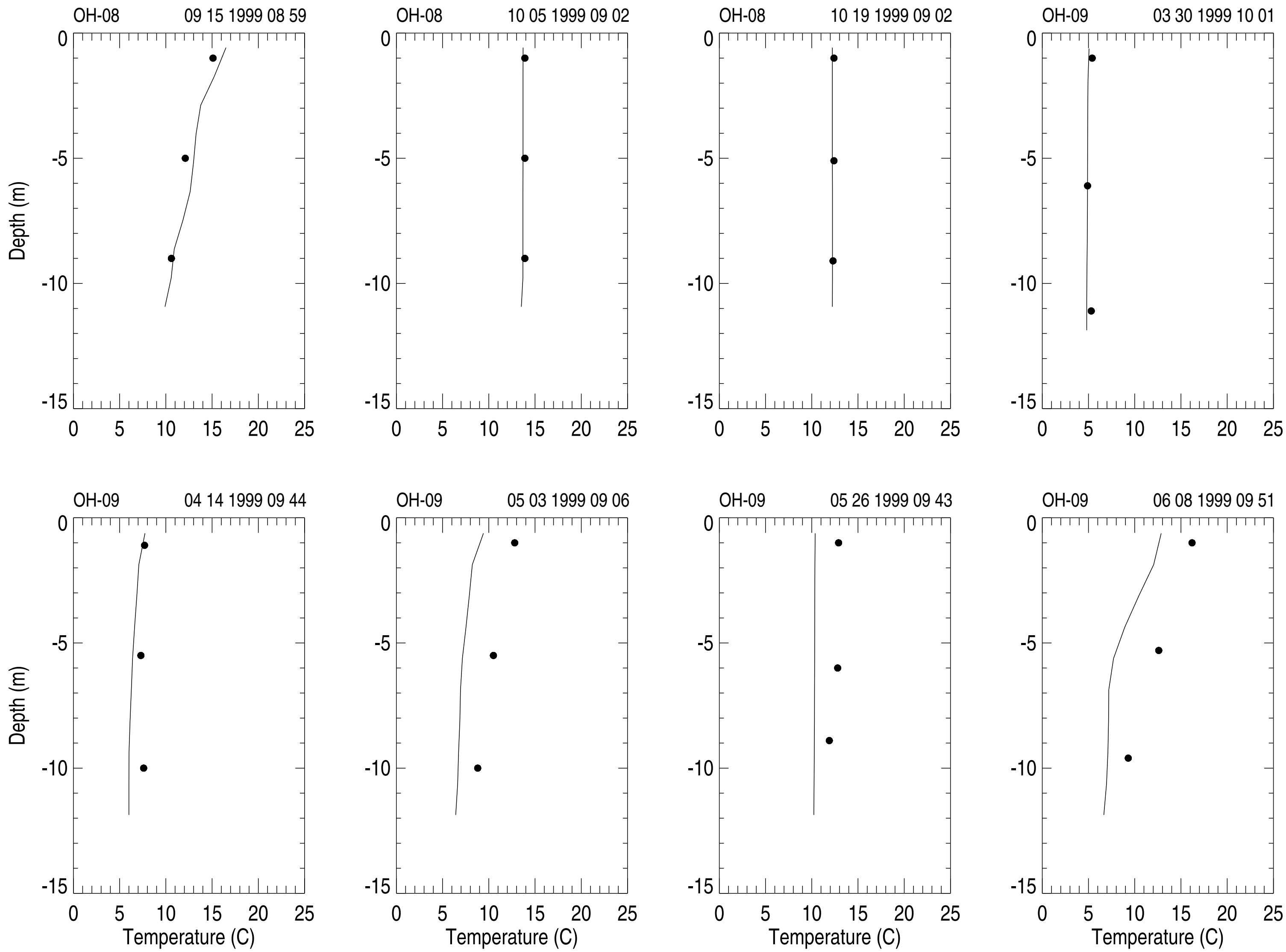


OH-06
10 05 1999 11 10
OH-06
10 19 1999 08 38
OH-07
03 30 1999 09 24
OH-07
04 14 1999 08 28
OH-07
05 03 1999 08 32
OH-07
05 26 1999 08 25
OH-07
06 08 1999 08 33
OH-07
06 21 1999 08 24
Depth (m)
Temperature (C)
0
-5
-10
-15
0
5
10
15
20
25

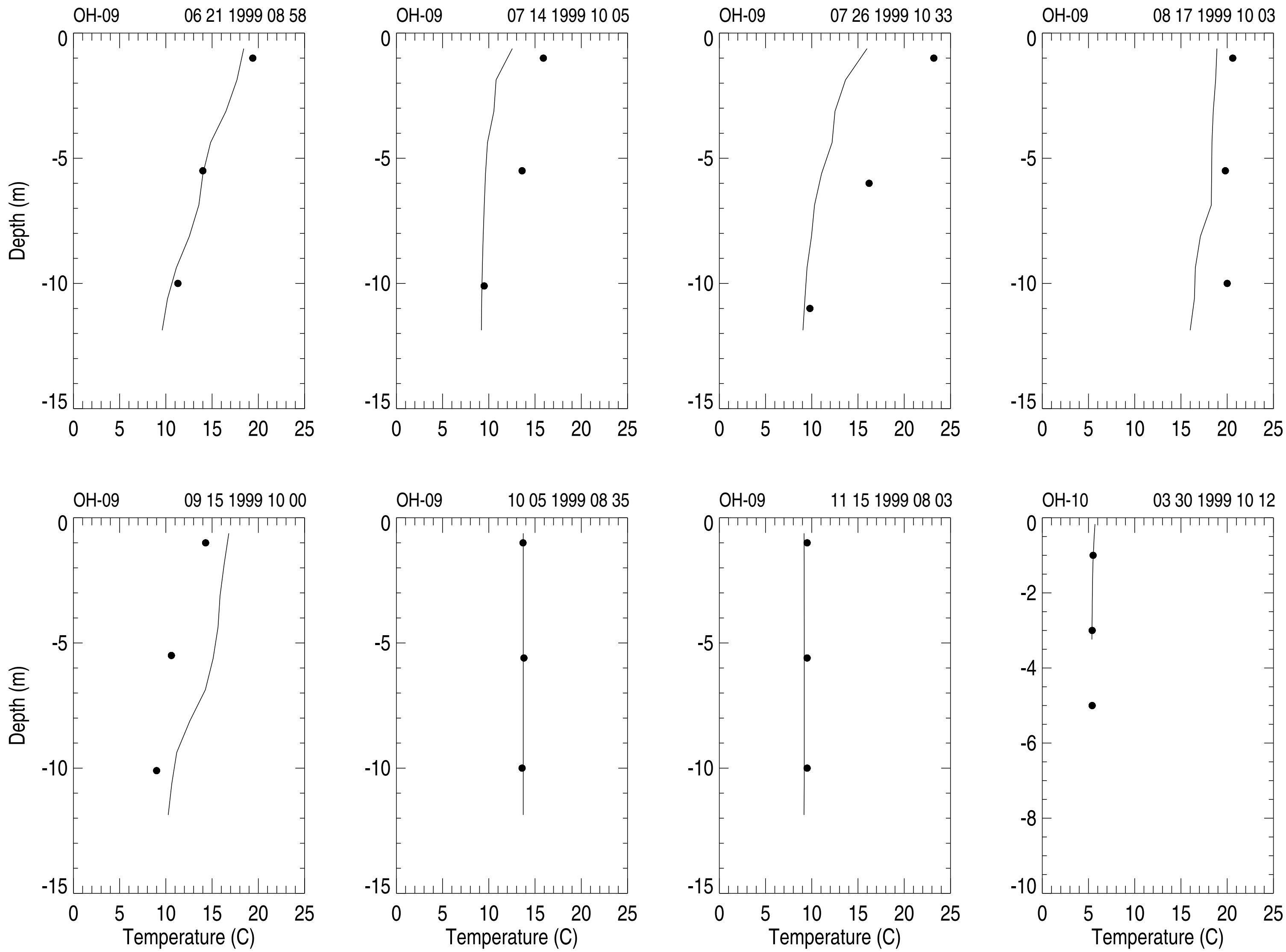

OH-07
07 14 1999 09 25
OH-07
07 26 1999 09 59
OH-07
08 17 1999 08 53
OH-07
09 15 1999 08 49
OH-07
10 05 1999 09 11
OH-07
10 19 1999 08 51
OH-07
11 15 1999 09 00
OH-08
03 30 1999 09 37
Depth (m)
Temperature (C)
0
-5
-10
-15
0
5
10
15
20
25



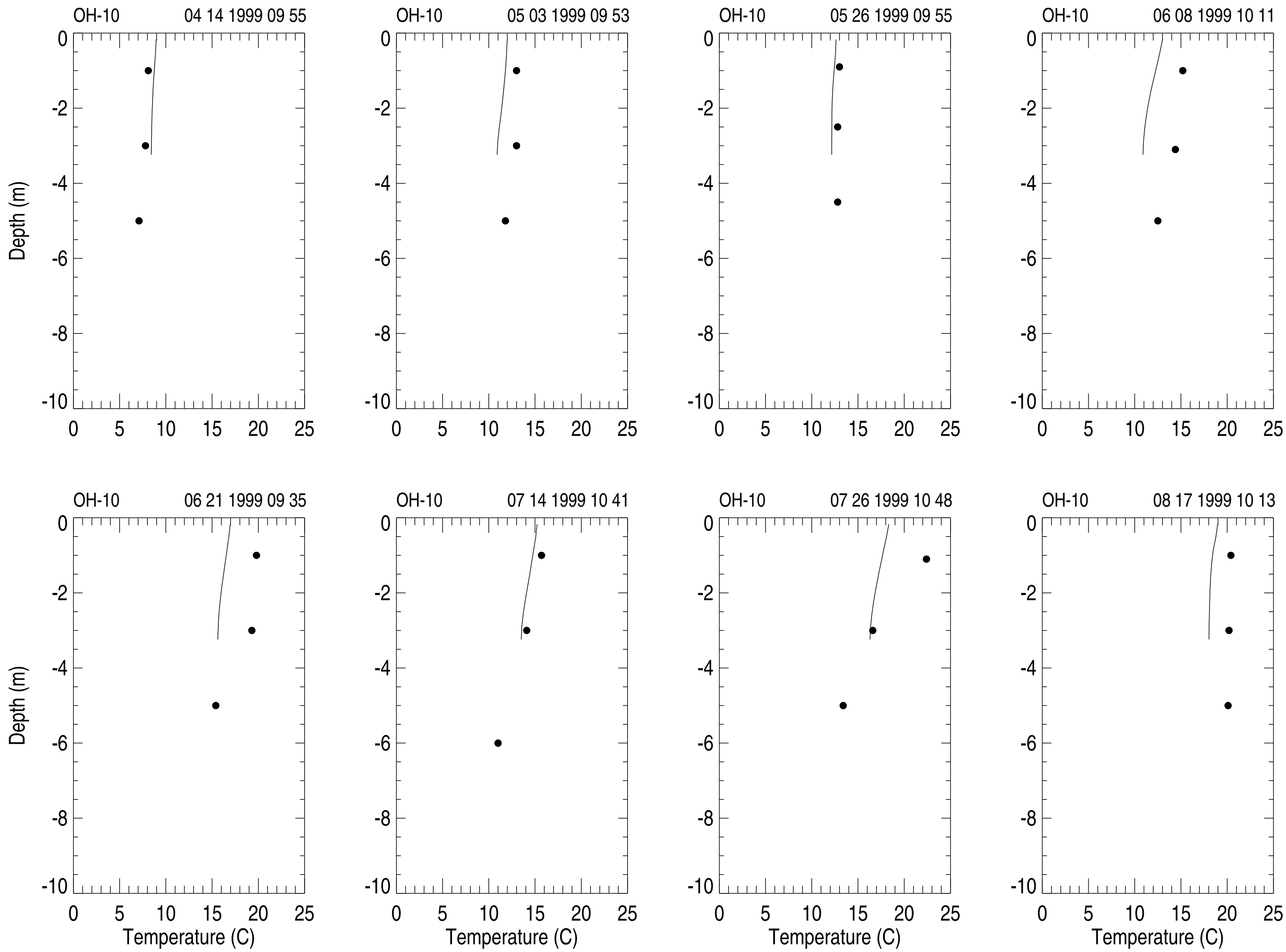
OH-08
04 14 1999 08 41
OH-08
05 03 1999 08 43
OH-08
05 26 1999 08 39
OH-08
06 08 1999 08 45
OH-08
06 21 1999 08 36
OH-08
07 14 1999 09 38
OH-08
07 26 1999 10 12
OH-08
08 17 1999 09 02
Depth (m)
Temperature (C)
0
-5
-10
-15
0
5
10
15
20
25



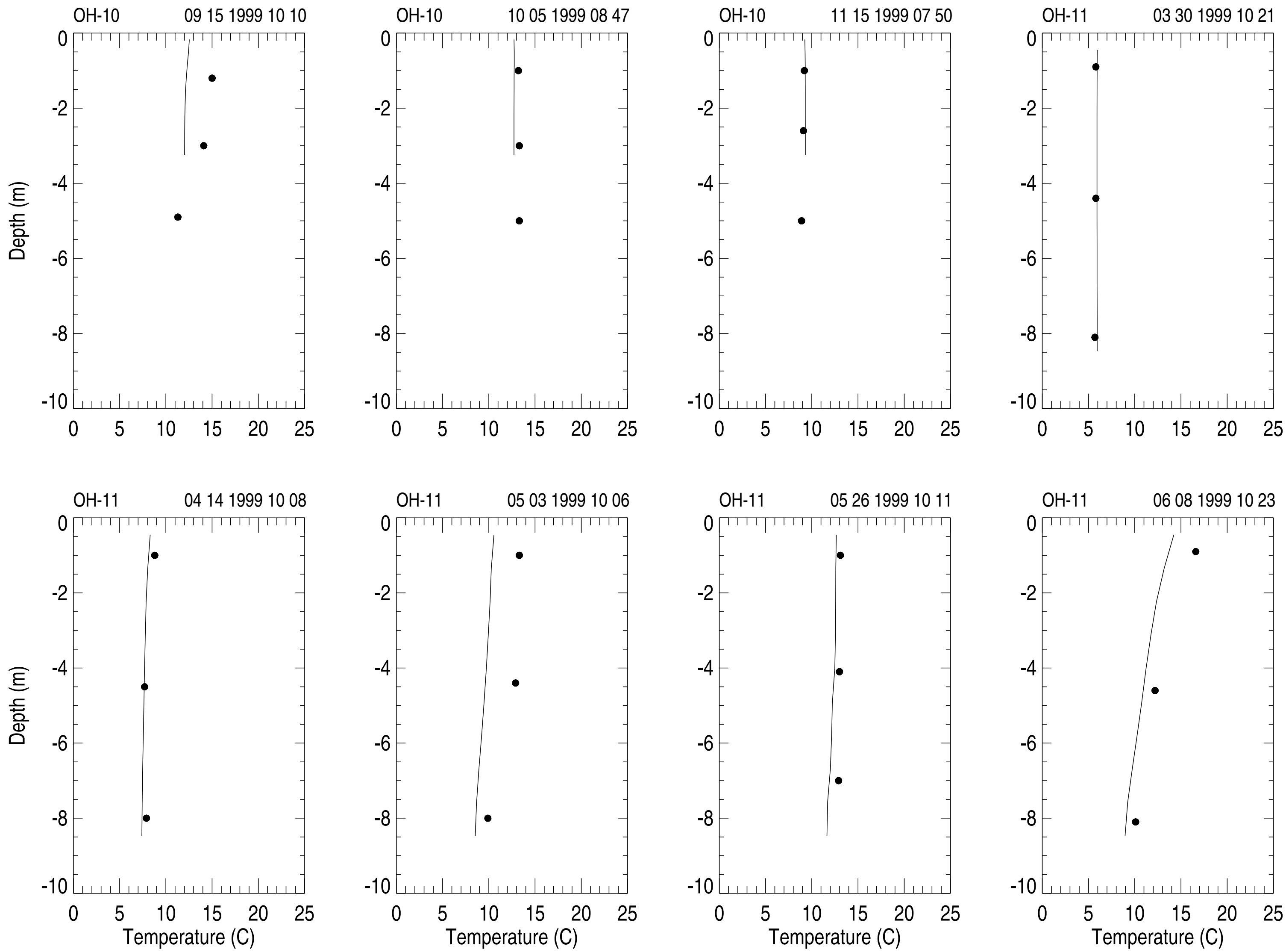
OH-08 09 15 1999 08 59
OH-08 10 05 1999 09 02
OH-08 10 19 1999 09 02
OH-09 03 30 1999 10 01
OH-09 04 14 1999 09 44
OH-09 05 03 1999 09 06
OH-09 05 26 1999 09 43
OH-09 06 08 1999 09 51
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25
Temperature (C)



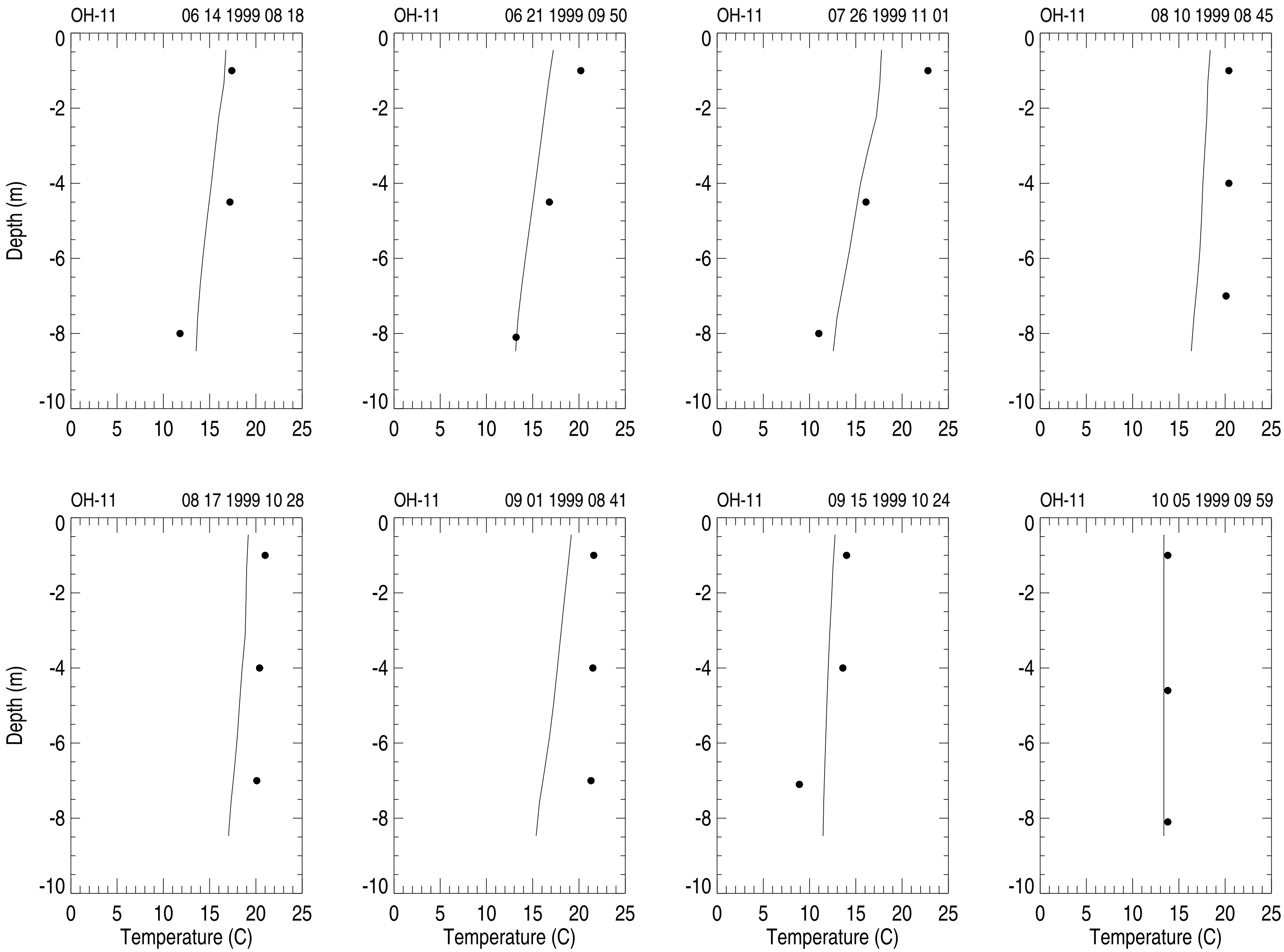
OH-09
06 21 1999 08 58
OH-09
07 14 1999 10 05
OH-09
07 26 1999 10 33
OH-09
08 17 1999 10 03
OH-09
09 15 1999 10 00
OH-09
10 05 1999 08 35
OH-09
11 15 1999 08 03
OH-10
03 30 1999 10 12
Depth (m)
Temperature (C)



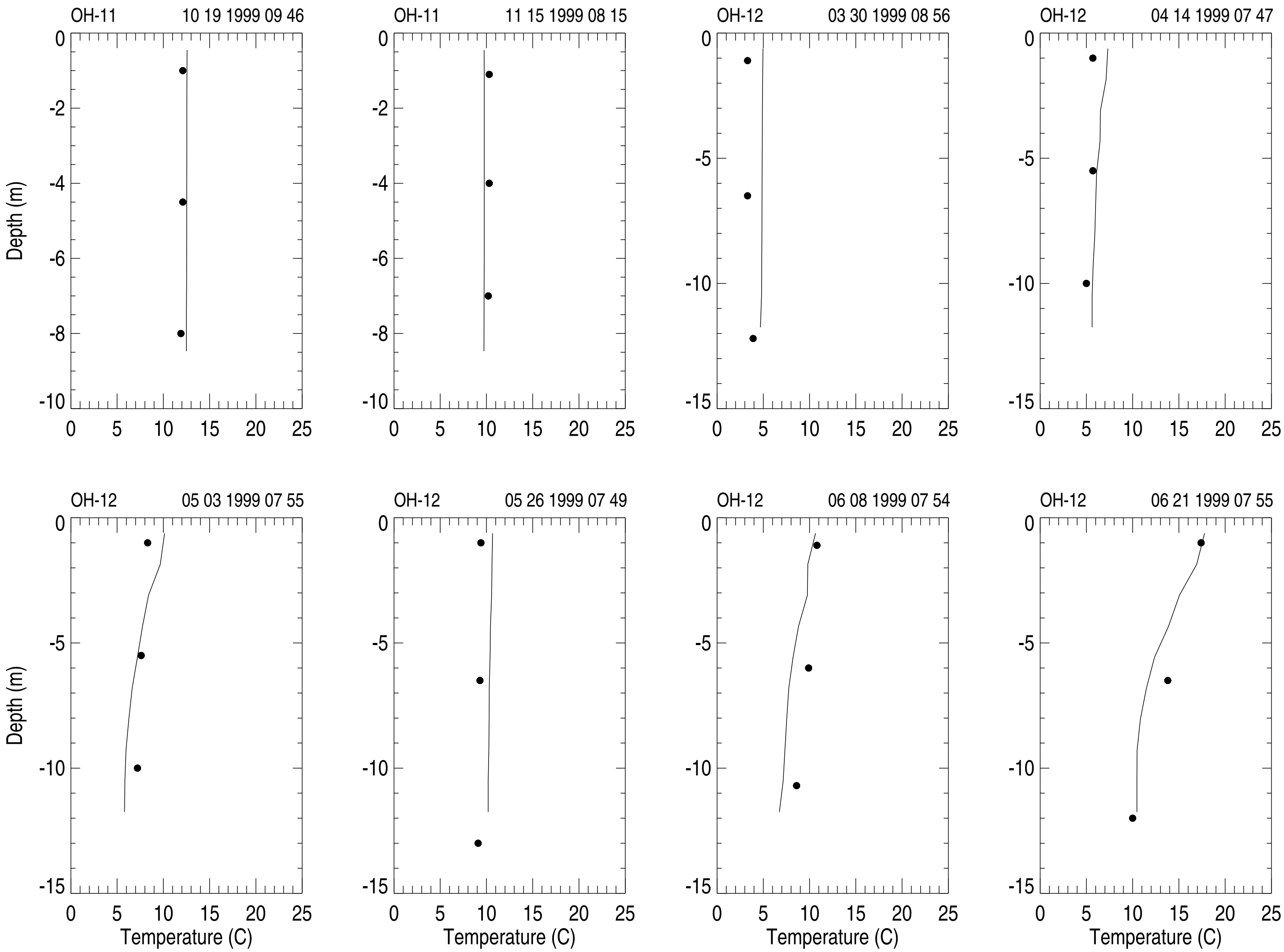
OH-10 04 14 1999 09 55
OH-10 05 03 1999 09 53
OH-10 05 26 1999 09 55
OH-10 06 08 1999 10 11
OH-10 06 21 1999 09 35
OH-10 07 14 1999 10 41
OH-10 07 26 1999 10 48
OH-10 08 17 1999 10 13
Depth (m)
Temperature (C)

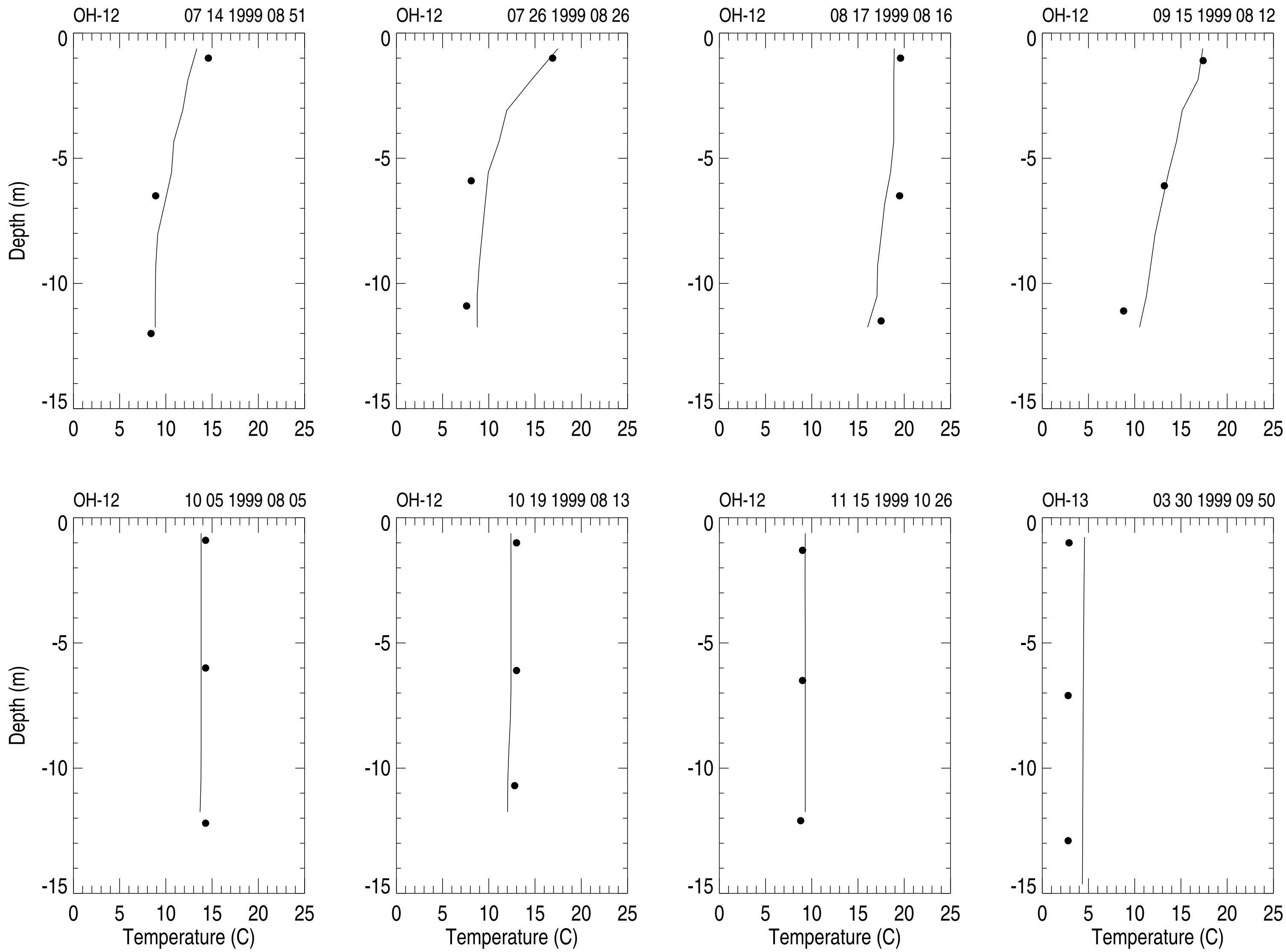


OH-10 09 15 1999 10 10
OH-10 10 05 1999 08 47
OH-10 11 15 1999 07 50
OH-11 03 30 1999 10 21
OH-11 04 14 1999 10 08
OH-11 05 03 1999 10 06
OH-11 05 26 1999 10 11
OH-11 06 08 1999 10 23
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

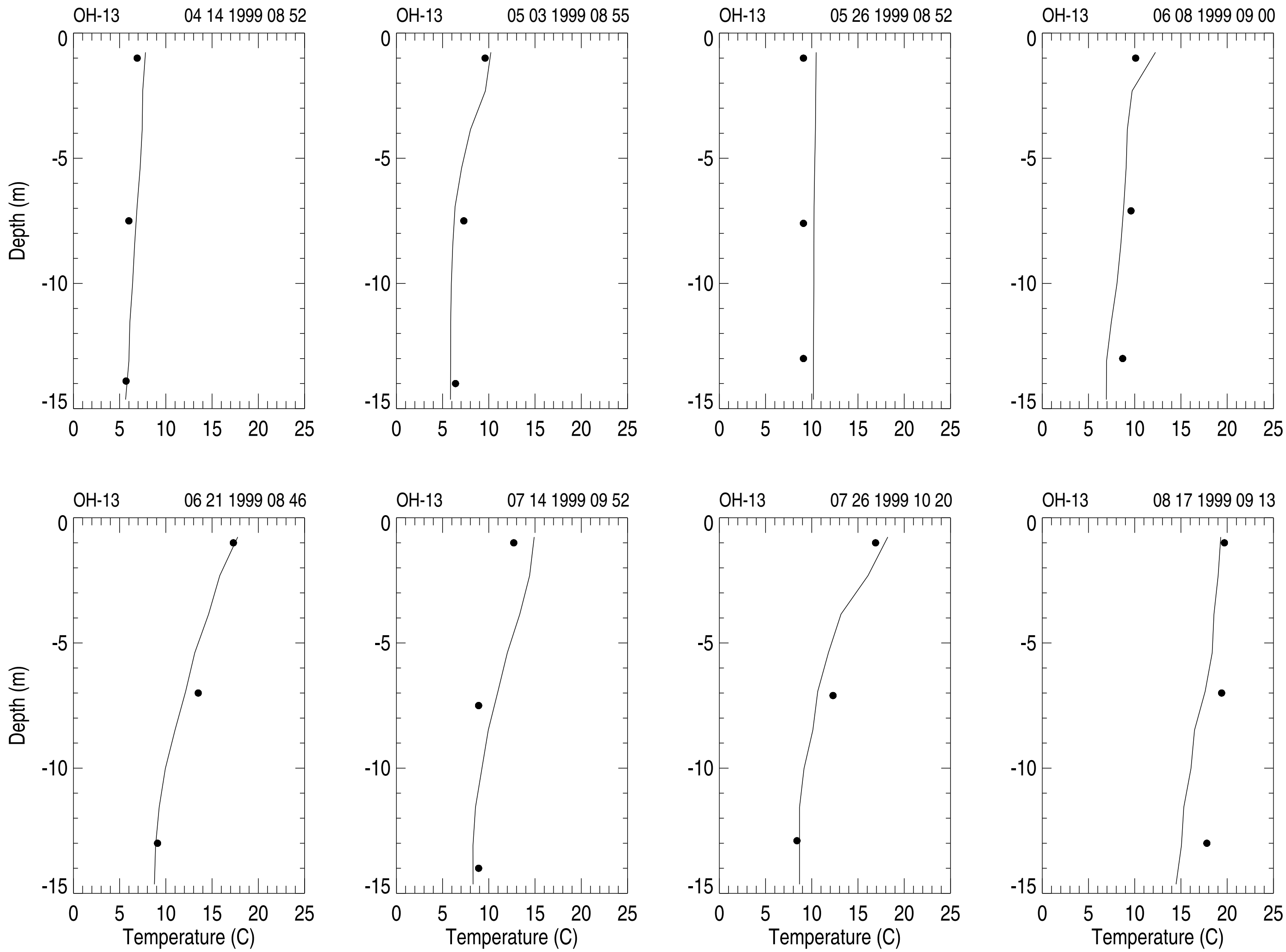


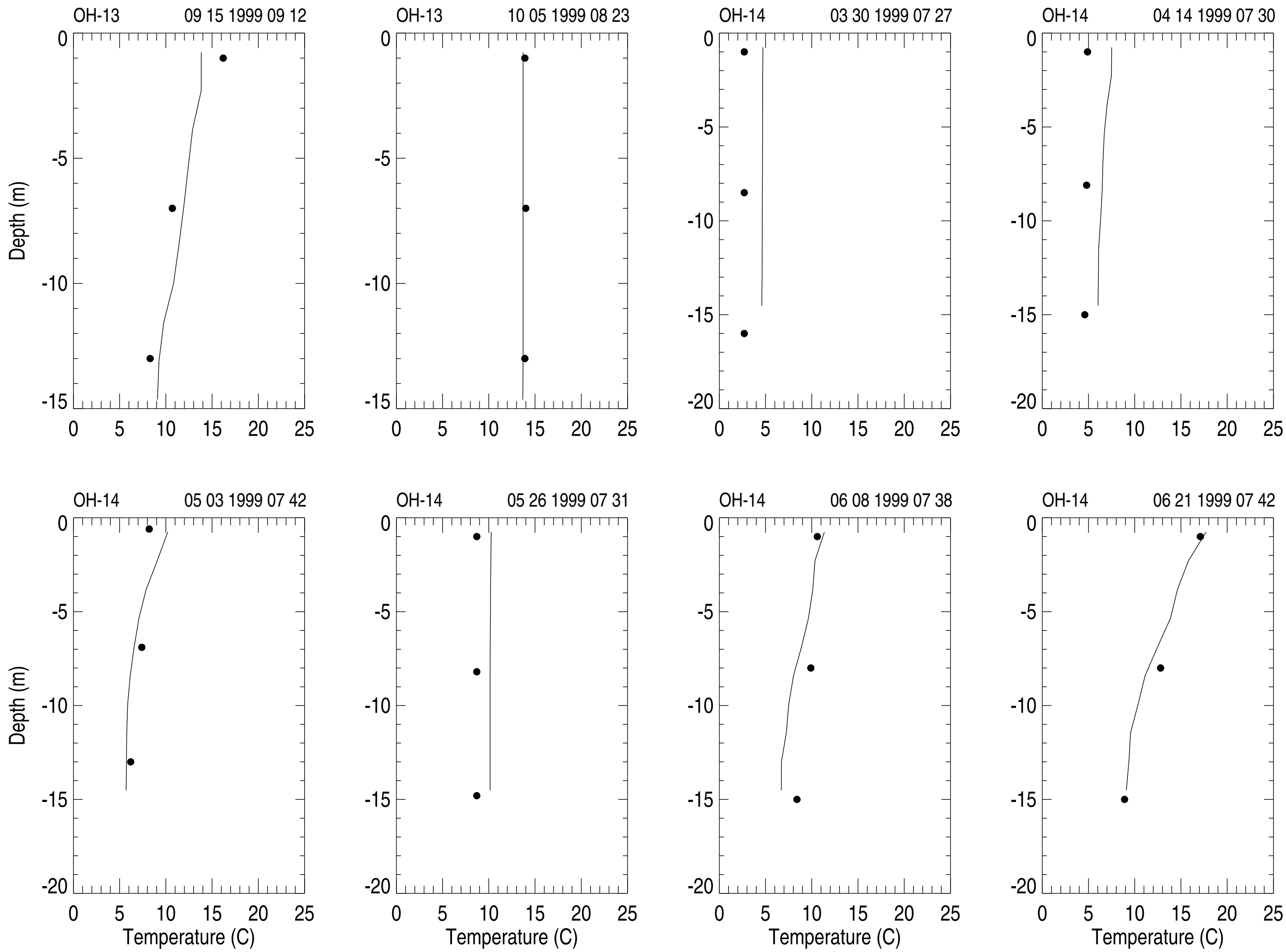
OH-11 06 14 1999 08 18
OH-11 06 21 1999 09 50
OH-11 07 26 1999 11 01
OH-11 08 10 1999 08 45
OH-11 08 17 1999 10 28
OH-11 09 01 1999 08 41
OH-11 09 15 1999 10 24
OH-11 10 05 1999 09 59
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

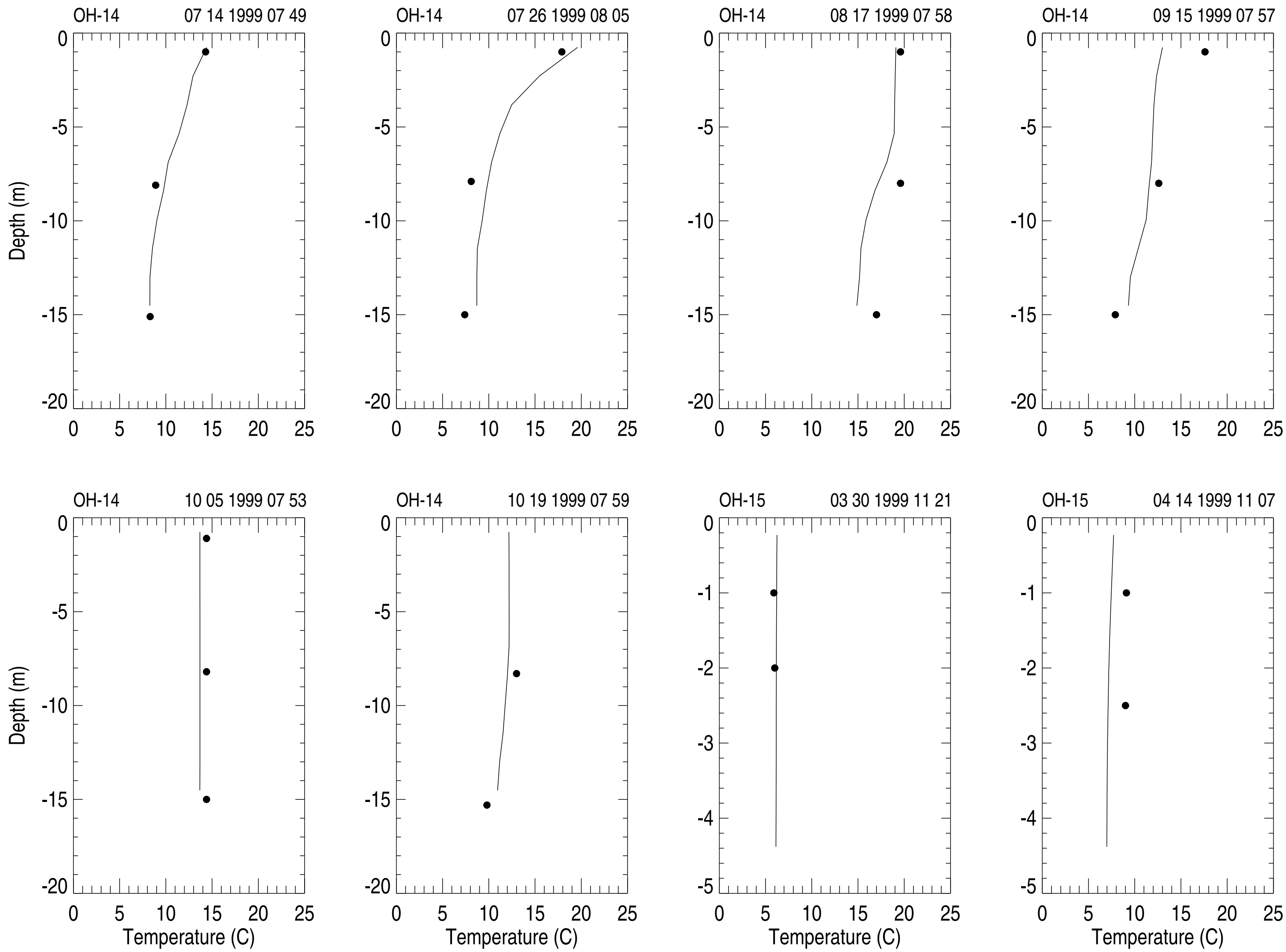

OH-11 10 19 1999 09 46
OH-11 11 15 1999 08 15
OH-12 03 30 1999 08 56
OH-12 04 14 1999 07 47
OH-12 05 03 1999 07 55
OH-12 05 26 1999 07 49
OH-12 06 08 1999 07 54
OH-12 06 21 1999 07 55
Depth (m)
Temperature (C)

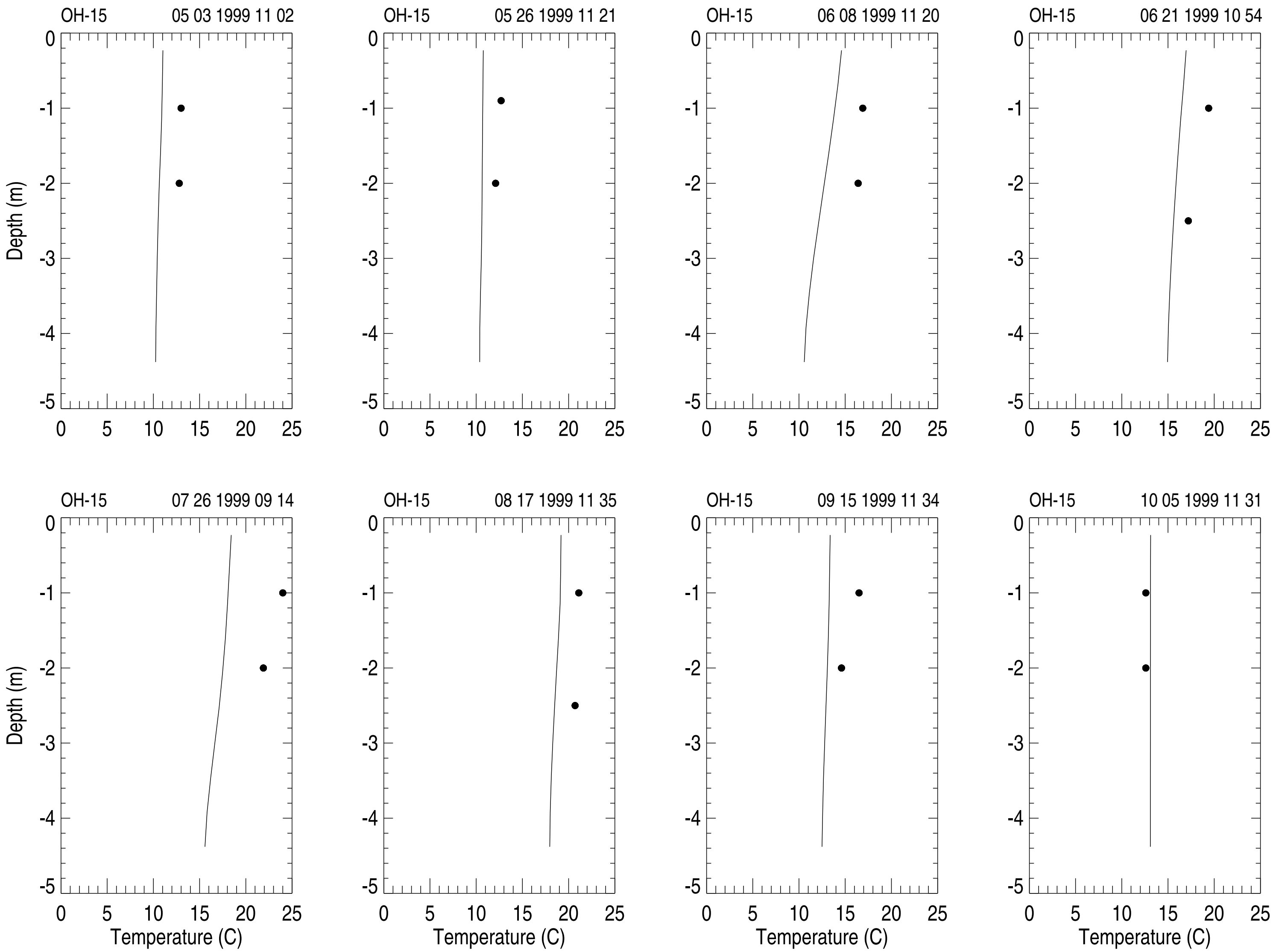


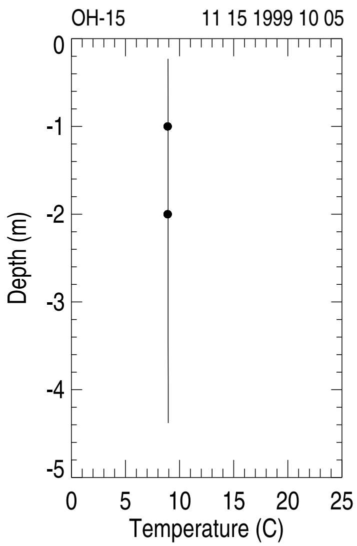
OH-12
07 14 1999 08 51
OH-12
07 26 1999 08 26
OH-12
08 17 1999 08 16
OH-12
09 15 1999 08 12
OH-12
10 05 1999 08 05
OH-12
10 19 1999 08 13
OH-12
11 15 1999 10 26
OH-13
03 30 1999 09 50
Depth (m)
Temperature (C)
0
-5
-10
-15
0
5
10
15
20
25


OH-13
04 14 1999 08 52
OH-13
05 03 1999 08 55
OH-13
05 26 1999 08 52
OH-13
06 08 1999 09 00
OH-13
06 21 1999 08 46
OH-13
07 14 1999 09 52
OH-13
07 26 1999 10 20
OH-13
08 17 1999 09 13
Depth (m)
Temperature (C)
0
-5
-10
-15
0
5
10
15
20
25

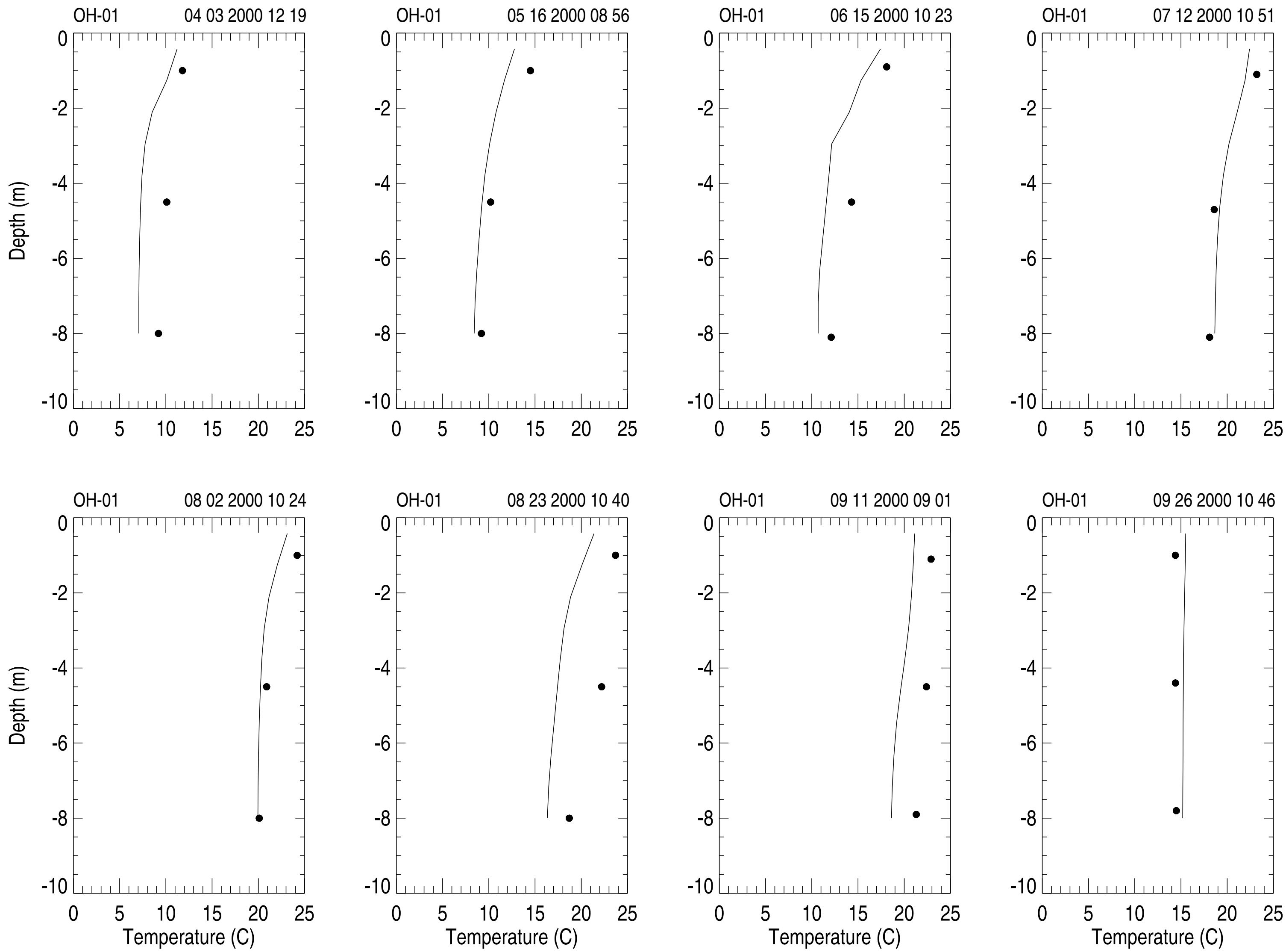

OH-13 09 15 1999 09 12
OH-13 10 05 1999 08 23
OH-14 03 30 1999 07 27
OH-14 04 14 1999 07 30
OH-14 05 03 1999 07 42
OH-14 05 26 1999 07 31
OH-14 06 08 1999 07 38
OH-14 06 21 1999 07 42
Depth (m)
Temperature (C)
0
-5
-10
-15
-20
0 5 10 15 20 25

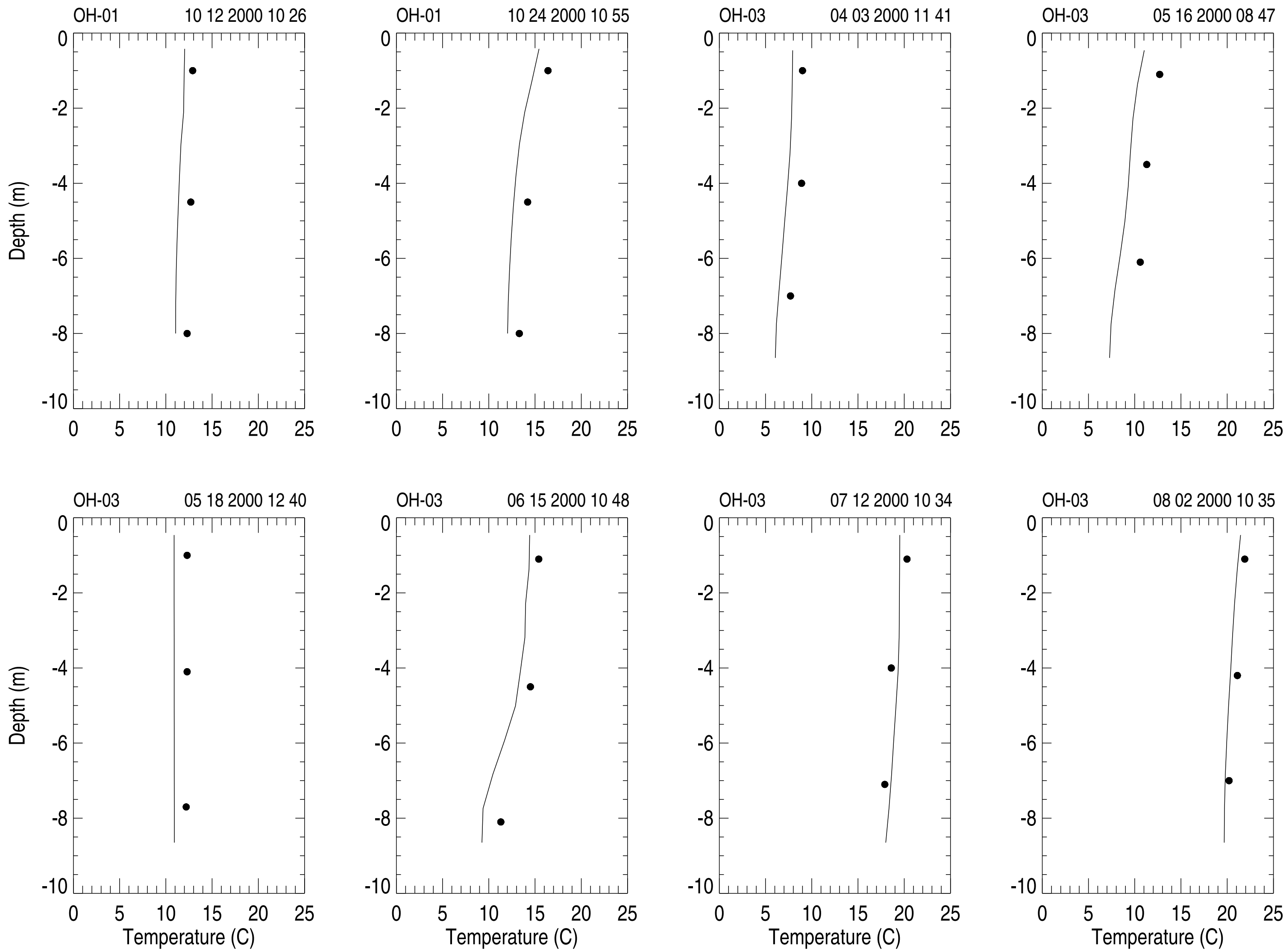

OH-14 07 14 1999 07 49
OH-14 07 26 1999 08 05
OH-14 08 17 1999 07 58
OH-14 09 15 1999 07 57
OH-14 10 05 1999 07 53
OH-14 10 19 1999 07 59
OH-15 03 30 1999 11 21
OH-15 04 14 1999 11 07
Depth (m)
Temperature (C)
0
-5
-10
-15
-20
-1
-2
-3
-4
0 5 10 15 20 25


OH-15
05 03 1999 11 02
OH-15
05 26 1999 11 21
OH-15
06 08 1999 11 20
OH-15
06 21 1999 10 54
OH-15
07 26 1999 09 14
OH-15
08 17 1999 11 35
OH-15
09 15 1999 11 34
OH-15
10 05 1999 11 31
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0
5
10
15
20
25

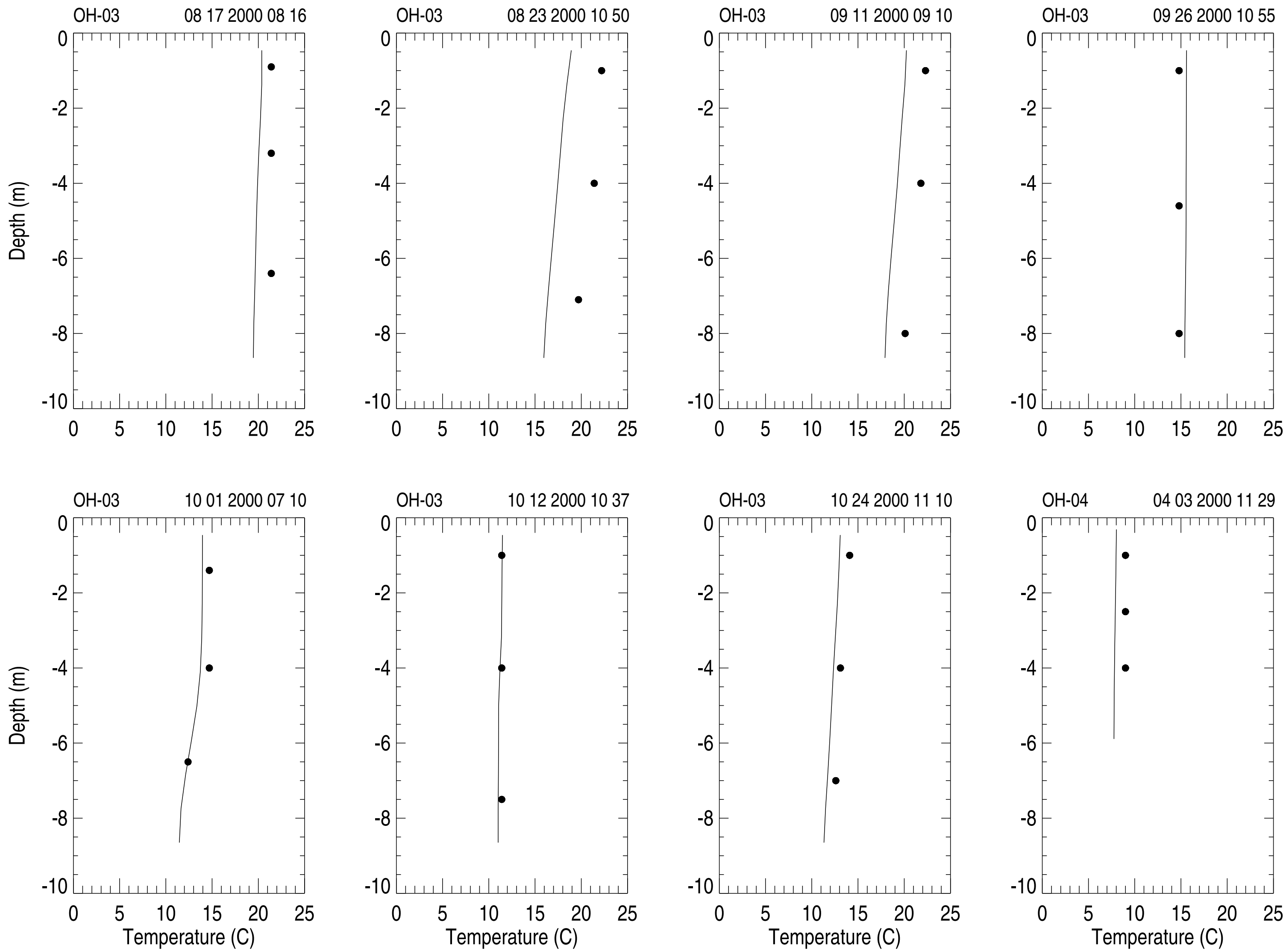


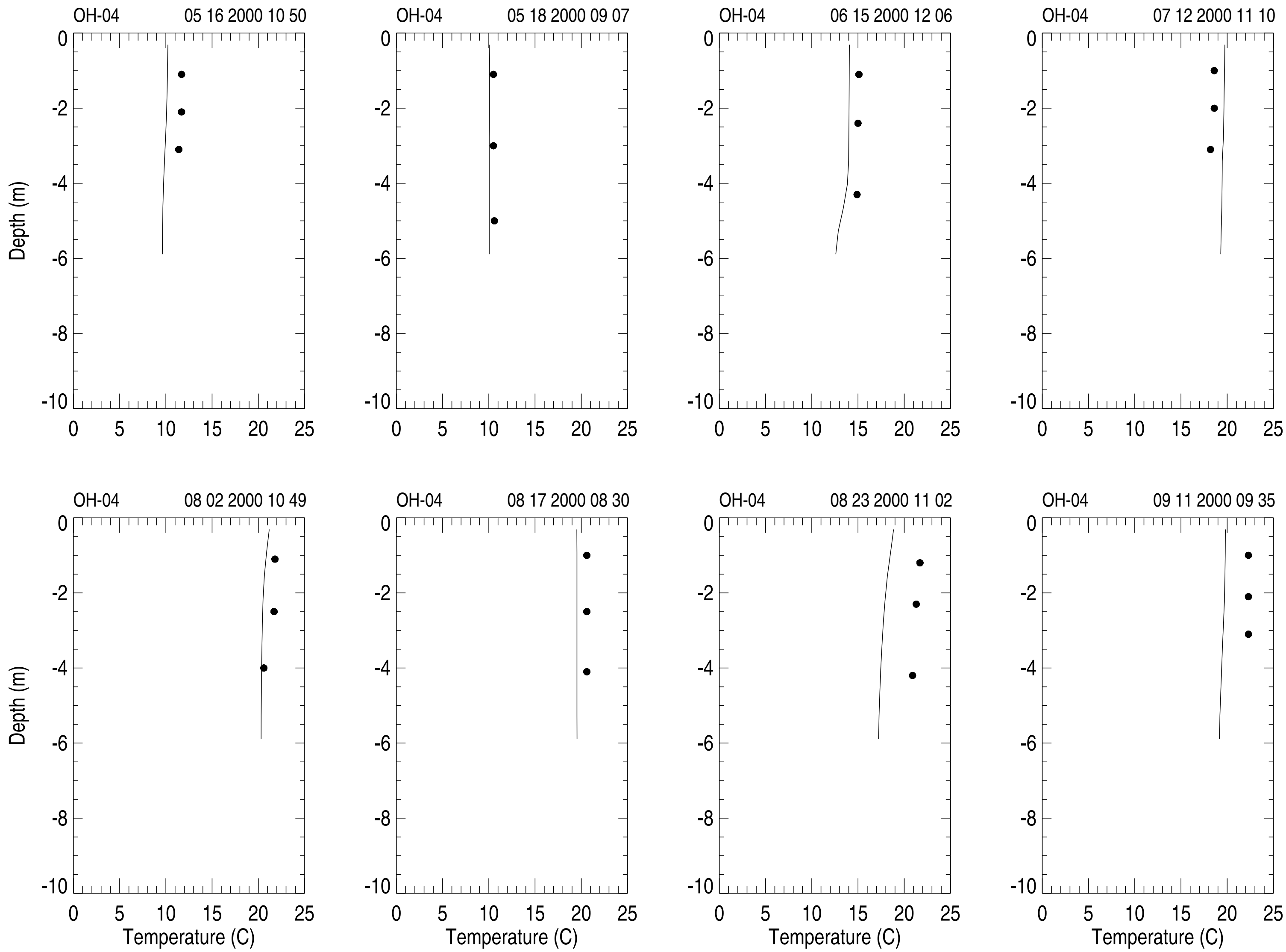
OH-15
11 15 1999 10 05
0
-1
-2
-3
-4
-5
Depth (m)
0
5
10
15
20
25
Temperature (C)

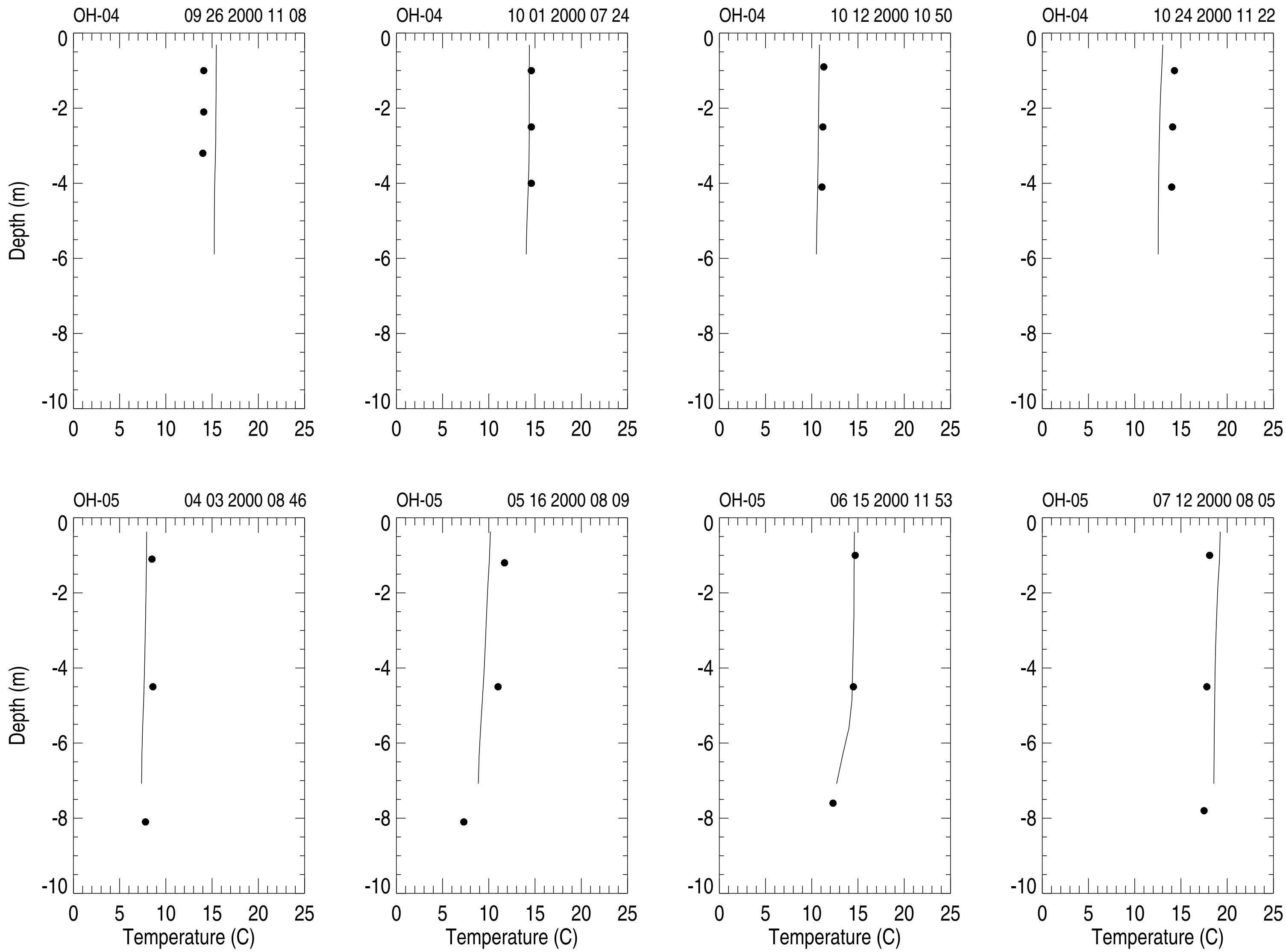

OH-01
04 03 2000 12 19
OH-01
05 16 2000 08 56
OH-01
06 15 2000 10 23
OH-01
07 12 2000 10 51
OH-01
08 02 2000 10 24
OH-01
08 23 2000 10 40
OH-01
09 11 2000 09 01
OH-01
09 26 2000 10 46
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25

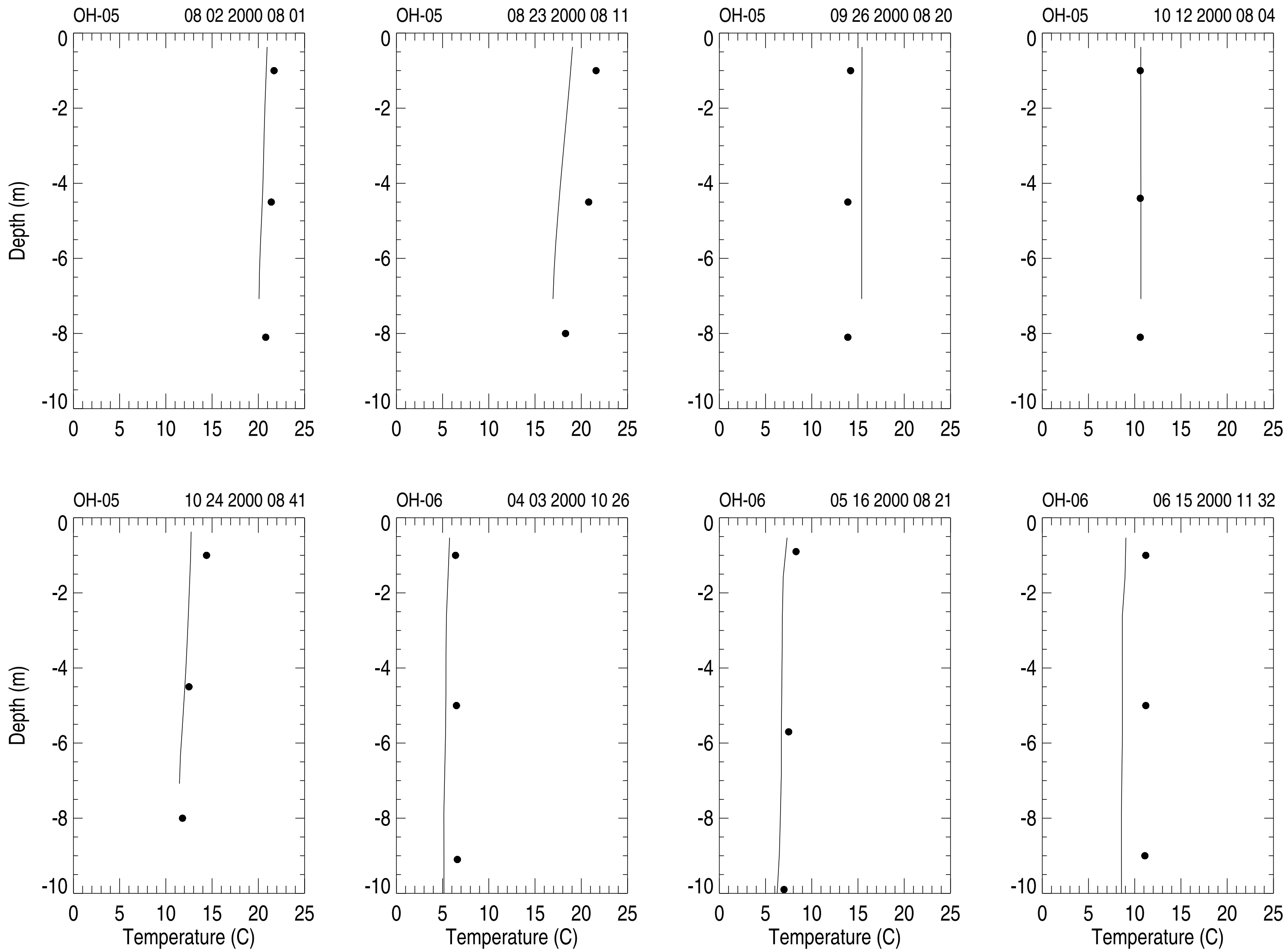


OH-01 10 12 2000 10 26
OH-01 10 24 2000 10 55
OH-03 04 03 2000 11 41
OH-03 05 16 2000 08 47
OH-03 05 18 2000 12 40
OH-03 06 15 2000 10 48
OH-03 07 12 2000 10 34
OH-03 08 02 2000 10 35
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

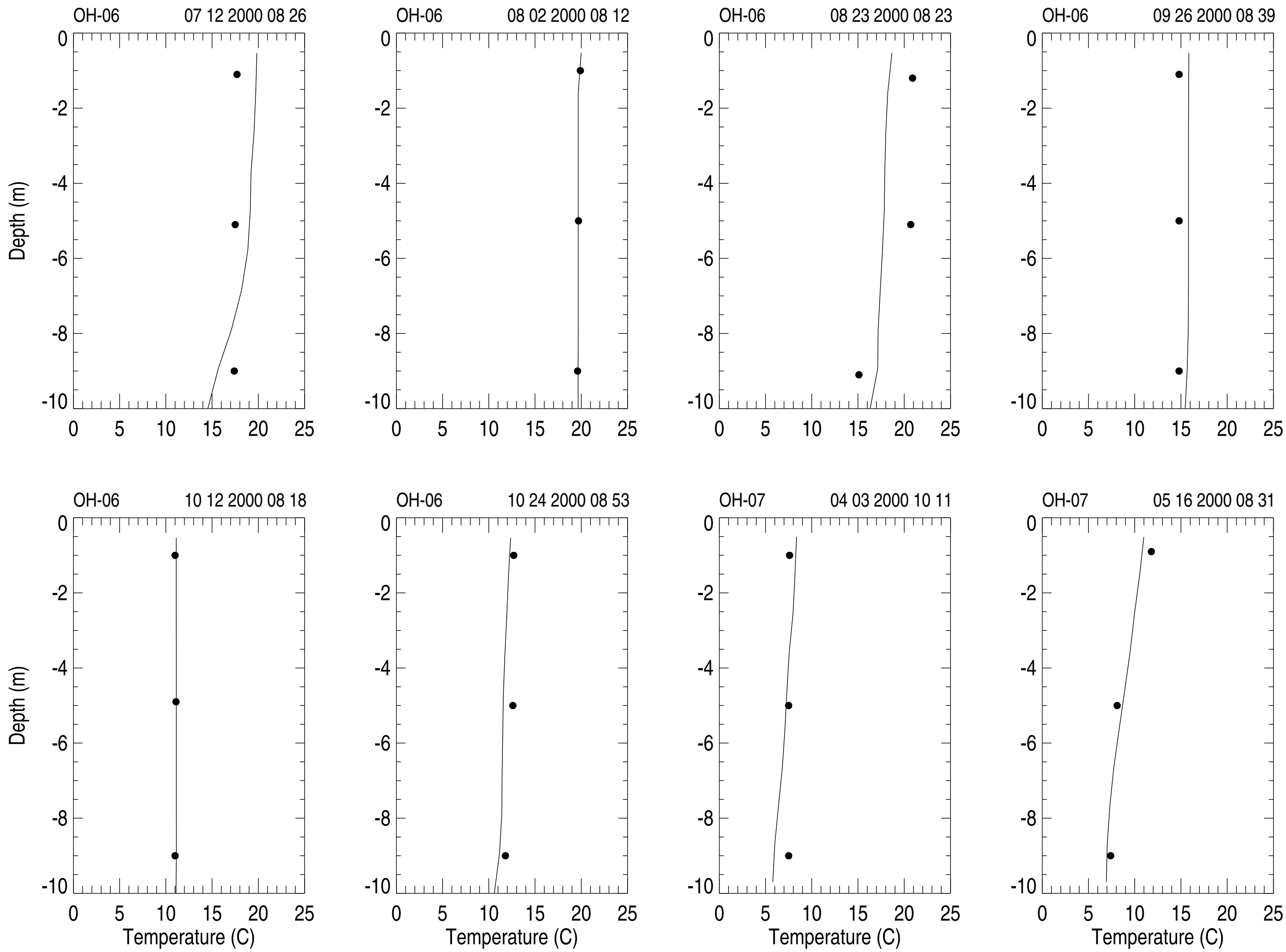

OH-03
08 17 2000 08 16
OH-03
08 23 2000 10 50
OH-03
09 11 2000 09 10
OH-03
09 26 2000 10 55
OH-03
10 01 2000 07 10
OH-03
10 12 2000 10 37
OH-03
10 24 2000 11 10
OH-04
04 03 2000 11 29
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

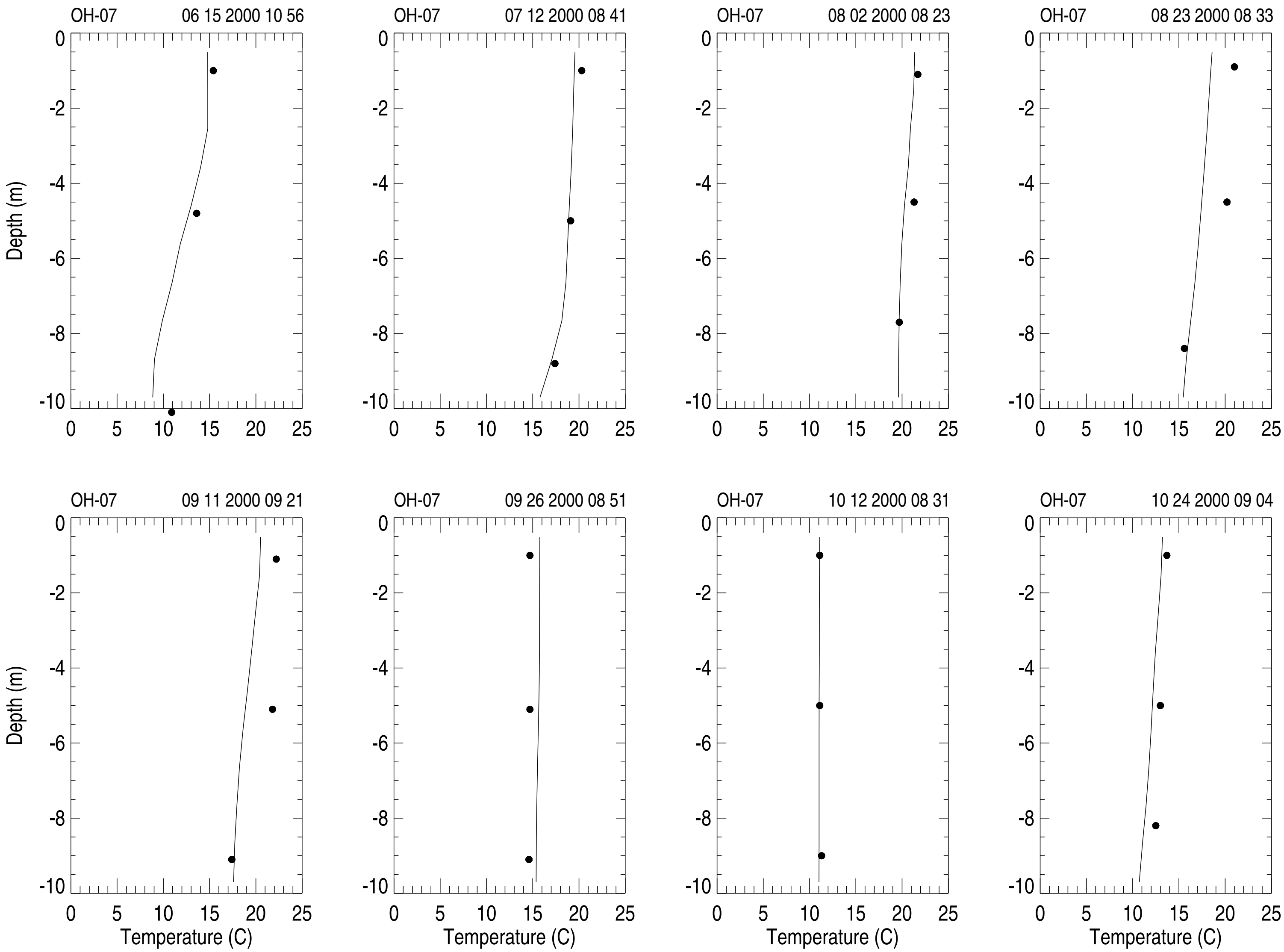

OH-04
05 16 2000 10 50
OH-04
05 18 2000 09 07
OH-04
06 15 2000 12 06
OH-04
07 12 2000 11 10
OH-04
08 02 2000 10 49
OH-04
08 17 2000 08 30
OH-04
08 23 2000 11 02
OH-04
09 11 2000 09 35
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25


OH-04 09 26 2000 11 08
OH-04 10 01 2000 07 24
OH-04 10 12 2000 10 50
OH-04 10 24 2000 11 22
OH-05 04 03 2000 08 46
OH-05 05 16 2000 08 09
OH-05 06 15 2000 11 53
OH-05 07 12 2000 08 05
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

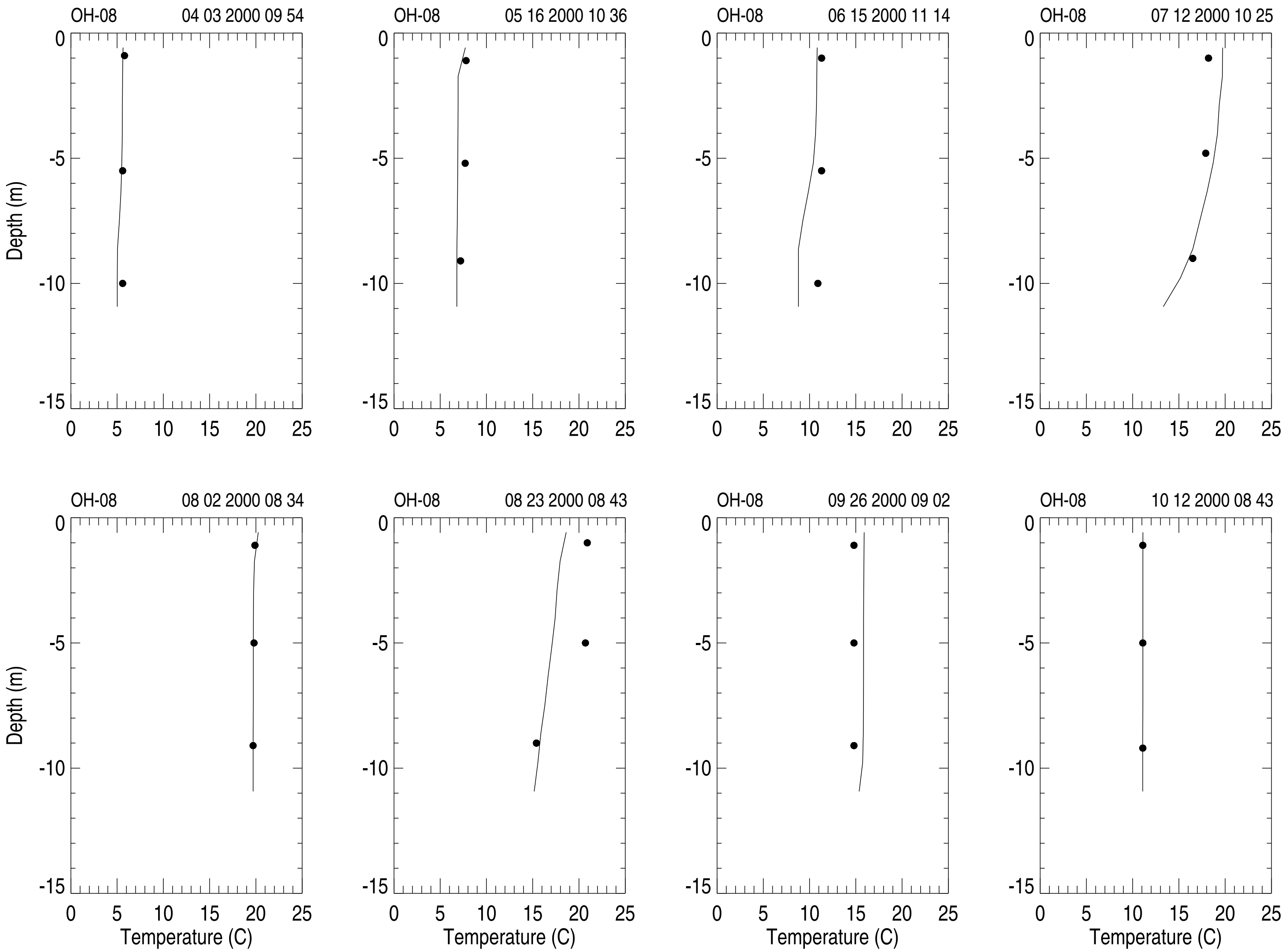


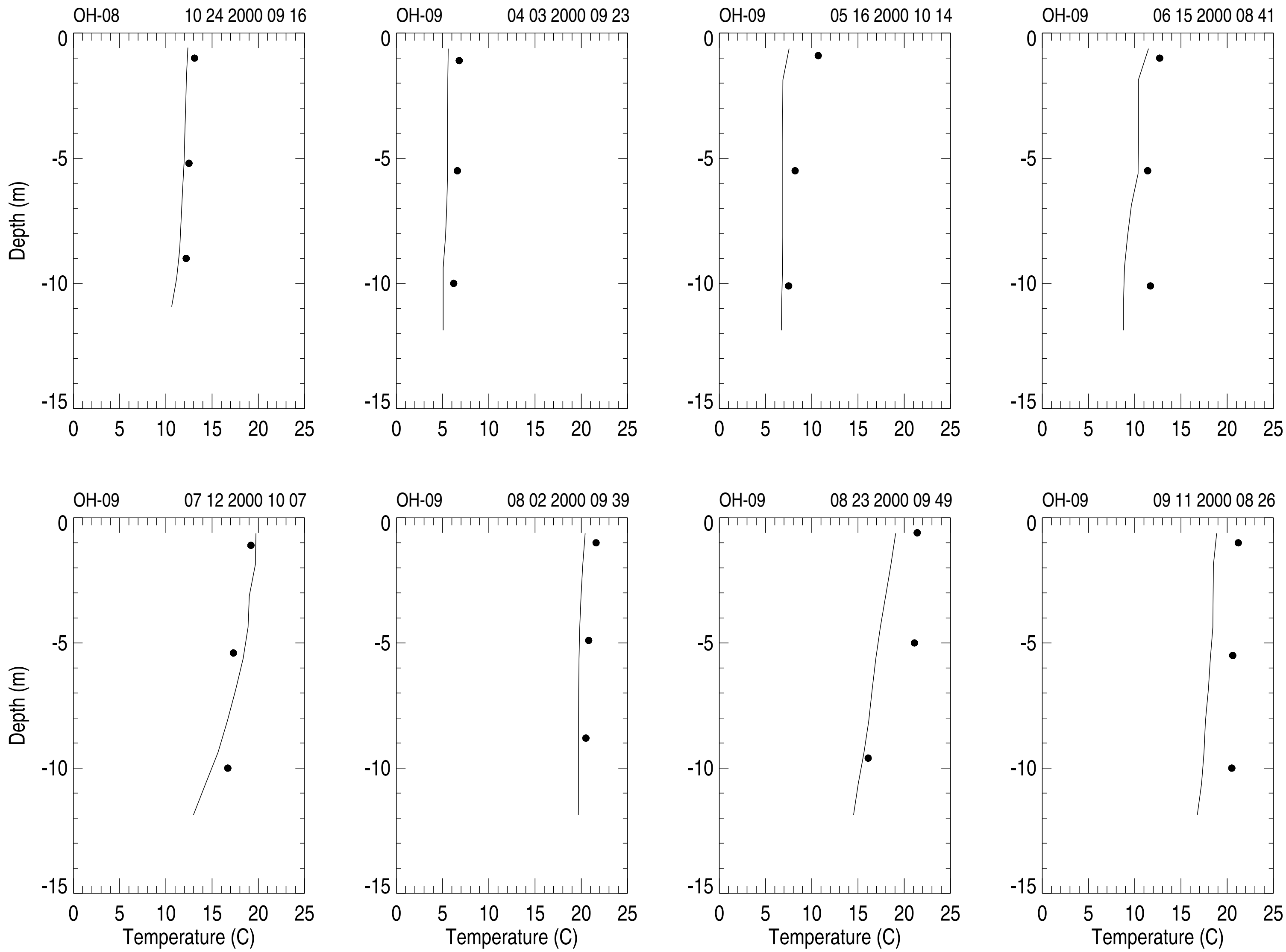
OH-05 08 02 2000 08 01
OH-05 08 23 2000 08 11
OH-05 09 26 2000 08 20
OH-05 10 12 2000 08 04
OH-05 10 24 2000 08 41
OH-06 04 03 2000 10 26
OH-06 05 16 2000 08 21
OH-06 06 15 2000 11 32
Depth (m)
Temperature (C)

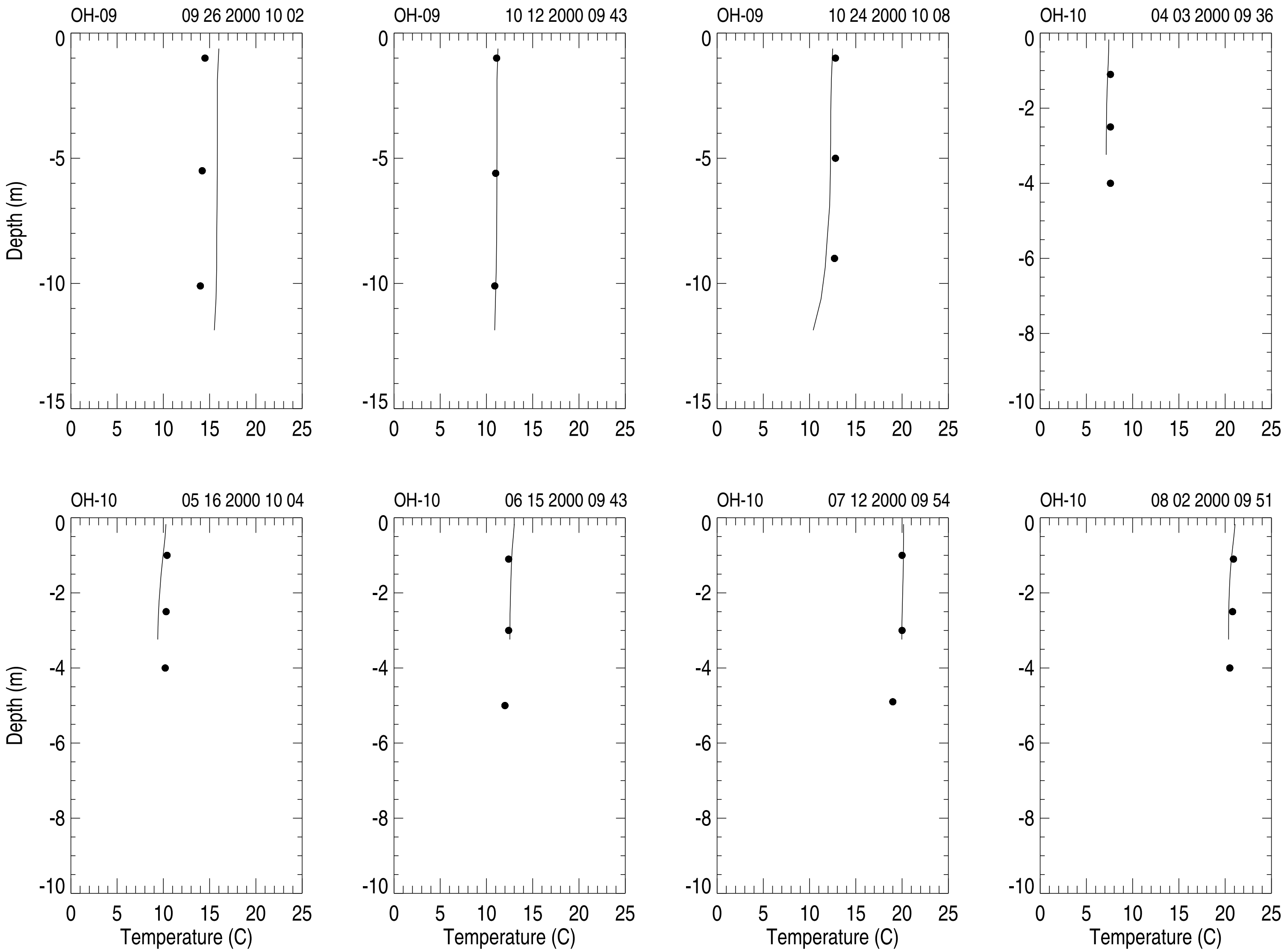

OH-06
07 12 2000 08 26
OH-06
08 02 2000 08 12
OH-06
08 23 2000 08 23
OH-06
09 26 2000 08 39
OH-06
10 12 2000 08 18
OH-06
10 24 2000 08 53
OH-07
04 03 2000 10 11
OH-07
05 16 2000 08 31
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)



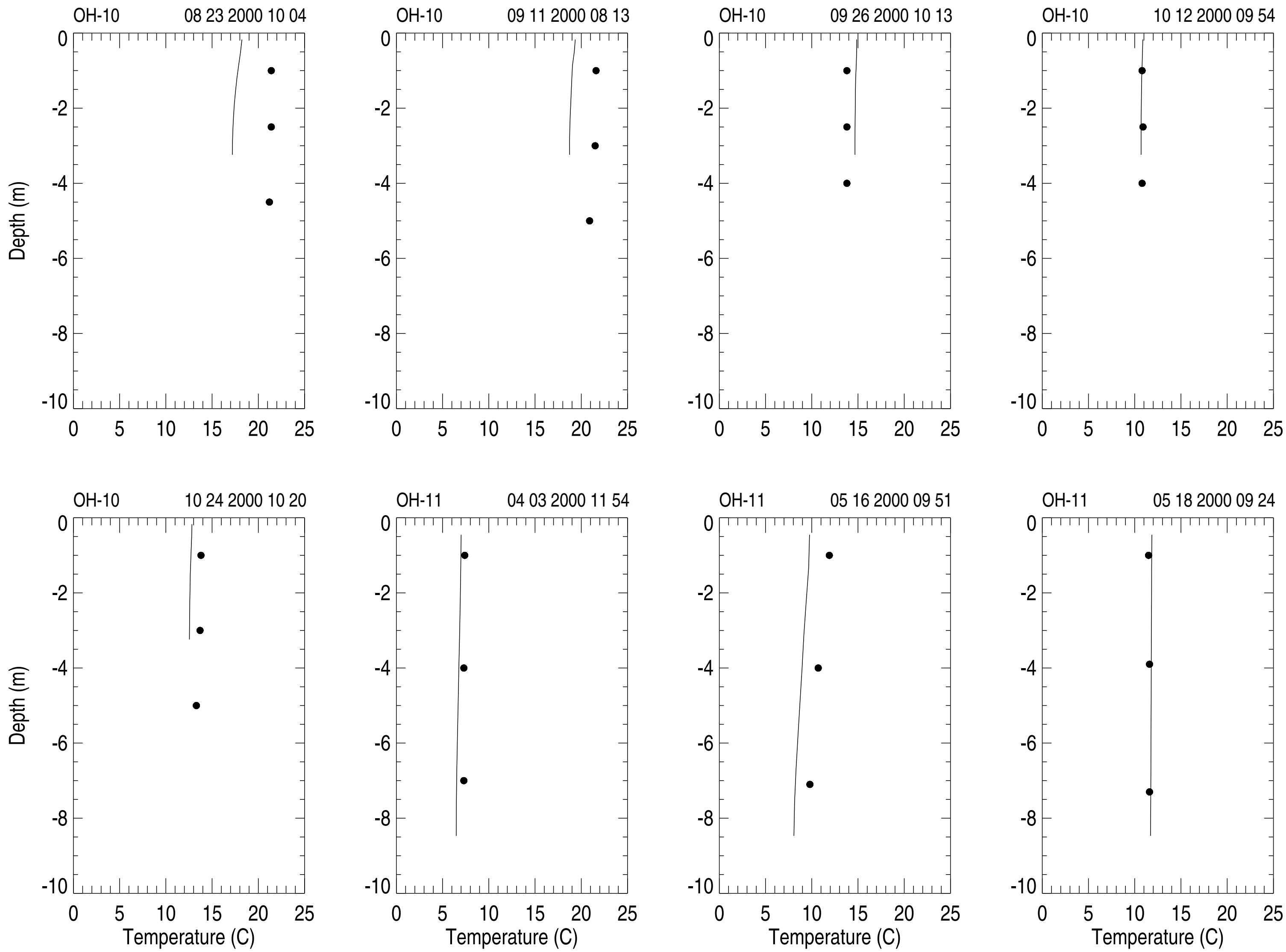
OH-07 06 15 2000 10 56
OH-07 07 12 2000 08 41
OH-07 08 02 2000 08 23
OH-07 08 23 2000 08 33
OH-07 09 11 2000 09 21
OH-07 09 26 2000 08 51
OH-07 10 12 2000 08 31
OH-07 10 24 2000 09 04
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

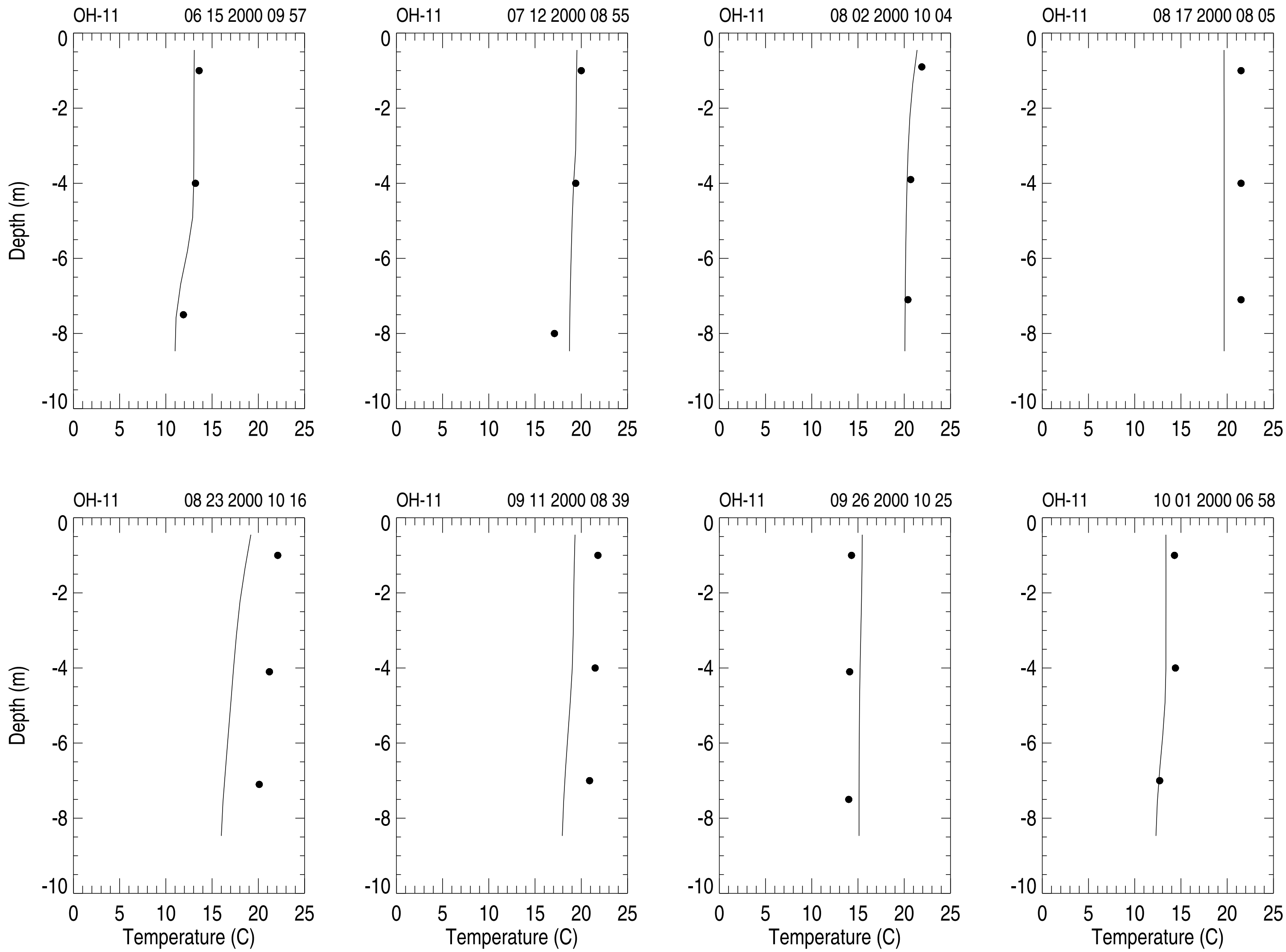

OH-08
04 03 2000 09 54
OH-08
05 16 2000 10 36
OH-08
06 15 2000 11 14
OH-08
07 12 2000 10 25
OH-08
08 02 2000 08 34
OH-08
08 23 2000 08 43
OH-08
09 26 2000 09 02
OH-08
10 12 2000 08 43
Depth (m)
Temperature (C)
0
-5
-10
-15
0
5
10
15
20
25


OH-08 10 24 2000 09 16
OH-09 04 03 2000 09 23
OH-09 05 16 2000 10 14
OH-09 06 15 2000 08 41
OH-09 07 12 2000 10 07
OH-09 08 02 2000 09 39
OH-09 08 23 2000 09 49
OH-09 09 11 2000 08 26
Depth (m)
Temperature (C)
0
-5
-10
-15
0 5 10 15 20 25

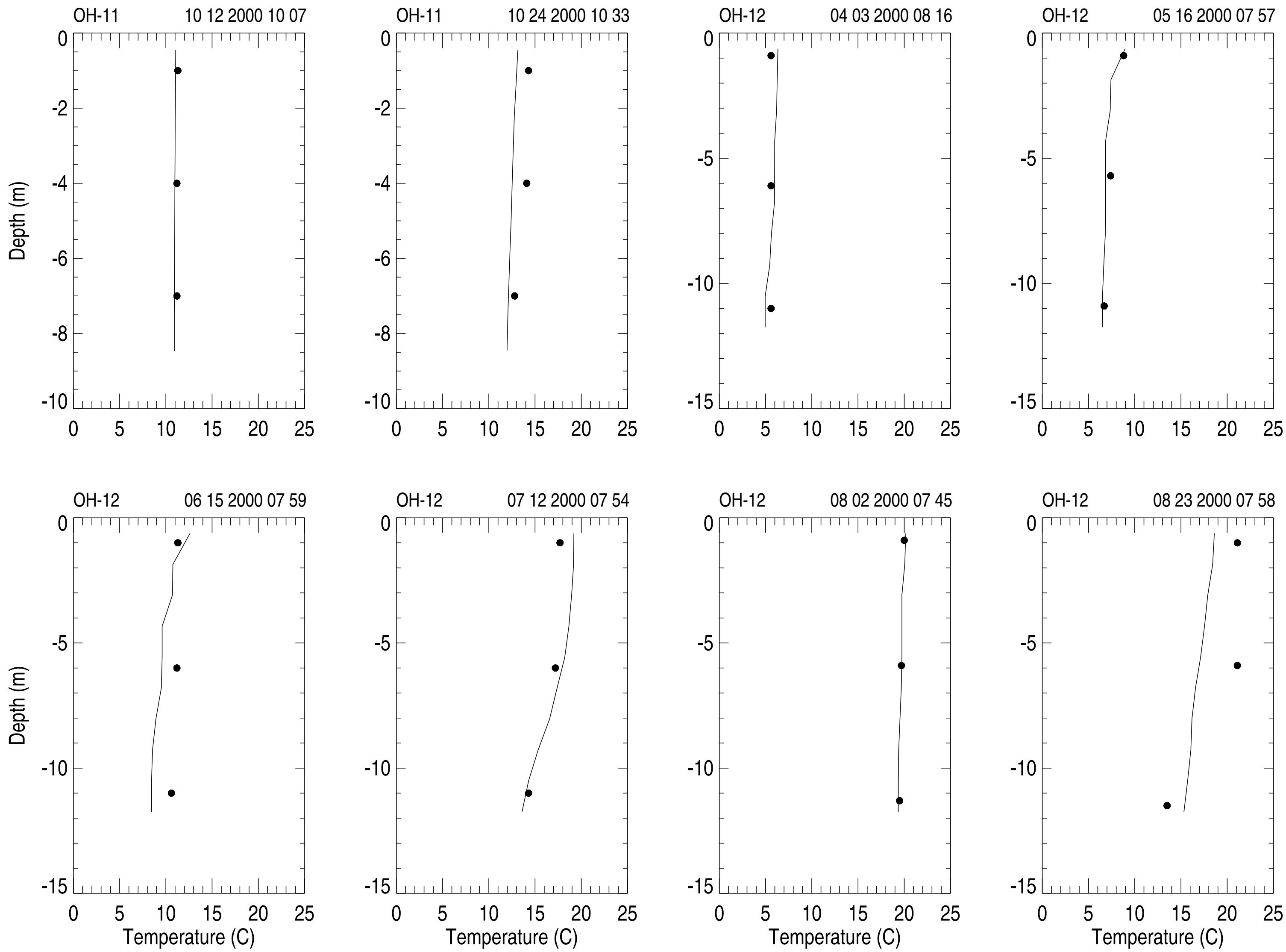


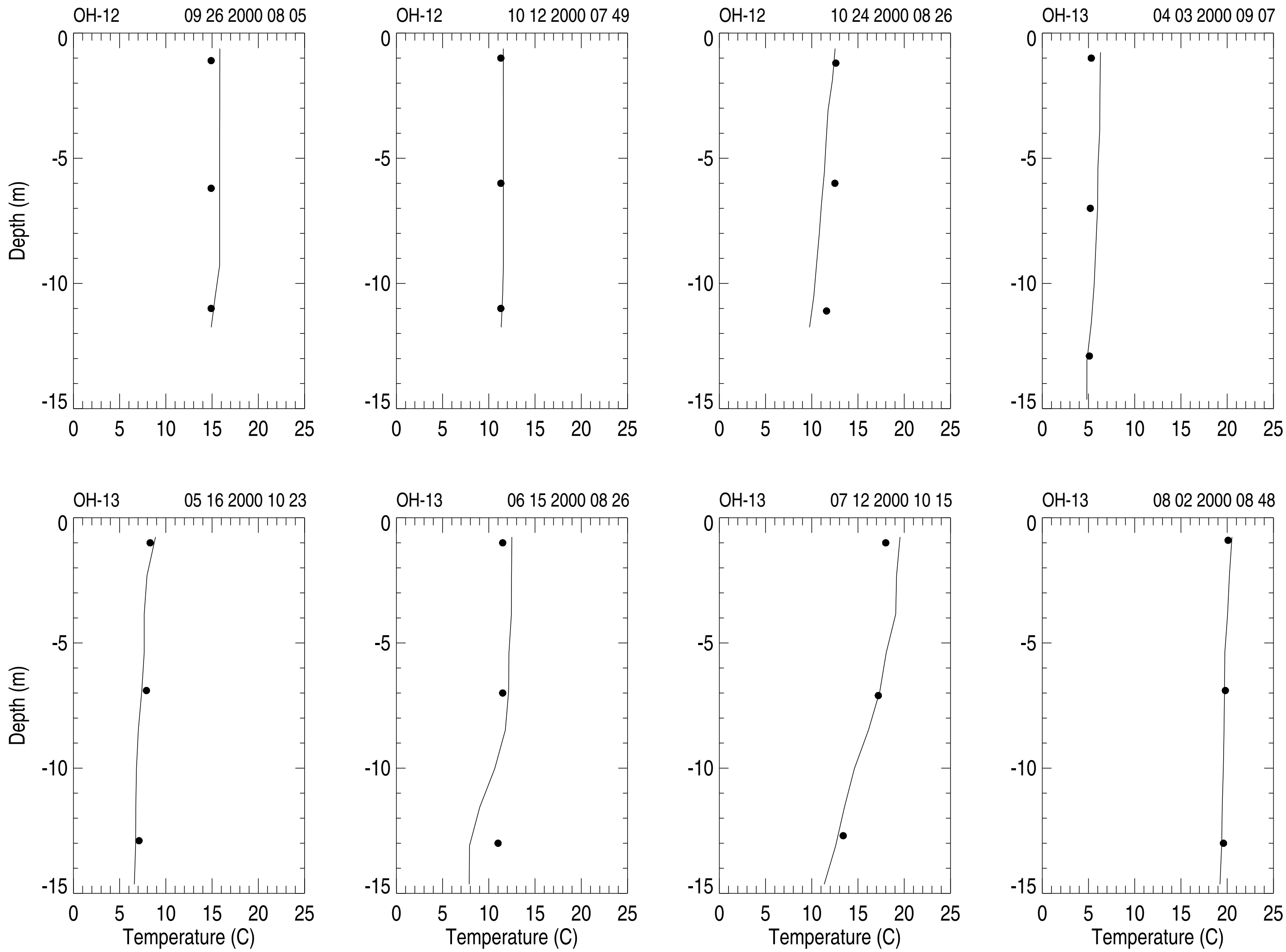
OH-09
09 26 2000 10 02
OH-09
10 12 2000 09 43
OH-09
10 24 2000 10 08
OH-10
04 03 2000 09 36
OH-10
05 16 2000 10 04
OH-10
06 15 2000 09 43
OH-10
07 12 2000 09 54
OH-10
08 02 2000 09 51
Depth (m)
Temperature (C)


OH-10
08 23 2000 10 04
OH-10
09 11 2000 08 13
OH-10
09 26 2000 10 13
OH-10
10 12 2000 09 54
OH-10
10 24 2000 10 20
OH-11
04 03 2000 11 54
OH-11
05 16 2000 09 51
OH-11
05 18 2000 09 24
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

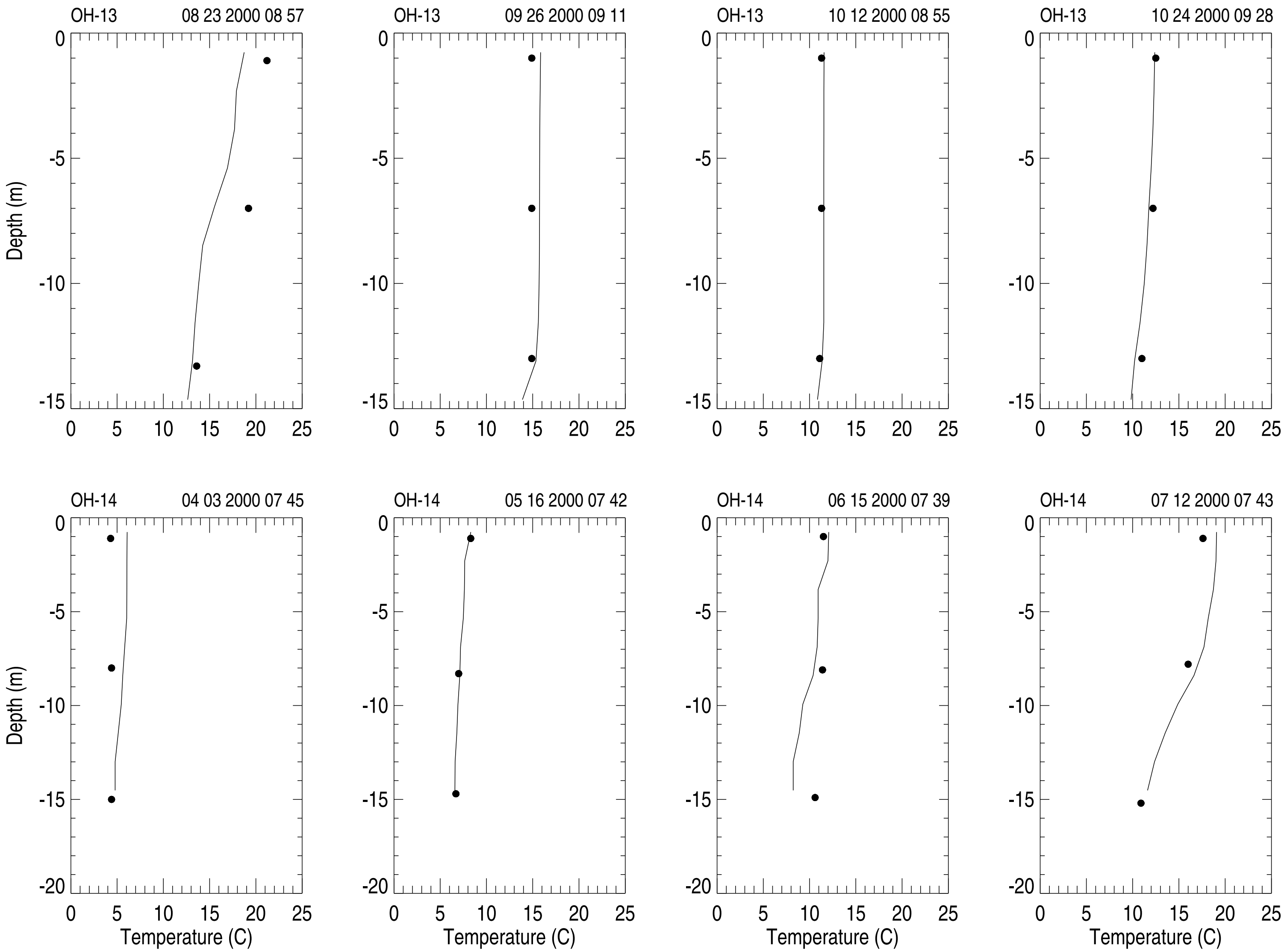


OH-11
06 15 2000 09 57
07 12 2000 08 55
08 02 2000 10 04
08 17 2000 08 05
08 23 2000 10 16
09 11 2000 08 39
09 26 2000 10 25
10 01 2000 06 58
Depth (m)
Temperature (C)

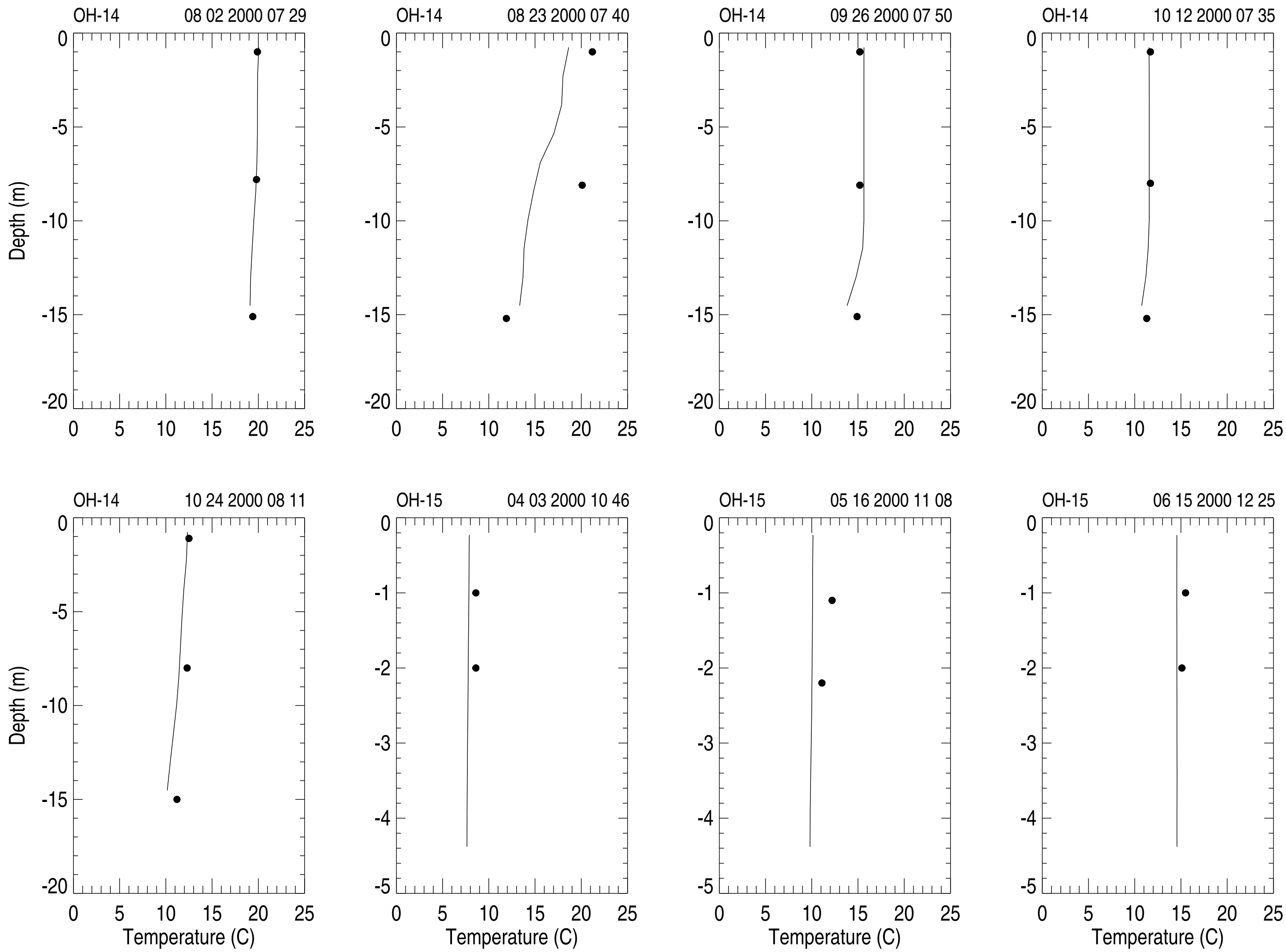

OH-11
10 12 2000 10 07
OH-11
10 24 2000 10 33
OH-12
04 03 2000 08 16
OH-12
05 16 2000 07 57
OH-12
06 15 2000 07 59
OH-12
07 12 2000 07 54
OH-12
08 02 2000 07 45
OH-12
08 23 2000 07 58
Depth (m)
Depth (m)
0
-2
-4
-6
-8
-10
-5
-15
0
5
10
15
20
25
Temperature (C)
Temperature (C)
Temperature (C)
Temperature (C)



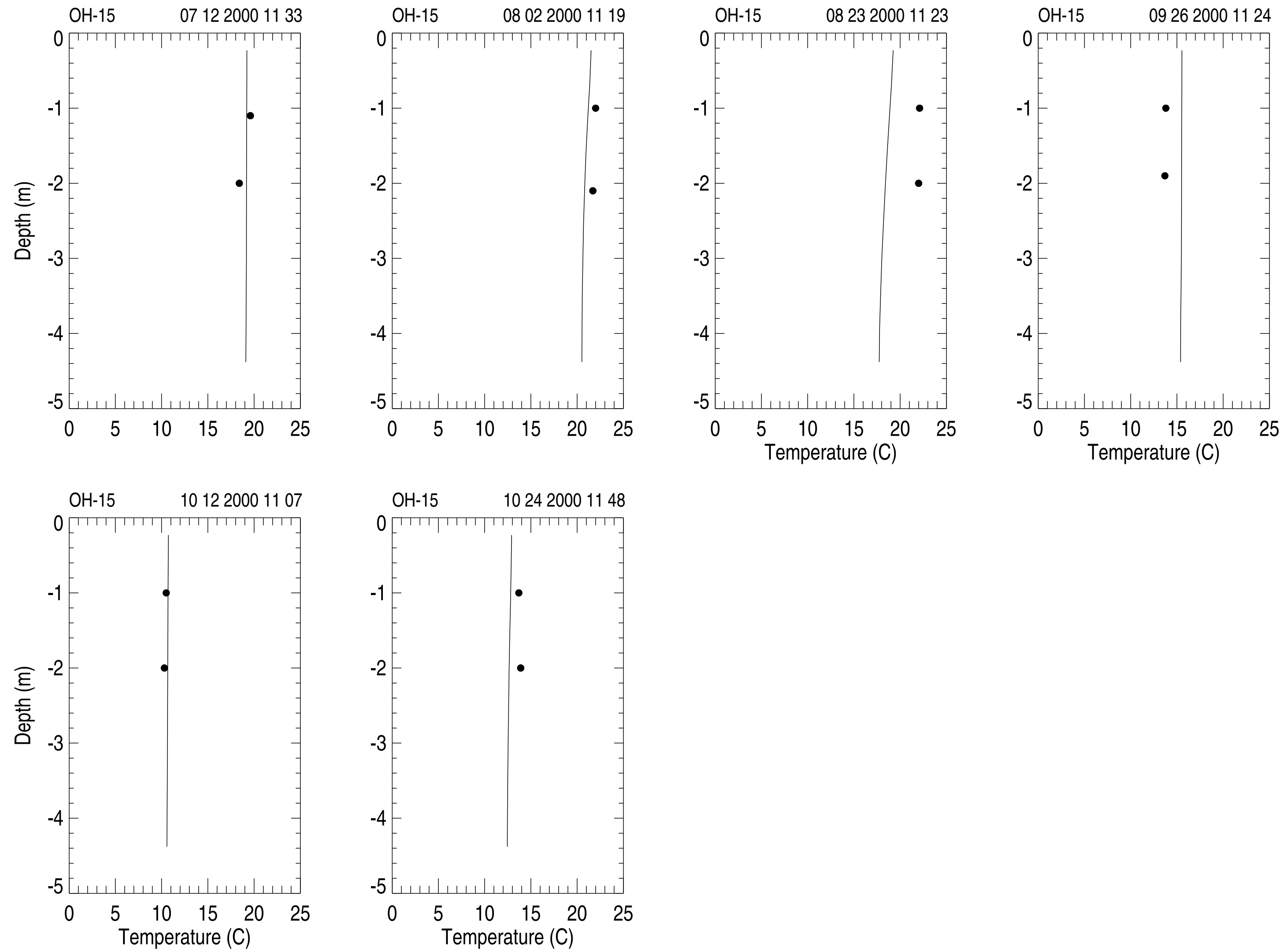
OH-12
09 26 2000 08 05
OH-12
10 12 2000 07 49
OH-12
10 24 2000 08 26
OH-13
04 03 2000 09 07
OH-13
05 16 2000 10 23
OH-13
06 15 2000 08 26
OH-13
07 12 2000 10 15
OH-13
08 02 2000 08 48
Depth (m)
Temperature (C)



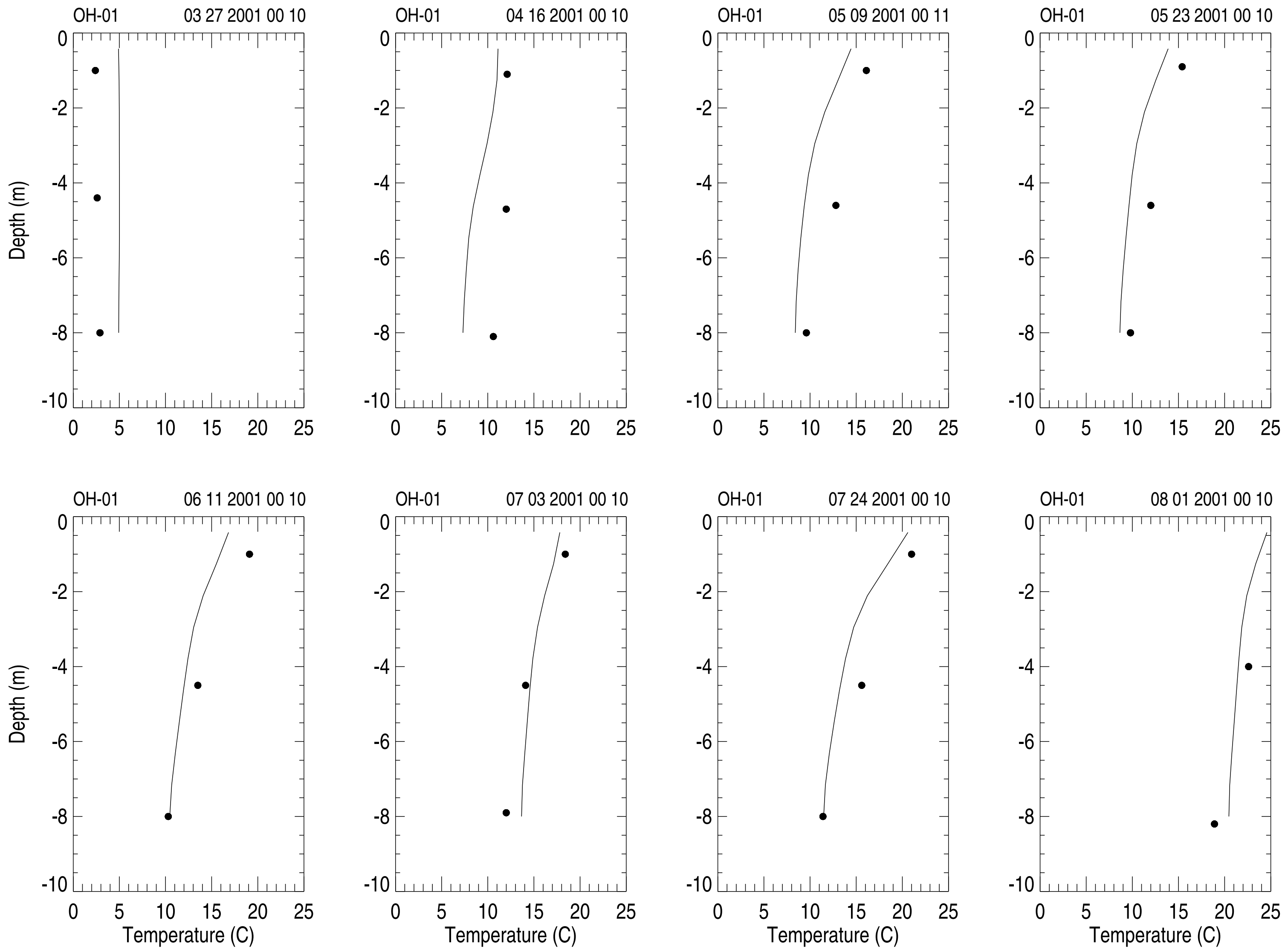
OH-13
08 23 2000 08 57
OH-13
09 26 2000 09 11
OH-13
10 12 2000 08 55
OH-13
10 24 2000 09 28
OH-14
04 03 2000 07 45
OH-14
05 16 2000 07 42
OH-14
06 15 2000 07 39
OH-14
07 12 2000 07 43
Depth (m)
Temperature (C)

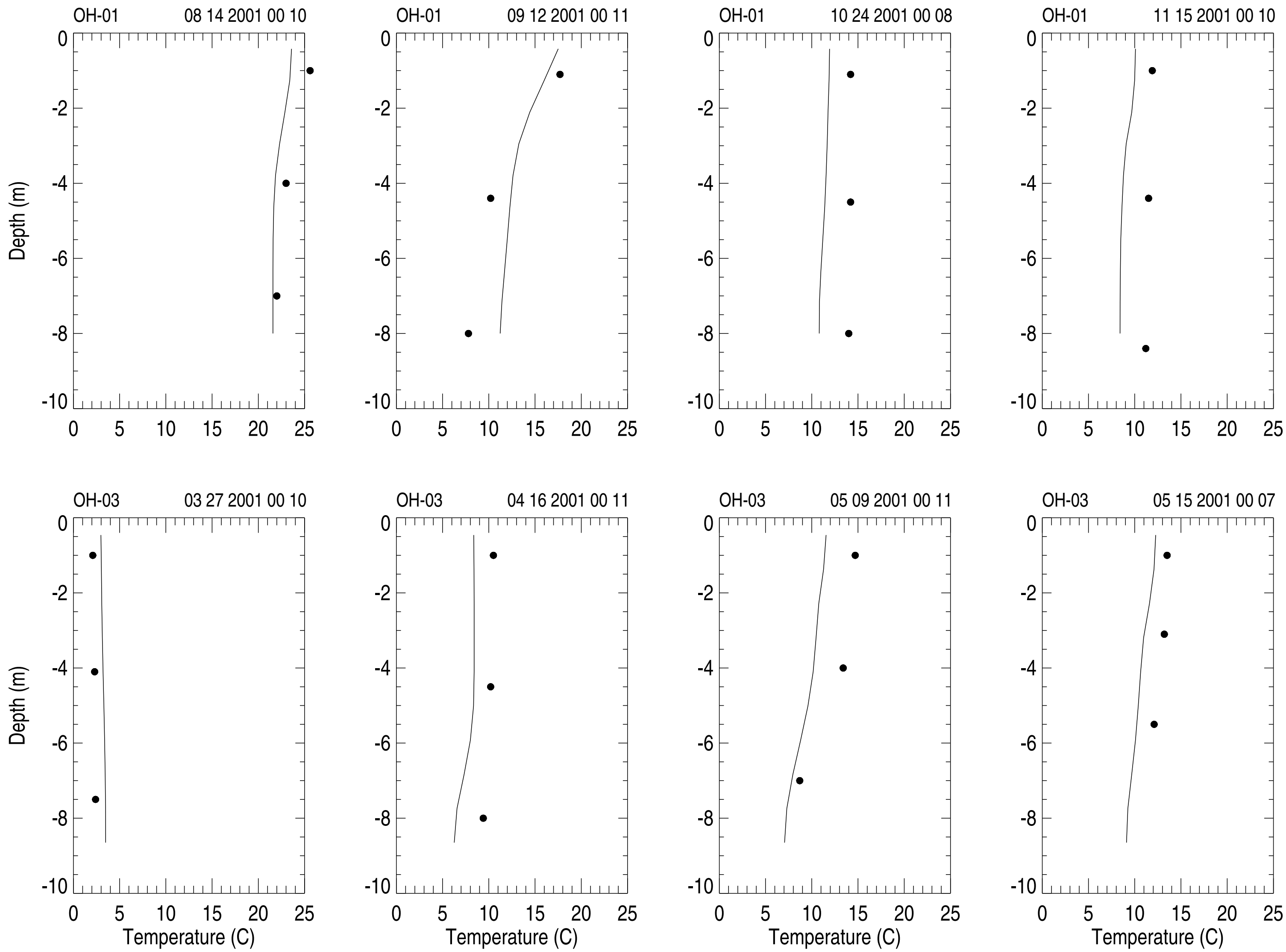


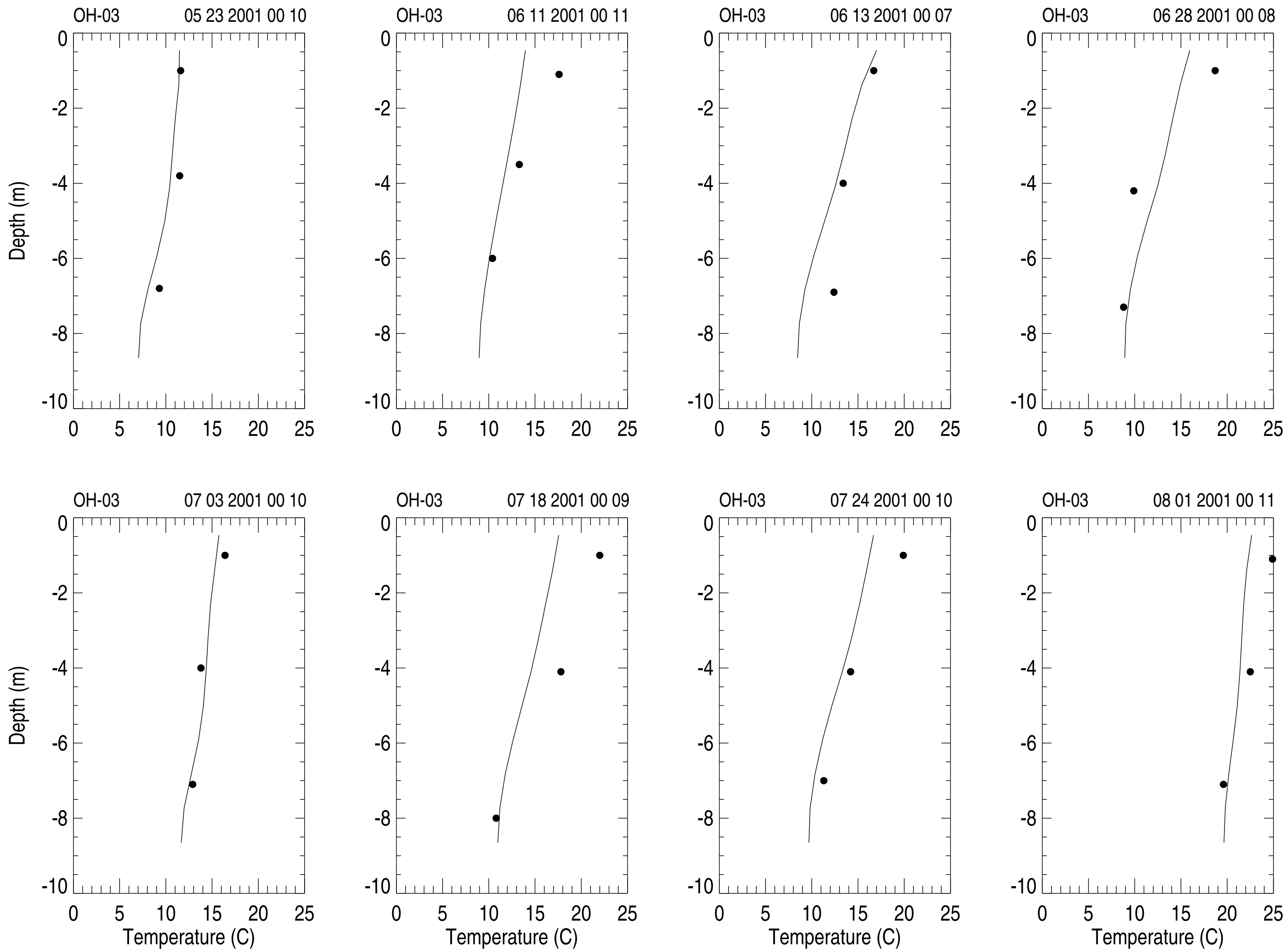
OH-14
08 02 2000 07 29
OH-14
08 23 2000 07 40
OH-14
09 26 2000 07 50
OH-14
10 12 2000 07 35
OH-14
10 24 2000 08 11
OH-15
04 03 2000 10 46
OH-15
05 16 2000 11 08
OH-15
06 15 2000 12 25
Depth (m)
Temperature (C)

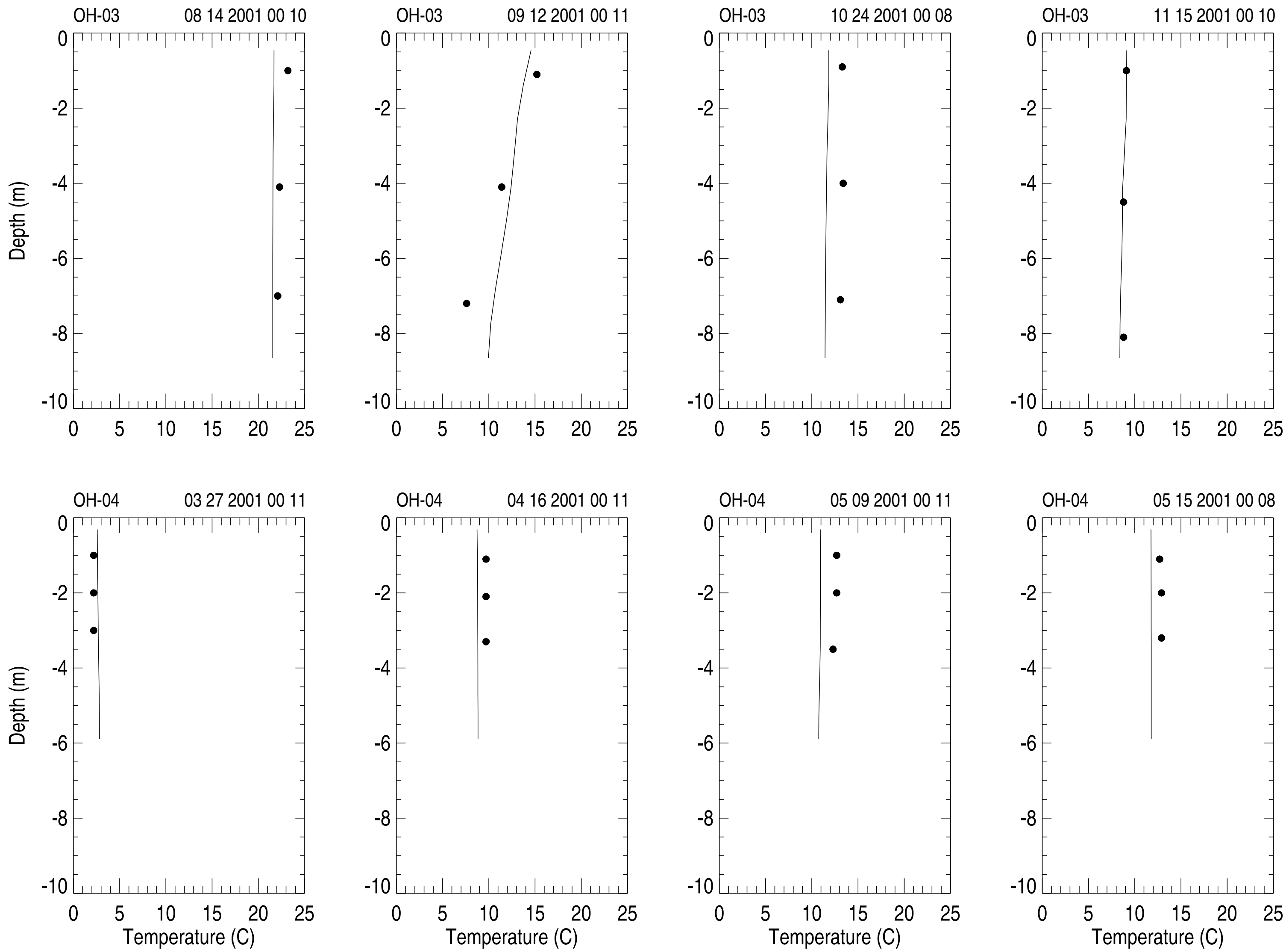


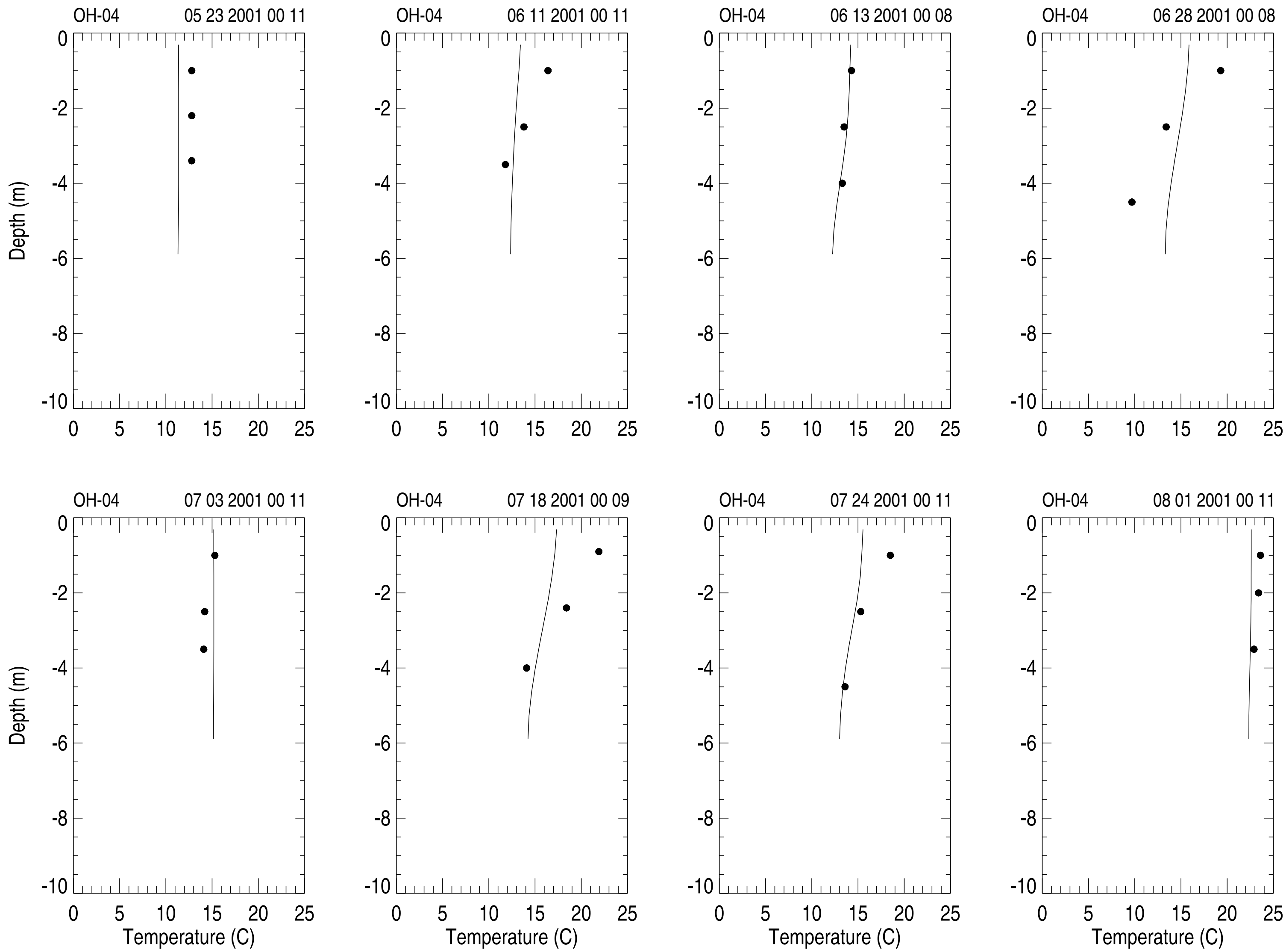
OH-15 07 12 2000 11 33
OH-15 08 02 2000 11 19
OH-15 08 23 2000 11 23
OH-15 09 26 2000 11 24
OH-15 10 12 2000 11 07
OH-15 10 24 2000 11 48
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25


OH-01 03 27 2001 00 10
OH-01 04 16 2001 00 10
OH-01 05 09 2001 00 11
OH-01 05 23 2001 00 10
OH-01 06 11 2001 00 10
OH-01 07 03 2001 00 10
OH-01 07 24 2001 00 10
OH-01 08 01 2001 00 10
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

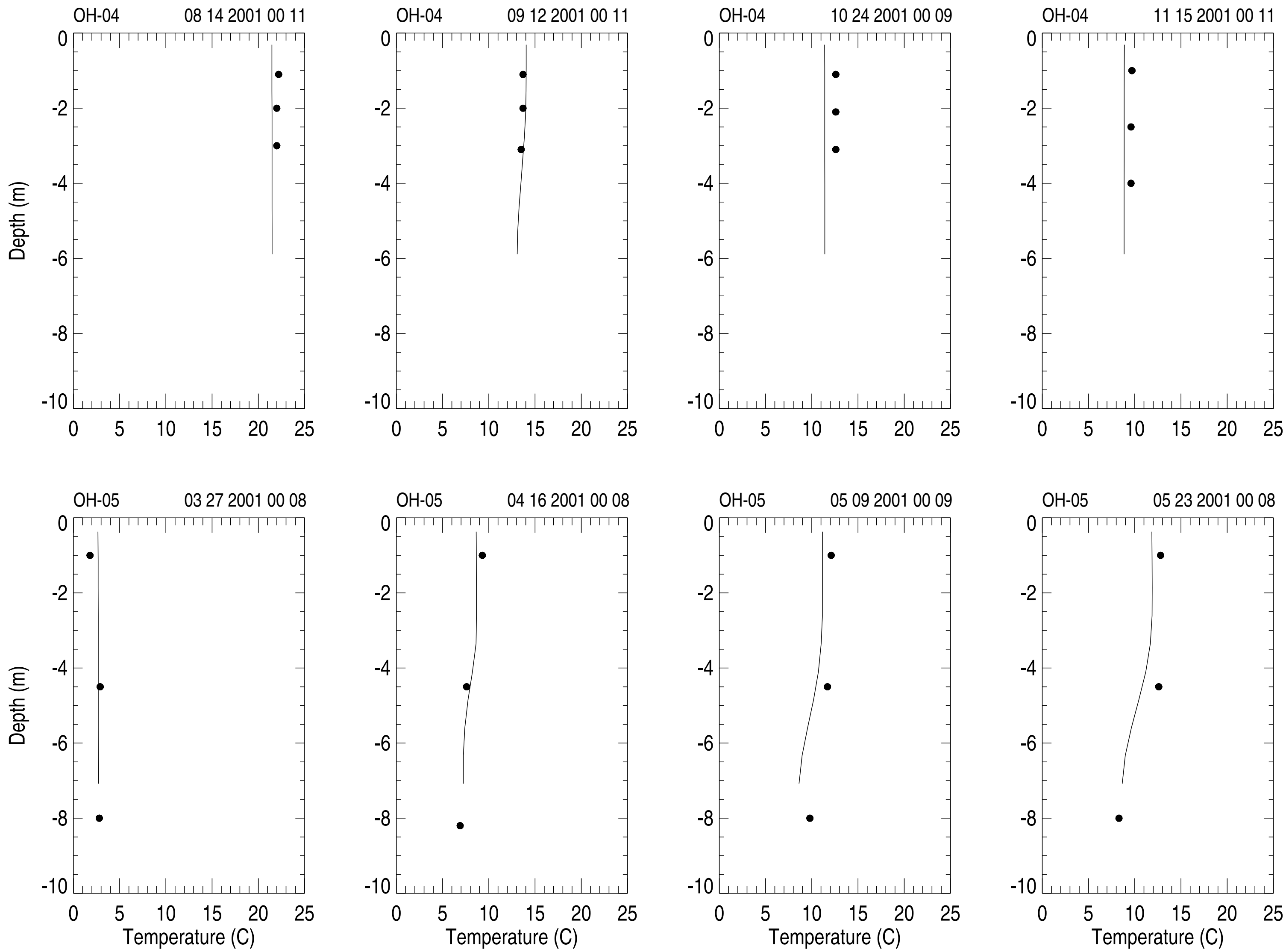

OH-01
08 14 2001 00 10
09 12 2001 00 11
10 24 2001 00 08
11 15 2001 00 10
OH-03
03 27 2001 00 10
04 16 2001 00 11
05 09 2001 00 11
05 15 2001 00 07
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25


OH-03
05 23 2001 00 10
OH-03
06 11 2001 00 11
OH-03
06 13 2001 00 07
OH-03
06 28 2001 00 08
OH-03
07 03 2001 00 10
OH-03
07 18 2001 00 09
OH-03
07 24 2001 00 10
OH-03
08 01 2001 00 11
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

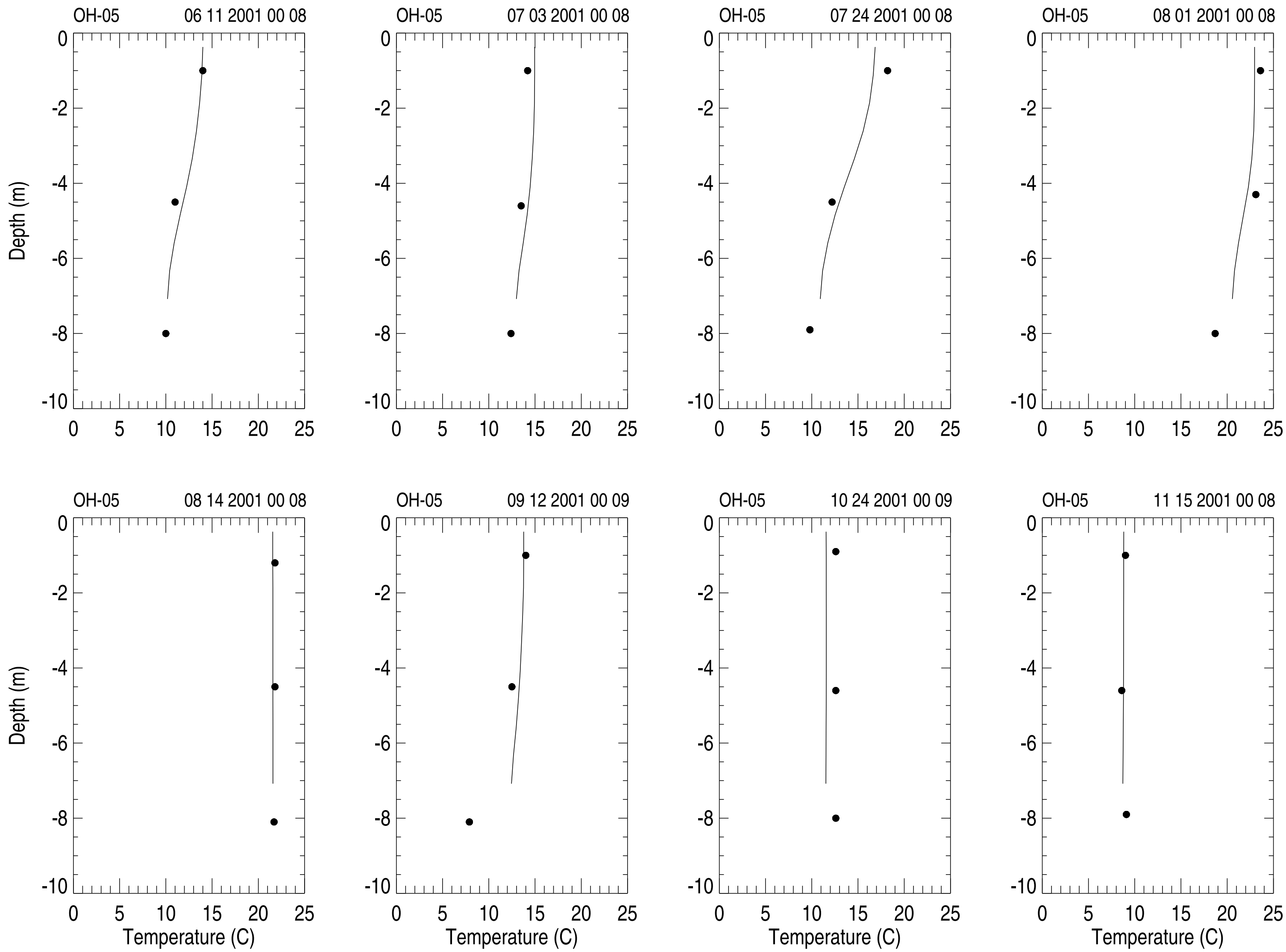

OH-03
08 14 2001 00 10
OH-03
09 12 2001 00 11
OH-03
10 24 2001 00 08
OH-03
11 15 2001 00 10
OH-04
03 27 2001 00 11
OH-04
04 16 2001 00 11
OH-04
05 09 2001 00 11
OH-04
05 15 2001 00 08
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25



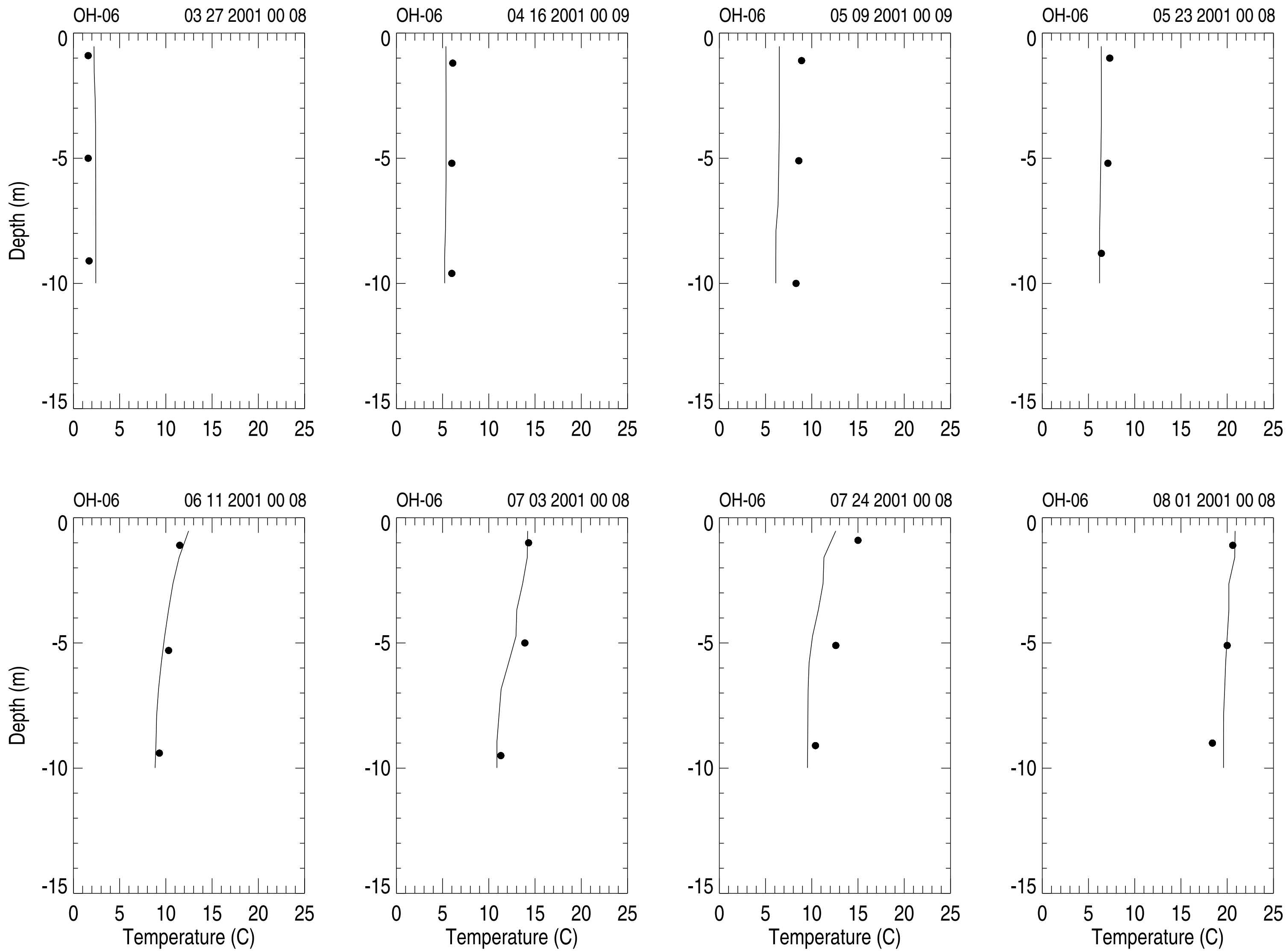
OH-04 05 23 2001 00 11
OH-04 06 11 2001 00 11
OH-04 06 13 2001 00 08
OH-04 06 28 2001 00 08
OH-04 07 03 2001 00 11
OH-04 07 18 2001 00 09
OH-04 07 24 2001 00 11
OH-04 08 01 2001 00 11
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25



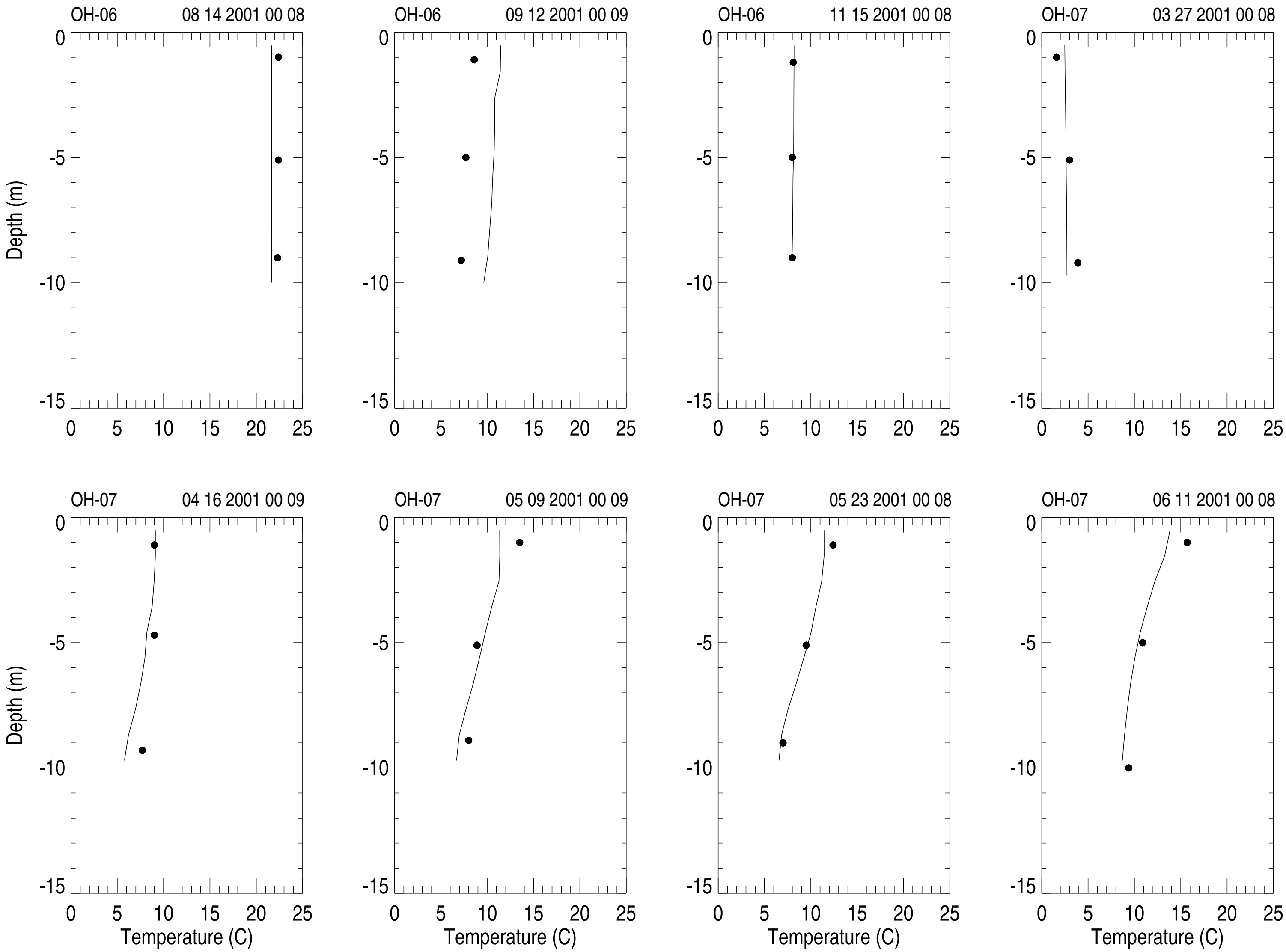
OH-04
08 14 2001 00 11
OH-04
09 12 2001 00 11
OH-04
10 24 2001 00 09
OH-04
11 15 2001 00 11
OH-05
03 27 2001 00 08
OH-05
04 16 2001 00 08
OH-05
05 09 2001 00 09
OH-05
05 23 2001 00 08
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25



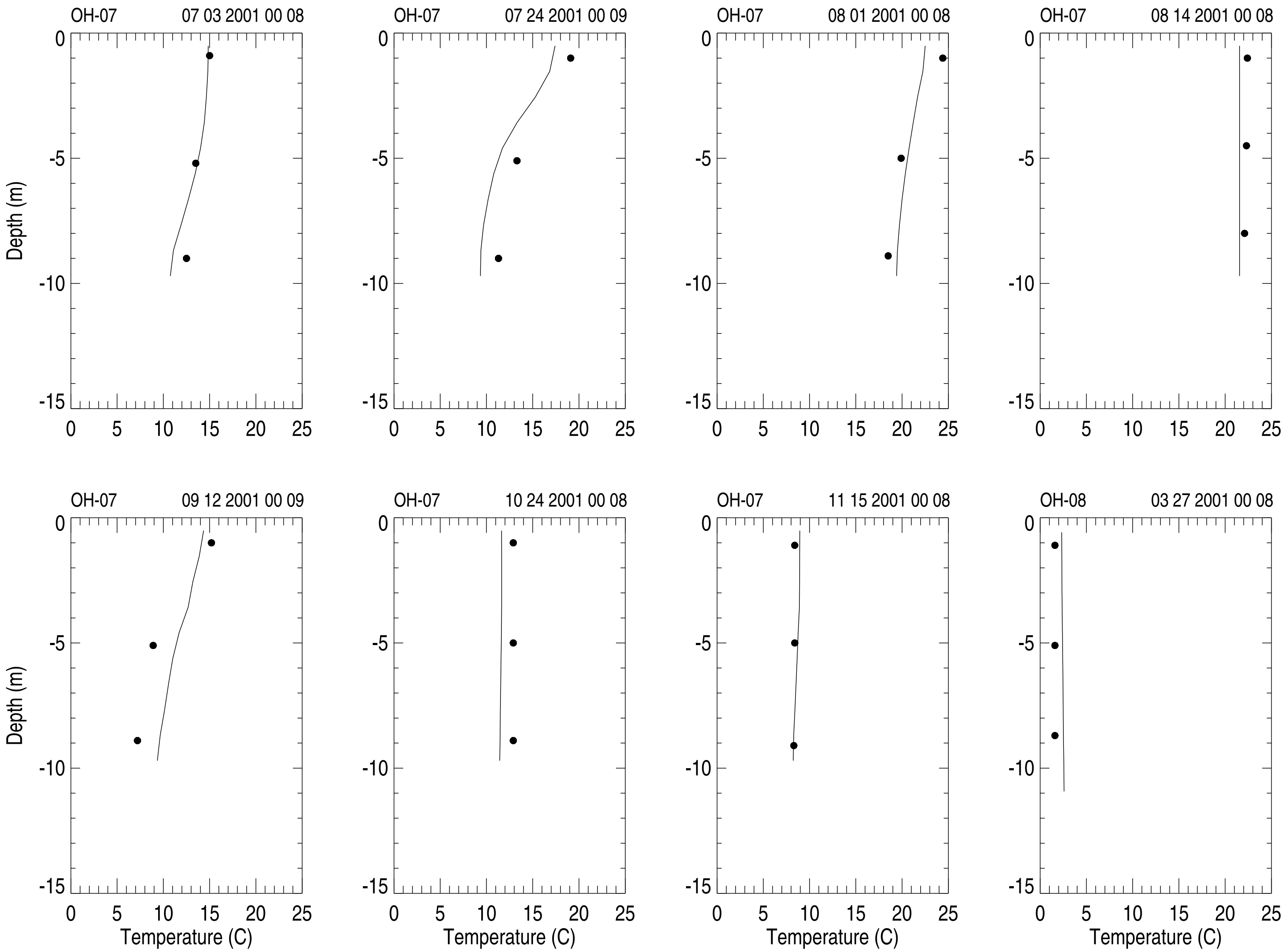
OH-05
06 11 2001 00 08
OH-05
07 03 2001 00 08
OH-05
07 24 2001 00 08
OH-05
08 01 2001 00 08
OH-05
08 14 2001 00 08
OH-05
09 12 2001 00 09
OH-05
10 24 2001 00 09
OH-05
11 15 2001 00 08
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25

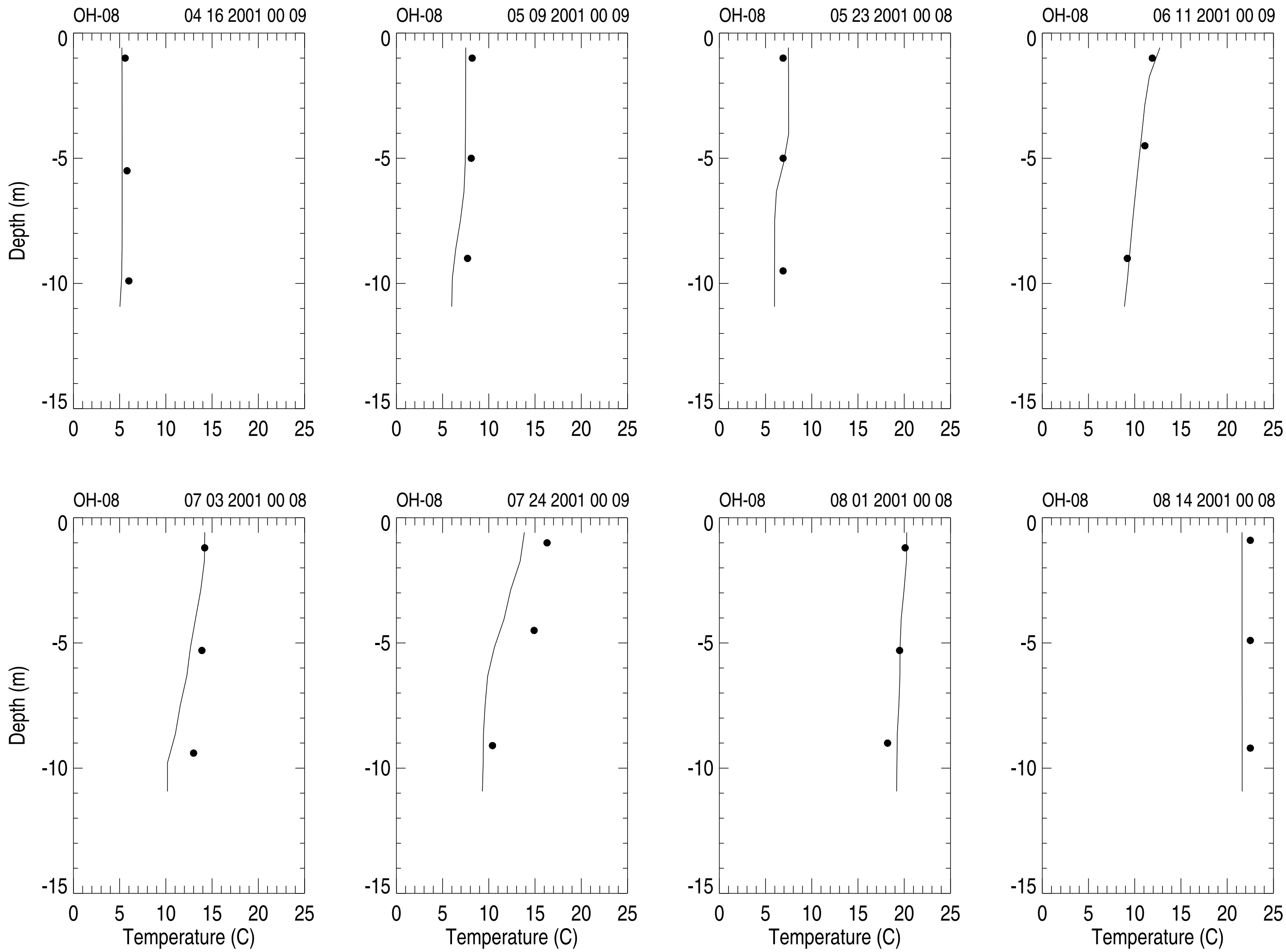


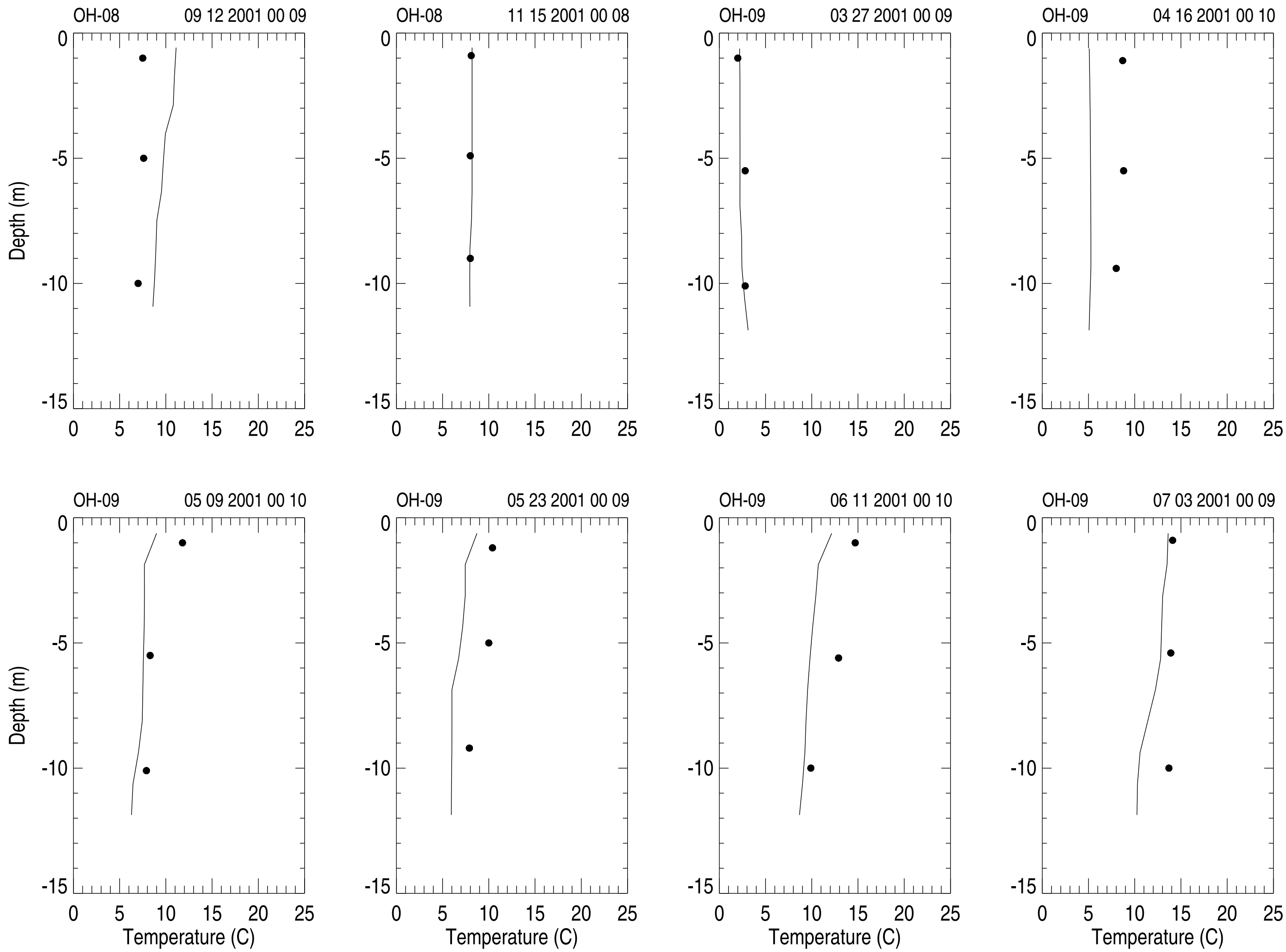
OH-06
03 27 2001 00 08
OH-06
04 16 2001 00 09
OH-06
05 09 2001 00 09
OH-06
05 23 2001 00 08
OH-06
06 11 2001 00 08
OH-06
07 03 2001 00 08
OH-06
07 24 2001 00 08
OH-06
08 01 2001 00 08
Depth (m)
Temperature (C)

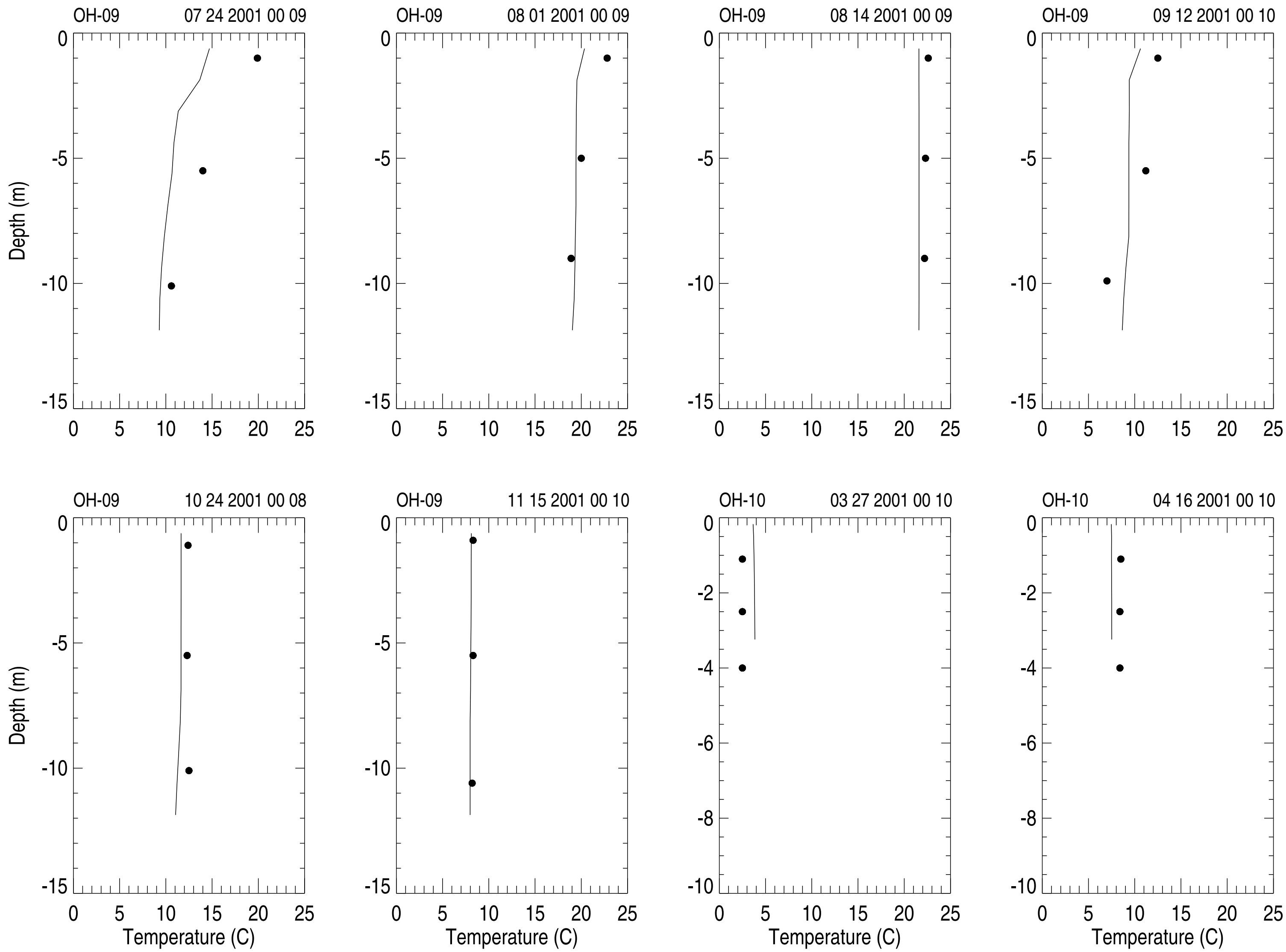


OH-06
08 14 2001 00 08
OH-06
09 12 2001 00 09
OH-06
11 15 2001 00 08
OH-07
03 27 2001 00 08
OH-07
04 16 2001 00 09
OH-07
05 09 2001 00 09
OH-07
05 23 2001 00 08
OH-07
06 11 2001 00 08
Depth (m)
Temperature (C)
0
-5
-10
-15
0
5
10
15
20
25

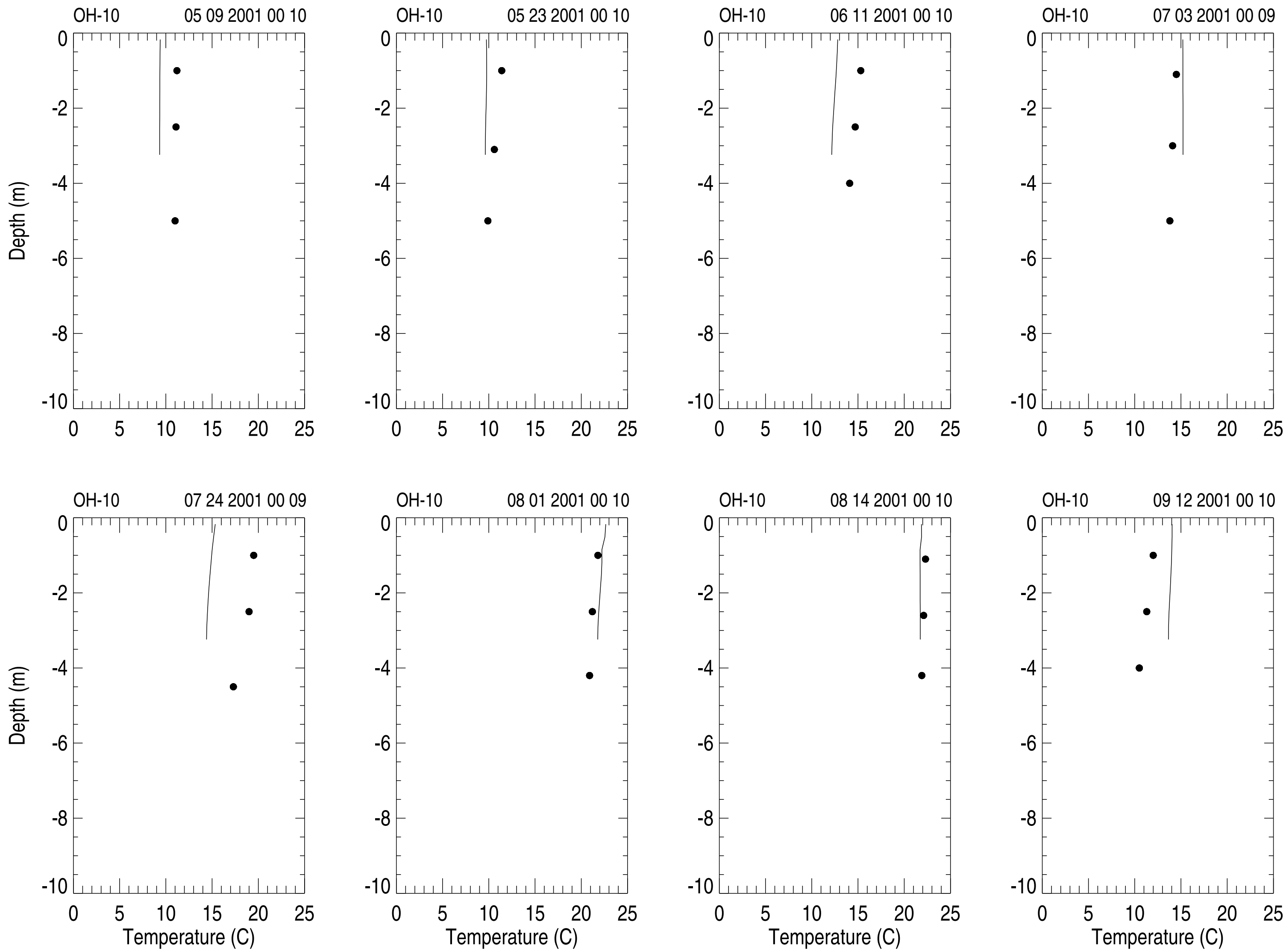

OH-07 07 03 2001 00 08
OH-07 07 24 2001 00 09
OH-07 08 01 2001 00 08
OH-07 08 14 2001 00 08
OH-07 09 12 2001 00 09
OH-07 10 24 2001 00 08
OH-07 11 15 2001 00 08
OH-08 03 27 2001 00 08
Depth (m)
Temperature (C)
0
-5
-10
-15
0 5 10 15 20 25

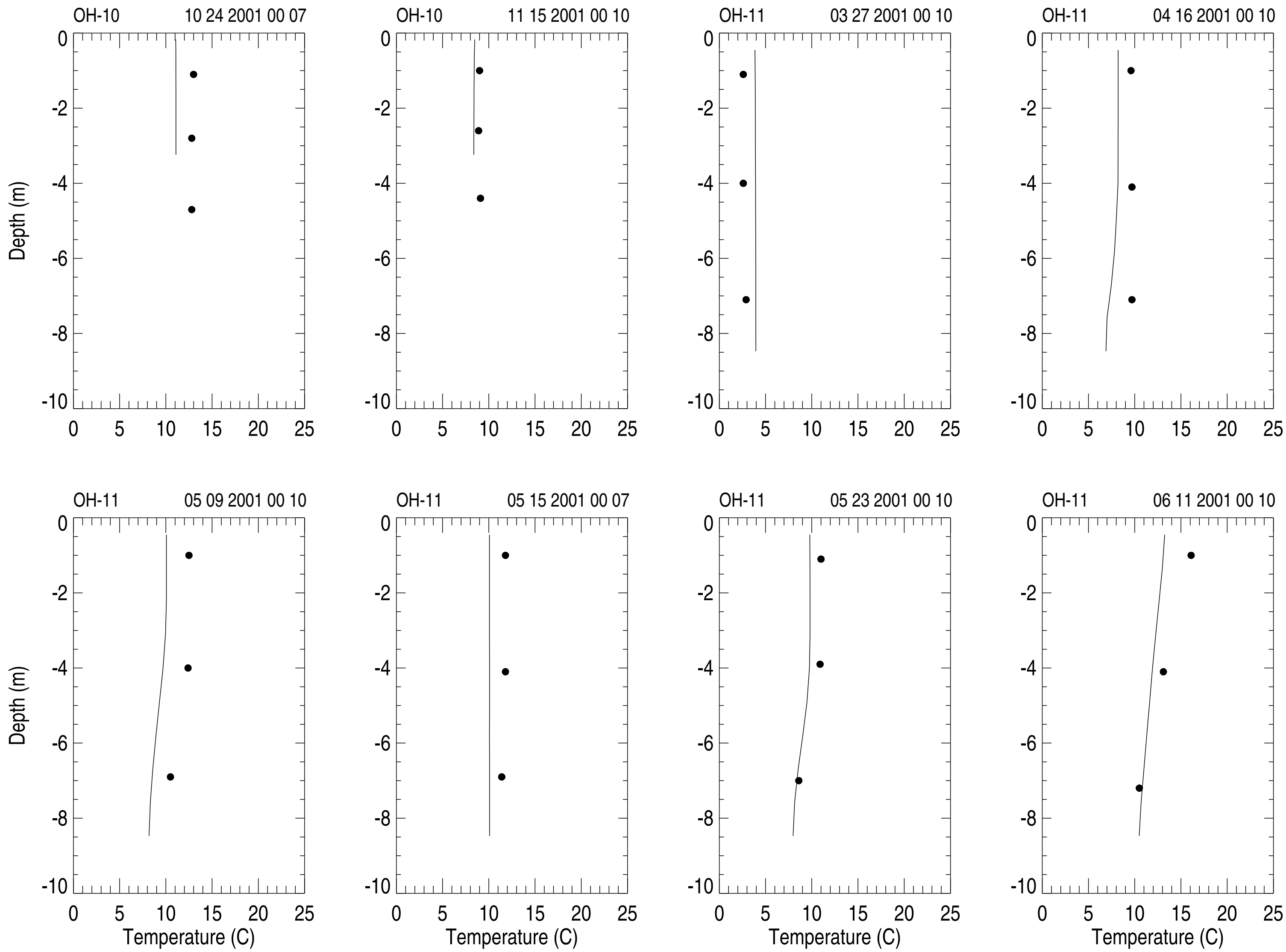

OH-08
04 16 2001 00 09
OH-08
05 09 2001 00 09
OH-08
05 23 2001 00 08
OH-08
06 11 2001 00 09
OH-08
07 03 2001 00 08
OH-08
07 24 2001 00 09
OH-08
08 01 2001 00 08
OH-08
08 14 2001 00 08
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25
Temperature (C)

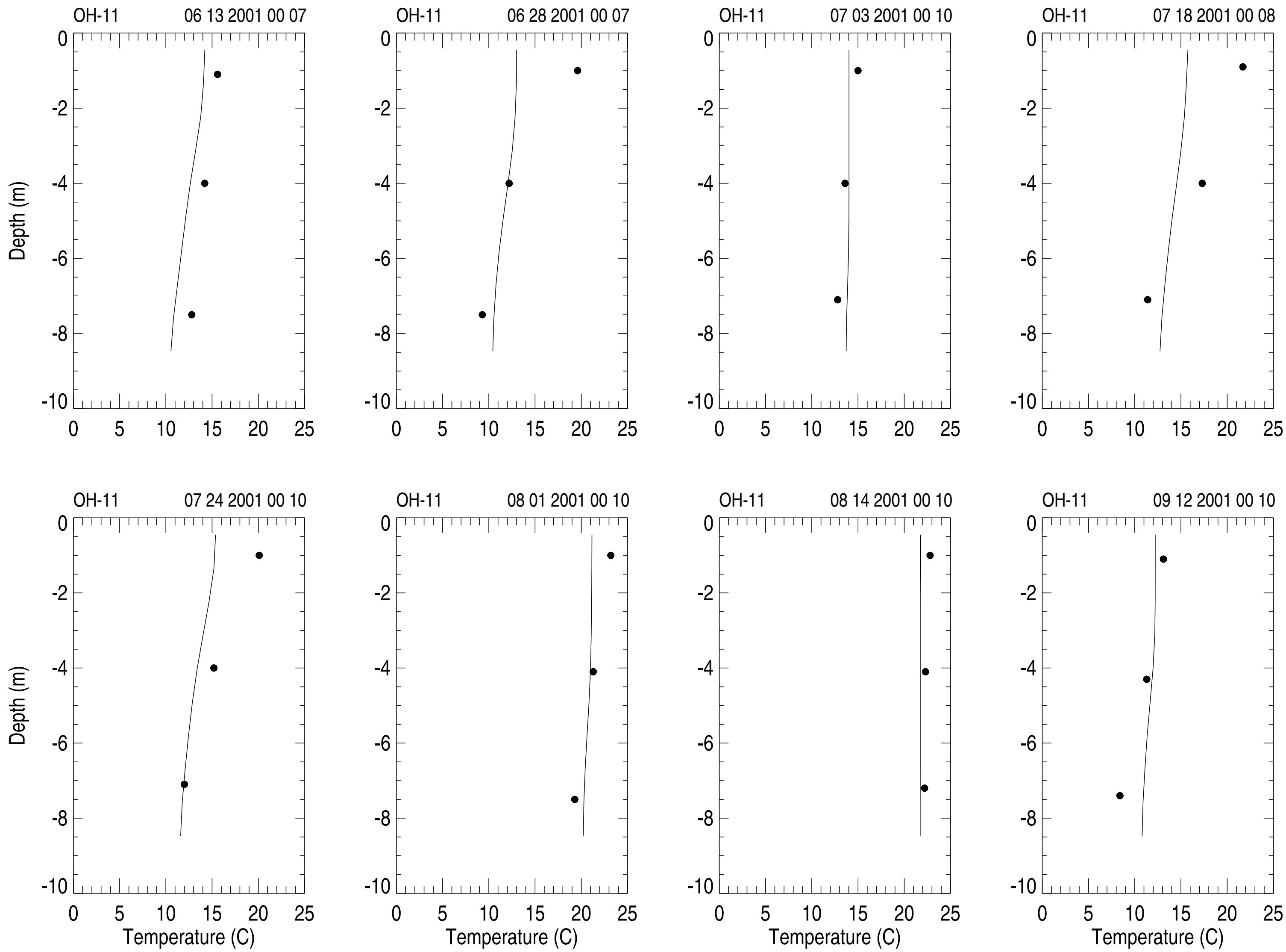

OH-08 09 12 2001 00 09
OH-08 11 15 2001 00 08
OH-09 03 27 2001 00 09
OH-09 04 16 2001 00 10
OH-09 05 09 2001 00 10
OH-09 05 23 2001 00 09
OH-09 06 11 2001 00 10
OH-09 07 03 2001 00 09
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25
Temperature (C)

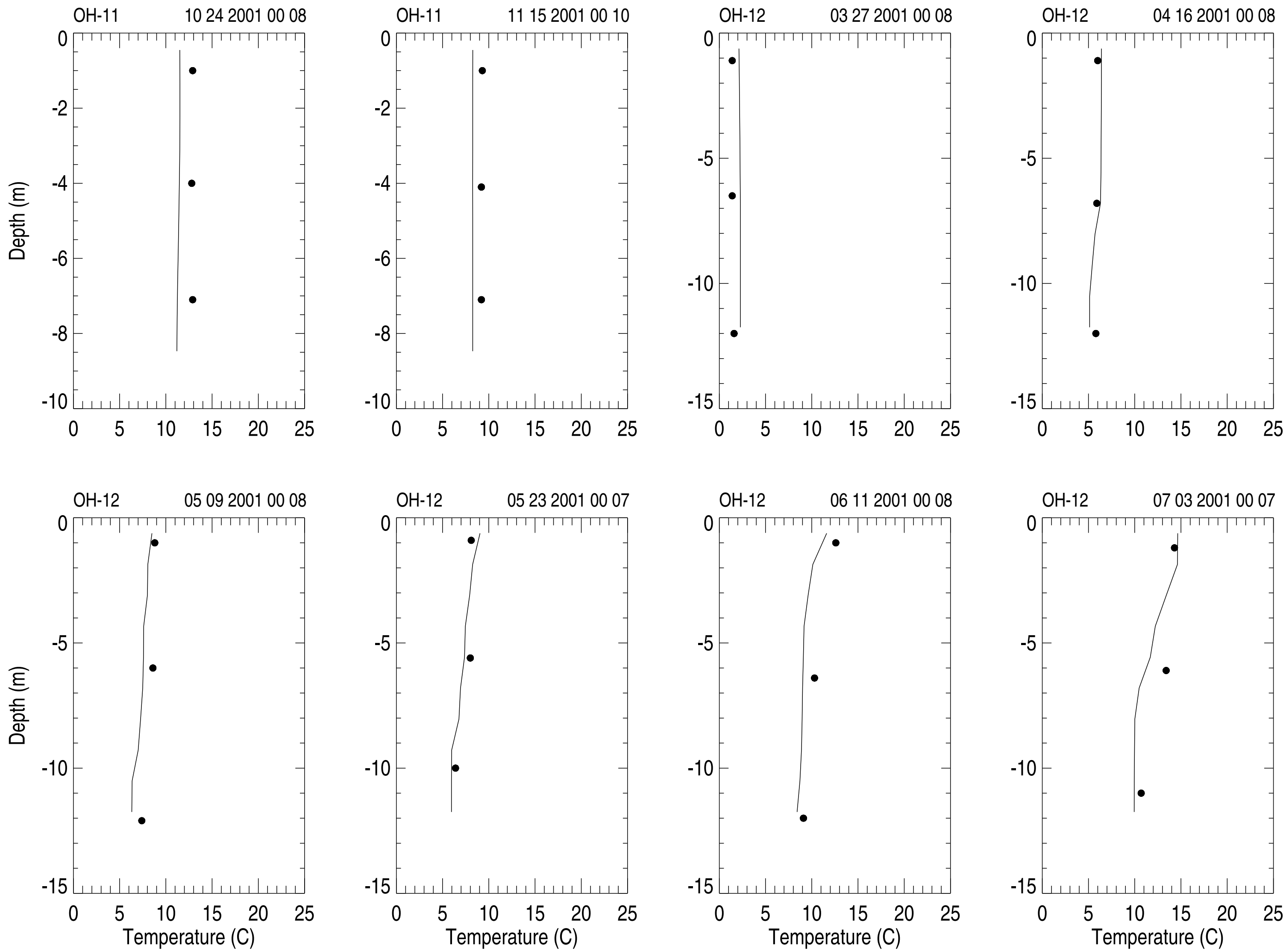


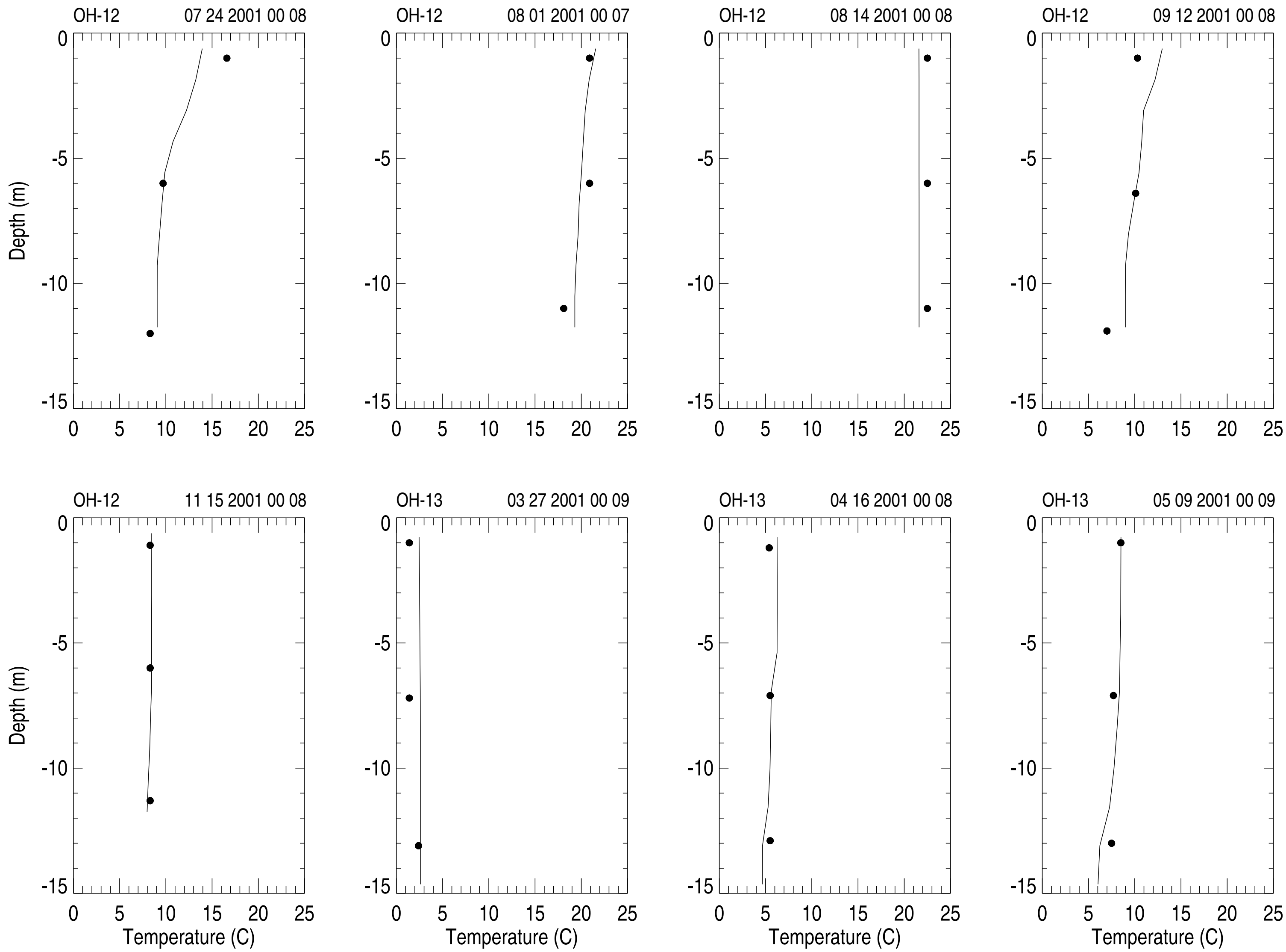
OH-09 07 24 2001 00 09
OH-09 08 01 2001 00 09
OH-09 08 14 2001 00 09
OH-09 09 12 2001 00 10
OH-09 10 24 2001 00 08
OH-09 11 15 2001 00 10
OH-10 03 27 2001 00 10
OH-10 04 16 2001 00 10
Depth (m)
Temperature (C)

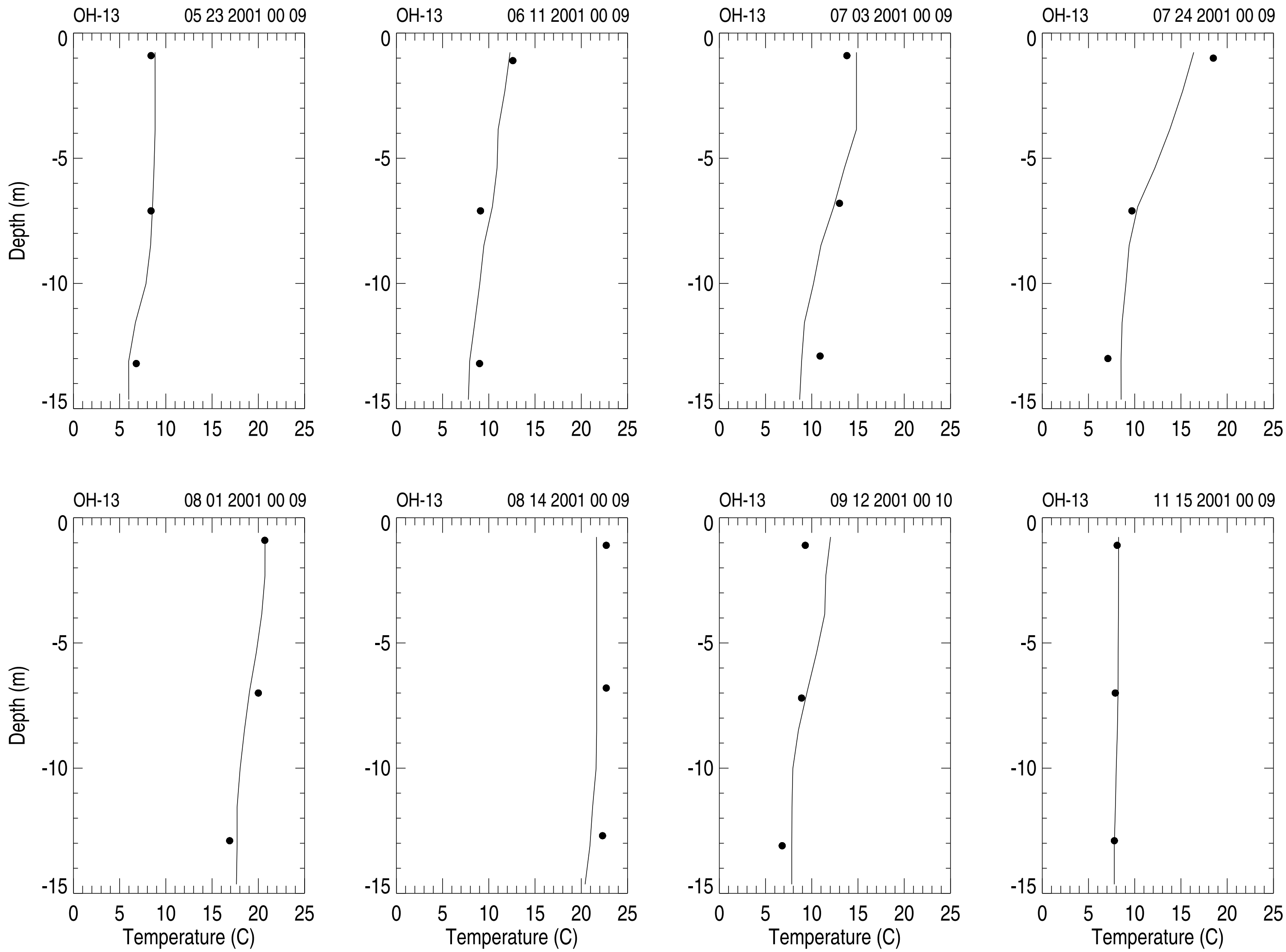

OH-10
05 09 2001 00 10
OH-10
05 23 2001 00 10
OH-10
06 11 2001 00 10
OH-10
07 03 2001 00 09
OH-10
07 24 2001 00 09
OH-10
08 01 2001 00 10
OH-10
08 14 2001 00 10
OH-10
09 12 2001 00 10
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25

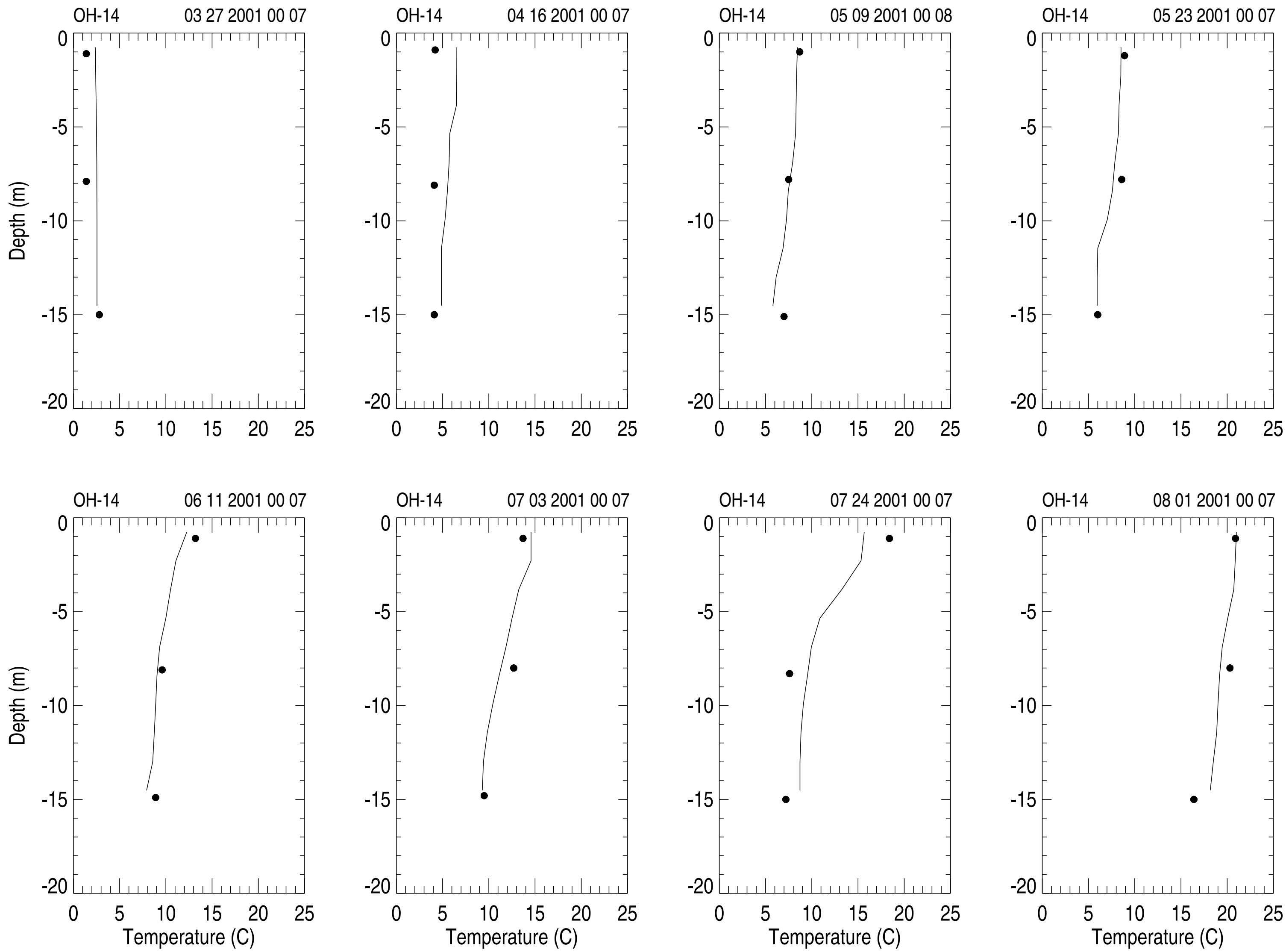

OH-10
10 24 2001 00 07
OH-10
11 15 2001 00 10
OH-11
03 27 2001 00 10
OH-11
04 16 2001 00 10
OH-11
05 09 2001 00 10
OH-11
05 15 2001 00 07
OH-11
05 23 2001 00 10
OH-11
06 11 2001 00 10
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25

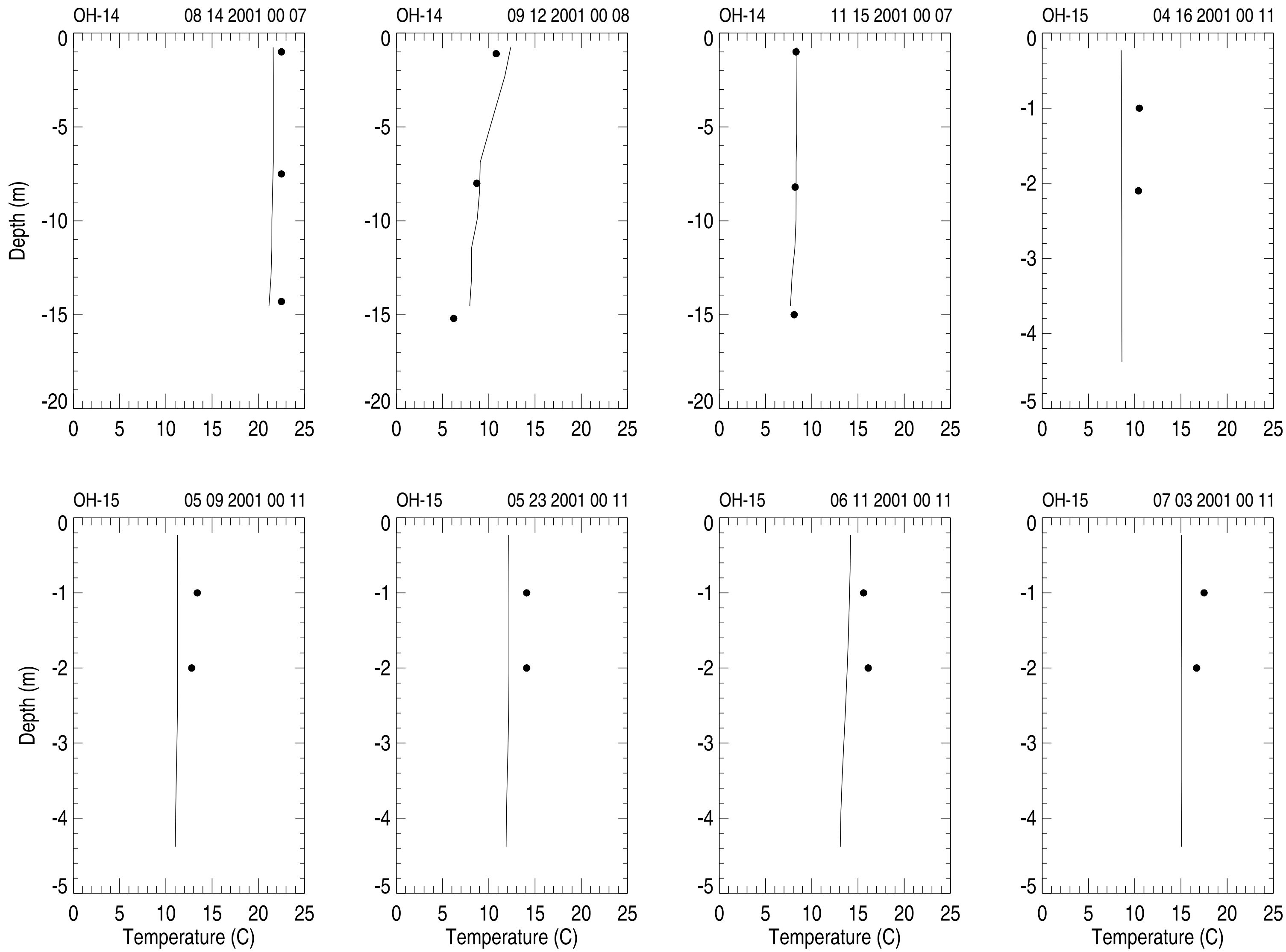

OH-11
06 13 2001 00 07
OH-11
06 28 2001 00 07
OH-11
07 03 2001 00 10
OH-11
07 18 2001 00 08
OH-11
07 24 2001 00 10
OH-11
08 01 2001 00 10
OH-11
08 14 2001 00 10
OH-11
09 12 2001 00 10
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

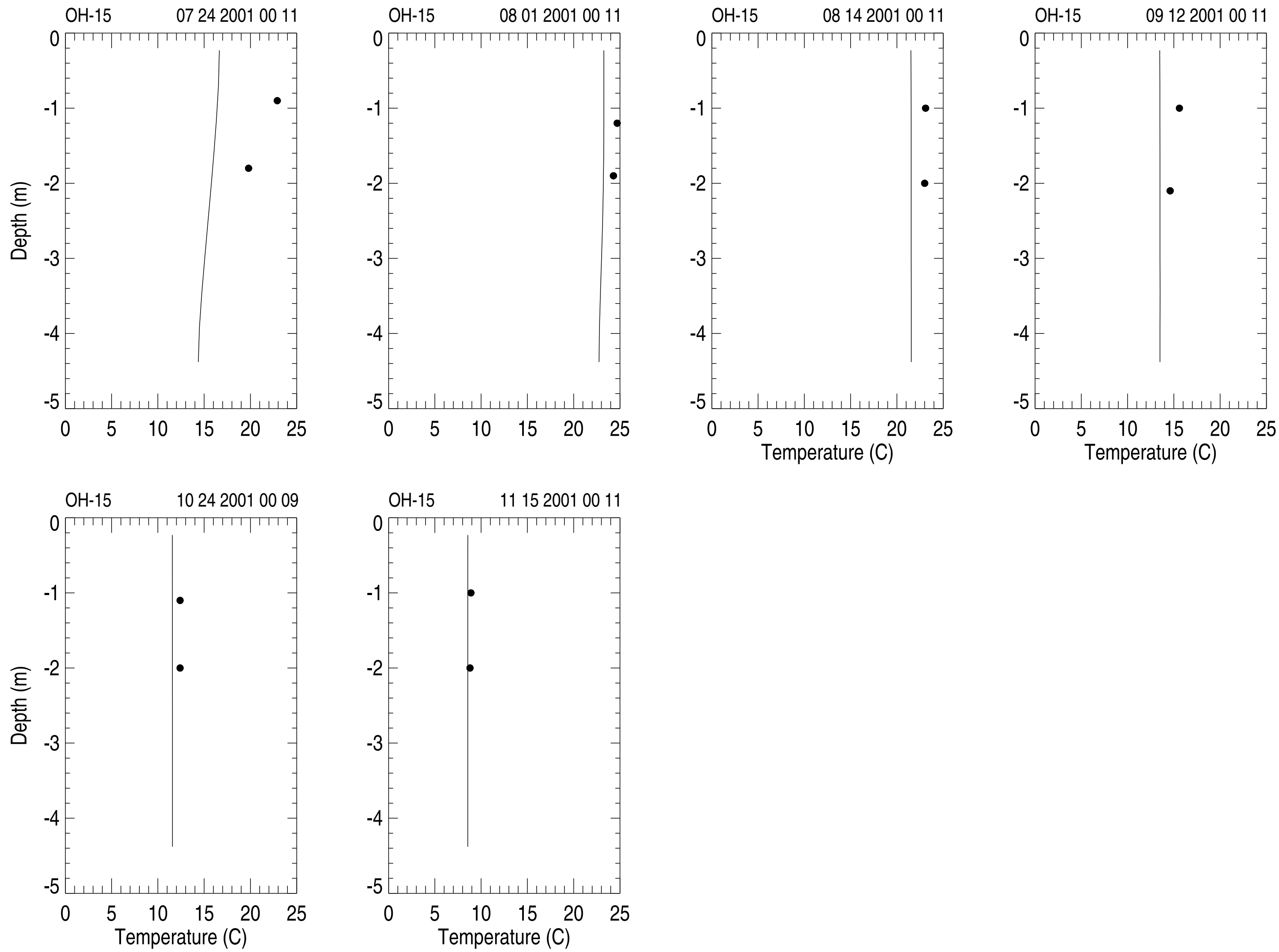

OH-11 10 24 2001 00 08
OH-11 11 15 2001 00 10
OH-12 03 27 2001 00 08
OH-12 04 16 2001 00 08
OH-12 05 09 2001 00 08
OH-12 05 23 2001 00 07
OH-12 06 11 2001 00 08
OH-12 07 03 2001 00 07
Depth (m)
Temperature (C)

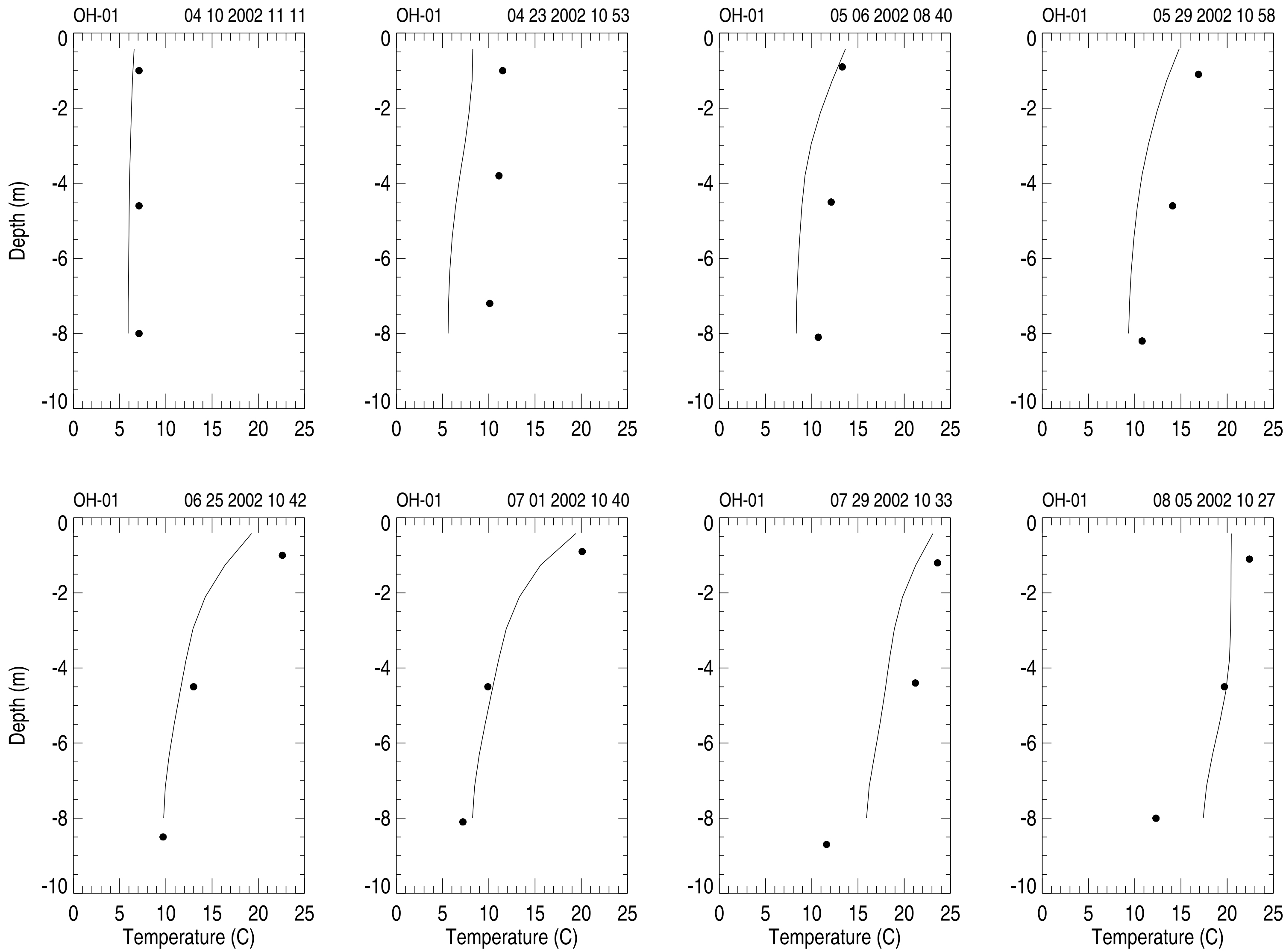

OH-12 07 24 2001 00 08
OH-12 08 01 2001 00 07
OH-12 08 14 2001 00 08
OH-12 09 12 2001 00 08
OH-12 11 15 2001 00 08
OH-13 03 27 2001 00 09
OH-13 04 16 2001 00 08
OH-13 05 09 2001 00 09
Depth (m)
Temperature (C)
0
-5
-10
-15
0 5 10 15 20 25

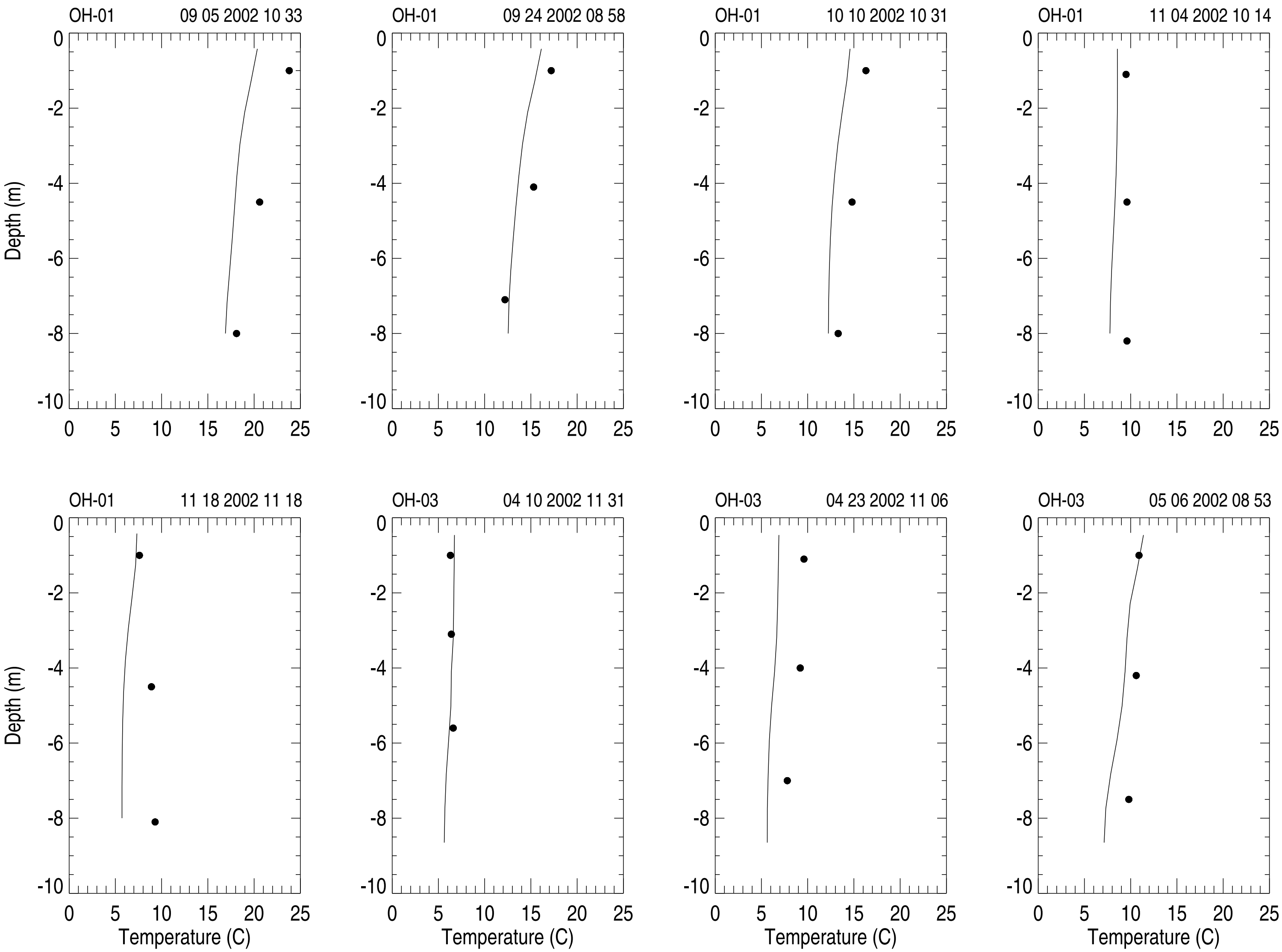

OH-13
05 23 2001 00 09
OH-13
06 11 2001 00 09
OH-13
07 03 2001 00 09
OH-13
07 24 2001 00 09
OH-13
08 01 2001 00 09
OH-13
08 14 2001 00 09
OH-13
09 12 2001 00 10
OH-13
11 15 2001 00 09
Depth (m)
0
-5
-10
-15
0
5
10
15
20
25
Temperature (C)

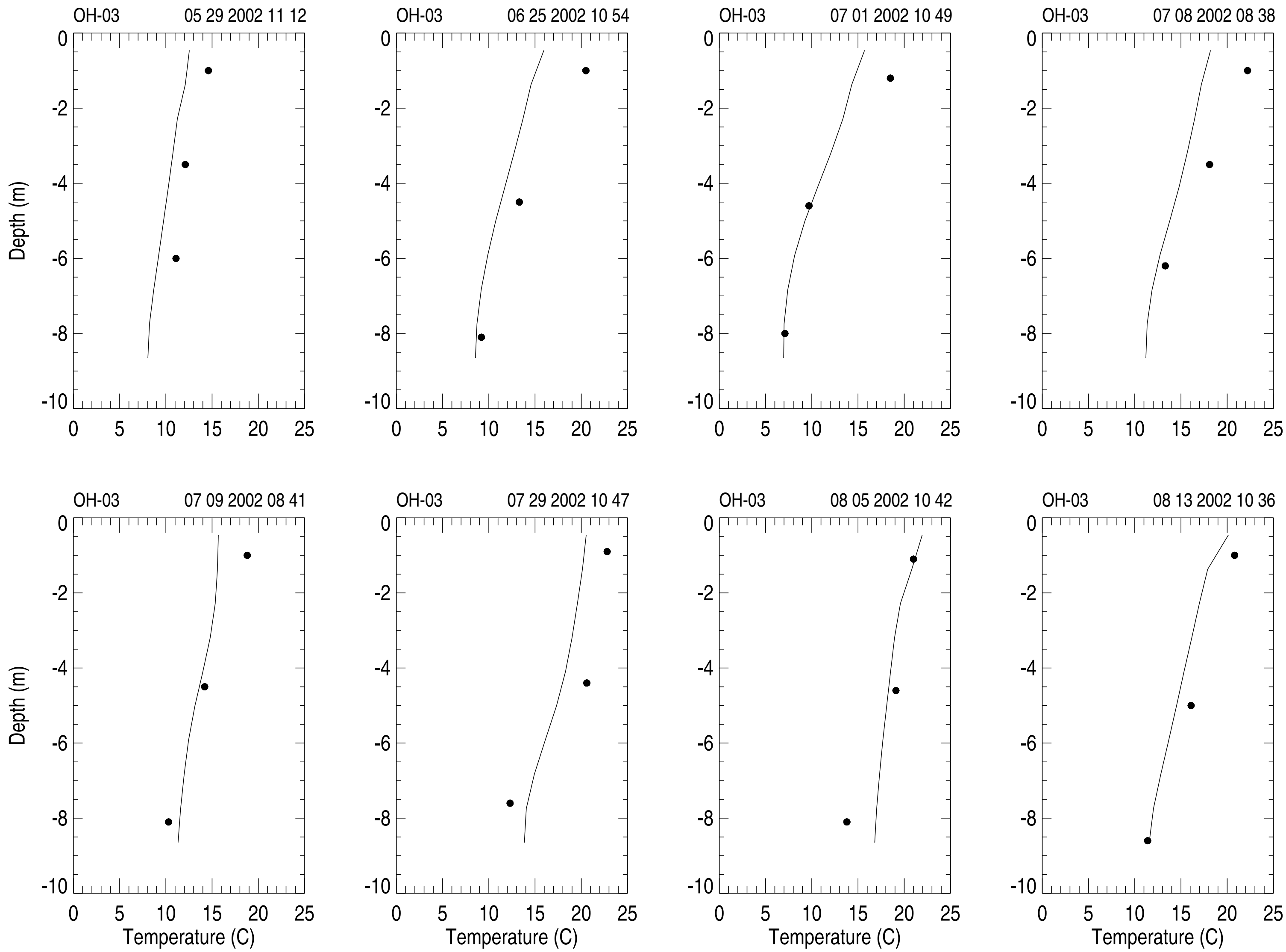

OH-14
03 27 2001 00 07
OH-14
04 16 2001 00 07
OH-14
05 09 2001 00 08
OH-14
05 23 2001 00 07
OH-14
06 11 2001 00 07
OH-14
07 03 2001 00 07
OH-14
07 24 2001 00 07
OH-14
08 01 2001 00 07
Depth (m)
0
-5
-10
-15
-20
0 5 10 15 20 25
Temperature (C)

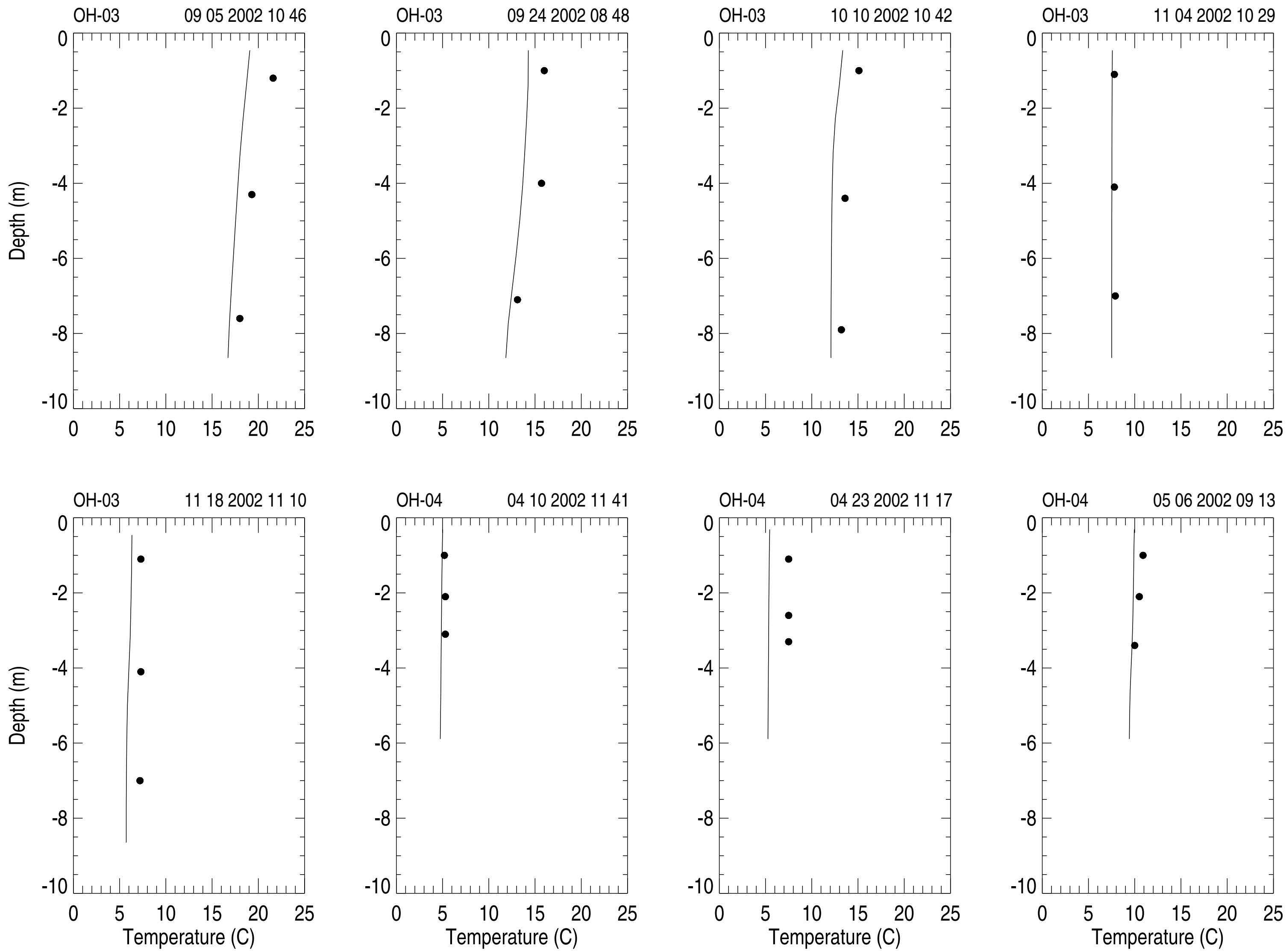

OH-14
08 14 2001 00 07
OH-14
09 12 2001 00 08
OH-14
11 15 2001 00 07
OH-15
04 16 2001 00 11
OH-15
05 09 2001 00 11
OH-15
05 23 2001 00 11
OH-15
06 11 2001 00 11
OH-15
07 03 2001 00 11
Depth (m)
Temperature (C)


OH-15
07 24 2001 00 11
OH-15
08 01 2001 00 11
OH-15
08 14 2001 00 11
OH-15
09 12 2001 00 11
OH-15
10 24 2001 00 09
OH-15
11 15 2001 00 11
Depth (m)
0
-1
-2
-3
-4
-5
0
5
10
15
20
25
Temperature (C)

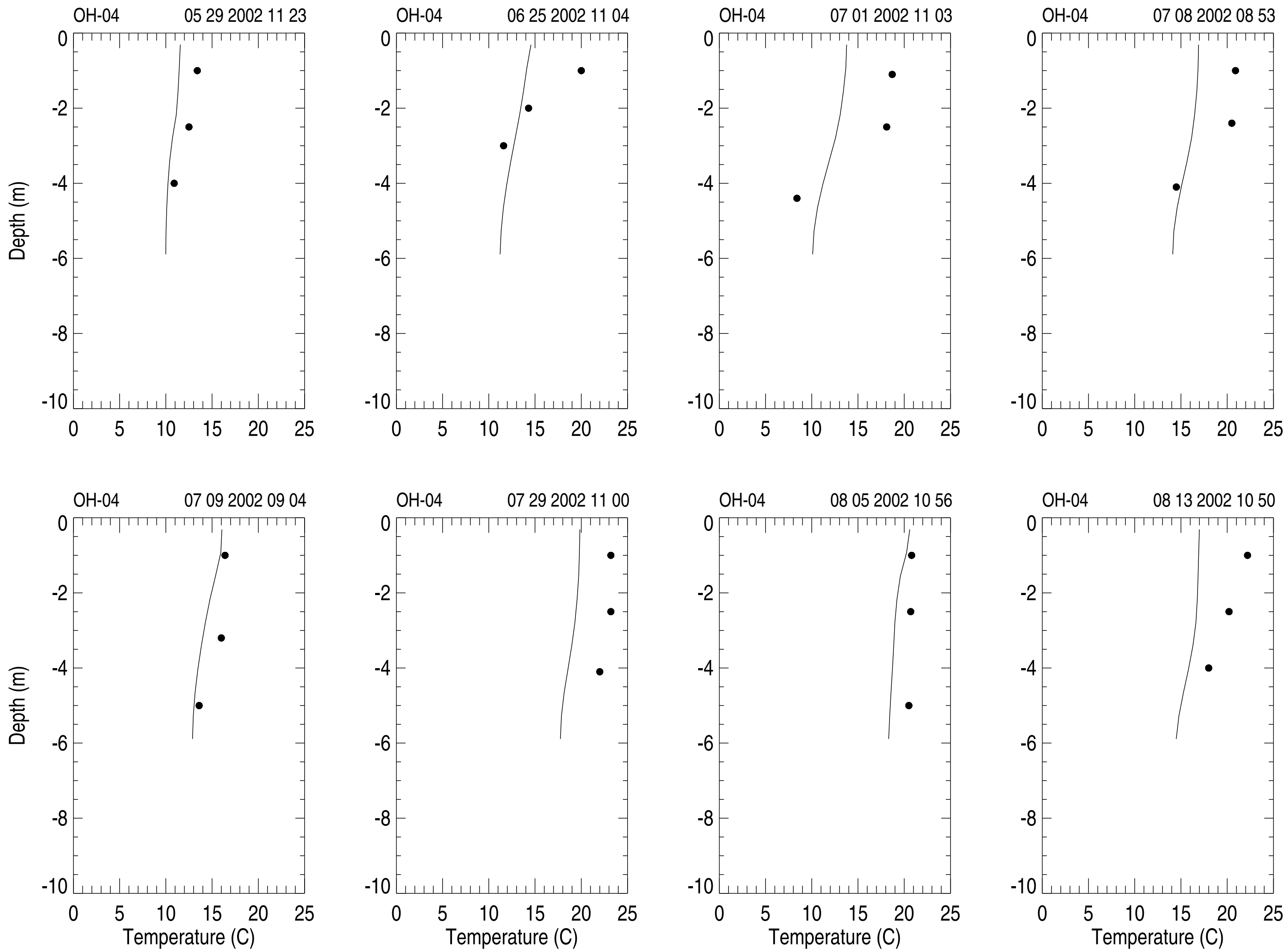

OH-01
04 10 2002 11 11
OH-01
04 23 2002 10 53
OH-01
05 06 2002 08 40
OH-01
05 29 2002 10 58
OH-01
06 25 2002 10 42
OH-01
07 01 2002 10 40
OH-01
07 29 2002 10 33
OH-01
08 05 2002 10 27
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

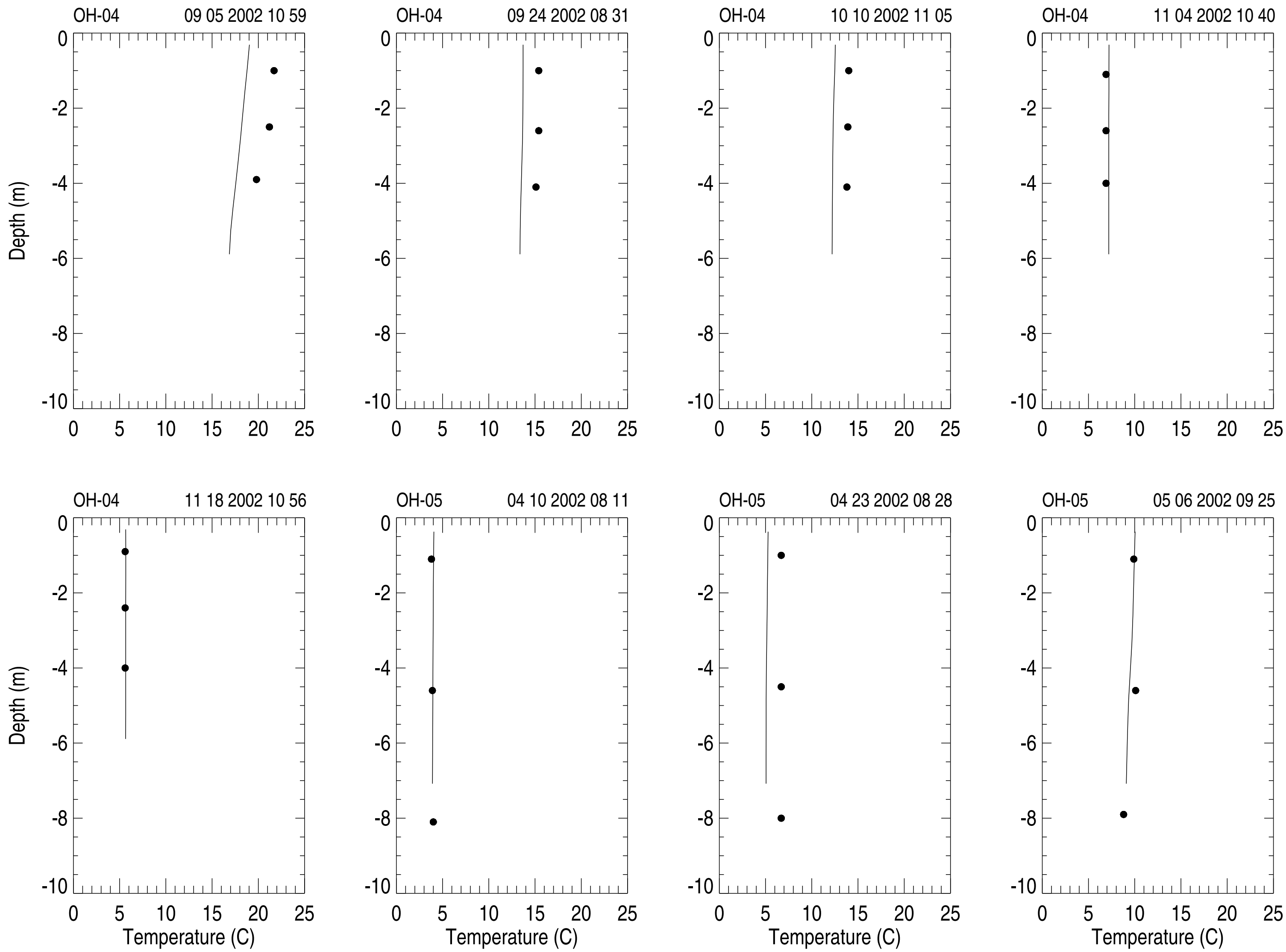

OH-01
09 05 2002 10 33
OH-01
09 24 2002 08 58
OH-01
10 10 2002 10 31
OH-01
11 04 2002 10 14
OH-01
11 18 2002 11 18
OH-03
04 10 2002 11 31
OH-03
04 23 2002 11 06
OH-03
05 06 2002 08 53
Depth (m)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
Temperature (C)

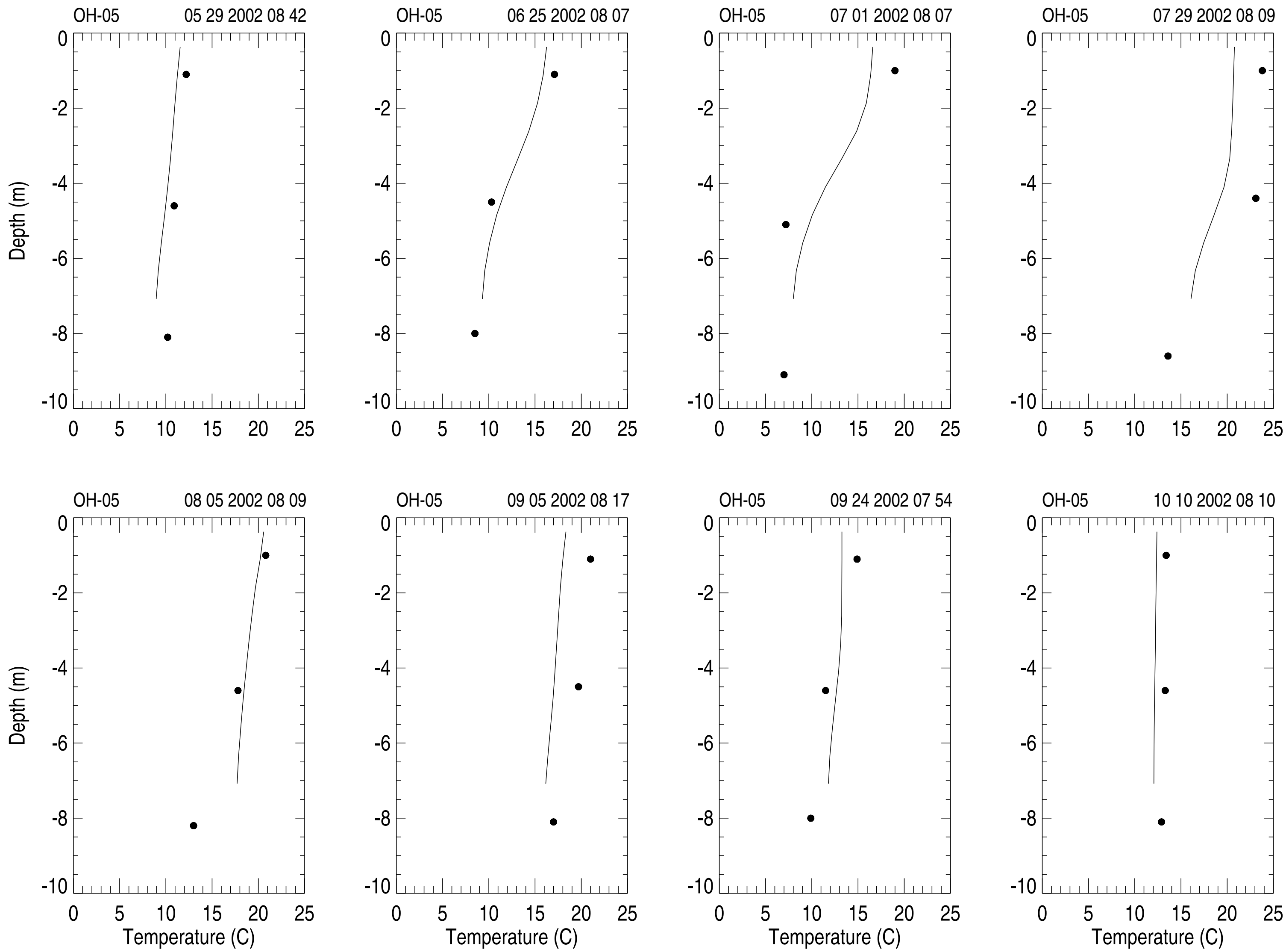

OH-03
05 29 2002 11 12
OH-03
06 25 2002 10 54
OH-03
07 01 2002 10 49
OH-03
07 08 2002 08 38
OH-03
07 09 2002 08 41
OH-03
07 29 2002 10 47
OH-03
08 05 2002 10 42
OH-03
08 13 2002 10 36
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25

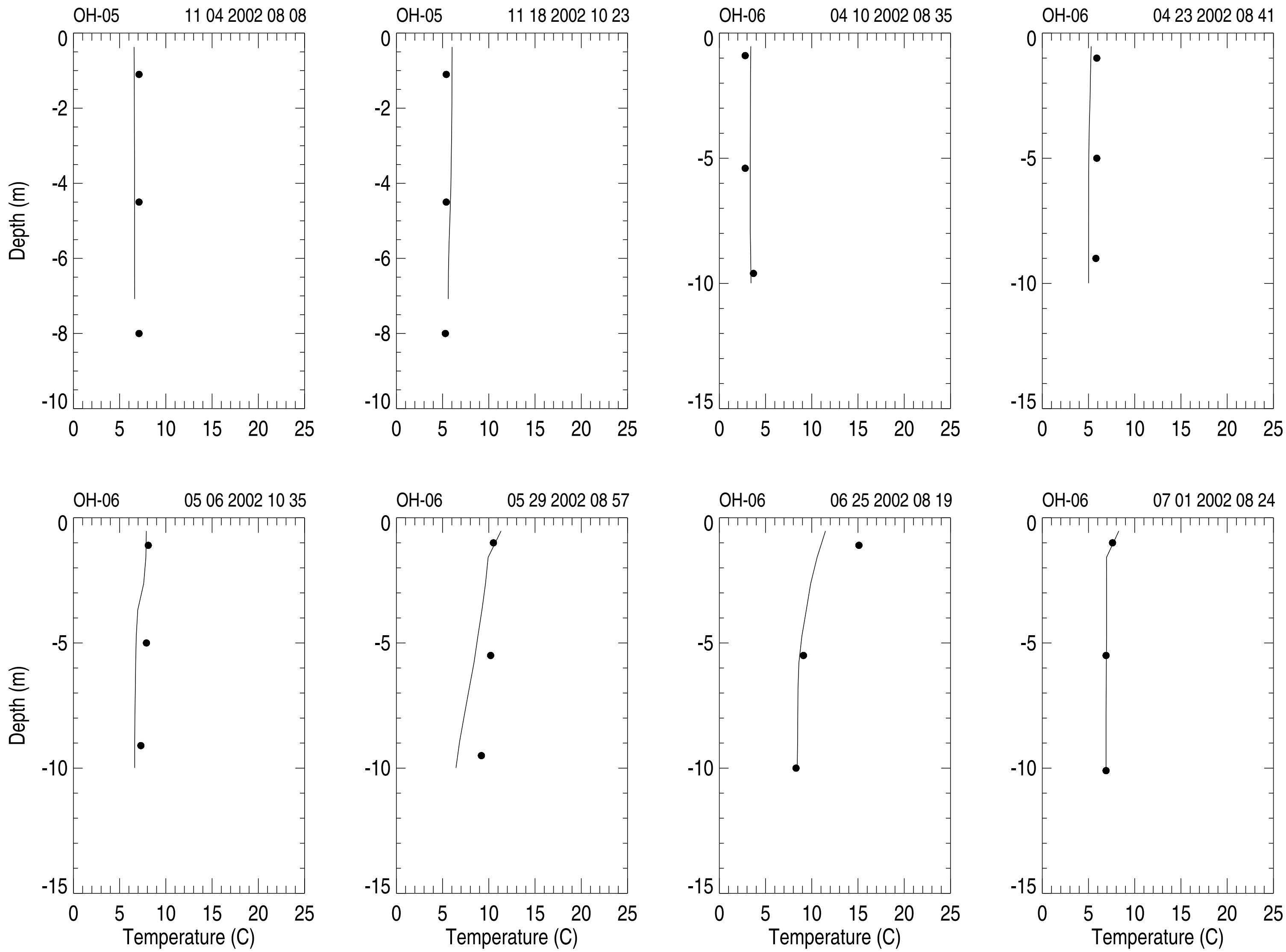


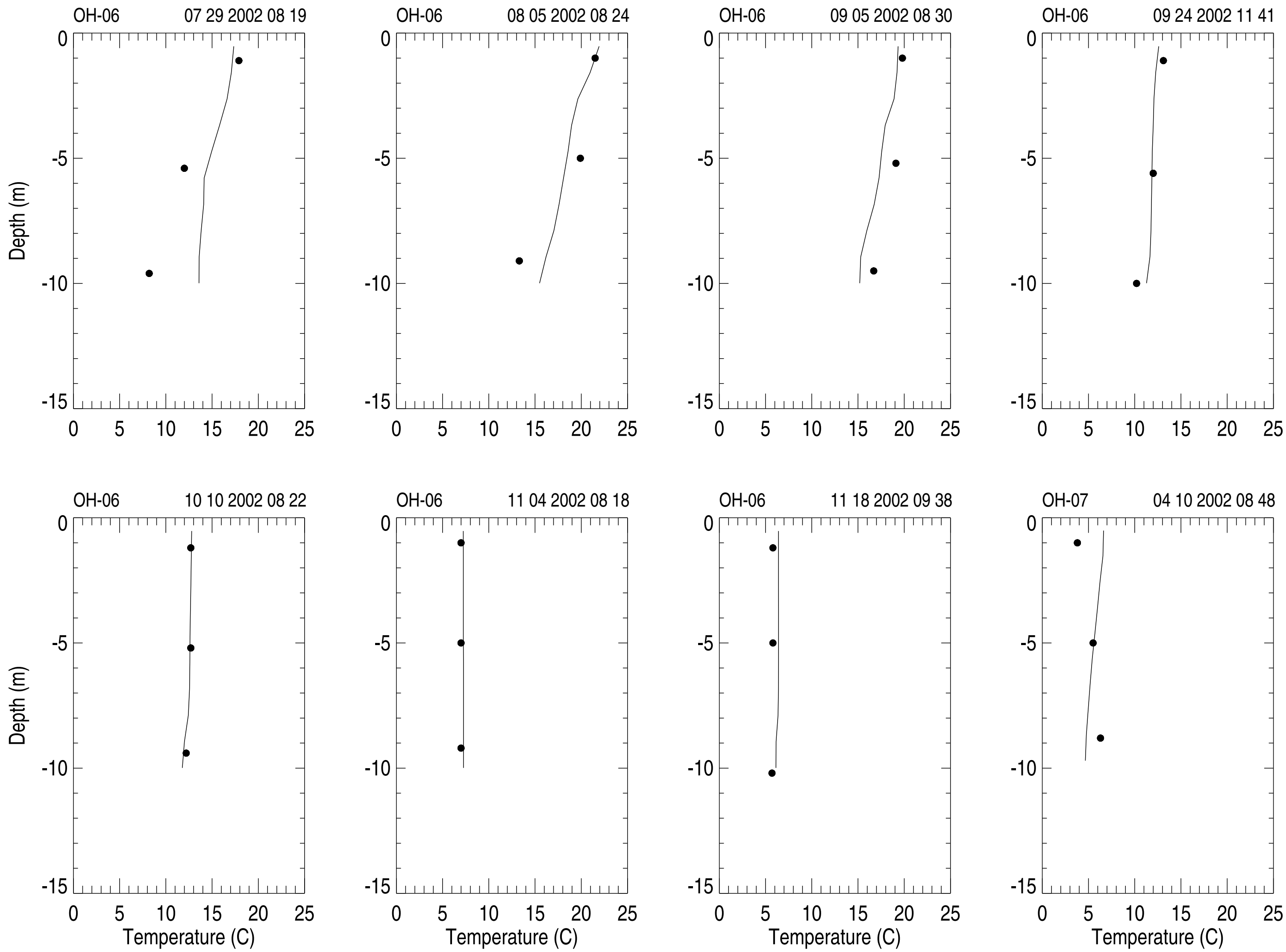
OH-03 09 05 2002 10 46
OH-03 09 24 2002 08 48
OH-03 10 10 2002 10 42
OH-03 11 04 2002 10 29
OH-03 11 18 2002 11 10
OH-04 04 10 2002 11 41
OH-04 04 23 2002 11 17
OH-04 05 06 2002 09 13
Depth (m)
Temperature (C)


OH-04 05 29 2002 11 23
OH-04 06 25 2002 11 04
OH-04 07 01 2002 11 03
OH-04 07 08 2002 08 53
OH-04 07 09 2002 09 04
OH-04 07 29 2002 11 00
OH-04 08 05 2002 10 56
OH-04 08 13 2002 10 50
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

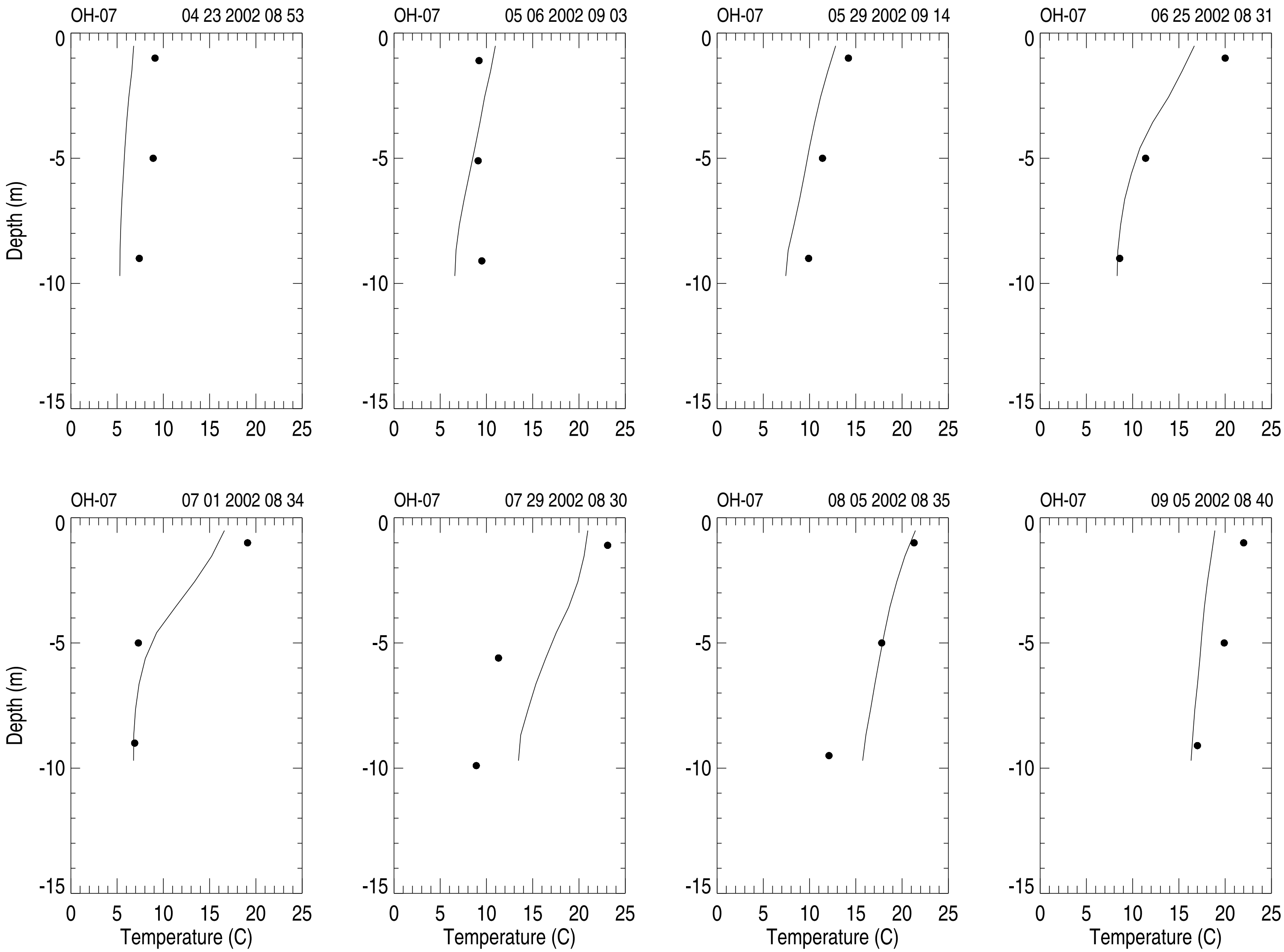

OH-04
09 05 2002 10 59
OH-04
09 24 2002 08 31
OH-04
10 10 2002 11 05
OH-04
11 04 2002 10 40
OH-04
11 18 2002 10 56
OH-05
04 10 2002 08 11
OH-05
04 23 2002 08 28
OH-05
05 06 2002 09 25
Depth (m)
Temperature (C)

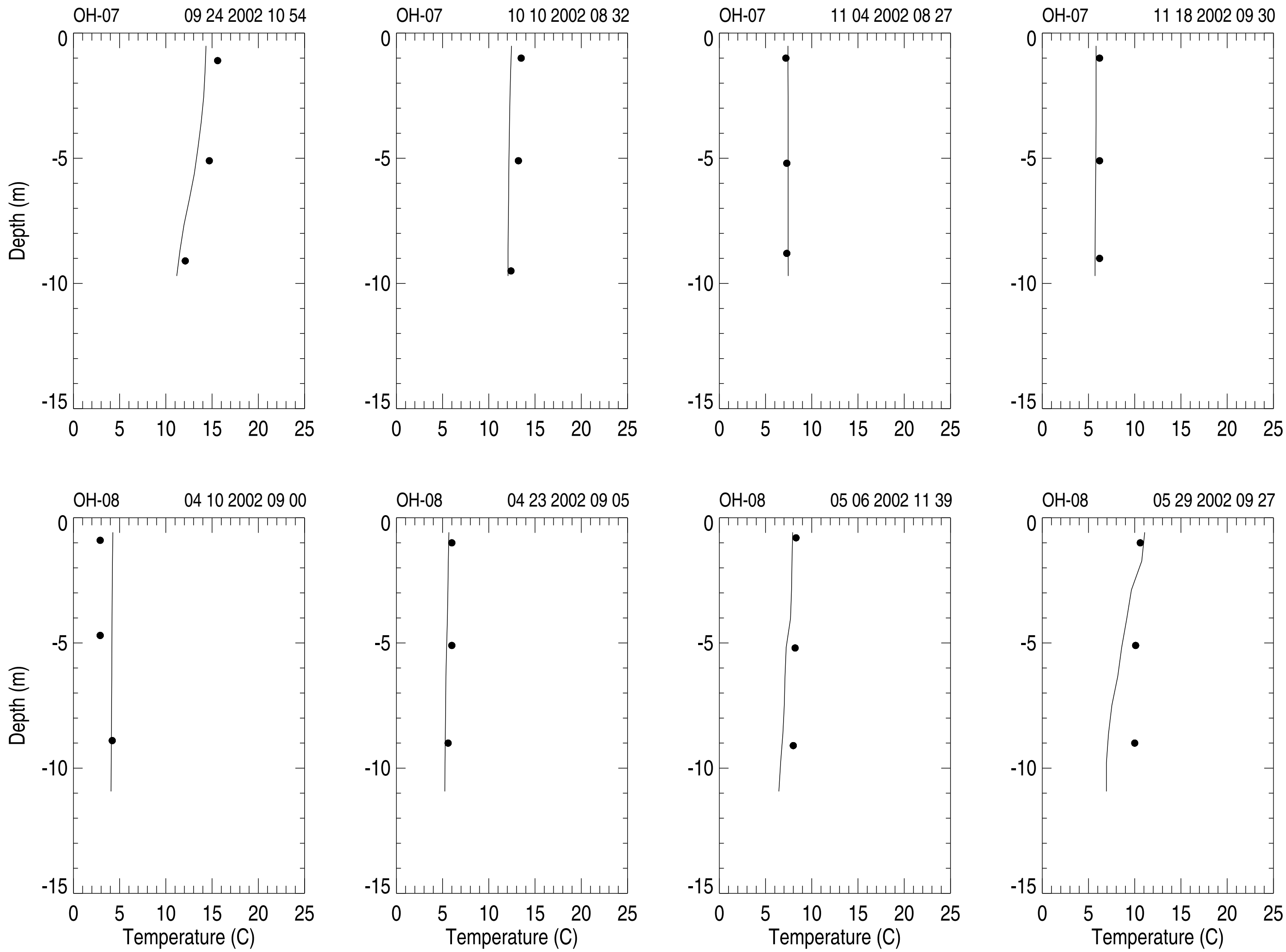

OH-05
05 29 2002 08 42
OH-05
06 25 2002 08 07
OH-05
07 01 2002 08 07
OH-05
07 29 2002 08 09
OH-05
08 05 2002 08 09
OH-05
09 05 2002 08 17
OH-05
09 24 2002 07 54
OH-05
10 10 2002 08 10
Depth (m)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
Temperature (C)

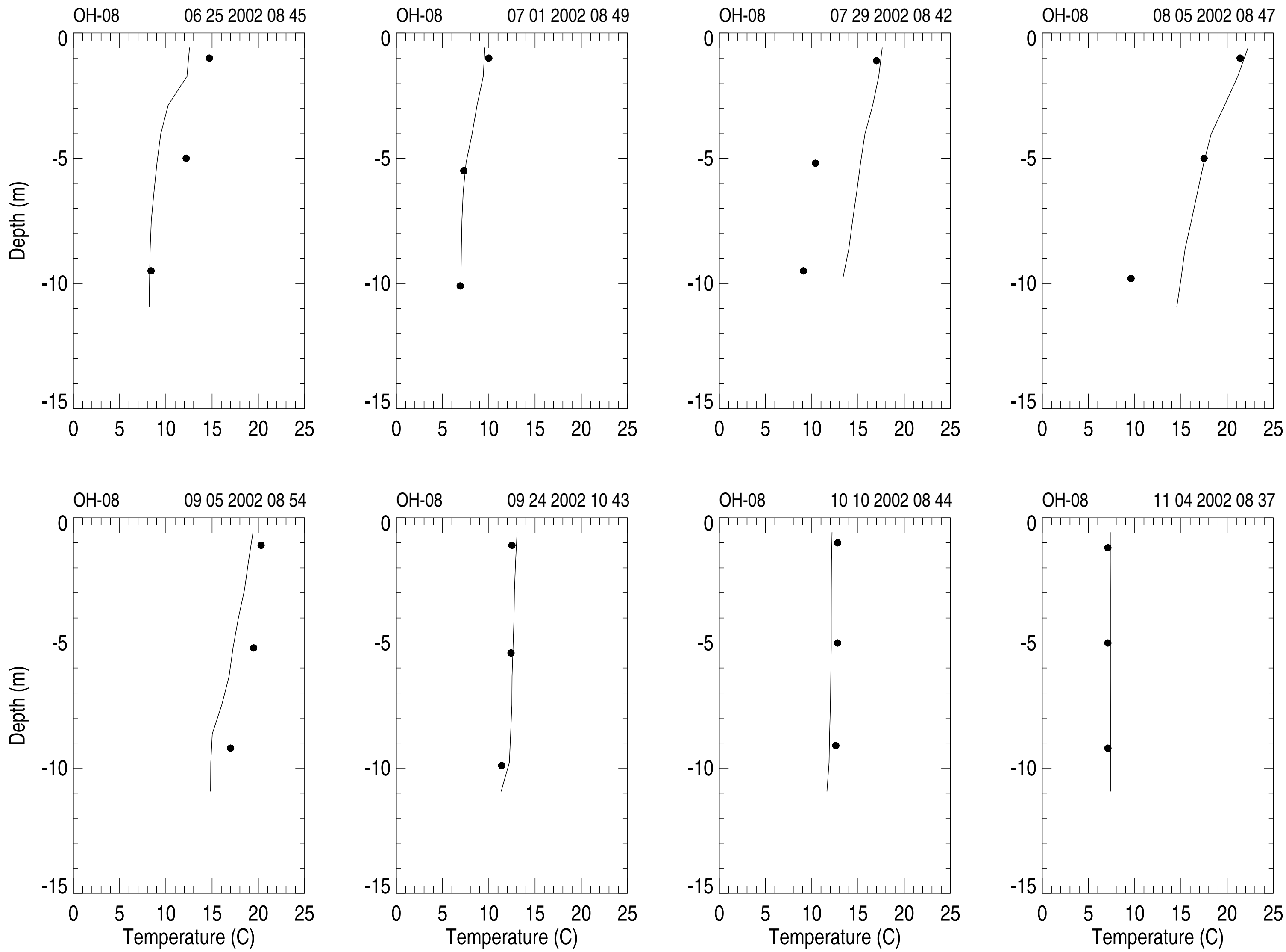

OH-05 11 04 2002 08 08
OH-05 11 18 2002 10 23
OH-06 04 10 2002 08 35
OH-06 04 23 2002 08 41
OH-06 05 06 2002 10 35
OH-06 05 29 2002 08 57
OH-06 06 25 2002 08 19
OH-06 07 01 2002 08 24
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
-5
-15
0 5 10 15 20 25

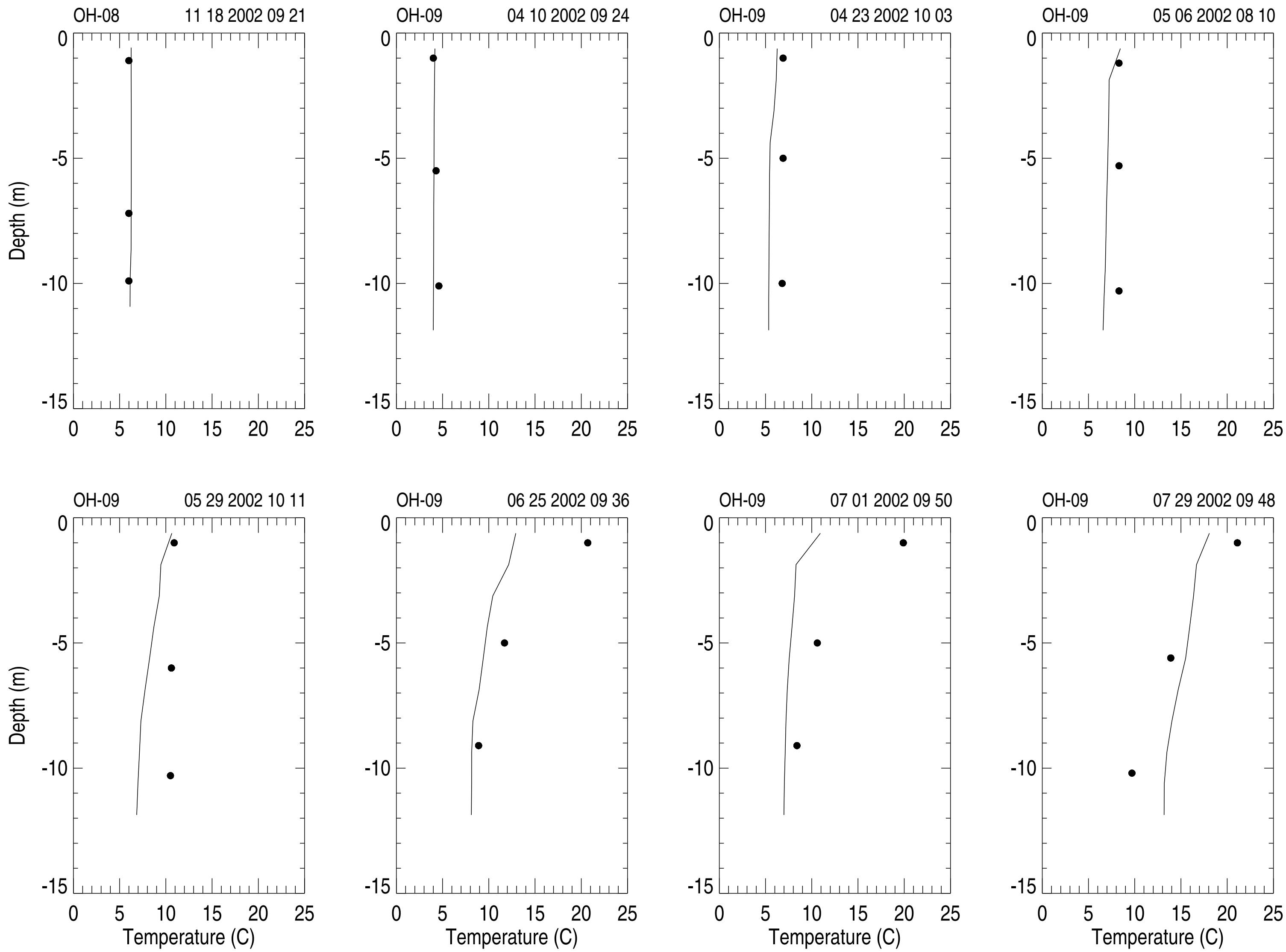


OH-06
07 29 2002 08 19
OH-06
08 05 2002 08 24
OH-06
09 05 2002 08 30
OH-06
09 24 2002 11 41
OH-06
10 10 2002 08 22
OH-06
11 04 2002 08 18
OH-06
11 18 2002 09 38
OH-07
04 10 2002 08 48
Depth (m)
Temperature (C)
0
-5
-10
-15
0 5 10 15 20 25

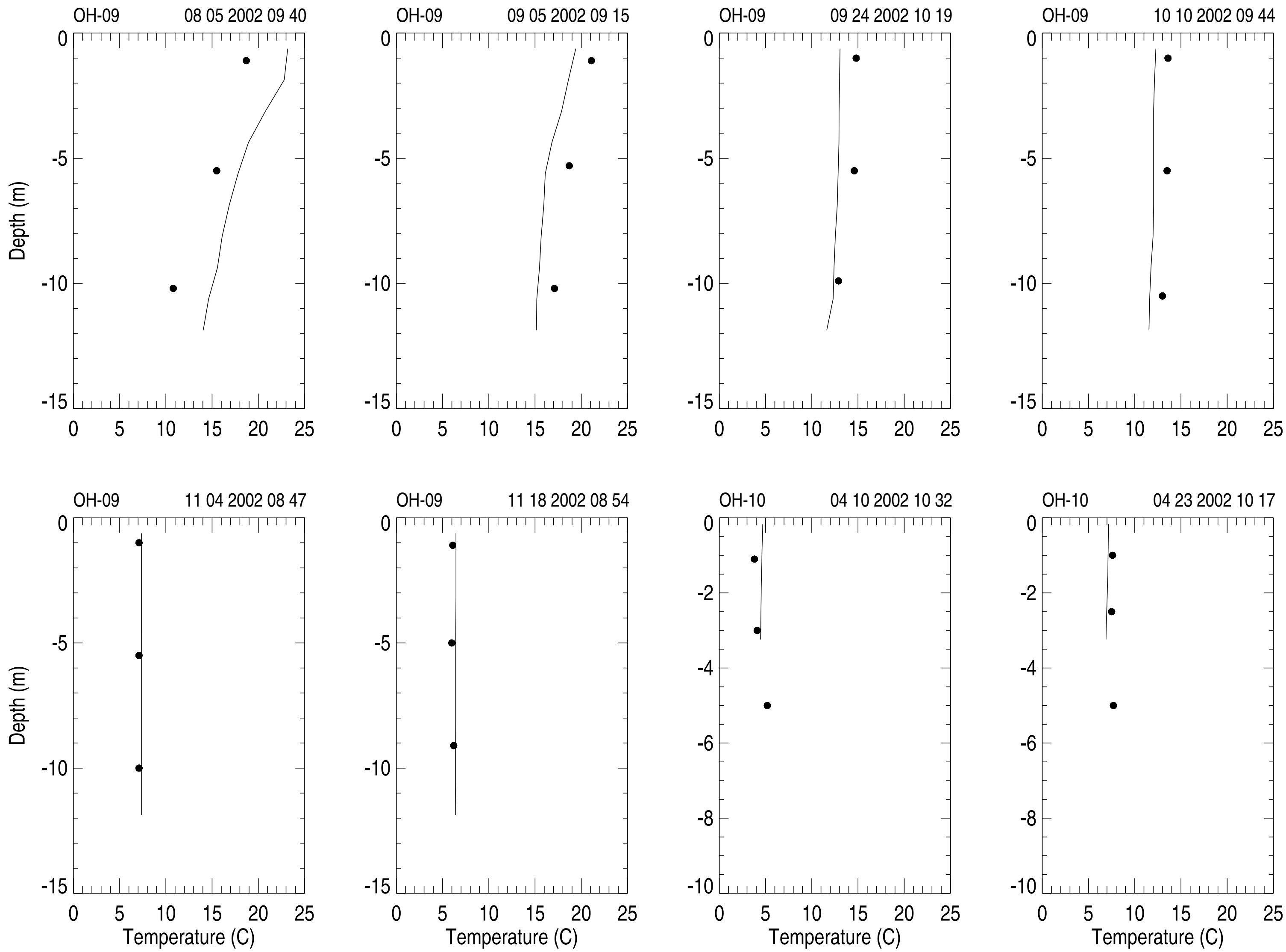

OH-07
04 23 2002 08 53
OH-07
05 06 2002 09 03
OH-07
05 29 2002 09 14
OH-07
06 25 2002 08 31
OH-07
07 01 2002 08 34
OH-07
07 29 2002 08 30
OH-07
08 05 2002 08 35
OH-07
09 05 2002 08 40
Depth (m)
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25
Temperature (C)
Temperature (C)
Temperature (C)
Temperature (C)


OH-07
09 24 2002 10 54
OH-07
10 10 2002 08 32
OH-07
11 04 2002 08 27
OH-07
11 18 2002 09 30
OH-08
04 10 2002 09 00
OH-08
04 23 2002 09 05
OH-08
05 06 2002 11 39
OH-08
05 29 2002 09 27
Depth (m)
0
-5
-10
-15
0
5
10
15
20
25
Temperature (C)

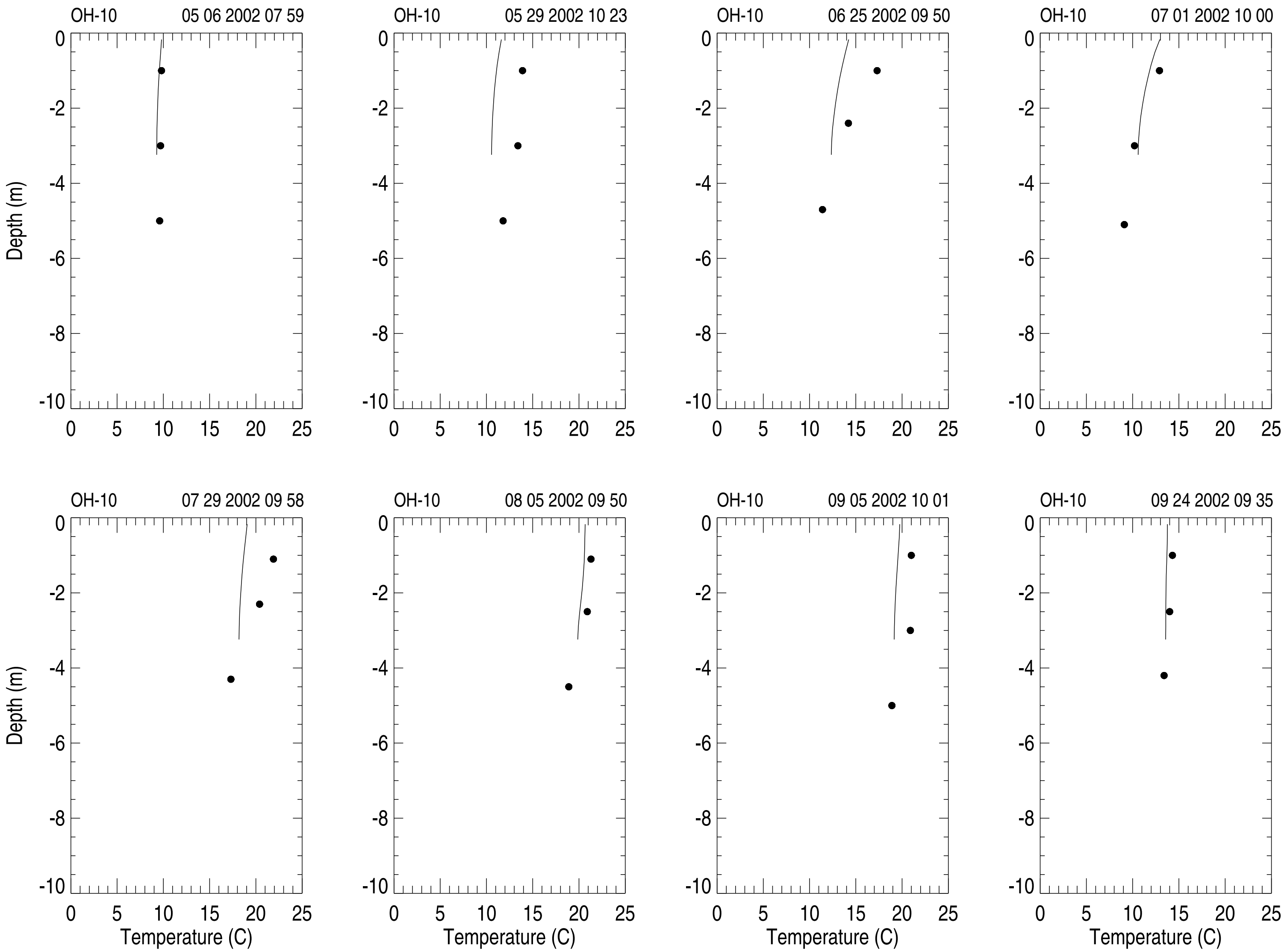

OH-08
06 25 2002 08 45
OH-08
07 01 2002 08 49
OH-08
07 29 2002 08 42
OH-08
08 05 2002 08 47
OH-08
09 05 2002 08 54
OH-08
09 24 2002 10 43
OH-08
10 10 2002 08 44
OH-08
11 04 2002 08 37
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25
Temperature (C)

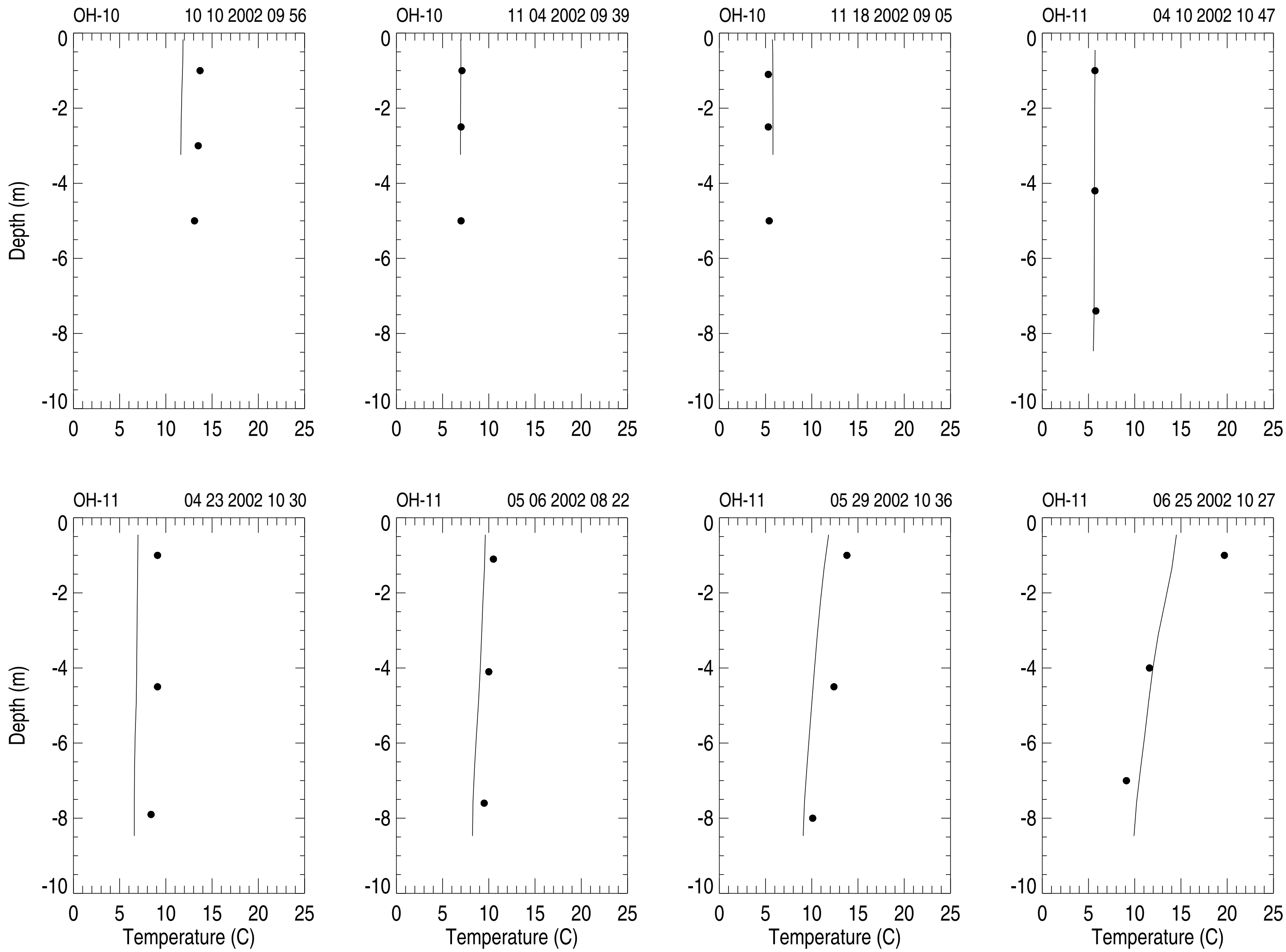


OH-08
11 18 2002 09 21
OH-09
04 10 2002 09 24
OH-09
04 23 2002 10 03
OH-09
05 06 2002 08 10
OH-09
05 29 2002 10 11
OH-09
06 25 2002 09 36
OH-09
07 01 2002 09 50
OH-09
07 29 2002 09 48
Depth (m)
Temperature (C)

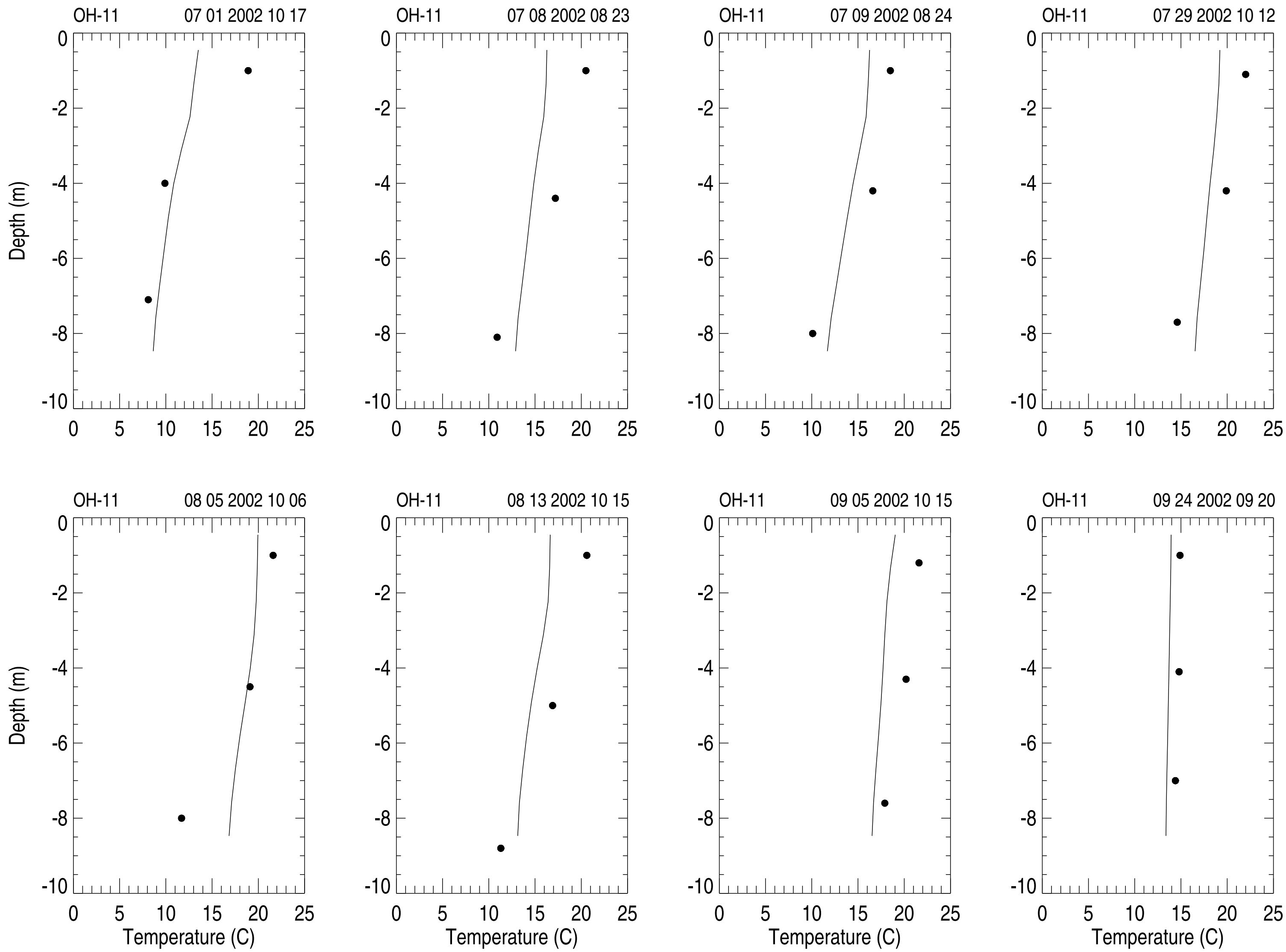


OH-09
08 05 2002 09 40
OH-09
09 05 2002 09 15
OH-09
09 24 2002 10 19
OH-09
10 10 2002 09 44
OH-09
11 04 2002 08 47
OH-09
11 18 2002 08 54
OH-10
04 10 2002 10 32
OH-10
04 23 2002 10 17
Depth (m)
Temperature (C)

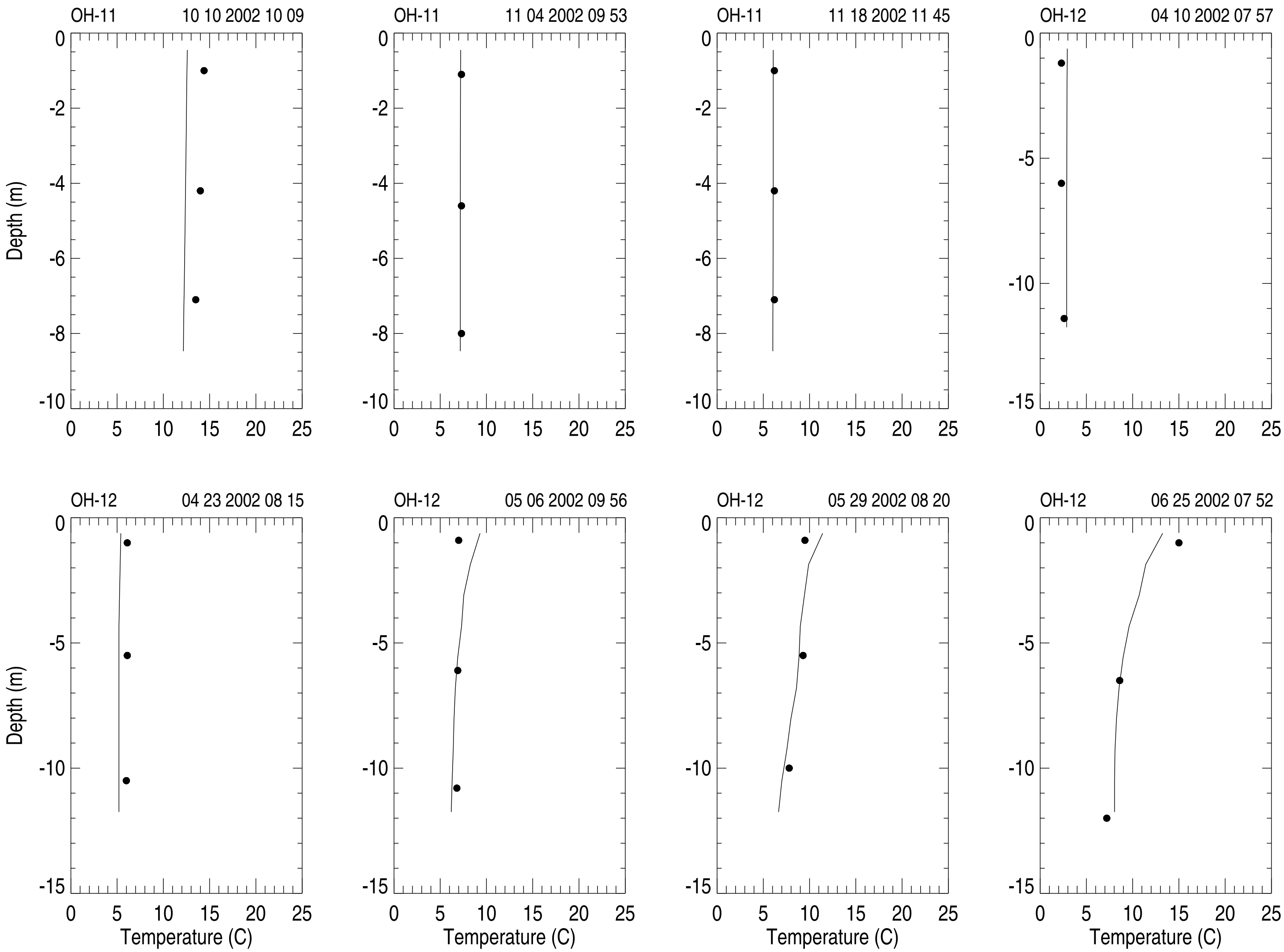

OH-10 05 06 2002 07 59
OH-10 05 29 2002 10 23
OH-10 06 25 2002 09 50
OH-10 07 01 2002 10 00
OH-10 07 29 2002 09 58
OH-10 08 05 2002 09 50
OH-10 09 05 2002 10 01
OH-10 09 24 2002 09 35
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)

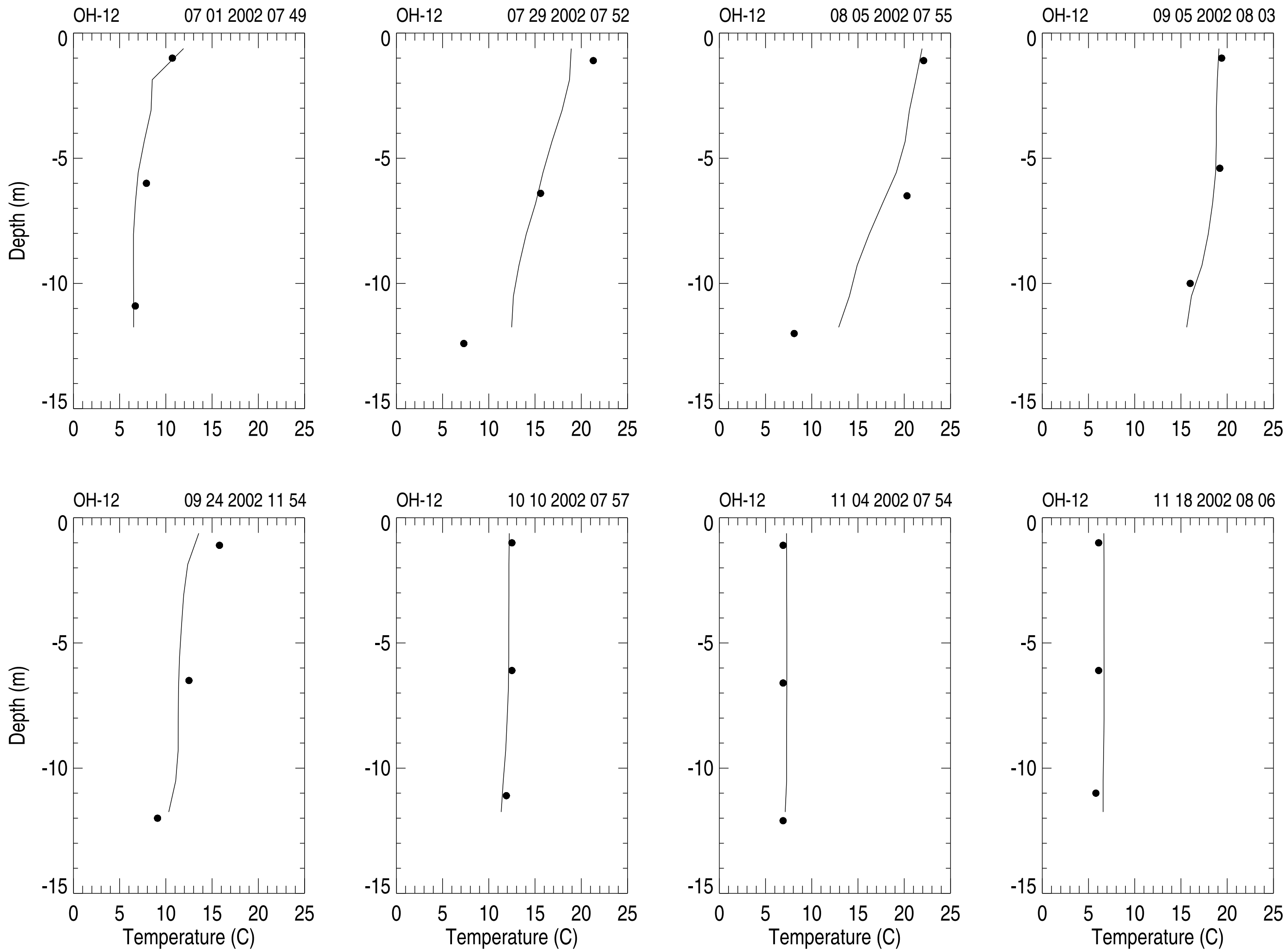


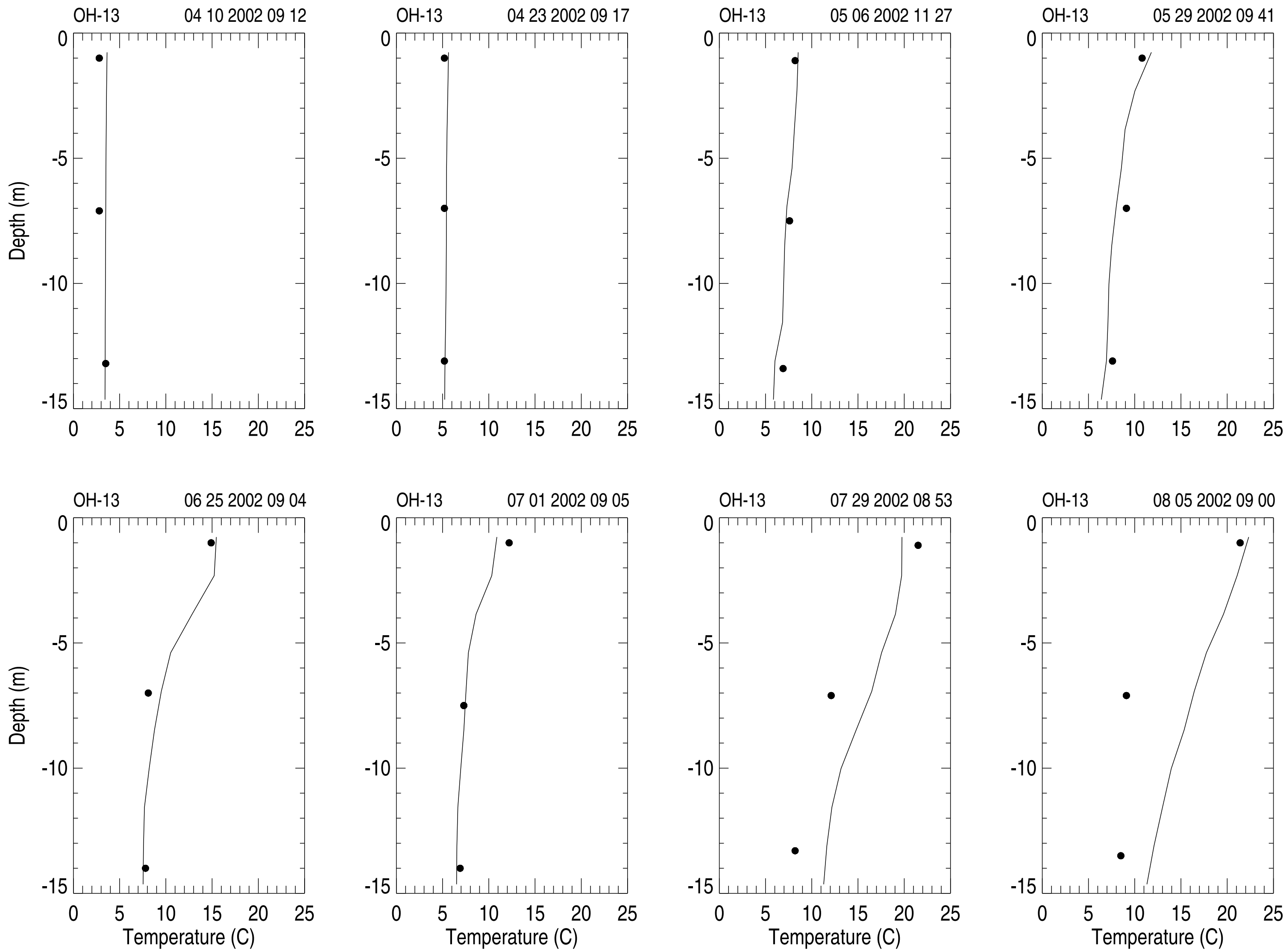
OH-10 10 10 2002 09 56
OH-10 11 04 2002 09 39
OH-10 11 18 2002 09 05
OH-11 04 10 2002 10 47
OH-11 04 23 2002 10 30
OH-11 05 06 2002 08 22
OH-11 05 29 2002 10 36
OH-11 06 25 2002 10 27
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25
Temperature (C)



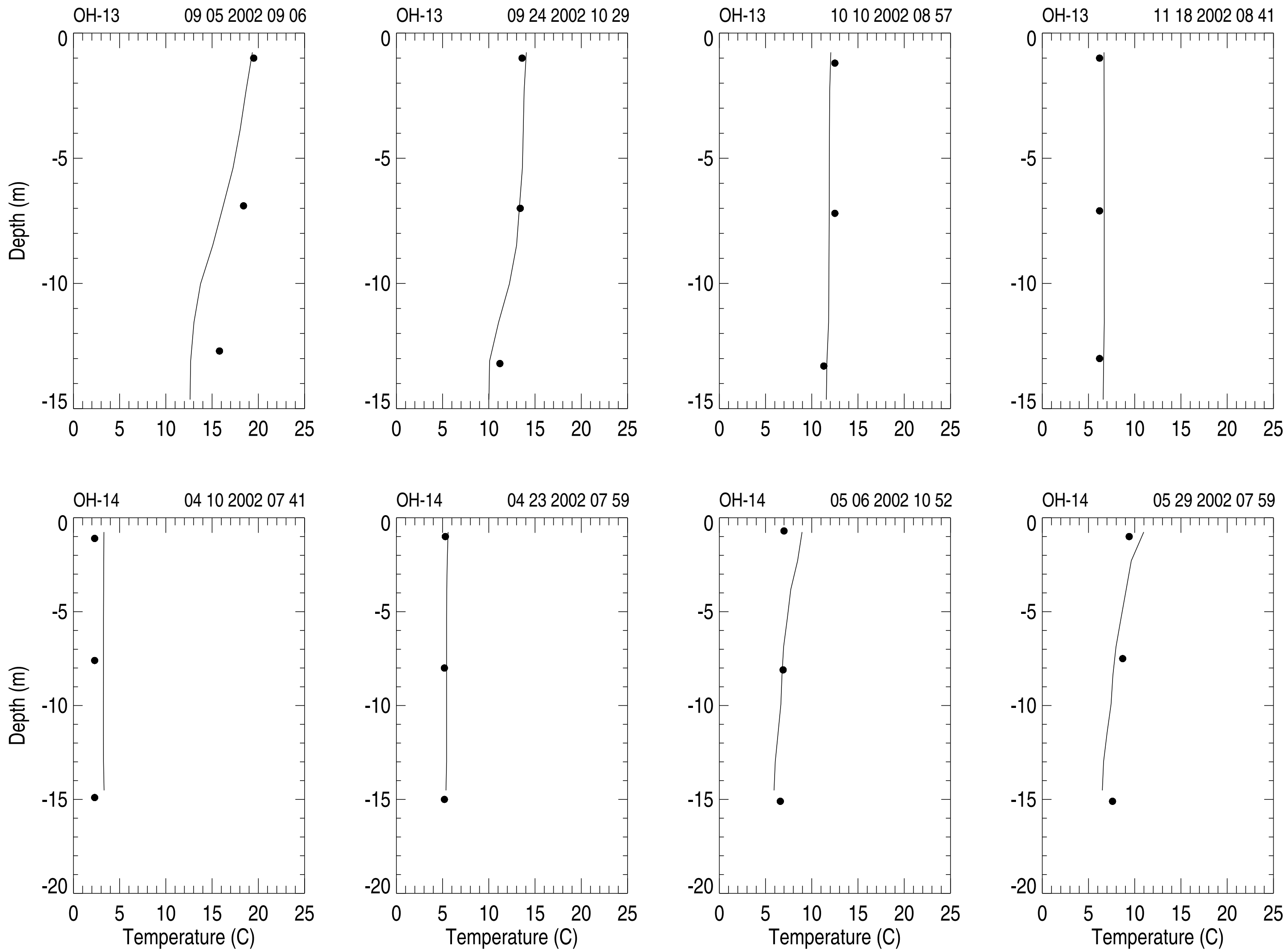
OH-11
07 01 2002 10 17
OH-11
07 08 2002 08 23
OH-11
07 09 2002 08 24
OH-11
07 29 2002 10 12
OH-11
08 05 2002 10 06
OH-11
08 13 2002 10 15
OH-11
09 05 2002 10 15
OH-11
09 24 2002 09 20
Depth (m)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
Temperature (C)

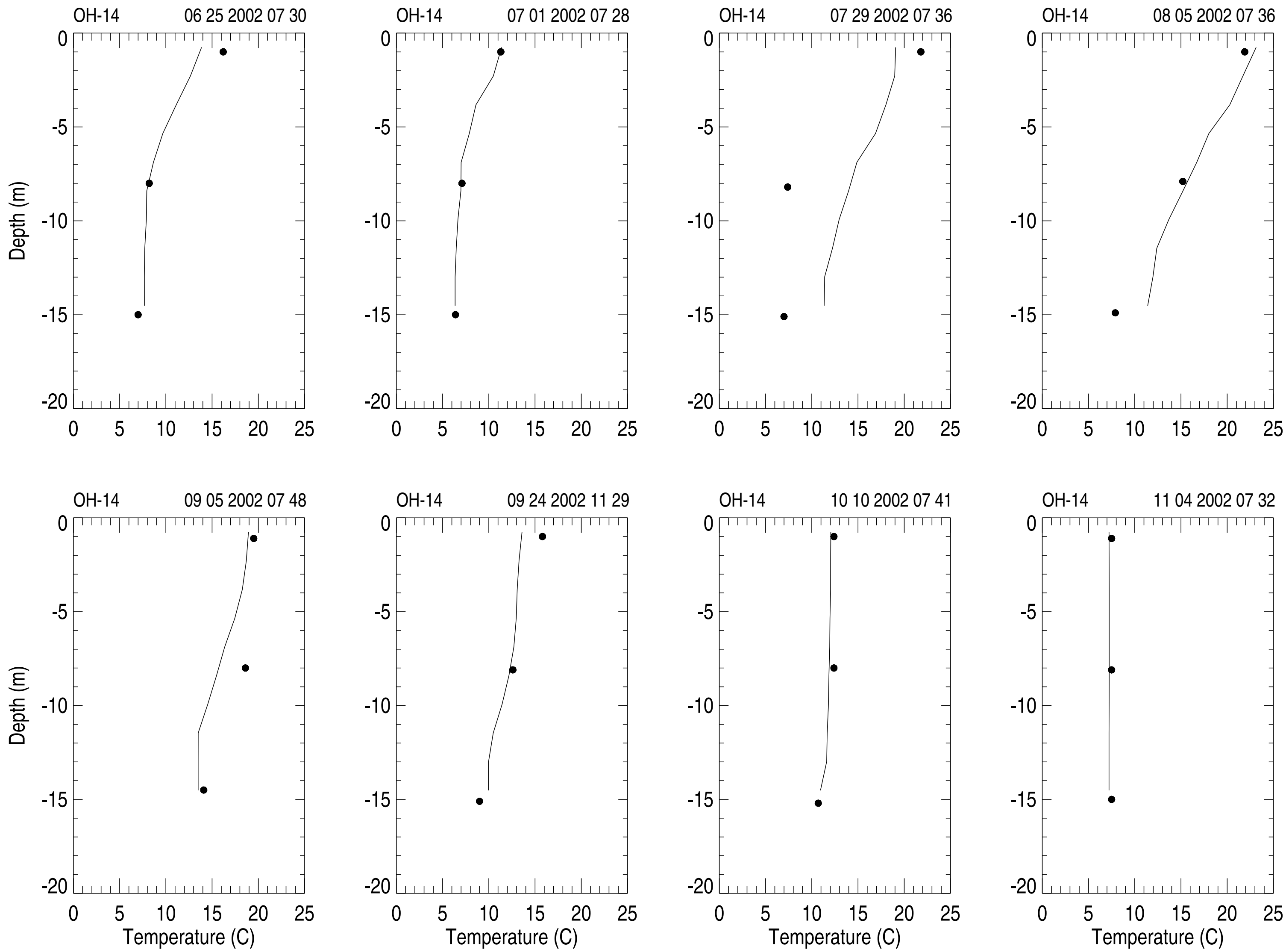

OH-11
10 10 2002 10 09
OH-11
11 04 2002 09 53
OH-11
11 18 2002 11 45
OH-12
04 10 2002 07 57
OH-12
04 23 2002 08 15
OH-12
05 06 2002 09 56
OH-12
05 29 2002 08 20
OH-12
06 25 2002 07 52
Depth (m)
Temperature (C)

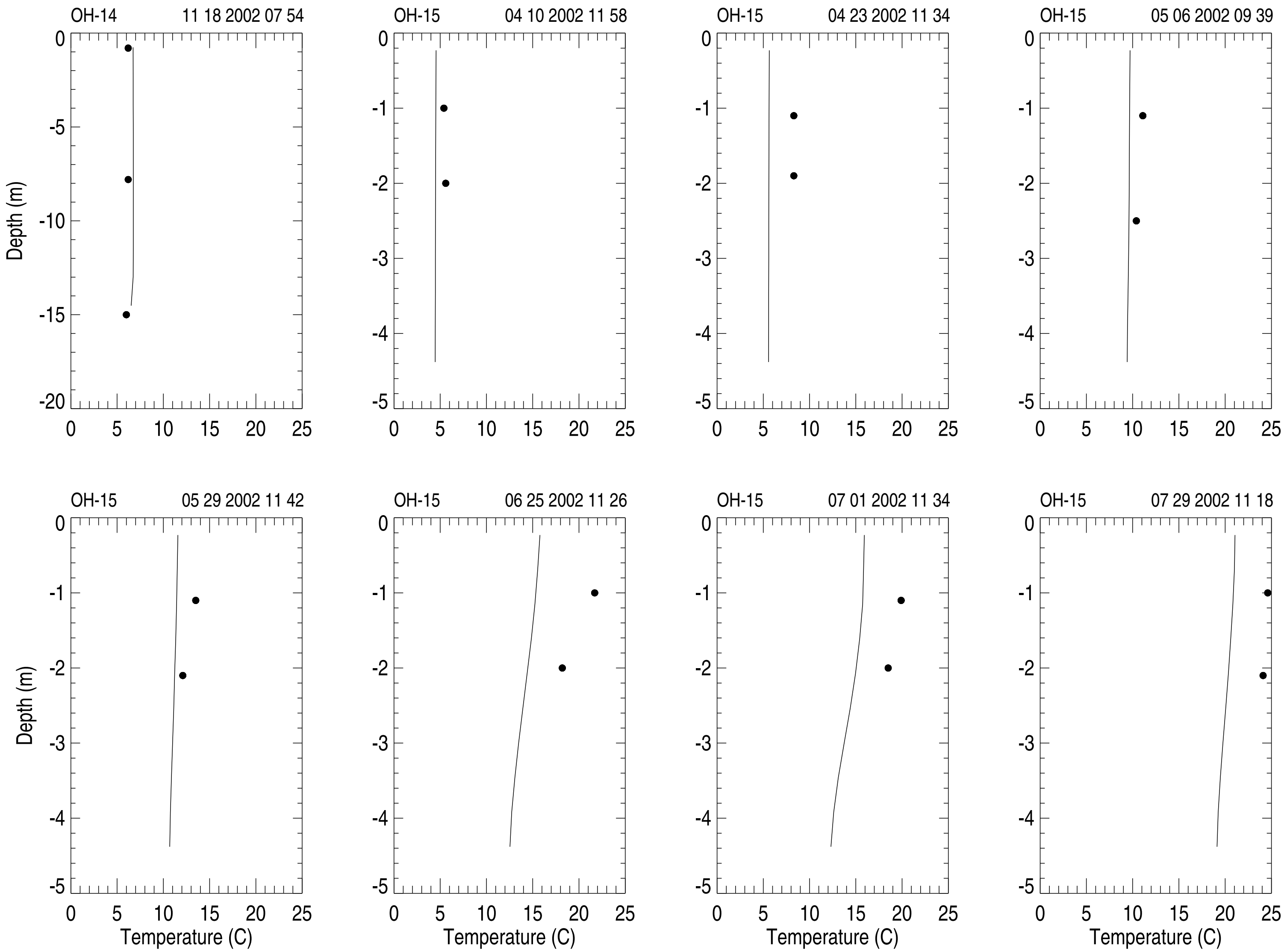

OH-12
07 01 2002 07 49
OH-12
07 29 2002 07 52
OH-12
08 05 2002 07 55
OH-12
09 05 2002 08 03
OH-12
09 24 2002 11 54
OH-12
10 10 2002 07 57
OH-12
11 04 2002 07 54
OH-12
11 18 2002 08 06
Depth (m)
0
-5
-10
-15
0
5
10
15
20
25
Temperature (C)

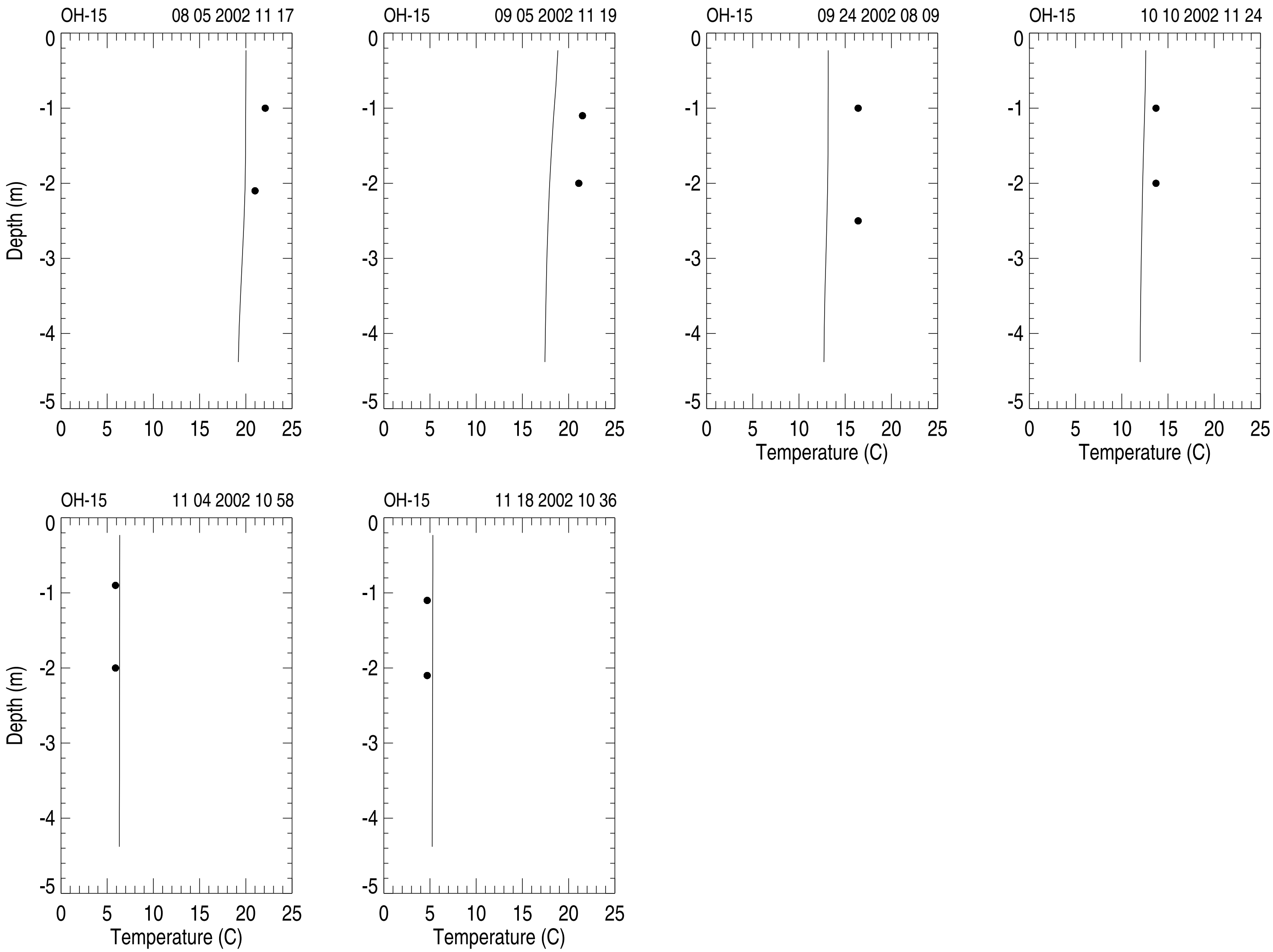


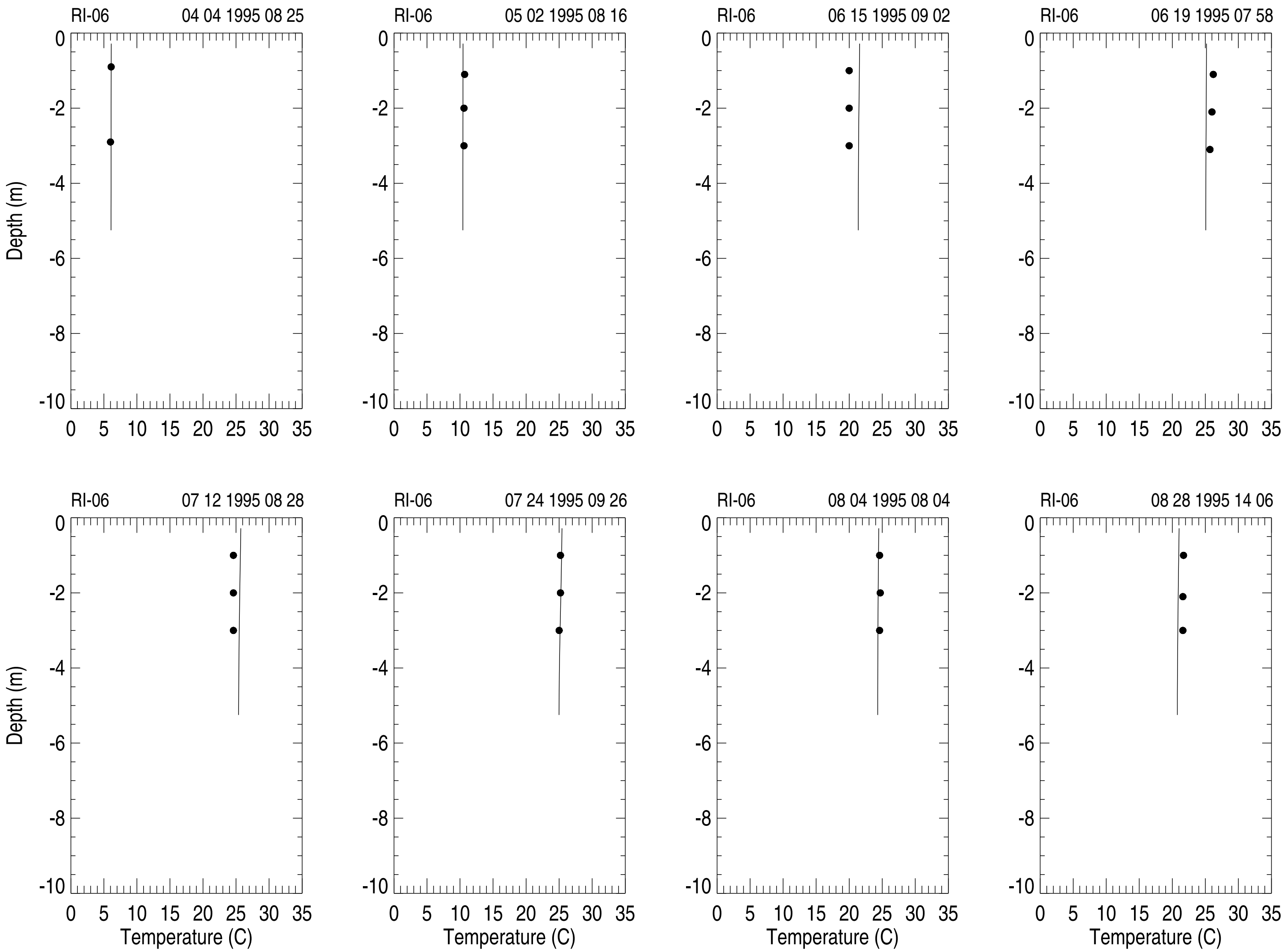
OH-13
04 10 2002 09 12
OH-13
04 23 2002 09 17
OH-13
05 06 2002 11 27
OH-13
05 29 2002 09 41
OH-13
06 25 2002 09 04
OH-13
07 01 2002 09 05
OH-13
07 29 2002 08 53
OH-13
08 05 2002 09 00
Depth (m)
Temperature (C)
0
-5
-10
-15
0 5 10 15 20 25

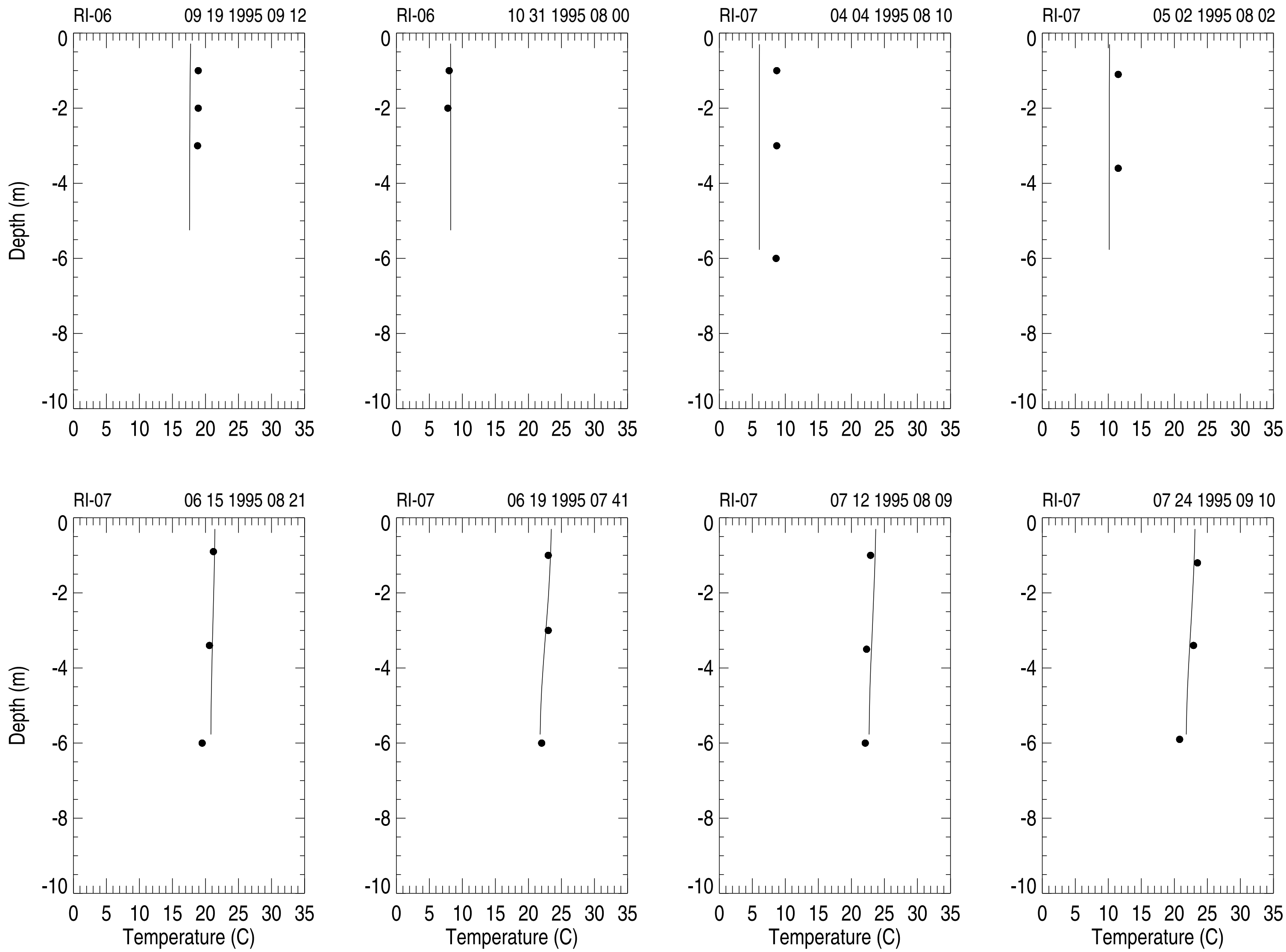

OH-13 09 05 2002 09 06
OH-13 09 24 2002 10 29
OH-13 10 10 2002 08 57
OH-13 11 18 2002 08 41
OH-14 04 10 2002 07 41
OH-14 04 23 2002 07 59
OH-14 05 06 2002 10 52
OH-14 05 29 2002 07 59
Depth (m)
Temperature (C)
0
-5
-10
-15
-20
0
5
10
15
20
25

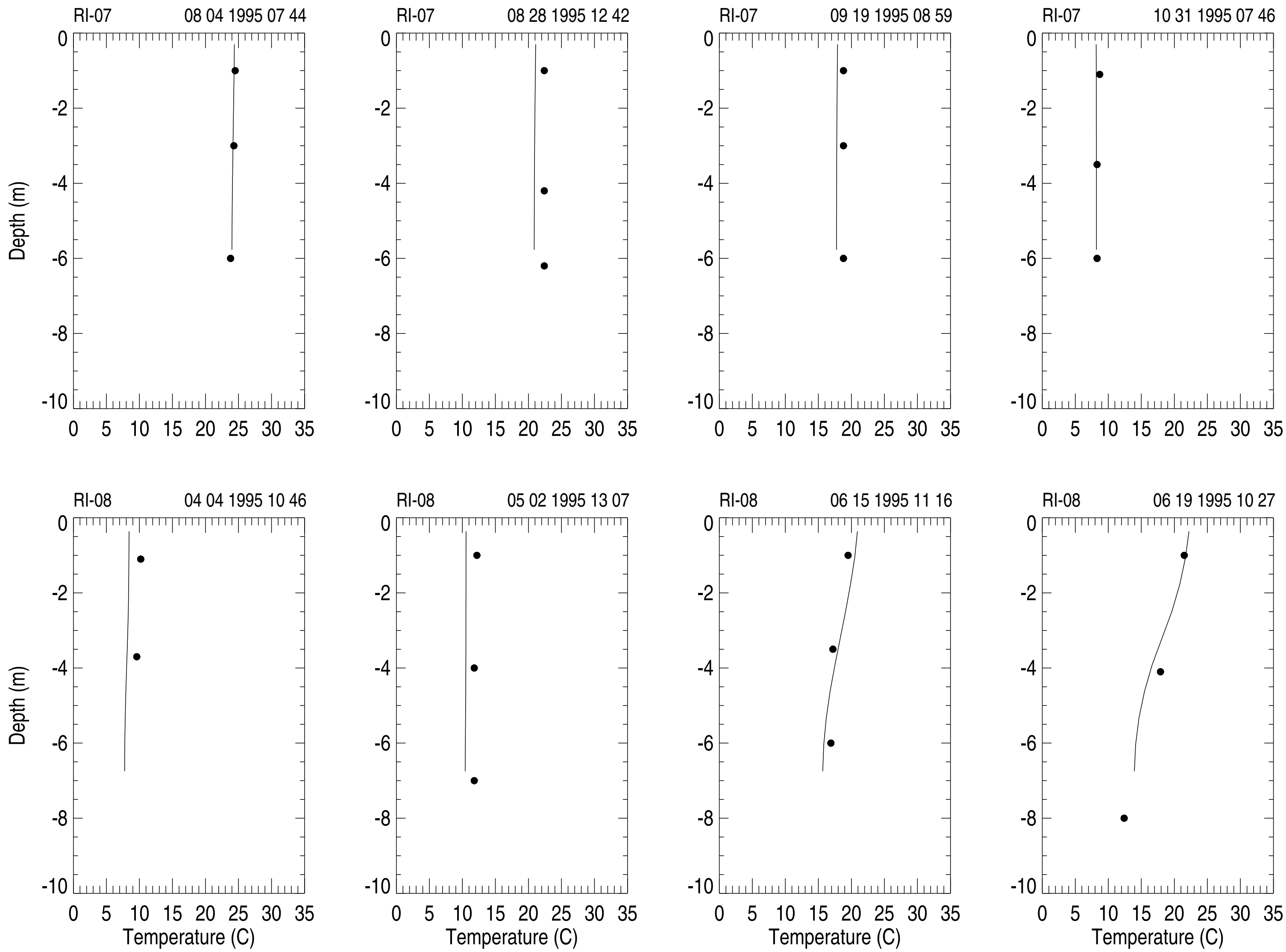

OH-14
06 25 2002 07 30
OH-14
07 01 2002 07 28
OH-14
07 29 2002 07 36
OH-14
08 05 2002 07 36
OH-14
09 05 2002 07 48
OH-14
09 24 2002 11 29
OH-14
10 10 2002 07 41
OH-14
11 04 2002 07 32
Depth (m)
Temperature (C)
0
-5
-10
-15
-20
0
5
10
15
20
25

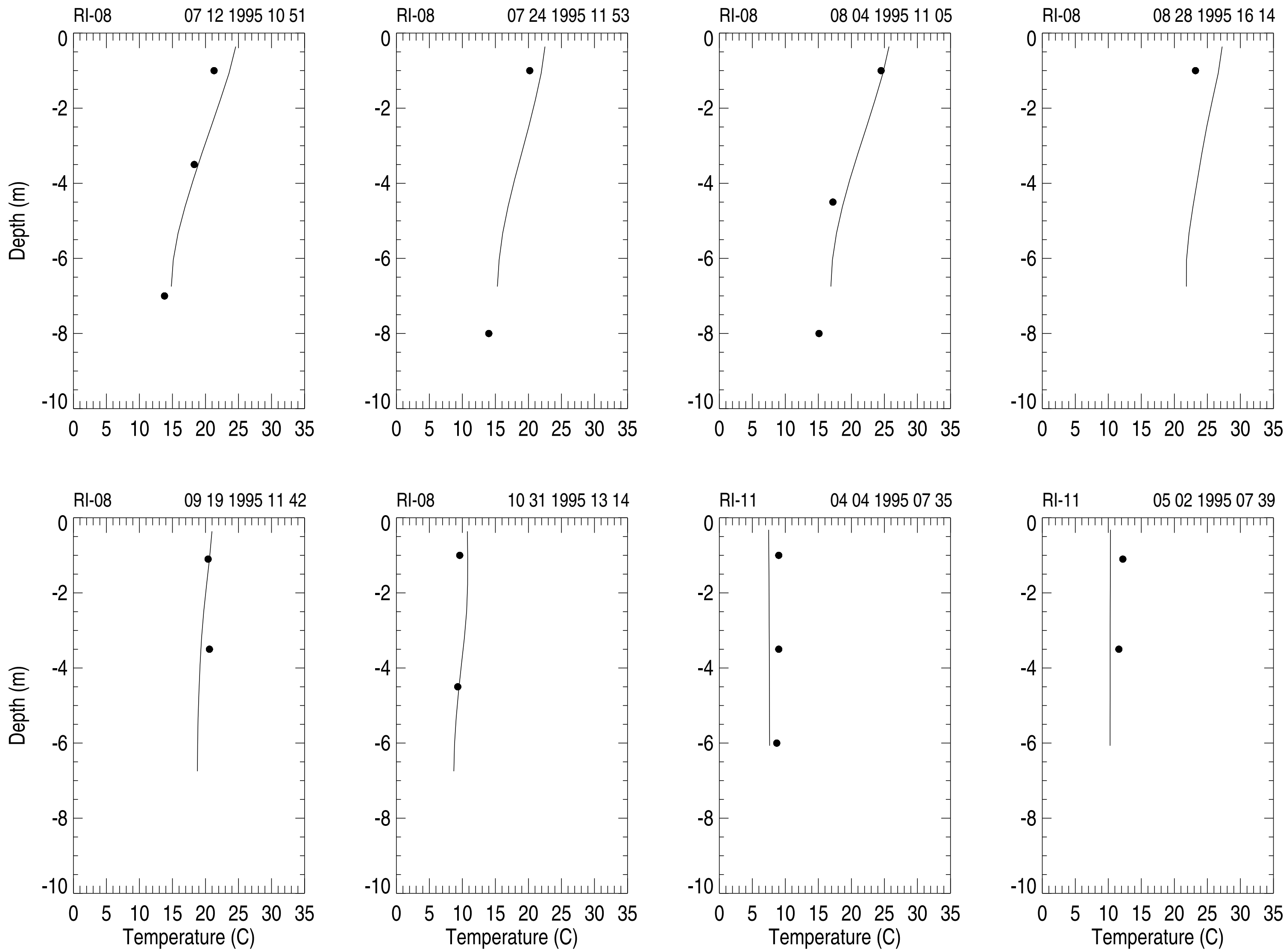

OH-14
11 18 2002 07 54
OH-15
04 10 2002 11 58
OH-15
04 23 2002 11 34
OH-15
05 06 2002 09 39
OH-15
05 29 2002 11 42
OH-15
06 25 2002 11 26
OH-15
07 01 2002 11 34
OH-15
07 29 2002 11 18
Depth (m)
Temperature (C)

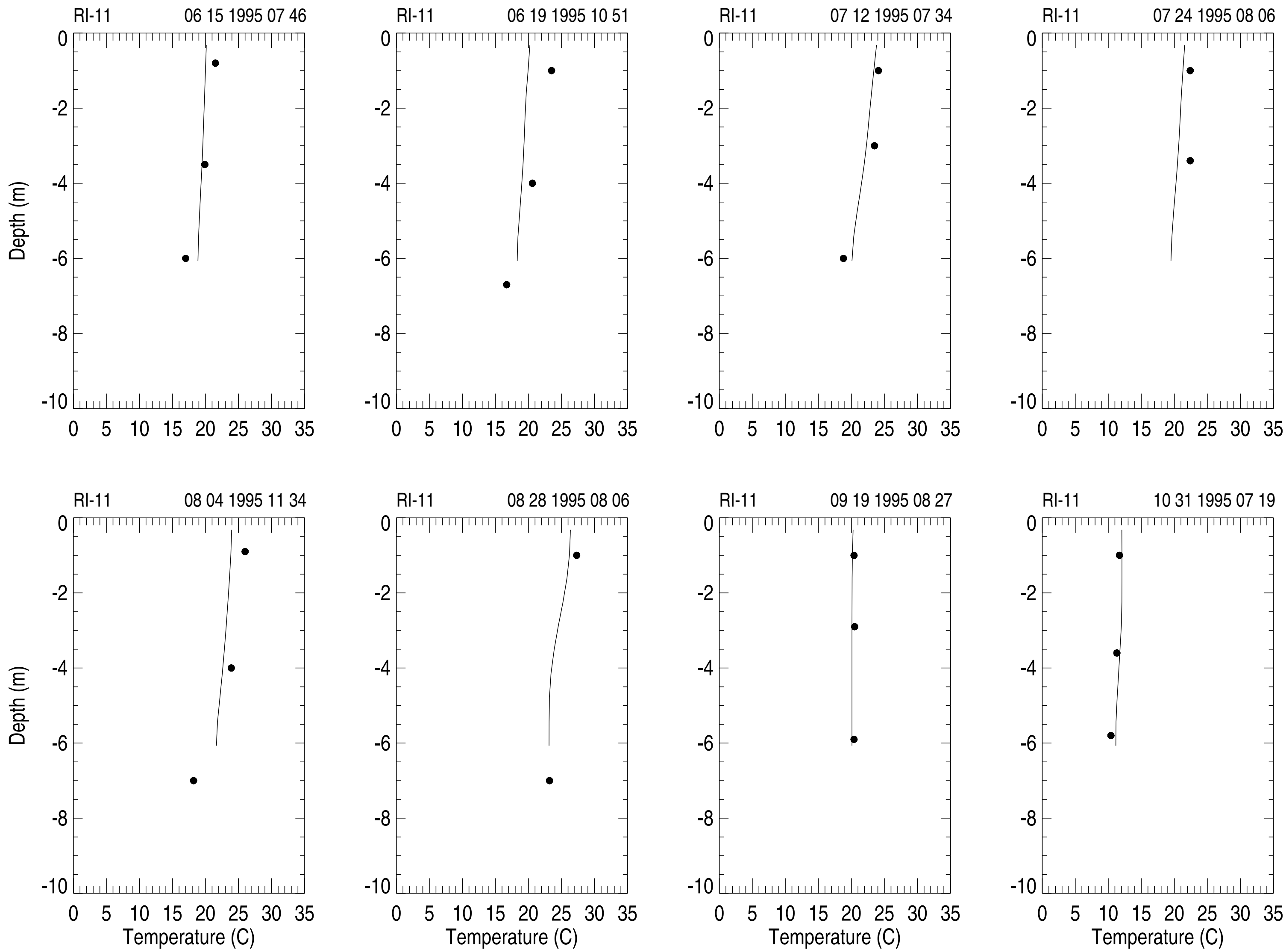

OH-15
08 05 2002 11 17
OH-15
09 05 2002 11 19
OH-15
09 24 2002 08 09
OH-15
10 10 2002 11 24
OH-15
11 04 2002 10 58
OH-15
11 18 2002 10 36
Depth (m)
0
-1
-2
-3
-4
-5
Temperature (C)
0
5
10
15
20
25

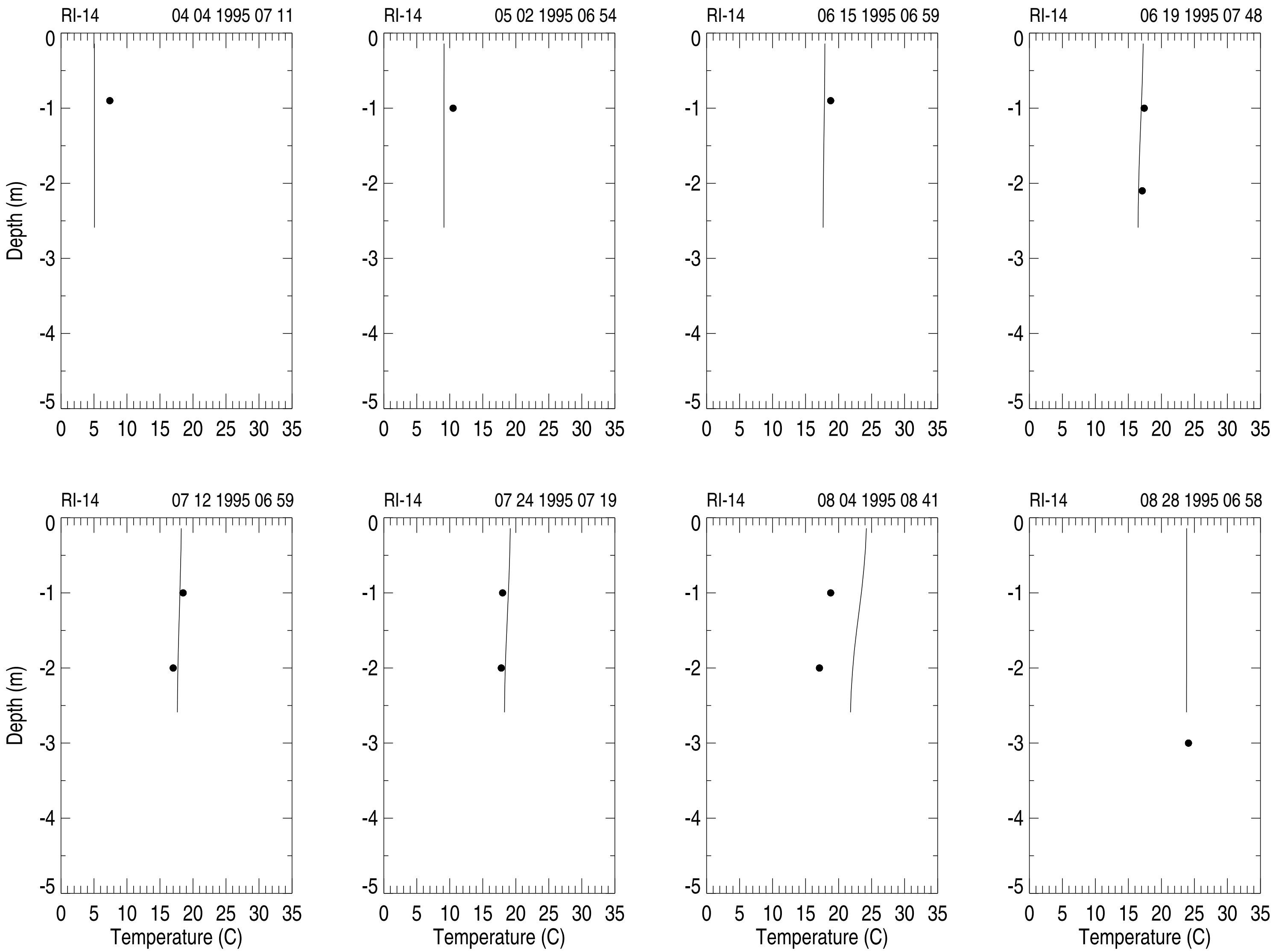

RI-06 04 04 1995 08 25
RI-06 05 02 1995 08 16
RI-06 06 15 1995 09 02
RI-06 06 19 1995 07 58
RI-06 07 12 1995 08 28
RI-06 07 24 1995 09 26
RI-06 08 04 1995 08 04
RI-06 08 28 1995 14 06
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)


RI-06 09 19 1995 09 12
RI-06 10 31 1995 08 00
RI-07 04 04 1995 08 10
RI-07 05 02 1995 08 02
RI-07 06 15 1995 08 21
RI-07 06 19 1995 07 41
RI-07 07 12 1995 08 09
RI-07 07 24 1995 09 10
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

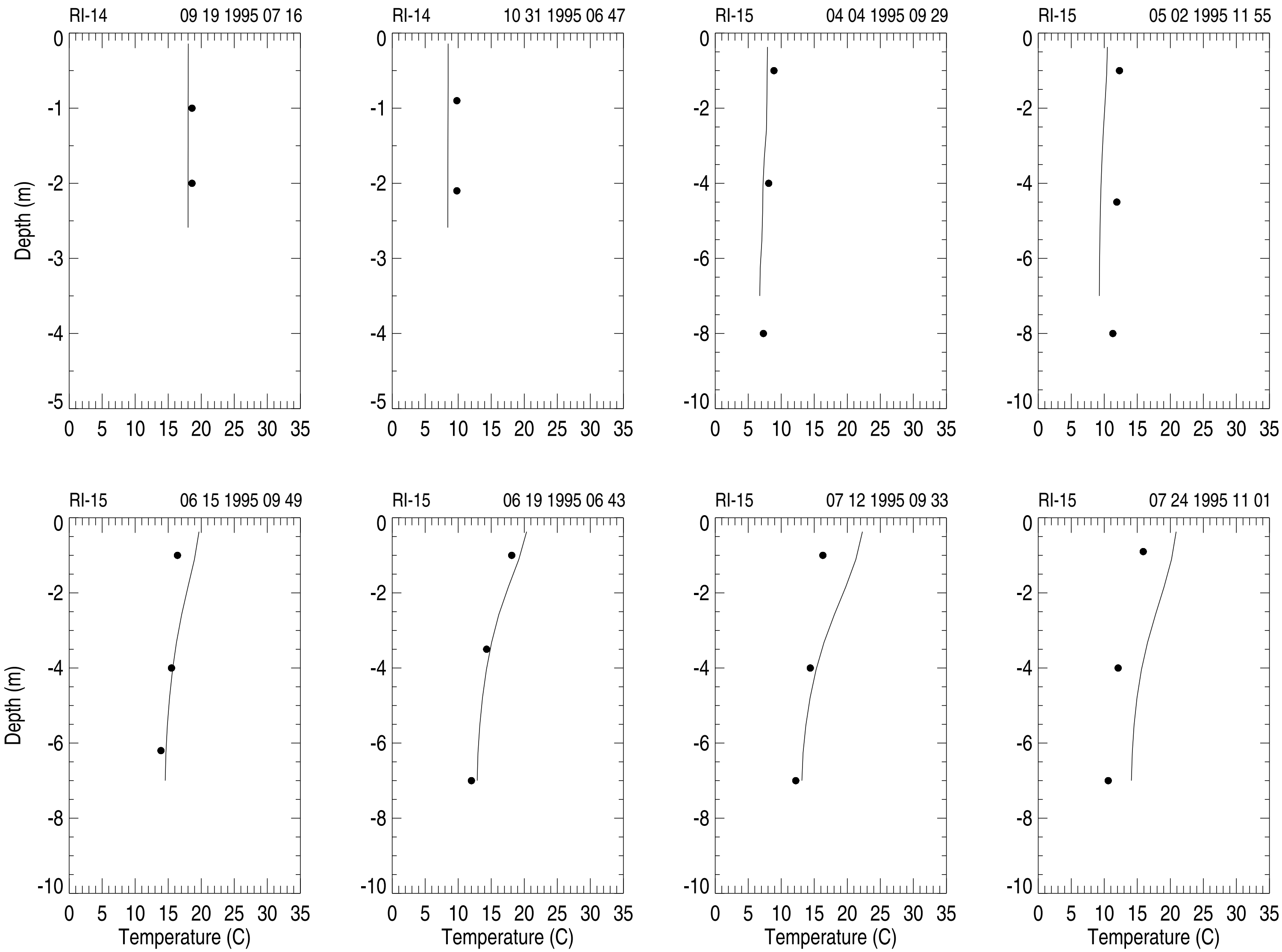

RI-07 08 04 1995 07 44
RI-07 08 28 1995 12 42
RI-07 09 19 1995 08 59
RI-07 10 31 1995 07 46
RI-08 04 04 1995 10 46
RI-08 05 02 1995 13 07
RI-08 06 15 1995 11 16
RI-08 06 19 1995 10 27
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

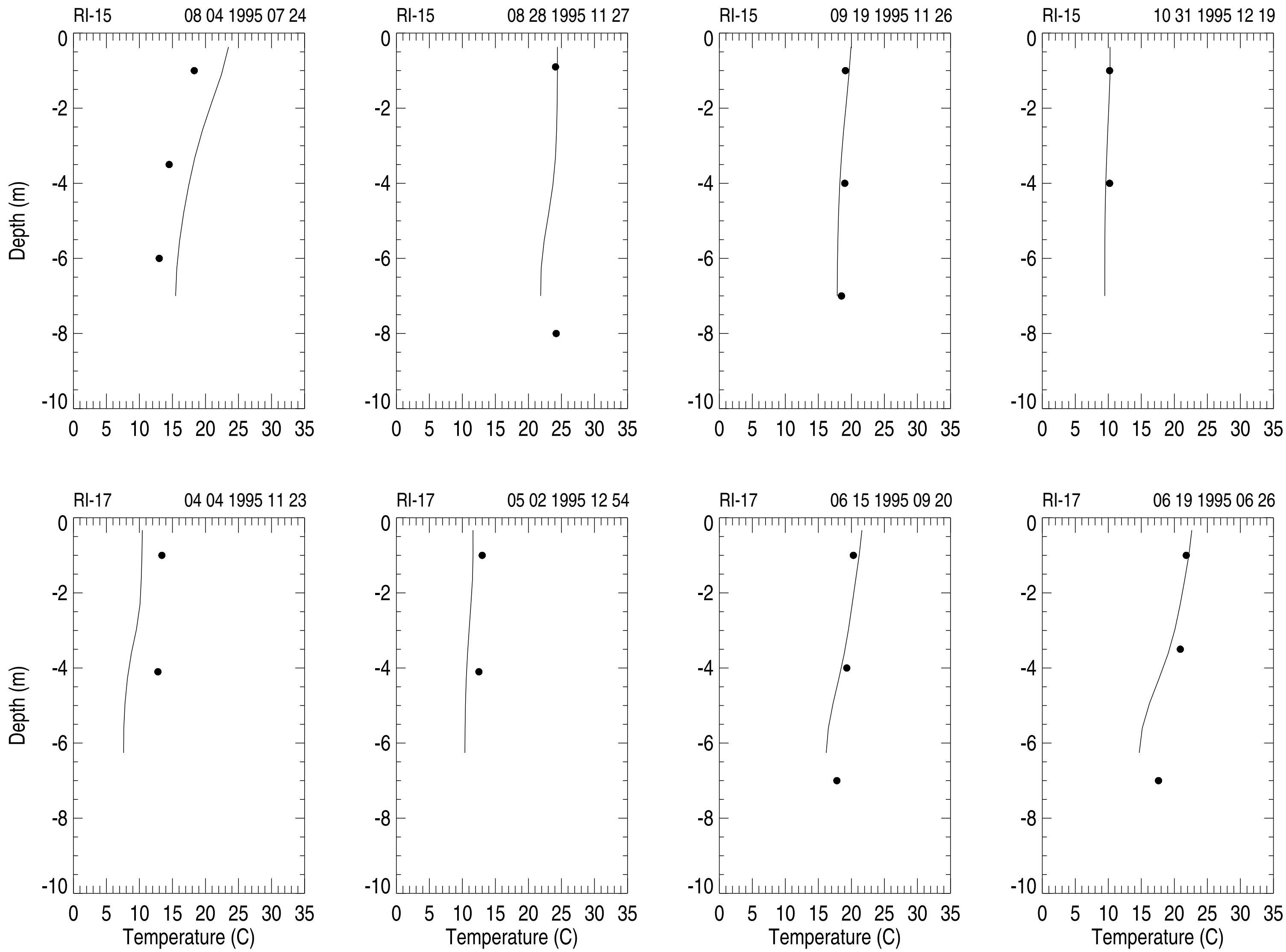

RI-08 07 12 1995 10 51
RI-08 07 24 1995 11 53
RI-08 08 04 1995 11 05
RI-08 08 28 1995 16 14
RI-08 09 19 1995 11 42
RI-08 10 31 1995 13 14
RI-11 04 04 1995 07 35
RI-11 05 02 1995 07 39
Depth (m)
0 -2 -4 -6 -8 -10
0 5 10 15 20 25 30 35
Temperature (C)

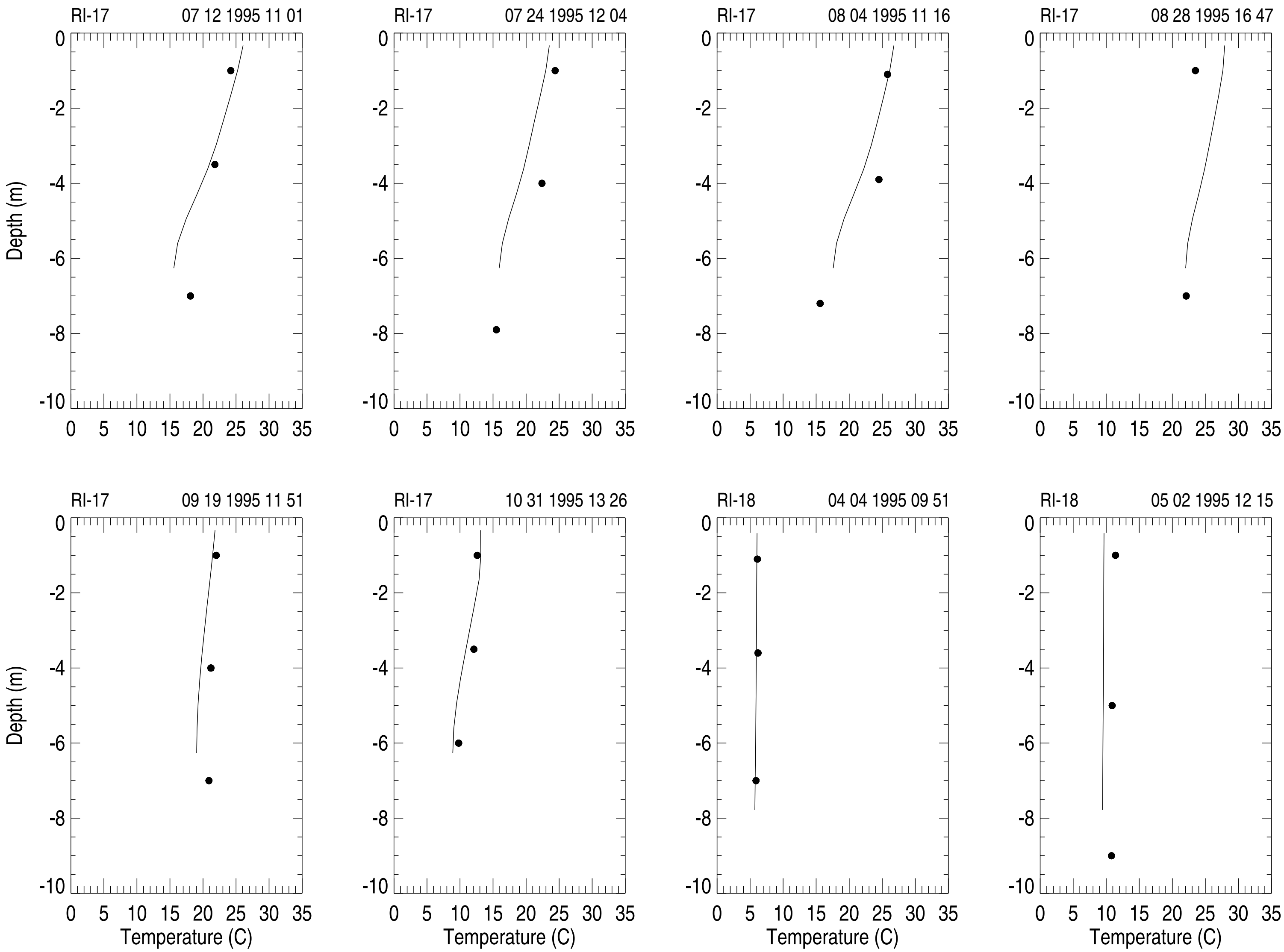

RI-11
06 15 1995 07 46
RI-11
06 19 1995 10 51
RI-11
07 12 1995 07 34
RI-11
07 24 1995 08 06
RI-11
08 04 1995 11 34
RI-11
08 28 1995 08 06
RI-11
09 19 1995 08 27
RI-11
10 31 1995 07 19
Depth (m)
Temperature (C)

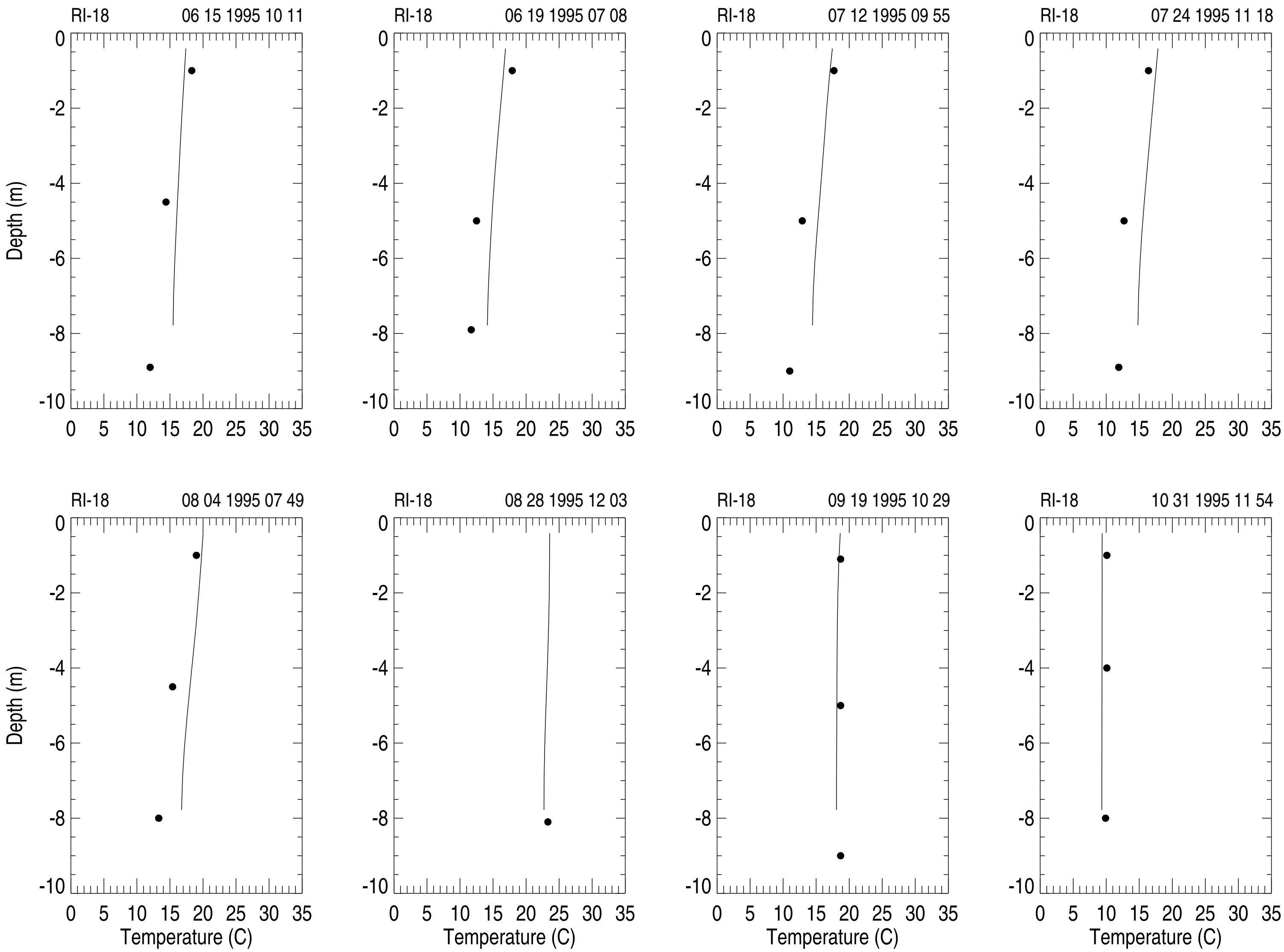


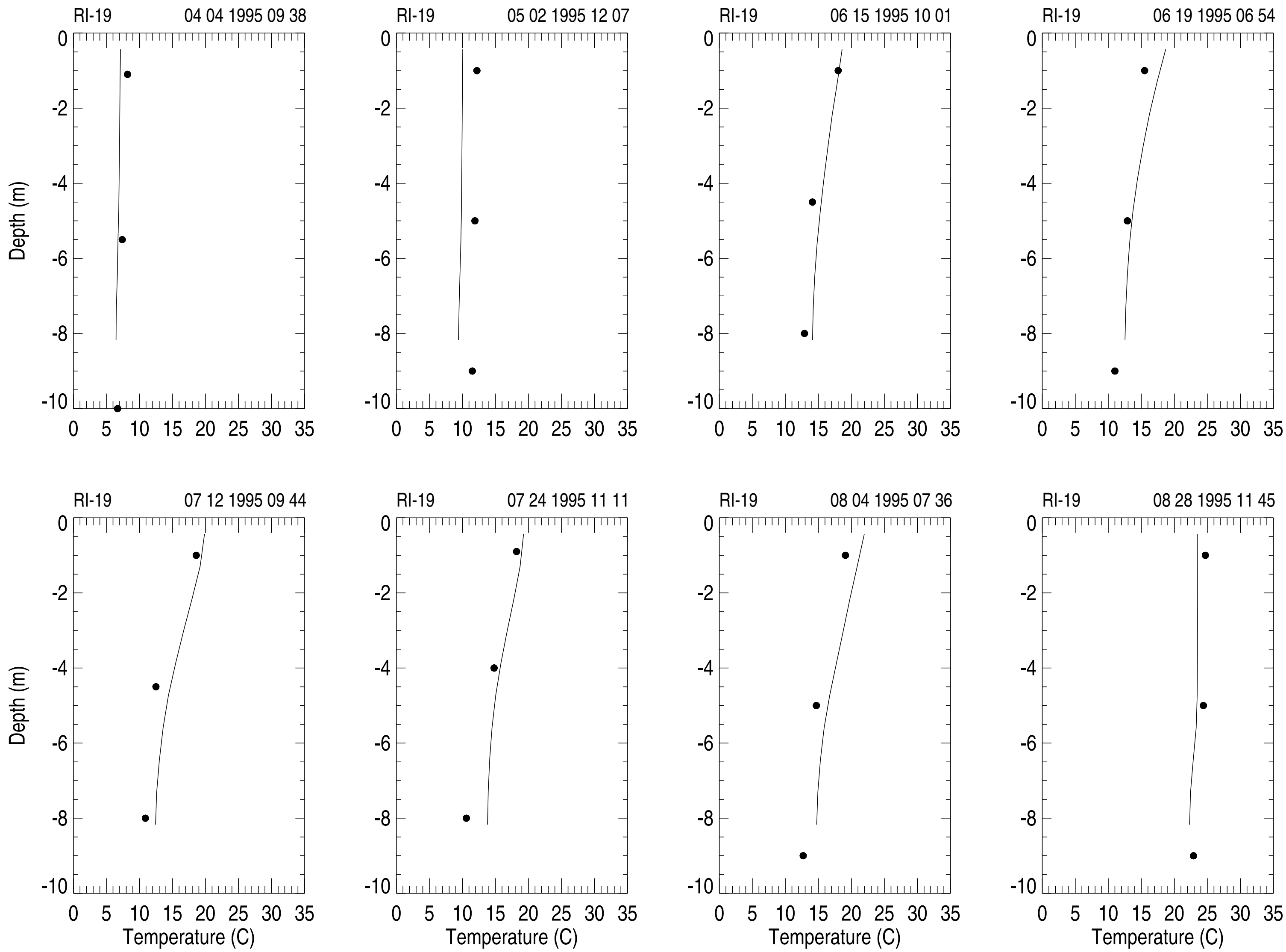
RI-14
04 04 1995 07 11
RI-14
05 02 1995 06 54
RI-14
06 15 1995 06 59
RI-14
06 19 1995 07 48
RI-14
07 12 1995 06 59
RI-14
07 24 1995 07 19
RI-14
08 04 1995 08 41
RI-14
08 28 1995 06 58
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35

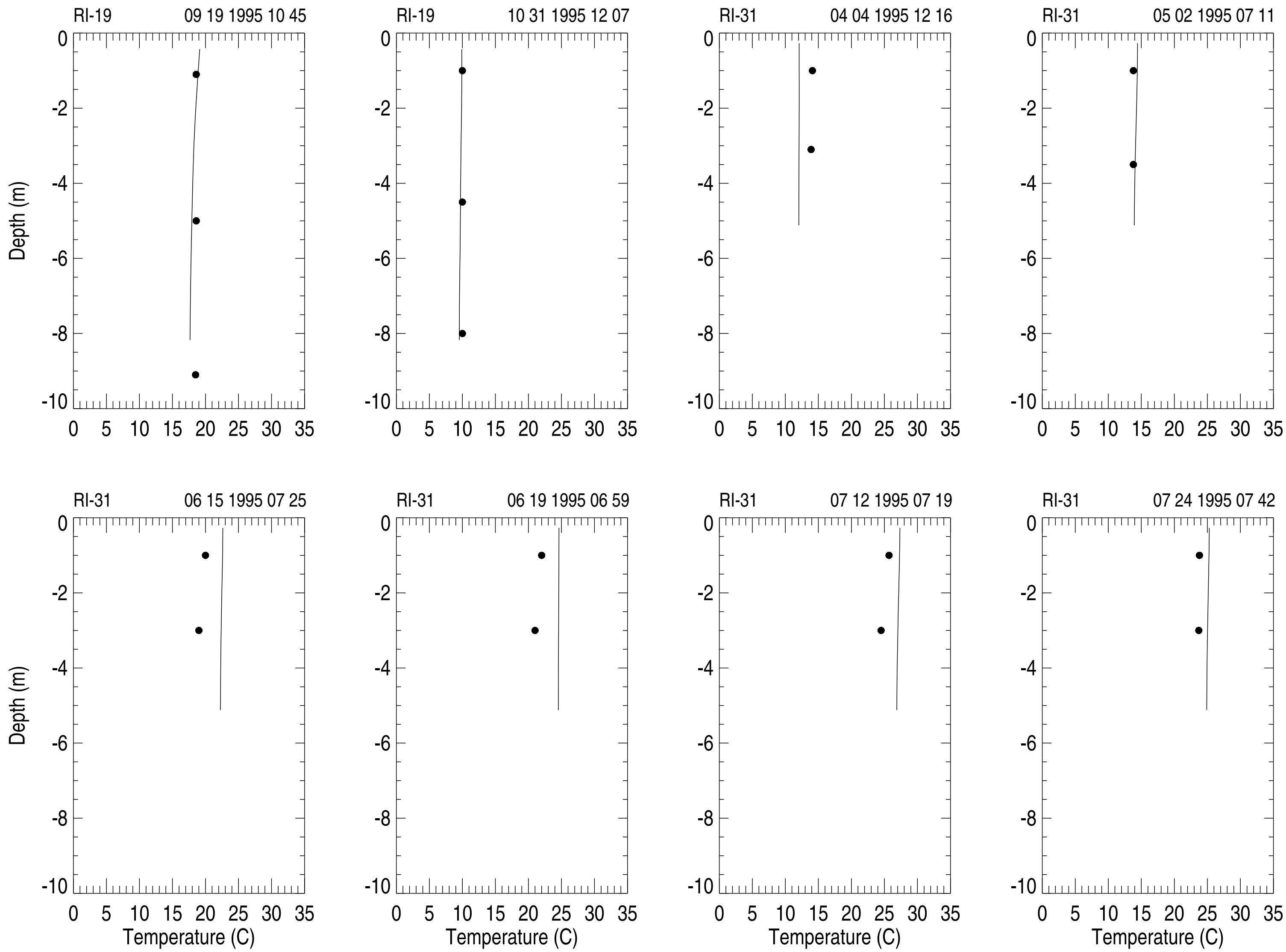

RI-14
09 19 1995 07 16
RI-14
10 31 1995 06 47
RI-15
04 04 1995 09 29
RI-15
05 02 1995 11 55
RI-15
06 15 1995 09 49
RI-15
06 19 1995 06 43
RI-15
07 12 1995 09 33
RI-15
07 24 1995 11 01
Depth (m)
Temperature (C)


RI-15
08 04 1995 07 24
RI-15
08 28 1995 11 27
RI-15
09 19 1995 11 26
RI-15
10 31 1995 12 19
RI-17
04 04 1995 11 23
RI-17
05 02 1995 12 54
RI-17
06 15 1995 09 20
RI-17
06 19 1995 06 26
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

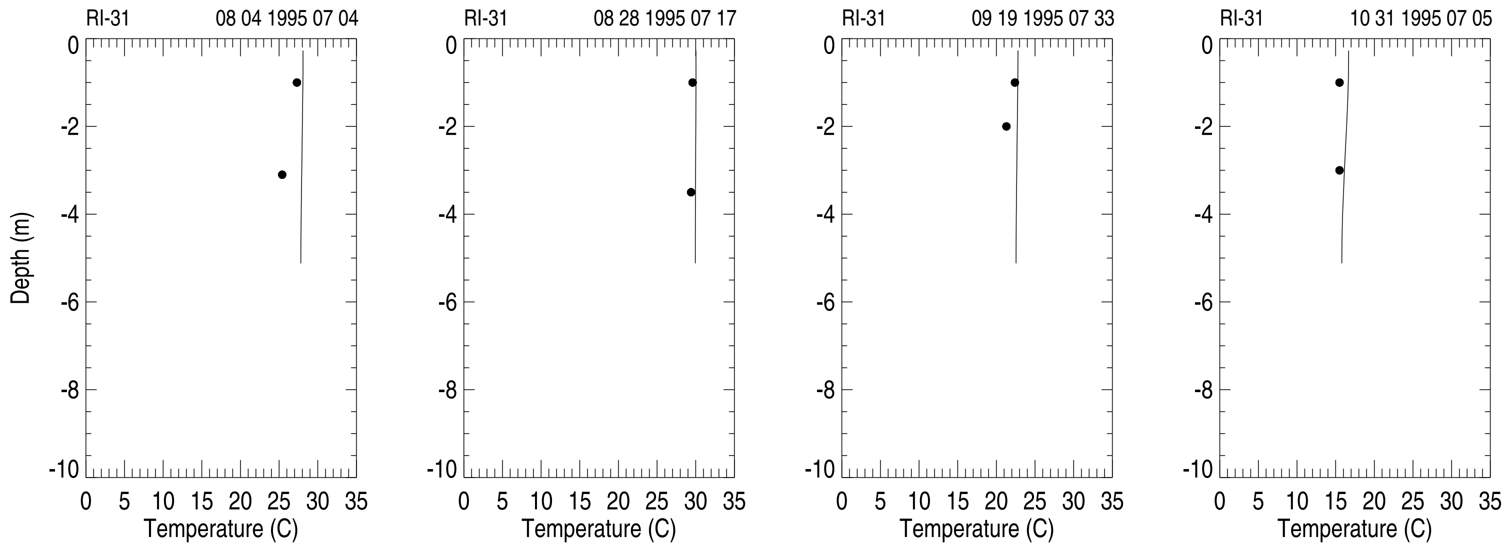

RI-17 07 12 1995 11 01
RI-17 07 24 1995 12 04
RI-17 08 04 1995 11 16
RI-17 08 28 1995 16 47
RI-17 09 19 1995 11 51
RI-17 10 31 1995 13 26
RI-18 04 04 1995 09 51
RI-18 05 02 1995 12 15
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)


RI-18 06 15 1995 10 11
RI-18 06 19 1995 07 08
RI-18 07 12 1995 09 55
RI-18 07 24 1995 11 18
RI-18 08 04 1995 07 49
RI-18 08 28 1995 12 03
RI-18 09 19 1995 10 29
RI-18 10 31 1995 11 54
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

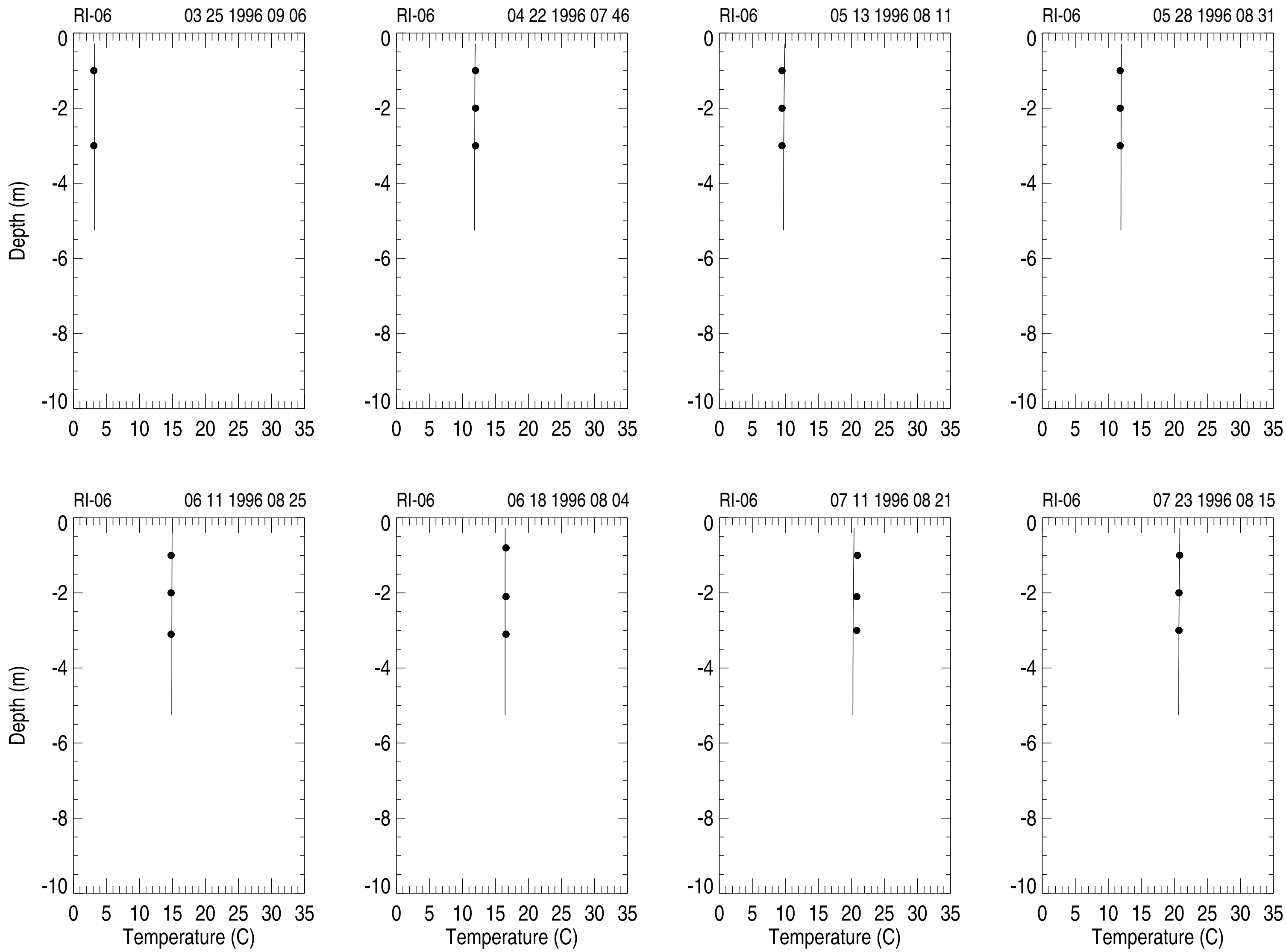

RI-19
04 04 1995 09 38
RI-19
05 02 1995 12 07
RI-19
06 15 1995 10 01
RI-19
06 19 1995 06 54
RI-19
07 12 1995 09 44
RI-19
07 24 1995 11 11
RI-19
08 04 1995 07 36
RI-19
08 28 1995 11 45
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

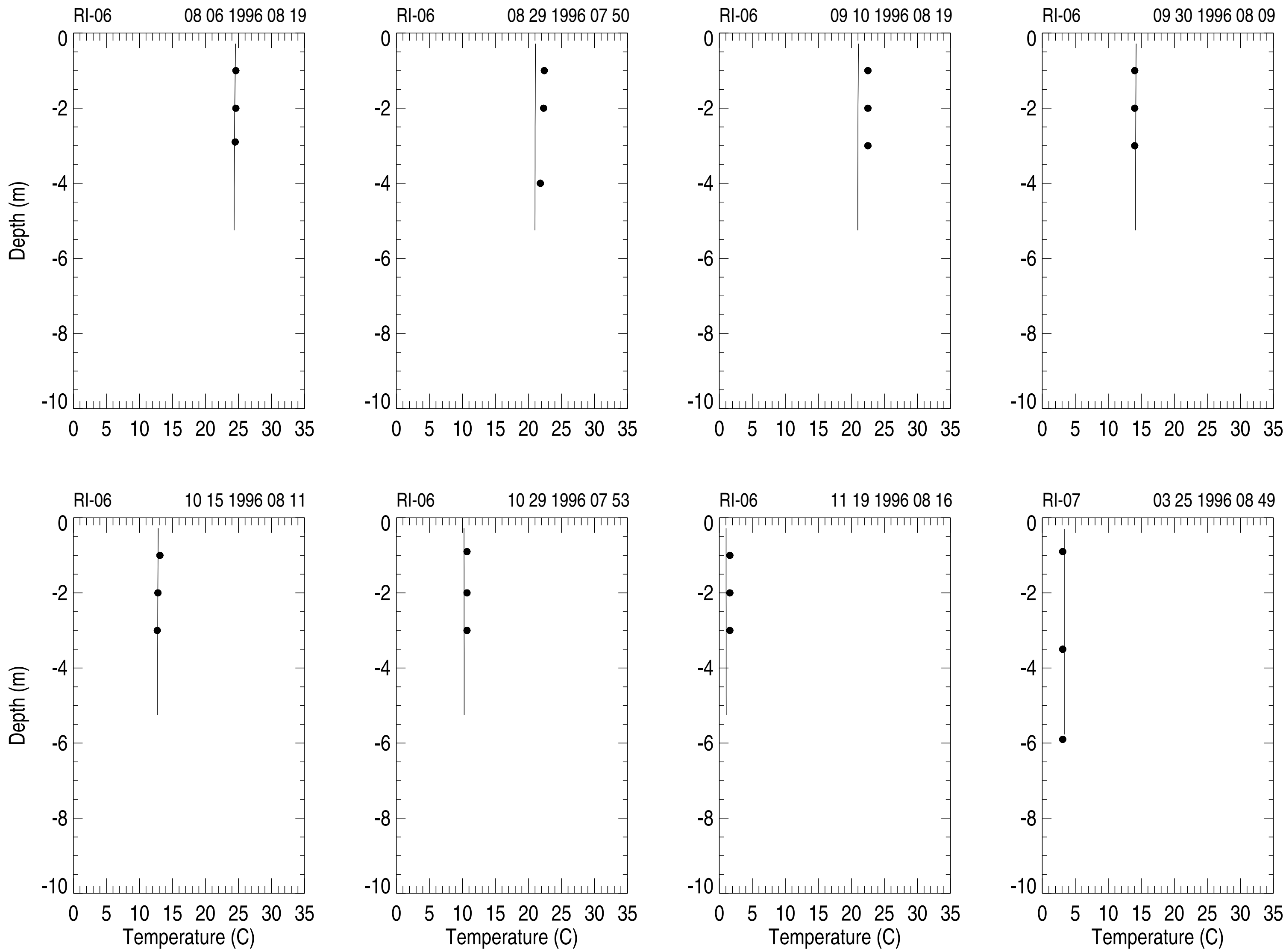


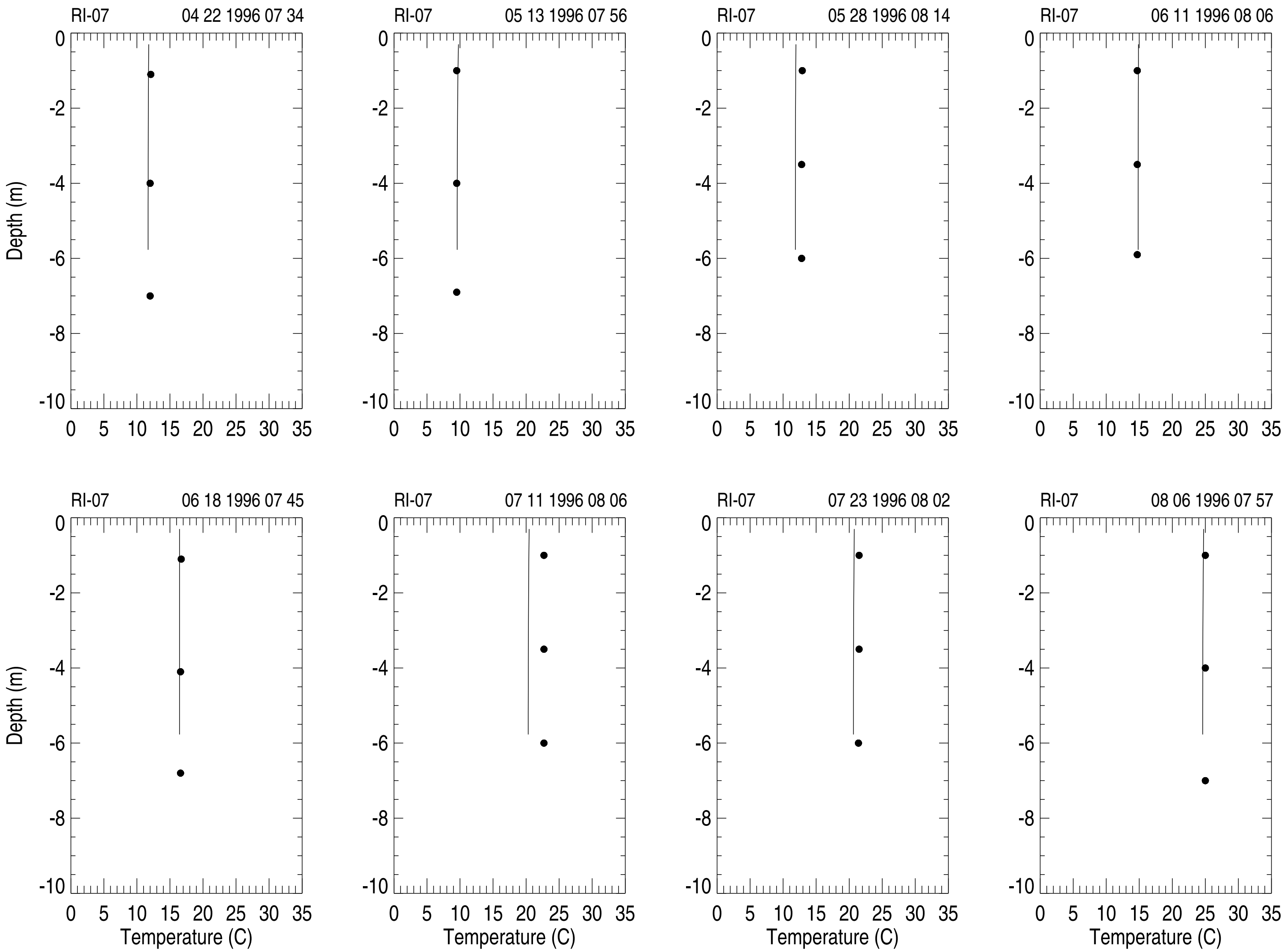
RI-19
09 19 1995 10 45
RI-19
10 31 1995 12 07
RI-31
04 04 1995 12 16
RI-31
05 02 1995 07 11
RI-31
06 15 1995 07 25
RI-31
06 19 1995 06 59
RI-31
07 12 1995 07 19
RI-31
07 24 1995 07 42
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

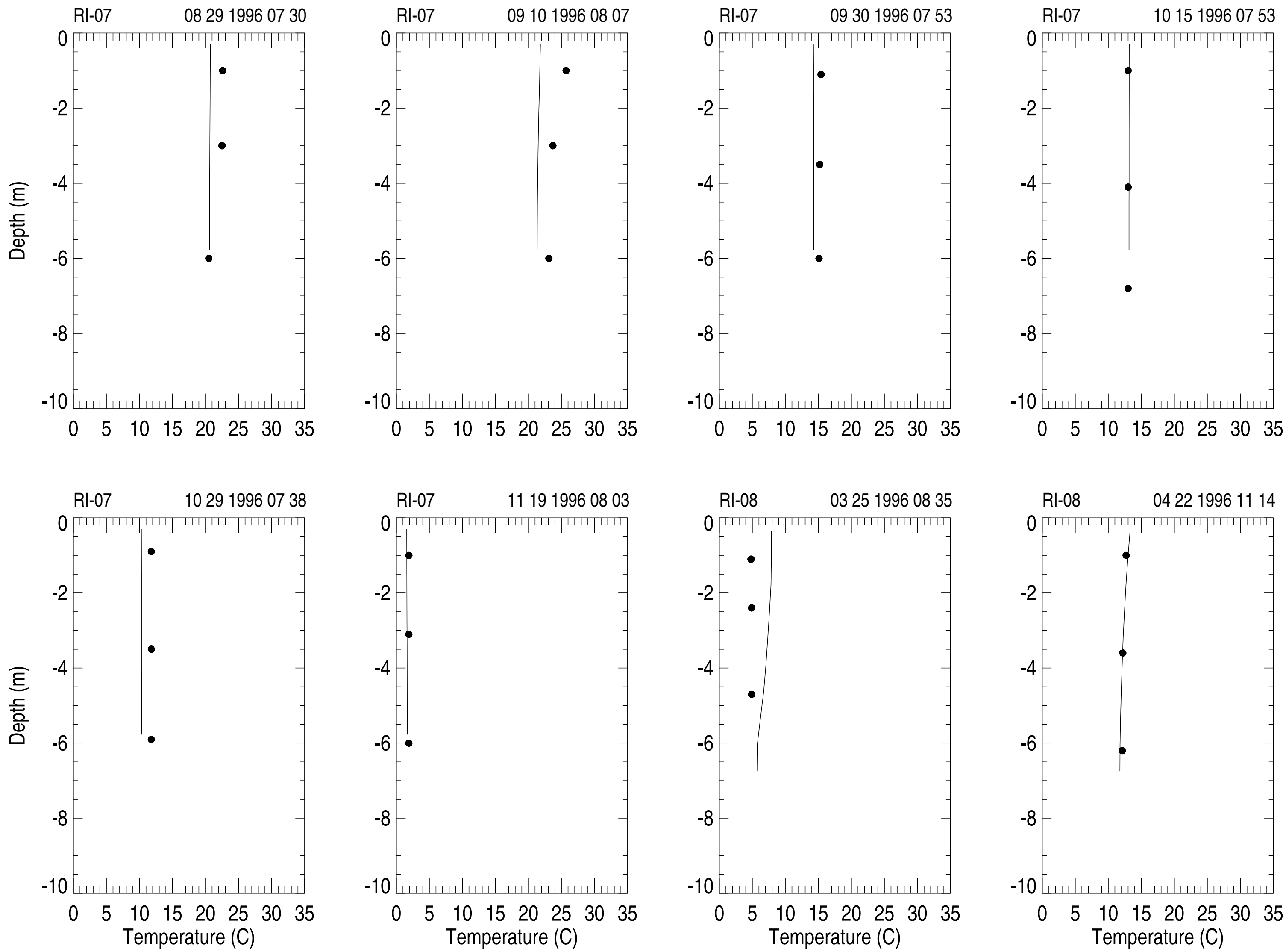


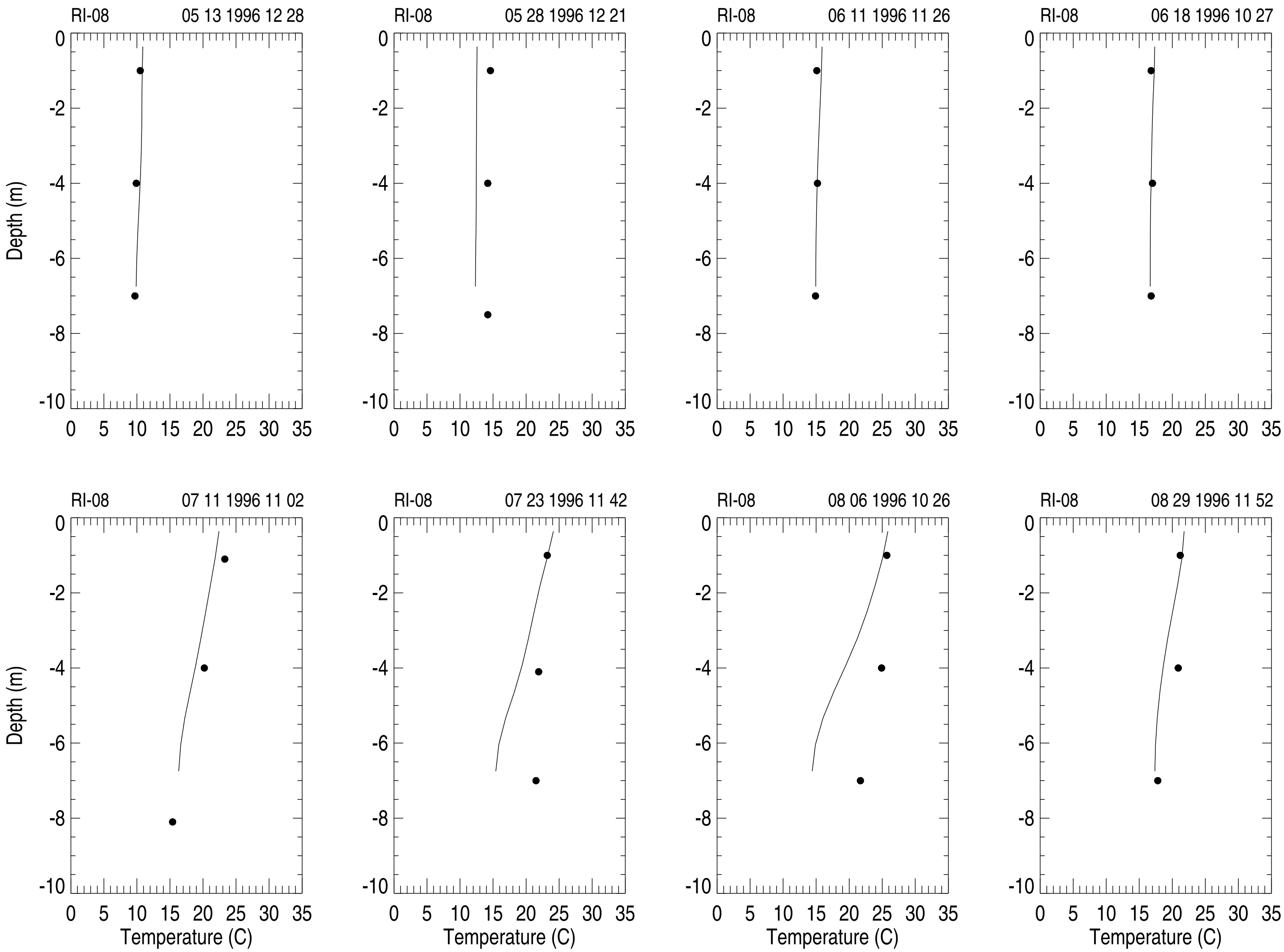
RI-31
08 04 1995 07 04
RI-31
08 28 1995 07 17
RI-31
09 19 1995 07 33
RI-31
10 31 1995 07 05
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

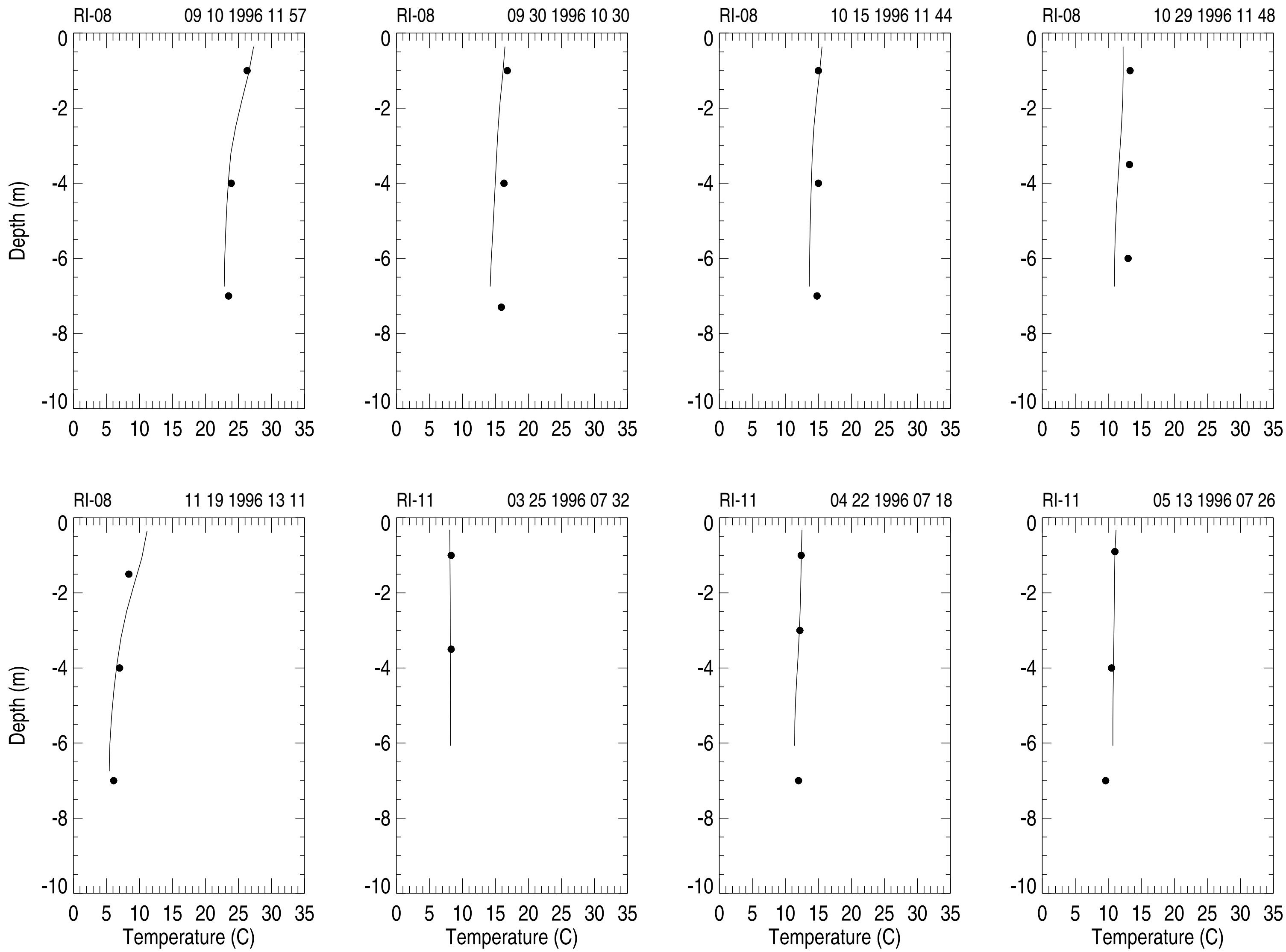

RI-06
03 25 1996 09 06
RI-06
04 22 1996 07 46
RI-06
05 13 1996 08 11
RI-06
05 28 1996 08 31
RI-06
06 11 1996 08 25
RI-06
06 18 1996 08 04
RI-06
07 11 1996 08 21
RI-06
07 23 1996 08 15
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

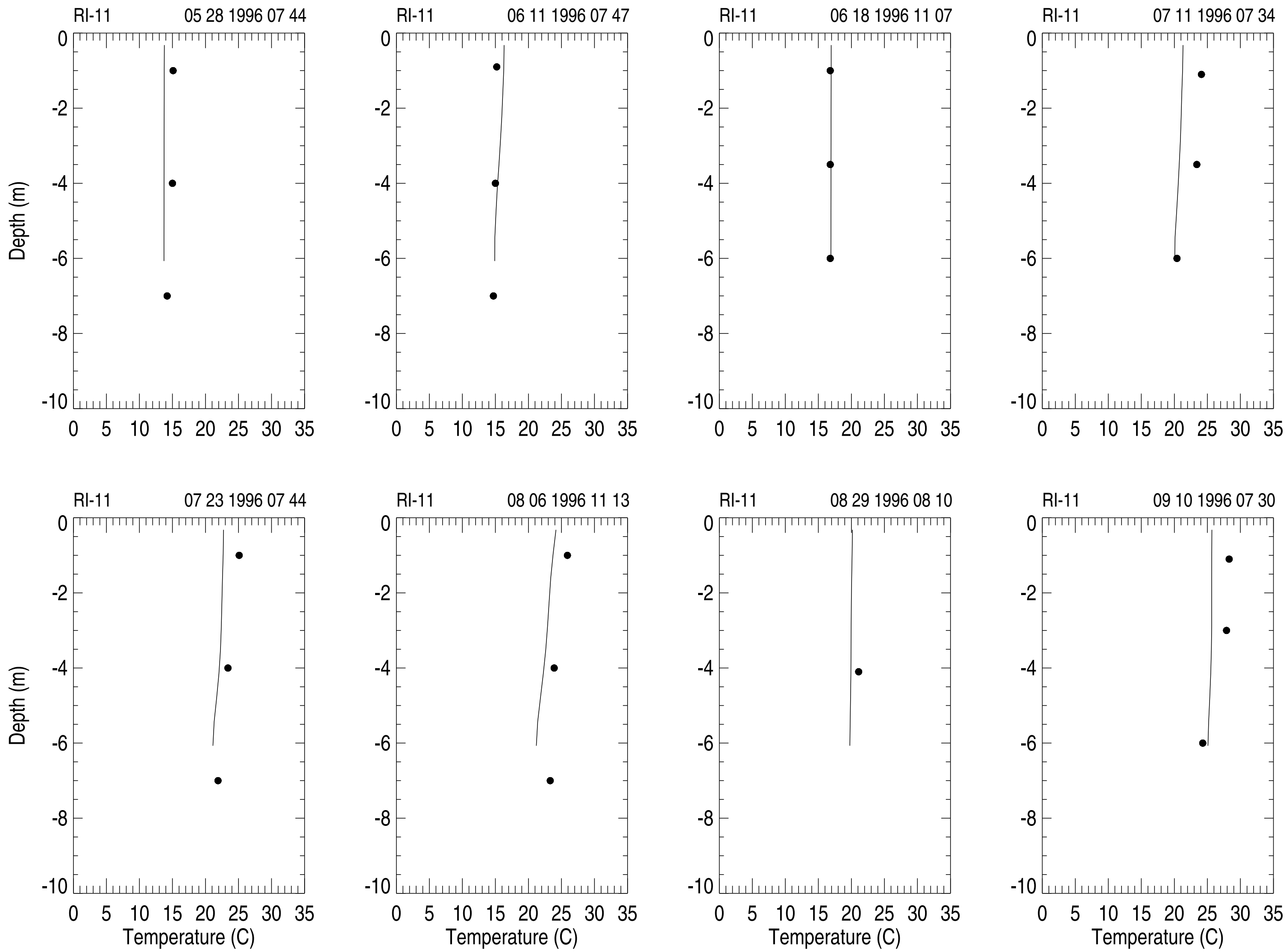

RI-06 08 06 1996 08 19
RI-06 08 29 1996 07 50
RI-06 09 10 1996 08 19
RI-06 09 30 1996 08 09
RI-06 10 15 1996 08 11
RI-06 10 29 1996 07 53
RI-06 11 19 1996 08 16
RI-07 03 25 1996 08 49
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35


RI-07 04 22 1996 07 34
RI-07 05 13 1996 07 56
RI-07 05 28 1996 08 14
RI-07 06 11 1996 08 06
RI-07 06 18 1996 07 45
RI-07 07 11 1996 08 06
RI-07 07 23 1996 08 02
RI-07 08 06 1996 07 57
Depth (m)
0 -2 -4 -6 -8 -10
Temperature (C)
0 5 10 15 20 25 30 35

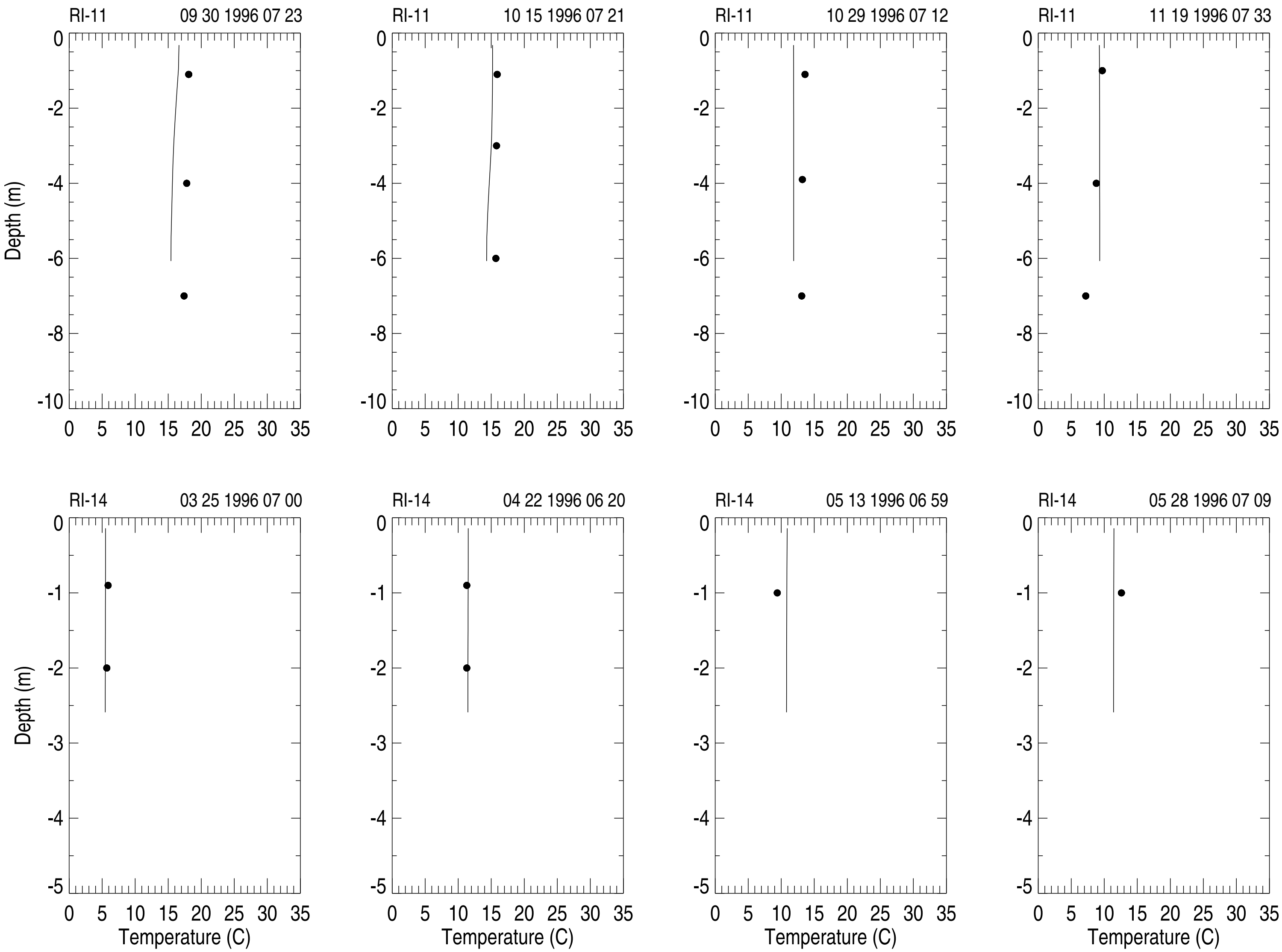

RI-07
08 29 1996 07 30
RI-07
09 10 1996 08 07
RI-07
09 30 1996 07 53
RI-07
10 15 1996 07 53
RI-07
10 29 1996 07 38
RI-07
11 19 1996 08 03
RI-08
03 25 1996 08 35
RI-08
04 22 1996 11 14
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

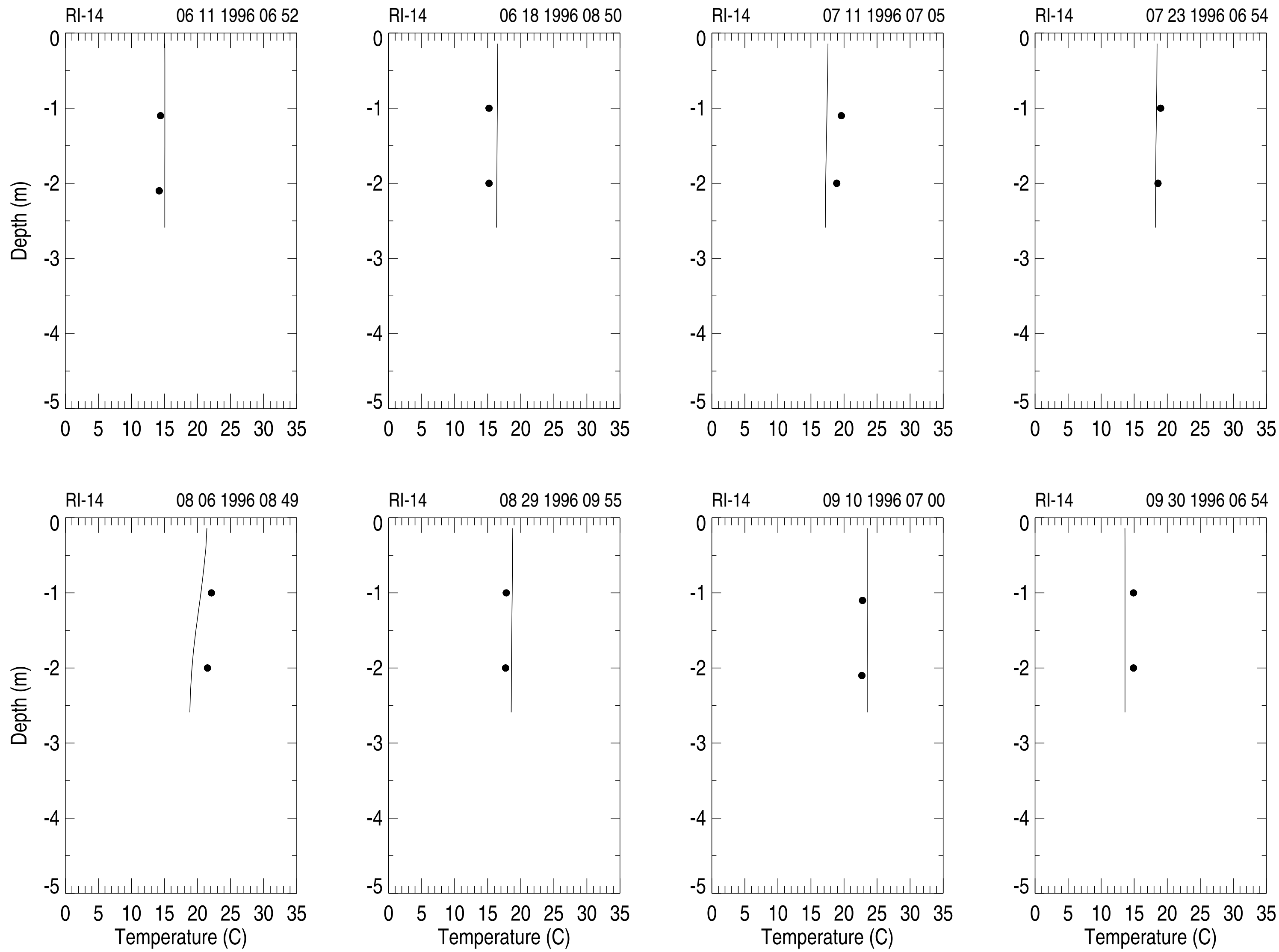

RI-08
05 13 1996 12 28
RI-08
05 28 1996 12 21
RI-08
06 11 1996 11 26
RI-08
06 18 1996 10 27
RI-08
07 11 1996 11 02
RI-08
07 23 1996 11 42
RI-08
08 06 1996 10 26
RI-08
08 29 1996 11 52
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

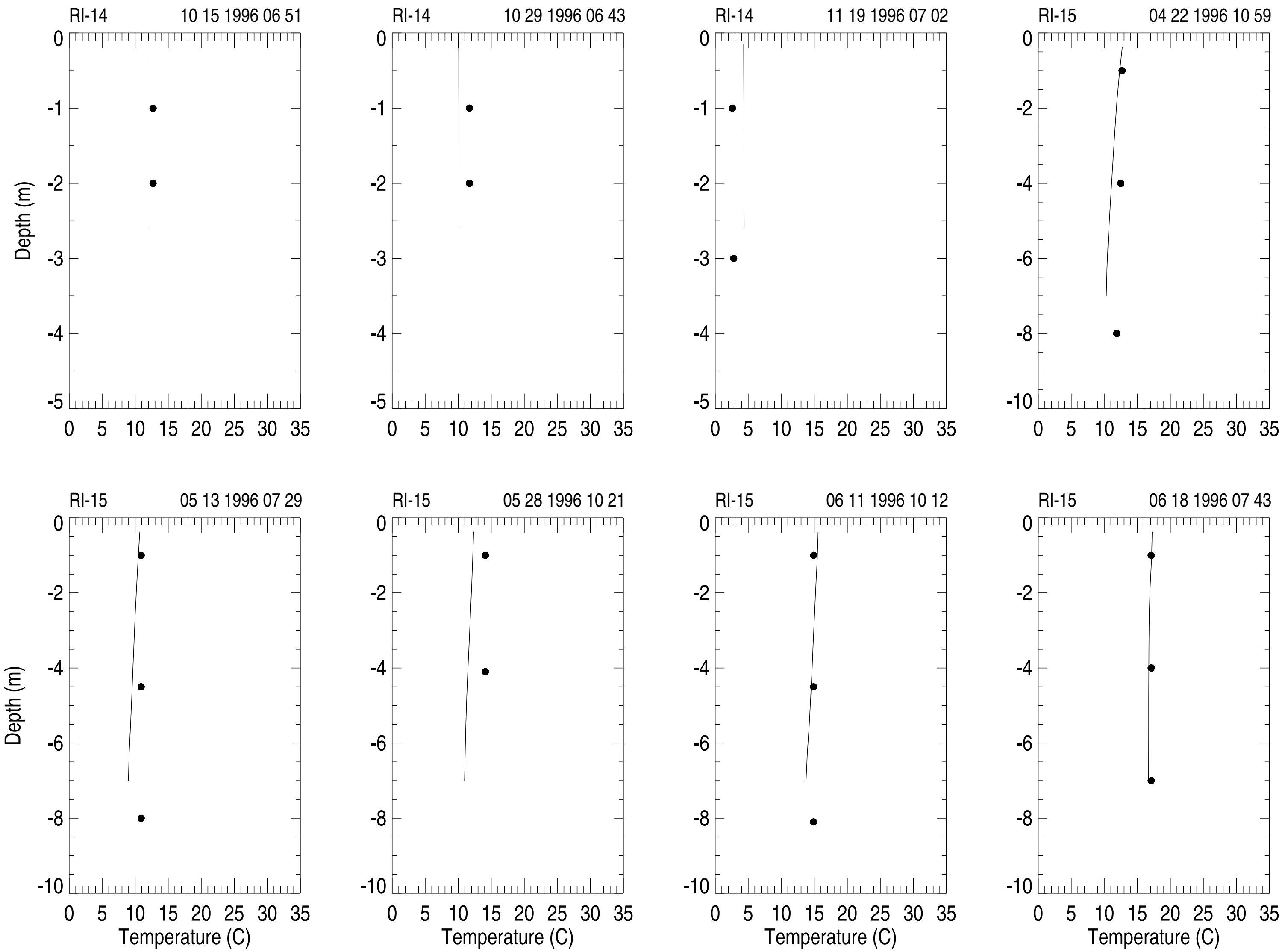

RI-08 09 10 1996 11 57
RI-08 09 30 1996 10 30
RI-08 10 15 1996 11 44
RI-08 10 29 1996 11 48
RI-08 11 19 1996 13 11
RI-11 03 25 1996 07 32
RI-11 04 22 1996 07 18
RI-11 05 13 1996 07 26
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

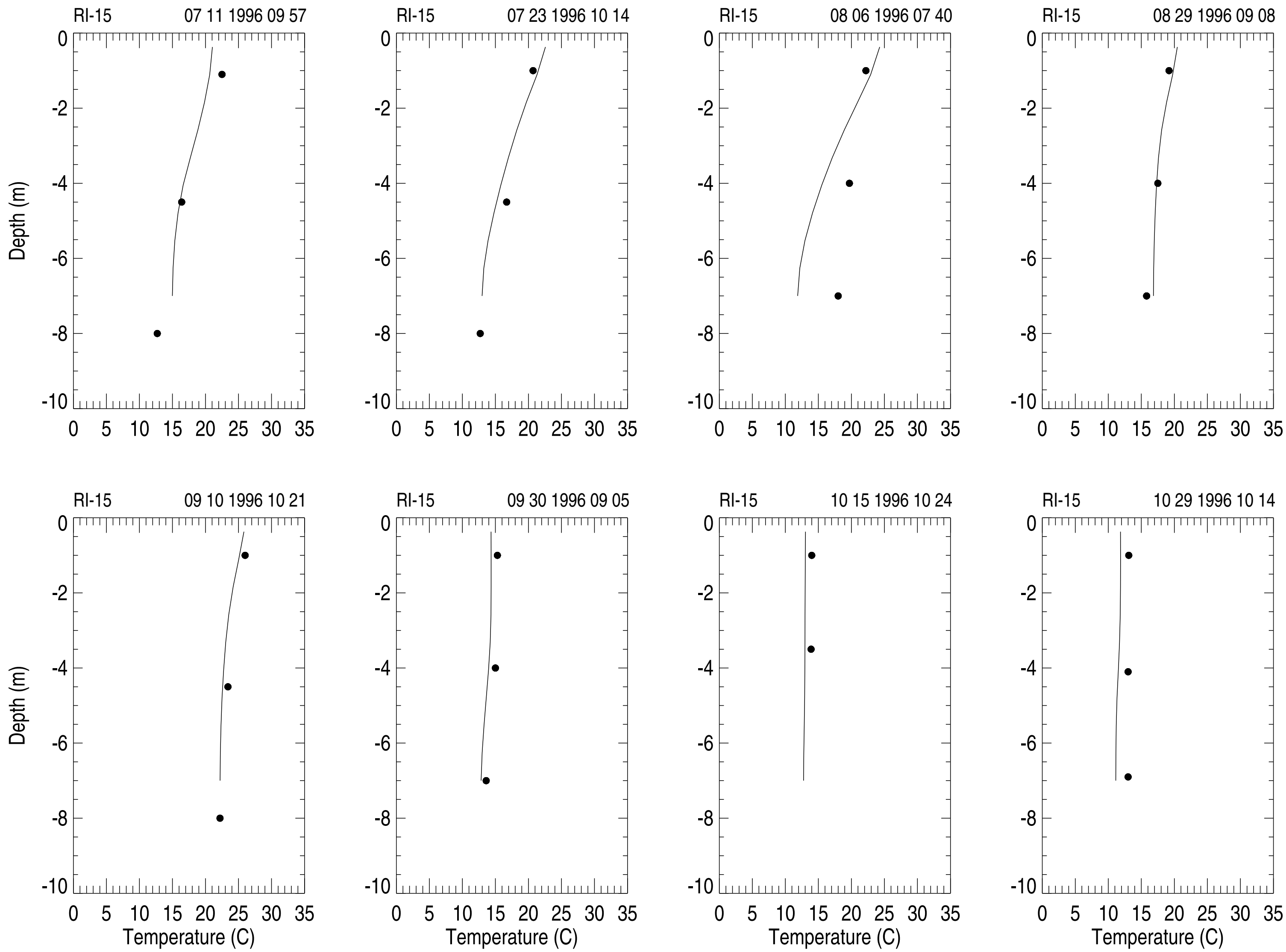


RI-11 05 28 1996 07 44
RI-11 06 11 1996 07 47
RI-11 06 18 1996 11 07
RI-11 07 11 1996 07 34
RI-11 07 23 1996 07 44
RI-11 08 06 1996 11 13
RI-11 08 29 1996 08 10
RI-11 09 10 1996 07 30
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

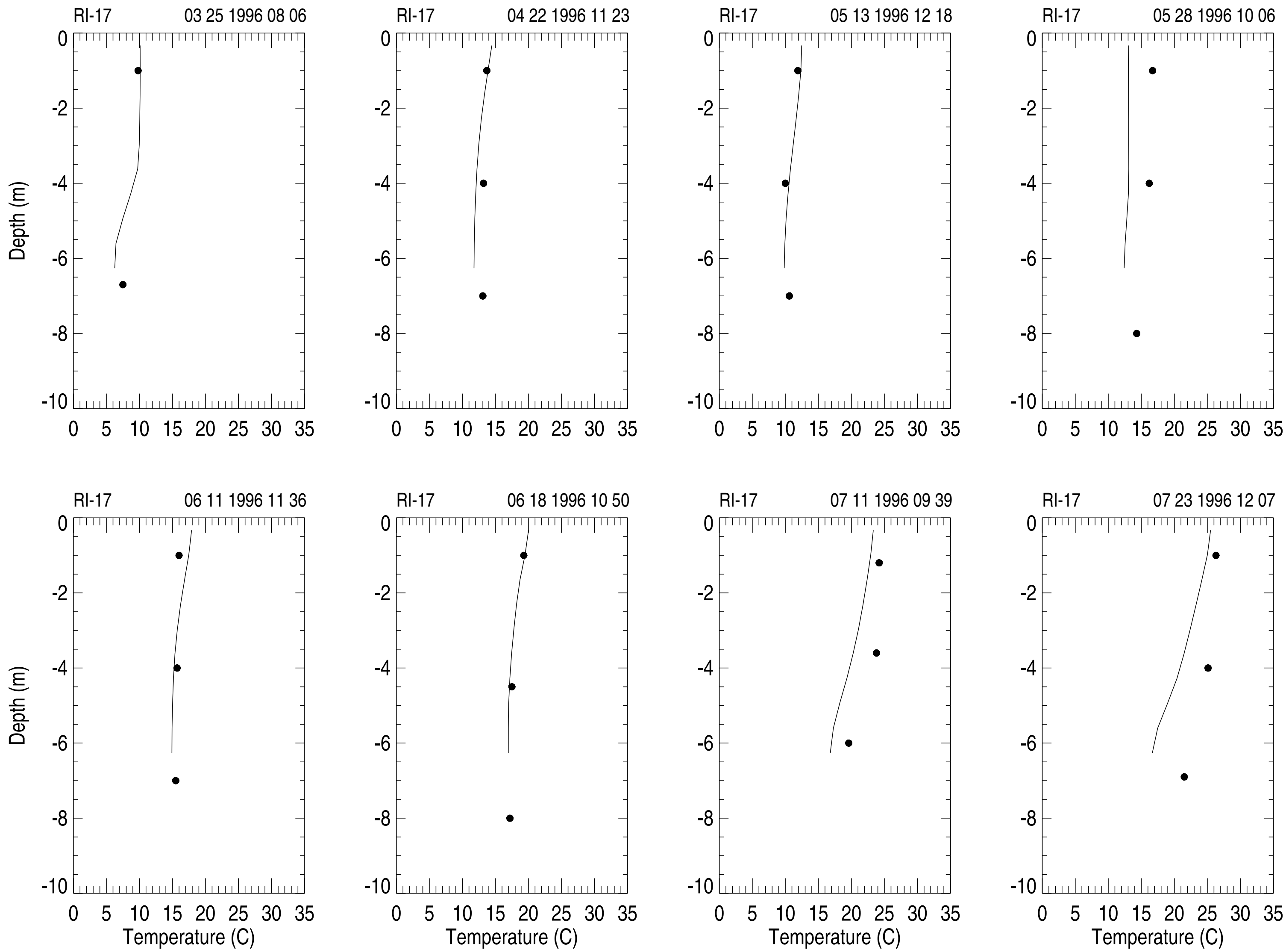

RI-11 09 30 1996 07 23
RI-11 10 15 1996 07 21
RI-11 10 29 1996 07 12
RI-11 11 19 1996 07 33
RI-14 03 25 1996 07 00
RI-14 04 22 1996 06 20
RI-14 05 13 1996 06 59
RI-14 05 28 1996 07 09
Depth (m)
Temperature (C)

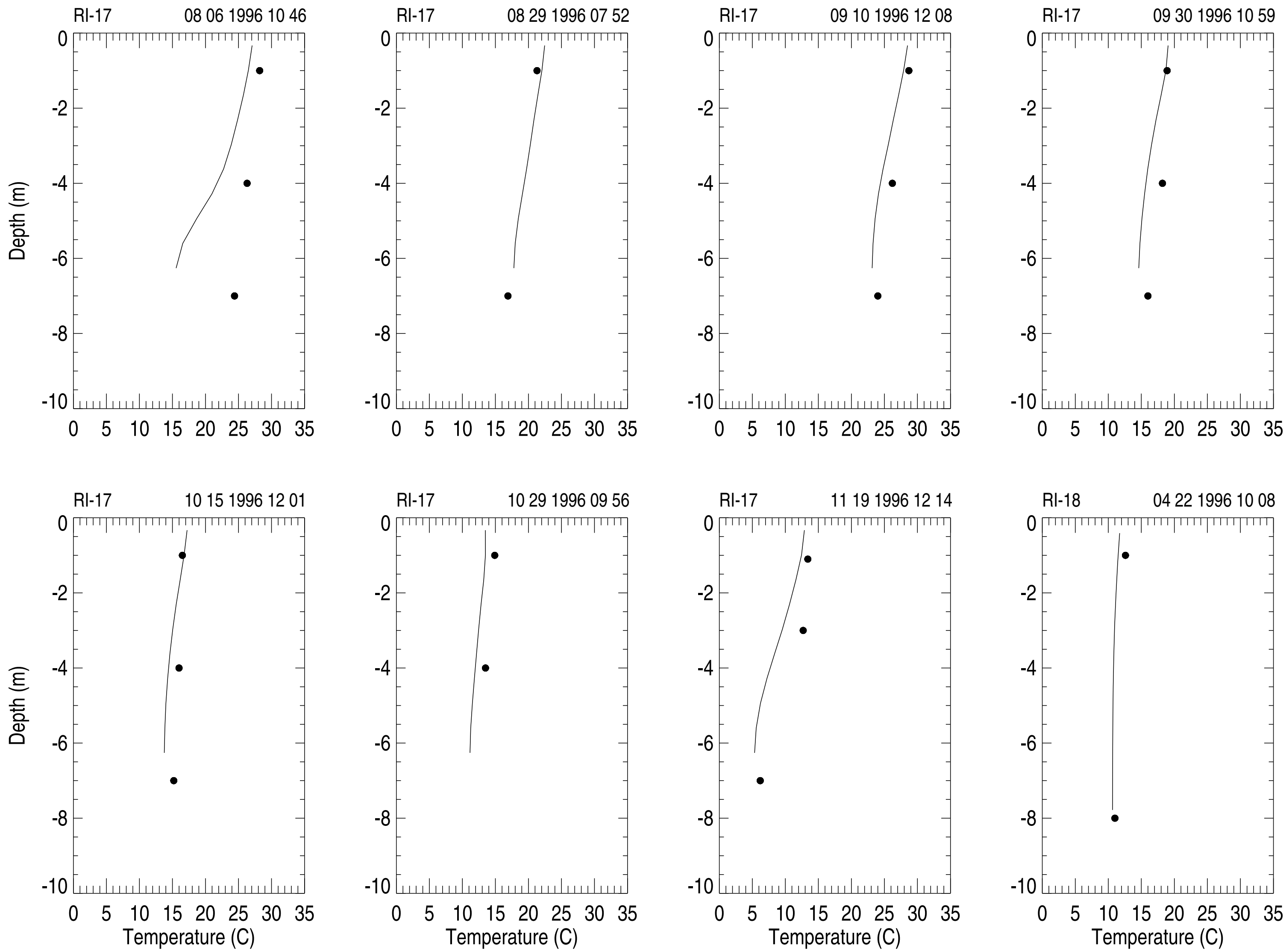

RI-14
06 11 1996 06 52
RI-14
06 18 1996 08 50
RI-14
07 11 1996 07 05
RI-14
07 23 1996 06 54
RI-14
08 06 1996 08 49
RI-14
08 29 1996 09 55
RI-14
09 10 1996 07 00
RI-14
09 30 1996 06 54
Depth (m)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35
Temperature (C)


RI-14 10 15 1996 06 51
RI-14 10 29 1996 06 43
RI-14 11 19 1996 07 02
RI-15 04 22 1996 10 59
RI-15 05 13 1996 07 29
RI-15 05 28 1996 10 21
RI-15 06 11 1996 10 12
RI-15 06 18 1996 07 43
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
-6
-8
-10
0 5 10 15 20 25 30 35

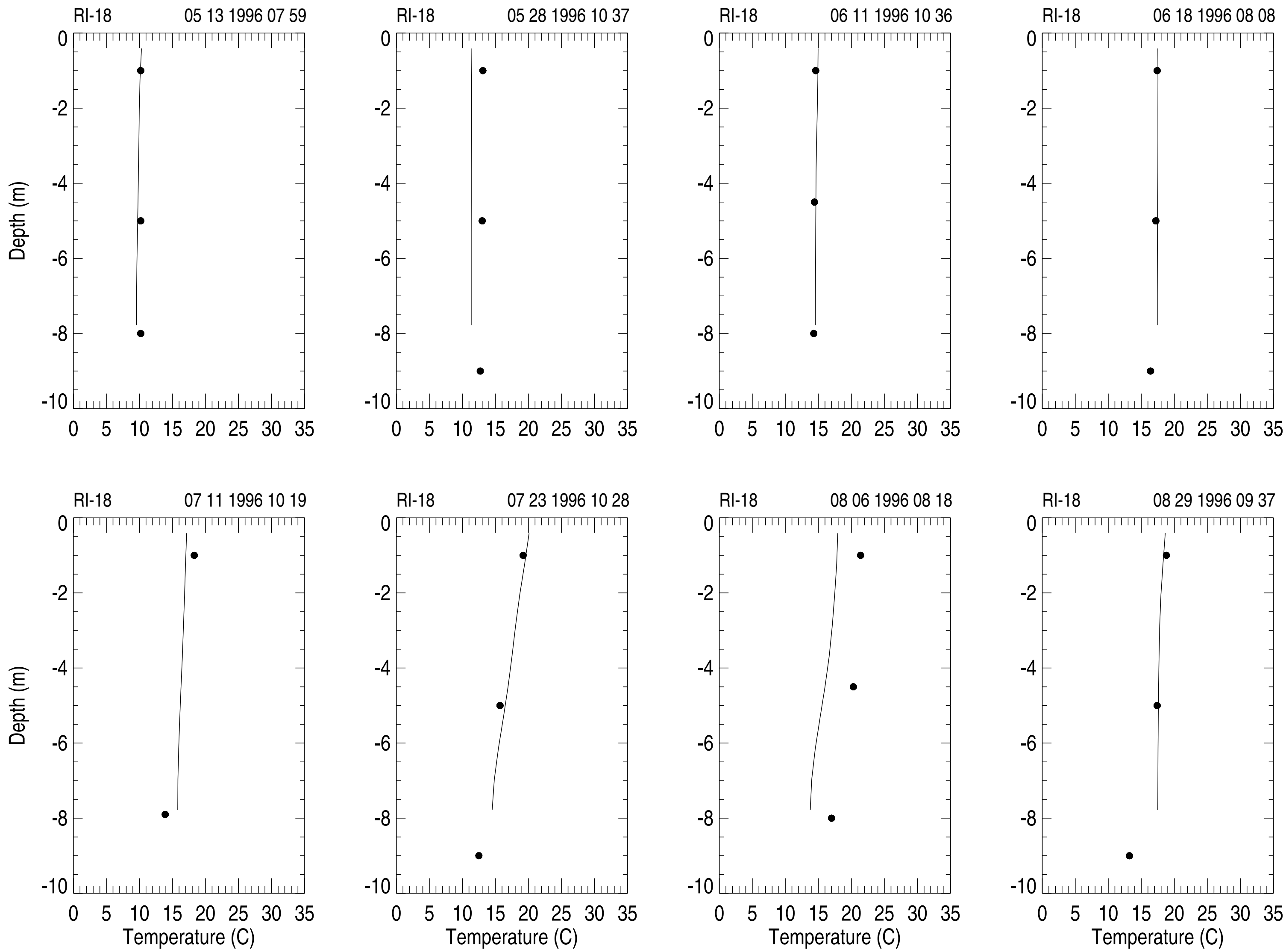


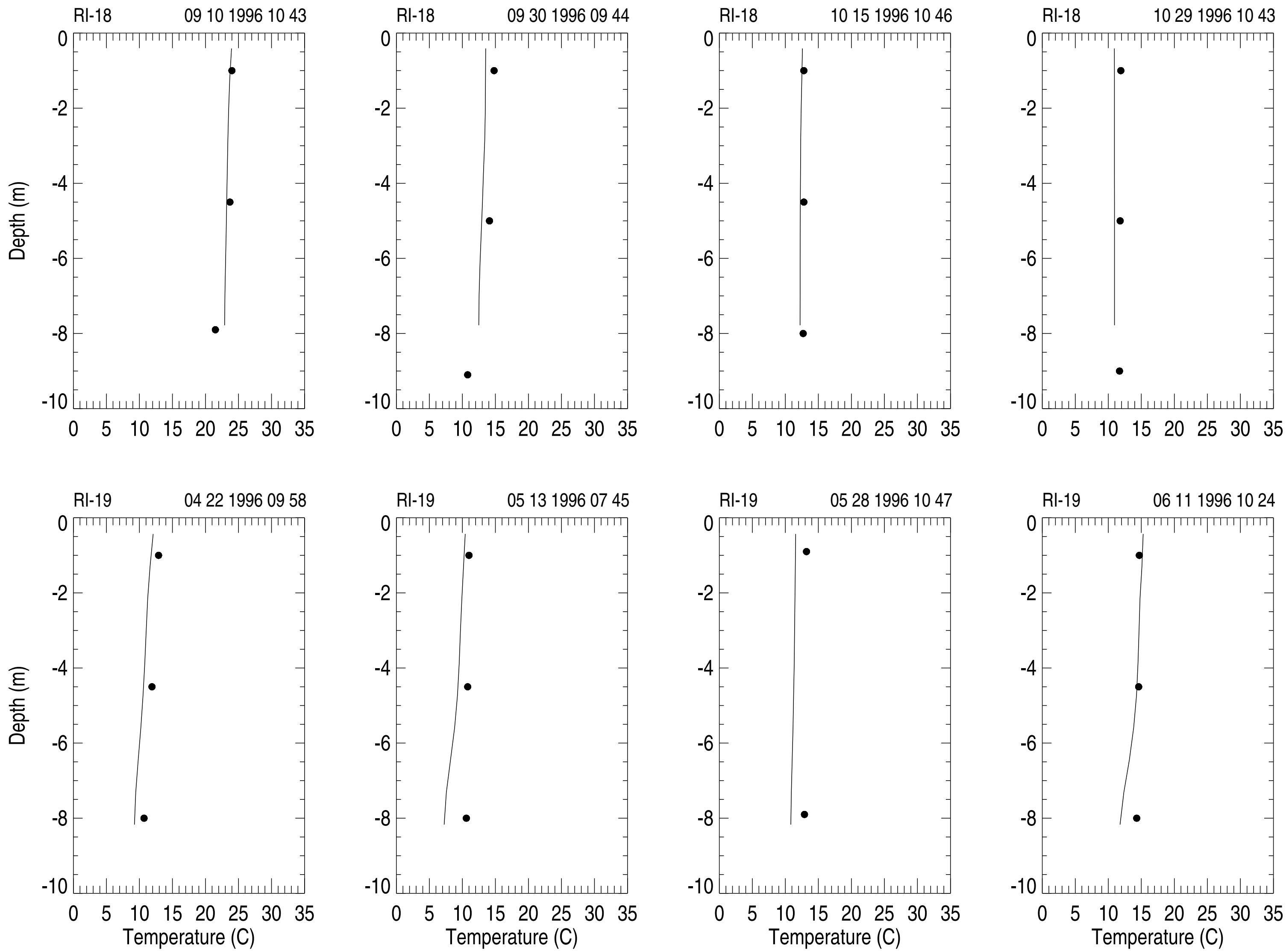
RI-15
07 11 1996 09 57
07 23 1996 10 14
08 06 1996 07 40
08 29 1996 09 08
09 10 1996 10 21
09 30 1996 09 05
10 15 1996 10 24
10 29 1996 10 14
Depth (m)
Temperature (C)

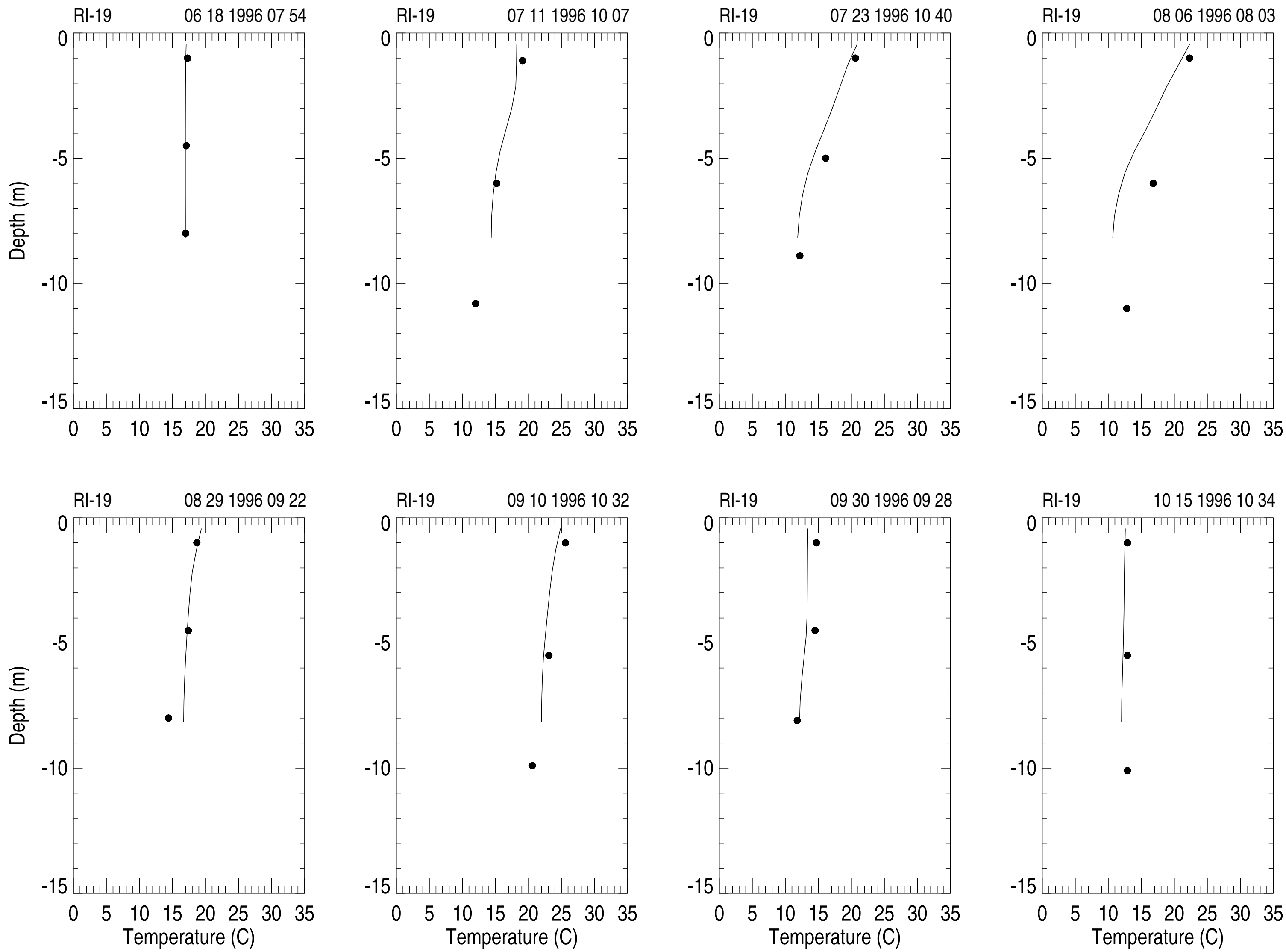

RI-17
03 25 1996 08 06
RI-17
04 22 1996 11 23
RI-17
05 13 1996 12 18
RI-17
05 28 1996 10 06
RI-17
06 11 1996 11 36
RI-17
06 18 1996 10 50
RI-17
07 11 1996 09 39
RI-17
07 23 1996 12 07
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

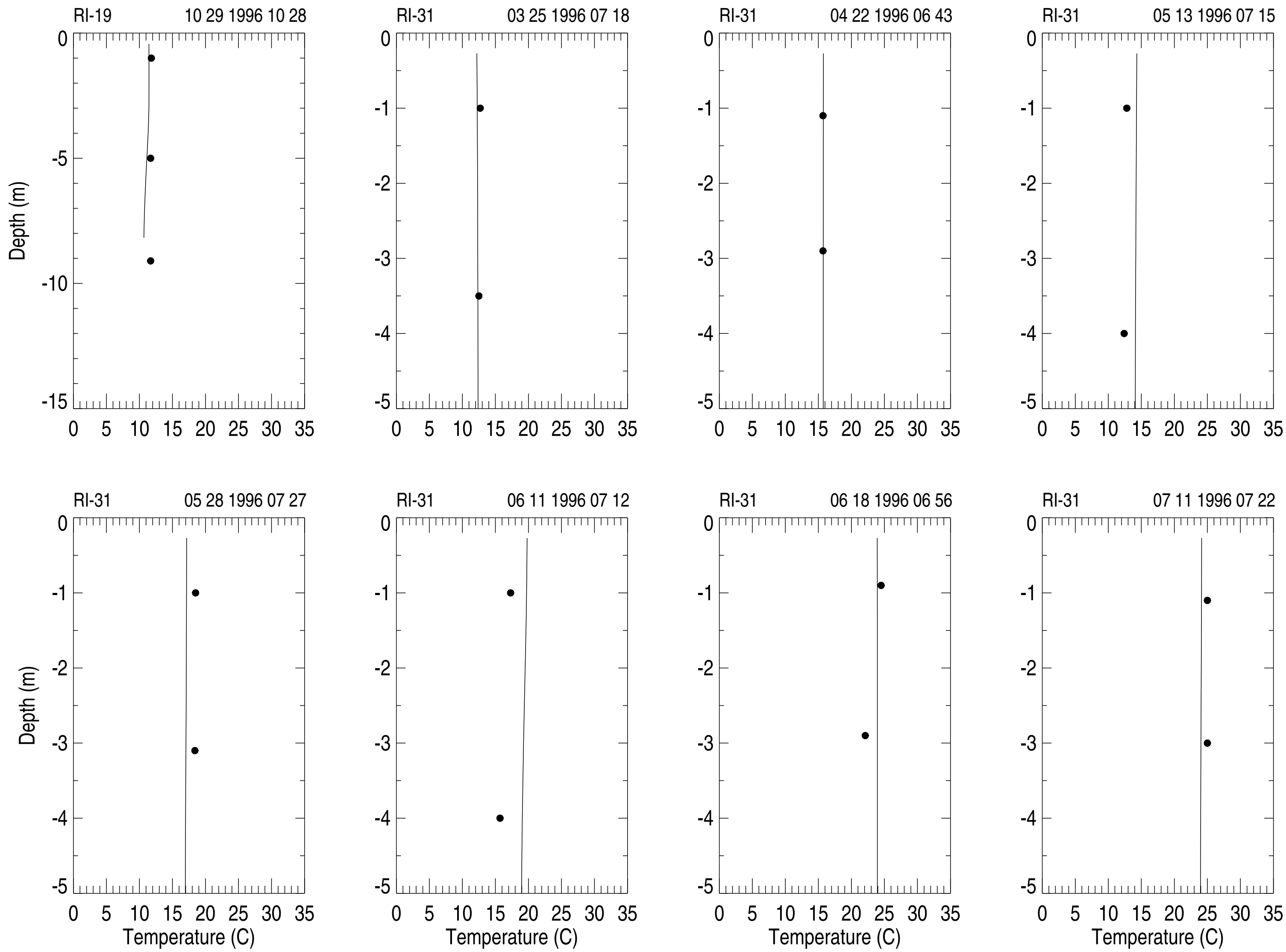


RI-17 08 06 1996 10 46
RI-17 08 29 1996 07 52
RI-17 09 10 1996 12 08
RI-17 09 30 1996 10 59
RI-17 10 15 1996 12 01
RI-17 10 29 1996 09 56
RI-17 11 19 1996 12 14
RI-18 04 22 1996 10 08
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

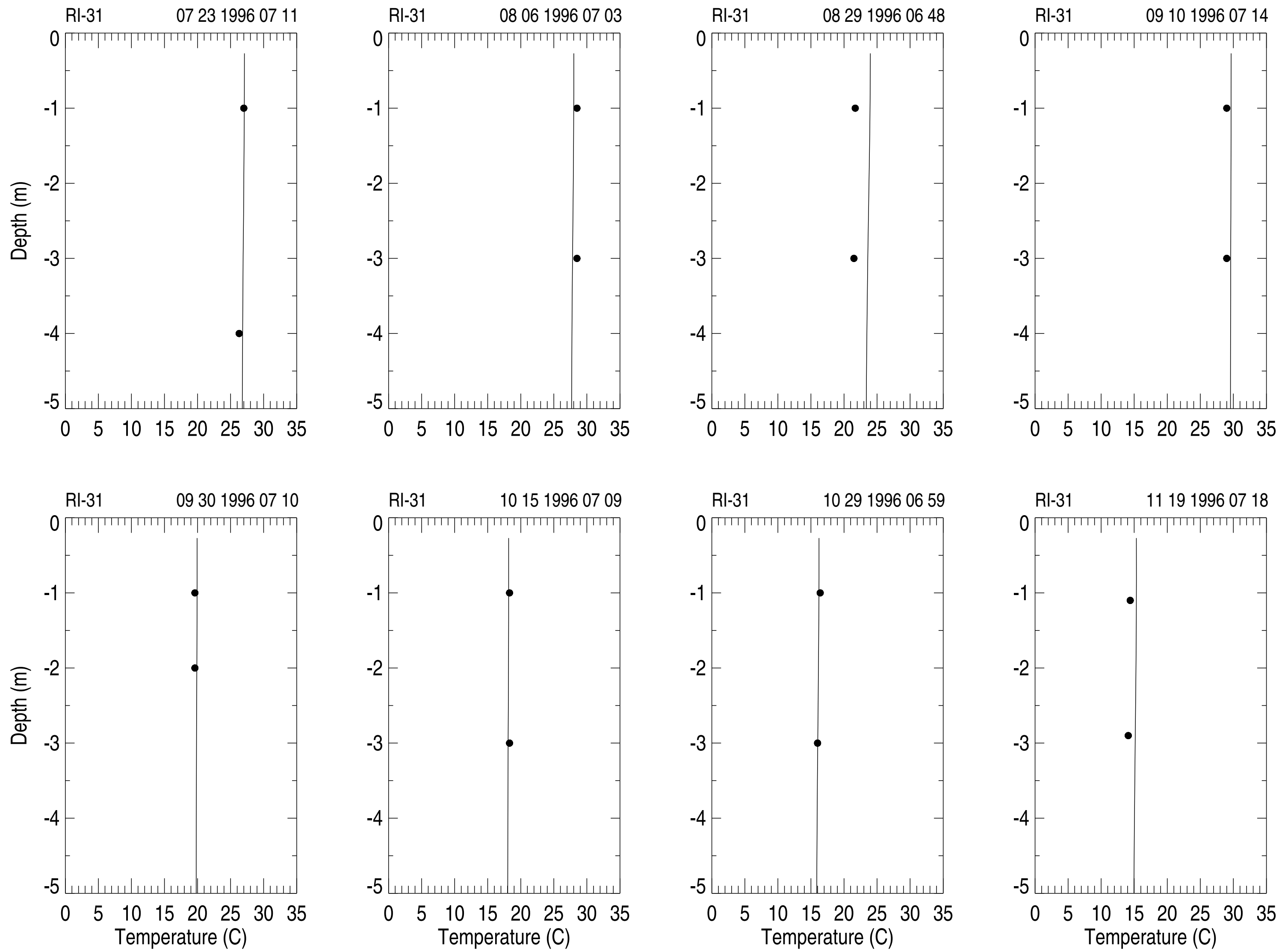

RI-18
05 13 1996 07 59
RI-18
05 28 1996 10 37
RI-18
06 11 1996 10 36
RI-18
06 18 1996 08 08
RI-18
07 11 1996 10 19
RI-18
07 23 1996 10 28
RI-18
08 06 1996 08 18
RI-18
08 29 1996 09 37
Depth (m)
Temperature (C)

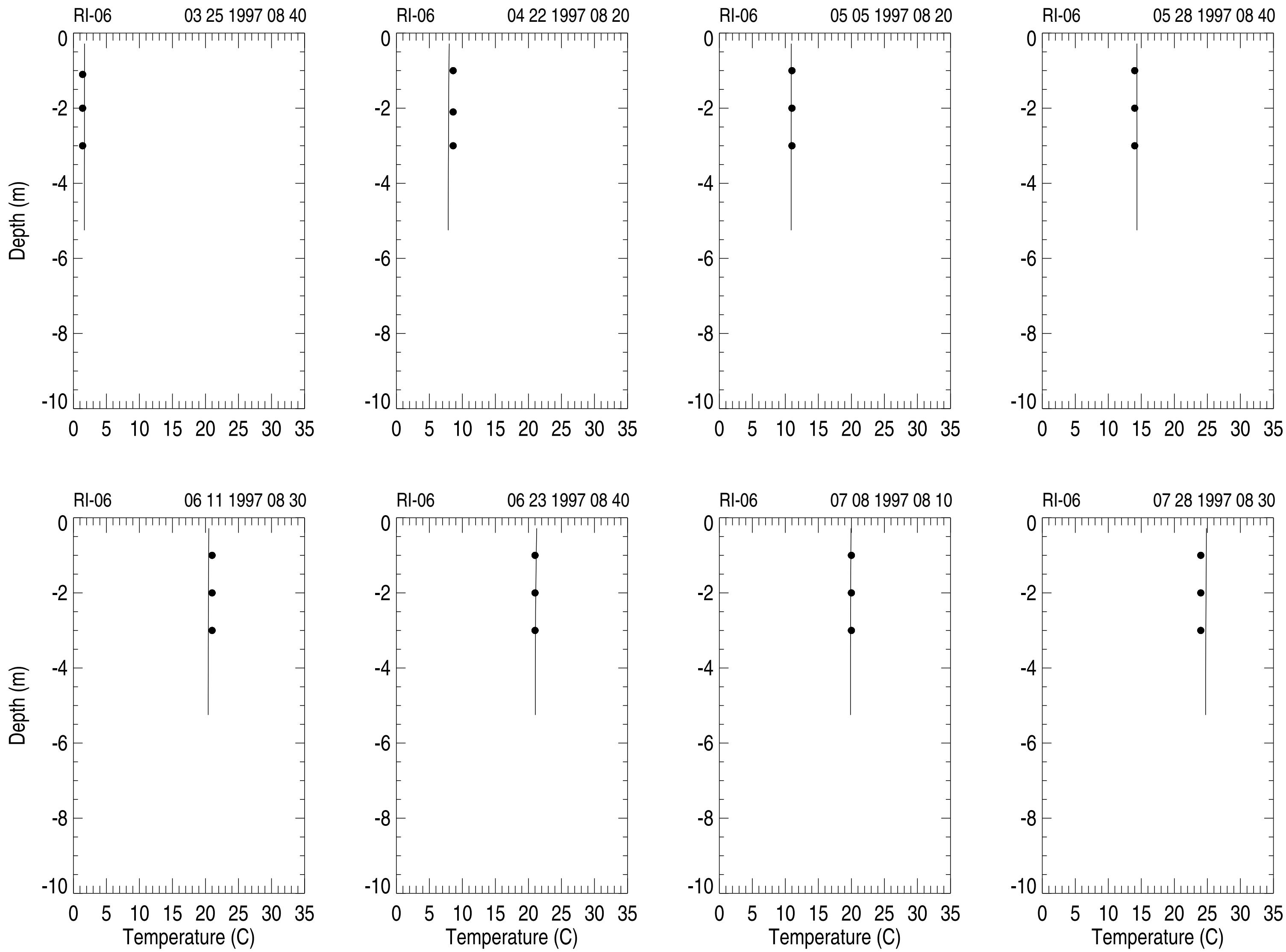

RI-18
09 10 1996 10 43
RI-18
09 30 1996 09 44
RI-18
10 15 1996 10 46
RI-18
10 29 1996 10 43
RI-19
04 22 1996 09 58
RI-19
05 13 1996 07 45
RI-19
05 28 1996 10 47
RI-19
06 11 1996 10 24
Depth (m)
Temperature (C)


RI-19
06 18 1996 07 54
RI-19
07 11 1996 10 07
RI-19
07 23 1996 10 40
RI-19
08 06 1996 08 03
RI-19
08 29 1996 09 22
RI-19
09 10 1996 10 32
RI-19
09 30 1996 09 28
RI-19
10 15 1996 10 34
Depth (m)
0
-5
-10
-15
0 5 10 15 20 25 30 35
Temperature (C)

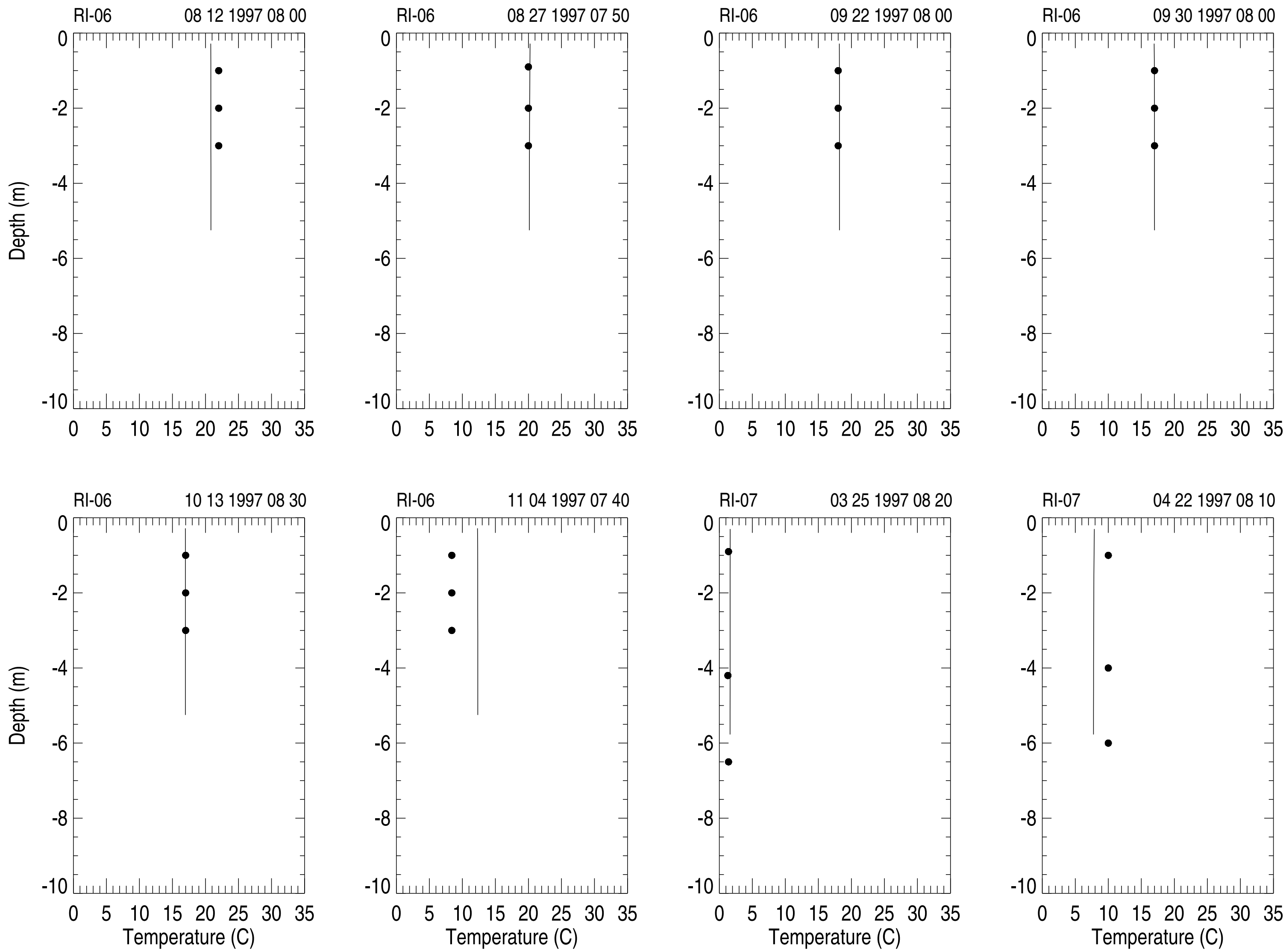


RI-19
10 29 1996 10 28
RI-31
03 25 1996 07 18
RI-31
04 22 1996 06 43
RI-31
05 13 1996 07 15
RI-31
05 28 1996 07 27
RI-31
06 11 1996 07 12
RI-31
06 18 1996 06 56
RI-31
07 11 1996 07 22
Depth (m)
Temperature (C)

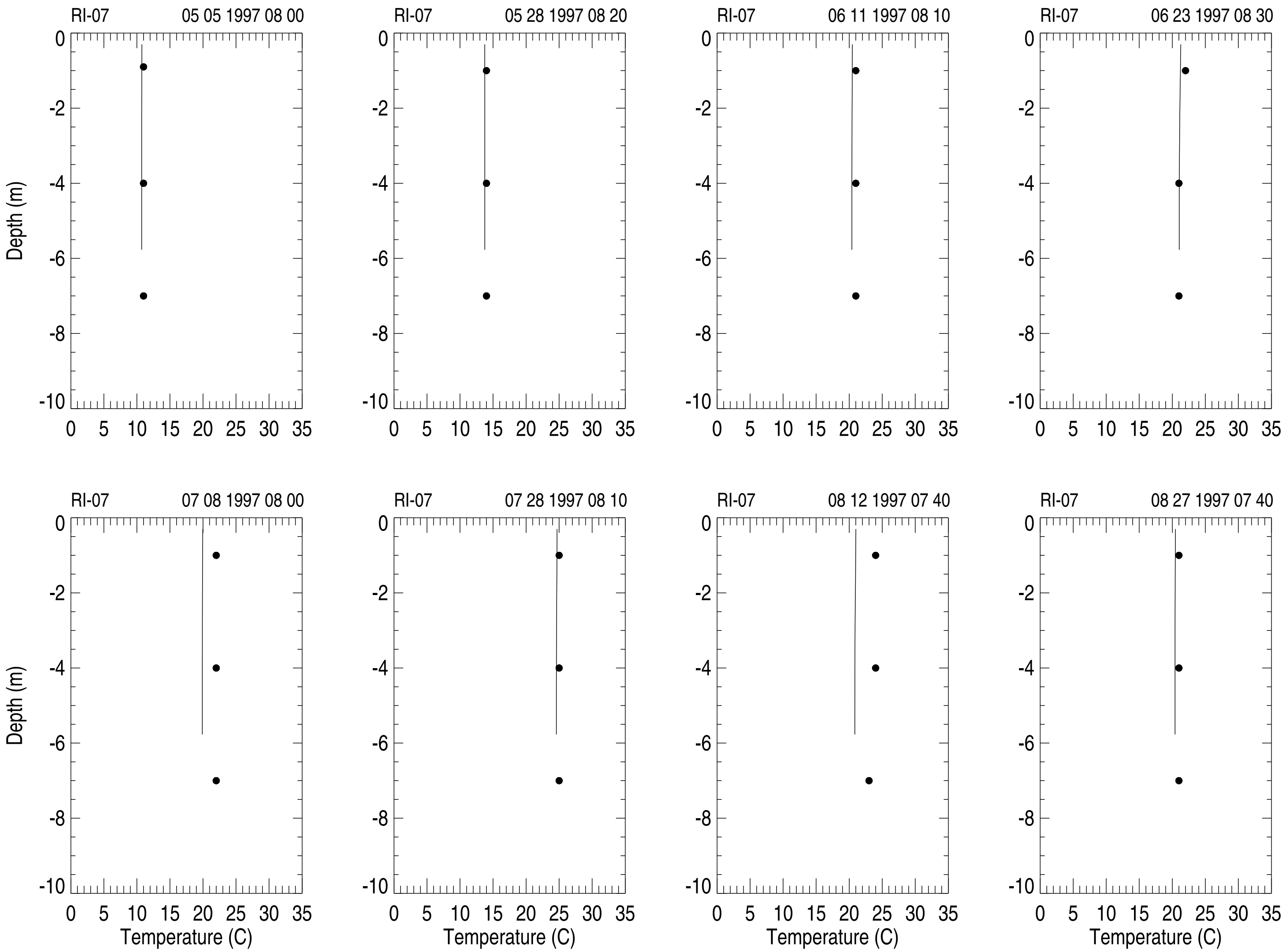

RI-31
07 23 1996 07 11
RI-31
08 06 1996 07 03
RI-31
08 29 1996 06 48
RI-31
09 10 1996 07 14
RI-31
09 30 1996 07 10
RI-31
10 15 1996 07 09
RI-31
10 29 1996 06 59
RI-31
11 19 1996 07 18
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35

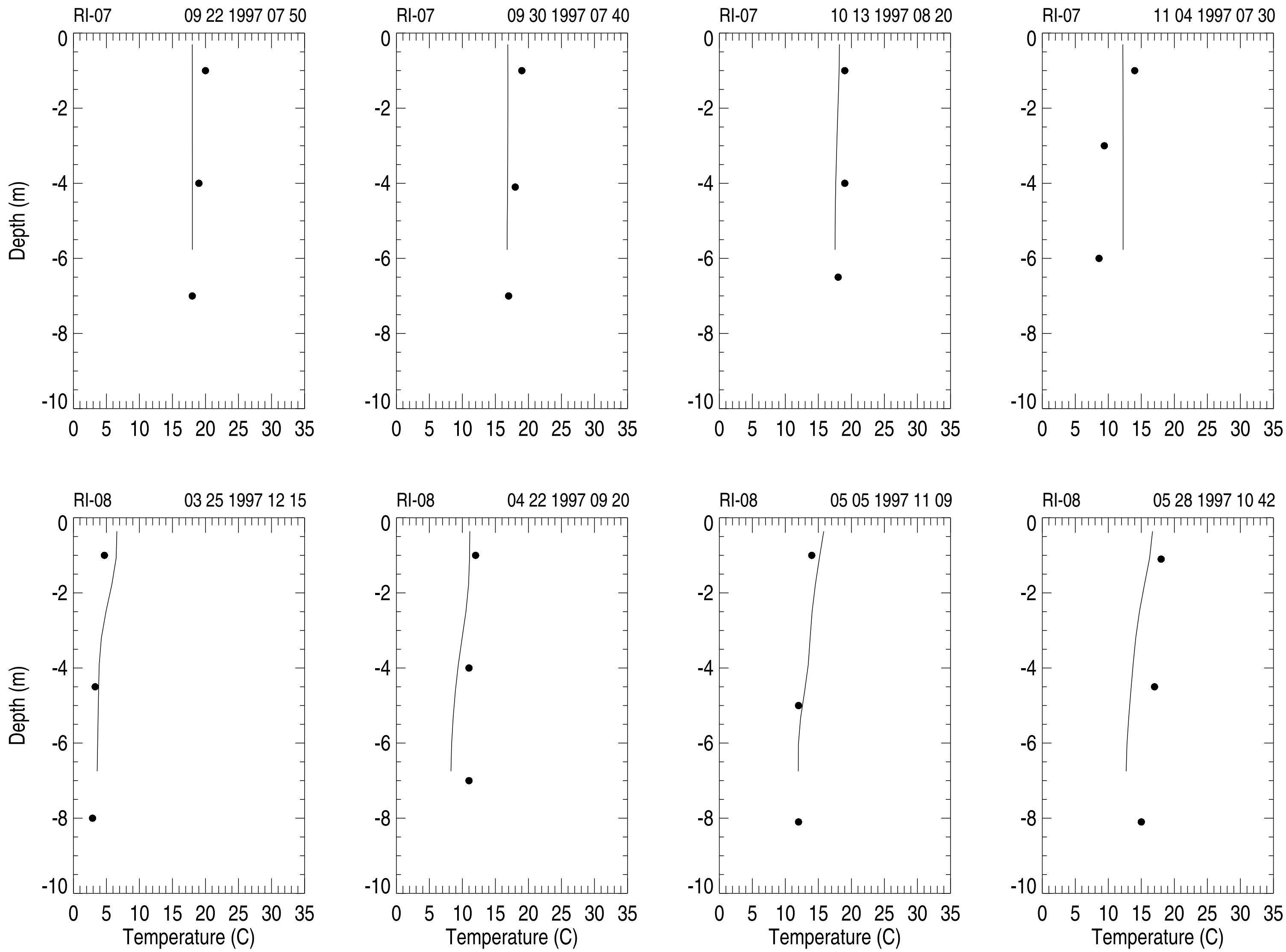


RI-06
03 25 1997 08 40
RI-06
04 22 1997 08 20
RI-06
05 05 1997 08 20
RI-06
05 28 1997 08 40
RI-06
06 11 1997 08 30
RI-06
06 23 1997 08 40
RI-06
07 08 1997 08 10
RI-06
07 28 1997 08 30
Depth (m)
Temperature (C)

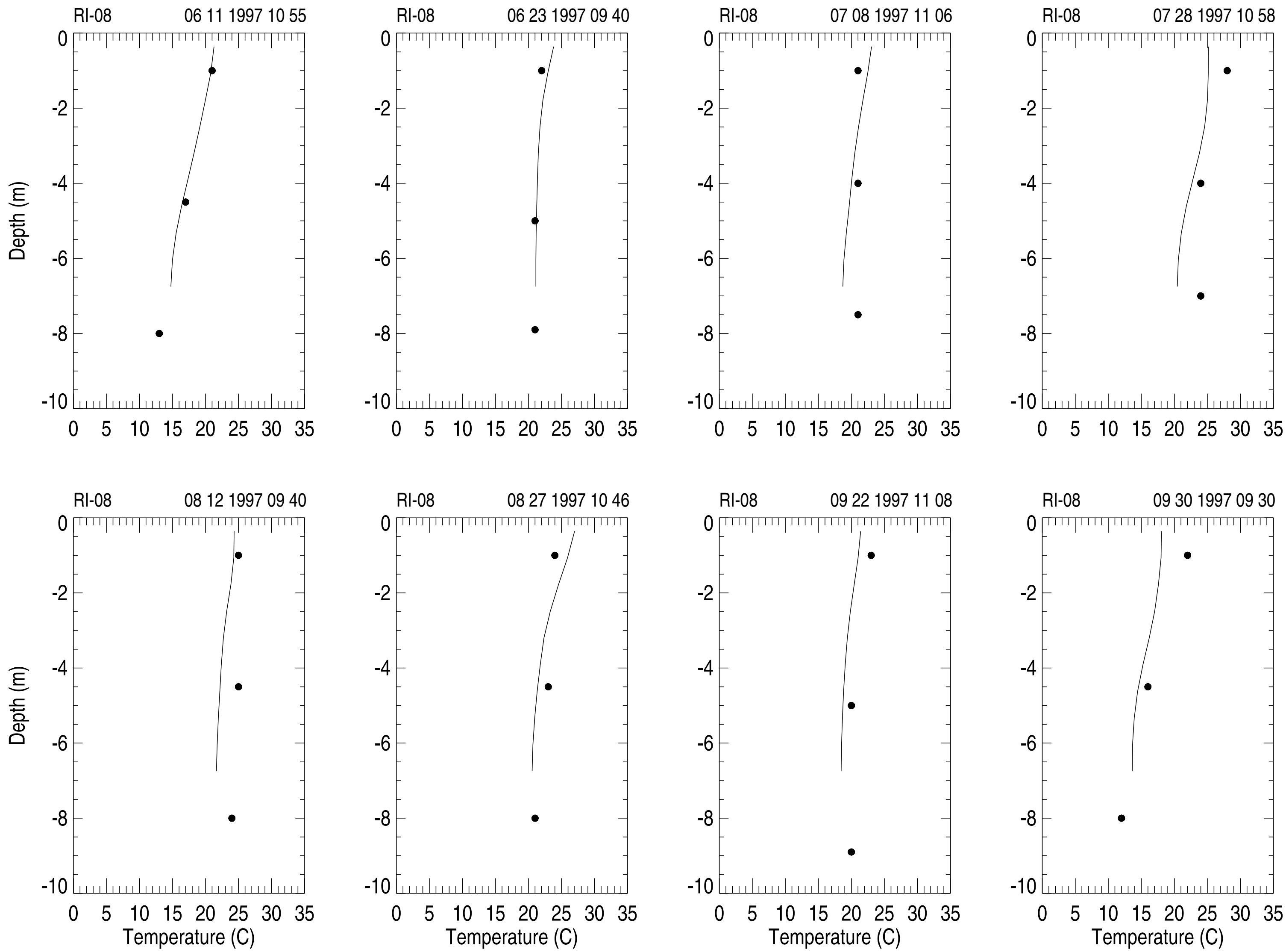


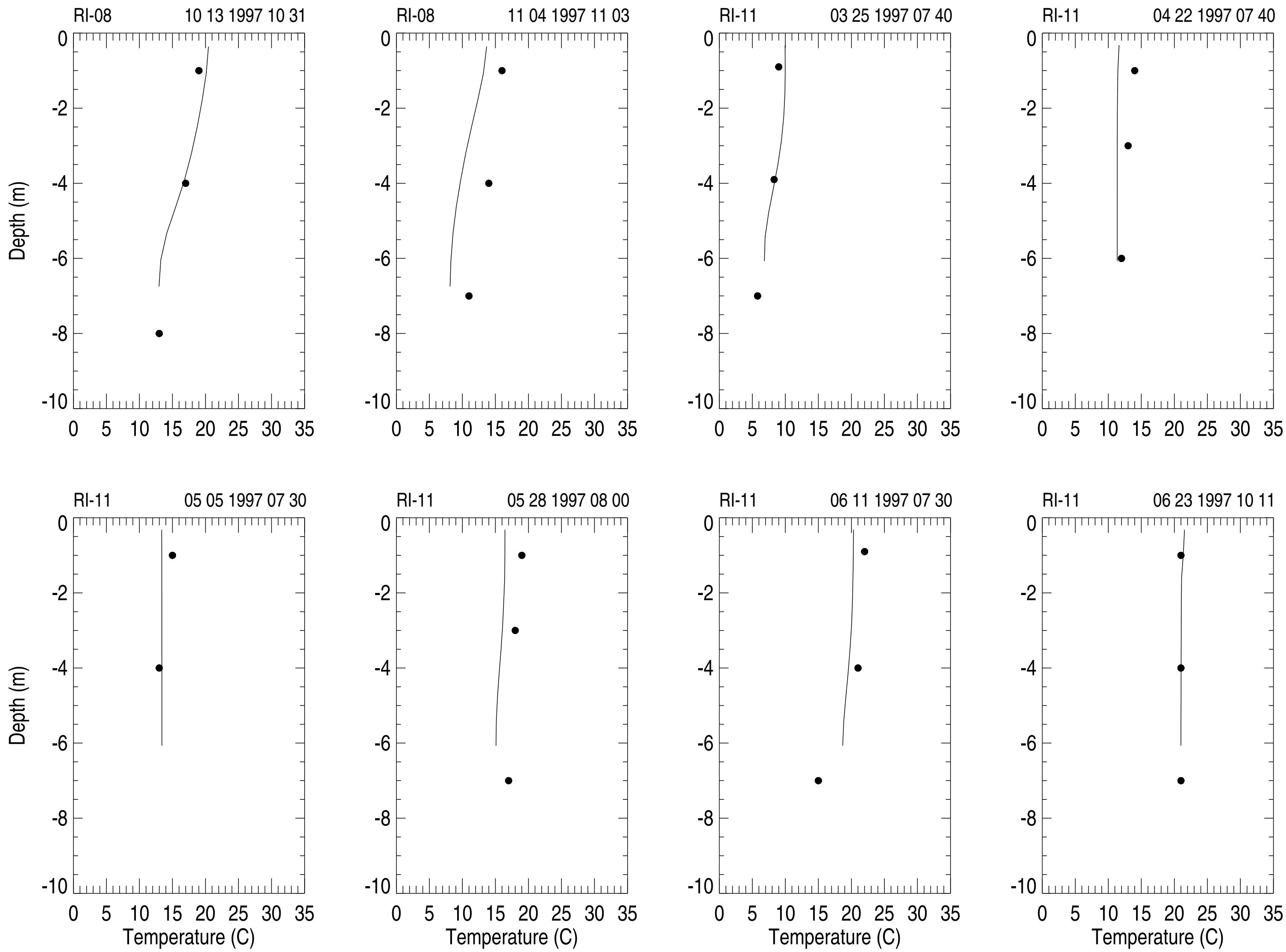
RI-06
08 12 1997 08 00
RI-06
08 27 1997 07 50
RI-06
09 22 1997 08 00
RI-06
09 30 1997 08 00
RI-06
10 13 1997 08 30
RI-06
11 04 1997 07 40
RI-07
03 25 1997 08 20
RI-07
04 22 1997 08 10
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)


RI-07
05 05 1997 08 00
RI-07
05 28 1997 08 20
RI-07
06 11 1997 08 10
RI-07
06 23 1997 08 30
RI-07
07 08 1997 08 00
RI-07
07 28 1997 08 10
RI-07
08 12 1997 07 40
RI-07
08 27 1997 07 40
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

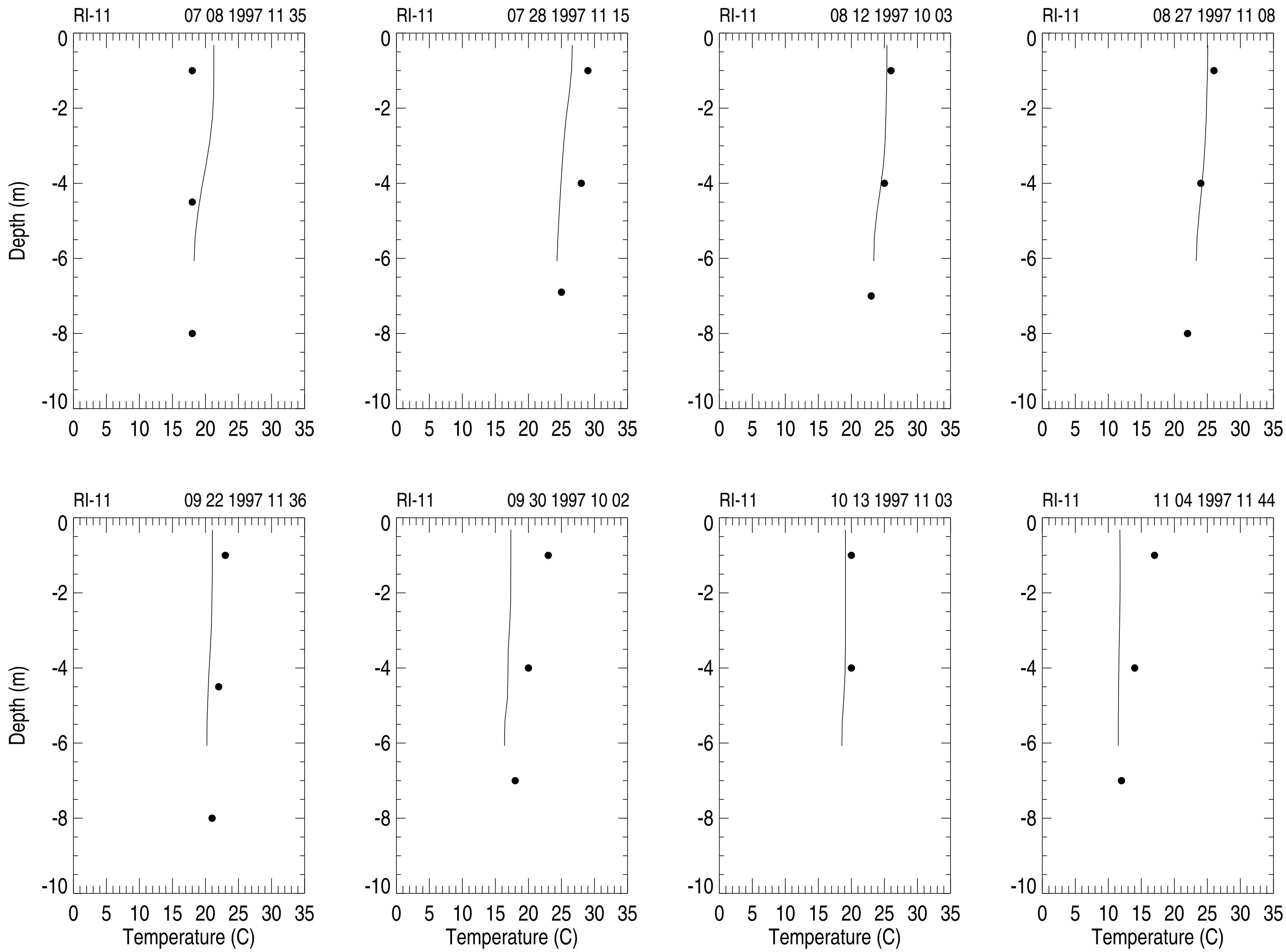


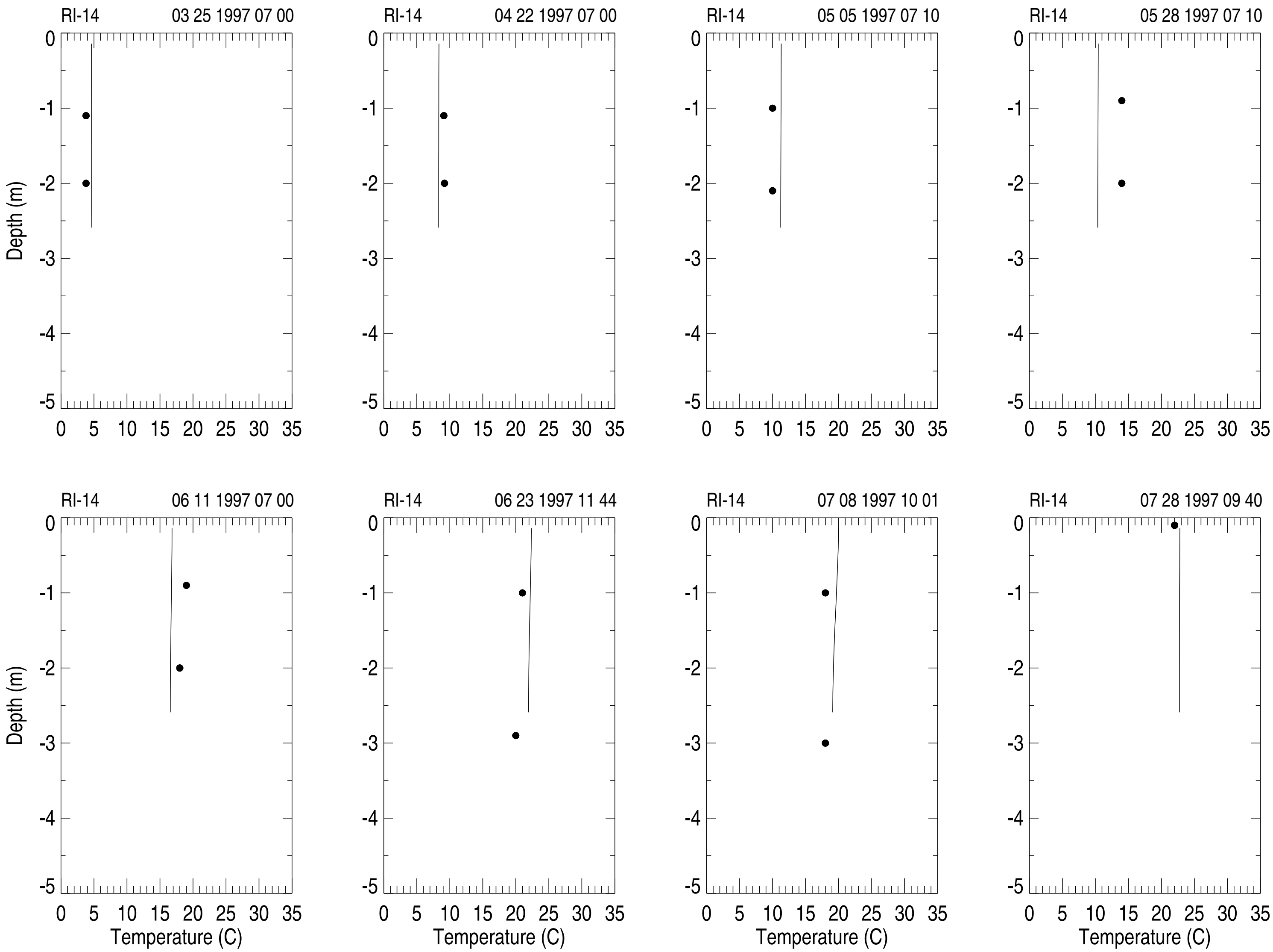
RI-07
09 22 1997 07 50
RI-07
09 30 1997 07 40
RI-07
10 13 1997 08 20
RI-07
11 04 1997 07 30
RI-08
03 25 1997 12 15
RI-08
04 22 1997 09 20
RI-08
05 05 1997 11 09
RI-08
05 28 1997 10 42
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

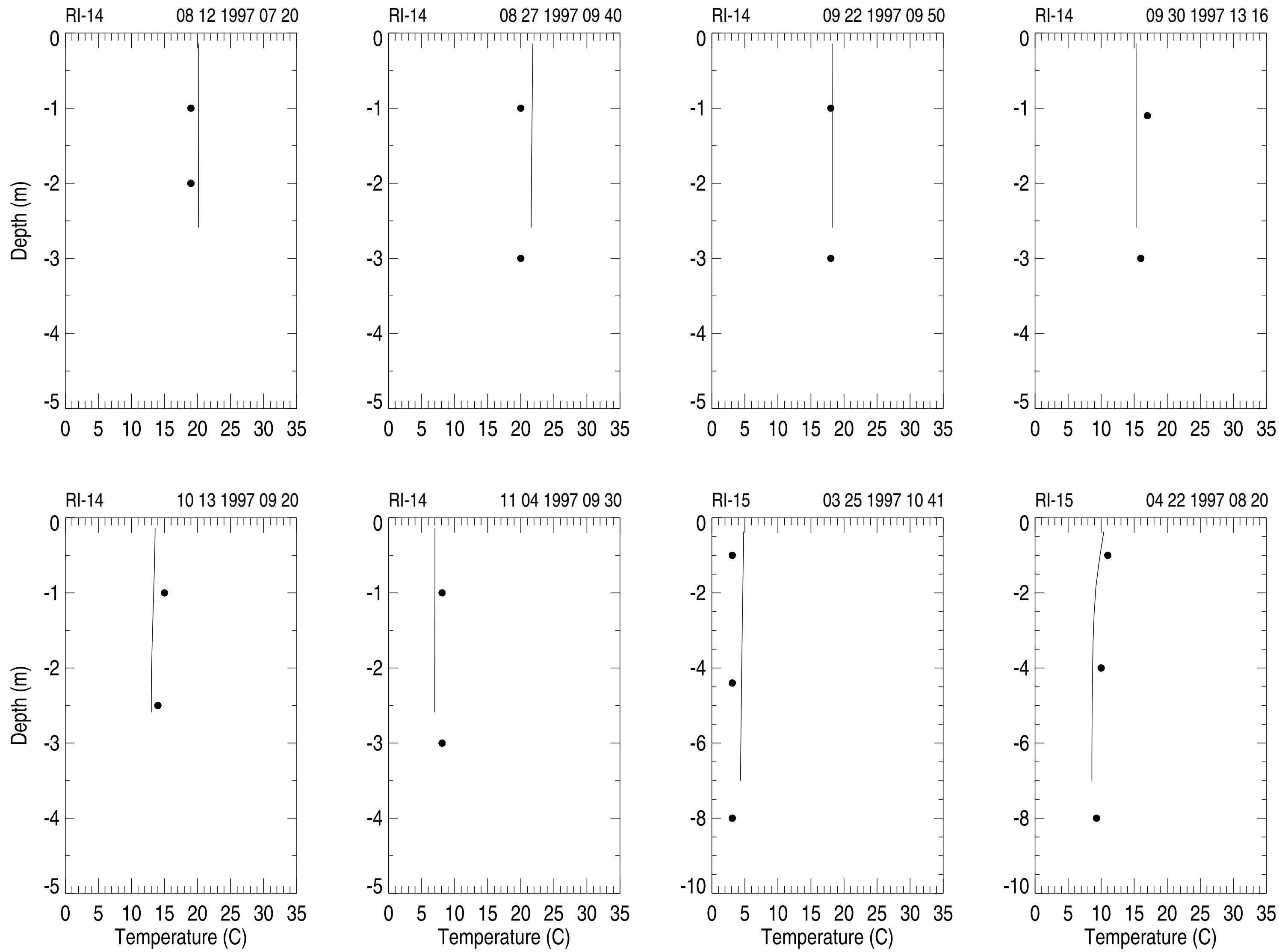

RI-08
06 11 1997 10 55
RI-08
06 23 1997 09 40
RI-08
07 08 1997 11 06
RI-08
07 28 1997 10 58
RI-08
08 12 1997 09 40
RI-08
08 27 1997 10 46
RI-08
09 22 1997 11 08
RI-08
09 30 1997 09 30
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

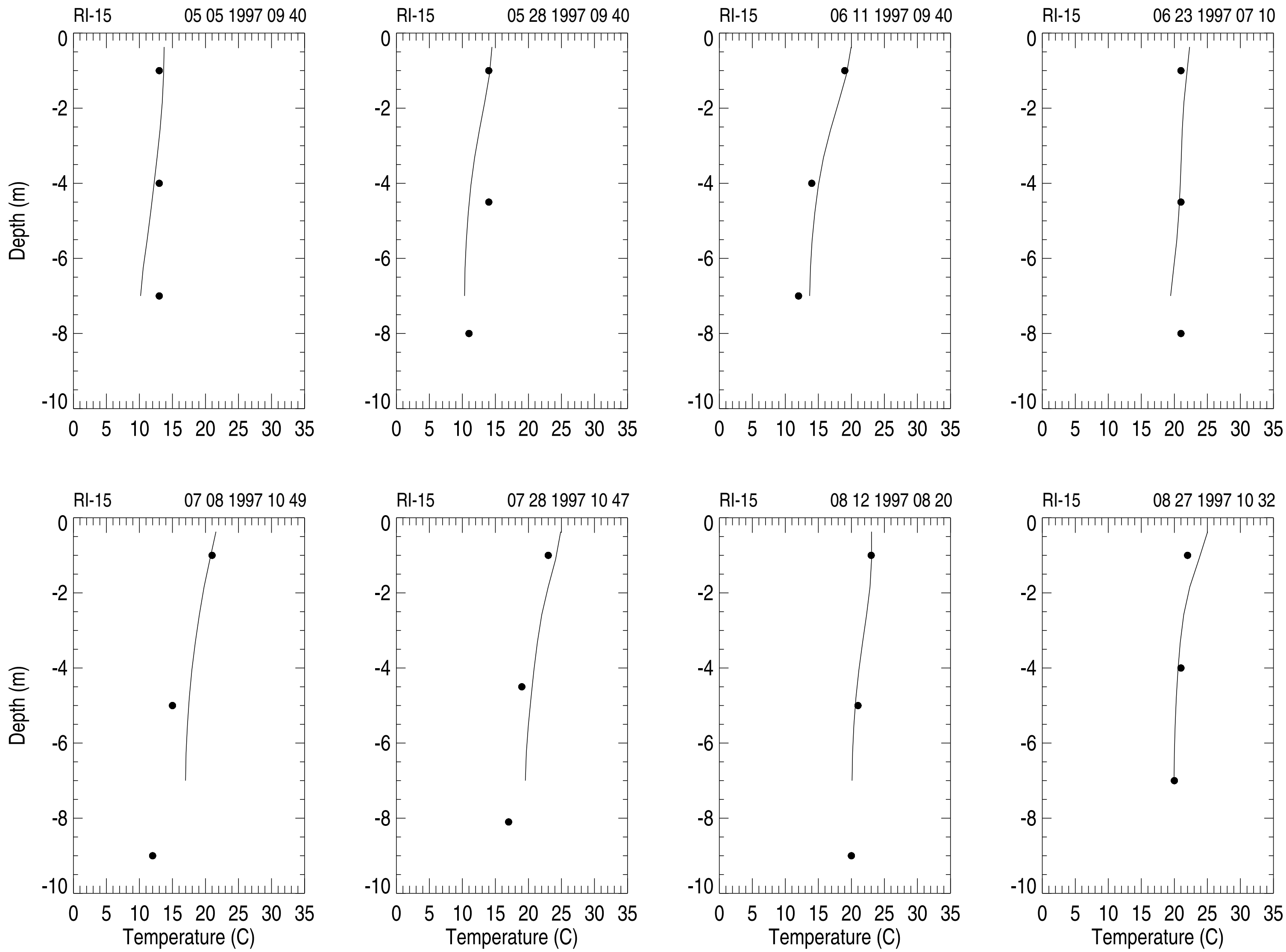


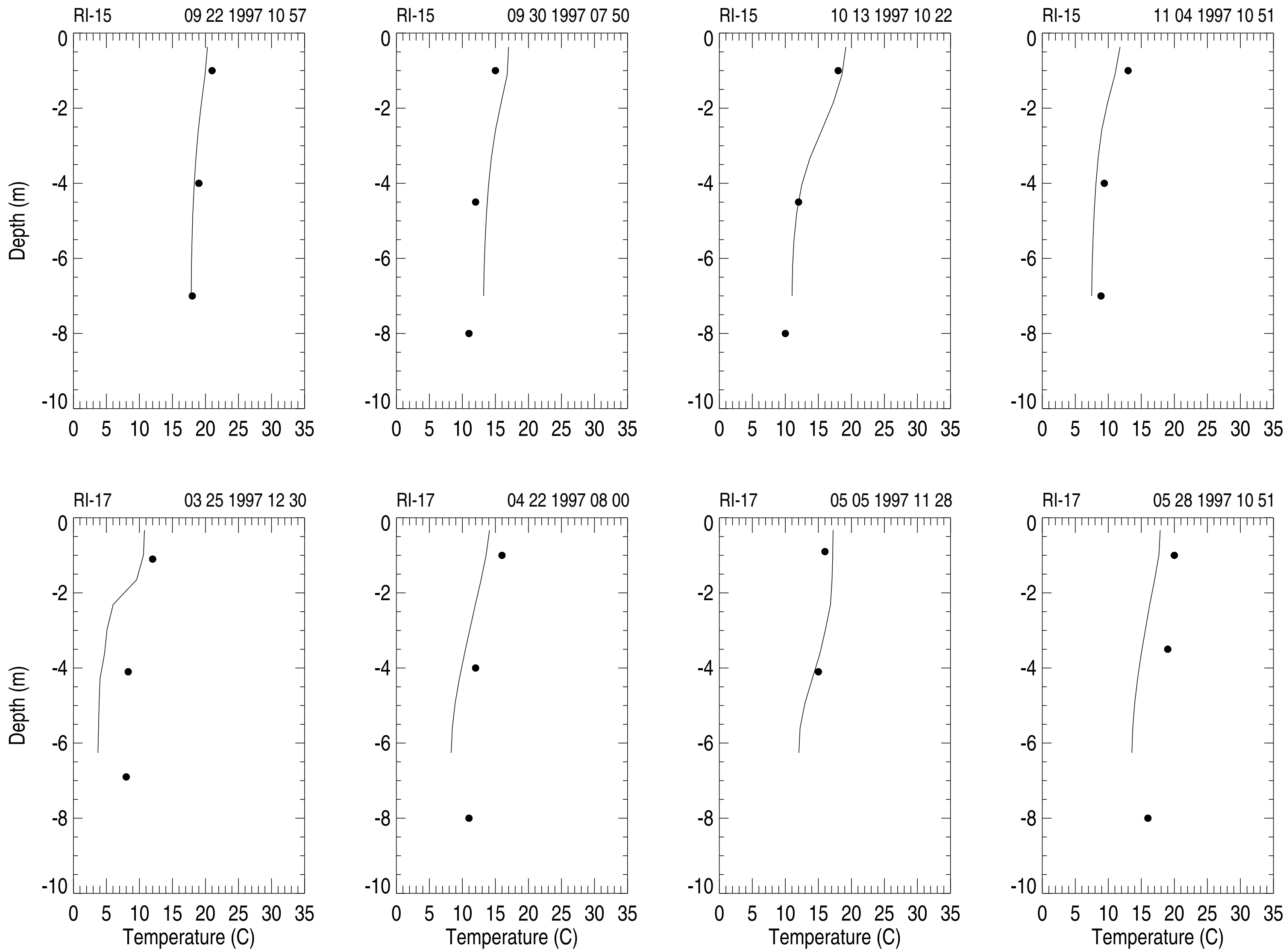
RI-08 10 13 1997 10 31
RI-08 11 04 1997 11 03
RI-11 03 25 1997 07 40
RI-11 04 22 1997 07 40
RI-11 05 05 1997 07 30
RI-11 05 28 1997 08 00
RI-11 06 11 1997 07 30
RI-11 06 23 1997 10 11
Depth (m)
Temperature (C)

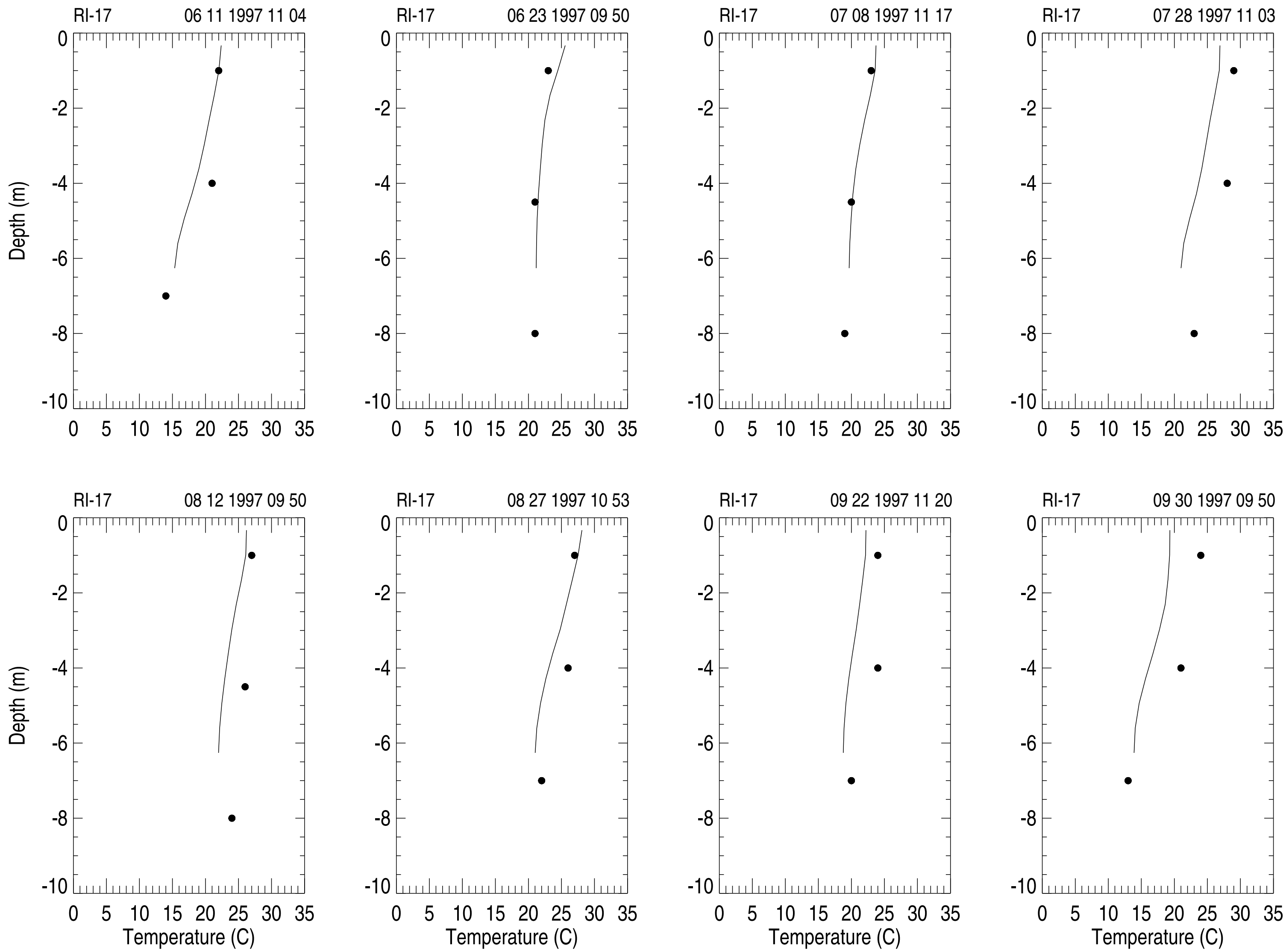

RI-11 07 08 1997 11 35
RI-11 07 28 1997 11 15
RI-11 08 12 1997 10 03
RI-11 08 27 1997 11 08
RI-11 09 22 1997 11 36
RI-11 09 30 1997 10 02
RI-11 10 13 1997 11 03
RI-11 11 04 1997 11 44
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

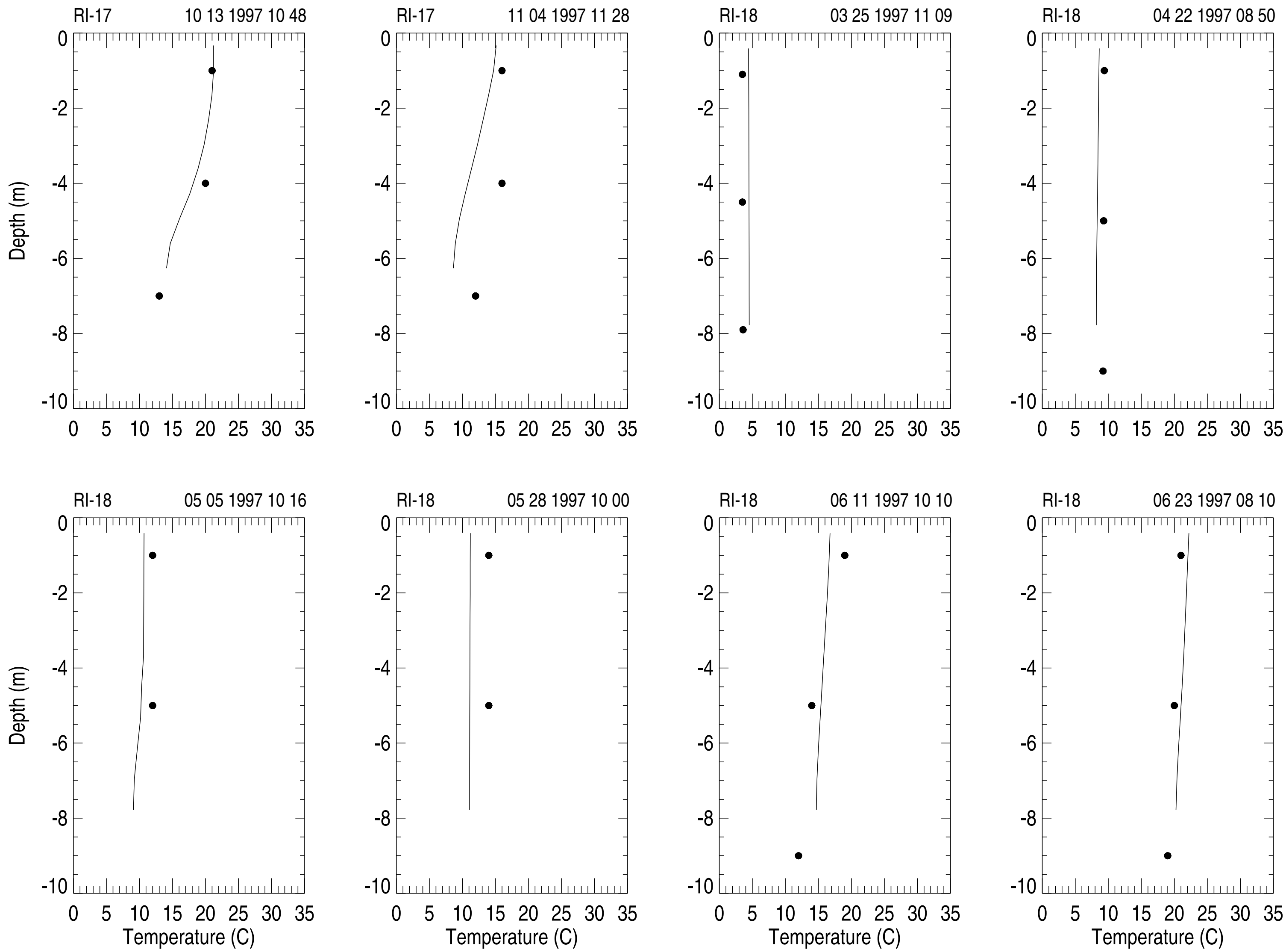

RI-14
03 25 1997 07 00
RI-14
04 22 1997 07 00
RI-14
05 05 1997 07 10
RI-14
05 28 1997 07 10
RI-14
06 11 1997 07 00
RI-14
06 23 1997 11 44
RI-14
07 08 1997 10 01
RI-14
07 28 1997 09 40
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35


RI-14 08 12 1997 07 20
RI-14 08 27 1997 09 40
RI-14 09 22 1997 09 50
RI-14 09 30 1997 13 16
RI-14 10 13 1997 09 20
RI-14 11 04 1997 09 30
RI-15 03 25 1997 10 41
RI-15 04 22 1997 08 20
Depth (m)
Temperature (C)

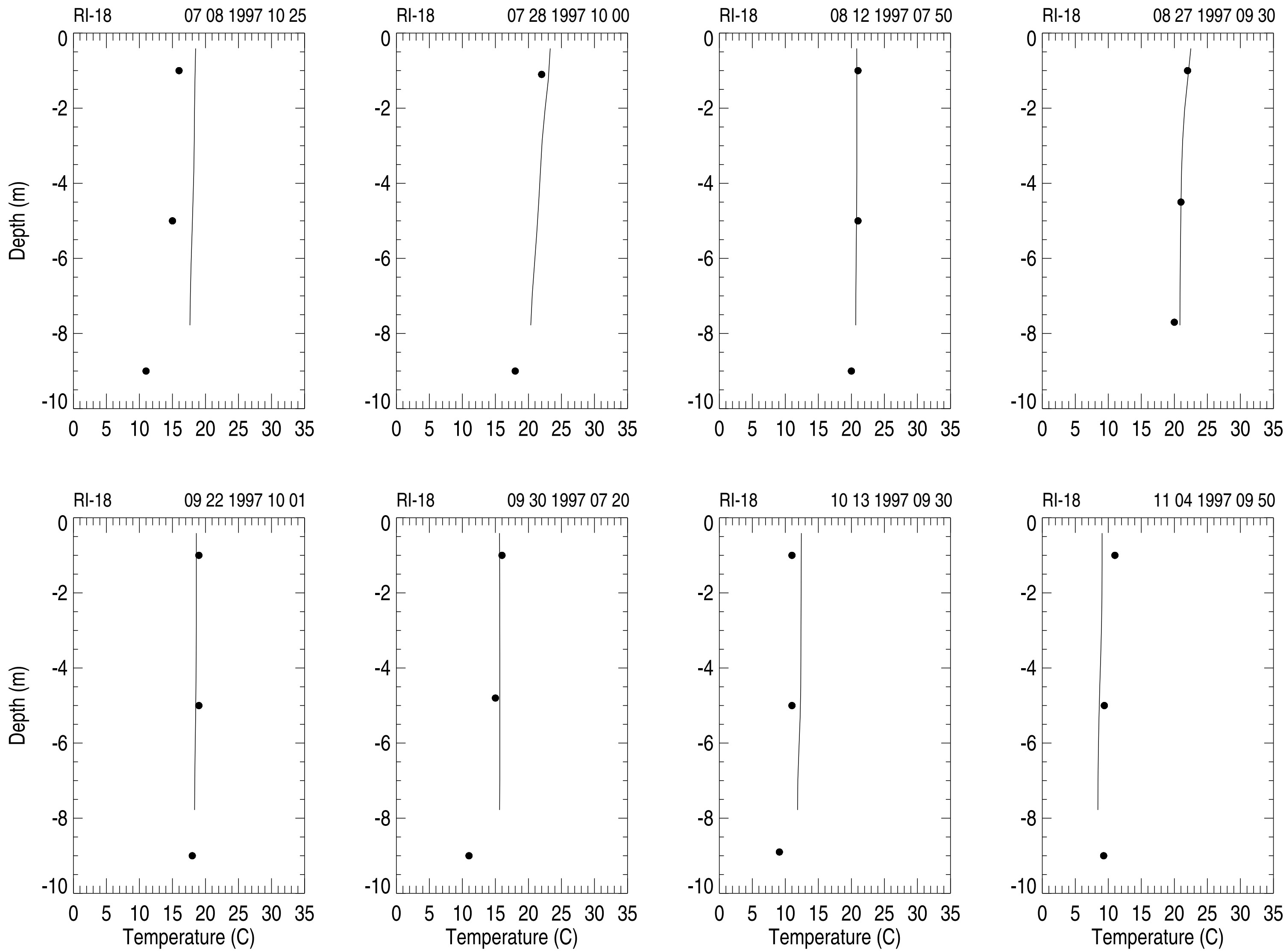

RI-15
05 05 1997 09 40
05 28 1997 09 40
06 11 1997 09 40
06 23 1997 07 10
07 08 1997 10 49
07 28 1997 10 47
08 12 1997 08 20
08 27 1997 10 32
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

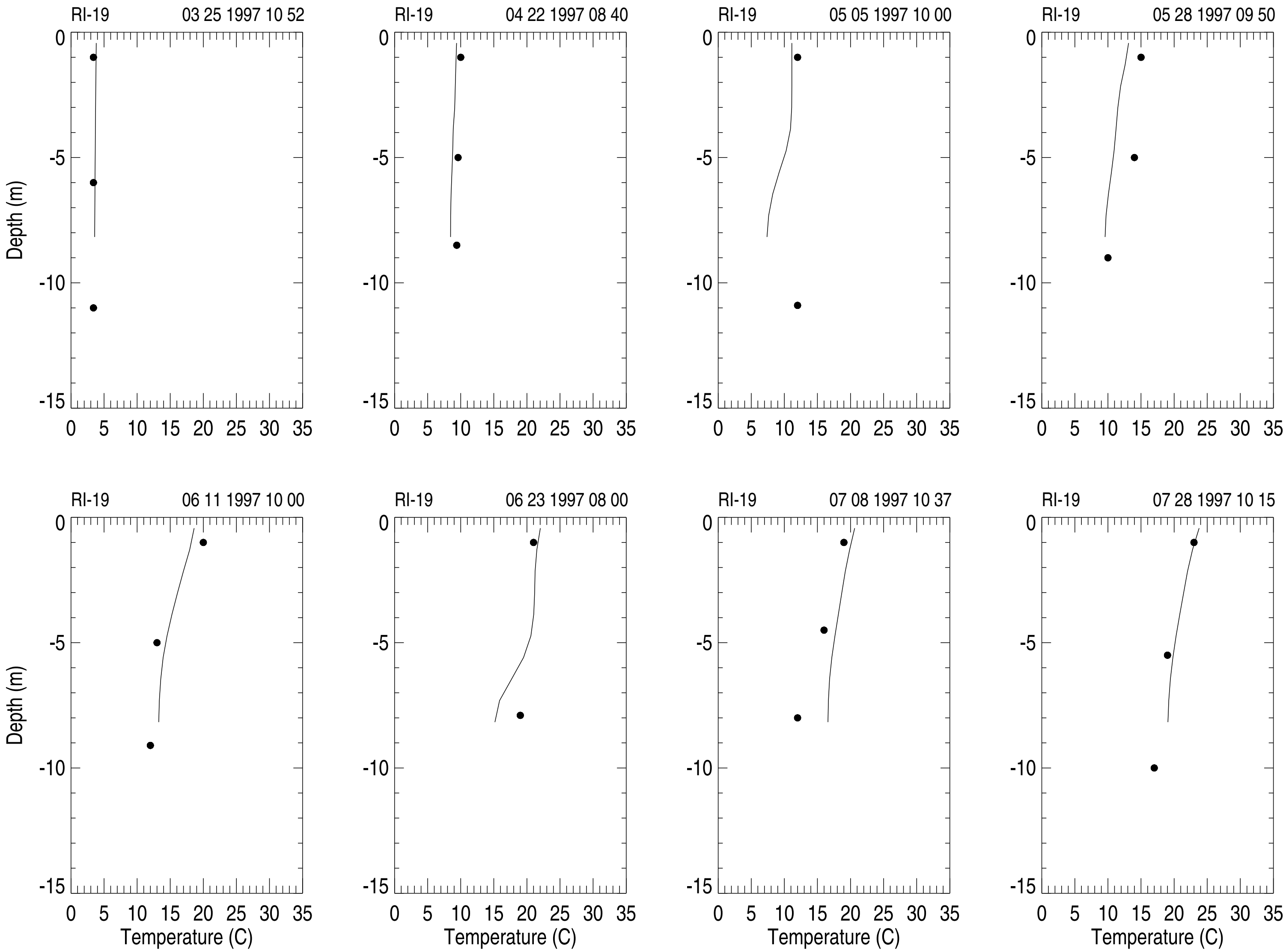

RI-15 09 22 1997 10 57
RI-15 09 30 1997 07 50
RI-15 10 13 1997 10 22
RI-15 11 04 1997 10 51
RI-17 03 25 1997 12 30
RI-17 04 22 1997 08 00
RI-17 05 05 1997 11 28
RI-17 05 28 1997 10 51
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

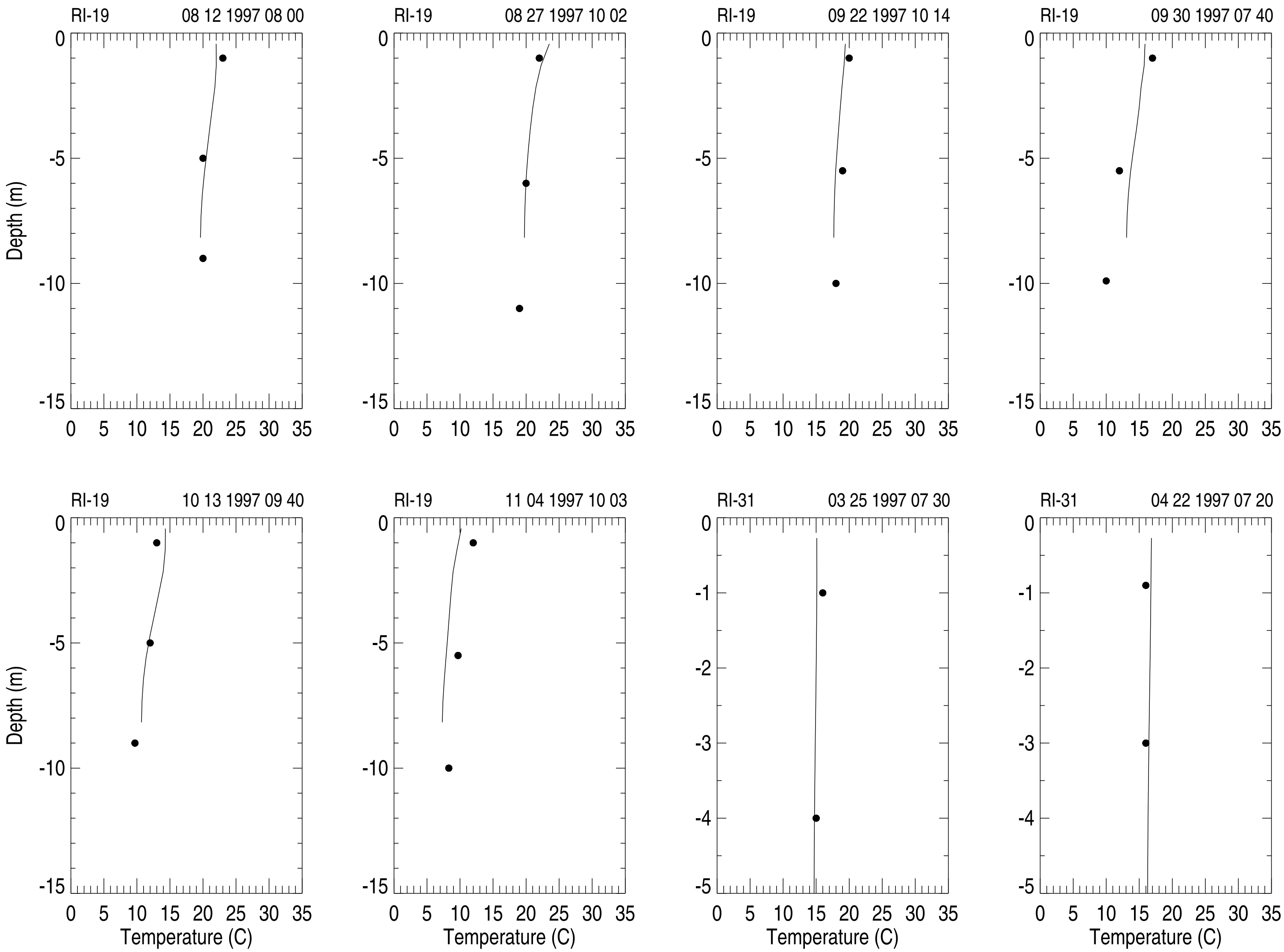

RI-17 06 11 1997 11 04
RI-17 06 23 1997 09 50
RI-17 07 08 1997 11 17
RI-17 07 28 1997 11 03
RI-17 08 12 1997 09 50
RI-17 08 27 1997 10 53
RI-17 09 22 1997 11 20
RI-17 09 30 1997 09 50
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)



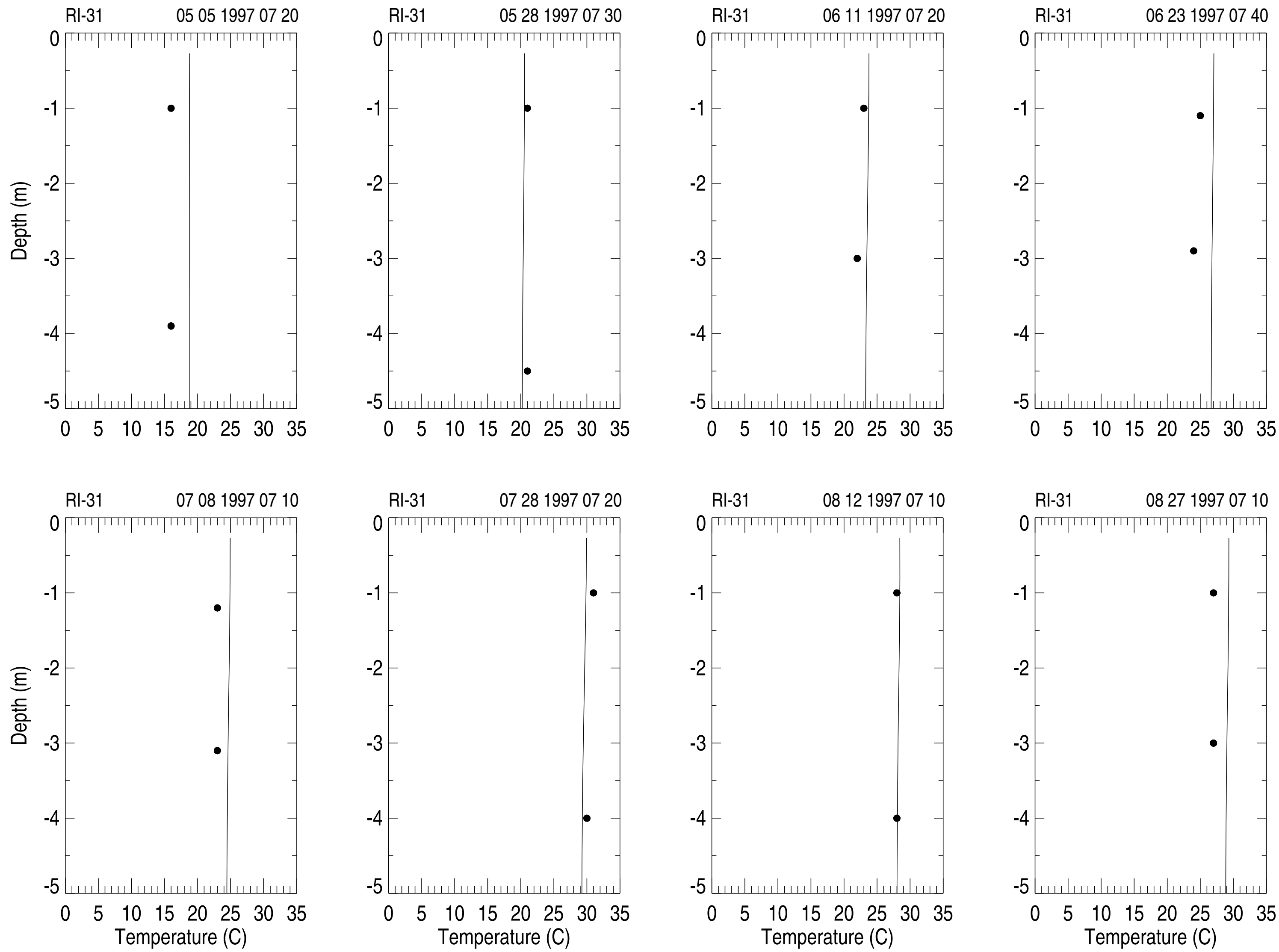
RI-17 10 13 1997 10 48
RI-17 11 04 1997 11 28
RI-18 03 25 1997 11 09
RI-18 04 22 1997 08 50
RI-18 05 05 1997 10 16
RI-18 05 28 1997 10 00
RI-18 06 11 1997 10 10
RI-18 06 23 1997 08 10
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

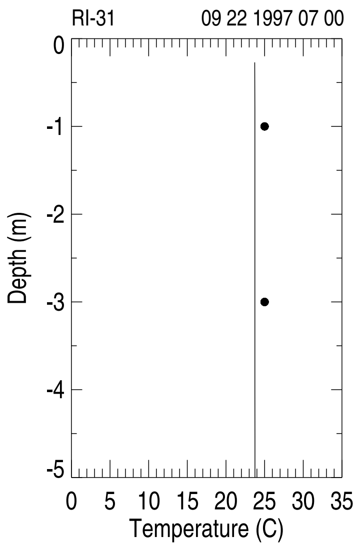

RI-18
07 08 1997 10 25
RI-18
07 28 1997 10 00
RI-18
08 12 1997 07 50
RI-18
08 27 1997 09 30
RI-18
09 22 1997 10 01
RI-18
09 30 1997 07 20
RI-18
10 13 1997 09 30
RI-18
11 04 1997 09 50
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

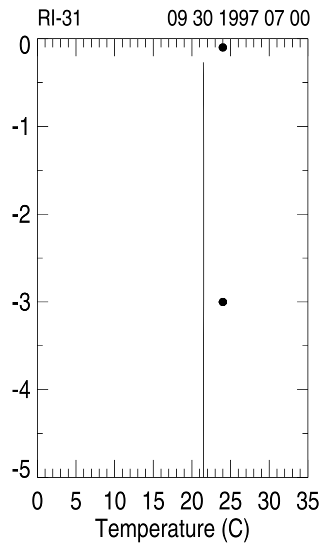

RI-19
03 25 1997 10 52
RI-19
04 22 1997 08 40
RI-19
05 05 1997 10 00
RI-19
05 28 1997 09 50
RI-19
06 11 1997 10 00
RI-19
06 23 1997 08 00
RI-19
07 08 1997 10 37
RI-19
07 28 1997 10 15
Depth (m)
Temperature (C)
0
-5
-10
-15
0 5 10 15 20 25 30 35

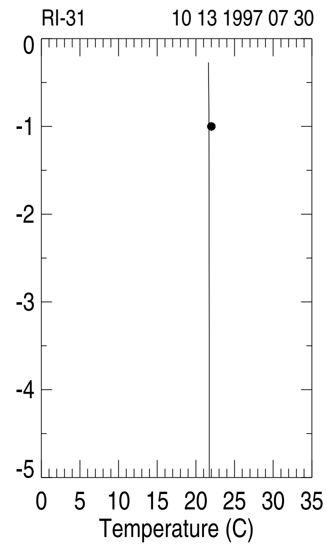


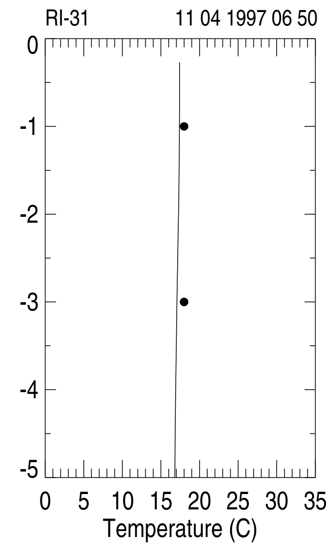
RI-19 08 12 1997 08 00
RI-19 08 27 1997 10 02
RI-19 09 22 1997 10 14
RI-19 09 30 1997 07 40
RI-19 10 13 1997 09 40
RI-19 11 04 1997 10 03
RI-31 03 25 1997 07 30
RI-31 04 22 1997 07 20
Depth (m)
Temperature (C)

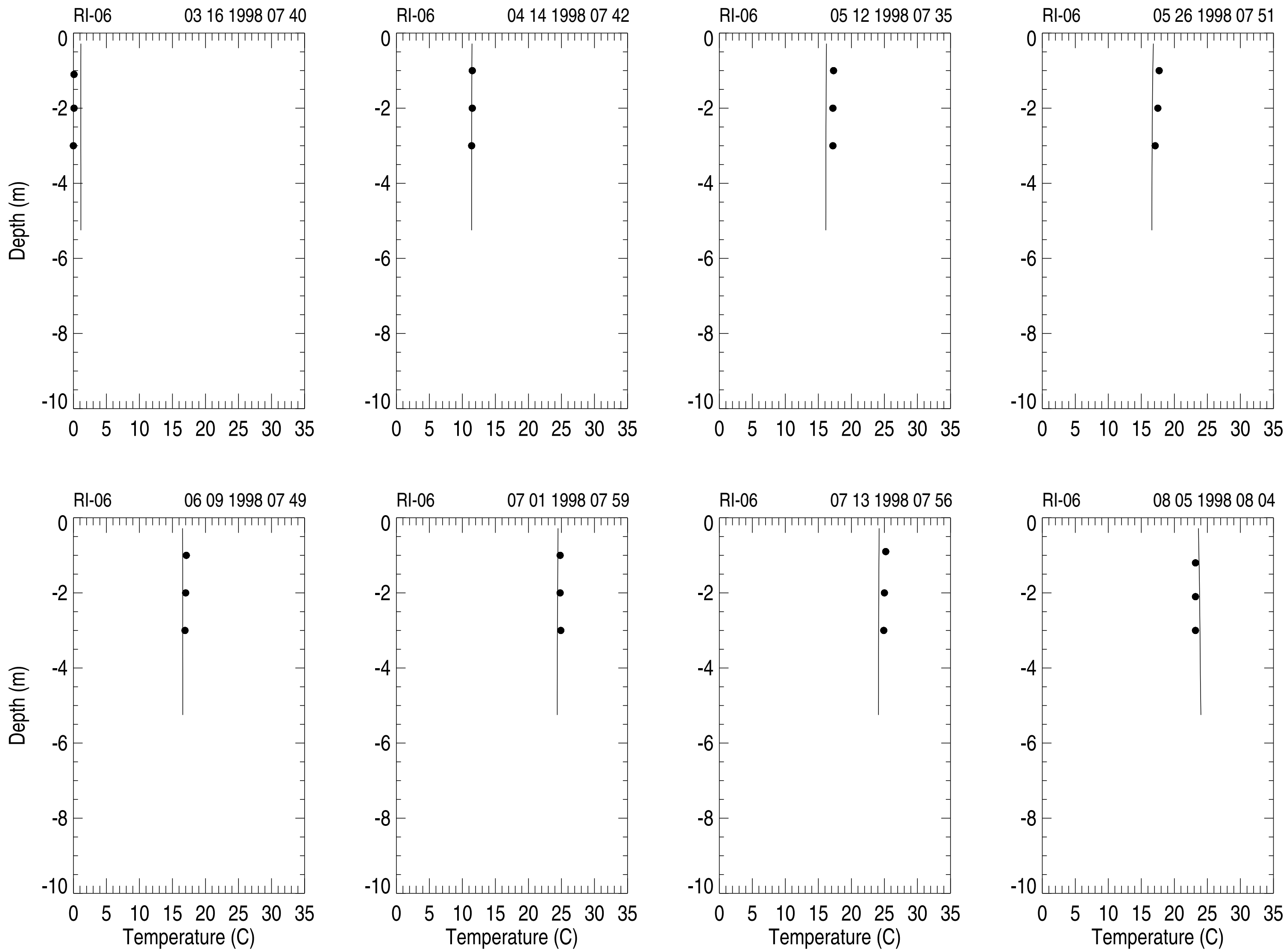

RI-31 05 05 1997 07 20
RI-31 05 28 1997 07 30
RI-31 06 11 1997 07 20
RI-31 06 23 1997 07 40
RI-31 07 08 1997 07 10
RI-31 07 28 1997 07 20
RI-31 08 12 1997 07 10
RI-31 08 27 1997 07 10
Depth (m)
Temperature (C)
0 -1 -2 -3 -4 -5
0 5 10 15 20 25 30 35

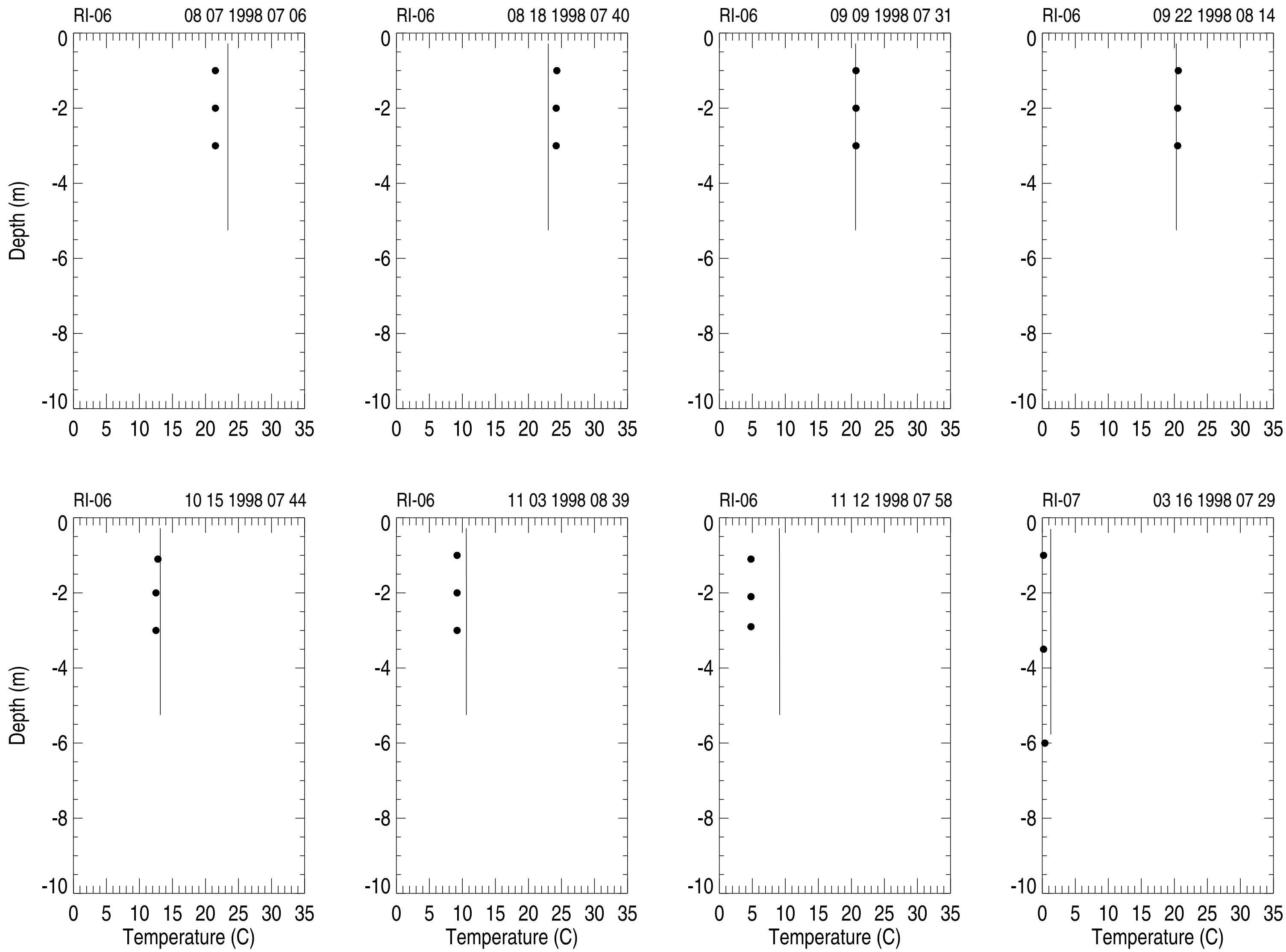

RI-31
09 22 1997 07 00
Depth (m)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35
Temperature (C)

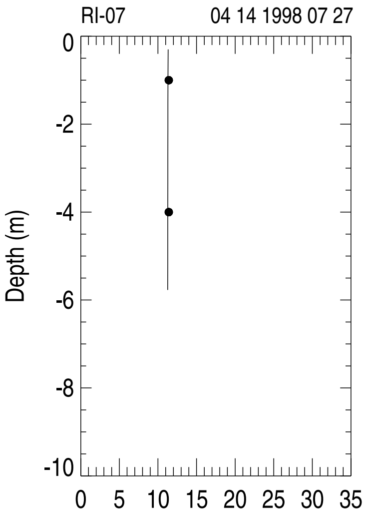

RI-31
09 30 1997 07 00
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35
Temperature (C)

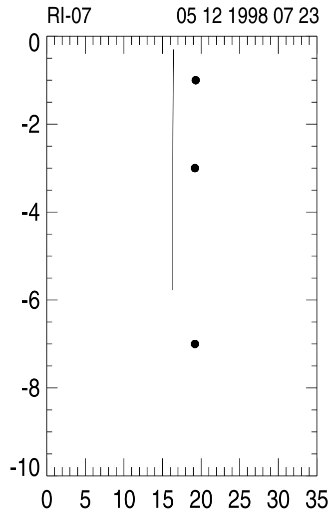

RI-31
10 13 1997 07 30
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35
Temperature (C)

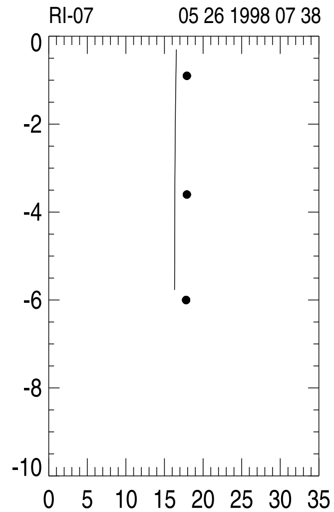

RI-31
11 04 1997 06 50
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35
Temperature (C)

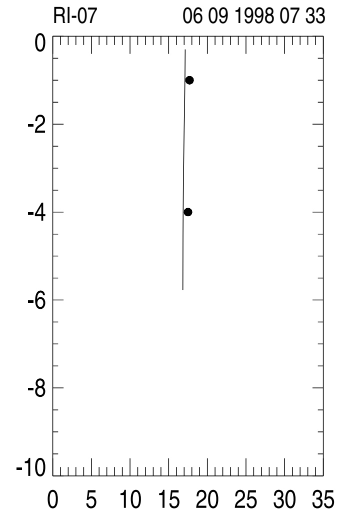

RI-06
03 16 1998 07 40
RI-06
04 14 1998 07 42
RI-06
05 12 1998 07 35
RI-06
05 26 1998 07 51
RI-06
06 09 1998 07 49
RI-06
07 01 1998 07 59
RI-06
07 13 1998 07 56
RI-06
08 05 1998 08 04
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

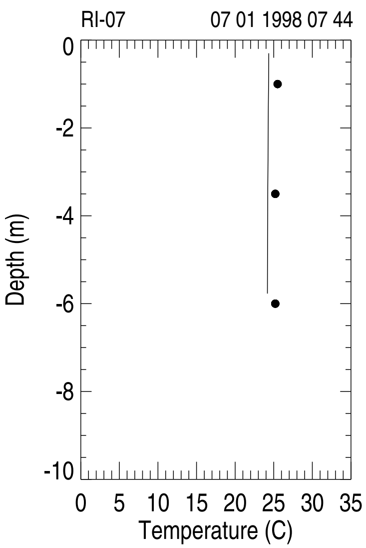

RI-06 08 07 1998 07 06
RI-06 08 18 1998 07 40
RI-06 09 09 1998 07 31
RI-06 09 22 1998 08 14
RI-06 10 15 1998 07 44
RI-06 11 03 1998 08 39
RI-06 11 12 1998 07 58
RI-07 03 16 1998 07 29
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

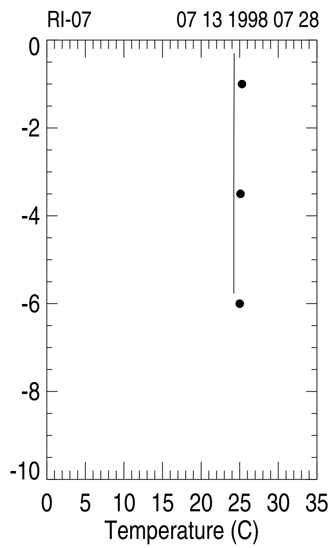

RI-07
04 14 1998 07 27
Depth (m)

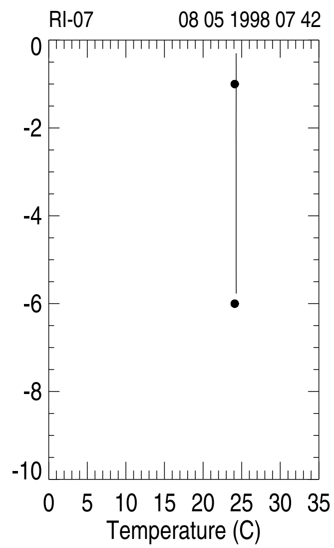

RI-07
05 12 1998 07 23

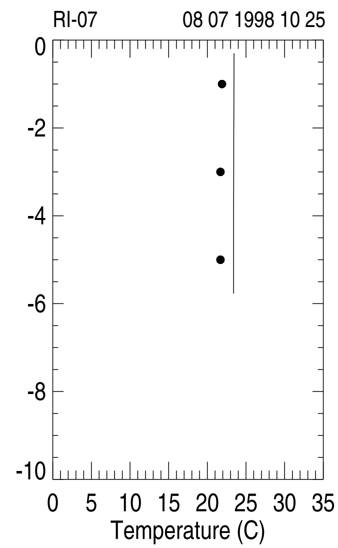

RI-07
05 26 1998 07 38

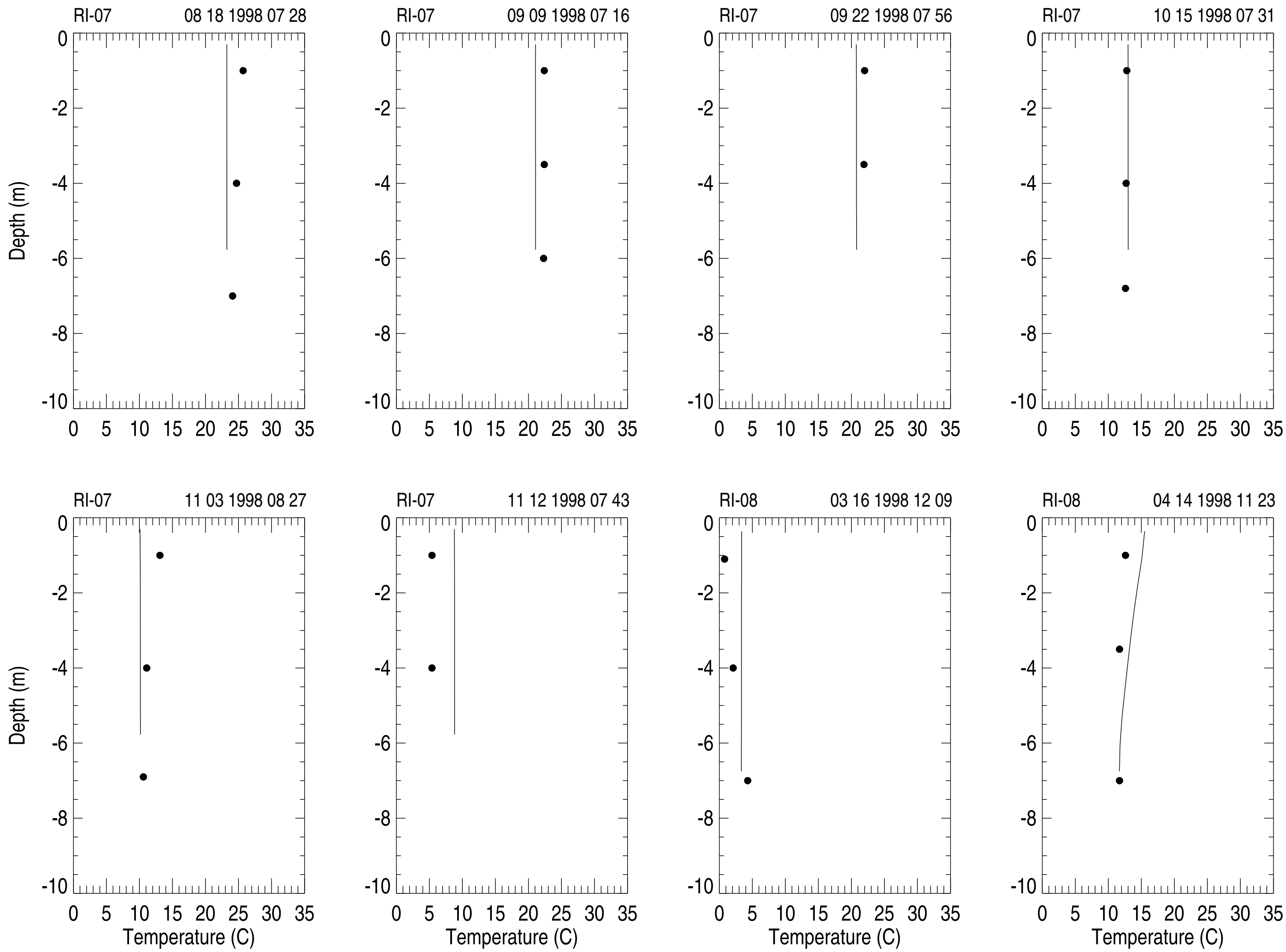

RI-07
06 09 1998 07 33

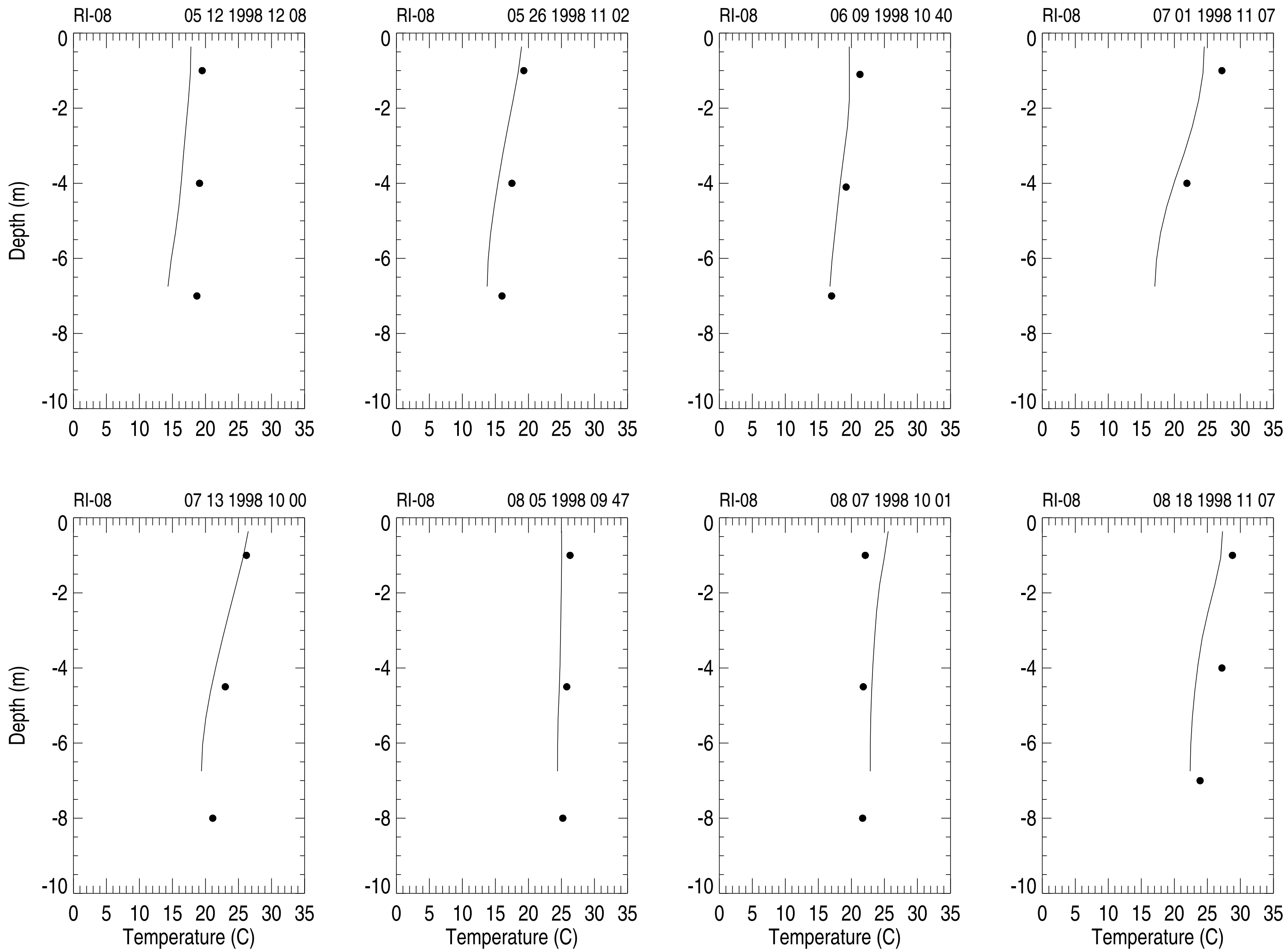

RI-07
07 01 1998 07 44
Depth (m)
Temperature (C)

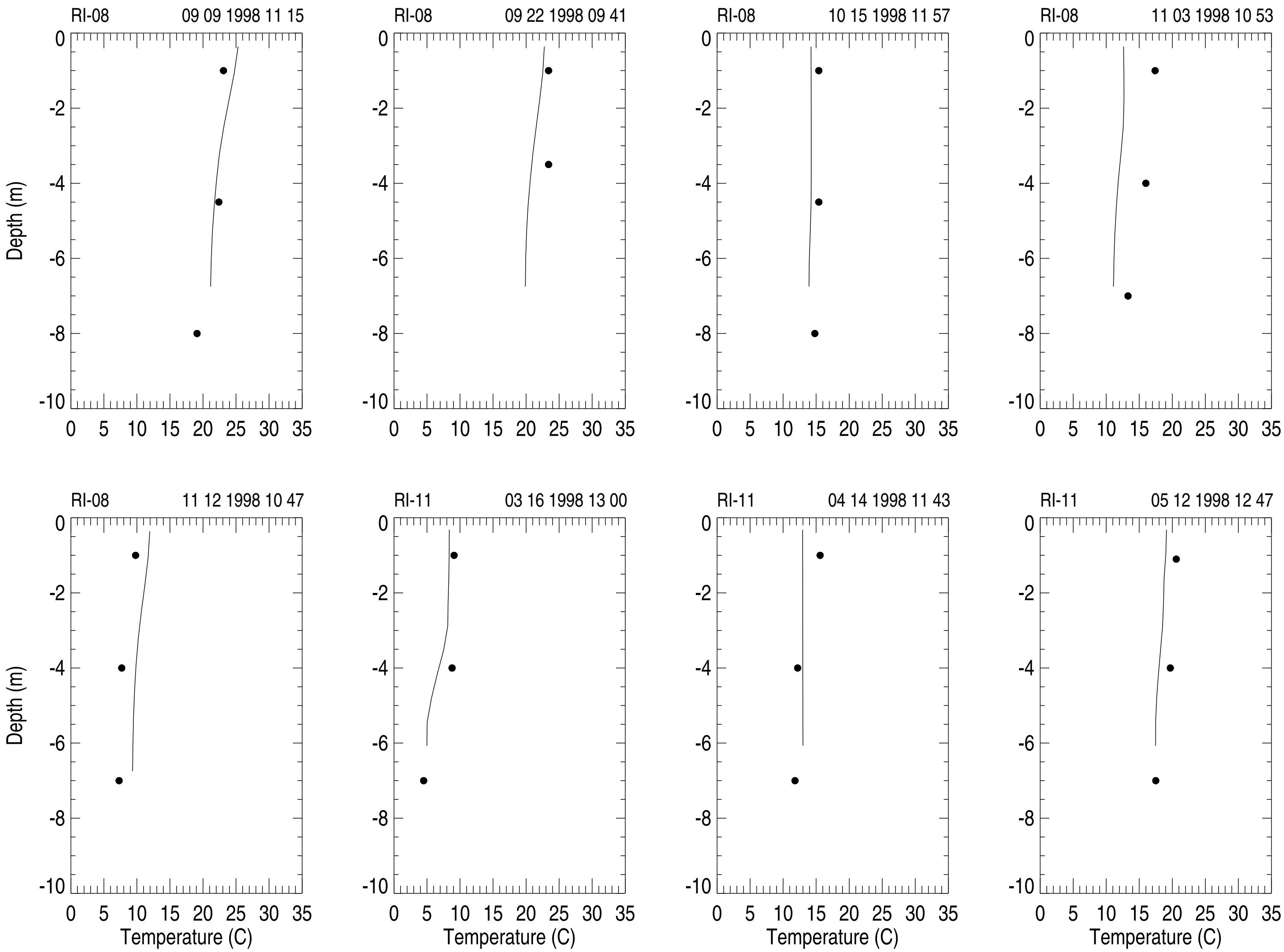

RI-07
07 13 1998 07 28
Temperature (C)

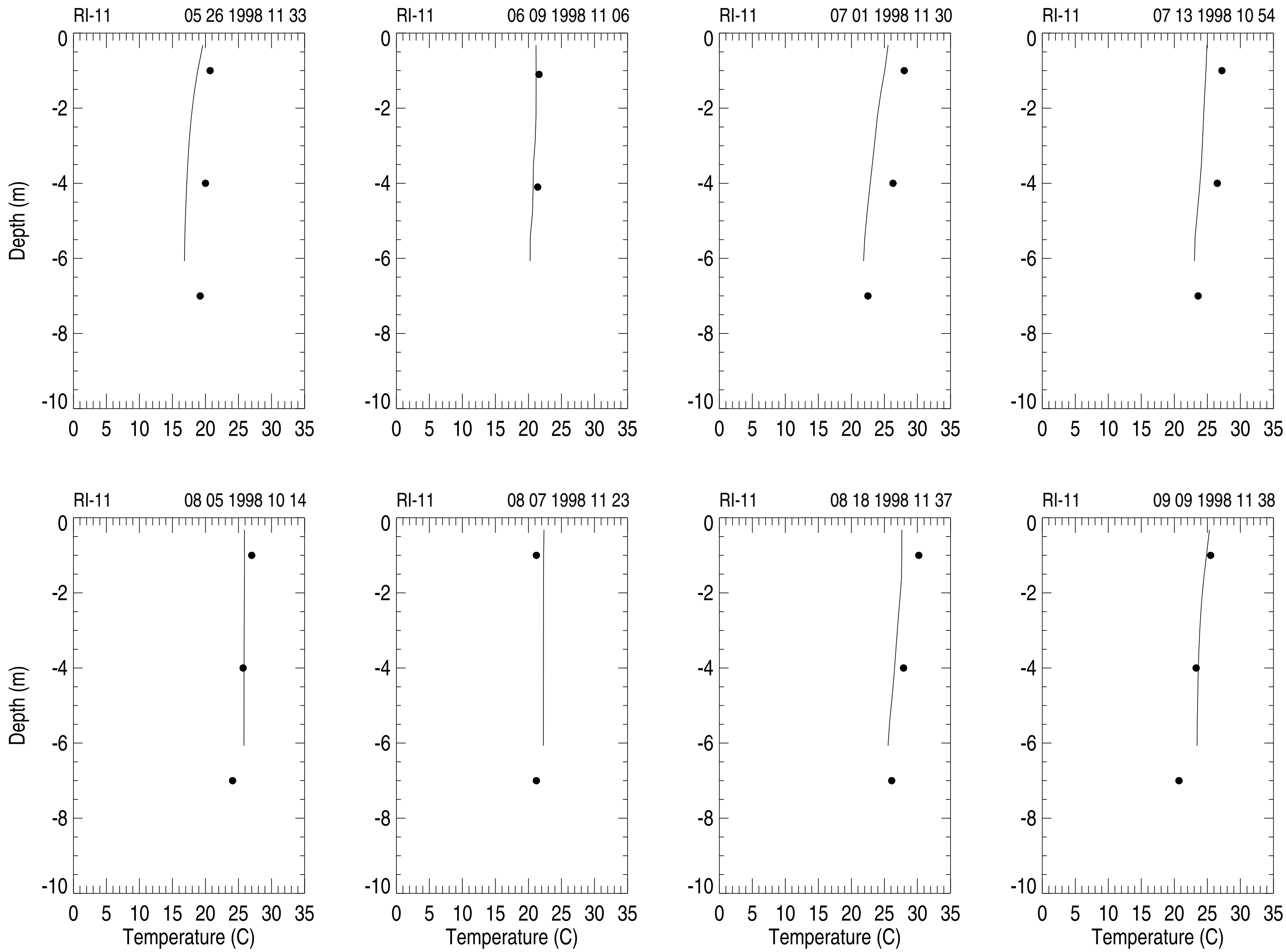

RI-07
08 05 1998 07 42
Temperature (C)


RI-07
08 07 1998 10 25
Temperature (C)

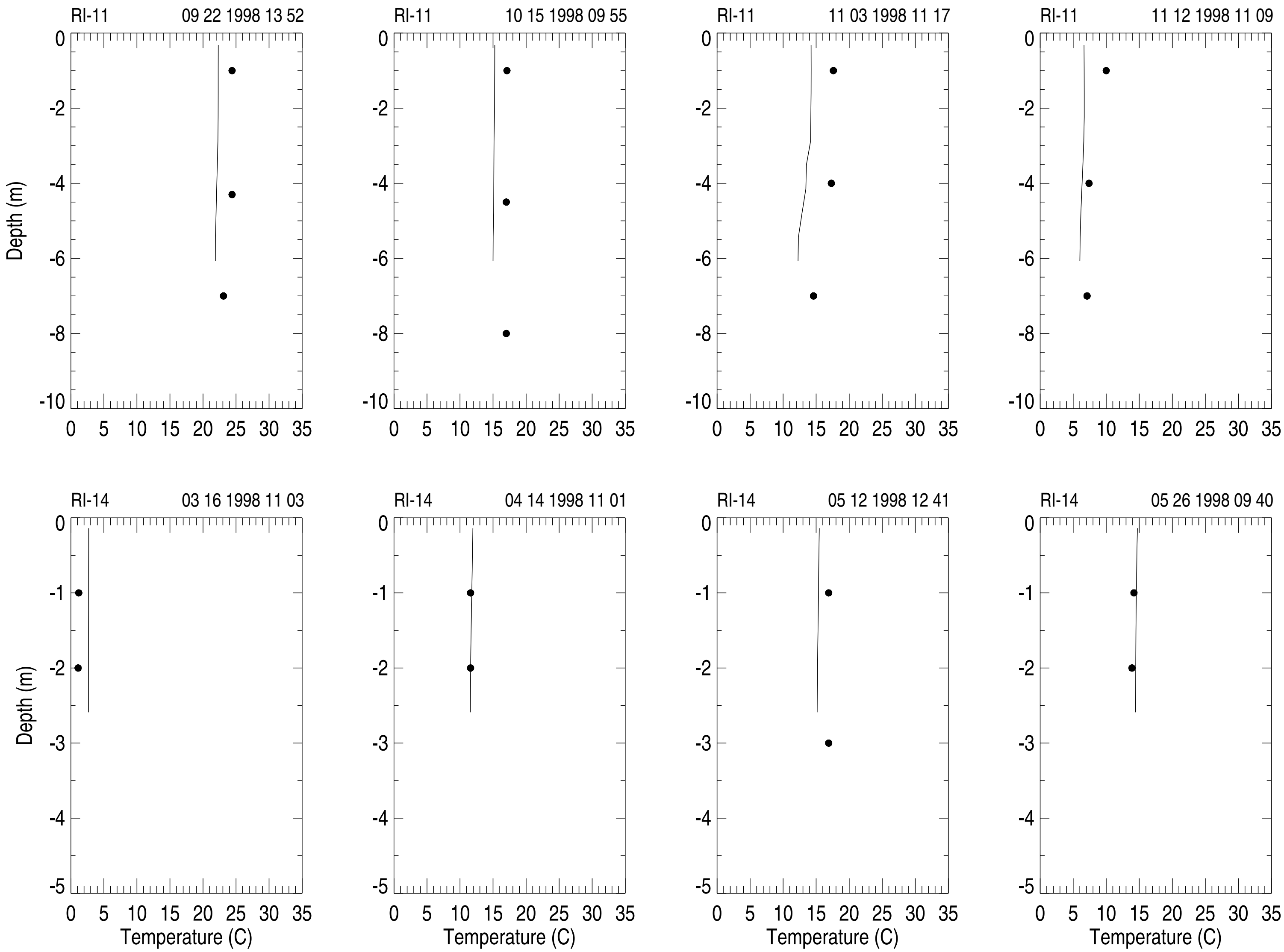

RI-07 08 18 1998 07 28
RI-07 09 09 1998 07 16
RI-07 09 22 1998 07 56
RI-07 10 15 1998 07 31
RI-07 11 03 1998 08 27
RI-07 11 12 1998 07 43
RI-08 03 16 1998 12 09
RI-08 04 14 1998 11 23
Depth (m)
Temperature (C)

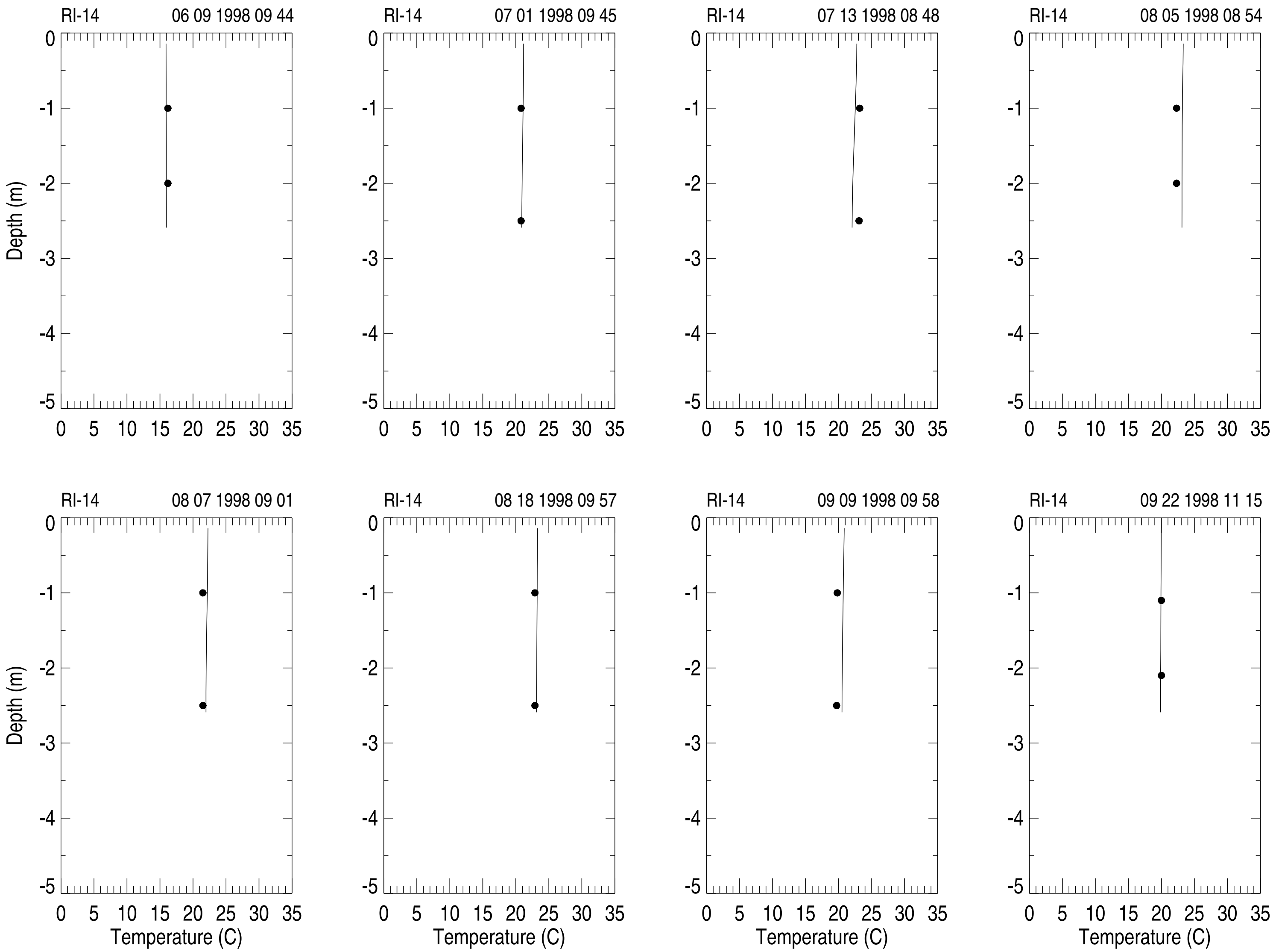

RI-08
05 12 1998 12 08
RI-08
05 26 1998 11 02
RI-08
06 09 1998 10 40
RI-08
07 01 1998 11 07
RI-08
07 13 1998 10 00
RI-08
08 05 1998 09 47
RI-08
08 07 1998 10 01
RI-08
08 18 1998 11 07
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

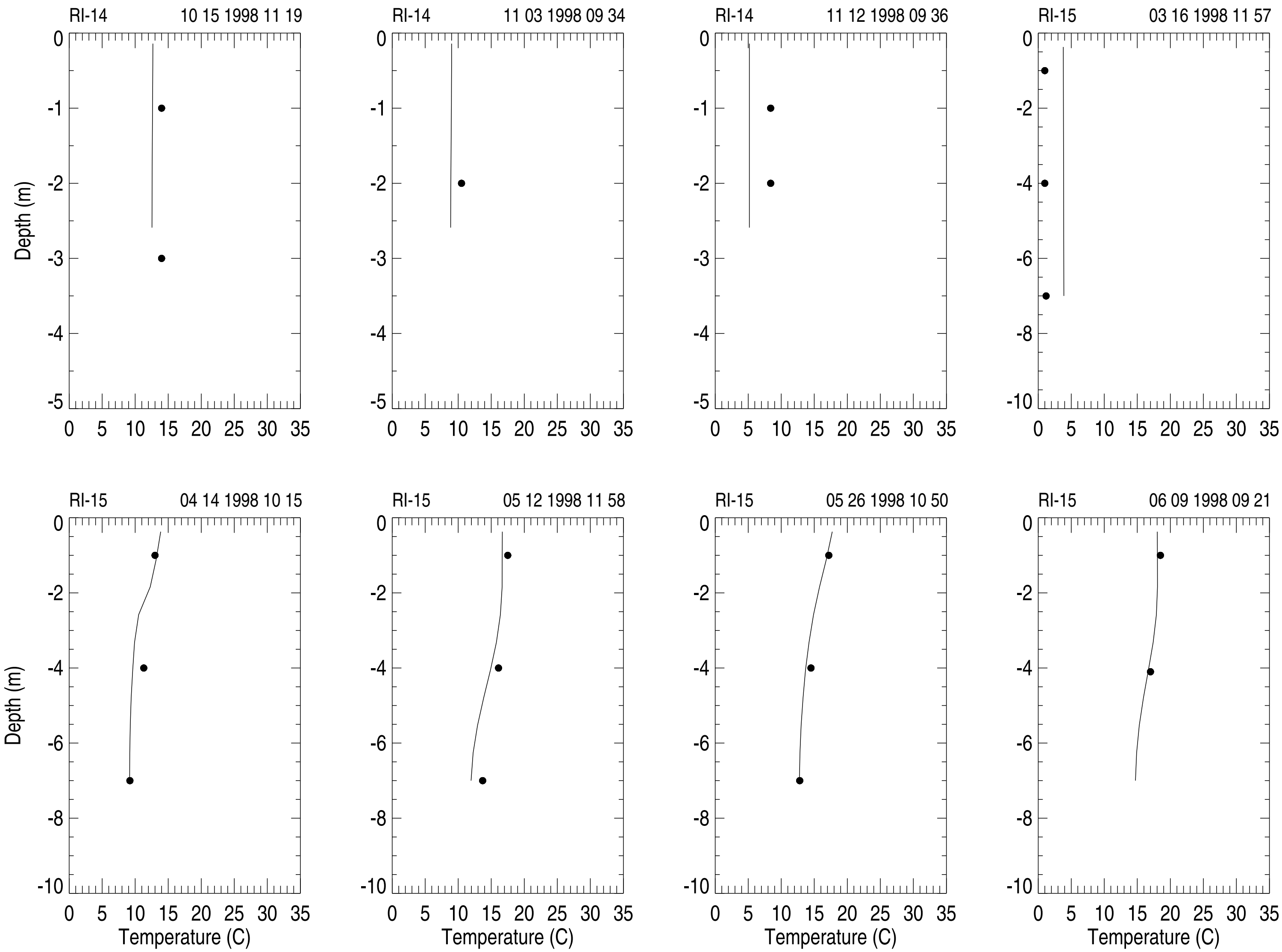

RI-08 09 09 1998 11 15
RI-08 09 22 1998 09 41
RI-08 10 15 1998 11 57
RI-08 11 03 1998 10 53
RI-08 11 12 1998 10 47
RI-11 03 16 1998 13 00
RI-11 04 14 1998 11 43
RI-11 05 12 1998 12 47
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

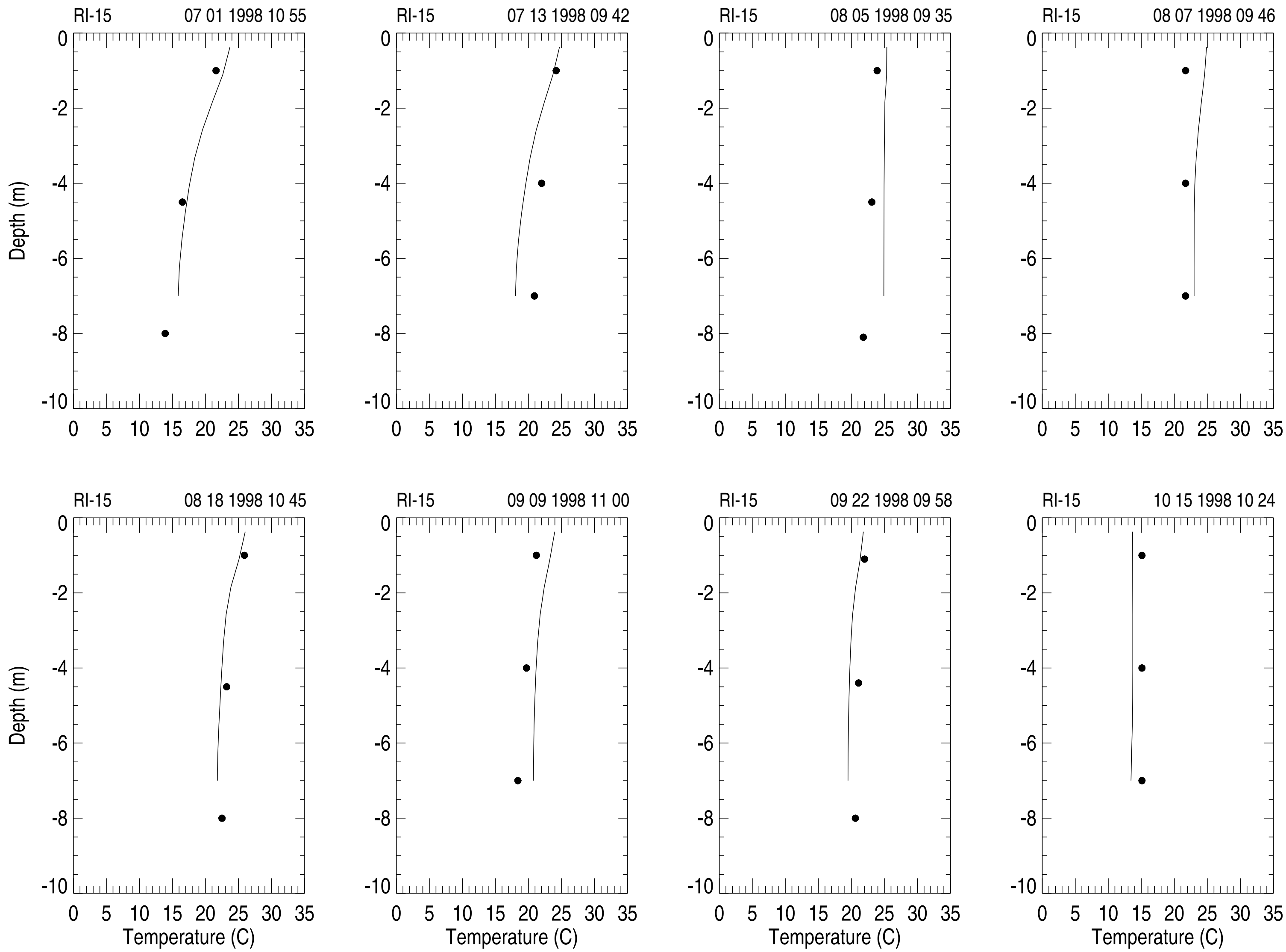


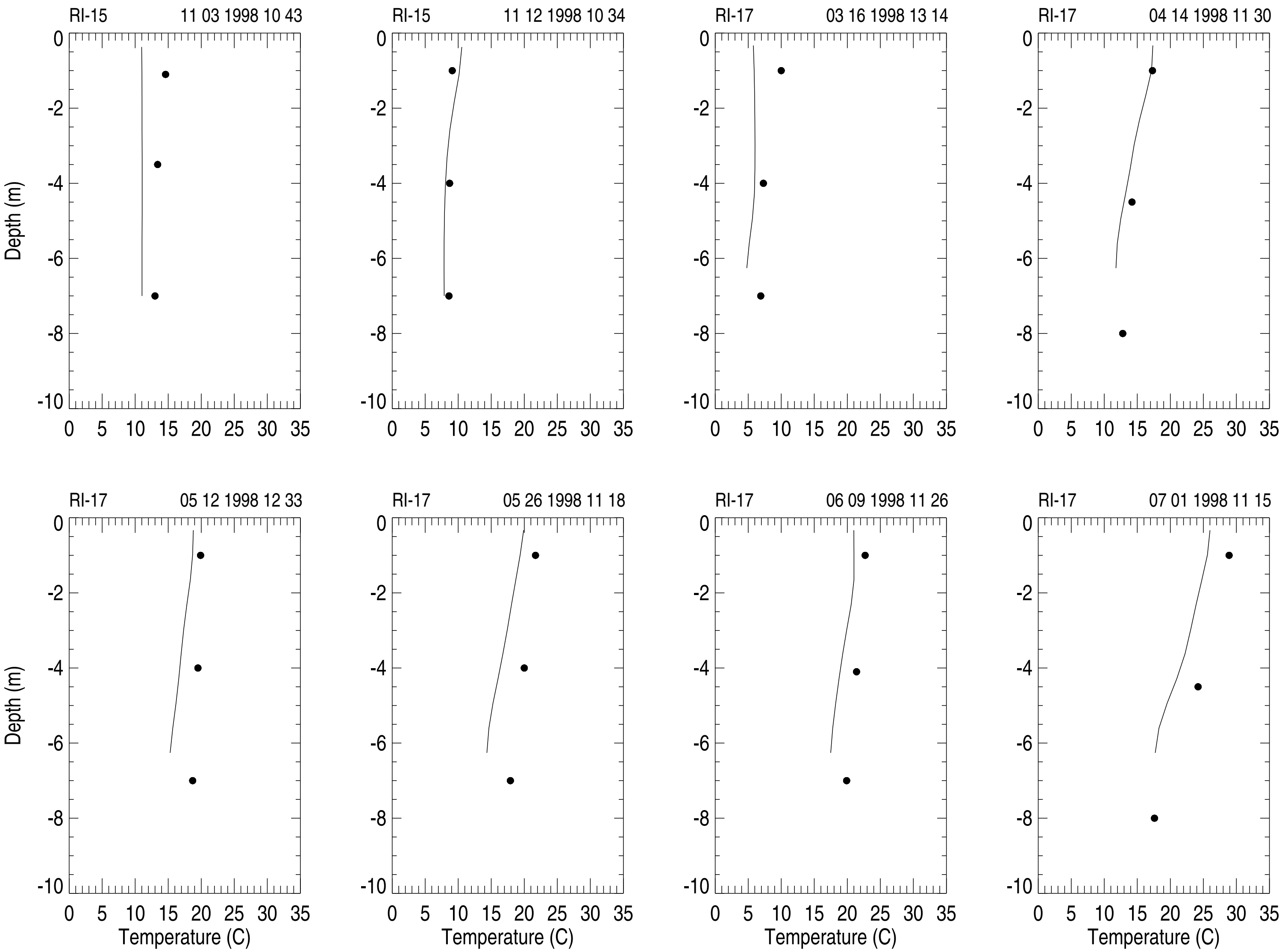
RI-11
05 26 1998 11 33
RI-11
06 09 1998 11 06
RI-11
07 01 1998 11 30
RI-11
07 13 1998 10 54
RI-11
08 05 1998 10 14
RI-11
08 07 1998 11 23
RI-11
08 18 1998 11 37
RI-11
09 09 1998 11 38
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

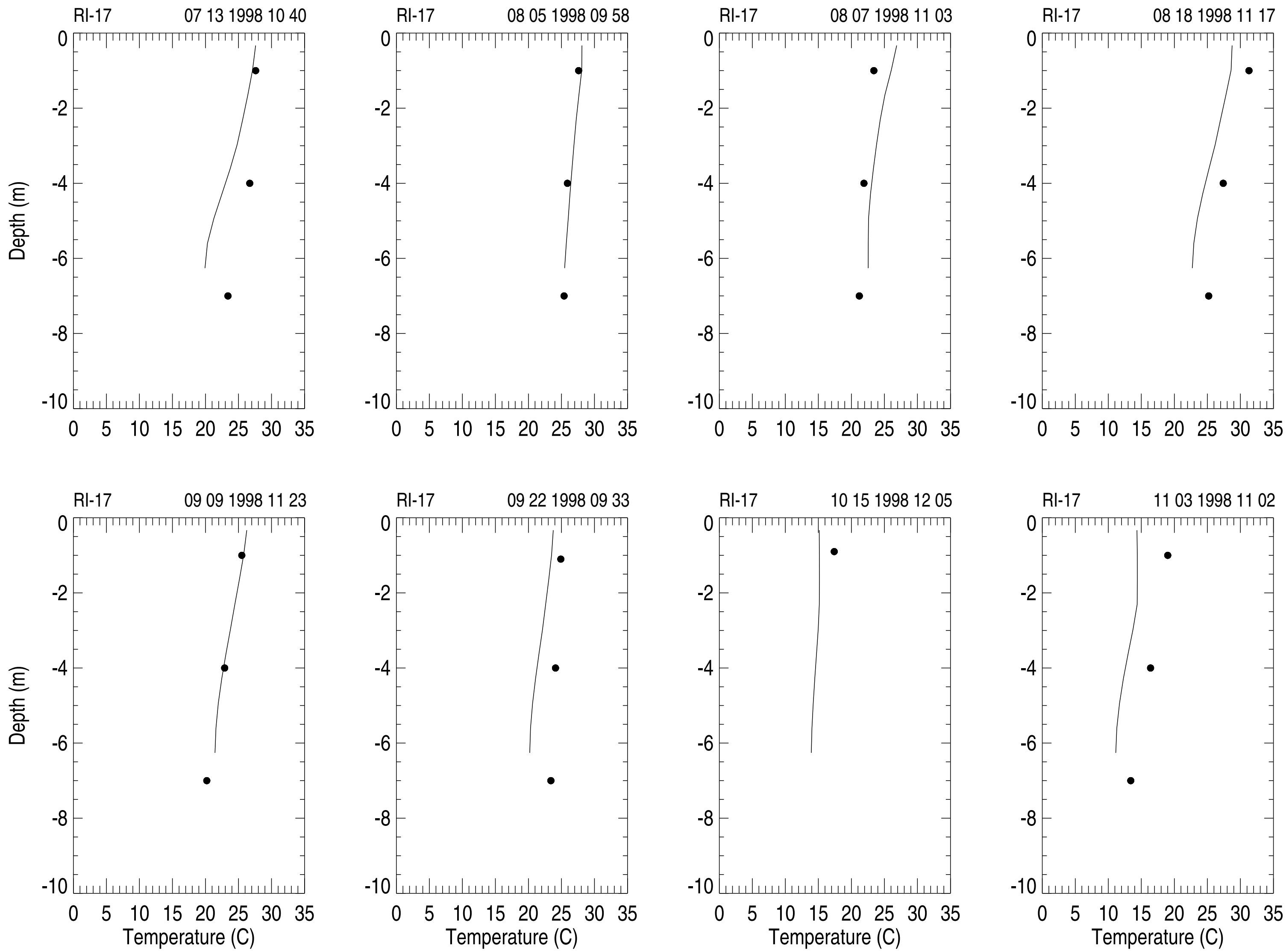

RI-11 09 22 1998 13 52
RI-11 10 15 1998 09 55
RI-11 11 03 1998 11 17
RI-11 11 12 1998 11 09
RI-14 03 16 1998 11 03
RI-14 04 14 1998 11 01
RI-14 05 12 1998 12 41
RI-14 05 26 1998 09 40
Depth (m)
0
-2
-4
-6
-8
-10
-1
-3
-5
0 5 10 15 20 25 30 35
Temperature (C)

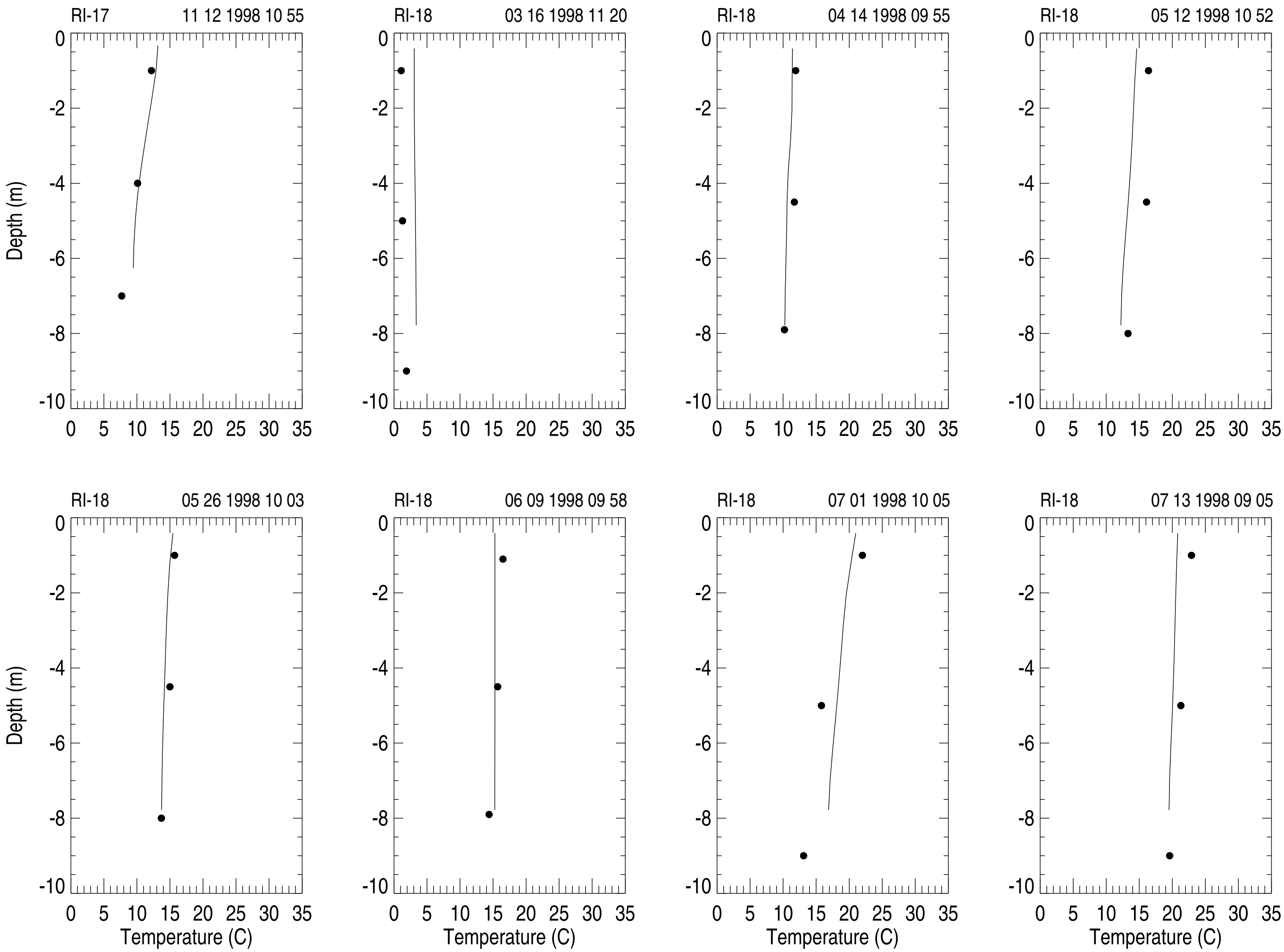

RI-14 06 09 1998 09 44
RI-14 07 01 1998 09 45
RI-14 07 13 1998 08 48
RI-14 08 05 1998 08 54
RI-14 08 07 1998 09 01
RI-14 08 18 1998 09 57
RI-14 09 09 1998 09 58
RI-14 09 22 1998 11 15
Depth (m)
Temperature (C)


RI-14 10 15 1998 11 19
RI-14 11 03 1998 09 34
RI-14 11 12 1998 09 36
RI-15 03 16 1998 11 57
RI-15 04 14 1998 10 15
RI-15 05 12 1998 11 58
RI-15 05 26 1998 10 50
RI-15 06 09 1998 09 21
Depth (m)
Temperature (C)
0 5 10 15 20 25 30 35
0 -1 -2 -3 -4 -5
0 -2 -4 -6 -8 -10

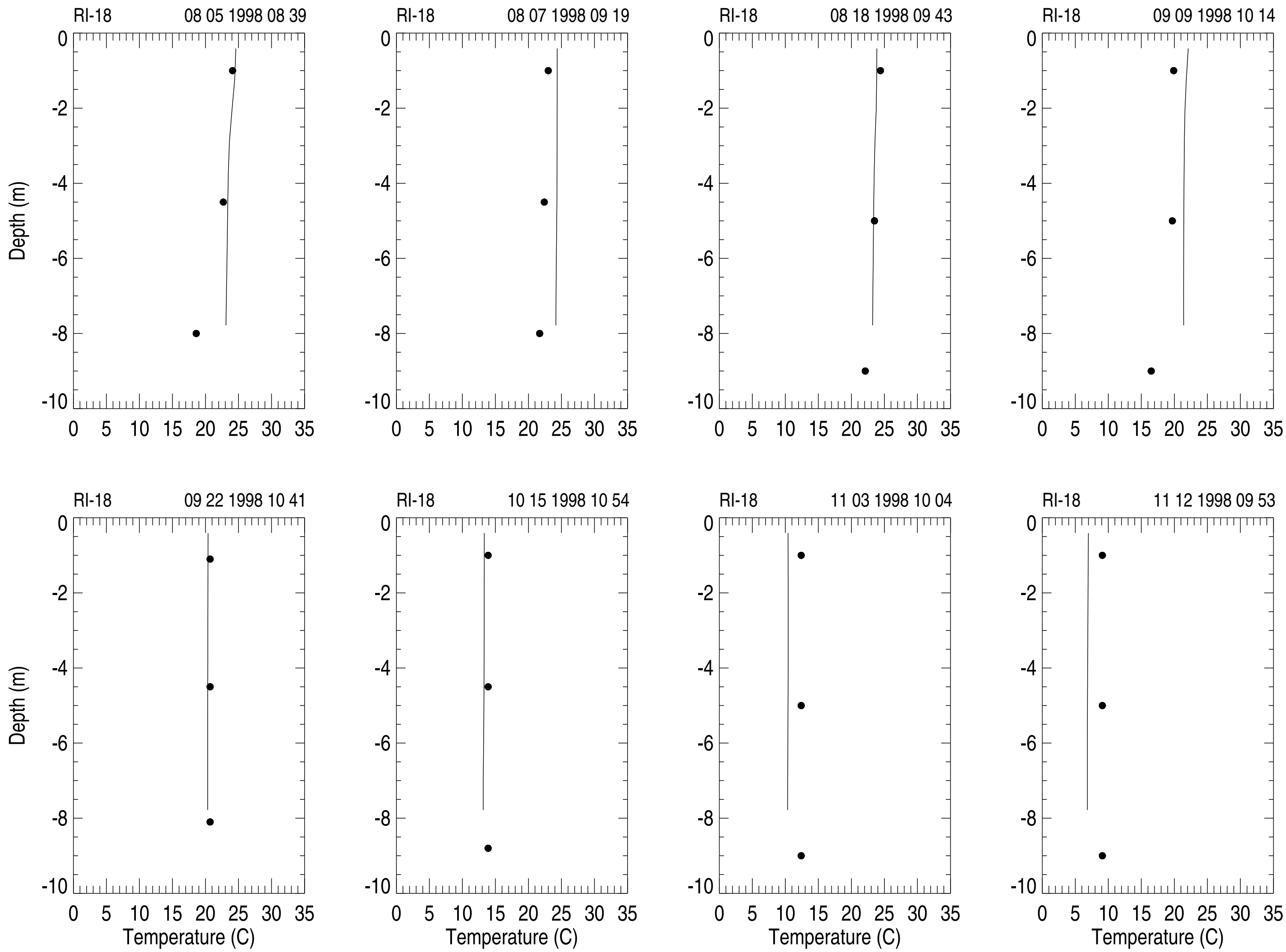

RI-15
07 01 1998 10 55
RI-15
07 13 1998 09 42
RI-15
08 05 1998 09 35
RI-15
08 07 1998 09 46
RI-15
08 18 1998 10 45
RI-15
09 09 1998 11 00
RI-15
09 22 1998 09 58
RI-15
10 15 1998 10 24
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

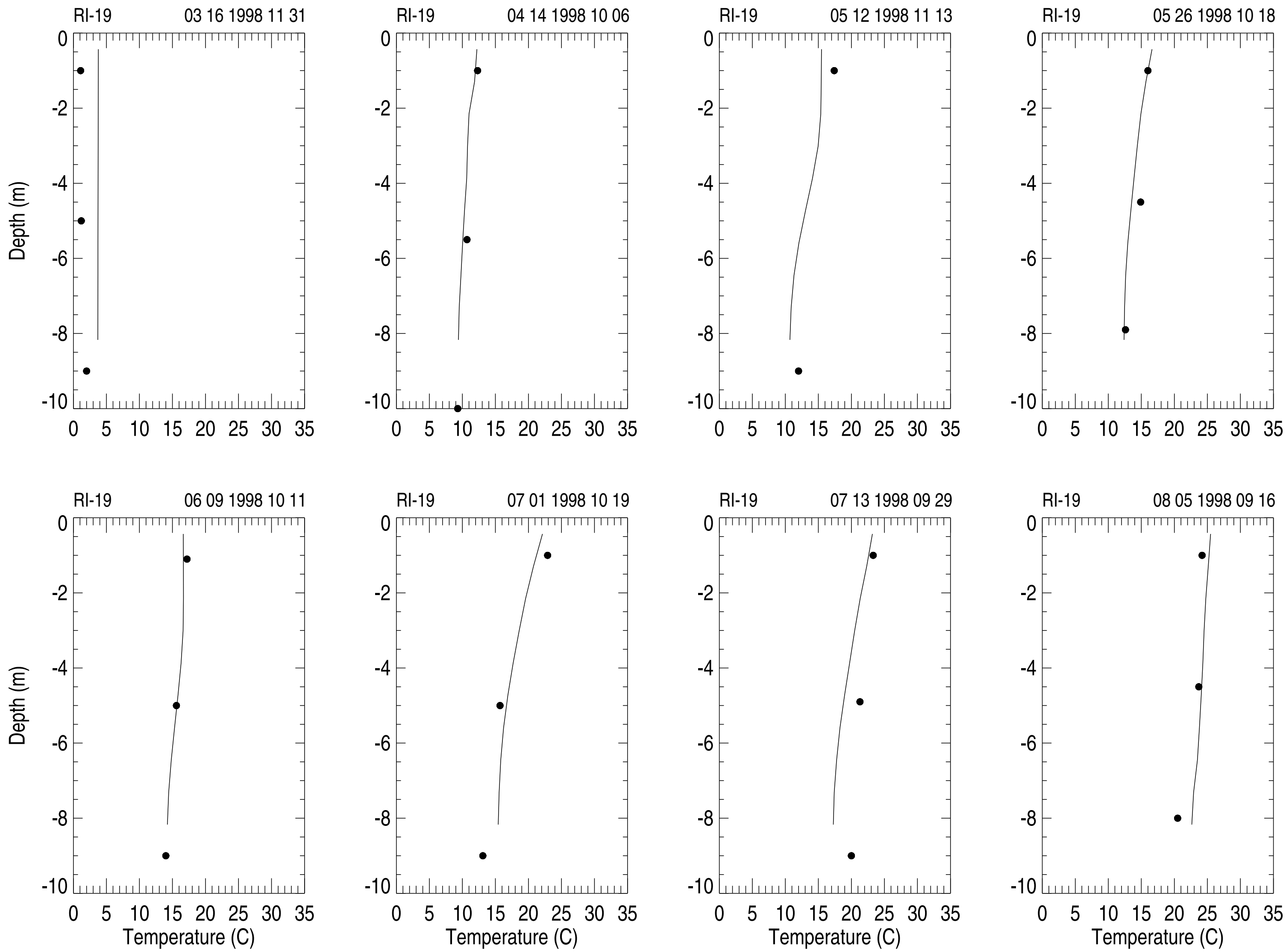

RI-15 11 03 1998 10 43
RI-15 11 12 1998 10 34
RI-17 03 16 1998 13 14
RI-17 04 14 1998 11 30
RI-17 05 12 1998 12 33
RI-17 05 26 1998 11 18
RI-17 06 09 1998 11 26
RI-17 07 01 1998 11 15
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

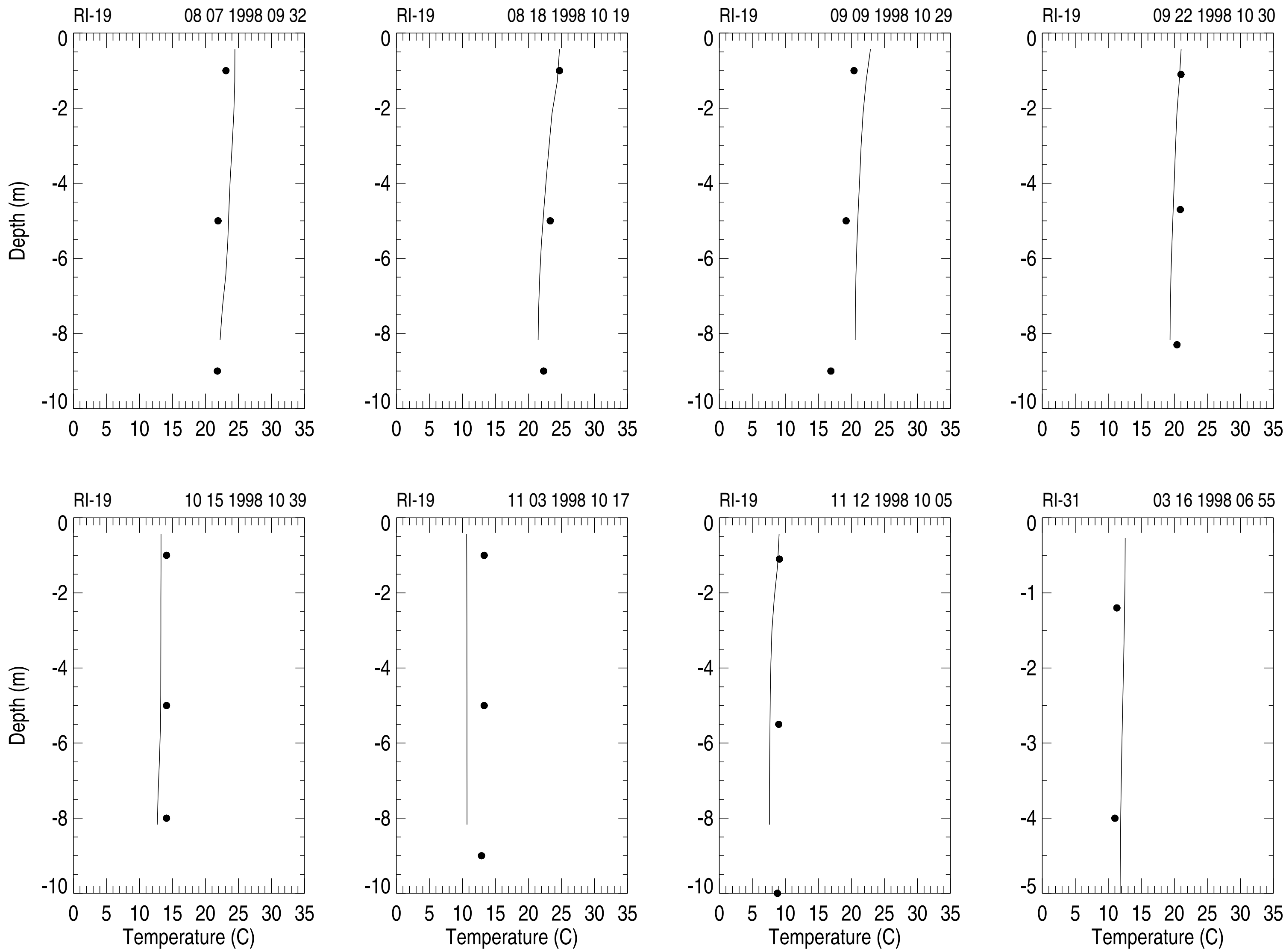

RI-17
07 13 1998 10 40
RI-17
08 05 1998 09 58
RI-17
08 07 1998 11 03
RI-17
08 18 1998 11 17
RI-17
09 09 1998 11 23
RI-17
09 22 1998 09 33
RI-17
10 15 1998 12 05
RI-17
11 03 1998 11 02
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

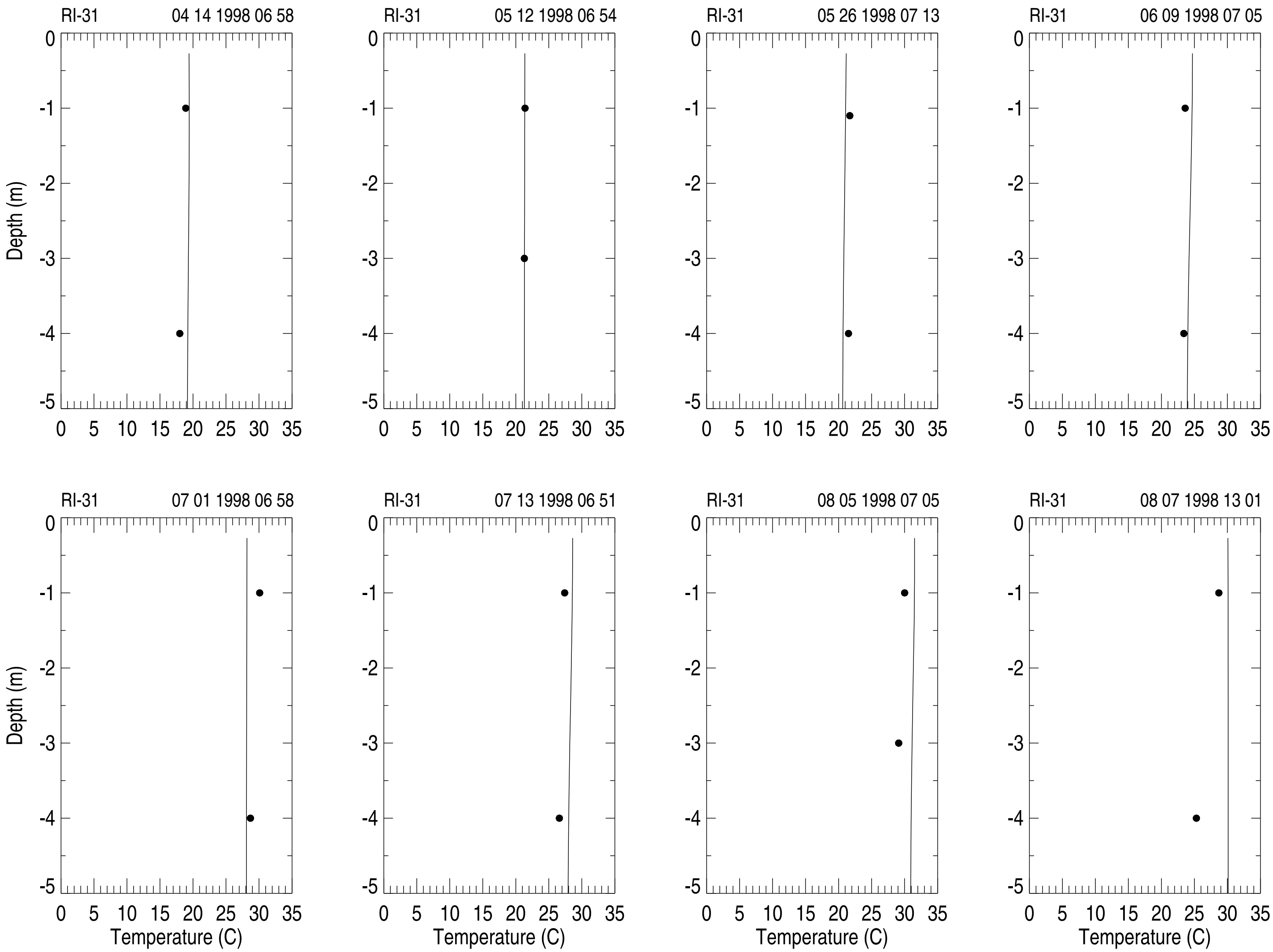


RI-17
11 12 1998 10 55
RI-18
03 16 1998 11 20
RI-18
04 14 1998 09 55
RI-18
05 12 1998 10 52
RI-18
05 26 1998 10 03
RI-18
06 09 1998 09 58
RI-18
07 01 1998 10 05
RI-18
07 13 1998 09 05
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

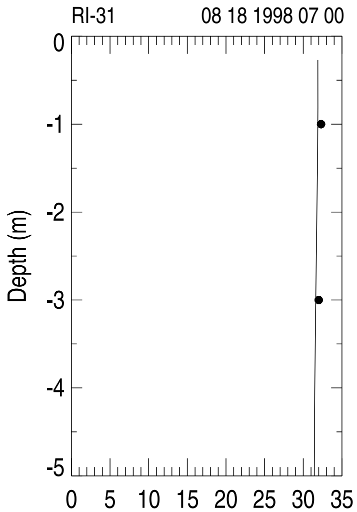

RI-18
08 05 1998 08 39
RI-18
08 07 1998 09 19
RI-18
08 18 1998 09 43
RI-18
09 09 1998 10 14
RI-18
09 22 1998 10 41
RI-18
10 15 1998 10 54
RI-18
11 03 1998 10 04
RI-18
11 12 1998 09 53
Depth (m)
Temperature (C)

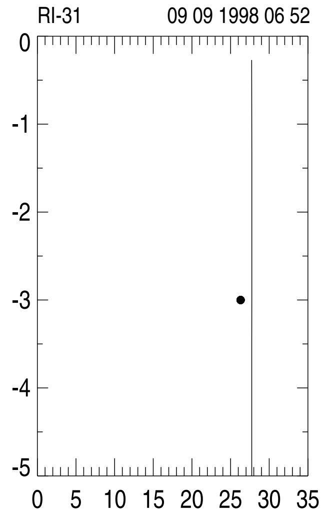

RI-19
03 16 1998 11 31
RI-19
04 14 1998 10 06
RI-19
05 12 1998 11 13
RI-19
05 26 1998 10 18
RI-19
06 09 1998 10 11
RI-19
07 01 1998 10 19
RI-19
07 13 1998 09 29
RI-19
08 05 1998 09 16
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

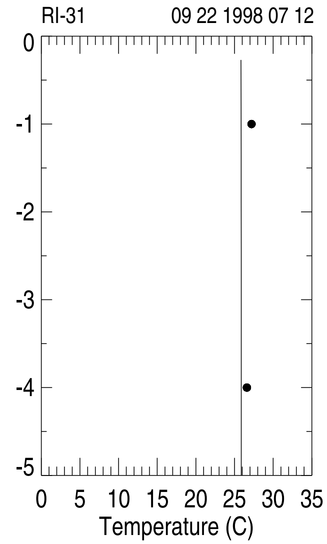

RI-19
08 07 1998 09 32
RI-19
08 18 1998 10 19
RI-19
09 09 1998 10 29
RI-19
09 22 1998 10 30
RI-19
10 15 1998 10 39
RI-19
11 03 1998 10 17
RI-19
11 12 1998 10 05
RI-31
03 16 1998 06 55
Depth (m)
Temperature (C)

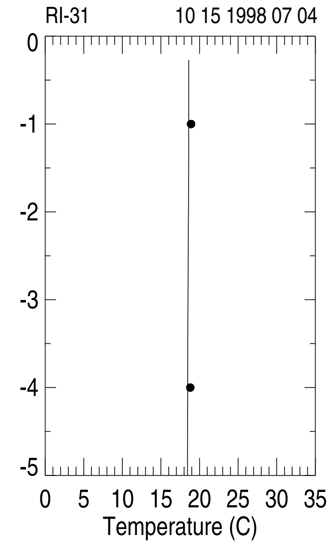


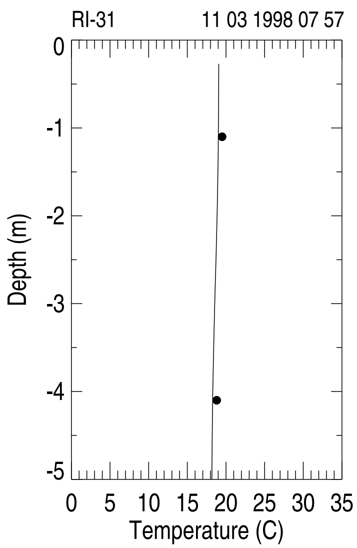
RI-31
04 14 1998 06 58
RI-31
05 12 1998 06 54
RI-31
05 26 1998 07 13
RI-31
06 09 1998 07 05
RI-31
07 01 1998 06 58
RI-31
07 13 1998 06 51
RI-31
08 05 1998 07 05
RI-31
08 07 1998 13 01
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35

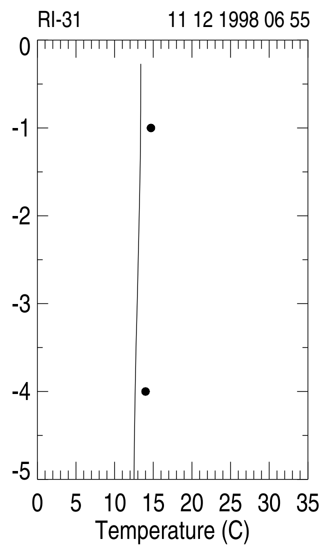

RI-31
08 18 1998 07 00
Depth (m)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35

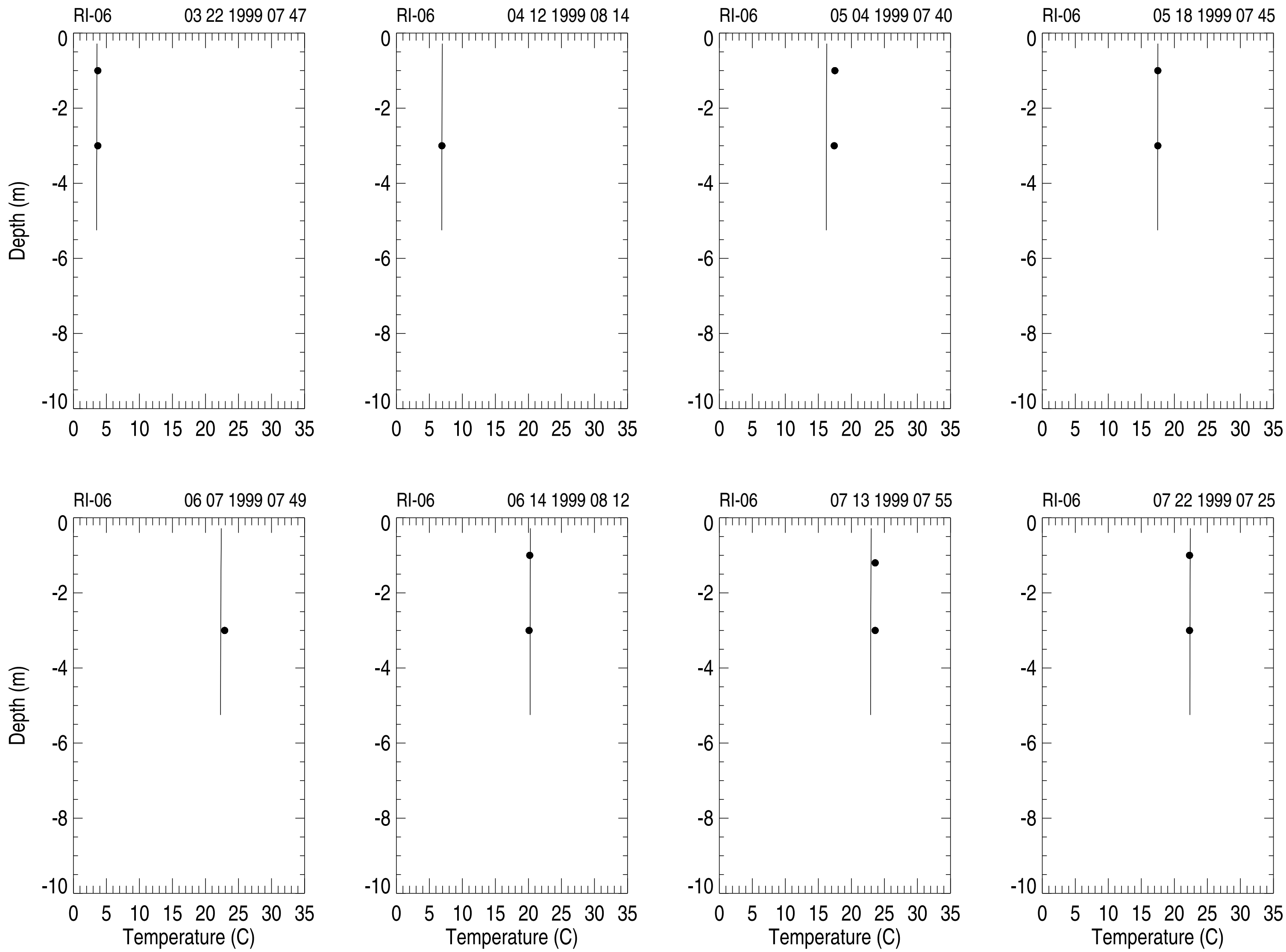

RI-31
09 09 1998 06 52
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35

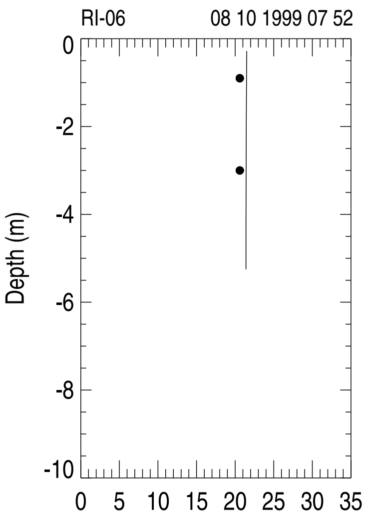

RI-31
09 22 1998 07 12
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35
Temperature (C)

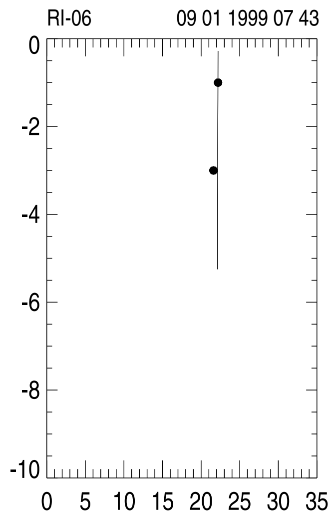

RI-31
10 15 1998 07 04
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35
Temperature (C)

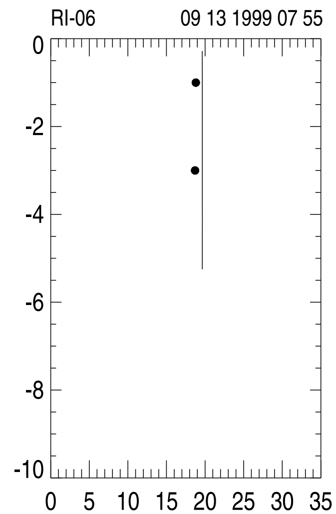

RI-31
11 03 1998 07 57
Depth (m)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35
Temperature (C)

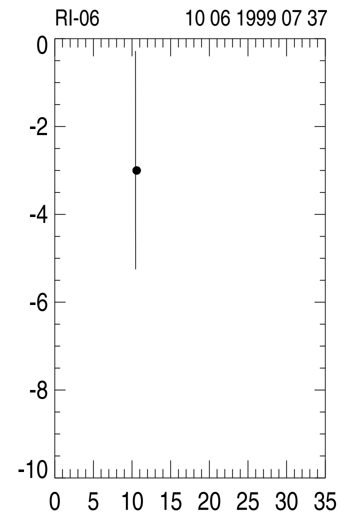

RI-31
11 12 1998 06 55
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35
Temperature (C)

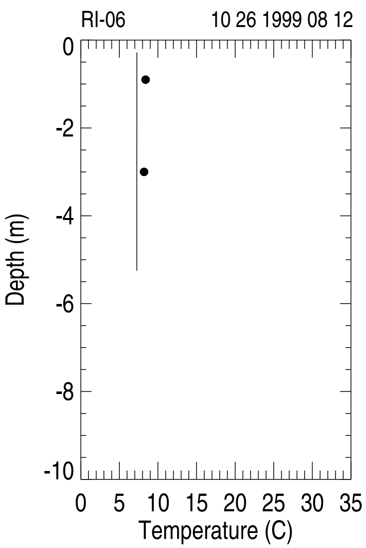

RI-06
03 22 1999 07 47
RI-06
04 12 1999 08 14
RI-06
05 04 1999 07 40
RI-06
05 18 1999 07 45
RI-06
06 07 1999 07 49
RI-06
06 14 1999 08 12
RI-06
07 13 1999 07 55
RI-06
07 22 1999 07 25
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

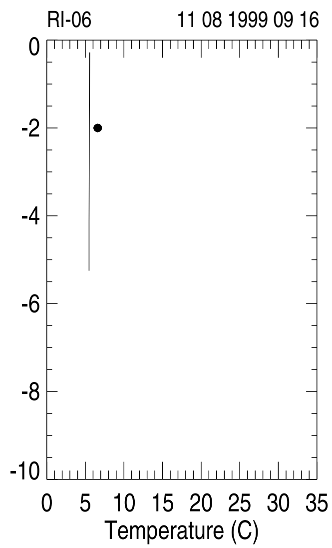

RI-06
08 10 1999 07 52
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

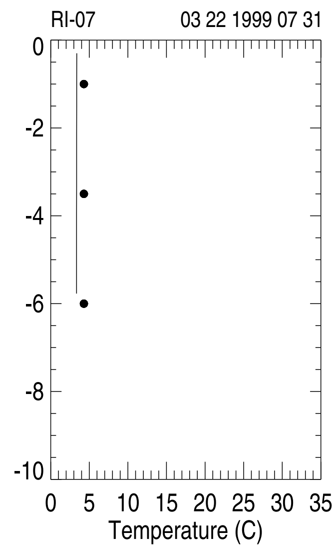

RI-06
09 01 1999 07 43
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

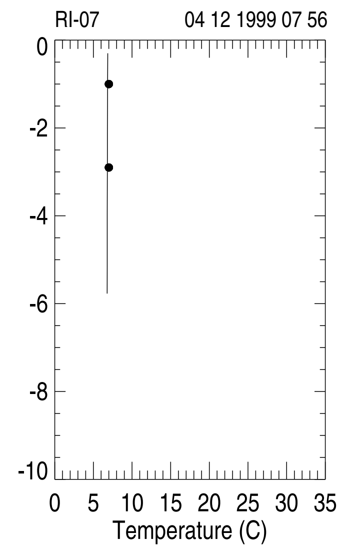

RI-06
09 13 1999 07 55
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

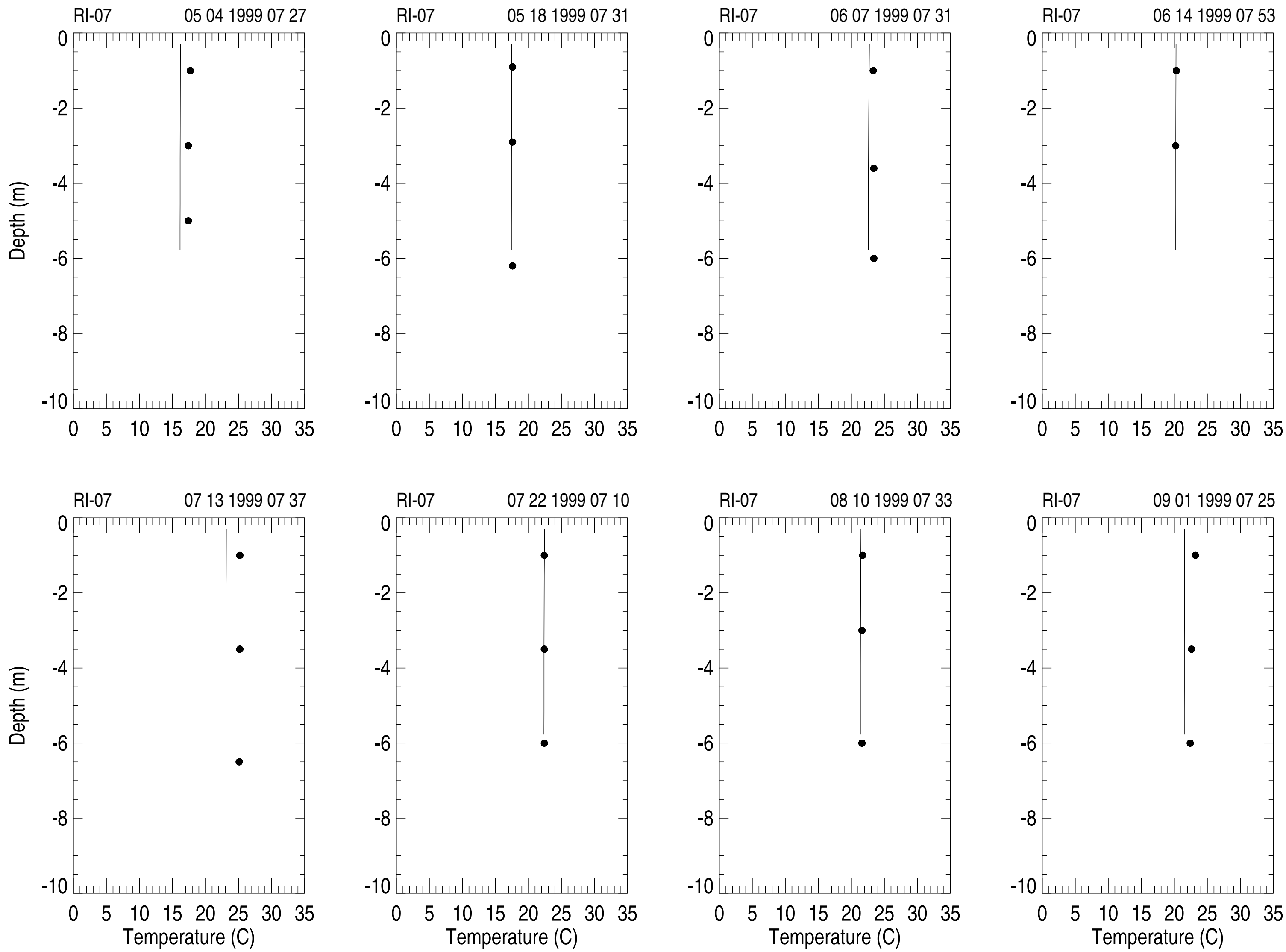

RI-06
10 06 1999 07 37
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35


RI-06
10 26 1999 08 12
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

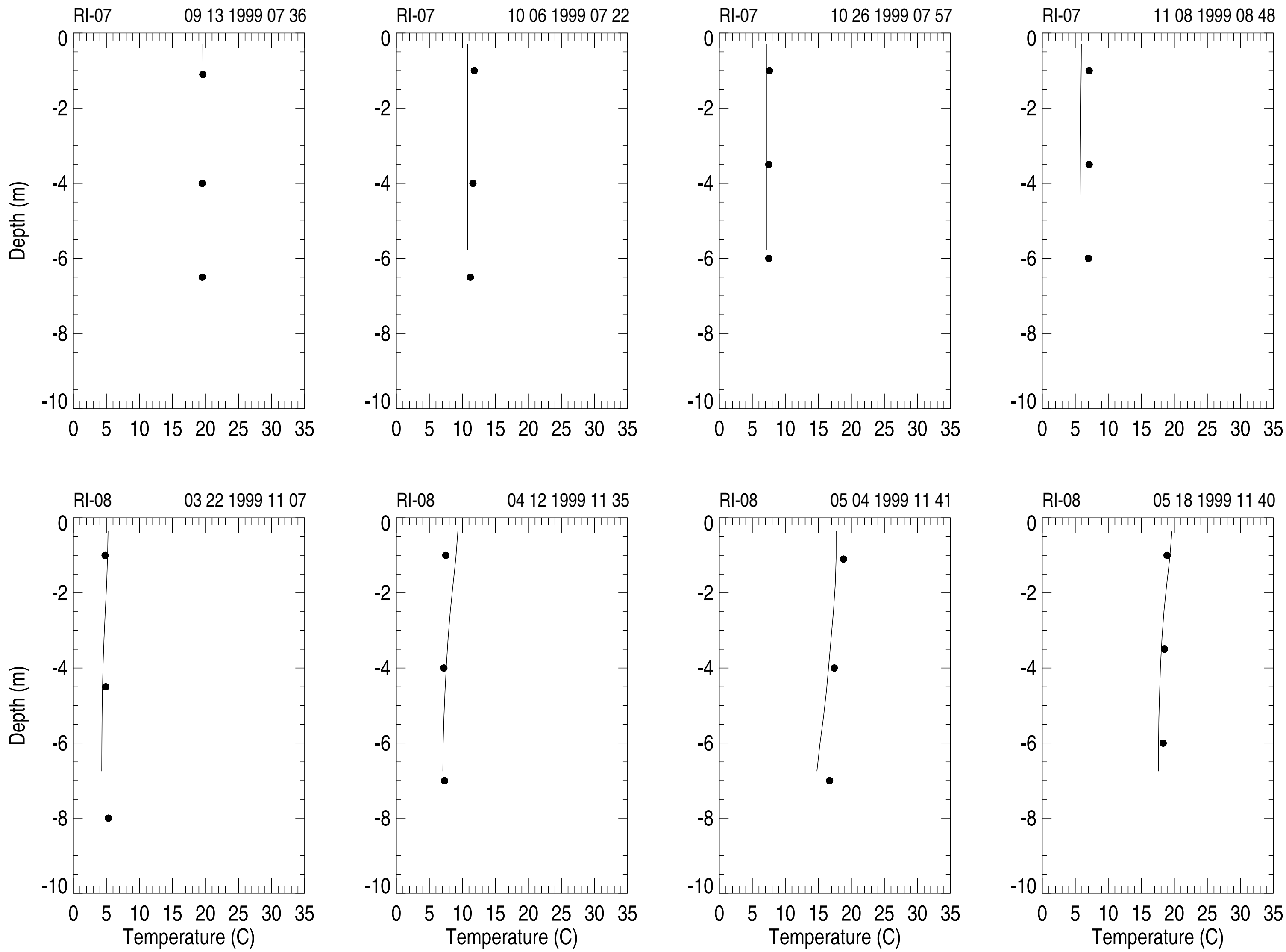

RI-06
11 08 1999 09 16
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)


RI-07
03 22 1999 07 31
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

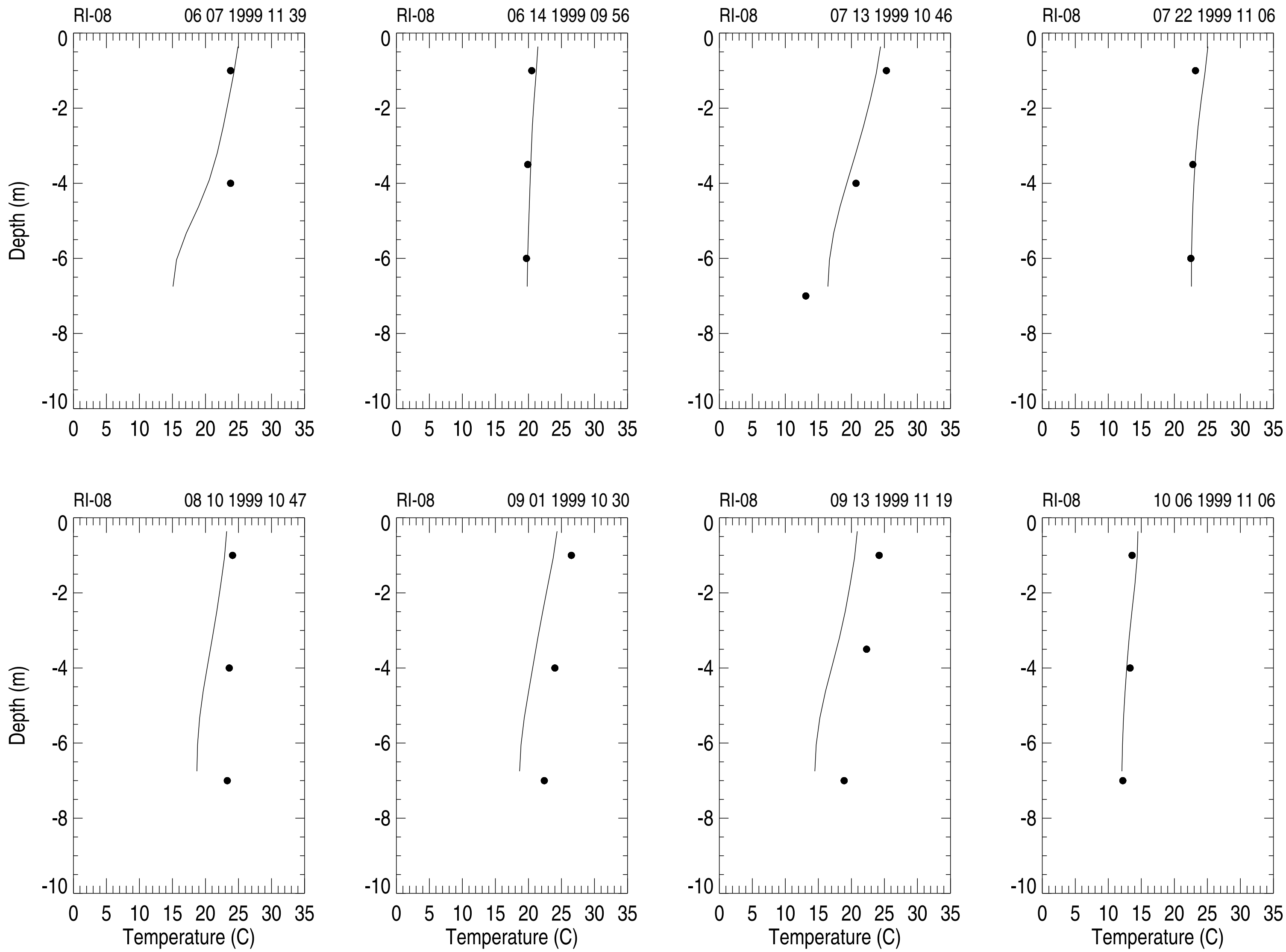

RI-07
04 12 1999 07 56
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)



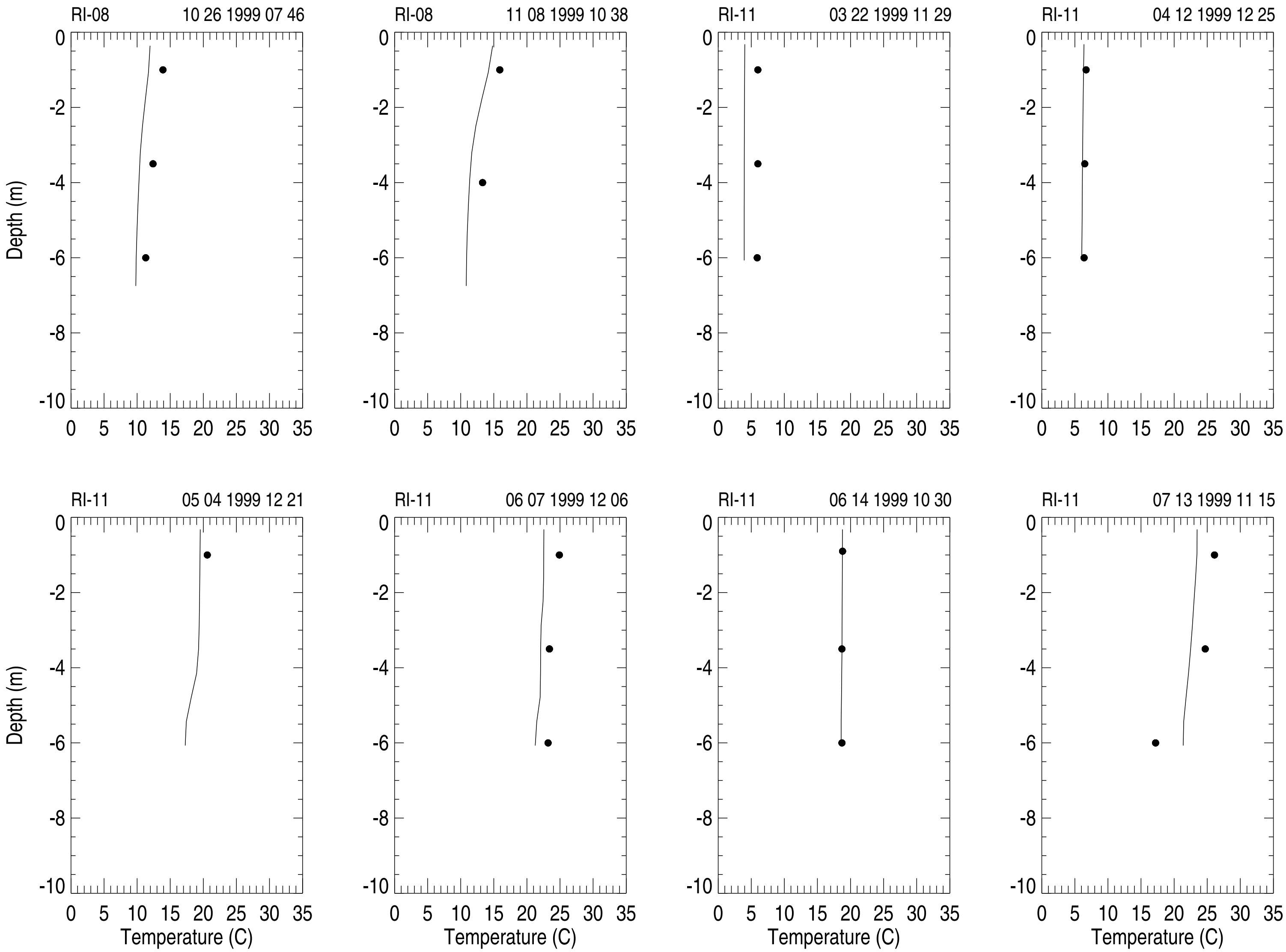
RI-07
05 04 1999 07 27
RI-07
05 18 1999 07 31
RI-07
06 07 1999 07 31
RI-07
06 14 1999 07 53
RI-07
07 13 1999 07 37
RI-07
07 22 1999 07 10
RI-07
08 10 1999 07 33
RI-07
09 01 1999 07 25
Depth (m)
Temperature (C)

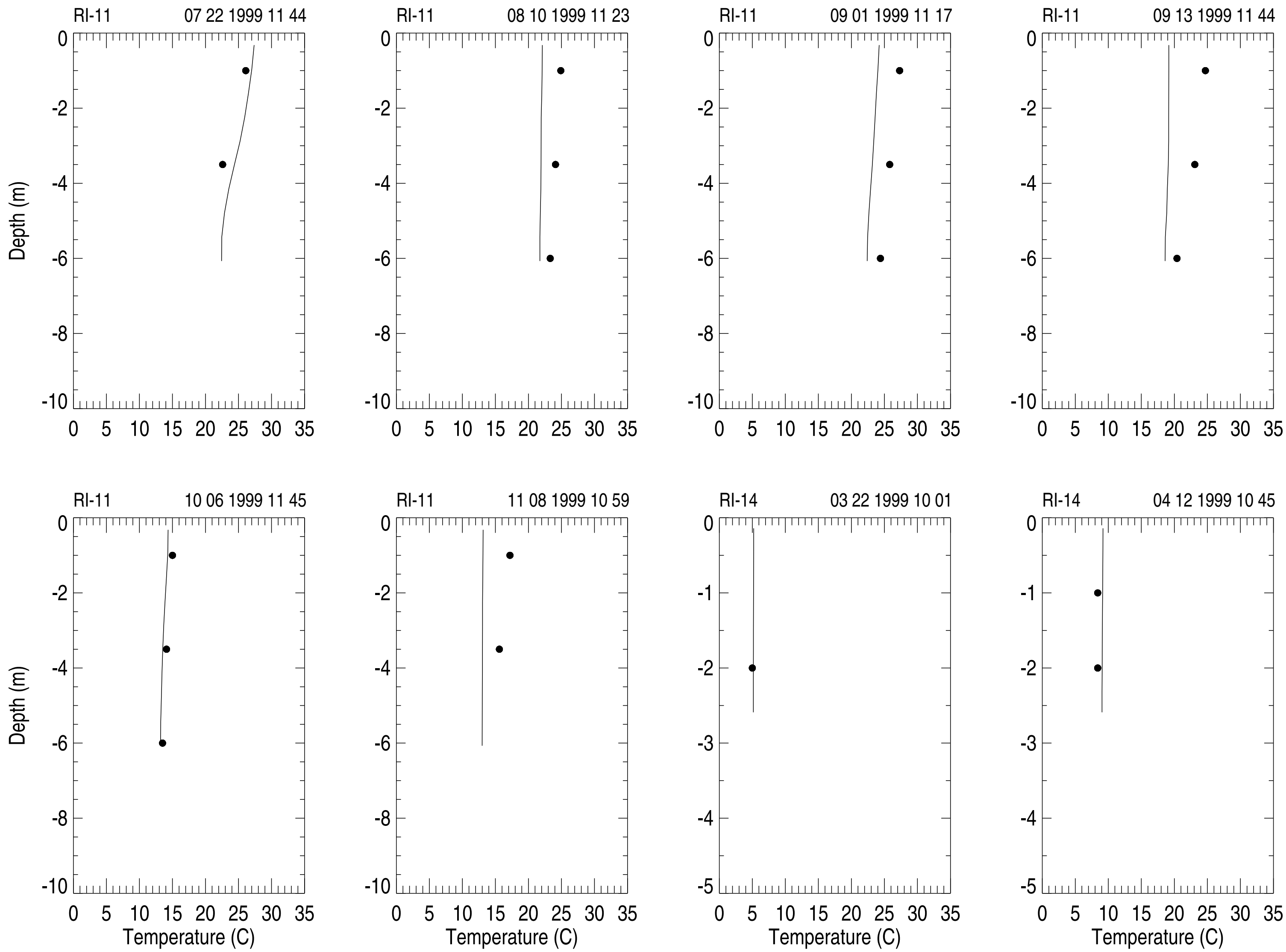


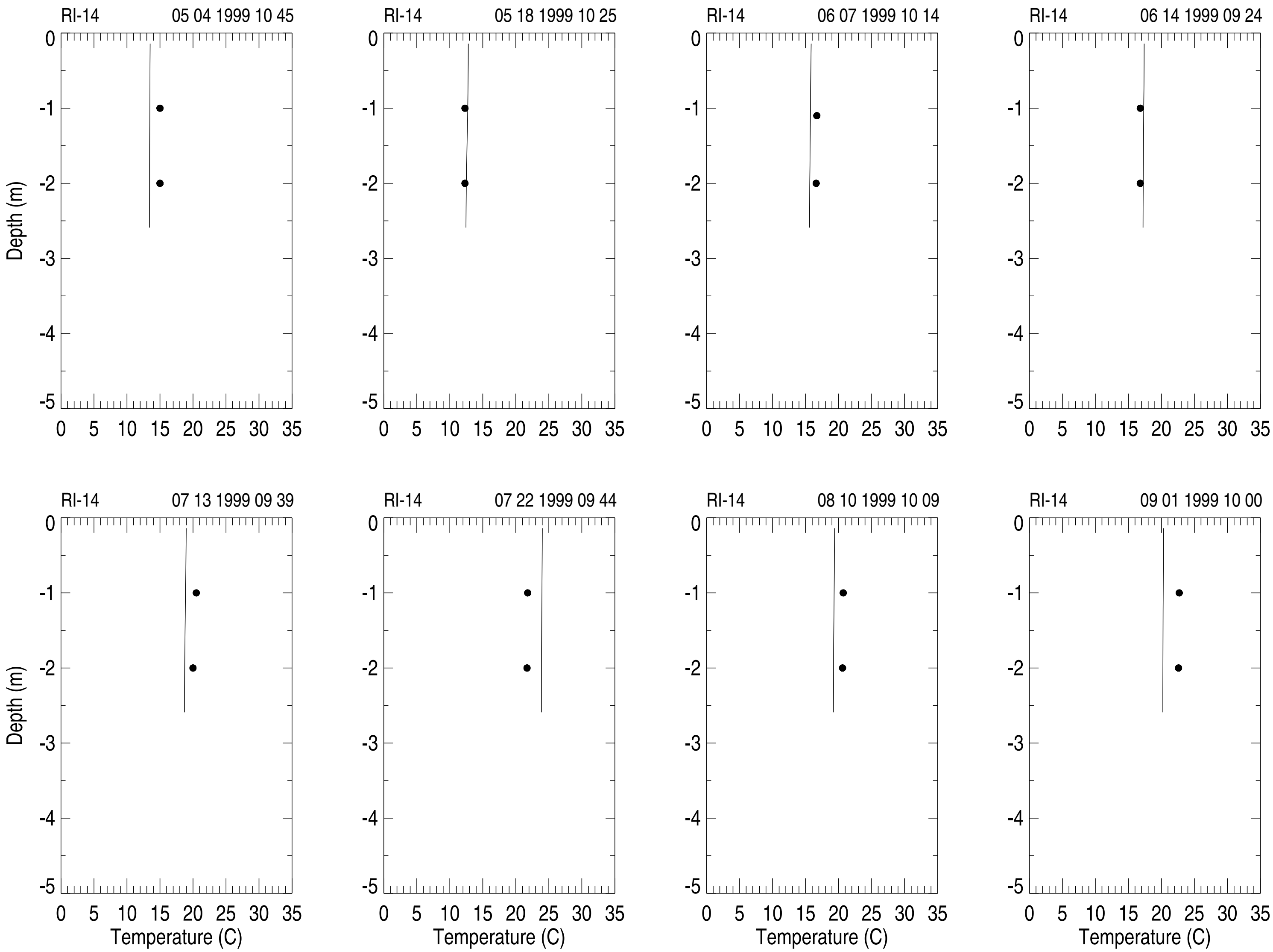
RI-07
09 13 1999 07 36
RI-07
10 06 1999 07 22
RI-07
10 26 1999 07 57
RI-07
11 08 1999 08 48
RI-08
03 22 1999 11 07
RI-08
04 12 1999 11 35
RI-08
05 04 1999 11 41
RI-08
05 18 1999 11 40
Depth (m)
Temperature (C)

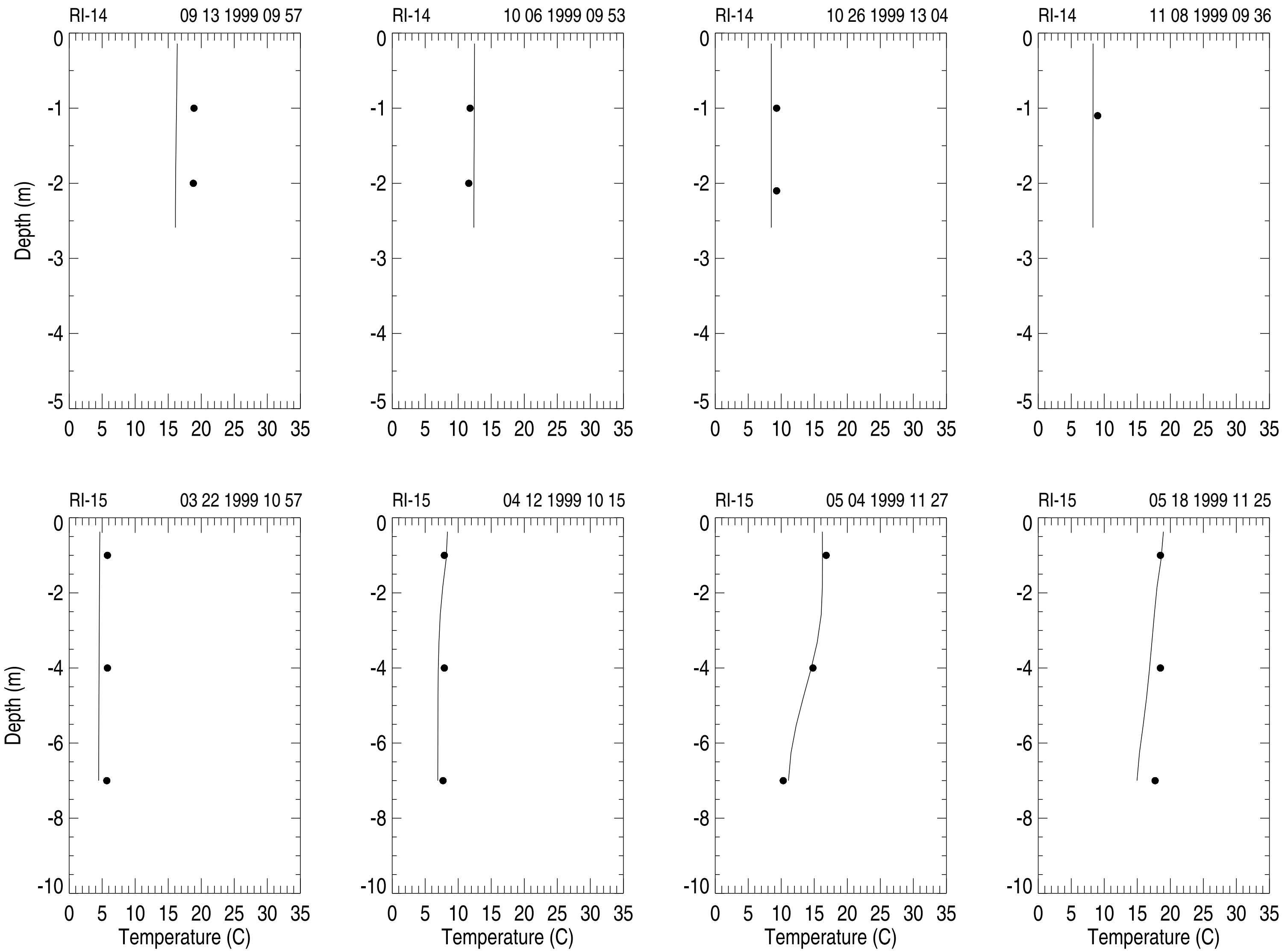


RI-08
06 07 1999 11 39
RI-08
06 14 1999 09 56
RI-08
07 13 1999 10 46
RI-08
07 22 1999 11 06
RI-08
08 10 1999 10 47
RI-08
09 01 1999 10 30
RI-08
09 13 1999 11 19
RI-08
10 06 1999 11 06
Depth (m)
Temperature (C)

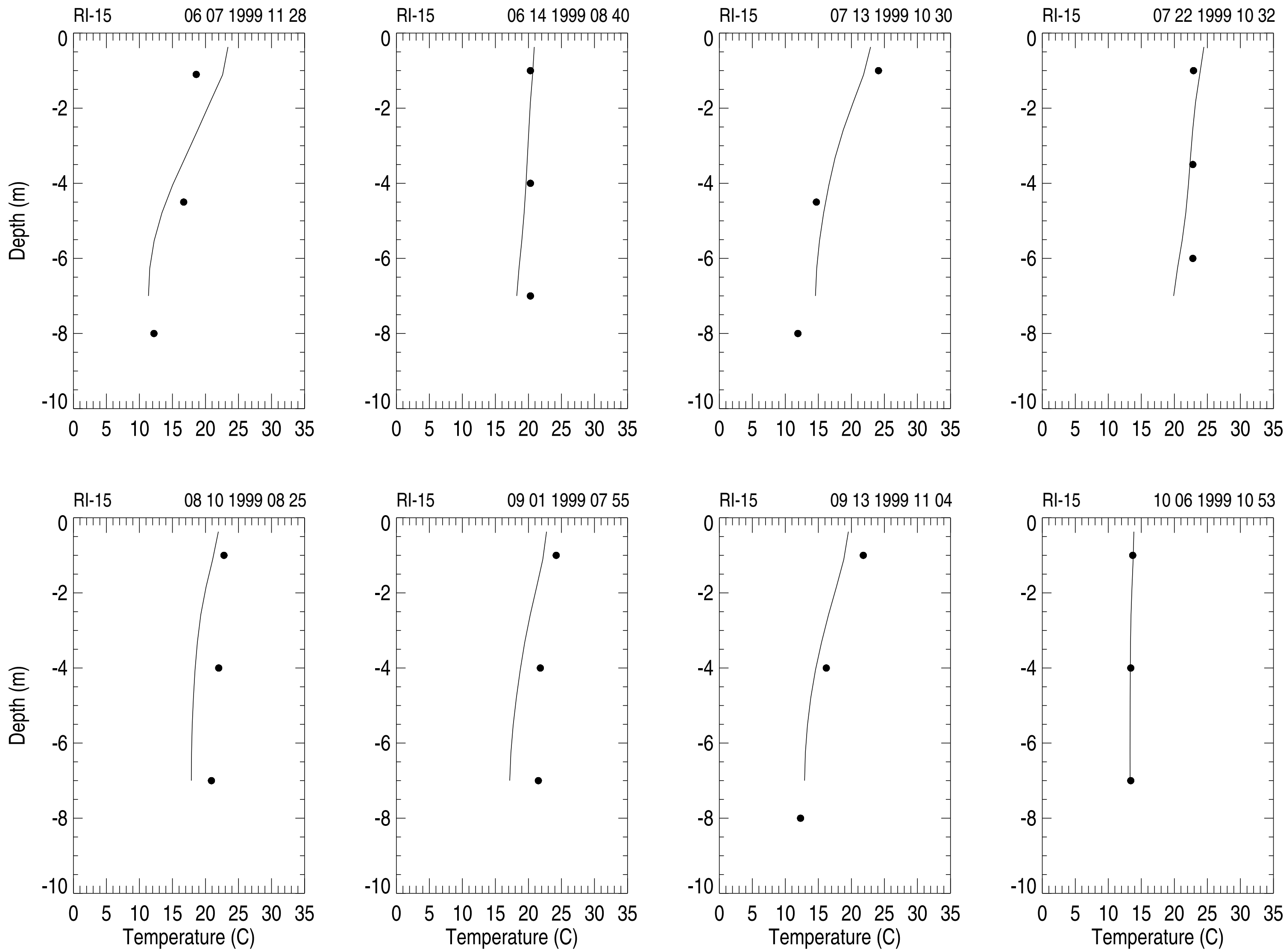

RI-08 10 26 1999 07 46
RI-08 11 08 1999 10 38
RI-11 03 22 1999 11 29
RI-11 04 12 1999 12 25
RI-11 05 04 1999 12 21
RI-11 06 07 1999 12 06
RI-11 06 14 1999 10 30
RI-11 07 13 1999 11 15
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

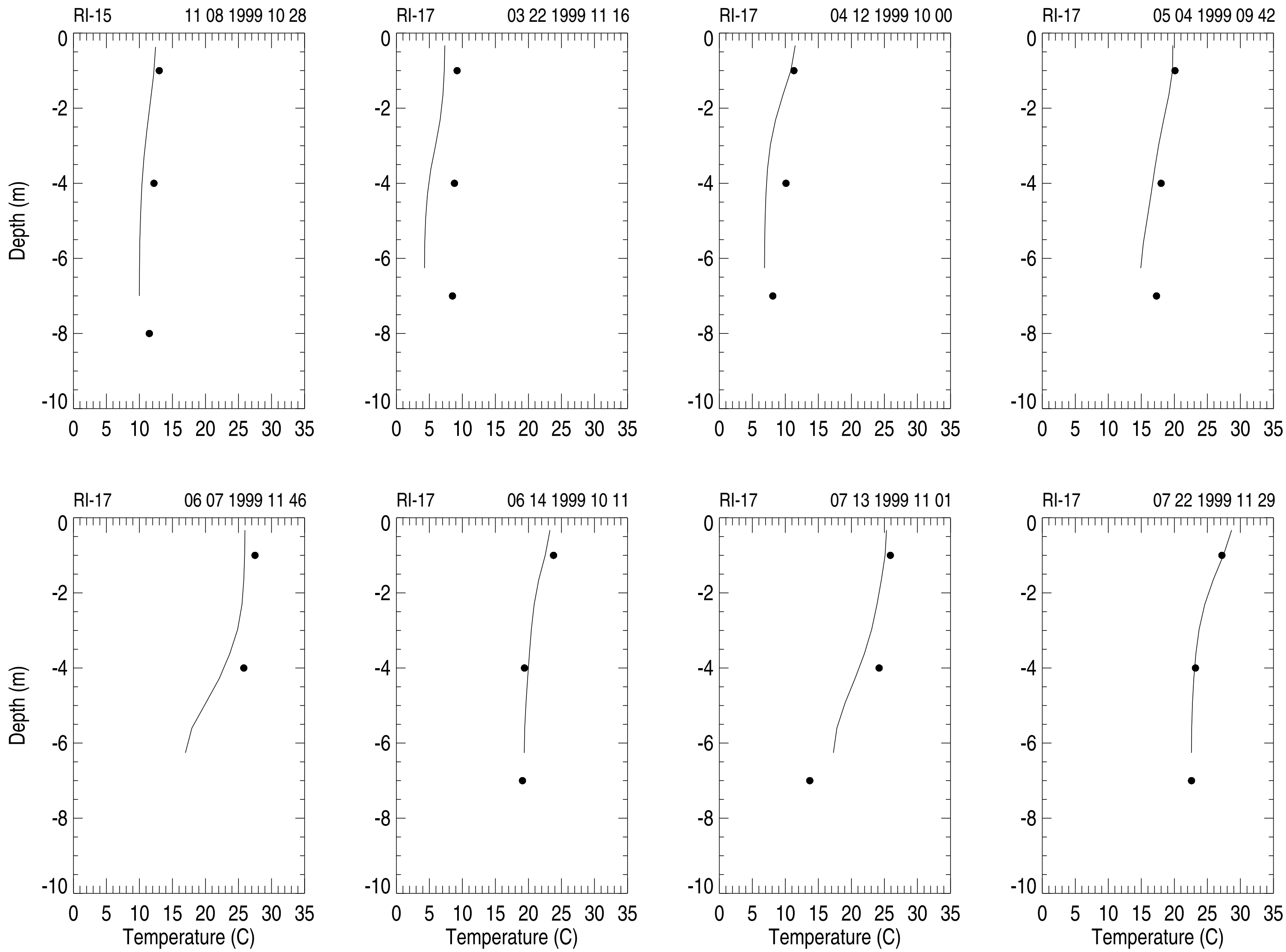

RI-11
07 22 1999 11 44
RI-11
08 10 1999 11 23
RI-11
09 01 1999 11 17
RI-11
09 13 1999 11 44
RI-11
10 06 1999 11 45
RI-11
11 08 1999 10 59
RI-14
03 22 1999 10 01
RI-14
04 12 1999 10 45
Depth (m)
Temperature (C)

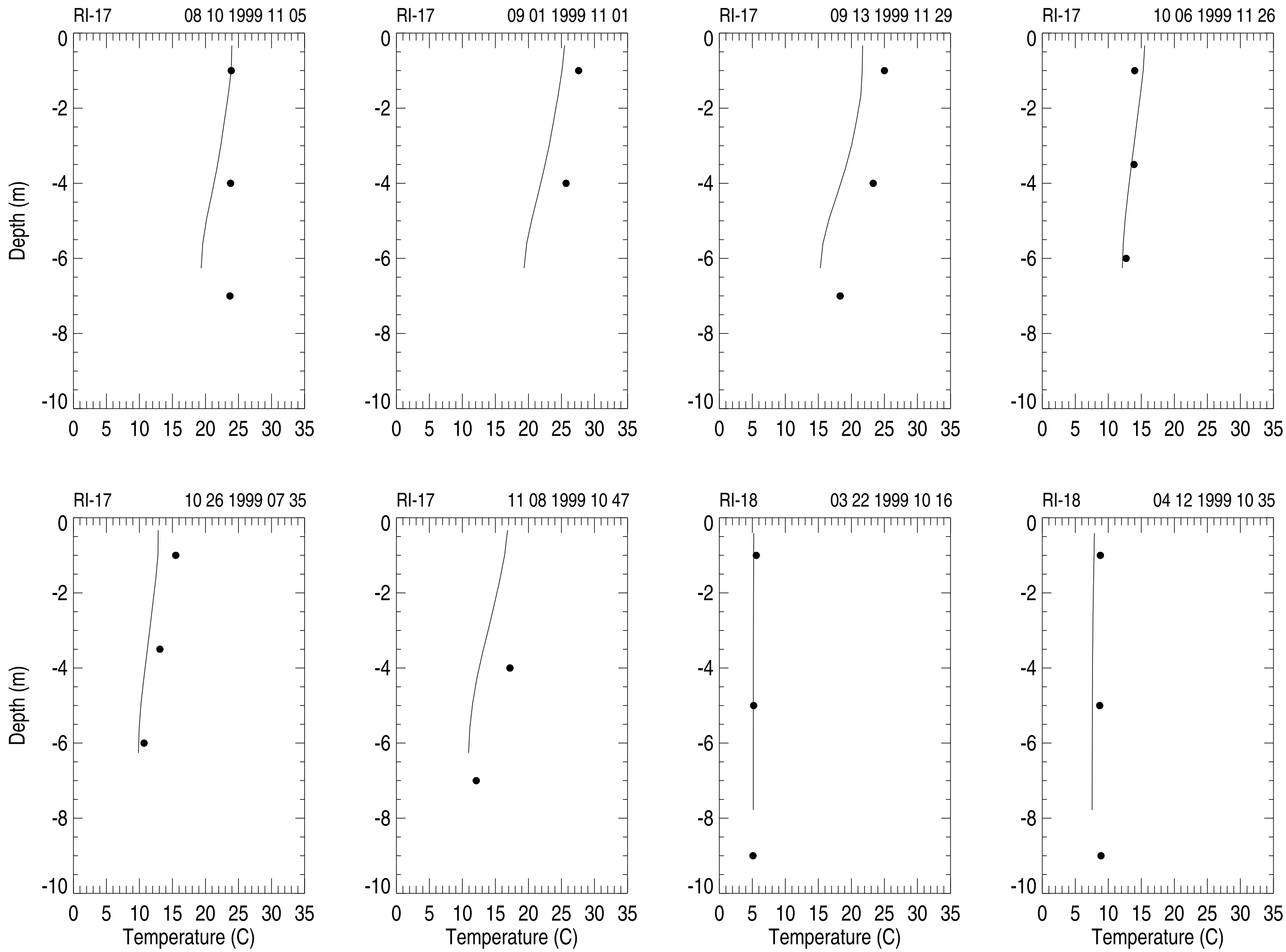

RI-14
05 04 1999 10 45
RI-14
05 18 1999 10 25
RI-14
06 07 1999 10 14
RI-14
06 14 1999 09 24
RI-14
07 13 1999 09 39
RI-14
07 22 1999 09 44
RI-14
08 10 1999 10 09
RI-14
09 01 1999 10 00
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35



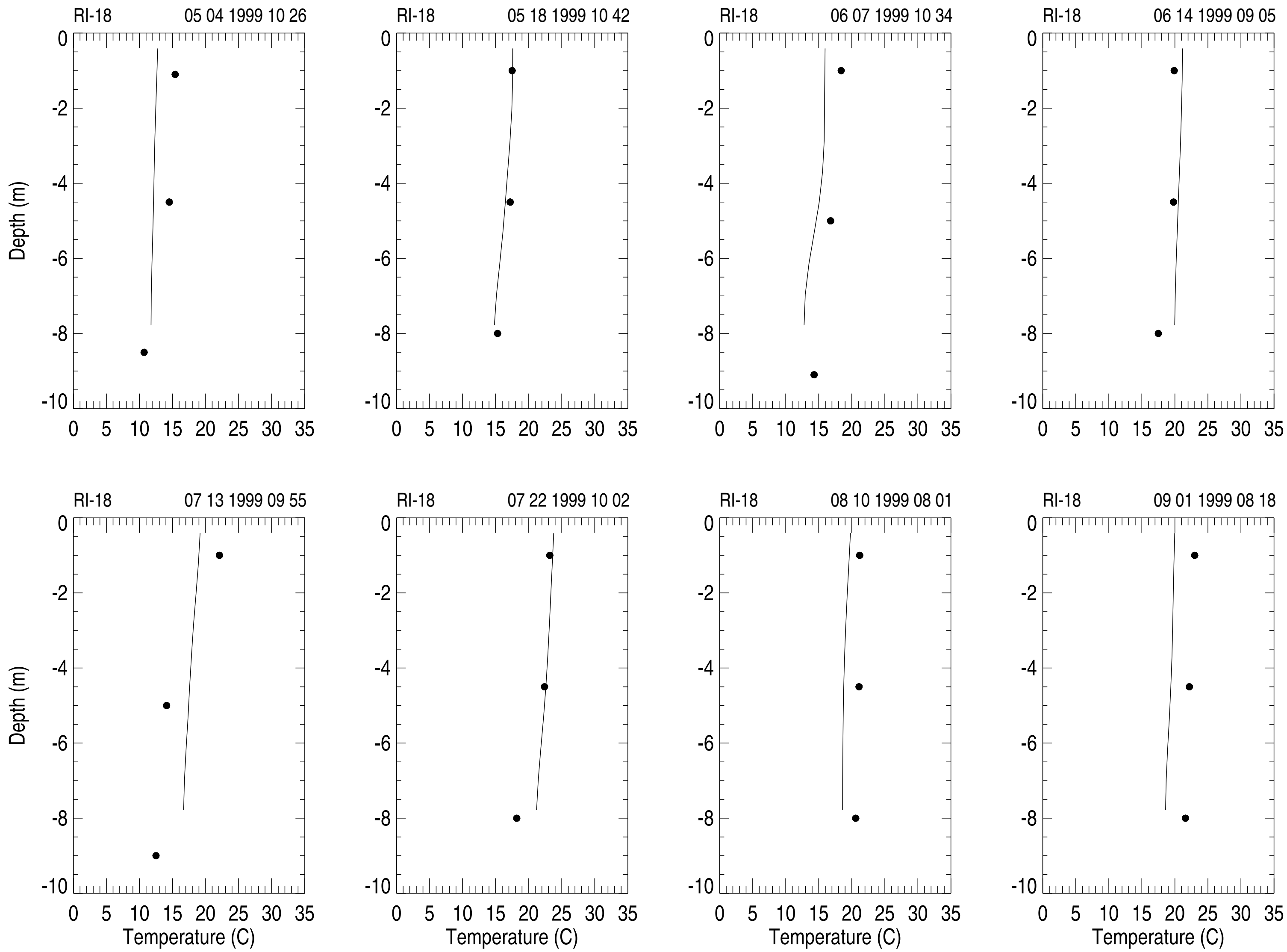
RI-14 09 13 1999 09 57
RI-14 10 06 1999 09 53
RI-14 10 26 1999 13 04
RI-14 11 08 1999 09 36
RI-15 03 22 1999 10 57
RI-15 04 12 1999 10 15
RI-15 05 04 1999 11 27
RI-15 05 18 1999 11 25
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
-6
-8
-10
0 5 10 15 20 25 30 35

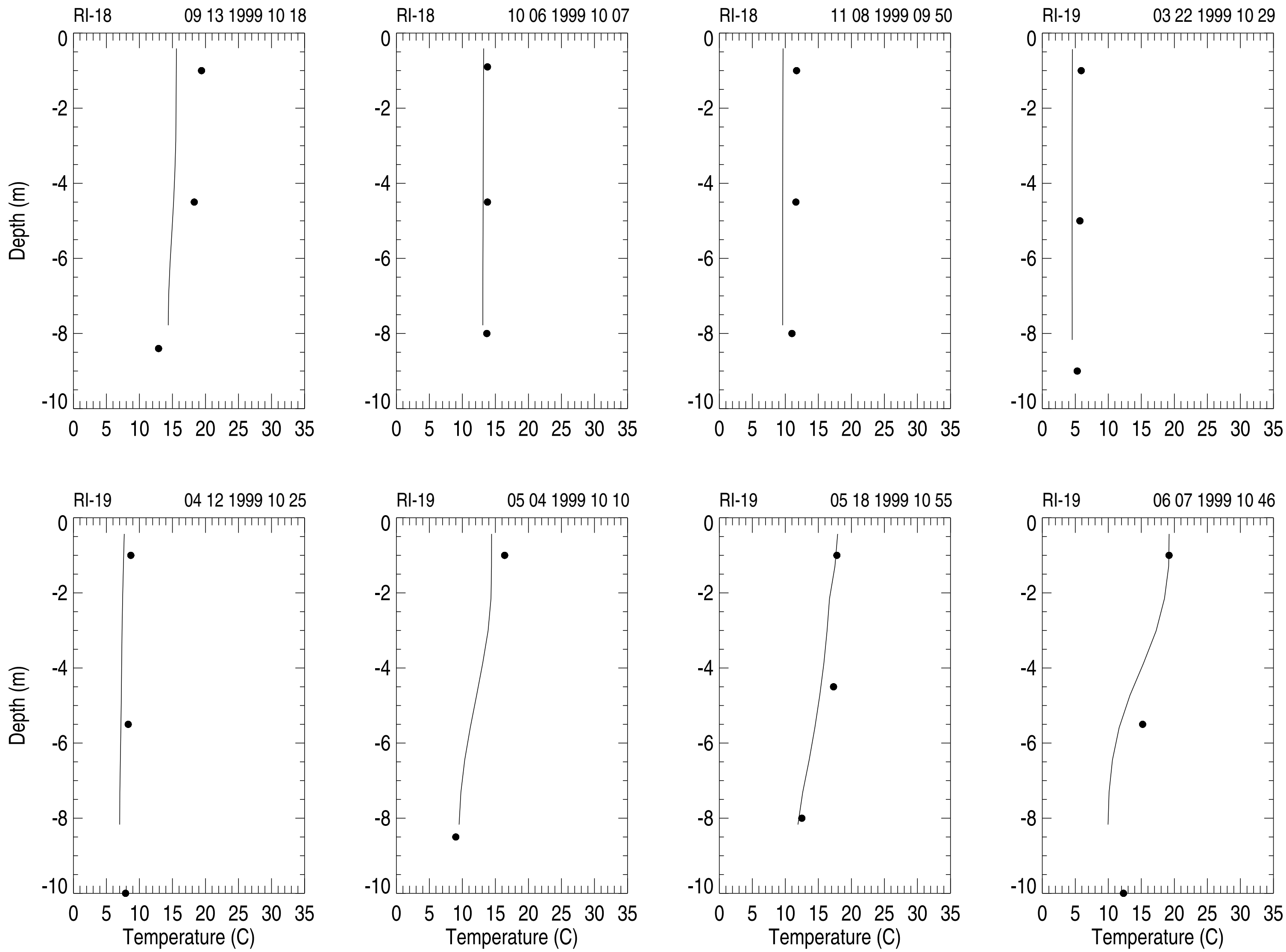

RI-15 06 07 1999 11 28
RI-15 06 14 1999 08 40
RI-15 07 13 1999 10 30
RI-15 07 22 1999 10 32
RI-15 08 10 1999 08 25
RI-15 09 01 1999 07 55
RI-15 09 13 1999 11 04
RI-15 10 06 1999 10 53
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35


RI-15 11 08 1999 10 28
RI-17 03 22 1999 11 16
RI-17 04 12 1999 10 00
RI-17 05 04 1999 09 42
RI-17 06 07 1999 11 46
RI-17 06 14 1999 10 11
RI-17 07 13 1999 11 01
RI-17 07 22 1999 11 29
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

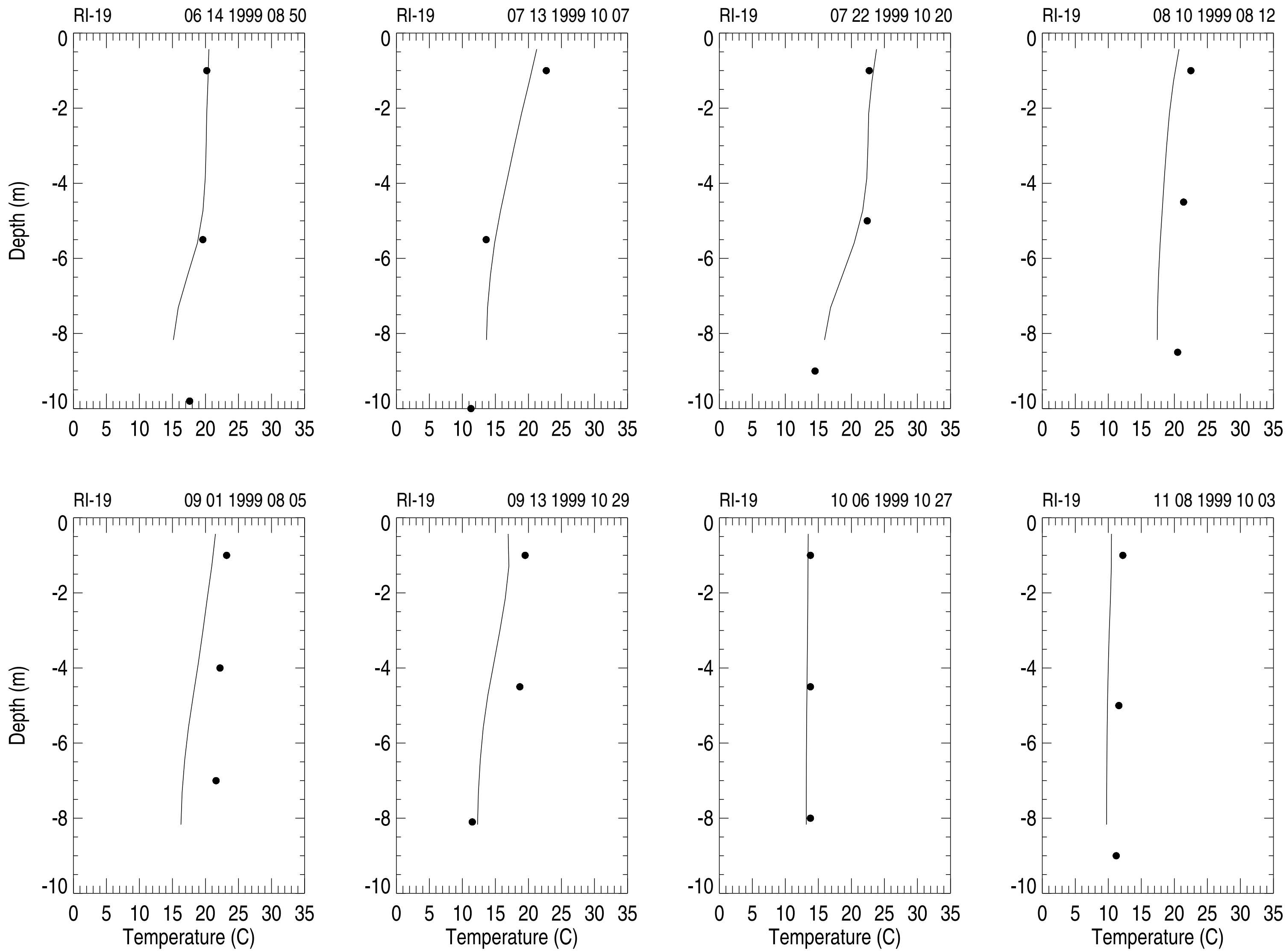


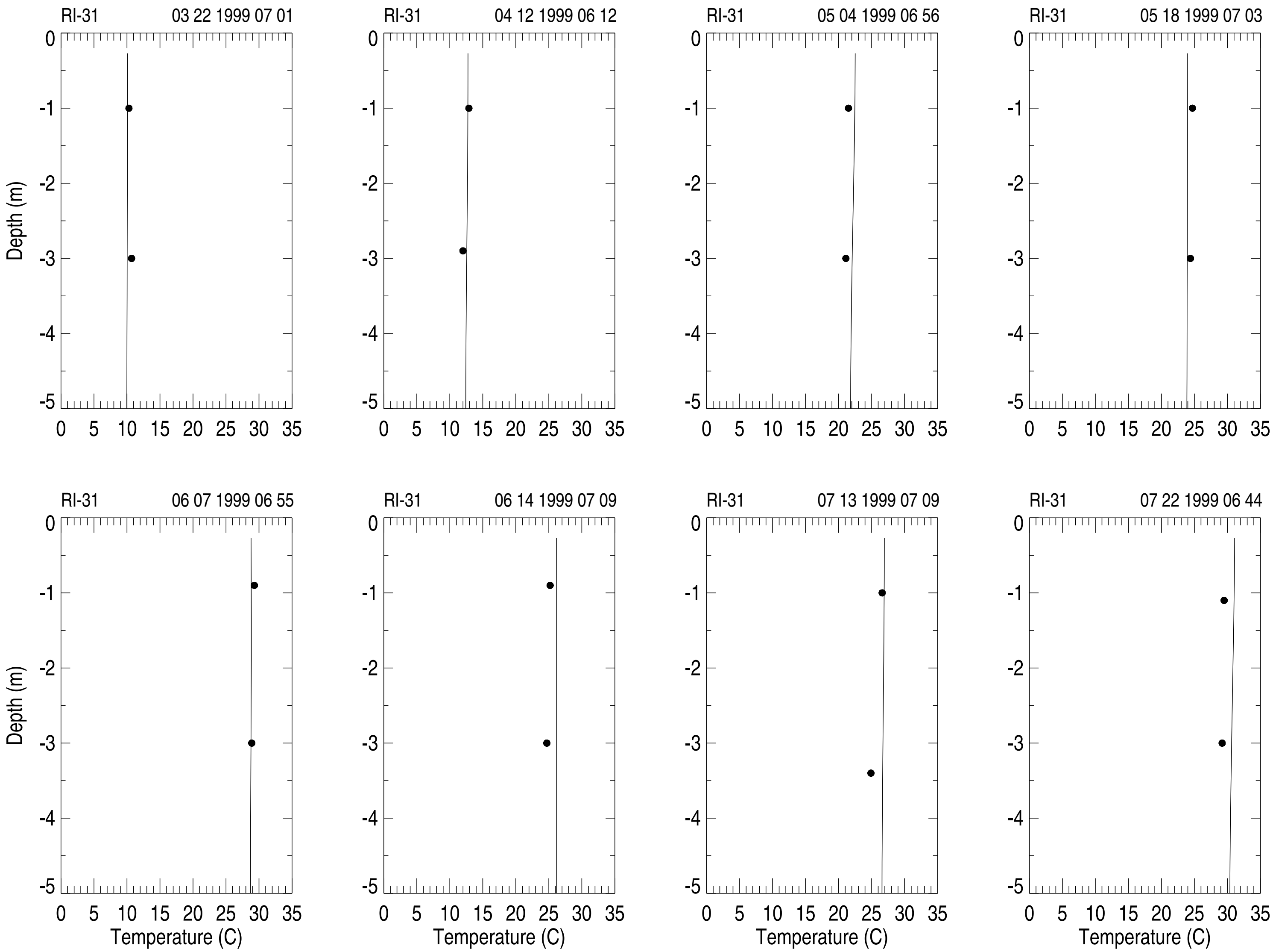
RI-17
08 10 1999 11 05
RI-17
09 01 1999 11 01
RI-17
09 13 1999 11 29
RI-17
10 06 1999 11 26
RI-17
10 26 1999 07 35
RI-17
11 08 1999 10 47
RI-18
03 22 1999 10 16
RI-18
04 12 1999 10 35
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

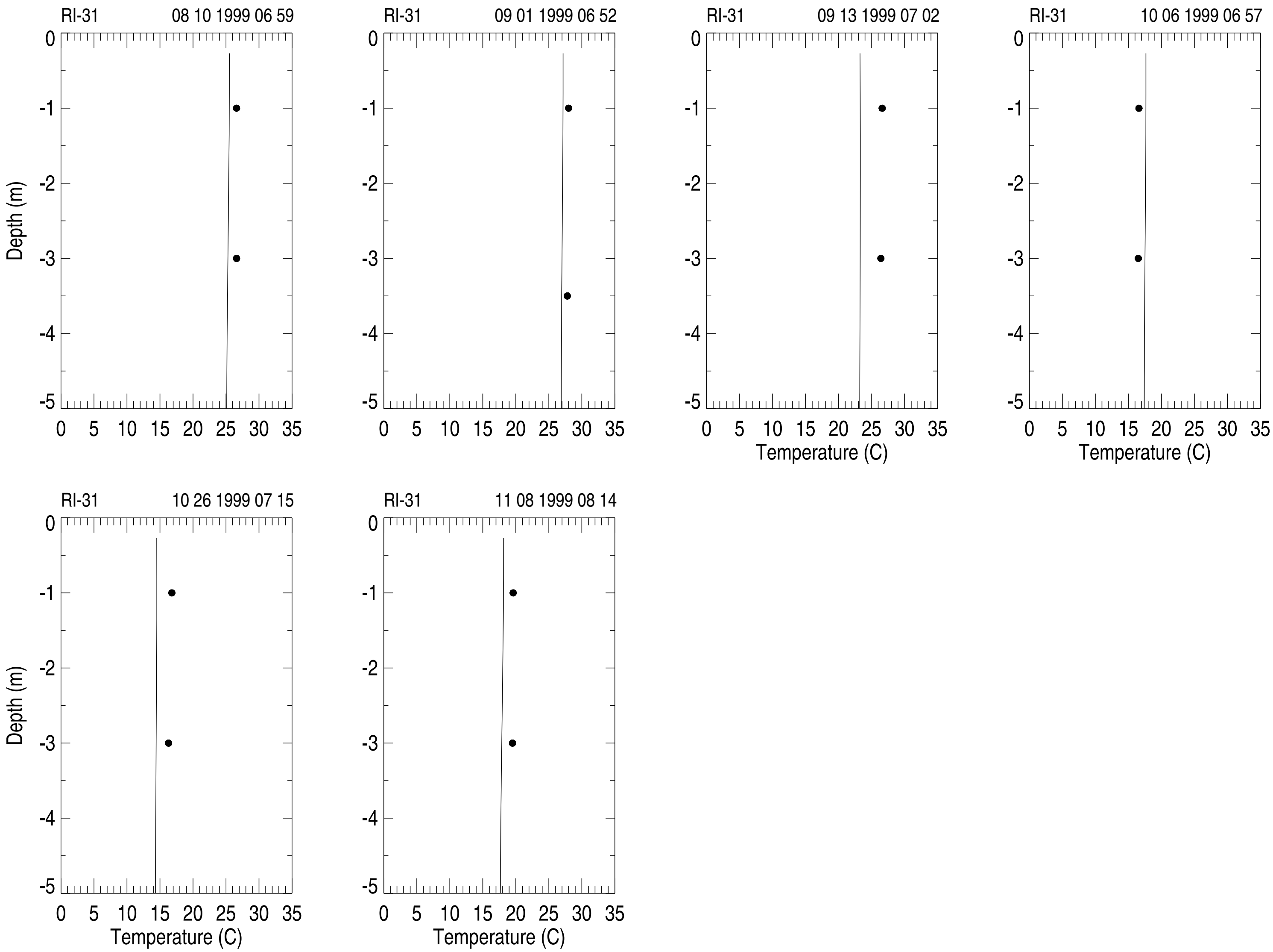

RI-18
05 04 1999 10 26
RI-18
05 18 1999 10 42
RI-18
06 07 1999 10 34
RI-18
06 14 1999 09 05
RI-18
07 13 1999 09 55
RI-18
07 22 1999 10 02
RI-18
08 10 1999 08 01
RI-18
09 01 1999 08 18
Depth (m)
Temperature (C)

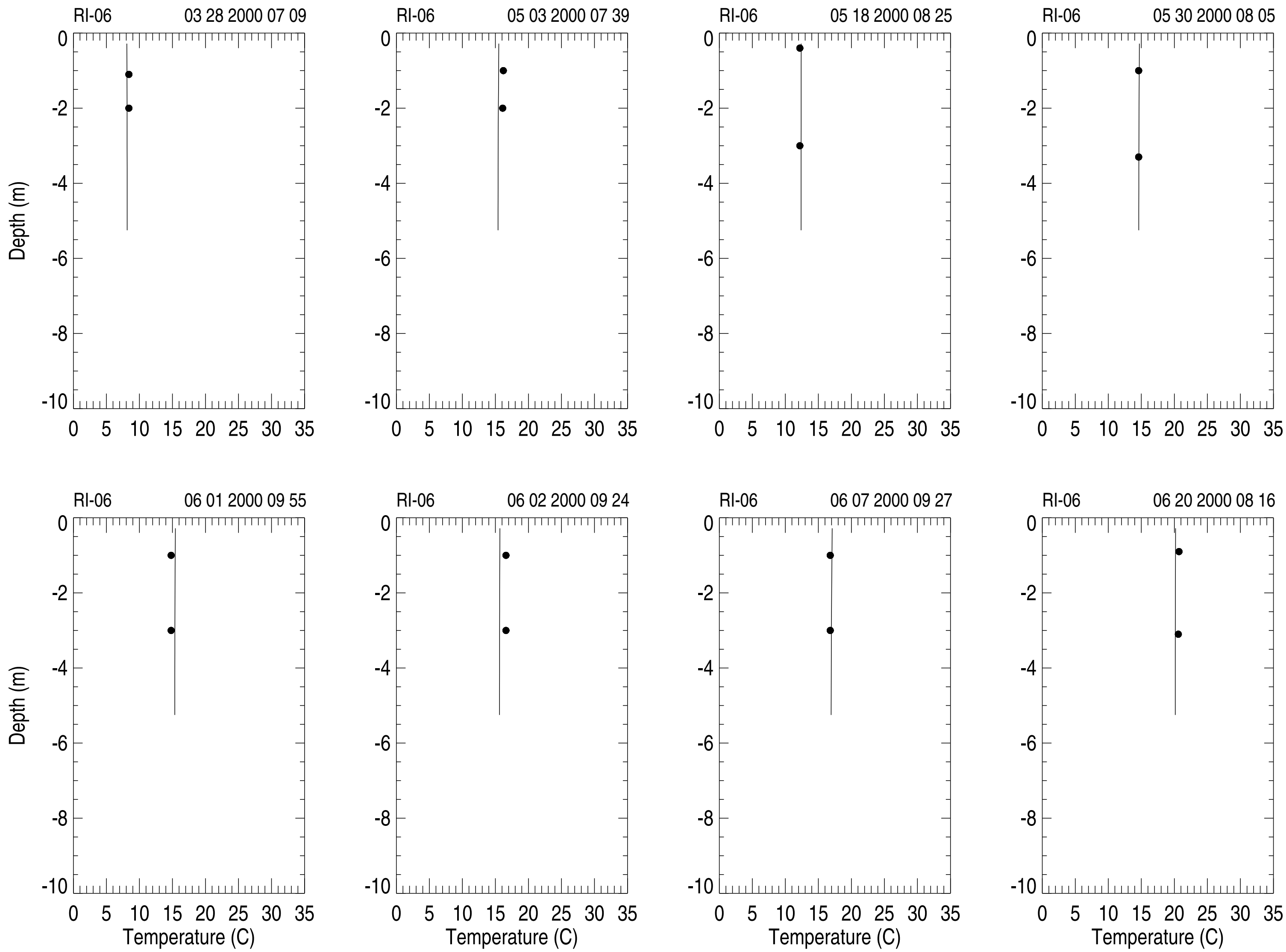


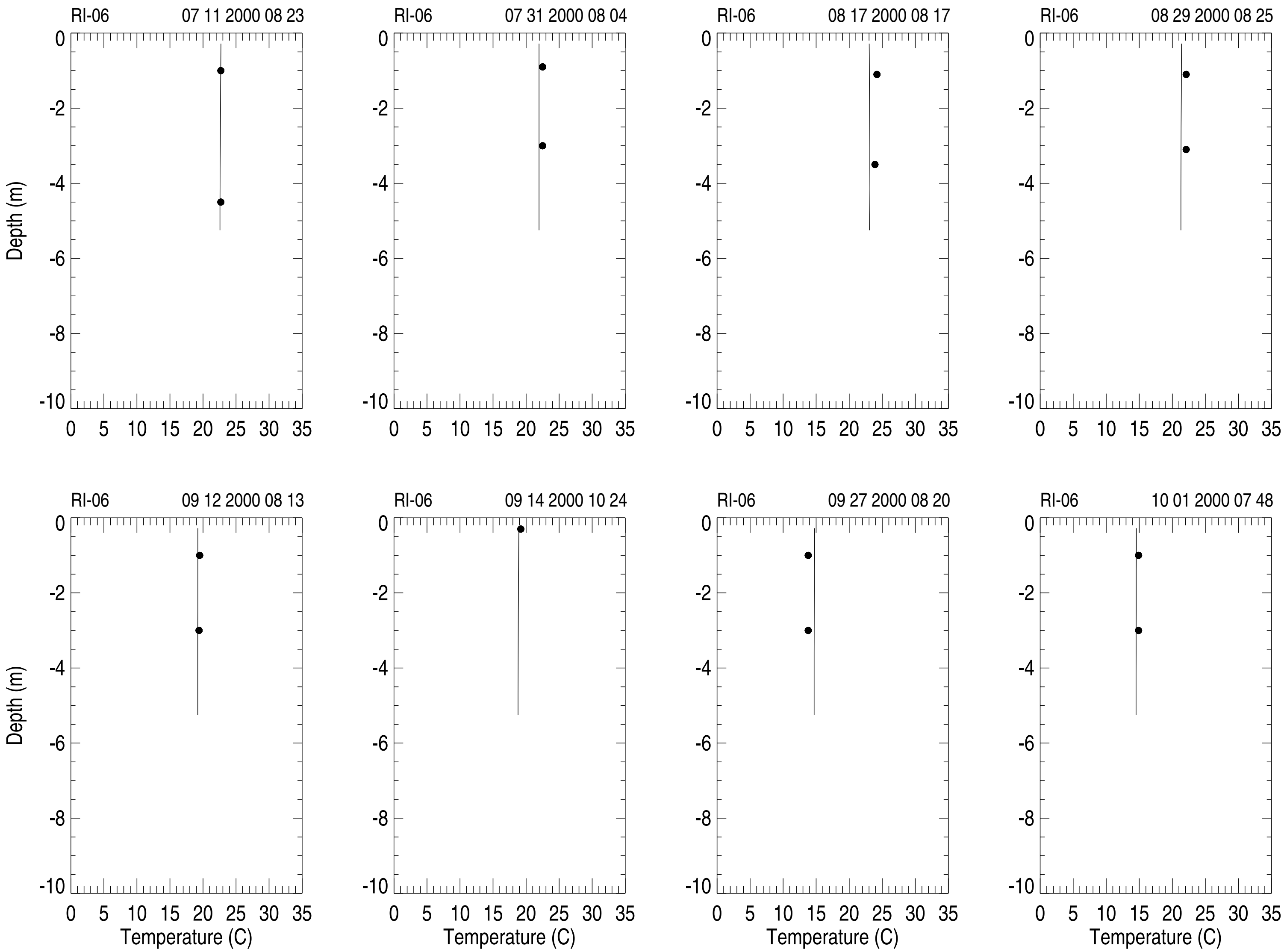
RI-18 09 13 1999 10 18
RI-18 10 06 1999 10 07
RI-18 11 08 1999 09 50
RI-19 03 22 1999 10 29
RI-19 04 12 1999 10 25
RI-19 05 04 1999 10 10
RI-19 05 18 1999 10 55
RI-19 06 07 1999 10 46
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

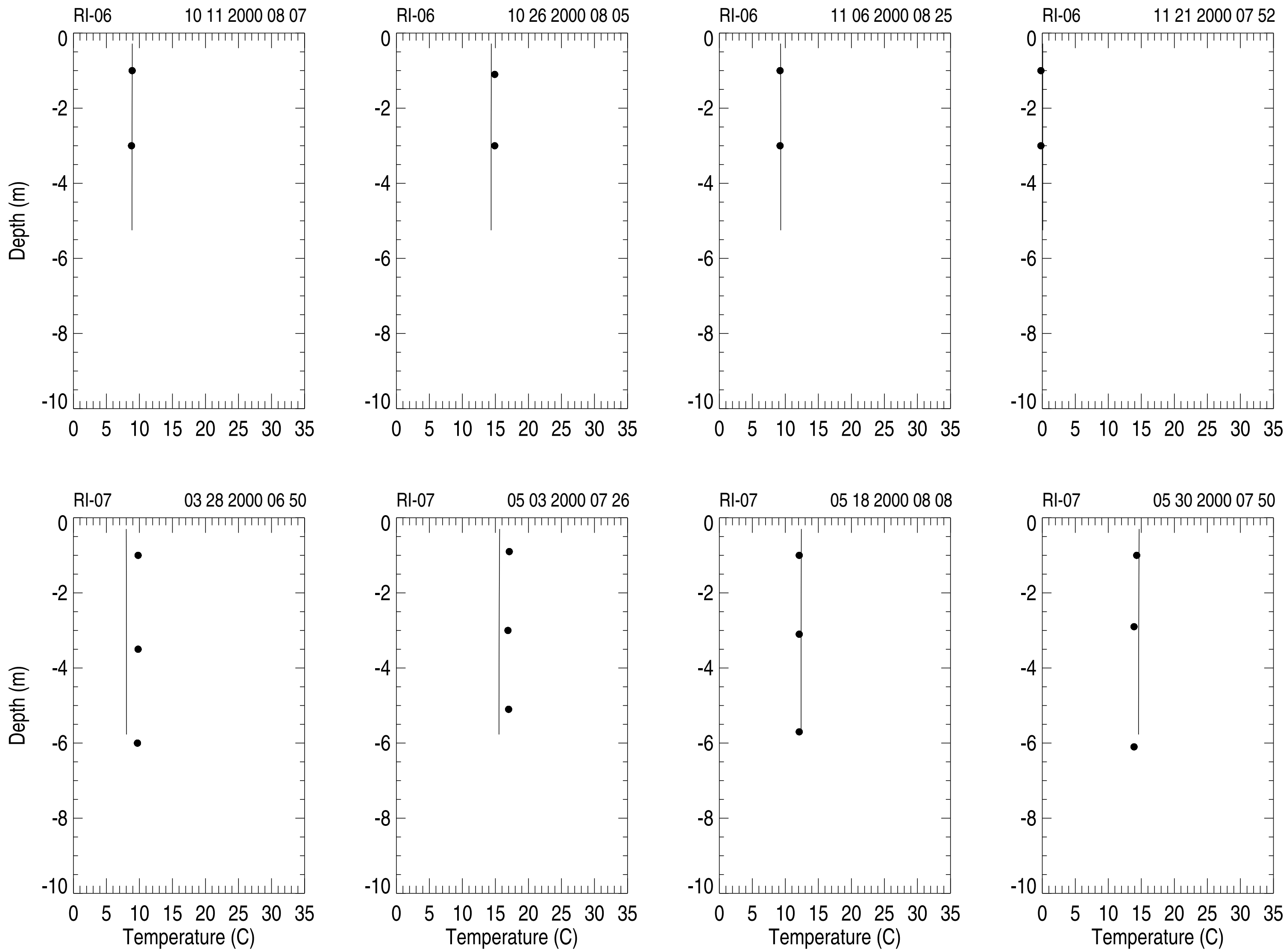

RI-19
06 14 1999 08 50
07 13 1999 10 07
07 22 1999 10 20
08 10 1999 08 12
09 01 1999 08 05
09 13 1999 10 29
10 06 1999 10 27
11 08 1999 10 03
Depth (m)
Temperature (C)

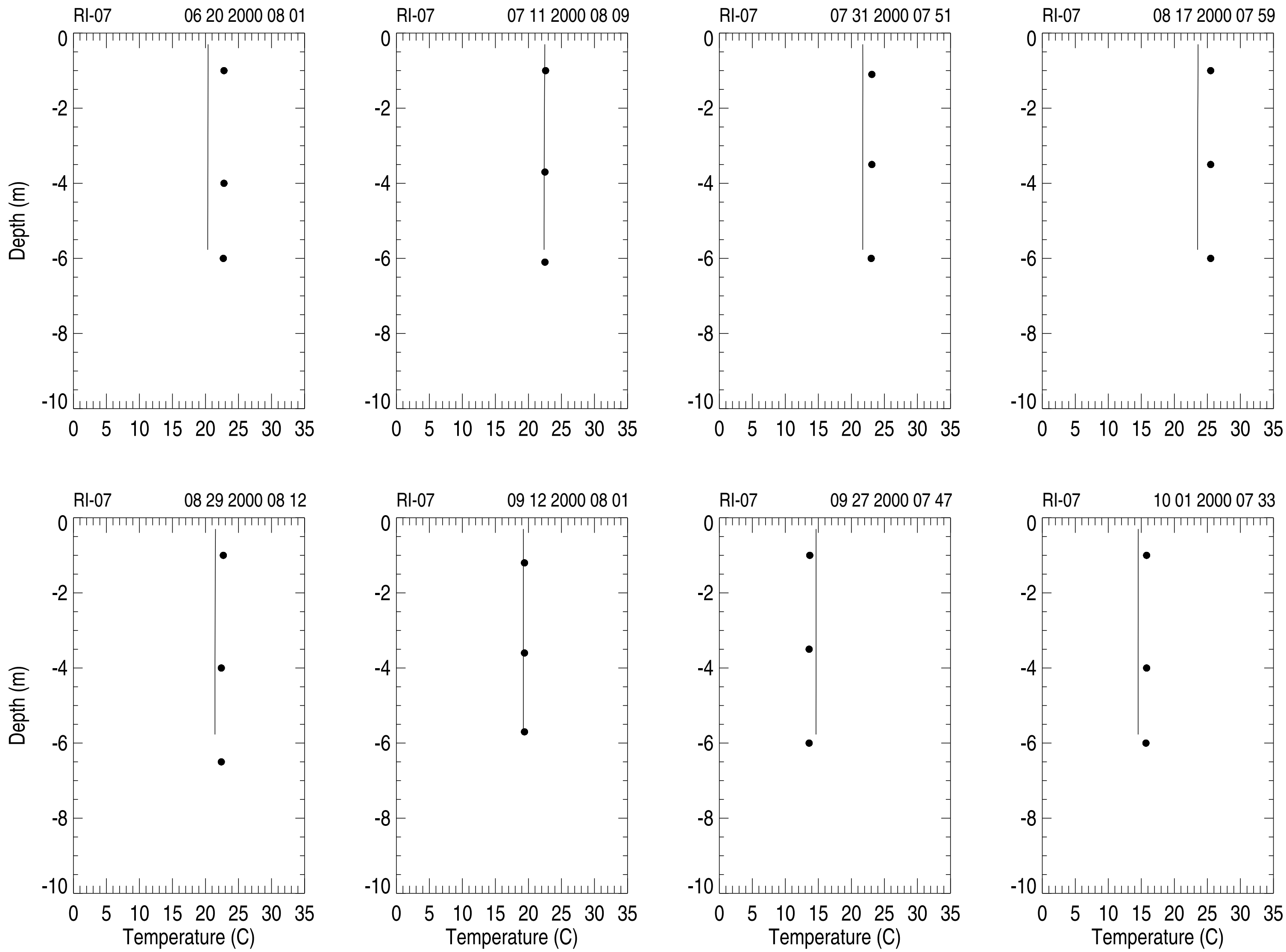

RI-31
03 22 1999 07 01
RI-31
04 12 1999 06 12
RI-31
05 04 1999 06 56
RI-31
05 18 1999 07 03
RI-31
06 07 1999 06 55
RI-31
06 14 1999 07 09
RI-31
07 13 1999 07 09
RI-31
07 22 1999 06 44
Depth (m)
Temperature (C)

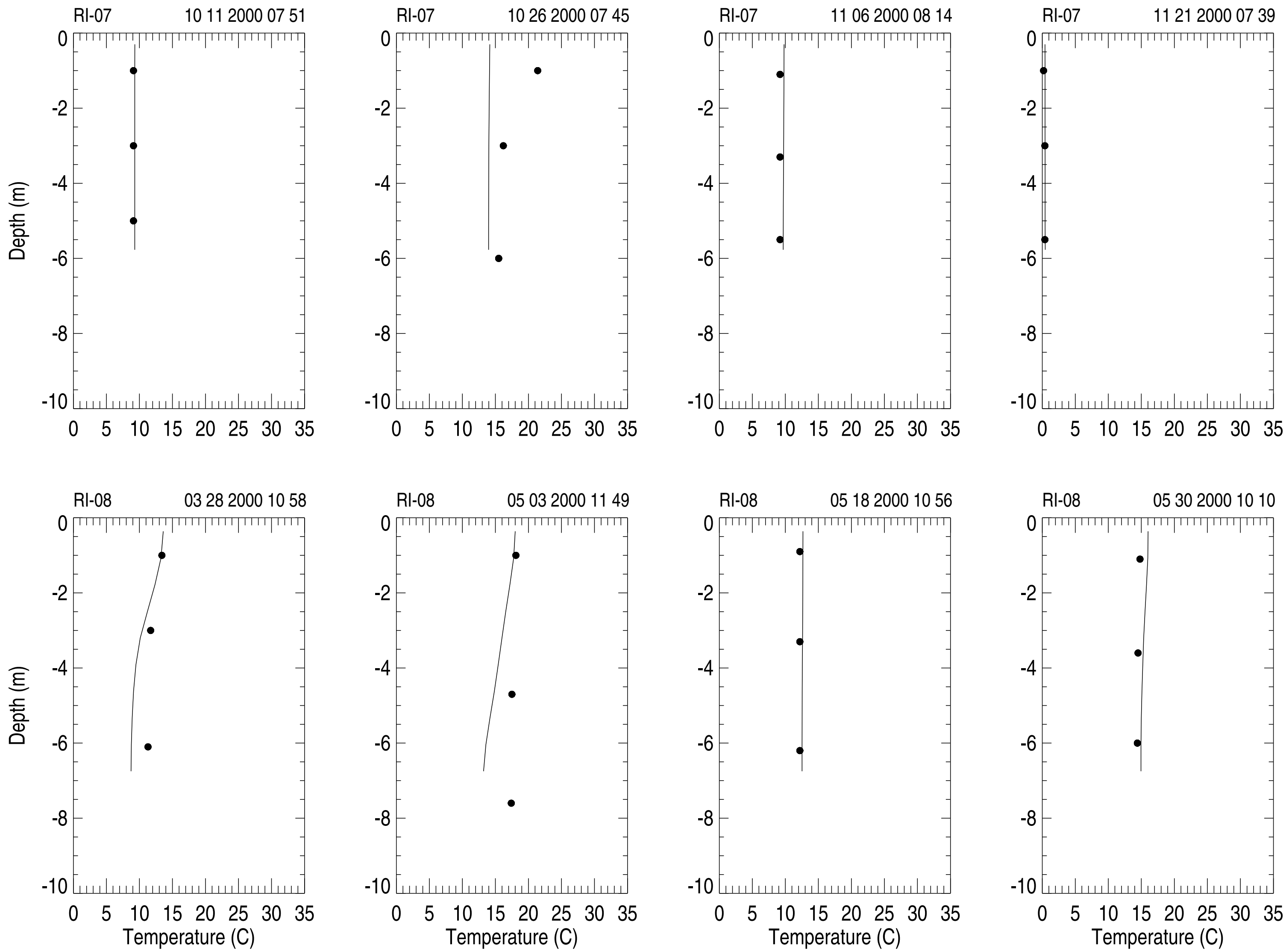

RI-31
08 10 1999 06 59
RI-31
09 01 1999 06 52
RI-31
09 13 1999 07 02
RI-31
10 06 1999 06 57
RI-31
10 26 1999 07 15
RI-31
11 08 1999 08 14
Depth (m)
Temperature (C)


RI-06
03 28 2000 07 09
RI-06
05 03 2000 07 39
RI-06
05 18 2000 08 25
RI-06
05 30 2000 08 05
RI-06
06 01 2000 09 55
RI-06
06 02 2000 09 24
RI-06
06 07 2000 09 27
RI-06
06 20 2000 08 16
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

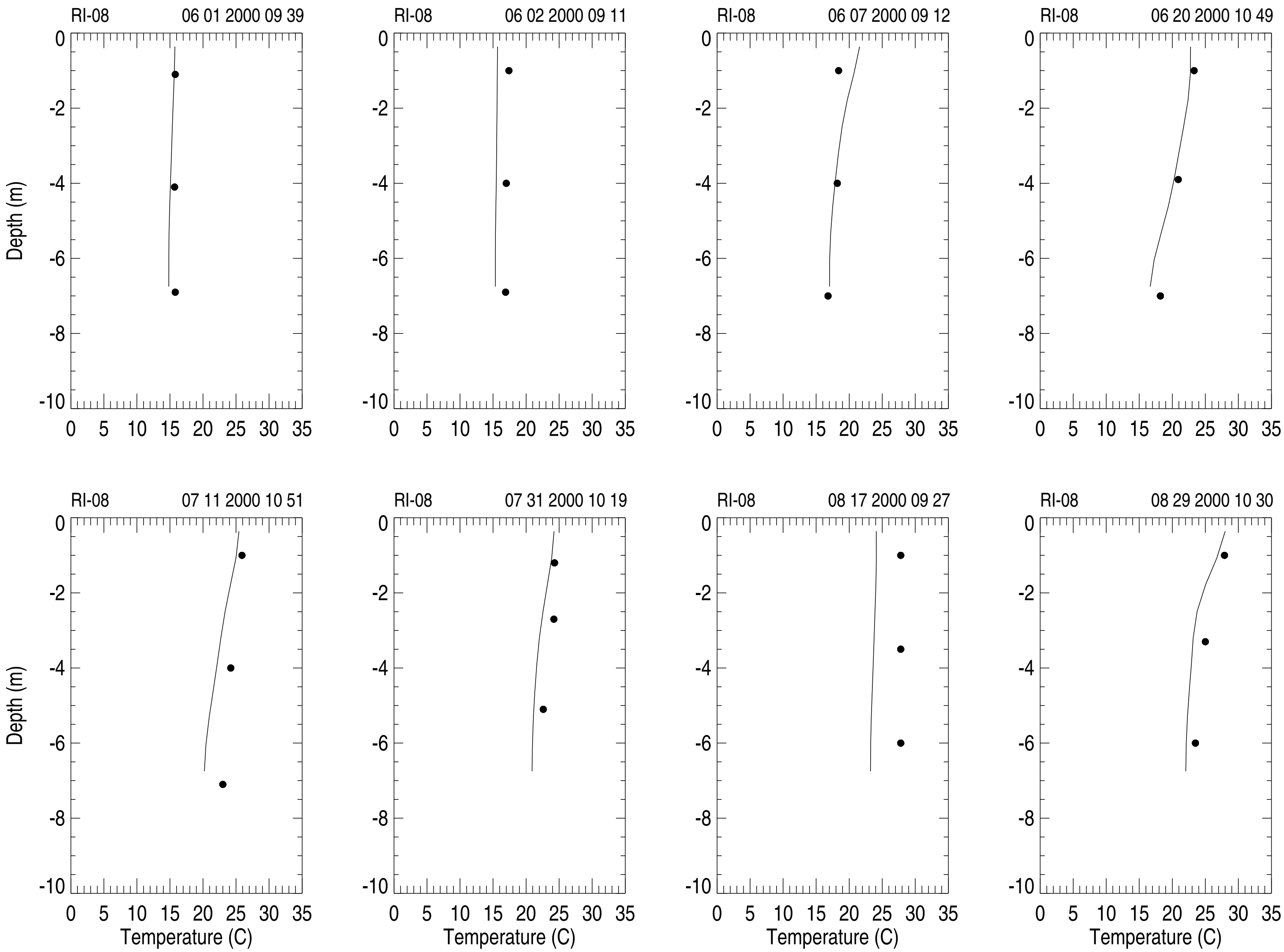

RI-06
07 11 2000 08 23
RI-06
07 31 2000 08 04
RI-06
08 17 2000 08 17
RI-06
08 29 2000 08 25
RI-06
09 12 2000 08 13
RI-06
09 14 2000 10 24
RI-06
09 27 2000 08 20
RI-06
10 01 2000 07 48
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

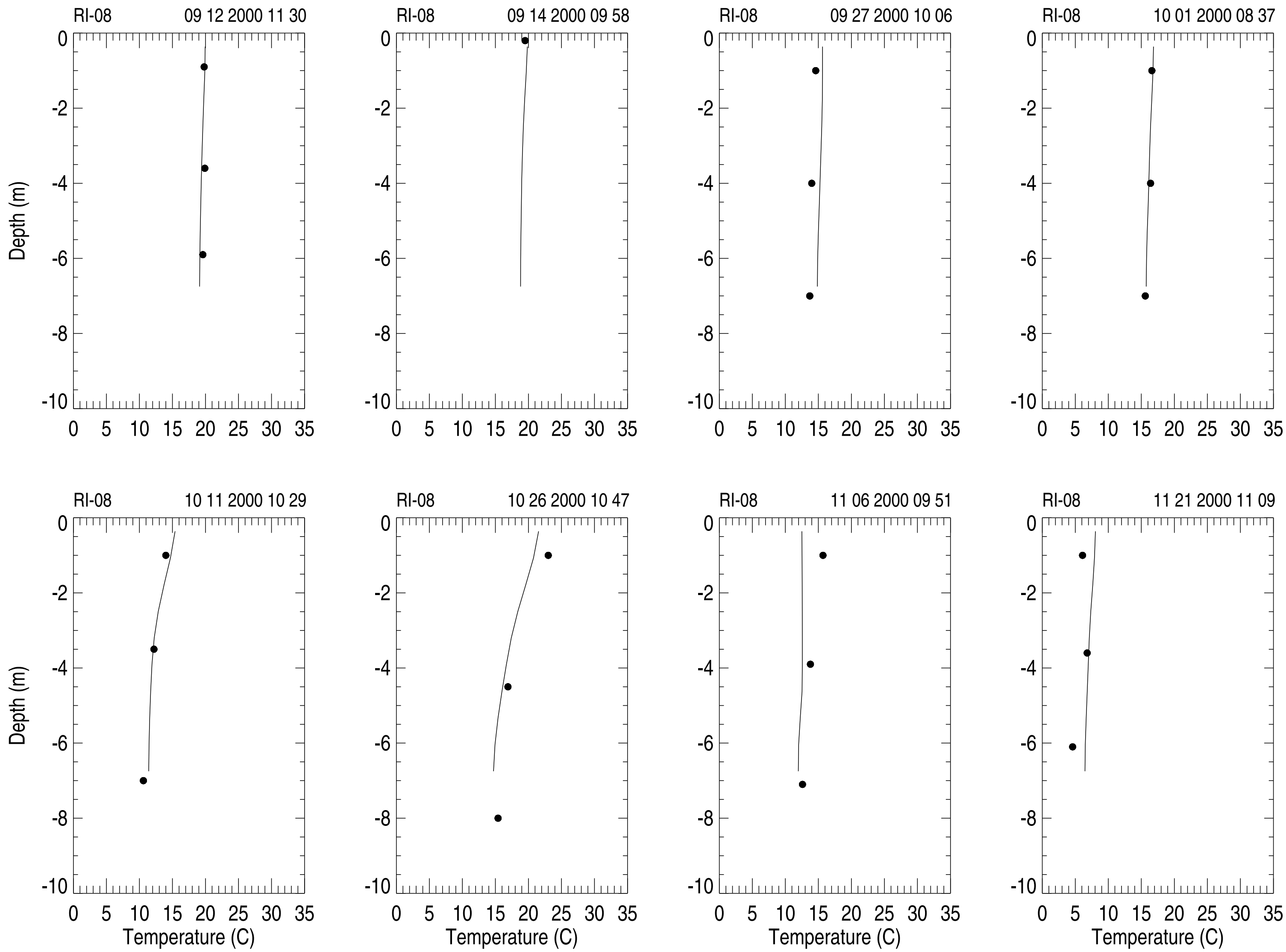

RI-06 10 11 2000 08 07
RI-06 10 26 2000 08 05
RI-06 11 06 2000 08 25
RI-06 11 21 2000 07 52
RI-07 03 28 2000 06 50
RI-07 05 03 2000 07 26
RI-07 05 18 2000 08 08
RI-07 05 30 2000 07 50
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

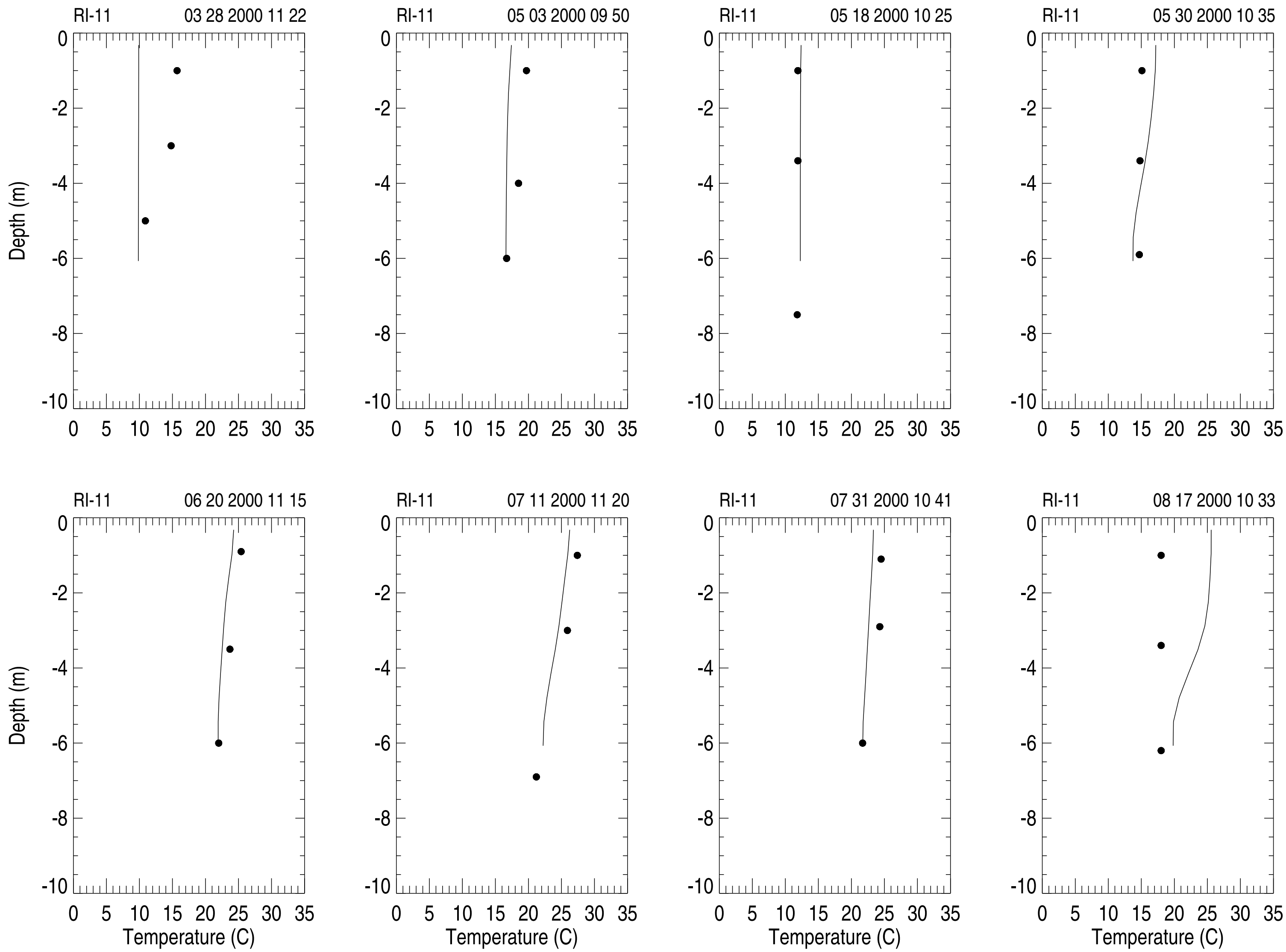

RI-07
06 20 2000 08 01
RI-07
07 11 2000 08 09
RI-07
07 31 2000 07 51
RI-07
08 17 2000 07 59
RI-07
08 29 2000 08 12
RI-07
09 12 2000 08 01
RI-07
09 27 2000 07 47
RI-07
10 01 2000 07 33
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

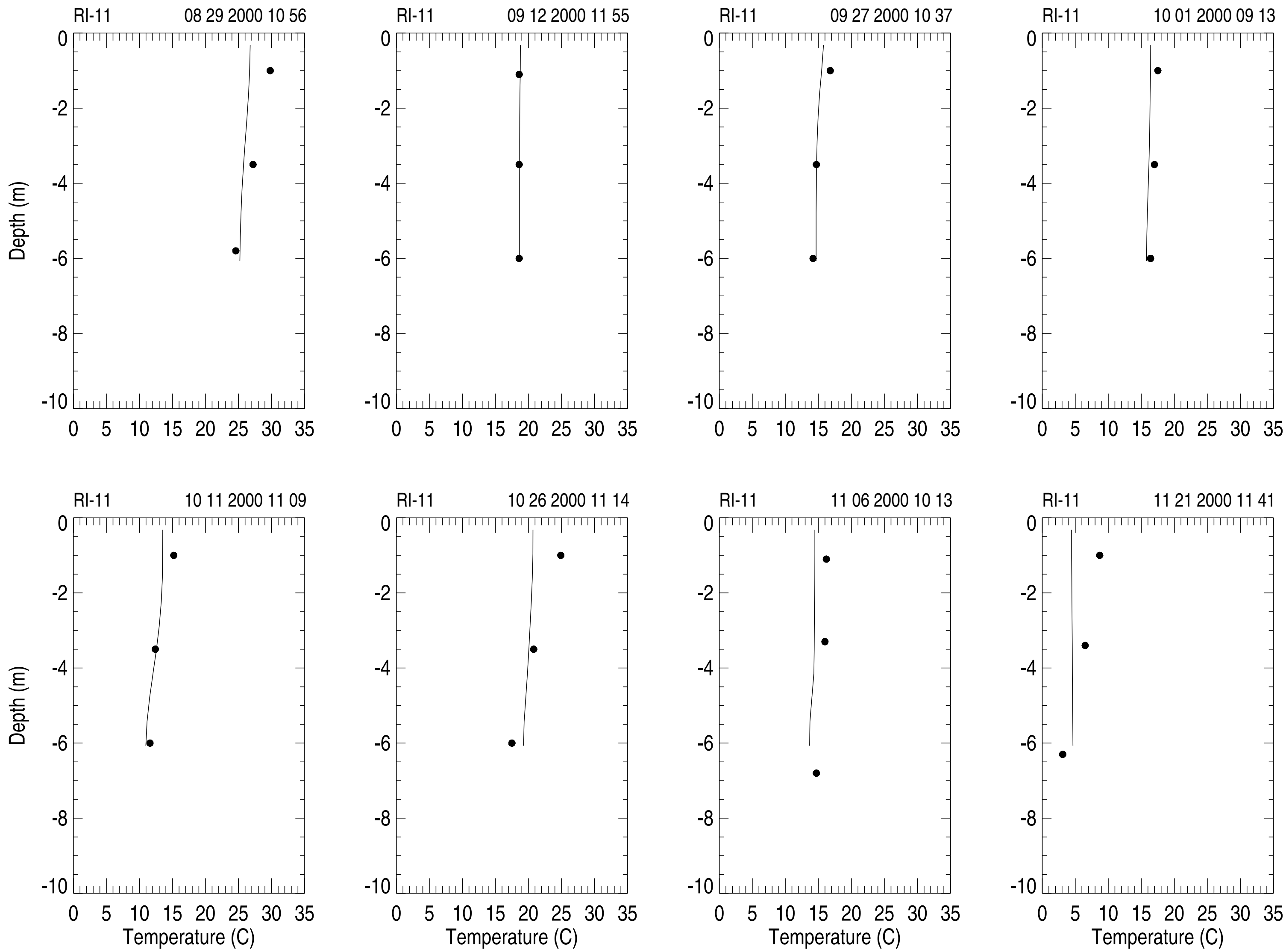


RI-07 10 11 2000 07 51
RI-07 10 26 2000 07 45
RI-07 11 06 2000 08 14
RI-07 11 21 2000 07 39
RI-08 03 28 2000 10 58
RI-08 05 03 2000 11 49
RI-08 05 18 2000 10 56
RI-08 05 30 2000 10 10
Depth (m)
Temperature (C)

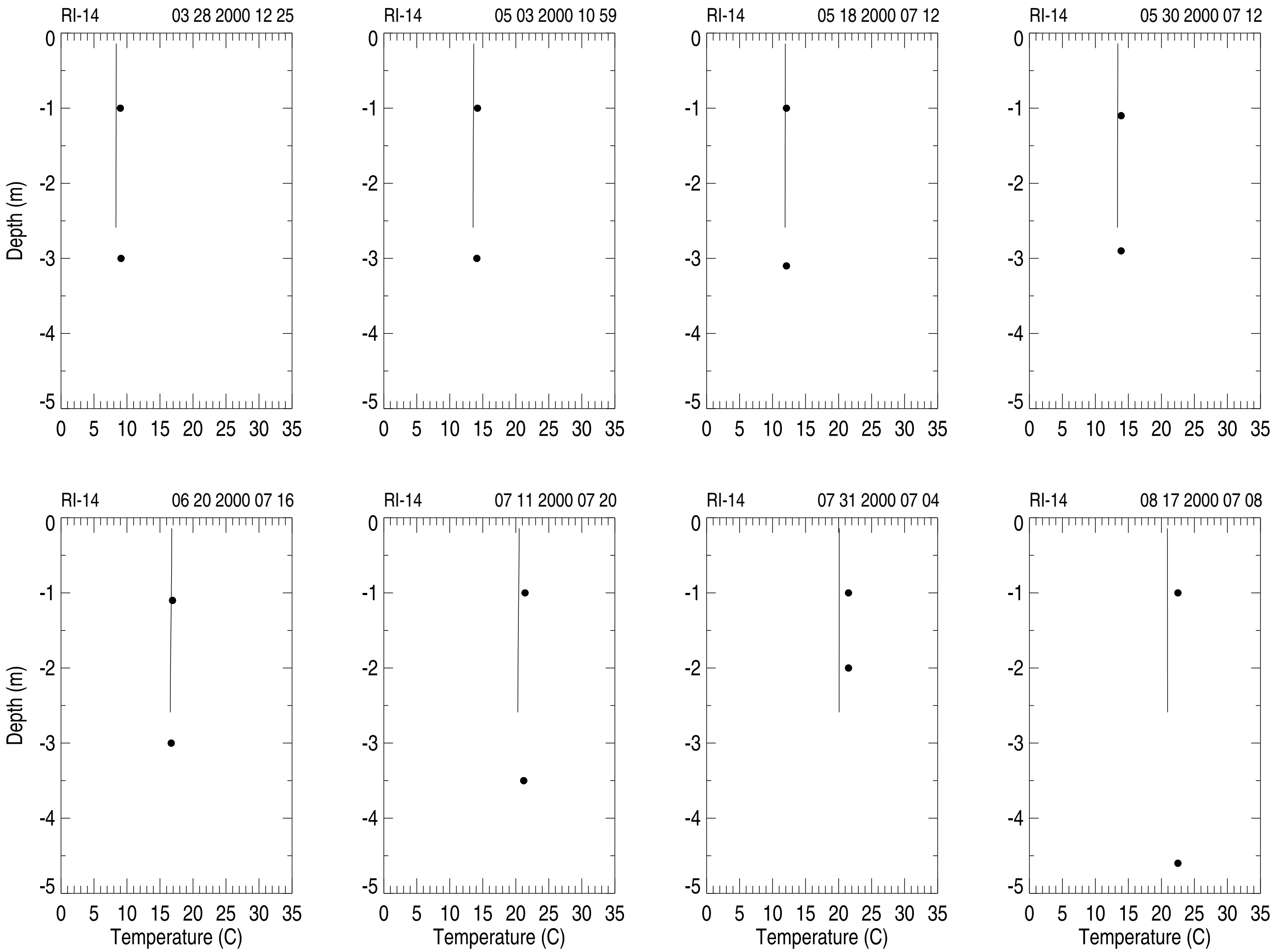

RI-08 06 01 2000 09 39
RI-08 06 02 2000 09 11
RI-08 06 07 2000 09 12
RI-08 06 20 2000 10 49
RI-08 07 11 2000 10 51
RI-08 07 31 2000 10 19
RI-08 08 17 2000 09 27
RI-08 08 29 2000 10 30
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

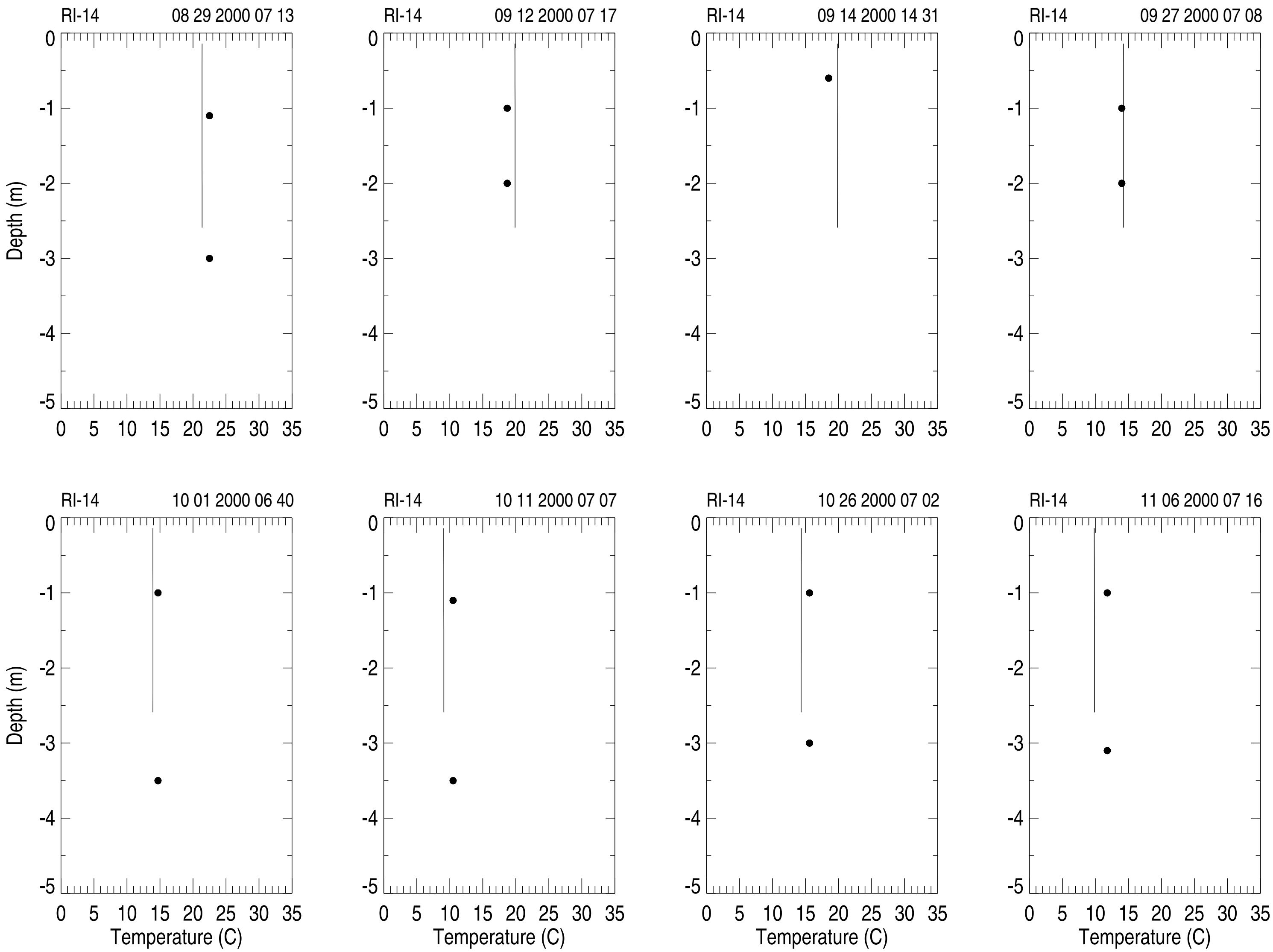

RI-08
09 12 2000 11 30
RI-08
09 14 2000 09 58
RI-08
09 27 2000 10 06
RI-08
10 01 2000 08 37
RI-08
10 11 2000 10 29
RI-08
10 26 2000 10 47
RI-08
11 06 2000 09 51
RI-08
11 21 2000 11 09
Depth (m)
Temperature (C)

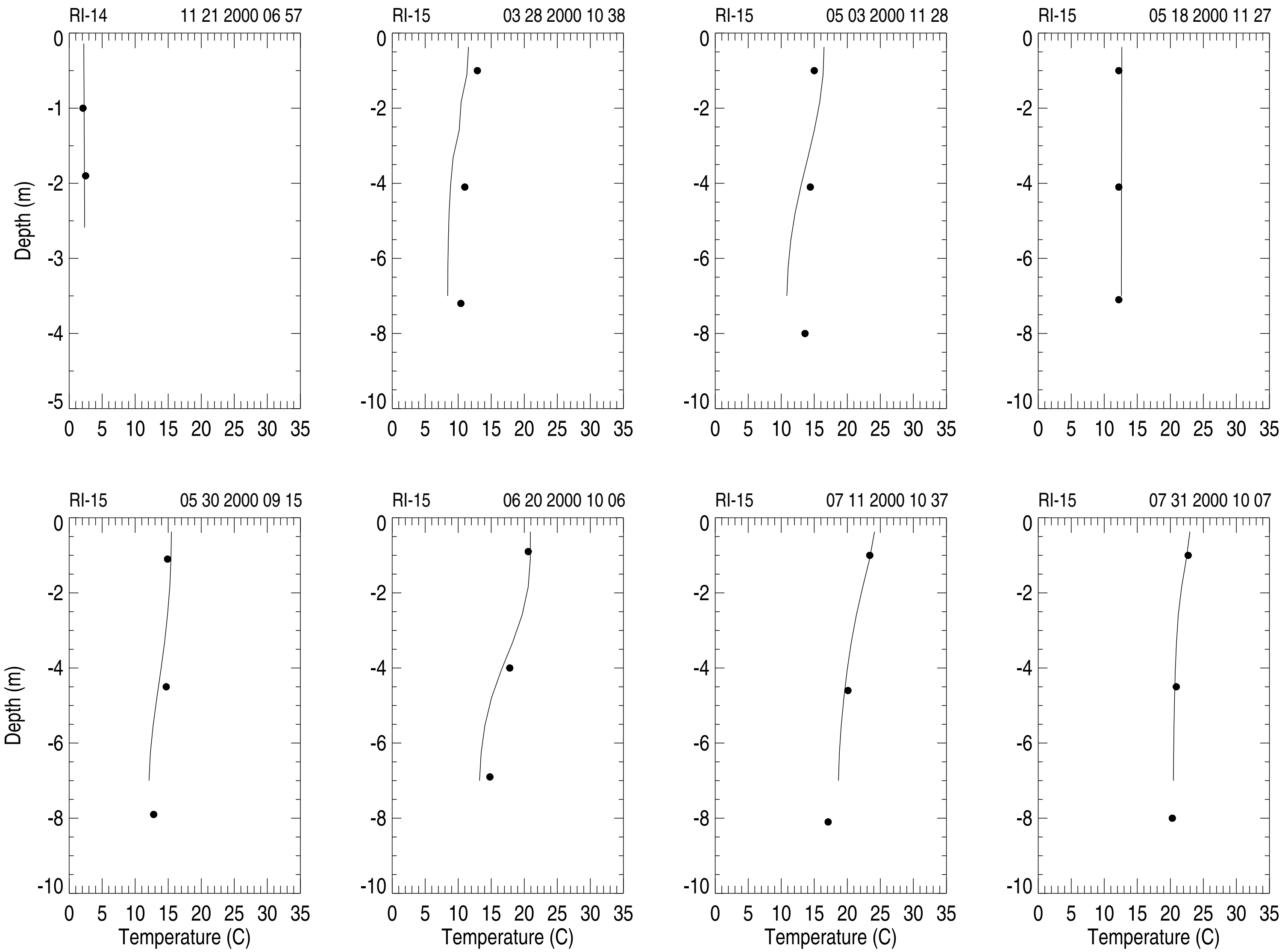

RI-11
03 28 2000 11 22
05 03 2000 09 50
05 18 2000 10 25
05 30 2000 10 35
06 20 2000 11 15
07 11 2000 11 20
07 31 2000 10 41
08 17 2000 10 33
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)



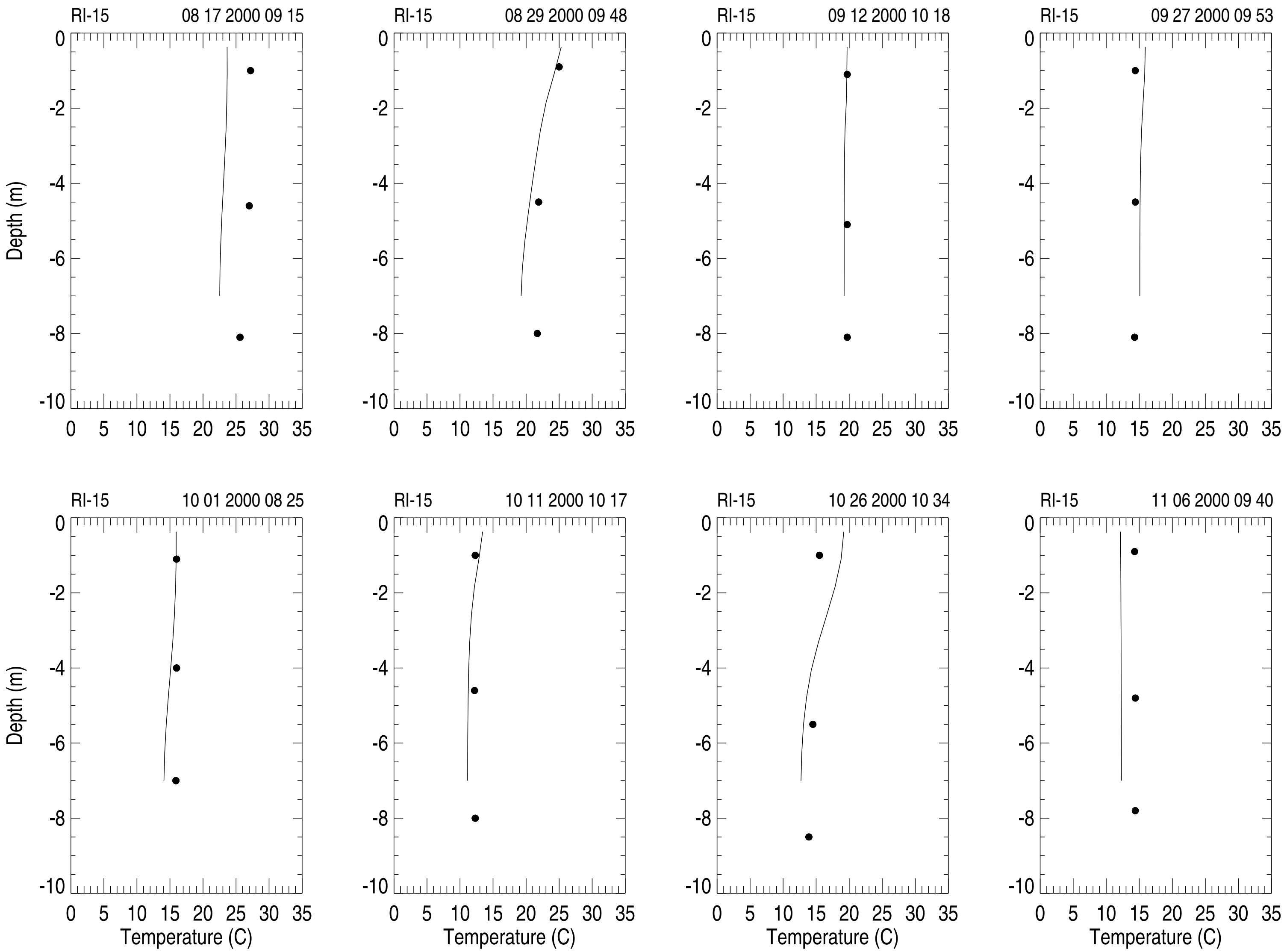
RI-11
08 29 2000 10 56
09 12 2000 11 55
09 27 2000 10 37
10 01 2000 09 13
10 11 2000 11 09
10 26 2000 11 14
11 06 2000 10 13
11 21 2000 11 41
Depth (m)
Temperature (C)

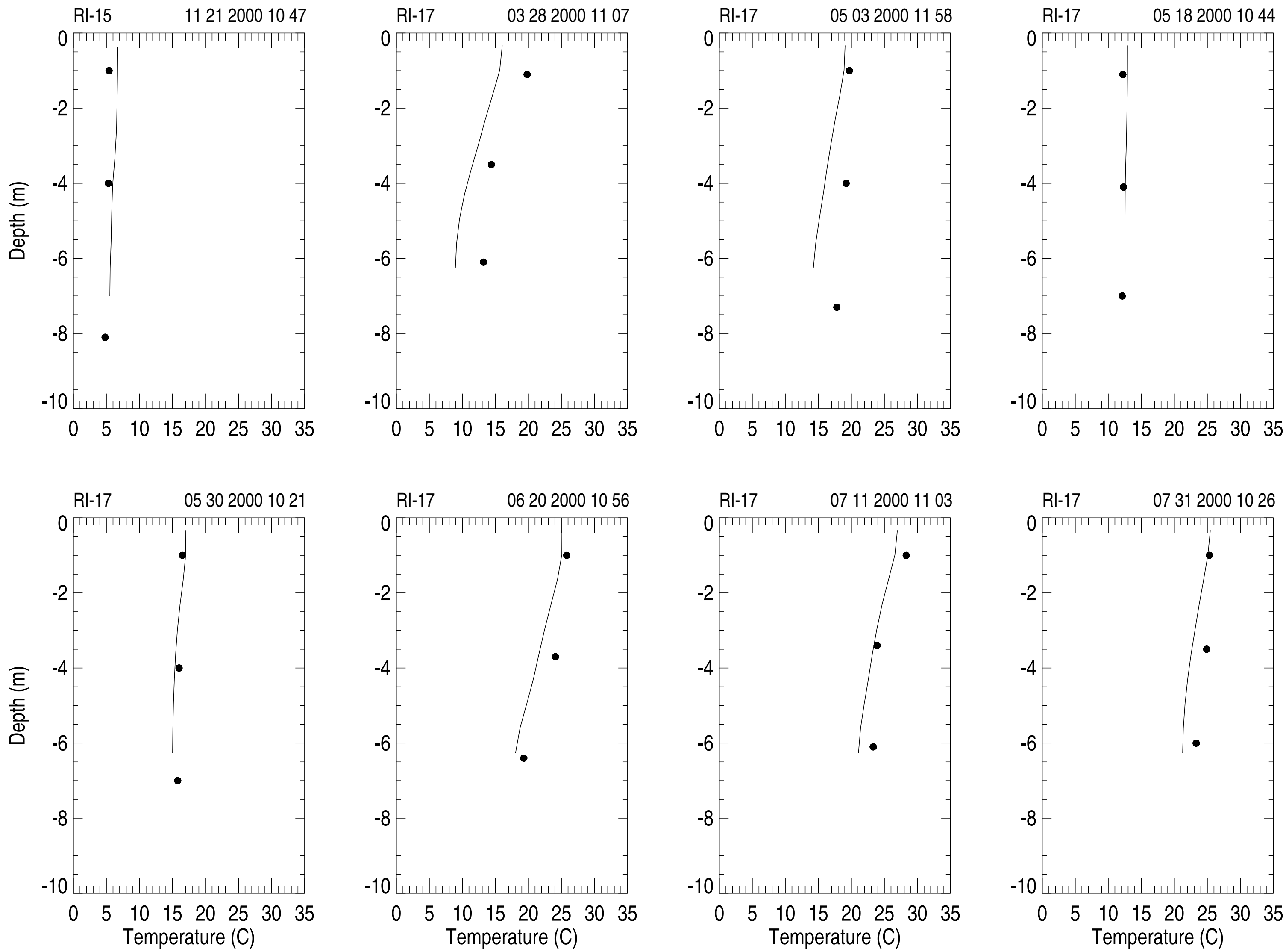

RI-14
03 28 2000 12 25
05 03 2000 10 59
05 18 2000 07 12
05 30 2000 07 12
06 20 2000 07 16
07 11 2000 07 20
07 31 2000 07 04
08 17 2000 07 08
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35

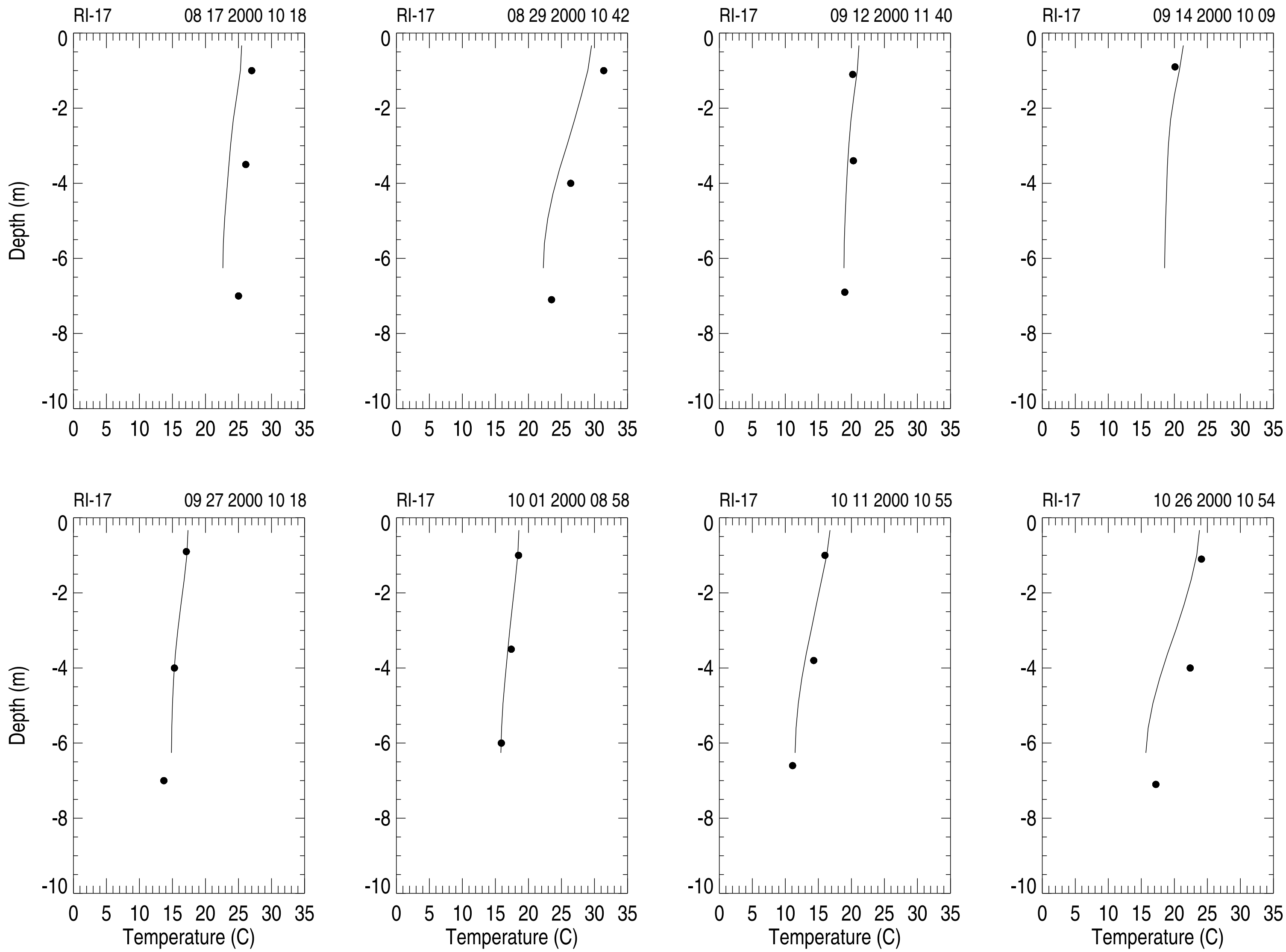

RI-14
08 29 2000 07 13
RI-14
09 12 2000 07 17
RI-14
09 14 2000 14 31
RI-14
09 27 2000 07 08
RI-14
10 01 2000 06 40
RI-14
10 11 2000 07 07
RI-14
10 26 2000 07 02
RI-14
11 06 2000 07 16
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35



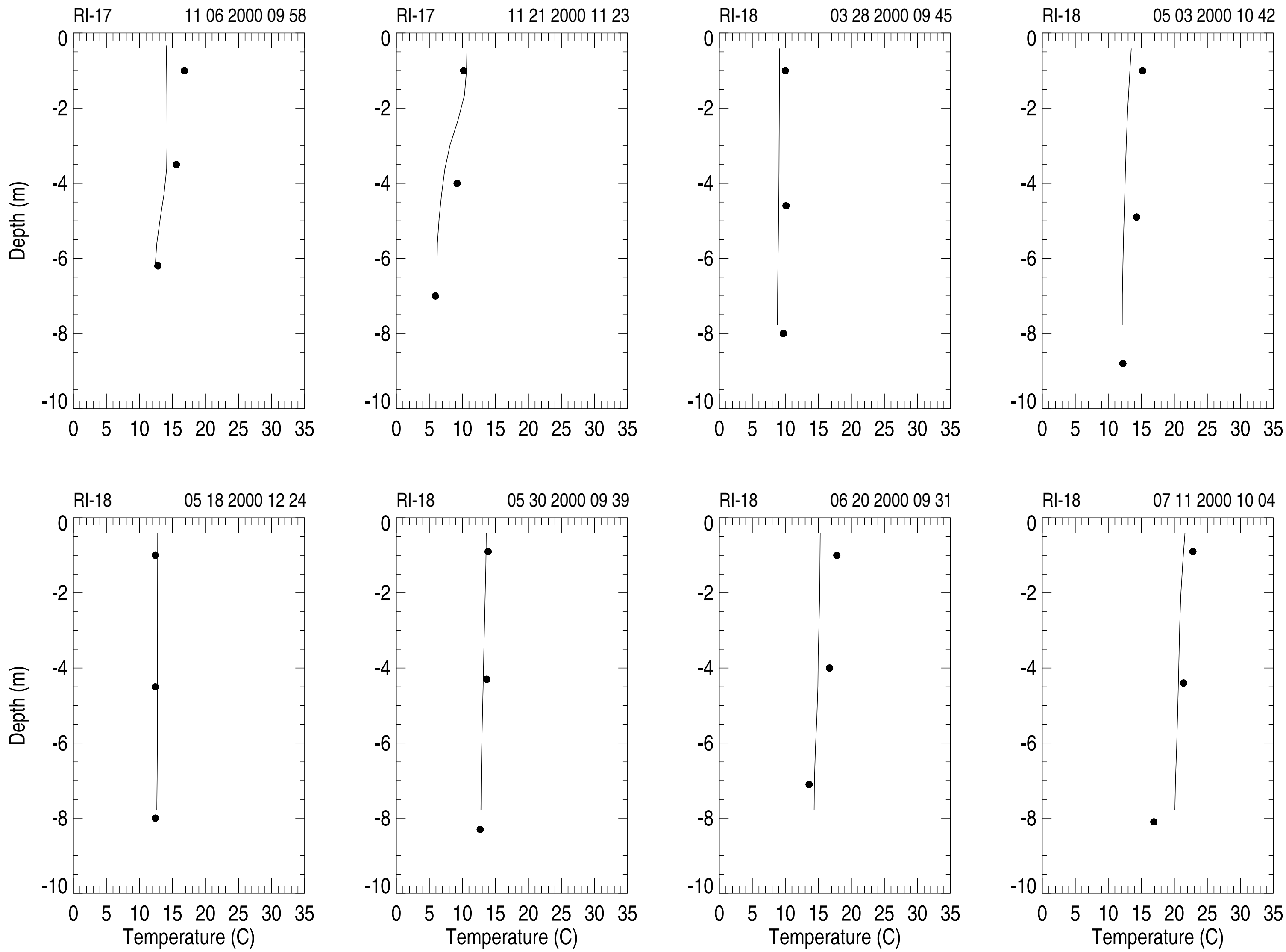
RI-14
11 21 2000 06 57
RI-15
03 28 2000 10 38
RI-15
05 03 2000 11 28
RI-15
05 18 2000 11 27
RI-15
05 30 2000 09 15
RI-15
06 20 2000 10 06
RI-15
07 11 2000 10 37
RI-15
07 31 2000 10 07
Depth (m)
Temperature (C)

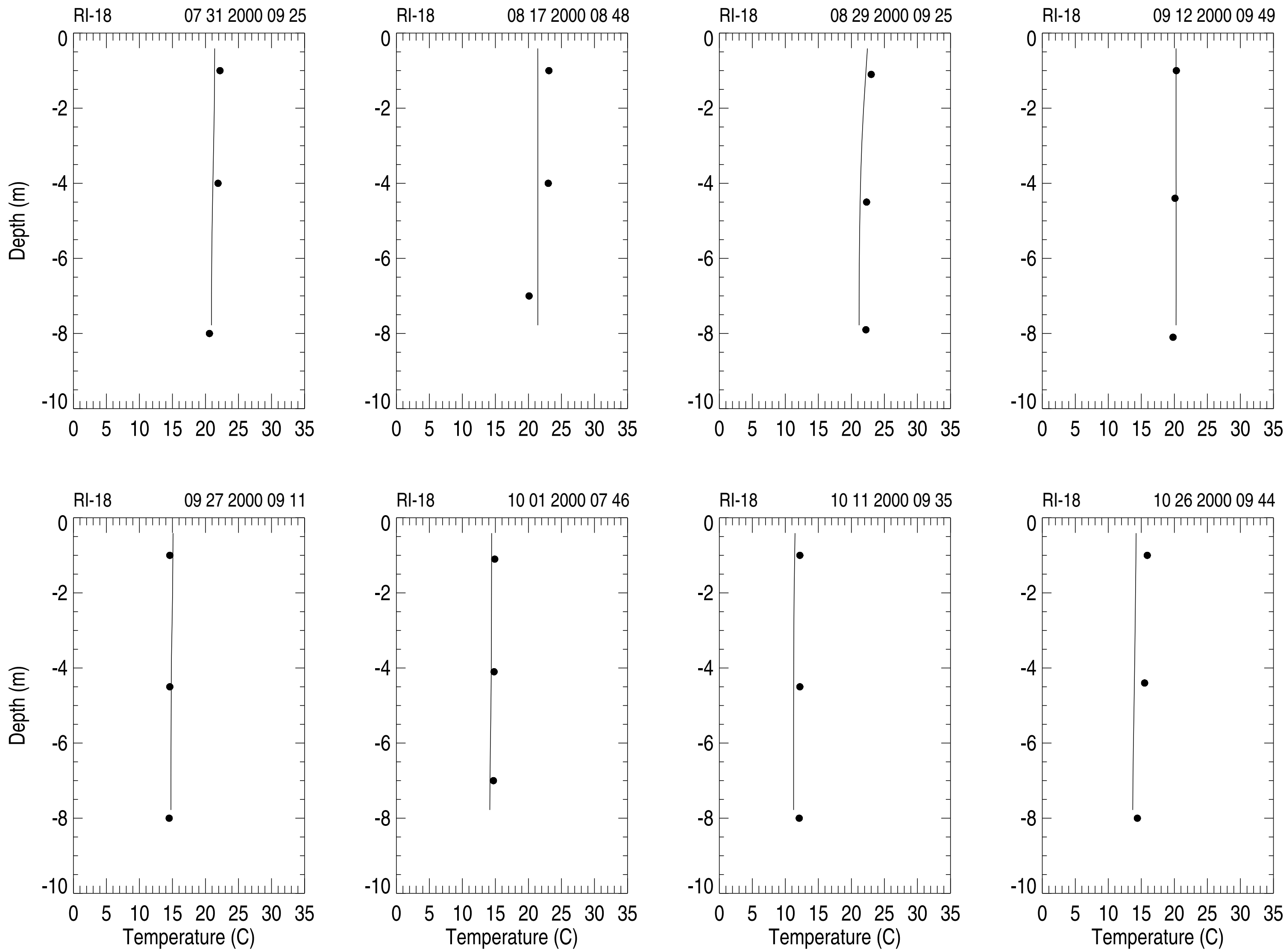

RI-15
08 17 2000 09 15
RI-15
08 29 2000 09 48
RI-15
09 12 2000 10 18
RI-15
09 27 2000 09 53
RI-15
10 01 2000 08 25
RI-15
10 11 2000 10 17
RI-15
10 26 2000 10 34
RI-15
11 06 2000 09 40
Depth (m)
0
-2
-4
-6
-8
-10
Temperature (C)
0 5 10 15 20 25 30 35

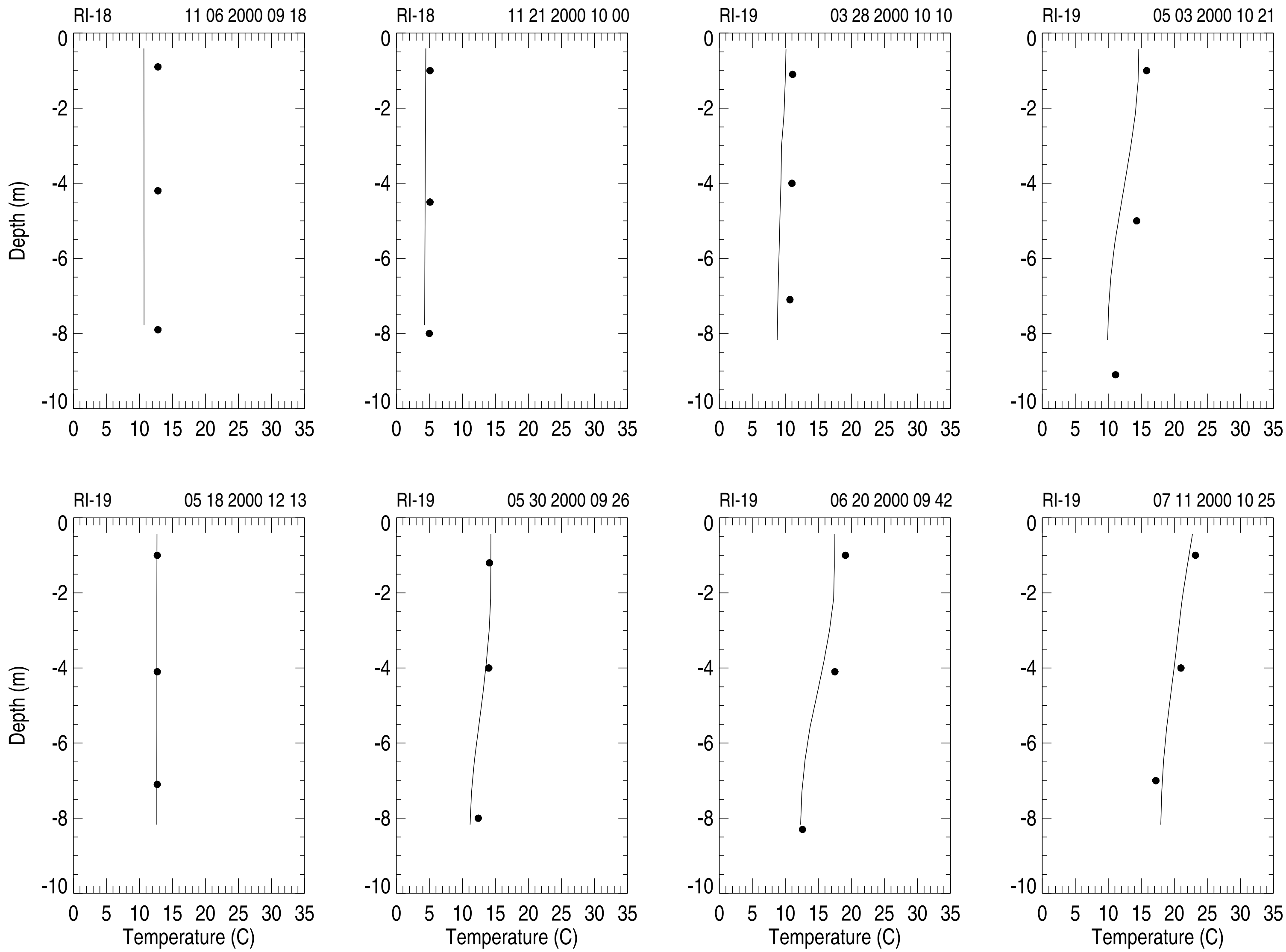

RI-15
11 21 2000 10 47
RI-17
03 28 2000 11 07
RI-17
05 03 2000 11 58
RI-17
05 18 2000 10 44
RI-17
05 30 2000 10 21
RI-17
06 20 2000 10 56
RI-17
07 11 2000 11 03
RI-17
07 31 2000 10 26
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

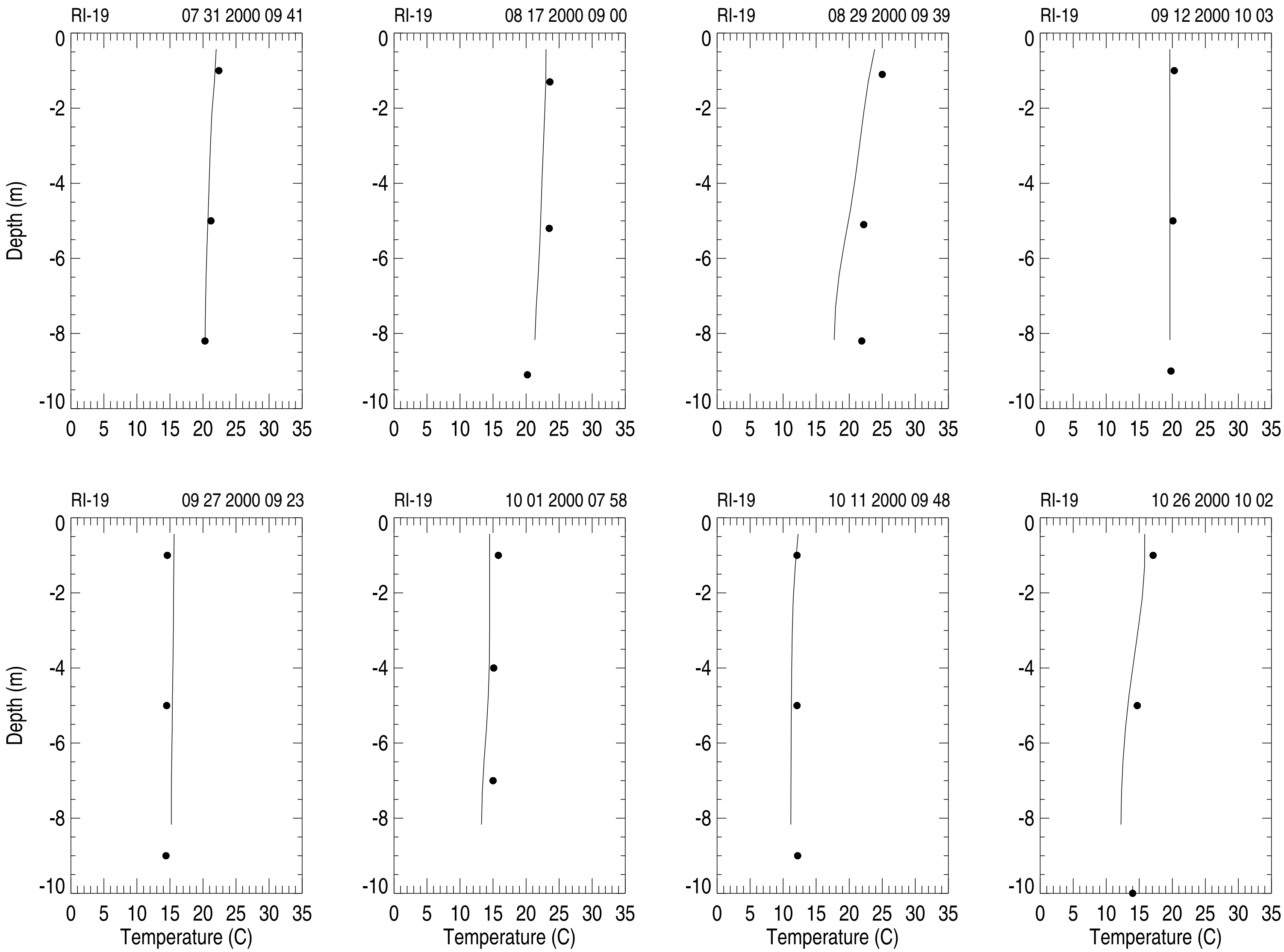


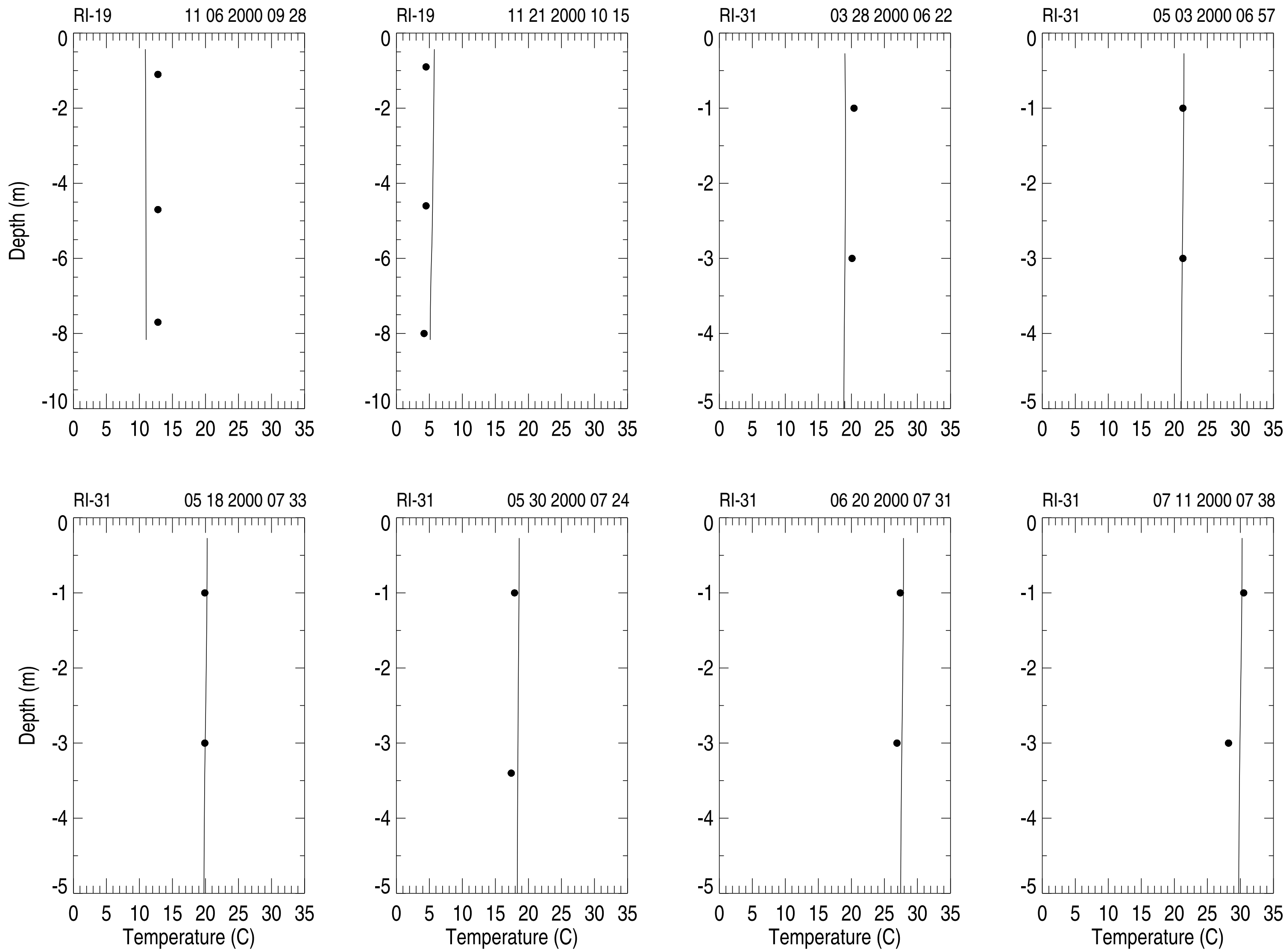
RI-17
08 17 2000 10 18
RI-17
08 29 2000 10 42
RI-17
09 12 2000 11 40
RI-17
09 14 2000 10 09
RI-17
09 27 2000 10 18
RI-17
10 01 2000 08 58
RI-17
10 11 2000 10 55
RI-17
10 26 2000 10 54
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

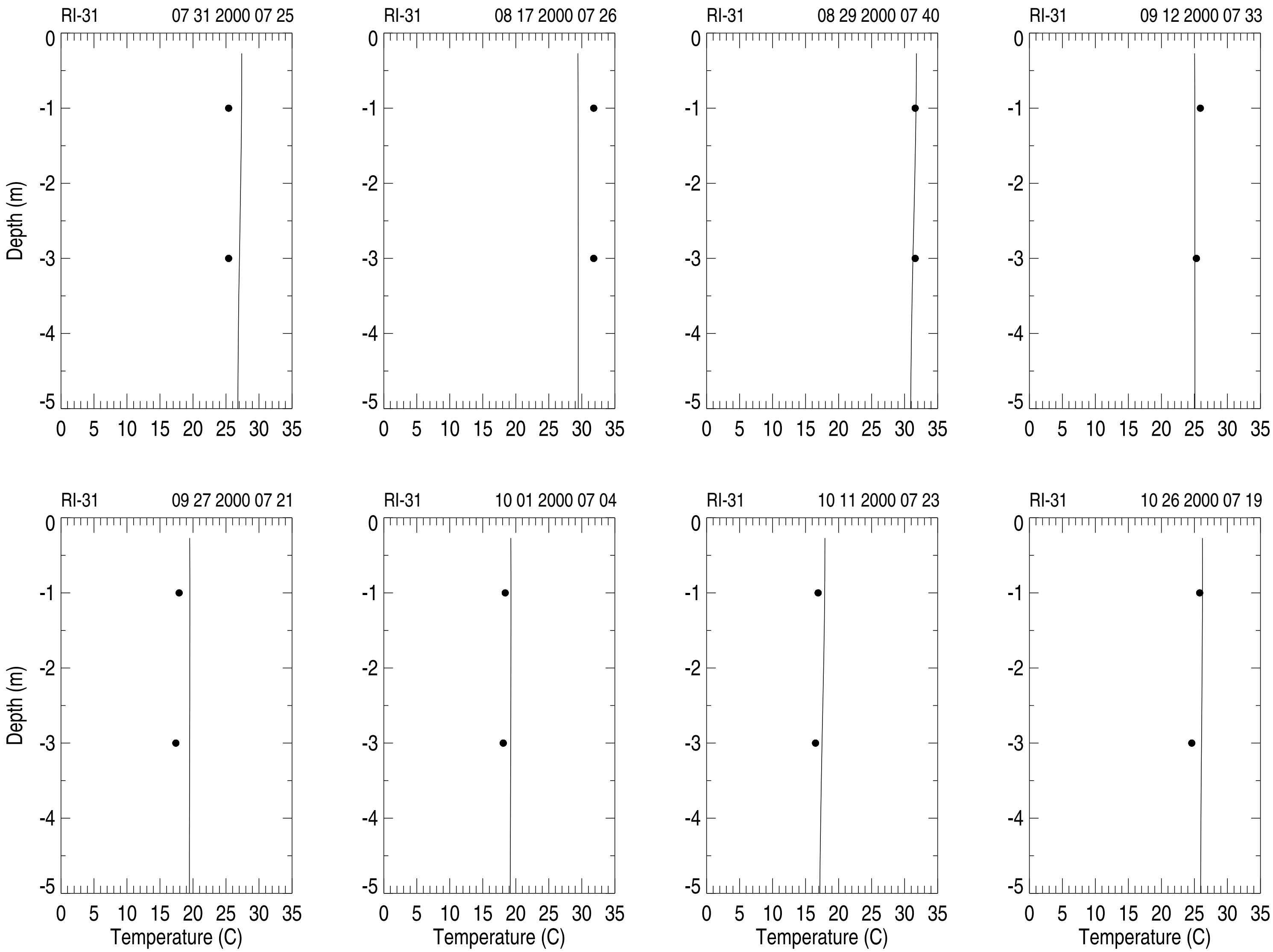

RI-17 11 06 2000 09 58
RI-17 11 21 2000 11 23
RI-18 03 28 2000 09 45
RI-18 05 03 2000 10 42
RI-18 05 18 2000 12 24
RI-18 05 30 2000 09 39
RI-18 06 20 2000 09 31
RI-18 07 11 2000 10 04
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35


RI-18
07 31 2000 09 25
RI-18
08 17 2000 08 48
RI-18
08 29 2000 09 25
RI-18
09 12 2000 09 49
RI-18
09 27 2000 09 11
RI-18
10 01 2000 07 46
RI-18
10 11 2000 09 35
RI-18
10 26 2000 09 44
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

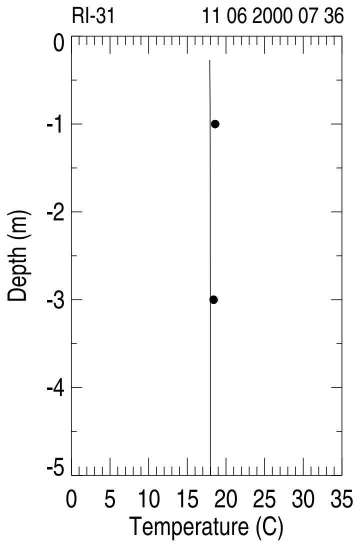

RI-18 11 06 2000 09 18
RI-18 11 21 2000 10 00
RI-19 03 28 2000 10 10
RI-19 05 03 2000 10 21
RI-19 05 18 2000 12 13
RI-19 05 30 2000 09 26
RI-19 06 20 2000 09 42
RI-19 07 11 2000 10 25
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)


RI-19
07 31 2000 09 41
RI-19
08 17 2000 09 00
RI-19
08 29 2000 09 39
RI-19
09 12 2000 10 03
RI-19
09 27 2000 09 23
RI-19
10 01 2000 07 58
RI-19
10 11 2000 09 48
RI-19
10 26 2000 10 02
Depth (m)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
30
35
Temperature (C)

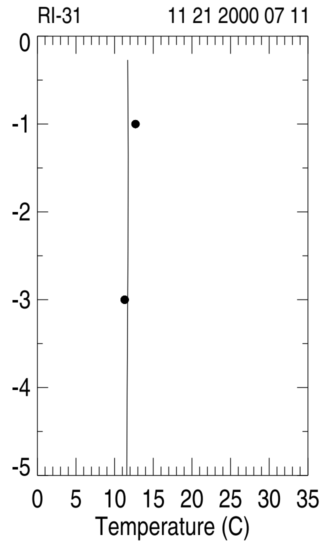

RI-19 11 06 2000 09 28
RI-19 11 21 2000 10 15
RI-31 03 28 2000 06 22
RI-31 05 03 2000 06 57
RI-31 05 18 2000 07 33
RI-31 05 30 2000 07 24
RI-31 06 20 2000 07 31
RI-31 07 11 2000 07 38
Depth (m)
Temperature (C)



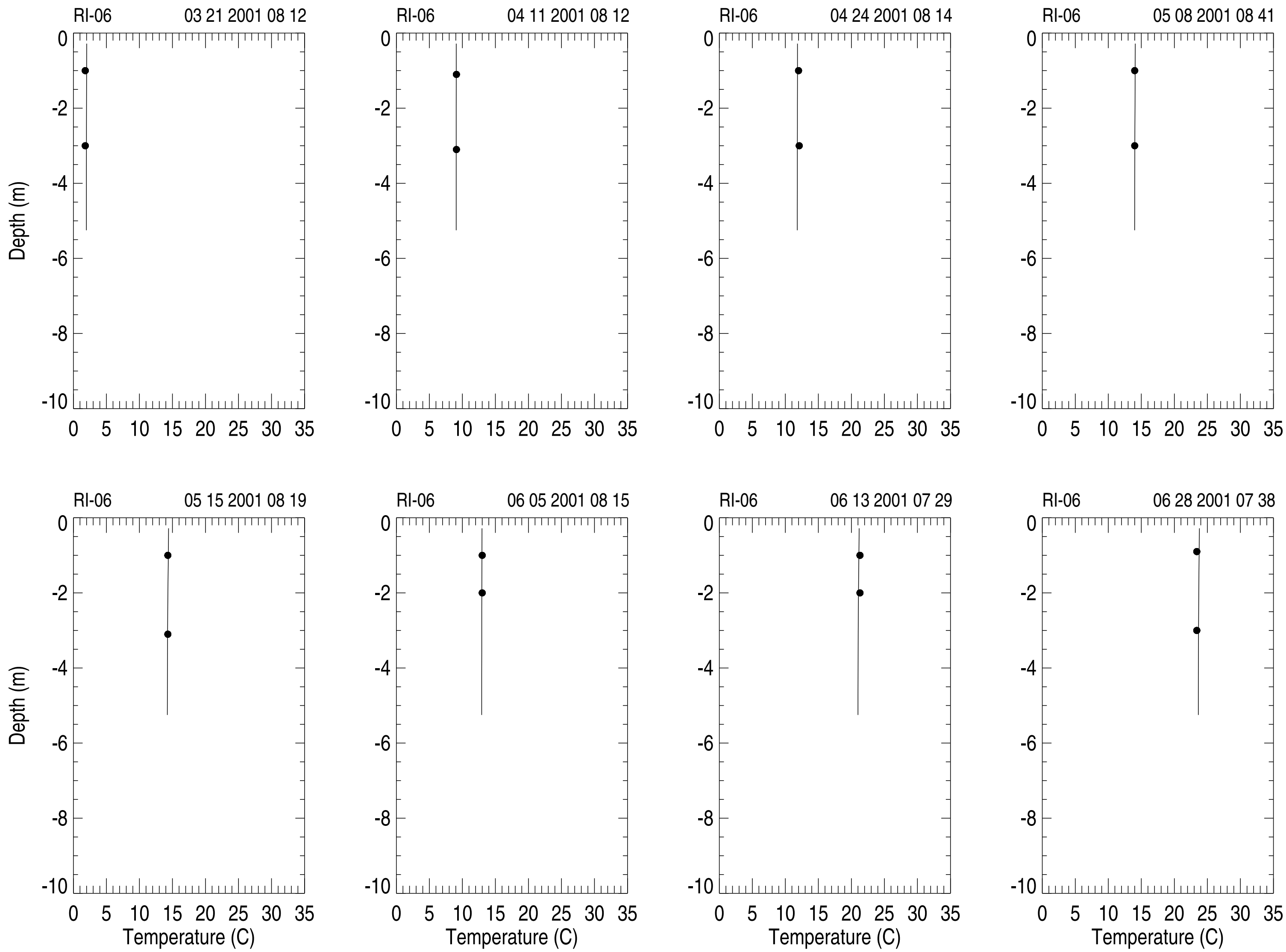
RI-31
07 31 2000 07 25
RI-31
08 17 2000 07 26
RI-31
08 29 2000 07 40
RI-31
09 12 2000 07 33
RI-31
09 27 2000 07 21
RI-31
10 01 2000 07 04
RI-31
10 11 2000 07 23
RI-31
10 26 2000 07 19
Depth (m)
0
-1
-2
-3
-4
-5
Temperature (C)
0 5 10 15 20 25 30 35



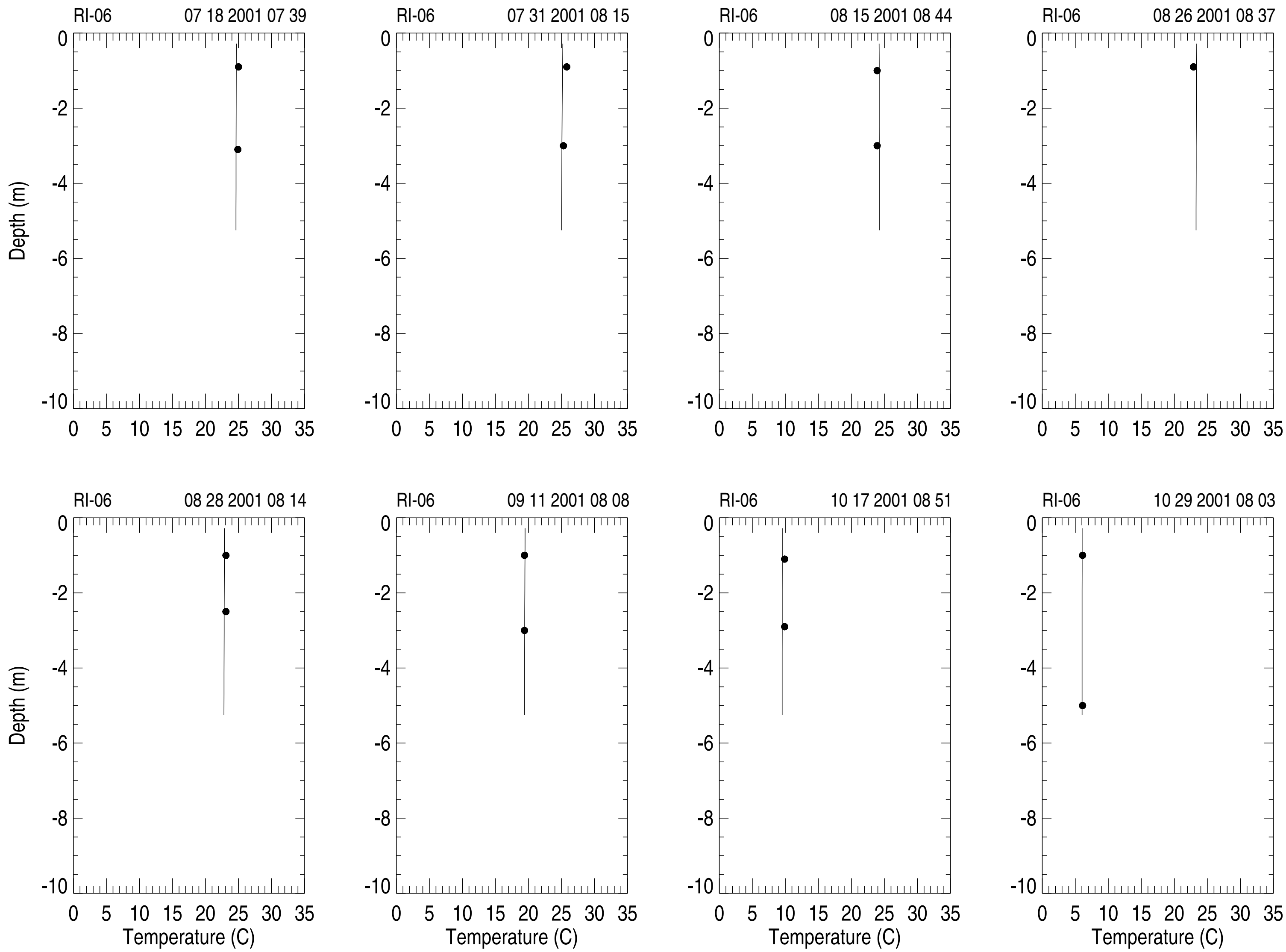
RI-31
11 06 2000 07 36
0
-1
-2
-3
-4
-5
Depth (m)
0 5 10 15 20 25 30 35
Temperature (C)

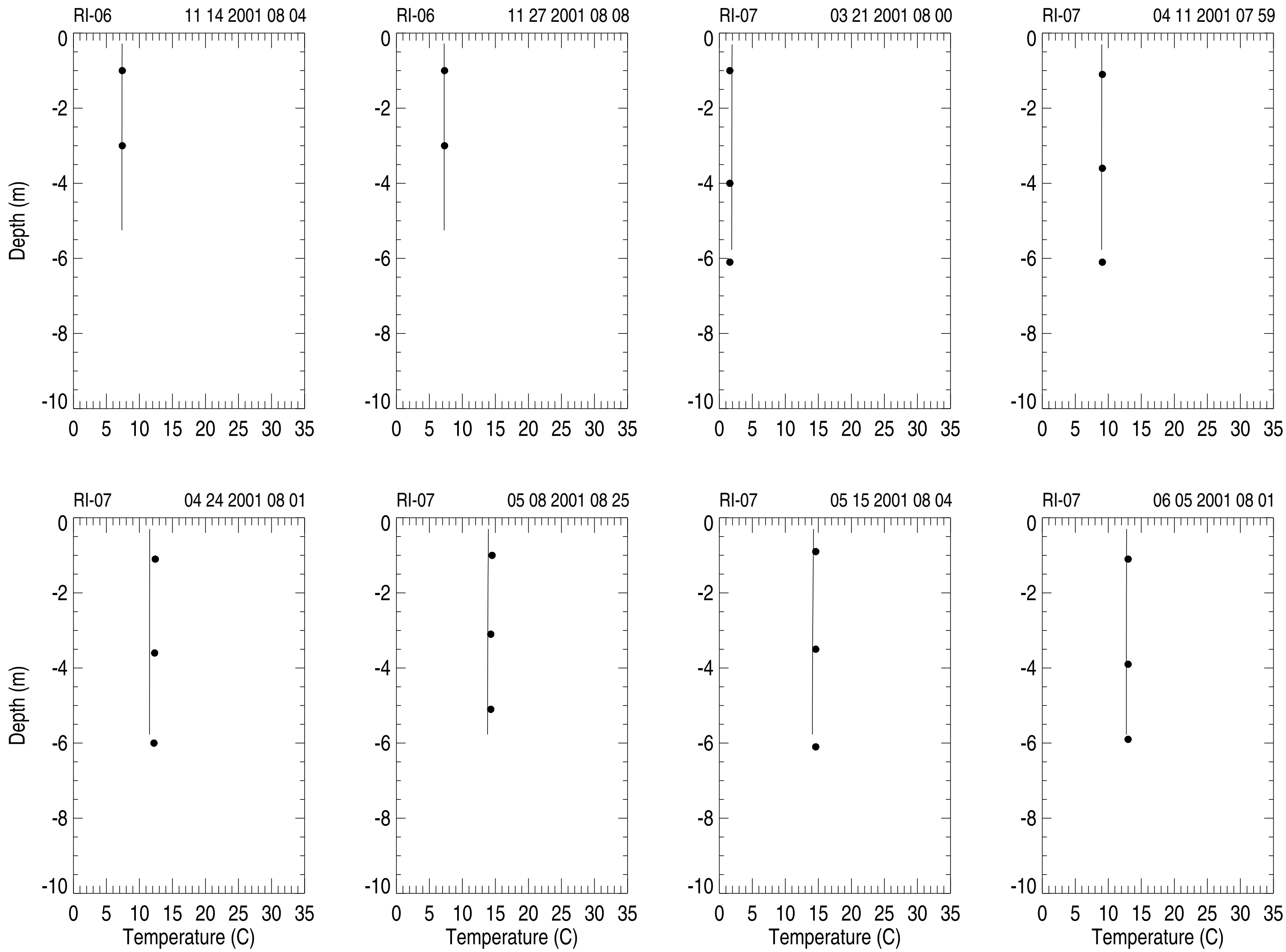


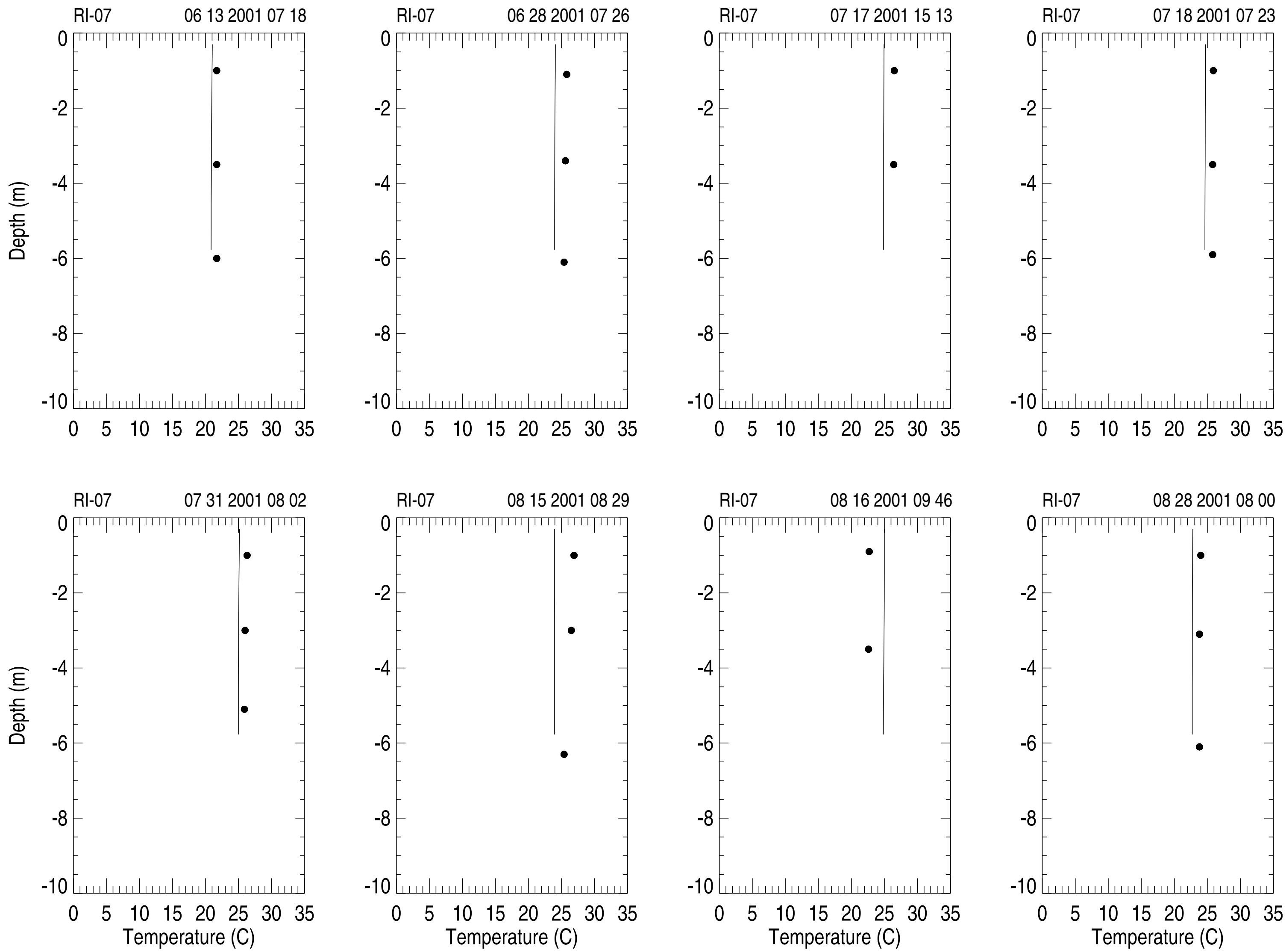
RI-31
11 21 2000 07 11
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35
Temperature (C)



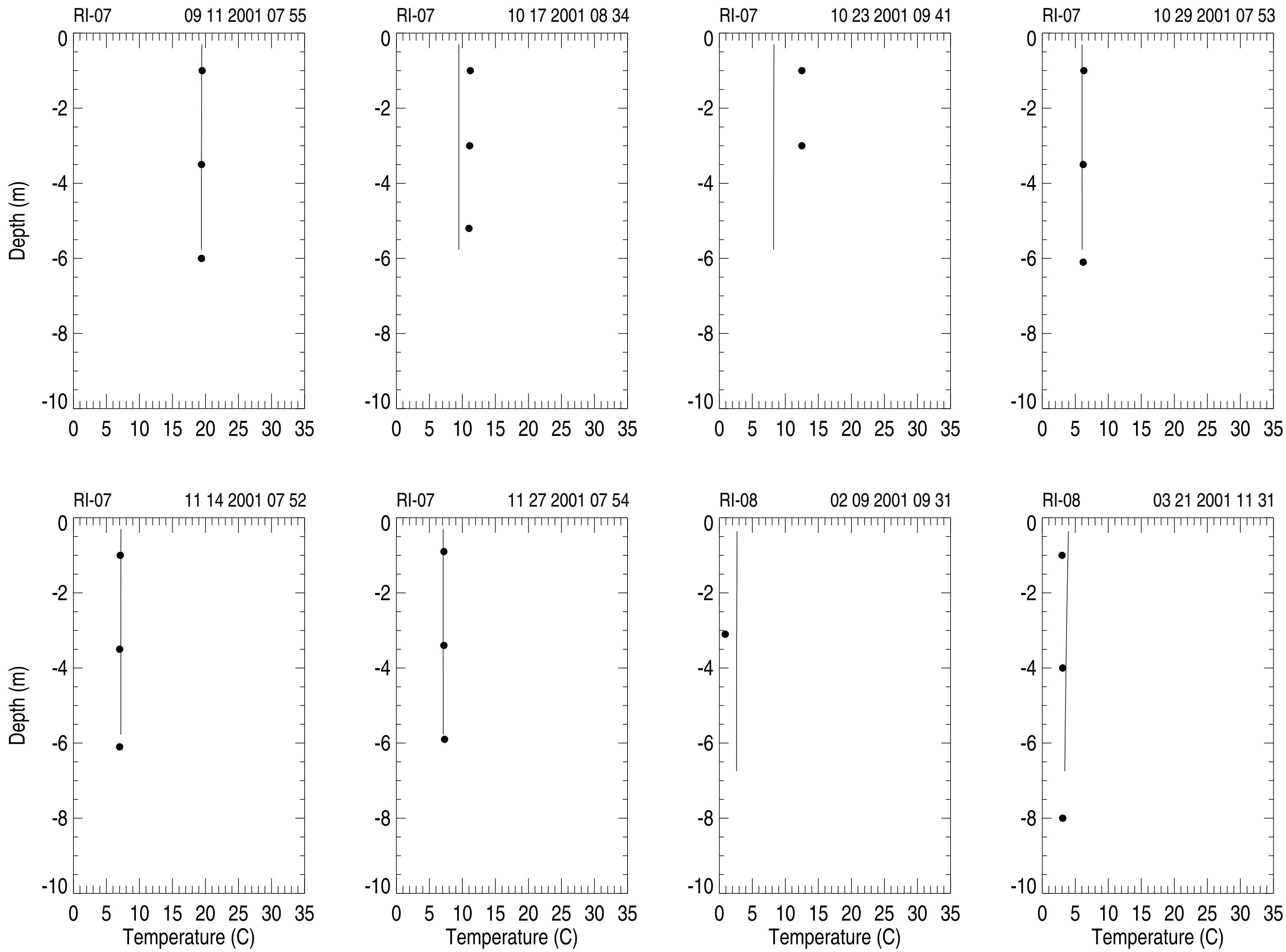
RI-06
03 21 2001 08 12
RI-06
04 11 2001 08 12
RI-06
04 24 2001 08 14
RI-06
05 08 2001 08 41
RI-06
05 15 2001 08 19
RI-06
06 05 2001 08 15
RI-06
06 13 2001 07 29
RI-06
06 28 2001 07 38
Depth (m)
Temperature (C)


RI-06
07 18 2001 07 39
RI-06
07 31 2001 08 15
RI-06
08 15 2001 08 44
RI-06
08 26 2001 08 37
RI-06
08 28 2001 08 14
RI-06
09 11 2001 08 08
RI-06
10 17 2001 08 51
RI-06
10 29 2001 08 03
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

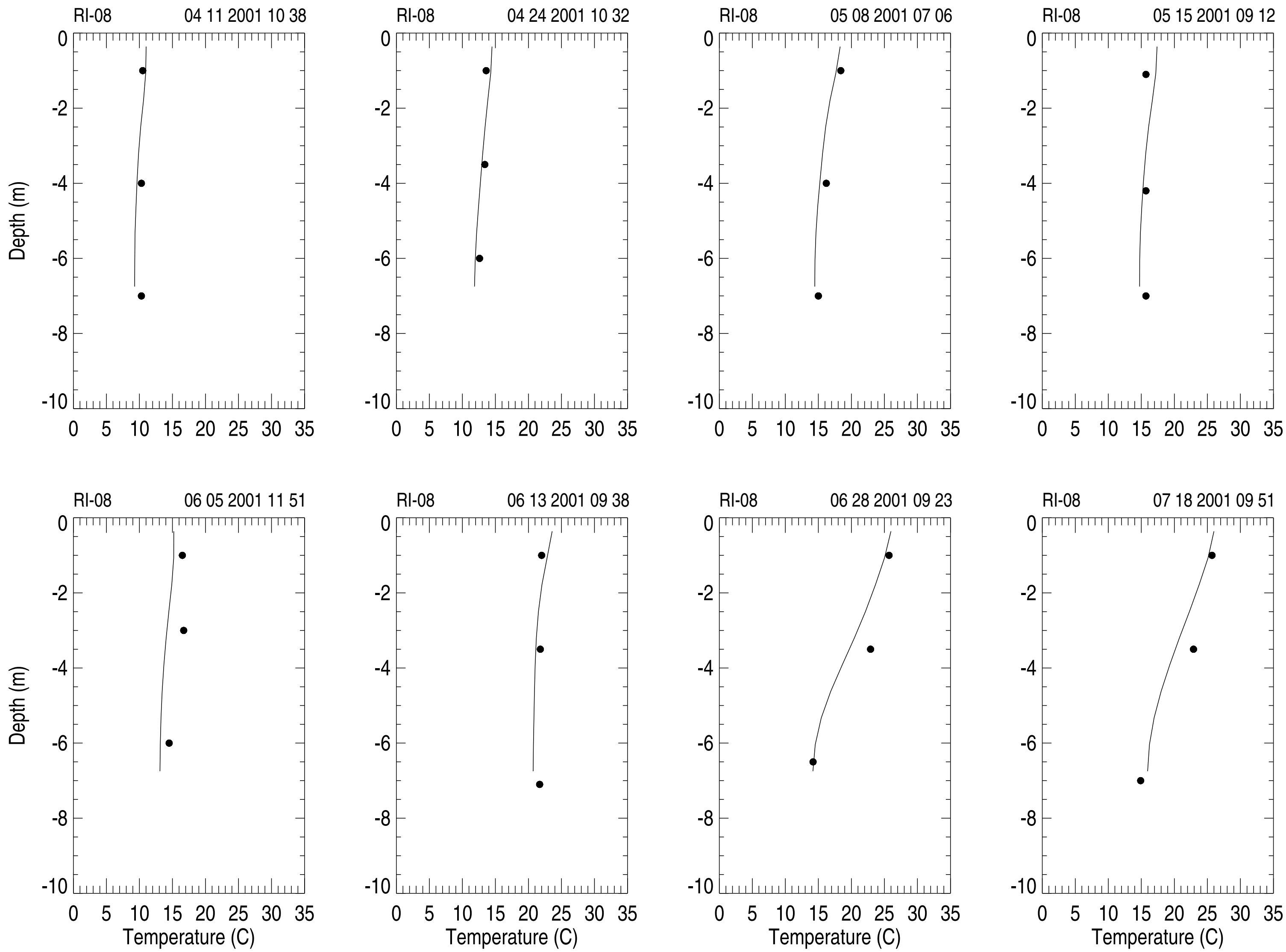

RI-06 11 14 2001 08 04
RI-06 11 27 2001 08 08
RI-07 03 21 2001 08 00
RI-07 04 11 2001 07 59
RI-07 04 24 2001 08 01
RI-07 05 08 2001 08 25
RI-07 05 15 2001 08 04
RI-07 06 05 2001 08 01
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)



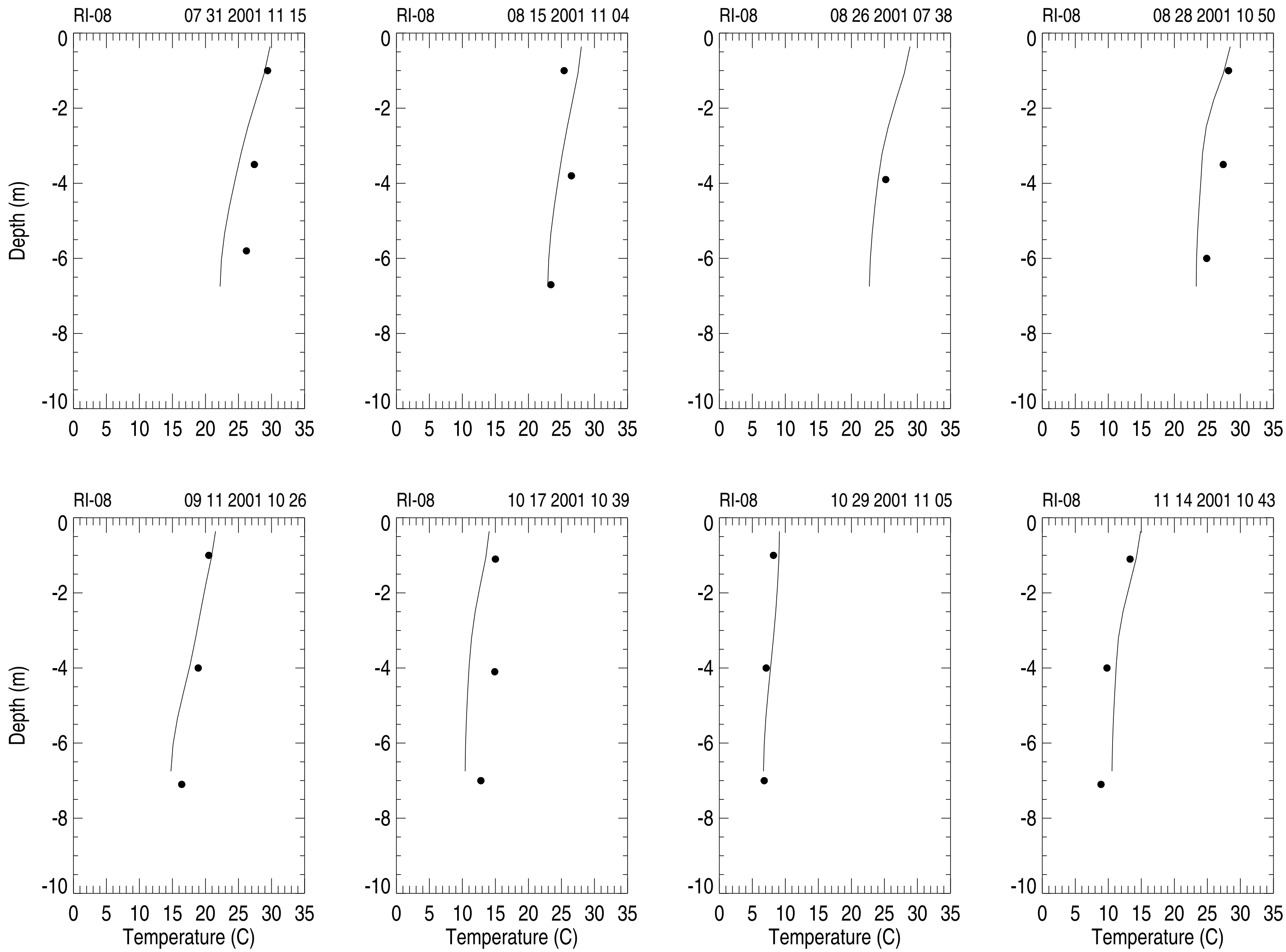
RI-07
06 13 2001 07 18
RI-07
06 28 2001 07 26
RI-07
07 17 2001 15 13
RI-07
07 18 2001 07 23
RI-07
07 31 2001 08 02
RI-07
08 15 2001 08 29
RI-07
08 16 2001 09 46
RI-07
08 28 2001 08 00
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35



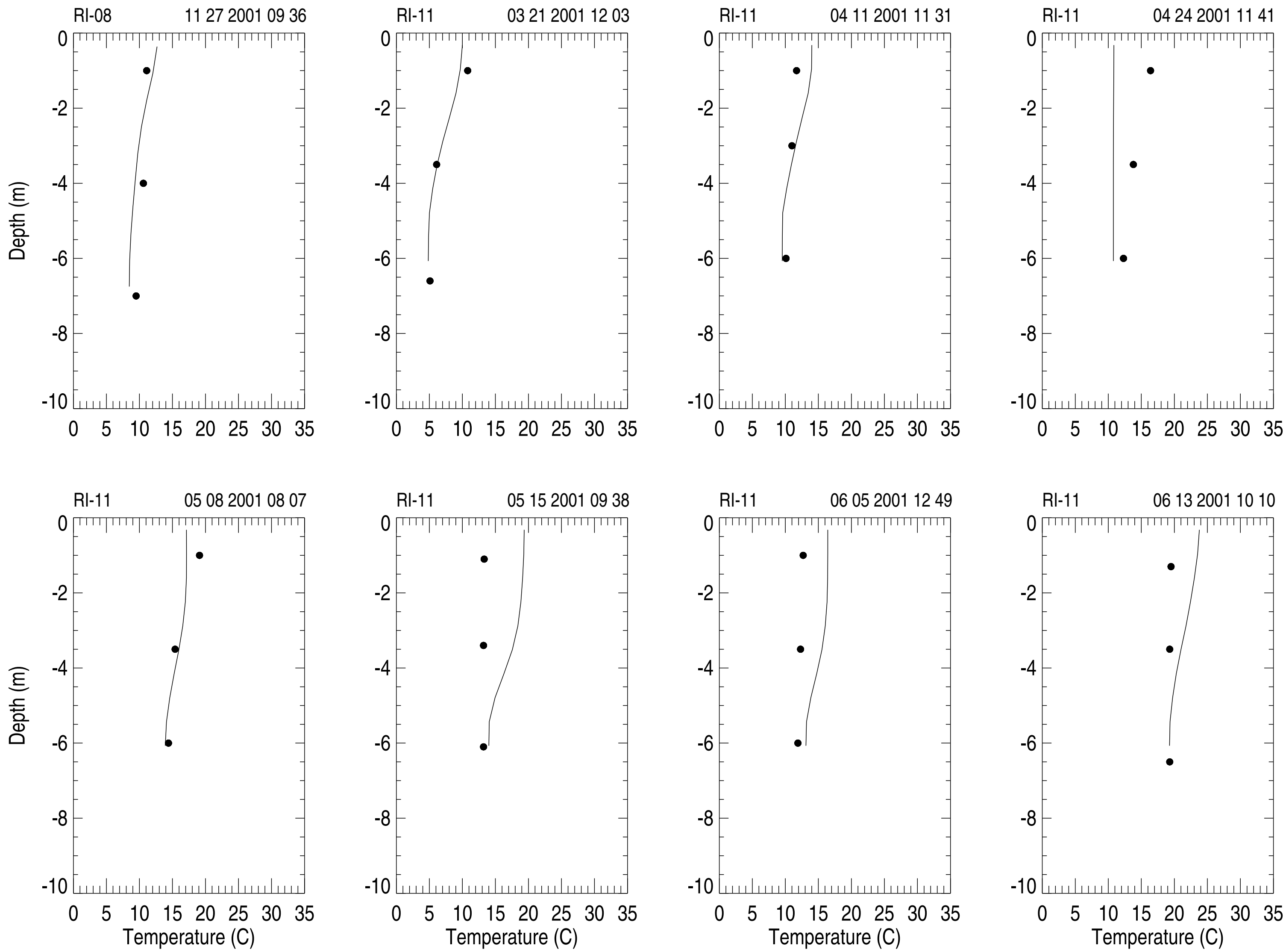
RI-07 09 11 2001 07 55
RI-07 10 17 2001 08 34
RI-07 10 23 2001 09 41
RI-07 10 29 2001 07 53
RI-07 11 14 2001 07 52
RI-07 11 27 2001 07 54
RI-08 02 09 2001 09 31
RI-08 03 21 2001 11 31
Depth (m)
Temperature (C)
0 -2 -4 -6 -8 -10
0 5 10 15 20 25 30 35

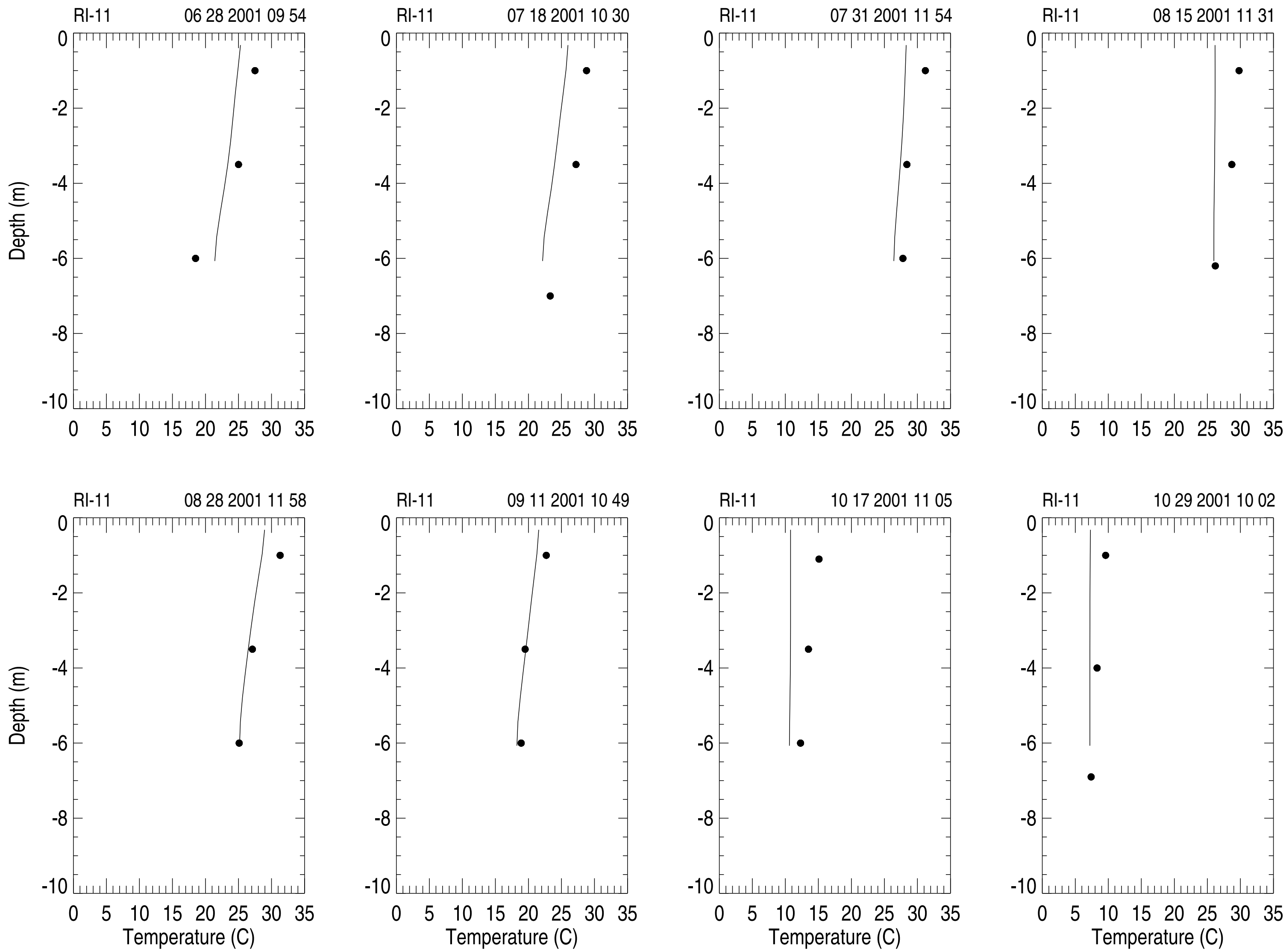


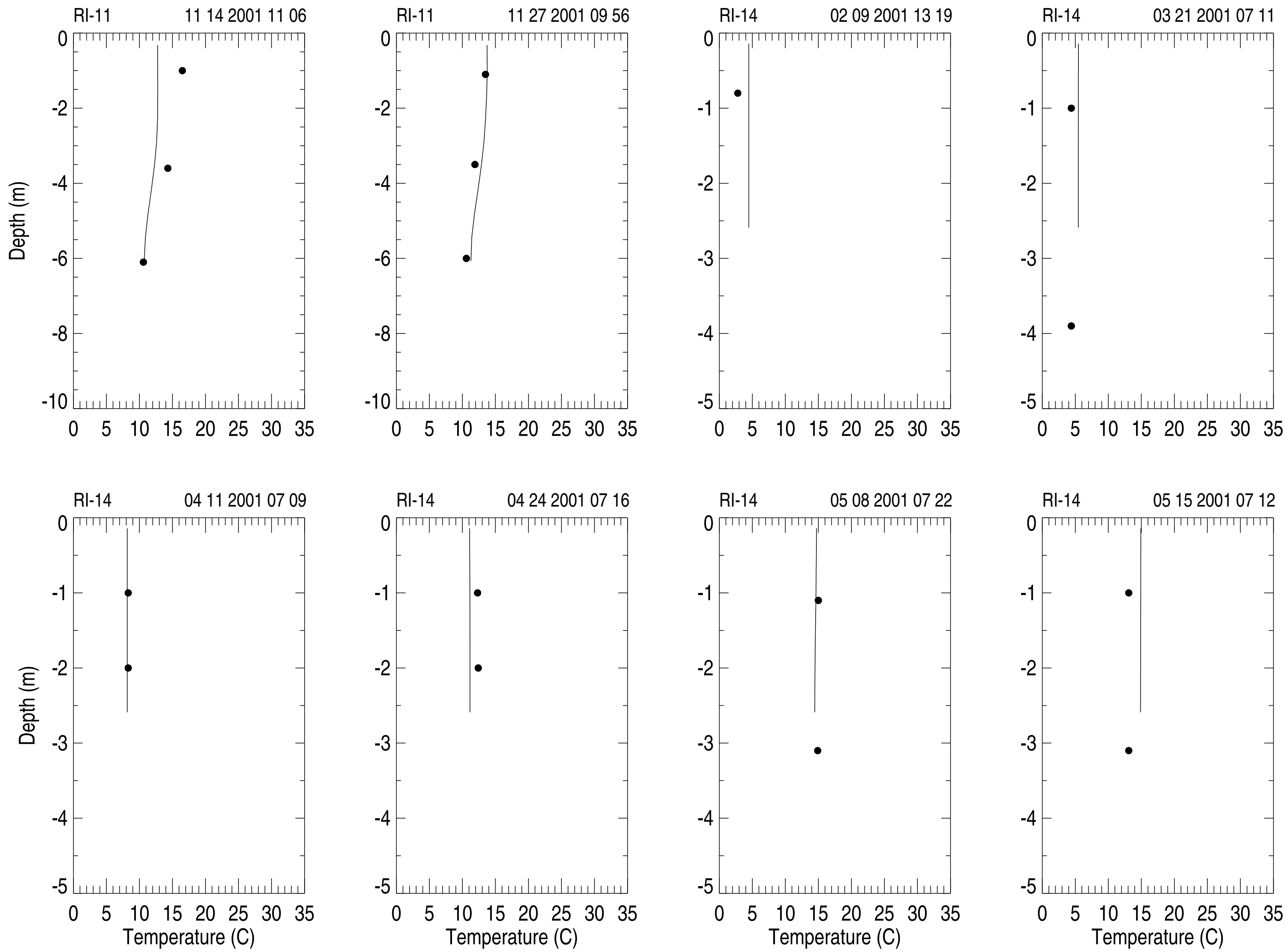
RI-08
04 11 2001 10 38
RI-08
04 24 2001 10 32
RI-08
05 08 2001 07 06
RI-08
05 15 2001 09 12
RI-08
06 05 2001 11 51
RI-08
06 13 2001 09 38
RI-08
06 28 2001 09 23
RI-08
07 18 2001 09 51
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

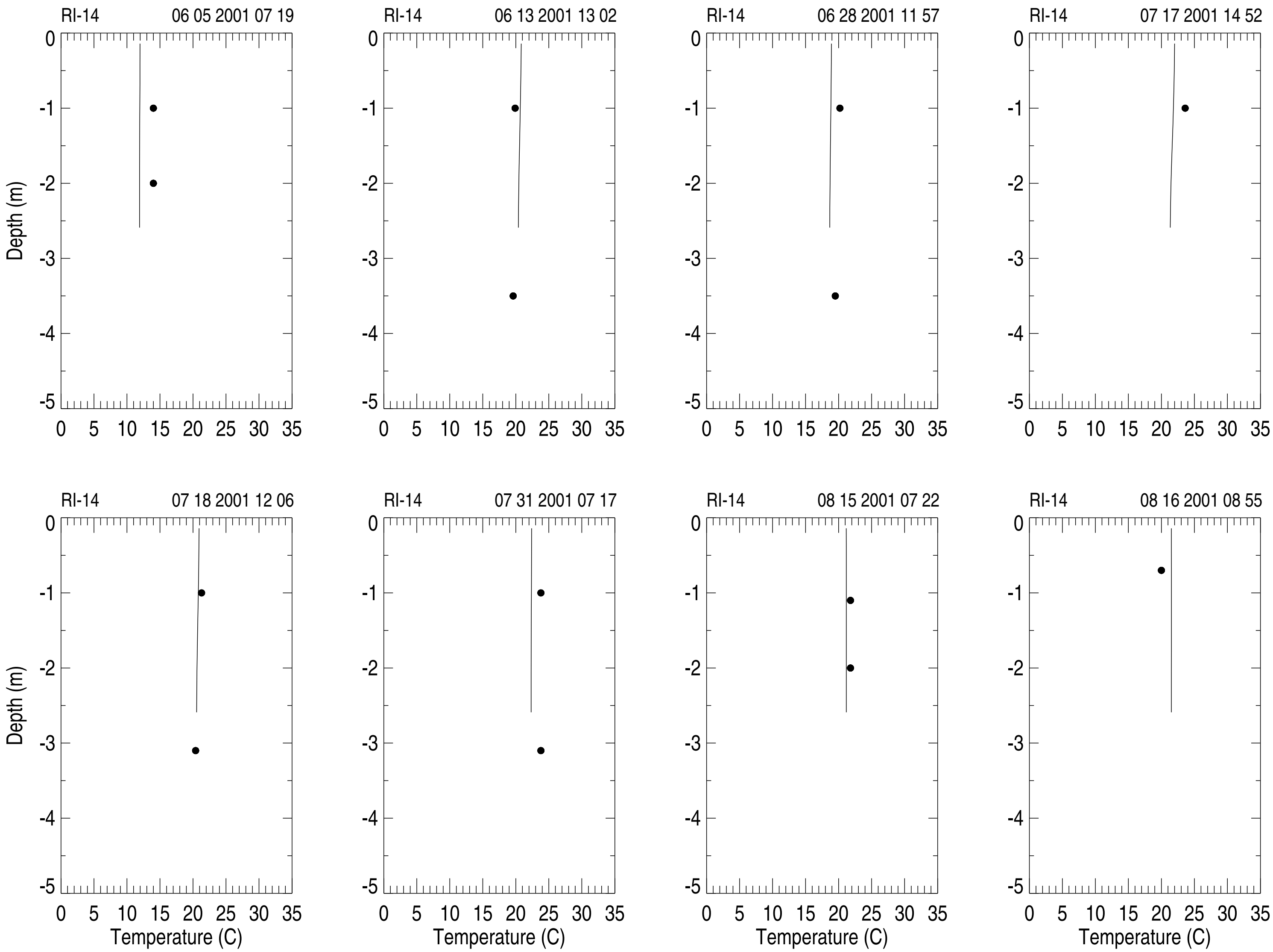


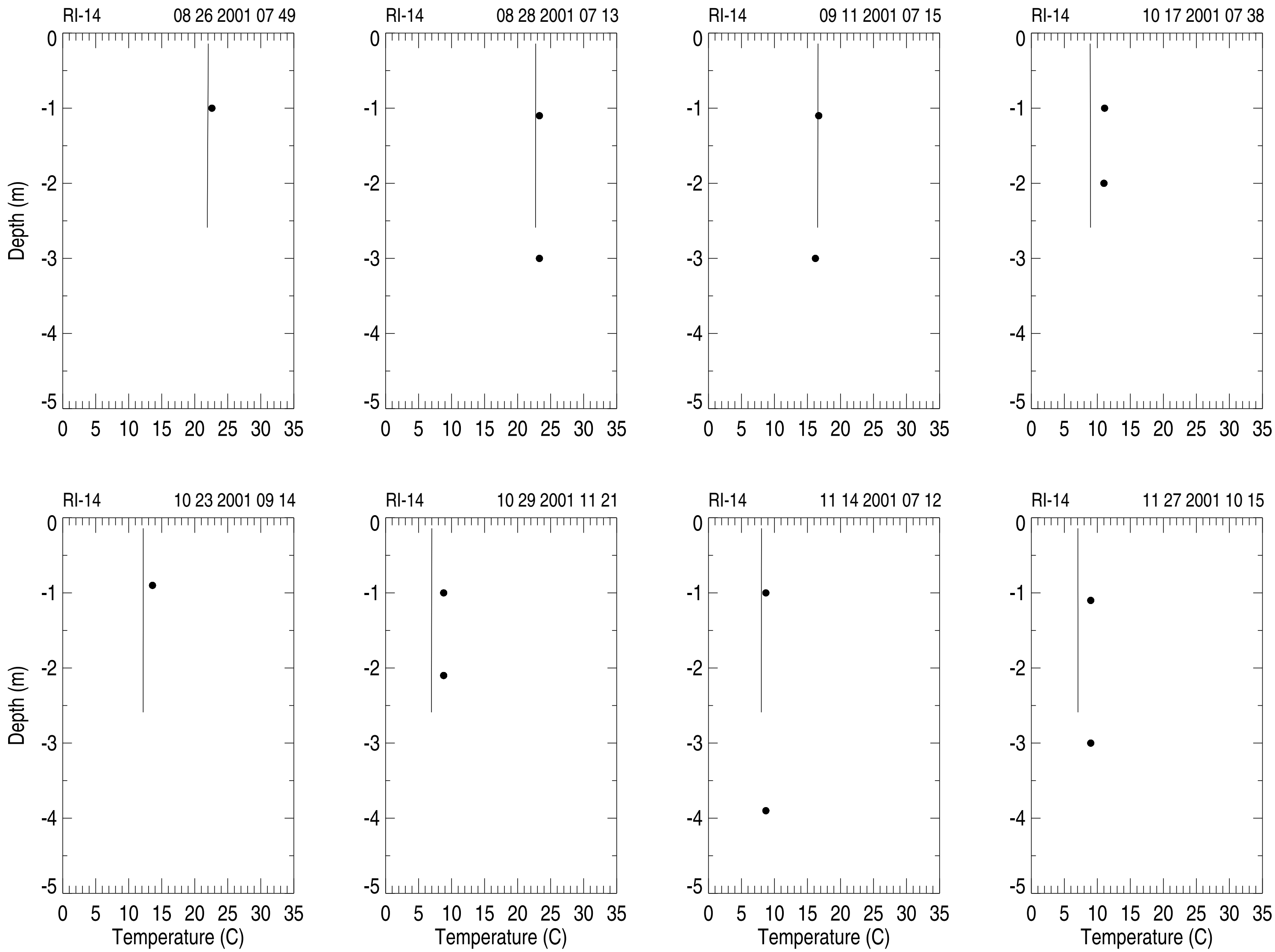
RI-08
07 31 2001 11 15
RI-08
08 15 2001 11 04
RI-08
08 26 2001 07 38
RI-08
08 28 2001 10 50
RI-08
09 11 2001 10 26
RI-08
10 17 2001 10 39
RI-08
10 29 2001 11 05
RI-08
11 14 2001 10 43
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35


RI-08
11 27 2001 09 36
RI-11
03 21 2001 12 03
RI-11
04 11 2001 11 31
RI-11
04 24 2001 11 41
RI-11
05 08 2001 08 07
RI-11
05 15 2001 09 38
RI-11
06 05 2001 12 49
RI-11
06 13 2001 10 10
Depth (m)
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
30
35
Temperature (C)

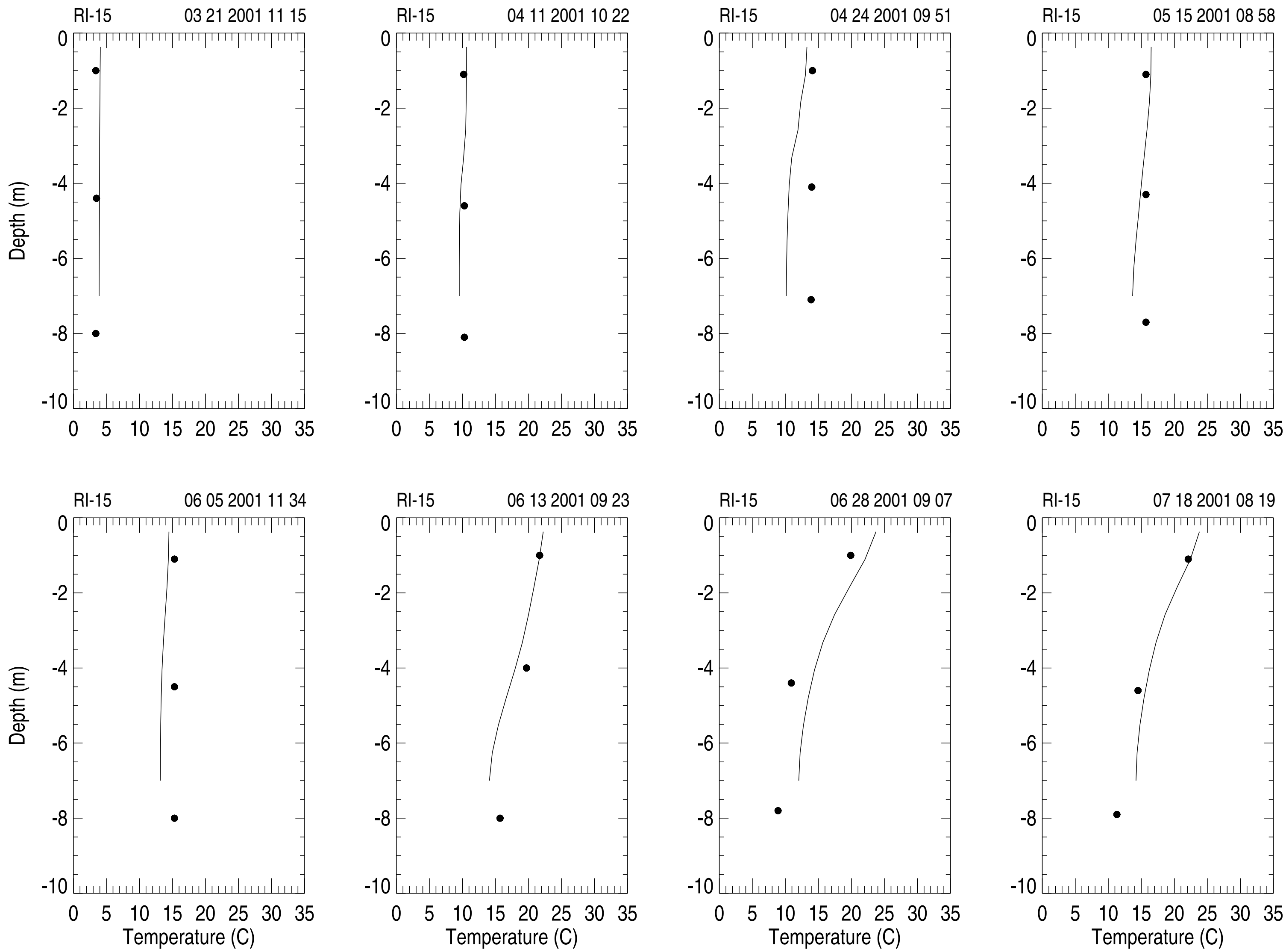

RI-11
06 28 2001 09 54
RI-11
07 18 2001 10 30
RI-11
07 31 2001 11 54
RI-11
08 15 2001 11 31
RI-11
08 28 2001 11 58
RI-11
09 11 2001 10 49
RI-11
10 17 2001 11 05
RI-11
10 29 2001 10 02
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

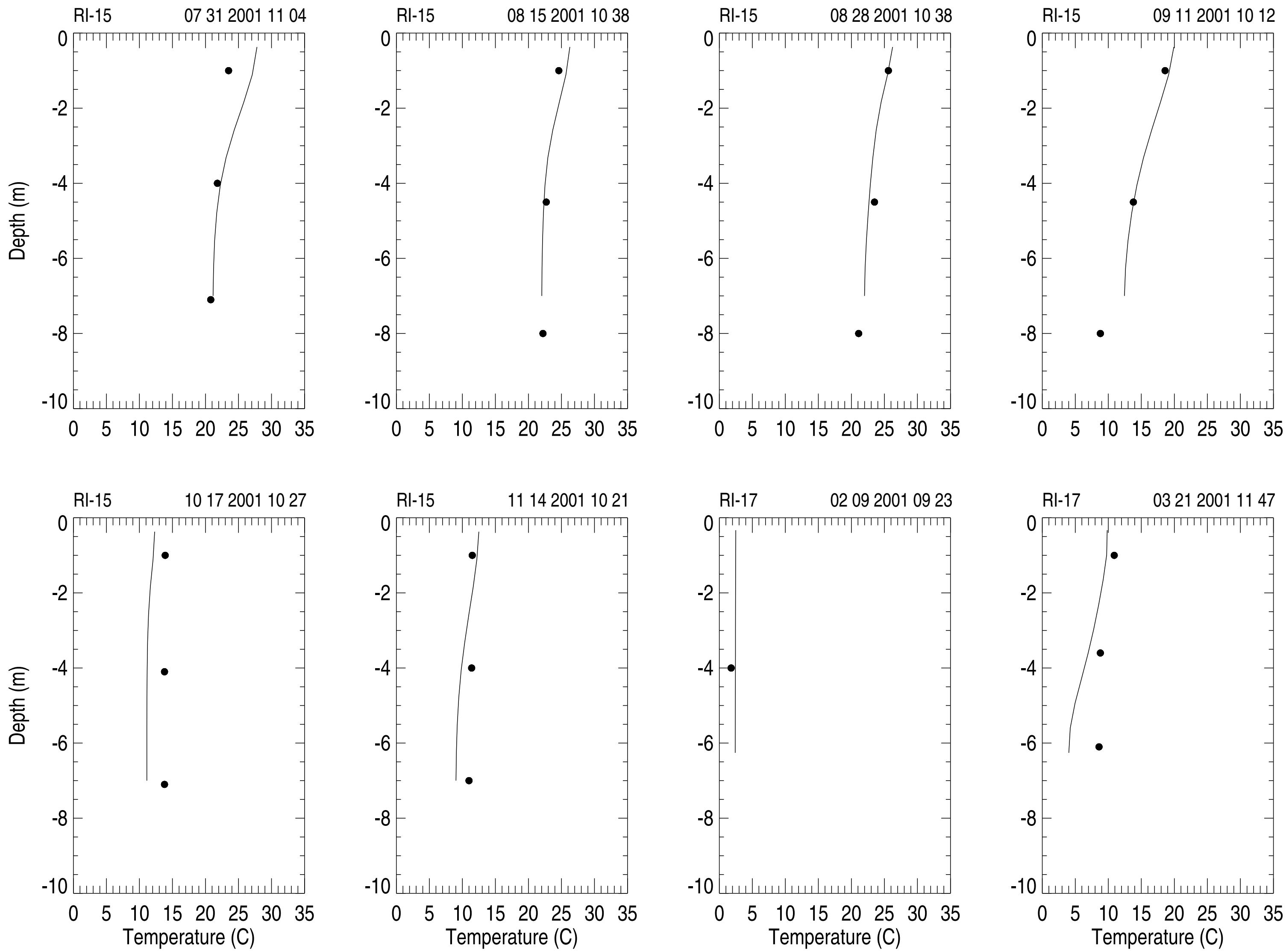

RI-11
11 14 2001 11 06
RI-11
11 27 2001 09 56
RI-14
02 09 2001 13 19
RI-14
03 21 2001 07 11
RI-14
04 11 2001 07 09
RI-14
04 24 2001 07 16
RI-14
05 08 2001 07 22
RI-14
05 15 2001 07 12
Depth (m)
Temperature (C)

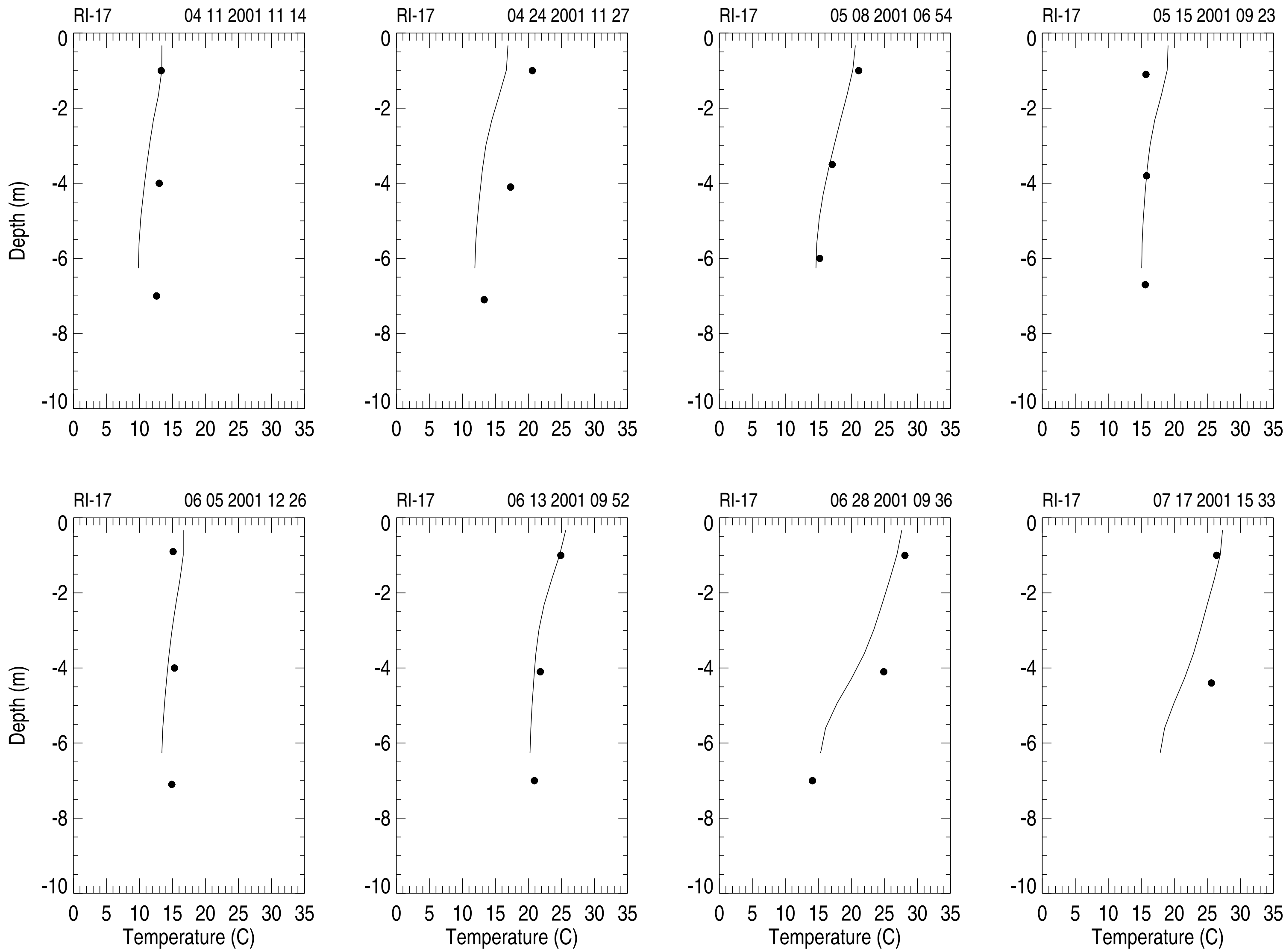

RI-14
06 05 2001 07 19
RI-14
06 13 2001 13 02
RI-14
06 28 2001 11 57
RI-14
07 17 2001 14 52
RI-14
07 18 2001 12 06
RI-14
07 31 2001 07 17
RI-14
08 15 2001 07 22
RI-14
08 16 2001 08 55
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35



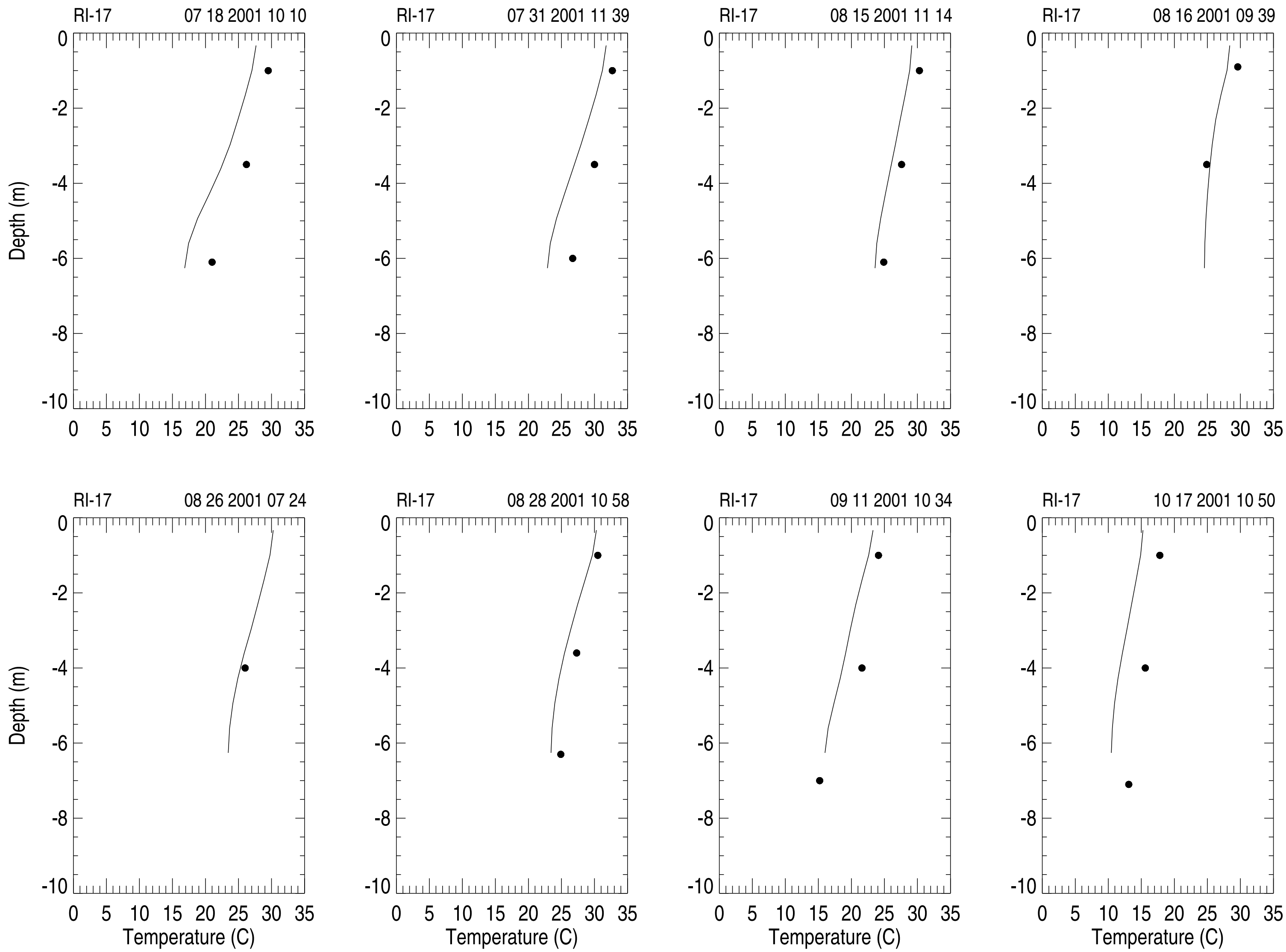
RI-14 08 26 2001 07 49
RI-14 08 28 2001 07 13
RI-14 09 11 2001 07 15
RI-14 10 17 2001 07 38
RI-14 10 23 2001 09 14
RI-14 10 29 2001 11 21
RI-14 11 14 2001 07 12
RI-14 11 27 2001 10 15
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35

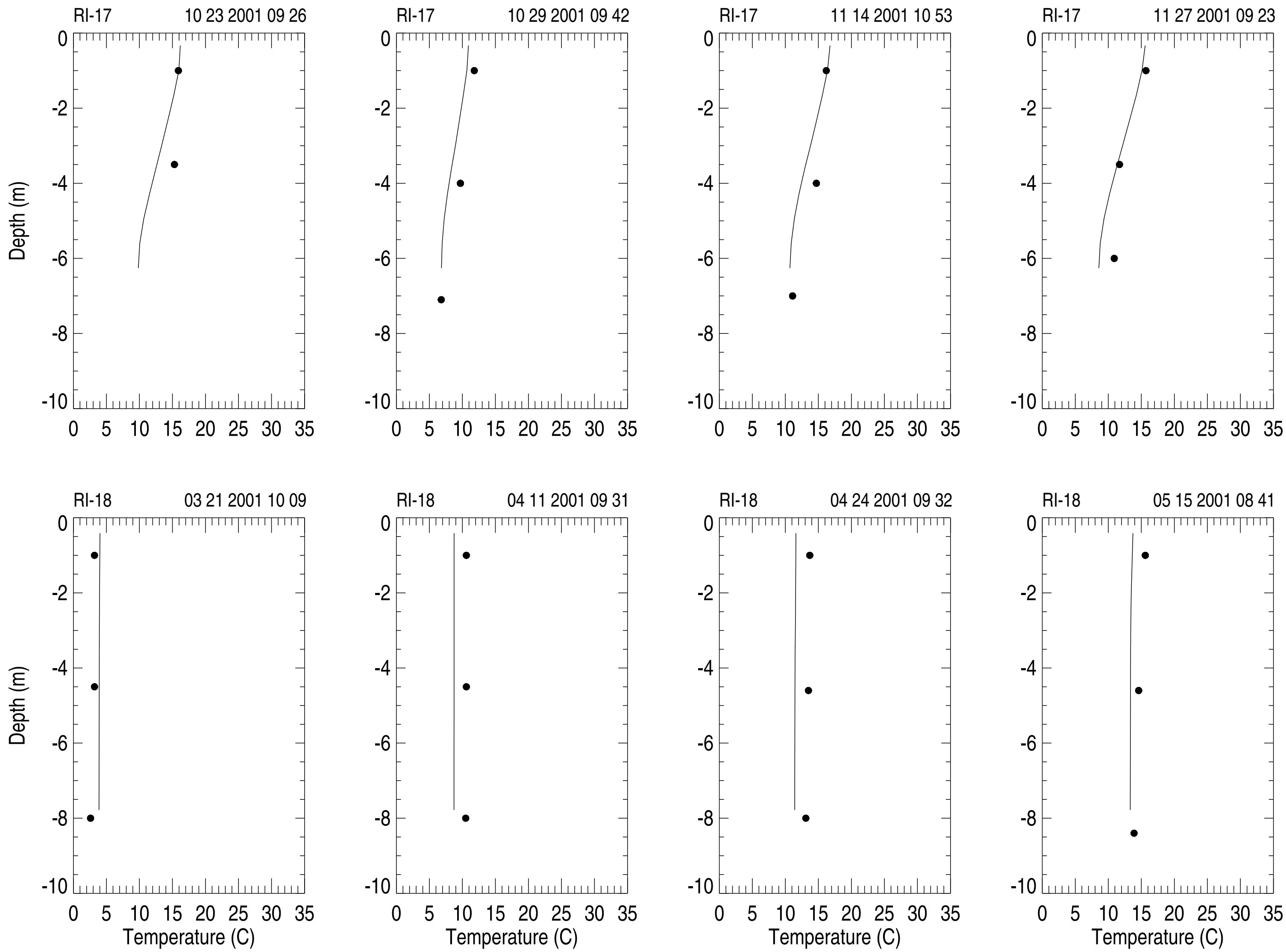

RI-15
03 21 2001 11 15
04 11 2001 10 22
04 24 2001 09 51
05 15 2001 08 58
06 05 2001 11 34
06 13 2001 09 23
06 28 2001 09 07
07 18 2001 08 19
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

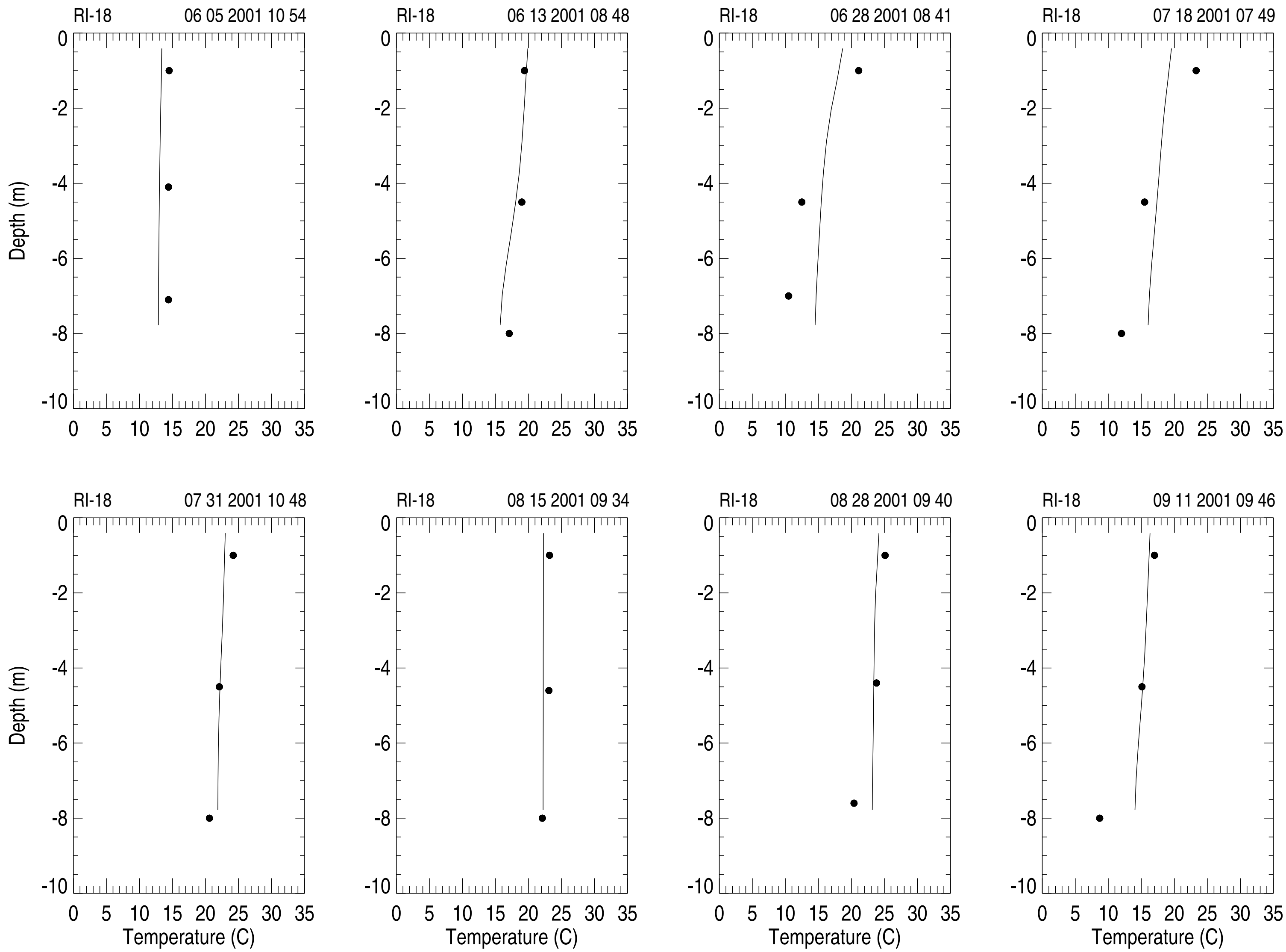

RI-15 07 31 2001 11 04
RI-15 08 15 2001 10 38
RI-15 08 28 2001 10 38
RI-15 09 11 2001 10 12
RI-15 10 17 2001 10 27
RI-15 11 14 2001 10 21
RI-17 02 09 2001 09 23
RI-17 03 21 2001 11 47
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

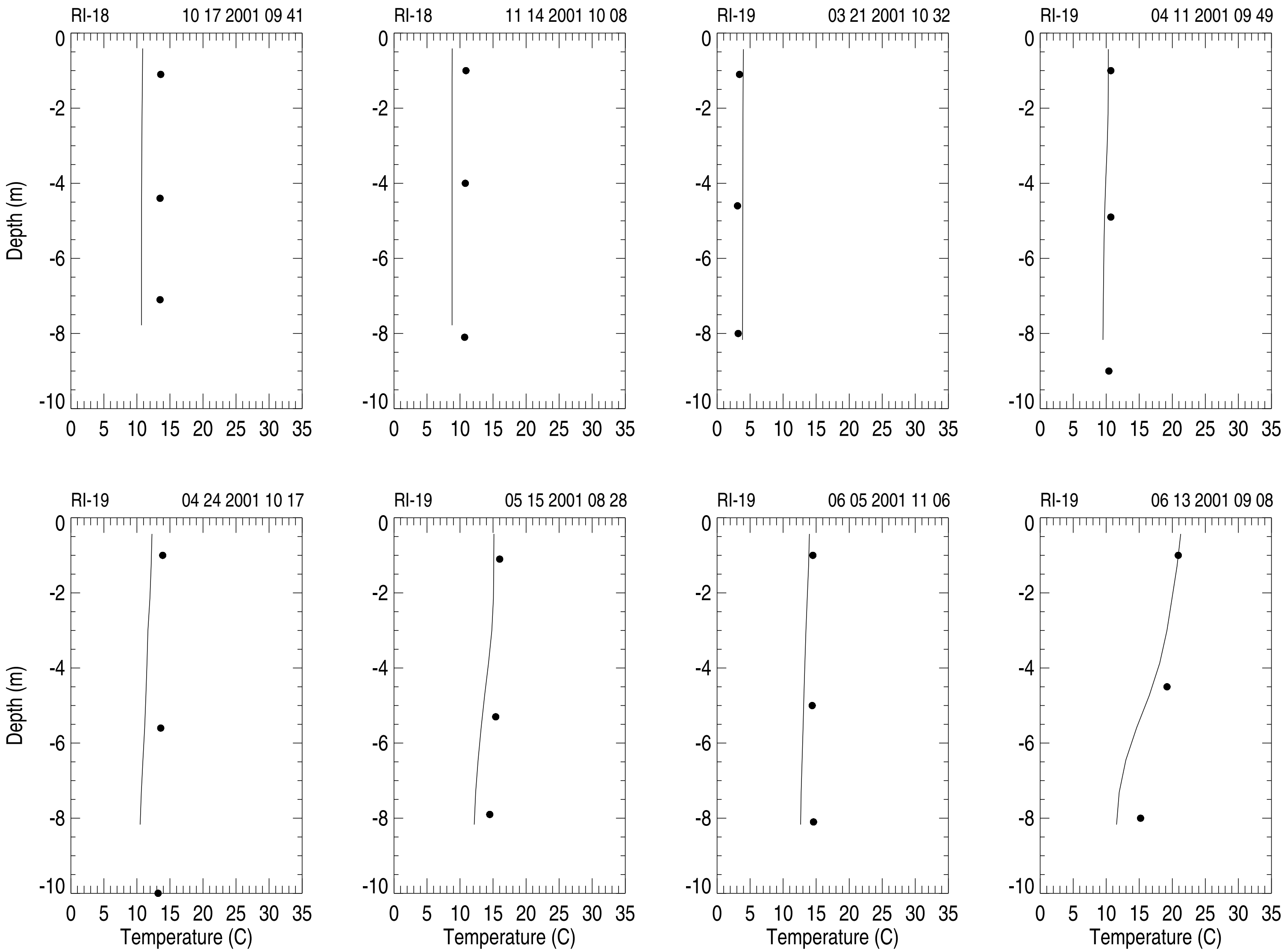


RI-17
04 11 2001 11 14
RI-17
04 24 2001 11 27
RI-17
05 08 2001 06 54
RI-17
05 15 2001 09 23
RI-17
06 05 2001 12 26
RI-17
06 13 2001 09 52
RI-17
06 28 2001 09 36
RI-17
07 17 2001 15 33
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

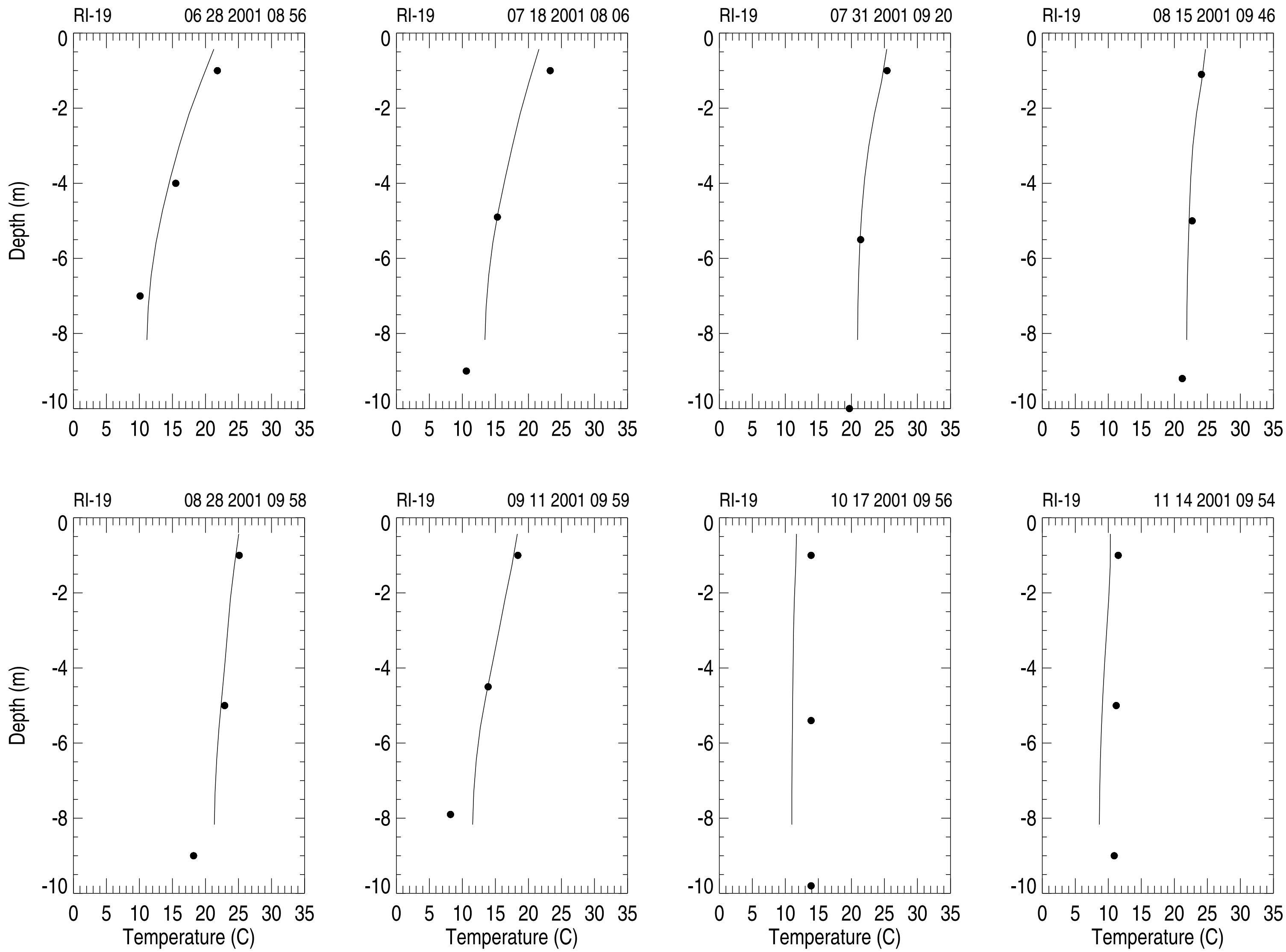

RI-17 07 18 2001 10 10
RI-17 07 31 2001 11 39
RI-17 08 15 2001 11 14
RI-17 08 16 2001 09 39
RI-17 08 26 2001 07 24
RI-17 08 28 2001 10 58
RI-17 09 11 2001 10 34
RI-17 10 17 2001 10 50
Depth (m)
Temperature (C)


RI-17 10 23 2001 09 26
RI-17 10 29 2001 09 42
RI-17 11 14 2001 10 53
RI-17 11 27 2001 09 23
RI-18 03 21 2001 10 09
RI-18 04 11 2001 09 31
RI-18 04 24 2001 09 32
RI-18 05 15 2001 08 41
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

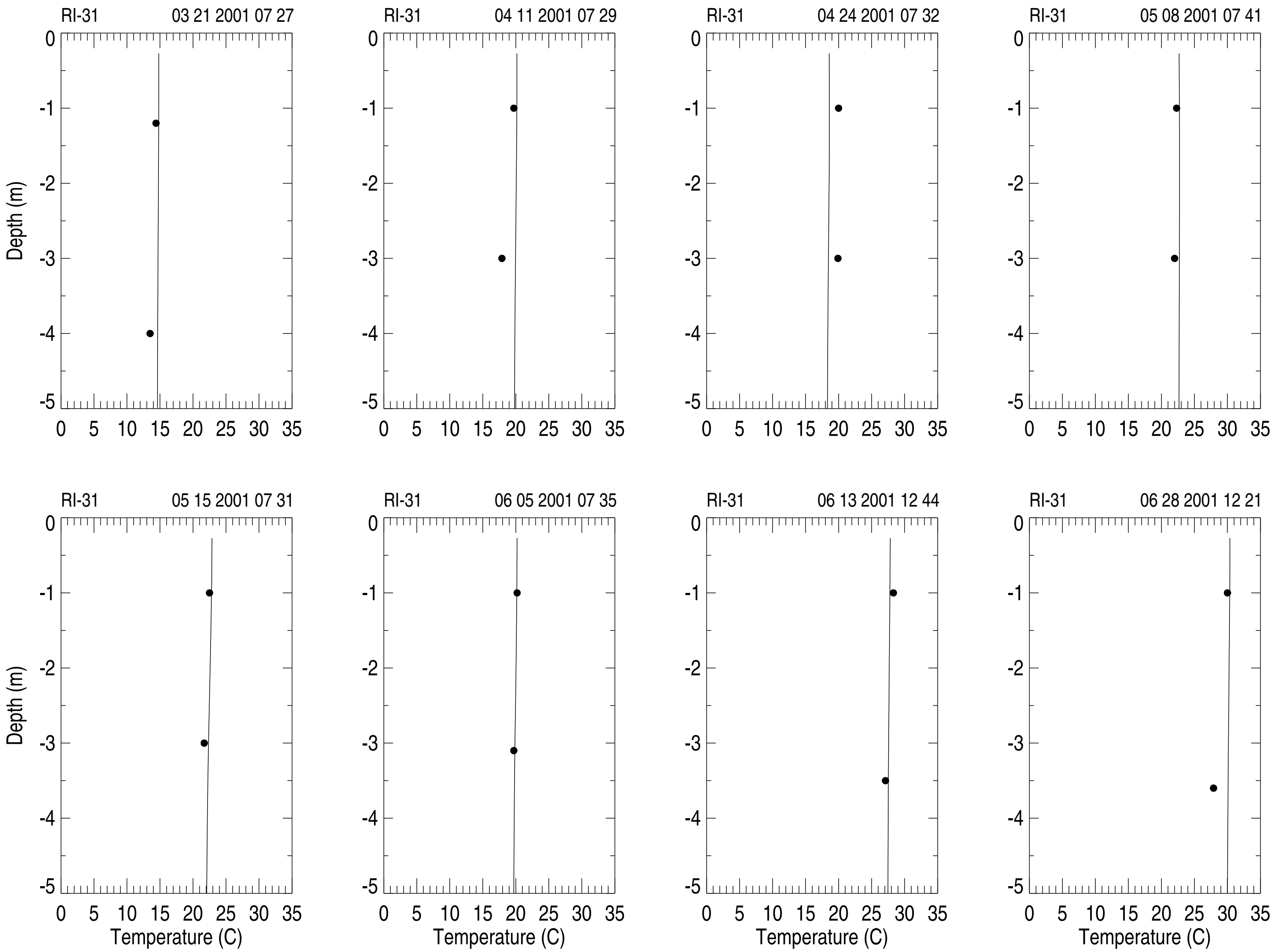

RI-18 06 05 2001 10 54
RI-18 06 13 2001 08 48
RI-18 06 28 2001 08 41
RI-18 07 18 2001 07 49
RI-18 07 31 2001 10 48
RI-18 08 15 2001 09 34
RI-18 08 28 2001 09 40
RI-18 09 11 2001 09 46
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)



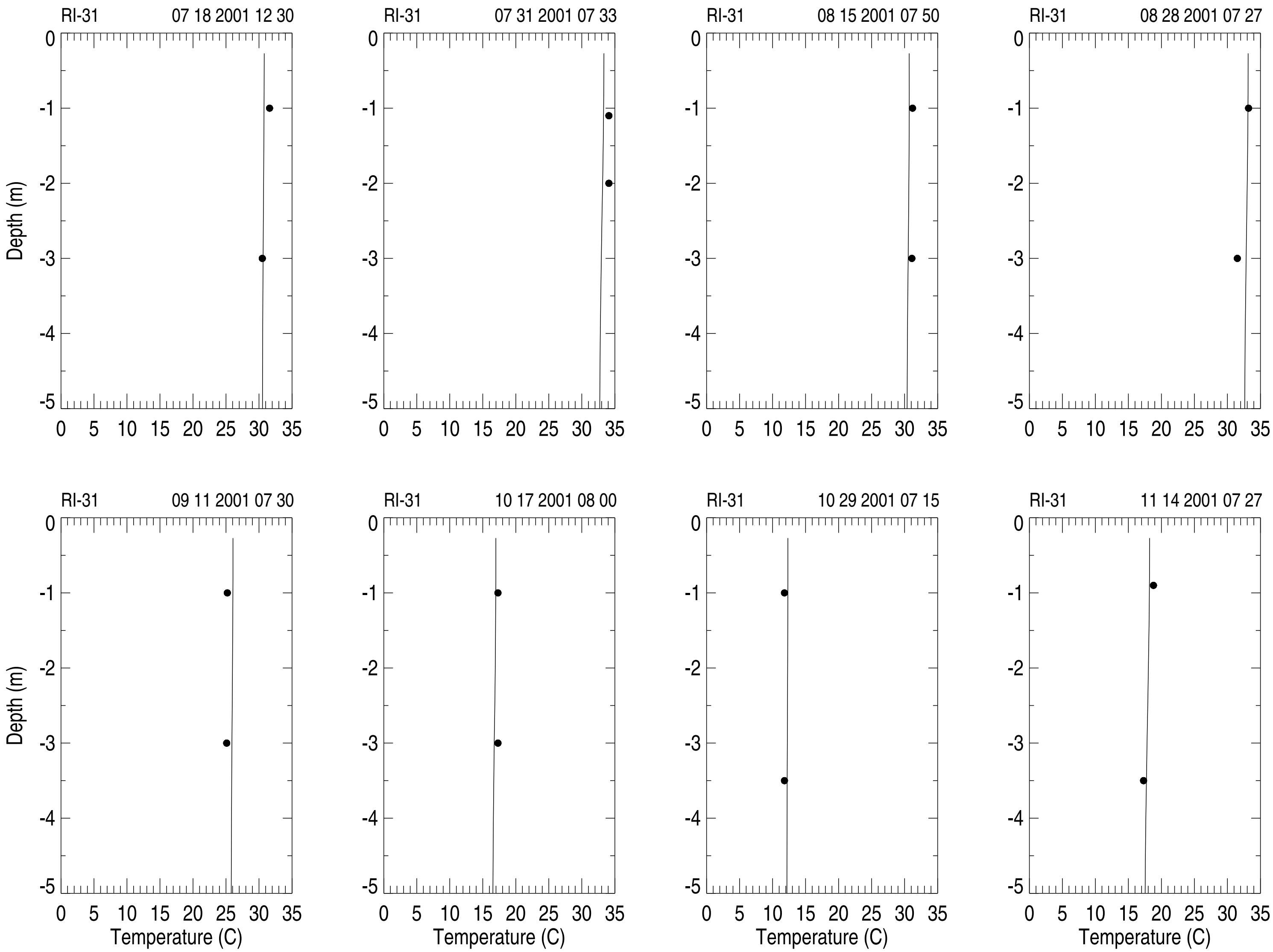
RI-18 10 17 2001 09 41
RI-18 11 14 2001 10 08
RI-19 03 21 2001 10 32
RI-19 04 11 2001 09 49
RI-19 04 24 2001 10 17
RI-19 05 15 2001 08 28
RI-19 06 05 2001 11 06
RI-19 06 13 2001 09 08
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

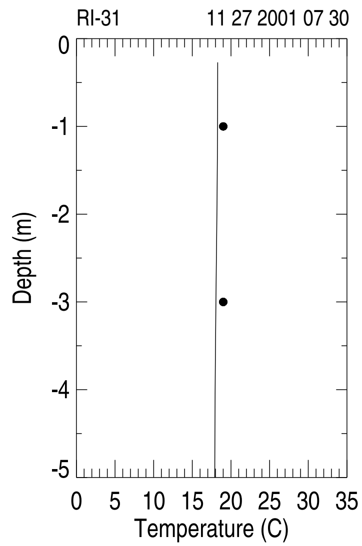


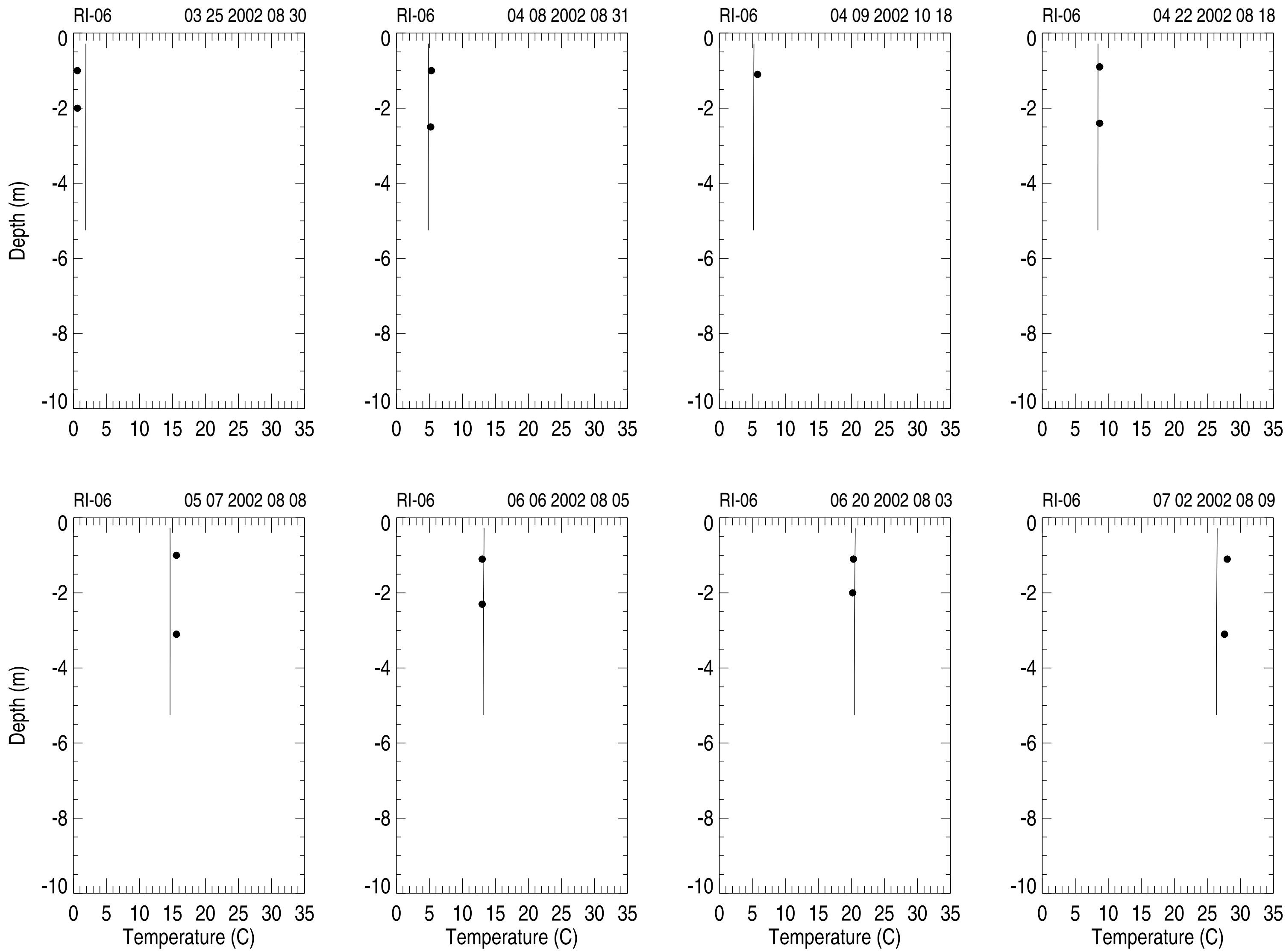
RI-19
06 28 2001 08 56
RI-19
07 18 2001 08 06
RI-19
07 31 2001 09 20
RI-19
08 15 2001 09 46
RI-19
08 28 2001 09 58
RI-19
09 11 2001 09 59
RI-19
10 17 2001 09 56
RI-19
11 14 2001 09 54
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

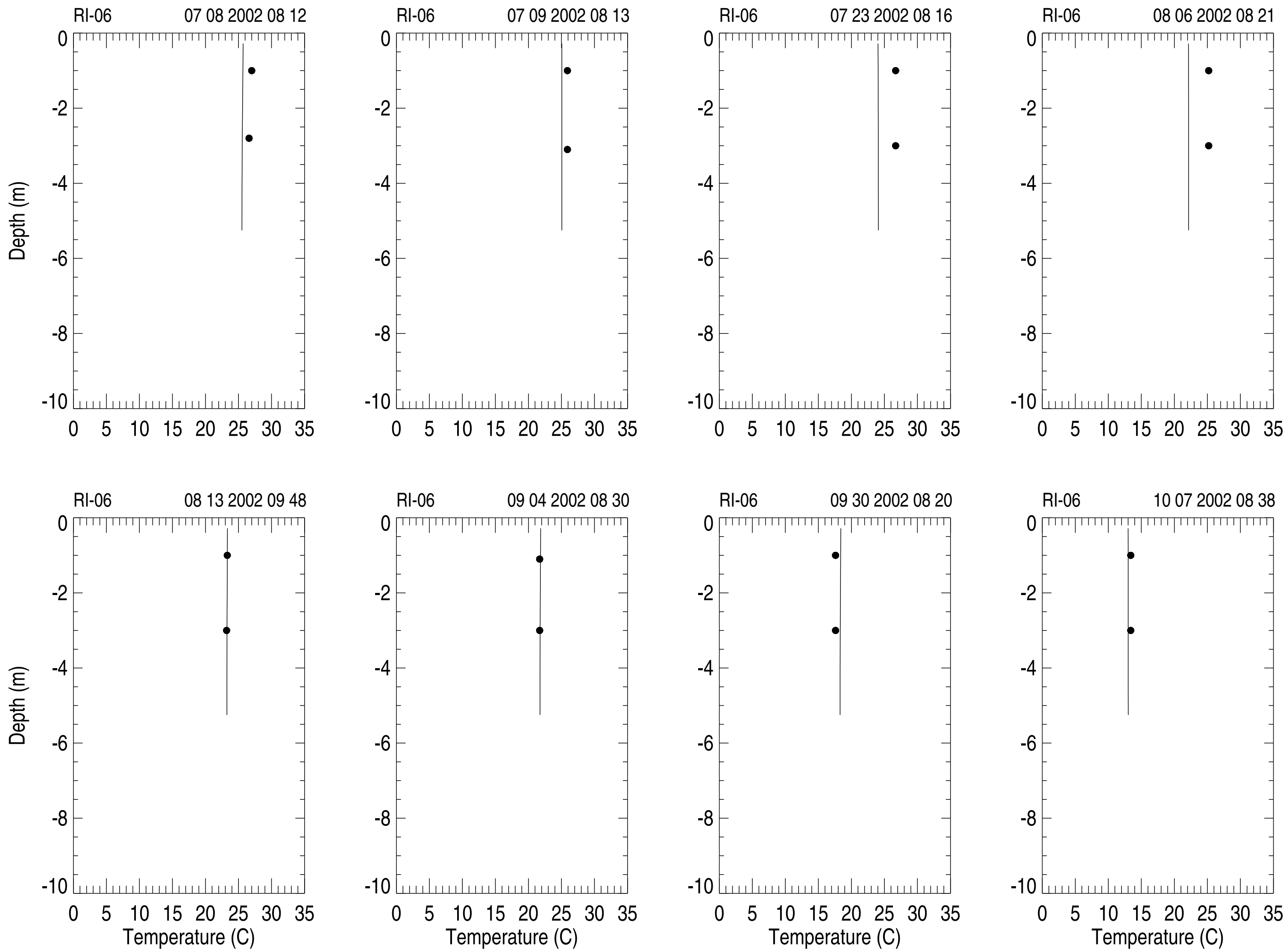


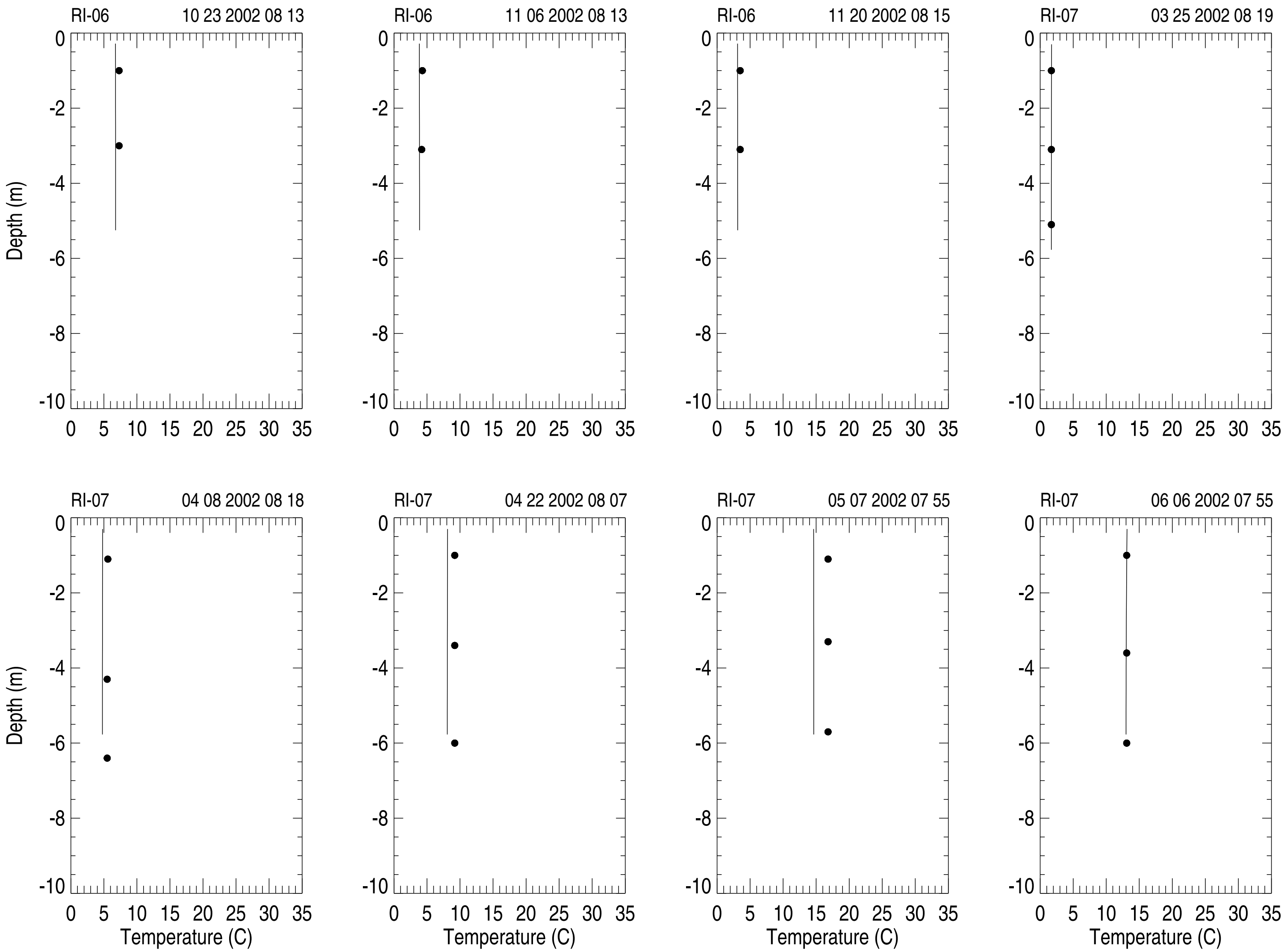
RI-31
03 21 2001 07 27
RI-31
04 11 2001 07 29
RI-31
04 24 2001 07 32
RI-31
05 08 2001 07 41
RI-31
05 15 2001 07 31
RI-31
06 05 2001 07 35
RI-31
06 13 2001 12 44
RI-31
06 28 2001 12 21
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35

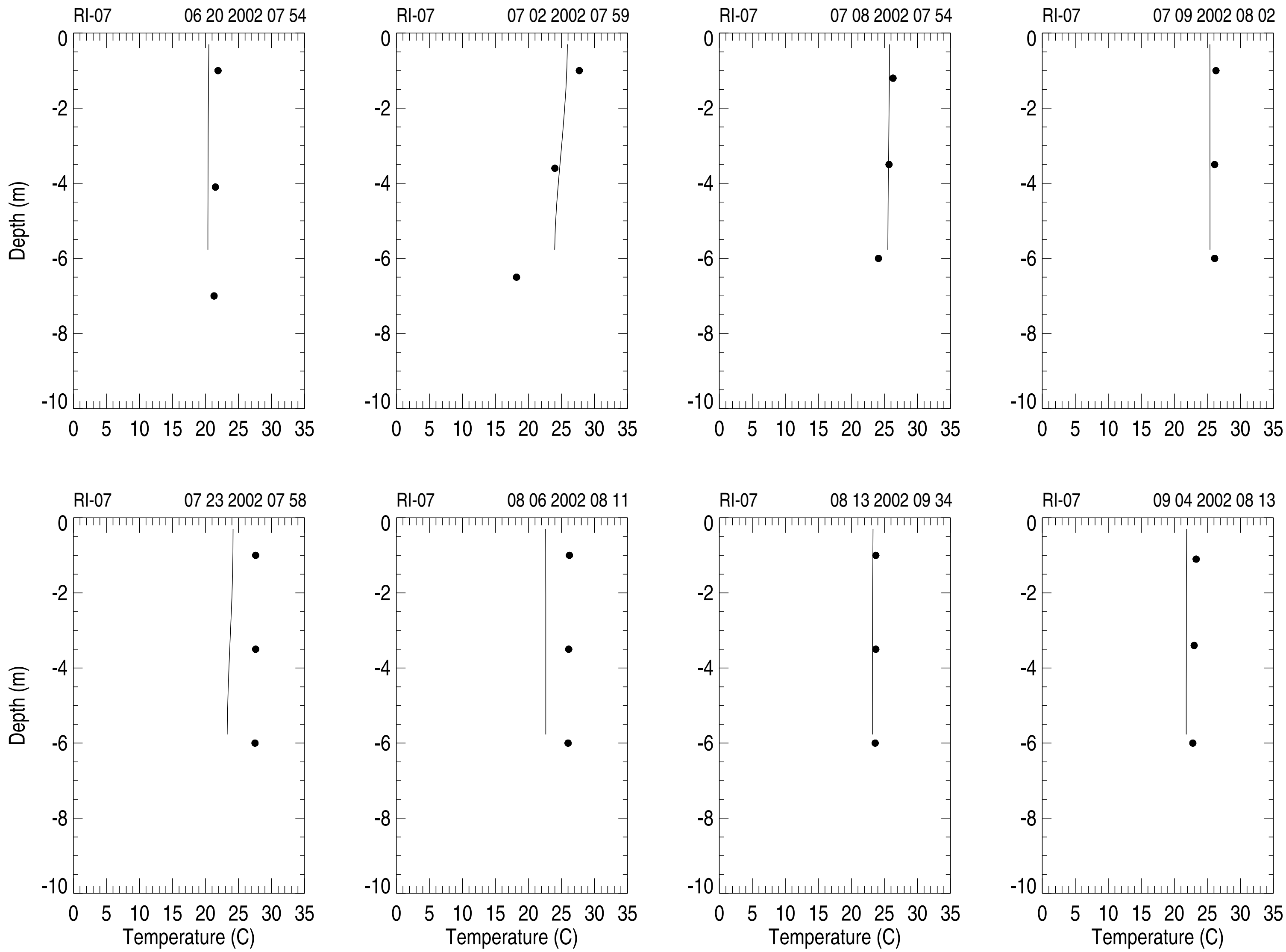

RI-31
07 18 2001 12 30
RI-31
07 31 2001 07 33
RI-31
08 15 2001 07 50
RI-31
08 28 2001 07 27
RI-31
09 11 2001 07 30
RI-31
10 17 2001 08 00
RI-31
10 29 2001 07 15
RI-31
11 14 2001 07 27
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35

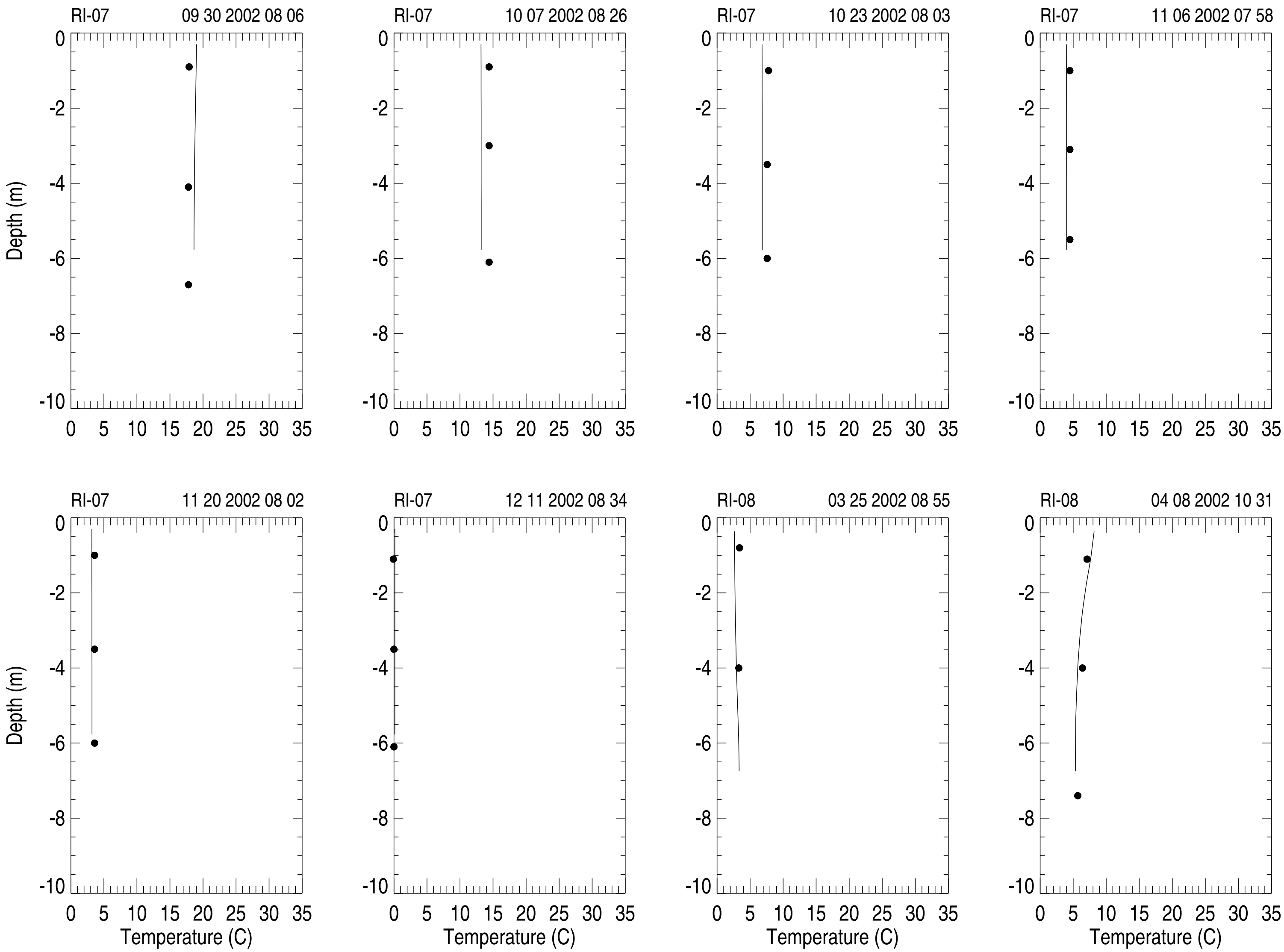

RI-31
11 27 2001 07 30
0
-1
-2
-3
-4
-5
Depth (m)
0 5 10 15 20 25 30 35
Temperature (C)

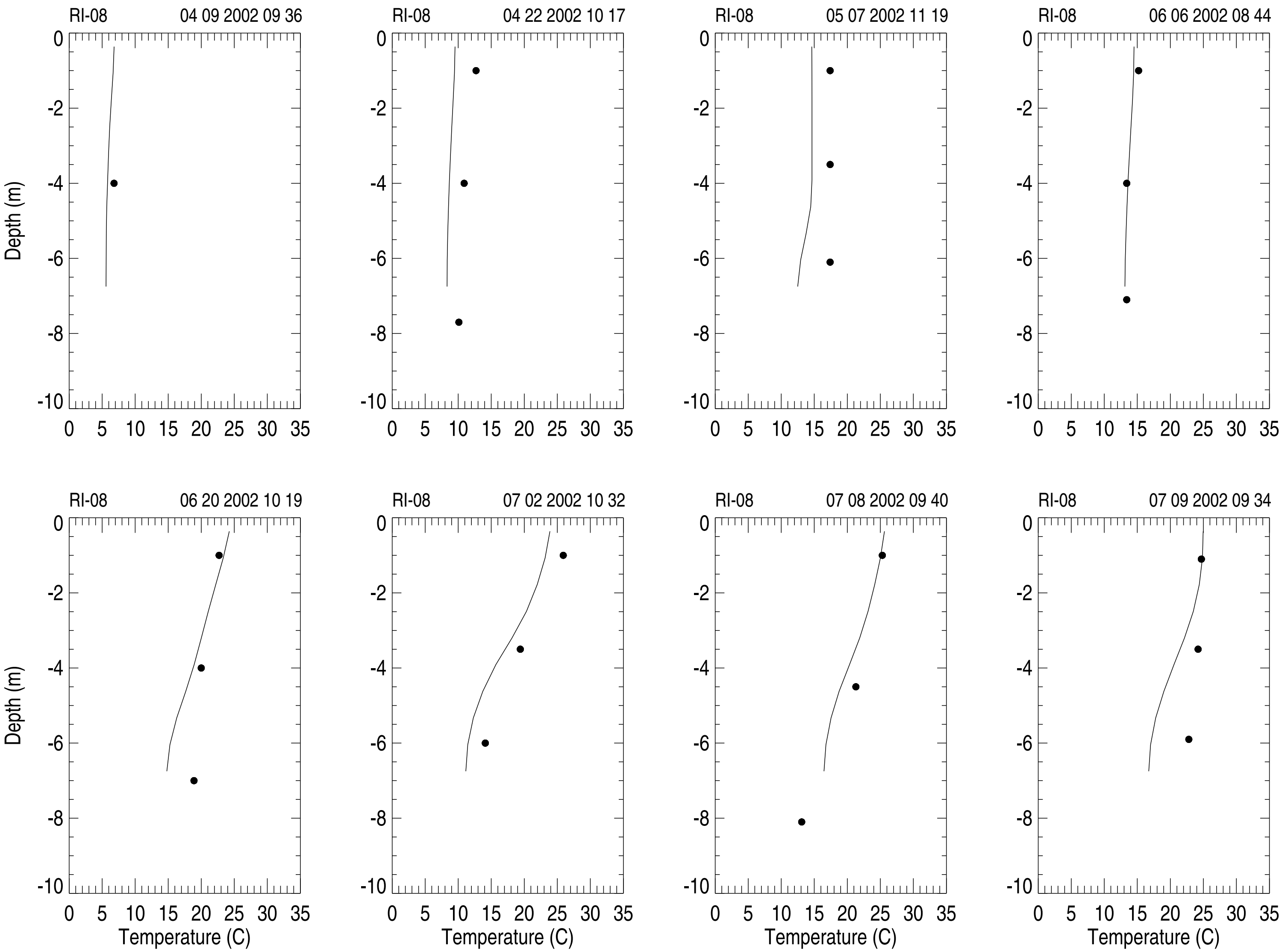

RI-06
03 25 2002 08 30
RI-06
04 08 2002 08 31
RI-06
04 09 2002 10 18
RI-06
04 22 2002 08 18
RI-06
05 07 2002 08 08
RI-06
06 06 2002 08 05
RI-06
06 20 2002 08 03
RI-06
07 02 2002 08 09
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

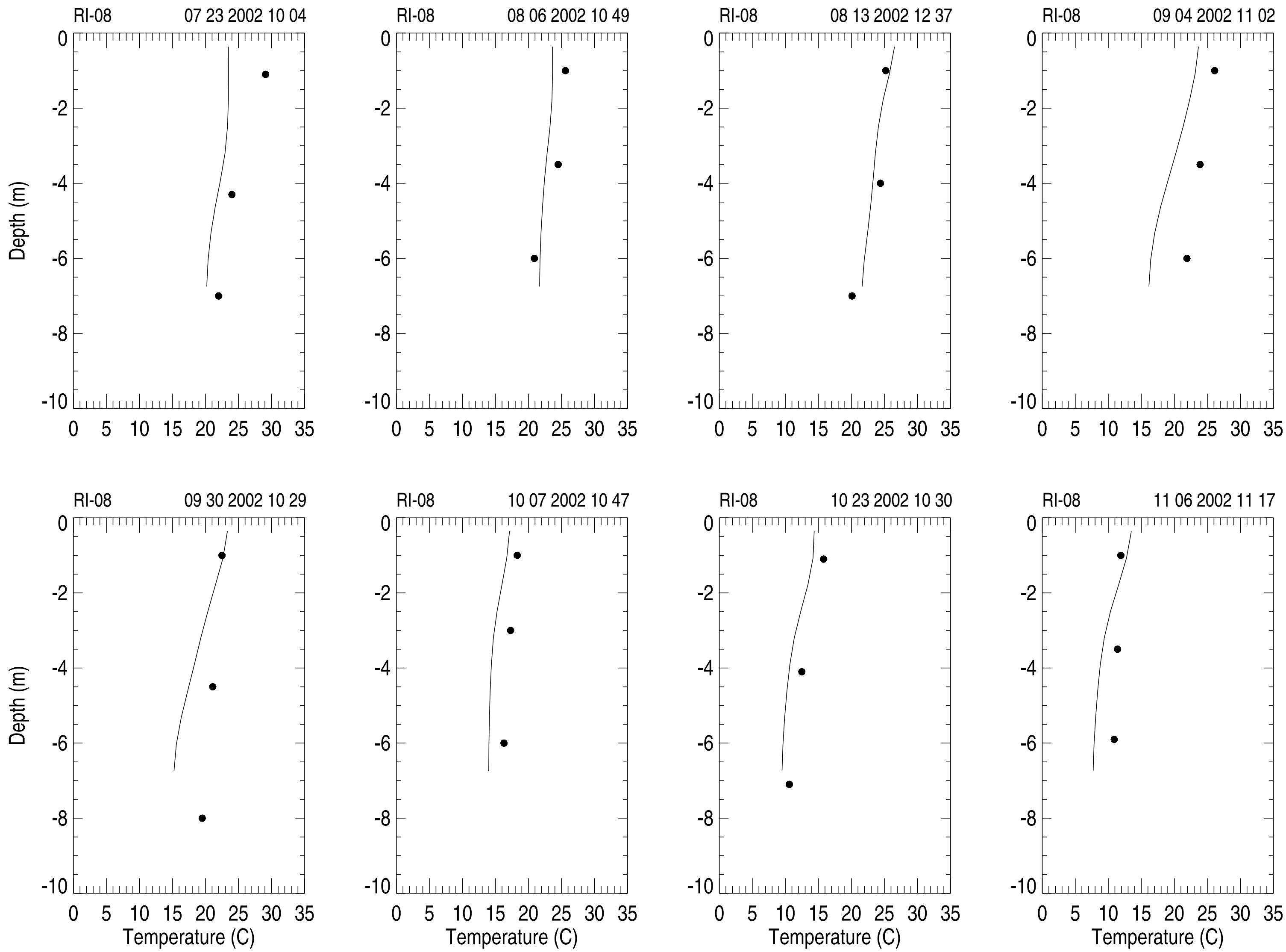

RI-06
07 08 2002 08 12
RI-06
07 09 2002 08 13
RI-06
07 23 2002 08 16
RI-06
08 06 2002 08 21
RI-06
08 13 2002 09 48
RI-06
09 04 2002 08 30
RI-06
09 30 2002 08 20
RI-06
10 07 2002 08 38
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

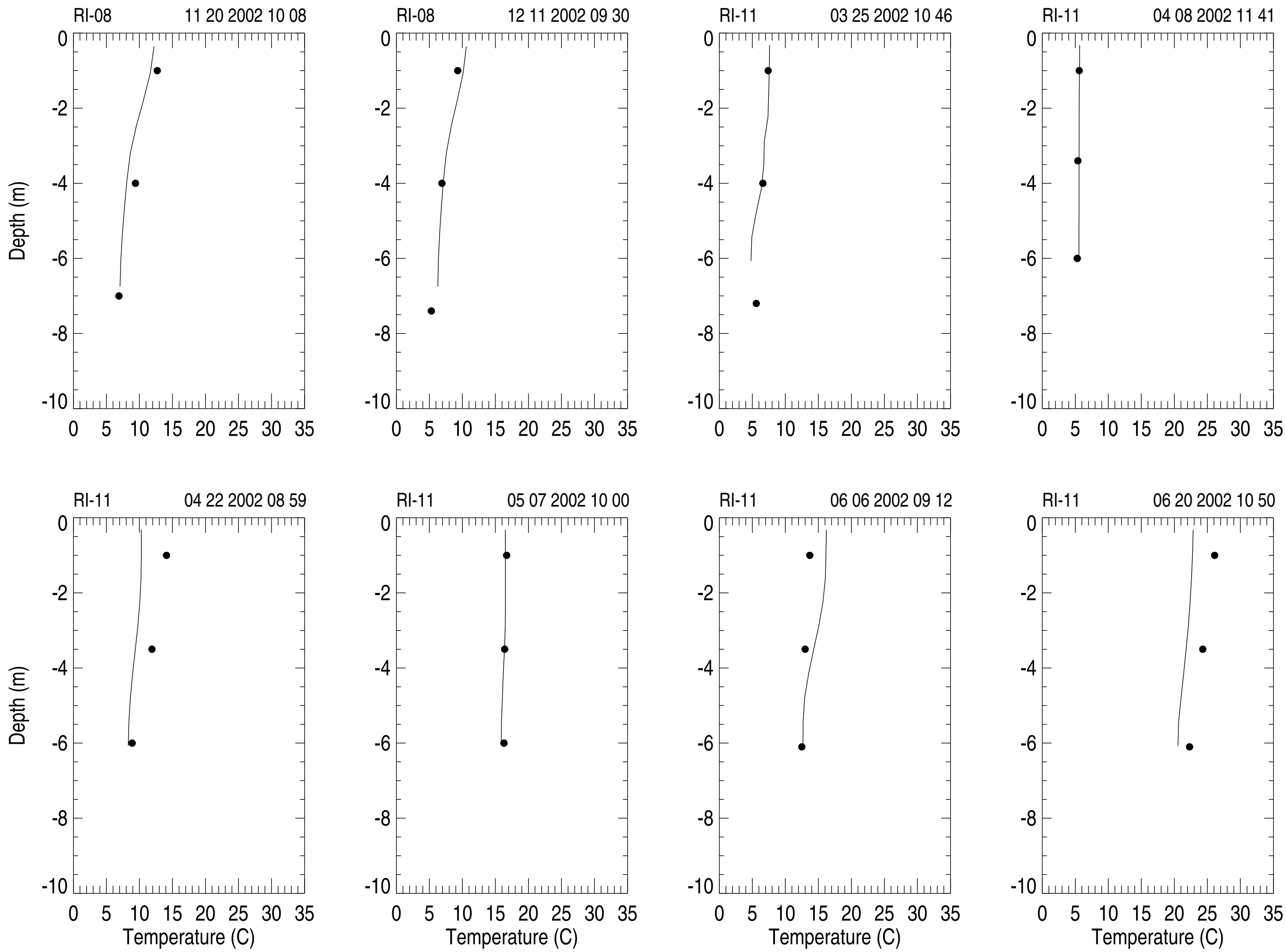

RI-06 10 23 2002 08 13
RI-06 11 06 2002 08 13
RI-06 11 20 2002 08 15
RI-07 03 25 2002 08 19
RI-07 04 08 2002 08 18
RI-07 04 22 2002 08 07
RI-07 05 07 2002 07 55
RI-07 06 06 2002 07 55
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

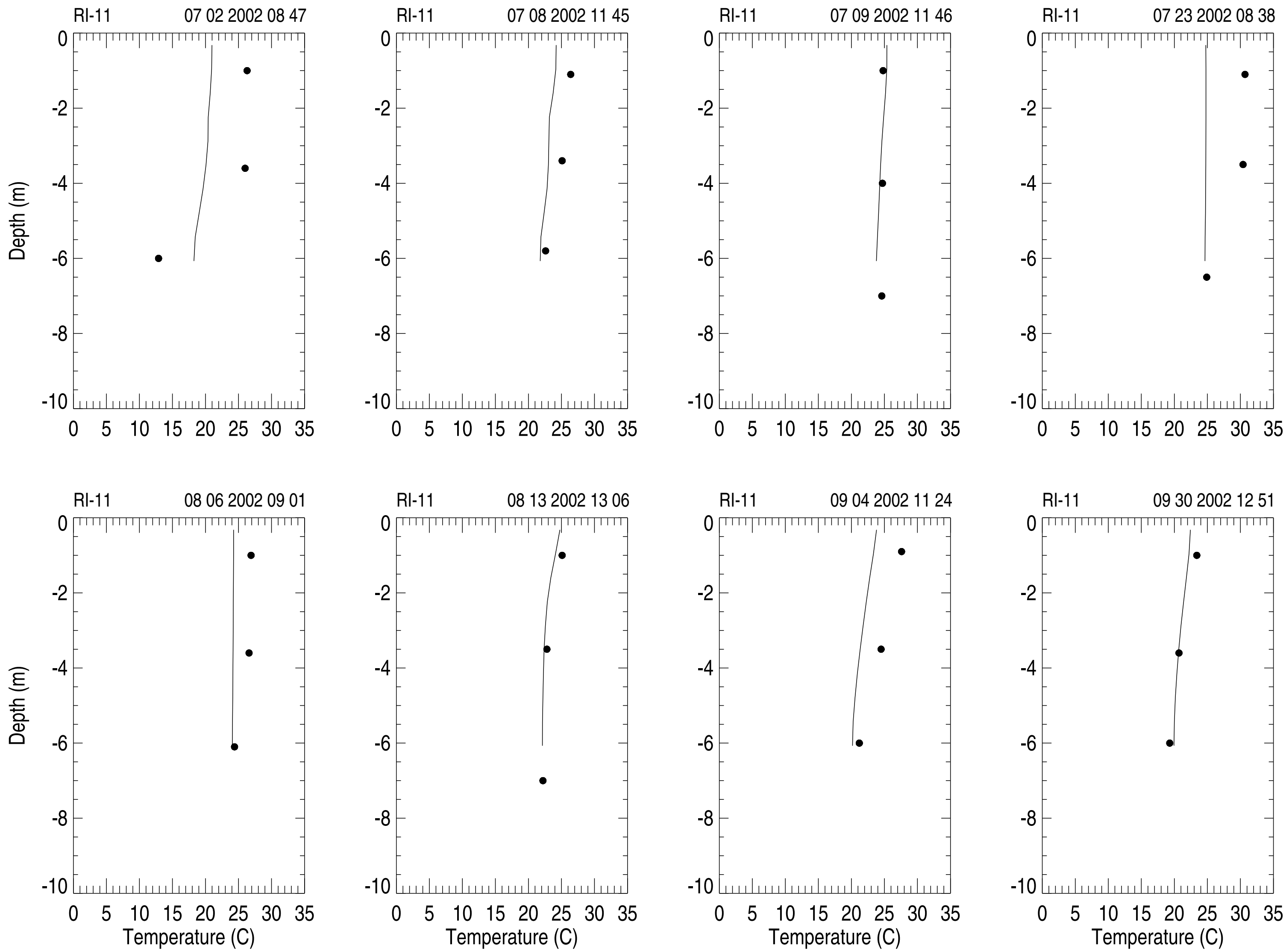

RI-07
06 20 2002 07 54
RI-07
07 02 2002 07 59
RI-07
07 08 2002 07 54
RI-07
07 09 2002 08 02
RI-07
07 23 2002 07 58
RI-07
08 06 2002 08 11
RI-07
08 13 2002 09 34
RI-07
09 04 2002 08 13
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35


RI-07 09 30 2002 08 06
RI-07 10 07 2002 08 26
RI-07 10 23 2002 08 03
RI-07 11 06 2002 07 58
RI-07 11 20 2002 08 02
RI-07 12 11 2002 08 34
RI-08 03 25 2002 08 55
RI-08 04 08 2002 10 31
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

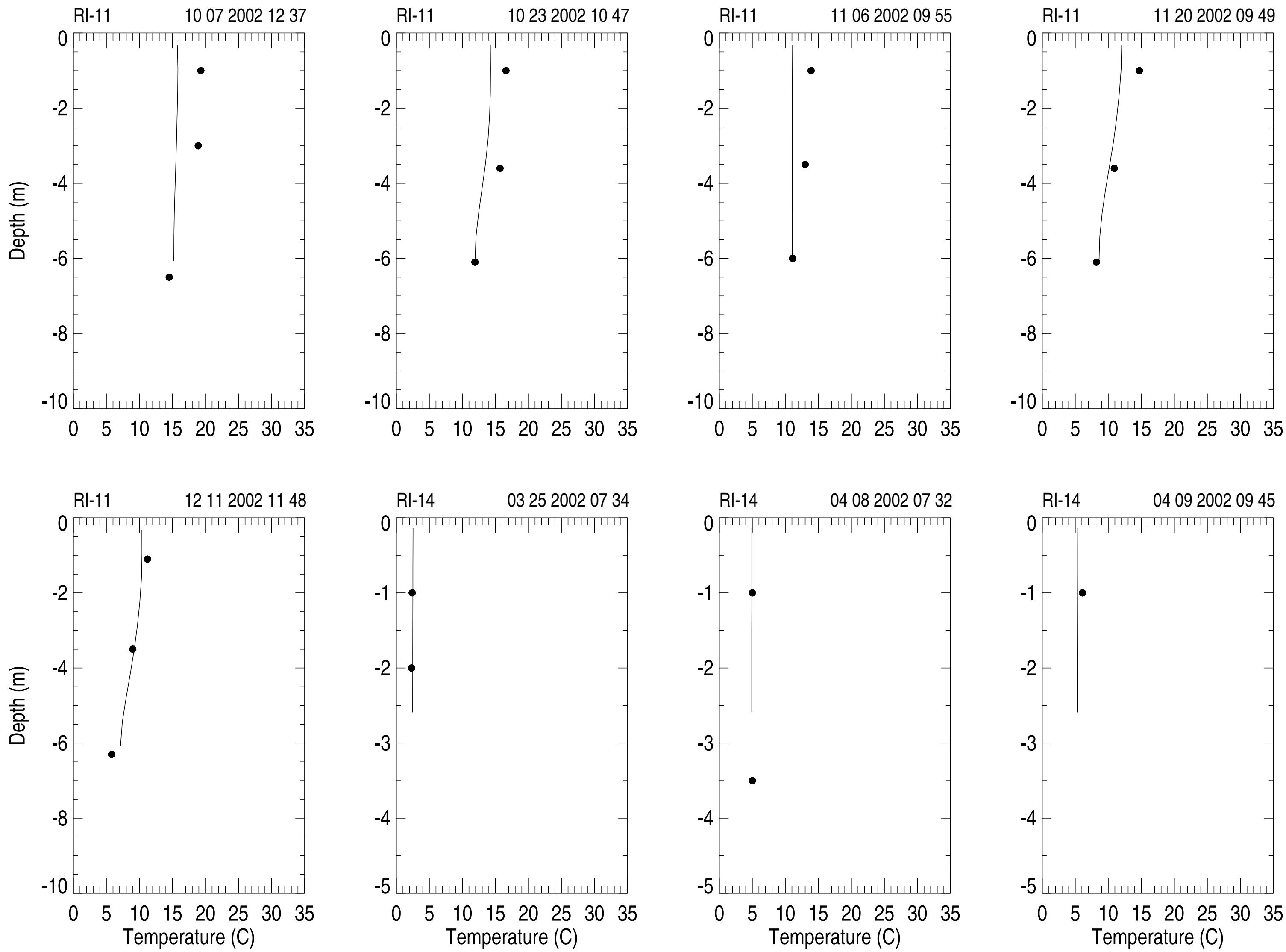

RI-08
04 09 2002 09 36
RI-08
04 22 2002 10 17
RI-08
05 07 2002 11 19
RI-08
06 06 2002 08 44
RI-08
06 20 2002 10 19
RI-08
07 02 2002 10 32
RI-08
07 08 2002 09 40
RI-08
07 09 2002 09 34
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35


RI-08
07 23 2002 10 04
RI-08
08 06 2002 10 49
RI-08
08 13 2002 12 37
RI-08
09 04 2002 11 02
RI-08
09 30 2002 10 29
RI-08
10 07 2002 10 47
RI-08
10 23 2002 10 30
RI-08
11 06 2002 11 17
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

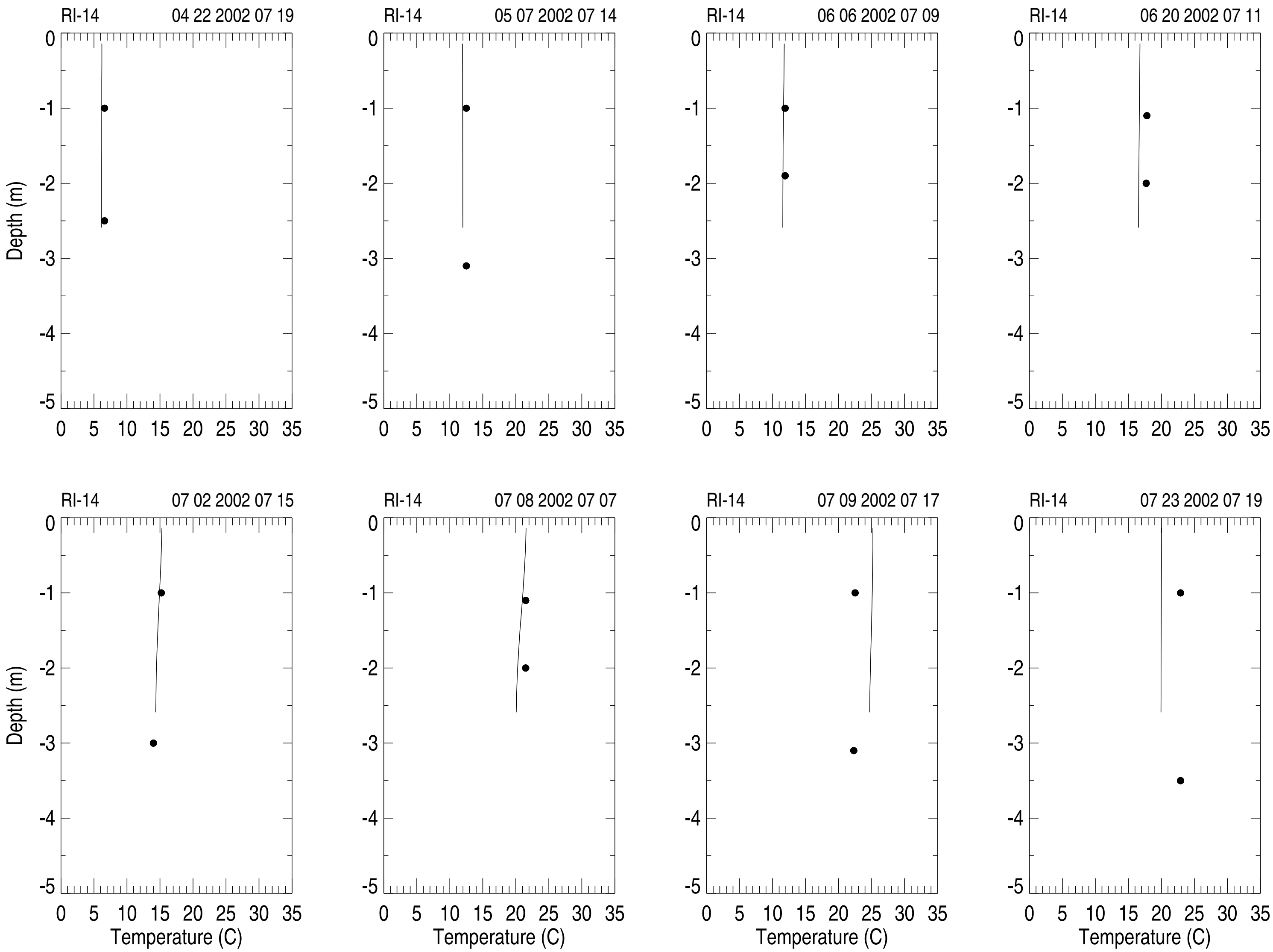

RI-08 11 20 2002 10 08
RI-08 12 11 2002 09 30
RI-11 03 25 2002 10 46
RI-11 04 08 2002 11 41
RI-11 04 22 2002 08 59
RI-11 05 07 2002 10 00
RI-11 06 06 2002 09 12
RI-11 06 20 2002 10 50
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

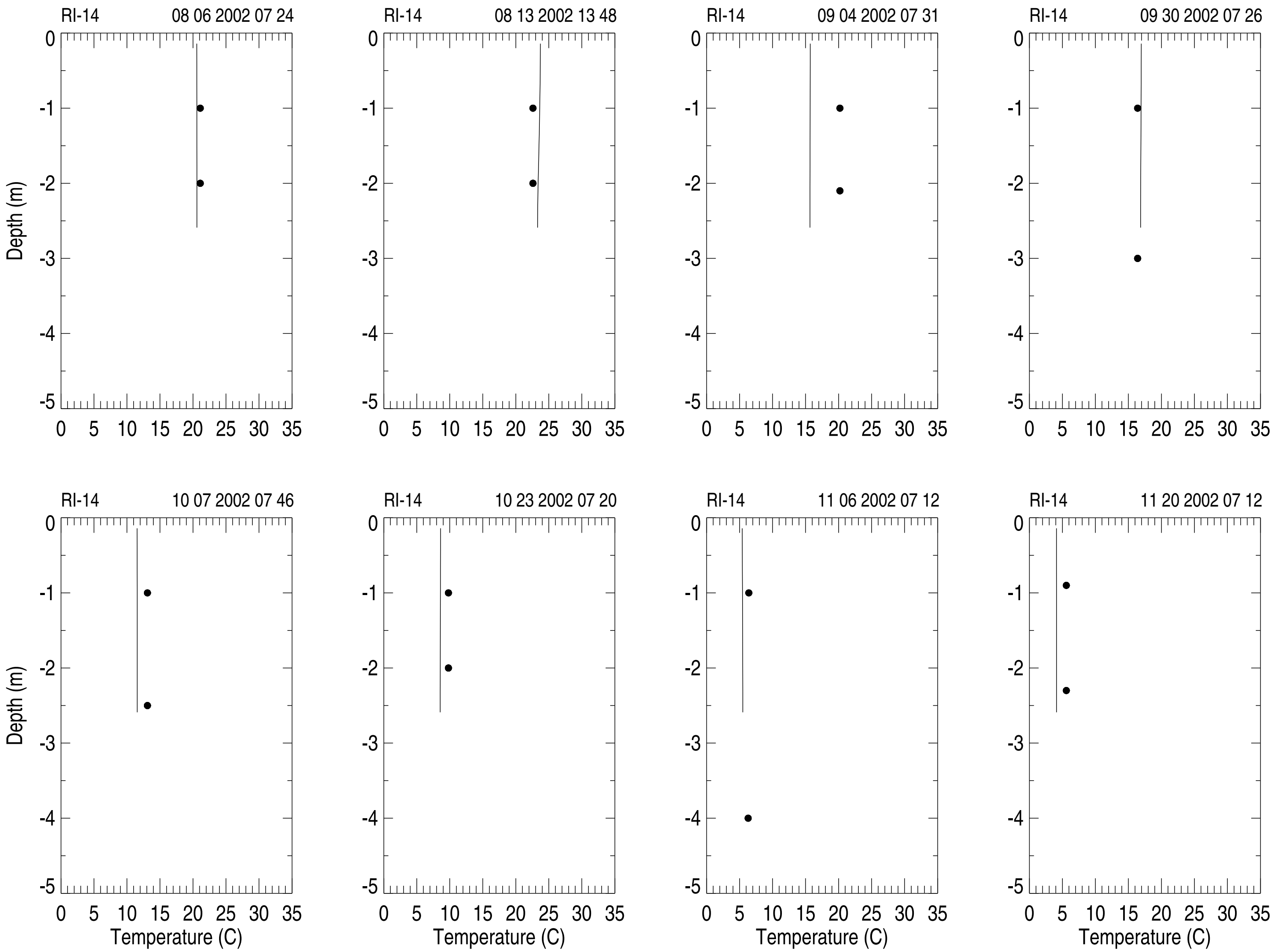


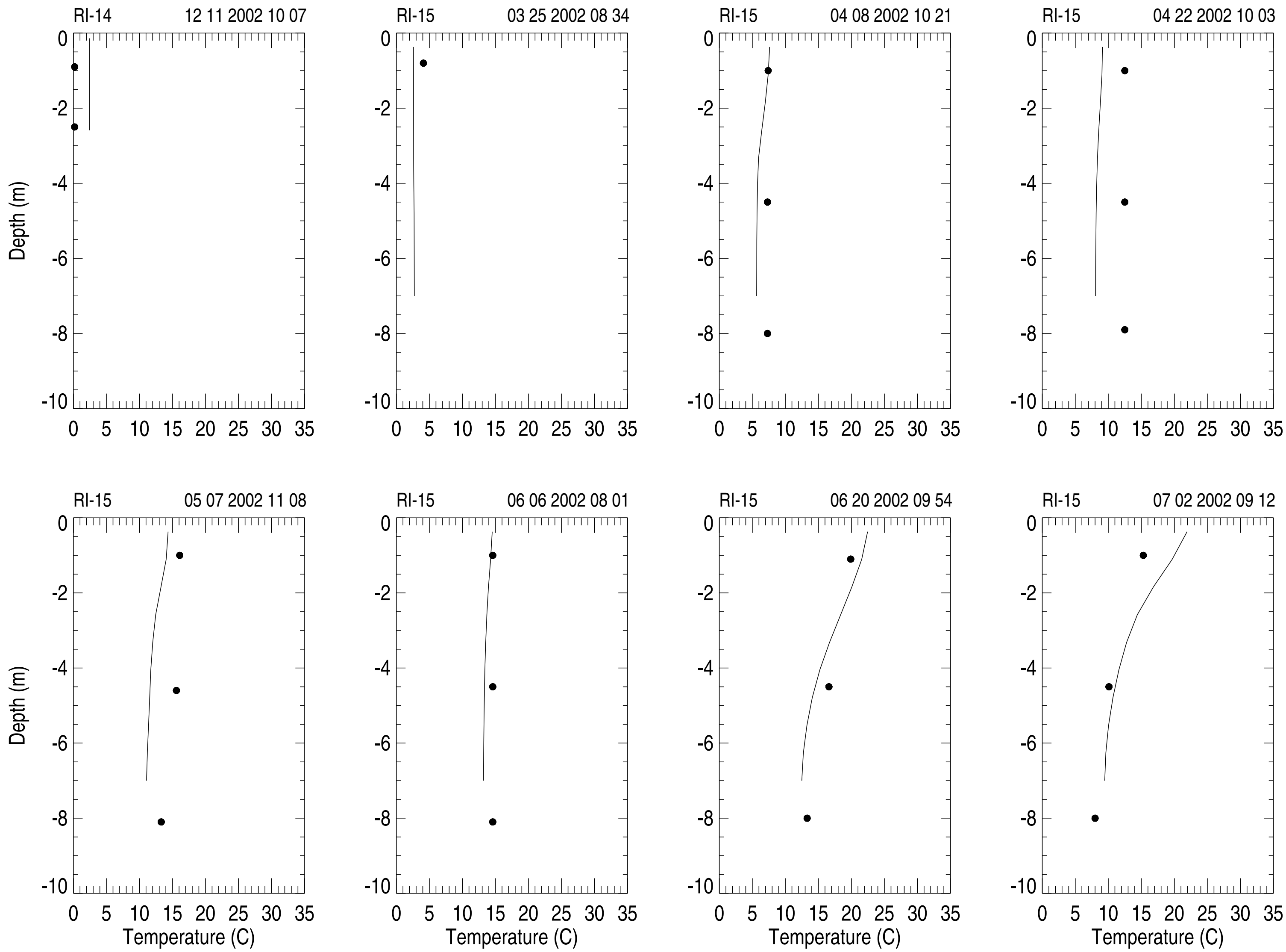
RI-11 07 02 2002 08 47
RI-11 07 08 2002 11 45
RI-11 07 09 2002 11 46
RI-11 07 23 2002 08 38
RI-11 08 06 2002 09 01
RI-11 08 13 2002 13 06
RI-11 09 04 2002 11 24
RI-11 09 30 2002 12 51
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

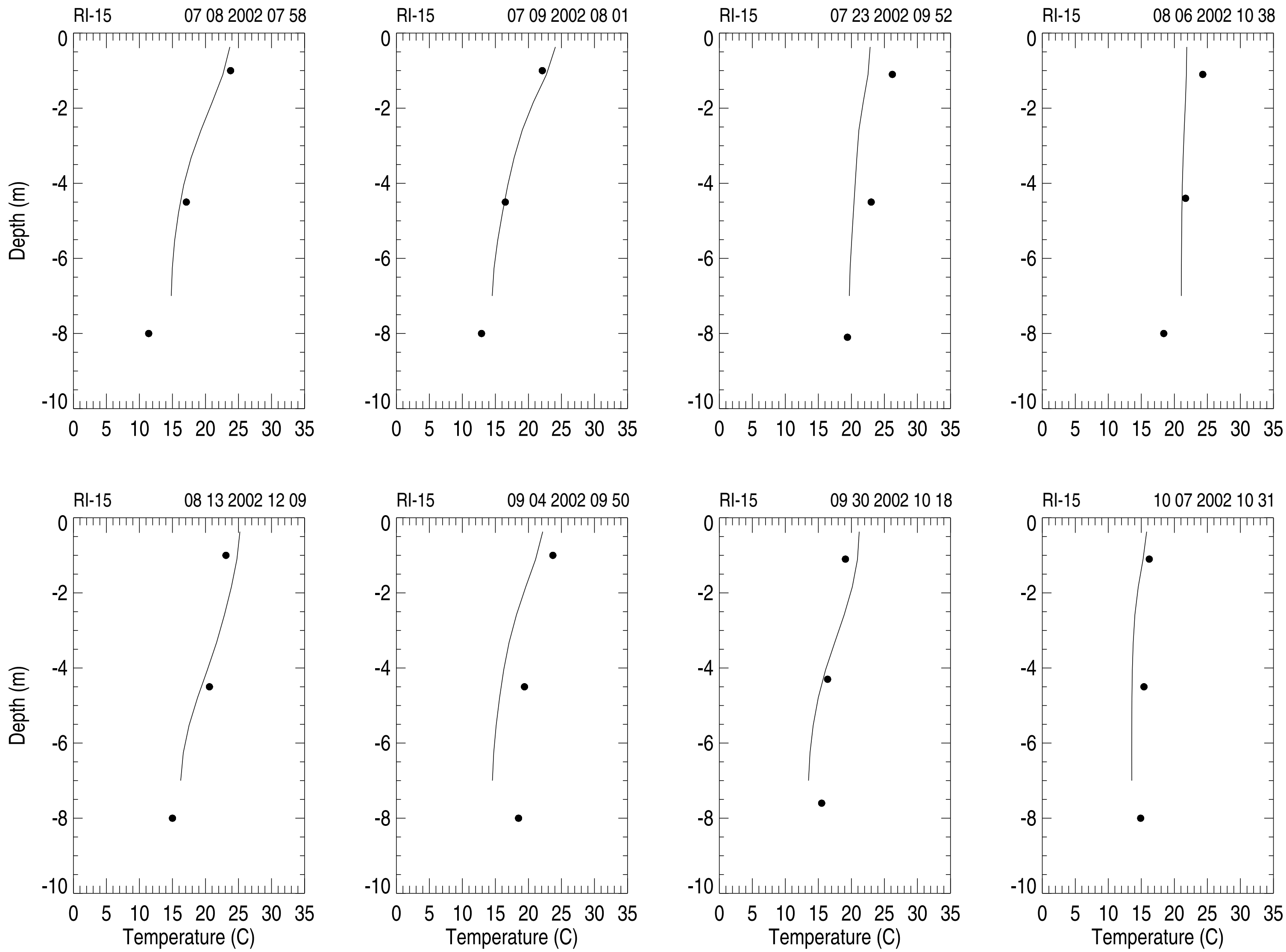


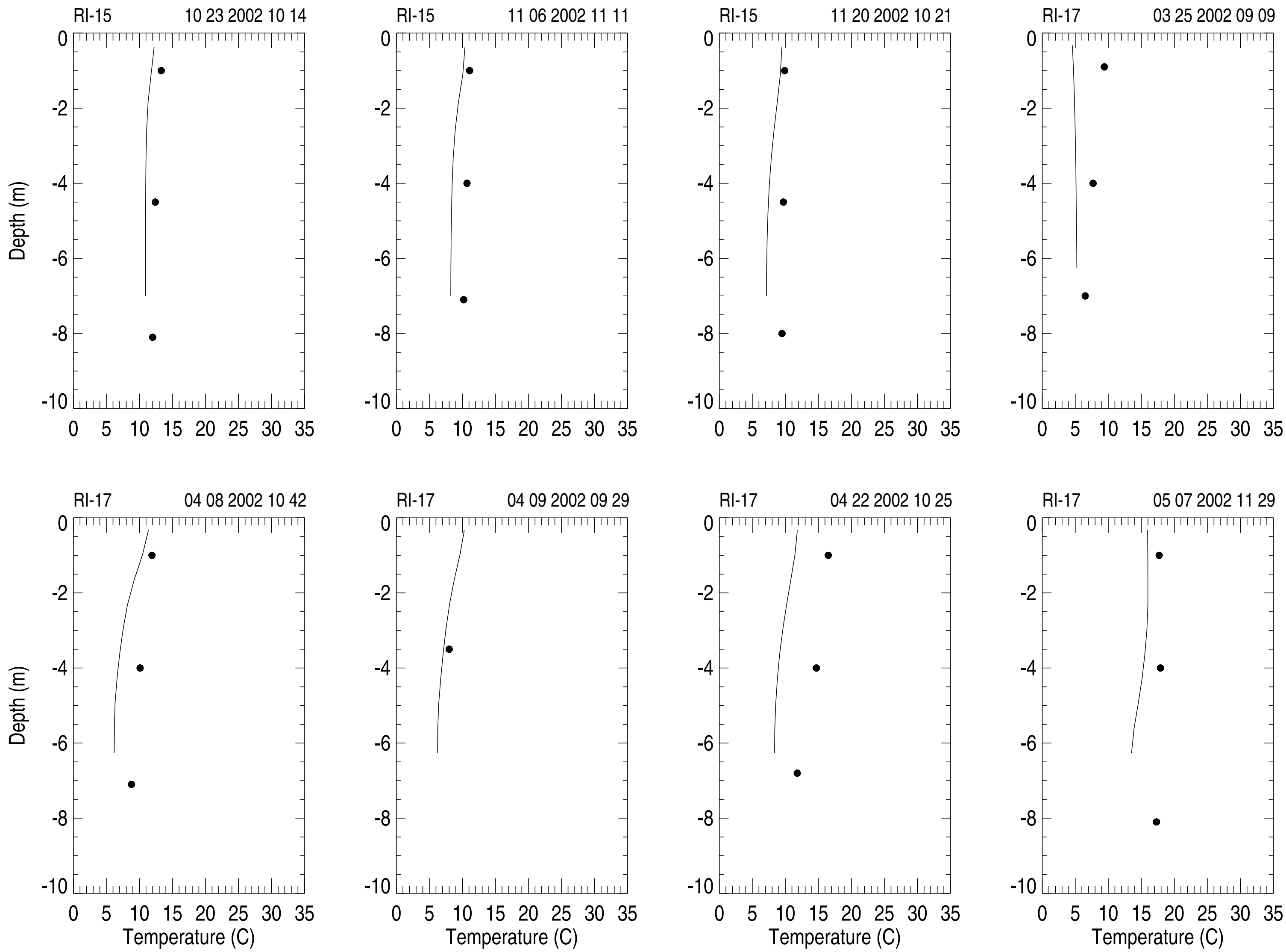
RI-11 10 07 2002 12 37
RI-11 10 23 2002 10 47
RI-11 11 06 2002 09 55
RI-11 11 20 2002 09 49
RI-11 12 11 2002 11 48
RI-14 03 25 2002 07 34
RI-14 04 08 2002 07 32
RI-14 04 09 2002 09 45
Depth (m)
Temperature (C)


RI-14
04 22 2002 07 19
05 07 2002 07 14
06 06 2002 07 09
06 20 2002 07 11
07 02 2002 07 15
07 08 2002 07 07
07 09 2002 07 17
07 23 2002 07 19
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35

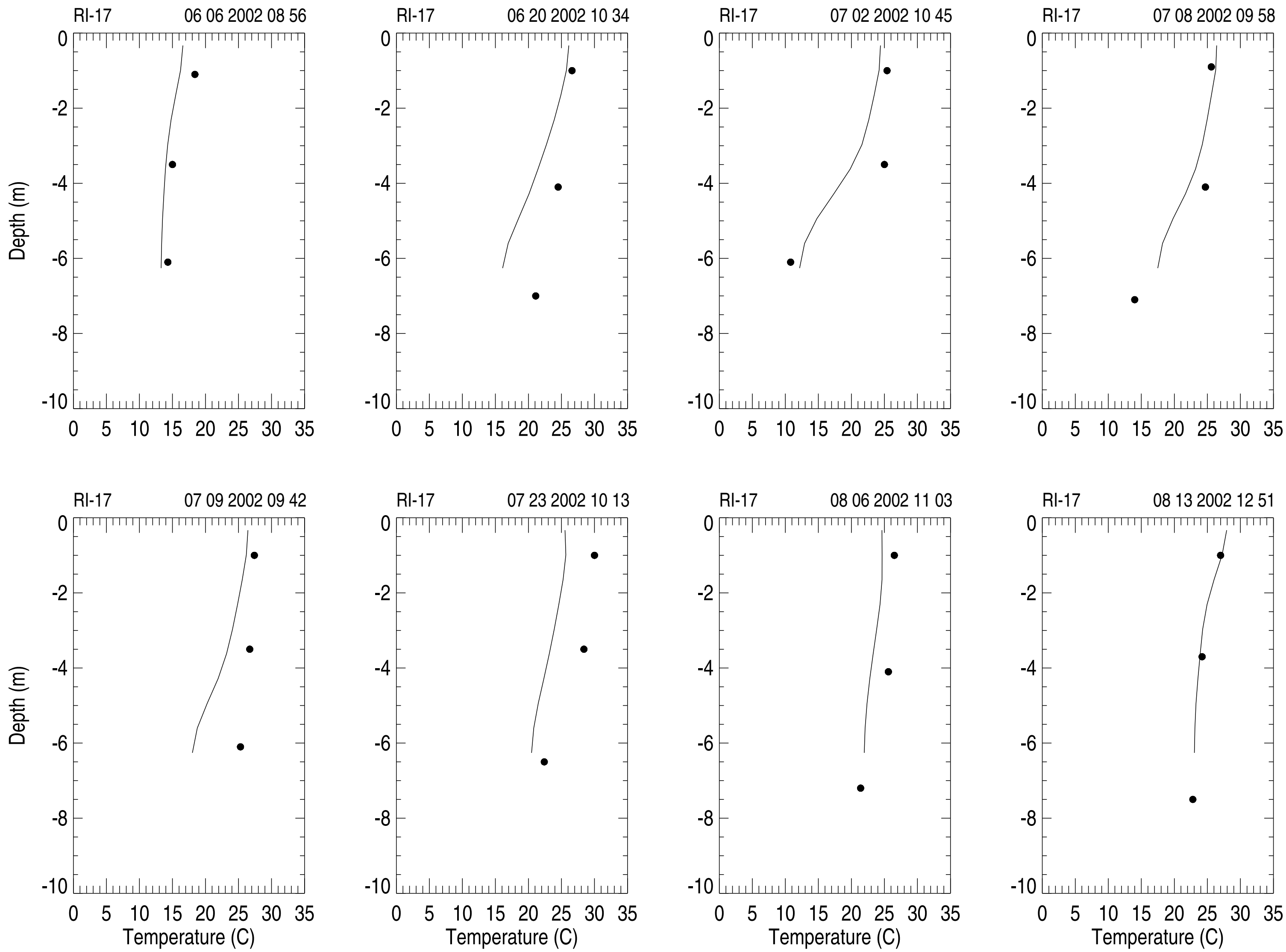

RI-14
08 06 2002 07 24
08 13 2002 13 48
09 04 2002 07 31
09 30 2002 07 26
10 07 2002 07 46
10 23 2002 07 20
11 06 2002 07 12
11 20 2002 07 12
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35

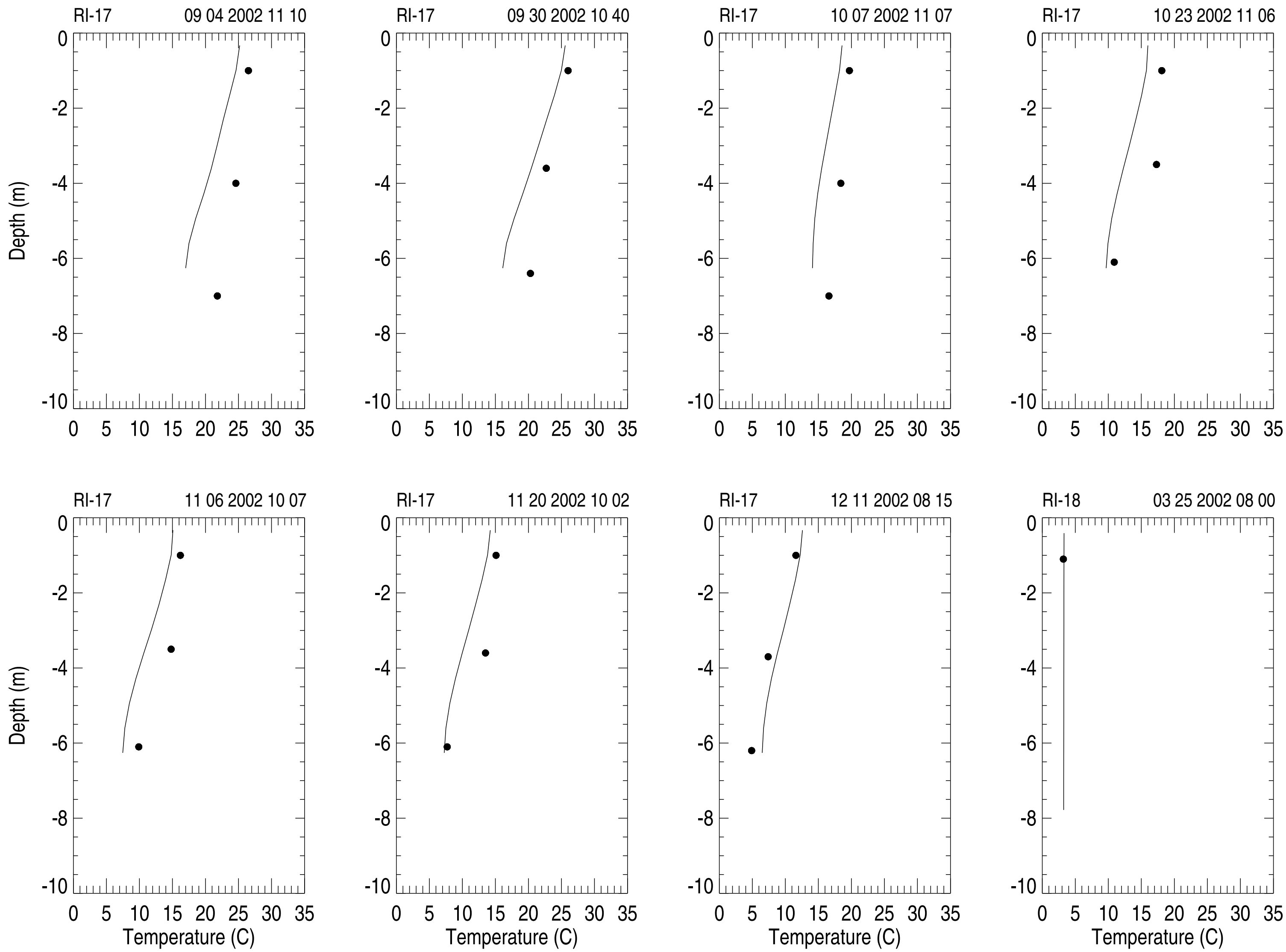

RI-14
12 11 2002 10 07
RI-15
03 25 2002 08 34
RI-15
04 08 2002 10 21
RI-15
04 22 2002 10 03
RI-15
05 07 2002 11 08
RI-15
06 06 2002 08 01
RI-15
06 20 2002 09 54
RI-15
07 02 2002 09 12
Depth (m)
Temperature (C)

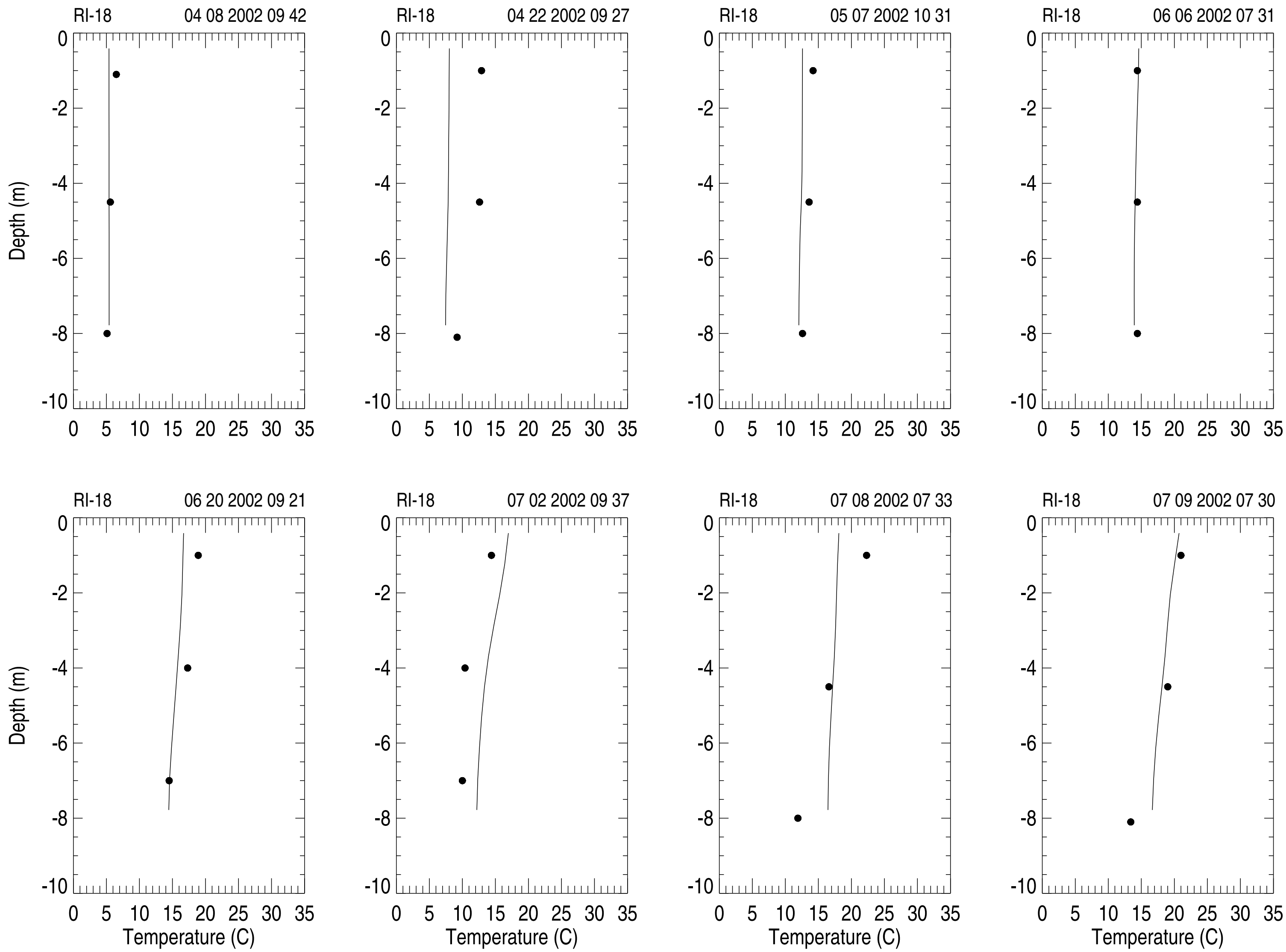

RI-15 07 08 2002 07 58
RI-15 07 09 2002 08 01
RI-15 07 23 2002 09 52
RI-15 08 06 2002 10 38
RI-15 08 13 2002 12 09
RI-15 09 04 2002 09 50
RI-15 09 30 2002 10 18
RI-15 10 07 2002 10 31
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

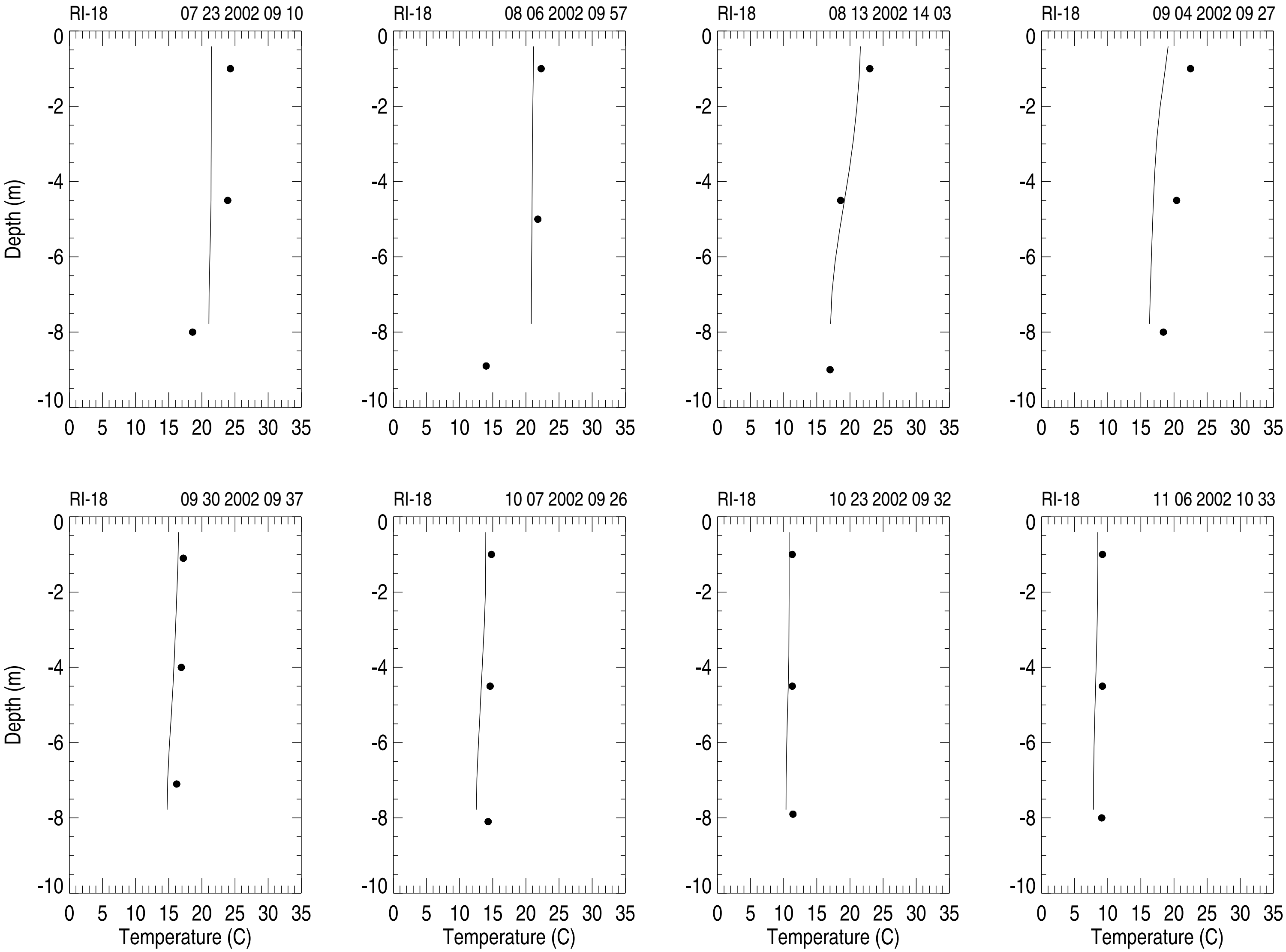


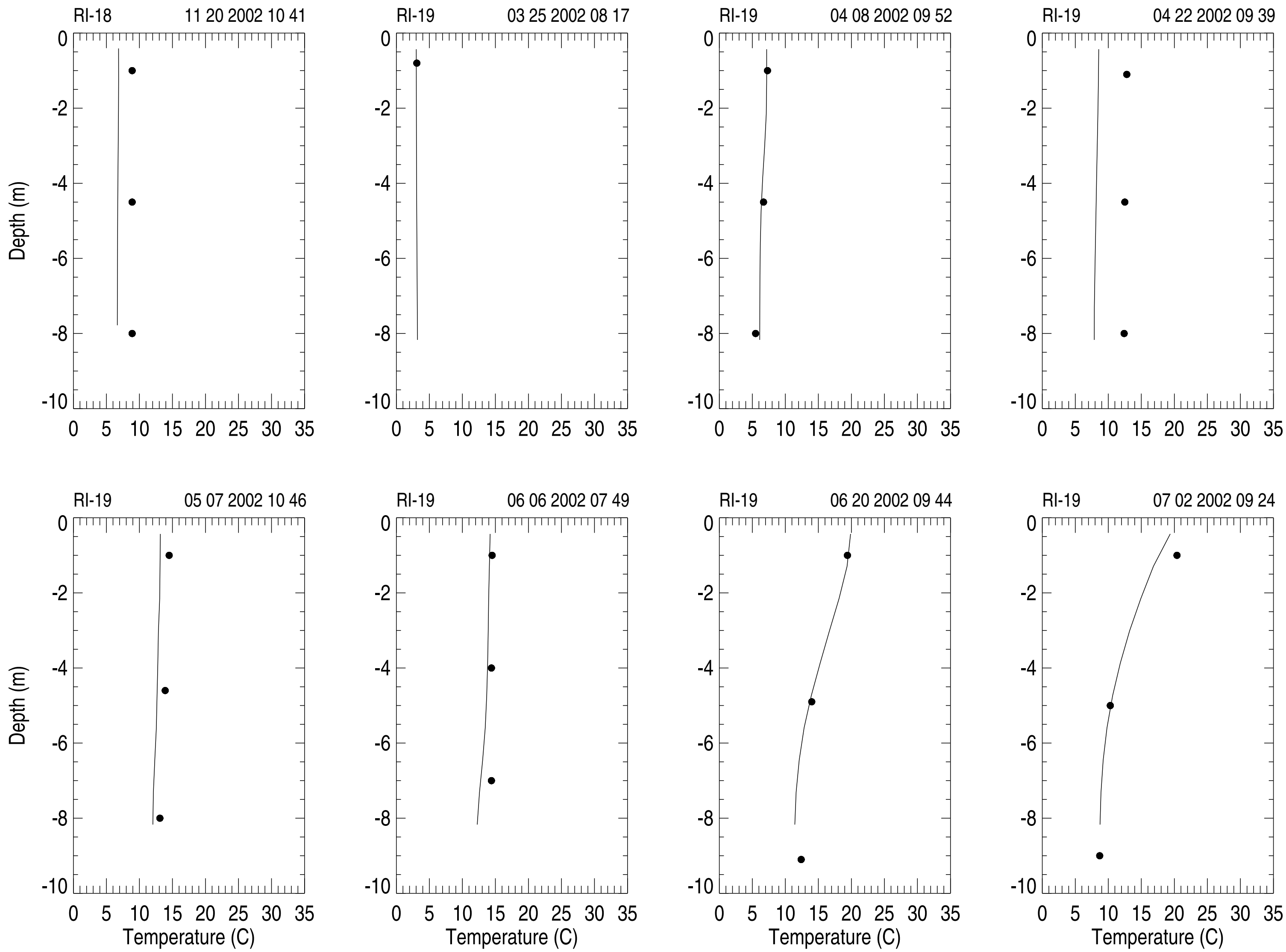
RI-15
10 23 2002 10 14
RI-15
11 06 2002 11 11
RI-15
11 20 2002 10 21
RI-17
03 25 2002 09 09
RI-17
04 08 2002 10 42
RI-17
04 09 2002 09 29
RI-17
04 22 2002 10 25
RI-17
05 07 2002 11 29
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

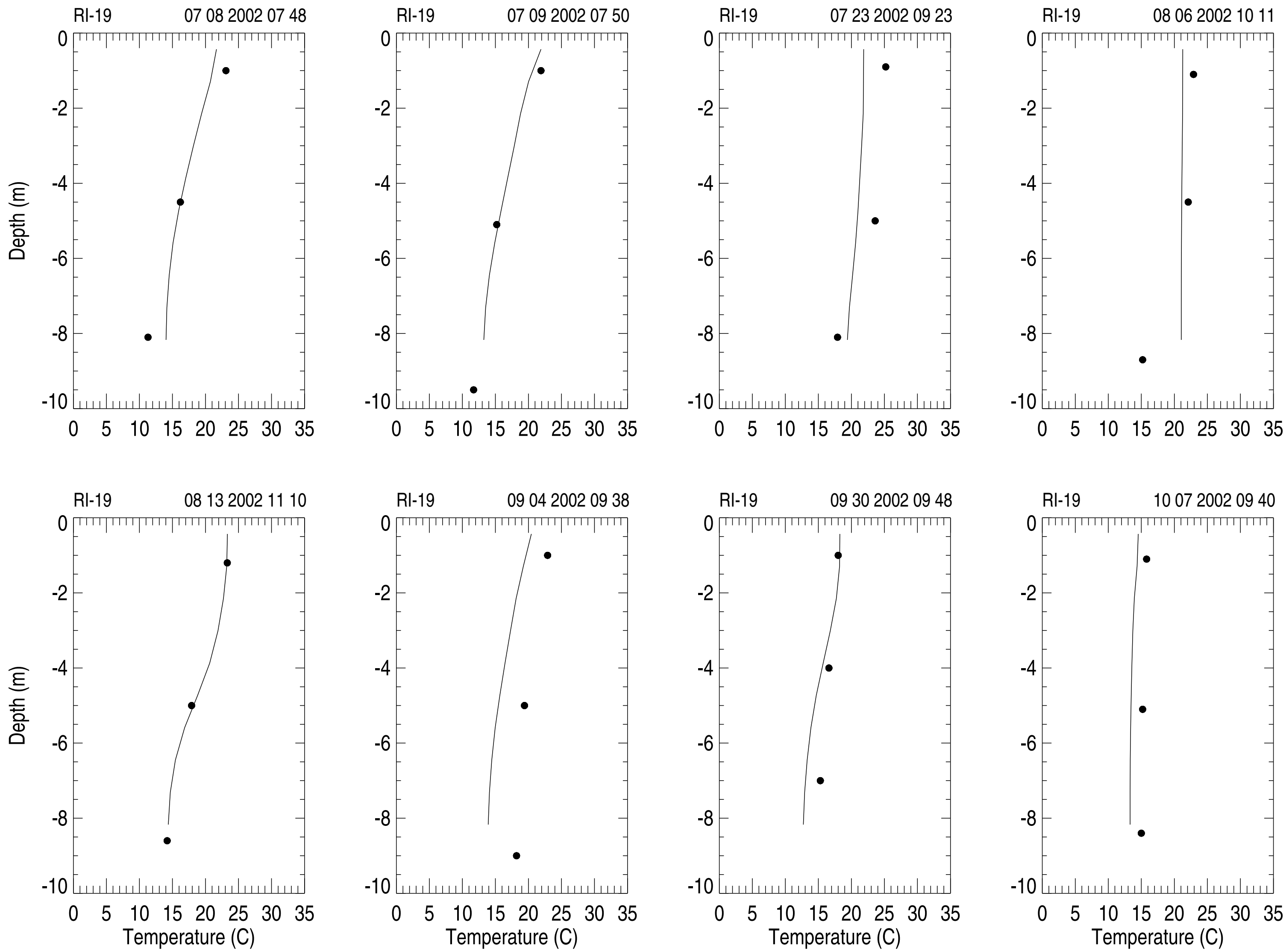

RI-17
06 06 2002 08 56
06 20 2002 10 34
07 02 2002 10 45
07 08 2002 09 58
07 09 2002 09 42
07 23 2002 10 13
08 06 2002 11 03
08 13 2002 12 51
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35

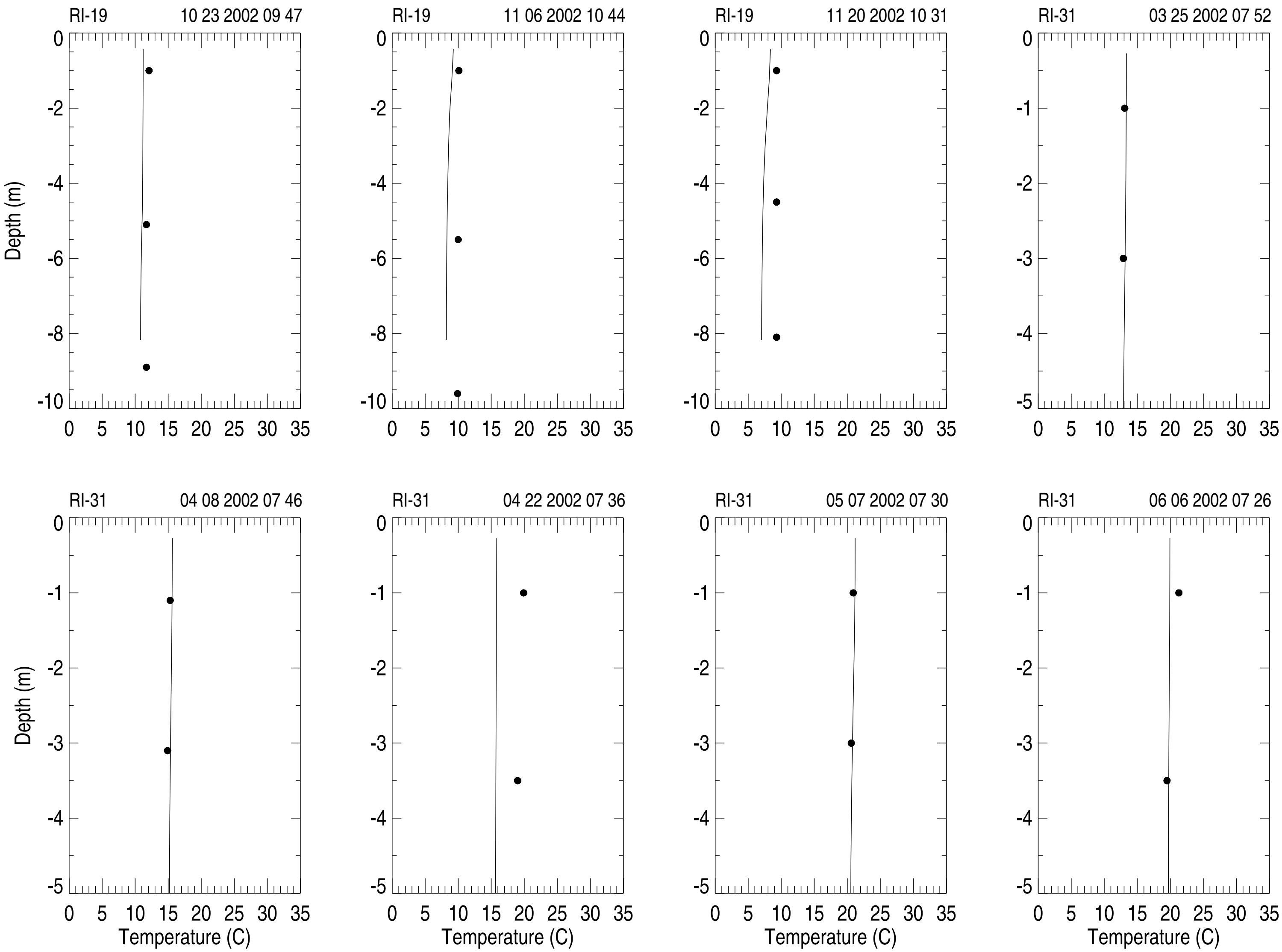

RI-17
09 04 2002 11 10
RI-17
09 30 2002 10 40
RI-17
10 07 2002 11 07
RI-17
10 23 2002 11 06
RI-17
11 06 2002 10 07
RI-17
11 20 2002 10 02
RI-17
12 11 2002 08 15
RI-18
03 25 2002 08 00
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

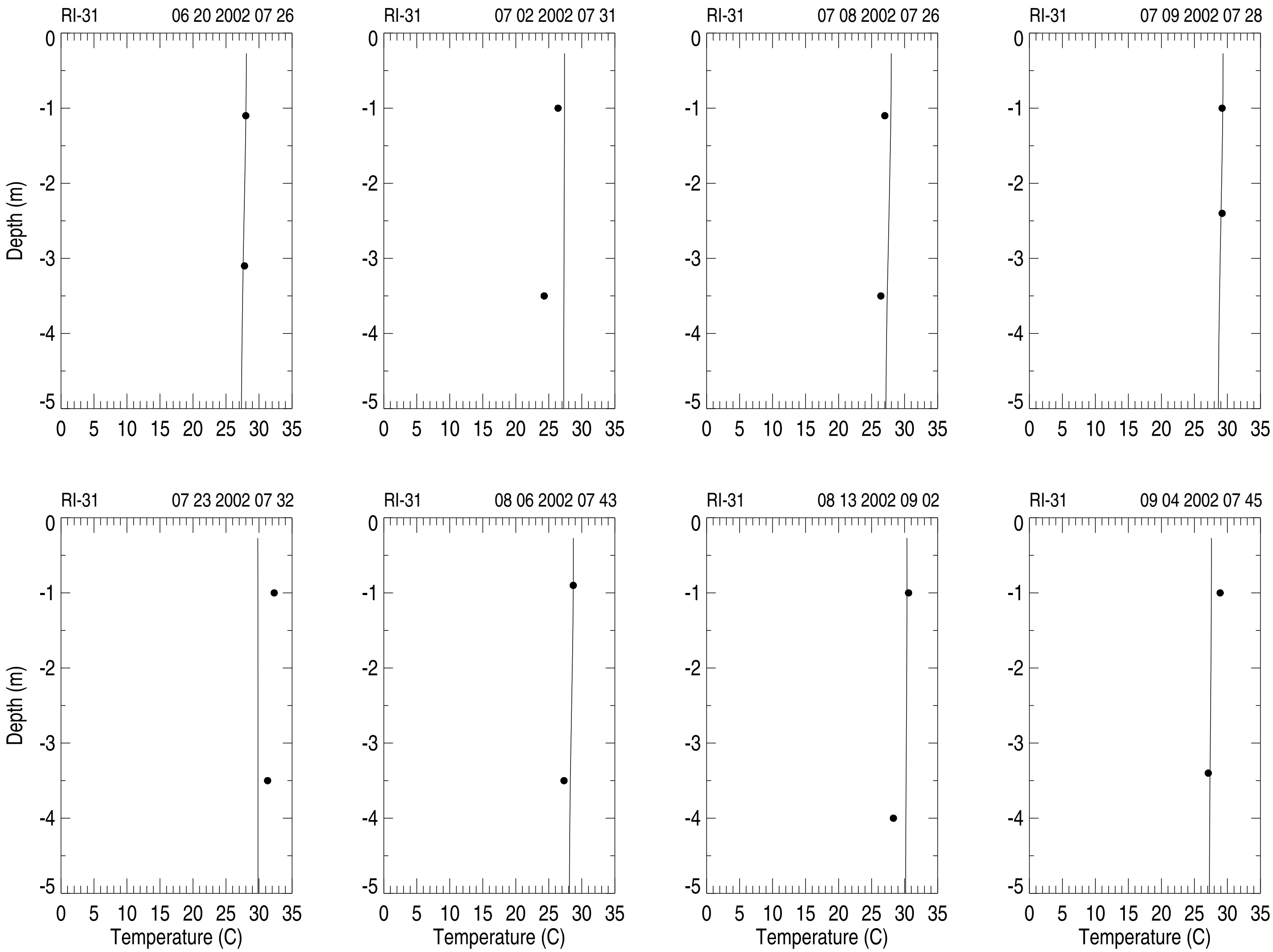

RI-18
04 08 2002 09 42
RI-18
04 22 2002 09 27
RI-18
05 07 2002 10 31
RI-18
06 06 2002 07 31
RI-18
06 20 2002 09 21
RI-18
07 02 2002 09 37
RI-18
07 08 2002 07 33
RI-18
07 09 2002 07 30
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)

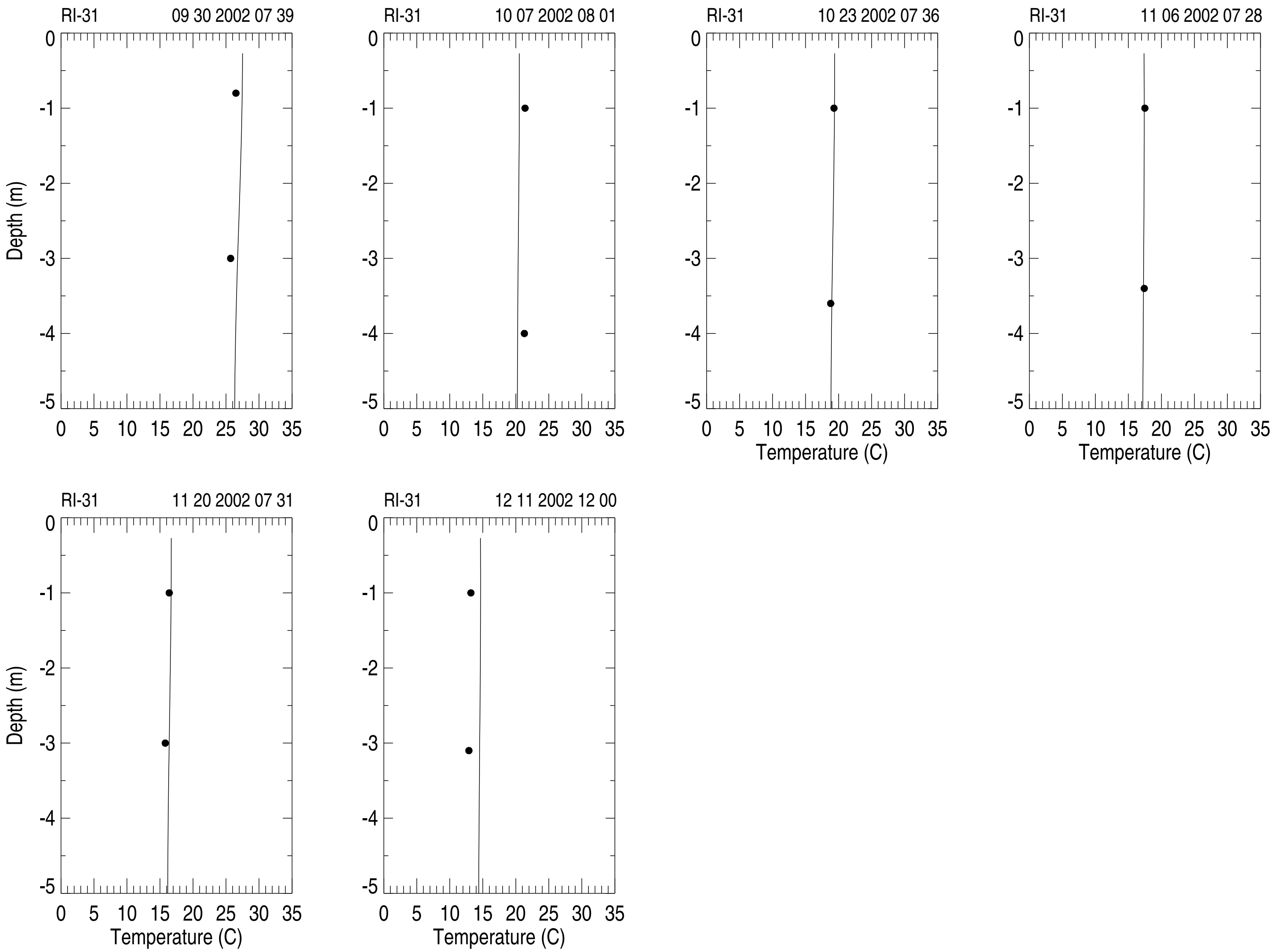

RI-18 07 23 2002 09 10
RI-18 08 06 2002 09 57
RI-18 08 13 2002 14 03
RI-18 09 04 2002 09 27
RI-18 09 30 2002 09 37
RI-18 10 07 2002 09 26
RI-18 10 23 2002 09 32
RI-18 11 06 2002 10 33
Depth (m)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35
Temperature (C)


RI-18
11 20 2002 10 41
RI-19
03 25 2002 08 17
RI-19
04 08 2002 09 52
RI-19
04 22 2002 09 39
RI-19
05 07 2002 10 46
RI-19
06 06 2002 07 49
RI-19
06 20 2002 09 44
RI-19
07 02 2002 09 24
Depth (m)
Temperature (C)

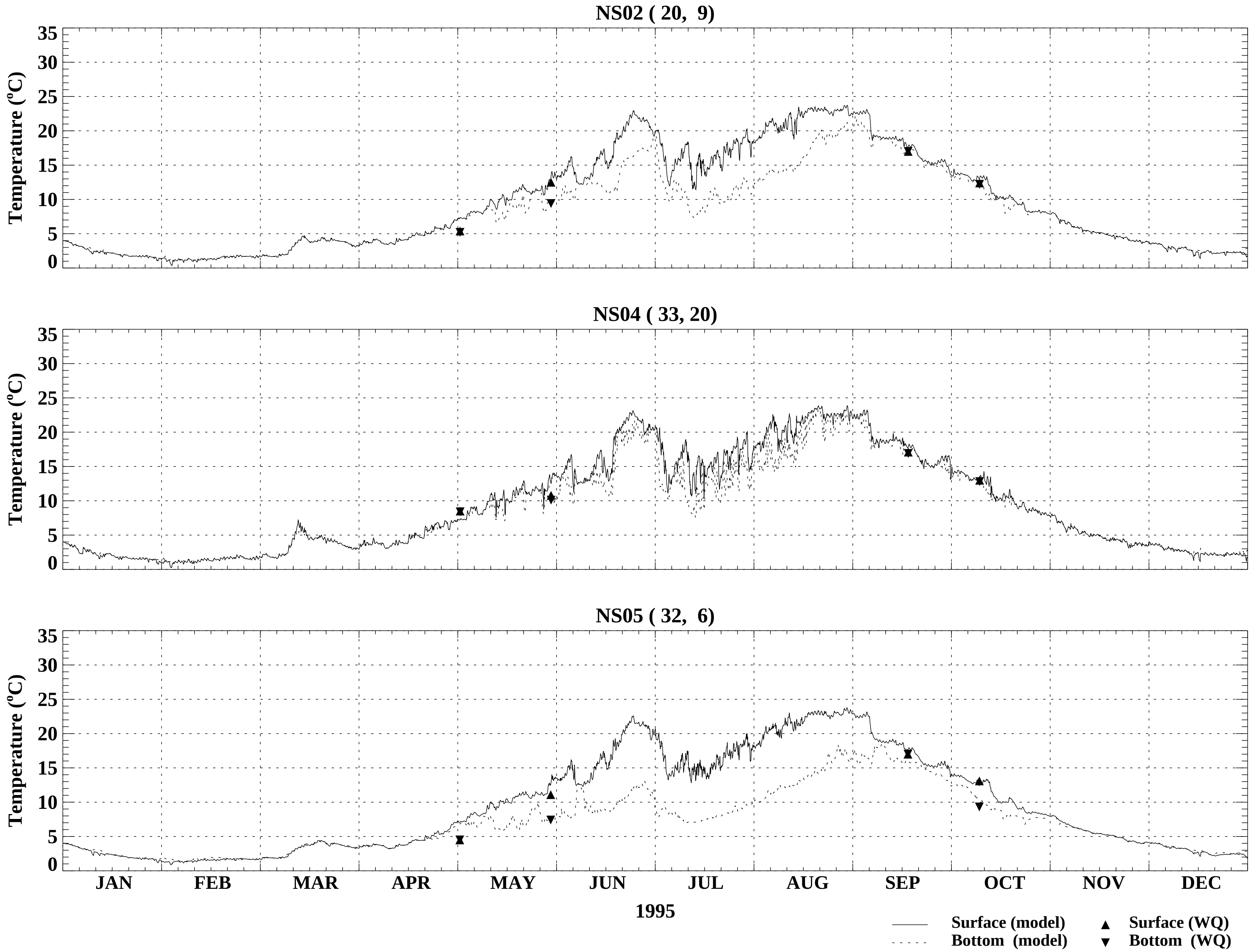

RI-19
07 08 2002 07 48
RI-19
07 09 2002 07 50
RI-19
07 23 2002 09 23
RI-19
08 06 2002 10 11
RI-19
08 13 2002 11 10
RI-19
09 04 2002 09 38
RI-19
09 30 2002 09 48
RI-19
10 07 2002 09 40
Depth (m)
Temperature (C)
0
-2
-4
-6
-8
-10
0 5 10 15 20 25 30 35


RI-19 10 23 2002 09 47
RI-19 11 06 2002 10 44
RI-19 11 20 2002 10 31
RI-31 03 25 2002 07 52
RI-31 04 08 2002 07 46
RI-31 04 22 2002 07 36
RI-31 05 07 2002 07 30
RI-31 06 06 2002 07 26
Depth (m)
0
-2
-4
-6
-8
-10
-1
-3
-5
0 5 10 15 20 25 30 35
Temperature (C)

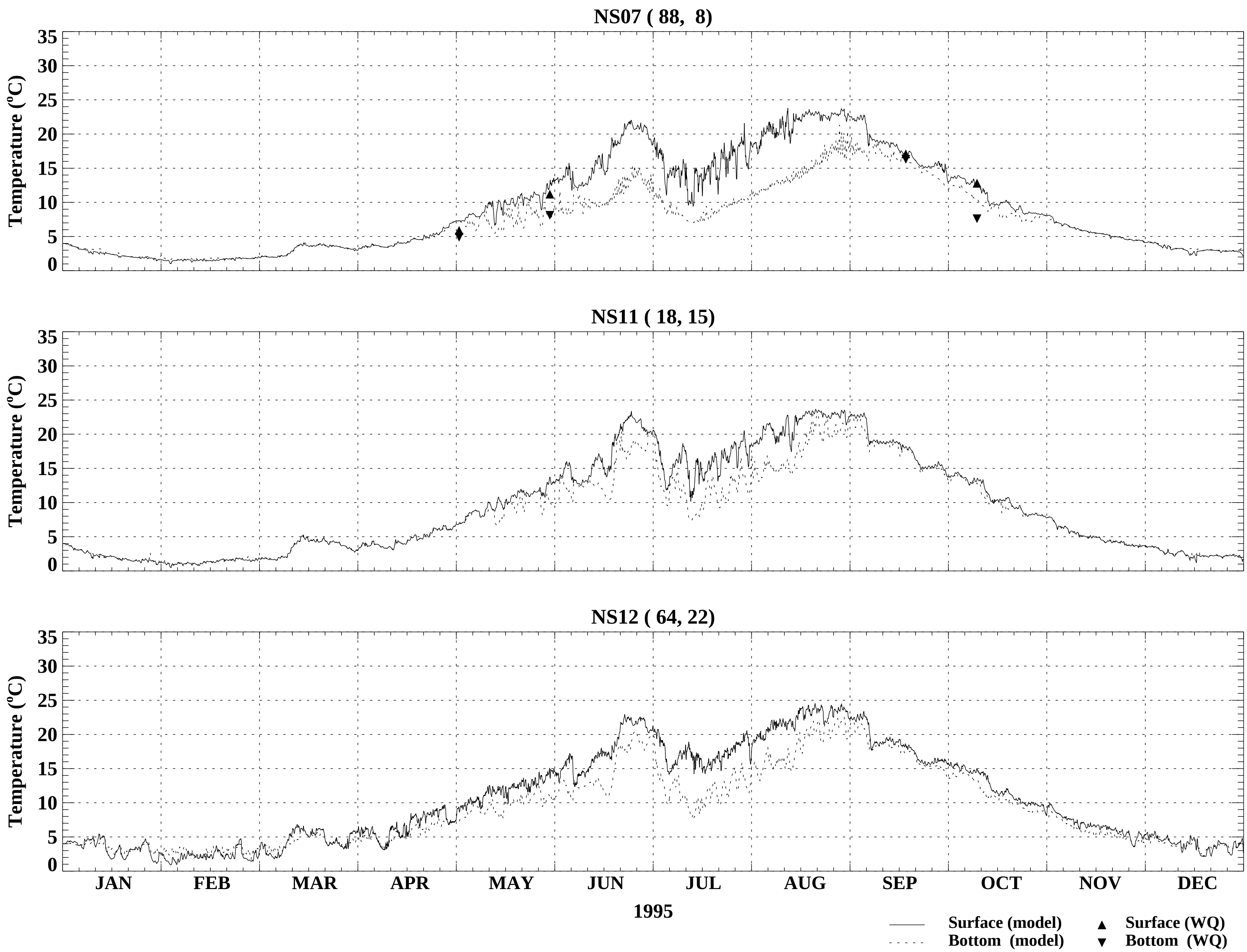

RI-31
06 20 2002 07 26
RI-31
07 02 2002 07 31
RI-31
07 08 2002 07 26
RI-31
07 09 2002 07 28
RI-31
07 23 2002 07 32
RI-31
08 06 2002 07 43
RI-31
08 13 2002 09 02
RI-31
09 04 2002 07 45
Depth (m)
Temperature (C)
0
-1
-2
-3
-4
-5
0 5 10 15 20 25 30 35


RI-31
09 30 2002 07 39
RI-31
10 07 2002 08 01
RI-31
10 23 2002 07 36
RI-31
11 06 2002 07 28
RI-31
11 20 2002 07 31
RI-31
12 11 2002 12 00
Depth (m)
Temperature (C)

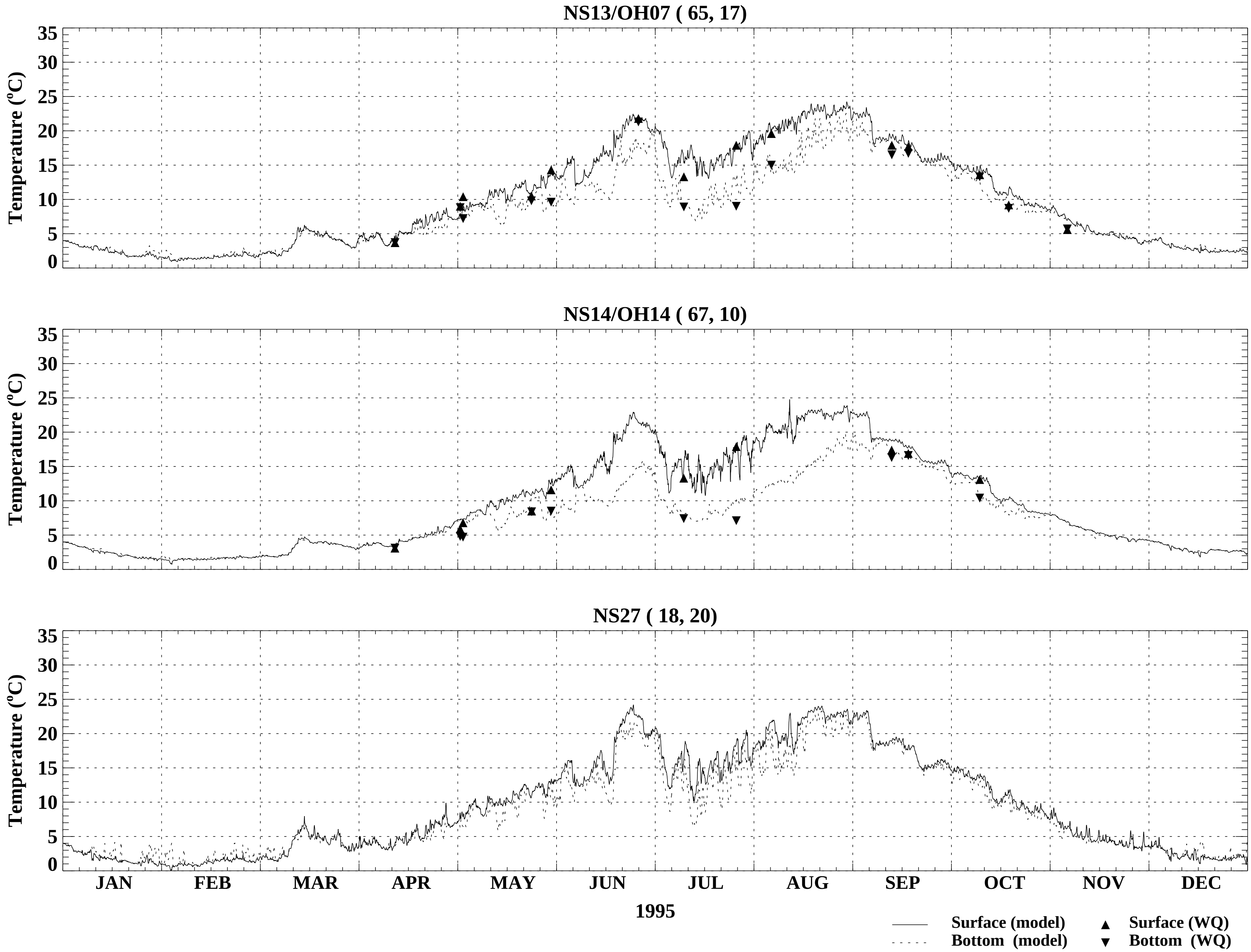
APPENDIX 2
COMPARISON OF THE COMPUTED AND OBSERVED SURFACE AND BOTTOM TEMPERATURES AT 34 MMSD SAMPLING STATIONS



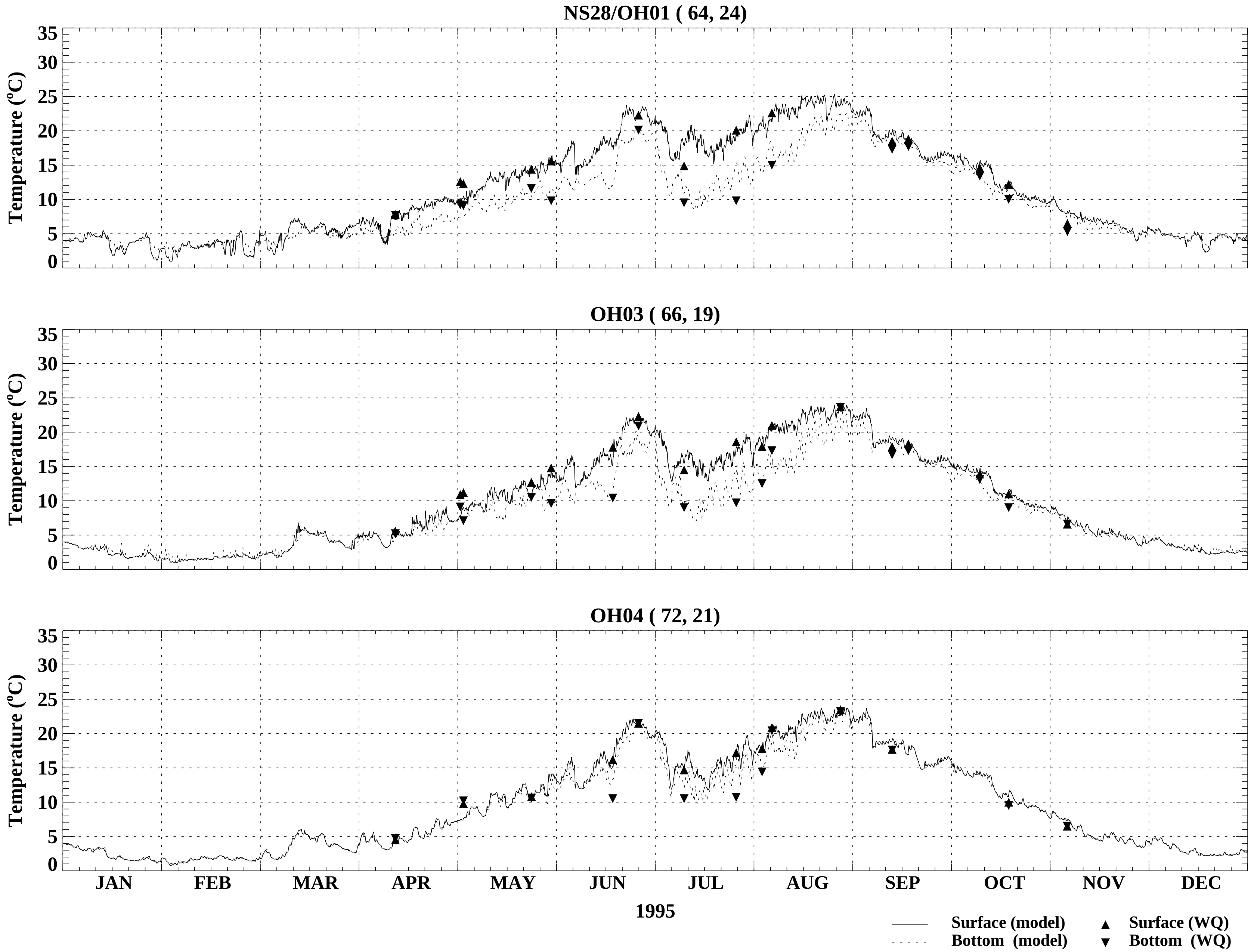
NS02 (20, 9)
NS04 (33, 20)
NS05 (32, 6)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1995
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)



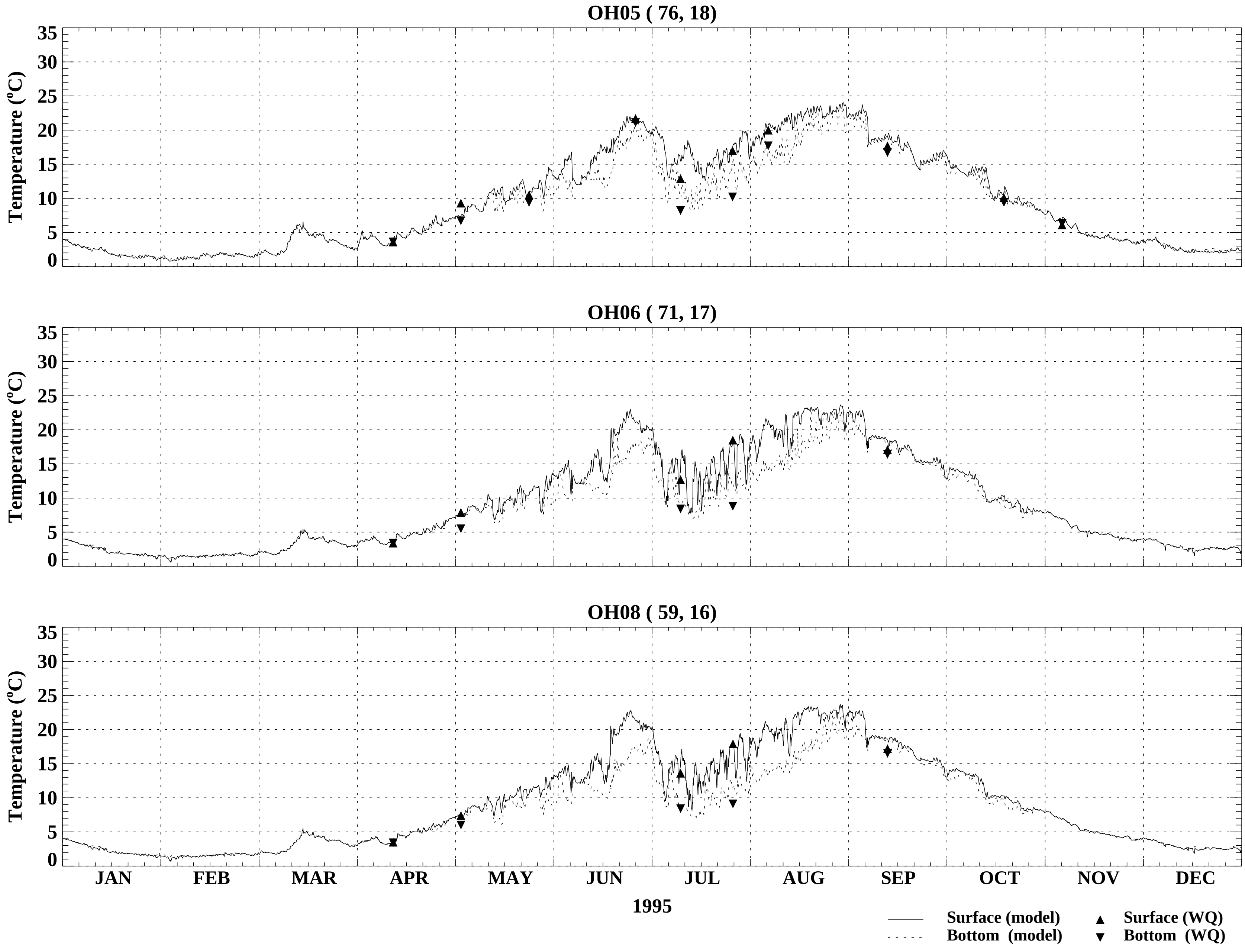
NS07 (88, 8)
NS11 (18, 15)
NS12 (64, 22)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1995
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)



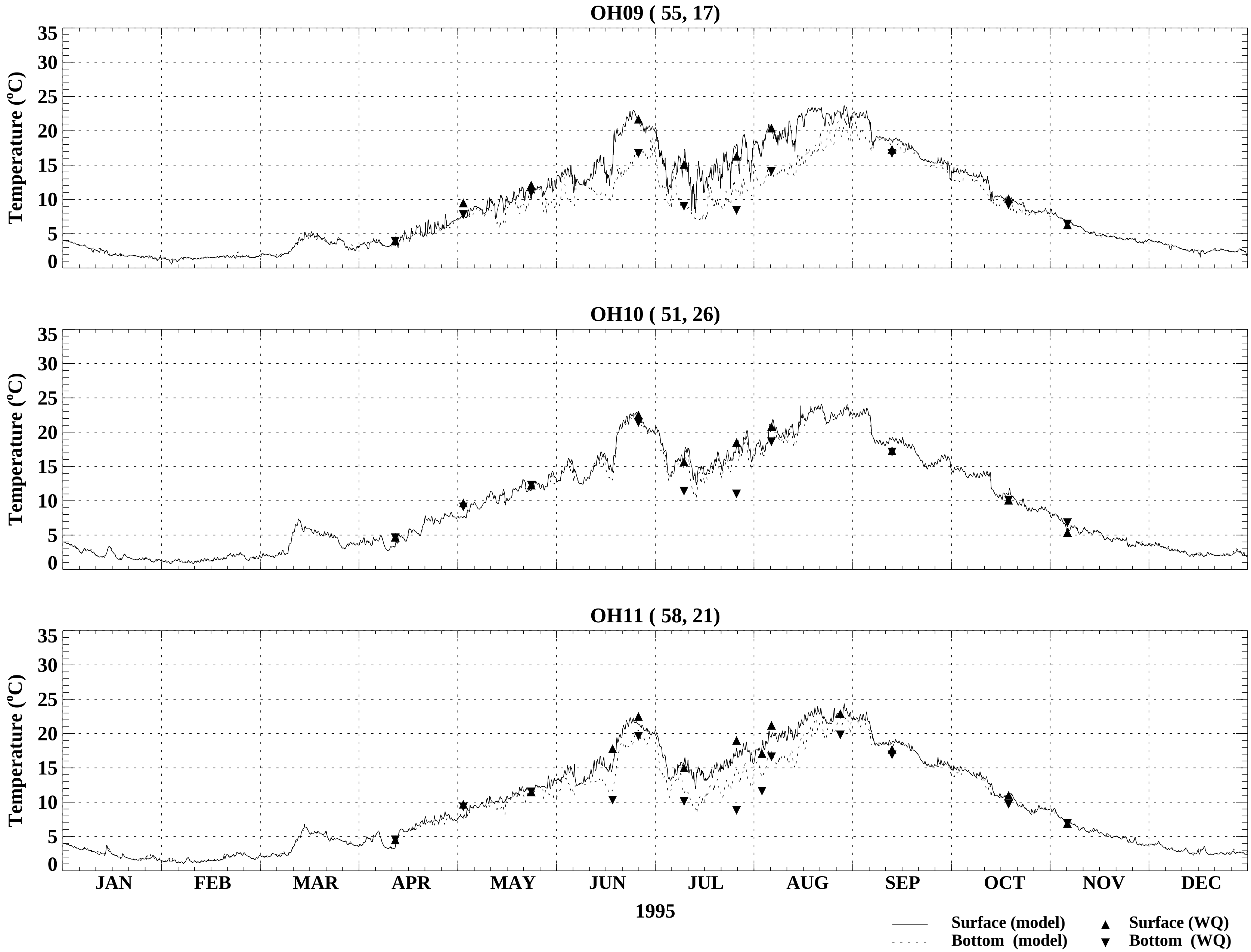
NS13/OH07 (65, 17)
NS14/OH14 (67, 10)
NS27 (18, 20)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1995
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

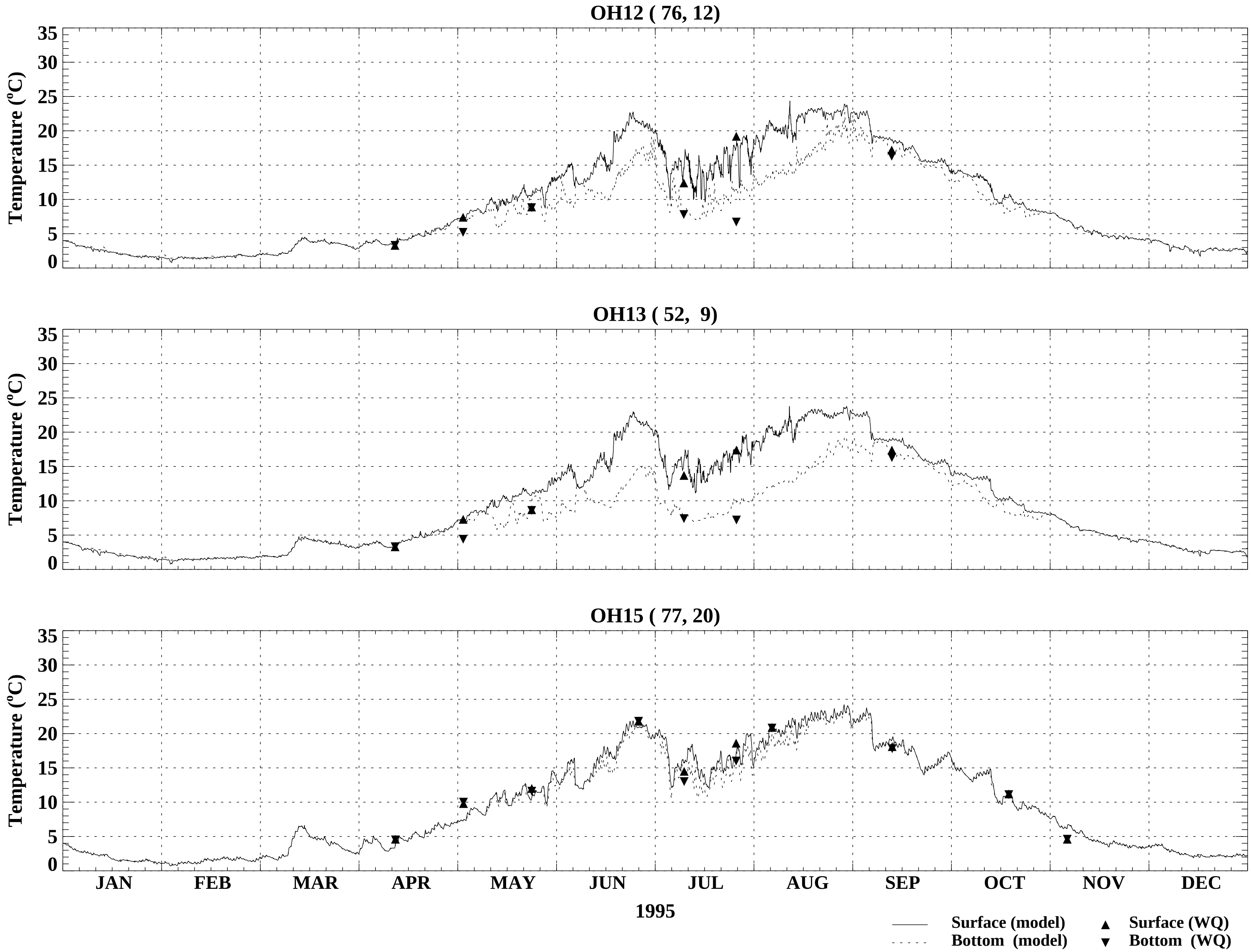


NS28/OH01 (64, 24)
OH03 (66, 19)
OH04 (72, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1995
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

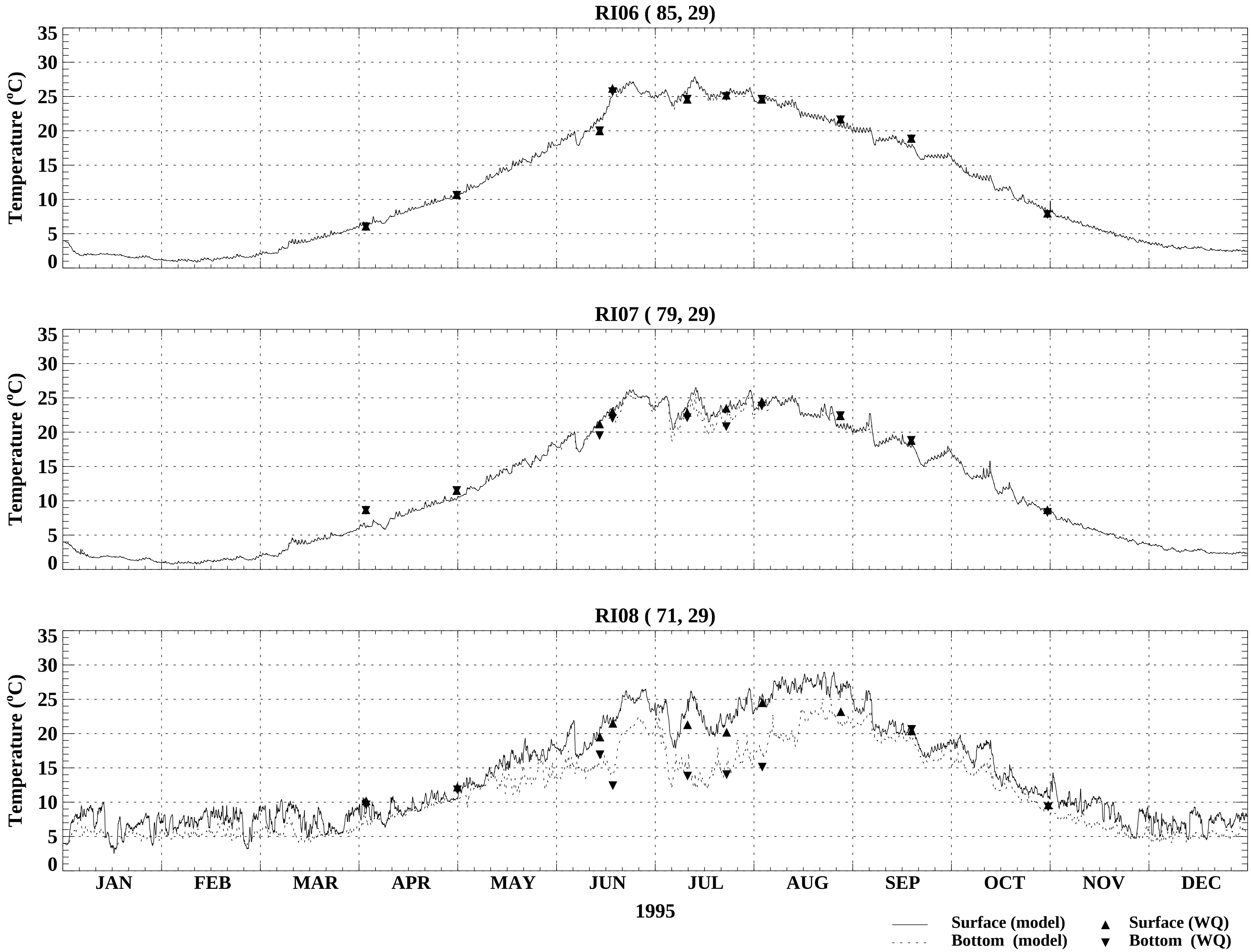


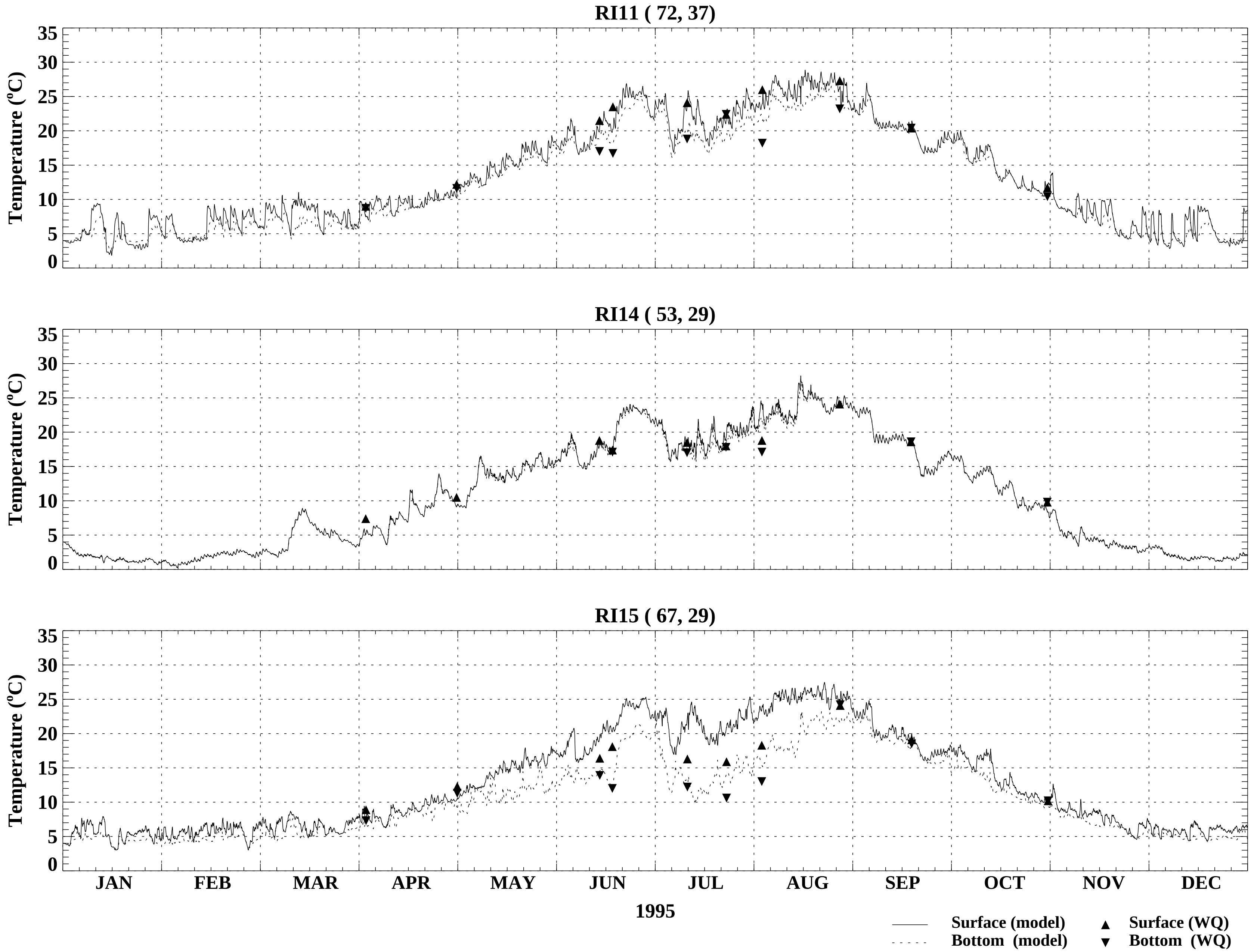
OH05 (76, 18)
OH06 (71, 17)
OH08 (59, 16)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1995
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


OH09 (55, 17)
OH10 (51, 26)
OH11 (58, 21)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1995
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

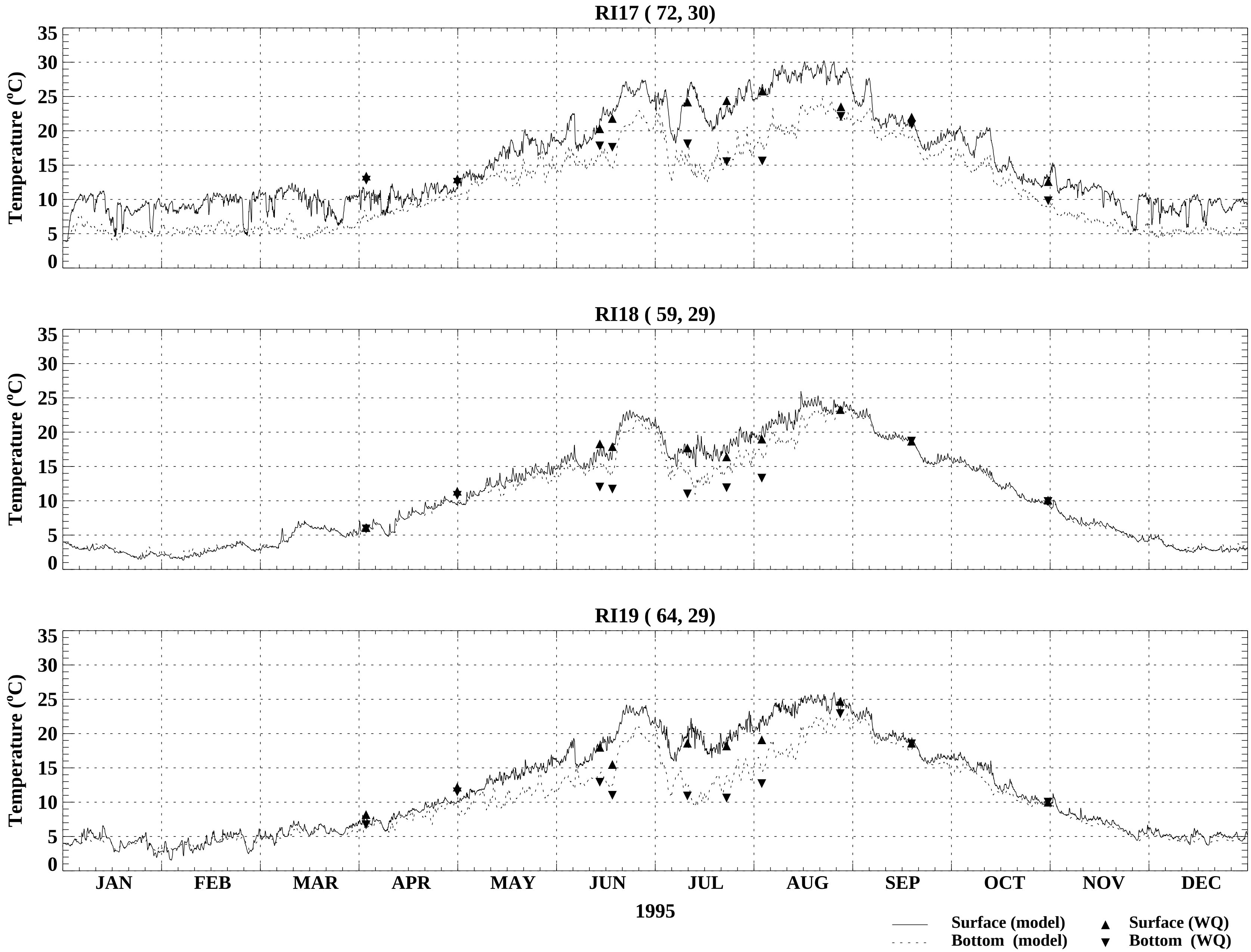


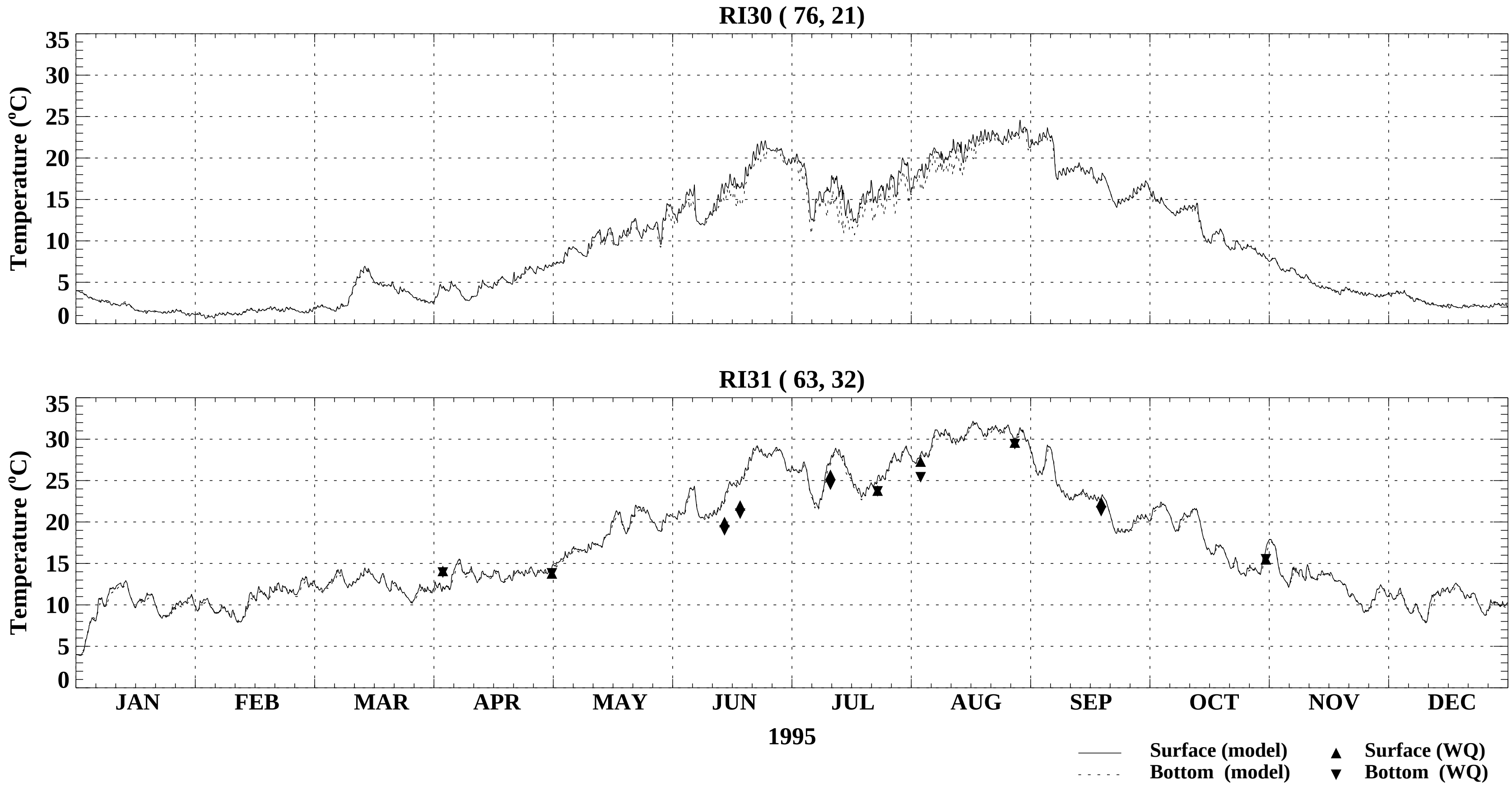
OH12 (76, 12)
OH13 (52, 9)
OH15 (77, 20)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1995
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


RI06 (85, 29)
RI07 (79, 29)
RI08 (71, 29)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1995
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

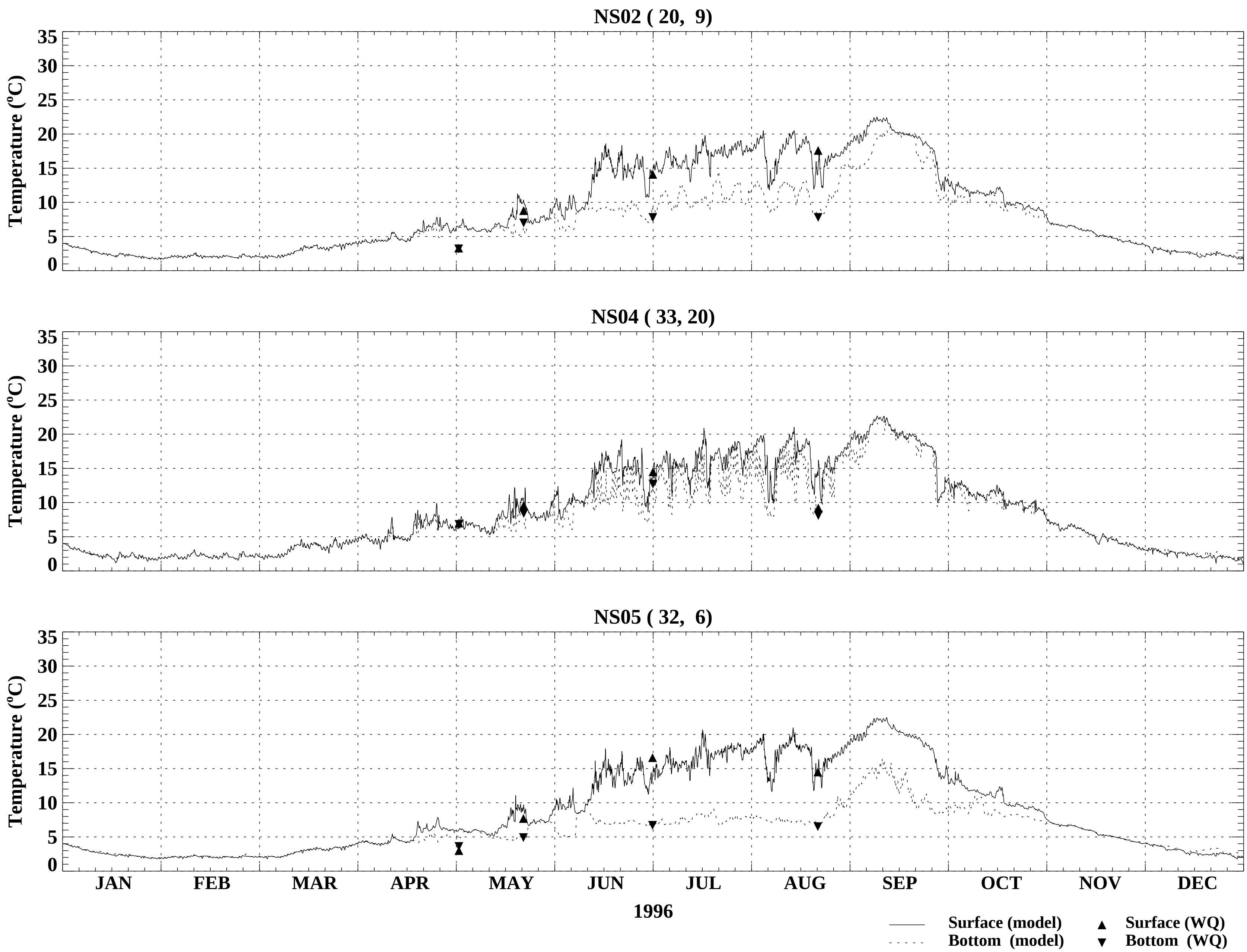


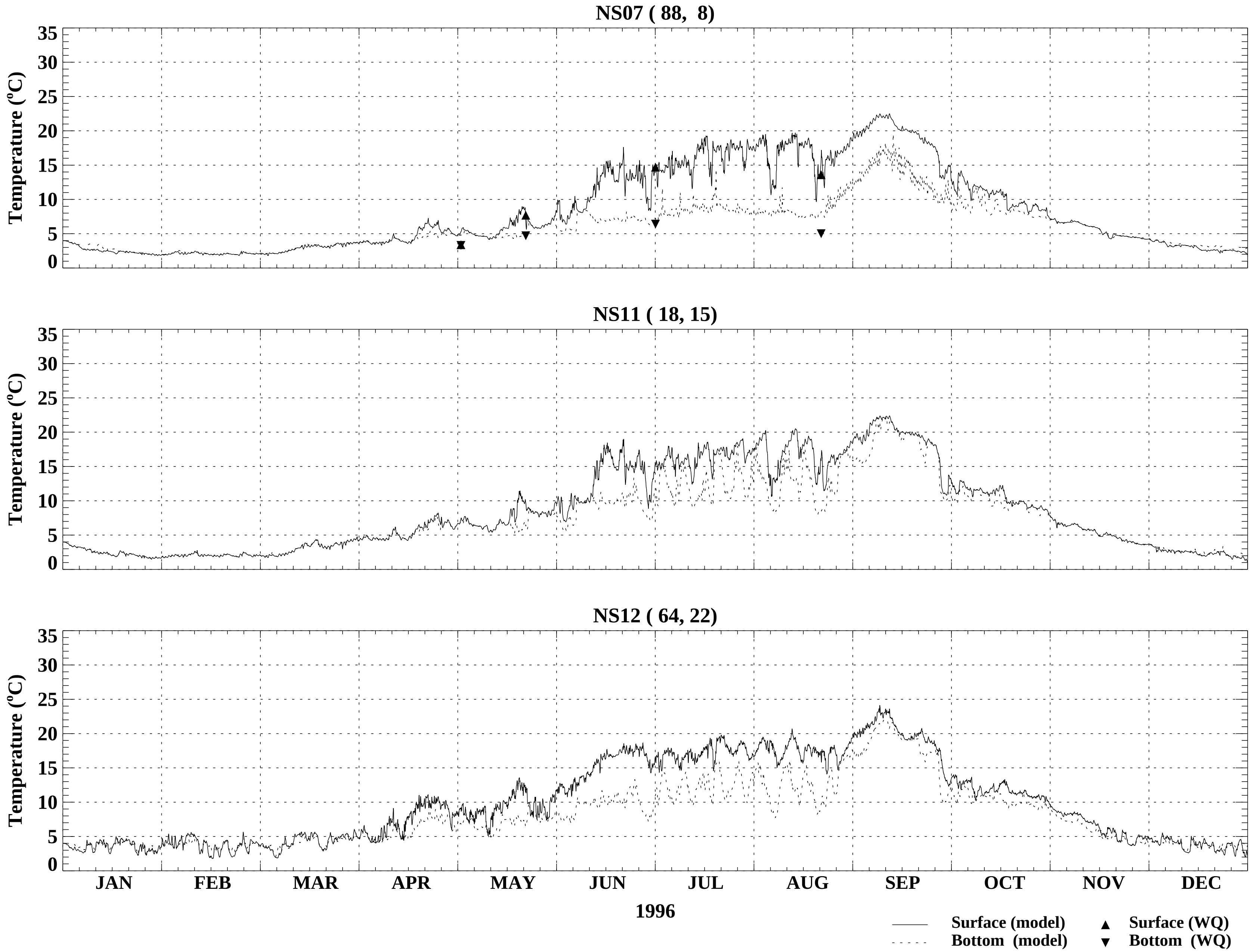
RI11 (72, 37)
RI14 (53, 29)
RI15 (67, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1995
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

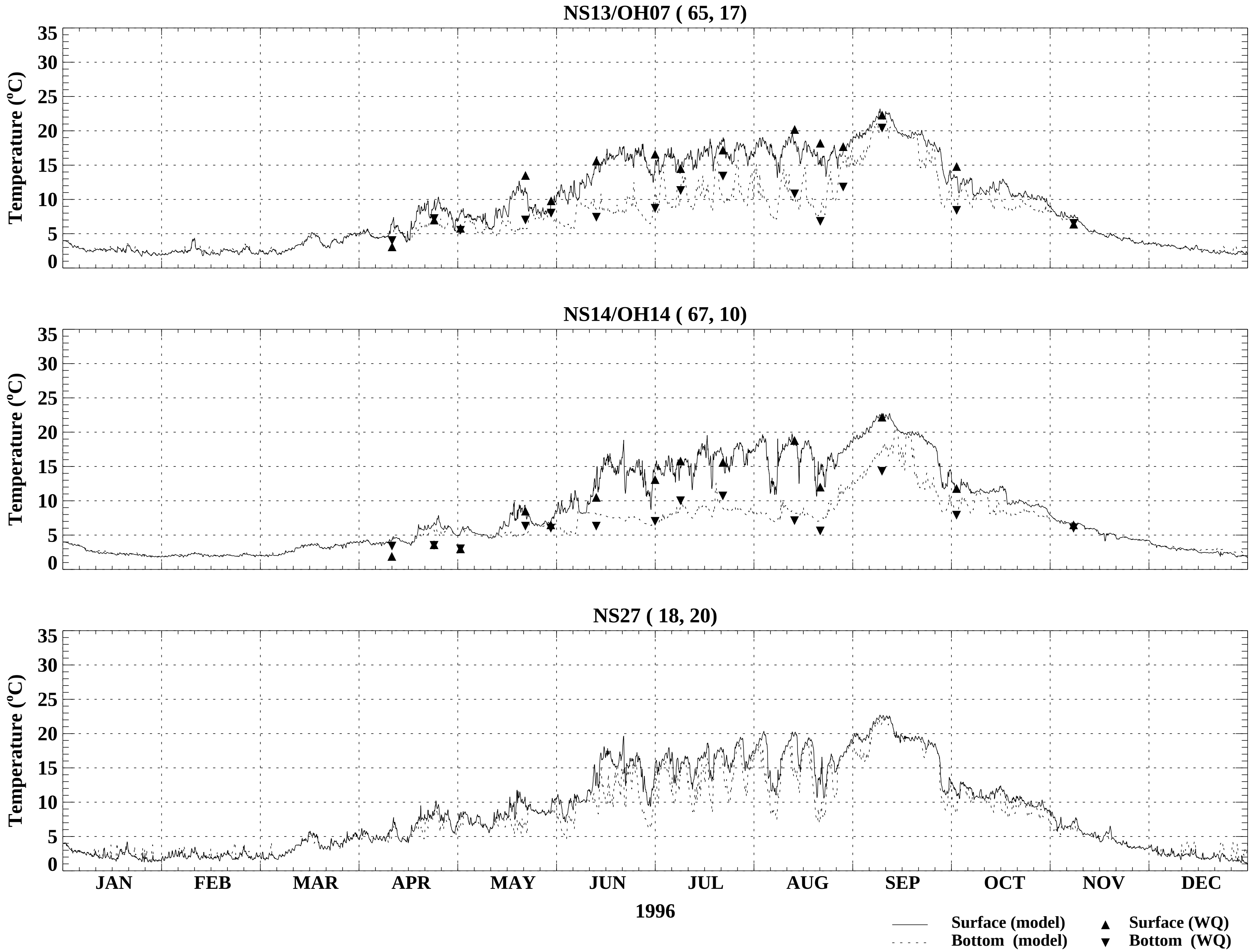

RI17 (72, 30)
RI18 (59, 29)
RI19 (64, 29)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1995
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

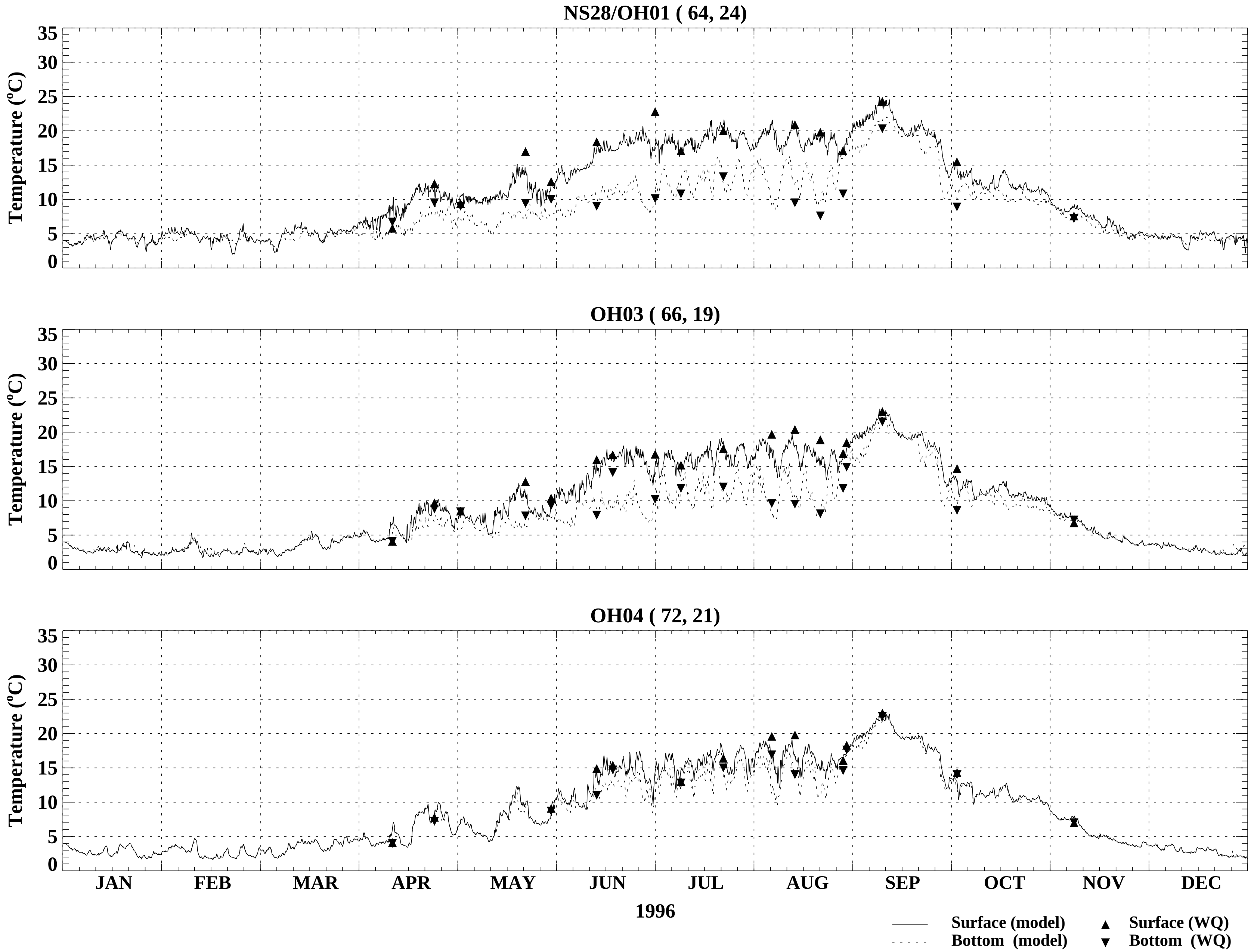


RI30 (76, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
RI31 (63, 32)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1995
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

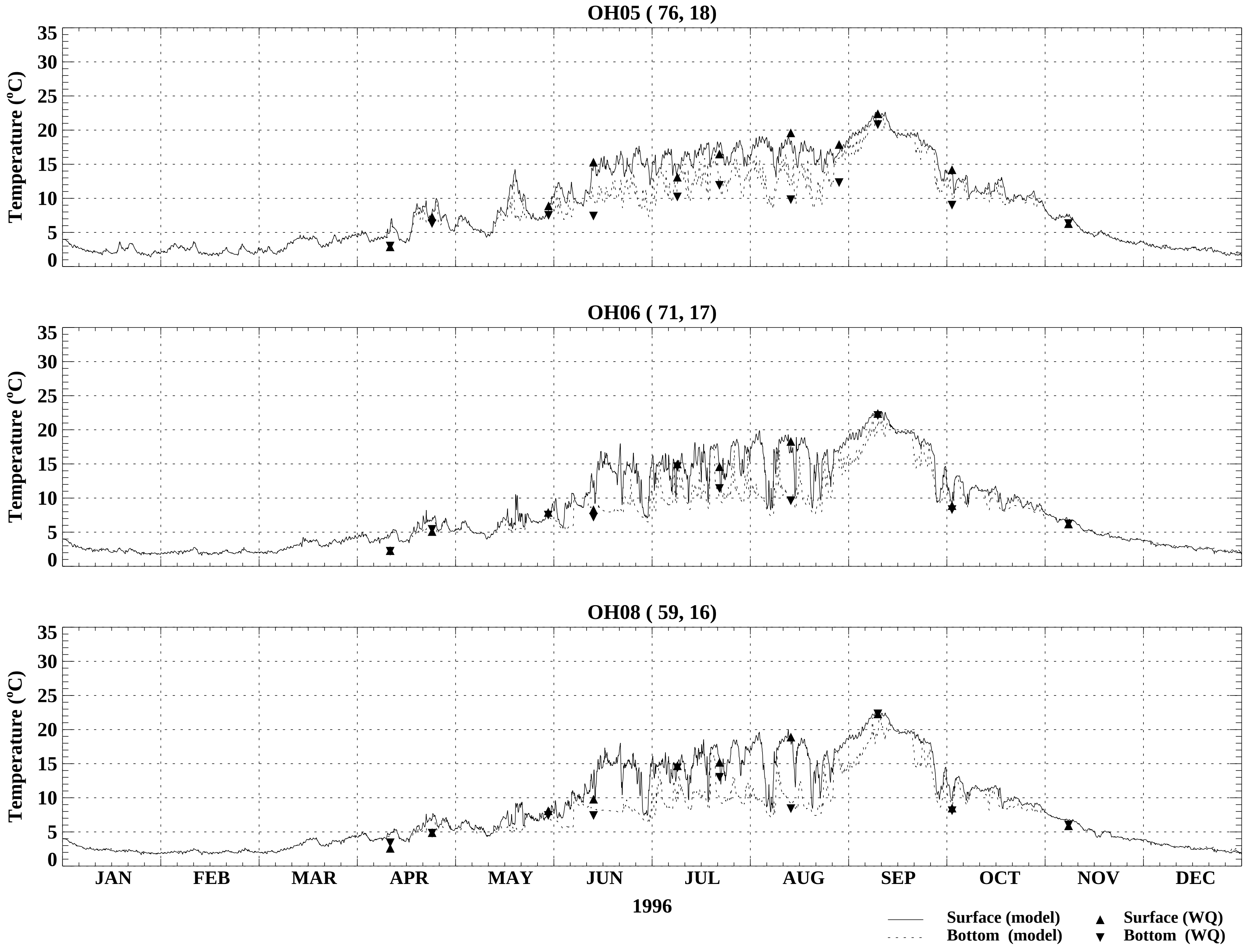

NS02 (20, 9)
NS04 (33, 20)
NS05 (32, 6)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1996
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

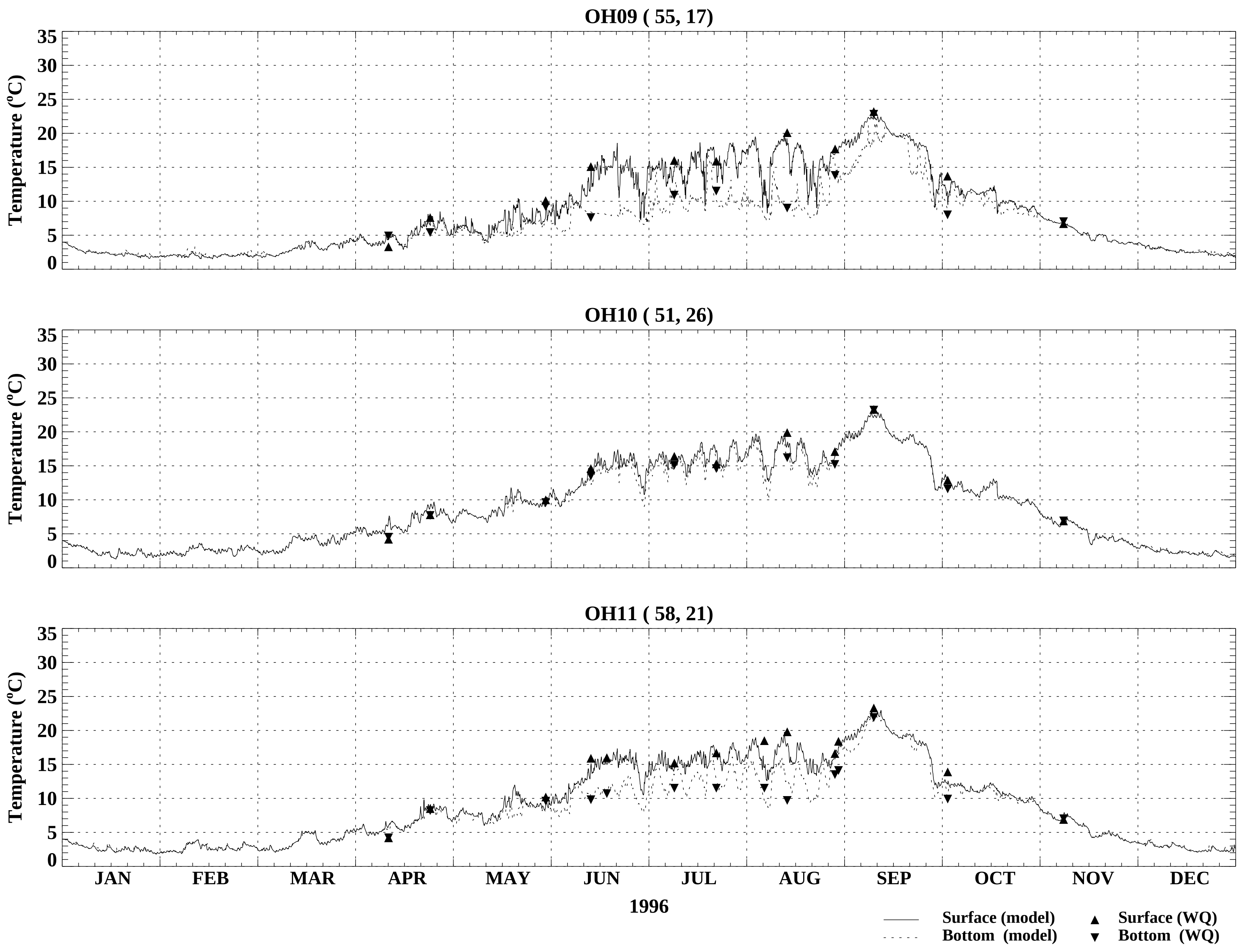

NS07 (88, 8)
NS11 (18, 15)
NS12 (64, 22)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1996
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

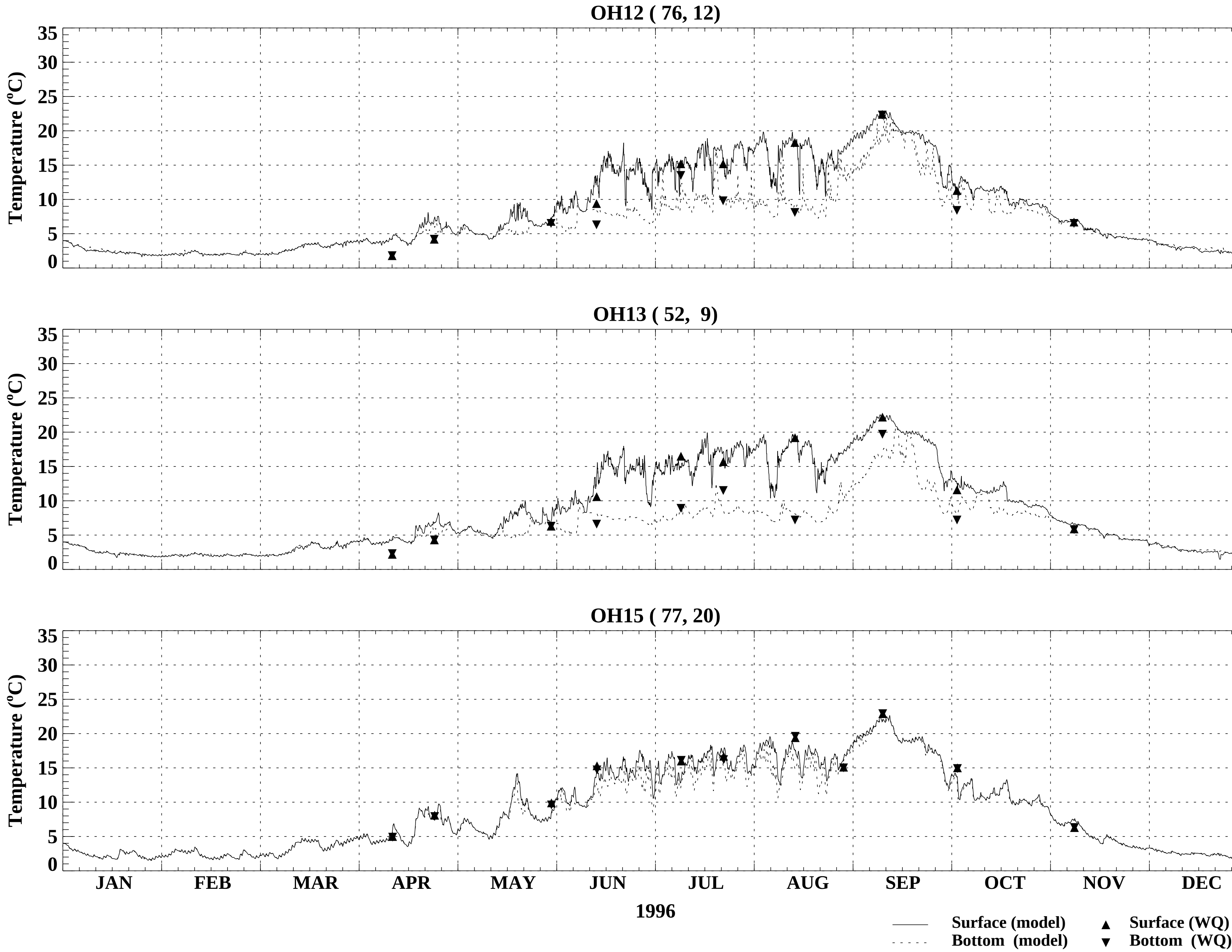

NS13/OH07 (65, 17)
NS14/OH14 (67, 10)
NS27 (18, 20)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1996
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

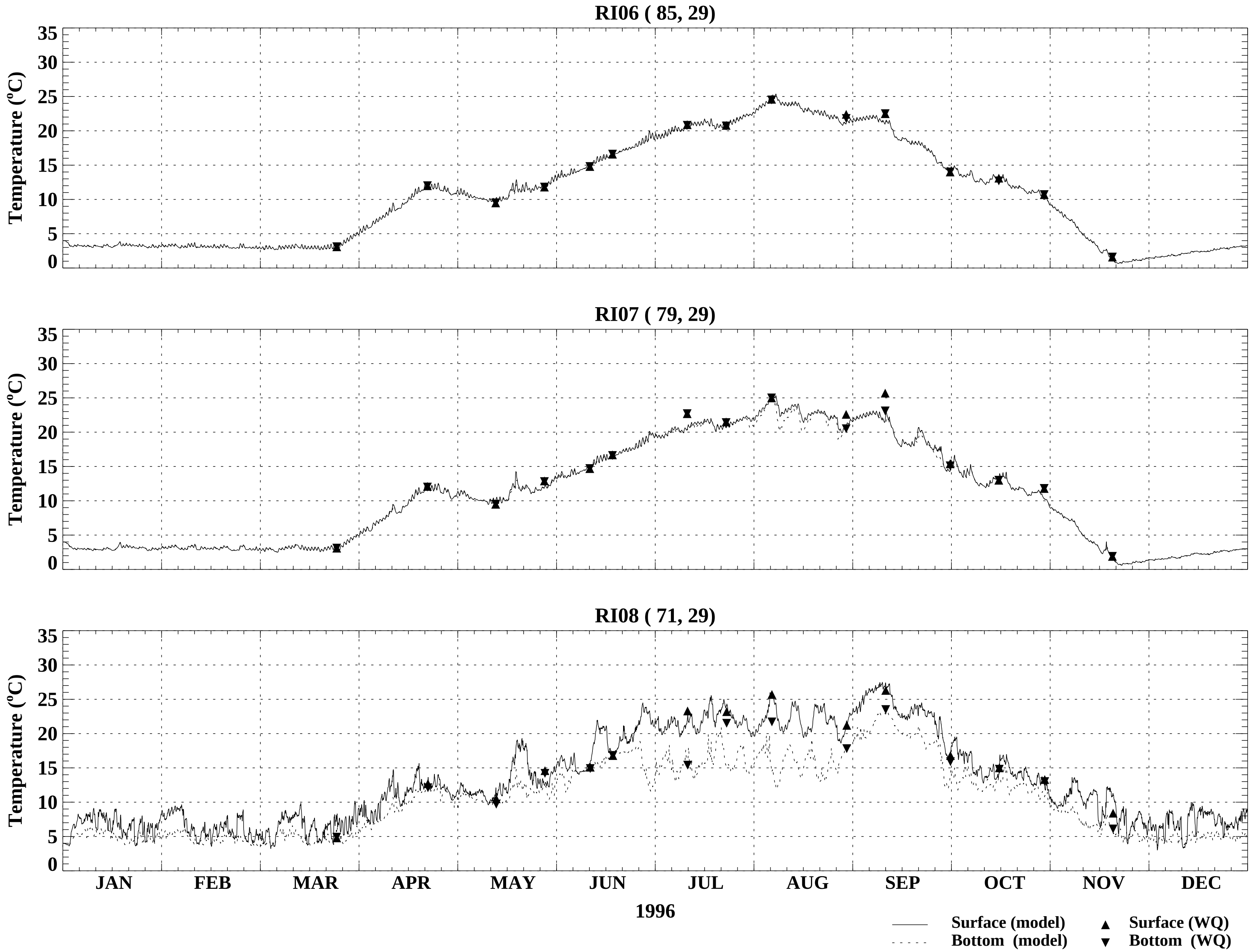


NS28/OH01 (64, 24)
OH03 (66, 19)
OH04 (72, 21)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1996
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

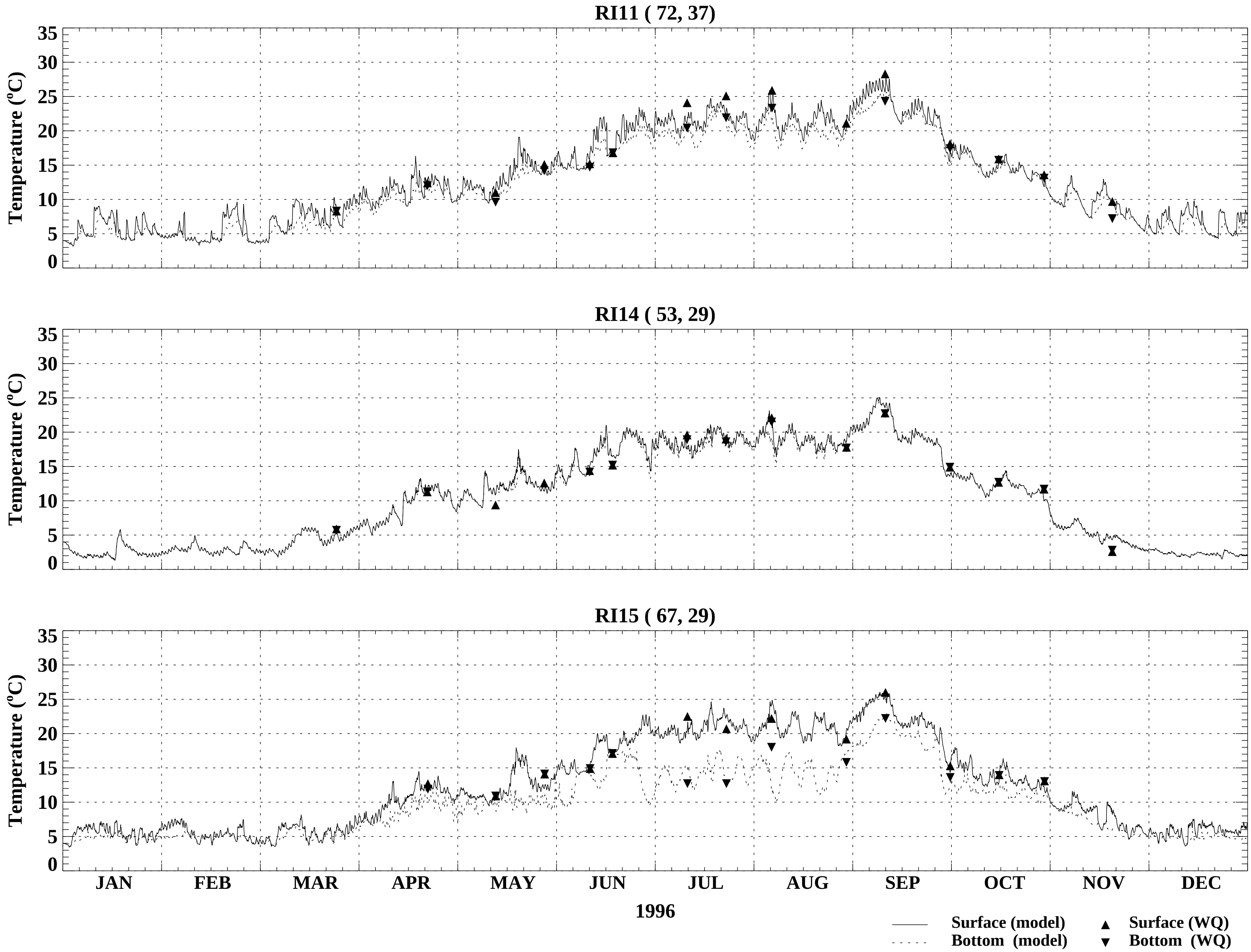

OH05 (76, 18)
OH06 (71, 17)
OH08 (59, 16)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1996
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

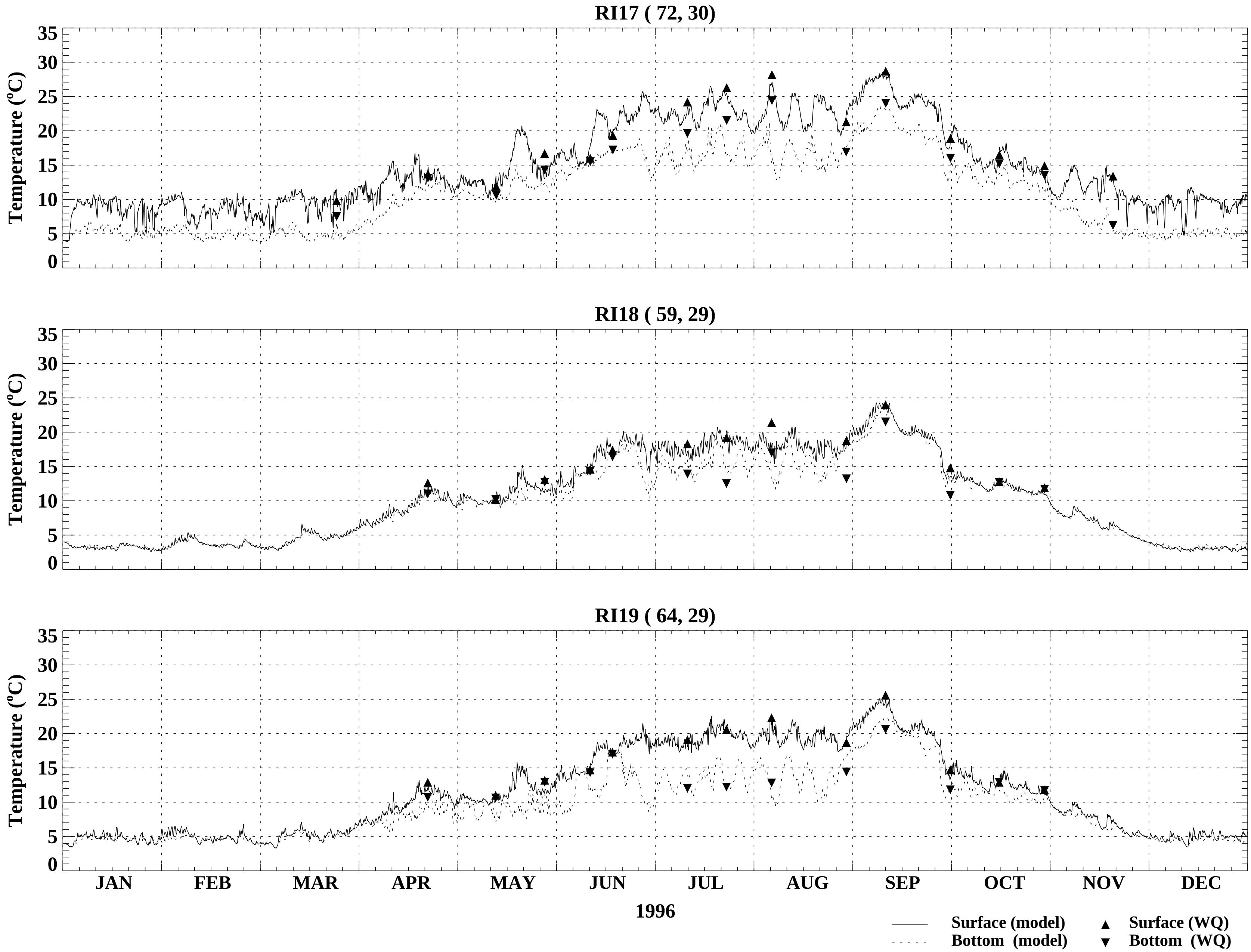

OH09 (55, 17)
OH10 (51, 26)
OH11 (58, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1996
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

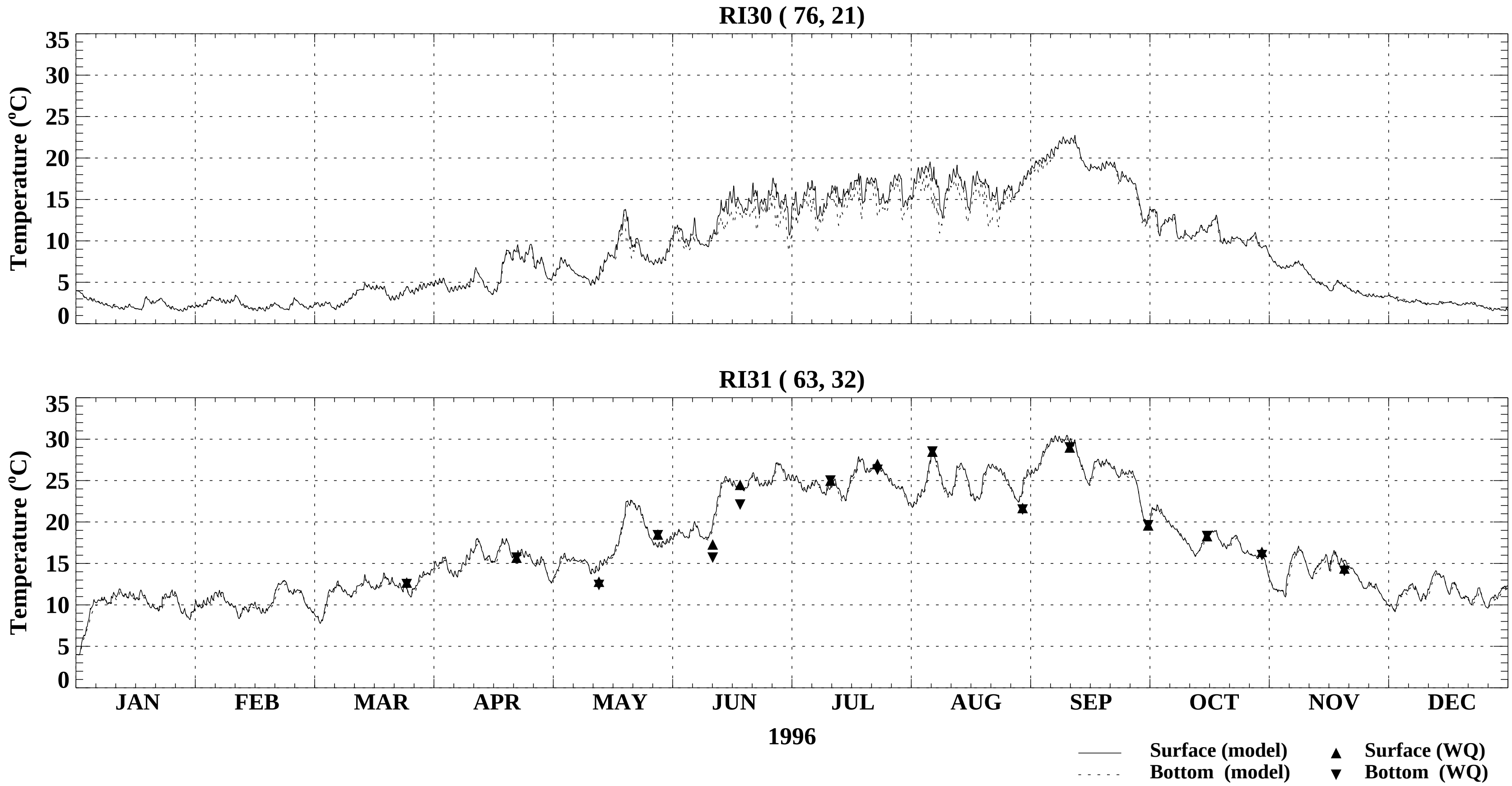

OH12 (76, 12)
OH13 (52, 9)
OH15 (77, 20)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1996
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)



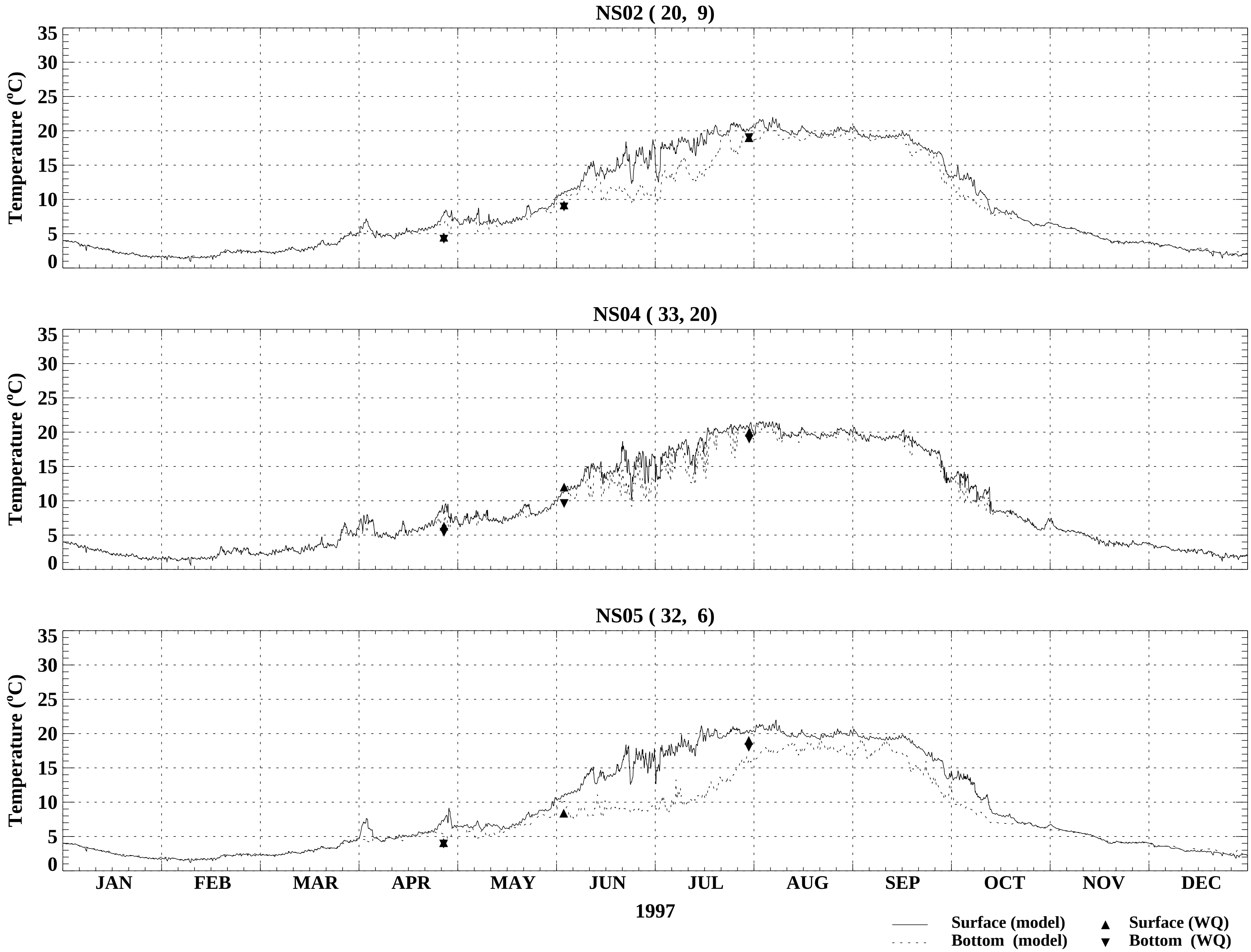
RI06 (85, 29)
RI07 (79, 29)
RI08 (71, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1996
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

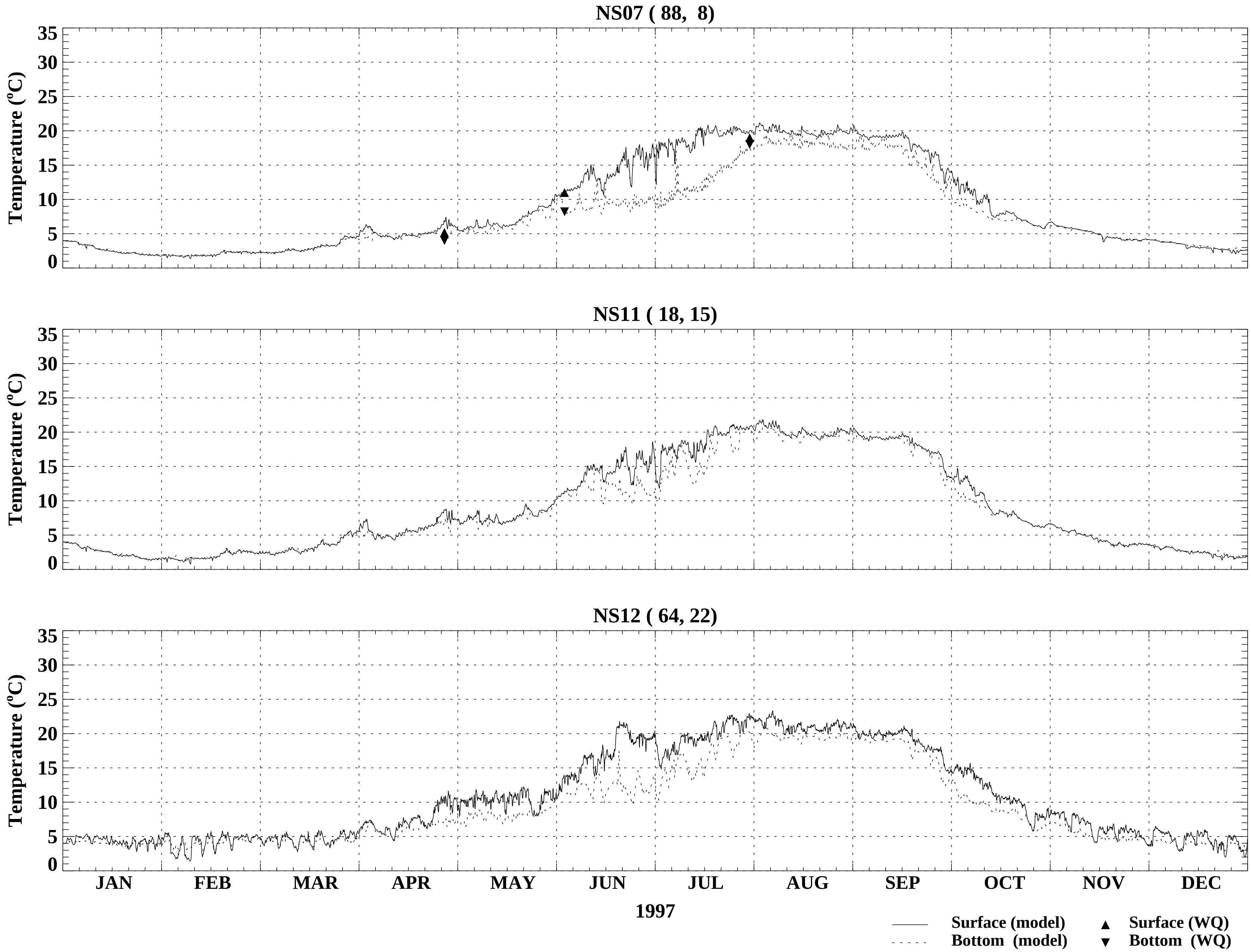

RI11 (72, 37)
RI14 (53, 29)
RI15 (67, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1996
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

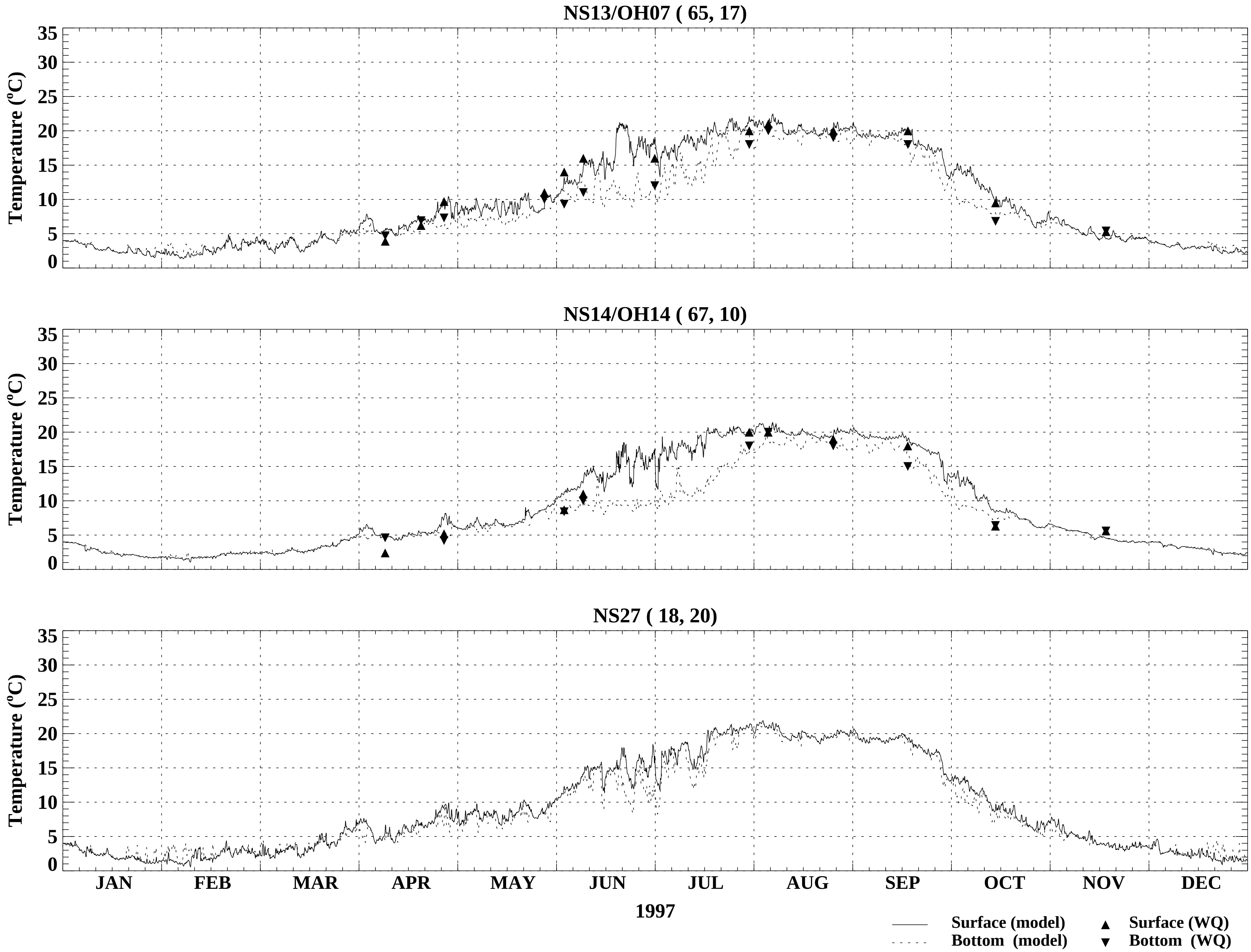

RI17 (72, 30)
RI18 (59, 29)
RI19 (64, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1996
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

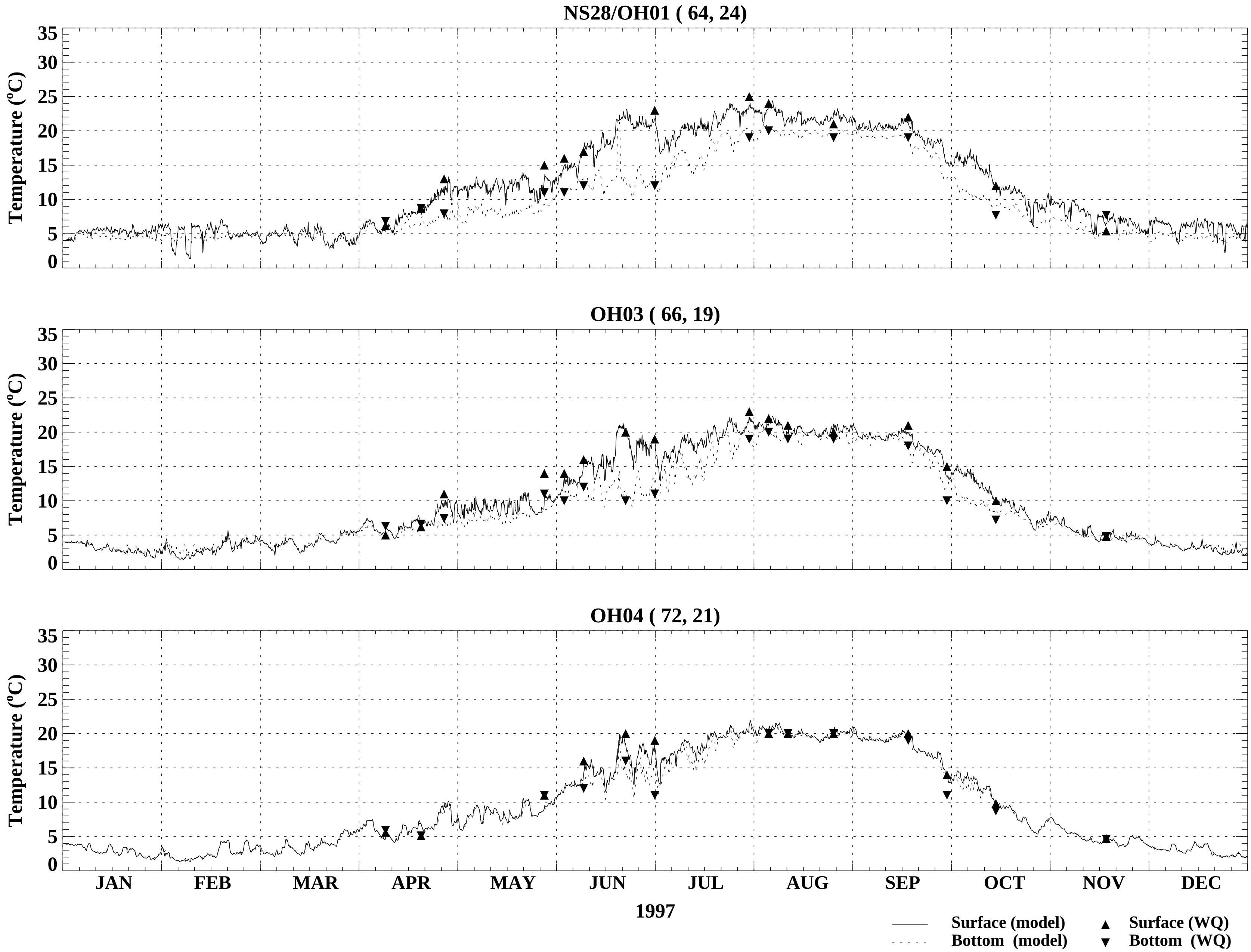


RI30 (76, 21)
RI31 (63, 32)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1996
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

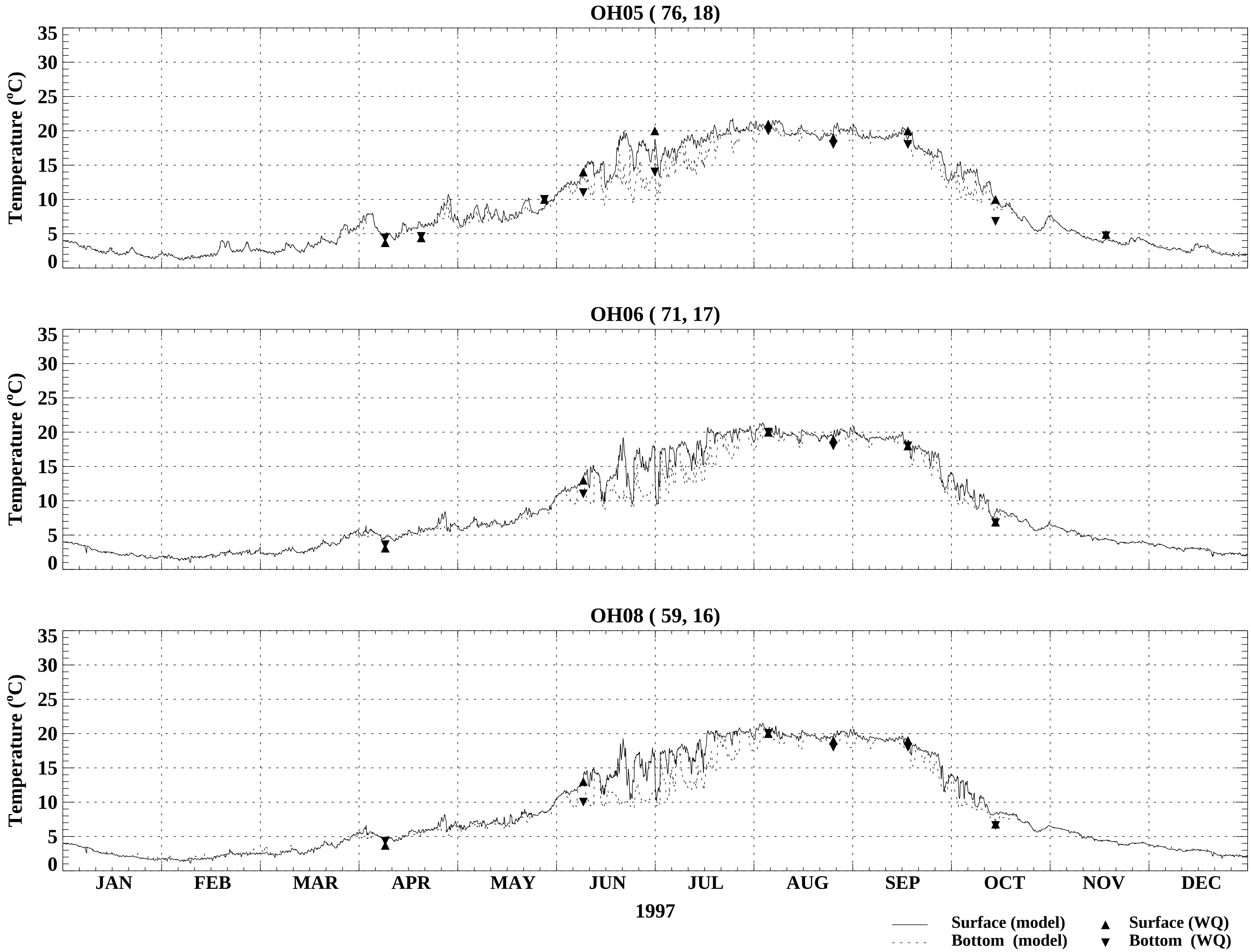

NS02 (20, 9)
NS04 (33, 20)
NS05 (32, 6)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1997
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

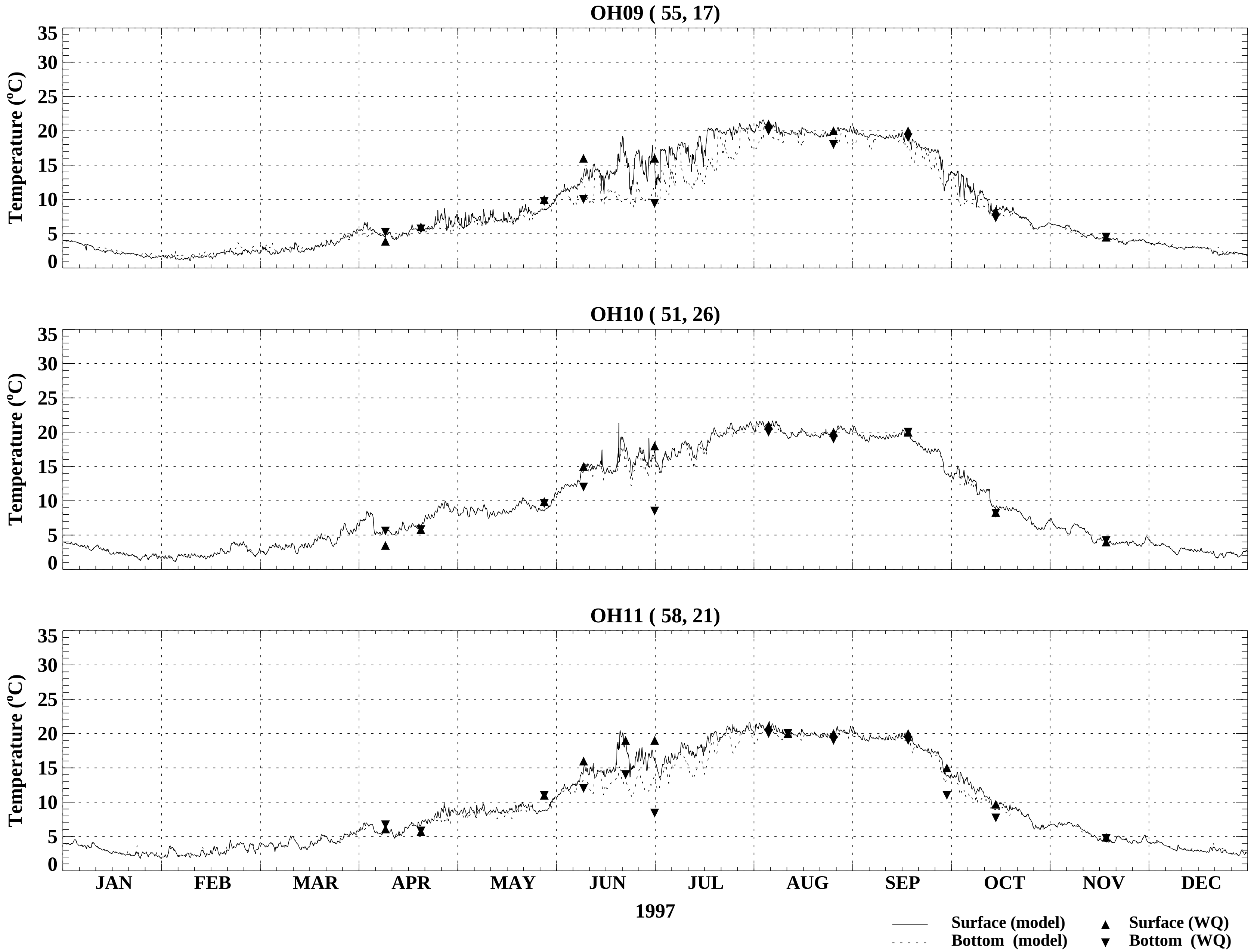

NS07 (88, 8)
NS11 (18, 15)
NS12 (64, 22)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1997
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

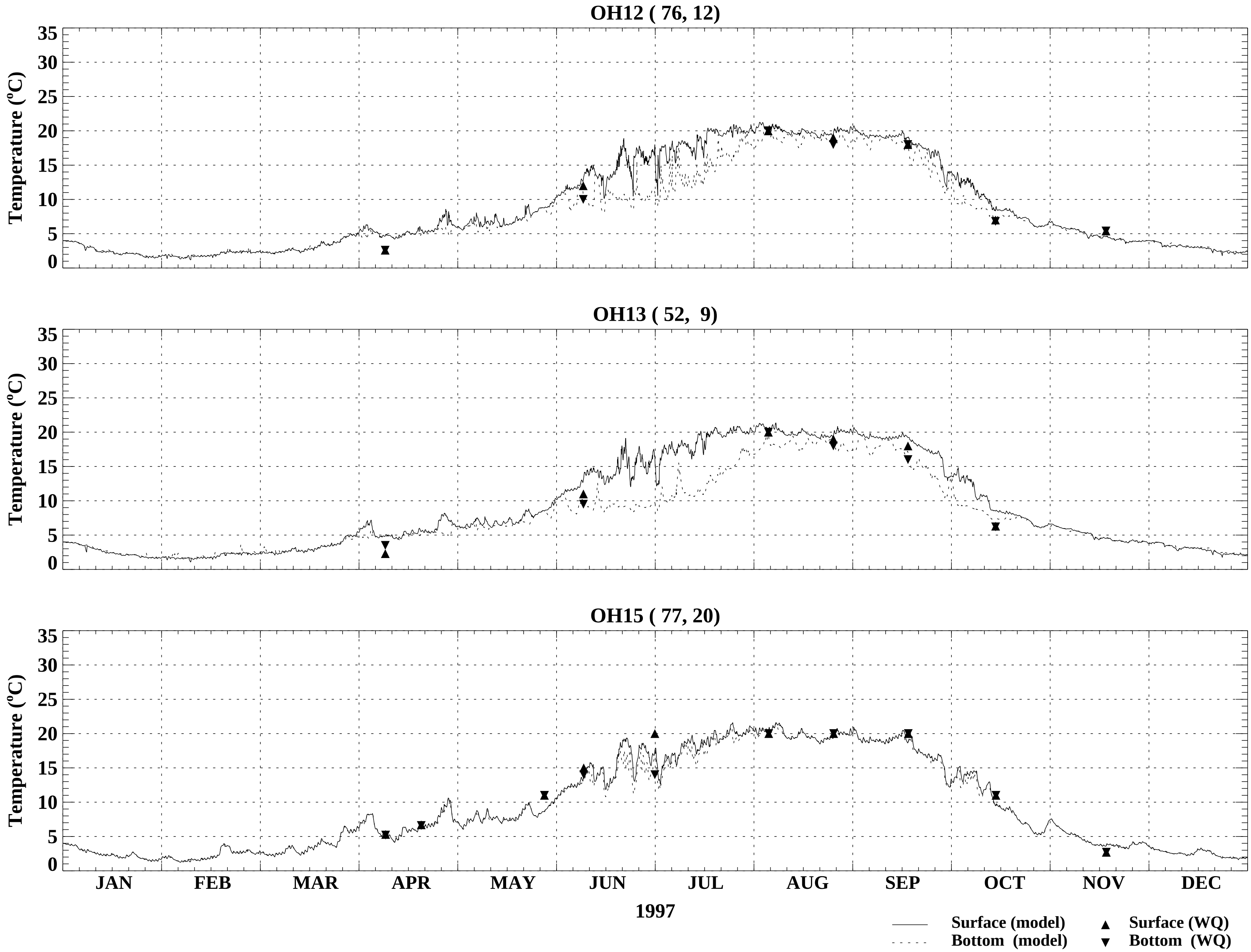

NS13/OH07 (65, 17)
NS14/OH14 (67, 10)
NS27 (18, 20)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1997
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)



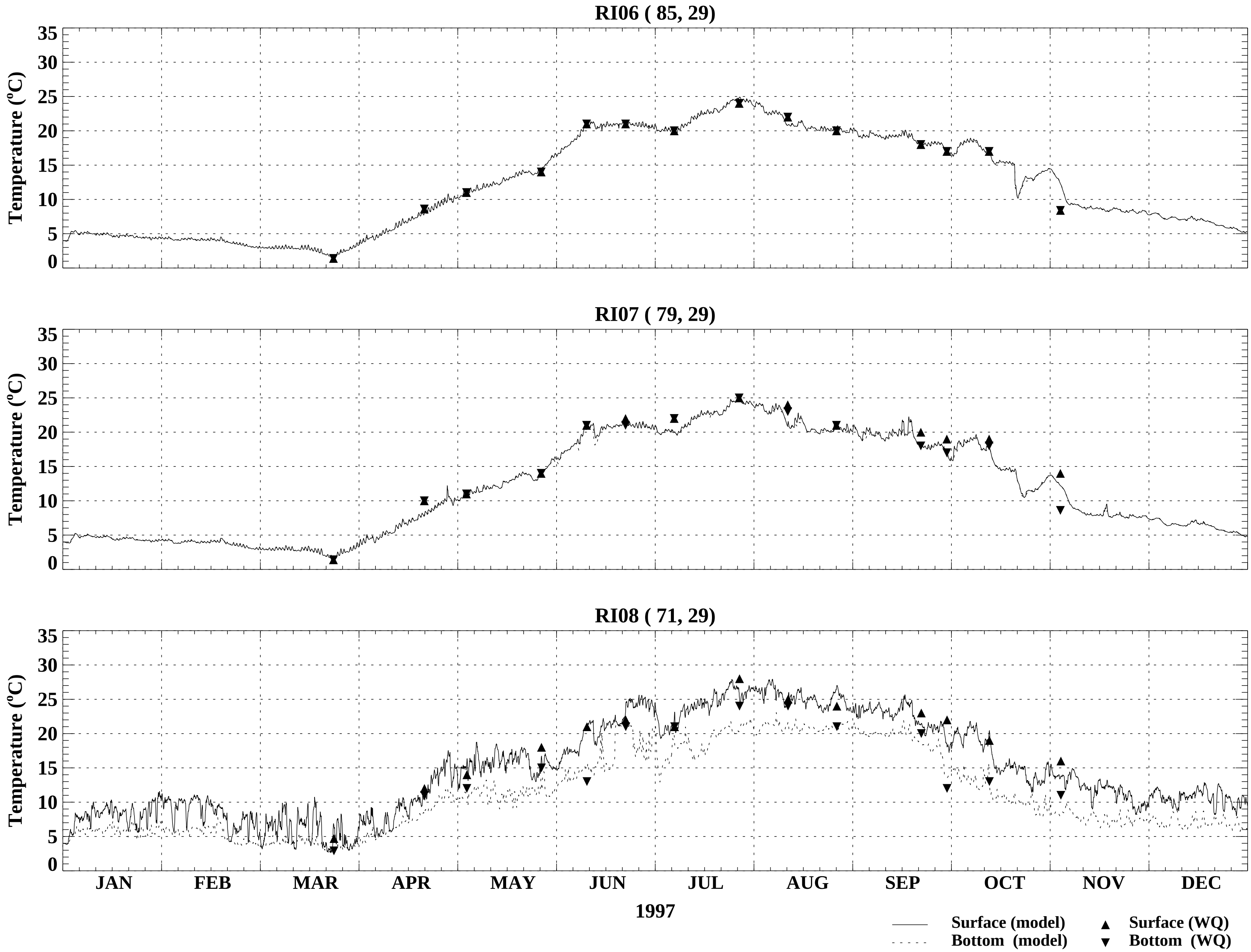
NS28/OH01 (64, 24)
OH03 (66, 19)
OH04 (72, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1997
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

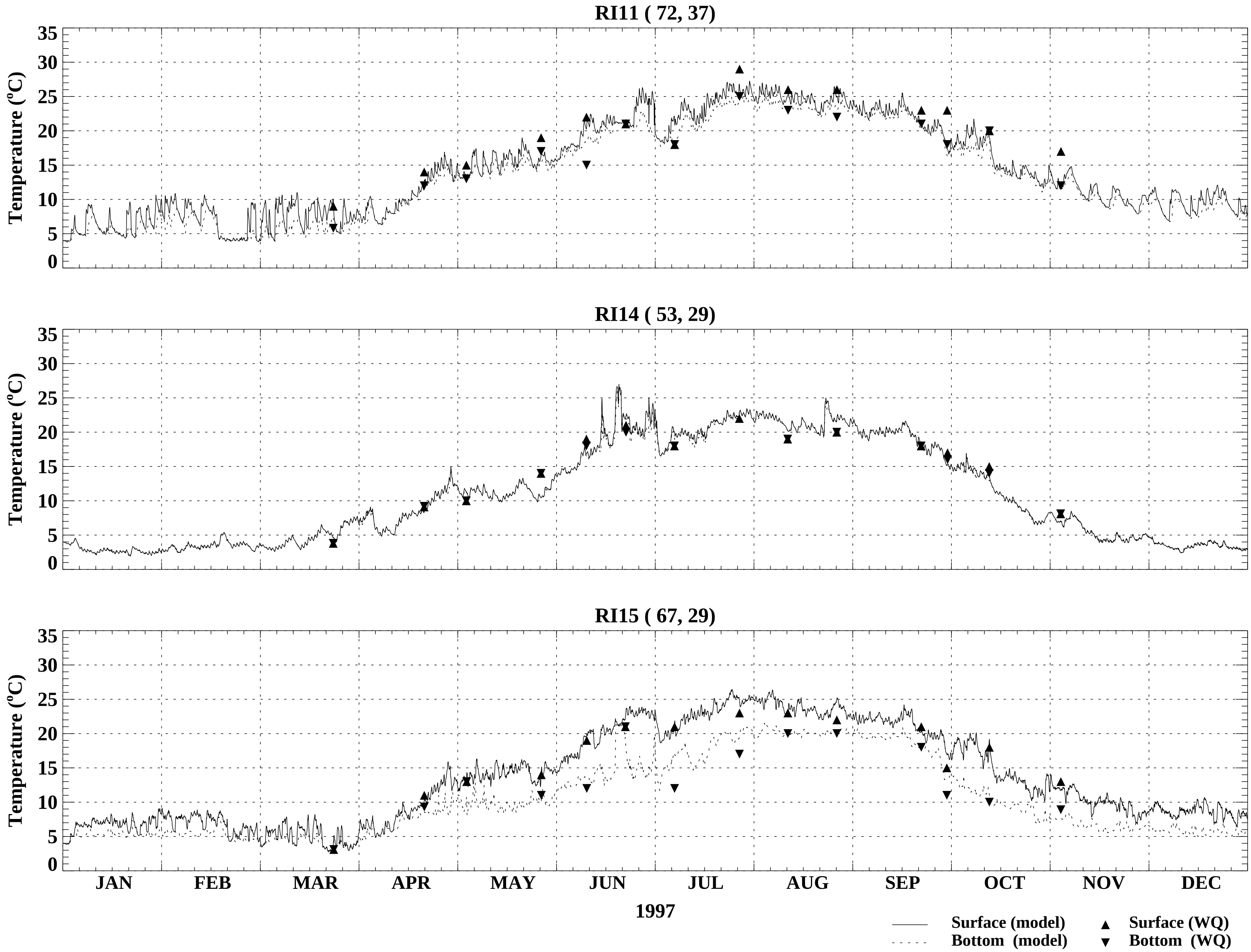

OH05 (76, 18)
OH06 (71, 17)
OH08 (59, 16)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1997
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

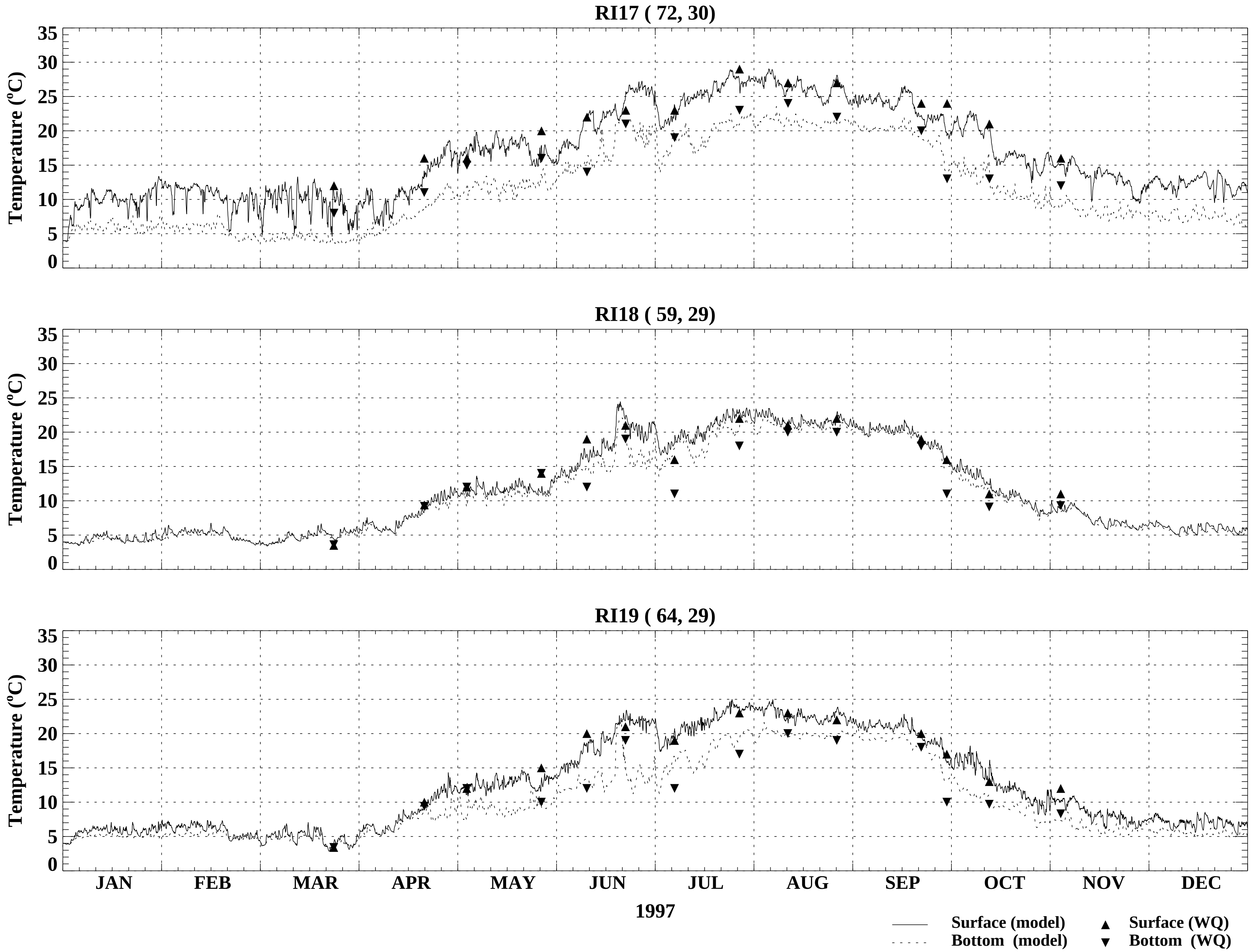

OH09 (55, 17)
OH10 (51, 26)
OH11 (58, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1997
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

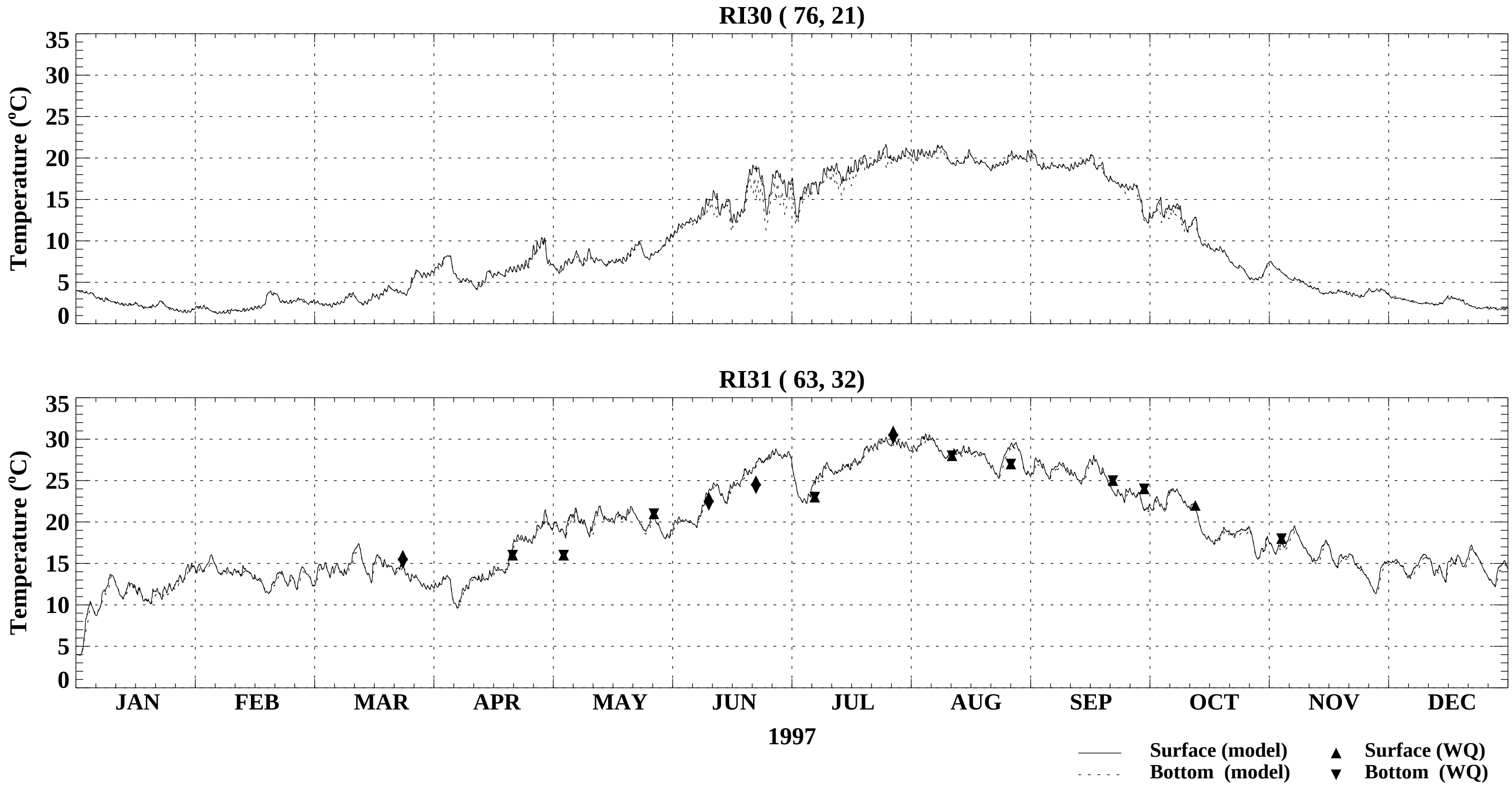


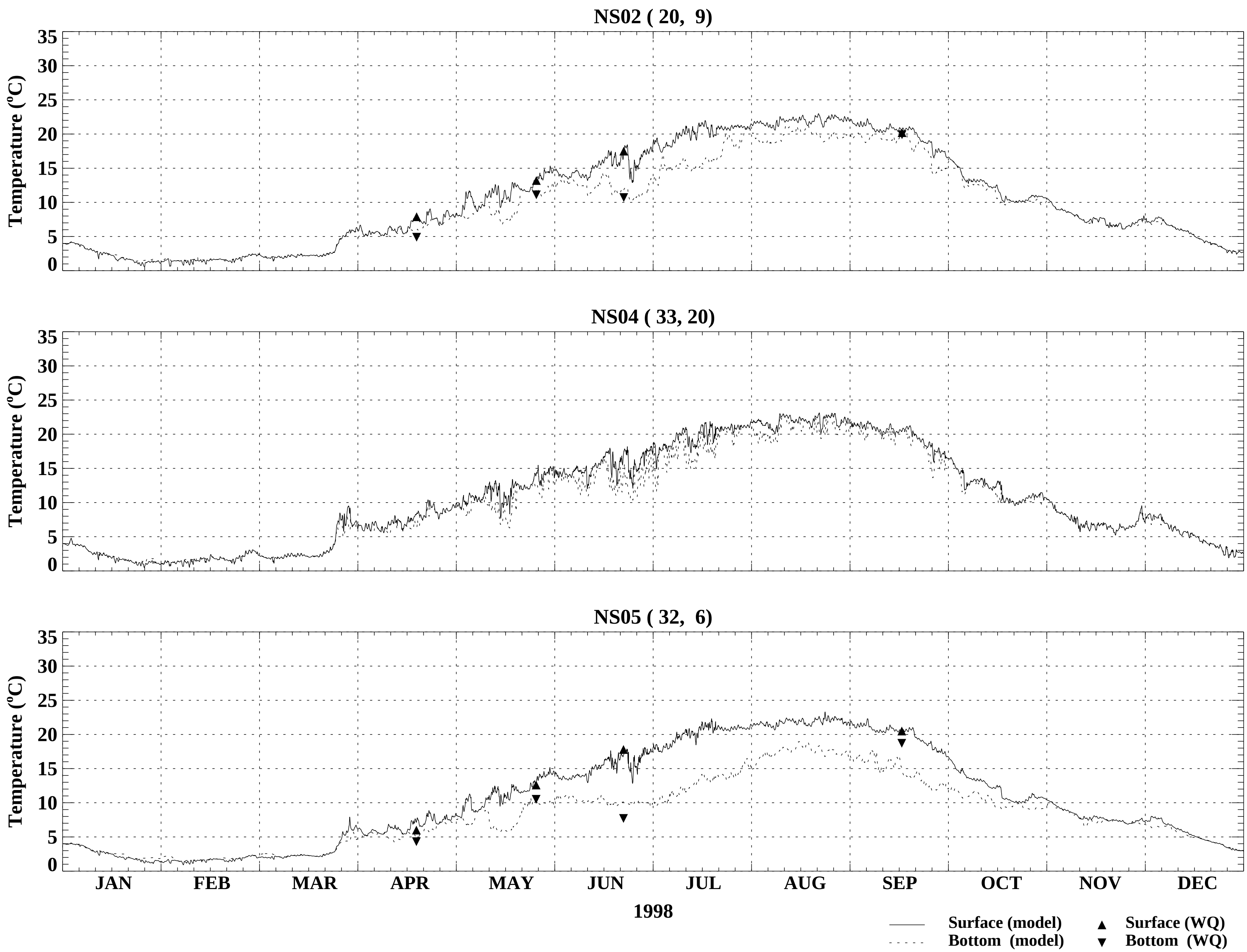
OH12 (76, 12)
OH13 (52, 9)
OH15 (77, 20)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1997
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


RI06 (85, 29)
RI07 (79, 29)
RI08 (71, 29)
Temperature (°C)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1997
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

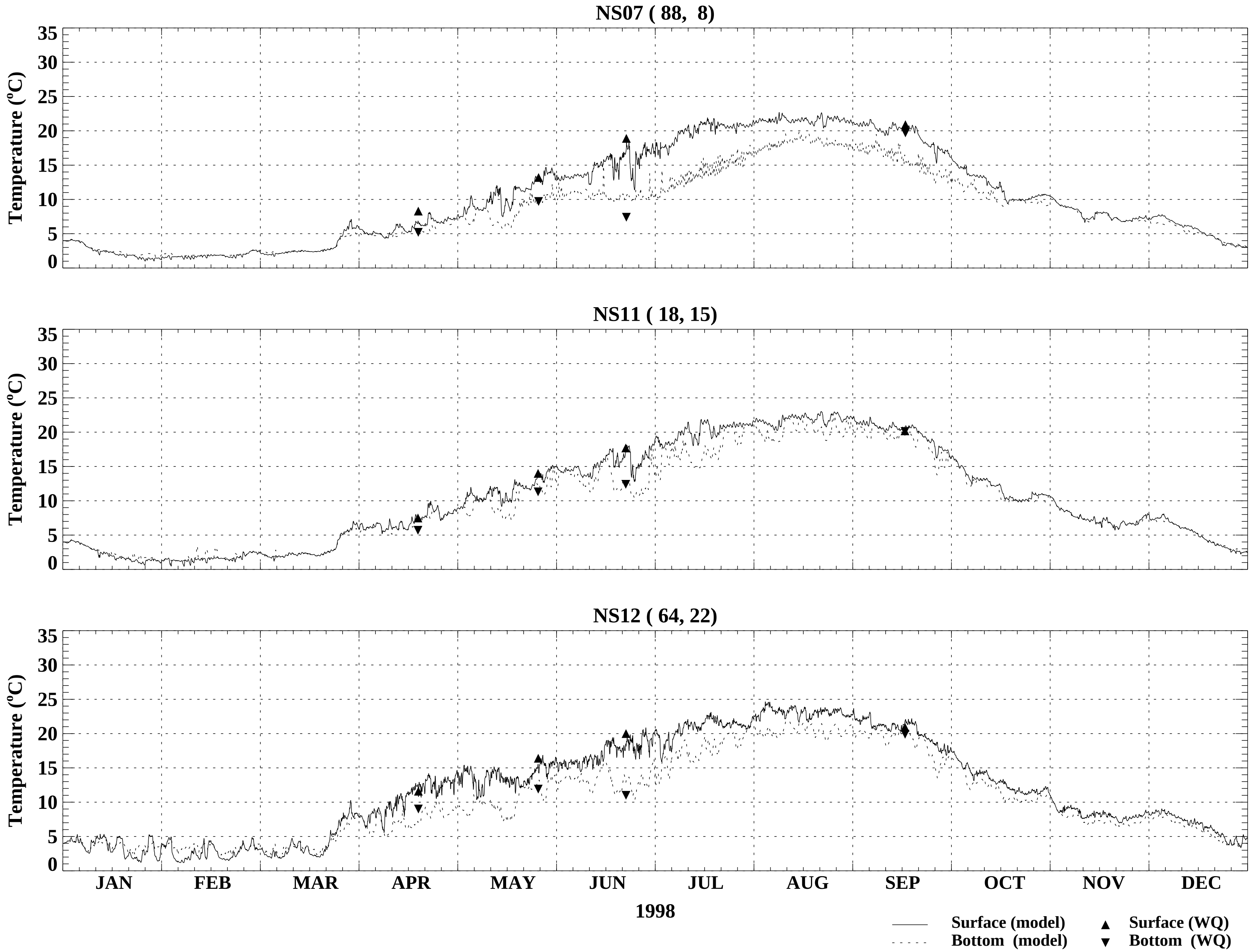

RI11 (72, 37)
RI14 (53, 29)
RI15 (67, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1997
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

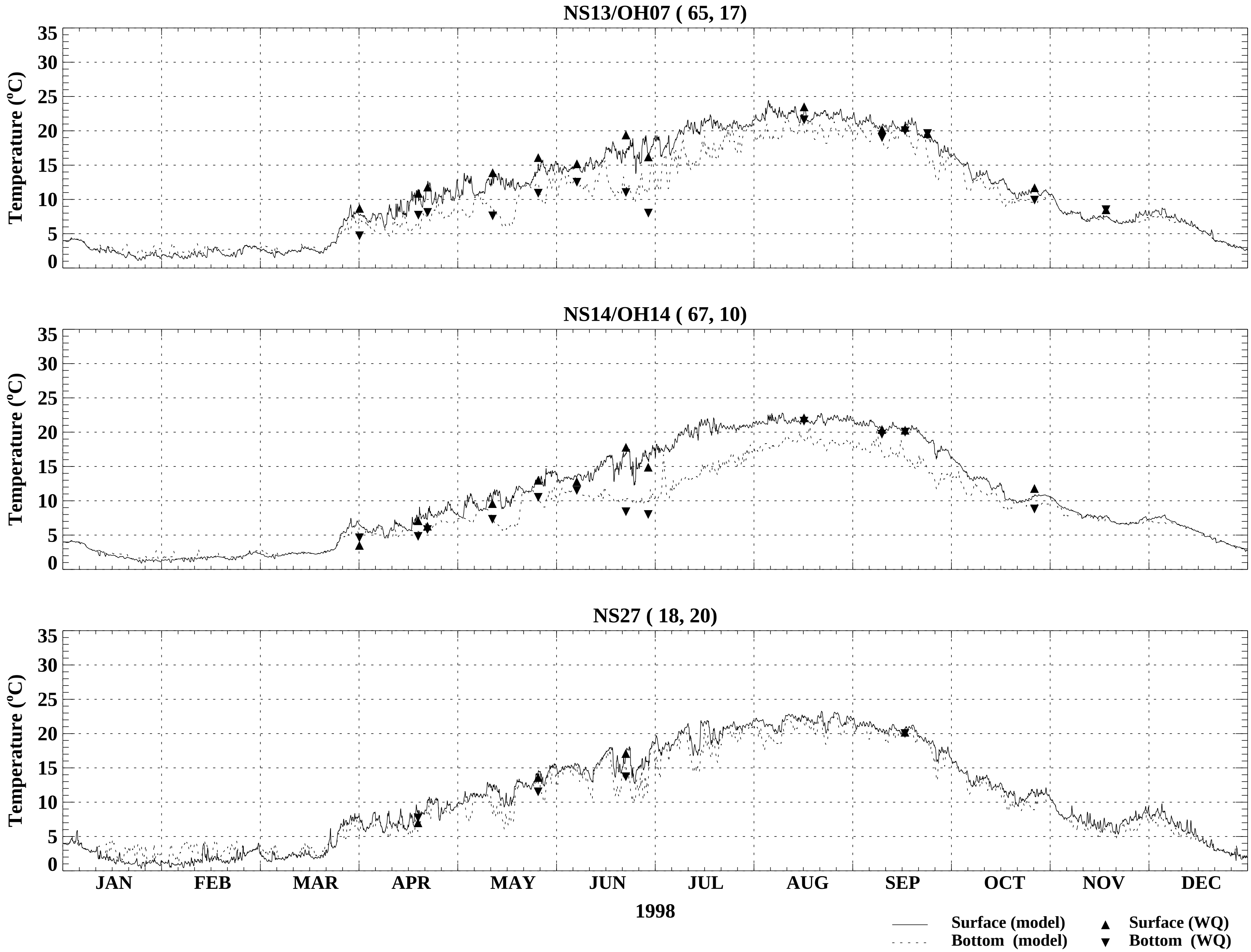

RI17 (72, 30)
RI18 (59, 29)
RI19 (64, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1997
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

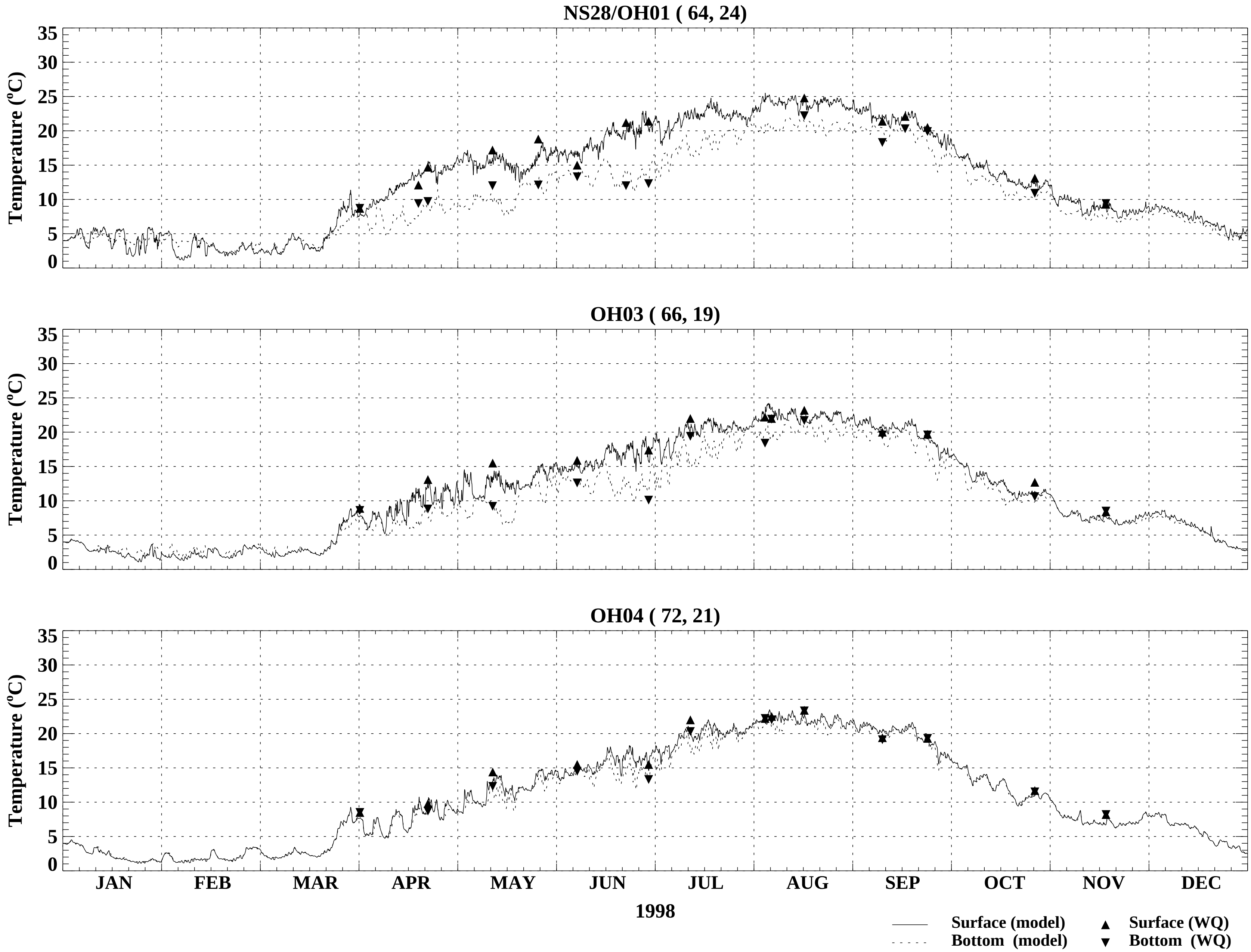

RI30 (76, 21)
RI31 (63, 32)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1997
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

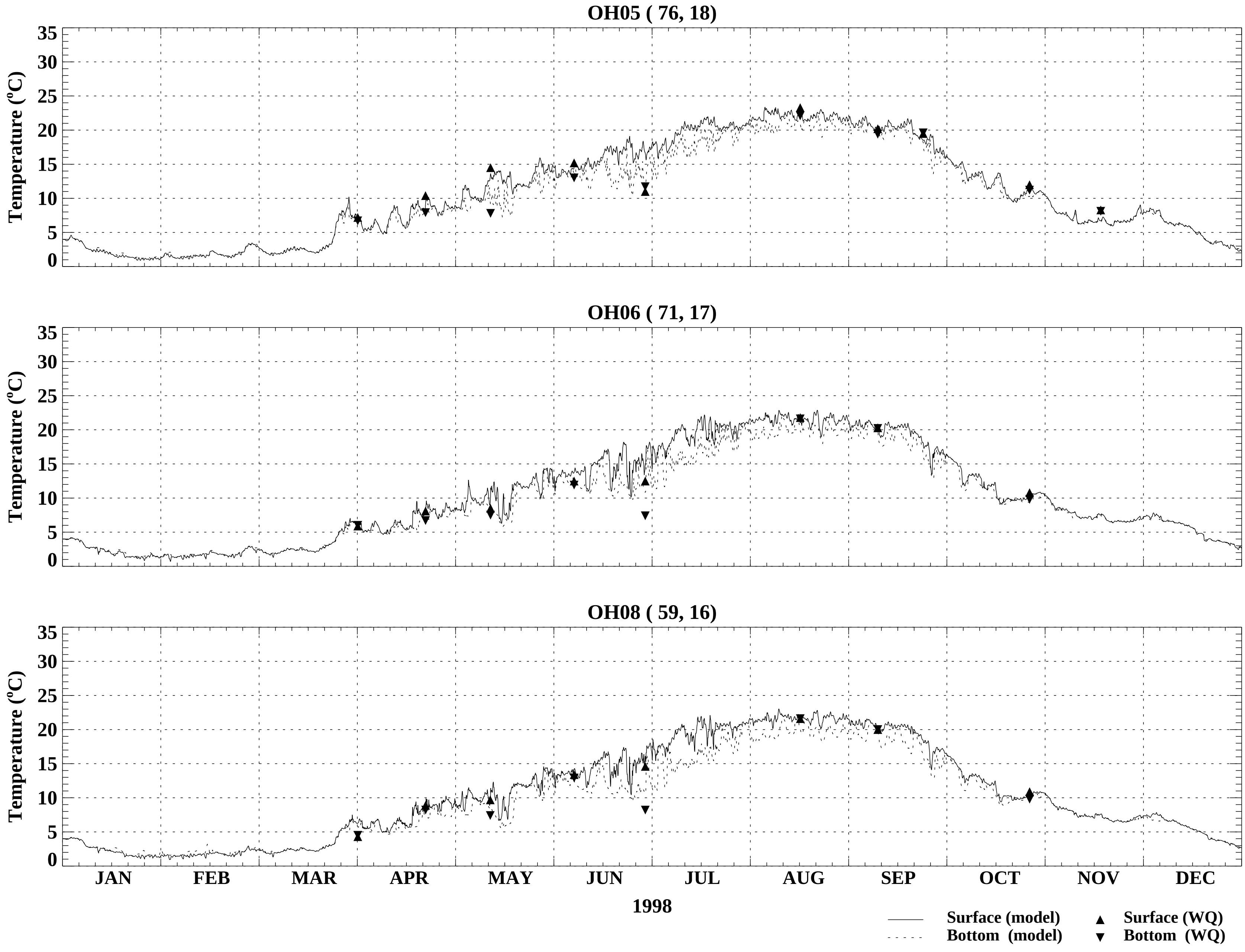


NS02 (20, 9)
NS04 (33, 20)
NS05 (32, 6)
Temperature (°C)
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1998
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

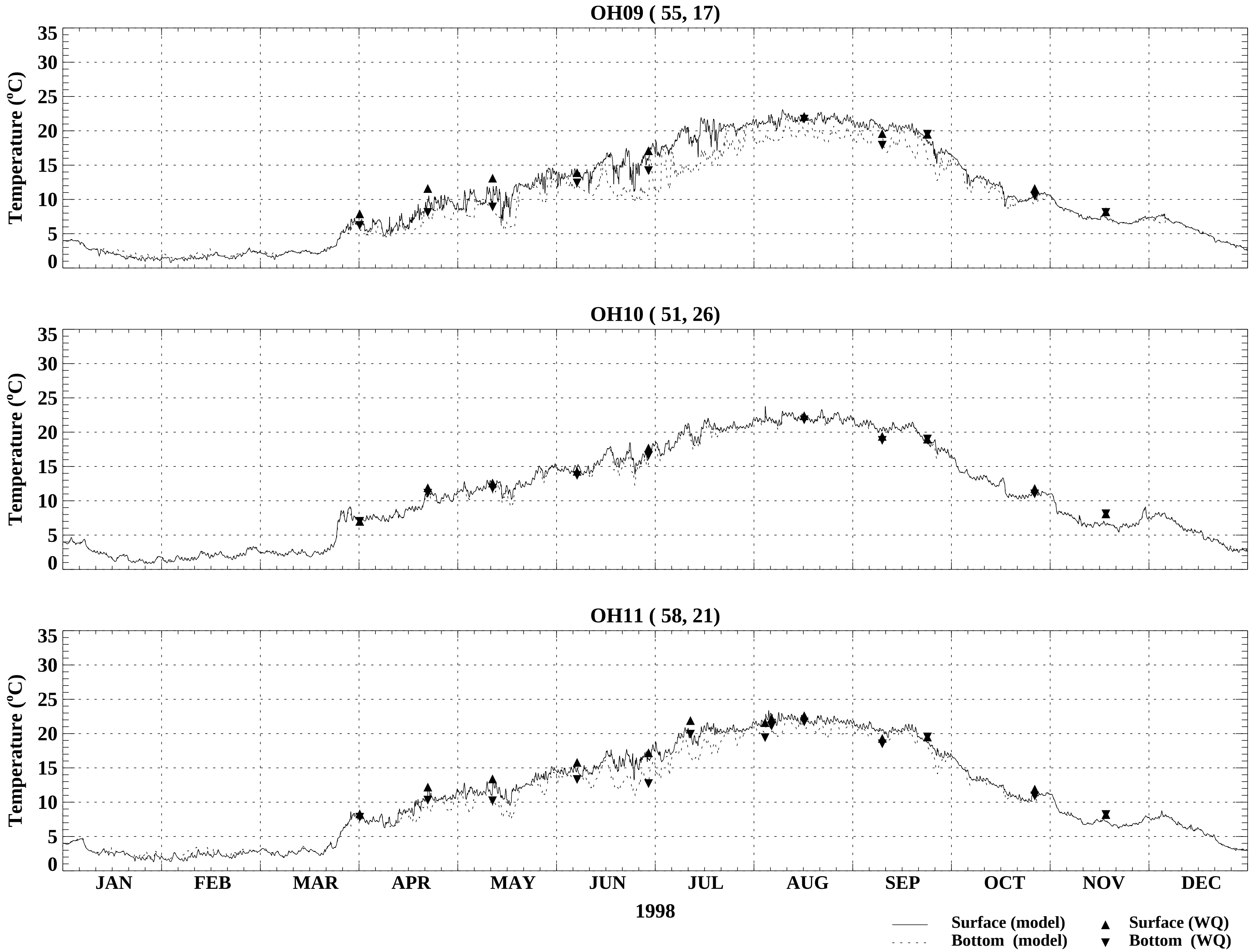

NS07 (88, 8)
NS11 (18, 15)
NS12 (64, 22)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1998
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

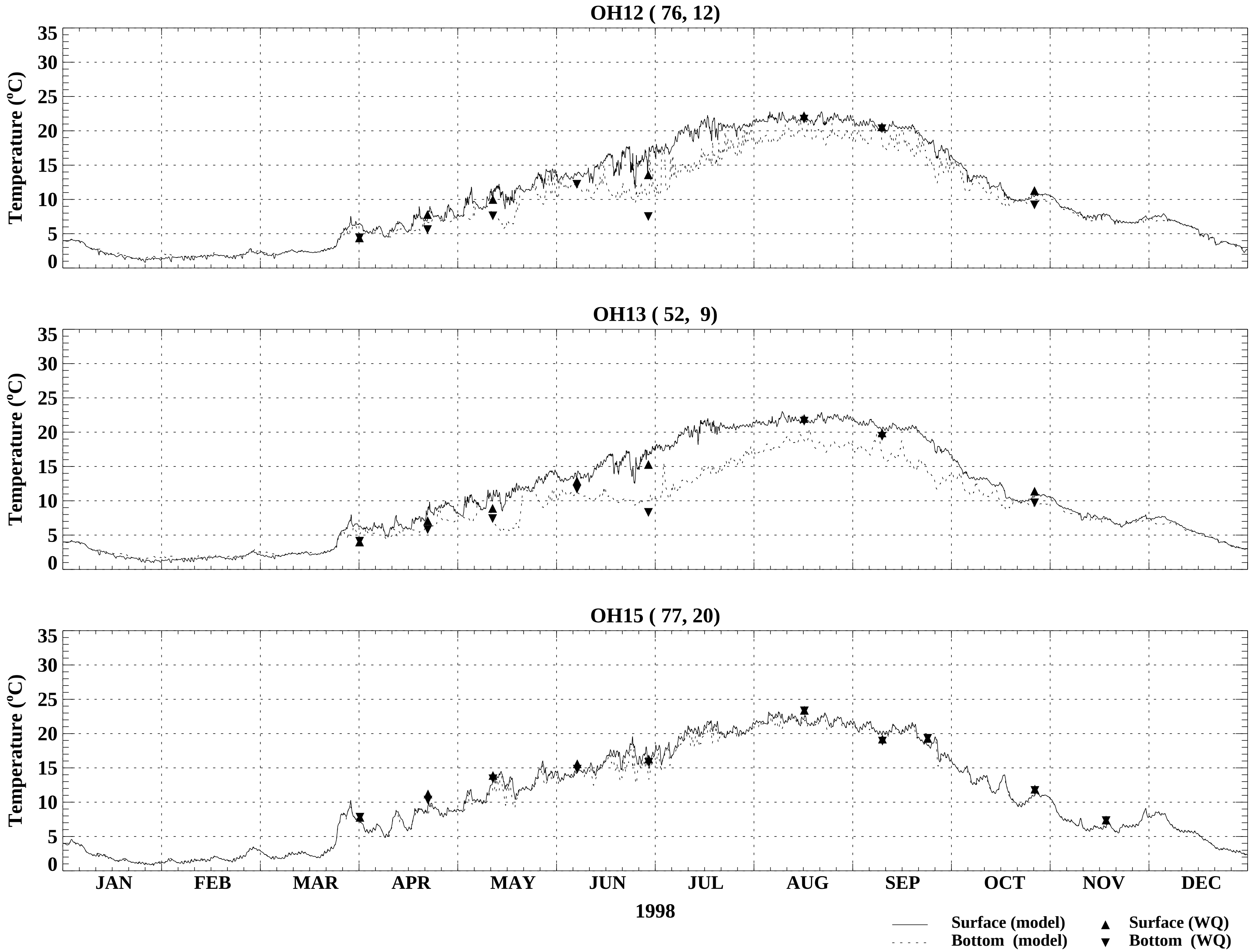

NS13/OH07 (65, 17)
NS14/OH14 (67, 10)
NS27 (18, 20)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1998
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

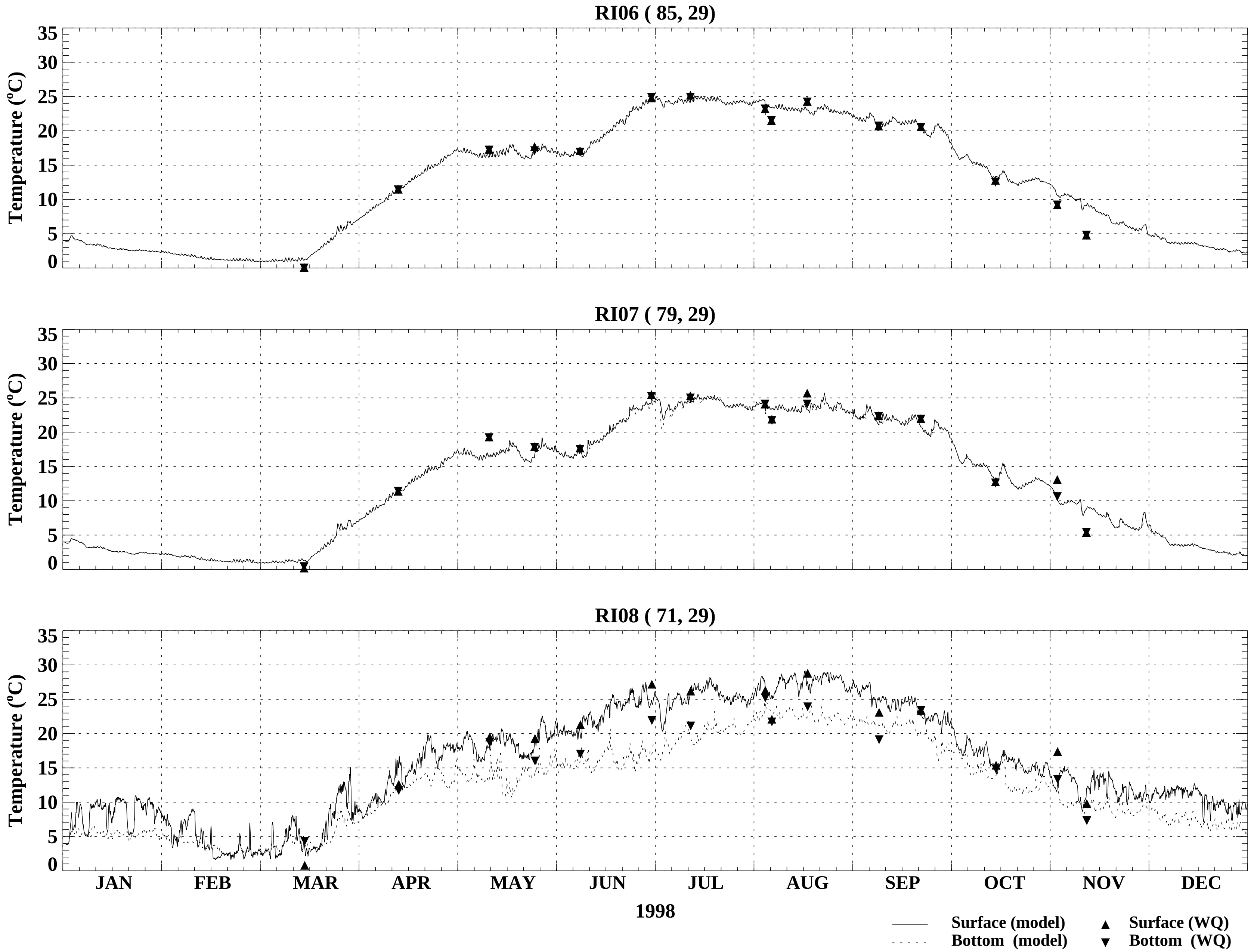

NS28/OH01 (64, 24)
OH03 (66, 19)
OH04 (72, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1998
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

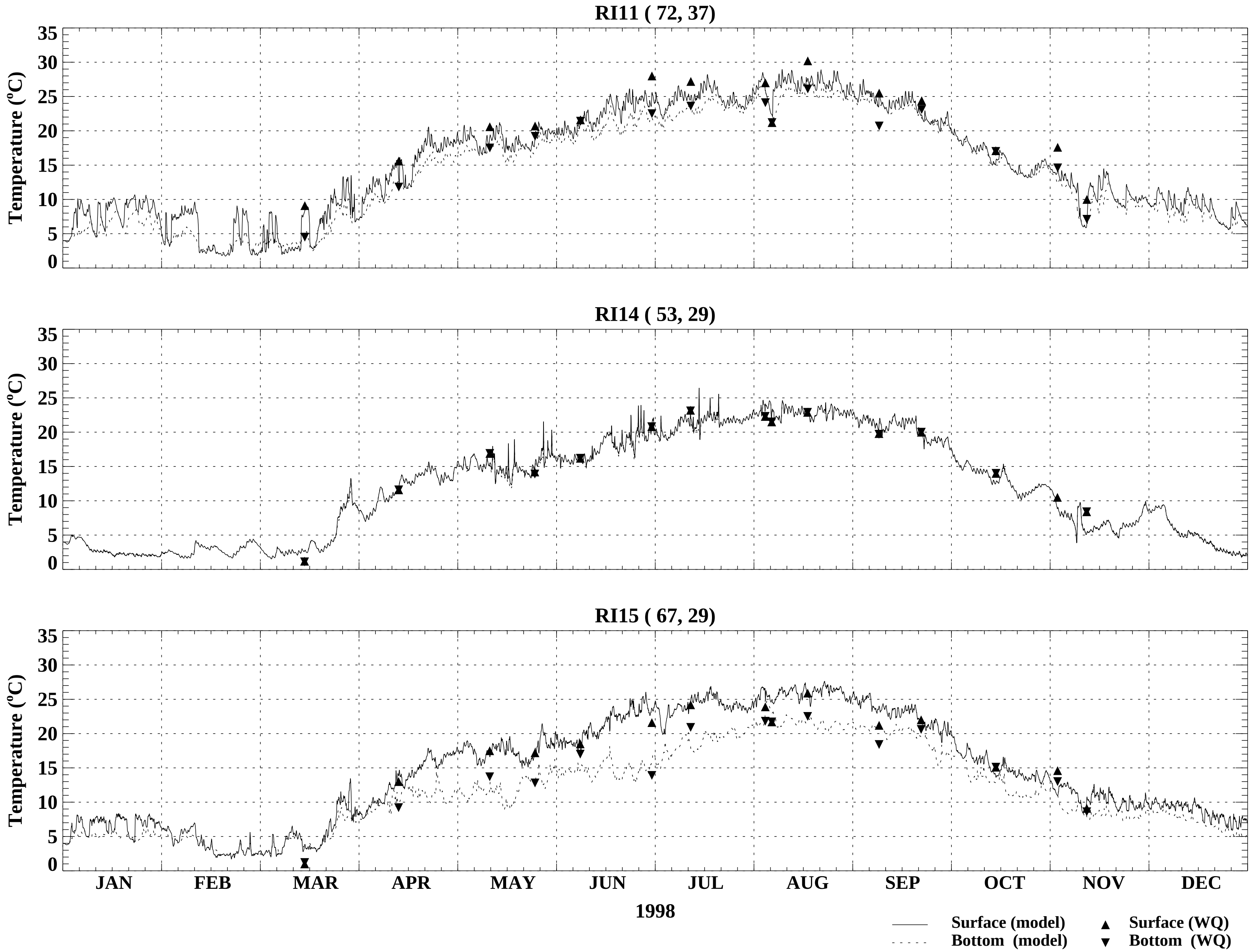


OH05 (76, 18)
OH06 (71, 17)
OH08 (59, 16)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1998
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

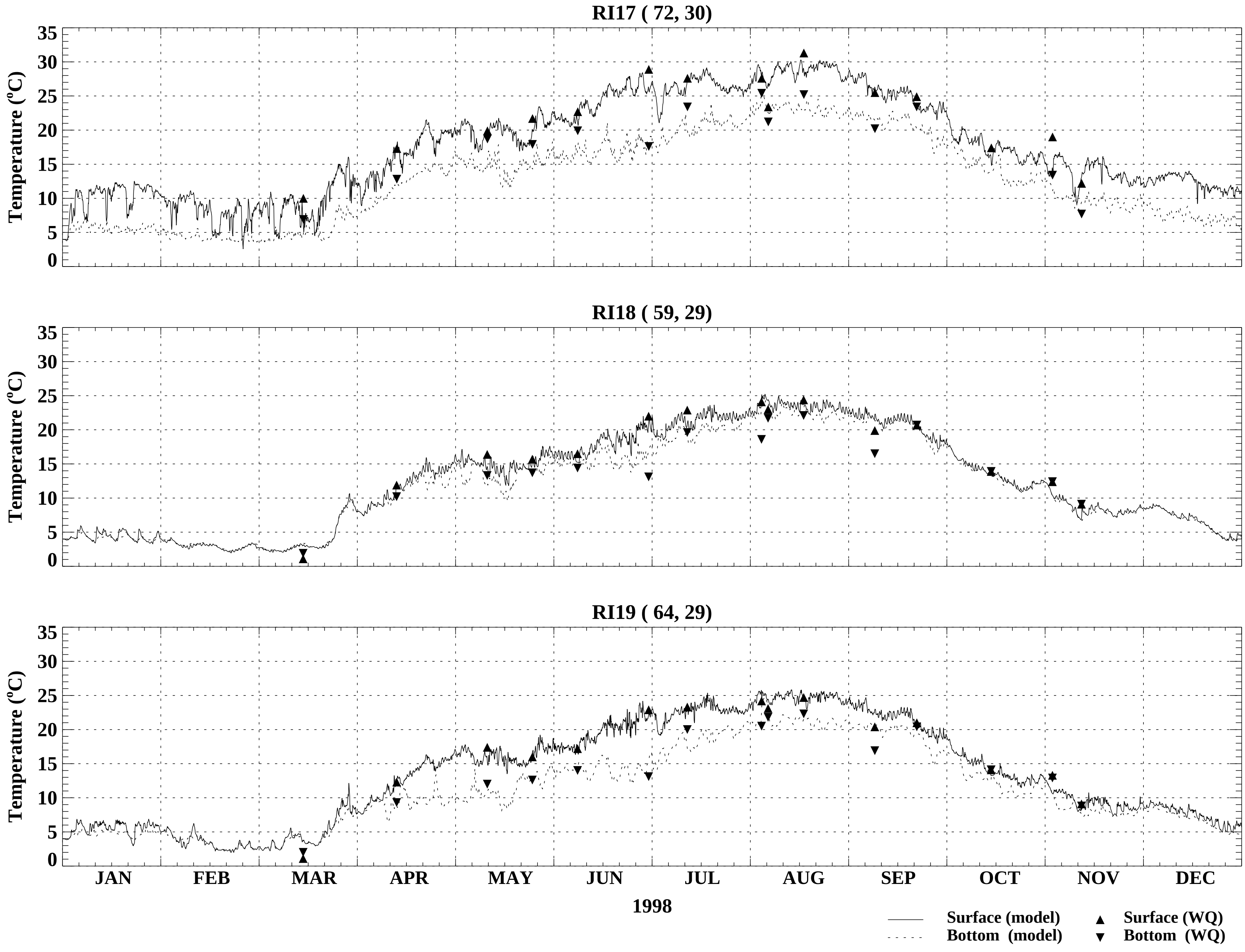

OH09 (55, 17)
OH10 (51, 26)
OH11 (58, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1998
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

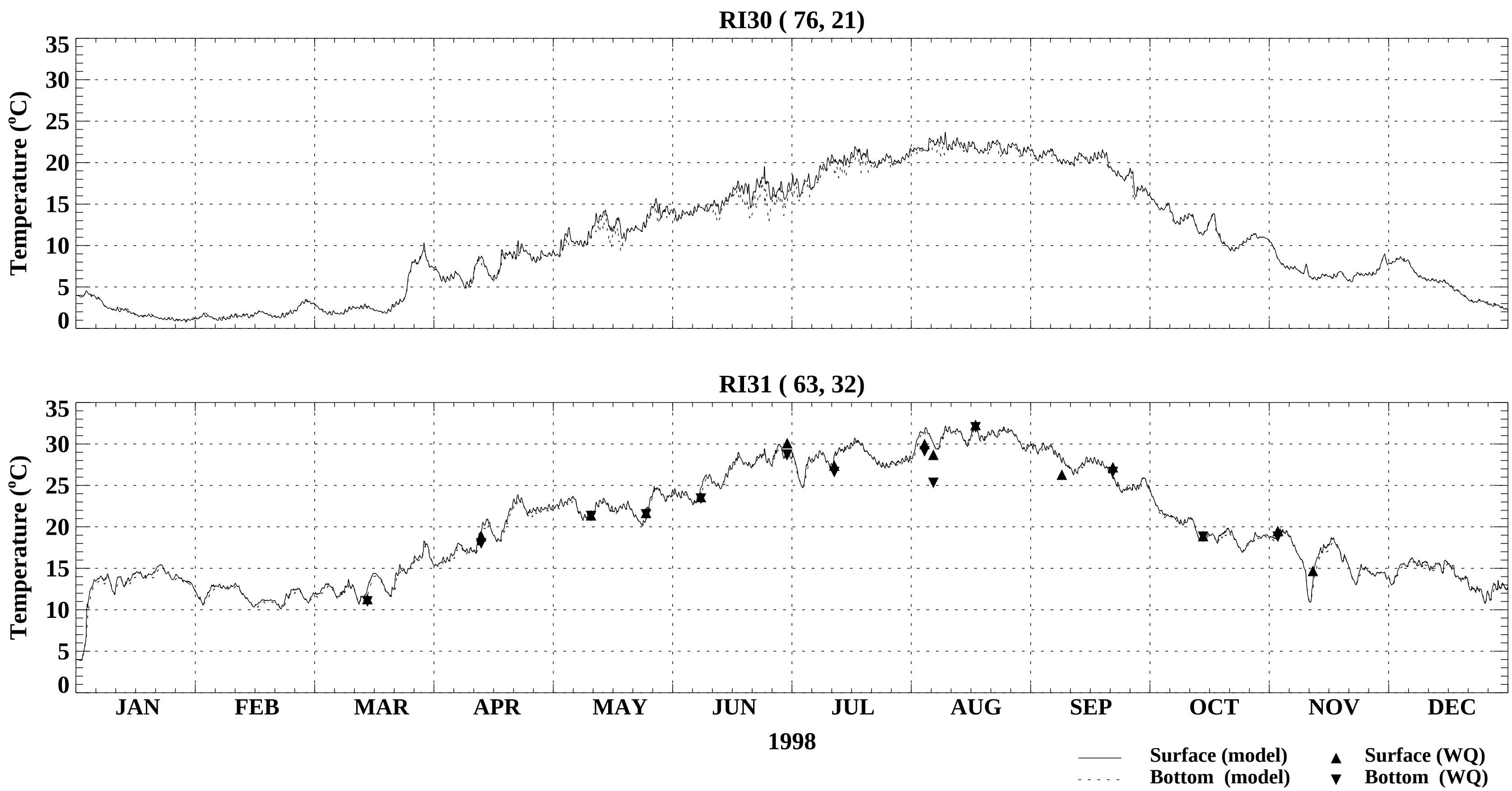

OH12 (76, 12)
OH13 (52, 9)
OH15 (77, 20)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1998
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

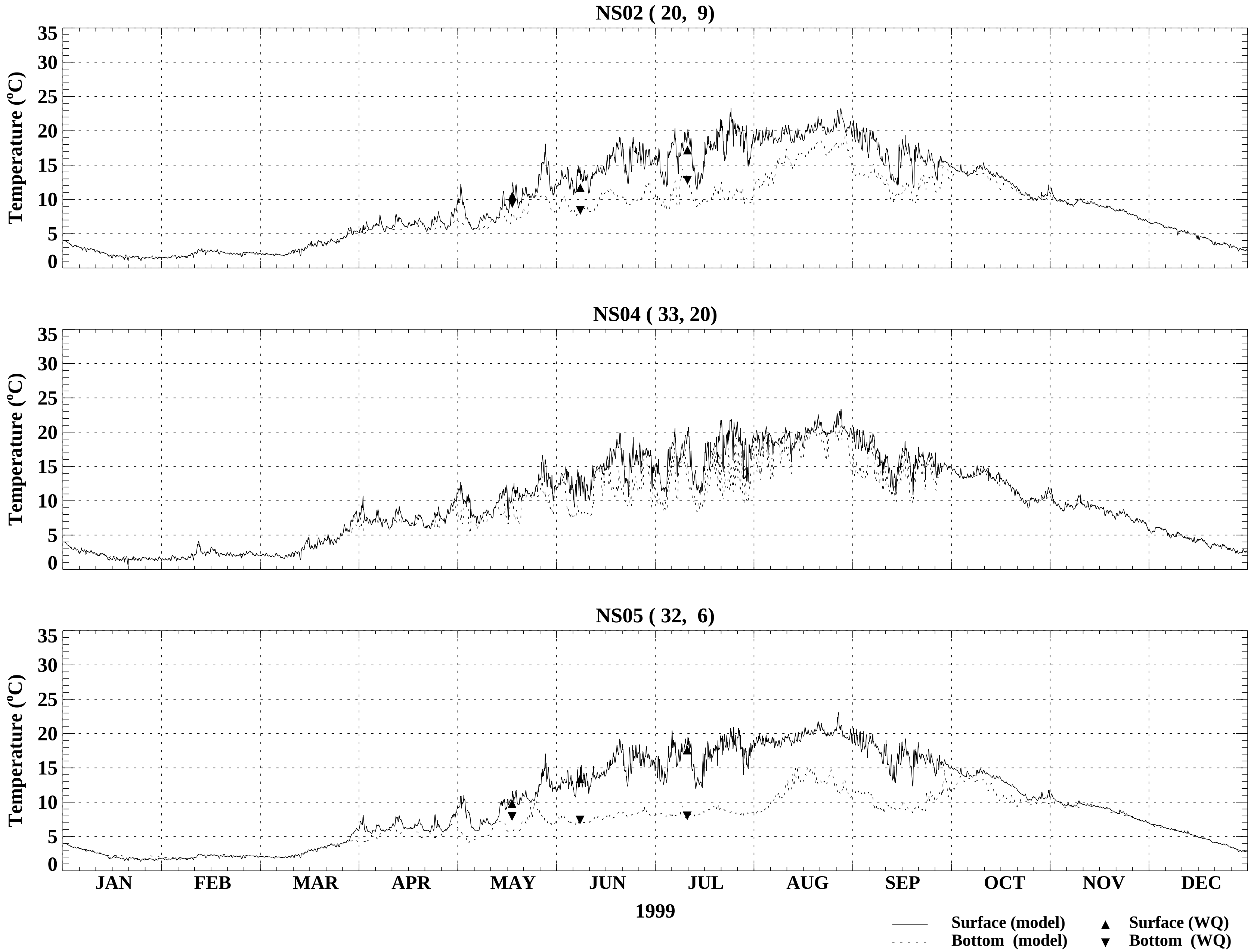

RI06 (85, 29)
RI07 (79, 29)
RI08 (71, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1998
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

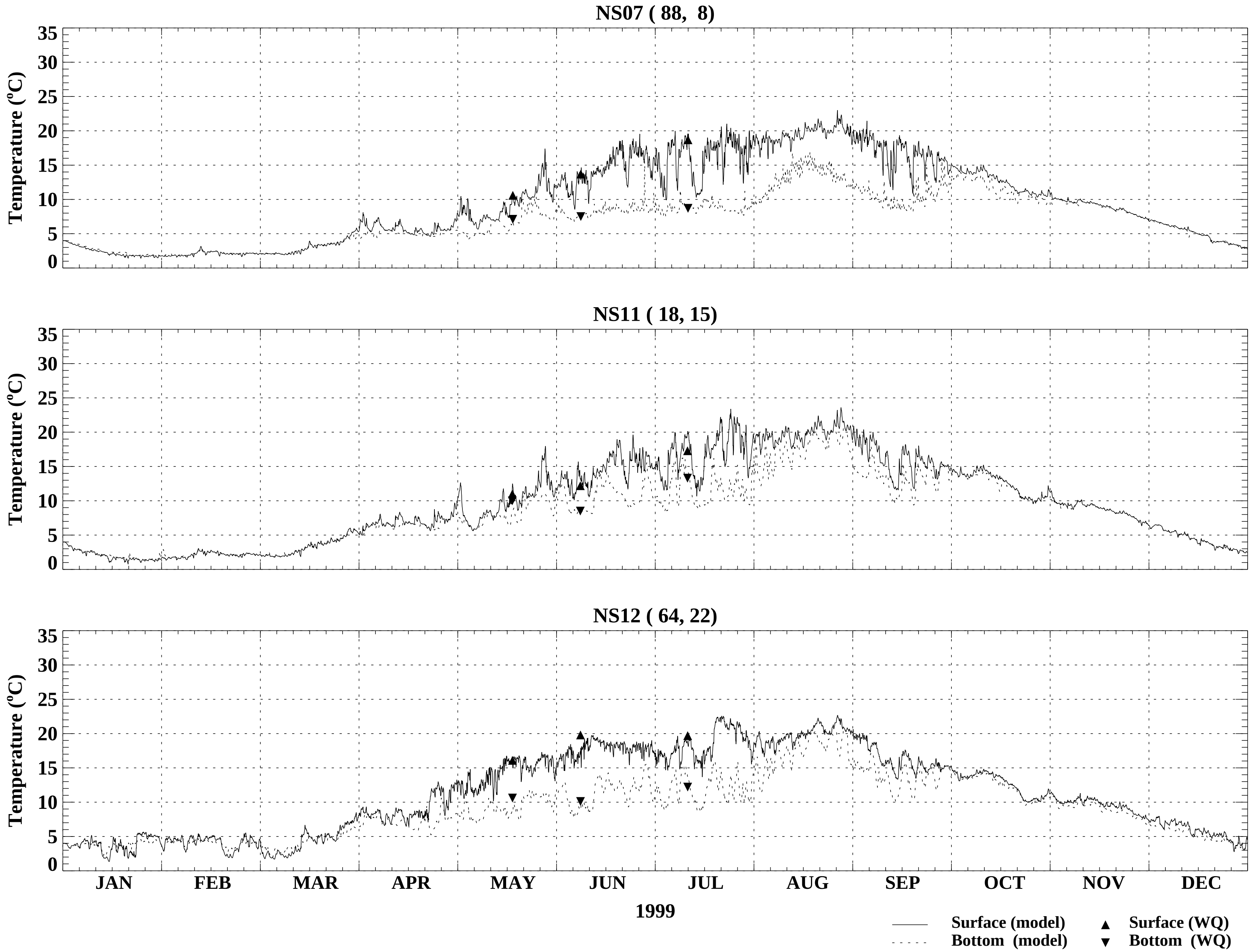


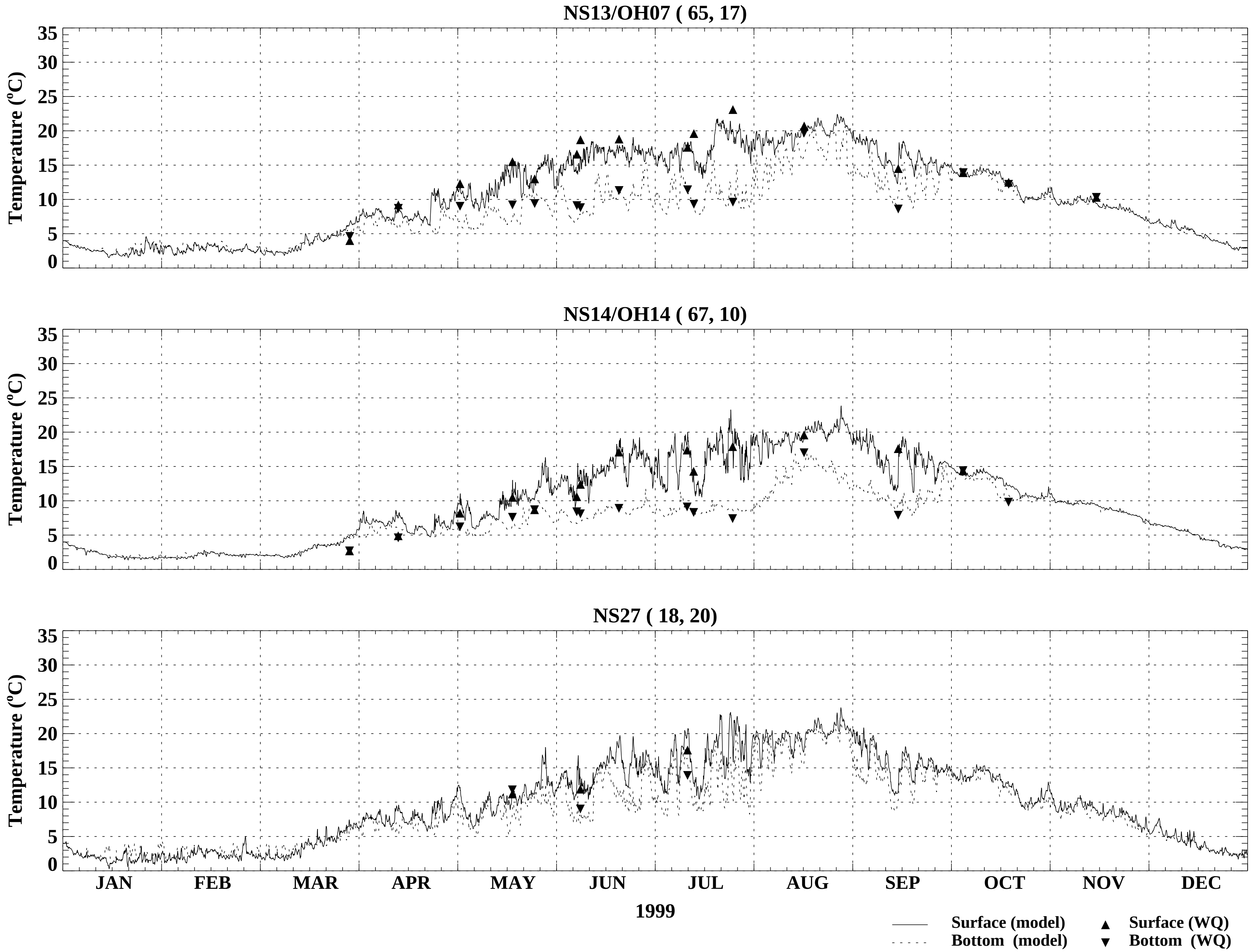
RI11 (72, 37)
RI14 (53, 29)
RI15 (67, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1998
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

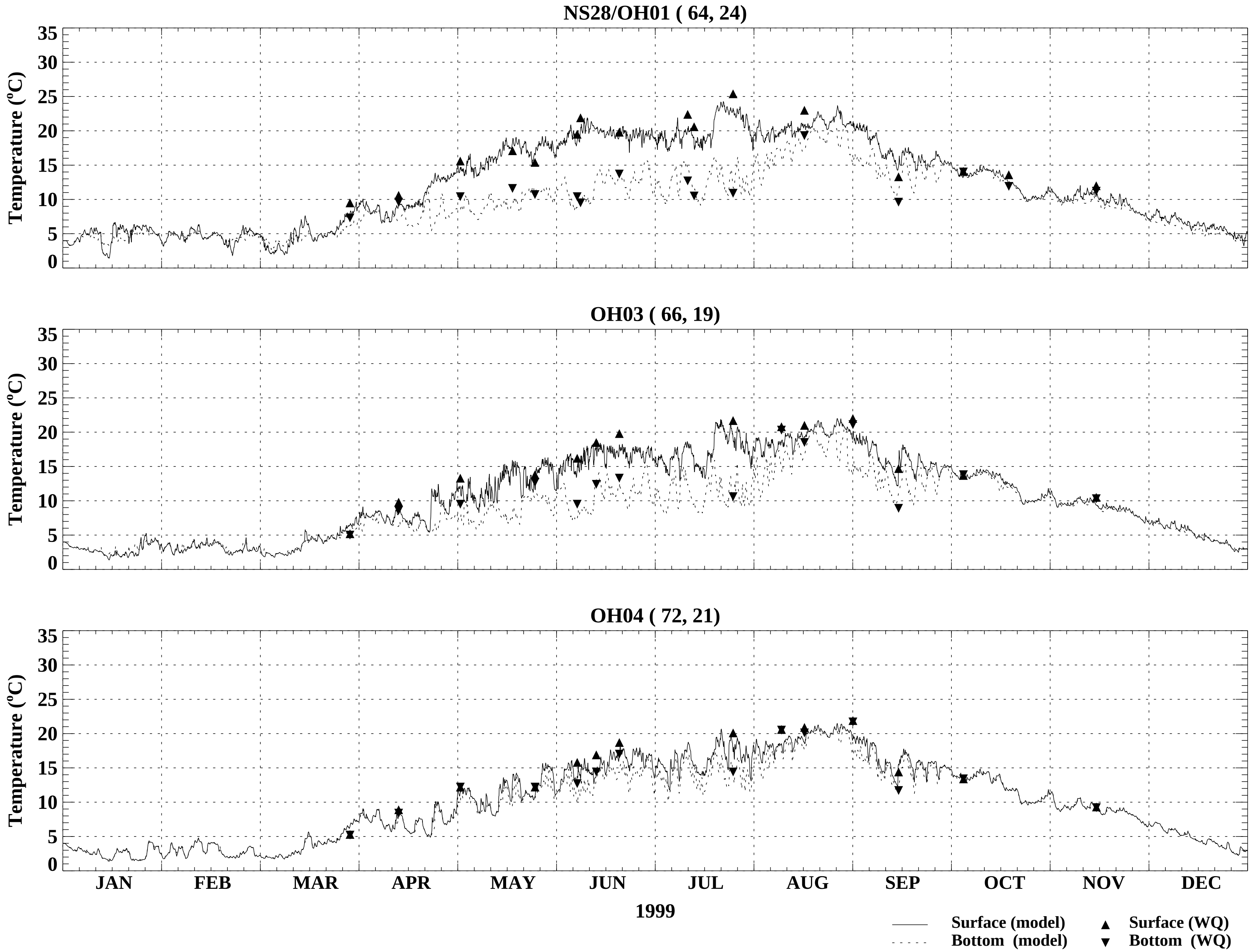

RI17 (72, 30)
RI18 (59, 29)
RI19 (64, 29)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1998
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


RI30 (76, 21)
RI31 (63, 32)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1998
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

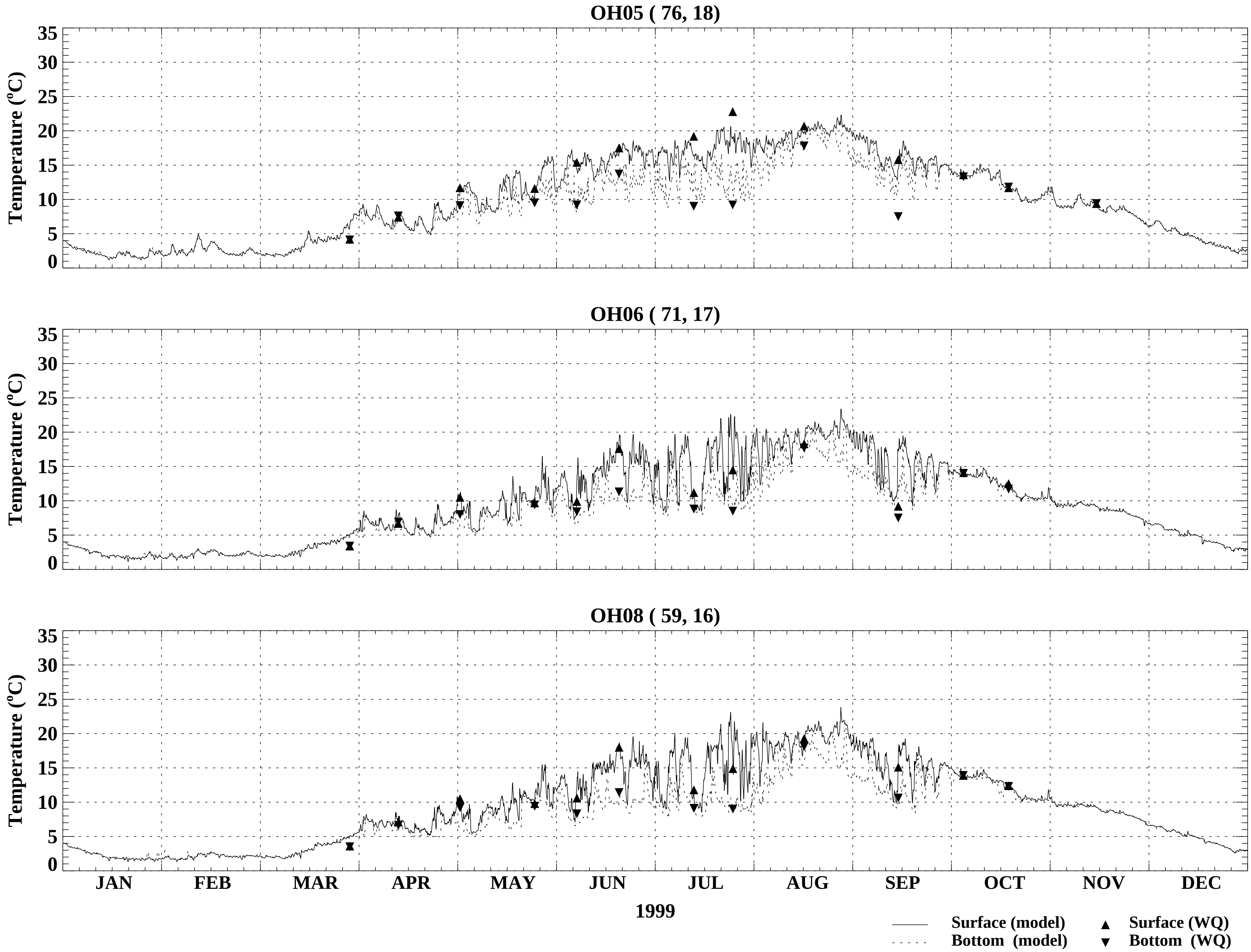

NS02 (20, 9)
NS04 (33, 20)
NS05 (32, 6)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1999
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

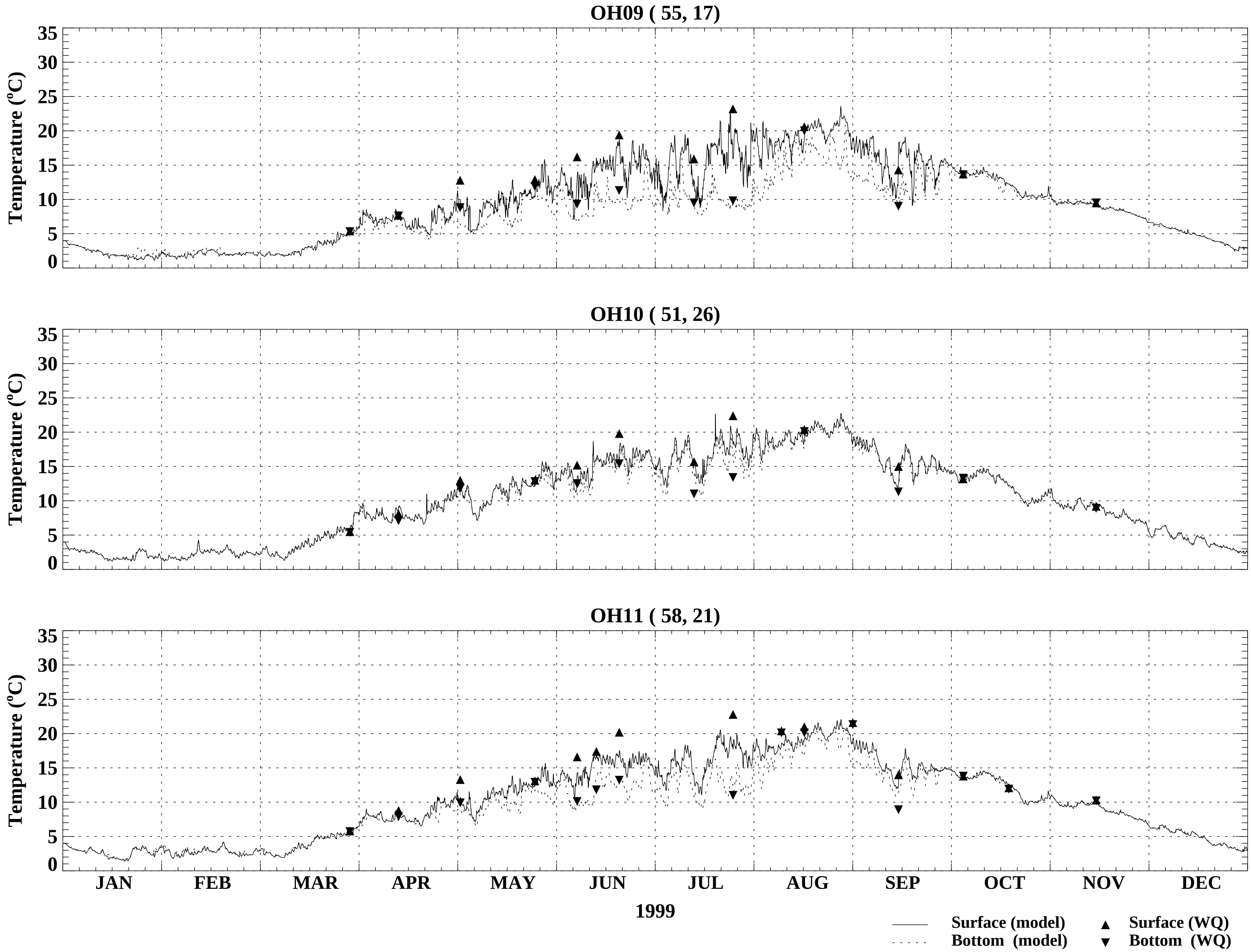

NS07 (88, 8)
NS11 (18, 15)
NS12 (64, 22)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1999
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


NS13/OH07 (65, 17)
NS14/OH14 (67, 10)
NS27 (18, 20)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1999
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

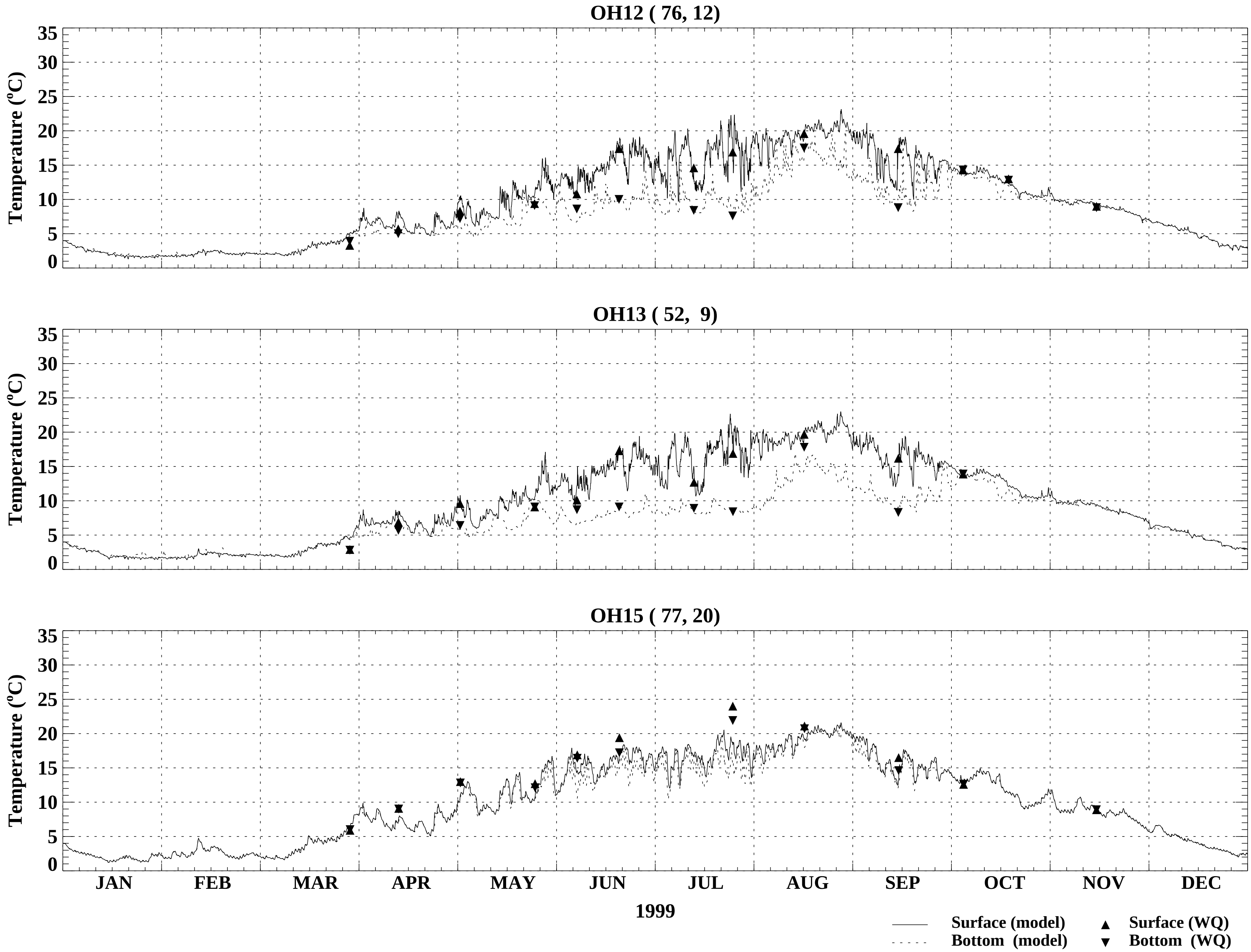


NS28/OH01 (64, 24)
OH03 (66, 19)
OH04 (72, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1999
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

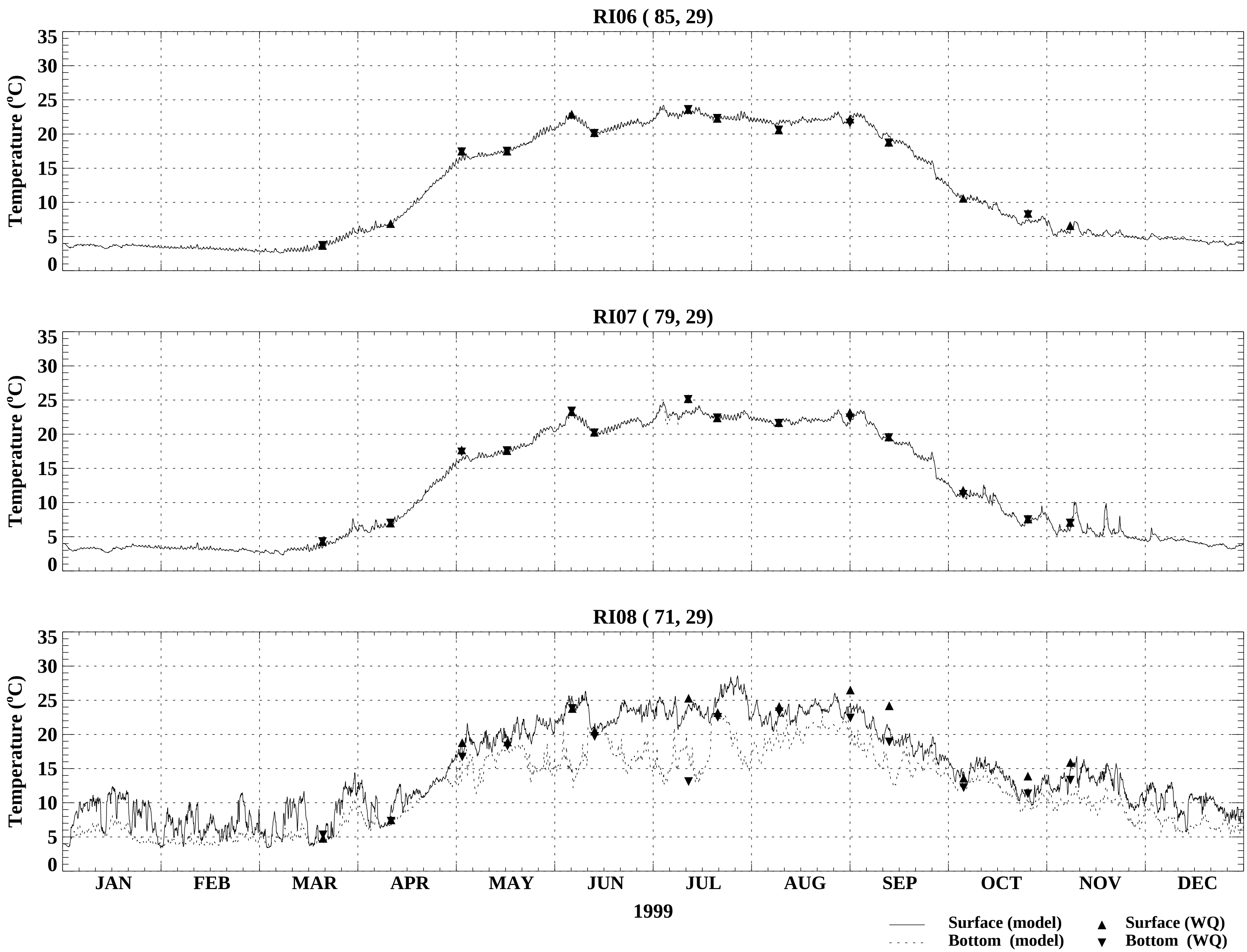

OH05 (76, 18)
OH06 (71, 17)
OH08 (59, 16)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1999
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)



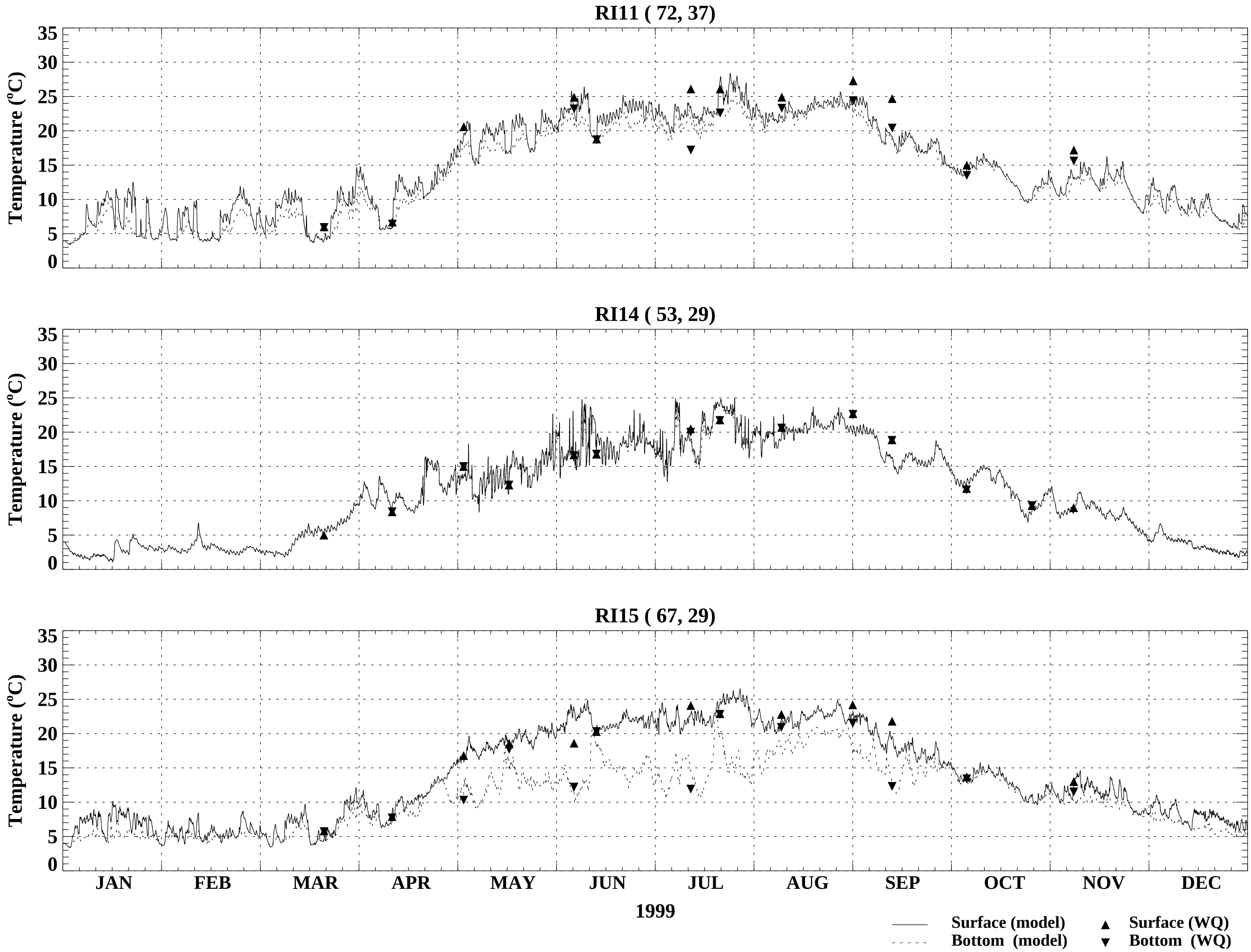
OH09 (55, 17)
OH10 (51, 26)
OH11 (58, 21)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1999
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

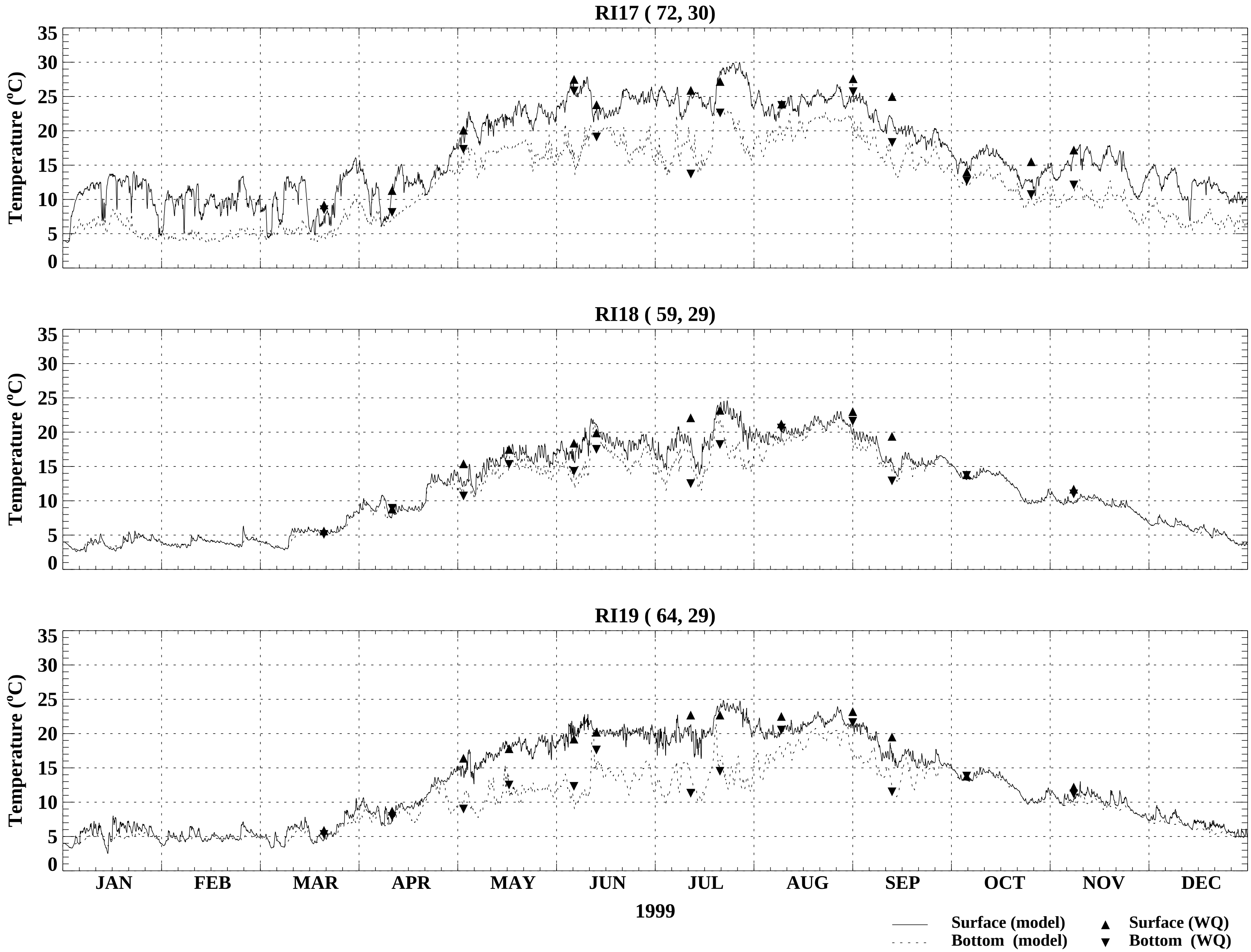


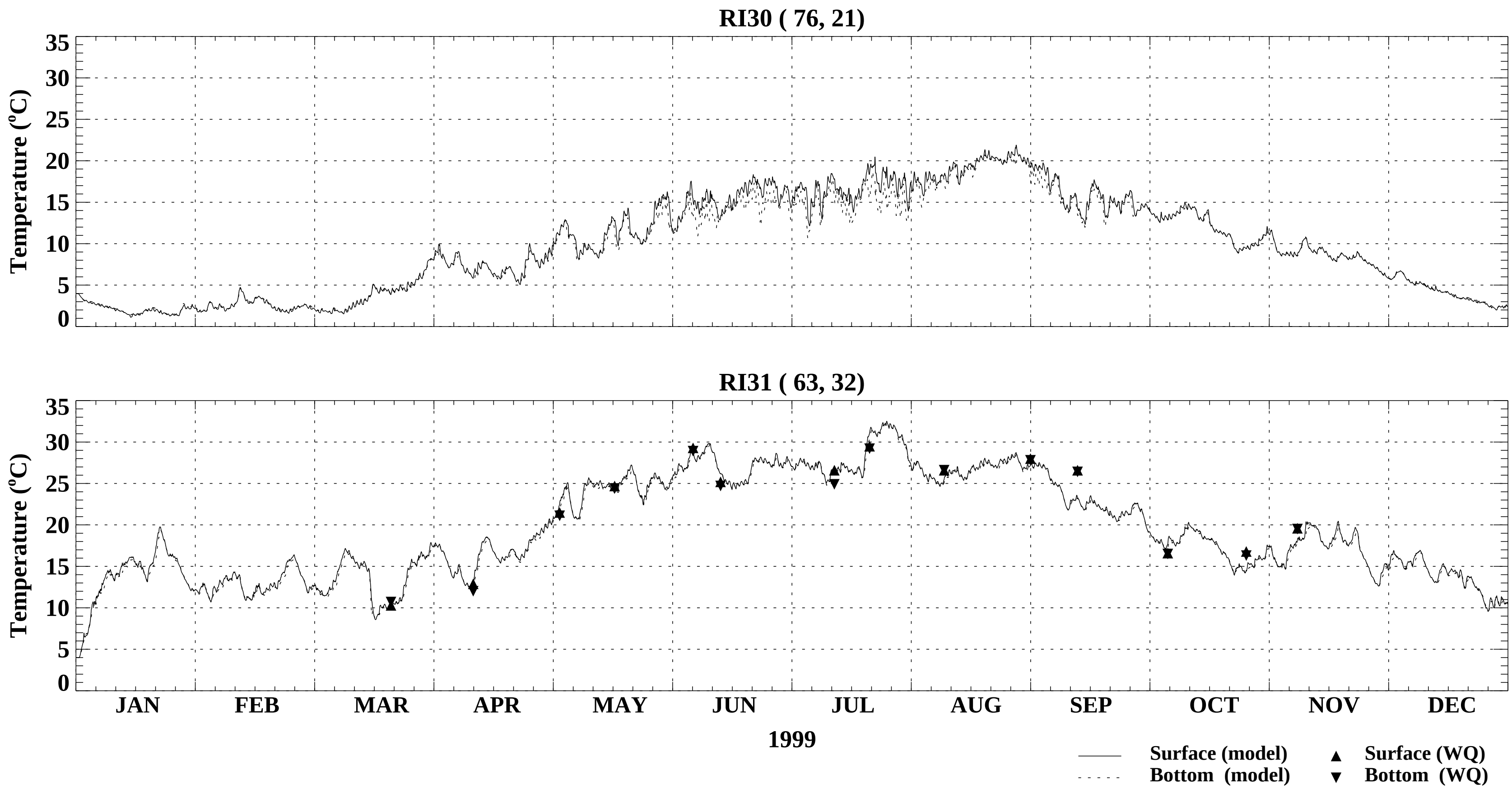
OH12 (76, 12)
OH13 (52, 9)
OH15 (77, 20)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1999
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)



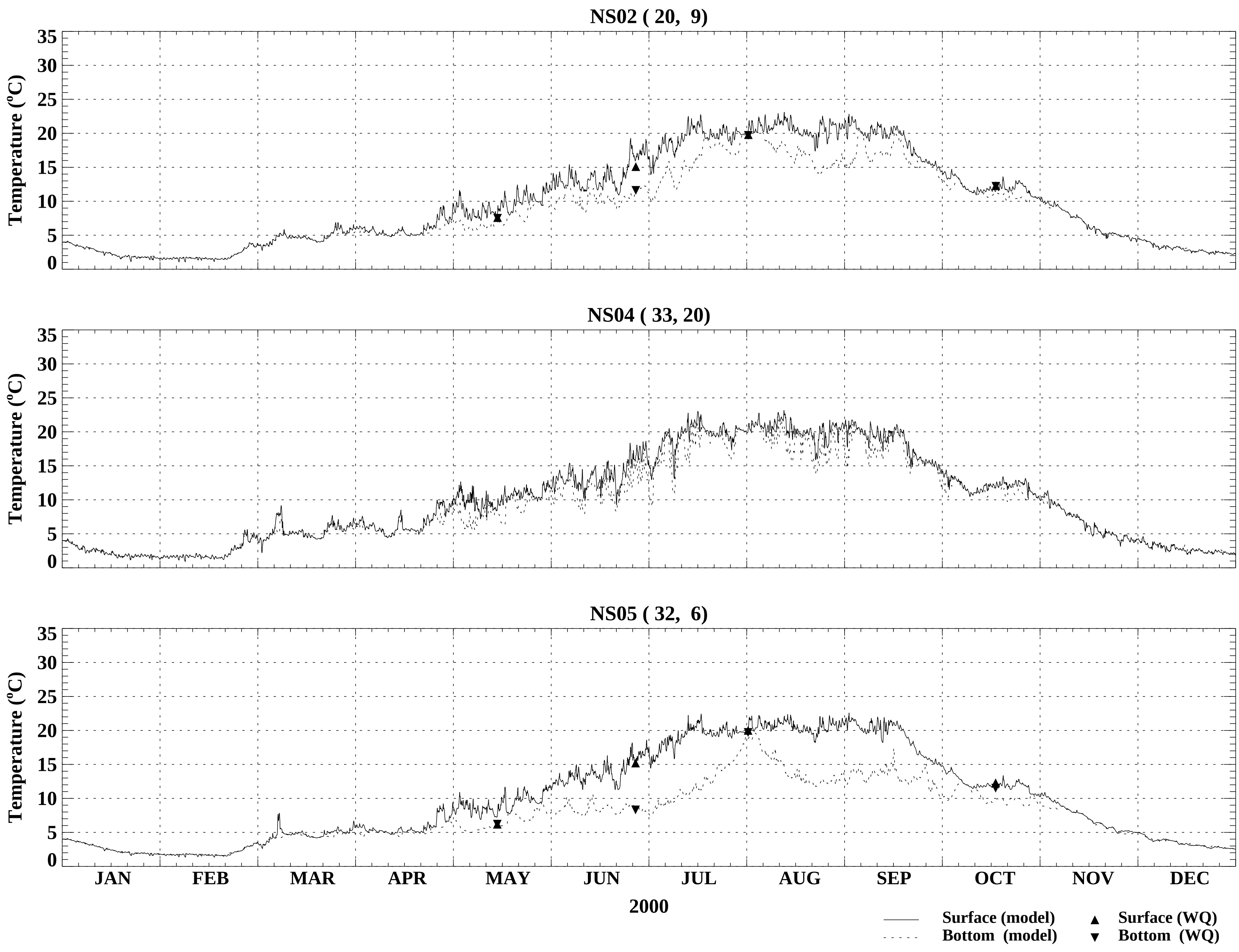
RI06 (85, 29)
RI07 (79, 29)
RI08 (71, 29)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1999
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


RI11 (72, 37)
RI14 (53, 29)
RI15 (67, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1999
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

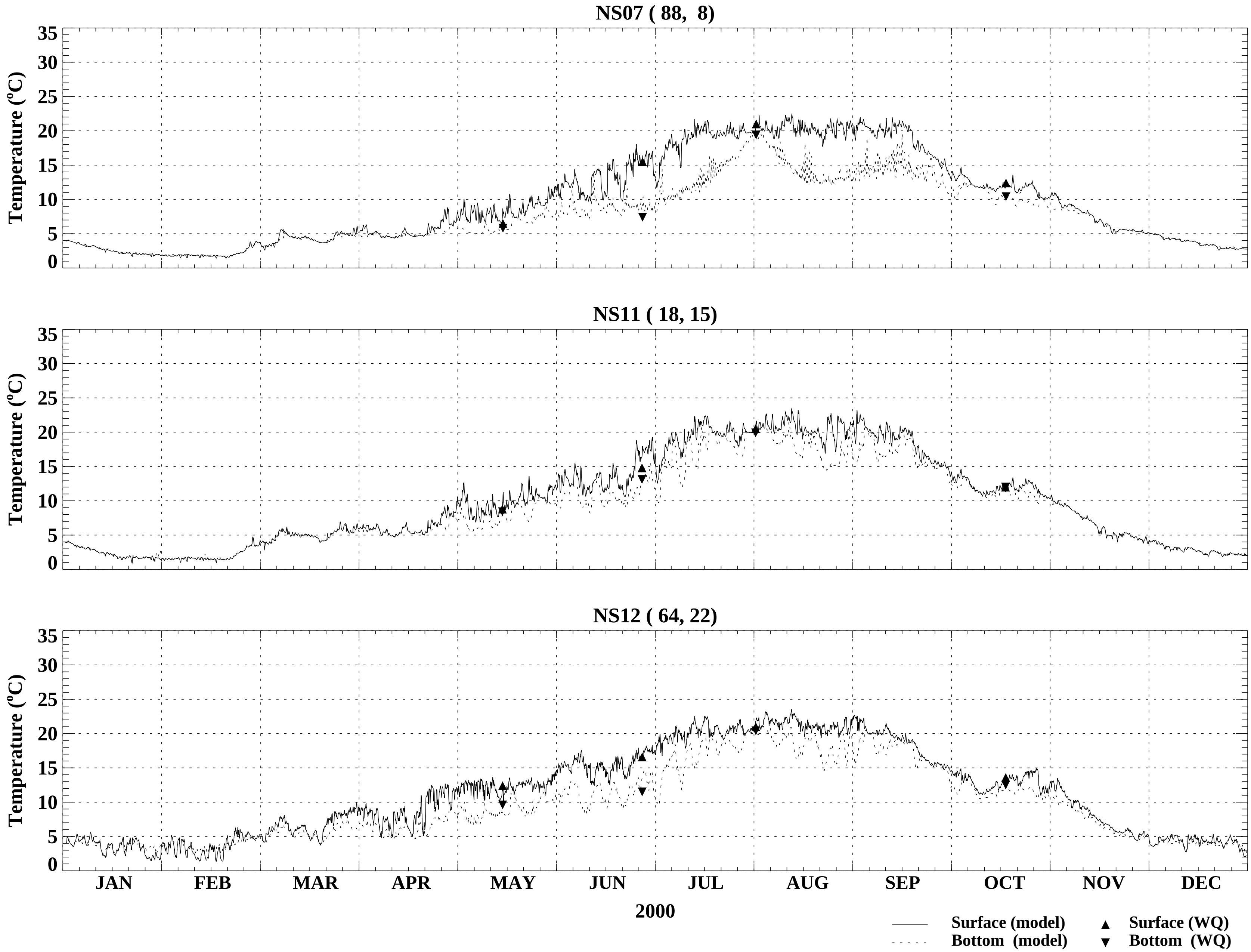

RI17 (72, 30)
RI18 (59, 29)
RI19 (64, 29)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1999
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

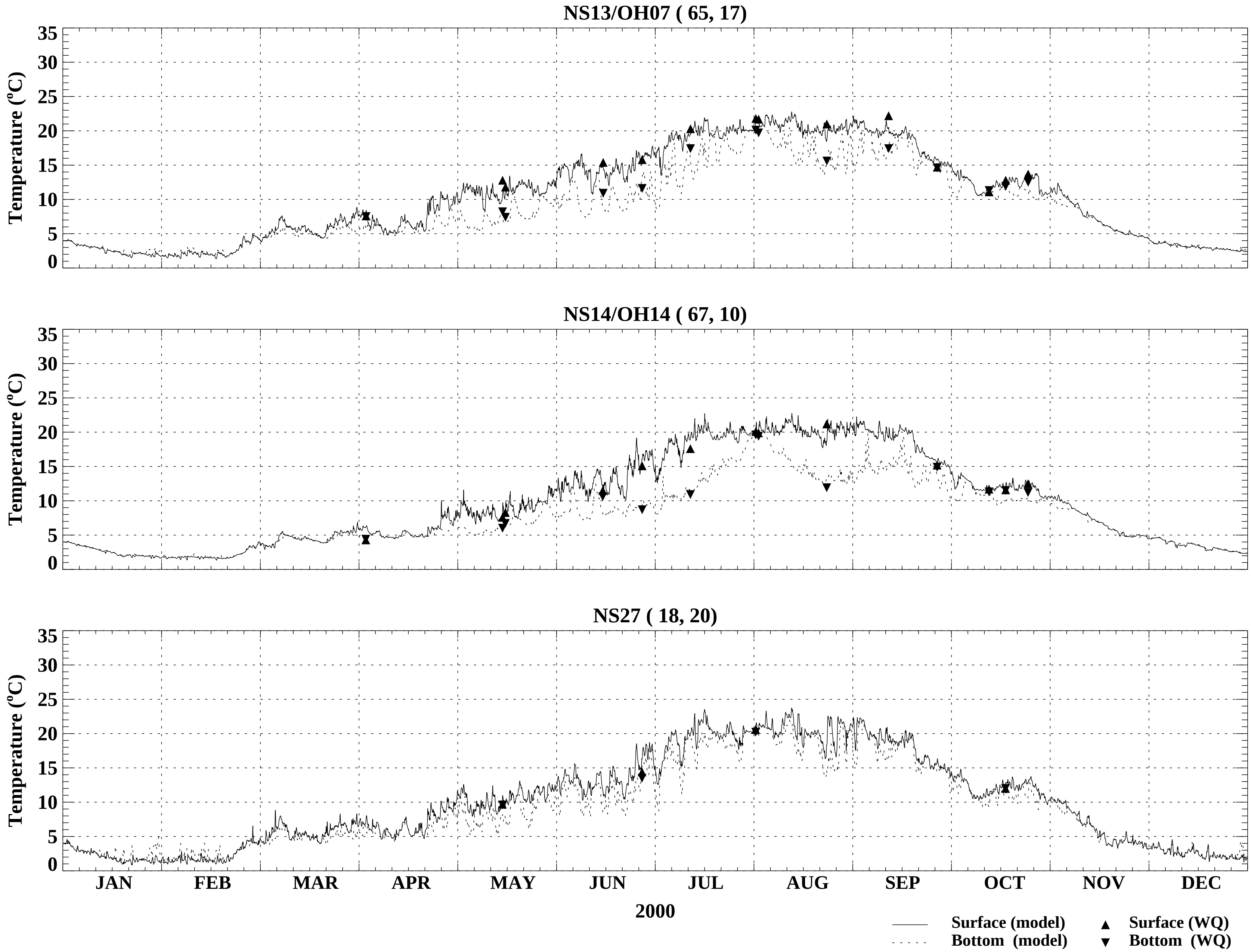


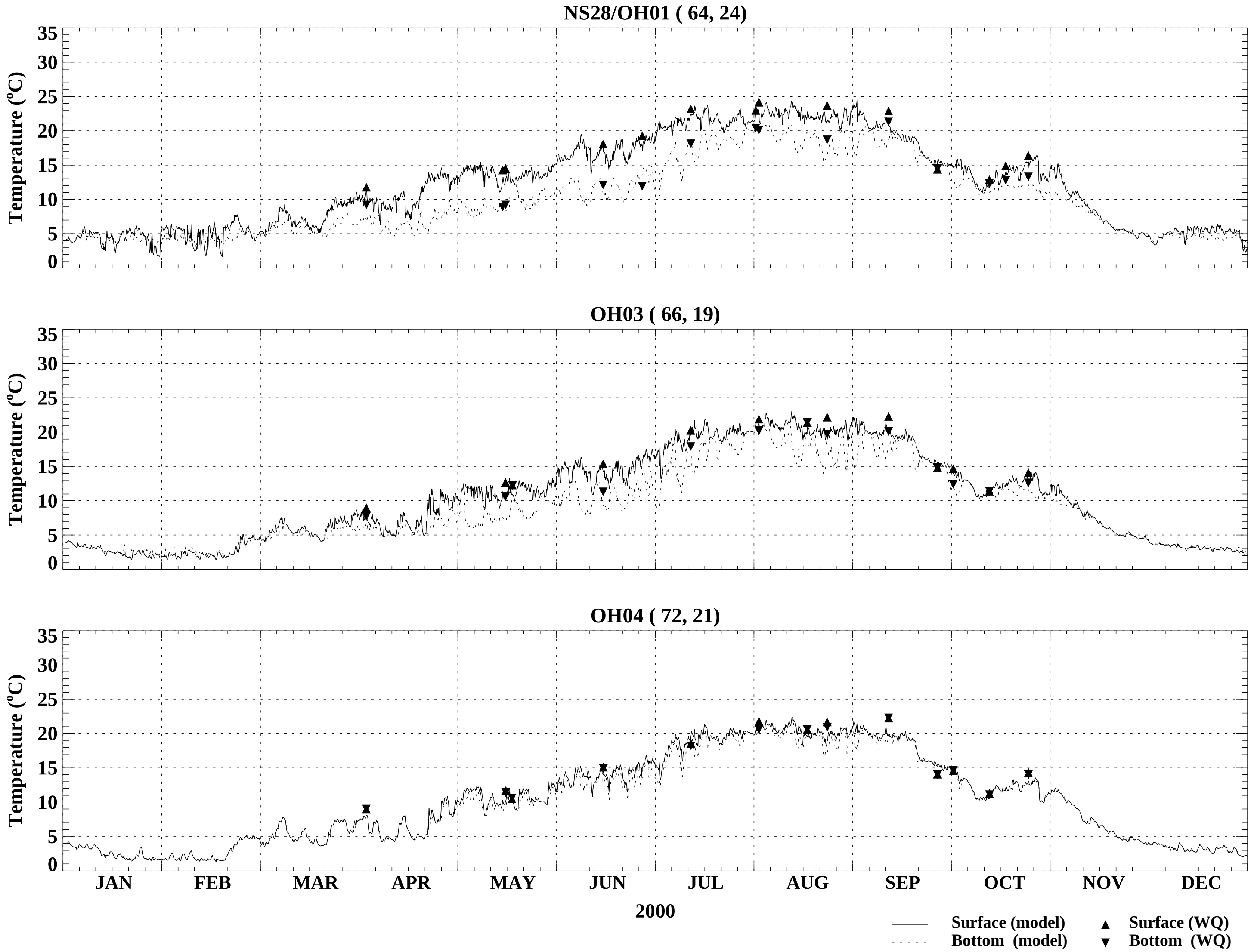
RI30 (76, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
RI31 (63, 32)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1999
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

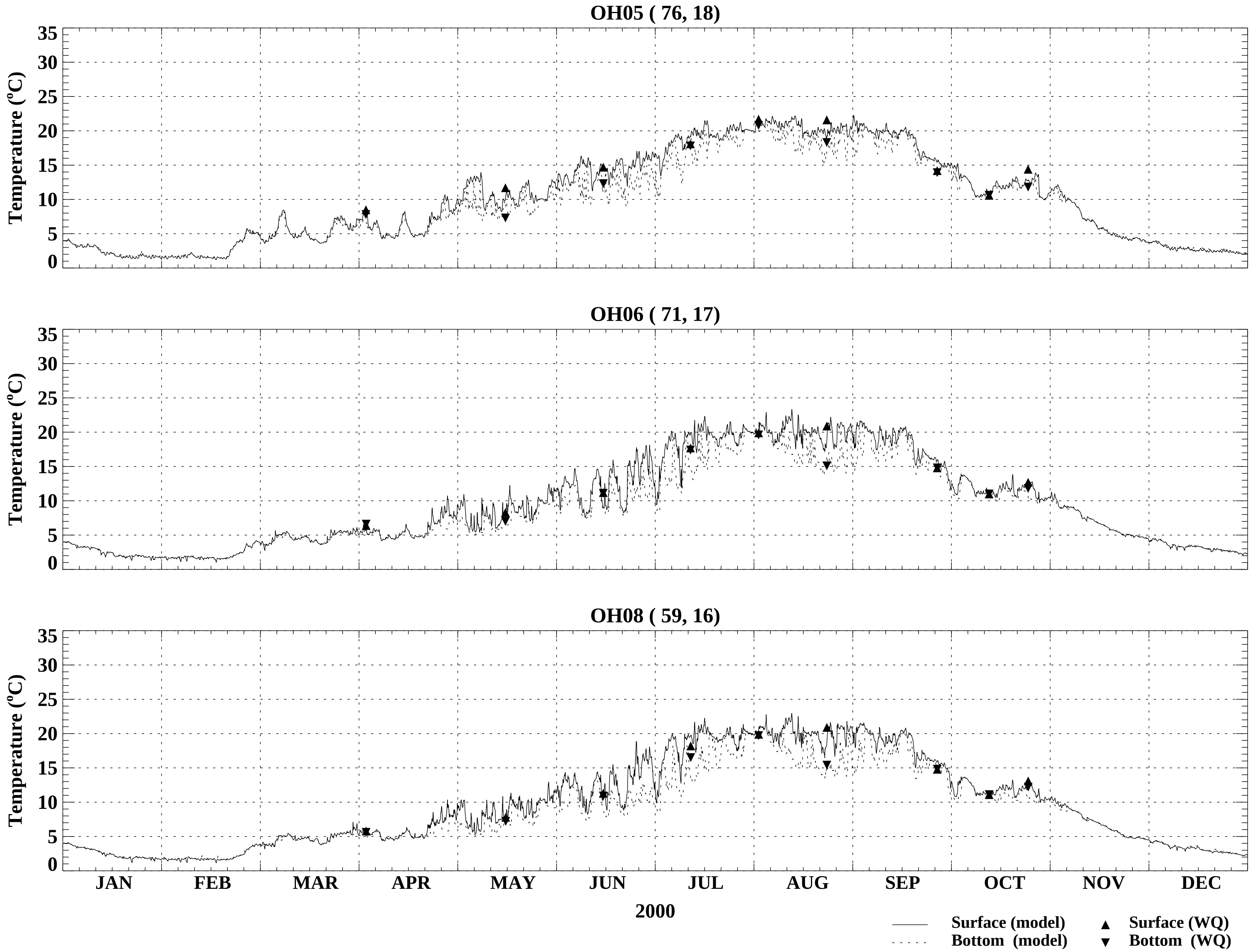


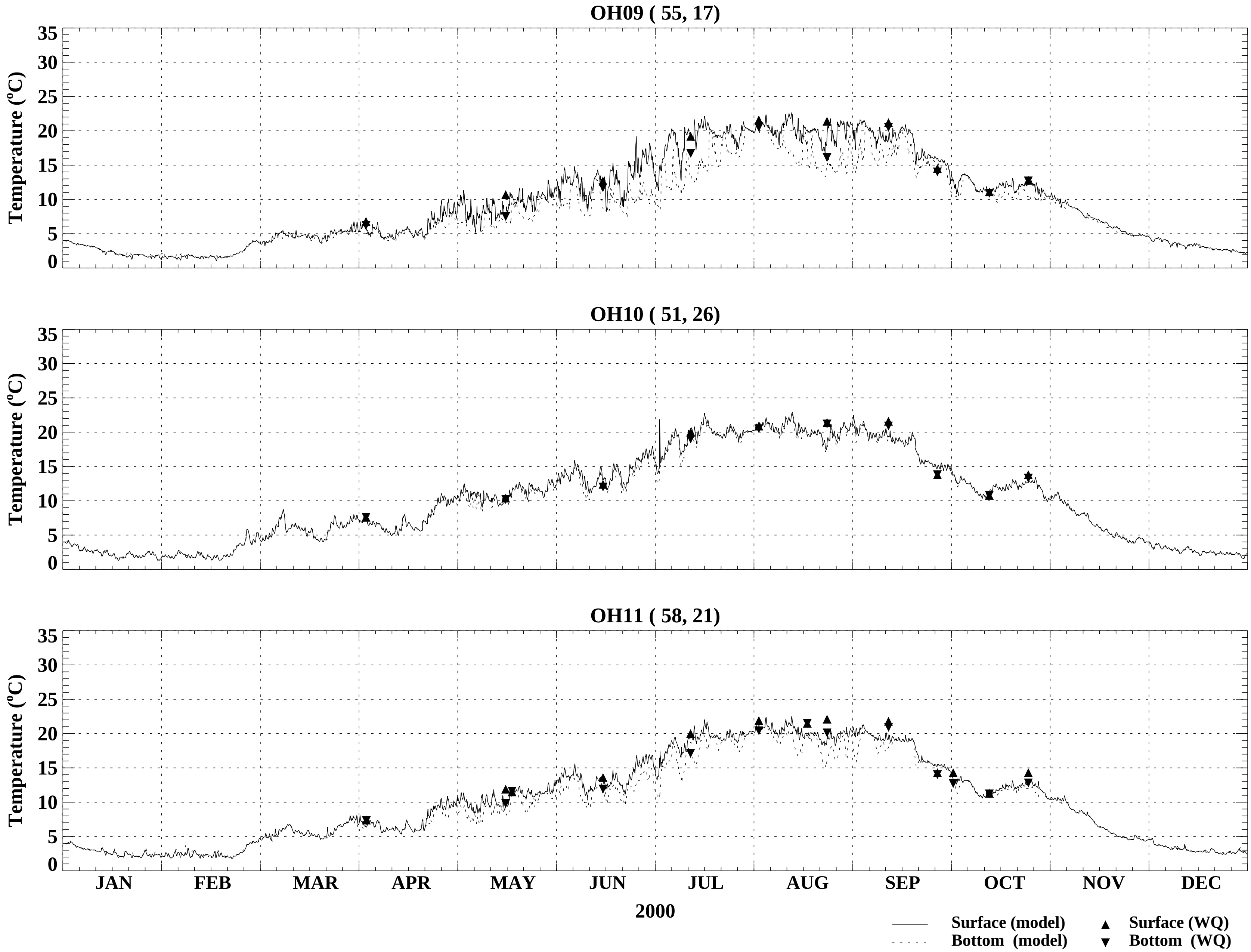
NS02 (20, 9)
NS04 (33, 20)
NS05 (32, 6)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2000
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


NS07 (88, 8)
NS11 (18, 15)
NS12 (64, 22)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2000
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

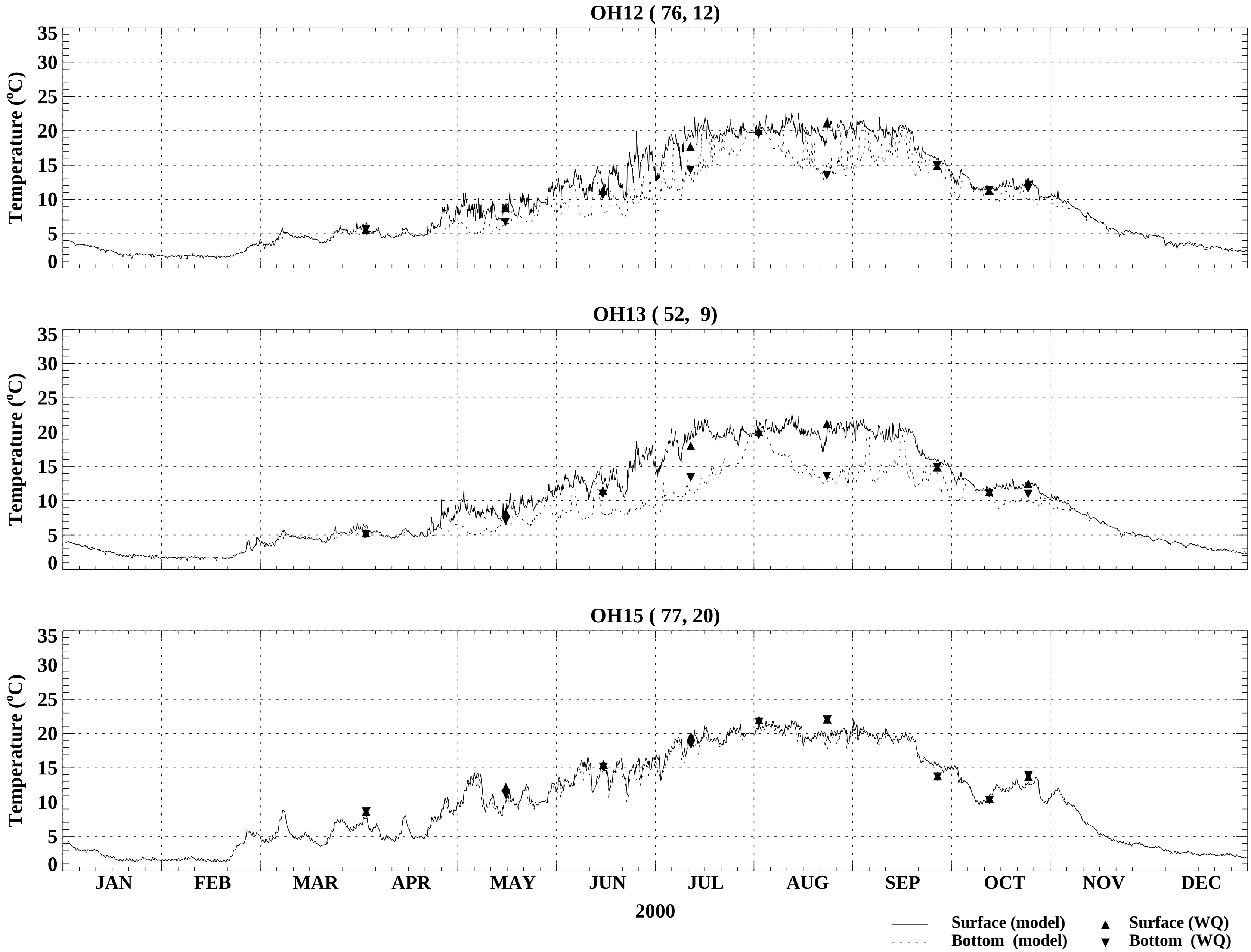

NS13/OH07 (65, 17)
NS14/OH14 (67, 10)
NS27 (18, 20)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2000
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

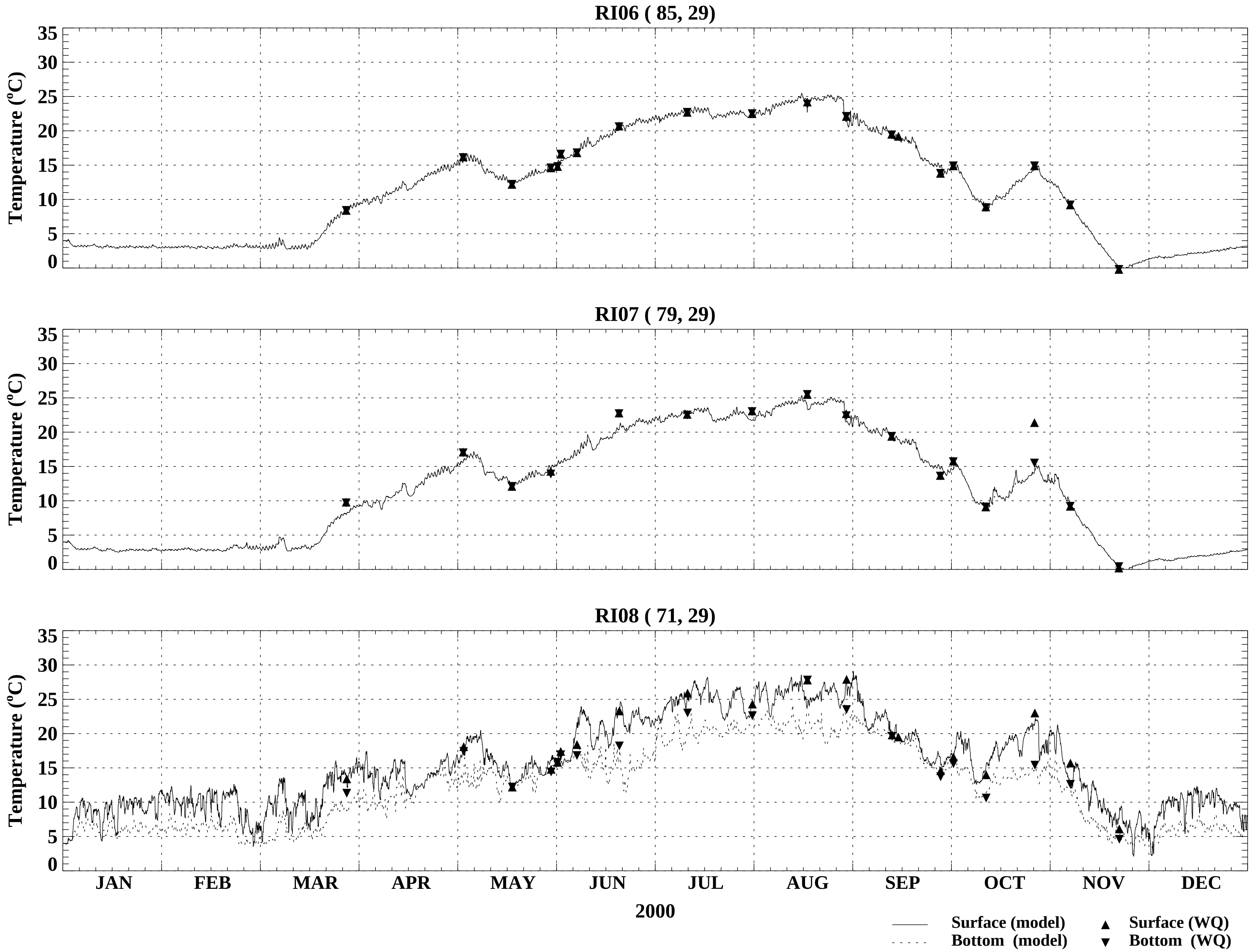

NS28/OH01 (64, 24)
OH03 (66, 19)
OH04 (72, 21)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2000
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


OH05 (76, 18)
OH06 (71, 17)
OH08 (59, 16)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2000
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

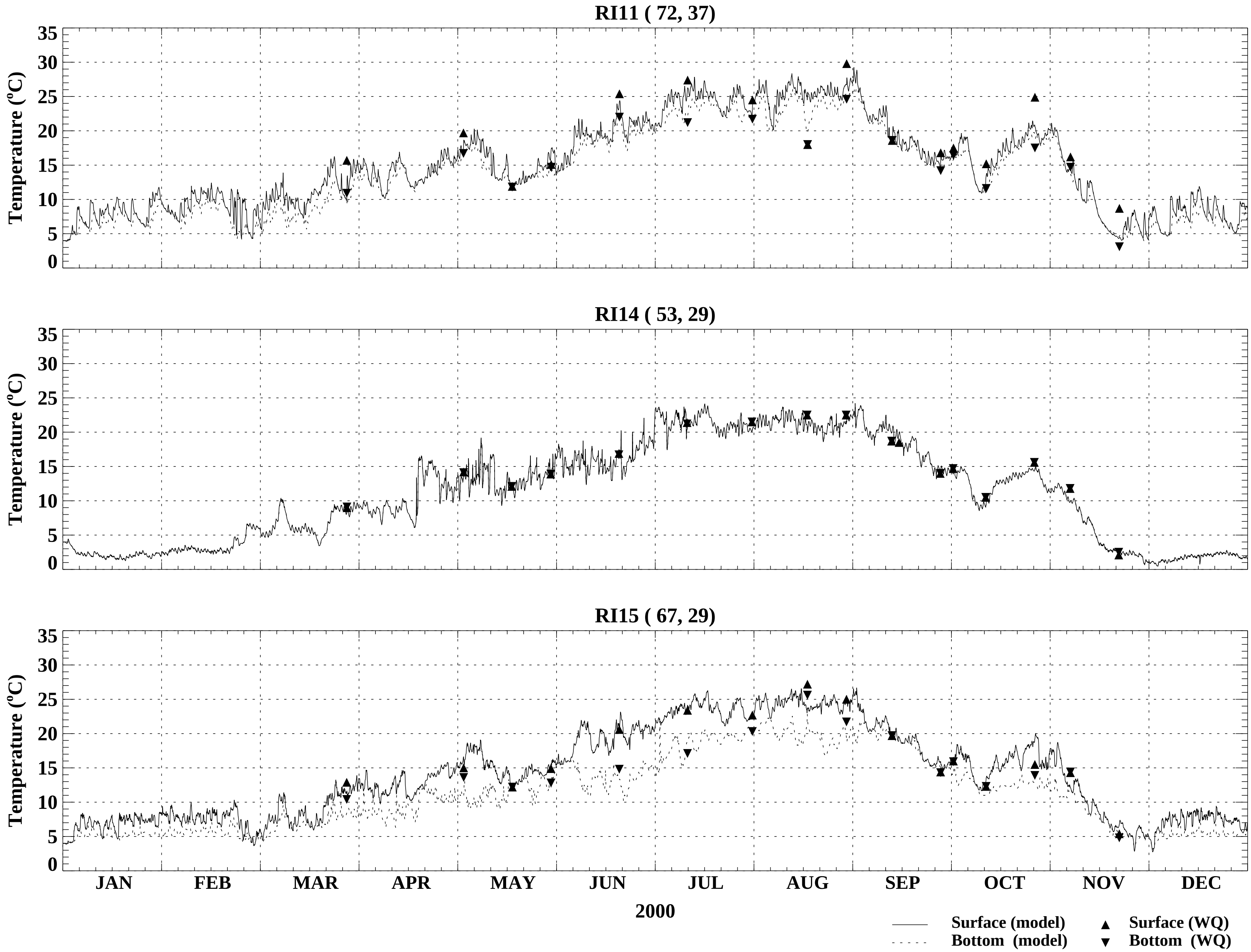


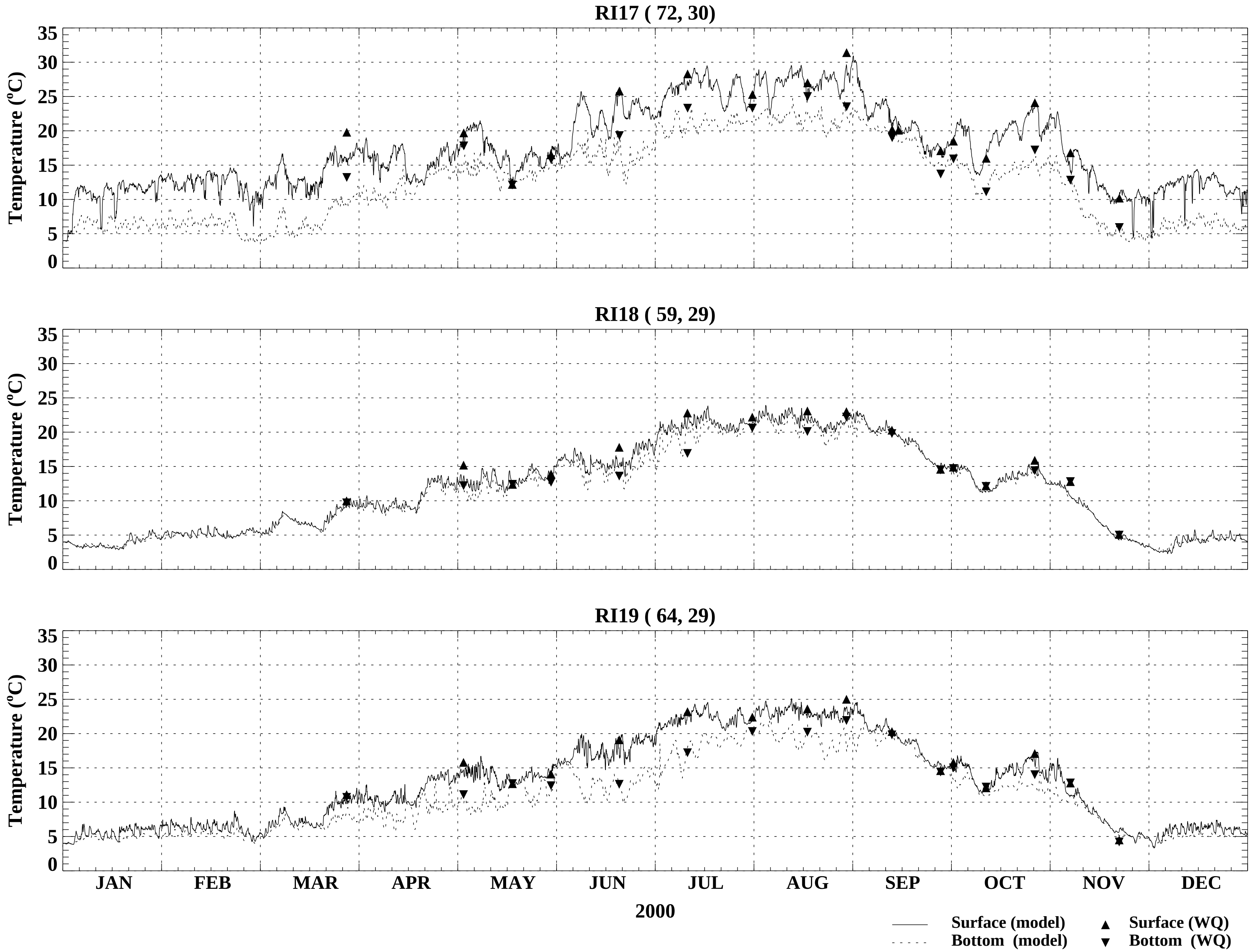
OH09 (55, 17)
OH10 (51, 26)
OH11 (58, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2000
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

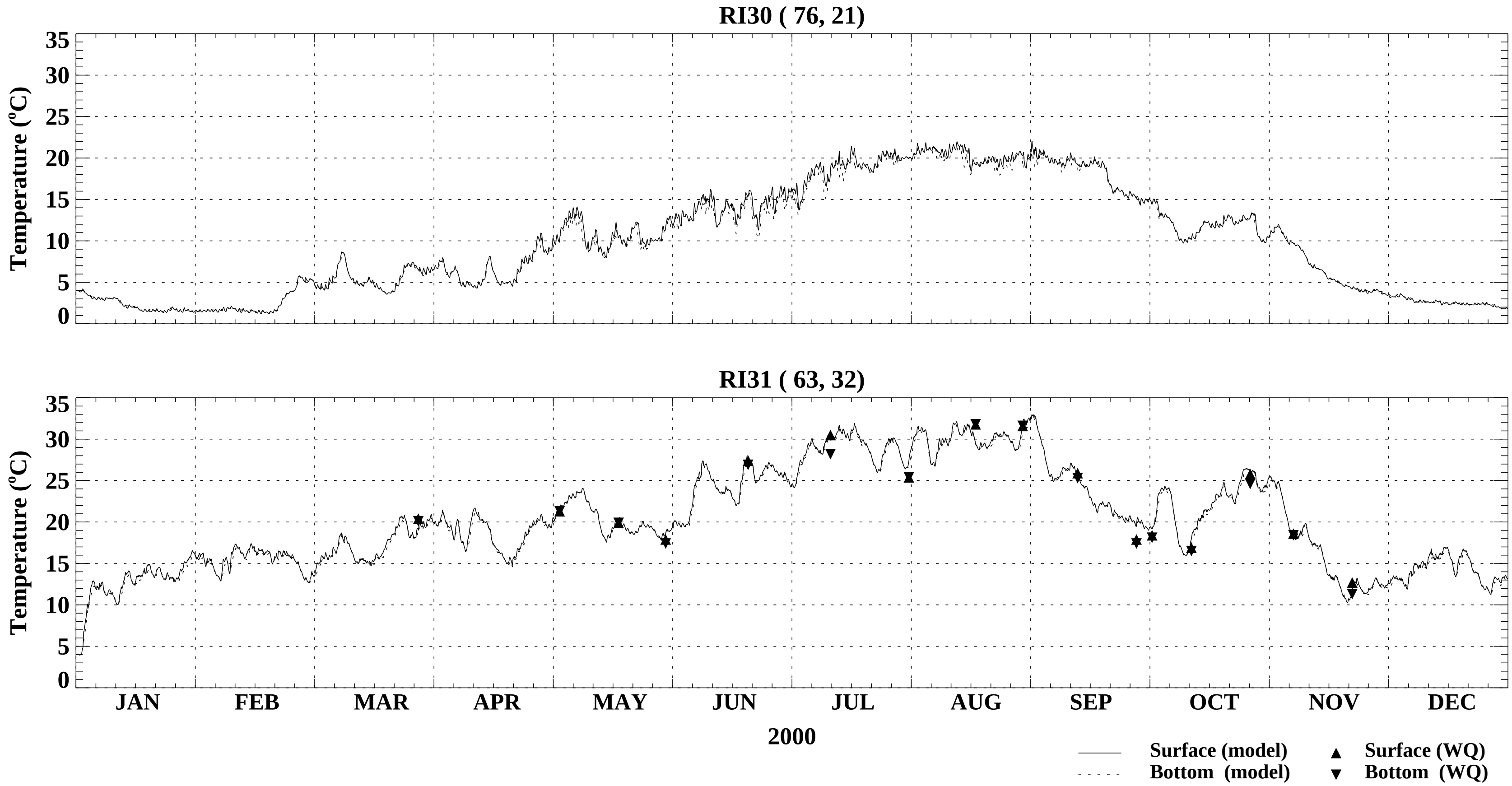

OH12 (76, 12)
OH13 (52, 9)
OH15 (77, 20)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2000
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

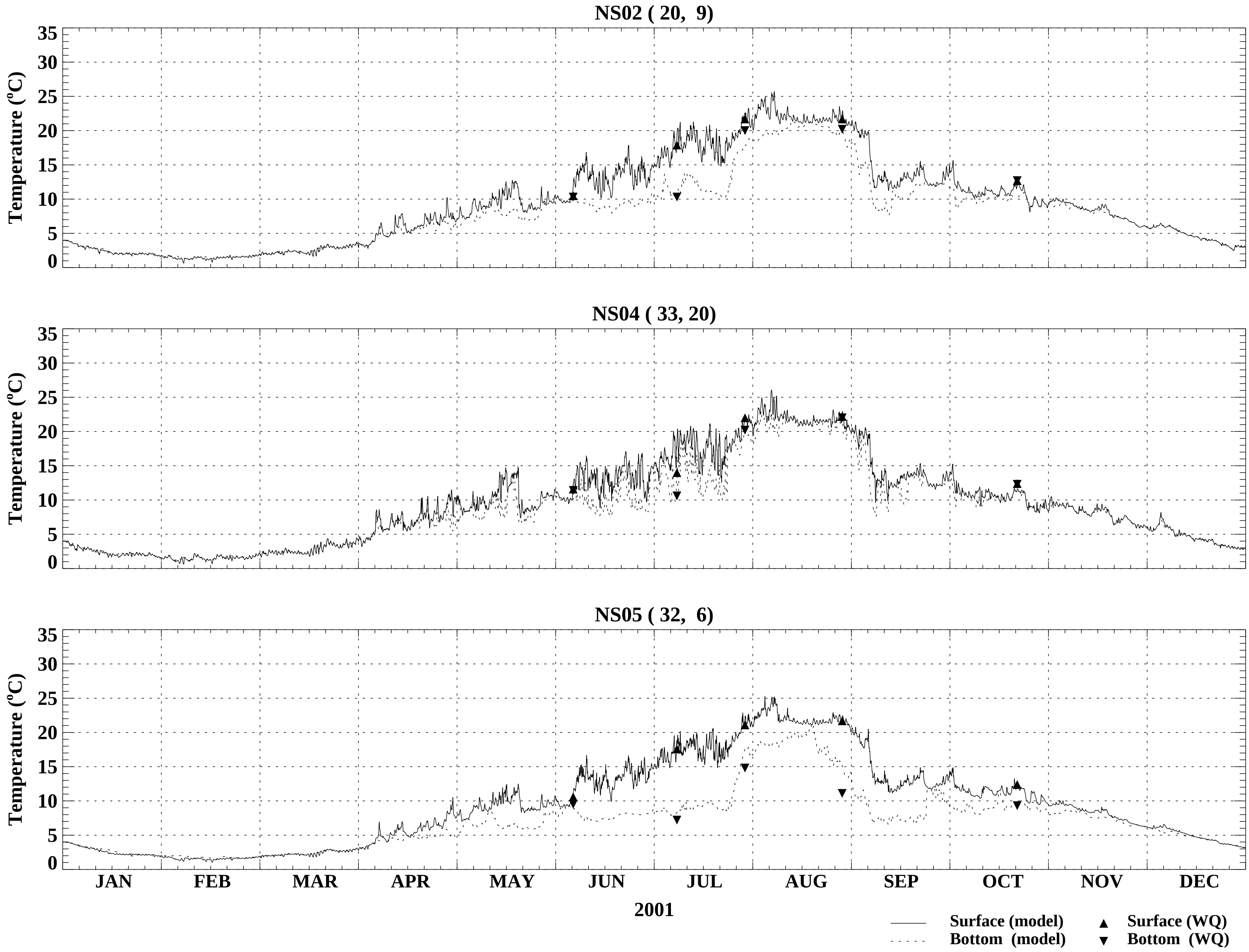


RI06 (85, 29)
RI07 (79, 29)
RI08 (71, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2000
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

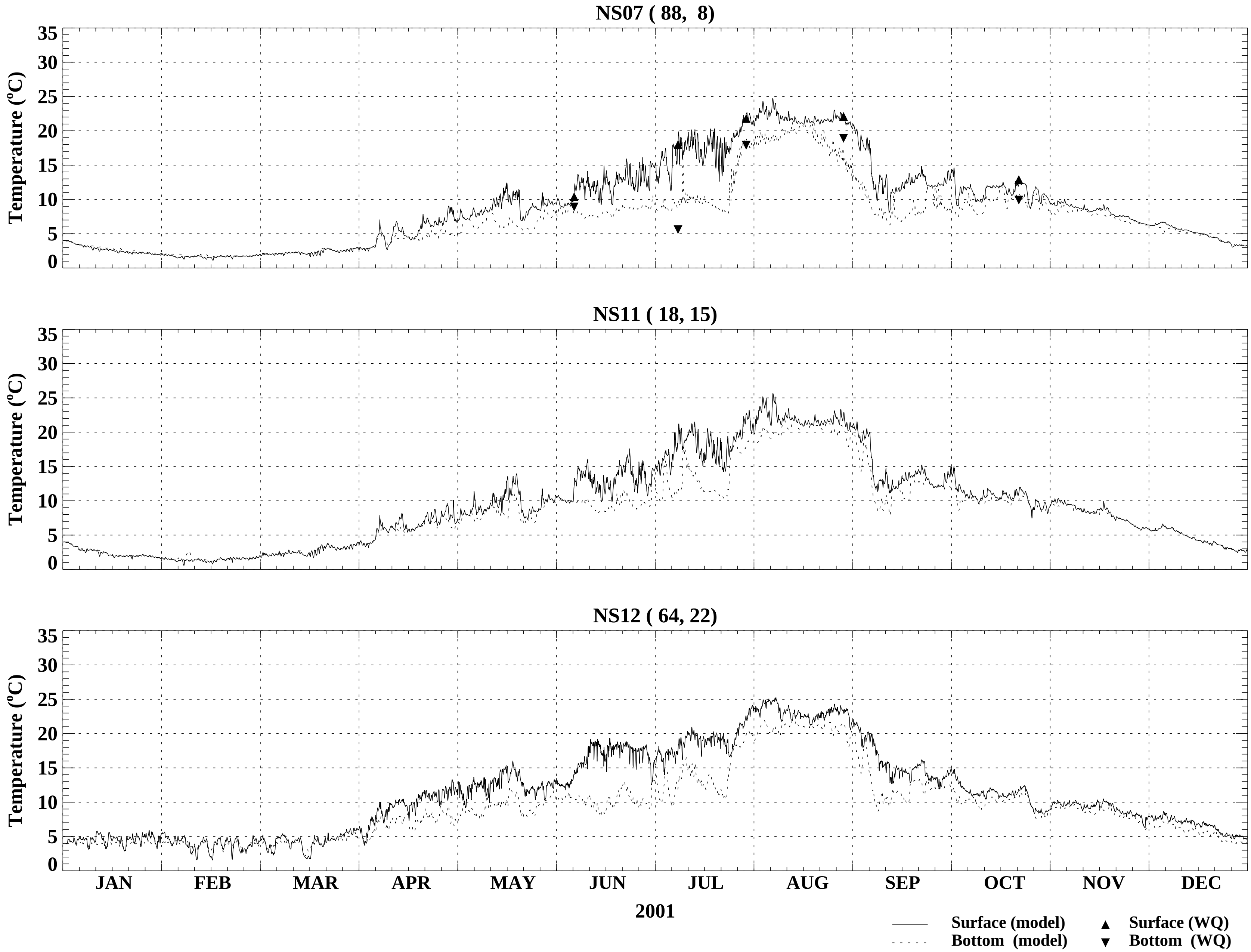

RI11 (72, 37)
RI14 (53, 29)
RI15 (67, 29)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2000
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

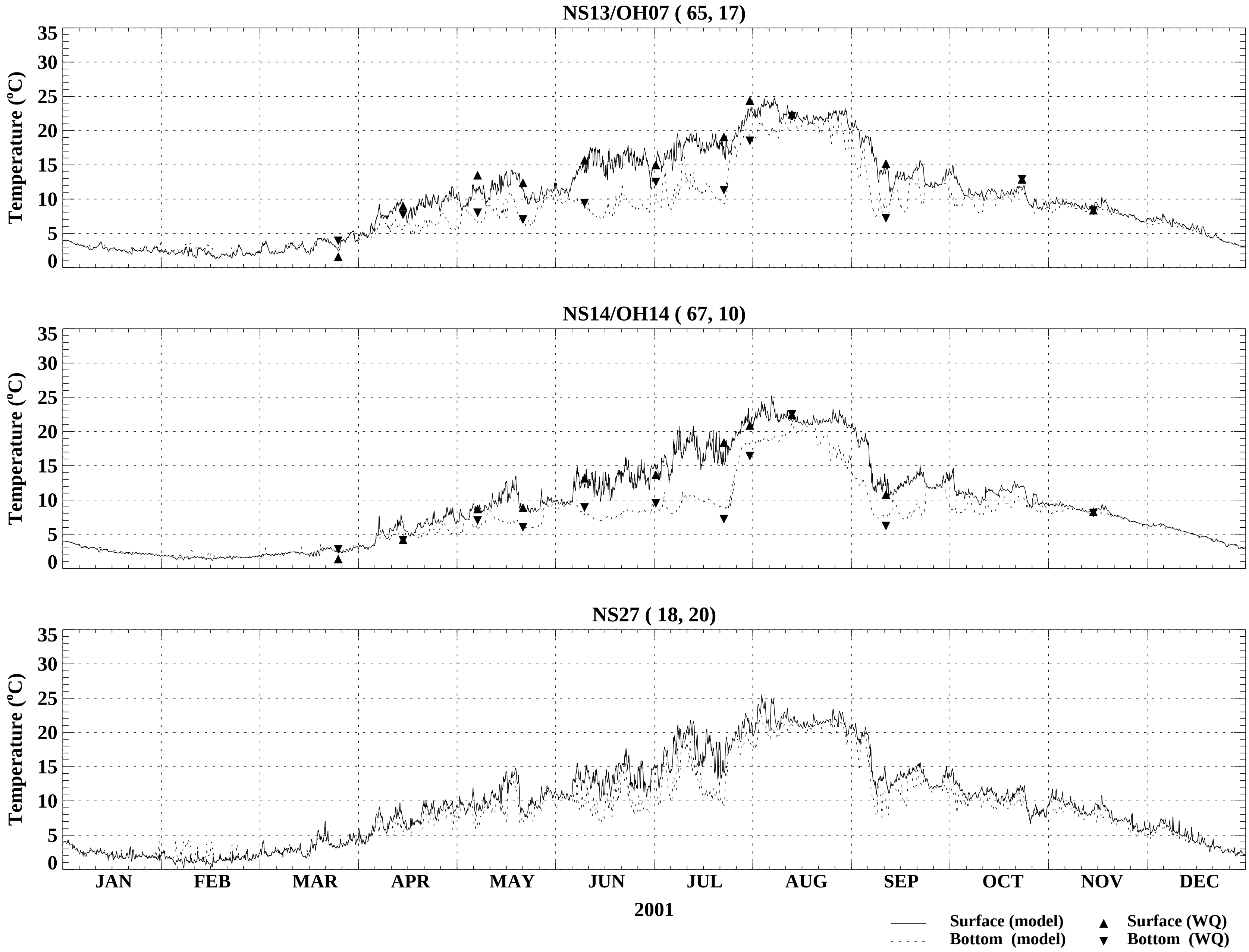

RI17 (72, 30)
RI18 (59, 29)
RI19 (64, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2000
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

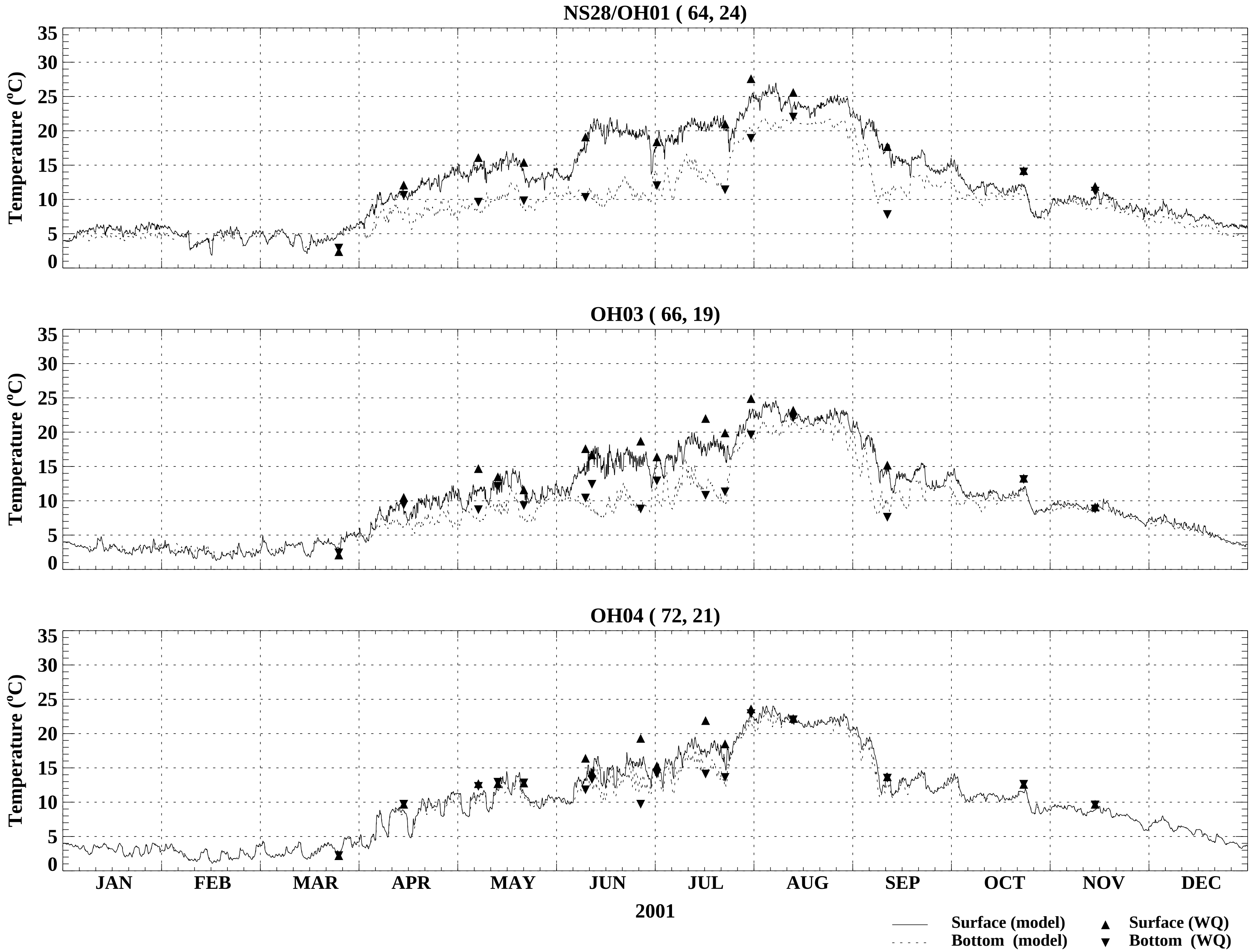

RI30 (76, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
RI31 (63, 32)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2000
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)



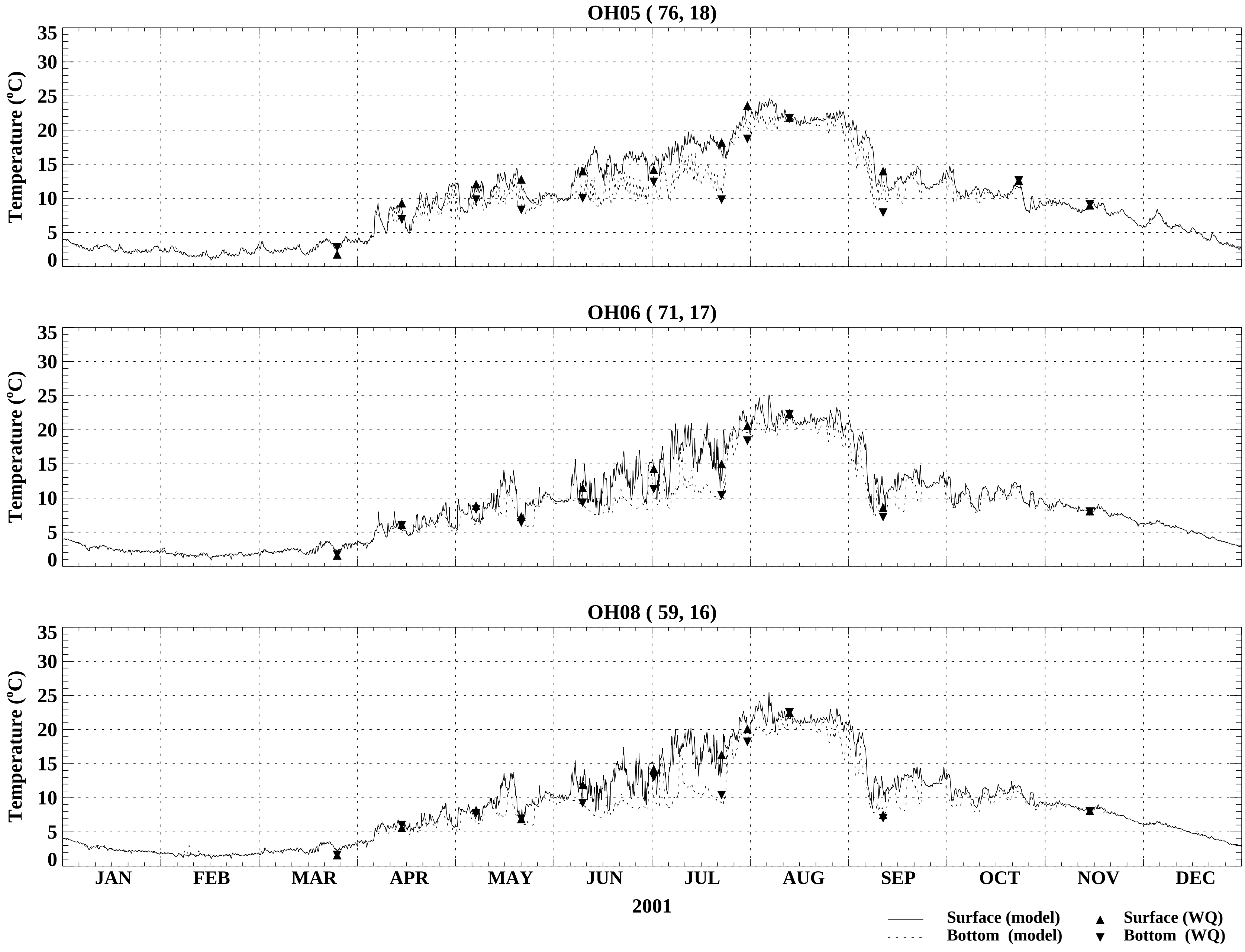
NS02 (20, 9)
NS04 (33, 20)
NS05 (32, 6)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2001
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

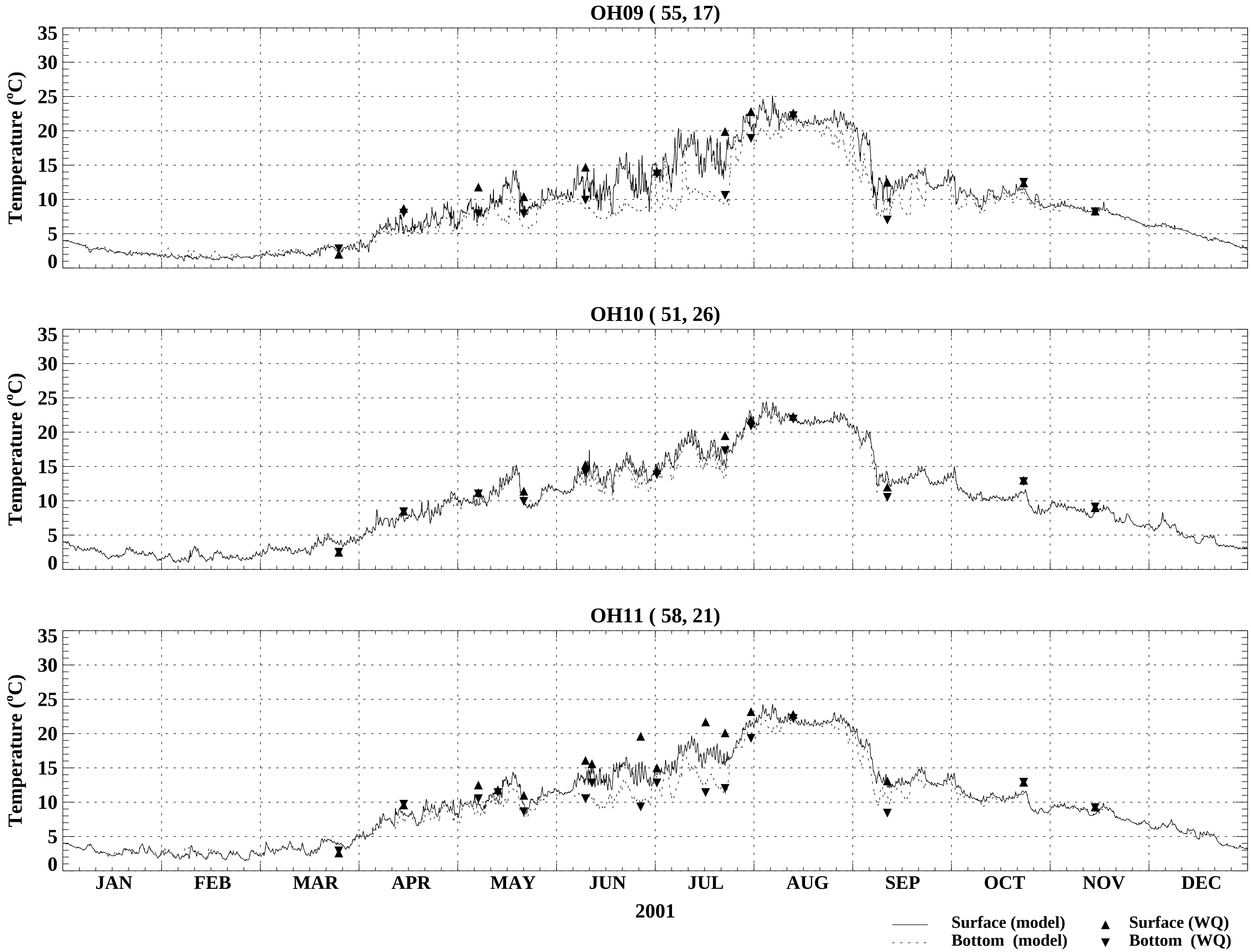

NS07 (88, 8)
NS11 (18, 15)
NS12 (64, 22)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2001
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


NS13/OH07 (65, 17)
NS14/OH14 (67, 10)
NS27 (18, 20)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2001
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

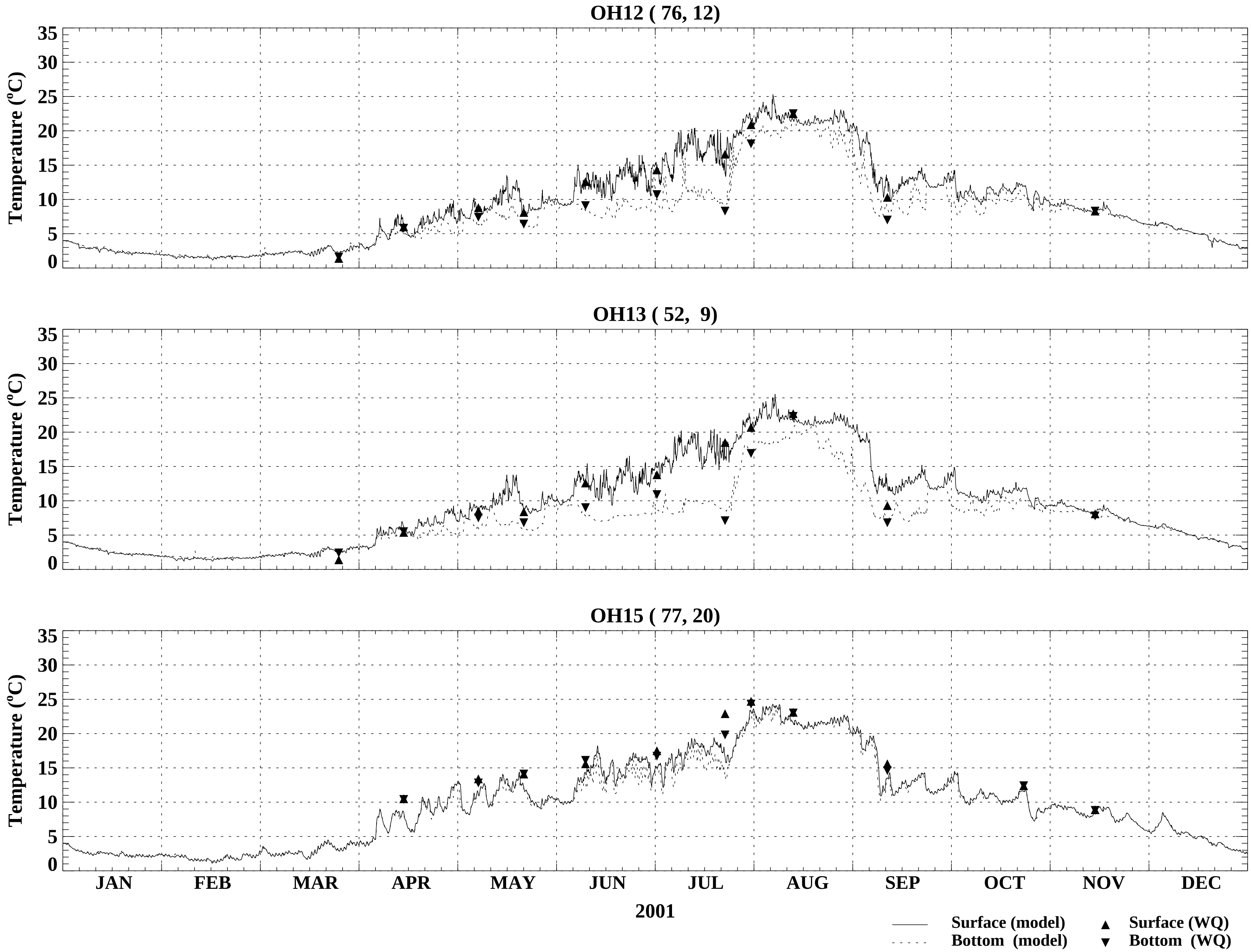


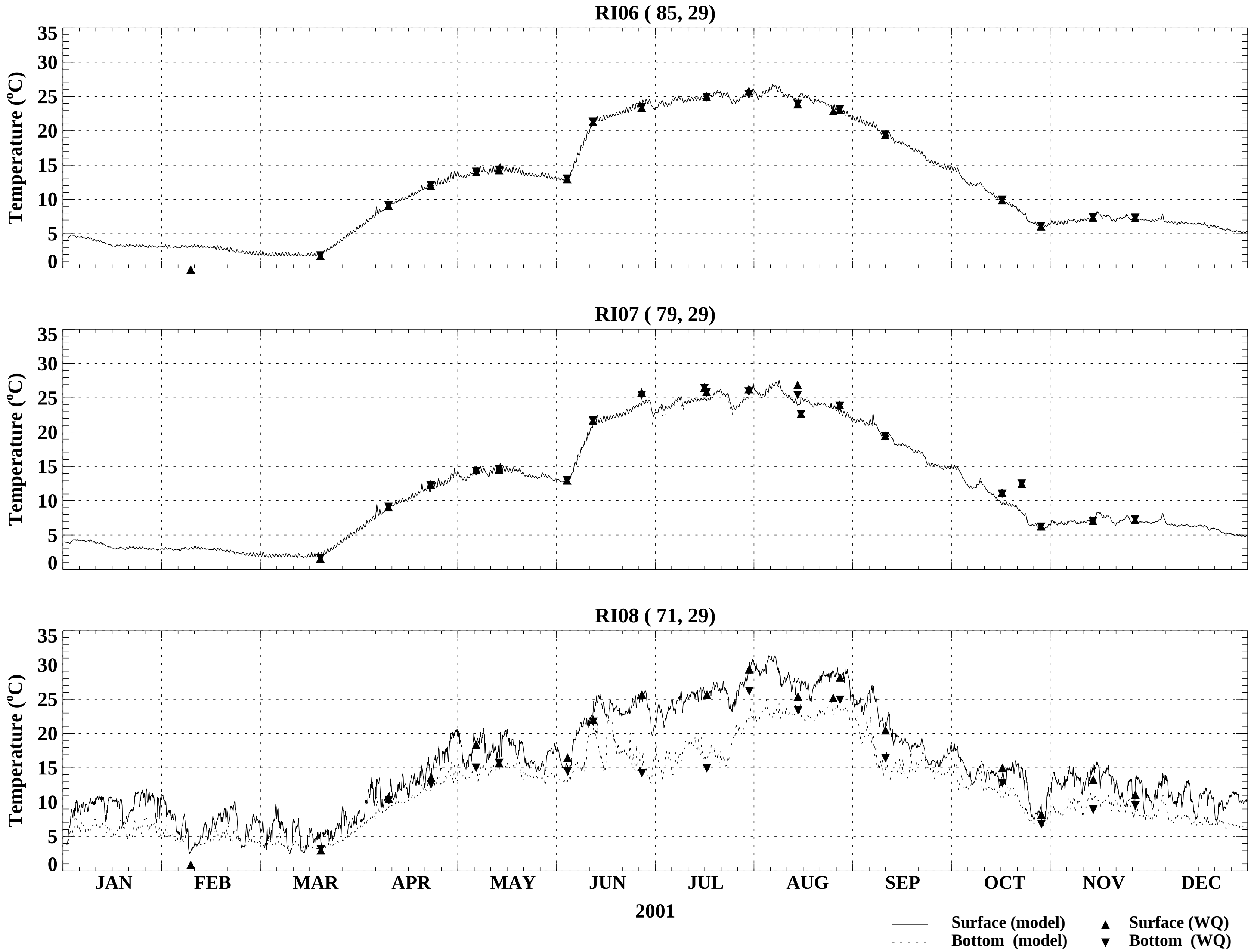
NS28/OH01 (64, 24)
OH03 (66, 19)
OH04 (72, 21)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2001
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


OH05 (76, 18)
OH06 (71, 17)
OH08 (59, 16)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2001
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

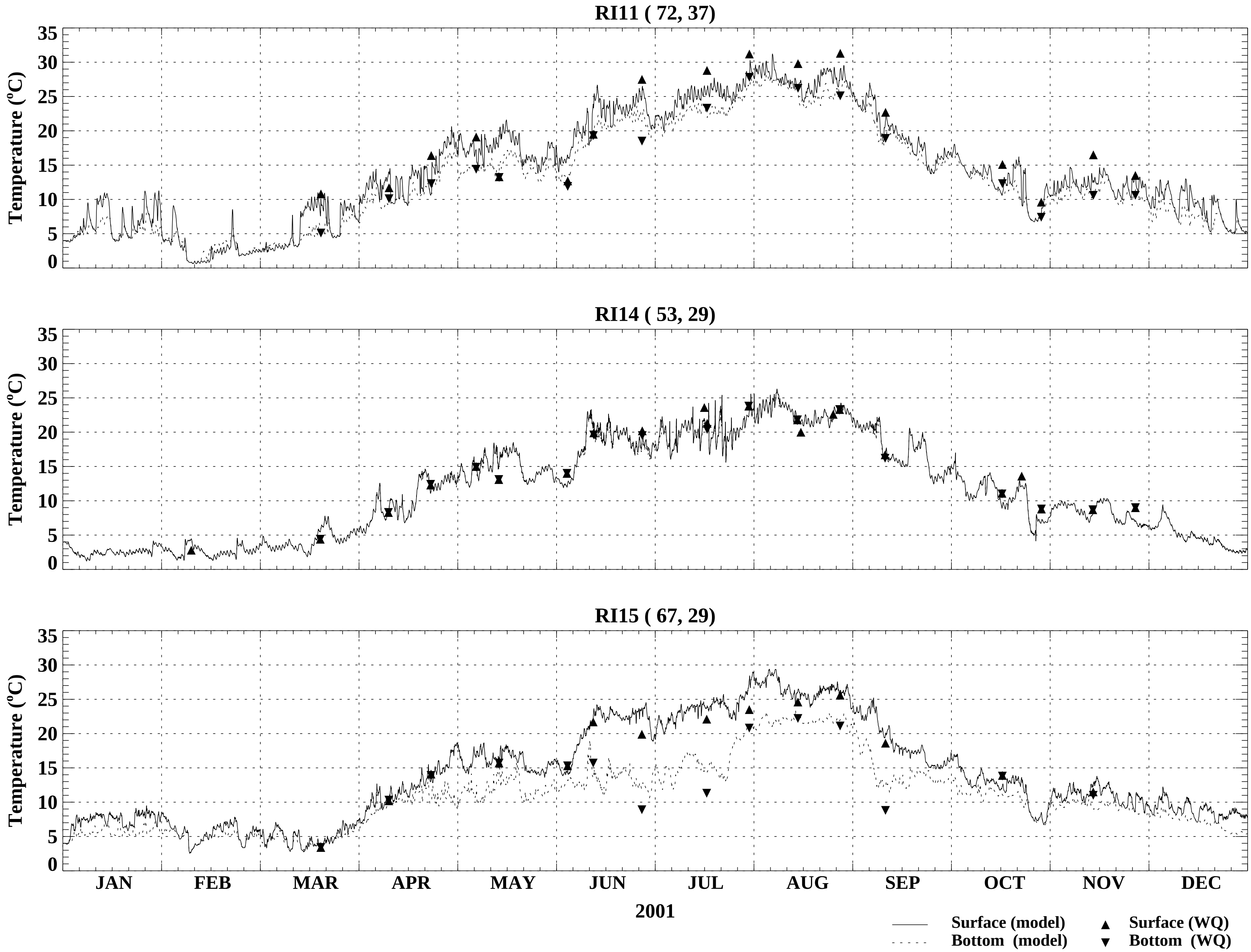


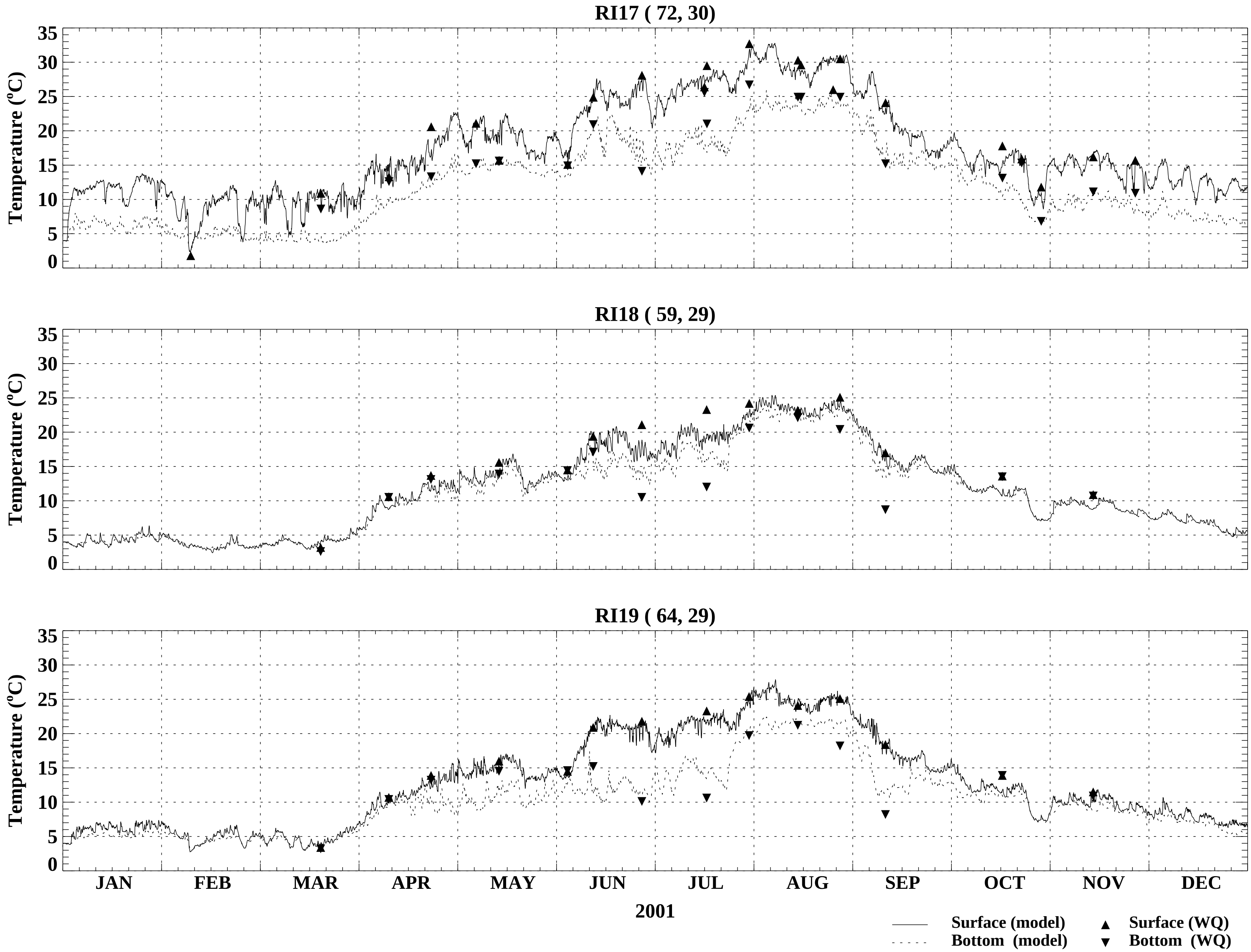
OH09 (55, 17)
OH10 (51, 26)
OH11 (58, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2001
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

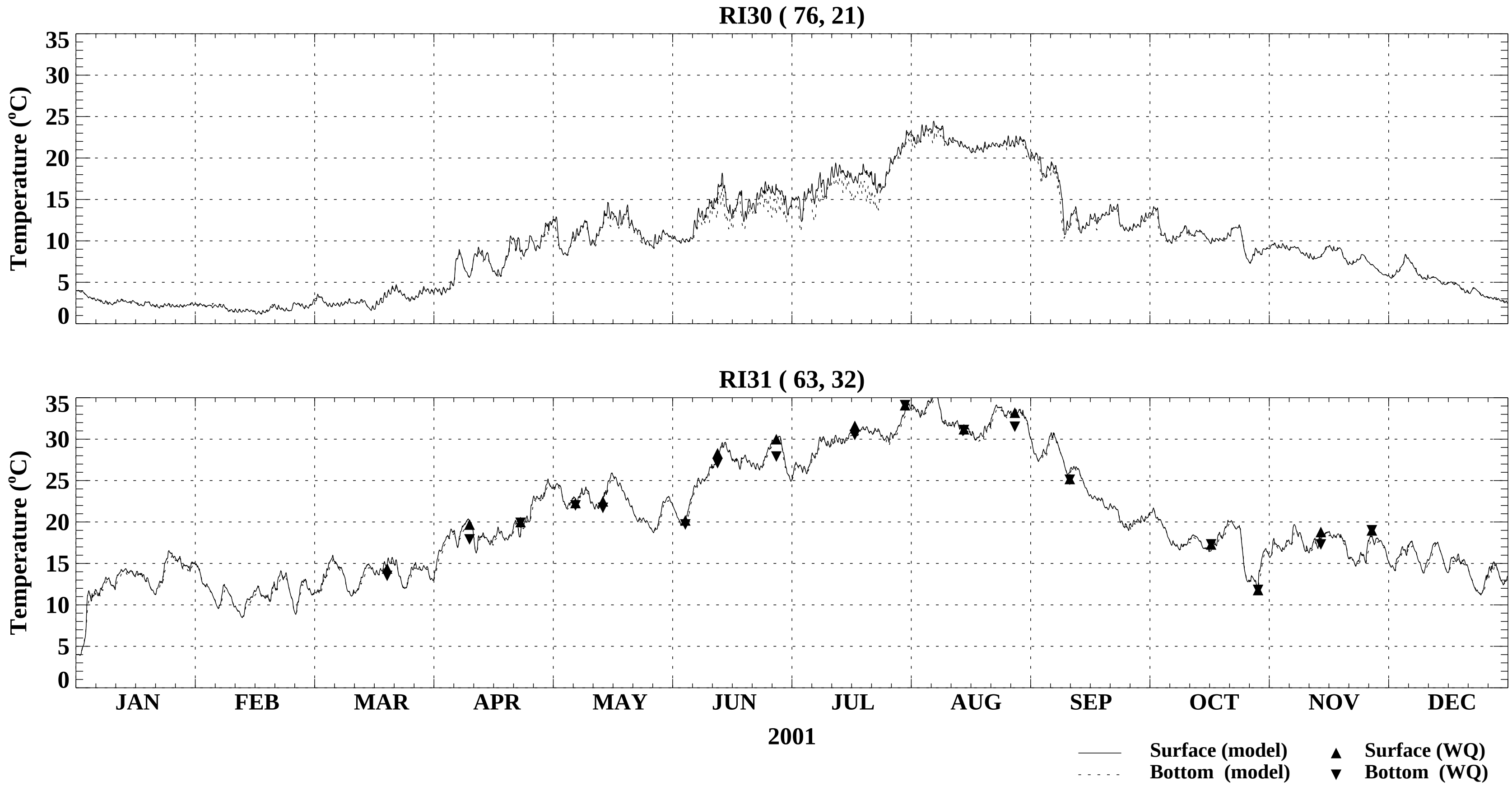

OH12 (76, 12)
OH13 (52, 9)
OH15 (77, 20)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2001
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)



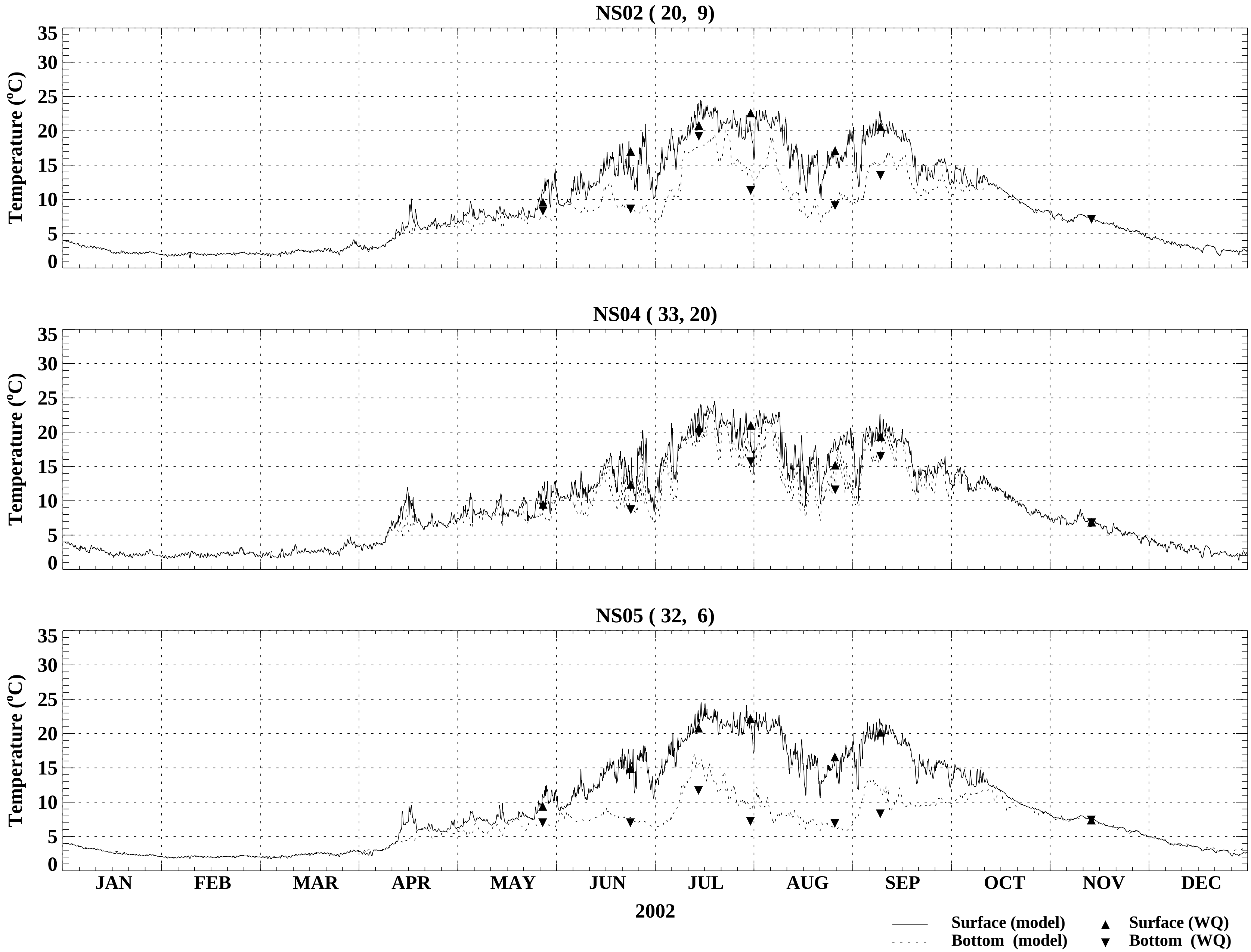
RI06 (85, 29)
RI07 (79, 29)
RI08 (71, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2001
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

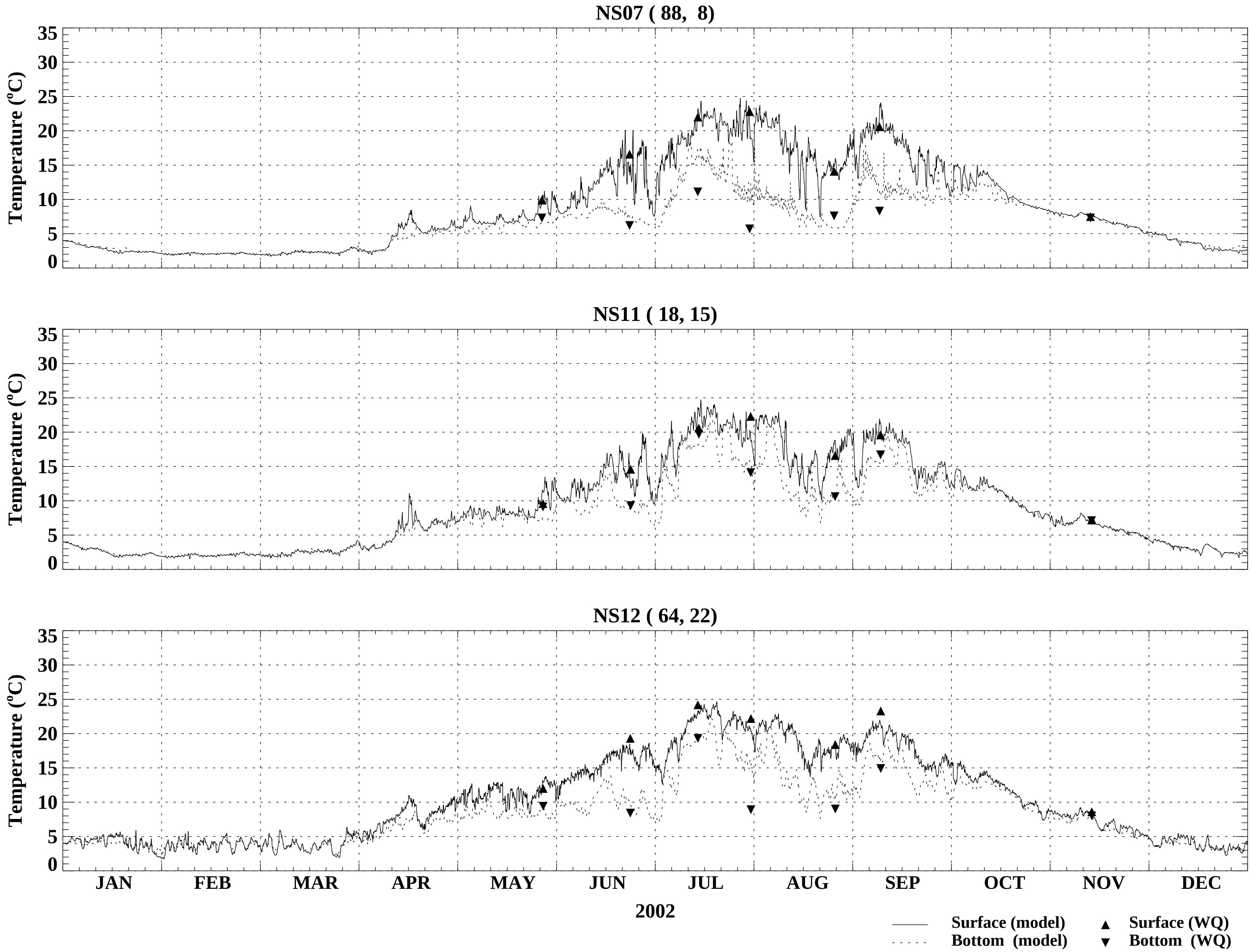

RI11 (72, 37)
RI14 (53, 29)
RI15 (67, 29)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2001
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

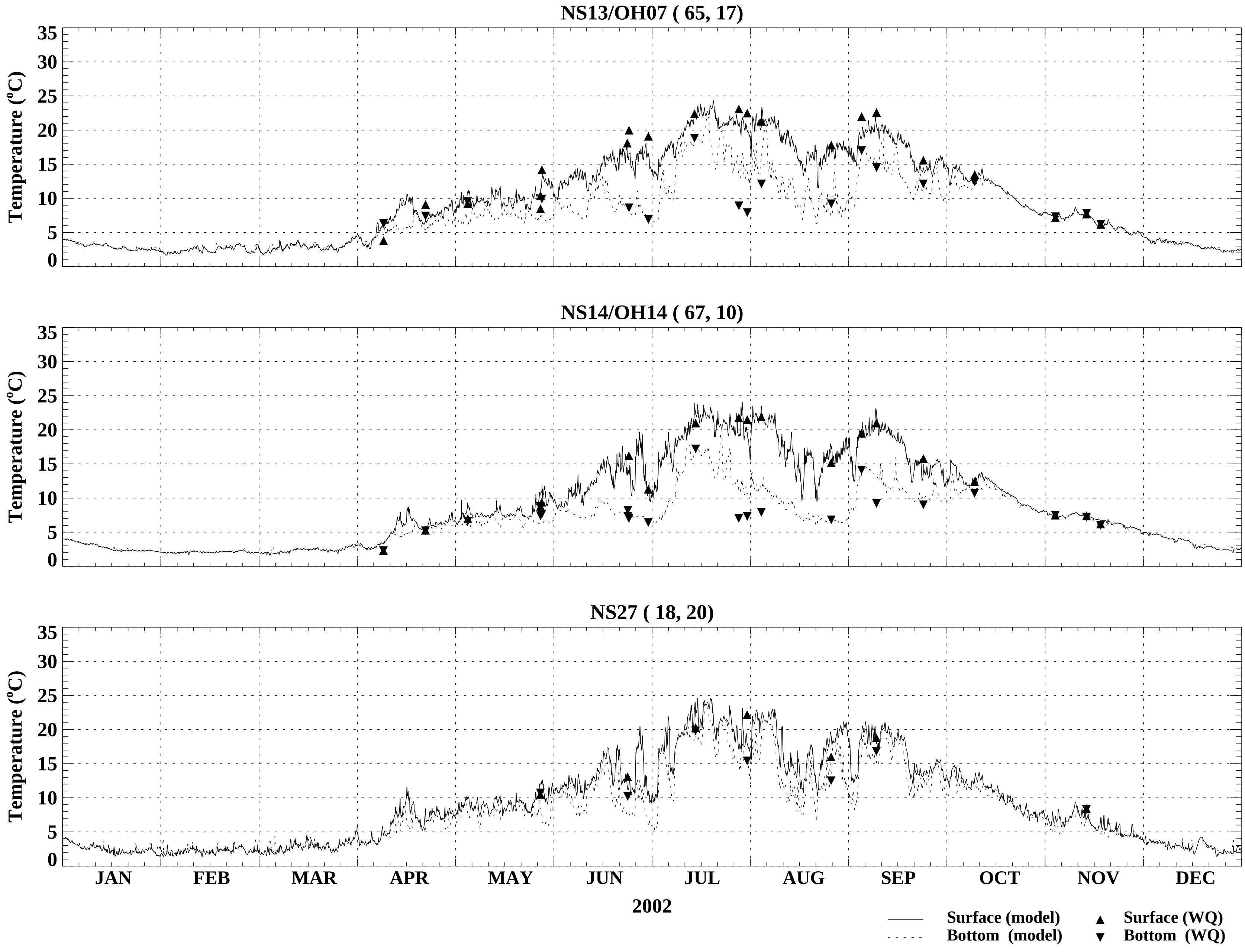

RI17 (72, 30)
RI18 (59, 29)
RI19 (64, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2001
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

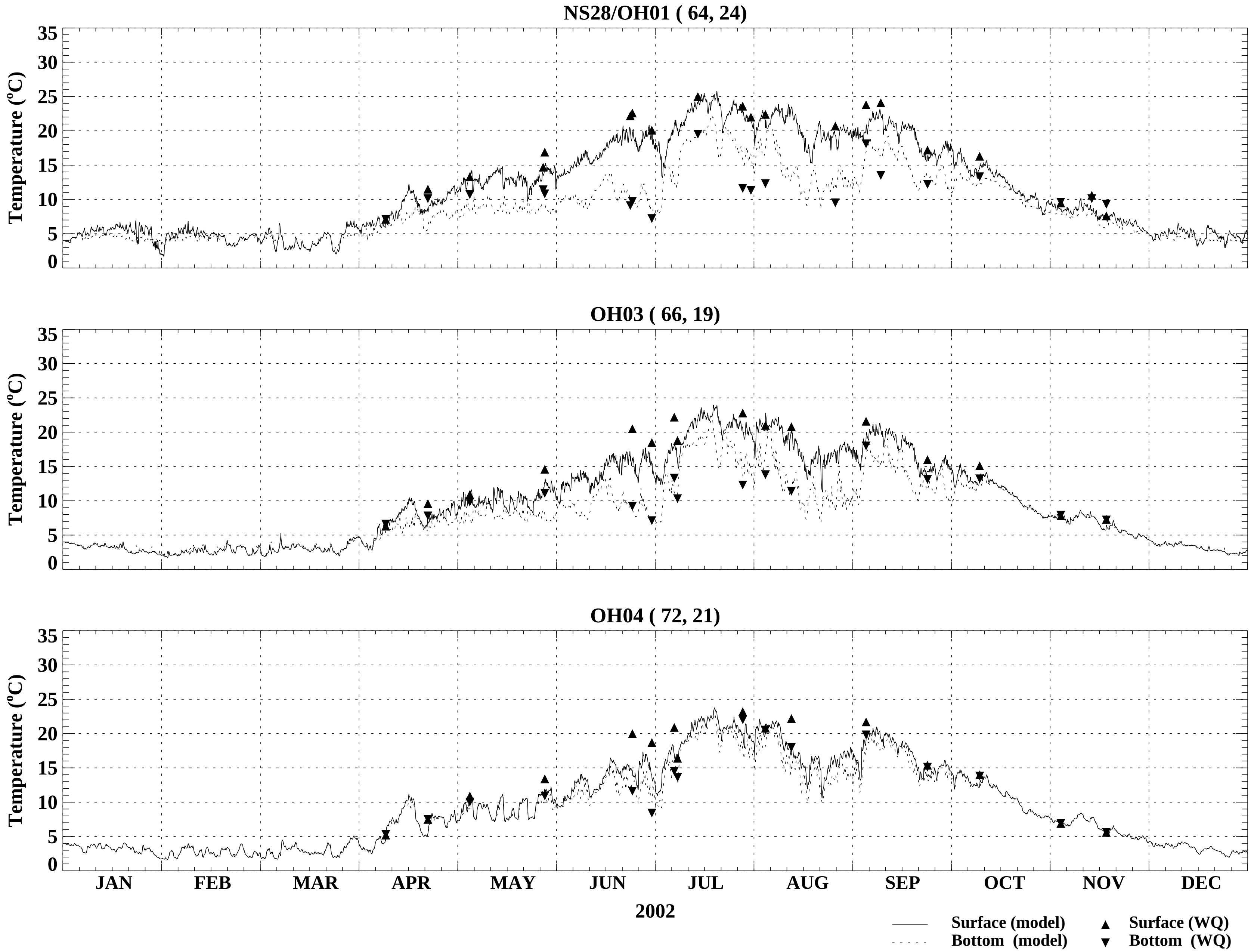


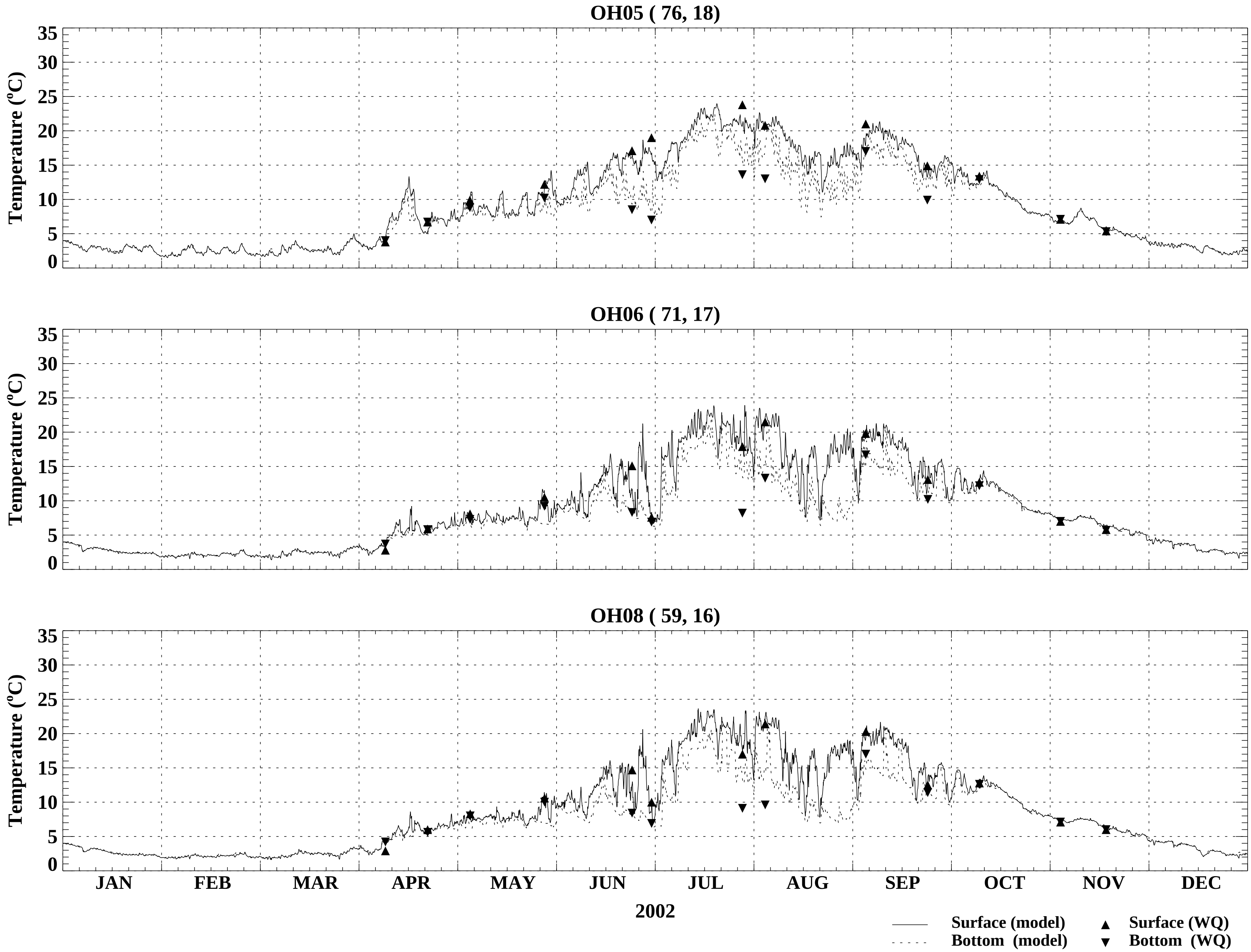
RI30 (76, 21)
RI31 (63, 32)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2001
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


NS02 (20, 9)
NS04 (33, 20)
NS05 (32, 6)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2002
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

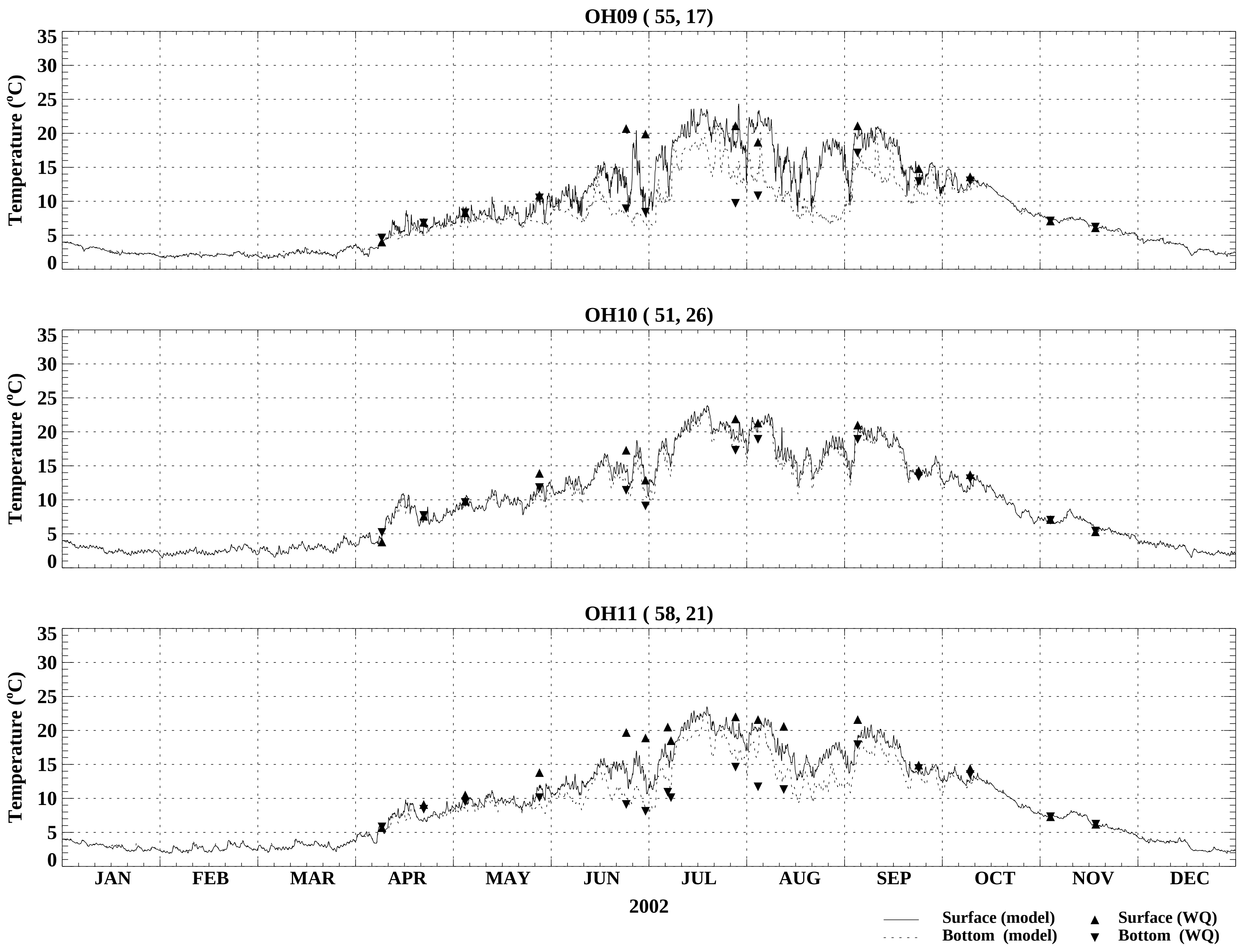

NS07 (88, 8)
NS11 (18, 15)
NS12 (64, 22)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2002
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


NS13/OH07 (65, 17)
NS14/OH14 (67, 10)
NS27 (18, 20)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2002
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

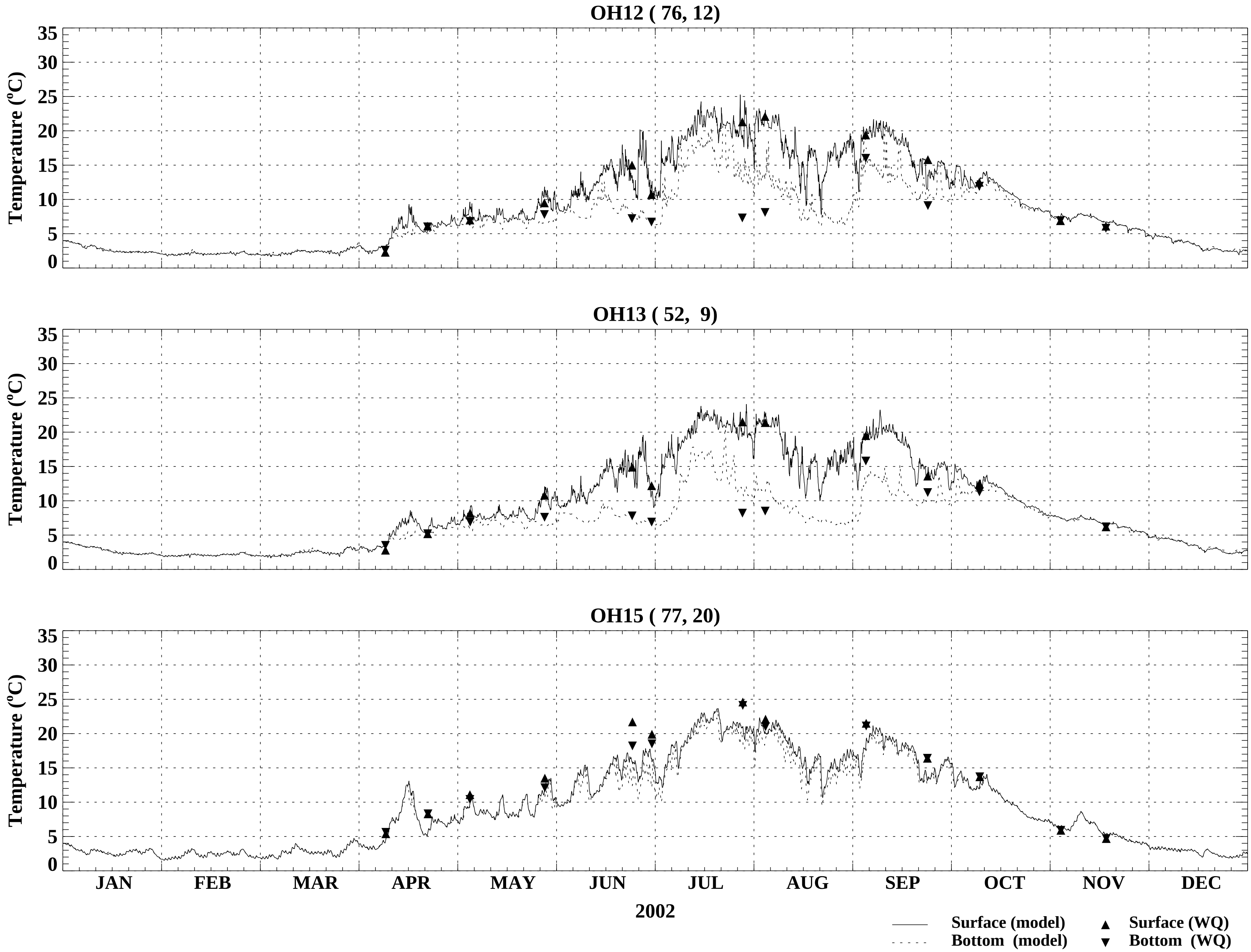

NS28/OH01 (64, 24)
OH03 (66, 19)
OH04 (72, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2002
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

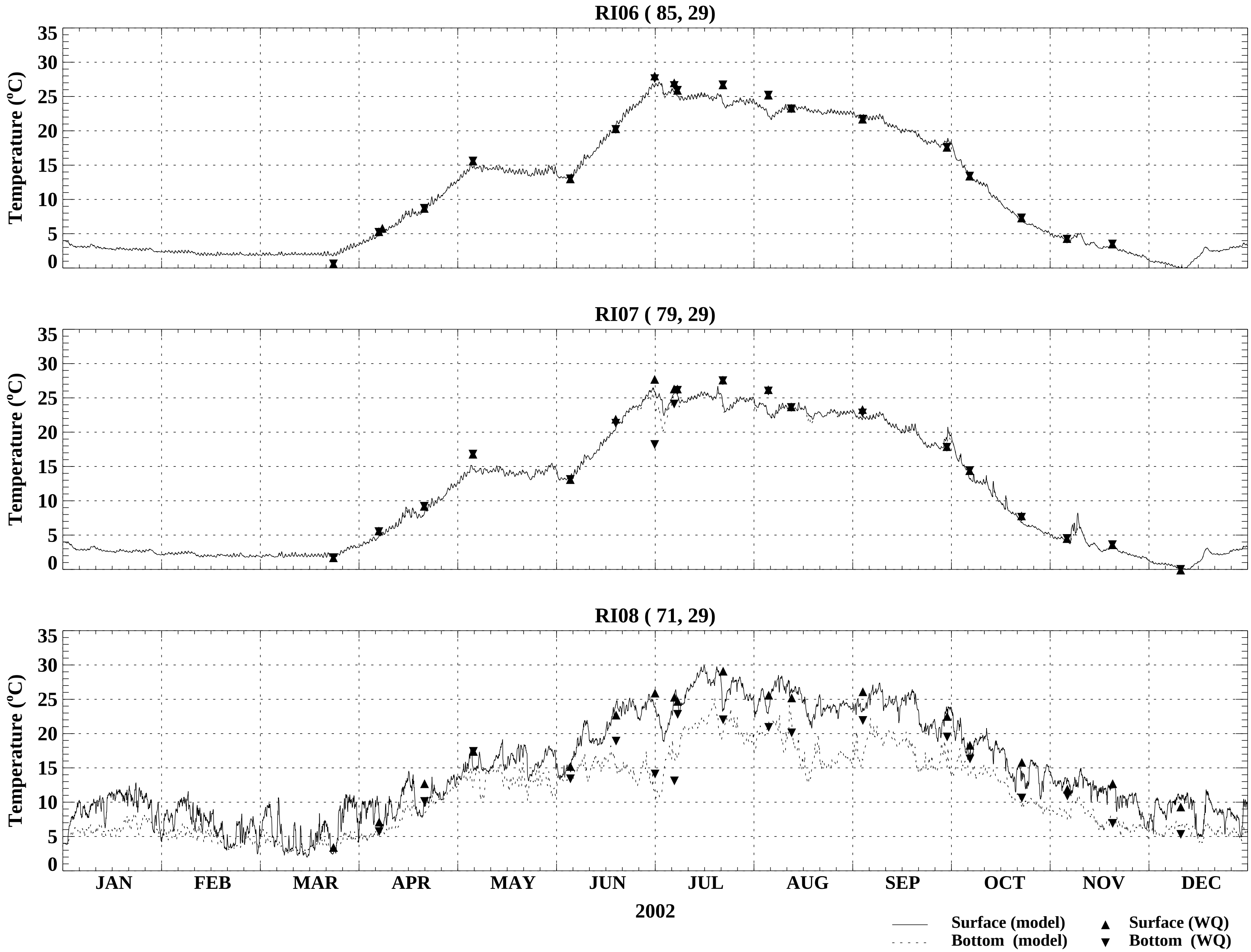


OH05 (76, 18)
OH06 (71, 17)
OH08 (59, 16)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2002
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

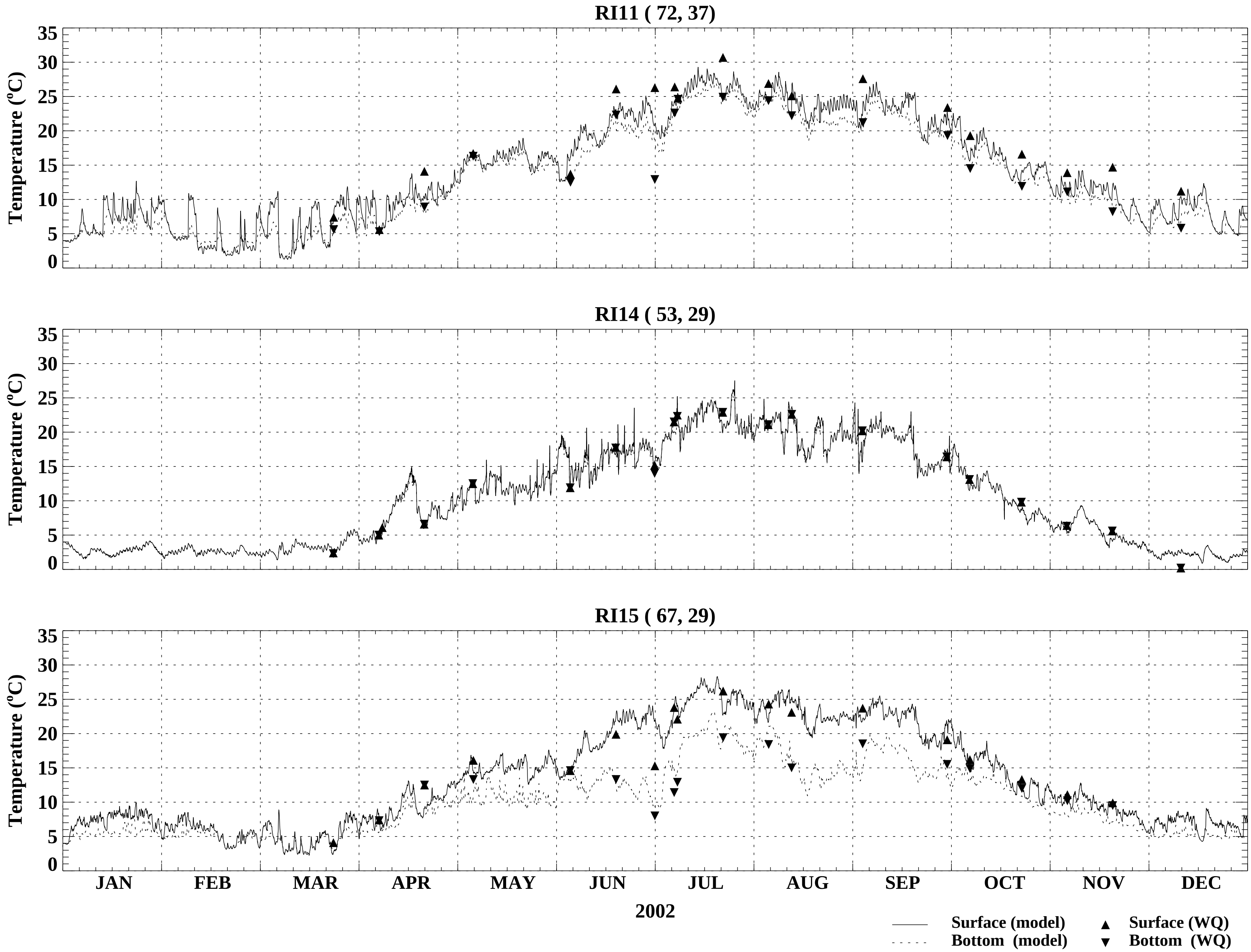


OH09 (55, 17)
OH10 (51, 26)
OH11 (58, 21)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2002
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

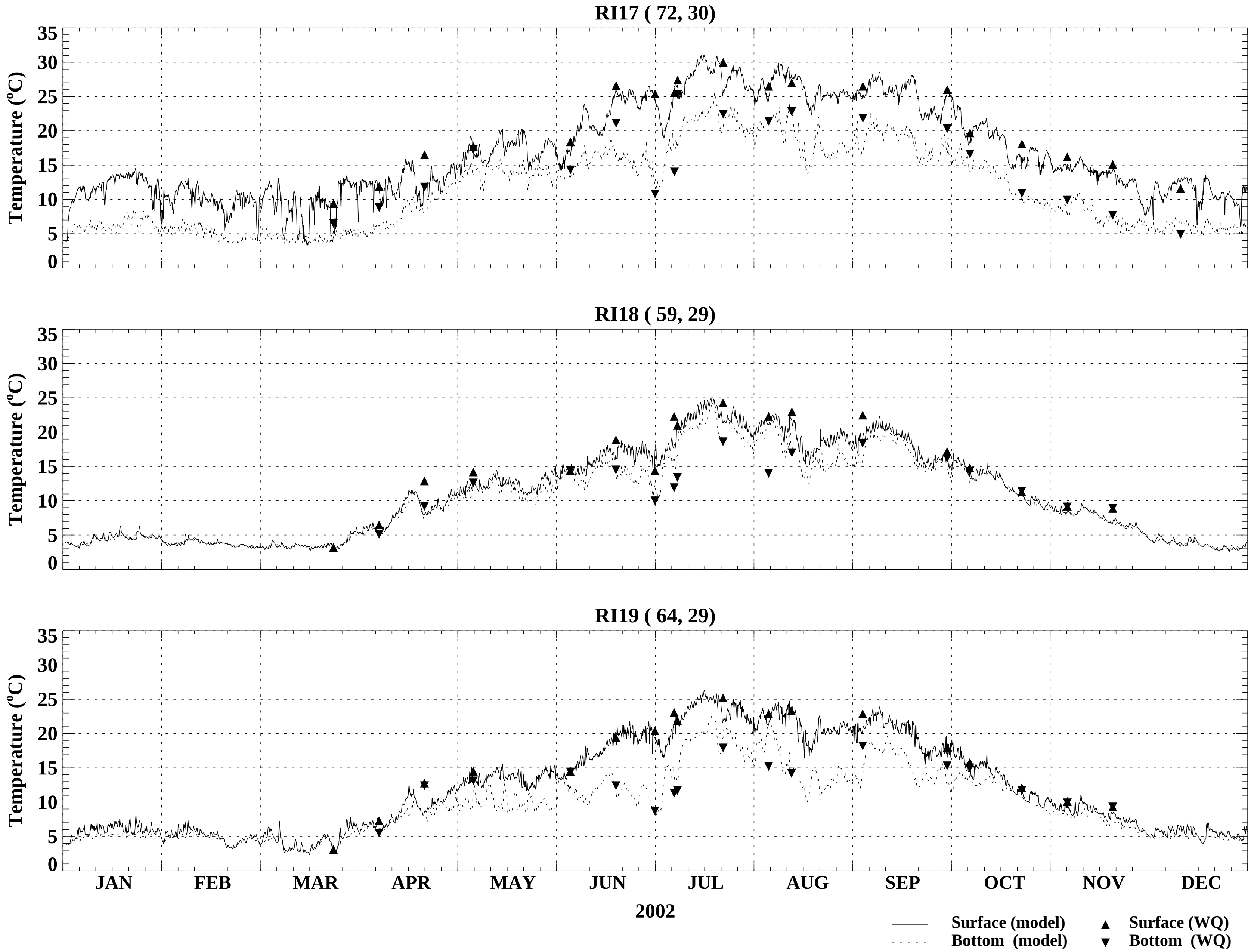

OH12 (76, 12)
OH13 (52, 9)
OH15 (77, 20)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2002
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)



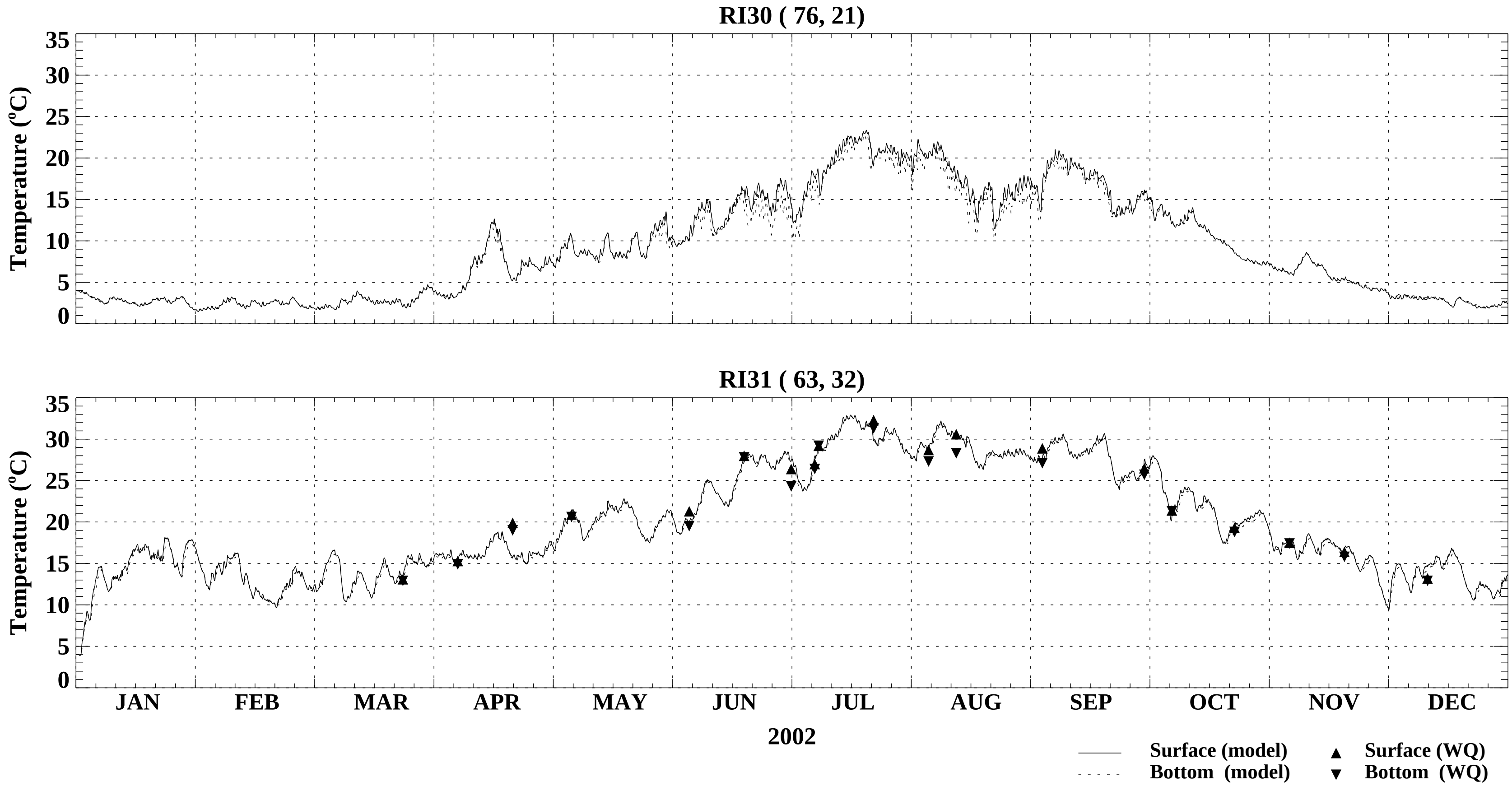
RI06 (85, 29)
RI07 (79, 29)
RI08 (71, 29)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2002
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)



RI11 (72, 37)
RI14 (53, 29)
RI15 (67, 29)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2002
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)



RI17 (72, 30)
RI18 (59, 29)
RI19 (64, 29)
Temperature (°C)
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2002
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)


RI30 (76, 21)
Temperature (°C)
35
30
25
20
15
10
5
0
RI31 (63, 32)
Temperature (°C)
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2002
Surface (model)
Bottom (model)
Surface (WQ)
Bottom (WQ)

2020 Facility Planning Project

Technical Memorandum

MMSD Contract #: M03002P01
MMSD File Code #: M009PE000.7300

Project Name: 2020 Facilities Planning Project

To: Ronald Prince, SEWRPC
Michael Hahn, SEWRPC
William Krill, HNTB
cc: Troy Deibert, HNTB

From: Andrew Thuman, HydroQual
Cristhian Mancilla, HydroQual

Date: December 3, 2007

Subject: Estuary Model Water Quality Calibration/Validation

1.0 EXECUTIVE SUMMARY

The time-variable, three-dimensional water quality model, RCA, was developed and configured to the Milwaukee, Menomonee, and Kinnickinnic Rivers, Milwaukee Harbor and Lake Michigan. The near shore Lake Michigan part of the model extends from Fox Point (WI) in the north to Wind Point (WI) in the south and extends approximately 4-6 miles offshore to the east. The water quality model was comprised of two components: eutrophication and bacteria models. The eutrophication model includes the following main parameters: organic nitrogen, ammonia nitrogen, nitrite+nitrate nitrogen, organic phosphorus, orthophosphorus, organic carbon, dissolved oxygen, and phytoplankton (chlorophyll-a). The bacteria model includes the following parameters: total copper, total zinc and fecal coliform. Details of the eutrophication and bacteria models are presented in Section 6.

Extensive data measurements that have been collected throughout the study area were used to drive the water quality model for the period of 1995 through 2002. These data sets include:

- Milwaukee River (#04087000), Menomonee River (#04087120), Kinnickinnic River (#04087159), and Oak Creek (#04087204) water quality;
- Jones Island, South Shore and South Milwaukee wastewater treatment plant (WWTP) effluent quality;
- Combined sewer overflows (CSOs)/sanitary sewer overflows (SSOs)/combined area stormwater (CSSWs) discharge quality;
- Discharges from the Milwaukee and Kinnickinnic River flushing tunnels; and
- Solar radiation from the General Mitchell Airport in Milwaukee.

In addition, two special studies were completed in 2004 to measure: the long term BOD (LTBOD) of river, harbor and effluent samples; and sediment oxygen demand (SOD) and sediment nutrient fluxes. Although these studies did not coincide with the calibration and validation periods, they were useful in defining model parameters and in the calibration/validation of the sediment flux submodel.

The water quality model calibration and validation efforts were completed with water quality data at 25 MMSD sampling stations located in the Milwaukee, Menomonee, and Kinnickinnic Rivers, Milwaukee Harbor and near shore Lake Michigan. The calibration and validation periods were from 1995 through 1998 and from 1999 through 2002, respectively, that encompassed a range of river flows and also included various sized CSO/SSO/CSSW overflow events. Model calibration and validation were assessed based on a weight of evidence approach. A combination of visual model and data time-series comparisons and model error analyses were completed. The model error analyses included model bias, relative model bias, mean absolute error and median relative error, and used to compare computed water quality results to observed data.

2.0 CONCLUSIONS

The water quality models reasonably reproduce observed water quality measurements and, therefore, the overall water quality dynamics in the model domain are well represented. The calibrated and validated water quality models are capable of reproducing the river, harbor, and lake conditions of the Milwaukee, Menomonee and Kinnickinnic Rivers, Milwaukee Harbor, and near shore Lake Michigan and is suitable for completing production runs as part of the 2020 Facilities Planning process in this river-lake system.

3.0 RECOMMENDATIONS

The current water quality model calibration and validation were based on assigning measured water quality from MMSD monitoring at the three river boundaries and Oak Creek. When the upstream watershed models are completed, the watershed model calculated water quality will be assigned at the river boundaries. This will fill in the periods between the dates when MMSD sampling is completed (roughly bi-weekly from April to October) and will be presented as an additional technical memorandum.

4.0 INTRODUCTION

In order to provide an integrated modeling framework for the 2020 Facilities Planning process, the Loading Simulation Program C++ (LSPC) upstream river watershed models (Milwaukee River, Menomonee River, Kinnickinnic River and Oak Creek) were coupled to the downstream Milwaukee Harbor estuary model. In addition, LSPC calculated direct stormwater drainage to Lake Michigan was also included in the estuary model. As part of this process, HydroQual calibrated and validated the Milwaukee Harbor estuary model, which includes a hydrodynamic model (ECOMSED) and water quality model (RCA) for the years 1995-1998 and 1999-2002, respectively. This memorandum describes the preparation of the water quality model inputs for the 2020 Facilities Planning process and resulting calibration and validation results. This planning process is being guided and implemented by the Milwaukee Metropolitan Sewerage District (MMSD) and Southeastern Wisconsin Regional Planning Commission (SEWRPC).

5.0 STUDY AREA

The study area can be described as being a part of what is known as the Greater Milwaukee area watersheds. According to a report completed by the Wisconsin Department of Natural Resources (WDNR, 2001), the Milwaukee River Basin is located in portions of seven counties and is divided into six major watersheds. Three of the watersheds contain the Milwaukee River (Milwaukee River North, Milwaukee River East-West and Milwaukee River South) whereas the remaining three are named after the rivers they contain: Cedar Creek, Kinnickinnic River and Menomonee River. The confluence of the three major rivers in this basin leads to Milwaukee Harbor where it connects to Lake Michigan through a series of openings in the Outer Harbor breakwall.

The modeling study area includes the Milwaukee River (upstream to the old North Avenue Dam), Menomonee River (upstream to the old Falk Corporation Dam) and Kinnickinnic River (upstream to 11th Street), Milwaukee Harbor and the near-shore Lake Michigan, within a single modeling grid framework. The model lake boundary extends east to approximately the 30-60 meter bathymetric contour in Lake Michigan, to Fox Point (WI) in the north and to Wind Point (WI) in the south. An orthogonal, curvilinear grid system used in the present study is shown in Figures 1a, 1b and 1c along with MMSD monitoring stations, USGS and NOAA gage locations, and major point sources. The system consists of a 96×42 segment grid in the horizontal plane and 11 equally spaced σ-levels in the vertical plane, which results in 10 vertical segments. The transformed σ-coordinate system in the vertical plane allows the model to have an equal number of vertical segments in all of the computational grid boxes independent of water depth. In the horizontal, the curvilinear grid system allows for much finer grid resolution near areas of interest, such as in the river/harbor areas, where the grid size is as small as 90×50 meters. A coarser grid system was adopted in the Lake Michigan areas, where the maximum size of the grid is as large as 1500×1000 meters. Using this technique, an efficient and computationally time-effective modeling framework was designed.

There is a breakwall located in the outer harbor extending from the Milwaukee Yacht Club in the north and to just south of the South Shore beach area (Figure 1a). This breakwall protects the harbor from rough water conditions in Lake Michigan and has a number of openings or gaps along its length for passage from the harbor to the lake. The breakwall tends to trap flow and constituent loads (e.g., solids, bacteria) within the harbor area and cause distinct river plumes to emanate from the openings in the breakwall during high river flow events. The breakwall was uniquely represented in the hydrodynamic and water quality models through the use of "thin wall dams" in the model framework. This model representation of the breakwall allows for the effective and realistic calculation of water transport, circulation, and water quality between the harbor and Lake Michigan.

6.0 WATER QUALITY MODEL KINETICS

The water quality models used in the study are bacteria and eutrophication models with both models directly coupled with the hydrodynamic model. In addition, a sediment flux submodel is also included in the eutrophication model to allow calculation of sediment oxygen demand (SOD) and sediment nutrient fluxes in response to settled organic matter and its subsequent decay in the sediment. The coupled water quality/hydrodynamic model has been successfully applied in numerous studies, including those of the Hudson-Raritan Estuary (NY/NJ); Long Island Sound (NY/CT); Chesapeake Bay (MD/DE); Massachusetts Bay and Boston Harbor (MA); Jamaica Bay (NY); Tar-Pamlico Estuary (NC); St. Jones, Broadkill, Little, Smryna, Leipsic and Blackbird Rivers (DE); and the Upper Mississippi River (MN).

6.1 EUTROPHICATION MODEL FRAMEWORK

The eutrophication model includes the modeling of one phytoplankton group (although winter, summer, and fall groups are available), salinity (used for specific conductance), dissolved oxygen (DO), and the various organic and inorganic forms of nitrogen, phosphorus, silica and carbon or biochemical oxygen demand (BOD). The diagram presented in Figure 2 presents the various general kinetic pathways involved in the modeling framework. A brief description of the 26 state variables and their various kinetic pathways is presented below.

6.1.1 Phytoplankton

The eutrophication model includes three algal groups, a winter, summer, and fall population, which are represented by algal carbon in the model framework (PC1, PC2, PC3). Inputs of algal carbon (phytoplankton) from boundaries and tributaries are included in the modeling framework. The basic kinetics affecting phytoplankton growth and death are identical for the three groups, with a distinction in the assigned growth kinetic constants for each group. Phytoplankton growth is dependent upon temperature, ambient light and nutrient levels, which modify the maximum growth rate to ambient conditions. The growth rates of the three algal groups are controlled through the use of temperature optimums that maximize growth at a certain temperature and decrease growth above and below this temperature. In this manner, growth of winter, summer, and fall algal groups can peak at different times of the year or within different temperature regimes. In the Milwaukee Harbor model, only one phytoplankton group was used because the available algal data did not show multiple seasonal peaks. Ambient surface light conditions are input externally and decrease with depth as a function of light extinction coefficients calculated from measured secchi depths. The surface light conditions are based upon ambient solar radiation conditions within the day. Algal growth is further decreased when the ambient nutrients (phosphorus, nitrogen and silica) approach their respective limiting concentration. Silica is not modeled in the Milwaukee Harbor model but is presented as part of the overall eutrophication model description. Nutrient limitation factors are calculated for phosphorus, nitrogen and silica, with the minimum factor chosen to adjust the growth rate. The ambient growth rate, which is adjusted for temperature, light and nutrient limitations, is then used to determine the oxygen produced through photosynthesis during growth.

The loss of biomass from the water column through respiration, zooplankton grazing and settling is identical between the three algal groups. The respiration formulation for each algal group uses a variable respiration rate, which is a function of the ambient growth rate plus a minimum basal rate. During respiration, dissolved oxygen is consumed and nutrients are recycled to the phosphorus, nitrogen and silica systems. Zooplankton grazing is accounted for through a temperature-dependent decay rate and recycles nutrients and carbon. Algal settling to the sediment is a temperature-dependent process that increases as the nutrient limitation factor decreases (nutrient-stressed settling).

6.1.2 Phosphorus

Particulate and dissolved organic phosphorus forms are included in the model, with further distinctions based upon reactivity. These reactivity distinctions, in turn, are based upon relative decay rates for the organics. A labile fraction describes organic material that decays on a time scale of several weeks to a month or two, while a refractory fraction accounts for decay processes lasting months to a year. The labile fractions decay primarily in the water column or else rapidly in the sediments; the refractory components mainly decompose in the sediments. The inorganic form of phosphorus, orthophosphate (PO_4), is also modeled, for a total of five state variables for phosphorus: refractory particulate organic phosphorus (RPOP), labile particulate organic phosphorus (LPOP), refractory dissolved organic phosphorus (RDOP), labile dissolved organic phosphorus (LDOP), and orthophosphate (PO4).

Particulate organic phosphorus, whether refractory or labile, decomposes to dissolved organic phosphorus through hydrolysis, which is a temperature- and bacterial biomass-mediated reaction. The size of the bacterial population involved in decomposing organic compounds in the water column affects the rate at which this process occurs. Because bacterial biomass is not directly modeled, algal biomass is used as a surrogate tracking variable for computational purposes. The particulate fraction of organic phosphorus settles within the water column at a temperature-dependent rate and is deposited to the sediment where it is further decomposed through anaerobic processes. The dissolved form of organic phosphorus further decomposes through mineralization into the inorganic form of phosphorus (PO_4), which is affected by the same factors controlling hydrolysis. Inorganic phosphorus, PO_4, is lost through its utilization by algae as a nutrient essential for growth and is supplied from or lost to the sediment through sediment fluxes. All forms of phosphorus, organic and inorganic, are supplied as a consequence of algal respiration and zooplankton grazing, which is termed algal nutrient recycling. Inputs of organic and inorganic phosphorus from the boundaries, tributaries, nonpoint and point sources are also accounted for in the modeling framework.

6.1.3 Nitrogen

Organic nitrogen is divided into the same four components or state variables as organic phosphorus. The addition of two inorganic forms of nitrogen, ammonia (NH_3) and nitrite plus nitrate nitrogen (NO_2+NO_3), produce a total of six state variables for nitrogen: refractory particulate organic nitrogen (RPON), labile particulate organic nitrogen (LPON), refractory dissolved organic nitrogen (RDON), labile dissolved organic nitrogen (LDON), ammonia (NH3) and nitrite plus nitrate (NO23).

The particulate and dissolved forms of nitrogen decompose through the same reaction pathways as phosphorus, with the particulate fractions settling to the sediment. The dissolved organic forms mineralize to ammonia, which is subsequently nitrified to nitrite and nitrate via a reaction in which dissolved oxygen is consumed. Nitrification is an aerobic reaction, therefore, the reaction decreases as dissolved oxygen concentrations decrease below a certain value. The nitrification reaction is, therefore, dependent upon water column dissolved oxygen concentrations as well as temperature. The denitrification of nitrate to nitrogen gas is an anaerobic reaction that varies with temperature. Ammonia and nitrite plus nitrate are utilized by algae as nutrients for growth with ammonia being the preferred nutrient. A preference scheme for determining ammonia or nitrite plus nitrate preference at varying concentrations is used in the model. Algal nutrient recycling replenishes the four organic forms of nitrogen and ammonia during algal respiration and zooplankton grazing. Sediment fluxes of ammonia and nitrate are either a source of or a sink for these nutrients in the water column. External inputs of all forms of nitrogen are also accounted for within the model.

6.1.4 Carbon

Organic carbon is divided into the same groups as organic nitrogen and phosphorus, with three additional state variables: reactive dissolved organic carbon, reactive particulate organic carbon, and algal exudate carbon. Highly reactive dissolved and particulate organic material represents inputs such as carbonaceous inputs associated with wastewater treatment plants or CSOs. These organic materials decay on a time scale of days to a week or two and are classified as reactive dissolved organic carbon and reactive particulate organic carbon. Excretion of dissolved organic carbon by phytoplankton during photosynthesis is included as the seventh state variable, algal exudate. Algal exudate decays on a time scale similar to that for reactive dissolved organic carbon. The seven state variables described for carbon are: refractory particulate organic carbon (RPOC), labile particulate organic carbon (LPOC), refractory dissolved organic carbon (RDOC), labile dissolved organic carbon (LDOC), reactive dissolved organic carbon (REDOC), reactive particulate organic carbon (REPOC) and algal exudates carbon (EXDOC).

The particulate and dissolved forms of carbon decompose through the same reaction pathways as phosphorus and nitrogen, with the particulate fractions settling to the sediment. The dissolved forms of carbon oxidize to carbon dioxide, using dissolved oxygen during the process. Oxidation of dissolved organic carbon is aerobic and, therefore, is reduced at low water column dissolved oxygen concentrations. The oxidation process is also modified by temperature and bacterial biomass levels, which are indirectly represented by algal biomass. Algal recycling due to zooplankton grazing is a source of both refractory and labile particulate and dissolved organic carbon. External inputs of organic carbon are also included in the modeling framework.

6.1.5 Silica

Although silica is not modeled in the Milwaukee Harbor model, it is presented as part of the eutrophication model description. Two silica forms are included in the model: particulate biogenic silica, which is unavailable for algal growth, and silica, which is available for algal growth (primarily for diatoms). Particulate biogenic silica is mineralized to available silica at a temperature- and bacterial biomass-dependent rate and can also settle to the sediment. Available silica is utilized as a nutrient during algal growth and can interact with the sediment through silica fluxes. Algal recycling supplies the particulate biogenic silica system through algal respiration and zooplankton grazing. The two state variables for silica are: biogenic silica (BSI) and available silica (SI). External inputs of organic carbon are also included in the modeling framework.

6.1.6 Dissolved Oxygen

Levels of dissolved oxygen (state variable DO) are affected by the nitrification of ammonia, denitrification of nitrate, oxidation of dissolved organic carbon (BOD), algal oxygen production and respiration, sediment oxygen demand (SOD) and atmospheric reaeration. The sediment oxygen demand is calculated via the coupled sediment flux submodel. Dissolved oxygen saturation is computed from water column temperature obtained from the hydrodynamic model. The effects of algal photosynthesis and respiration on dissolved oxygen are briefly described in the previous phytoplankton section.

6.1.7 Sediment Flux Submodel

A sediment flux submodel is incorporated into the eutrophication model. The sediment receives fluxes of particulate organic and algal carbon (POC), particulate organic nitrogen (PON), and particulate organic phosphorus (POP), which are collectively referred to as particulate organic matter (POM). The water column model state-variables that are deposited to the sediment include: detrital algae, reactive, labile and refractory POC, labile and refractory PON, labile and refractory POP. The fluxes of these variables make up the incoming sources of particulate organic matter to the sediment. Mineralization, which is termed diagenesis, produces soluble end products. These products can react in the aerobic and anaerobic layers of the sediment. The difference between the resulting aerobic dissolved concentration and the overlying water concentration determines the flux to or from the sediment. The magnitude of the flux is determined by the surface mass transfer coefficient.

It is important to model an annual cycle with the sediment submodel because of the storage capacity of the sediments and the subsequent effects on nutrient fluxes and sediment oxygen demand (SOD). Organic matter (nitrogen, phosphorus and carbon) deposited in the sediments during the winter and spring undergoes slower decay pathways due to the cooler temperatures. When the temperature increases during the summer months, stored organic matter decays at a faster rate, which results in different nutrient fluxes and SOD. Without the modeling of an annual cycle (i.e., modeling of summertime alone), summer nutrient fluxes and SOD would be under-computed because stored organic matter would not be included. Compared with the water column, the sediment takes a longer time to reach steady state and it is important to perform iterations with the sediment model so that the sediment concentrations reach steady state with the overlying water column.

6.2 BACTERIA MODEL

A separate bacteria model was developed for Milwaukee Harbor for fecal coliform that also included total copper and total zinc. The mathematical framework for the bacteria and metals model uses the same mass-balance approach as the eutrophication model; only the state variables and reaction rates differ. The bacteria model includes 5 state variables: total copper (CU), total zinc (ZN), and three fecal coliform systems (BAC1, BAC2, BAC3). The model incorporates a first-order decay or die-off rate for fecal coliform in addition to a die-off component due to light (solar radiation). The three fecal coliform systems are used to track bacteria sources separately (CSO/SSO, river and lake boundary conditions). Total copper and total zinc are modeled with a first-order decay rate that is currently set to zero (modeled as conservative substances).

7.0 WATER QUALITY MODEL INPUTS

7.1 SOLAR RADIATION AND LIGHT EXTINCTION

The ambient light level is a major factor controlling the growth of phytoplankton in an aquatic environment, therefore, it must be accurately represented in any modeling analysis. Ambient light levels can be determined directly from measurements of solar radiation near the water surface, or indirectly, from empirical relationships relating cloud cover to solar radiation. In the 2020 Facilities Planning Project, ambient light levels were obtained from solar radiation that was estimated from cloud cover measurements at the Milwaukee General Mitchell International Airport and developed by SEWRPC for the entire calibration and validation period of 1995 through 2002. The water quality model requires daily average solar radiation in langleys/day as model input. Attachment 12 (Meteorological Parameters) in HydroQual's *Hydrodynamic Model Technical Memo* (2007) shows the hourly average solar radiation for the calibration and validation periods. The data exhibit the typical annual cycle average solar radiation levels (lower during the winter, higher in the summer) in addition to the lower levels during cloudy periods.

Another important factor controlling the growth of phytoplankton is the surface light attenuation with depth (light extinction). Available ambient light decreases with depth due to turbidity, which can be caused by suspended solids, color and also phytoplankton. The contribution to light extinction by phytoplankton is termed 'algal self shading'. Light extinction coefficients can be determined directly, through the analysis of light level data with depth, or indirectly, using relationships between light extinction and secchi depth measurements. The basic equation used to calculate light as a function of depth is:

$$I = I_0 e^{-K_{et}H}$$

where: I – light intensity at depth;

I_0 – surface light intensity;

K_{et} – total light extinction coefficient (1/m); and

H – depth (m).

In the 2020 Facilities Planning Project, the total light extinction coefficients were calculated from secchi depth data and corrected for algal concentrations in the water column (algal self shading). Total light extinction coefficients calculated from these analyses include the effects of both non-algal sources (suspended solids, color, etc.) and algal self-shading. The equation that relates the calculated total light extinction coefficient to secchi depth readings is as follows: $K_{et} = 1.7/\text{secchi depth}$. Since the water quality model internally computes the total light extinction coefficient (K_{et}) due to algal self-shading based on computed chlorophyll-a levels (chl-a), input of the base light extinction coefficient is required. The base light extinction coefficient (non-algal related) is determined from the following equation: $K_{et} = K_{eb} + 0.017Chl\text{-}a$. Figure 3 presents the calculated base light extinction coefficients for the years 1995 through 2002. For the River Group, 2001 data was not available and, therefore, 2002 data was used. The data is presented as the filled circles and the model input as the solid lines. The base light extinction functions input in the model are both time and spatially variable. For model input, the calculated base light extinction coefficients were divided into three groups: a river group (RI-08, 15, 17, 18, 19), a harbor group (OH-01, 02, 03, 04, 05, 07, 09, 10, 11, 15, NS-12, 13), and a lake group (NS-01, 02, 03, 05, 07, 08, 10, 11, 14, OH-06, 08, 12, 13, 14). The average base light extinction coefficients from each sampling date for each group were assigned in the model for the three regions represented by the groups. There were usually no measurements between the late fall and the early spring seasons and data gaps were filled with the interpolated/extrapolated values based on the late fall and the early spring samples. As part of the calibration and validation process, the calculated base light extinction coefficients were decreased by 25% in the harbor to increase algal growth and improve comparison to measured chlorophyll-a values. This was considered valid because the conversion of secchi depth data to light extinction coefficients is approximate and ultimately the model comparison to measured chlorophyll-a data more important. In addition since secchi depth data was not available above station RI-18 in the Kinnickinnic River and more turbidity (solids) are expected in the upper reaches of the river, the assigned light extinction coefficients were doubled from station RI-14 upstream. Table 1 shows the eight-year statistics of the base light extinction coefficients and considerable variations can be seen between the three groups and from year to year. Generally, light extinction coefficients have the highest values in the rivers due to higher turbidity (suspended solids) and lowest values in the lake where the water is clear.

Table 1. Yearly Average Base Light Extinction Coefficients			
Year	**River Group**	**Harbor Group**	**Lake Group**
1995	1.57	1.01	0.41
1996	2.60	1.21	0.44
1997	1.54	1.14	0.39
1998	2.09	1.30	0.49
1999	2.79	1.34	0.43
2000	2.54	0.98	0.29
2001	1.91	1.16	0.31
2002	1.91	1.01	0.29

7.2 INITIAL AND BOUNDARY CONDITIONS

7.2.1 Initial Conditions

The initial conditions for each state variable in the water column for the model period were set up using MMSD water quality data in the three rivers, Milwaukee Harbor and Lake Michigan. The initial conditions in the sediment, include sediment temperature, particulate organic matter (PON, POP, POC) in three reactivity classes (G1, G2, G3), inorganic nutrients (PO_4, NO_2+NO_3, and NH_4), methane, sulfate, and hydrogen sulfide in sediment layers 1 and 2, and benthic stress, were set up with reasonable initial estimates. Sediment initial conditions have a much larger effect on model results than the water column initial conditions because the sediment takes a much longer time to reach steady state. In order to ensure that the sediment reaches steady state, the water quality model (coupled with the sediment flux sub-model) was cycled for at least 5 years to obtain approximate equilibrium conditions in the sediment. The initial conditions were developed for the year 1995 since this was the first year in the calibration and validation period. After 1995, initial conditions in both the water column and sediment are obtained from model output from the end of the previous year (e.g., 12/31/95 results used for 1/1/96 start-up).

7.2.2 Boundary Conditions

Water quality boundary conditions need to be assigned to account for the concentration of each water quality state variable and specific conductivity at the river and open water lake boundaries during the calibration (1995-1998) and validation periods (1999-2002). Figure 1a presents the model domain with the grid and highlights the locations of both the river and lake boundary condition segments. The lake boundary values were based on measurements from the MMSD monitoring program at the following near shore stations when possible: NS-01 and NS-10. Due to limited observation data at these stations, the data were vertically averaged and interpolated to develop the model lake boundary conditions. The upstream river boundary values were based on measurement at stations RI-05 (Milwaukee), RI-13 (Kinnickinnic), RI-20 (Menomonee) and OC-07 (Oak Creek). For fecal coliform and TSS, flow relationships ($C=aQ^b$) were developed at the three river boundaries to better relate the input of these parameters to flow since the data indicates increasing concentrations with increasing flow. As the upstream LSPC watershed model calibrations and validations are completed, the river boundary conditions will be switched to use the LSPC output instead of measured data. This should not affect the estuary model calibration and validation since the LSPC model was compared to the same data used to initially set up the boundary conditions. In addition, the LSPC output will fill in the gaps between data measurement dates.

The available data to develop the boundary parameters included DO, chl-a, organic carbon (total and dissolved), total phosphorous, orthophosphate, ammonia, nitrite and nitrate, total kjeldahl nitrogen (TKN), fecal coliform, total copper and total zinc. Due to the limited data available in the lake for DO, the lake DO boundary condition was specified at the DO saturation level as a function of model calculated temperature in the lake. This was necessary to better represent the DO levels at the lake boundary as a function of time. Organic nitrogen is the difference between TKN and ammonia, and organic phosphorous is the difference between total phosphorous and orthophosphate. Because there were no data concerning the percentage of dissolved versus particulate forms of nitrogen and phosphorus, the organic carbon distribution of the dissolved and particulate forms was applied to organic nitrogen and phosphorus. The data from MMSD suggest that around 60% of organic matter is particulate and 40% is dissolved in the lake/river. The split between labile and refractory organic matter was based on former modeling experience since information was not available. In general, organic material generated from the upstream watersheds is more reactive (labile, younger origin) than organic material present in the lake (refractory, older origin) due to the nature and history of the sources. The final values used were a 75/25 labile/refractory split was assigned for the upstream river boundaries and also for the lake open boundaries. Figures 4 to 9 present the boundary conditions for the Milwaukee Harbor model as based on the measured river/lake data.

For organic carbon at the river boundary locations, the measured BOD_5 was used to represent labile dissolved organic carbon (LDOC) and along with the measured dissolved organic carbon (DOC) was used to estimate the refractory dissolved organic carbon (RDOC). The measured BOD_5 was converted to BODu using a BODu/BOD_5 ratio and then converted to LDOC using an O_2/C ratio of 2.67 (Thomann & Mueller, 1987 & USEPA, 1985). The BODu/BOD_5 ratio of 4.5 was based on long term BOD (LTBOD) studies completed by the MMSD (MMSD, 2004) on river samples that indicated a BOD decay rate of approximately 0.05/day, which results in a BODu/BOD_5 ratio of 4.5. For calculating RPOC and LPOC, the 75/25 labile/refractory split was used with the measured POC data. Very limited data was available for assigning organic carbon boundary conditions in the lake. Limited data available at MMSD stations NS-11 and NS-14 indicated an average TOC value of 1.9 mg/L (ranging from 1-4 mg/L). Therefore, a constant total organic carbon value of 2 mg/L was used for the open lake boundary along with a 50/50 particulate/dissolved split and a 75/25 labile/refractory split.

The LTBOD studies were conducted on three dates in 2004 (4/21, 5/19, 7/21) at the following stations: Milwaukee River (RI-05, RI-07, RI-15), Menomonee River (RI-17, RI-20), Kinnickinnic River (RI-13, RI-14, RI-19), and Harbor (OH-01, OH-03, OH-04, OH-11). In addition, a sample was collected and analyzed from the Jones Island effluent. The samples collected were setup to determine BOD over roughly 60 days, which can be used to determine the ultimate oxygen demand of the sample in addition to the BOD decay rate. Duplicate samples were incubated at approximately 20°C at 4 different sample volumes (300, 150, 60 and 30mL) and DO measurements were taken over time to determine the BOD. In addition, NO_2+NO_3 measurements were completed during the LTBOD tests to make an estimate of potential nitrification and ultimately the nitrogenous component of the BOD. Generally, build-up of NO_2+NO_3 during the test indicates nitrification of ammonia. The NO_2+NO_3 build-up during the tests was not too significant (increases of 0.2-0.6 mg/L) and many times the measurements were quite variable throughout the test. Therefore, the BOD results were not corrected for any nitrification.

Figures 10 through 13 present the results of the river/harbor LTBOD studies on 4/21/2004 for the 300mL sample volume with the entire dataset presented in Appendix 1. The Jones Island effluent LTBOD studies for all three sample dates are presented in Figure 14 for the 30mL sample volume. The calculated ultimate BOD (BODu) and BOD decay rate (Kd) from the non-linear regressions are tabulated on these figures. The non-linear BOD equation used to fit the data is:

$$BOD_t = BOD_u \left(1 - e^{Kd \times time}\right)$$

where: *BODt* – BOD (mg/L) at time, t;

BODu – ultimate BOD (mg/L); and

Kd – BOD decay rate (1/d).

Since the LTBOD studies were completed in 2004 and not coincident with the calibration and validation period (1995-2002), the results were used as a guide to assign the BOD decay rate in the model (0.05/day at 20°C) and to determine a BODu/BOD_5 ratio (4.5) for converting measured BOD_5 to BODu. Table 2 presents a summary of the BODu and Kd results from all stations on all dates.

7.3 LOADS

Several point sources are located in the Milwaukee Harbor study area along the Milwaukee, Menomonee and Kinnickinnic Rivers, in Milwaukee Harbor and in Lake Michigan. Combined sewer overflow (CSO), sanitary sewer overflow (SSO) and combined system stormwater (CSSW) point sources are contributors of organic matter and bacterial loads in the study area. There are also three municipal wastewater treatment plants (WWTP) and two power plant discharges in the model domain. The City of Milwaukee also utilizes flushing tunnels to improve water quality within the Milwaukee and Kinnickinnic Rivers. These flushing tunnels operate by withdrawing water from the outer harbor and discharging it into the Milwaukee and Kinnickinnic Rivers during periods of low dissolved oxygen (DO) in these rivers. Therefore, the flushing tunnels can also be considered as point sources in the model.

Table 2. LTBOD Study Results (2004)

Station	4/21/2004		5/19/2004		7/21/2004	
	BODu (mg/L)	Kd (1/d)	BODu (mg/L)	Kd (1/d)	BODu (mg/L)	Kd (1/d)
JI Effluent[a]	48.7	0.06	28.8	0.05	22.8	0.03
RI-05	12.0	0.06	9.4	0.04	5.6	0.05
RI-07	10.1	0.07	9.4	0.04	6.0	0.04
RI-13	21.1[b]	0.13[b]	4.8	0.04	5.9	0.04
RI-14	17.3[b]	0.09[b]	13.1	0.05	5.1	0.06
RI-15	12.3	0.09	8.4	0.03	3.7	0.05
RI-19	7.8	0.05	7.7	0.04	4.1	0.05
RI-17	11.6	0.09	7.7	0.05	5.1	0.04
RI-20	10.4	0.07	6.5	0.04	5.2	0.05
OH-01	11.1	0.07	8.2	0.04	4.3	0.05
OH-03	6.6	0.06	7.3	0.04	3.9	0.05
OH-04	3.3	0.05	4.9	0.04	5.2	0.05
OH-11	5.1	0.05	5.7	0.04	2.6	0.05

All river results based on 300mL sample
a – Effluent sample based on average of 30 and 60mL samples
b – Results based on 150mL samples (300mL samples not valid due to DO issues in bottle)

7.3.1 CSO/SSO/CSSW Loads

CSO/SSO water quality data were obtained and analyzed by Triad/TetraTech (*Point Source Memo*, 12/13/2004) to investigate typical concentration levels from these sources. The CSO/SSO data covered the period from 1994-2002, although these data were not necessarily collected at even time increments during this period. Stormwater data was available from MMSD from 2000-2003 at 17 locations and geometric means of this data were used to develop the loads for the CSSW inputs. These data were collected from 20 CSO, 10 SSO and 17 CSSW outfalls within the MMSD service area and a summary of the concentrations used in the modeling is presented in Table 3.

CSO/SSO/CSSW volumes were obtained from Brown & Caldwell conveyance system modeling as presented in their memorandum *"Draft Memo of CSO and SSO Hydrographs*

1988-2002" (12/2004). This overflow information is available at main outfall locations when an overflow occurred for the specific events that occurred during the 1995-2002 modeling calibration and validation period. Figures 15 and 16 present a summary of total CSO and SSO volumes in the three rivers and Lake Michigan. The overflow volume and duration provided were also used in the hydrodynamic model as flow inputs (HydroQual, 2007). These figures indicate that the overflow events occurred more often and were the largest in 1997 through 2000. Table 4 presents a summary of the total overflow volumes (CSO, SSO and CSSW) by location during the calibration and validation period.

The CSO/SSO/CSSW loadings were developed for the required model inputs and all organic matter was considered as labile only. The BOD_5 data were used to derive the organic carbon inputs in a similar manner as used for the boundary conditions. The particulate/dissolved split for phosphorus was 85/15, for nitrogen was 45/55, and for carbon was 65/35. In addition, a $BODu/BOD_5$ ratio of 3 was used to represent the more reactive nature of CSO/SSO/CSSW carbon inputs and further split between labile and reactive carbon of 25/75.

7.3.2 WWTP Loads

Treated municipal wastewater from the Jones Island, South Shore and South Milwaukee WWTPs directly discharge to the outer harbor (Jones Island WWTP) and Lake Michigan (South Shore and South Milwaukee WWTPs) through submerged outfalls. The information on the WWTP effluent flow and temperature for the calibration and validation periods was described in HydroQual's *Hydrodynamic Model Technical Memorandum* (HydroQual, 2007). Discharge information for various water quality parameters were obtained from Discharge Monitoring Reports (DMR) or plant data and used to define the loading of water quality parameters from these three WWTPs. Typically, the effluent water quality information was available on a daily, weekly or monthly monitoring frequency. Figures 17 through 19 present effluent data for these three WWTPs for available parameters during the calibration and validation periods. The particulate/dissolved split for nitrogen, phosphorus and carbon was 25/75, the labile/refractory split was 75/25, and the $BODu/BOD_5$ ratio used was 5. The black symbols are the measured data used for model input and the gray symbols are estimates used for model input. For certain parameters, observed data were not available (e.g., Jones Island TKN and NO_2+NO_3, SP) and, therefore, it was necessary to estimate values for the periods when data was missing. The following relationships to other parameters or values were used to estimate effluent inputs when data were missing.

- Jones Island WWTP
  - $TKN = 1.11*NH_3+3.624$
  - $NO_2+NO_3 = 5.264$
  - $SP = 0.46*TP$
- South Shore WWTP
  - $TKN = 1.055*NH_3+1.742$
  - $NO_2+NO_3 = 12*\exp(-0.097*NH_3)$
  - $SP = 0.474*TP$
  - DO = Jones Island WWTP DO
- South Milwaukee WWTP

- TKN = 9.9
- NH3 & NO_2+NO_3 = 4.7
- SP = 0.5*TP
- DO = Jones Island WWTP DO

7.3.3 Miscellaneous Point Sources

The WE Energies Menomonee Valley Power Plant has two side-by-side intake structures located in the Menomonee River and discharges cooling water into the study area on a relatively continuous basis through two outfalls, which are located in the South Menomonee Canal that in turn connects to the Menomonee River downstream from their intake structures. This cooling water system is represented in both the hydrodynamic and water quality models for proper representation of the operation of the power plant. On a regular basis, the WE Energies Menomonee Valley Power Plant discharges approximately 79 MGD through each of the two cooling water outfalls (HydroQual, 2007). For water quality state variables, the calculated concentration in the Menomonee River at the intake location was assigned as the cooling water discharge concentration to the South Menomonee Canal. In addition, the WE Energies Oak Creek Power Plant intake and discharge to Lake Michigan is also included in both the hydrodynamic and water quality models in the same manner.

There are two flushing tunnels in the study area, one on the Milwaukee River and one on the Kinnickinnic River. Both of these tunnels pull water from the outer harbor (near McKinley Marina and near South Shore Beach) and discharge the water to their respective rivers during periods of low river DO. The flows through the flushing tunnels were represented in the same manner as the WE Energies Valley Power Plant in both the hydrodynamic and water quality models (HydroQual, 2007). The water quality state variables calculated in the outer harbor at the intake location are assigned as the discharge concentration to the rivers. Operation of the flushing tunnels is based on historic operating records during the calibration and validation periods.

Table 3. CSO/SSO/CSSW Water Quality Concentrations for Modeling							
Parameter	**Milwaukee River CSO**	**Menomonee River CSO (w/o CT5/6)**	**Menomonee River CSO (CT5/6)**	**Kinnickinnic River CSO**	**Lake Michigan CSO**	**SSO**	**CSSW[1]**
BOD_5 (mg/L)	9.0	9.0	54.0	9.0	8.0	26.0	16.0
DO (mg/L)	3.4	3.4	3.4	3.4	3.4	0.0	6.3
TSS (mg/L)	56	56	116	56	43	95	71
TP (mg/L)	0.48	0.64	1.07	0.64	0.43	2.50	0.50
PO_4 (mg/L)*	0.19	0.26	0.43	0.26	0.17	1.00	0.20
TN (mg/L)	3.0	3.0	8.3	3.0	3.0	4.7	3.4
TON (mg/L)	1.3	1.3	5.4	1.3	1.3	3.3	2.1
NH_3 (mg/L)	0.7	0.7	1.9	0.7	0.7	1.4	0.4
NO_2+NO_3 (mg/L)	1.0	1.0	1.0	1.0	1.0	0.0	0.9
Fecal Coliform (#/100mL)	160,000	160,000	160,000	160,000	78,000	450,000	14,000
Copper (mg/L)	0.02	0.02	0.02	0.02	0.01	0.02	0.02
Zinc (mg/L)	0.09	0.09	0.12	0.09	0.08	0.13	0.09

Data Source: Point Source Loadings Calculations for Purposes of Watercourse Modeling; MMSD Planning Area (Triad/TetraTech Memo, 12/13/2004.

[1] – Geometric means of MMSD stormwater data collected between 2000-2003

* – Assumed PO_4 = 0.4*TP

Table 4. CSO/SSO Volume Summary (Calibration/Validation)			
Location	**CSO (MG)**	**SSO (MG)**	**CSSW (MG)**
Milwaukee River	4,667	0	146
Menomonee River	2,044	0	815
Kinnickinnic River	1,297	106	0
Outer Harbor/Lake Michigan	1,347	0	0

7.3.4 Lake Michigan Direct Drainage

Stormwater runoff and associated pollutant loadings along the shoreline of Lake Michigan were also included in the eutrophication and bacteria modeling. These direct drainage loads were developed by Tetra Tech using the LSPC model as setup for the drainage areas directly contributing runoff and loadings to Lake Michigan. Figure 20 presents the direct drainage areas modeled with the LSPC model by Tetra Tech along with the estuary model grid. The LSPC model inputs were developed based on the calibration and validation work completed in the surrounding watersheds (e.g., Milwaukee, Menomonee, Kinnickinnic, Oak Creek) with the sub-watershed areas delineated based on topography. The runoff and loadings generated from the LSPC direct drainage areas were assigned in the estuary model by dividing the total runoff and loading equally into adjacent model segments over the top two layers of the model. Both the runoff (hydrodynamic model) and loadings (water quality models) were assigned on an hourly basis for the entire calibration and validation periods. Figure 21 presents a summary of the direct drainage output as concentration versus runoff flow for two areas near McKinley/Bradford Beaches (Segment 3) and South Shore Beach (Segment 8). The model output in this figure are presented as daily average paired values of concentration and flow (small gray circles) and as a concentration mean +/- one standard deviation in 0.4 log unit flow bins (black circles and ranges) to highlight the concentration relationship to flow. In general, the concentrations increase with flow to a maximum and either level off or decrease at higher flows. Figure 22 presents this same output as a function of time and indicates a maximum daily average TN level of 3 mg/L, TP of 0.5 mg/L and fecal coliform of 84,000 #/100mL.

7.4 CONSTANTS

There are 157 constants for the eutrophication model. Because each of the algal groups has 27 constants and only one algal group was modeled, the actual number of constants needed to develop the model was 103. A summary of the more relevant final calibration and validation constants is presented in Table 5. Atmospheric reaeration is represented in the model through the assignment of an oxygen transfer coefficient (K_L – ft/d). A typical open water oxygen transfer rate of 2 ft/d (0.61 m/d) was assigned to the lake, 1 ft/d (0.31 m/d) for the outer harbor and a reduced value of 0.5 ft/d (0.15 m/d) assigned to the rivers to reflect the reduced wind speeds in the river and harbor area due to the surrounding city.

Table 5. Summary of Eutrophication Model Constants		
Parameter	**Value at 20°C**	**Source**
Phytoplankton		
Growth Rate (1/d)	2.5	1987 Milwaukee Harbor Modeling
Respiration Rate (1/d)	0.3 (base rate of 0.05)	1987 Milwaukee Harbor Modeling
Zooplankton Grazing Rate (1/d)	0.025	Typical Value
Carbon/Chla Ratio	40	1987 Milwaukee Harbor Modeling
Nitrogen/Carbon Ratio	0.176	Redfield Stoichiometry
Phosphorus/Carbon Ratio	0.025	Redfield Stoichiometry
Algal Settling (m/d)	0.3	Typical Value
Nitrogen		
Hydrolysis Rate (1/d) (particulate to dissolved organic)	0.01 - Refractory 0.05 – Labile	Other Studies
Mineralization Rate (1/d) (dissolved to ammonia)	0.01 - Refractory 0.05 – Labile	Other Studies
Nitrification Rate (1/d)	0.05	Other Studies
Particulate Settling (m/d)	0.3	Typical Value
Phosphorus		
Hydrolysis Rate (1/d) (particulate to dissolved organic)	0.01 - Refractory 0.05 – Labile	Other Studies
Mineralization Rate (1/d) (dissolved to orthophosphate)	0.01 - Refractory 0.05 – Labile	Other Studies
Particulate Settling (m/d)	0.3	Typical Value
Carbon		
Hydrolysis Rate (1/d) (particulate to dissolved organic)	0.01 - Refractory 0.05 – Labile	Other Studies
Oxidation Rate (1/d)	0.01 - Refractory 0.05 – Labile 0.25 – Reactive (CSO)	Other Studies (Labile BOD decay rate from MMSD LTBOD study)
Particulate Settling (m/d)	0.3	Typical Value

7.5 SEDIMENT FLUX SUBMODEL

The sediment sub-model requires inputs of initial conditions and various sediment related coefficients. The initial conditions, as described previously, were set up with best estimates and cycled to an equilibrium condition. Sediment model coefficients used in the model are based on numerous other studies around the country and typically require little adjustment to reproduce measured SOD and nutrient flux measurements. The MMSD conducted a number of sediment studies in the rivers and outer harbor that resulted in estimates of SOD and nutrient fluxes in addition to measurement of sediment characteristics (e.g. particulate concentrations, porosity). The study was completed by the Great Lakes WATER Institute in 2004 and was titled *"Milwaukee Harbor Sediment Oxygen Demand Study 2004"* (GLWI, 2004). In general, the studies included the collection of sediment cores and the subsequent incubation in the laboratory under controlled temperature and light conditions. The measurement of SOD is completed by monitoring DO over time in the cores and for ammonia flux (J_{NH4}) and phosphate flux (J_{PO4}), ammonia and phosphate is monitored over time. The resulting rates of change determine the SOD, J_{NH4} and J_{PO4} rates. These data will be compared to model output from the sediment flux sub-model that calculated these rates as a function of settled organic matter and its subsequent decay in the sediments. Table 6 presents a summary of the sediment study results.

7.6 BACTERIA MODEL

The bacteria model inputs have the same structure as the eutrophication model, including initial conditions, boundary conditions, nonpoint and point source loads, time functions and constants. As in the eutrophication model, an initial condition file was set up with either available data or with best estimates. In this phase of the modeling, fecal coliform was modeled based on previous fecal coliform modeling during the MMSD BSTF Study. The river boundary conditions were setup using measured data at stations RI-05 (Milwaukee), RI-13 (Kinnickinnic), RI-20 (Menomonee) and OC-07 (Oak Creek) together with a flow relationship. As the upstream LSPC watershed model calibrations and validations are completed, the river boundary conditions will be switched to use the LSPC output instead of measured data. This should not affect the estuary model calibration and validation since the LSPC model was compared to the same data used to initially set up the boundary conditions. In addition, the LSPC output will fill in the gaps between data measurement dates. For the lake boundary condition a constant fecal coliform concentration of 2 #/100mL was used and also treated as conservative (no die-off) to represent background fecal coliform levels. Figures 23 through 28 present the fecal coliform, copper and zinc boundary conditions used for the calibration and validation periods. The nonpoint and point source loads were based on measured data from WWTP DMRs and for CSO/SSO/CSSW geometric mean data presented in Table 3. As in the eutrophication model, the same three time functions were used in the bacteria model: time variable solar radiation and fraction day light functions, and time and spatially variable base light extinction coefficients.

There are 6 constants used in the bacteria model and represent bacteria die-off (3) and copper/zinc first-order decay rates. The final calibration and validation constants used in the bacteria model are presented in Table 7.

Table 6. Milwaukee River/Harbor 2004 Sediment Study Results			
Station	**SOD ($gO_2/m^2/d$)**	**J_{NH4} ($mgN/m^2/d$)**	**J_{PO4} ($mgP/m^2/d$)***
July 21			
RI-19	1.30	–	–
OH-04	1.15	–	–
OH-11	1.12	–	–
July 27			
RI-07	0.77	73.8	10.3 / 1.7
RI-11	0.88	149.3	16.1 / 56.1
RI-14	1.41	181.8	9.3 / 25.3
August 5			
RI-19	1.32	117.8	42.3 / 87.1
OH-04	0.92	55.3	3.3 / 18.6
OH-11	1.08	64.1	10.1 / 18.4
August 10			
RI-07	0.72	72.1	6.6 / 3.0
RI-11	1.12	65.1	19.3 / 72.4
RI-14	1.40	76.5	3.2 / 41.9
September 9			
RI-19	1.30	67.3	2.2 / 37.2
OH-04	0.76	53.9	-0.2 / 14.6
OH-11	0.83	29.5	3.9 / 9.2

* - First number is aerobic release, second number is anaerobic release

Table 7. Summary of Bacteria Model Constants		
Parameter	**Value at 20°C**	**Source**
Base fecal coliform die-off rate (1/d)	0.0 – lake bacteria 1.0 – river bacteria 2.0 – CSO/SSO bacteria	1987 Milwaukee Harbor Modeling
Sun-light dependent die-off rate (1/ly-day)	0.042	Other Studies
Copper Decay Rate (1/d)	0.0	Calibration/Validation
Zinc Decay Rate (1/d)	0.0	Calibration/Validation

8.0 MODEL CALIBRATION AND VALIDATION

As previously described, the calibration period included the years from 1995-1998 and the validation period, from 1999-2002. Although calibration and validation should be completed separately, they are ultimately linked because the goal of model calibration and validation is to develop a consistent set of model parameters that reproduce both the observed calibration and validation data. To some extent if validation model/data comparisons need improvement, model parameters are adjusted and then calibration and validation model/data comparisons re-assessed. Initial calibration efforts were completed with the four year calibration period (1995-1998) and then tested with the validation period (1999-2002). If model parameter adjustments were necessary in the validation period, then the calibration was re-run and re-assessed. In a sense, a moving calibration and validation were completed to develop a model that best represents both periods. For the model/data comparisons to follow, the calibration and validation periods are presented together for ease of viewing but also to highlight the fact that the final model parameters reproduce the observed data in both the calibration and validation periods. A vertical line was added between the calibration and validation periods to distinguish the two periods.

The water quality models are directly coupled to the hydrodynamic model calculated circulation (flow, dispersion, volume) and, therefore, the water quality calculations also represent the effects of wind driven circulation, time-variable river and point source flows, atmospheric heating and cooling, and large-scale lake driven circulation. Development, calibration and validation of the hydrodynamic model are presented in HydroQual's *Hydrodynamic Model Technical Memo* (2007). The water quality models are run in a time-variable mode (continuous simulation) for the two 4-year calibration and validation periods with detailed model output generated every 6 hours at MMSD monitoring stations and points of interest, in addition to all model output at all segments generated every 1 or 5 days. The model inputs are based upon the best available information at the time of model development and include loads from the upstream rivers, WWTPs, powerplants, CSO/SSO/CSSW discharges, and direct drainage along the Lake Michigan shoreline. Currently, the model calibration and validation uses available MMSD monitoring data on the Milwaukee River, Menomonee River, Kinnickinnic River and Oak Creek to setup model boundary conditions. As the upstream LSPC watershed model calibration and validation is completed, these boundary conditions will be switched from using data to the watershed model output. This should not affect the estuary model calibration and validation since the LSPC model was compared to the same data used to initially set up the boundary conditions. In addition, the LSPC output will fill in the gaps between data measurement dates.

8.1 EUTROPHICATION & BACTERIA MODELS

The eutrophication and bacteria model results are presented as a time-series from 1995 to 2002 that encompasses the calibration and validation periods for the following parameters: TN, NH_4, NO_2+NO_3, TP, SP, chlorophyll-a, DO, BOD_5, TSS, copper, zinc, and fecal coliform. Surface monitoring data are represented as upward pointing blue triangles and bottom data as downward pointing green triangles. A solid vertical line separates the calibration and validation periods. Model surface output is presented as the solid line and the bottom output as the gray line. The model calibration and validation at a select number of MMSD monitoring stations is presented in Figures 29 through 35 for stations RI-11 (Menomonee River), RI-15 (Milwaukee River), RI-18 (Kinnickinnic River), OH-01 (confluence at Hoan Bridge), and in the outer harbor at OH-04, OH-03 and OH-11. A complete set of model calibration and validation figures at all RI and OH stations are presented in Appendix 2.

In general, both the eutrophication and bacteria models represent the measured data throughout the three rivers, inner/outer harbors and near shore Lake Michigan. This includes the general decrease in parameter levels from the rivers through the harbor and into Lake Michigan. In addition, the seasonal cycle of certain parameters (e.g., DO, chlorophyll-a) is also represented in the model. That is, DO levels are typically lower during the warmer periods of the year when oxygen demands are greater and chlorophyll-a levels are typically greater due to the increased growth during the warmer periods of the year. The primary model coefficients adjusted to achieve the model calibration and validation results are described below.

- Oxygen transfer coefficients (K_L) – these coefficients affect the supply of oxygen from the atmosphere to the water column and are generally based on wind speed and can be affected by the sheltering of a water body. To reflect the more open nature of the near shore lake areas, the oxygen transfer coefficients were based on an open water value (2 ft/day), reduced in the outer harbor to 1 ft/day, and reduced to 0.5 ft/day in the rivers. The reduction in the rivers and outer harbor improved the DO calibration/validation and were justified based on the sheltering effect of the city around these areas.
- Light extinction coefficients (K_e) – these coefficients affect the amount of light available for algal growth and were based on measured secchi depth data. Secchi depth measurements are somewhat subjective but do serve as a guide in establishing the light extinction coefficients. The calculated light extinction coefficients were increased by 25% over the calculated values in the outer harbor and increased in the upper reach of the Kinnickinnic River to reflect the more turbid conditions present in this area of the river.
- Sediment oxygen demand and nutrient fluxes (SOD, J_{NH4}, J_{PO4}) – these rates are calculated by the sediment flux submodel as result of settled organic matter but can not properly represent past discharges of organic material. For instance, the MMSD inline storage system (deep tunnel) became operational in 1994 and reduced CSO/SSO

discharges substantially. Prior to this time, CSO/SSO organic matter was discharged and settled in the river areas of the Milwaukee Harbor system due to the general reduction of water velocities as the rivers enter the inner harbor area. This material has probably accumulated over the years and can provide a source of organic material decay and resulting SOD and nutrient fluxes. In order to represent this phenomena in the rivers, calculated SOD and nutrient fluxes were increased by five in the upper reaches of the Kinnickinnic River and by 2.5 in the upper reaches of the Menomonee River. The increase in these rates was generally based on reproducing the measured DO levels in the upper reaches of the rivers and is considered reasonable given the past discharges of organic material from CSO/SSO discharges prior to 1994.

Minor adjustments were made to other coefficients but beyond the adjustments noted above, the detailed assignment of river boundary conditions and loads (WWTP, CSO/SSO) and most importantly the proper representation of water circulation as calculated with the hydrodynamic model resulted in a good level of model calibration and validation to observed data.

In addition, the sediment model output was compared to the measurements completed in 2004 (i.e., SOD, ammonia and phosphate fluxes). Although the measurements were completed in 2004 and modeling completed from 1995-2002, the comparisons were completed to compare sediment model output to observations (at least qualitatively). Figure 36 presents sediment flux model output and data for SOD, ammonia, nitrate (model only) and phosphate fluxes at stations RI-07, RI-11, RI-14, RI-19, OH-04, and OH-11 for the calibration and validation periods. It should be noted that the data were collected in 2004 but are repeated for each year of the calibration/validation period (1995-2002). The blue symbols for phosphate flux data represent aerobic releases and the green symbols represent anaerobic releases. In general, the sediment flux model output reproduces the measured levels for SOD and flux rates at all of the stations. Since ammonia and phosphate fluxes are dependent on overlying water column DO levels, aerobic and anaerobic flux data are presented and may also contribute to some of the lower computed ammonia fluxes than those observed at the outer harbor stations. Figure 37 presents an alternate way of looking at the ammonia fluxes. The model and data ammonia flux is presented as a function of the SOD/DO ratio for the six stations. The SOD/DO ratio represents the transfer coefficient between sediment and water, and increases at low DO levels as does the ammonia flux. This general pattern of increasing ammonia flux at low DO levels is observed in both the model output and data.

8.2 MODEL ERROR ANALYSES

In order to quantitatively assess the level of model calibration and validation, error analyses were completed. Typically, model calibration and validation are completed based on a weight of evidence approach. That is, model comparison to observed data is completed in a qualitative manner by the modeler to achieve a best fit of the model to data at all monitoring stations for the parameters being analyzed. Although this method balances model comparison to data with the modeler's understanding of the physical, chemical and biological characteristics of the system it does not provide a quantitative measure of the goodness of fit.

Ultimately, the goal of model calibration and validation is "not to curve fit model to data, but to describe the behavior of the data with a modeling framework of the principal mechanisms relevant to the problem" (Thomann, 1982).

There are number of measures that can be used to quantitatively assess model goodness of fit. Many of these measures are described in detail along with a good discussion of overall model verification assessments in a number of journal papers (Thomann, 1982; Ambrose and Roesch, 1982; Reckhow et al., 1990). Not all measures are suitable for the error analysis due to inherent benefits and disadvantages in the measure. The following measures were selected for the Milwaukee Harbor Estuary Model error analysis.

- Model Bias: $= \overline{Y} - \overline{X}$;
- Relative Model Bias: $= 100 \times \dfrac{\overline{Y} - \overline{X}}{\overline{X}}$;
- Mean Absolute Error: $= \dfrac{1}{n} \sum_{i=1}^{n} \left| Y_i - X_i \right|$;
- Median Relative Error: $= 100 \times \dfrac{(Y_i - X_i)}{X_i}$;
- where: Y = model, X = data, $\overline{Y}$ = average of Y, $\overline{X}$ = average of X.

Table 8 presents the results of the error analyses at eight monitoring stations in the Milwaukee (RI-07, RI-15), Menomonee (RI-11) and Kinnickinnic Rivers (RI-18); and Milwaukee Harbor (OH-01, OH-03, OH-04 and OH-11). The error analyses were completed for DO, chlorophyll-a, TSS, TN, TP and fecal coliform. These eight stations were selected because they represent the three main rivers entering the harbor (RI station), the confluence of all three rivers (OH-01) and the outer harbor (OH-04, OH-03 and OH-11). This table presents the data and model averages, model bias, relative model bias, mean absolute error and median relative error. In general, the relative measures can be sensitive to the magnitude of the parameter (particularly at low values) and, therefore, it is important to also consider the other measures such as model bias (difference between model and data averages and mean absolute error). The median relative error for the 8 stations ranged from -9 to 6% for DO, -8 to 133% for chlorophyll-a, -31 to -1% for TN, -7 to 14% for TP, -13 to 20% for TSS and -16 to -4% for fecal coliform. Overall using all RI and OH station analyses, the median relative error was approximately 2% for DO, 81% for chlorophyll-a, -14% for TN, 9% for TP, 11% for TSS and -12% for fecal coliform. With exception to chlorophyll-a, all parameters had a median relative error less than 15%, which is less than the MMSD Comprehensive Modeling and Real Time Control Strategy Implementation Plan guidelines.

Figure 38 presents point to point model/data comparisons at stations RI-07, RI-11, RI-15, RI-18, OH-01, OH-03, OH-04 and OH-11. These figures extract daily average model output and compare to the grab sample data on the date of collection for DO, chlorophyll-a, TN, TP, TSS and fecal coliform. Although the grab samples and daily average model output are not truly comparable, these figures can be used to examine whether the model/data comparison generally follow a one to one relationship (diagonal line on the figures) and that the spread about this line is generally equal (i.e., no bias). This is generally the case for most parameters at all stations (e.g., DO, TN, TP) but for some parameters there is either more variability in the data or model (e.g., chlorophyll-a, TSS). In general given the grab sample and model daily average differences, the model/data comparisons are reasonable when viewing in this format.

Another way to view model-data comparisons is through probability distributions of model output and observed data. Probability distributions are useful for presenting the mean and variation of a data set, and also provide a means for determining compliance (percent exceedance) from a given value (e.g., a water quality standard). The method for developing the distribution is to rank the data set from lowest to highest, calculate a percentage for each point (i/n-1) and to plot the transformed data on a probability scale, which implies a normal or log-normal distribution. The x-scale represents the percentage of data that are less than a corresponding y-scale value (% less than or equal to) or conversely, 100 minus this percentage represents the percentage of the data exceeding the y-scale value. Figure 39 presents the probability distributions at the eight stations for DO, chlorophyll-a, TN, TP, TSS and fecal coliform. In these figures the model is represented as the filled circles and the data as the open diamonds. In general, the model output for these parameters captures the overall variability observed in the data in addition to the median observed levels.

Considering an overall weight of evidence approach to assessing the model calibration and validation, the water quality model reasonably represents the observed data in the Milwaukee Harbor system. That is, the qualitative (best visual fit of model to data) and quantitative (error analyses) comparisons between model and data are very reasonable given the complex nature of the Milwaukee Harbor system.

9.0 SUMMARY

The eutrophication and bacteria models were developed with a very detailed and extensive database consisting of instream water quality data, meteorological data, LTBOD and SOD studies, and external loading data (WWTPs, CSO/SSO/CSSW). These models were coupled to a calibrated and validated hydrodynamic model that supplies water circulation to the water quality models. The water quality models were calibrated and validated to available water quality data in the Milwaukee, Menomonee and Kinnickinnic Rivers, inner/outer harbors and near shore Lake Michigan. The calibration period was from 1995-1998 and the validation period from 1999-2002. Both the eutrophication and bacteria models represented the observed data well spatially (rivers, harbor, lake), seasonally (summer, winter) and temporally (1995-2002). To the extent that the water quality models represent the observed data well, they are considered suitable for assessing potential water quality impacts associated with the long range planning alternatives and needs of MMSD and SEWRPC.

Table 8. Model Error Statistics							
Station	**Parameter**	**Data Mean**	**Model Mean**	**Model Bias**	**Relative Model Bias**	**Mean Absolute Error**	**Median Relative Error**
RI-07	DO	8.45	8.59	0.15	1.76	2.23	-1.1
	Chl-a	24.6	23.2	-1.4	-5.6	13.9	11.7
	TSS	39.9	25.2	-14.7	-36.9	25.2	-12.9
	TN	2.06	1.91	-0.14	-6.88	0.46	-2.1
	TP	0.141	0.133	-0.008	-5.820	0.074	1.3
	log Fecal Col	6.14	5.75	-0.39	-6.35	1.86	-6.8
RI-11	DO	6.31	6.74	0.43	6.8	2.14	6.4
	Chl-a	5.7	9.2	3.4	59.8	6.1	102.3
	TSS	25.0	16.6	-8.4	-33.5	15.8	-3.8
	TN	1.68	1.60	-0.07	-4.4	0.37	-1.5
	TP	0.139	0.099	-0.040	-28.8	0.072	-7.0
	log Fecal Col	5.82	5.72	-0.10	-1.8	1.92	-3.7
RI-15	DO	7.58	8.05	0.47	6.2	1.56	4.4
	Chl-a	6.7	13.0	6.3	93.8	8.0	117.2
	TSS	30.6	17.2	-13.4	-43.7	21.5	-10.8
	TN	1.73	1.59	-0.15	-8.5	0.46	-7.6
	TP	0.113	0.101	-0.013	-11.1	0.063	1.0
	log Fecal Col	5.44	4.92	-0.52	-9.5	1.91	-13.5
RI-18	DO	7.13	6.47	-0.66	-9.3	1.88	-8.5
	Chl-a	5.9	8.7	2.9	48.6	6.5	133.3
	TSS	13.9	11.7	-2.3	-16.2	9.6	-3.7
	TN	1.61	1.45	-0.16	-9.9	0.45	-8.4
	TP	0.075	0.082	0.007	9.5	0.038	9.8
	log Fecal Col	4.86	4.05	-0.81	-16.7	1.98	-13.4
OH-01	DO	8.22	8.72	0.50	6.1	1.44	3.2

Table 8. Model Error Statistics							
Station	**Parameter**	**Data Mean**	**Model Mean**	**Model Bias**	**Relative Model Bias**	**Mean Absolute Error**	**Median Relative Error**
	Chl-a	6.1	8.5	2.3	38.3	4.4	41.9
	TSS	9.3	13.0	3.7	39.2	6.2	20.0
	TN	1.58	1.36	-0.22	-13.7	0.54	-13.1
	TP	0.066	0.071	0.006	8.4	0.032	3.2
	log Fecal Col	4.45	3.99	-0.46	-10.4	1.88	-16.2
OH-03	DO	9.10	9.85	0.75	8.2	1.70	6.0
	Chl-a	6.8	6.0	-0.8	-11.9	4.2	6.5
	TSS	8.5	7.8	-0.7	-8.0	4.8	5.1
	TN	1.47	1.01	-0.46	-31.1	0.57	-25.7
	TP	0.069	0.049	-0.020	-28.5	0.043	6.3
	log Fecal Col	4.13	3.47	-0.66	-16.1	1.67	-14.6
OH-04	DO	9.59	10.20	0.61	6.3	1.72	4.7
	Chl-a	8.7	6.0	-2.7	-31.3	6.0	-7.9
	TSS	5.1	5.4	0.2	4.7	2.8	2.5
	TN	1.22	0.86	-0.36	-29.3	0.48	-30.7
	TP	0.046	0.041	-0.005	-10.0	0.027	-2.6
	log Fecal Col	3.15	2.67	-0.48	-15.2	1.25	-13.3
OH-11	DO	9.32	9.83	0.51	5.5	1.72	1.7
	Chl-a	8.1	6.2	-1.8	-22.6	5.6	-1.9
	TSS	5.4	6.4	1.0	18.7	3.1	17.9
	TN	1.39	1.06	-0.33	-24.0	0.47	-25.1
	TP	0.047	0.050	0.004	7.8	0.026	13.9
	log Fecal Col	3.33	3.11	-0.21	-6.4	1.31	-9.5
Units: DO – mg/L, Chl-a – µg/L, TSS – mg/L, TN – mg/L, TP – mg/L, Fecal Col – #/100mL							

10.0 REFERENCES

Ambrose, R.B. and S.E. Roesch, 1982. *Dynamic Estuary Model Performance*. Journal of Environmental Engineering, Vol. 108, pp. 51-71.

Brown & Caldwell, 2004. *Draft Memo of CSO and SSO Hydrographs 1988-2002*. December 2004. From MMSD-2020 Facility Planning Project (MMSD Contract No: M03002 P01).

Great Lakes WATER Institute, 2004. *Milwaukee Harbor Sediment Oxygen Demand Study 2004, Final Report*. December 2004. From MMSD-2020 Facility Planning Project (MMSD Contract No: M03006 P01).

Milwaukee Metropolitan Sewerage District, 2004. Personal Correspondence with Christopher Magruder.

HydroQual, 2007. *Estuary Model Hydrodynamic Calibration/Validation Technical Memorandum.* September 2007. From MMSD-2020 Facility Planning Project (MMSD Contract No: M03002 P01).

Reckhow, K.H., J.T. Clements and R.C. Dodd, 1990. *Statistical Evaluation of Mechanistic Water-Quality Models*. Journal of Environmental Engineering, Vol. 116, pp. 250-268.

Thomann, R.V., 1982. *Verification of Water Quality Models*. Journal of Environmental Engineering, Vol. 108, pp. 923-940.

Thomann, R.V. & J.A. Mueller, 1987. *Principles of Surface Water Quality Modeling and Control.* Harper & Row, Publishers, Inc., New York, NY.

USEPA, 1985. *Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Second Edition).* USEPA Environmental Research Laboratory. EPA/600/3-85/040, June 1985.

Wisconsin Department of Natural Resources, 2001. *The State of the Milwaukee River Basin*. August 2001. PUBL WT 704 2001.

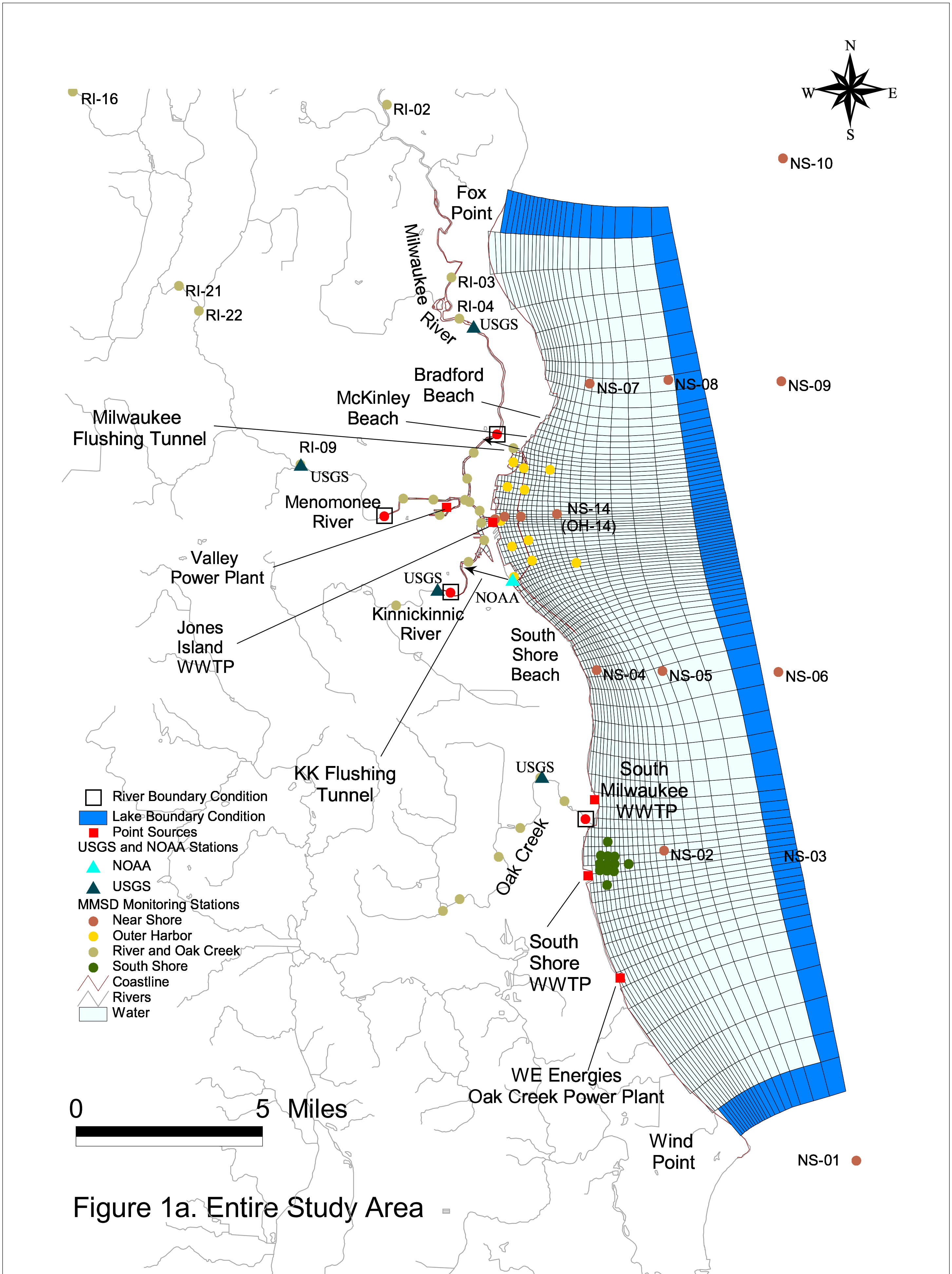


Figure 1a. Entire Study Area

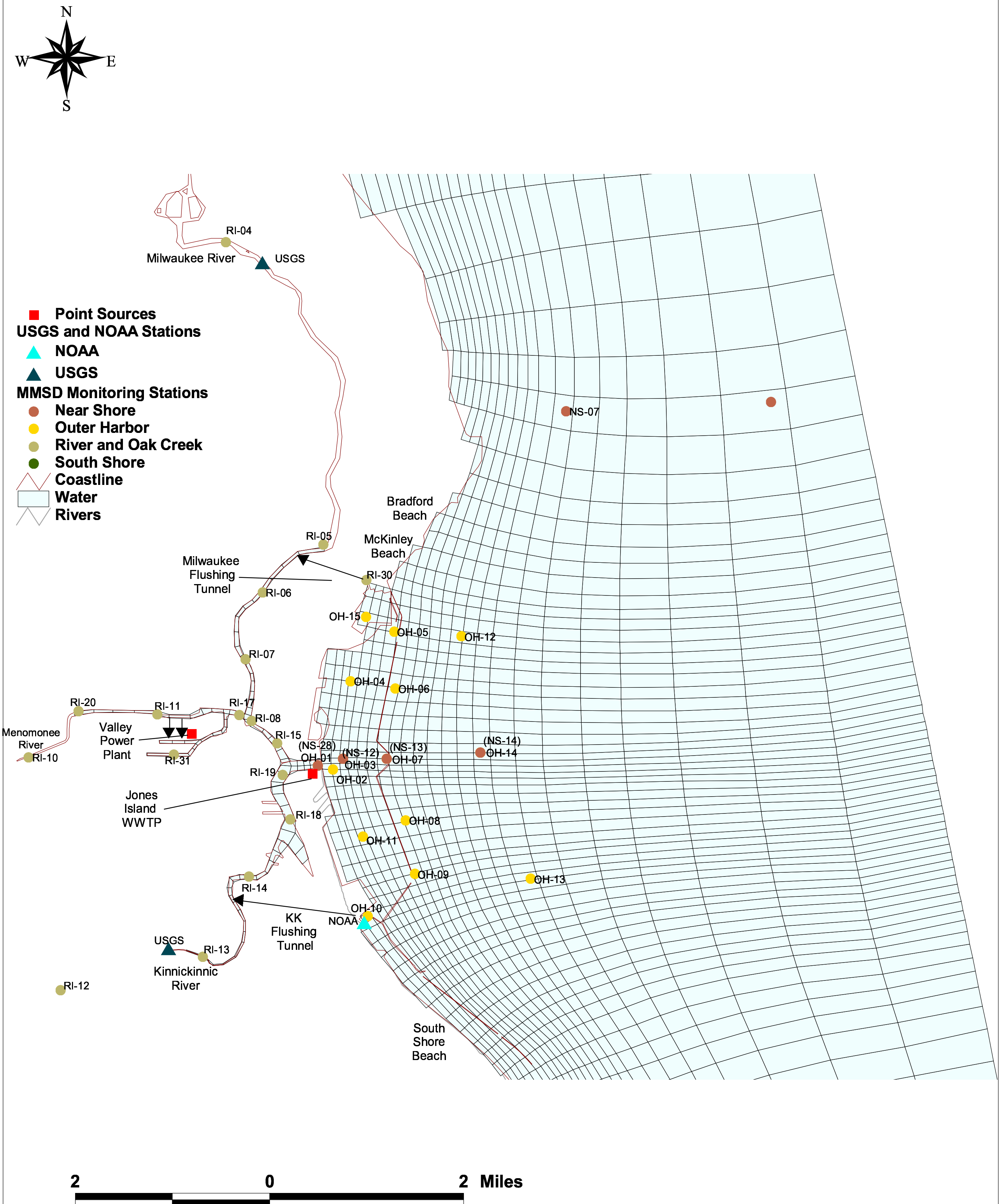


Figure 1b. Harbor Study Area

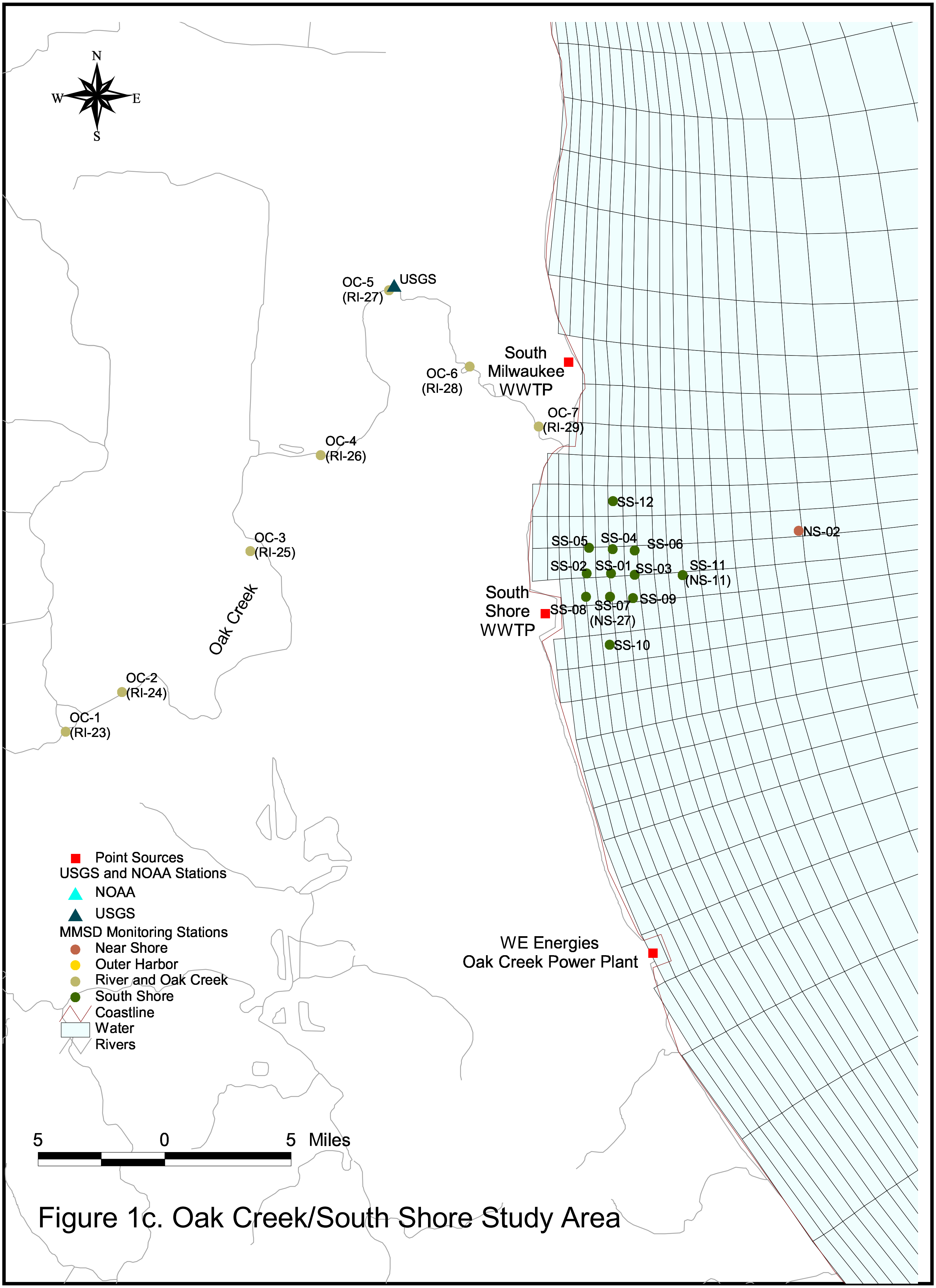


Figure 1c. Oak Creek/South Shore Study Area

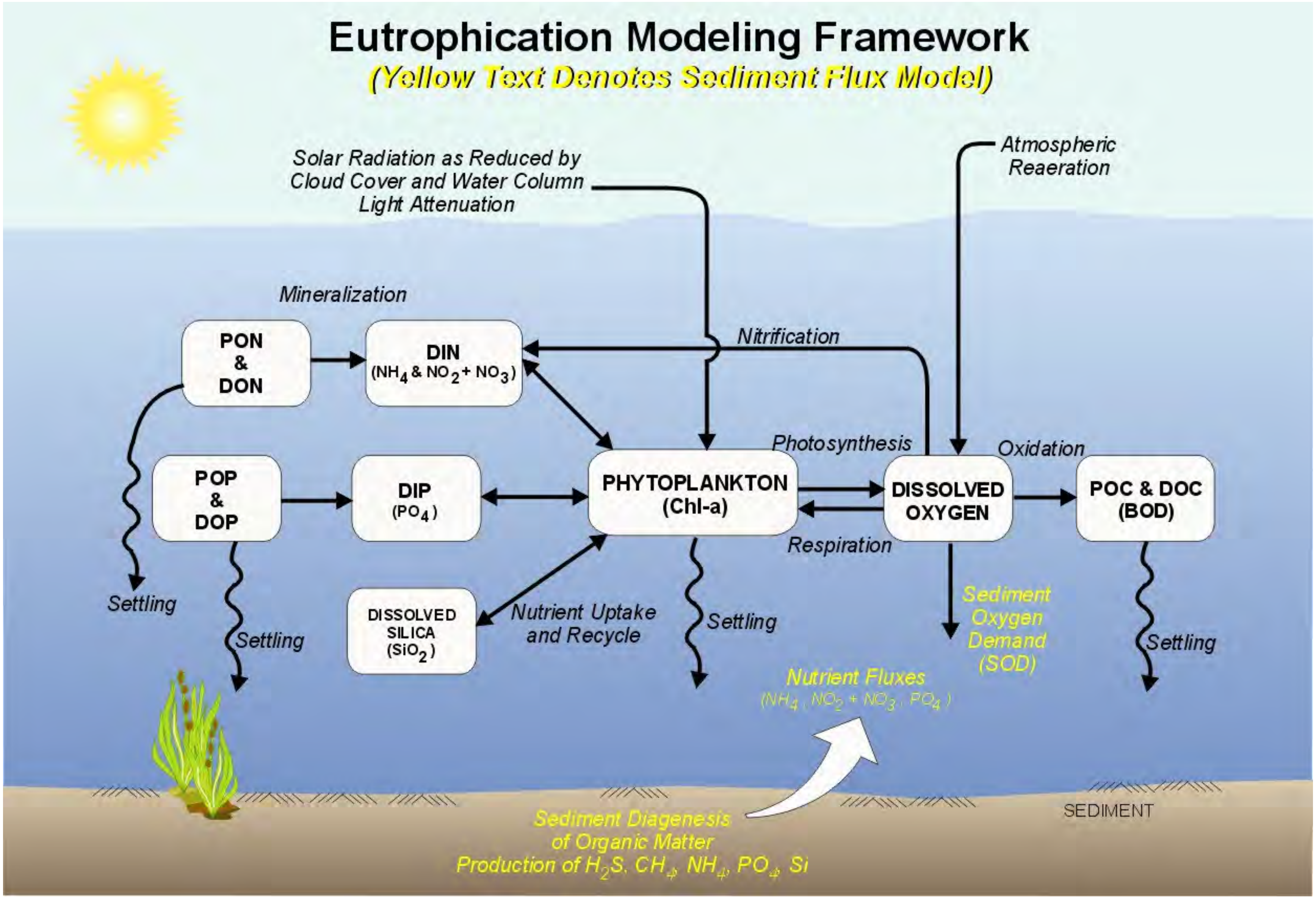


Figure 2. Eutrophication Model Framework

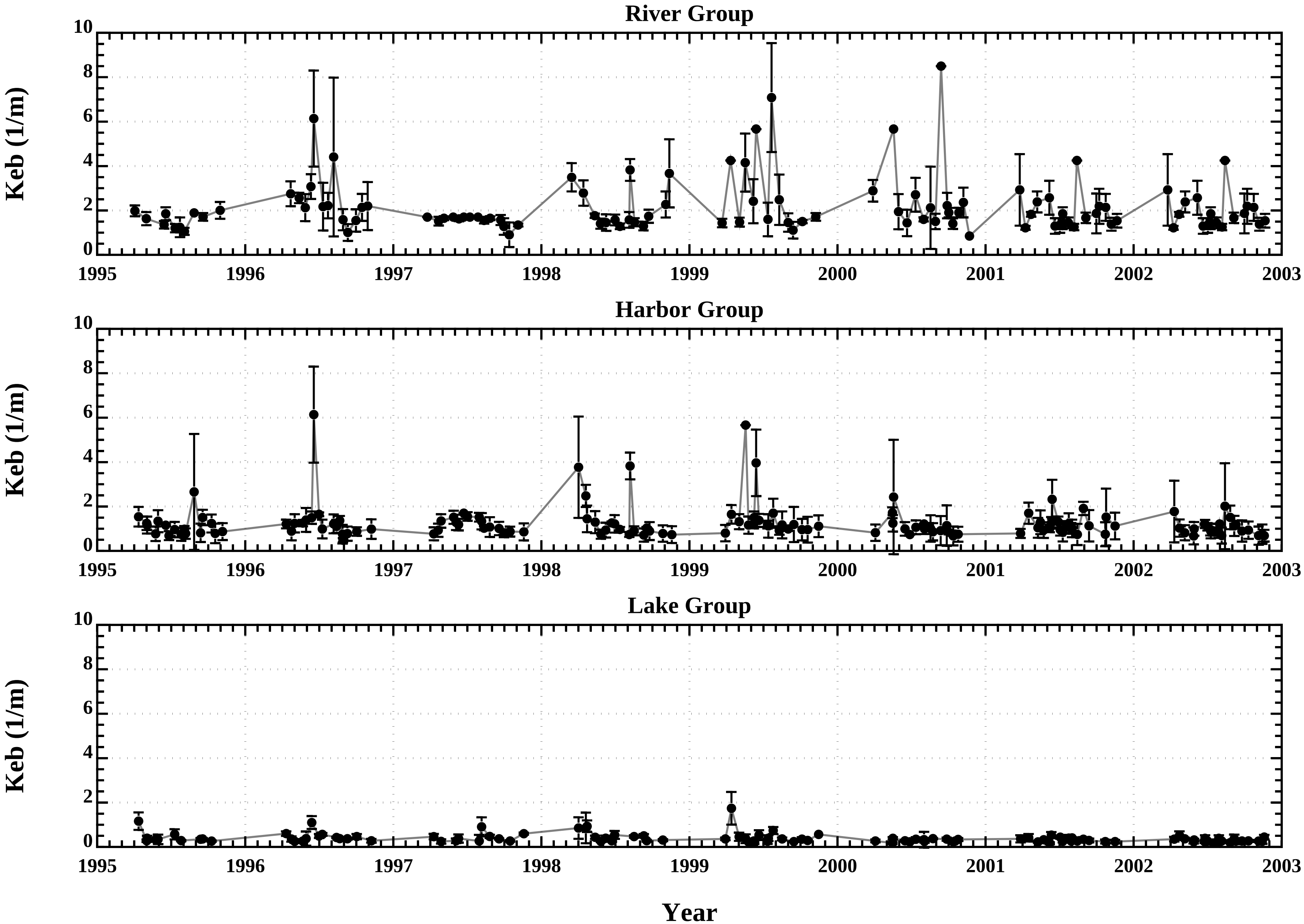


Figure 3. Base Light Extinction Coefficient Inputs for River, Harbor and Lake Groups
(Symbol & Range: Mean +/- Standard Deviation)

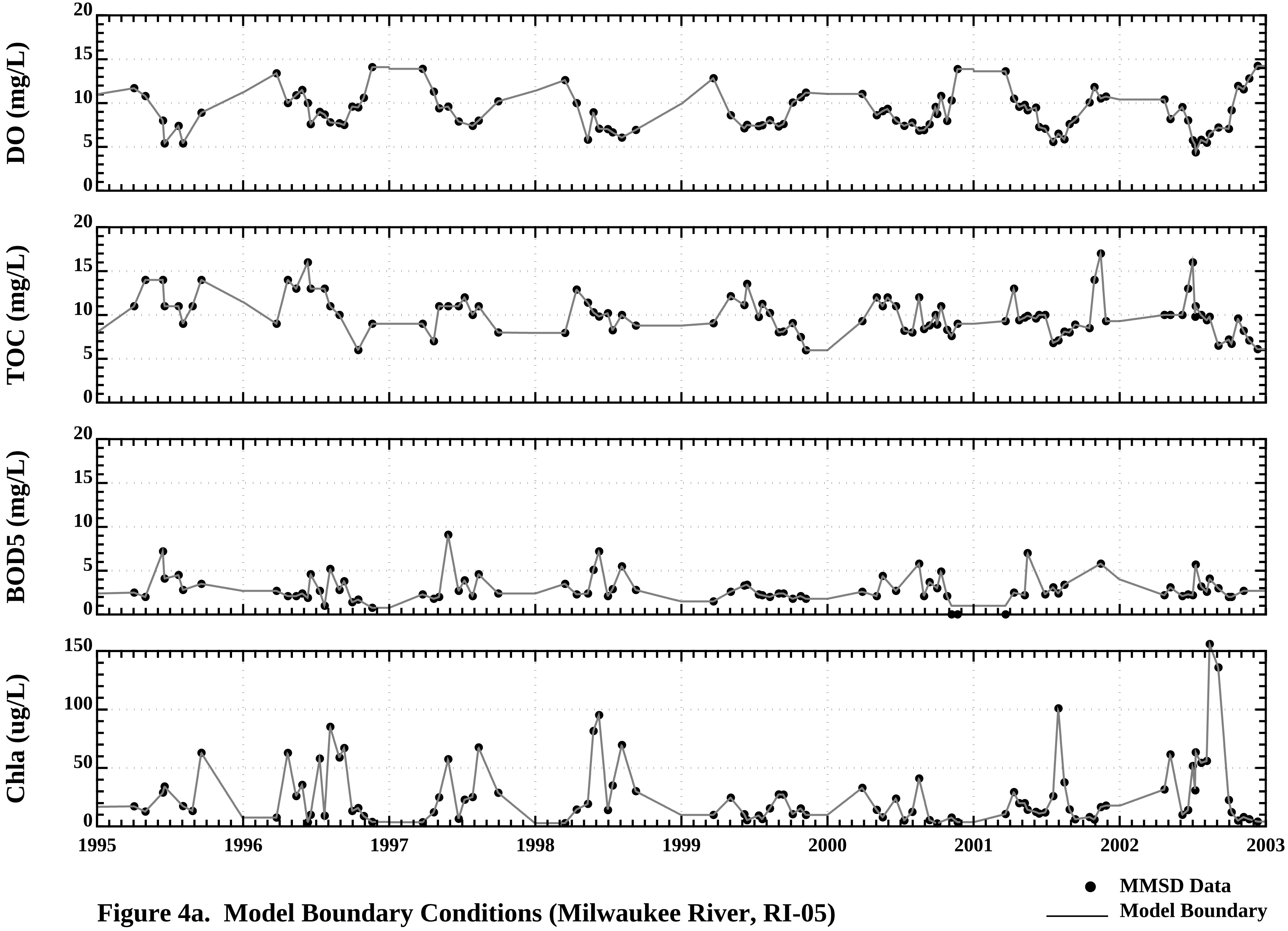


Figure 4a. Model Boundary Conditions (Milwaukee River, RI-05)

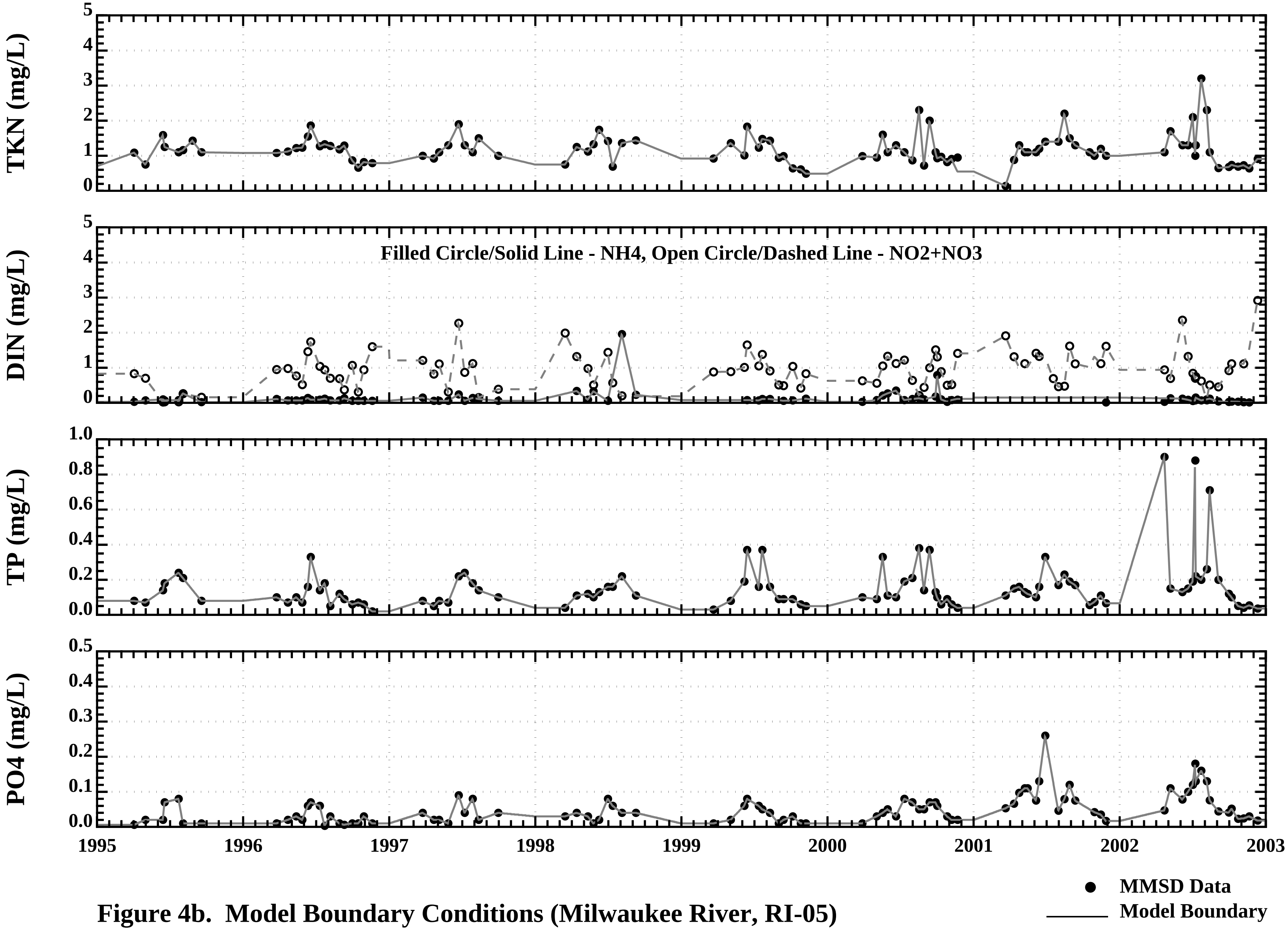


Figure 4b. Model Boundary Conditions (Milwaukee River, RI-05)

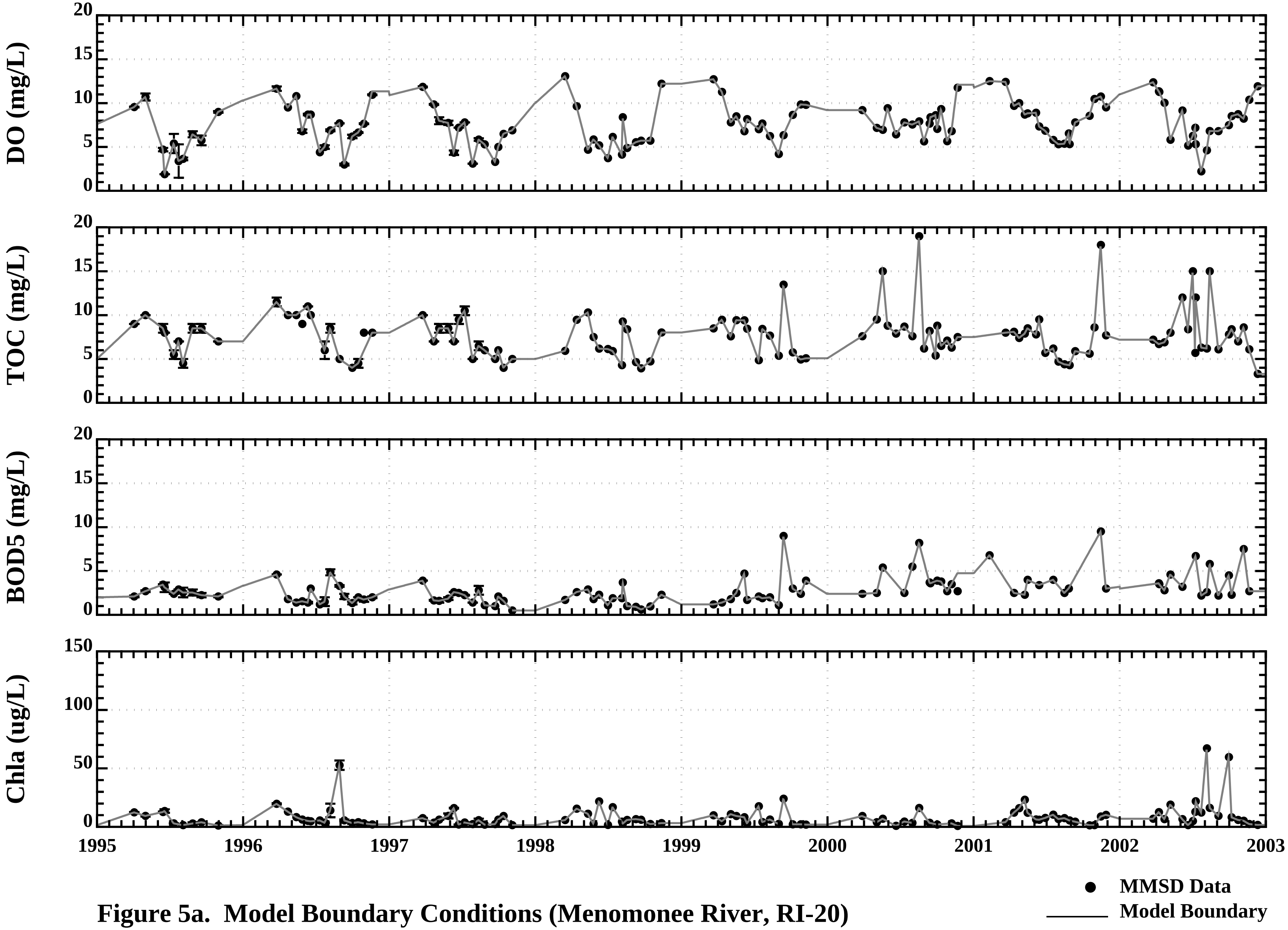


Figure 5a. Model Boundary Conditions (Menomonee River, RI-20)

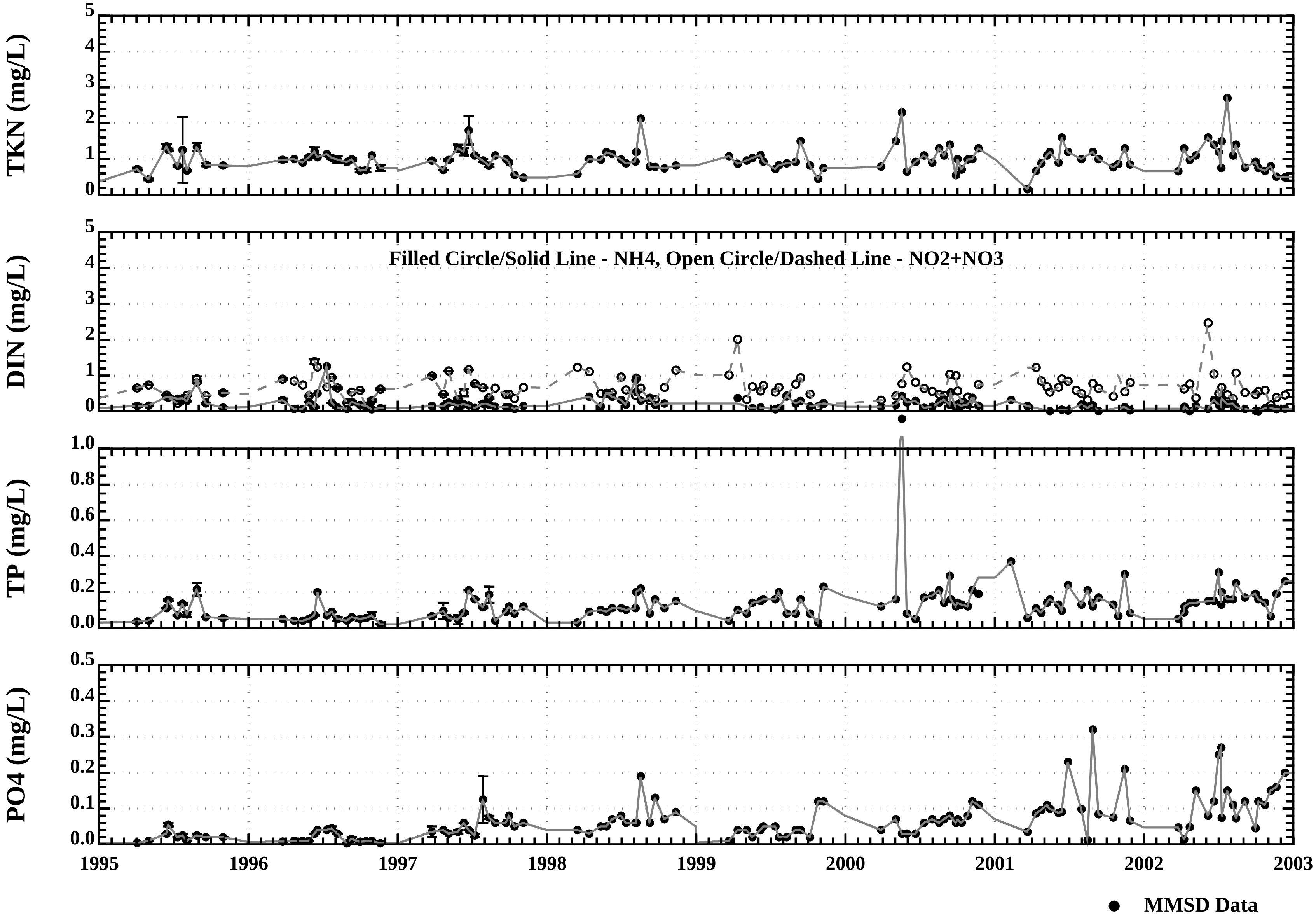


Figure 5b. Model Boundary Conditions (Menomonee River, RI-20)

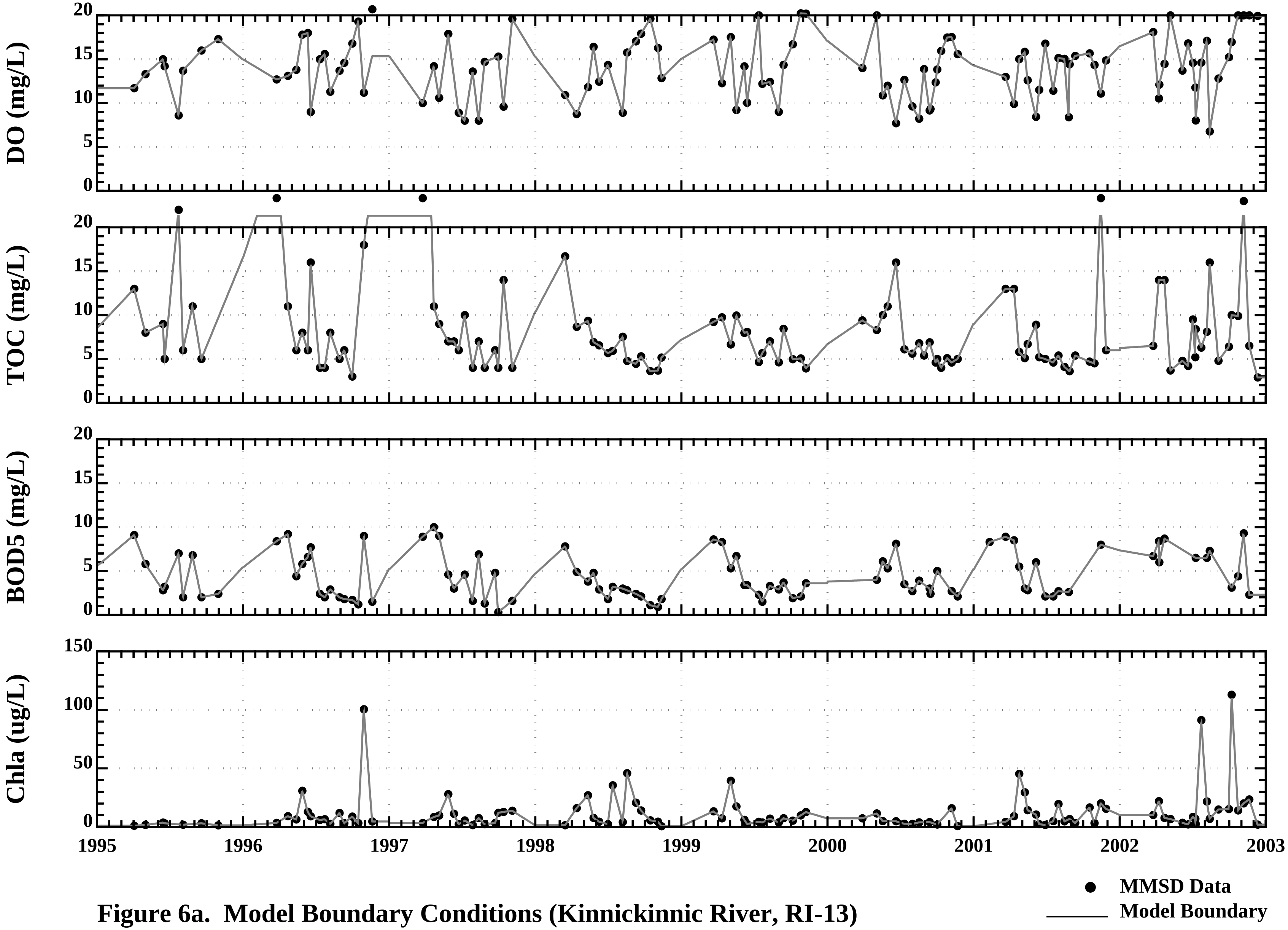


Figure 6a. Model Boundary Conditions (Kinnickinnic River, RI-13)

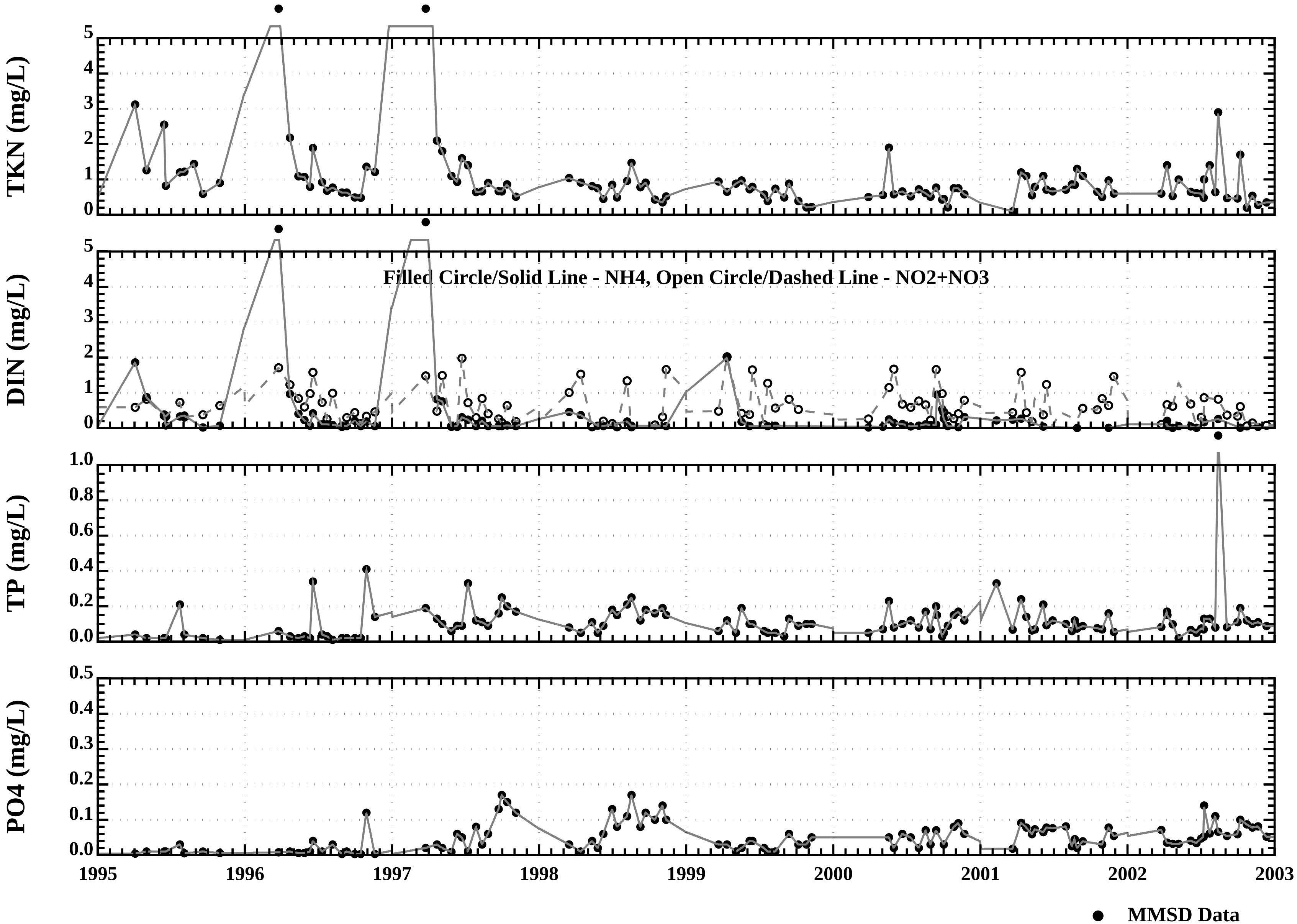


Figure 6b. Model Boundary Conditions (Kinnickinnic River, RI-13)

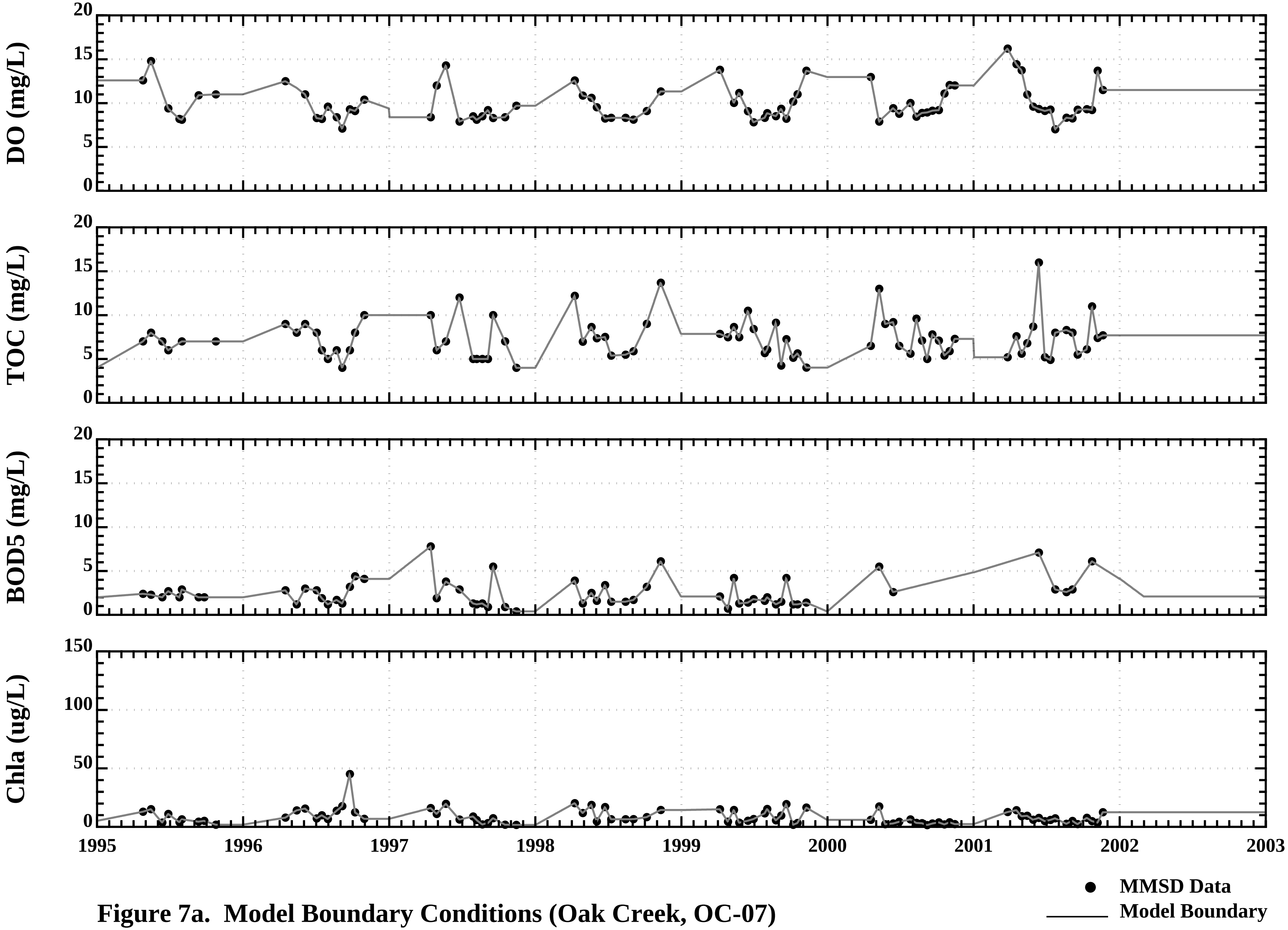


Figure 7a. Model Boundary Conditions (Oak Creek, OC-07)

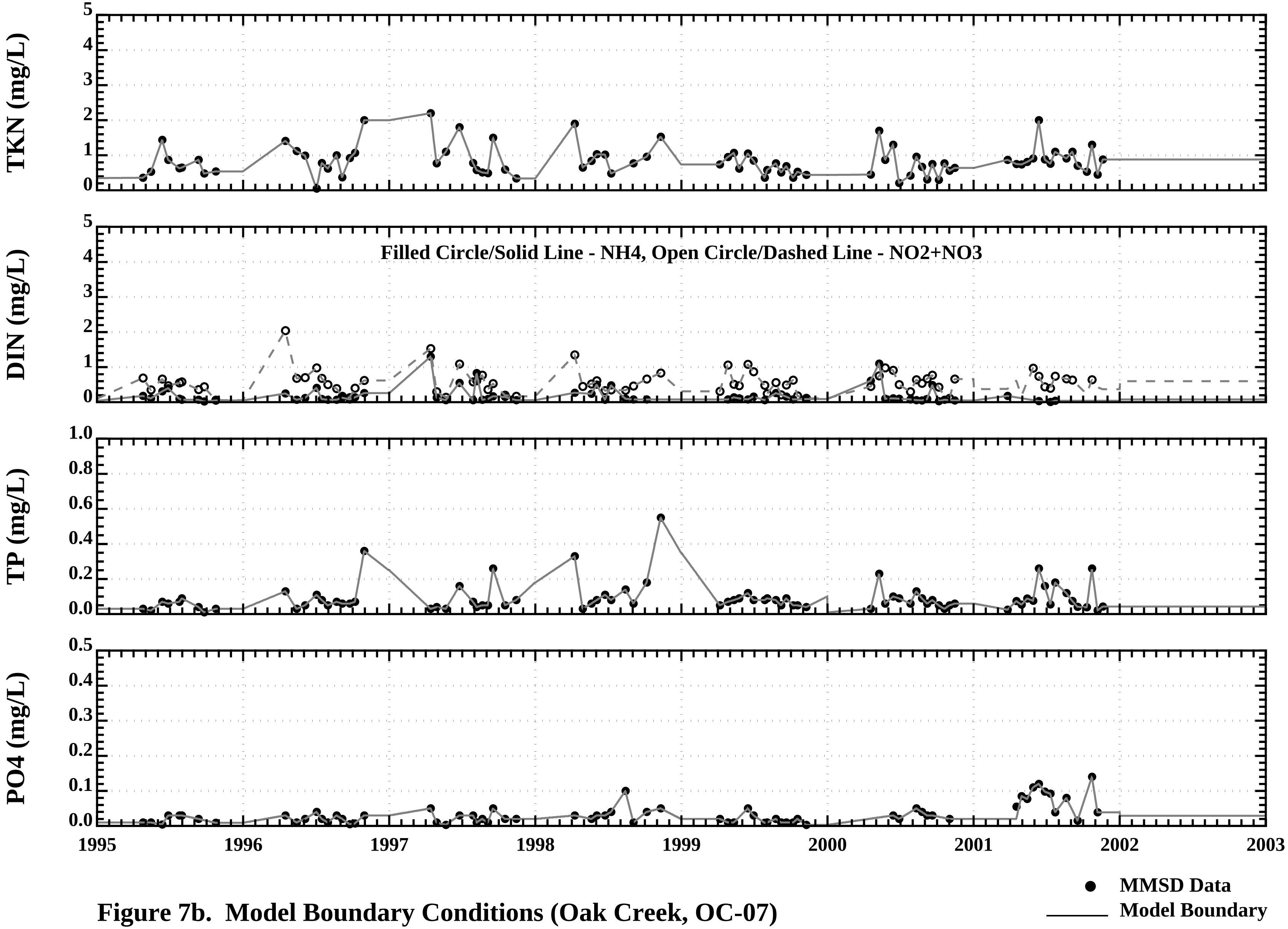


Figure 7b. Model Boundary Conditions (Oak Creek, OC-07)

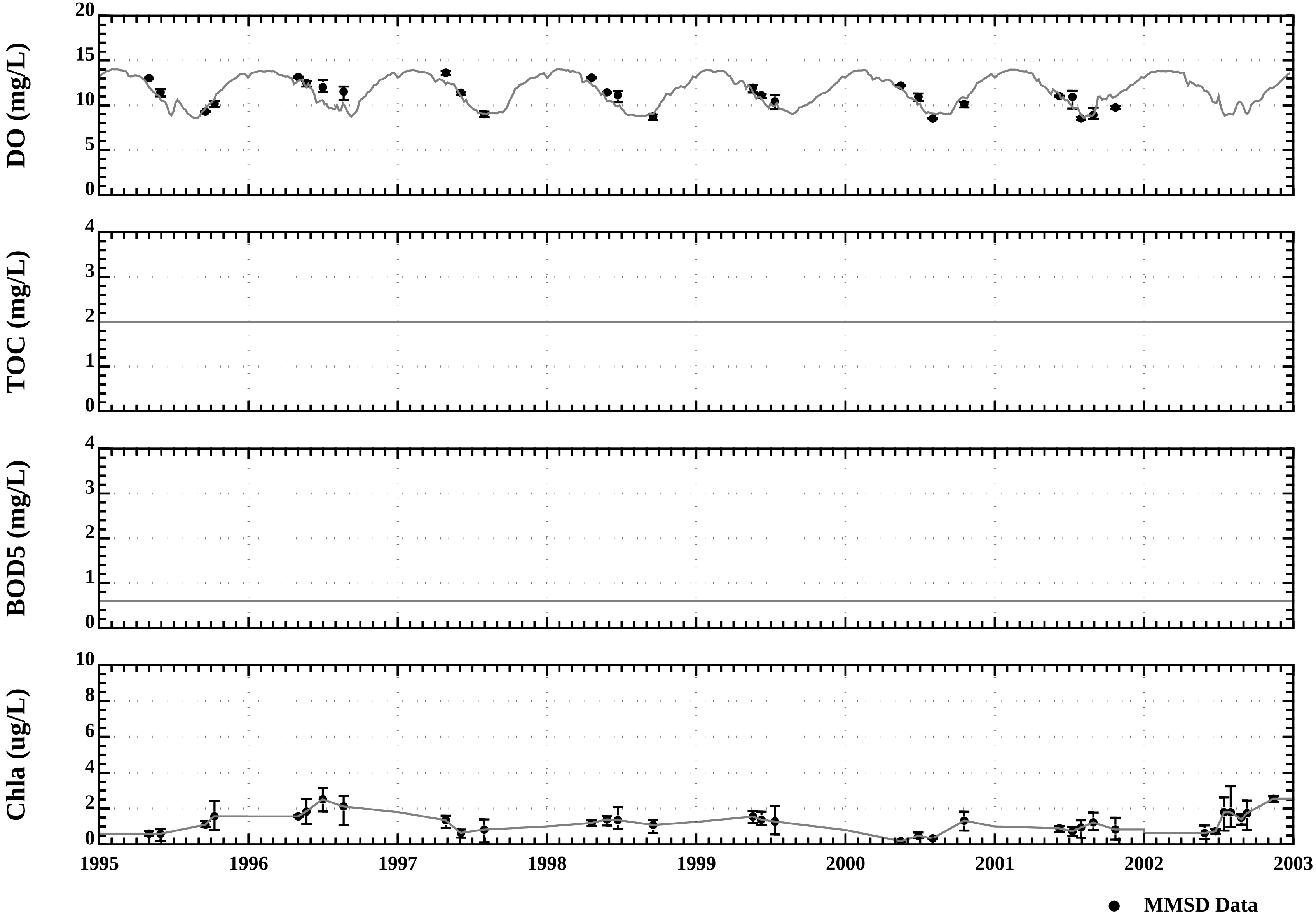


Figure 8a. Model Boundary Conditions (Lake Michigan, NS-01)

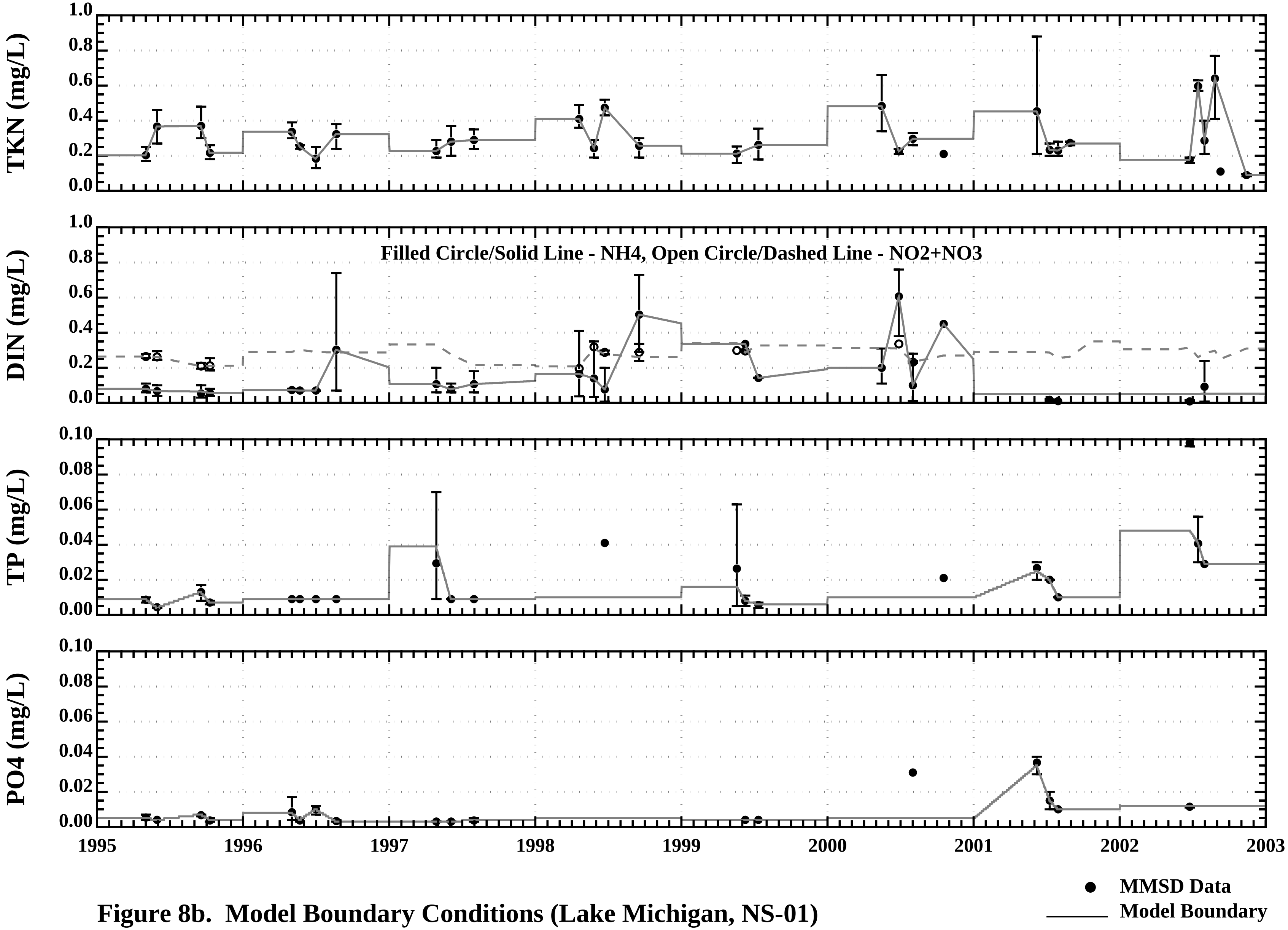


Figure 8b. Model Boundary Conditions (Lake Michigan, NS-01)

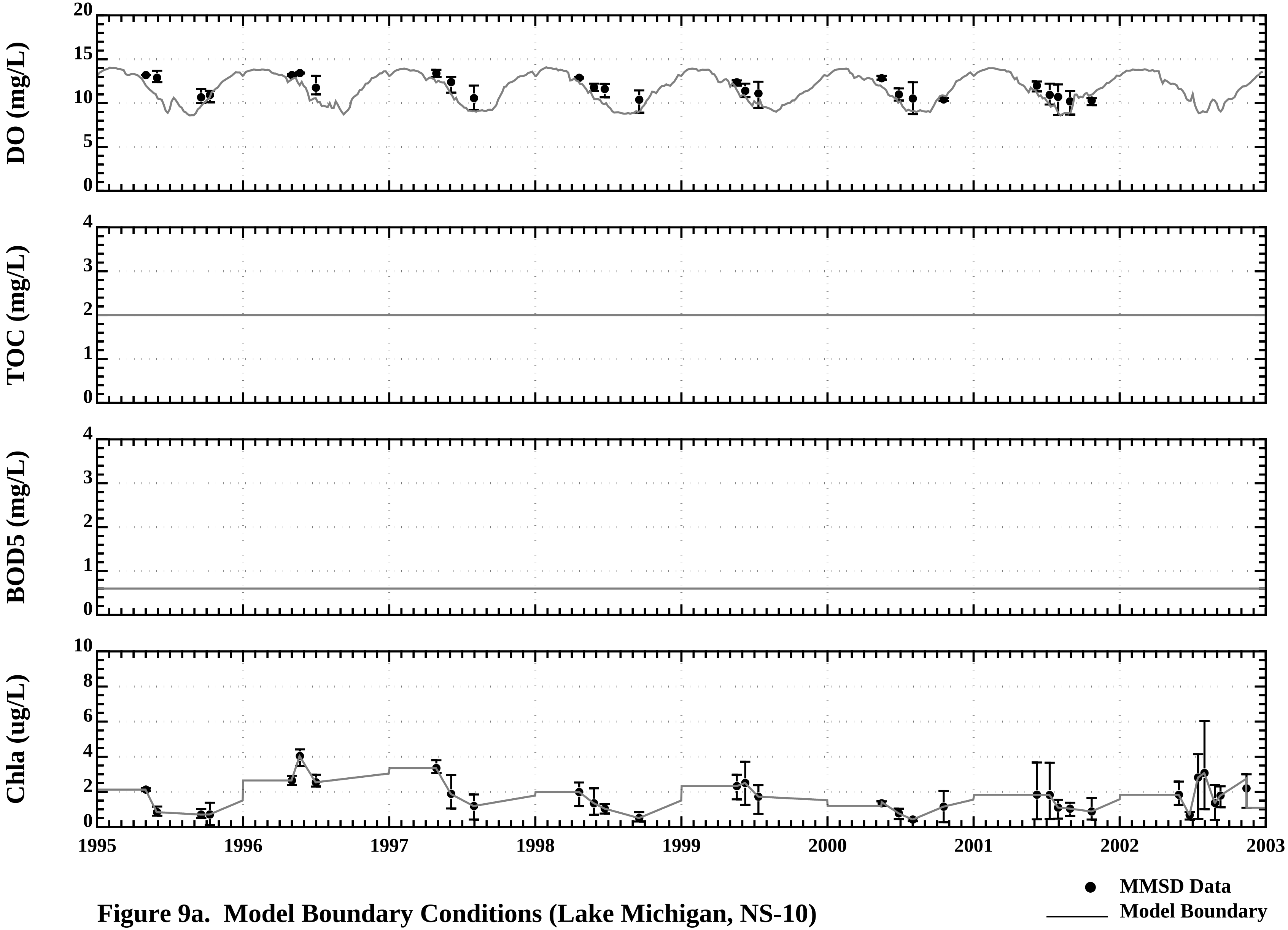


Figure 9a. Model Boundary Conditions (Lake Michigan, NS-10)

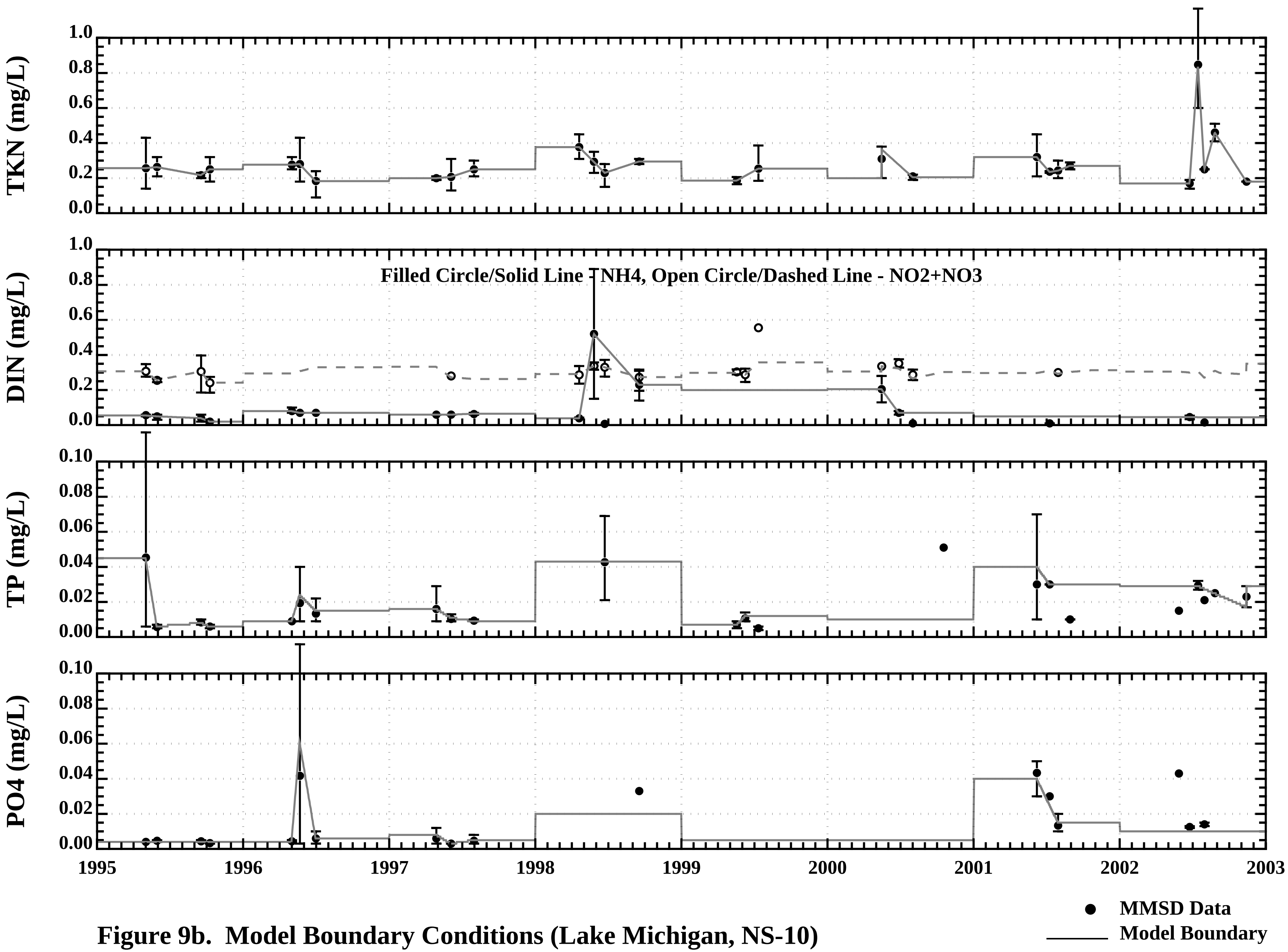


Figure 9b. Model Boundary Conditions (Lake Michigan, NS-10)

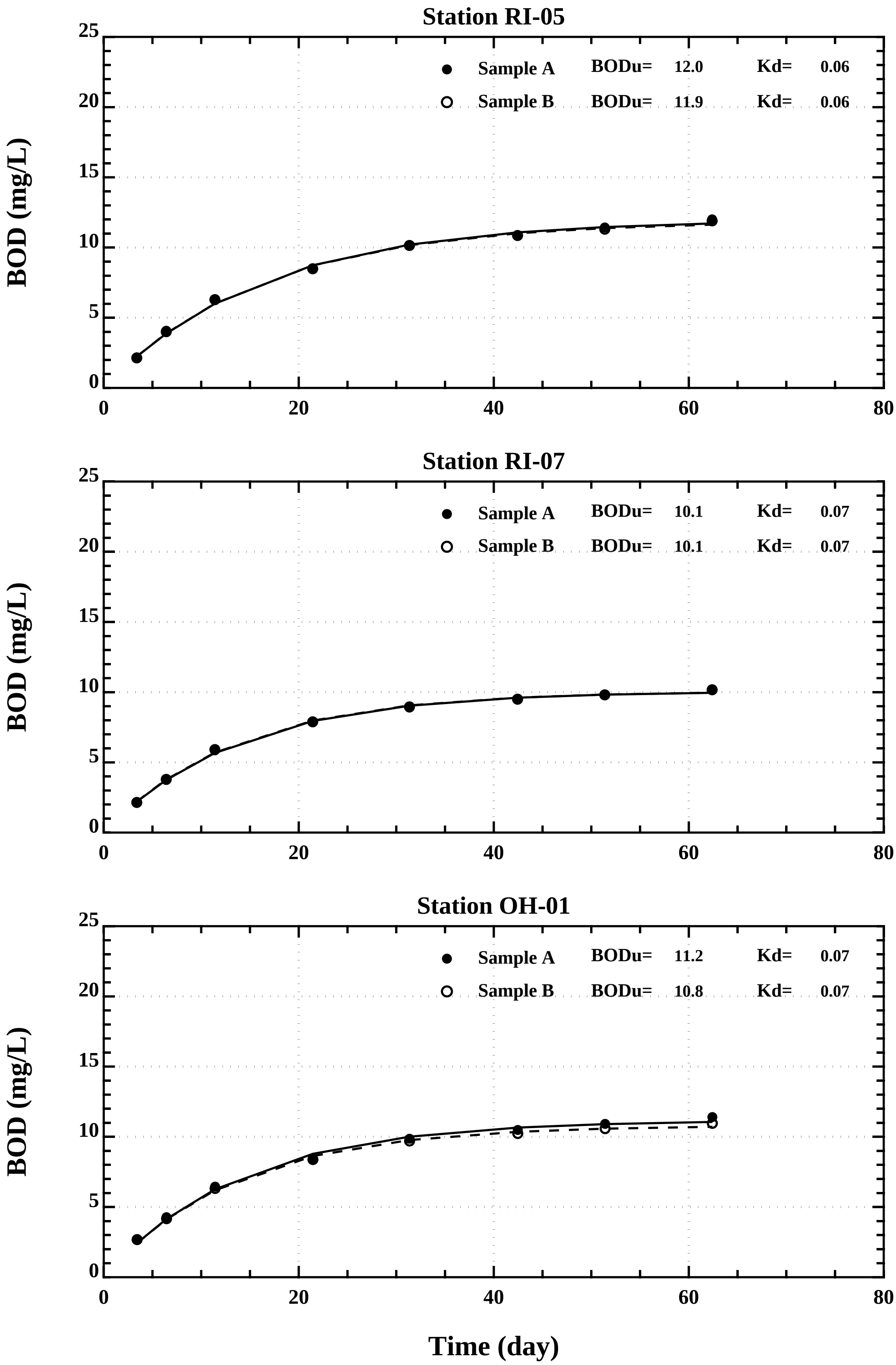


Figure 10. Milwaukee River LTBOD Data (4/21/2004)
(Circles - Test Replicates, Lines - Non-Linear Regressions)

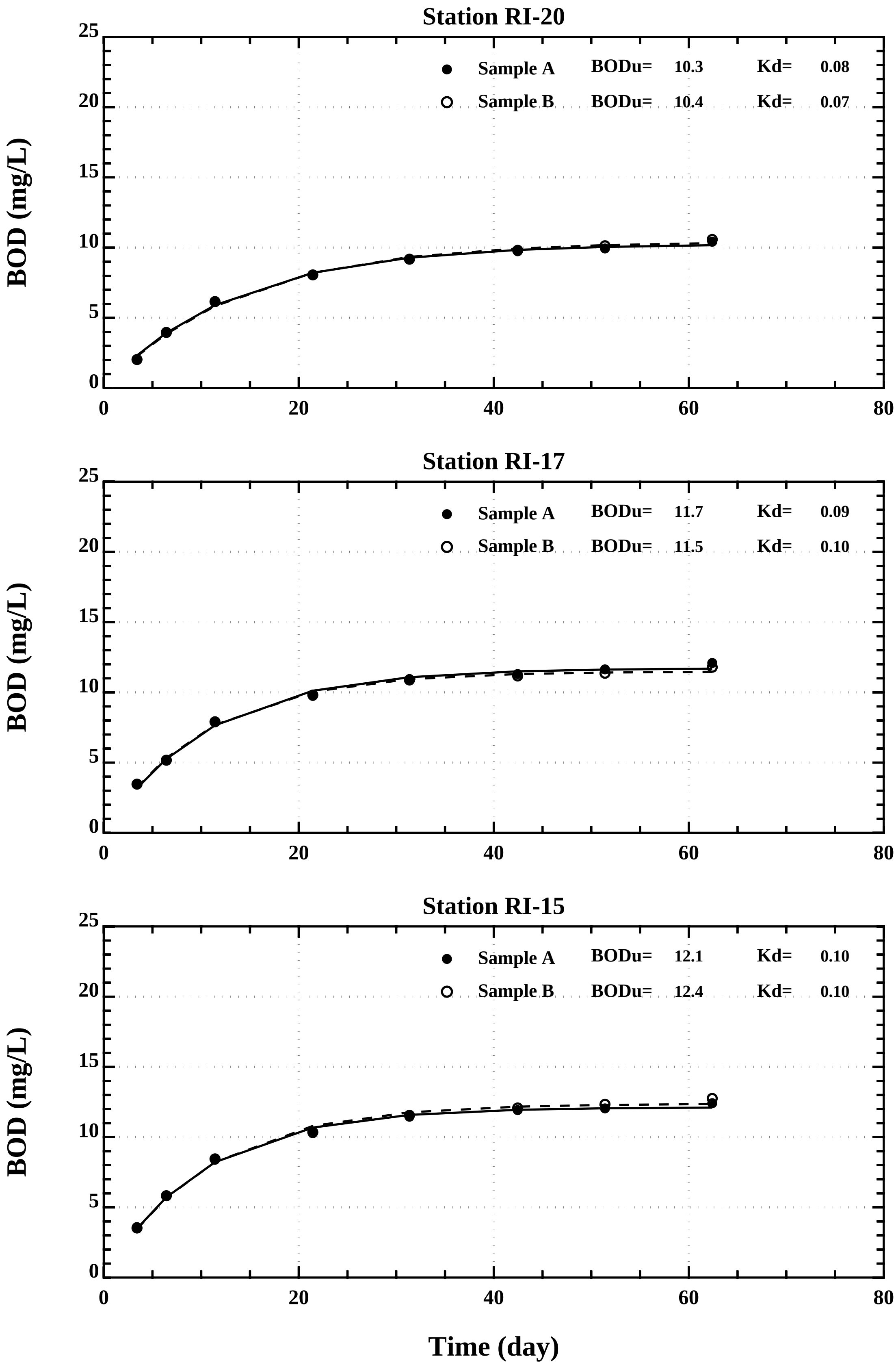


Figure 11. Menomonee River LTBOD Data (4/21/2004)
(Circles - Test Replicates, Lines - Non-Linear Regressions)

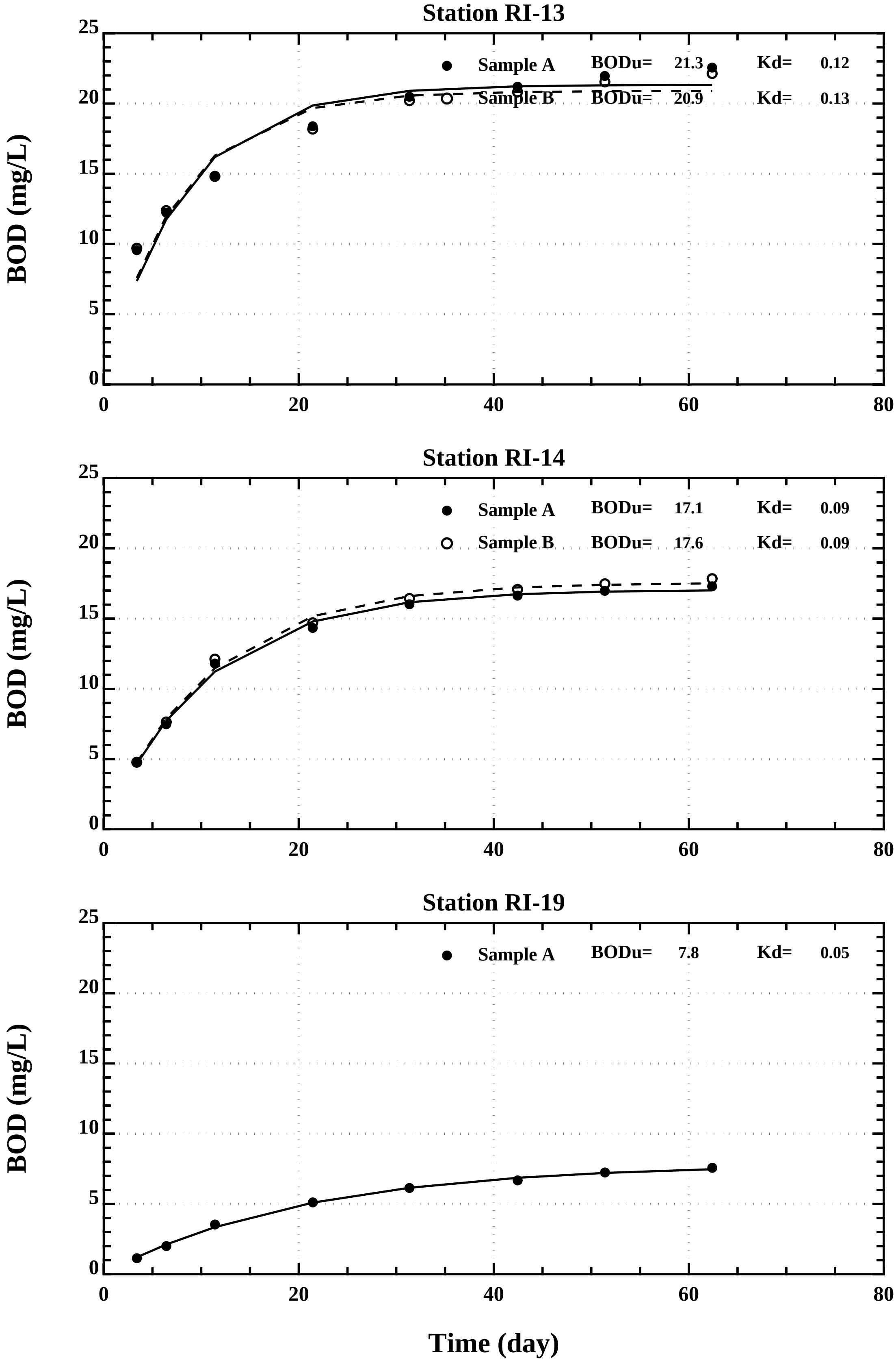


Figure 12. Kinnickinnic River LTBOD Data (4/21/2004)
(Circles - Test Replicates, Lines - Non-Linear Regressions)

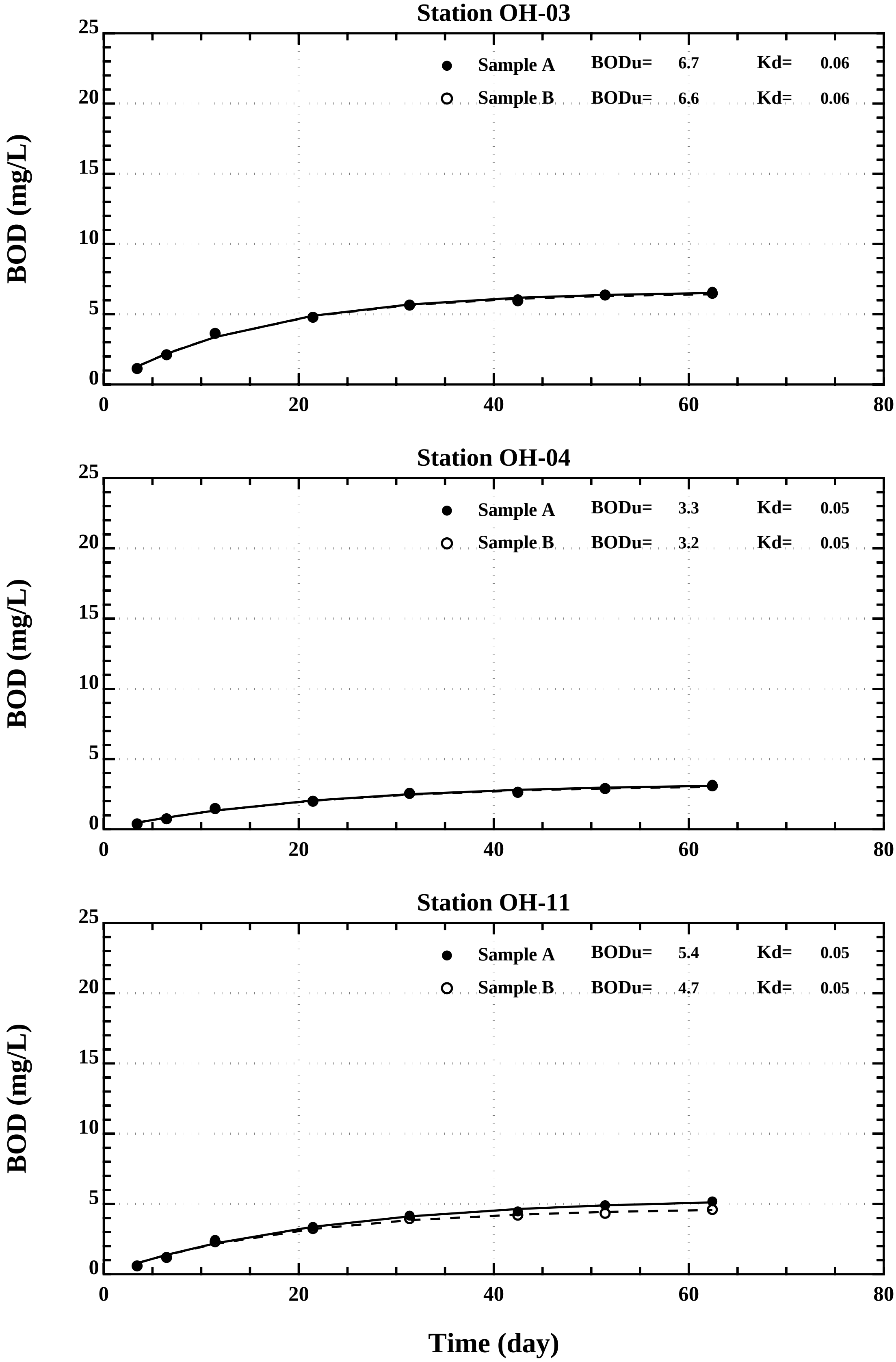


Figure 13. Outer Harbor LTBOD Data (4/21/2004)
(Circles - Test Replicates, Lines - Non-Linear Regressions)

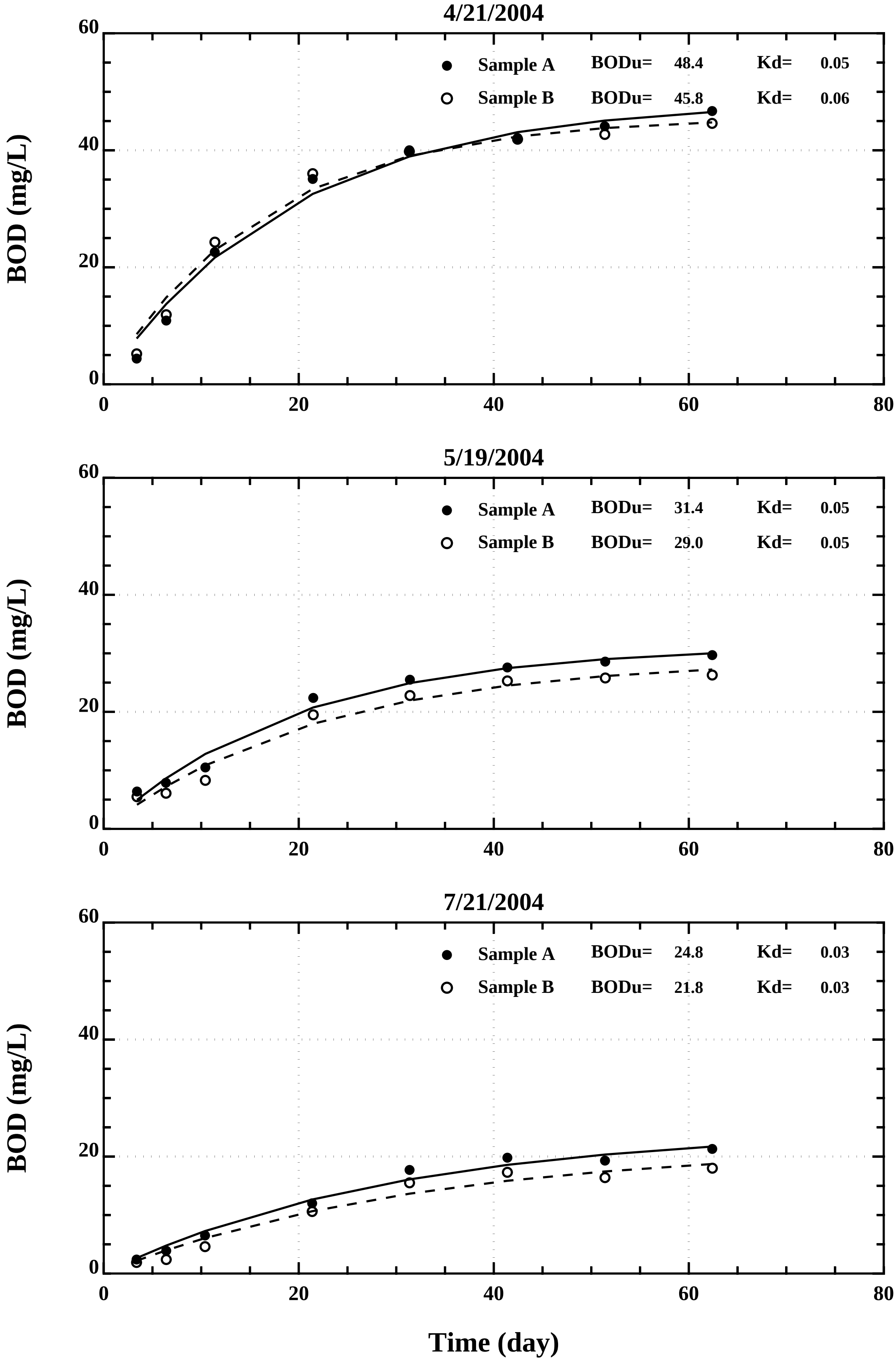


Figure 14. Jones Island Effluent LTBOD Data
(Circles - Test Replicates, Lines - Non-Linear Regressions)

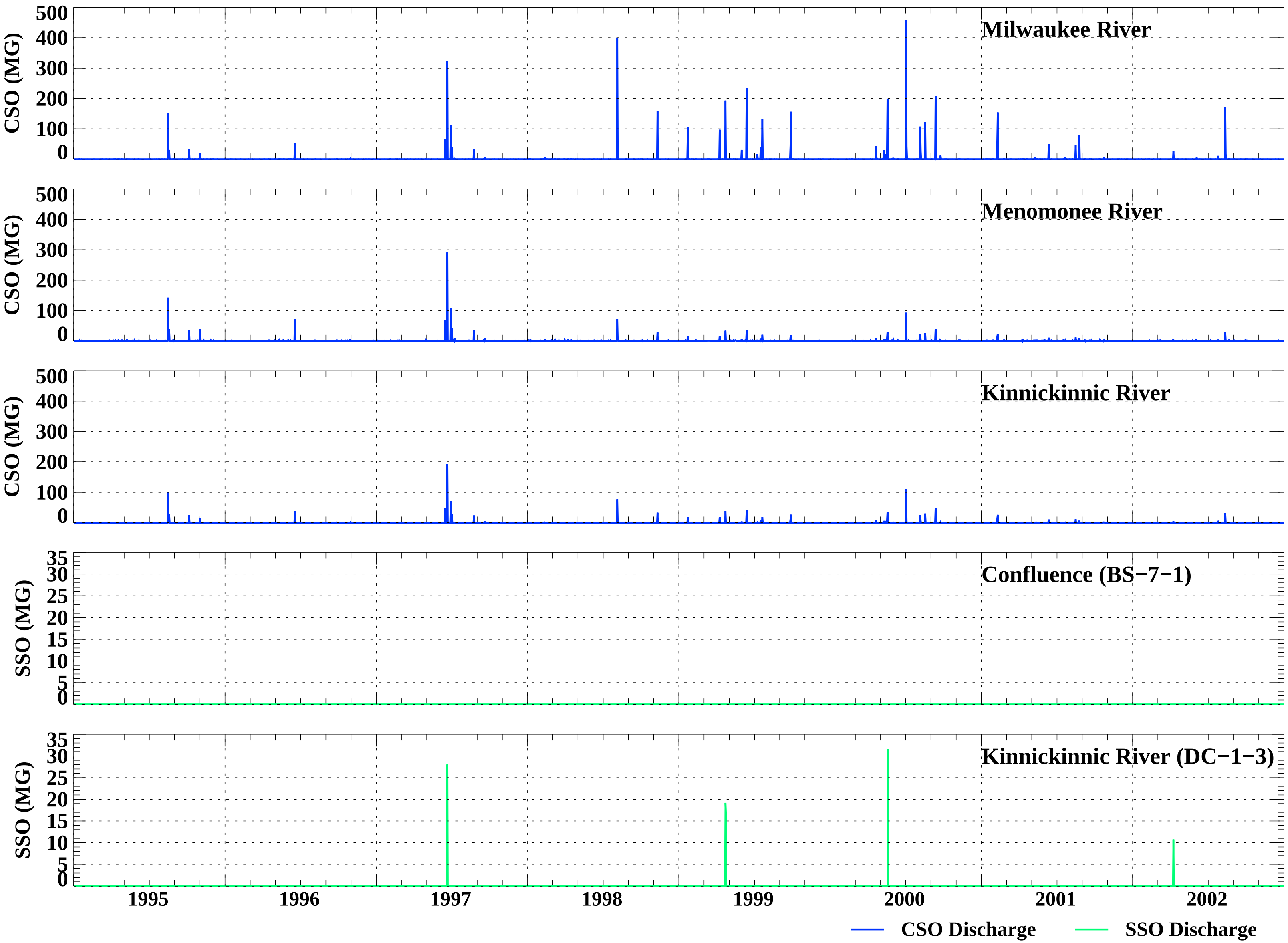


Figure 15. CSO/SSO Volumes Discharged to the Milwaukee, Menomonee and Kinnickinnic Rivers.

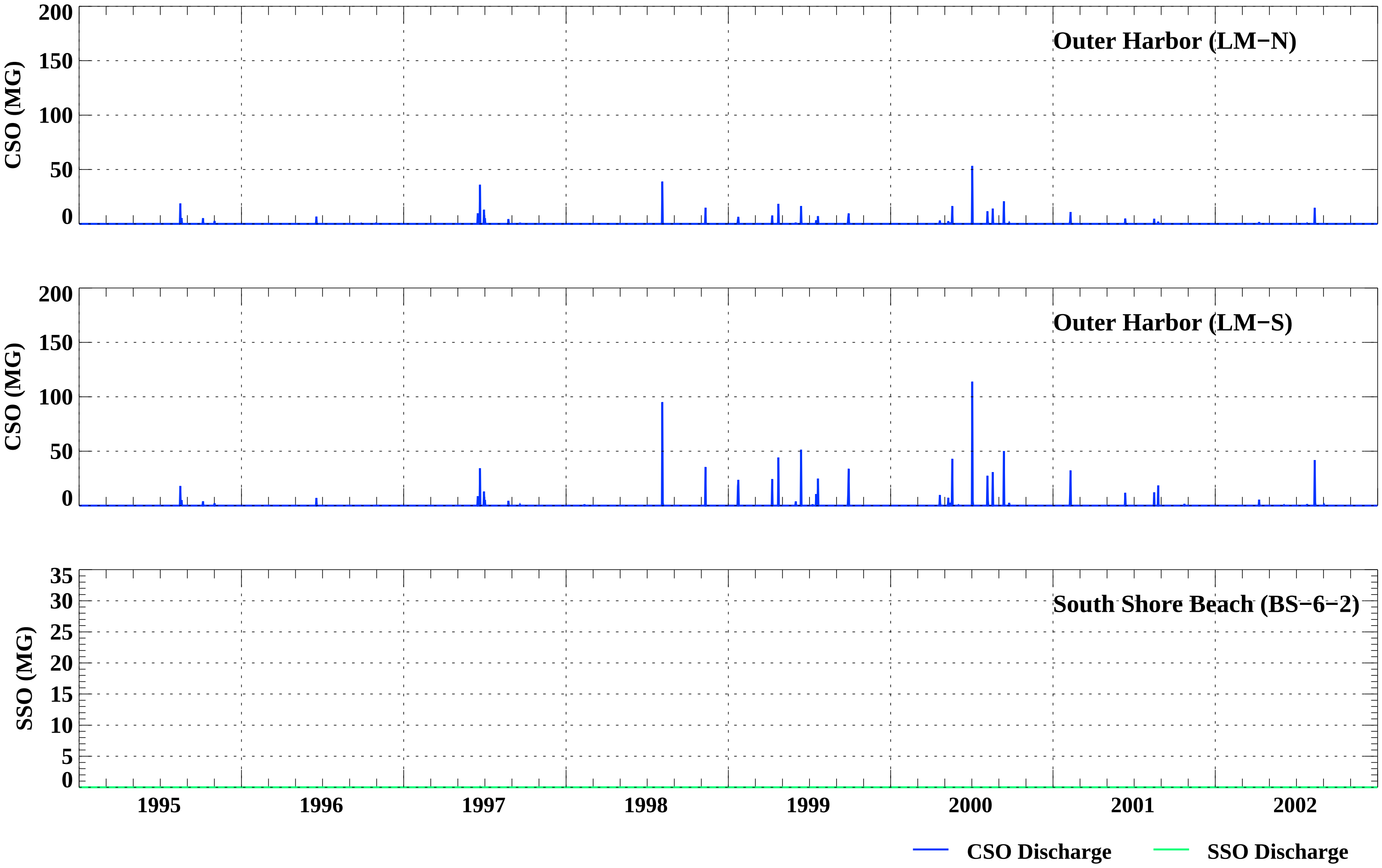


Figure 16. CSO/SSO Volumes Discharged to Lake Michigan.

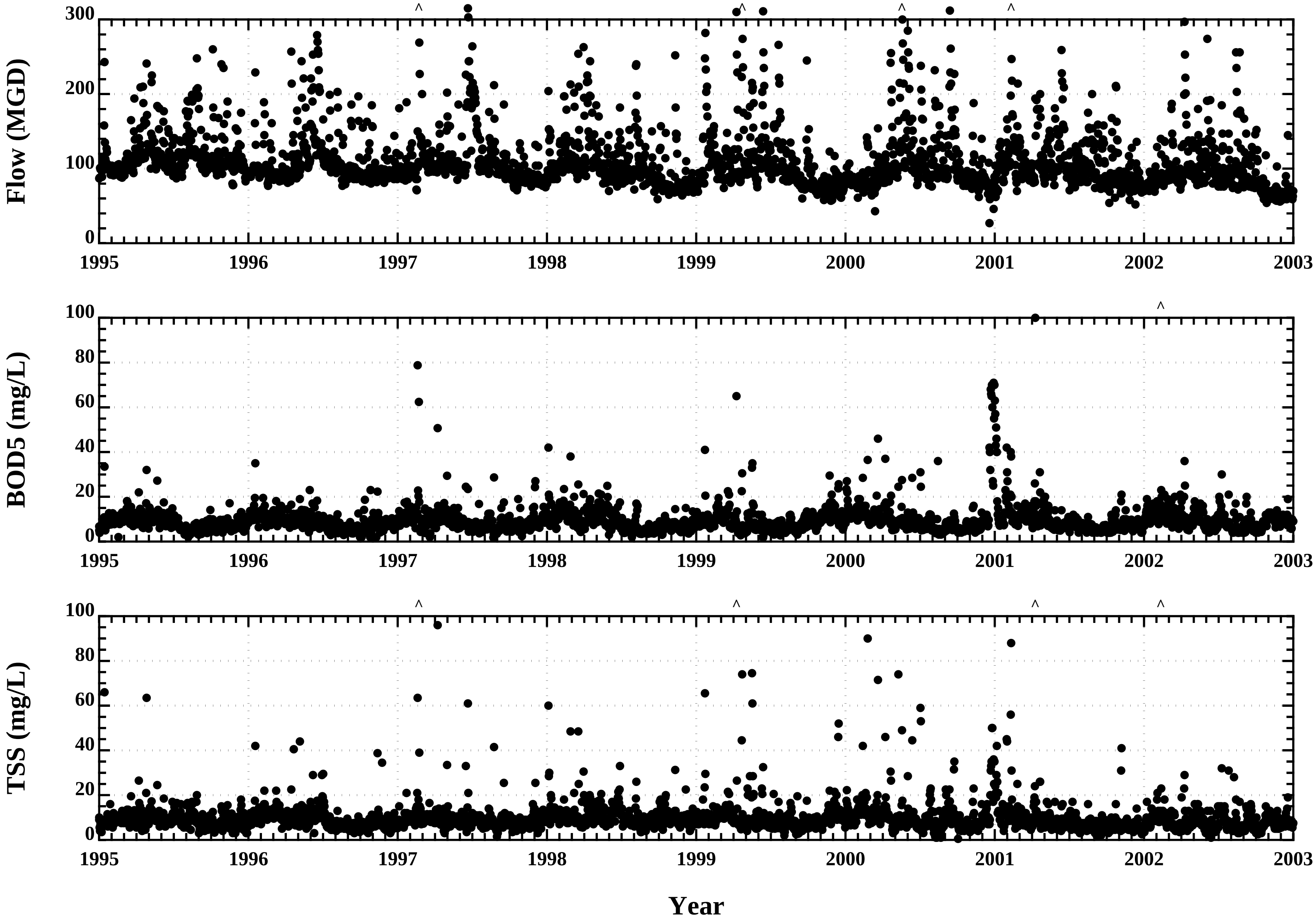


Figure 17a. Jones Island WWTP Effluent Data

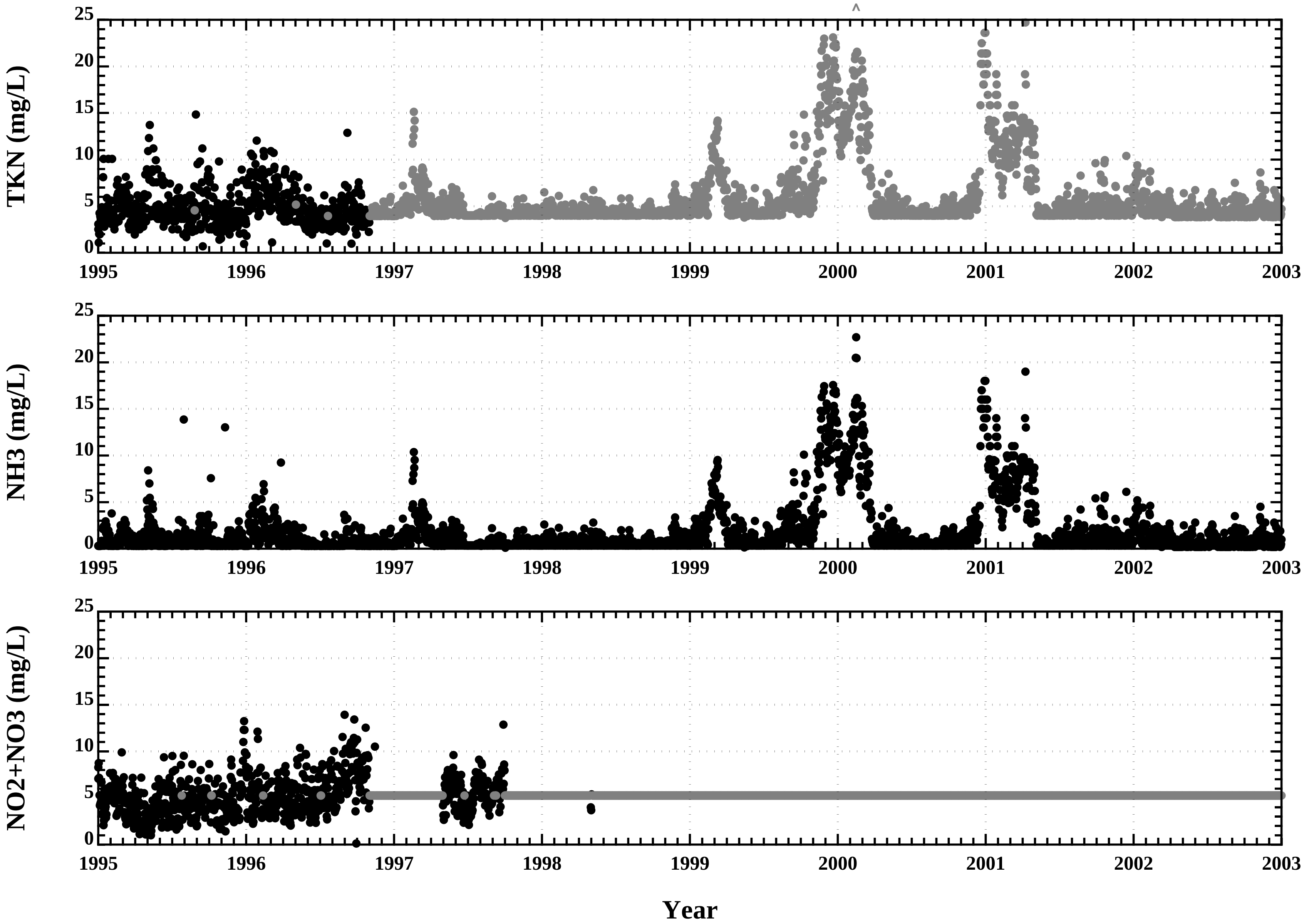


Figure 17b. Jones Island WWTP Effluent Data

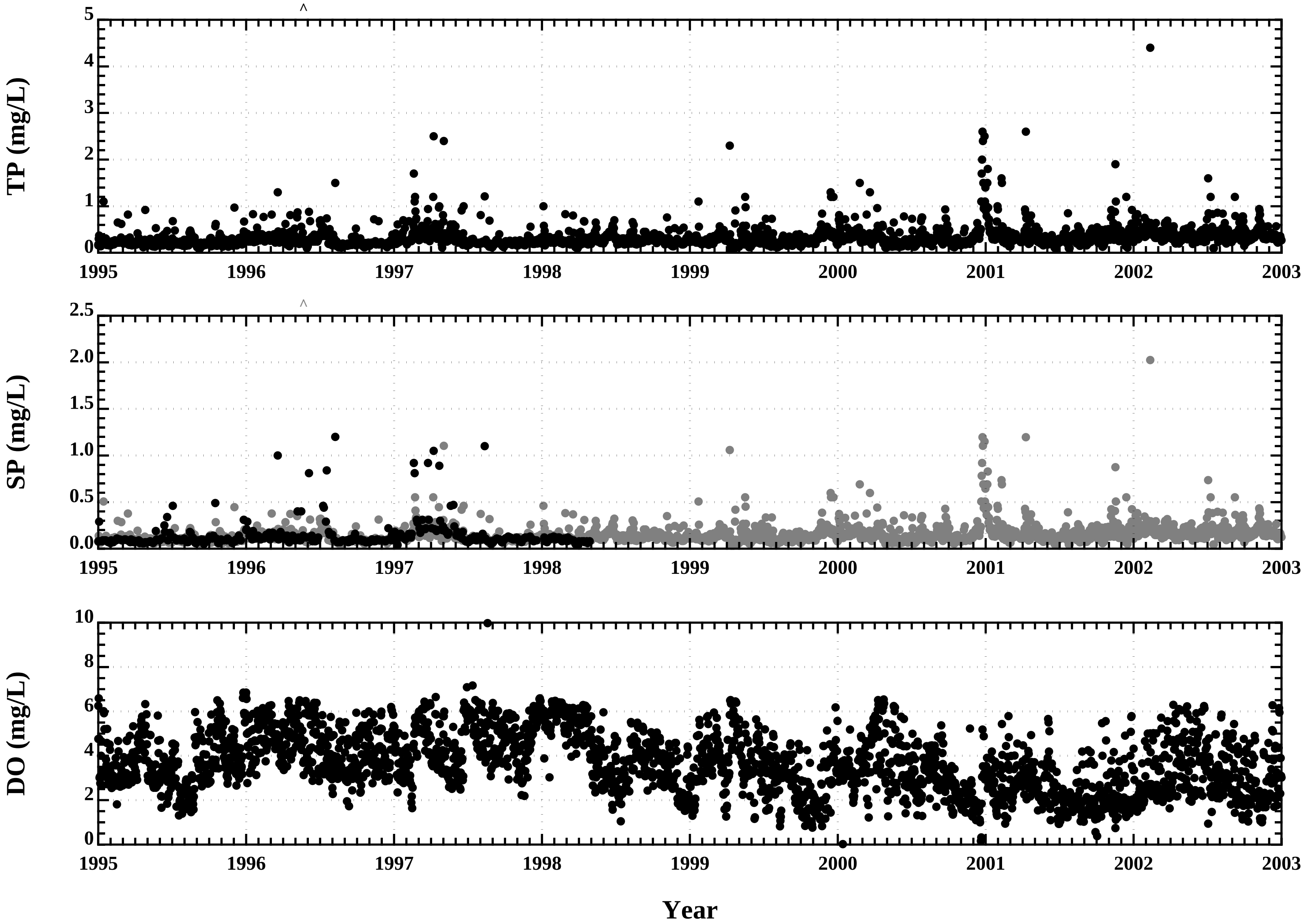


Figure 17c. Jones Island WWTP Effluent Data

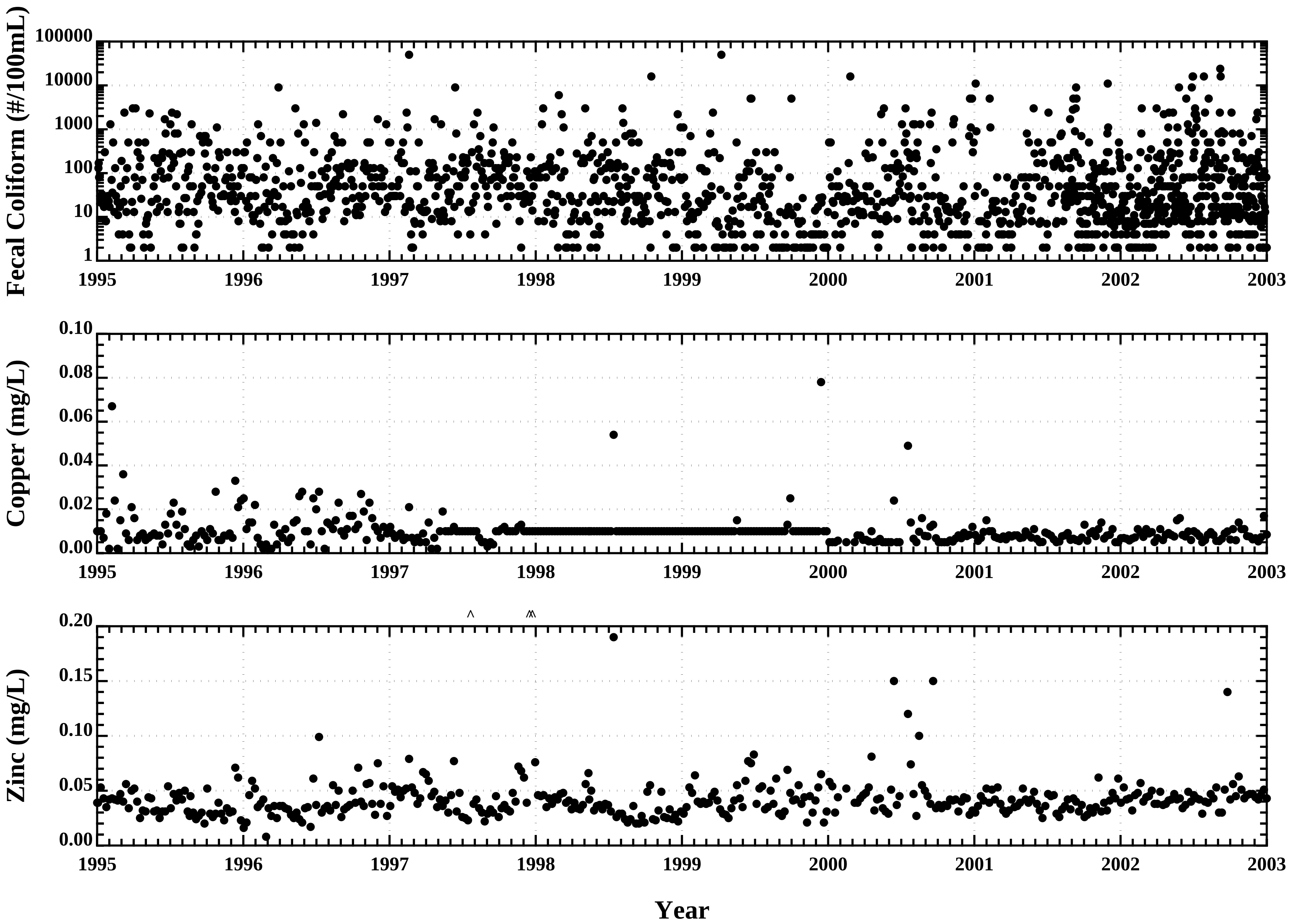


Figure 17d. Jones Island WWTP Effluent Data

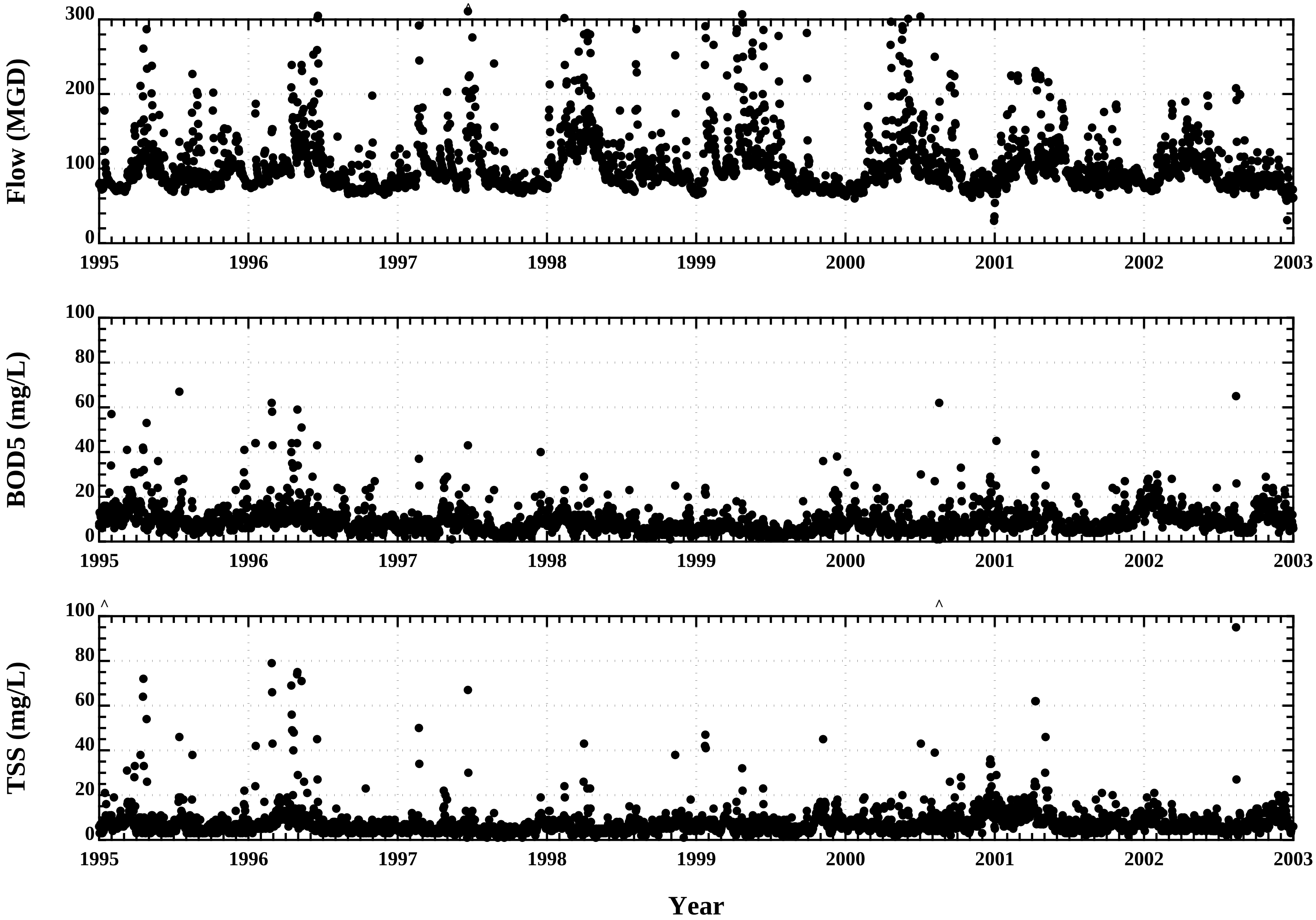


Figure 18a. South Shore WWTP Effluent Data

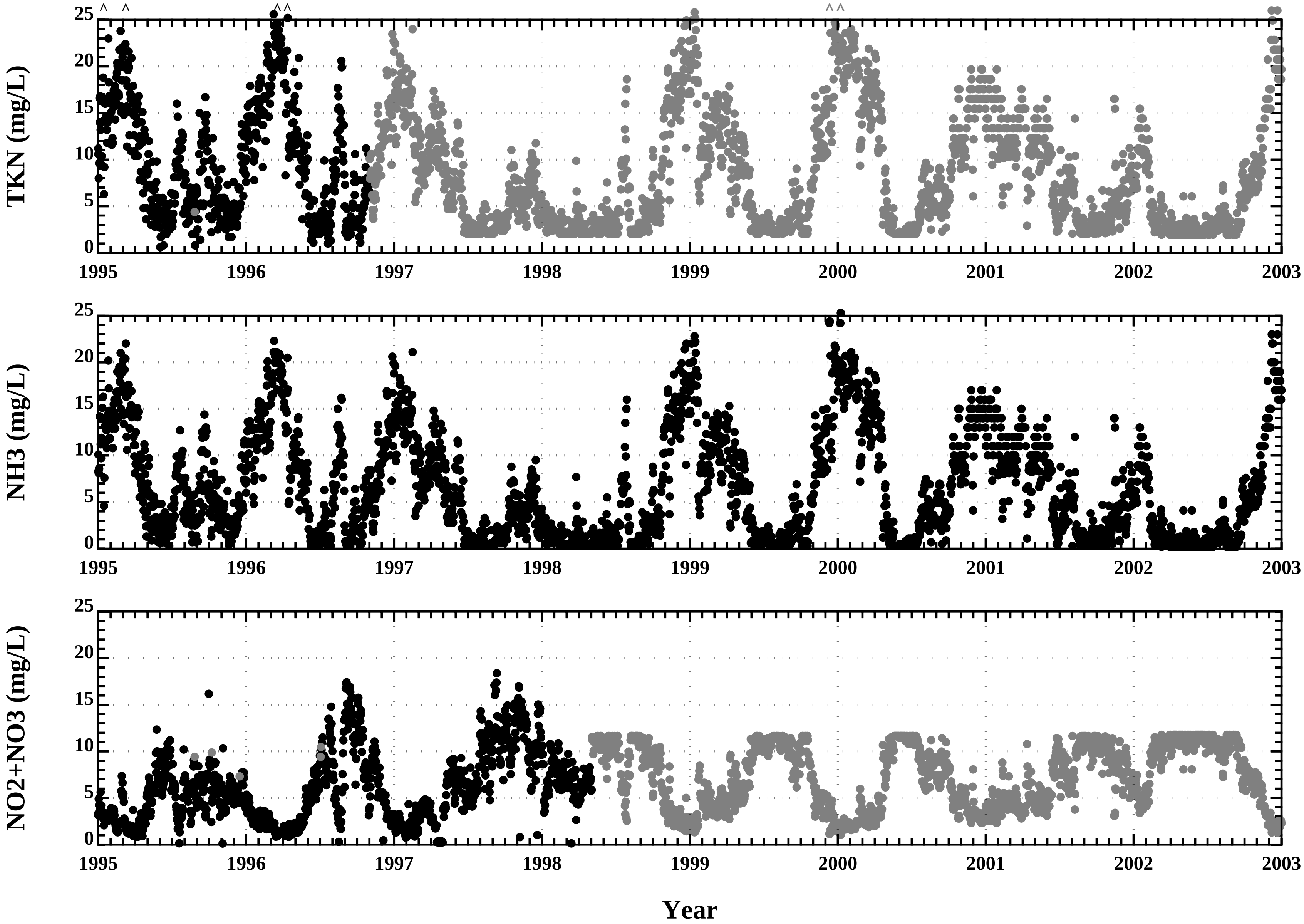


Figure 18b. South Shore WWTP Effluent Data

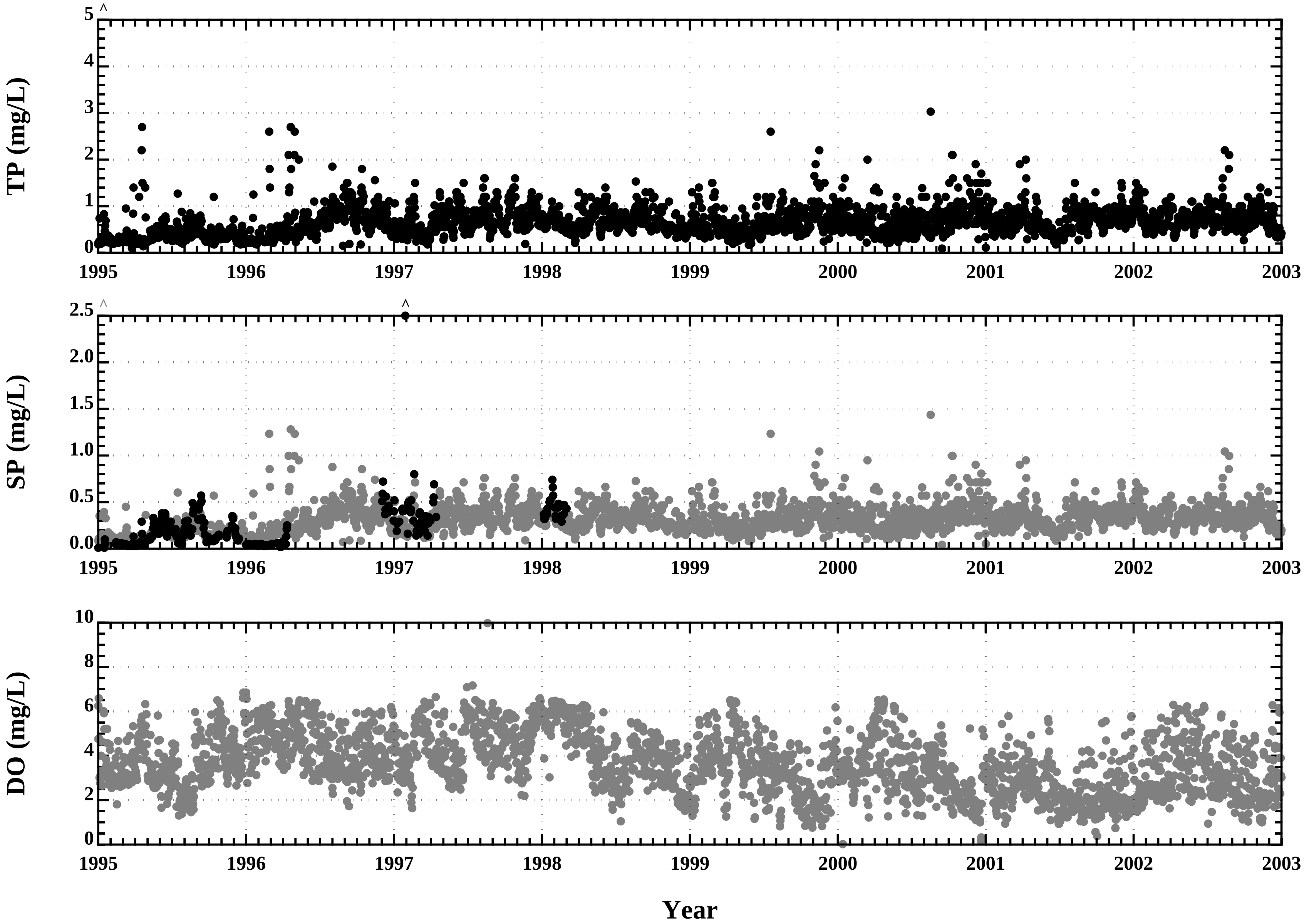


Figure 18c. South Shore WWTP Effluent Data

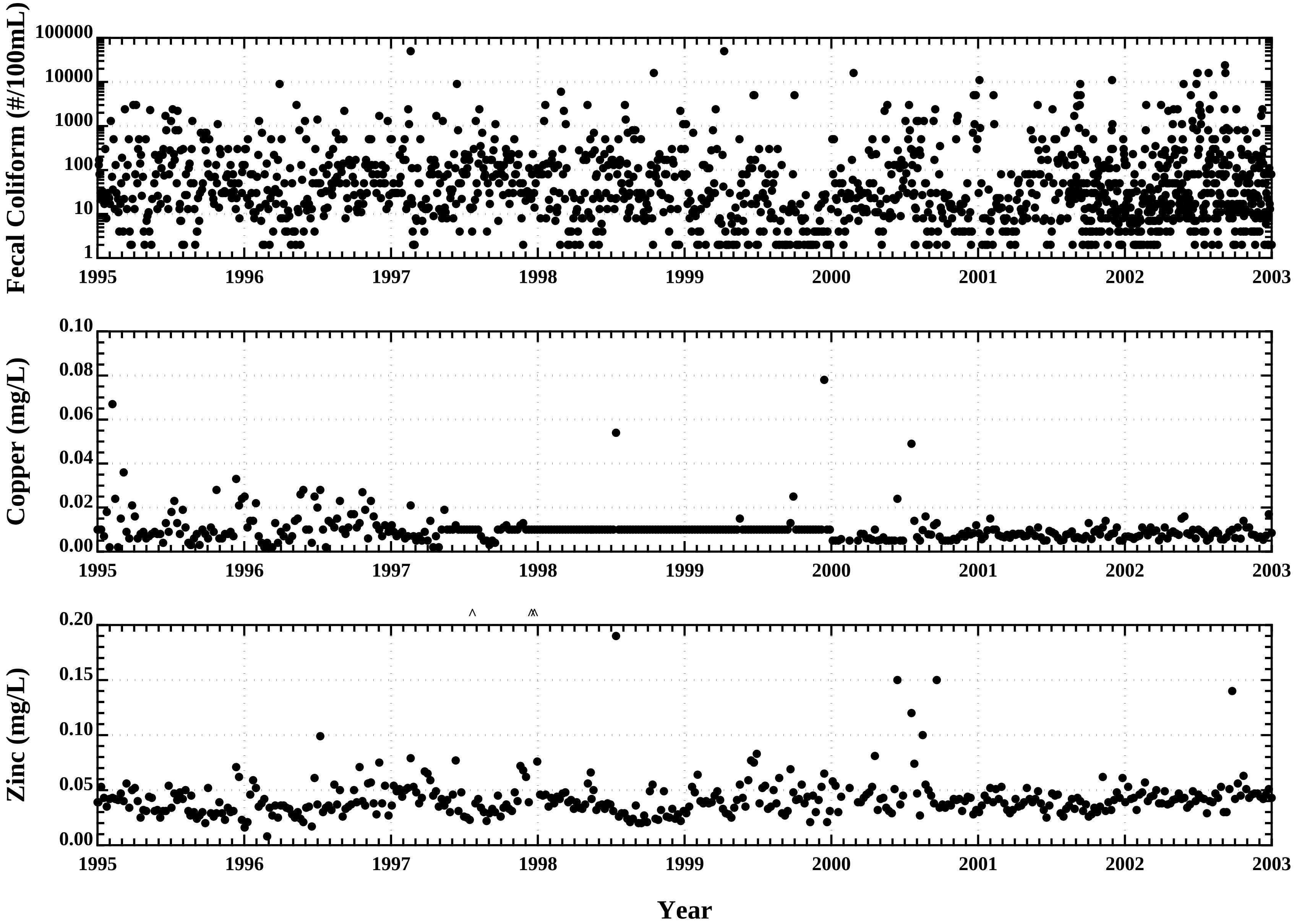


Figure 18d. South Shore WWTP Effluent Data

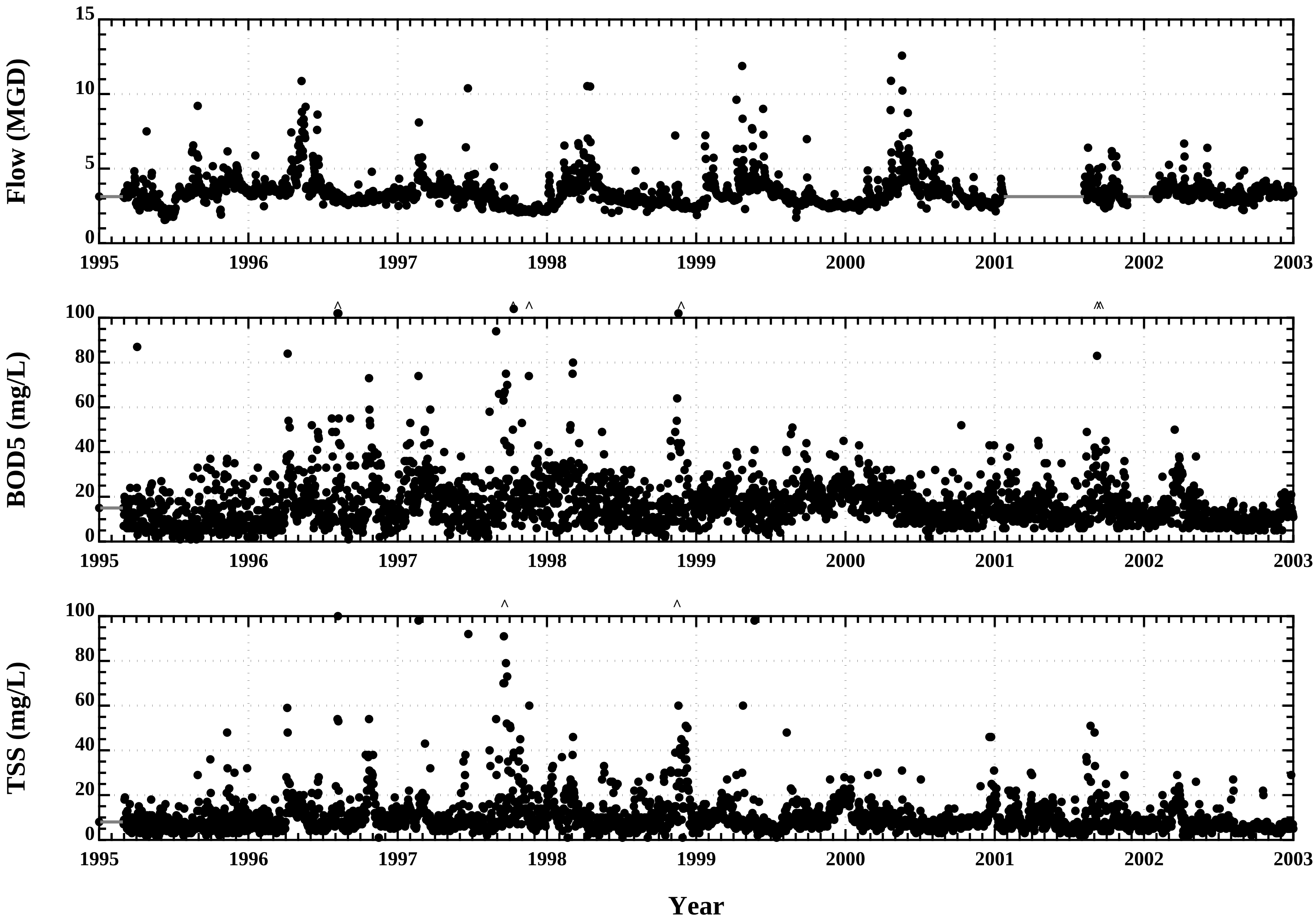


Figure 19a. South Milwaukee WWTP Effluent Data

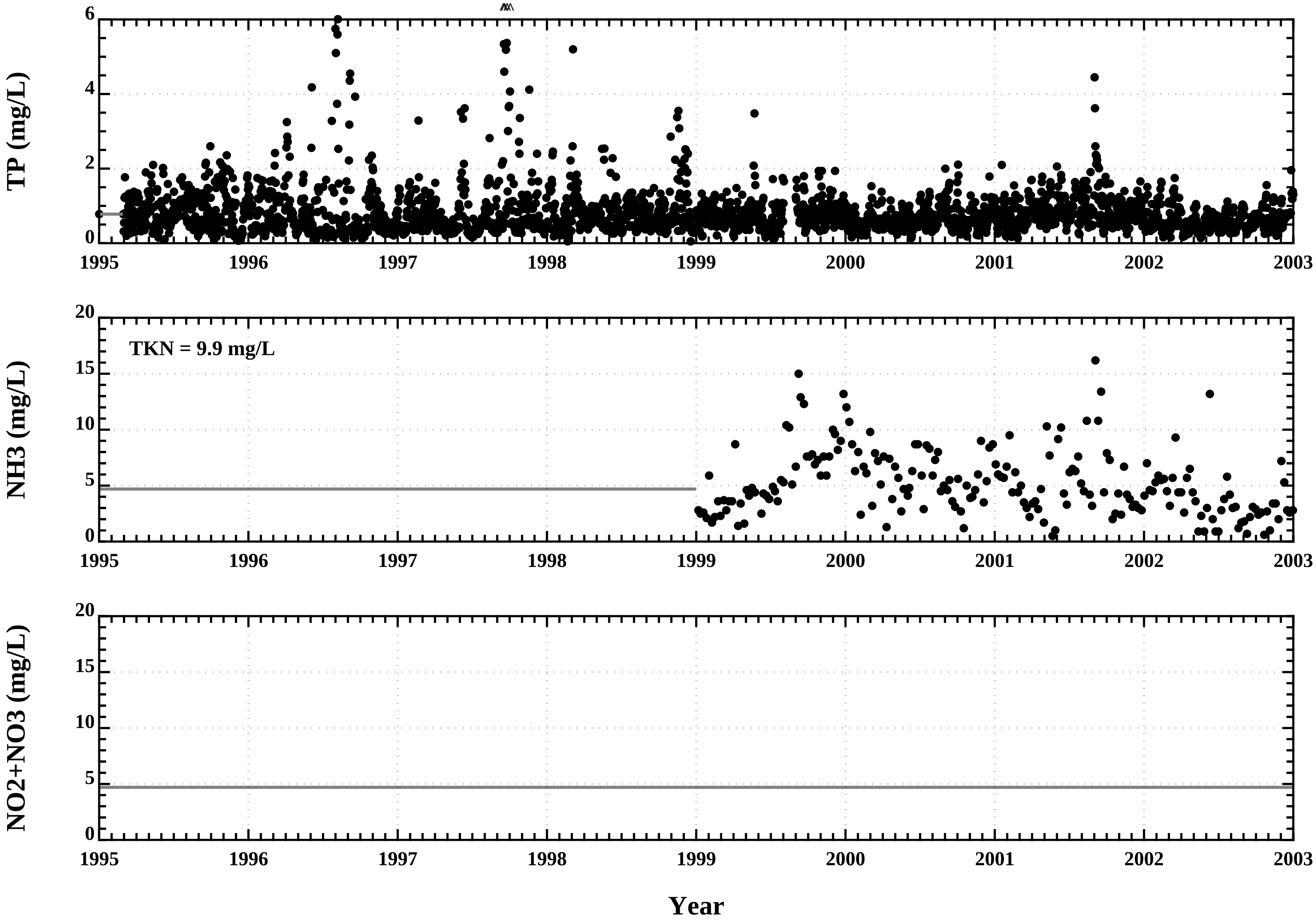


Figure 19b. South Milwaukee WWTP Effluent Data

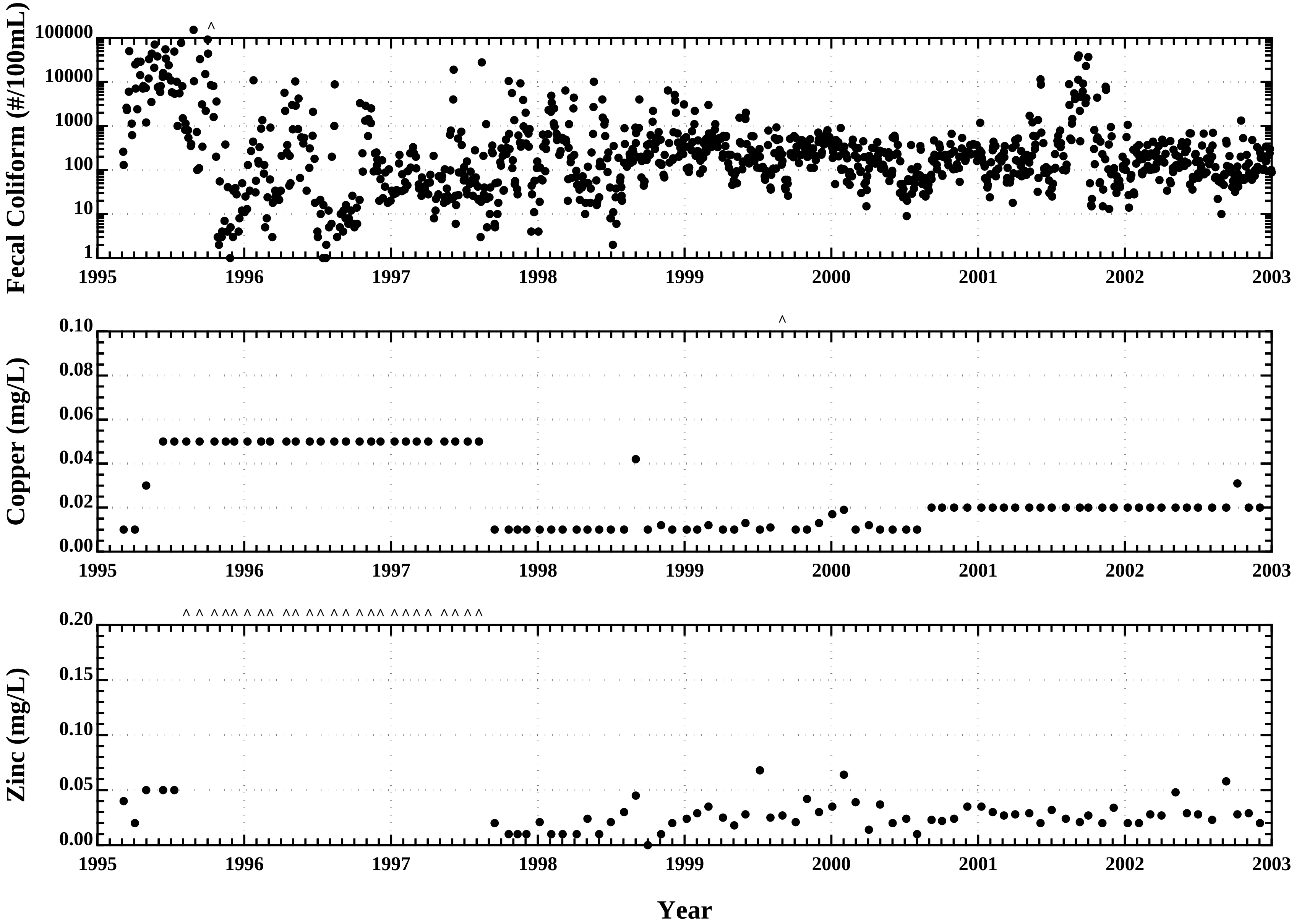


Figure 19c. South Milwaukee WWTP Effluent Data

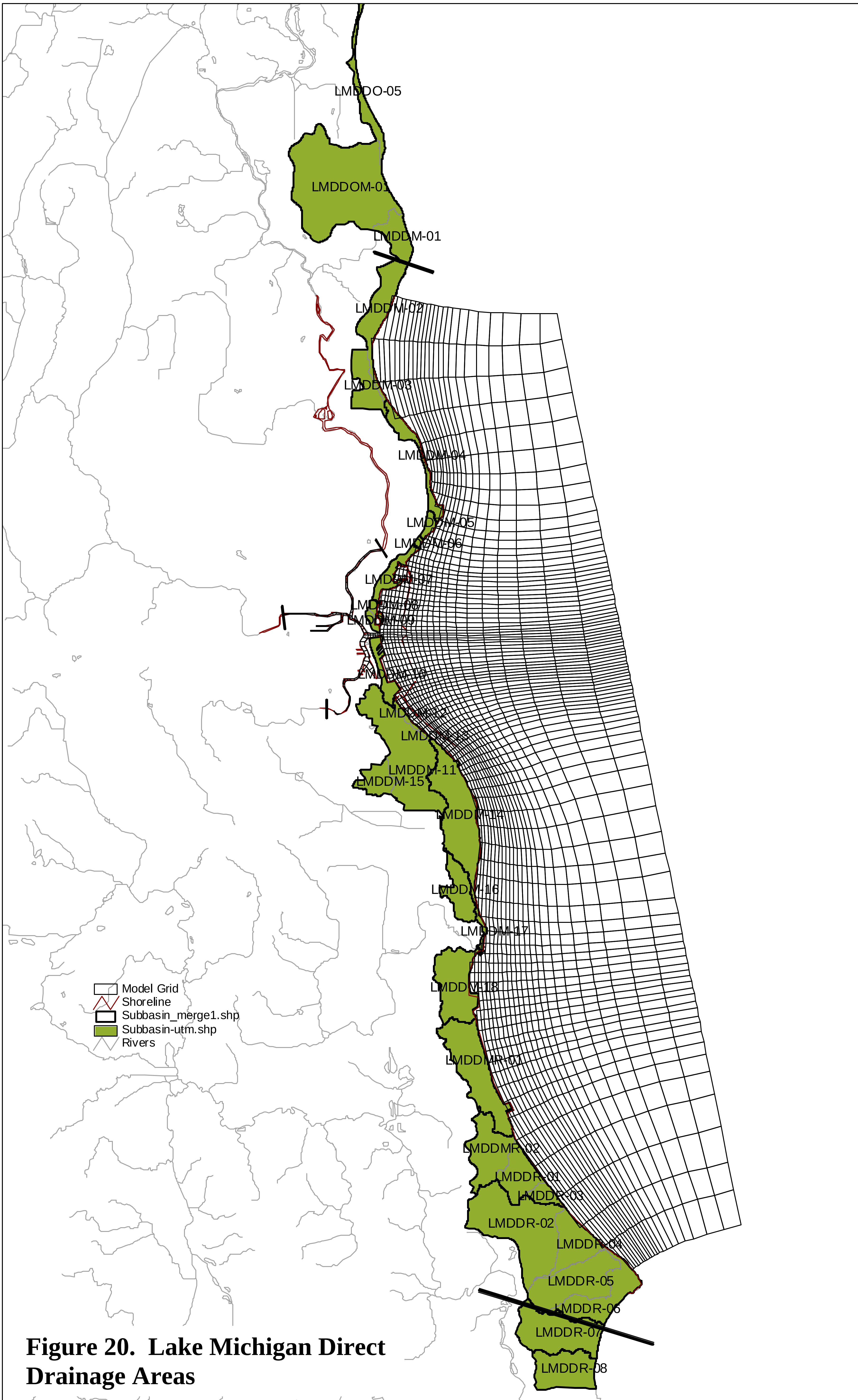


Figure 20. Lake Michigan Direct Drainage Areas

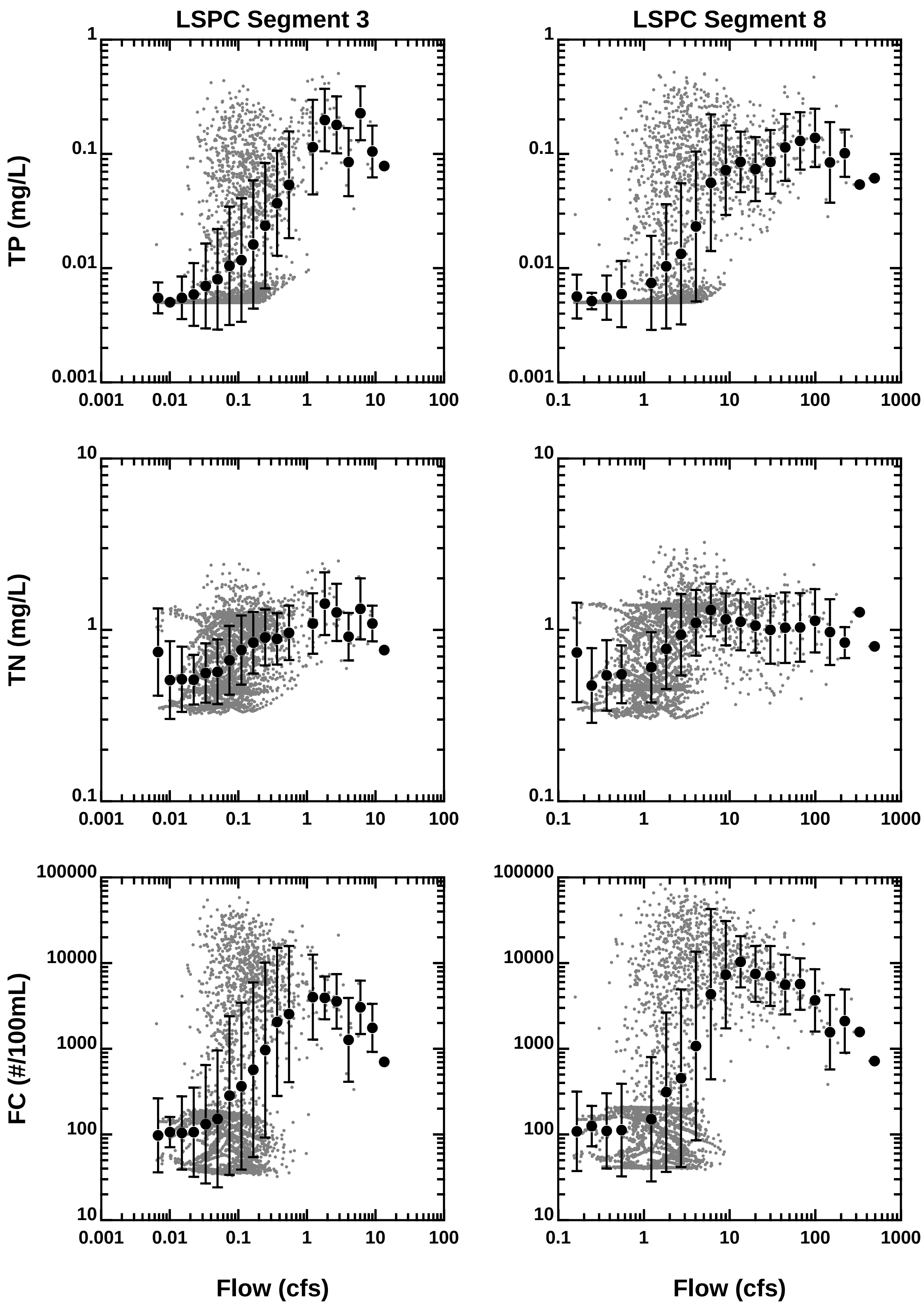


Figure 21. LSPC Direct Drainage Output Concentration vs. Flow

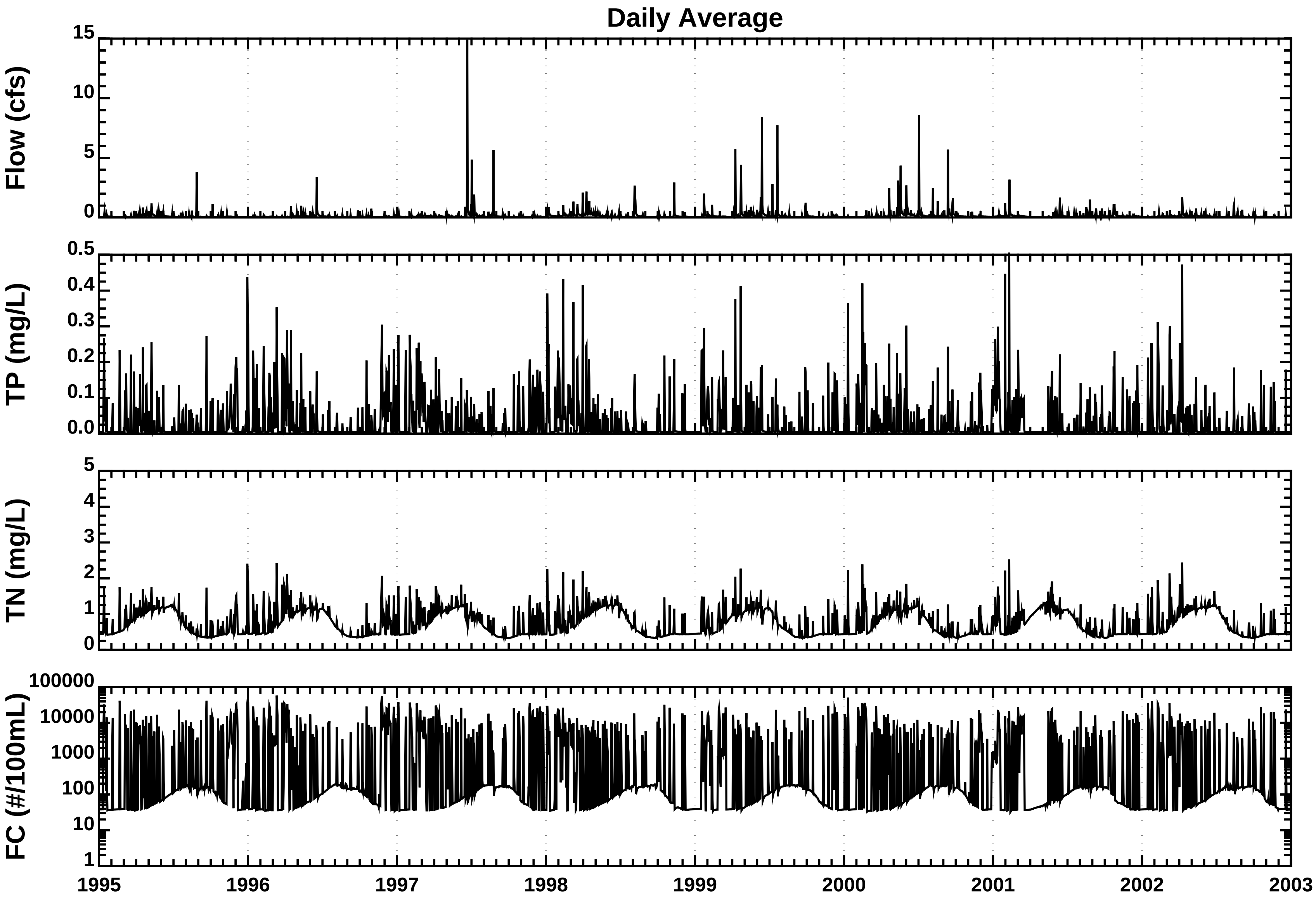


Figure 22a. Lake Michigan Direct Runoff LSPC Output (Segment 03 - McKinley/Bradford Beach)

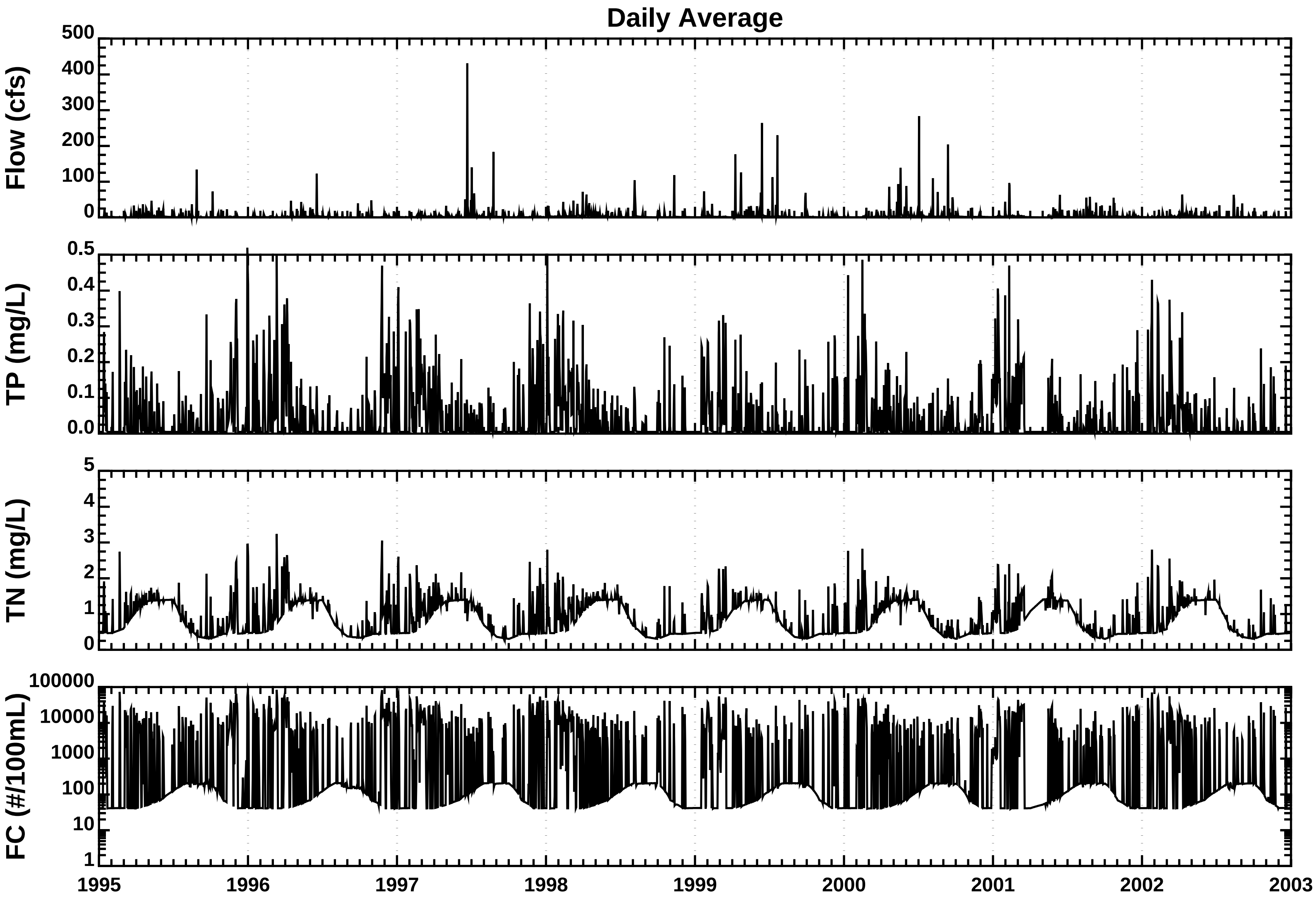


Figure 22b. Lake Michigan Direct Runoff LSPC Output (Segment 08 - South Shore Beach)

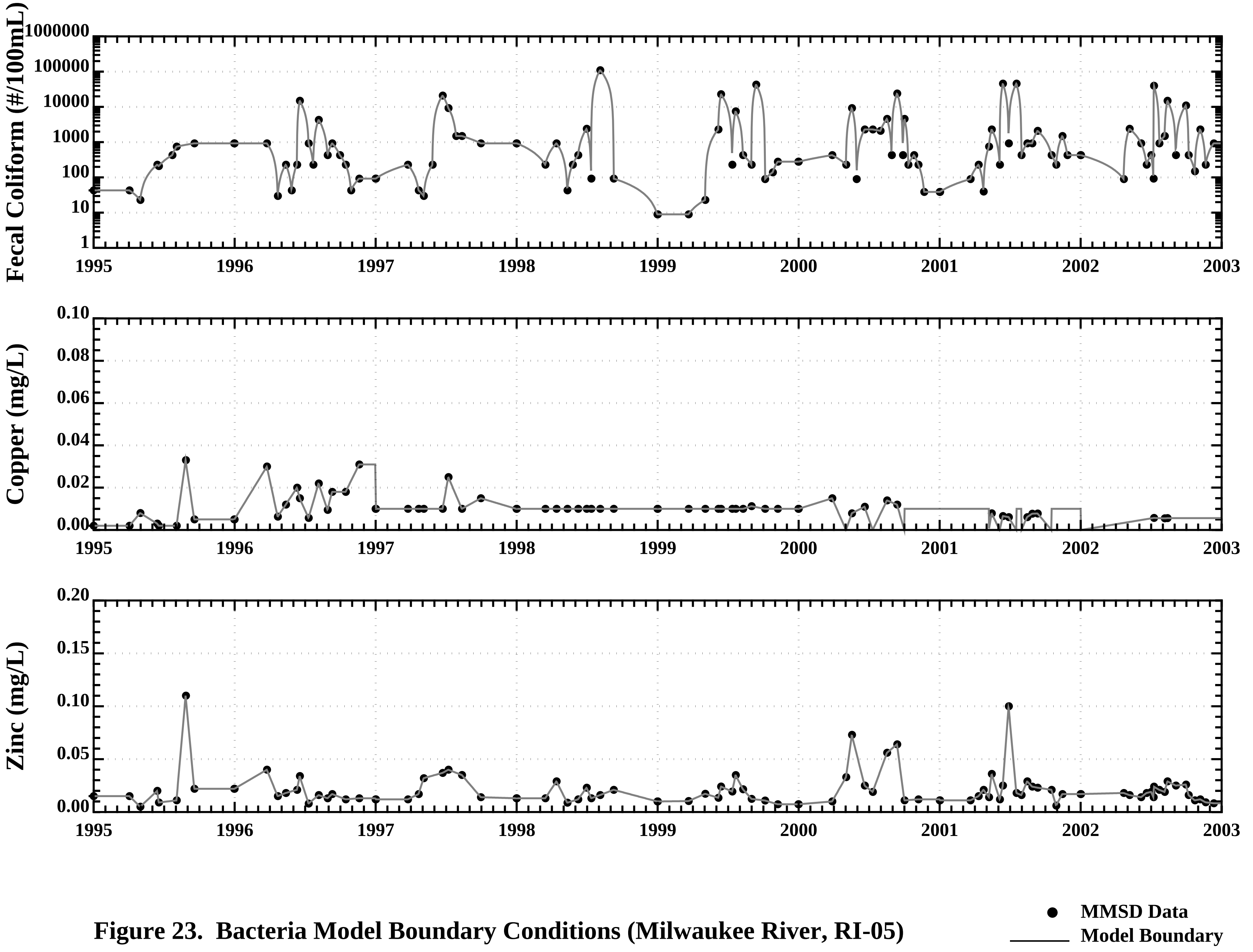


Figure 23. Bacteria Model Boundary Conditions (Milwaukee River, RI-05)

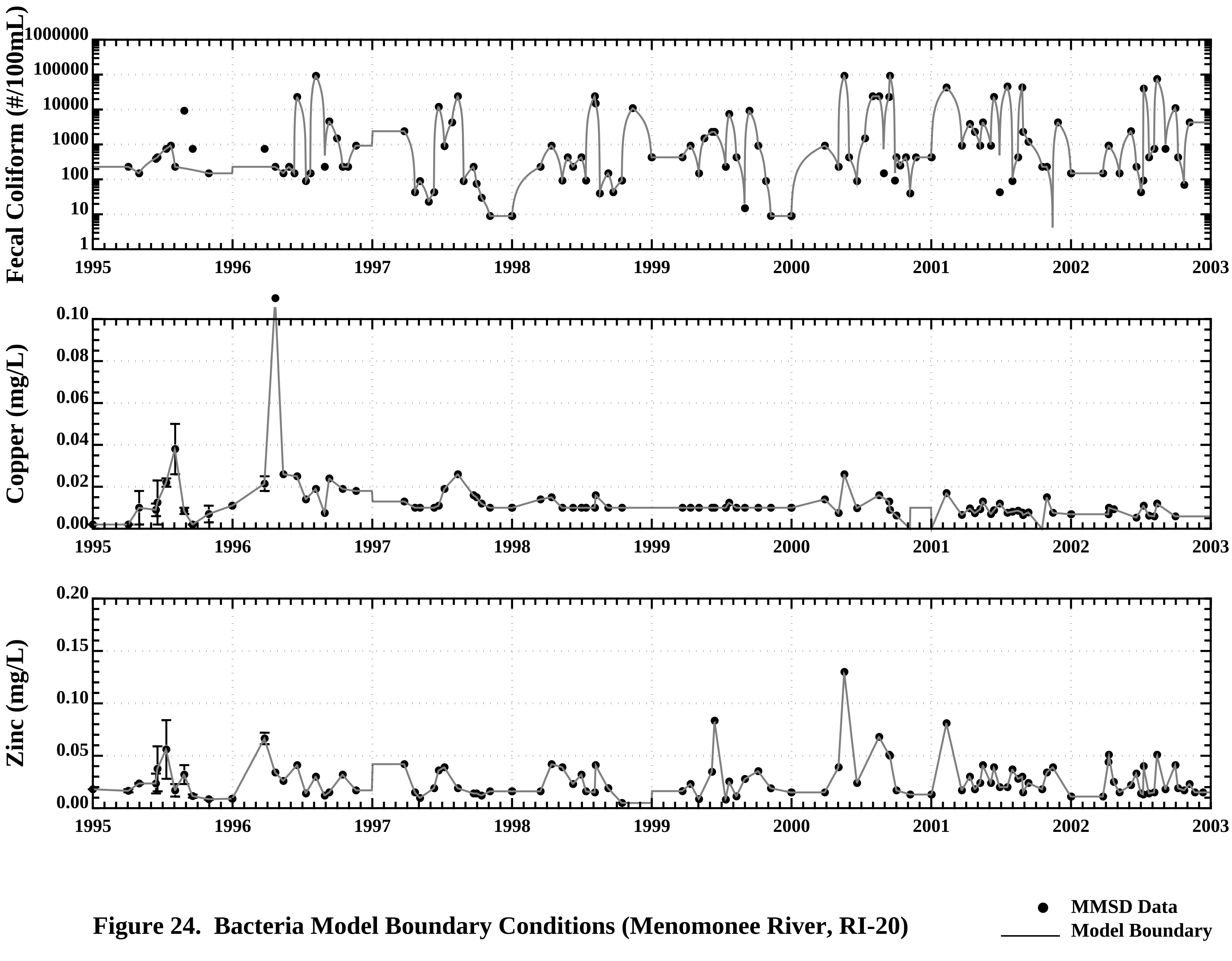


Figure 24. Bacteria Model Boundary Conditions (Menomonee River, RI-20)

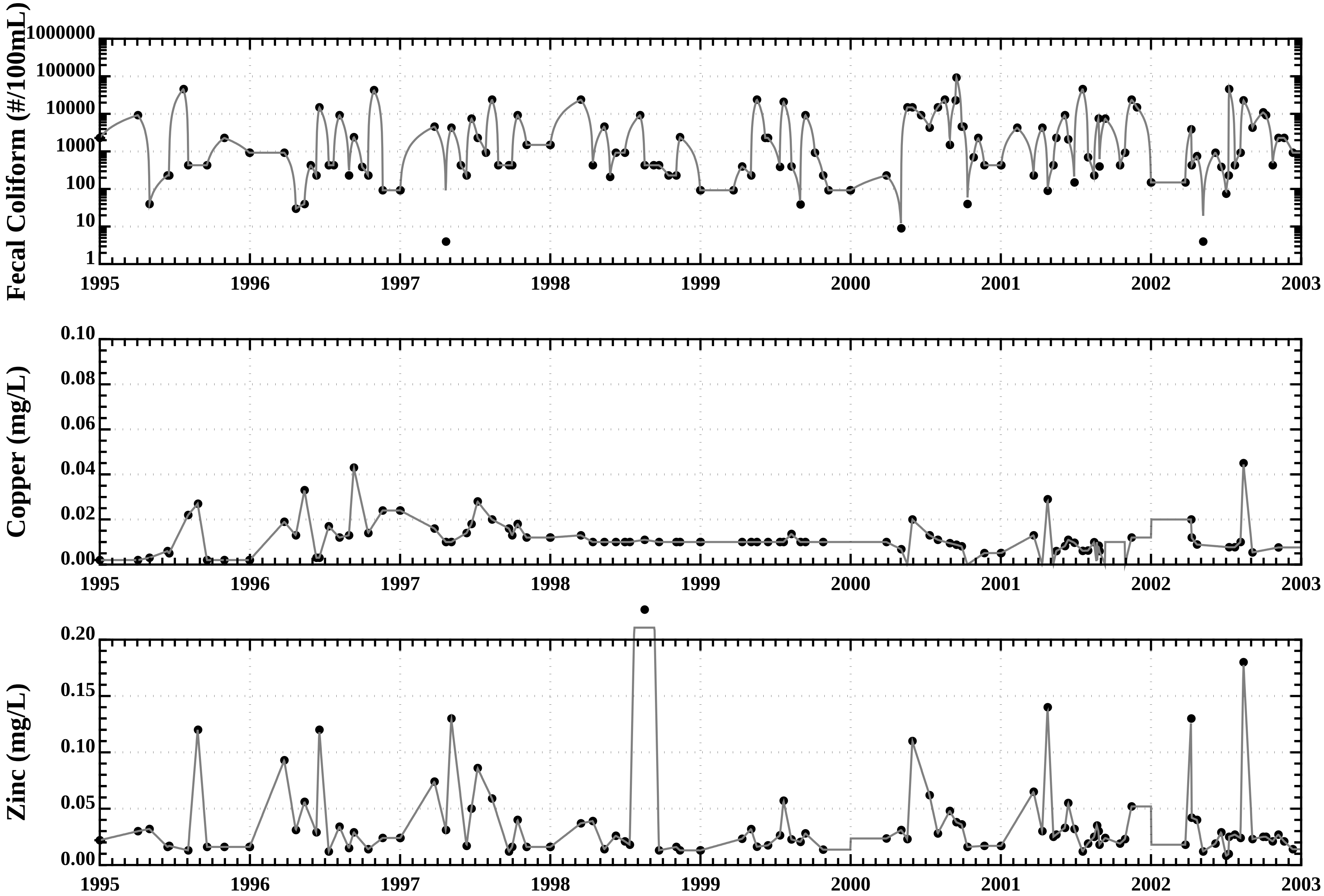


Figure 25. Bacteria Model Boundary Conditions (Kinnickinnic River, RI-13)

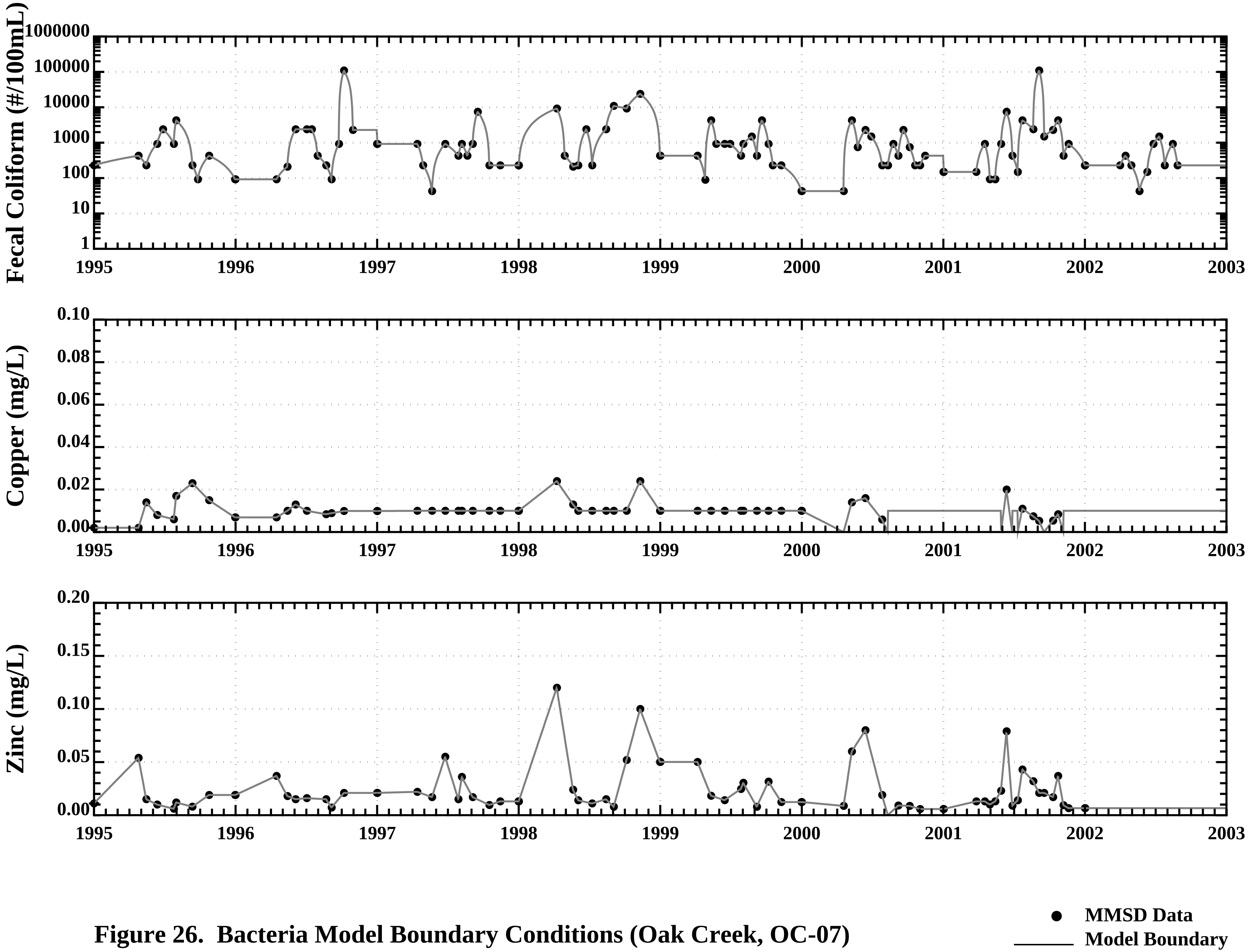


Figure 26. Bacteria Model Boundary Conditions (Oak Creek, OC-07)

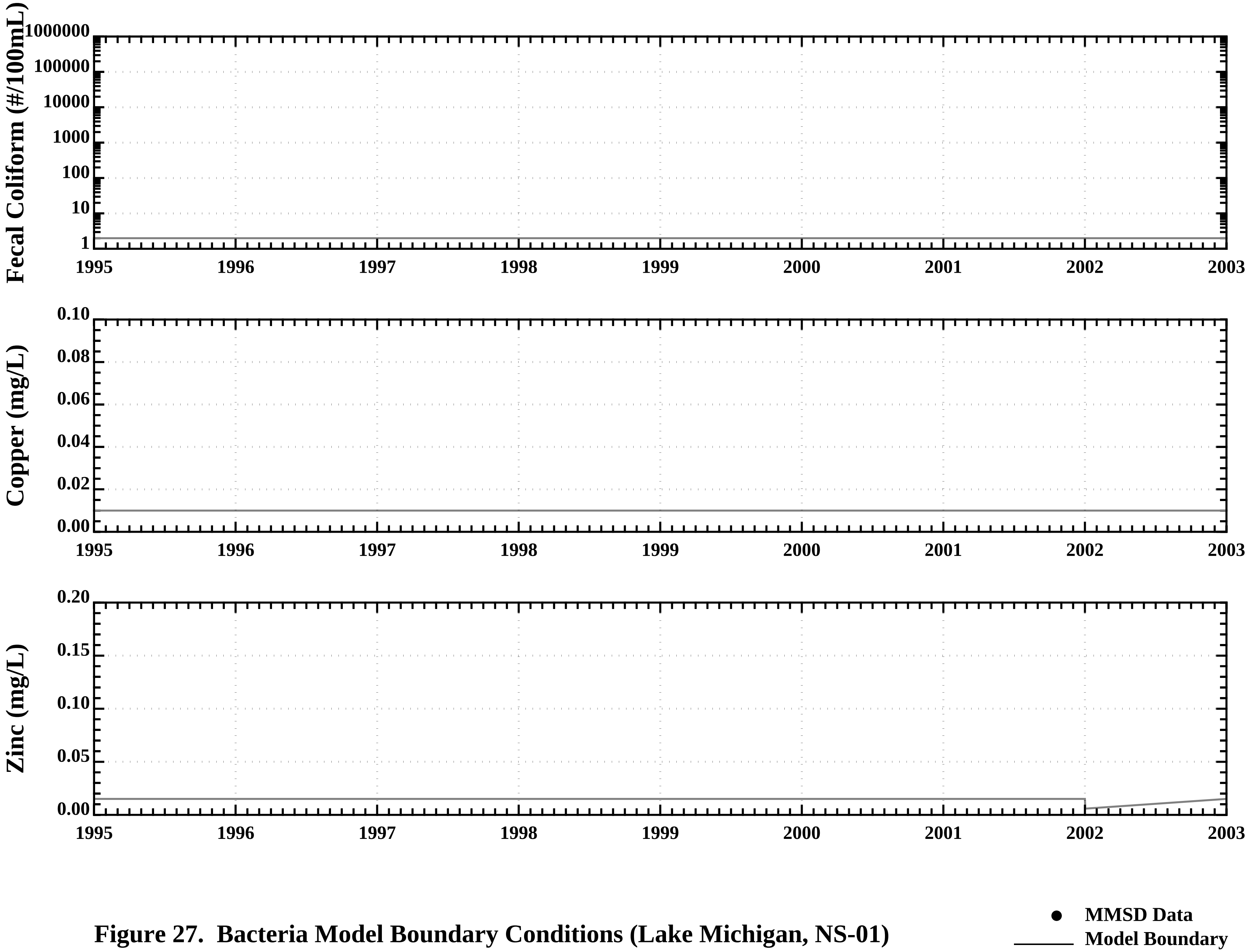


Figure 27. Bacteria Model Boundary Conditions (Lake Michigan, NS-01)

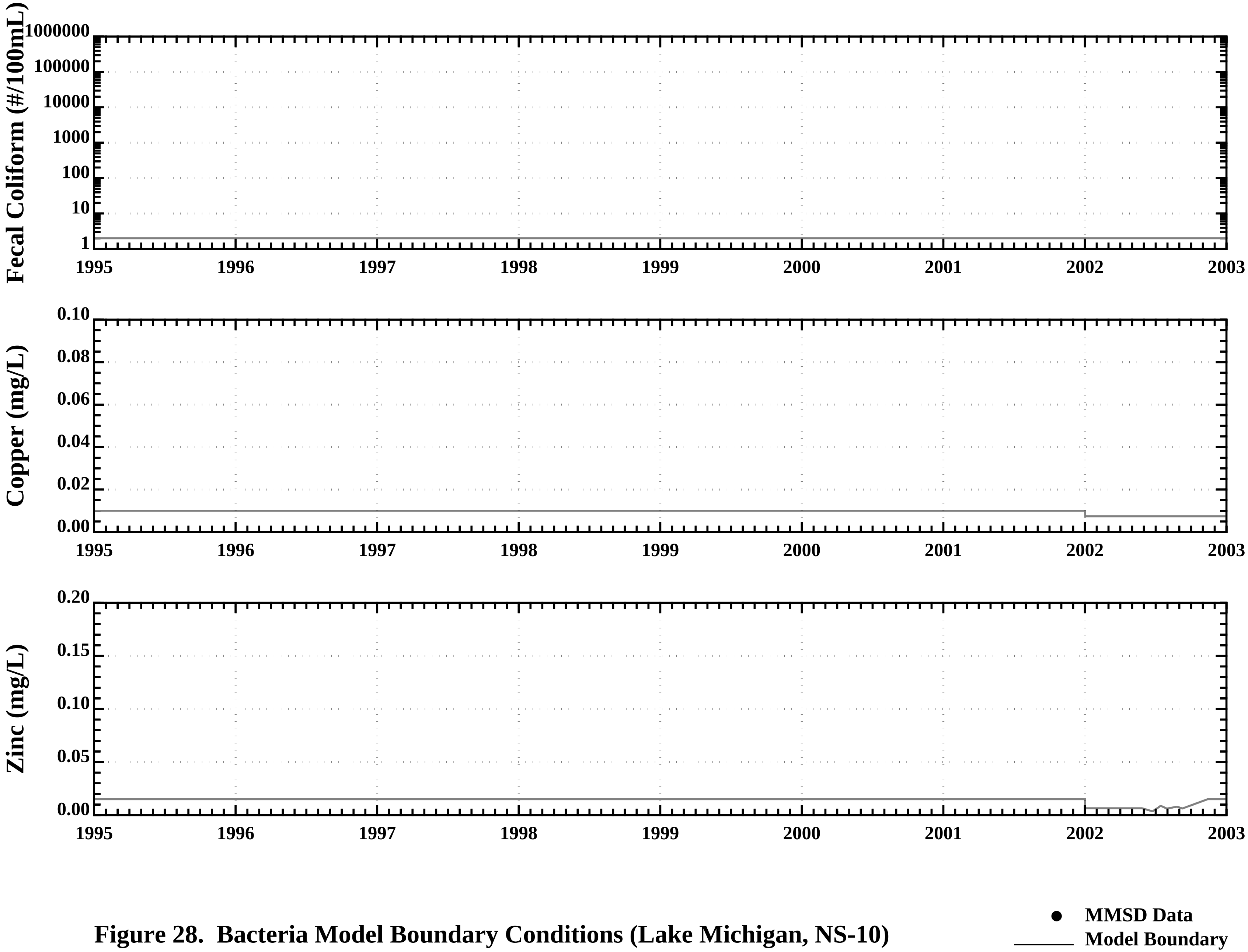


Figure 28. Bacteria Model Boundary Conditions (Lake Michigan, NS-10)

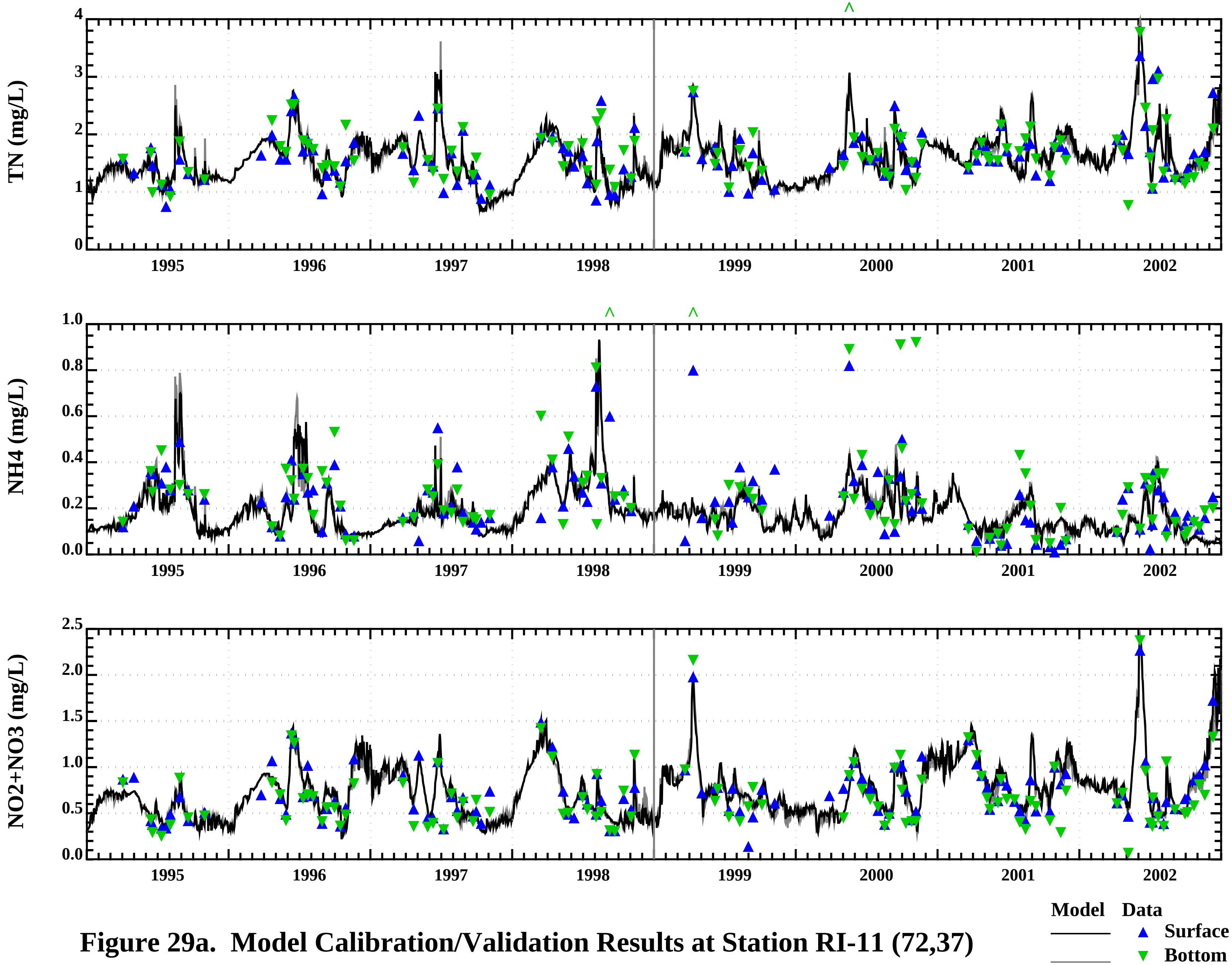


Figure 29a. Model Calibration/Validation Results at Station RI-11 (72,37)

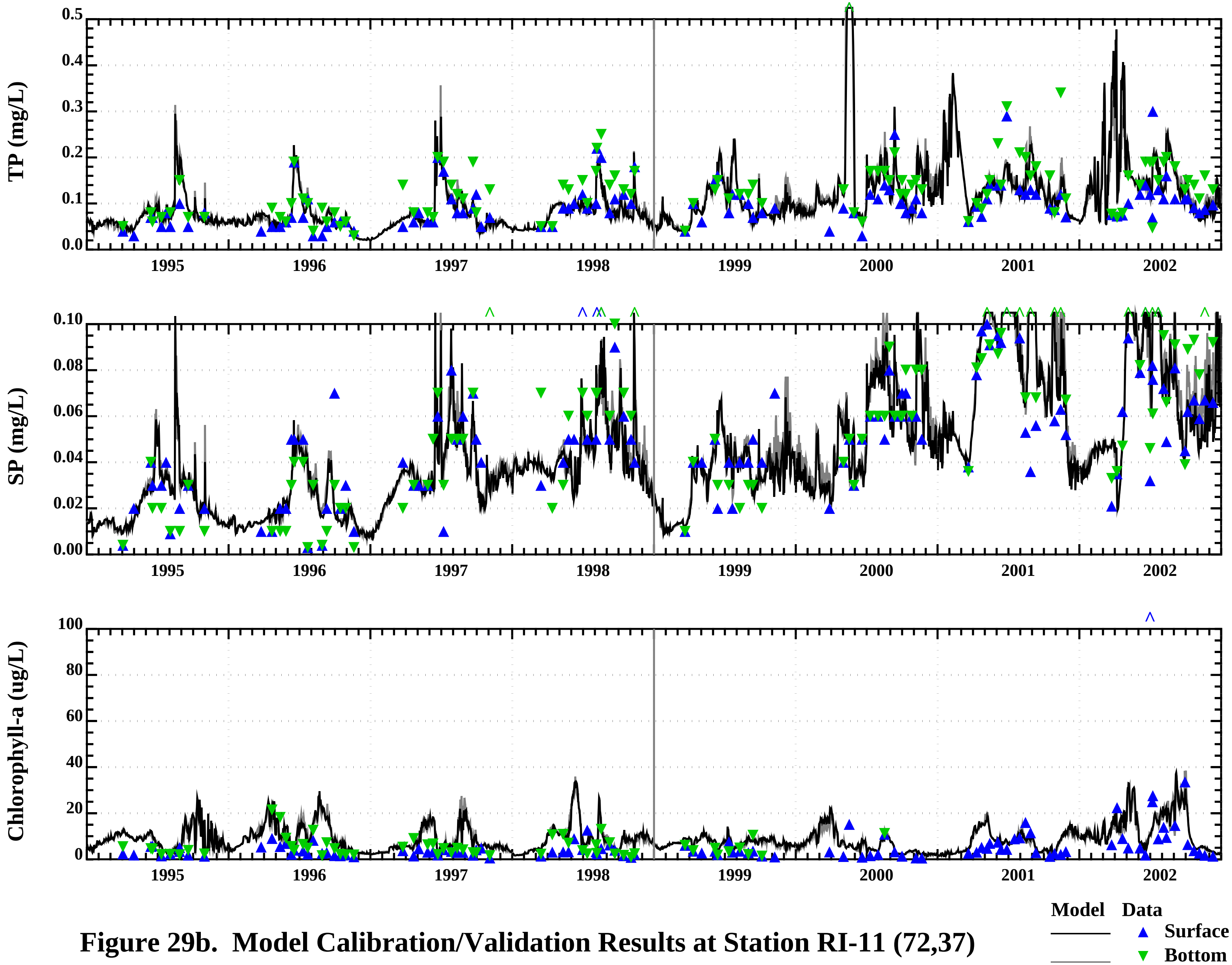


Figure 29b. Model Calibration/Validation Results at Station RI-11 (72,37)

/coral3/hntb0020/RCA_2020/PLOT/rical2.gdp
DATE: 11/27/2007 TIME: 15:46:26

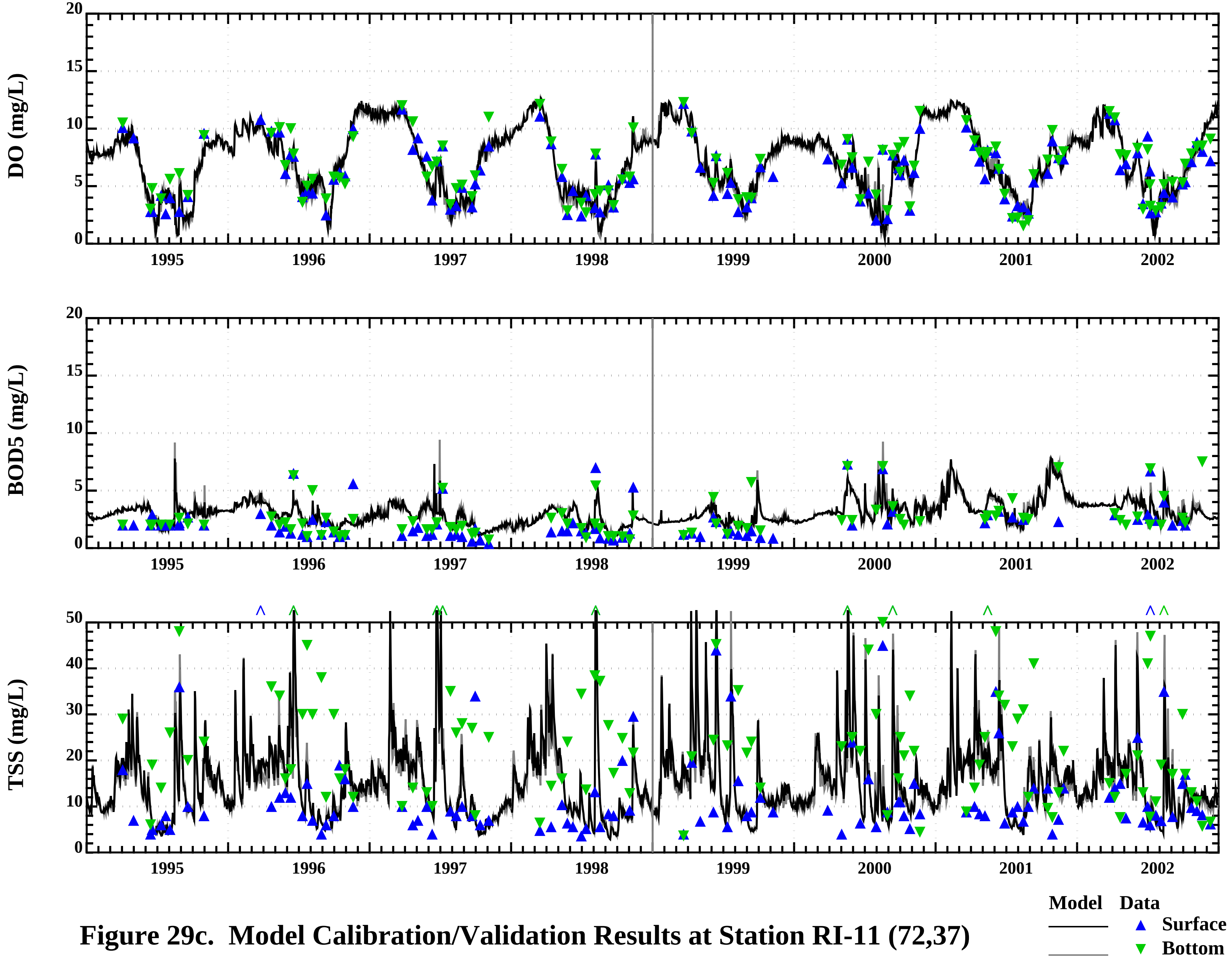


Figure 29c. Model Calibration/Validation Results at Station RI-11 (72,37)

/coral3/hntb0020/RCA_2020/PLOT/rical2.gdp
DATE: 11/27/2007 TIME: 15:46:26

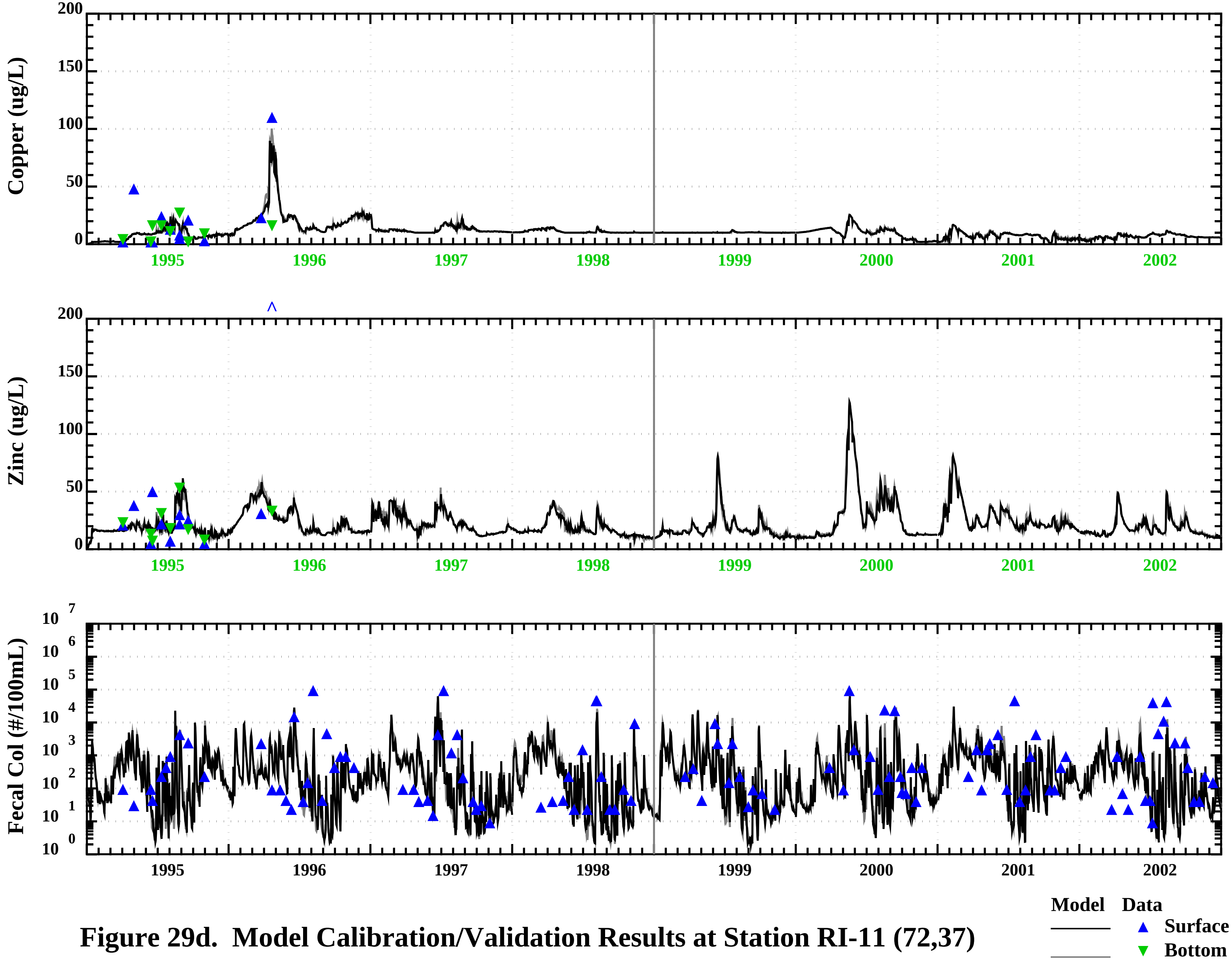


Figure 29d. Model Calibration/Validation Results at Station RI-11 (72,37)

/coral3/hntb0020/RCA_2020/PLOT/rical2.gdp
DATE: 11/27/2007 TIME: 15:46:26

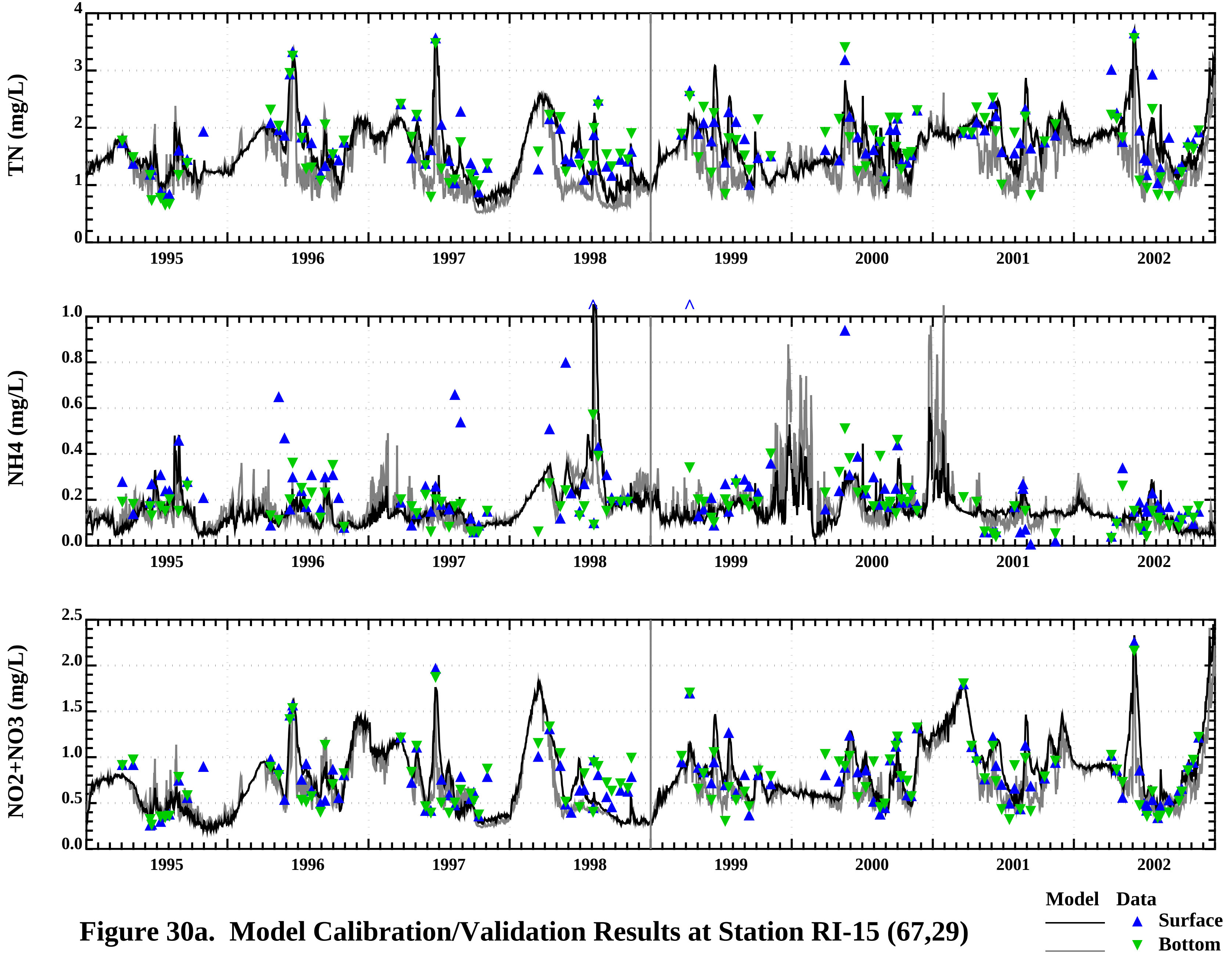


Figure 30a. Model Calibration/Validation Results at Station RI-15 (67,29)

/coral3/hntb0020/RCA_2020/PLOT/rical2.gdp
DATE: 11/27/2007 TIME: 15:47:32

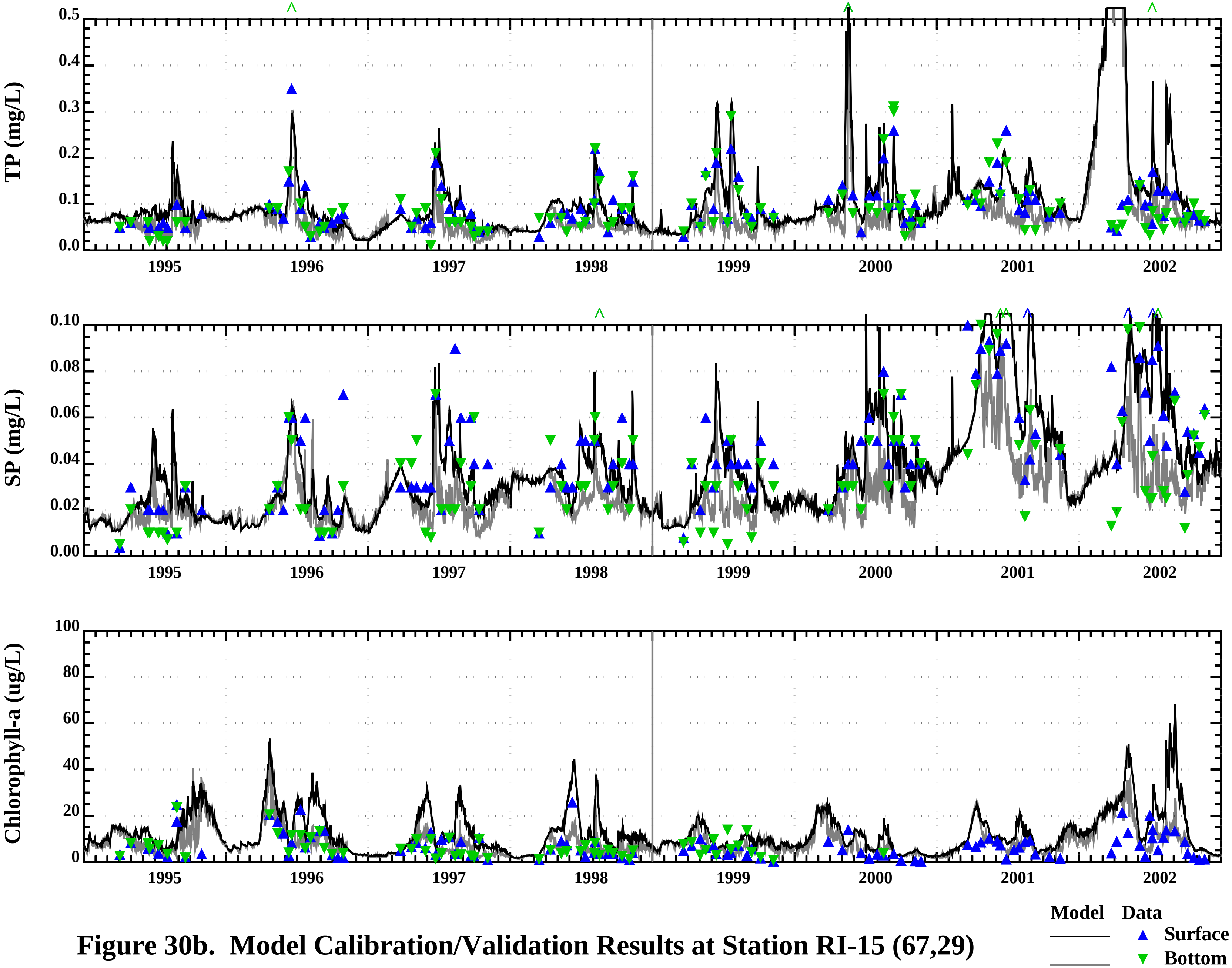


Figure 30b. Model Calibration/Validation Results at Station RI-15 (67,29)

/coral3/hntb0020/RCA_2020/PLOT/rical2.gdp
DATE: 11/27/2007 TIME: 15:47:32

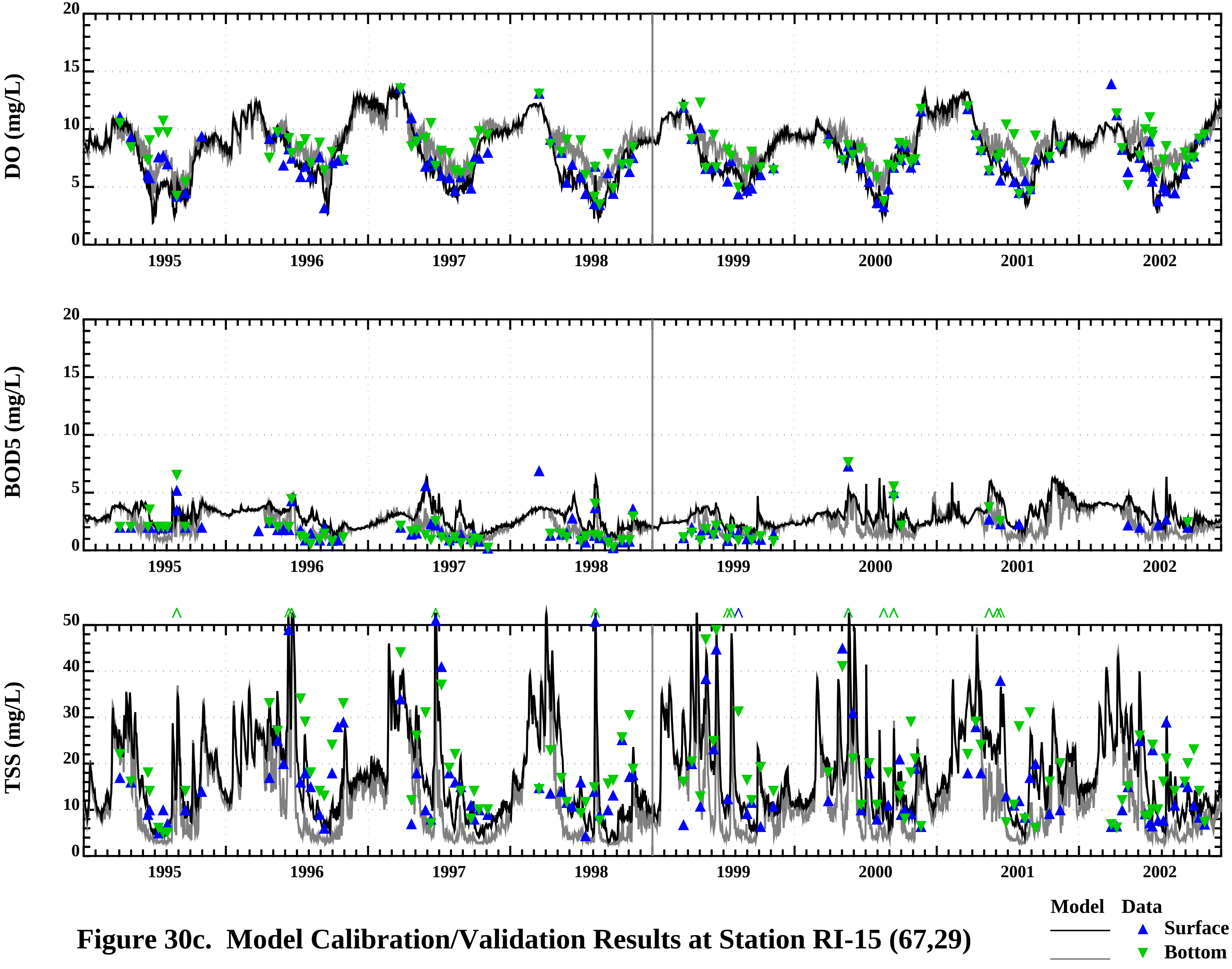


Figure 30c. Model Calibration/Validation Results at Station RI-15 (67,29)

/coral3/hntb0020/RCA_2020/PLOT/rical2.gdp
DATE: 11/27/2007 TIME: 15:47:32

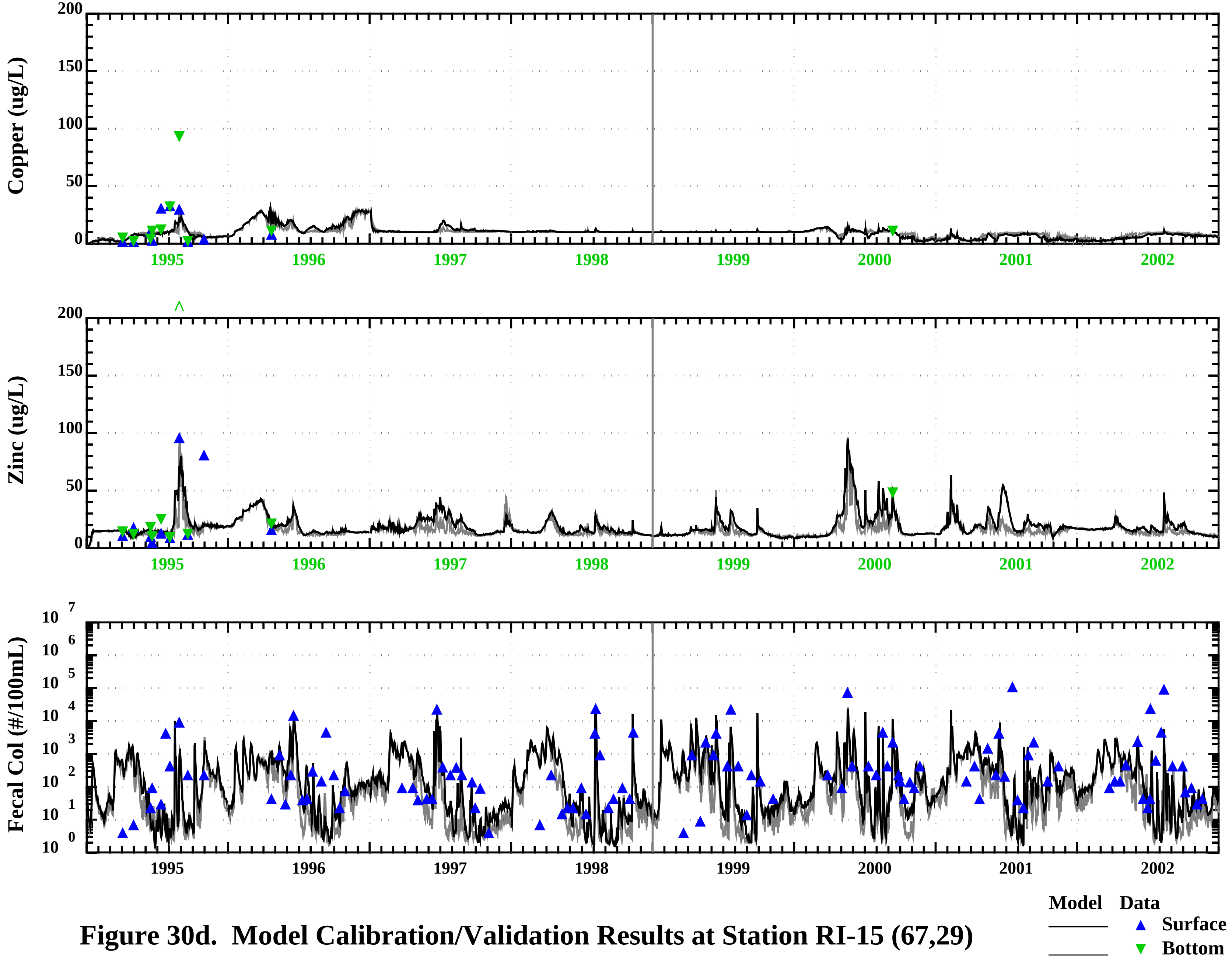


Figure 30d. Model Calibration/Validation Results at Station RI-15 (67,29)

/coral3/hntb0020/RCA_2020/PLOT/rical2.gdp
DATE: 11/27/2007 TIME: 15:47:32

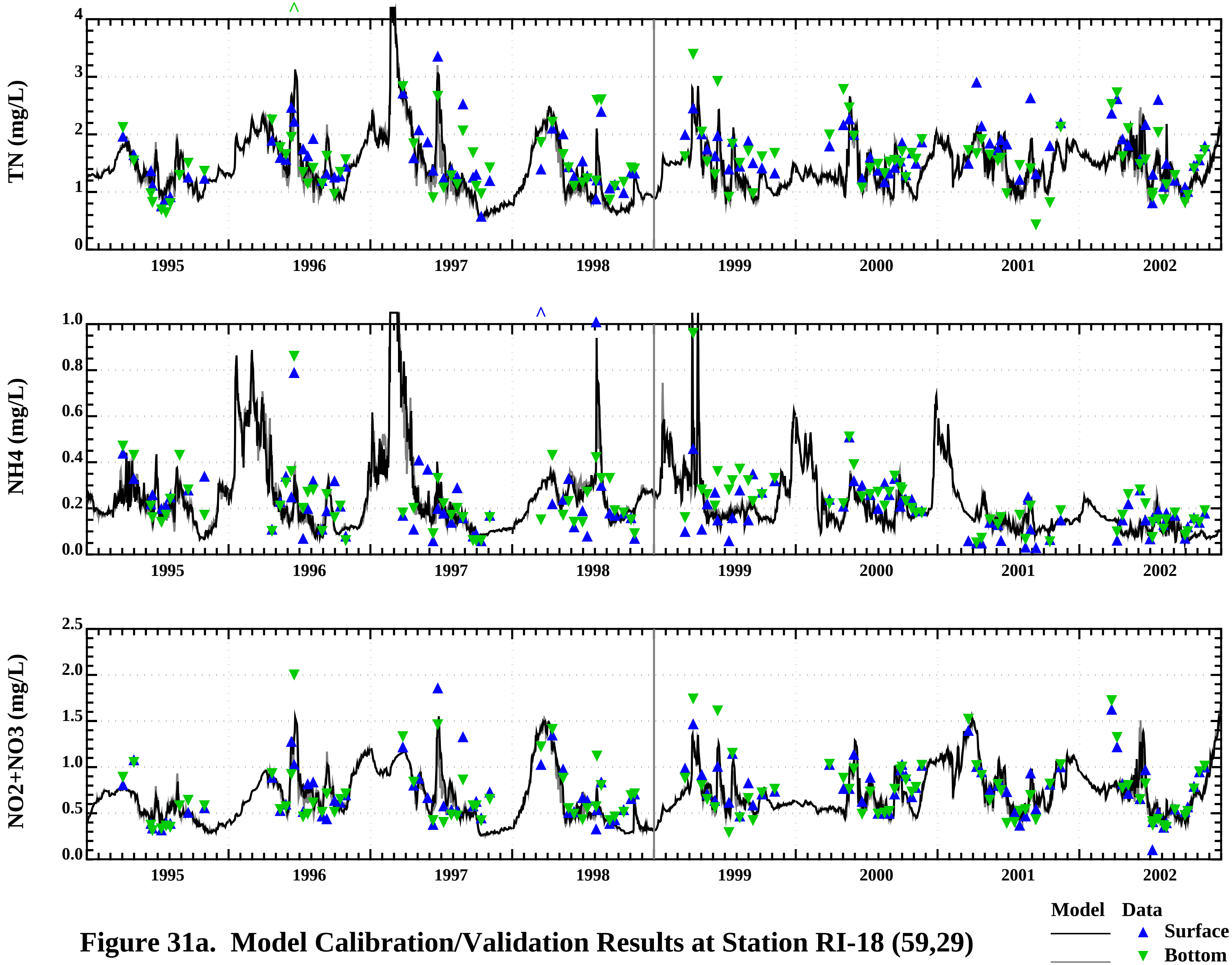


Figure 31a. Model Calibration/Validation Results at Station RI-18 (59,29)

/coral3/hntb0020/RCA_2020/PLOT/rical2.gdp
DATE: 11/27/2007 TIME: 15:48:39

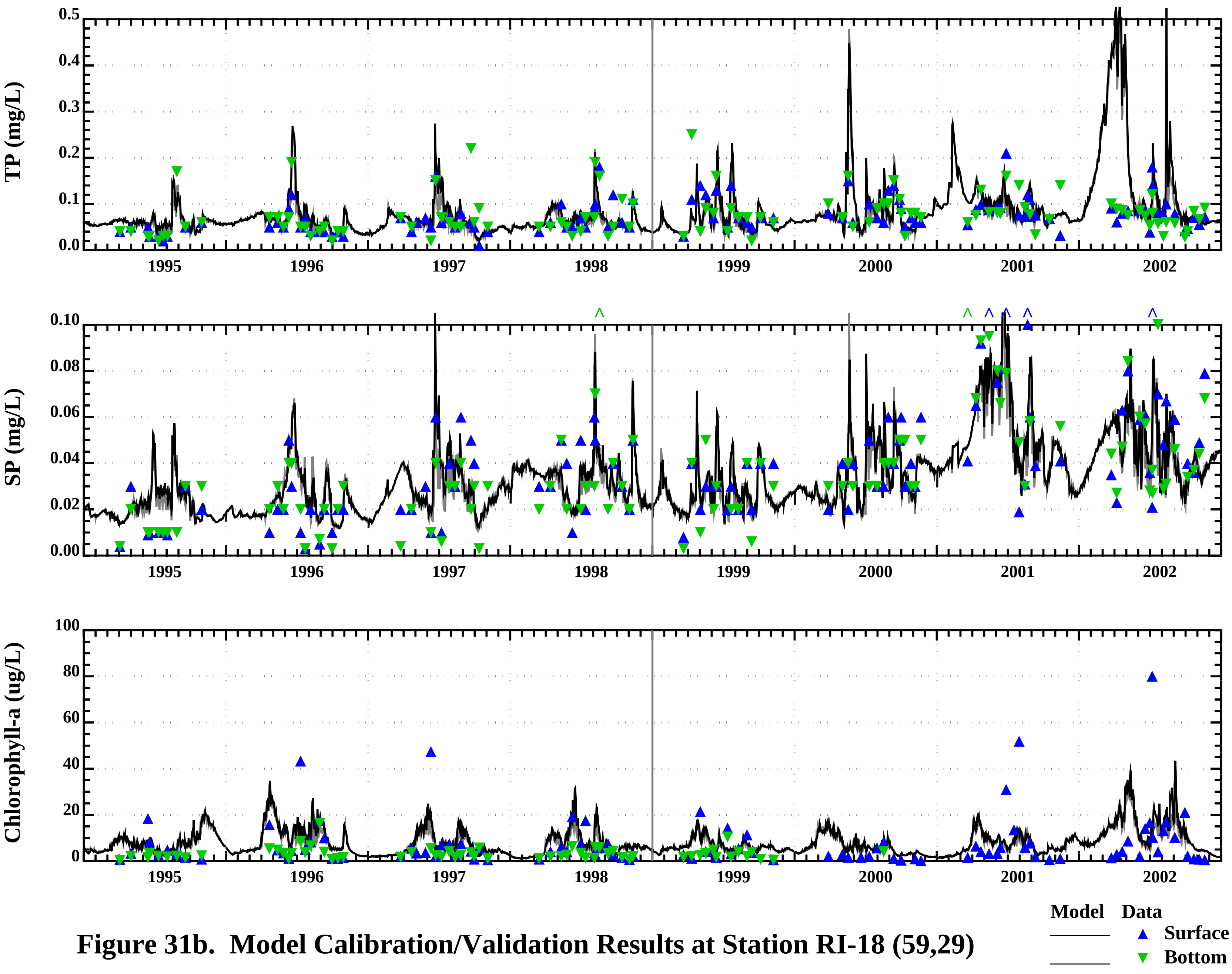


Figure 31b. Model Calibration/Validation Results at Station RI-18 (59,29)

/coral3/hntb0020/RCA_2020/PLOT/rical2.gdp
DATE: 11/27/2007 TIME: 15:48:39

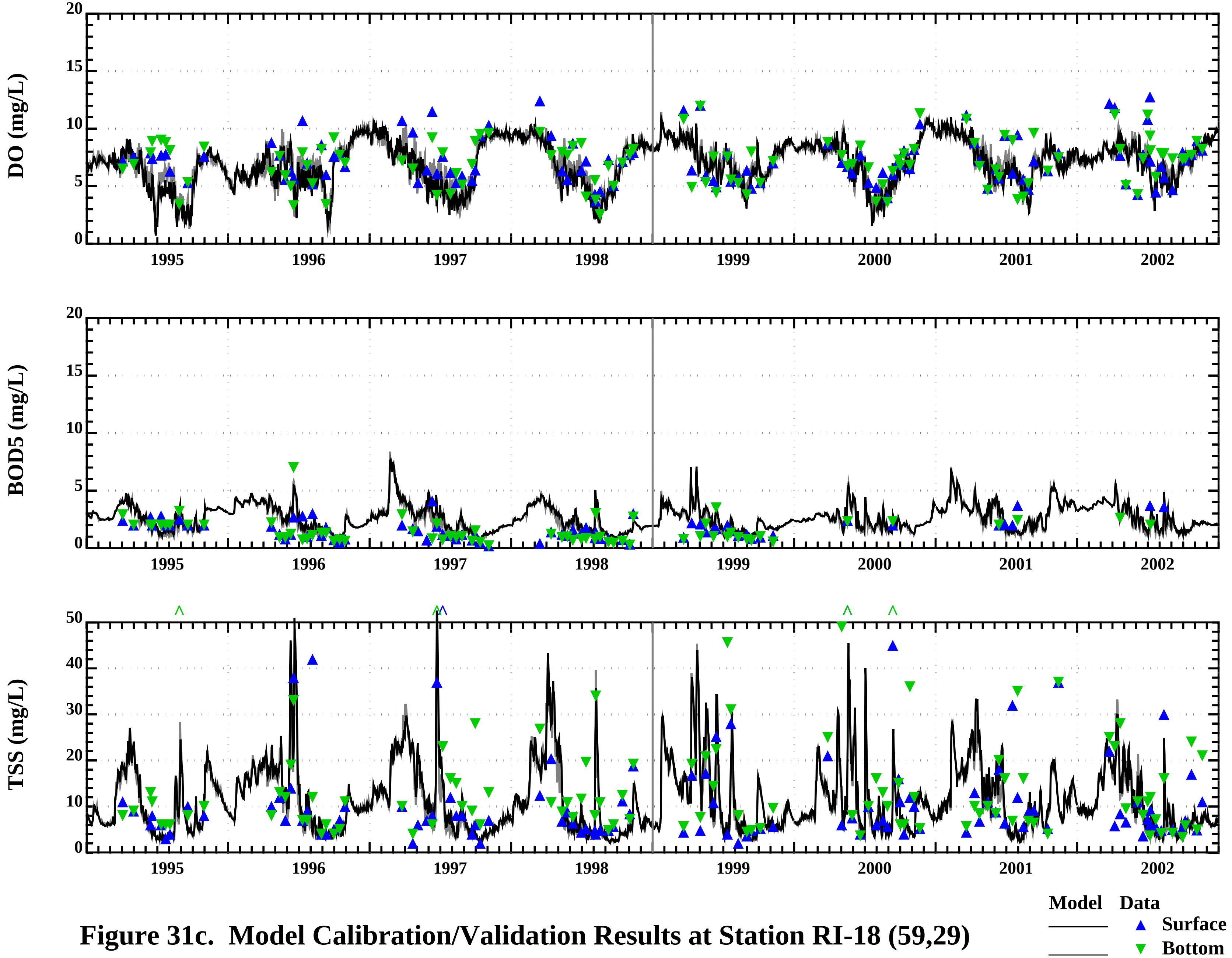


Figure 31c. Model Calibration/Validation Results at Station RI-18 (59,29)

/coral3/hntb0020/RCA_2020/PLOT/rical2.gdp
DATE: 11/27/2007 TIME: 15:48:39

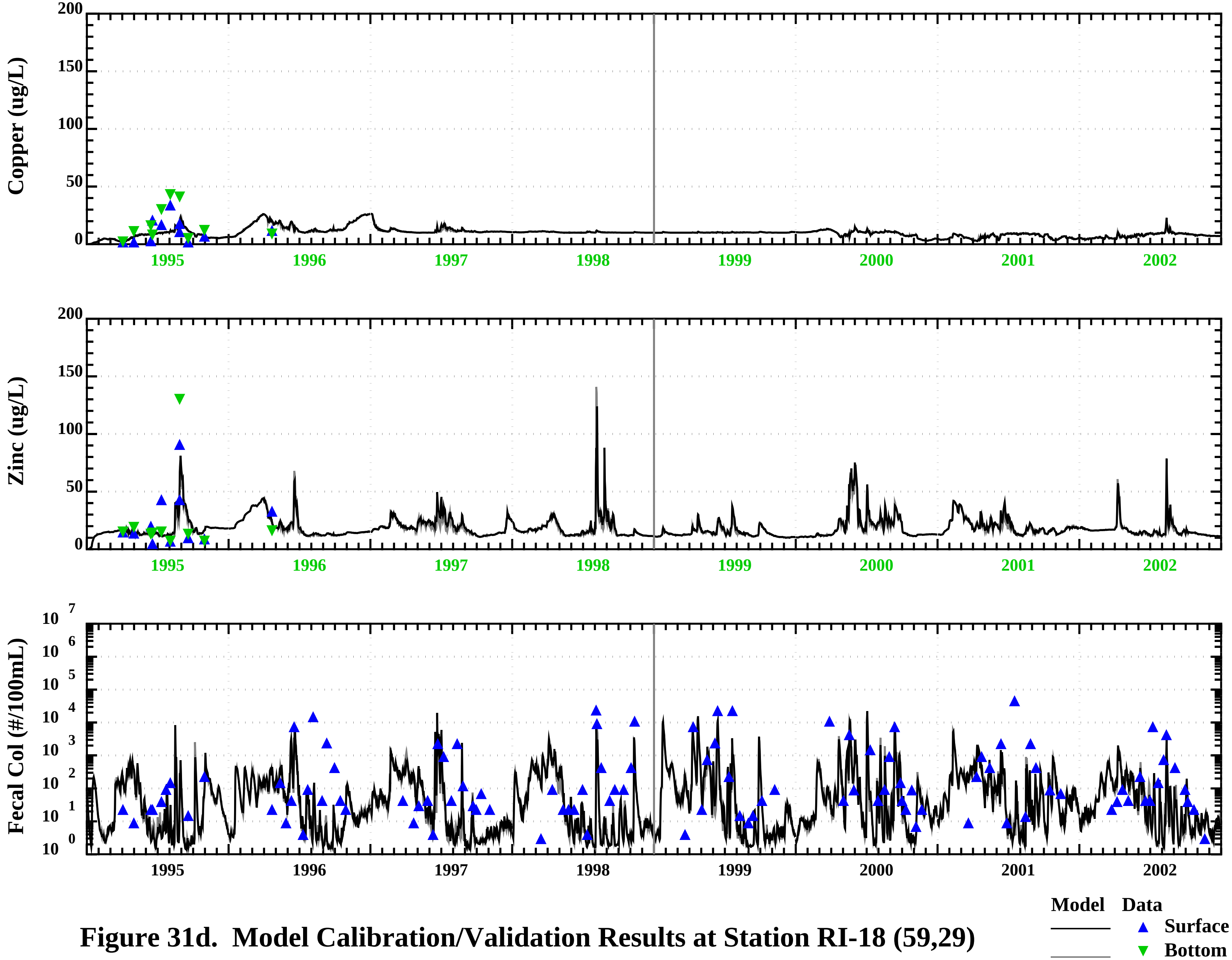


Figure 31d. Model Calibration/Validation Results at Station RI-18 (59,29)

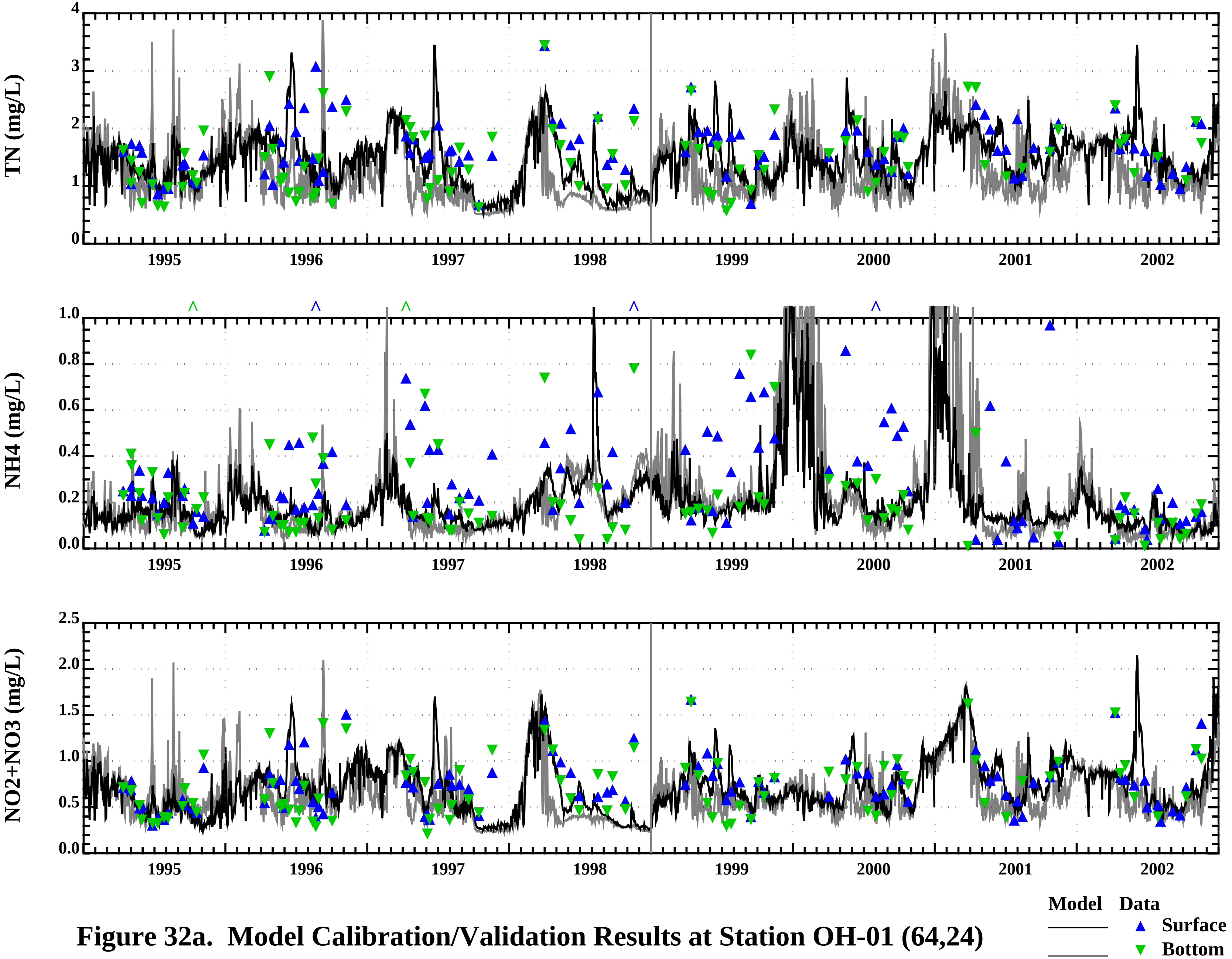


Figure 32a. Model Calibration/Validation Results at Station OH-01 (64,24)

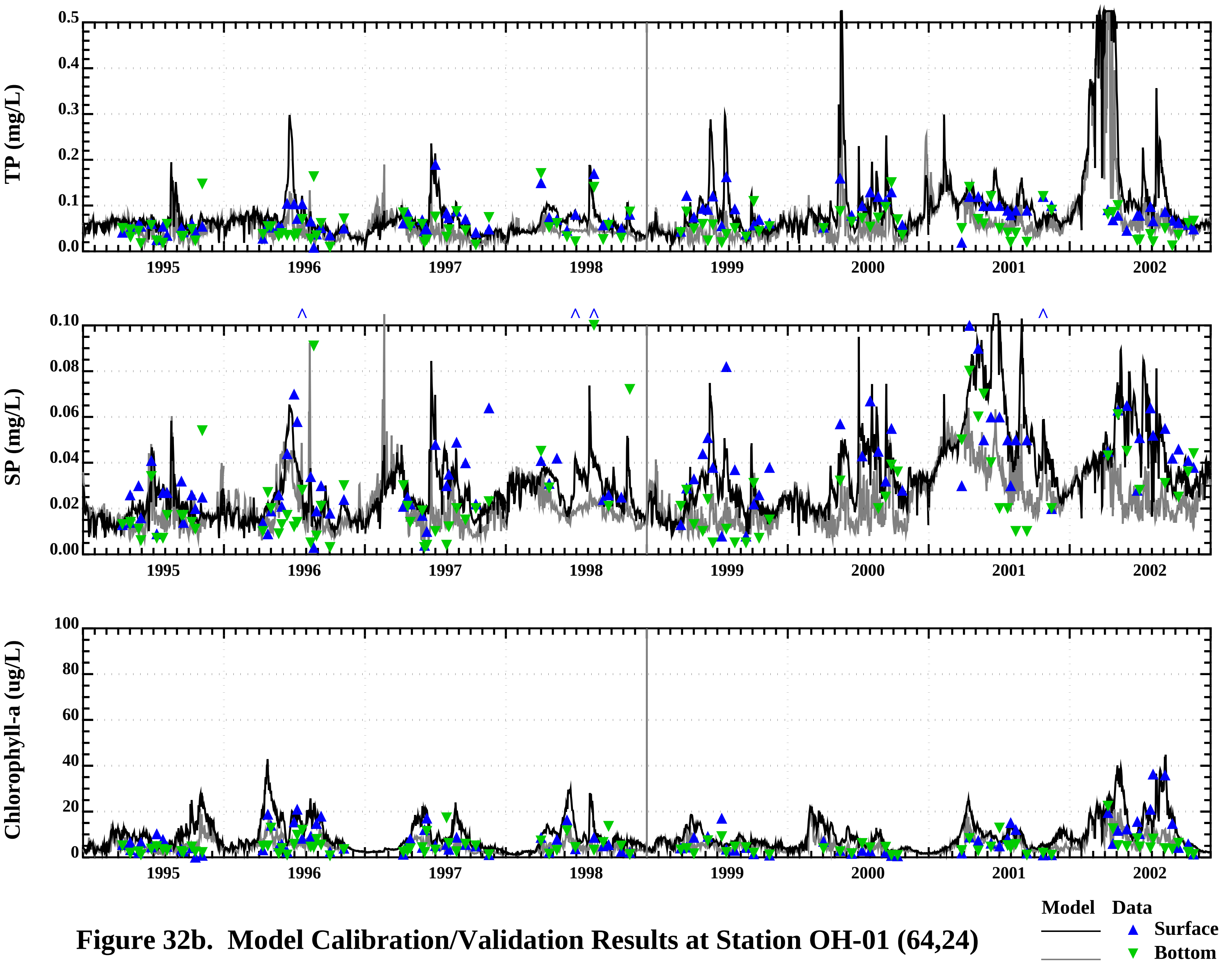


Figure 32b. Model Calibration/Validation Results at Station OH-01 (64,24)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:49:46

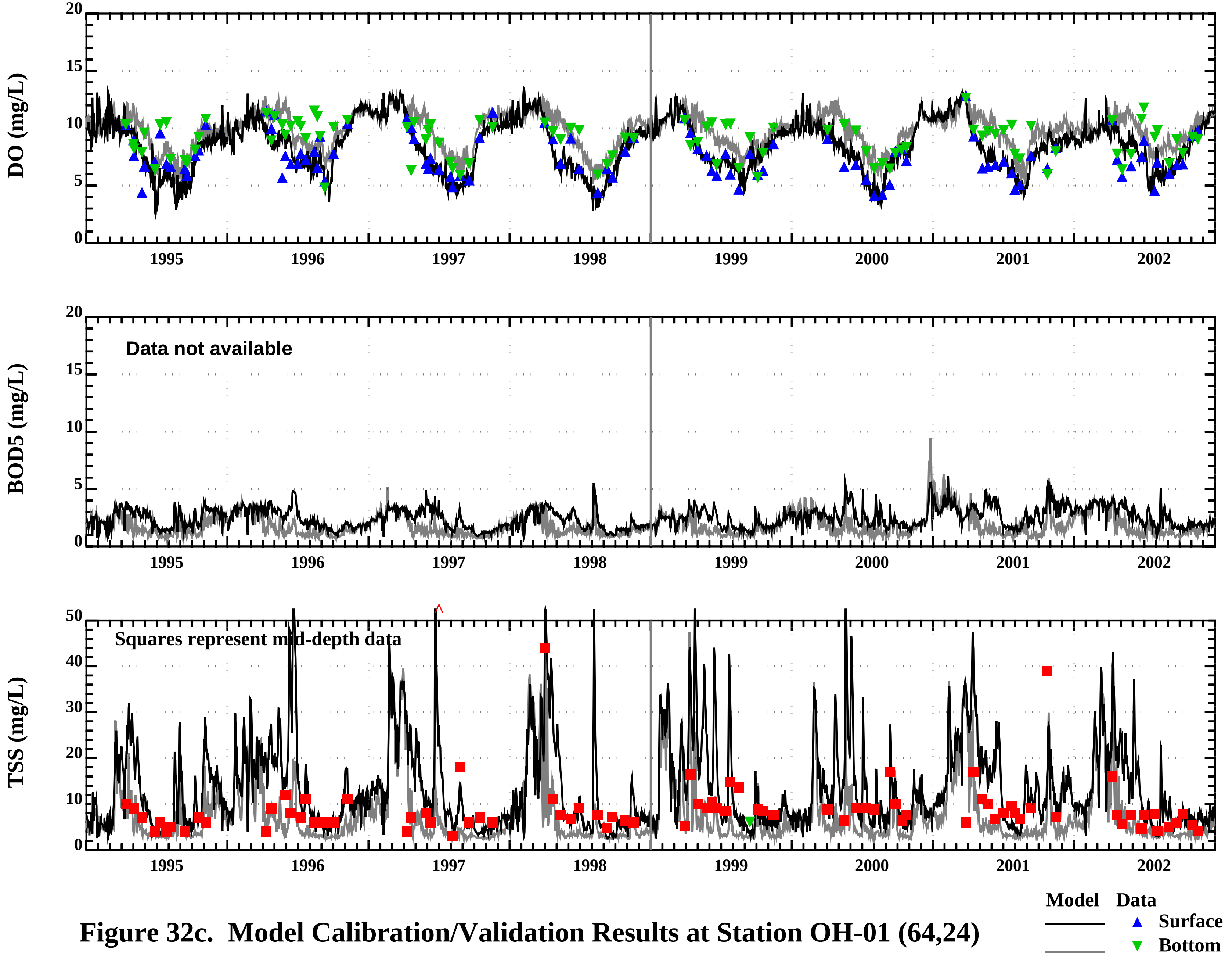


Figure 32c. Model Calibration/Validation Results at Station OH-01 (64,24)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:49:46

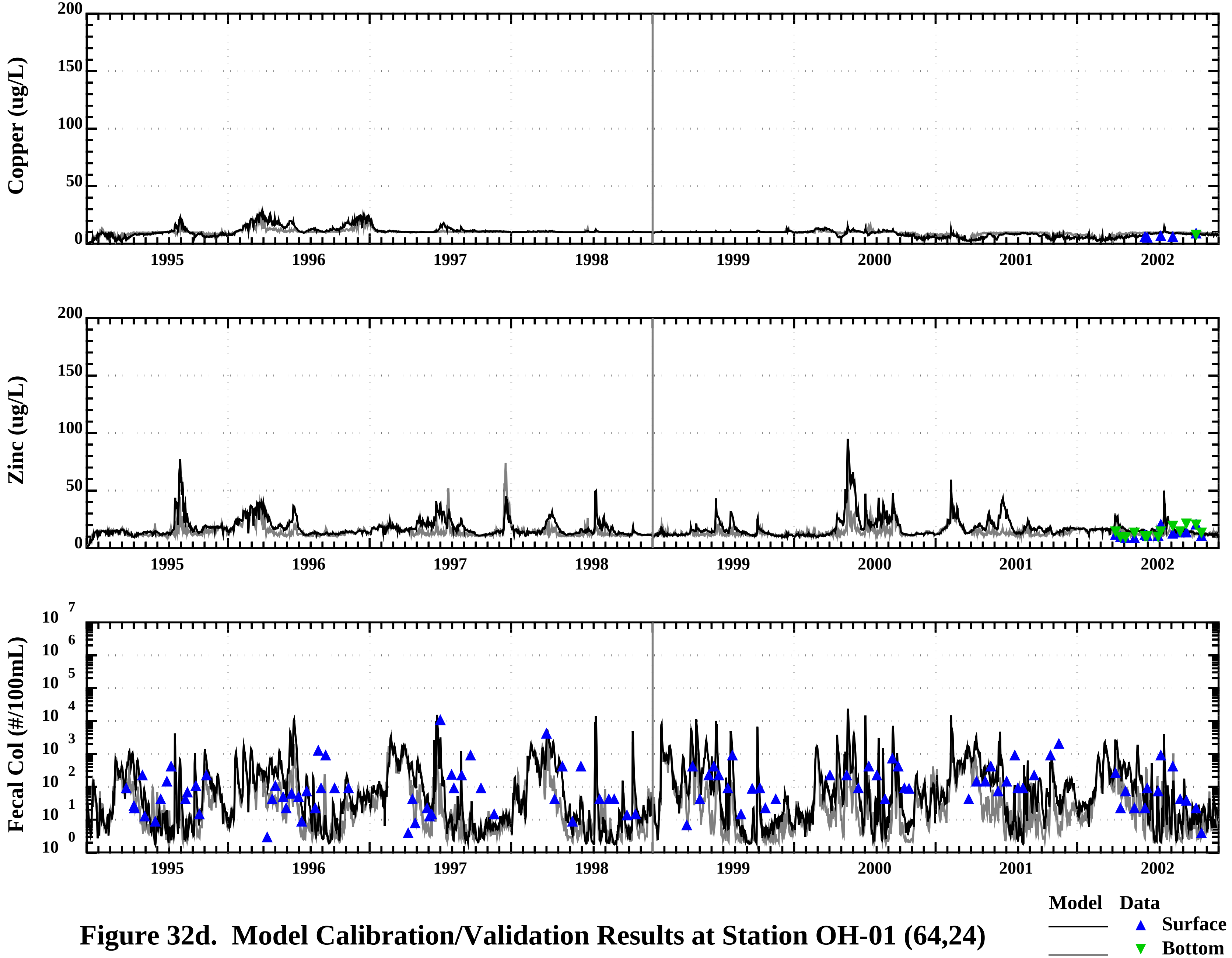


Figure 32d. Model Calibration/Validation Results at Station OH-01 (64,24)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:49:46

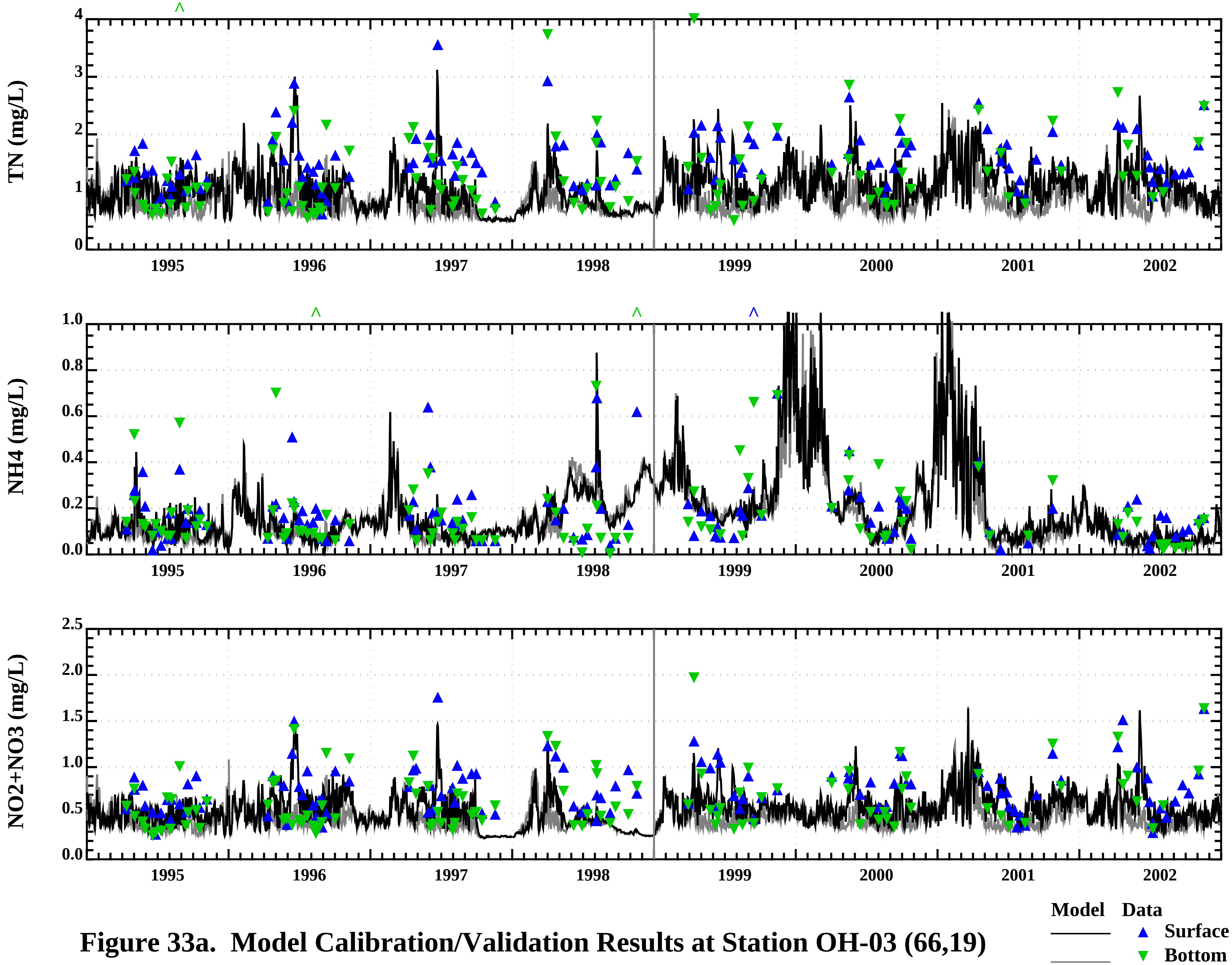


Figure 33a. Model Calibration/Validation Results at Station OH-03 (66,19)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:50:53

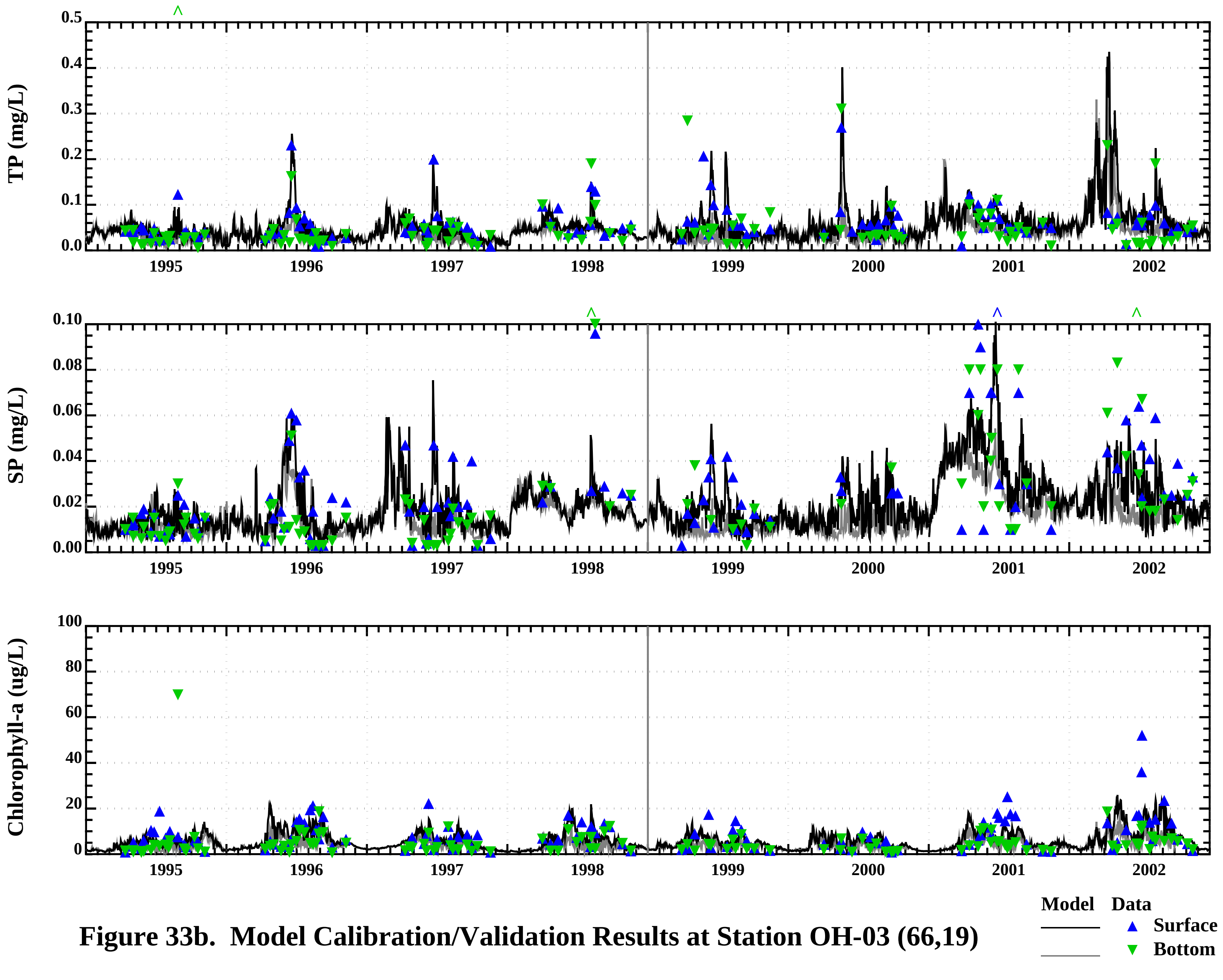


Figure 33b. Model Calibration/Validation Results at Station OH-03 (66,19)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:50:53

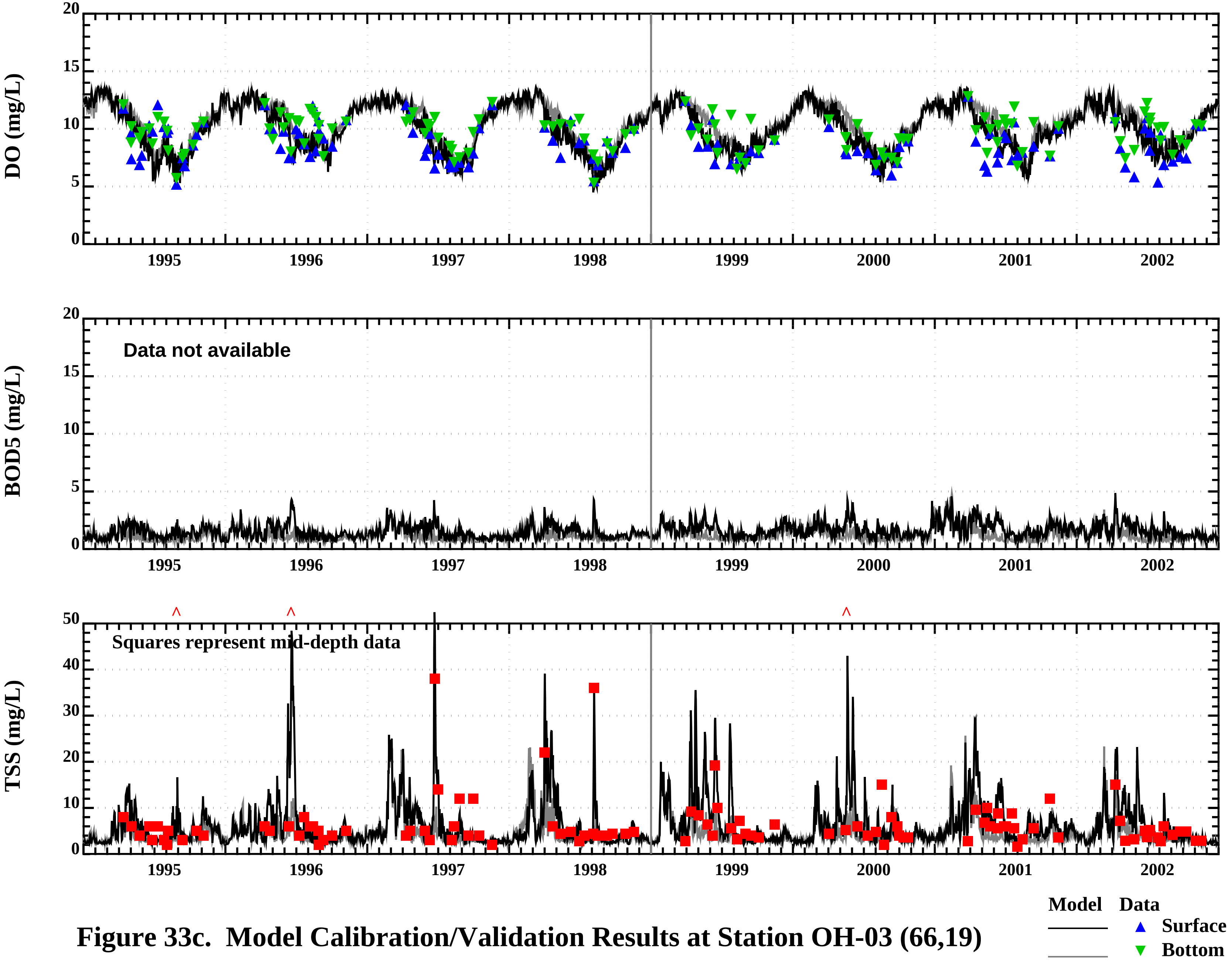


Figure 33c. Model Calibration/Validation Results at Station OH-03 (66,19)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:50:53

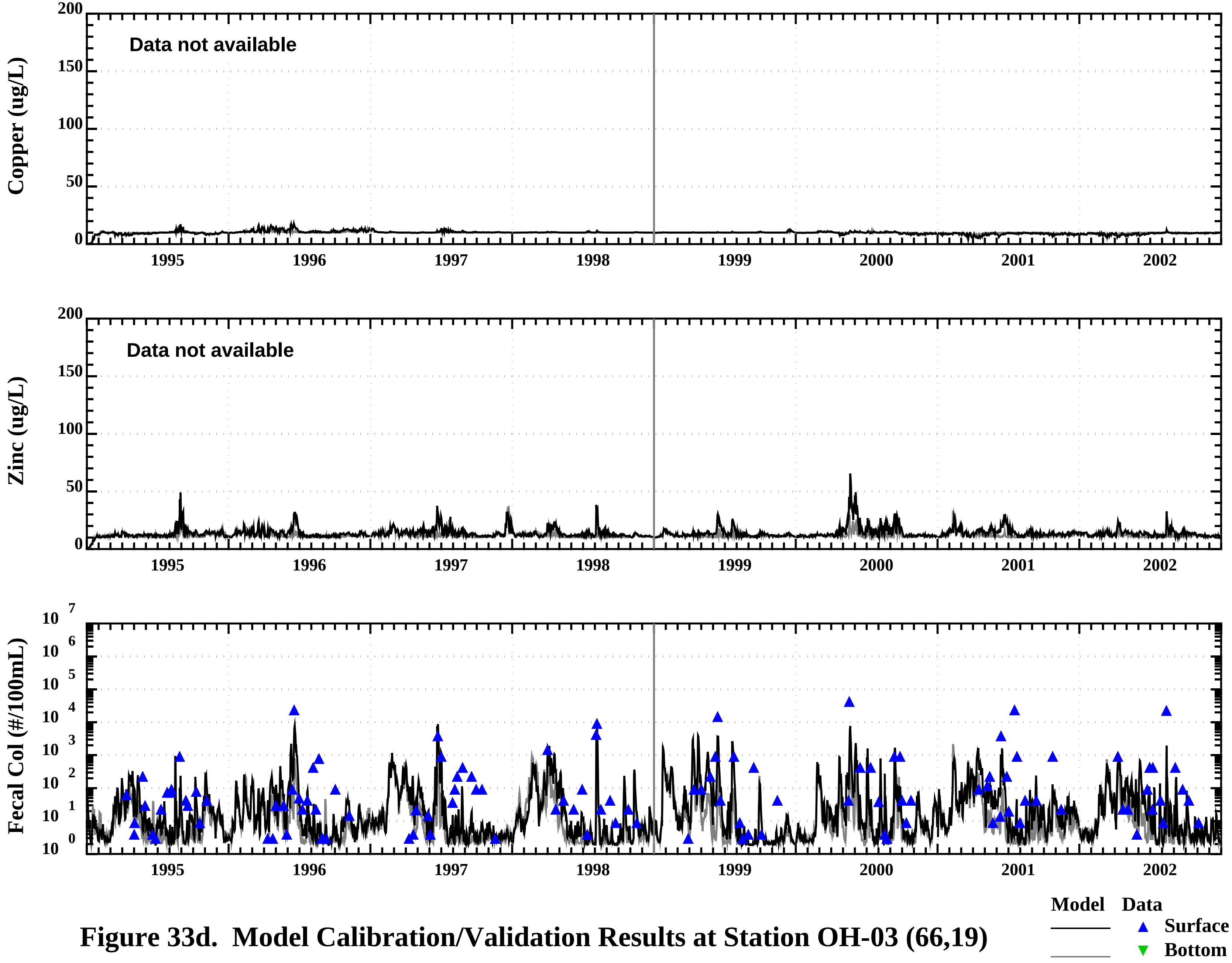


Figure 33d. Model Calibration/Validation Results at Station OH-03 (66,19)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:50:53

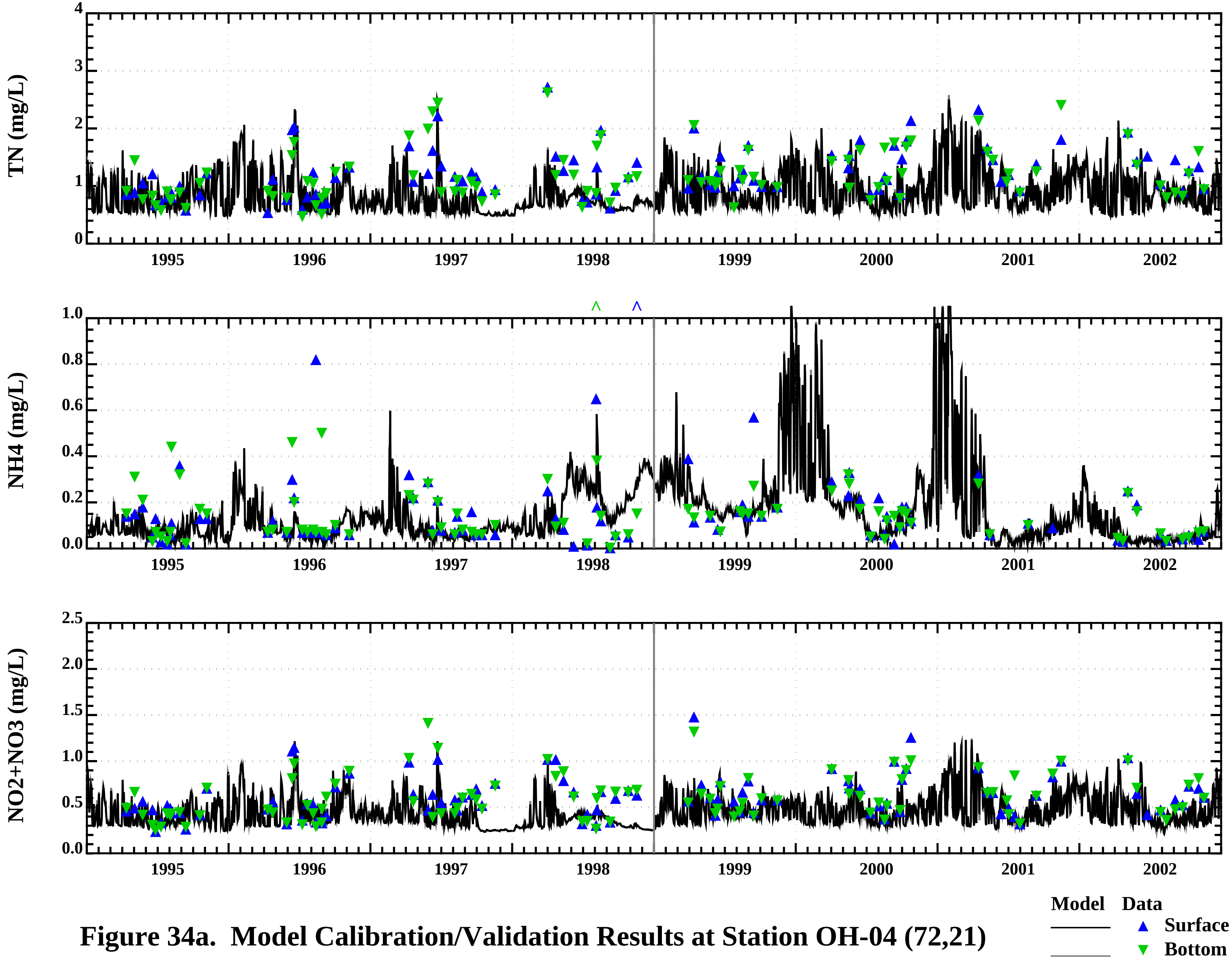


Figure 34a. Model Calibration/Validation Results at Station OH-04 (72,21)

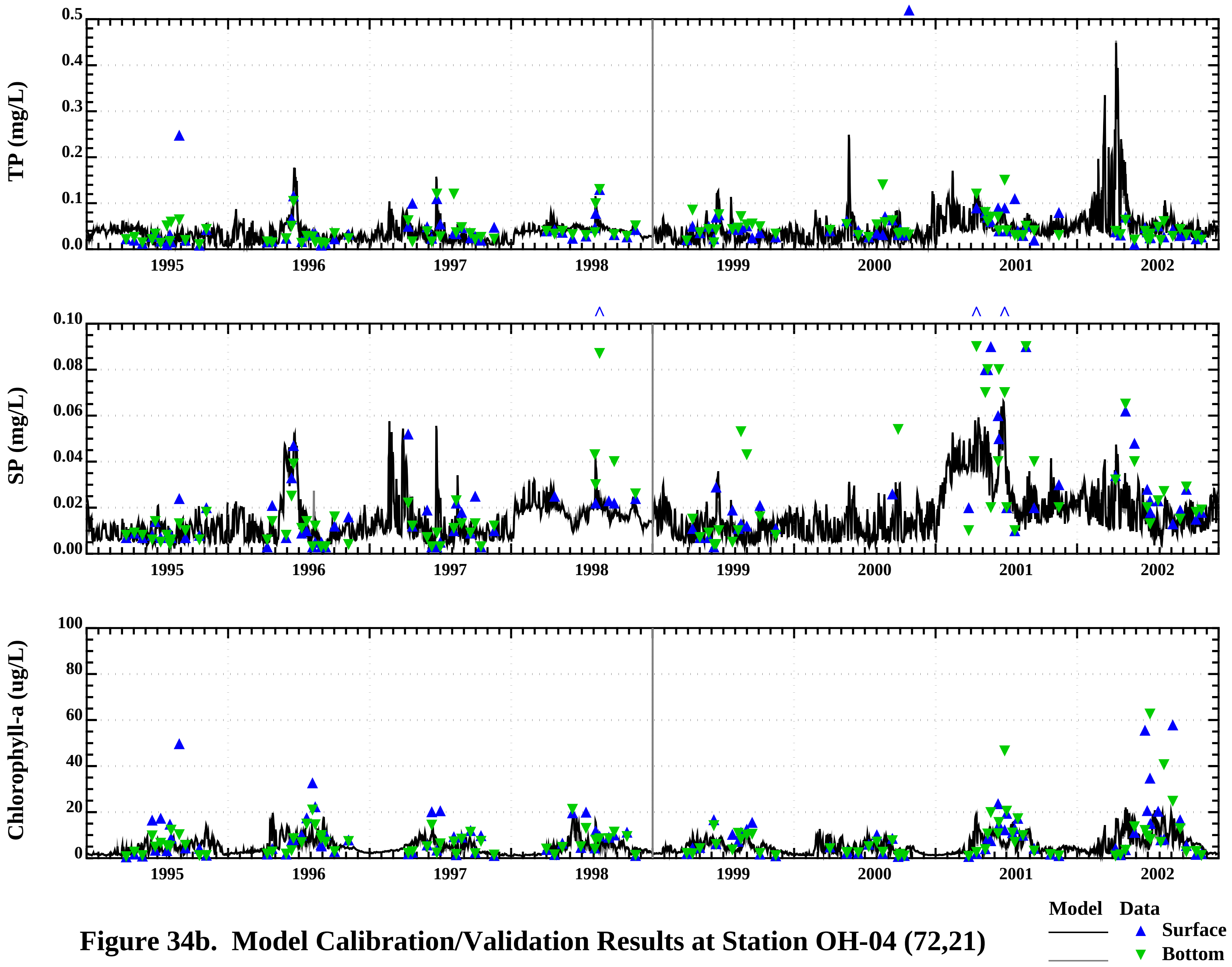


Figure 34b. Model Calibration/Validation Results at Station OH-04 (72,21)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:52: 0

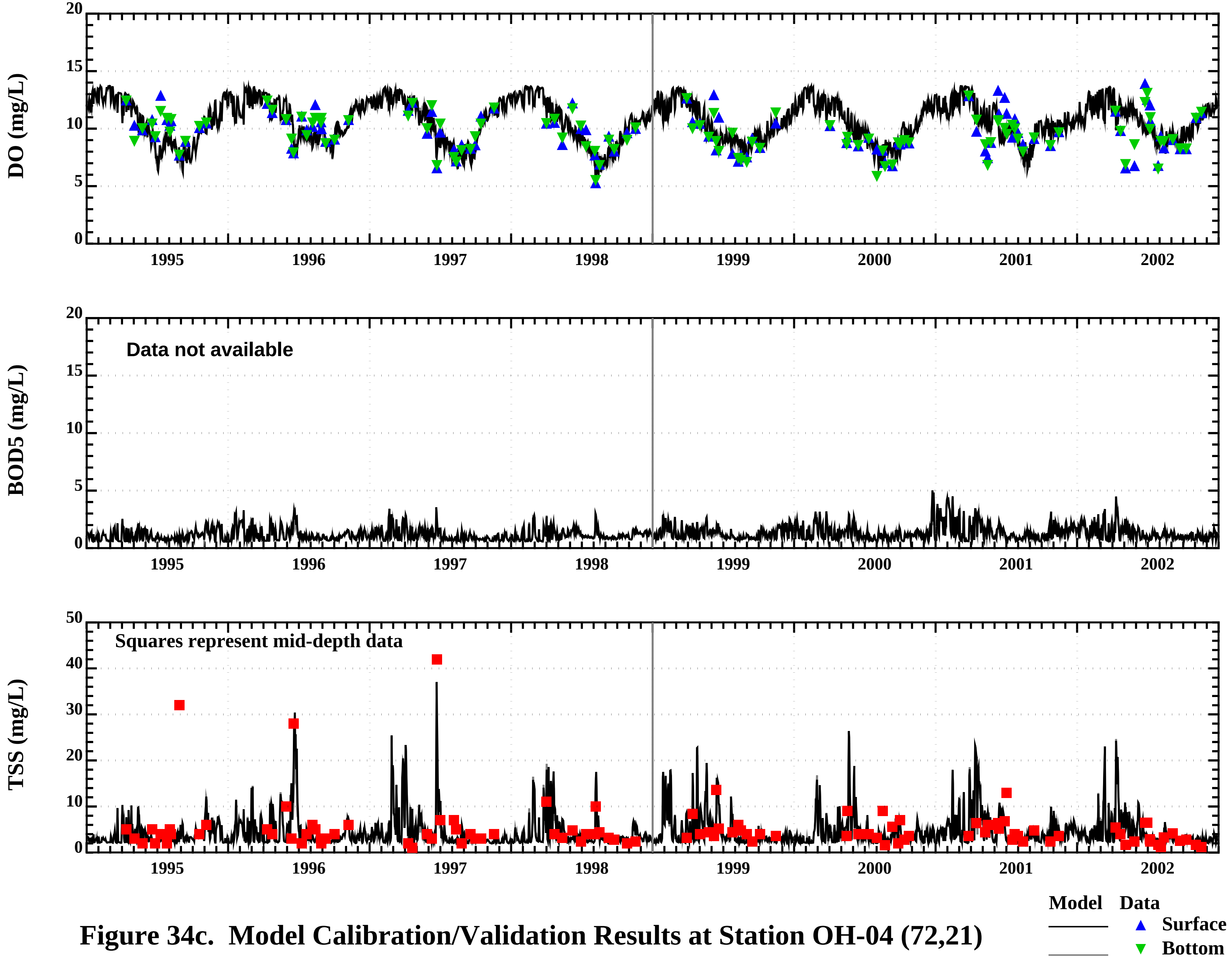


Figure 34c. Model Calibration/Validation Results at Station OH-04 (72,21)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:52: 0

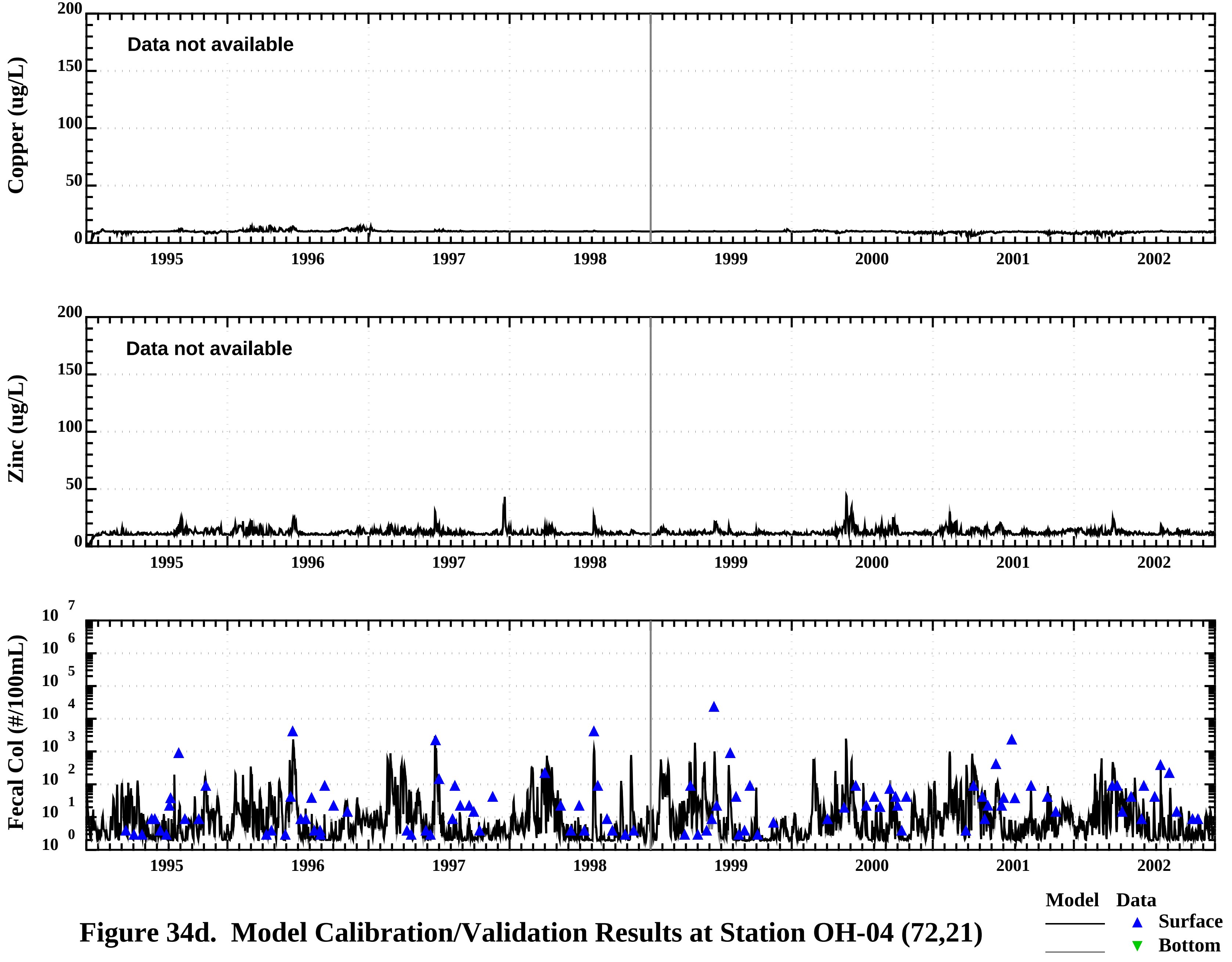


Figure 34d. Model Calibration/Validation Results at Station OH-04 (72,21)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:52: 0

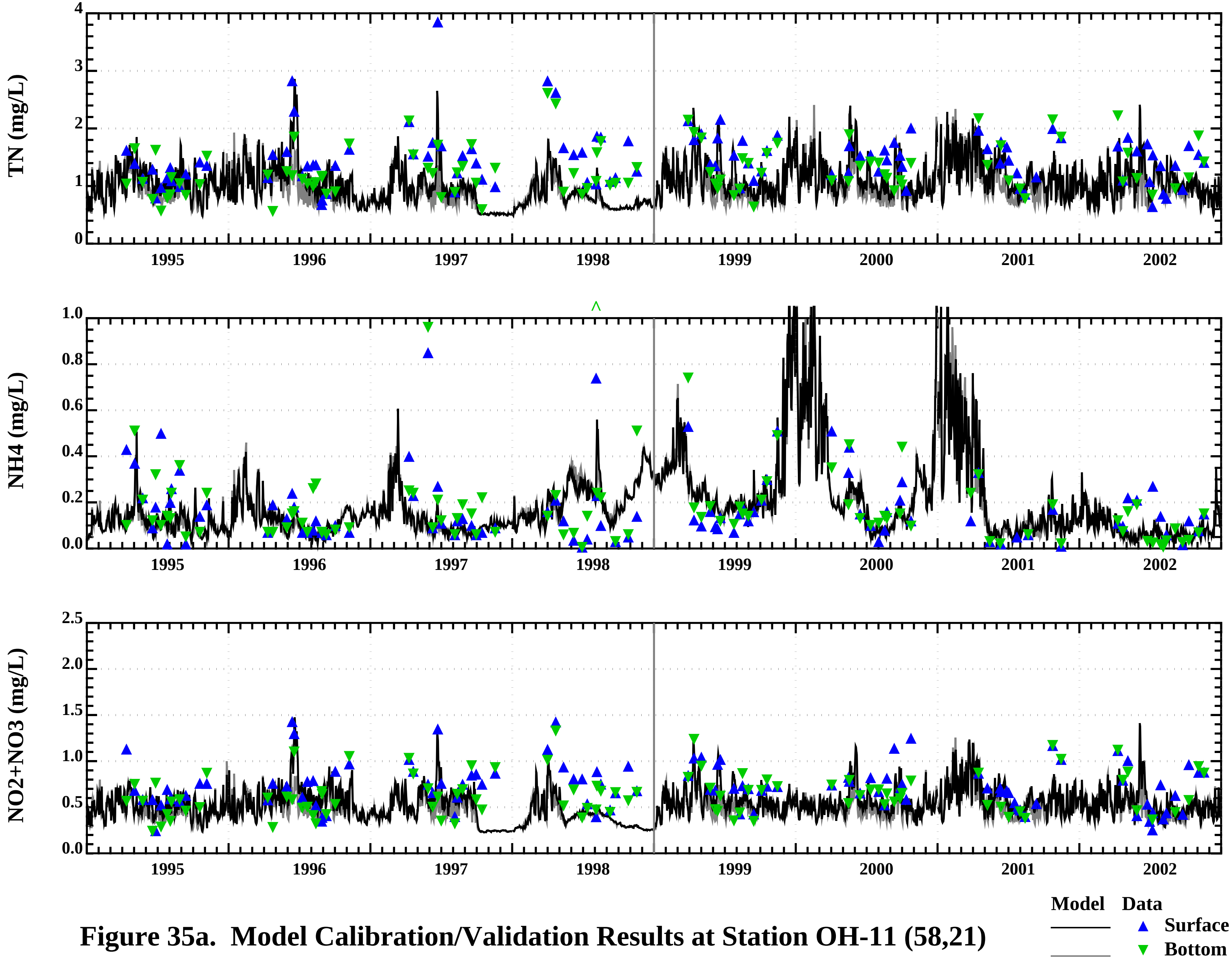


Figure 35a. Model Calibration/Validation Results at Station OH-11 (58,21)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:53: 7

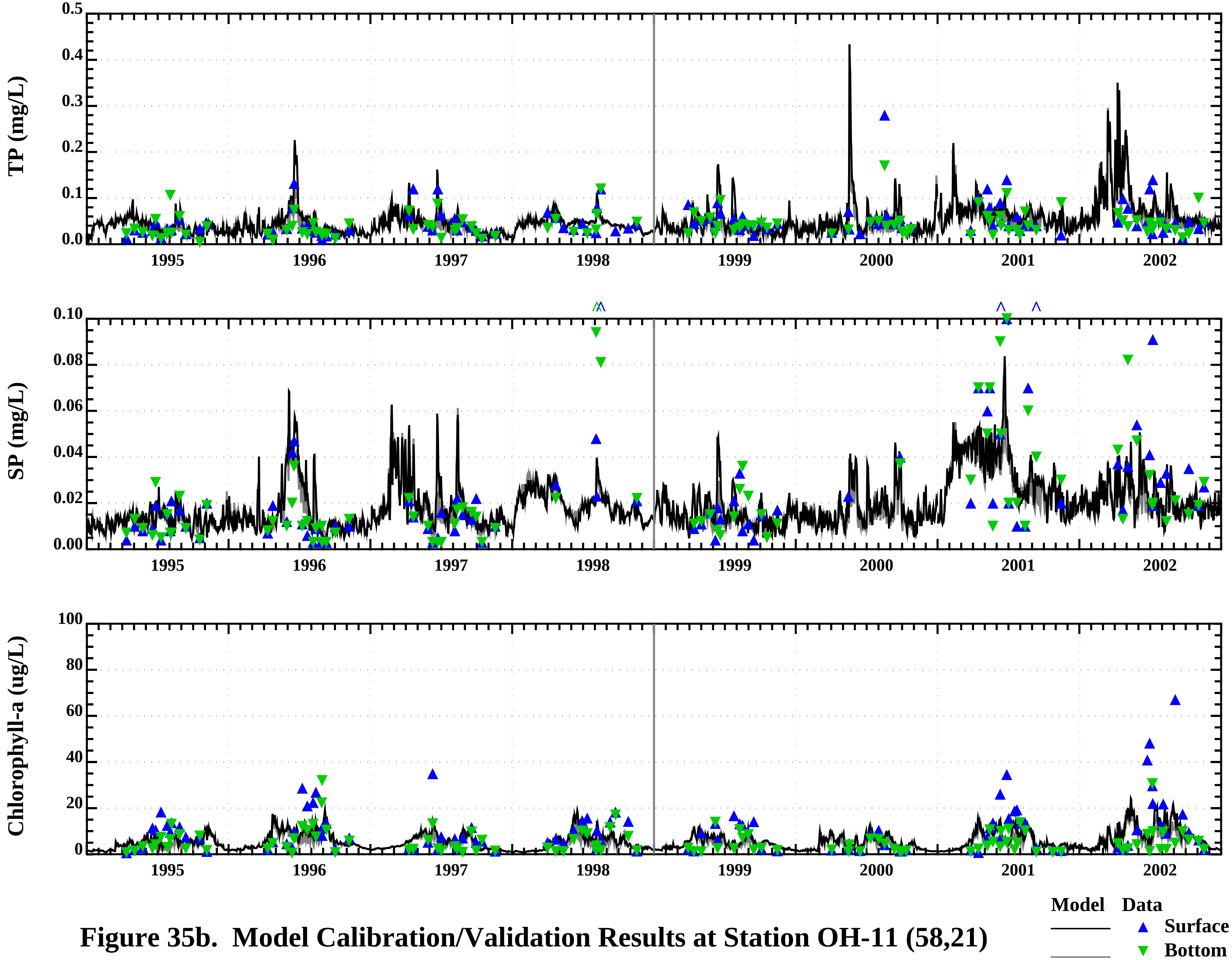


Figure 35b. Model Calibration/Validation Results at Station OH-11 (58,21)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:53: 7

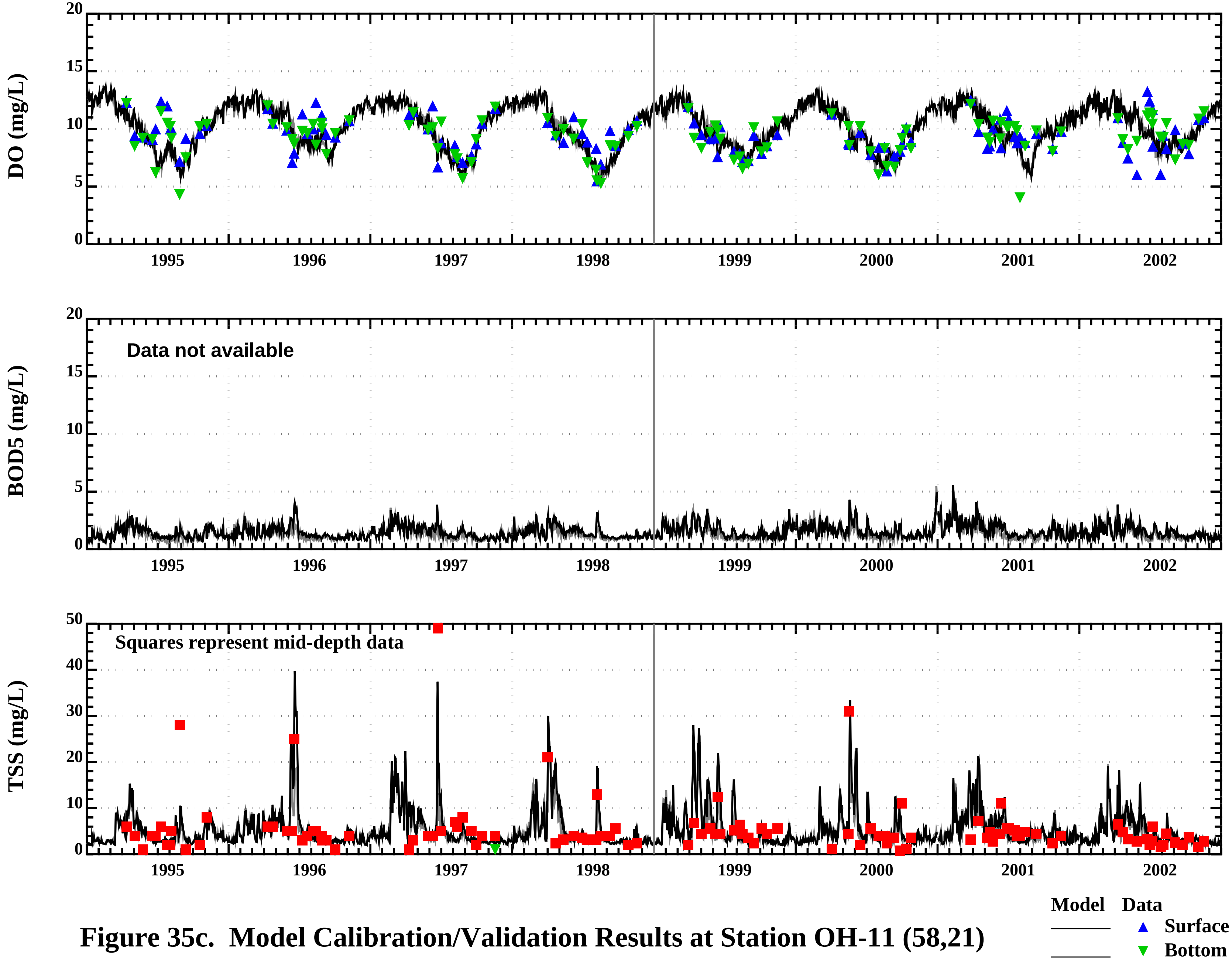


Figure 35c. Model Calibration/Validation Results at Station OH-11 (58,21)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:53: 7

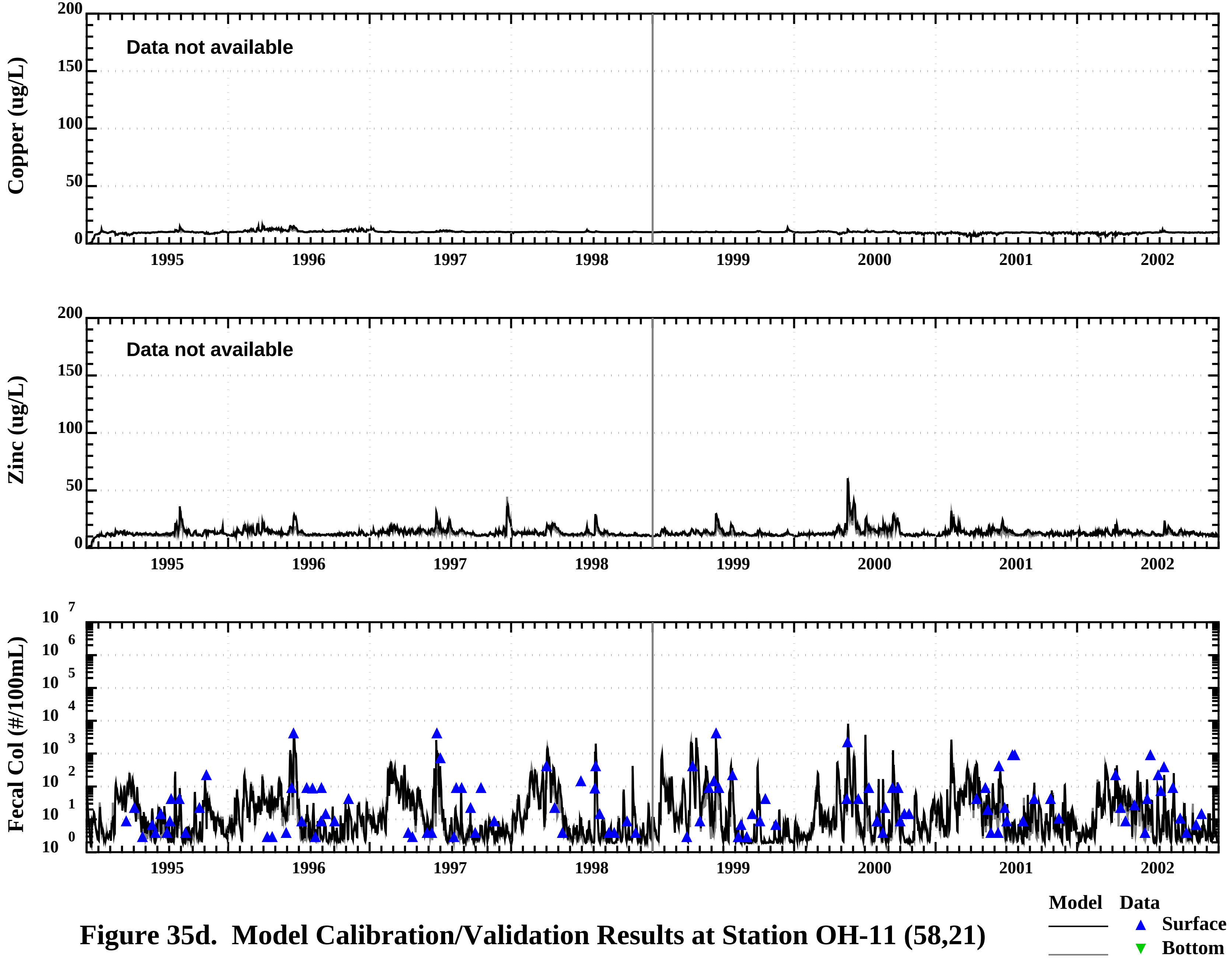


Figure 35d. Model Calibration/Validation Results at Station OH-11 (58,21)

/coral3/hntb0020/RCA_2020/PLOT/ohcal2.gdp
DATE: 11/27/2007 TIME: 15:53: 7

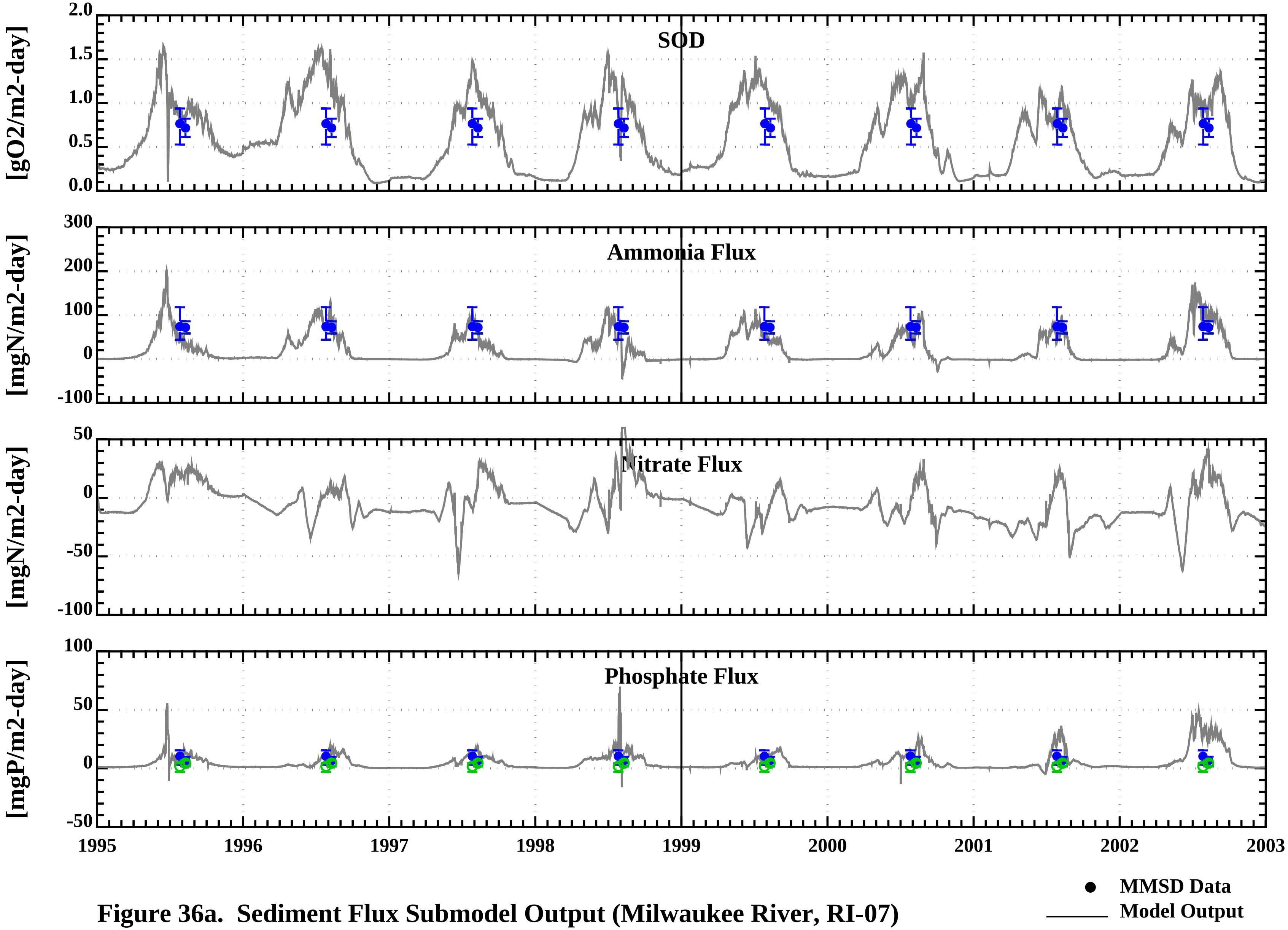


Figure 36a. Sediment Flux Submodel Output (Milwaukee River, RI-07)

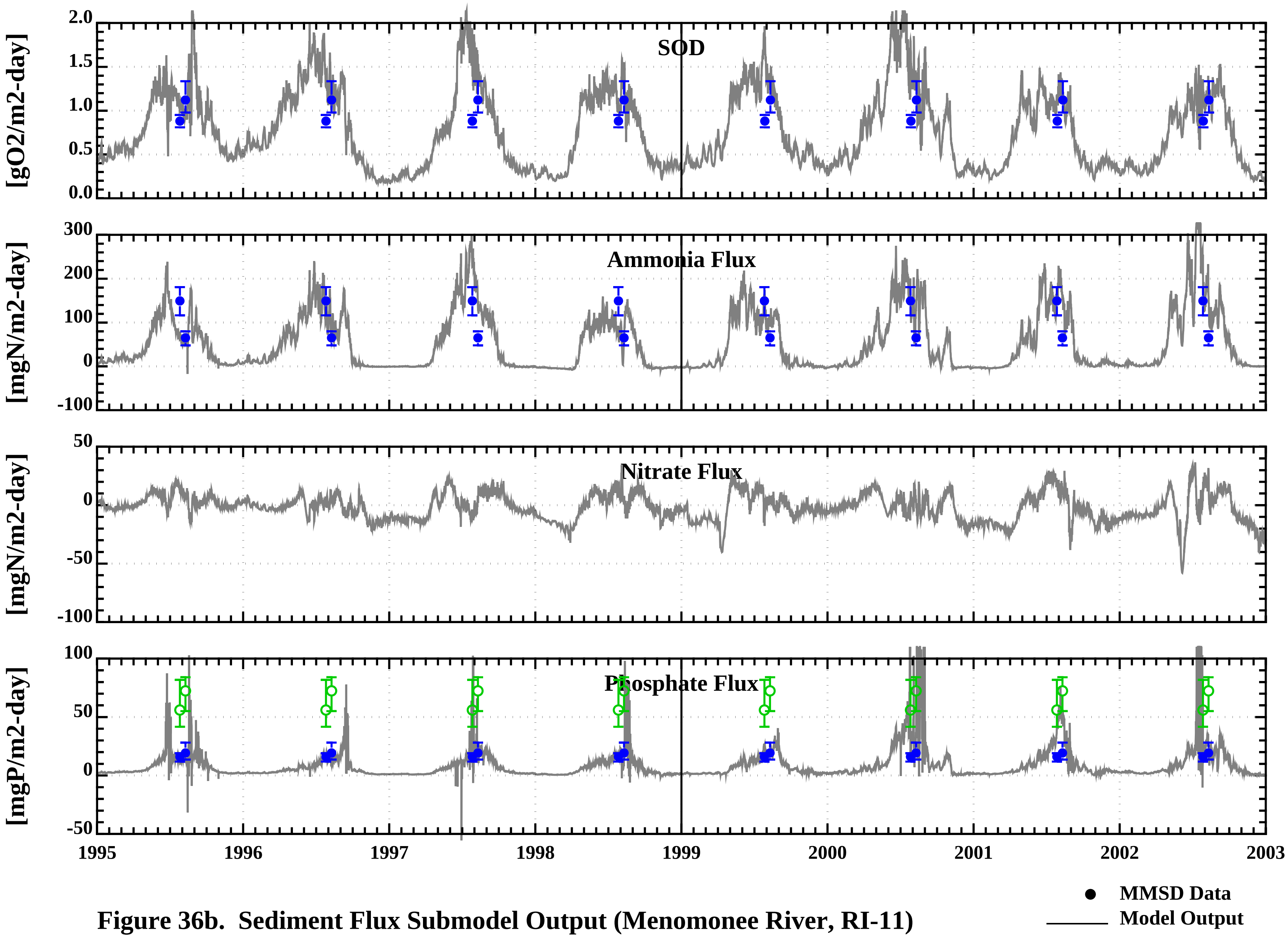


Figure 36b. Sediment Flux Submodel Output (Menomonee River, RI-11)

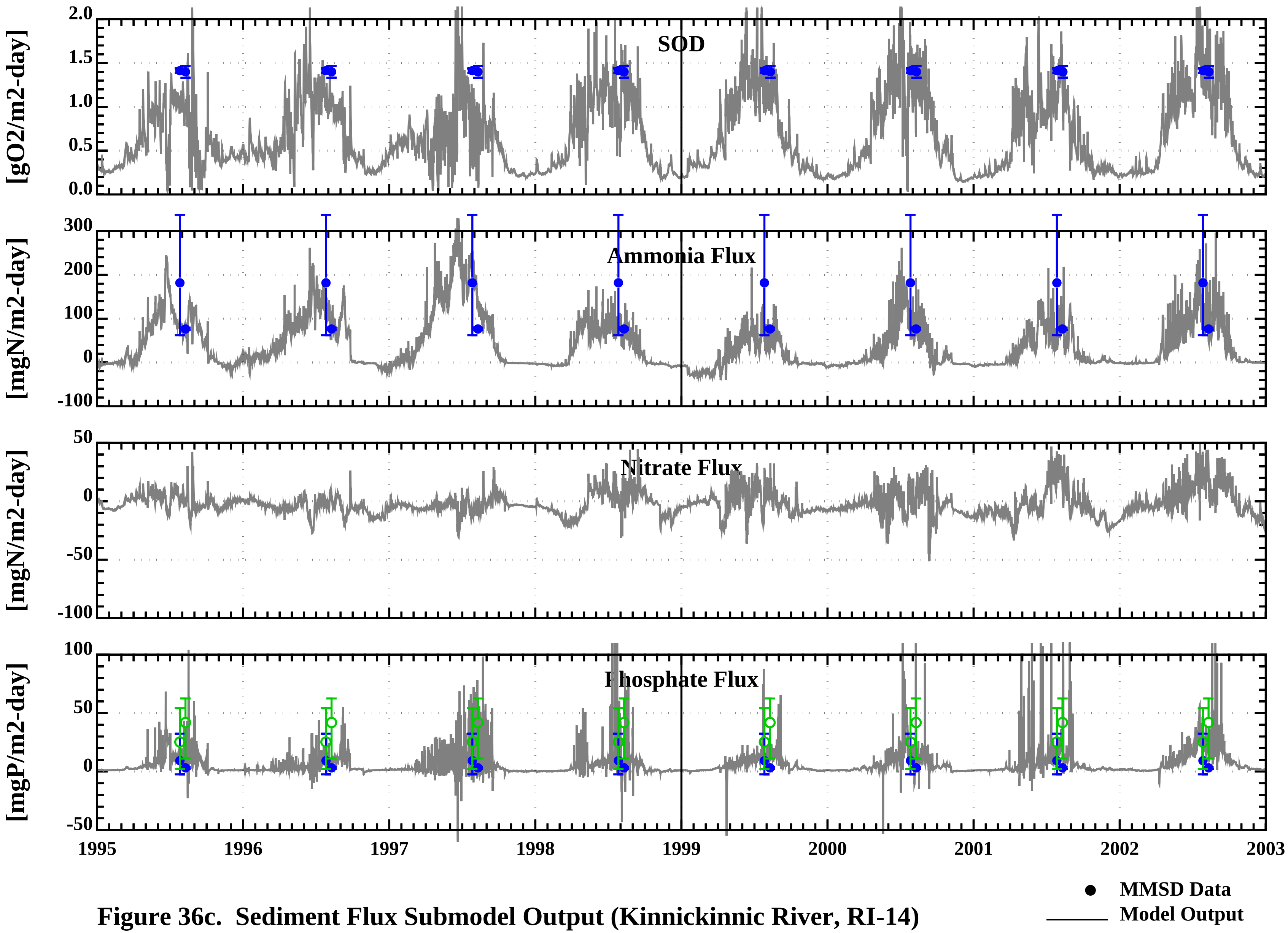


Figure 36c. Sediment Flux Submodel Output (Kinnickinnic River, RI-14)

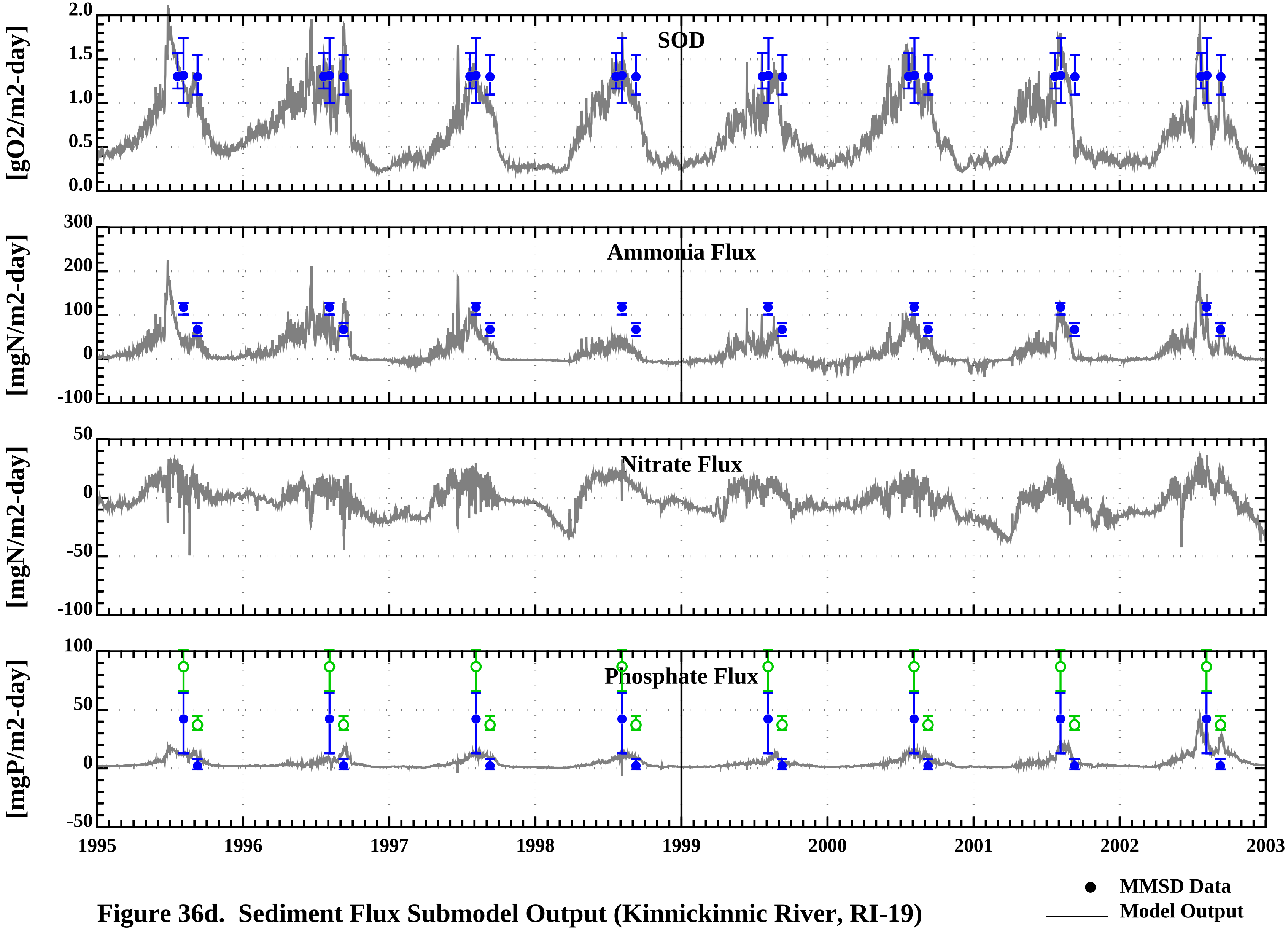


Figure 36d. Sediment Flux Submodel Output (Kinnickinnic River, RI-19)

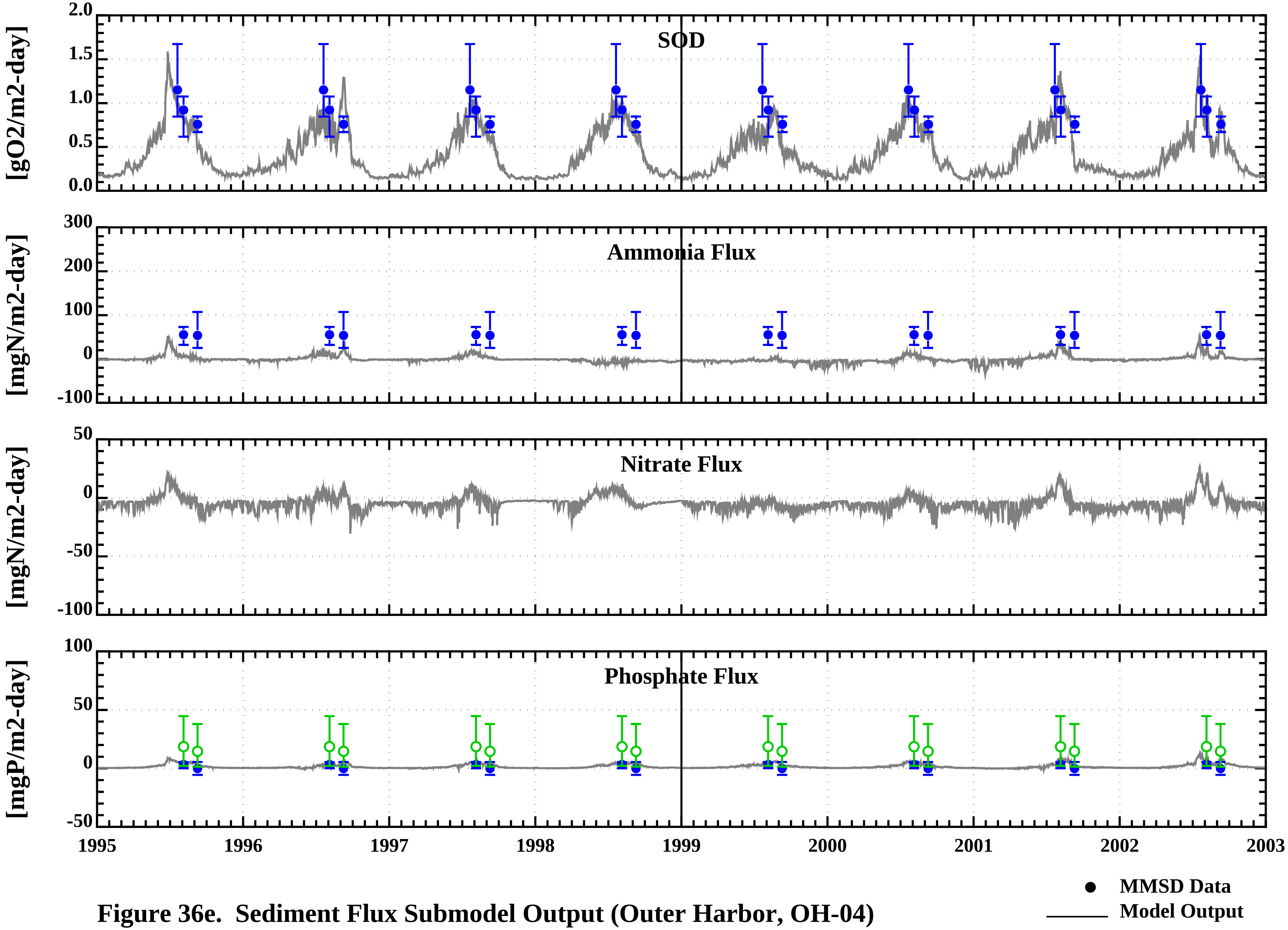


Figure 36e. Sediment Flux Submodel Output (Outer Harbor, OH-04)

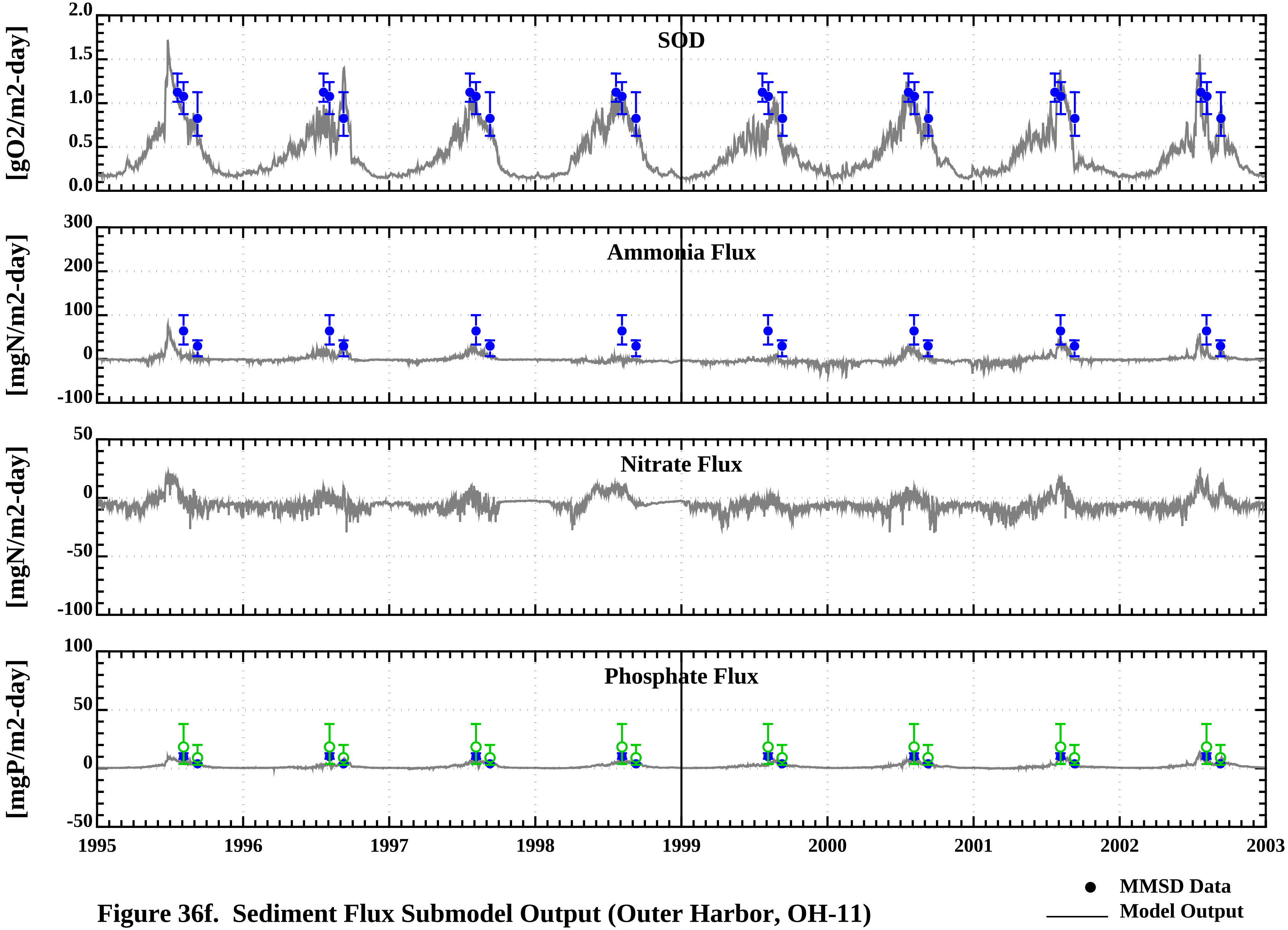


Figure 36f. Sediment Flux Submodel Output (Outer Harbor, OH-11)

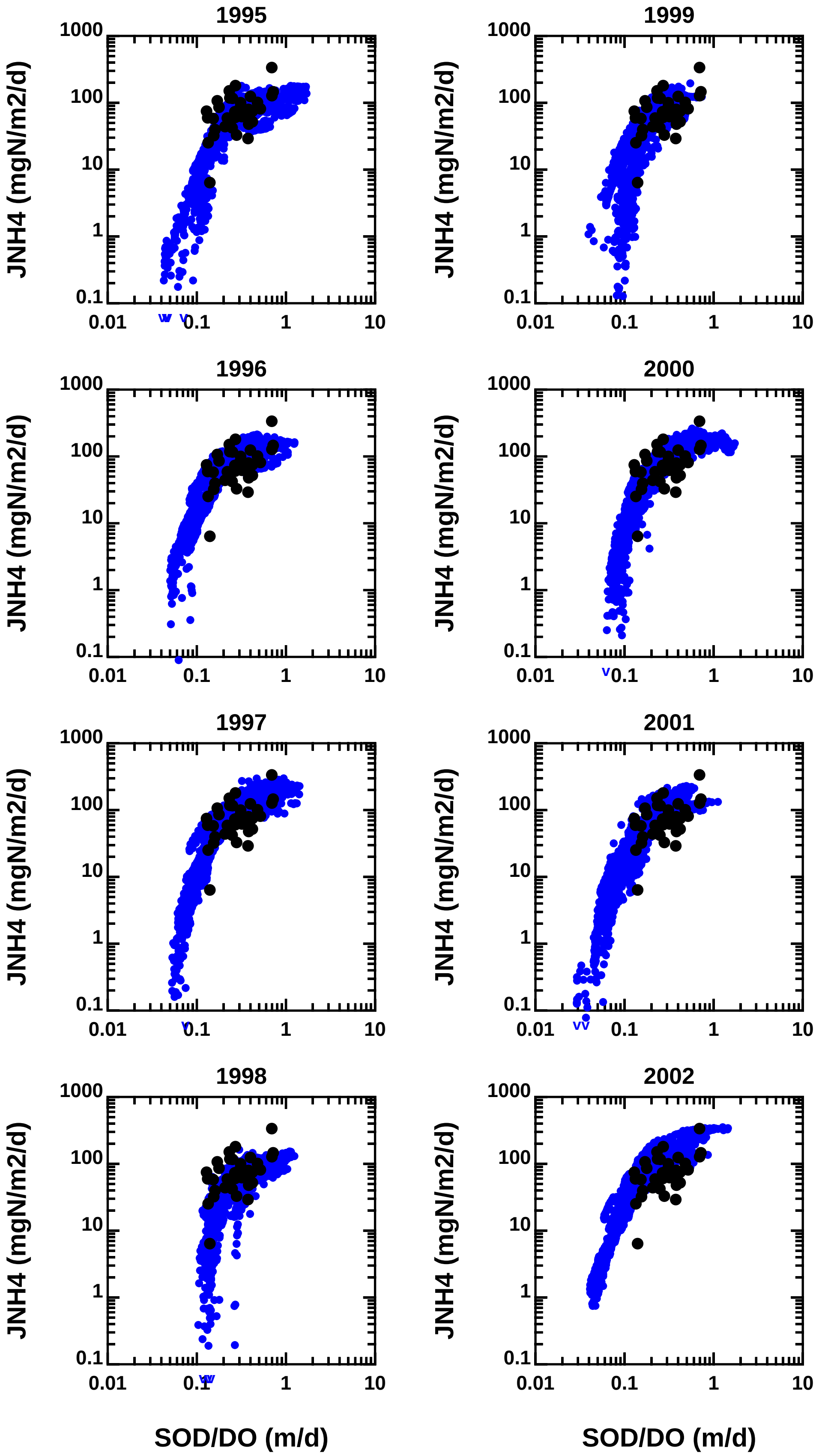


Figure 37. Milwaukee Harbor Sediment Flux Model Calibration
(Black - 2004 Data, Blue - 1995-2002 Model)

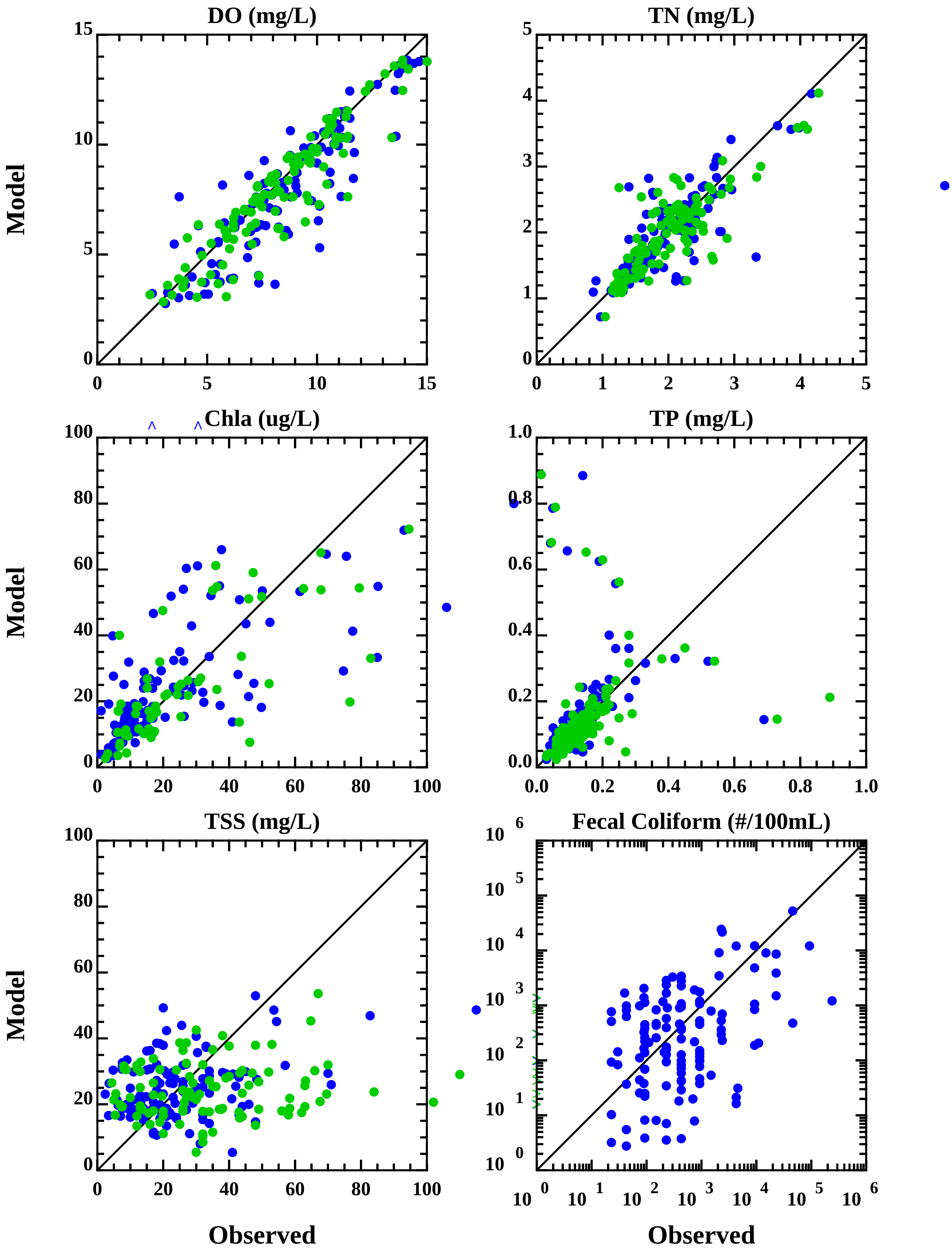


Figure 38a. Model Point to Point Comparisons at Station RI-07
(1995-2002 Period, Blue - Surface, Green - Bottom)

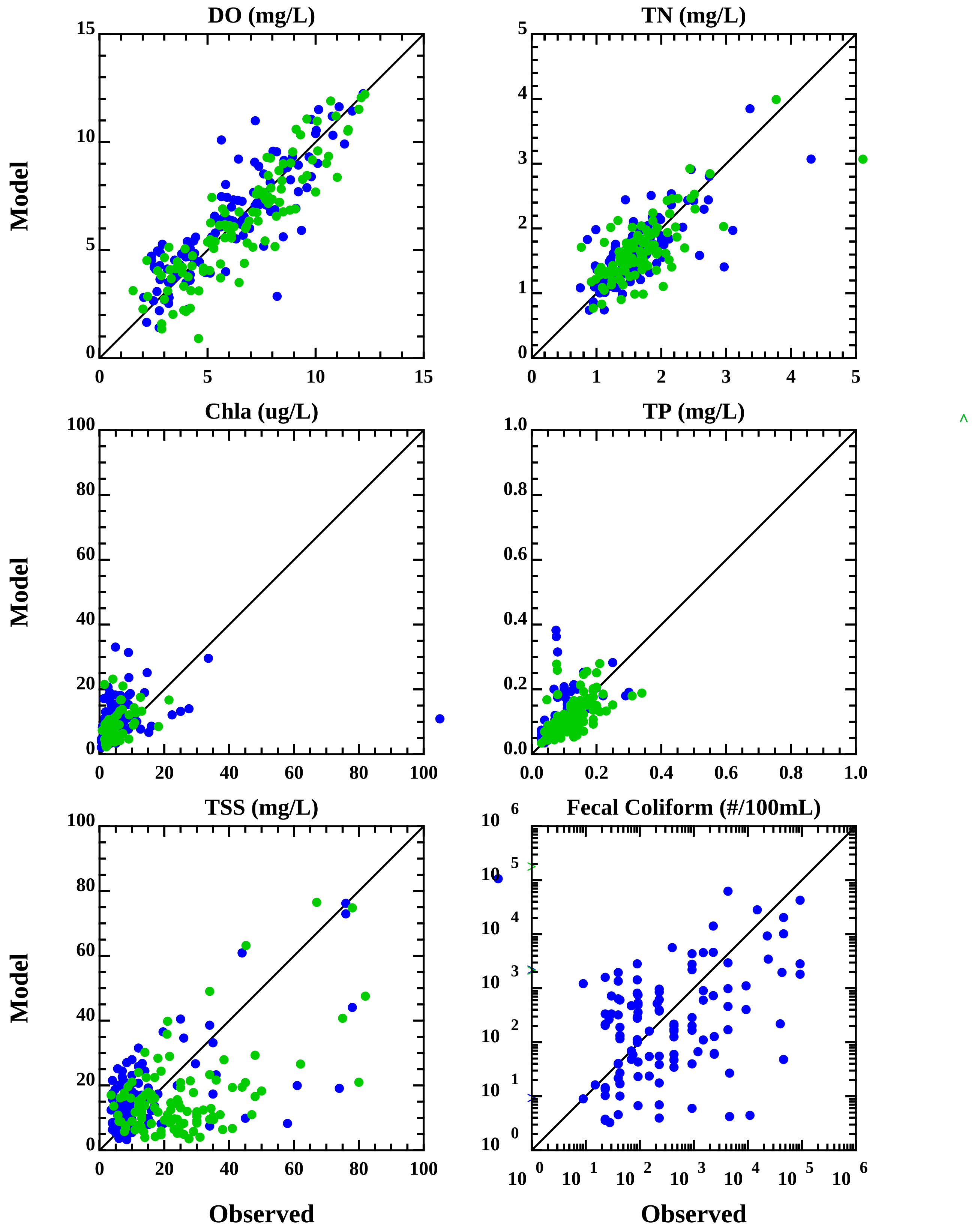


Figure 38b. Model Point to Point Comparisons at Station RI-11
(1995-2002 Period, Blue - Surface, Green - Bottom)

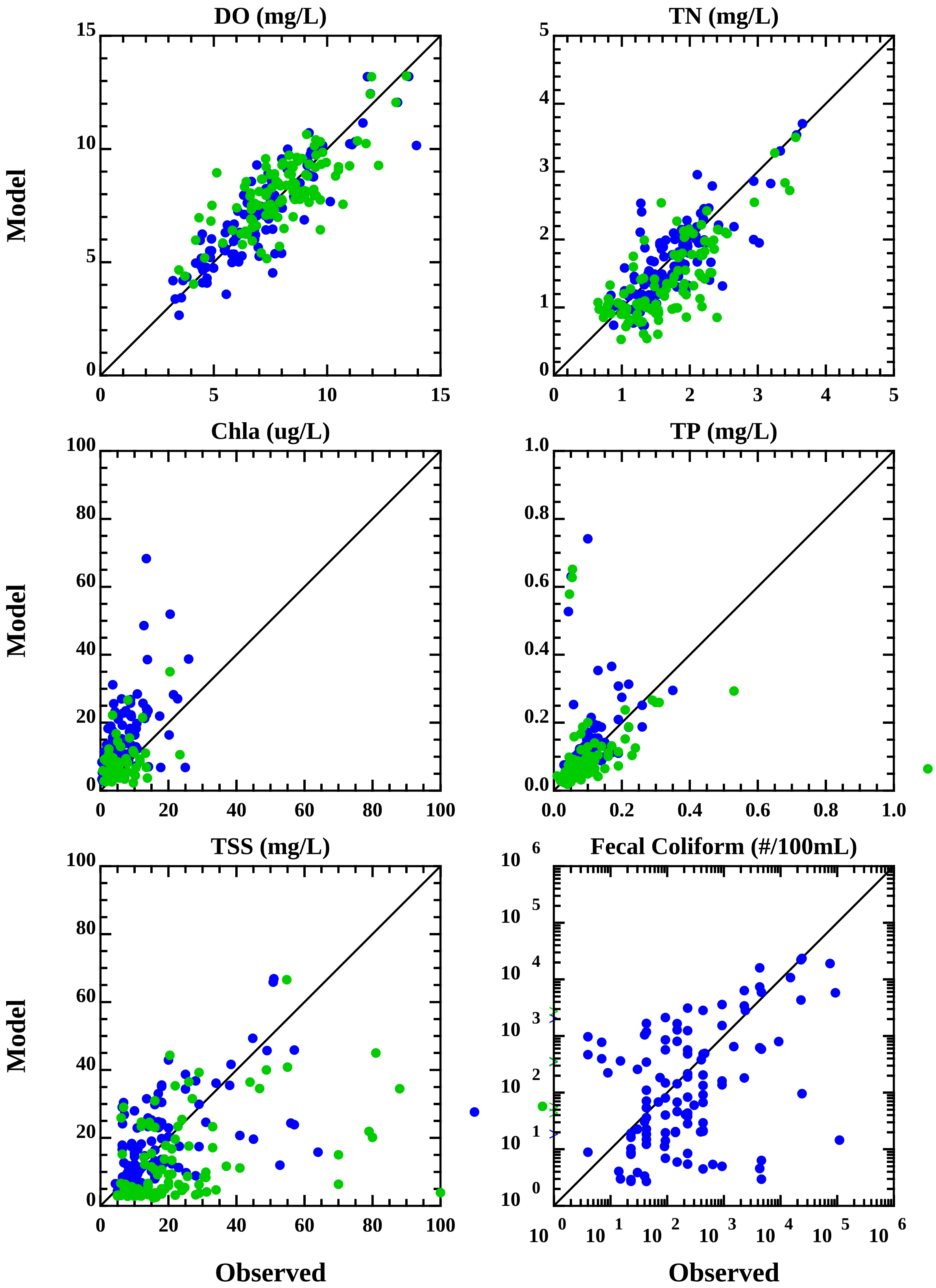


Figure 38c. Model Point to Point Comparisons at Station RI-15
(1995-2002 Period, Blue - Surface, Green - Bottom)

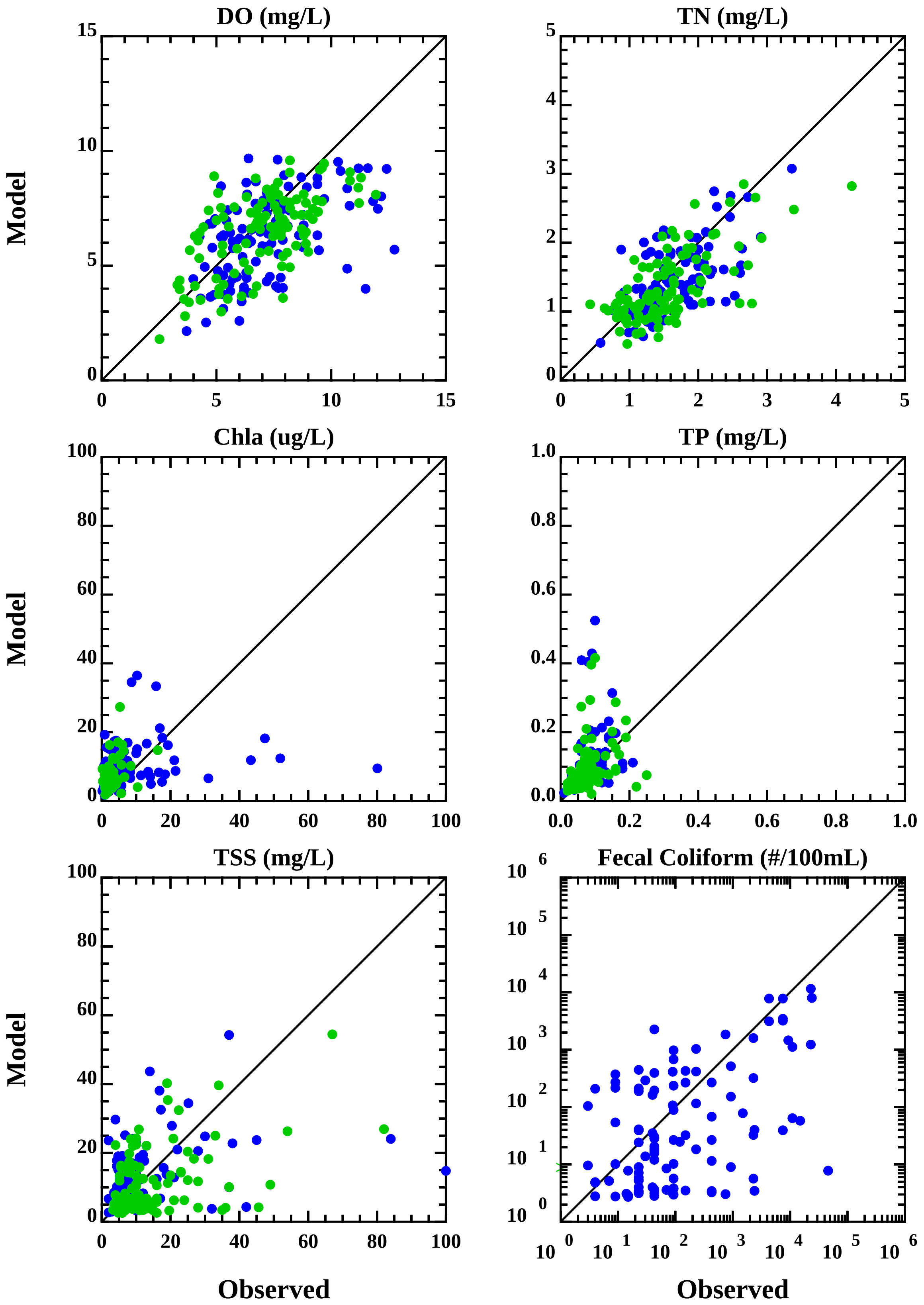


Figure 38d. Model Point to Point Comparisons at Station RI-18
(1995-2002 Period, Blue - Surface, Green - Bottom)

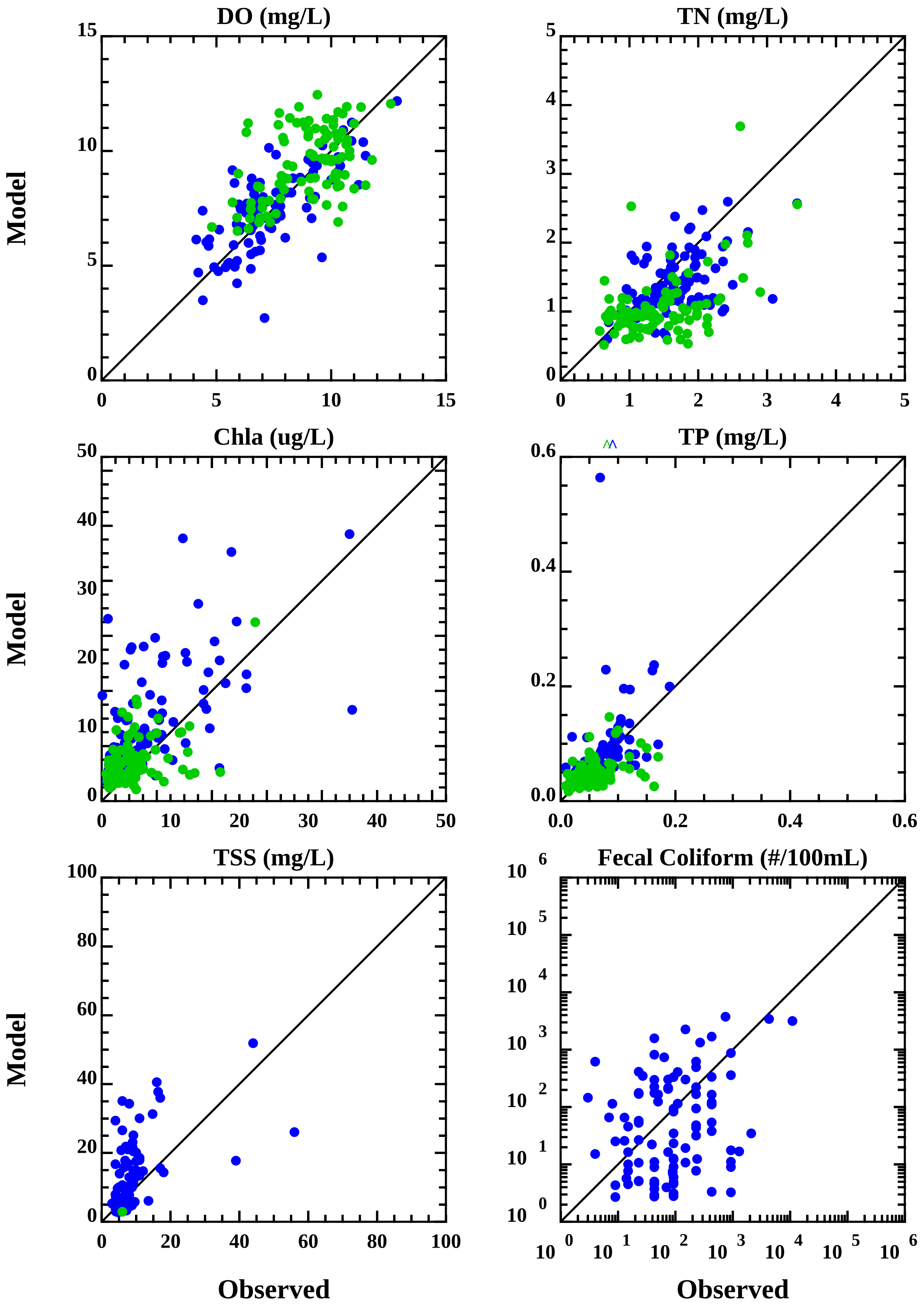


Figure 38e. Model Point to Point Comparisons at Station OH-01
(1995-2002 Period, Blue - Surface, Green - Bottom)

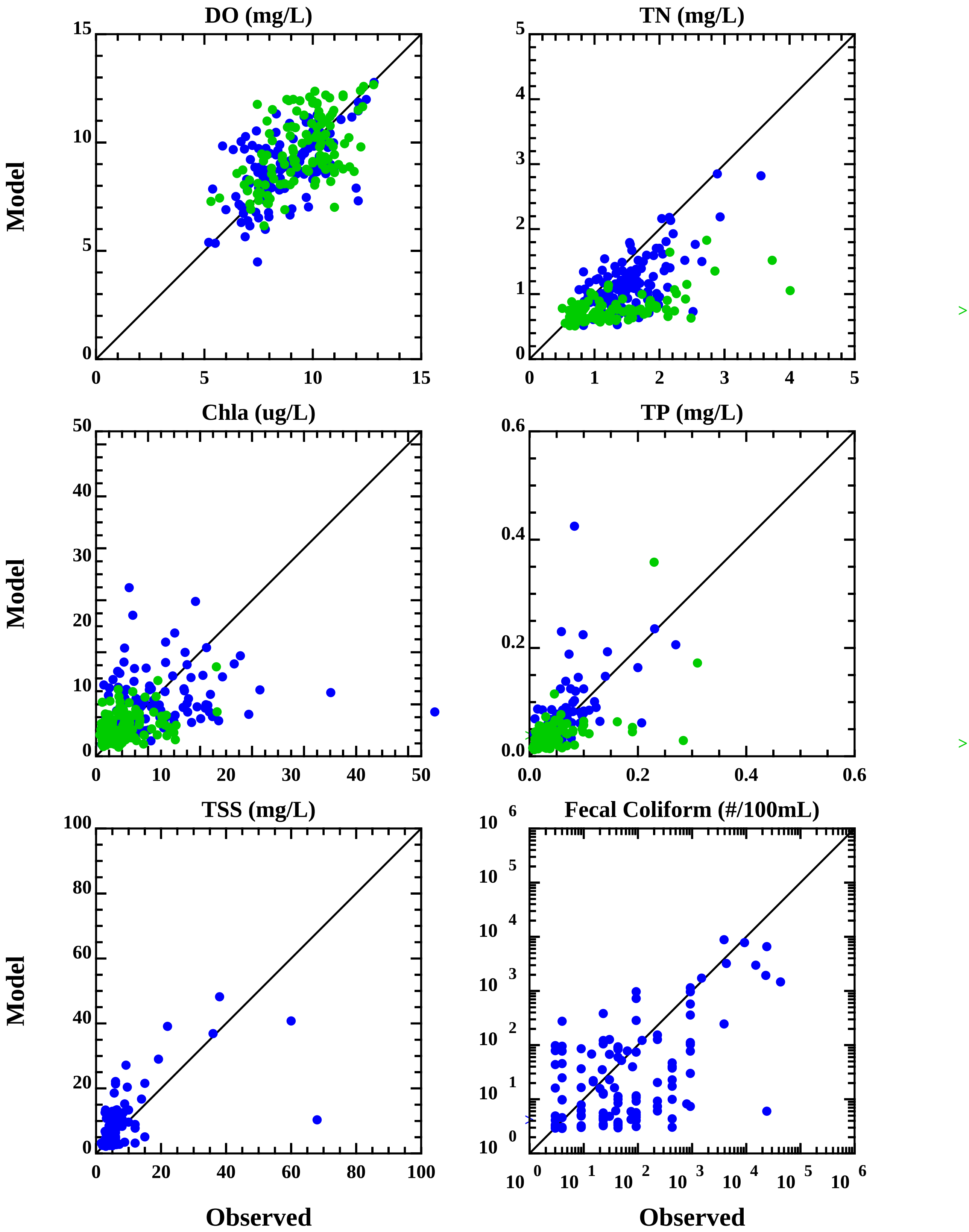


Figure 38f. Model Point to Point Comparisons at Station OH-03
(1995-2002 Period, Blue - Surface, Green - Bottom)

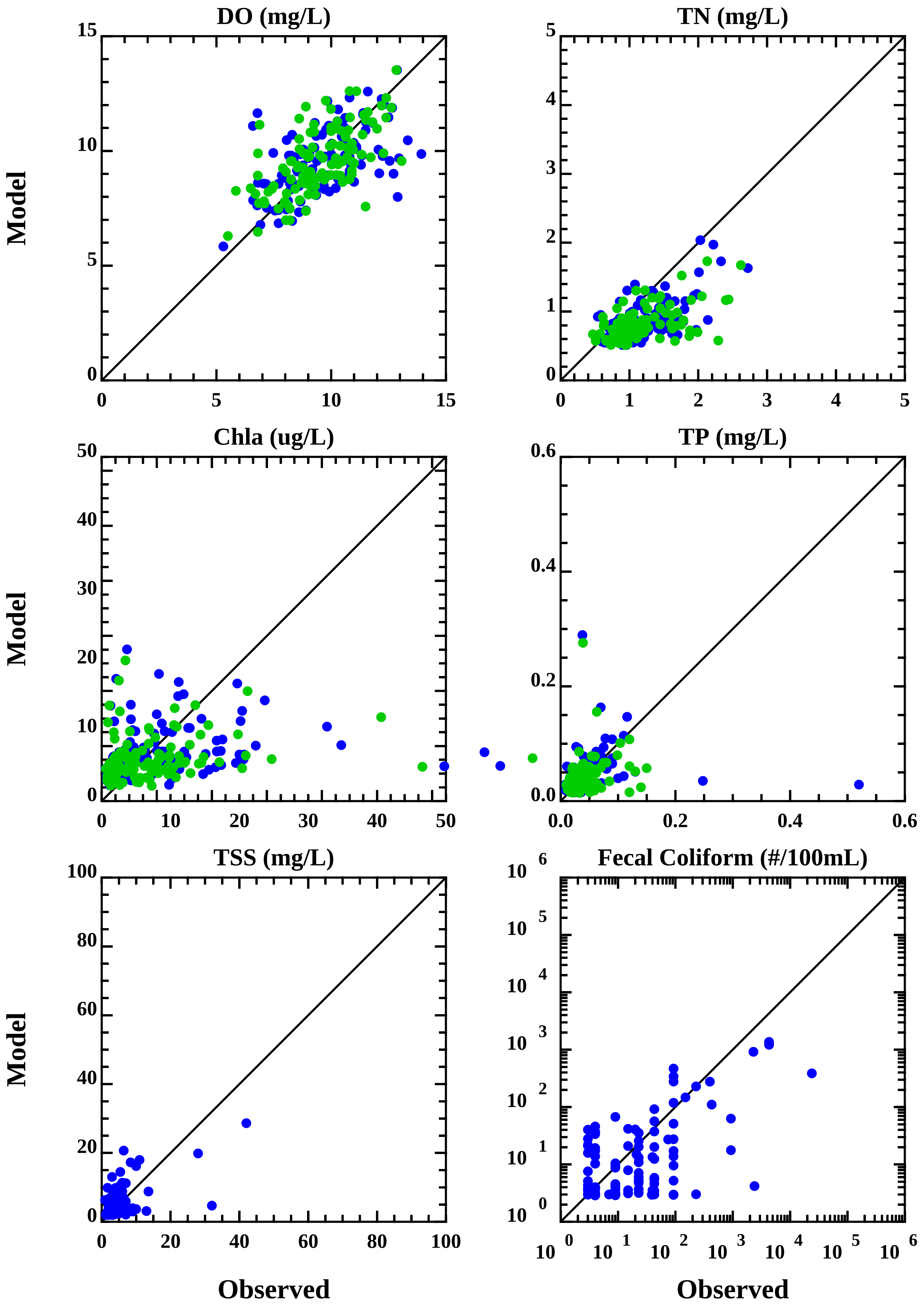


Figure 38g. Model Point to Point Comparisons at Station OH-04
(1995-2002 Period, Blue - Surface, Green - Bottom)

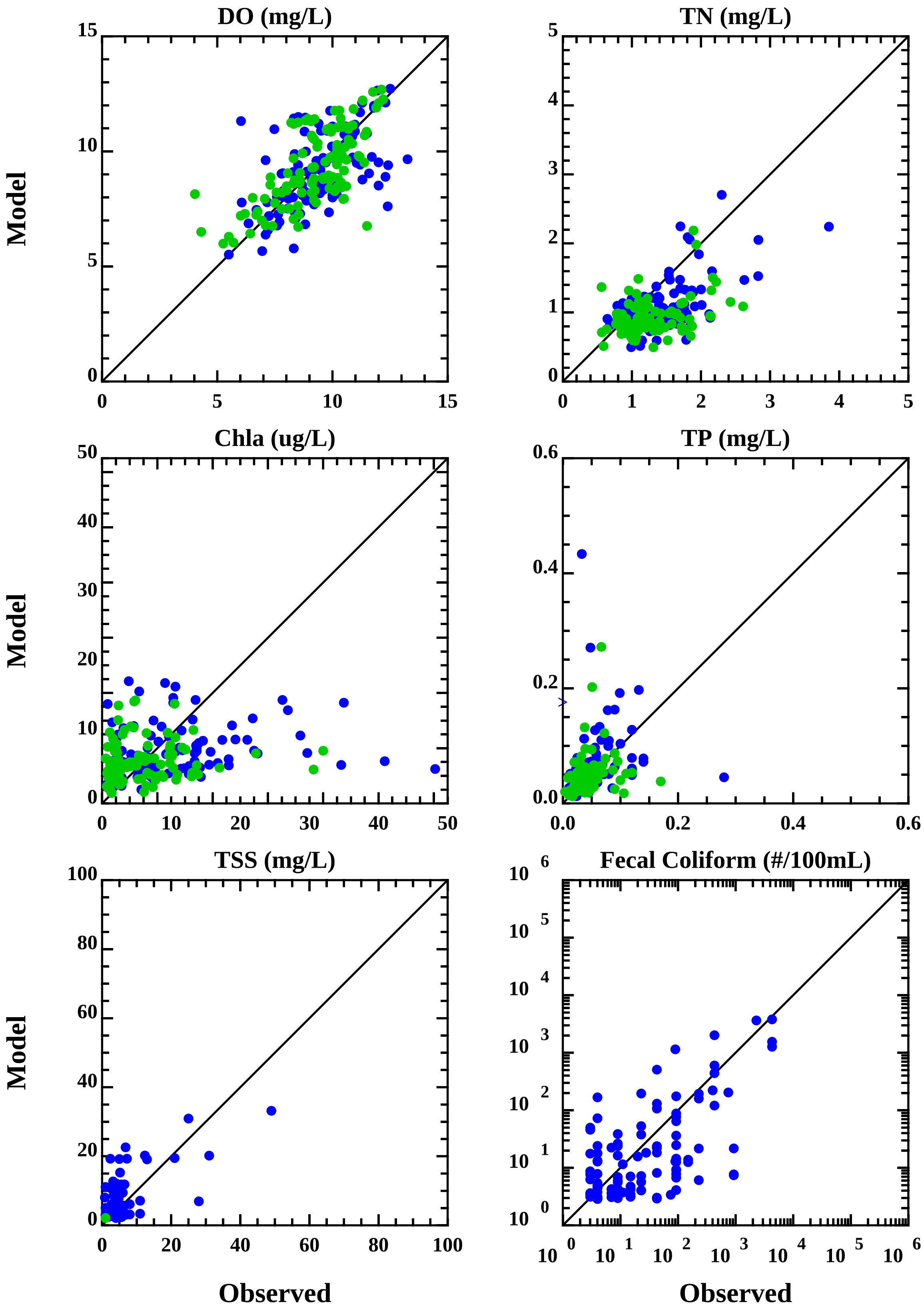


Figure 38h. Model Point to Point Comparisons at Station OH-11
(1995-2002 Period, Blue - Surface, Green - Bottom)

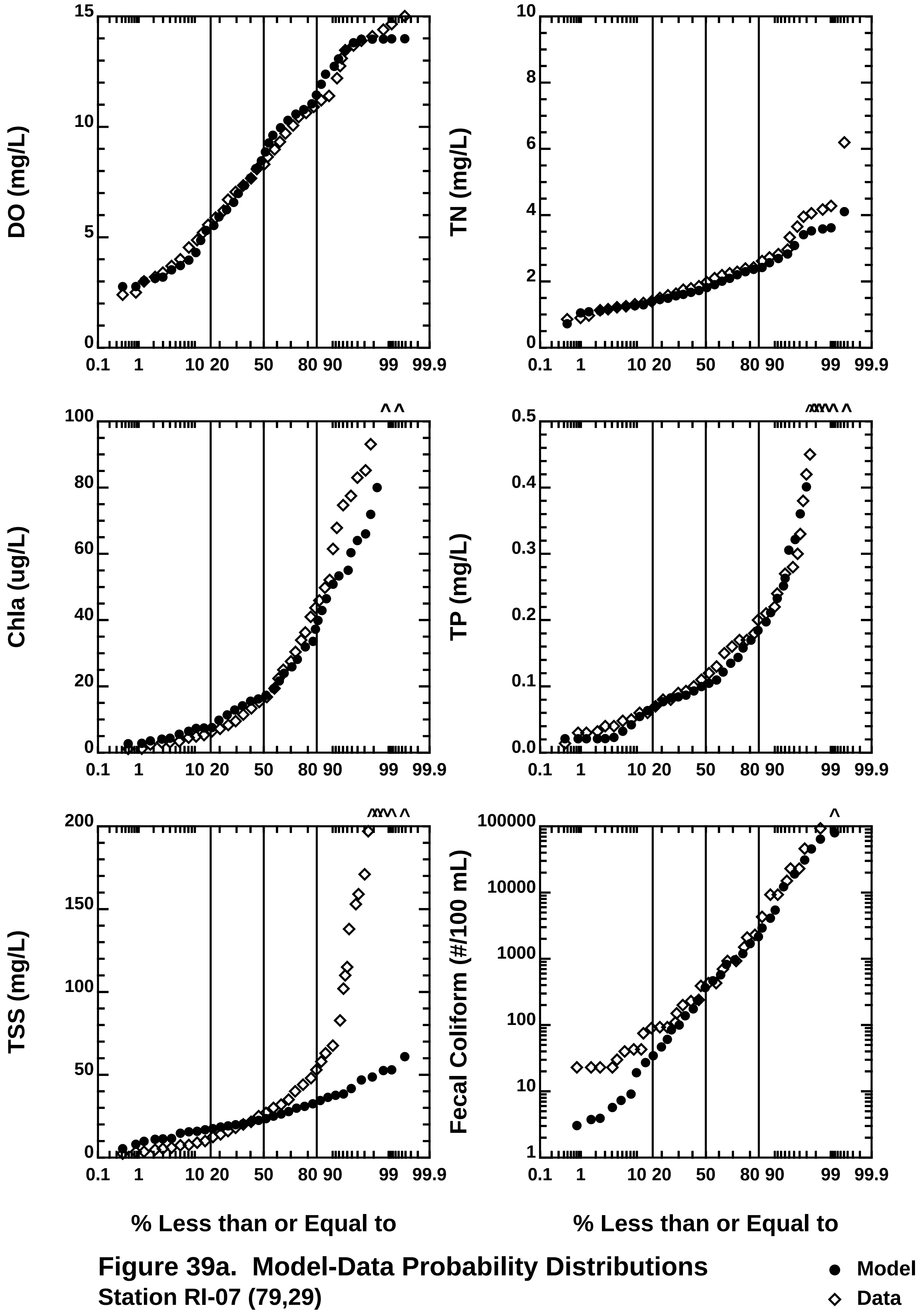


Figure 39a. Model-Data Probability Distributions
Station RI-07 (79,29)

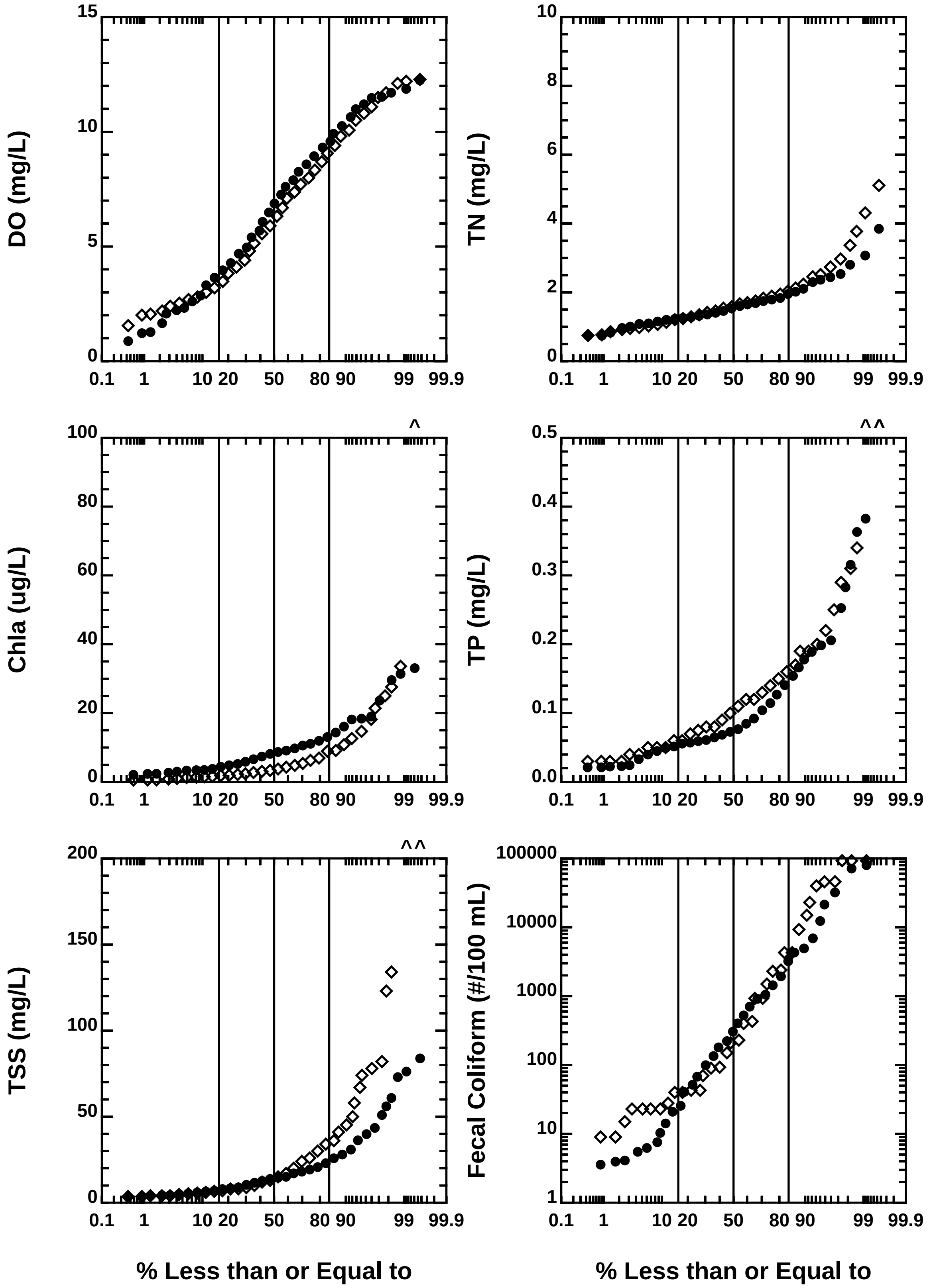


Figure 39b. Model-Data Probability Distributions
Station RI-11 (72,37)

● Model
◇ Data

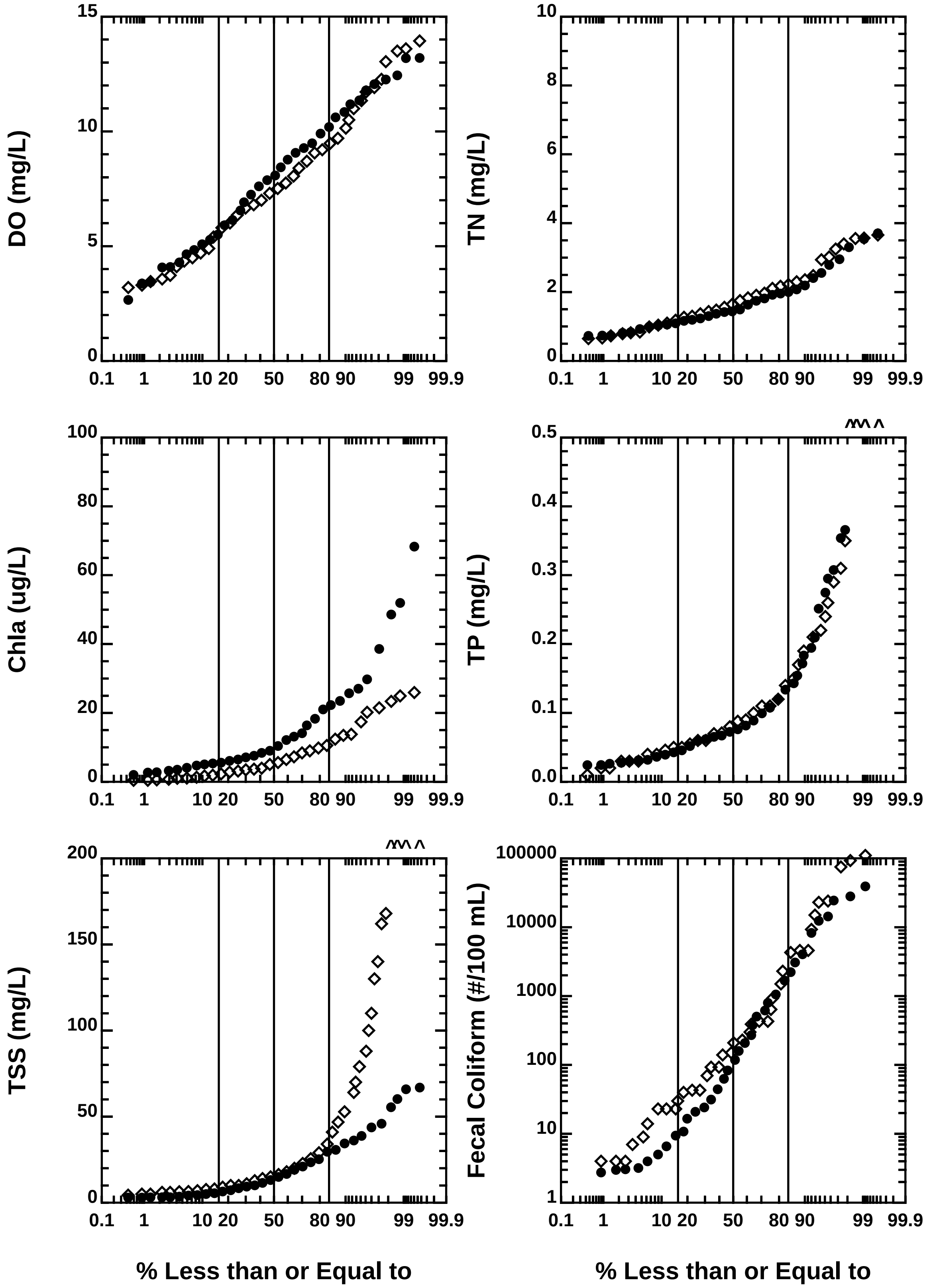


Figure 39c. Model-Data Probability Distributions
Station RI-15 (67,29)

● Model
◇ Data

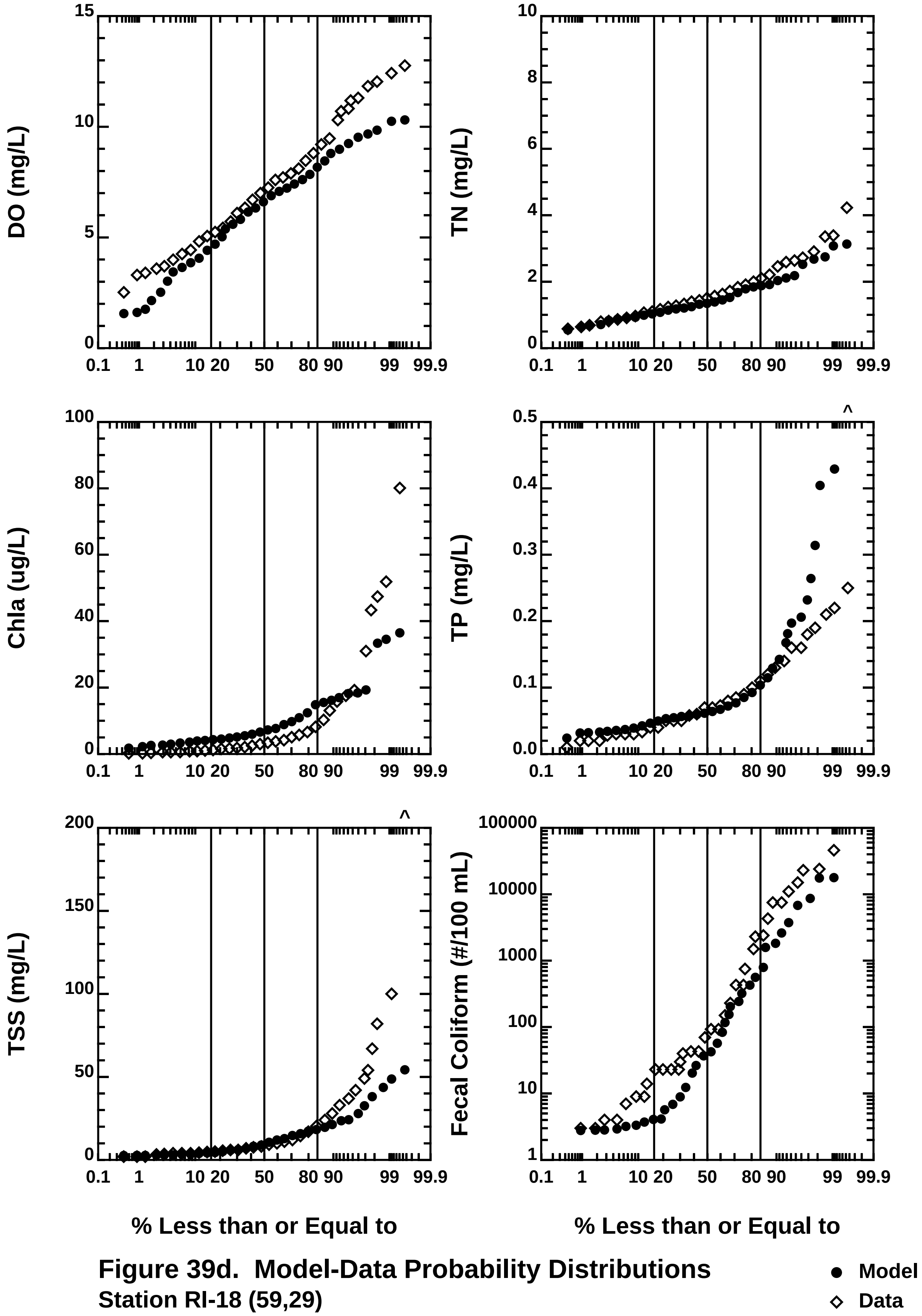


Figure 39d. Model-Data Probability Distributions
Station RI-18 (59,29)

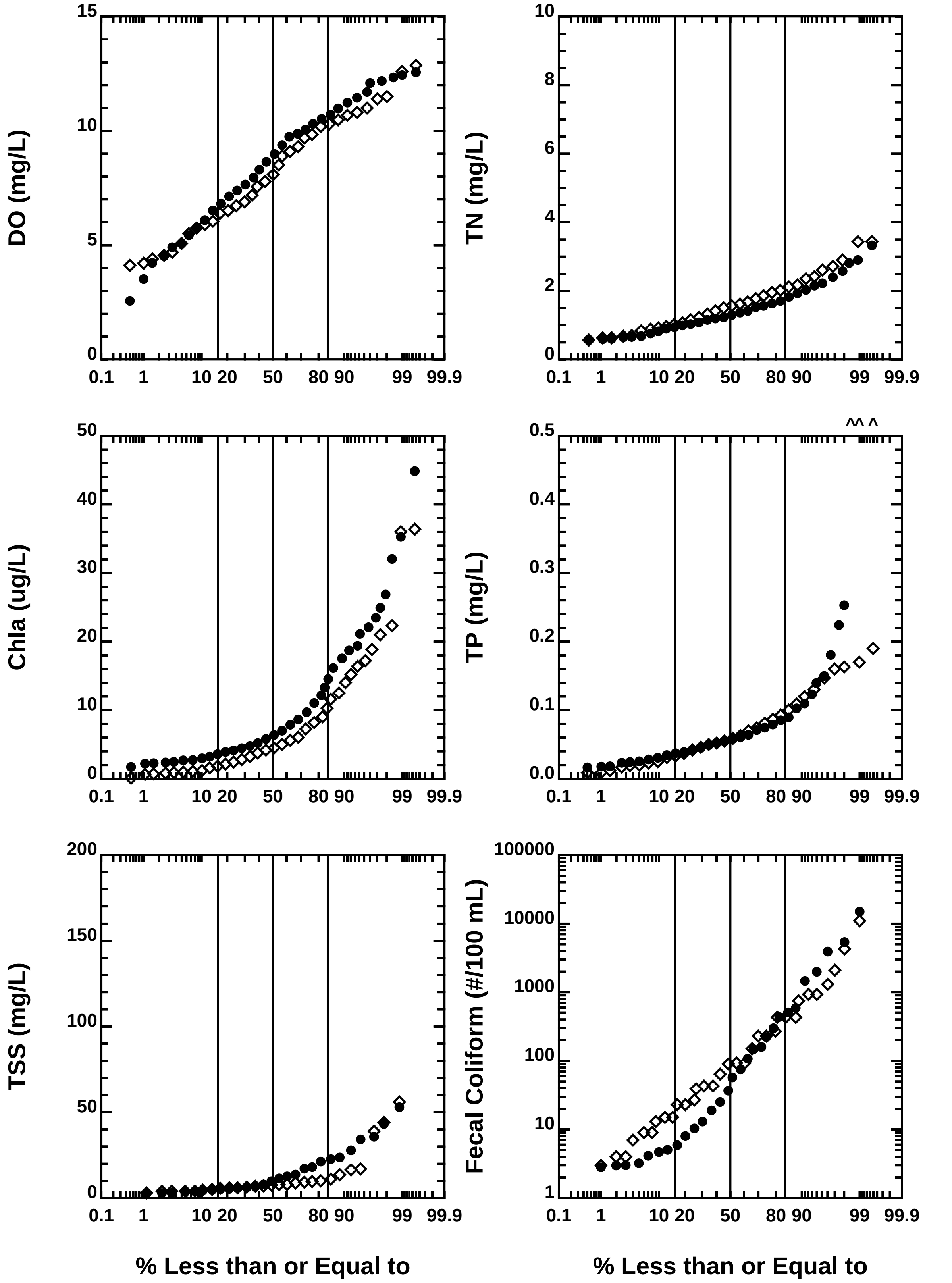


Figure 39e. Model-Data Probability Distributions
Station OH-01 (64,24)

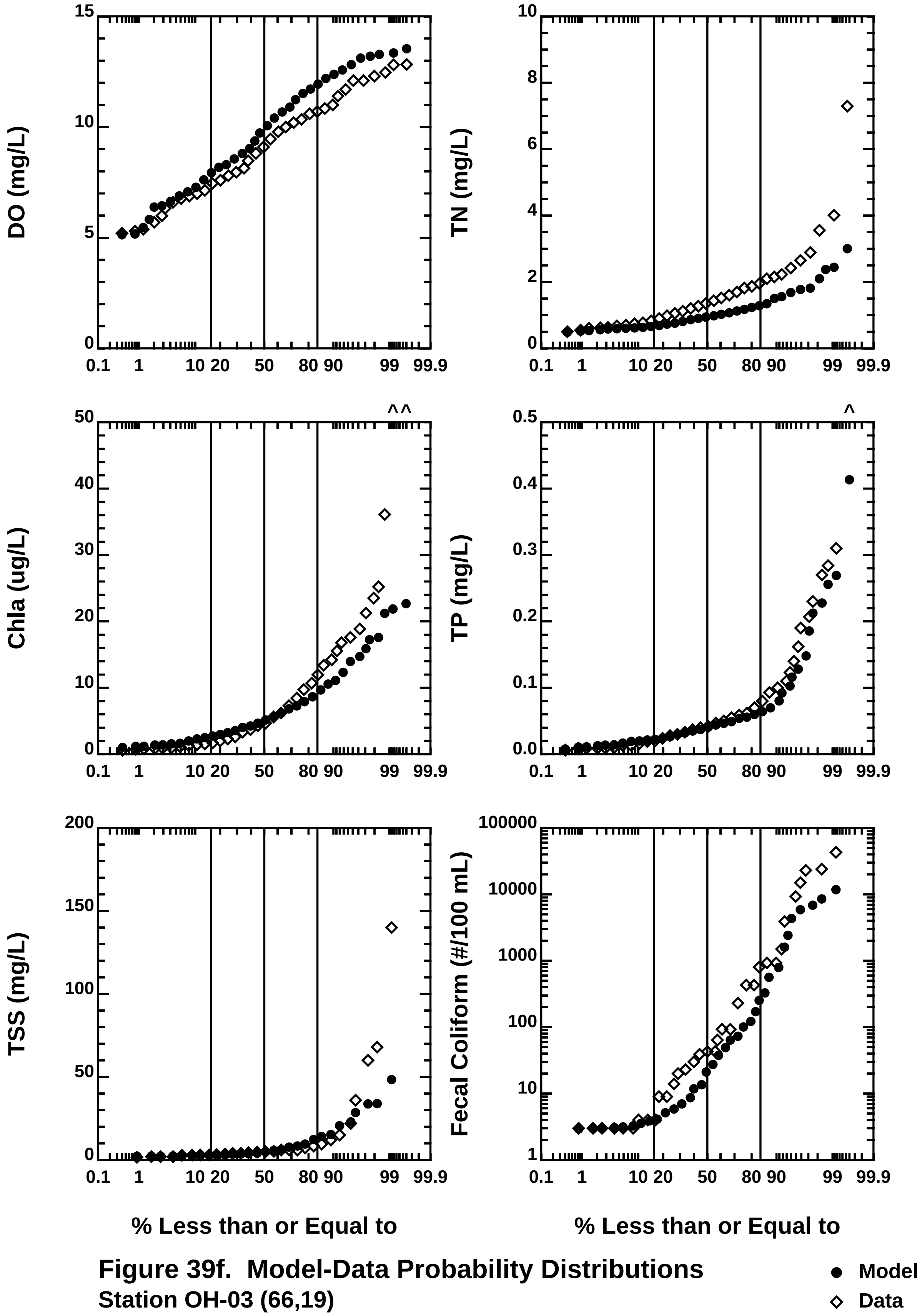


Figure 39f. Model-Data Probability Distributions
Station OH-03 (66,19)

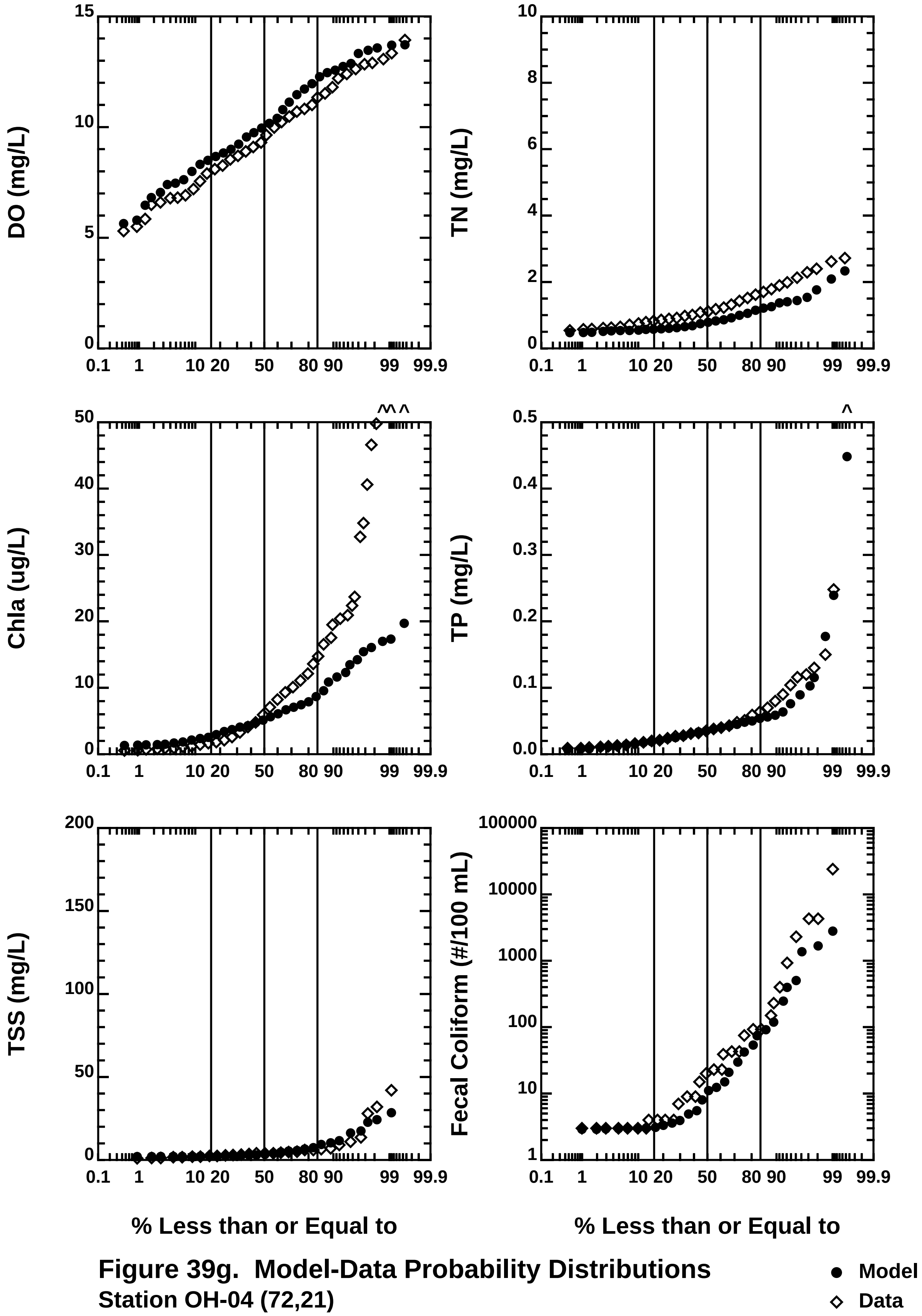


Figure 39g. Model-Data Probability Distributions
Station OH-04 (72,21)

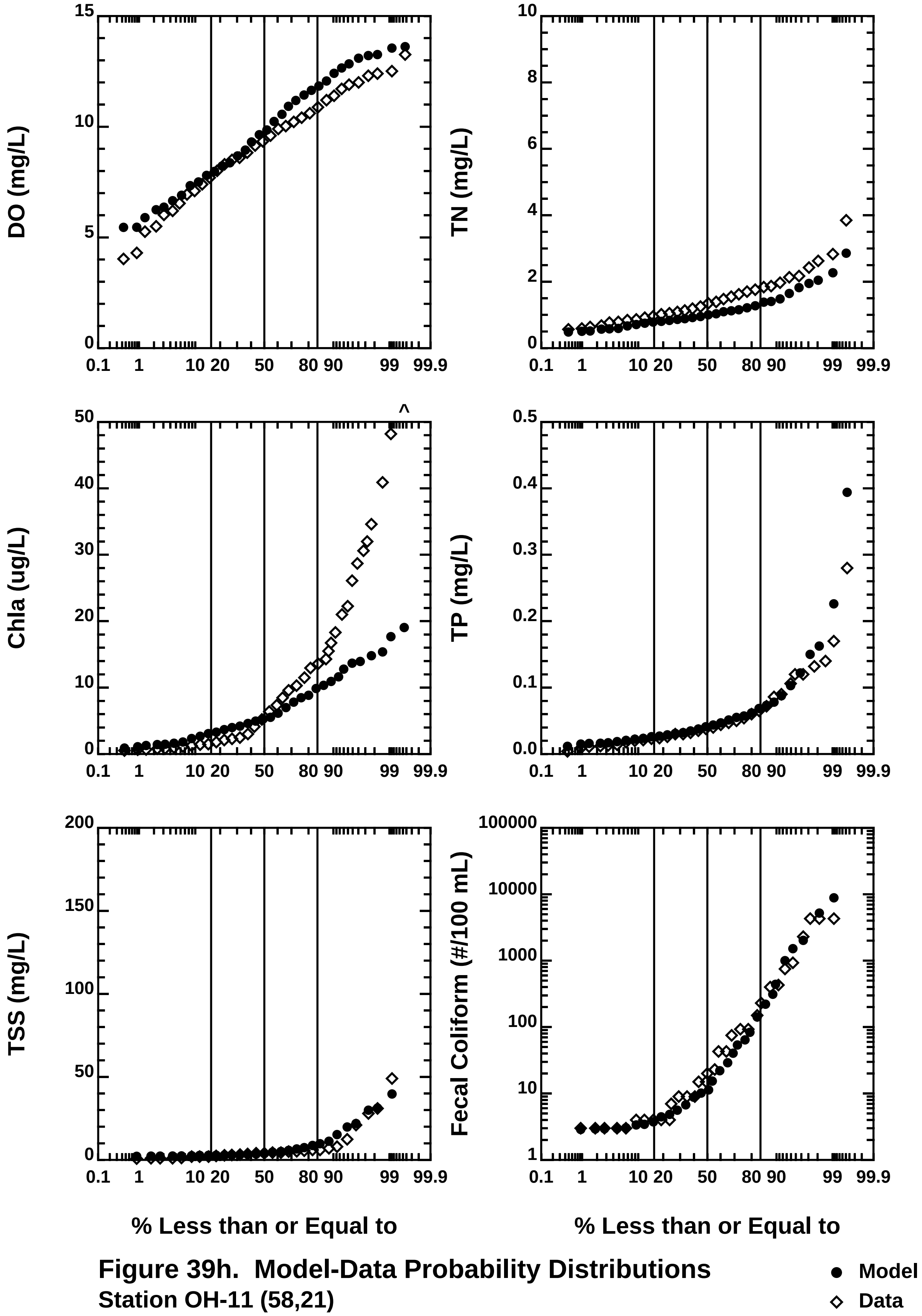
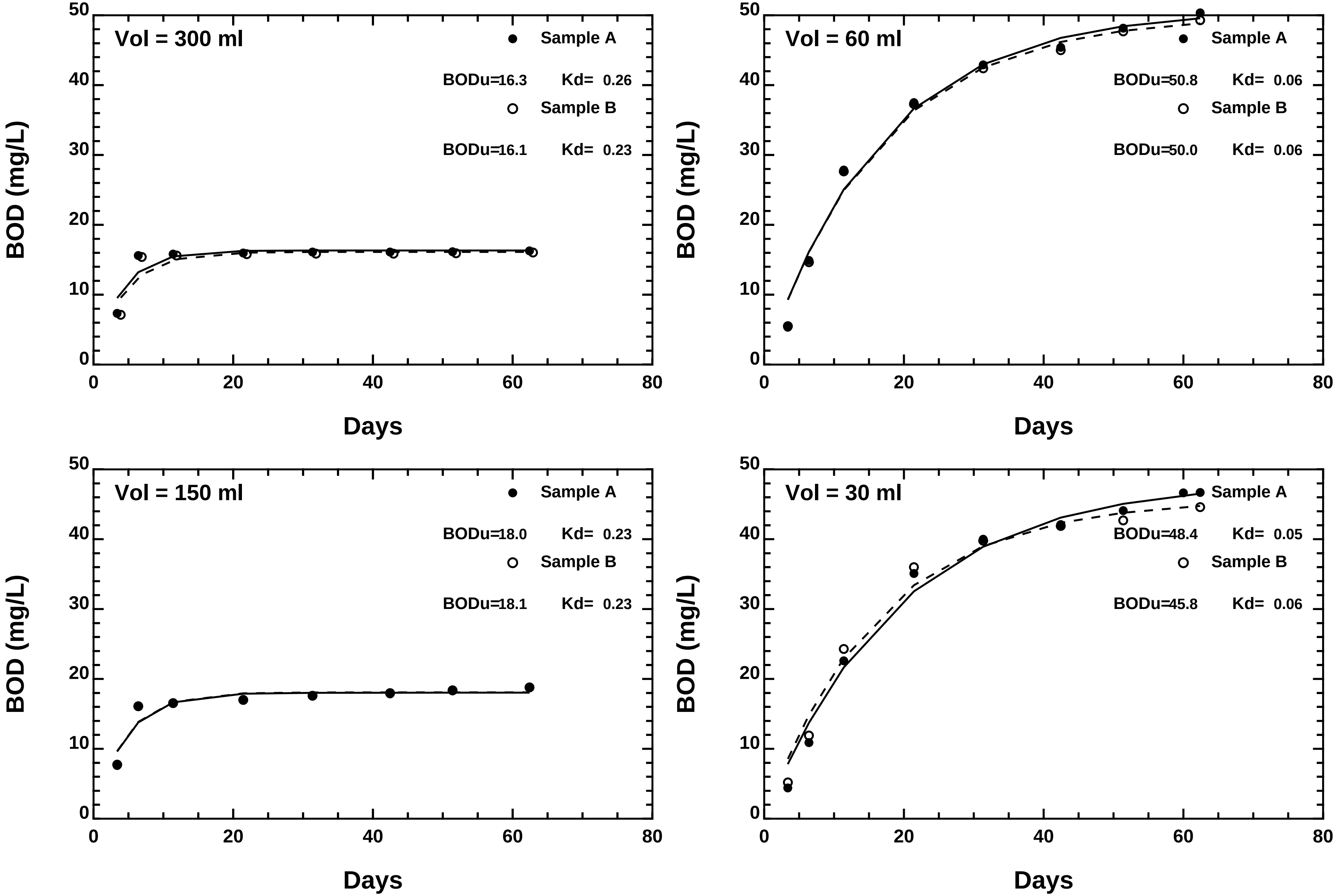


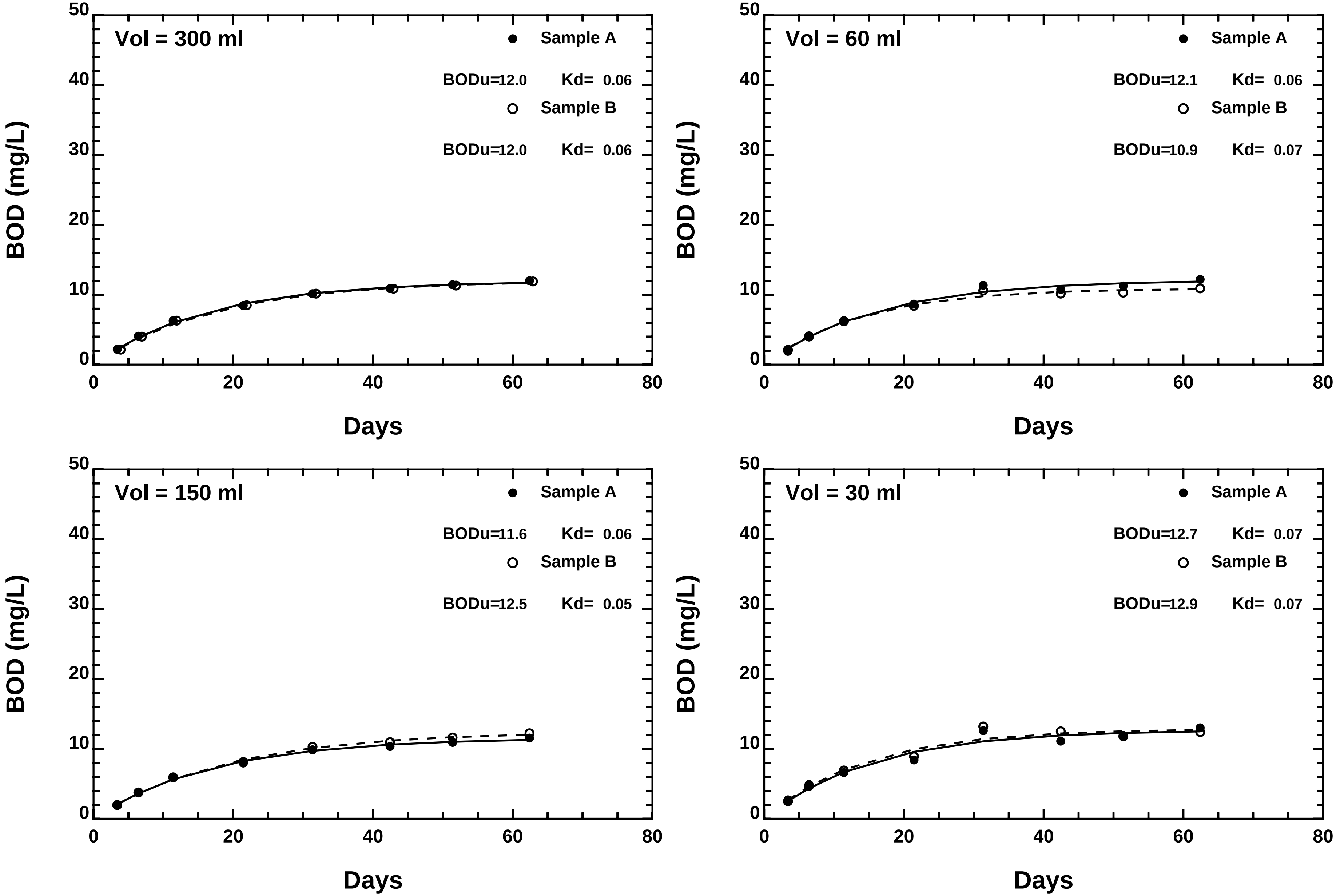
Figure 39h. Model-Data Probability Distributions
Station OH-11 (58,21)

APPENDIX 1

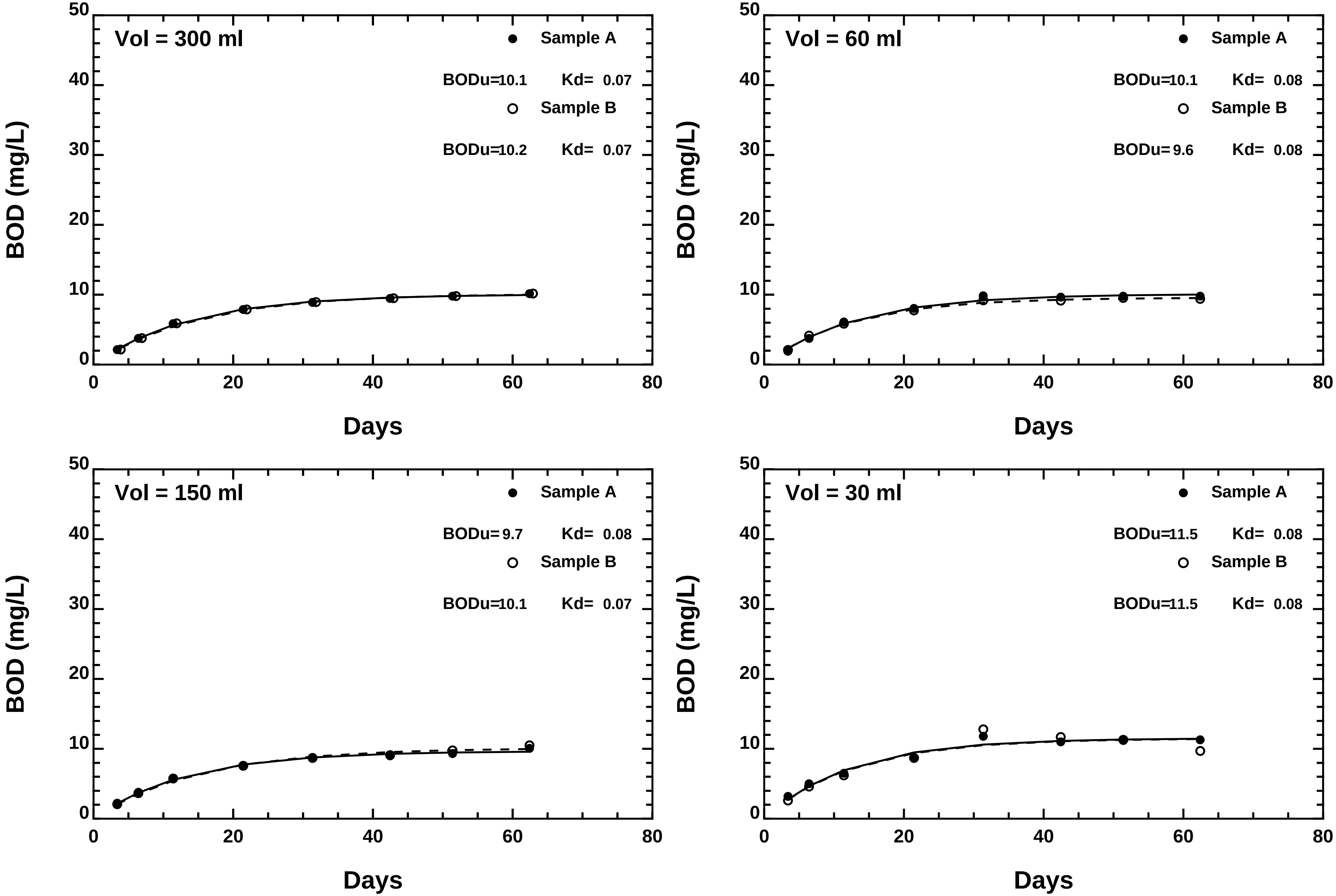
LTBOD STUDY 2004 RESULTS



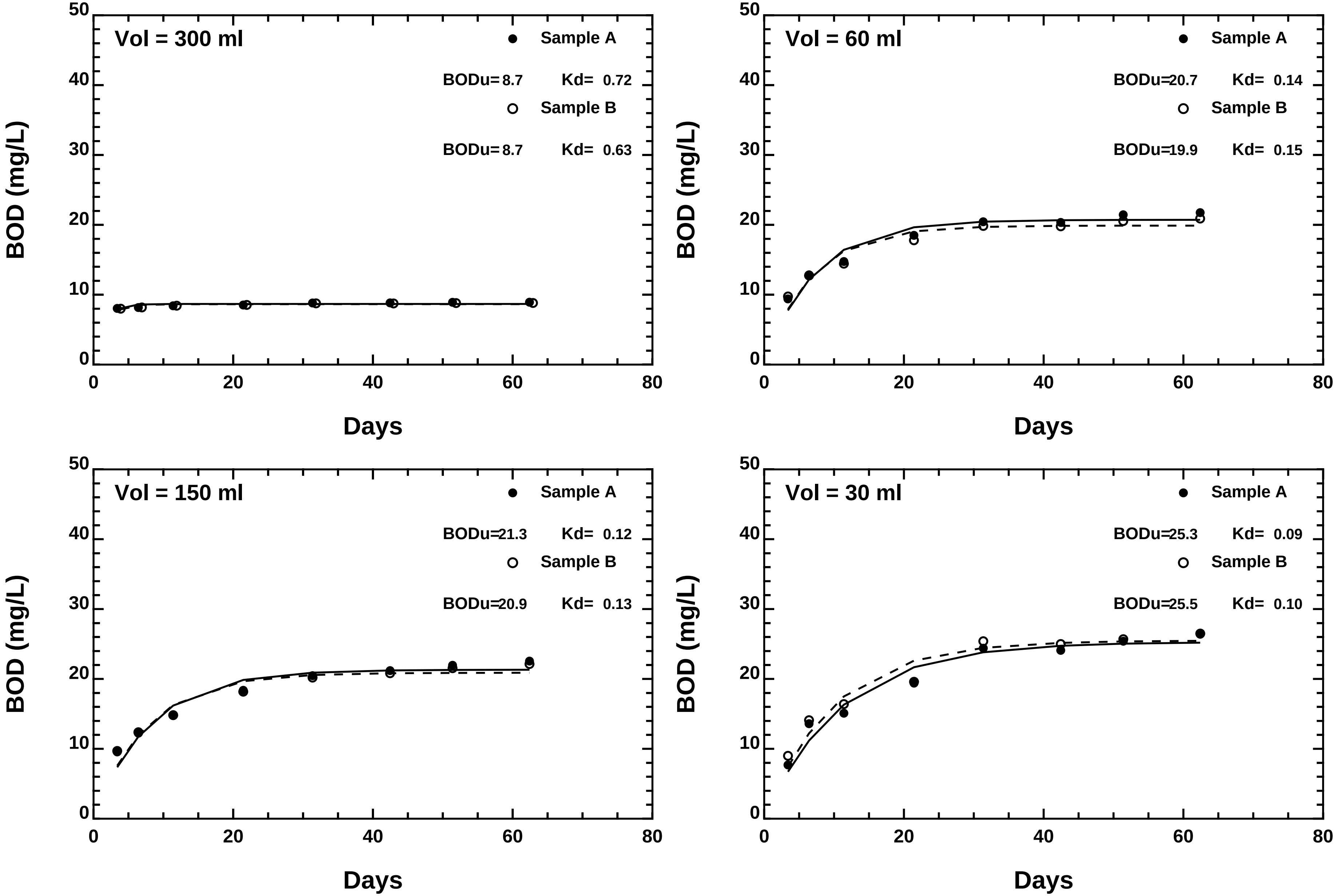
LTBOD analysis, Station JIEF, 4/21/2004



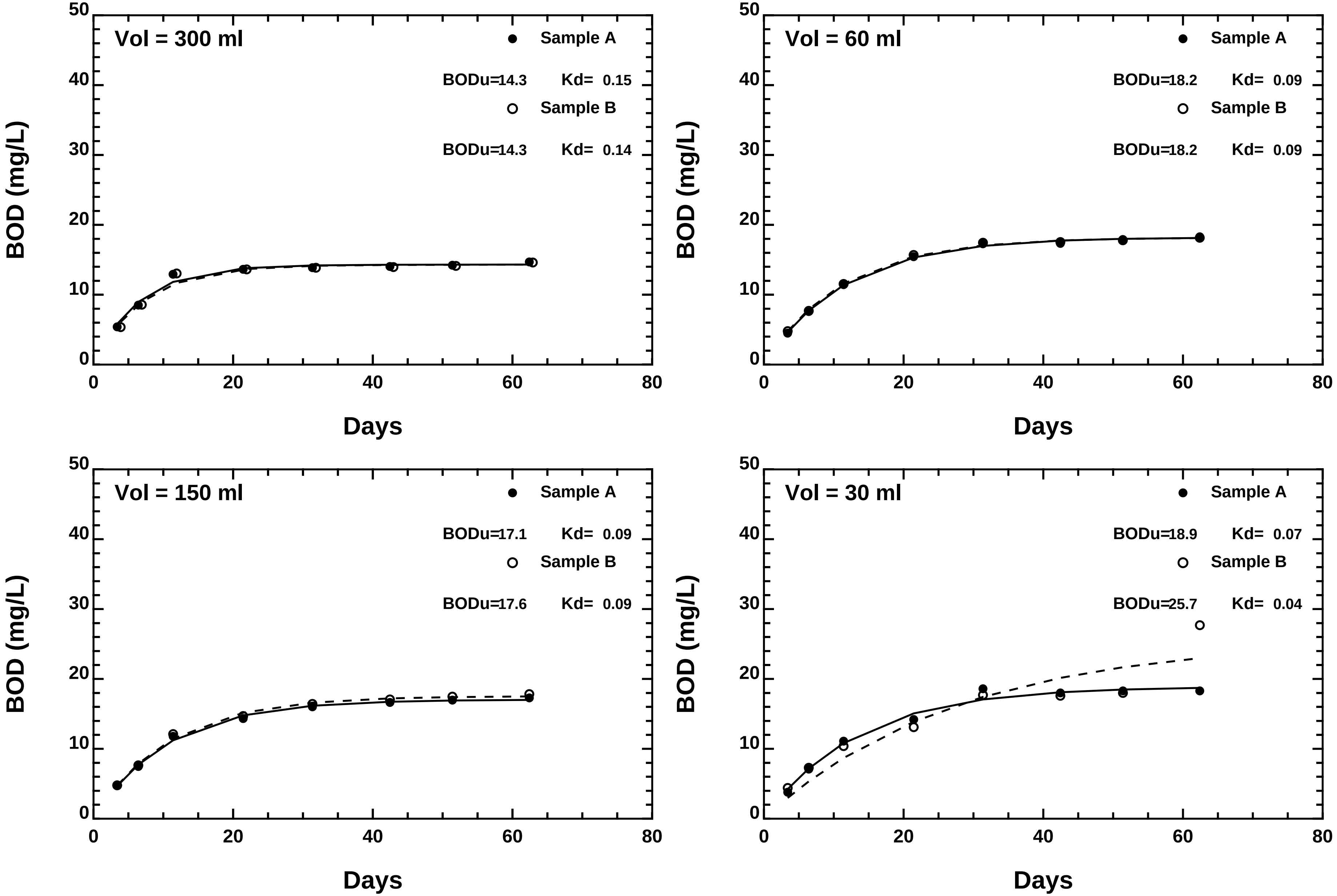
LTBOD analysis, Station MI05, 4/21/2004



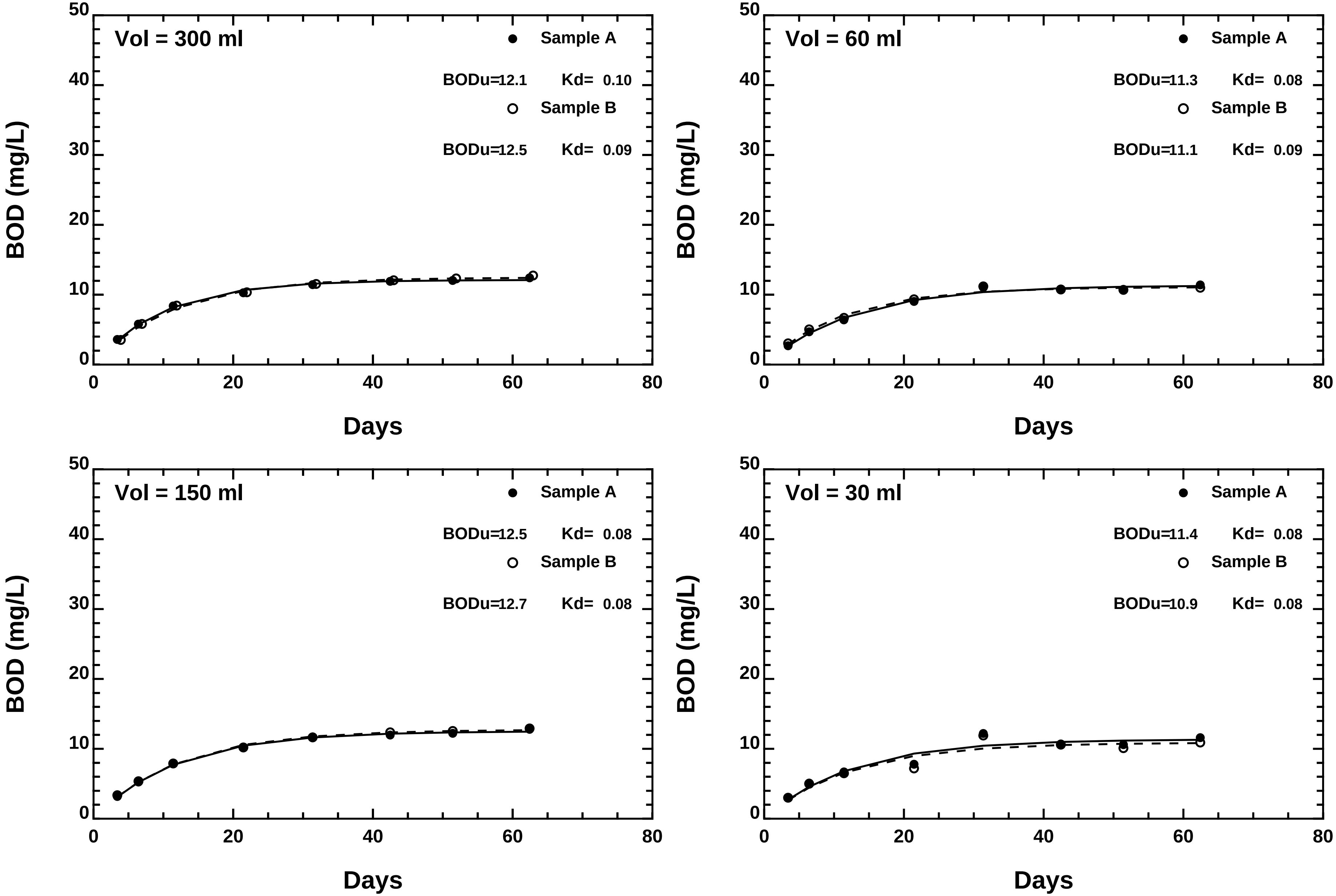
LTBOD analysis, Station MI07, 4/21/2004



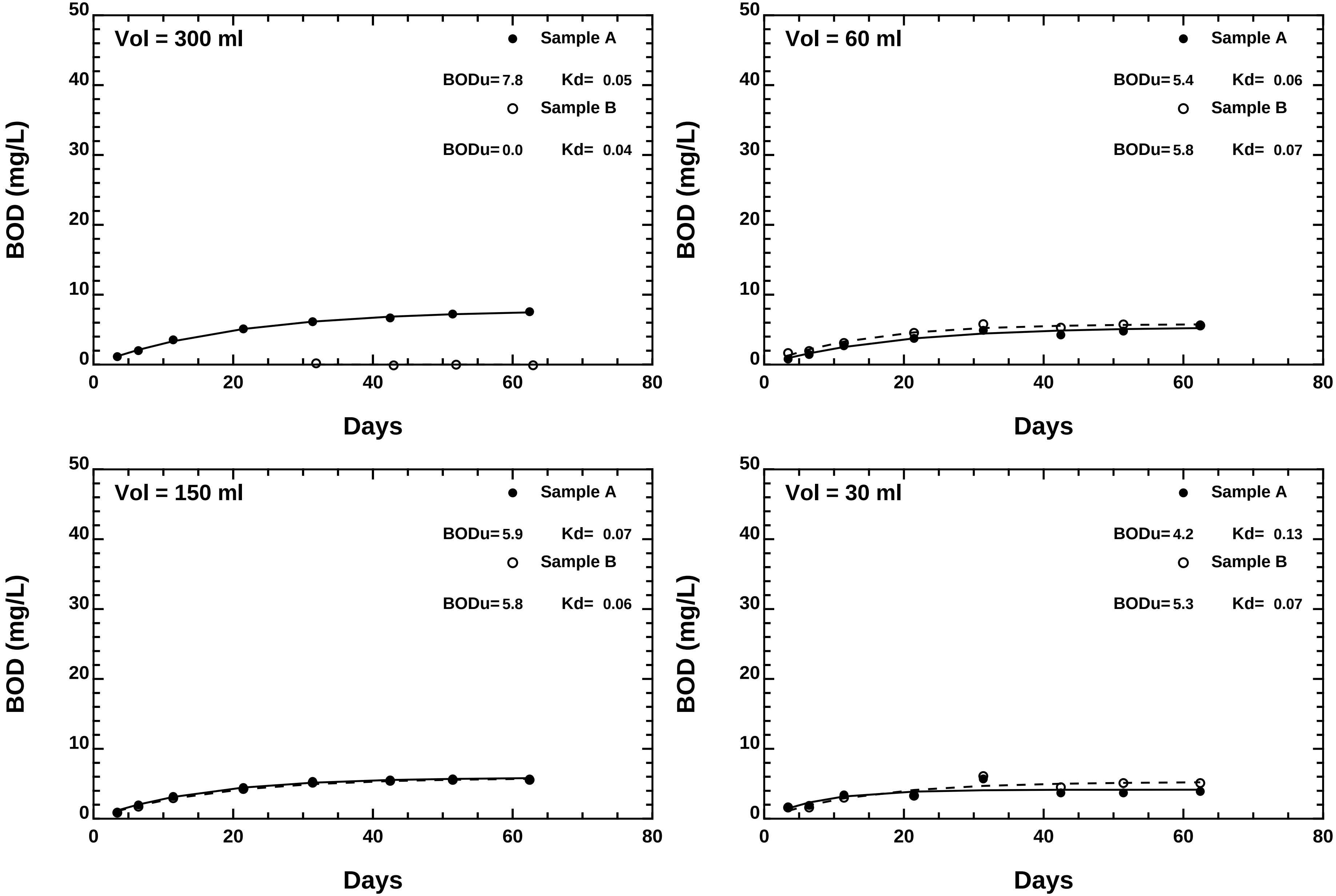
LTBOD analysis, Station KK13, 4/21/2004



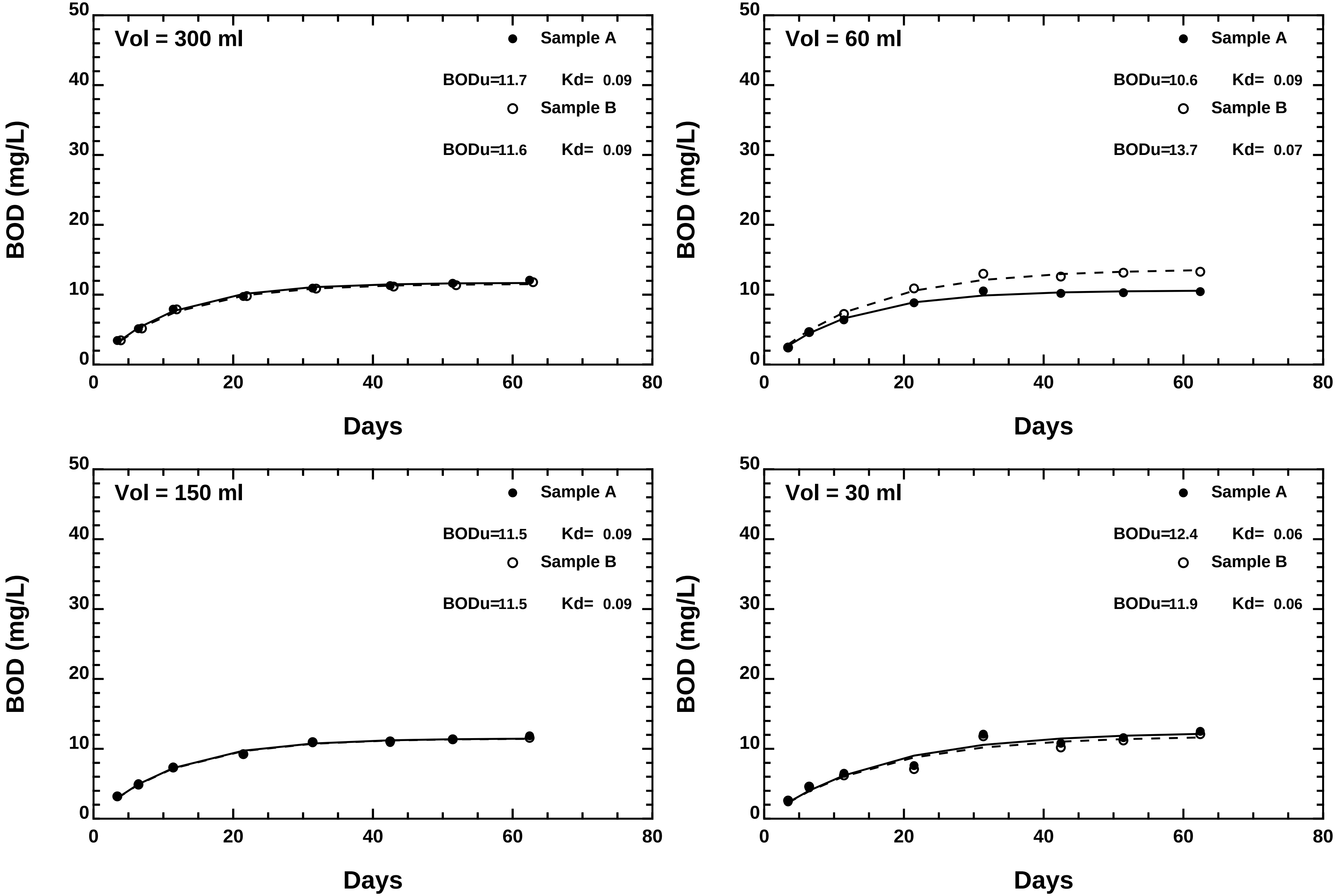
LTBOD analysis, Station KK14, 4/21/2004



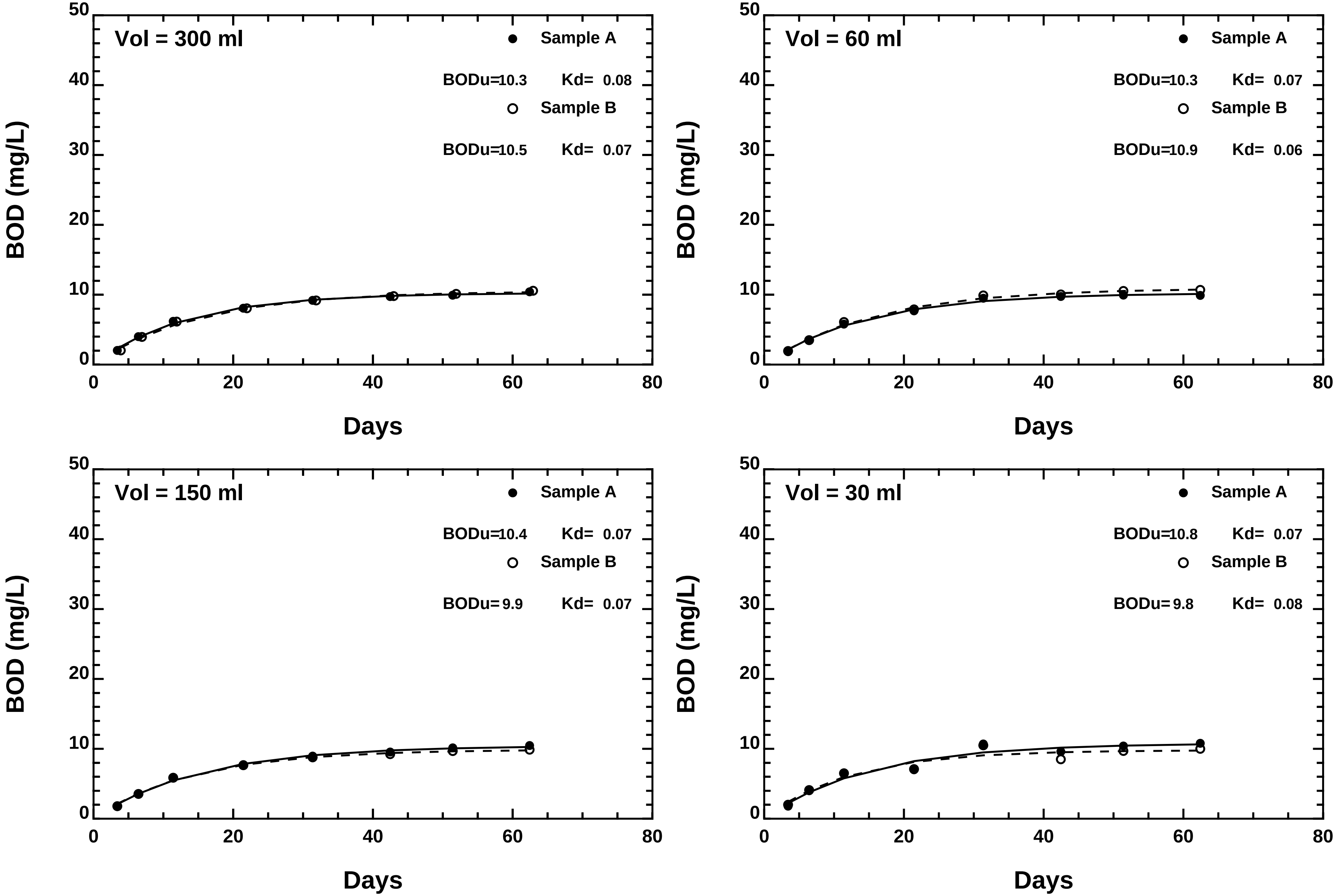
LTBOD analysis, Station CO15, 4/21/2004



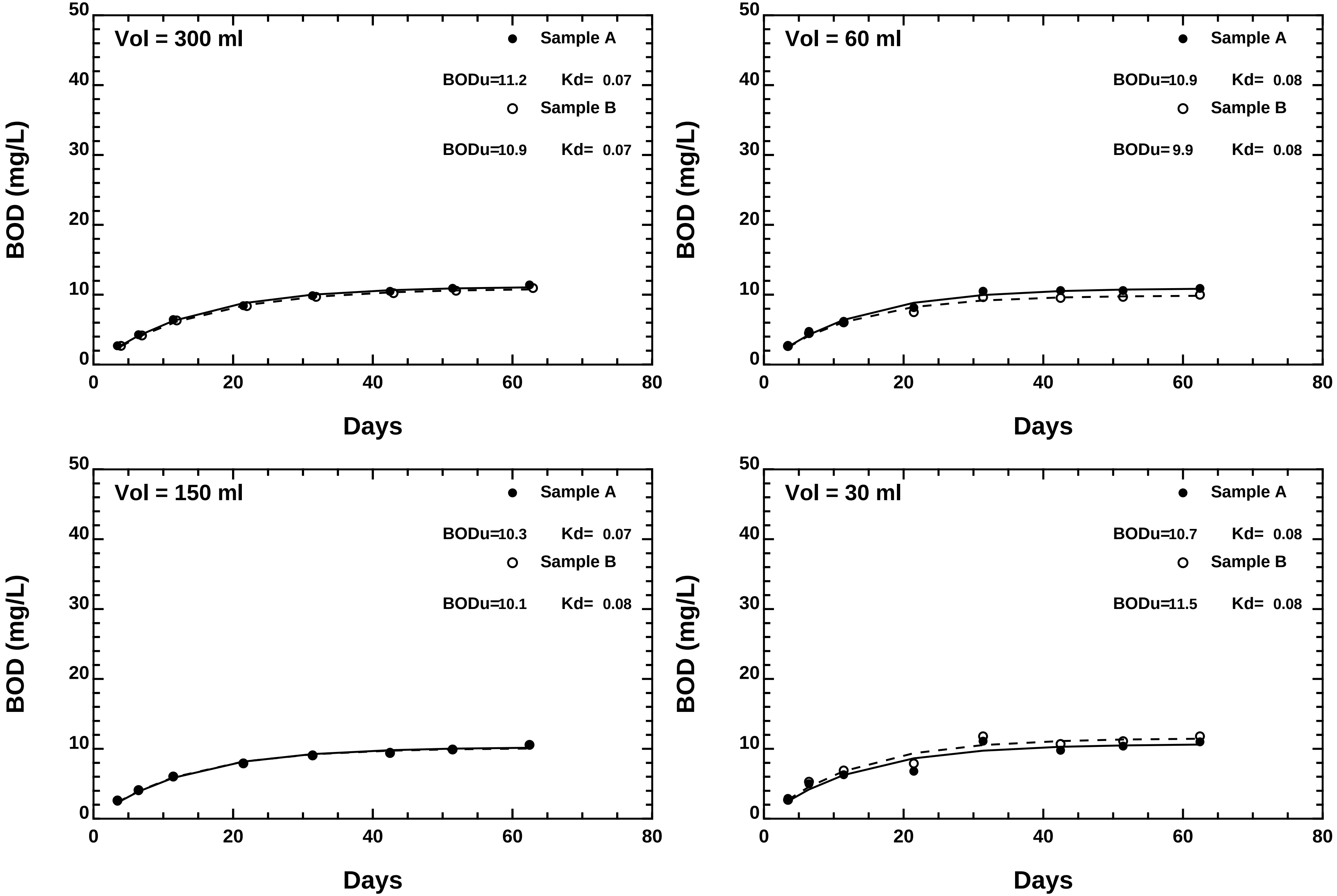
LTBOD analysis, Station CO19, 4/21/2004



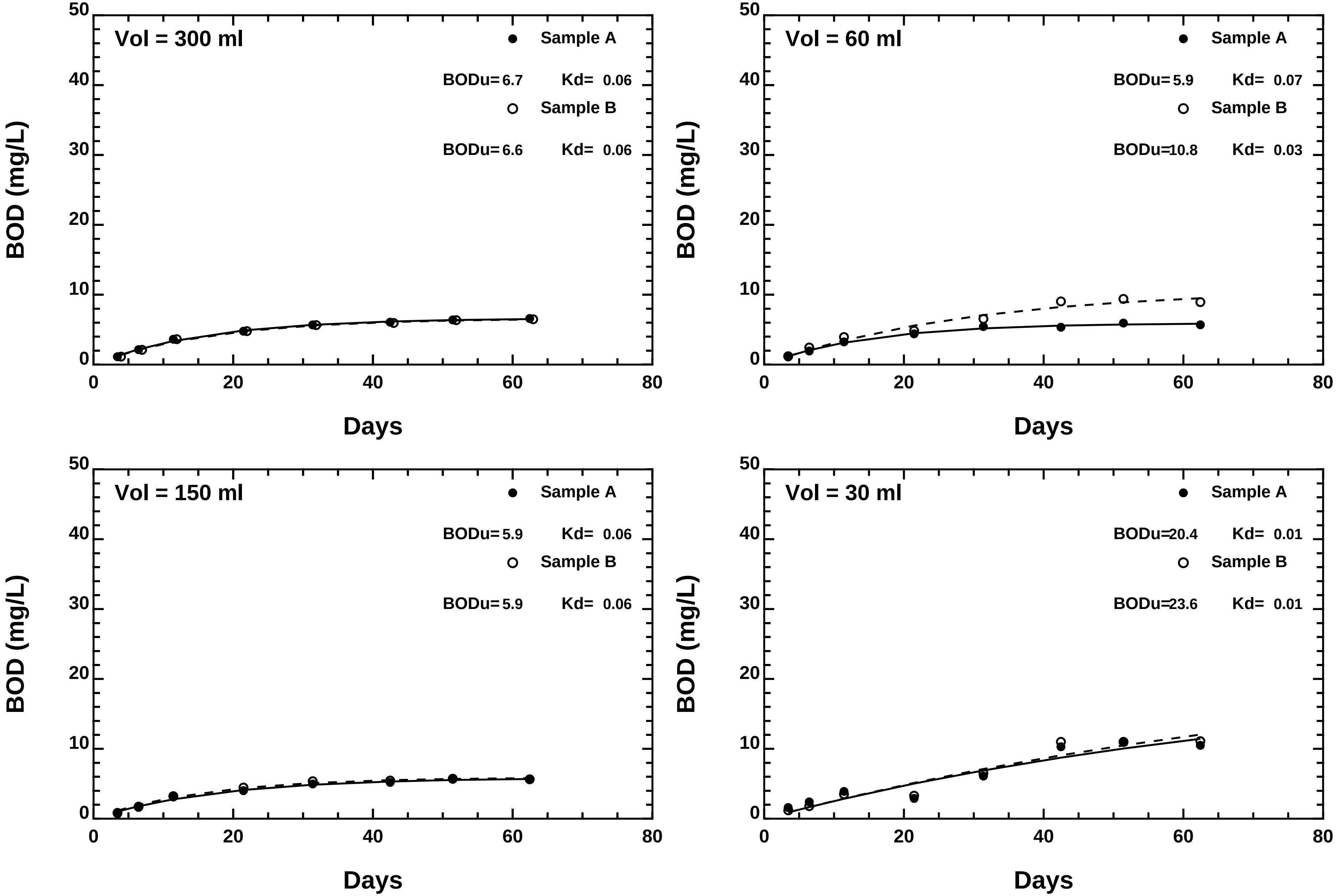
LTBOD analysis, Station ME17, 4/21/2004



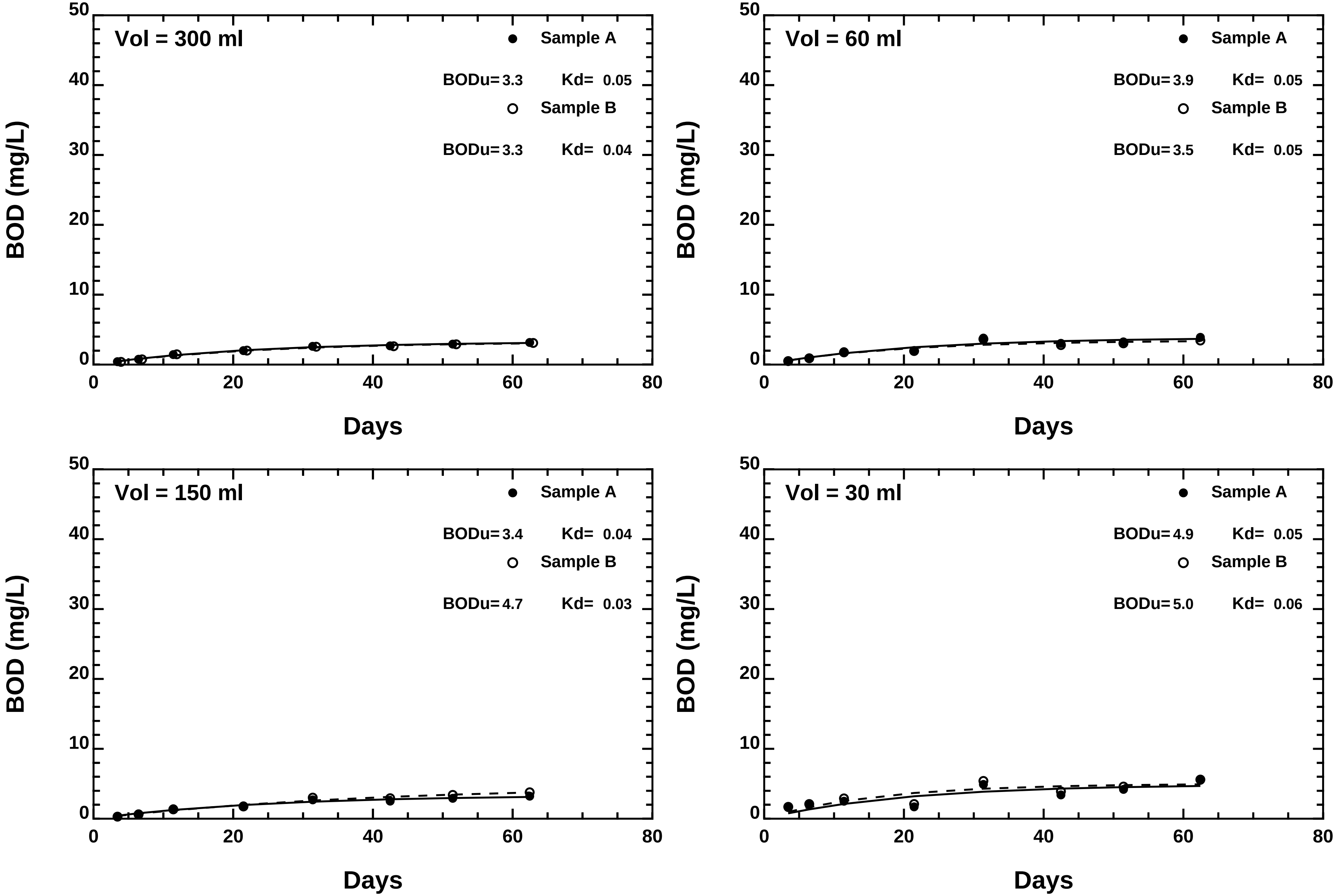
LTBOD analysis, Station ME20, 4/21/2004



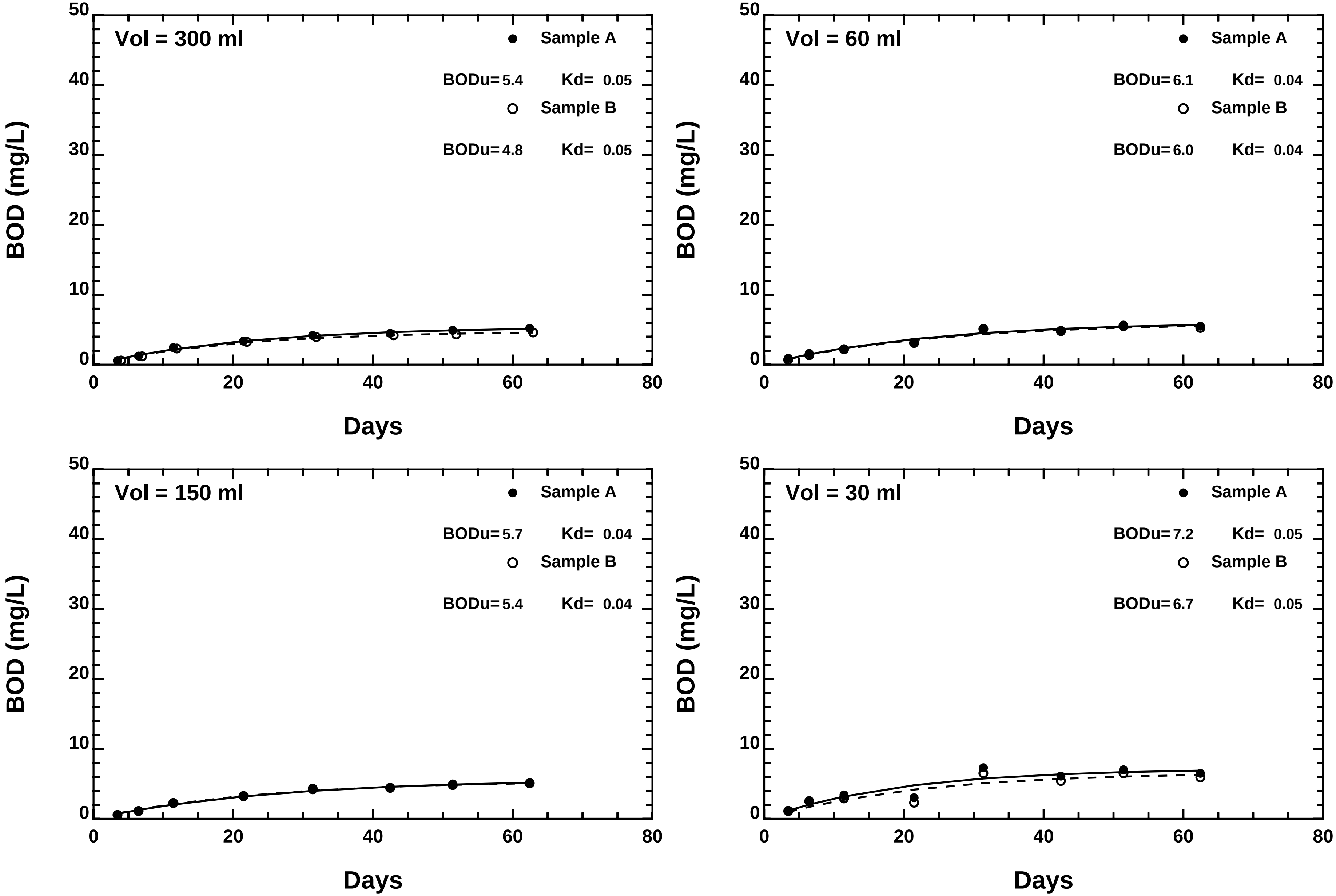
LTBOD analysis, Station OH01, 4/21/2004



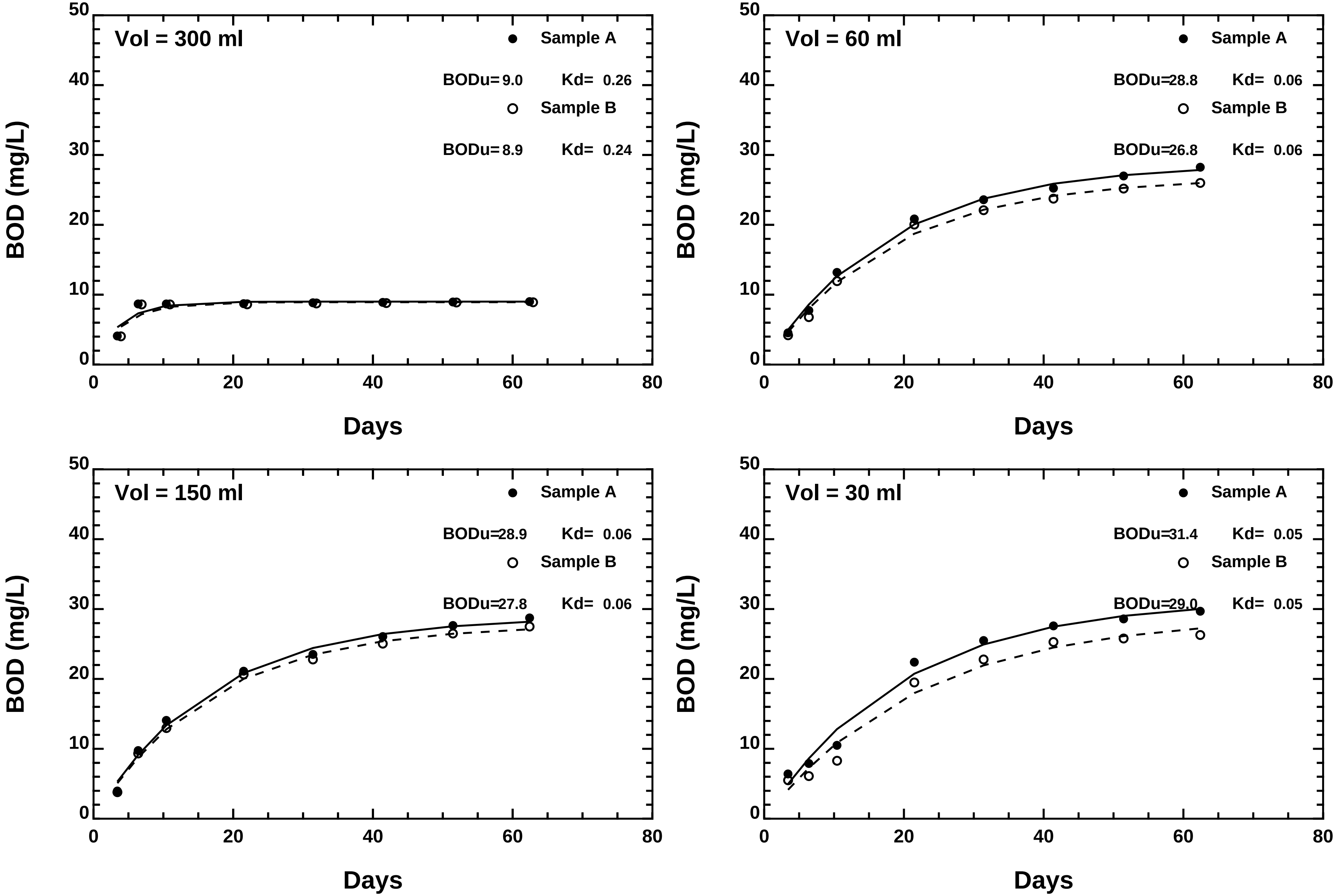
LTBOD analysis, Station OH03, 4/21/2004



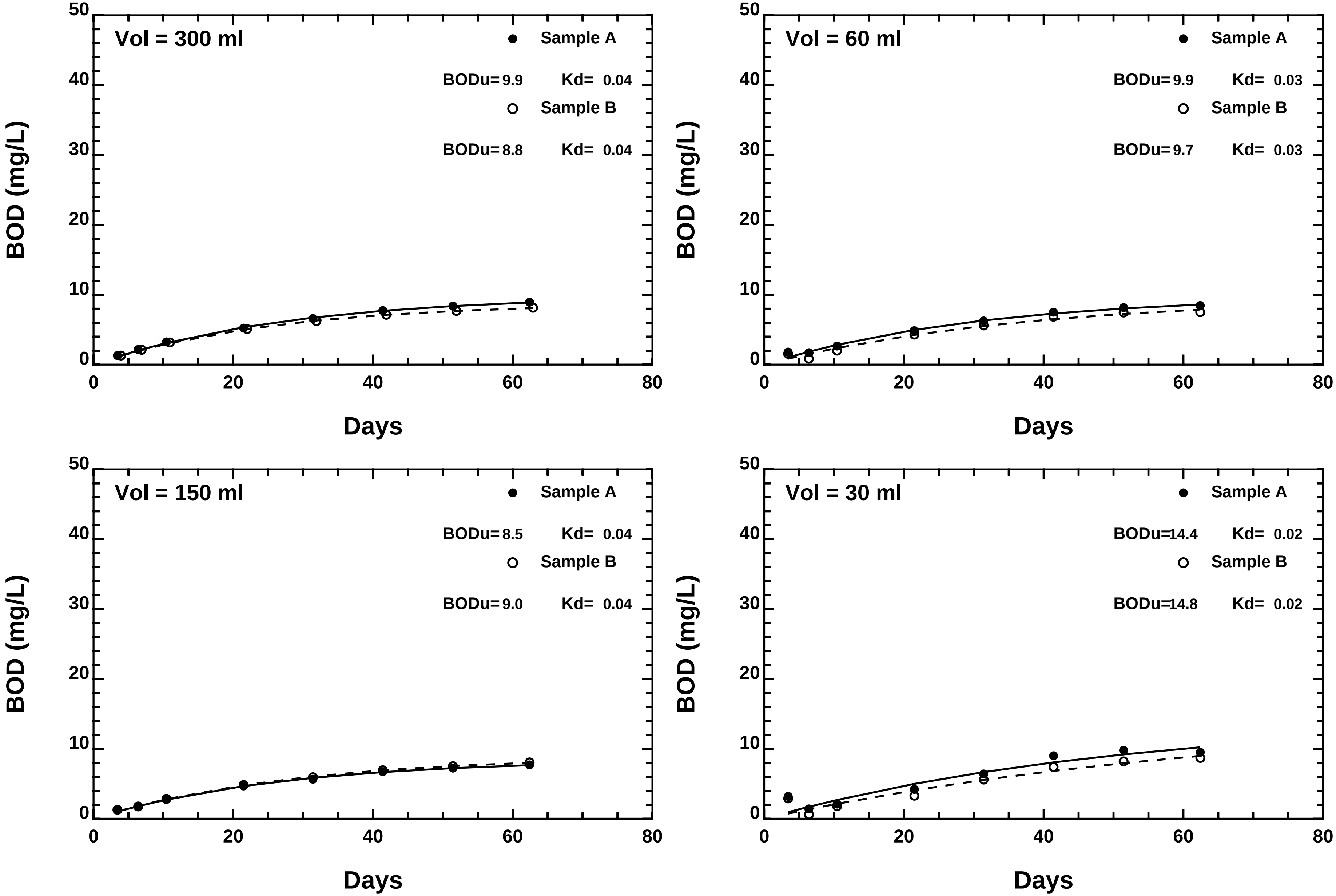
LTBOD analysis, Station OH04, 4/21/2004



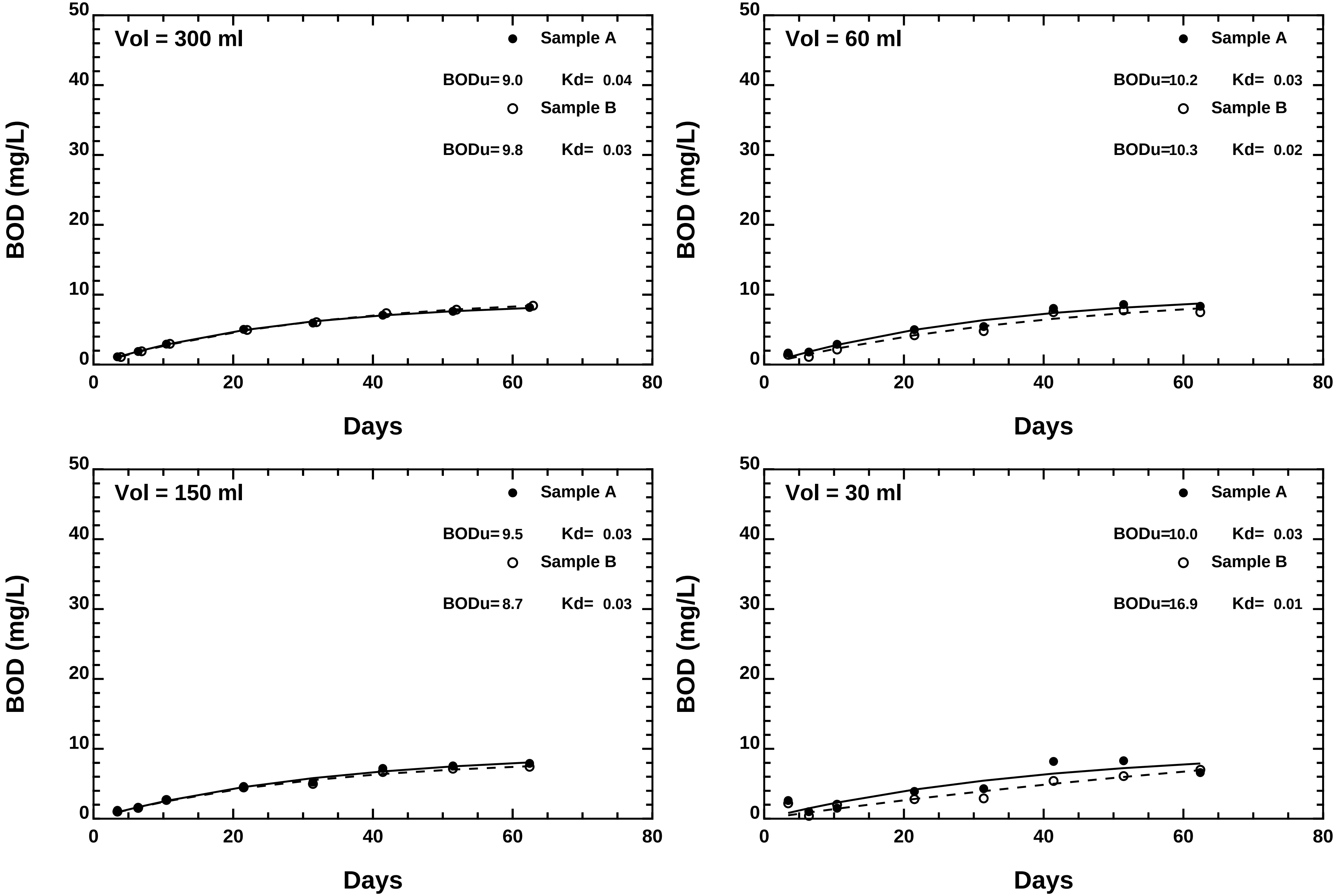
LTBOD analysis, Station OH11, 4/21/2004



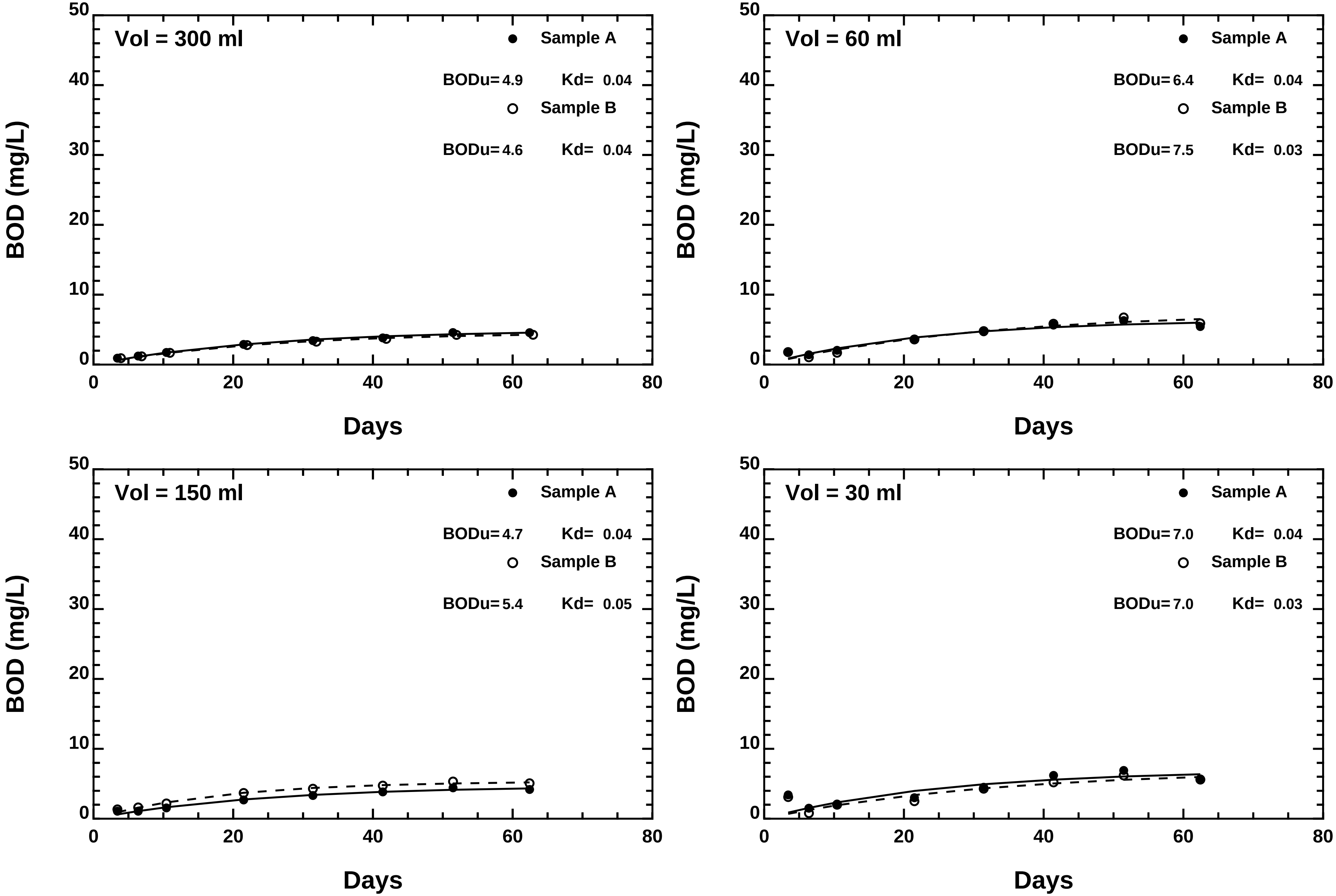
LTBOD analysis, Station JIEF, 5/19/2004



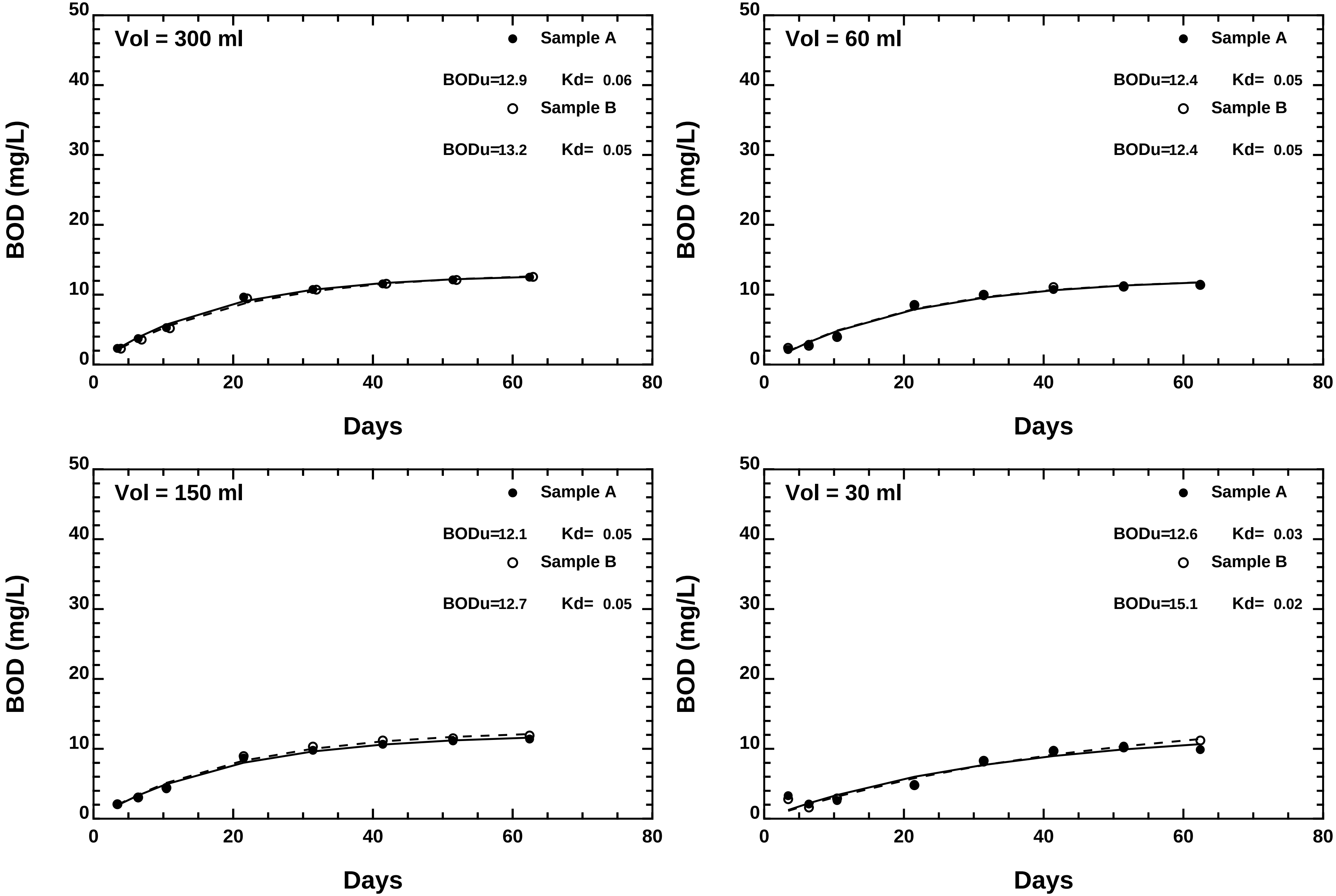
LTBOD analysis, Station MI05, 5/19/2004



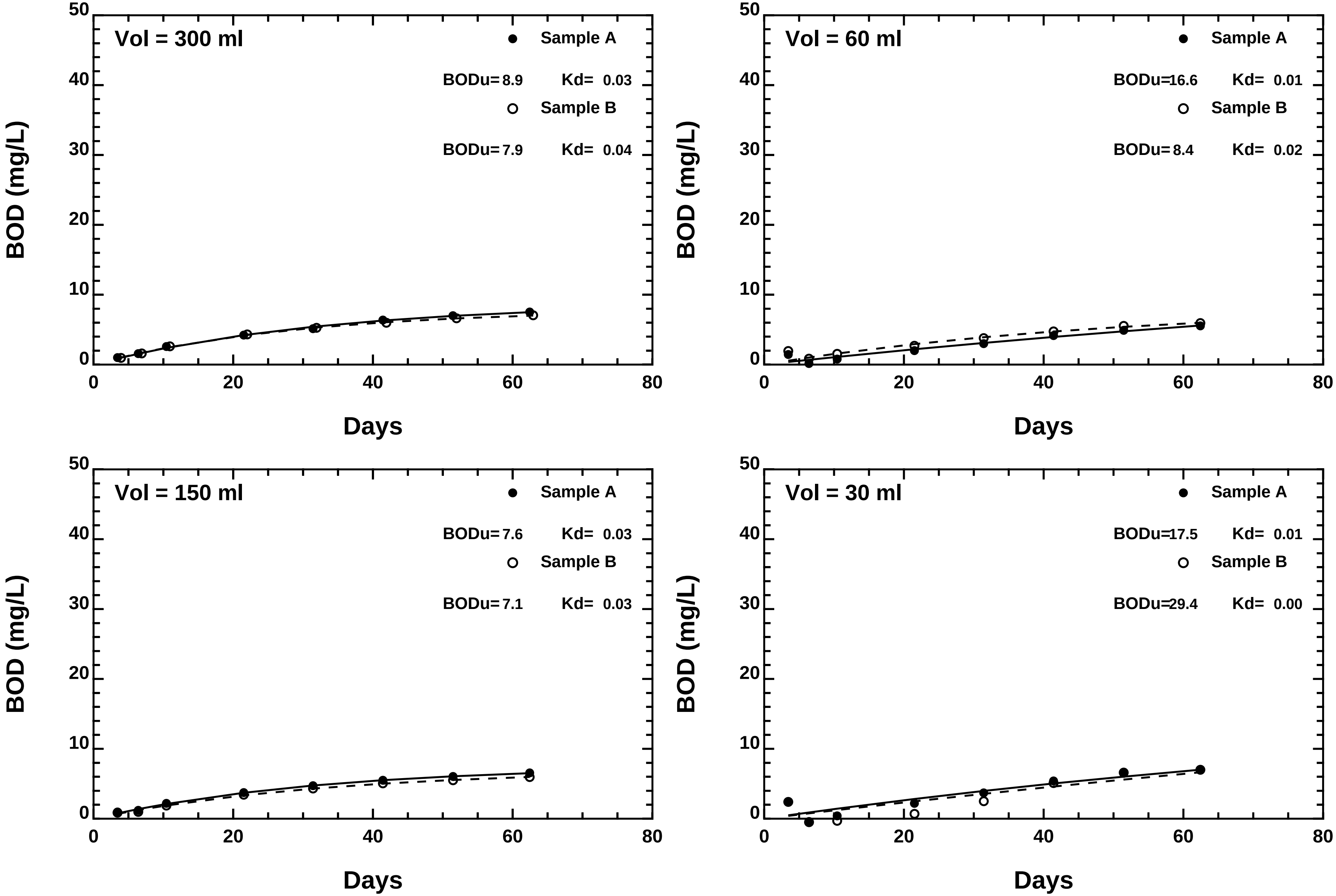
LTBOD analysis, Station MI07, 5/19/2004



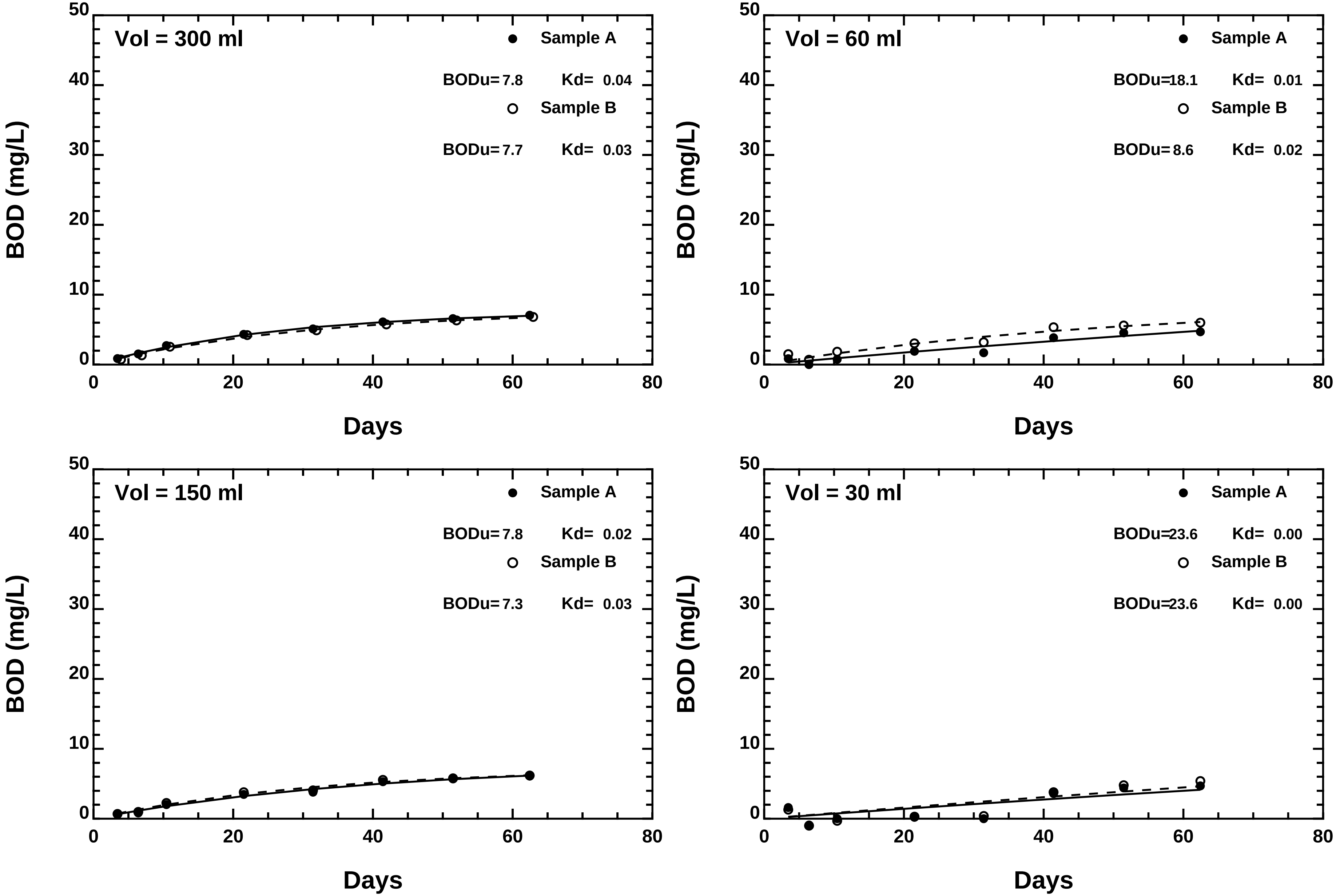
LTBOD analysis, Station KK13, 5/19/2004



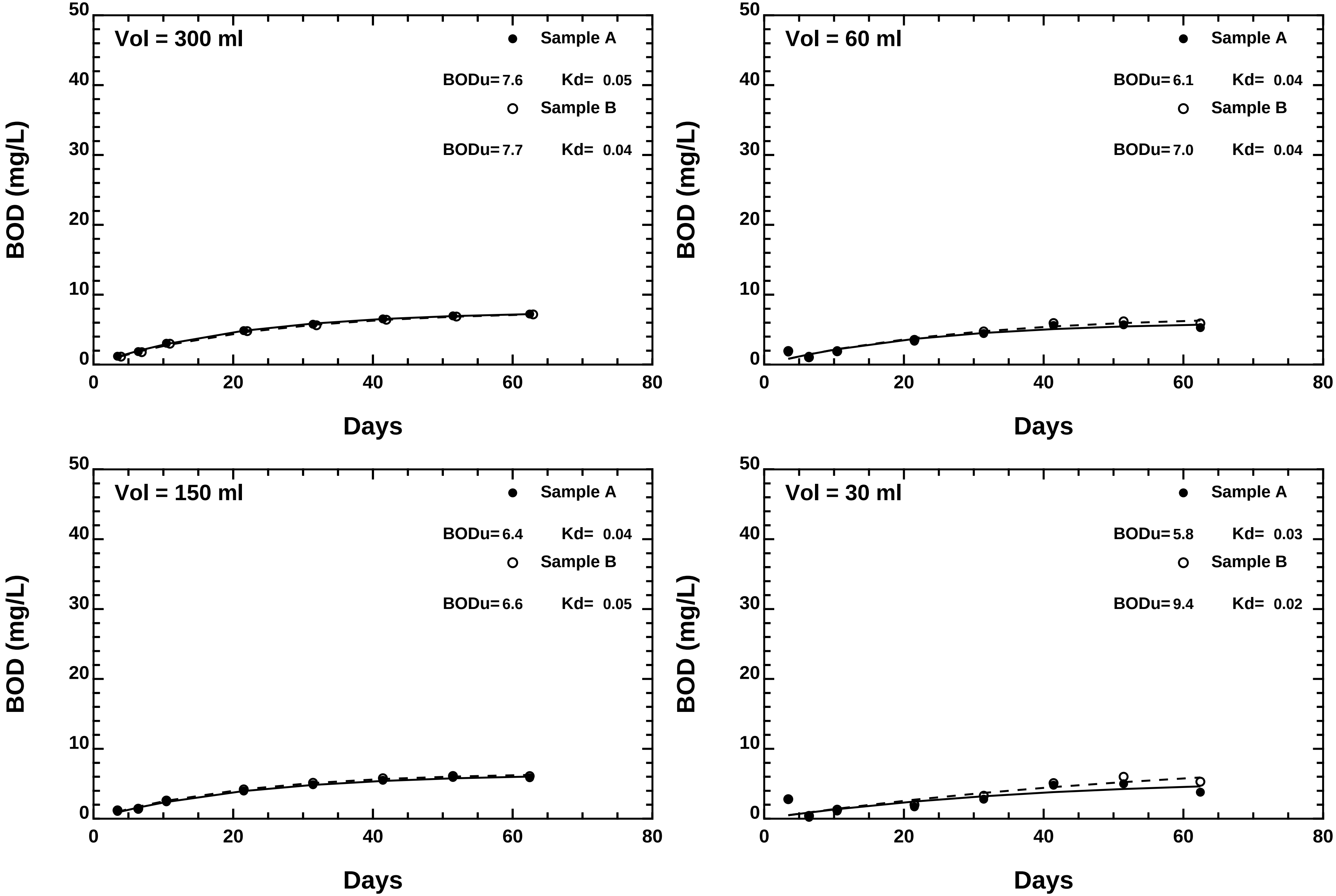
LTBOD analysis, Station KK14, 5/19/2004



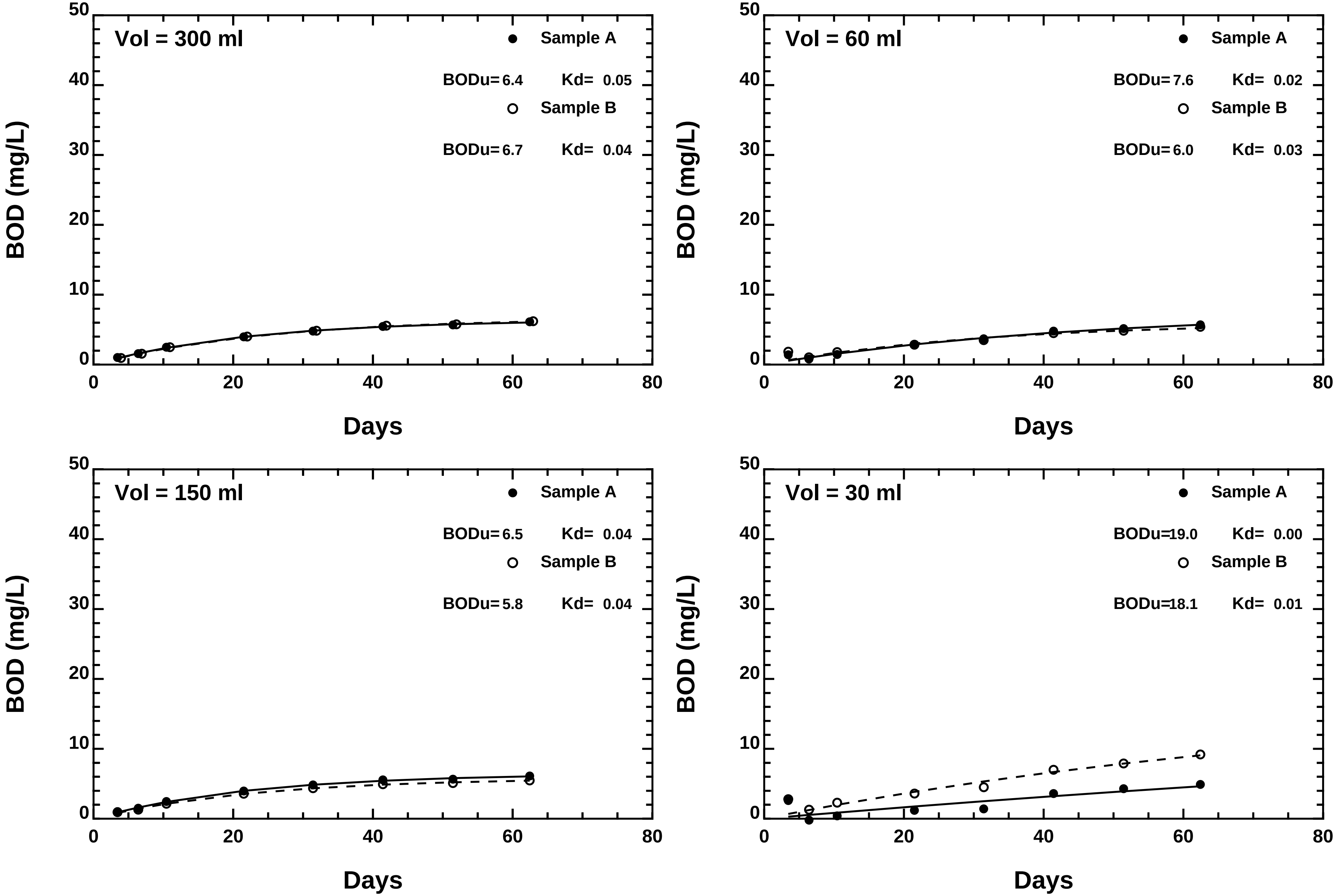
LTBOD analysis, Station CO15, 5/19/2004



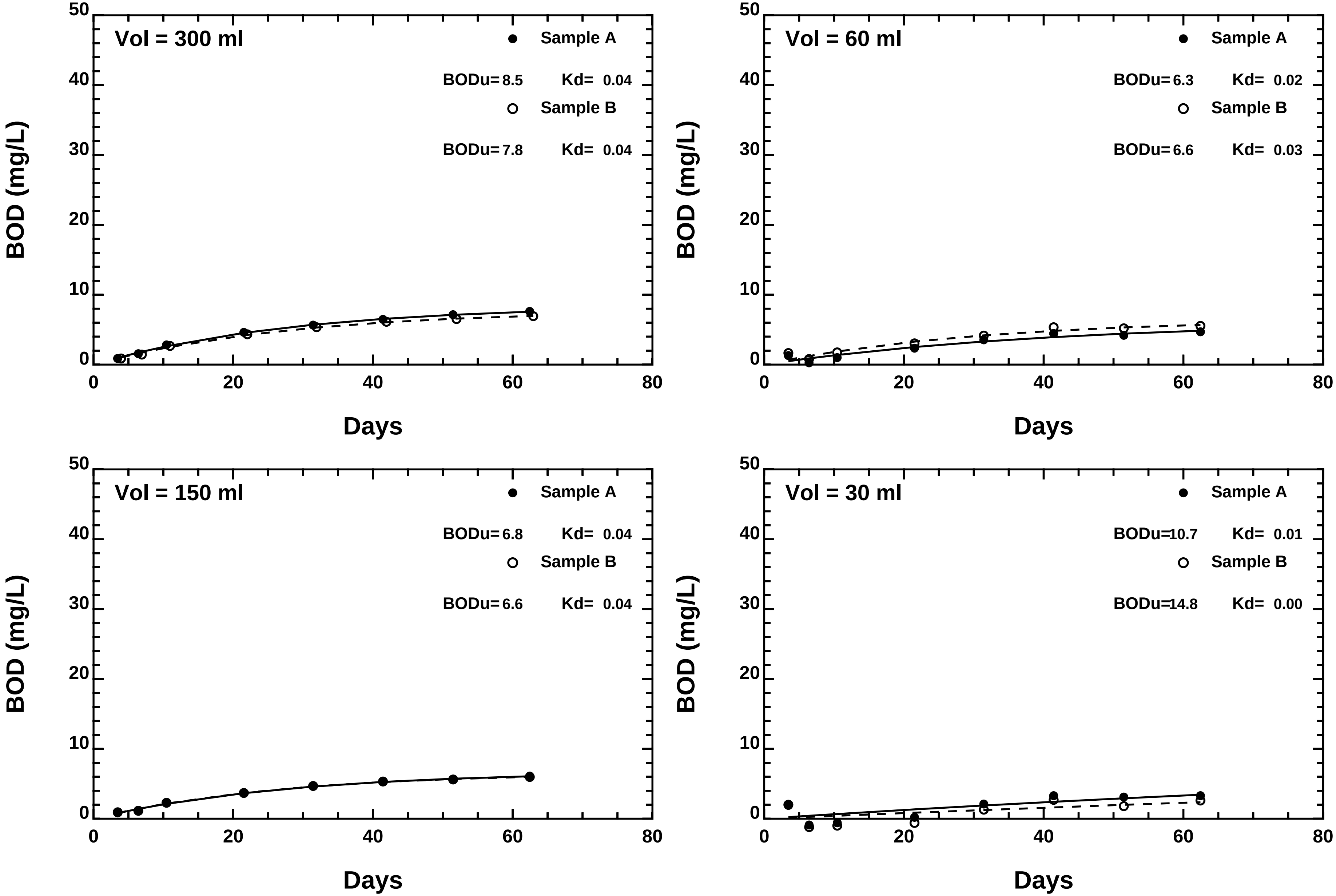
LTBOD analysis, Station CO19, 5/19/2004



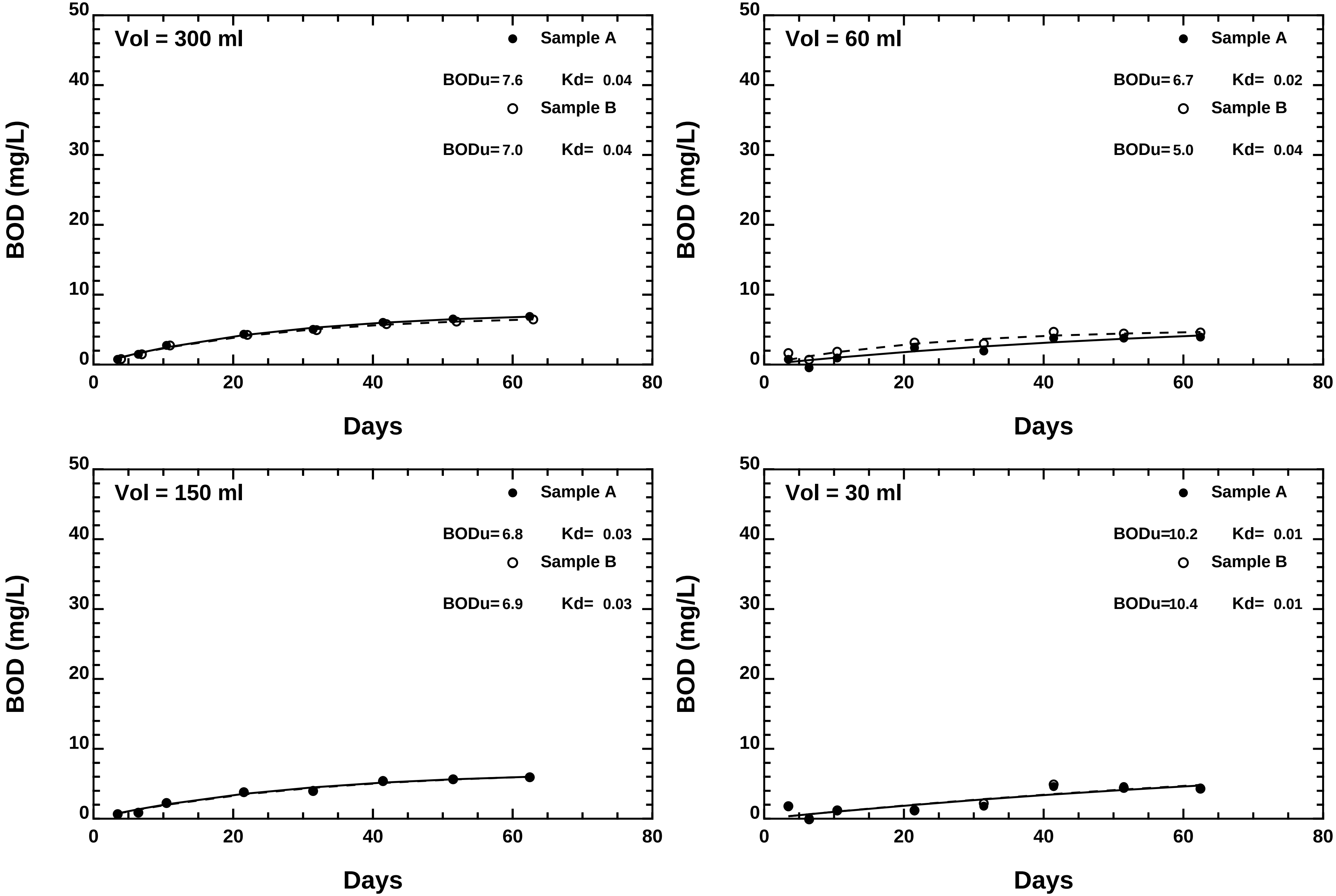
LTBOD analysis, Station ME17, 5/19/2004



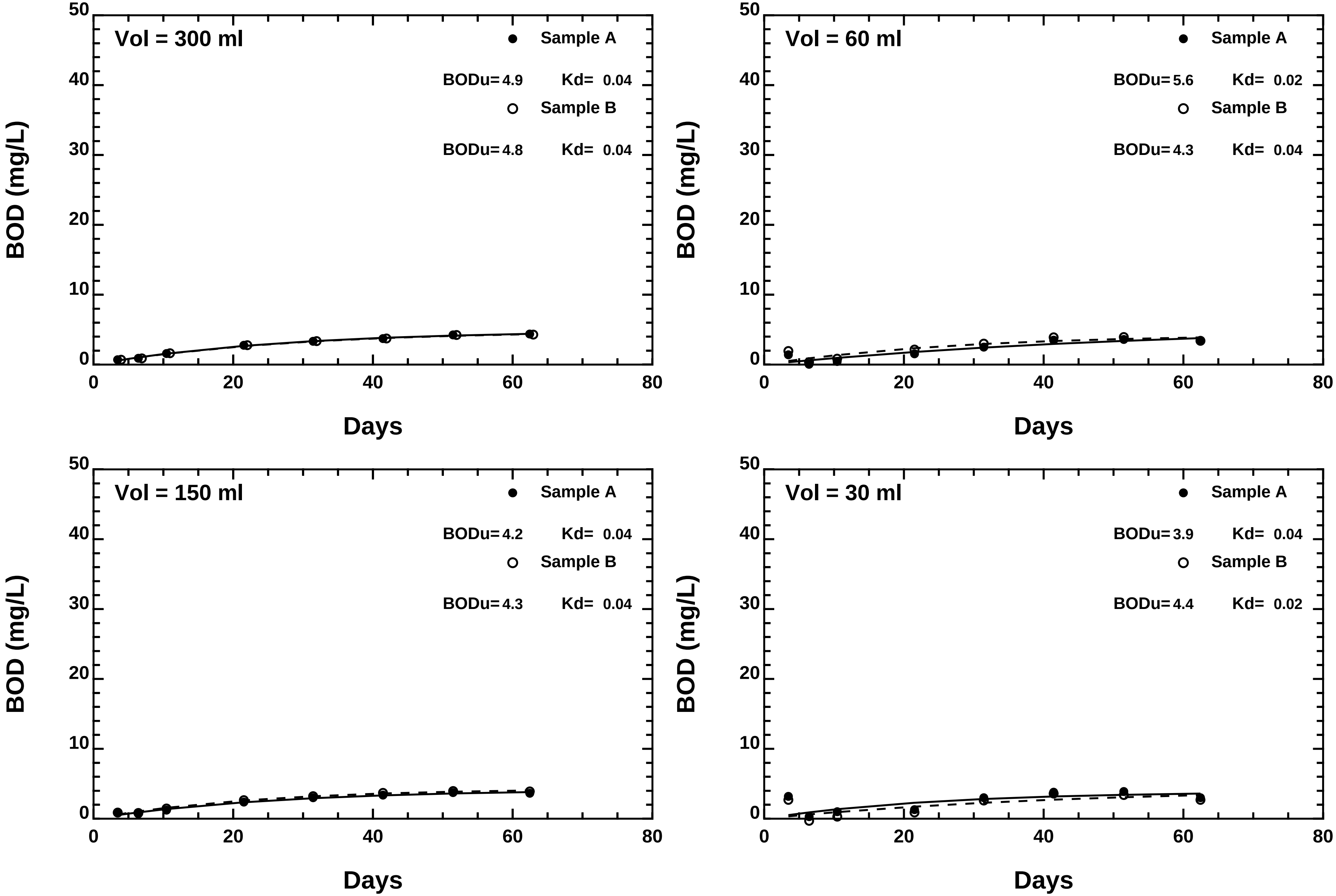
LTBOD analysis, Station ME20, 5/19/2004



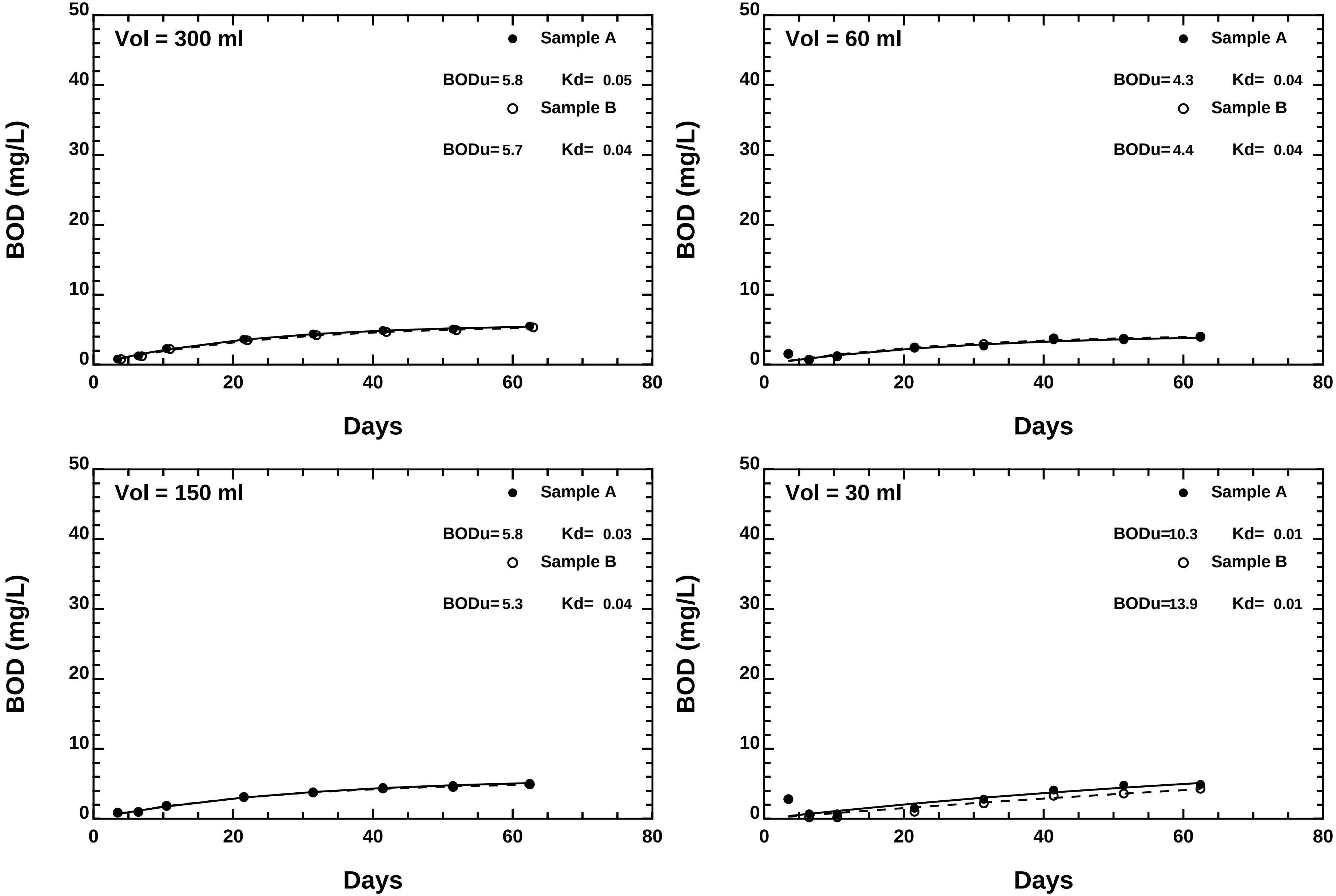
LTBOD analysis, Station OH01, 5/19/2004



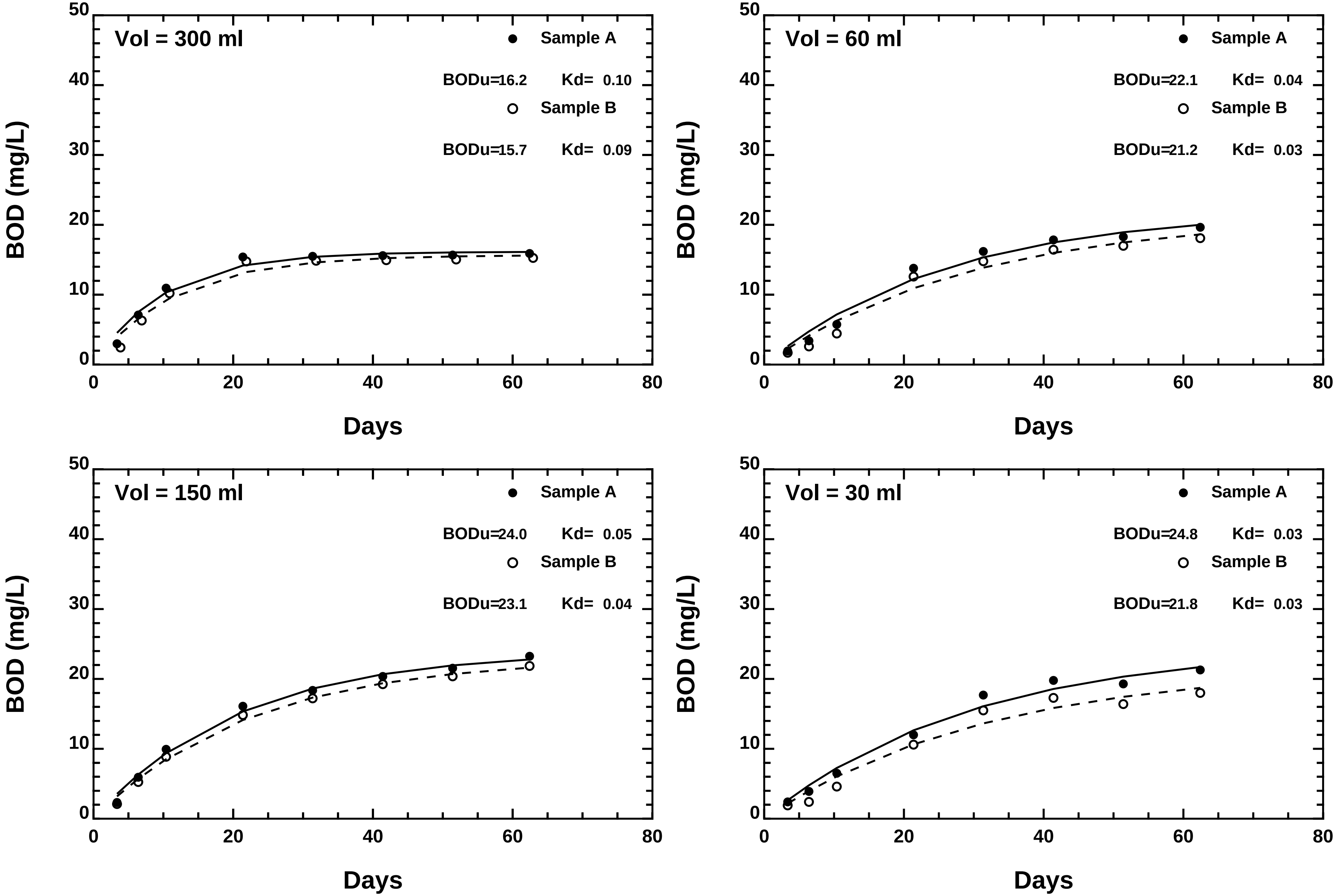
LTBOD analysis, Station OH03, 5/19/2004



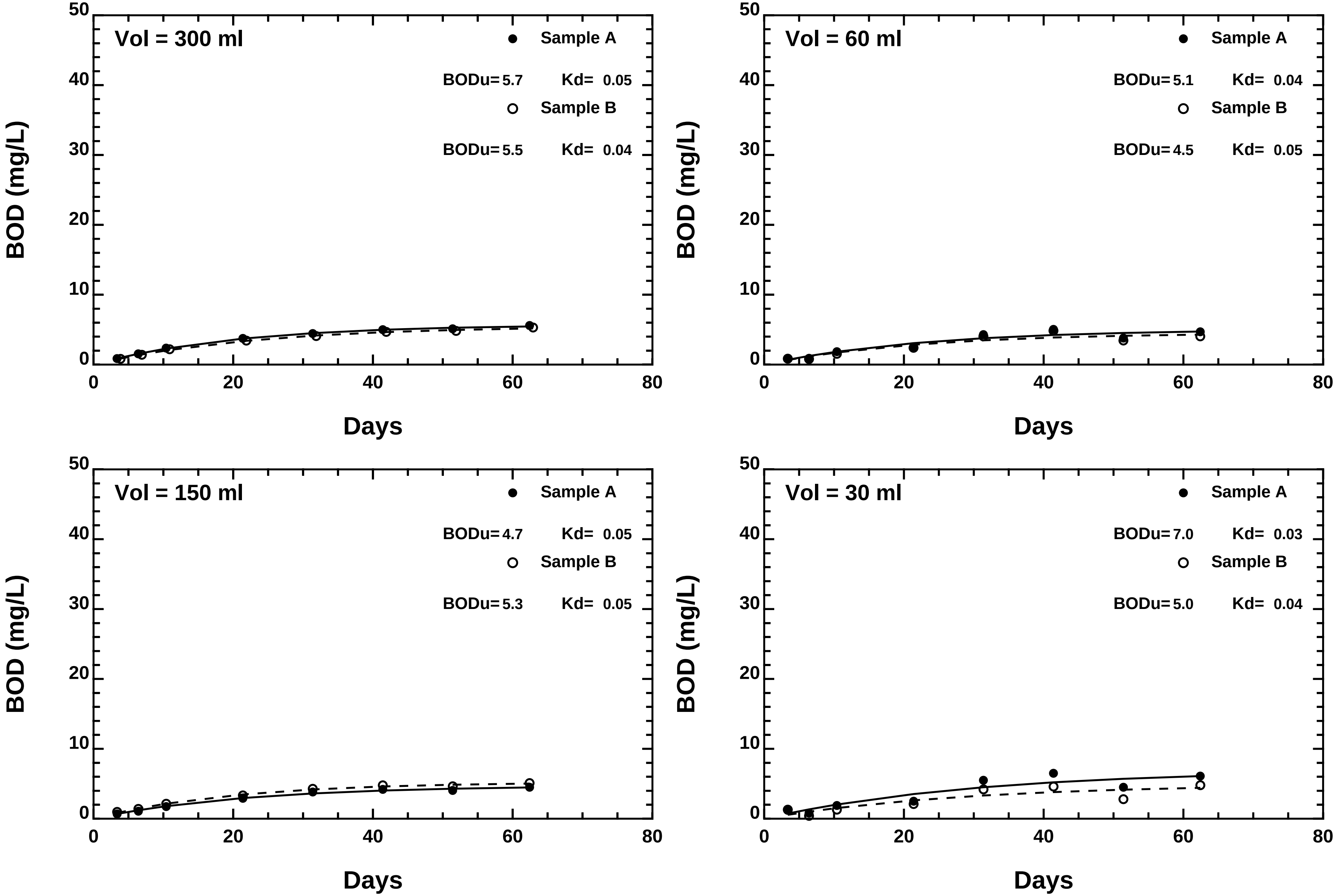
LTBOD analysis, Station OH04, 5/19/2004



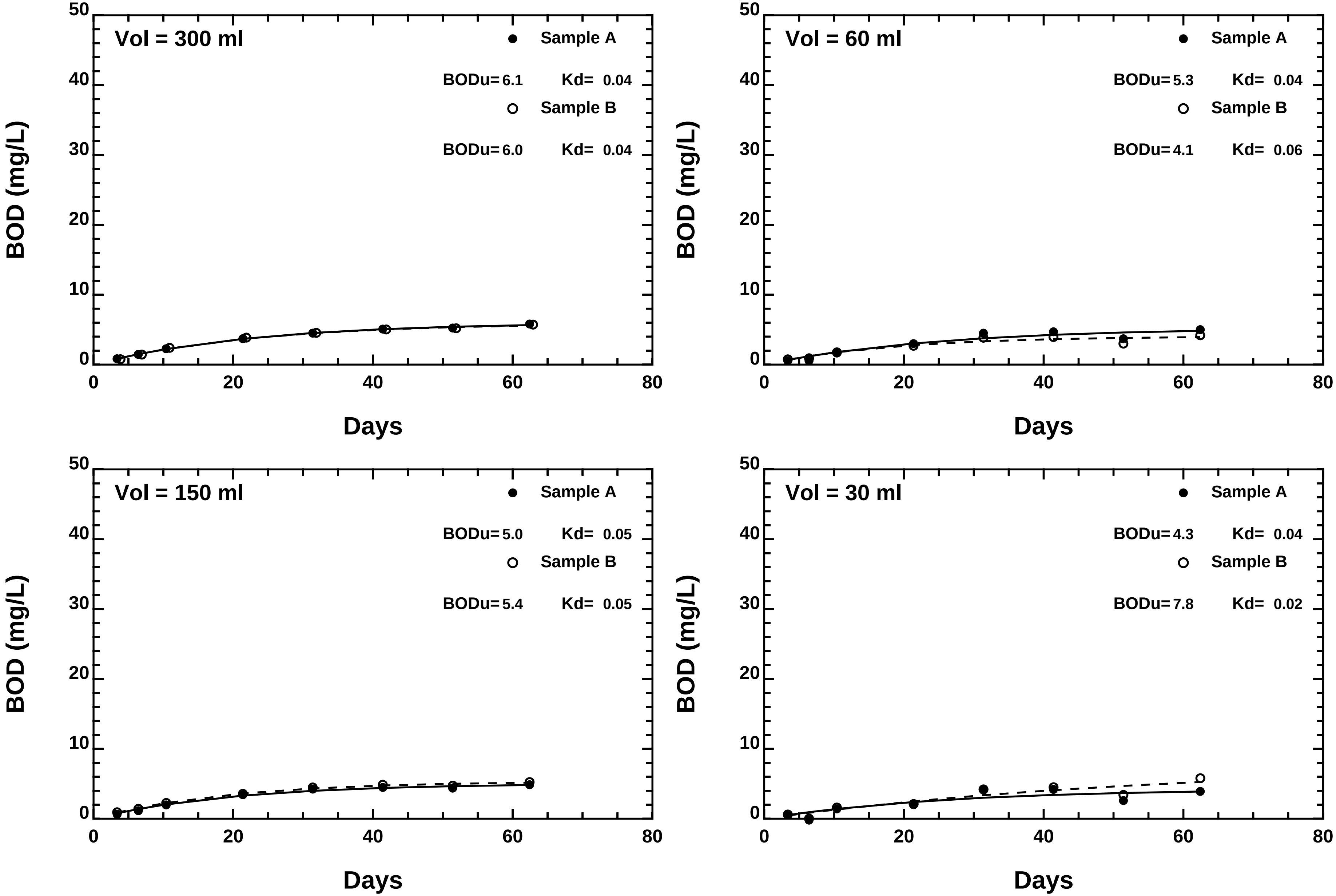
LTBOD analysis, Station OH11, 5/19/2004



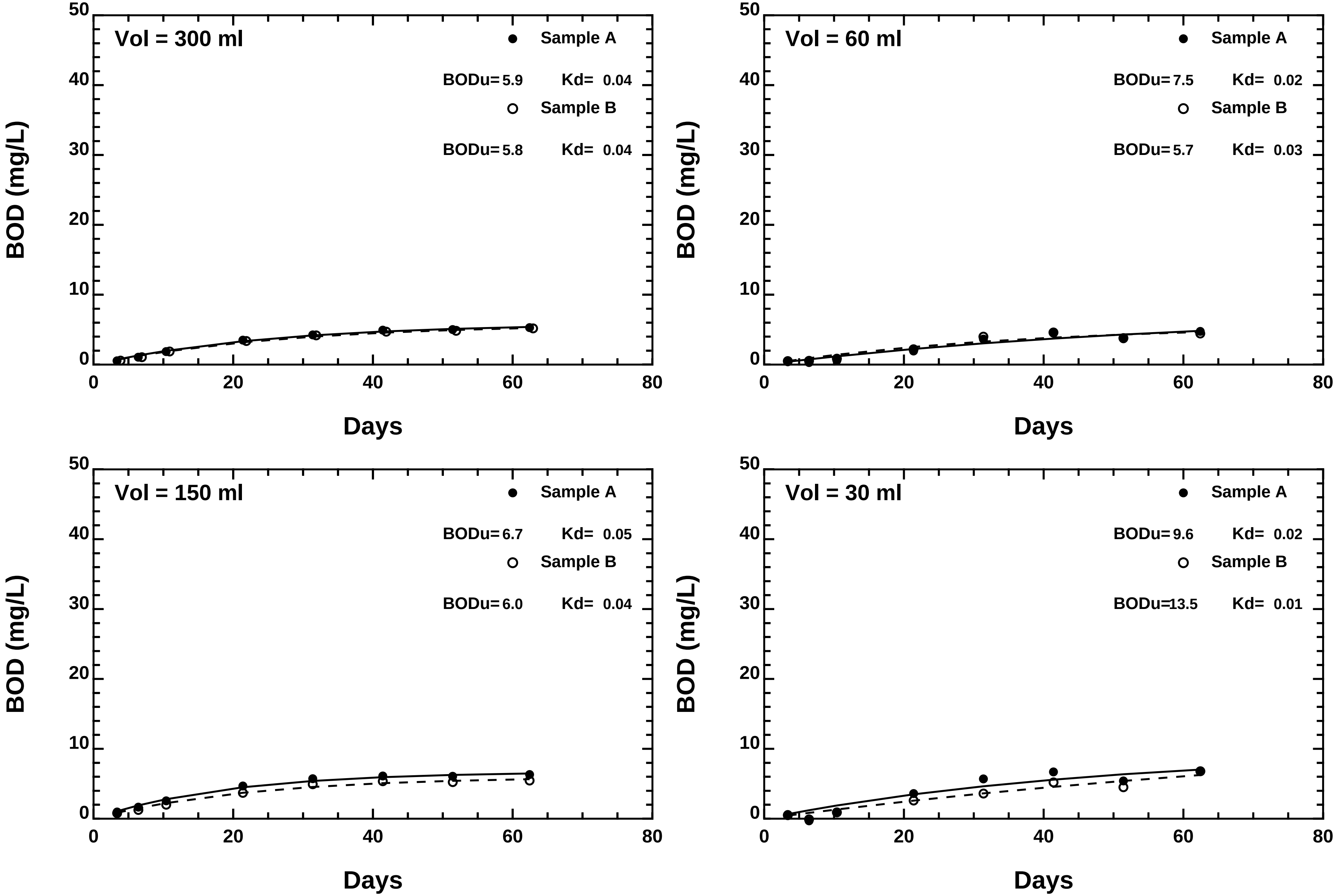
LTBOD analysis, Station JIEF, 7/21/2004



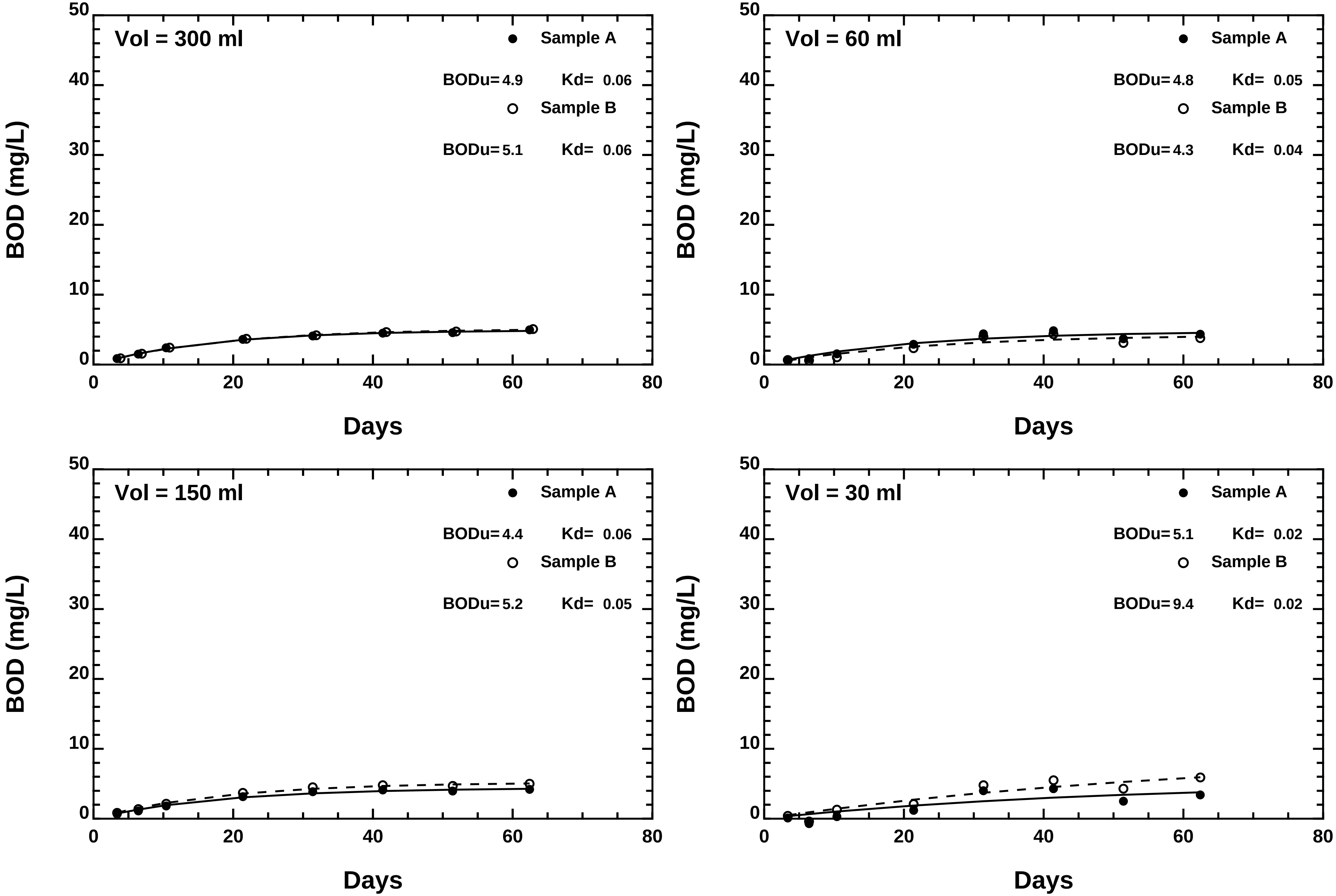
LTBOD analysis, Station MI05, 7/21/2004



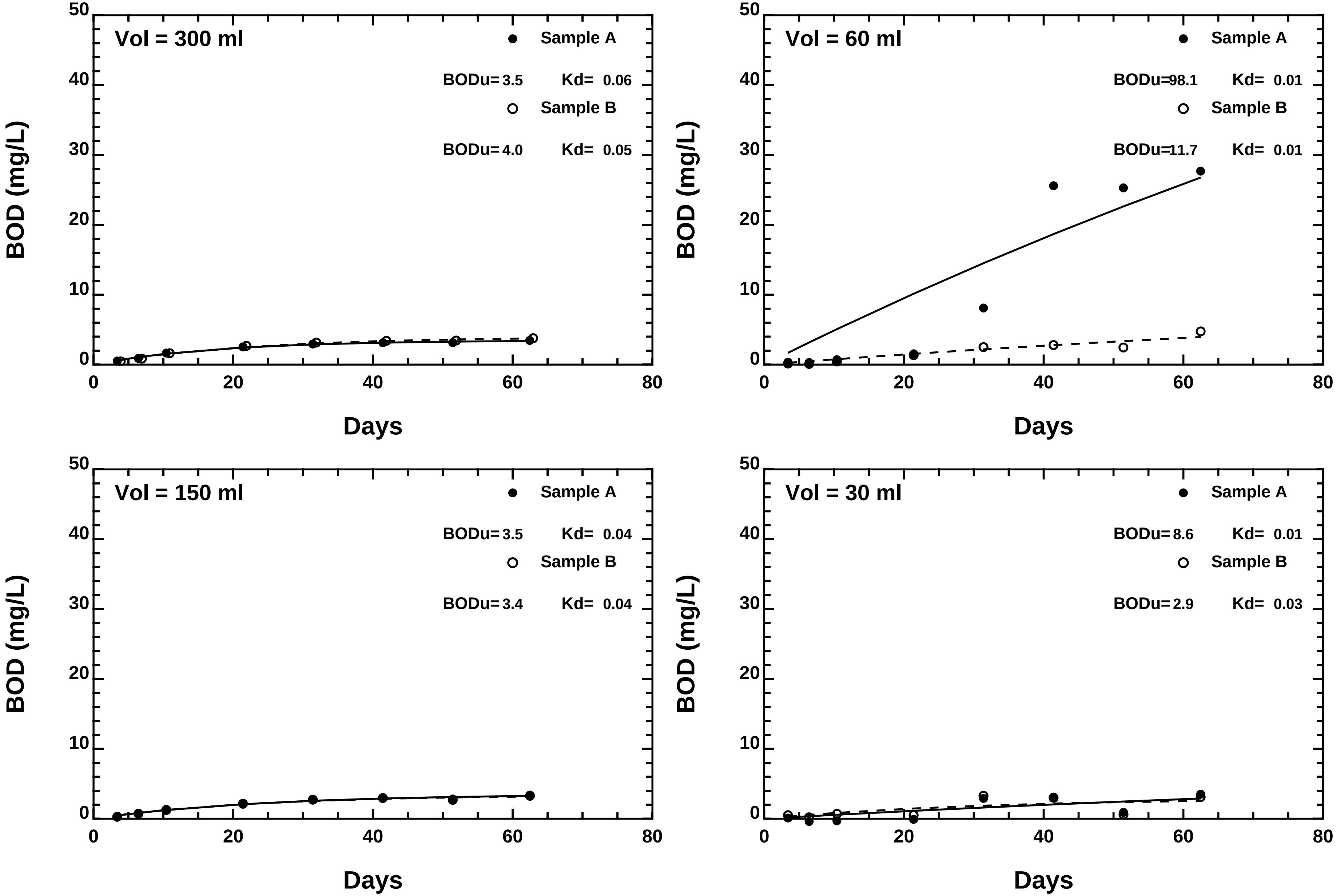
LTBOD analysis, Station MI07, 7/21/2004



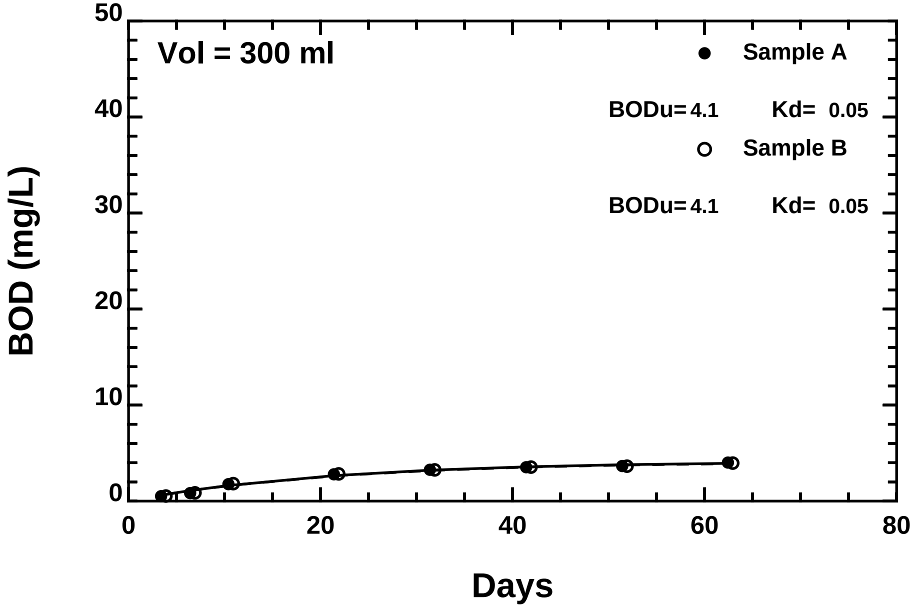
LTBOD analysis, Station KK13, 7/21/2004

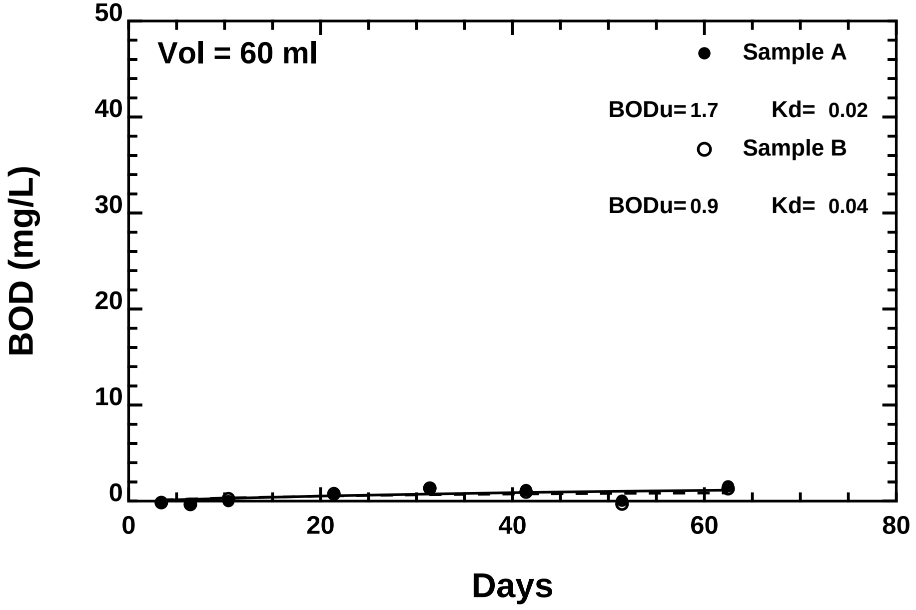


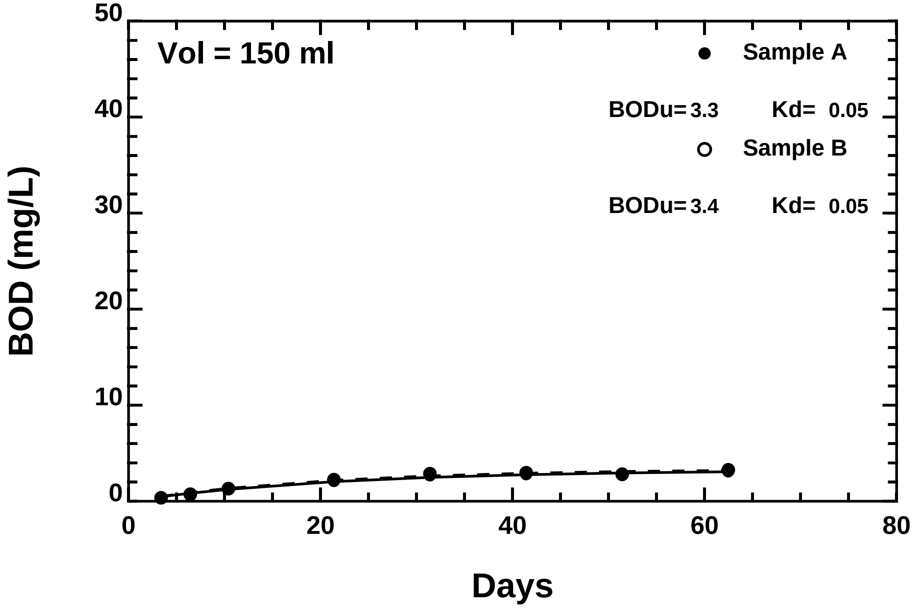
LTBOD analysis, Station KK14, 7/21/2004

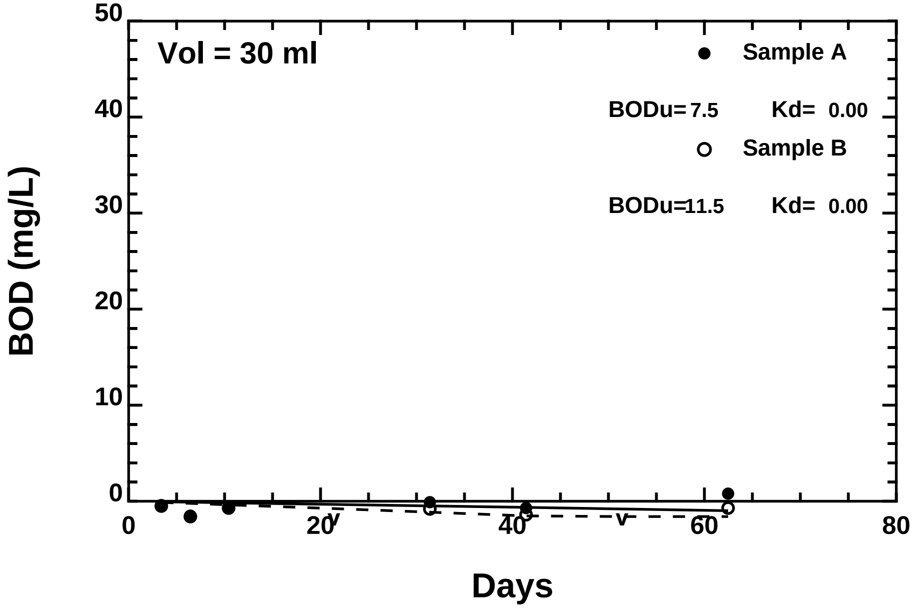


LTBOD analysis, Station CO15, 7/21/2004

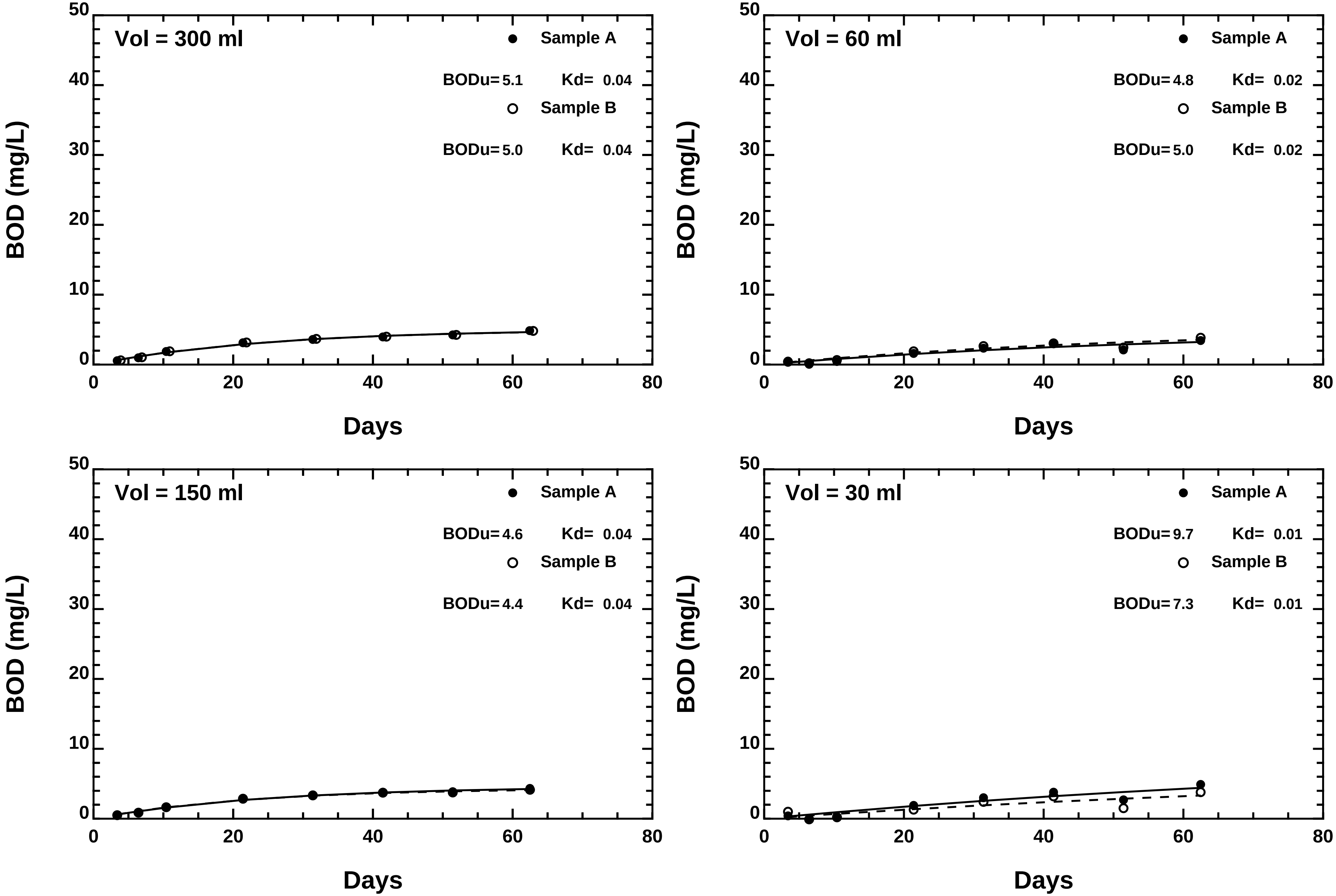




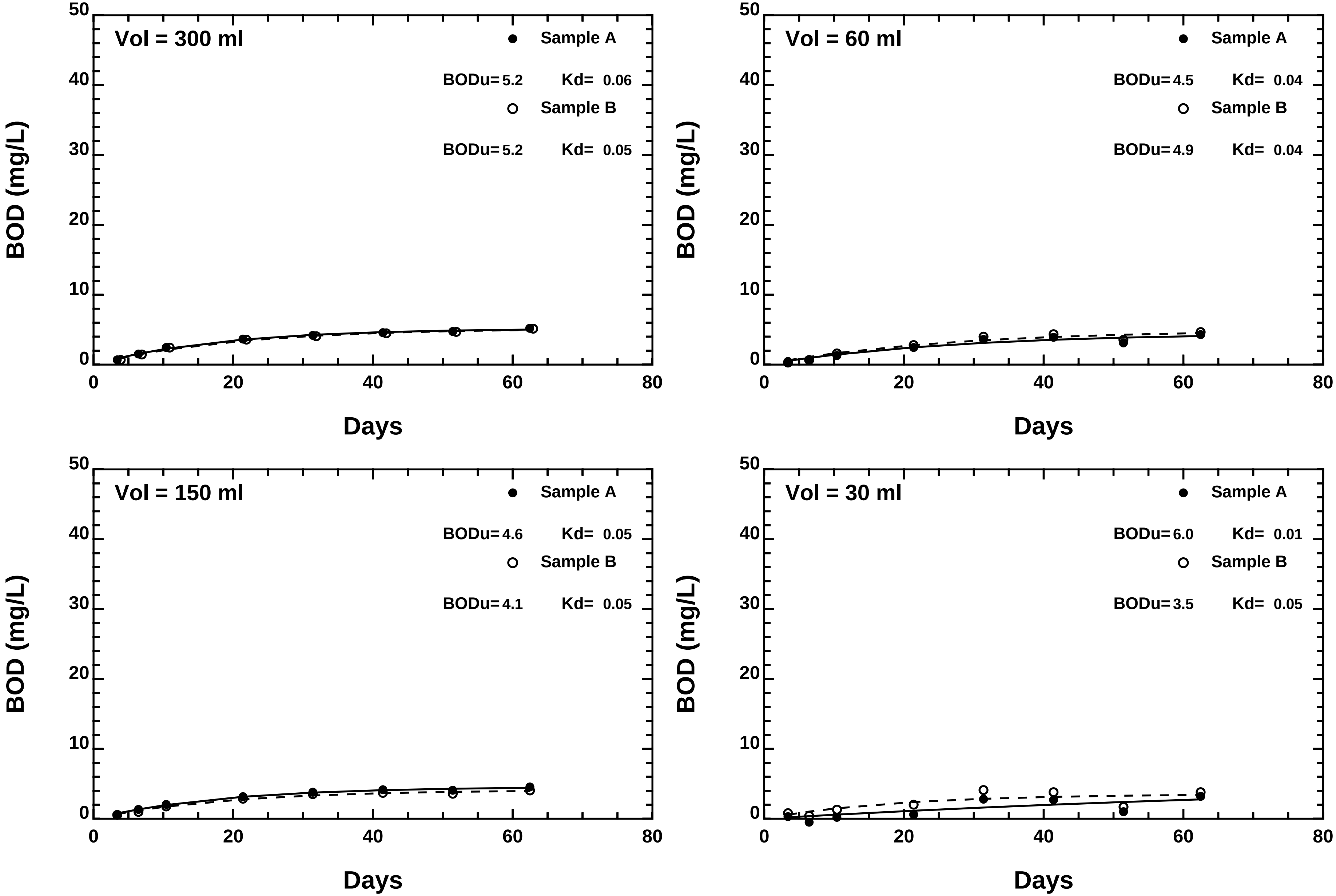




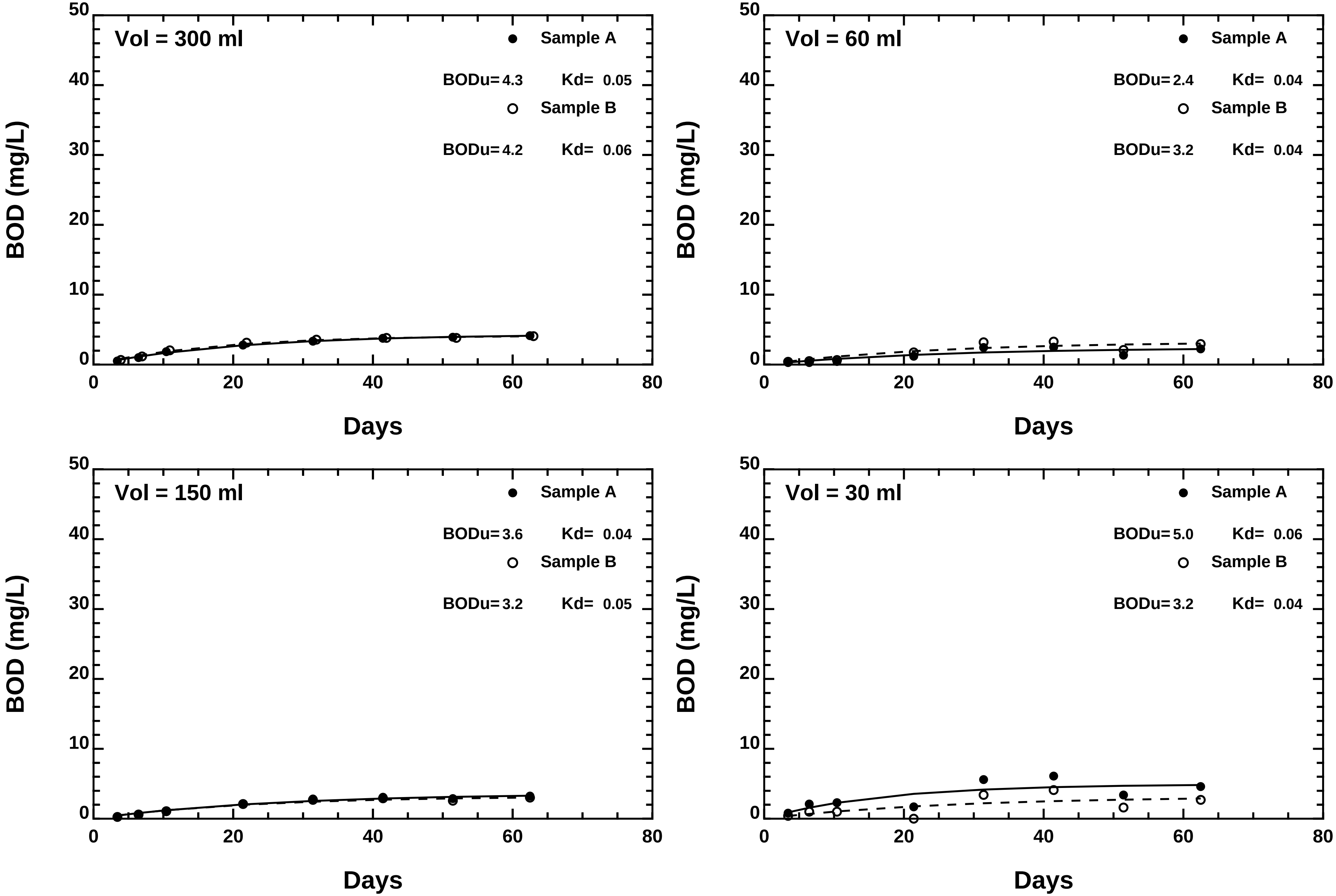
LTBOD analysis, Station CO19, 7/21/2004



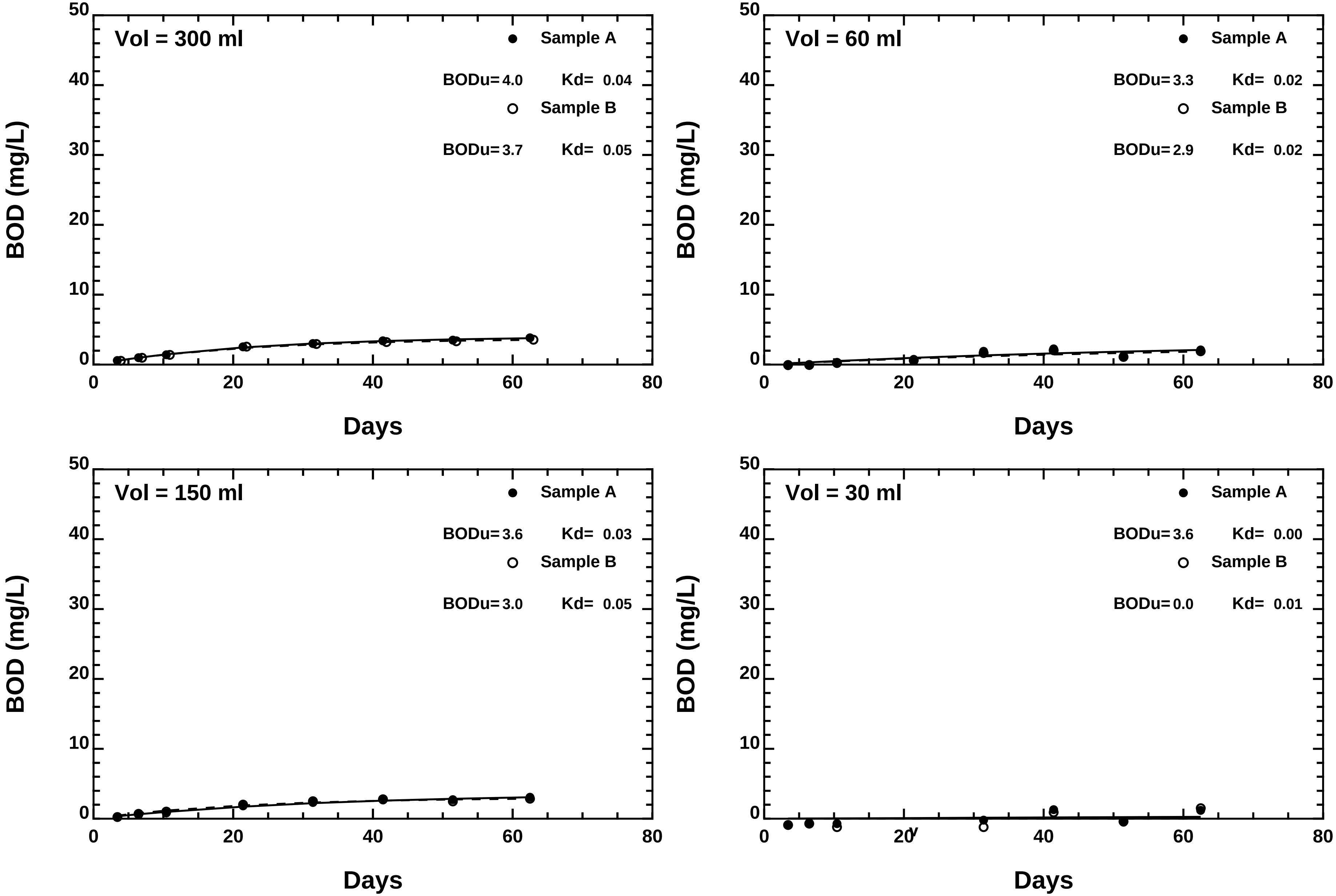
LTBOD analysis, Station ME17, 7/21/2004



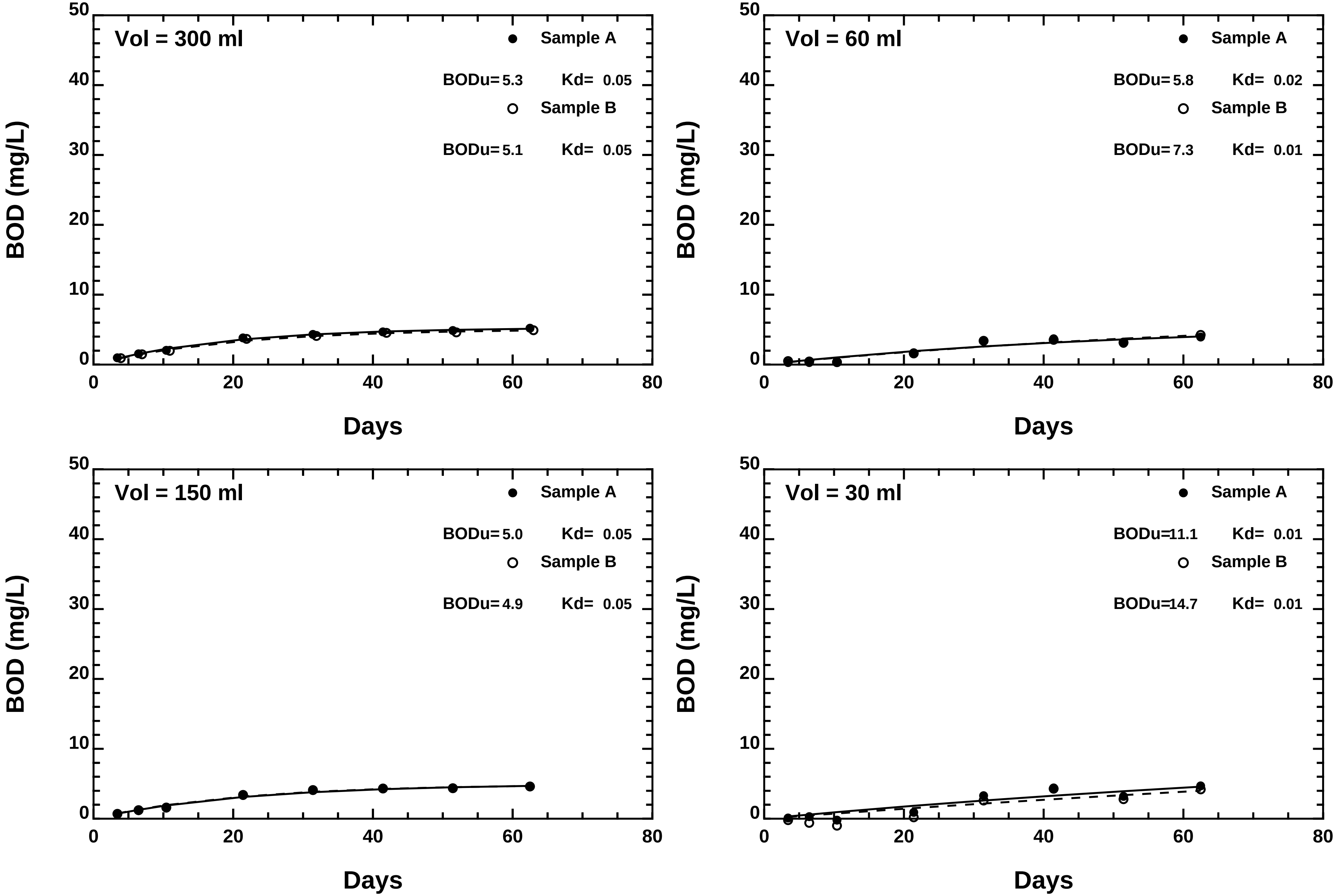
LTBOD analysis, Station ME20, 7/21/2004



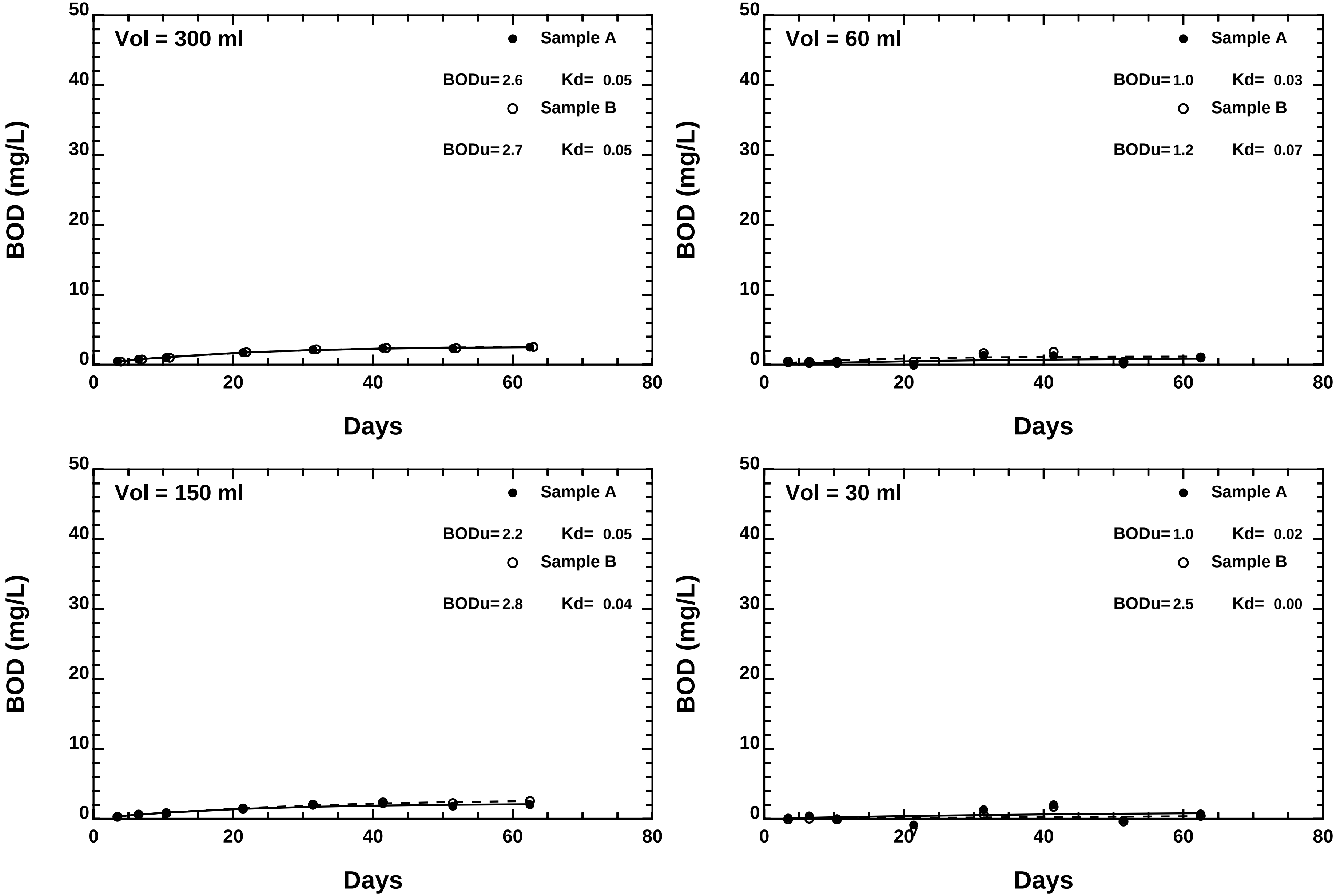
LTBOD analysis, Station OH01, 7/21/2004



LTBOD analysis, Station OH03, 7/21/2004



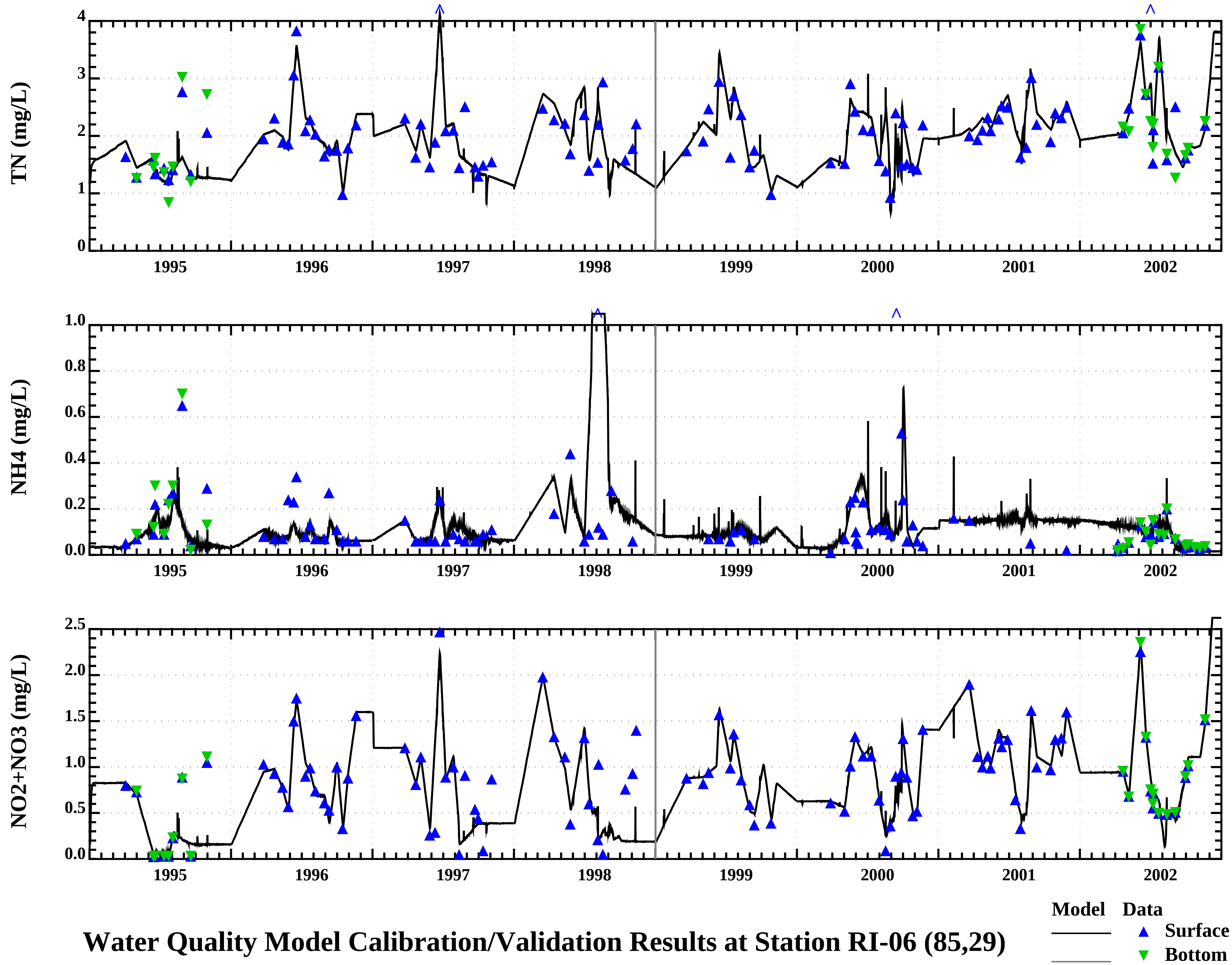
LTBOD analysis, Station OH04, 7/21/2004



LTBOD analysis, Station OH11, 7/21/2004

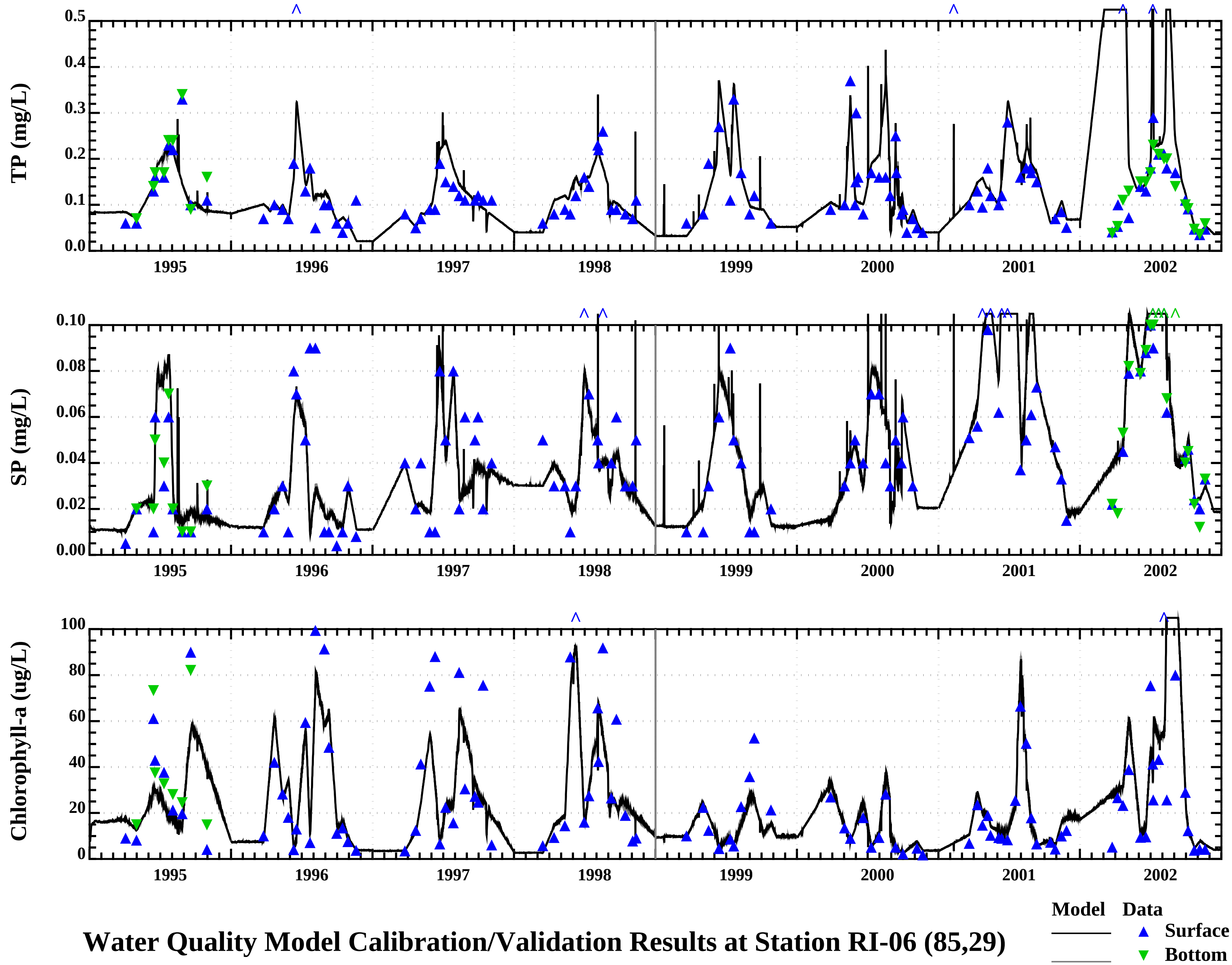
APPENDIX 2

MODEL CALIBRATION/VALIDATION RESULTS



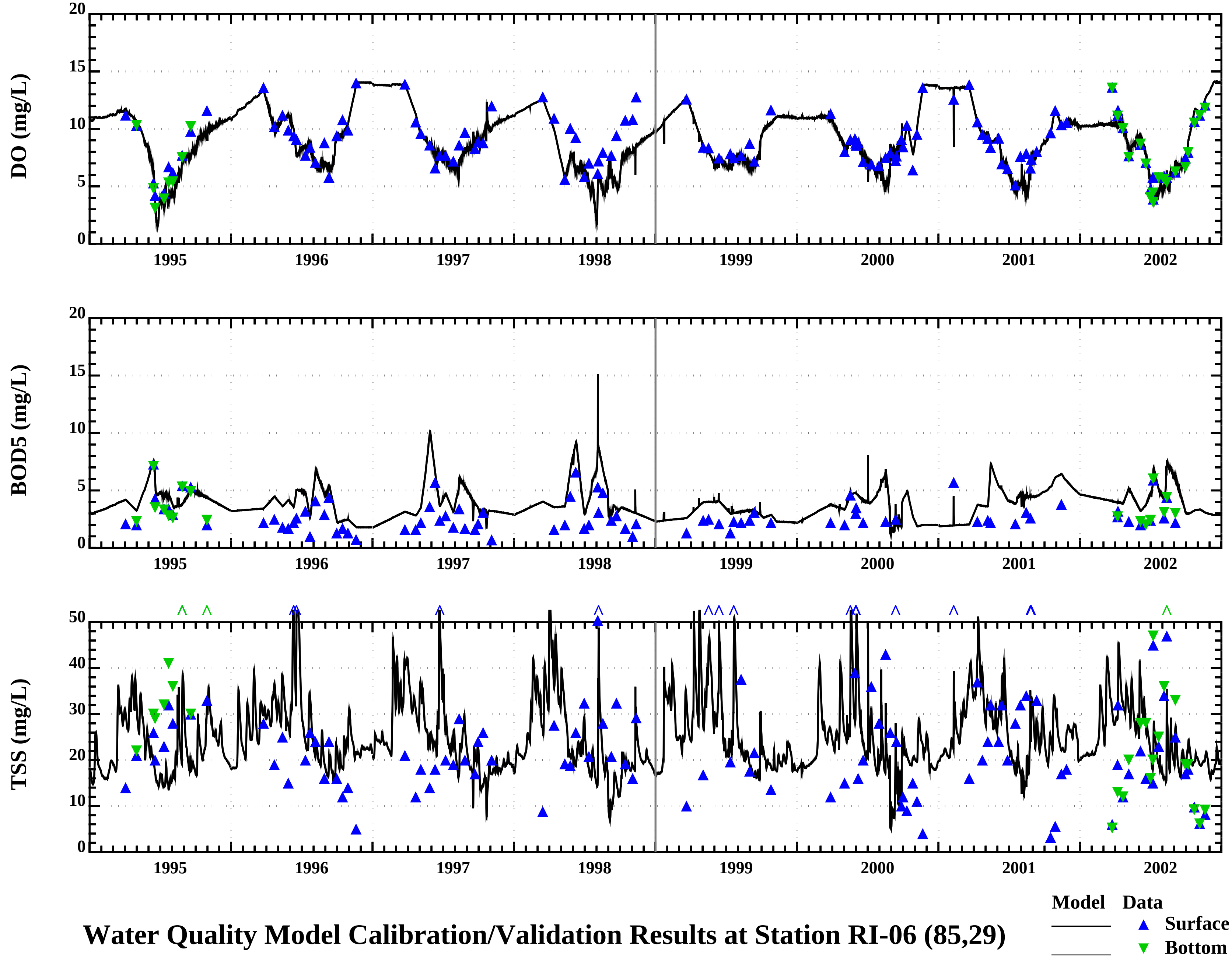
Water Quality Model Calibration/Validation Results at Station RI-06 (85,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:42:38



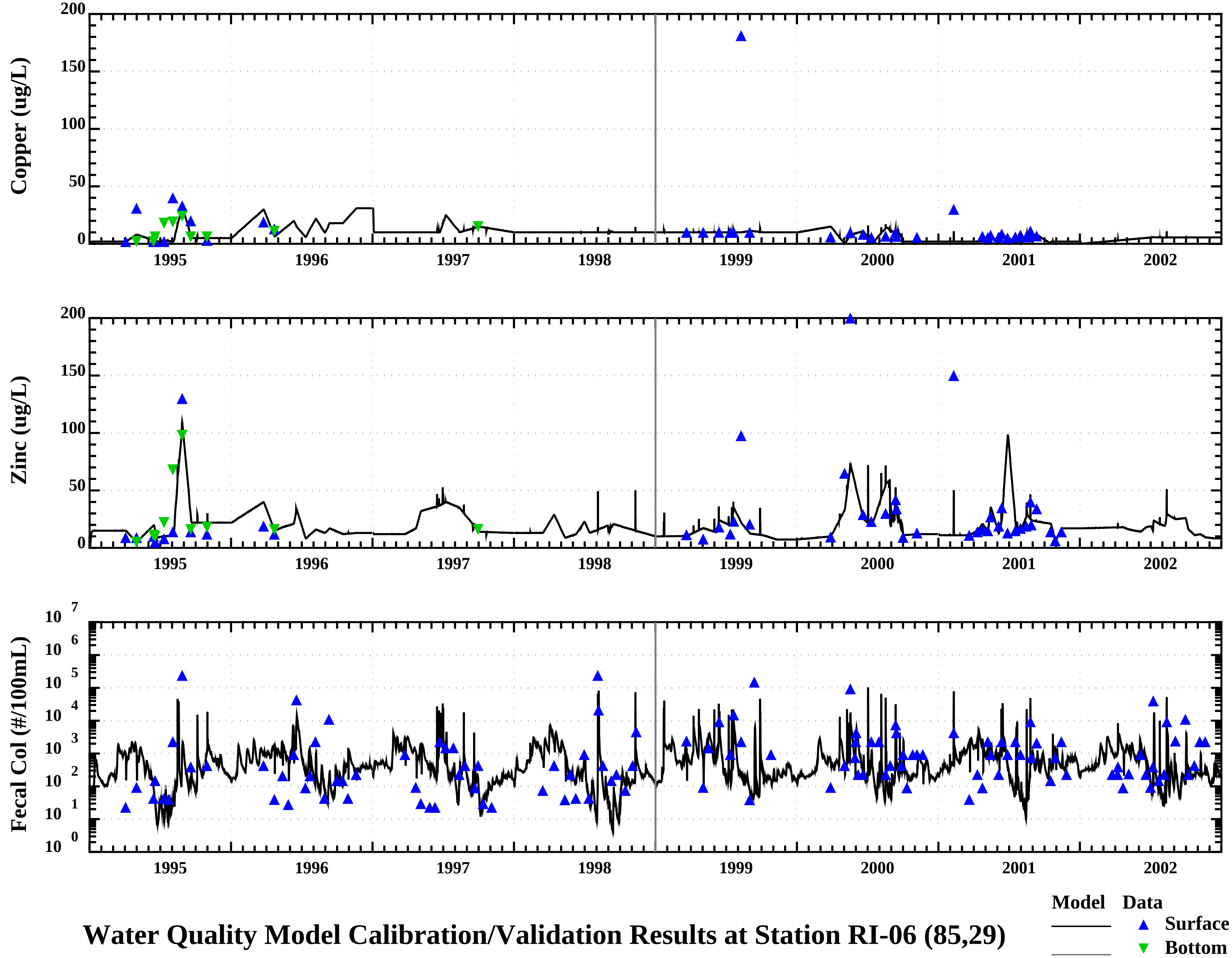
Water Quality Model Calibration/Validation Results at Station RI-06 (85,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:42:38



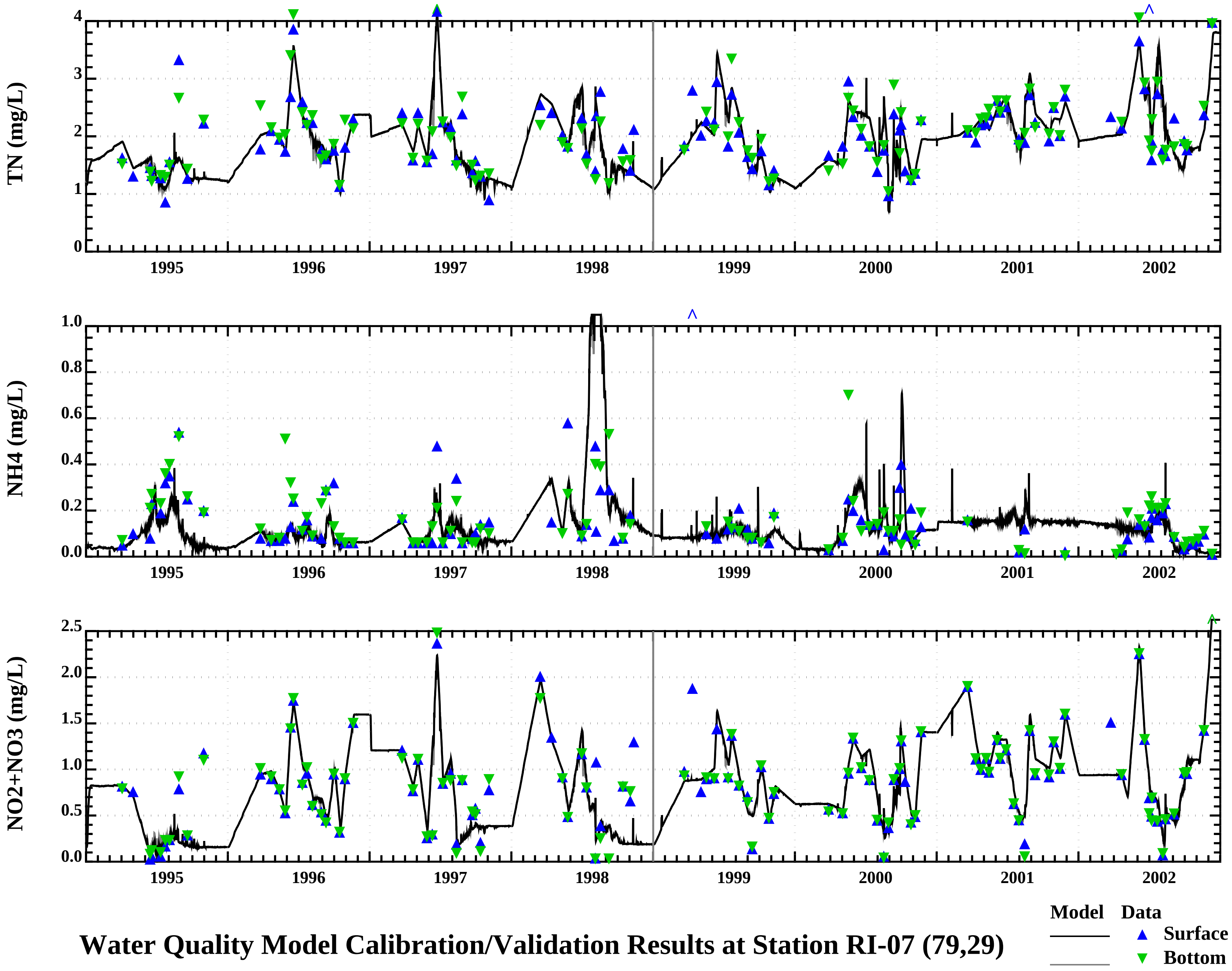
Water Quality Model Calibration/Validation Results at Station RI-06 (85,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:42:38



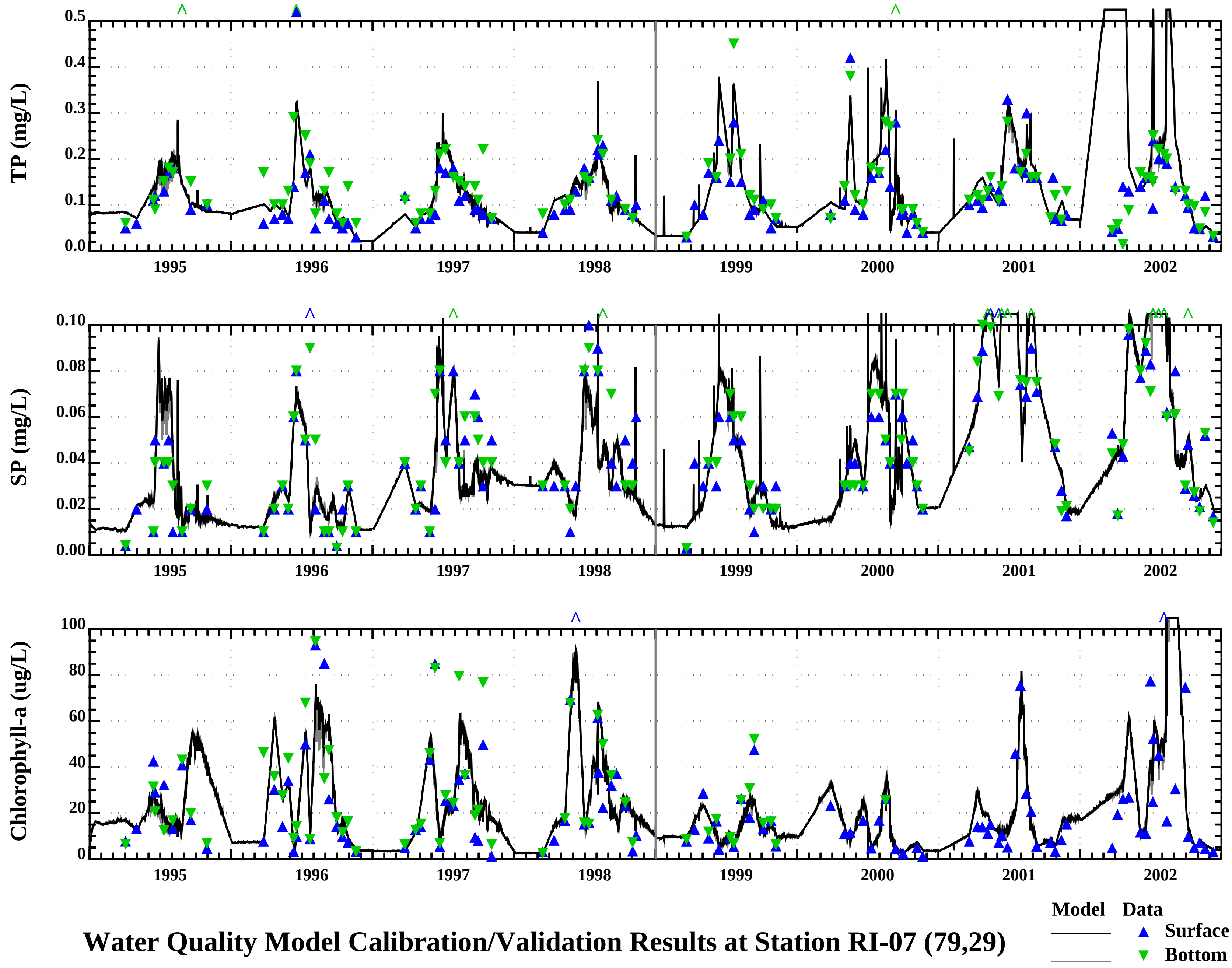
Water Quality Model Calibration/Validation Results at Station RI-06 (85,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:42:38



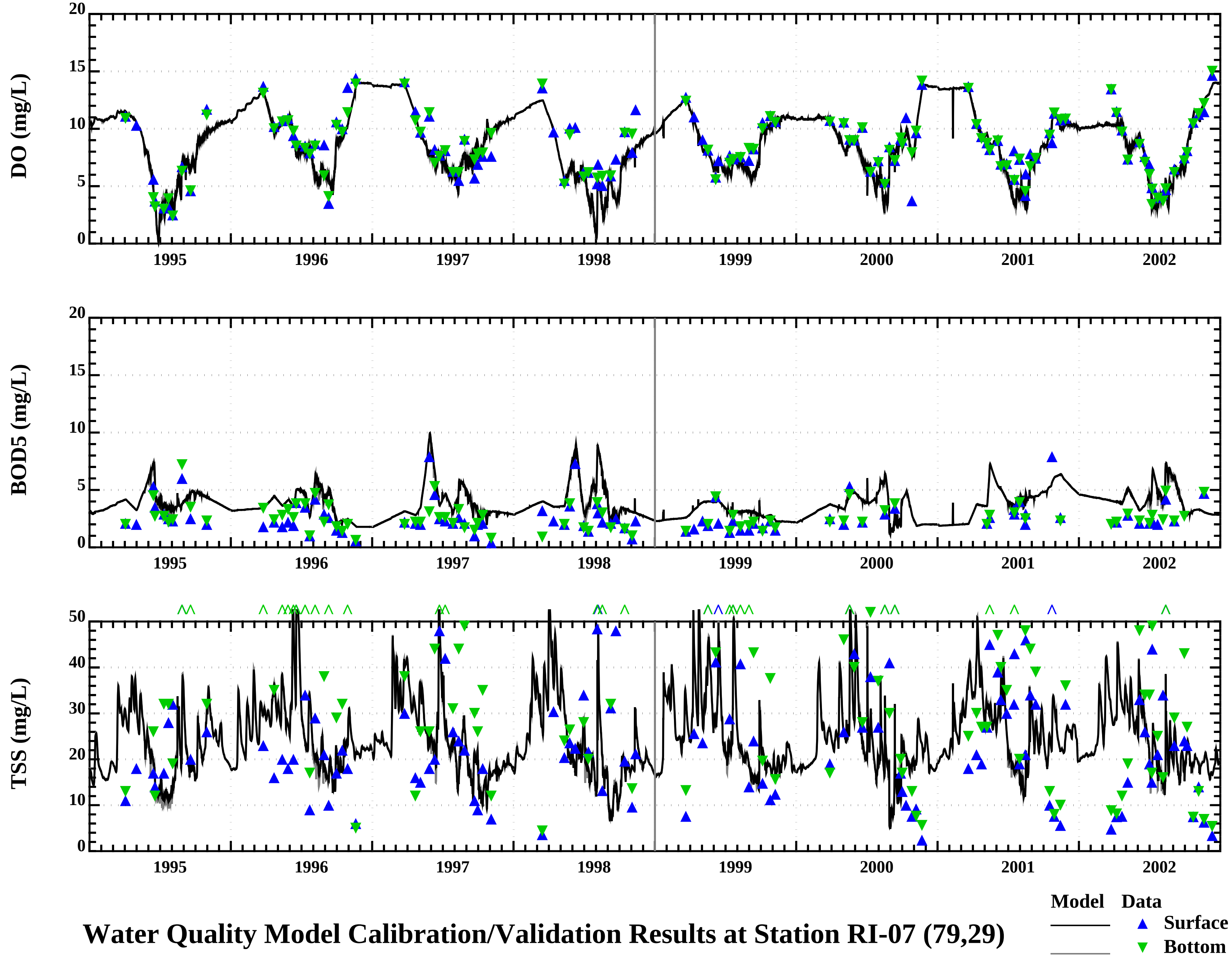
Water Quality Model Calibration/Validation Results at Station RI-07 (79,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:43:42



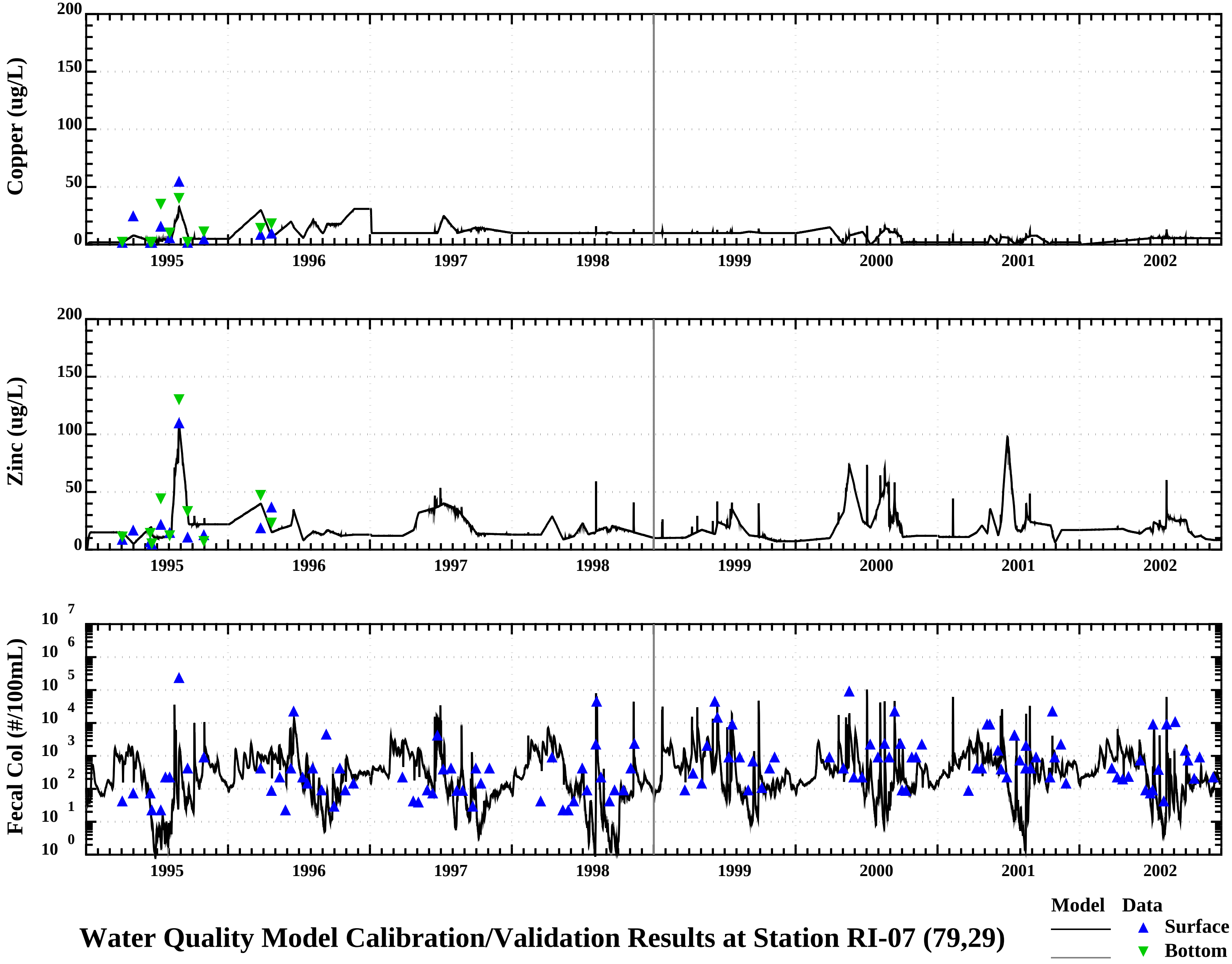
Water Quality Model Calibration/Validation Results at Station RI-07 (79,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:43:42



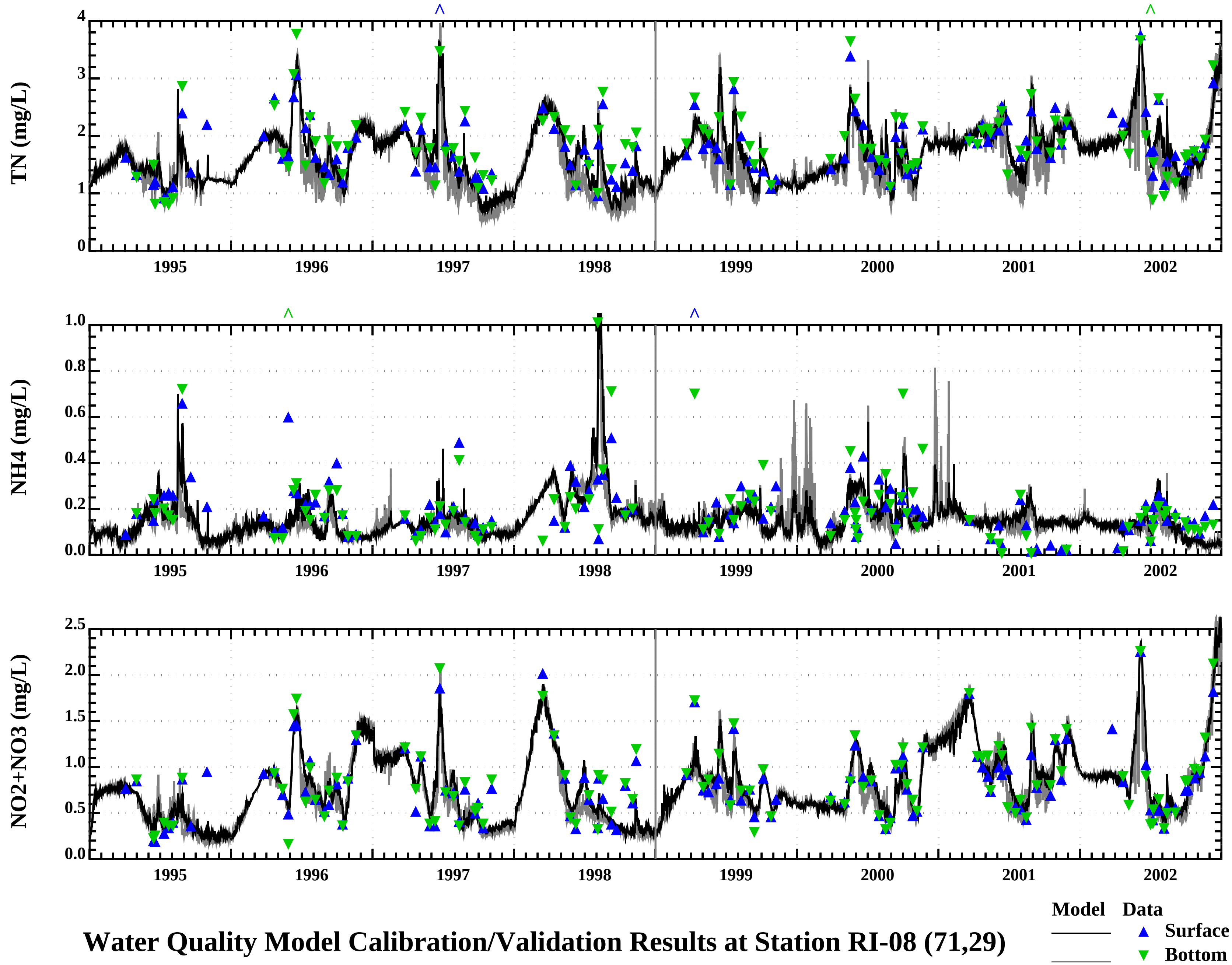
Water Quality Model Calibration/Validation Results at Station RI-07 (79,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:43:42



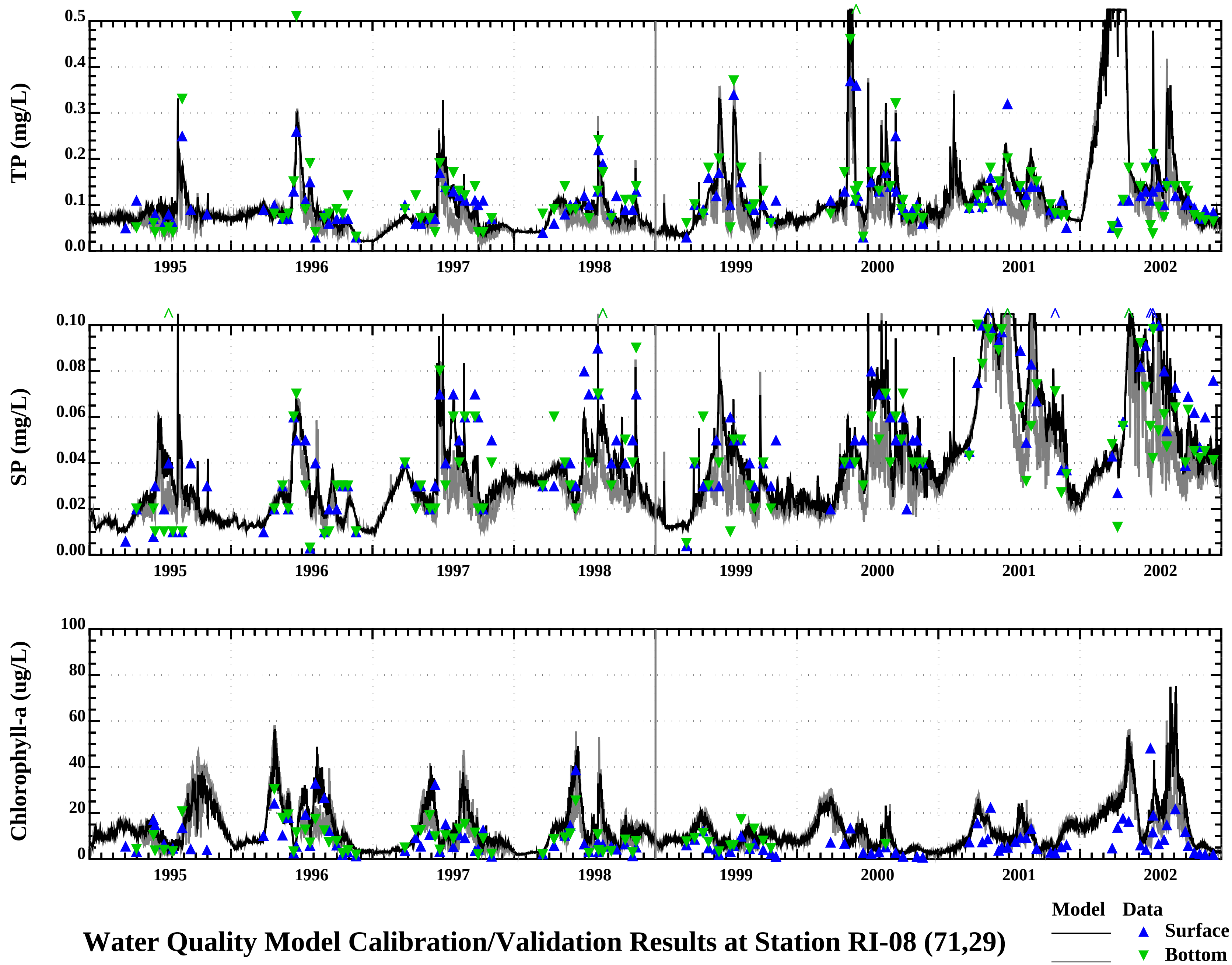
Water Quality Model Calibration/Validation Results at Station RI-07 (79,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:43:42



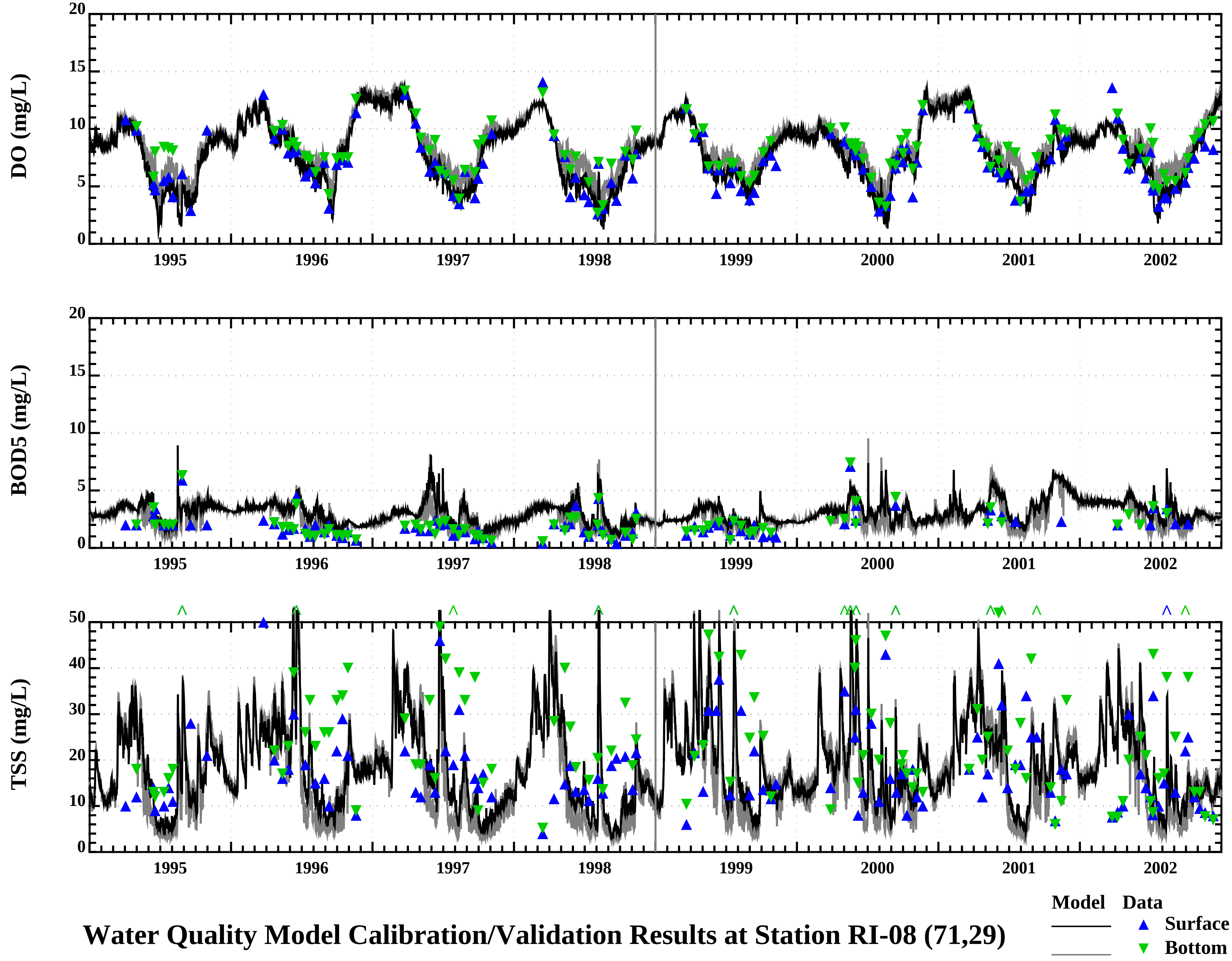
Water Quality Model Calibration/Validation Results at Station RI-08 (71,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:44:46



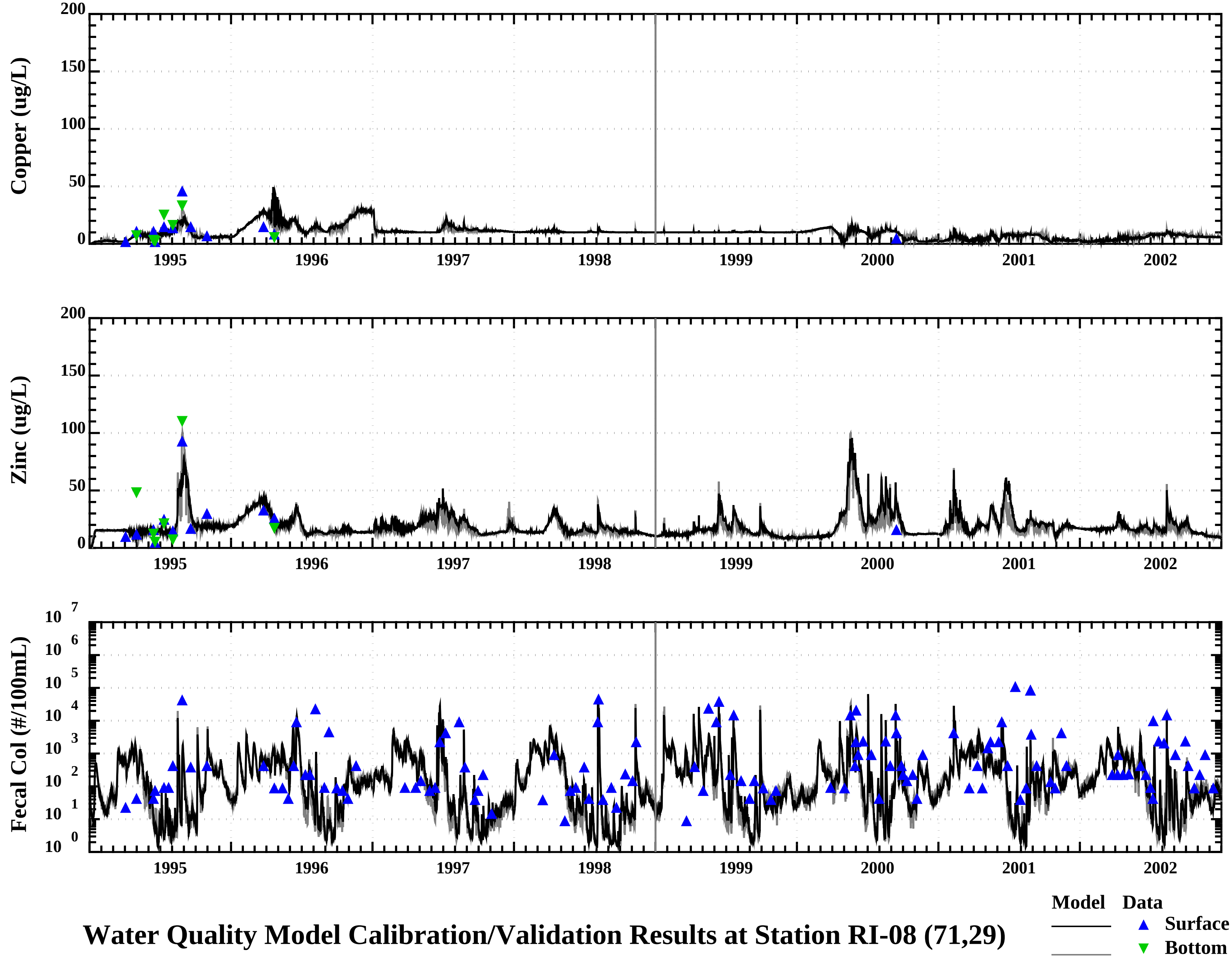
Water Quality Model Calibration/Validation Results at Station RI-08 (71,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:44:46



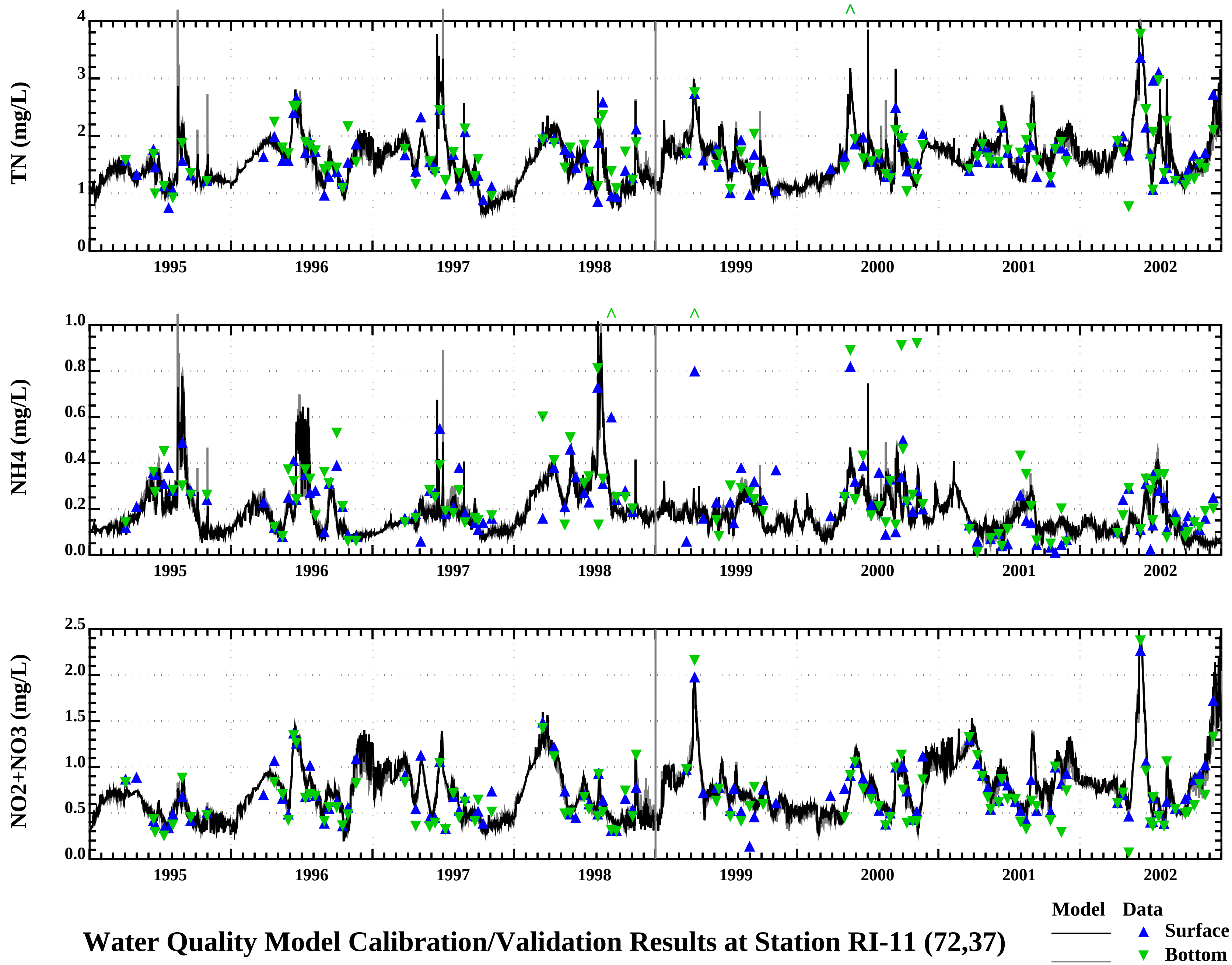
Water Quality Model Calibration/Validation Results at Station RI-08 (71,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:44:46



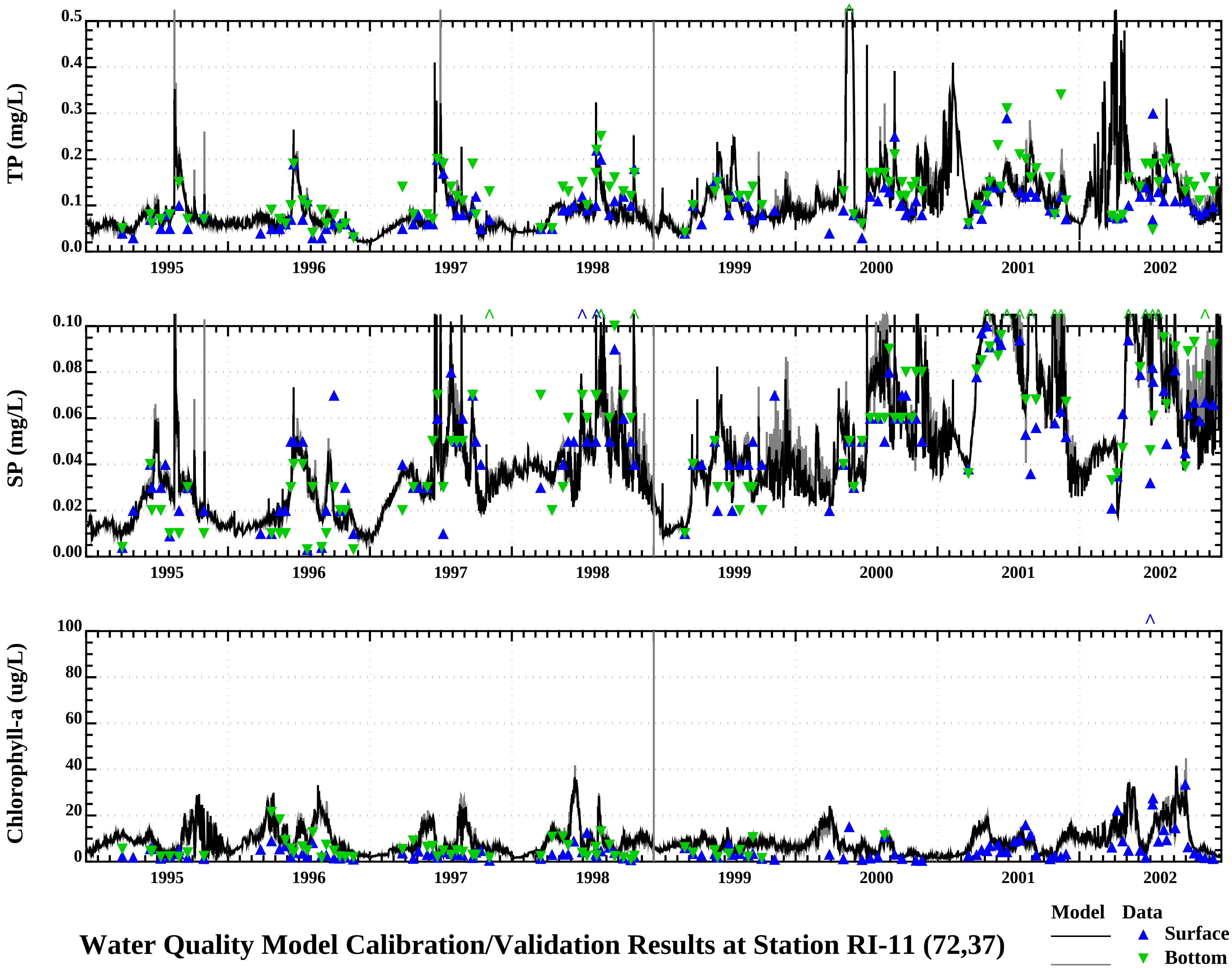
Water Quality Model Calibration/Validation Results at Station RI-08 (71,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:44:46



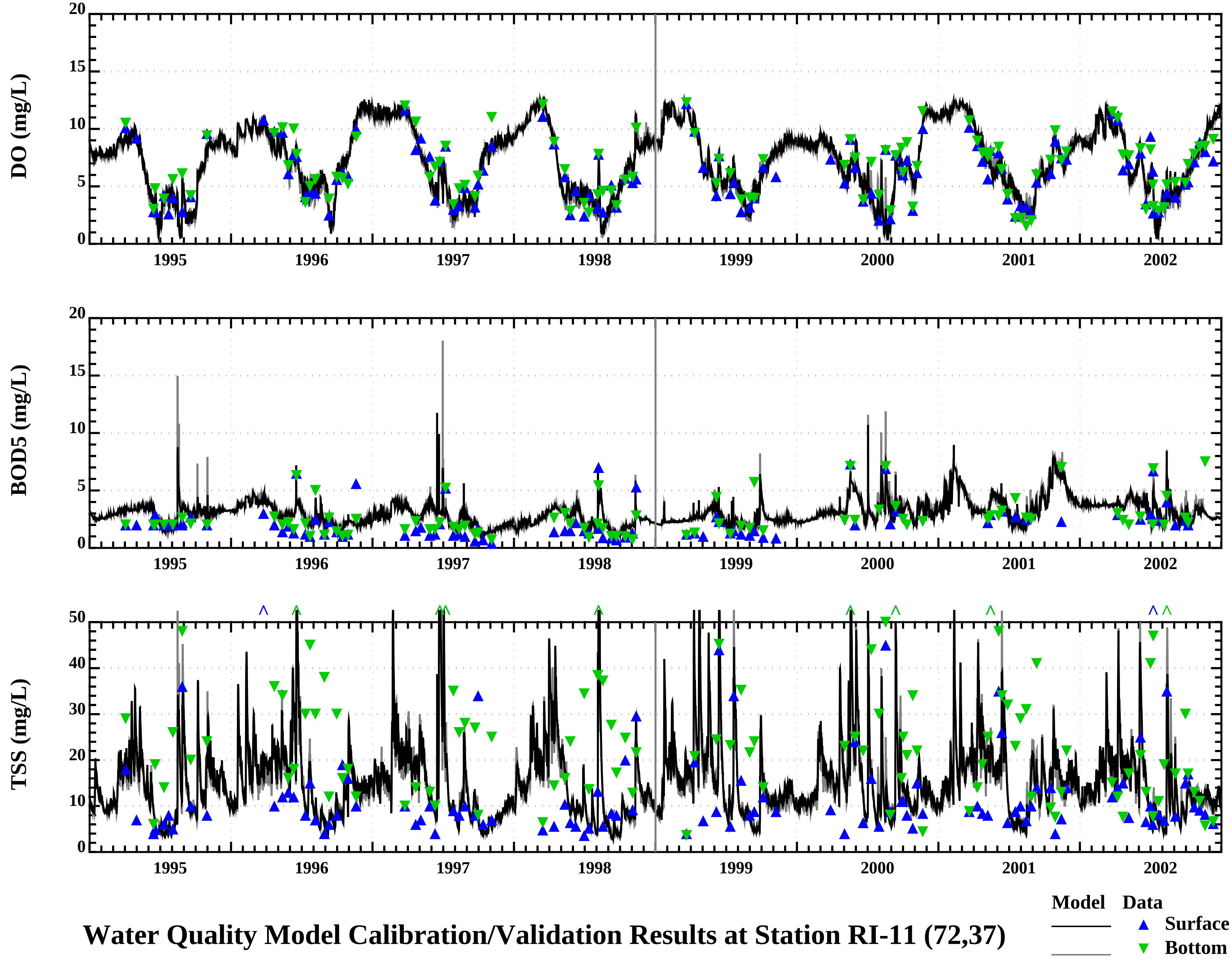
Water Quality Model Calibration/Validation Results at Station RI-11 (72,37)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:46:54



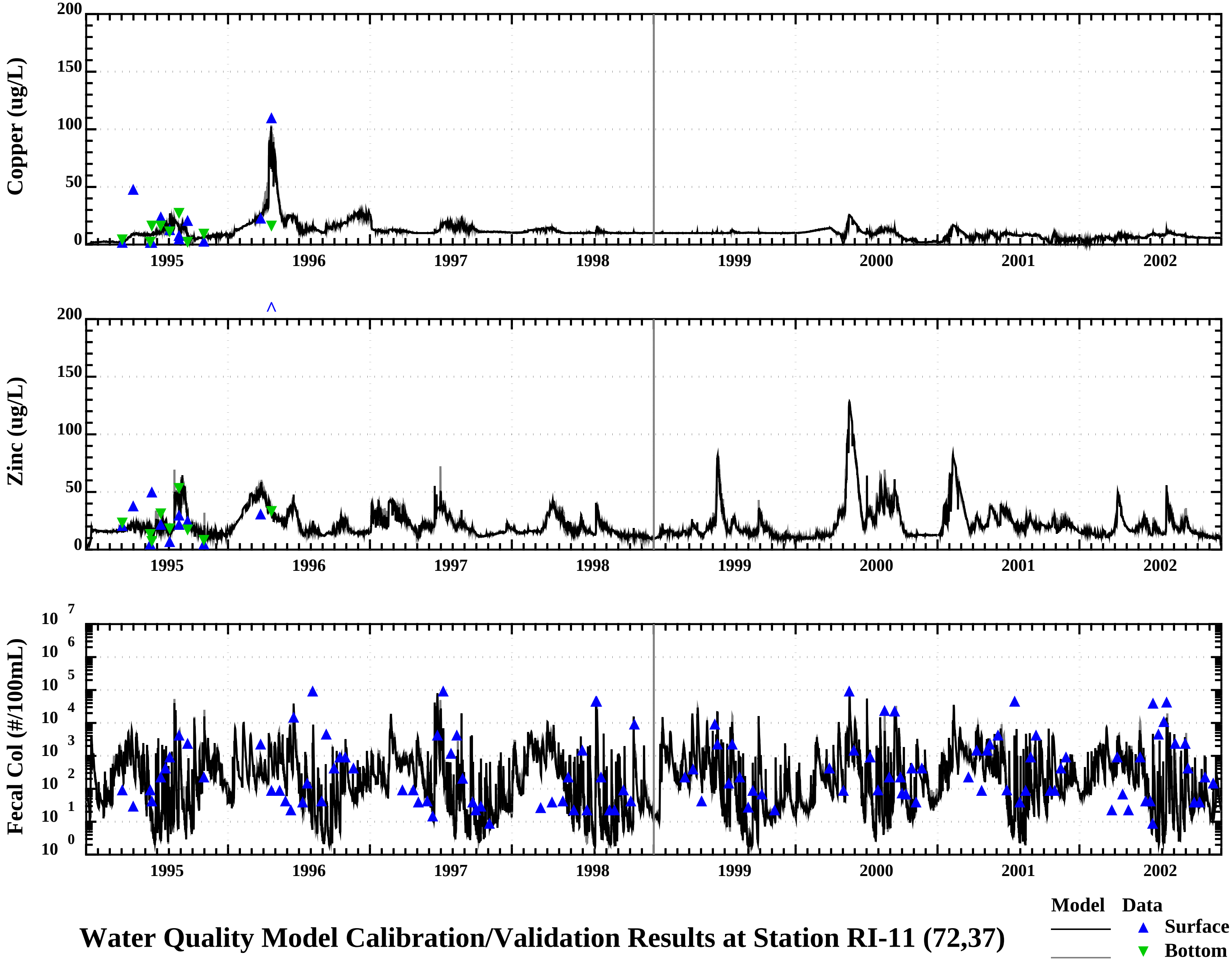
Water Quality Model Calibration/Validation Results at Station RI-11 (72,37)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:46:54



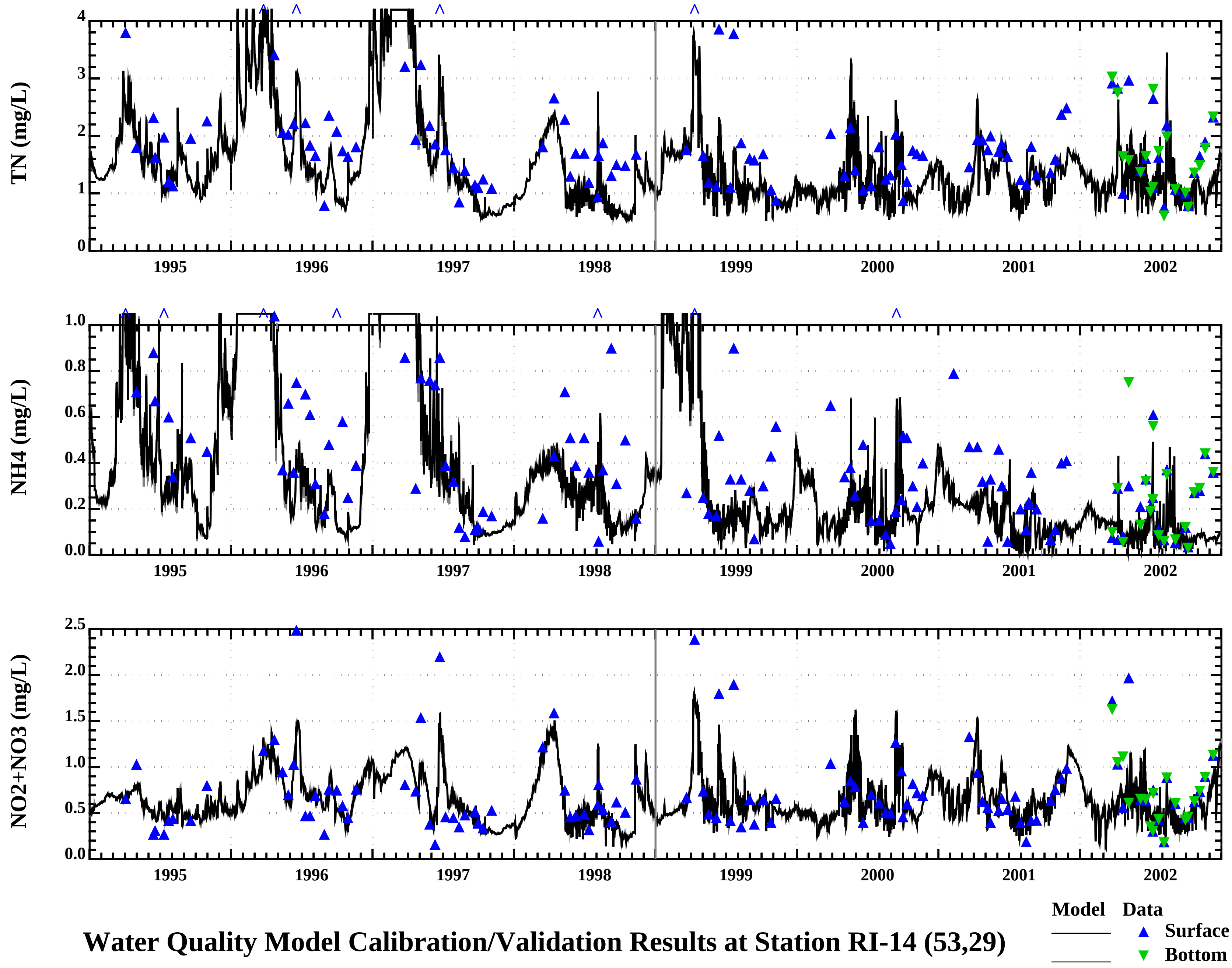
Water Quality Model Calibration/Validation Results at Station RI-11 (72,37)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:46:54



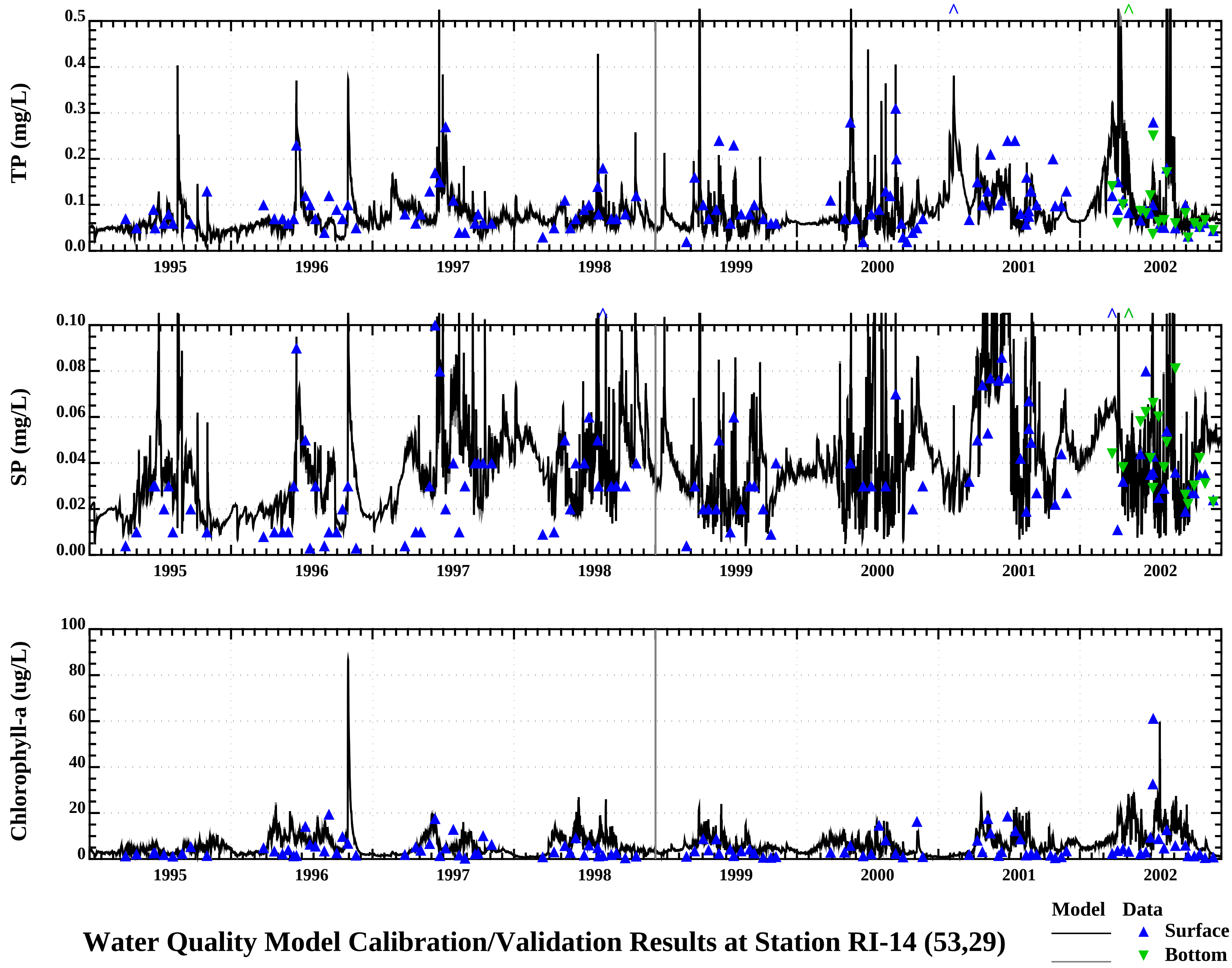
Water Quality Model Calibration/Validation Results at Station RI-11 (72,37)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:46:54



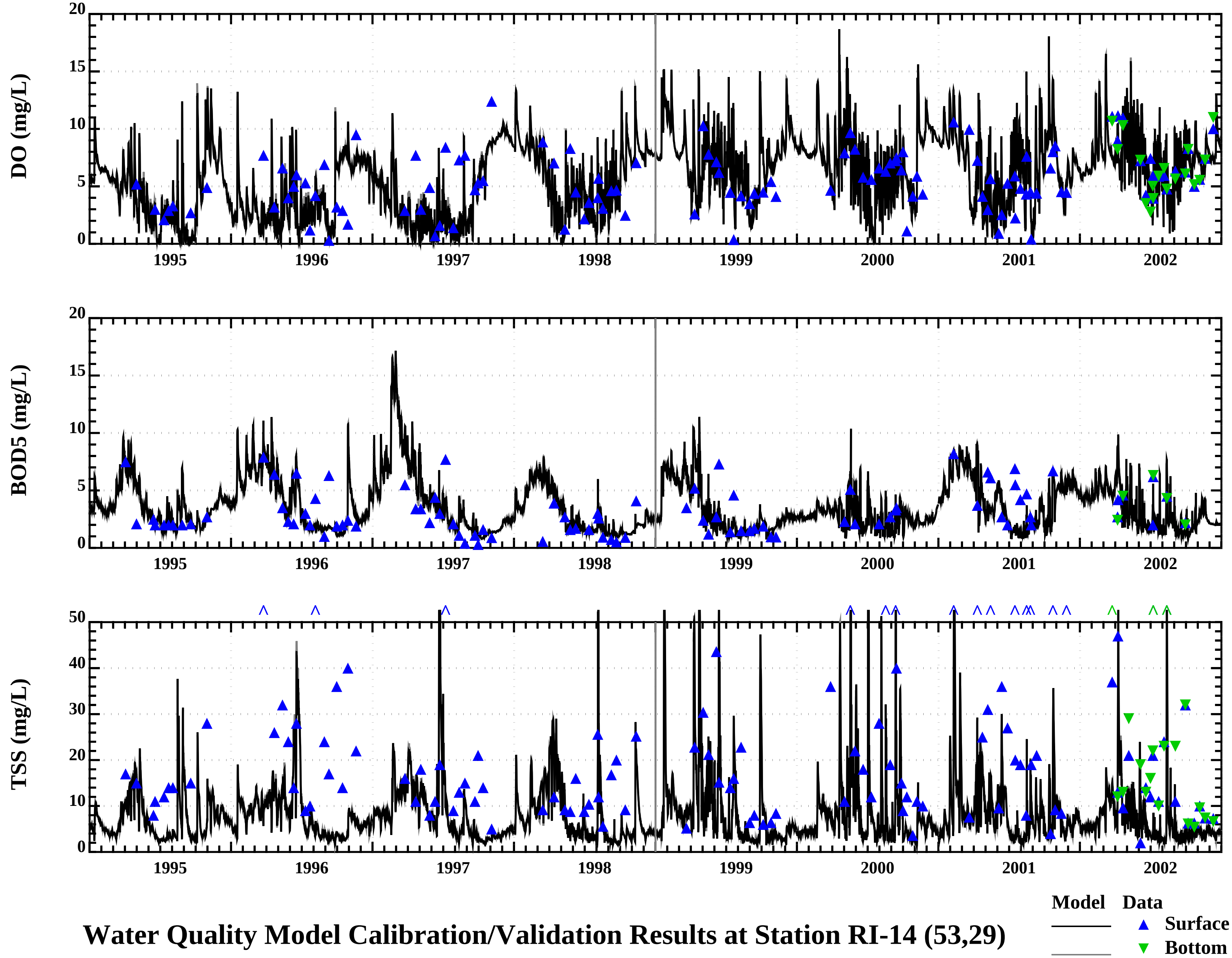
Water Quality Model Calibration/Validation Results at Station RI-14 (53,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:49: 1



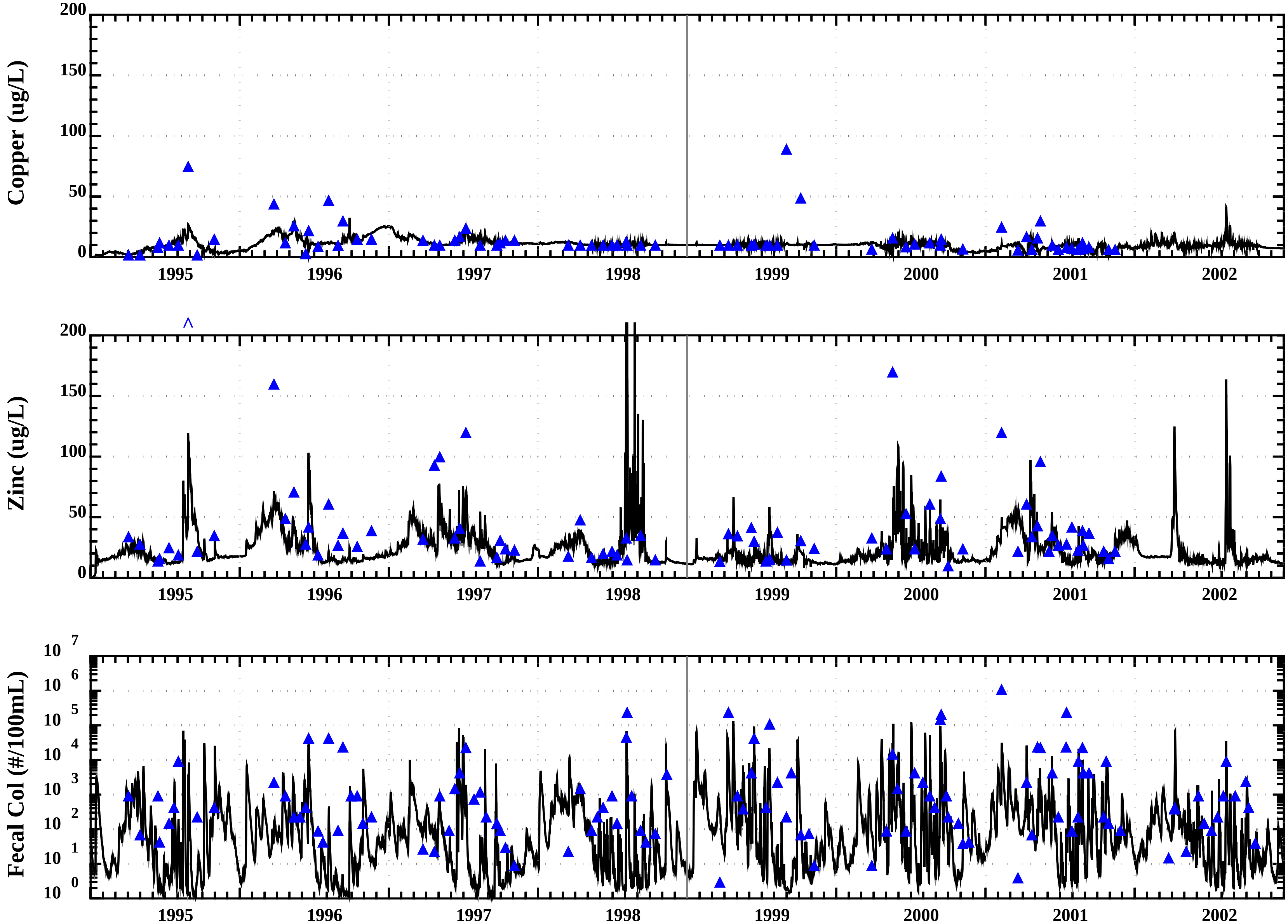
Water Quality Model Calibration/Validation Results at Station RI-14 (53,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:49: 1



Water Quality Model Calibration/Validation Results at Station RI-14 (53,29)

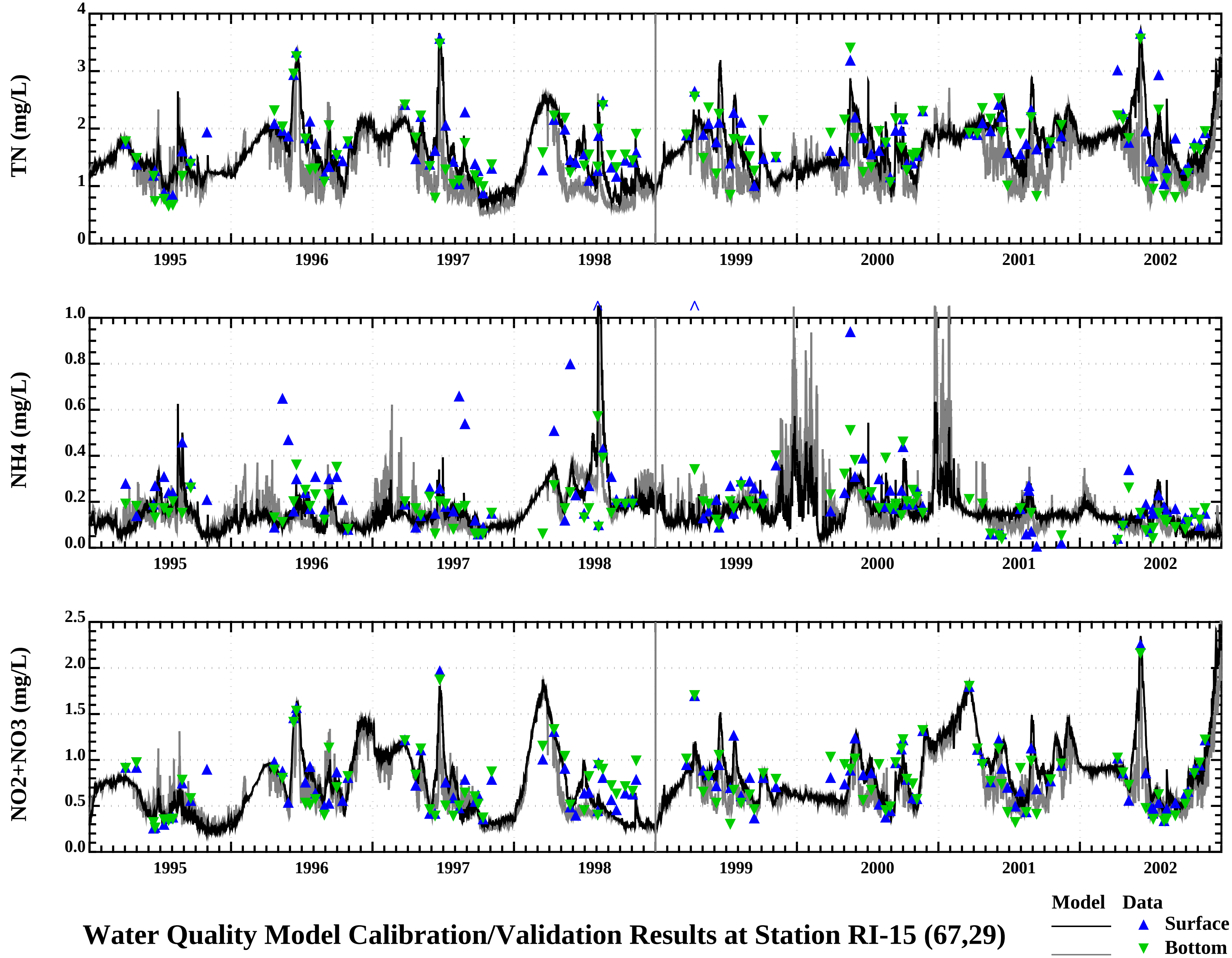
/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:49: 1



Model Data
Surface
Bottom

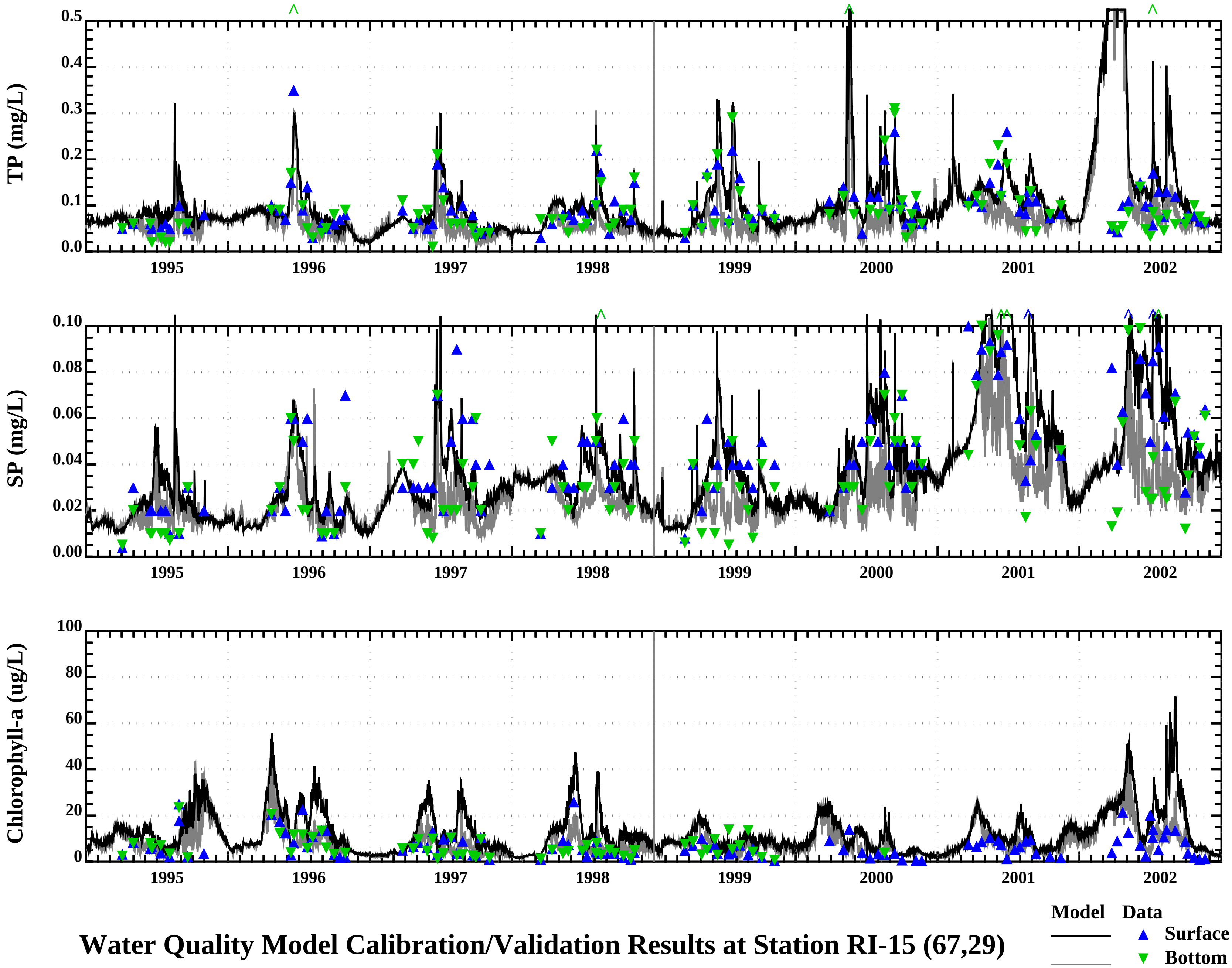
Water Quality Model Calibration/Validation Results at Station RI-14 (53,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:49: 1



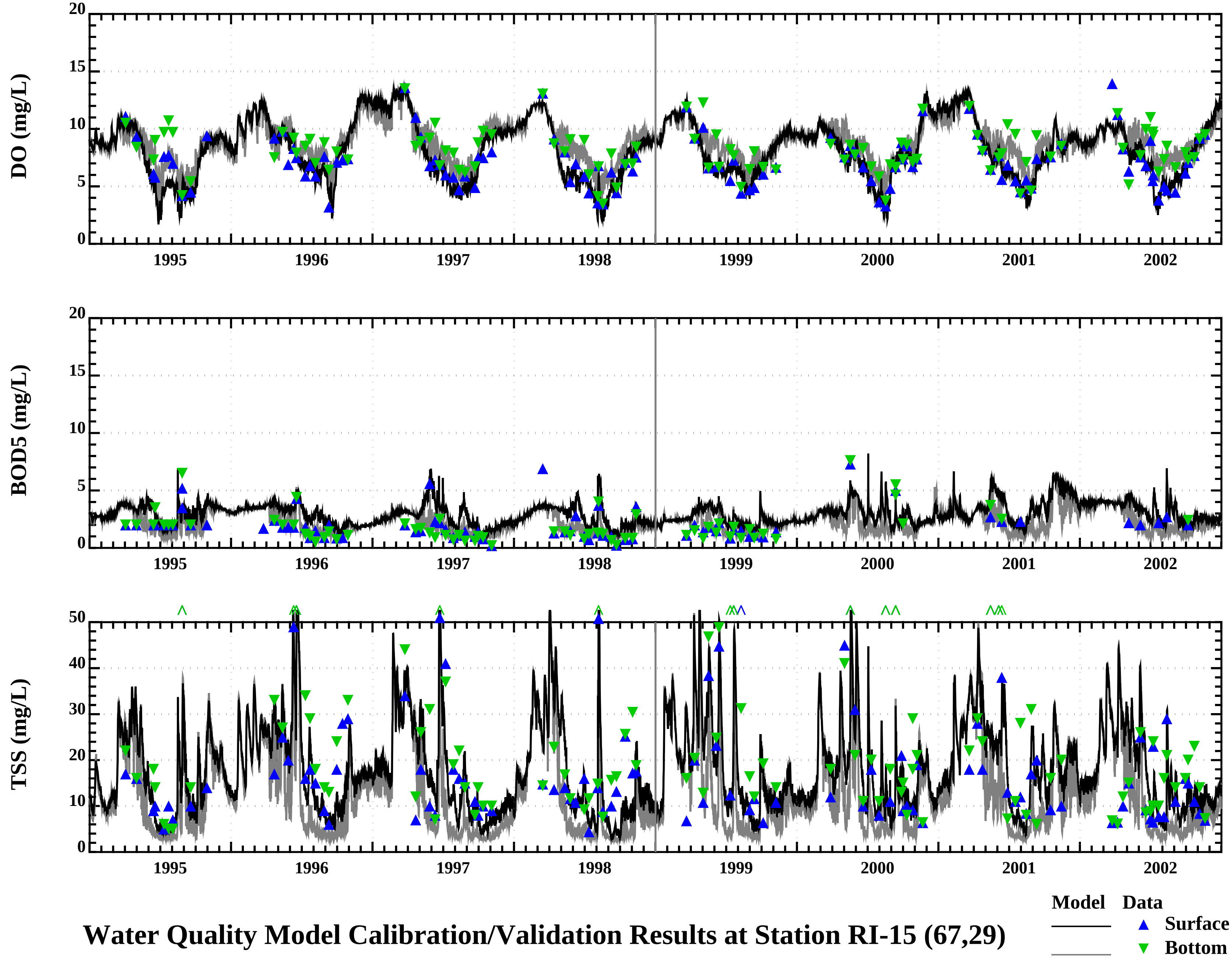
Water Quality Model Calibration/Validation Results at Station RI-15 (67,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:45:50



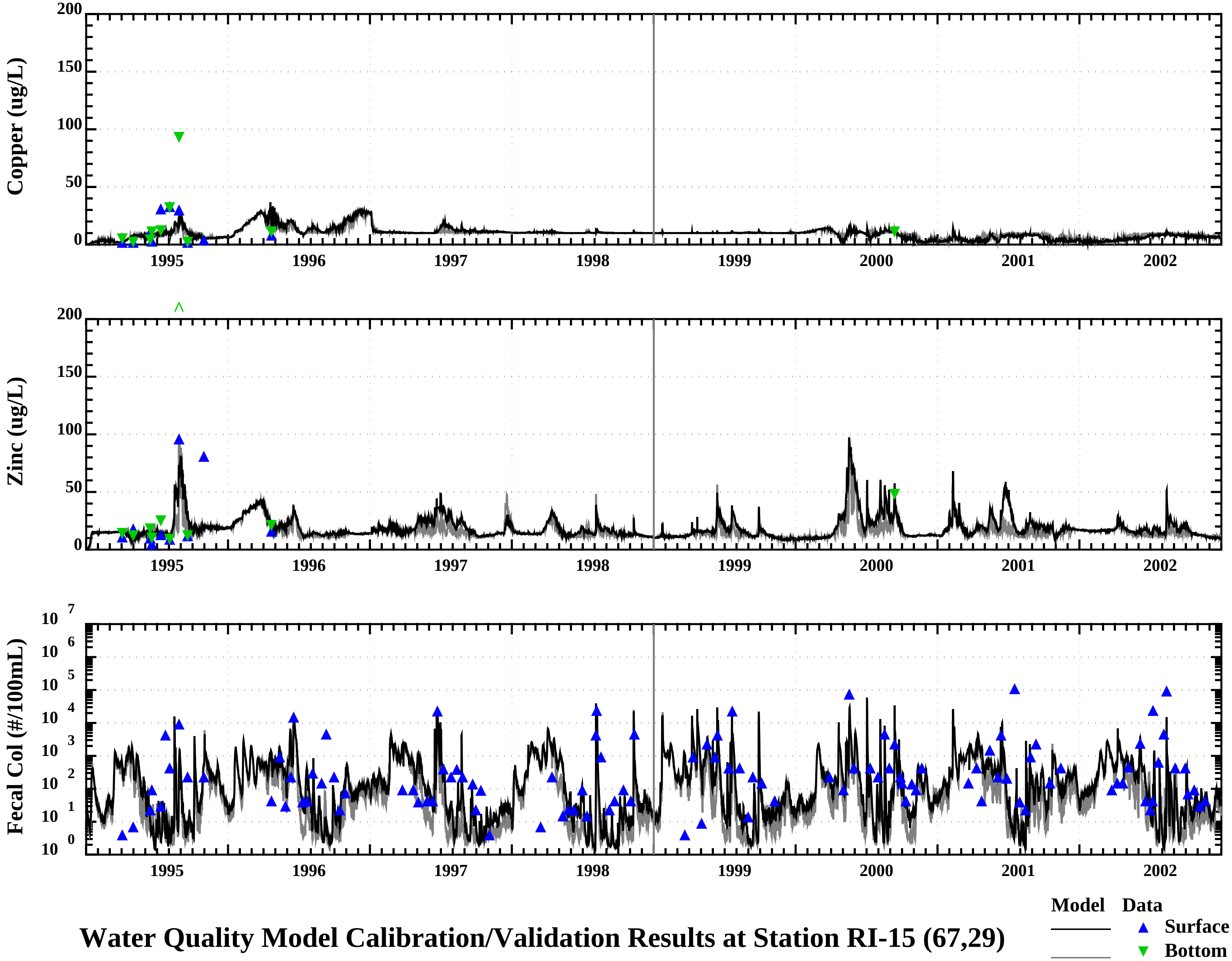
Water Quality Model Calibration/Validation Results at Station RI-15 (67,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:45:50



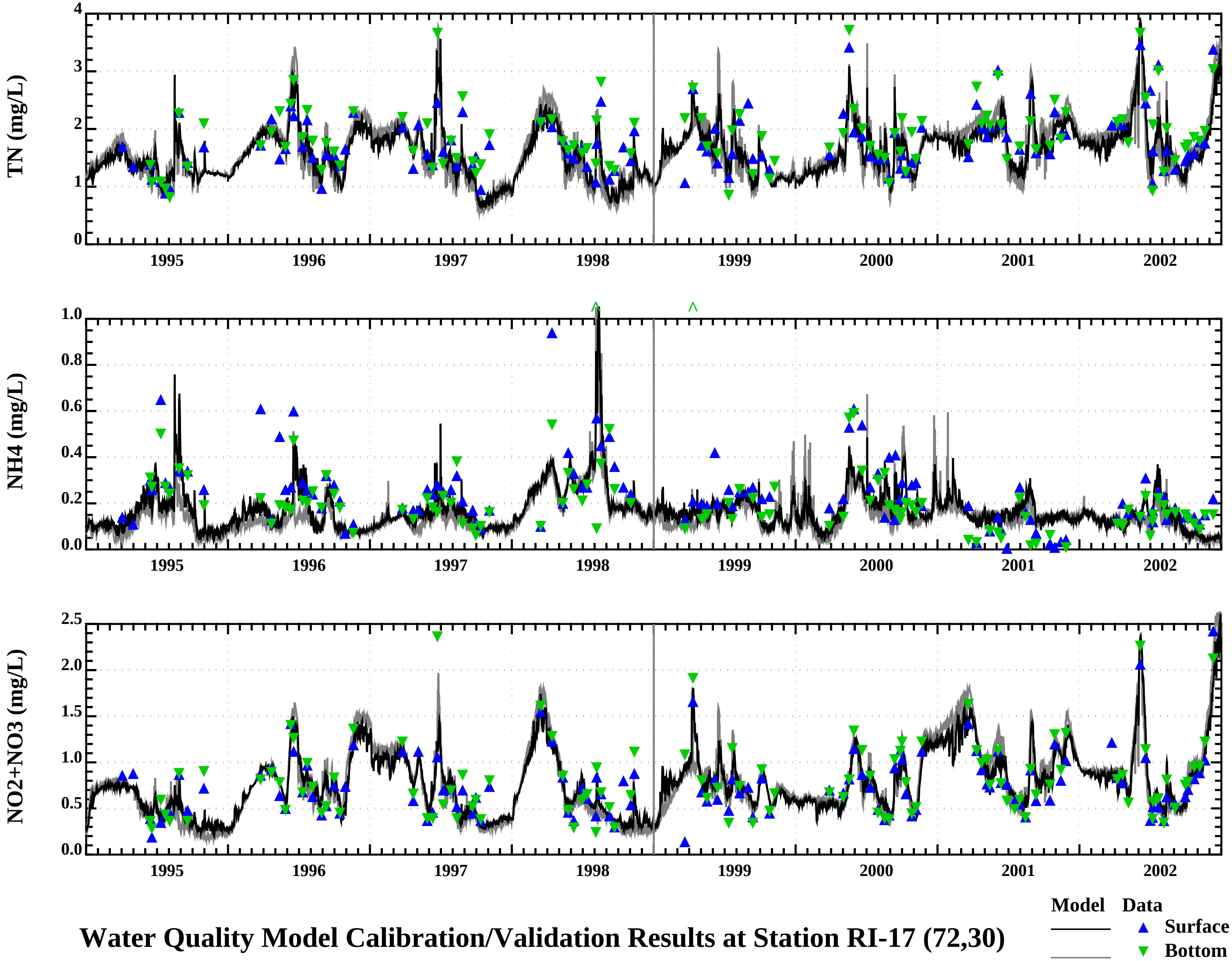
Water Quality Model Calibration/Validation Results at Station RI-15 (67,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:45:50



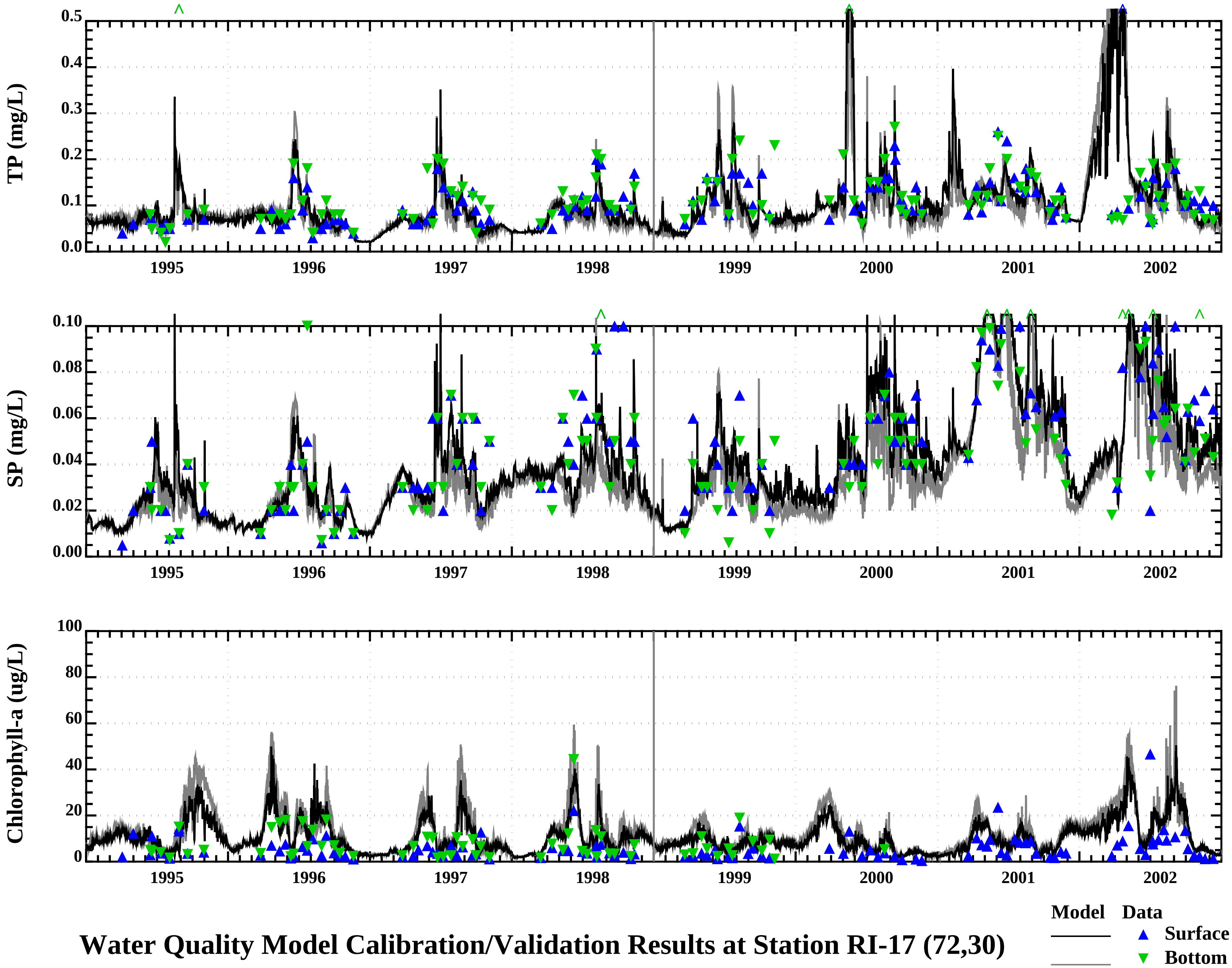
Water Quality Model Calibration/Validation Results at Station RI-15 (67,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:45:50



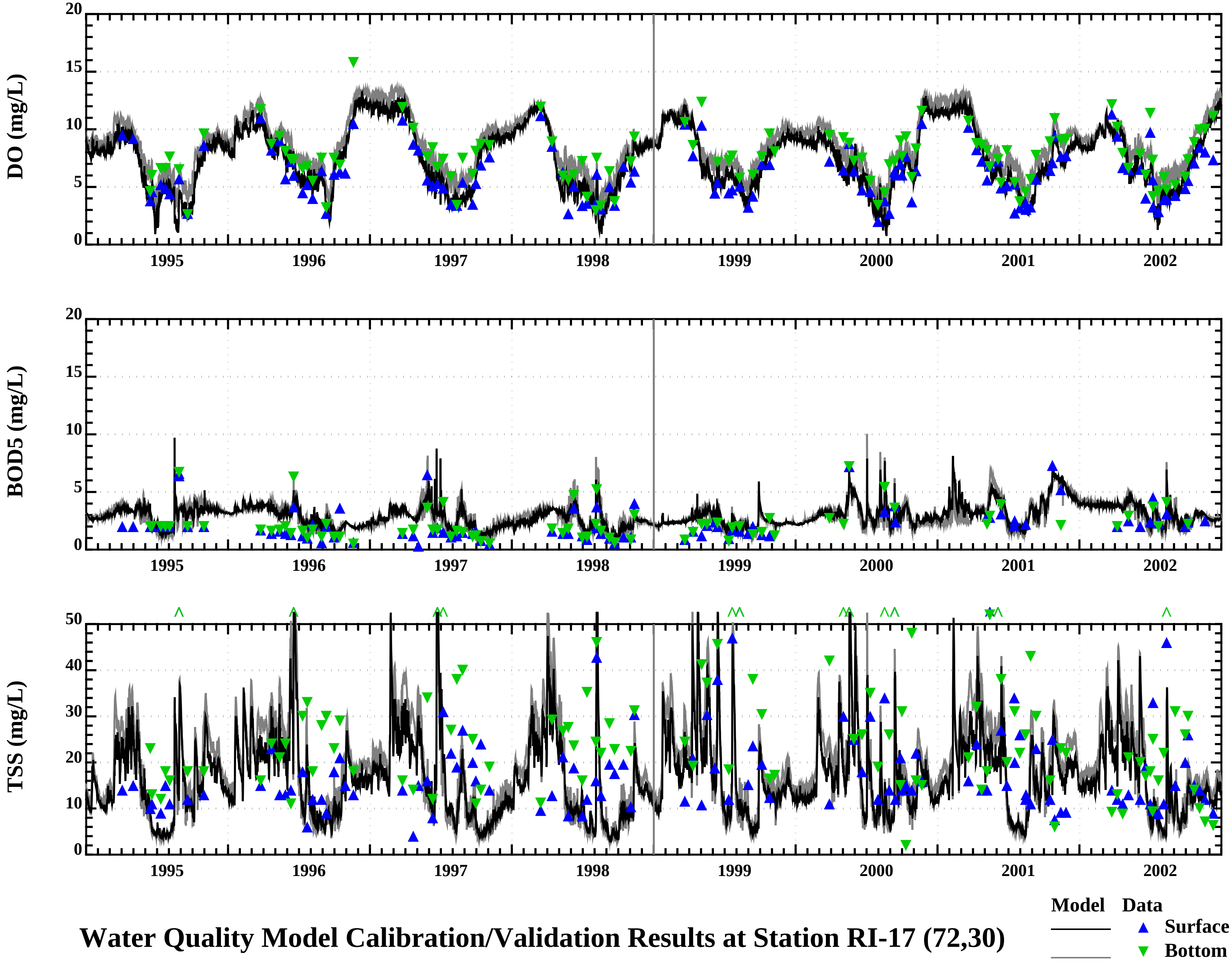
Water Quality Model Calibration/Validation Results at Station RI-17 (72,30)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:47:57



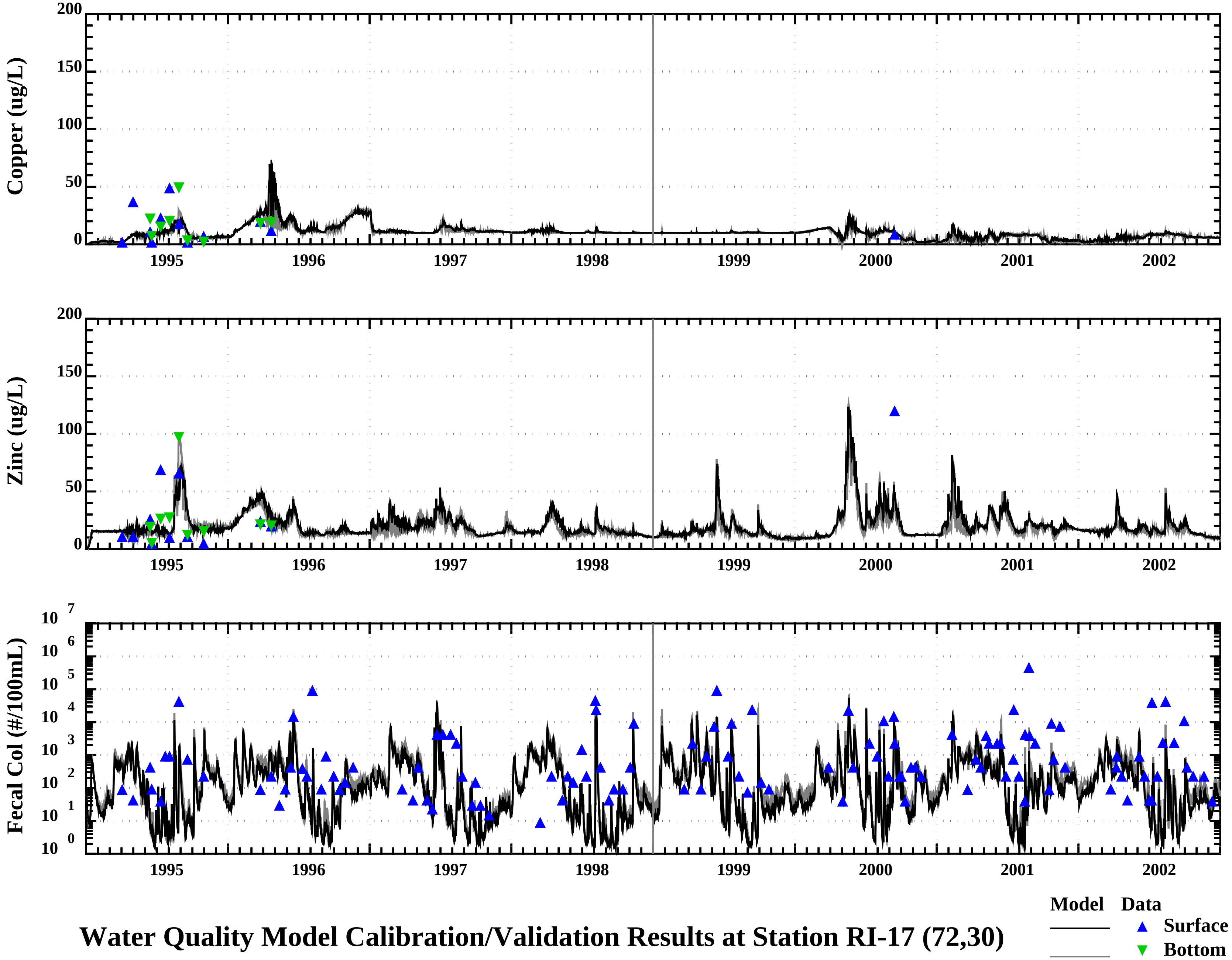
Water Quality Model Calibration/Validation Results at Station RI-17 (72,30)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:47:57



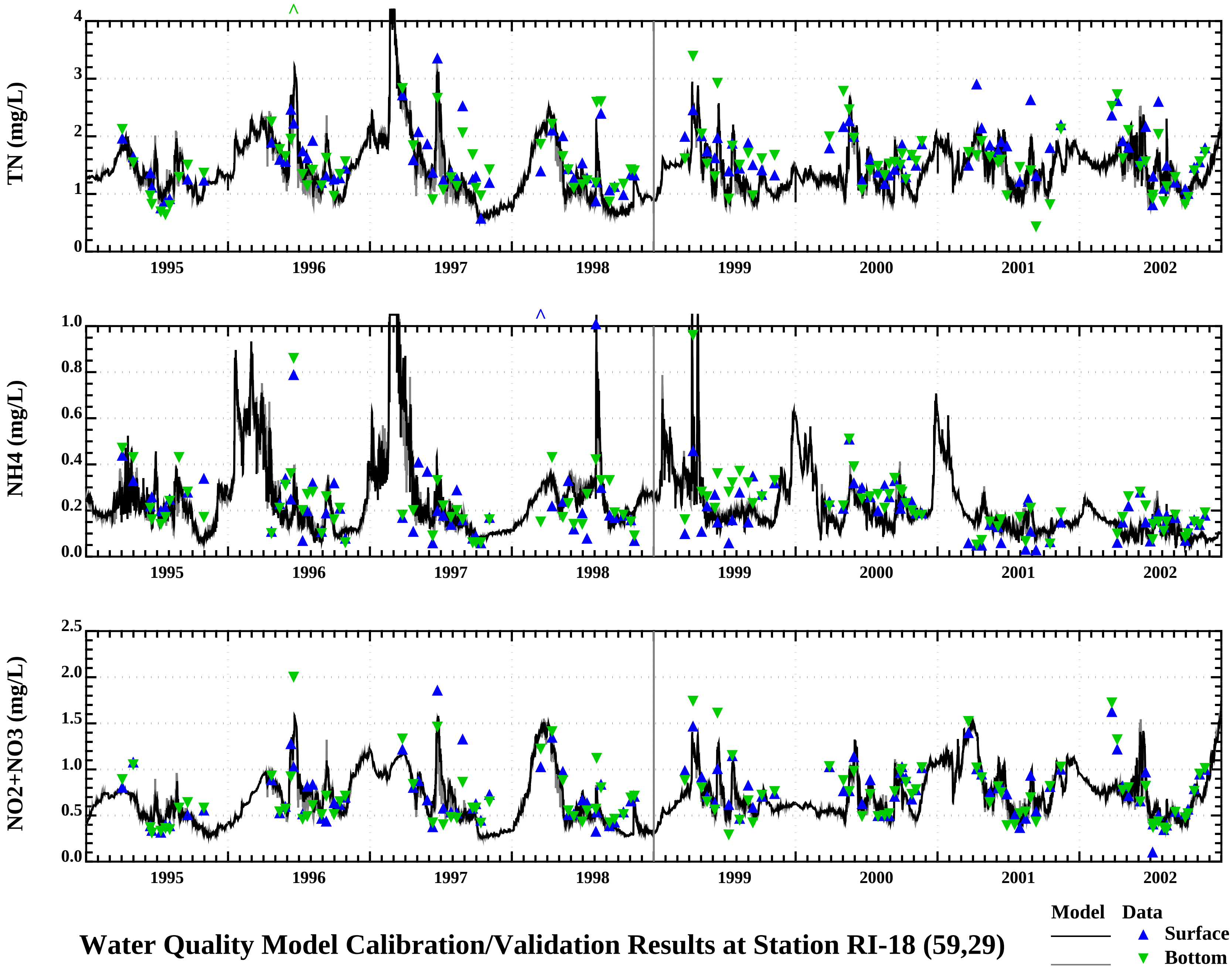
Water Quality Model Calibration/Validation Results at Station RI-17 (72,30)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:47:57



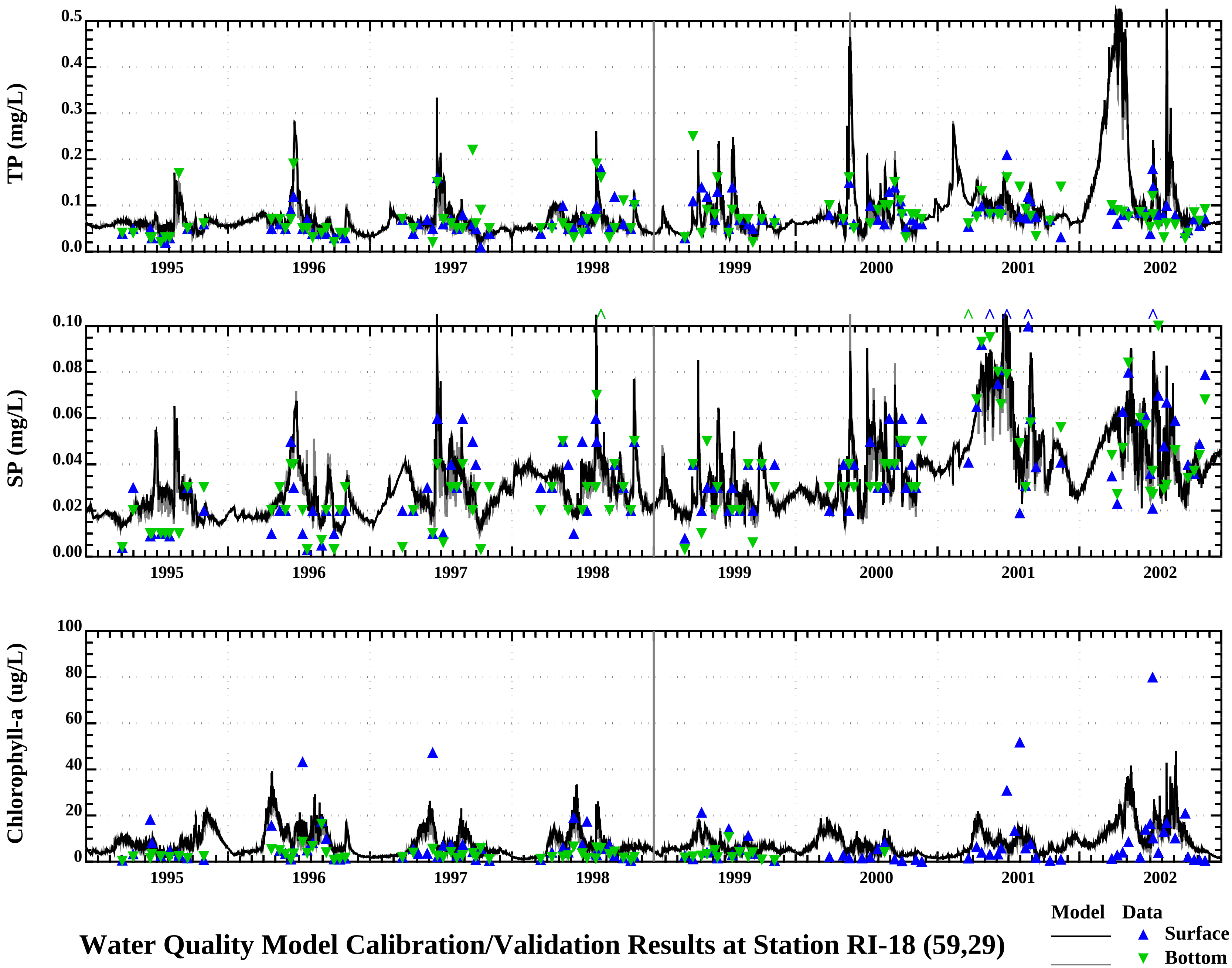
Water Quality Model Calibration/Validation Results at Station RI-17 (72,30)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:47:57



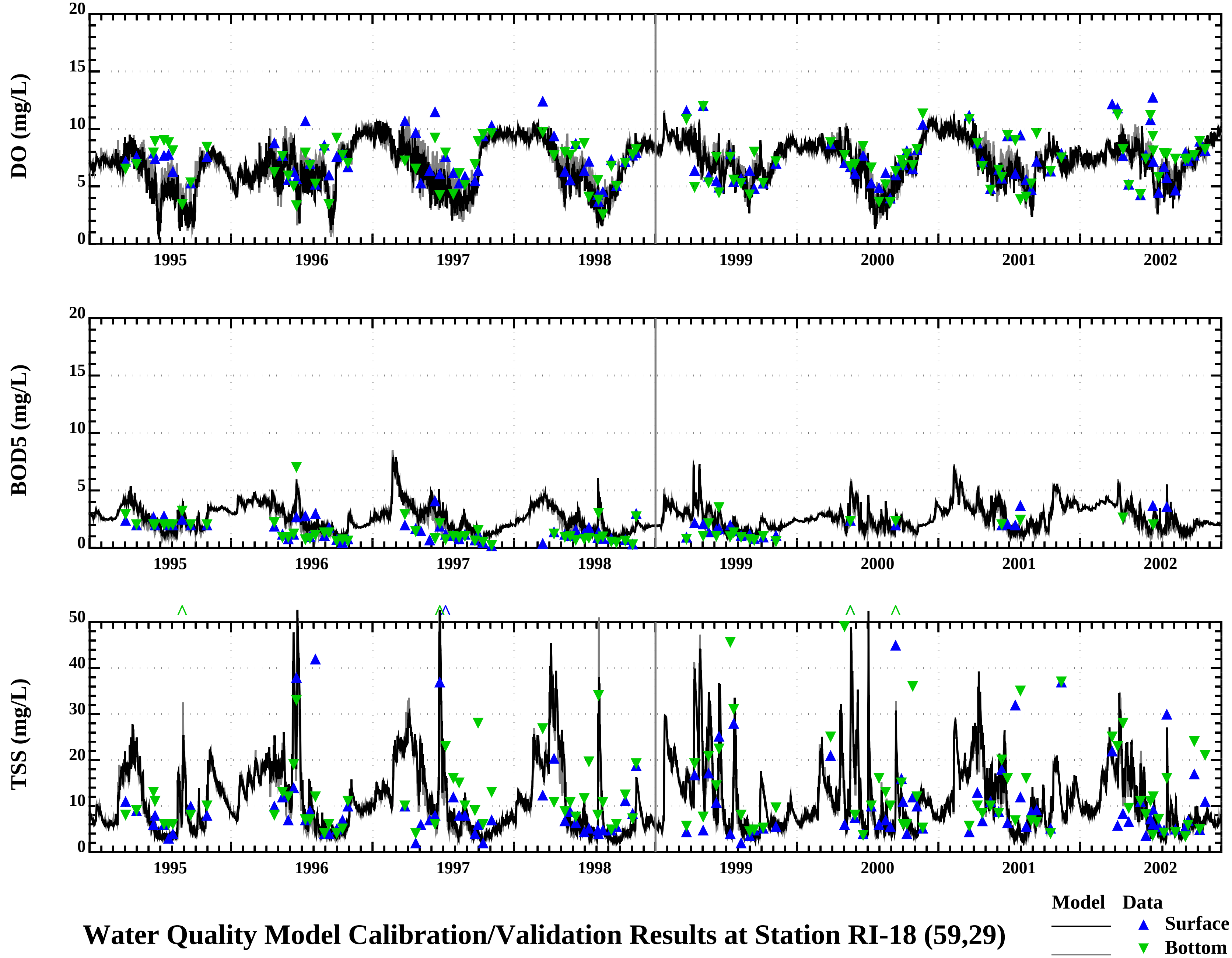
Water Quality Model Calibration/Validation Results at Station RI-18 (59,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:50: 4



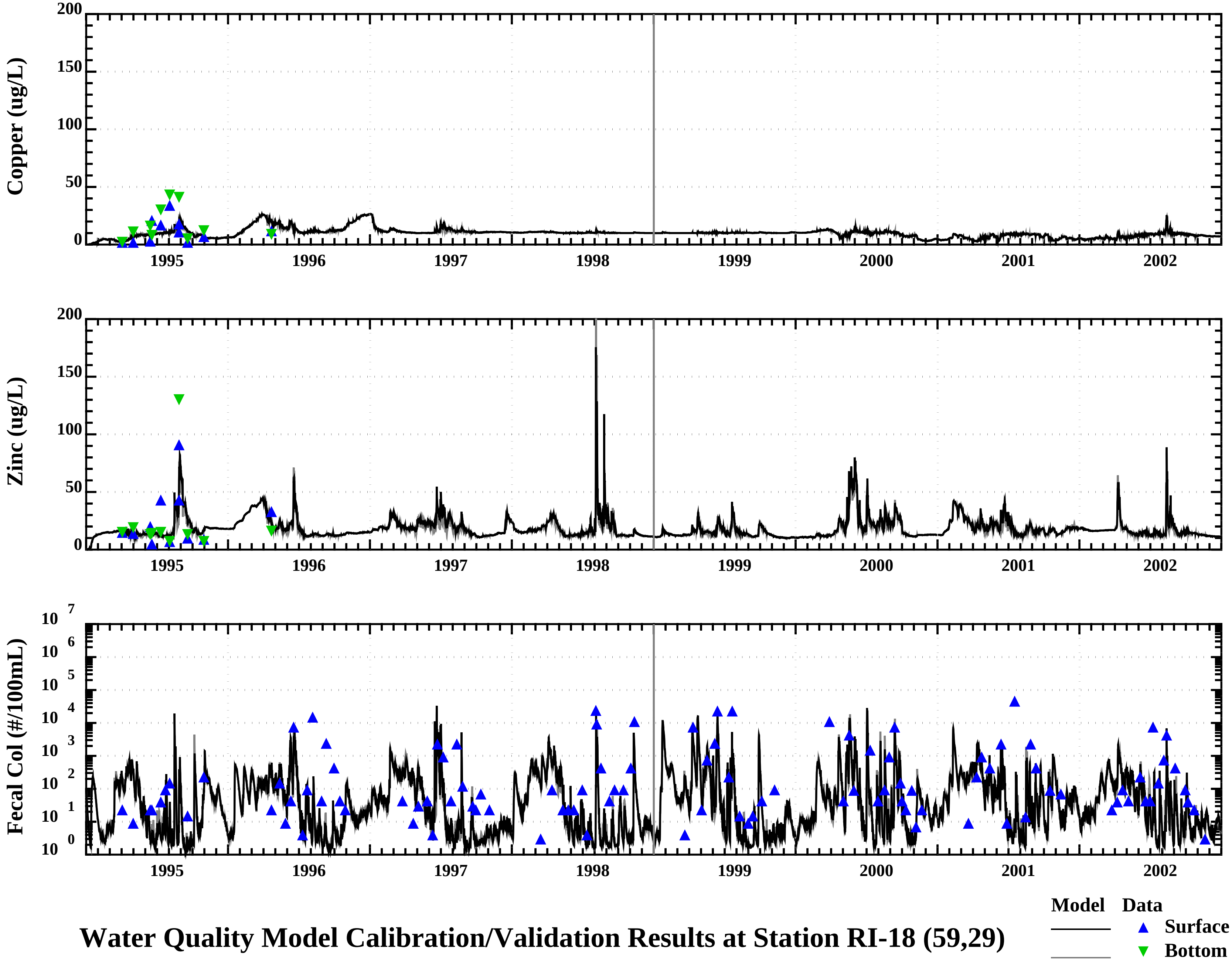
Water Quality Model Calibration/Validation Results at Station RI-18 (59,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:50: 4



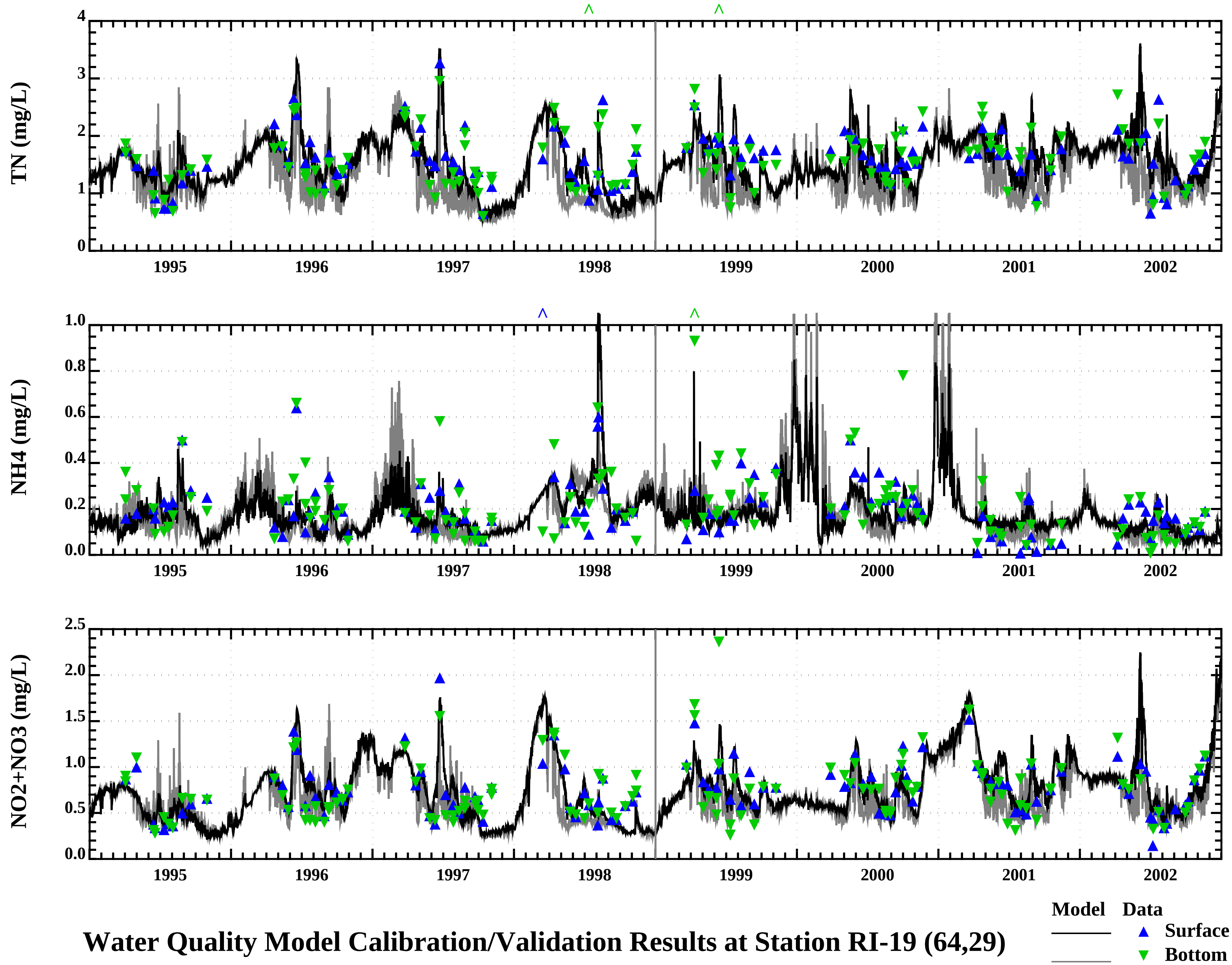
Water Quality Model Calibration/Validation Results at Station RI-18 (59,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:50: 4



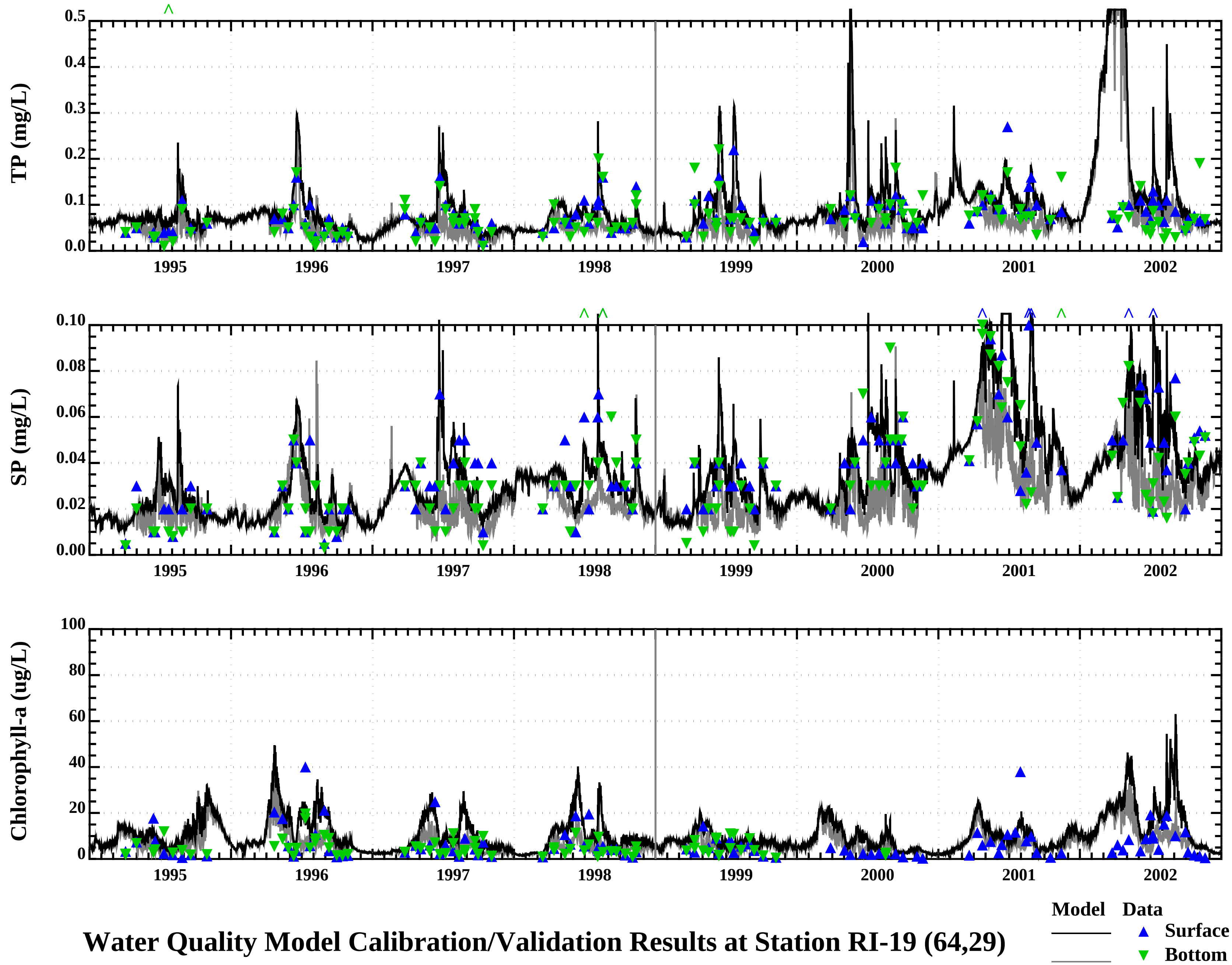
Water Quality Model Calibration/Validation Results at Station RI-18 (59,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:50: 4



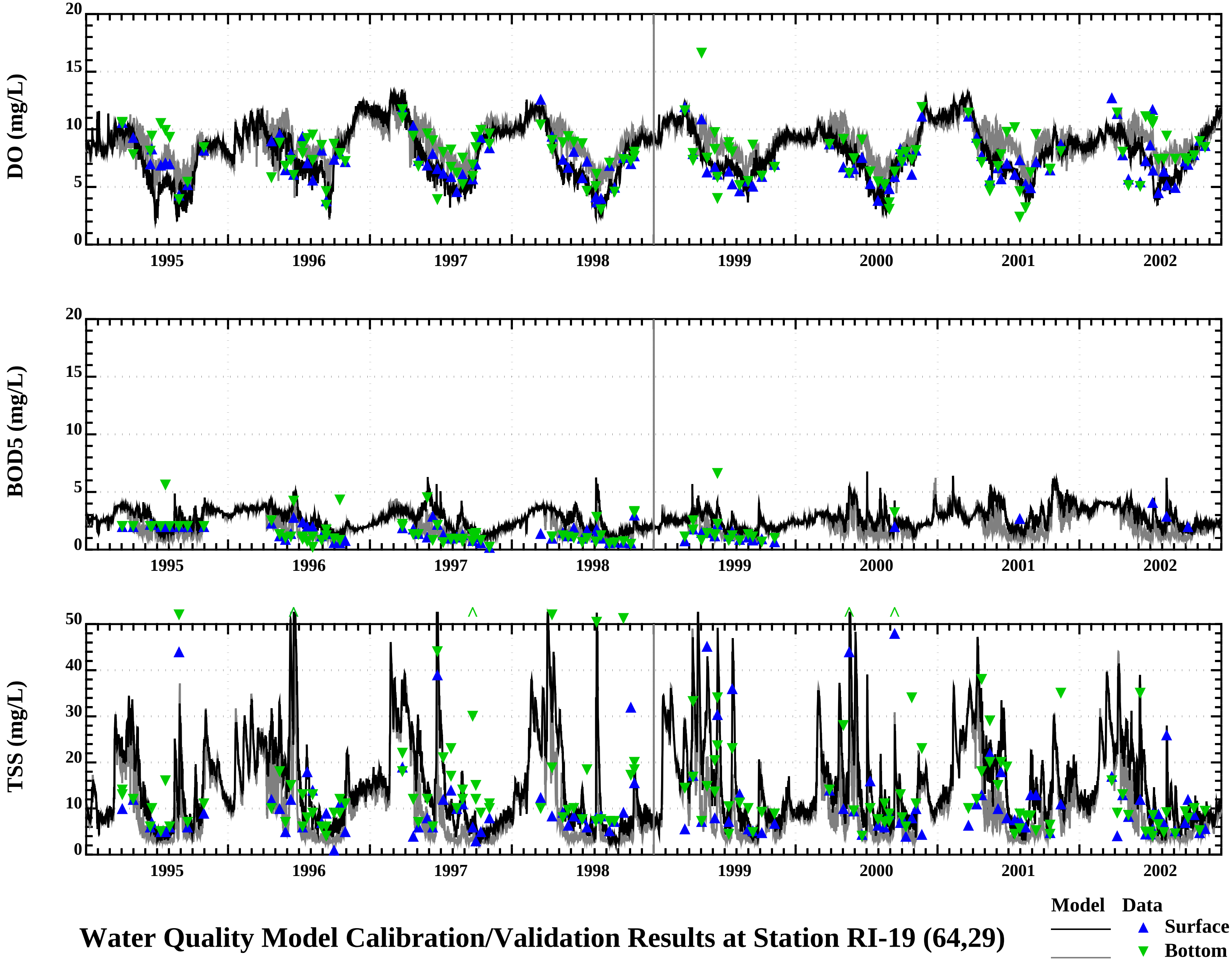
Water Quality Model Calibration/Validation Results at Station RI-19 (64,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:51: 8



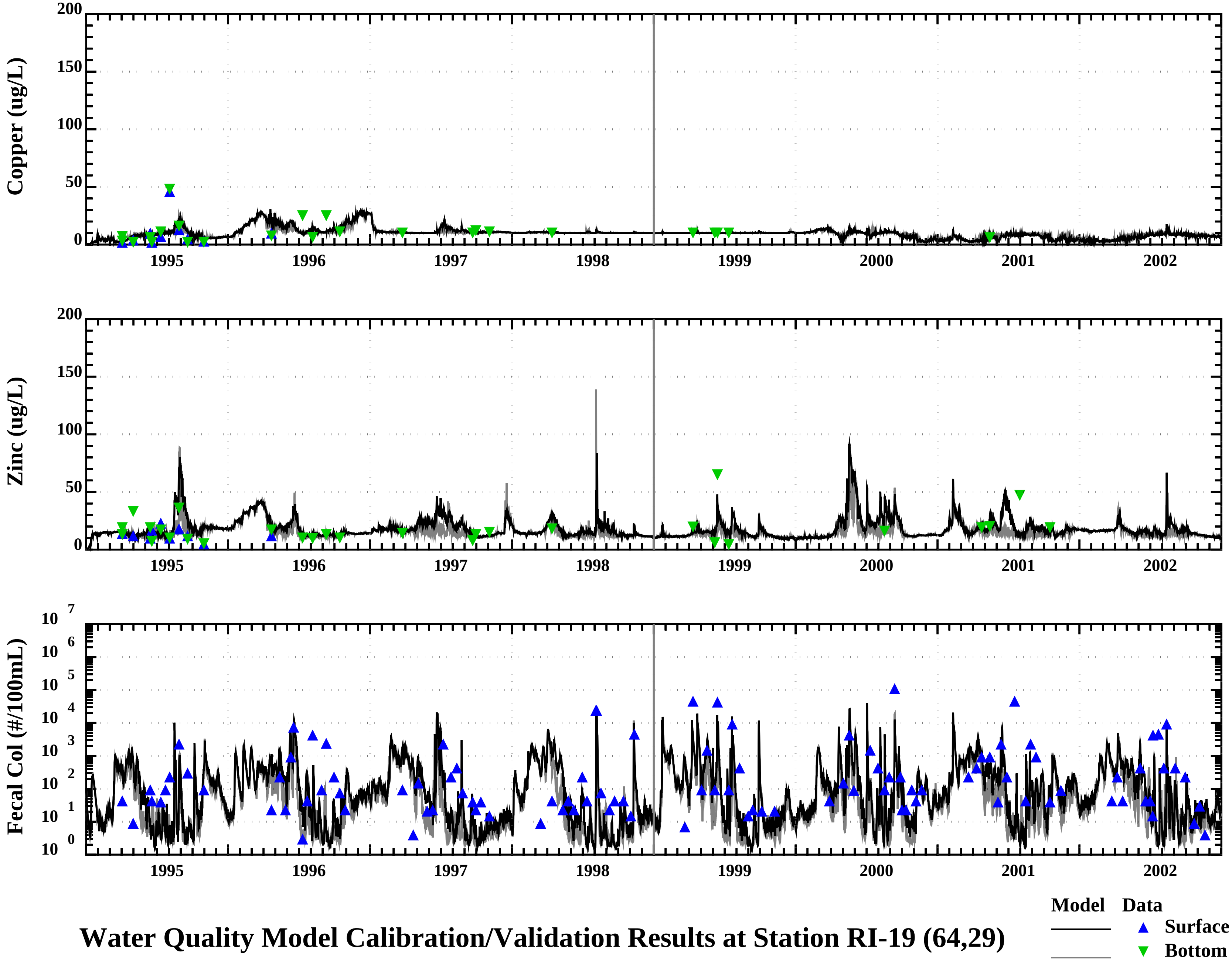
Water Quality Model Calibration/Validation Results at Station RI-19 (64,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:51: 8



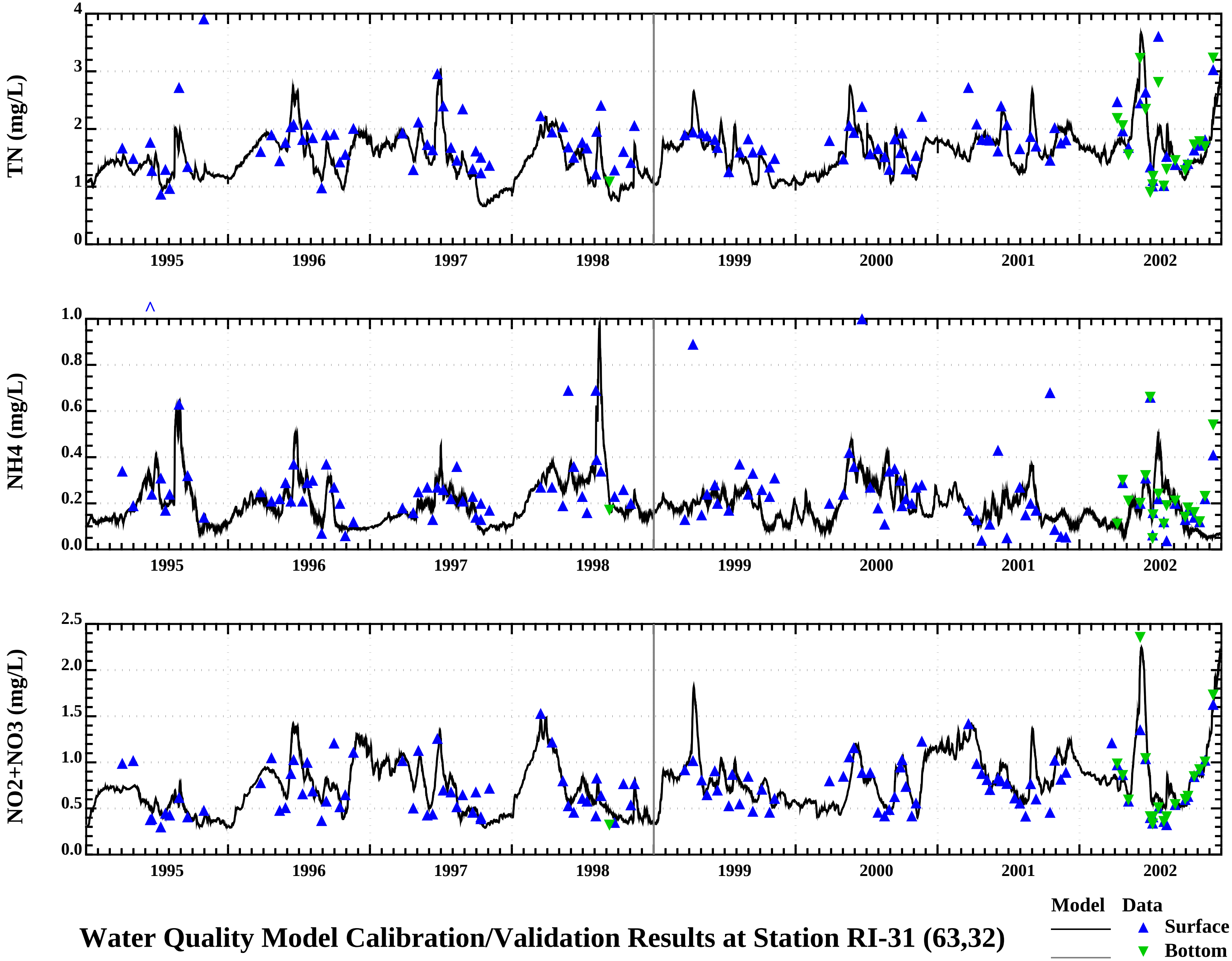
Water Quality Model Calibration/Validation Results at Station RI-19 (64,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:51: 8



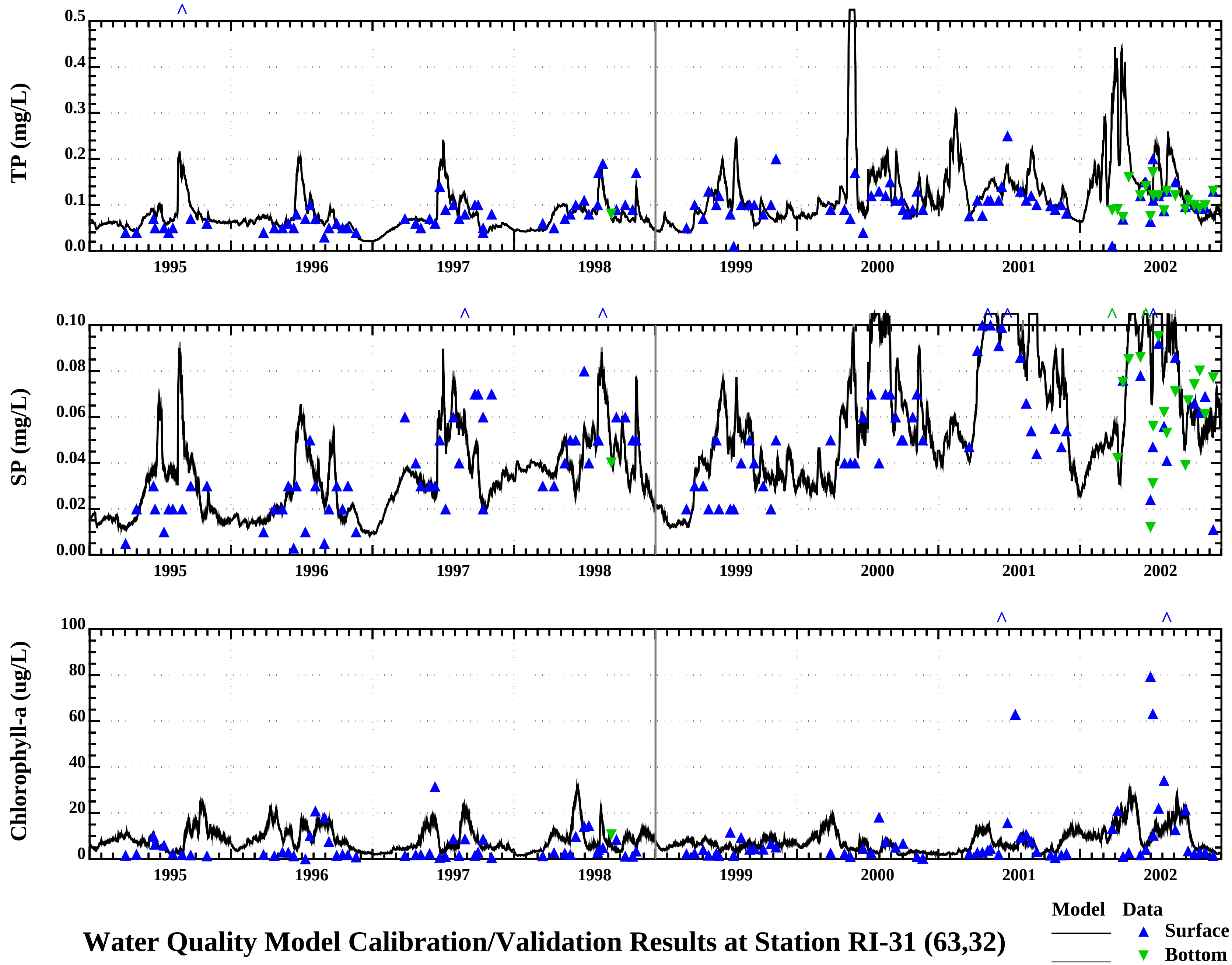
Water Quality Model Calibration/Validation Results at Station RI-19 (64,29)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:51: 8



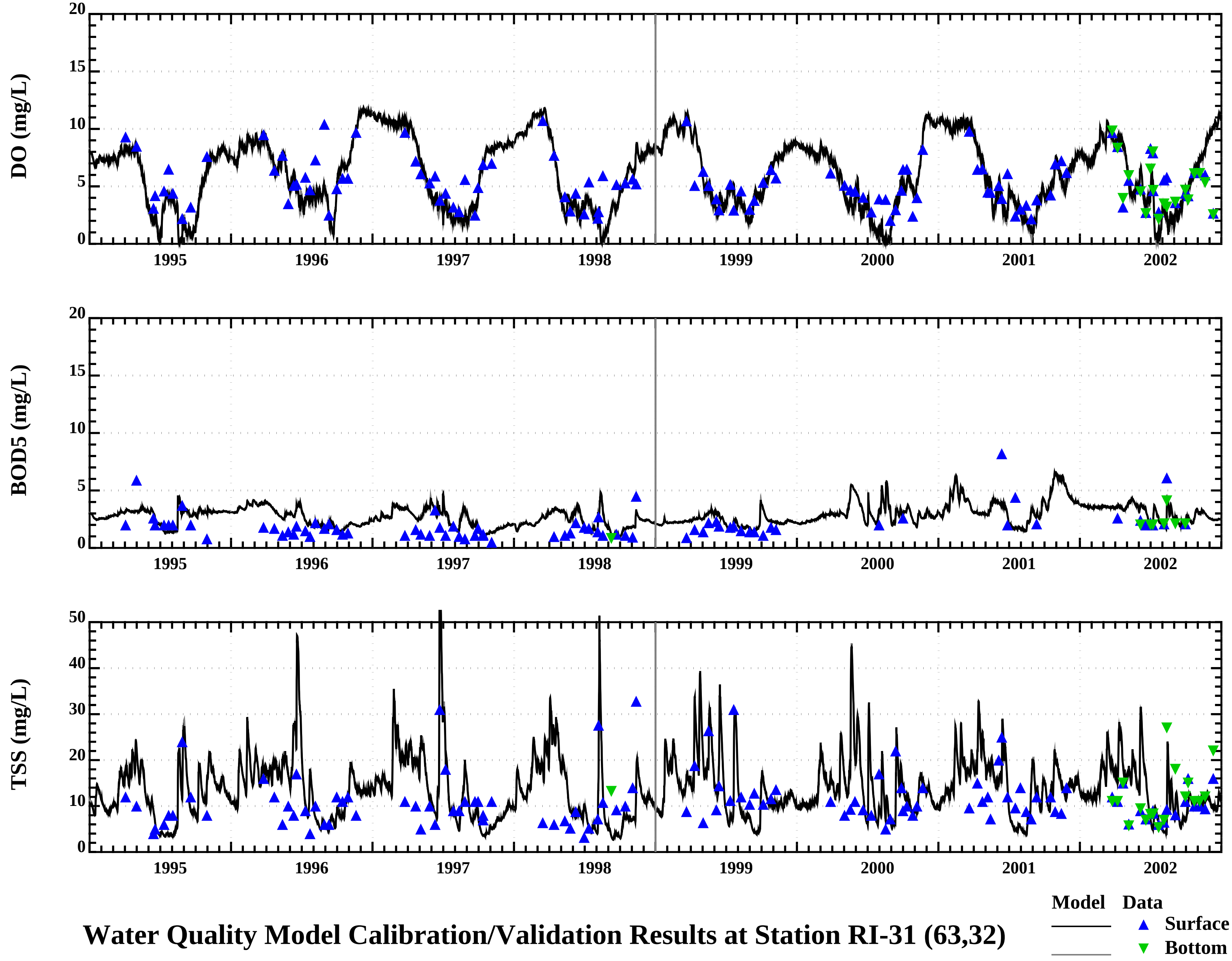
Water Quality Model Calibration/Validation Results at Station RI-31 (63,32)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:52:12



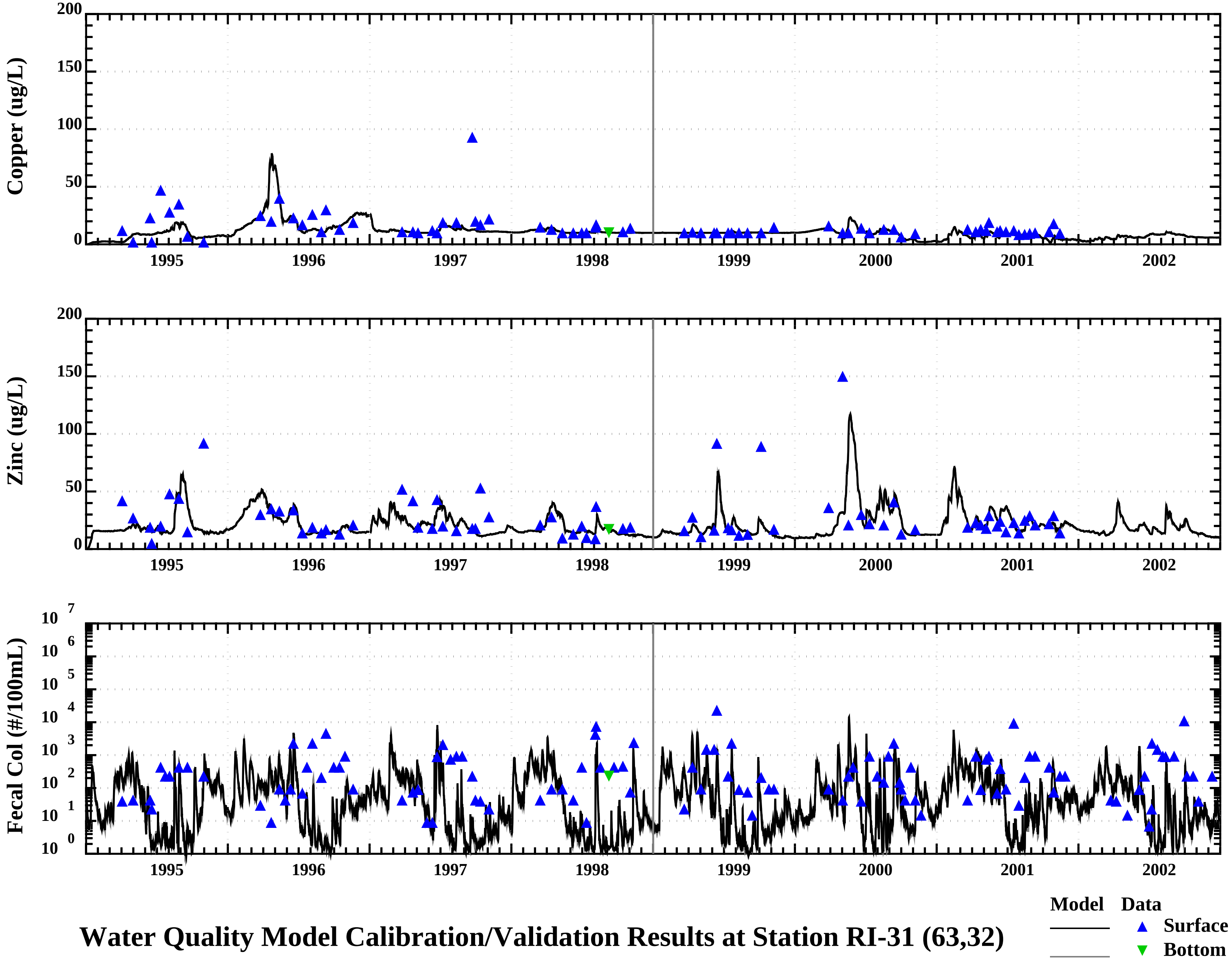
Water Quality Model Calibration/Validation Results at Station RI-31 (63,32)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:52:12



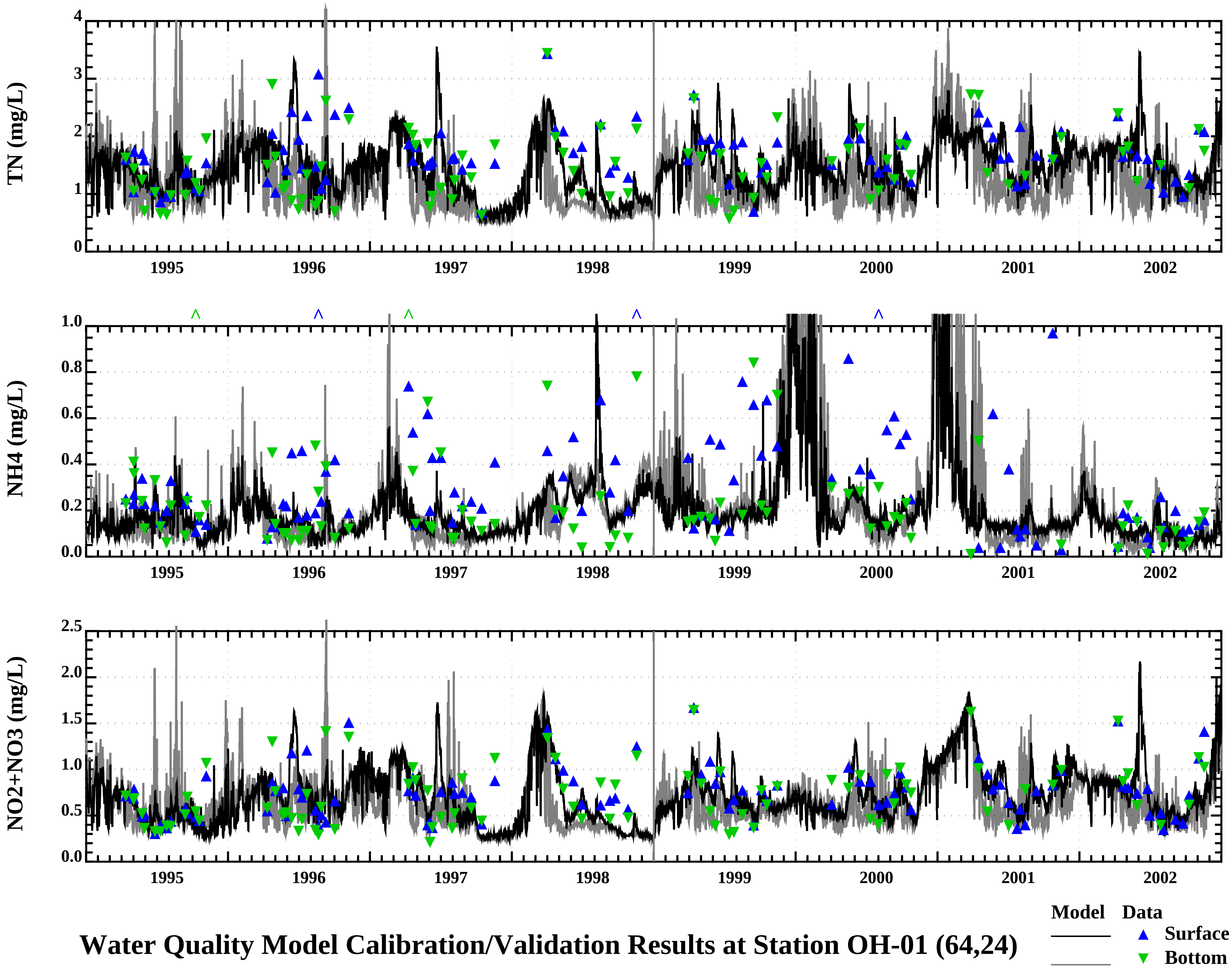
Water Quality Model Calibration/Validation Results at Station RI-31 (63,32)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:52:12



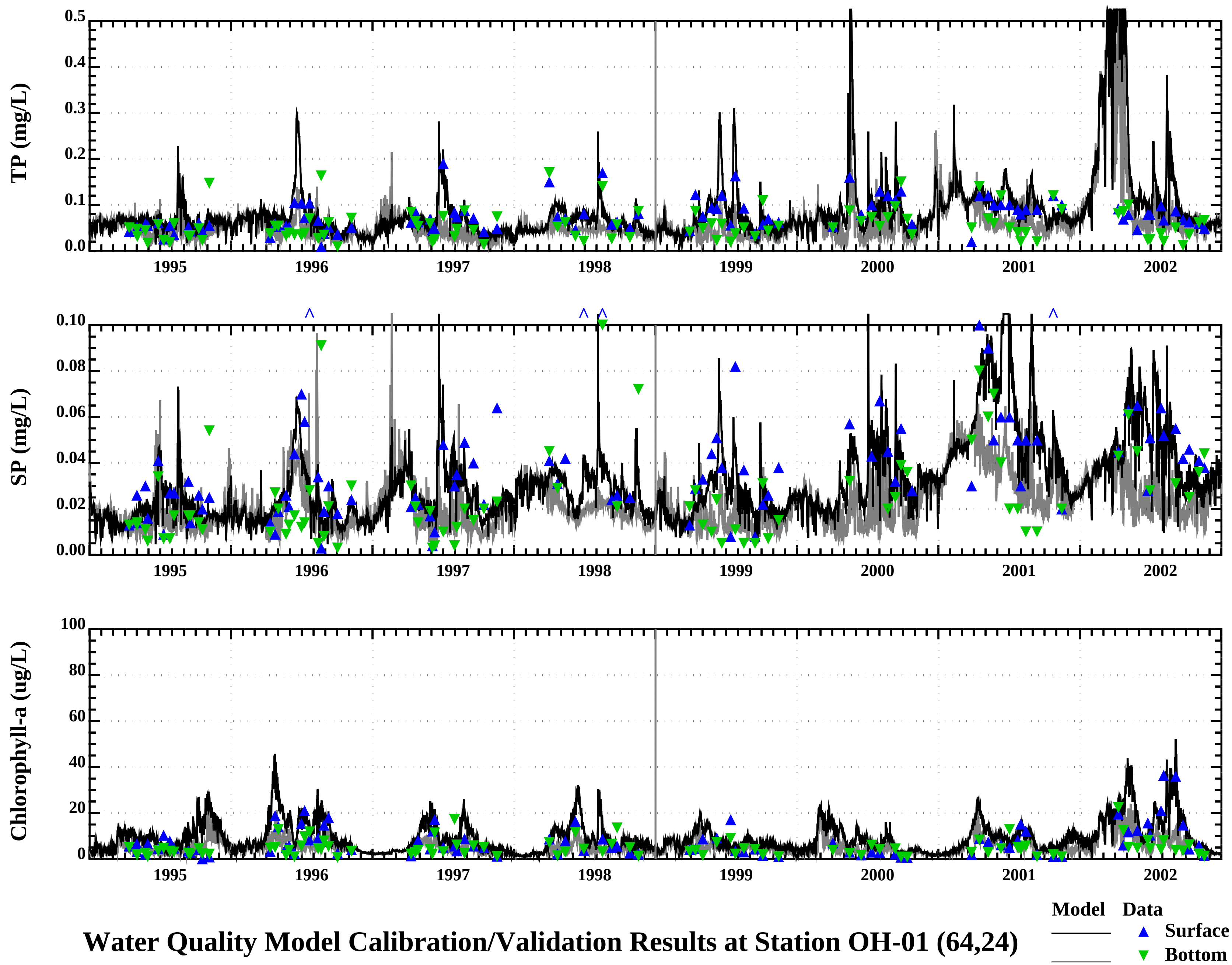
Water Quality Model Calibration/Validation Results at Station RI-31 (63,32)

/coral3/hntb0020/RCA_2020/PLOT/riwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:52:12



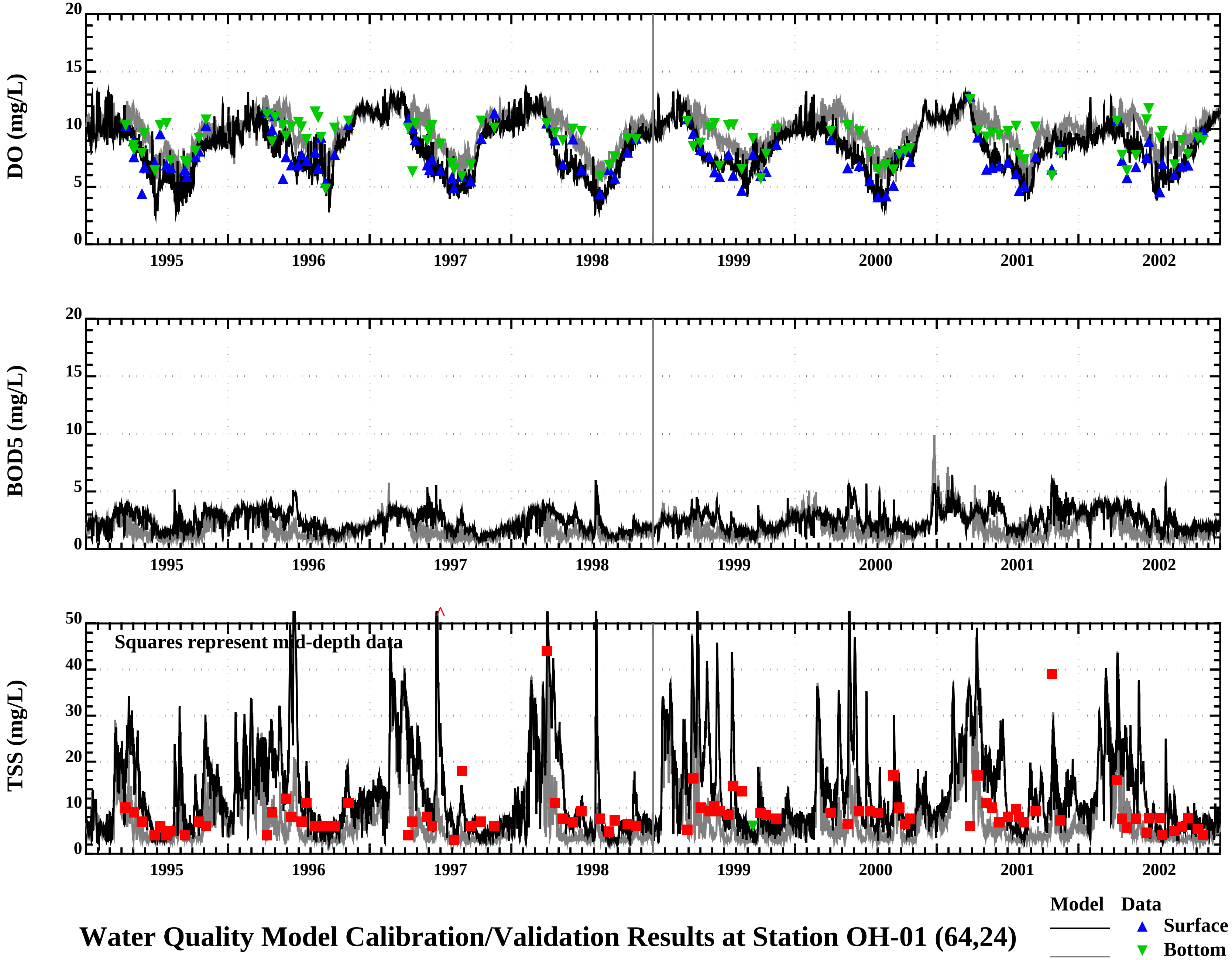
Water Quality Model Calibration/Validation Results at Station OH-01 (64,24)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:53:16



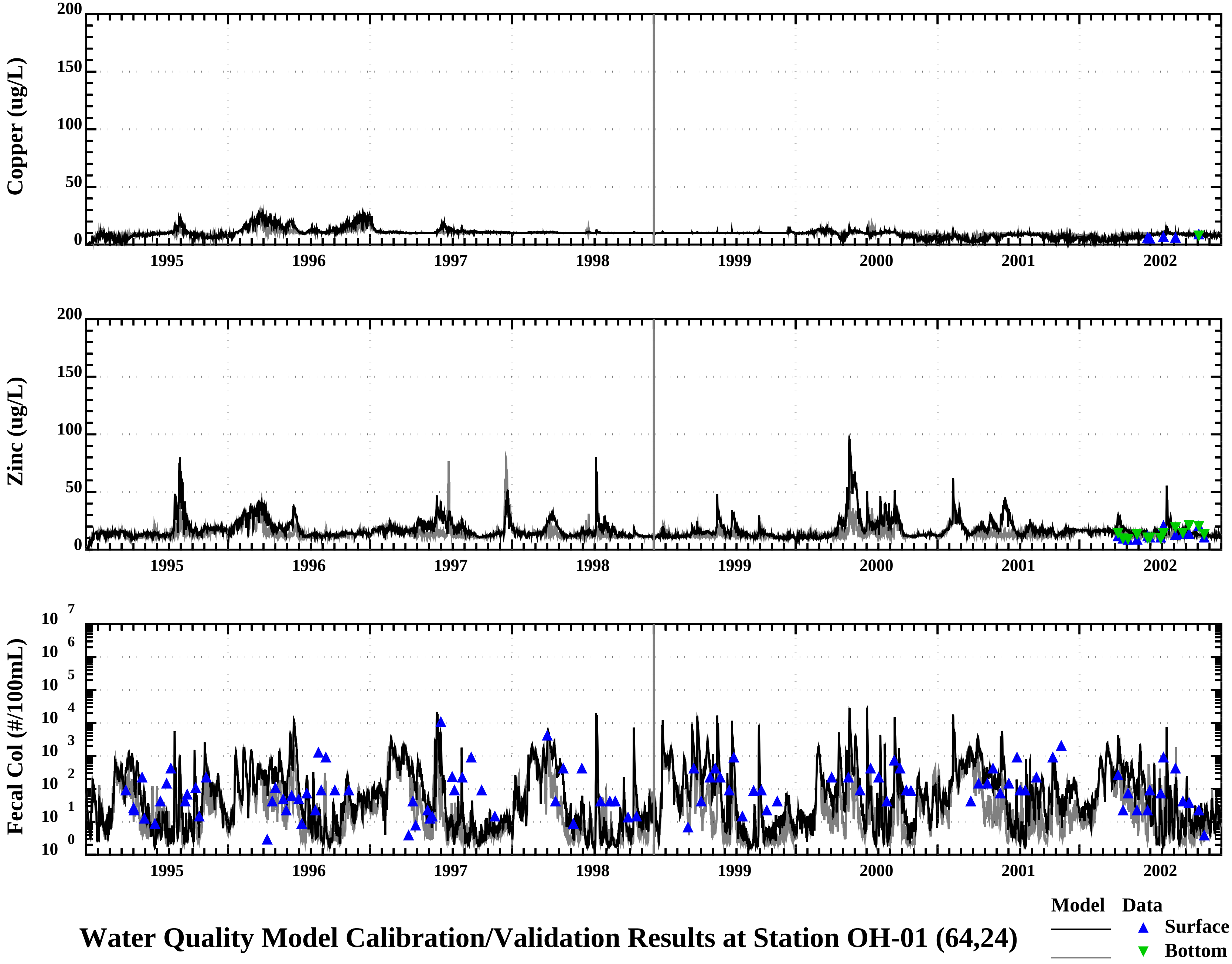
Water Quality Model Calibration/Validation Results at Station OH-01 (64,24)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:53:16



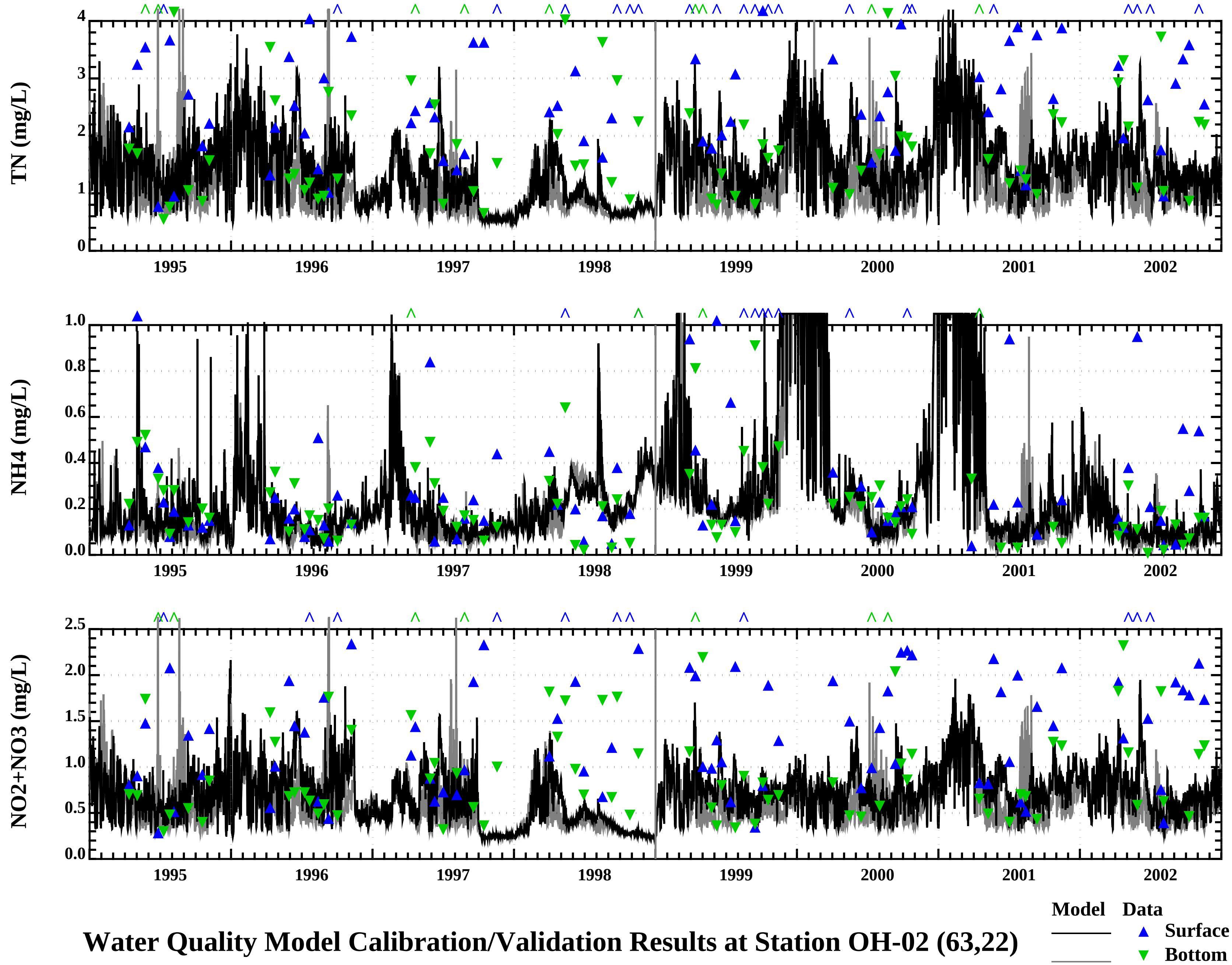
Water Quality Model Calibration/Validation Results at Station OH-01 (64,24)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:53:16



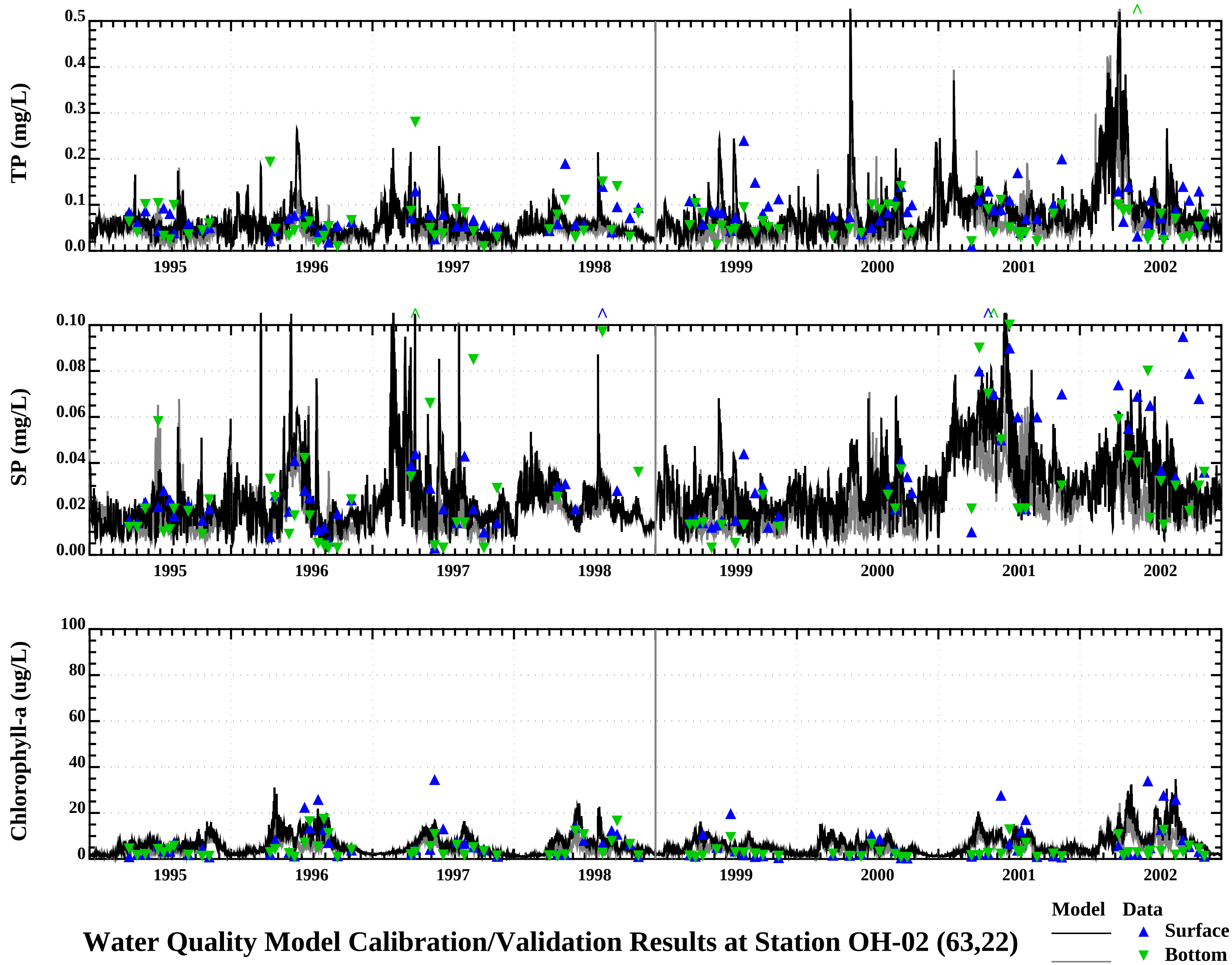
Water Quality Model Calibration/Validation Results at Station OH-01 (64,24)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:53:16



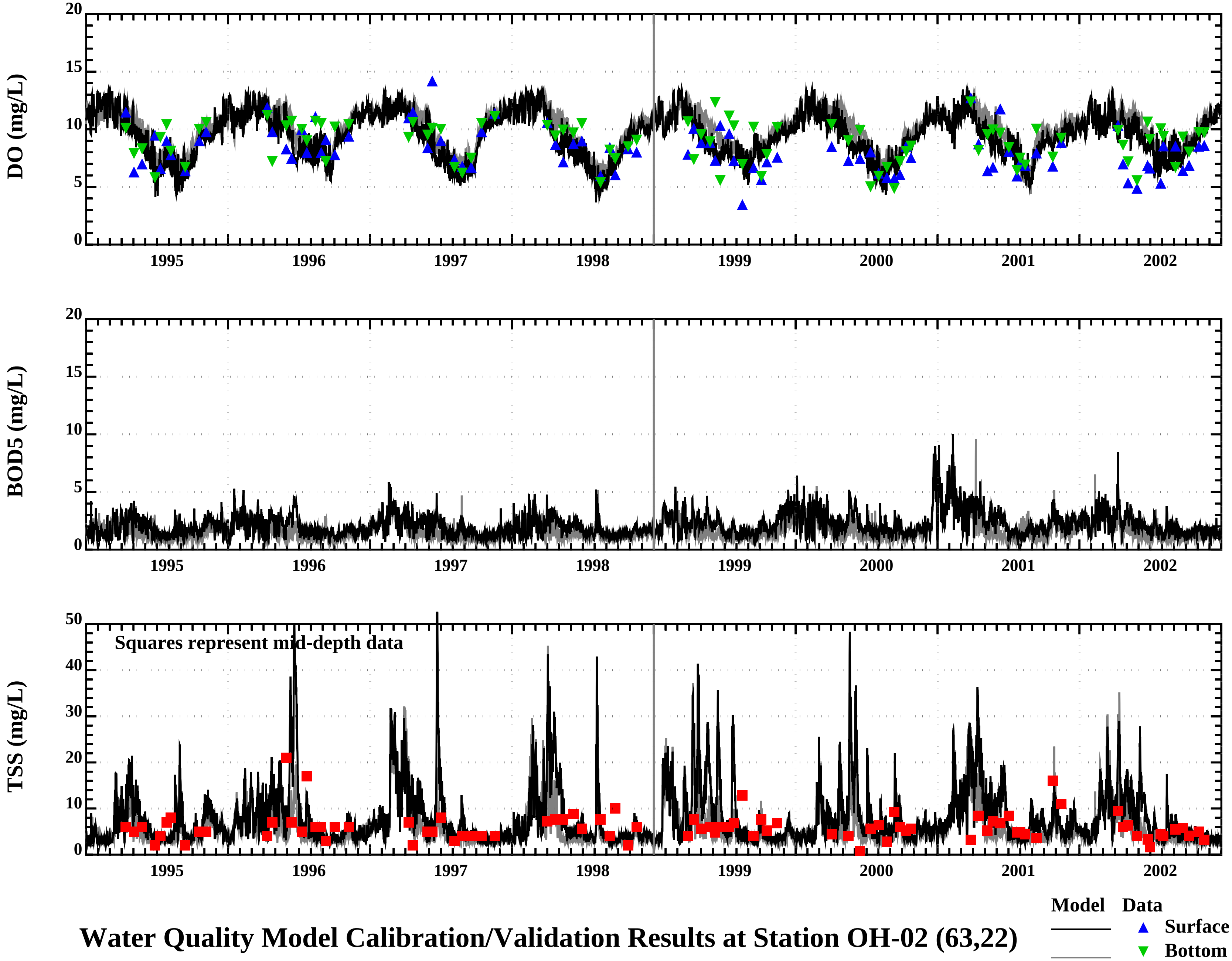
Water Quality Model Calibration/Validation Results at Station OH-02 (63,22)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:54:20



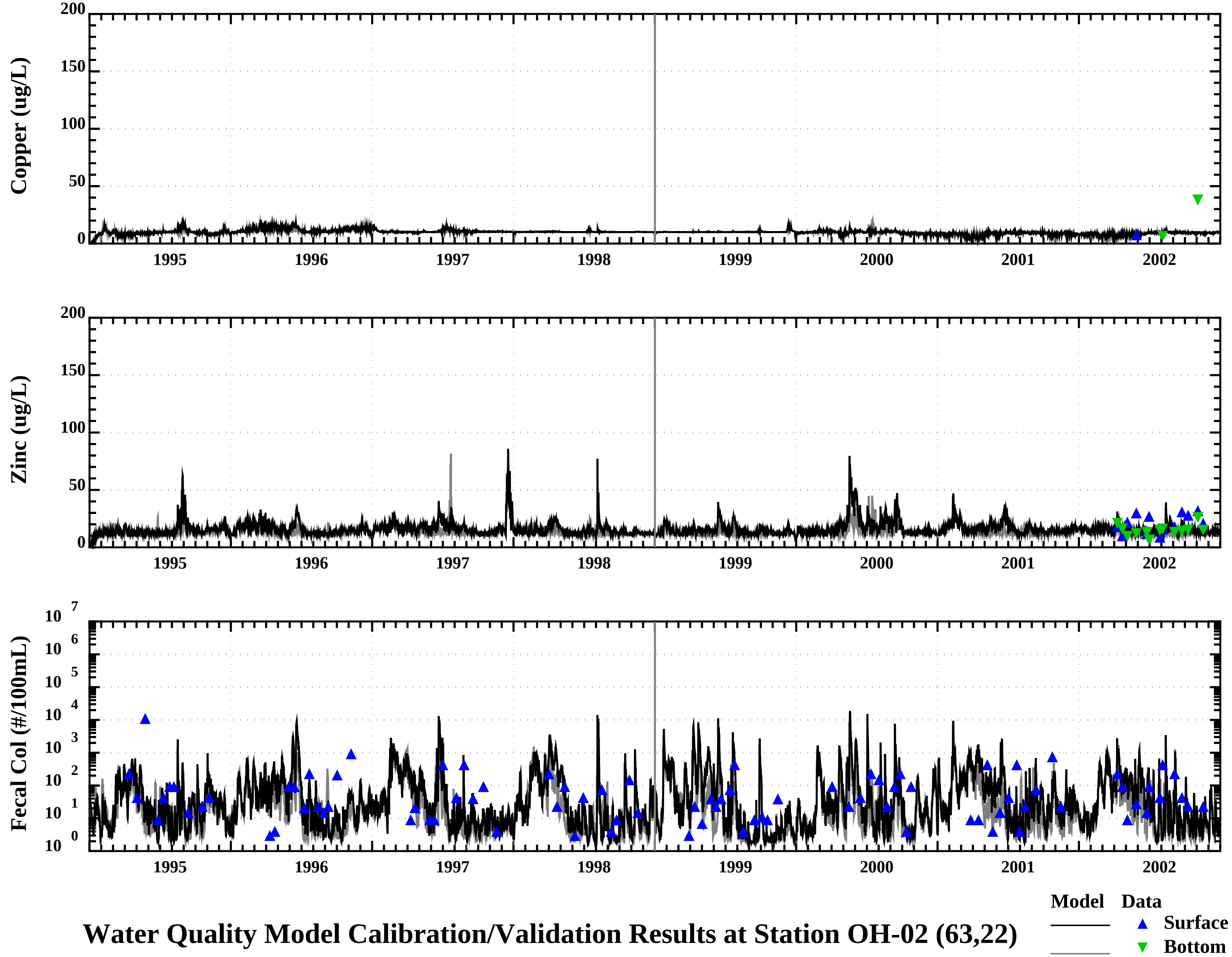
Water Quality Model Calibration/Validation Results at Station OH-02 (63,22)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:54:20



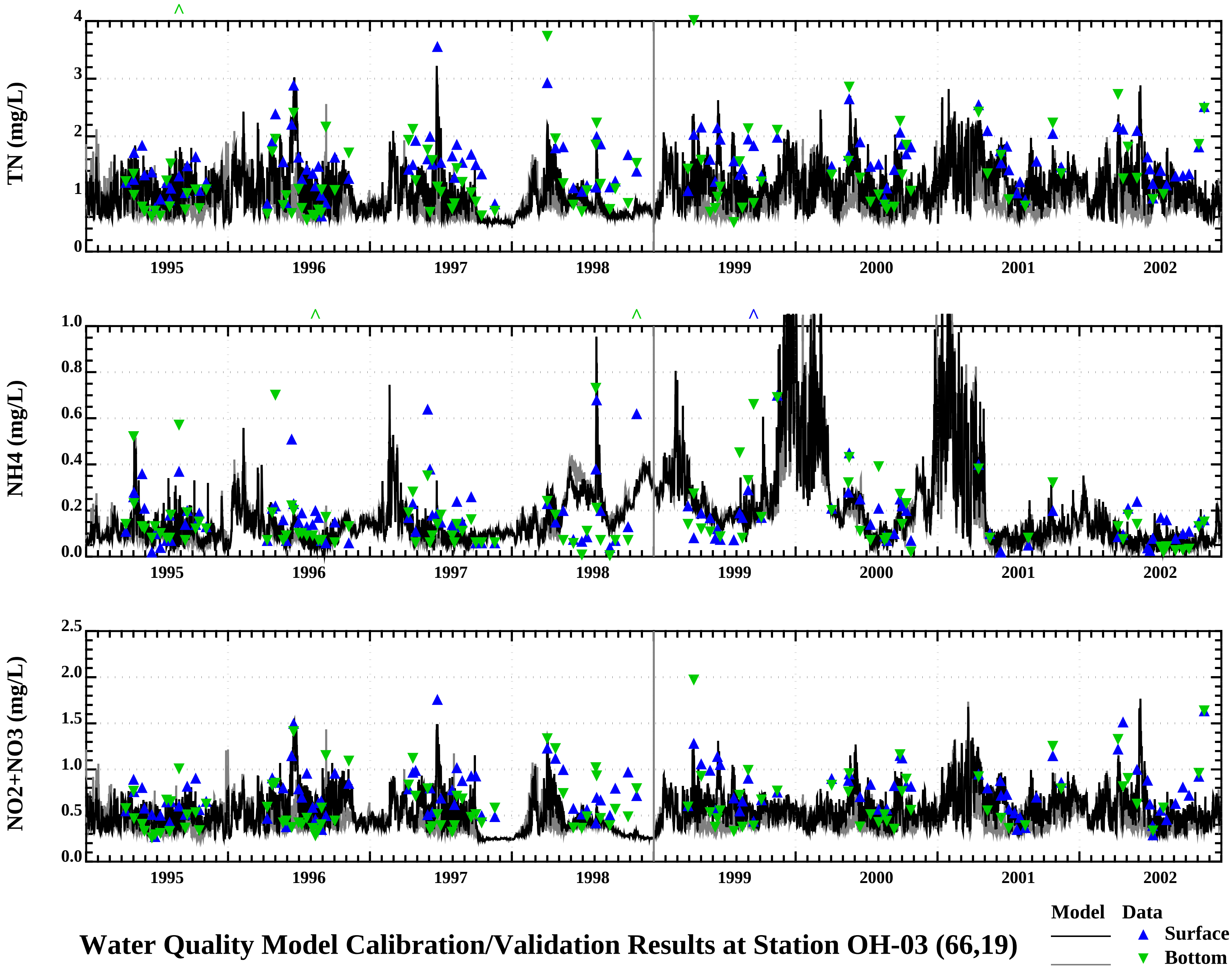
Water Quality Model Calibration/Validation Results at Station OH-02 (63,22)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:54:20



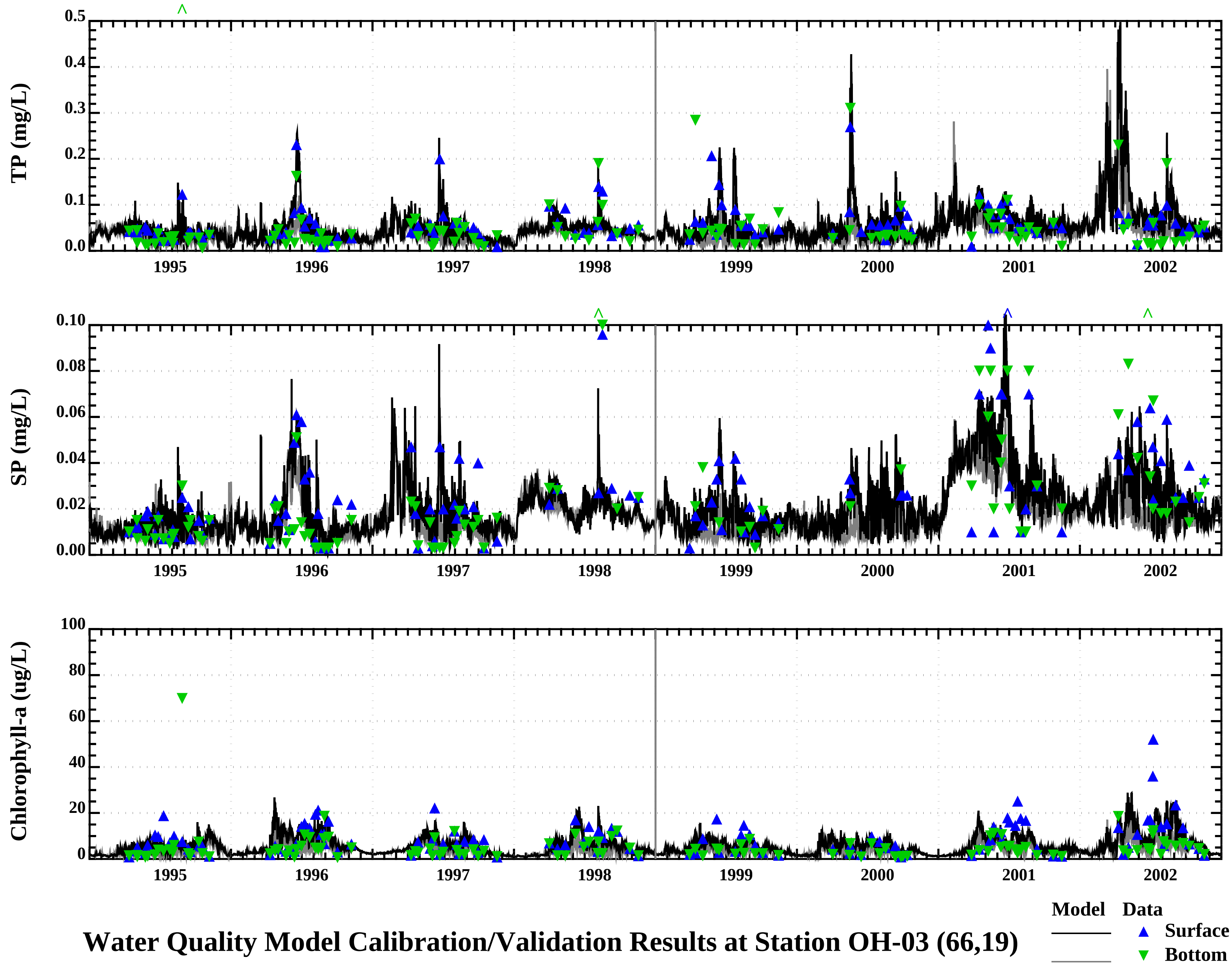
Water Quality Model Calibration/Validation Results at Station OH-02 (63,22)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:54:20



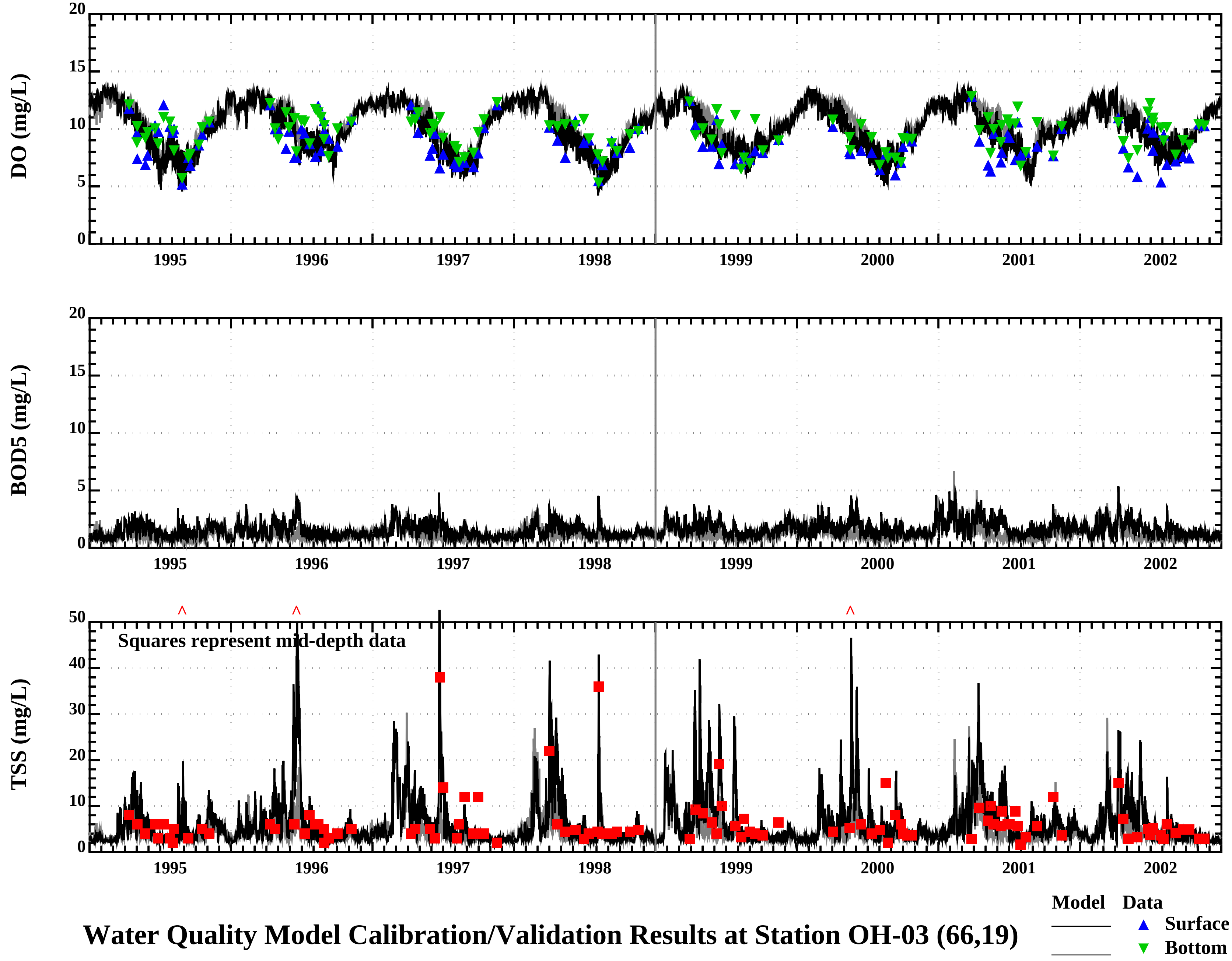
Water Quality Model Calibration/Validation Results at Station OH-03 (66,19)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:55:24



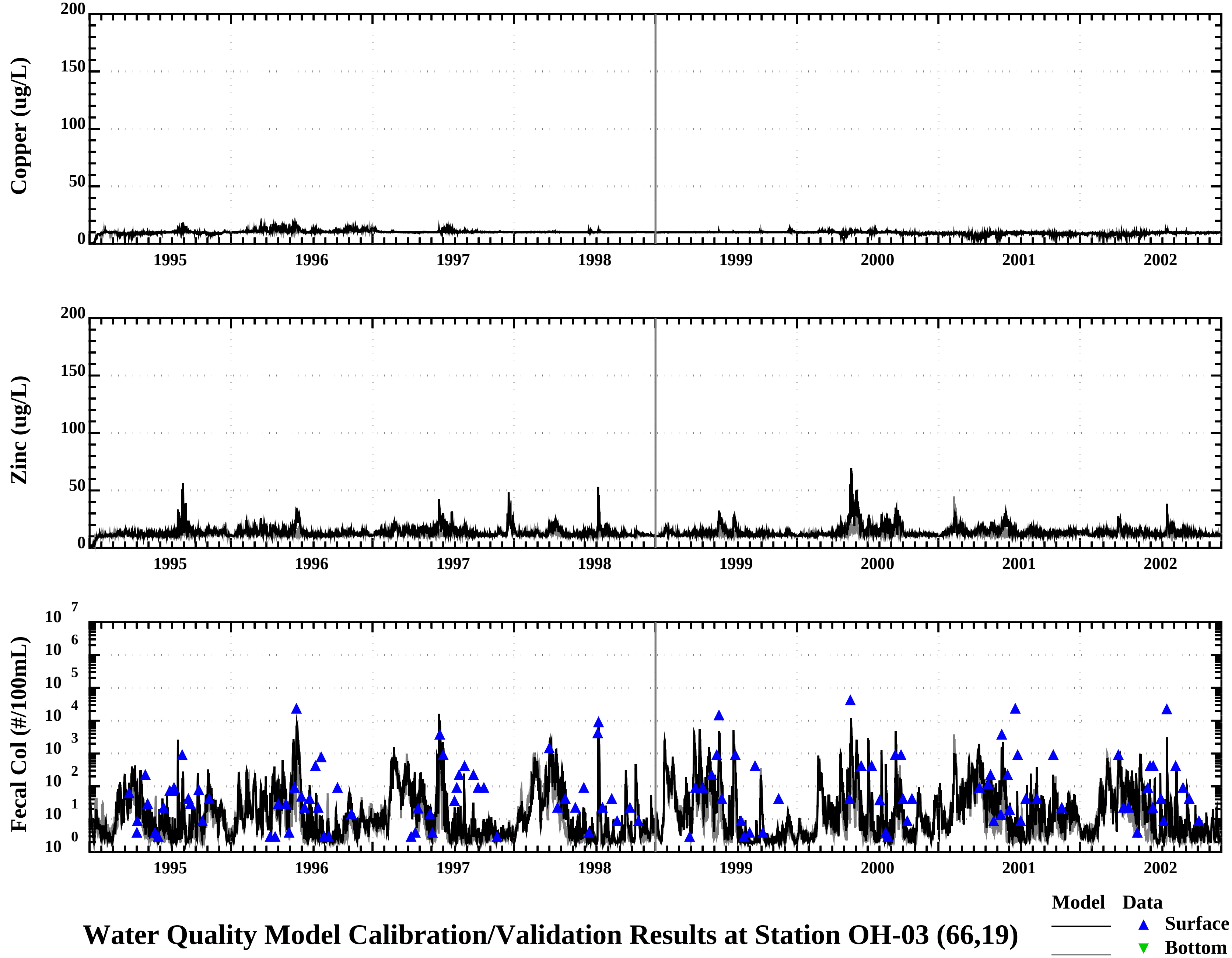
Water Quality Model Calibration/Validation Results at Station OH-03 (66,19)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:55:24



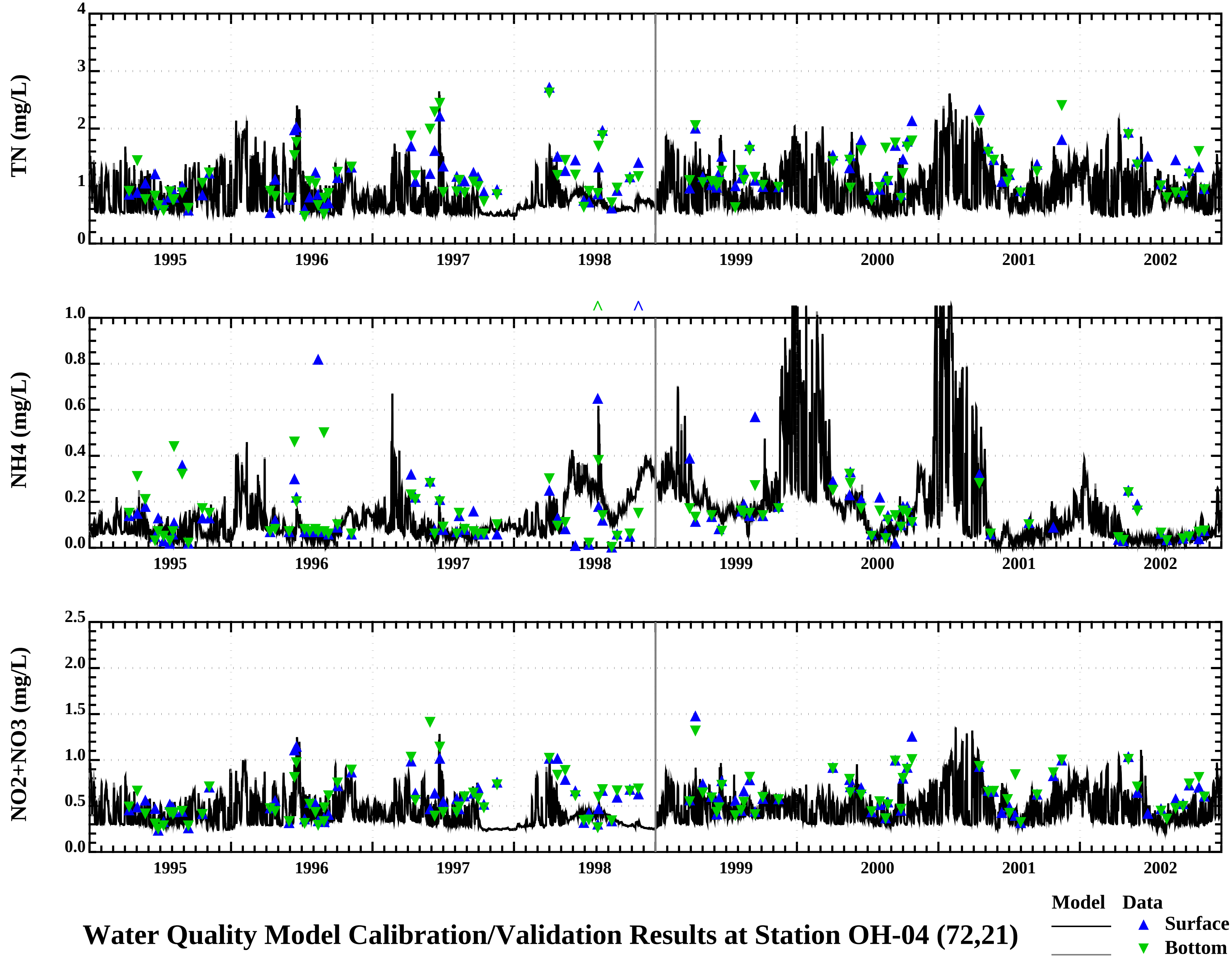
Water Quality Model Calibration/Validation Results at Station OH-03 (66,19)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:55:24



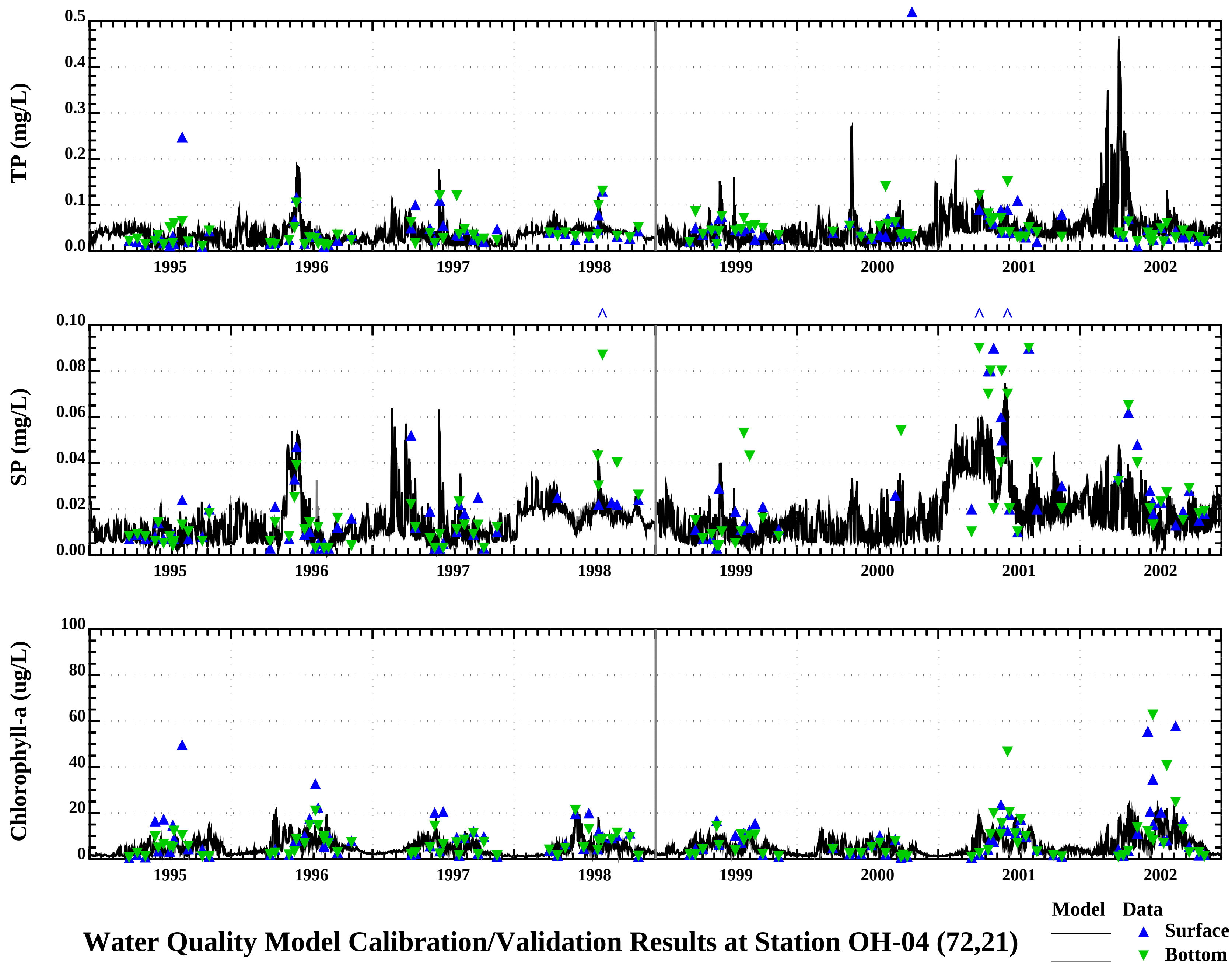
Water Quality Model Calibration/Validation Results at Station OH-03 (66,19)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:55:24



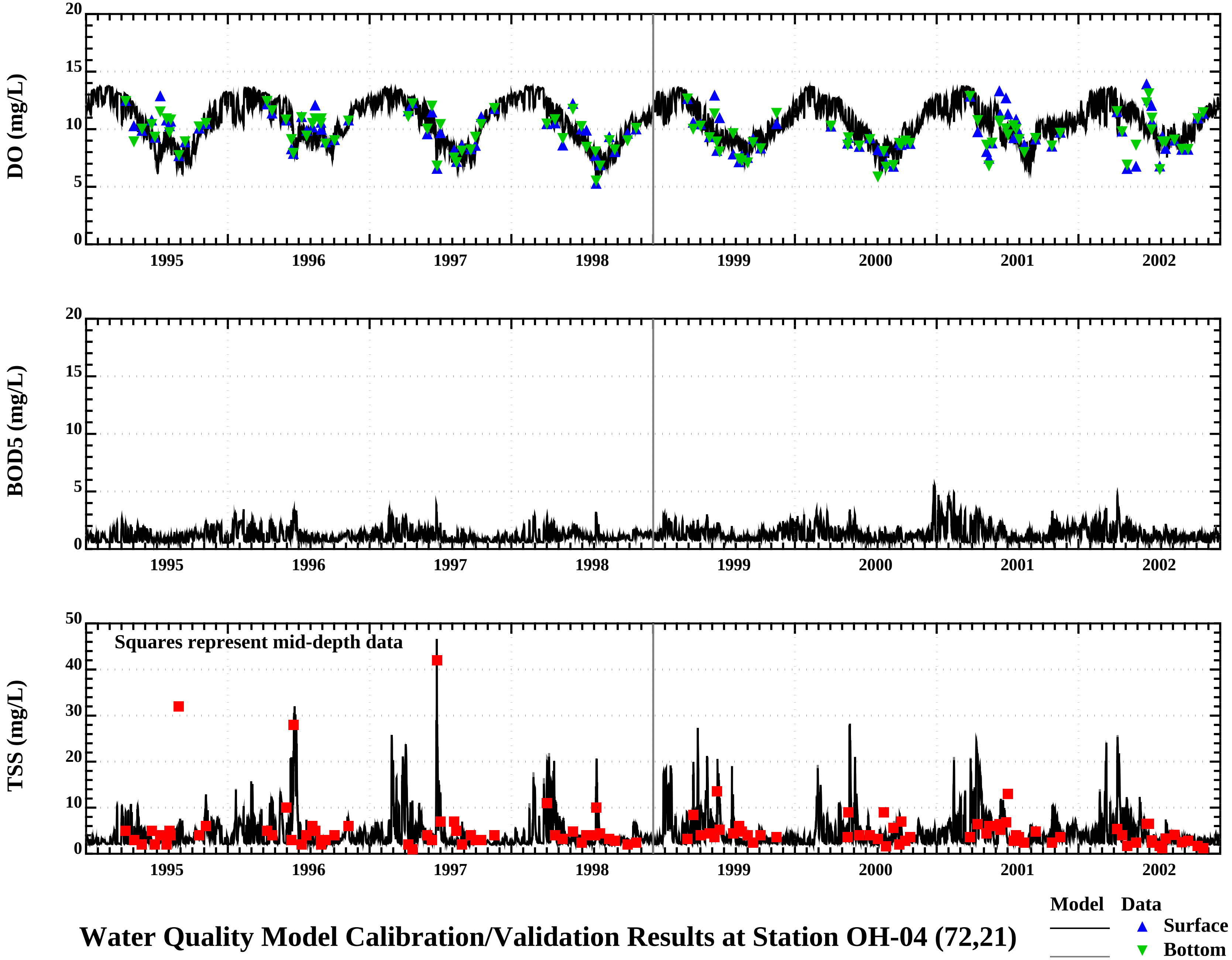
Water Quality Model Calibration/Validation Results at Station OH-04 (72,21)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:56:28



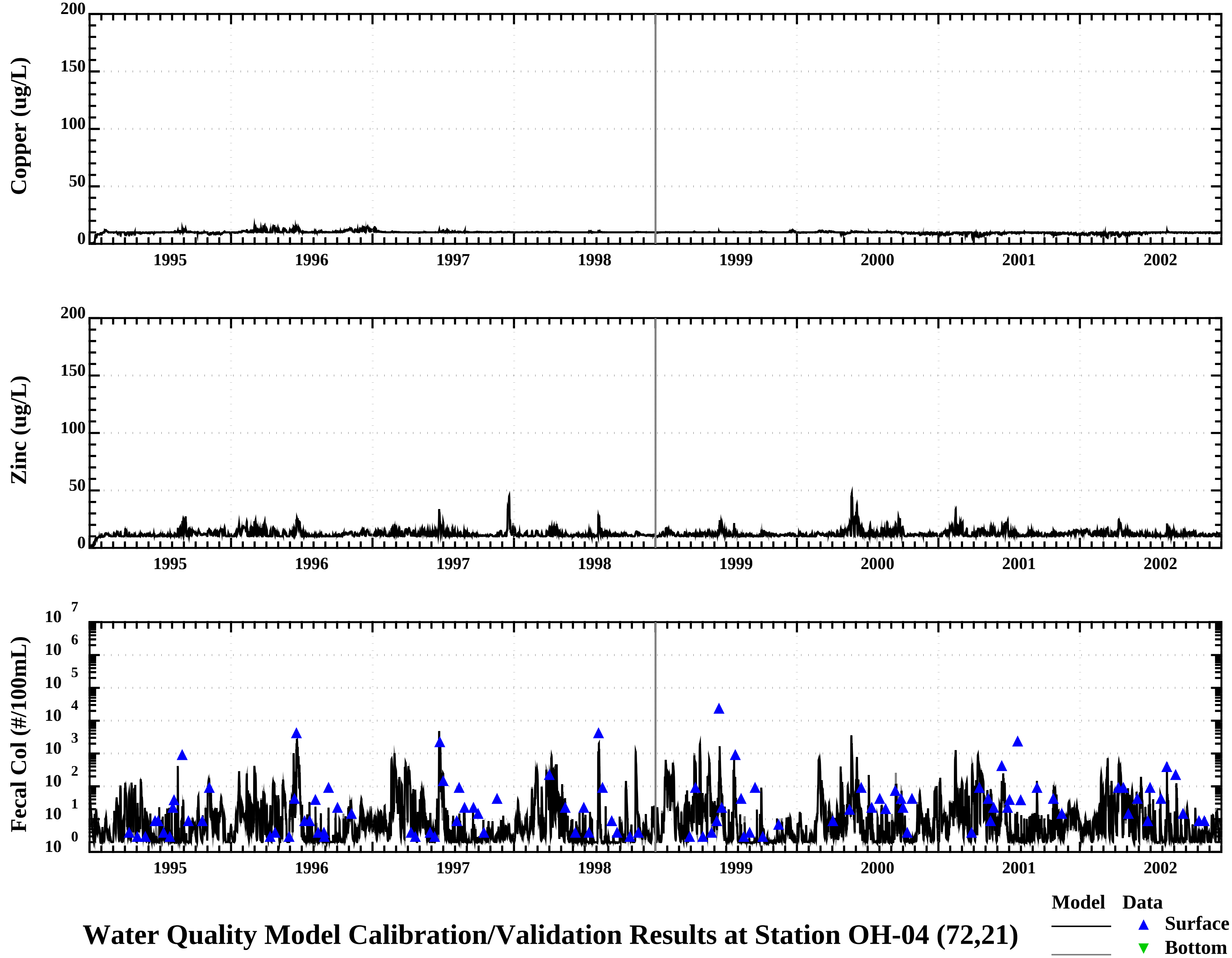
Water Quality Model Calibration/Validation Results at Station OH-04 (72,21)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:56:28



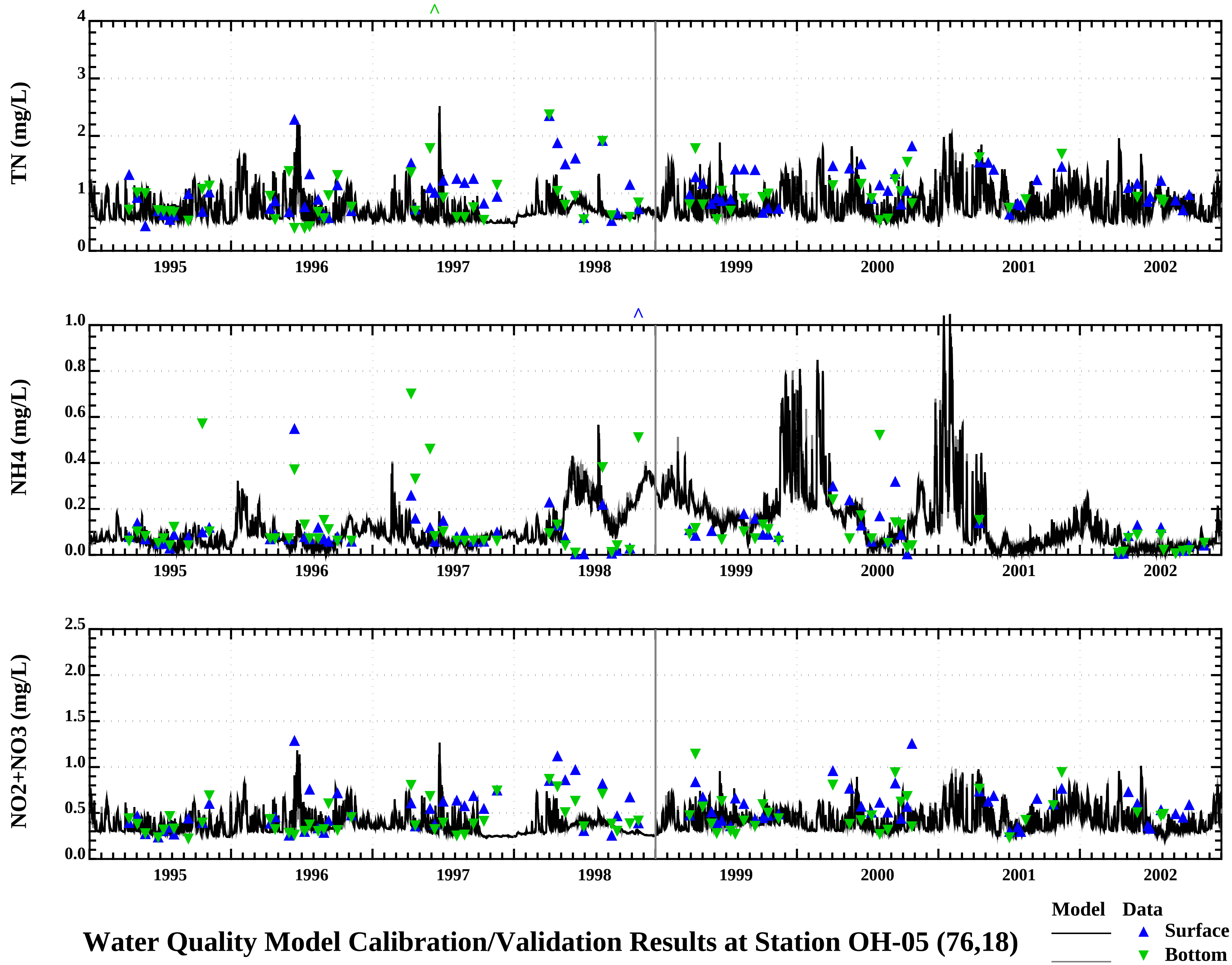
Water Quality Model Calibration/Validation Results at Station OH-04 (72,21)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:56:28



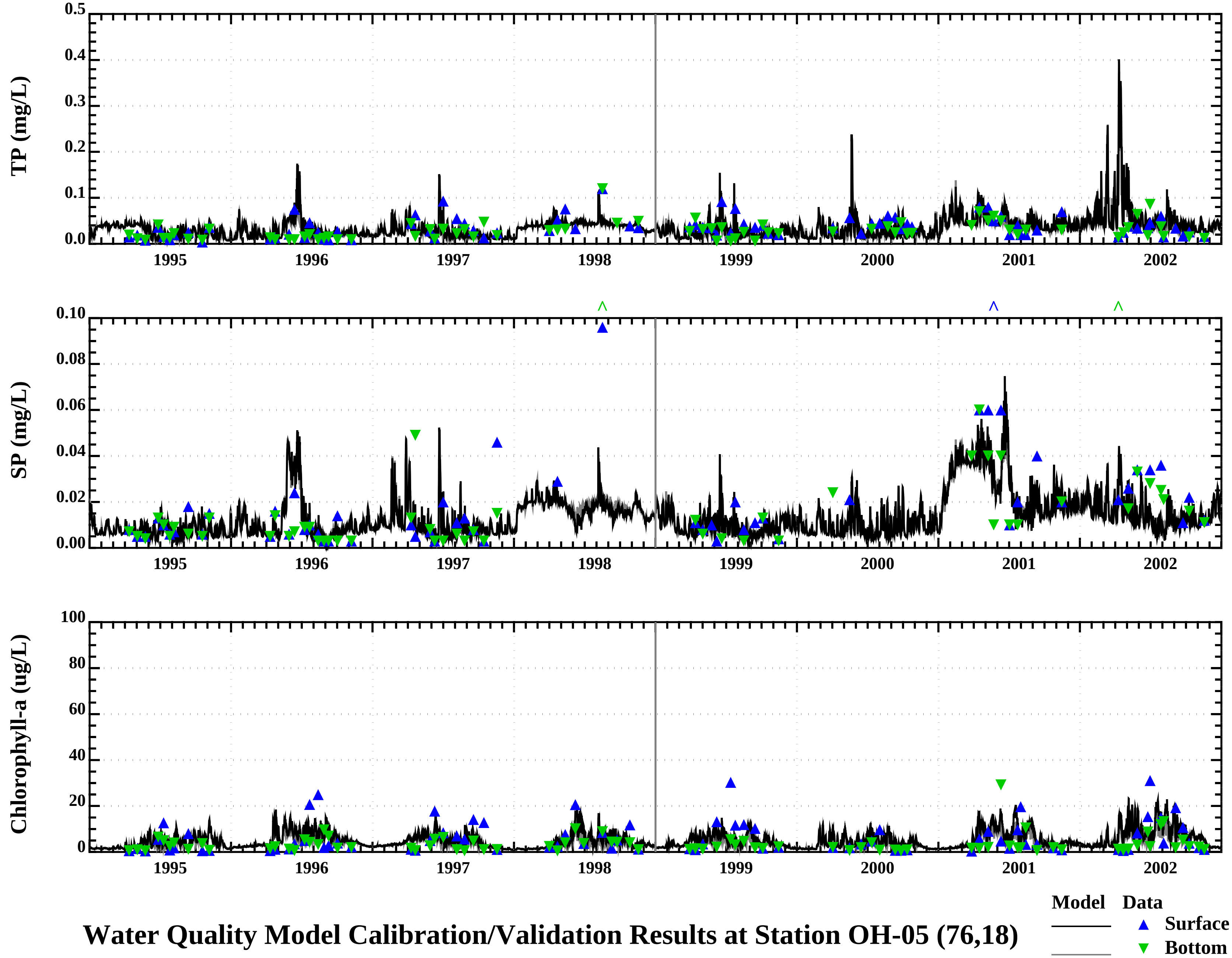
Water Quality Model Calibration/Validation Results at Station OH-04 (72,21)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:56:28



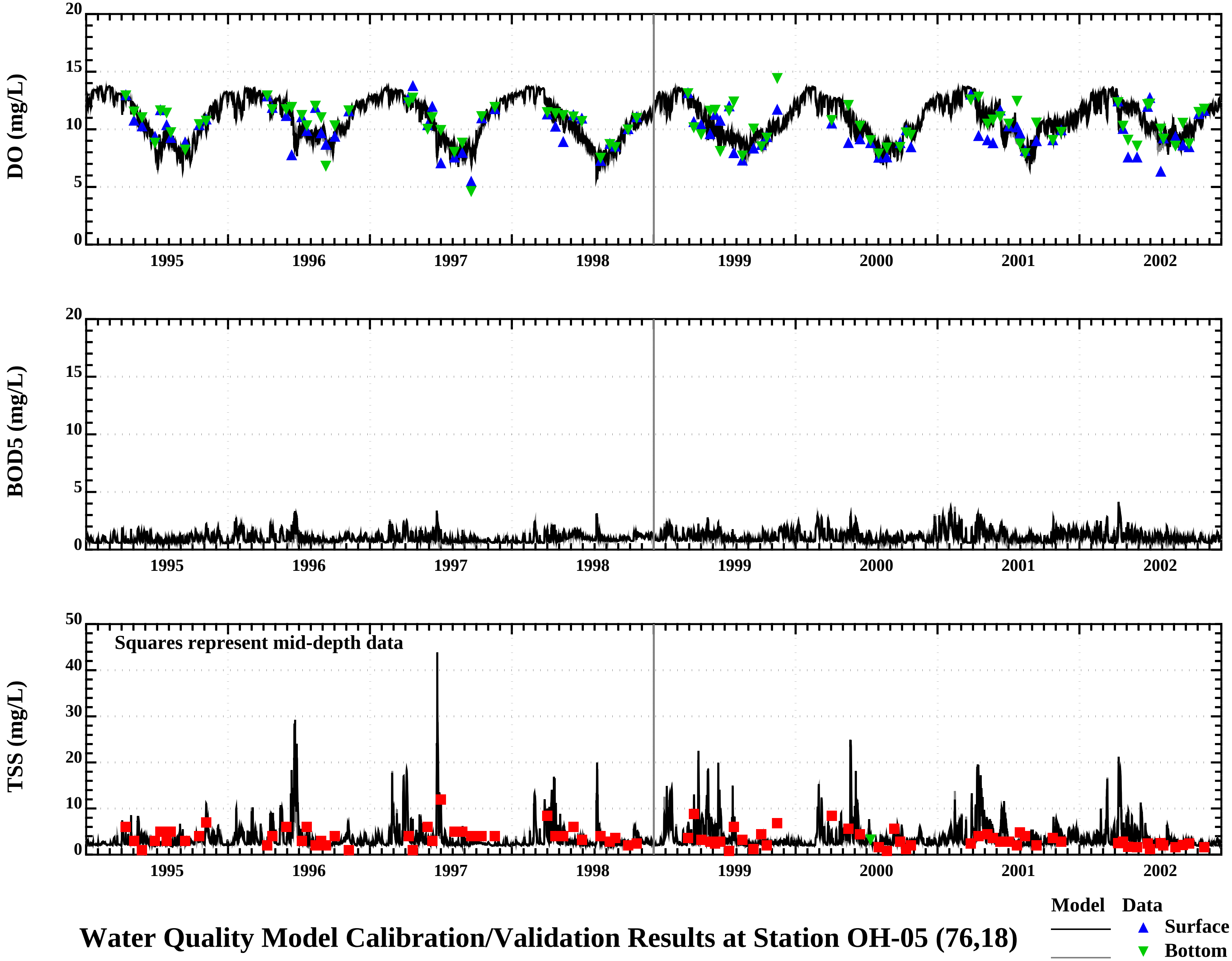
Water Quality Model Calibration/Validation Results at Station OH-05 (76,18)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:57:32



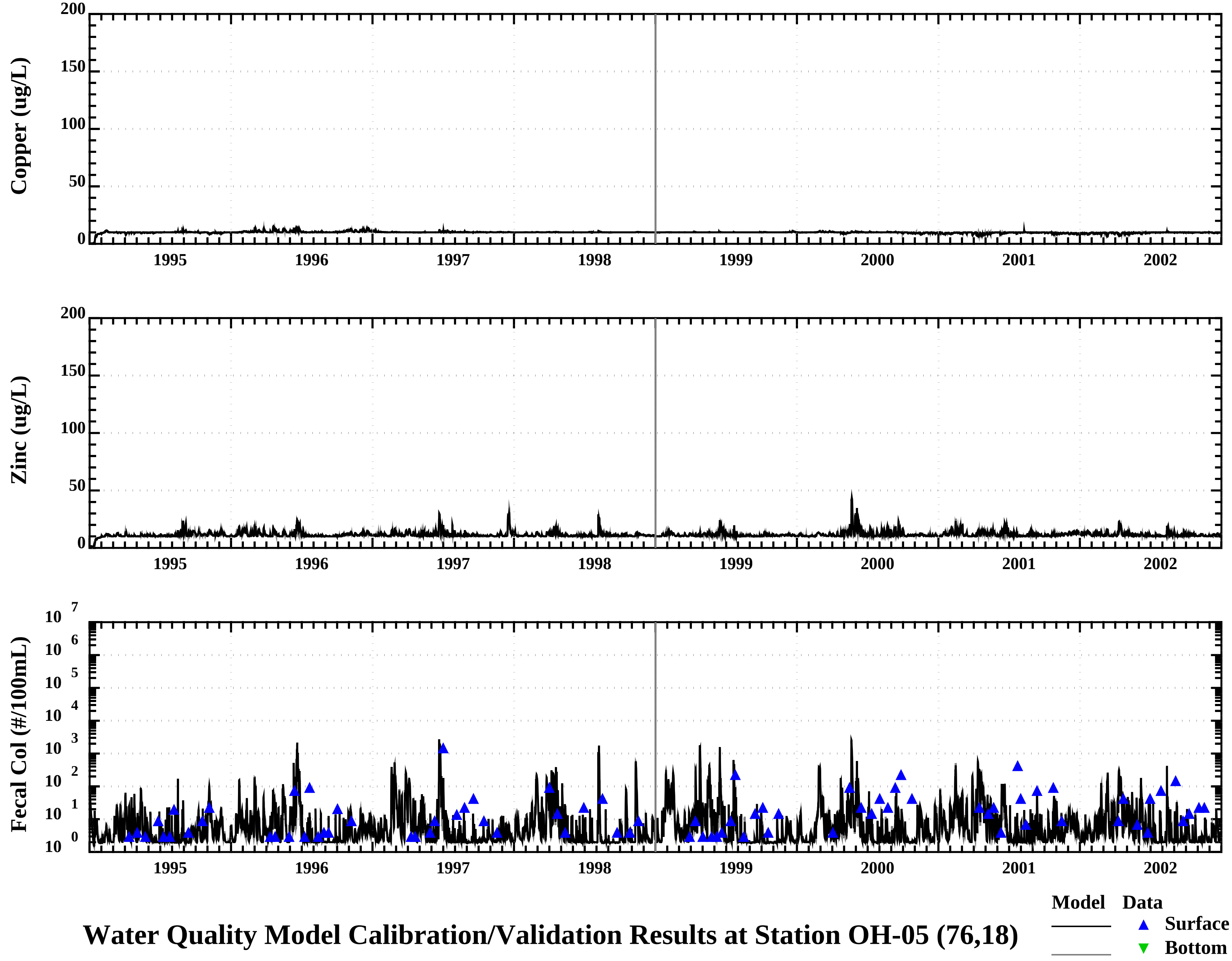
Water Quality Model Calibration/Validation Results at Station OH-05 (76,18)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:57:32



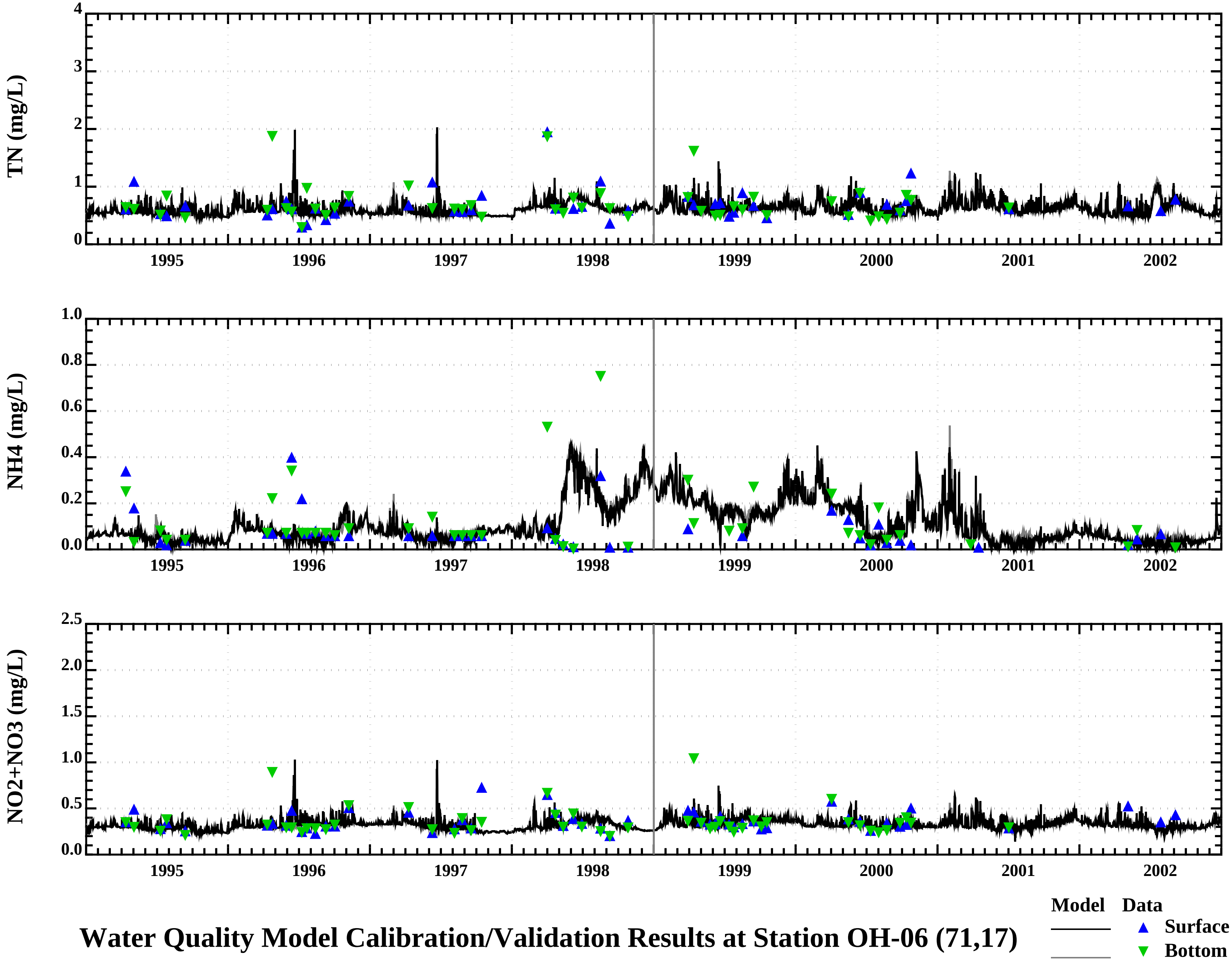
Water Quality Model Calibration/Validation Results at Station OH-05 (76,18)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:57:32

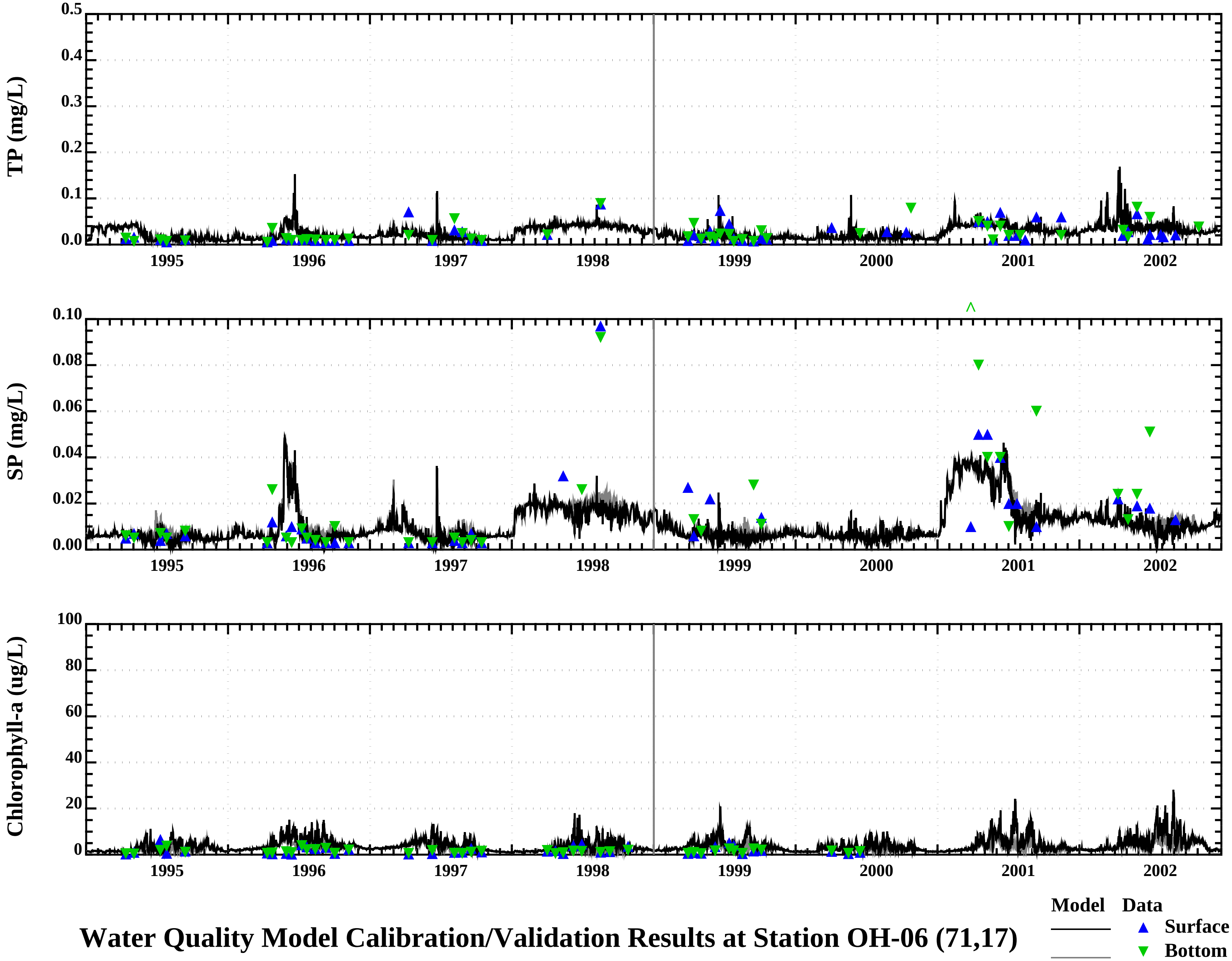


Water Quality Model Calibration/Validation Results at Station OH-05 (76,18)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:57:32

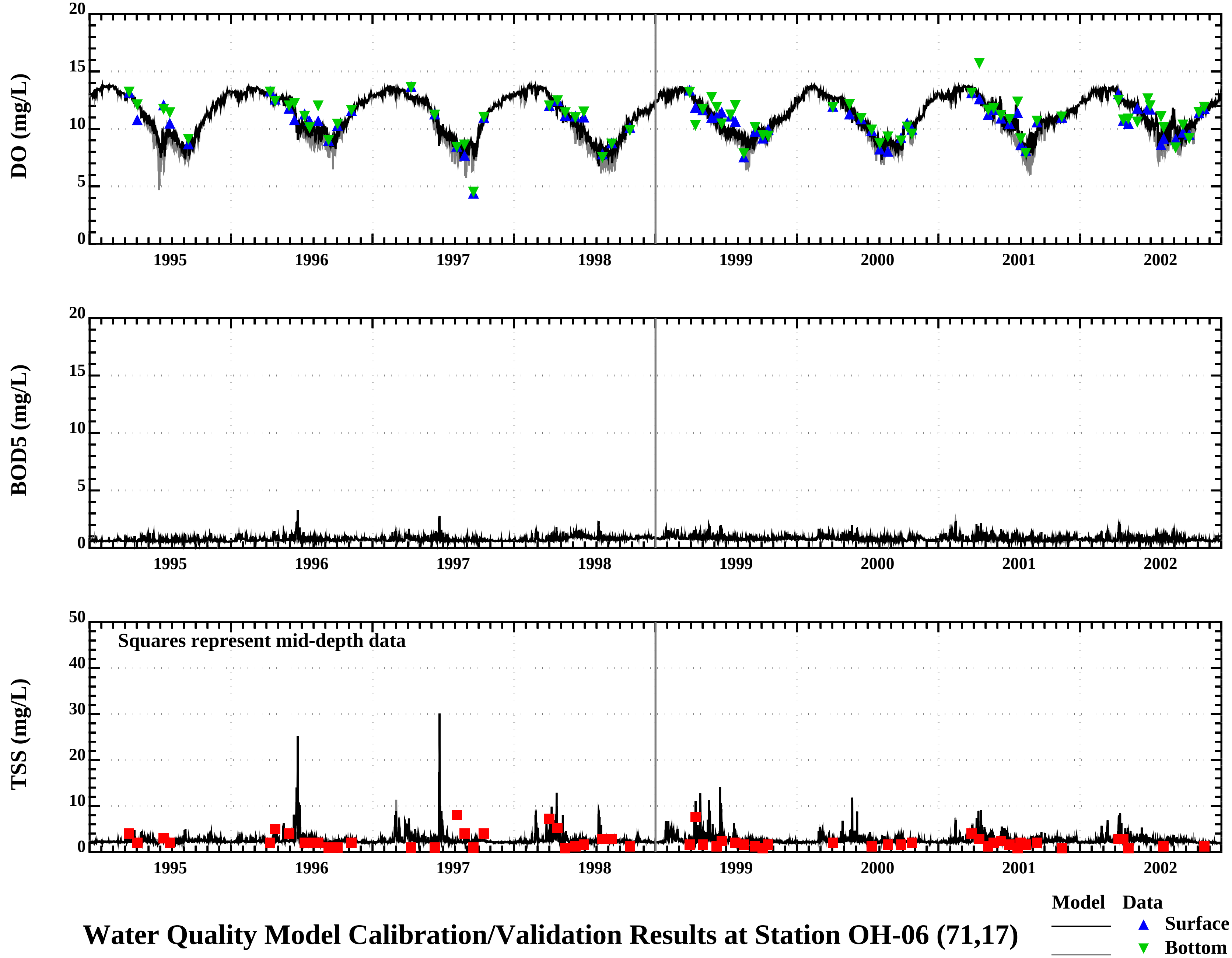


Water Quality Model Calibration/Validation Results at Station OH-06 (71,17)



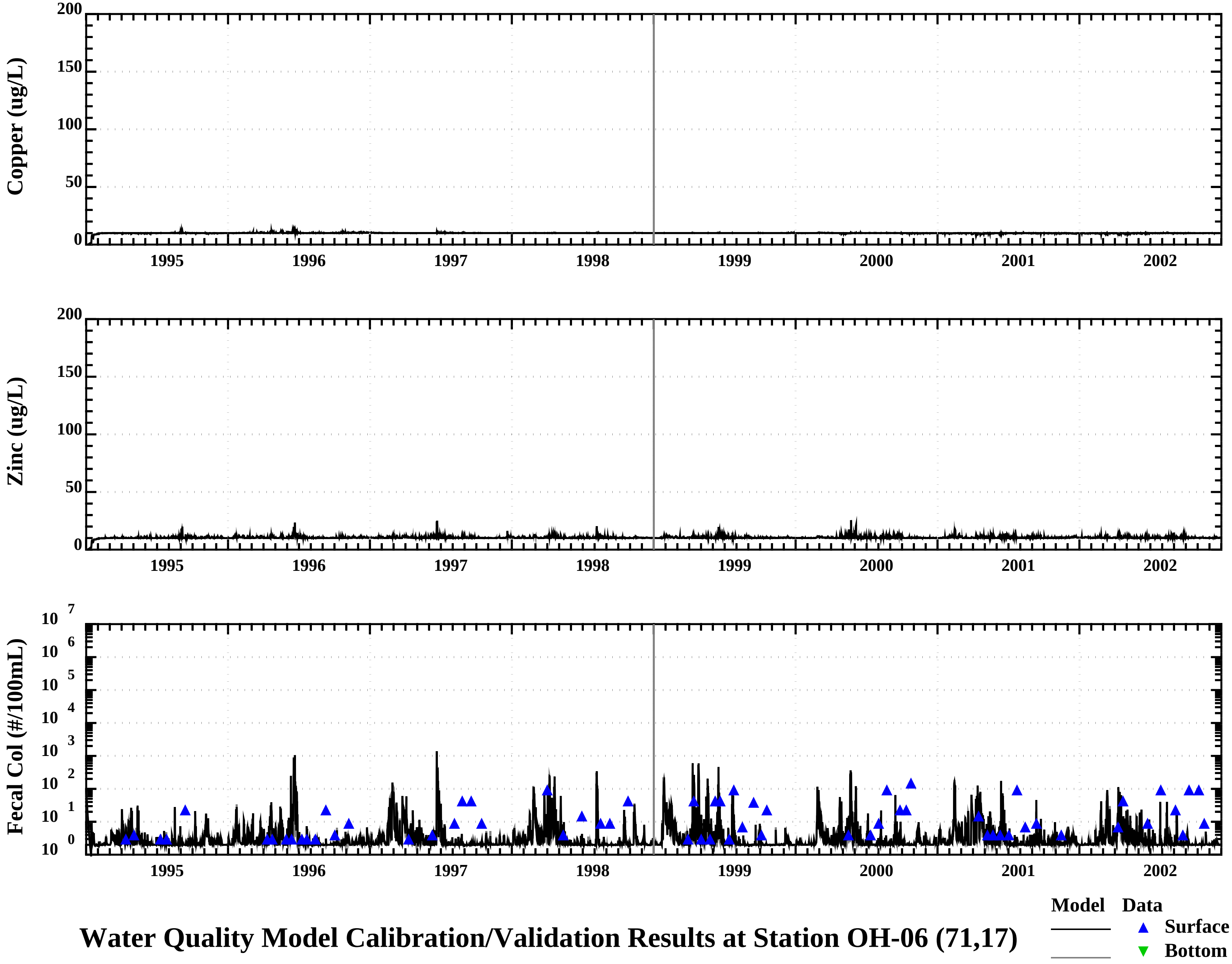
Water Quality Model Calibration/Validation Results at Station OH-06 (71,17)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:58:36



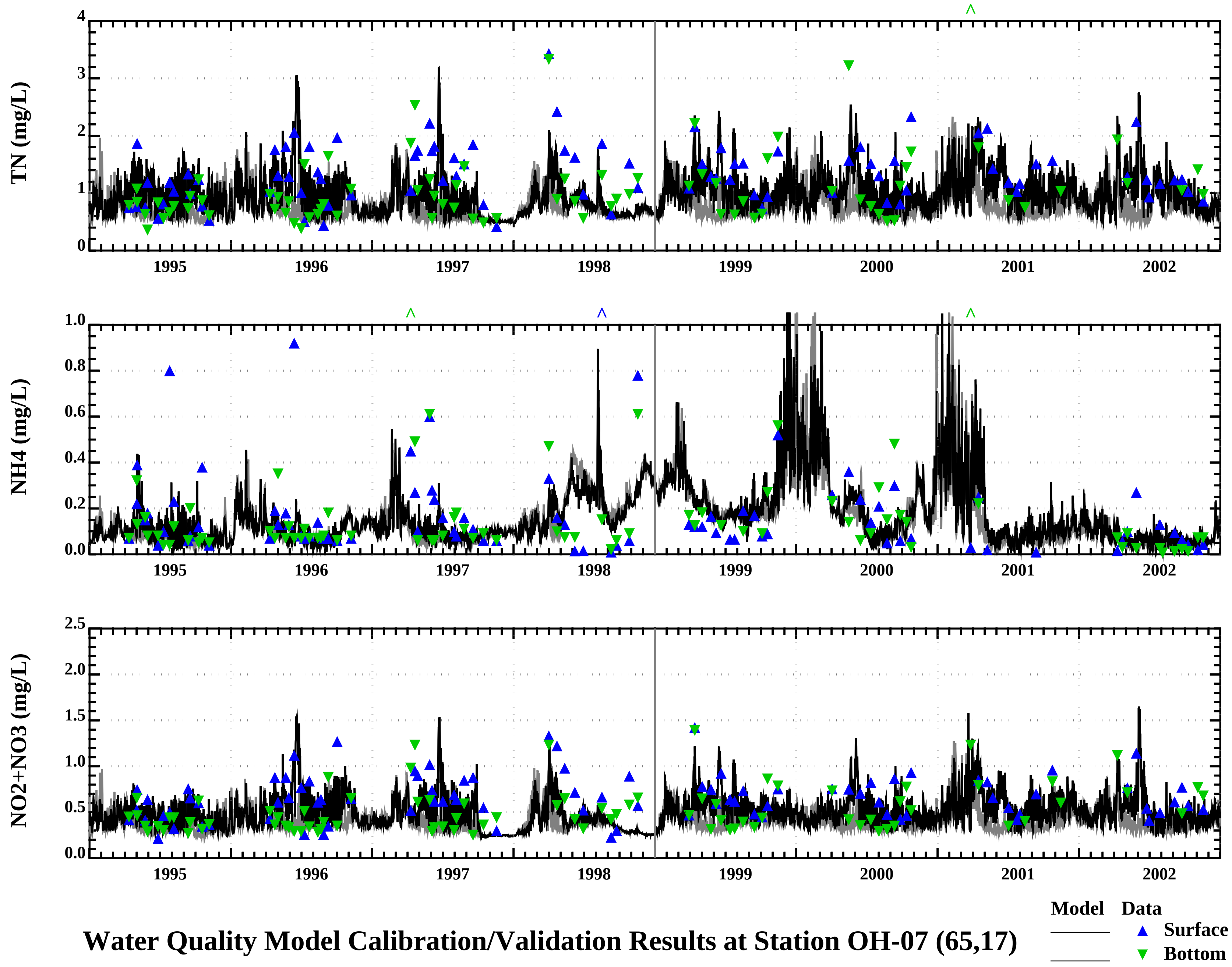
Water Quality Model Calibration/Validation Results at Station OH-06 (71,17)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:58:36



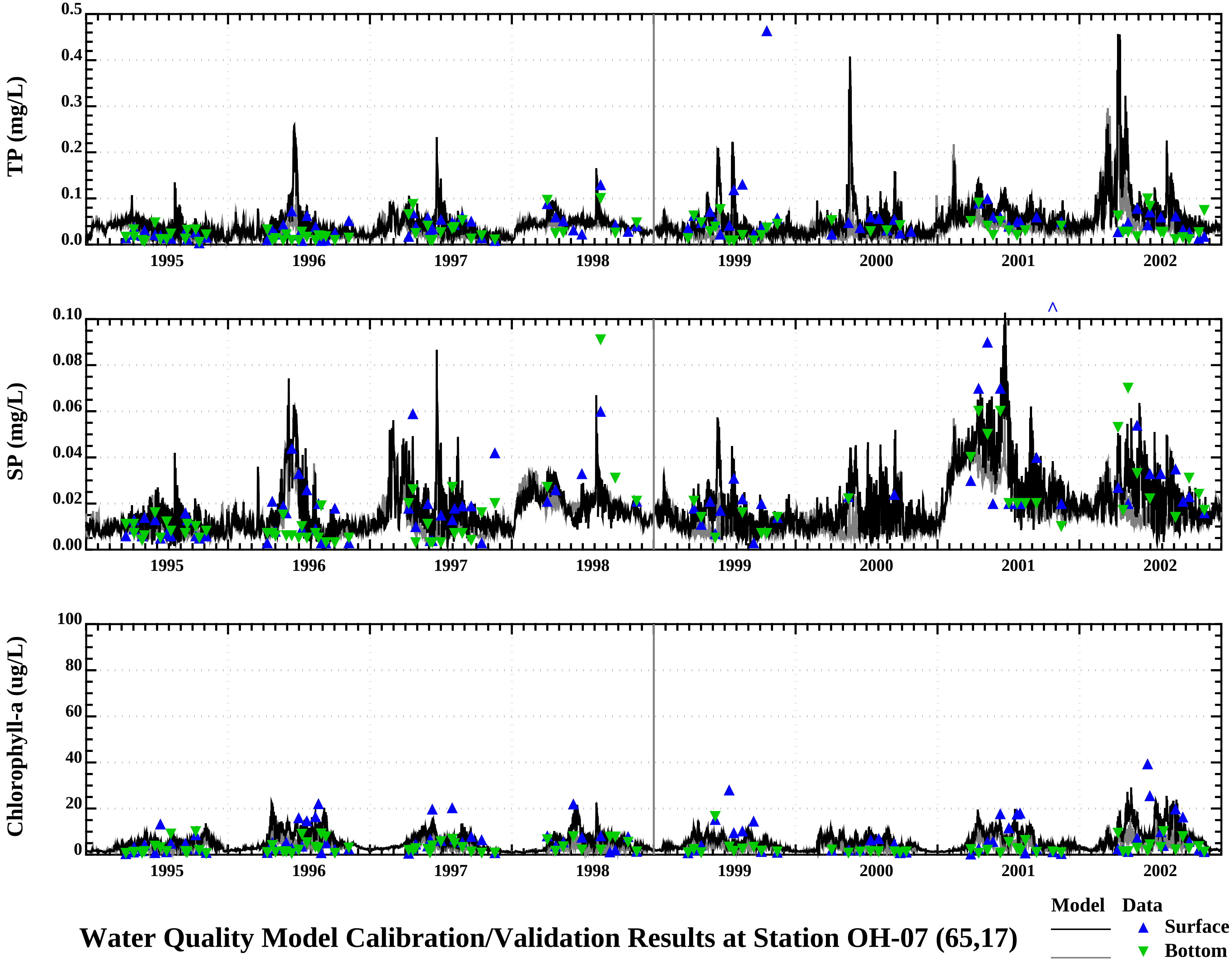
Water Quality Model Calibration/Validation Results at Station OH-06 (71,17)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:58:36



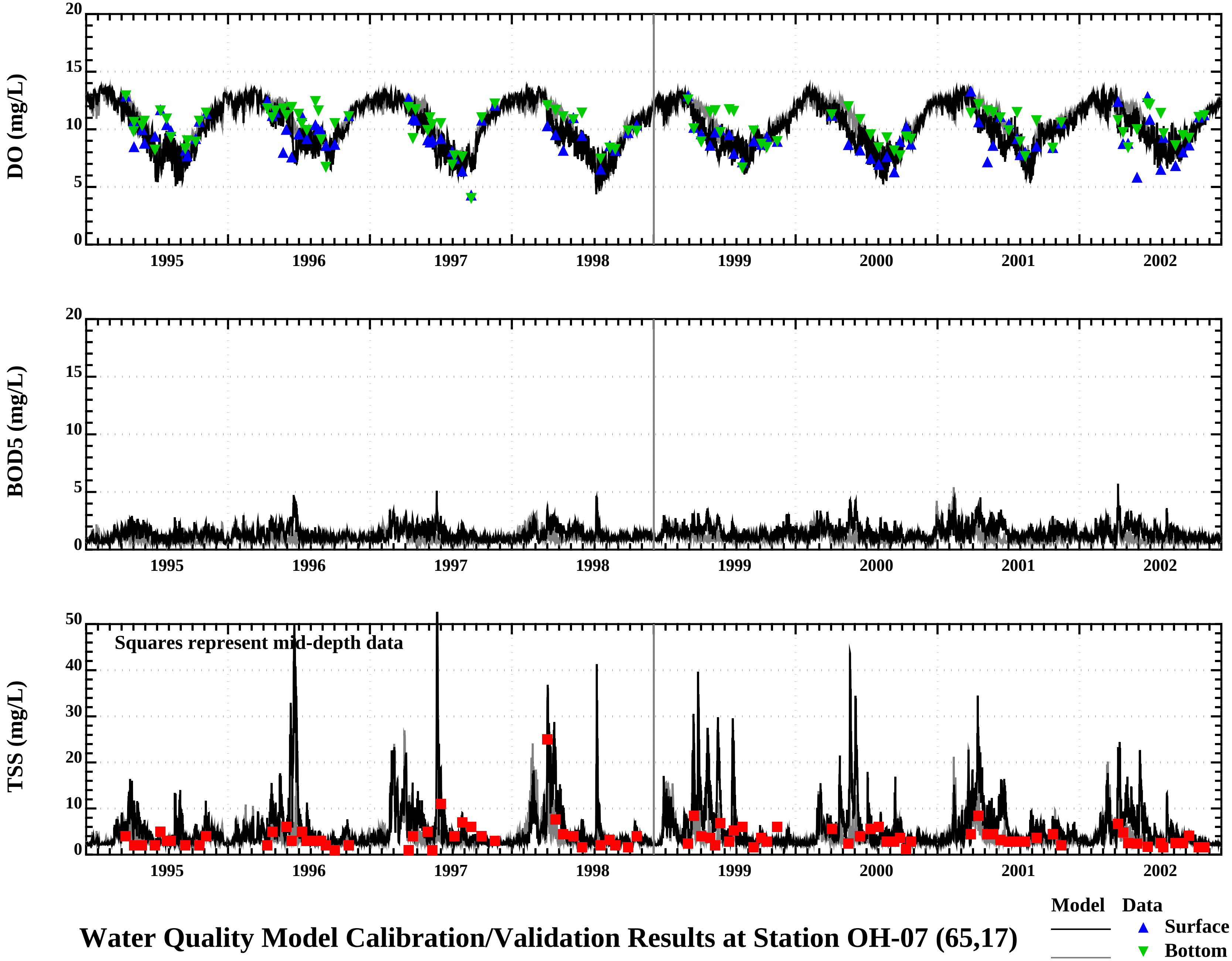
Water Quality Model Calibration/Validation Results at Station OH-07 (65,17)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:59:39



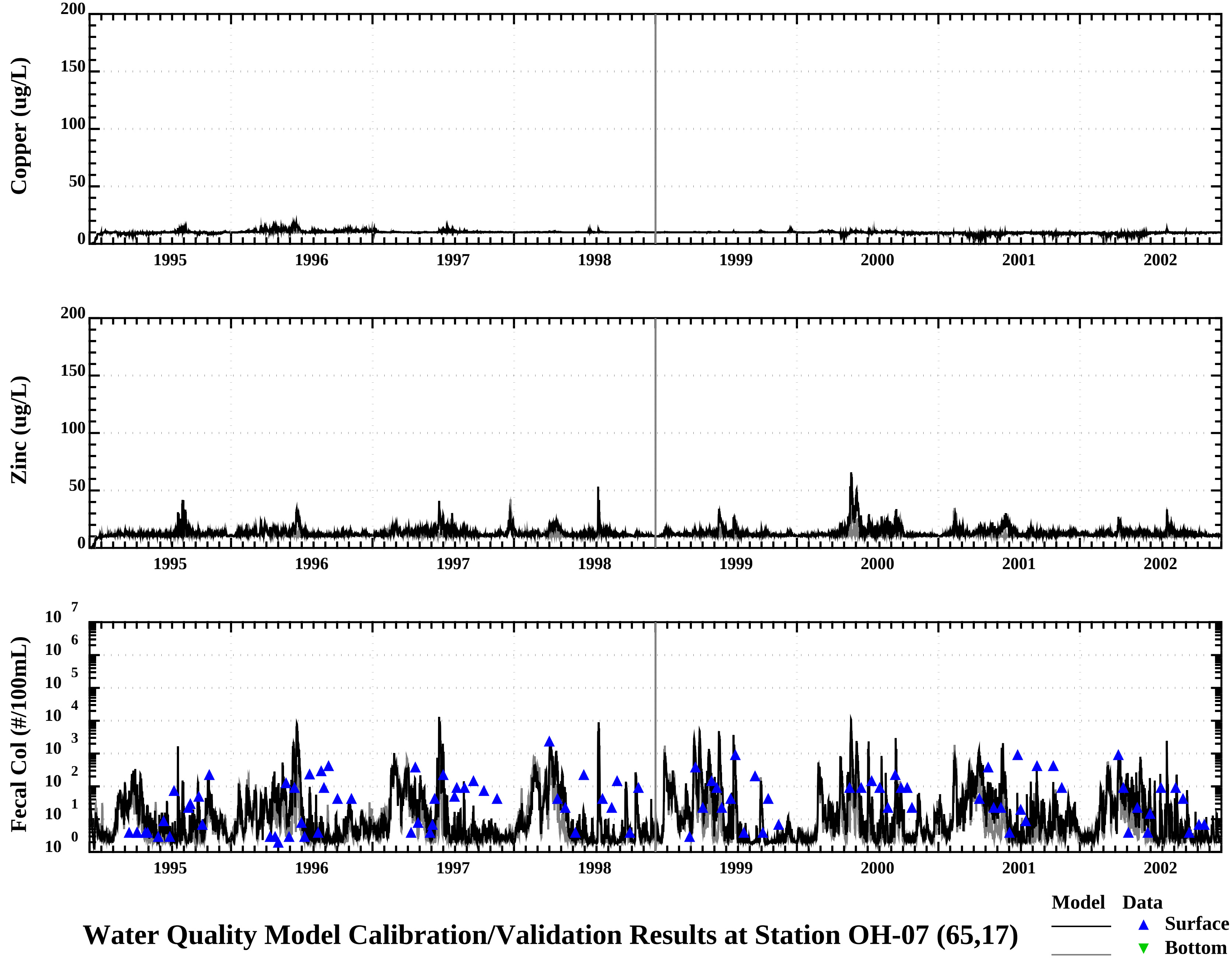
Water Quality Model Calibration/Validation Results at Station OH-07 (65,17)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:59:39



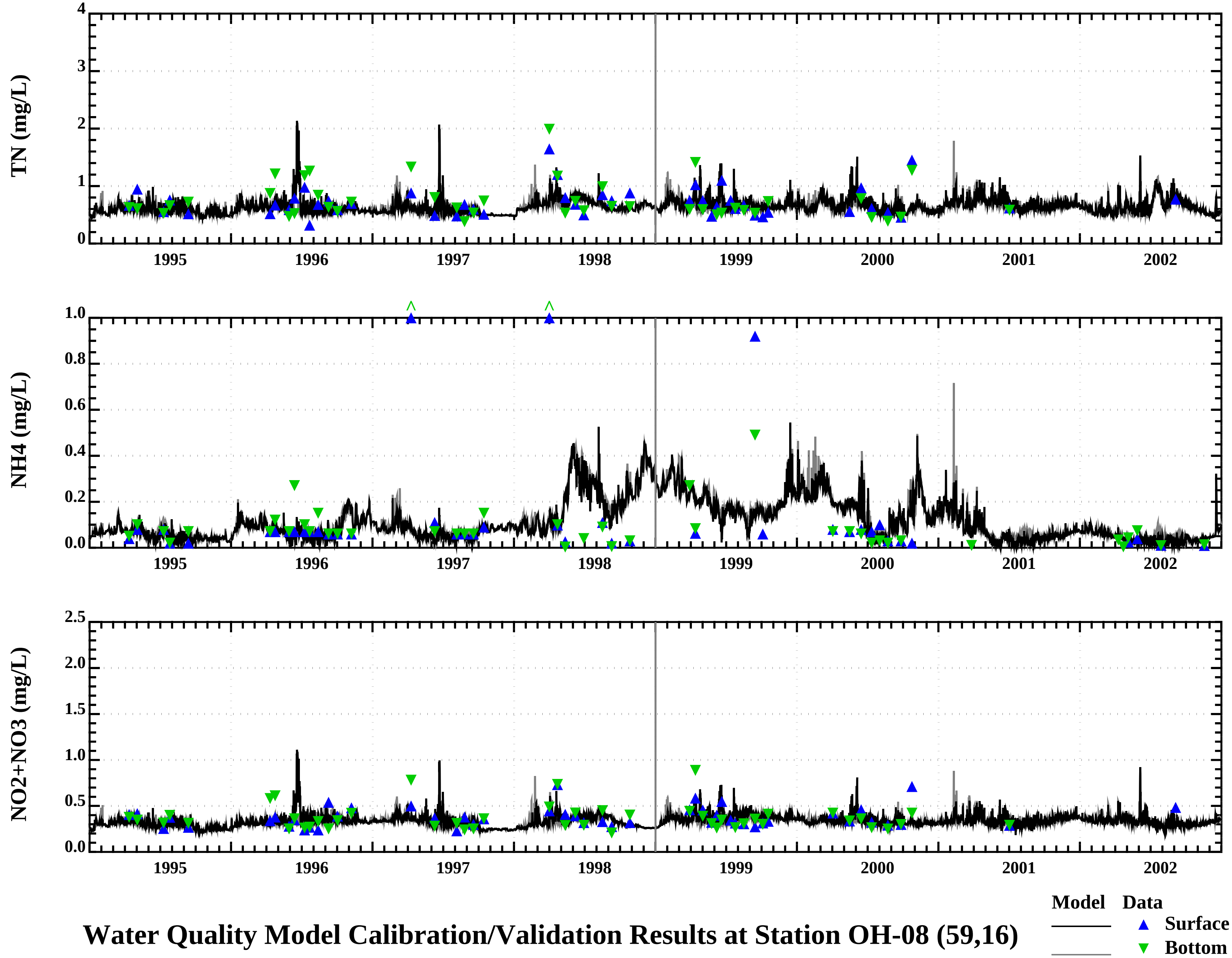
Water Quality Model Calibration/Validation Results at Station OH-07 (65,17)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:59:39



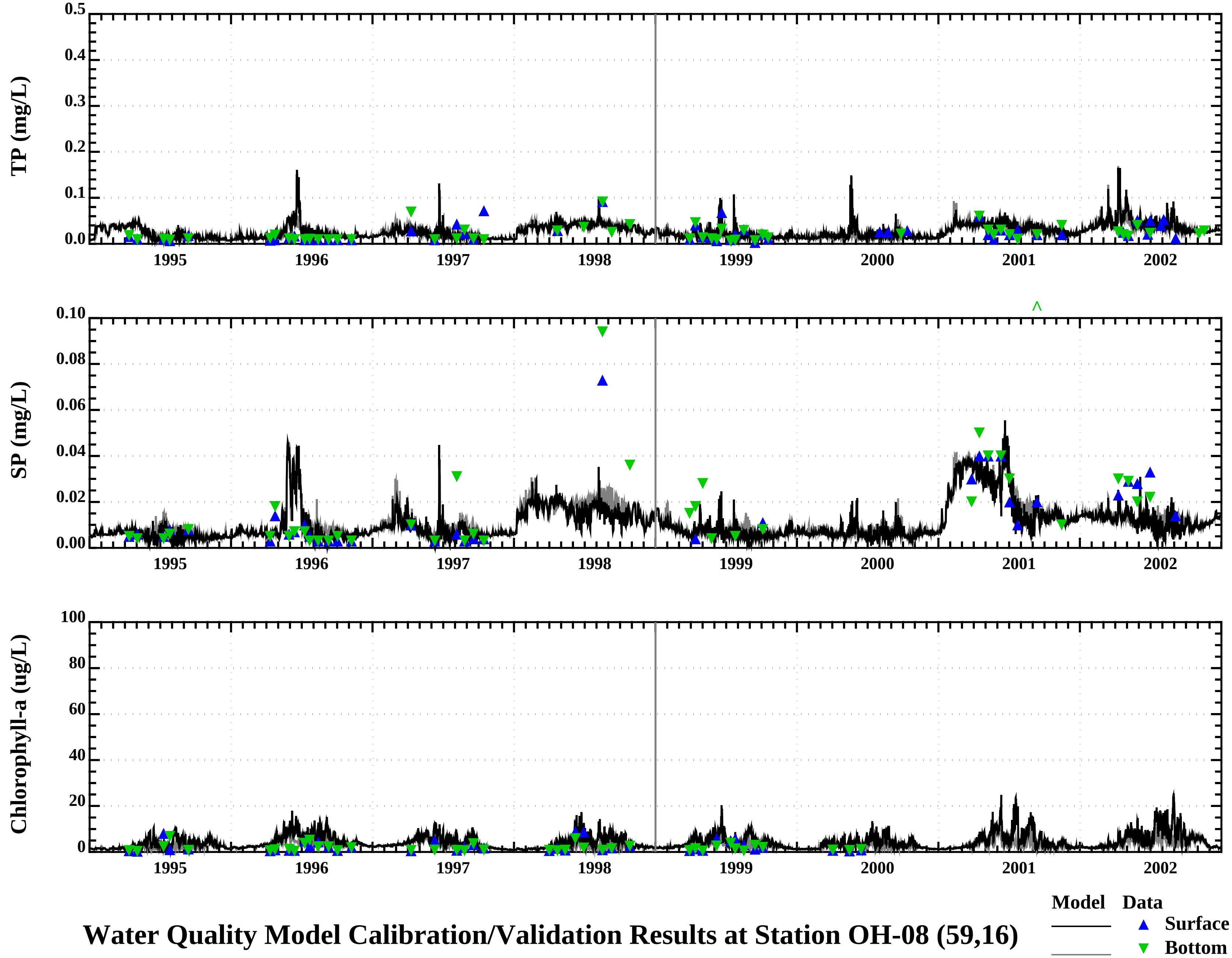
Water Quality Model Calibration/Validation Results at Station OH-07 (65,17)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 9:59:39



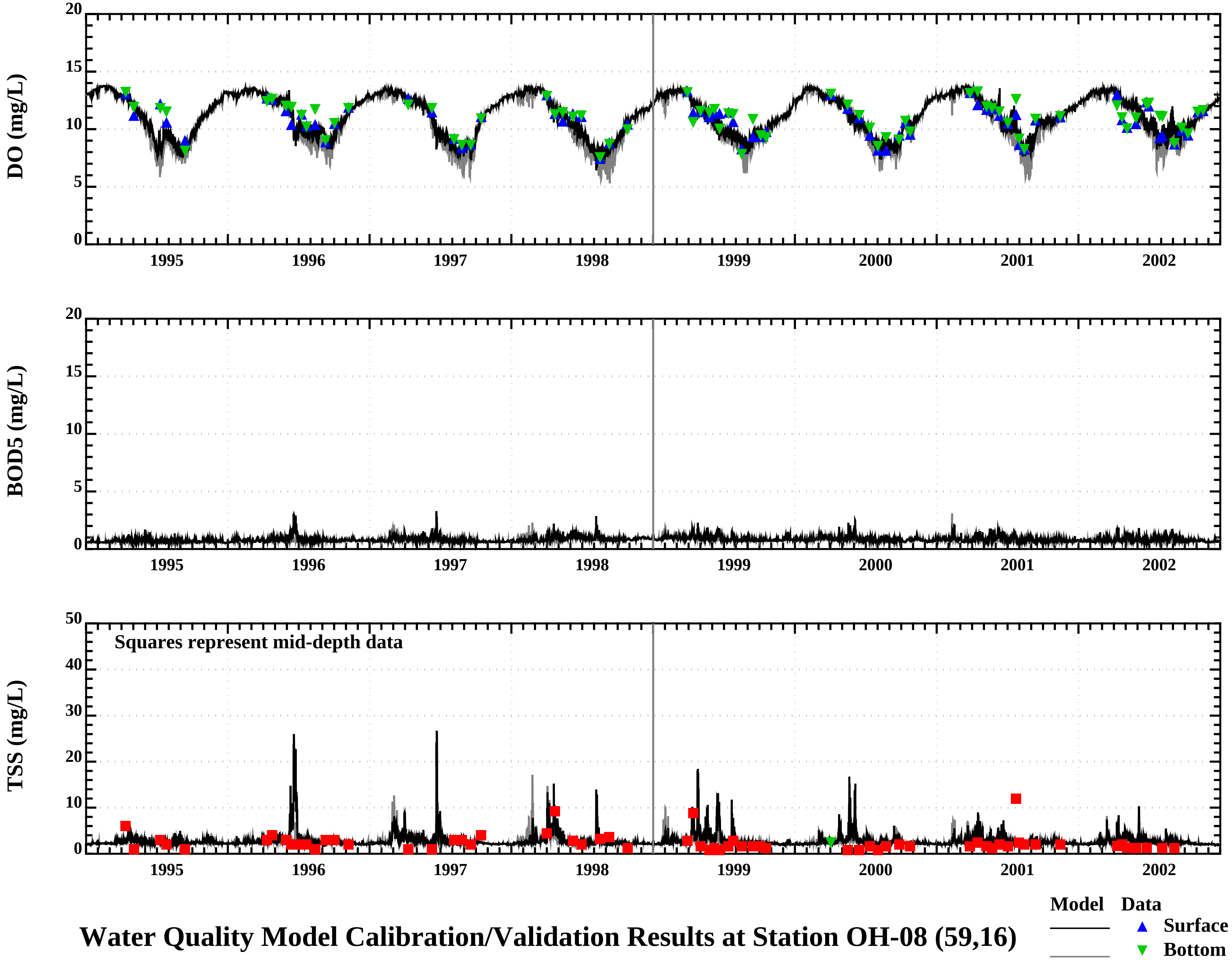
Water Quality Model Calibration/Validation Results at Station OH-08 (59,16)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 0:44



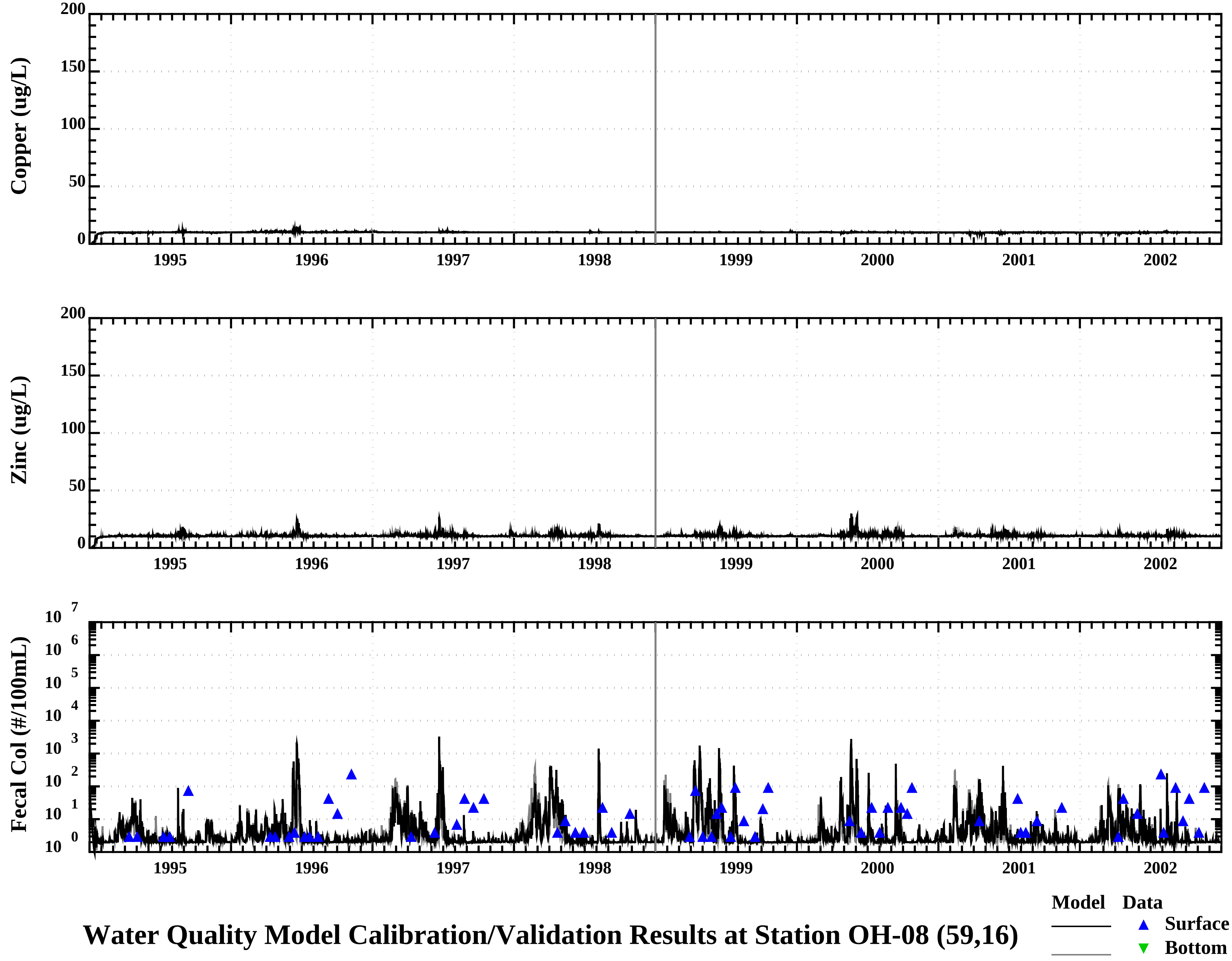
Water Quality Model Calibration/Validation Results at Station OH-08 (59,16)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 0:44



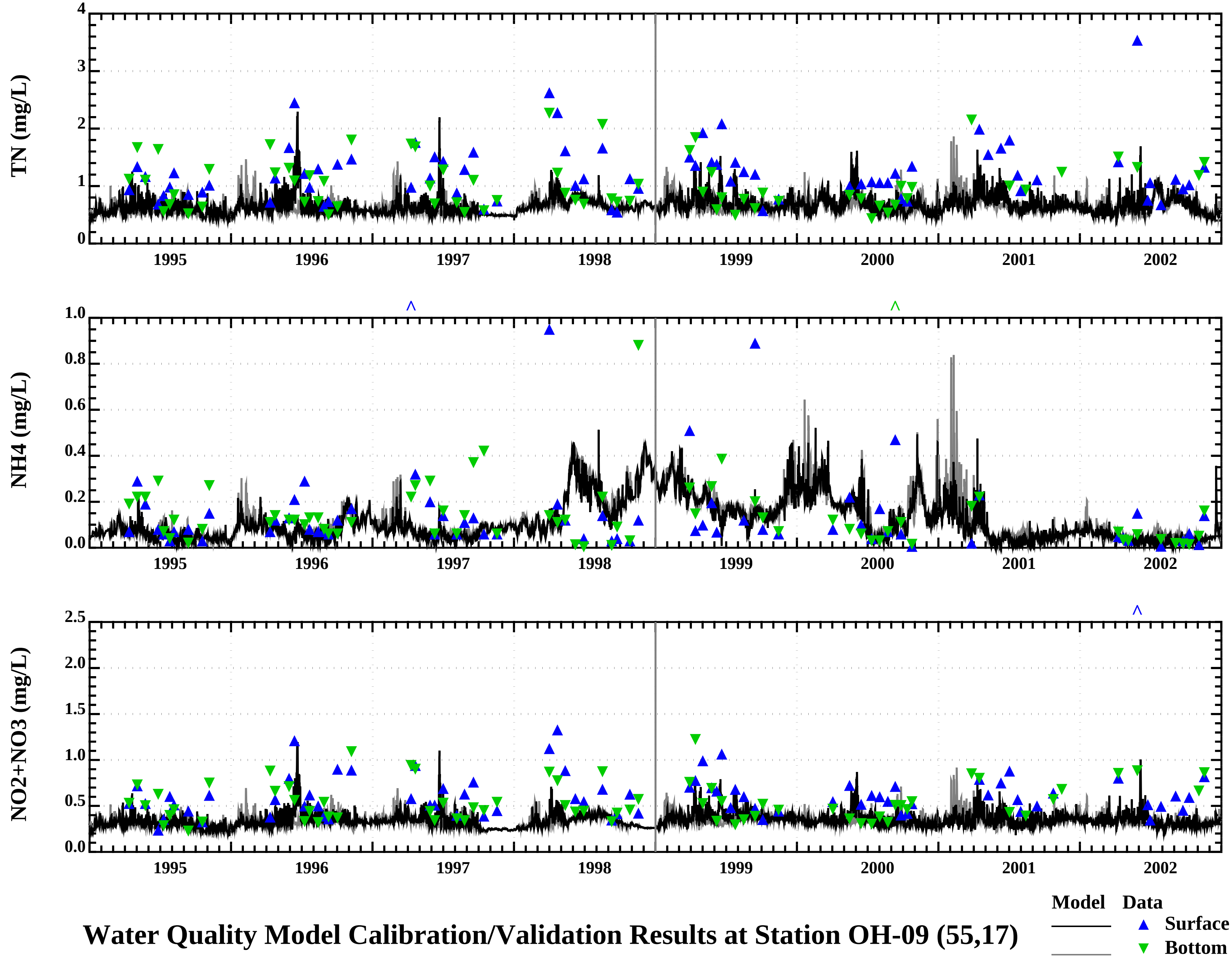
Water Quality Model Calibration/Validation Results at Station OH-08 (59,16)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 0:44



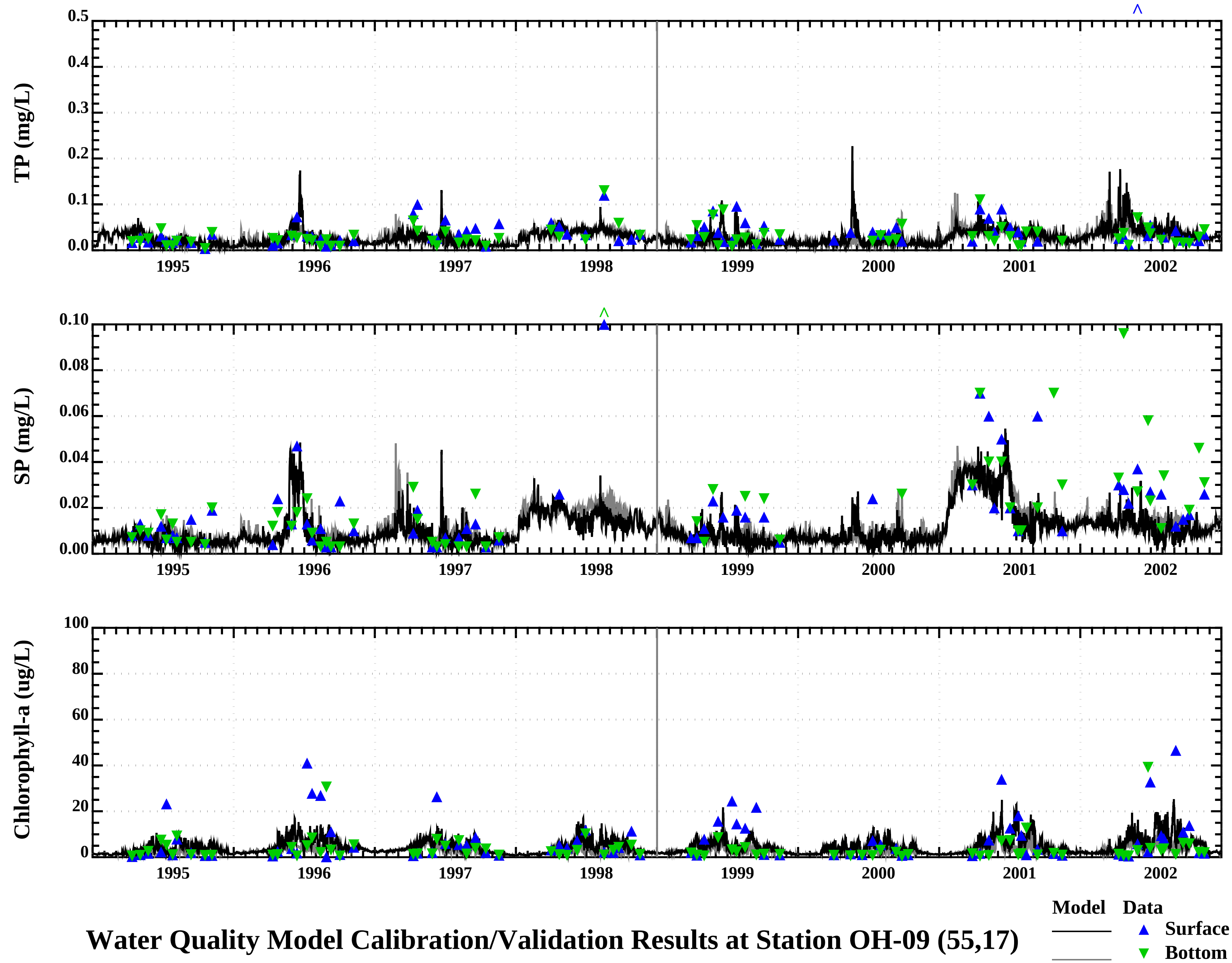
Water Quality Model Calibration/Validation Results at Station OH-08 (59,16)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 0:44



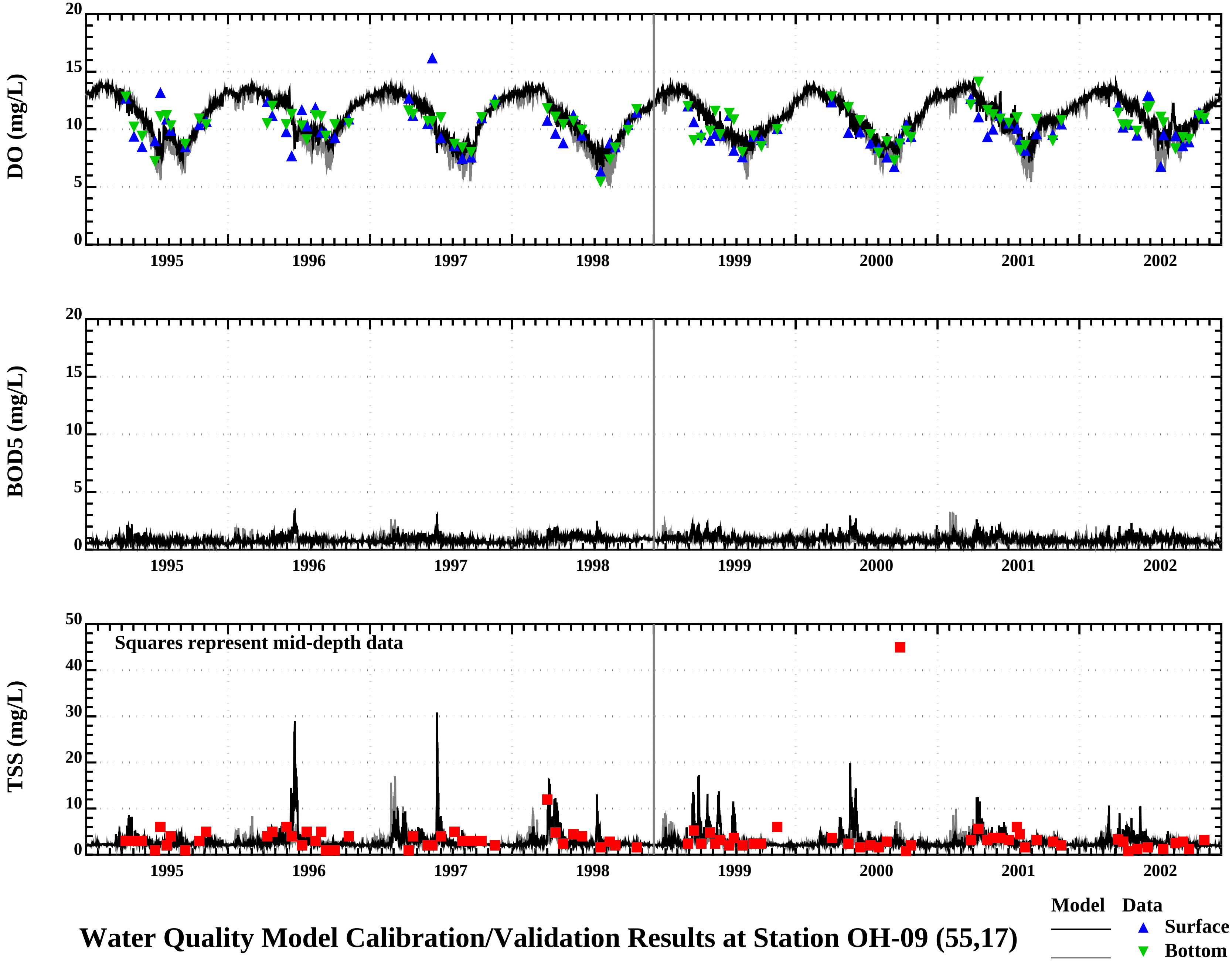
Water Quality Model Calibration/Validation Results at Station OH-09 (55,17)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 1:48



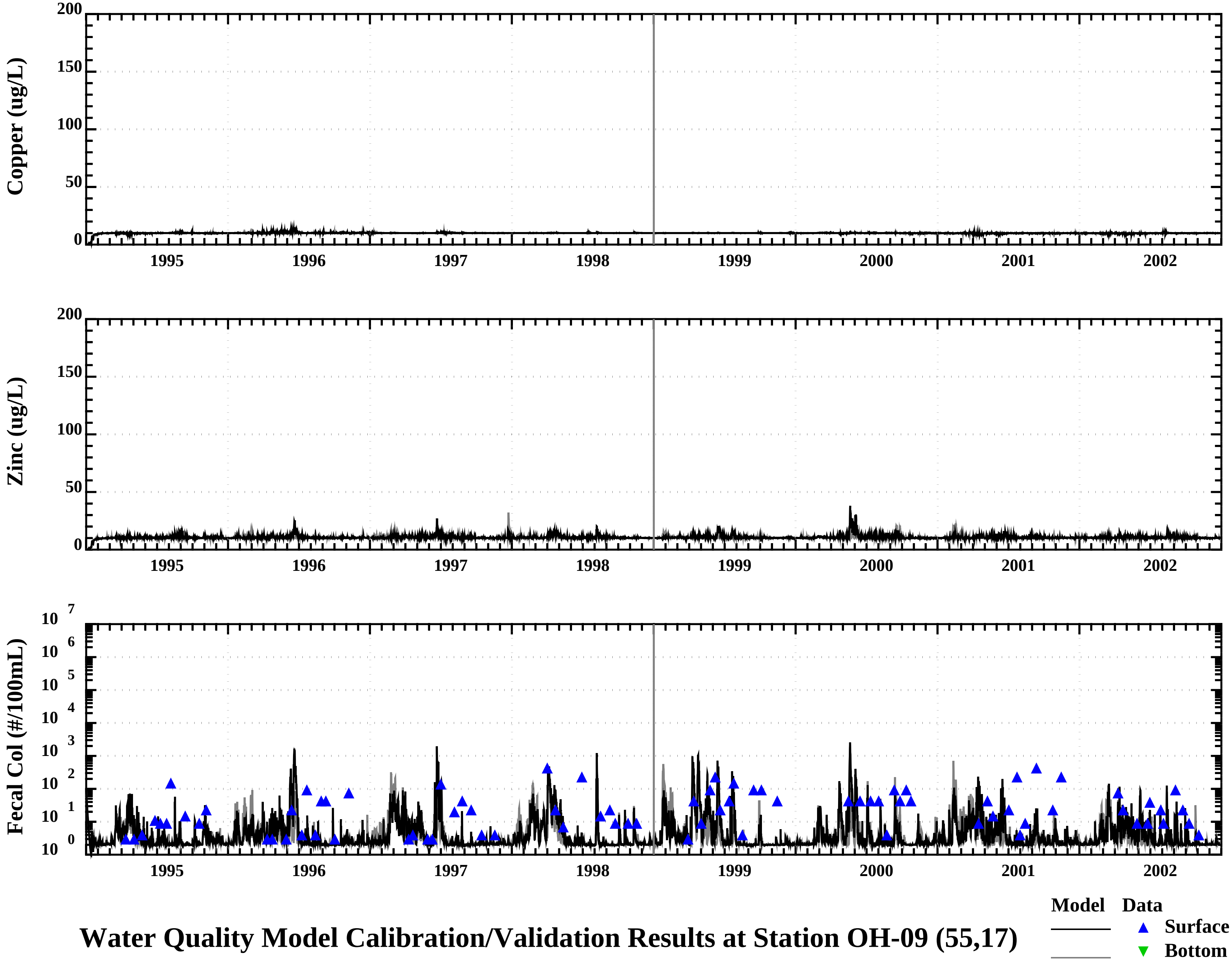
Water Quality Model Calibration/Validation Results at Station OH-09 (55,17)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 1:48



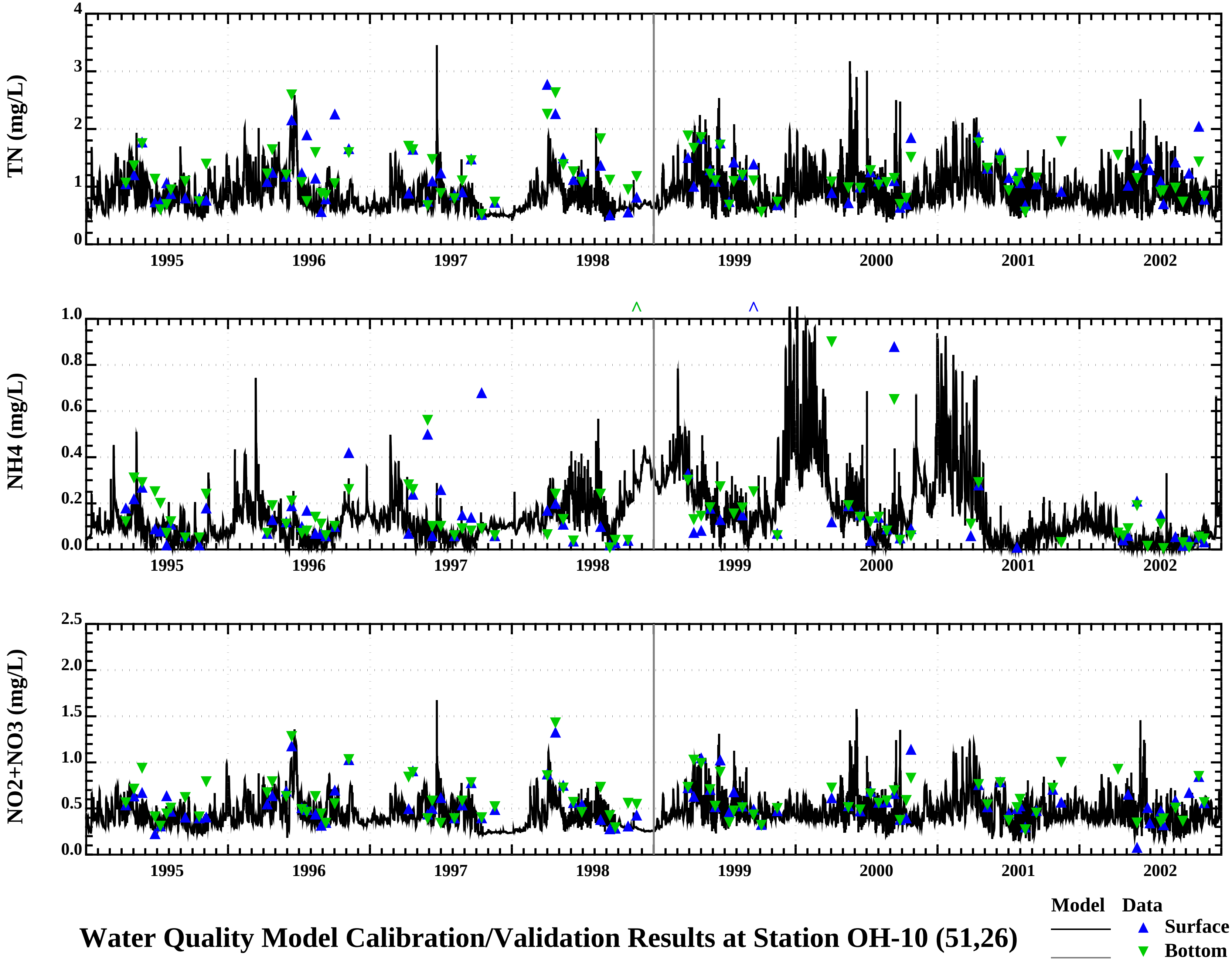
Water Quality Model Calibration/Validation Results at Station OH-09 (55,17)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 1:48



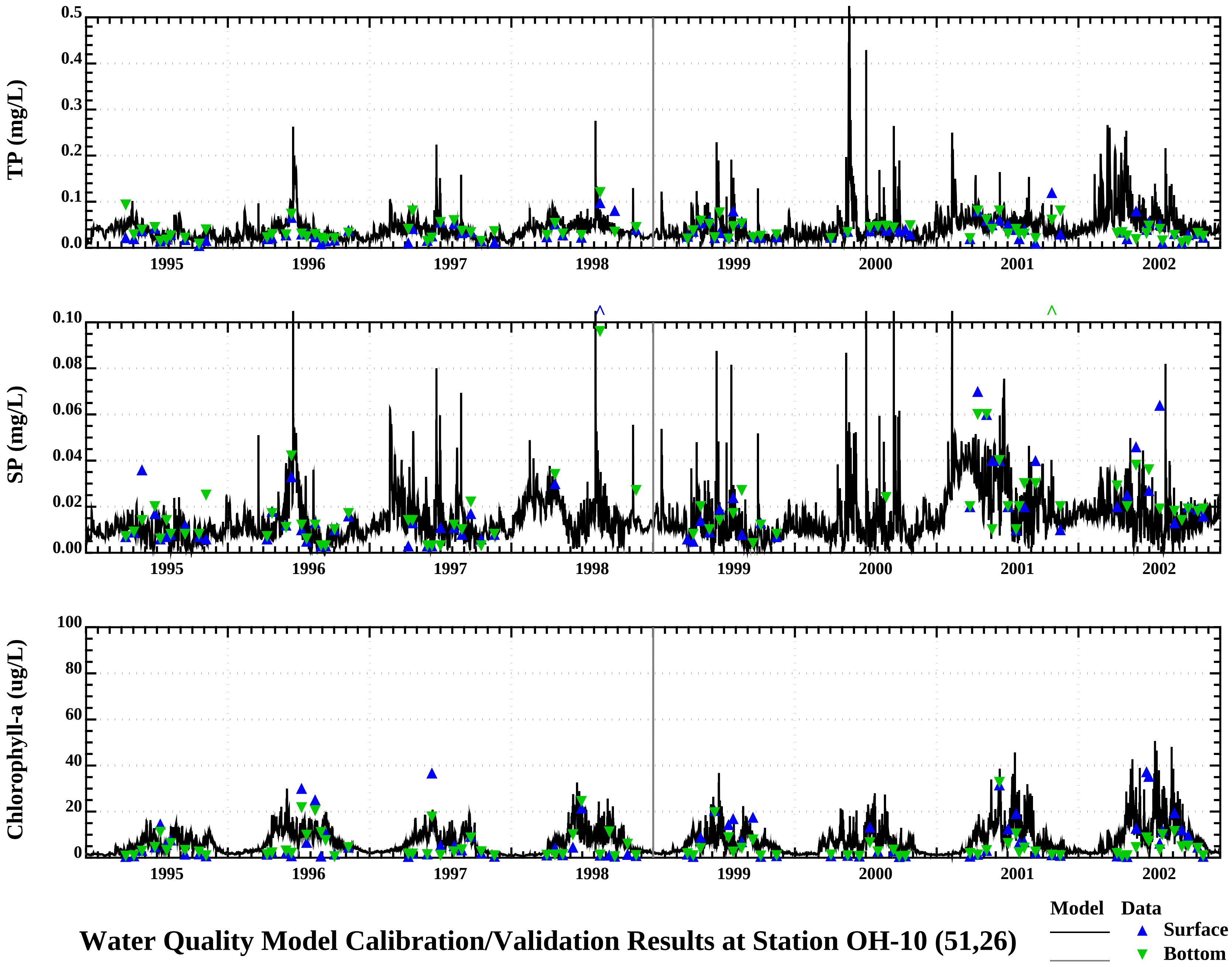
Water Quality Model Calibration/Validation Results at Station OH-09 (55,17)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 1:48



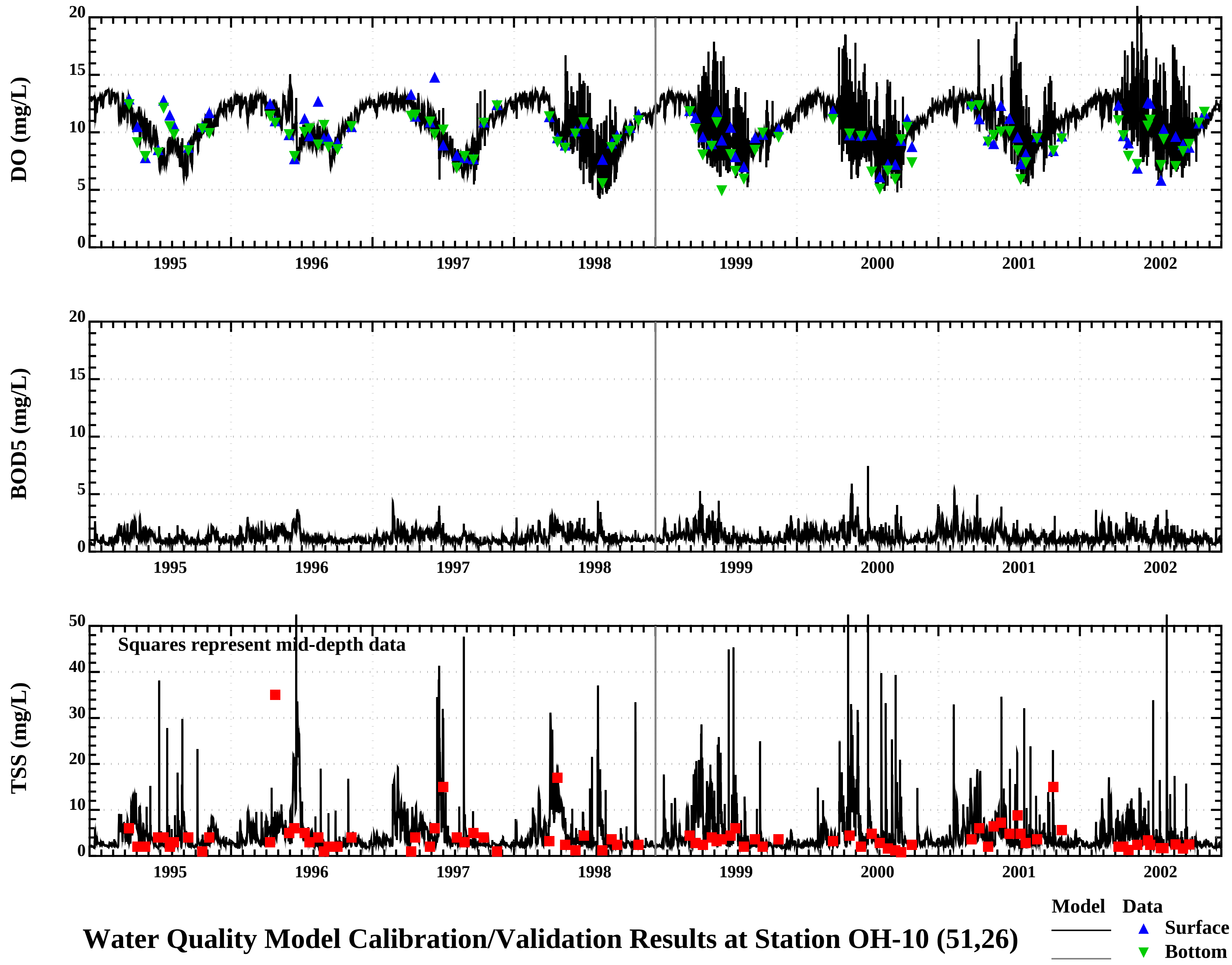
Water Quality Model Calibration/Validation Results at Station OH-10 (51,26)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 2:52



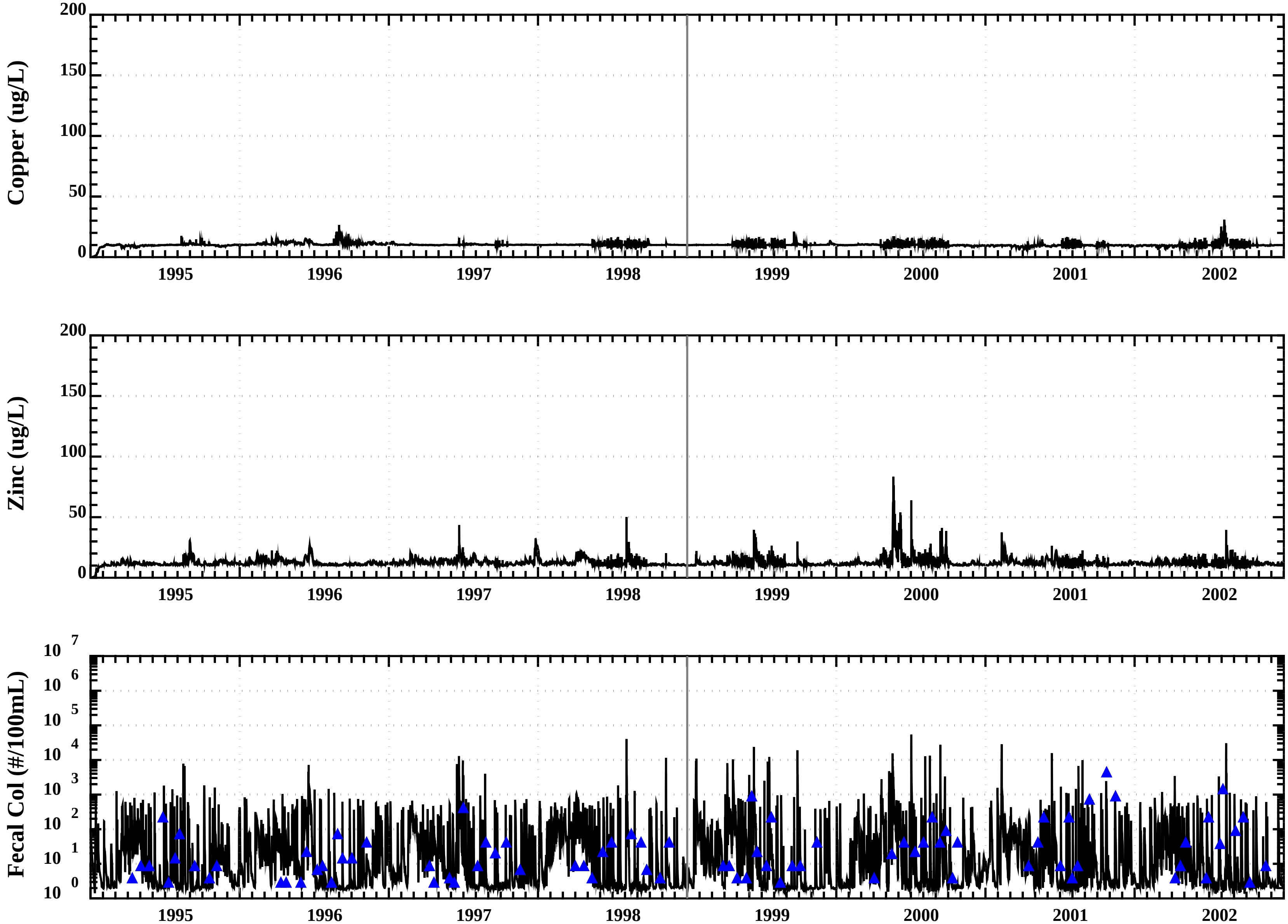
Water Quality Model Calibration/Validation Results at Station OH-10 (51,26)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 2:52



Water Quality Model Calibration/Validation Results at Station OH-10 (51,26)

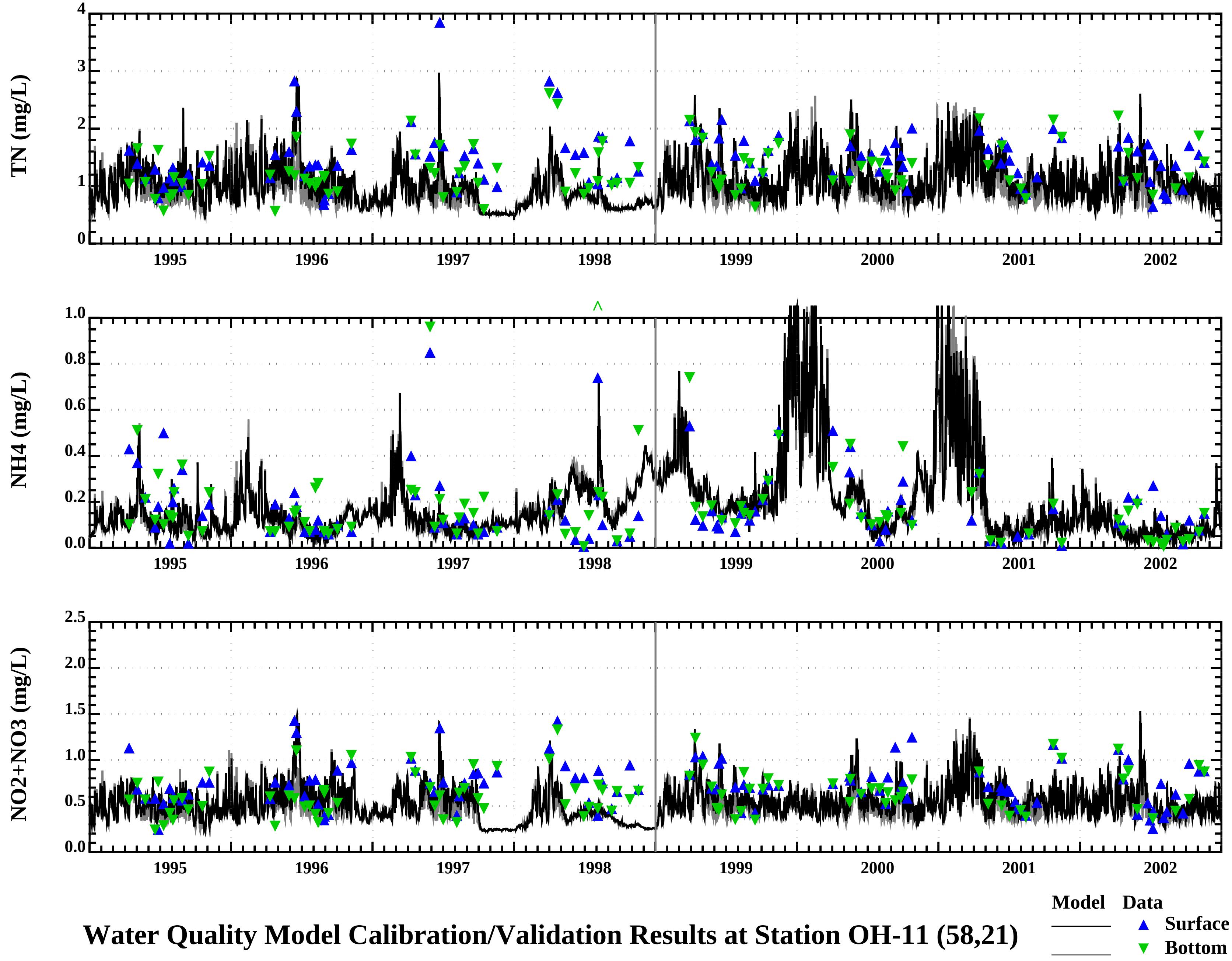
/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 2:52



Model Data
Surface
Bottom

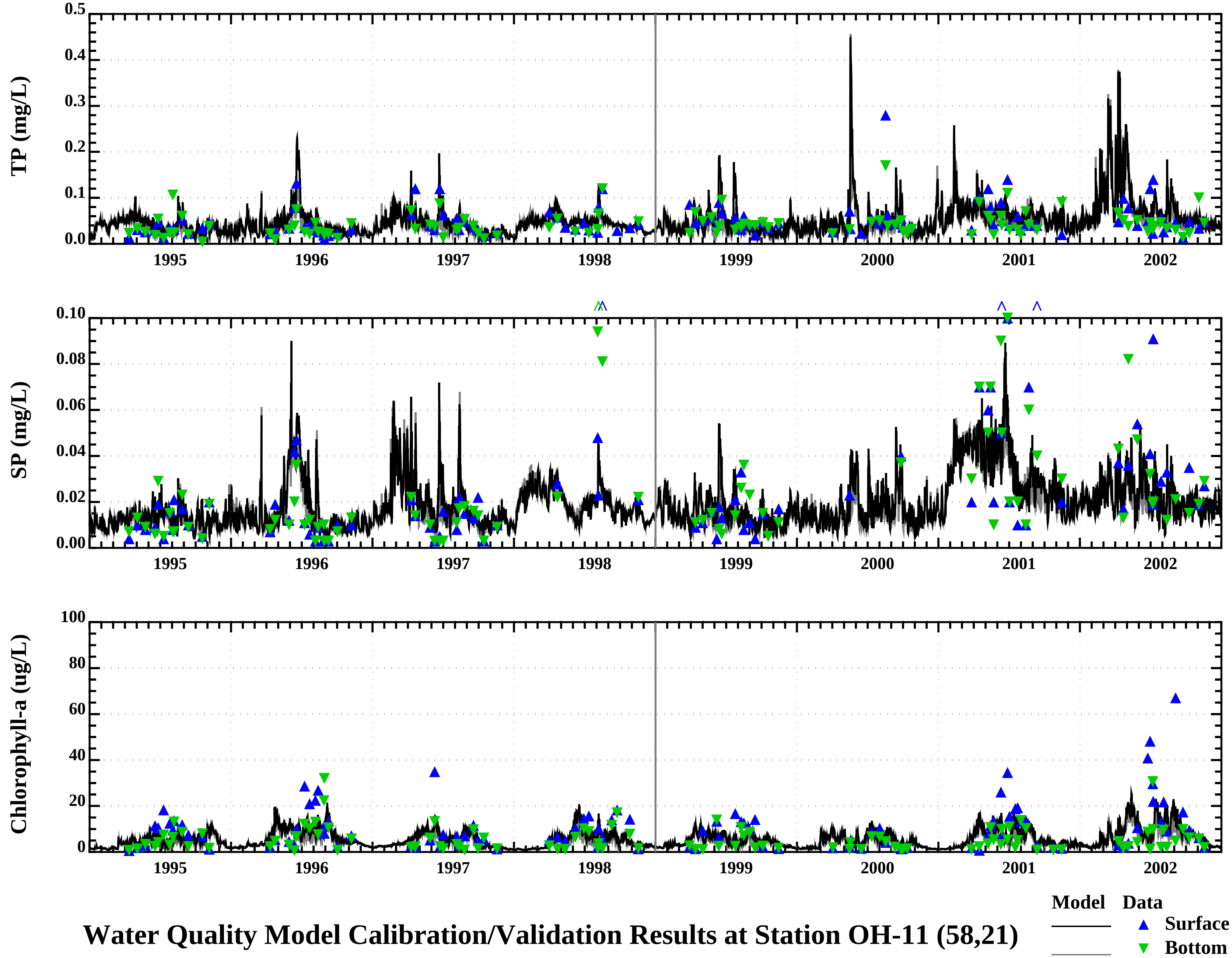
Water Quality Model Calibration/Validation Results at Station OH-10 (51,26)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 2:52



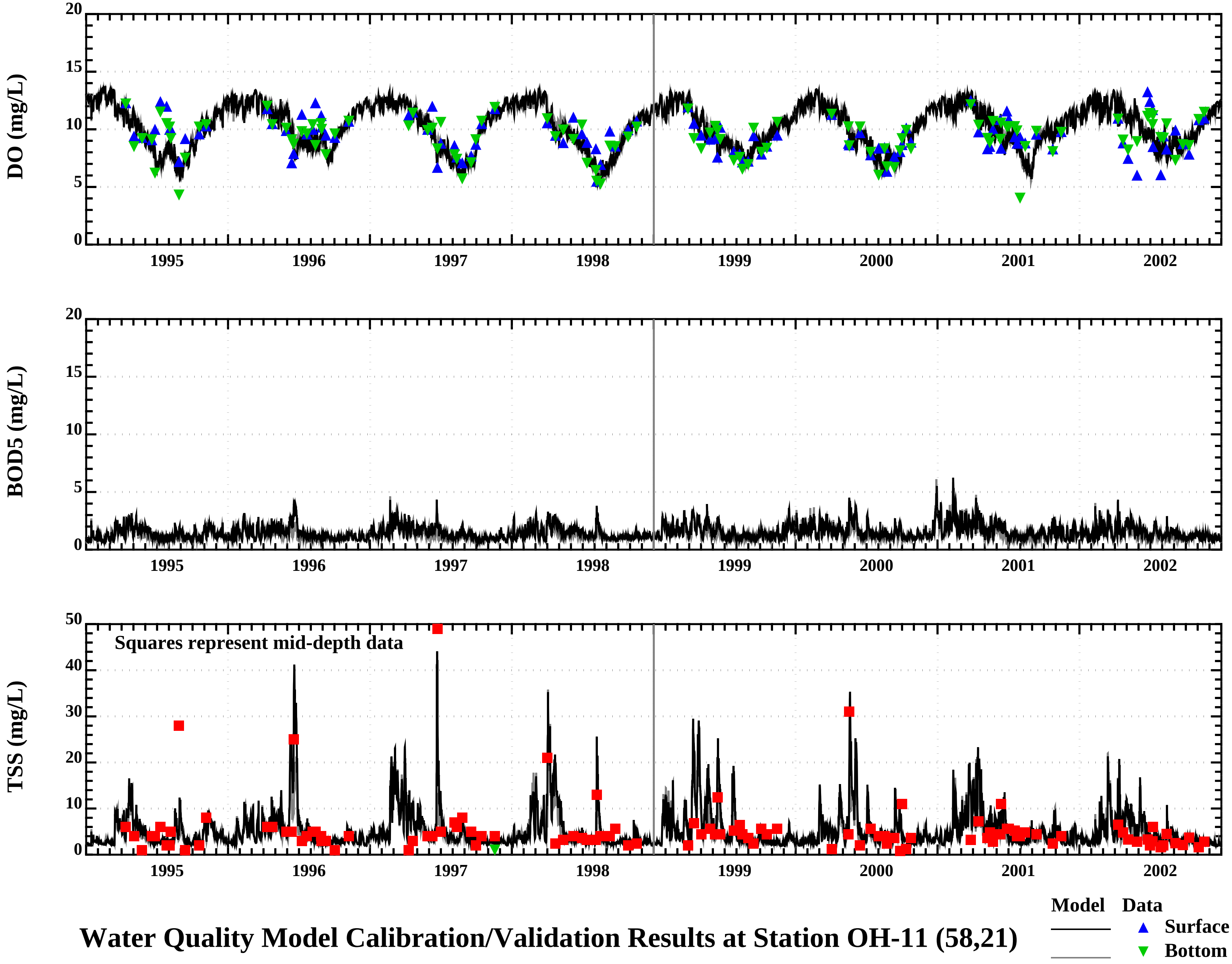
Water Quality Model Calibration/Validation Results at Station OH-11 (58,21)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 3:56



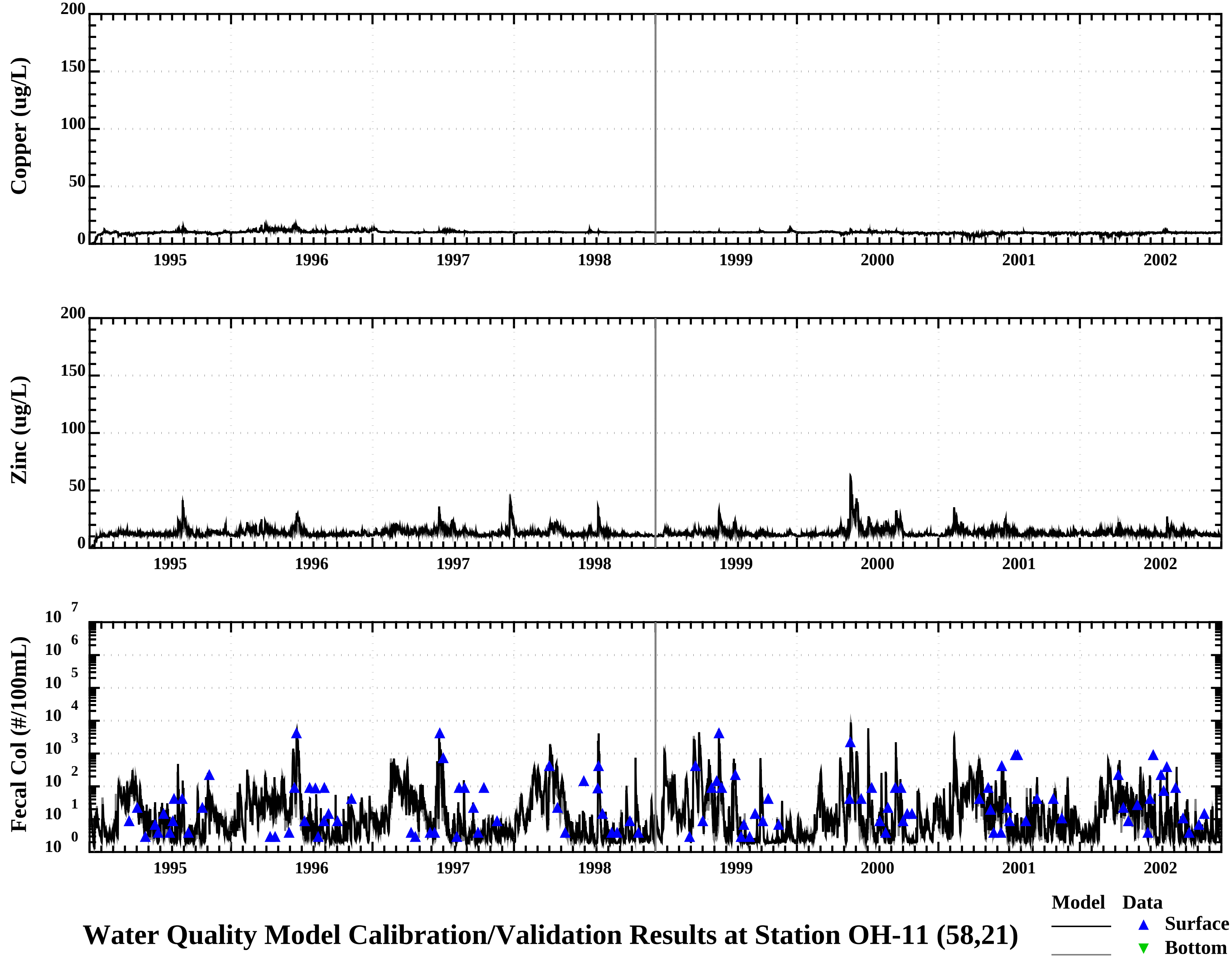
Water Quality Model Calibration/Validation Results at Station OH-11 (58,21)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 3:56



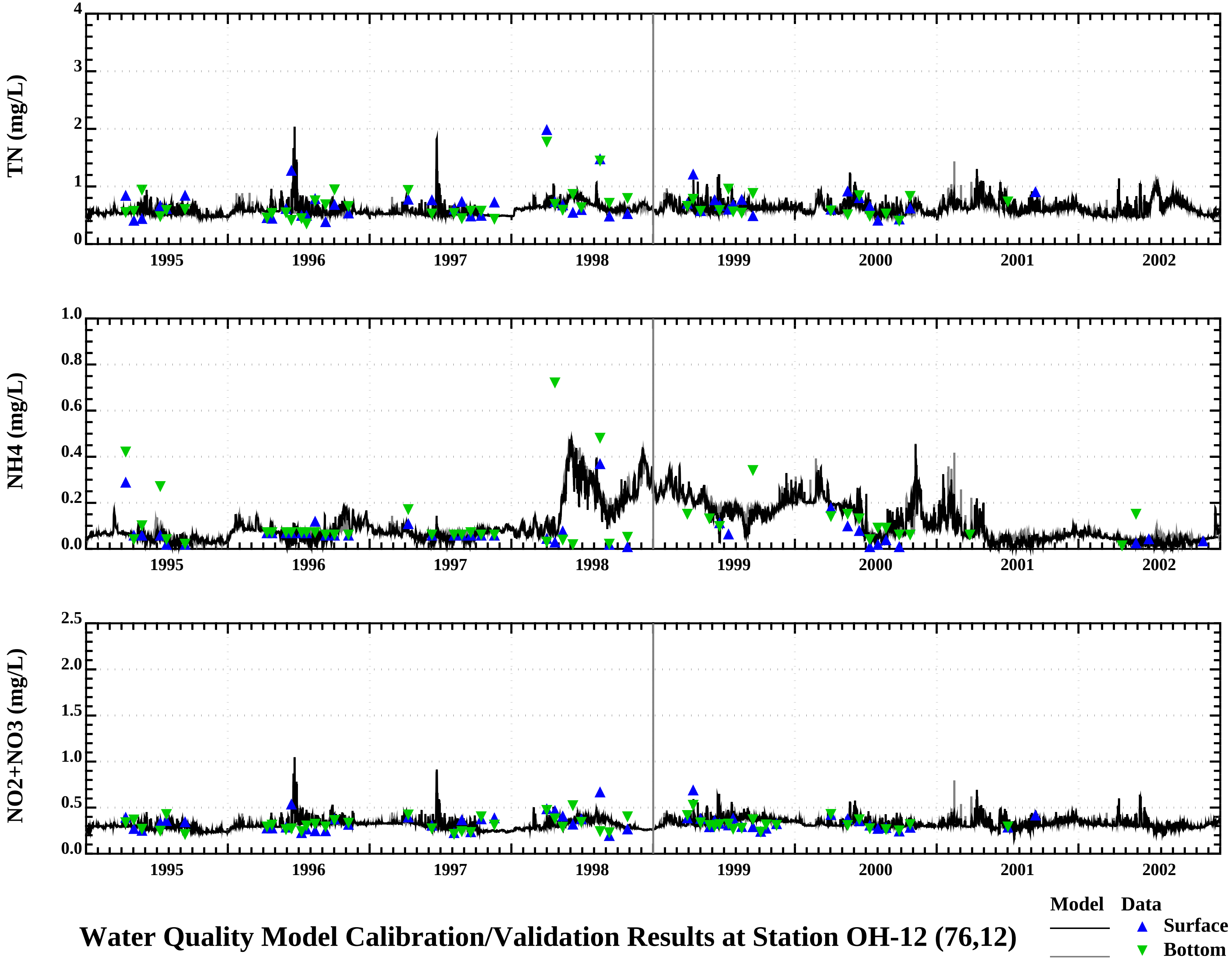
Water Quality Model Calibration/Validation Results at Station OH-11 (58,21)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 3:56



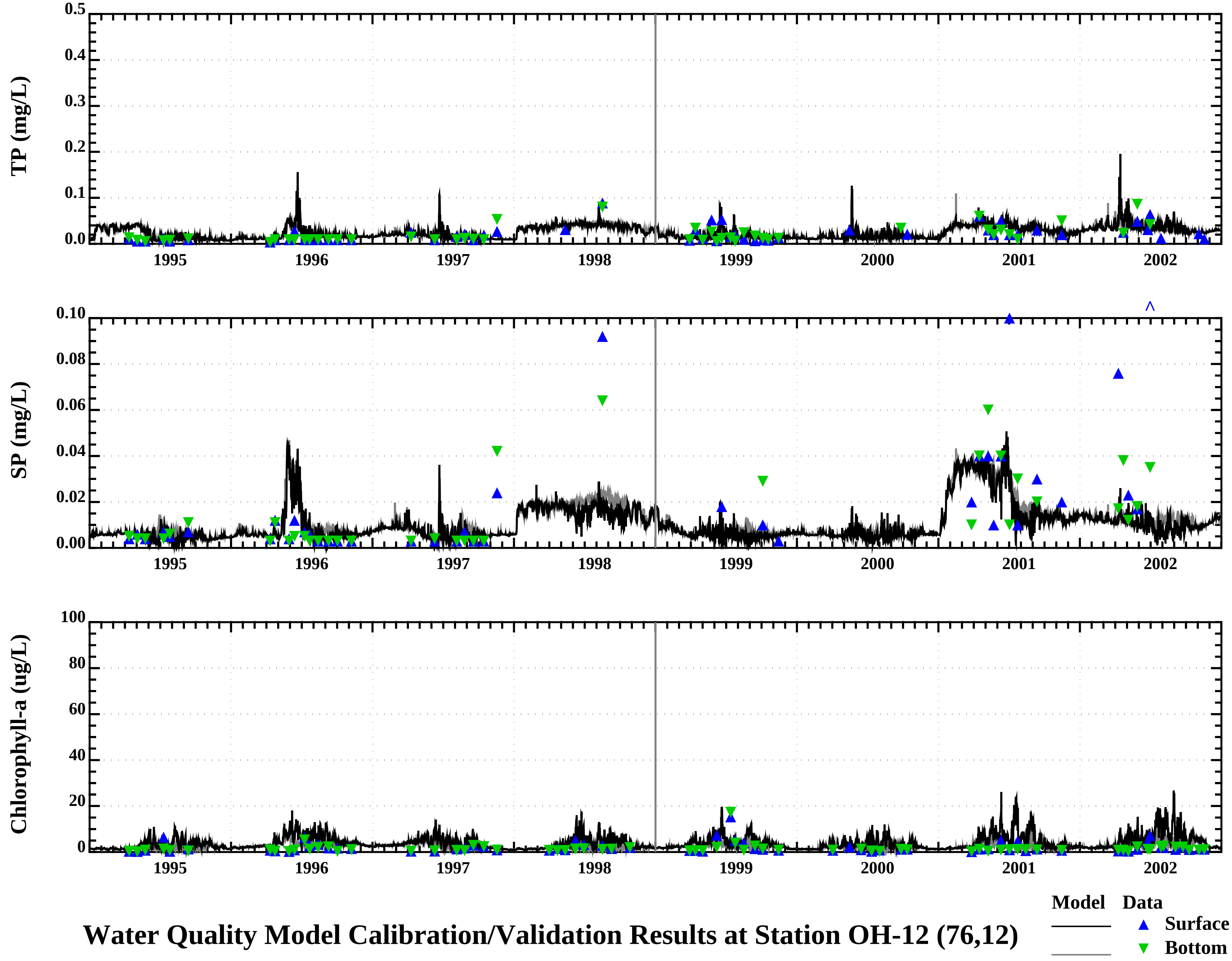
Water Quality Model Calibration/Validation Results at Station OH-11 (58,21)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 3:56



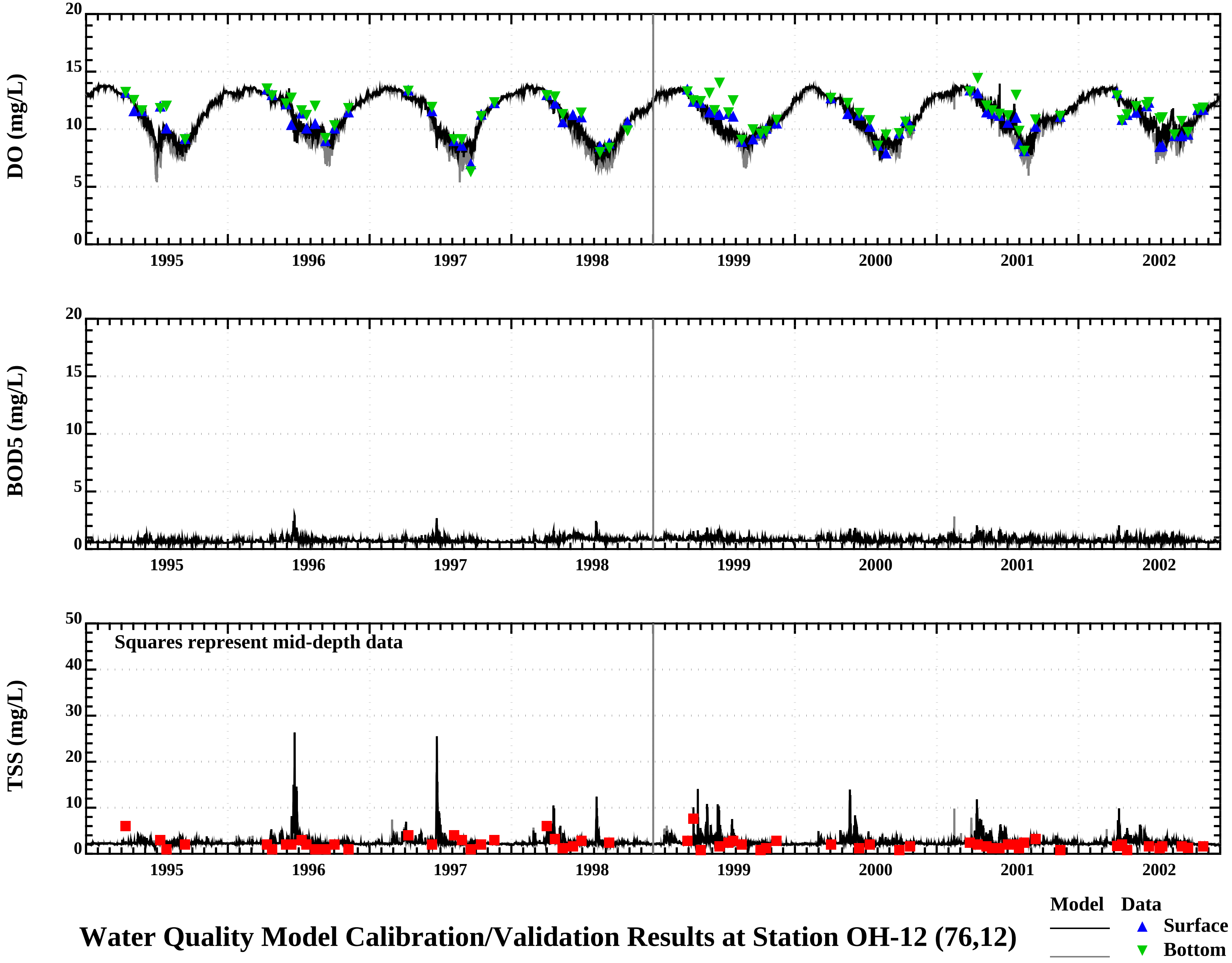
Water Quality Model Calibration/Validation Results at Station OH-12 (76,12)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 4:59



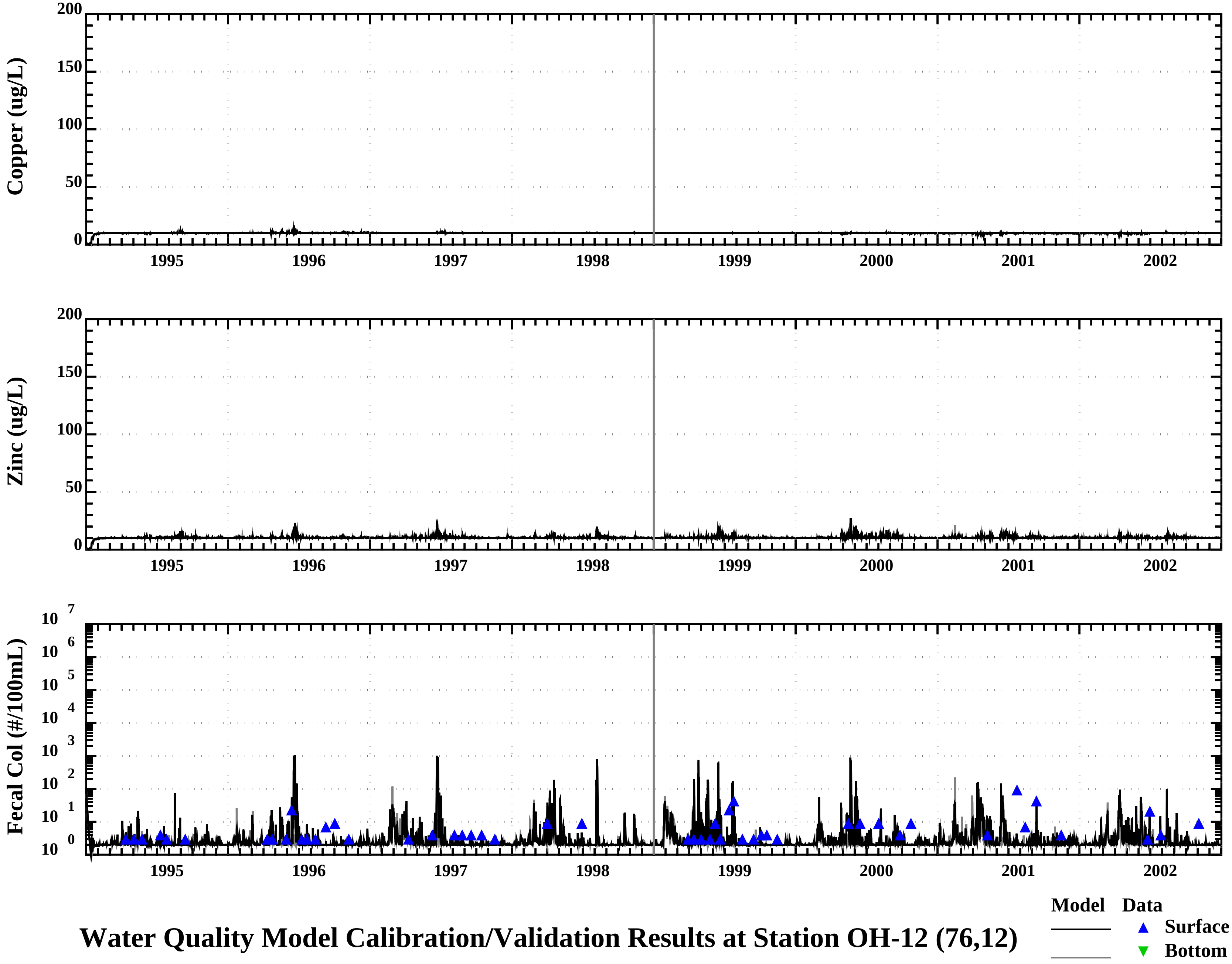
Water Quality Model Calibration/Validation Results at Station OH-12 (76,12)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 4:59



Water Quality Model Calibration/Validation Results at Station OH-12 (76,12)

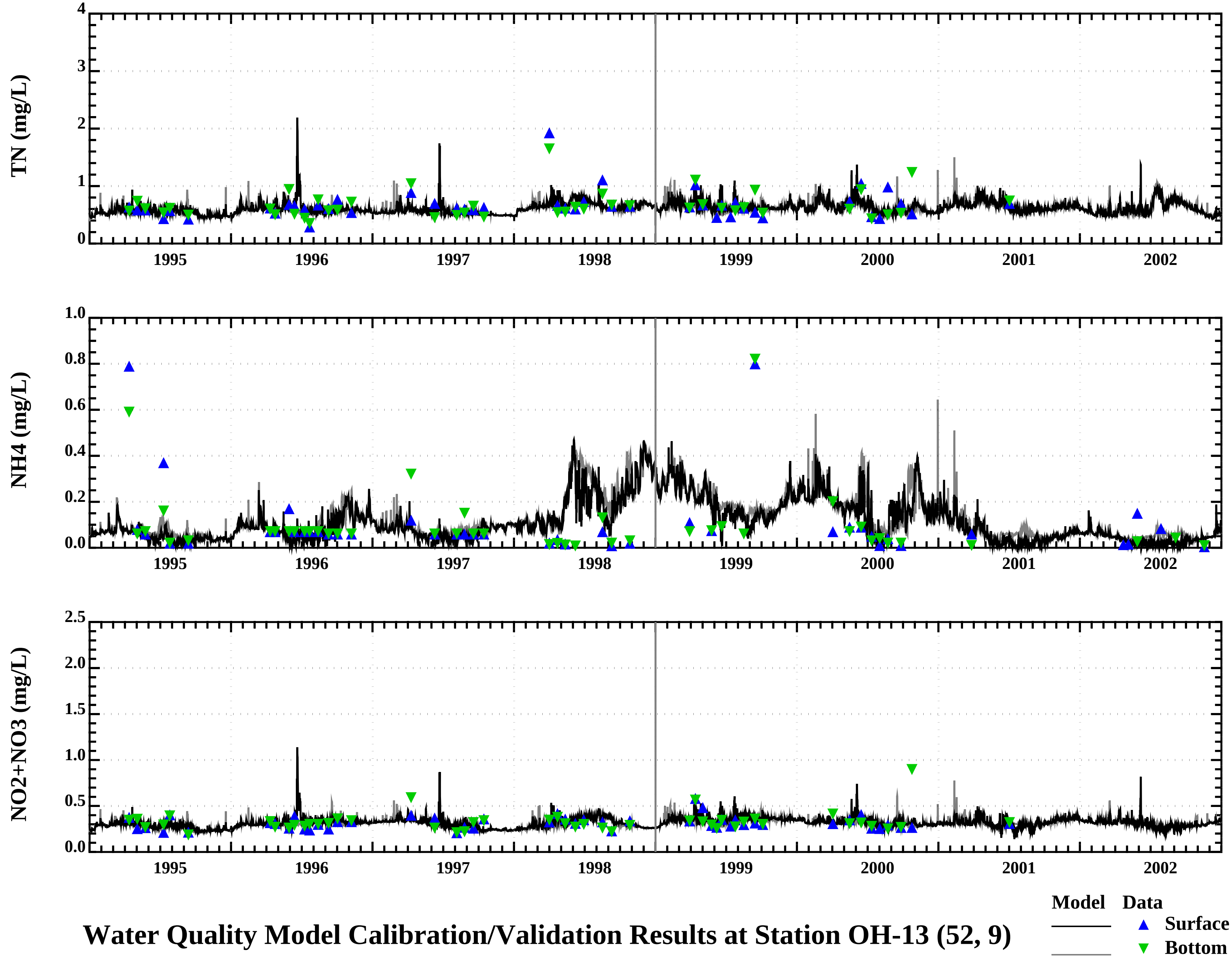
/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 4:59



Water Quality Model Calibration/Validation Results at Station OH-12 (76,12)

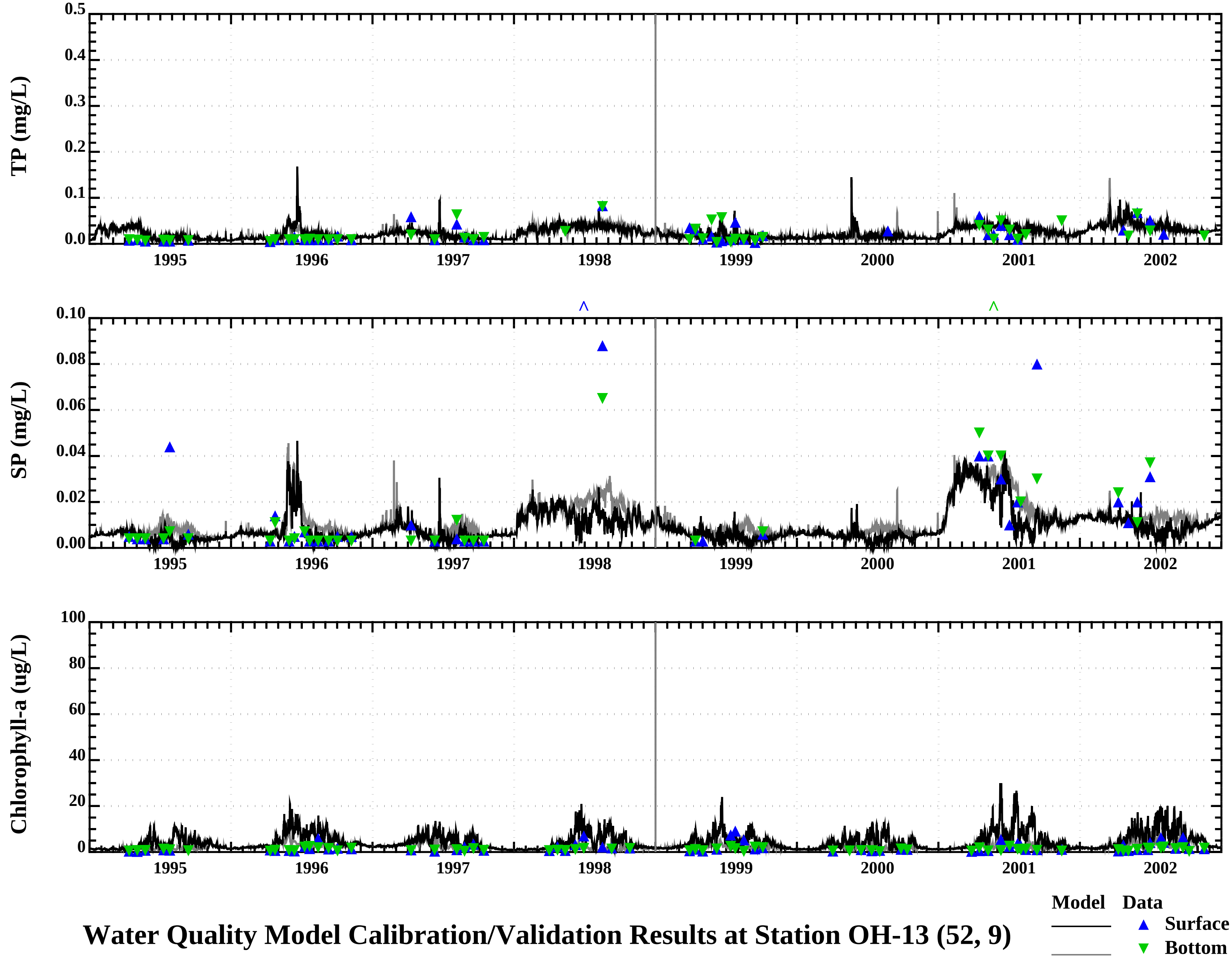
/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp

DATE: 12/03/2007 TIME: 10: 4:59



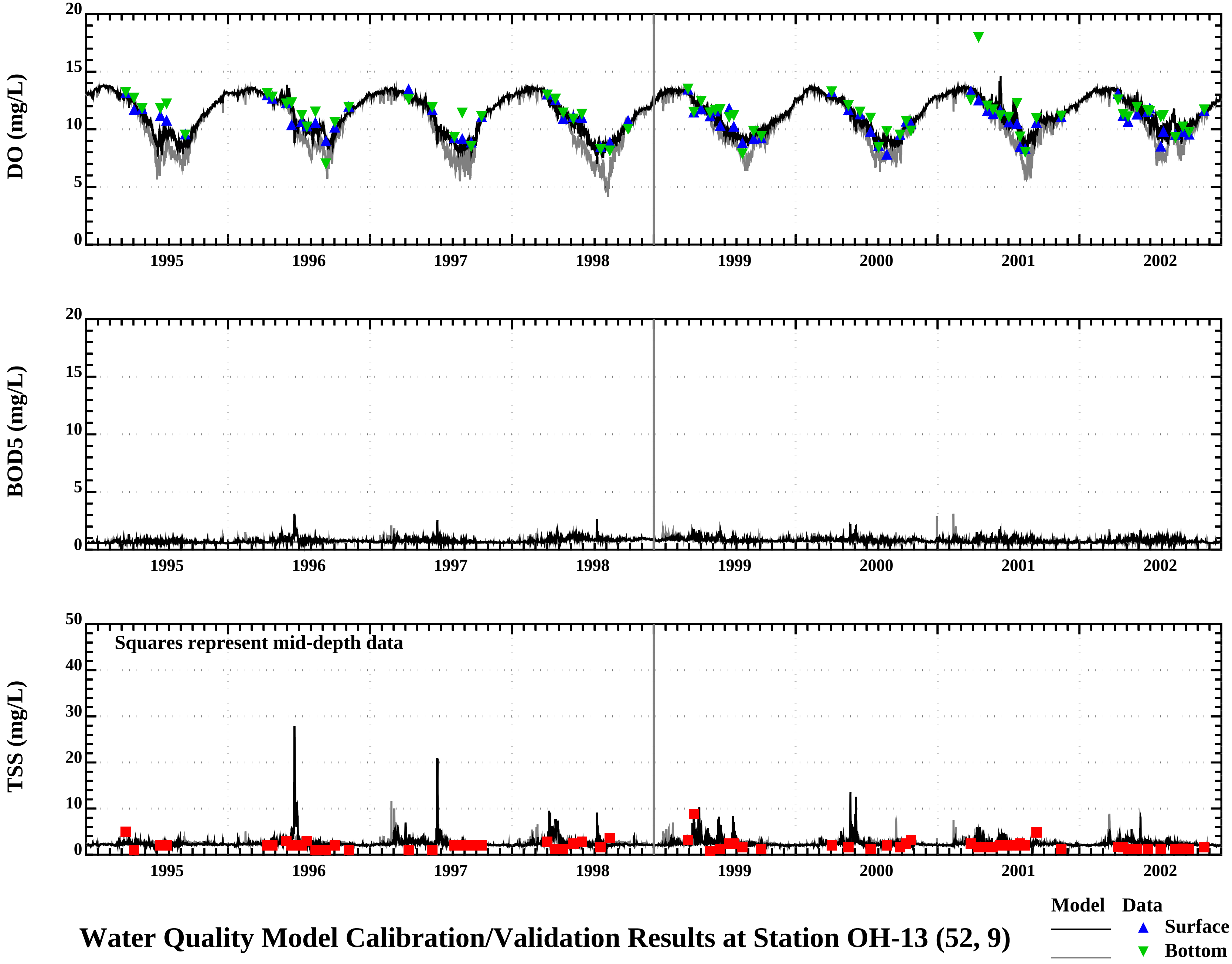
Water Quality Model Calibration/Validation Results at Station OH-13 (52, 9)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 6: 3



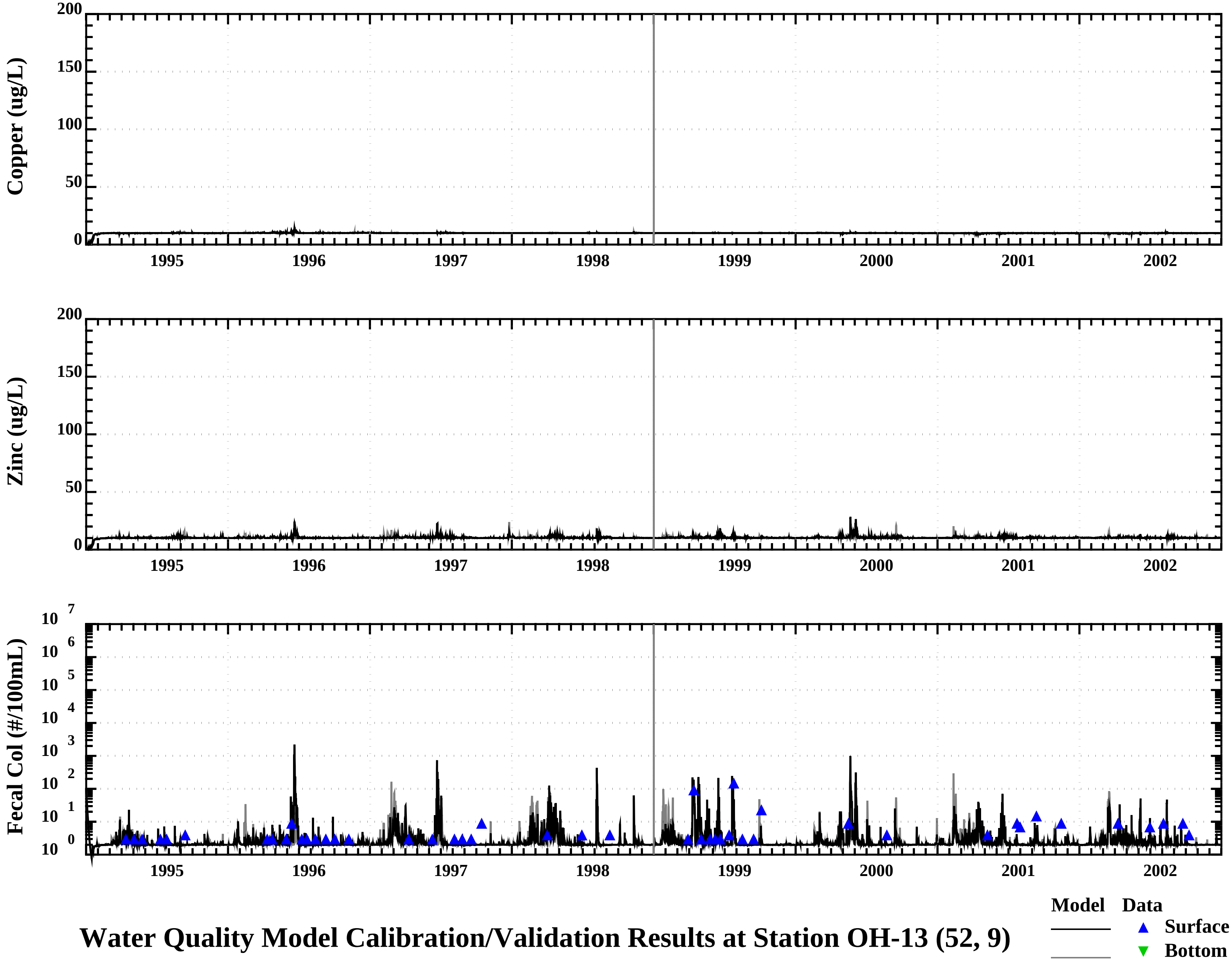
Water Quality Model Calibration/Validation Results at Station OH-13 (52, 9)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 6: 3



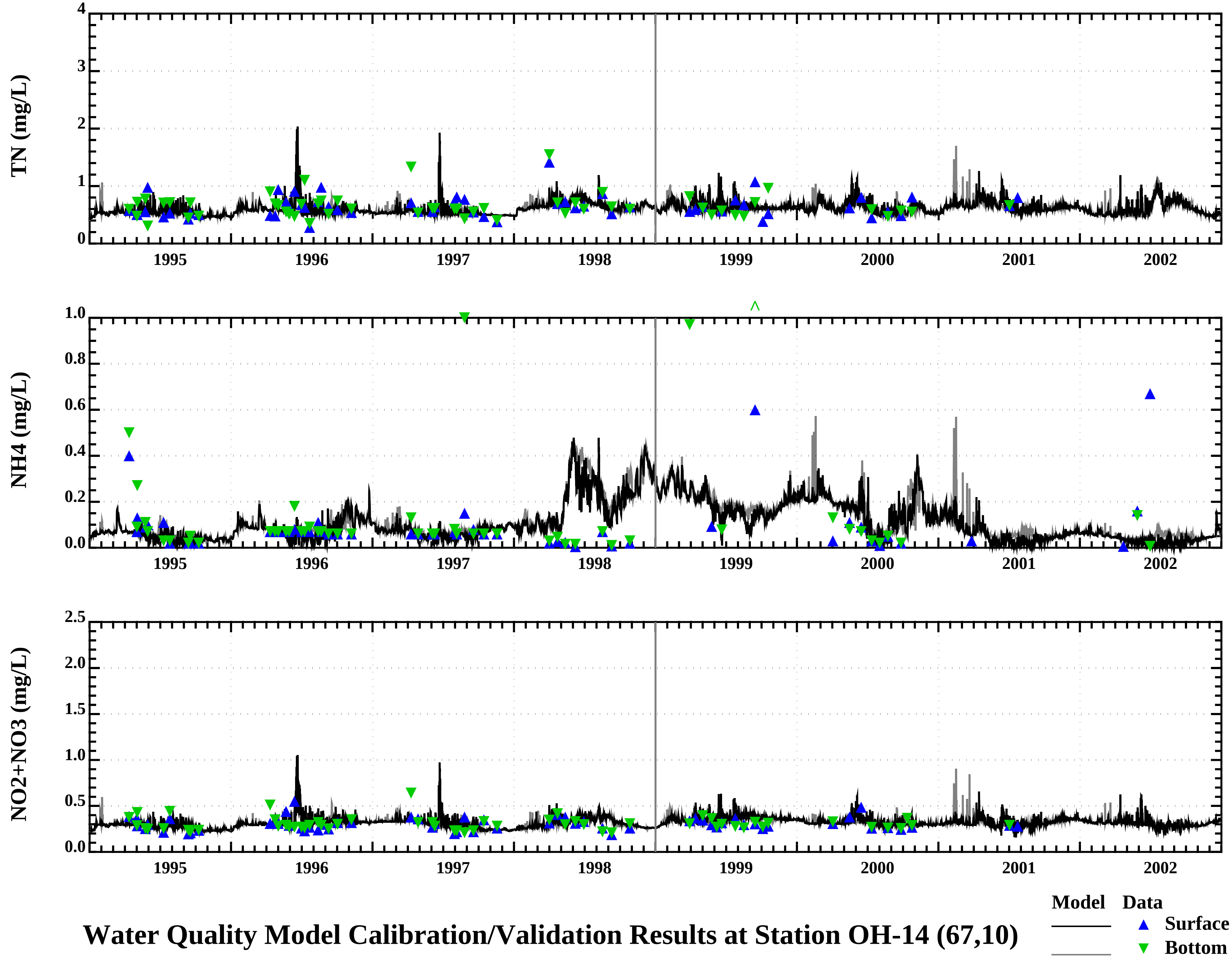
Water Quality Model Calibration/Validation Results at Station OH-13 (52, 9)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 6: 3



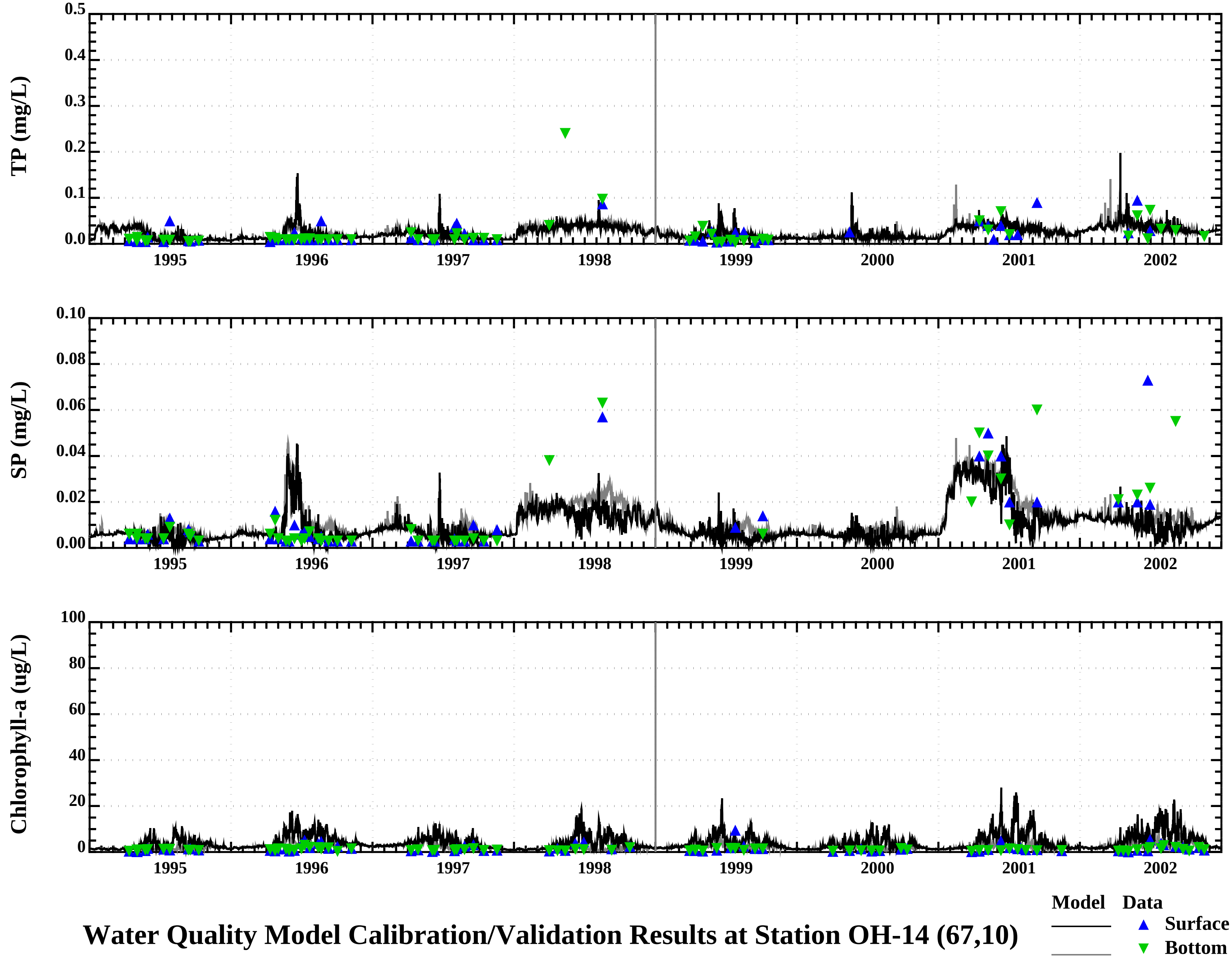
Water Quality Model Calibration/Validation Results at Station OH-13 (52, 9)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 6: 3



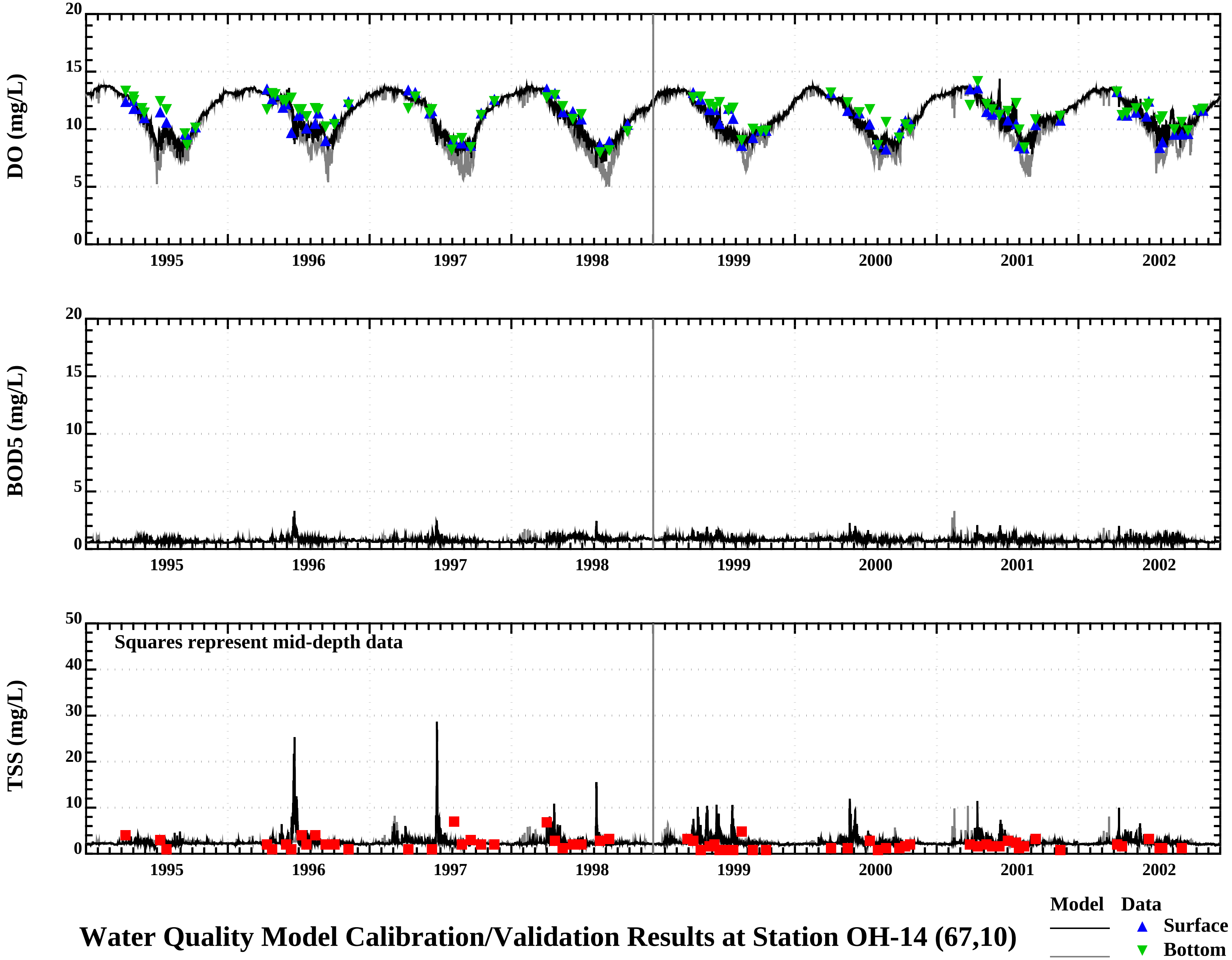
Water Quality Model Calibration/Validation Results at Station OH-14 (67,10)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 7: 7



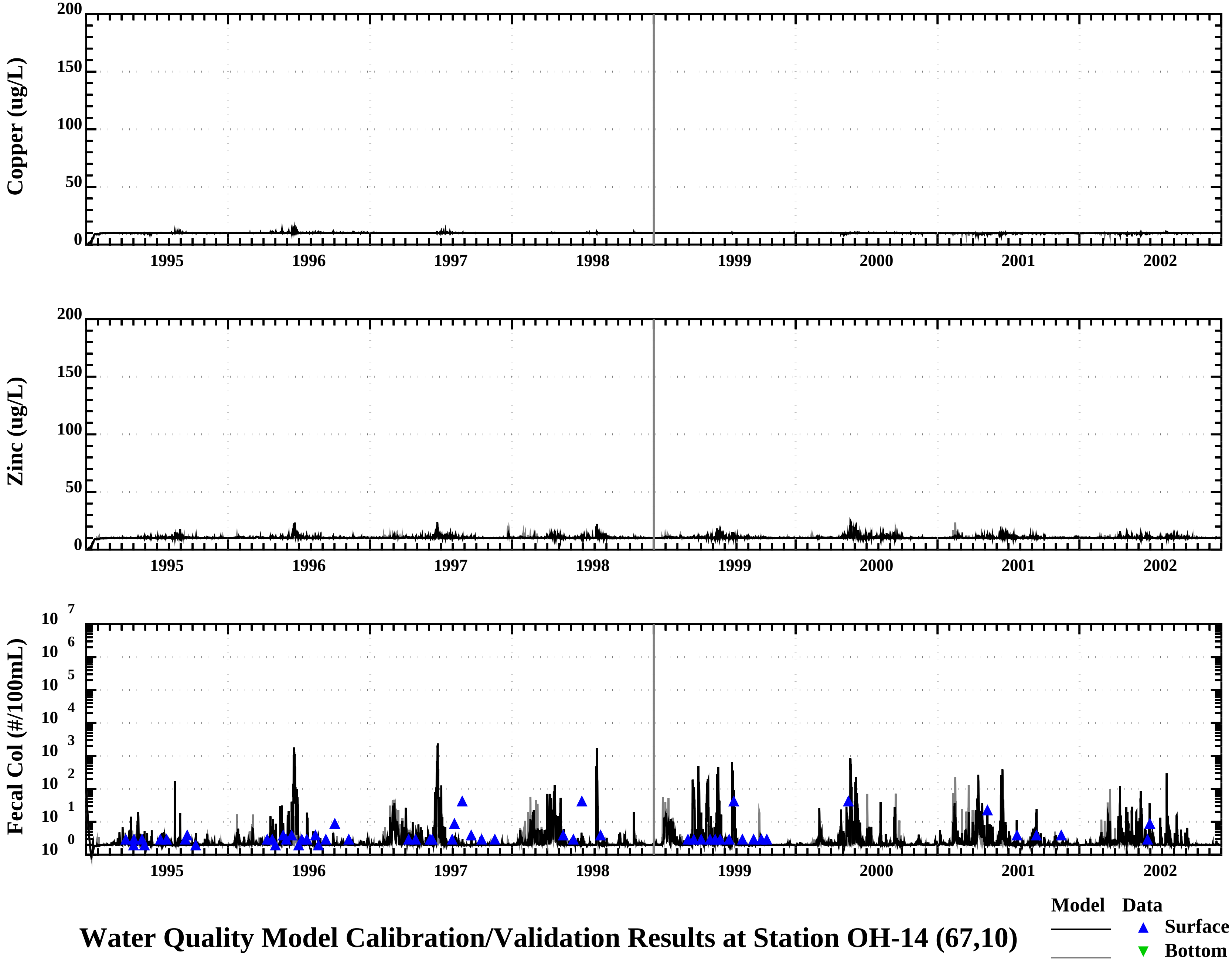
Water Quality Model Calibration/Validation Results at Station OH-14 (67,10)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 7: 7



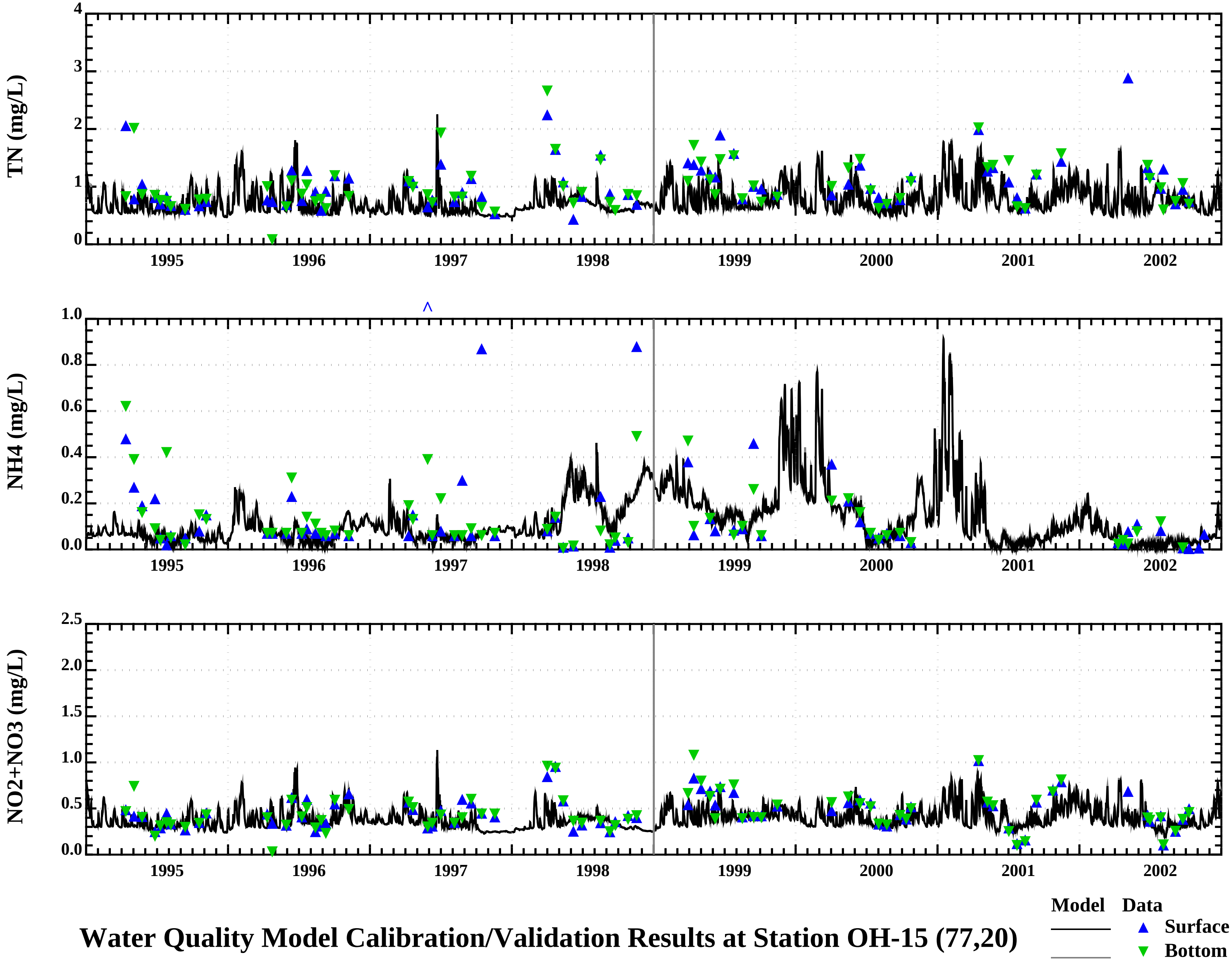
Water Quality Model Calibration/Validation Results at Station OH-14 (67,10)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 7: 7



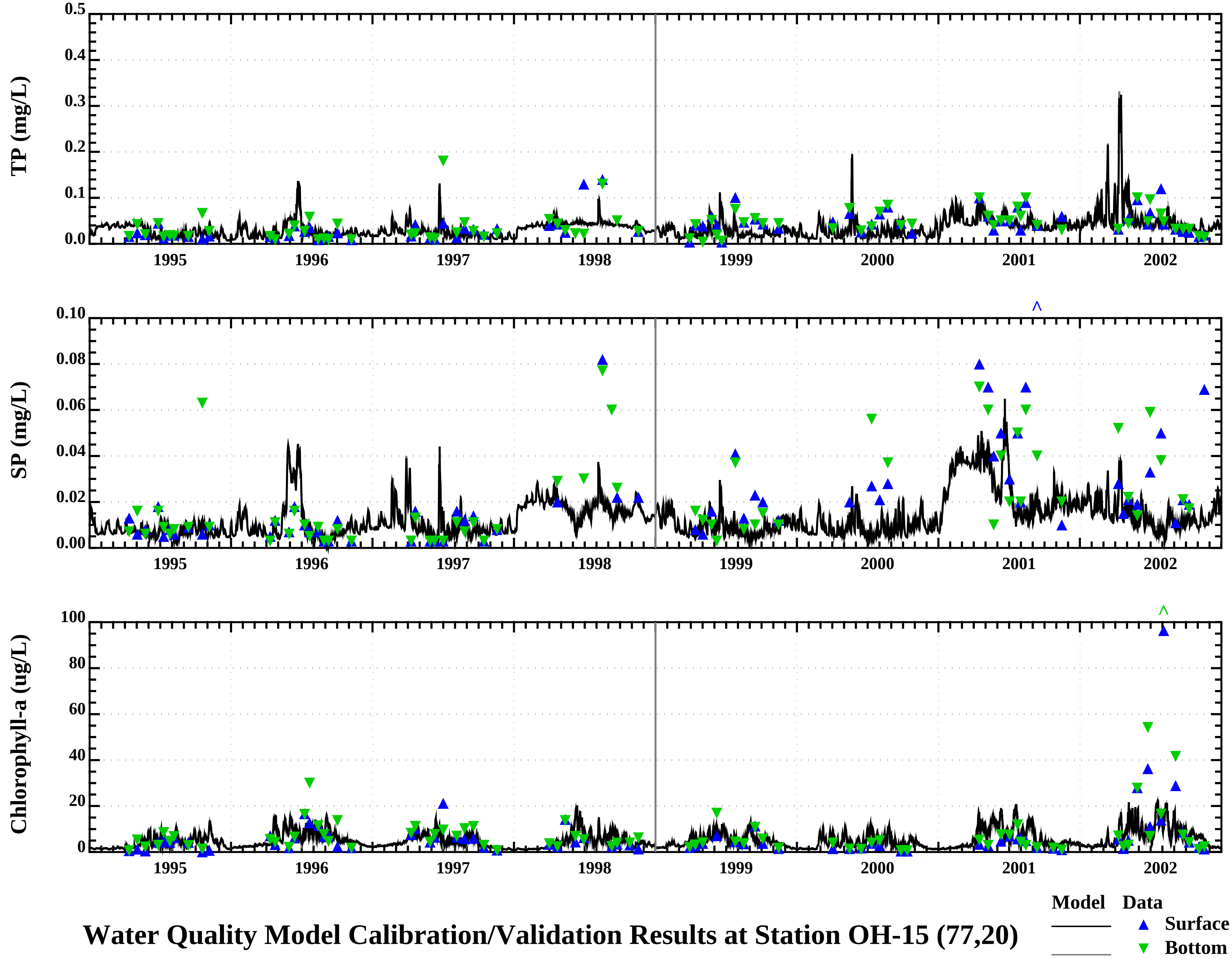
Water Quality Model Calibration/Validation Results at Station OH-14 (67,10)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 7: 7



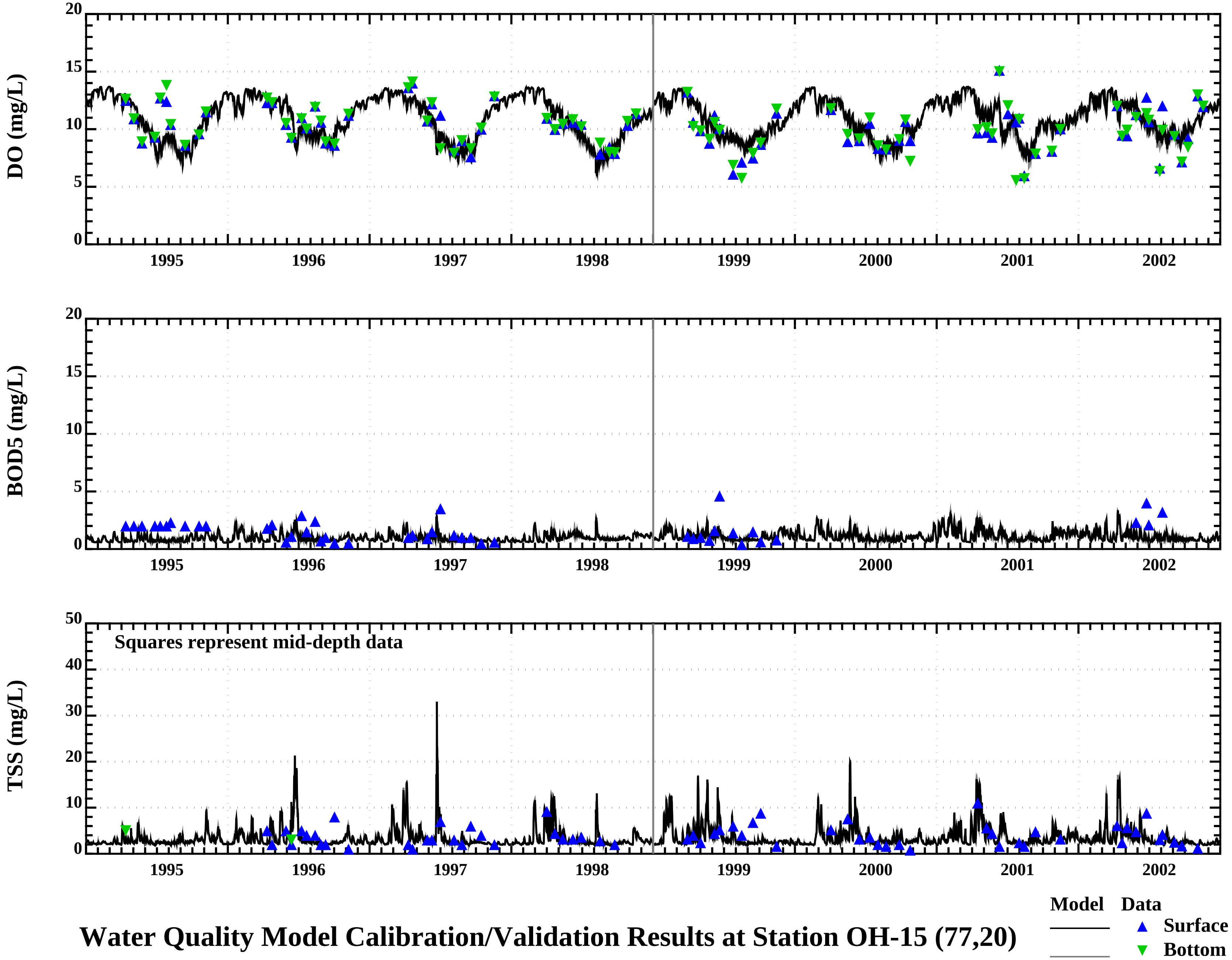
Water Quality Model Calibration/Validation Results at Station OH-15 (77,20)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 8:11



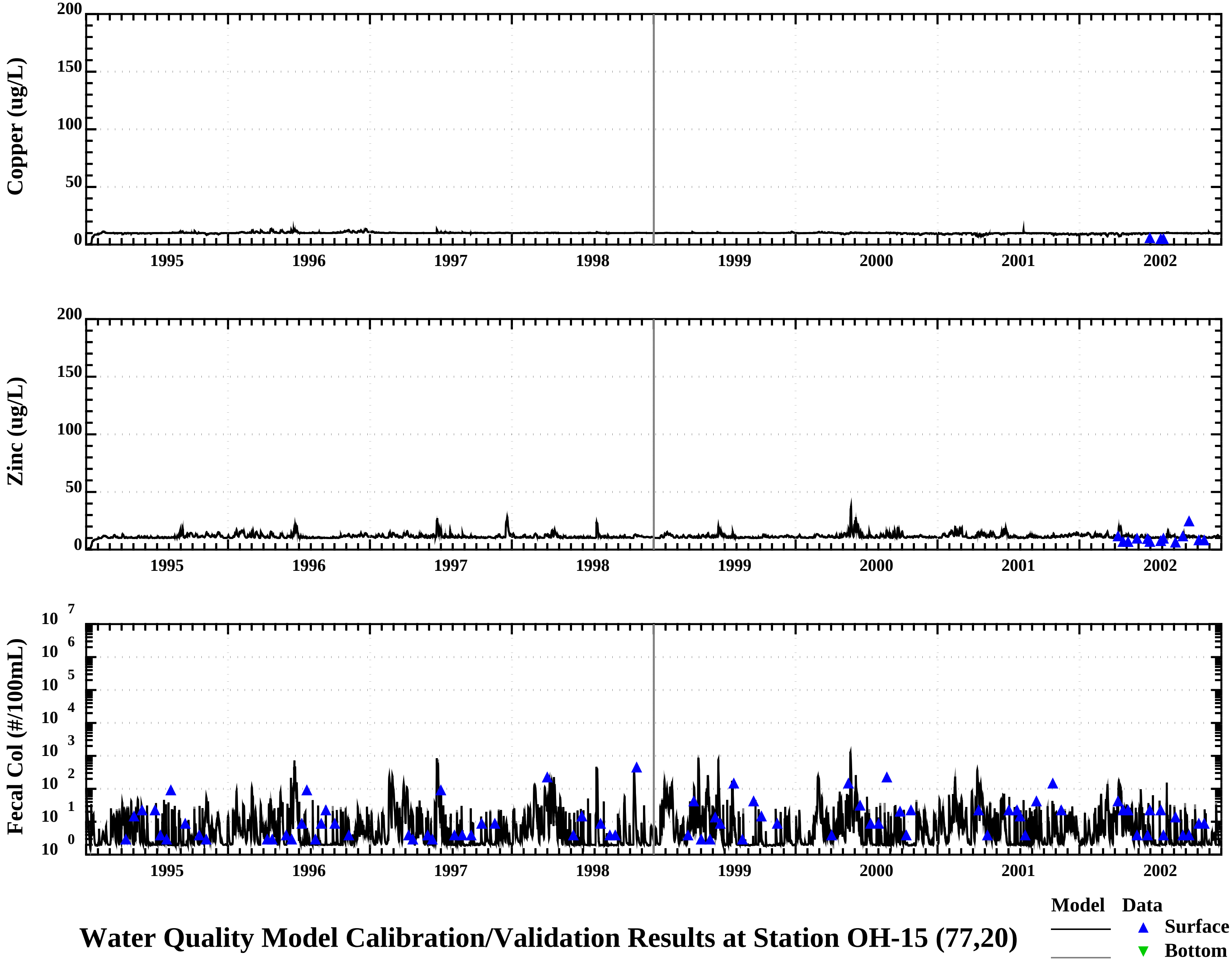
Water Quality Model Calibration/Validation Results at Station OH-15 (77,20)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 8:11



Water Quality Model Calibration/Validation Results at Station OH-15 (77,20)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 8:11



Water Quality Model Calibration/Validation Results at Station OH-15 (77,20)

/coral3/hntb0020/RCA_2020/PLOT/ohwqp-8y2.gdp
DATE: 12/03/2007 TIME: 10: 8:11