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Water Quality Model of F.E. Walter Reservoir and the Lehigh River : Evaluating the effects of changing operational pool heights and release scenarios on downstream fisheries conditions and recreational opportunities in the Lehigh River Phase II

Executive Summary

The US Army Engineer District, Philadelphia (NAP) requested the assistance the US Army Engineering Research and Development Center (ERDC) to develop a numerical model of the Lehigh River system including F. E. Walter Reservoir, Beltzville Reservoir, approximately 45 miles of the Lehigh River below F. E. Walter Reservoir, and approximately 4.5 miles below Beltzville Reservoir to the confluence of the Lehigh River. F. E. Walter Dam is located five miles upstream of White Haven, Pennsylvania, on the Lehigh River. Flood control was the authorized purpose for the reservoir. Later, recreation was added as an authorized purpose but is secondary to flood control operations. The reservoir operation is historically run-of-river.

During Phase I of the study CE-QUAL-W2 was calibrated for temperature, flow, and stage for the Leigh River study area. The model was calibrated and verified on two very different water years. Calibration was performed for 2001 a dry water year, and verification was performed on 2003 a wet water year. Temperature calibration results for 2001 for all stations in F. E. Walter, Beltzville, and Lehigh River were within the target AME for temperature and were considered acceptable – most predicted temperature values were within 1 ^{o}C or less of observed. In the 2003 verification simulation, boundary conditions for temperature and flow were lacking on tributaries to the Lehigh River. Consequently, tributary boundary data for 2003 were set using both reservoir temperature inflow data observed at F.E. Walter and Beltzville depending on location of a tributary to the reservoirs. Flow values for the tributaries were estimated from flow values measured in the Lehigh River. Having no boundary conditions for the tributaries, did not affect verification of reservoir temperatures since boundary data were available at the reservoir inflow station. However, in the Lehigh River section of the grid, model results compared less favorable to observed because of the use of estimated data. In spite of data shortages, temperature results were within the target AME values most of the time and percent cumulative distribution plots showed most temperature ranges being correctly predicted for both years. With favorable results for calibration and verification, the model is a good management tool to test scenarios of operational changes to in-pool and downstream temperatures in the Lehigh system. The model quite accurately captures the physics of both reservoirs and the riverine sections. Any alteration in the physics should be predicted with a high degree of accuracy.

During Phase I, six scenario simulations were run. These scenarios were:

- Scenario 1 operated with 2008 reservoir releases with no modifications to release structure (NoMod) and water surface elevation (WSEL) at 417.71 meters (m) or 1370 feet (ft)
- Scenario 2 operated with 2008 reservoir releases with a selective withdrawal structure (SW) and WSEL at 417.71 m (1370 ft)
- Scenario 3 operated with “Fisheries only” reservoir release goals with NoMod and WSEL at 417.71 m (1370 ft)
- Scenario 4 operated with “Fisheries only” reservoir release goals with both NoMod and SW and WSEL at 424.56 m (1392 ft)
- Scenario 5 operated with “Maximizing whitewater events” while augmenting flow for fisheries during non-whitewater release goals with NoMod and WSEL at 417.71 m (1370 ft)
- Scenario 6 operated with “Maximizing whitewater events” while augmenting flow for fisheries during non-whitewater release goals for both NoMod and SW and WSEL at 424.56 m (1392 ft)

Scenario results indicated that SC6–NoMod had the most affect to release temperatures when compared to the base case (SC1–NoMod) results. Improvements were considered a successful when release temperatures were 20 ^{o}C or less during the warmer summer period downstream of F. E. Walter. Release water temperatures for SC6–NoMod were cooler or of similar values to SC1-NoMod and the other scenario results. In contrast, SW release temperature results for most of the simulation period were usually warmer than NoMod release temperatures. This is counter-intuitive to what was expected since the purpose of selective withdrawal is to have more choices for elevations of water releases. Thus in Phase II adjustments to release elevations were considered with the intent of preserving cooler water in the hypolimnion for summer releases.

Phase II of the study focused on adding water quality and metal constituents to the CE-QUAL-W2 (W2) models already set up in Phase I for temperature and flow. Results for for water quality calibration and verification were considered acceptable given the AME values for all predicted water quality constituents and metals were within in the acceptable range of the target AME values. As discussed for temperature lack of tributary boundary conditions in 2003 predictions of water quality and metals were over or under predicted but still followed data trends of observed. Six new proposed operational scenarios jointly developed and agreed to by ACOE (Army Corps of Engineers, Philadelphia), PADCNR Parks and Pennsylvania Fish and Boat Commission (PFBC), at F.E. Walter Dam were modeled to enhance downstream and in-lake recreation and habitat. Scenario runs were conducted using initial and boundary conditions from calibration and verification runs with the new F. E. Walter reservoir releases. Also Beltzville Reservoir maintained the same reservoir release for the scenario runs that were modeled during 2001 calibration and 2003 verification runs. The new scenarios runs are:

- Scenario 1 can be described as “Fisheries only, with selective withdrawal to the dam” and is designed to maximized benefits to downstream fisheries. This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360, and 1380 ft and WSEL at 424.24 m (1392 ft).
- Scenario 2 can be described as “Maximizing whitewater events” while augmenting flow for fisheries during non-whitewater release goals with 2010 release schedule. This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360 and 1380 ft and WSEL at 417.71 m (1370 ft).
- Scenario 3 can be described as “Maximizing whitewater events” while augmenting flow for fisheries during non-whitewater release goals with 2010 release schedule. This scenario operated without a selective withdrawal structure (SW) with portals at elevations 1265, and 1297 ft and WSEL at 417.71 m (1370 ft).
- Scenario 4 goals are to provide whitewater releases on alternating weekends from in May and June, every weekend July through September; create optimal in-lake spawning areas in May and June by limiting the pool fluctuations to 5 feet; and maximize the benefit to cold water fisheries downstream by augmenting flows between July 1 and September 30 by a minimum of 50 cfs with the cooler water. This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360 and 1380 ft and WSEL at 424.56 m (1392 ft).
- Scenario 5 is based on the 2010 release schedule with outflow thermal targets as per Chapter 93 CWF thresholds. This operation was for producing and sustaining a fishery tailwater while satisfying whitewater interests. This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360, 1380, 1400, and 1420 ft with initial WSEL at 438.42 m (1438 ft).
- Scenario 6 is based, in part, on the 2010 release schedule. The intent is to investigate if periodic large pulses of reservoir releases, similar to the 2010 whitewater releases, can keep enough river rock substrate wetted to maintain downstream thermal target at Tannery Bridge of 68 ^{o}F (20 ^{o}C). This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360, 1380, 1400, and 1420 ft with initial WSEL at 438.42 m (1438 ft).

During the Phase II study new features added to W2 were implemented which helped improve the likelihood of maximizing the benefits of selective withdrawal to improve downstream temperatures. With the new optimization routine in W2 V3.7, many simulations were made with quicker turn around to help make critical decision on reservoir operations. Criteria for judgment of improvement from one scenario to the other was again whether release temperatures were maintained at 20 ^oC (68 ^oF) or less during the warmer summer period downstream of F. E. Walter. Phase II scenarios 5 and 6 met these criteria as far downstream as LH08 and LH10, respectively. Meaning that scenario 5 river temperatures were maintained at 20 ^oC (68 ^oF) or less as far downstream as station LH08 in 2001 and scenario 6 river temperatures were maintained at 20 ^oC (68 ^oF) or less as far downstream as LH10 in 2003. Similar to results in Phase I, temperature results at stations below these were dominated by tributary inflow temperatures reducing influence from F. E. Walter dam releases. Downstream of LH08, differences in water temperature between the scenarios become minimal because tributary flows become the dominating factor for Lehigh River temperatures. As expected, water temperatures show the greatest differences immediately downstream of the dam before tributary influences begin to monopolize. Using scenario results from these simulations, the Philadelphia District will be able to make informed decisions in regard to adjustments to reservoir operations to help improve fishery habitat and boating recreation within and downstream of F. E. Walter Reservoir.

An overall statement can be made that changes to water quality releases from optimized runs are mostly attributed to release port location (i.e., actual layers release water is being pulled from) and the degree of stratification of water quality profiles. Release results for PO4, TP, TOC, and TSS for each scenario run are not very different from one scenario to the next. This is because almost isochemical conditions are present through the water column for these constituents for each scenario after Julian Day 225; thus scenario results show very little difference since water quality concentrations would be similar at any elevation released. Except for DO, most of the concentration differences for these water quality constituents at station LH02 are not detrimental to living resources downstream of F. E. Walter Reservoir. Decline in DO concentrations is noticeable in results for scenarios 5 and 6 for both runs using original and optimized release flows. Values of DO in 2003 can be as low as 2mg/L which stress living resources. From the 2003 profile results, this behavior is attributed to the formation of a DO minimum in the area of the release port elevations in the epilimnion. This may have formed through mortality, respiration, and decay from increased chlorophyll *a*, TOC and total suspended solids (TSS) concentrations in the area of the releases ports in the epilimnion of the reservoir. By the time water is transported from station LH02 to station LH03, DO concentrations have reaerated to levels of 7 mg/L or more. As water is transported downstream to station LH17, all concentration differences become diminished. Over all, the total metals modeled during scenario runs have concentrations that are below the levels considered to be harmful to the living resources for dissolved metal forms.

It is still recommended that for future modeling studies of F. E. Walter Reservoir, Beltzville Reservoir and riverine sections below, the District monitor inflow temperatures and water quality parameters to major tributaries and inflow points to the reservoir to improve on this calibration. W2 did extremely well at F. E. Walter, Beltzville and the Lehigh River for 2001. W2 results for 2003 were favorable in the reservoirs but lack of data from tributaries entering into the Lehigh River below F. E. Walter caused predicted values to be less favorable compared to results in 2001. As presented and discussed above, calibration/verification results were considered quite good considering tributary boundary data for 2003 used both F.E. Walter and Beltzville reservoir inflow data depending on location of tributary to the reservoirs. W2 was able to predict behavior trends of constituents if not always the exact value. AME values were within acceptable values of the target AME values. Although W2 performance is quite acceptable for this study, better boundary data to improve on this calibration would help improve model predictions and reduce the uncertainty associated with the lack of data.

1 Introduction

Background

As a continuation of the 2009 report entitled " Temperature and Flow Model of F.E. Walter Reservoir and the Lehigh River : Evaluating the effects of changing operational pool heights and release scenarios on downstream fisheries conditions and recreational opportunities in the Lehigh River," this report documents the calibration of other water quality parameters of interest for the years modeled previously (e.g., 2001 and 2003) and as well as the effects to downstream temperature from six new operation scenarios jointly developed and agreed to by ACOE (Army Corps of Engineers, Philadelphia), PA Department of Conservation and Natural Resources (PADCNR), and Pennsylvania Fish and Boat Commission (PFBC). Previous scenarios that looked at operational changes and effects to downstream temperature were:

- Scenario 1 operated with 2008 reservoir releases with no modifications to release structure (NoMod) and water surface elevation (WSEL) at 417.71 meters (m) or 1370 feet (ft)
- Scenario 2 operated with 2008 reservoir releases with a selective withdrawal structure (SW) and WSEL at 417.71 m (1370 ft)
- Scenario 3 operated with "Fisheries only" reservoir release goals with NoMod and WSEL at 417.71 m (1370 ft)
- Scenario 4 operated with "Fisheries only" reservoir release goals with both NoMod and SW and WSEL at 424.56 m (1392 ft)
- Scenario 5 operated with "Maximizing whitewater events" while augmenting flow for fisheries during non-whitewater release goals with NoMod and WSEL at 417.71 m (1370 ft)
- Scenario 6 operated with "Maximizing whitewater events" while augmenting flow for fisheries during non-whitewater release goals for both NoMod and SW and WSEL at 424.56 m (1392 ft)

Findings from the first study indicated that of all scenario runs, SC6-NoMod temperature results show the coolest water being released through the summer until around Julian Day 200 (July 19) for both years when water temperatures are above 20 ^{o}C (68 ^{o}F). This scenario run had goals of maximizing the number of white water events while augmenting flow for fisheries starting with an initial water surface elevation of 1392 ft. None of the scenario runs in Phase 1 were optimized to conserve cooler water temperatures for use later in the summer.

Objective

The US Army Corps of Engineers, Philadelphia District, in partnership with the PA Department of Conservation and Natural Resources and the PA Fish and Boat Commission, is investigating whether changes in reservoir operations (releases) and pool levels at the F.E. Walter Dam have the potential to provide additional downstream fisheries habitat improvements and enhanced recreational opportunities. If the Section 22 study demonstrates that temporary manipulation of pool levels alone cannot provide more favorable water temperature conditions downstream, then the District may evaluate permanent reallocation of storage and/or structural modifications at F.E. Walter Dam that allow selective withdrawal capabilities for improved downstream temperature control. The dam presently has bottom flood control gates used for most reservoir releases and a smaller capacity bypass system approximately 50 feet above the flood control gates.

There are a couple of objectives to complete the second Phase of this study. First, water quality and metal constituents were added to the temperature and flow CE-QUAL-W2 (W2) models set up for two reservoirs (F. E. Walter and Beltzville) and approximately 60 river miles on the Lehigh River and Pohopoco Creek. Additionally, six new proposed operational scenarios agreed upon by the study partners at F.E. Walter Dam were modeled to enhance downstream and in-lake recreation and habitat. The extent of the modeled system is the same as Phase I and extends from F. E. Walter Reservoir (including Beltzville Dam on the Pohopoco Creek) downstream to Northampton, PA, a distance of approximately 45 miles (Figure 1).

Temperature and flow are still the major concerns addressed in this Section 22 study but at the same time there is concern for other water quality parameters such as low dissolved oxygen (DO), sulfide, reduced iron and manganese. W2 models will be updated to add the potential to model these constituents for future downstream concerns. General water quality observations as a result of new scenario runs will be provided.

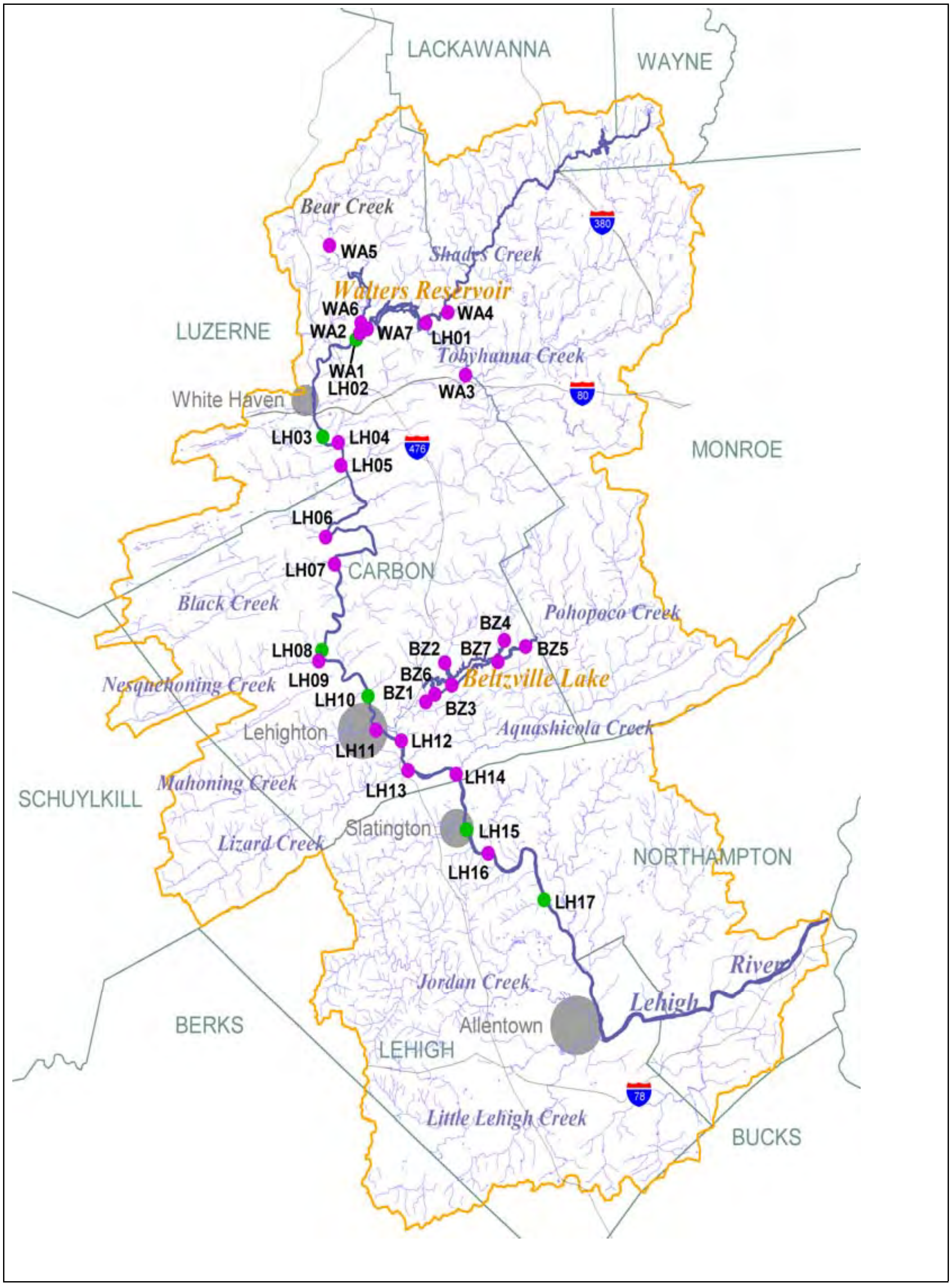

Figure 1. Study site showing temperature monitoring sites (pink indicate tributaries stations and green indicate main stem stations) on the Lehigh River

Approach

W2 was applied to F. E. Walter and Beltzville Reservoirs, 45 miles of the Lehigh River downstream of F. E. Walter Reservoir, and Pohopoco Creek downstream of Beltzville Reservoir (Figure 1). Phase 2 continued the 2007 temperature and flow model development for the Lehigh River.W2 models set up for this study have been updated to CE-QUAL-W2 Version 3.6 (W2 V3.6) and Version 3.7 (W2 V3.7), which are both versions of a two-dimensional (laterally-averaged) hydrodynamic and water quality model for simulating surface water systems, including rivers, lakes, reservoirs, and estuaries. W2 V3.6 is still being used in phase 2 but in order to use some of the new features added to W2 V3.7, the decision was made to use both versions. Several new features listed below were used and include:

1. Fish Habitat Volumes and Volume-Weighted Averages of Eutrophication State Variables (example results in Appendix A)
2. Selective Withdrawal and Volume at Specified Temperatures
3. Environmental Performance Criteria (available but not used)
4. Hypolimnetic Aeration (available but not used)

The water quality constituents available in W2 V 3.6 and W2 V3.7 to model are listed in Table 1.

Table 1
CE-QUAL-W2 V3.7 state variables

Tracer, g/m^3	Residence Time, days
Total dissolved solids, g/m^3	Coliform bacteria, #/100 ml
Arbitrary constituent, g/m^3	Suspended solids (inorganic) 1
Suspended solids (inorganic) 2	Suspended solids (inorganic) 3
Suspended solids (inorganic) 4	Suspended solids (inorganic) 5
Suspended solids (inorganic) 6	Suspended solids (inorganic) 7
Suspended solids (inorganic) 8	Ammonium nitrogen
Ortho-Phosphorus	Dissolved Silica
Nitrate+Nitrite nitrogen	Iron
Particulate Silica	Refractory dissolved organic matter
Labile dissolved organic matter	Refractory particulate organic matter
Labile particulate organic matter	Algae 1
Algae 2	Algae 3

Table 1
Concluded

Algae 4	Algae 5
Algae 6	Dissolved Oxygen (DO)
Carbonaceous biochemical oxygen	Alkalinity
Total Inorganic Carbon	Temperature

Of these constituents (Table 1), water quality constituents modeled during this study are presented in Table 2. These were selected based on observed data availability (Table 2).

Table 2
Water quality constituents modeled

Tracer, g/m^3	Ammonium nitrogen (NH3)
Total dissolved solids, g/m^3	Iron
Arbitrary constituent, g/m^3	Refractory dissolved organic matter
Ortho-Phosphorus (PO4)	Refractory particulate organic matter
Nitrate+Nitrite nitrogen (NO2+NO3)	Algae 1
Dissolved Oxygen (DO)	Carbonaceous biochemical oxygen demand (CBOD5)
Labile dissolved organic matter	Total Inorganic Carbon
Labile particulate organic matter	
Algae 2	
Alkalinity	
Temperature	

With temperature and flow calibration complete for 2001 (dry water year) and 2003 (wet water year) in the previous study, calibration of all other interested water quality constituents for these years was one focus of this study. Additionally, the Philadelphia District requested that water year 2002 also be modeled if data were available. The 2002 data set provided observed lake and inflow sampling results under pool conditions at 1392 ft as the reservoir was being operated under emergency drought storage that year and maintained an elevated pool level throughout much of the 2002 season. From data analysis, it was decided to model 2002 in a similar fashion as 2003. Both years had inflow boundary and in-pool data at F. E. Walter and Beltzville reservoirs but no boundary data for tributaries on the Lehigh River which made it difficult to calibrate the Lehigh River section of the grid.

There were limited data to model metals. Of the data that were available, an analysis was performed to key in on metals that could possibly exceed state health limits. These metals were iron, aluminum, cadmium, zinc, and manganese. Sulphur was also considered but there were no sulphur data available for the stations on the Lehigh River or for tributaries of the Lehigh River. Metals were modeled as generic nonconservative constituents which mean they were modeled with first-order decay, oxidation/reduction, settling, and absorption. A discussion can be found in the CE-QUAL-W2 user manual for the equation representation of a nonconservative constituent and assumptions that are made (Cole and Wells, 2006). The only year where enough metal data were available to model all sections of the Lehigh River grid with confidence was 2001. Data were available at many of the stations on the Lehigh River and some of the tributaries. No metals profile data or inflow data were available at F. E. Walter and Beltzville reservoirs for this year, for this reason inflow data to these reservoirs were set using data from station LH02 for F. E. Walter and data from LH14 for Beltzville. There were two dates in 2002 at F. E. Walter and Beltzville that had profiles of metals data but no data to use as boundary conditions to the reservoirs or Lehigh River. Consequently the 2002 models were set up to model metals but metal constituents were turned off because of the lack of data.

Once the system was calibrated and verified, scenario runs were conducted using initial and boundary conditions from the calibration (2001) and verification (2003) runs with new F. E. Walter reservoir releases. Maintaining downstream temperature 20 ^{o}C (68 ^{o}F) or below was the goal of the scenario runs. A total of six scenario runs, jointly developed and agreed to by ACOE (Army Corps of Engineers, Philadelphia), PADCNR and Pennsylvania Fish and Boat Commission (PFBC), were made for each year and included:

- Scenario 1 can be described as “Fisheries only, with selective withdrawal to the dam” and is designed to maximized benefits to downstream fisheries. This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360, and 1380 ft and WSEL at 424.24 m (1392 ft).

- Scenario 2 can be described as “Maximizing whitewater events” while augmenting flow for fisheries during non-whitewater release goals with 2010 release schedule. This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, and 1360 ft and WSEL at 417.71 m (1370 ft).

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- Scenario 5 is based on the 2010 release schedule with outflow thermal targets as per Chapter 93 CWF thresholds. This operation was for producing and sustaining a fishery tailwater while satisfying whitewater interests. This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360, 1380, 1400, and 1420 ft with initial WSEL at 438.42 m (1438 ft).

- Scenario 6 is based, in part, on the 2010 release schedule. The intent is to investigate if periodic large pulses of reservoir releases, similar to the 2010 whitewater releases, can keep enough river rock substrate wetted to maintain downstream thermal target at Tannery Bridge of 68 ^{o}F (20 ^{o}C). This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360, 1380, 1400, and 1420 ft with initial WSEL at 438.42 m (1438 ft).

Initially scenarios 1 through 4 were developed by the study partners. Based on results from these scenarios, guidance to develop rules for scenarios 5 and 6 were derived.

2 Input Data

Data for the water quality applications include all the data needed for temperature and flow calibration/verification simulations as well as observed data for water quality constituents of interest. Below is a review of the data required for a W2 application:

1. initial conditions
   a. bathymetry
   b. water surface elevation
   c. temperature
   d. water quality constituents
2. boundary conditions
   a. inflow/outflow
   b. temperature
   c. water quality
   d. meteorology

These data are used to set initial conditions at the start of a model run and to provide time-varying inputs that drive the model during the course of a simulation. Additional data such as outlet descriptions, tributary and withdrawal locations, etc., are also required to complete the physical description of the prototype. Table 3 contains location of many of the tributaries included in the model set up, observed data locations in the Lehigh River as well as in-pool and boundary data for F. E. Walter and Beltzville. In-pool data including water surface elevations, temperatures, and water quality constituent concentrations are also required during model calibration in order to assess model performance.

Distinction between initial and boundary conditions and in-pool data is made to help users understand importance of data and how it affects model results. In-pool data have no effect on model performance - they are used only to assess model performance. Initial and boundary conditions are of greater importance because they directly affect model performance. Unfortunately, boundary conditions are rarely determined with a frequency that most modelers deem sufficient to accurately describe the forcing functions that are responsible for observed temperature and water quality conditions. This study, at least for the calibration year, had more than adequate data for calibration. Model years 2002 and 2003 were lacking in tributary boundary conditions.

Table 3
Lehigh River Water Quality Model Sample Station Location Key

Station	PADEP Water Use	Watershed Site	Location Description	Latitude	Longitude
LH1	HQ-CWF, MF	Lehigh	Upstream of Walter Dam at confluence of Tobyhanna Creek	41.12232	75.64992
LH2	HQ-CWF, MF	Lehigh	1,000 feet downstream of Walter Dam	41.10987	75.72527
LH3	HQ-CWF, MF	Lehigh	Tannery Bridge	41.03863	75.76092
LH4	HQ-CWF, MF	Tributary	Hayes Creek	41.03472	75.74387
LH5	HQ-CWF, MF	Tributary	Sandy Run	41.01803	75.74103
LH6	HQ-CWF, MF	Tributary	Buck Mountain Creek	40.96535	75.75695
LH7	CWF, MF	Tributary	Black Creek	40.94567	75.74697
LH8	HQ-CWF, MF	Lehigh	Glen Onoko	40.88277	75.75992
LH9	CWF, MF	Tributary	Nesquehoning Creek	40.87487	75.76337
LH10	TSF, MF	Lehigh	Near Lehighton water intake	40.84948	75.70950
LH11	CWF, MF	Tributary	Downstream of sewage treatment outfall on Mahoning Creek	40.82473	75.70050
LH12	CWF, MF	Tributary	Pohopoco Creek leading from Beltzville Reservoir	40.81713	75.67272
LH13	TSF, MF	Tributary	Lizard Creek	40.79547	75.66538
LH14	TSF, MF	Tributary	Aquashicola Creek	40.79317	75.61298
LH15	TSF, MF	Lehigh	Walnutport Gauge	40.75263	75.60143
LH16	CWF, MF	Tributary	Bertsch Creek	40.73543	75.57743
LH17	TSF, MF	Lehigh	Northampton treatment plant intake	40.70180	75.51655
WA-1	HQ-CWF, MF	Lehigh	1,000 feet downstream of Walter Dam	41.10987	75.72527
WA-2	Not Considered	Reservoir Body	F.E. Walter control tower	41.11404	75.60580
WA-3	HQ-CWF	Tributary	Tobyhanna Creek Gage site upstream of Walter Reservoir at SR940	41.08472	75.60583
WA-4	HQ-CWF	Tributary	Lehigh River Gage Site upstream of Walter Reservoir at SR115	41.13028	75.62583
WA-5	HQ-CWF	Tributary	Bear Creek Upstream of the reservoir at Bear Creek Road	41.17775	75.75549
WA-6	Not Considered	Reservoir Body	Bear Creek arm of the lake	41.12160	75.71994
WA-7	Not Considered	Reservoir Body	Lehigh arm of the lake	41.11700	75.71260
BZ-1	CWF	Tributary	Downstream of dam outflow at USGS Gage on Pohopoco Creek	40.84556	75.64611
BZ-2	CWF, MF	Tributary	Pine Run upstream of the reservoir	40.87151	75.62566
BZ-3	Not Considered	Reservoir Body	Beltzville mid-lake Station	40.86000	75.61664
BZ-4	EV	Tributary	Wild Creek downstream of Pohopoco Drive upstream of the Reservoir	40.88954	75.56190
BZ-5	CWF	Tributary	Pohopoco Creek Upstream of Beltzville at SR 2011	40.88752	75.53818
BZ-6	Not Considered	Reservoir Body	Beltzville Tower Station	40.85192	75.63676
BZ-7	Not Considered	Reservoir Body	Beltzville upstream end of lake	40.87596	75.56719

HQ- High Quality Waters EV- Exceptional Value Waters MF- Migratory Fishes TSF- Trout Stocking
CWF- Cold Water Fishes WWF- Warm Water Fishes

Bathymetry

Hydraulic instability on the main stem of the Lehigh River made simulation of the complete grid difficult so for that reason the bathymetry grid was divided into five grid sections. Each grid section was modeled separately, and outflow from one section became inflow to another section. There were a total of seven water bodies making up the five sections – two reservoirs and five riverine branches. Figure 2 shows the total grid including all water bodies making up the five sections. Discussion of how the reservoir and river sections were modeled can be found in Appendix B from Tillman and Lewis-Coker (2010).

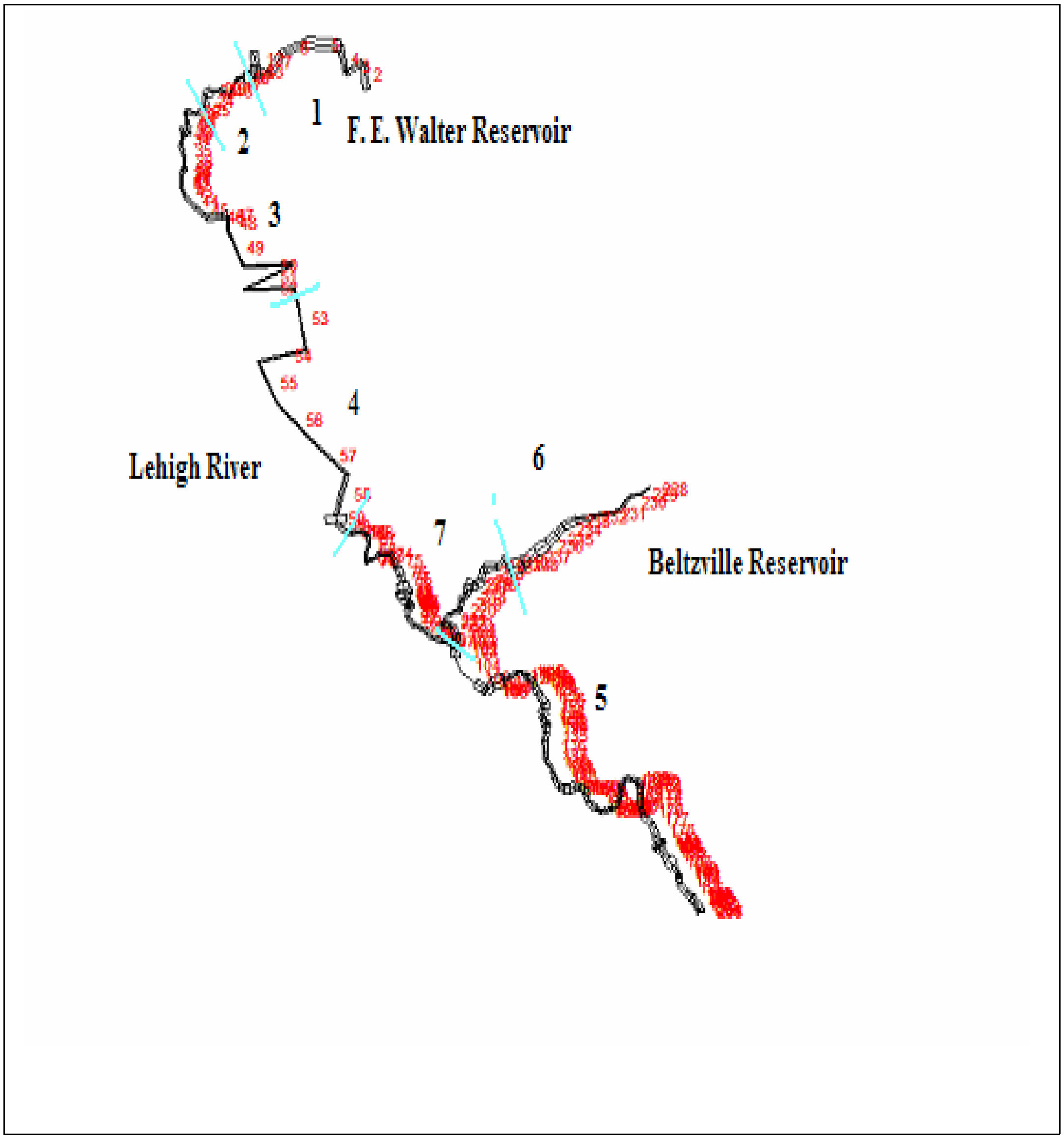


Figure 2. Grid of whole study site of Lehigh River showing seven sections modeled

Segment cell layer heights for both reservoirs and for the Lehigh River were constant and set to 0.4 meters (m) while segment lengths varied. Once the segment lengths and layer heights were finalized for each reservoir and river sections, average widths were determined for each active cell from sediment range data, TIN maps, and DAMBRK data provided by the Philadelphia District. An active cell is defined as potentially containing water. Initial bathymetry data supplied were inadequate to develop a grid for the 45 miles of Lehigh River and F. E. Walter Reservoir. The original TIN maps sent were only for the bottom 20 miles of the Lehigh River. After searching through old studies, District personnel found an old HEC-2 study and a DAMBRK model which provided helpful information in completing the grid of the river for the 25 miles below F. E. Walter Reservoir. Sediment range data for Beltzville were not provided in an Excel format needed for the model. Bathymetry was therefore estimated from flat plots of cross sections taken from a pre-dam study.

In-Pool Data

In-pool temperature and water quality data for F. E. Walter Reservoir and Beltzville Reservoir were received from the U. S. Army Engineer District, Philadelphia. Monthly or bi-monthly profile data were collected and provided for the years 2001 through 2007. Data were provided for stations WA2, WA6 (Bear Creek) and WA7 at F. E. Walter Reservoir and for stations BZ06, BZ03, and BZ07 at Beltzville (Figure 1). For the calibration year 2001, temperature and water quality profile data were available for comparison of model predictions for the dates July 18, August 9, September 27, and October 23 which corresponds to the calibration period. Calibration period was limited by the period tributary stations along the Lehigh River were monitored. Likewise, profiles for the verification year (2003) were available monthly for the dates June 10, July 16 and August 13 at F. E. Walter and June 11, July 17, August 14, and September 25 at Beltzville.

Initial Conditions

The following options are available for setting initial conditions in the model:

1. initialize all cells in the grid to a single value
2. initialize all cells in the grid based on vertical variations
3. initialize all cells in the grid based on vertical and longitudinal variations

For the calibration/verification years, simulation start date and initial conditions at each reservoir were set to the first date that data were available for both boundary and initial conditions. For calibration, this date was June 20, 2001, and for verification, this date was May 1, 2003. To set initial conditions in 2001, option 2 was used at F. E. Walter Reservoir to set temperature and option 1 to set all other water quality constituents model. At Beltzville in 2001, option 1 was used to set temperature and all other water quality constituents except DO which used option 2. In 2003 at F. E. Walter, initial conditions for temperature used option 2 and all other water quality constituents used option 1. Finally in 2003 at Beltzville, initial conditions were set for temperature using option 3 and option 1 for all other water quality constituents. Temperature and water quality concentration for all riverine sections were initialized using option 1 for both years.

Boundary Conditions

Meteorology

Data required by W2 for surface heat exchange were air temperature, dew point temperature, wind speed and direction, cloud cover, and solar radiation. Meteorological variables provided by the District were air temperature, relative humidity, wind speed, wind direction, and solar radiation. Hourly meteorology data were provided by the Philadelphia District at F. E. Walter Reservoir and Beltzville Reservoir for the simulation period during the calibration year, 2001. Since data at both reservoirs were only taken for half the simulation period, meteorological data for the verification year (2003) were combined into one data set. For instance, meteorological data at F. E. Walter Reservoir were measured from March through July while data at Beltzville Reservoir was measured from July through October. Hence to have data for the entire simulation period, data were combined into one file. Meteorological data for both model years were also obtained from the U.S. Air Force 14th Weather Squadron for Allentown, PA to supplement the District data since all variables needed by W2 were not provided. Cloud cover values from the Allentown, PA station were combined with data provided by the District to complete meteorological data requirements. For the 2002 simulation year meteorological data were not available from either project, thus data from Allentown, PA were used in all modeled sections of the study area. Additionally, dew point temperature values were not provided but were estimated from relative humidity using the equations:

$$e_{sat} = 4.596e^{\frac{17\ 27*T_{air}}{237\ 3+T_{air}}} \qquad \text{Eq. 1}$$

Where: T_{air} = air temperature (Celcius)

e_{sat} = saturation vapor pressure,

$$e_{air} = \frac{R_h * e_{sat}}{100} \qquad \text{Eq. 2}$$

Where: R_h= relative humidity

and

$$T_d = \frac{273.3}{\left(17.27 \big/ \ln\left(e_{air} / 4.596\right)\right) - 1} \qquad \text{Eq. 3}$$

Where: T_d = dew point temperature (Celsius)

Inflows

The Philadelphia District provided calculated inflows measured every hour for the years 1999 through 2007 for both reservoirs. Reservoir inflows were calculated based on daily average outflows and changes in water surface elevations. Figure 2 shows the main reservoir inflows applied at F. E. Walter and Beltzville for calibration and verification. Because outflow values provided by the Philadelphia District were from the White Haven Lehigh River gage there may be slight error introduced from ungaged runoff since the actual gage is approximately ¾ of a mile or 1.2 kilometers (km) from the dam.

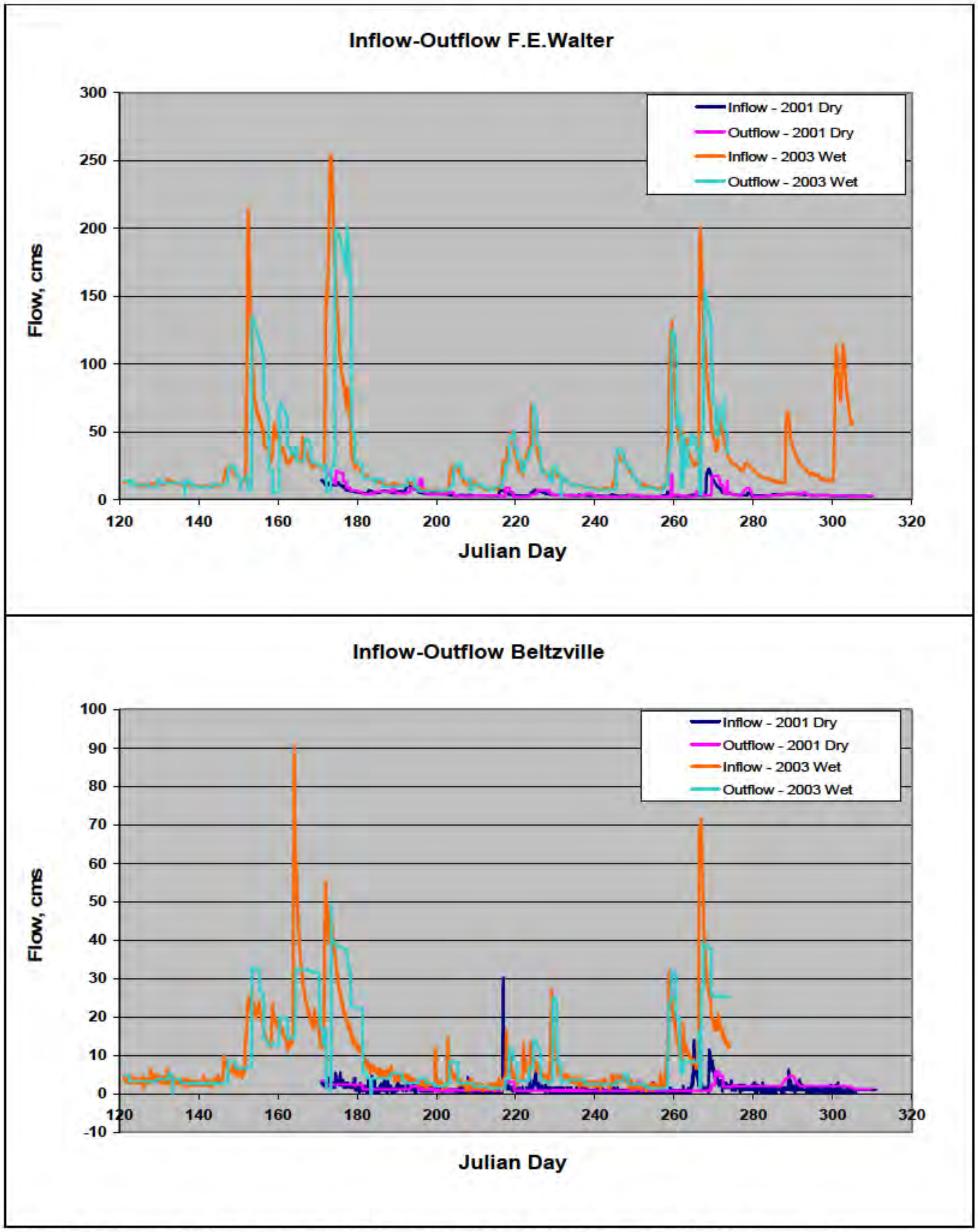


Figure 3. Reservoir inflows and outflows provided by NAP for F. E. Walter Reservoir

Tributary inflow data for the calibration year 2001 was provided by the Philadelphia District. Inflow data for the verification year 2003 were estimated from the flows at stations in the Lehigh River. For example, flows at LH03 and LH10 were known. By subtracting LH03 from LH10 the total flow from tributaries between these two stations could be could be estimated. Flows for tributaries were then found by dividing the total flow between stations by the number of tributaries contributing flow between these two stations. This introduces some uncertainty because from flow values in 2001, some tributaries contribute more flow than others. For this reason water quality boundary condition concentration will either be diluted or more concentrated based on how flow values used compare to flows that actually occurred.

Outflows

The Philadelphia District provided outflows measured every hour for the years 1999 through 2007 at F. E. Walter and Beltzville Reservoirs. Flow measured at White Haven (LH03 Figure 1) represented F. E. Walter reservoir outflow. The majority of the releases at F. E. Walter Reservoir are made through the three flood control gates. These gates are 5'8" by 10'. The intake invert elevation is 1250.0 ft or 381.13 m. The bypass system has two portals that are 2'by 4' and their invert elevation is 1297 ft NGVD. The bypass system can discharge about 300 cfs. During the years modeled, only the flood control gates were operated.

Beltzville's selective withdrawal system has 8 portals at elevations 612 m, 615 m, 603.33 m, 591.67 m, 580 m, 568.33 m, 556.67 m, and 545.5 m. Records for Beltzville Reservoir indicated flow was coming from only one port, but when asked to verify this, District personnel indicated that flow was usually split equally between ports 4 and 7. Therefore, the flows provided were equally split between these ports.

Inflow Temperatures and Water Quality

The Philadelphia District provided reservoir inflow temperature and some water quality data on an hourly basis for the main branch of F. E. Walter Reservoir and Beltzville Reservoir for the years 2001 through 2007. Hourly tributary inflow temperatures along the Lehigh River were only provided for the calibration year 2001. Tributary temperatures for 2003 were set to values used at the inflows to the two reservoirs depending on the location of the tributary. For instance tributaries above river station LH10 (Figure 1) were set to the same values as inflow temperatures to F. E. Walter Reservoir and tributaries of the Lehigh River below river station LH10 were set to inflow temperatures values entering Beltzville Reservoir. Inflow water quality data to both reservoirs (Tables 4 though 7) and tributaries were provided bi-weekly or monthly depending on what was available for the years of interest. In 2001 water quality data for the main tributaries of the Lehigh River were provided and included LH04, LH05, LH06, LH07, LH09, LH11, LH12, LH13, LH14 and LH16 (See Figure 1). In 2003, there were no temperature or water quality data available on the tributaries so the assumption was made that values for tributaries above the confluence of the Pohopoco Creek and the Lehigh River were similar to inflows into F. E. Walter. In a similar manner, values for tributaries below the confluence were assumed to be the same as inflows into Beltzville. This will introduce some uncertainty but there was not enough data to develop regression equations to predict temperature and water quality on tributaries.

Table 4
Water Quality inflow data for 2001 to F. E. Walter Reservoir

JDAY	TDS	PO4	NH4	NO3+NO2	LDOM	RDOM	LPOM	RPOM	BOD	ALG1	ALG2	DO	TIC	ALK
114.50	28.00	0.05	0.10	0.11	2.42	5.65	0.91	2.13	3.00	0.06	0.06	8.96	5.00	5.00
143.50	28.00	0.05	0.10	0.41	2.45	5.72	0.88	2.06	3.00	0.03	0.03	10.23	5.00	6.00
164.50	84.00	0.06	0.10	0.11	0.45	1.04	0.22	0.51	1.00	0.03	0.03	9.48	1.00	7.00
199.50	58.00	0.05	0.10	0.11	2.46	5.73	0.88	2.05	2.00	0.03	0.03	8.79	5.00	7.00
221.50	34.00	0.05	0.11	0.20	2.46	5.75	0.87	2.03	2.00	0.04	0.04	8.41	5.00	18.00
270.50	54.00	0.06	0.10	0.20	2.54	5.93	1.46	3.40	2.00	0.05	0.05	8.50	5.00	10.00
296.50	72.00	0.07	0.10	0.20	2.35	5.49	0.98	2.29	2.00	0.02	0.02	11.04	5.00	14.00

Table 5
Water Quality inflow data for 2001 to Beltzville

JDAY	TDS	PO4	NH4	NO3+NO2	LDOM	RDOM	LPOM	RPOM	BOD	ALG1	ALG2	DO	TIC	ALK
114.00	82.00	0.06	0.10	0.21	2.44	5.69	0.81	1.90	3.00	0.10	0.10	9.63	5.00	11.00
144.00	82.00	0.05	0.10	1.03	2.47	5.75	0.82	1.92	3.00	0.06	0.06	9.63	5.00	10.00
165.00	72.00	0.05	0.10	0.11	2.47	5.75	0.82	1.92	2.00	0.05	0.05	8.10	5.00	6.00
198.00	86.00	0.11	0.10	0.51	2.06	4.80	0.69	1.60	2.00	0.74	0.74	7.14	5.00	13.00
219.00	44.00	0.07	0.10	1.30	2.47	5.76	0.82	1.92	2.00	0.05	0.05	7.08	5.00	13.00
268.00	89.00	0.28	0.10	0.90	2.41	5.62	0.80	1.87	1.00	0.15	0.15	7.82	5.00	20.00
297.00	92.00	0.07	0.10	1.30	2.48	5.79	0.83	1.93	2.00	0.03	0.03	9.03	5.00	14.00

Table 6
Water Quality inflow data for 2003 to F. E. Walter Reservoir

JDAY	TDS	PO4	NH4	NO2+NO3	LDOM	RDOM	LPOM	RPOM	BOD	ALG1	ALG2	DO	TIC	ALK
135.42	43.00	0.01	0.06	0.11	2.00	4.67	0.67	1.56	3.70	0.29	0.29	10.32	1.10	6.30
161.43	33.00	0.01	0.03	0.07	2.65	6.18	0.88	2.06	4.20	1.00	1.00	9.01	1.50	3.20
197.43	55.00	0.01	0.06	0.13	2.05	4.78	0.68	1.59	2.50	0.28	0.28	7.65	1.90	6.30
225.40	41.50	0.01	0.04	0.06	4.45	10.38	1.48	3.46	5.60	0.53	0.53	8.09	2.50	3.70
267.43	40.00	0.01	0.04	0.82	4.90	11.43	1.63	3.81	3.20	0.58	0.58	9.55	1.80	1.90
275.43	40.00	0.01	0.04	0.82	4.90	11.43	1.63	3.81	3.20	0.58	0.58	9.55	1.80	1.90

Table 7
Water Quality inflow data for 2003 to Beltzville

JDAY	TDS	PO4	NH3	No2+NO3	LDOM	RDOM	LPOM	RPOM	BOD5	ALG1	ALG2	DO	TIC	ALK
136.30	53.00	0.01	0.04	1.42	0.70	1.63	0.23	0.54	2.80	0.14	0.14	9.48	3.00	10.40
162.33	63.00	0.01	0.03	1.32	0.75	1.75	0.25	0.58	5.60	0.12	0.12	8.56	3.30	10.50
198.32	59.00	0.01	0.05	1.42	0.70	1.63	0.23	0.54	3.40	0.17	0.17	7.21	3.10	10.20
226.31	77.00	0.01	0.03	1.42	1.40	3.27	0.47	1.09	5.60	0.17	0.17	7.09	3.70	13.60
268.30	58.00	0.02	0.09	1.22	1.50	3.50	0.50	1.17	3.40	0.32	0.32	9.23	3.80	12.00
275.30	58.00	0.02	0.09	1.22	1.50	3.50	0.50	1.17	3.40	0.32	0.32	9.23	3.80	12.00

3 Calibration

The concept of calibration/verification of a model has changed in recent years. Previously, calibration was performed for a chosen year with coefficients being adjusted to give the best comparison between computed and observed data. Verification involved applying the model to another year without changing coefficients. In reality, if the results for the verification year were inadequate, both years were revisited and coefficients adjusted until an adequate fit of both years was achieved, essentially making both data sets calibration years. Including additional years for calibration further obscures the distinction between calibration and verification data sets.

Successful model application requires calibrating the model to observed in-pool and riverine water quality. If at all possible, two or more years should be modeled with widely varying hydrology and/or water quality if corresponding water quality data are available. For the Lehigh River study, data collected in 2001 were used for calibration representing an average or low flow year, and data collected in 2003 were used as verification representing a high flow year.

Calibration was accomplished through an iterative process that included; 1) running W2 and comparing model output to observed data, 2) modifying kinetic rates and parameters based upon comparison of results to observed data using statistical calculation, and 3) running the model again until model performance was satisfactory. Model performance was evaluated by comparing model output with comparison (observed) data. Two forms of graphical comparison were used: time-series plots and percent cumulative distribution plots. Time-series plots of daily-averaged model output and observed data demonstrate model performance over time and provide indications of interactions between modeled parameters. Percent cumulative distribution “less than” plots according to Miller and Freund (1985) present how the total percentage of observations that are less than a certain class boundary percentage (i.e., percentages of low to high concentrations of water quality parameters grouped by concentration level). Comparison of predicted and observed percent cumulative distribution plots can indicate how the model is performing. For instance, if predicted DO concentrations are always 10% lower than observed concentrations monitored at 5 m/L or less, this indicates that a calibration coefficient may need adjusting or a source of DO is not being accounted for in the modeling effort.

When interpreting temperature and water quality from W2, several points need to be kept in mind. First, temperature and water quality predictions are averaged over the length, height, and width of a cell whereas observed data represent values at a specific point in the reservoir or river. Second, exact times observed data were taken were not always available, so model output was taken at around 12 noon for days when collection time was not available for comparison. Third, measurement errors also exist with regards to measured depths, temperatures, and water quality. As a consequence, expecting the model to exactly match measured observations is unrealistic.

Three statistics were used to compare computed and observed in-pool and riverine observations. The mean error indicates on average how the model is doing. For example, a positive mean error indicates predictions are less than observed, and a negative mean error indicates predictions exceed observed. The equation is:

$$ME = \frac{\sum \left(\Pr edicted - Observed \right)}{number\ of\ \ observations} \qquad \text{Eq. 4}$$

The absolute mean error (AME) indicates how far, on the average, computed values are from observed values and is computed according to the following equation:

$$AME = \frac{\sum \left| \Pr edicted - Observed \right|}{number\ of\ \ observations} \qquad \text{Eq. 5}$$

An AME of 0.5 °C means that the computed temperatures are, on the average, within ± 0.5 °C of the observed temperatures.

The root mean square error (RMS) indicates the spread of how far the computed values deviate from the observed data and is given by the following equation:

$$RMS = \sqrt{\frac{\sum \left(\Pr edicted - Observed \right)^2}{number\ of\ \ observations}} \qquad \text{Eq. 6}$$

A RMS error of 0.5 °C means that 67 percent of the computed temperatures are within 0.5 °C of the observed temperatures.

Values for all model parameters adjusted to achieve calibration are included in Appendix C for model years 2001 and 2003. In this appendix, the W2 control file for each application of modeled sections of the Lehigh River will be included. A discussion of the format and each model parameter can be found in the CE-QUAL-W2 user manual (Cole and Wells, 2008).

Calibration Results and Discussion

Dates presented in many of the plots below are Julian dates. To convert back to a Gregorian Date, use Table 8 below.

Table 8
Julian day converter for Regular years:
(2001, 2002, 2003, 2005, 2006, 2007, 2009, 2010, ...)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	32	60	91	121	152	182	213	244	274	305	335
2	2	33	61	92	122	153	183	214	245	275	306	336
3	3	34	62	93	123	154	184	215	246	276	307	337
4	4	35	63	94	124	155	185	216	247	277	308	338
5	5	36	64	95	125	156	186	217	248	278	309	339
6	6	37	65	96	126	157	187	218	249	279	310	340
7	7	38	66	97	127	158	188	219	250	280	311	341
8	8	39	67	98	128	159	189	220	251	281	312	342
9	9	40	68	99	129	160	190	221	252	282	313	343
10	10	41	69	100	130	161	191	222	253	283	314	344
11	11	42	70	101	131	162	192	223	254	284	315	345
12	12	43	71	102	132	163	193	224	255	285	316	346
13	13	44	72	103	133	164	194	225	256	286	317	347
14	14	45	73	104	134	165	195	226	257	287	318	348
15	15	46	74	105	135	166	196	227	258	288	319	349
16	16	47	75	106	136	167	197	228	259	289	320	350
17	17	48	76	107	137	168	198	229	260	290	321	351
18	18	49	77	108	138	169	199	230	261	291	322	352
19	19	50	78	109	139	170	200	231	262	292	323	353
20	20	51	79	110	140	171	201	232	263	293	324	354
21	21	52	80	111	141	172	202	233	264	294	325	355
22	22	53	81	112	142	173	203	234	265	295	326	356
23	23	54	82	113	143	174	204	235	266	296	327	357
24	24	55	83	114	144	175	205	236	267	297	328	358
25	25	56	84	115	145	176	206	237	268	298	329	359
26	26	57	85	116	146	177	207	238	269	299	330	360
27	27	58	86	117	147	178	208	239	270	300	331	361
28	28	59	87	118	148	179	209	240	271	301	332	362
29	29		88	119	149	180	210	241	272	302	333	363
30	30		89	120	150	181	211	242	273	303	334	364
31	31		90		151		212	243		304		365

Calibration results will be presented in two types of plots in Figures 3 through 79. The first set will be profile plots for F. E. Walter at station WA02 (Figures 4 – 16), the station closest to the dam, and for Beltzville at station BZ06 (Figures 17 – 28) also the closest station to the dam. Time series calibration plots will be the second type of plots presented for stations LH02, LH03, LH08, LH10, LH15, and LH17 (Figures 31 - 52) on the Lehigh River. This sequence will also be presented for 2003 results. Additional reservoir station results (WA06, WA07, BZ03 and BZ07) will be found in Appendix D in PDF format. On each plot circles represent observed data while a solid line represents model results. Tables 9 through 11 include the AME target value for all observed data in the reservoirs and on the Lehigh River. The AME target value is described by Smith et al. (2010) as a good indicator of model performance. It is calculated as 10% of the range of observed data:

$$Target = (maximum\ observed - minimum\ observed) * 0.1 \qquad \text{Eq. 7}$$

Table 9
2001 Target AME values for Walter and Beltzville Reservoirs

Constituent	Walter Target AME	Beltzville Target AME
Alk	1.0	0.60
BOD	0.0	0.50
Chla	2.7	1.18
DO	0.66	0.95
NH3	0.02	0.02
NO2+NO3	0.09	0.07
pH	0.11	0.18
PO4	0.01	0.24
TIC	0.0	0.00
TOC	0.3	0.00
TDS	15.20	9.40

Table 10
2003 Target AME values for Walter and Beltzville Reservoirs

Constituent	Walter Target AME	Beltzville Target AME
Alk	0.9	1.33
BOD	0.33	0.34
Chla	0.83	0.74

Table 10
2003 Target AME values for Walter and Beltzville Reservoirs (Concluded)

DO	0.41	1.00
NH3	0.01	0.03
NO2+NO3	0.08	0.08
pH	0.13	0.12
PO4	0.001	0.002
TIC	0.2	0.6
TOC	0.91	0.24
TDS	2.6	3.2

Table 11
Target AME values for Lehigh River

Constituent	2001	2003
Alk	8.5	0.26
BOD	1.2	0.10
Chla	0.83	0.30
DO	0.94	0.34
NH3	0.15	0.02
NO2+NO3	0.42	0.05
pH	0.74	0.03
PO4	0.96	0.001
TIC	1.1	0.4
TOC	1.0	0.21

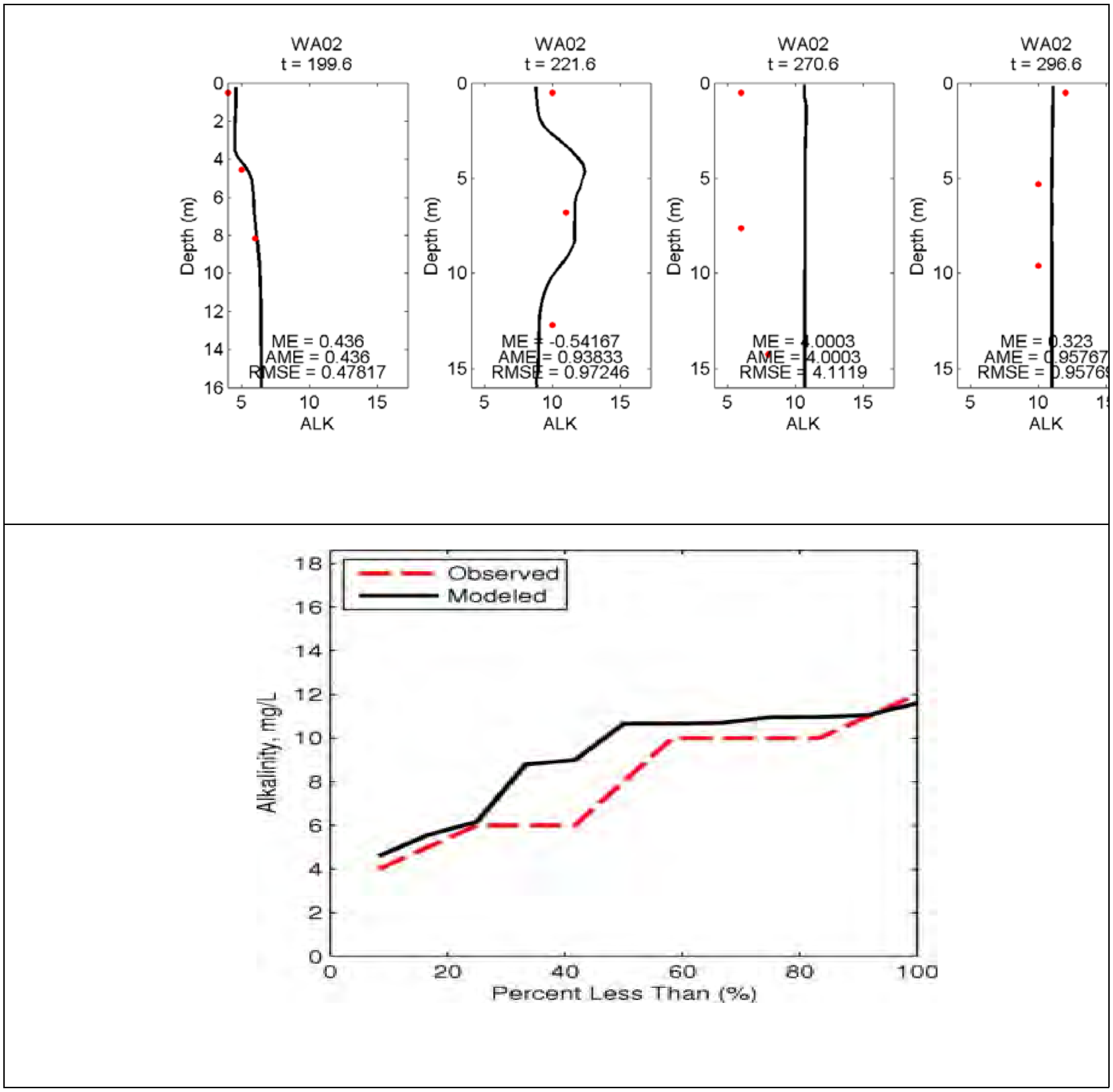


Figure 4. 2001 Calibration profile results and percent cumulative distribution plot at station WA02 for alkalinity at F. E. Walter for 4 Julian dates.

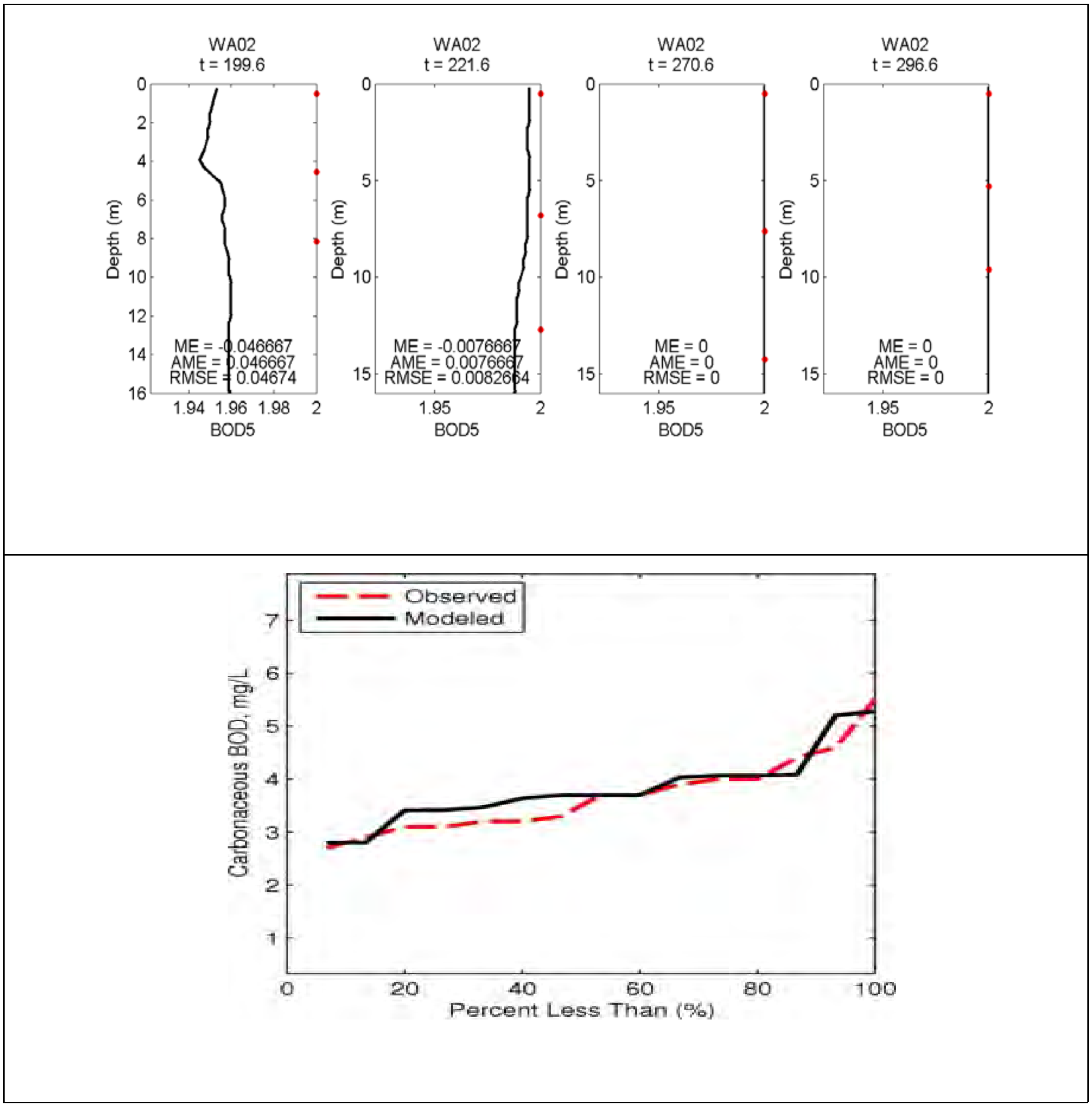


Figure 5. 2001 Calibration profile results and percent cumulative distribution plot at station WA02 for BOD5 at F. E. Walter for 4 Julian dates.

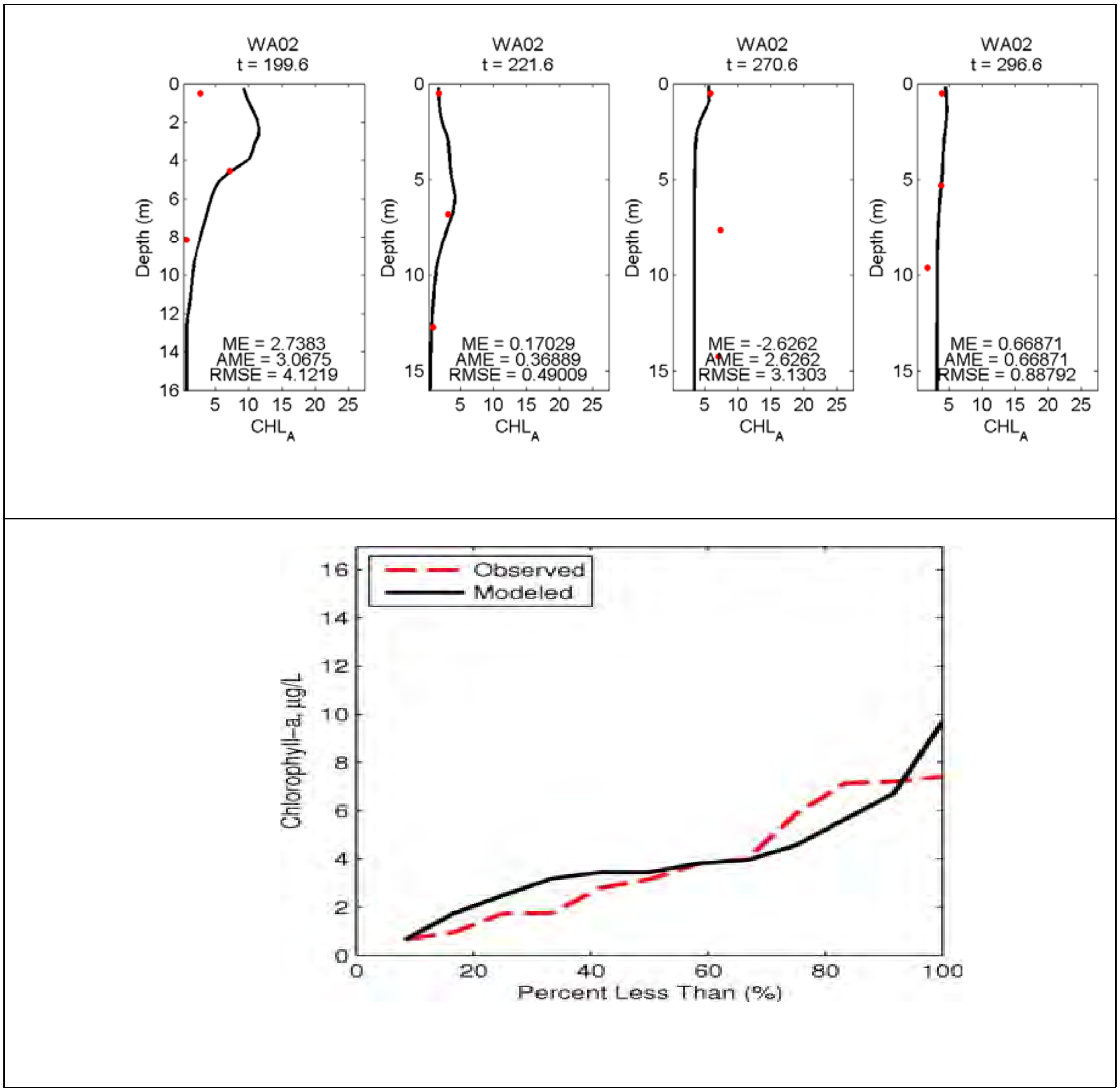


Figure 6. 2001 Calibration profile results and percent cumulative distribution plot at station WA02 for Chla at F. E. Walter for 4 Julian dates.

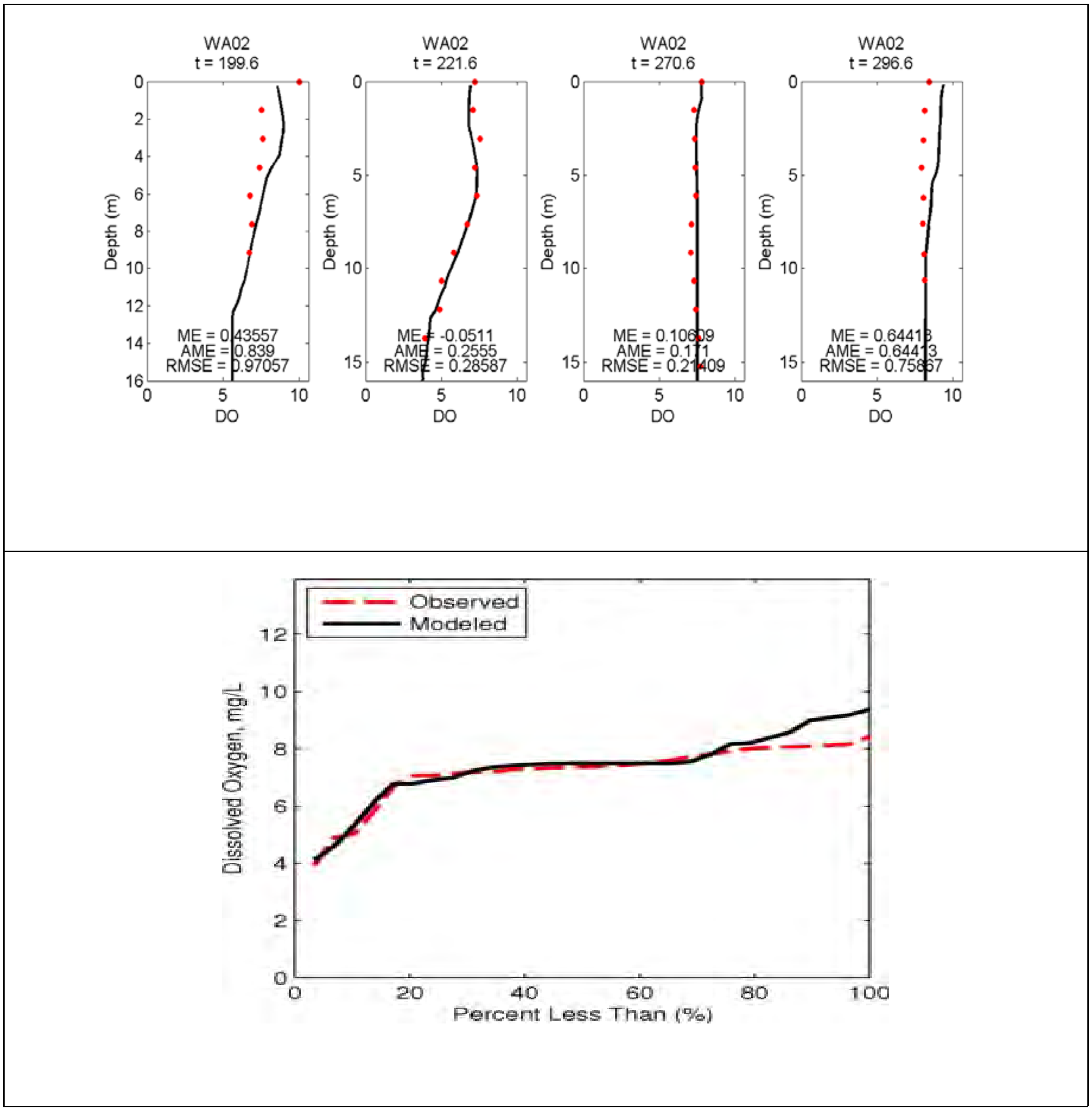


Figure 7. 2001 Calibration profile results and percent cumulative distribution plot at station WA02 for DO at F. E. Walter for 4 Julian dates.

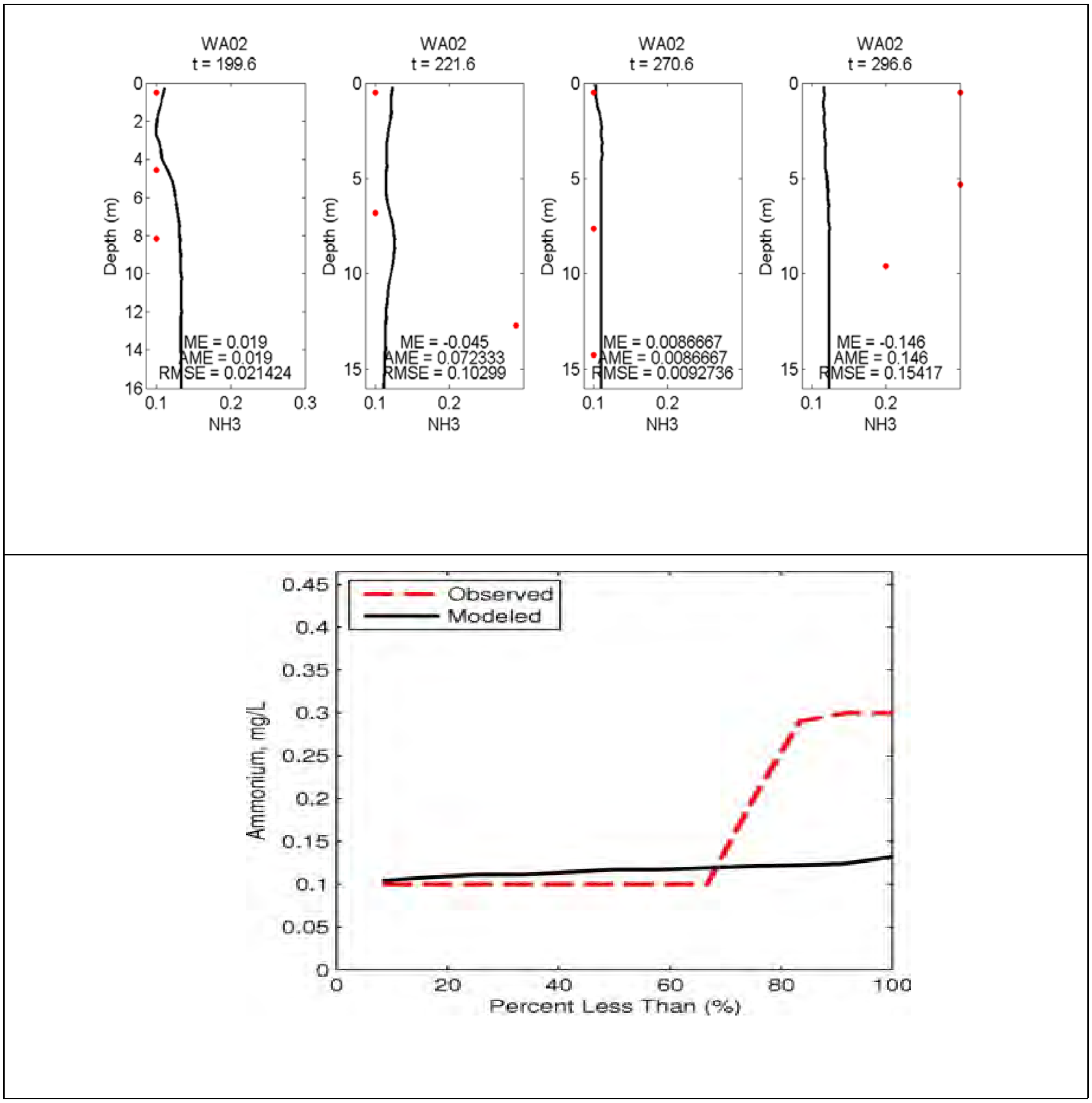


Figure 8. 2001 Calibration profile results and percent cumulative distribution plot at station WA02 for NH_3 at F. E. Walter for 4 Julian dates.

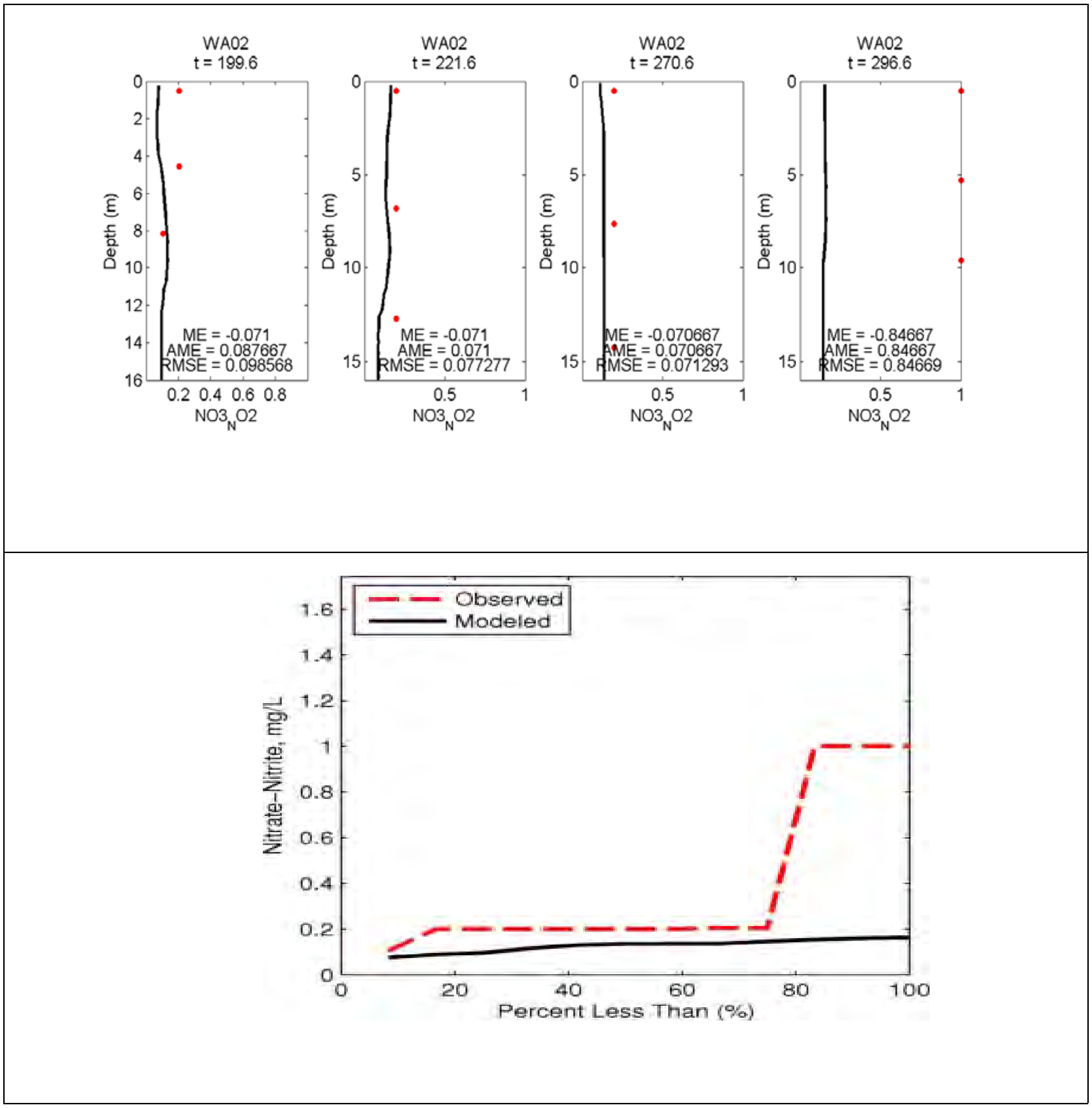


Figure 9. 2001 Calibration profile results and percent cumulative distribution plot at station WA02 for NO_2+NO_3 at F. E. Walter for 4 Julian dates.

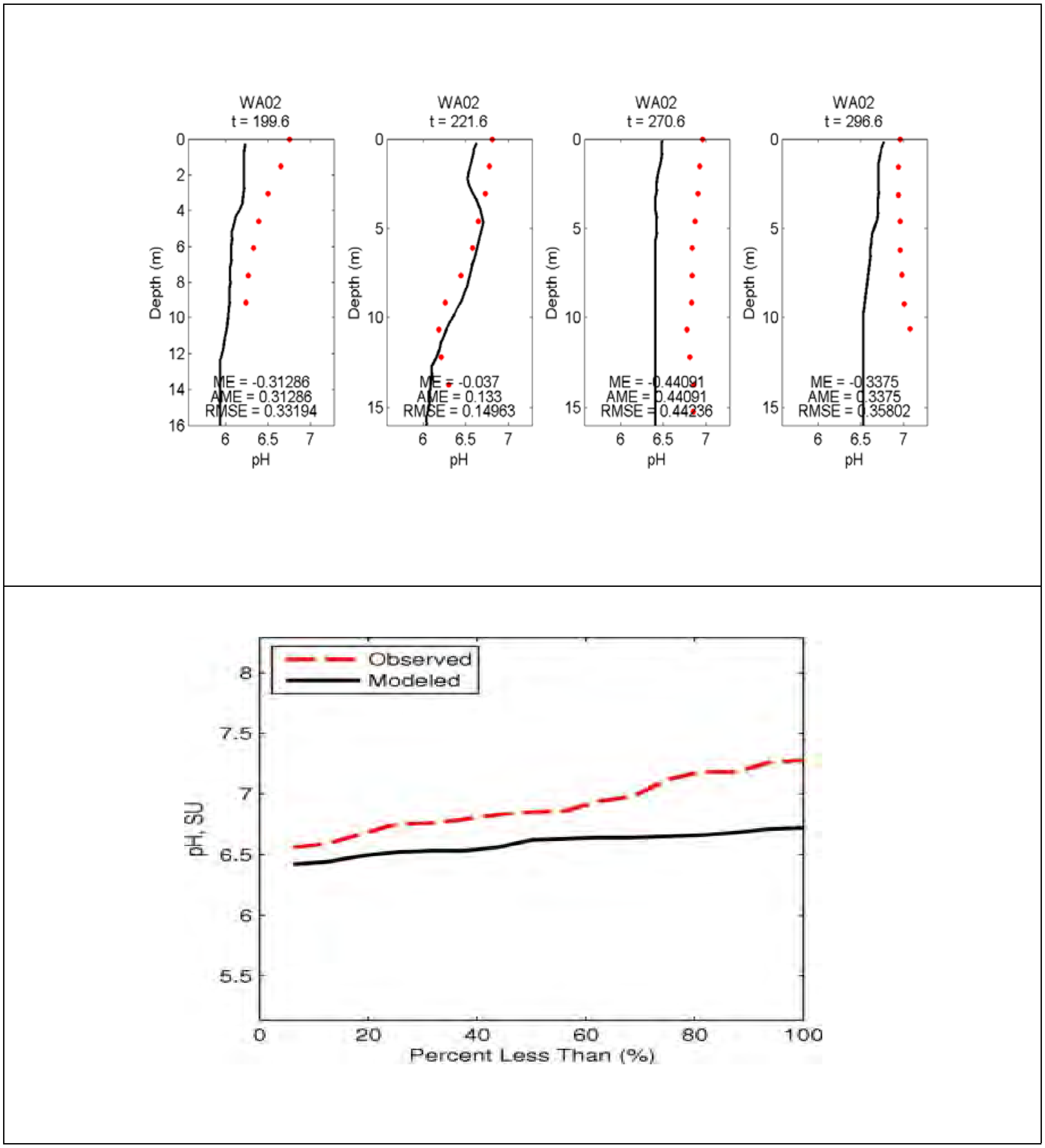


Figure 10. 2001 Calibration profile results and percent cumulative distribution plot at station WA02 for pH at F. E. Walter for 4 Julian dates.

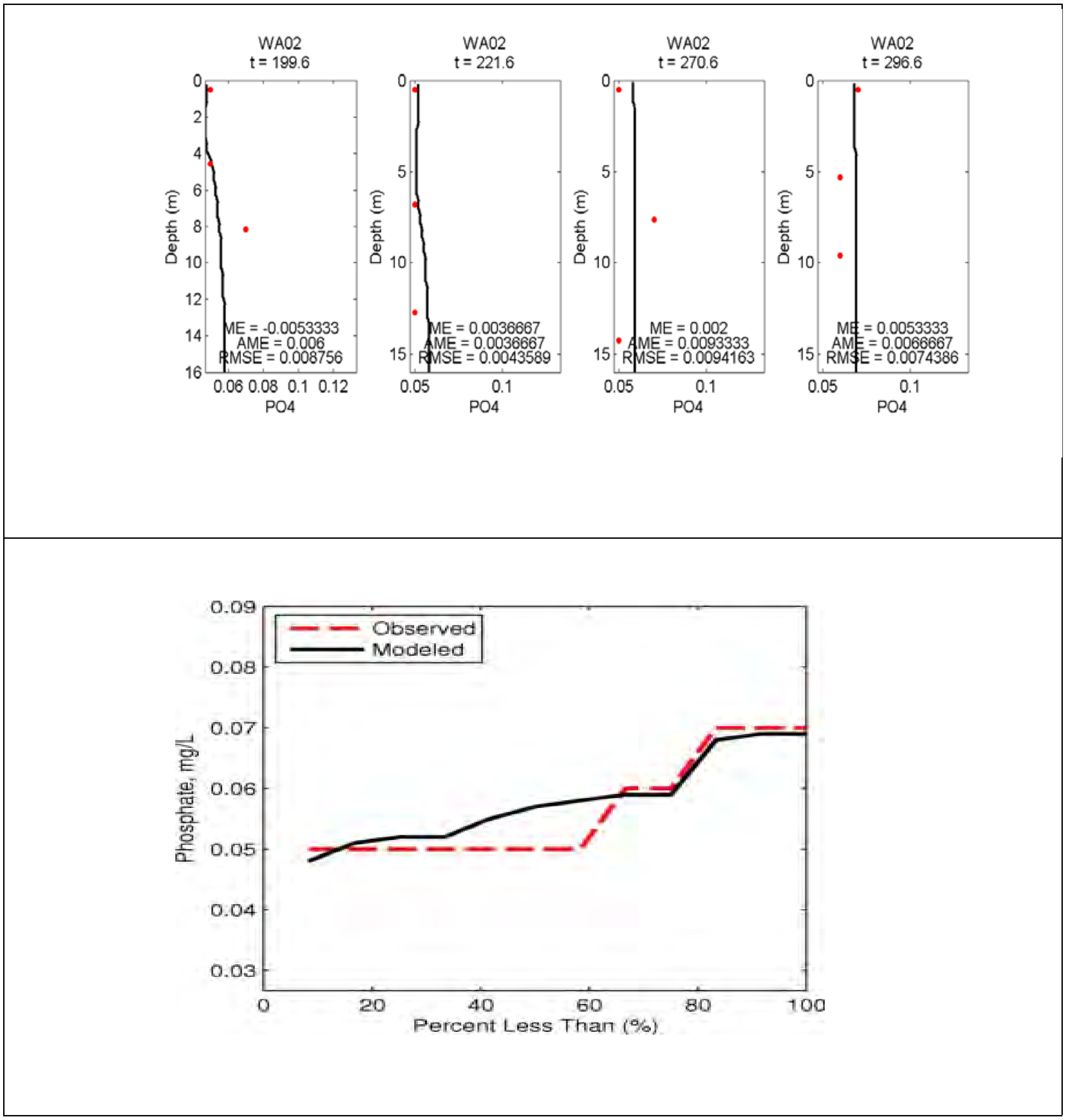


Figure 11. 2001 Calibration profile results and percent cumulative distribution plot station WA02 for PO_4 at F. E. Walter for 4 Julian dates.

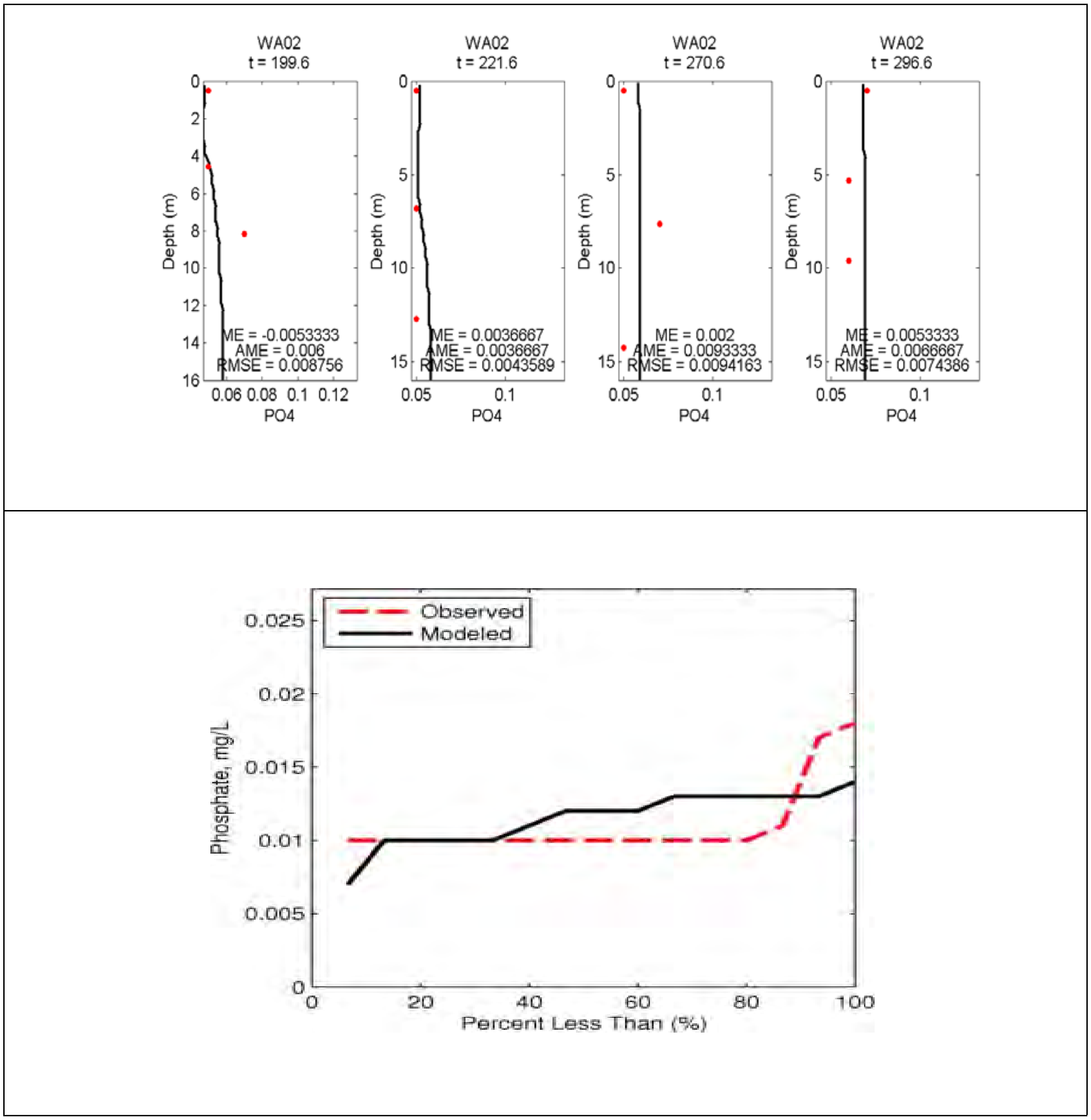


Figure 12. 2001 Calibration profile results and percent cumulative distribution plot at station WA02 for PO_4 at F. E. Walter for 4 Julian dates.

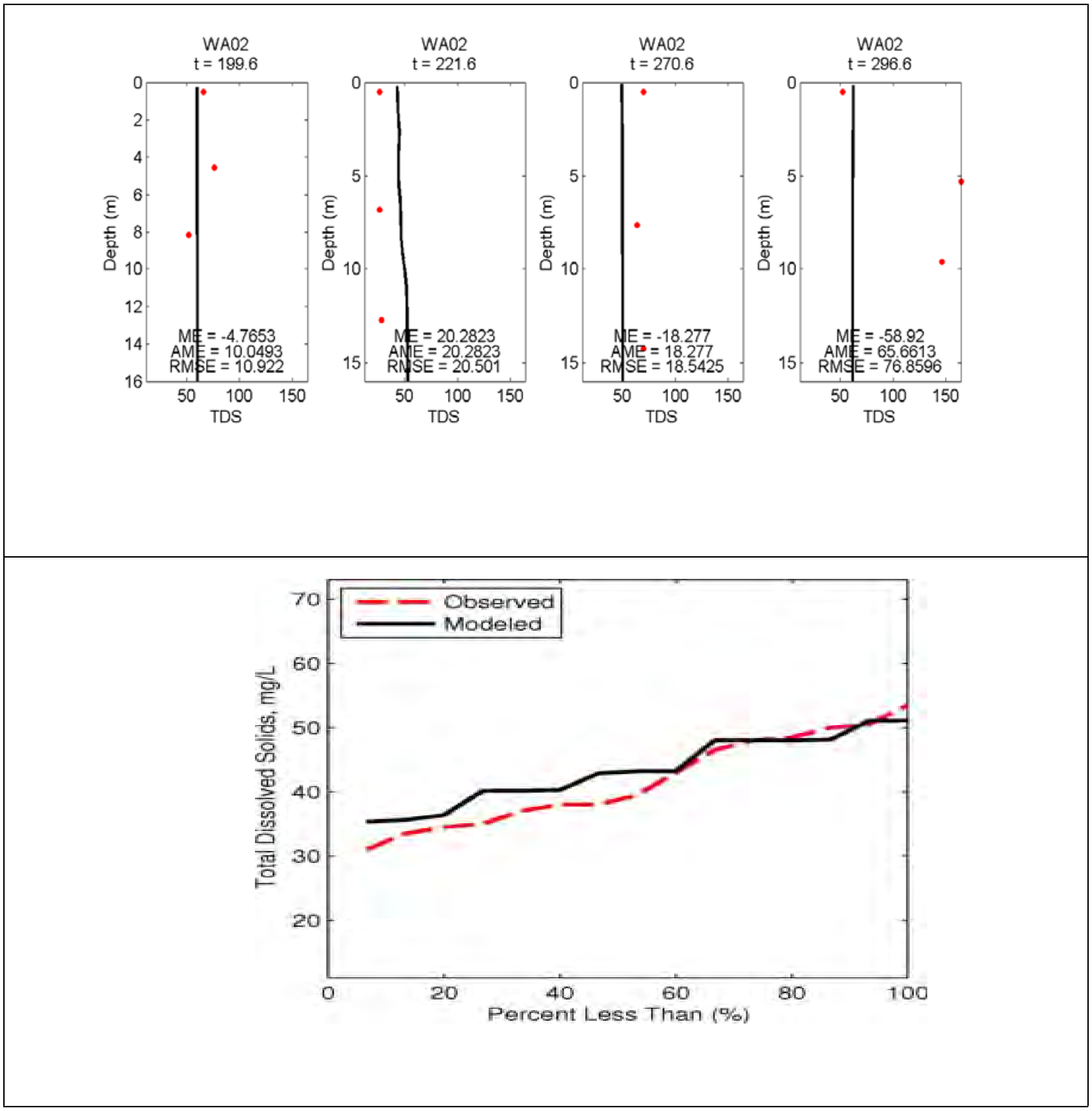


Figure 13. 2001 Calibration profile results and percent cumulative distribution plot at station WA02 for TDS at F. E. Walter for 4 Julian dates.

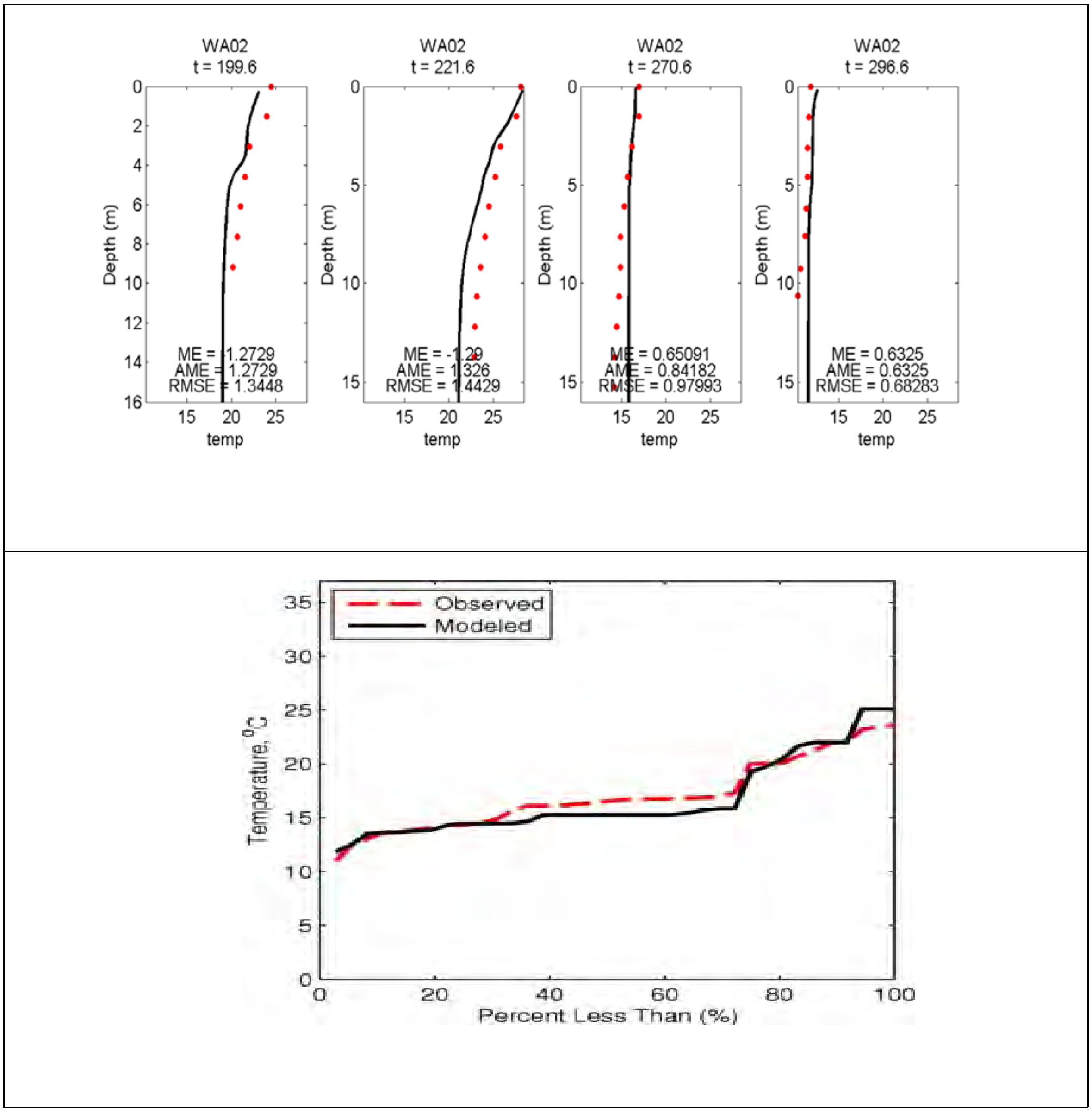


Figure 14. 2001 calibration profile results and percent cumulative distribution plot at station WA02 for temperature at F. E. Walter for 4 Julian dates.

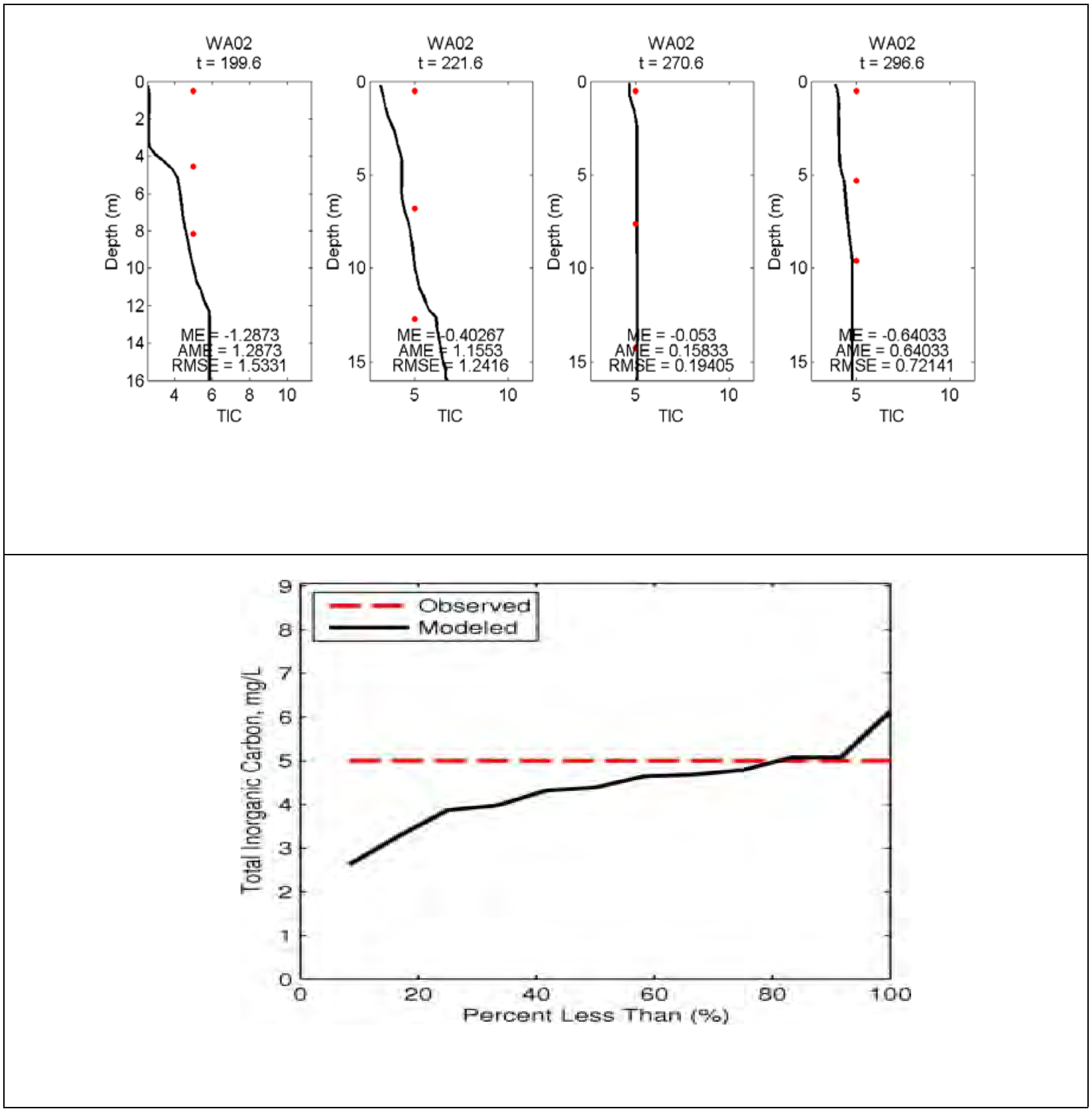


Figure 15. 2001 calibration profile results and percent cumulative distribution plot at station WA02 for TIC at F. E. Walter for 4 Julian dates.

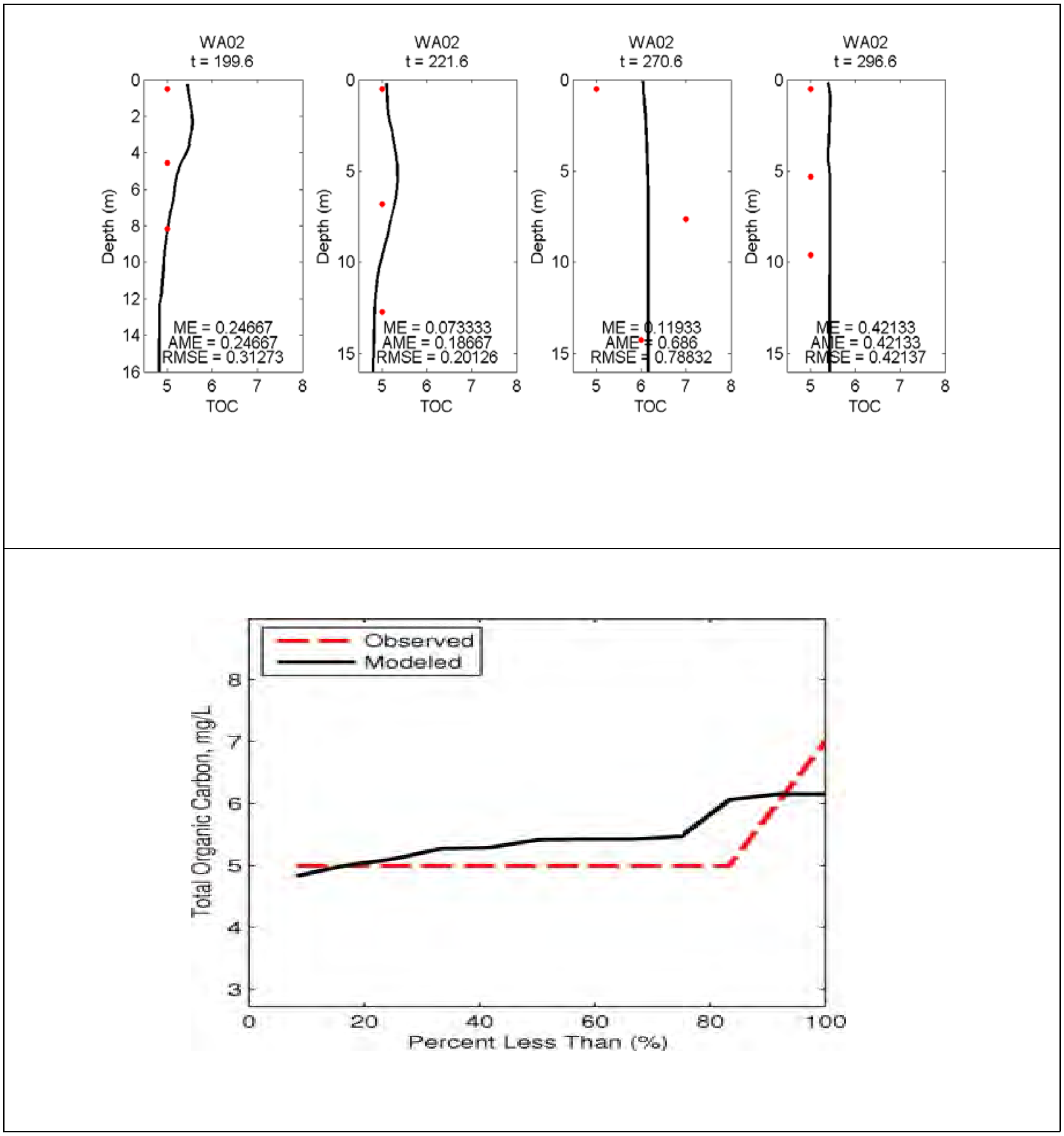


Figure 16. 2001 calibration profile results and percent cumulative distribution plot at station WA02 for TOC at F. E. Walter for 4 Julian dates.

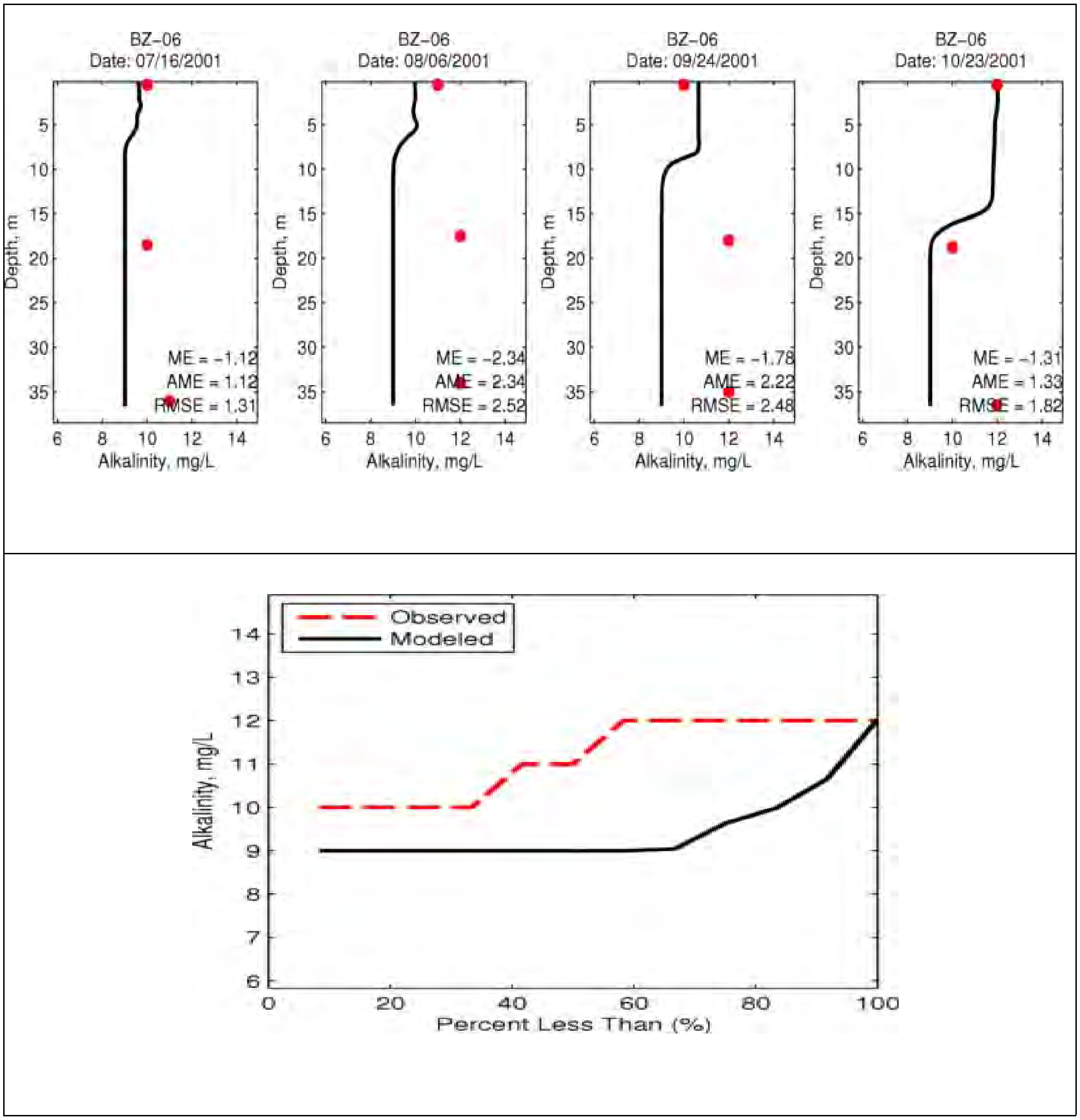


Figure 17. 2001 Calibration profile results and percent cumulative distribution plot at station BZ06 for Alkalinity at Beltzville for 4 Julian dates.

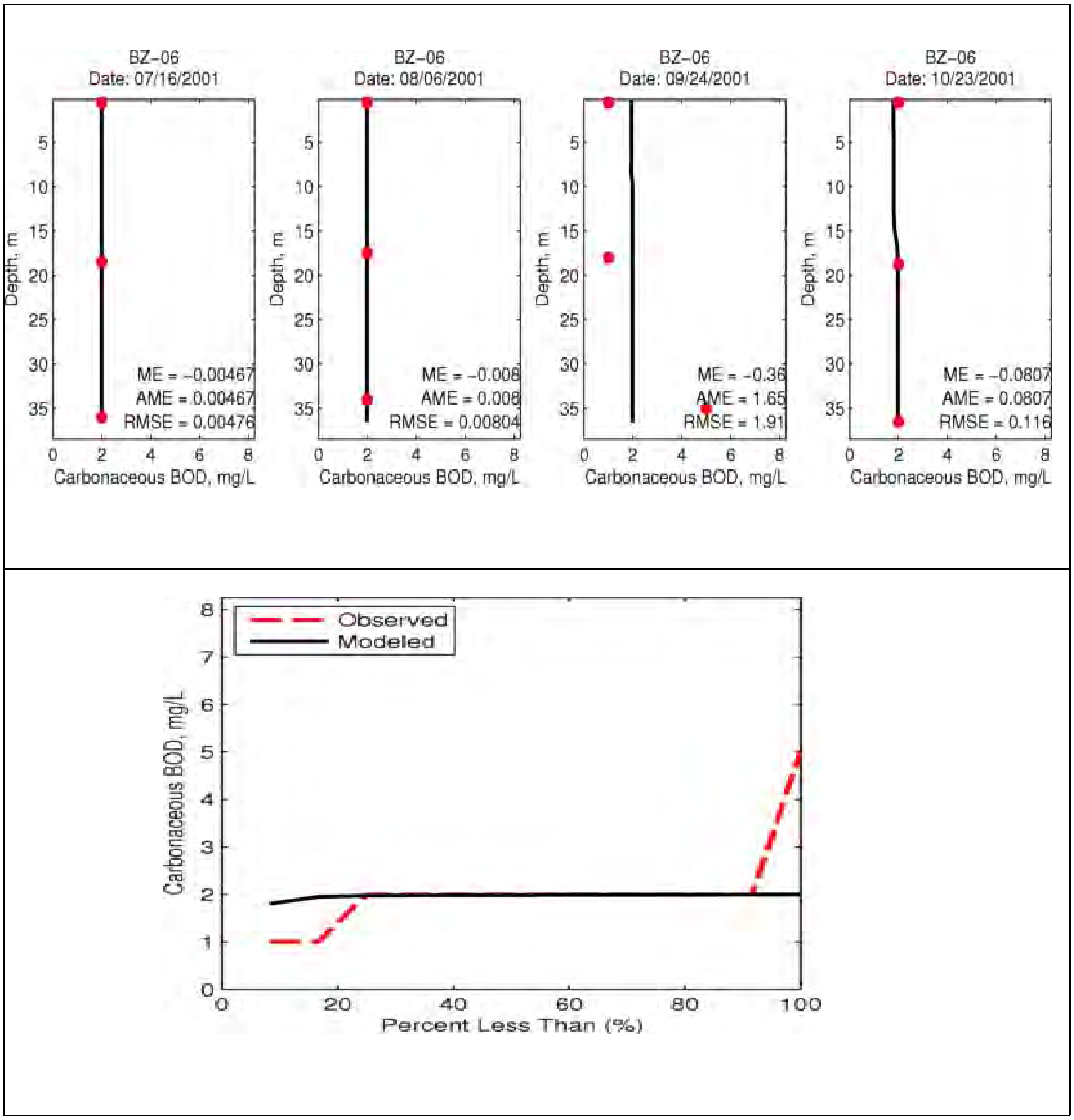


Figure 18. 2001 Calibration profile results and percent cumulative distribution plot at station BZ06 for CBOD5 at Beltzville for 4 Julian dates.

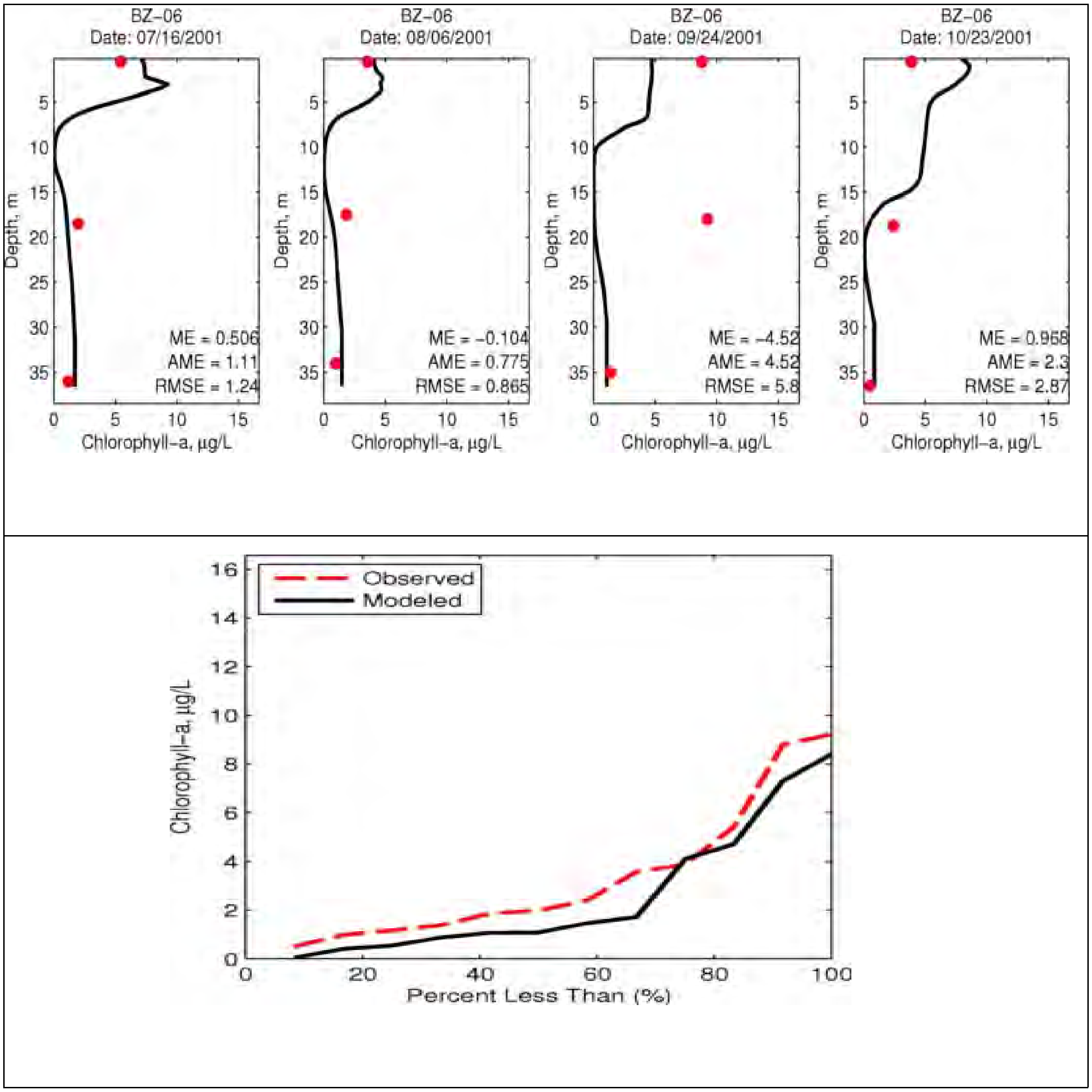


Figure 19. 2001 Calibration profile results and percent cumulative distribution plot at station BZ06 for Chlorophyll *a* at Beltzville for 4 Julian dates.

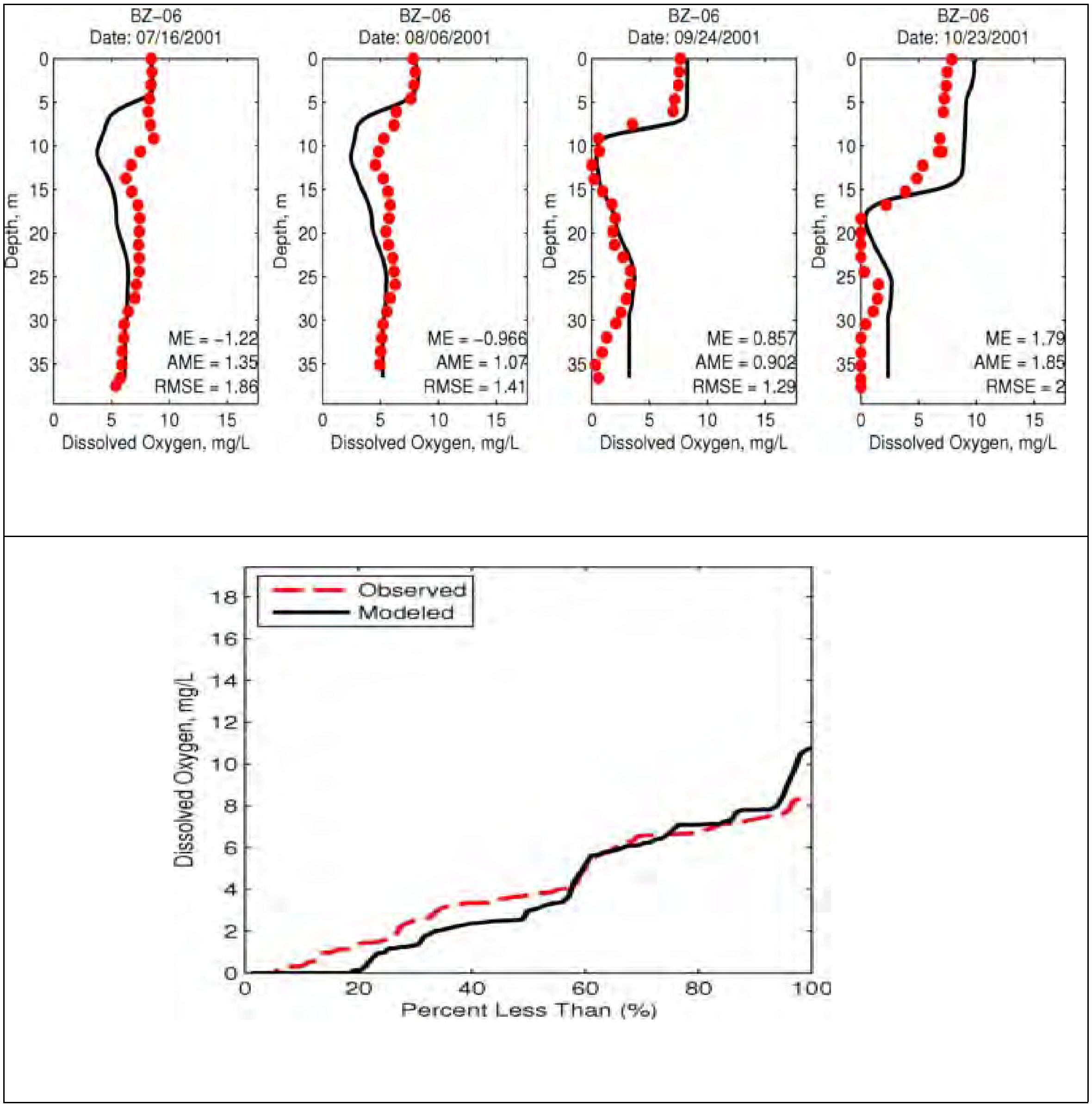


Figure 20. 2001 Calibration profile results and percent cumulative distribution plot at station BZ06 for DO at Beltzville for 4 Julian dates.

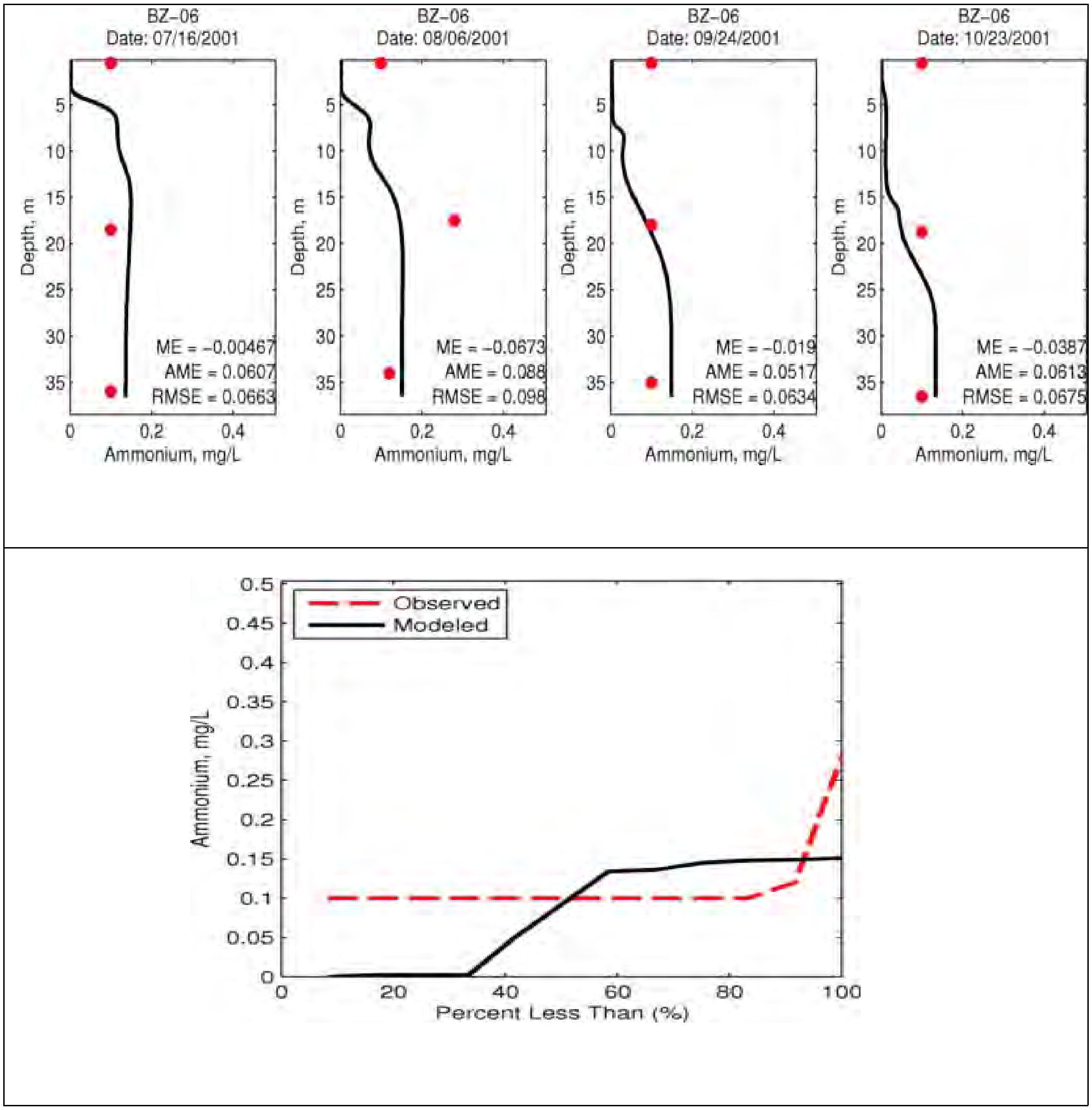


Figure 21. 2001 Calibration profile results and percent cumulative distribution plot at station BZ06 for ammonium at Beltzville for 4 Julian dates.

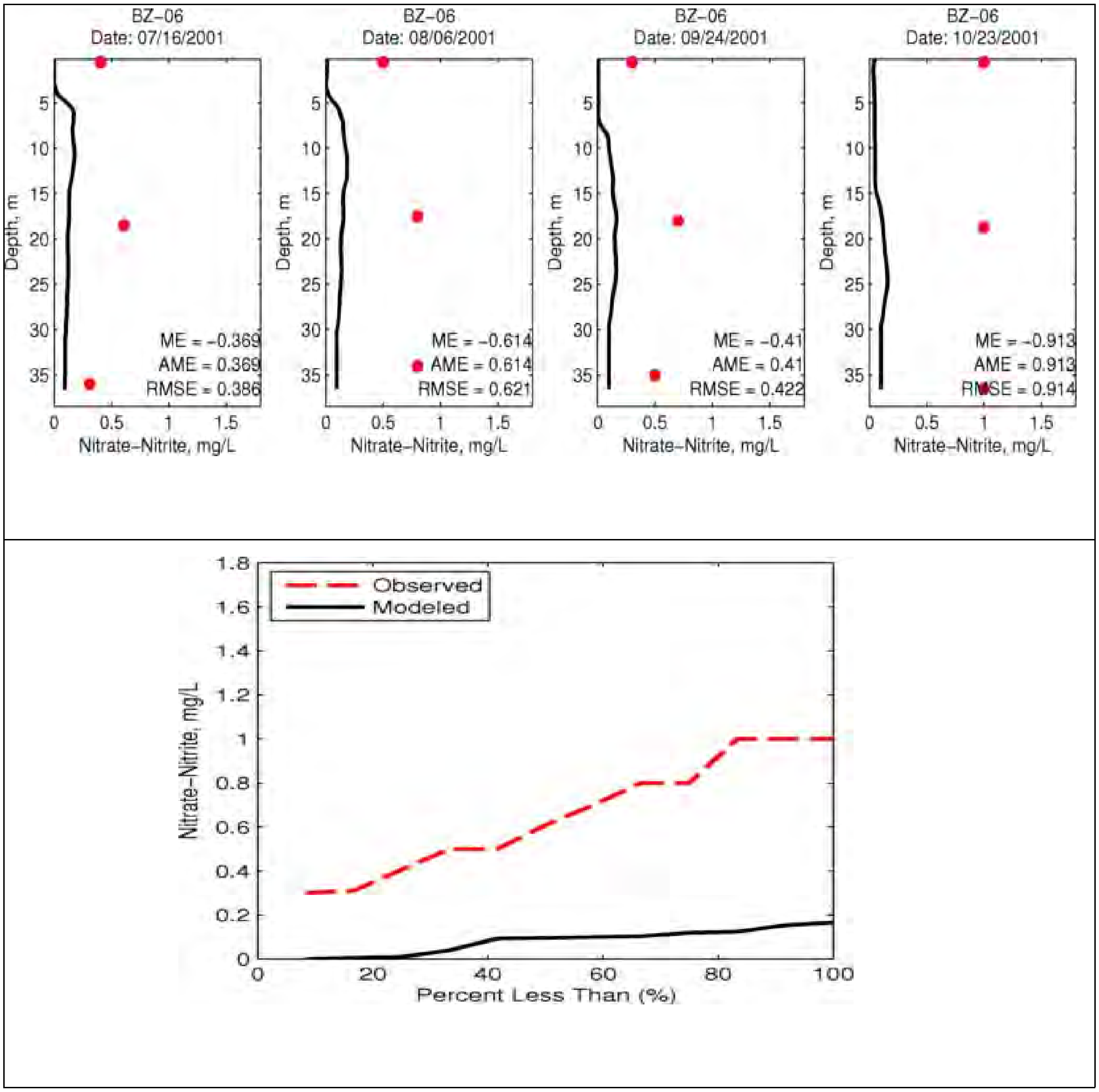


Figure 22. 2001 Calibration profile results and percent cumulative distribution plot at station BZ06 for Nitrate-Nitrite at Beltzville for 4 Julian dates.

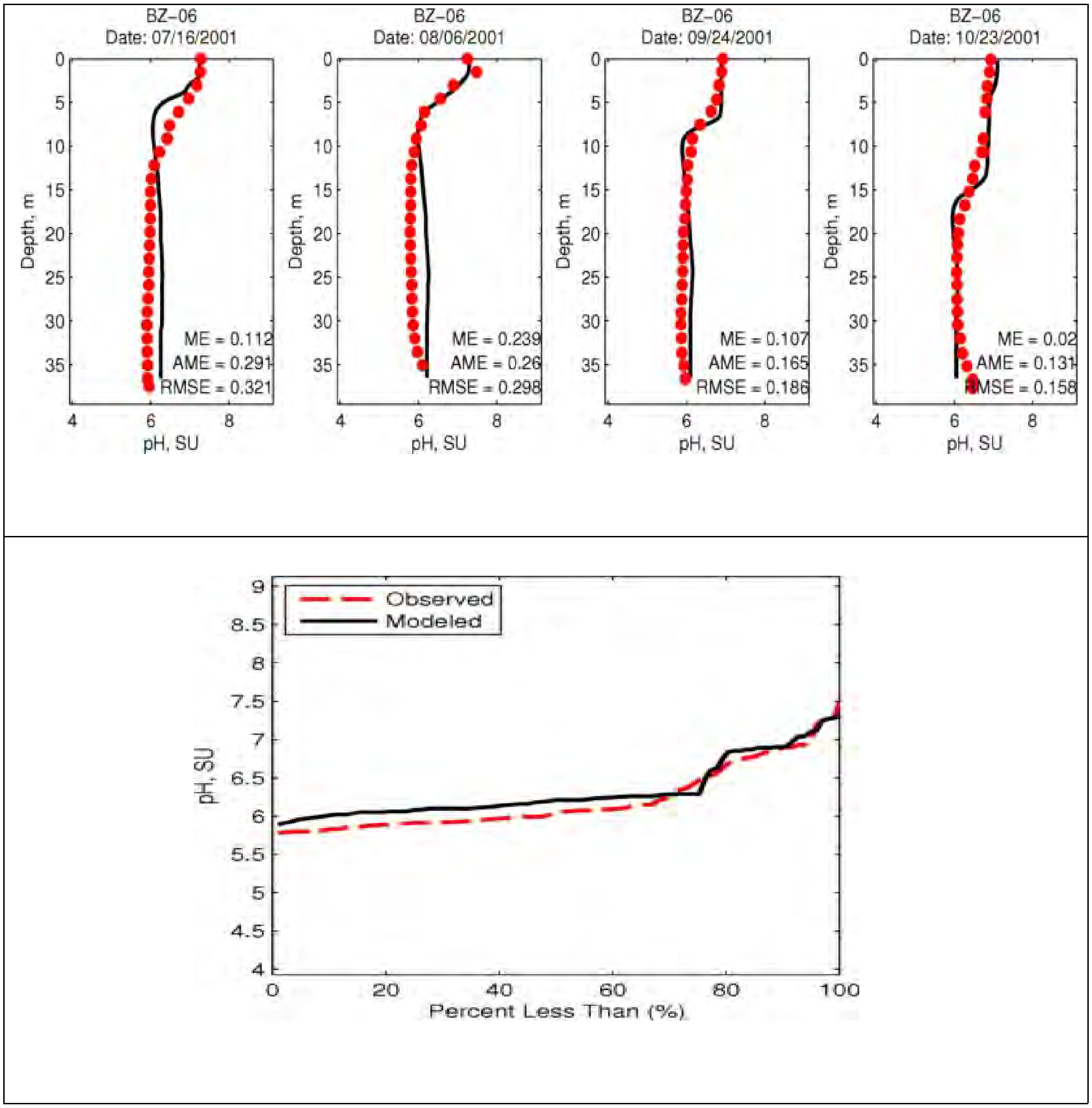


Figure 23. 2001 Calibration profile results and percent cumulative distribution plot at station BZ06 for pH at Beltzville for 4 Julian dates.

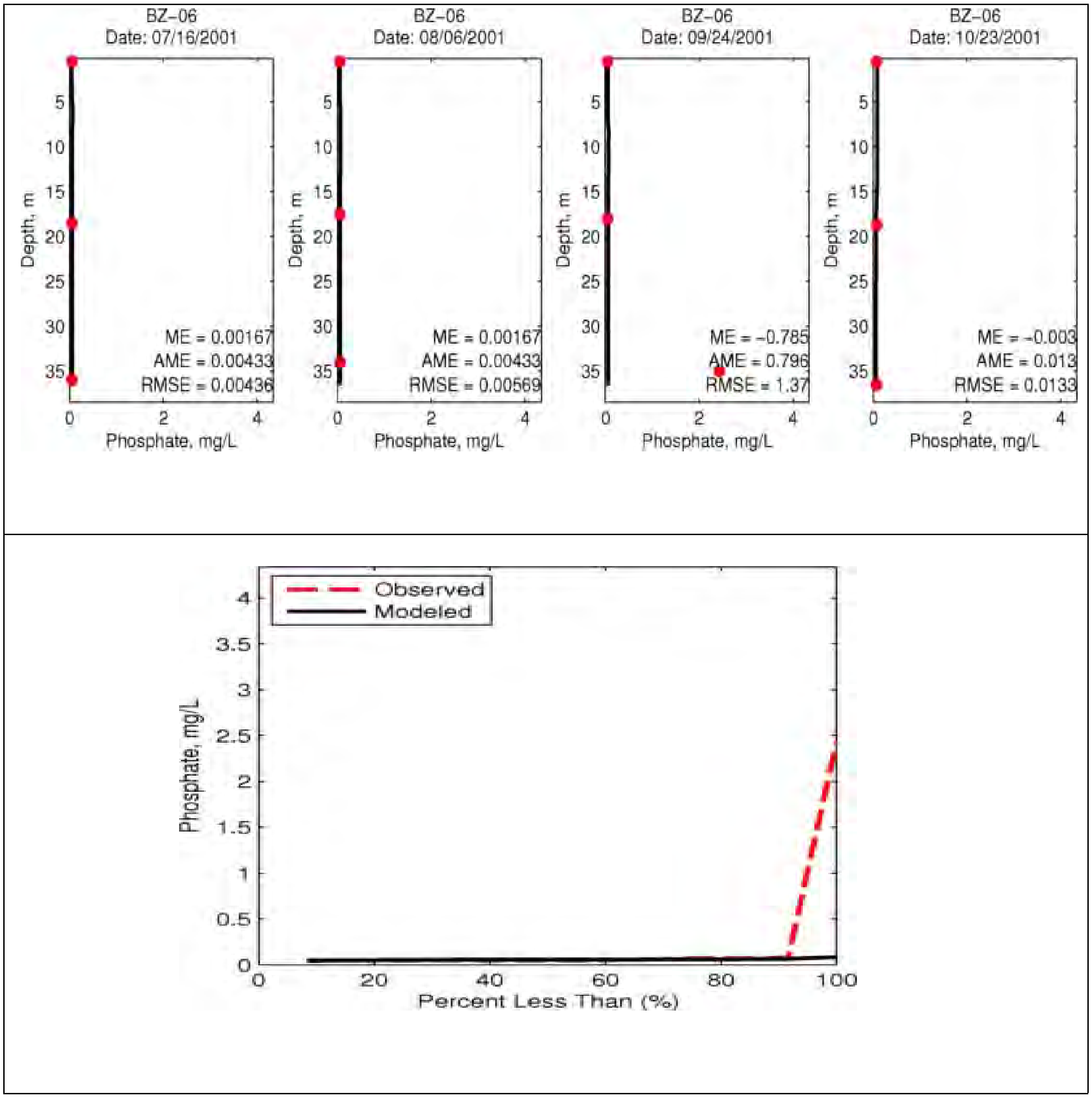


Figure 24. 2001 Calibration profile results and percent cumulative distribution plot at station BZ06 for Phosphate at Beltzville for 4 Julian dates.

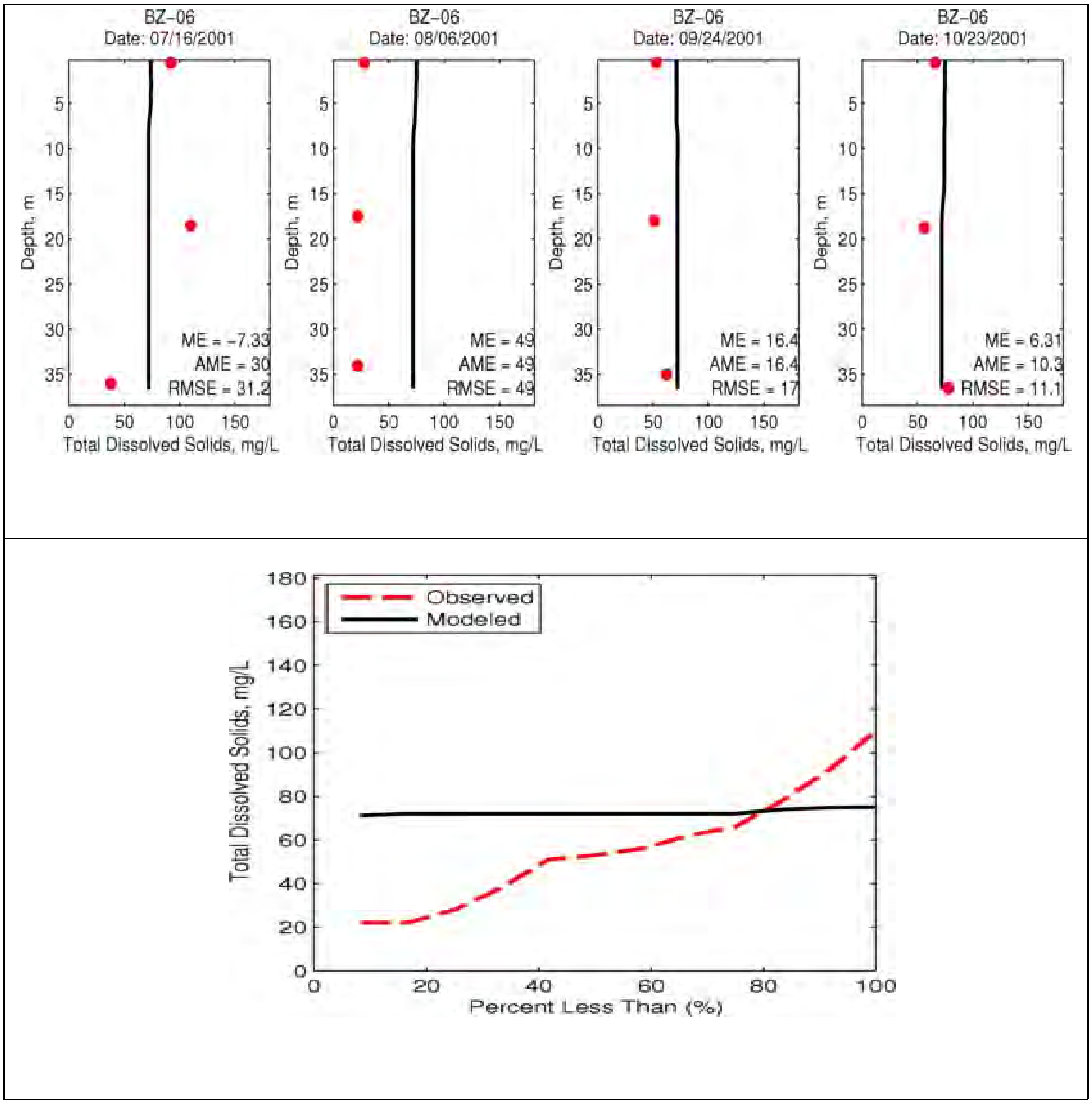


Figure 25. 2001 Calibration profile results and percent cumulative distribution plot station BZ06 for TDS at Beltzville for 4 Julian dates.

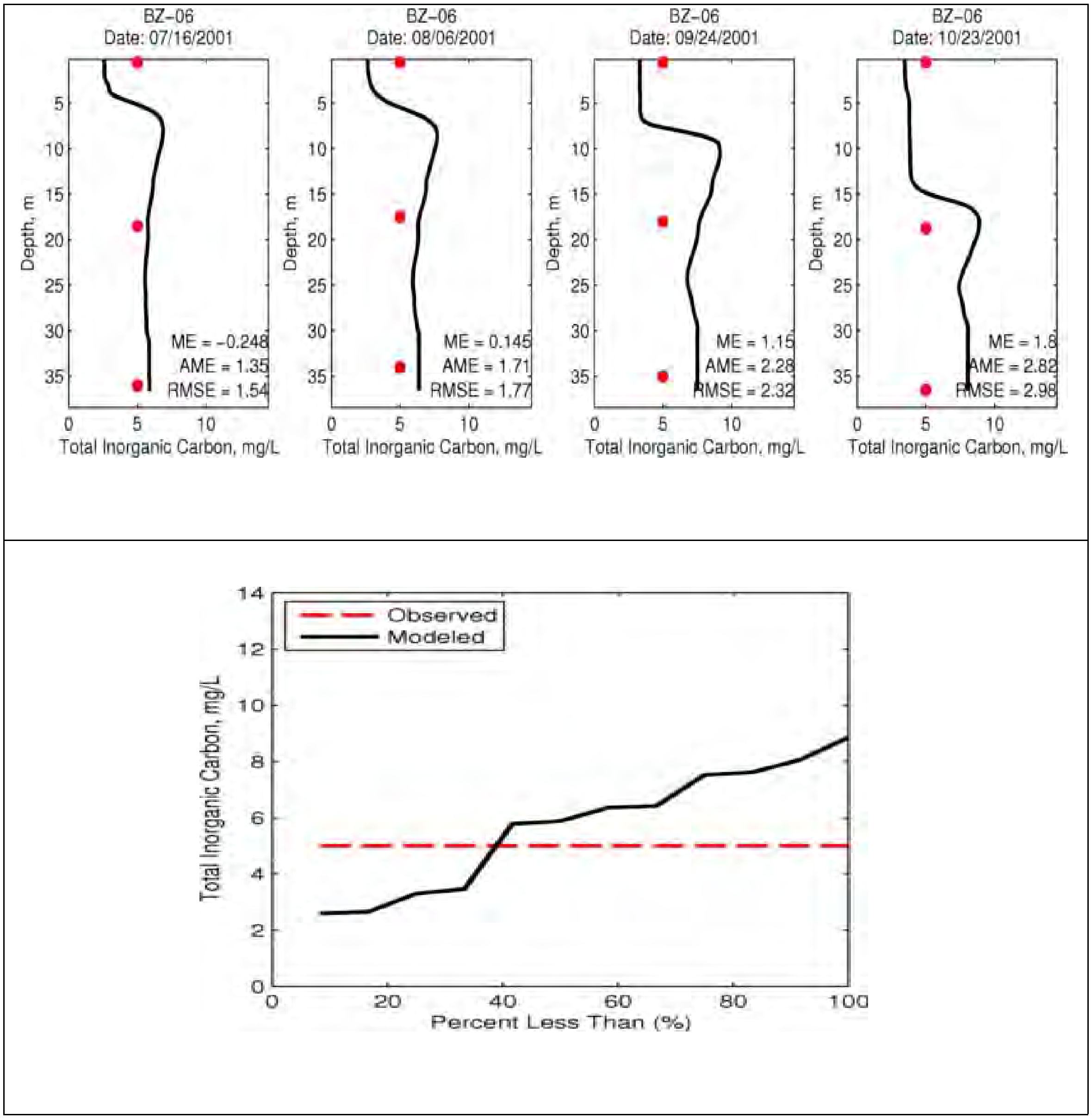


Figure 26. 2001 Calibration profile results and percent cumulative distribution plot station BZ06 for TIC at Beltzville for 4 Julian dates.

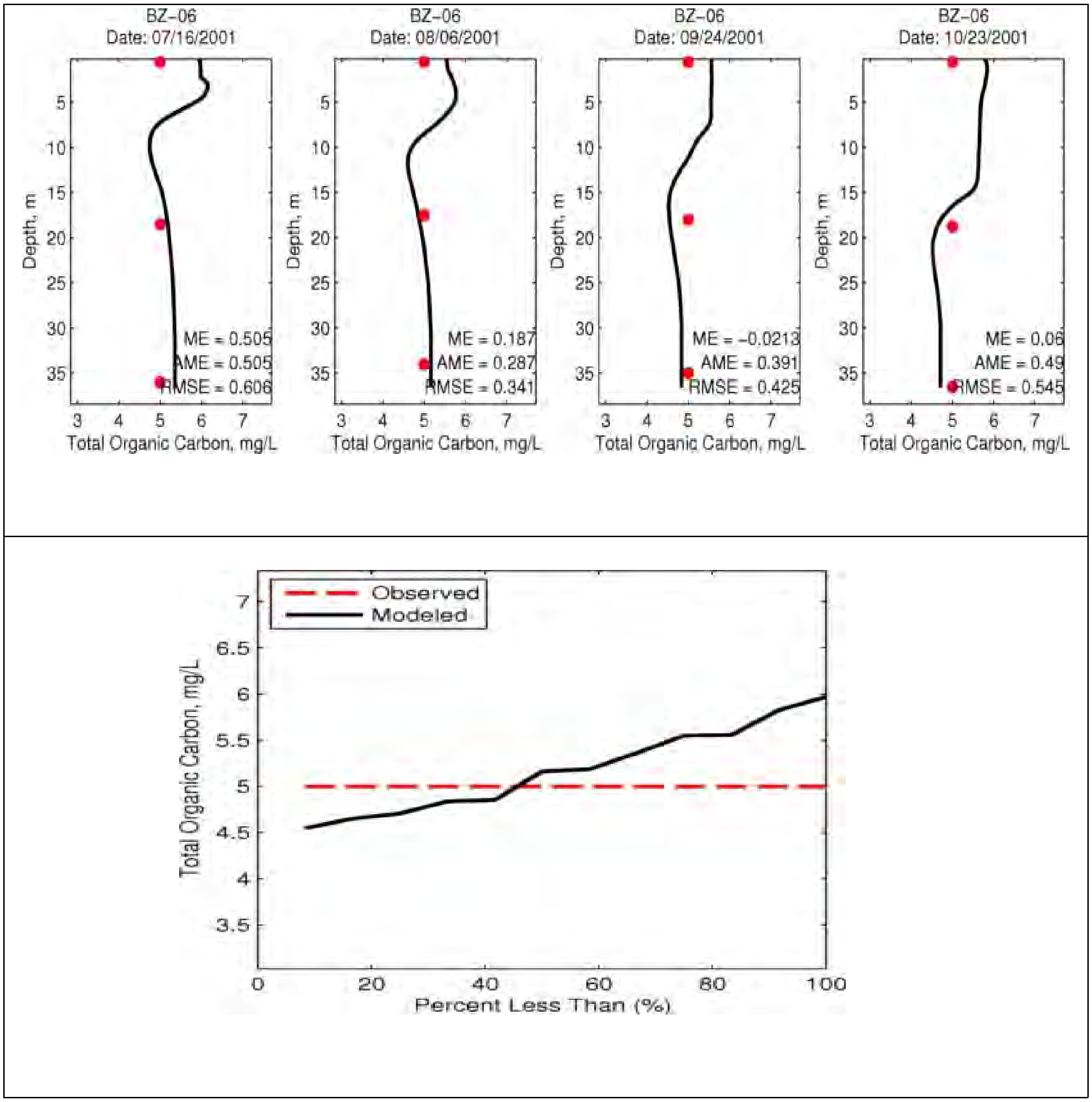


Figure 27. 2001 Calibration profile results and percent cumulative distribution plot at station BZ06 for TOC at Beltzville for 4 Julian dates.

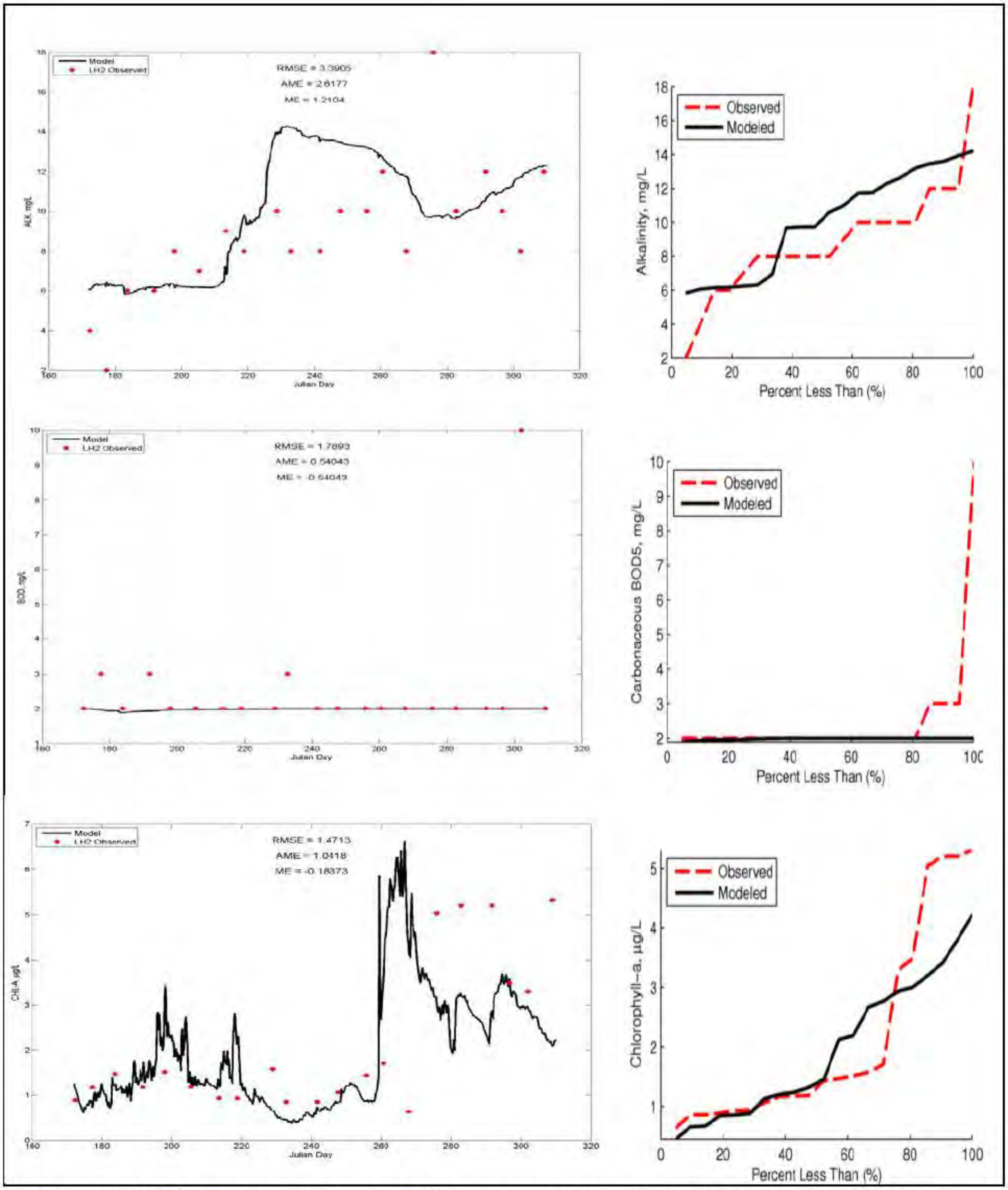


Figure 28. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH02 for alkalinity, BOD5, and Chla.

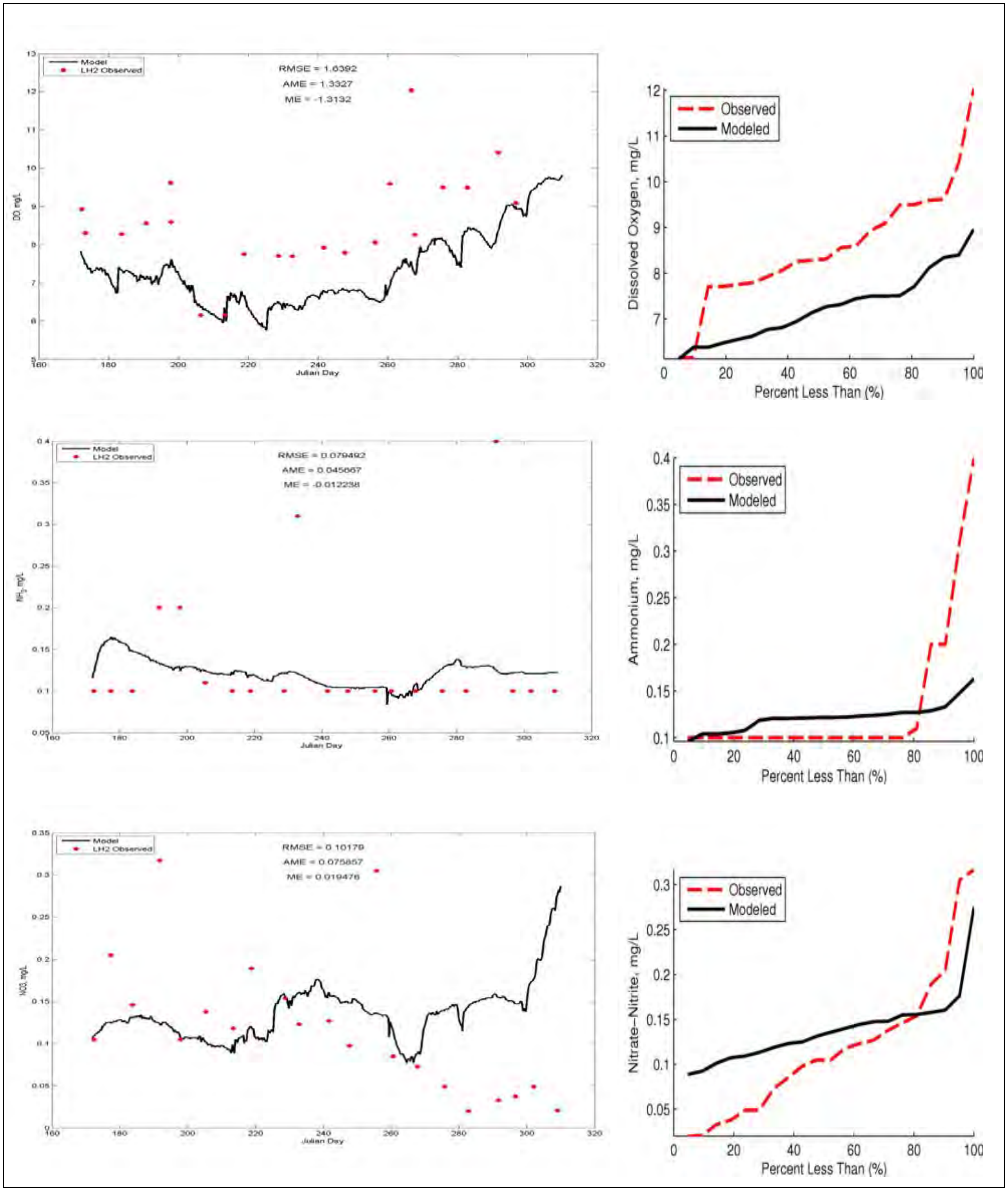


Figure 29. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH02 for DO, NH3, and NO2+NO3.

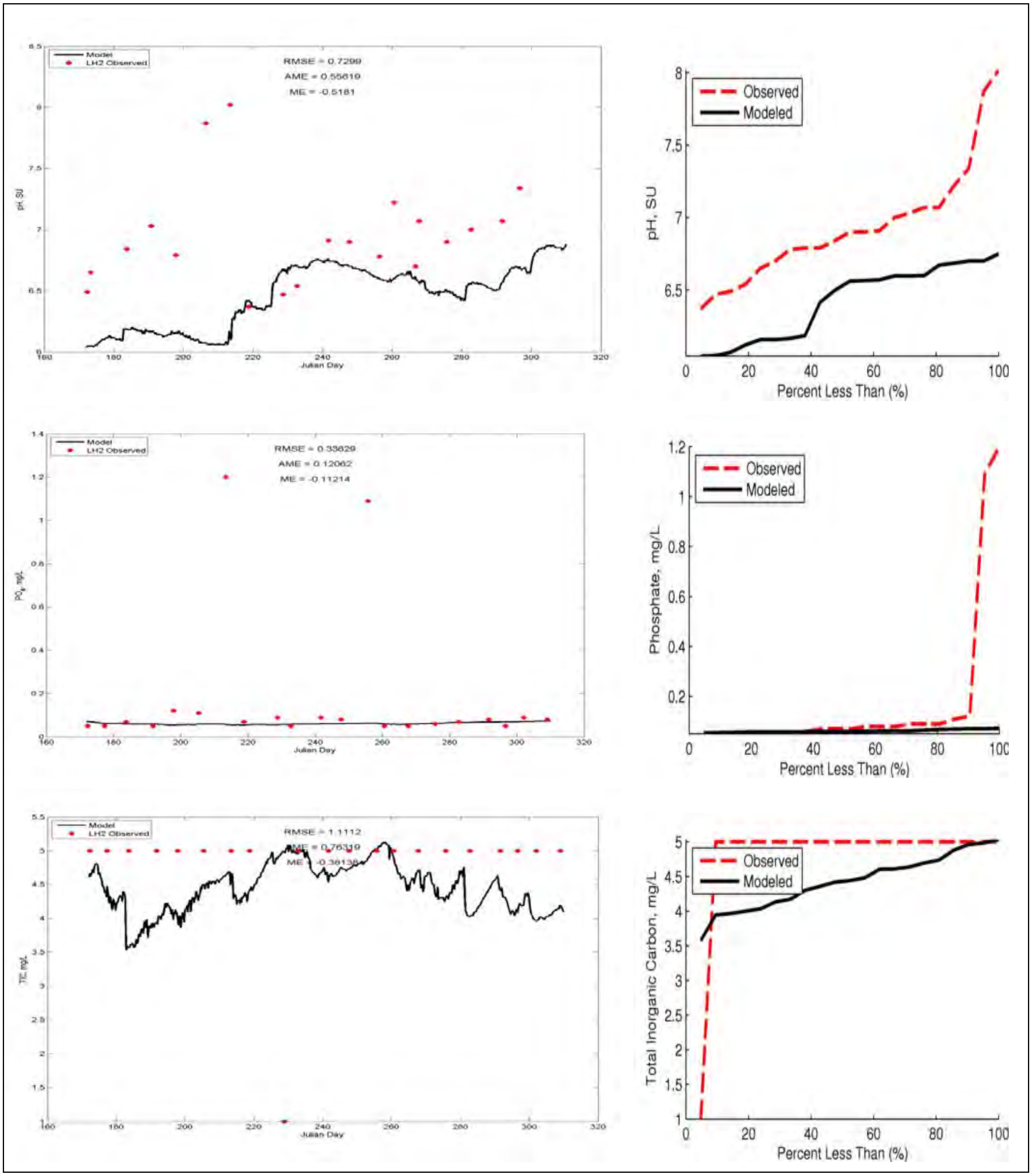


Figure 30. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH02 for pH, PO4, and TIC.

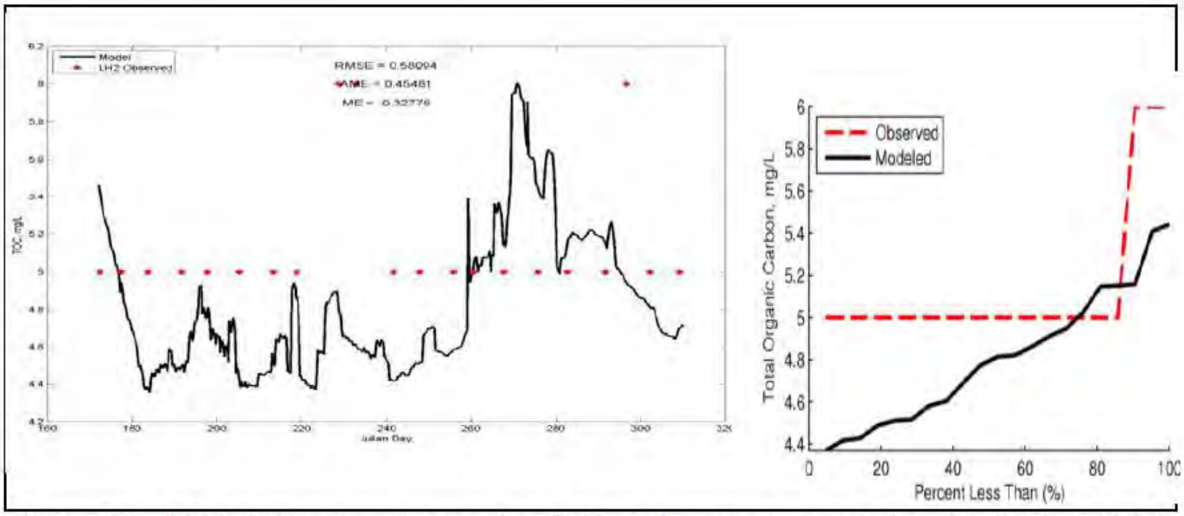


Figure 31. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH02 for TOC.

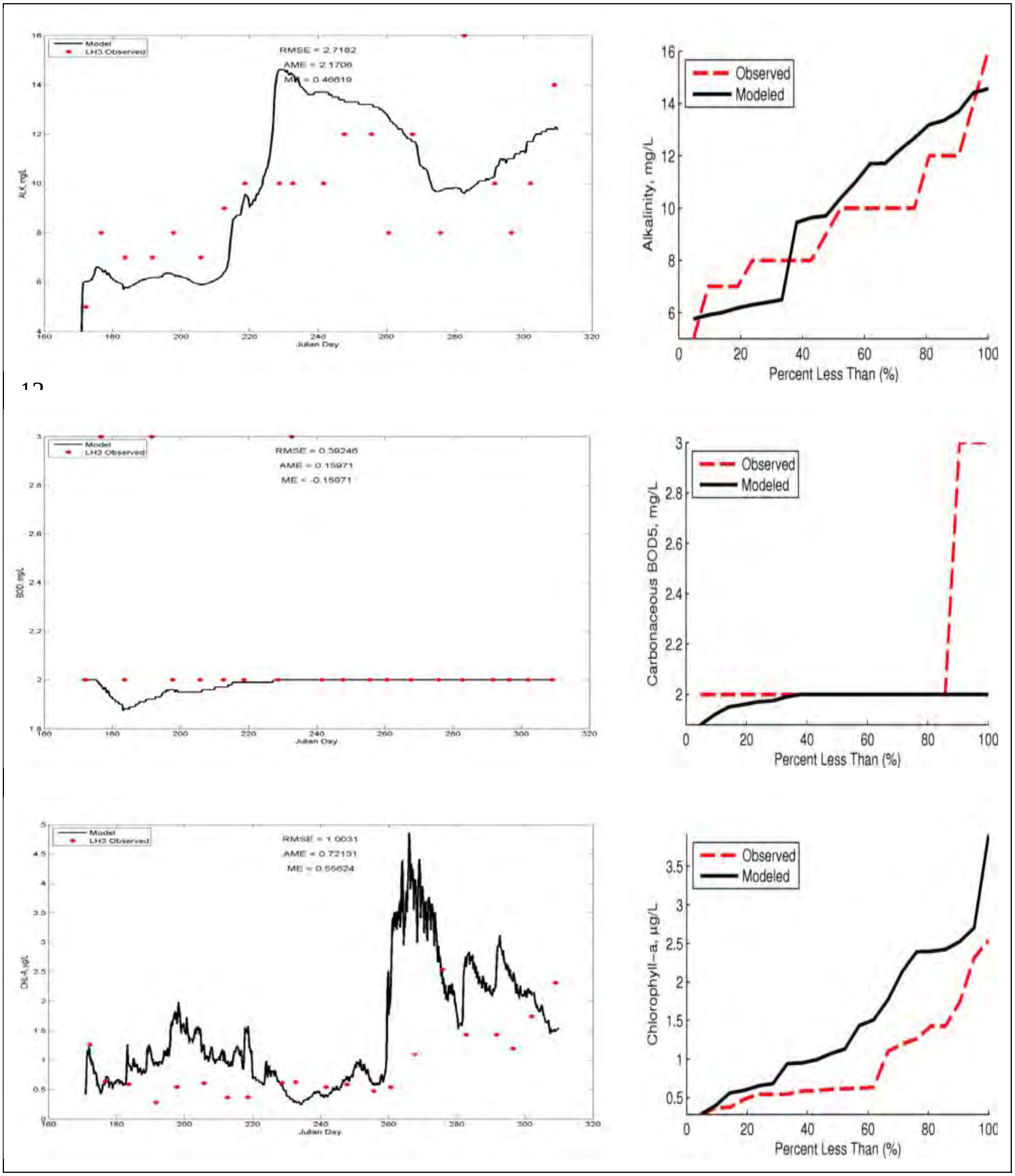


Figure 32. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH03 for alkalinity, BOD5, and Chla.

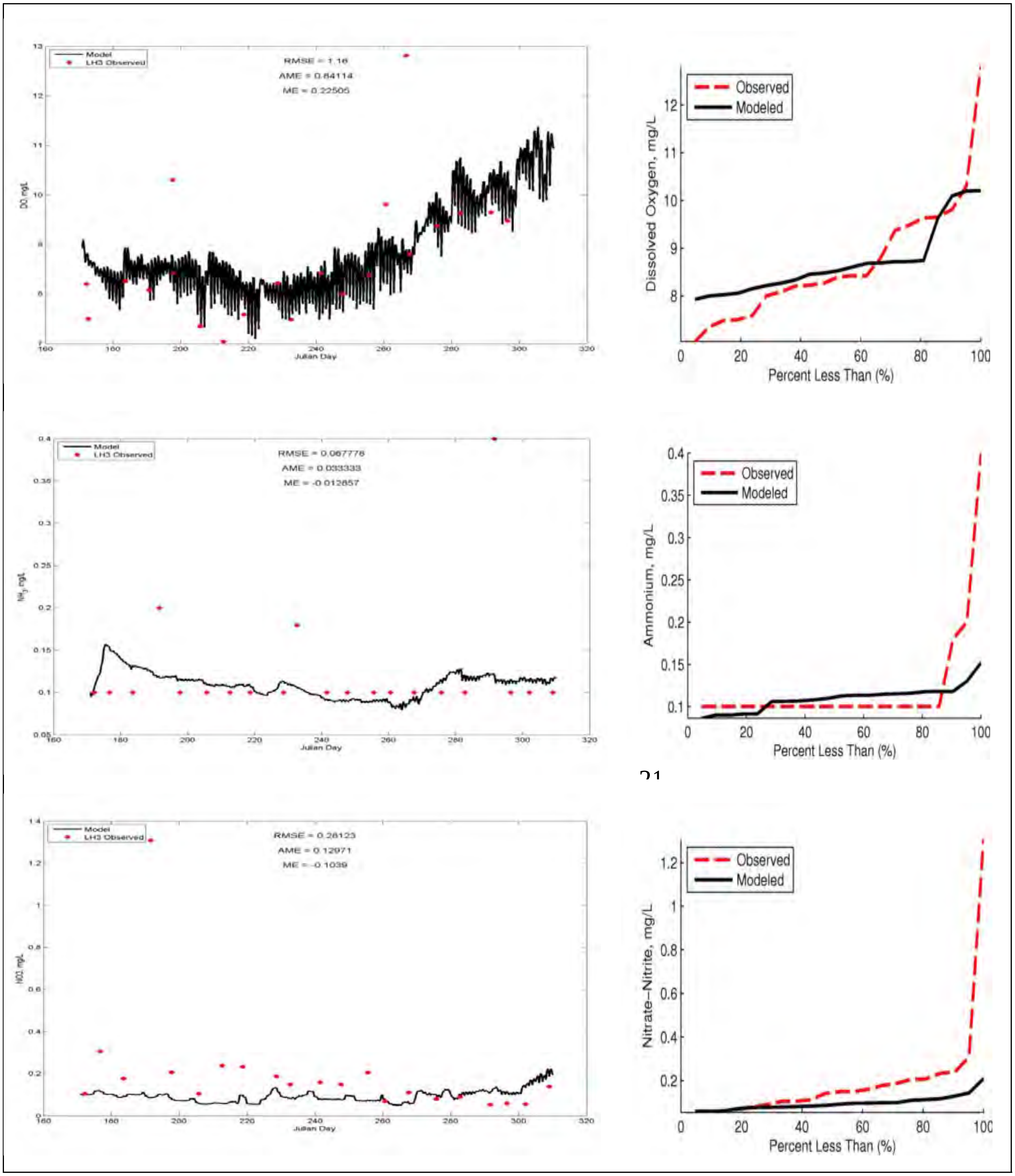


Figure 33. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH03 for DO, NH3, and NO2+NO3.

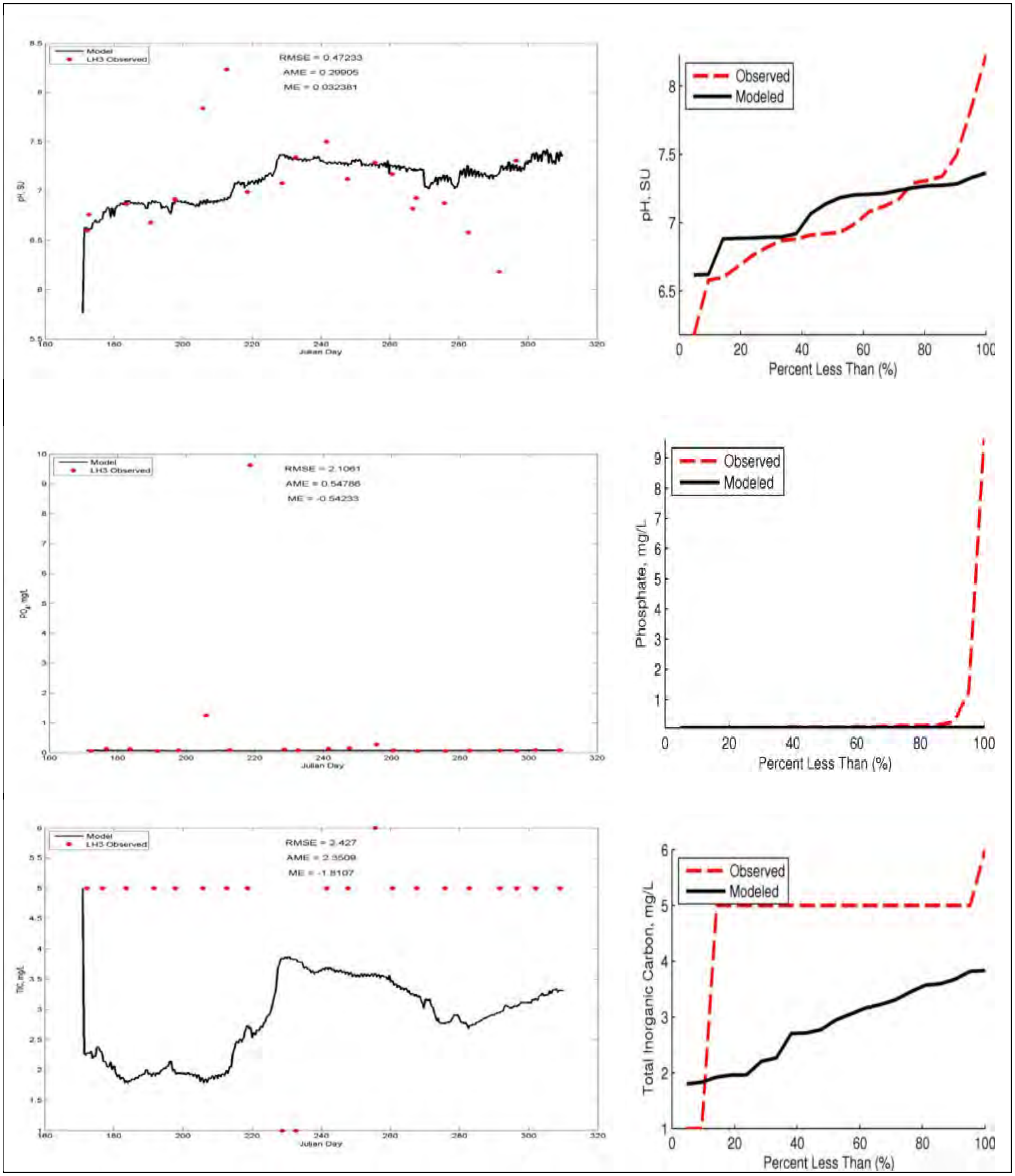


Figure 34. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH03 for pH, PO4, and TIC.

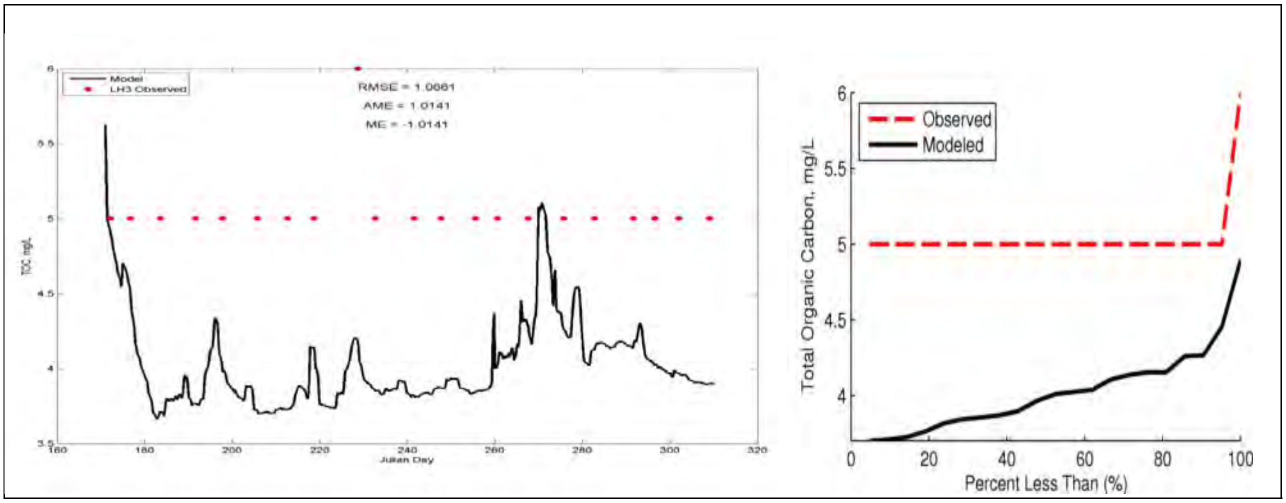


Figure 35. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH03 for TOC.

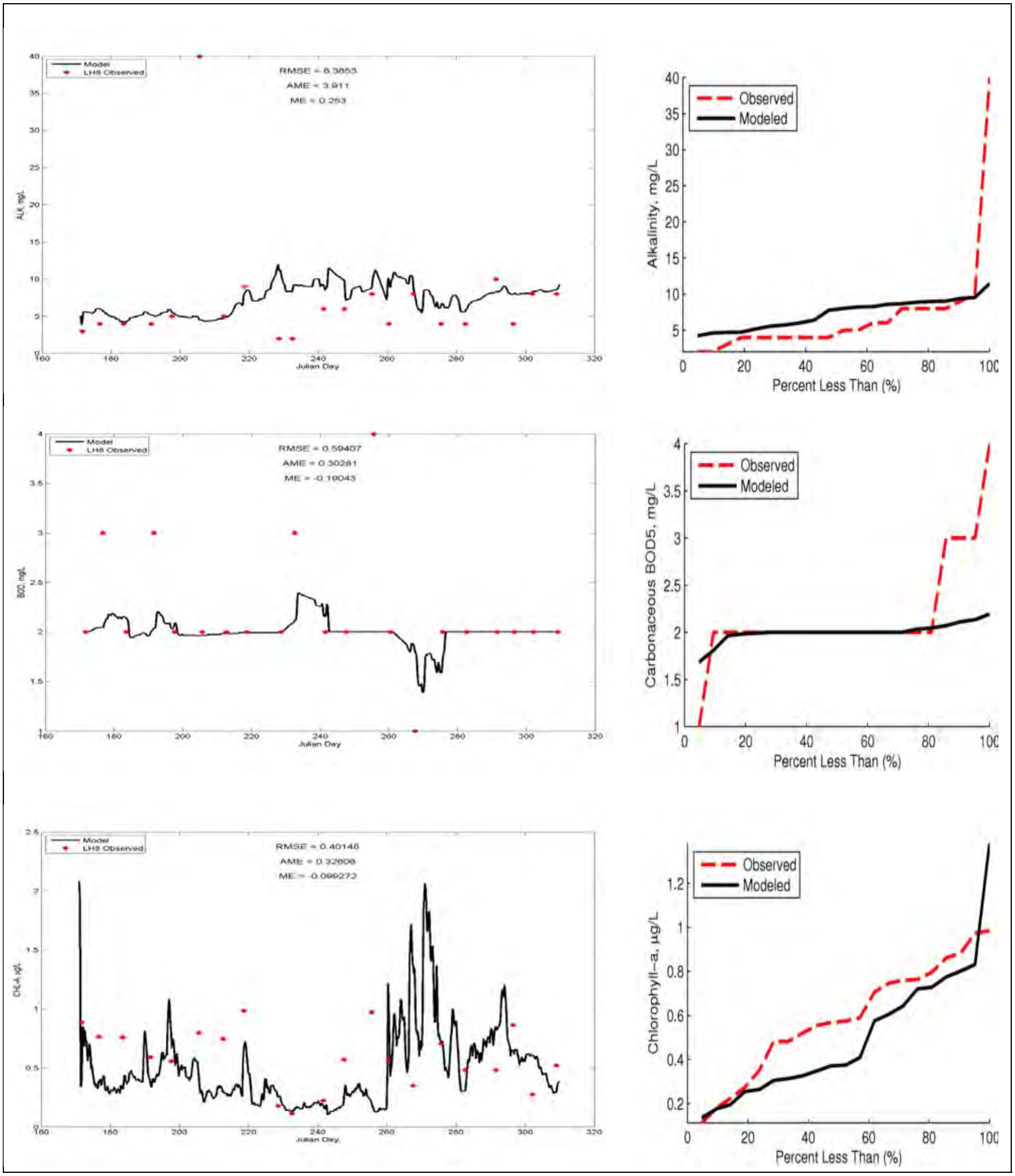


Figure 36. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH08 for alkalinity, BOD5, and Chla.

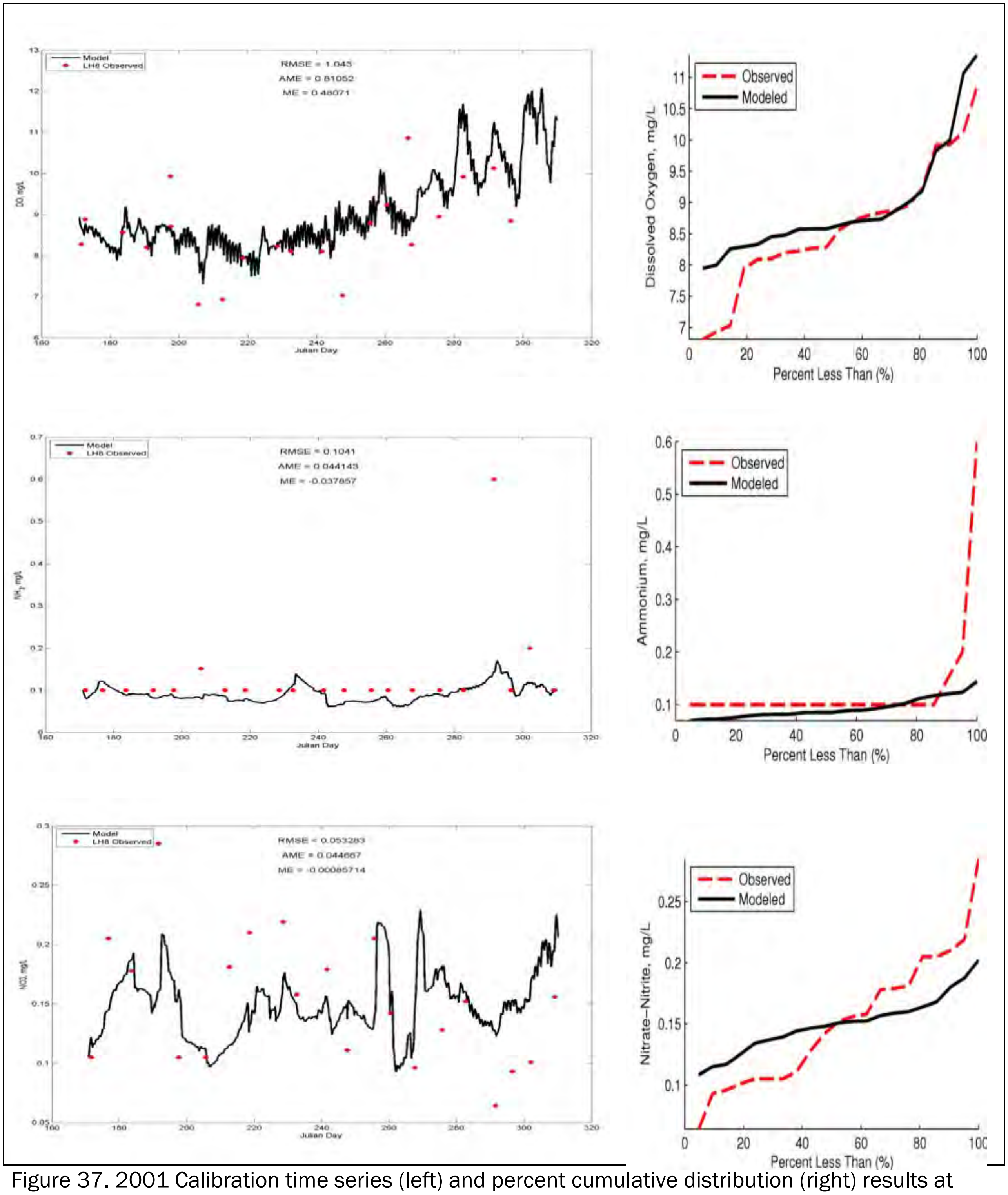


Figure 37. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH08 for DO, NH3, and NO2+NO3.

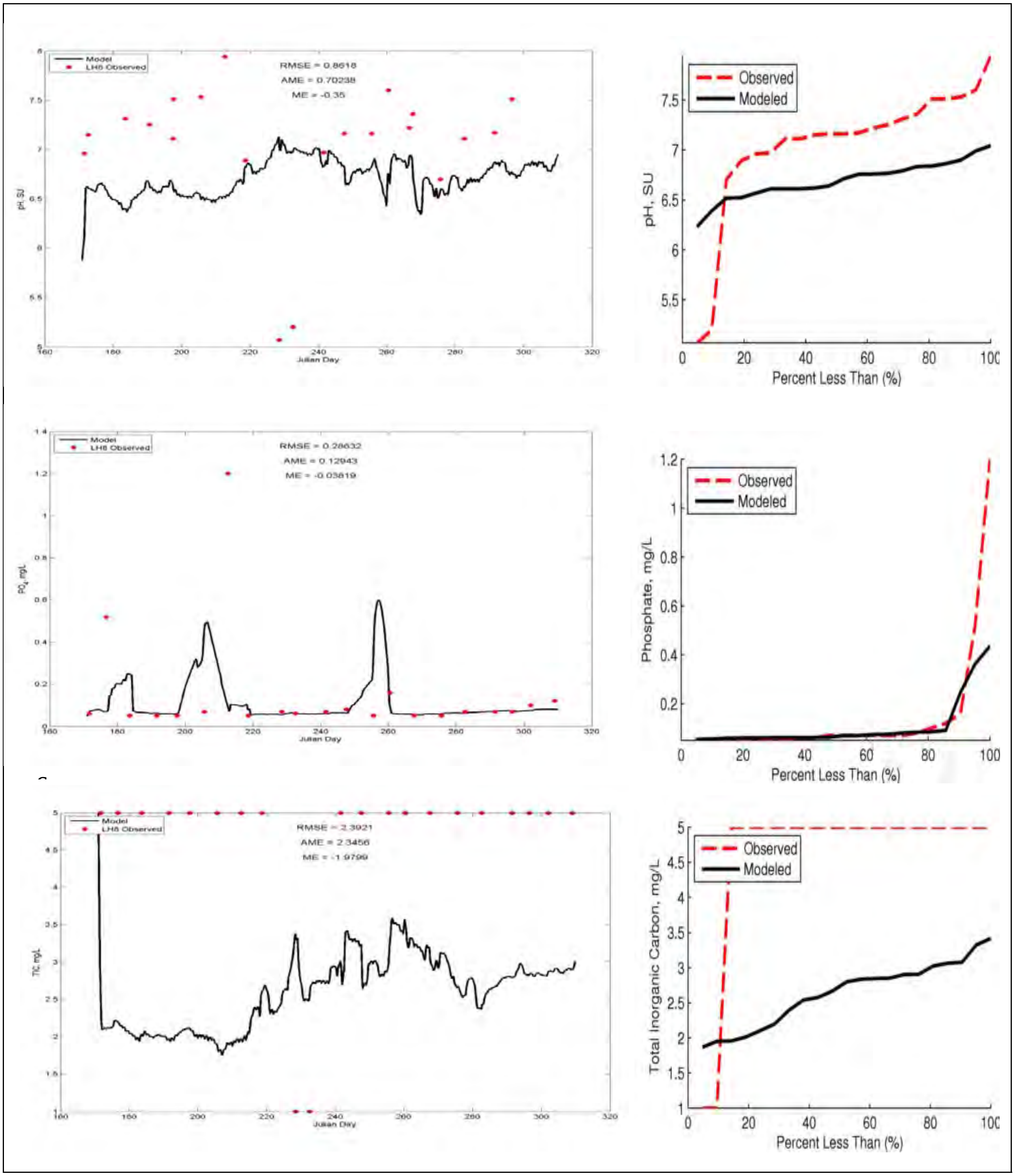


Figure 38. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH08 for pH, PO4, and TIC.

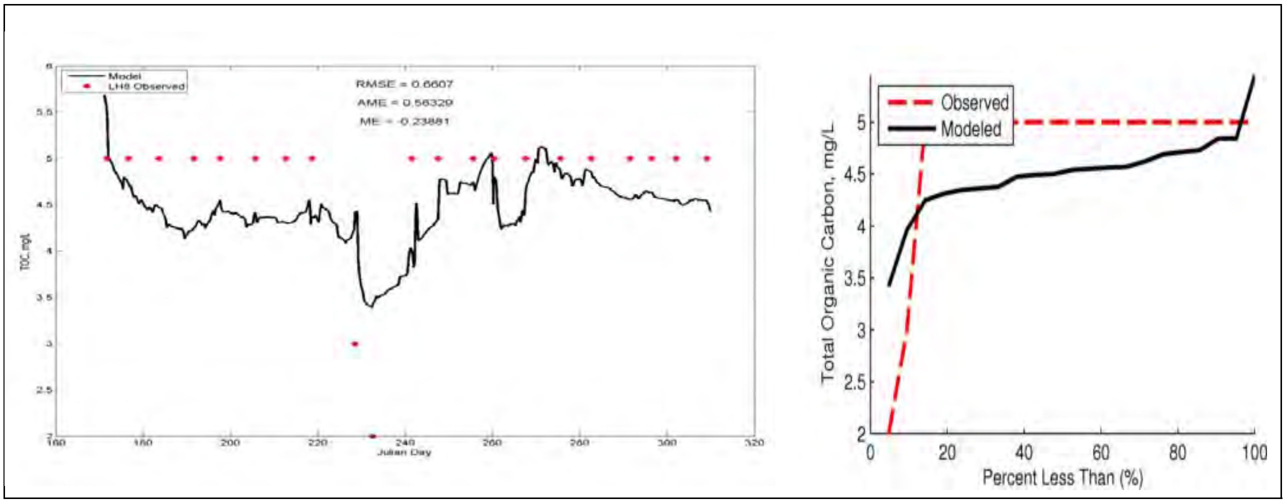


Figure 39. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH08 for TOC.

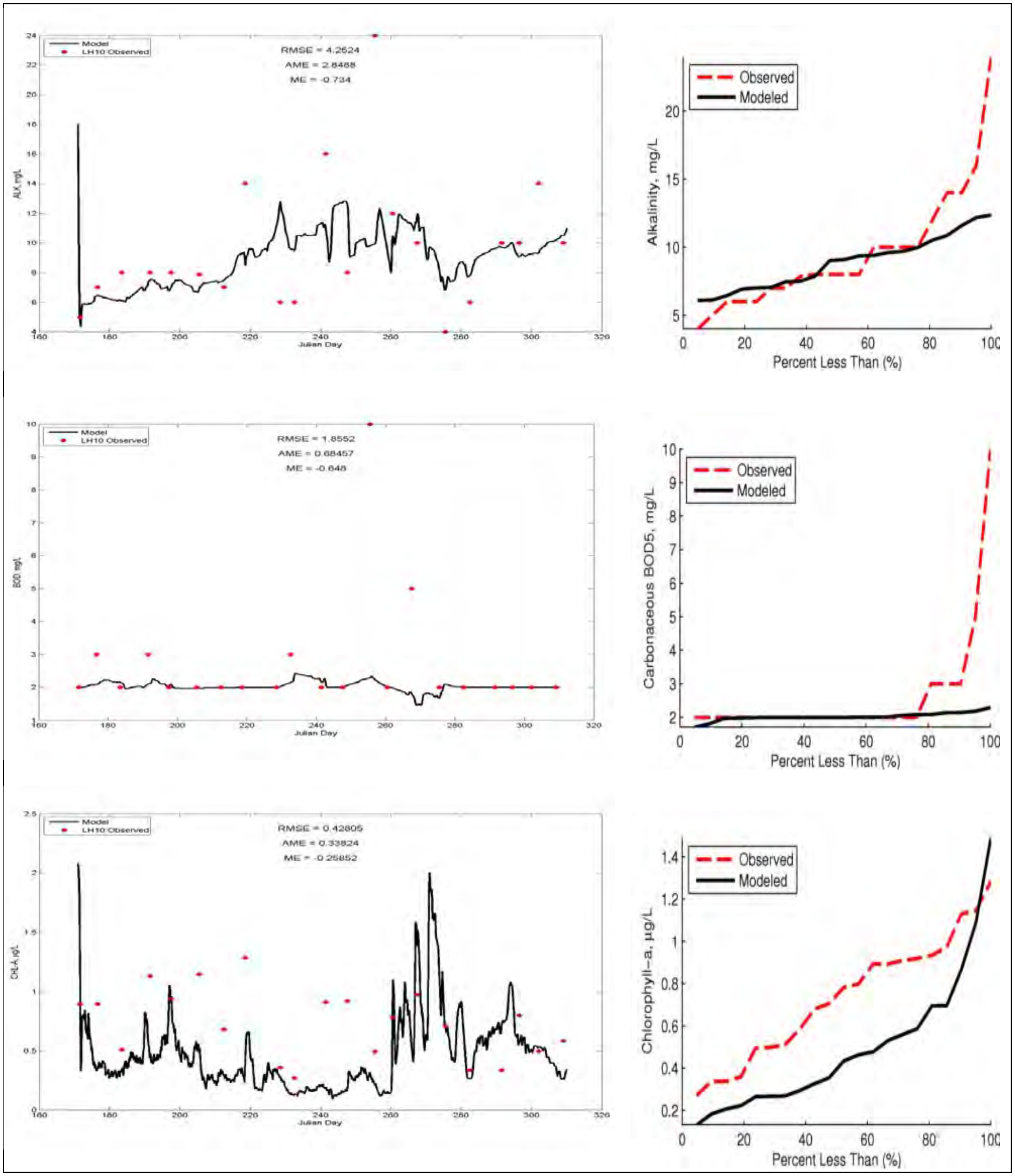


Figure 40. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH10 for alkalinity, BOD5, and Chla.

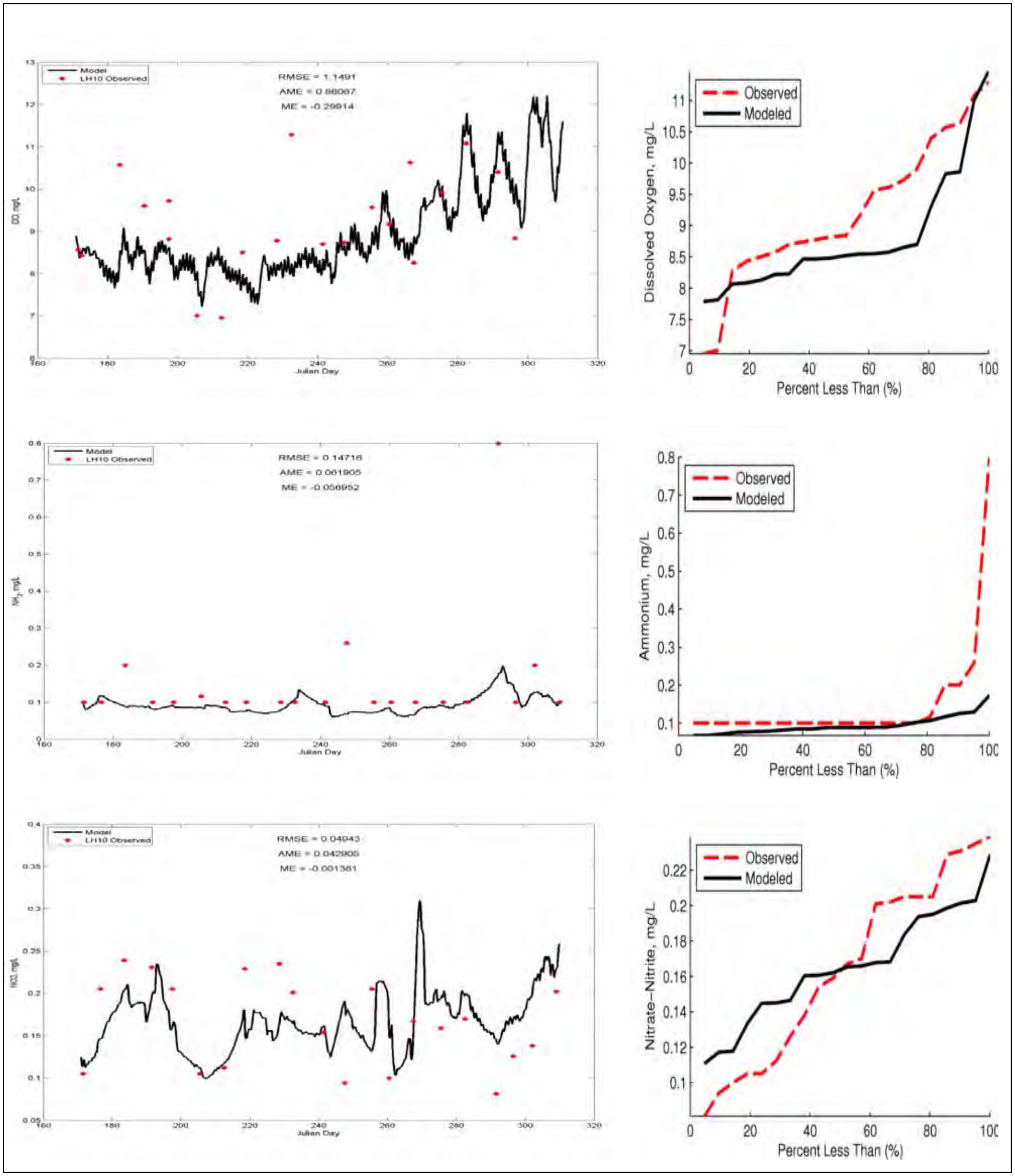


Figure 41. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH10 for DO, NH3, and NO2+NO3.

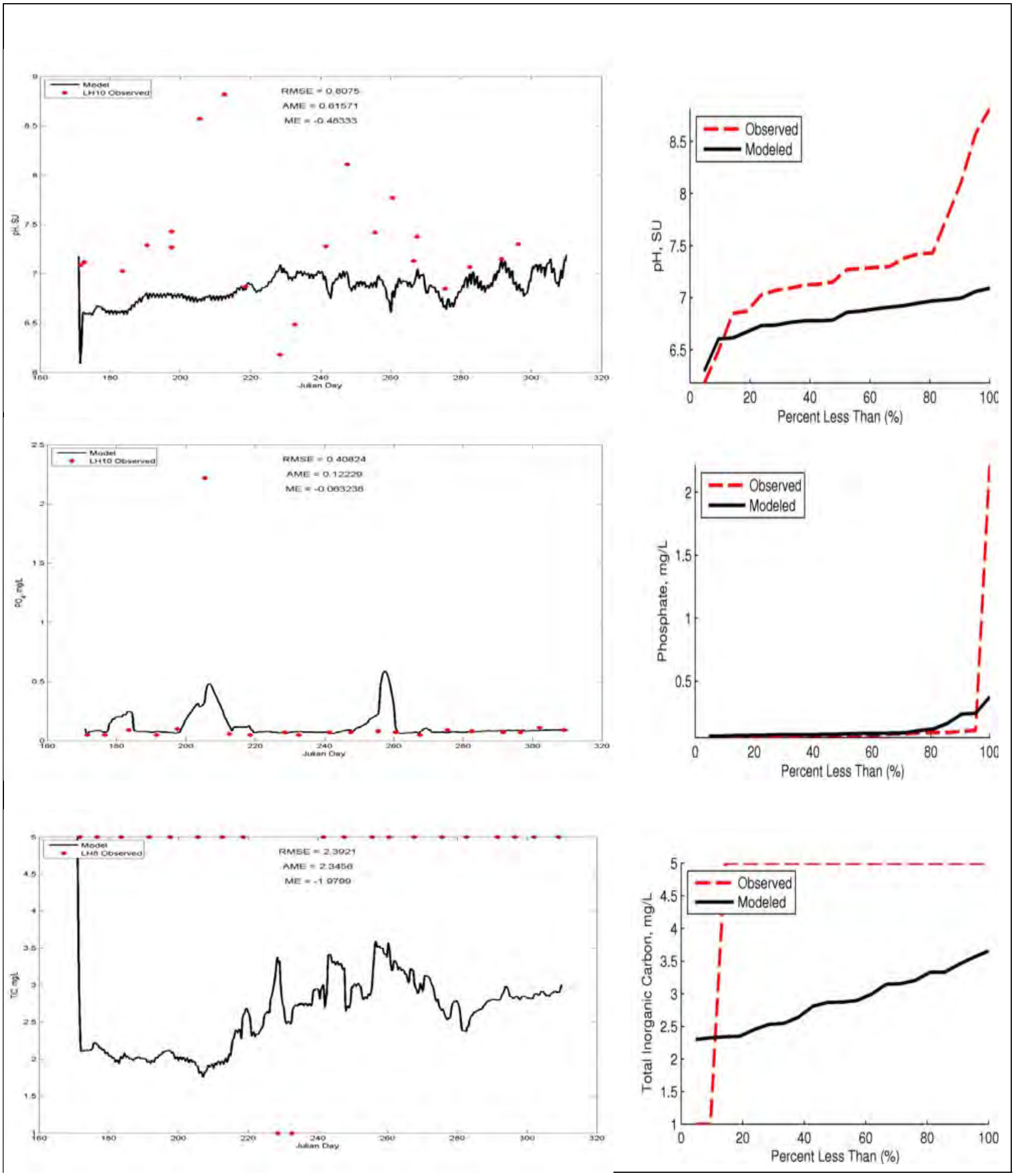


Figure 42. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH10 for pH, PO4, and TIC.

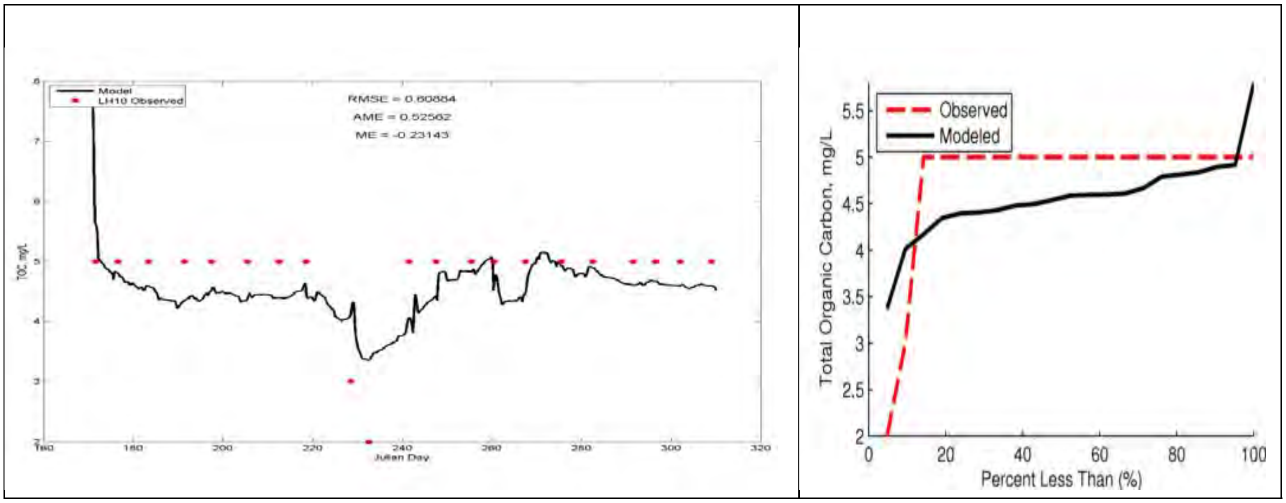


Figure 43. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH10 for TOC.

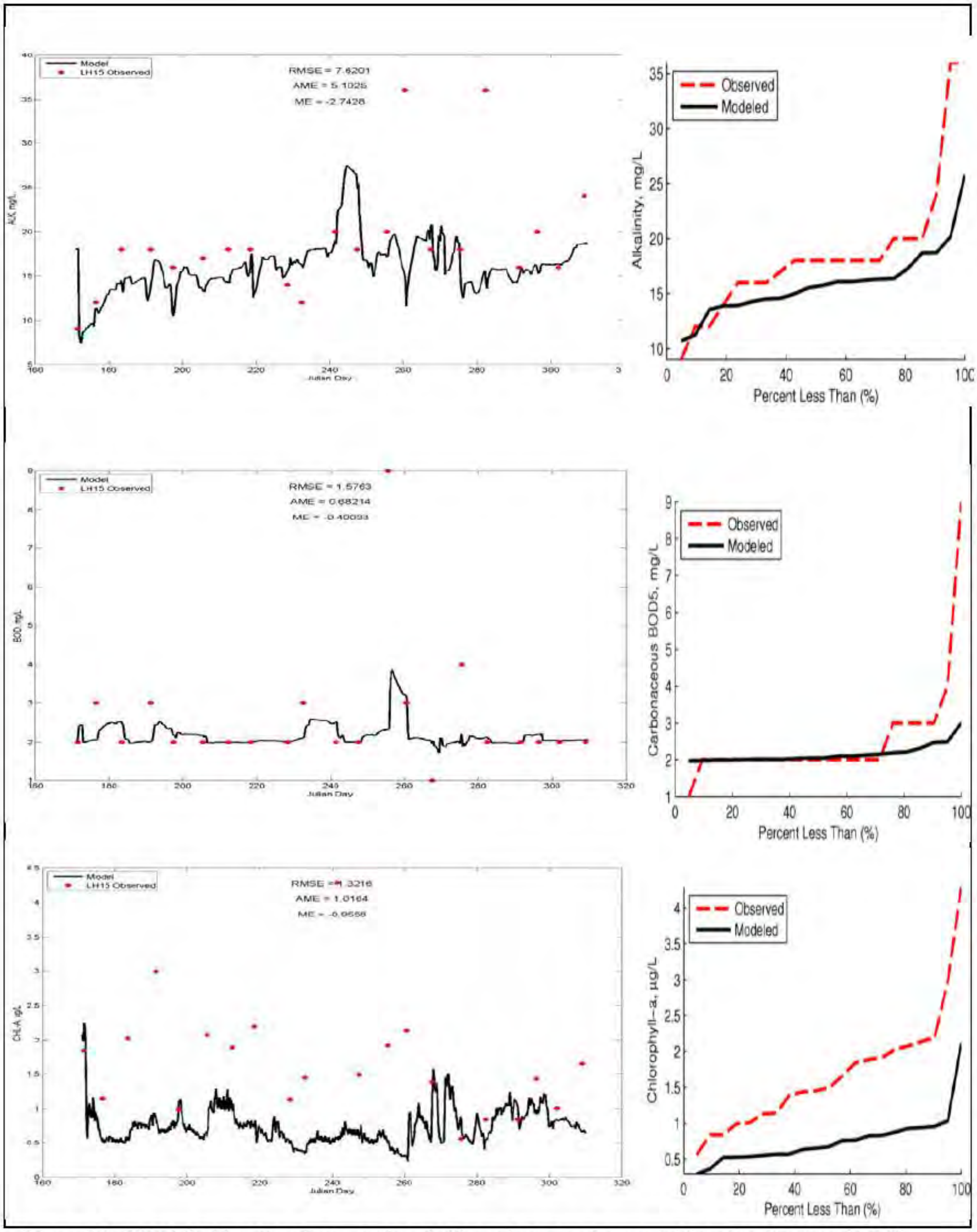


Figure 44. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH15 for alkalinity, BOD5, and Chla.

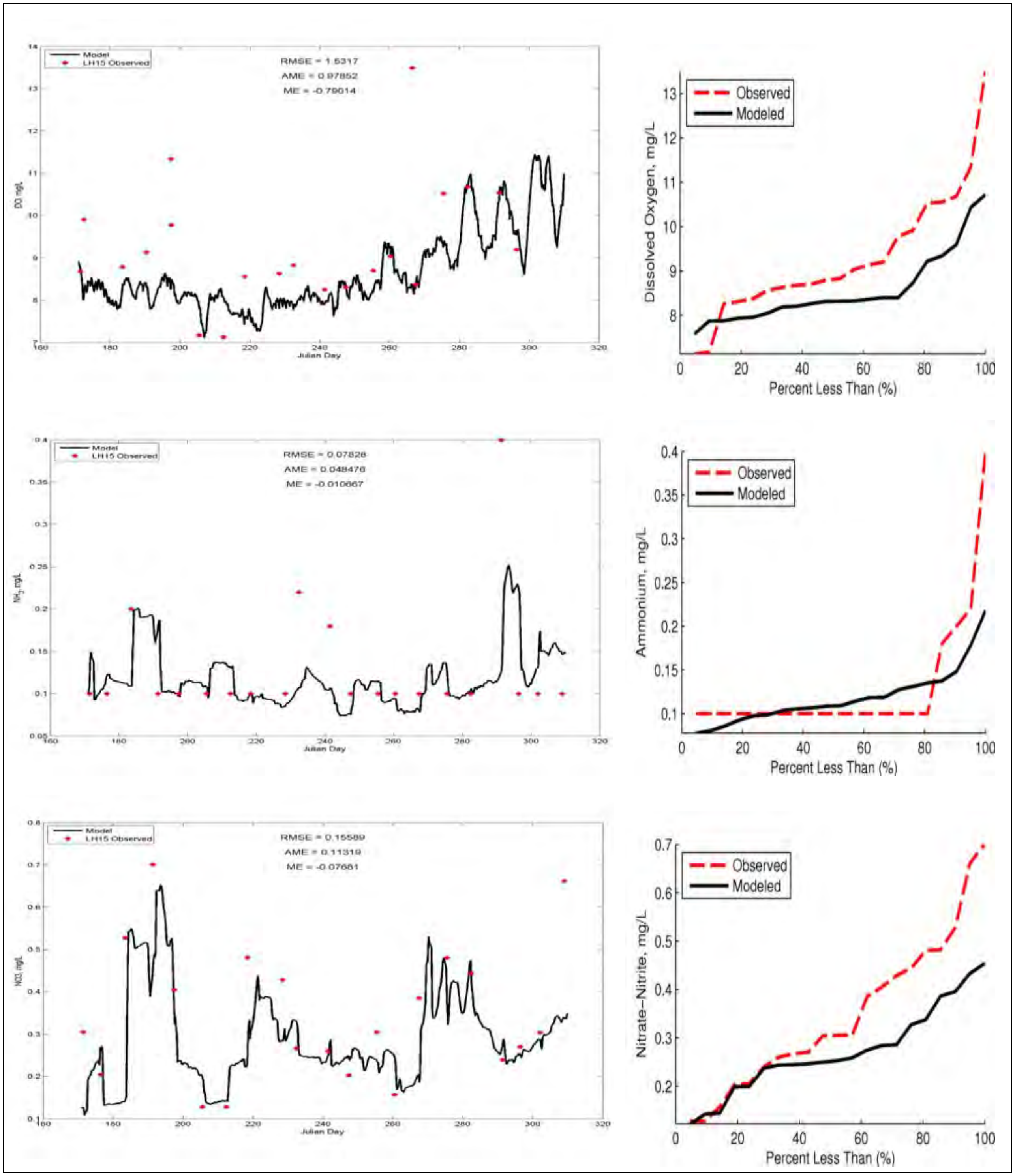


Figure 45. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH15 for DO, NH3, and NO2+NO3.

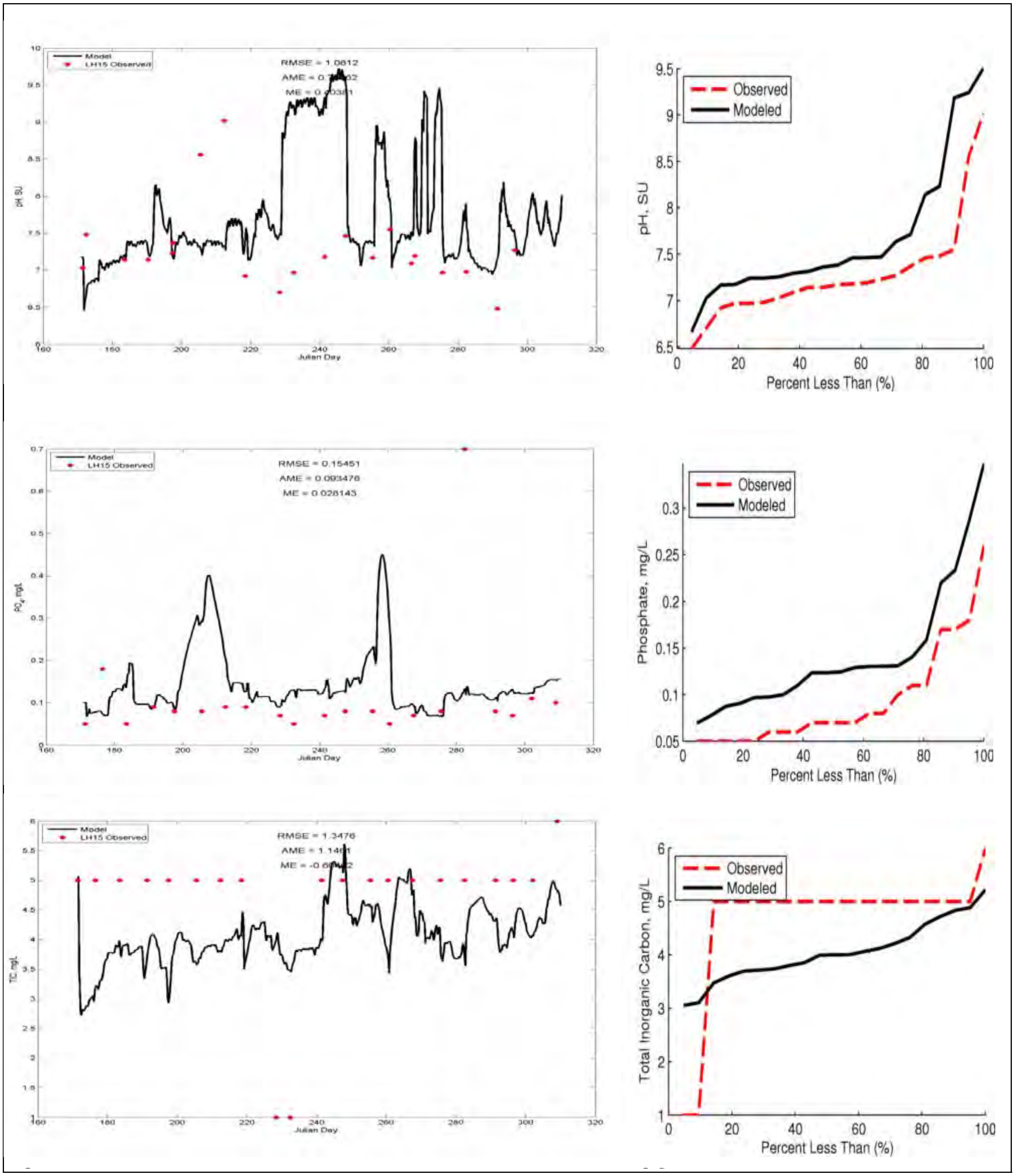


Figure 46. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH15 for pH, PO4, and TIC.

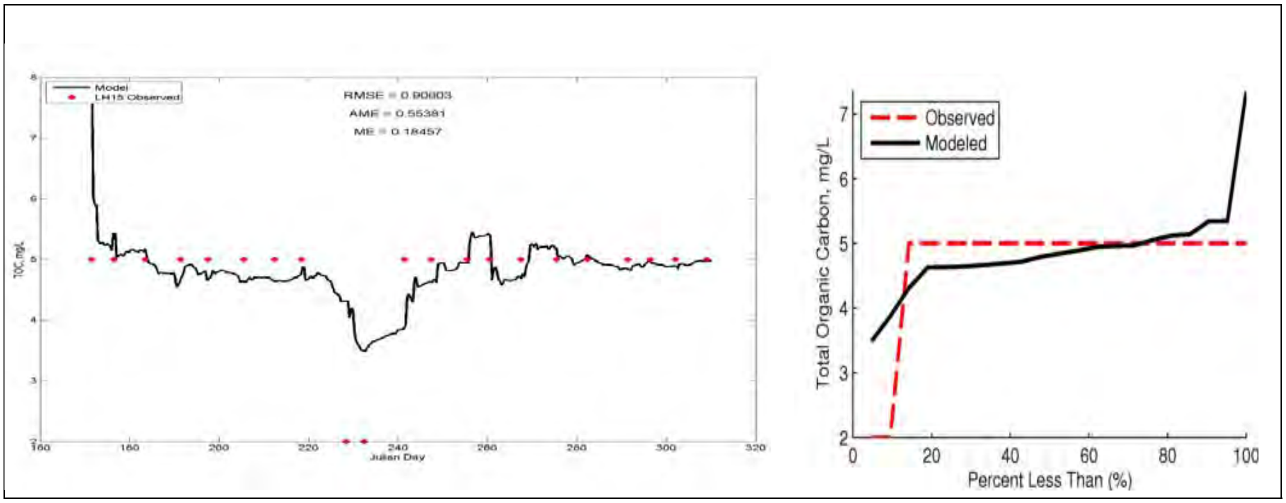


Figure 47. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH15 for TOC.

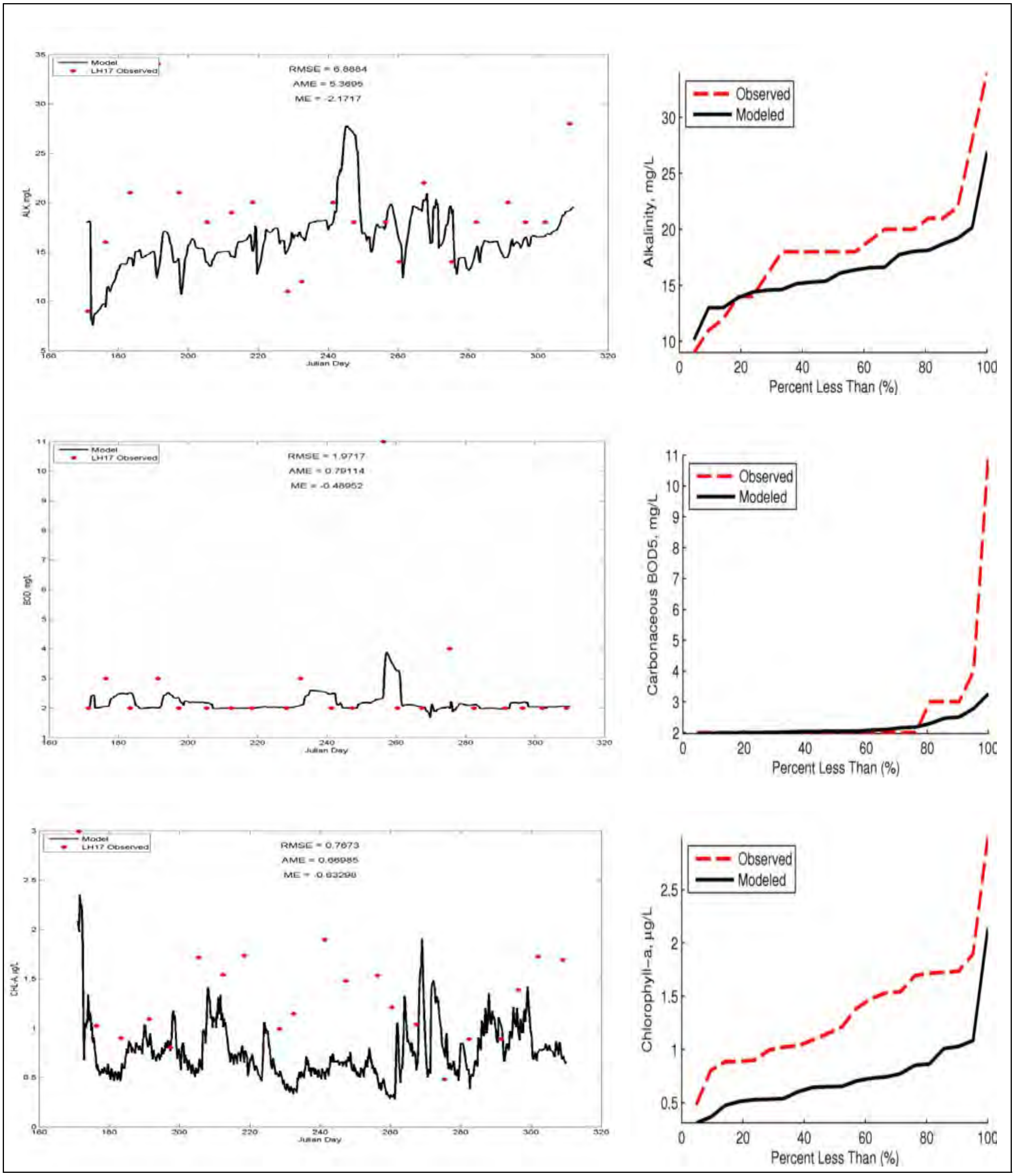


Figure 48. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH17 for alkalinity, BOD5, and Chla.

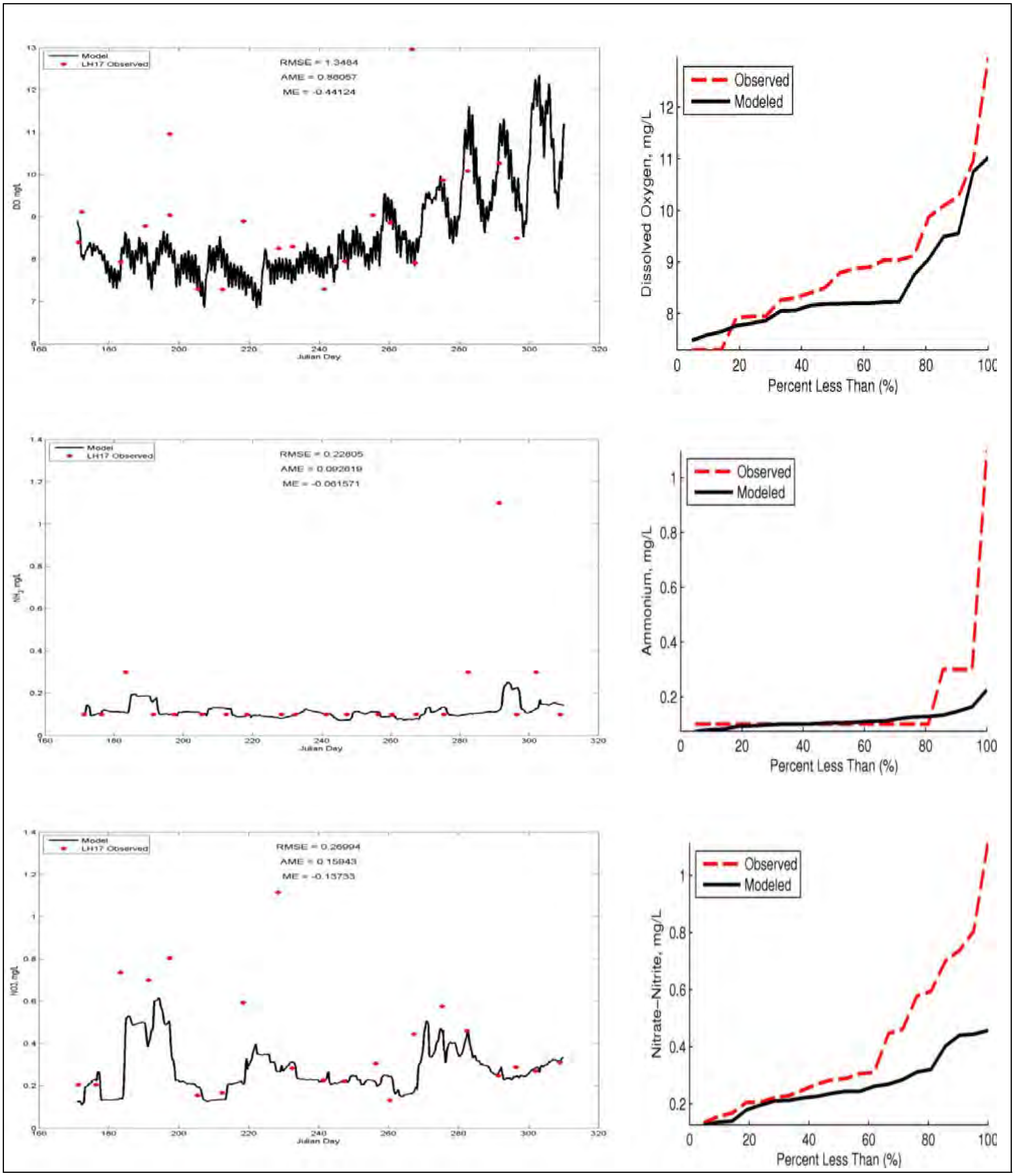


Figure 49. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH17 for DO, NH3, and NO2+NO3.

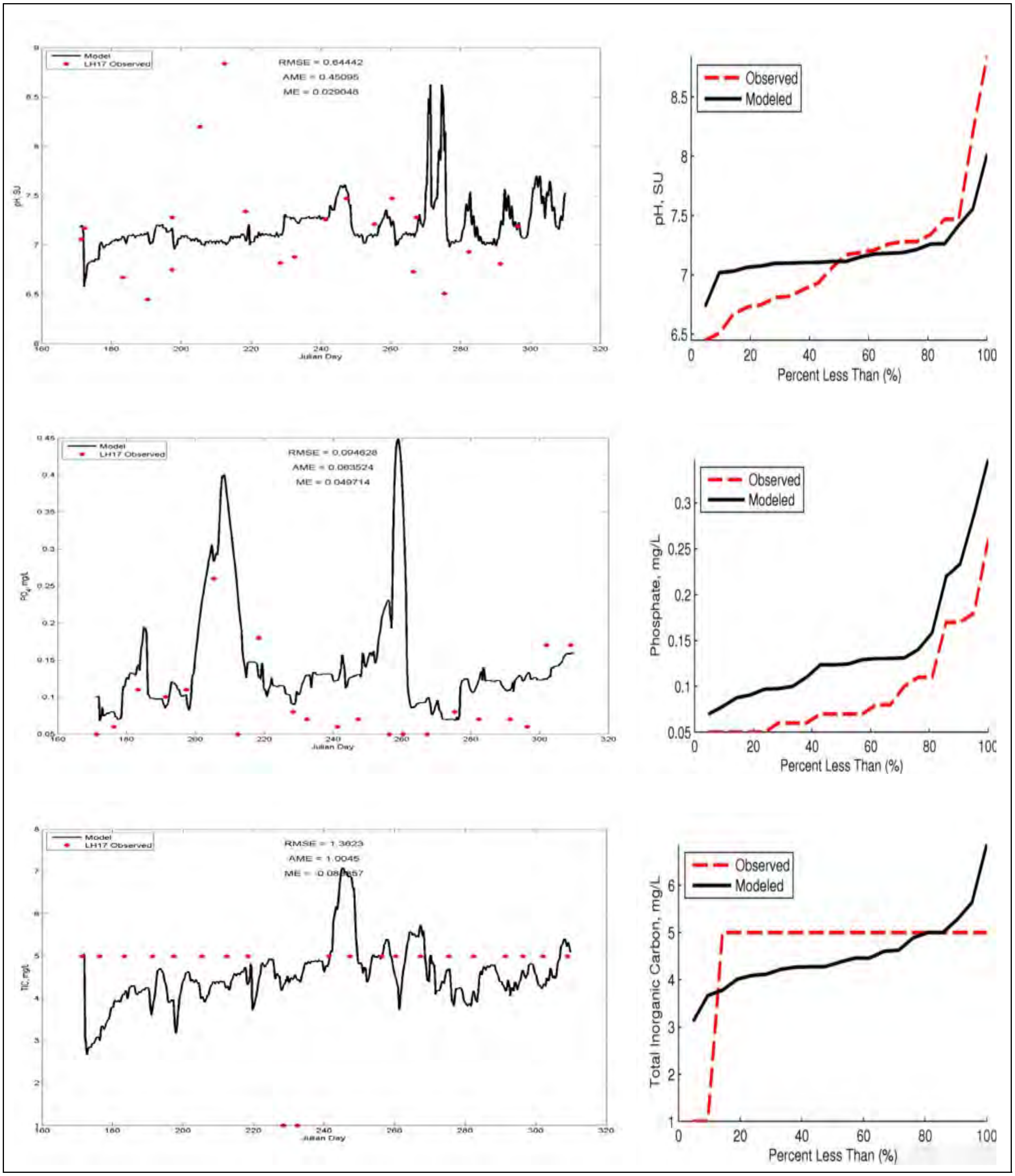


Figure 50. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH17 for pH, PO4, and TIC.

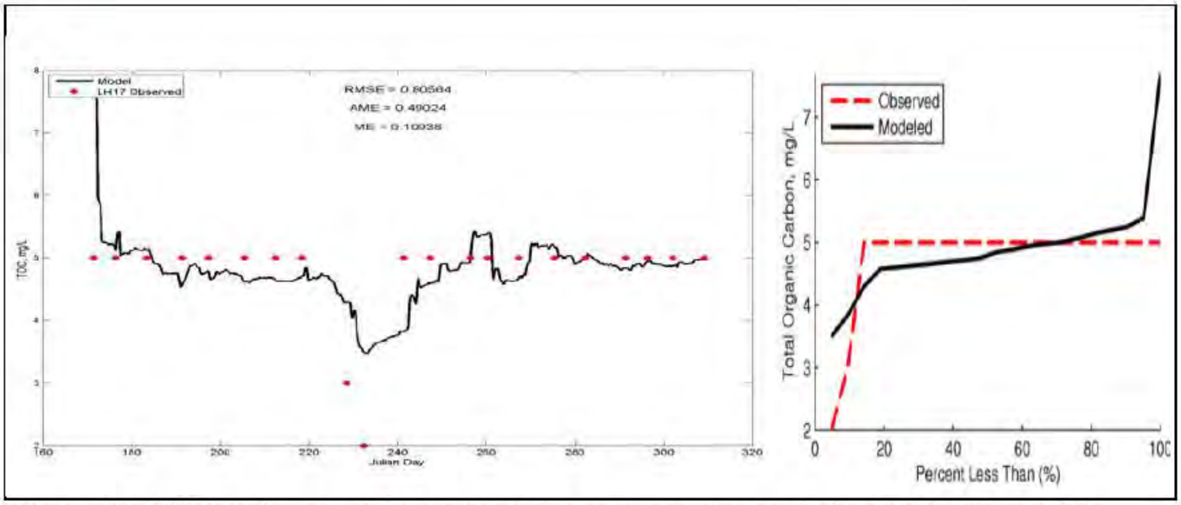


Figure 51. 2001 Calibration time series (left) and percent cumulative distribution (right) results at station LH17 for TOC.

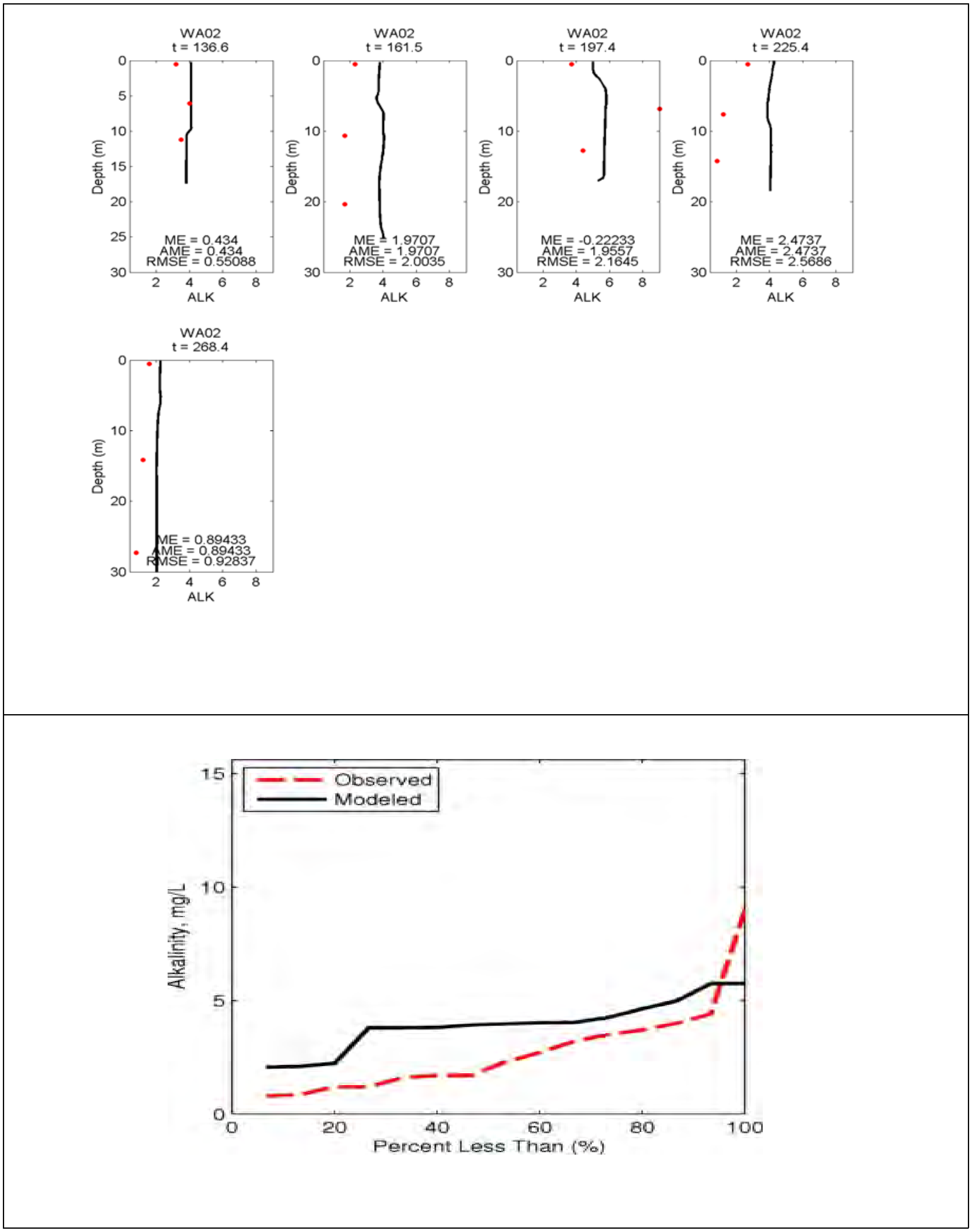


Figure 52. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results for alkalinity at station WA02 at F. E. Walter for 5 Julian dates.

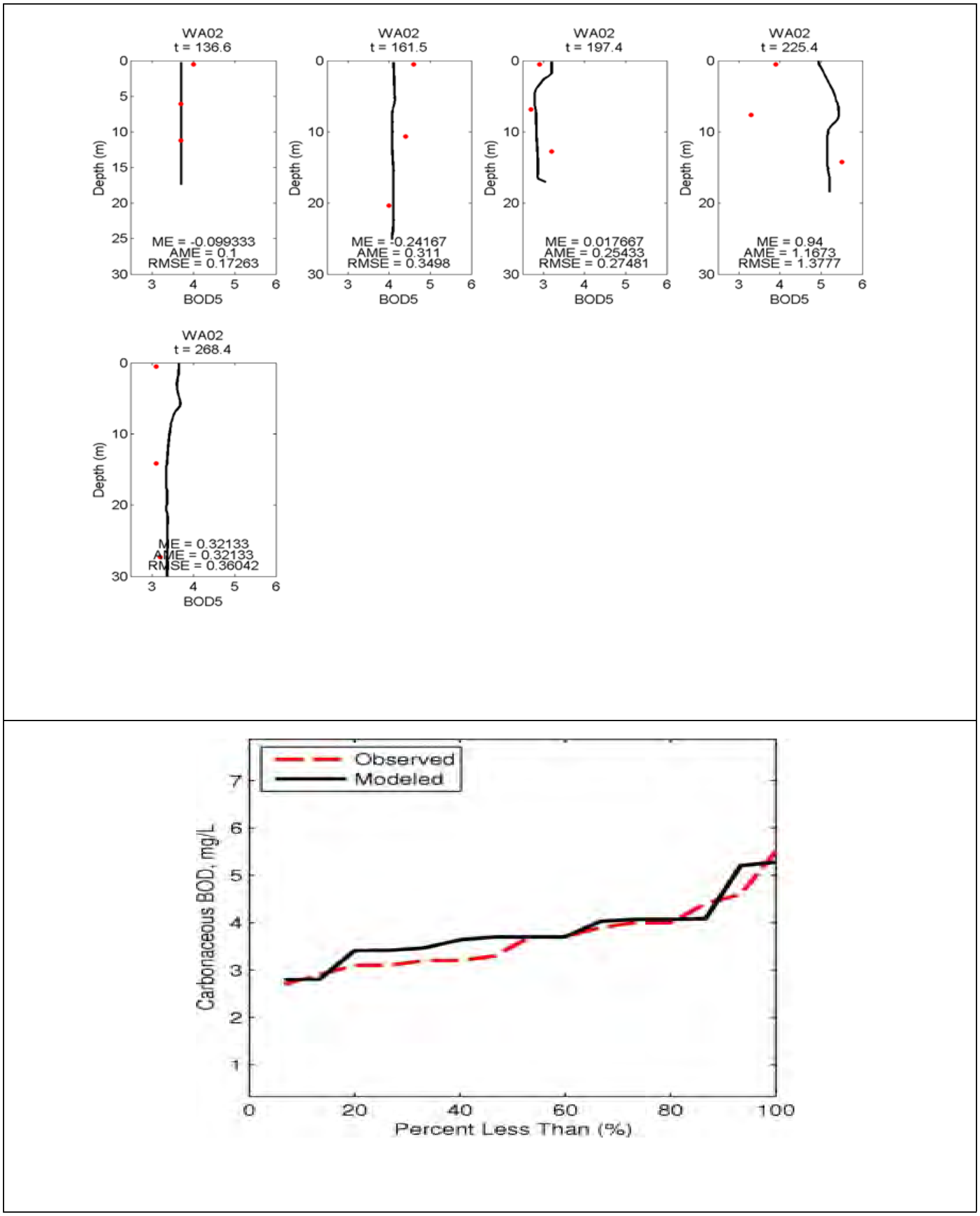


Figure 53. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results for BOD5 at station WA02 at F. E. Walter for 5 Julian dates.

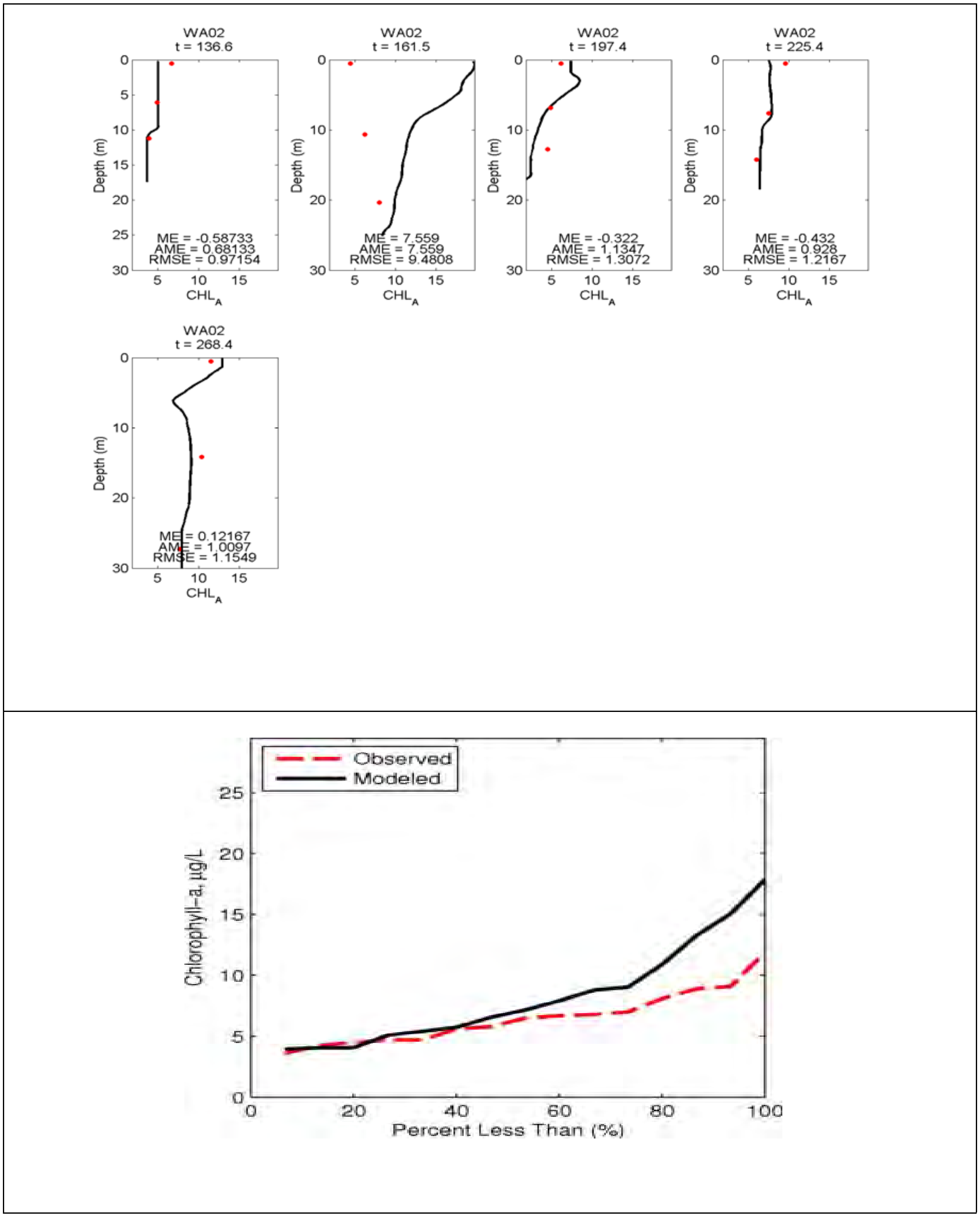


Figure 54. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results for chlorophyll *a* (CHLA) at station WA02 at F. E. Walter for 5 Julian dates.

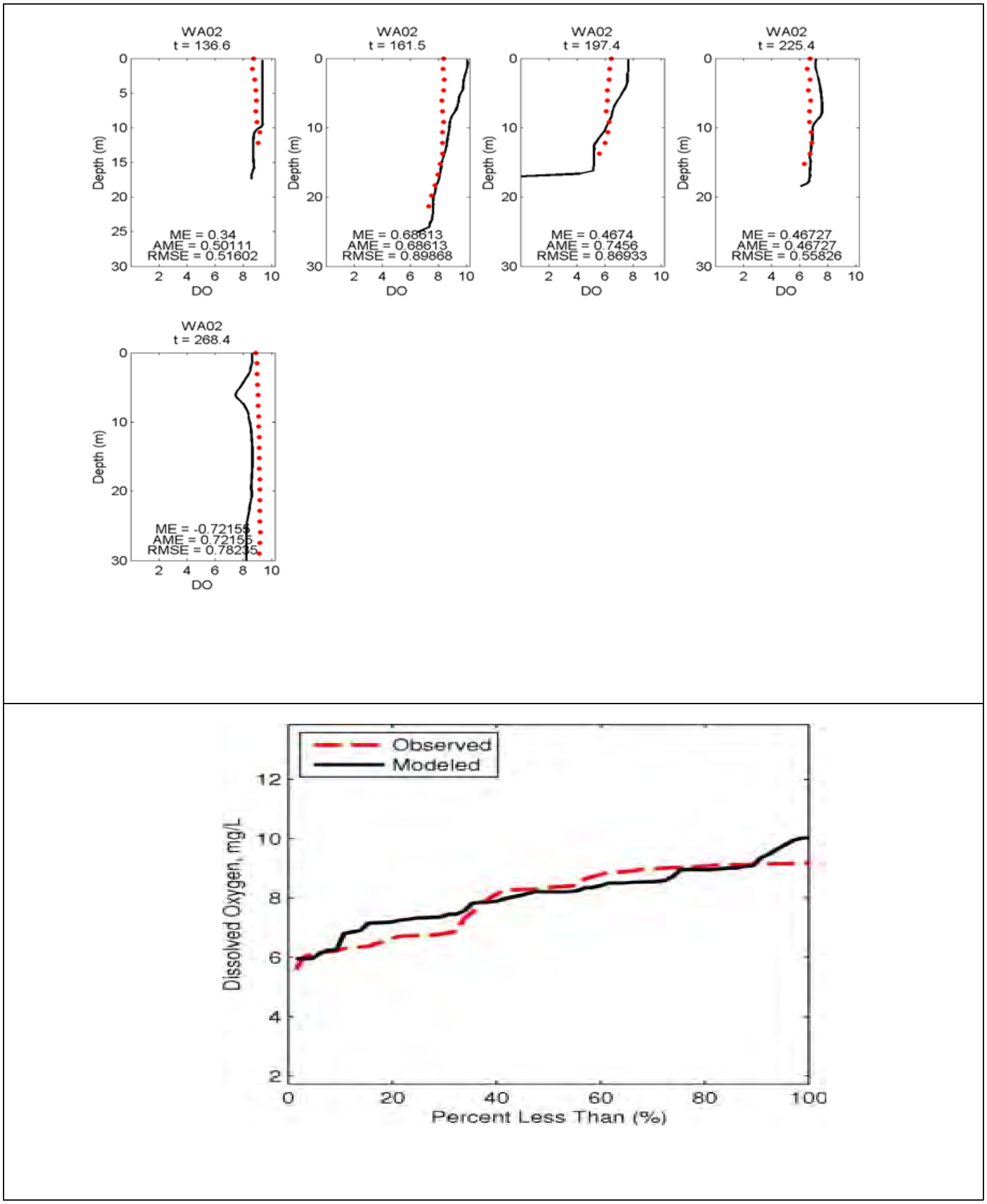


Figure 55. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results for DO at station WA02 at F. E. Walter for 5 Julian dates.

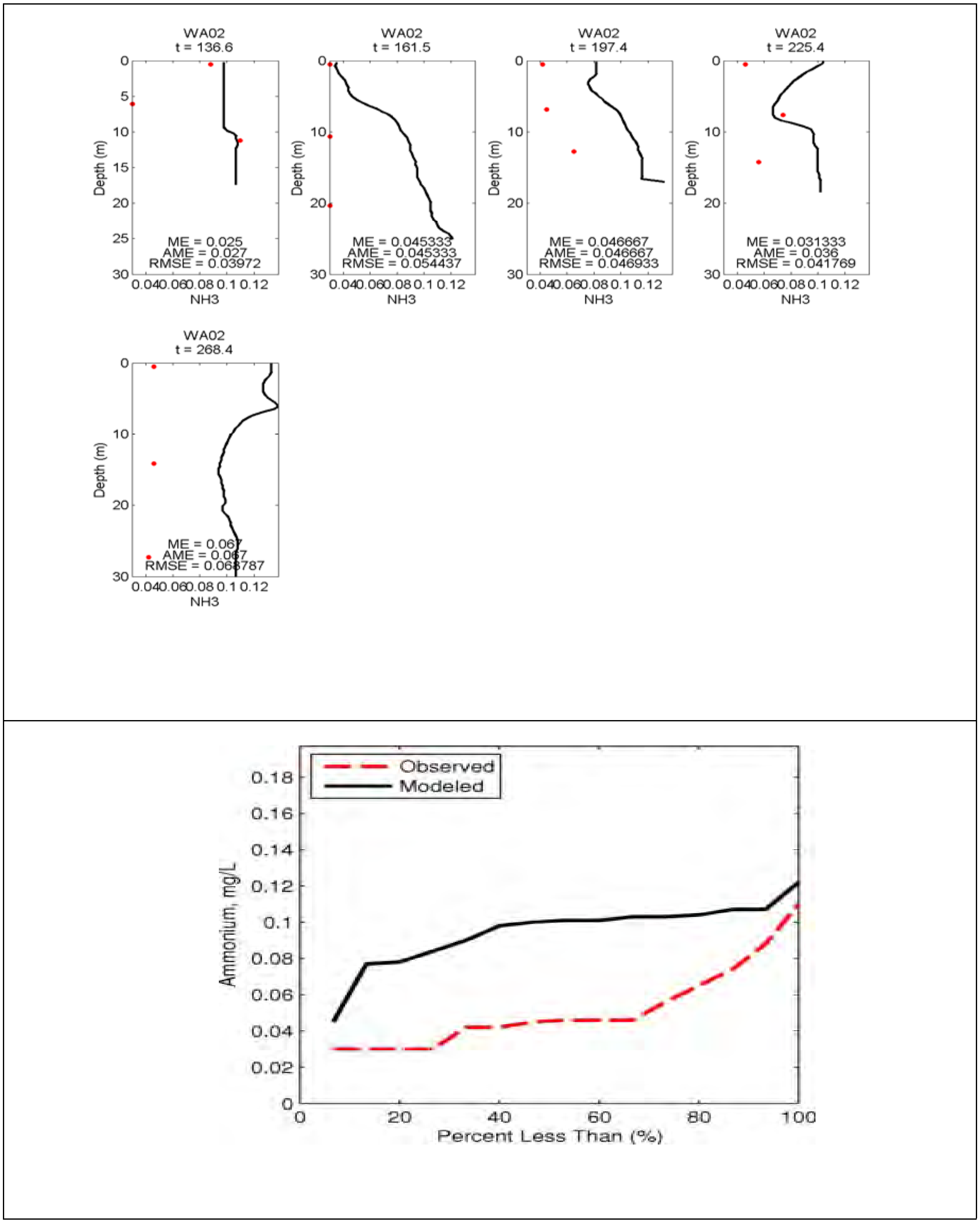


Figure 56. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results for NH3 at station WA02 at F. E. Walter for 5 Julian dates.

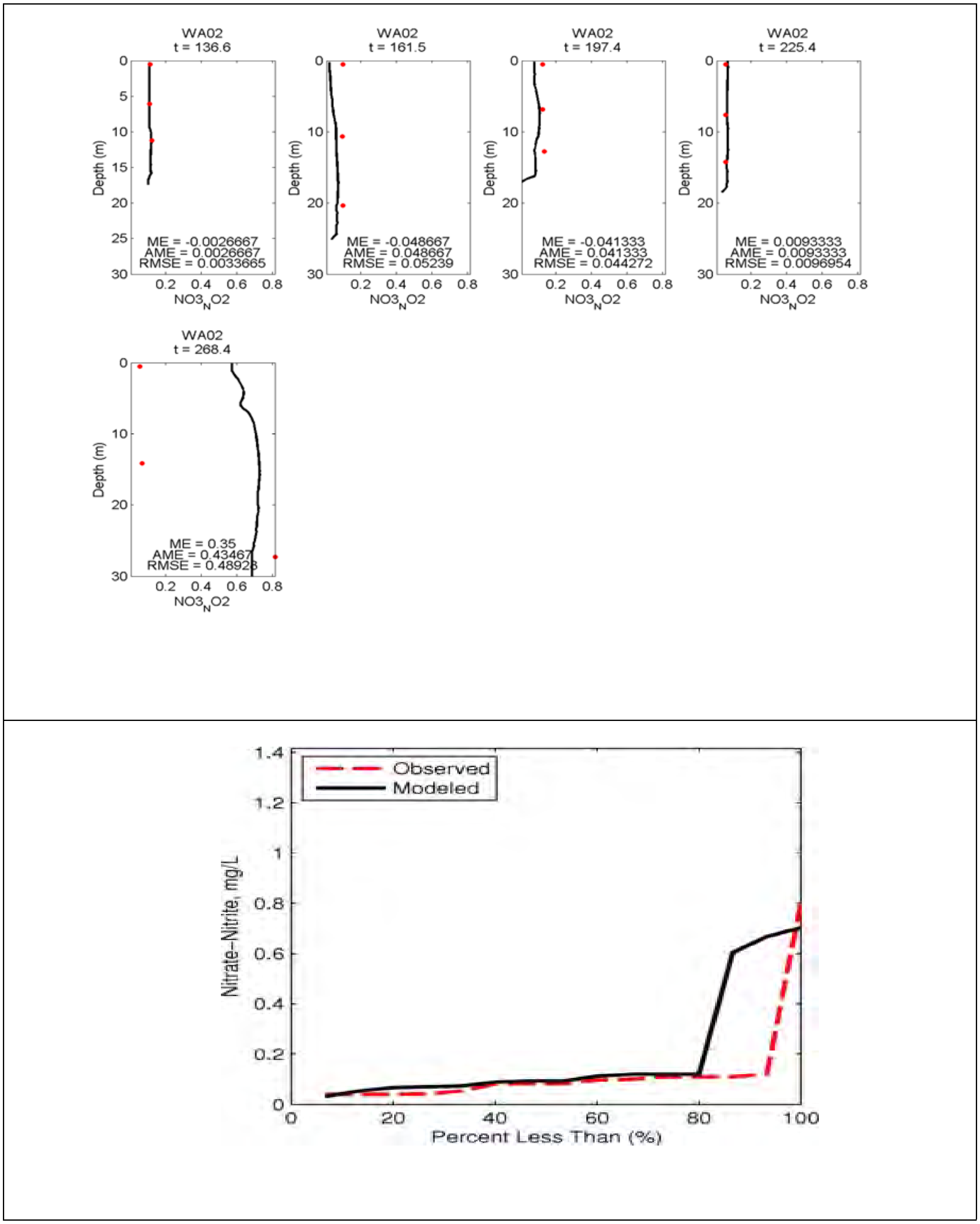


Figure 57. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results for NO3-NO2 at station WA02 at F. E. Walter for 5 Julian dates.

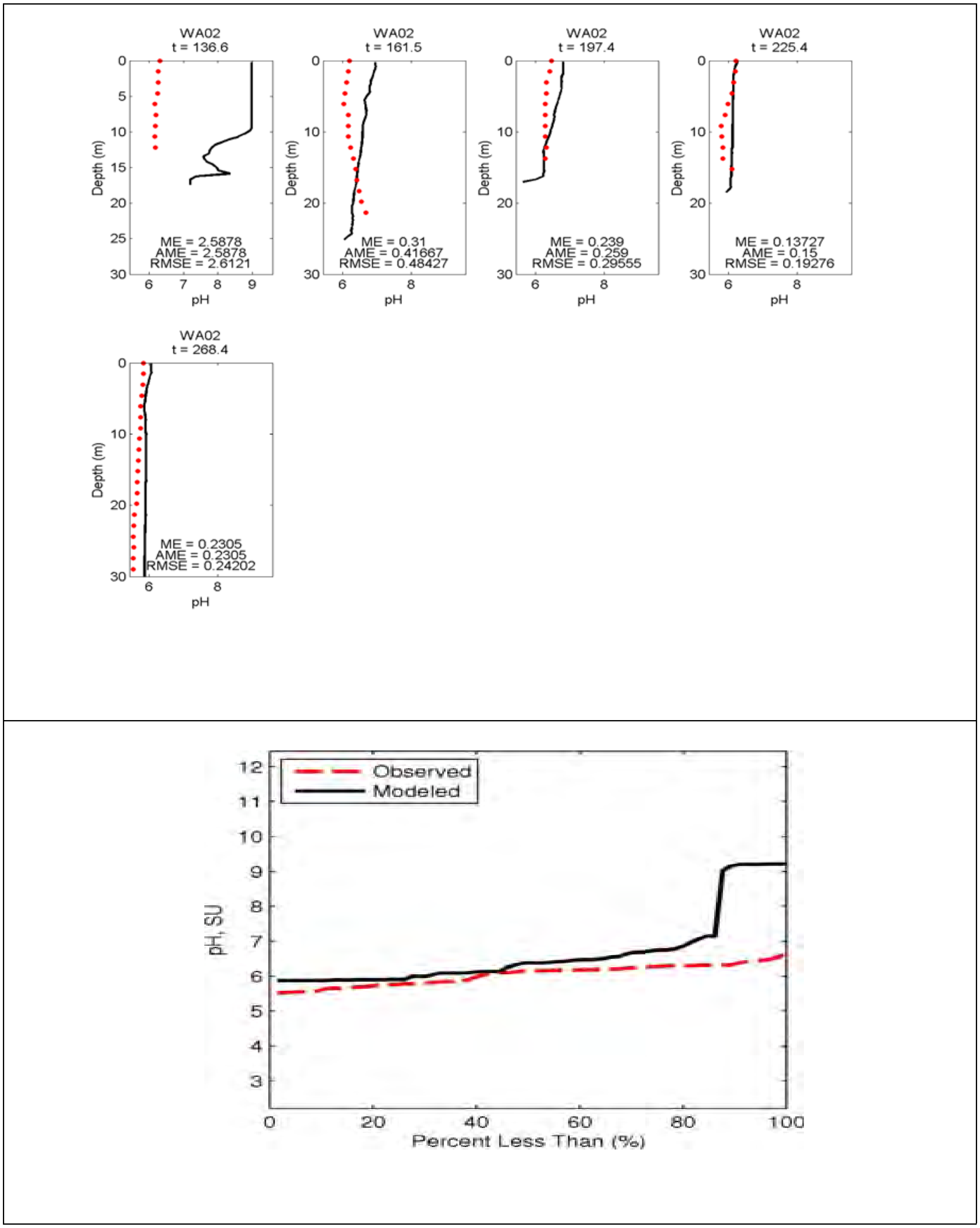
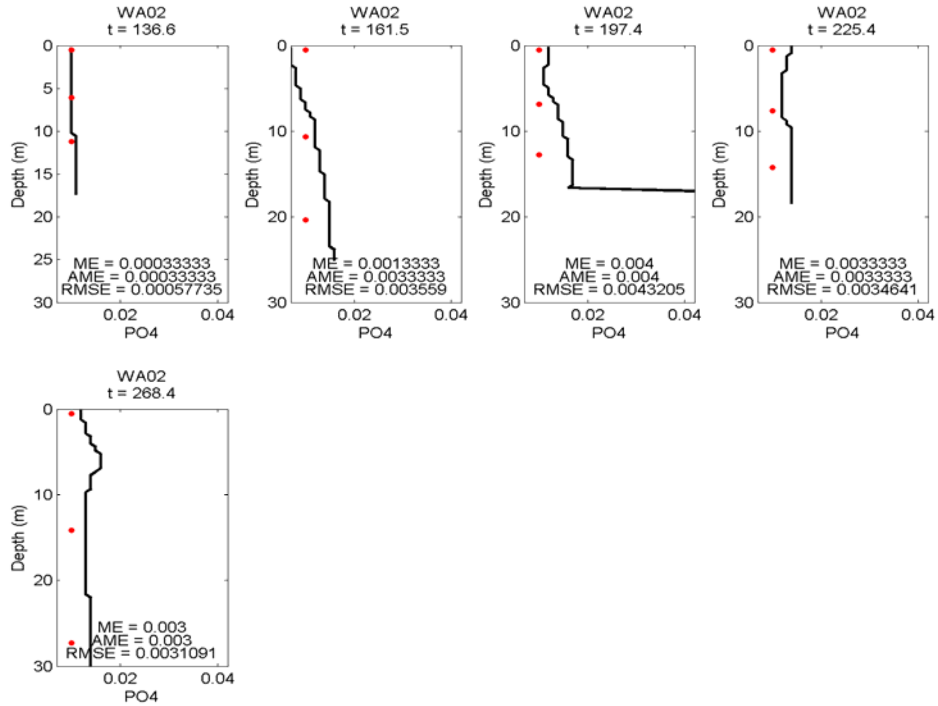


Figure 58. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results for pH at station WA02 at F. E. Walter for 5 Julian dates.



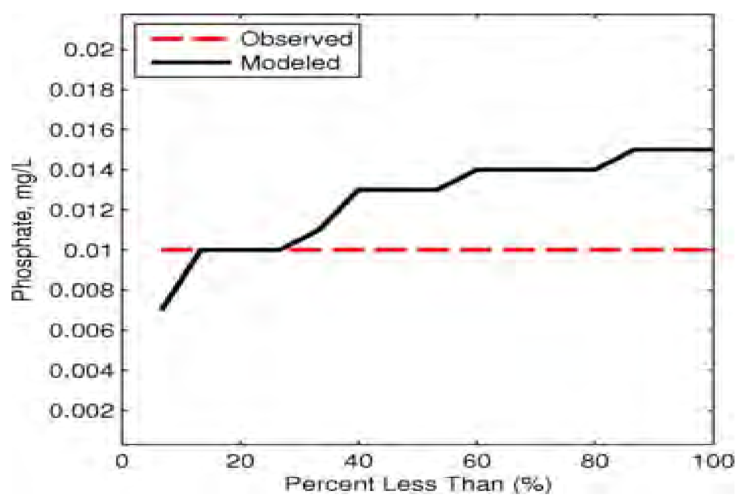


Figure 59. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results pH and PO4 at station WA02 at F. E. Walter for 5 Julian dates.

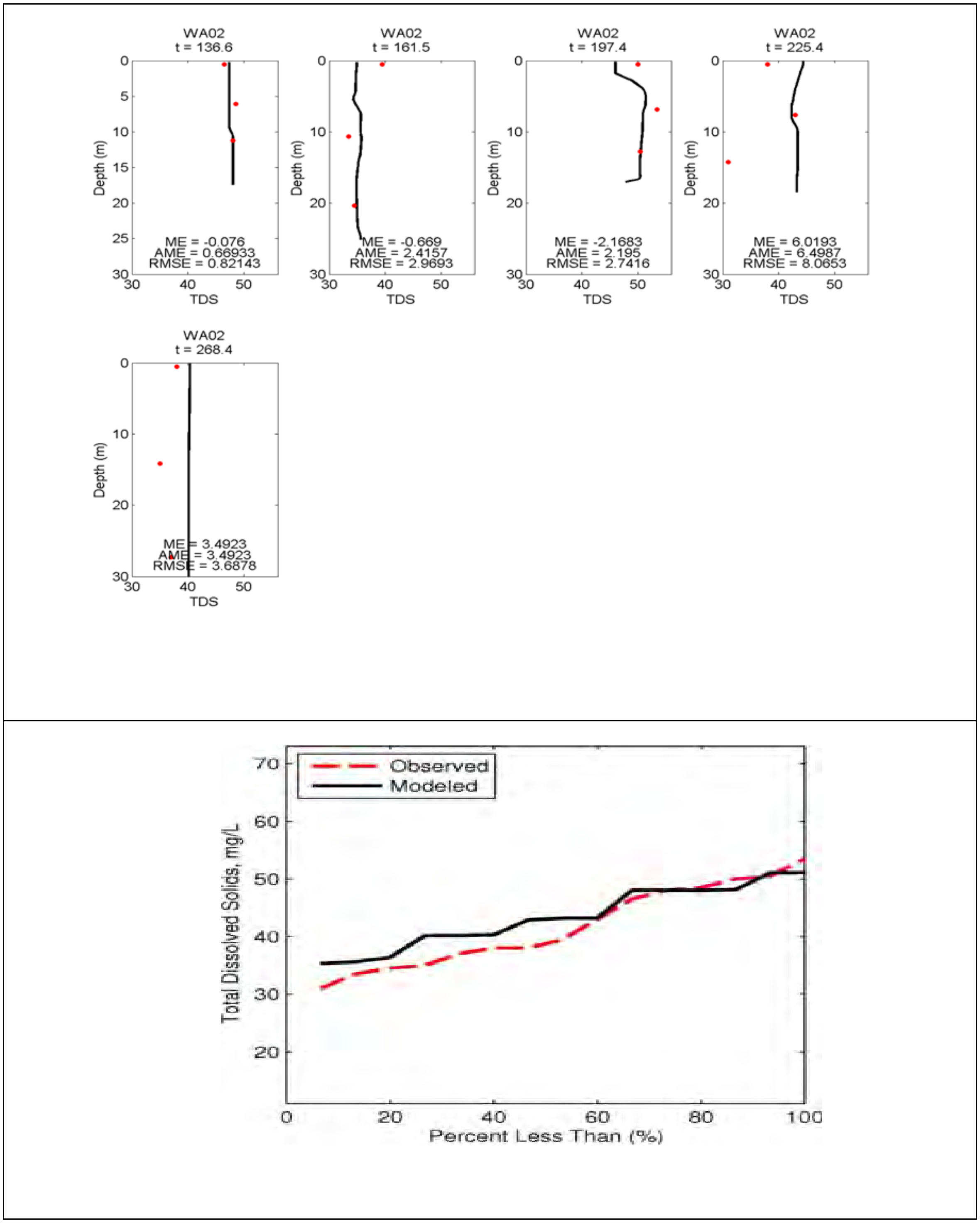


Figure 60. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results for TDS at station WA02 at F. E. Walter for 5 Julian dates.

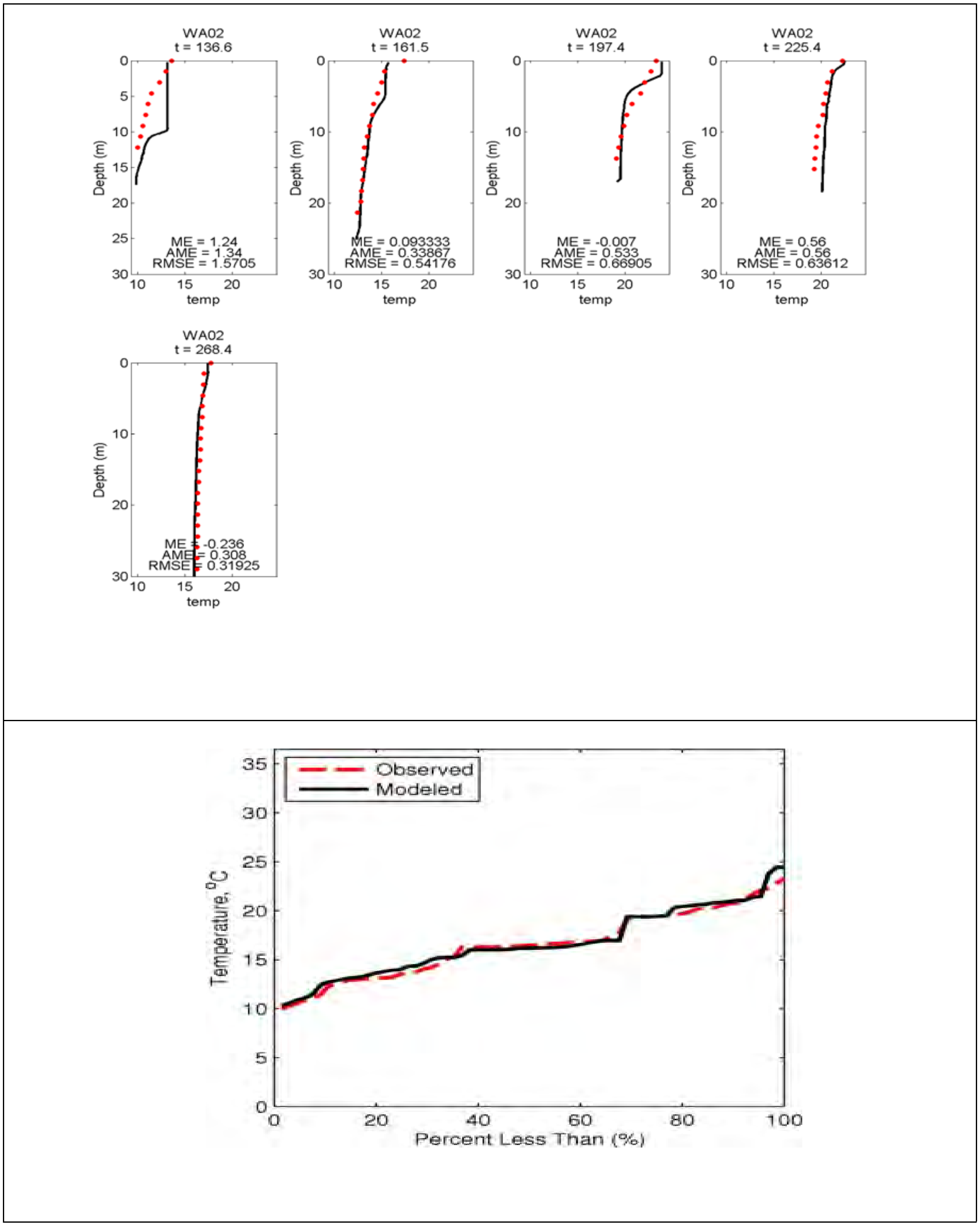


Figure 61. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results for TDS and temperature at station WA02 at F. E. Walter for 5 Julian dates.

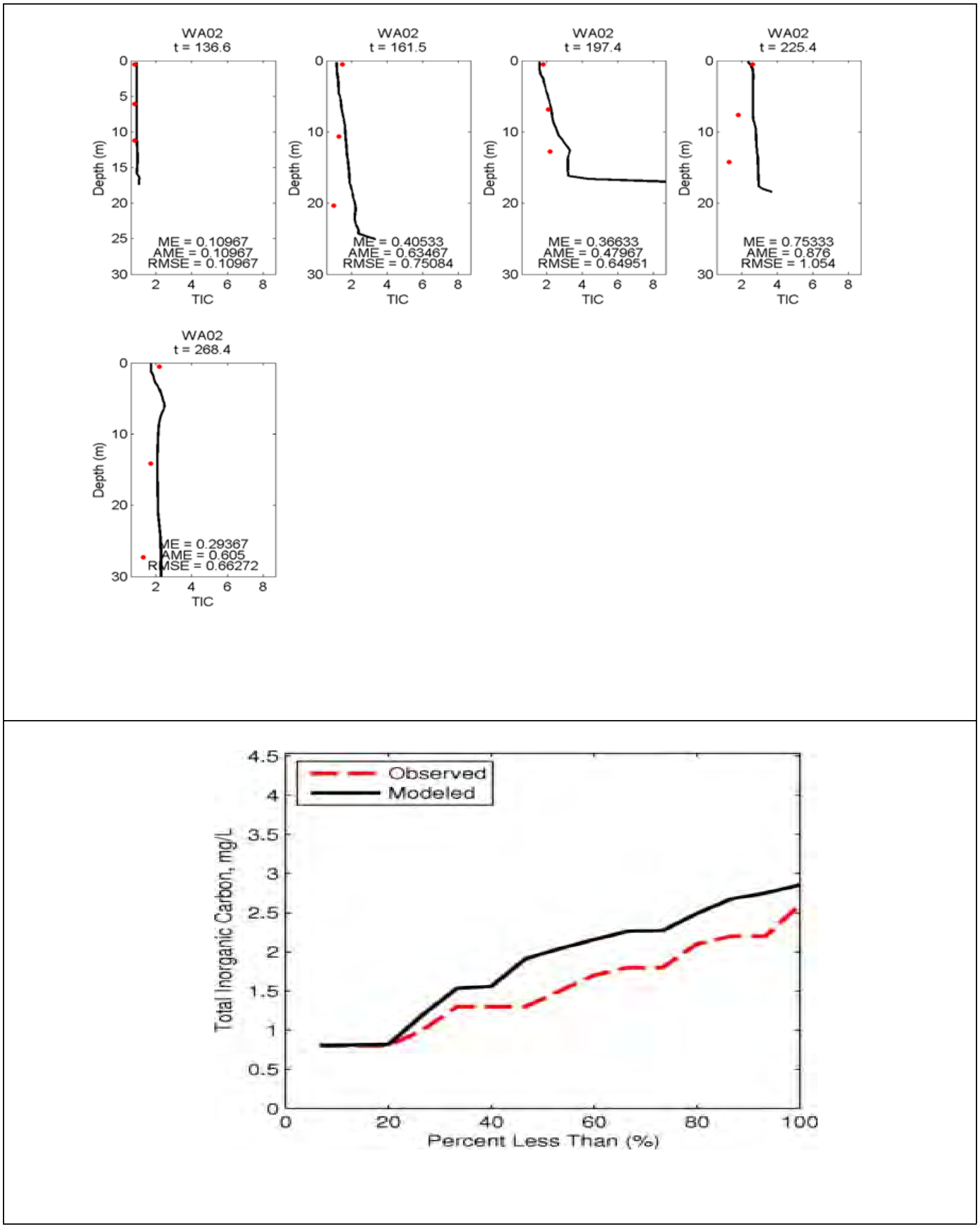


Figure 62. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results for TIC at station WA02 at F. E. Walter for 5 Julian dates.

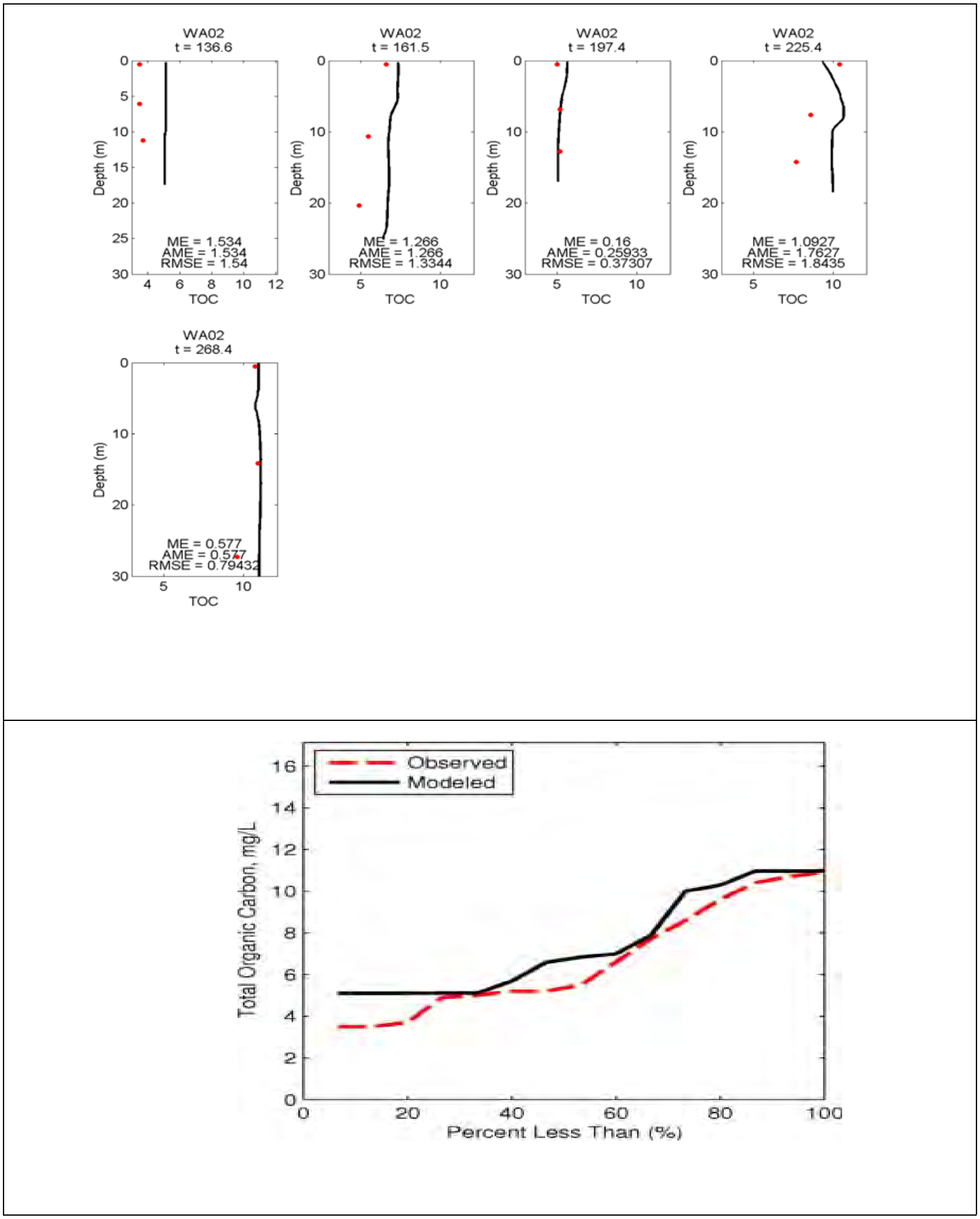


Figure 63. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results for TOC at station WA02 at F. E. Walter for 5 Julian dates.

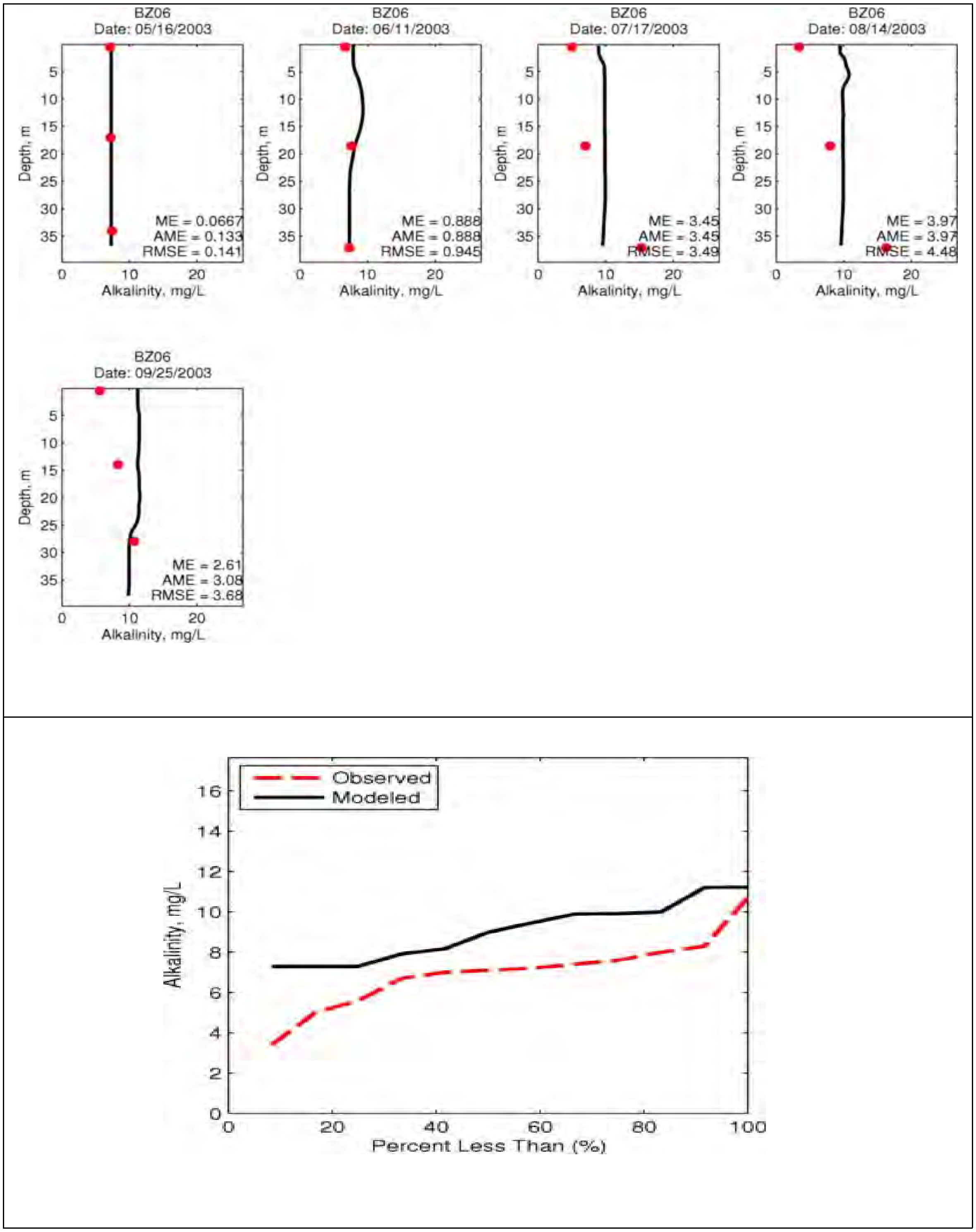


Figure 64. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results at station BZ06 for Alkalinity at Beltzville for 5 Julian dates.

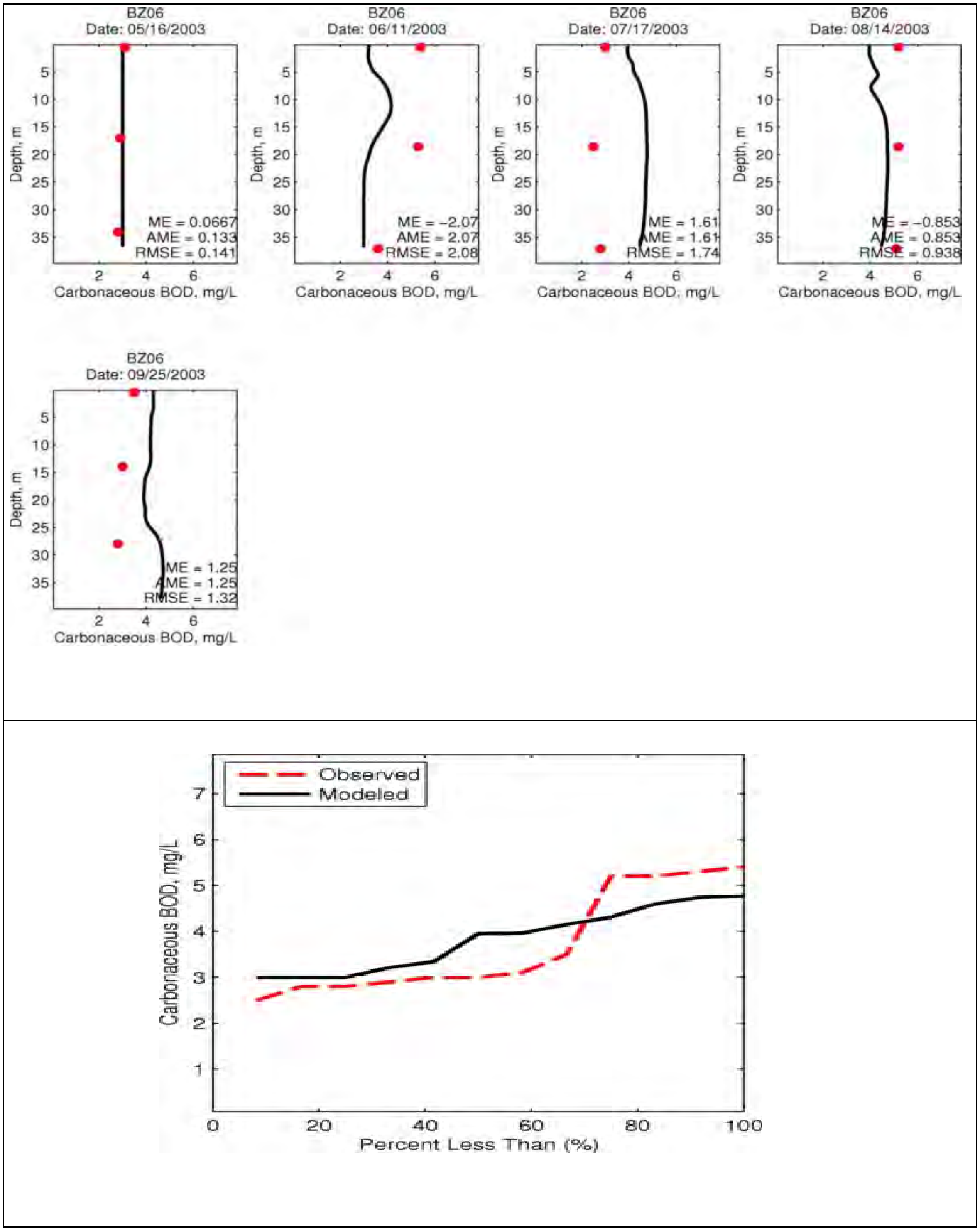


Figure 65. Calibration profiles (upper) and percent cumulative distribution (lower) results at station BZ06 for CBOD5 at Beltzville for 5 Julian dates.

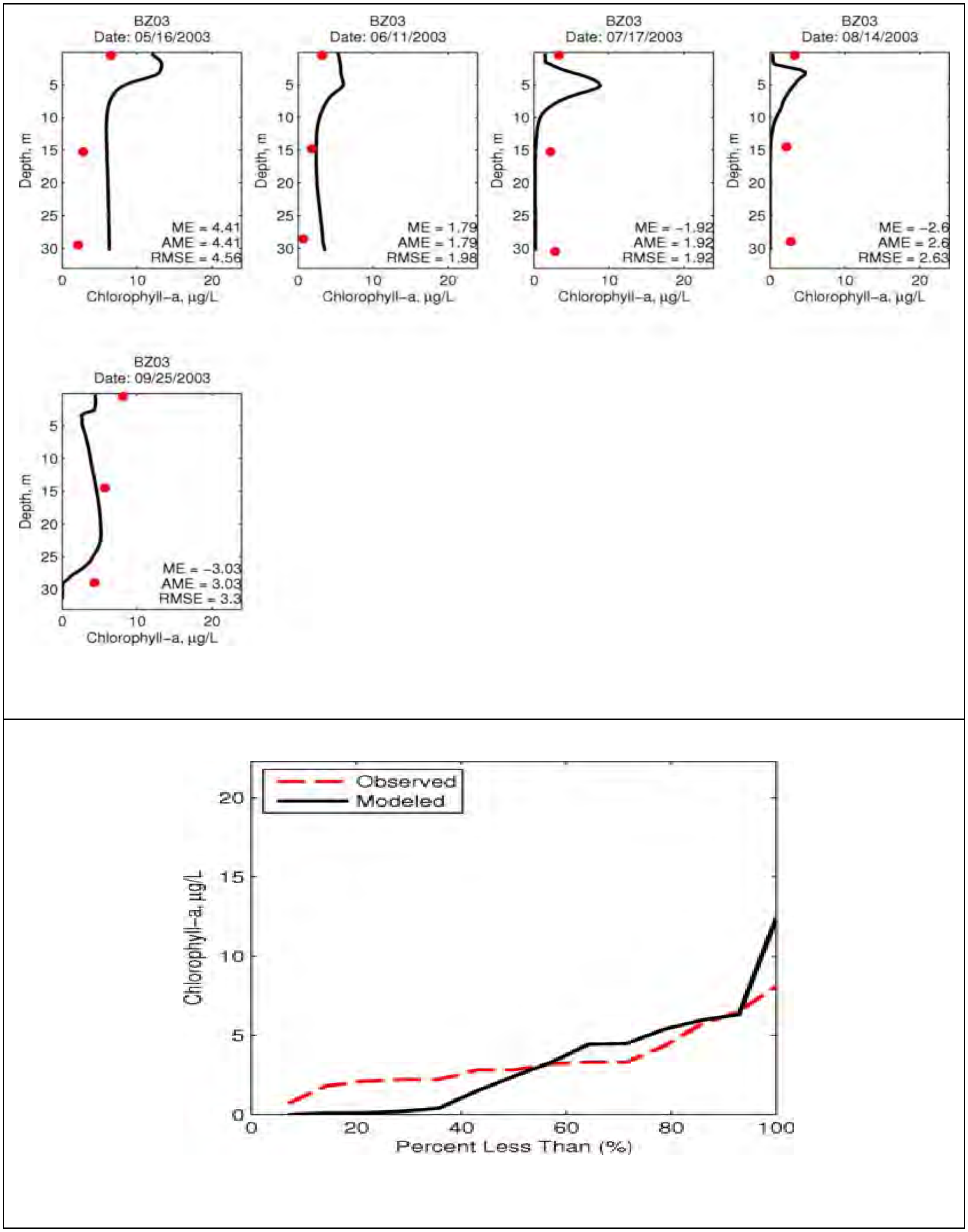


Figure 66. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results at station BZ06 for Chlorophyll *a* at Beltzville for 5 Julian dates.

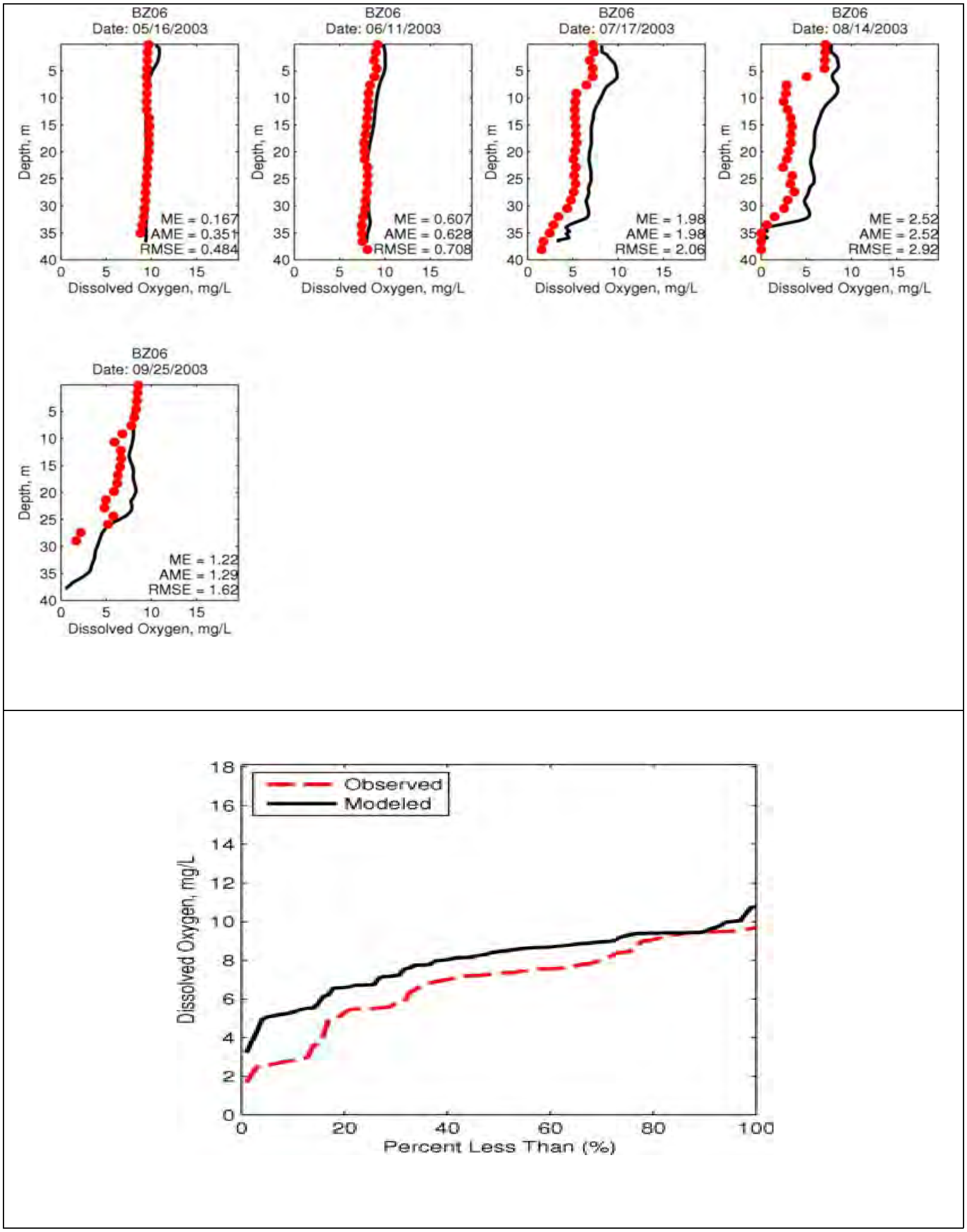


Figure 67. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results at station BZ06 for DO at Beltzville for 5 Julian dates.

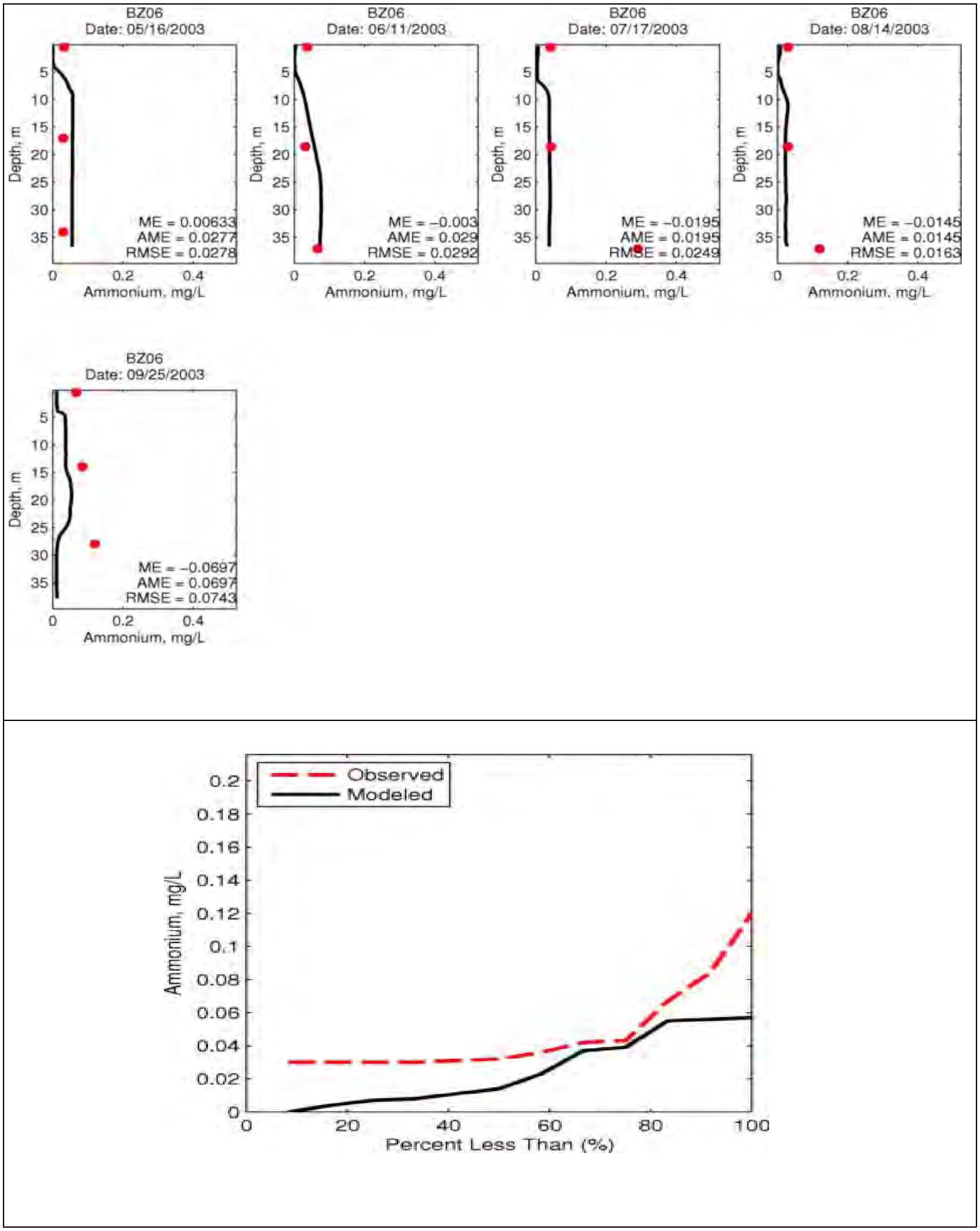


Figure 68. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results at station BZ06 for ammonium at Beltzville for 5 Julian dates.

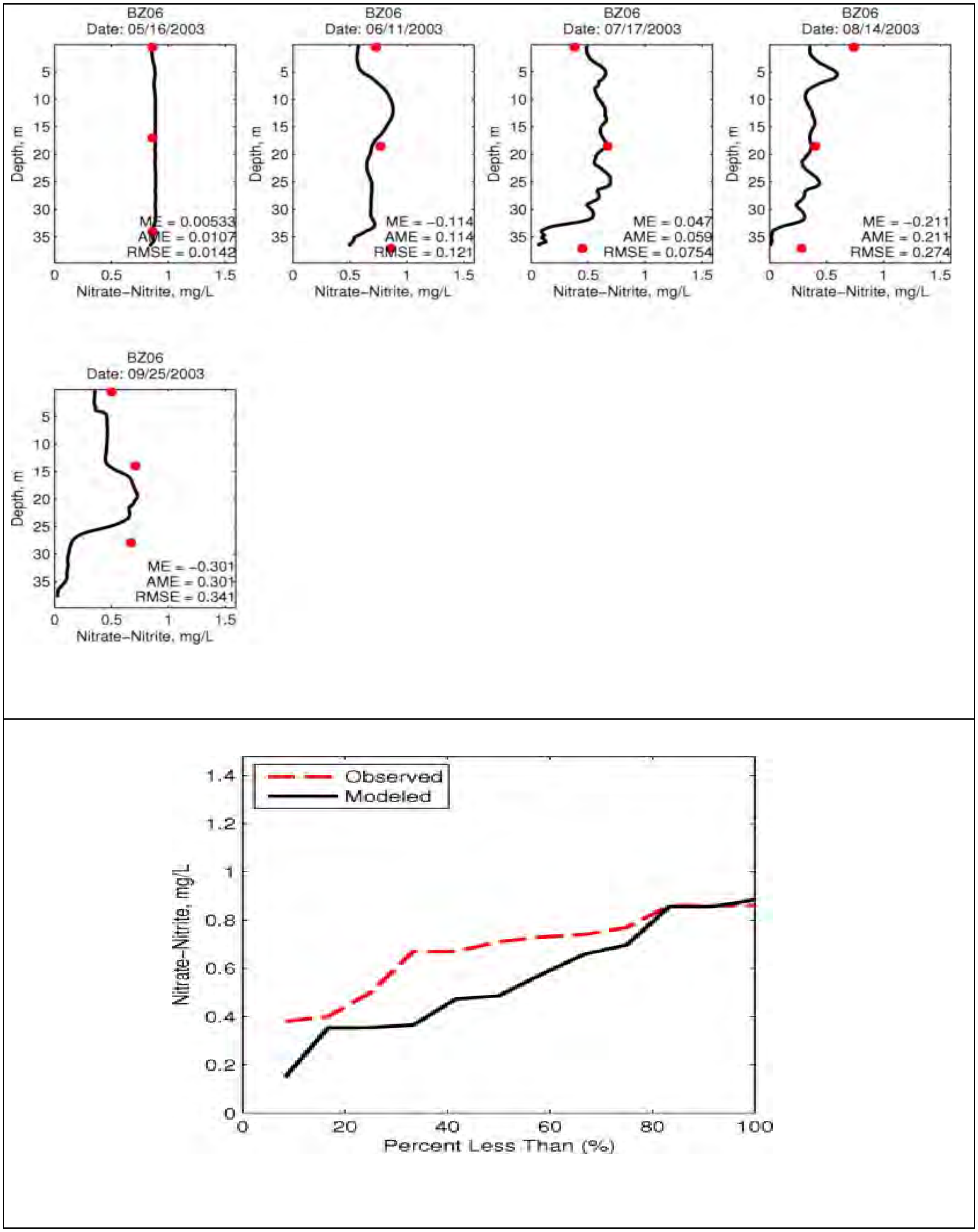


Figure 69. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results at station BZ06 for Nitrate-Nitrite at Beltzville for 5 Julian dates.

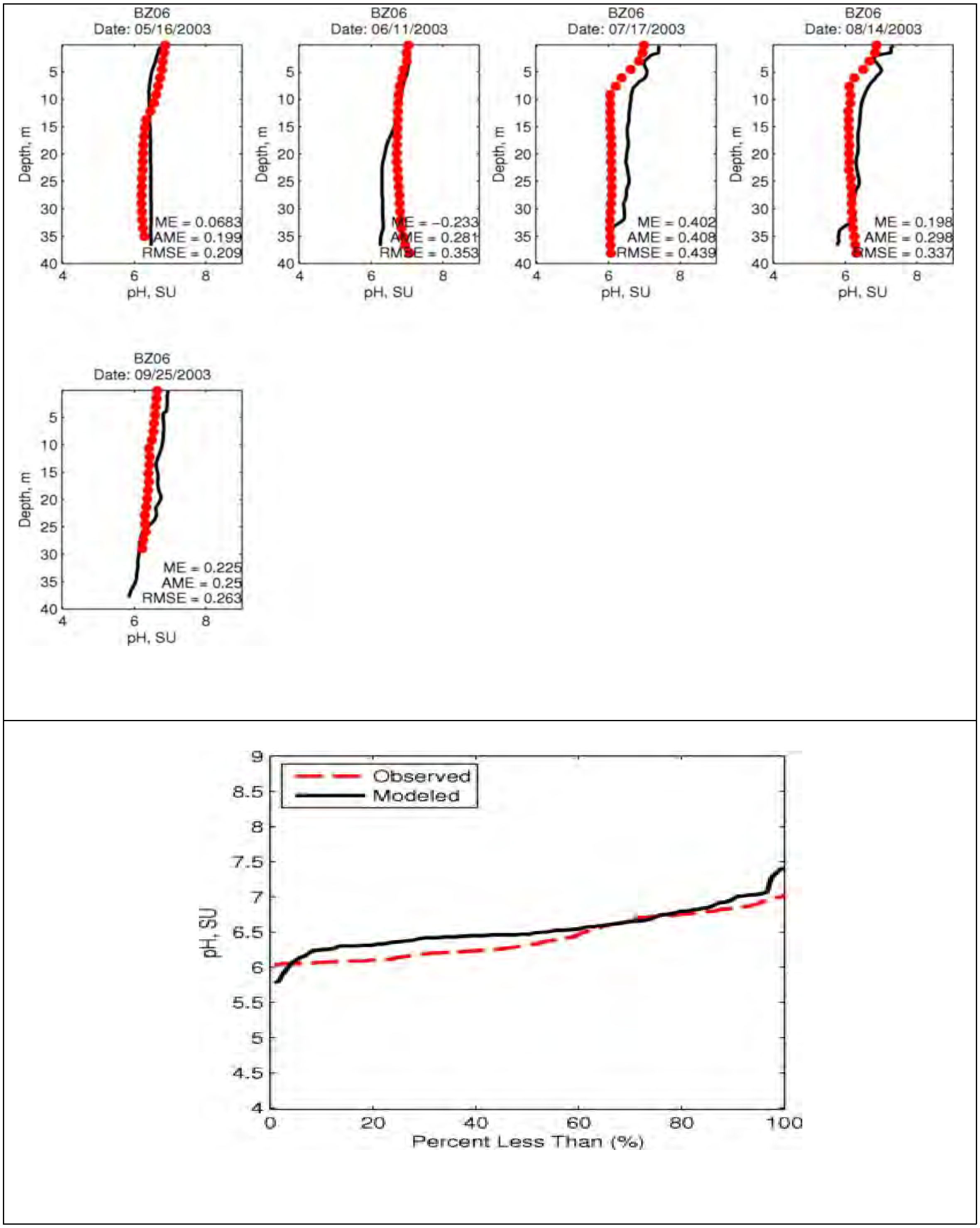


Figure 70. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results at station BZ06 for pH at Beltzville for 5 Julian dates.

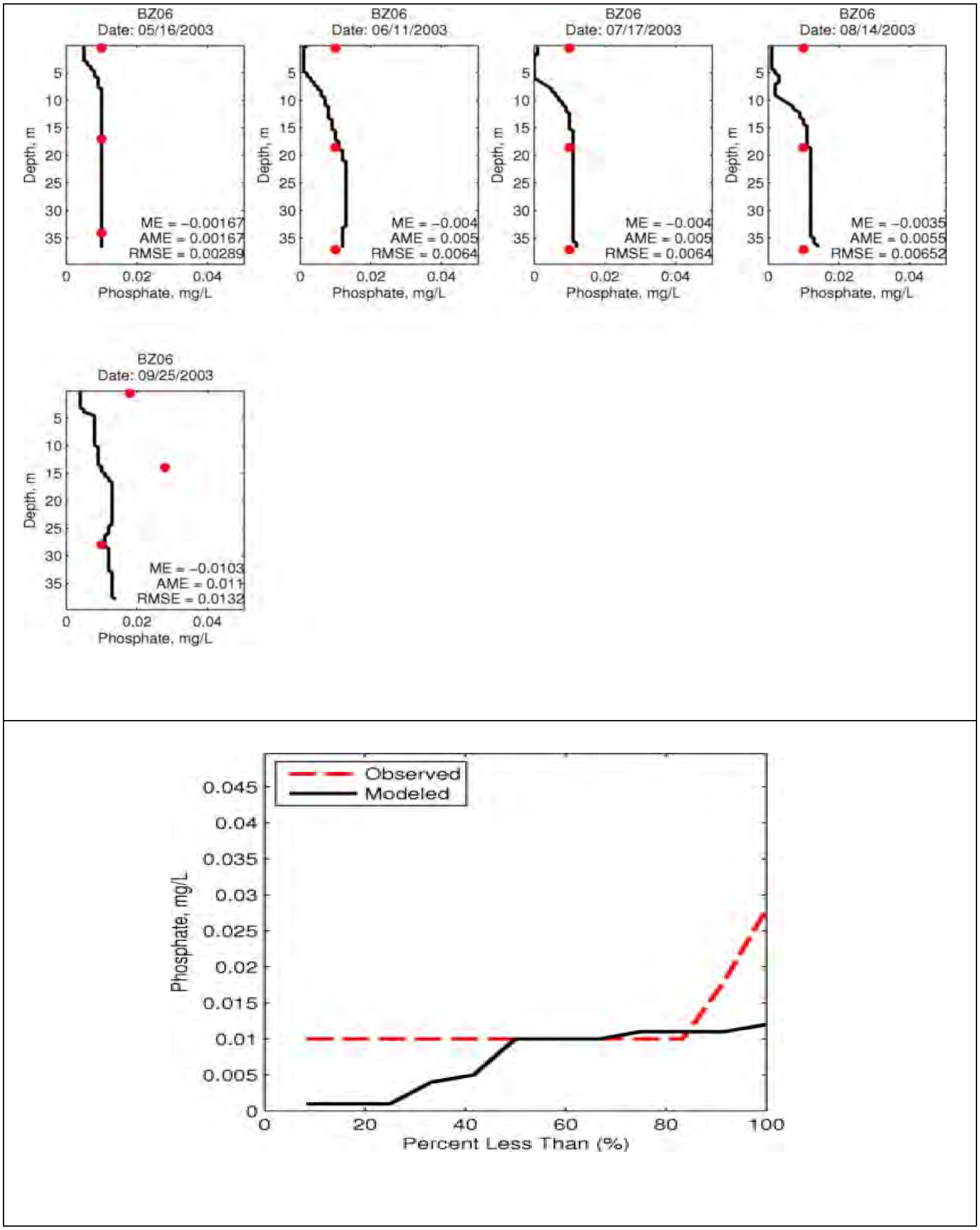


Figure 71. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results at station BZ06 for Phosphate at Beltzville for 5 Julian dates.

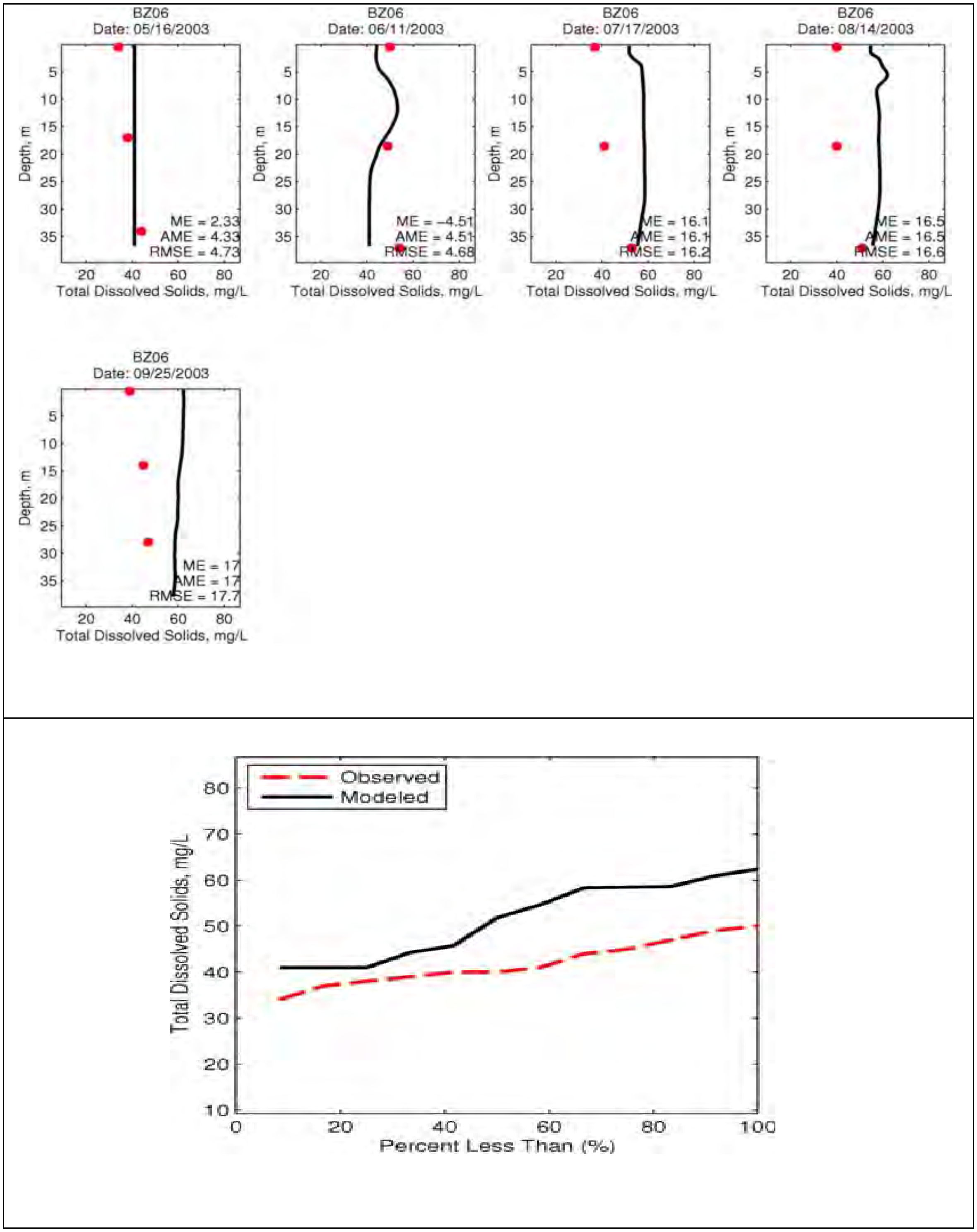


Figure 72. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results at station BZ06 for TDS at Beltzville for 5 Julian dates.

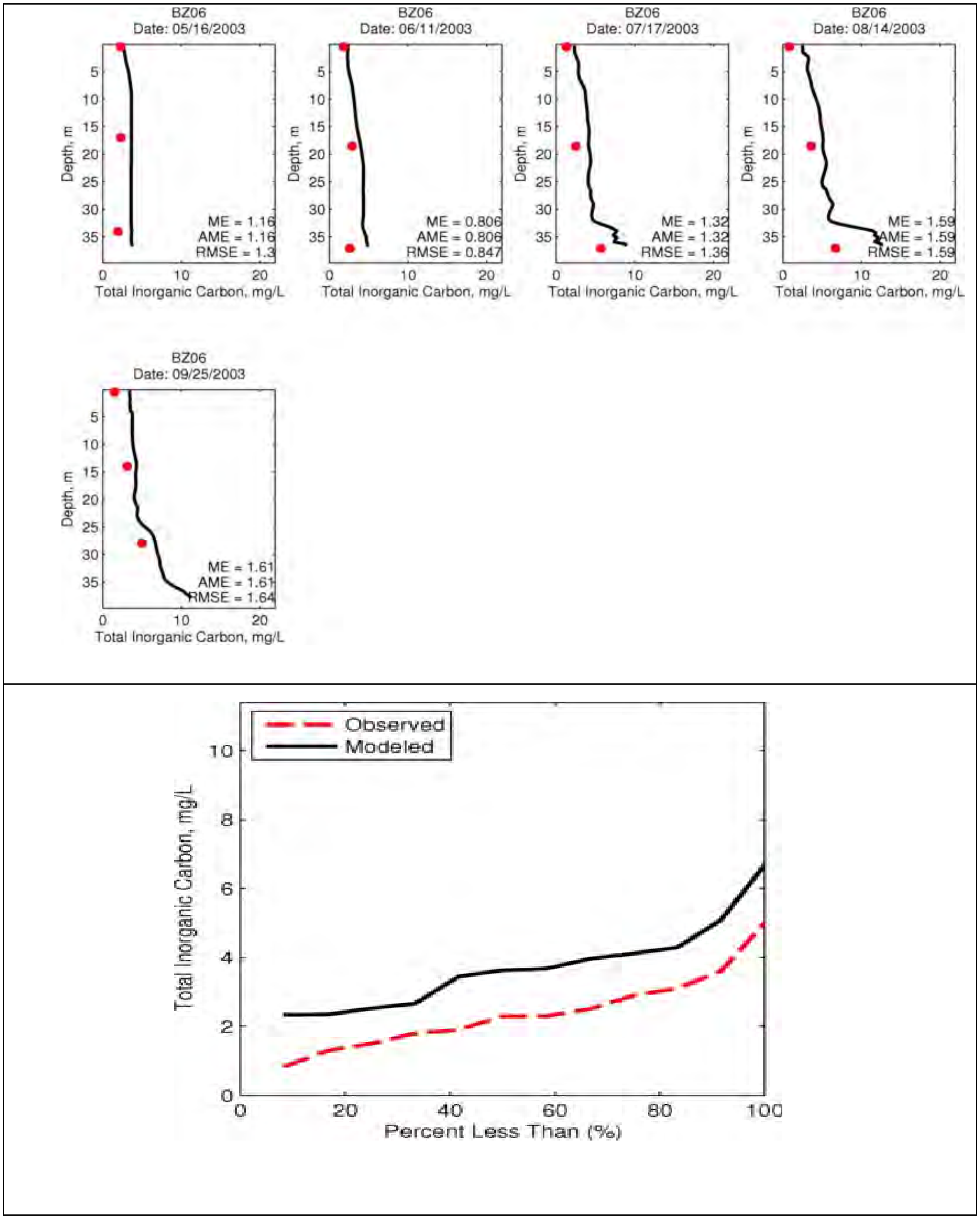


Figure 73. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results at station BZ06 for TIC at Beltzville for 5 Julian dates.

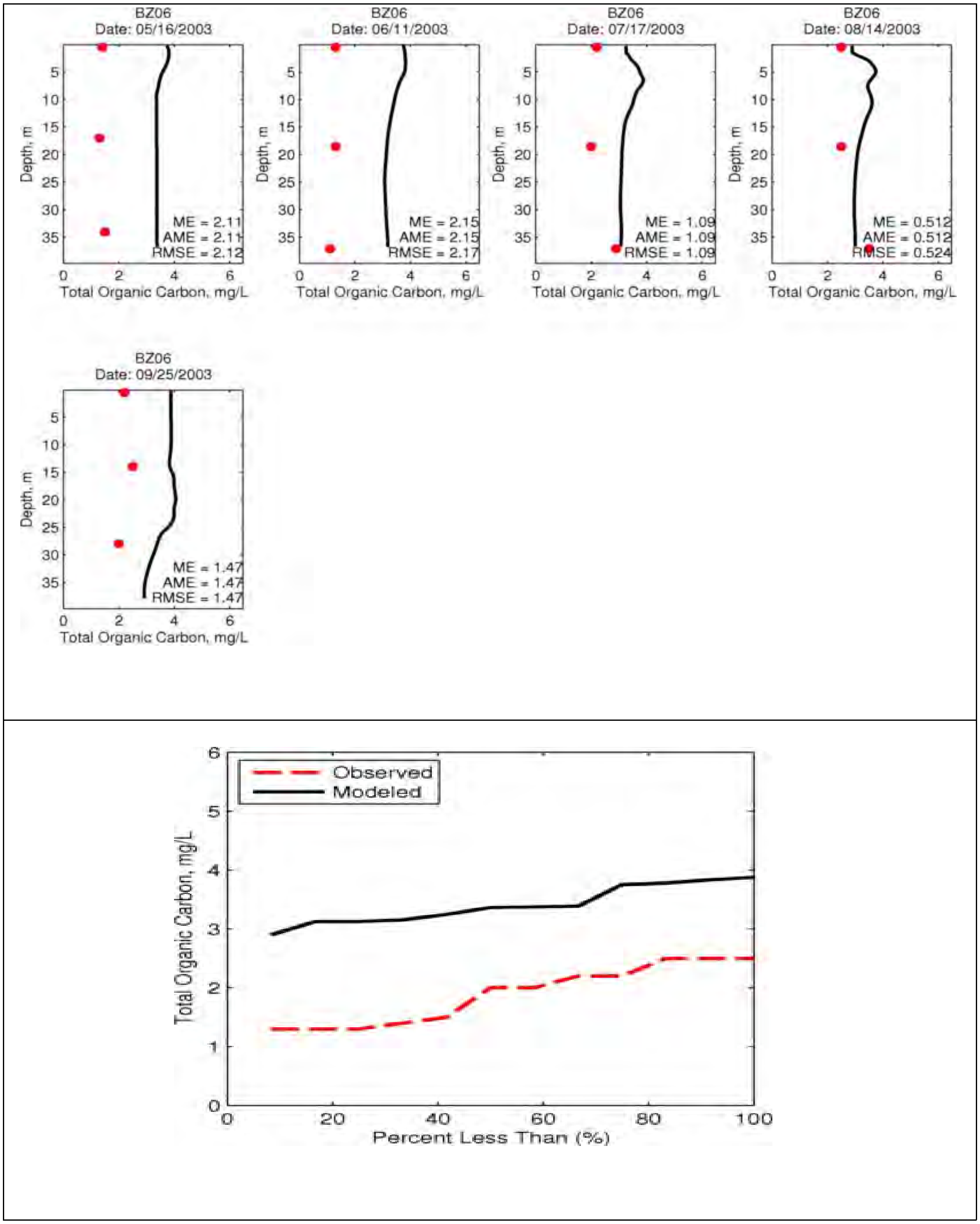


Figure 74. 2003 Calibration profiles (upper) and percent cumulative distribution (lower) results at station BZ06 for TOC at Beltzville for 5 Julian dates.

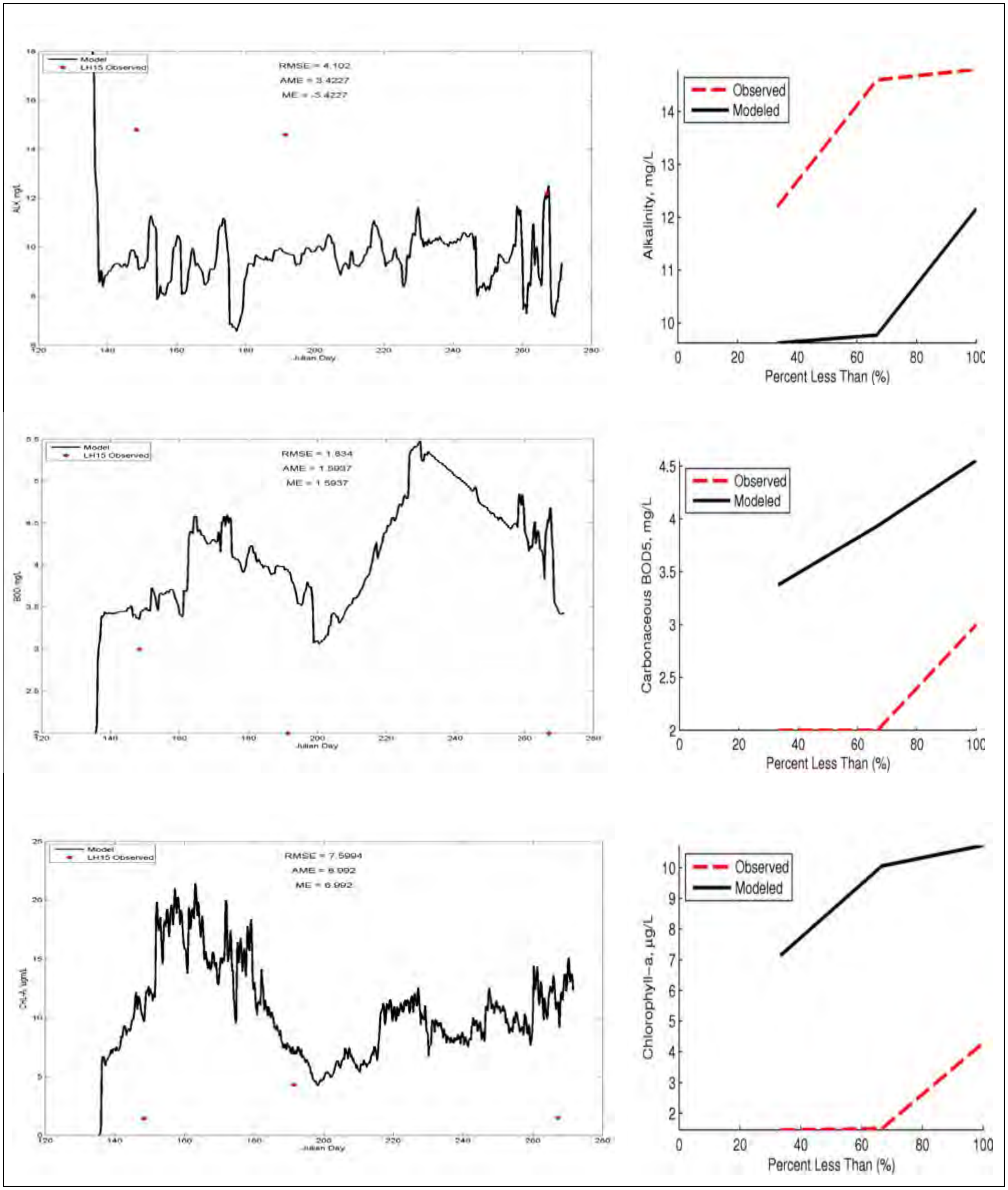


Figure 75. 2003 Calibration time series (left) and percent cumulative distribution (right) results at station LH15 for alkalinity, BOD5, and Chla.

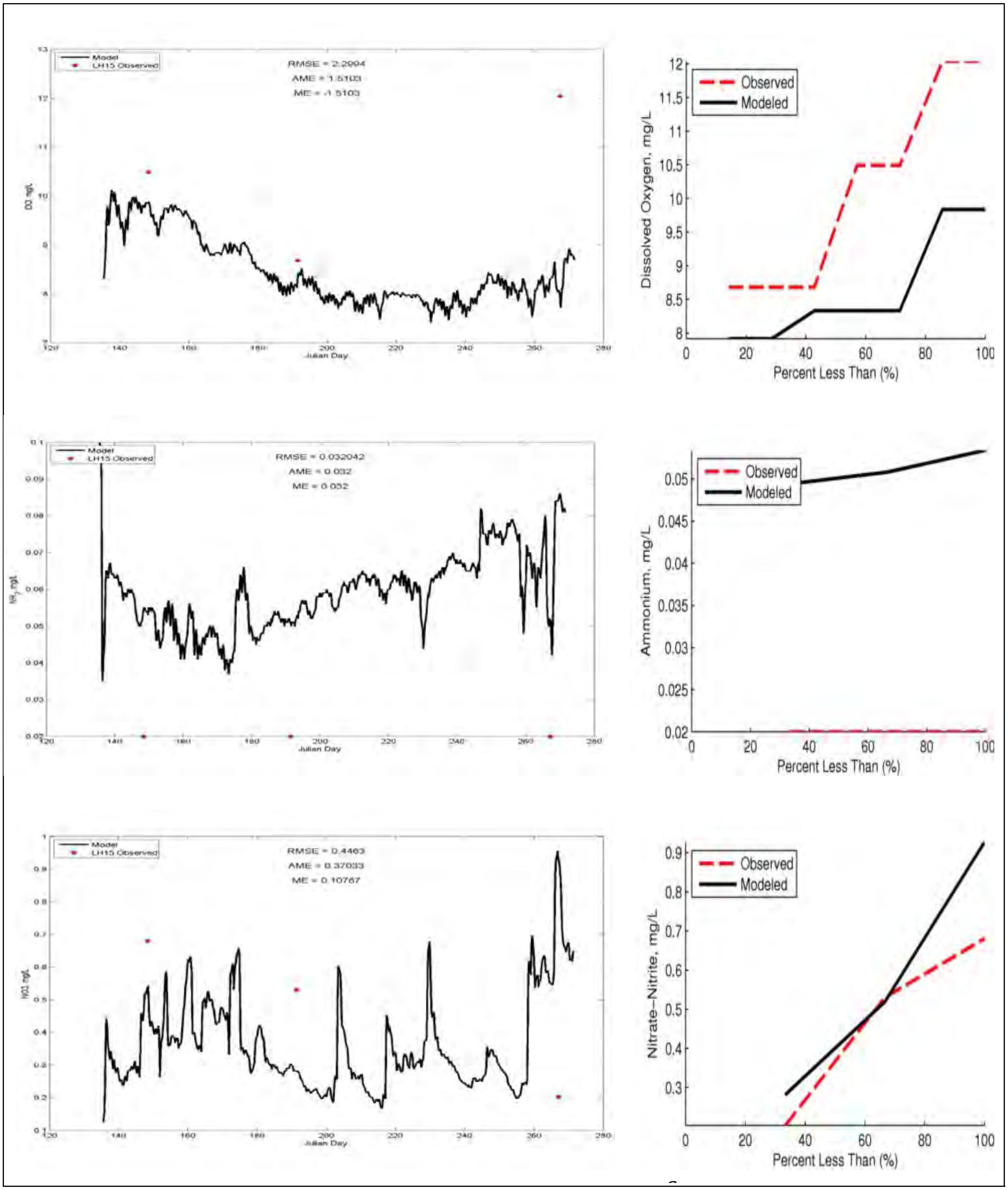


Figure 76. 2003 Calibration time series (left) and percent cumulative distribution (right) results at station LH15 for DO, NH3, and NO2+NO3.

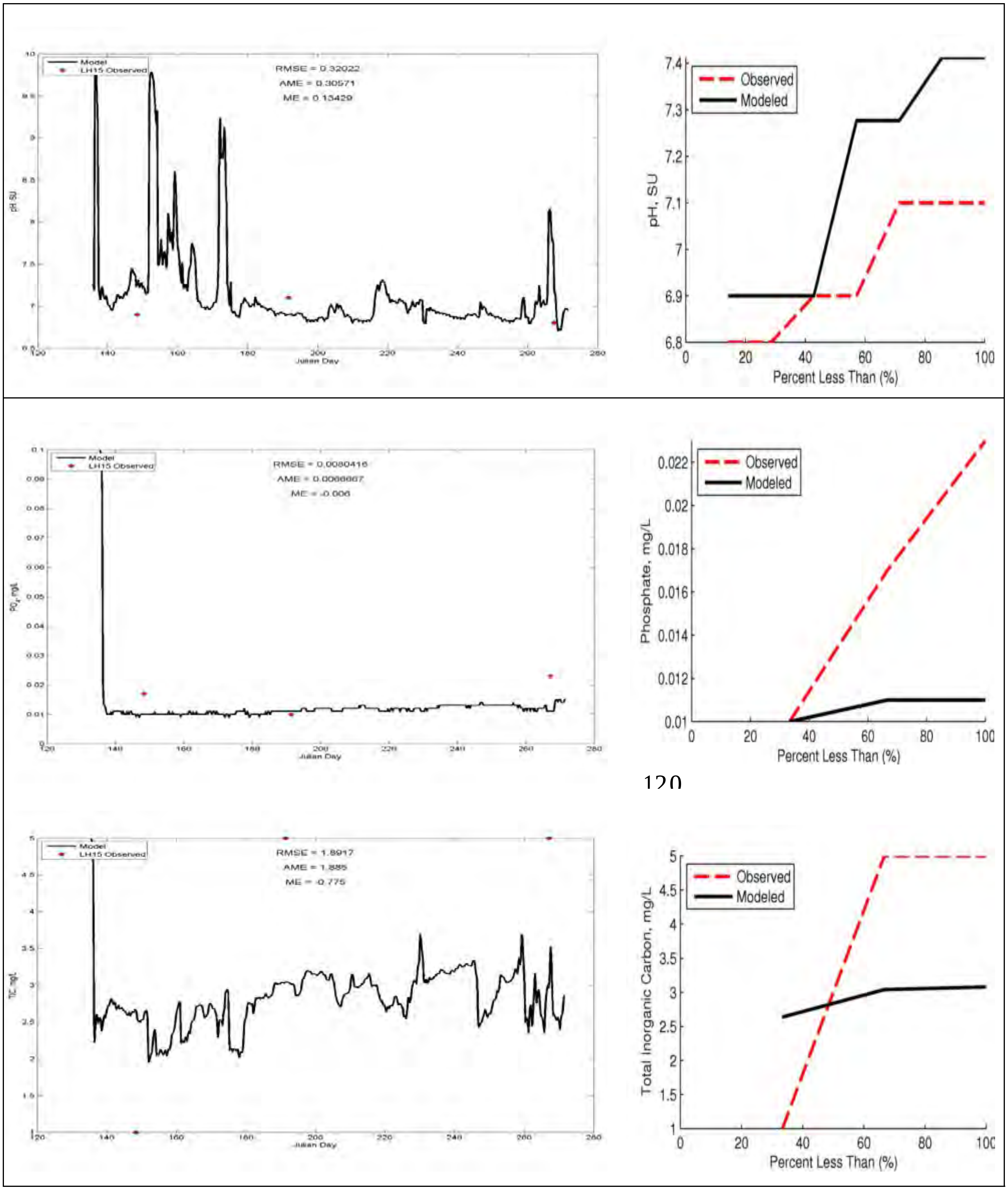


Figure 77. 2003 Calibration time series (left) and percent cumulative distribution (right) results at station LH15 for pH, PO4, and TIC.

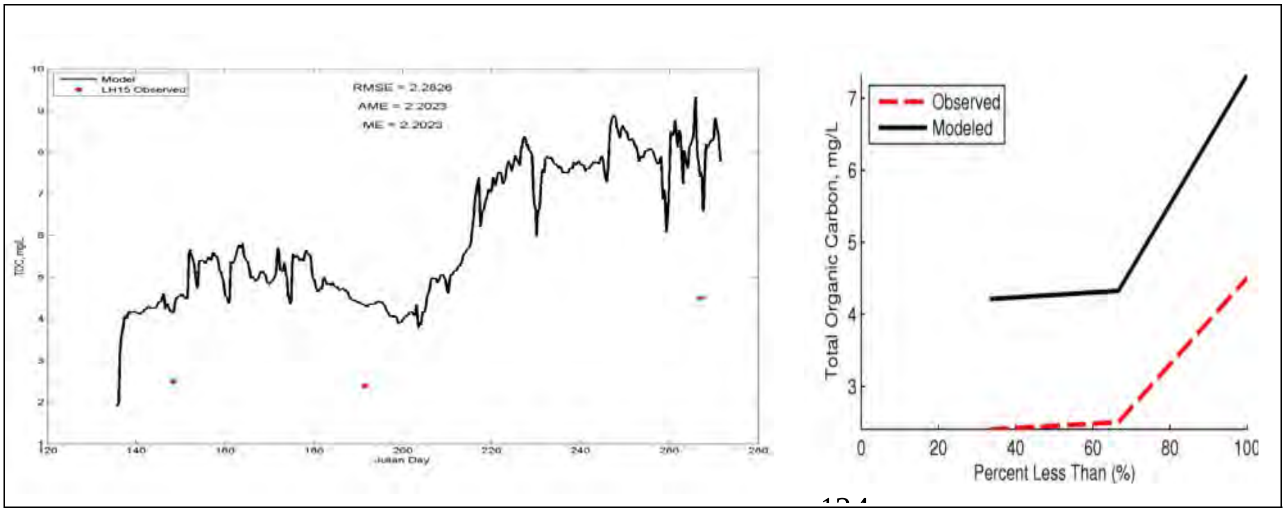


Figure 79. 2003 Calibration time series (left) and percent cumulative distribution (right) results at station LH15 for TOC.

Temperature. Temperature calibration and verification results were discussed in the Phase 1 report for 2001 and 2003. Results for these years will not be presented here. Temperature results for 2002 will not be discussed other than to say temperature results for 2002 were comparable to results in 2001 and 2003. Simulation of 2002 temperature and water quality data were not part of the Scope of Work (SOW) but were attempted at the request of the Philadelphia District since water surface elevations were held at a higher conservation pool than the other two years. Profile and time series results can be found for F. E. Walter and Beltzville stations and station LH15 on the Lehigh River, respectively in Appendix D as Adobe “pdf” files.

Dissolved Oxygen. W2 is reproducing DO profiles in F.E. Walter in 2001 and 2003 (Figures 7 and 55, respectively) favorably. DO Profiles in 2001 seen in Figure 7 show slight stratification in the early to mid period of the simulation. In this figure, DO concentrations in the hypolimnion are 5 mg/L (milligrams per liter) or less than with the surface DO around 8 mg/L in the first half of the simulation period. As the simulation continues, increases in DO concentrations in the hypolimnion are seen and the shapes of the profiles are more isochemical with concentrations around 8 to 9 mg/L. W2 does a good job capturing this behavior. As the percent cumulative distributions plot in Figure 7 demonstrates, 80 percent of the time concentrations below 8 mg/L are being predicted close to observed and for concentrations greater than 8 mg/L W2 slightly over-predicts. Target AME (Table 9) is around 0.7 mg/L and the high AME for any profile was 0.84 at F. E. Walter. This was considered acceptable. In 2003, observed profiles show even less stratification than in 2001. This year was wetter than 2001 thus greater releases occurred during the wet periods. This allowed lower water to be replaced quicker keeping sinks of DO from reducing concentrations. Again looking at Figure 55, The AME of each profile is within an acceptable range of the target AME (Table 10) value of 0.4 mg/L. The percent cumulative distribution plot (Figure 55) shows for the most part predicted DO concentrations are only slightly over-predicted in the lower concentration values (40% of time) and higher concentration range (10%). For the mid range of DO concentrations, W2 does a very good job reproducing values.

Similar to profiles at F. E. Walter, observed DO profiles (Figure 20) at Beltzville in 2001 show more stratification with DO concentrations in the hypolimnion going anoxic toward the end of the simulation. W2 is capturing the stratification but does not completely go anoxic. AME values greater than the target AME value (Table 9) of 1.0 for Beltzville DO profiles occurred toward the end of the simulation. Although DO concentrations were predicted too high in the hypolimnion, behavior of chemical stratification of profiles at BZ06 was very similar to observed. In the first three observed profiles, a DO minimum was noted near the 10 meter depth. W2 is capturing this trend but falls short on predicting anoxic conditions at the end of the simulation. For profile results in 2003, DO profiles (Figure 67) show less chemical stratification but do approach anoxia conditions toward the end of the simulation similar to 2001 observed DO profile. Again W2 does a good job predicting this behavior.

DO predictions (Figures 29, 33, 37, 41, 45, and 49) for 2001 at the Lehigh River stations follow observed data trends very well. Observed DO concentrations at the beginning of the simulation are around 9 mg/L being released from F. E. Walter (Figure 29). However, W2 is predicting around 8 mg/L and stays within 1mg/L of observed data. It is believed that reaeration occurring at the release is not being accurately predicted here but as water travels downstream the AME improves to values less than the target AME of 0.94 mg/L. In 2003 because observed water quality data was not available for boundary conditions, assumptions were made that water quality on tributaries above LH10 (near Lehighton) were similar to water quality inflows to F. E. Walter and for tributaries below LH10 their water quality was similar to water quality inflows at Beltzville. This assumption was not bad for temperature (Tillman and Lewis-Coker, 2010) since meteorological data drives the heat budget. As seen from results in 2003 for temperature, using meteorological data at F. E. Walter Reservoir measured from March through July and from Beltzville Reservoir measured from July through October results were quite comparable to observed.

On the other hand, different geochemical conditions and allochthonous sources of water quality being brought into the river from the watershed have a great impact on water quality. Setting water quality concentrations to values of a close source does not always represent what actually occurred. This only works well when water quality conditions are very similar. At any rate predictions at LH15 (Walnutport), the only station on the Lehigh River with observed data in 2003 , matched the first two observed data points fairly well and were within the target AME (Figure 76). The last observed data point in the time series was way under predicted probably because in using Beltzville inflow values for tributaries inflows, a high DO concentration had originally occurred on tributaries in the region but did not occur at Beltzville. Thus DO concentrations for this date at LH15 could not be predicted.

Chlorophyll *a*. Chlorophyll *a* and CBOD concentrations in F. E. Walter and Beltzville indicate no eutrophication problems. According to Kiely (1997) a eutrophic system has a mean chlorophyll *a* concentration around 19.2 ug/L. Most observed chlorophyll *a* concentrations at F. E. Walter and Beltzville were between 2 and 10 ug/L indicating a system between mesotrophic and eutrophic. W2 is capturing chlorophyll *a* profiles in F.E. Walter in 2001 and 2003 (Figures 6 and 54) fairly well. Except for two dates out of both years modeled most profile trends and concentrations are being predicted. Chlorophyll *a* profiles for F. E. Walter are seen in Figure 6 for 2001 and show concentrations are within the target AME value of 2.7 ug/L (Table 9) except on Julian Day 199 (July 18, 2001). On this day (Figure 6) chlorophyll *a* concentrations are being over-predicted in the epilimnion yet in the metalimnion and hypolimnion chlorophyll values are similar to observed. It is not clear why over-prediction occurs, but over-prediction of nutrients does not appear to be causing this. Over all, the percent cumulative distribution plot (Figure 6) indicates chlorophyll *a* values less than 4 ug/L make up 50% of the concentration range and are slightly over-predicted by W2. Similarly in 2003 at F. E. Walter (Figure 54) chlorophyll *a* values again are being predicted comparable to observed values except for Julian day 161 (June 10, 2003). On this day predicted profile concentrations show higher concentrations in the surface decreasing with depth while observed data show opposite behave with lower value in the surface and slightly increasing in the bottom. There is no noticeable increase in nutrients that might trigger this but by the same token chlorophyll values by the next comparison date were very similar to observed and AME value for this profile was close to the target AME (Table 10). With only six inflow observed boundary data points to drive the model, concentrations of nutrients or chlorophyll *a* occurring between boundary dates may have been missed that could account for this.

Similar to profiles at F. E. Walter, observed chlorophyll *a* profiles at Beltzville in 2001 (Figure 19) show most of the differences between observed and predicted occurring in the epilimnion. In the epilimnion on two of the observed dates, W2 over-predicts values. This is also illustrated in the percent cumulative distribution plot where values above 3 ug/L make up about 40% of the data range and indicate most differences between observed and predicted occur at higher concentrations. In 2003 at Beltzville chlorophyll *a* predictions (Figure 66) are being under-predicted in the hypolimnion. Chlorophyll *a* concentrations appear to be influenced by under-prediction of ammonium. AME values for profiles during this year were higher than the target AME (Table 10). From the percent cumulative distribution plot (Figure 66) chlorophyll *a* values less than 4 ug/L represent 50% of the data range and are being under-predicted by W2 while values greater are slightly over-predicted.

Chlorophyll *a* predictions (Figures 28, 32, 36, 40, 44, and 48) for 2001 at Lehigh River stations follow observed data trends very well. Observed chlorophyll *a* concentrations at the beginning of the simulation period at LH02 are around 1 ug/L being released from F. E. Walter and increase toward the end of the simulation at this station. Likewise W2 is predicting the same behavior - around 1 ug/L chlorophyll *a* concentration is being released for F. E. Walter and increases to 4 ug/L by the end of the simulation. AME values indicated on the figures for chlorophyll *a* at all stations stay very close to the target AME of 0.84 ug/L. Percent cumulative distribution plots for all stations (Figures 28, 32, 36, 40, 44, and 48) show predicted concentrations at all concentration levels are being under-predicted by W2. In 2003 lack of observed data needed for tributary boundary conditions is believed to be the source of over prediction of chlorophyll *a* predictions at LH15 (Figure 75). Over-prediction of chlorophyll *a* could be resulting from boundary conditions for ammonium being set too high. By using Beltzville inflow boundary conditions for tributaries inflowing into this reach of the Lehigh River, ammonium concentration may be higher than what actually occurred resulting in higher chlorophyll *a* concentrations. Boundary concentrations for the other nutrients appear to be reasonable since predictions at LH15 for these nutrients are within the target AME.

Carbonaceous Biological Oxygen Demand (CBOD5). CBOD in W2 is assumed to be allochthonous inputs and forms of autochthonous organic matter are kept track of in various other organic matter compartments (i.e., labile and particulate organic matter). For this study BOD was assumed to be CBOD5. Observed CBOD5 concentrations as discussed above under chlorophyll *a* section are low. CBOD5 concentrations in F. E. Walter during 2001 were a constant 2 mg/L and during 2003 varied from 2.7 to 6 mg/L. At Beltzville in 2001, CBOD5 concentrations varied from 1.0 to 6.0 mg/L and during 2003 varied from 2.5 to 6 mg/L. As depicted in Figures 5, 18, 53, and 65, W2 is reproducing the shape and trend of COD5 profiles favorably. AME values for both projects in 2001 compare better to the target AME (Table 9) values than they do in 2003 (Table 10). At both projects in 2003, higher AME values when compared to target AME values may be attributed to not enough decay of BOD sources. Values are so low that the slight over prediction does not seem to affect other constituents.

Observed CBOD5 concentrations in 2001 on the Lehigh River at all stations for the most part have values in the 2.0 to 3.0 mg/L range (Figures 28, 32, 36, 40, 44, and 48). Between Julian days 240 to 260 (August 28 to September 17) of this year, CBOD5 concentrations at and downstream of station LH10 were measured around 10 mg/L. An increase was predicted by W2 but not to the same concentration level. In 2003, as previously mentioned there were no tributary boundary conditions and only observed data at LH15 to use for comparison purposes. CBOD5 concentrations at this station are being over-predicted with an AME value of 1.5. It is believed that using water quality inflow boundary conditions from Beltzville on the tributaries in this section of the Lehigh River caused CBOD5 values to be higher than they normally would causing the over-prediction. Percent cumulative distribution plots for 2001 indicate good agreement at all concentration levels except for the higher concentrations making up about 20% of the range (Figure 30). In 2003, the percent cumulative distribution plot for station LH15 shows for all ranges of concentrations (Figure 75), W2 over-predicts. Overall, it was felt W2 was predicting very well when enough observed data were available.

Total Organic Carbon (TOC). TOC in W2 is not a state variable but a derived constituent estimated from dissolved (labile and refractory) organic carbon and particulate (labile and refractory) organic carbon compartments. The model keeps track of any compartment (i.e. algae, macrophytes) contributing to either of these organic carbon compartments. If any of these compartments have kinetic rates set too low or high this will show up in unfavorable TOC concentrations. Equally important is the fact that organic matter as modeled by W2 is estimated from TOC, POC and/or DOC, thus some error will be introduced by estimating the split between dissolved and particulate and labile and refractory if POC or DOC data are not available.

Observed TOC profile concentrations in F. E. Walter during 2001 were almost a constant 5 mg/L isochemical profile at all levels except for Julian day 270 (September 27) where the concentration in the metalimnion increases to around 7 mg/L (Figure 16). W2 predictions were comparable for all days even for the day TOC concentrations increased. On Julian Day 270 (September 27), the W2 profile was more isochemical than the observed but bottom level concentrations matched the observed and the mid and upper concentrations were between the observed values at these levels (Figure 16). At Beltzville in 2001, predicted TOC concentrations are very similar to observed with all profiles being isochemical at 5 mg/L. AME values for this year at both projects indicate very favorable results. Most values are lower than target AME values (Table 9). In 2003 TOC concentrations at both reservoirs are being over-predicted occurring more so at Beltzville. Beltzville observed TOC concentrations are lower than what was observed in 2001 with a constant value of around 2 mg/L for all dates. Although W2 is over-predicting on average about 1.2 mg/L, the shape and trend of the profile is very similar to observed. F. E. Walter profiles in 2003 are on average over-predicted about 1.0 mg/L compared to target AME. Nevertheless, the trend of increasing TOC concentrations from the beginning of the simulation to the end is being captured by W2. Percent cumulative distribution plots (Figure 16) for 2001 indicate good agreement at all concentration levels with exceptions occurring at the higher concentrations especially at Beltzville. In 2003, the percent cumulative distributions plot for F. E. Walter and Beltzville (Figures 63 and 74) shows all ranges of concentrations being slightly over-predicted by W2.

TOC concentrations in 2001 on the Lehigh River at all stations are being predicted extremely well (Figures 31, 35, 39, 43, 47, and 51). As further indicated by the AME values at all stations, W2 derived TOC concentrations are below the target AME of 1 mg/L (Table 9). In 2003, as previously mentioned there were no tributary boundary conditions and only observed data at LH15 to use for comparison purposes for TOC. TOC concentrations at this station are being over-predicted with an AME value of 2.2 mg/L. In spite of over-predicting, trends in concentration levels of the observed data are being predicted. For example, spring concentrations are higher than summer and fall and concentrations increase similar to observed data. Over-prediction is believed to be caused by using water quality inflow boundary conditions from Beltzville on the tributaries below LH10 and these concentrations were higher than what actually occurred on the tributaries. Percent cumulative distribution plots (Figures 31, 35, 39, 43, 47, and 51) for 2001 indicate good agreement at all concentration levels except at the higher concentrations level which make up about 5% of the range. In 2003, the percent cumulative distribution plot for station LH15 (Figure 78) shows for all ranges of concentrations, W2 over-predicts. Overall, it was felt W2 was predicting very well when enough data were available to properly account for forcing functions.

Nutrients. Nutrients modeled during this study were ammonium, nitrate-nitrite, and phosphate. Ammonium and nitrate-nitrite results for 2001 and 2003 at F. E. Walter show W2 is capturing profiles (Figures 8, 9, 56, and 57) fairly well. Except for ammonium profiles in 2003 all profile AME values for nitrate-nitrite and ammonium are close to the target AME (Tables 9 and 10). Percent cumulative distribution plots (Figures 8, 9, 56, and 57) for these constituents show lower concentrations of nitrate-nitrite and ammonium which represent 70% to 75% of the concentration range are being predicted comparable to observed data. At the higher concentrations W2 is under-predicting the concentrations (Figures 8, 9, 56, and 57).

Similar to profiles at F. E. Walter, observed ammonium and nitrate-nitrite profiles at Beltzville in 2001 and 2003 (Figures 21, 22, 68, and 69) are being predicted comparable to observe data. W2 is predicting the shapes of the profiles however values are usually under-predicted (Figures 21, 22, 68, and 69). In 2001 ammonium concentrations are around 0.1 mg/L while in 2003 ammonium concentrations were slightly lower 0.07 mg/L or less. Nitrate-nitrite concentrations for both years are in the range of 0.5 to 1.0 mg/L. Percent cumulative distribution plots for both constituents show W2 under-predicts for most of the time except in 2001 for ammonium (Figure 21) where values greater than 0.1 mg/L are over-predicted. These concentration occurrences make up about 45% of the concentration distribution.

Ammonium and nitrate-nitrite predictions (Figures 29, 33, 37, 41, 45, and 49) for 2001 at Lehigh River stations follow observed data trends very well. Observed nitrate-nitrite concentrations for the most part vary between 0.1 to 0.4 mg/L while ammonium concentrations vary between 0.1 and 0.2 mg/L. AME values for ammonium and nitrate-nitrite at all stations are very close to the target AME of 0.15 mg/L and 0.42 mg/L, respectively. Percent cumulative distribution plots for all stations (Figures 29, 33, 37, 41, 45, and 49) show predicted concentrations at LH02 are being slightly over-predicted and as water moves downstream concentrations levels are closer to observed. As discussed for other constituents the use of Beltzville inflow data in 2003 for tributary boundary conditions is believed to have caused ammonium and nitrate-nitrite predictions at LH15 to be over predicted (Figure 75). In spite of that, Nitrate-nitrite concentrations at LH15 are not quite as unreasonable as ammonium illustrated in Figure 75.

Phosphate results for 2001 and 2003 at F. E. Walter and Beltzville show favorable comparisons to observed data profiles (Figures 11, 24, 59 and 71, respectively).

Results in 2001 for both reservoirs (Figures 11 and 24) demonstrate how well W2 is predicting the trends of the phosphate concentrations. This is verified by the values of all profiles in both reservoirs having AME values less than the target AME value (Table 9). From the percent cumulative distribution plot, one can see that when W2 results stray from observed, concentrations are usually slightly over predicted. This occurs more in 2003 at both reservoirs (Figures 59 and 71). Predicted phosphate concentrations at stations on the Lehigh River in 2001 are overlaying the observed percent cumulative distribution values 90% of the time (Figures 30, 34, 38, 42, 46, and 50). W2 misses predicting high concentrations that occur. Although in 2001 at LH17 W2 does predict the PO4 increase around Julian day 210 (July 29). Higher observed values may result from higher tributary inflows that occurred between measured dates. Having more frequent inflow data would help improve predictions.

Alkalinity, Total Inorganic Carbon (TIC), and pH. Because pH was an important constituent in this study which at certain levels (between 5.5 and 12 SU) can precipitate aluminum, it was included in this modeling effort. To solve for pH, TIC and alkalinity must be modeled as well. Alkalinity in W2 is treated as a conservative constituent which means there is no interaction with other constituents and no first order decay assumed. Changes in concentrations are attributed to dilution and concentration of tributary boundary conditions. Alkalinity profile concentrations in 2001 at F. E. Walter are being predicted within the target AME for all dates but one. On this day, W2 over-predicts profile concentration level. It is reasonable to assume that reservoir inflow values near that date are not frequent enough to capture the decrease in observed alkalinity (Figure 4). For instance, if one looks at the observed profile of the previous date, the predicted concentration is in the same concentration level as was over predicted. Thus W2 interpolated between observed reservoir inflow values which were similar so not much change resulted. As indicated in the percent cumulative distribution plot (Figure 4) over-prediction occurs in the concentration range of 6 to 10 mg/L. Alkalinity values at Beltzville in 2001 are being under-predicted for all concentration ranges (Figure 17) and AME values for each profile are above the target AME value of 0.3 mg/L (Table 9). This could also be the result of the infrequency of inflow boundary conditions. In spite of that, profile shapes and trends are being correctly predicted. It should be noted that alkalinity concentrations at Beltzville are more constant at around 10 mg/L through the simulation than at F. E. Walter. At F. E. Walter, alkalinity profiles increase from around 5 to 10 mg/L throughout the simulation. In 2003 the opposite is seen in profile plots. For the 2003 profile concentrations at F. E. Walter, values are constant throughout the simulation at around 2 mg/L while at Beltzville they increase from 6 to 10 mg/L. As indicated in the percent cumulative distribution plot

(Figures 52 and 64) for both reservoirs, over-prediction occurs in all concentration ranges and most differences occur in the epilimnion at Beltzville and at all profile levels at F.E. Walter.

Alkalinity predictions (Figures 28, 32, 36, 40, 44, and 48) for 2001 at Lehigh River stations are following observed data trends very well. Observed alkalinity concentrations vary between 1 to 86 mg/L. AME values for alkalinity at all stations are lower than the target AME of 8.5 mg/L (Table 11). Percent cumulative distribution plots for all stations (Figures 28, 32, 36, 40, 44, and 48) show predicted concentrations at LH02 and LH03 are being slightly over-predicted for concentrations in the mid range and as water moves downstream concentrations are being slightly under-predicted. In 2003 lack of observed data needed for tributary boundary conditions was believed to be the reason for alkalinity predictions at LH15 being under-predicted (Figure 75). Under-prediction as previously discussed is probably the result of using F. E. Walter or Beltzville inflow condition for tributary boundary conditions which appear to be too low for alkalinity.

TIC observed profile concentrations in 2001 at F. E. Walter are constant at 5 mg/L throughout the simulation. W2 is predicting the profile concentrations and trend with good agreement. On days where W2 is off, TIC concentrations are slightly under-predicted in the epilimnion. Since TIC concentrations increase from organic matter decay or surface reaeration, the model may be under- predicting the source of TIC. As indicated in the percent cumulative distribution plot (Figure 15) under-prediction occurs in the concentration range of 3 to 5 mg/L. TIC profile values at Beltzville in 2001 are being under-predicted in the epilimnion and over-predicted in the hypolimnion. This may indicate that in the epilimnion W2 is under-predicting because not enough TIC is being gained from reaeration. In 2003 TIC profile concentrations at both reservoirs are lower than what occurred in 2001. Nevertheless, W2 is doing a good job at maintaining and predicting the profile shapes and trends. Profile concentrations at F. E. Walter are constant throughout the simulation at around 2 mg/L while at Beltzville they stay fairly constant around 4 mg/L. As indicated in the percent cumulative distribution plots (Figures 15 and 26) for both reservoirs, under-prediction occurs in all concentration ranges. AME values at both reservoirs are slightly higher than the target AME (Table 10) but are acceptable.

TIC concentration predictions (Figures 30, 34, 38, 42, 46, and 50) for 2001 at all Lehigh River stations are showing more variability than observed values. The constant value of 5 mg/L for observed TIC in the Lehigh River seems to be an anomaly in such a steep, fast moving river. With reaeration being a source of TIC it would seem normal to have more variability in the observed concentrations. Observed TIC concentrations vary between 1 to 12 mg/L for tributaries contributing to the Lehigh River but values measured in the Lehigh River are 5 mg/L. AME values for TIC at 3 stations are lower than the target AME of 1.1 mg/L but the three stations below LH02 (i.e., LH03, LH08, and LH10) are higher with AME values around 2.3 mg/L. Percent cumulative distribution plots for all stations (Figures 30, 34, 38, 42, 46, and 50) show predicted concentrations at all stations are being under-predicted more so for the lower concentrations than the higher. In 2003 because of the lack of observed data needed for tributary boundary conditions, TIC predictions at LH15 were being under-predicted as depicted in the percent cumulative distribution plot (Figure77). Under-prediction as previously discussed for other constituents in 2003 is probably resulting from use of F. E. Walter or Beltzville inflow conditions for tributary boundary conditions which for TIC appear to be too low.

Observed pH profile concentrations in 2001 at F. E. Walter (Figure 10) and Beltzville (Figure 24) vary from 7.3 to 6.3 and 7.5 to 5.7 SU, respectively. W2 is producing profile concentrations and trends with good agreement for both years modeled especially at Beltzville. At F. E. Walter on days where W2 is off, pH values are usually under-predicted in 2001 which is probably related to TIC concentrations also being under-predicted. Since TIC is an integral component of predicting pH, this would be a reasonable conclusion. During 2003, F. E. Walter (Figure 58) profiles show pH being predicted favorably except of the first day of observed data. In checking constituent concentrations used to calculate pH (i.e., alkalinity, temperature, TDS and TIC), all compare well to observed data so the reason why pH for this one date is highly over-predicted is not readily discernable. Values for both years at Beltzville show pH profile values following behavior of observed and AME values are slightly higher than target AME values (Tables 9 and 10) but within an acceptable range. Percent cumulative distribution plots for all years modeled shows W2 slightly over-predicts at all pH ranges except 2001 F. E. Walter results which under-predicts at all ranges. All reservoir results for pH were deemed acceptable.

Predictions for pH (Figures 30, 34, 38, 42, 46, and 50) for 2001 at all Lehigh River stations are showing less variability than observed values throughout the simulation. The average pH value in the system is about 7 SU. Upper reaches and releases from F. E. Walter have pH values about 0.5 SU less when compared to values at stations below LH10. Three tributaries (Sandy, Buck Mountain Creek and Black Creek) between LH03 and LH08 have lower alkalinity and pH compared to other tributaries included in the model. Granted that pH from these tributaries are lower but pH values in the Lehigh River do not appear to be greatly affected. AME values at each station on the Lehigh are equivalent to the target AME value (Table 11) or lower. At three stations (LH02, LH08, and LH10) percent cumulative distribution plots show under prediction of pH values for concentration ranges occurring. At the other three stations pH values are close to observed with the occasional slight over predictions (Figures 30, 46 and 50). In 2003 pH predictions at LH15 were being over predicted as depicted in the percent cumulative distribution plot (Figure 77). Over prediction as previously discussed for other constituents in 2003 is probably resulting from use of F. E. Walter or Beltzville 2003 inflow conditions for tributary boundary conditions. Even though pH is being over predicted, the AME value of 0.3 is acceptable.

Metals. There were limited data to model metals. The data available for metals were collected in 2001 on the Lehigh River and at a few of the tributaries monitored. Concentrations of total metals were available for all dates data were collected and dissolved metal concentrations were only available for one date. Consequently, the metals modeled were modeled as total concentrations and not dissolved. Of the data that were available, an analysis was performed to identify metals that could possibly exceed state health limits. These metals were iron, aluminum, cadmium, zinc, and manganese. Because pH at certain levels (between 5.5 and 12 SU) can precipitate aluminum, the nonconservative constituent code representing aluminum was modified to allow this process to occur. In Appendix E, Table F-1 lists data available for metals and at which stations for 2001. No metals profile data or inflow data were available at F. E. Walter and Beltzville reservoirs for this year. Figure F-1 through Figure F-9 present results for metals at stations on the Lehigh River. For the data available, all results for metals were comparing well with observed data. Because LHo2 data was used as inflow data to F. E. Walter, there is a slight shifting of predicted data not exactly matching the observed. This is attributed to using concentrations that occurred farther downstream than at the actual inflow point causing a slight phase shift in the predicted data values. Regardless, behavior trends of metals are being captured by W2.

4 Scenario Applications

Parameters for the calibrated/verified models of the Lehigh system were retained for making scenario runs. The only difference between the calibration/verification runs and the scenario runs was the new reservoir operation releases from F. E. Walter. A couple of differences between these scenario runs and the scenario runs from Phase I are: 1) In 2001 and 2003, F. E. Walter reservoir was initialized to a profile more representative of the scenario simulation start date which from historical data profiles for this time of year was very similar to Beltzville 2003 profile and 2) F. E. Walter release flows were optimized for scenarios 1, 4, 5, and 6.

The specifications for the new reservoir operations for each scenario run were jointly determined by the ACOE, PADCNR, and PFBC and are presented below.

Scenario 1

Scenario 1 can be described as “Fisheries only, with selective withdrawal to the dam” and is designed to maximize benefits to downstream fisheries. The plan assumes that the dam has been equipped with selective withdrawal capabilities. Portals are modeled with inverts at elevations 1300, 1320, 1340, 1360 and 1380. The portals at 1360 and 1380 have a capacity of 3000 cfs each and the remaining portals have a 500 cfs capacity. The capacity of the individual portals is based solely on the desire of the shareholders. No engineering calculations were performed to determine the design of the portals. This scenario has a starting pool elevation of 1392 ft. NGVD and there are no whitewater releases.

As in Phase I, the goals of the release schedule are to create optimal in-lake spawning areas in May and June by limiting the pool fluctuations to 5 feet and to maximize the amount of cooler water released for downstream fisheries. In May and early June, releases to maintain lower downstream temperatures are made from the upper portals in order to preserve colder water. As the summer progresses, releases are made from a combination of portals.

Pool Elevation: 1392 ft NGVD

Withdrawal Capabilities: Selective withdrawal.

Portal #	Elevation (ft. NGVD)	Capacity (cfs)
1	1380	3000
2	1360	3000
3	1340	500
4	1320	500
5	1300	500

Release Plan:

- In May and June, pool fluctuations are limited to 5 feet. (1387– 1392)
- In May the target release will be 200 cfs, and in June the target minimum release is 200-250 cfs. Releases will match inflow down to 50 cfs to maintain pool between 1387 and 1392
- 16-30 June, the target release temperature is 64^0 F
- 1 July to 31 August, release 125 cfs of 55^0 F water from a lower level port and mix with releases from upper level ports.
- 1 - 15 September, augment flows by 160 cfs of 64^0 F water from a lower level port and mix with releases from upper level ports.
- 16-30 September, augment flows by 100 cfs at the prevailing temperature.

Scenario 2

This plan is based on the 2010 release schedule and is modified to better manage release temperatures assuming that the dam has been equipped with selective withdrawal capabilities. The starting pool elevation is 1370. The selective withdrawal system has been modeled with portals at elevations 1300, 1320, 1340, and 1360. The capacity of the intake at 1360 is modeled as 3,000 cfs. The remaining portals have a 500 cfs capacity. The goals of the release schedule are to create optimal in-lake spawning areas in May and June by limiting the pool fluctuations to 5 feet; maximize the benefit to cold water fisheries downstream by augmenting flows between July 1 and September 30 by a minimum of 50 cfs with the cooler water; and provide whitewater releases on alternating weekends from late May to July and every weekend in August through mid-September.

Pool Elevation: 1370 ft NGVD

Withdrawal Capabilities: Selective withdrawal.

Portal #	Elevation (ft. NGVD)	Capacity (cfs)
1	1360	3000
2	1340	500
3	1320	500
4	1300	500

Release Plan: (based on 2010 plan)

- Whitewater releases on alternating weekends starting on the last weekend in May. Whitewater releases start at 0100 hours and end at 1300 hours.
- In May and June, pool fluctuations are limited to 5 feet. (1365 – 1370)
- In May the target release will be 200 cfs, and in June the target minimum release is 225 cfs. Releases will match inflow down to 50 cfs to maintain pool between 1365 and 1370.
- Maximum whitewater release is 650 plus inflow up to a maximum of 800 cfs in May, 750 cfs in June, July, and August. . September whitewater releases are dependent on available storage and will be a maximum of 650 plus inflow up to 750 cfs. Sufficient storage must remain to insure the 50 cfs fisheries release thru the end of September before whitewater releases will be scheduled.
- In July through September there will be a constant 1:6 ration of weekday/non whitewater weekend to whitewater weekend augmentation. Weekday/non-whitewater weekend flows in July-September are augmented based on date and amount of storage remaining.
- 16-30 June, the target release temperature is 64^0 F
- 1 July to 31 August, target release temperatures are 62^0 F for daily releases and 66^0 F for whitewater releases.
- 1 - 15 September, target release temperature is 64^0 F
- 16-30 October, augment flows by 100 cfs at the prevailing temperature.

Scenario 3

Scenario 3 is based on the 2010 release schedule (discussed below) from F E Walter Dam without any structural modifications to the project. The goals of the release schedule are to create optimal in-lake spawning areas in May and June by limiting the pool fluctuations to 5 feet; maximize the benefit to cold water fisheries downstream by augmenting flows between July1 and September 30 by a minimum of 50 cfs with the cooler water; and provide whitewater releases on alternating weekends from late May to mid September. The pool would be raised to 1370 and releases would be made from the existing structure. The bypass gates at elevation 1297 could release a maximum of 300 cfs. All other discharges would be made from the flood control gates at elevation1265.

Pool Elevation: 1370 ft NGVD

Withdrawal Capabilities: Limited selective withdrawal. Releases made through flood control gates (Invert @ 1265) and bypass systems (invert at 1297).

Release Plan:

- Whitewater releases on alternating weekends starting on the last weekend in May.
- Whitewater releases start at 0100 hours and end at 1300 hours.
- In May and June, pool fluctuations are limited to 5 feet. (1365 – 1370)
- In May the target release will be 200 cfs, and in June the target minimum release is 200-250 cfs. Releases will match inflow down to 50 cfs to maintain pool between 1365 and 1370.
- Maximum whitewater release is 650 plus inflow up to a maximum of 800 cfs in May, 750 cfs in June, July, and August. September whitewater releases are dependent on available storage and will be a maximum of 650 plus inflow up to 750 cfs. Sufficient storage must remain to insure the 50 cfs fisheries release through the end of September before whitewater releases will be scheduled.

Scenario 4

This plan is also based on the 2010 release schedule. However, this plan investigates how a selective withdrawal system could be used to conserve cooler water for releases later in the summer while maximizing weekend whitewater releases. The goals of the release schedule are to provide whitewater releases on alternating weekends from in May and June, every weekend July through September; create optimal in-lake spawning areas in May and June by limiting the pool fluctuations to 5 feet; and maximize the benefit to cold water fisheries downstream by augmenting flows between July1 and September 30 by a minimum of 50 cfs with the cooler water.

Pool Elevation: 1392 ft NGVD

Withdrawal Capabilities: Selective withdrawal.

Portal #	Elevation (ft. NGVD)	Capacity (cfs)
1	1380	3000
2	1360	3000
3	1340	500
4	1320	500
5	1300	500

Release Plan: (based on 2010 plan)

- Whitewater releases on alternating weekends starting on the second weekend in May and June, every weekend in July, August and September.
- Whitewater releases start at 0100 hours and end at 1300 hours.
- In May and June, pool fluctuations are limited to 5 feet. (1387-1392)
- In May the target release will be 200 cfs, and in June the target minimum release is 225 cfs. Releases will match inflow down to 50 cfs to maintain pool between 1387 and 1392.
- Maximum whitewater release is 750 plus inflow up to a maximum of 900 cfs in May, 850 cfs in June, July, and August and September.
- On the first and last Sunday of July, August, and September whitewater releases are 1,200 cfs plus inflow up to a maximum of 2,000 cfs. Sufficient storage must remain to insure the 50 cfs fisheries release thru the end of September before whitewater releases will be scheduled.
- 16-30 June, the target release temperature is 64^0 F
- 1 July to 31 August, target release temperatures are 64^0 F during the week and 66^0 F on whitewater release weekends.
- 1 - 15 September, target release temperature is 64^0 F
- 16-30 October, augment flows by 100 cfs at the prevailing temperature.

Scenario 5

This plan is based on the 2010 release schedule with outflow thermal targets as per Chapter 93 CWF thresholds. To monitor performance of the scenario for producing and sustaining a fishery tailwater while satisfying whitewater interests, temperature tracers will be used to describe thermal variation on a daily basis at key locations. These include outflow (LH02; RM 76.51), Tannery Bridge (LH03; RM 70.39), Hickory Run (RM 67.30), Rockport (RM 62.70), Black Creek (RM 55.95), Glen Onoko (LH08; RM 49.78), Lehighton (LH10; RM 42.80), and Walnutport (LH15; RM 33.62).

This scenario also assumes a significant modification to the existing Dam with an additional 36 feet of storage elevation being added as originally proposed in 1984 project, termed “Walter Mod”. This would create a dam breast at 1,504 feet. Given the hypothetical nature of this scenario, the addition of the proposed storage does not take into account the need for storage easements, probability of refill, re-authorizations, or other impacts incurred by high pool elevations and presumed modifications. The Walter Mod project adds a total of 72,827 acre feet of storage (1,427 feet elevation) for long-term recreational storage. Inclusion of an additional 15% encroachment into flood control storage (16,298 acre feet) generates approximately 89,125 acre feet (1,438 feet) of storage for recreational use. Given the additional storage capacity, the starting elevation is 1,438 feet. As a point of interest, the probability of refill of the Walter Mod with a long-term pool at 1,438 feet, represents the upper extreme limit from a practical view point. The selective withdrawal system has portals at a series of elevations by 20 foot increments beginning at 1,300 feet. The capacities of two intakes are 3,000 cfs at 1,420 feet and 1,400 feet whereas the remaining intakes are 500 cfs capacity. The intent is to provide enough selective withdrawal at the lake’s surface to support the whitewater releases during late spring through early summer when water temperatures are still favorable to trout and thus conserve the hypolimnion for later in the season. Initial reservoir profiles will incorporate the derived profile for Beltzville. Optimization (iterative model runs) is recommended to maximize the temperature benefit as performed with Scenarios 1 and 4.

The goals of the release schedule are to create optimal in-lake spawning areas in May and June by limiting the pool fluctuations to 5 feet; maximize the benefit to cold water fisheries downstream by augmenting flows between July 1 and September 30 by a minimum of 50 cfs with the cooler water; and provide whitewater releases on alternating weekends from mid-May (i.e., Mother’s Day) to late-July and every weekend in late-July through mid-September.

Pool Elevation: 1,438 feet NGVD

Withdrawal Capabilities: Selective withdrawal.

Portal #	Elevation (ft. NGVD)	Capacity (cfs)
1	1420	3000
2	1400	3000
3	1380	500
4	1360	500
5	1340	500
6	1320	500
7	1300	500

Release Plan: (based on 2010 plan – see below)

- Whitewater releases on alternating weekends starting in mid-May (i.e., Mother's Day) to late-July and every weekend in late-July through mid-September. Whitewater releases start at 0100 hours and end at 1300 hours. For the other 12 hour periods of the white water weekends, the release will revert to the fisheries enhancement augmentation release rate. A total of 24 events are to be planned for the recreation season.
- Fisheries releases, in July through August, storage will be utilized for weekday and weekend fisheries enhancement releases of 100 cfs above inflow, up to a total of 300 cfs. Dependent on storage, for the period of September – October, fisheries enhancement will augment inflow by 50 cfs or increased to 100 cfs based on available storage. Priorities are outline as per the Francis E. Walter Reservoir Recreation Operations Plan for 2010.
- In May and June, pool fluctuations are limited to 5 feet. (1433 – 1438)
- In May the target release will be 200 cfs, and in June the target minimum release is 225 cfs. Releases will match inflow down to 50 cfs to maintain pool between 1,433 and 1,438.
- Maximum whitewater release is 650 plus inflow up to a maximum of 800 cfs in May, 750 cfs in June, July, and August. September whitewater releases will be a maximum of 650 plus inflow up to 750 cfs. Sufficient storage must remain to insure the 50 cfs fisheries release thru the end of September before whitewater releases will be scheduled.
- In July through September there will be a constant 1:6 ratio of weekday/non whitewater weekend to whitewater weekend augmentation. Weekday/non-whitewater weekend flows in July-September are augmented based on date and amount of storage remaining.
- 16-30 June, the target release temperature is 64^0 F at outflow

- 1 July to 31 August, target release temperatures are 62^0 F for daily releases and 66^0 F for whitewater releases at outflow.
- 1 - 15 September, target release temperature is 64^0 F at outflow
- 16-30 October, augment flows by 100 cfs at the prevailing temperature.
- Adjustment of the seasonal target temperatures may occur through the model optimization process to best use cold water reserves available at selective release tower portals.

Scenario 6

This scenario is based, in part, on the 2010 release schedule. The intent is to investigate if periodic large pulses of reservoir releases, similar to the 2010 whitewater releases, can keep enough river rock substrate wetted to maintain downstream thermal target at Tannery Bridge of 68 ^{o}F (20 ^{o}C). As in the 2010 release schedule a single large pulse of water will be released on both weekend days as well as a third large pulse of similar magnitude will be routinely released on a single day, mid-week. To monitor performance of the scenario for producing and sustaining a fishery tailwater, temperature tracers will be used to describe thermal variation on a daily basis at key locations. These include outflow (LH02; RM 76.51), Tannery Bridge (LH03; RM 70.39), Hickory Run (RM 67.30), Rockport (RM 62.70), Black Creek (RM 55.95), Glen Onoko (LH08; RM 49.78), Lehighton (LH10; RM 42.80), and Walnutport (LH15; RM 33.62).

This scenario also includes the Walter Mod project, tower configurations, starting pool elevation (1,438 feet), and initial lake profile (i.e., Beltzville) as discussed in Scenario 5.

The goal of the release schedule are to investigate if additional storage from a long-term pool generated by Walter Mod, can sustain a downstream thermal target of 68^{o}F (20^{o}C) at Tannery Bridge (RM 70.39). Optimization (iterative model runs) is recommended to maximize the temperature benefit as performed with Scenarios 1 and 4. Additional objectives include optimizing in-lake spawning areas in May and June by limiting the pool fluctuations to 5 feet; provide large pulsed releases on alternating weekends from the second weekend in May through June and every weekend in July, August, and September, and weekday pulsed releases one day during mid-week following the second weekend in May through September.

Pool Elevation: 1,438 feet NGVD

Withdrawal Capabilities: Selective withdrawal.

Portal #	Elevation (ft. NGVD)	Capacity (cfs)
1	1420	3000
2	1400	3000
3	1380	500
4	1360	500
5	1340	500
6	1320	500
7	1300	500

Release Plan: (based in part on 2010 plan)

- Weekend releases on alternating weekends starting on the second weekend in May and June, every weekend in July, August and September. Weekday releases follow same schedule, but occur on a single day mid-week (i.e., Wednesday).
- All releases start at 0100 hours and end at 1300 hours.
- In May and June, pool fluctuations are limited to 5 feet. (1,433-1,438)
- In May the target release will be 200 cfs, and in June the target minimum release is 225 cfs. Releases will match inflow down to 50 cfs to maintain pool between 1,433 ft and 1,438 ft.
- Maximum releases are 750 plus inflow up to a maximum of 900 cfs in May, 850 cfs in June, July, and August and September.
- Minimum releases are 100 cfs in July through October.
- On the first and last Sunday of July, August, and September releases are 1,200 cfs plus inflow up to a maximum of 2,000 cfs.

Francis E. Walter Reservoir Recreation Operations Plan for 2010

Introduction

The plan for 2010 will be different from that of 2009. While the 2009 plan was able to satisfy all of the plan features due to it being a very wet year, modifications are being made to better match planned releases to the time of the season when they are perceived as most beneficial based on public comment and modeling results from the Phase I Lehigh River Flow Study. This year water is again being allocated to insure early season (July through August 21st) white water recreational and fisheries releases (July through September 10th) while relying on seasonal precipitation and additional water accumulations to allow scheduling of releases for later in the season (September and October). Other modifications to release rates as well as changes to October operations are also planned.

Planned white water release dates are listed below:

May: 15, 29, 30

June: 12, 13, 26, 27

July: 10, 11, 24, 25, 31

August: 1, 7, 8, 14, 15, 21, 22*, 28*, 29*

September: 4*, 5*, 17**

* With the pool at 1365 on 1 July, storage is sufficient to support white water recreation and fisheries augmentations releases through 21 August and 10 September respectively. After those dates additional storage must be accumulated during the recreation season to make additional releases possible.

**The September 17th date will only occur if sufficient stored water is available. This is the last added increment for the 2010 recreation plan. Fisheries releases through October 17th will be assured before the September 17th release will be announced. The September 17th (Friday) release is planned for 4000 cfs. Ramping down from that release rate will be accomplished over the following weekend (September 18 and 19)

Total: 24 white water release dates planned, late season white water events and fisheries enhancement releases are dependent upon additional water storage becoming available during the year.

Details of planned operations are presented below.

Initial Filling:

For the 2010 season, the maximum storage level will be the same as last year, elevation 1370. On or before 1 April 2010 storage will be initiated at F. E. Walter Dam. The exact date that storage is initiated will be determined by the Corps of Engineers based on basin hydrologic conditions at the time. Storage could start earlier if precipitation raises the pool above elevation 1300. During this period outflows will be limited to 250 cfs on weekdays and during weekends the outflow will normally be set equal to inflow up to a maximum release rate of 1000 cfs. The weekend limit could be lowered to 750 cfs and the weekday limit lowered to 225 cfs if hydrologic conditions were such that reaching the target level of 1370 by 15 May 2010 was determined to be in jeopardy. The storage of excess inflows will continue until the pool reaches the elevation of 1370. Once pool level reaches 1370, outflow will match inflow until the start of the recreation season (15 May). The pool elevation of 1370 is expected to be reached no later than midnight Friday 14 May 2010, in time for the first planned white water release to begin on Saturday 15 May 2010 at 1 AM. If for any reason the target pool elevation is not reached in time for the first white water release, the agencies will reconvene to determine the appropriate course of action.

Special operations will prevail for the first two weekends of trout season (17-18 April and 24-25 April). Releases will be restricted to a maximum of 400 cfs for these two weekends. This restriction is consistent with DCNR restrictions placed on commercial boaters in the upper reaches of the Lehigh River from White Haven to Rockport. This may result in a pool level above elevation 1370 for brief periods.

Pool elevations above elevation 1370 at any time are generally considered undesirable encroachments into flood control storage and will normally be evacuated as quickly as possible in accordance with the Corps' F.E. Walter Reservoir Water Control Manual. If weather forecasts are favorable, the encroachment into flood control storage may be retained for brief periods to support planned recreational opportunities. The Corps of Engineers will be solely responsible for making this determination. As in previous years, flood control objectives take priority and if necessary any of the storage above elevation 1300 could be released if deemed necessary by the U.S Army Corps of Engineers.

15 May- 30 June

White water weekend events are planned to start on May 15th (Saturday only). As in previous years, the planned releases will be made for 12 hour periods from 1AM until 1 PM on Saturdays and Sundays.

The pool elevation will be maintained between elevations 1365 and 1370 from 15 May through 30 June. The 5 foot pool limit is intended to help conserve cooler water for later in the season, and to help in-lake fish spawning. As noted before, a pool level above elevation 1370 is an undesirable encroachment into flood control storage which will normally be evacuated as quickly as possible. After pool elevation of 1370 is reached, weekday releases for fisheries enhancement for the period from 15 May thru 31 May will be 200 cfs and will be in the 200-250 cfs range in June. Weekend white water recreation releases during this period will be made as long as sufficient storage exists above elevation 1365 with a release target of 800 cfs in May and 750 cfs in June. Tables 12 and 13 provide priorities for determining the length and magnitude of white water recreation releases to be made in May and June if storage is not sufficient to make full releases for the planned 12 hour periods. Releases for fisheries enhancement on weekends when white water releases are not planned will be set to match inflow up to a maximum of 400 cfs during this period. If storage is not available above elevation 1365, releases will be set equal to inflow to maintain the 1365 elevation until 1 July. On Wednesday June 9th, the existing situation will be evaluated to determine if sufficient storage remains above elevation 1365 to maintain the fisheries releases and the remaining June white water releases (12/13 and 26/27 June). If it is determined that sufficient storage does not remain, adjustments in operations for the remainder of June will be made to best utilize available storage. Any cancellations or modifications of release plans will be announced (posted on Corps webpage).

July - August

Starting in July, there will no longer be any specific flow targets or limits on pool levels. In July, storage will be utilized for weekday and weekend fisheries enhancement releases of 100 cfs above inflow, up to a total of 300 cfs. On white water recreation weekends, for the 12 hour periods from 1AM until 1 PM on both Saturday and Sunday, releases will be set at inflow plus 600 cfs up to a maximum of 800 cfs in July and inflow plus 650 cfs up to 850 for white water events through 21 August. For the other 12 hour periods of the white water weekends, the release will revert to the fisheries enhancement augmentation release rate.

Initially, fisheries enhancement releases will be 100 cfs plus inflow up to 300 cfs. Storage capacity at elevation 1365 at the end of June is sufficient to make the planned releases for white water weekends through 21 August and fisheries enhancements through 10 September.

September - October

The 2010 plan is similar to the 2009 plan in that both fisheries enhancement and white water releases will utilize available storage as long as it is present and rely on additional inflow during the recreation season to make late season releases possible. If at any time precipitation occurs to allow sufficient additional water to accumulate; planned white water recreation releases and additional fisheries enhancement releases will be scheduled. The volume of accumulated water will be allocated equitably between the white water and fisheries enhancement purposes, and as precipitation dependent release weekends are scheduled, fisheries enhancement releases will be increased from 50 cfs to 100 cfs, or additional release days of 50 cfs or 100 cfs will be added based on how much additional storage is accumulated and at what point in the season the additional storage becomes available as outlined in the next paragraph. For the additional volume allocated for white water releases, priorities for water use for the remaining white water events are listed in Table 14. Final release amounts and durations will be determined and posted on the Corps webpage the Wednesday prior to the weekend. If sufficient water is available, each scheduled white water event will be held for both Saturday and Sunday at the full amount before subsequent planned white water events will be scheduled. Additional weekend releases will not be scheduled unless storage is sufficient to allow at least a one day (12 hour) release of 600 cfs. As additional releases become possible due to accumulation of water, the additional fisheries enhancement releases and white water release amounts will be announced.

Additional precipitation and additional releases from storage is proposed to occur in the following priority order through the July – October time period.

- When additional storage is accumulated, add whitewater releases on August 22 (650 cfs) and August 28 (750 cfs) and additional fisheries releases of 50 cfs thru September 10 and 100 cfs thru August 6. Releases for fisheries enhancement will be the augmentation amount plus inflow up to a maximum of 300 cfs.
- Next add the white water event for August 29th (750 cfs) and increase fisheries releases of 100 cfs thru August 17th.
- Next add whitewater flows on September 4th (650 cfs) and increase fisheries releases of 100 cfs thru August 24th.

- Next add whitewater flows on September 5th (650 cfs), add fisheries releases of 50 cfs thru September 13th and increase fisheries releases of 100 cfs thru August 30th.
- Next add fisheries releases of 50 cfs thru October 17th.
- Next increase fisheries releases to 100 cfs thru October 17th
- Storage in excess of above flow needs may be released Friday, September 17th for a higher flow whitewater release. The scheduling of this release will allow those interested in larger white water recreation releases to plan accordingly. The release rate will be based on the amount of water available. Release will be set at a maximum of 4000 cfs. Final scheduling and amount of this release will be determined and posted by Wednesday, 15 September 2010. No float fishing releases are planned. Significant ramping for this event will allow float fishing and white water opportunities during the ramping period.

Following this procedure may mean that white water events and additional fisheries enhancement releases become scheduled or modified with little advance notice. Also since the last large release is scheduled well before the end of the fisheries release period, excess water may become available. This water beyond what is necessary to make all the planned releases will be released at the discretion of the Corps of Engineers. Release plans will be posted on the Corps webpage.

Table 12
May Release Rate Priority

Saturday		Sunday		
Rate	Duration	Rate	Duration	Volume Required
(CFS)	(HRS)	(CFS)	(HRS)	(DSF)
600	12			300
650	12			325
700	12			350
700	12	500	6	475
750	12	550	6	512.5
800	12	600	6	550
800	12	700	6	575
800	12	600	12	700
800	12	700	12	750
800	12	800	12	800

Maximum release 800cfs in May

Table 13
June Release Rate Priority

Saturday		Sunday		
Rate (CFS)	Duration (HRS)	Rate (CFS)	Duration (HRS)	Volume Required (DSF)
600	12			300
650	12			325
700	12			350
700	12	500	6	475
750	12	550	6	512.5
750	12	600	6	525
750	12	700	6	550
750	12	750	6	562.5
750	12	750	12	750

Maximum release 750 cfs in June

Table 14
July-September Release Rate Priority

Saturday		Sunday		
Rate (CFS)	Duration (HRS)	Rate (CFS)	Duration (HRS)	Volume Required (DSF)
600	12			300
650	12			325
700	12			350
700	12	500	6	475
750	12	550	6	512.5
750	12	600	6	525
750	12	700	6	550
750	12	600	12	675
750	12	700	12	725
750	12	750	12	750

Planned releases in this period vary between 600-750 cfs plus inflow

Tracer Runs

Tracer runs were conducted for the 2001 (calibration) and 2003 (verification) simulation years. The purpose of the runs was to estimate the percentage of flow tributaries contribute to the Lehigh River flow. Runs were conducted by setting a tracer concentration to 1.0 mg/L on all modeled tributaries entering into the Lehigh River. For the main stem of the Lehigh River upstream, below, and in F. E. Walter Reservoir tracer concentrations for boundary and initial conditions were set to 0.0 mg/L. By setting conditions to these values, tracer concentration showing up in the Lehigh River can only be attributed to the tributaries being modeled. Figures 79 and 80 show tracer concentrations (bottom plot in figures) and flow at the end of each water body modeled. For instance, WB1 represents F. E. Walter Reservoir plus the Lehigh River to just past LH02. There are no tributaries modeled in this reach. WB2 represents the Lehigh River from the end of WB1 to just below LH03 (Tannery Bridge) and includes Hayes Creek and Sandy Run modeled as tributaries. WB3 represents the Lehigh River from the end of WB2 to just below LH08 (Glen Onoko) and includes Buck Mountain Creek, Black Creek and Nesquehoning Creek modeled as tributaries. These concentrations can easily be converted to percentage of flow contributed by the tributaries by multiplying the tracer concentration by 100.

Using LH04 and LH05 as the tributaries to find their percent contribution to the Lehigh River flow, the equation to calculate percent flow from tributaries is:

$$((Q\text{trib1}+Q\text{trib2})/QTOT)*100 = Percent\ Trib\ Flow \qquad \text{Eq. 8}$$

Percent flow can be calculated by plugging in the following numbers contributed to the Lehigh River by LH04 and LH05 on Julian Day 210 (July 29):

$Q_{F.E.Walter}$ = 3.04 cms
Q_{LH4} = 0.295 cms
Q_{LH5} = 0.41 cms
Q_{tot} = 3.04 + 0.295 + 0.41

% Tri b Flow = ((0.295+ 0.41)/3.745)*100 = 18.83% Eq. 9

Concentration changes as tributaries enter the Lehigh River using the equation:

$$(QF.E.Walter*CF.E.Walter+QTribs*CTribs)Qtot= Ctot \qquad \text{Eq. 10}$$

Where:

$Q_{F.E.Walter}$ = Flow from F.E. Walter

$C_{F.E.Walter}$ = tracer concentration from F.E. Walter

Q_{Tribs} = Flow from tributaries

C_{Tribs} = tracer concentration from tributaries

Q_{tot} = Combined flow from F.E. Walter + tributaries

C_{tot} = tracer concentration from F.E. Walter + tributaries

Eq. 10 is information W2 provides in output. If numbers are plugged into the above Eq. 10 and then multiplied by 100, the result is equivalent to percentage of flow contributed by the tributaries as calculated from Eq. 9. For example to estimate the % flow from tributaries at the end of WB2, assume the following flows and tracer concentrations from F. E. Walter, LH04 and LH05 on Julian Day 210 (July 29):

$Q_{F.E.Walter}$ = 3.04 cms

$C_{F.E.Walter}$ = 0.0 mg/L

Q_{LH4} = 0.295 cms

C_{LH4} = 1.0 mg/L

Q_{LH5} = 0.41 cms

C_{LH5} = 1.0 mg/L

Q_{tot} = 3.04 + 0.295 + 0.41

C_{TOT} = (3.04*0.0 + 0.295*1.0 + 0.41*1.0)/3.745 = .1883

Multiplying C_{TOT} by 100 gives the same result (18.83) which is the same as percent flow contributed by tributaries estimated from Eq. 9 above. Therefore results in Figures 79 and 80 showing tracer concentrations (bottom plot) can be multiplied by 100 to get percent flow contributed by tributaries downstream of F. E. Walter. When looking at scenario results this will give the reader insight as to why reducing temperatures in the upstream reaches may not matter in the downstream reaches. Once tributary contributions become greater than F.E.

Walter releases, temperature and water quality concentrations will approach the greater influence.

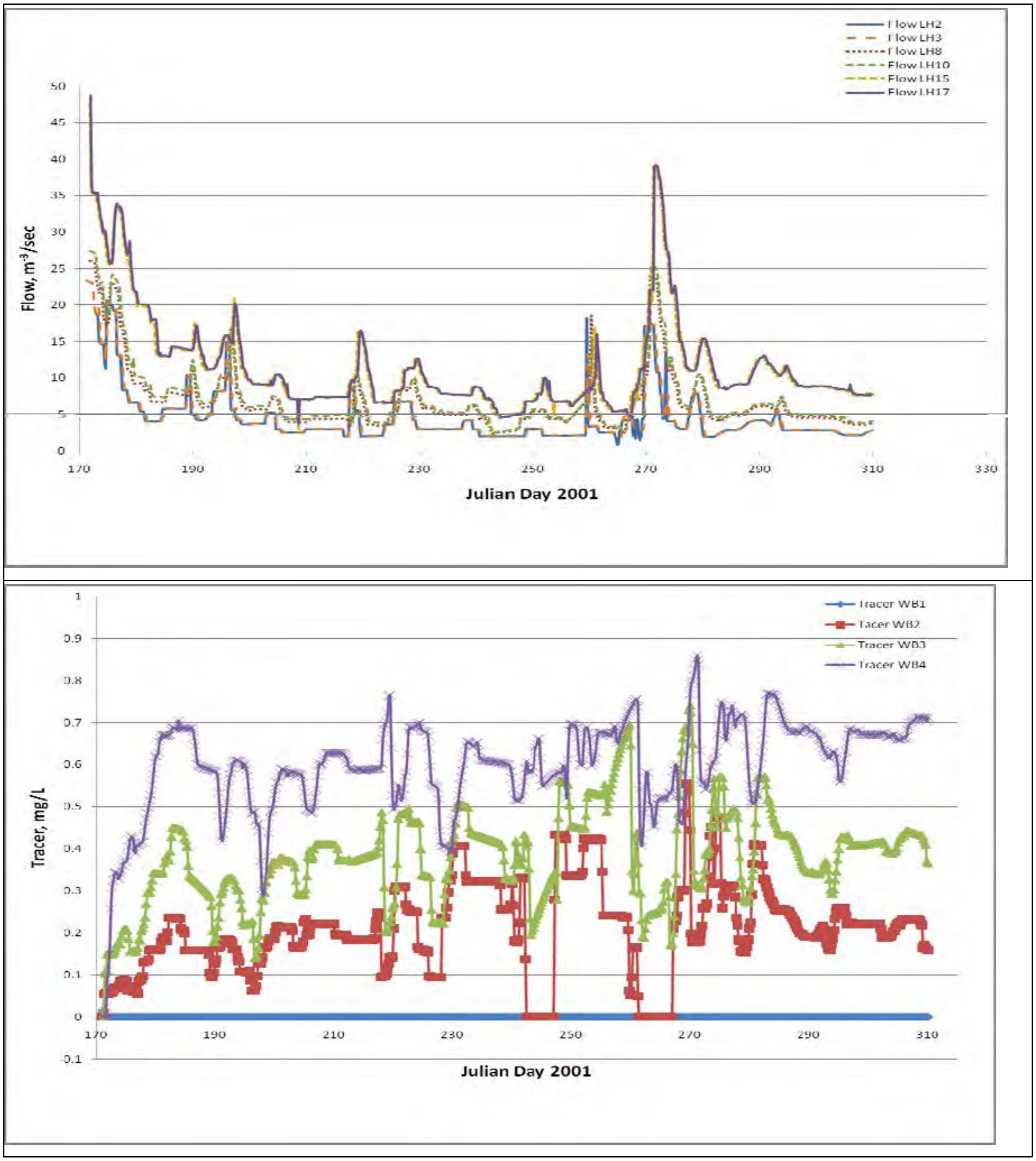


Figure 79. Flow and tracer results for 2001 in the Lehigh River at river stations and at the end of water bodies modeled, respectively.

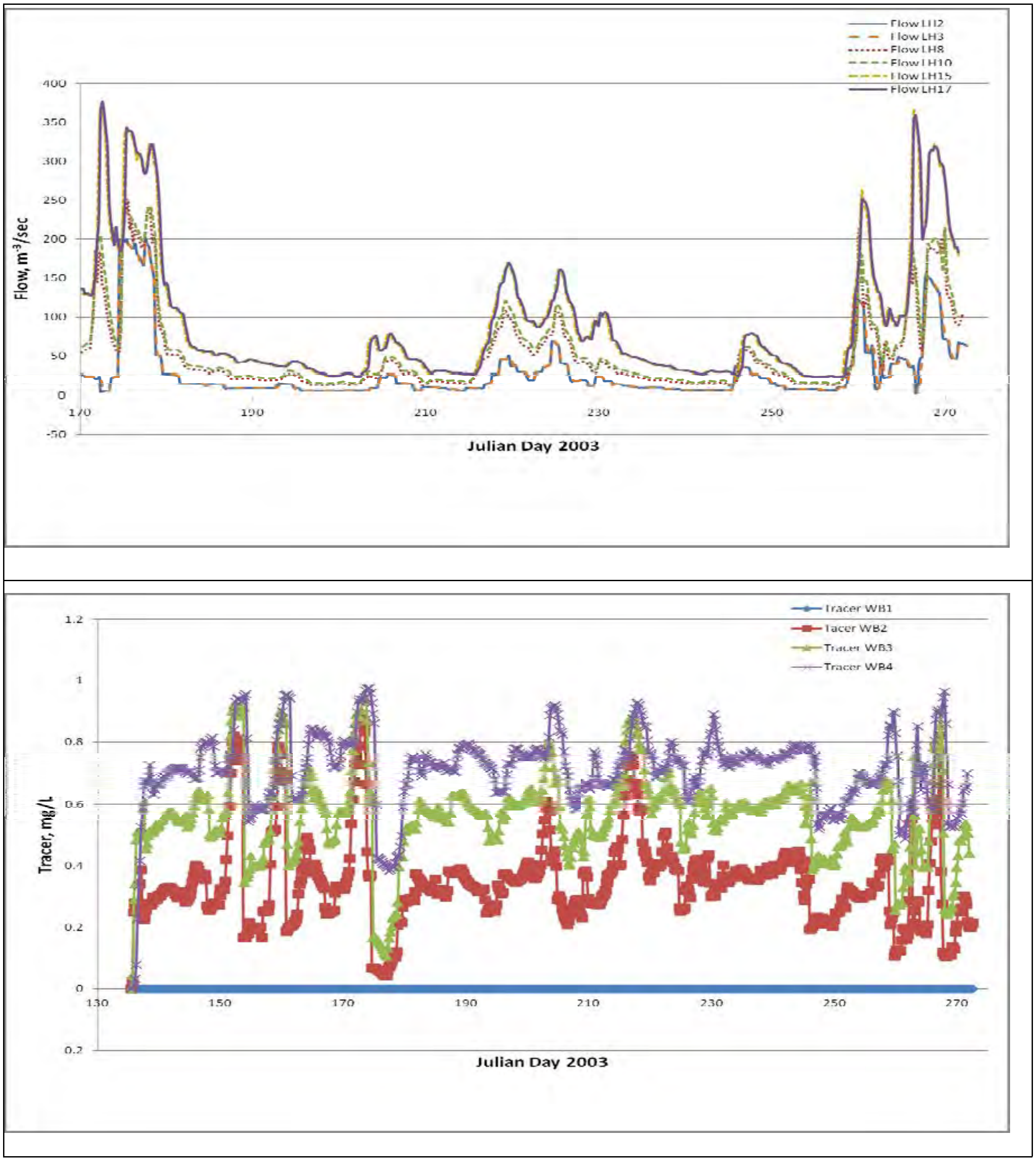


Figure 80.Flow and tracer results for 2003 in the Lehigh River at river stations and at the end of water bodies modeled, respectively.

Scenario Results and Discussion

Results for scenario runs are presented in two types of plots: 1) reservoir temperature profiles plots from station WA02 upstream of the F. E. Walter dam and 2) temperature time series plots at six river locations on the Lehigh River downstream of F. E. Walter dam for both years modeled (i.e., 2001 and 2003). Scenario runs were considered either no modification or selective withdrawal.

During scenario runs, Beltzville Reservoir operation releases were the same as what was used for the calibration/verification release runs. Outflow temperature release time series were presented in Tillman and Lewis-Coker (2010) in Figure 11 for Beltzville Reservoir.

F. E. Walter Reservoir outflow releases for all scenarios are shown in Figures 81 through 89 for 2001 and 2003. Initially release flows for the first four scenarios were received from the Philadelphia District and were simulated as received. In addition, F. E. Walter water temperature was initialized in 2001 using an isothermal profile of 11 °C. Later, based on historical data from the start period, it was decided to use a stratified profile with cooler water in the hypolimnion since scenario simulations started earlier in the year than calibration. Figures 91 and 92 show temperature profile results from the 2001 and 2003 scenario simulations using both initial conditions for the first four scenario runs. Using the stratified profile with cooler water in the hypolimnion did not show an improvement in release temperatures (see Figure 93). There were only minimal differences between release temperature results from the two runs. This was contributed to using the same release locations for both runs. Since the releases were from higher in the reservoir (1360 ft) from Julian Day 168 (June 17) to Julian Day 245 (September 2), cooler water was not being accessed soon enough. It would help to lower the release port to elevation 1320 ft around Julian day 180 (June 29) or split between elevations 1320 ft and 1340 ft. This would access cooler water during this period then release from 1300 ft and the flood gates during the warmest time of the summer. After discussing simulation results with study partners it was decided to use the new optimization routine added to W2 in the summer of 2011 for scenarios 1 and 4 to improve temperature results. Based on results from these first four scenarios, guidance to develop rules for scenarios 5 and 6 were derived.

Release flows are shown in Figures 81 through 90 for all scenarios. Figures 81, 82, and 85 through 90 contain original release flows (upper plot) and optimized (lower plot) release flows for scenarios 1 and 4 through 6. To optimize for better temperature releases at F. E. Walter, two options were available. The first option is to let W2 automatically move up or down releasing from one port at a time to try to meet the release temperature criteria. Option two is to split release flow between two ports that are specified to meet a release temperature. All total flow for each released amounts stayed the same as original flows. For this study the first option was applied, and then the second option was used to try to further conserve cooler water temperatures.

Figures 81 through 90 show that to maintain release temperatures around 15 ^{o} C, optimized releases had water being released from deeper in the water column earlier in the simulation than original release flows. Moreover, optimized releases had water being released from flood gates earlier than original releases. In 2003 optimized releases show fewer differences from original releases for scenario 5 and 6. A similar statement can be said about scenarios 1 and 4 in 2003 until around Julian day 190 (July 9) when releases from the flood gate occur earlier in the year than before. Optimized releases for these two scenarios are releasing water from the flood gates much earlier than the original releases.

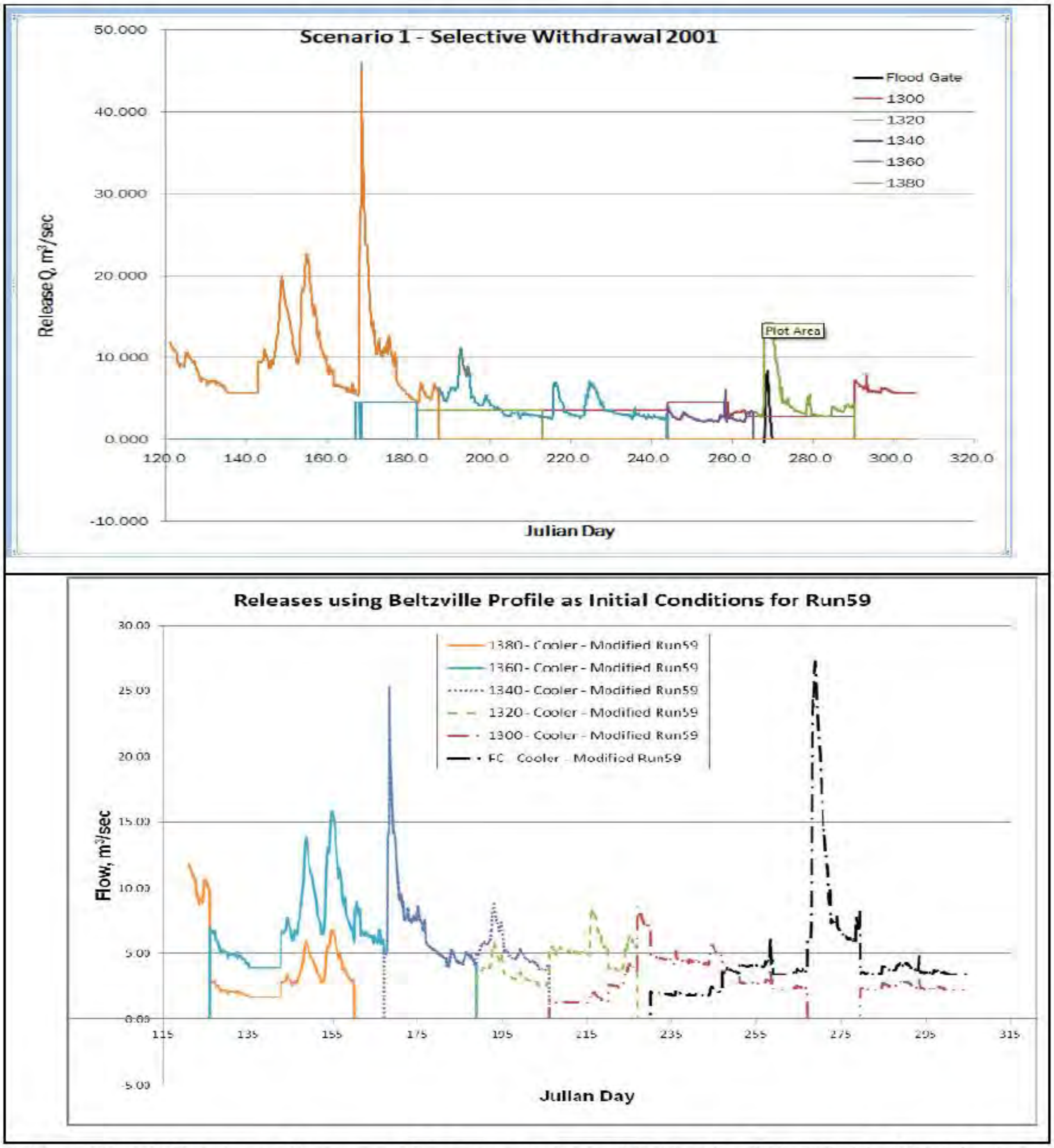


Figure 81. 2001 release flows used for scenario 1 provided by the Philadelphia District – top is original release flows and bottom is optimized release flows.

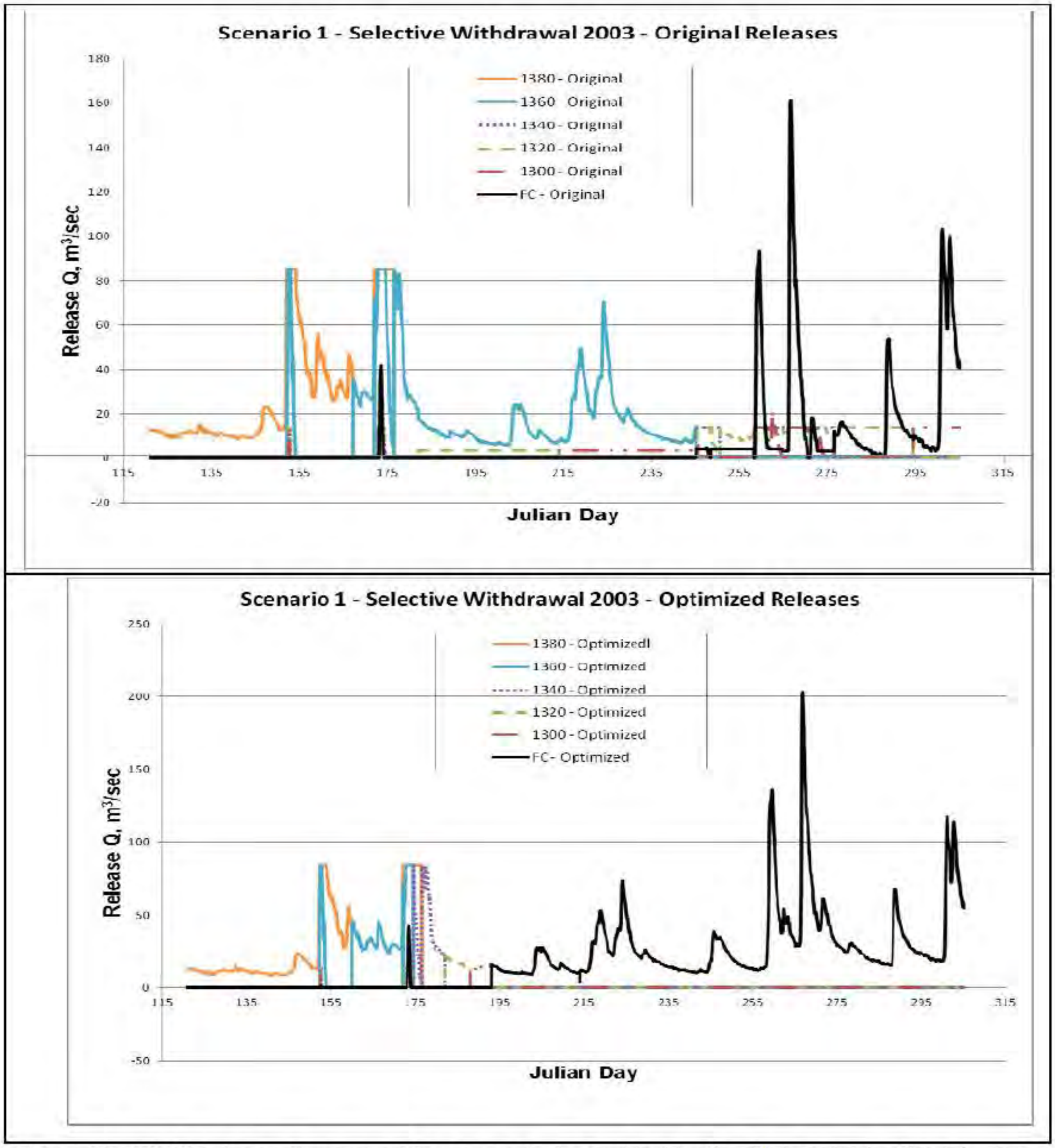


Figure 82. 2003 release flows used for scenario 1 provided by the Philadelphia District – top is original release flows and bottom is optimized release flows.

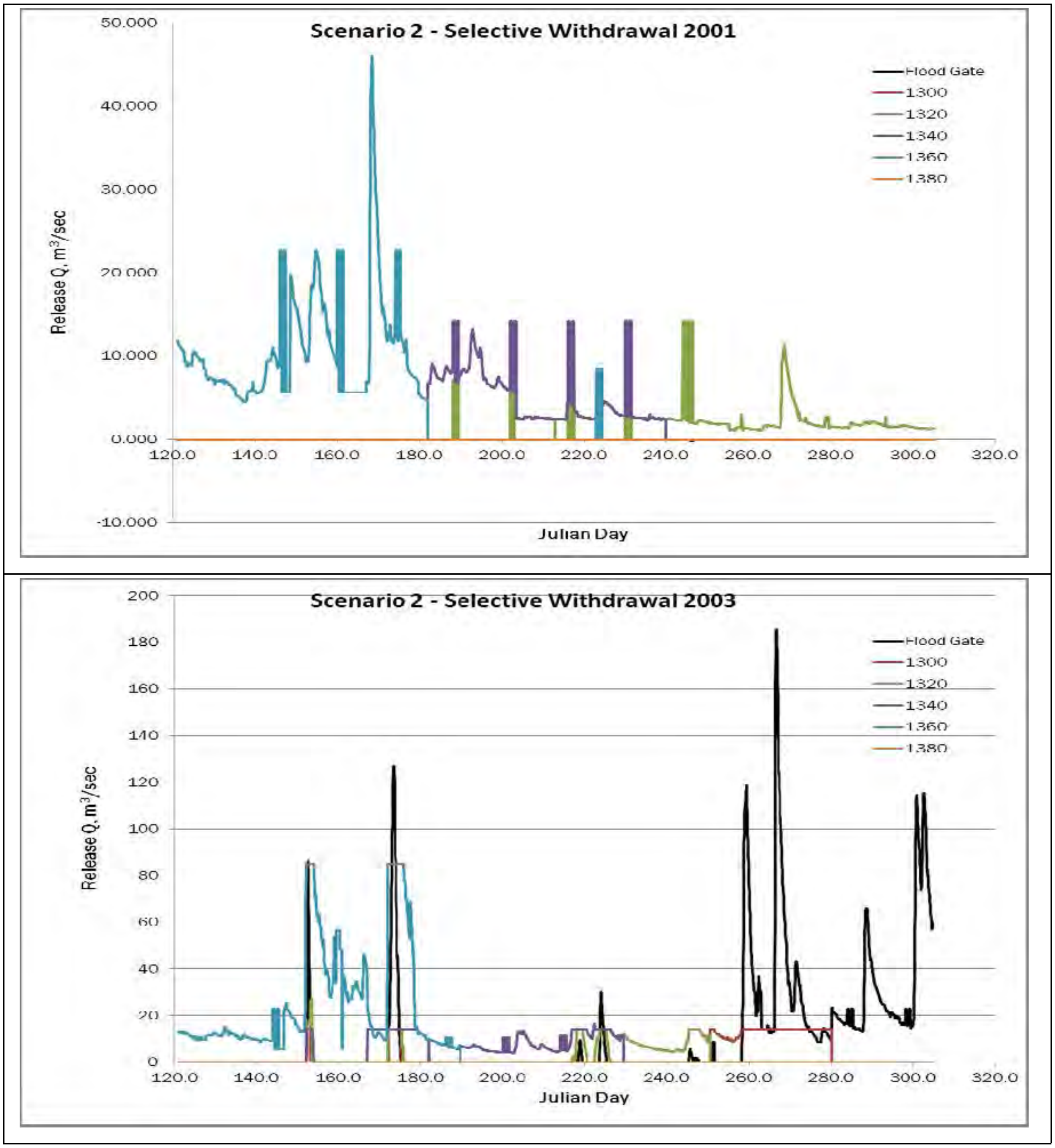


Figure 83. Scenario 2 release flows at F. E. Walter for 2001 (upper) and 2003 (lower)

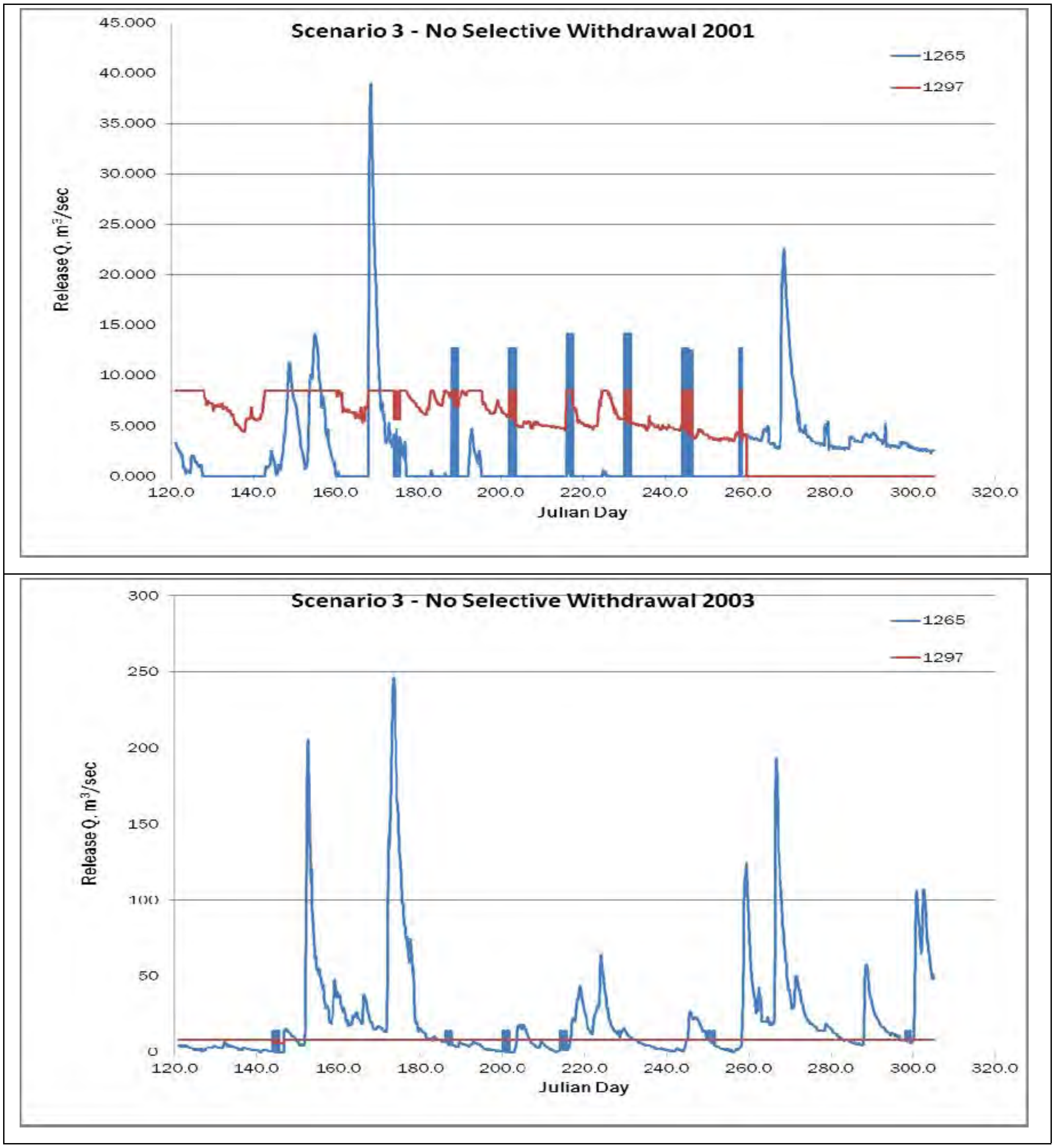


Figure 84. Scenario 3 release flows at F. E. Walter for 2001 (upper) and 2003 (lower)

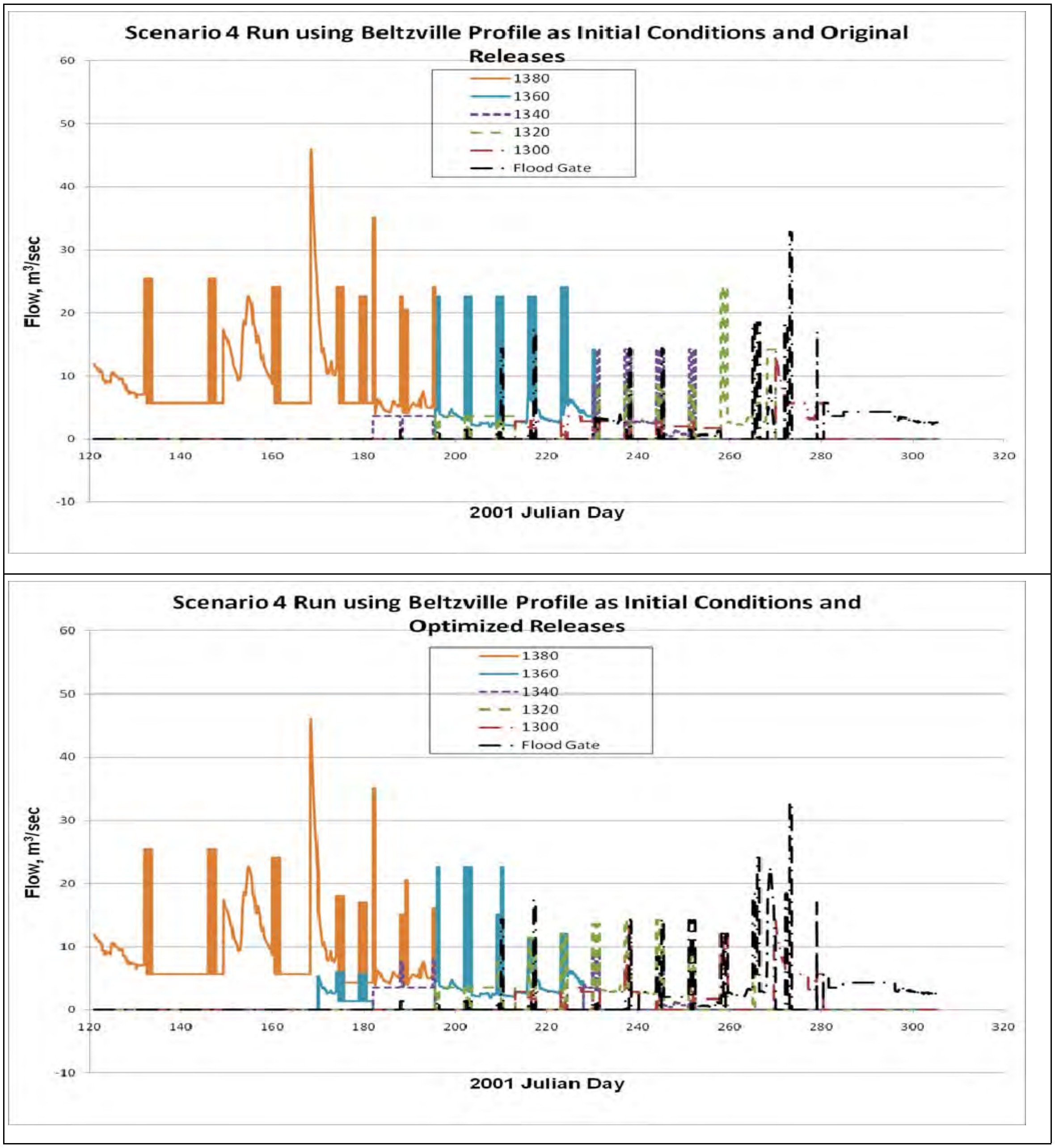
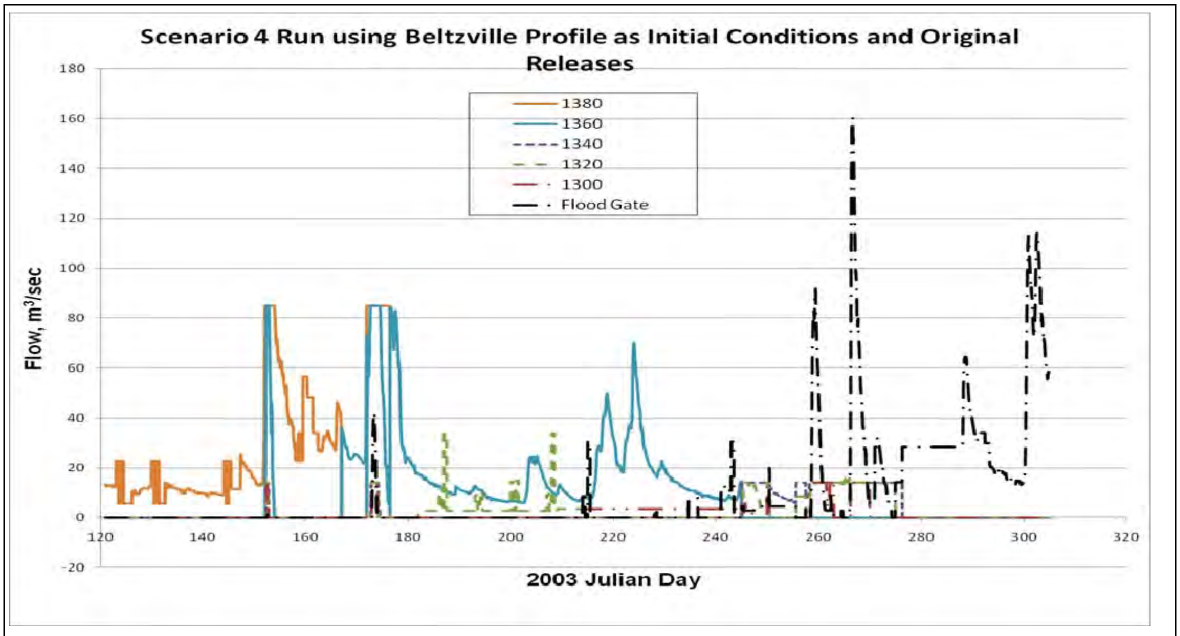


Figure 85. 2001 release flows used for scenario 4 provided by the Philadelphia District – top is original release flows and bottom is optimized release flows.



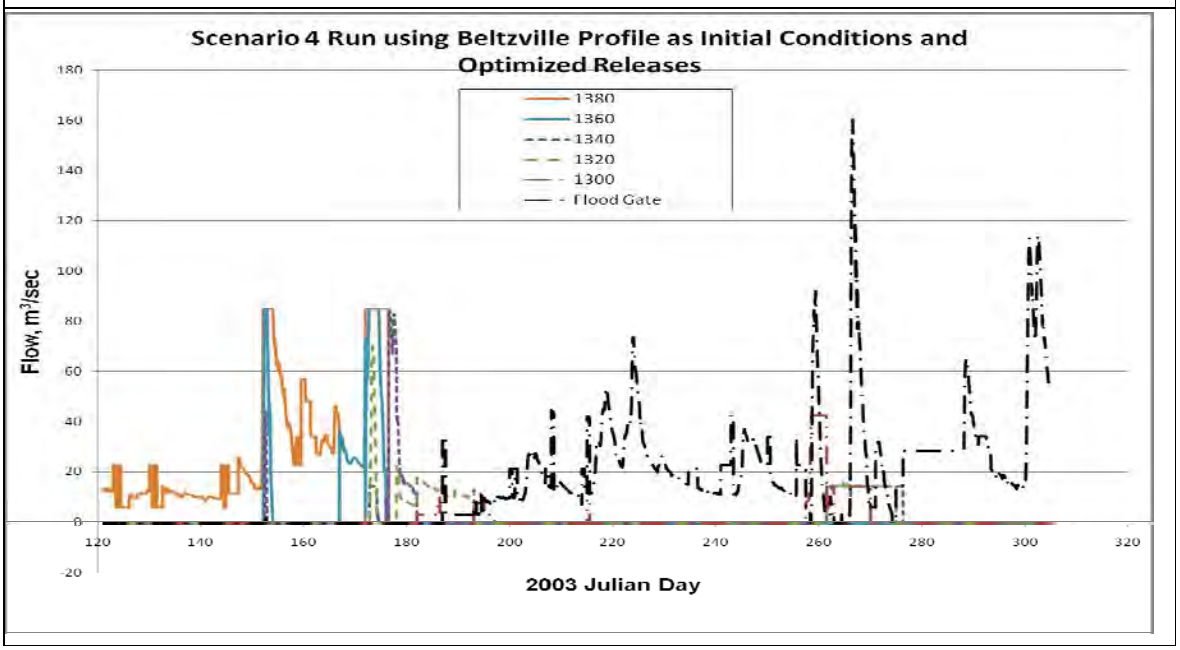


Figure 86. 2003 release flows used for scenario 4 provided by the Philadelphia District – top is original release flows and bottom is optimized release flows.

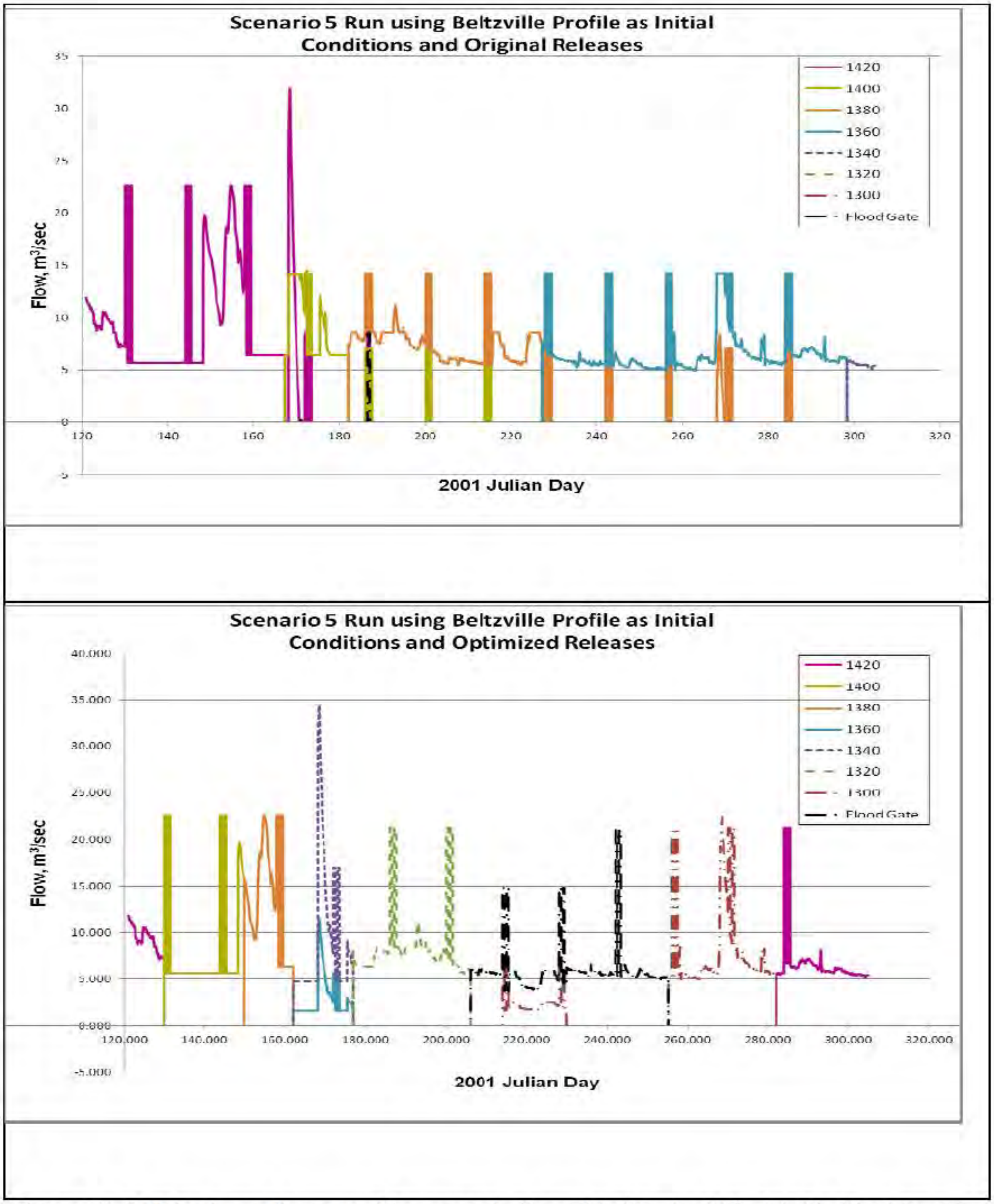


Figure 87. 2001 release flows used for scenario 5 provided by the Philadelphia District – top is original release flows and bottom is optimized release flows.

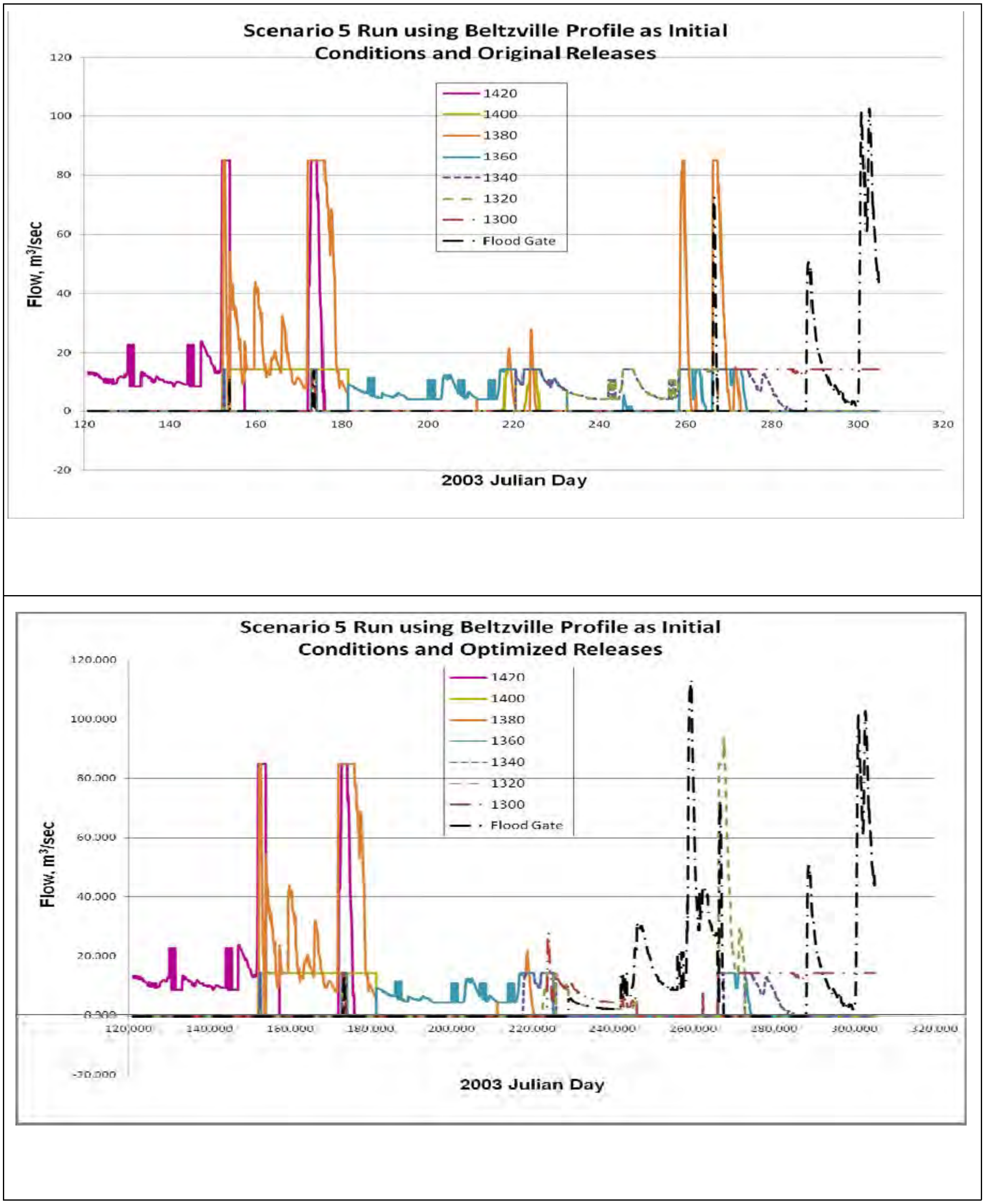


Figure 88. 2003 release flows used for scenario 5 provided by the Philadelphia District – top is original release flows and bottom is optimized release flows.

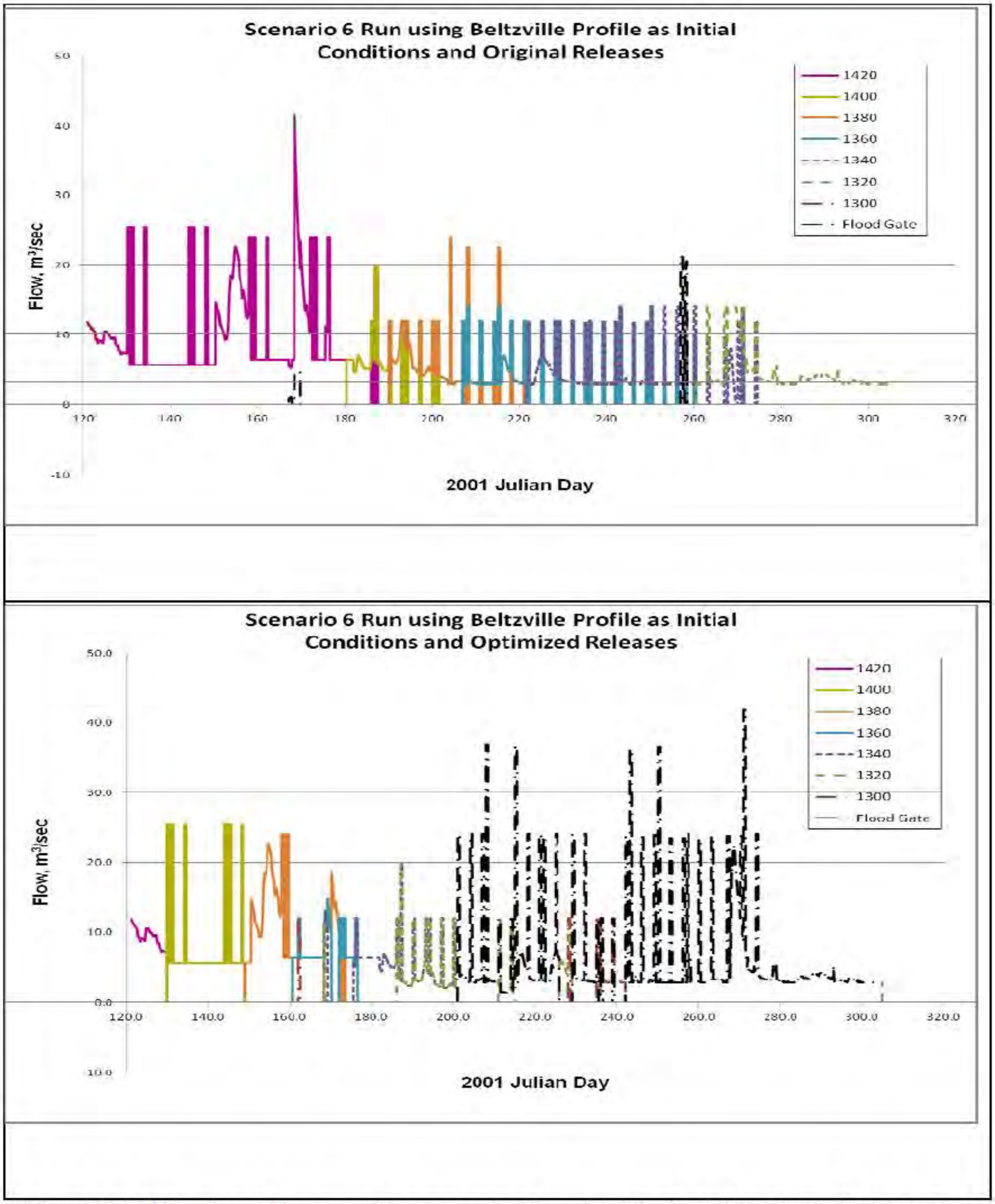
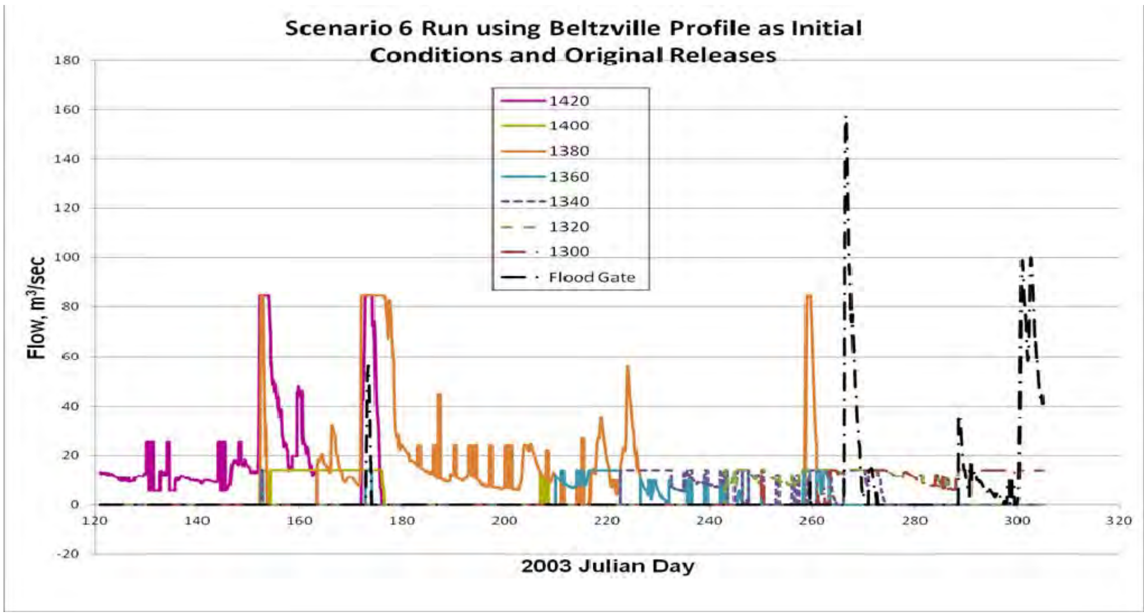


Figure 89. 2001 release flows used for scenario 6 provided by the Philadelphia District – top is original release flows and bottom is optimized release flows.



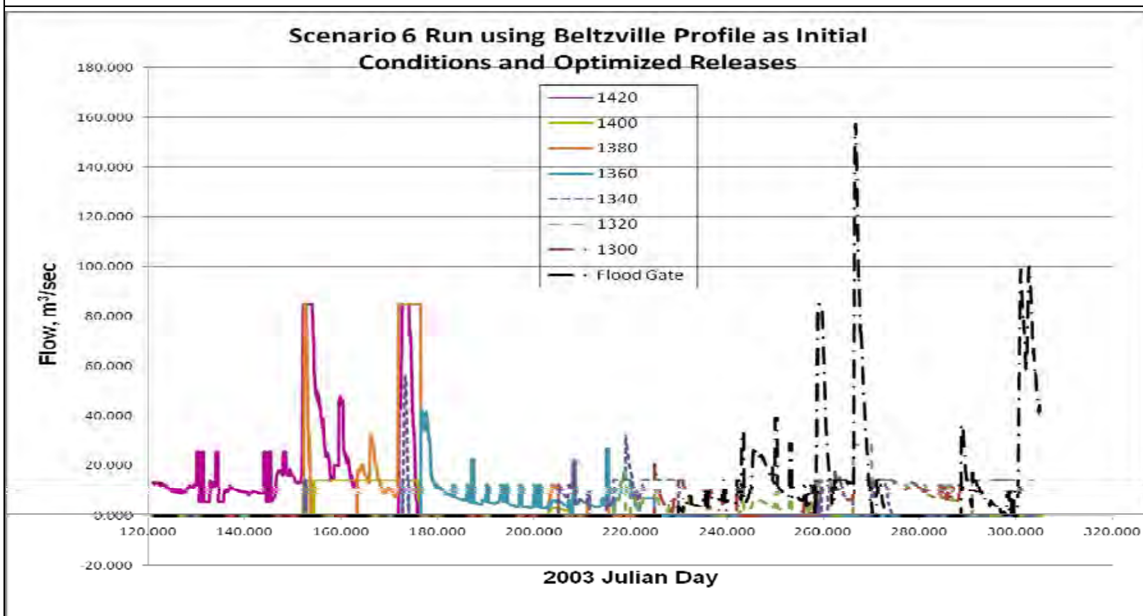


Figure 90. 2003 release flows used for scenario 6 provided by the Philadelphia District – top is original release flows and bottom is optimized release flows.

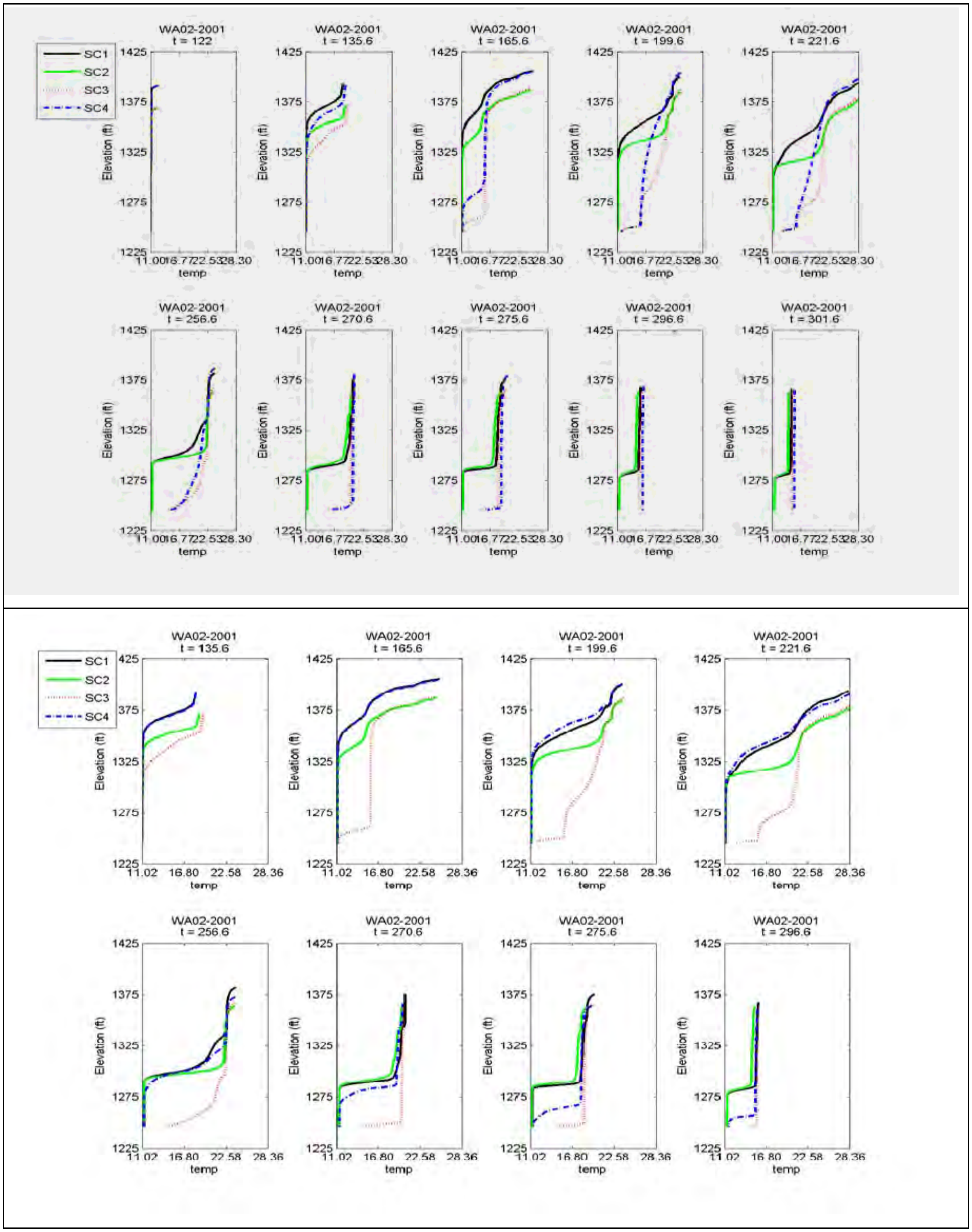


Figure 91. 2001 Temperature profile results at station WA02 at F. E. Walter for 10 Julian dates during simulation period using 11°C or 51.8 °F (upper) and stratified (lower) initial conditions without optimization. Scenario 4 was initially run as a non-selective withdrawal simulation (upper) but later rerun as a selective withdrawal option (lower).

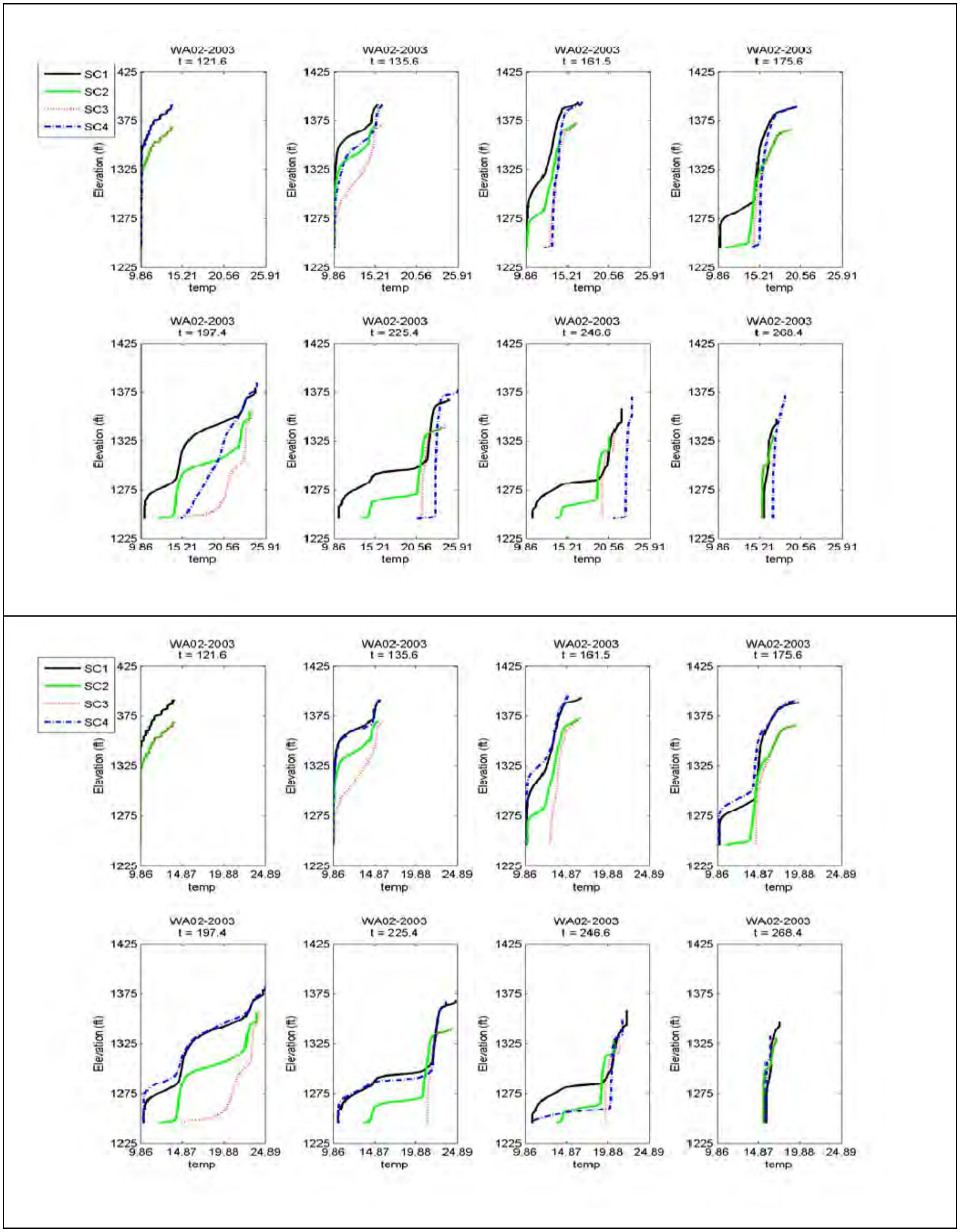


Figure 92. 2003 profile results at station WA02 at F. E. Walter for eight Julian dates during simulation period. Scenario 4 was initially run as a non-selective withdrawal simulation (upper) but later rerun as a selective withdrawal option (lower).

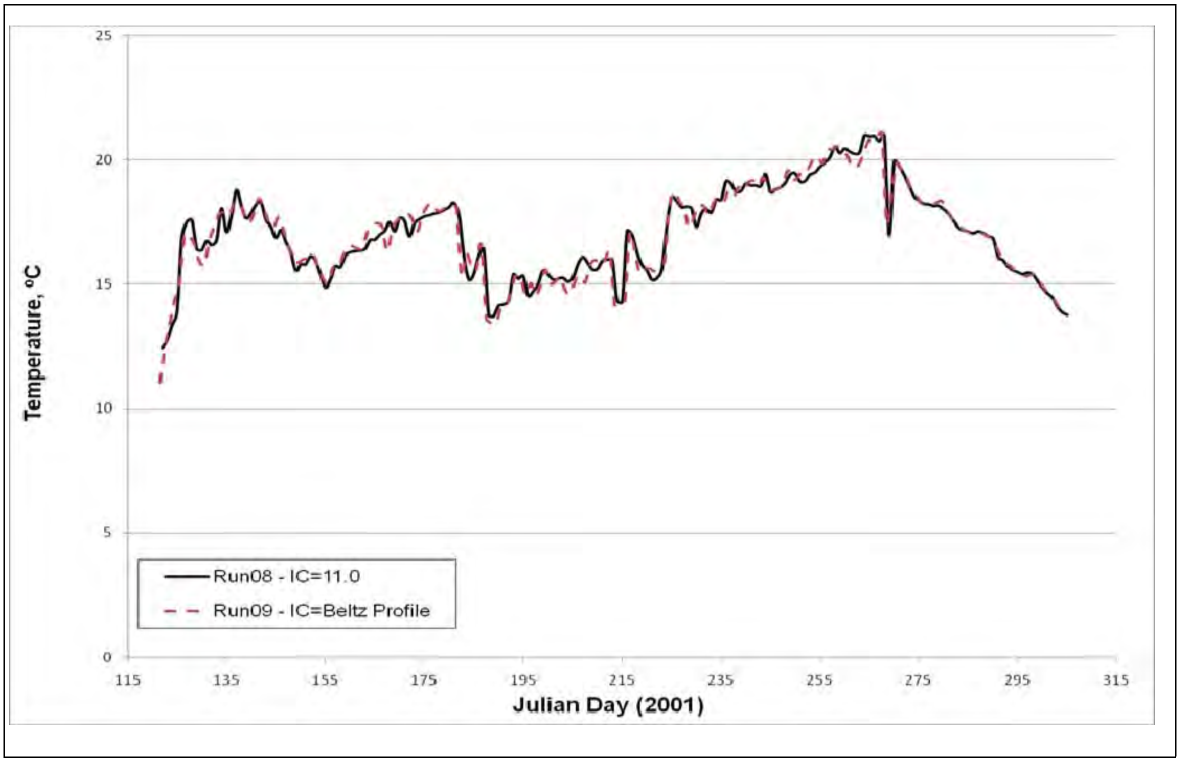


Figure 93. 2001 temperature time series results at station LH02 with F. E. Walter initialized to 11 °C or 51.8 °F (black line) and to a historical stratified profile (red dashed line).

Results for all final scenario runs are shown in profile plots at station WA02 for F. E. Walter and as time series plots at the six stations in the Lehigh River (i.e., LH02, LH03, LH08, LH10, LH15, and LH17). Figures 94 and 100 present a comparison of profiles results of all scenarios runs for 2001 and 2003, respectively. Finally, Figures 94-99 and 101-106 present original (upper plot) and optimized (lower plot) time series results for all scenarios runs at stations LH02, LH03, LH08, LH10, LH15, and LH17 (see locations in Figure 1) in the Lehigh River.

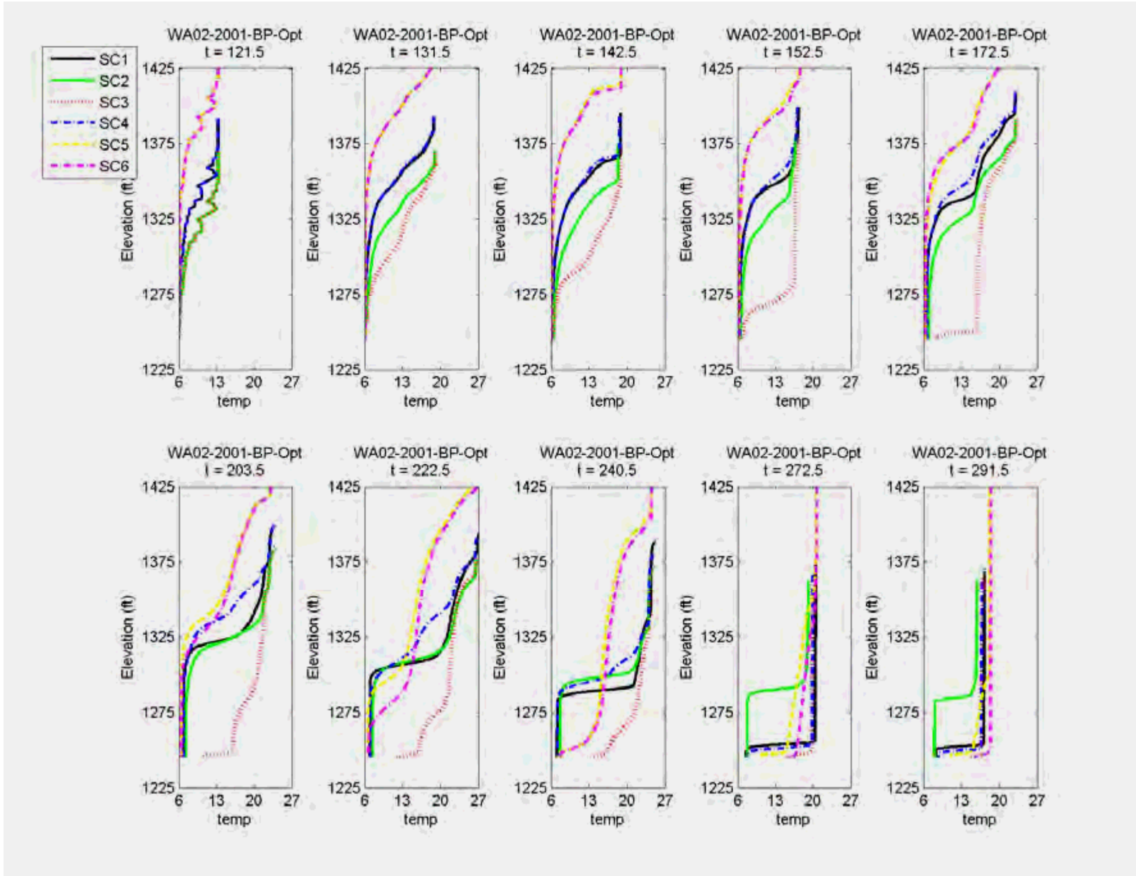


Figure 94. 2001 Profile results at station WA02 with selective withdrawal scenario 1 (SC1), scenario 4 (SC4), scenario 5 (SC5), and scenario 6 (SC6) optimized. Other scenario runs were not optimized.

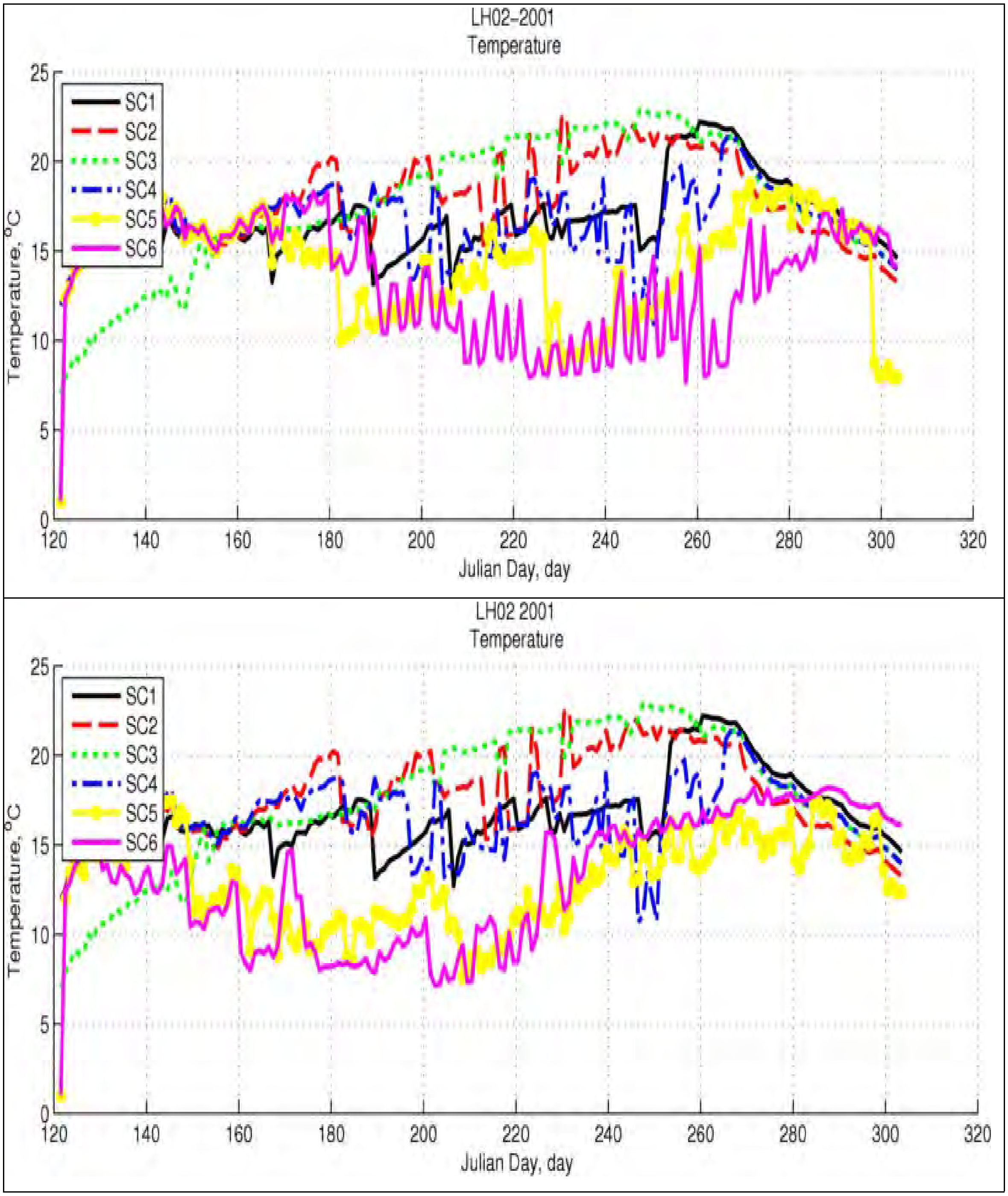


Figure 95. 2001 Scenario results at stations LH02 with upper plot showing release flows optimized for Scenario 1 and 4 while release flows for other scenarios are original flows from Philadelphia District compared to lower plot having release flows optimized for Scenarios 1, 4, 5,and 6 while other release flows are original flows from Philadelphia District

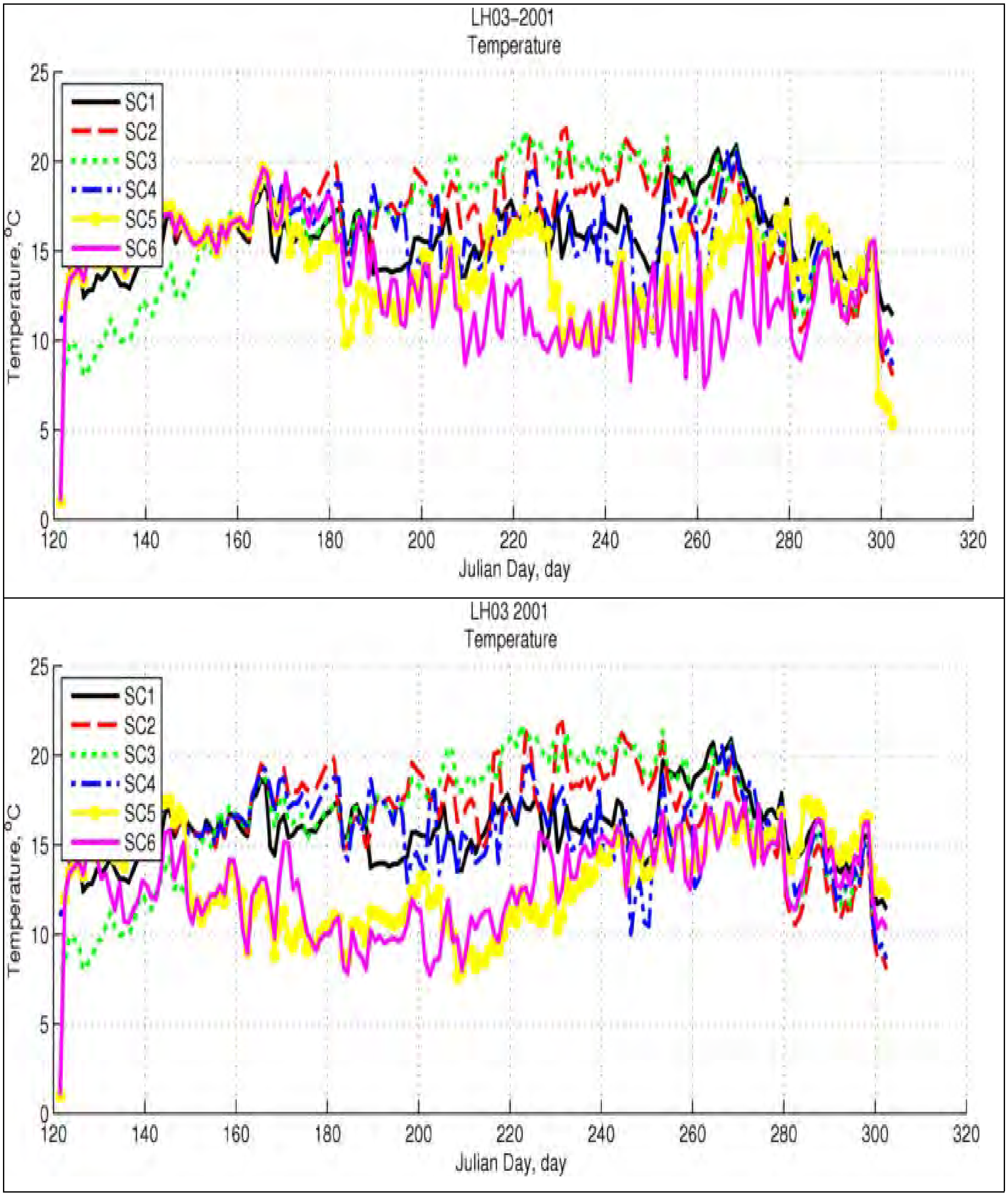


Figure 96. 2001 Scenario results at stations LH03 with upper plot showing release flows optimized for Scenarios 1 and 4 while release flows for other scenarios are original flows from Philadelphia District compared to lower plot having release flows optimized for Scenarios 1, 4, 5,and 6 while other release flows are original flows from Philadelphia District

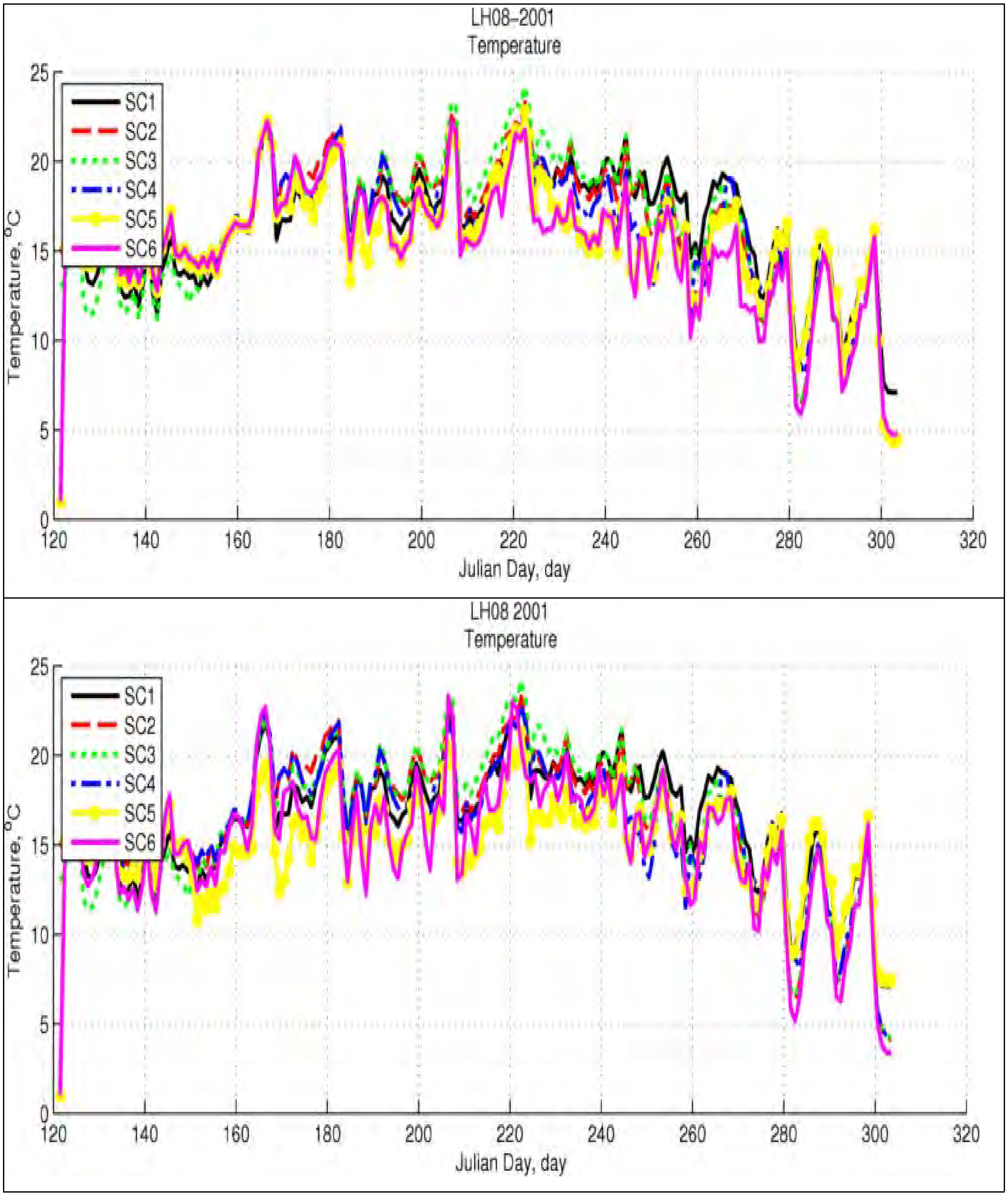


Figure 97. 2001 Scenario results at stations LH08 with upper plot showing release flows optimized for Scenarios 1 and 4 while release flows for other scenarios are original flows from Philadelphia District compared to lower plot having release flows optimized for Scenarios 1, 4, 5,and 6 while other release flows are original flows from Philadelphia District

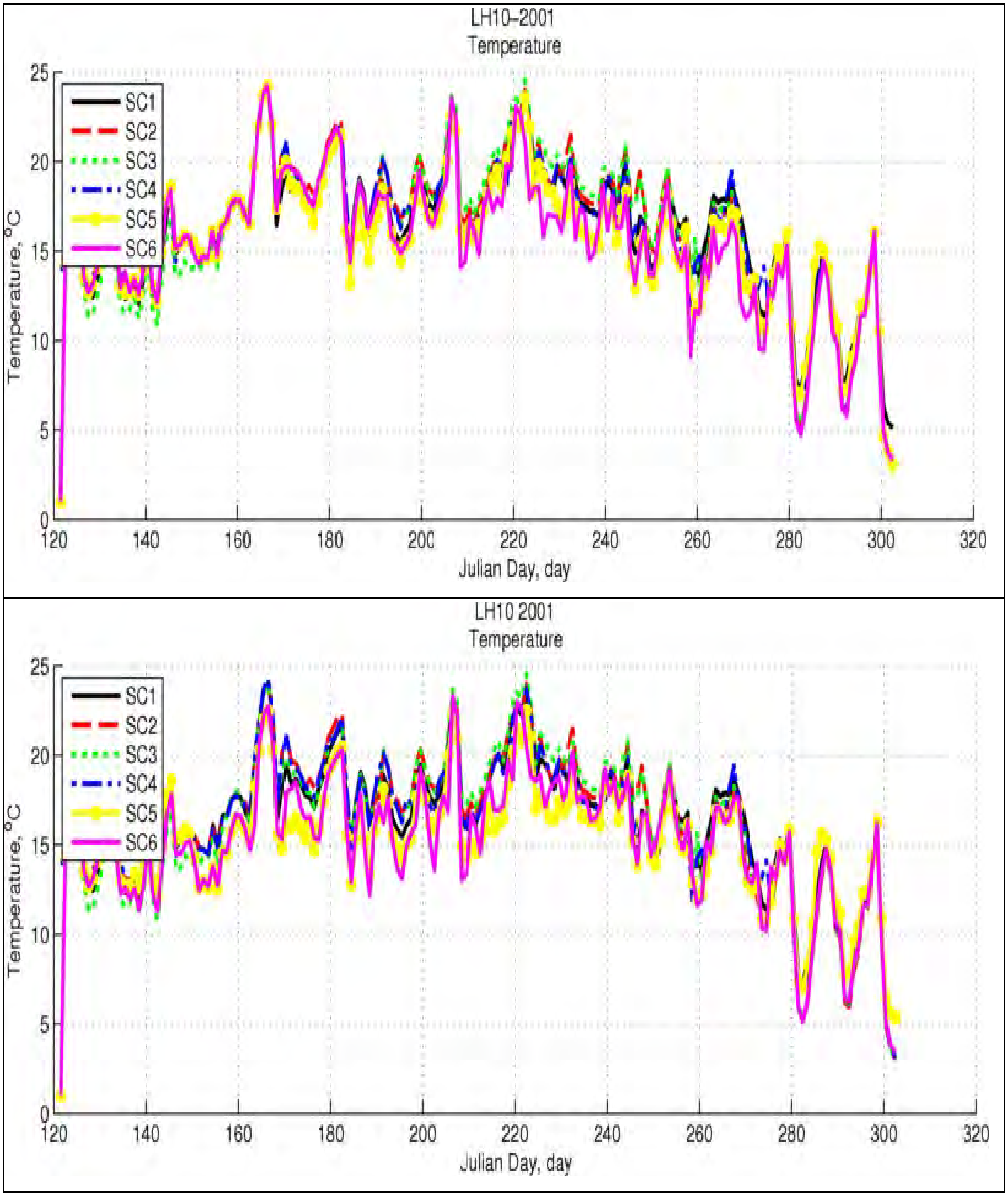


Figure 98. 2001 Scenario results at stations LH10 with upper plot showing release flows optimized for Scenarios 1 and 4 while release flows for other scenarios are original flows from Philadelphia District compared to lower plot having release flows optimized for Scenarios 1, 4, 5,and 6 while other release flows are original flows from Philadelphia District

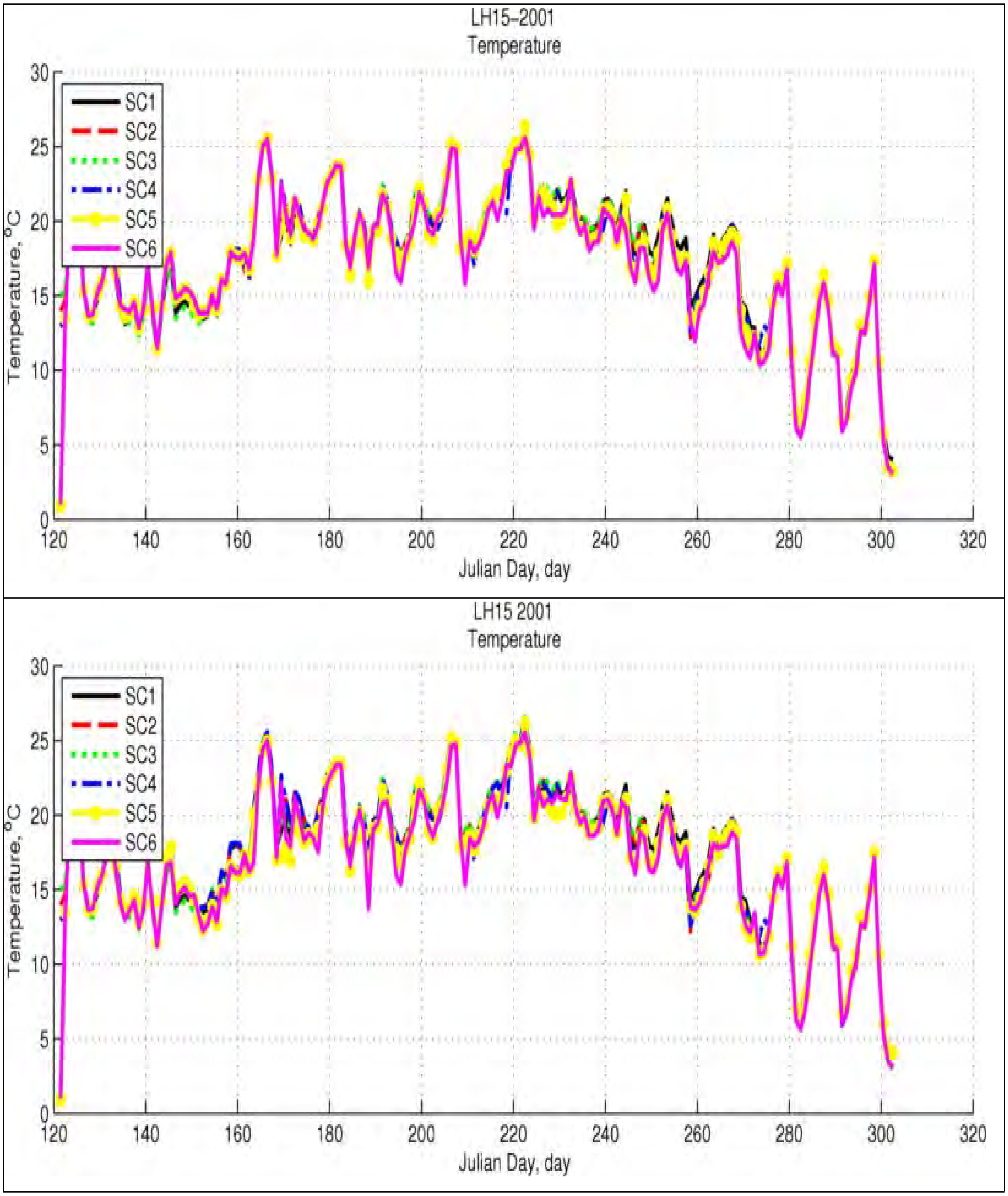


Figure 99. 2001 Scenario results at stations LH15 with upper plot showing release flows optimized for Scenarios 1 and 4 while release flows for other scenarios are original flows from Philadelphia District compared to lower plot having release flows optimized for Scenarios 1, 4, 5,and 6 while other release flows are original flows from Philadelphia District

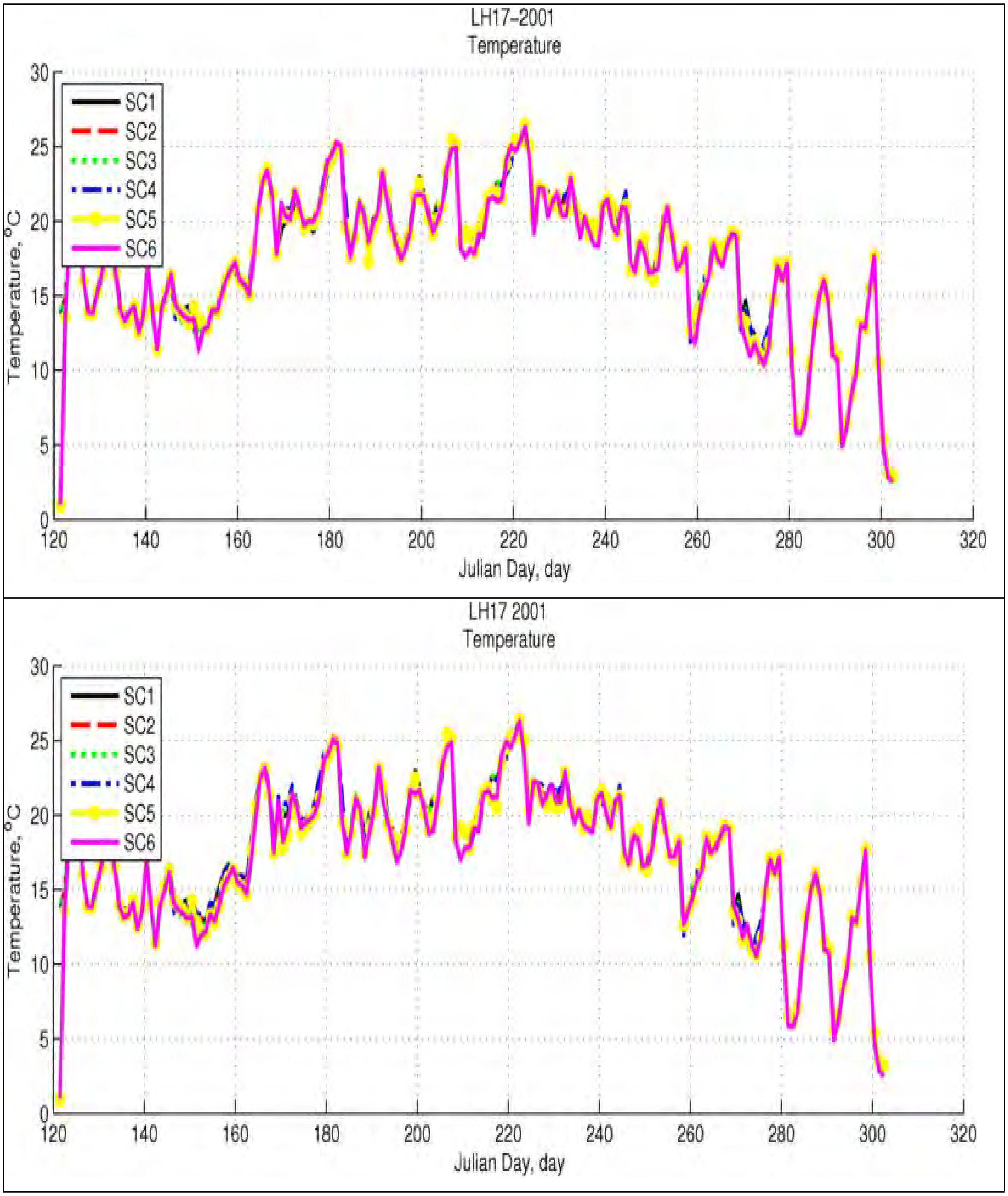


Figure 100. 2001 Scenario results at stations LH17 with upper plot showing release flows optimized for Scenarios 1 and 4 while release flows for other scenarios are original flows from Philadelphia District compared to lower plot having release flows optimized for Scenarios 1, 4, 5,and 6 while other release flows are original flows from Philadelphia District

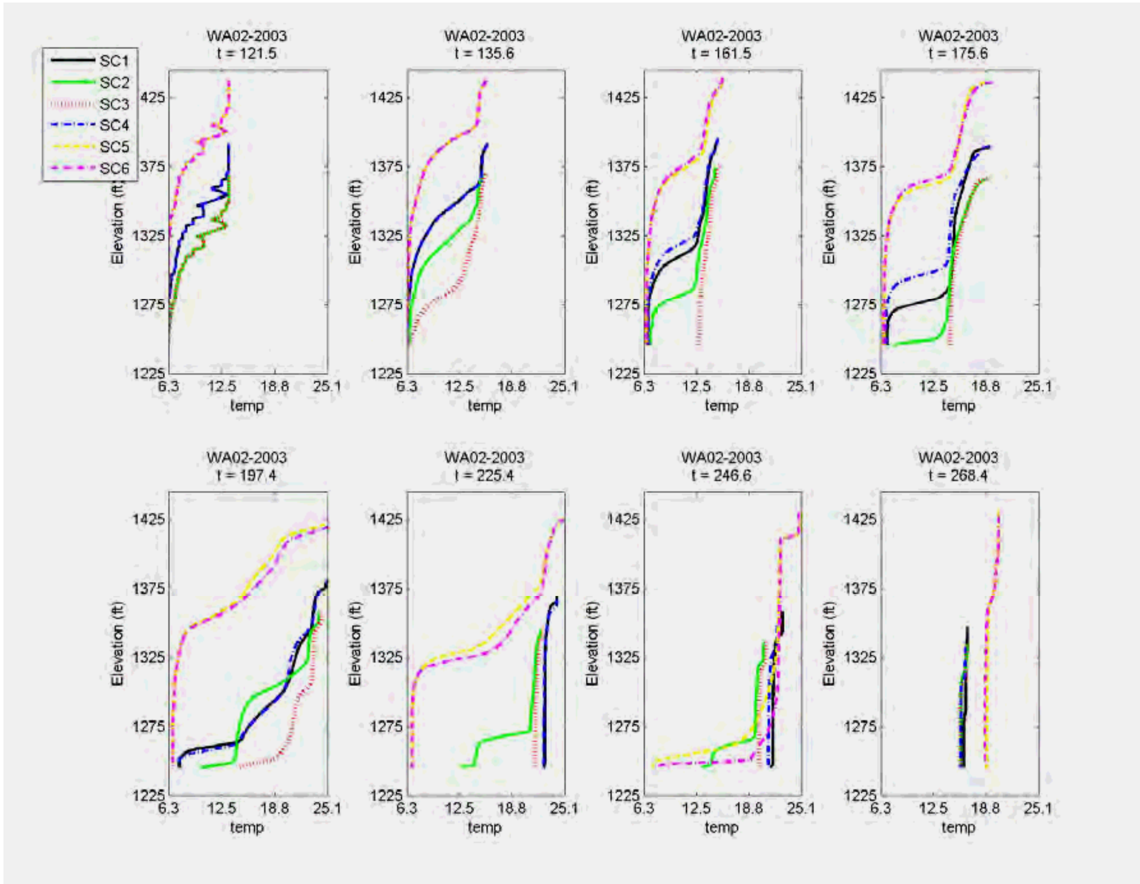


Figure 101. 2003 profile results at station WA02 with selective withdrawal scenario 1 (SC1), scenario 4 (SC4), scenario 5 (SC5), and scenario 6 (SC6) optimized. Other scenario runs were not optimized.

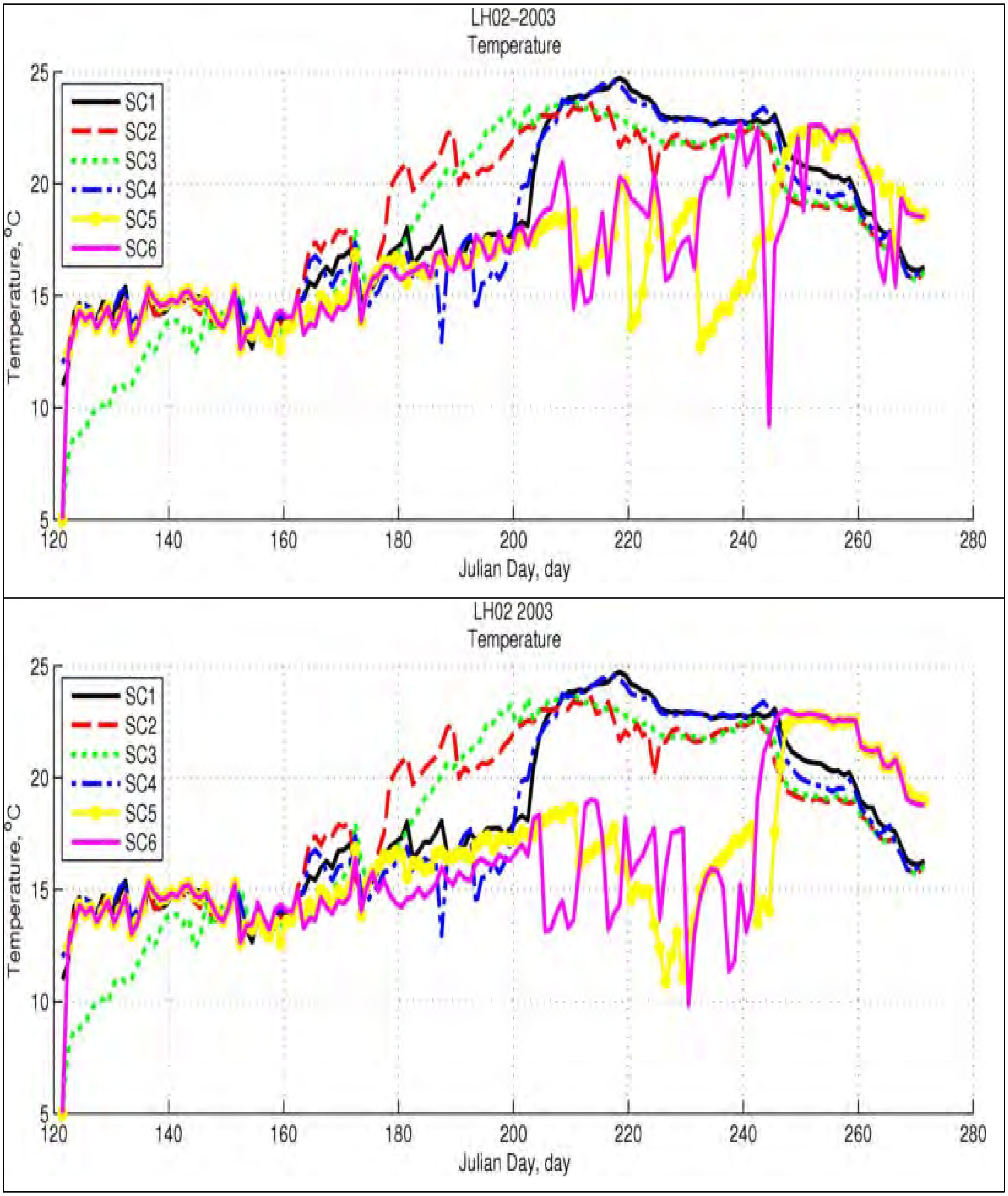


Figure 102. 2003 Scenario results at stations LH02 with upper plot showing release flows optimized for Scenario 1 and 4 while release flows for other scenarios are original flows from Philadelphia District compared to lower plot having release flows optimized for Scenarios 1, 4, 5,and 6 while other release flows are original flows from Philadelphia District

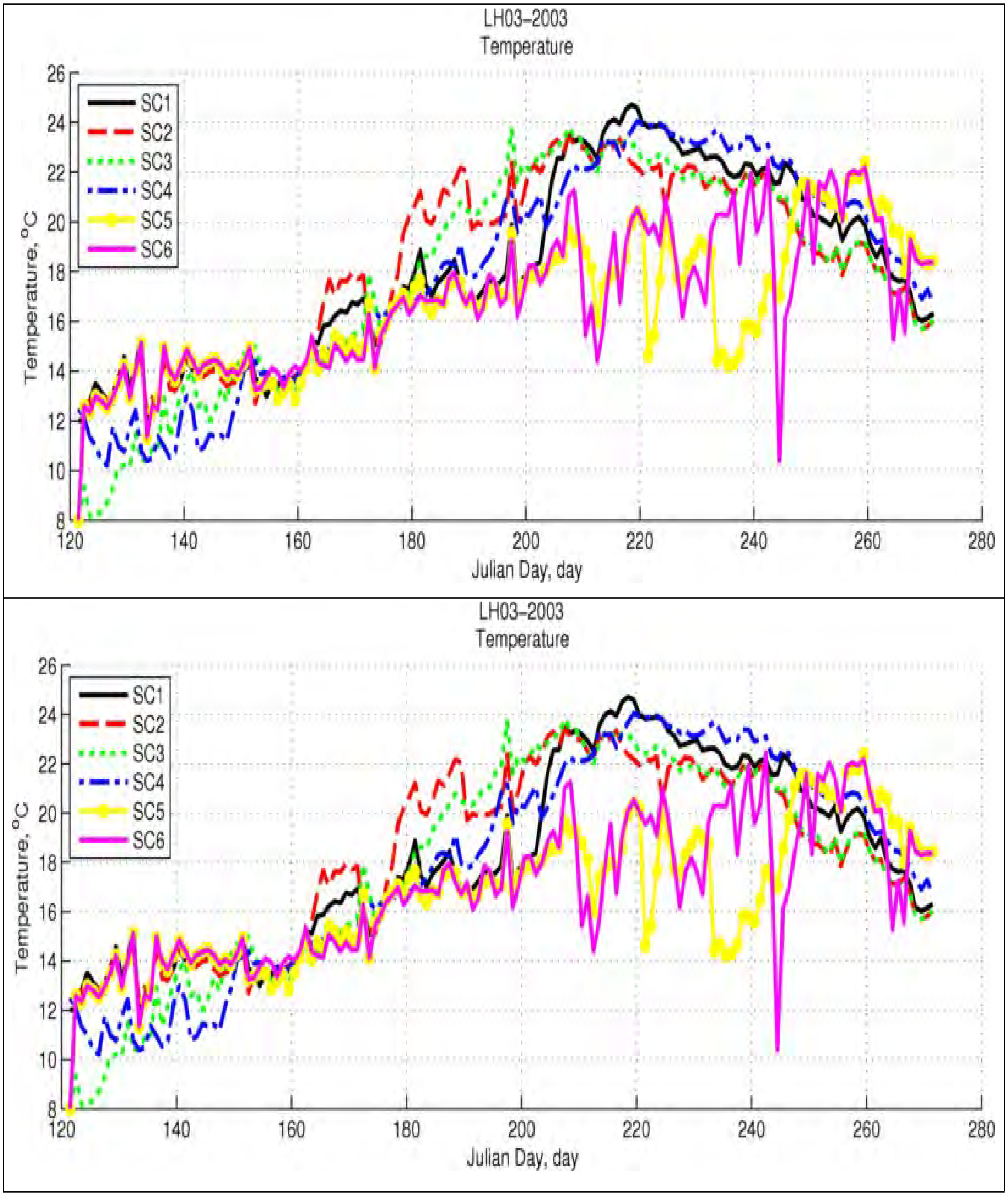


Figure 103. 2003 Scenario results at stations LH03 with upper plot showing release flows optimized for Scenario 1 and 4 while release flows for other scenarios are original flows from Philadelphia District compared to lower plot having release flows optimized for Scenarios 1, 4, 5,and 6 while other release flows are original flows from Philadelphia District

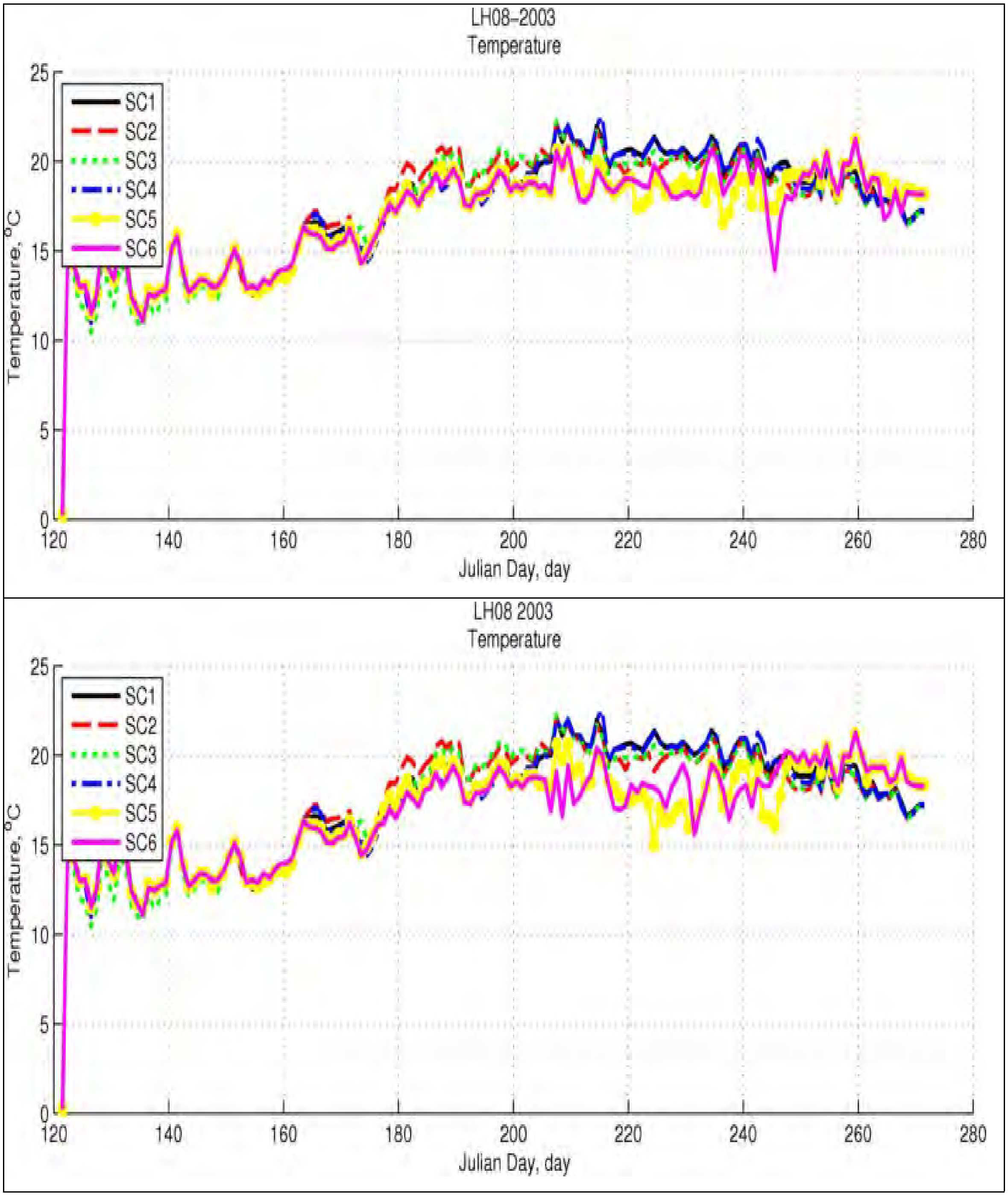


Figure 104. 2003 Scenario results at stations LH08 with upper plot showing release flows optimized for Scenario 1 and 4 while release flows for other scenarios are original flows from Philadelphia District compared to lower plot having release flows optimized for Scenarios 1, 4, 5,and 6 while other release flows are original flows from Philadelphia District

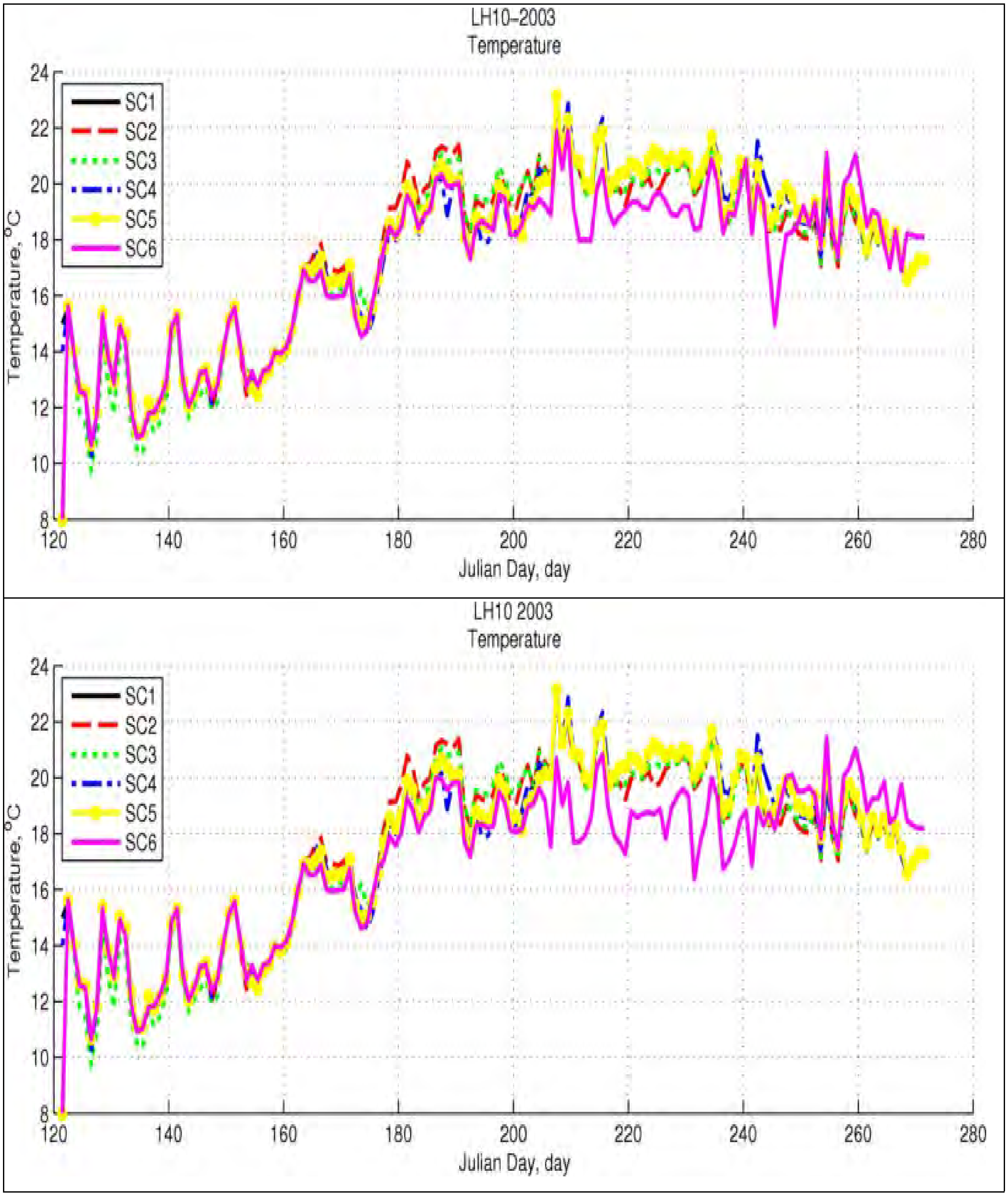


Figure 105. 2003 Scenario results at stations LH10 with upper plot showing release flows optimized for Scenario 1 and 4 while release flows for other scenarios are original flows from Philadelphia District compared to lower plot having release flows optimized for Scenarios 1, 4, 5,and 6 while other release flows are original flows from Philadelphia District

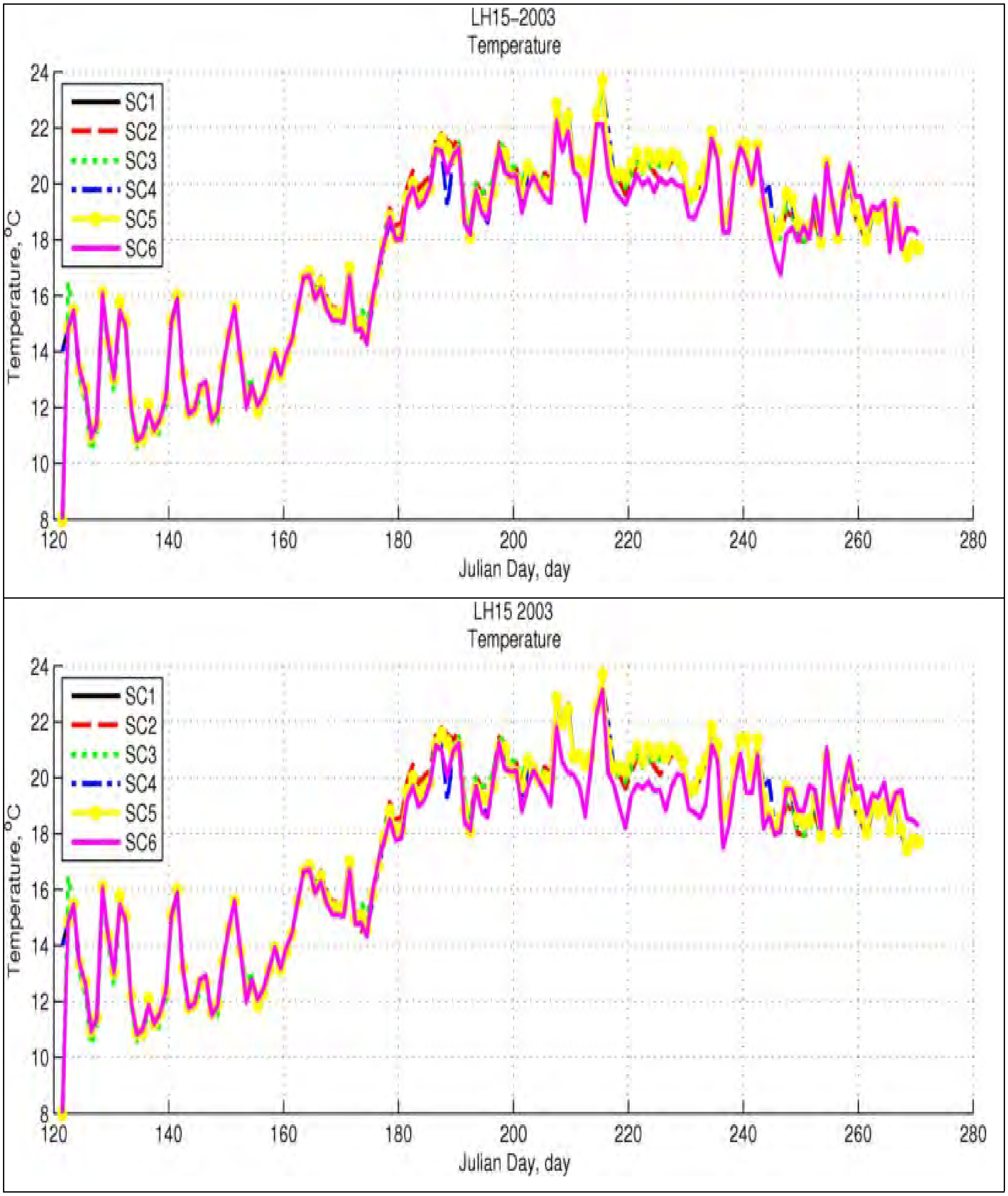


Figure 106. 2003 Scenario results at stations LH15 with upper plot showing release flows optimized for Scenario 1 and 4 while release flows for other scenarios are original flows from Philadelphia District compared to lower plot having release flows optimized for Scenarios 1, 4, 5,and 6 while other release flows are original flows from Philadelphia District

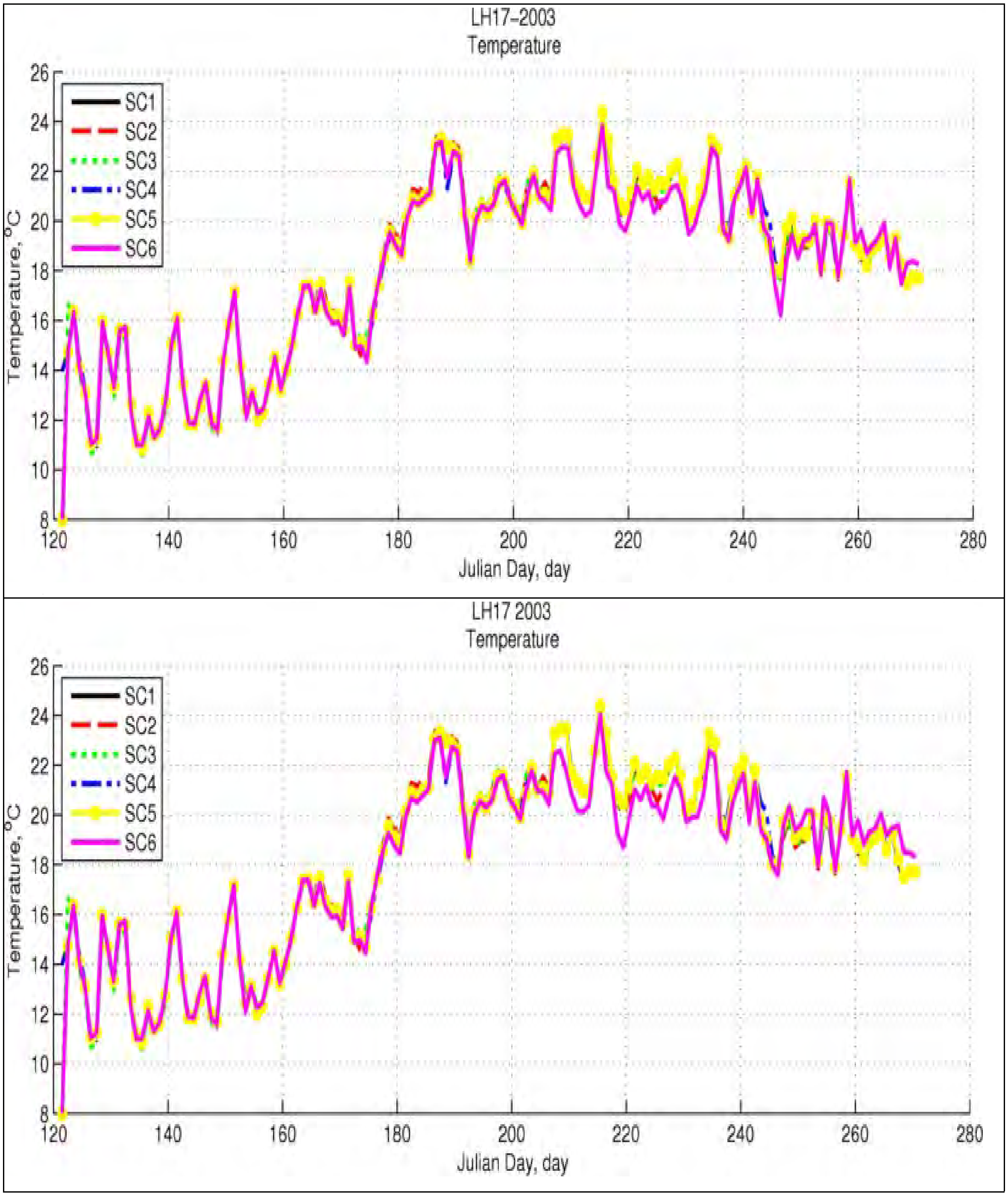


Figure 107. 2003 Scenario results at stations LH17 with upper plot showing release flows optimized for Scenario 1 and 4 while release flows for other scenarios are original flows from Philadelphia District compared to lower plot having release flows optimized for Scenarios 1, 4, 5,and 6 while other release flows are original flows from Philadelphia District

Temperature profiles upstream of F. E. Walter Dam for both years (shown in Figures 94 and 101) demonstrate how reservoir outflow release operations and port locations affect water quality in the reservoir. Depending on the reservoir operation goal (i.e., “Fisheries only”), pool levels to maintain, how much water to release and from which port elevation would be best for fish habitat, reservoir operations can vary widely. This is illustrated in temperature profile plots for all scenarios. For example, scenario 5’s goal is to produce and sustain a fishery tailwater while satisfying whitewater interests while scenario 4’s goals are to conserve cooler water for releases later in the summer while maximizing weekend whitewater releases. From Figures 95 and 102, time series plots at station LH02 show for scenario 5 cooler water is being released for most of the simulation period compared to scenario 4 releases. Of course one of the reasons for this is that scenario 5 conservation pool is maintained at 1438 ft while scenario 4 conservation pool is maintained at 1392 ft. As a result, cooler water can be conserved for warmer periods later in the summer. Even though the profiles in Figure 94 indicate around Julian day 240 (August 28), scenario 4 still has cooler water in the hypolimnion than scenario 5, time series plot at LH02 shows release temperature for both scenarios to be similar. Looking back at Figures 85 (scenario 4) and 87 (scenario 5) showing releases from ports, scenario 4 releases are coming from three ports while scenario 5 releases are coming from two. Both scenarios have releases coming from the flood gate and from elevation 1300 ft while scenario 4’s releases are also coming from elevation 1320 ft.

Comparing releases from original to optimized runs show some differences for the better. Mostly it can be noted that to keep temperatures below 20 ^{o}C, lower ports had to be accessed sooner in 2001 than original releases. By optimizing releases in 2001, there is a shift of releasing cooler water earlier and warmer water toward the fall period. Scenario 5 optimized releases produced temperatures below 20 ^{o}C (68 ^{o}F) as far down as station LH08 (Figure 97) with temperature violations at LH10 occurring during four short periods (Figure 98). At stations LH15 and LH17, all scenario results show very similar results with temperature results showing sinusoidal behavior as values go above and below 20 ^{o}C (68 ^{o}F) between Julian days 160-255 (June 9 – September 12). As found in Phase 1 once water reaches this far downstream of F. E. Walter, tributary flows entering the Lehigh River close to these locations contribute more than 50 percent of flow in the Lehigh River and have a greater influence on water temperatures than releases from F. E. Walter.

In 2003, optimization of releases doesn’t start until around Julian Day 175 (June 24) and keeps temperatures below 20 ^{o}C (68 ^{o}F) until around Julian Day 246

(September 3) at LH02. Scenario 6 optimized release flows produced temperatures for the most part below 20 °C (68 °F) as far downstream as station LH10 with only short periods between Julian Days 200-260 (July 19 – September 17) having temperatures slightly above 20 °C. Similar to 2001 results, tributary inflows once past this station have greater influence on main stem temperatures thus helping to produce more periods with temperatures above 20 °C. Comparing optimized flows at station LH02 to original releases provided by the Philadelphia District, Scenario 5 and 6 results produced temperatures below 20 °C (68 °F) between Julian days 200-246 (July 19 – September 17). After Julian day 246 (September 17) temperatures stayed around 22.5 °C. Of the six 2003 scenario results at station LH17, Scenario 6 results show the lowest temperatures until Julian Day 246 (September 17). After this date, there is limited or no cool water in the water column close to the release port water is being withdraw from to keep temperature releases below 20 °C (Figure F-14).

Of all scenario runs, scenario 5 in 2001 and scenario 6 in 2003 produced the best temperature results as far downstream as LH08 and LH10. These scenarios had goals of producing and sustaining a fishery tailwater while satisfying whitewater interests and releasing periodic large pulses of reservoir releases, similar to the 2010 whitewater releases, to keep enough river rock substrate wetted to maintain downstream thermal target at Tannery Bridge of 68 °F (20 °C), respectively. These results were an improvement over Phase I results. In particular two operating procedure changes tested in Phase II that were not considered in Phase I were maintaining a higher conservation pool in scenario 5 and 6 and having the ability to optimize reservoirs releases to maximize operation potential.

Scenario water quality results are presented in Appendix F, Figures F-1 through F-28. Two graphical result types are presented and are: 1) profile results at the closest station to the F. E. Walter Dam and 2) times series results for all stations on the Lehigh River downstream of F. E. Walter Reservoir. An overall statement can be made that changes to water quality from optimized runs are mostly attributed to release port location (i.e., actual layers release water is being pulled from) and the degree of stratification of water quality profiles. For instance in Figure F-7, the profile results for PO4, TOC, and TSS for each scenario are not very stratified from one scenario to the next. This is because almost isochemical conditions are present through the water column for these constituents for each scenario toward the end of the simulation; thus scenario results will show very little difference in water quality concentrations since concentrations would be similar at any elevation released. Thus at station LH02 (Figure F-1) scenario results for these constituent concentrations do not vary a great during periods of little stratification. This is also seen in Figures F-7, F-14, F21, and F28 for alkalinity and chlorophyll a (CHLa). It can be noted that both constituents have periods where concentrations are more isochemical in the water column before or after certain dates (i.e., after Julian Day 222.5, CHLa release scenario profile concentrations are very similar and after Julian Day, 222.5 alkalinity scenario profile concentrations become more varied). After Julian Day 222.5 CHLa release concentrations become quite similar as indicated by results at station LH02 (Figure F-1) and before this date results at station LH02 show much more variation in scenario result concentrations. Alkalinity results (Figure F-1) show very similar release concentrations for all scenarios until Julian Day 222.5. After this date alkalinity concentrations become more varied in the water column (Figures F-7, F-14, F21, and F28). Consequently, at station LH02 more variation is seen in the alkalinity concentration results. For other constituents such as TDS, No2No3, NH3, DO, and pH where the profiles results for each scenario and constituent show more concentration variations in the water column for all dates, the withdrawal location affects how varied release concentrations of these constituents will be at station LH02 (Figure F-1). Except for DO, most of the concentration differences for these water quality constituents at station LH02 are not detrimental to living resources downstream of F. E. Walter Reservoir. As water is transported downstream to station LH17, all concentration differences become diminished (Figures F-1 and F-8).

Decline in DO concentrations is noticeable in results for scenarios 5 and 6 for both runs using original and optimized release flows. From Figures F-15 and F-22, Scenario 5 and 6 results from runs using original release flows show DO concentrations for both years modeled declined from initial values around 8mg/L to 3 mg/L or 2 mg/L depending on the year. During 2001, decline in DO concentrations occurs between Julian Day 140 to around 285 for scenario 5 and between Julian Day 140 to Julian 292 for scenario 6. In 2003 (Figure 22), results from scenario 5 and 6 runs using original release flows show decline in DO concentrations occurring between Julian Day 155 to around 272. Decline in DO concentrations for scenario 5 and 6 from optimized release flow runs during 2003 occurs during the same period as results for 2003 optimized release flows (Figure 8). Decline in DO concentrations still occurs for runs with optimized release flows for both years, but reductions in DO concentrations are not as severe. Results for scenarios 1 through 4 using both optimized and original release flows show similar declining DO concentrations between Julian Day 180 to around Julian Day 265. Scenario runs for these scenarios in 2001 do not go below 4 mg/L. Of the two years modeled, declining DO concentrations are worst for 2003. This can be seen in 2003 for all scenarios time series at station LH02.

From the 2003 profile results, this behavior is attributed to the formation of a DO minimum in the area of the release port elevations in the epilimnion. This may have formed through mortality, respiration, and decay from increased chlorophyll *a*, TOC and total suspended solids (TSS) concentrations in the area of the releases ports in the epilimnion of the reservoir. By the time water is transported from station LH02 to station LH03, DO concentrations have reaerated to levels of 7 mg/L or more. Also not being capture by the model is the natural reaeration occurring through the pipes in the dam. This is why calibration DO results at this station are about 1 mg/L lower than observed. At the end of the study reach (station LH17), DO concentration differences are minimal. Since the objective of this study was to conserve cooler water for warmer periods to maintain temperature criteria of 20 ^{o}C as far downstream as possible, maintaining DO concentrations were not considered. However, results from this study can be used as an indicator of the type of conditions that could result from maintaining a higher conservation pool having a selective withdrawal component when operating. Maintaining higher conservation pools may lead to the necessity of more frequent profile monitoring to avoid releasing low DO water from increased chlorophyll concentrations and the related processes influenced from by this.

Scenario profile and time series results for total metals are presented in Figures F-29 through F-33. As mentioned previously metals were run using W2 Version 3.6 which did not have optimization in this version. For this reason, results will only be shown for simulations using original releases. In addition, metal results will only be presented and discussed for 2001 since no boundary data were available in 2003 for metals to run them as active constituents. Similar to profiles of TDS, No2No3, NH3, DO, and pH which show more stratification in the water column, total metal profile results are stratified showing more variation in total metal results at station LH02. Most differences for total metals are not considered extreme concentration differences. Concern for metals toxicity is usually reserved for the dissolved form of the metals which are bioavailable for living resources and can cause harm for these resources in F. E. Walter and on the Lehigh River. Because there were very little observed dissolved metals data, it is difficult to tell if scenario results produce chronic levels of bioavailable dissolved metals as indicated in Table 15. Of the total metals being released from F. E. Walter Reservoir (Figure F-29), most concentrations are below or within levels considered chronic for dissolved metals except AL. This would be a problem if total metal concentrations are assumed to be completely in the dissolved form. For example, AL concentrations released are above the chronic level of 0.087 mg/L for dissolved AL but since total AL the is being modeled and not dissolved, the entire total would have to be assumed in the dissolved form for this to have detrimental consequences. In the observed data file there is one date that has observed concentrations for dissolved and total forms of AL at LH02 which are 0.03 mg/L and0.16 mg/L, respectively. It is noted that on this day the dissolved form is only 18% of the total. The maximum scenario release concentration for total AL is 0.14 mg/L and if the percentage of the dissolved form is around 18% of this value like in the observed data then the dissolved concentrations would be around 0.027 mg/L. This is below the chronic value of 0.087 mg/L for AL. Some of the higher concentrations of total AL noticed downstream at stations LH08 and LH10 are attributed to high concentrations of boundary conditions at tributaries Buck Mountain Creek (LH06) and Black Creek (LH07). Over all, the total metals modeled during scenario runs have concentrations that are below the levels considered to be harmful to the living resources for dissolved metal forms.

Table 15. State and Federal Chronic Criteria for Dissolved Metals

Agency	Dissolved AL	Dissolved CD	Dissolved Fe	Dissolved MN	Dissolved ZN
Delaware River Basin Commission Chronic	0.087	0.001	none	none	0.82
Pennslyvannia Department of Environmental Program Chronic	none	none	1.5	1.0	none
New Jersey Department of Environmental Program Chronic	none	none	none	none	1.0
EPA Chronic	none	0.002	none	none	1.2

The results presented in this study are the best these scenario simulations will produce based on the release conditions modeled and the ability to conserve cool water through selective withdrawal. The top two ports in the hypothetical selective withdrawal structure has release capacity of up to 3000 cfs that realistically may not be fully supported with present available technology. During normal operations, the District will not have the advantage of being able to optimize different operations in question as was available for this study. What can be done is that for a range of historical conditions (i.e., meteorological, flow and water quality) the District can simulate many scenario runs to cover all possible conditions they may encounter to come up with the best reservoir release operations and create a table of release options based on observed conditions similar to what was modeled. Guidance could be developed for reservoir operating procedures to be used for the conditions being observed at the time of decision making. This would allow District personnel to make the best operational decisions to meet water quality goals.

5 Summary and Conclusions

CE-QUAL-W2 has been calibrated for temperature, flow, and water quality at F. E. Walter and Beltzville Reservoirs and 45 miles downstream of F.E. Walter Reservoir on the Lehigh River. The model was calibrated and verified on two very different water years. Calibration was performed for 2001 a dry water year, and verification was performed on 2003 a wet water year. W2 performed well for calibration and verification. When using the calibrated model as a management tool, one would have the most confidence using the model to investigate how operational changes would affect temperature. The model quite accurately captures the physics of both reservoirs and the riverine sections. Any alteration in the physics should be predicted with a high degree of accuracy.

The primary focus of this study was to add water quality and metal constituents to the temperature and flow CE-QUAL-W2 (W2) models developed for two reservoirs (F. E. Walter and Beltzville) and approximately 60 river miles on the Lehigh River and Pohopoco Creek. Additionally, six new proposed operational scenarios agreed upon by the study partners at F.E. Walter Dam were modeled to enhance downstream and in-lake recreation and habitat.

Although temperature, water quality and flow boundary conditions were lacking on tributaries to the Lehigh River for 2003, verification water quality results compared favorably in both reservoirs to observed data. In the Lehigh River, model results it is believe would have been closer to observed data if tributary boundary conditions had been available. In spite of the lack of tributary boundary data most variables followed the trends of observed water quality behavior. Comparison of model profile results for both reservoirs showed good agreement for both years. Most water quality constituent results were within the target AME values and percent cumulative distribution plots showed most concentration ranges being correctly predicted. There were some exceptions. All in all for calibration and verification, results were considered favorable given limited data for verification.

Once the system was calibrated and verified, scenario runs looking at temperature in the Lehigh River were conducted using initial and boundary conditions from calibration and verification runs with new F. E. Walter reservoir releases. A total of six scenario runs, jointly developed and agreed to by ACOE

(Army Corps of Engineers, Philadelphia), PADCNR Parks and Pennsylvania Fish and Boat Commission (PFBC), were made for each year and included:

- Scenario 1 can be described as “Fisheries only, with selective withdrawal to the dam” and is designed to maximized benefits to downstream fisheries. This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360, and 1380 ft and WSEL at 424.24 m (1392 ft).
- Scenario 2 can be described as “Maximizing whitewater events” while augmenting flow for fisheries during non-whitewater release goals with 2010 release schedule. This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360 and 1380 ft and WSEL at 417.71 m (1370 ft).
- Scenario 3 can be described as “Maximizing whitewater events” while augmenting flow for fisheries during non-whitewater release goals with 2010 release schedule. This scenario operated without a selective withdrawal structure (SW) with portals at elevations 1265, and 1297 ft and WSEL at 417.71 m (1370 ft).
- Scenario 4 goals are to provide whitewater releases on alternating weekends from in May and June, every weekend July through September; create optimal in-lake spawning areas in May and June by limiting the pool fluctuations to 5 feet; and maximize the benefit to cold water fisheries downstream by augmenting flows between July 1 and September 30 by a minimum of 50 cfs with the cooler water. This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360 and 1380 ft and WSEL at 424.56 m (1392 ft).
- Scenario 5 is based on the 2010 release schedule with outflow thermal targets as per Chapter 93 CWF thresholds. This operation was for producing and sustaining a fishery tailwater while satisfying whitewater interests. This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360, 1380, 1400, and 1420 ft with initial WSEL at 438.42 m (1438 ft).
- Scenario 6 is based, in part, on the 2010 release schedule. The intent is to investigate if periodic large pulses of reservoir releases, similar to the 2010 whitewater releases, can keep enough river rock substrate wetted to maintain downstream thermal target at Tannery Bridge of 68 ^{o}F (20 ^{o}C). This scenario operated with a selective withdrawal structure (SW) with portals at elevations 1300, 1320, 1340, 1360, 1380, 1400, and 1420 ft with initial WSEL at 438.42 m (1438 ft).

Beltzville Reservoir maintained the same release discharges for the scenario runs as were used during 2001 calibration and 2003 verification runs.

Using scenario results from these simulations, the Philadelphia District will be able to make informed decisions in regard to adjustments to reservoir operations to help improve fishery habitat and boating recreation within and downstream of F. E. Walter Reservoir. With the new optimization routine in W2 V3.7, many simulations can be made with quicker turn around to help make critical decision on reservoir operations. Criteria for judgment of improvement from one scenario to the other was whether release temperatures were maintained at 20 °C (68 °F) or less during the warmer summer period downstream of F. E. Walter. Scenarios 5 and 6 met these criteria as far downstream as LH08 and LH10, respectively. Meaning that scenario 5 river temperatures were maintained at 20 °C (68 °F) or less as far downstream as station LH08 and during the wet year scenario 6 river temperatures were maintained at at 20 °C (68 °F) or less as far downstream as LH10. As seen in Phase I, beyond these stations tributary inflows dominated flow in Lehigh River reducing influence from the dam. Downstream of LH08, differences in water temperature become minimal. As expected, water temperatures show the greatest differences immediately downstream of the dam before tributary influences begin to monopolize.

An overall statement can be made that changes to water quality releases from optimized runs are mostly attributed to release port location (i.e., actual layers release water is being pulled from) and the degree of stratification of water quality profiles. Release results for PO4, TP, TOC, and TSS for each scenario run are not very different from one scenario to the next. This is because almost isochemical conditions are present through the water column for these constituents for each scenario; thus scenario results will show very little difference since water quality concentrations would be similar at any elevation released. Except for DO, most of the concentration differences for these water quality constituents at station LH02 are not detrimental to living resources downstream of F. E. Walter Reservoir. Decline in DO concentrations is noticeable in results for scenarios 5 and 6 for both runs using original and optimized release flows. Values of DO can be as low as 2mg/L which stress living resources. From the 2003 profile results, this behavior is attributed to the formation of a DO minimum in the area of the release port elevations in the epilimnion. This may have formed through mortality, respiration, and decay from increased chlorophyll *a*, TOC and total suspended solids (TSS) concentrations in the area of the releases ports in the epilimnion of the reservoir. By the time water is transported from station LH02 to station LH03, DO concentrations have reaerated to levels of 7 mg/L or more. As water is transported downstream to station LH17, all concentration differences become diminished. Over all, the total metals modeled during scenario runs have concentrations that are below the levels considered to be harmful to the living resources for dissolved metal forms.

It is still recommended that for future modeling studies of F. E. Walter Reservoir, Beltzville Reservoir and riverine sections below, the District monitor inflow temperatures, metals and water quality parameters to major tributaries and inflow points to the reservoir to improve on this calibration. W2 did extremely well for 2001 but for 2003 lack of data from tributaries entering into the Lehigh River below F. E. Walter caused predicted values to be less favorable compared to results in 2001. As presented and discussed above, calibration/verification results were considered quite good considering tributary boundary data for 2003 used reservoir inflow data depending on location of tributary to the reservoirs. W2 was able to predict behavior trends of constituents if not always the exact value. Most of the time AME values were within target AME values. Although W2 performance is quite acceptable, better boundary data to drive the model would help improve model predictions and reduce the uncertainty associated with the lack of data.

References

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Appendix A: Fish Habitat Volume

For Phase II the version of CE-QUAL-W2 was updated from 3.5 to 3.6 to allow for fish habitat volume in the reservoir and downstream to be estimated based on critical temperature and dissolved oxygen (DO) values. During the initial scenario runs (scenarios 1 – 4) this feature was turned on to demonstrate the benefit of this information.

The CE-QUAL-W2 model allows for the computation of:

- Volume of fish habitat based on temperature and dissolved oxygen targets for various fish species

- Segment volume weighted averages of dissolved oxygen, NO3-N, NH4-N, PO4-P, Total P, and chlorophyll a

- Surface volume weighted averages of dissolved oxygen, NO3-N, NH4-N, PO4-P, Total P, and chlorophyll a

An input file, w2_habitat.npt, was created and put in the directory for each scenario run with the same fish species and temperature and DO criteria (Table A-1). Information in this table were provided by personal communications with Mark Hartle and? This file is read by the CE-QUAL-W2 model when 'HABTATC' is set to 'ON' in the control file, w2_con.npt. Habitat volumes for the indicated fish species and criteria, volume-weighted averages of eutrophication parameters and first order sediment oxygen uptake as predicted by the model will be output. For this demonstration only habitat volumes were of interest.

The file, w2_habitat, is set up as a text file in free format with commas delimiting fields with titles between lines explaining the following lines. Each fish species is given a temperature target, both a low and a high target, and a dissolved oxygen target not to go below. If DO is not being modeled the oxygen limits are ignored. Note that the time of output of all these variables and volumes are at the frequency of the time series frequency output (TSR files) (Wells and Cole, 2008). For the output presented below (Figures A-1 through A-4), the output frequency was two week averages. Each Figure represents results from a particular scenario run with the upper plot representing a run with both temperature and DO criteria and the lower plot only temperature criteria. Figures A-1 through A-4 demonstrate that when setting a temperature and DO criteria there is less volume available for fish habitat than if just setting temperature criteria only. As seen in figures having a temperature and DO criteria, DO concentration is the limiting factor for available habitat volume.

Table A-1. Criteria for estimating % fish habitat volume

Species	Minimum Temperature	Maximum Temperature	DO Minimum
RainbowTrout	0.00	23.90	5
BrownTrout	0.00	27.20	5
BrookTrout	0.00	23.90	5
CPickerel	0.00	29.60	4
RockBass	0.00	33.00	4
Fallfish	0.00	28.00	4
SmallmouthBass	0.00	32.00	4
RBreastSunfish	0.00	33.00	4
WhiteSuckers	0.00	31.60	4
LargemouthBass	2.00	29.40	4

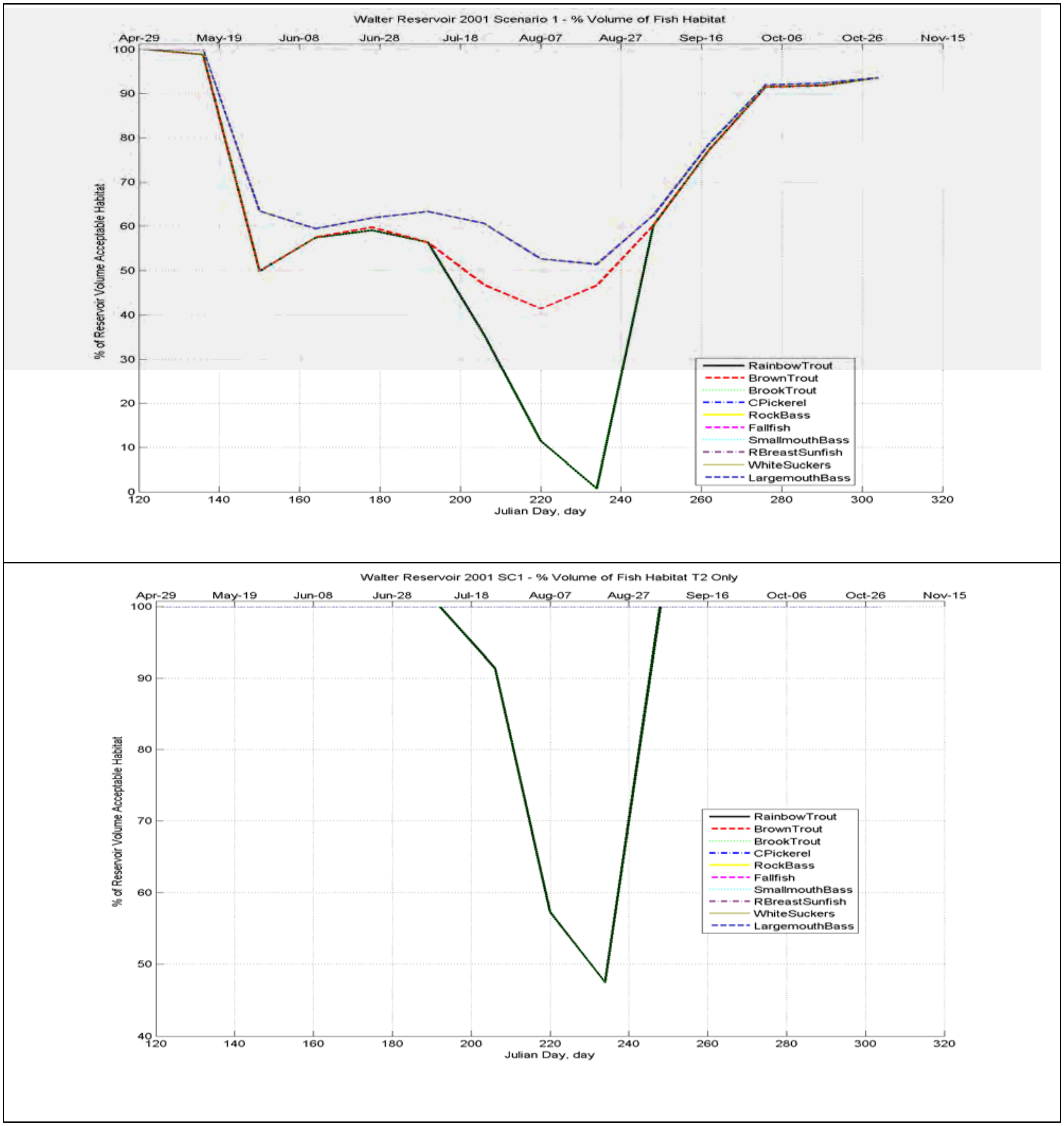

Figure A-1. 2001 Scenario 1 two week averaged % habitat volume at F. E. Walter with Temperature and DO criteria (upper) and with Temperature Only criteria (Bottom).

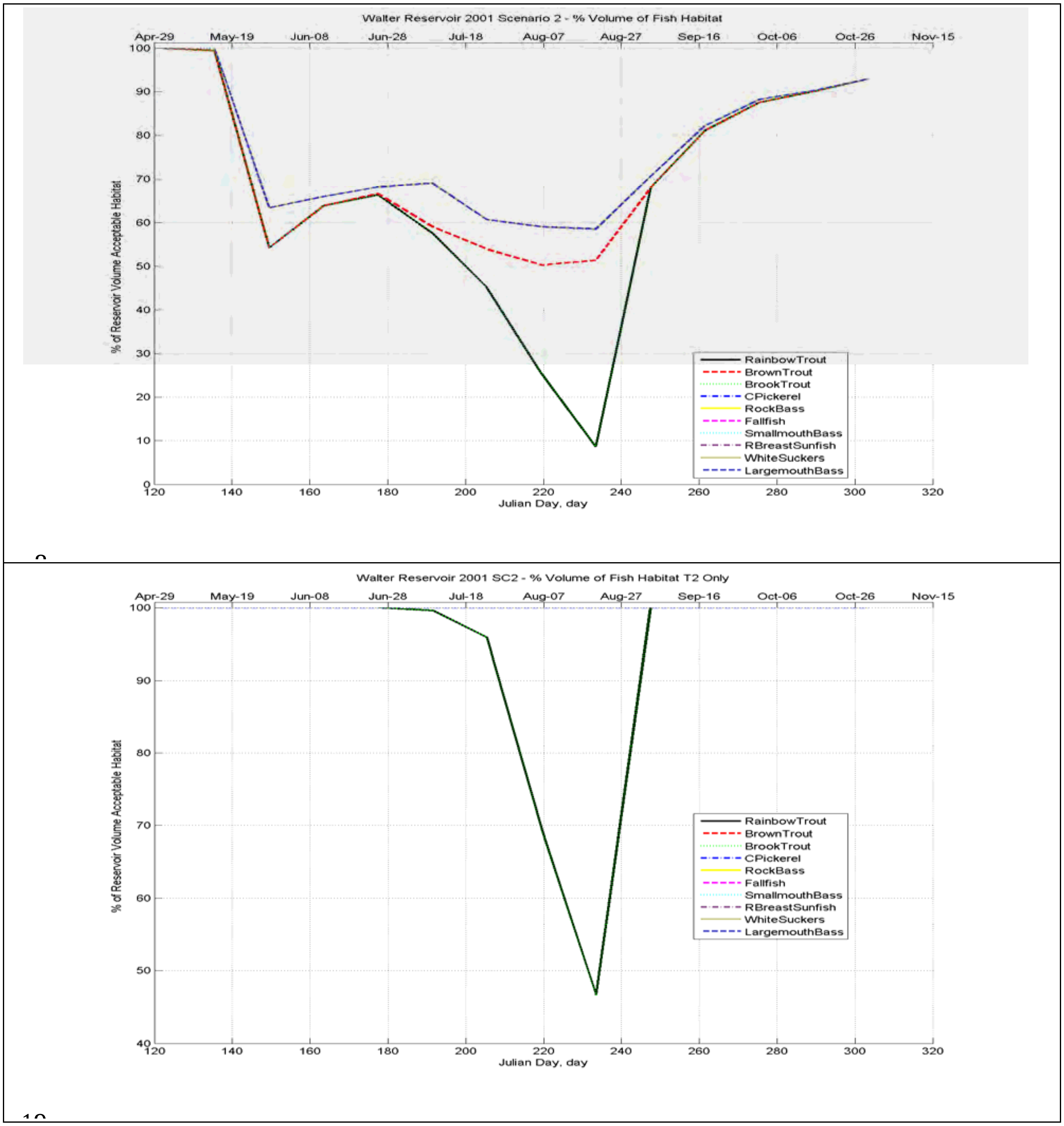

Figure A-2. 2001 Scenario 2 two week averaged % habitat volume at F. E. Walter with Temperature and DO criteria (upper) and with Temperature Only criteria (Bottom).

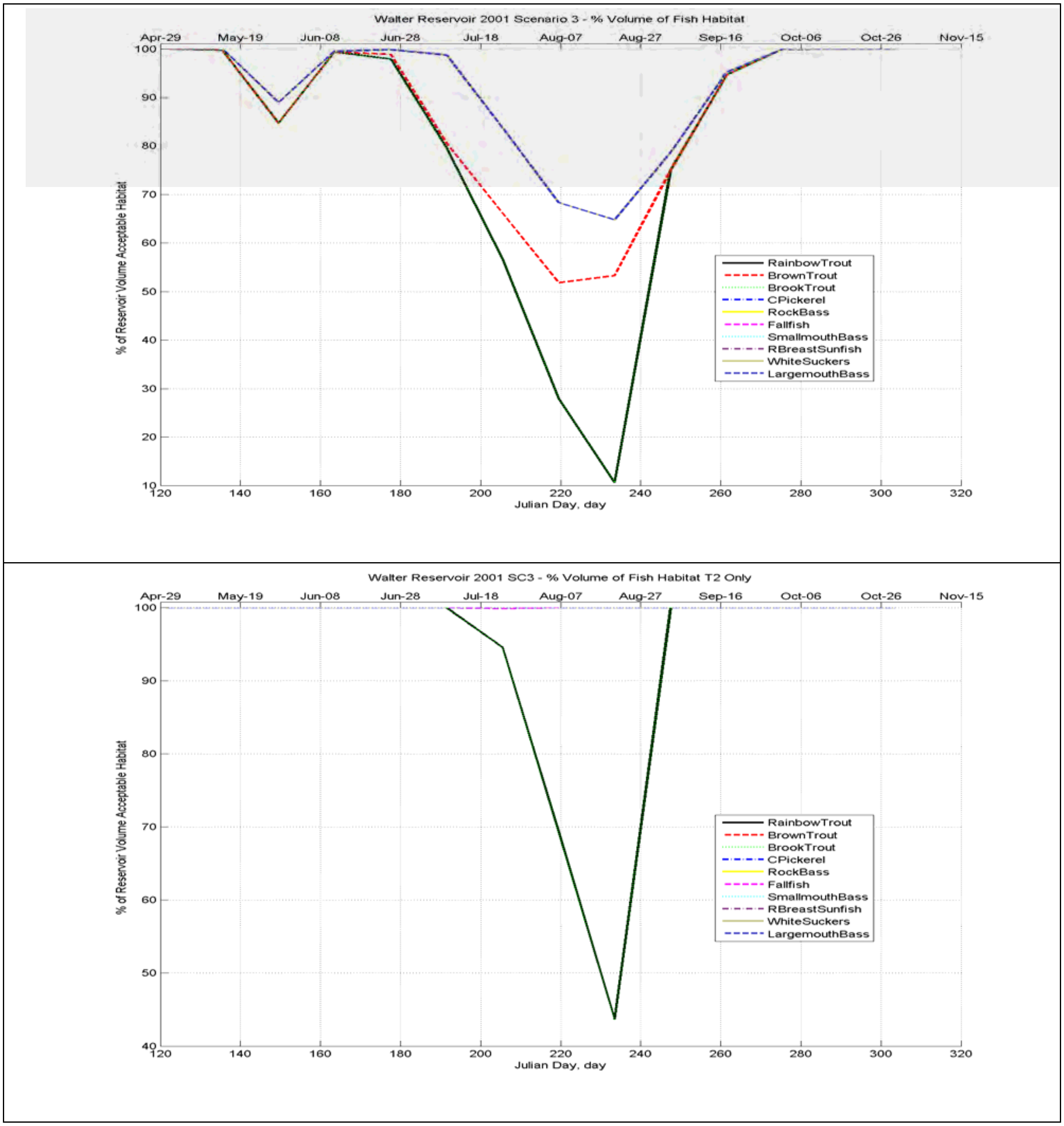

Figure A-3. 2001 Scenario 3 two week averaged % habitat volume at F. E. Walter with Temperature and DO criteria (upper) and with Temperature Only criteria (Bottom).

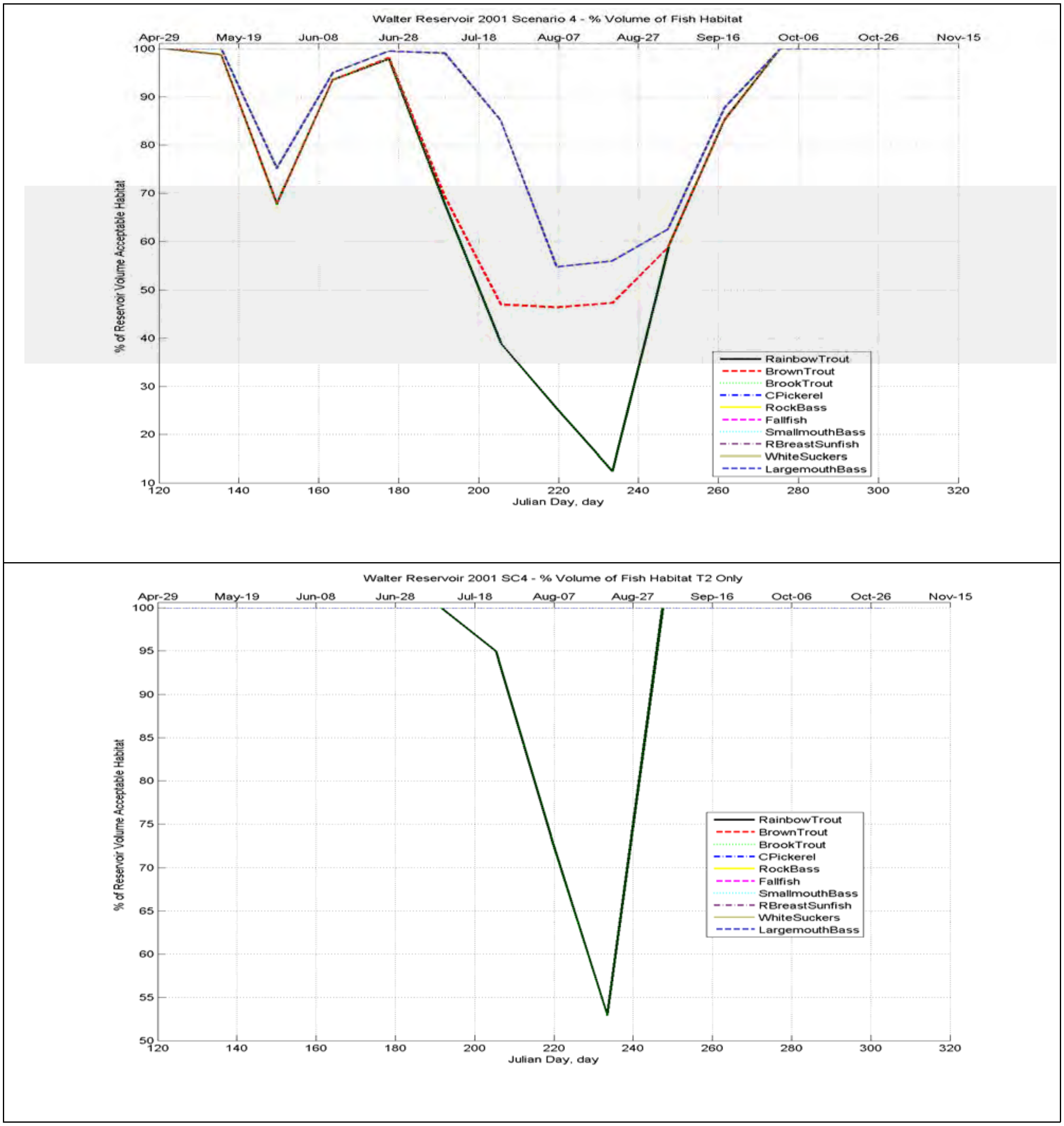

Figure A-4. 2001 Scenario 4 two week averaged % habitat volume at F. E. Walter with Temperature and DO criteria (upper) and with Temperature Only criteria (Bottom).

Appendix B: Water body Grids for Each Section of the Lehigh River Modeled

Figures B-1, B-2, B-3, B-4, and B-5 show the five grid sections modeled separately and are:

1. Water body 1: F. E. Water Reservoir and the first 5545 m (Figure B-1) on the Lehigh River.

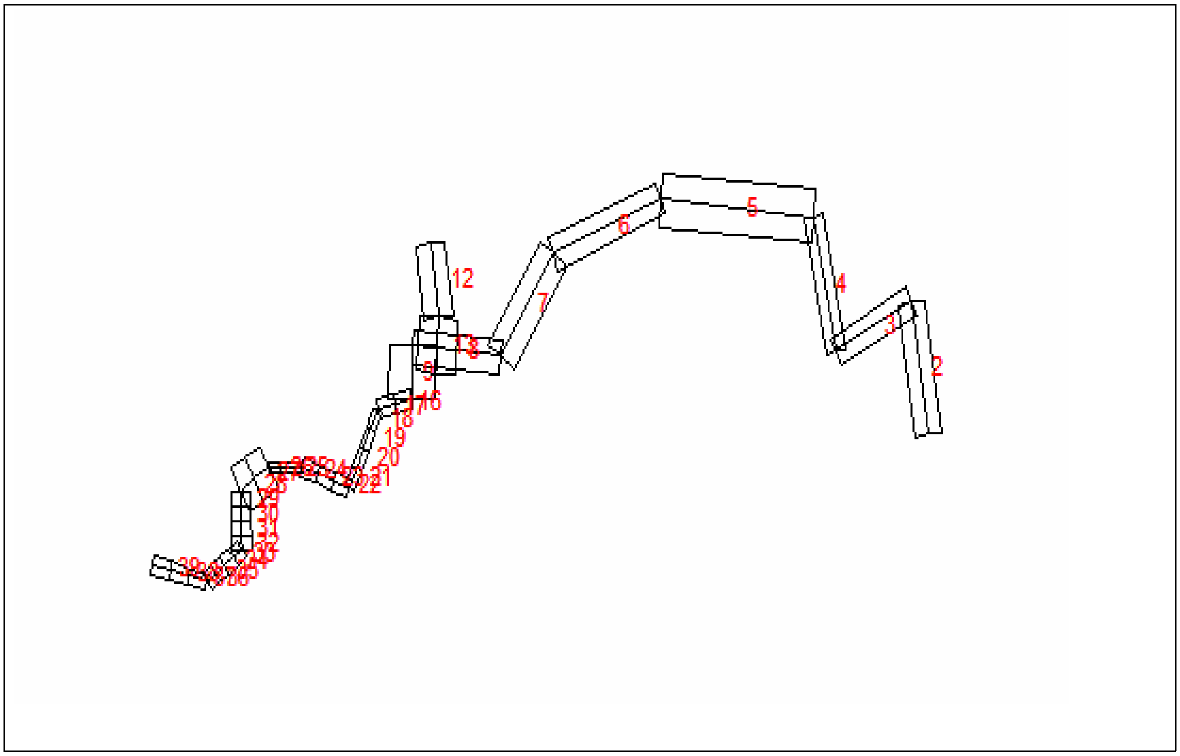

Figure B-1. Grid of Water body 1 containing F. E. Walter Reservoir and 22 segments on the Lehigh River.

2. Water body 2: approximately 20807 m (Figure B-2) below water body 1 on the Lehigh River.

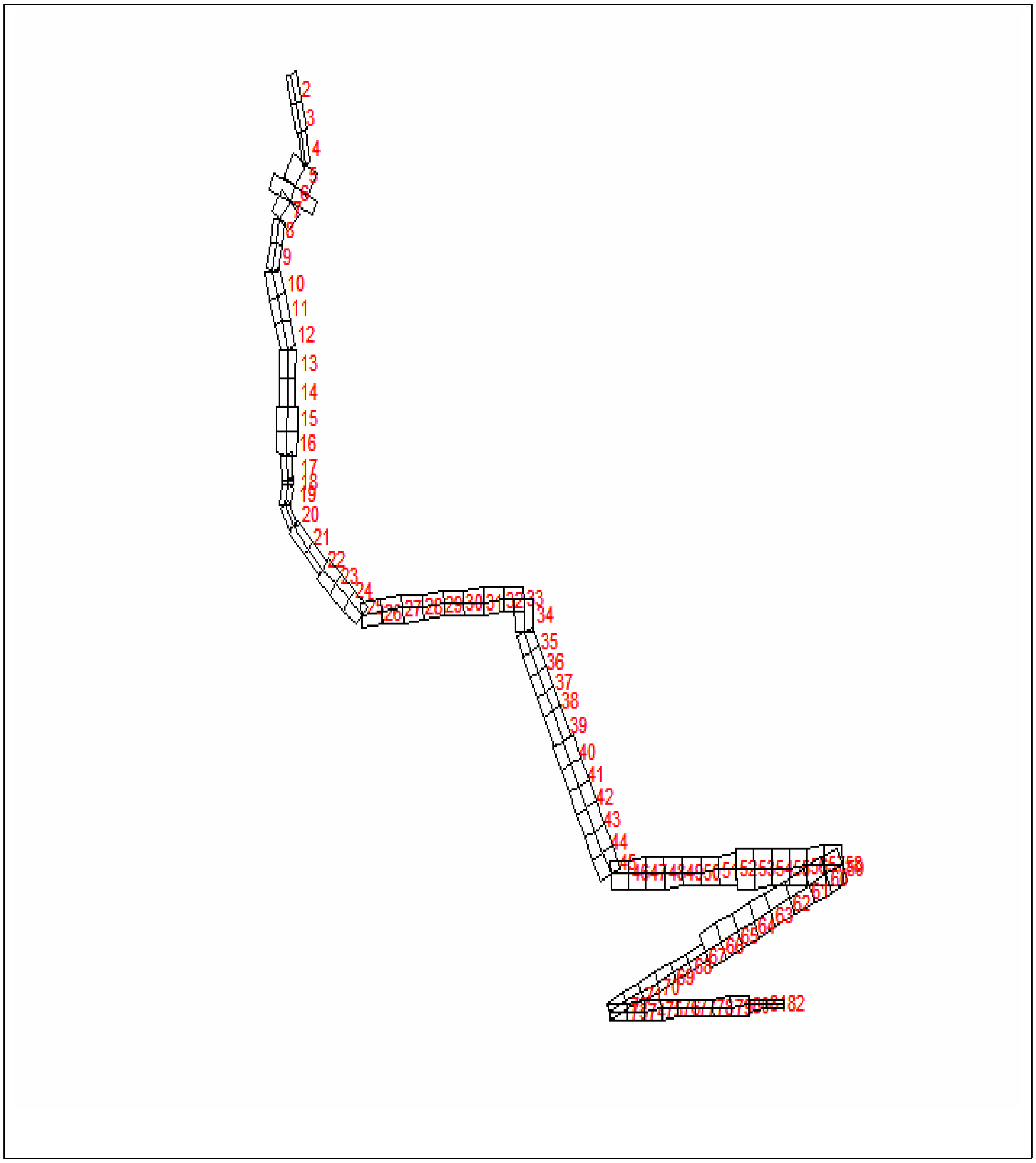

Figure B-2. Grid for Water body 2 containing 81 active segments on the Lehigh River.

3. Water body 3: approximately 21698 m (Figure B-3) below water body 2 on the Lehigh River.

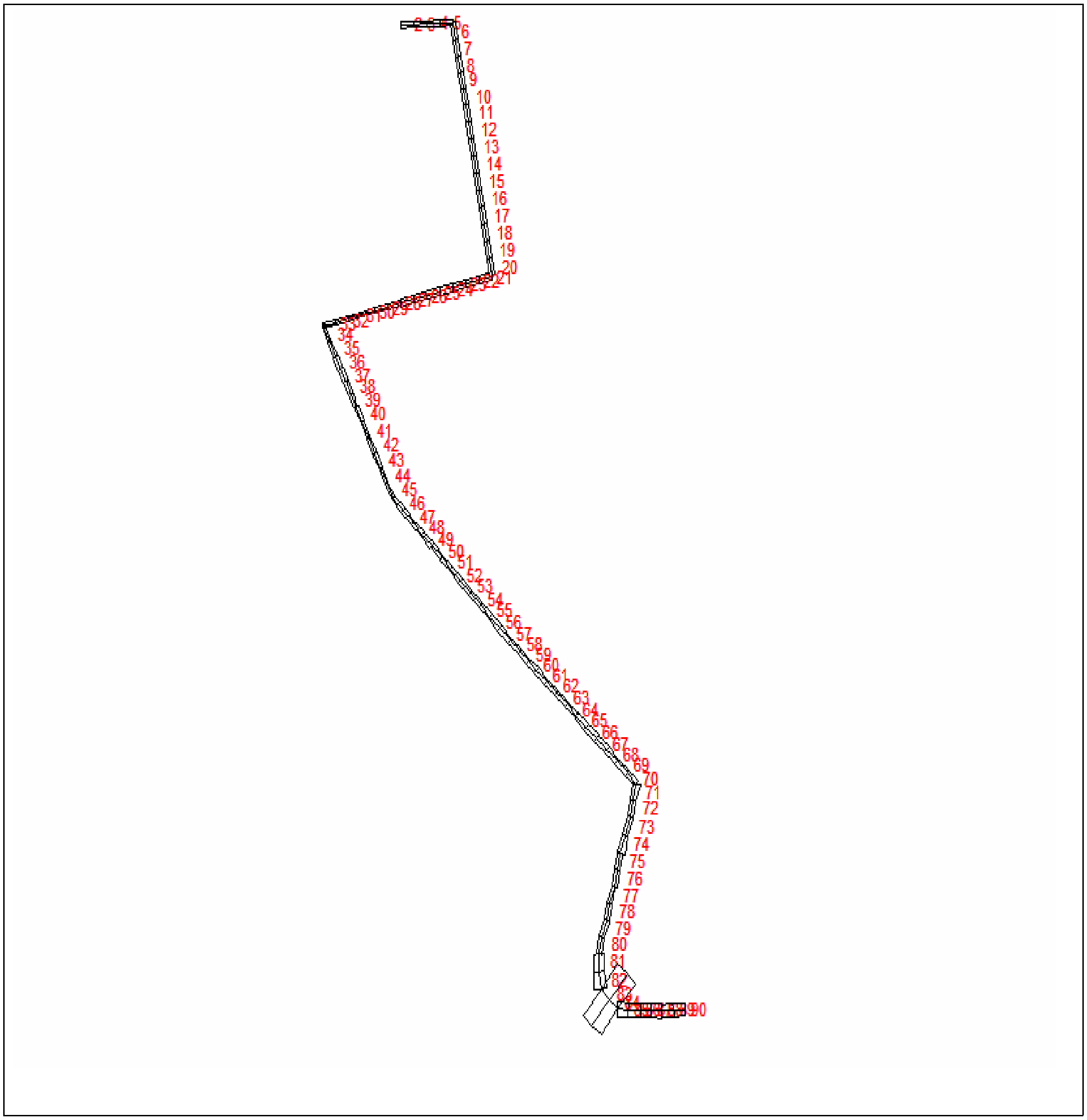

Figure 6. Grid for Water body 3 containing 89 active segments on the Lehigh River.

4. Water body 4: approximately 42976 m (Figure B-4) below water body 3 on the Leigh River.

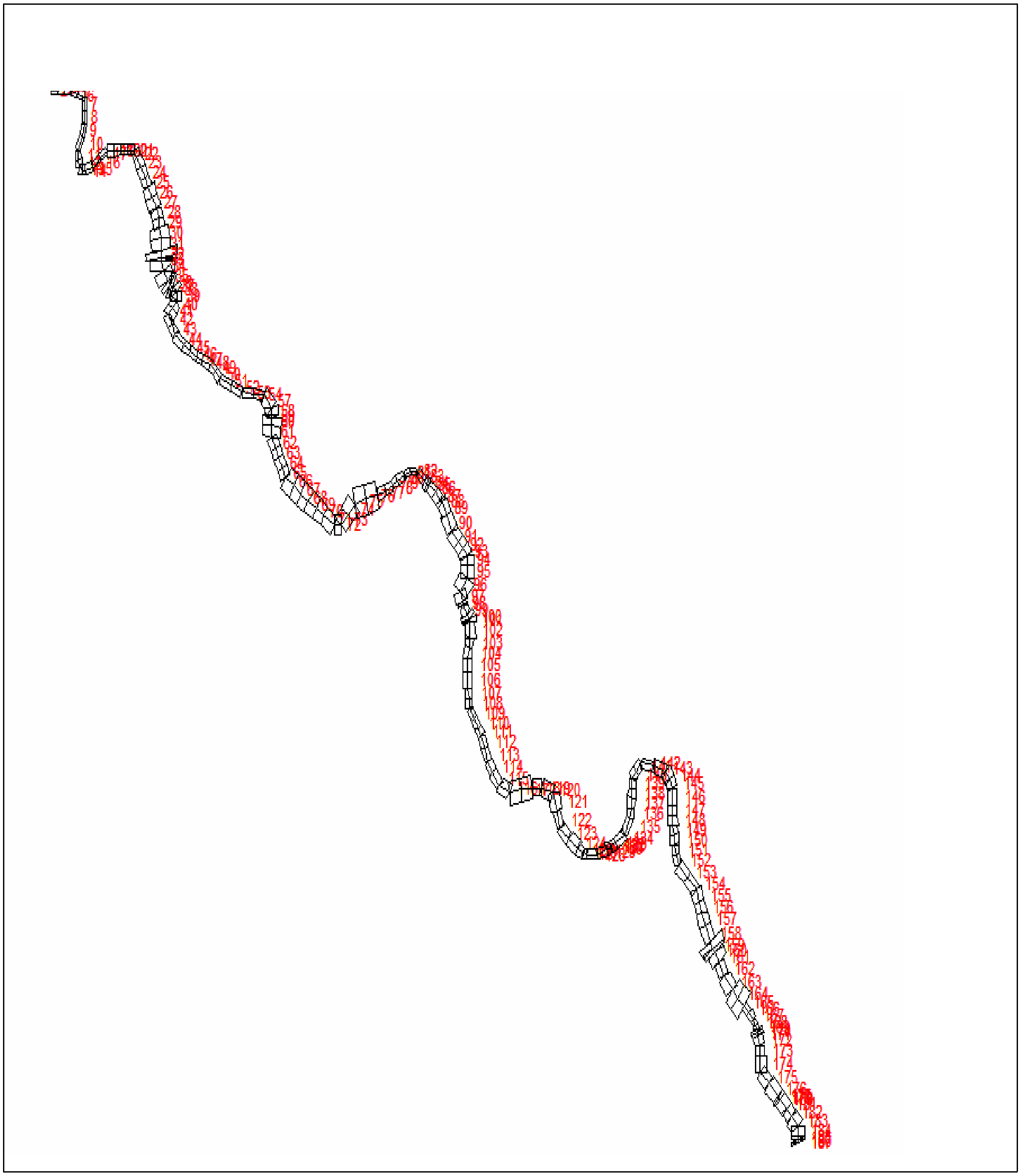

Figure 7. Grid for Water body 4 containing 183 active segments on the Lehigh River.

5. Water Body 5: Beltzville Reservoir and 8675 m (Figure B-5) on the Pohopoco Creek.

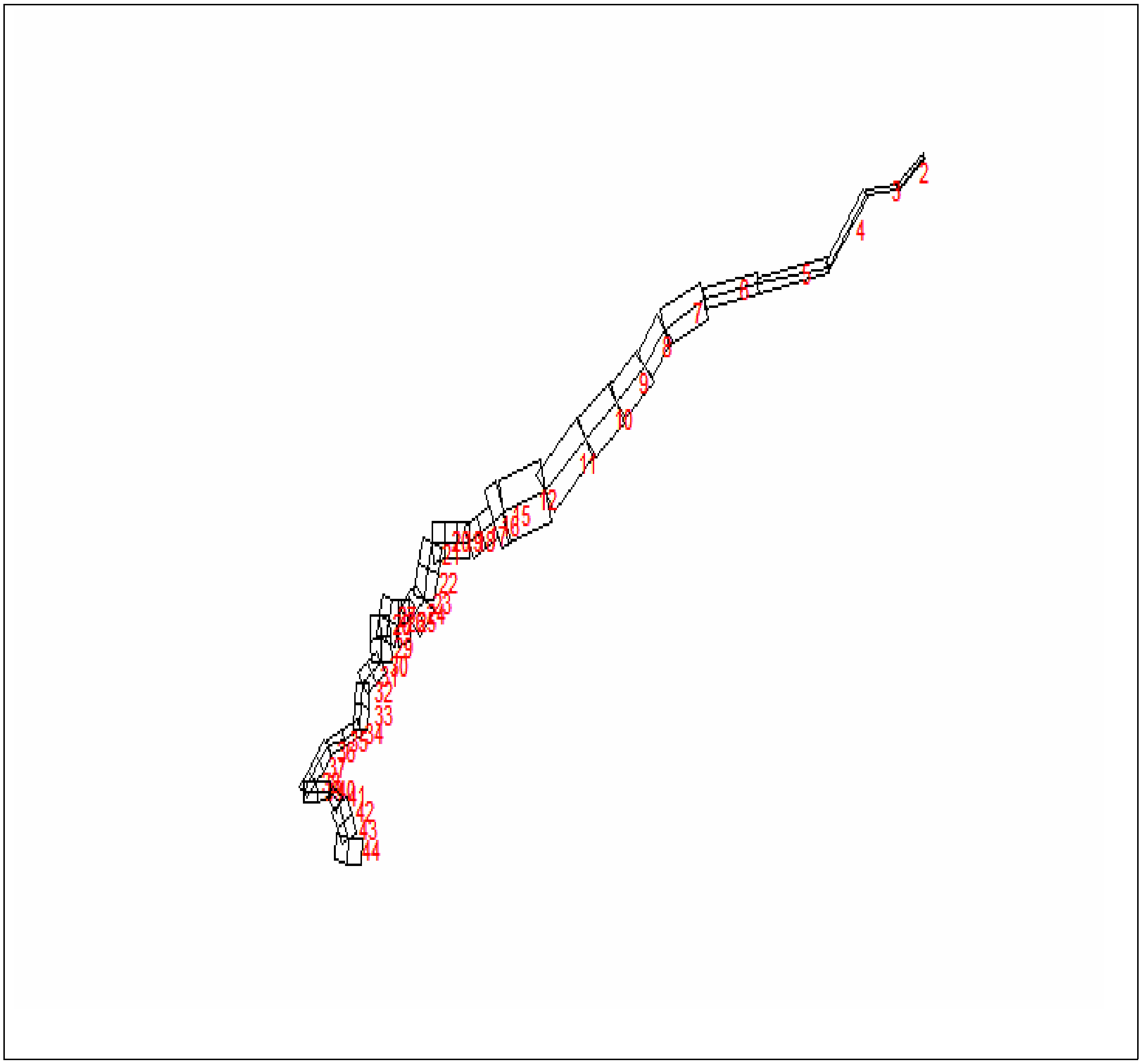

Figure 8. Section 5 containing Beltzville Reservoir (11 segments) and 30 active segments on the Pohopoco Creek.

Segment cell layer heights for both reservoirs and for the Lehigh River were constant and set to 0.4 meters (m) while segment lengths varied. Once the segment lengths and layer heights were finalized for each reservoir and river sections, average widths were determined for each active cell from sediment range data, TIN maps, and DAMBRK data provided by the Philadelphia District. An active cell is defined as potentially containing water. Initial bathymetry data supplied were inadequate to develop a grid for the 45 miles of Lehigh River and F. E. Walter Reservoir. The original TIN maps sent were only for the bottom 20 miles of the Lehigh River. After searching through old studies, District personnel found an old HEC-2 study and a DAMBRK model which provided helpful information in completing the grid of the river for the 25 miles below F. E. Walter Reservoir. Sediment range data for Beltzville were not provided in an Excel format as requested. Bathymetry was estimated from flat plots of cross sections taken for pre-dam study.

Water Body 1

Water Body 1 consists of two water bodies with three branches comprising 38 active segments and a maximum of 179 layers. Originally when modeling the entire study area with one grid, F. E. Reservoir was the determining water body for the maximum number of layers modeled. After the decision was made to split the grid into five sections, the maximum layer numbers remained the same. This was retained for future examination of factors causing the instabilities in the hydrodynamics and possibly making adjustments so that sections could be combined and run as a whole. Segment widths varied from 5 to 710 m. The main branch of the F. E. Walter Reservoir represents the Lehigh River. The remaining branches represent Lehigh River below F. E. Walter Reservoir and Bear Creek. Figure B-1 shows a top view of this section. A comparison of computed volume-elevation curve and Philadelphia District data for F. E. Walter Reservoir is presented in Figure B-6. The computed versus observed volume-elevation curve closely matches the data from the F. E. Walter Reservoir.

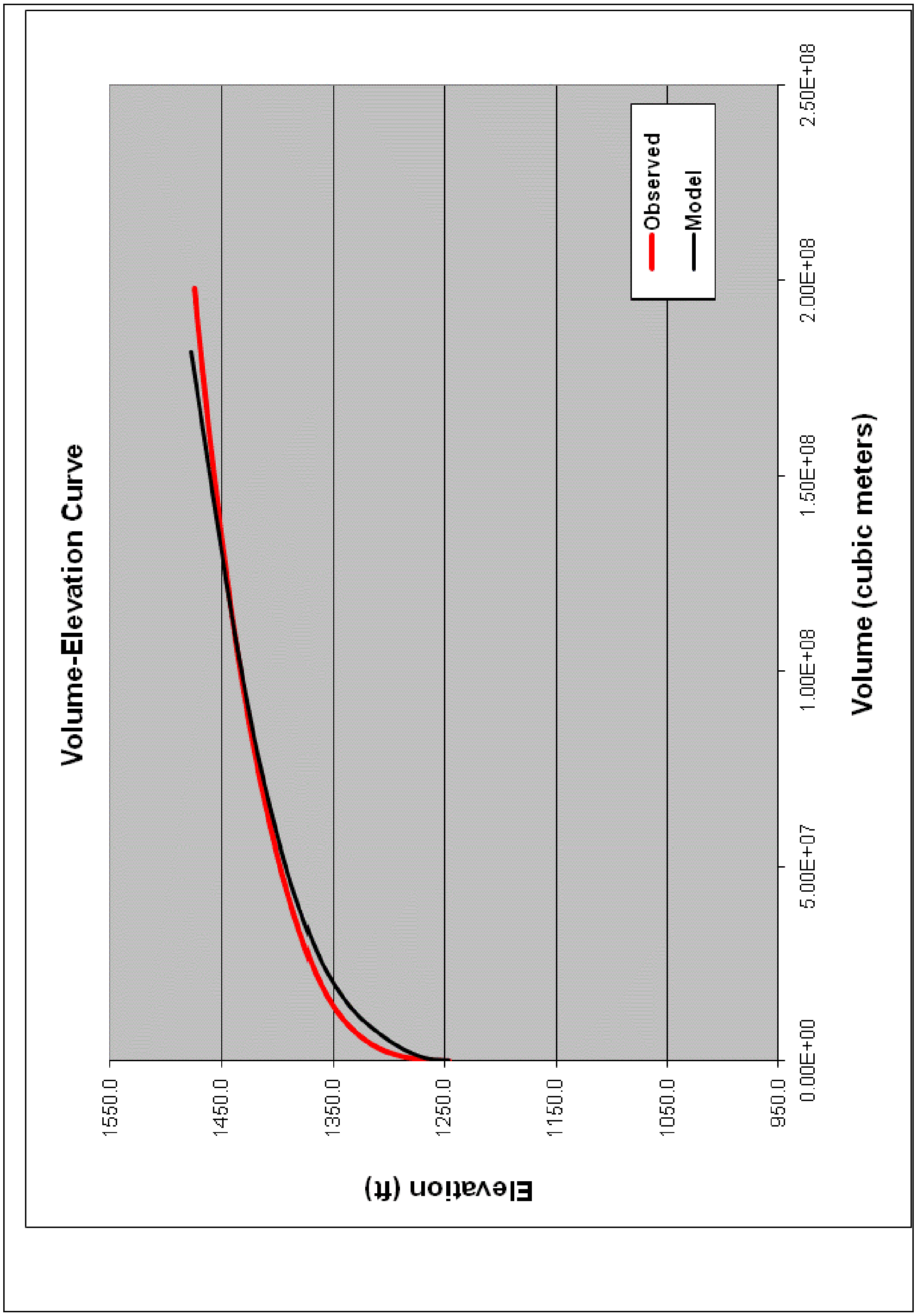

Figure B-6. Observed verse model volume elevation curve at F. E. Walter Reservoir.

Water Body 2

Water body 2 consists of one water body with one branch on the Lehigh River below water body 1. It contains 81 active segments and a maximum of 179 layers. Segment widths varied from 5 to 673 m. Figure B-2 shows a top view of this branch. Two tributaries enter the Lehigh River at segments 53 and 81 and are Hayes Creek and Sandy Run, respectively.

Water Body 3

Water body 3 consists of one water body with one branch on the Lehigh River below water body 2 comprising 89 active segments and a maximum of 179 layers. Segment widths varied from 5 to 990 m. Figure B-3 shows a top view of this branch. Three tributaries enter the Lehigh River at segments 28, 40 and 85 and are Buck Mountain Creek, Black Creek, and Nesquehoning Creek, respectively.

Water Body 4

Water body 4 consists of one water body with two branches on the Lehigh River below water body 3 comprising 188 active segments and a maximum of 179 layers (Figure B-4). Segment widths varied from 5 to 979 m. Figure B-4 shows a top view of this section. Five tributaries enter the Lehigh River at segment 44, 53, 66, 86, and 118 and are Mahoning Creek, Lizard Creek, Aquashicola Creek, Pohopoco Creek, and Bertsch Creek, respectively.

Water Body 5

Water body 5 consists of two water bodies with two branches on the Pohopoco Creek comprising 41 active segments and a maximum of 179 layers (Figure B-5). Segment widths varied from 5 to 883 m. Water body one represents the first branch in the grid and is Beltzville Reservoir. The remaining branch is water body 7 representing the Pohopoco Creek below Beltzville Reservoir (see Figure 2). A comparison of computed volume-elevation curve and Philadelphia District data is presented in Figure B-7. The computed volume-elevation curve closely matches the Philadelphia District data.

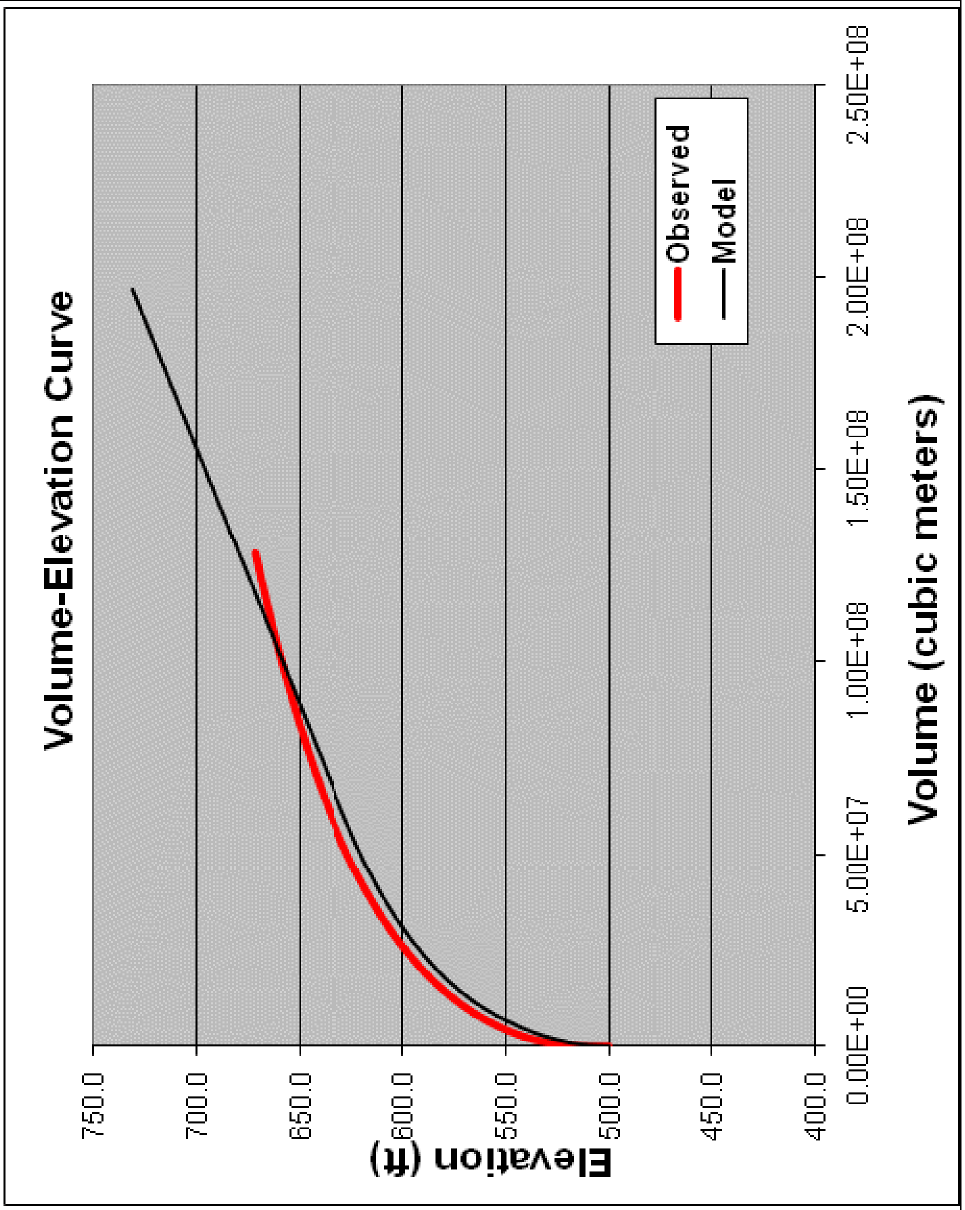

Figure B-7. Observed verse model volume elevation curve at Beltzville Reservoir

Appendix C: CE-QUAL-W2 Control Files for 2001 and 2003

CE-QUAL-W2 control files for each w2 model application set up for the five sections modeled were inserted as a PDF file in this appendix. Double click on the pages below to get each PDF file to open.

```
  PSU W2 Model Version 3.7

TITLE C
..............................TITLE..WY01...............................
..
        1 Walter + Lehigh River WB1 only
        2 Initial Setup
        3 VERSION 3.7
        4 run for animation output - tsr 20 = LH02
        5 New bathy on river section (additional < bot 2 layers seg16-
30)
        6 WY01_wq_run85 -08/09/10- Same as run78 except BC comes in seg8
        7 Output from dam qwo_39 and two_39: POINT>LINE; TERM>ET WB1
        8 Default hydraulic and kinetic coefficients:  ACHLA .06>0.12
        9 First run using V3.7 ; INITUWL ( ON) ; DLTINTR (OFF)
        10 Toni Toney : Improve runtimes - dht

GRID          NWB     NBR     IMX     KMX   NPROC  CLOSEC
                2       4      43     179       1     OFF

IN/OUTFL      NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
                0       1       0       1       0       1       0       0

CONSTITU      NCG     NSS     NAL     NEP    NBOD     NMC     NZP
                3       1       2       0       1       0       0

MISCELL      NDAY SELECTC HABTATC ENVIRPC AERATEC INITUWL
              100     OFF      ON     OFF     OFF      ON

TIME CON   TMSTRT   TMEND    YEAR
          171.000 310.000    2001

DLT CON       NDT  DLTMIN DLTINTR
               10 0.10000     OFF

DLT DATE     DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
DLTD
            171.0   173.0   189.0  216.00   218.0   247.0   249.0   263.5
270.0
            310.0

DLT MAX    DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
DLTMAX
              8.0     8.0     5.0     1.0     5.0     0.5     5.0     1.0
5.0
              5.0

DLT FRN      DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
DLTF
             0.25    0.25    0.50    0.25    0.50    0.10    0.25    0.25
0.25
             0.25

DLT LIMI     VISC    CELC
WB 1           ON      ON
WB 2           ON      ON

BRANCH G       US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE
SLOPEC
BR1             2       9       0       0       0       0       1    0.00
```

```
                                   w2_con
  PSU W2 Model Version 3.7

TITLE C ..............................TITLE..WY 01...............................
        1 Lehigh River -- WB2 only
        2 Initial Setup
        3 VERSION 3.7
        4
        5 Animation
        6 WY01_wq_run33 -- shading 0.60;Manning N adj:
        7 updated qin/tin files to come from wb1 qwo/two_42 WQ run54
        8 Default hydraulic and kinetic coefficients:
        9
        10 Seg 23 = LH03: same as run32 except V3.7

GRID          NWB      NBR      IMX      KMX    NPROC   CLOSEC
                1        1       83      179        1      OFF

IN/OUTFL      NTR      NST      NIW      NWD      NGT      NSP      NPI      NPU
                2        0        0        0        0        1        0        0

CONSTITU      NCG      NSS      NAL      NEP     NBOD      NMC      NZP
                3        1        2        0        1        0        0

MISCELL      NDAY  SELECTC  HABTATC  ENVIRPC  AERATEC  INITUWL
              100      OFF       ON      OFF      OFF       ON

TIME CON   TMSTRT    TMEND     YEAR
          171.000  310.000     2001

DLT CON       NDT   DLTMIN  DLTINTR
                7  0.40000       ON

DLT DATE     DLTD     DLTD     DLTD     DLTD     DLTD     DLTD     DLTD     DLTD     DLTD
            171.0    173.0   200.00   240.0    260.0    300.0    310.0

DLT MAX    DLTMAX   DLTMAX   DLTMAX   DLTMAX   DLTMAX   DLTMAX   DLTMAX   DLTMAX   DLTMAX
              8.0      8.0      8.0      8.0      8.0      8.0     10.0

DLT FRN      DLTF     DLTF     DLTF     DLTF     DLTF     DLTF     DLTF     DLTF     DLTF
             0.10     0.10     0.25     0.25     0.25     0.25     0.50      0.5

DLT LIMI     VISC     CELC
WB 1           ON       ON

BRANCH G       US       DS      UHS      DHS      UQB      DQB    NLMIN    SLOPE   SLOPEC
BR1             2       82        0        0        0        0        1   0.0037   0.0037

LOCATION      LAT     LONG     EBOT       BS       BE     JBDN
WB 1        40.49    75.40    249.5        1        1        1

INIT CND      T2I     ICEI   WTYPEC    GRIDC
WB 1        20.08    0.000    FRESH     RECT

CALCULAT      VBC      EBC      MBC      PQC      EVC      PRC
WB 1          OFF      OFF      OFF       ON      OFF      OFF

DEAD SEA    WINDC     QINC    QOUTC    HEATC
WB 1           ON       ON       ON       ON

INTERPOL    QINIC    DTRIC     HDIC
BR1            ON      OFF      OFF

HEAT EXCH   SLHTC     SROC   RHEVAP    METIC   FETCHC      AFW      BFW      CFW    WINDH
```

```
                                    w2_con
  PSU W2 Model Version 3.7

TITLE C ..............................TITLE..WY 01...............................
        1 Lehigh River -- WB3 only
        2 Initial Setup
        3 VERSION 3.7
        4
        5 Animation
        6 WY01_wq_run11 --08-15-10-- :
        7 updated qin/tin files to correspond to qwo/two/cwo_82 from wb2 run30
        8 Default hydraulic and kinetic coefficients:
        9 Tammy L. Threadgill :
        10 TSEDF = 0.5;Same as run10 except V3.7

GRID          NWB     NBR     IMX     KMX   NPROC  CLOSEC
                1       1      91     179       1     OFF

IN/OUTFL      NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
                3       0       0       0       0       1       0       0

CONSTITU      NCG     NSS     NAL     NEP    NBOD     NMC     NZP
                3       1       2       0       1       0       0

MISCELL      NDAY SELECTC HABTATC ENVIRPC AERATEC INITUWL
              100     OFF      ON     OFF     OFF      ON

TIME CON   TMSTRT   TMEND    YEAR
          171.000 310.000    2001

DLT CON       NDT  DLTMIN DLTINTR
                8 0.40000      ON

DLT DATE     DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
            171.0   173.0   185.0  190.00   240.0   260.0   300.0   308.0  315.00

DLT MAX    DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
              8.0     8.0     8.0     8.0     8.0     8.0     5.0     2.0     2.0

DLT FRN      DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
             0.10    0.10    0.25    0.25    0.25    0.25    0.25     0.1     0.1

DLT LIMI     VISC    CELC
WB 1           ON      ON

BRANCH G       US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE  SLOPEC
BR1             2      90       0       0       0       0       1  0.0038  0.0038

LOCATION      LAT    LONG    EBOT      BS      BE    JBDN
WB 1        40.49   75.40   149.5       1       1       1

INIT CND      T2I    ICEI  WTYPEC   GRIDC
WB 1        20.20   0.000   FRESH    RECT

CALCULAT      VBC     EBC     MBC     PQC     EVC     PRC
WB 1          OFF     OFF     OFF      ON     OFF     OFF

DEAD SEA    WINDC    QINC   QOUTC   HEATC
WB 1           ON      ON      ON      ON

INTERPOL    QINIC   DTRIC    HDIC
BR1            ON     OFF     OFF

HEAT EXCH   SLHTC    SROC  RHEVAP   METIC  FETCHC     AFW     BFW     CFW   WINDH
                                    Page 1
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                                    w2_con
  PSU W2 Model Version 3.7

TITLE C ..............................TITLE..WY 01...............................
        1 Lower 2 branches of Lehigh River - WB4 Only
        2 Initial Setup
        3 VERSION 3.7
        4 Animation
        5
        6 WY01_wq_run14; w/ bath03(bth_lhr_lower_2br_6_test2.npt)
        7 TSEDF=0.5- BETA=0.25; shd=0.9: TSED=14(14); AT41 28>32
        8 Default hydraulic & kinetic coefficients:
        9 same as run13 except for V3.7
        10 LH10 = seg27; LH15 = seg99; LH17 = seg150;

GRID          NWB     NBR     IMX     KMX   NPROC  CLOSEC
                1       2     173     179       2     OFF

IN/OUTFL      NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
                5       0       0       0       0       1       0       0

CONSTITU      NCG     NSS     NAL     NEP    NBOD     NMC     NZP
                3       1       2       0       1       0       0

MISCELL      NDAY SELECTC HABTATC ENVIRPC AERATEC INITUWL
              100     OFF      ON     OFF     OFF      ON

TIME CON   TMSTRT   TMEND    YEAR
          171.000 310.000    2001

DLT CON       NDT  DLTMIN DLTINTR
                9 0.40000      ON

DLT DATE     DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
            171.0   172.0   175.0   220.0   230.0   240.0   268.0   309.0   310.0

DLT MAX    DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
              1.0     5.0     5.0     5.0     5.0     5.0     5.0     5.0     5.0

DLT FRN      DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
             0.10    0.50    0.50    0.50    0.50    0.50    0.50    0.50     0.5

DLT LIMI     VISC    CELC
WB 1           ON      ON

BRANCH G       US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE  SLOPEC
BR1             2      52       0      55       0       0       1  0.0022  0.0022
BR2            55     172      52       0       0       0       1  0.0015  0.0015

LOCATION      LAT    LONG    EBOT      BS      BE    JBDN
WB 1        40.49   75.40    75.7       1       2       2

INIT CND      T2I    ICEI  WTYPEC   GRIDC
WB 1        11.20   0.000   FRESH    RECT

CALCULAT      VBC     EBC     MBC     PQC     EVC     PRC
WB 1          OFF     OFF     OFF      ON     OFF     OFF

DEAD SEA    WINDC    QINC   QOUTC   HEATC
WB 1           ON      ON      ON      ON

INTERPOL    QINIC   DTRIC    HDIC
BR1            ON     OFF     OFF
BR2            ON     OFF     OFF
                                    Page 1
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                                    w2_con_run08
  PSU W2 Model Version 3.6

TITLE C ..............................TITLE..WY 01................................
        1 Beltzville Reservoir + Pohopoco River
        2 Initial Setup
        3 VERSION 3.6
        4 Toni Apr 2010 Run 1
        5 CIN file has same values as CDT file Station BZ05
        6 WY01_wq_run08 -- 090210 --
        7 AT41 25>28 AT12AT32 8>6
        8 Default hydraulic and kinetic coefficients:
        9 Tammy L. Threadgill
        10 toni toney  apr 2010

GRID          NWB      NBR      IMX      KMX    NPROC   CLOSEC
                2        3       60      179        1      OFF

IN/OUTFL      NTR      NST      NIW      NWD      NGT      NSP      NPI      NPU
                0        2        0        0        0        1        0        0

CONSTITU      NCG      NSS      NAL      NEP     NBOD      NMC      NZP
                3        1        2        0        1        0        0

MISCELL      NDAY
              100

TIME CON   TMSTRT    TMEND     YEAR
          171.000  310.000     2001

DLT CON       NDT   DLTMIN
                9  0.50000

DLT DATE     DLTD     DLTD     DLTD     DLTD     DLTD     DLTD     DLTD     DLTD     DLTD
            171.0    173.0    181.0    225.0    245.0    260.0    270.0    280.0    310.0

DLT MAX    DLTMAX   DLTMAX   DLTMAX   DLTMAX   DLTMAX   DLTMAX   DLTMAX   DLTMAX   DLTMAX
              5.0     10.0      5.0     10.0      5.0     10.0      5.0      5.0     10.0

DLT FRN      DLTF     DLTF     DLTF     DLTF     DLTF     DLTF     DLTF     DLTF     DLTF
             0.50     0.50     0.50     0.50     0.50     0.50     0.50     0.50     0.50

DLT LIMI     VISC     CELC
WB 1           ON       ON
WB 2           ON       ON

BRANCH G       US       DS      UHS      DHS      UQB      DQB    NLMIN    SLOPE
BR1             2       12        0        0        0        0        1   0.0000
BR2            15       19      -12       22        0        0        1   0.0012
BR3            22       59       19        0        0        0        1   0.0014

LOCATION      LAT     LONG     EBOT       BS       BE     JBDN
WB 1        40.64    79.62    152.2        1        1        1
WB 2        40.49    75.40   128.50        2        3        3

INIT CND      T2I     ICEI   WTYPEC
WB 1         -2.0    0.000    FRESH
WB 2        13.63    0.000    FRESH

CALCULAT      VBC      EBC      MBC      PQC      EVC      PRC
WB 1          OFF      OFF      OFF       ON      OFF      OFF
WB 2          OFF      OFF      OFF       ON      OFF      OFF

DEAD SEA    WINDC     QINC    QOUTC    HEATC
                                      Page 1
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                                        w2_con
  PSU W2 Model Version 3.7

TITLE C ..............................TITLE..WY 02...............................
        1 Walter + Lehigh River WB1 only
        2 Initial Setup
        3 VERSION 3.7
        4
        5 animation: SOD 0.5 > 2.0, 3.0, and 4.0
        6 WY02_run27: SLHTC = ET for WB2;
        7 Verification 2002: no distributed tributaries;
        8 Default hydraulic and kinetic coefficients:
        9 Changed algae IC from .24 to .101 for both groups
        10 Long Prof used for temp&DO  w/run19; run27 SOD increased

GRID          NWB     NBR     IMX     KMX   NPROC  CLOSEC
                2       4      43     179       2     OFF

IN/OUTFL      NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
                0       1       0       0       0       1       0       0

CONSTITU      NCG     NSS     NAL     NEP    NBOD     NMC     NZP
                3       1       2       0       1       0       0

MISCELL      NDAY SELECTC HABTATC ENVIRPC AERATEC INITUWL
              100     OFF      ON     OFF     OFF      ON

TIME CON   TMSTRT   TMEND    YEAR
          141.300 277.500    2002

DLT CON       NDT  DLTMIN DLTINTR
               10 0.40000      ON

DLT DATE     DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
            141.3   145.0   148.0  151.00   156.0   159.0   170.0   177.0  193.00
            289.0

DLT MAX    DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
              8.0     8.0     5.0     8.0     1.0     8.0     5.0     5.0     1.0
              5.0

DLT FRN      DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
             0.25    0.25    0.10    0.25    0.10    0.25    0.25    0.25    0.25
             0.25

DLT LIMI     VISC    CELC
WB 1           ON      ON
WB 2           ON      ON

BRANCH G       US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE  SLOPEC
BR1             2       9       0       0       0       0       1    0.00   0.000
BR2            12      13       0       8       0       0       1    0.00   0.000
BR3            16      17      -9      20       0       0       1  0.0040  0.0040
BR4            20      42      17       0       0       0       1  0.0045  0.0045

LOCATION      LAT    LONG    EBOT      BS      BE    JBDN
WB 1        41.12   75.71  379.48       1       2       1
WB 2        40.49   75.40   349.4       3       4       4

INIT CND      T2I    ICEI  WTYPEC   GRIDC
WB 1         -2.0 0.00000   FRESH    RECT
WB 2        12.05   0.000   FRESH    RECT

CALCULAT      VBC     EBC     MBC     PQC     EVC     PRC
                                        Page 1
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                                   w2_con
  PSU W2 Model Version 3.7

TITLE C ..............................TITLE..WY 02...............................
        1 Lehigh River -- WB2 only
        2 Initial Setup
        3 VERSION 3.7
        4
        5
        6 WY02_run04_V37: shading 0.60;Man N adj
        7  Verification run for 2002: new qin&tin - TSEDF 0.5;BETA=0.25
        8 Default hydraulic and kinetic coefficients:
        9 Tammy L. Threadgill
       10 Same as run02 but using V3.7

GRID          NWB     NBR     IMX     KMX   NPROC  CLOSEC
                1       1      83     179       1     OFF

IN/OUTFL      NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
                2       0       0       0       0       1       0       0

CONSTITU      NCG     NSS     NAL     NEP    NBOD     NMC     NZP
                3       1       2       0       1       0       0

MISCELL      NDAY SELECTC HABTATC ENVIRPC AERATEC INITUWL
              100     OFF      ON     OFF     OFF      ON

TIME CON   TMSTRT   TMEND    YEAR
          142.300 277.500    2002

DLT CON       NDT  DLTMIN DLTINTR
                8 0.40000      ON

DLT DATE     DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
            142.0   143.2   147.0  160.00   240.0   260.0   300.0   310.0

DLT MAX    DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
              8.0     5.0     5.0     5.0     5.0     5.0     5.0    10.0

DLT FRN      DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
             0.25    0.50    0.10    0.50    0.25    0.25    0.25     0.5

DLT LIMI     VISC    CELC
WB 1           ON      ON

BRANCH G       US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE  SLOPEC
BR1             2      82       0       0       0       0       1  0.0037  0.0037

LOCATION      LAT    LONG    EBOT      BS      BE    JBDN
WB 1        40.49   75.40   249.5       1       1       1

INIT CND      T2I    ICEI  WTYPEC   GRIDC
WB 1        11.63   0.000   FRESH    RECT

CALCULAT      VBC     EBC     MBC     PQC     EVC     PRC
WB 1          OFF     OFF     OFF      ON     OFF     OFF

DEAD SEA    WINDC    QINC   QOUTC   HEATC
WB 1           ON      ON      ON      ON

INTERPOL   QINIC   DTRIC    HDIC
BR1            ON     OFF     OFF

HEAT EXCH   SLHTC    SROC  RHEVAP   METIC  FETCHC     AFW     BFW     CFW   WINDH
                                   Page 1
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                                   w2_con
  PSU W2 Model Version 3.7

TITLE C ..............................TITLE..WY 02...............................
        1 Lehigh River -- WB3 only
        2 Initial Setup
        3 VERSION 3.7
        4
        5 Scenario run Selective with wet year
        6 WY02_run03_V37 --08-18-12-- same as run01
        7 Verification run using qin/tin from wb2
        8 Default hydraulic and kinetic coefficients:
        9 Tammy L. Threadgill:
        10

GRID          NWB     NBR     IMX     KMX   NPROC  CLOSEC
                1       1      91     179       1     OFF

IN/OUTFL      NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
                3       0       0       0       0       1       0       0

CONSTITU      NCG     NSS     NAL     NEP    NBOD     NMC     NZP
                3       1       2       0       1       0       0

MISCELL      NDAY  SELECTC HABTATC ENVIRPC AERATEC INITUWL
              100     OFF      ON     OFF     OFF      ON

TIME CON   TMSTRT   TMEND    YEAR
          142.300 277.000    2002

DLT CON       NDT  DLTMIN DLTINTR
                8 0.40000      ON

DLT DATE     DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
            142.3   150.0  160.00   200.0   240.0   258.0   261.0   310.0

DLT MAX    DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
              0.5     0.5     1.0     1.0     1.0     1.0     1.0     1.0    10.0


DLT FRN      DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
             0.10    0.50    0.50    0.50    0.50    0.50    0.50     0.5     0.5

DLT LIMI     VISC    CELC
WB 1           ON      ON

BRANCH G       US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE  SLOPEC
BR1             2      90       0       0       0       0       1  0.0038  0.0038

LOCATION      LAT    LONG    EBOT      BS      BE    JBDN
WB 1        40.49   75.40   149.5       1       1       1

INIT CND      T2I    ICEI  WTYPEC   GRIDC
WB 1        13.20   0.000   FRESH    RECT

CALCULAT      VBC     EBC     MBC     PQC     EVC     PRC
WB 1          OFF     OFF     OFF      ON     OFF     OFF

DEAD SEA    WINDC    QINC   QOUTC   HEATC
WB 1           ON      ON      ON      ON

INTERPOL    QINIC   DTRIC    HDIC
BR1            ON     OFF     OFF

                                   Page 1
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                                    w2_con
  PSU W2 Model Version 3.7

TITLE C ..............................TITLE..WY 02................................
        1 Lower 2 branches of Lehigh River (WB4)
        2 Initial Setup
        3 VERSION 3.7
        4 Animation - no adjustments - extra tsr files
        5 adjusted sp height from 75.8 to 76.1;TSEDF= 0.5;shade=0.9
        6 WY02_run04_V37 - 08/19/12 - same as run02 but V3.7
        7 Verification run: new qin/tin files from wb3
        8 Default hydraulic and kinetic coeff;
        9 Tammy L. Threadgill
        10

GRID          NWB     NBR     IMX     KMX   NPROC  CLOSEC
                1       2     173     179       1     OFF

IN/OUTFL      NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
                5       0       0       0       0       1       0       0

CONSTITU      NCG     NSS     NAL     NEP    NBOD     NMC     NZP
                3       1       2       0       1       0       0

MISCELL      NDAY SELECTC HABTATC ENVIRPC AERATEC INITUWL
              100     OFF      ON     OFF     OFF      ON

TIME CON   TMSTRT   TMEND    YEAR
          142.500 276.500    2002

DLT CON       NDT  DLTMIN DLTINTR
                8 0.10000      ON

DLT DATE     DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
            142.0   143.0   148.5   153.0   162.0   170.0   265.0   272.0

DLT MAX    DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
              8.0     5.0     8.0     8.0     8.0     8.0     8.0     8.0     1.0

DLT FRN      DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
             0.25    0.50    0.10    0.25    0.10    0.25    0.25    0.25     0.5

DLT LIMI     VISC    CELC
WB 1           ON      ON

BRANCH G       US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE  SLOPEC
BR1             2      52       0      55       0       0       1  0.0022  0.0022
BR2            55     172      52       0       0       0       1  0.0015  0.0015

LOCATION      LAT    LONG    EBOT      BS      BE    JBDN
WB 1        40.49   75.40    75.7       1       2       2

INIT CND      T2I    ICEI  WTYPEC   GRIDC
WB 1        11.20   0.000   FRESH    RECT

CALCULAT      VBC     EBC     MBC     PQC     EVC     PRC
WB 1          OFF     OFF     OFF      ON     OFF     OFF

DEAD SEA    WINDC    QINC   QOUTC   HEATC
WB 1           ON      ON      ON      ON

INTERPOL    QINIC   DTRIC    HDIC
BR1            ON     OFF     OFF
BR2            ON     OFF     OFF
                                    Page 1
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                                        w2_con
  PSU W2 Model Version 3.6

TITLE C ..............................TITLE..WY 02...............................
         1 Beltzville Reservoir + Pohopoco River
         2 Initial Setup
         3 VERSION 3.6
         4
         5
         6 WY02_run03_wq -- 09/22/10 -- Run01 with some shading over lower Pohopoco
         7   Verification 2002: Add flood gate flood (NSTR=3 instead of 2)
         8 Default hydraulic and kinetic coefficients: vpr file used (1/16/09)
         9 Tammy L. Threadgill
        10

GRID         NWB     NBR     IMX     KMX   NPROC  CLOSEC
               2       3      60     179       1     OFF

IN/OUTFL     NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
               0       3       0       0       0       1       0       0

CONSTITU     NCG     NSS     NAL     NEP    NBOD     NMC     NZP
               3       1       2       0       1       0       0

MISCELL     NDAY
             100

TIME CON  TMSTRT   TMEND    YEAR
         142.400 277.000    2002

DLT CON      NDT  DLTMIN
              10 0.50000

DLT DATE    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
           121.0   142.0   143.5   160.0   224.0   230.0   240.0   256.0   260.0
           310.0

DLT MAX   DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
             1.0     0.5     5.0     5.0     5.0     1.0     5.0     1.0     5.0
             5.0

DLT FRN     DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
            0.10    0.50    0.50    0.50    0.50    0.50    0.50     0.5     0.5
            0.50

DLT LIMI    VISC    CELC
WB 1          ON      ON
WB 2          ON      ON

BRANCH G      US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE
BR1            2      12       0       0       0       0       1  0.0000
BR2           15      19     -12      22       0       0       1  0.0012
BR3           22      59      19       0       0       0       1  0.0014

LOCATION     LAT    LONG    EBOT      BS      BE    JBDN
WB 1       40.64   79.62   152.2       1       1       1
WB 2       40.49   75.40  128.50       2       3       3

INIT CND     T2I    ICEI  WTYPEC
WB 1       -1.00   0.000   FRESH
WB 2       11.05   0.000   FRESH

CALCULAT     VBC     EBC     MBC     PQC     EVC     PRC
WB 1         OFF     OFF     OFF      ON     OFF     OFF
                                       Page 1
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PH  PSU W2 Model Version 3.7

TITLE C ..............................TITLE..WY
03................................
        1 Walter + Lehigh River WB1 only
        2 Initial Setup
        3 VERSION 3.7
        4
        5 animation
        6 WY03_run08: SLHTC = ET for WB2 ; PONIT>LINE;BC seg 9>8
        7 Verification 2003: no distributed tributaries
        8 Default hydraulic and kinetic coefficients:TSEDF=0.5;BETA=0.25
        9 Tammy L. Threadgill; Select With top=2 instead of 20
        10 same as V3.7 run07 - spr dates changed

GRID         NWB     NBR     IMX     KMX   NPROC  CLOSEC
               2       4      43     179       1     OFF

IN/OUTFL     NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
               0       1       0       1       0       1       0       0

CONSTITU     NCG     NSS     NAL     NEP    NBOD     NMC     NZP
               3       1       2       0       1       0       0

MISCELL     NDAY SELECTC HABTATC ENVIRPC AERATEC INITUWL
             100     OFF      ON     OFF     OFF      ON

TIME CON  TMSTRT   TMEND    YEAR
         135.500 272.500    2003

DLT CON      NDT  DLTMIN DLTINTR
              11 0.10000      ON

DLT DATE    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
DLTD
           135.5   137.0   141.0   148.0   171.0  178.00   200.0   230.0
245.0
           265.5  275.00

DLT MAX   DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
DLTMAX
             0.5     8.0     1.0     8.0     1.0     5.0     3.0     8.0
3.0
             1.0     5.0

DLT FRN     DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
DLTF
            0.25    0.25    0.10    0.25    0.10    0.10    0.25    0.10
0.25
            0.10    0.25

DLT LIMI    VISC    CELC
WB 1          ON      ON
WB 2          ON      ON

BRANCH G      US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE
SLOPEC
BR1            2       9       0       0       0       0       1    0.00
0.000
BR2           12      13       0       8       0       0       1    0.00
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                                        w2_con
  PSU W2 Model Version 3.7

TITLE C ..............................TITLE..WY 03..............................
        1 Lehigh River -- WB2 only
        2 Initial Setup
        3 VERSION 3.7
        4
        5 New qwo_seg9 and Two_seg9 input files from sc2 Selective with
        6 WY03_run03_100710: shading 0.60;Man N adj; ALK ave 12 value for BC
        7  Verification run for 2003: new qin&tin - TSEDF 0.5;BETA=0.25
        8 Default hydraulic and kinetic coefficients: TSED 10 to 14
        9 Tammy L. Threadgill
        10 Same as run02 but V3.7

GRID          NWB     NBR     IMX     KMX   NPROC  CLOSEC
                1       1      83     179       1     OFF

IN/OUTFL      NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
                2       0       0       0       0       1       0       0

CONSTITU      NCG     NSS     NAL     NEP    NBOD     NMC     NZP
                3       1       2       0       1       0       0

MISCELL      NDAY SELECTC HABTATC ENVIRPC AERATEC INITUWL
              100     OFF      ON     OFF     OFF      ON

TIME CON   TMSTRT   TMEND    YEAR
          135.500 272.500    2003

DLT CON       NDT  DLTMIN DLTINTR
                8 0.40000      ON

DLT DATE     DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
            121.0   172.0   173.0  200.00   240.0   260.0   300.0   310.0

DLT MAX    DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
              8.0     8.0     8.0     8.0     8.0     8.0     8.0    10.0

DLT FRN      DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
             0.25    0.25    0.25    0.25    0.25    0.25    0.25     0.5

DLT LIMI     VISC    CELC
WB 1           ON      ON

BRANCH G       US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE  SLOPEC
BR1             2      82       0       0       0       0       1  0.0037  0.0037

LOCATION      LAT    LONG    EBOT      BS      BE    JBDN
WB 1        40.49   75.40   249.5       1       1       1

INIT CND      T2I    ICEI  WTYPEC   GRIDC
WB 1        20.20   0.000   FRESH    RECT

CALCULAT      VBC     EBC     MBC     PQC     EVC     PRC
WB 1          OFF     OFF     OFF      ON     OFF     OFF

DEAD SEA    WINDC    QINC   QOUTC   HEATC
WB 1           ON      ON      ON      ON

INTERPOL   QINIC   DTRIC    HDIC
BR1           ON     OFF     OFF

HEAT EXCH   SLHTC    SROC  RHEVAP   METIC  FETCHC     AFW     BFW     CFW   WINDH
                                        Page 1
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                                   w2_con
  PSU W2 Model Version 3.7

TITLE C ..............................TITLE..WY 03...............................
        1 Lehigh River -- WB3 only
        2 Initial Setup
        3 VERSION 3.7
        4
        5 Scenario run Selective with wet year
        6 WY03_run04_100710 --10/16/08-- run03 : shd=0.6
        7 Verification run using qin/tin from wb2 : Alk ave 12 instead of 1
        8 Default hydraulic and kinetic coefficients: took out first two tribs
        9 Tammy L. Threadgill: Adjusted DLT MAX at day 259 1.0>0.5
        10 Same as run03 but V3.7

GRID          NWB     NBR     IMX     KMX   NPROC  CLOSEC
                1       1      91     179       1     OFF

IN/OUTFL      NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
                3       0       0       0       0       1       0       0

CONSTITU      NCG     NSS     NAL     NEP    NBOD     NMC     NZP
                3       1       2       0       1       0       0

MISCELL      NDAY SELECTC HABTATC ENVIRPC AERATEC INITUWL
              100     OFF      ON     OFF     OFF      ON

TIME CON   TMSTRT   TMEND    YEAR
          135.500 272.000    2003

DLT CON       NDT  DLTMIN DLTINTR
                8 0.10000     OFF

DLT DATE     DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
            121.0   123.0   185.0  200.00   240.0   258.0   261.0   310.0

DLT MAX    DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
              1.0     5.0     5.0     1.0     1.0     0.5     1.0    10.0

DLT FRN      DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
             0.10    0.10    0.50    0.50    0.50    0.10    0.10     0.5

DLT LIMI     VISC    CELC
WB 1           ON      ON

BRANCH G       US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE  SLOPEC
BR1             2      90       0       0       0       0       1  0.0038  0.0038

LOCATION      LAT    LONG    EBOT      BS      BE    JBDN
WB 1        40.49   75.40   149.5       1       1       1

INIT CND      T2I    ICEI  WTYPEC   GRIDC
WB 1        13.20   0.000   FRESH    RECT

CALCULAT      VBC     EBC     MBC     PQC     EVC     PRC
WB 1          OFF     OFF     OFF      ON     OFF     OFF

DEAD SEA    WINDC    QINC   QOUTC   HEATC
WB 1           ON      ON      ON      ON

INTERPOL   QINIC    DTRIC    HDIC
BR1           ON      OFF     OFF

HEAT EXCH   SLHTC    SROC  RHEVAP   METIC  FETCHC     AFW     BFW     CFW   WINDH
                                   Page 1
```

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                                          w2_con
  PSU W2 Model Version 3.7

TITLE C ..............................TITLE..WY 03................................
        1 Lower 2 branches of Lehigh River (WB4)
        2 Initial Setup
        3 VERSION 3.7
        4 Animation - no adjustments
        5 adjusted sp height from 75.8 to 76.1;TSEDF= 0.5;shade=0.9
        6 WY03_run04 - 06/13/10 - new up stream conditions
        7 Verification run:
        8 Default hydraulic and kinetic coeff;
        9 Tammy L. Threadgill
        10 SAme as run03 but w/ V3.7 and DLTMAX modified at 265

GRID          NWB     NBR     IMX     KMX   NPROC  CLOSEC
                1       2     173     179       1     OFF

IN/OUTFL      NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
                5       0       0       0       0       1       0       0

CONSTITU      NCG     NSS     NAL     NEP    NBOD     NMC     NZP
                3       1       2       0       1       0       0

MISCELL      NDAY SELECTC HABTATC ENVIRPC AERATEC INITUWL
              100     OFF      ON     OFF     OFF      ON

TIME CON   TMSTRT   TMEND    YEAR
          135.500 271.500    2003

DLT CON       NDT  DLTMIN DLTINTR
                9 0.10000      ON

DLT DATE     DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
            121.0   122.0   136.5   150.0   180.0   195.0   210.0   265.0   272.0

DLT MAX    DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
              8.0     8.0     5.0     8.0     8.0     8.0     8.0     5.0     1.0

DLT FRN      DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
             0.25    0.25    0.50    0.10    0.25    0.25    0.10    0.10     0.5

DLT LIMI     VISC    CELC
WB 1           ON      ON

BRANCH G       US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE  SLOPEC
BR1             2      52       0      55       0       0       1  0.0022  0.0022
BR2            55     172      52       0       0       0       1  0.0015  0.0015

LOCATION      LAT    LONG    EBOT      BS      BE    JBDN
WB 1        40.49   75.40    75.7       1       2       2

INIT CND      T2I    ICEI  WTYPEC   GRIDC
WB 1        11.20   0.000   FRESH    RECT

CALCULAT      VBC     EBC     MBC     PQC     EVC     PRC
WB 1          OFF     OFF     OFF      ON     OFF     OFF

DEAD SEA    WINDC    QINC   QOUTC   HEATC
WB 1           ON      ON      ON      ON

INTERPOL   QINIC   DTRIC    HDIC
BR1           ON     OFF     OFF
BR2           ON     OFF     OFF
                                          Page 1
```

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  PSU W2 Model Version 3.7

TITLE C ................................TITLE..WY
03..................................
        1 Beltsville Reservoir + Pohopoco River
        2 Initial Setup
        3 VERSION 3.7
        4
        5
        6 WY03_run02_wq -- 01/16/09 -- Run03 with some shading over
lower Pohopoco
        7   Verification 2003: Add flood gate flood (NSTR=3 instead of
2)
        8 Default hydraulic and kinetic coefficients: vpr file used
(1/16/09)
        9 Tammy L. Threadgill
        10

GRID          NWB     NBR     IMX     KMX   NPROC  CLOSEC
                2       3      60     179       1     OFF

IN/OUTFL      NTR     NST     NIW     NWD     NGT     NSP     NPI     NPU
                0       3       0       0       0       1       0       0

CONSTITU      NCG     NSS     NAL     NEP    NBOD     NMC     NZP
                3       1       2       0       1       0       0

MISCELL      NDAY  SELECTC HABTATC ENVIRPC AERATEC INITUWL
              100     OFF      ON     OFF     OFF     OFF

TIME CON  TMSTRT   TMEND    YEAR
         135.500 273.000    2003

DLT CON       NDT  DLTMIN DLTINTR
                7 0.10000      ON

DLT DATE     DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
DLTD
            121.0   122.0   140.0   160.0   224.0   275.0   310.0

DLT MAX    DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
DLTMAX
              1.0     5.0     5.0     5.0     5.0     5.0     5.0

DLT FRN      DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
DLTF
             0.10    0.25    0.50    0.50    0.50    0.50    0.50

DLT LIMI     VISC    CELC
WB 1           ON      ON
WB 2           ON      ON

BRANCH G       US      DS     UHS     DHS     UQB     DQB   NLMIN   SLOPE
BR1             2      12       0       0       0       0       1  0.0000
BR2            15      19     -12      22       0       0       1  0.0012
BR3            22      59      19       0       0       0       1  0.0014

LOCATION      LAT    LONG    EBOT      BS      BE    JBDN
WB 1        40.64   79.62   152.2       1       1       1
WB 2        40.49   75.40  128.50       2       3       3
```
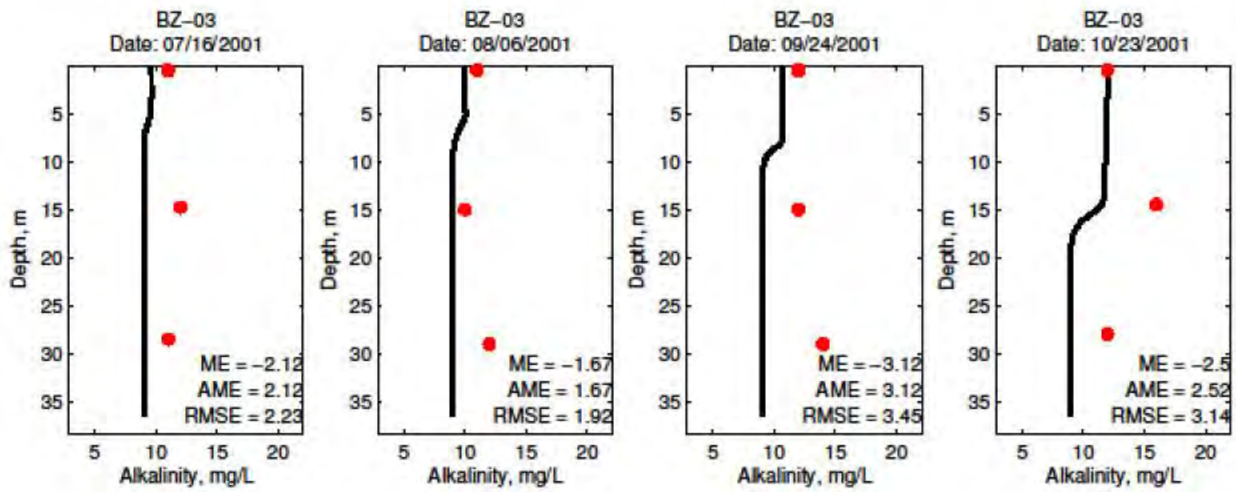
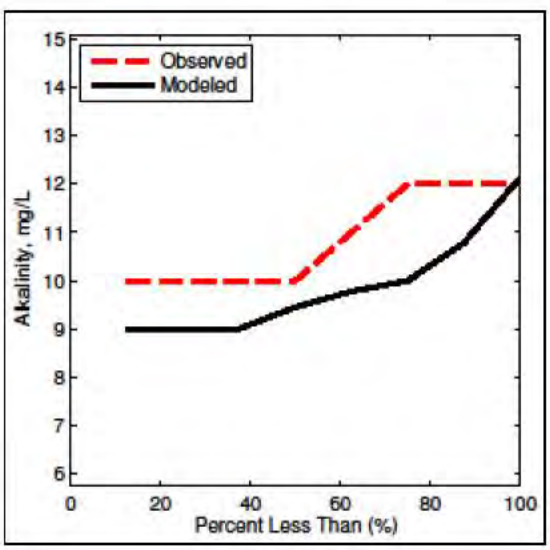
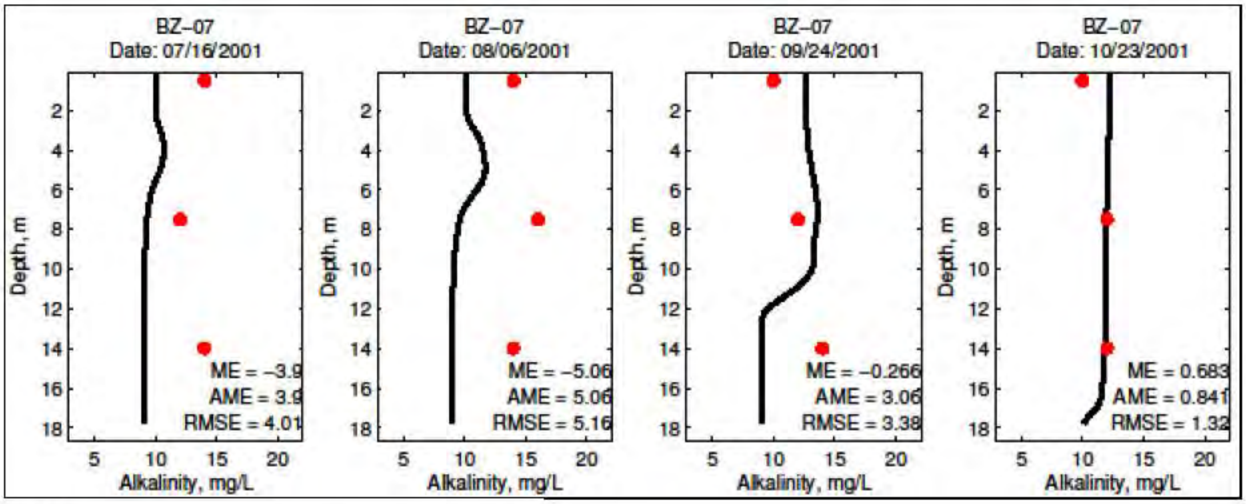
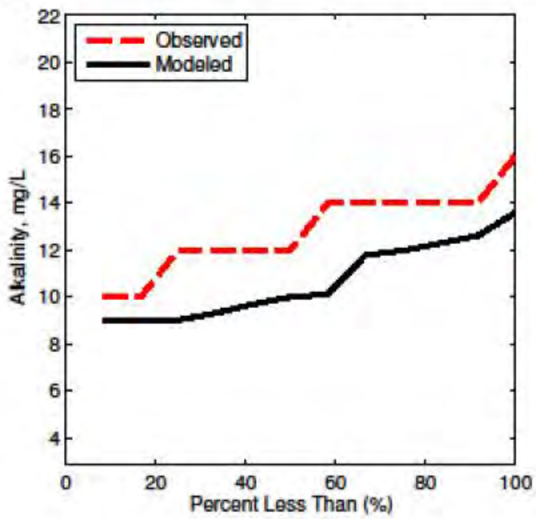
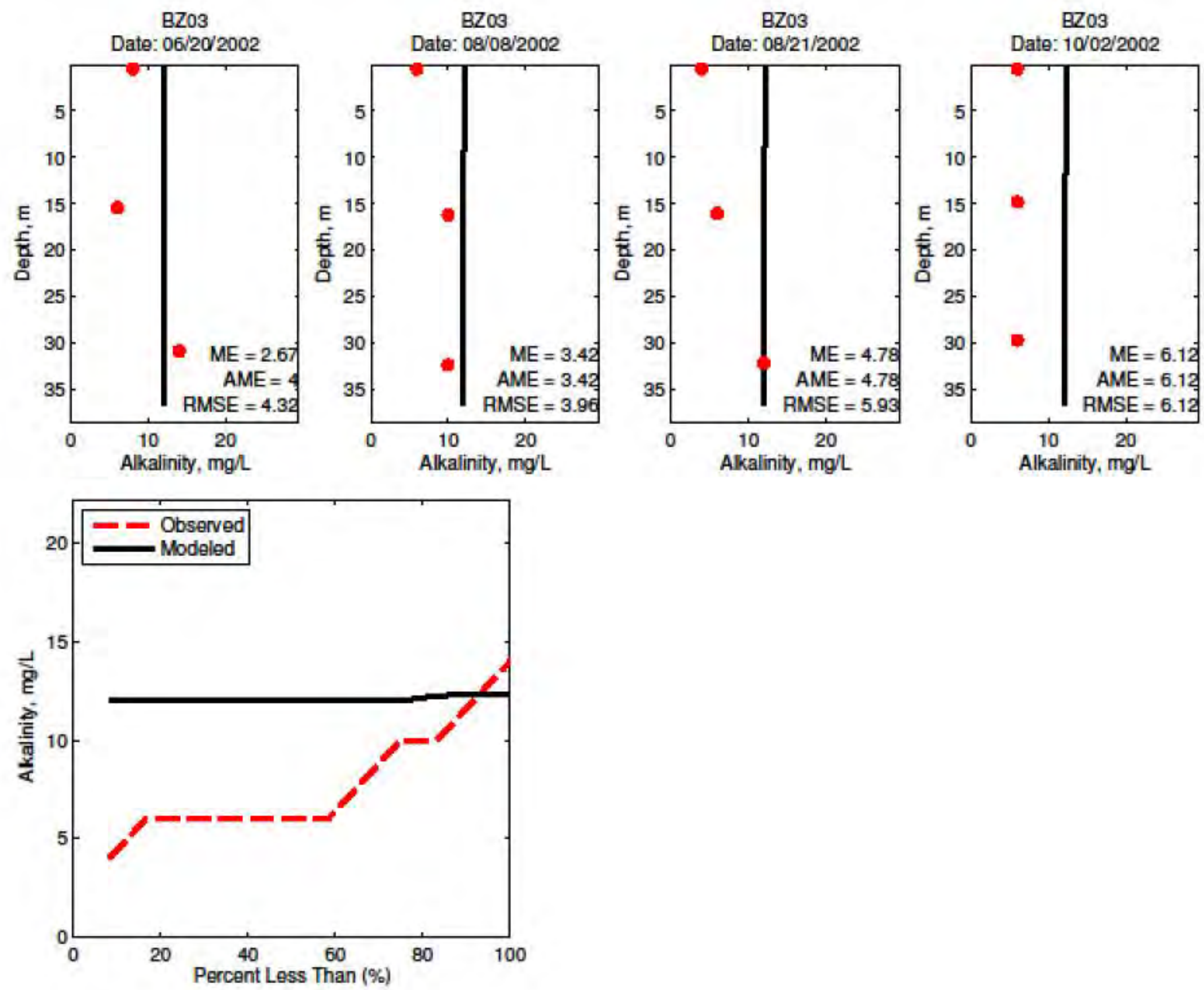

Appendix D: Additional Water Quality Calibration Results for 2001, 2003, and 2002

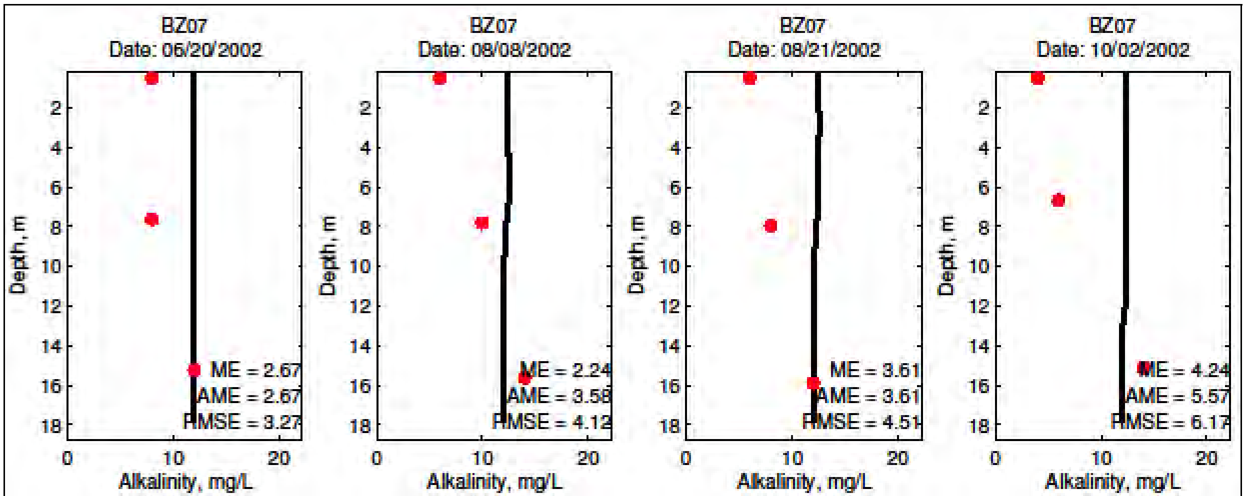




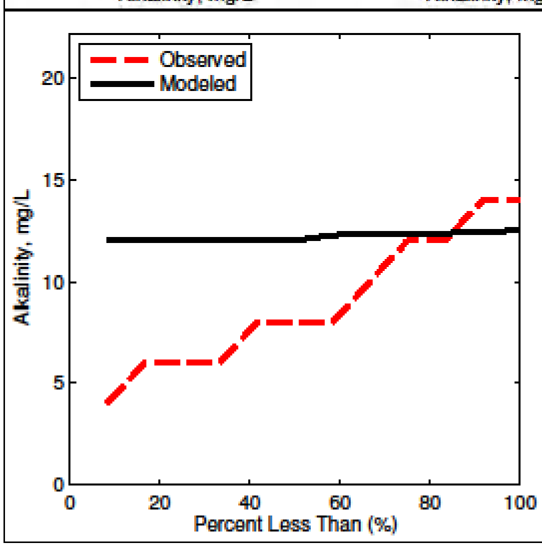

BZ–07
Date: 07/16/2001
ME = −3.9
AME = 3.9
RMSE = 4.01
BZ–07
Date: 08/06/2001
ME = −5.06
AME = 5.06
RMSE = 5.16
BZ–07
Date: 09/24/2001
ME = −0.266
AME = 3.06
RMSE = 3.38
BZ–07
Date: 10/23/2001
ME = 0.683
AME = 0.841
RMSE = 1.32
Depth, m
Alkalinity, mg/L


Observed
Modeled
Alkalinity, mg/L
Percent Less Than (%)

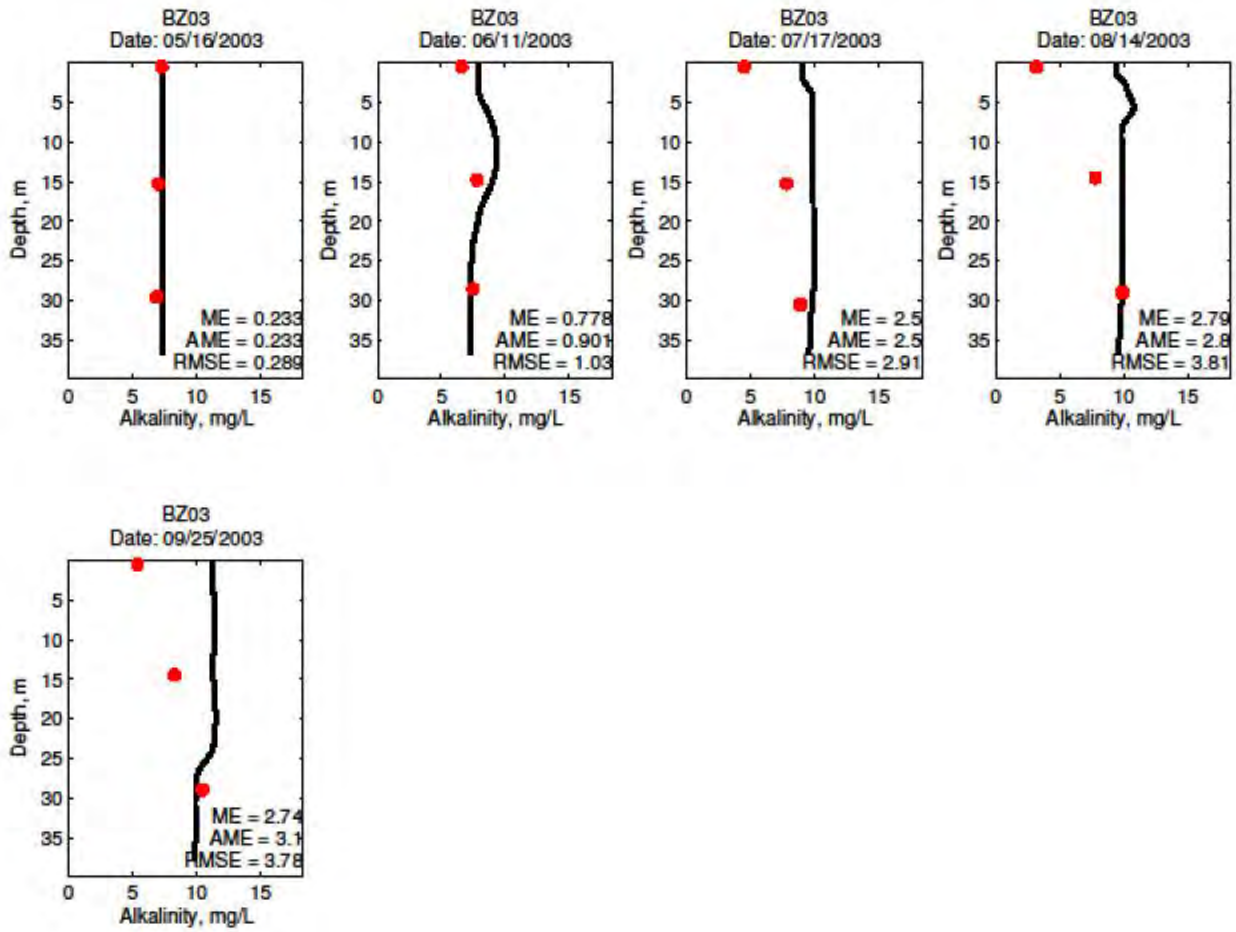

BZ03
Date: 06/20/2002
ME = 2.67
AME = 4
RMSE = 4.32
BZ03
Date: 08/08/2002
ME = 3.42
AME = 3.42
RMSE = 3.96
BZ03
Date: 08/21/2002
ME = 4.78
AME = 4.78
RMSE = 5.93
BZ03
Date: 10/02/2002
ME = 6.12
AME = 6.12
RMSE = 6.12
Depth, m
Alkalinity, mg/L
Observed
Modeled
Percent Less Than (%)

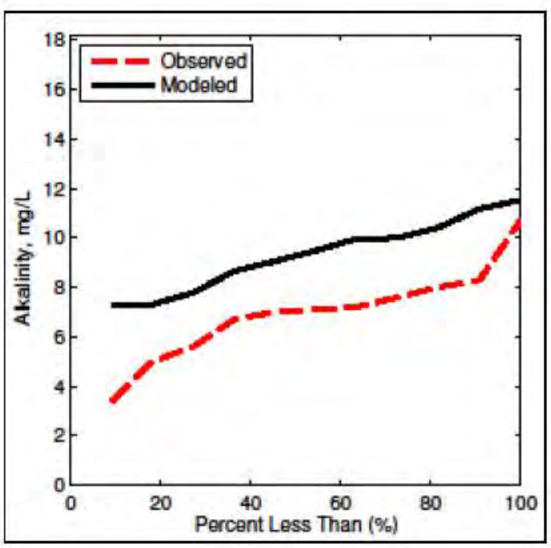


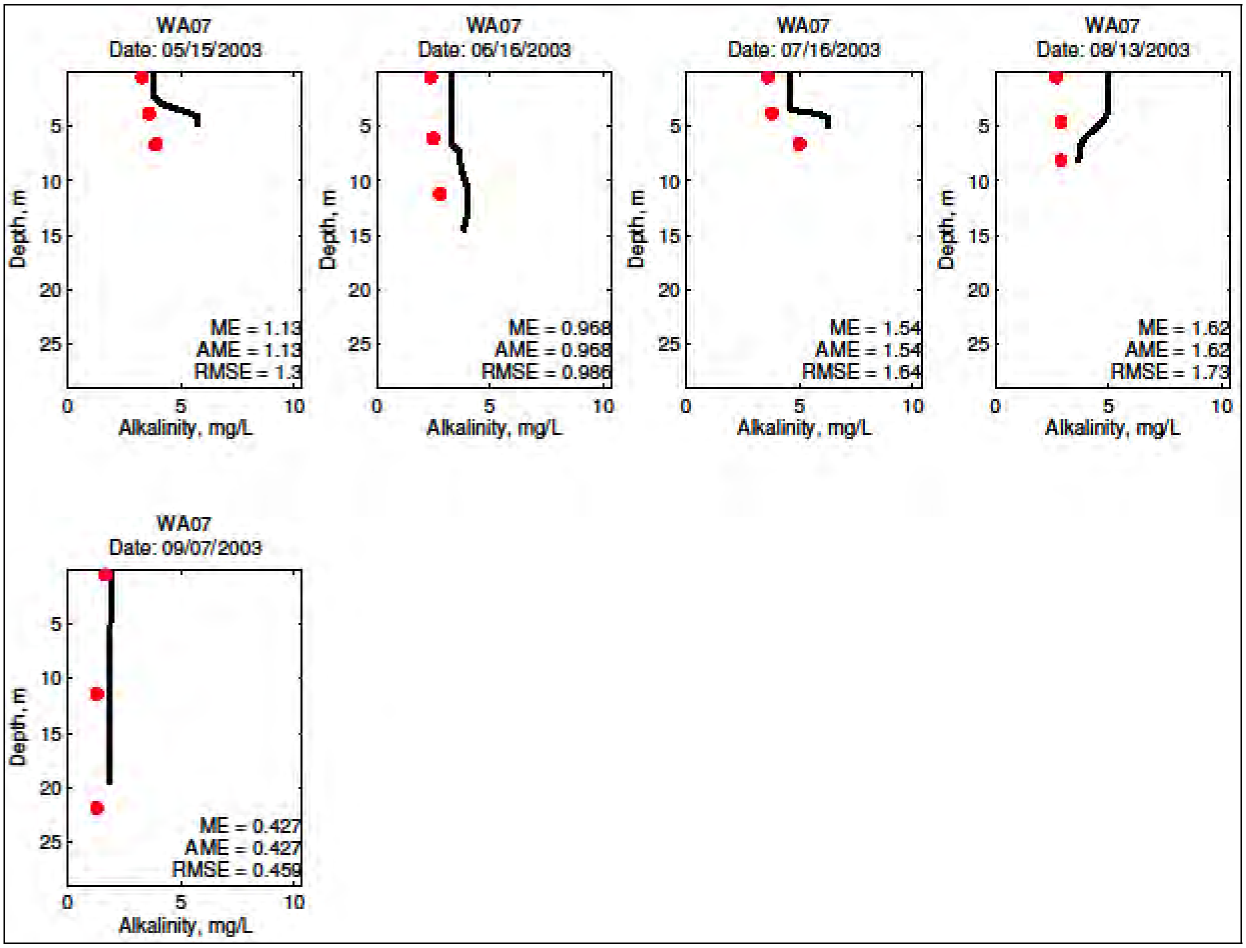
BZ07
Date: 06/20/2002
ME = 2.67
AME = 2.67
RMSE = 3.27
BZ07
Date: 08/08/2002
ME = 2.24
AME = 3.58
RMSE = 4.12
BZ07
Date: 08/21/2002
ME = 3.61
AME = 3.61
RMSE = 4.51
BZ07
Date: 10/02/2002
ME = 4.24
AME = 5.57
RMSE = 6.17
Depth, m
Alkalinity, mg/L

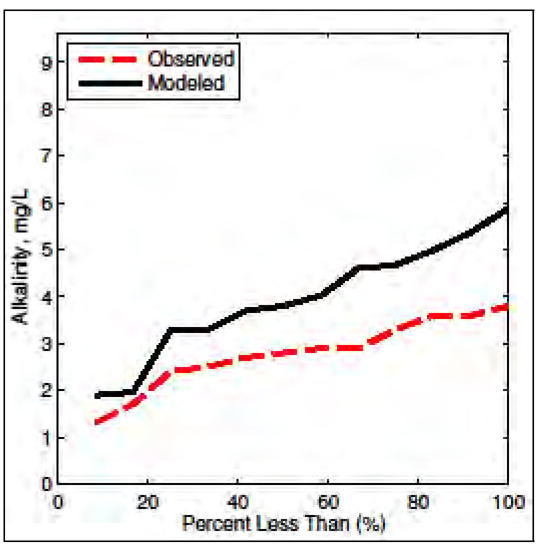


Observed
Modeled
Alkalinity, mg/L
Percent Less Than (%)


BZ03
Date: 05/16/2003
ME = 0.233
AME = 0.233
RMSE = 0.289
BZ03
Date: 06/11/2003
ME = 0.778
AME = 0.901
RMSE = 1.03
BZ03
Date: 07/17/2003
ME = 2.5
AME = 2.5
RMSE = 2.91
BZ03
Date: 08/14/2003
ME = 2.79
AME = 2.8
RMSE = 3.81
BZ03
Date: 09/25/2003
ME = 2.74
AME = 3.1
RMSE = 3.78
Depth, m
Alkalinity, mg/L


Observed
Modeled
Alkalinity, mg/L
Percent Less Than (%)


WA07
Date: 05/15/2003
ME = 1.13
AME = 1.13
RMSE = 1.3
WA07
Date: 06/16/2003
ME = 0.968
AME = 0.968
RMSE = 0.986
WA07
Date: 07/16/2003
ME = 1.54
AME = 1.54
RMSE = 1.64
WA07
Date: 08/13/2003
ME = 1.62
AME = 1.62
RMSE = 1.73
WA07
Date: 09/07/2003
ME = 0.427
AME = 0.427
RMSE = 0.459
Depth, m
Alkalinity, mg/L


Observed
Modeled
Alkalinity, mg/L
Percent Less Than (%)

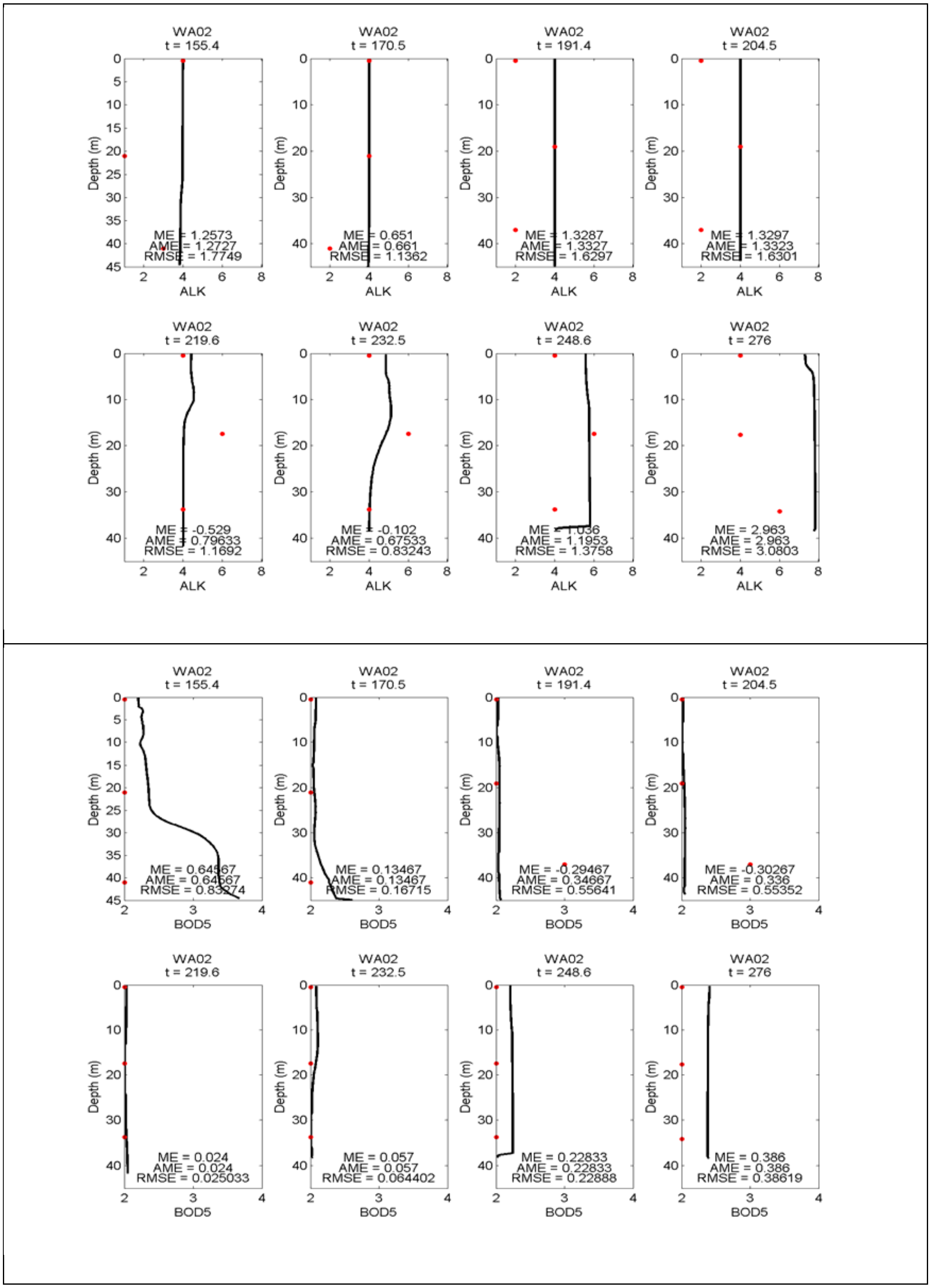


Figure D-1. 2002 Calibration profile results for Alk and BOD at station WA02 at F. E. Walter for 8 Julian dates.

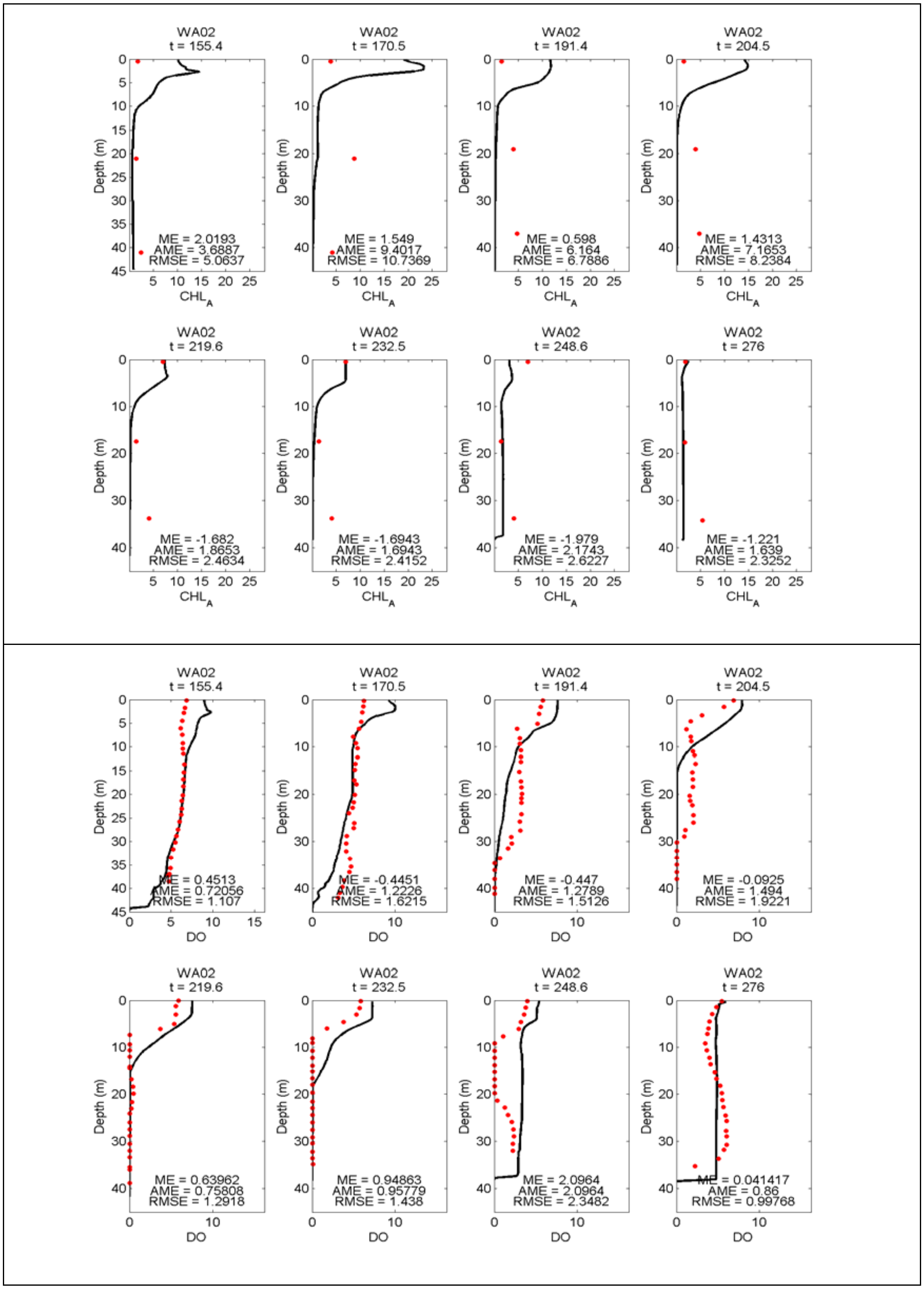


Figure D-2. 2002 Calibration profile results for Chla and DO at station WA02 at F. E. Walter for 8 Julian dates.

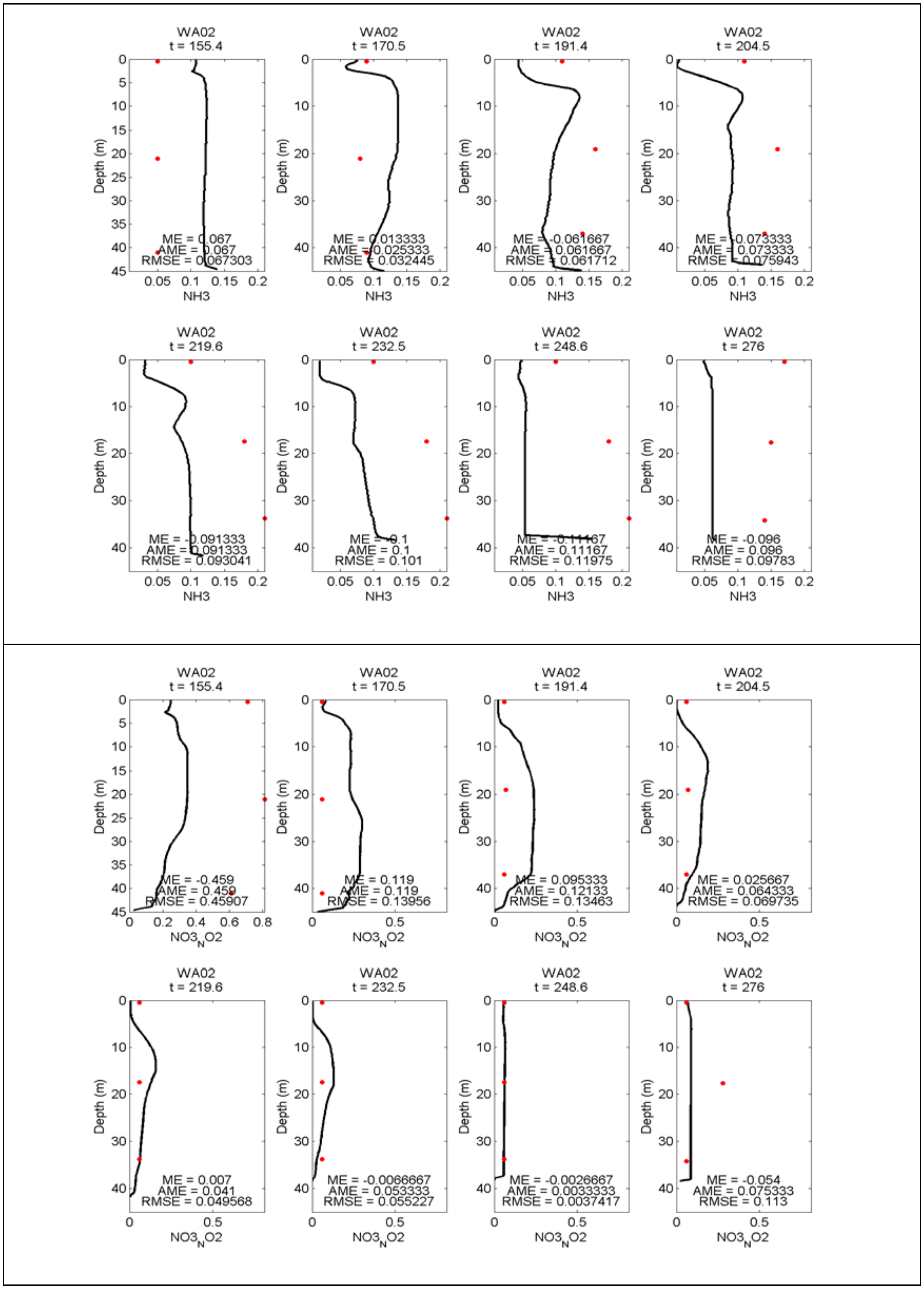


Figure D-3. 2002 Calibration profile results for NH3 and NO2+NO3 at station WA02 at F. E. Walter for 8 Julian dates.

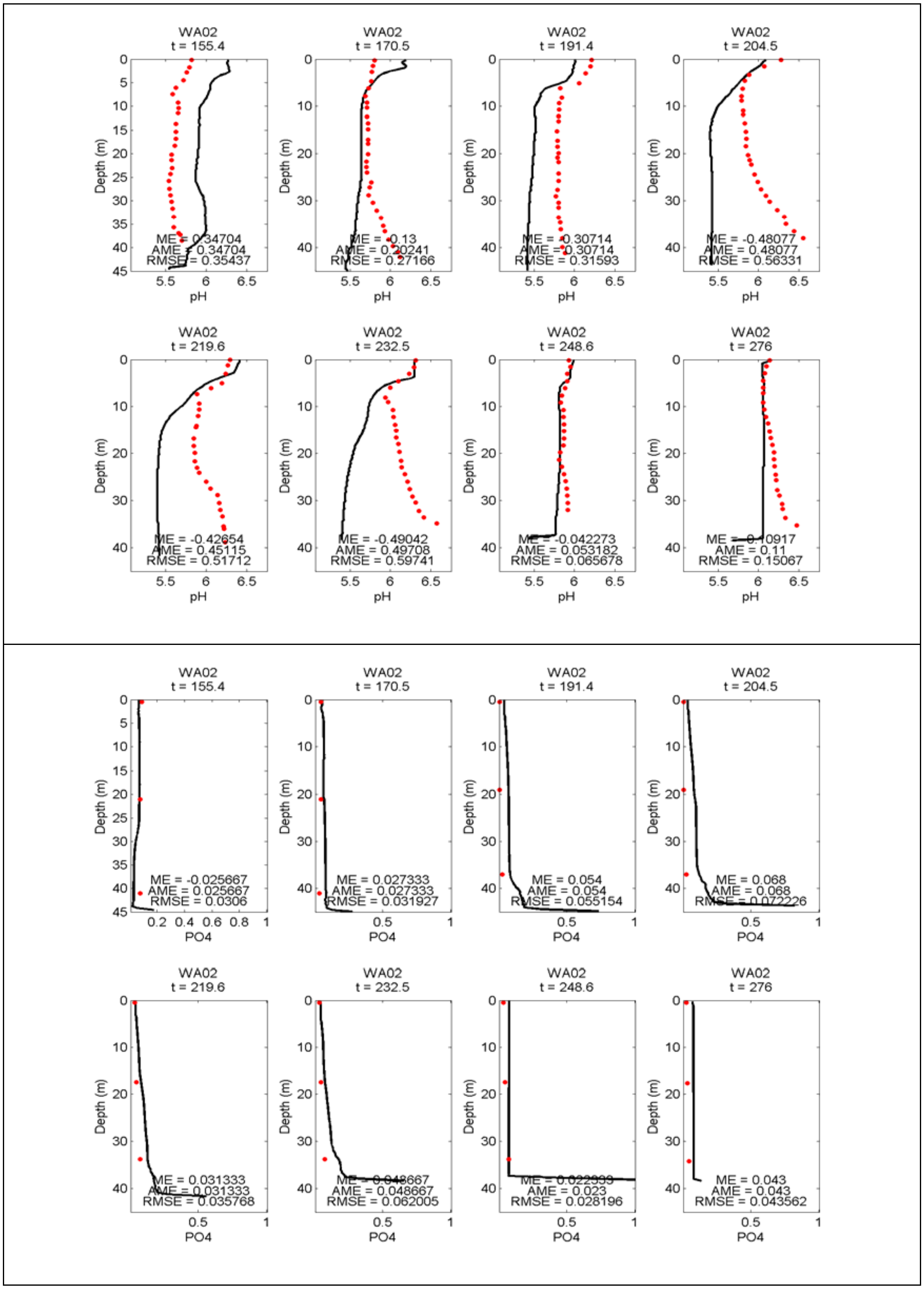


Figure D-4. 2002 Calibration profile results for pH and PO4 at station WA02 at F. E. Walter for 8 Julian dates.

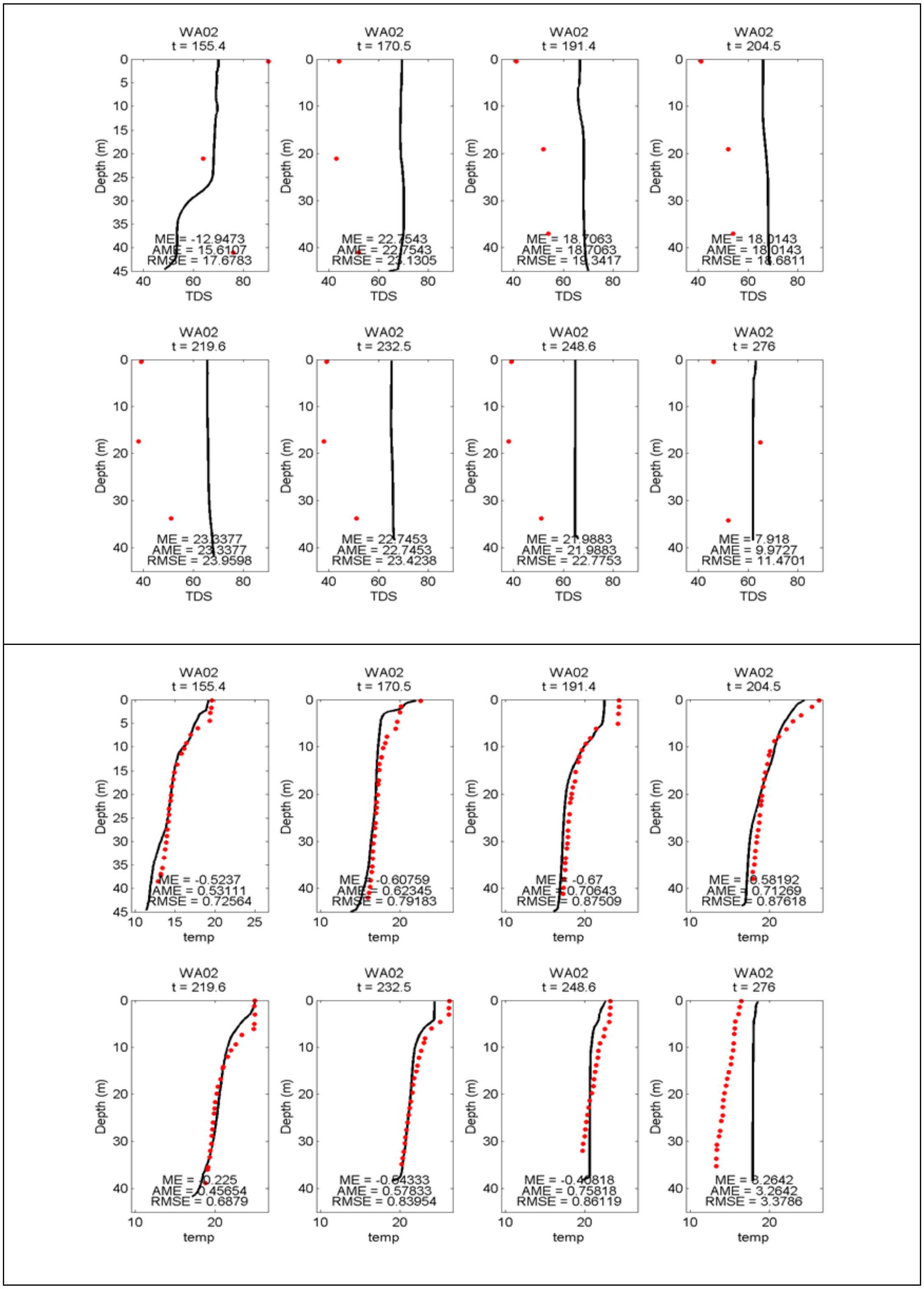


Figure D-5. 2002 Calibration profile results for TDS and temperature at station WA02 at F. E. Walter for 8 Julian dates.

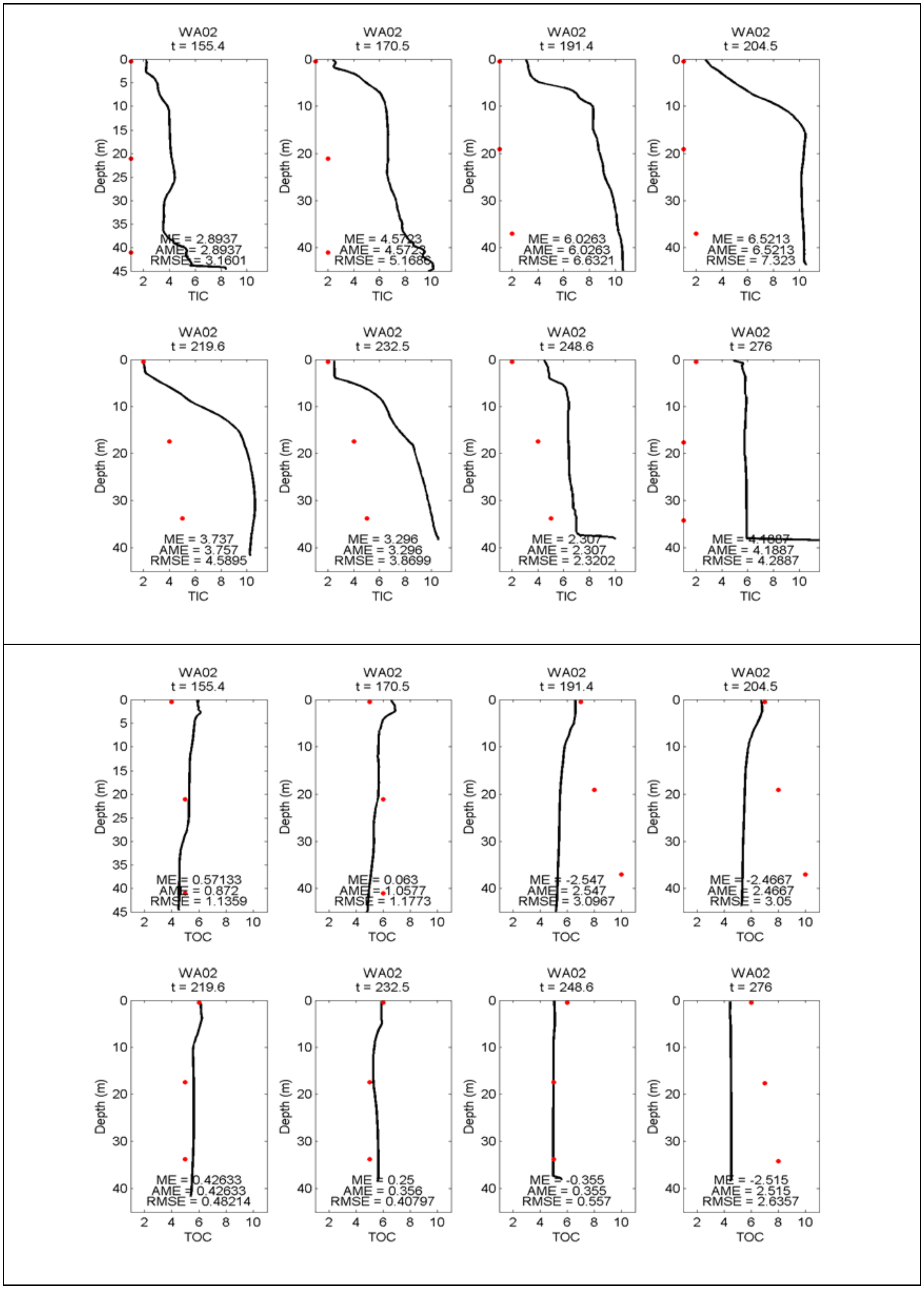
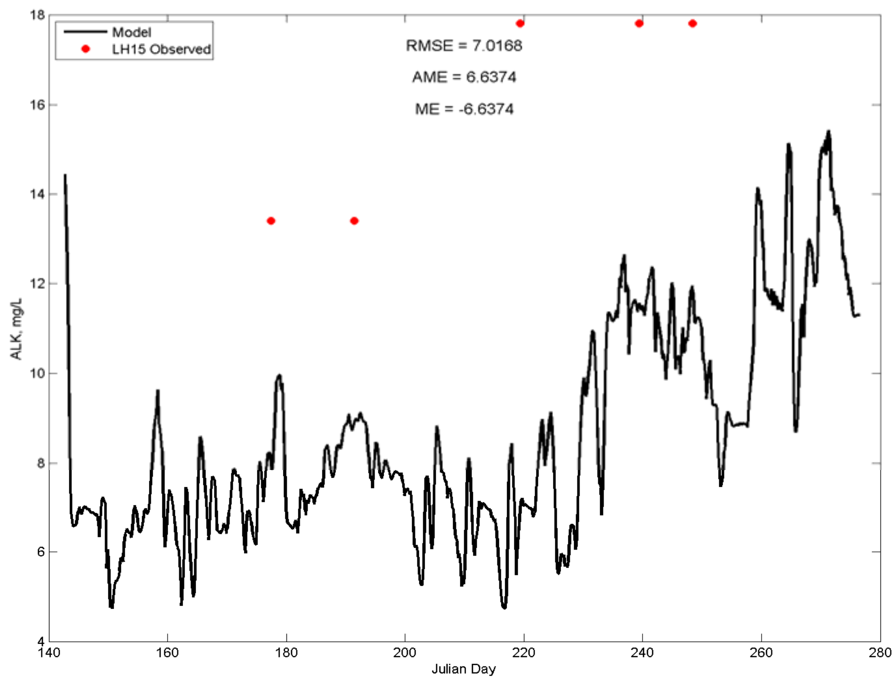


Figure D-6. 2002 Calibration profile results for TIC and TOC at station WA02 at F. E. Walter for 8 Julian dates.



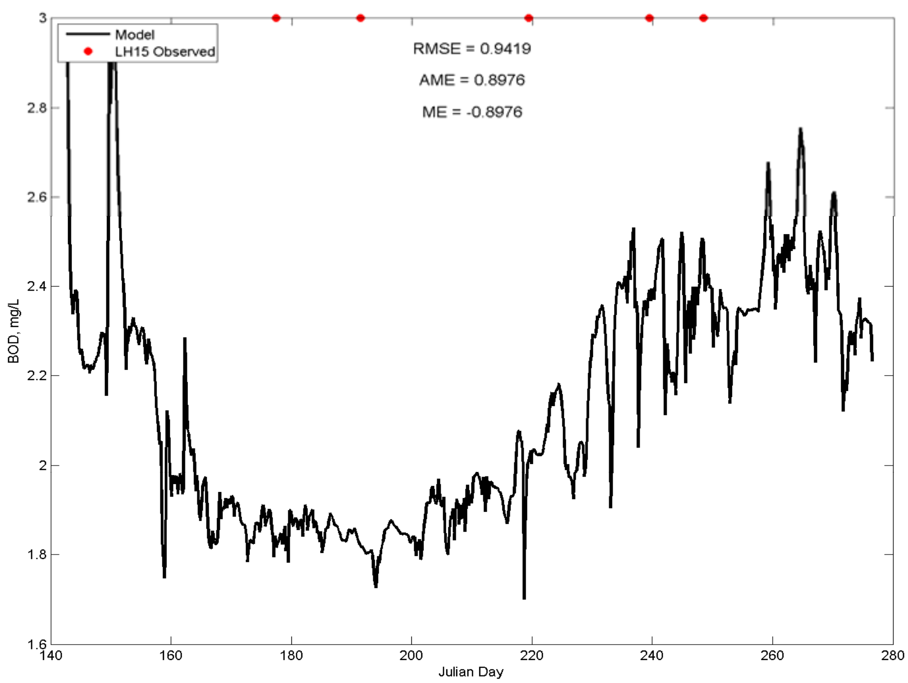


Figure D-7. 2002 Calibration results for Alkalinity and BOD at LH15.

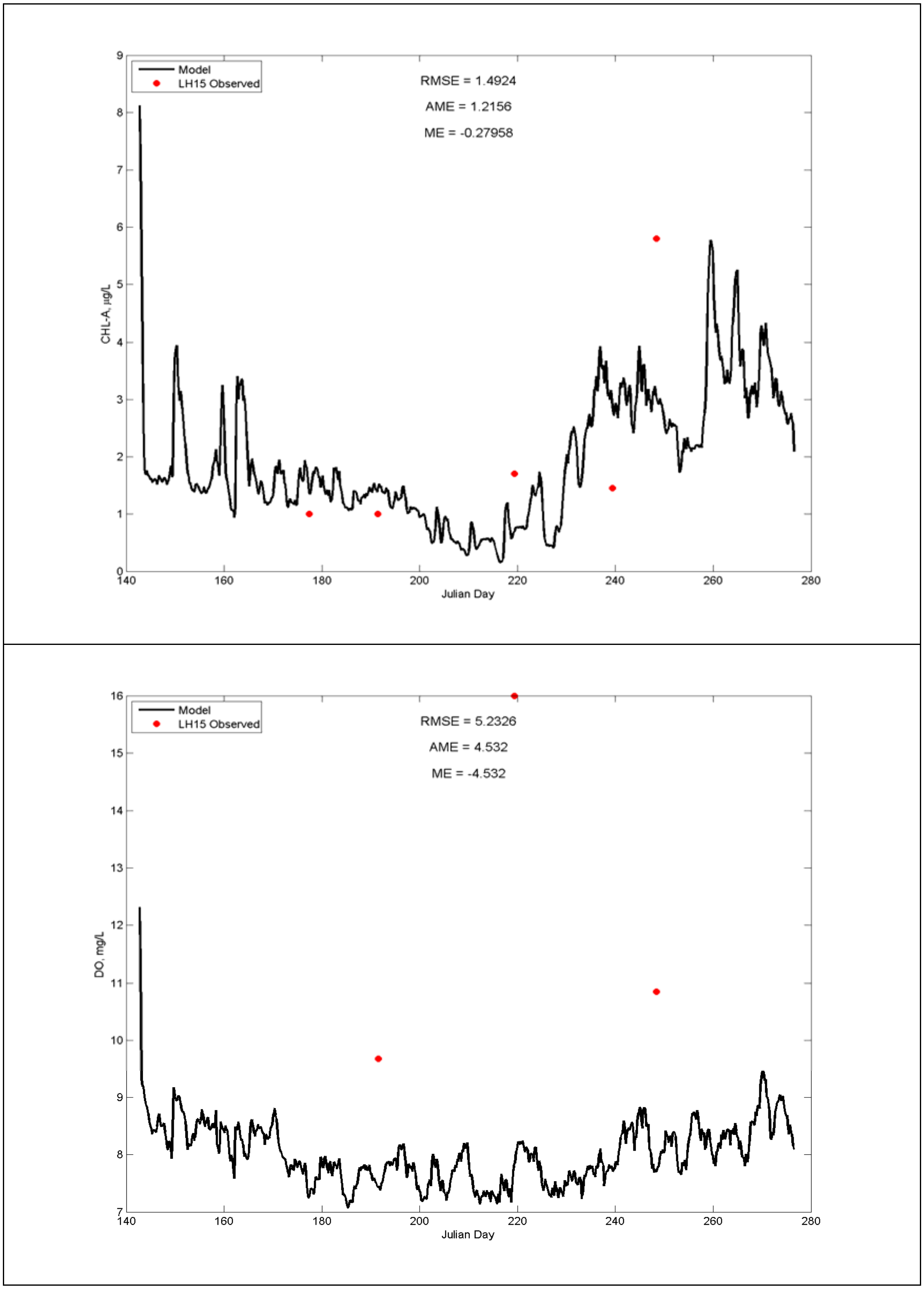


Figure D-8. 2002 Calibration results for Chla and DO at LH15.

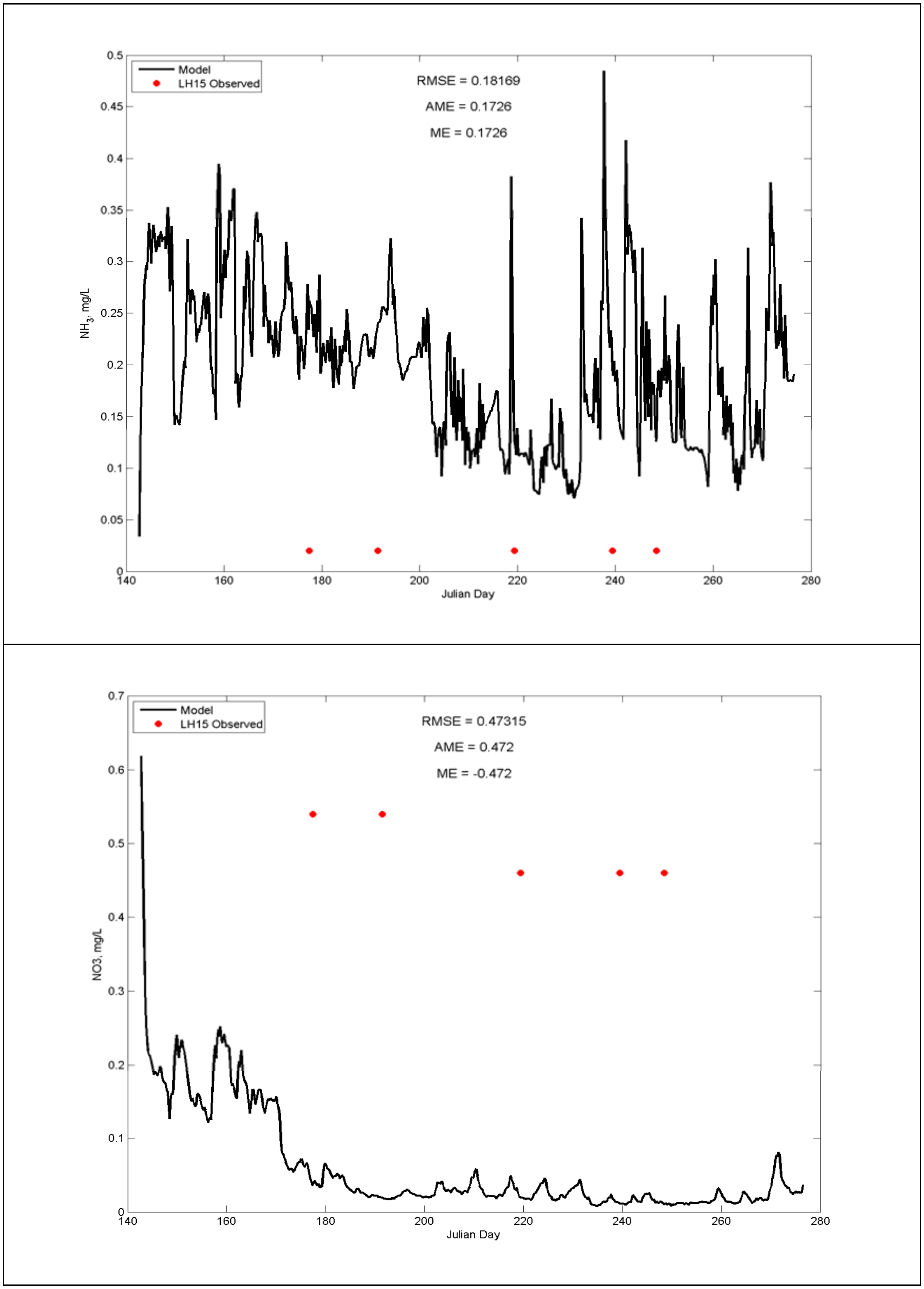
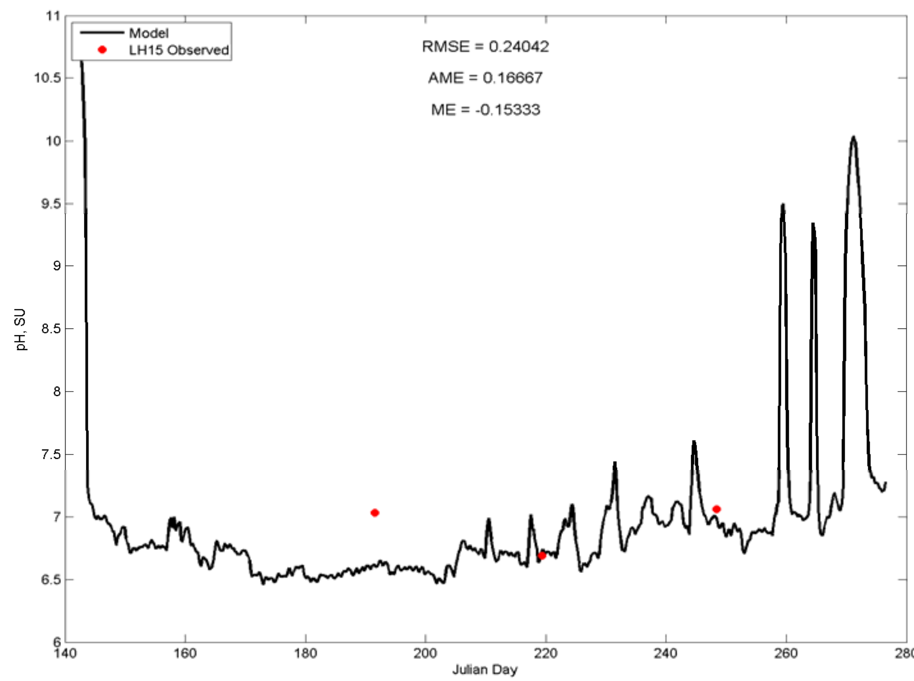


Figure D-9. 2002 Calibration results for NH3 and NO3 at LH15.



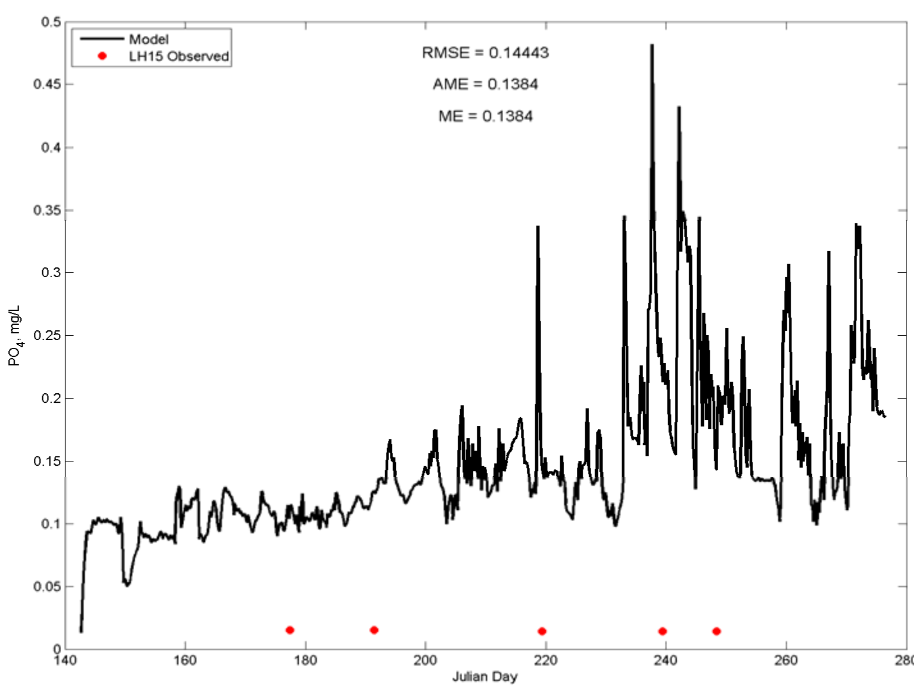
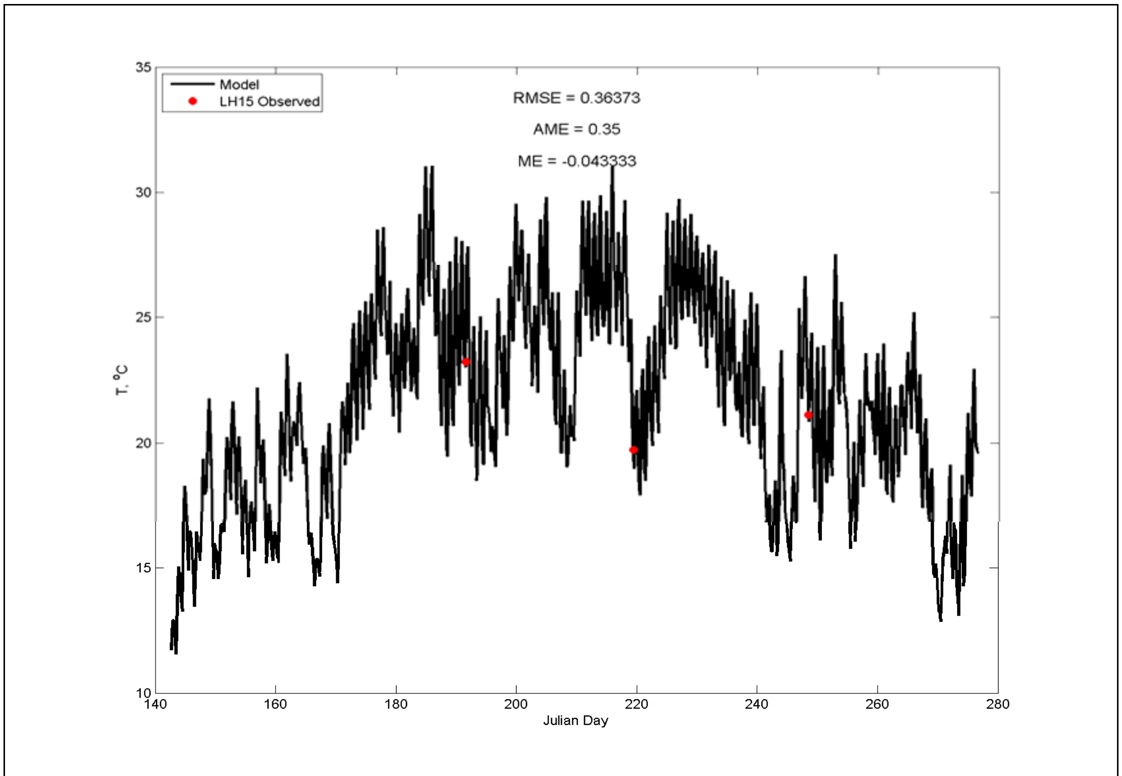


Figure D-10. 2002 Calibration results for pH and PO4 at LH15.



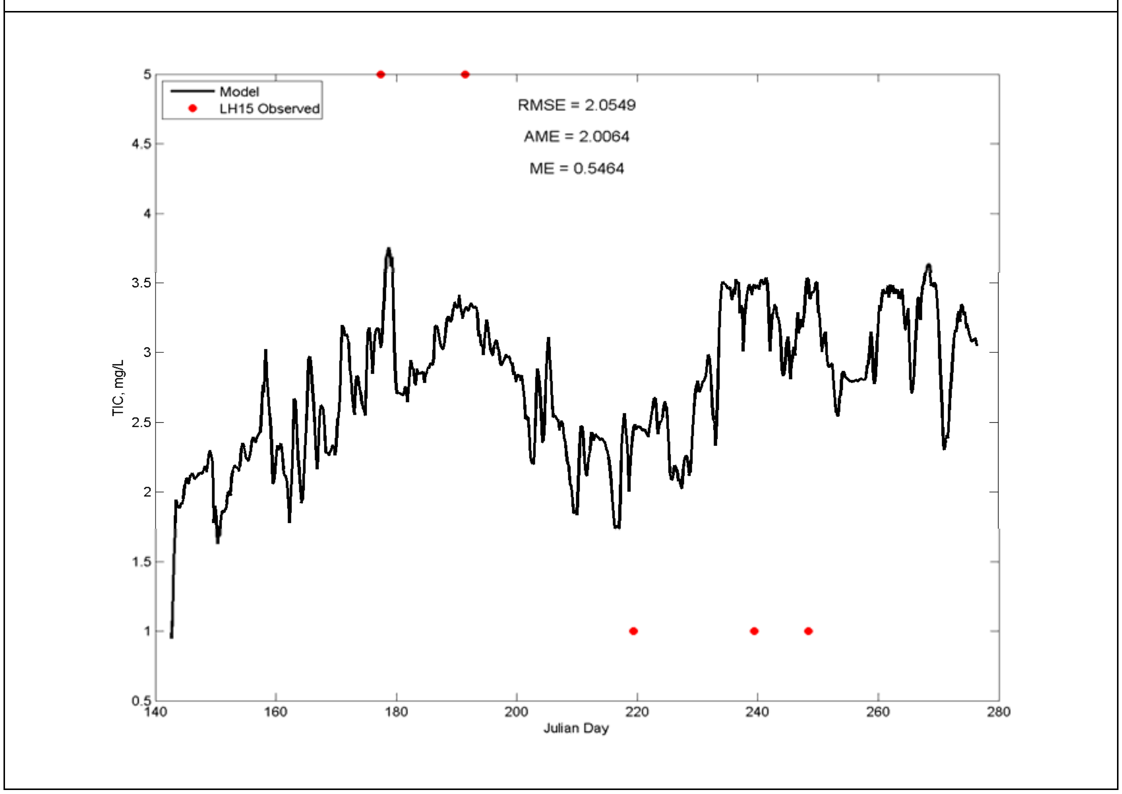


Figure D-11. 2002 Calibration results for T2 and TIC at LH15.

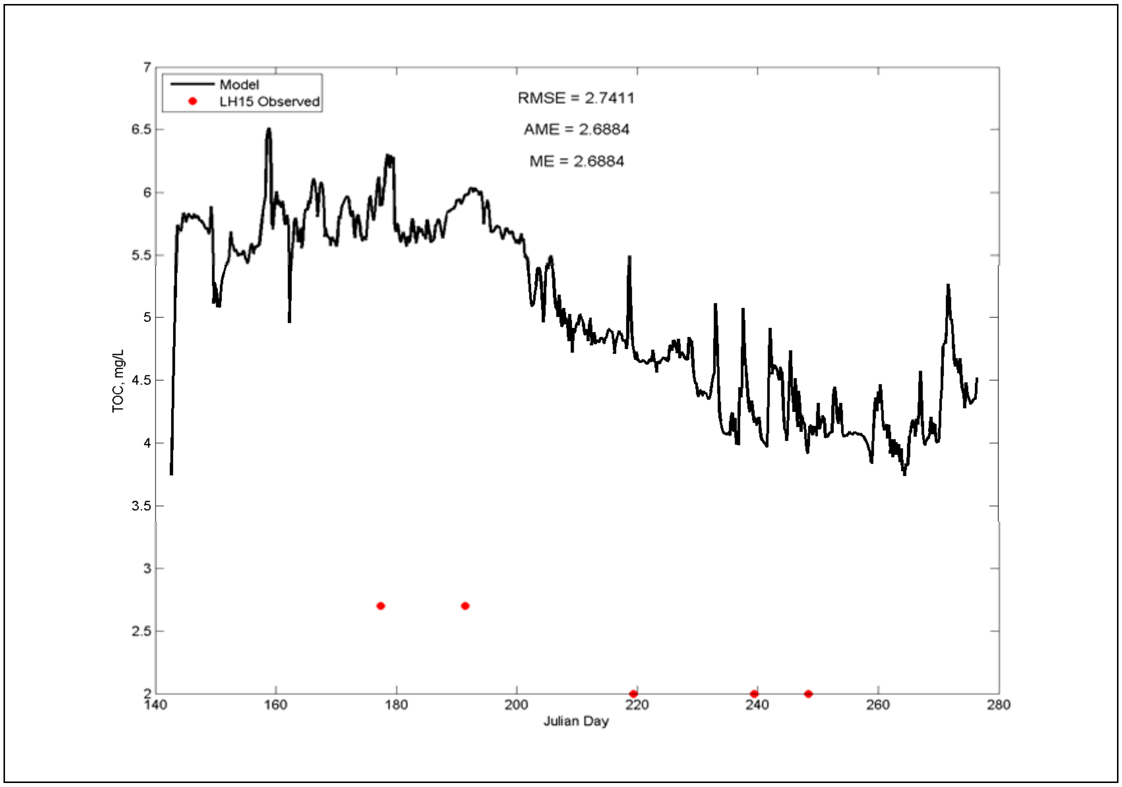


Figure D-12. 2002 Calibration results for TOC at LH15.

Appendix E: Metal Results for 2001

Table E-1. Observed metals data at stations on the Lehigh River used for model set up.

STATION	TIME	DATE	AL	CD	FE	MN	ZN
LH2	15:15	5/30/2001	0.12	0.005	0.292	0.065	0.016
LH3	14:18	5/30/2001	0.11	0.005	0.249	0.069	0.013
LH6	13:23	5/30/2001	0.17	0.005	0.23	0.08	0.01
LH7	12:42	5/30/2001	0.19	0.005	0.273	0.087	0.028
LH8	12:02	5/30/2001	0.22	0.005	0.184	0.082	0.017
LH10	11:24	5/30/2001	0.24	0.005	0.304	0.111	0.024
LH14	9:29	5/30/2001	0.23	0.005	0.297	0.105	0.025
LH17	7:16	5/31/2001	0.25	0.005	0.342	0.113	0.08
LH2	7:53	6/21/2001	0.16	0.005	0.227	0.101	0.005
LH3	6:24	6/21/2001	0.14	0.005	0.232	0.063	0.005
LH6	16:48	6/20/2001	1.26	0.005	0.237	0.54	0.158
LH7	16:11	6/20/2001	0.81	0.005	0.225	0.404	0.116
LH8	15:34	6/20/2001	0.26	0.005	0.23	0.077	0.005
LH10	12:49	6/20/2001	0.26	0.005	0.246	0.084	0.005
LH14	10:50	6/20/2001	0.35	0.005	0.435	0.121	0.072
LH17	9:18	6/20/2001	0.29	0.005	0.331	0.097	0.047
LH2	17:51	8/20/2001	0.02	0.005	0.139	0.112	0.005
LH3	15:49	8/20/2001	0.02	0.005	0.005	0.041	0.005
LH6	14:36	8/20/2001	4.74	0.005	0.005	1	0.276
continued							

Table E-1. Concluded

STATION	TIME	DATE	AL	CD	FE	MN	ZN
LH7	14:00	8/20/2001	1.64	0.005	0.005	0.584	0.057
LH8	13:28	8/20/2001	0.38	0.005	0.005	0.207	0.005
LH10	12:00	8/20/2001	0.06	0.005	0.005	0.196	0.005
LH14	10:51	8/20/2001	0.08	0.005	0.005	0.13	0.771
LH17	9:30	8/20/2001	0.02	0.005	0.005	0.095	0.005
LH2	17:34	9/13/2001	0.14	0.005	0.037	0.026	0.034
LH3	14:55	9/12/2001	0.13	0.005	0.037	0.034	0.01
LH6	14:07	9/12/2001	0.02	0.005	0.095	0.036	0.005
LH7	13:31	9/12/2001	0.06	0.005	0.282	0.095	0.026
LH8	12:59	9/12/2001	0.14	0.005	0.028	0.062	0.015
LH10	11:44	9/12/2001	0.13	0.005	0.025	0.078	0.027
LH14	10:07	9/12/2001	0.03	0.005	0.008	0.008	0.009
LH17	9:01	9/12/2001	0.02	0.005	0.053	0.023	0.005

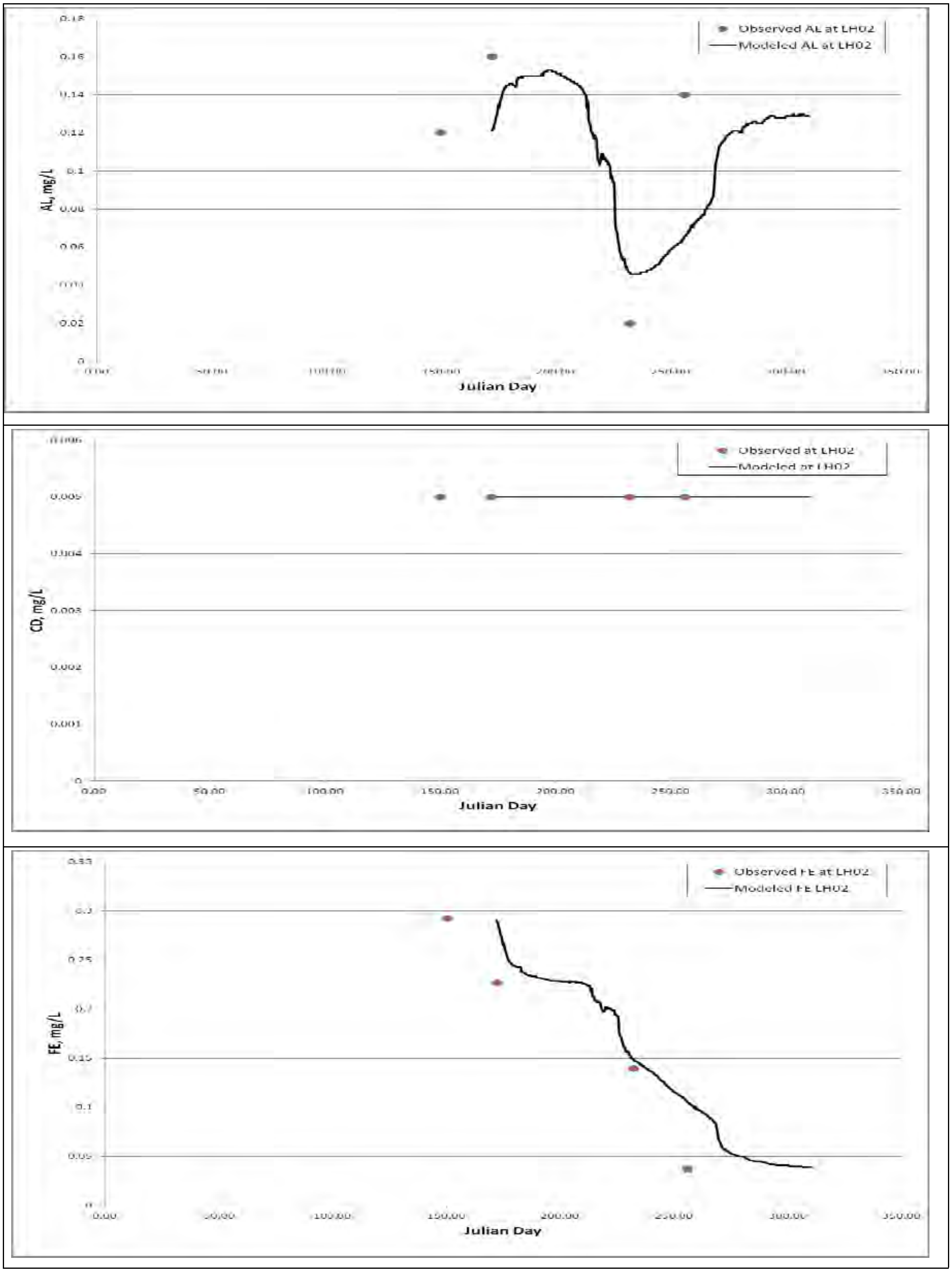


Figure E-1. 2001 Metals results at LH02 for AL, CD, FE

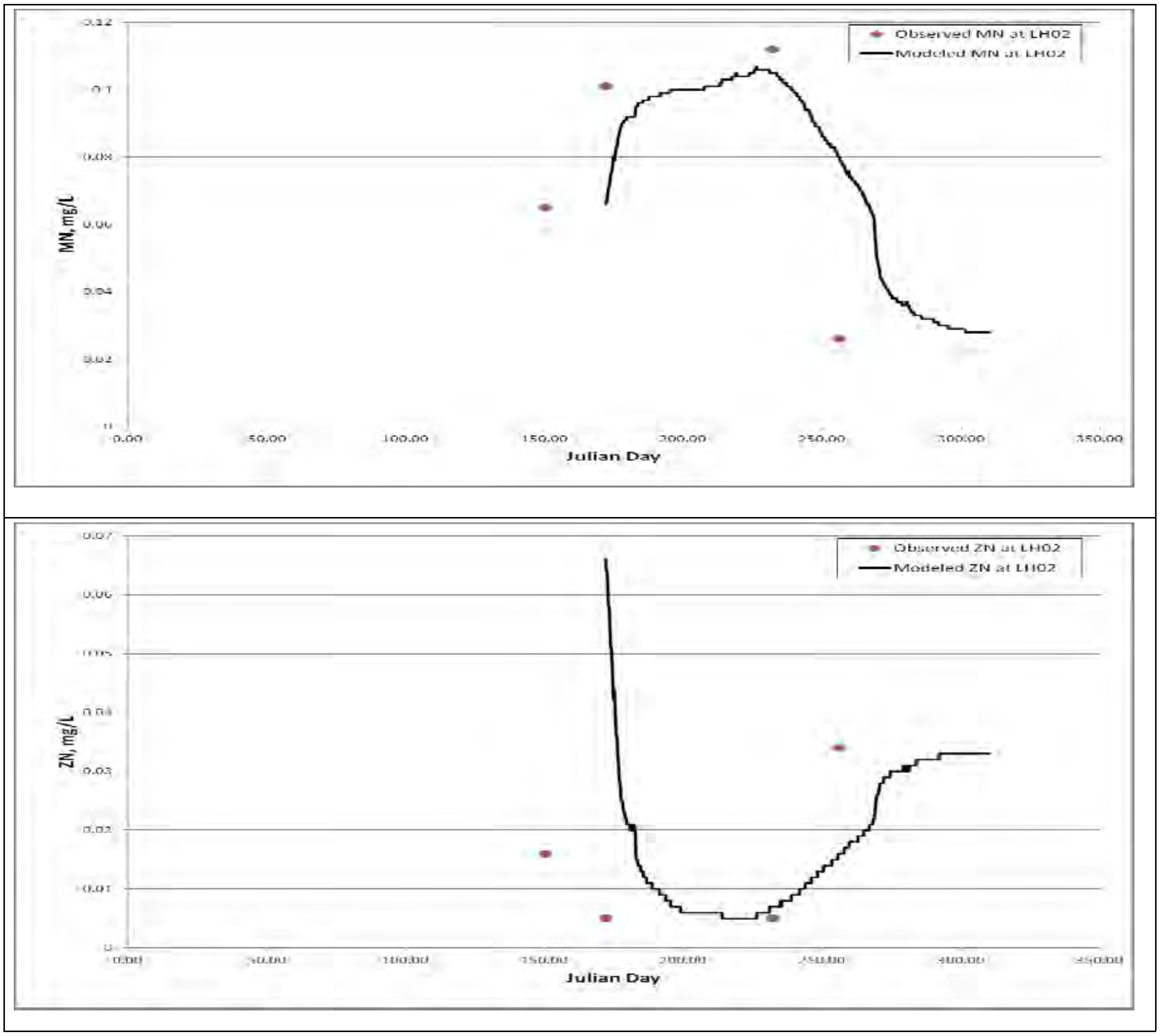


Figure E-2. 2001 Metals results at LH02 for MN an ZN

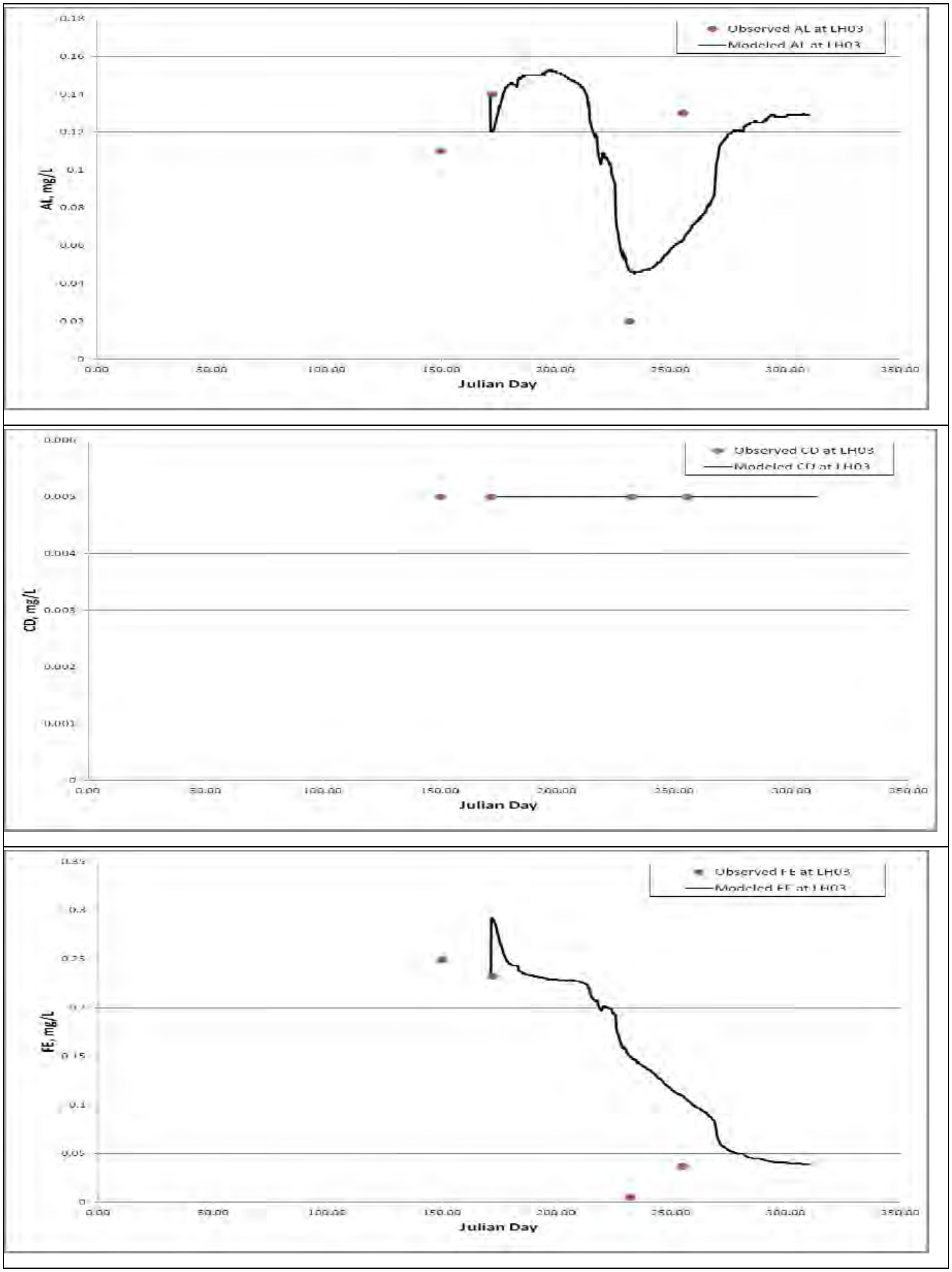


Figure E-3. 2001 Metals results at LH03 for AL, CD, FE

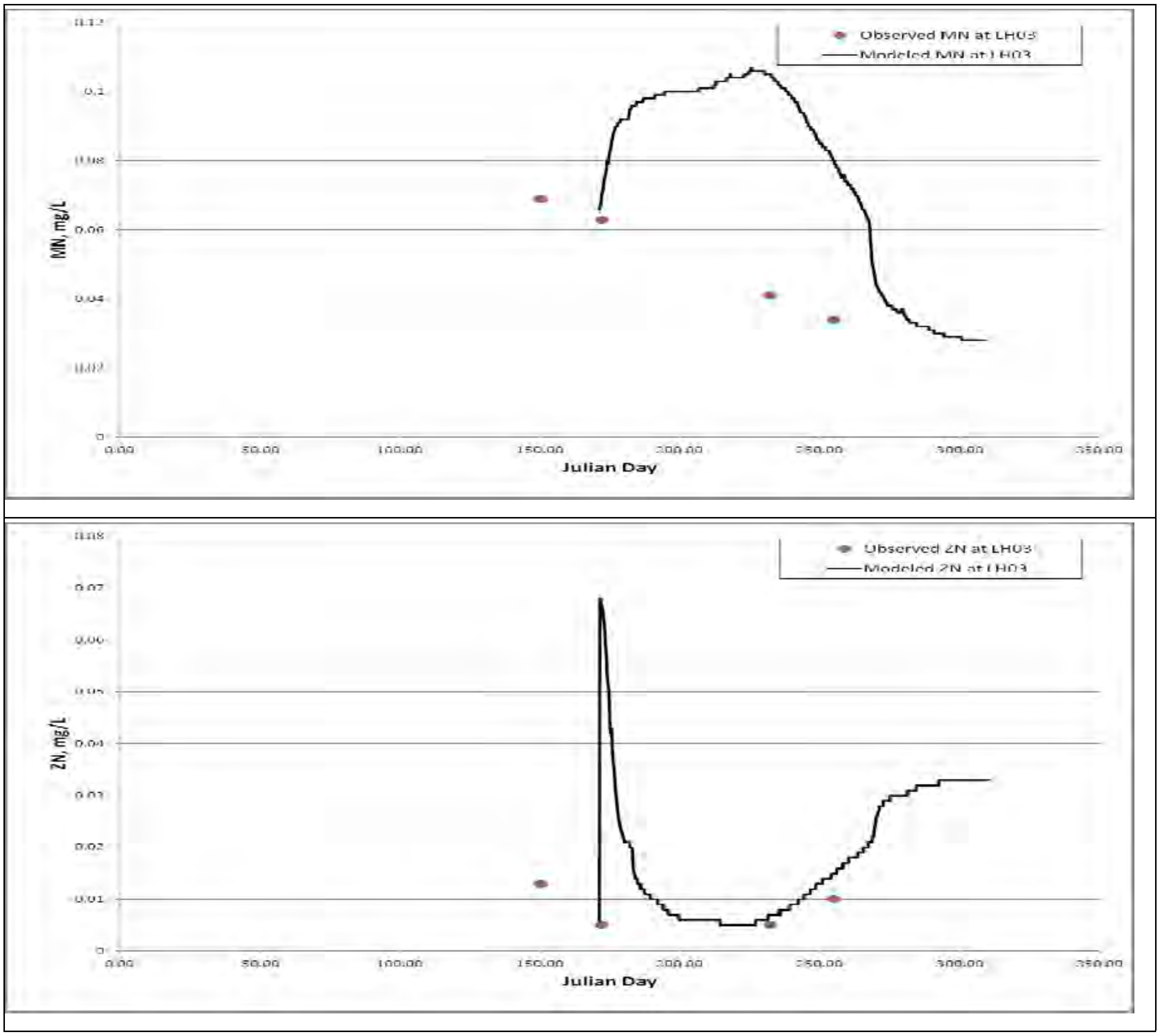


Figure E-4. 2001 Metals results at LH03 for MN an ZN

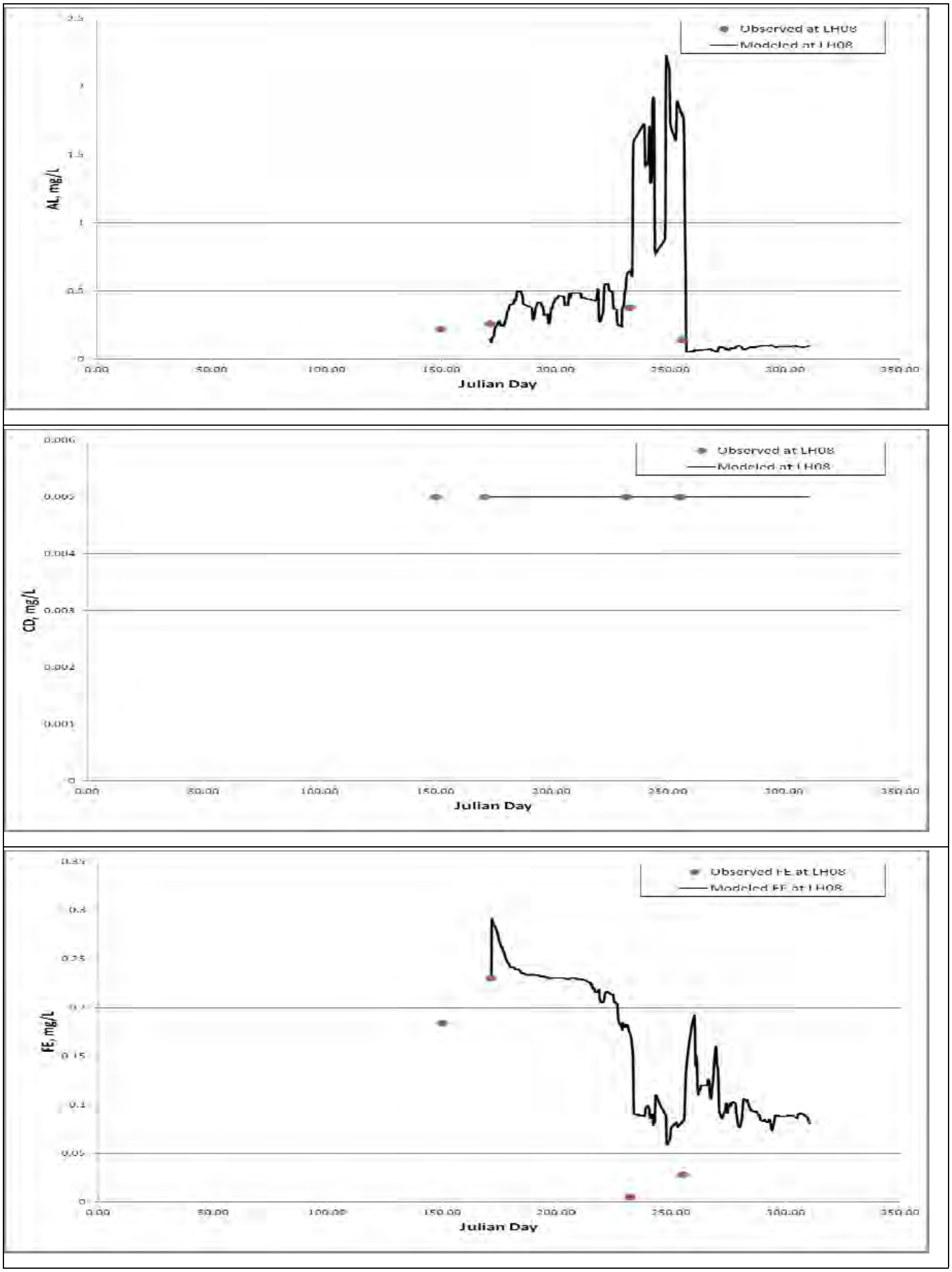


Figure E-5. 2001 Metals results at LH08 for AL, CD, FE

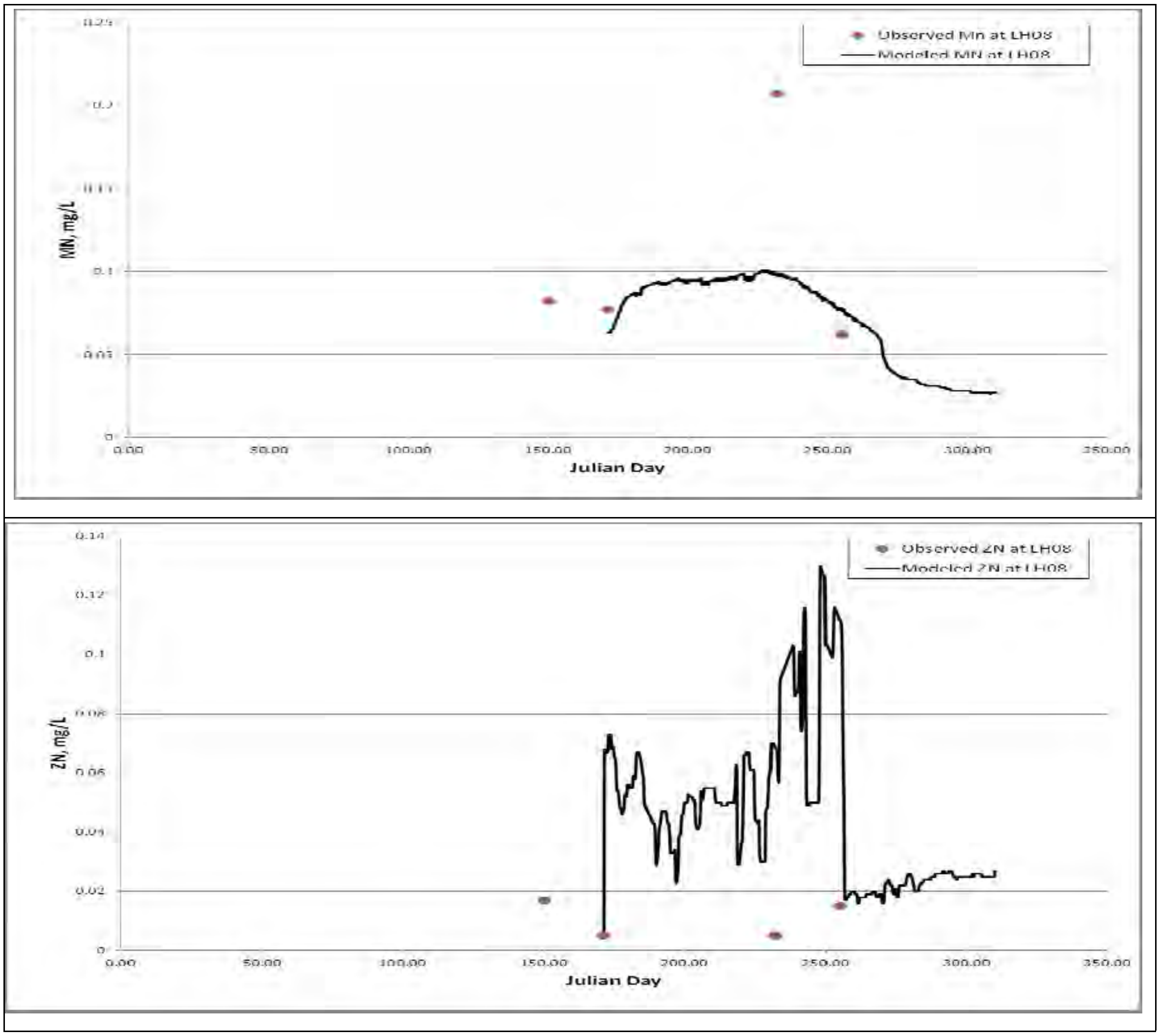


Figure E-6. 2001 Metals results at LH08 for MN an ZN

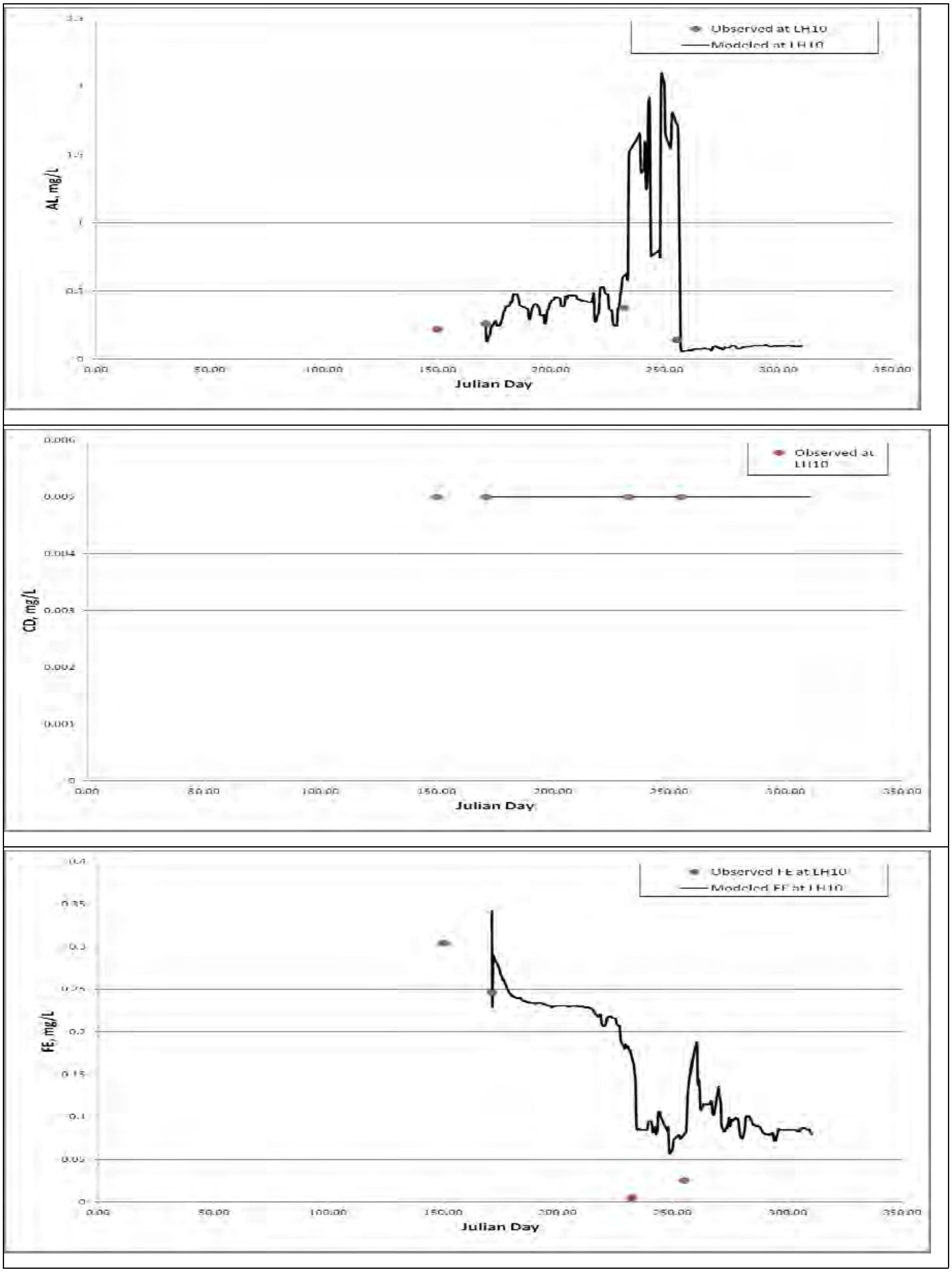


Figure E-7. 2001 Metals results at LH10 for AL, CD, FE

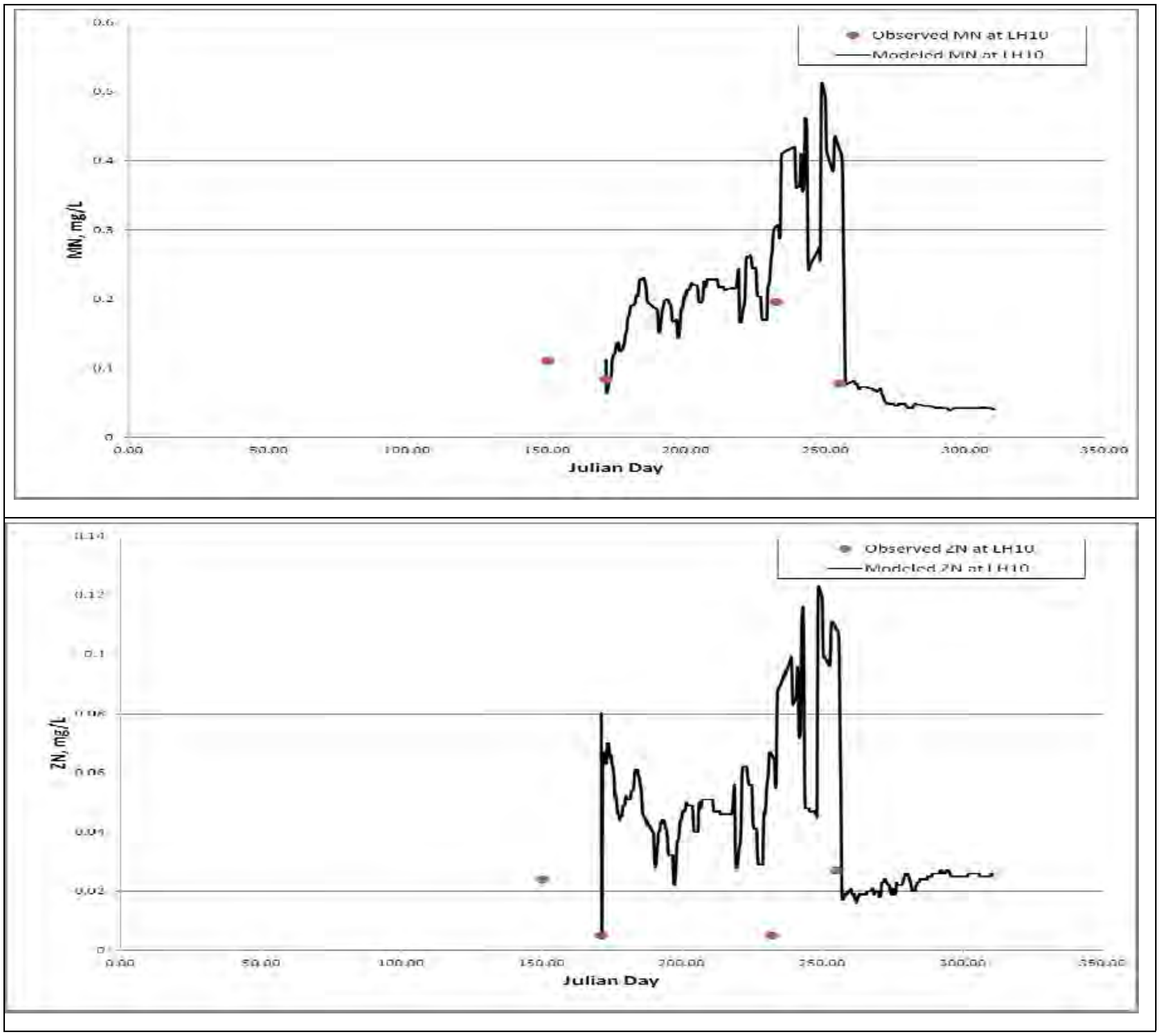


Figure E-8. 2001 Metals results at LH10 for MN an ZN

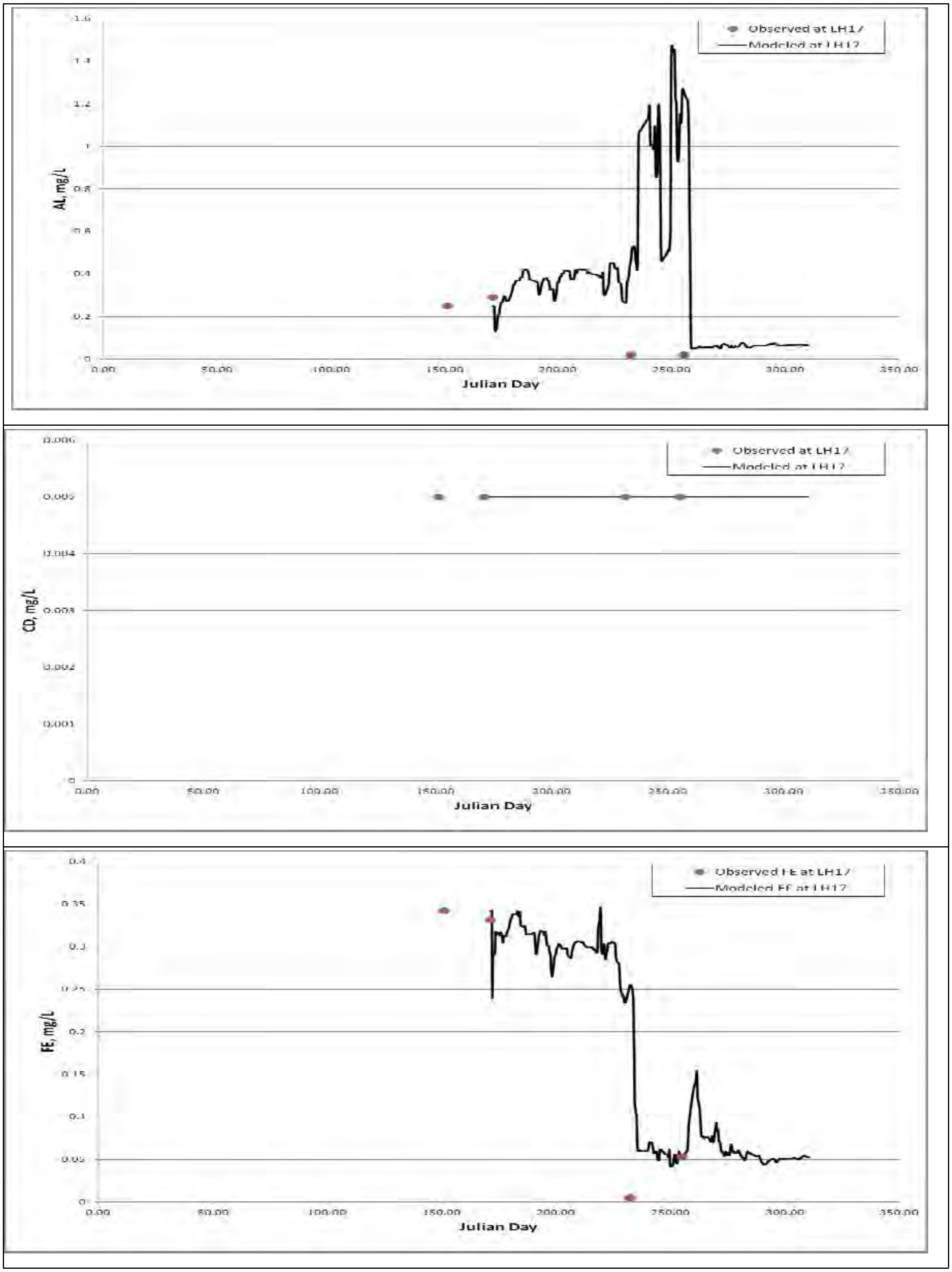


Figure E-9. 2001 Metals results at LH17 for AL, CD, FE

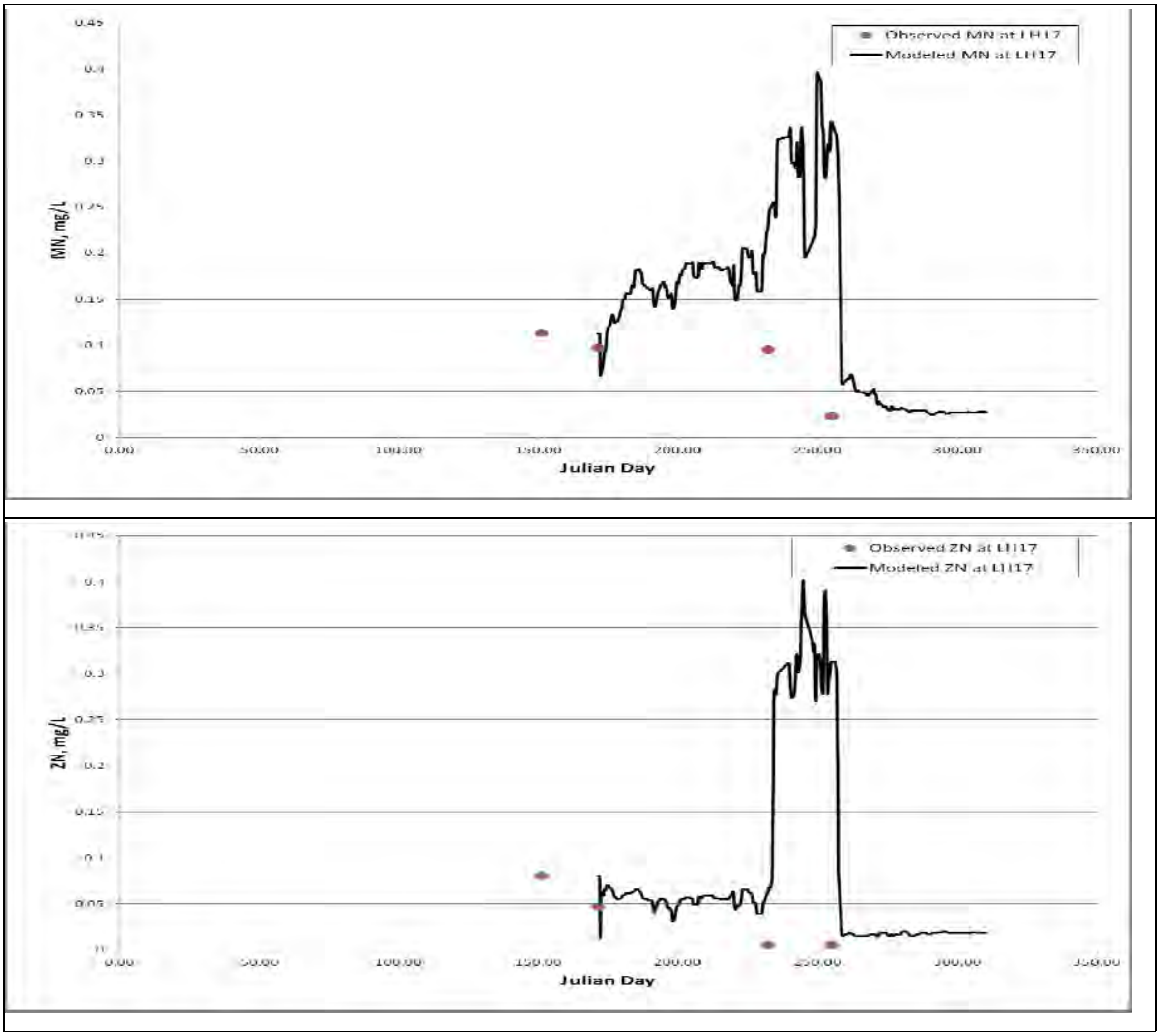


Figure E-10. 2001 Metals results at LH17 for MN and ZN

Appendix F: Water Quality and Metal Constituents Scenario Results

All figures are adobe "pdf" files containing water quality results for 21 constituents and five metals for all stations on the Lehigh River for 2001 and 2003. The first set of plots is for simulation runs without optimization and the second set of plots is with optimization for all scenario runs except Scenario 2 and Scenario 3. Metals results were only available for 2001 non-optimization runs for total forms of each metals (iron, cadmium, manganese, aluminum, and zinc) because the observed metals data were only available in the total forms for comparisons. Double click on each figure to open the set of water quality constituent plots. In metals plots generic constituent 1 is total aluminum, generic constituent 2 is total cadmium, generic constituent 3 is total iron, generic constituent 4 is total manganese, and generic constituent 5 is total zinc.

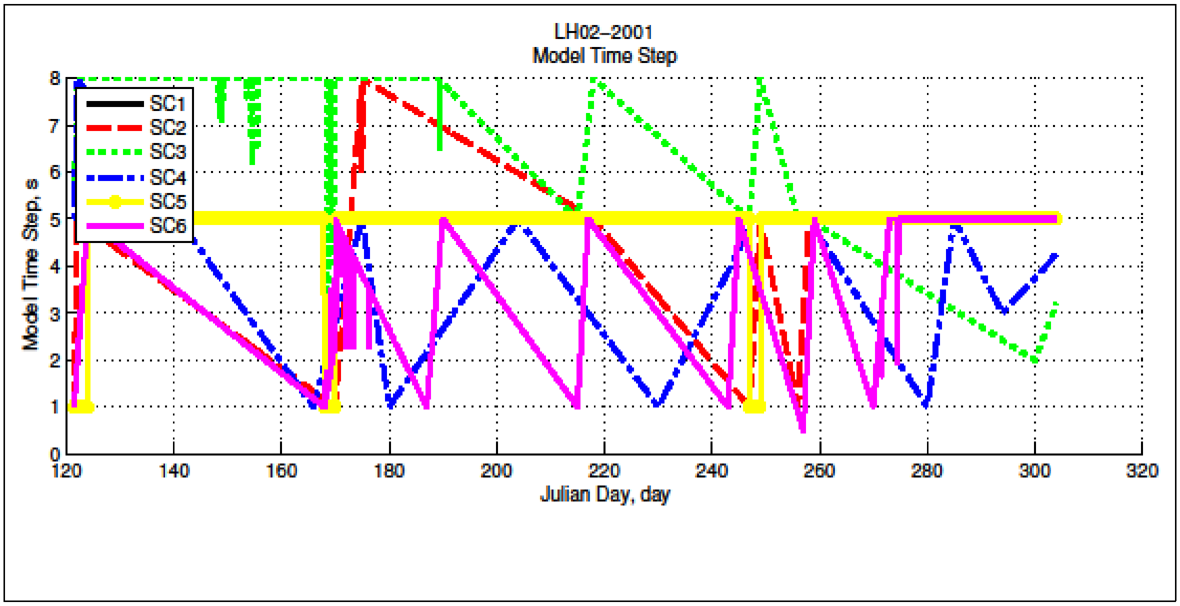


Figure F-1. 2001 Walter Quality scenario results at LH02 for optimized release flows.

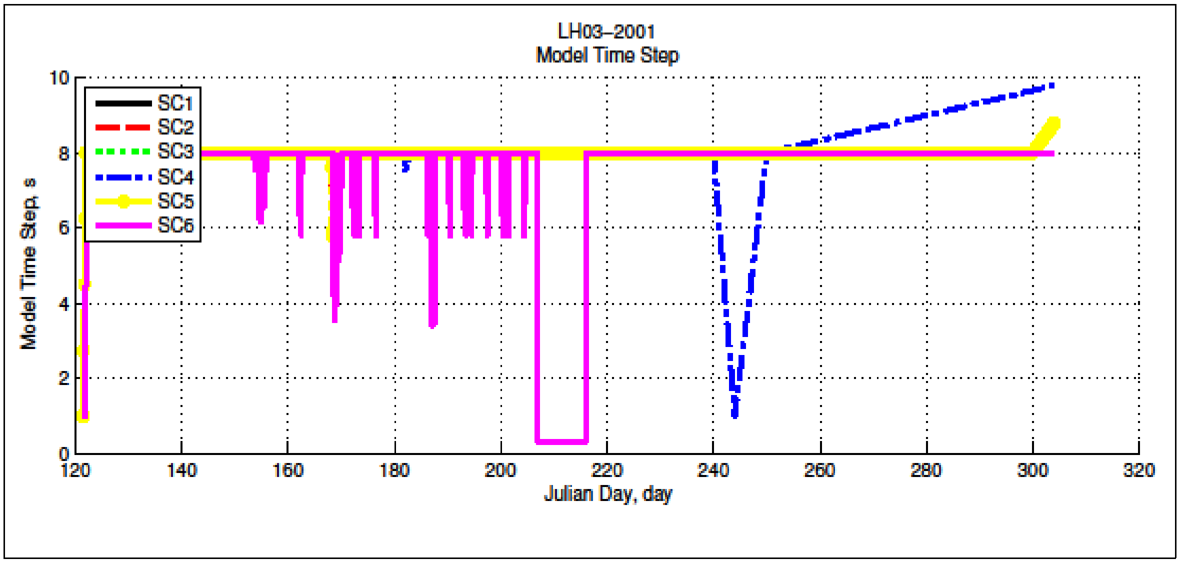


Figure F-2. 2001 Walter Quality scenario results at LH03 for optimized release flows.

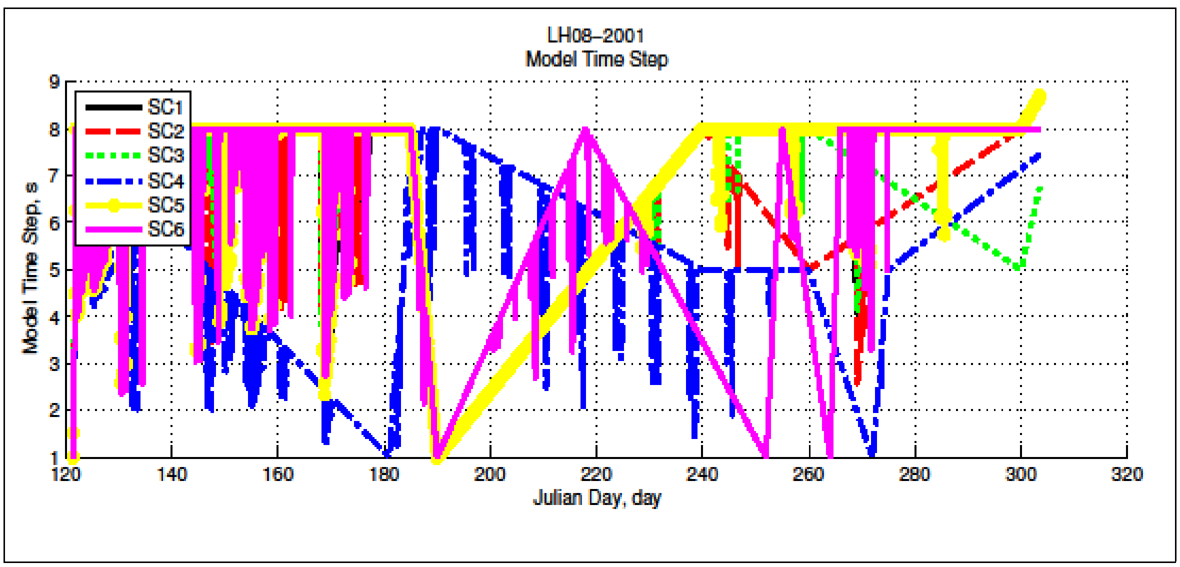


Figure F-3. 2001 Walter Quality scenario results at LH08 for optimized release flows.

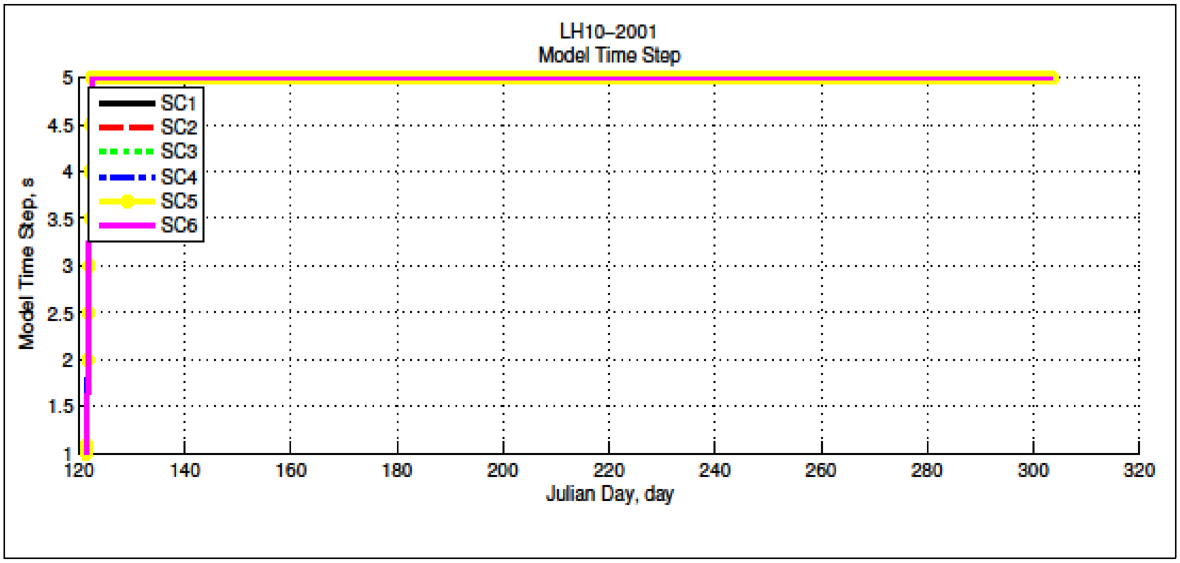


Figure F-4. 2001 Walter Quality scenario results at LH10 for optimized release flows.

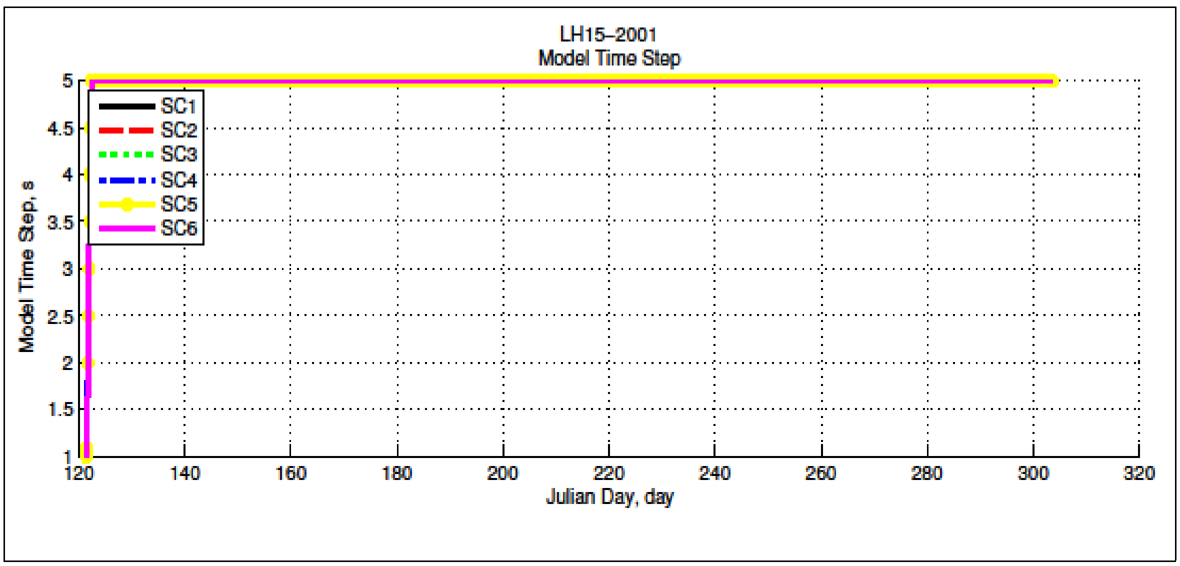


Figure F-5. 2001 Walter Quality scenario results at LH15 for optimized release flows.

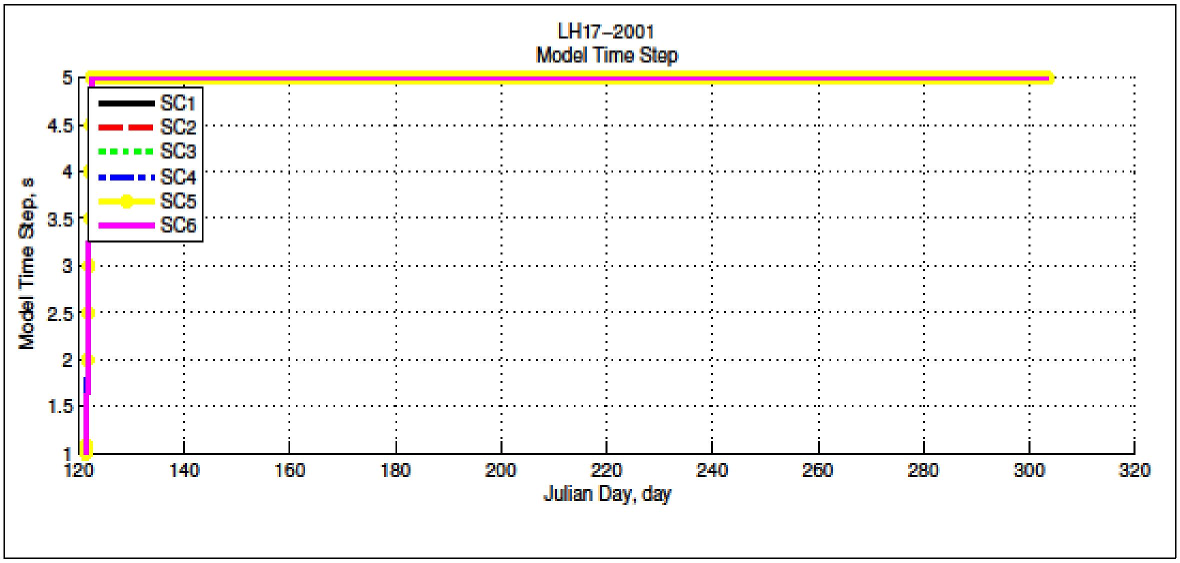


Figure F-6. 2001 Walter Quality scenario results at LH17 for optimized release flows.

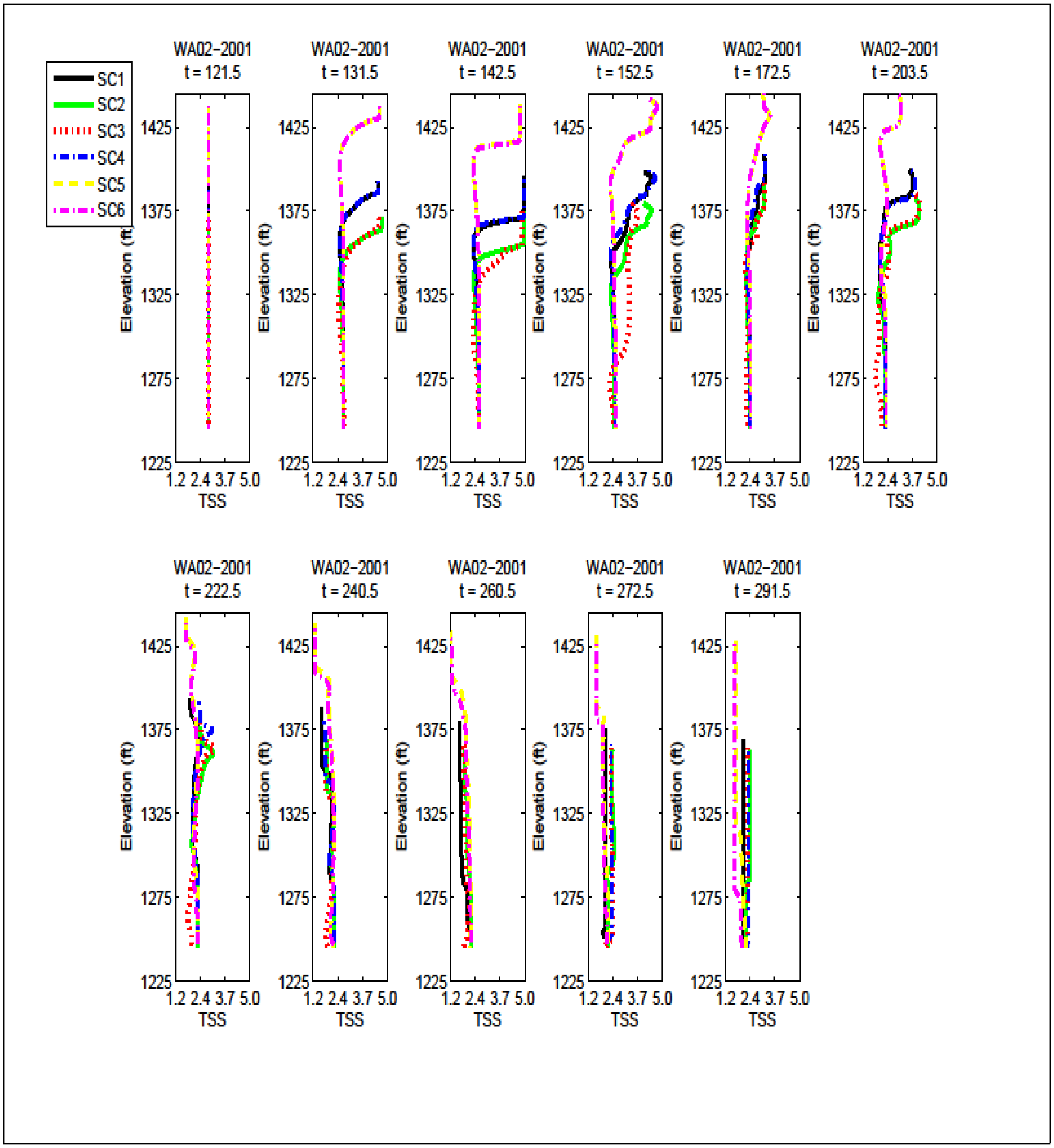


Figure F-7. 2001 Walter Quality scenario profile results at WA02 for optimized release flows.

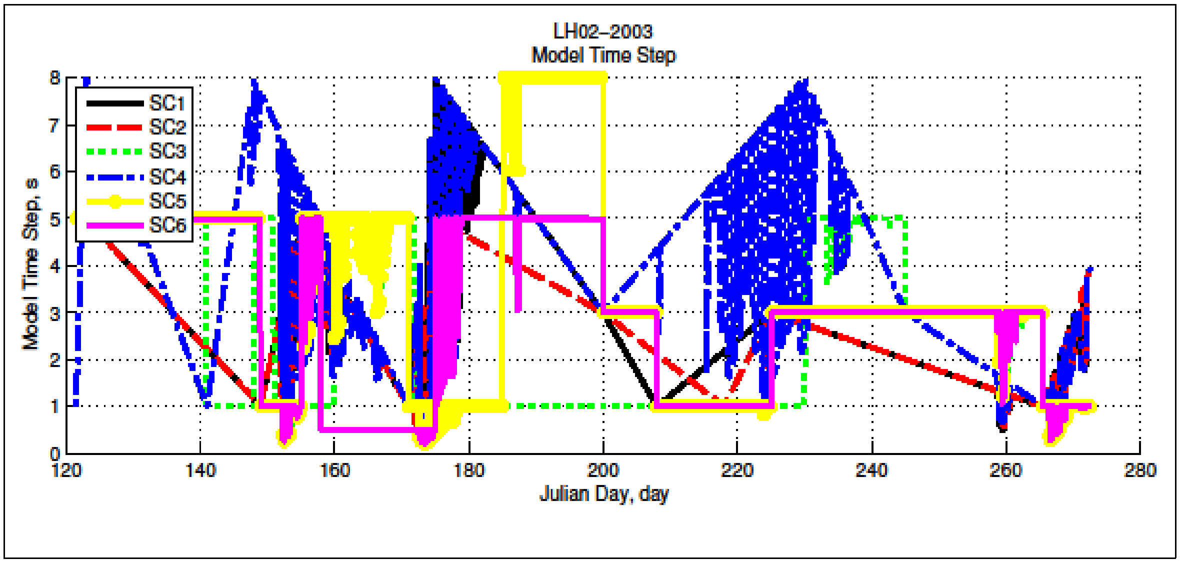


Figure F-8. 2003 Walter Quality scenario results at LH02 for optimized release flows.

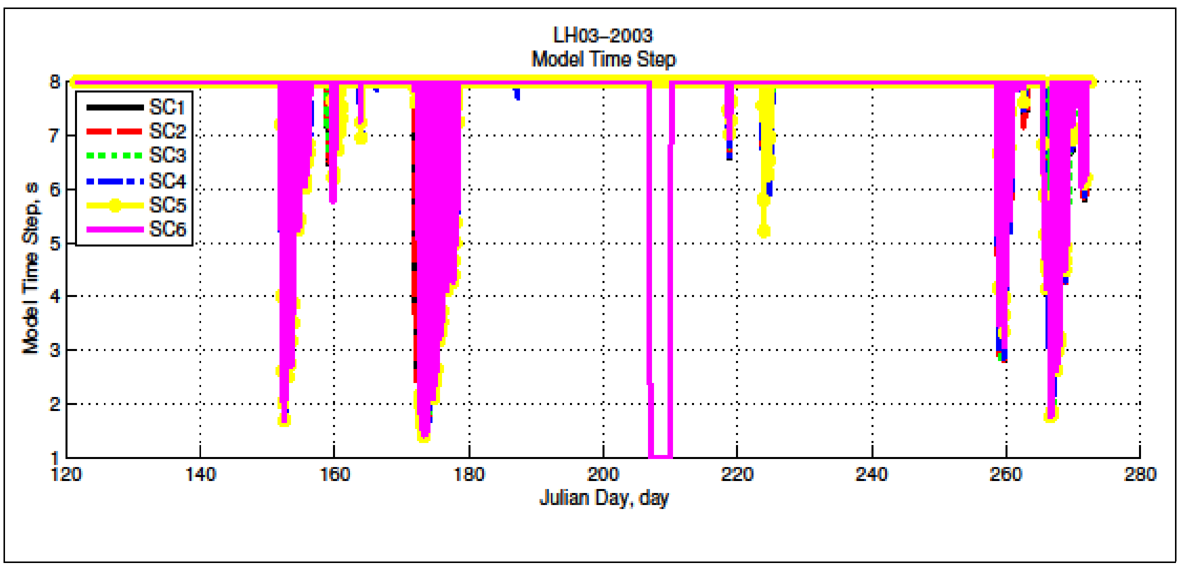


Figure F-9. 2003 Walter Quality scenario results at LH03 for optimized release flows.

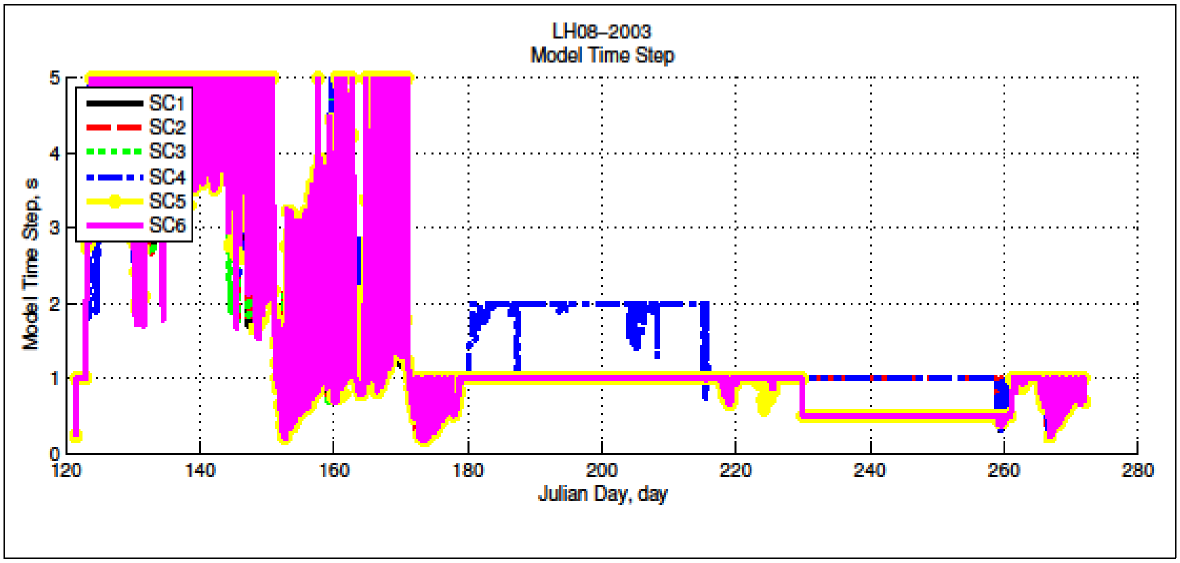


Figure F-10. 2003 Walter Quality scenario results at LH08 for optimized release flows.

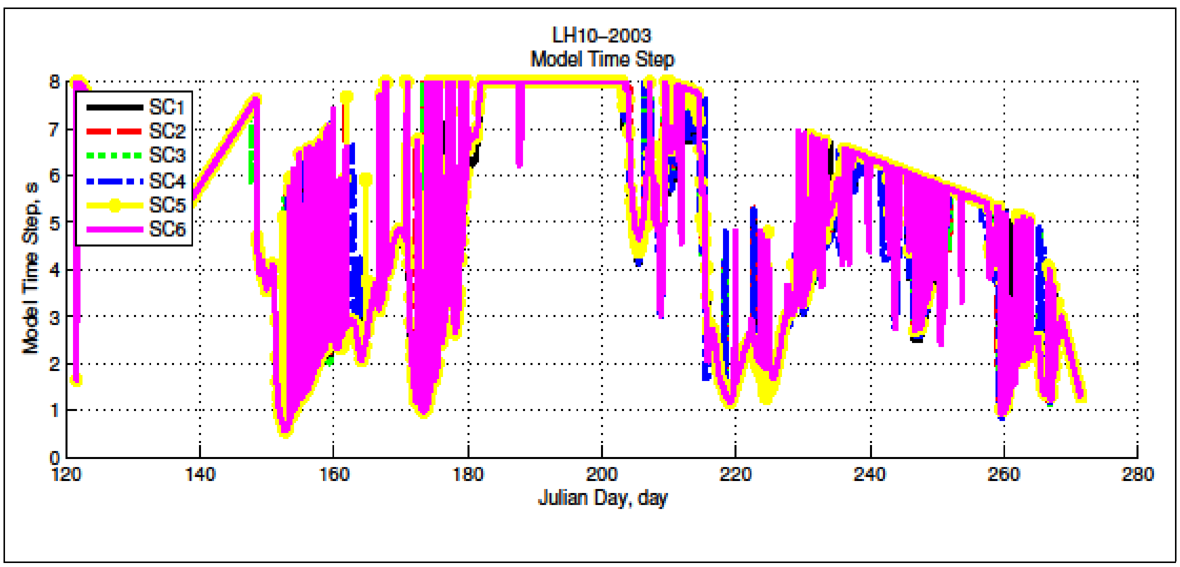


Figure F-11. 2003 Walter Quality scenario results at LH10 for optimized release flows.

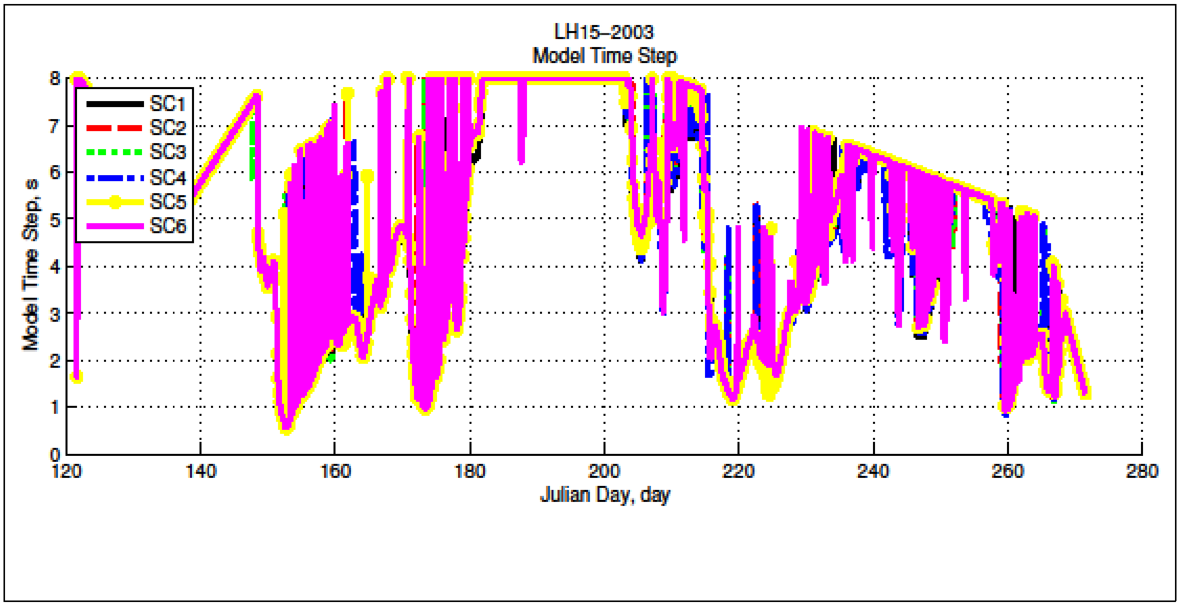


Figure F-12. 2003 Walter Quality scenario results at LH15 for optimized release flows.

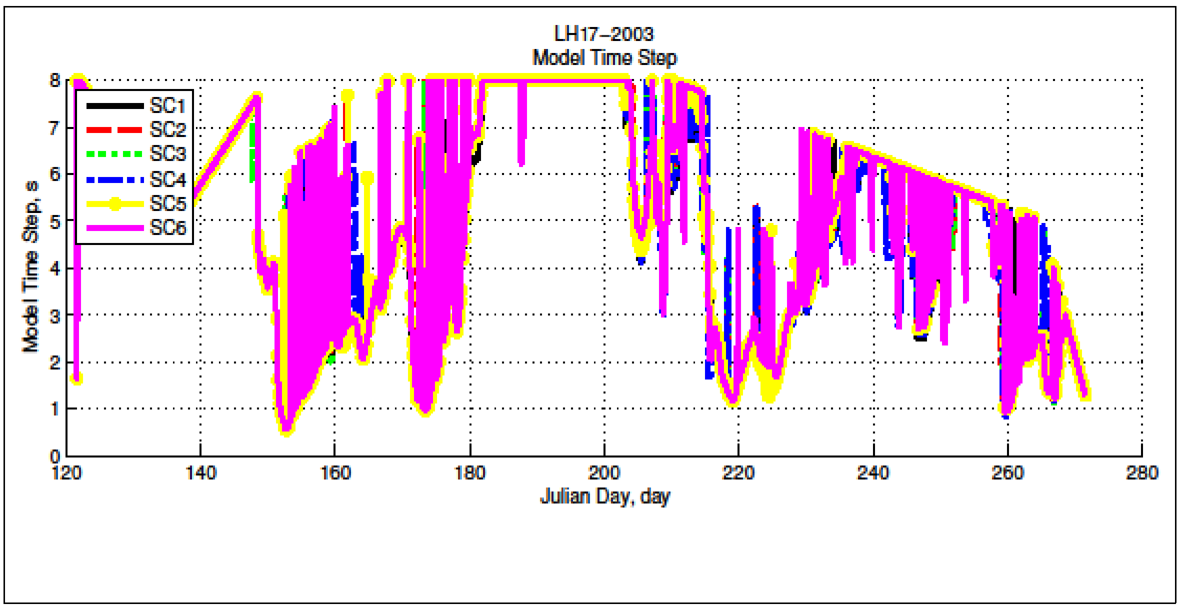


Figure F-13. 2003 Walter Quality scenario results at LH17 for optimized release flows.

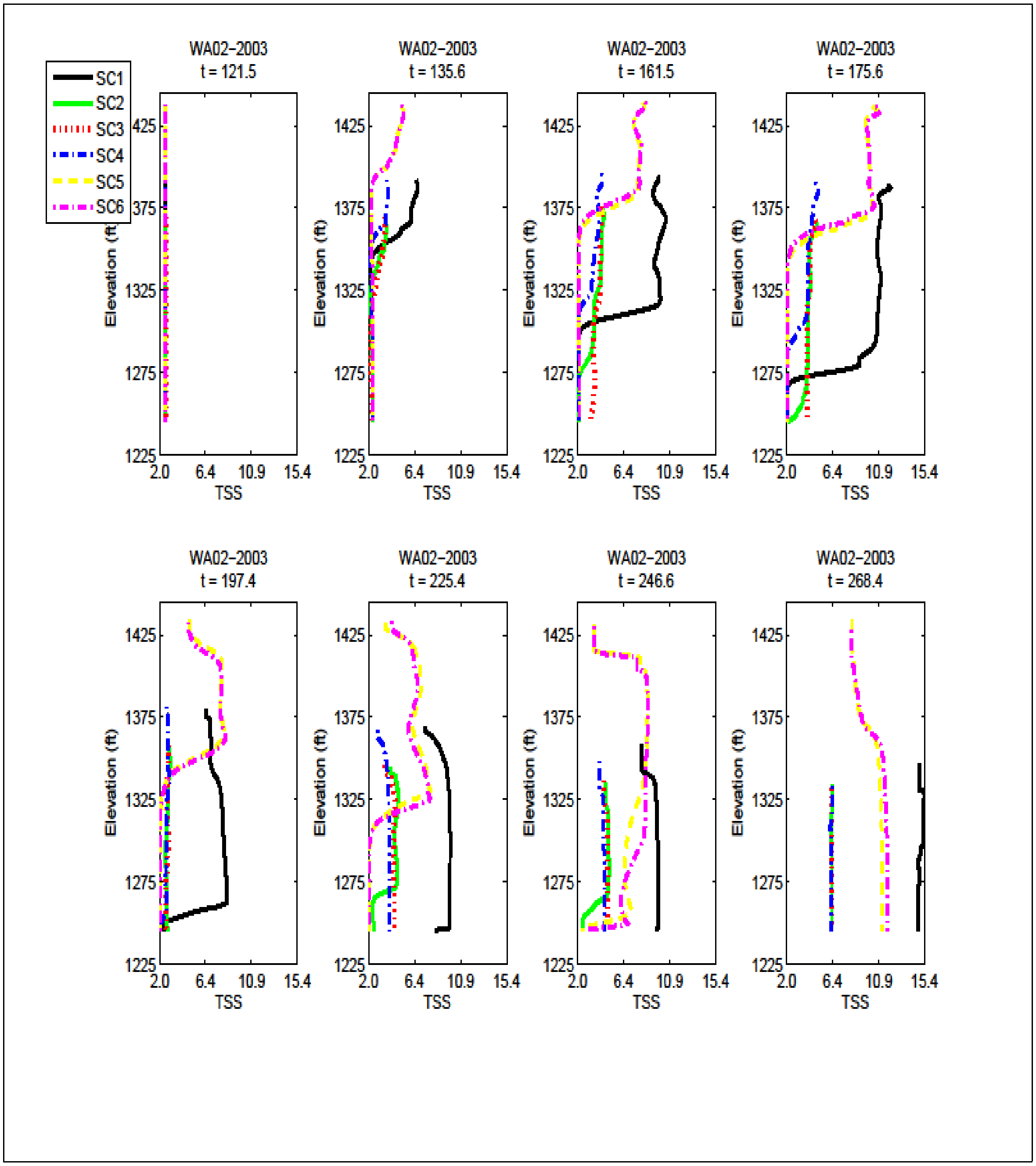


Figure F-14. 2003 Walter Quality scenario profile results at station WA02 for optimized release flows.

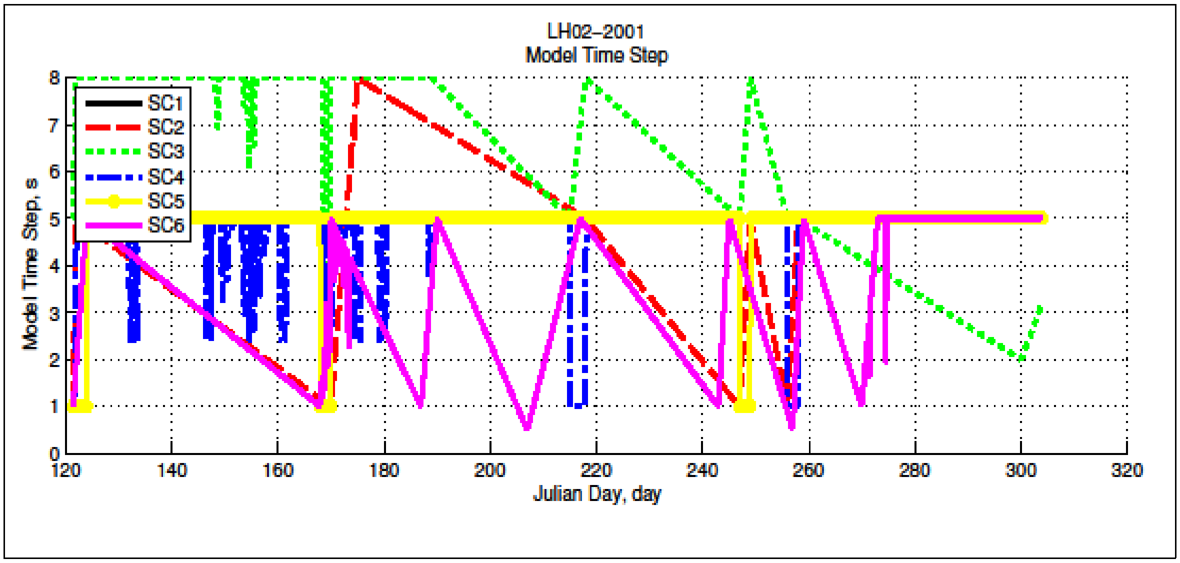


Figure F-15. 2001 Walter Quality scenario results at LH02 for original release flows.

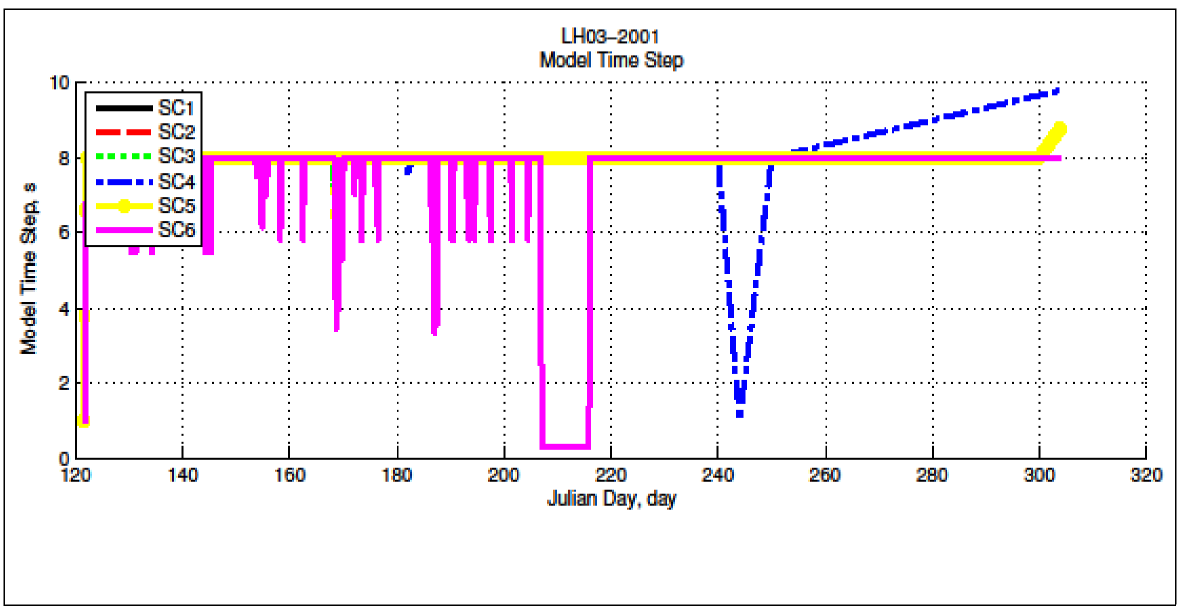


Figure F-16. 2001 Walter Quality scenario results at LH03 for original release flows.

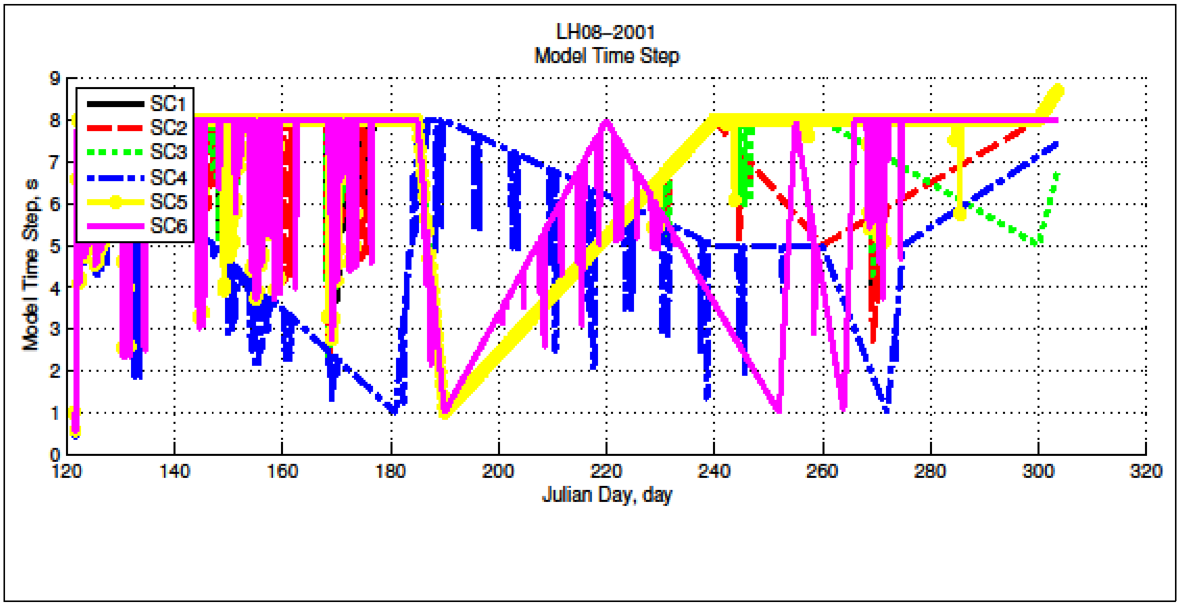


Figure F-17. 2001 Walter Quality scenario results at LH08 for original release flows.

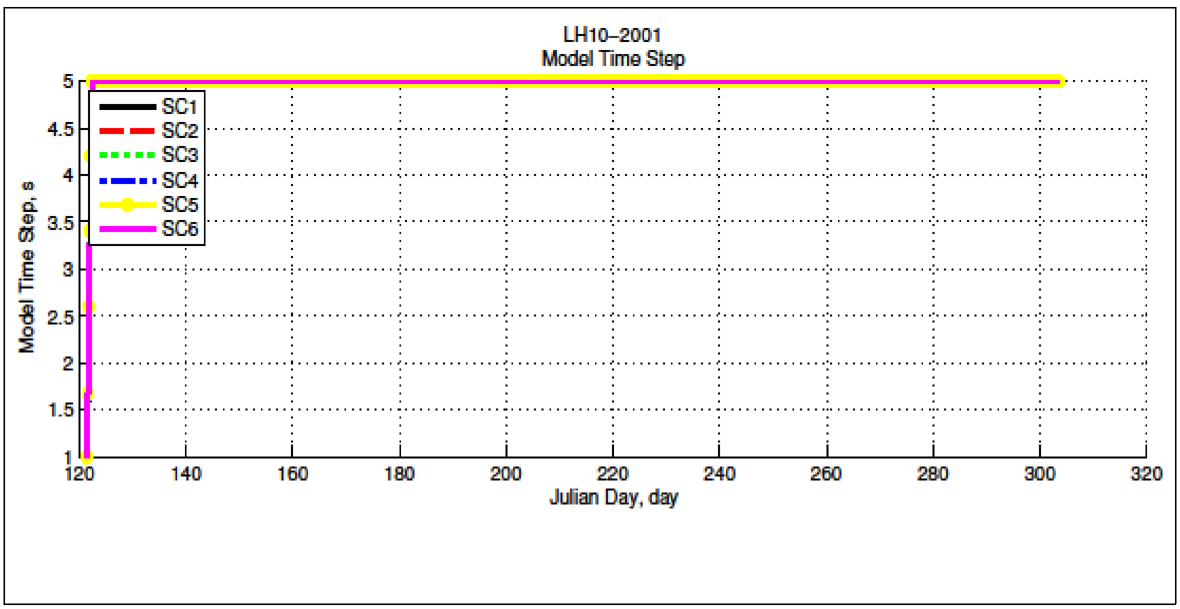


Figure F-18. 2001 Walter Quality scenario results at LH10 for original release flows.

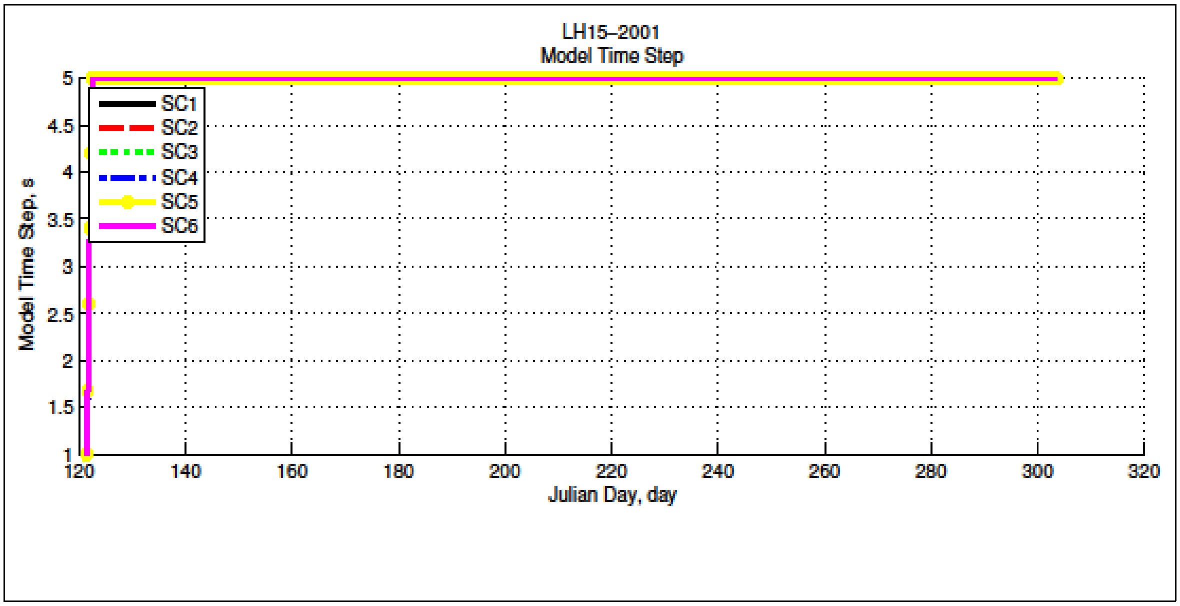


Figure F-19. 2001 Walter Quality scenario results at LH15 for original release flows.

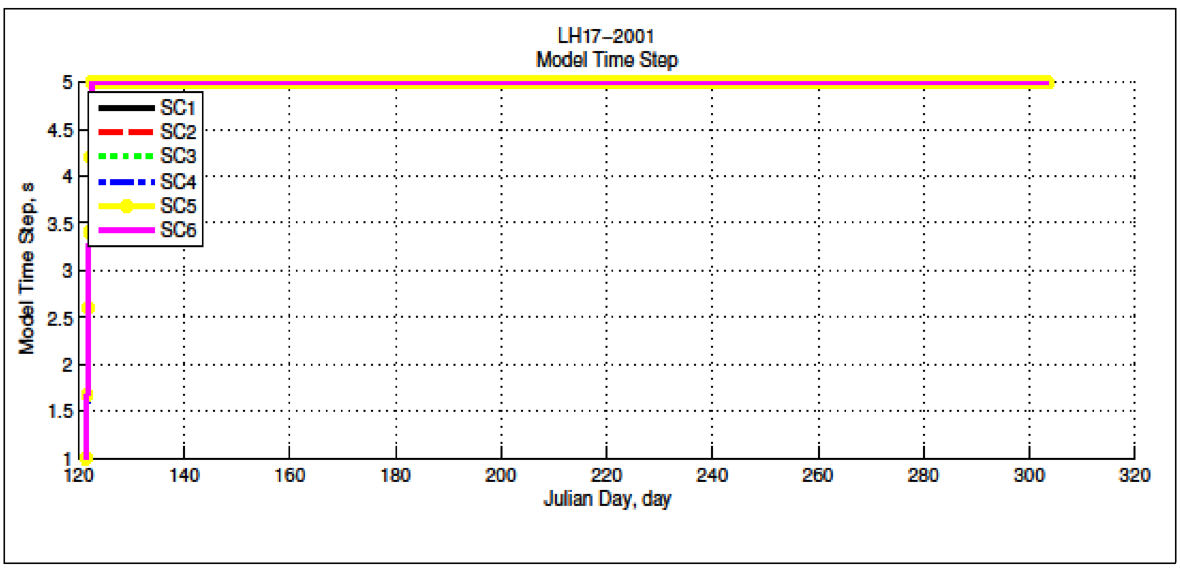


Figure F-20. 2001 Walter Quality scenario results at LH17 for original release flows.

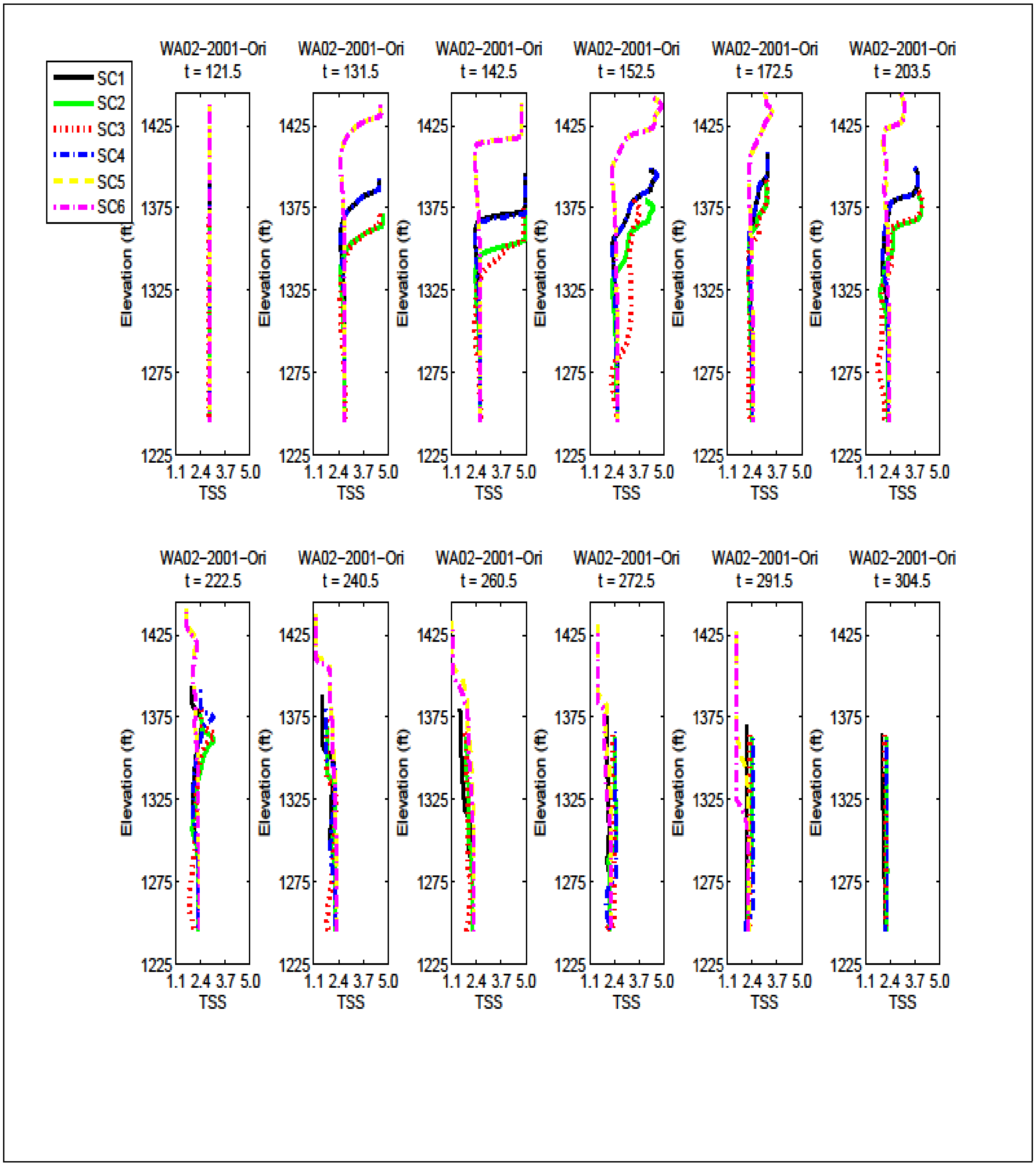


Figure F-21. 2001 Walter Quality scenario profile results at station WA02 for original release flows.

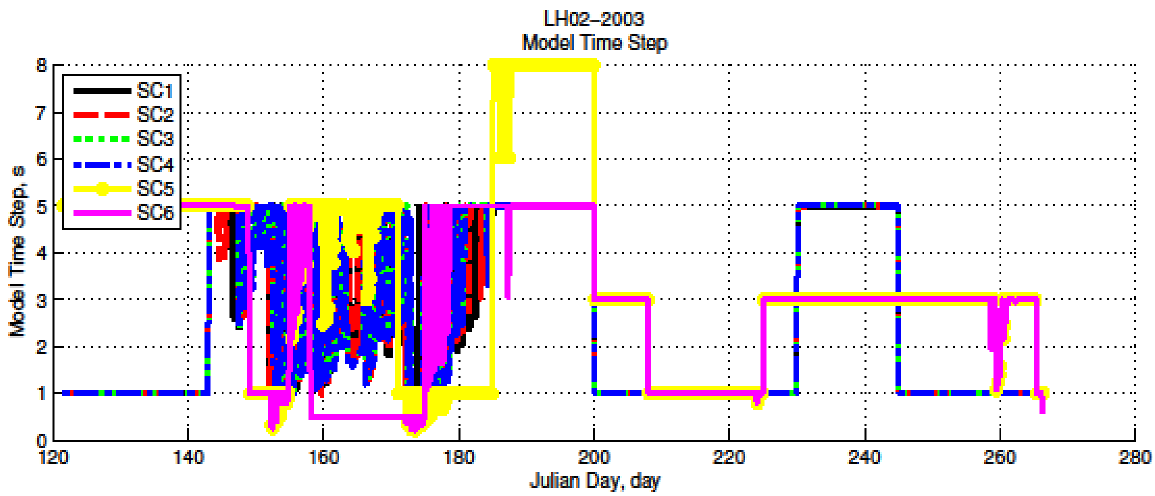


Figure F-22. 2003 Walter Quality scenario results at LH02 for original release flows.

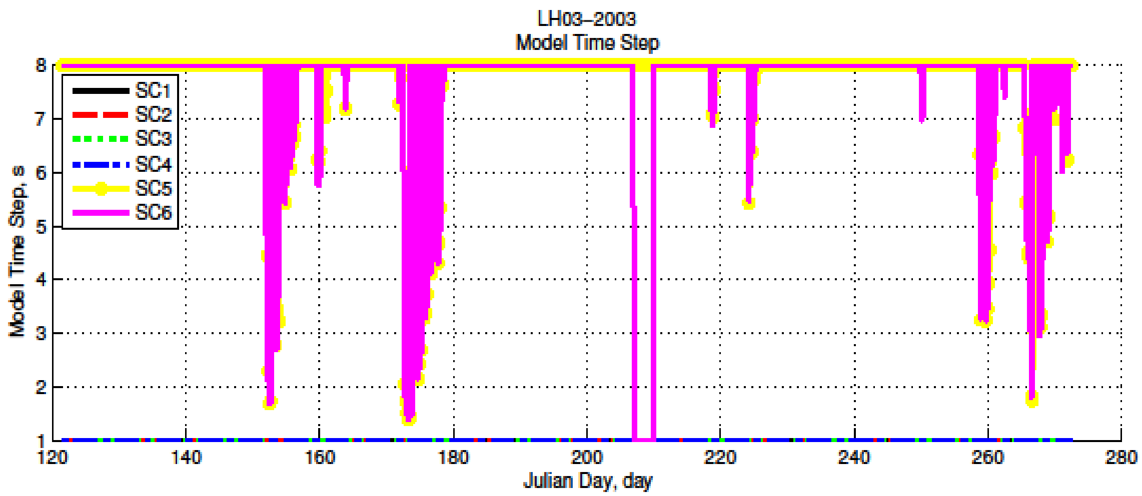


Figure F-23. 2003 Walter Quality scenario results at LH03 for original release flows.

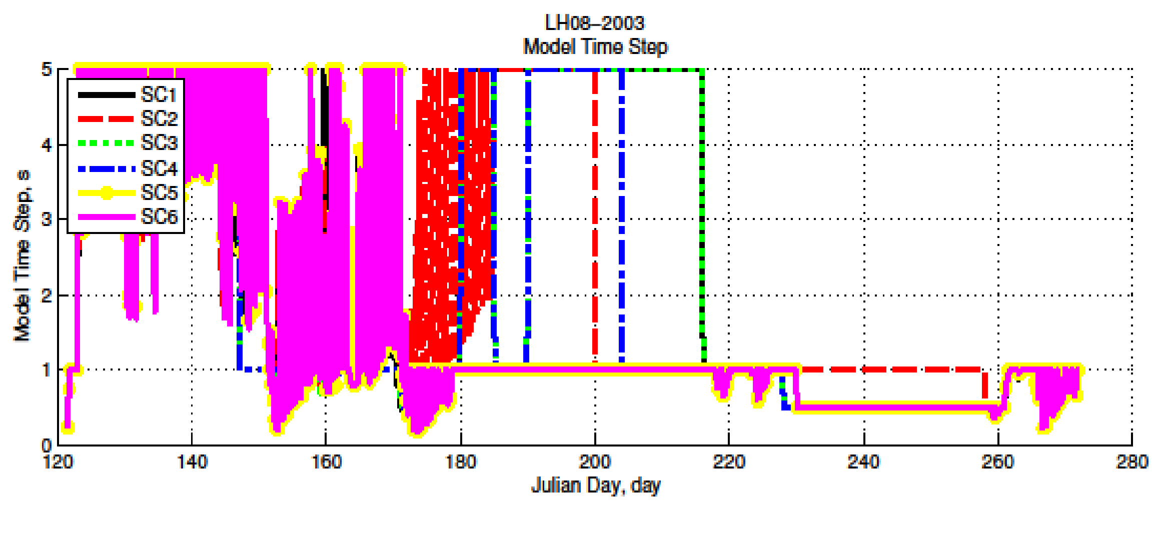


Figure F-24. 2003 Walter Quality scenario results at LH08 for original release flows.

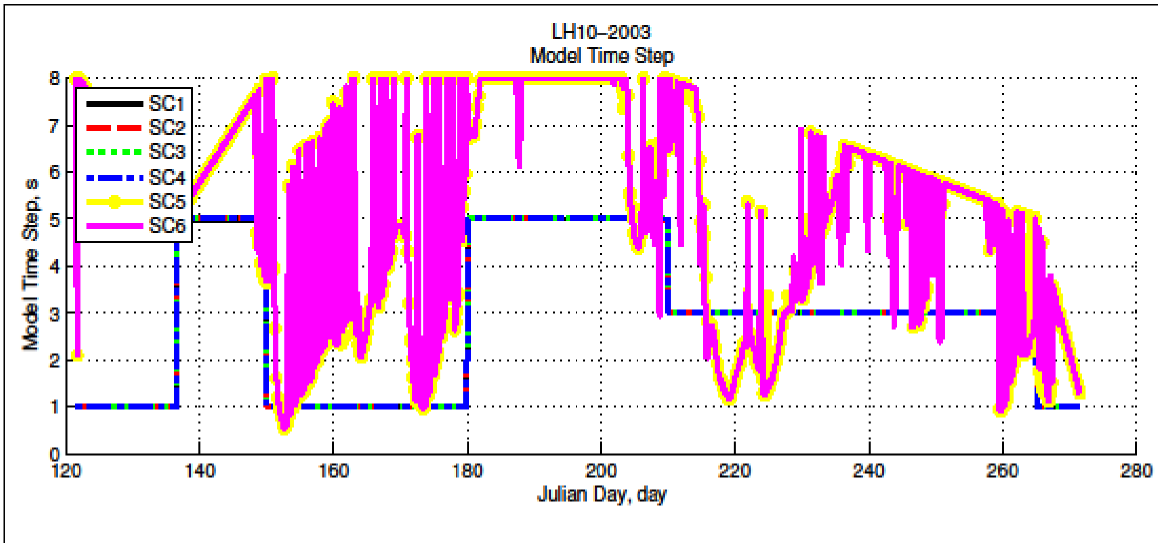


Figure F-25. 2003 Walter Quality scenario results at LH10 for original release flows.

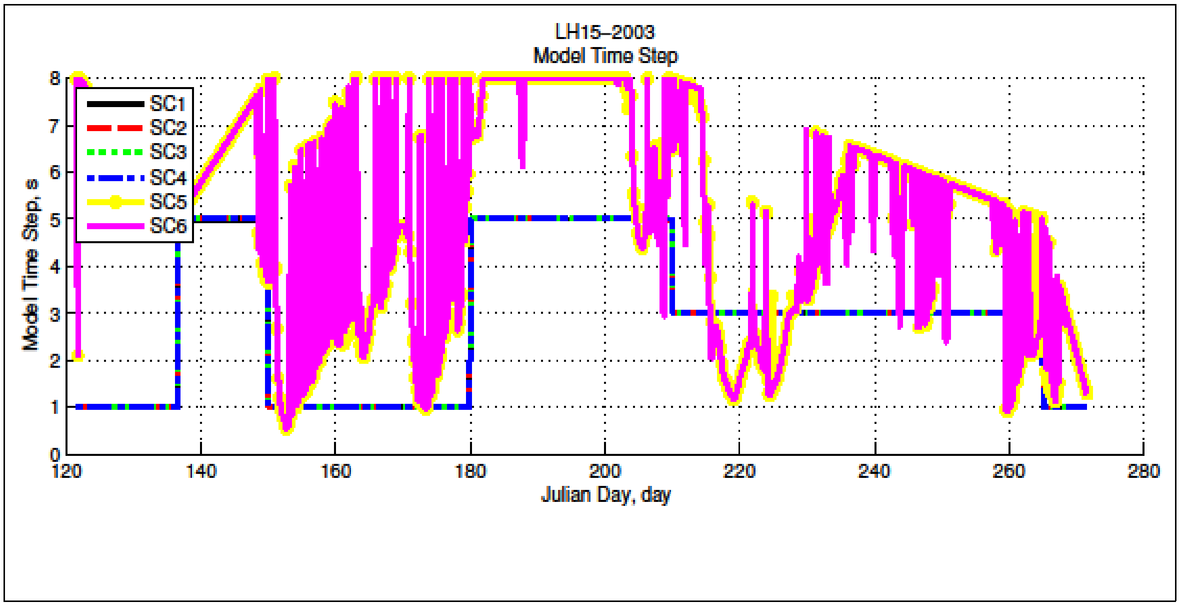


Figure F-26. 2003 Walter Quality scenario results at LH15 for original release flows.

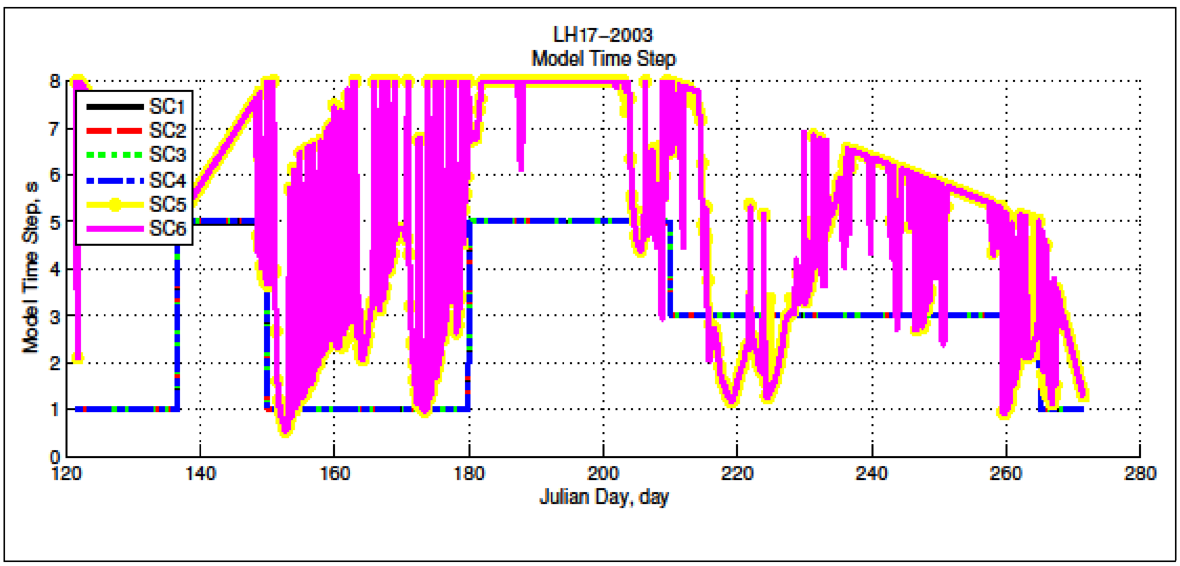


Figure F-27. 2003 Walter Quality scenario results at LH17 for original release flows.

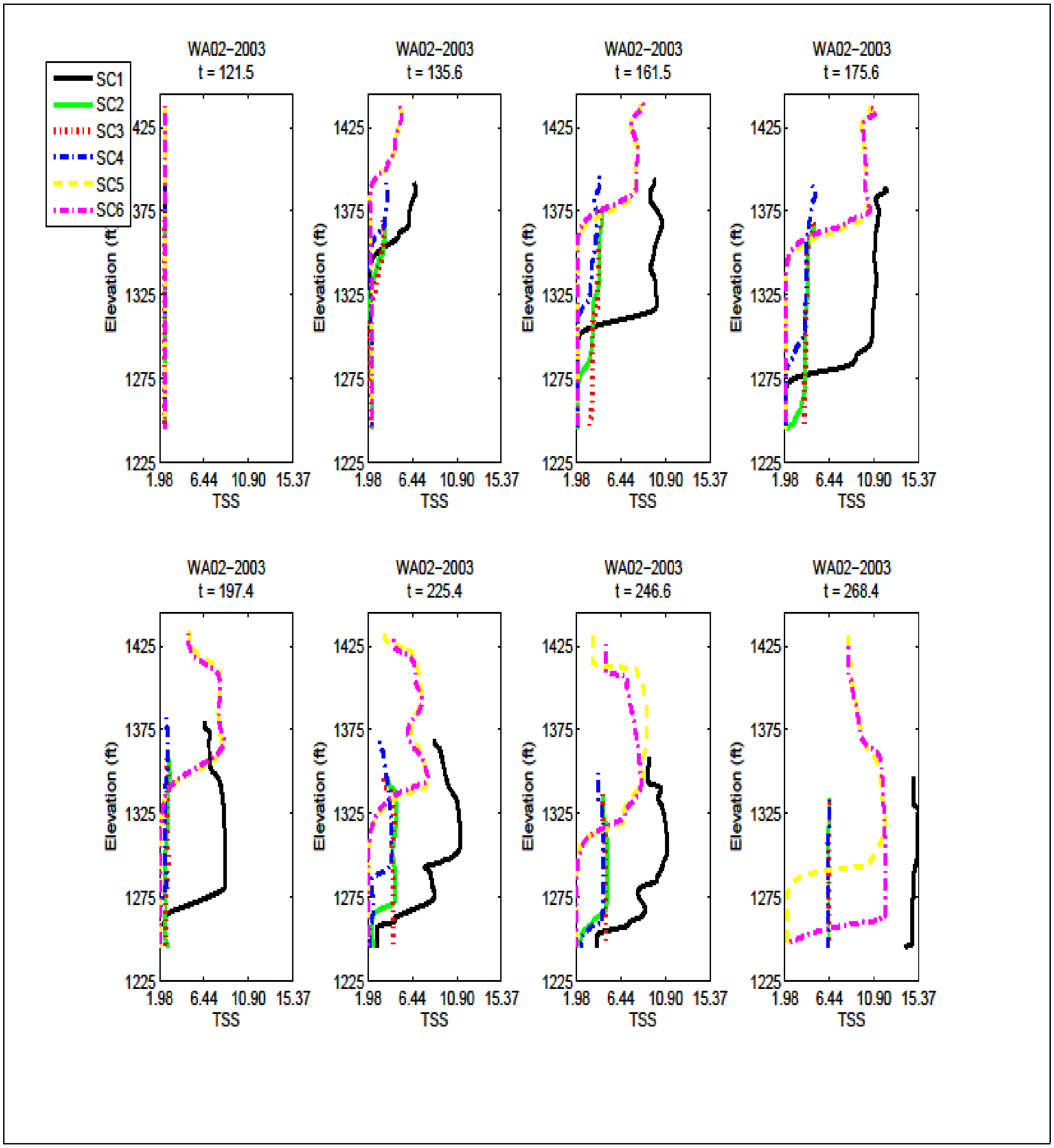


Figure F-28. 2003 Walter Quality scenario profile results at station WA02 for original release flows.

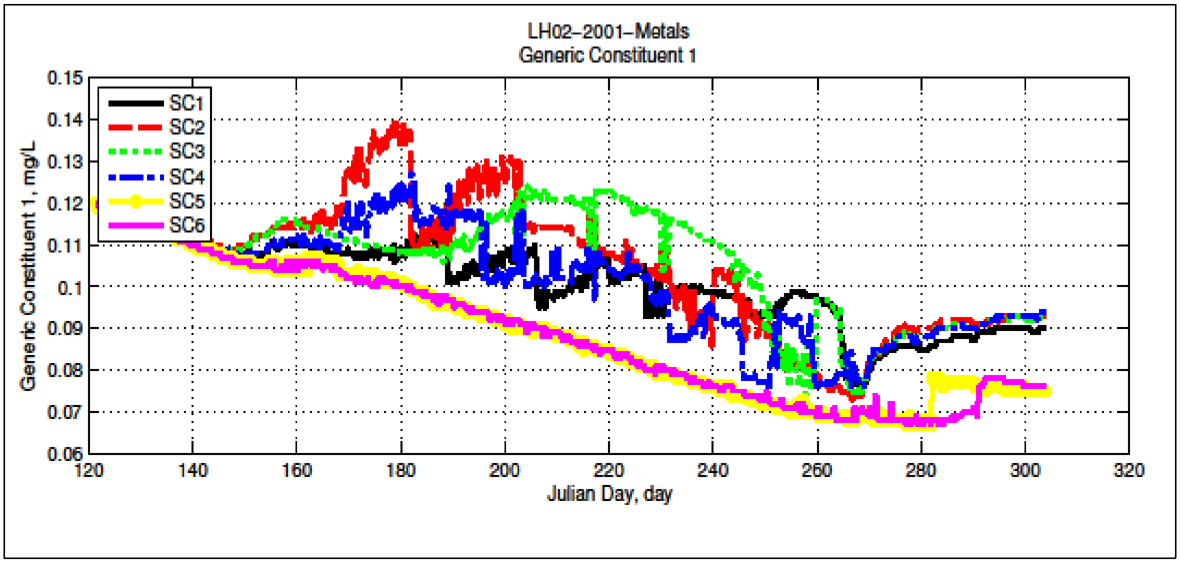


Figure F-29. 2001 Walter Quality scenario results for total metals at LH02 for original release flows.

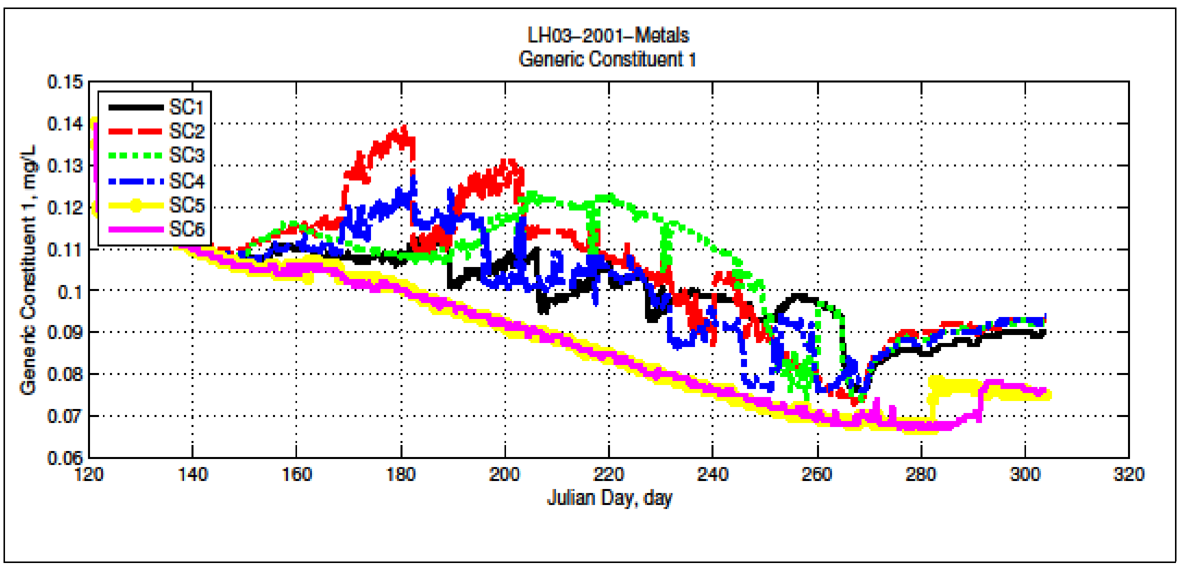


Figure F-30. 2001 Walter Quality scenario results for total metals at LH03 for original release flows.

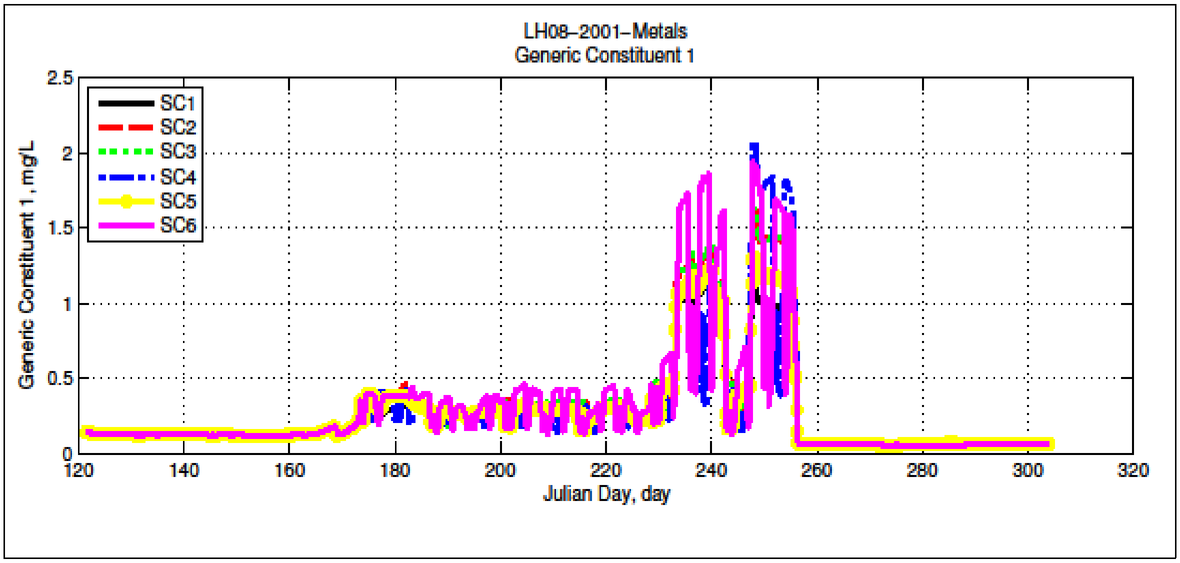


Figure F-31. 2001 Walter Quality scenario results for total metals at LH08 for original release flows.

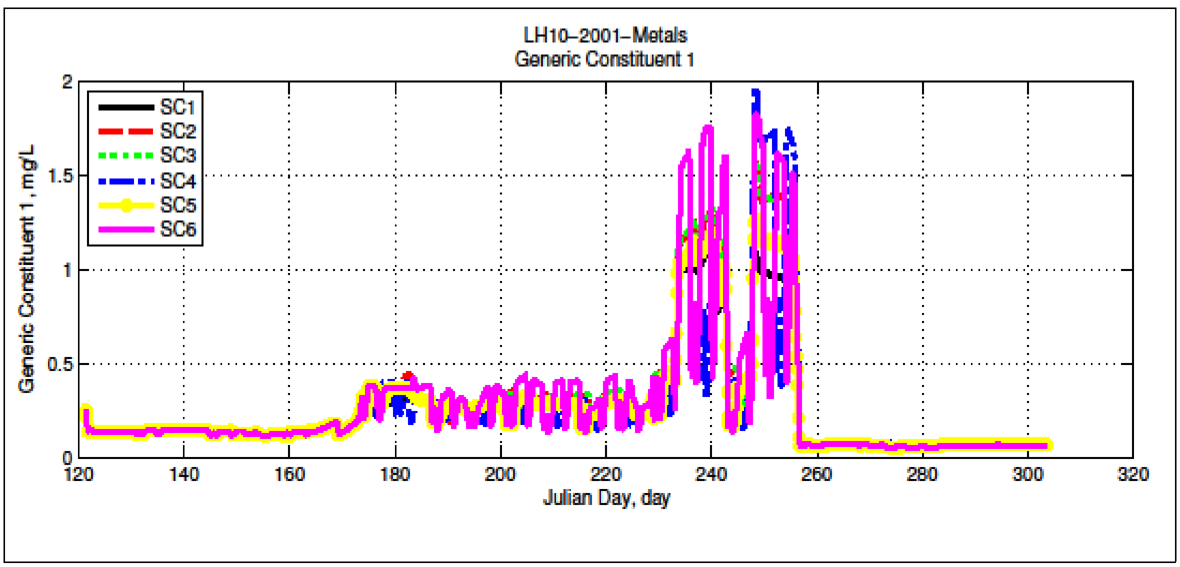


Figure F-32. 2001 Walter Quality scenario results for total metals at LH10 for original release flows.

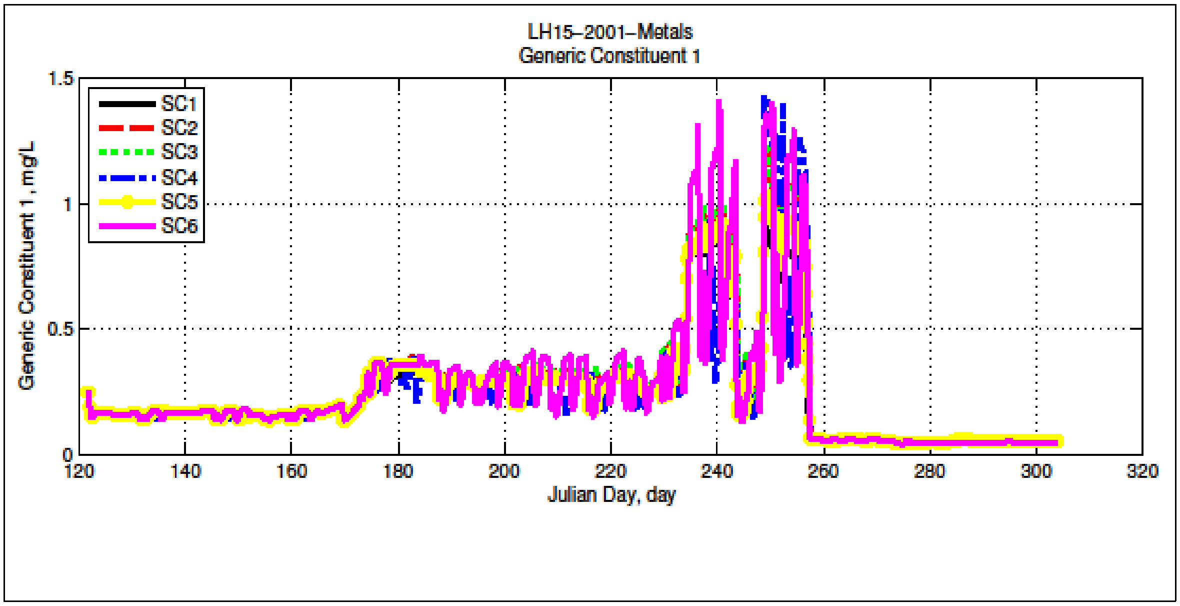


Figure F-32. 2001 Walter Quality scenario results for total metals at LH15 for original release flows.

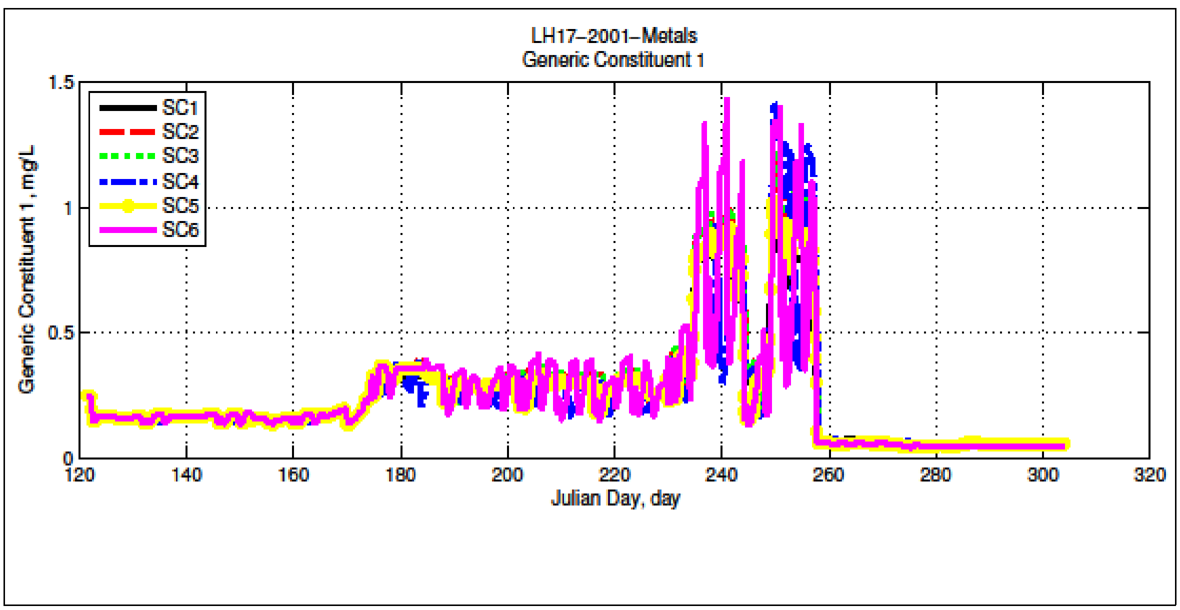


Figure F-32. 2001 Walter Quality scenario results for total metals at LH17 for original release flows.

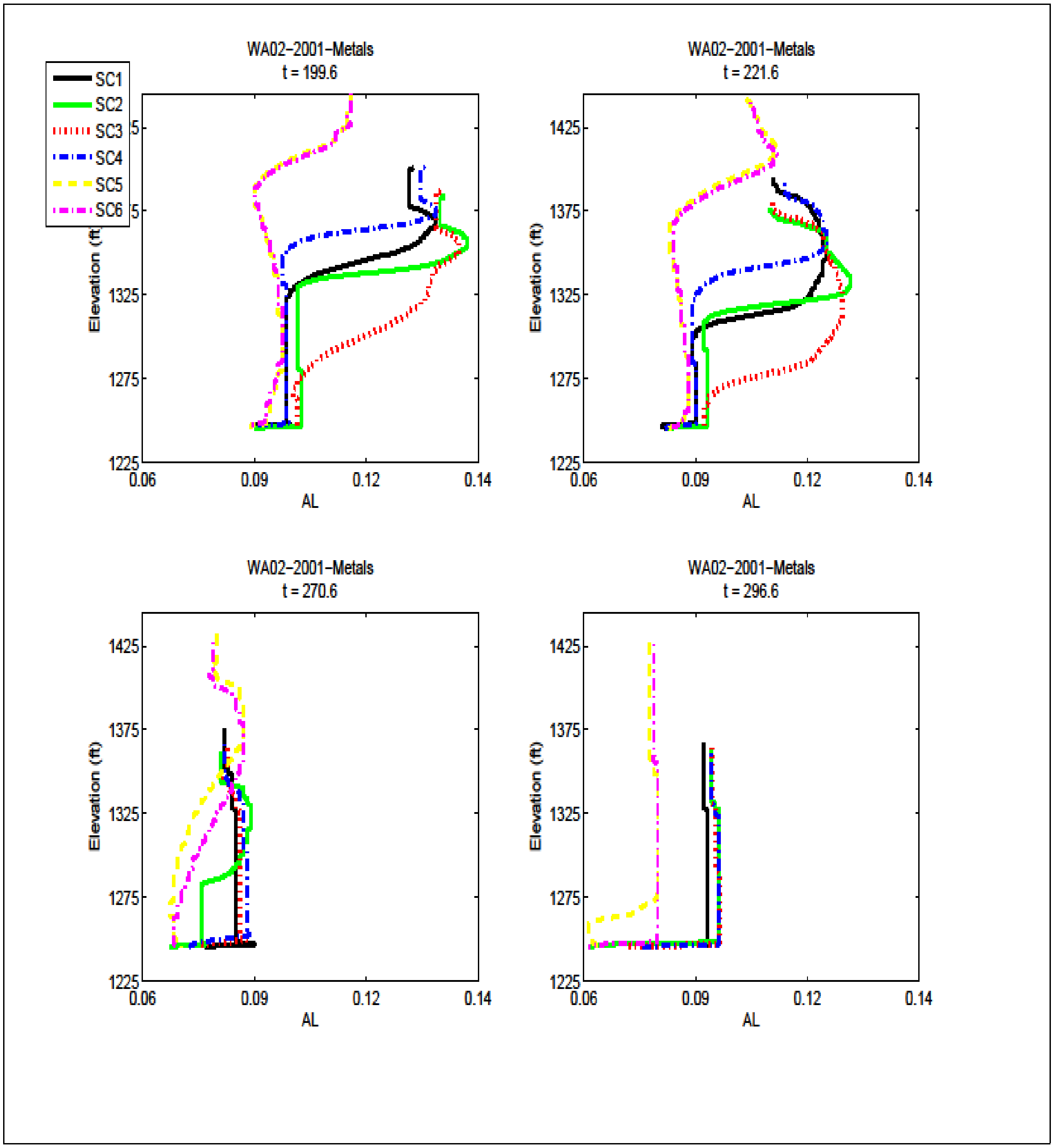


Figure F-33. 2001 Walter Quality scenario profile results at station WA02 for original release flows.