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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

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1 Introduction

Background

There is considerable interest in improving operational releases for boaters and aquatic resources downstream of F.E. Walter Dam. 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 (Figure 1). 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.

In terms of the Lehigh River system, Beltzville Dam is located 4.5 miles upstream of the confluence to the Lehigh River on Pohopoco Creek. The confluence of Pohopoco Creek with the Lehigh River is about 20 miles below F.E. Water Dam. Beltzville Dam has multilevel selective withdrawal release capability. Thus, the operation of Beltzville can influence temperatures in the Lehigh River some, but not as much as the operation of F.E. Walter Dam. Beltzville Reservoir is authorized for water supply, flood control, recreation, and water quality enhancement.

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 temporary changes in operational pool levels at the F.E. Walter Dam would provide downstream fisheries habitat improvements and 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.

The objective of this study is to model proposed operational scenarios at F.E. Walter Dam to enhance downstream and in-lake recreation and habitat. To accomplish this, a reservoir/river system flow and water quality model was developed for the Lehigh River from Walter and Beltzville Dams downstream to Northampton, PA, a distance of 45 miles.

Although temperature and flow are the major questions to be addressed in this Section 22 study, there is concern for other water quality parameters as well, especially low dissolved oxygen (DO), sulfide, and reduced iron and manganese. At the conclusion of this study, Phase 2 will begin and a second report will document the results.

Approach

The model used for this study was CE-QUAL-W2 Version 3.6, which is a two-dimensional (laterally-averaged) hydrodynamic and water quality model for simulating surface water systems, including rivers, lakes, reservoirs, and estuaries. CE-QUAL-W2 (W2) has been successfully applied to over 200 different systems throughout the U.S. and abroad. In addition to computing water surface elevations, horizontal/vertical velocities, and temperature, the model can simulate many other water quality state variables including algal/nutrient/dissolved oxygen interactions (Table 1). In addition to these water quality variables, W2 also solves for pH and the carbonate cycle (CO_3, HCO_3, and H2CO3) and sediment organic matter. Alkalinity, pH, and the carbonate species are all treated conservatively, but are based on carbonate chemistry equilibrium and total inorganic carbon.

Table 1. CE-QUAL-W2 V3 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
	(continued)

Table 1. (Concluded)

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
Algae 4	Algae 5
Algae 6	Dissolved Oxygen
Carbonaceous biochemical oxygen demand	Alkalinity
Total Inorganic Carbon	Temperature

W2 was applied to F. E. Walter and Beltzville Reservoirs, the Lehigh River downstream of F. E. Walter Reservoir, and Pohopoco Creek downstream of Beltzville Reservoir. The Lehigh River reach extended 45 river miles below F.E. Walter Dam. The focus of the study was on temperature and hydraulic calibration for the entire system.

The calibration year selected was 2001 because an extensive data collection was conducted that year. Figure 1 and Table 2 show or list observed stations on tributaries and the main stem of the Lehigh River as well as observed stations in F. E. Walter and Beltzville Reservoirs. For verification a different type water year was chosen to test the robustness of the model. Accordingly since 2001 was a dry year the verification year selected was a wet water year. Examination of flows into the F. E. Walter and Beltzville Reservoirs was performed to determine a high flow year for verification; from the data provided by the District, 2003 was chosen as the verification year. Before the final decision to use this year, all available temperature data were checked to make sure enough data were available to verify the model.

Once the system was calibrated and verified, scenario runs were conducted using initial and boundary conditions from the calibration (2001, a dry) and verification (2003, a wet water year) runs with new 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 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)

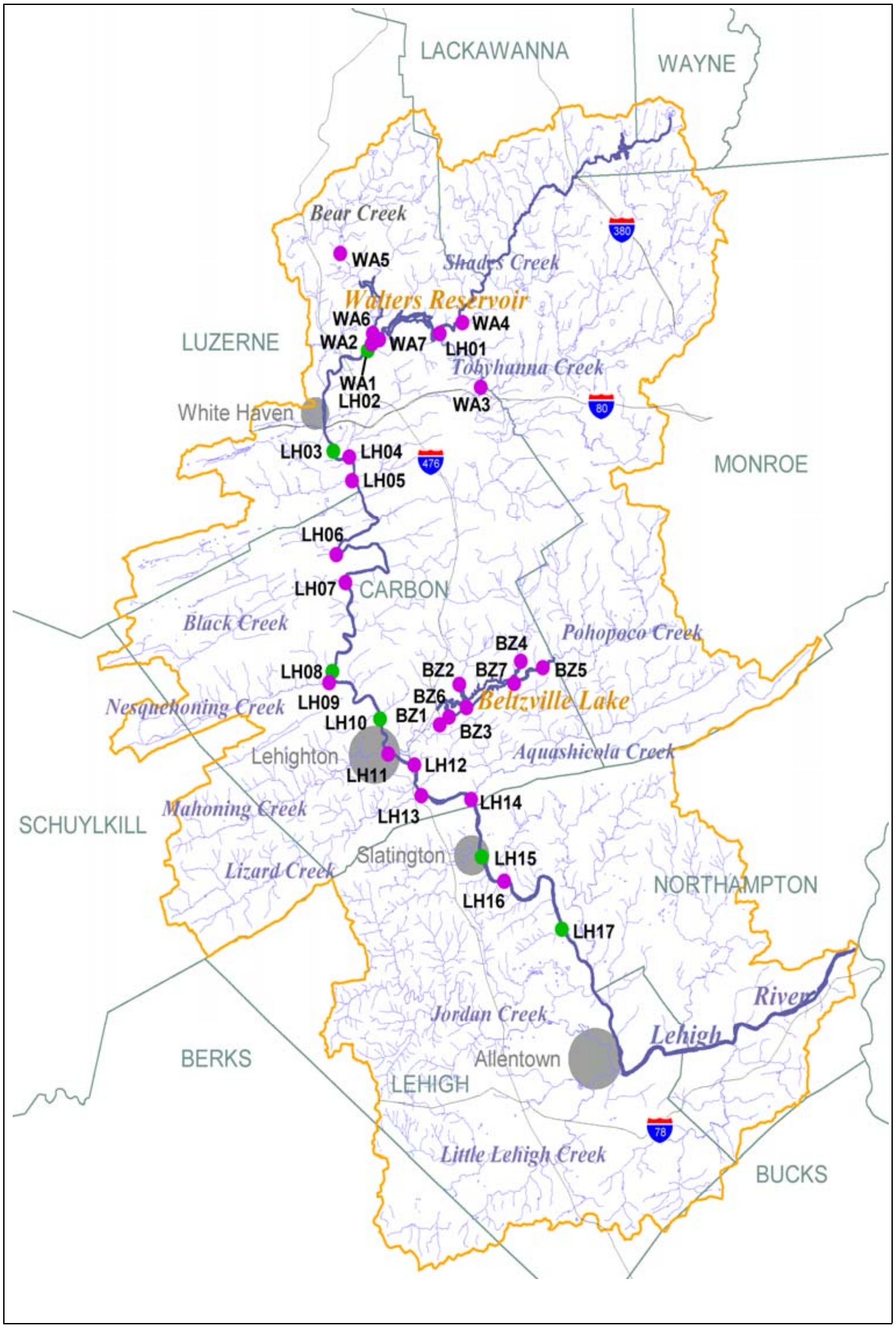


Figure 1. Study site showing temperature monitoring sites (pink indicate tributaries stations and green indicate mainstem stations) on the Lehigh River

Table 2. Lehigh River Water Quality Model Sample Station Location Key

Station	PADEP Water Use Cate-	Watershed Site	Location Description	Latitude	Longitude
LH1	HQ-CWF, MF	Lehigh	Upstream of Walters Dam at confluence of	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 Lehighton sewage treat-	40.82473	75.70050
LH12	CWF, MF	Tributary	Pohopoco Creek leading from Beltzville	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	Reservoir Body	F.E. Walter control tower	41.11404	75.60580
WA-3	HQ-CWF	Tributary	Tobyhanna Creek Gage site upstream of	41.08472	75.60583
WA-4	HQ-CWF	Tributary	Lehigh River Gage Site upstream of Walter	41.13028	75.62583
WA-5	HQ-CWF	Tributary	Bear Creek Upstream of the reservoir at	41.17775	75.75549
WA-6	Not	Reservoir Body	Bear Creek arm of the lake	41.12160	75.71994
WA-7	Not	Reservoir Body	Lehigh arm of the lake	41.11700	75.71260
BZ-1	CWF	Tributary	Downstream of dam outflow at USGS Gage	40.84556	75.64611
BZ-2	CWF, MF	Tributary	Pine Run upstream of the reservoir	40.87151	75.62566
BZ-3	Not	Reservoir Body	Beltzville mid-lake Station	40.86000	75.61664
BZ-4	EV	Tributary	Wild Creek downstream of Pohopoco Drive	40.88954	75.56190
BZ-5	CWF	Tributary	Pohopoco Creek Upstream of Beltzville at	40.88752	75.53818
BZ-6	Not	Reservoir Body	Beltzville Tower Station	40.85192	75.63676
BZ-7	Not	Reservoir Body	Beltzville upstream end of lake	40.87596	75.56719

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

2 Input Data

The following data are required for an application of W2:

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. In-pool data including water surface elevations, temperatures, and constituent concentrations are also required during model calibration in order to assess the performance of the model.

Distinction between initial and boundary conditions and in-pool data is made to help user 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.

Bathymetry

W2 is capable of modeling different water body types such as rivers, lakes, reservoirs, and estuaries. It requires that the water bodies be discretized into longitudinal segments and vertical layers that may vary in length and height. Segments make up branches that can represent a different type water body or a tributary not modeled as a point source. Figure 2 shows an example of a computational grid with four branches representing a reservoir, two tributaries and a riverine branch below the reservoir.

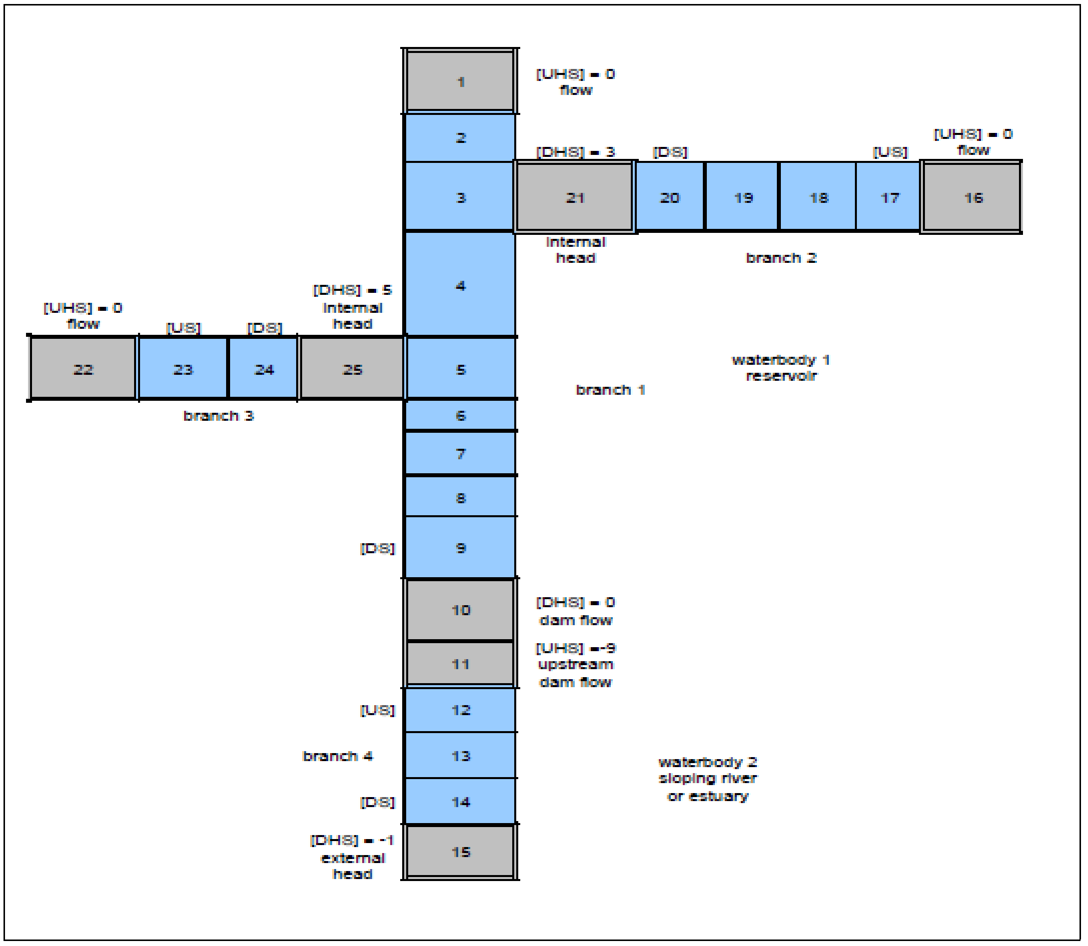


Figure 2. Example grid in the X-Y plane showing cell numbering and branch and water body connections (Cole and Wells 2006).

Because of hydraulic instability on the mainstem of the Lehigh River that made simulation of the complete grid difficult, the bathymetry grid was divided into five grid sections. Each grid section was modeled separately, and outflow from one section became the inflow to another section. There were a total of seven water bodies making up the five sections – two reservoirs and five riverine branches. Figure 3 shows the total grid including all water bodies making up the five sections.

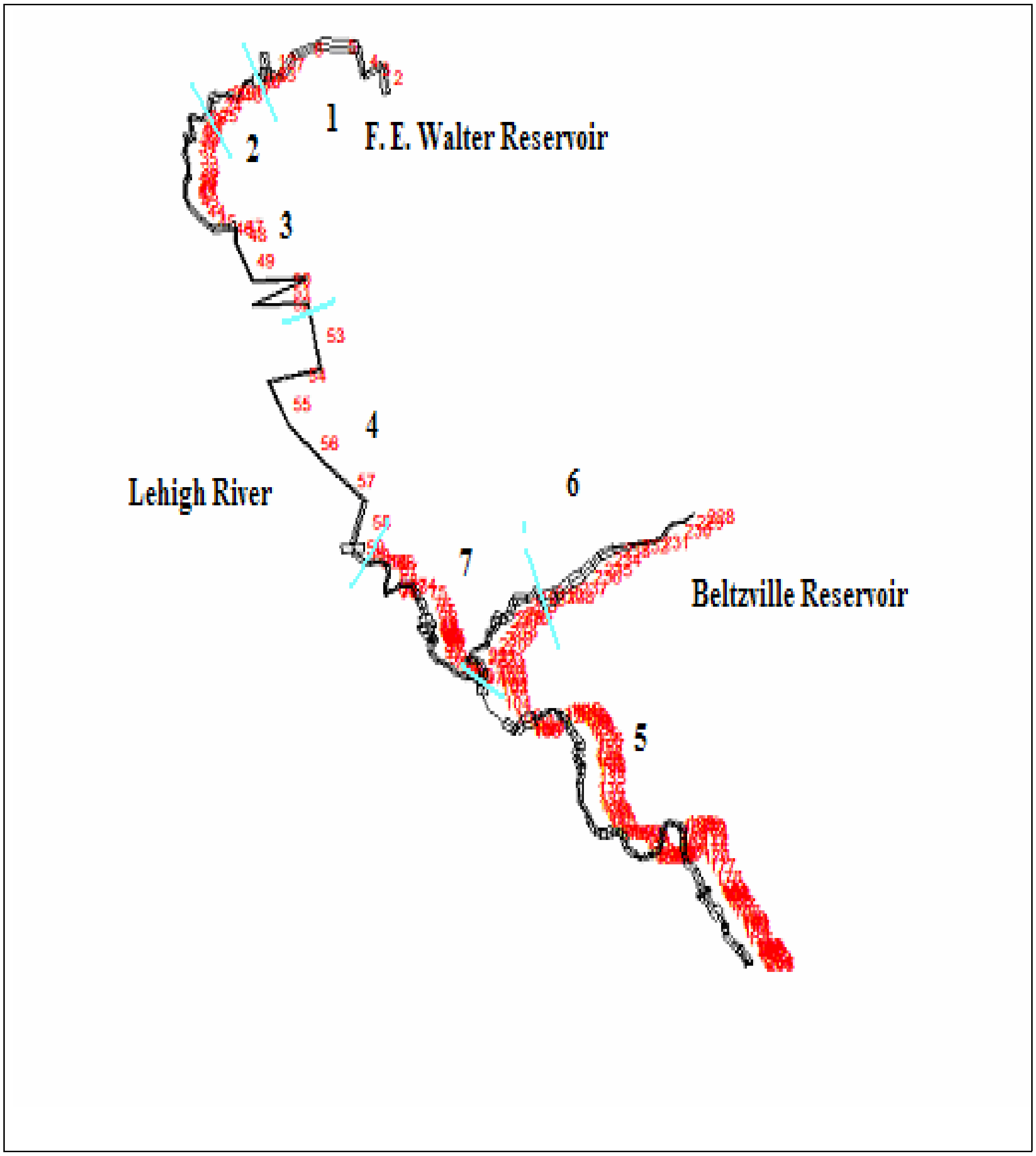


Figure 3. Grid of whole study site of Lehigh River showing seven water bodies.

Figures 4, 5, 6, 7, and 8 show the five grid sections modeled separately and are:

1. Section 1: F. E. Water Reservoir and the first 5545 m (Figure 4) on the Lehigh River.

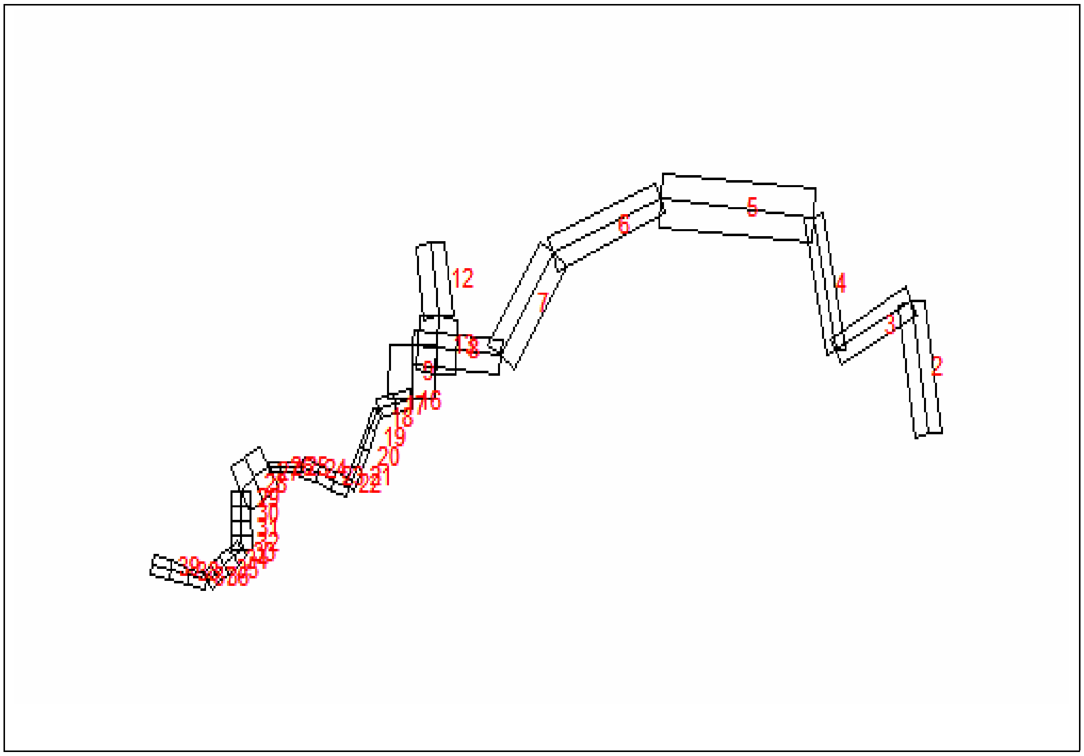


Figure 4. Section 1 grid containing F. E. Walter Reservoir and 22 segments on the Lehigh River.

2. Section 2: approximately 20807 m (Figure 5) below section 1 on the Lehigh River.

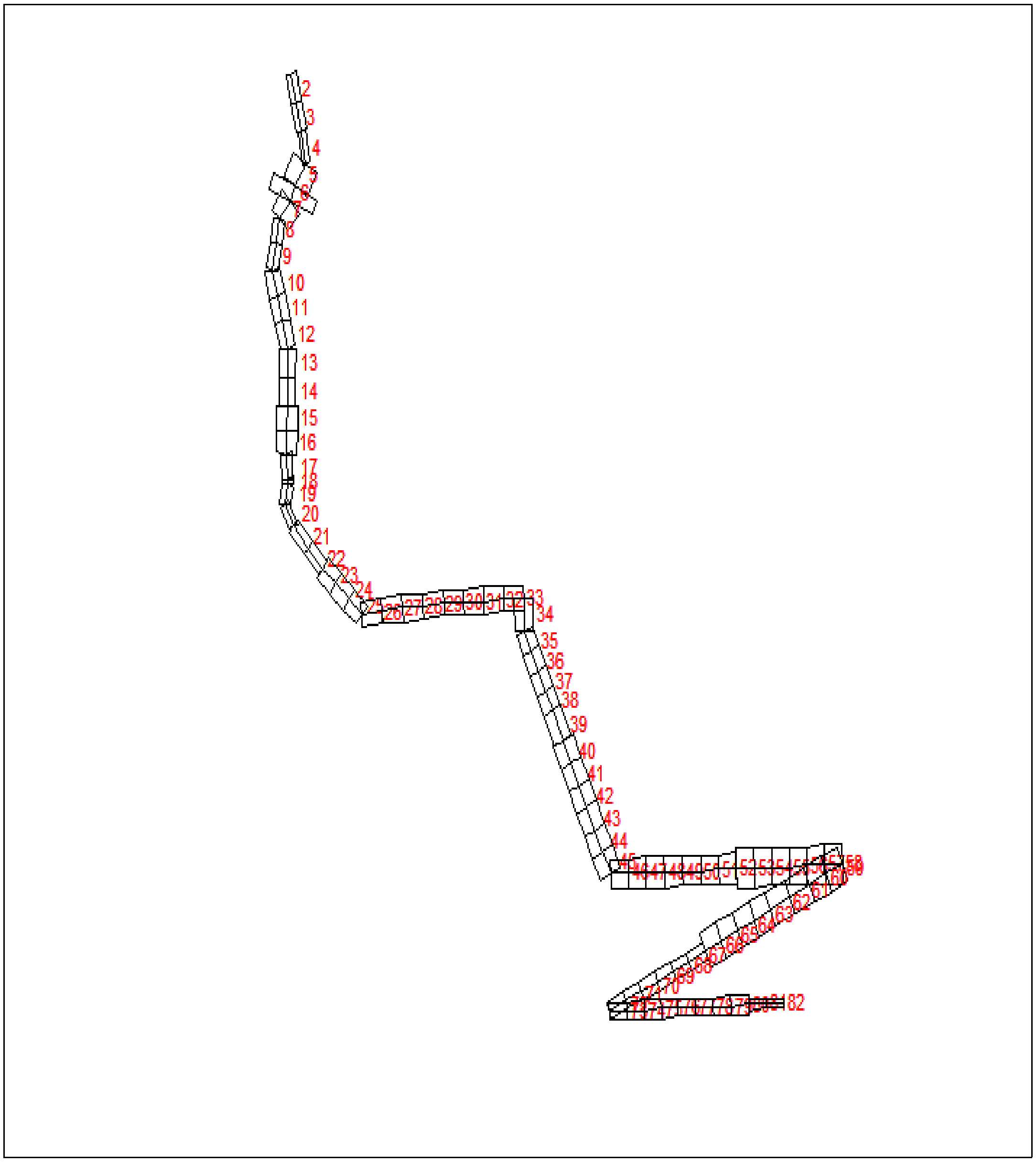


Figure 5. Section 2 containing 81 active segments on the Lehigh River.

3. Section 3: approximately 21698 m (Figure 6) below section 2 on the Lehigh River.

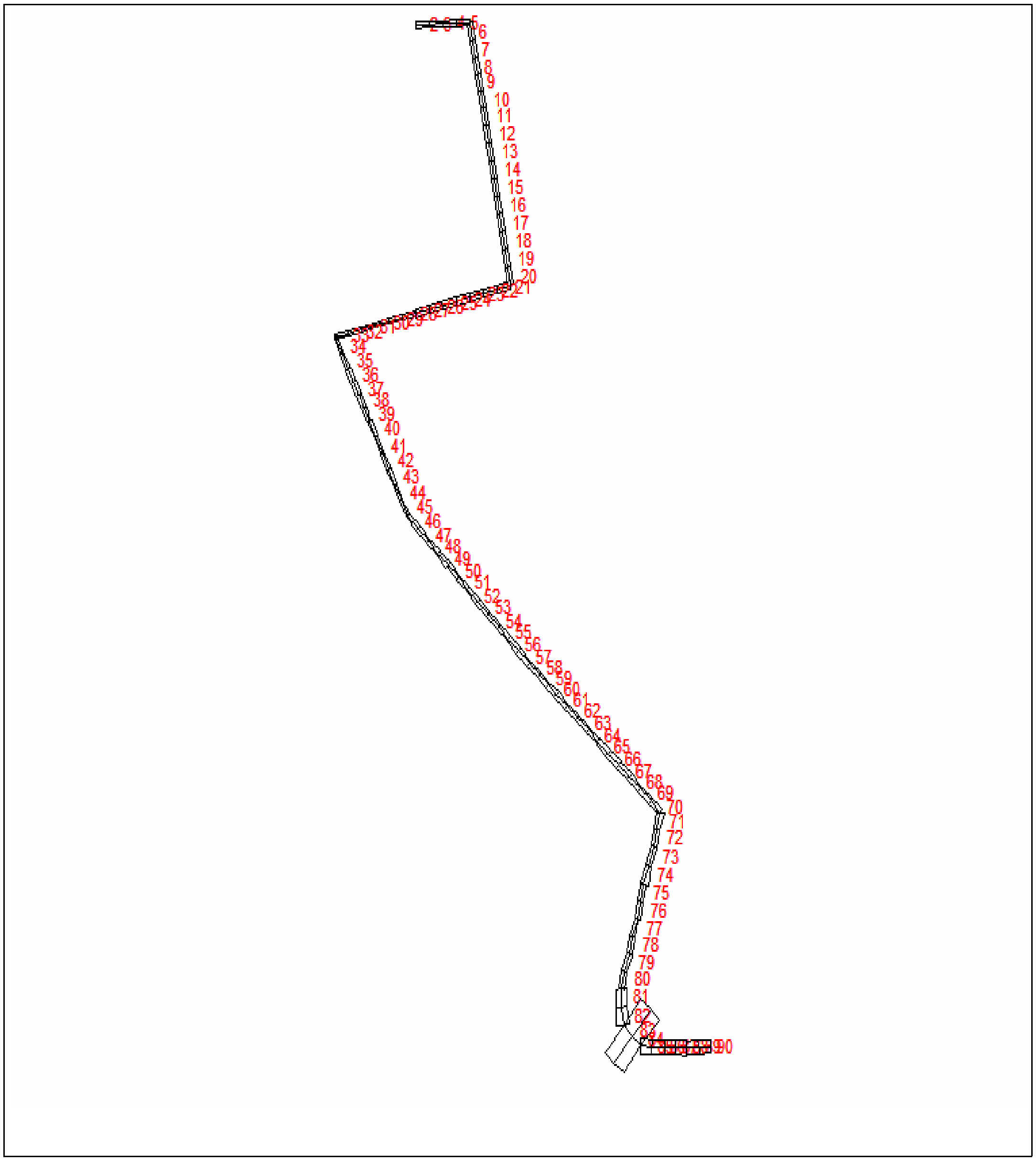


Figure 6. Section 3 containing 89 active segments on the Lehigh River.

4. Section 4: approximately 42976 m (Figure 7) below section 3 on the Leigh River.

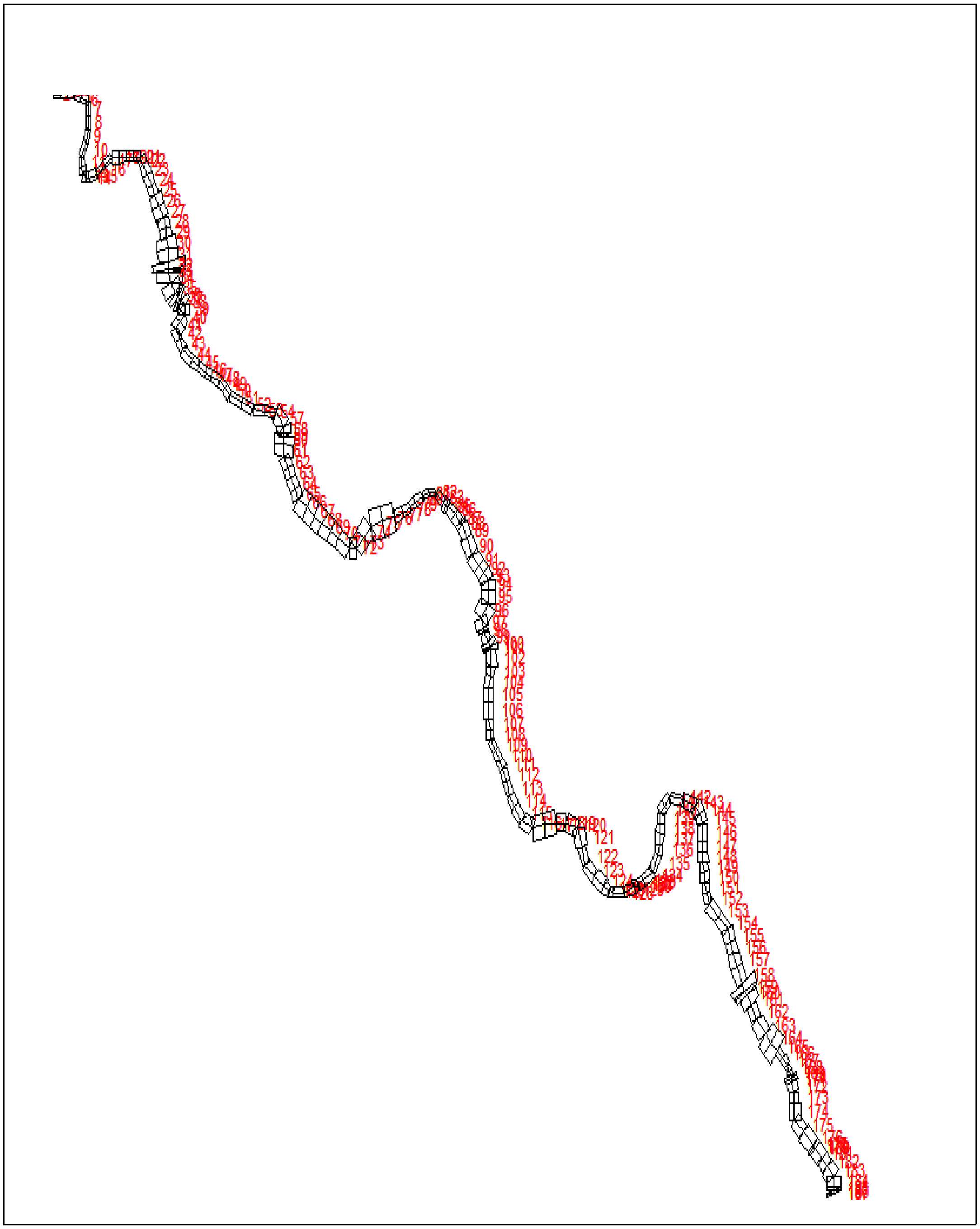


Figure 7. Section 4 containing 183 active segments on the Lehigh River.

5. Section 5: Beltzville Reservoir and 8675 m (Figure 8) on the Pohopoco Creek.

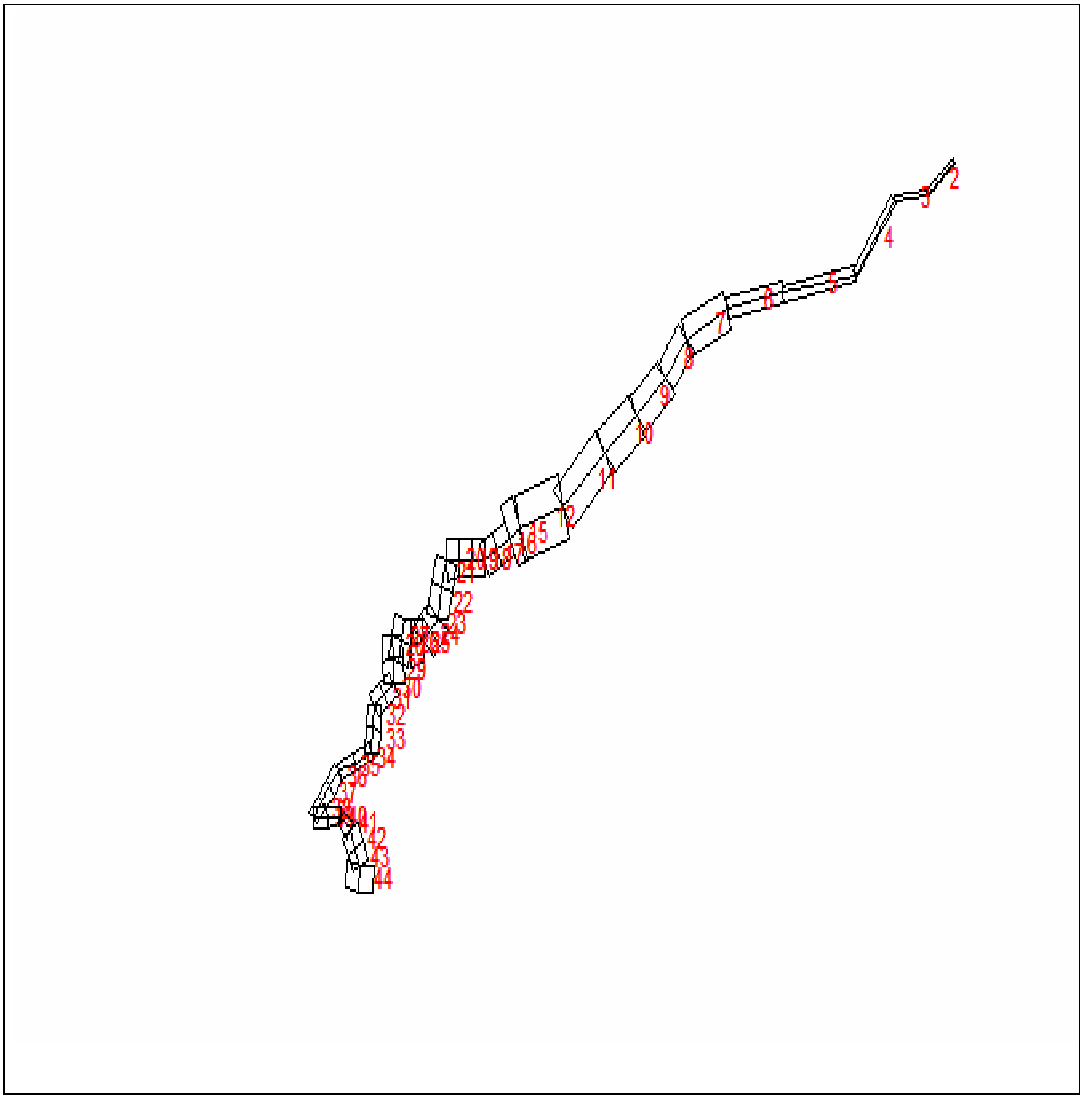


Figure 8. Section 5 containing Beltzville Reservoir (11 segments) and 30 active segments on the Pohopoco Creek.

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.

Section 1

Section 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 4 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 9. The computed versus observed volume-elevation curve closely matches the data from the F. E. Walter Reservoir.

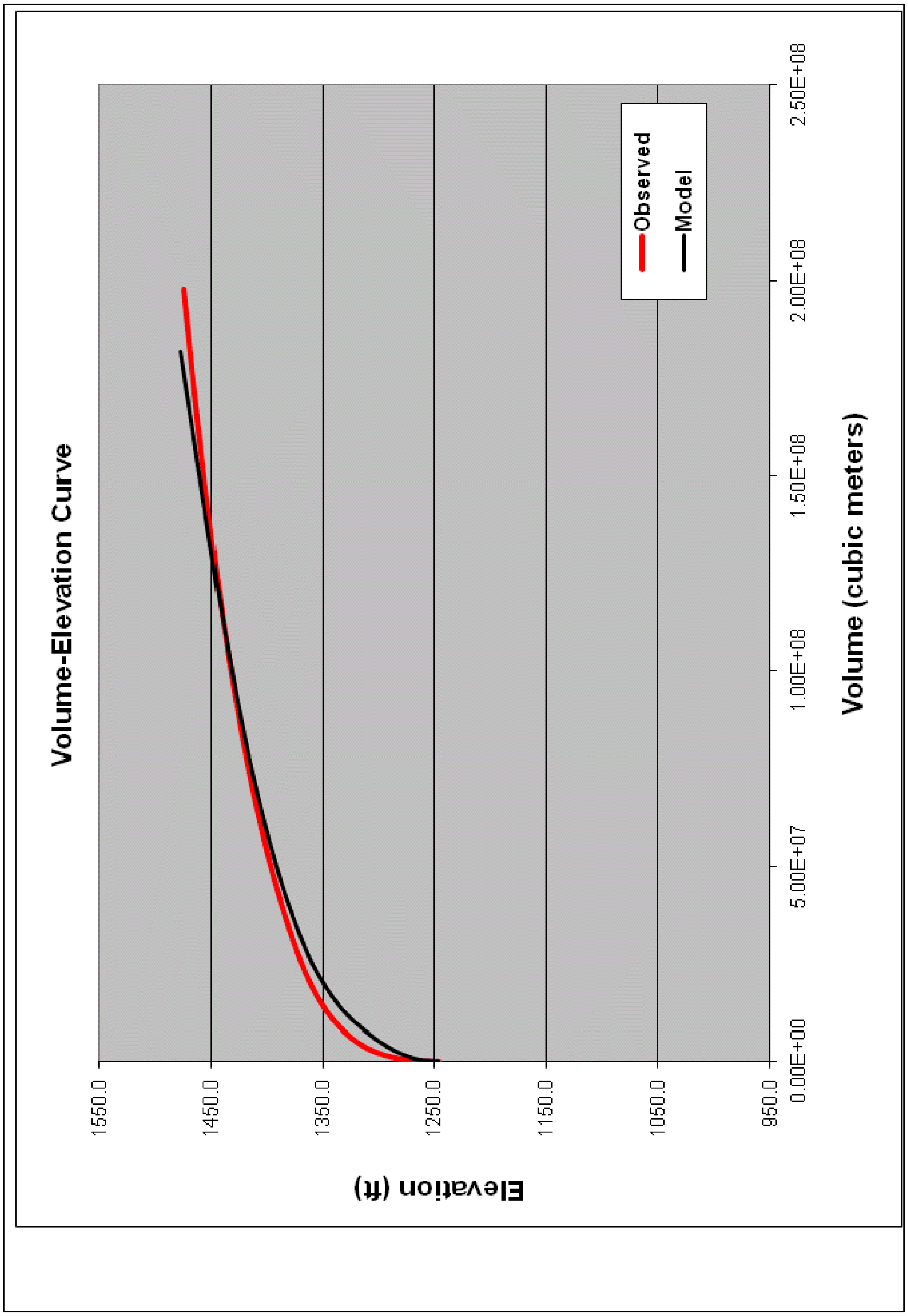


Figure 9. Observed verse model volume elevation curve at F. E. Walter Reservoir.

Section 2

Section 2 consists of one water body with one branch on the Lehigh River below section 1. It contains 81 active segments and a maximum of 179 layers. Segment widths varied from 5 to 673 m. Figure 5 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.

Section 3

Section 3 consists of one water body with one branch on the Lehigh River below section 2 comprising 89 active segments and a maximum of 179 layers. Segment widths varied from 5 to 990 m. Figure 6 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.

Section 4

Section 4 consists of one water body with two branches on the Lehigh River below section 3 comprising 188 active segments and a maximum of 179 layers (Figure 7). Segment widths varied from 5 to 979 m. Figure 7 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.

Section 5

Section 5 consists of two water bodies with two branches on the Pohopoco Creek comprising 41 active segments and a maximum of 179 layers (Figure 8). 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 two representing the Pohopoco Creek below Beltzville Reservoir (Figure 1). A comparison of computed volume-elevation curve and Philadelphia District data is presented in Figure 10. The computed volume-elevation curve closely matches the Philadelphia District data.

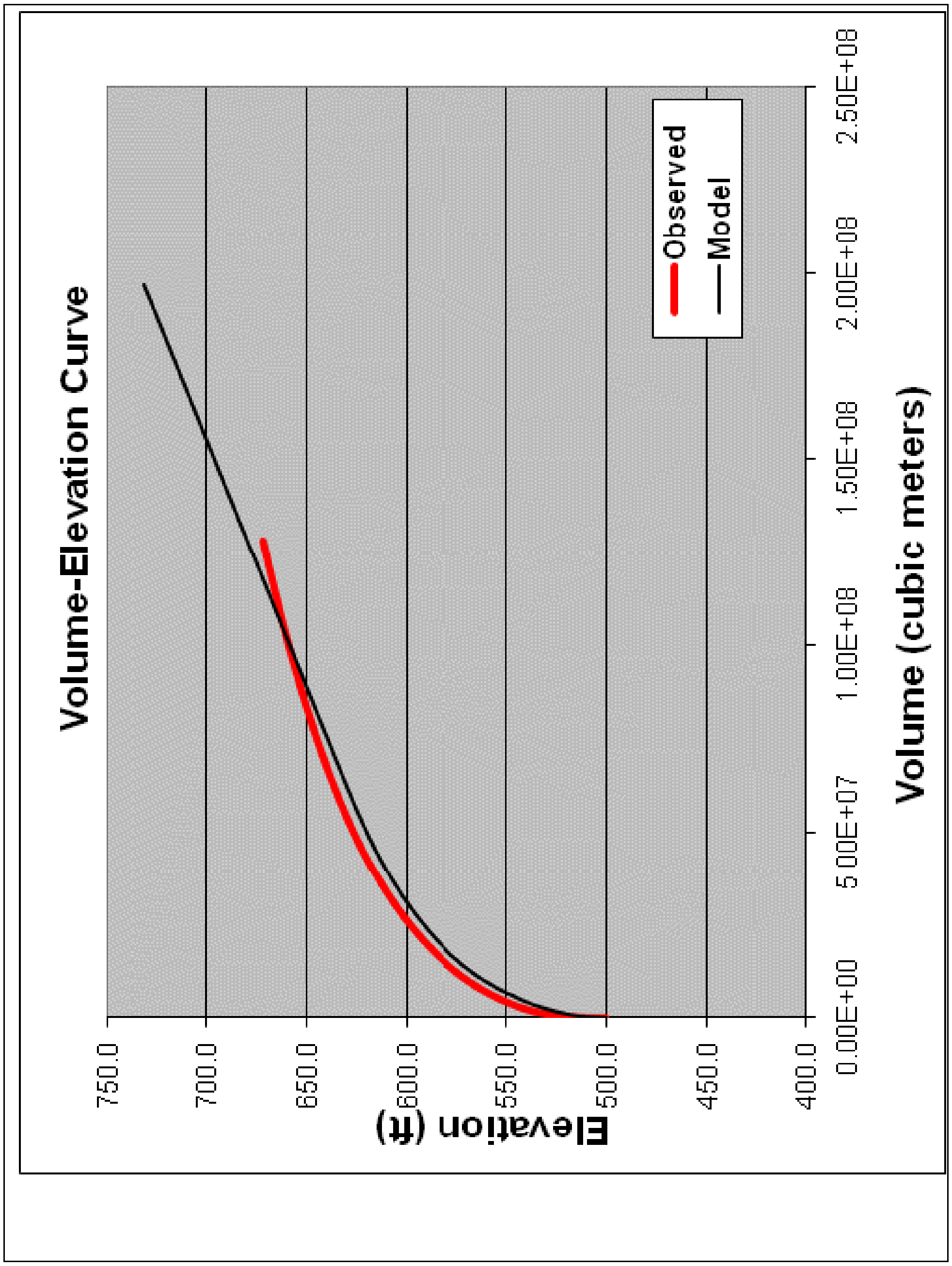


Figure 10. Observed verse model volume elevation curve at Beltzville Reservoir

In-Pool Data

In-pool temperature 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 (Figure 1). For the calibration year 2001, temperature 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. The calibration period was limited by the period tributaries 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 for the reservoirs, option 2 was used at F. E. Walter Reservoir and option 3 was used at Beltzville Reservoir. All riverine sections were initialized using option 1.

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. Additionally, dew point temperature values were not provided but were estimated from relative humidity using the equations:

$$e_{sat} = 4.596 e^{\frac{17.27 * T_{air}}{237.3 + T_{air}}} \quad \text{Eq. 1}$$

Where: T_{air} = air temperature (Celcius)
e_{sat} = saturation vapor pressure,

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

Where: R_h= relative humidity

and

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

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. During calibration and verification, discrepancies in the computed and observed water surface elevations were reconciled by adding or subtracting the appropriate amount of flow using the distributed tributary option in W2. Estimated distributed tributary inflows were calculated using a water balance program developed by Dr. Scott Wells of Portland State University requiring observed water surface elevations, predicted water surface elevations from the initial F. E. Walter calibration results, and estimated reservoir volume-elevation curve from W2. This program will initially compute the additional flows necessary for reproducing observed water surface elevations, but does not guarantee a perfect water balance. Distributed inflows are released into the surface layer weighted according to segment surface area of the designated branch. Figure 11 shows the main reservoir inflows applied at F. E. Walter and Beltzville for calibration and verification while Figure 12 shows the distributed tributary inflow values estimated and applied at F. E. Walter and Beltzville Reservoirs for both years. Because outflow values provided by the Philadelphia District were from the White Haven Lehigh River gage there may be some error introduced because the actual gage is some distance from the dam. This may be the reason for the negative flow values being estimated.

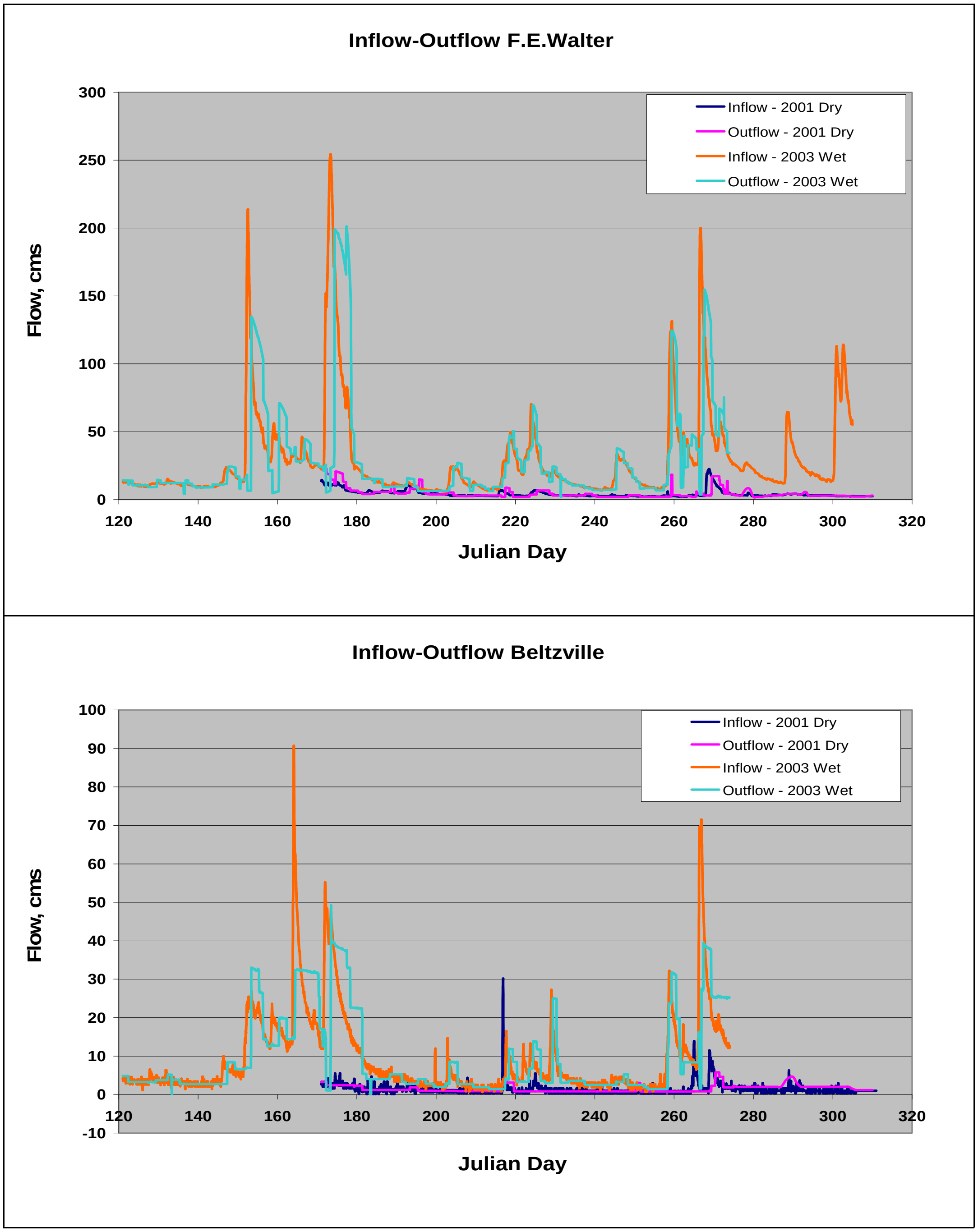


Figure 11. Reservoir inflows and outflows provided by NAP for F. E. Walter Reservoir

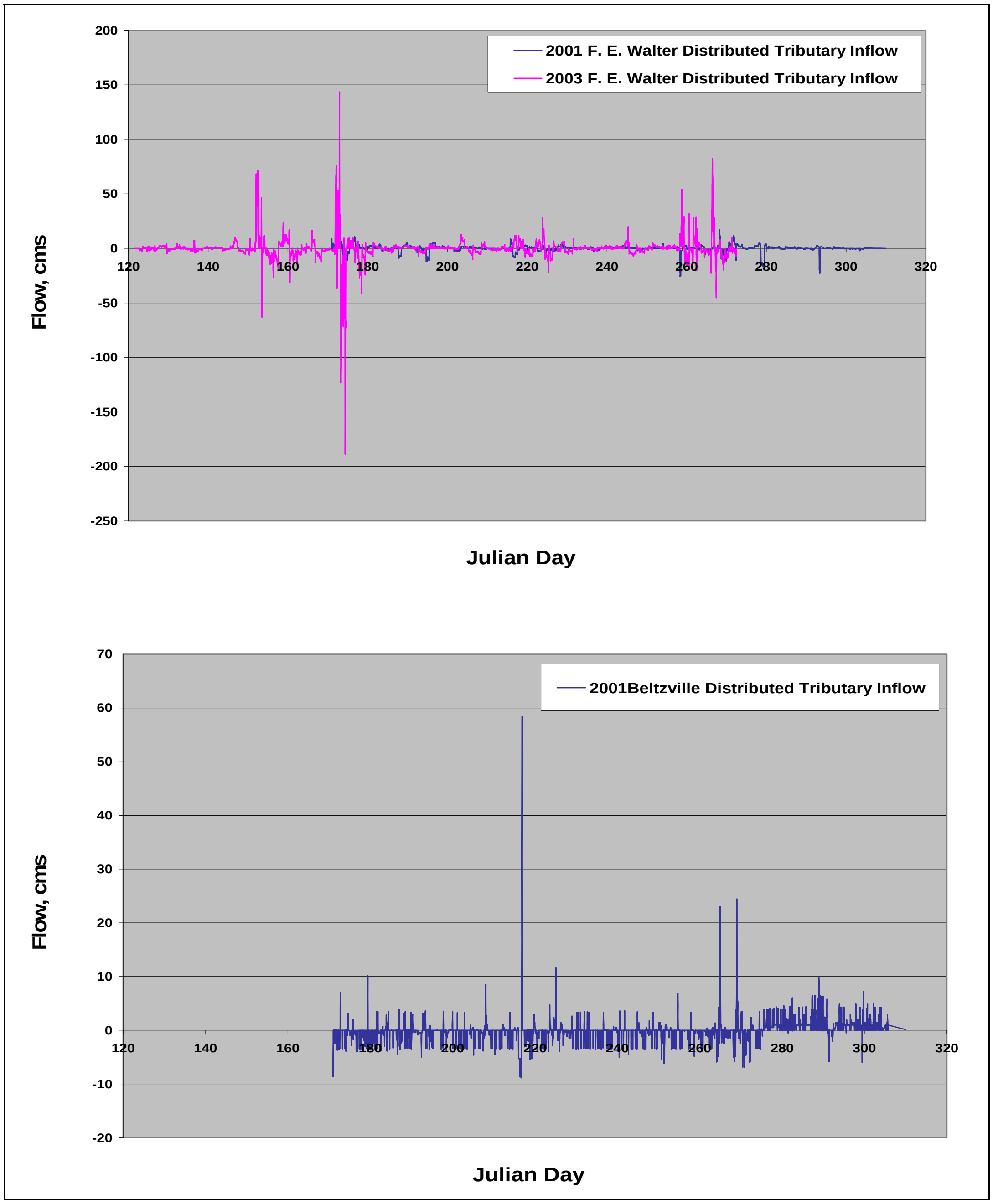


Figure 12. Reservoir distibuted tributary inflows estimated at F. E. Walter (upper) and Beltzville (lower) Resrvoirs

The Philadelphia District only provided tributary inflow data for the calibration year 2001. Inflows for the verification year 2003 were estimated based on linear regression using the Lehigh River flows at Walnutport station and tributary flows from 2001. The flow equations developed for each tributary are presented in Table 3 and Appendix A (linear regression plots).

Table 3. Tributary equations used to estimate 2003 tributary flow

Station	**Equation***	**R-squared**
LH04	Y = 0.0183X + 2.9159	0.6808
LH05	Y = 0.0179X + 12.334	0.2077
LH06	Y = 0.0032X + 6.5232	0.1204
LH07	Y = 0.0349X + 7.9806	0.6529
LHo9	Y = 0.0343X + 3.5233	0.8884
LH11	Y = 0.0293X – 0.495	0.6194
LH13	Y = 0.0506X + 3.393	0.7293
LH14	Y = 0.0519X + 14.007	0.5609
LH16	Y = 0.0021X + 2.0915	0.2437

*Note X equals independent variable, Walnutport flow.

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 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

The Philadelphia District provided reservoir inflow temperature 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.

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 plots present how distribution of the predicted values compare with observed distribution. Cumulative distribution may be presented as a number between zero and one or as a percent on the X-axis. If it is plotted as a decimal number between zero and one, it can be assumed as a percentage by multiplying by 100.

When interpreting temperature 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. A value of zero for ME would also indicate complete agreement between predicted and observed. The equation is:

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

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:

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

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:

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

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

Table 4 gives the values for all hydraulic and temperature parameters available for adjustment in the model. Values of parameters were the same between reservoirs. Riverine coefficients were the same except Manning's n roughness coefficient in the riverine sections were variable with values ranging from 0.03 to 0.10.

Table 4. Reservoir Hydraulic and Temperature Coefficient Calibration Values

Coefficient	Variable	F. E. Walter	Beltzville
Horizontal eddy viscosity	AX	1.0 $m^2\ s^{-1}$	1.0 $m^2\ s^{-1}$
Horizontal eddy diffusivity	DX	1.0 $m^2\ s^{-1}$	1.0 $m^2\ s^{-1}$
Manning's n bottom friction factor	Manning's n	0.03	0.03
Wind-sheltering	WINDSH	0.85	0.85
Fraction solar radiation absorbed at water surface	BETA	0.45	0.45
Light extinction for pure water	GAMMA	0.25 m^{-1}	0.25 m^{-1}
Coefficient of bottom heat exchange	CBHE	7.0 * 10^{-8} ºC $m^{-1}\ s^{-1}$	7.0 * 10^{-8} ºC $m^{-1}\ s^{-1}$

Calibration Results and Discussion

The results will be presented for each section of the grid beginning with section 1 containing F. E. Walter Reservoir and proceed immediately downstream.

F. E. Walter Reservoir

WSEL: Water surface elevations are predicted by the model based on the interactions between inflows, outflows, evaporation, and precipitation. Since the inflows provided include the effects of evaporation and precipitation, these options were not used during calibration. As discussed previously, any discrepancies between computed and observed elevations were eliminated by including either positive or negative inflows in the distributed tributary inflow file. Distributed tributary inflows enter the surface layer of all segments in a branch and are apportioned according to the surface area of each segment and represent unaccounted for nonpoint sources, groundwater or loss of flow by leakage at the dam. As shown in Figure 13, predicted elevations closely matched observed elevations.

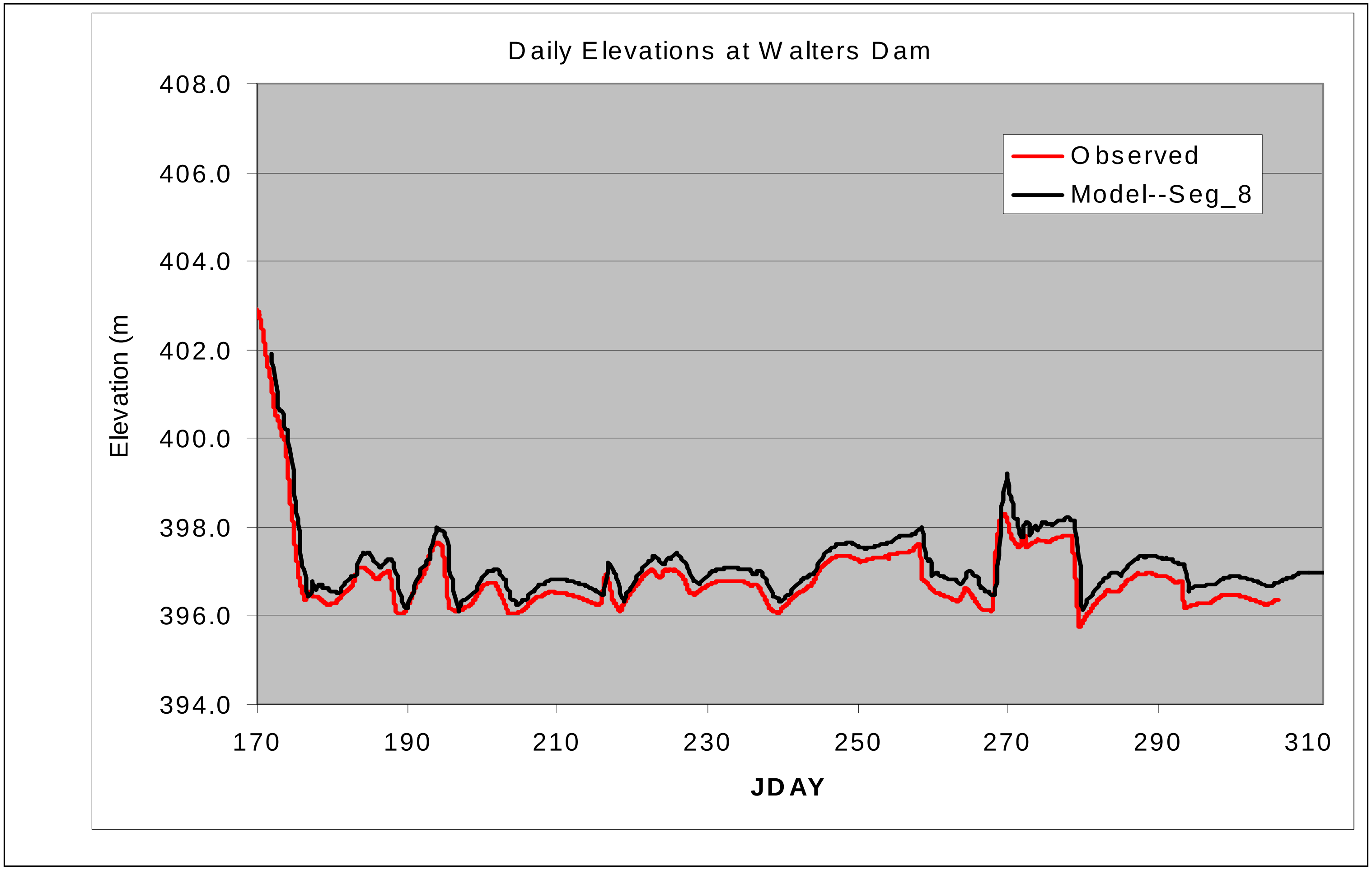


Figure 13. Predicted versus observed water surface elevation (WSEL) at F. E. Walter Reservoir with bottom elevation a t 379.5 m (1245 ft NGVD) for 2001.

In-Pool stations: Figures 14 through 16 show calibration profile results for F. E. Walter stations WA02, WA06 and WA07, respectively. Profile data at F. E. Walter Reservoir do not show much stratification through the simulation period. W2 is able to reproduce this behavior. Results show good agreement with observed data. Overall, ME values for the profiles range from -0.84 to 0.31 and indicate the model slightly under predicts temperaures especially in the hypolimnion. AME values are within the observed value range approximately +/- 0.2 to 0.84 ^{o}C, and finally, the RMS indicates a deviation from the observed in the range of 0.2 to 1.2 ^{o}C with only one date above 1 ^{o}C. These results are comparable to model performance at Allatoona and West Point Reservoirs (Cole and Tillman 2001).

The Cumulative Distribution plot (Figure 17) denotes that 60% of the time most predicted data is close to observed with slight under predictions between 10 and 15 ^{o}C at station WA02 and WA07. At higher temperatures (>22 ^{o}C), W2 is under predicting temperatures slightly at stations WA02 and WA07. At WA06 there is good agreement between observed and predicted data (Figure 17). The cumulative distribution plots for all F. E. Walter stations demonstrate what is indicated by the ME for the W2 results – overall, the model slightly under predicts.

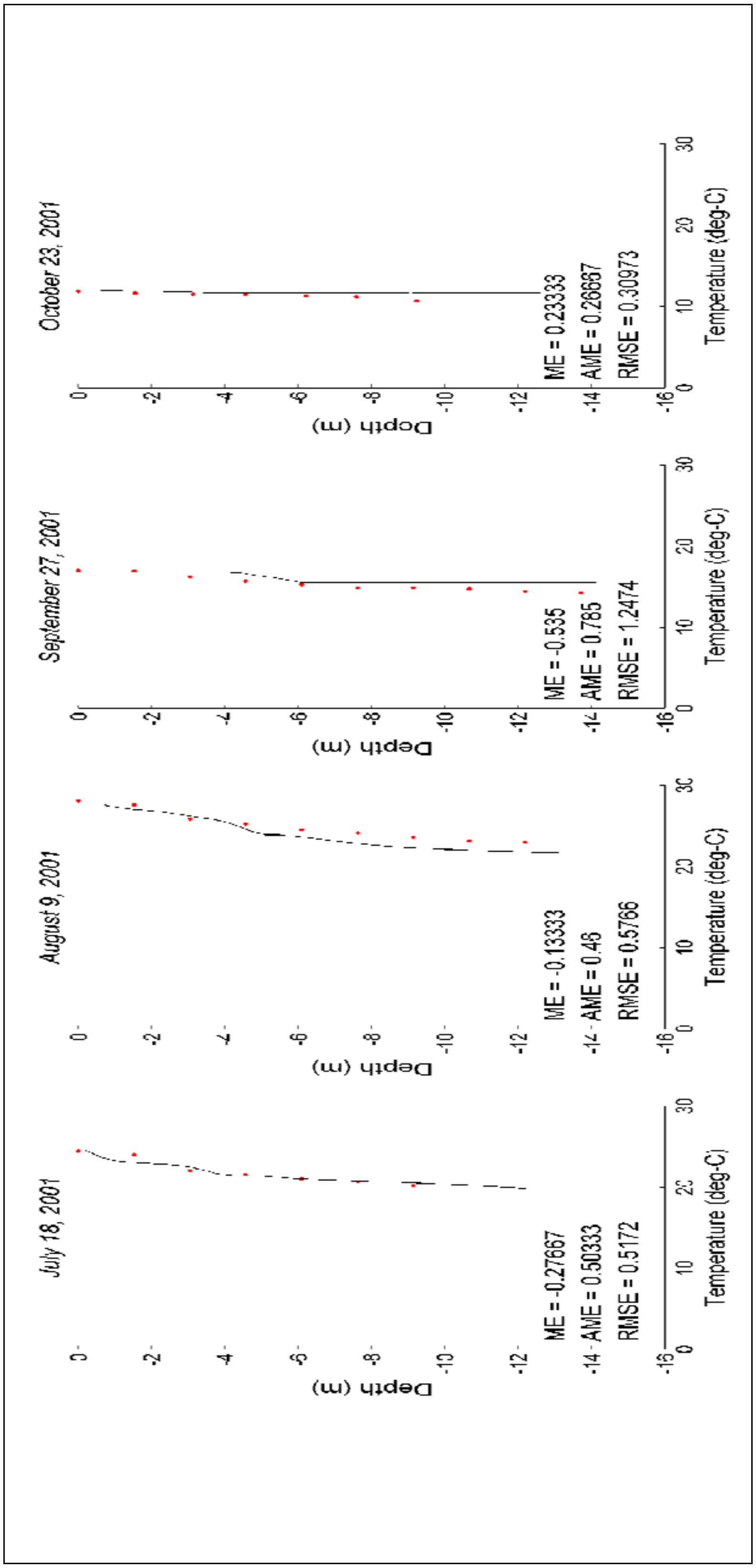


Figure 14. 2001 Calibration results (red dots = observed and black line = modeled) for station WA02 at F. E. Walter Reservoir.

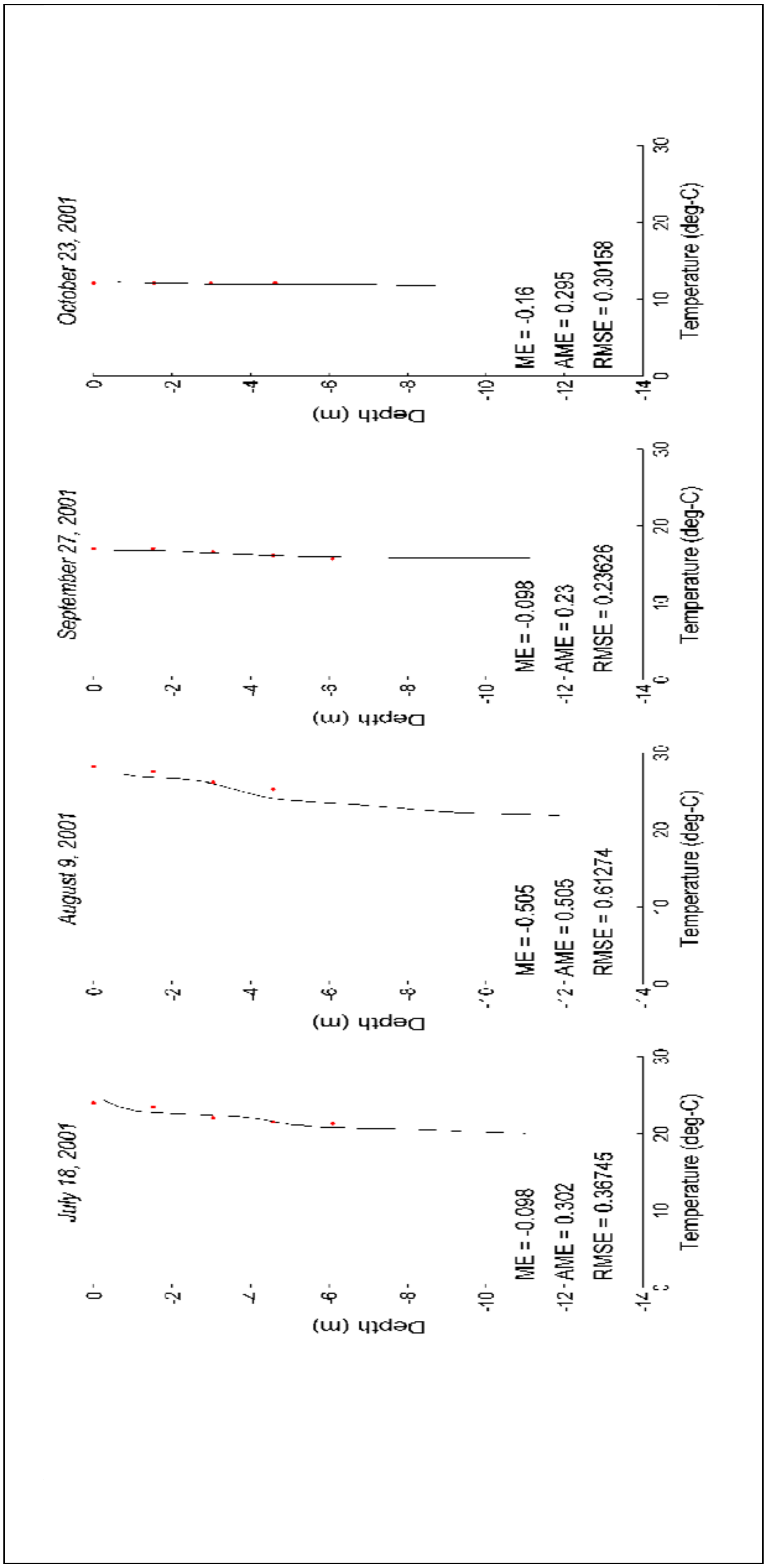


Figure 15. 2001 Calibration results (red dots = observed and black line = modeled) for station WA06 at F. E. Walter Reservoir.

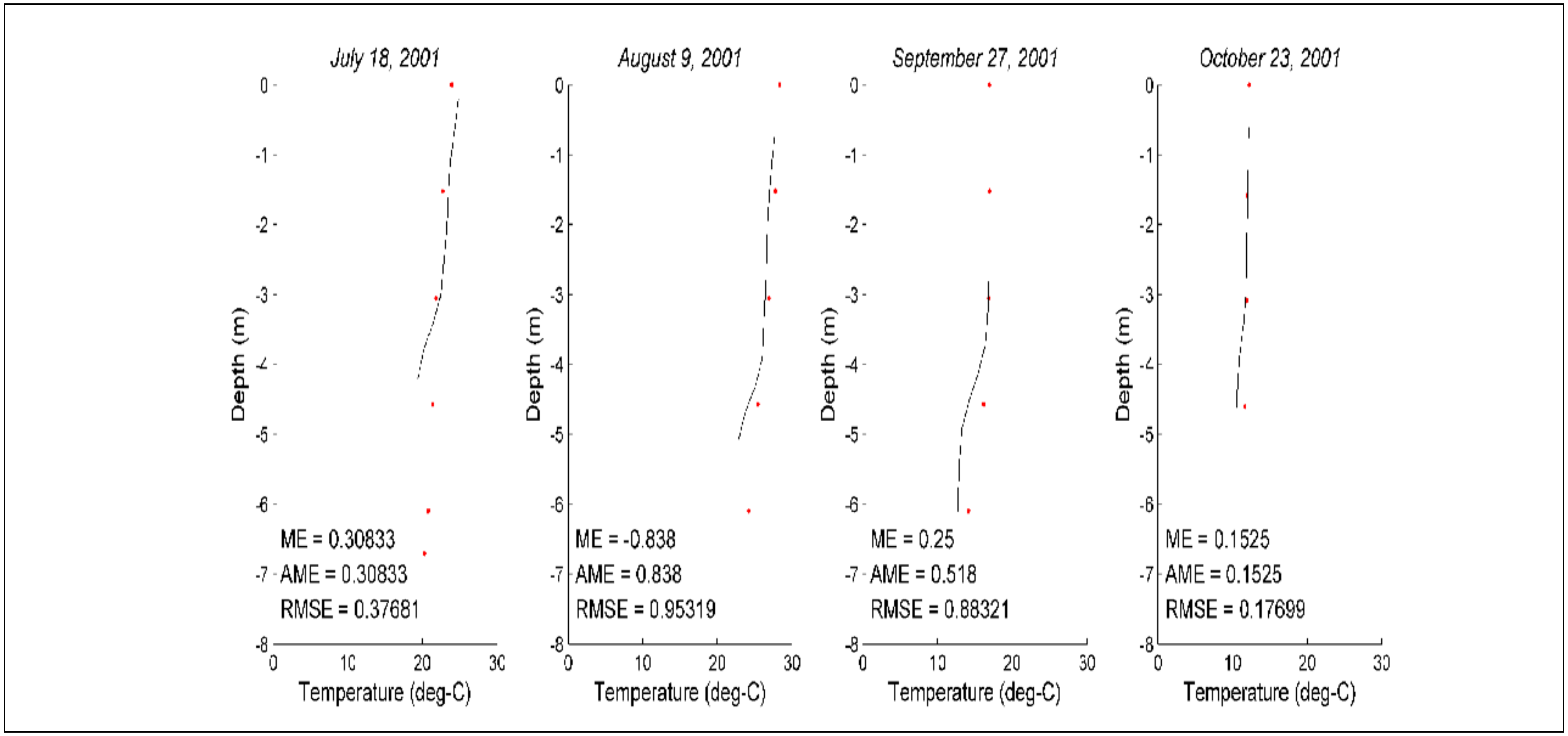


Figure 16. 2001 Calibration results (red dots = observed and black line = modeled) for station WA07 at F. E. Walter Reservoir.

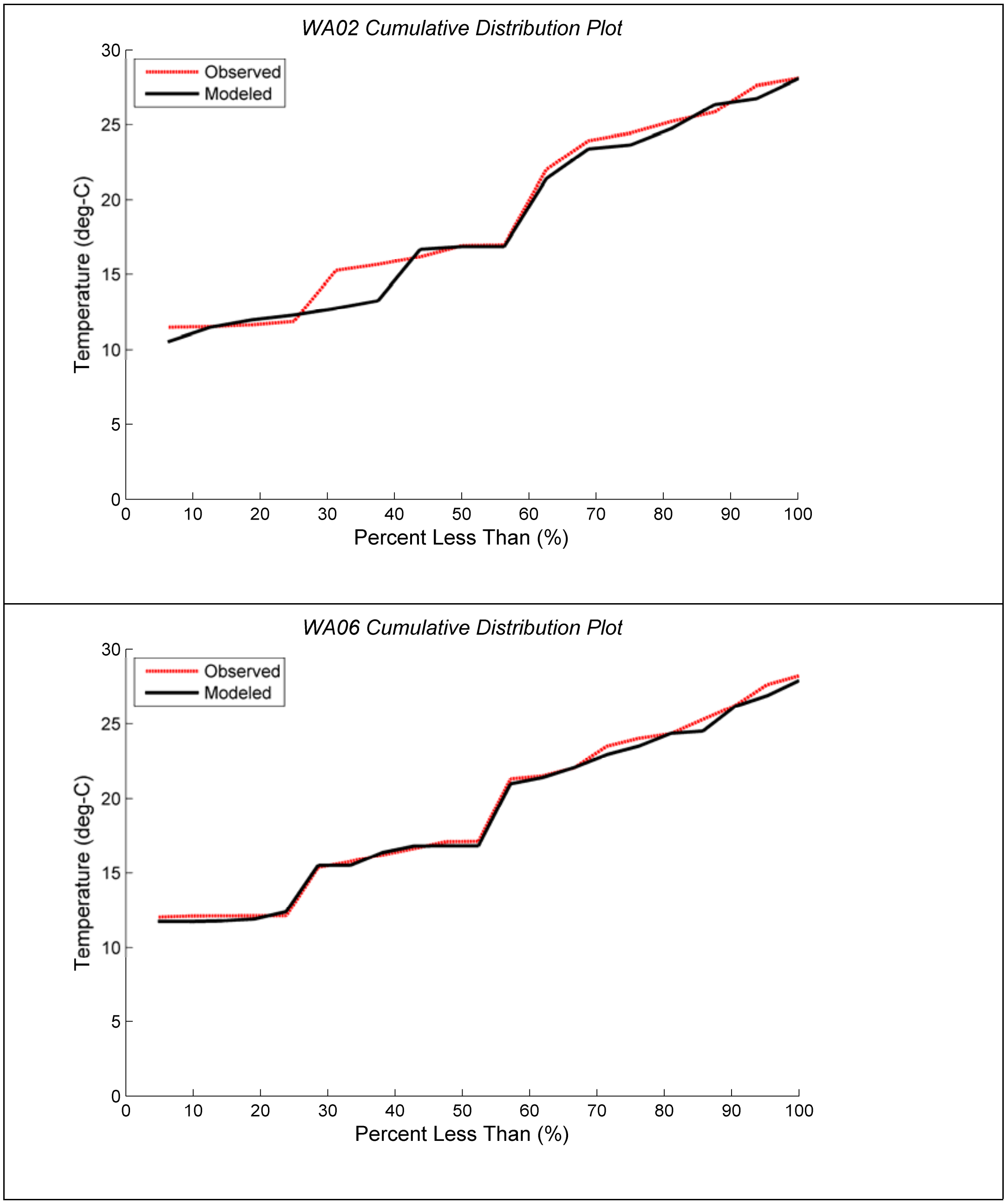


Figure 17. Model versus observed Cumulative Distribution for F. E. Walter Reservoir for stations WA02, WA06 , and WA07

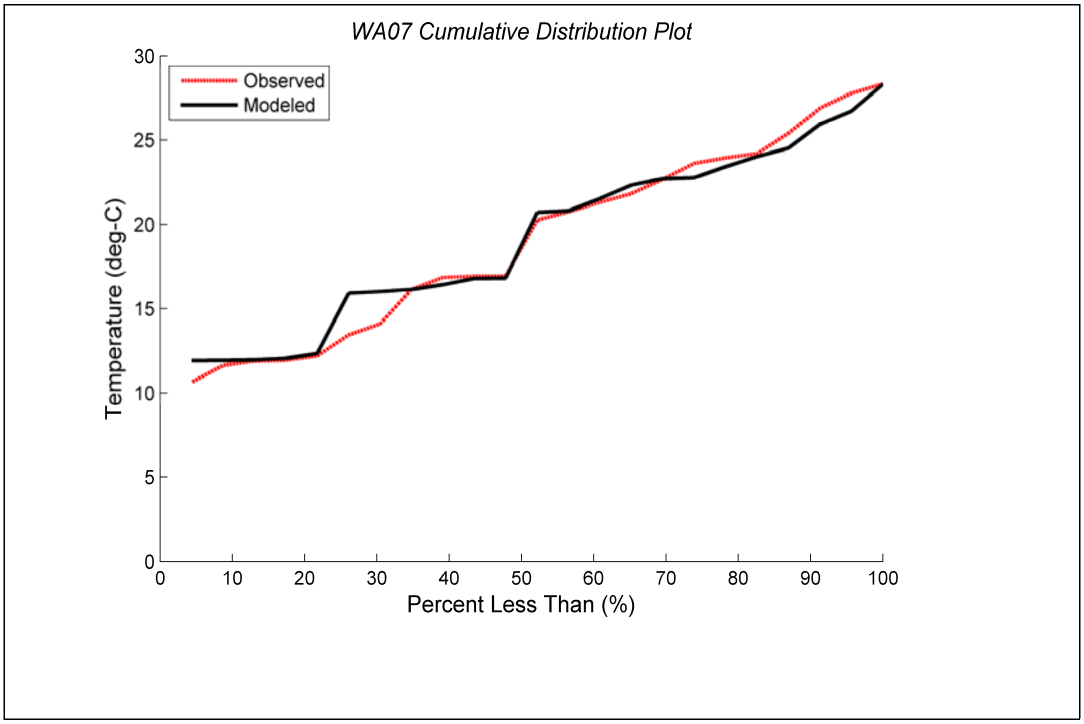


Figure 17. Concluded

Lehigh River

Riverine stations: Figure 18 contains calculated WSEL data for station LH02 and LH10 on the Lehigh River. At station LH02, W2 under predicts WSEL approximately 0.2 m or less. Adjustments to bottom elevation of ending segment and slope of branches were made to improve comparisons to observed WSEL. Differences between observed and model WSEL at station LH02 could be attributed to not accounting for ungaged flows (i.e. possibly leakage from the dam or groundwater). Differences in WSEL to observed data did not seem to affect temperature predictions adversely. Temperature predictions at this location were more affected by release conditions from the dam. Also in Figure 18, flow predictions at LH02 were compared with observed data and followed observed trends very well. Around Julian day 225 and 270 at station LH10 there appears to be a flow event that was not reflected in the boundary conditions. Since tributary flow boundary conditions were only available on a weekly to bi-weekly basis it is possible that a storm event occurred but was not represented in the data. Predicted WSEL at this station matched observed very well and on average was usually within 0.1 m.

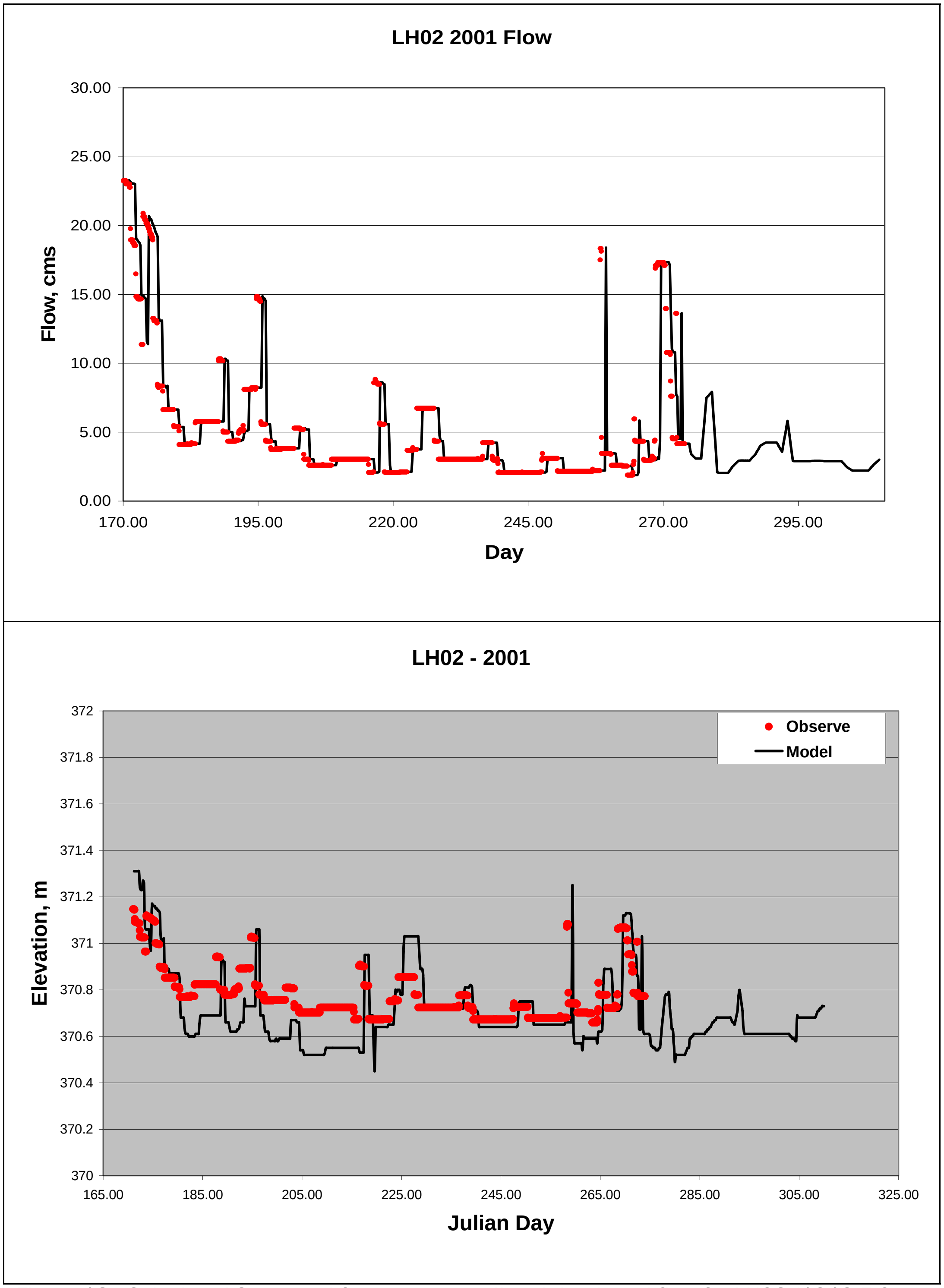


Figure 18. Calculated Stage and flow versus predicted depth and flow for LH02 (1212.5 ft NGVD) and LH10 (444.6 ft NGVD) on the Lehigh River (continued).

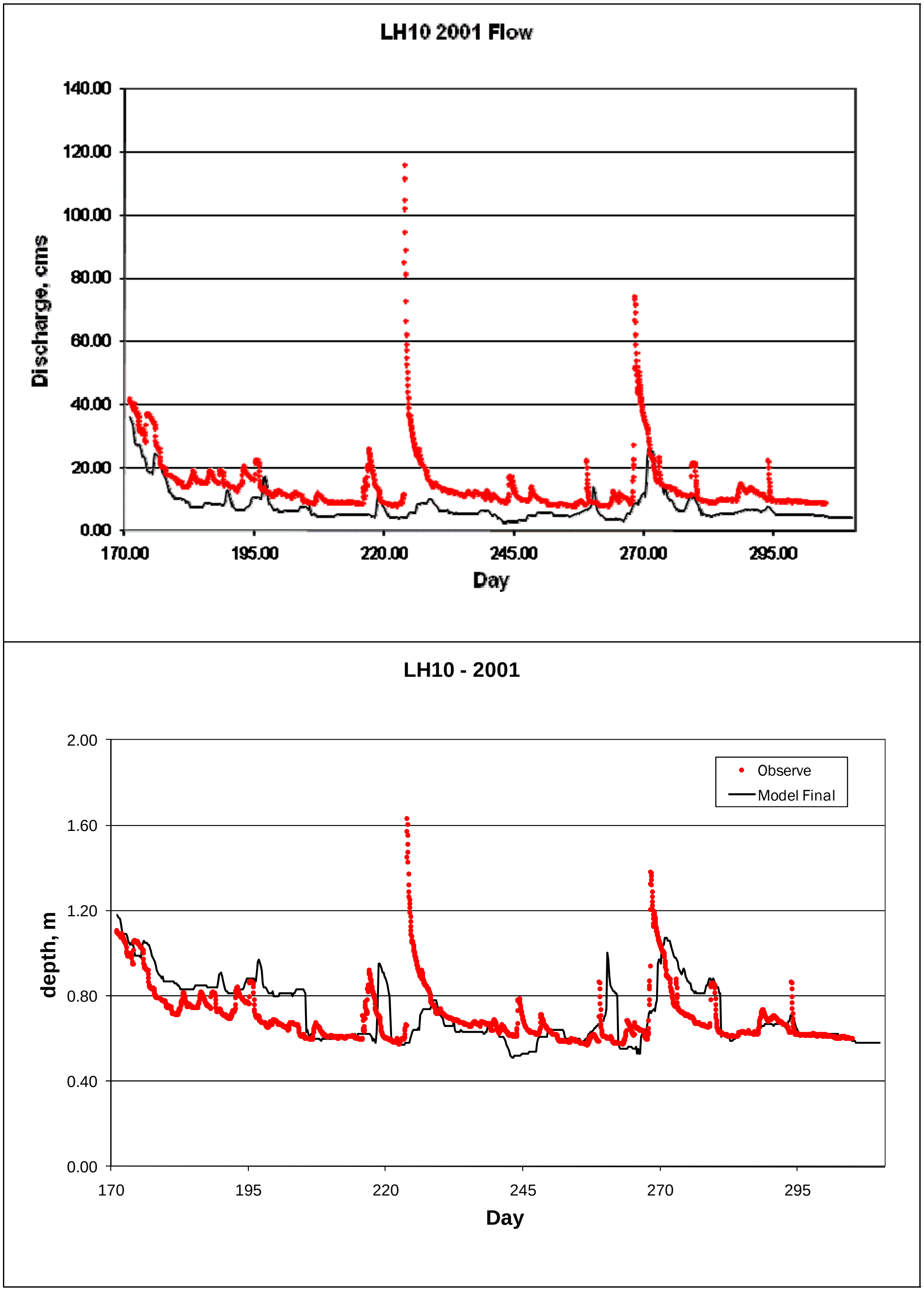
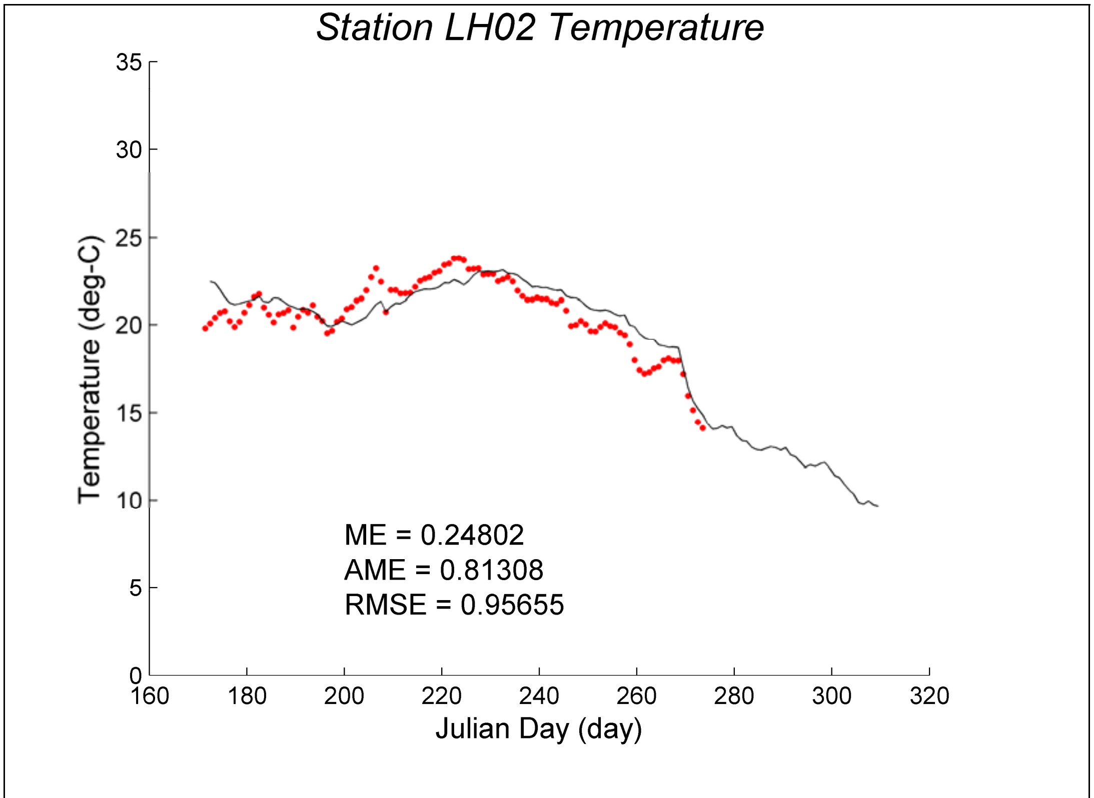


Figure 18. Concluded.

Figure 19 contains temperature results for all river stations beginning with LH02 and ending with LH17. Each plot contains the three statistics used to measure model performance. The trend of observed data of almost having a cyclic pattern occurring about every two weeks is being reproduced by W2. Also, the decrease in stream temperatures from August through November (Julian Day 213 through 310) is being predicted by W2. Overall W2 does very well in predicting average temperature through the Lehigh River downstream reaches. ME values range from -0.04 to 0.5 and indicate at most stations W2 slightly over predicts temperature. The only station where the ME value shows temperatures are not being over predicted is LH17. The AME indicates that on the average W2 is predicting temperature values within 1 ^{o}C and the spread of the predicted data to observed (RMS) is from 1.03 to 1.30 ^{o}C. These results show model performance is similar to results for the Spokane River in Oregon (Berger et al. 2002).

Cumulative Distribution plots in Figure 20 show most of the under predictions are for temperatures below 20 ^{o}C. Over prediction occurs in the temperature range of 20 to 25 ^{o}C. It is possible that during low flow periods water may heat up more than what is actually occurring. This may be caused by the differences in WSEL or meteorological data from Allentown being used for the Lehigh River.



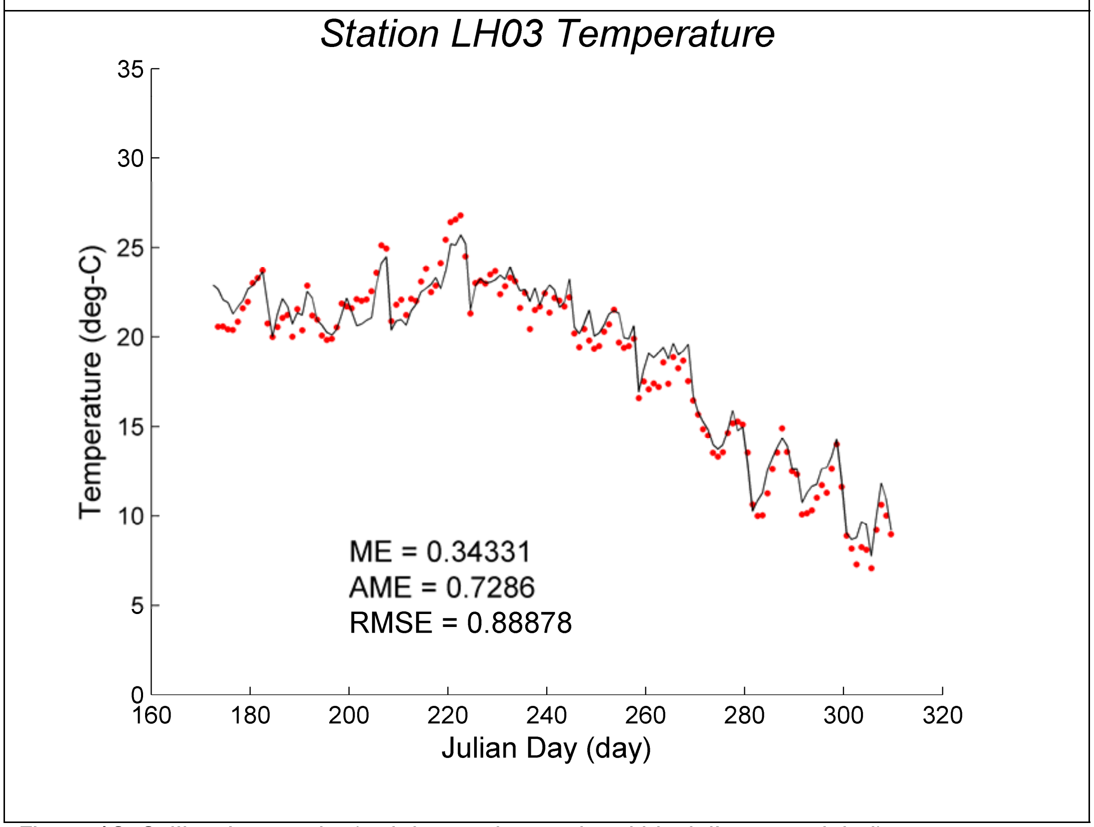


Figure 19. Calibration results (red dots = observed and black line = modeled) for LH02, LH03, LH08, LH10, LH15, and LH17 on the Lehigh River (continued).

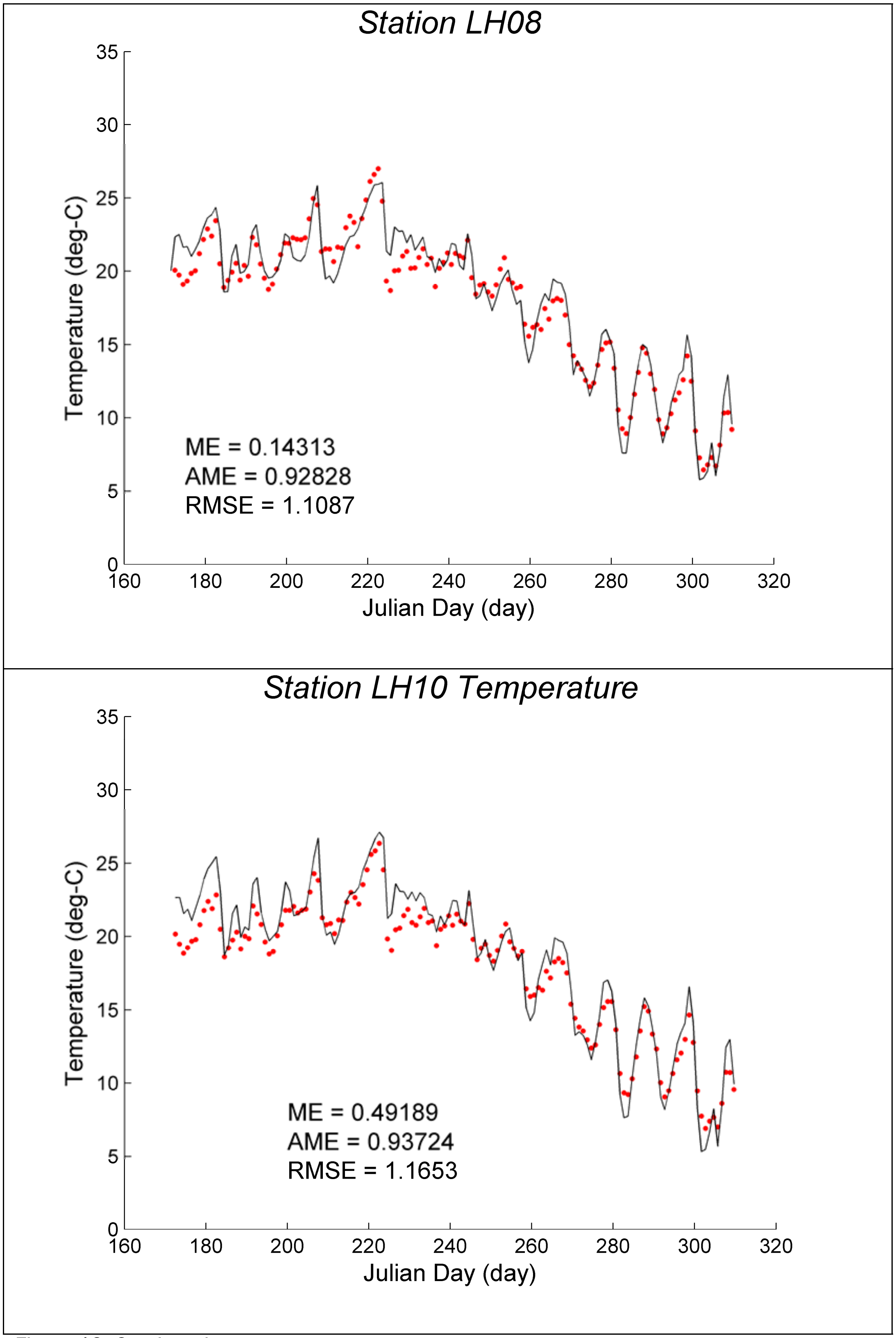


Figure 19. Continued.

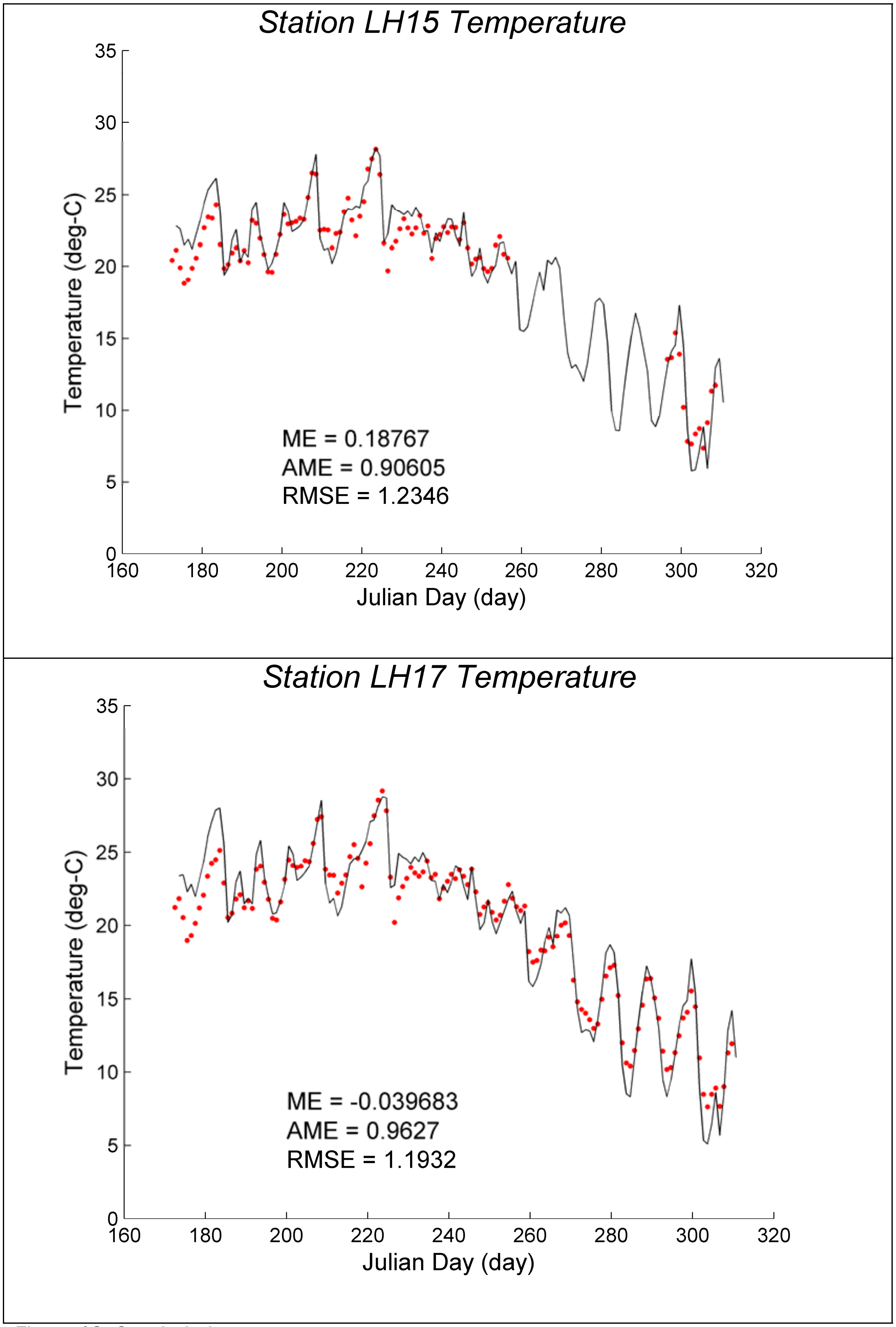
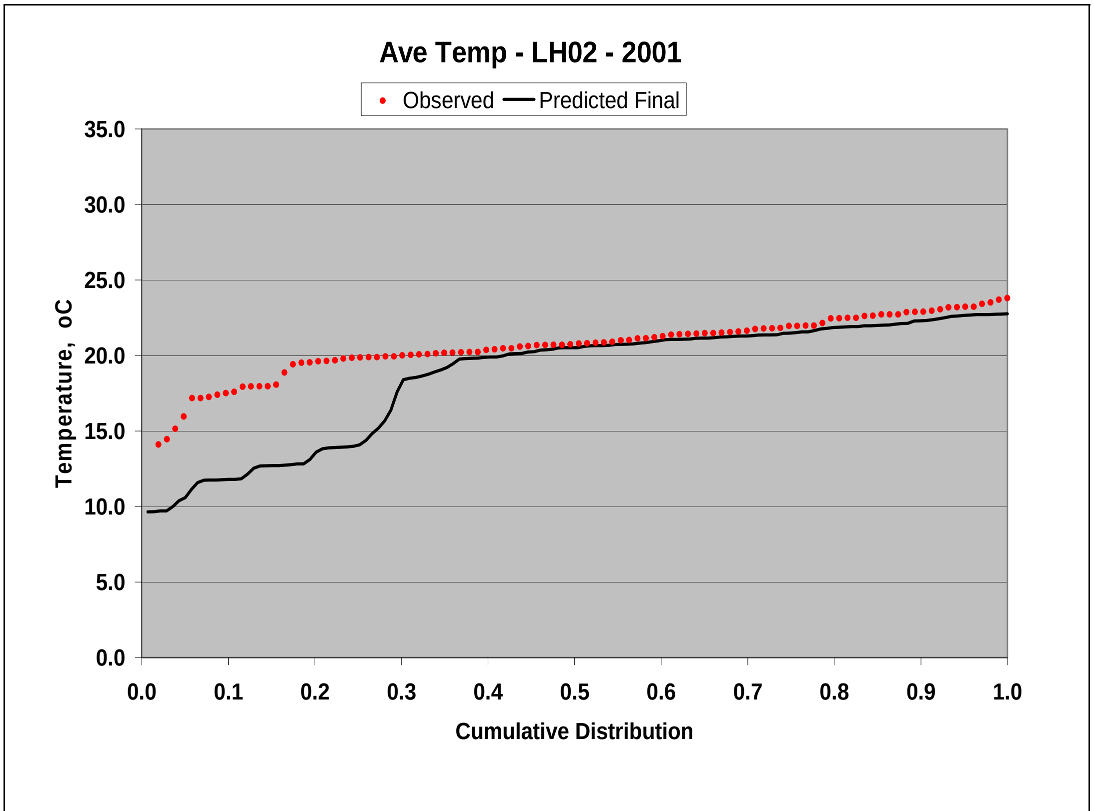


Figure 19. Concluded.



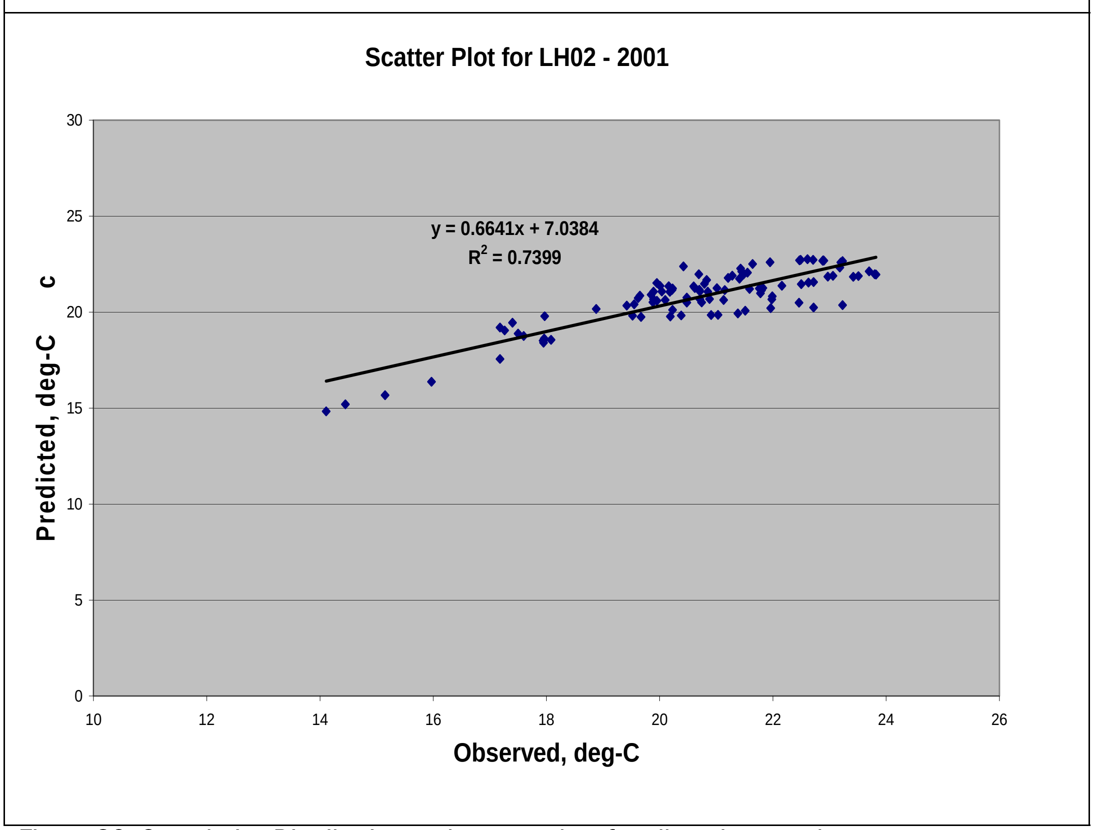
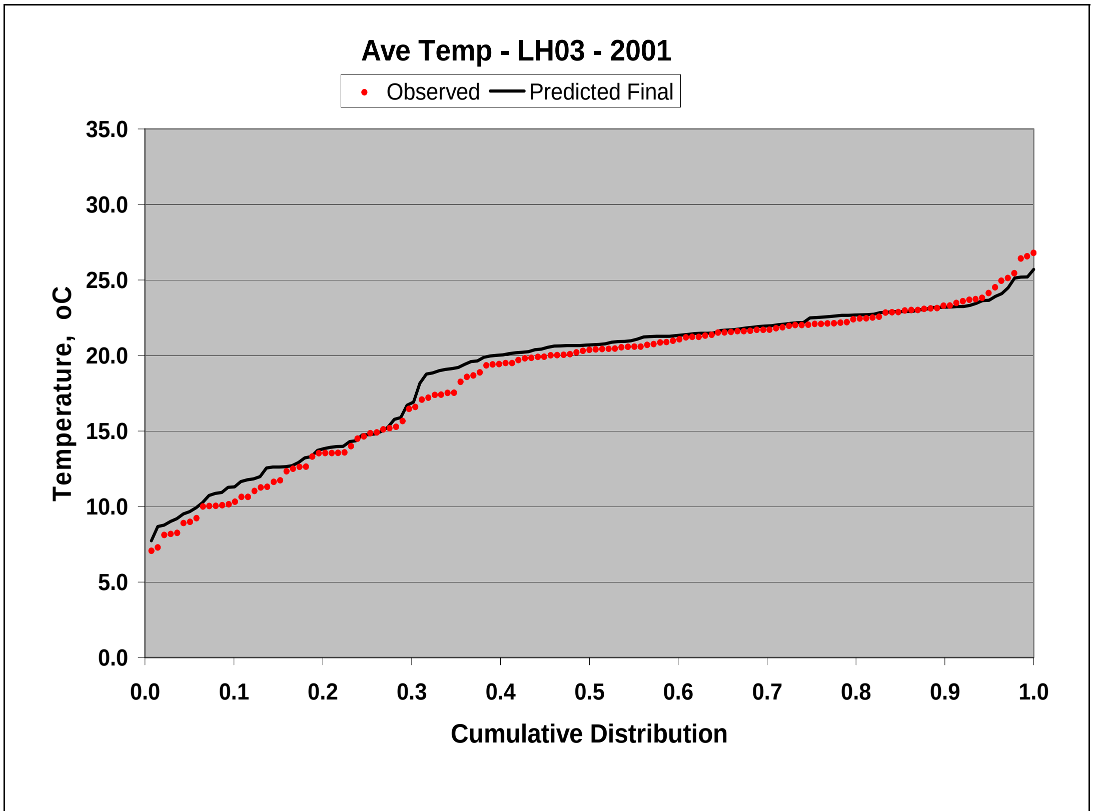


Figure 20. Cumulative Distribution and scatter plots for all stations on the Lehigh River (continued).



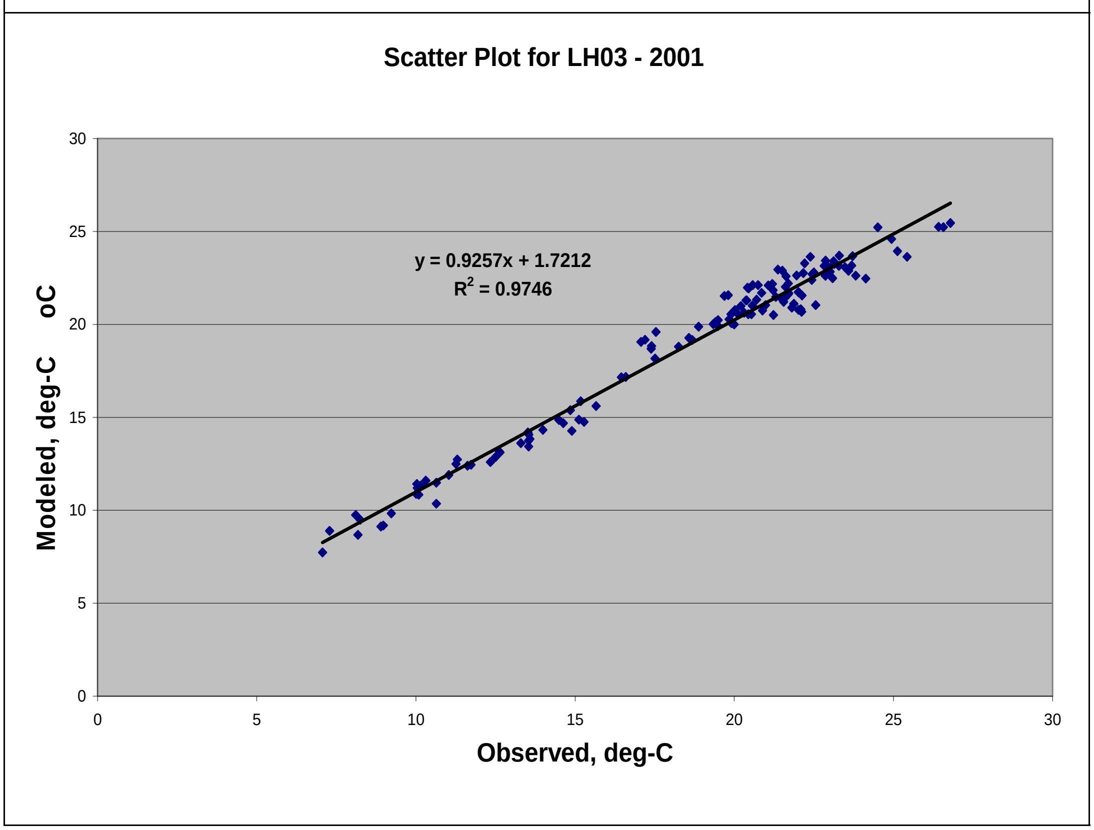
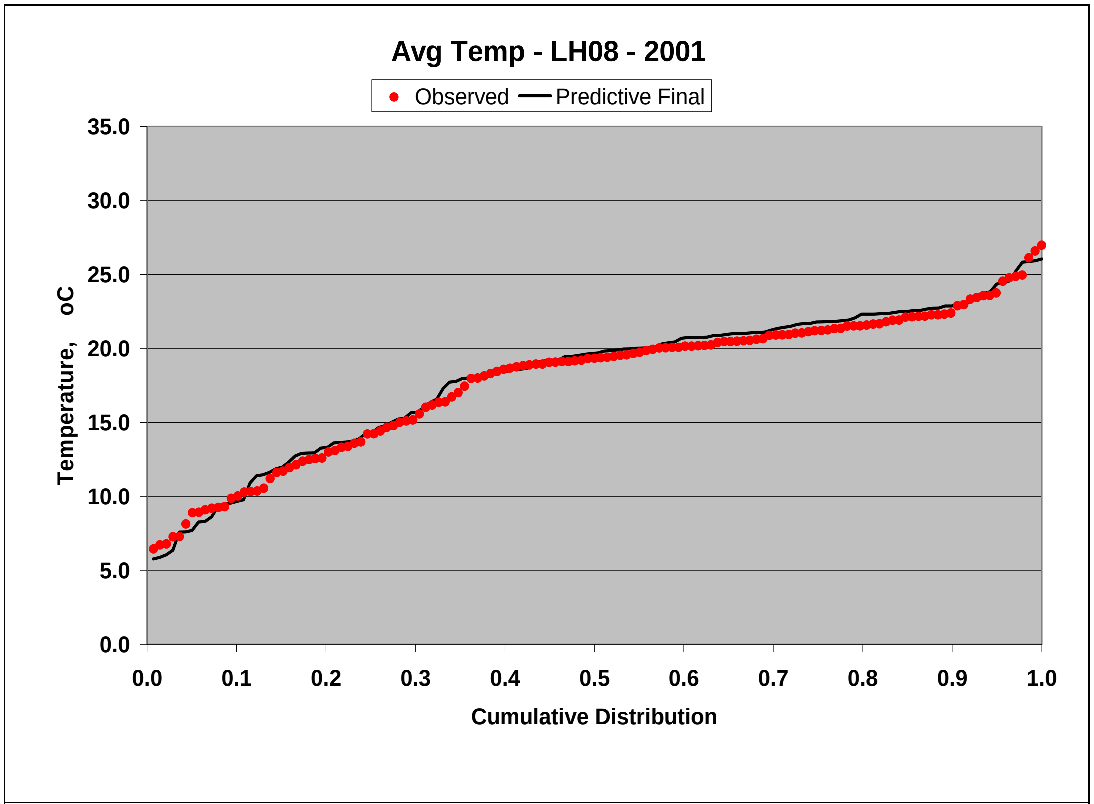


Figure 20. Continued.



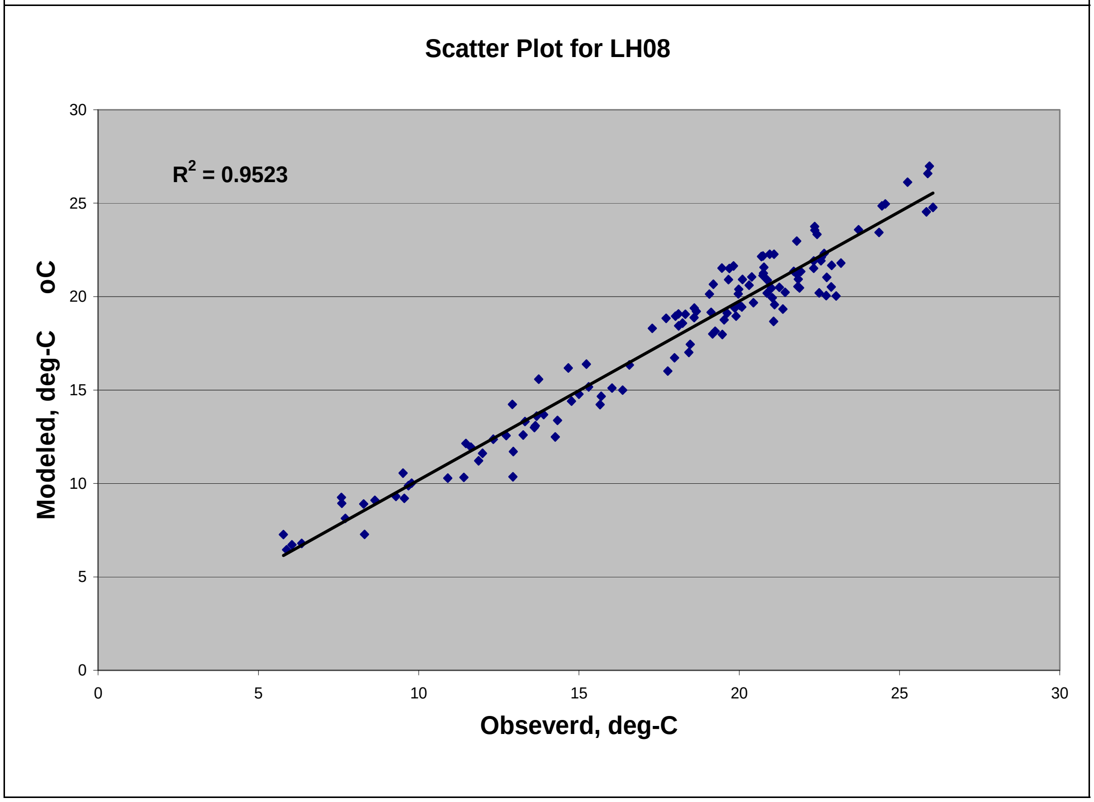
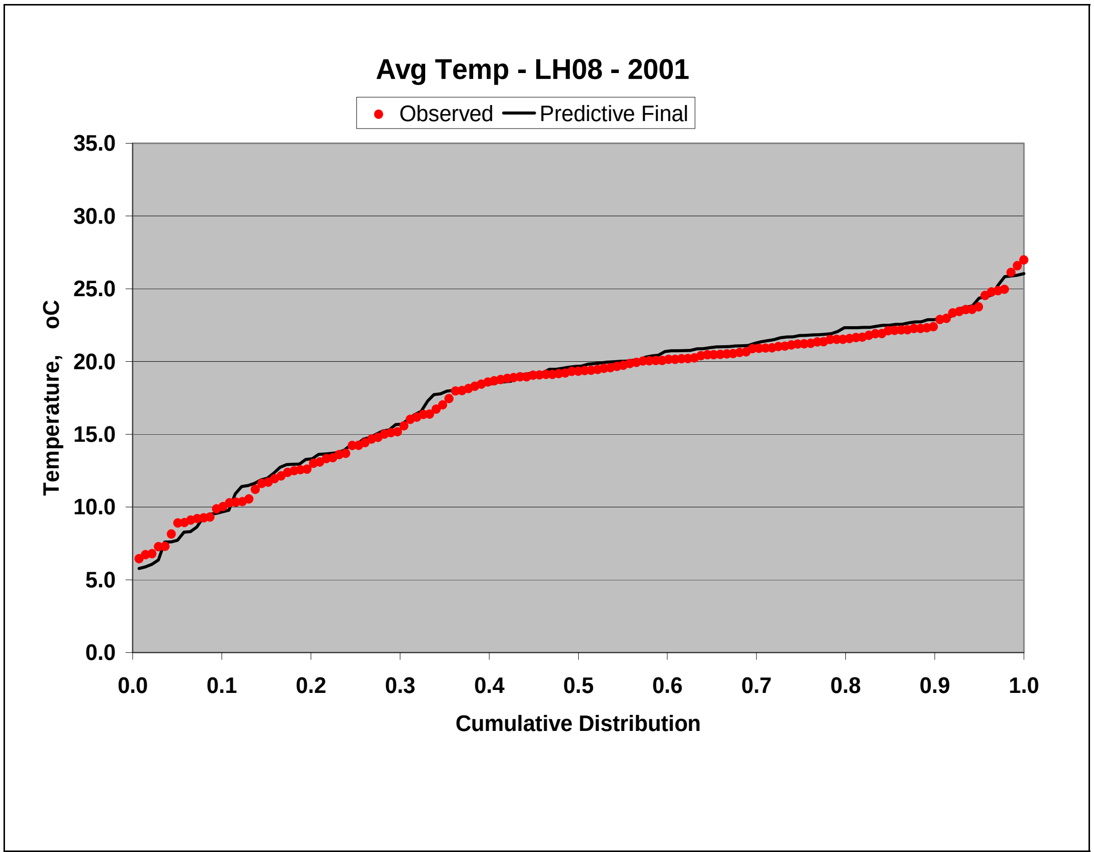


Figure 20. Continued.



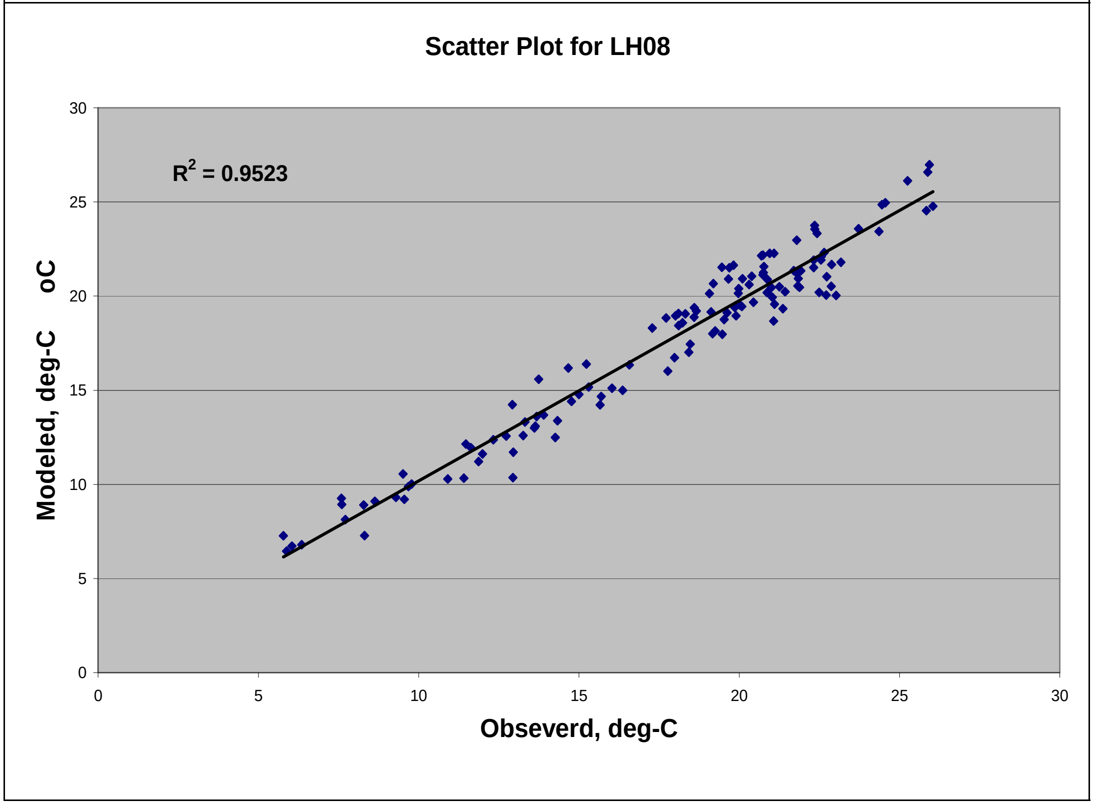
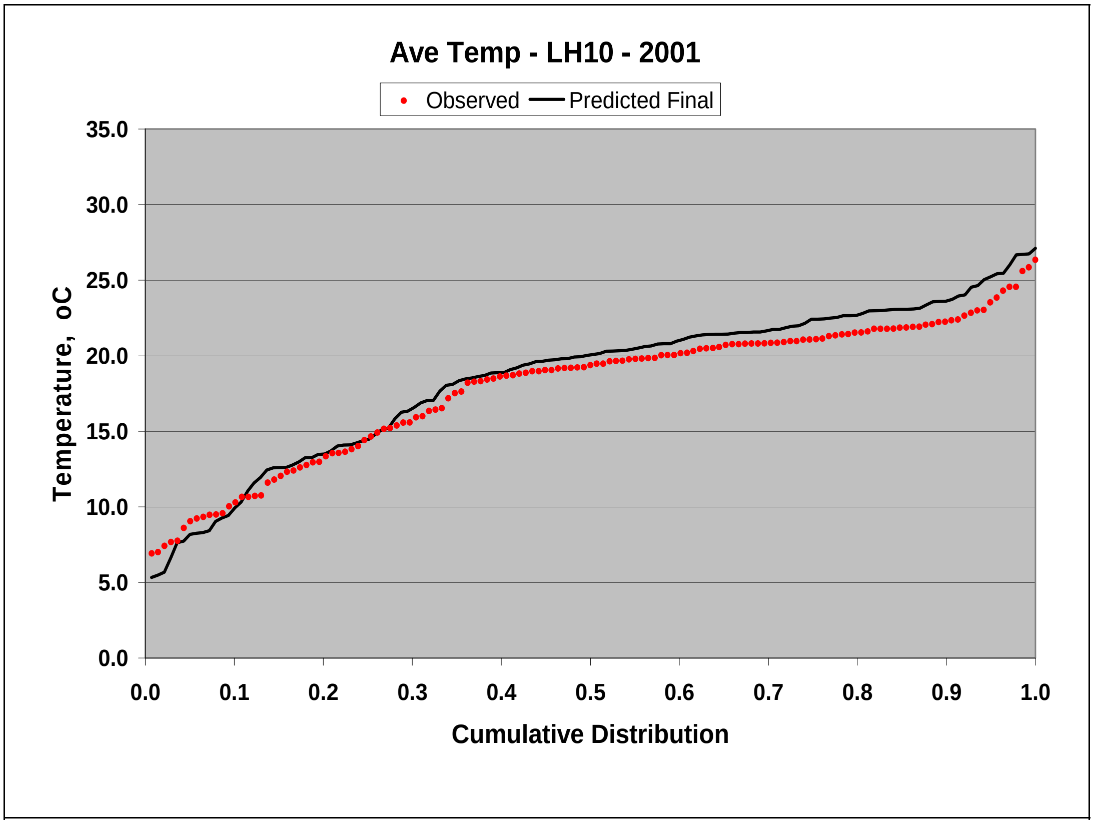


Figure 20. Continued.



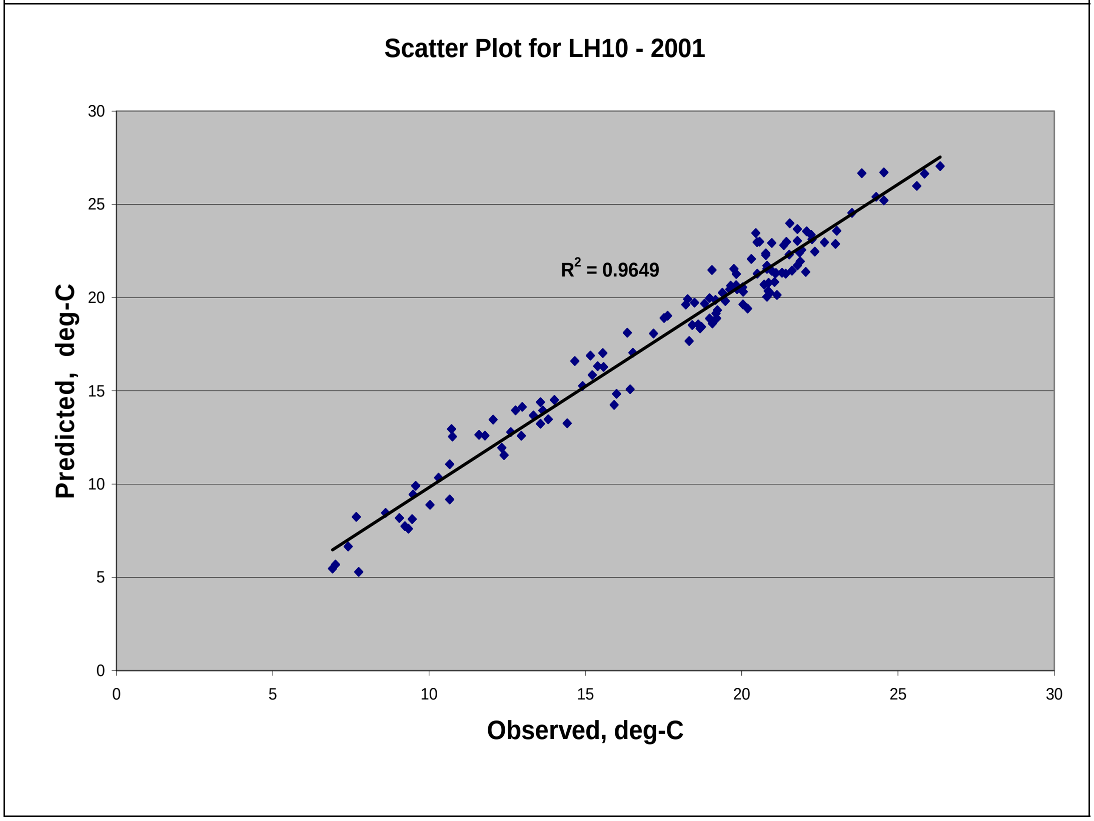
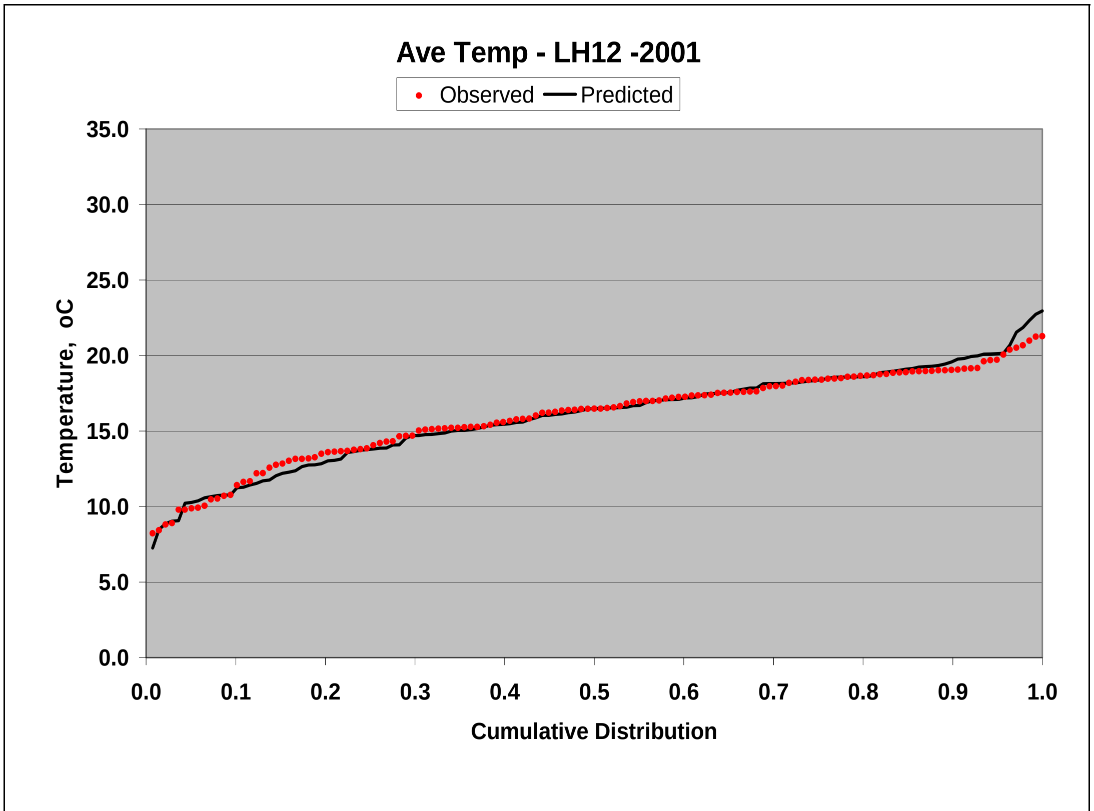


Figure 20. Continued.



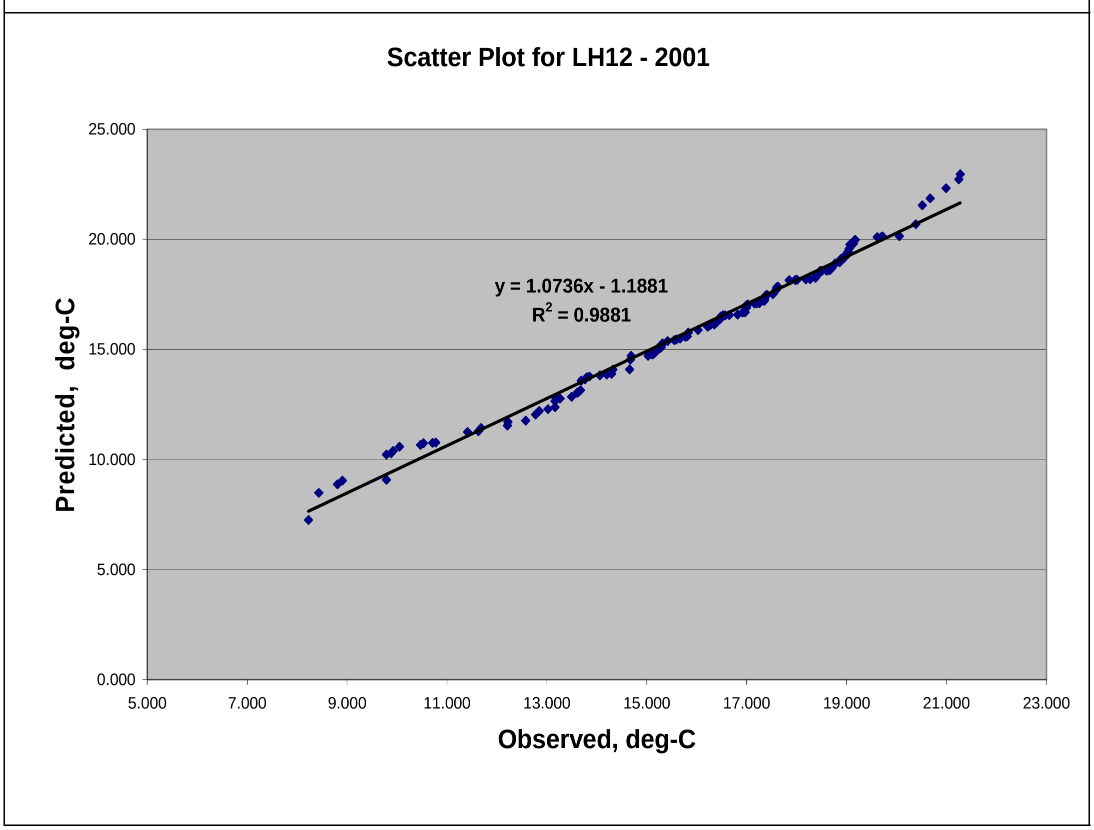
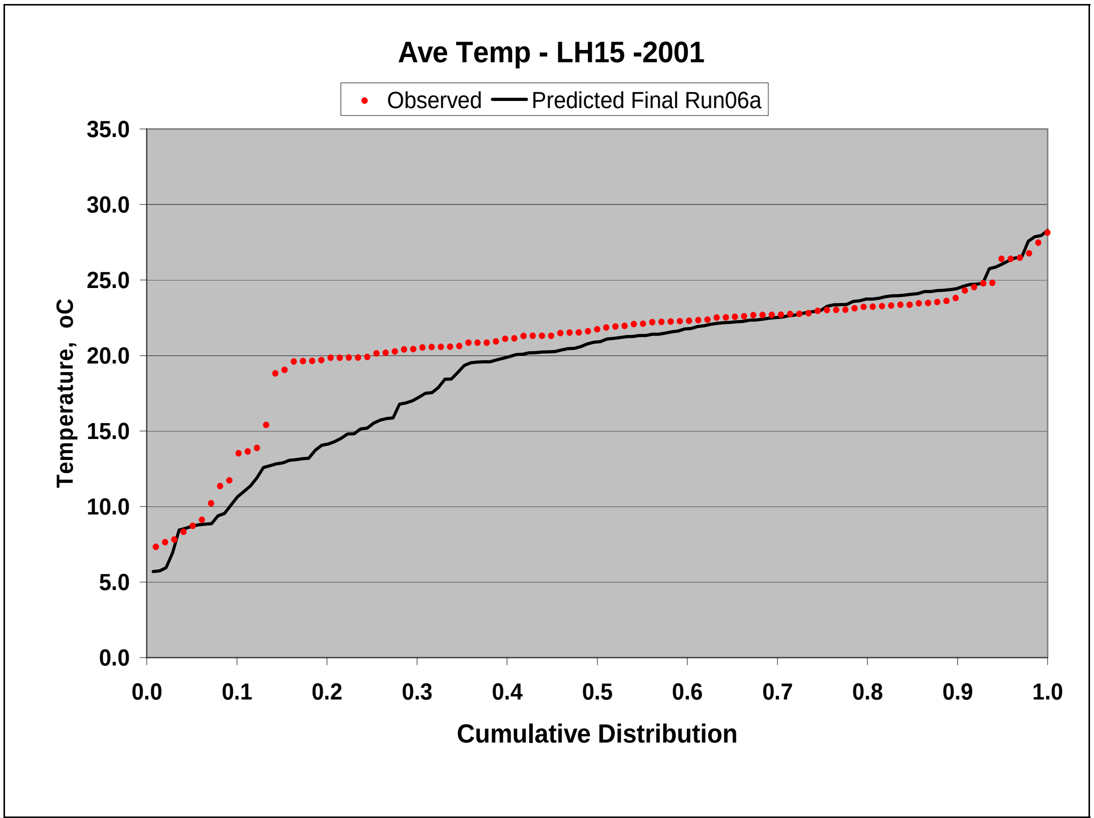


Figure 20. Continued.



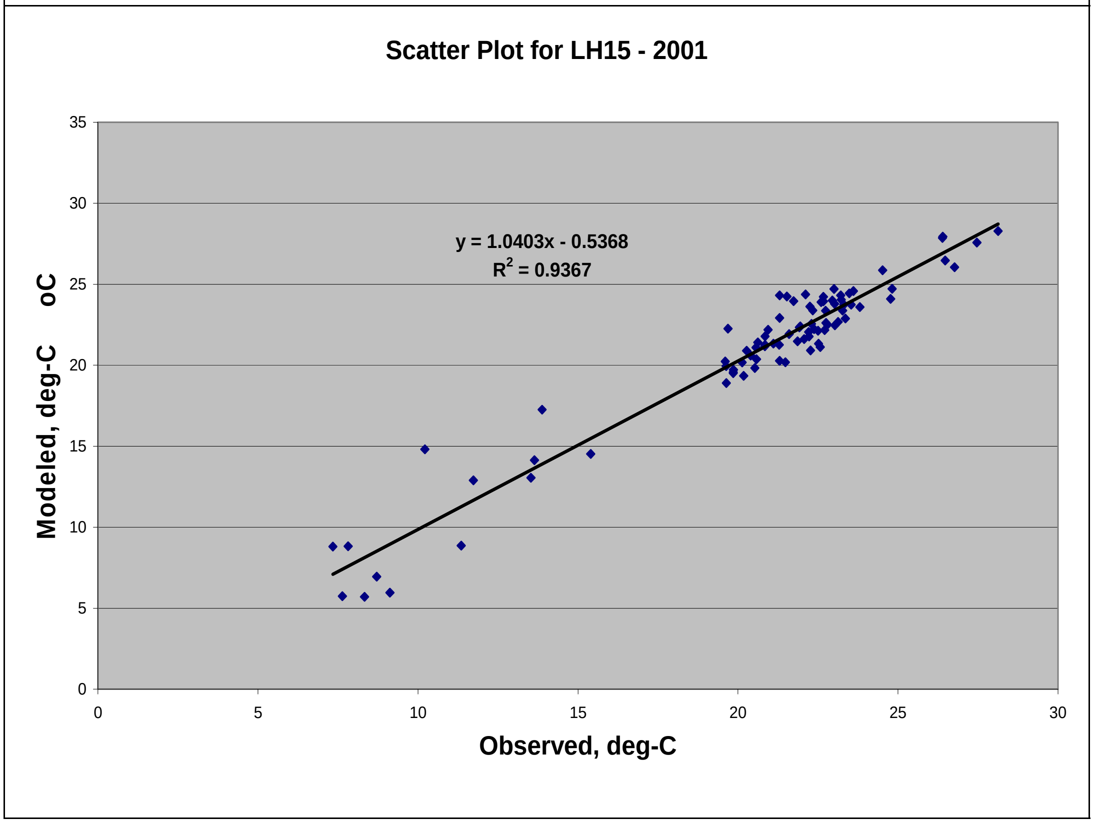


Figure 20. Continued.

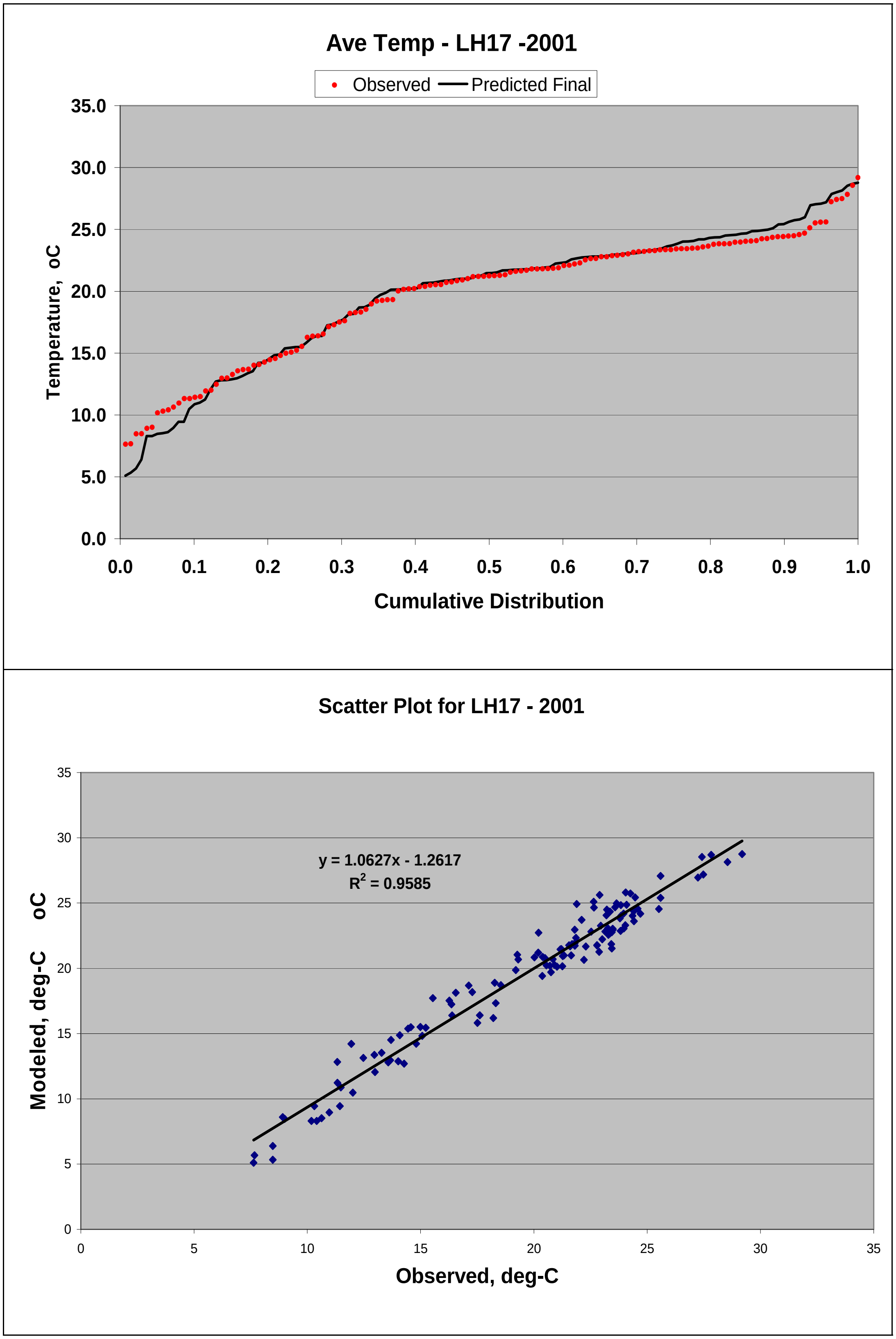


Figure 20. Concluded.

Beltzville Reservoir and Pohopoco Creek

WSEL: Water surface elevations are predicted by the model based on the interactions between inflows, outflows, evaporation, and precipitation. Since the inflows provided include the effects of evaporation and precipitation, these options were not used during calibration. Like F. E. Walter Reservoir, any discrepancies between computed and observed elevations were eliminated by including either positive or negative inflows in the distributed tributary inflow file. Distributed tributary flow values estimated for 2001 are shown in Figure 12. Distributed tributary inflows enter the surface layer of all segments in a branch and are apportioned according to the surface area of each segment. As shown in Figure 21, predicted elevations closely matched observed elevations.

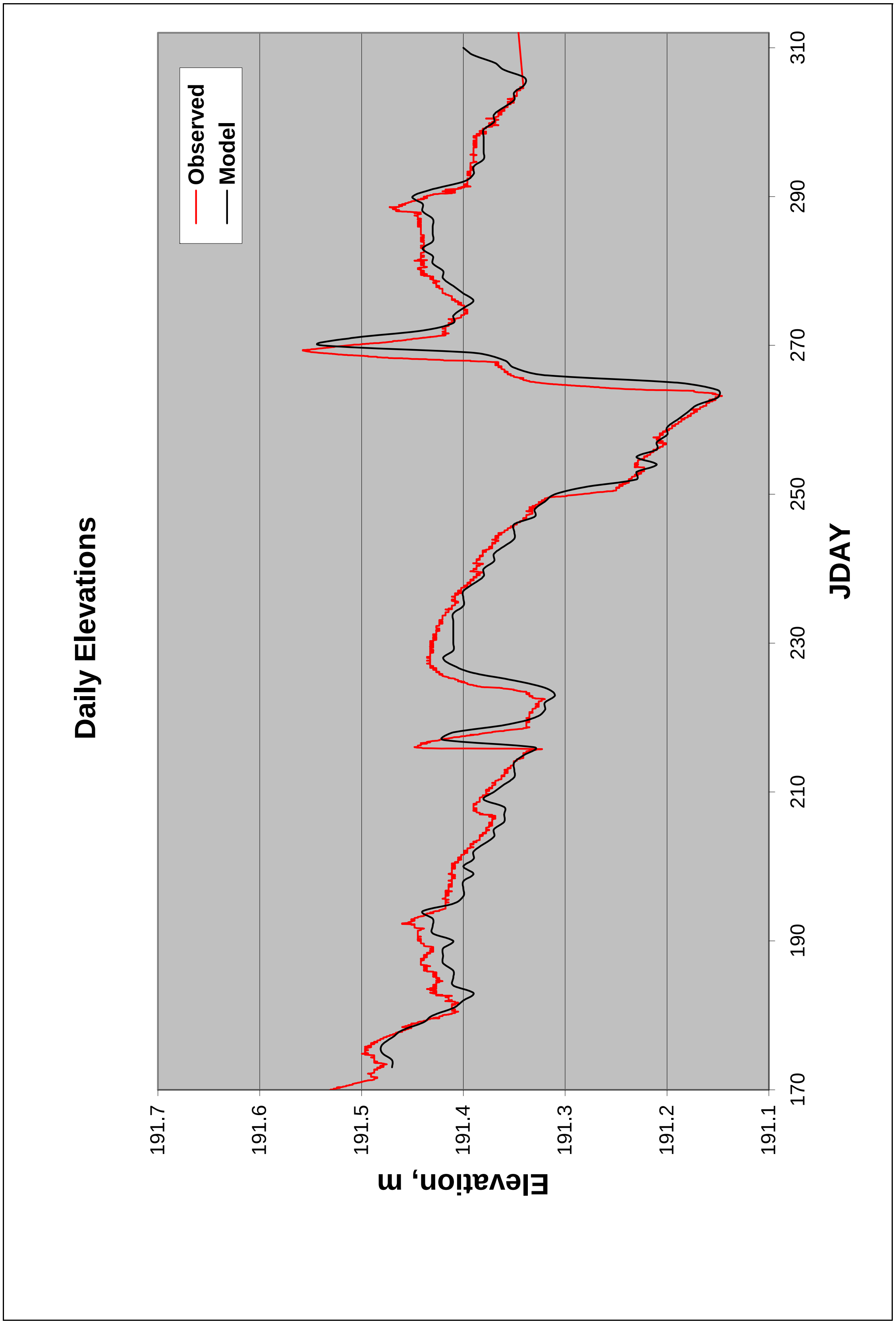


Figure 21. Predicted versus observed water surface elevation (WSEL) at Beltzville Reservoir with bottom elevation set to 499.2 ft (NGVD).

In-Pool stations: Figures 22 through 24 show calibration profile results for Beltzville stations BZ03, BZ06 and BZ07. Results indicate W2 is able to capture stratification in the summer especially at station BZ06 (closest to the dam) and in October is preparing for fall overturn. Results show good agreement with observed data. Overall, ME indicates the model slightly under-predicts temperature (-0.2) with the greatest difference occurring at the thermocline. On average, AME values are approximately ±0.6 ^{o}C of the observed values. The RMS for most stations BZ03 and BZ06 are within 1 ^{o}C but station BZ07 shows RMS as high as 1.75 ^{o}C. Most of the differences occur in the lower hypolimnion. Even with the higher RMS, the shape and behavior of the profiles are comparable to the observed.

The cumulative distribution plot (Figure 25) denotes that 75% of the time most predicted data is close to observed for values below 20 ^{o}C with slight over prediction occurring between 8 and 20 ^{o}C. At higher temperatures (>20 ^{o}C) there is good agreement to observed data.

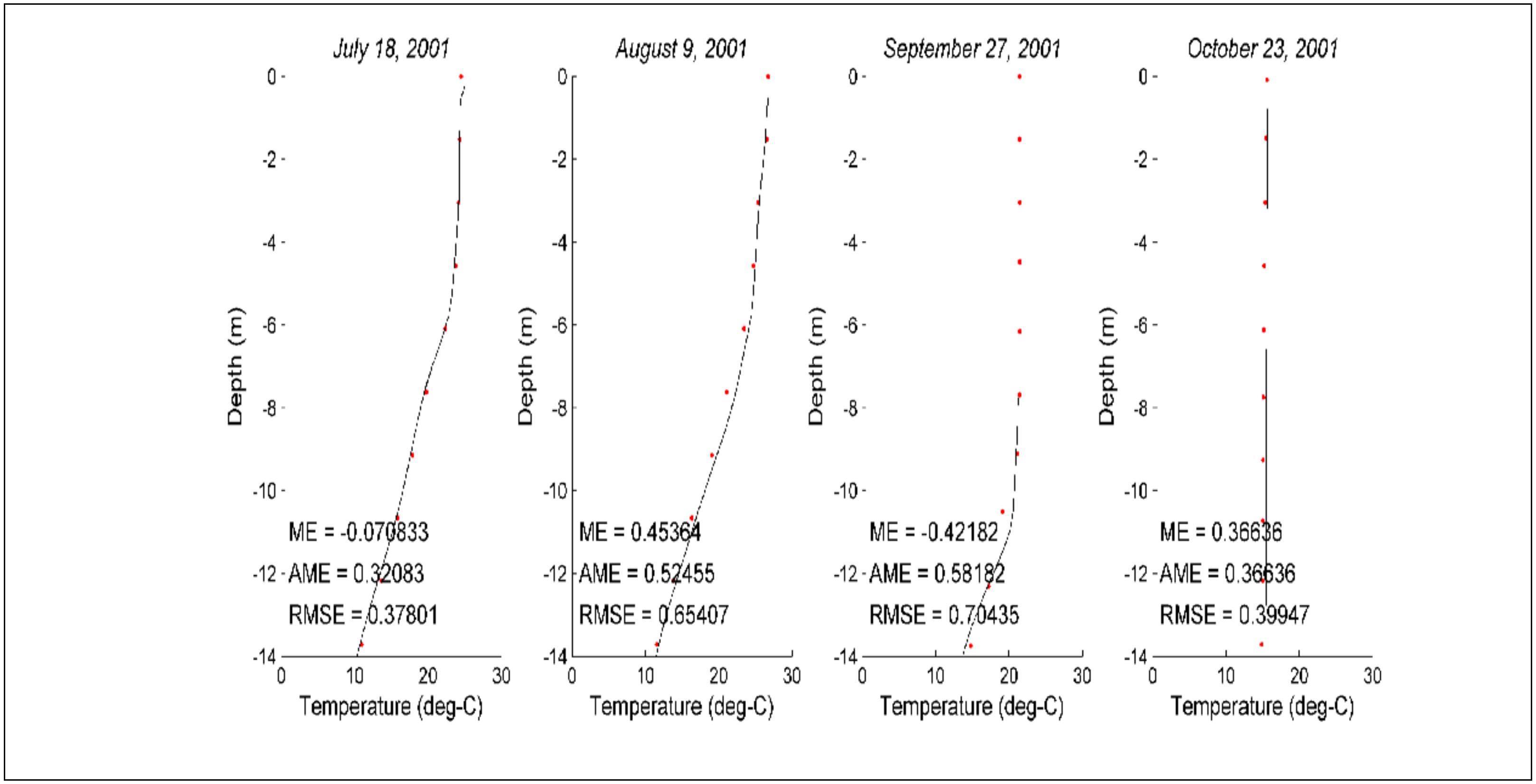


Figure 20. Temperature calibration results (red dots = observed and black line = modeled) for station BZ03 at Beltzville Reservoir

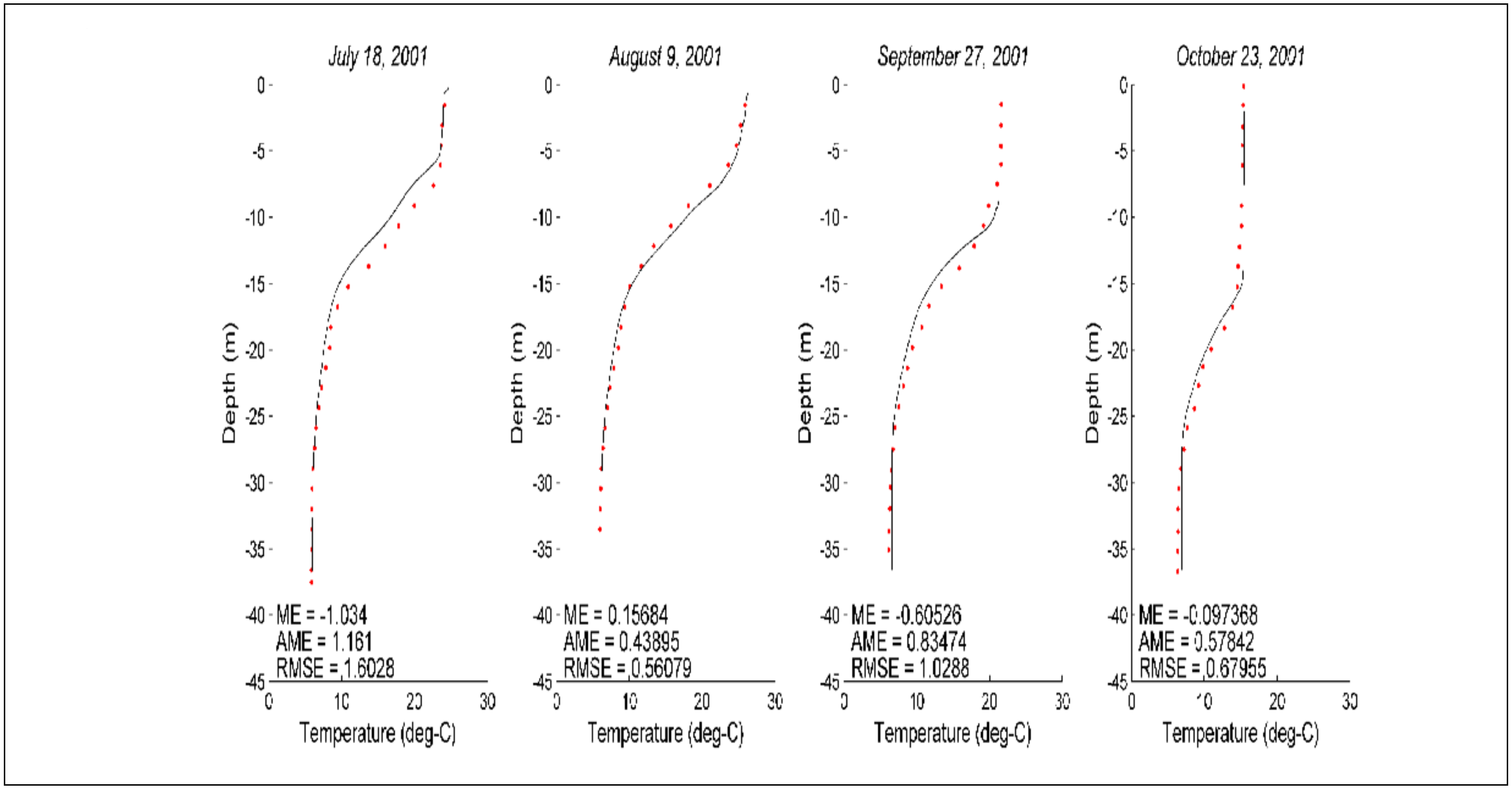


Figure 21. Temperature calibration results (red dots = observed and black line = modeled) for station BZ06 at Beltzville Reservoir

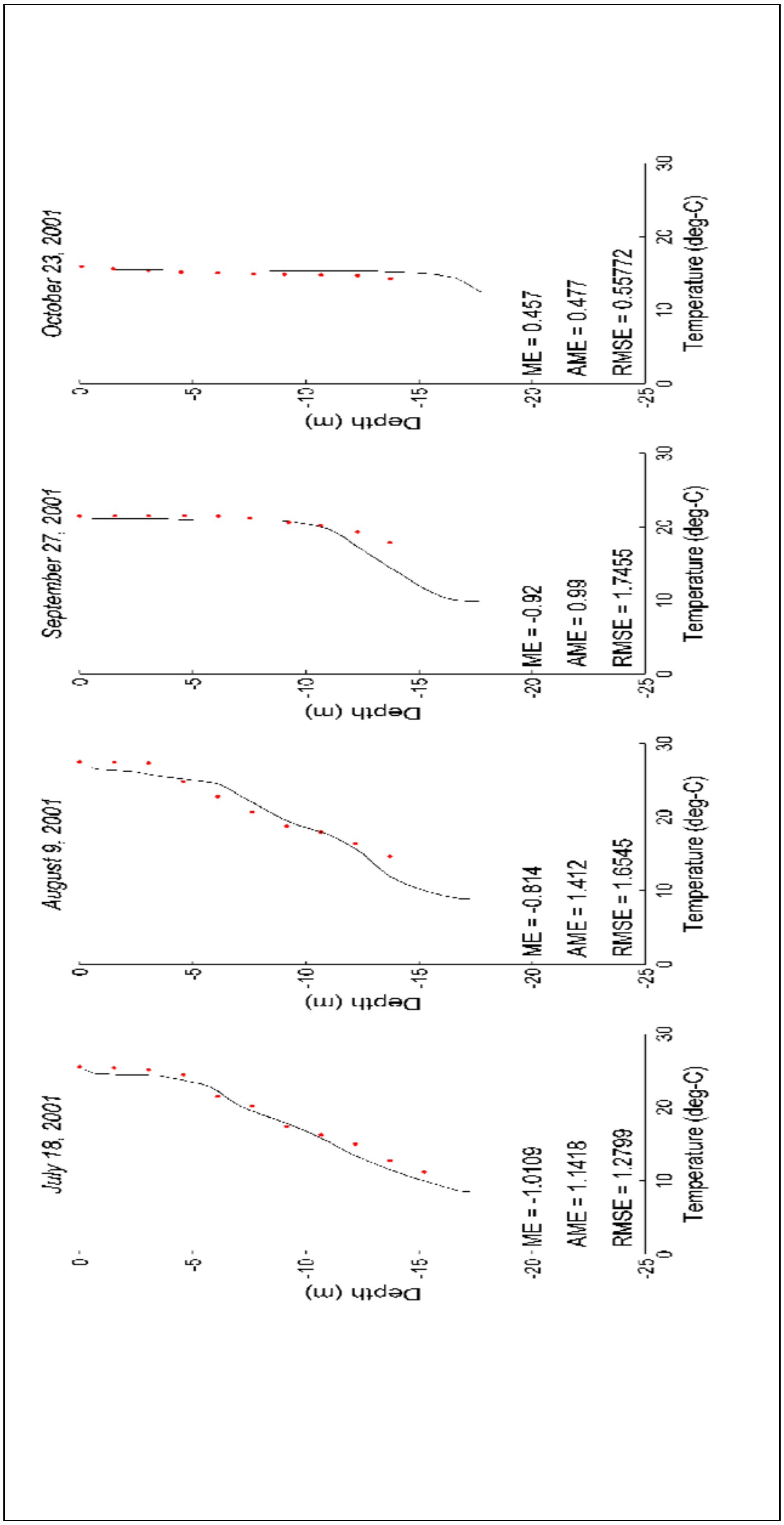


Figure 22. Temperature calibration results (red dots = observed and black line = modeled) for station BZ07 at Beltzville Reservoir

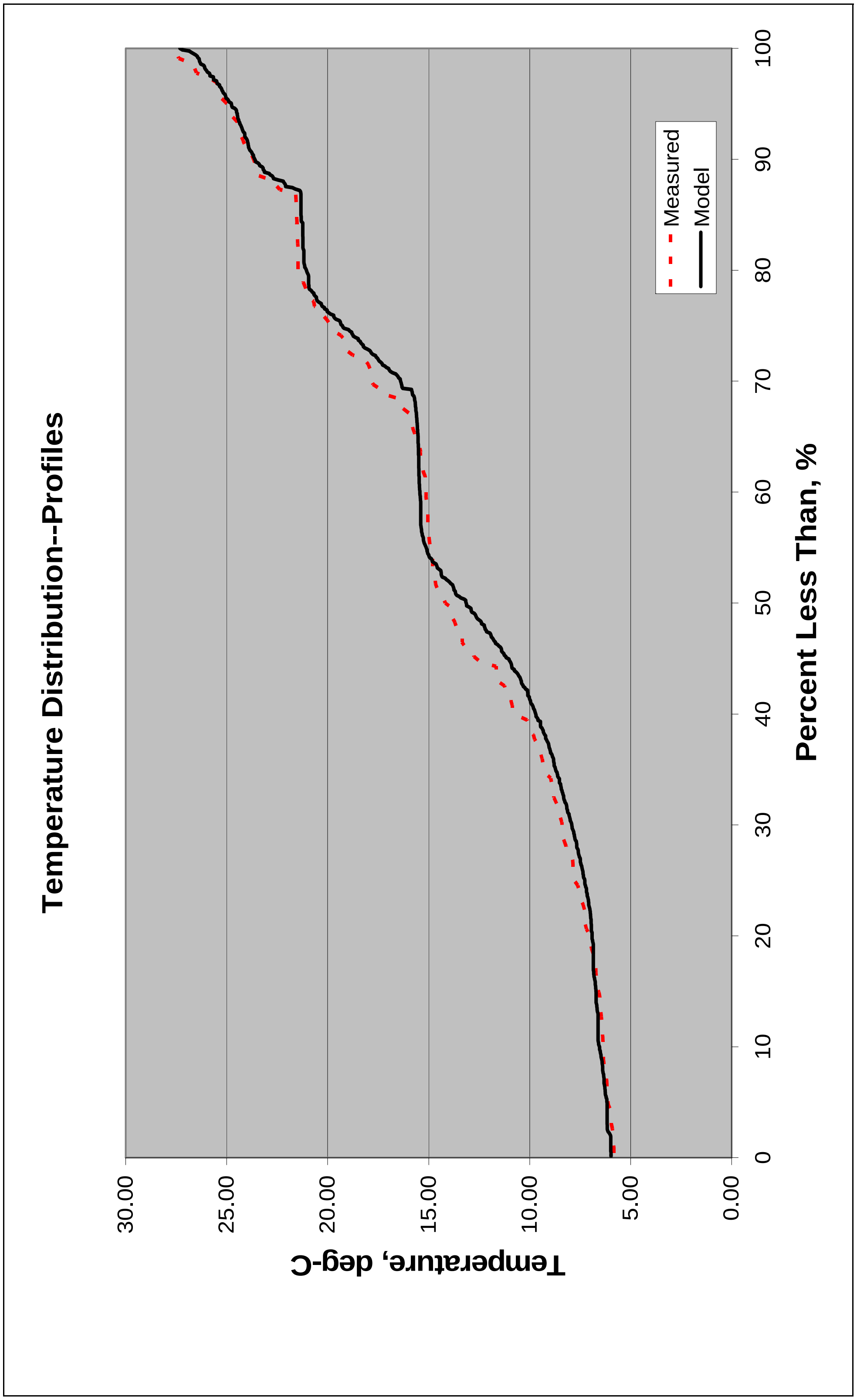


Figure 23. Cumulative Distribution plots all profiles at Beltzville Reservoir.

Riverine Stations: Figure 26 contains temperature results from river stations BZ01 and LH12. Each plot contains the three statistics used to measure model performance. The trend of observed data (like on the Lehigh River) is a cyclic pattern being repeated about every two weeks and is reproduced by W2. Also, the decrease in temperature from August through November is being predicted by W2. Overall W2 does very well in predicting temperature through the Pohopoco Creek. ME indicates at most stations W2 under-predicts temperature (approximately -0.15 overall). This is also denoted on the cumulative distribution plots in Figure 27 for temperature values in the range of 15 ^{o}C to 20 ^{o}C. In the riverine sections, over prediction is believed to be caused by low flow periods with water heating up more than what actually occurs possibly due to water depth being slightly under predicted.

Figure 28 contains calculated WSEL data for station BZ01 and LH12 on the Pohopoco Creek. At station BZ01, W2 under-predicts depth approximately 0.2 meters. As before on the Lehigh River, adjustments to layer widths or elevation of ending segment were made to improve predictionns. Differences again did not seem to affect temperature predictions adversely. In a like manner to temperatures at LH02, temperature predictions at this location were more affected by release conditions from the dam. Also in Figure 28, flow predictions were compared with observed and followed observed trends very well.

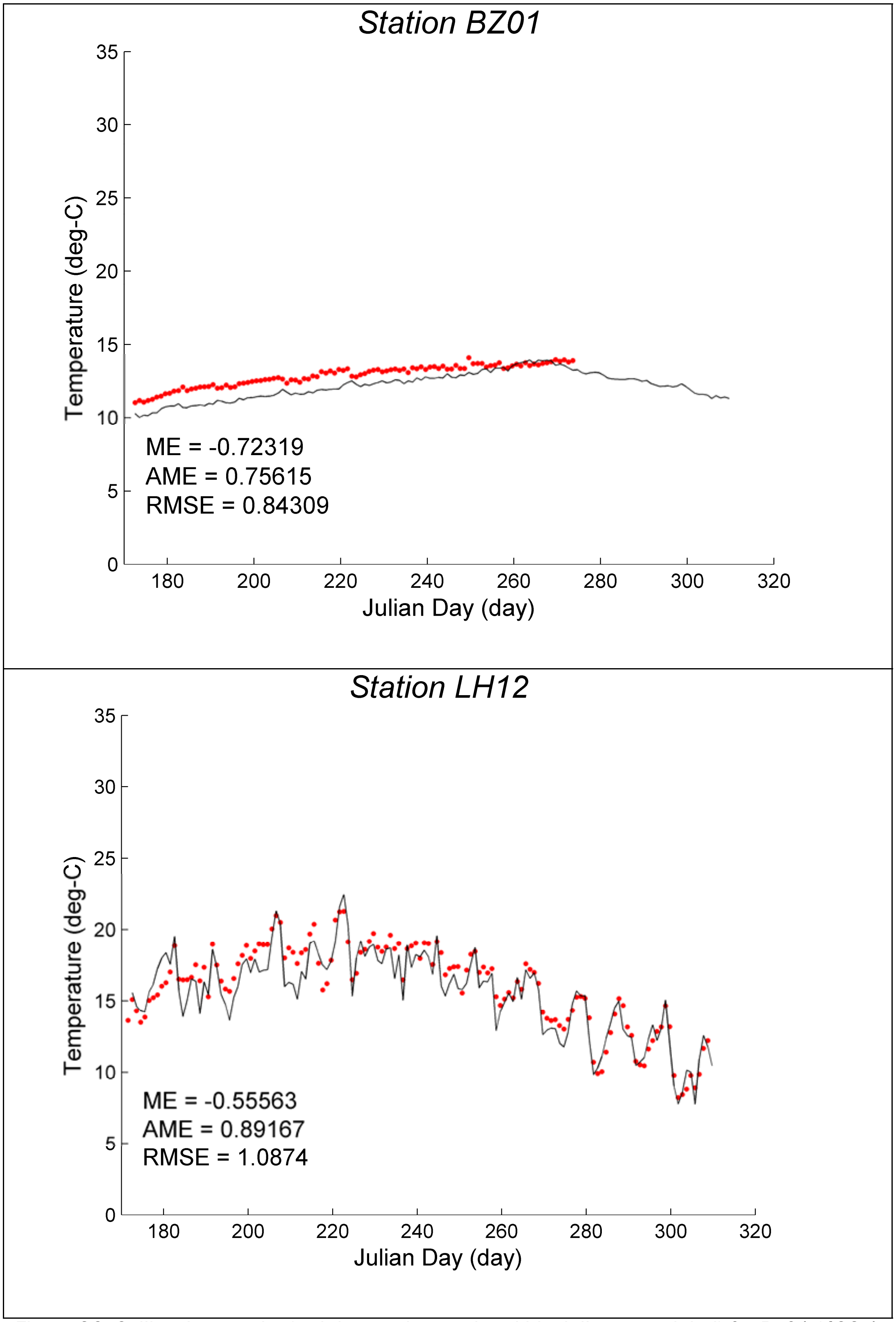


Figure 26. Calibration results (red dots = observed and black line = modeled) for BZ01 (492.1 ft NGVD) and LH12 on the Pohopoco Creek

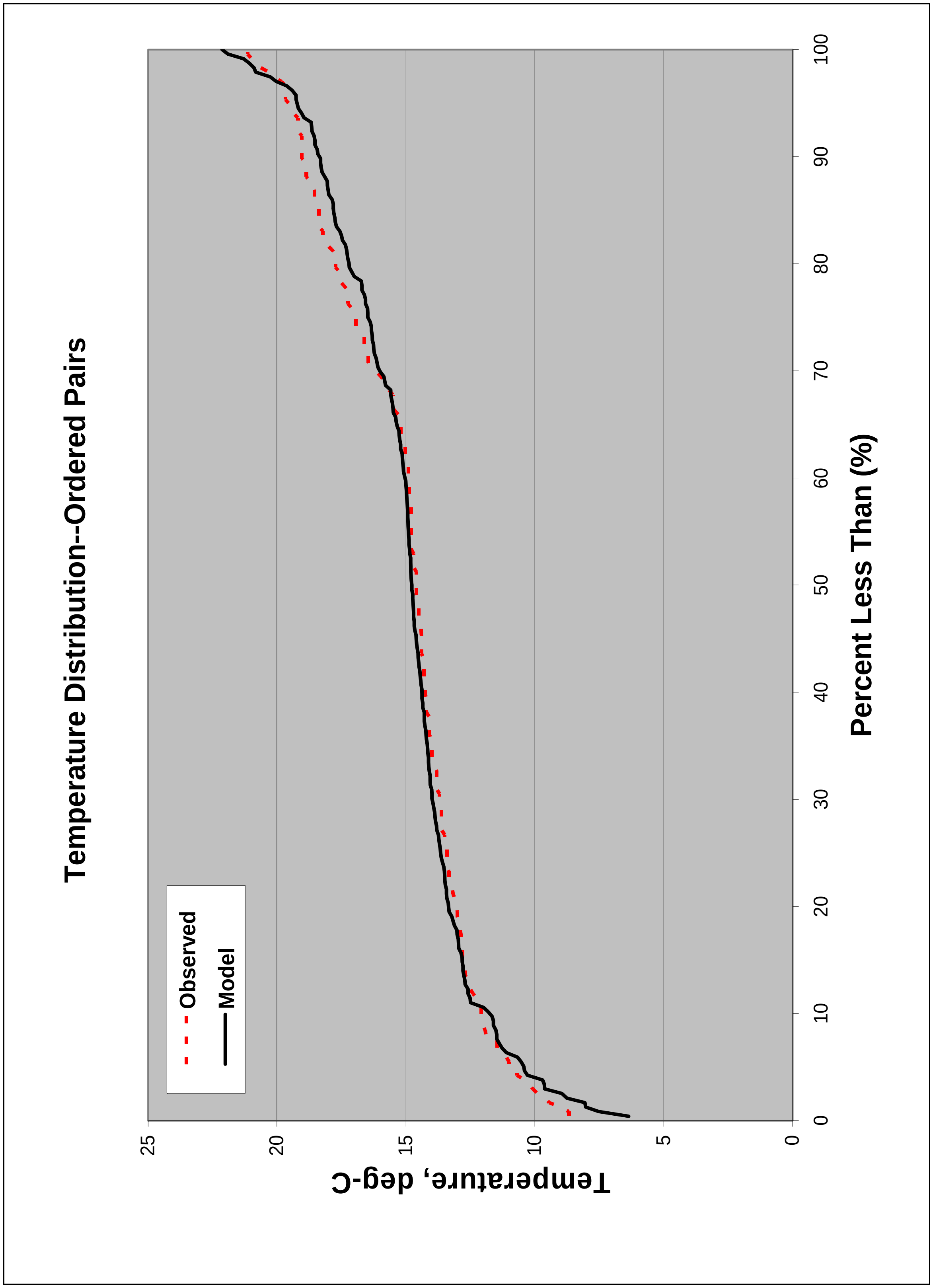


Figure 27. Cumulative Distribution for Pohopoco Creek stations

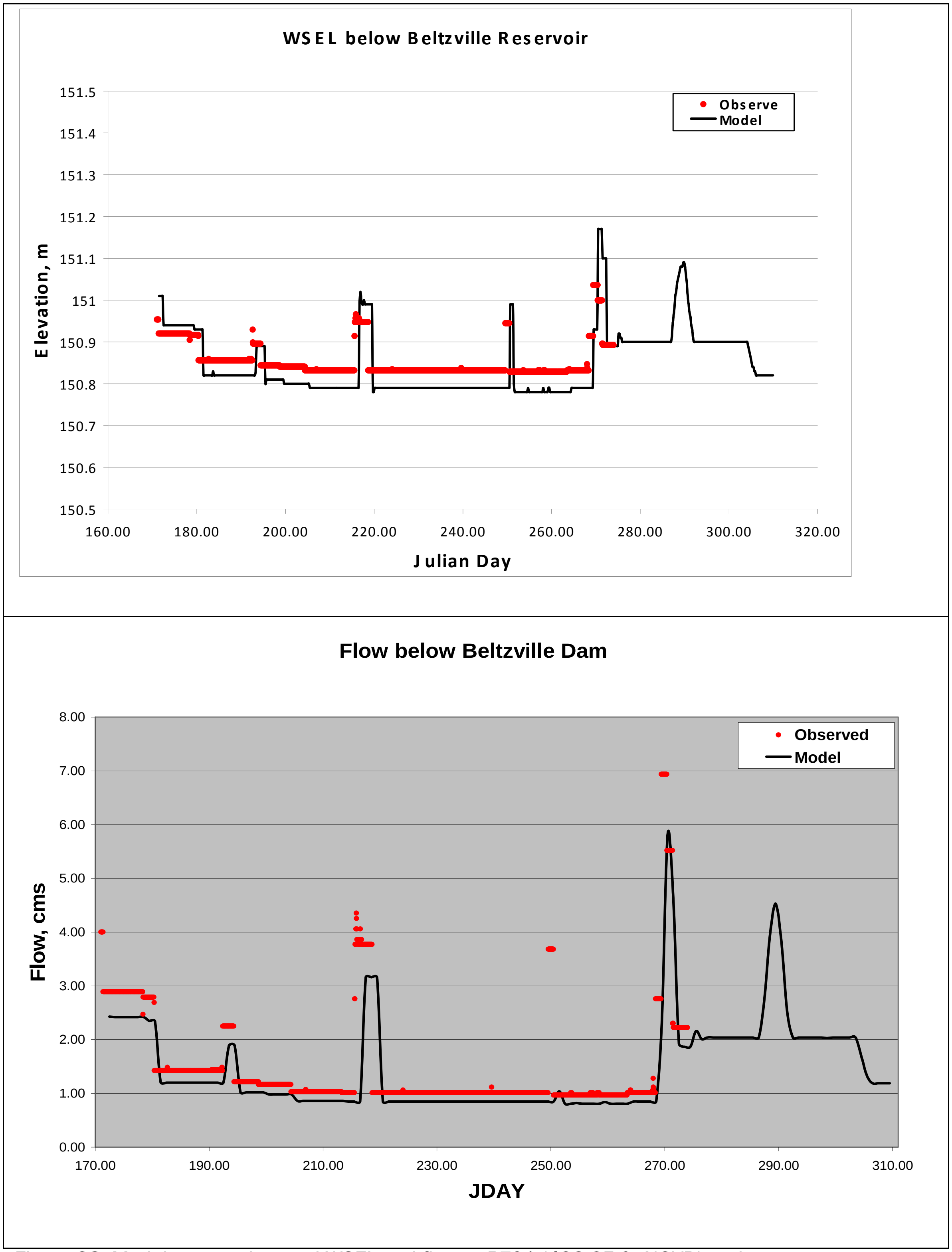


Figure 28. Model versus observed WSEL and flow at BZ01 (492.05 ft. NGVD) and LH12 on the Pohopoco Creek.

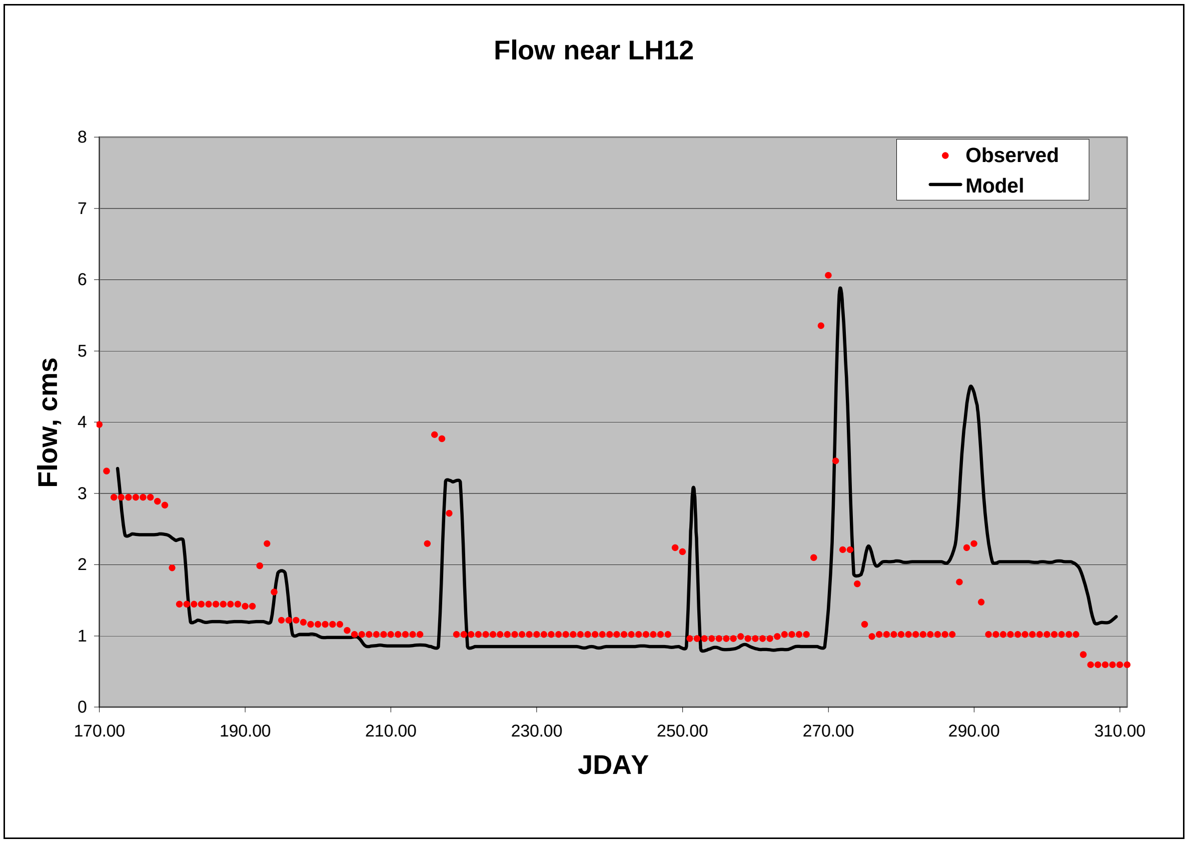


Figure 28. Concluded.

2003 Verification Results and Discussion

The verification year was chosen by comparing inflows to both reservoirs to see which year had the most consistent high flow events. The year chosen for verification was 2003. Analogous to the calibration results, the verification results will be presented for each section of the grid beginning with section 1 containing F. E. Walter Reservoir and proceeding immediately downstream.

F. E. Walter Reservoir

WSEL: Same as calibration, the inflows provided included the effects of evaporation and precipitation, thus these options were not used during calibration. Additionally, any discrepancies between computed and observed elevations were eliminated by including either positive or negative inflows in the distributed tributary inflow file. Values for distributed tributaries used in 2003 are shown in Figure 19. Distributed tributary inflows enter the surface layer of all segments in a branch and are apportioned according to the surface area of each segment. As shown in Figure 29, predicted elevations closely matched observed elevations at F. E. Walter Reservoir. In the figure, the initial WSEL can be seen (denoted by green line) as being over predicted from Julian Day 180 to around 260. This indicates the calculated reservoir inflows and outflows were not balanced. Consequently, the water balance program was run to get appropriate distributed tributary flow, and after inclusion of these values, final WSEL predictions (denoted by the red line) closely matched observed data.

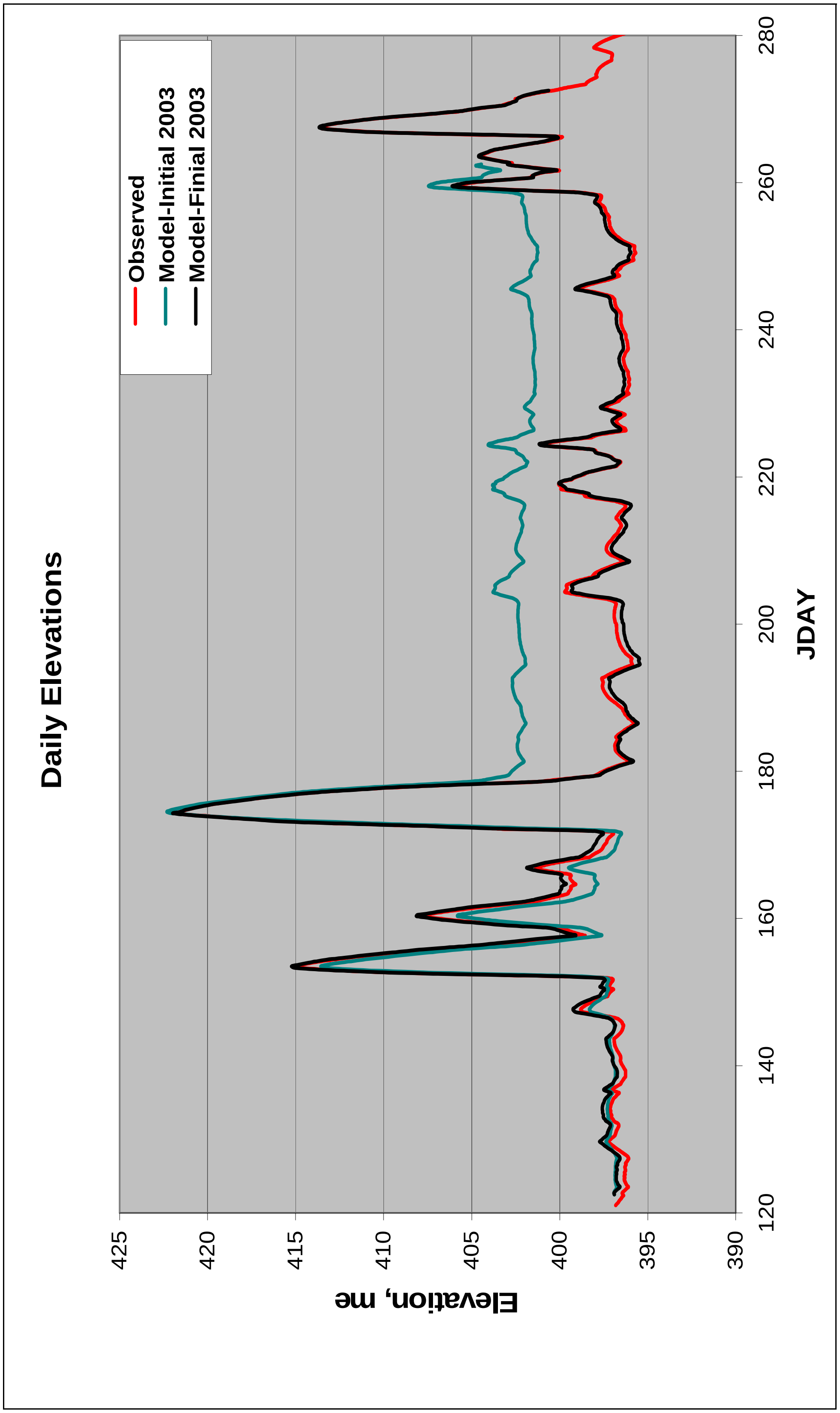


Figure 29. Predicted versus observed water surface elevation (WSEL) at F. E. Walter Reservoir for 2003.

In-Pool stations: Figures 30 through 32 show verification temperature profile results for F. E. Walter at stations WA02, WA06 and WA07. Results show model agreed for the most part with observed data. In June the model over predicts temperature on Bear Creek (WA06) and at the dam (WA02). Reasons for this could be that meteorological data had to be combined from three different locations to cover simulation period. This may have introduced some error in the predictions. Checking model operations with District personnel during this period ruled out any error that might have come from improper reservoir operations. Initially, there were concerns about whether the by-pass system or perhaps spillway is being used for releases as well as the bottom port, but this is not represented by the model. If so, this can also cause poor temperature predictions and affect profile set up. Presently, all reservoir releases are being output through the bottom port. For verification, the model would simulate only until Julian day 262. After viewing results, it was determined that the Bear Creek branch was becoming dry or low enough that the branch was lost. W2 can not continue to run if a branch dries up consequently the simulation stops. Because of this, model predictions could not be compared to the last observed profile in late September. Overall, ME indicates the model slightly over predicts temperatures on an average of 1 ^{o}C . AME values on average are within observed values approximately ±0.8 ^{o}C and the spread of the data (RMS) around observed are approximately 1.2 ^{o}C. Although results are not quite as good as calibration, results are acceptable since not having equivalent critical boundary conditions has introduced some error. Although there are differences, they are within the error of acceptability (Cole and Wells 2005).

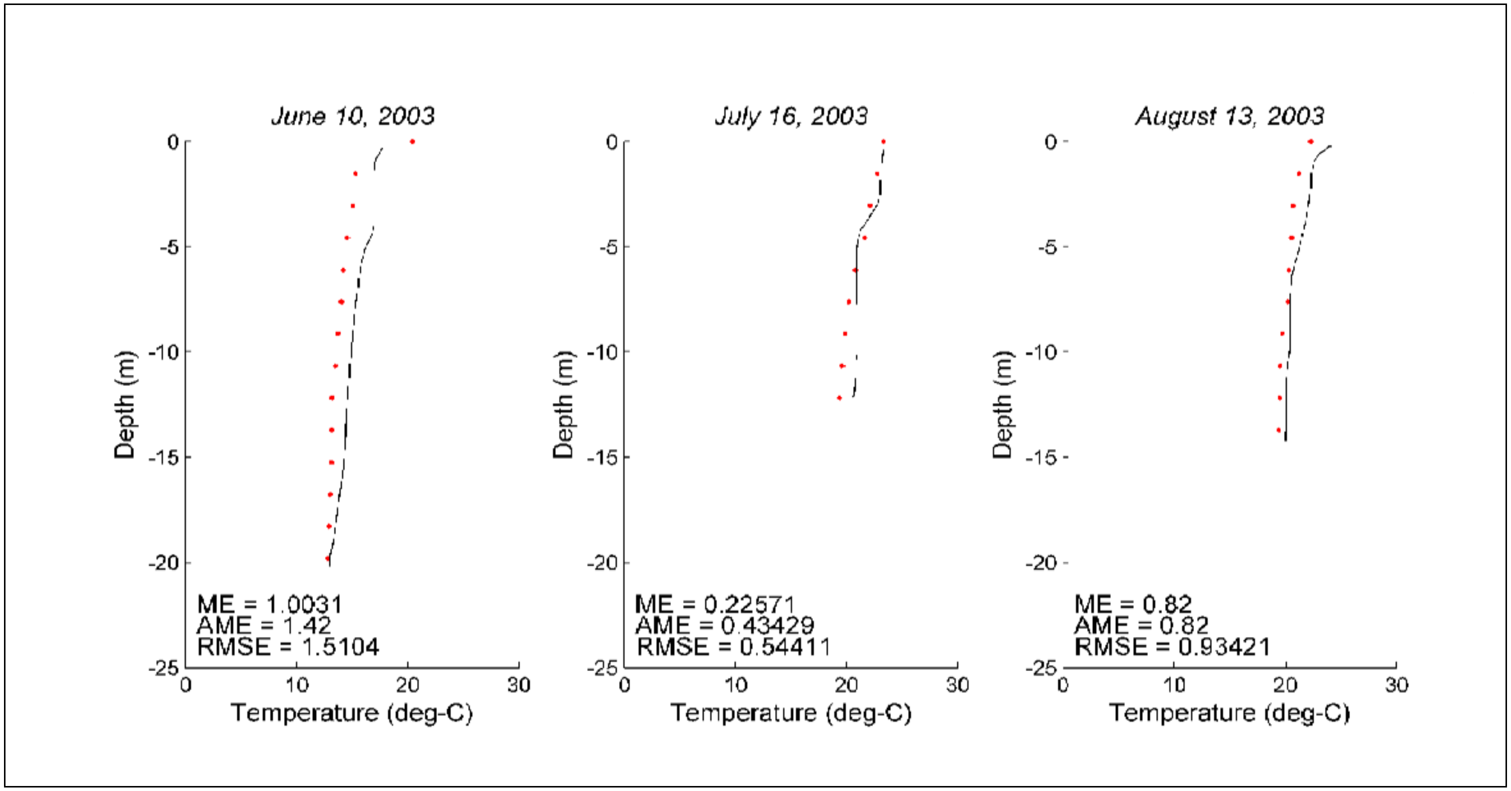


Figure 30. Temperature verification results (red dots = observed and black line = modeled) for station WA02 at F. E. Walter Reservoir.

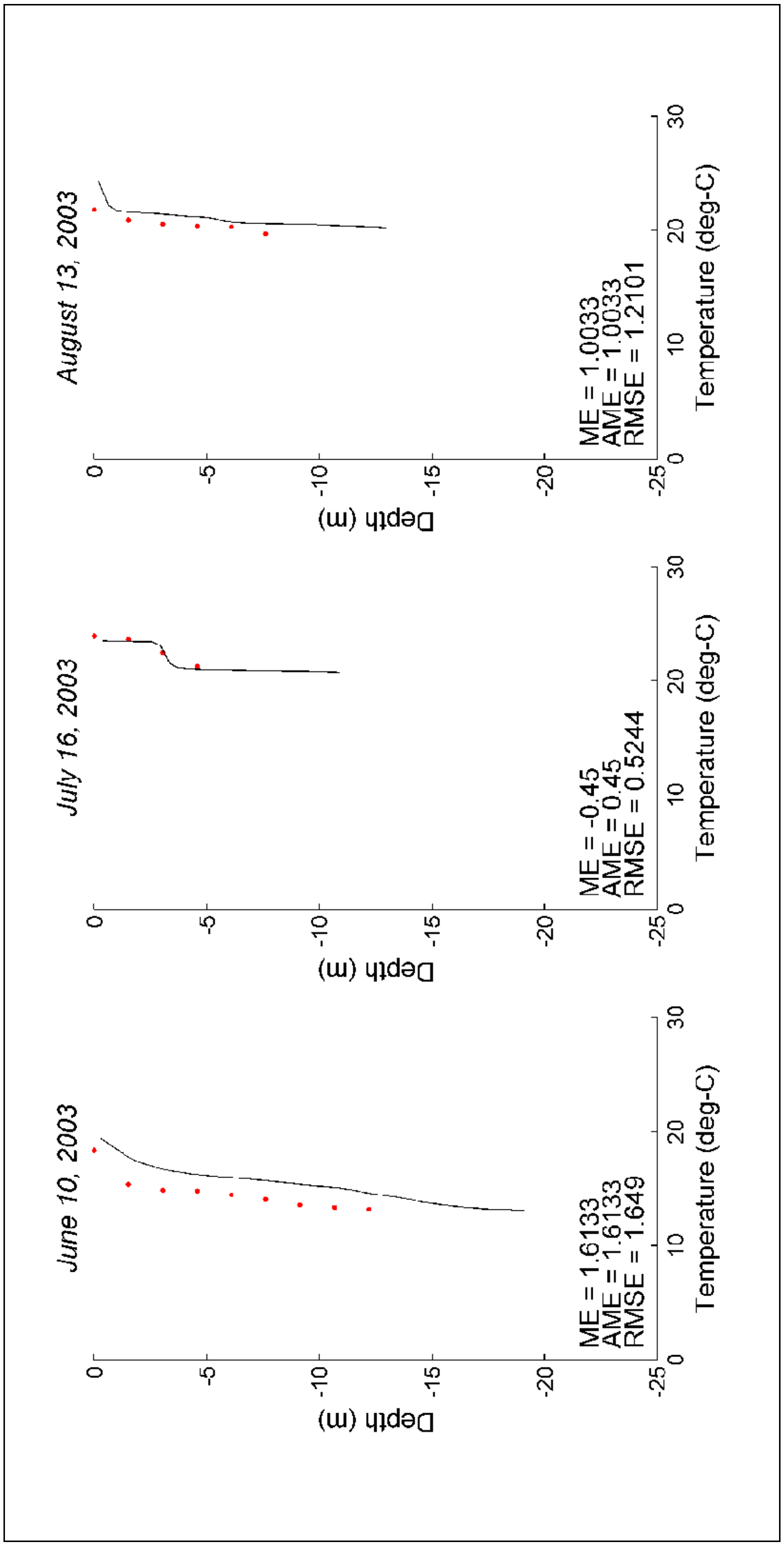


Figure 31. Temperature verification results (red dots = observed and black line = modeled) for station WA06 at F. E. Walter Reservoir.

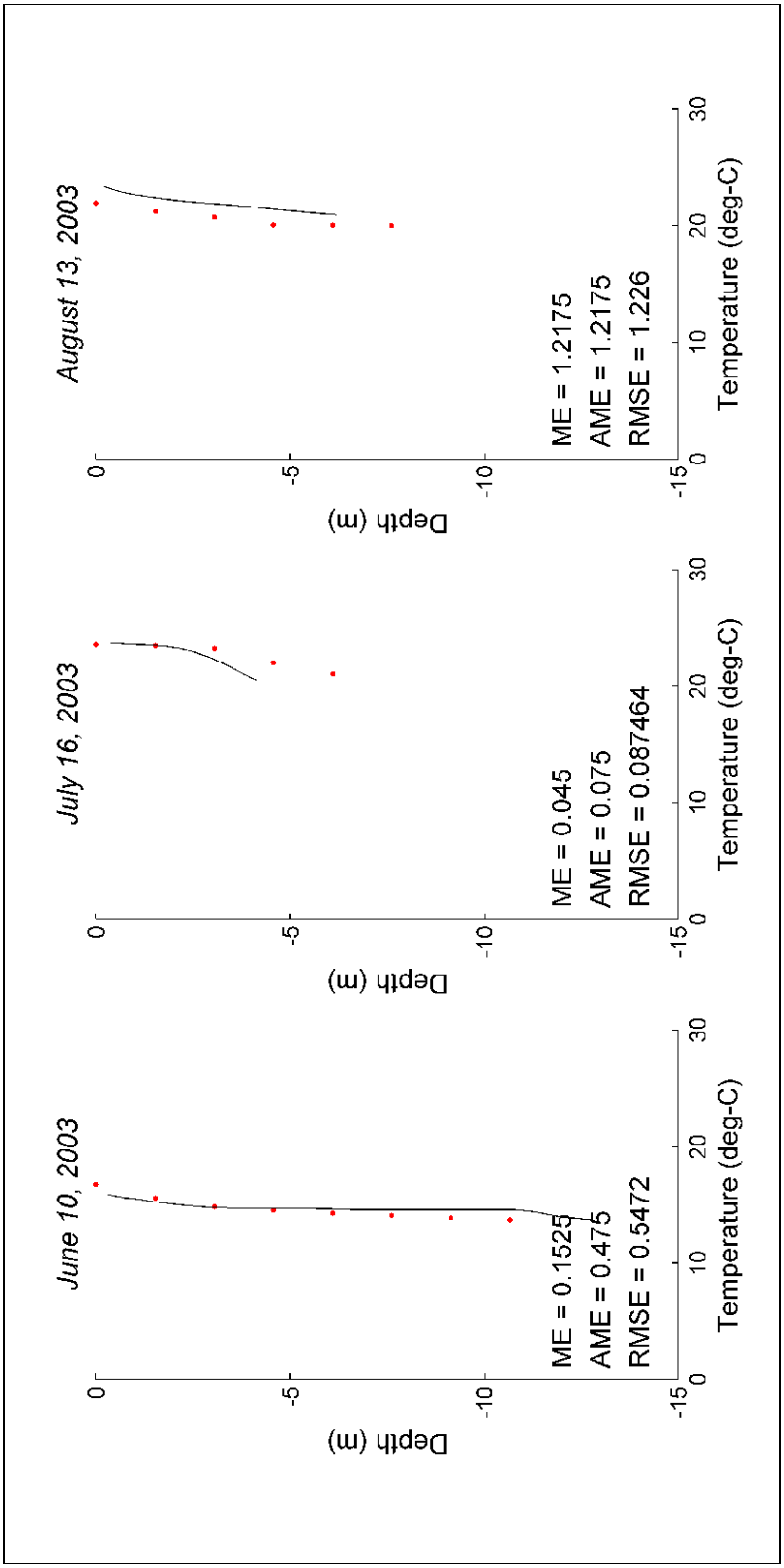


Figure 32. Temperature verification results (red dots = observed and black line = modeled) for station WA07 at F. E. Walter Reservoir.

Lehigh River

Riverine stations: Figure 33 contains temperature results from all river stations beginning with LH02 and ending with LH17 where observed data were available. Each plot contains the three statistics used to measure model performance. As before, the cyclic pattern occurring about every two weeks is being reproduced by W2. Also, the decrease in temperature from August through November is being predicted by W2. W2 does very well in predicting temperature at all stations even though inflow tributary temperatures needed for boundary conditions were not available for this year. As previously mentioned, tributary temperature data used as boundary conditions were set to the measured inflows to F. E. Walter and Beltzville Reservoir. Depending on where the tributary was in relation to the reservoir inflow determined which inflow was used. ME indicates at most stations W2 over predicts temperature. This is also indicated on the cumulative distribution plots in Figure 34. Figure 34 shows good distribution of predicted data with observed at station LH03, but at the other stations, temperatures below 20 °C are being over predicted.

Figure 35 contains calculated WSEL for station LH10 and LH15 on the Lehigh River. At station LH10, W2 over predicts depth at times as much as 1.5 m. It is believed that the estimated flows are being over estimated thus increasing depth. If this is not the case, Manning's n may be set too high, slowing water down too much. However this does not seem to be what is happening since most flow peaks are being predicted. Also, during calibration there were problems with hydraulic instability when adjustments to layer depths or widths so cross-section information was adjusted until problems occurred. This could have affected depths. This did not seem to affect temperature predictions adversely. Flow at this station followed patterns of observed flows except toward the end of simulation. At around Julian day 260 a flow peak was missed. At station LH15 depth followed the trend of observed but was approximately 1 m over predicted. It is believed to be for the same reason as at station LH10. Flow also follows observed data except toward the end of simulation. This may be from a storm event that was not captured in observed data.

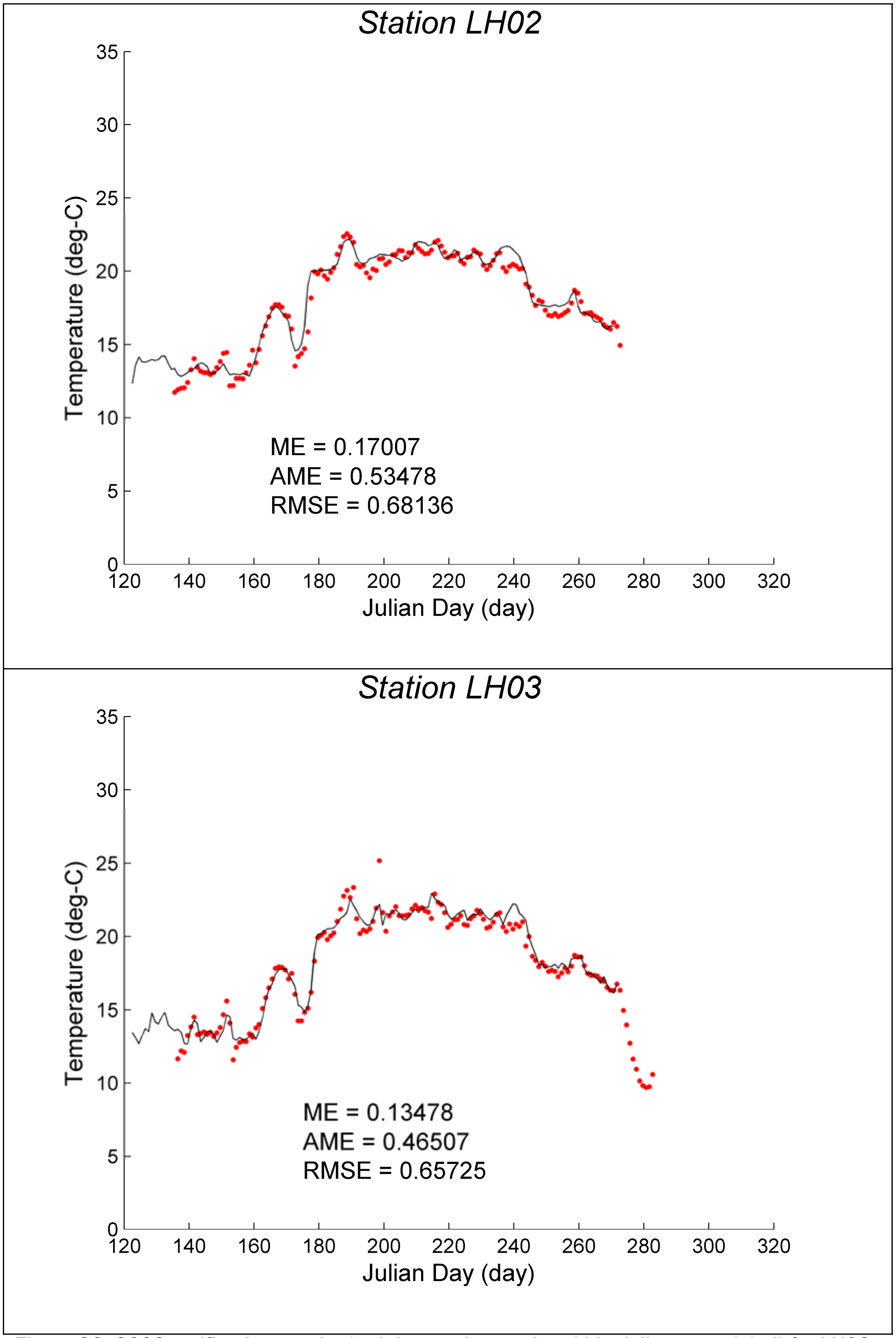
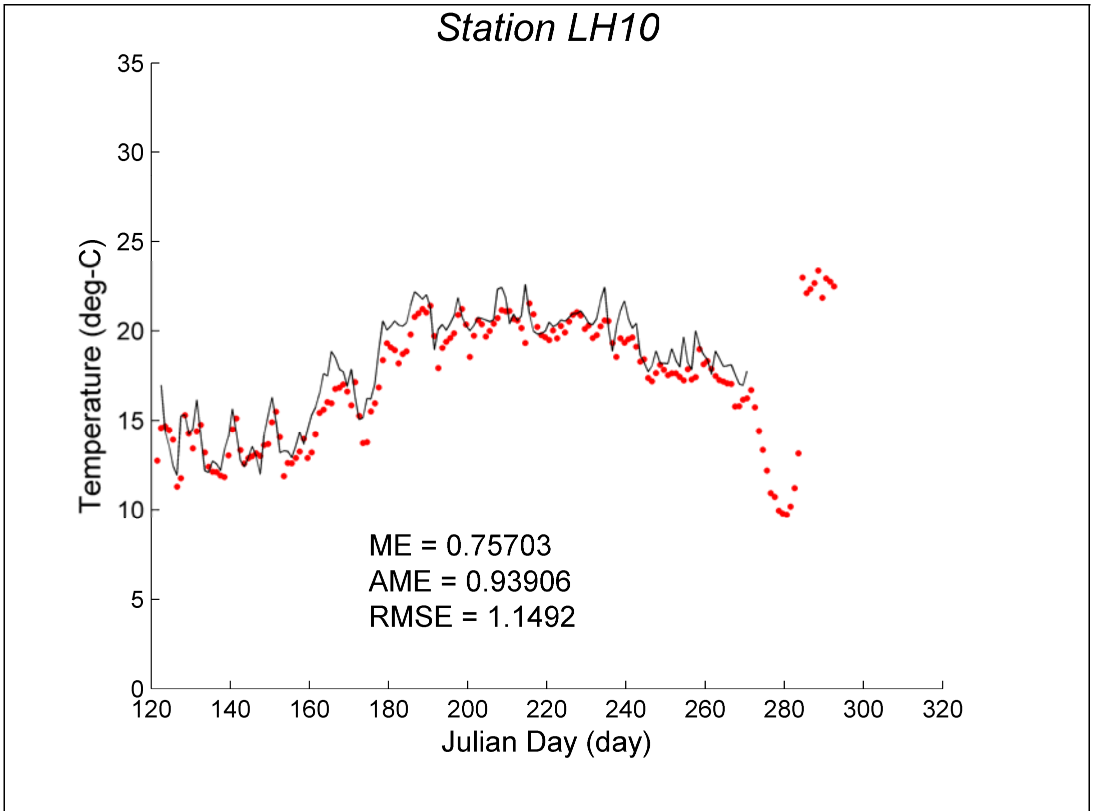


Figure 33. 2003 verification results (red dots = observed and blank line = modeled) for LH02, LH03, LH10, LH15, and LH17 on the Lehigh River



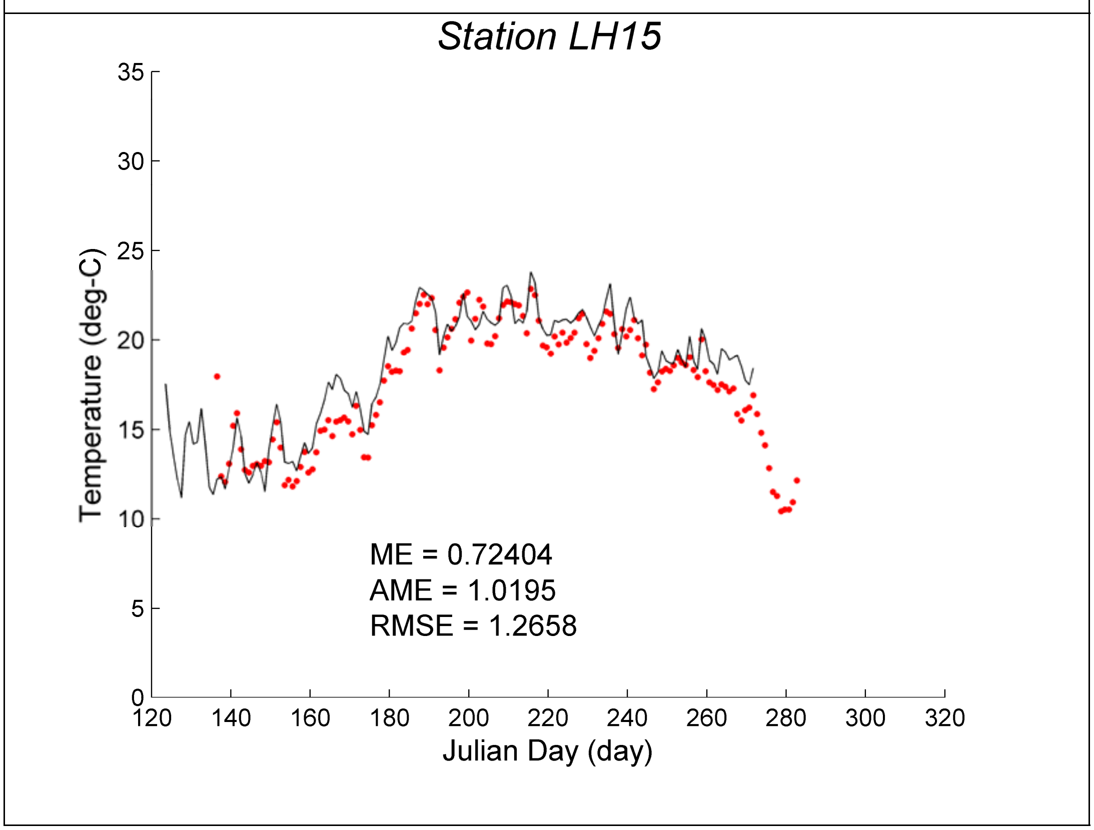


Figure 33. Continued.

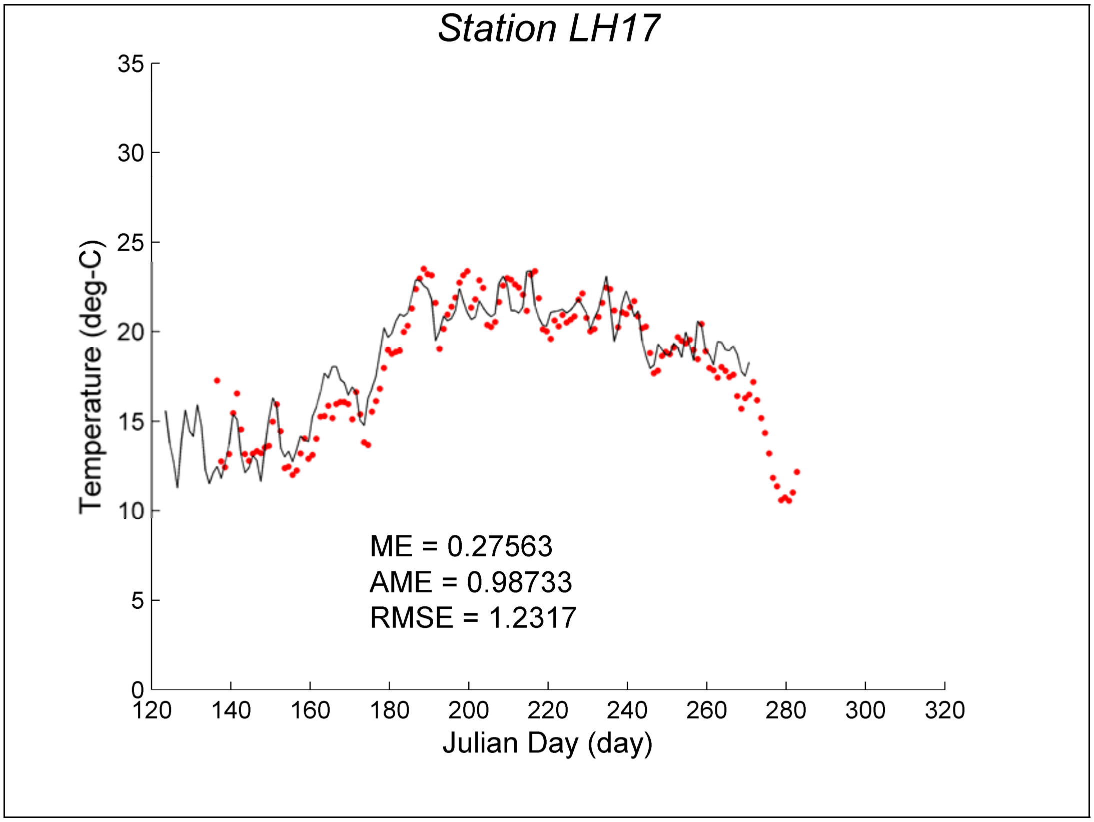
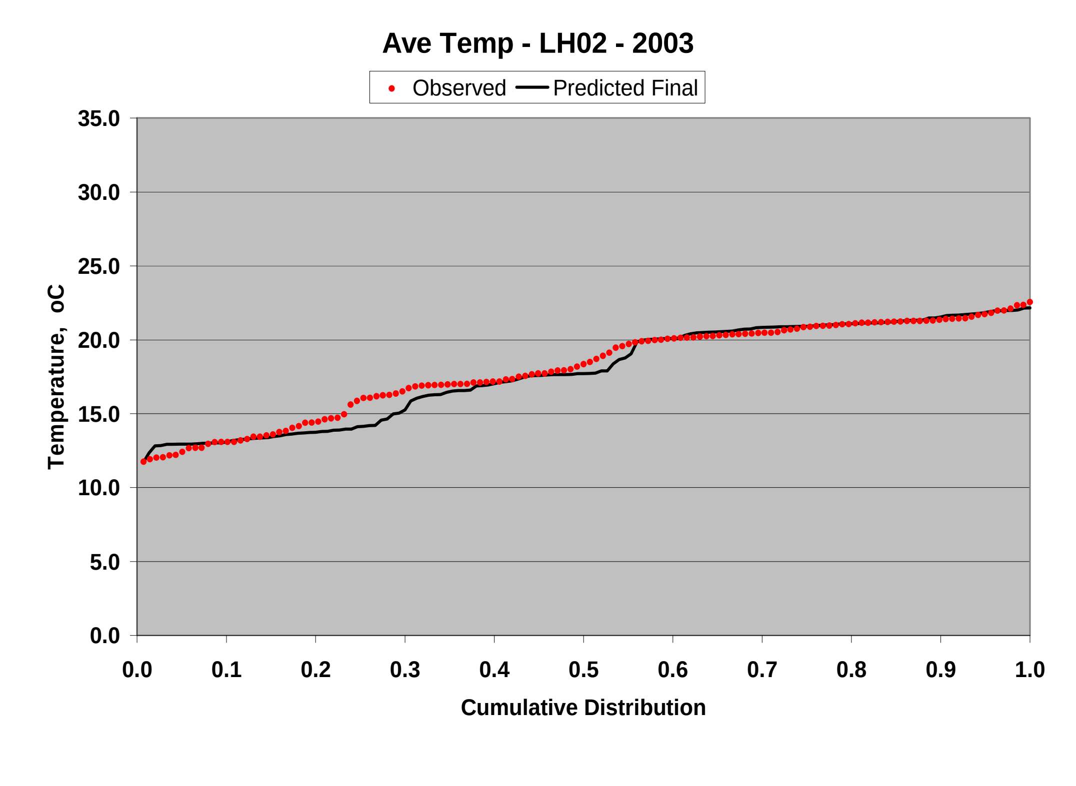


Figure 33. Concluded.



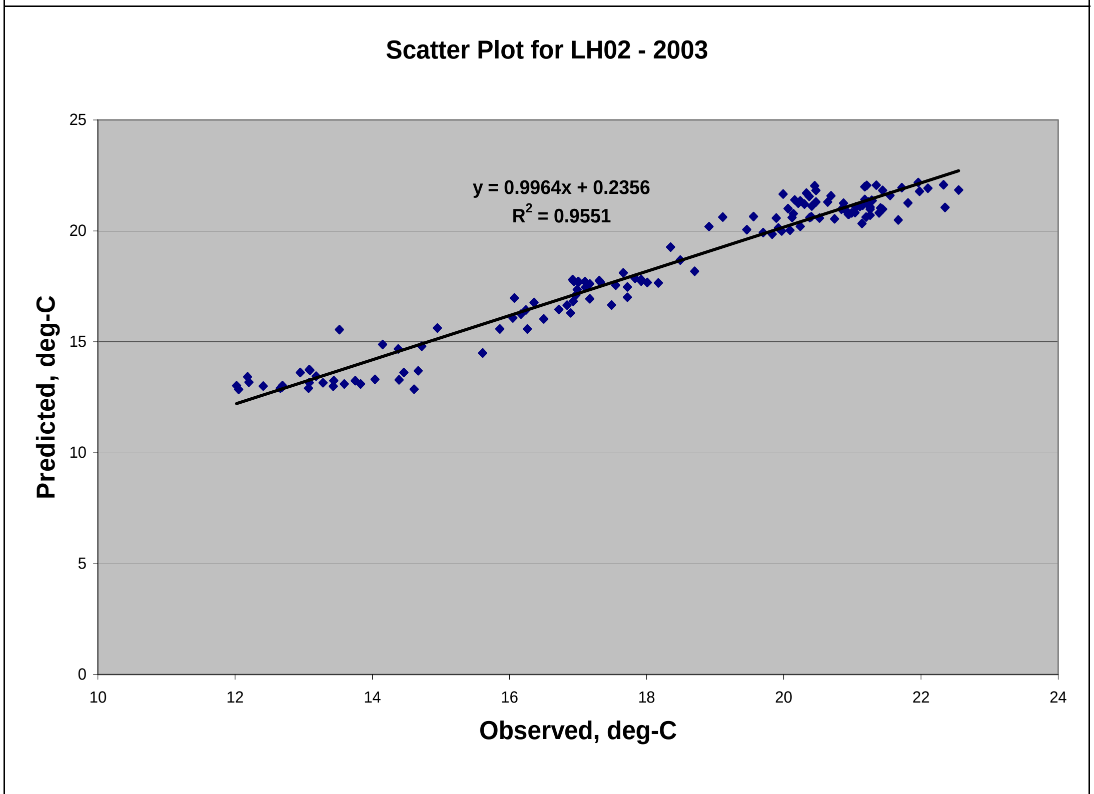


Figure 34. 2003 verification Cumulative Distribution and scatter plots for stations LH02, LH03, LH10, LH15 and LH17 on the Lehigh River.

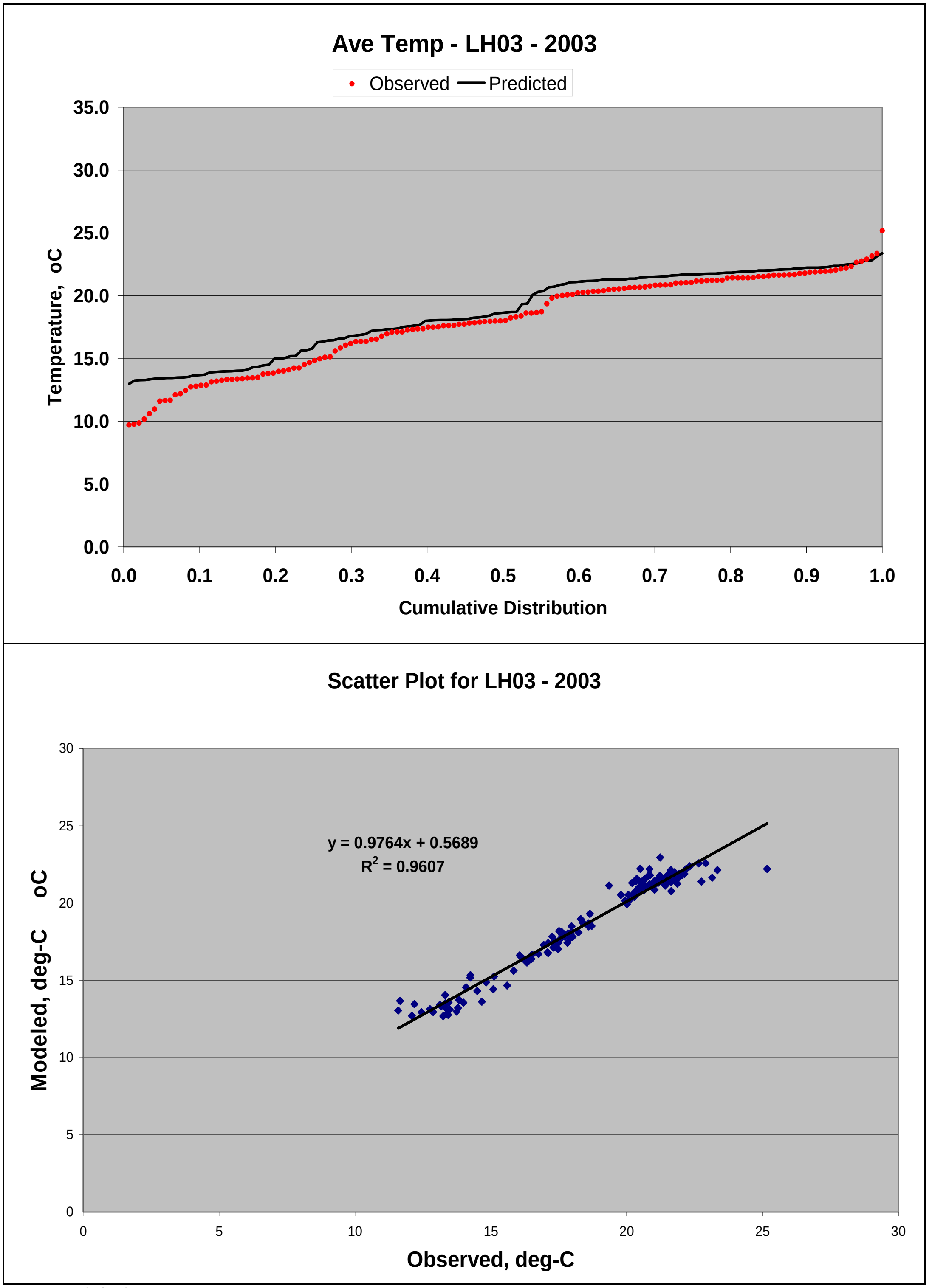
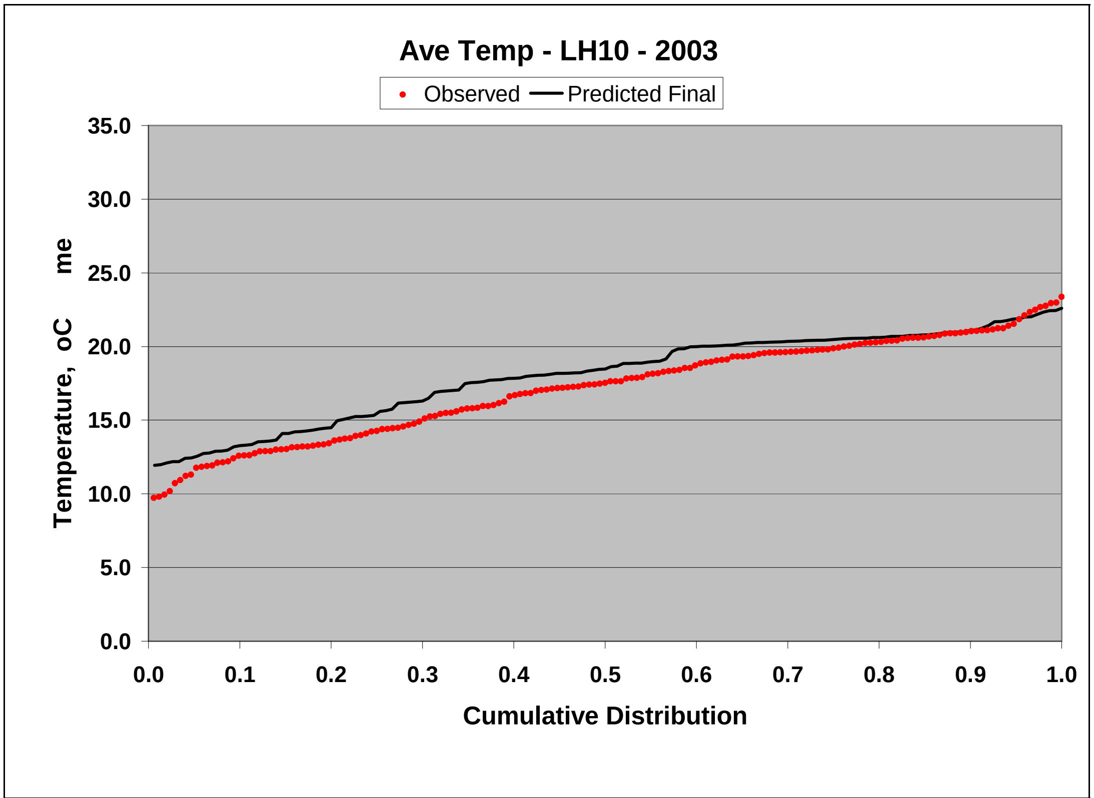


Figure 34. Continued.



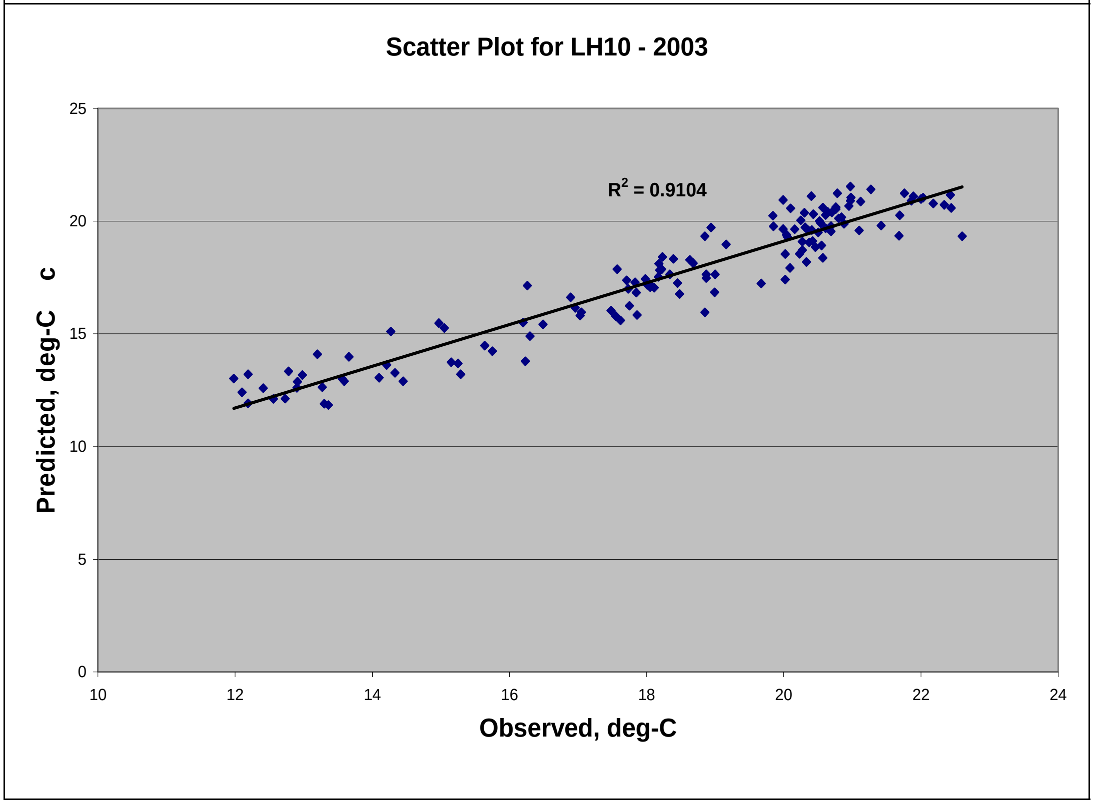


Figure 34. Continued.

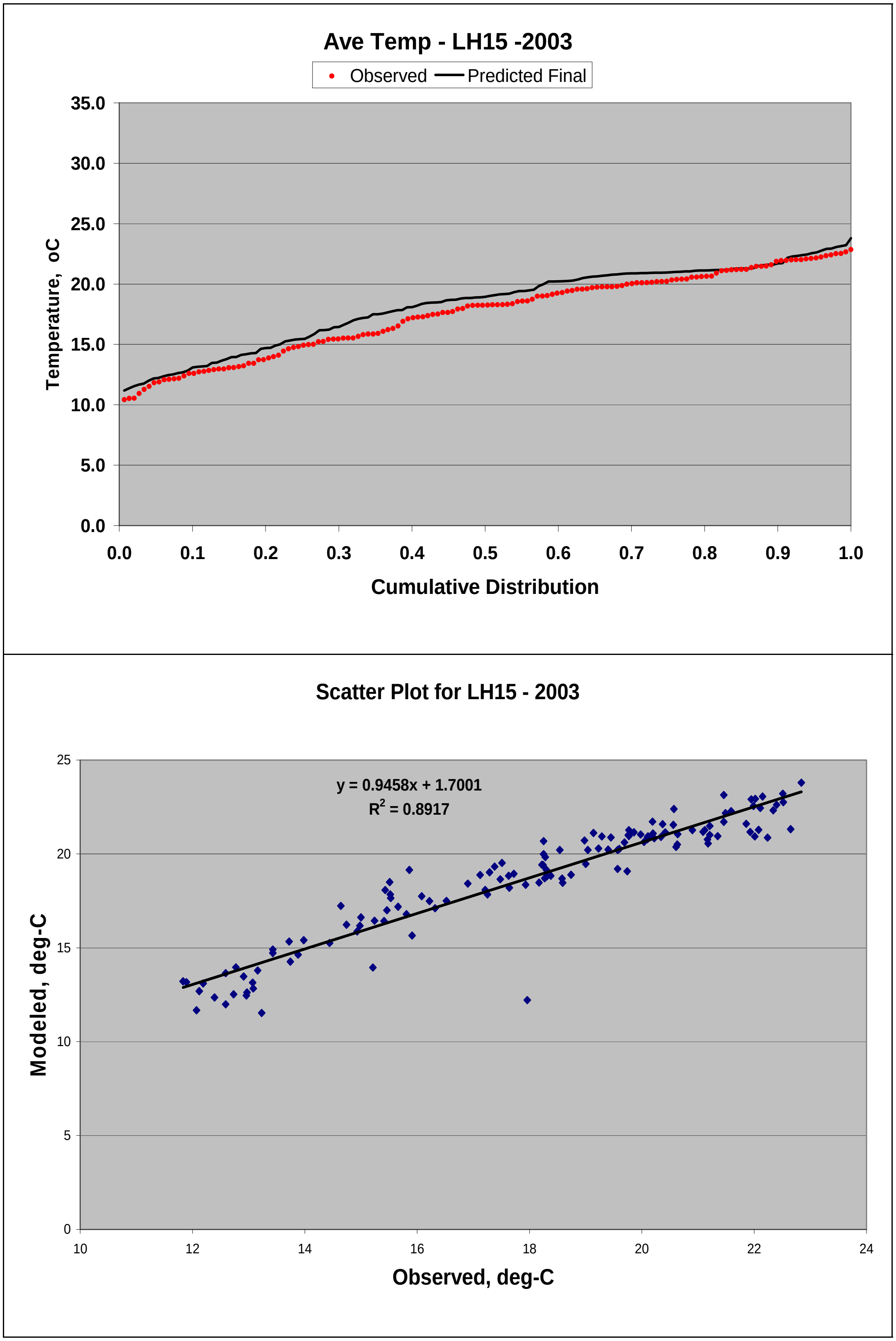


Figure 34. Continued.

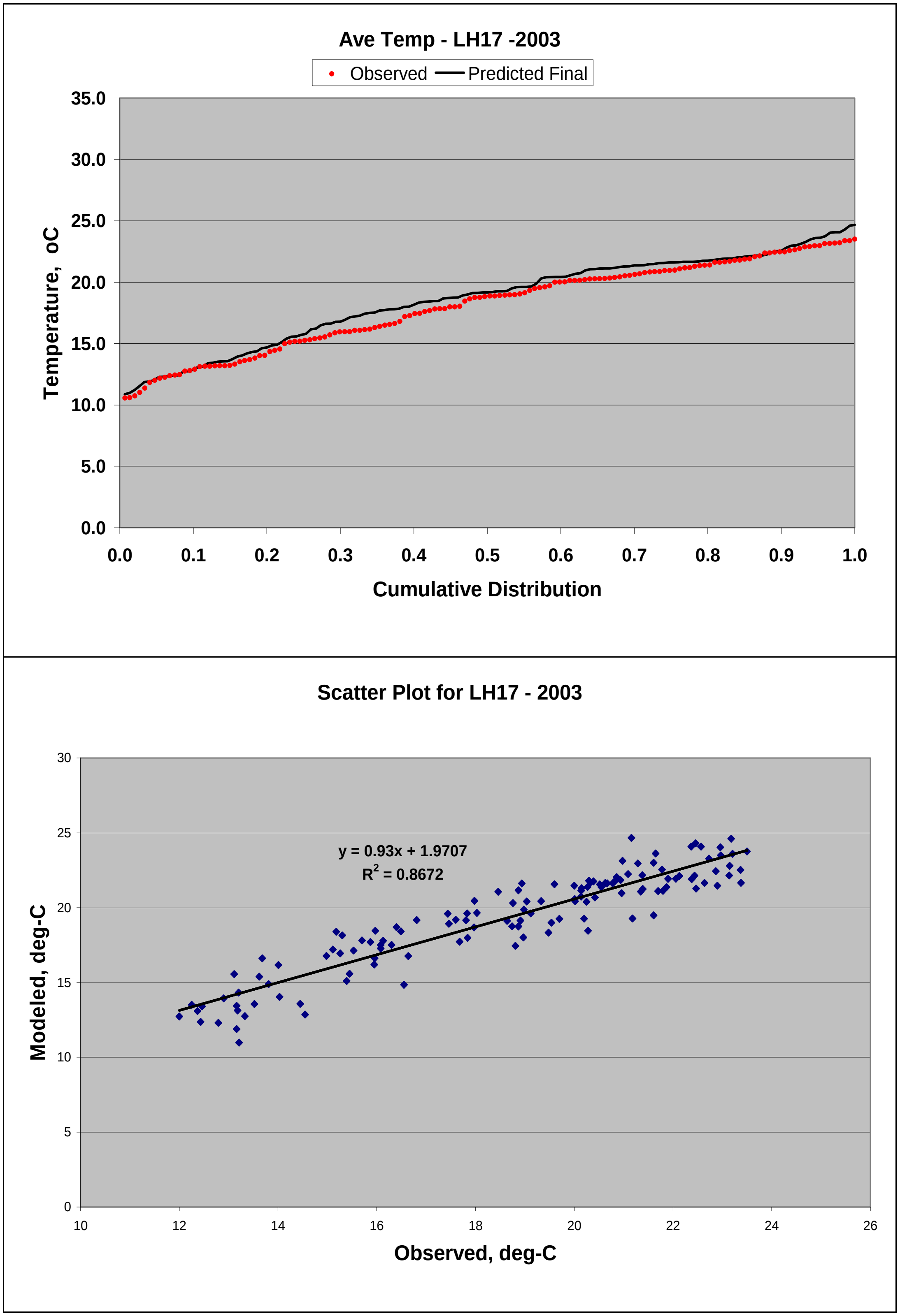


Figure 34. Concluded.

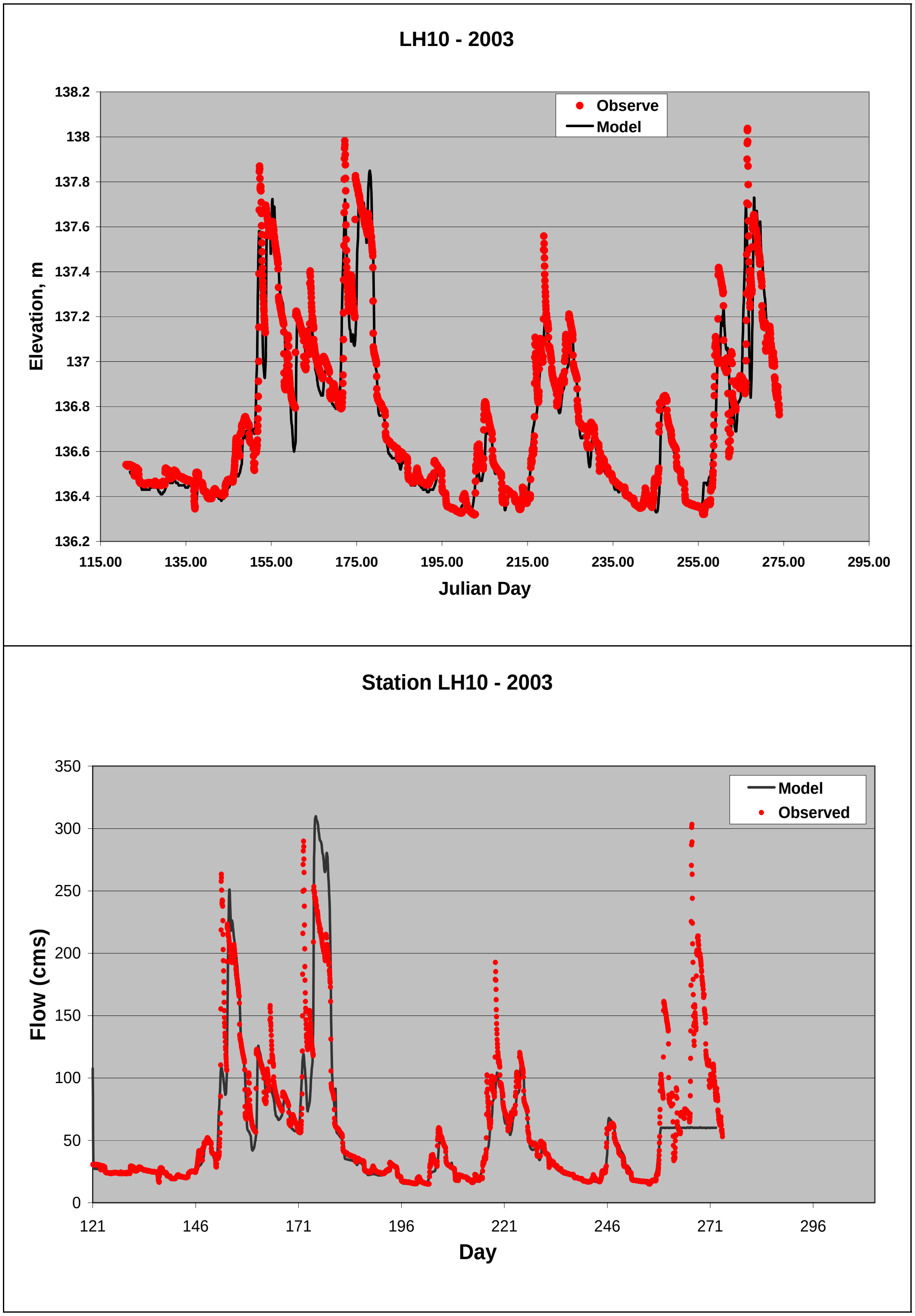


Figure 35. Model versus observed stage and flow at LH10 and LH15 on the Lehigh River.

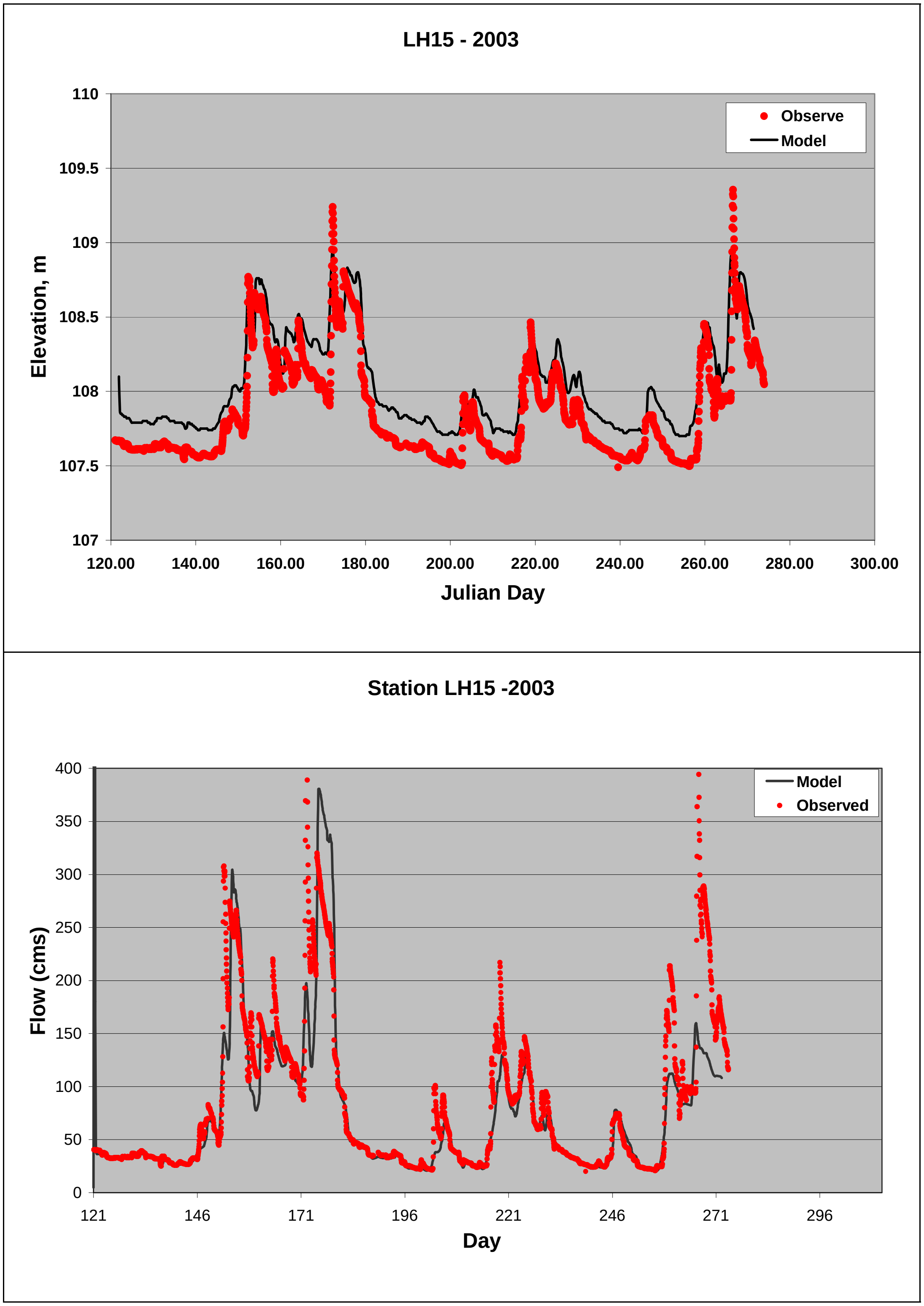


Figure 35. Concluded

Beltzville Reservoir and Pohopoco Creek

WSEL: Comparison of predicted WSEL to observed data for the verification year showed no discrepancies thus the inclusion of positive or negative inflows as a distributed tributary was not necessary. As shown in Figure 36, predicted elevations closely matched observed elevations (i.e., within 0.1 m).

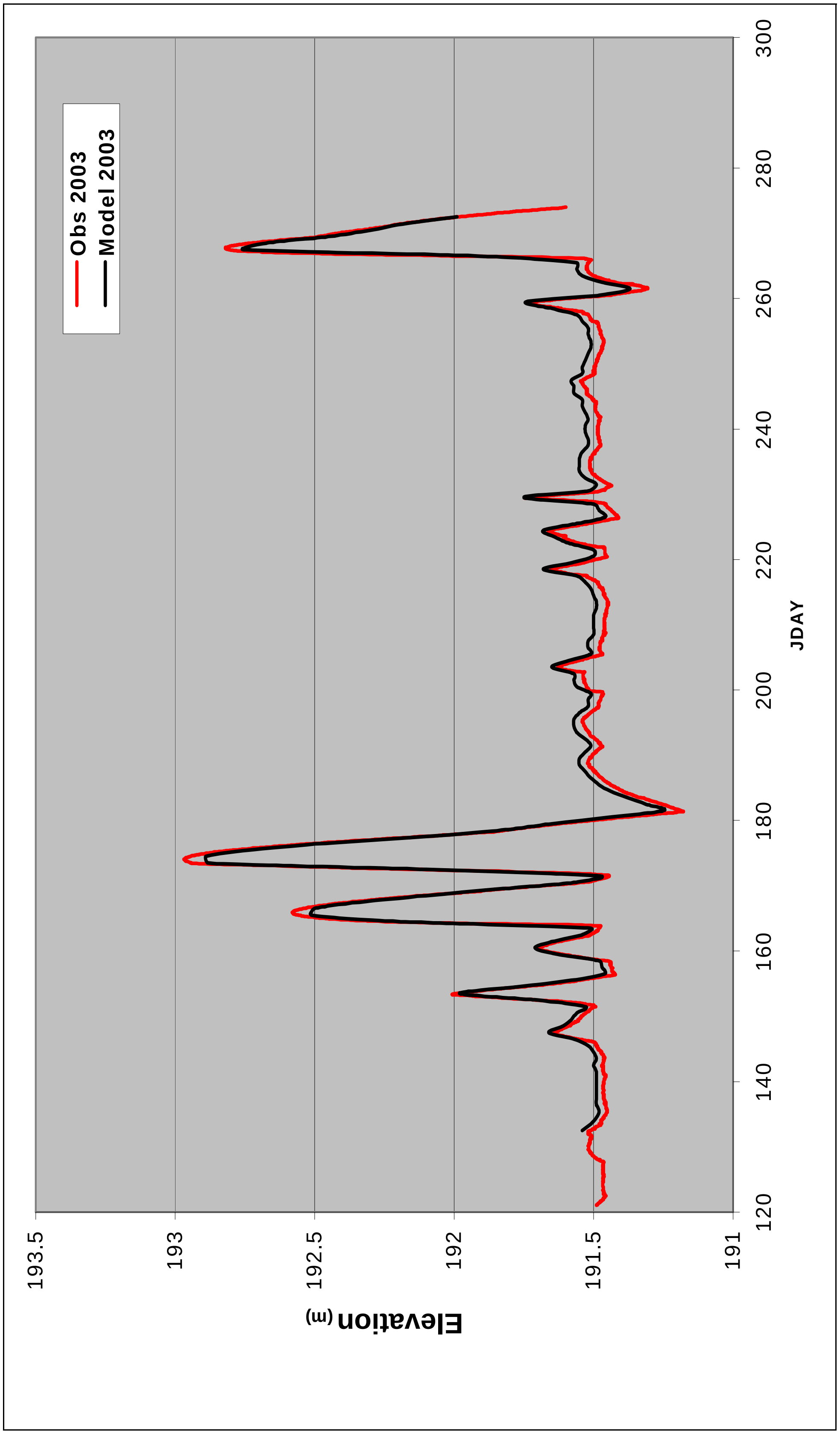


Figure 36. Predicted versus observed water surface elevation (WSEL) at Beltzville Reservoir for 2003.

In-Pool stations: Figures 37 through 39 show calibration results for Beltzville stations BZ06, BZ03, and BZ07. Similar to F.E. Walter Reservoir results, model results show good agreement with observed data except for the profile on June 10, 2003. On this date, temperatures in the hypolimnion are being over predicted. This could indicate problems with not representing reservoir operations accurately more so than meteorological data. Later in the simulation, onset of stratification is captured as well as fall turn over. ME indicates the model slightly under predicts in the range of -0.3 to 1.1 ^{o}C and on average AME is within the observed value approximately 1.0 ^{o}C. The RMS indicates a spread of about 1.5 ^{o}C. As in 2001, releases were split equally between ports 4 and 7.

The cumulative distribution plot (Figure 40) at BZ06 denotes that 25% of the time most predicted data are being over predicted at the lower temperatures (< 12 ^{o}C). At higher temperatures (>12 ^{o}C) there was very good agreement to observed data. Cumulative distribution for BZ03 and BZ07 show good agreement for most temperatures however temperatures at BZ07 in the range of 15 to 20 ^{o}C show slight over predictions.

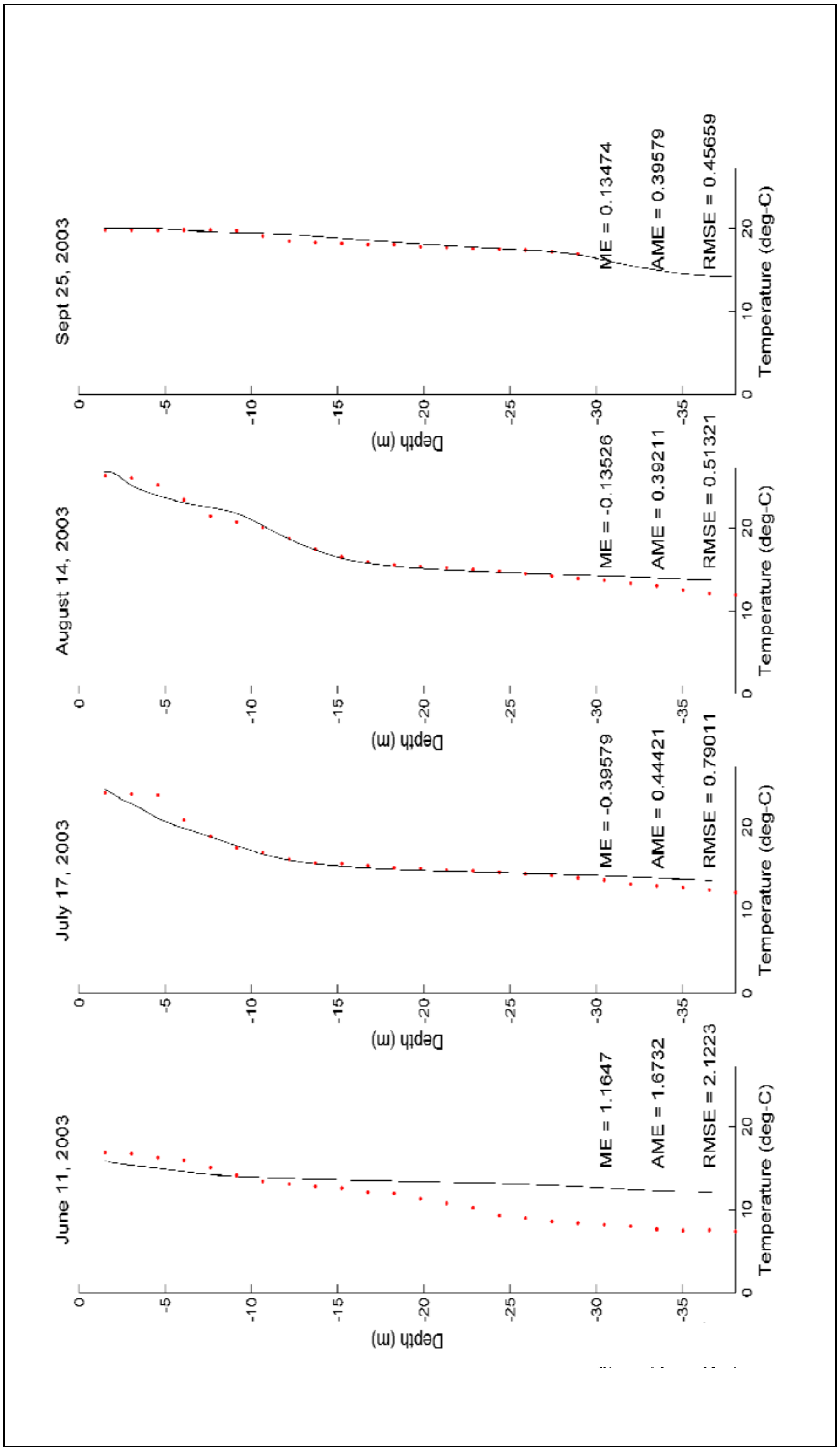


Figure 34. Temperature verification results (red dots = observed and black line = modeled) for station BZ06 at Beltzville Reservoir.

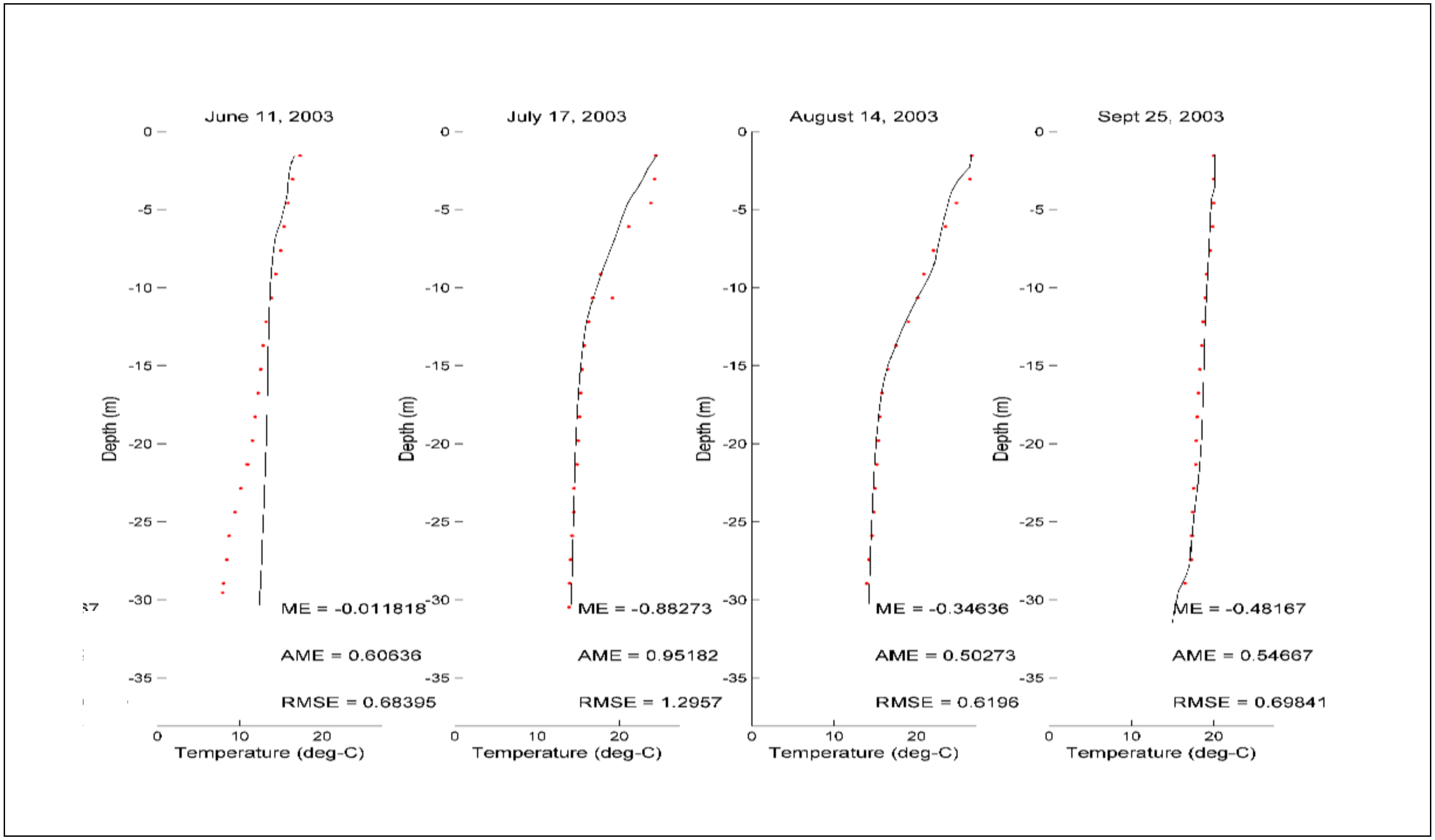


Figure 35. Temperature verification results (red dots = observed and black line = modeled) for station BZ03 at Beltzville Reservoir.

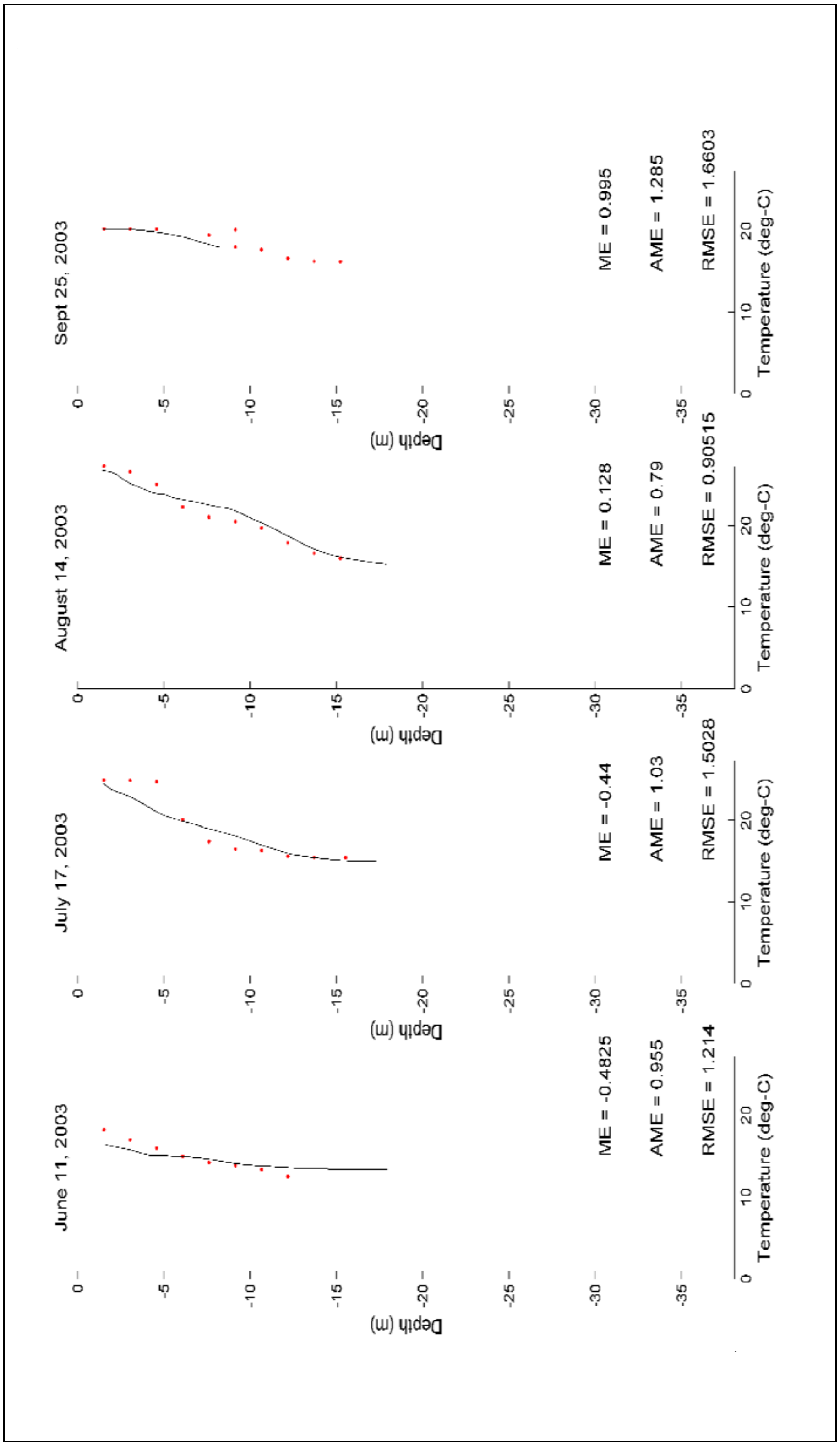


Figure 36. Temperature verification results (red dots = observed and black line = modeled) for station BZ07 at Beltzville Reservoir.

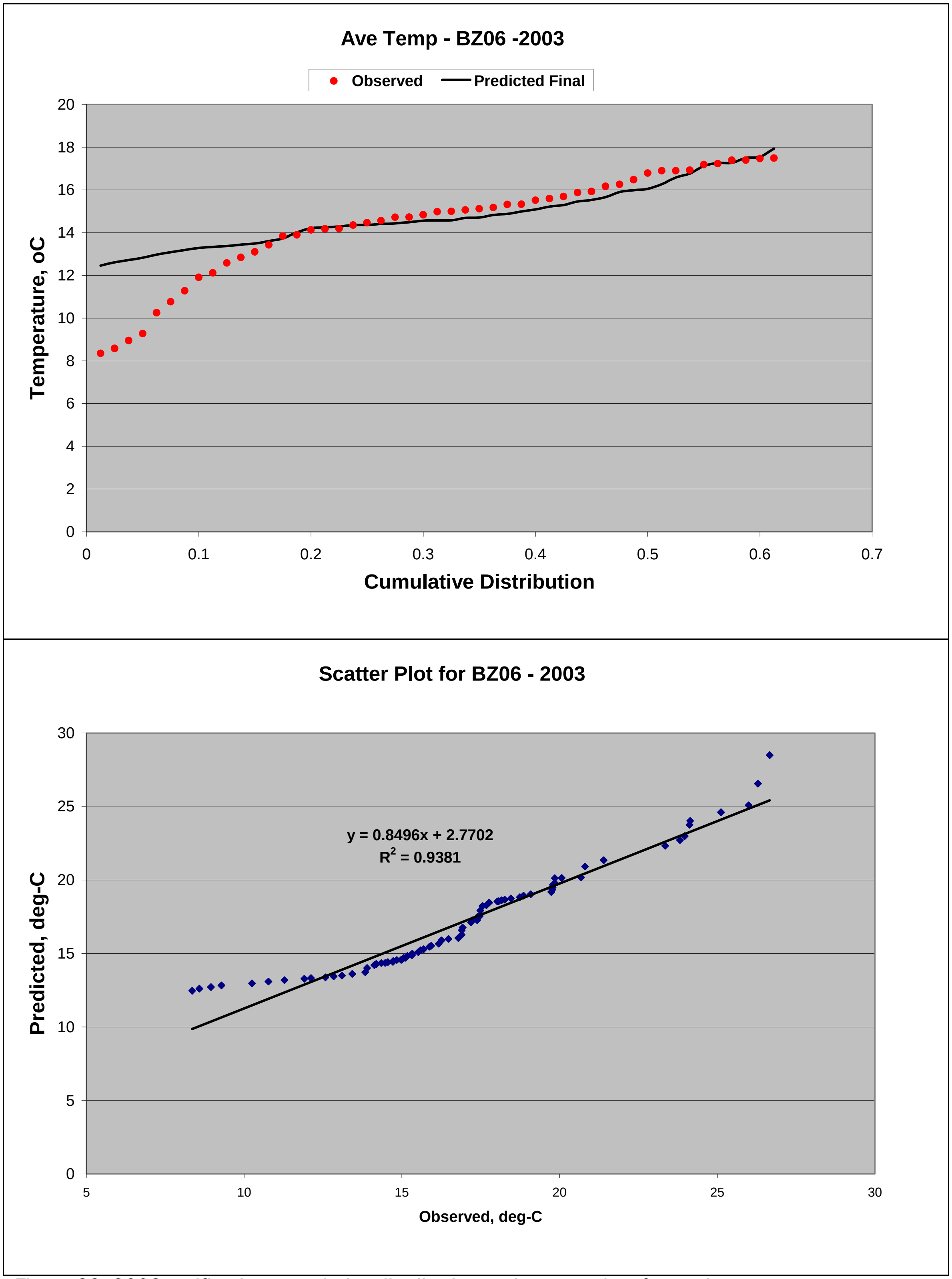
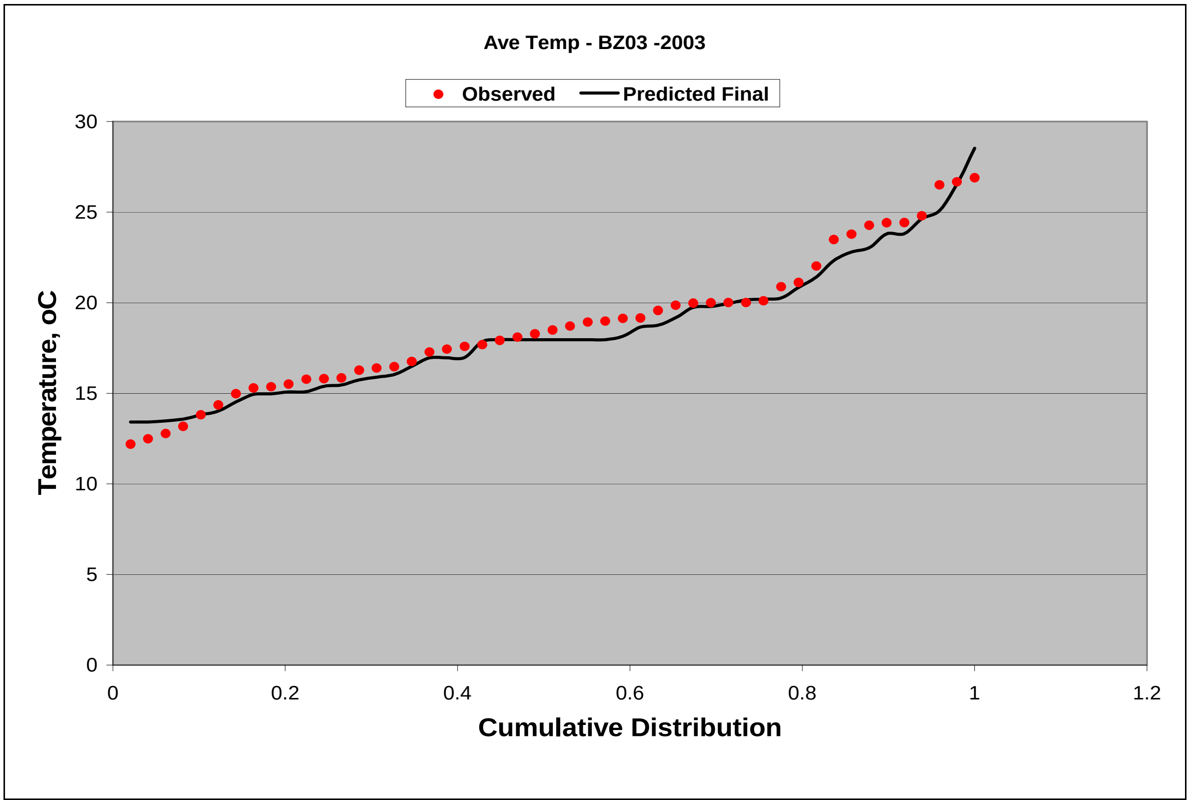


Figure 39. 2003 verification cumulative distribution and scatter plots for station in-pool stations at Beltzville Reservoir.



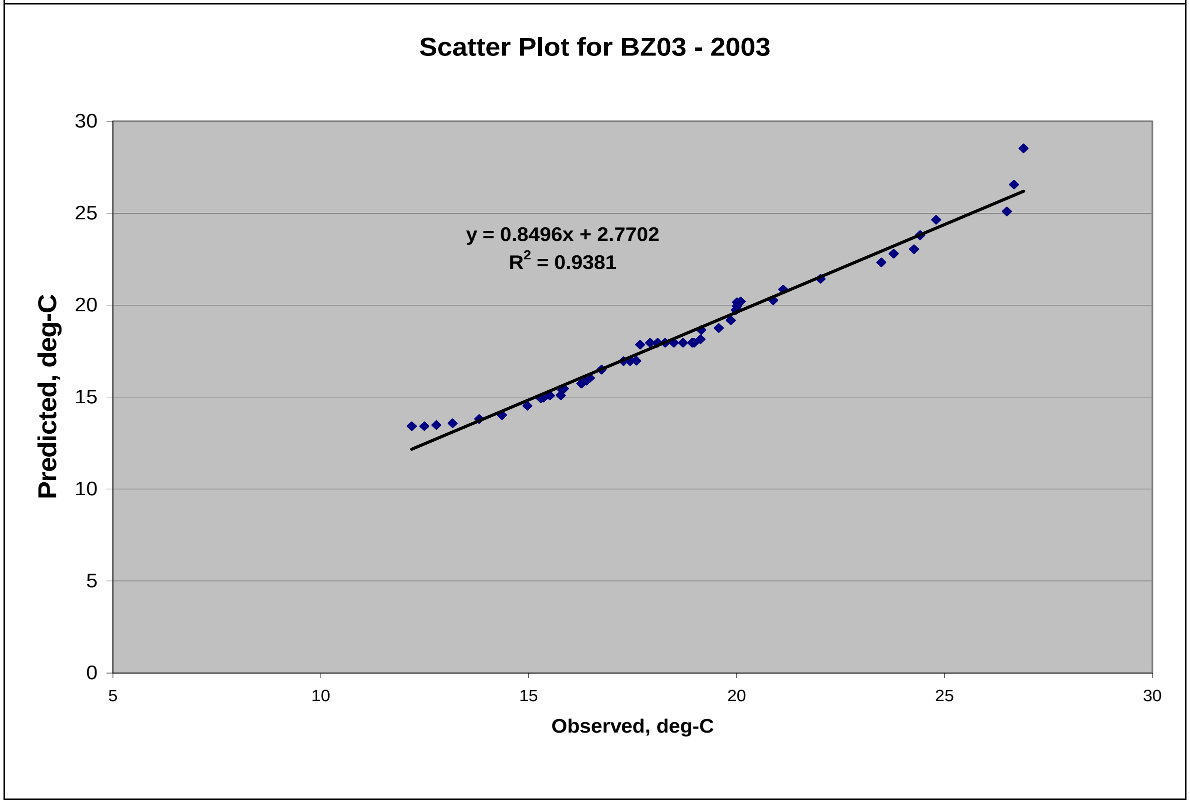
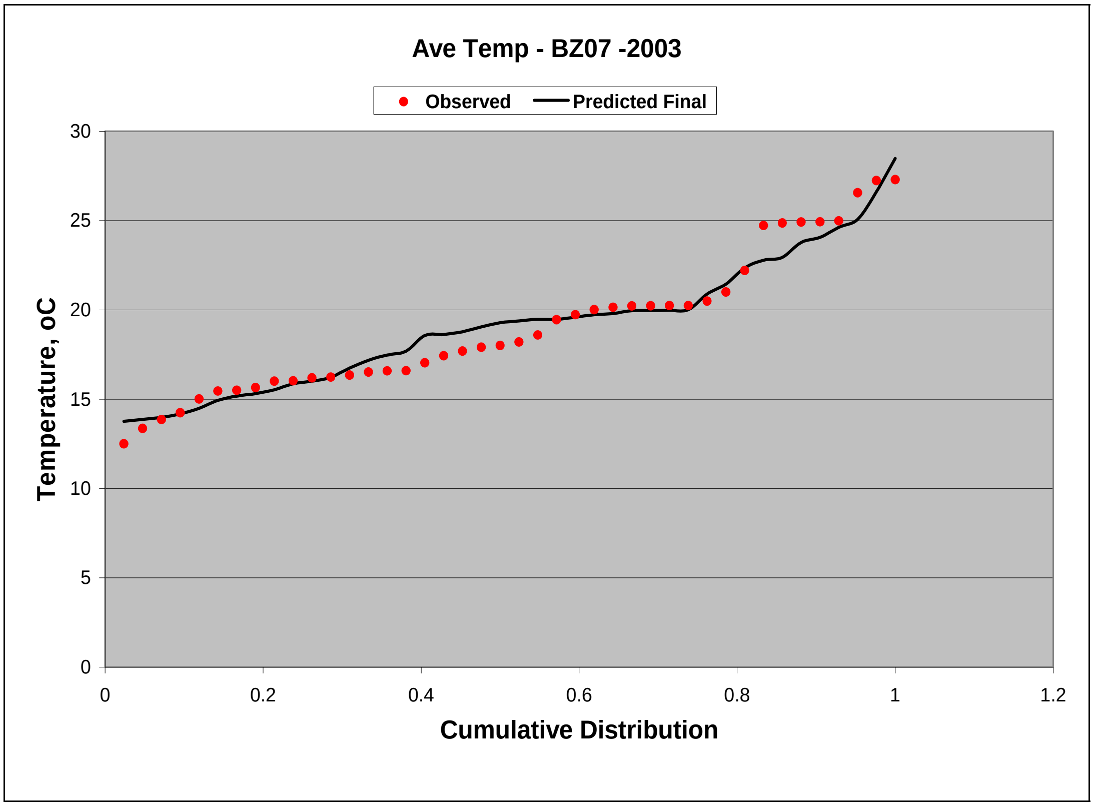


Figure 39. Continued.



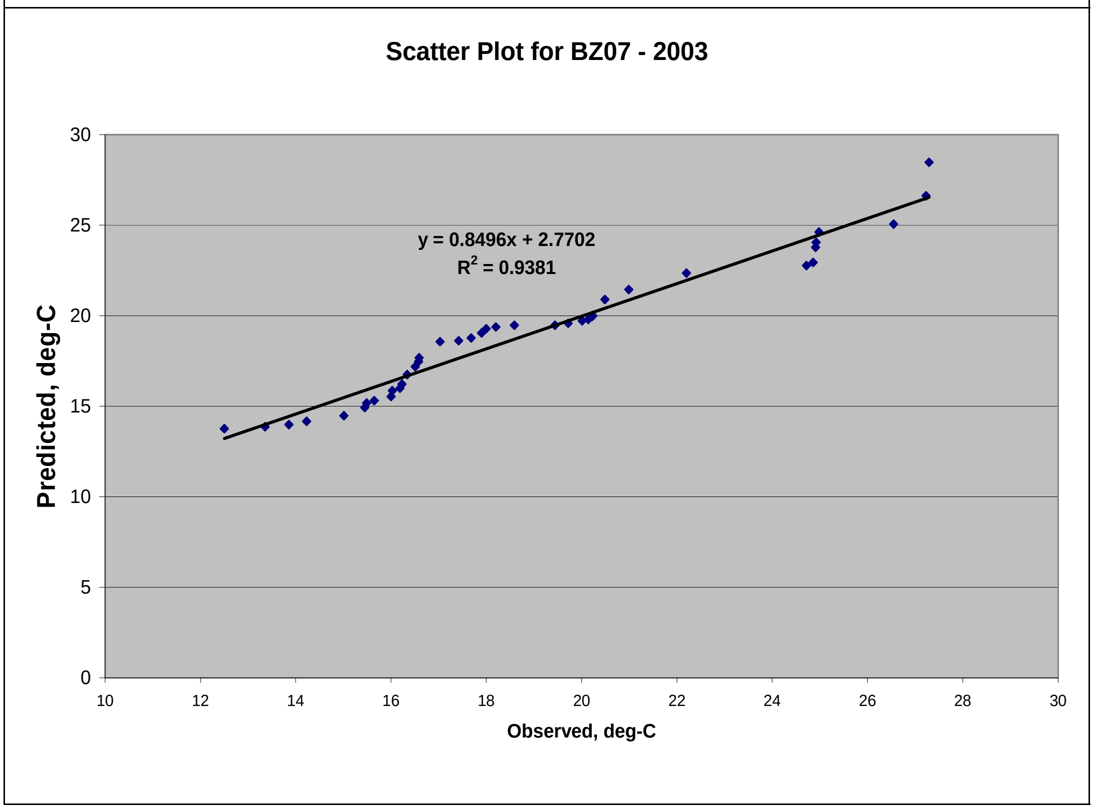


Figure 39. Concluded.

Riverine Stations: Limited observed data were available at stations on the Pohopoco Creek downstream below Beltzville Reservoir. Figure 40 contains temperature results for the river station BZ01 on the Pohopoco Creek with only a few observed data points for comparison to model results. The time of collection for the observed data was not known so comparisons were made to an averaged model result. Model predictions are following observations except at the end of the simulation. The statistics for this station are ME is 0.962, AME is 1.38, and RMS is 1.81 and appear to be highly influenced by the last observed data point. Based on the last point, the reservoir releases appear to come from deeper in the reservoir than W2's prediction would indicate. When looking at the predicted profile in Figure 34 for this date (September 25, 2003), model predictions are matching hypolimnetic temperatures thus it would seem reasonable to expect release temperature to be in the same range. However, the observed data shows much cooler release temperature for this date. This indicates a possible problem with the last observed data point at BZ01.

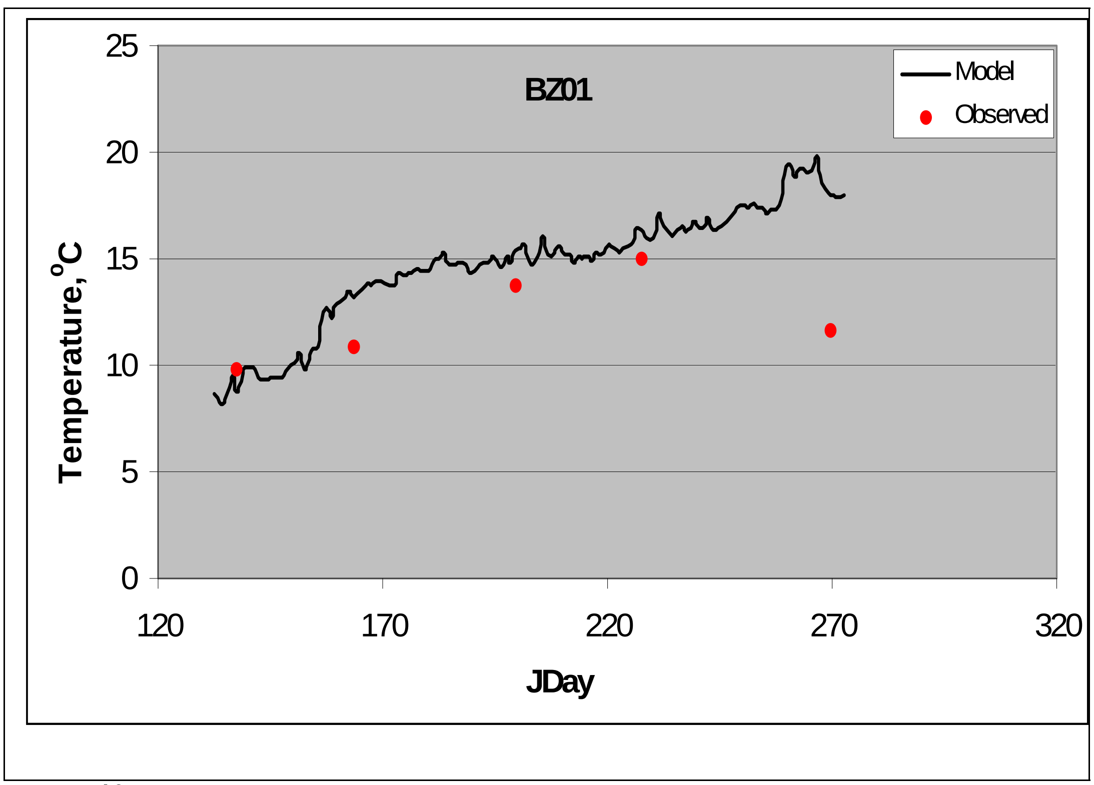


Figure 40. Model (black line) versus observed (red dots) temperature data at BZ01 on the Pohopoco Creek for the verification year, 2003.

4 Scenario Applications

The parameters for the calibrated/verified model were retained for making the scenario applications. The only difference between the calibration/verification runs and the scenario runs was the new reservoir operation releases. The specifications for the new reservoir operations for each scenario run, as jointly determined by the ACOE, PADCNR Parks, and PFBC, are discussed below.

Scenario 1

Scenario 1 is based on the 2008 release schedule 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 July 1 and September 30 by a minimum of 50 cfs with the cooler water; and provide whitewater releases on alternating weekends from May to September. The pool would be raised to 1370 ft and releases would be made from the existing structure. The bypass gates at elevation 1297 ft could release a maximum of 300 cfs (8.503 cms). All other discharges would be made from the flood control gates at elevation 1265 ft.

***Pool Elevation*:** 1370 ft NGVD

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

Release Plan:

- Whitewater releases on alternating weekends starting on the second weekend in May. (The first weekend release in May will be a one day event).
- 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 dependant 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.
- 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.

Scenario 2

Similar to Scenario 1, this plan is also based on the 2008 release schedule. However, this plan investigates how a selective withdrawal system could be used to conserve cooler water for releases later in the summer. 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 coolest water possible; and provide whitewater releases on alternating weekends from May to September.

Pool Elevation: 1370 ft NGVD

Withdrawal Capabilities: Selective withdrawal.

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

Release Plan: (based on 2008 plan)

- Whitewater releases on alternating weekends starting on the second weekend in May. (The first weekend release in May will be a one day event).
- 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 dependant 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.

Scenario 3

Scenario 3 can be described as "Fisheries only, with no modification to the dam". The pool is raised to elevation 1370 and there is no structural modification 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 and to maximize the amount of cooler water released for downstream fisheries. This plan was run to determine the optimal benefit that could be provided to downstream fisheries without modifying the dam.

Pool Elevation: *1370 ft NGVD*

Withdrawal Capabilities: Limited selective withdrawal. Releases made through flood control and bypass systems.

Release Plan:

- 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.
- Augment flows by 100 cfs from 1 July to 15 July.
- Augment flows by 150 cfs from 16 July to 9 August
- Augment flows by 100 cfs from 10 August to 30 September

Scenario 4: (there were two runs, one with no mod to the dam, and one with selective withdrawal added.)

Scenario 4 can be described as “Fisheries only, with selective withdrawal to the dam”. The pool is raised to elevation 1392 and selective withdrawal capability is added 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 and to maximize the amount of cooler water released for downstream fisheries. This plan was run to determine the optimal benefit that could be provided to downstream fisheries if the pool was higher and selective withdrawal capability was added to the project.

Pool Elevation: *1392 ft NGVD*

Withdrawal Capabilities: *Selective withdrawal.*

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

Release Plan:

- 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.
- Augment flows by 100 cfs from 1 July to 15 July.
- Augment flows by 150 cfs from 16 July to 9 August
- Augment flows by 100 cfs from 10 August to 30 September

Scenario 5

Scenario 5 primarily examines the maximizing the number of whitewater events while augmenting flow for fisheries during non-whitewater release times. The pool is raised to elevation 1370 and there is no structural modification to the project. The goals of this 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 downstream rafting by augmenting flows between July 1 and September 30 by as much water as possible. This plan was run to determine the optimal possible benefit to downstream recreation while providing some additional releases for fisheries.

Pool Elevation: *1370 ft NGVD*

Withdrawal Capabilities: *Limited selective withdrawal. Releases made through flood control and bypass systems.*

Release Plan:

- Whitewater releases on alternating weekends in May and June.
- 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.
- Whitewater releases every weekend July through September.
- 1 July through 28 August, on non-whitewater release days, flows will be augmented by 40 cfs.
- Maximum whitewater release is 650 plus inflow up to a maximum of 800 cfs in May, 750 cfs in June, July, and August.

Scenario 6: (there were two runs, one with NoMod to the dam, and one with selective withdrawal added.)

Scenario 6 primarily examines maximizing the number of whitewater events while augmenting flow for fisheries during non-whitewater release times. The pool is raised to elevation 1392 and selective withdrawal is added to the project. The goals of this release schedule are to create optimal in-lake spawning areas in May and June by limiting the pool fluctuations to 5 feet; to maximize downstream rafting by augmenting flows every weekend between July 1 and September 30; and to provide some benefit to fisheries by augmenting flows during non-whitewater release times. This plan was run to determine the optimal possible benefit to downstream recreation while providing some additional cooler water releases for fisheries.

Pool Elevation: *1392 ft NGVD*

Withdrawal Capabilities: *Selective withdrawal.*

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

Release Plan:

- Whitewater releases on alternating weekends in May and June.
- 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.
- Whitewater releases every weekend July through September.
- 1 July through 28 August, on non-whitewater release days, flows will be augmented by 40 cfs.
- Maximum whitewater release is 650 plus inflow up to a maximum of 800 cfs in May, 750 cfs in June, July, and August.

Scenario Results and Discussion

Results for scenario runs are presented in plots of reservoir temperature profiles upstream of the F. E. Walter dam (Figures 41 and 42) and times series of temperature at six river locations (Figures 43 and 44) on the Lehigh River downstream of the dam for both years modeled (i.e., 2001 and 2003). Scenario runs were considered either no modification or selective withdrawal. No modification runs labeled ‘NoMod” on the figures used existing ports for reservoir release locations. Selective withdrawal scenario runs labeled “SW” on figures used five possible locations for new ports for reservoir releases. Profiles and time series results for all scenarios were compared to scenario 1 (SC1) results. This scenario run was considered the base case since releases were based on reservoir operations in 2008.

F. E. Walter Reservoir outflow releases for all scenarios are shown in Figure 45 for 2001 and Figure 46 for 2003. All no modification runs were labeled ‘NoMod” on the figures and used existing ports for reservoir release locations. All selective withdrawal scenario runs were labeled “SW” on figures and used five possible locations for new port elevations for reservoir releases. In addition, the flood gate port was also used for selective withdrawal releases. NoMod scenarios were SC1, scenario 3 (SC3), scenario 4 (SC4), scenario 5 (SC5) and scenario 6 (SC6). Scenario 2 (SC2) was considered “selective withdrawal.” Although SC4 and SC6 were originally run as NoMod, they were also later run with selective withdrawal capabilities.

During the scenario runs, Beltzville Reservoir operations were not changed from how it was operated during 2001 and 2003 simulations. Outflow release time series were presented above in Figure 11 at Beltzville Reservoir.

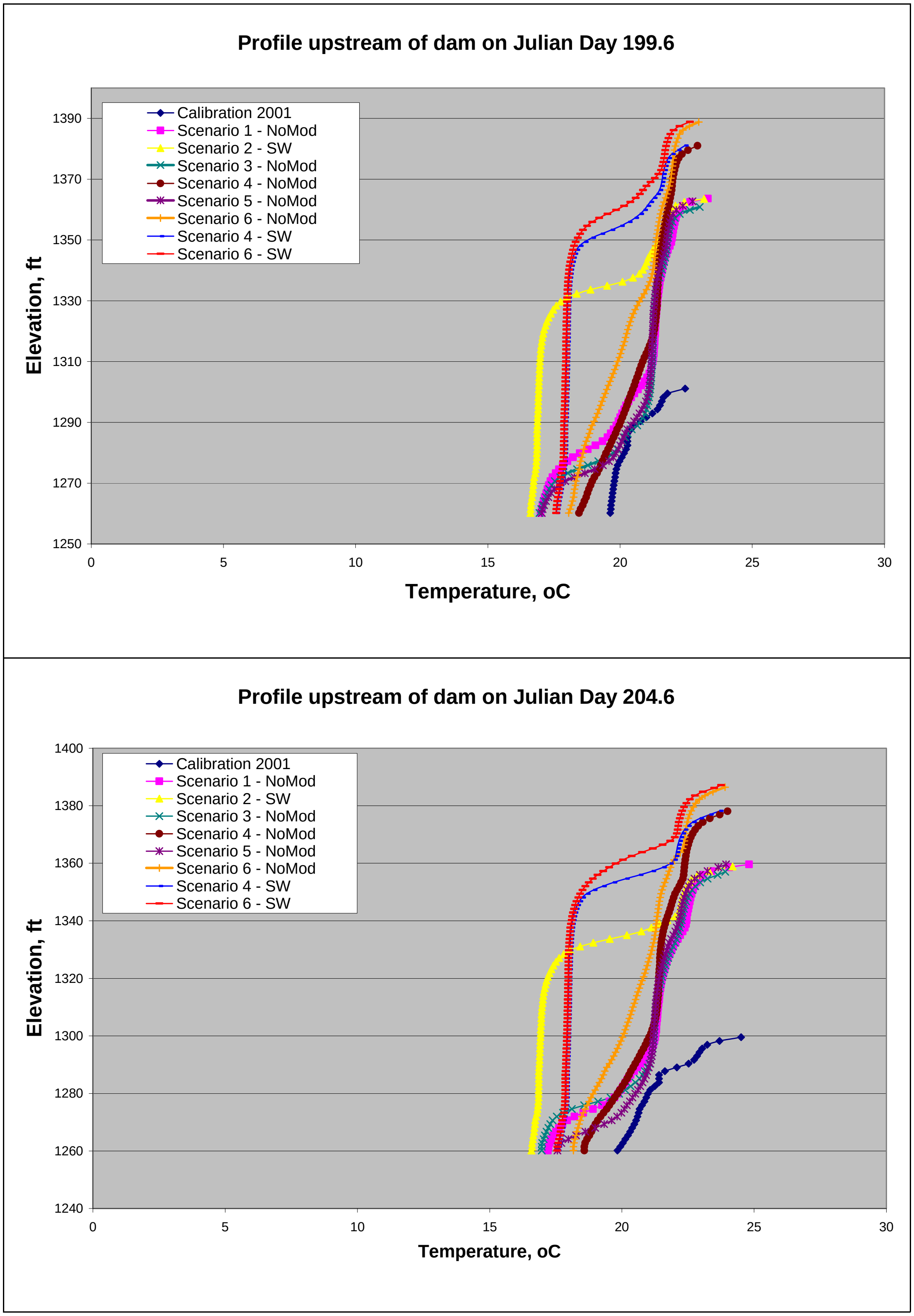
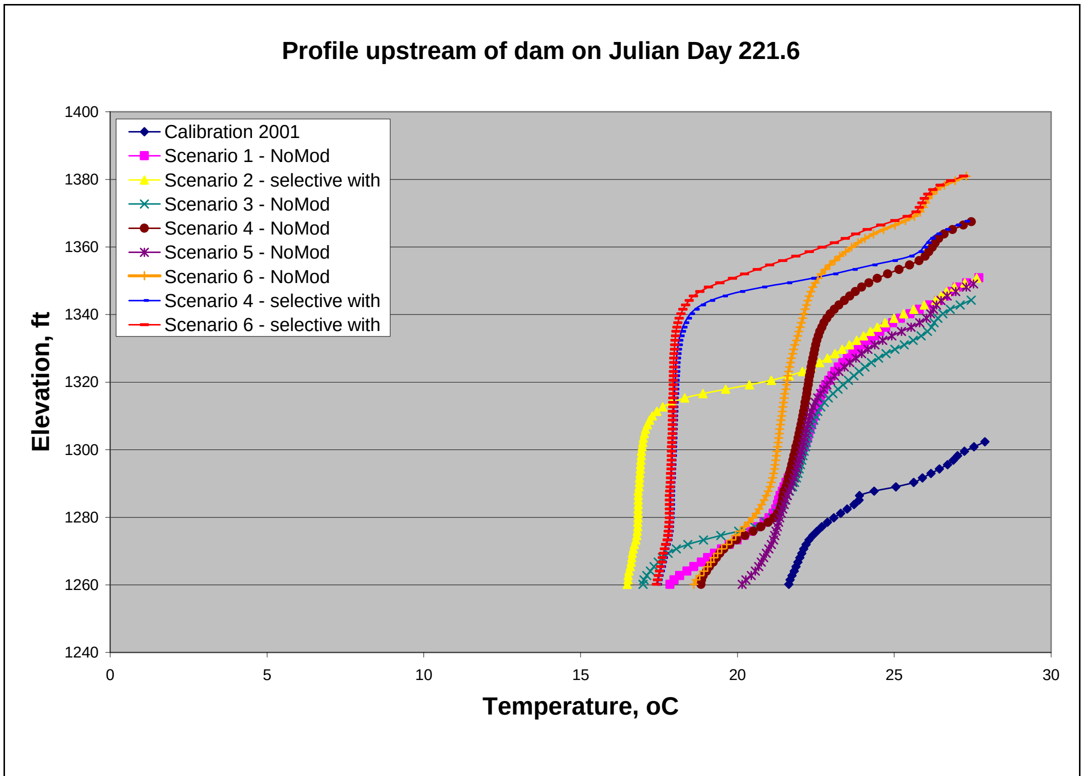


Figure 41. Examples of 2001 profiles for all scenario results



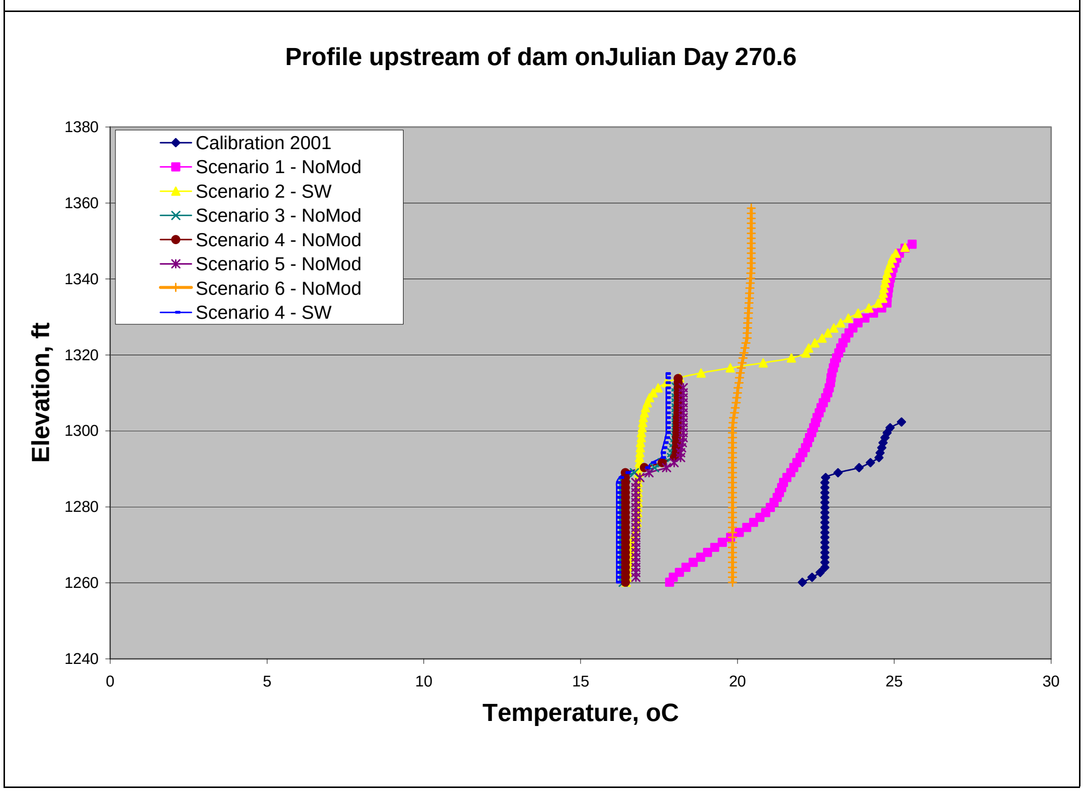
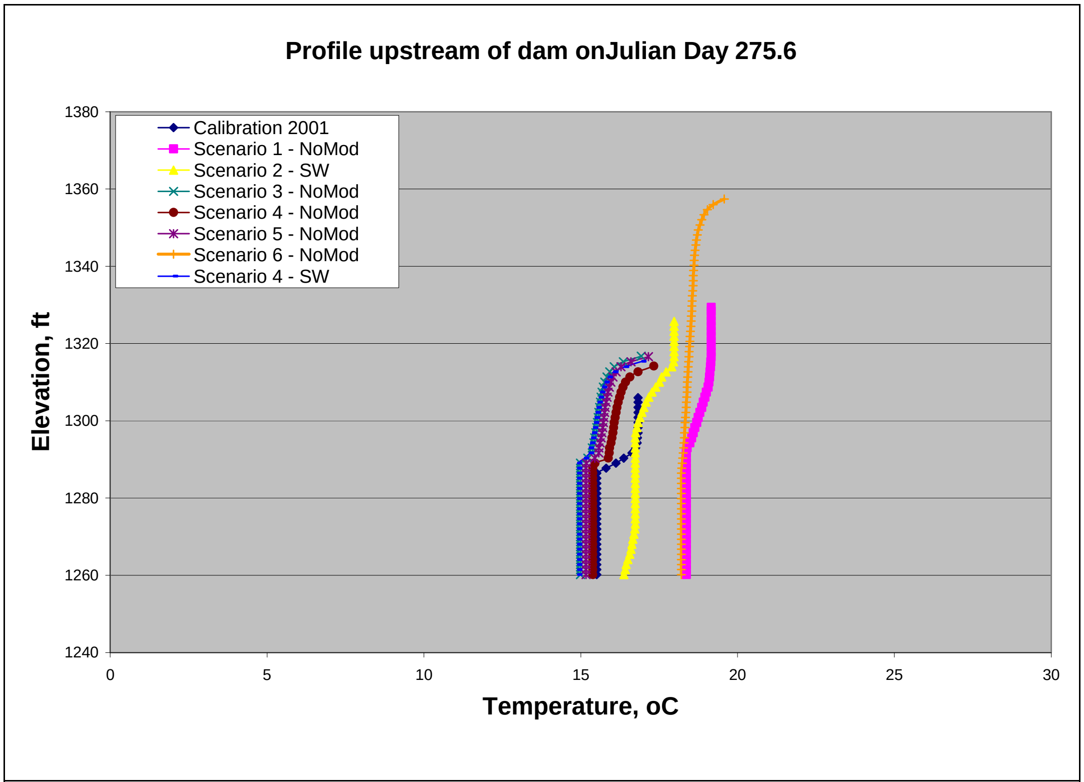


Figure 41. Continued



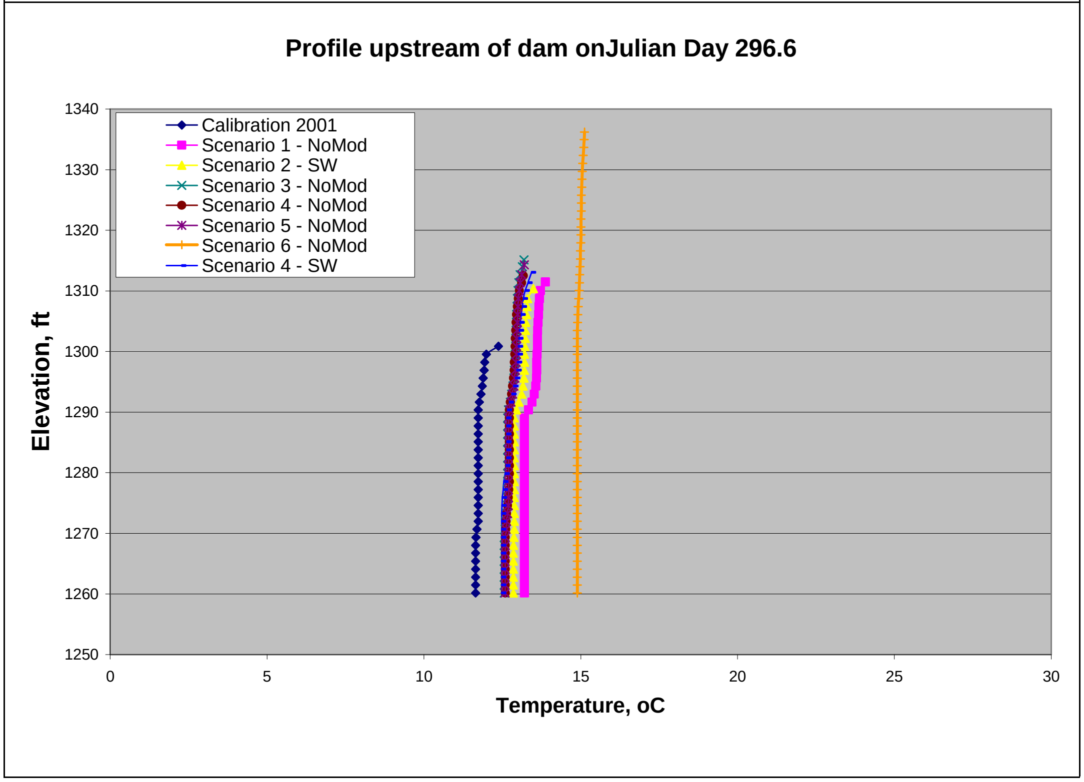


Figure 41. Continued

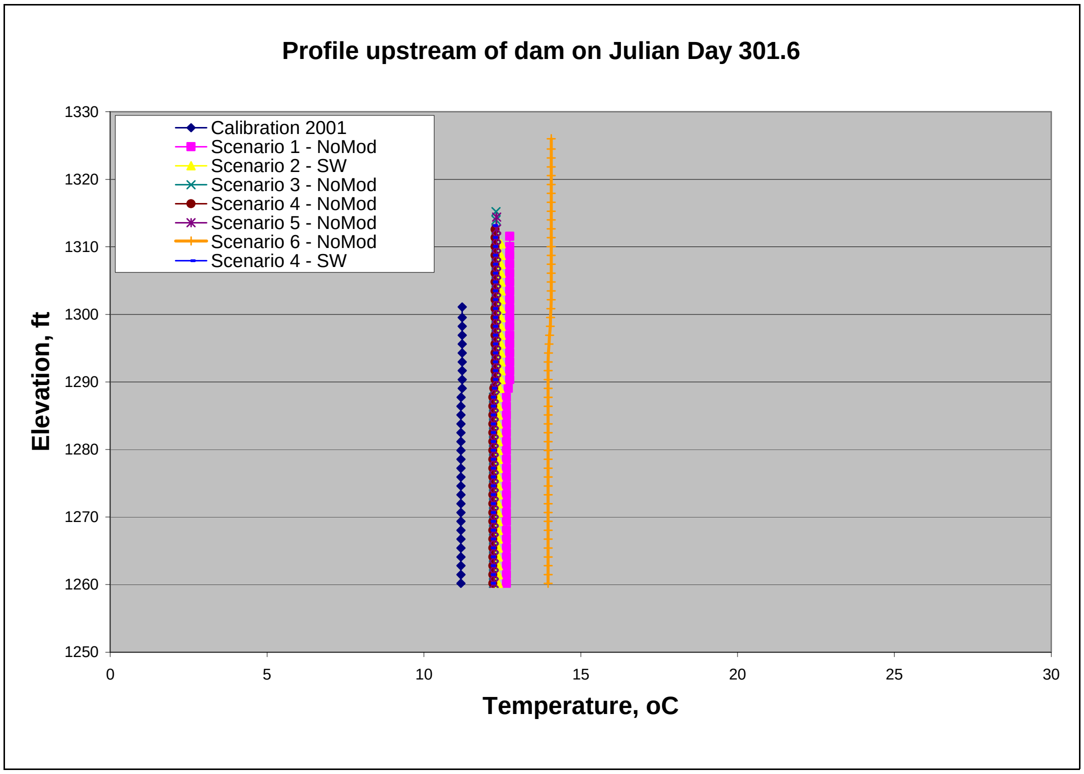
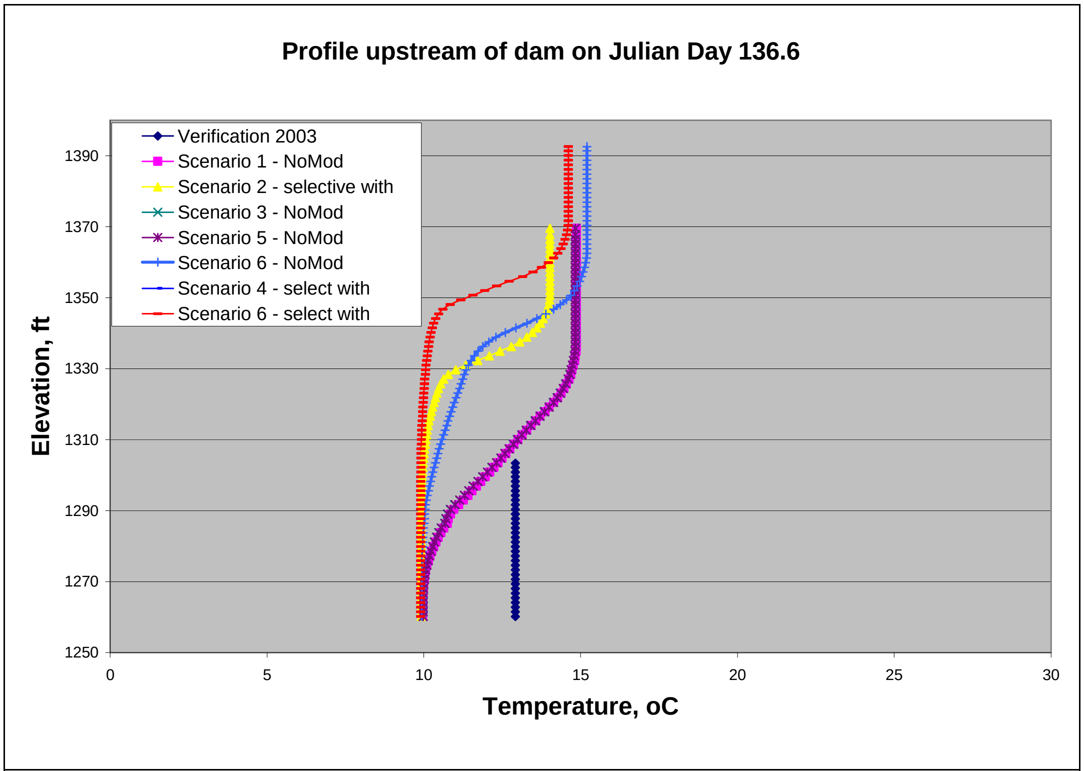


Figure 41. Continued



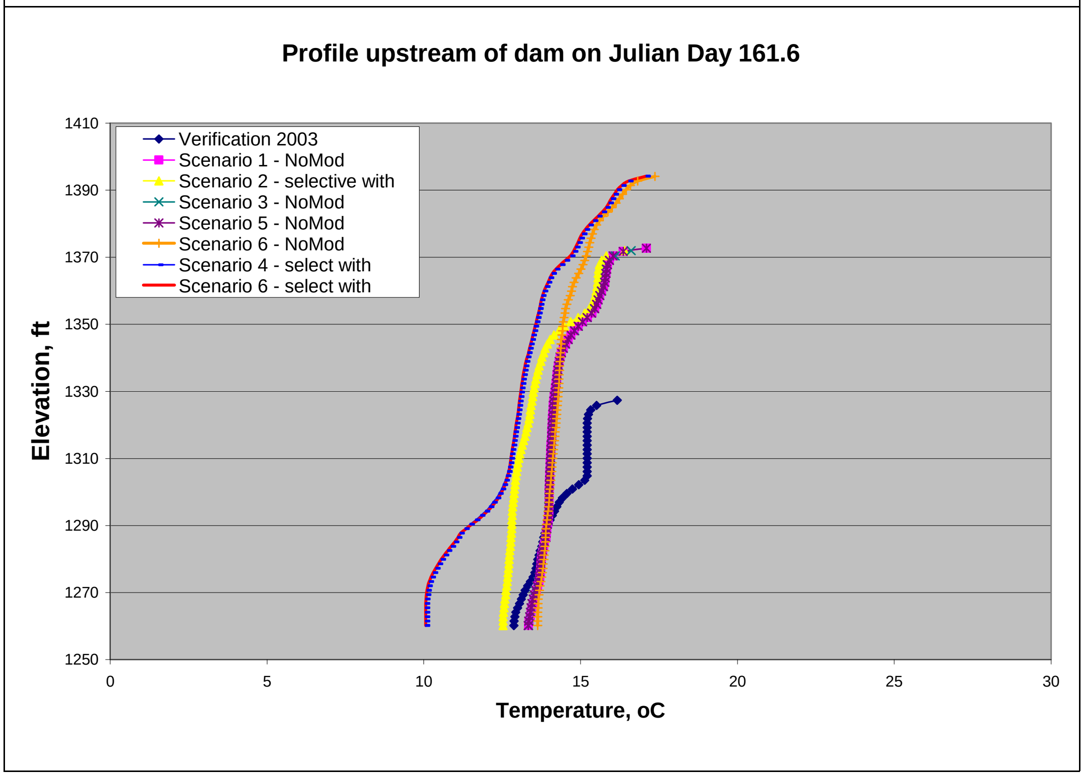


Figure 42. Examples of 2003 profiles for all scenario results

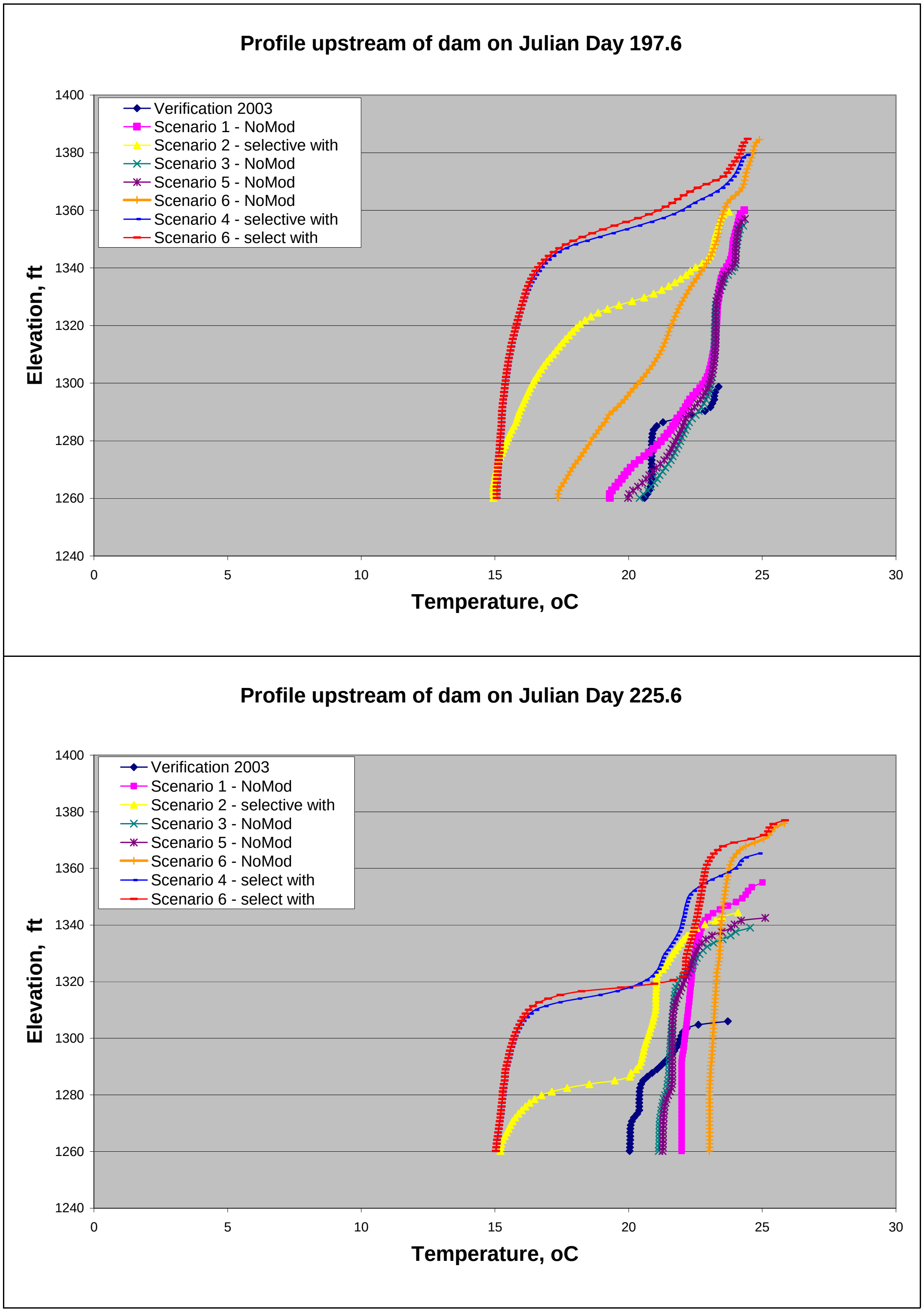


Figure 42. Continued

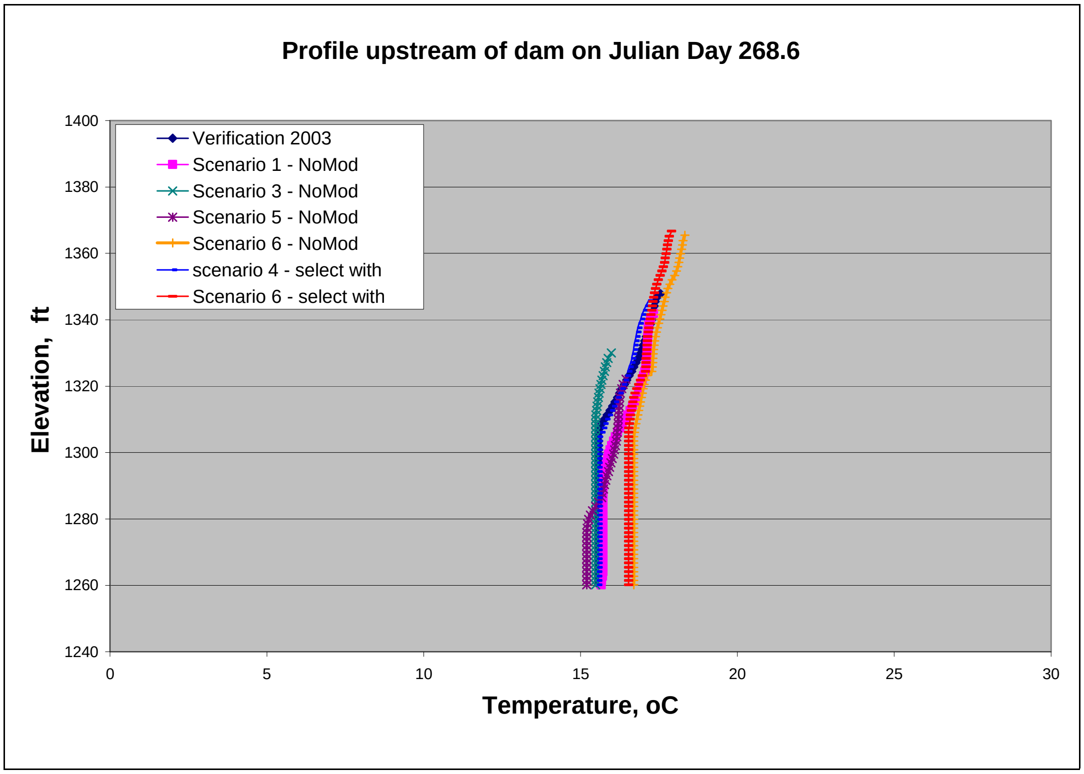


Figure 42. Concluded

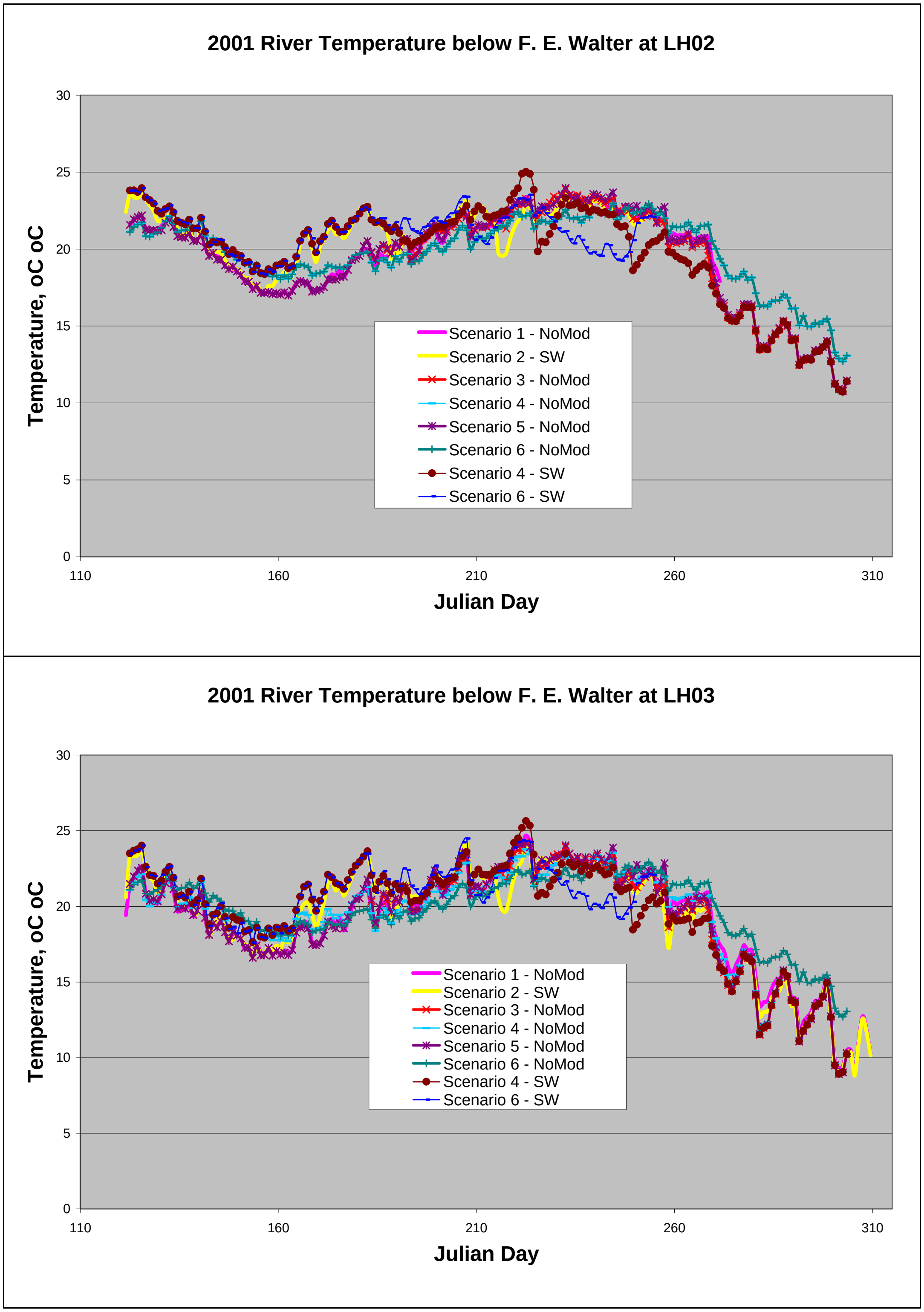
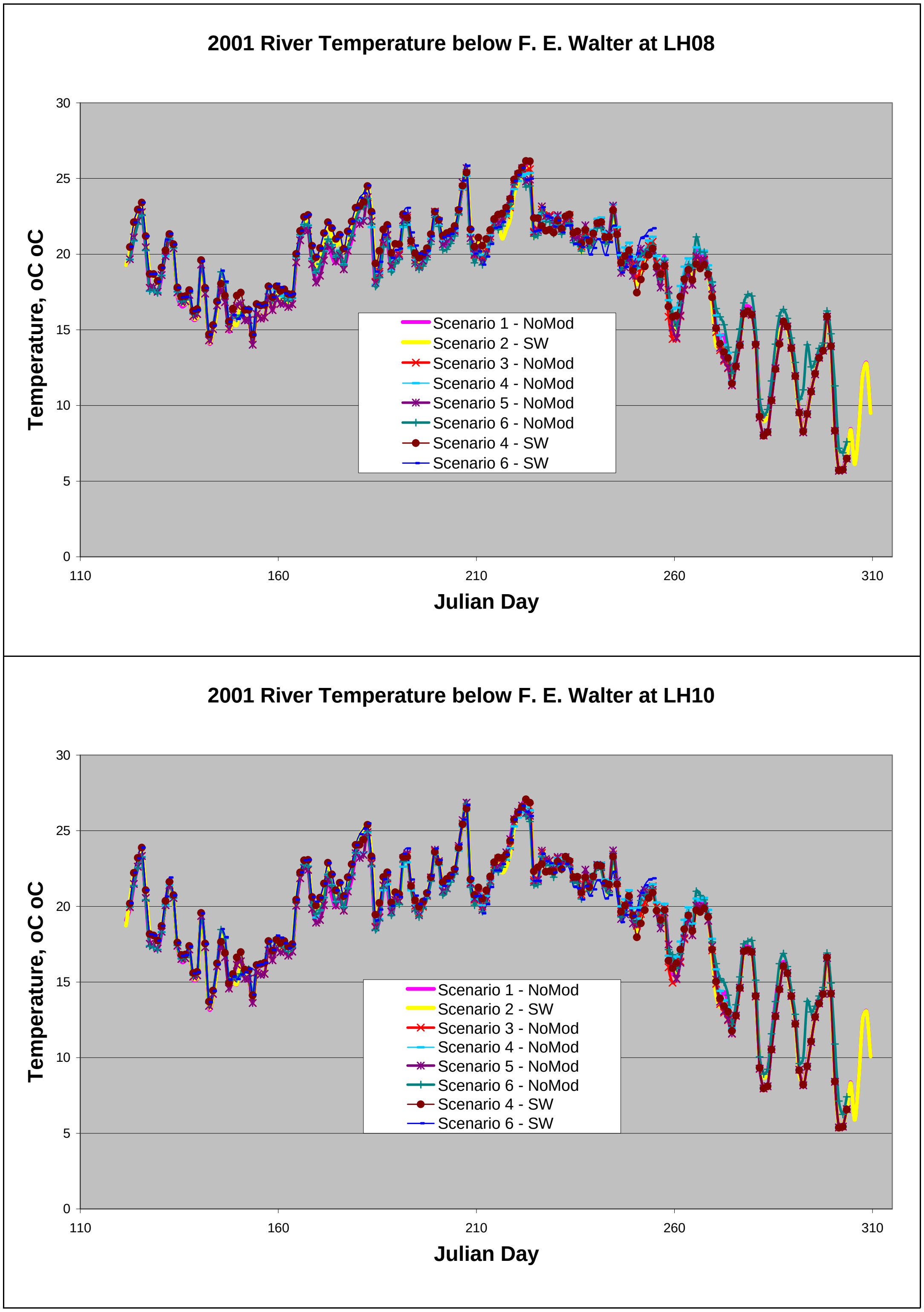


Figure 43. 2001 times series results at six locations (LH02, LH03, LH08, LH10, LH15, and LH17) on the Lehigh River.



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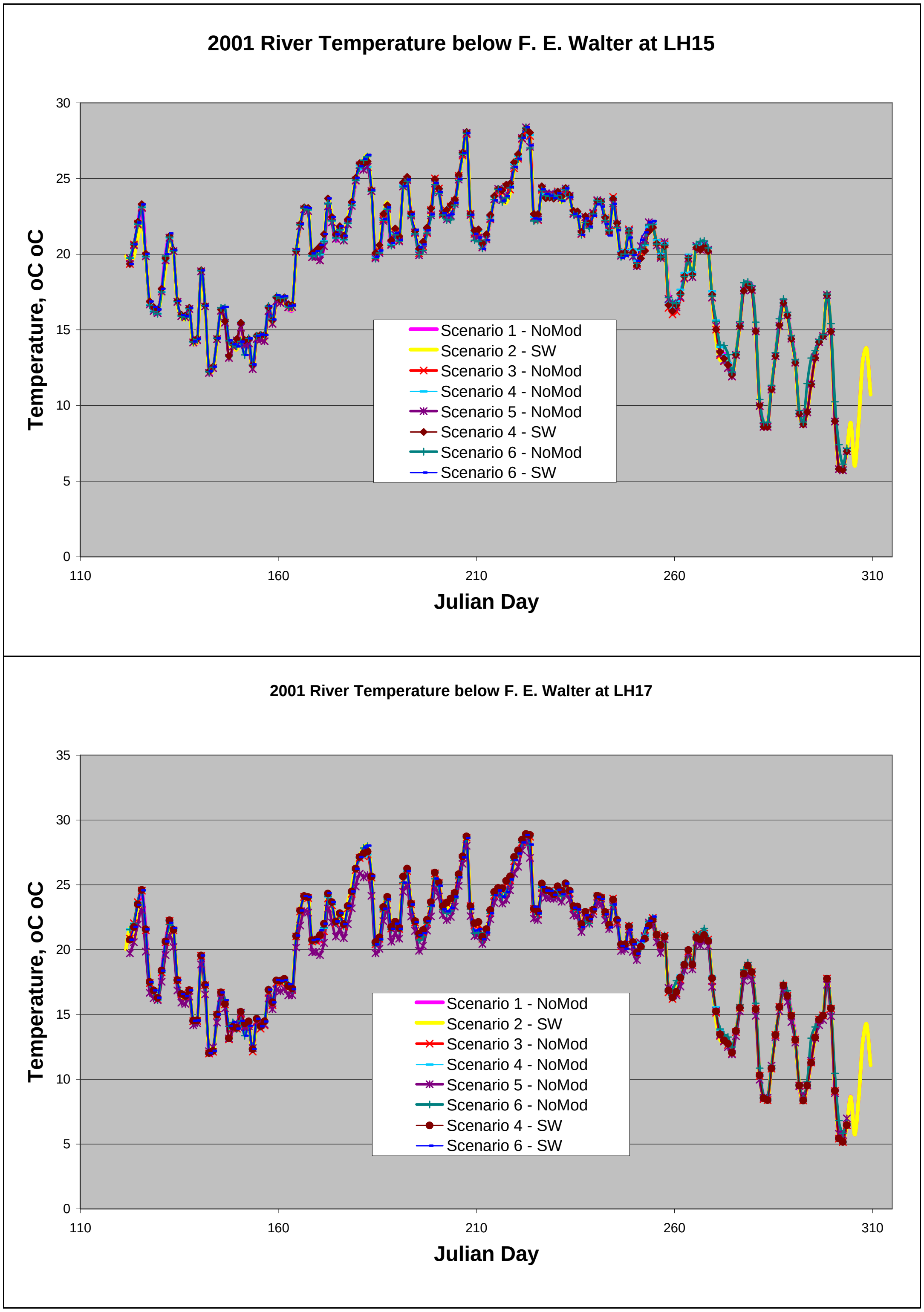
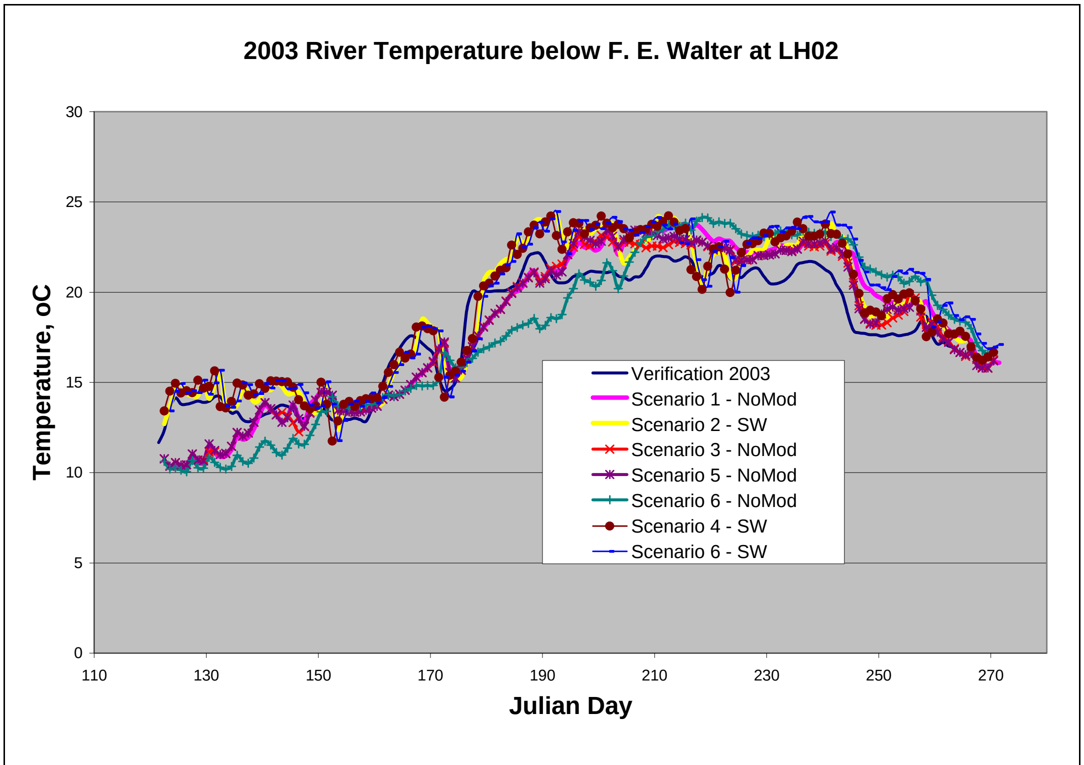


Figure 43. Concluded



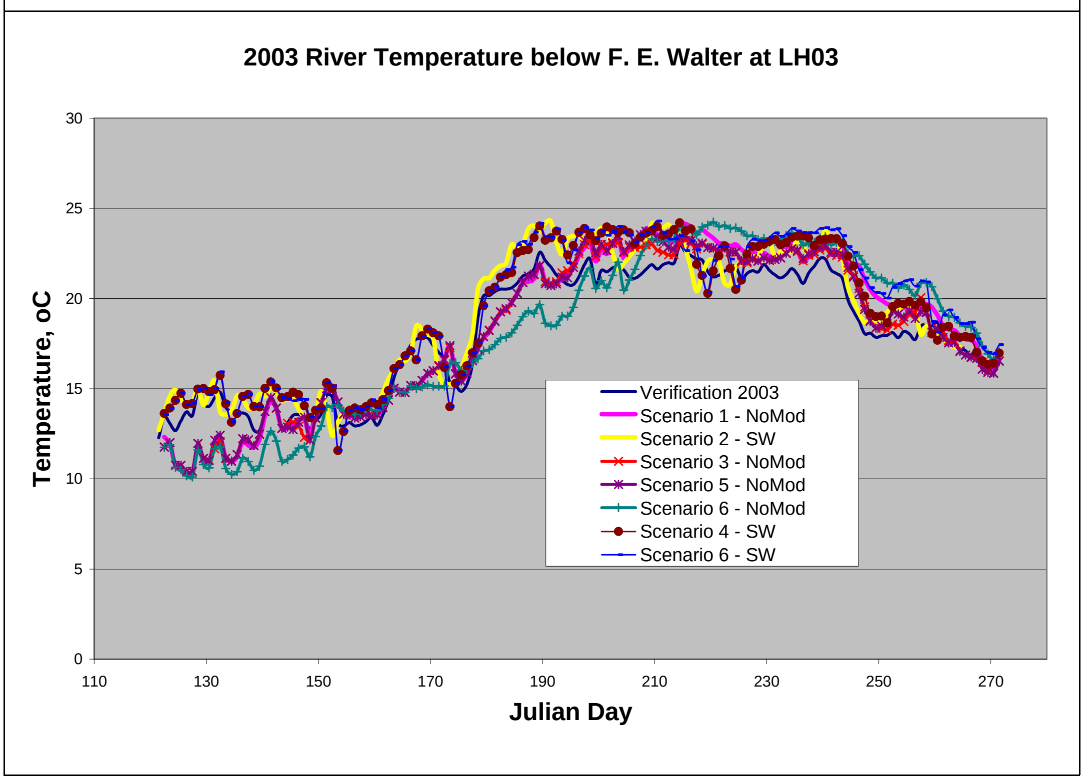
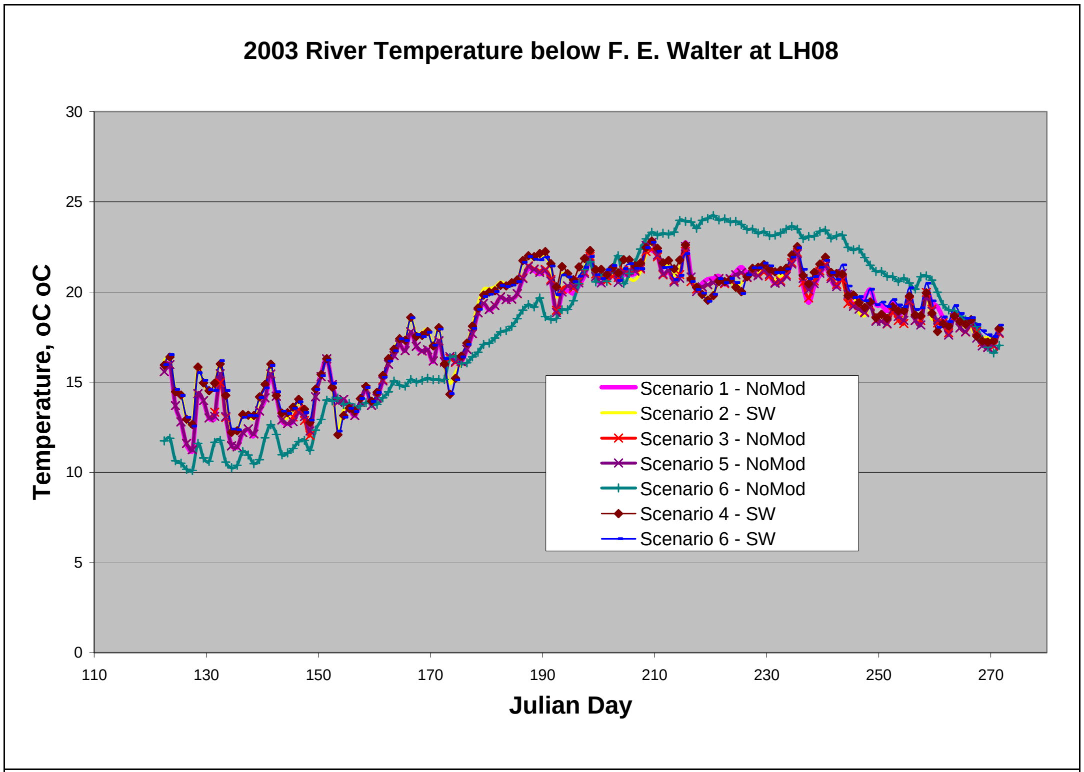


Figure 44. 2003 times series results at six locations (LH02, LH03, LH08, LH10, LH15, and LH17) on the Lehigh River.



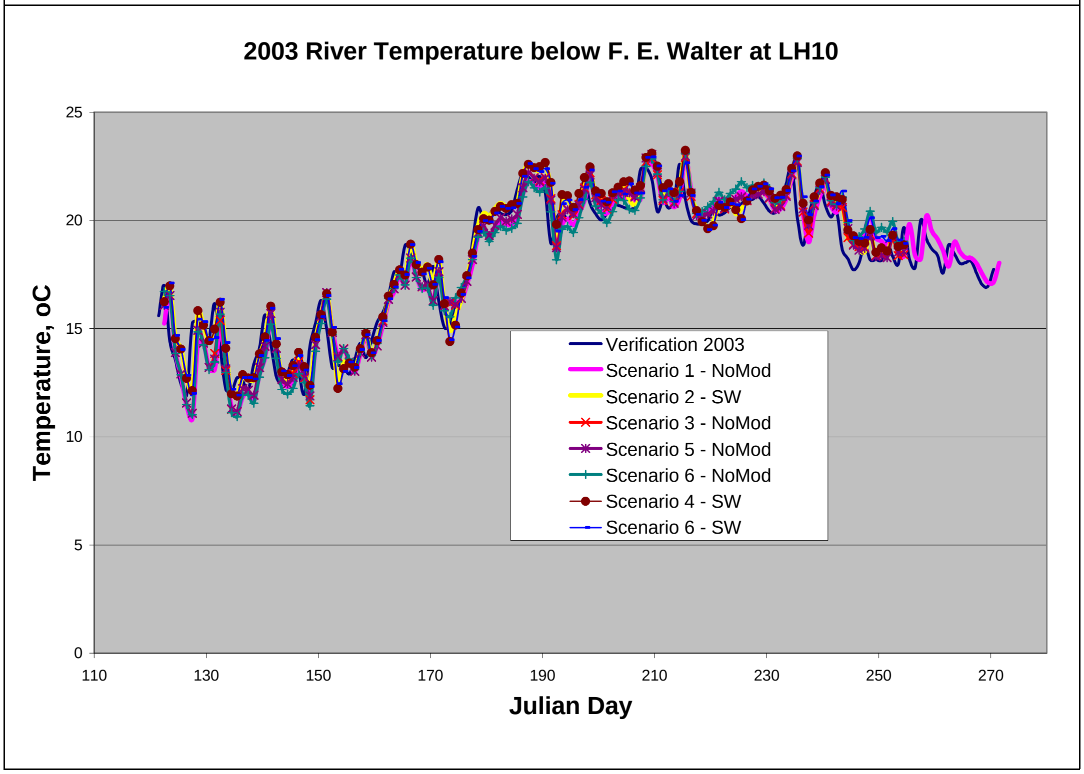
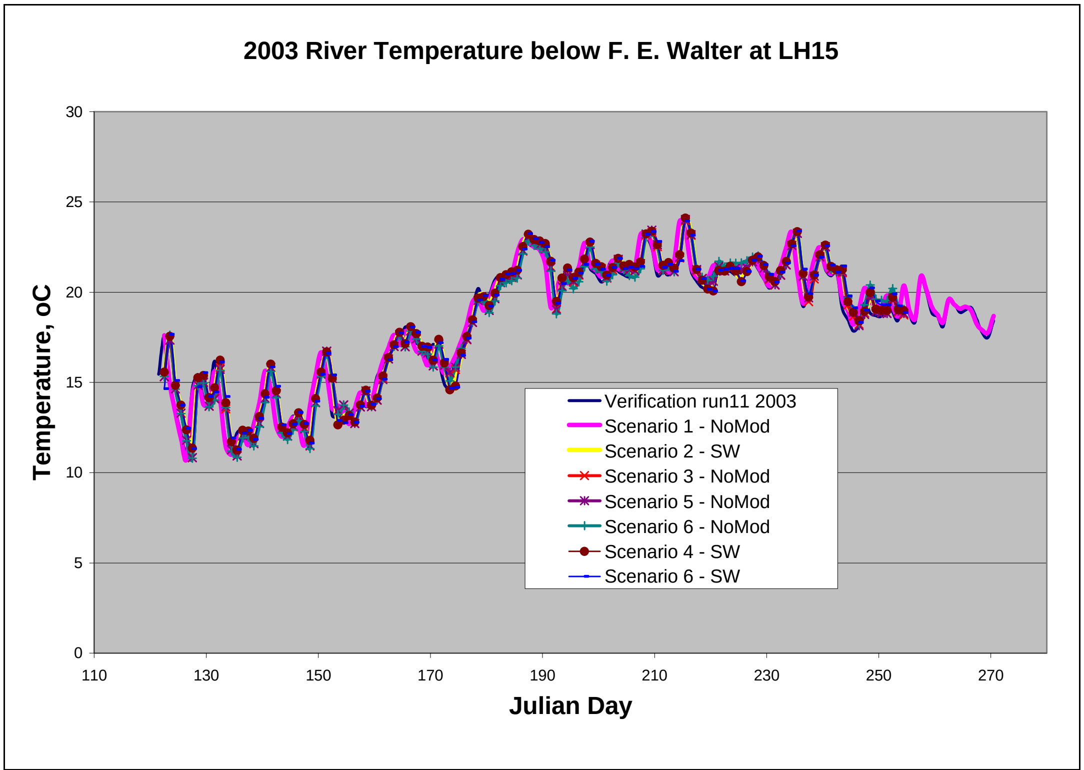
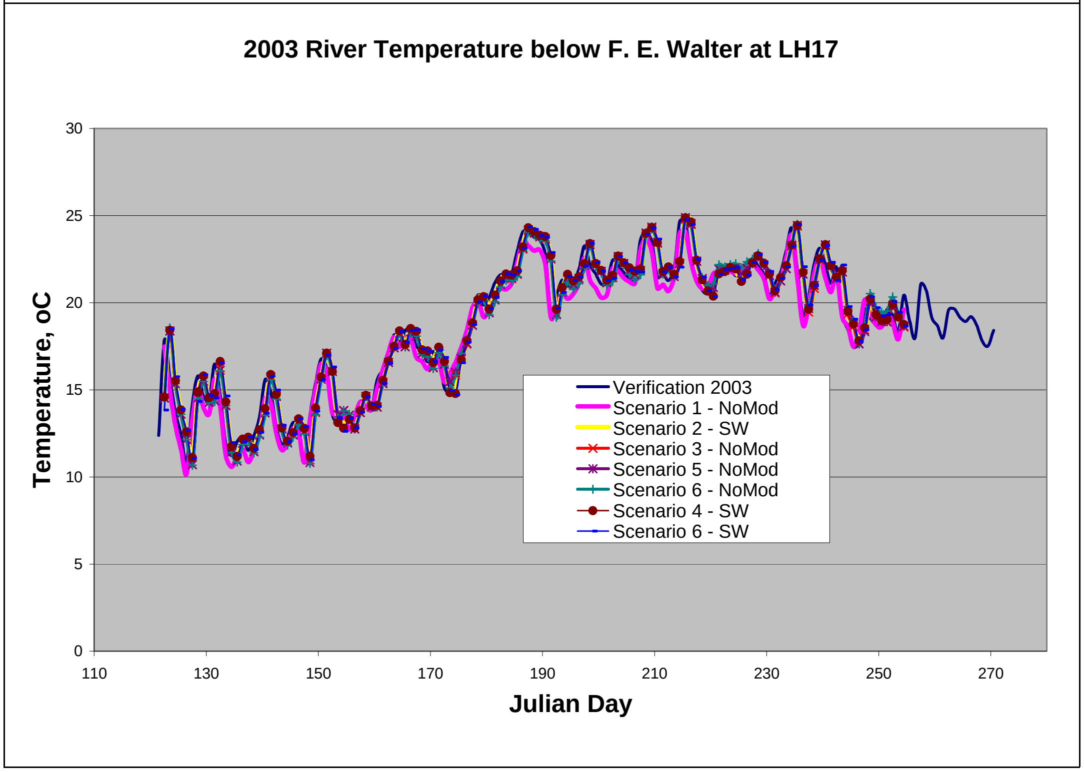


Figure 44. Continued





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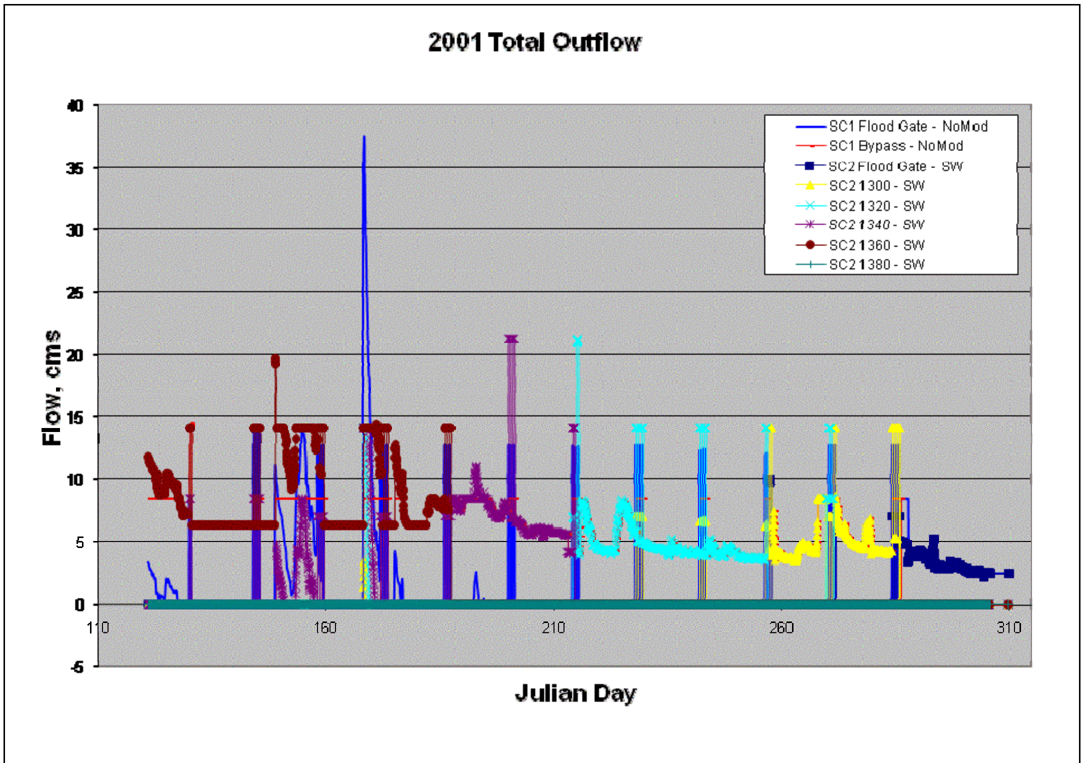


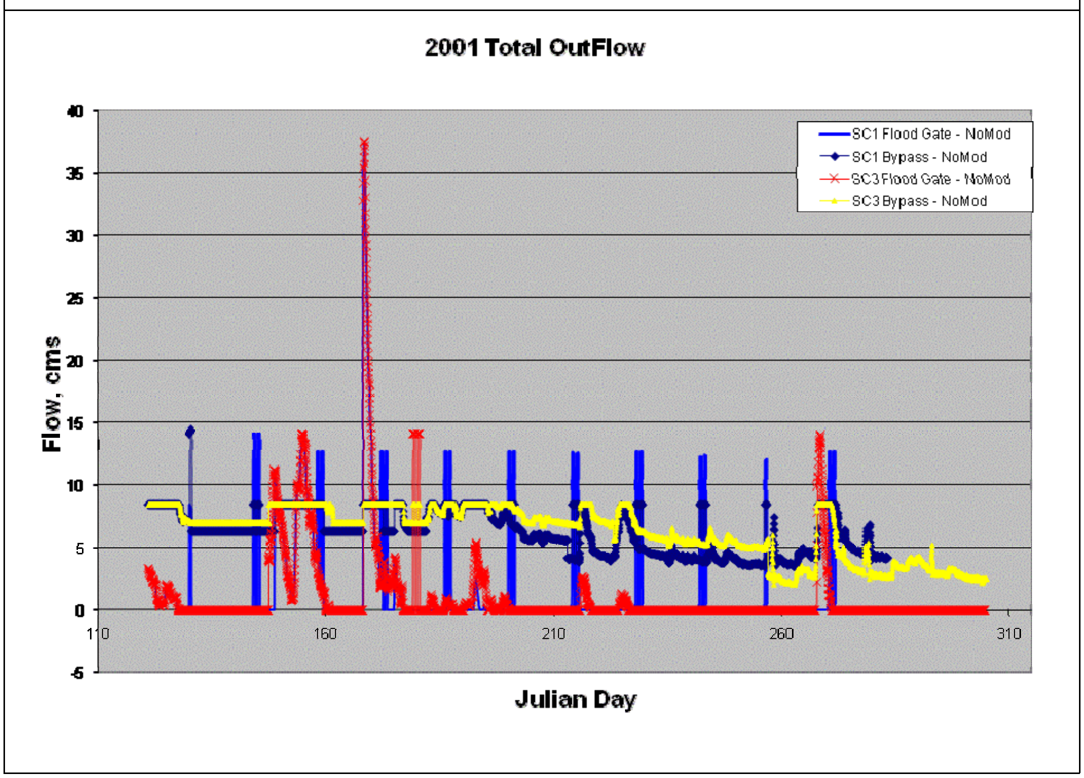
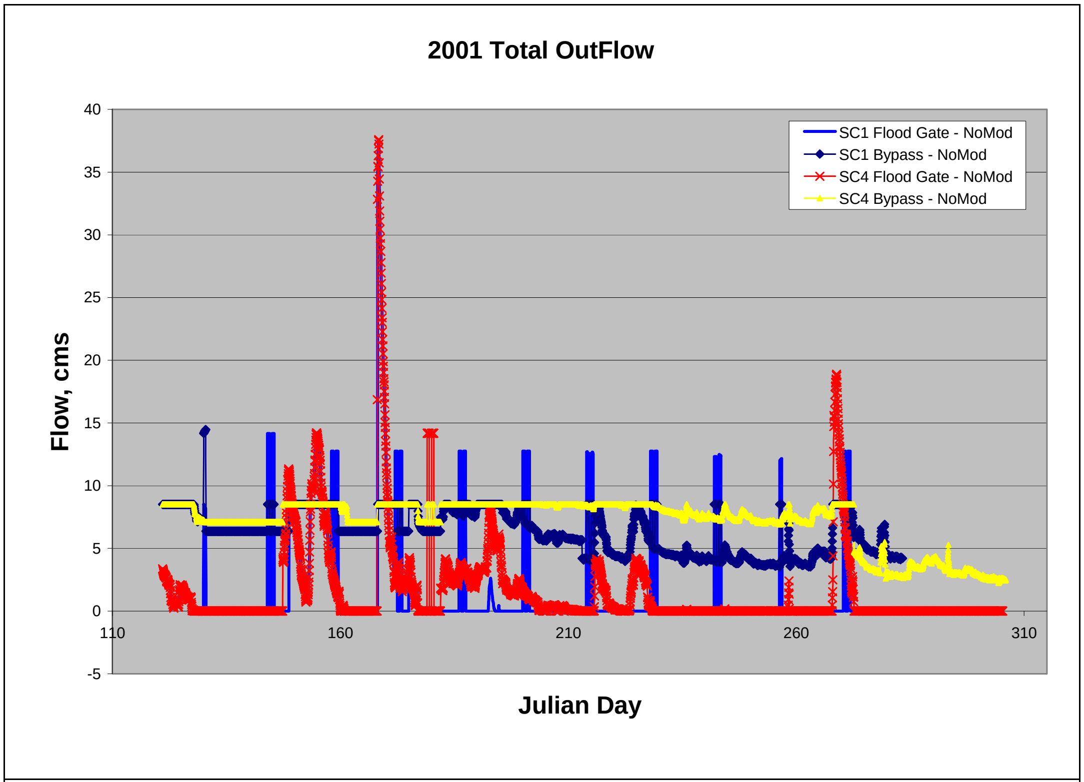
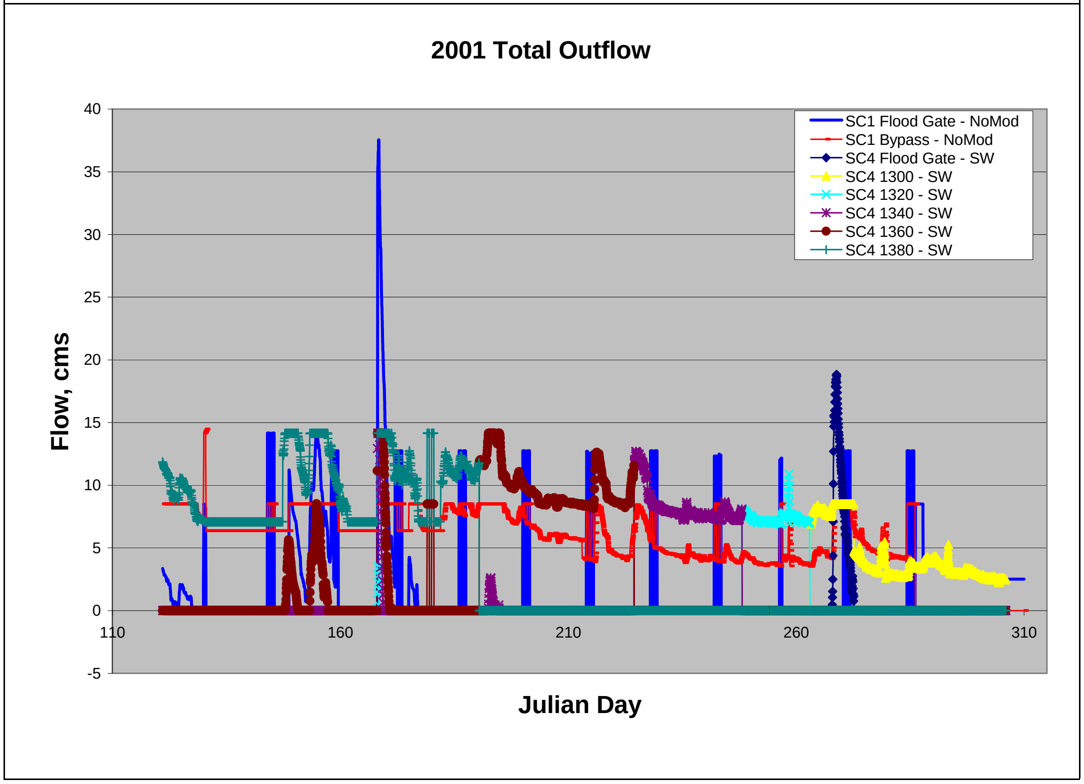


Figure 45. Comparison of reservoir outflows for each scenario to base scenario outflows denoted as SC1.





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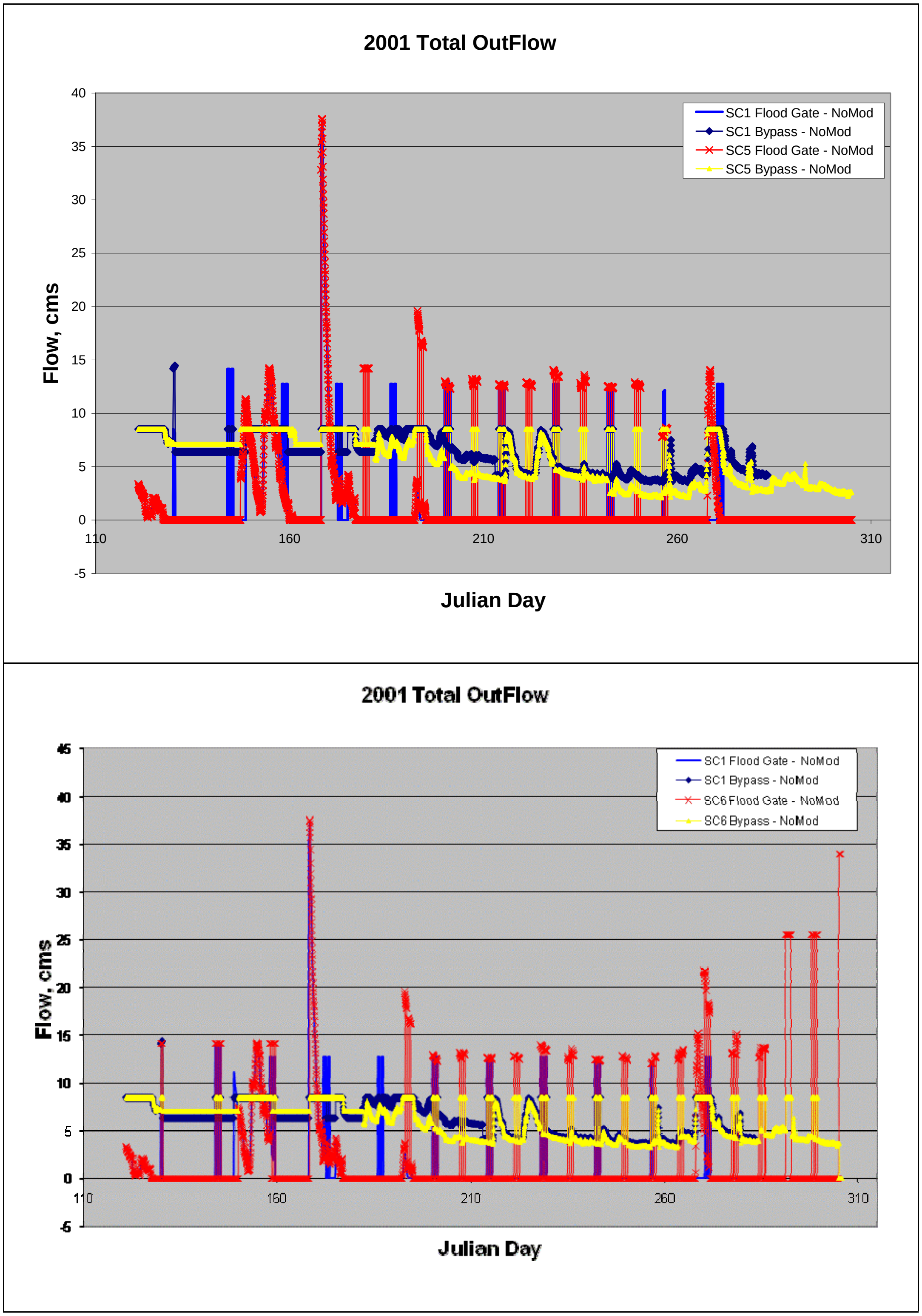

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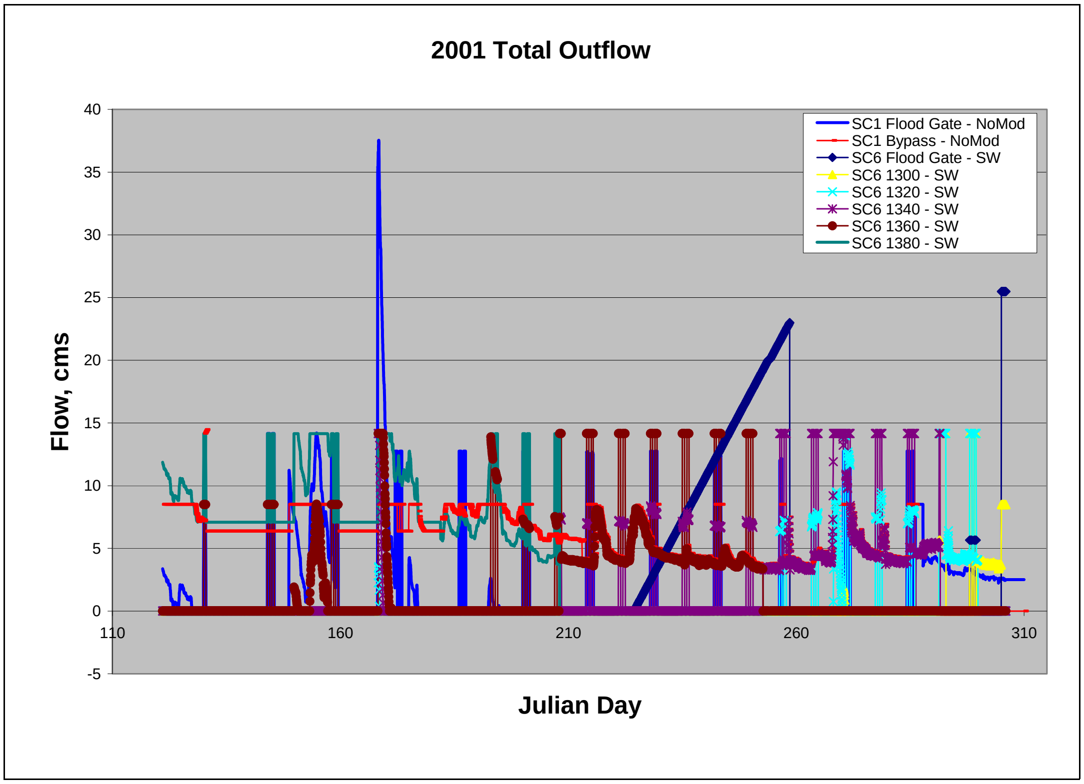

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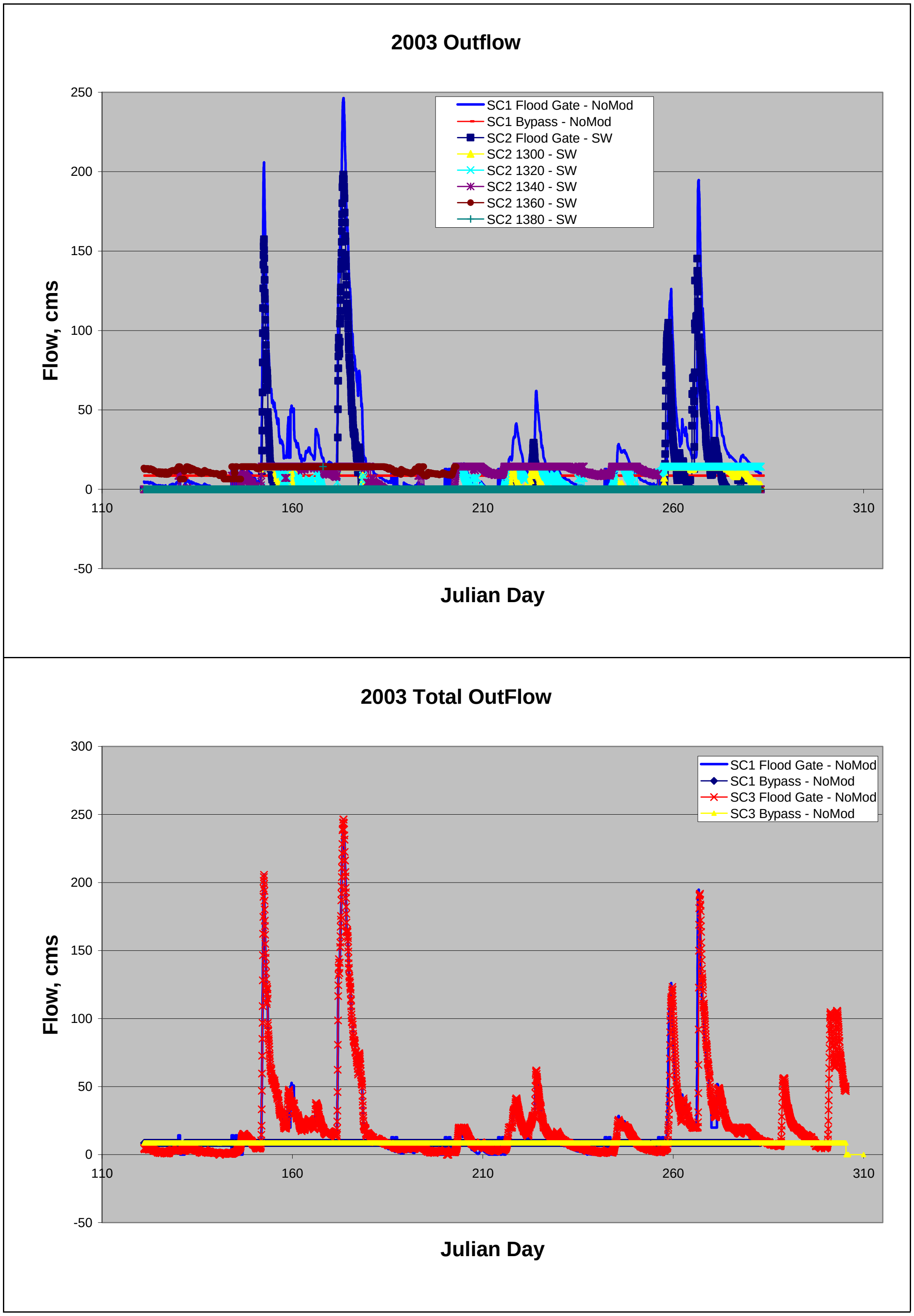
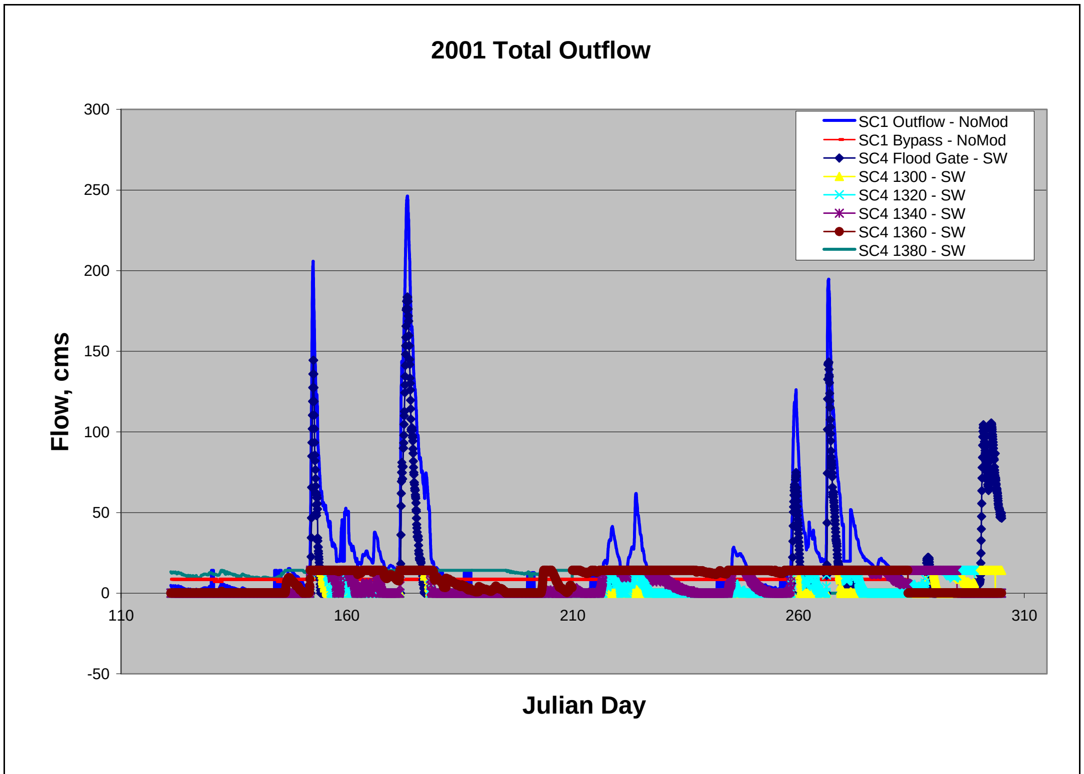


Figure 46. Comparison of 2003 reservoir outflows for each scenario to scenario outflows denoted as SC1.



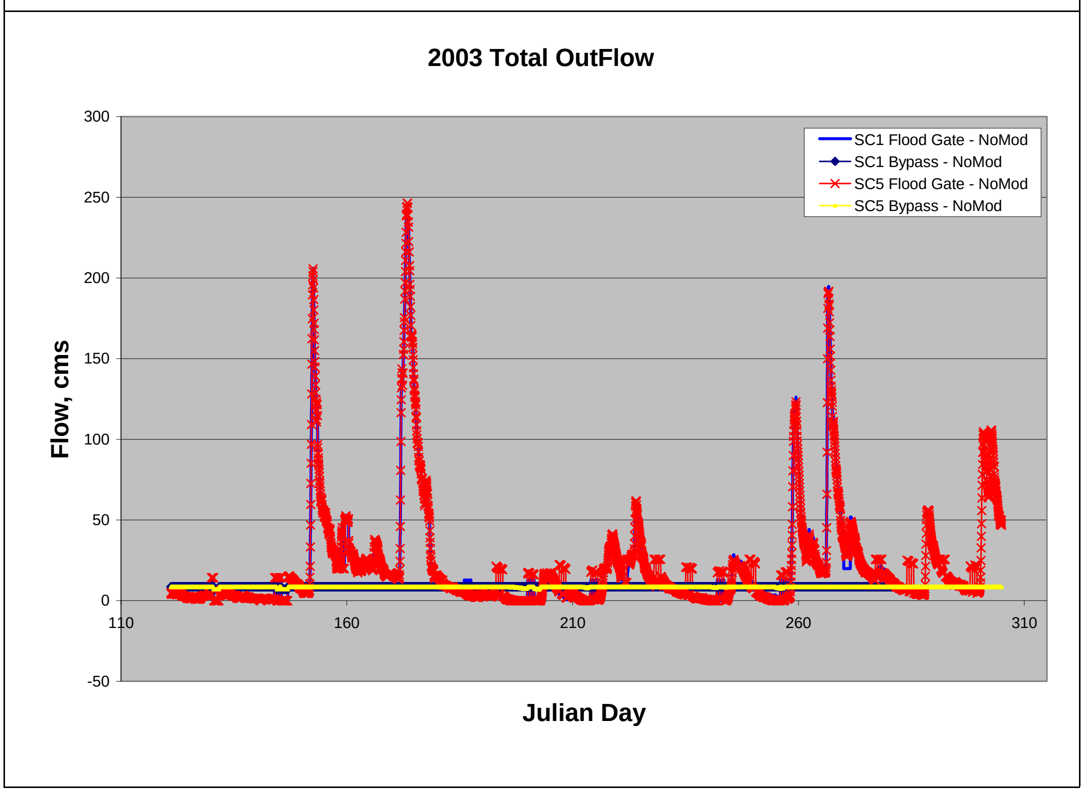
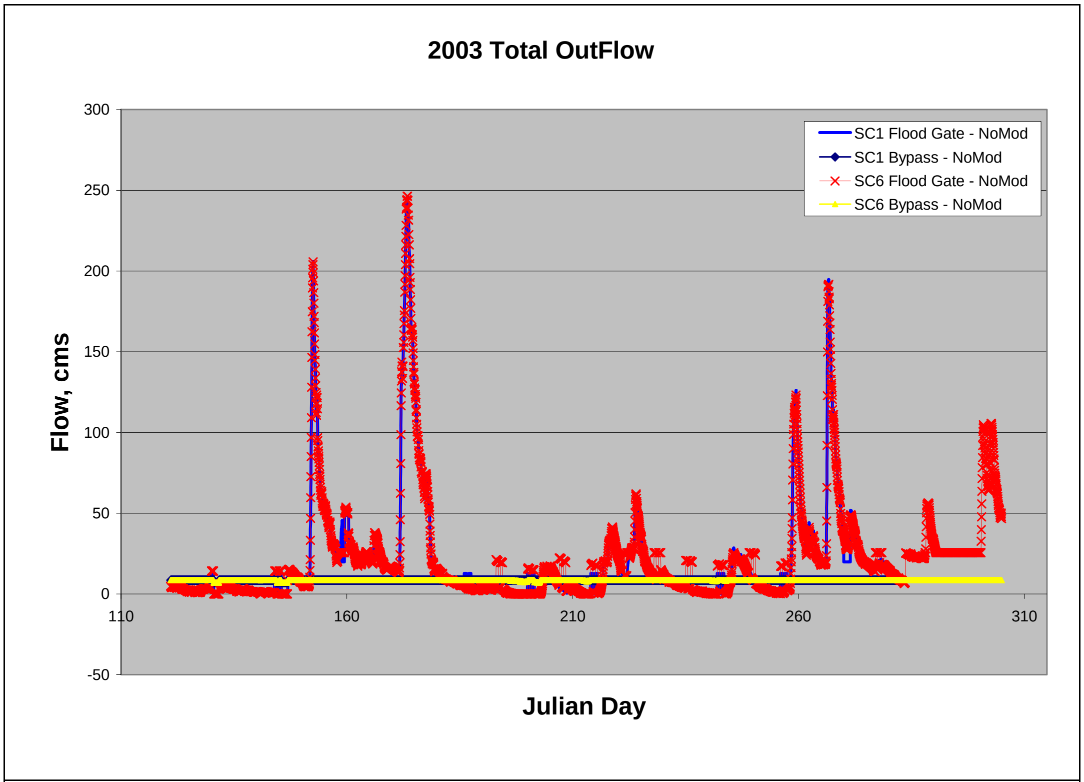


Figure 46. Continued



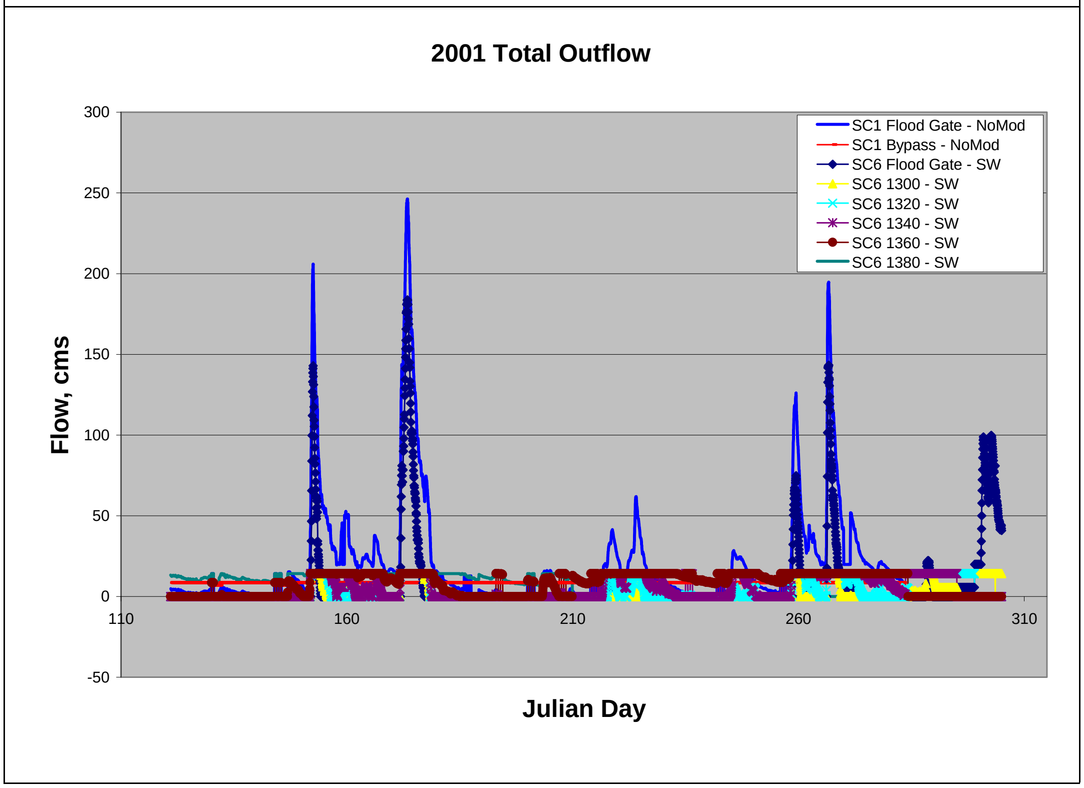


Figure 46. Concluded

Changes in temperature profiles upstream of F. E. Walter Dam demonstrate how different reservoir outflow release operations and port locations affect water quality in the reservoir. Reservoir operation goals dictate how much water and from what elevation water will be discharged (i.e., "Fisheries only"). Reservoir releases and port locations are presented in Figures 45 and 46 for the simulation period. These figures helped to identify why differences occur in outflow temperatures immediately downstream of the dam for the different scenario runs. As an illustration, the figures indicate that at the beginning of the simulations the scenarios classified as NoMod had reservoir releases discharged from the bypass system located at elevation 1297 ft while the scenarios classified as SW had reservoir releases discharged from ports at elevations 1360 or 1380 ft. Consequently, water temperatures at station LH02 are cooler for the NoMod scenarios (Figure 41 and 42) as compared to temperature results for SW scenarios. Furthermore, if profiles at the dam do not show that cooler water temperatures are available in the hypolimnion then no matter how operations are adjusted, there will not be cooler water released. To illustrate the importance of release elevation, the profile at station WA02 for SC1-NoMod on July 18, 2001 (Julian Day 199) shows the lowest hypolimnion temperatures around 17.0 ^{o}C (Figure 41). Nevertheless, SC1-NoMod operations on this day had reservoir discharge being released through the bypass system at elevation 1297 ft. At this elevation water temperatures are slightly greater than 20 ^{o}C. When you compare this to SC6-NoMod reservoir profile on this date, the coolest lowest hypolimnion temperatures for SC6-NoMod are around 18 ^{o}C with temperatures of 19.0 ^{o}C at the release elevation. As a result, in Figure 43 around Julian Day 199, the difference between SC1-NoMod and SC6-NoMod release temperatures is about 1.0 ^{o}C. To be able to utilize the cooler waters, the releases would have to be from the flood gates located at elevation 1265 ft, and the coolest release temperature would then be around 17 ^{o}C or 18 oC depending on reservoir operations.

For both years, scenarios with no modifications to the release structure (SC1 - NoMod, SC3 - NoMod, SC4 - NoMod, SC5 - NoMod, and SC6 – NoMod) began with some stratification but as simulations progressed profiles showed more stratification through the summer and less in the fall. The thermocline for these scenarios spans a steeper/deeper elevation change than what was observed for the SW scenarios (Figures 41 and 42) and the hypolimnion volume of cooler water is less during the summer (see Tables 5 and 6). For example, for the 2001 SC6-NoMod profile on Julian Day 204 (July 23) the beginning elevation of water less than 20 ^{o}C was found to be around 1299 ft. This elevation was then translated back to the volume-elevation table found in Appendix C (Table C-1) and for this elevation the volume of water is 5.37 x 10^6 m^3. Comparing this to results for SC2-SW for the same day (e.g., elevation equals 1334 ft and volume equals 12.65 x 10^6 m^3) results indicate that SC2-SW has more than twice the amount of cooler hypolimnetic water than SC6-NoMod.

Scenarios operating with SW capabilities (i.e., SC2-SW, SC4-SW, and SC6-SW) show stronger stratification during the summer months. As discussed above, SW scenarios exhibit a thermocline of a lesser gradient than the NoMod scenarios (e.g., change over 20 ft instead of 50 ft) and cooler water in the hypolimnion during the warmer summer period. Figures 41 and 42 show SC2 - SW, SC4 - SW and SC6 - SW with a greater volume of cooler hypolimnetic water with lower temperatures for the first half of the simulation compared to profiles results for NoMod scenarios. For the profiles presented in Figures 41 and 42, Tables 5 and 6 verify that for the scenarios operating with selective withdrawal capabilities a greater amount of cooler water is maintained in the lower elevations of the reservoir. Moreover, maintaining higher pool levels for the SW scenarios as well as in SC6-NoMod also seemed to reserve more cool water in the hypolimnion than the other scenarios. With the added elevation of water, a buffer is formed for the cooler hypolimnetic water such that there is a greater reserve to draw from. During the warmer period, stratification existed until around Julian Day 265, after which the reservoir begins to become isothermal. The elevation release pattern for all the selective withdrawal scenarios followed a similar behavior. Specifically, releases from the selective withdrawal structure began at the highest elevations and as summer progressed, reservoir release elevations became systematically lower as lower release ports were engaged. The difference between the SW operations was based on the goal of the operations (e.g., Fisheries only). Toward the end of the simulations for all scenarios, temperature profiles became more isothermal with SC6-SW and SC6-NoMod having the warmest temperature profiles in 2001 and 2003 indicating that the cooler hypolimnetic waters had been depleted earlier than for the other scenarios.

Table 5. Volume of water less than 20 oC in F. E. Walter Reservoir during warm summer period of 2001

Scenario	Year	Julian Day	Volume (m^3) < 20 °C
SC1-NoMod	2001	199	4.37 x 10^6
SC2-SW	2001	199	14.92 x 10^6
SC3-NoMod	2001	199	2.64 x 10^6
SC4-NoMod	2001	199	4.37 x 10^6
SC5-NoMod	2001	199	2.64 x 10^6
SC6-NoMod	2001	199	9.73 x 10^6
SC4-SW	2001	199	23.04 x 10^6
SC6-SW	2001	199	25.95 x 10^6
SC1-NoMod	2001	204	1.91 x 10^6
SC2-SW	2001	204	12.65 x 10^6
SC3-NoMod	2001	204	1.91 x 10^6
SC4-NoMod	2001	204	1.91 x 10^6
SC5-NoMod	2001	204	1.06 x 10^6
SC6-NoMod	2001	204	5.37 x 10^6
SC4-SW	2001	204	23.04 x 10^6
SC6-SW	2001	204	25.95 x 10^6
SC1-NoMod	2001	221	1.50 x 10^6
SC2-SW	2001	221	9.90 x 10^6
SC3-NoMod	2001	221	1.50 x 10^6
SC4-NoMod	2001	221	1.50 x 10^6
SC5-NoMod	2001	221	0.00 x 10^6
SC6-NoMod	2001	221	1.50 x 10^6
SC4-SW	2001	221	19.24 x 10^6
SC6-SW	2001	221	20.43 x 10^6

Continued

Table 5. Concluded

Scenario	Year	Julian Day	Volume (m^3) < 20 ^oC
SC1-NoMod	2001	270	1.50 x 10^6
SC2-SW	2001	270	9.90 x 10^6
SC3-NoMod	2001	270	1.50 x 10^6
SC4-NoMod	2001	270	1.50 x 10^6
SC5-NoMod	2001	270	0.00 x 10^6
SC6-NoMod	2001	270	1.50 x 10^6
SC4-SW	2001	270	19.24 x 10^6
SC6-SW	2001	270	20.43 x 10^6

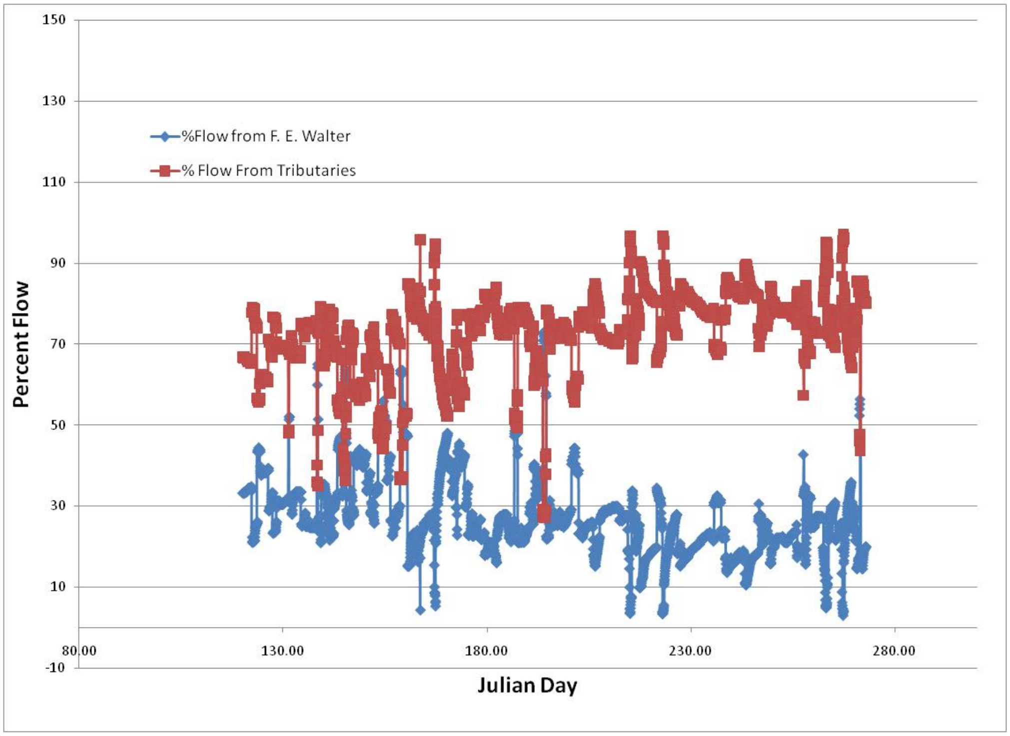
Table 6. Volume of water less than 20 oC in F. E. Walter Reservoir during warm summer period of 2003

Scenario	Year	Julian Day	Volume (m^3) < 20 ^oC
SC1-NoMod	2003	197	1.65 x 10^6
SC2-SW	2003	197	11.47 x 10^6
SC3-NoMod	2003	197	0.00 x 10^6
SC5-NoMod	2003	197	0.34 x 10^6
SC6-NoMod	2003	197	4.61 x 10^6
SC4-SW	2003	197	23.72 x 10^6
SC6-SW	2003	197	25.14 x 10^6
SC1-NoMod	2003	225	0.00 x 10^6
SC2-SW	2003	225	3.91 x 10^6
SC3-NoMod	2003	225	0.00 x 10^6
SC5-NoMod	2003	225	0.00 x 10^6
SC6-NoMod	2003	225	0.00 x 10^6
SC4-SW	2003	225	9.09 x 10^6
SC6-SW	2003	225	9.09 x 10^6

Time series of temperature results shown in Figures 43 and 44 for each scenario demonstrate that as water is transported downstream of the dam, temperature differences due to reservoir releases become minimal as tributary inflows begin to dominate flow in Lehigh River. Appendix B contains figures of temperature differences between SC1-NoMod and all other scenarios modeled. Differences were calculated as: difference = SC1-NoMod ^{o}C – SCX ^{o}C where X represents scenario 2, 3, 4, 5 or 6. Difference values of less than zero indicated the new scenario operation compared to SC1-NoMod increased temperatures in the Lehigh River. For instance for SC1-NoMod and SC2-SW, differences at LH02 showed SC2-SW operations increased temperatures as much as 3.3 ^{o}C during the summer period (Julian Day 150 to about 250). Difference values that were greater than zero at LH02 indicated a reduction in Lehigh River temperatures from the new SC2-SW reservoir operations. Differences demonstrate that water temperatures in the Lehigh River are influenced by dam releases as far downstream as station LH08 and beyond this station tributary inflows dominate the flow in the Lehigh River. Of course the influence of tributary inflows is highly dependent on the quantity of flow coming from the tributaries as compared to dam release flows. Between station LH02 and LH03 there were no tributaries modeled so Lehigh River temperatures were influenced only by F. E. Walter releases. Between station LH03 and LH08, there are four tributaries entering the Lehigh River (Hayes Creek and Sandy Run, Buck Mountain Creek, and Black Creek) that influenced water temperatures at LH08 such that temperature differences (+/-) decreased. This can be seen for both years although dam releases in 2001 have greater influence on water temperatures farther downstream. This was attributed to 2001 being an average to dry water year while 2003 was considered a wet water year. Thus during the warmer summer period with less contribution from tributary flows, dam releases have more influence on river water temperatures farther downstream until tributary inflows dominate. As expected, the greatest differences in water temperatures are immediately downstream of the dam before the influence of tributary inflows monopolizes Lehigh River temperatures. From Figures (43 and 44), SW release temperatures are warmer than the NoMod release temperatures for most of the simulation with short periods of being cooler. Differences can be as great as -4.9 oC signifying an increase in release temperatures from the SW operations. For most scenarios, release temperatures at station LH02 are above 20 ^{o}C for the Julian Day periods of 190-268 and 180-250 for 2001 and 2003, respectively. By the time water reaches LH10 (see location on Lehigh River in Figure 2), water temperature differences are beginning to converge to similar values with similar difference patterns. Between station LH08 and LH17, there was another five tributaries entering the Lehigh River (Mahoning Creek, Lizard Creek, Aquashicola Creek, Pohopoco Creek, and Bertsch Creek) that influenced water temperatures at LH10 and LH15. For these two stations differences were on average approximately (+/-) 0.5 °C for 2001 and (+/-) 1.5 °C for 2003 during the warmer part of the simulation (Julian day 160 to 260).

Percent calculation of flow coming from dam at station LH15 used the equation: % Dam Flow = (Release Flow/Flow at LH15) *100. This calculation does not take into account travel time or lag of flow to this station. It was simply used to get an estimate of the contribution of flow from the dam to LH15. Likewise the percent of flow coming from tributaries between the dam and LH15 was calculated as %Flow of Tributaries = ((Flow at LH15-Dam Flow/Flow at LH15)*100. Percentages (Figure 47) of the contribution of flow from the dam and flow from tributaries to flow at LH15, indicate that the dam releases contributes on average 35 % in 2001 and 30% in 2003 of the flow at LH15 and flow from tributaries contributes about 65% in 2001 and 70% of the flow at LH15 (Figure 47). Because of the dominance of tributary inflows at and beyond station LH10 (Figures B1 and B2), difference behavior are very similar between scenario differences for both years modeled. By this distance, tributary inflows overcome influences of dam releases. Depending on whether it was a dry or wet year, tributary inflows influenced Lehigh River temperatures to different degrees. For example, for the wet year temperatures at LH08 were more similar to tributary inflow temperatures than what was being released from F.E. Walter compared to 2001 differences at this station.

Of all the scenario runs, SC6-NoMod temperature results show the coolest water being released through the summer until around Julian Day 200 when water temperatures are above 20 °C. This scenario run had goals of maximizing the number of white water events while augmenting flow for fisheries. In comparing the dam discharges to SC1-NoMod discharges, more flow was released through the bypass gates for SC6-NoMod at the beginning of the simulation than for SC1-NoMod and there were a greater number of white water releases over the summer period. This resulted in cooler downstream temperatures until around Julian Day 200 for both years. After that, release temperatures remained similar or warmer than SC1-NoMod and all other scenario results.



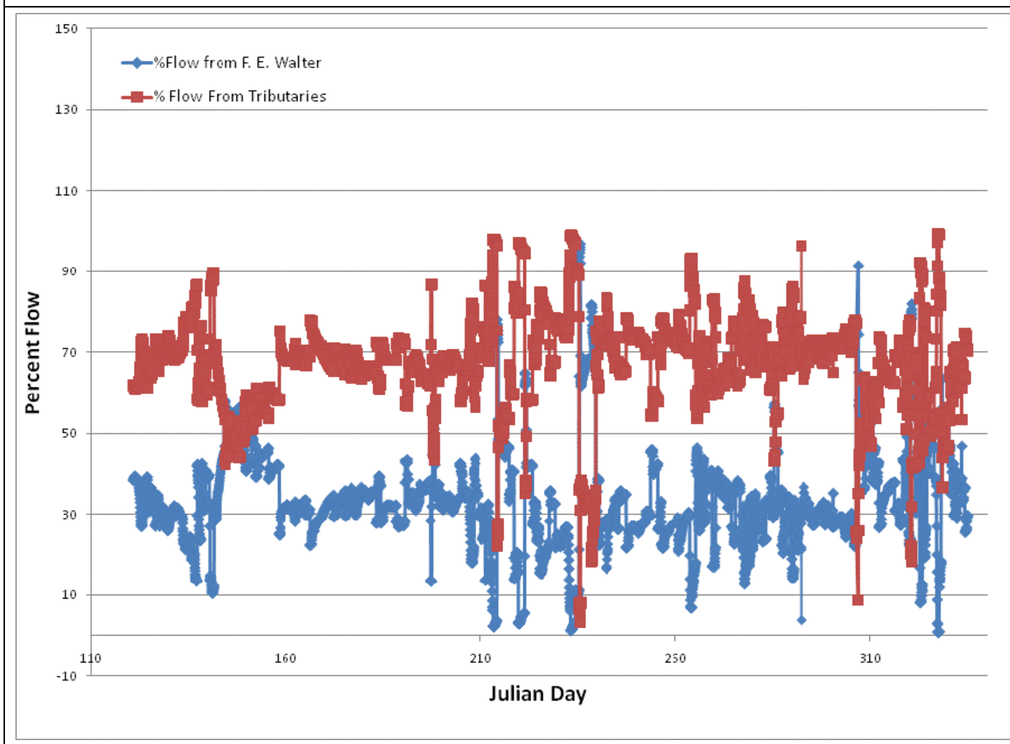


Figure 47. Percentage of Flow from F. E. Walter Dam and tributaries at LH15 for 2001 (upper) and 2003 (lower)

5 Summary and Conclusions

CE-QUAL-W2 has been calibrated for temperature and flow on 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. Initially there were questions about reservoir operations during certain times of the year but these questions were clarified, and the model was able to accurately predict temperatures when appropriate boundary conditions were available. 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 the study was on temperature and flow/stage calibration/verification for the entire system. Once the system was calibrated and verified scenario runs were made using initial and boundary conditions from the calibration (2001, a dry water year) and verification (2003, a wet water year) runs with new reservoir releases and WSEL. A total of six scenario runs were made for each year.

The volume-elevation curve WSEL in the F. E. Walter and Beltzville compared well with observed data. Inflows and outflows from the District produced WSEL within 0.5 meter agreement. This was improved by accounting un-gaged flows through the inclusion of distributed tributary flow. Additionally, W2 flow and WSEL measurements on the Lehigh River at LH10 and LH15 compared well with observed data. Slight adjustments to bathymetry widths were made when depths were lower or higher than observed to improve predictions.

Although temperature and flow boundary conditions were lacking on tributaries to the Lehigh River for 2003, verification temperature time series results compared very favorably to the observed temperature in the river. Comparison of model profile results for two reservoirs to observed data was in good agreement. Water temperatures are being over-predicted on the average of approximately 0.5 °C as indicated by the ME for both years. To some extent, the over-prediction of temperatures at this station can be explained by the under-prediction of depths. All in all for calibration and verification, results were considered favorable given limited data for verification.

Only six initial scenario runs were funded and conducted for no modification to the outlet structure and with selective withdrawal capabilities. The 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)

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

Using scenario results from these simulations, the Philadelphia District will be able to make adjustments to reservoir operations to help improve fishery habitat within and downstream of F. E. Walter Reservoir. This is an iterative process and for this reason, many simulations may be necessary to develop the best operations for fishery habitat improvement. From all the scenario runs conducted in this phase of the study, scenario results indicated that SC6–NoMod had the most affect to release temperatures when compared to the base case (SC1–NoMod) results. The criteria for judgment of improvement were whether release temperatures were 20 °C or less during the warmer summer period downstream of F. E. Walter. Release water temperatures were cooler or of similar to SC1-NoMod results and results from other scenario runs. 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. SW scenarios did have larger volumes of hypolimnion water with temperatures 20 °C or below. With adjustments to release elevations longer durations of release waters less than 20 °C could be establish. For future scenario runs, releasing from lower elevations earlier in the simulation period and making adjustments for conservation purposes may provide better results. Reservoir releases influenced downstream temperatures as far as LH08. Beyond this station tributary inflows dominated flow in Lehigh River dampening influence from the dam. Downstream of LH08, differences behavior in water temperature becomes minimal. As expected, water temperatures show the greatest differences immediately downstream of the dam before tributary influences begin to monopolize.

For future modeling studies of F. E. Walter Reservoir, Beltzville Reservoir and riverine sections below, it is highly recommend for the District to monitor inflow temperatures and water quality parameters to major tributaries and inflow points to the reservoir for future simulations. As presented and discussed above, calibration/verification results were considered quite favorable considering boundary data for 2003 had to be estimated from 2001 data. W2 was able to predict behavior trends of the temperature to within an average AME of 1.0 °C in the reservoir and 1.2 °C on the Lehigh River. The model quite accurately captures the physics of both reservoirs and the riverine sections. With a more complete data set to describe the system, improvement in model predictions especially on the Lehigh River would be anticipated.

References

Berger, C.; Annear, R. and Wells, S. (2002) “TMDL Development of the Spokane River-Long Lake System using CE-QUAL-W2,” Proceed-ings, Water Environment Federation National TMDL Science and Policy Conference, Phoenix , Nov 13-16, 2002 .

Cole, T.M., and S. A. Wells (2006). "CE-QUAL-W2: A two-dimensional, laterally averaged, Hy-drodynamic and Water Quality Model, Ver-sion 3.5," Instruction Report EL-06-1, US Army Engi-neering and Research Development Center, Vicksburg, MS.

Appendix A: Tributary Flow Regression Plots

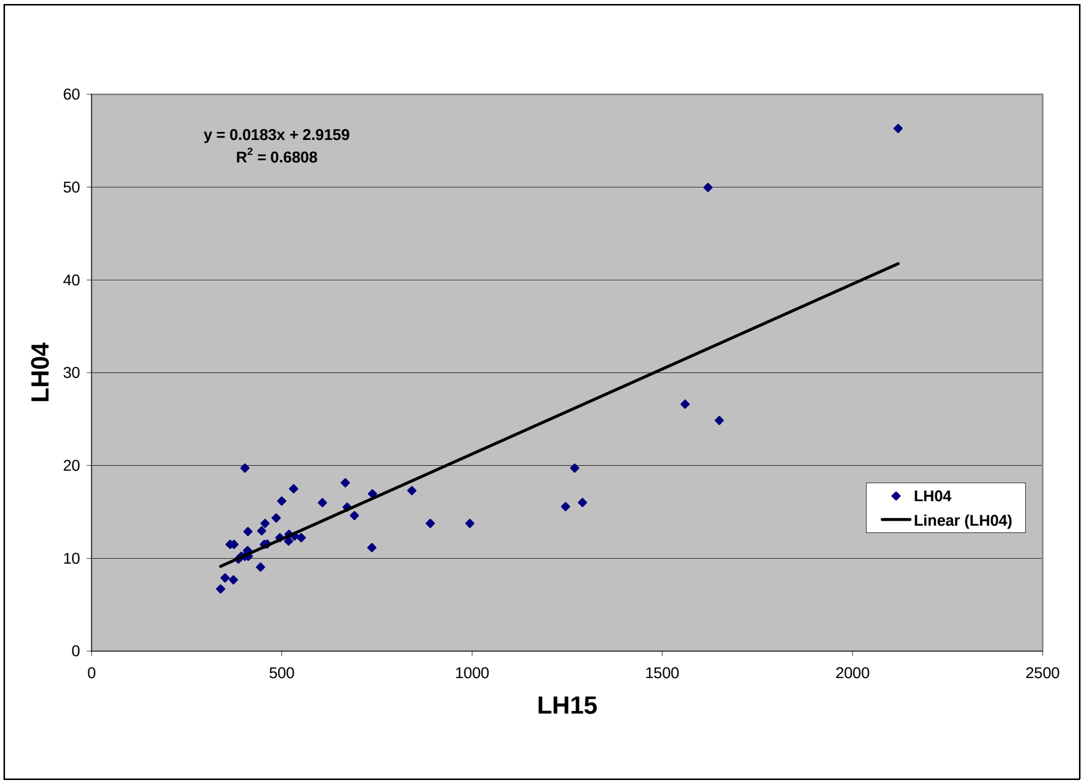
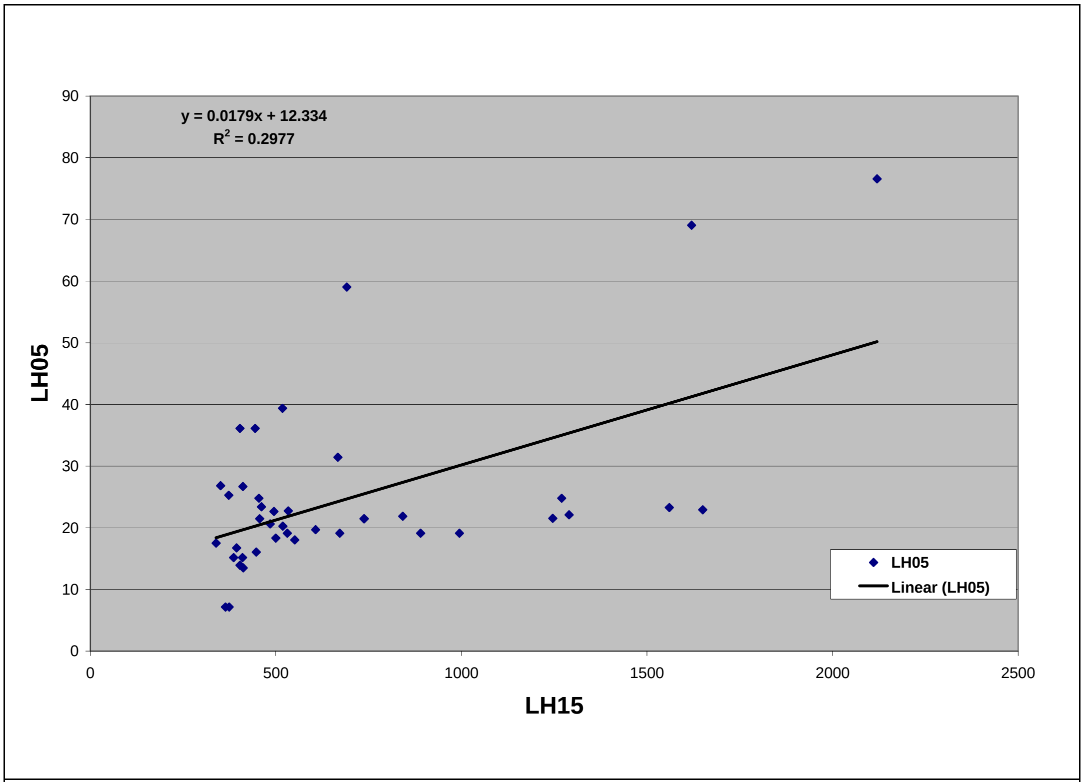
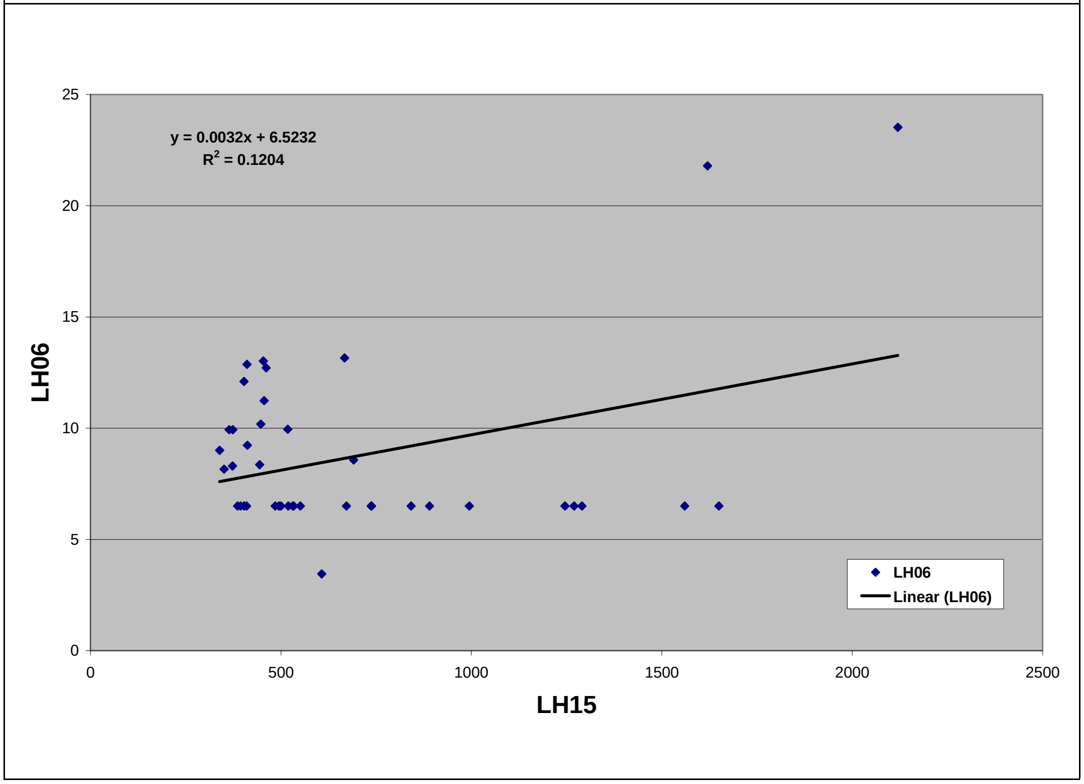


Figure A-1. Flow regression results for tributaries* flowing into the Lehigh River below F. E. Walter Reservoir.





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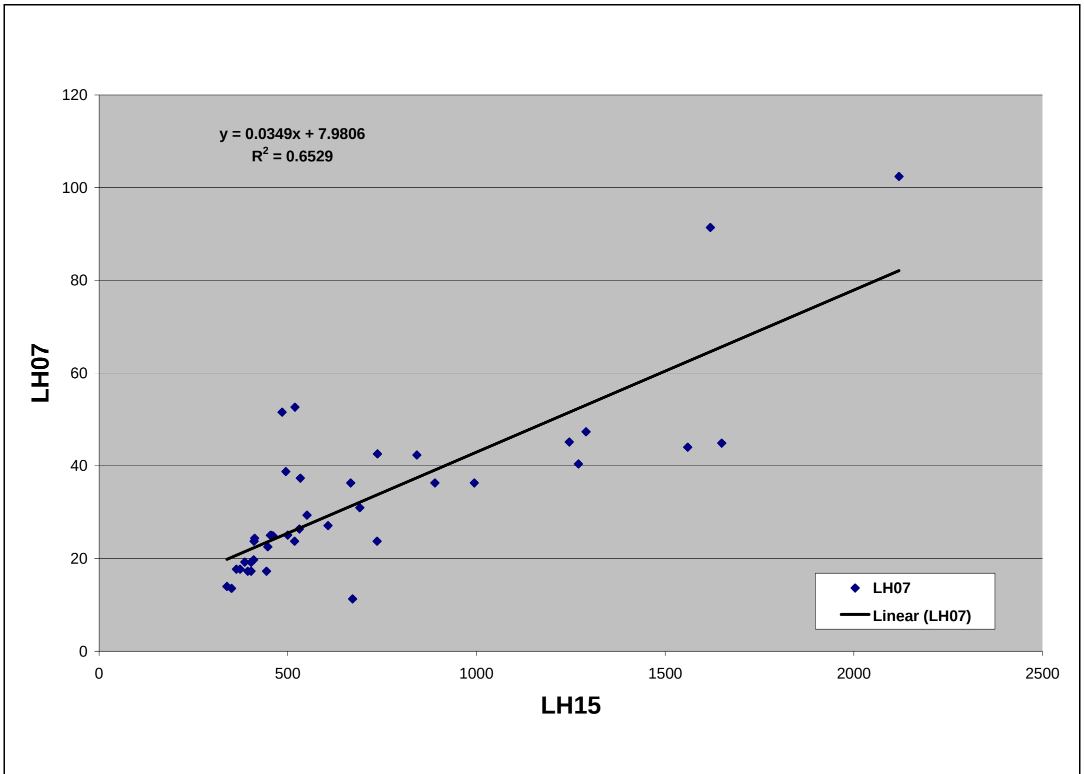

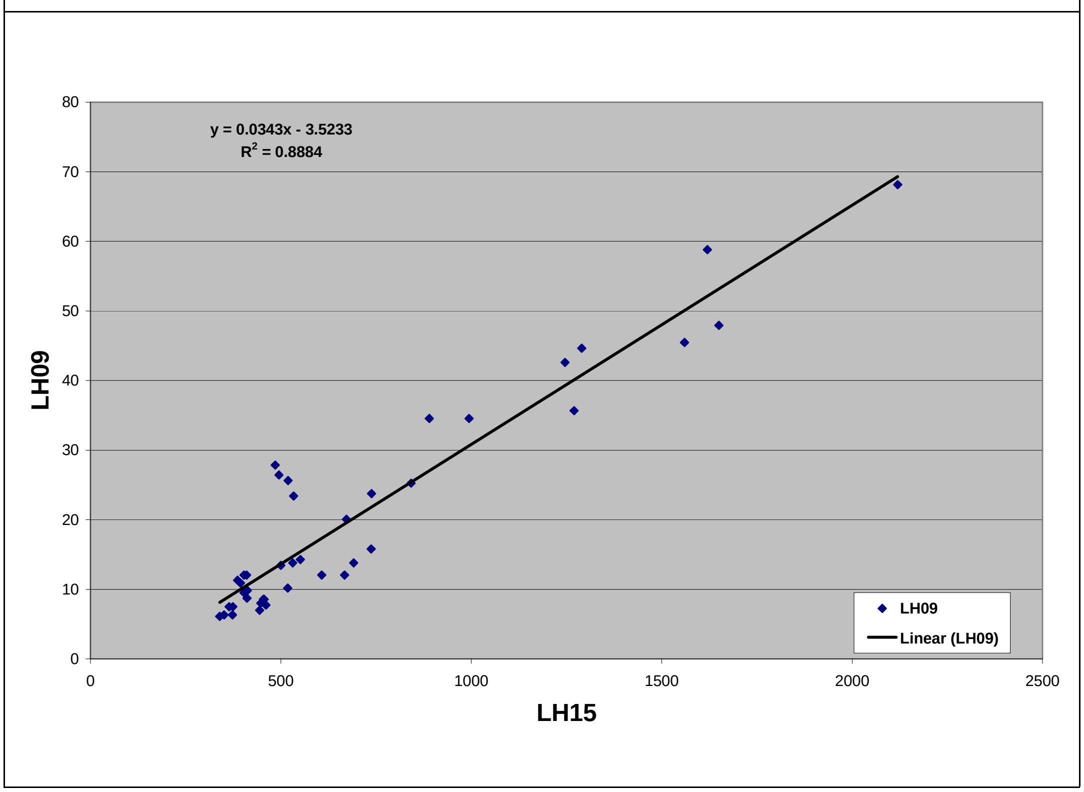

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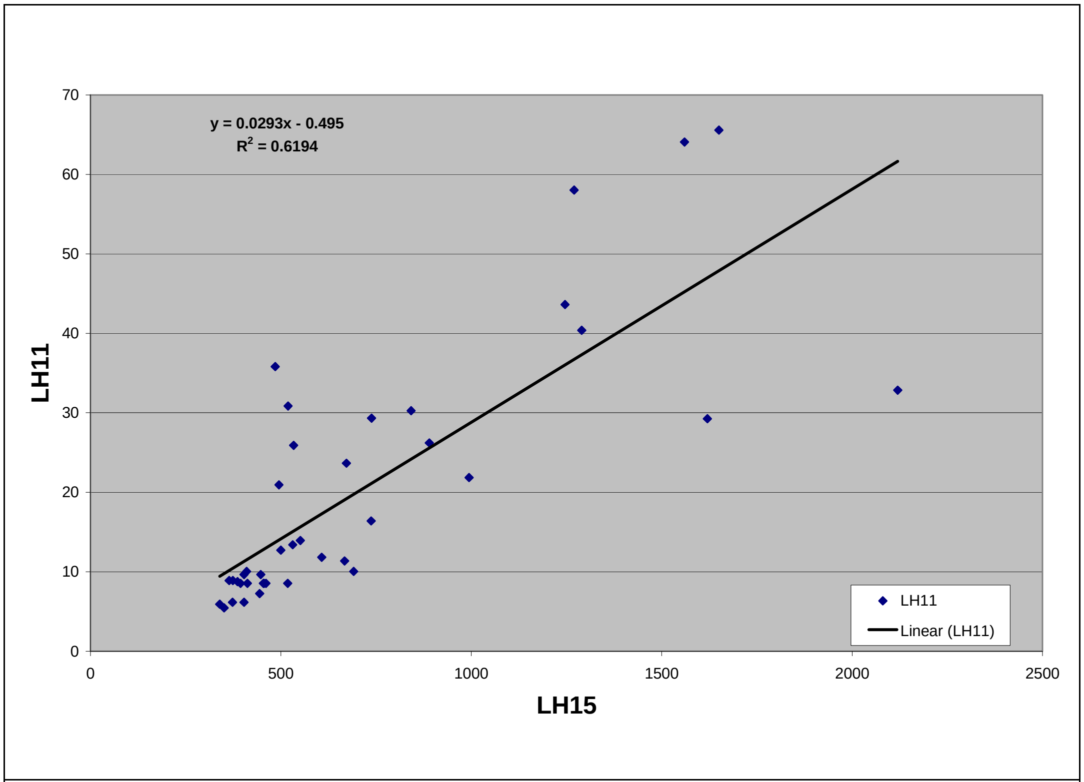


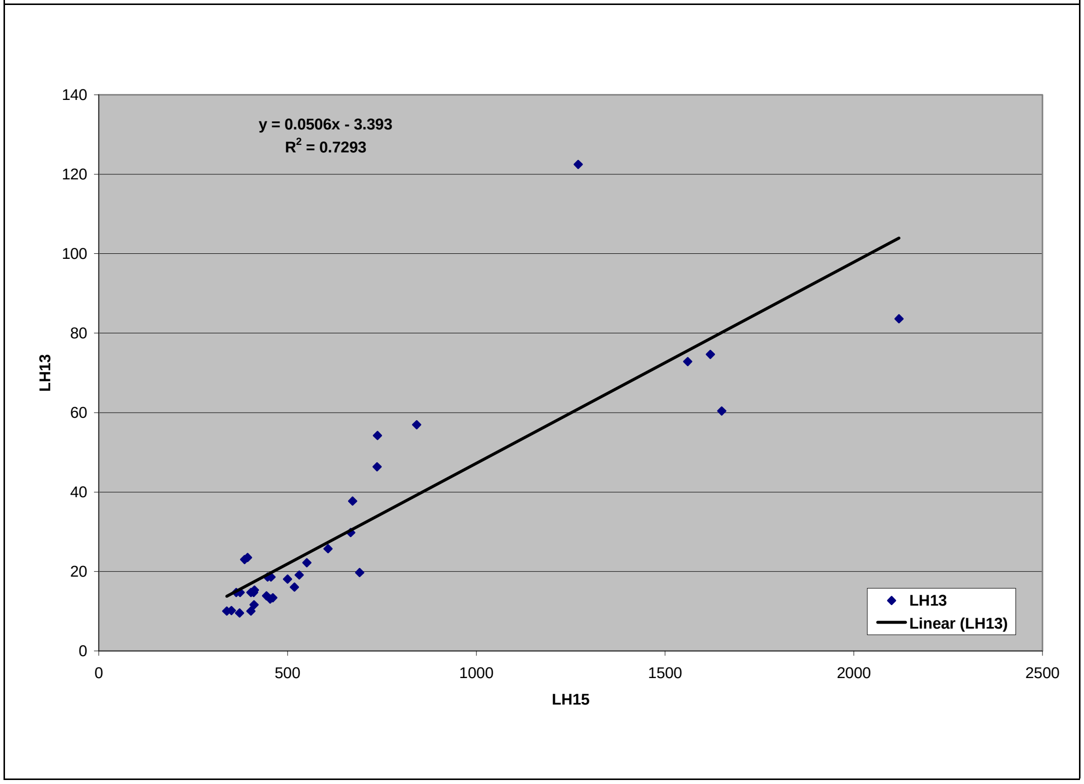
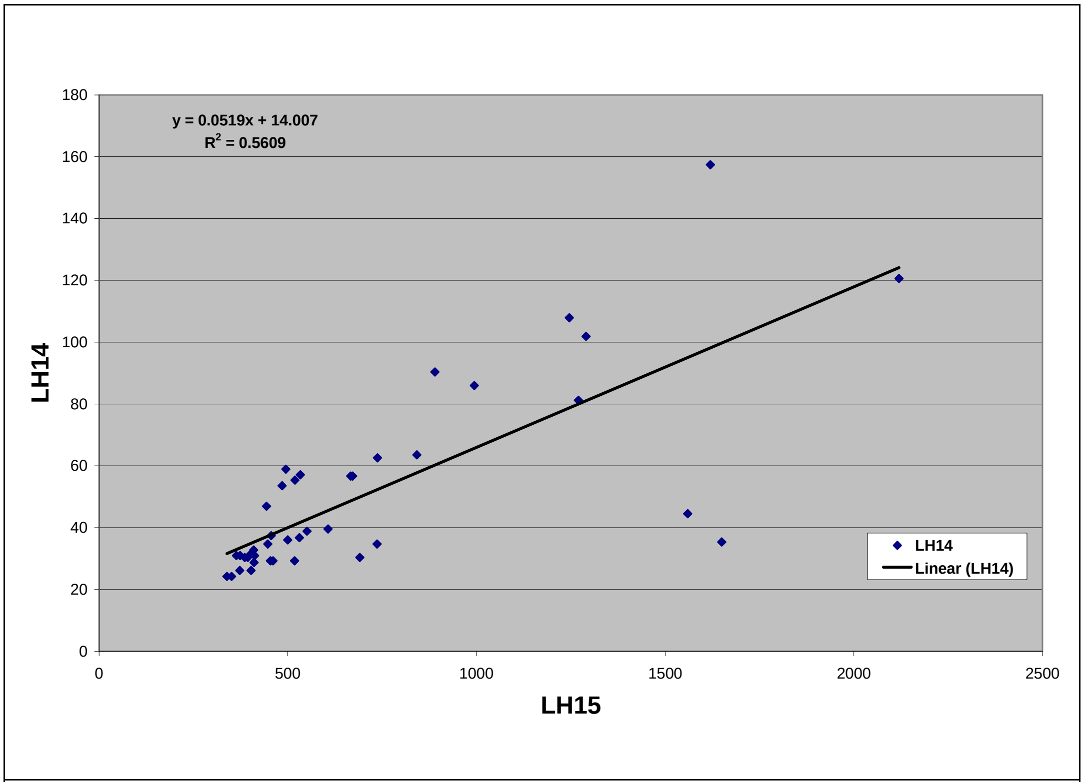


Figure A-1. Continued



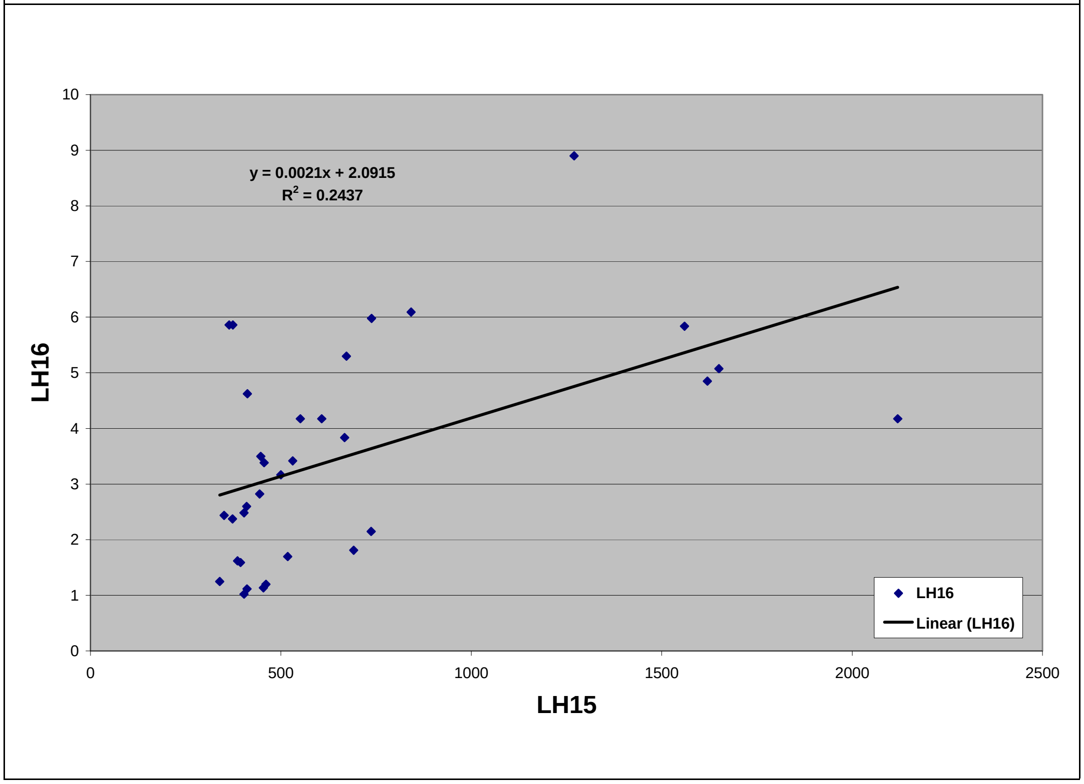


Figure A-1. Concluded

Note* - LH04 = Hayes Creek
LH05 = Sandy Run
LH06 = Buck Mountain
LH07 = Black Creek
LH09 = Nesquehoning Creek
LH11 = Mahoning Creek
LH13 = Lizard Creek
LH14 = Aquashicola Creek
LH16 = Bertsch Creek

Appendix B: Scenario Time Series Difference Plots

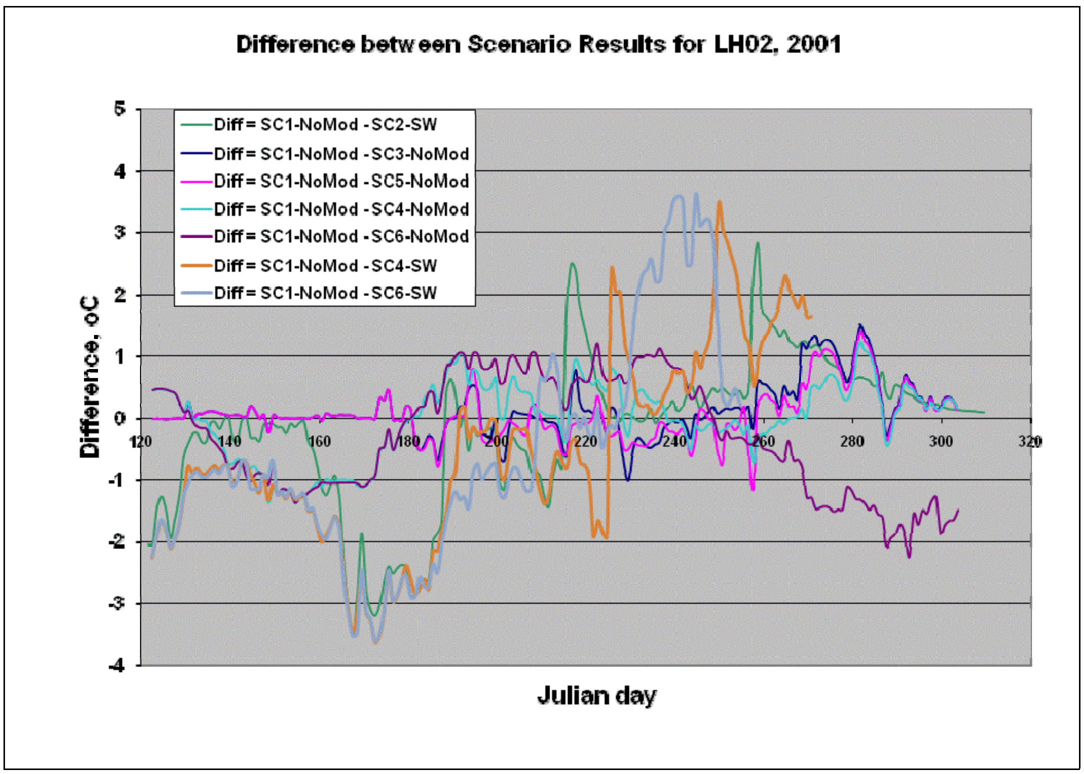


Figure B-1. Difference between SC1-NoMod and other scenarios at stations LH02, LH03, LH08, LH10, LH15, and LH17 for 2001

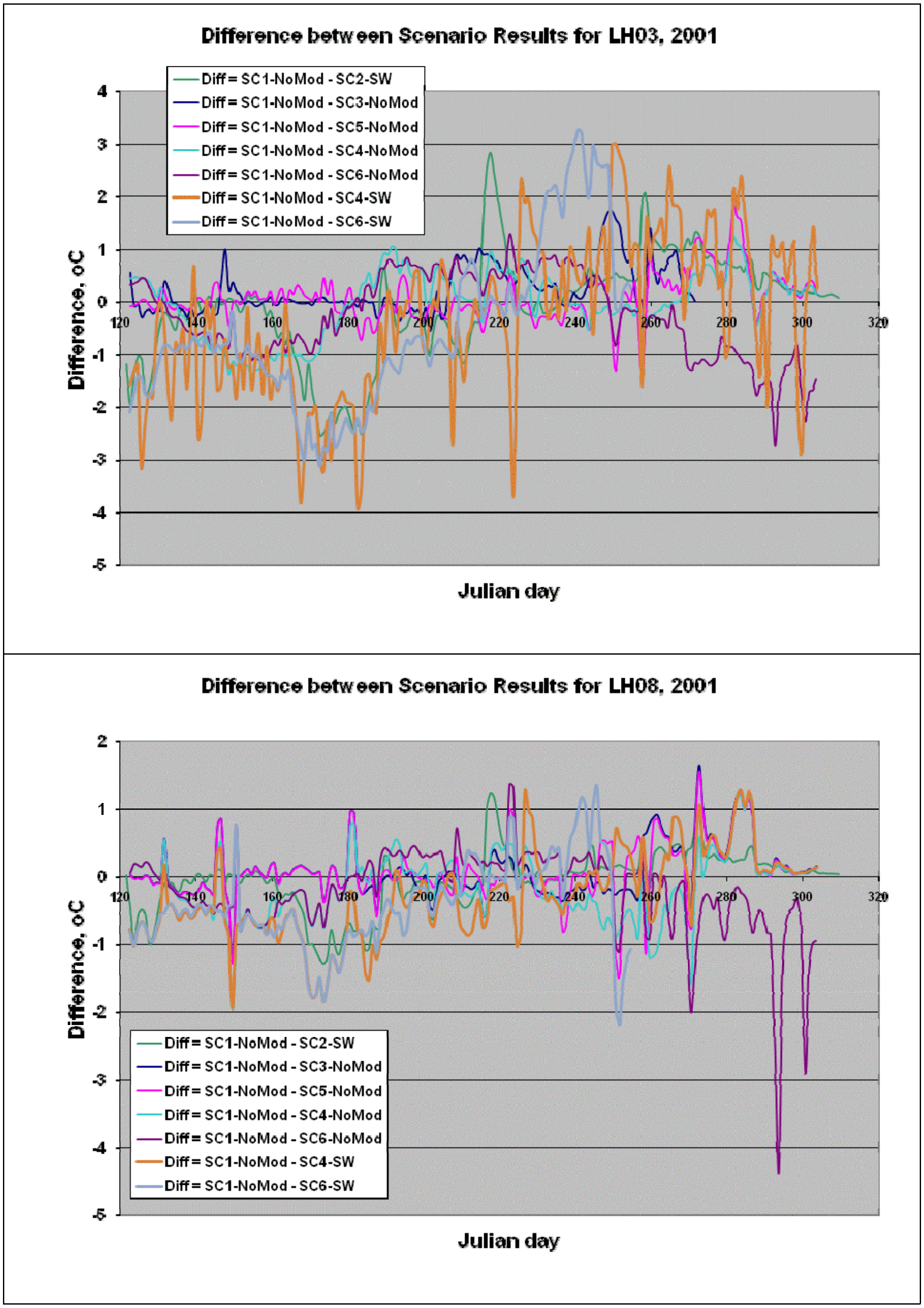
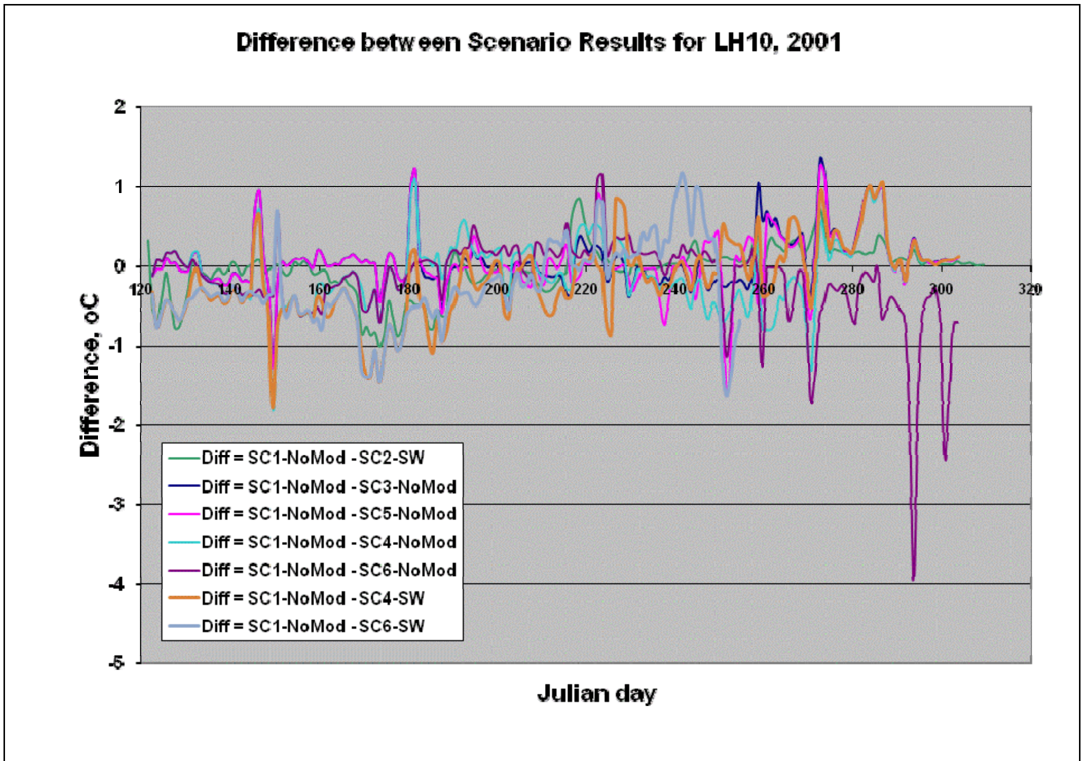


Figure B-1. Continued



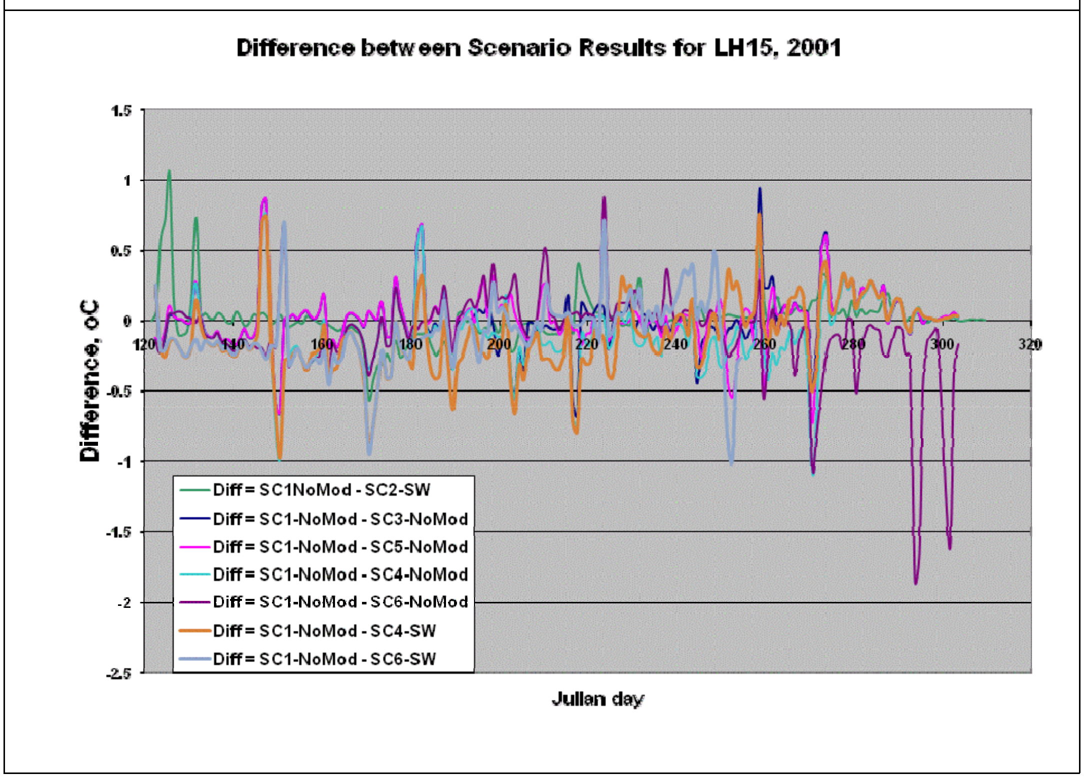


Figure B-1. Continued

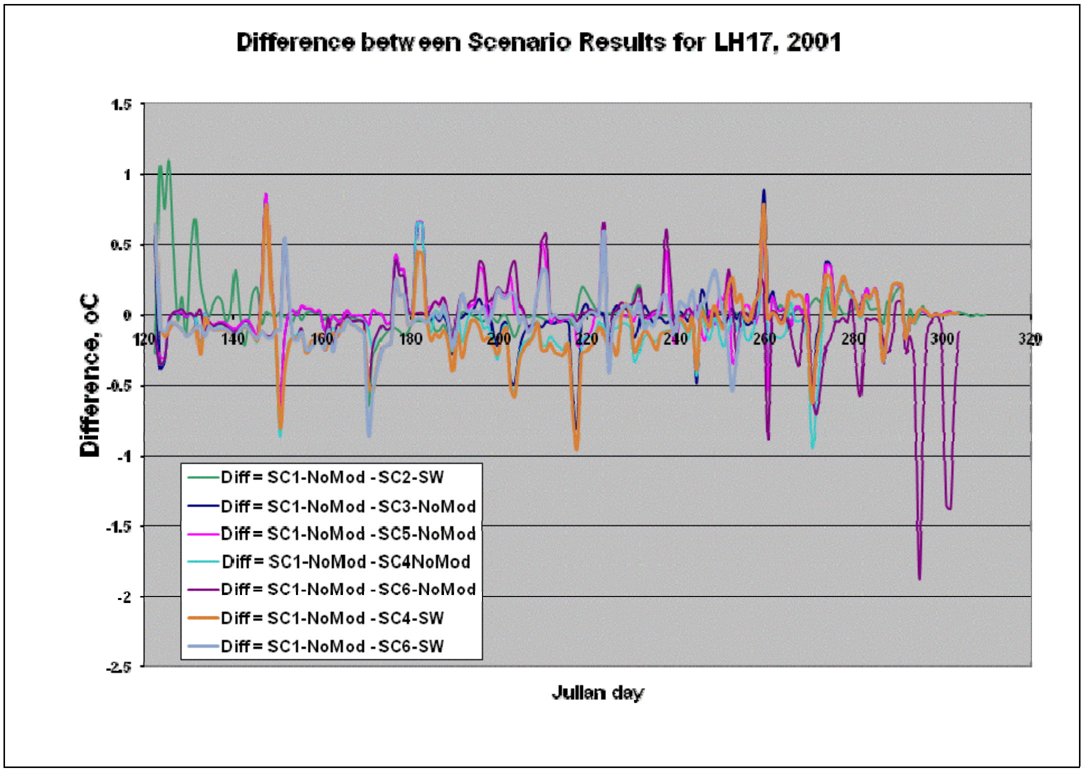
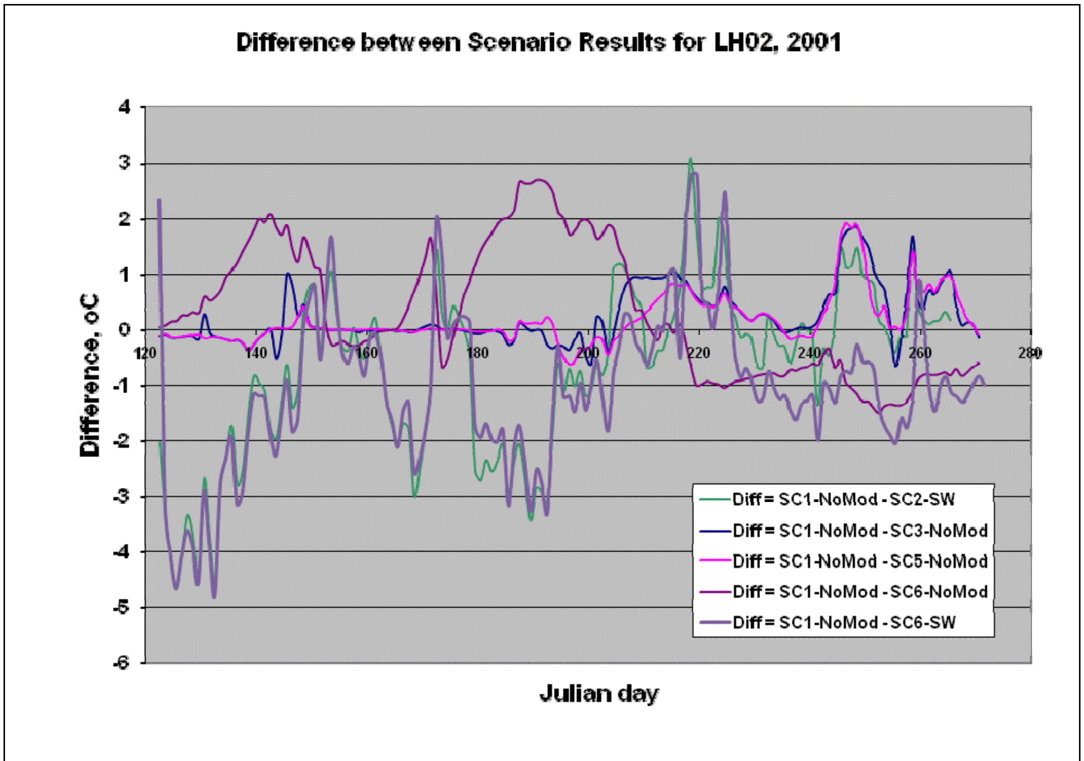


Figure B-1. Concluded



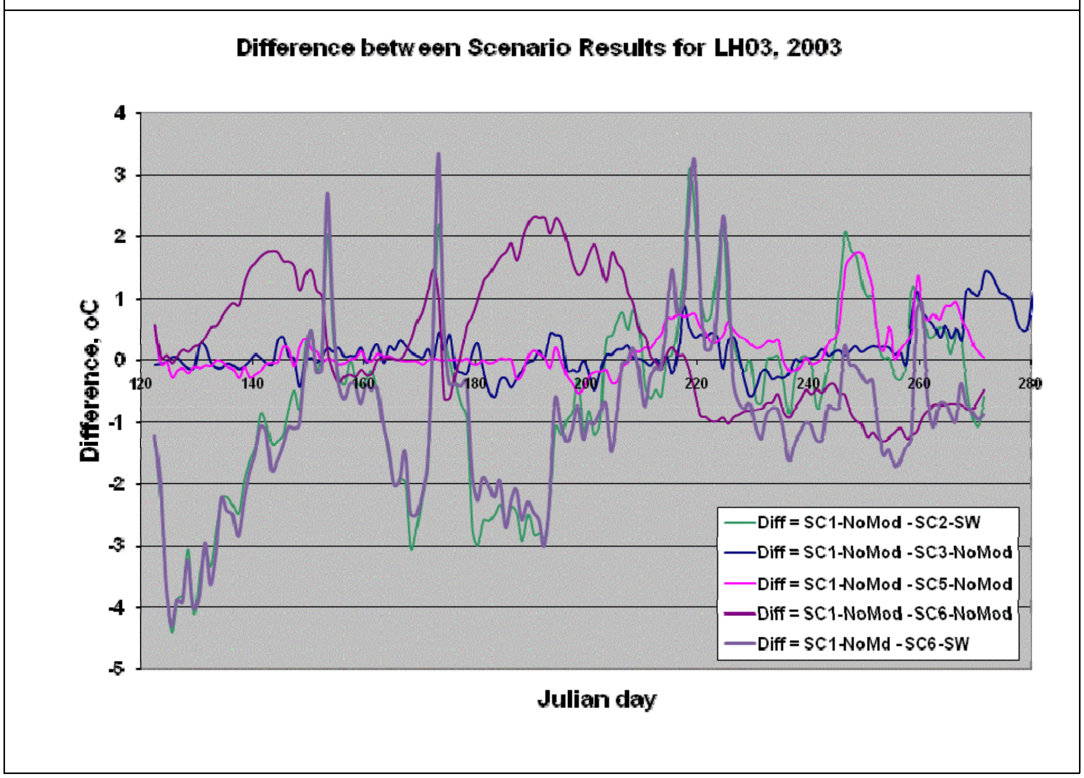
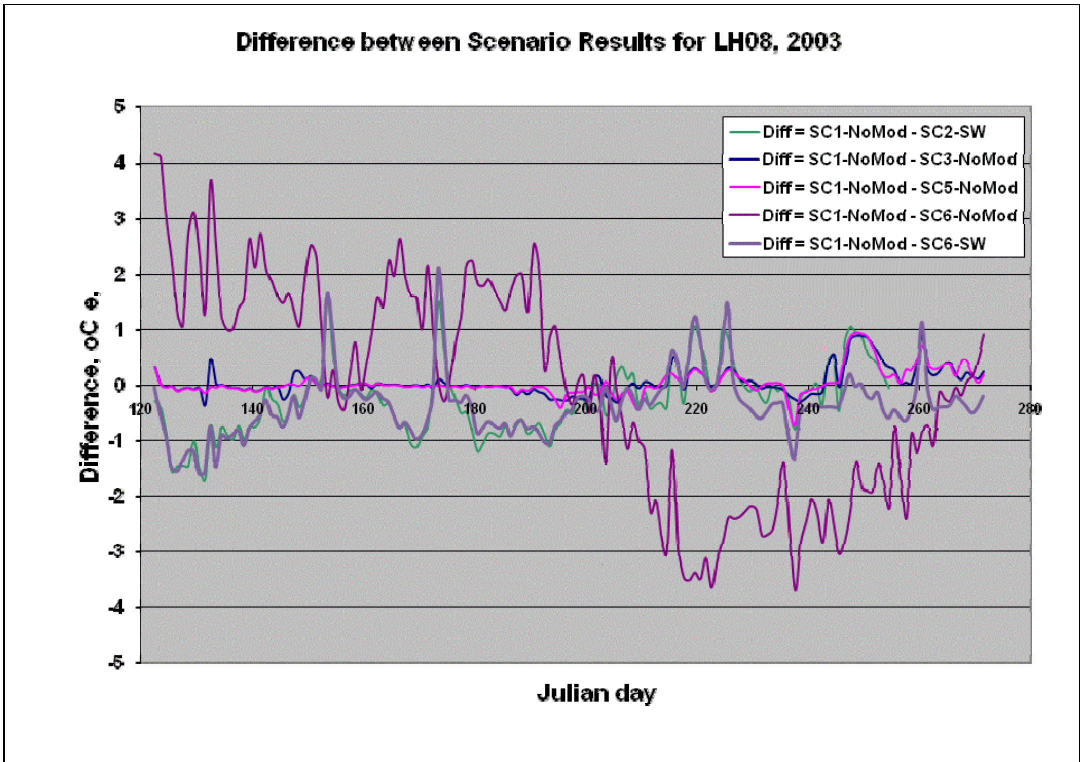


Figure B-2. Difference between SC1-NoMod and other scenarios at stations LH02, LH03, LH08, LH10, LH15, and LH17 for 2003



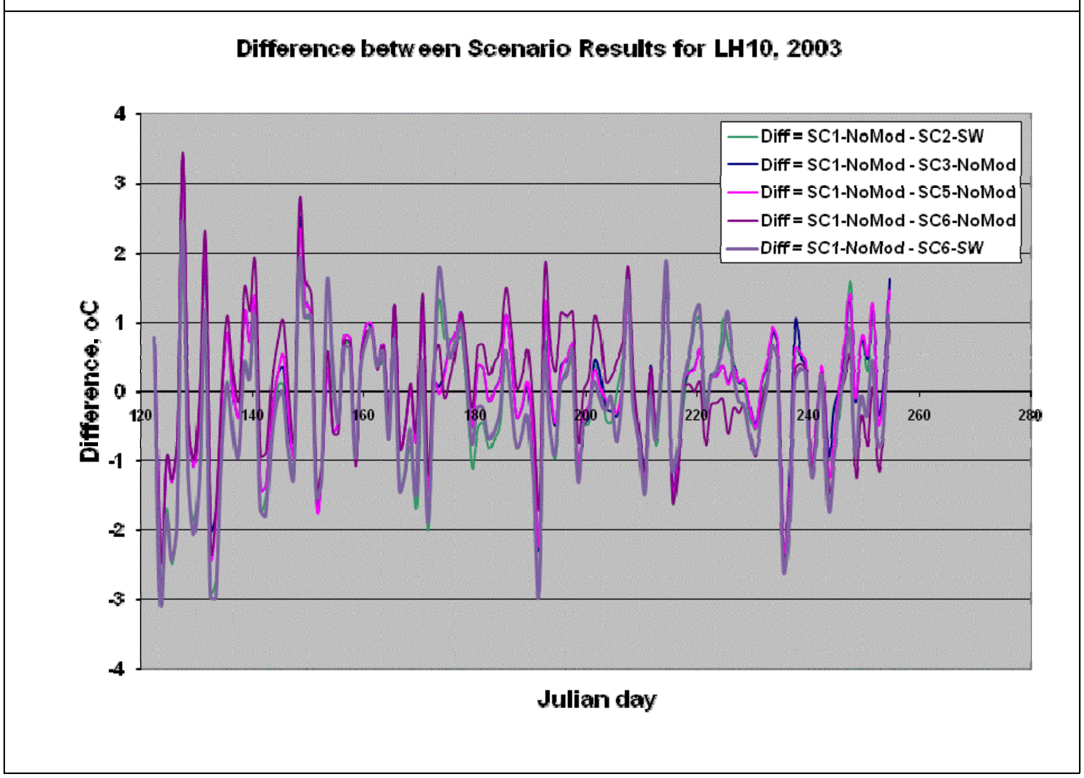
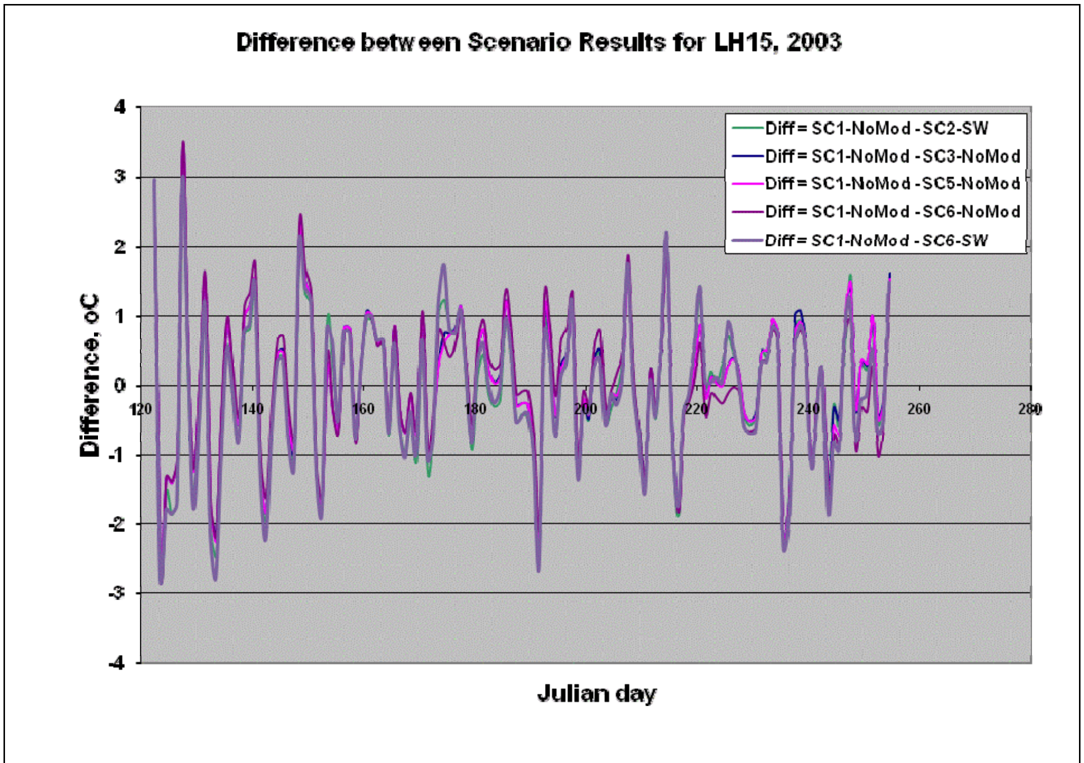


Figure B-2. Continued



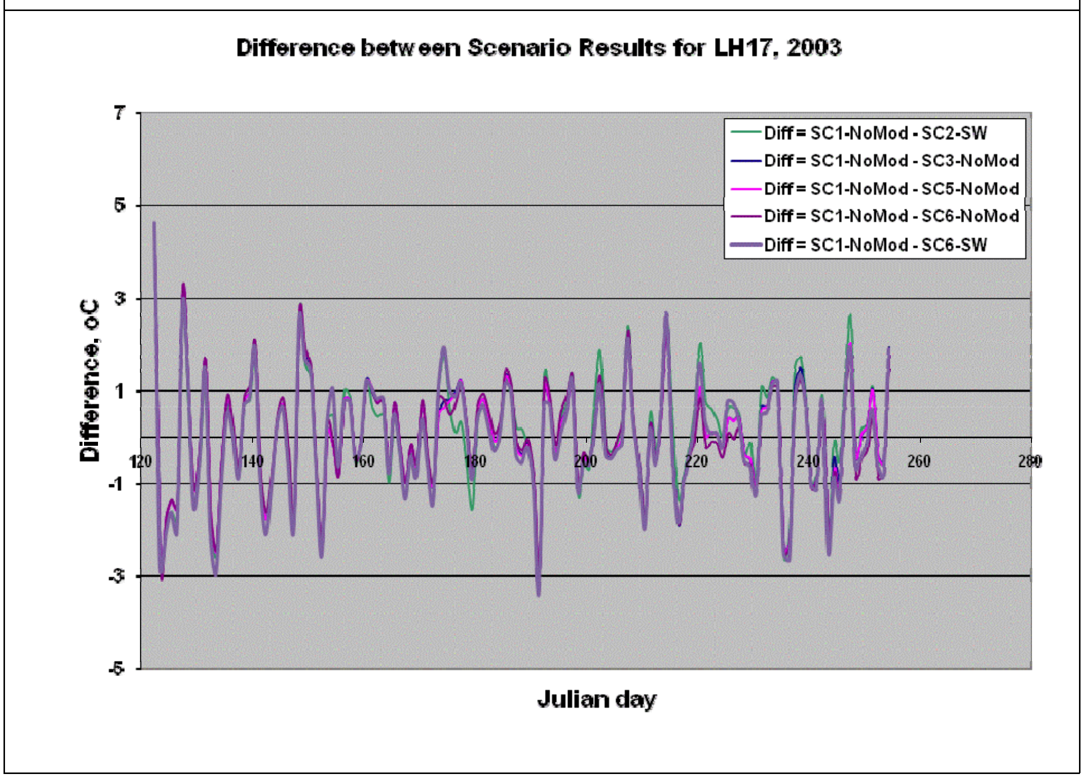


Figure B-2. Concluded

Appendix C: CE-QUAL-W2 Volume-Elevation Table

Table C-1. CE-QUAL-W2 Volume-Elevation Table

Elevation Ft	Volume m3	Elevation FT	Volume m3
1245.917	3000	1365.3	28518000
1247.229	13000	1366.612	29395000
1248.541	26000	1367.924	30288000
1249.852	40000	1369.236	31195000
1251.164	56000	1370.548	32117000
1252.476	73000	1371.86	33064000
1253.788	92000	1373.172	34044000
1255.1	113000	1374.483	35045000
1256.412	136000	1375.795	36064000
1257.724	162000	1377.107	37096000
1259.036	192000	1378.419	38142000
1260.348	232000	1379.731	39202000
1261.66	281000	1381.043	40276000
1262.971	337000	1382.355	41362000
1264.283	406000	1383.667	42464000
1265.595	489000	1384.979	43626000
1266.907	579000	1386.291	44803000
1268.219	678000	1387.602	45997000
1269.531	785000	1388.914	47208000
1270.843	915000	1390.226	48461000
1272.155	1057000	1391.538	49737000
1273.467	1203000	1392.85	51033000
1274.779	1350000	1394.162	52353000
1276.091	1499000	1395.474	53692000
1277.402	1649000	1396.786	55049000
1278.714	1803000	1398.098	56424000
1280.026	1961000	1399.41	57828000
1281.338	2122000	1400.722	59254000
1282.65	2293000	1402.033	60700000
1283.962	2467000	1403.345	62164000
1285.274	2644000	1404.657	63648000
1286.586	2835000	1405.969	65155000
1287.898	3034000	1407.281	66686000
1289.21	3242000	1408.593	68241000
1290.521	3458000	1409.905	69815000
1291.833	3679000	1411.217	71406000
1293.145	3906000	1412.529	73015000
1294.457	4137000	1413.841	74653000
1295.769	4373000	1415.153	76312000
1297.081	4613000	1416.464	78002000

1298.393	4858000	1417.776	79719000
1299.705	5108000	1419.088	81467000
1301.017	5367000	1420.4	83242000
1302.329	5630000	1421.712	85082000
1303.641	5896000	1423.024	86984000
1304.952	6167000	1424.336	88923000
1306.264	6441000	1425.648	90888000
1307.576	6719000	1426.96	92872000
1308.888	7001000	1428.272	94877000
1310.2	7288000	1429.583	96902000
1311.512	7578000	1430.895	98949000
1312.824	7872000	1432.207	1.01E+08
1314.136	8171000	1433.519	1.03E+08
1315.448	8474000	1434.831	1.05E+08
1316.76	8781000	1436.143	1.07E+08
1318.071	9093000	1437.455	1.1E+08
1319.383	9408000	1438.767	1.12E+08
1320.695	9726000	1440.079	1.14E+08
1322.007	10048000	1441.391	1.16E+08
1323.319	10373000	1442.703	1.18E+08
1324.631	10730000	1444.014	1.21E+08
1325.943	11096000	1445.326	1.23E+08
1327.255	11469000	1446.638	1.25E+08
1328.567	11850000	1447.95	1.28E+08
1329.879	12245000	1449.262	1.3E+08
1331.191	12652000	1450.574	1.32E+08
1332.502	13069000	1451.886	1.35E+08
1333.814	13496000	1453.198	1.37E+08
1335.126	13941000	1454.51	1.4E+08
1336.438	14419000	1455.822	1.42E+08
1337.75	14925000	1457.133	1.45E+08
1339.062	15437000	1458.445	1.47E+08
1340.374	15956000	1459.757	1.5E+08
1341.686	16482000	1461.069	1.52E+08
1342.998	17016000	1462.381	1.54E+08
1344.31	17557000	1463.693	1.57E+08
1345.622	18106000	1465.005	1.59E+08
1346.933	18665000	1466.317	1.62E+08
1348.245	19240000	1467.629	1.64E+08
1349.557	19831000	1468.941	1.67E+08
1350.869	20430000	1470.253	1.69E+08
1352.181	21048000	1471.564	1.72E+08
1353.493	21701000	1472.876	1.74E+08
1354.805	22366000	1474.188	1.77E+08
1356.117	23039000	1475.5	1.79E+08
1357.429	23723000	1476.812	1.82E+08
1358.741	24419000		
1360.052	25141000		
1361.364	25947000		