EXHIBIT ARWA-903

Technical Memorandum 5

Folsom Reservoir CE-QUAL-W2 Temperature Model

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1.0 INTRODUCTION

This technical report documents the Folsom Reservoir water temperature model. It was originally developed by Placer County Water Agency (PCWA) and has been used by the Sacramento Water Forum. The model was developed to test the ability of alternative hydrology and reservoir operations scenarios to meet regulatory water temperature requirements (or targets) in the lower American River at Watt Avenue. The water temperature targets are based on the Automated Temperature Selection Procedure (ATSP) schedules developed as part of the Sacramento Water Forum Flow Management Standard (FMS) (Water Forum 2004; Water Forum 2006). The primary water temperature management objective for the lower American River is to meet the best possible temperature schedule each year for Central Valley steelhead (summer rearing) and fall-run Chinook salmon spawning (fall months), given Folsom Reservoir inflows, available reservoir volume, and Folsom Reservoir outflows.

Folsom Dam was designed to be able to release water from various elevations within the reservoir simultaneously. Dam operators modify temperature control device (TCD) shutters on each of the three powerhouse generation penstocks to take water from different depths in the reservoir and blend outflows in order to meet downstream regulatory temperature requirements/targets. Operators also adjust the elevation of the Municipal Water Supply Intake (Municipal Intake) (Vermeyen, T.B. 1997) and operate the low level outlets on the dam to modify outflow water temperatures and preserve cold water resources in the reservoir. The water temperature model was developed to automatically determine the best ATSP outflow temperature schedule possible and utilize cold water in the reservoir most effectively. The model includes automated TCD and powerhouse flow split operations, a user specified target temperature for the variable elevation Municipal Intake, and use of the low level outlets in late fall to access cold water in the reservoir below the powerhouse outlets.

The model uses CE-QUAL-W2 (Cole and Wells, 2015), which is a 2-D hydrodynamic and temperature model. New model code was added to enhance and automate TCD modeling (including low-level outlets) and provide ATSP temperature schedule selection capability. The completed model allows modelers to run scenarios in which the model itself determines the optimal operations to meet downstream temperature targets.

The period between 2001 and 2011 was selected as the model calibration period because a considerable amount of data, including inflow rates and temperatures, in-reservoir temperature profiles, outflow operations, downstream water temperatures, and meteorological conditions were available for this time period. This report documents the model calibration data, the model calibration procedures, and results, including the development of the tools to fully automate the model.

2.0 BACKGOUND (FOLSOM DAM AND RESERVOIR)

Folsom Dam and Reservoir are located approximately 20 miles northeast of Sacramento, California, on the American River as shown in Map 1. The reservoir has a maximum volume of 976,000 acre-feet (1,203,878,290 cubic meters) and drains an area of approximately 1,875 square miles (4,856 square kilometers). The dam was built by the United States Army Corps of Engineers between 1948 and 1956, at which point operation of the dam was transferred to the United States Bureau of Reclamation (Reclamation) (U.S. Dept. of Interior, 2013). Downstream of Folsom Dam, the lower American River provides important habitat for fall-run Chinook salmon and threatened[1] Central Valley steelhead, among other species. Water temperatures in the river play a critical role in determining the health of the aquatic biota inhabiting the lower American River.

Folsom Dam was constructed with a total of twenty different outlets and outlet structures. There are three power generation penstocks, which are each fitted with an adjustable TCD that allows for four different configurations (discrete inflow elevations). These configurations allow the operator to pull water from different depths depending on water level and desired outflow temperature. In addition to the power generation penstock TCDs, a single variable elevation TCD has been installed on the Municipal Intake. The remaining outlets are all fixed location structures, including four rectangular medium elevation and four low elevation river outlets and eight spillway gates. These outlets and gates are generally used only for flood control and, occasionally, for temperature control in the late fall (i.e., the low level outlets).

3.0 CE-QUAL-W2 MODEL DEVELOPMENT

This section describes the CE-QUAL-W2 model development, including the following:

- CE-QUAL-W2 model background;
- Folsom Reservoir Model bathymetry;
- Model computational grid;
- Folsom Dam outlet structures;
- Model boundary condition data sources; and
- Automated model simulation tools.

3.1 CE-QUAL-W2 MODEL BACKGROUND

An earlier CE-QUAL-W2 model study of Folsom Reservoir was conducted in 2007 by Reclamation (Bender et al. 2007). That model had a comparatively coarser computational grid than was used in this current study, which is described below. The 2007 model study had an average mean in-reservoir temperature profile error of about 1.8 ^{o}F (1^{o}C). The model reportedly calibrated well to downstream temperatures; however no error statistics were provided in the model report.

For this work (PCWA and Sacramento Water Forum modeling), a new CE-QUAL-W2 model of Folsom Reservoir was developed and used. A customized version of CE-QUAL-W2 was required due to the complexity of reservoir operations. CE-QUAL-W2 (Cole and Wells, 2006; Cole and Wells 2015) is a public domain model that is maintained by the Portland State University Water Quality Research Group headed by Dr. Wells. The model user manual and documentation can be found at the Portland State University (PSU) website: http://www.cee.pdx.edu/w2. The model

[1] Threatened under the federal Endangered Species Act of 1973.

is a 2-dimensional (longitudinal-vertical) hydrodynamic and water quality model capable of predicting water surface elevation, velocity, temperature and many other water quality parameters in lakes, reservoirs, and rivers. The model is set up to predict these state variables in vertical layers within each longitudinal segment. Typical model longitudinal segment resolution is between 100 and 1,000 meter (m); vertical layer resolution is usually between 0.5 m and 2 m.

Dr. Wells and his modeling group have been the primary developers of the CE-QUAL-W2 model for the Engineer Research and Development Center (ERDC), Environmental Laboratory, Waterways Experiments Station Corps of Engineers for the last 15 years. Since 2000, the model has been used extensively throughout the world (116 different countries) to model lakes, reservoirs, estuaries, and river systems.

Dr. Wells developed the model by modifying the existing CE-QUAL-W2 code to facilitate the unique modeling requirements of Folsom Reservoir. The CE-QUAL-W2 code was modified to iteratively solve for the best down-river temperature schedule by modifying the position of individual penstock shutters and the proportion of water going through each penstock of Folsom Dam. The code was also modified to iteratively set the elevation of the Municipal Intake to track a user-supplied water temperature in the reservoir and to operate the low level outlets within a user-supplied range of dates and maximum daily volumes. The low-level outlet operations allow access to cold water below the power penstock intake elevations similar to how the low level outlets are currently operated in the fall to reduce river temperatures for fall spawning Chinook salmon.

3.2 Folsom Reservoir Model Bathymetry

Folsom Reservoir bathymetric data were provided by Reclamation to Cardno as Geographic Information System (GIS) shape files. These data were collected using two different methods: (1) multi-beam sonar with Real time Kinematic (RTK) GPS positioning; and (2) photogrammetry in September and October of 2005, respectively, as part of a sedimentation survey conducted by Reclamation (Ferrari, 2007). The survey used the California State Plane, zone 2, North American Datum of 1983 (NAD83) horizontal datum and National Geodetic Vertical Datum of 1929 (NGVD29) vertical datum (same as the Folsom Dam Project vertical datum). Figure 1 shows an example of the elevation contour lines near Folsom Dam calculated from data collected in the 2005 survey.

The data were converted in GIS to Universal Transverse Mercator (UTM) Zone 10 and the vertical units were converted from feet to meters (vertical datum used was NGVD29). These data were then converted to an x, y, z text file that was imported into SURFER (Golden Software). A 3-D grid file was created from these points using the kriging gridding method. The final SURFER-generated elevation contour map of Folsom Reservoir is shown in Figure 2.

3.3 Model Computational Grid

Following the creation of the 3-D SURFER topography, the CE-QUAL-W2 model domain was split into 191 longitudinal segments with 0.61 m (2 ft) vertical layers, comprising 3 separate branches

(Figure 3) to create the computational grid. Branch 1 was defined as the main branch and receives inflow from the North Fork American River (NFAR). Branch 2 receives inflow from the South Fork American River (SFAR) and branch 3 is a side branch off of branch 2.

Model grid details are summarized in

Table 1. Details regarding the configuration of each individual branch are summarized in Table 2.

Once the model computational grid was developed, the final grid input files were created and read into CE-QUAL-W2. The model's Graphical User Interface (GUI) interface allows the user to visually check the model configuration, including model side views and vertical segment slices as shown in Figure 4 and Figure 5.

In addition to visual checks, the bathymetry of the computational grid was tested by calculating the volume-water surface elevation (WSE) curve for the model grid, and comparing it to the WSE curve previously developed for the Folsom Reservoir system (Ferrari, 2007). A comparison of the volume-WSE curves from the two sources is shown in Figure 6.

3.4 FOLSOM DAM OUTLET STRUCTURES

Folsom Dam has twenty different controllable outlet structures. These structures, their locations, size, and shape are described in Table 3. Figure 7, Figure 8, and Figure 9 show an aerial view, ground view, and schematic, respectively, of the location of these outlet structures on Folsom Dam. The twenty outlet structures can be divided into four subsets: (1) Municipal Intake; (2) Power Generation Penstock Outlets; (3) River Outlet Gates; and (4) Spillway Gates. Water is also diverted by El Dorado Irrigation District (EID) from Folsom Reservoir upstream of the dam. The following sections discuss each outlet type in detail.

3.4.1 Municipal Intake

The Municipal Intake is a single, circular inlet built into the concrete structure of the dam on the north side of the power generation penstock intake structures. The TCD is installed in front of the intake. An aerial view of the structure is shown in Figure 10. The TCD can be raised or lowered to control the elevation of withdrawal. Under normal conditions, the TCD is operated between 401 ft. (122.2 m) and 331.5 ft. (101 m); however, under extreme conditions, when the water level is lower, the intake can drop to the elevation of the intake pipe centerline (317 ft.; 96.62 m). Attachment A, Figures 1 and 2, include schematics of the outlet structure and elevations. The water that enters the Municipal Intake is used to supply water to various communities (City of Folsom, Folsom Prison, the City of Roseville, Sacramento Suburban Water District and San Juan Water District).

3.4.2 Power Generation Penstock Outlets

There are three separate power penstock outlets incorporated into the structure of the dam. Figure 9, Figure 11, and Figure 12 show the power generation outlet structures, TCDs, and elevations. A separate TCD is installed in front of each of the power outlets. The TCDs can be raised or lowered to control the elevation of the withdrawal, but only with a relatively coarse step adjustment. The amount of water entering each power penstock can be controlled individually and varies depending on the amount of water being released for power generation demand and the mix of temperature needed to meet downstream temperature requirements.

Actual inflow into the TCDs occurs from a withdrawal zone. The withdrawal zone is not centered at the elevation of the TCD, but above the TCD opening. In CE-QUAL-W2 the centerline of the withdrawal zone was placed 8.9 feet (2.7 m) above the elevation of the edge of the shutter opening to approximate the centerline of the flow (Table 4). The extent of the withdrawal zone is calculated by a CE-QUAL-W2 algorithm based on the outlet geometry, outflow and in-pool densities. The TCD shutters on the penstocks do not fit together in a water tight manner and some leakage of water occurs through the shutters. The exact amount is unknown and potentially variable depending on shutter fit during installation and shutter configuration. The leakage is potentially cold hypolimnion water, which can affect cold water management. Prior to recognition of the potential leakage issue, calibration of the CE-QUAL-W2 model indicated that a large amount of cold water was getting into the power outlets (approximately 35% over the calibration period). This amount is well within the range of potential shutter leakage. Photographs of a submerged shutter with large gaps (openings) can be seen in Figure 13. As a result of the calibration (see below), 35% leakage has been assigned in the model to the shutters at the level of the power penstock inlets.

3.4.3 River Outlet Gates

Eight rectangular river outlets are incorporated into the concrete structure of the dam. These outlets are organized into two rows of four, with one set of four directly above the other set. The river outlets do not have TCDs. These outlets are used when water needs to be drawn down rapidly from the reservoir pool or the low level outlets have been used under specific conditions in the fall to access cold water stored in the reservoir below the powerhouse intakes. The low level outlets are a source of colder water for the lower American River during warm periods in the fall. There is also some leakage from these outlets. The water that enters the river outlets is discharged into the river channel/spillway area on the downstream side of the dam and bypasses the powerhouses. A summary of how these gates were used between 2001 and 2014 (both duration and flow) is shown in Table 5.

3.4.4 Spillway Gates

Eight spillway gates are located along the top of Folsom Dam at an elevation of 418 feet (127.4 m). Each spillway is controlled by a 42-foot (12.8 m) wide radial gate with a radius of 47 feet (14.3 m). These gates are used for flood control when the reservoir elevation exceeds 418 feet (127.4 m). All water released over the spillways is discharged into the river on the downstream side of the dam.

3.4.5 EL Dorado Irrigation District (EID) Diversion in Folsom Reservoir

In addition to water diverted for municipal water supply at the dam, water is also diverted by EID at a location approximately 3.5 miles to the northeast of Folsom Dam. The fixed elevation intake structure is set at an elevation of 320 feet (97.5 m). The location of the diversion structure is shown in Map 1. This location corresponds to model segment 151.

3.5 MODEL BOUNDARY CONDITION DATA SOURCES

Model boundary condition data for the 2001-2011 calibration period that were used in the development of the Folsom Reservoir CE-QUAL-W2 model include:

- Meteorological (MET);
- Reservoir inflows (flow rate and water temperature); and
- Reservoir outflows and temperature control device operations.

All data were quality controlled prior to use in the calibration model. The sources of these data and types of data available are summarized below.

3.5.1 Meteorological Data

The MET data required for Folsom Reservoir water temperature modeling included: air temperature; dew point temperature; wind speed and direction; cloud cover; and solar radiation. These data were obtained from three MET stations: Fair Oaks; Folsom/Dyke 8; and Mather Air Force Base (Mather AFB) (Table 6). The locations of the stations are shown in Map 1.

Air temperature, dew point temperature, and solar radiation data were used from the Fair Oaks weather station. This was the most complete and reliable dataset for these three parameters in the vicinity of Folsom Reservoir. Data plots for the parameters are shown in Figure 14, Figure 15, and Figure 16.

Wind speed and direction data were compiled and used from each of the sites during the calibration period (2001-2011) as there were numerous gaps in the individual data sets. Wind data from the Folsom/Dyke 8 and Mather AFB MET stations were used preferentially in that order. The composite “wind rose” plot showing wind speed and direction from the combined data set is shown in Figure 17. The Fair Oaks MET station consistently reported a substantially lower wind speed than the other sites. This indicated that the wind gage for the station was probably in a sheltered location. For this reason, the Fair Oaks MET station wind data were only used when no other data from the other three stations were available. A relationship between wind speed at the Fair Oaks MET station and the other MET stations was developed and applied to the Fair Oaks data when used. The relationship is summarized in Table 7. Wind speed data for the calibration period are shown in Figure 18.

Cloud cover data were obtained from the Mather AFB MET station. Cloud cover was recorded in five categories that represent different sky conditions (Table 8). Each category was assigned a value between zero and ten for use in the CE-QUAL-W2 model. Figure 19 shows the distribution of cloud cover values over the full calibration period.

3.5.2 Reservoir Inflows (Flow Rate and Water Temperature)

Folsom Reservoir is fed by three main inflows: the NFAR, the SFAR, and Newcastle Powerhouse/South Canal (i.e., Yuba-Bear river water). A summary of the gage station data is shown in Table 9. The location of each of these sites is shown in Map 1. Figure 20 shows the inflow rates to Folsom Reservoir for the calibration period 2001-2011. Figure 21 shows the water temperature of the main inflows to Folsom Reservoir.

North Fork American River

Flow

NFAR inflow to Folsom Reservoir (2001 – 2011) was obtained by combining the United States Geological Survey (USGS) gage on the NFAR at North Fork Dam, CA (USGS gage no. 11427000) and the Middle Fork American River (MFAR) near Foresthill gage (USGS gage no. 11433300). This is an estimate of NFAR inflow into Folsom only. The gages are upstream of the confluence of the two rivers and some inflows occur downstream of the gages. These inflows are taken into account in the water balance performed during the water level calibration for the reservoir model.

Water Temperature

The historical water temperature data (2001 – 2011) for the NFAR were obtained from the USGS gaging station/California Data Exchange Center (CDEC) station on the NFAR at Auburn Dam Site near Auburn, CA (USGS gage no. 11433790/ CDEC station NFA). The temperature gage is very close to the inflow of the NFAR into Folsom Reservoir.

South Fork American River

Flow

SFAR inflow to Folsom Reservoir (2001 – 2011) was based on the USGS/CDEC gaging station near Placerville, CA (USGS gage no. 11444500/ CDEC station CBR). This gage does not account for local inflows in between the gage site and Folsom Reservoir. These flows are taken into account in the water balance performed during the water level calibration for the reservoir model.

Water Temperature

The historical water temperature data (2001 – 2011) for the SFAR were obtained from USGS gaging station on the SFAR near Pilot Hill, CA (11446030).

South Canal Inflows

Yuba-Bear river water is imported into Folsom Reservoir via the South Canal inflows into Newcastle Powerhouse and Mormon Ravine.

Flow
Data (2001-2011) from the USGS Newcastle Power Plant near Newcastle, CA gage (USGS gage no. 11425416) and Mormon Ravine near Newcastle, CA gage (USGS gage no. 11433930) were used to quantify the South Canal river import water inflow to Folsom Reservoir.

Water Temperature
No single continuous water temperature data set was available for the period of calibration (2001-2011) for Newcastle Powerhouse/Mormon Ravine inflows. Instead, data from 7 different sources from the South Canal spanning various time periods were compiled and combined into a single average monthly water temperature estimate for the Newcastle Powerhouse. The data and methods for estimation are covered in detail in Attachment B.

3.5.3 Reservoir Outflows and Temperature Control Device Operations

Figure 22 shows an overview of the various outflows from Folsom Dam for the full calibration period (2001-2011) and the data sources are provided in Table 10. Details of the reservoir outflows (flow and water temperature) and TCD operations for the Municipal Intake, low level river outlets gates, spillway gates, power generation penstocks, and El Dorado Irrigation Diversion are provided below.

Municipal Intake - Flows and TCD Elevations

The Municipal Intake daily average flows were obtained from CDEC for station FOL (Discharge Pumping) for the complete calibration period (2001-2011).

The Municipal Intake water temperature and reservoir withdrawal TCD elevation data were obtained from daily operation logs available from January 2006 through December 2011[2]. The logs contained a daily recording of the Municipal Intake TCD gate elevation, measured intake temperature, and reservoir WSE. In order to estimate the water temperature and elevation of the Municipal Intake TCD during 2001-2005, the general operation pattern observed in the 2006-2011 data was used. In 2006-2011, the Municipal Intake TCD was generally operated about 50 feet below the reservoir WSE (approximately the 65°F temperature withdrawal zone in the summer) or at the maximum or minimum TCD elevation when “50 feet below WSE” was out of range of the Municipal Intake TCD. A “test” of the relative accuracy of the “50 feet below WSE” rule using the 2006-2011 temperature data is shown in Figure 23.

Low Level River Outlet Gates - Flows

Daily average low level river outlet flows were obtained from the CDEC FOL station (Control Regulating Discharge) for the complete calibration period (2001-2001). The flows were converted to hourly values.

Spillway Gates - Flows

[2] Data sheets provided by the Folsom Dam operator, Marlon Premo (Reclamation), to Craig Addley (Cardno) July 20, 2012.

Daily average spillway flows were obtained from the CDEC FOL station (Spillway Discharge) from the complete calibration period (2001-2011). The flows were converted to hourly values.

Power Generation Penstock - Flows and Shutter Elevations

Daily average flows for each power generation penstock and daily TCD configuration records were obtained for the years 2001 – 2011 from Reclamation[3] and are shown in Figure 24.

Hourly power generation flows were calculated using a flow mass balance approach based on the CDEC FOL station data sets. Hourly power generation was calculated by subtracting daily average Discharge Pumping, daily average Spillway Discharge, and daily average Control Regulating Discharge from the hourly Reservoir Outflow data set. The calculation used the assumption that the flows for the Municipal Intake, spillway and low level outlets were generally constant over the period of a day[4]. Also, the hourly power generation data indicated that each penstock has a leakage rate of approximately 7 cubic feet per second (cfs) when offline; therefore, the minimum power generation flow through the three penstocks was assumed to be 21 cfs.

El Dorado Irrigation District Diversion - Flows

Monthly EID diversion volumes (acre-feet per month) from Folsom Reservoir were available for 2001-2011 (EID 2005, 2007, 2012). The data were obtained from the 2005, 2007 and 2012 EID Water Division reports (Table 11). The monthly volumes were converted into cubic meters per second for modeling purposes.

3.6 AUTOMATIC MODEL SIMULATION TOOLS

Three custom CE-QUAL-W2 model tools were developed (Automatic Municipal Intake Elevation, Automatic Shutter Operations, and Automatic Temperature Schedule Selection) and tested using boundary condition and MET data from the 2001-2011 calibration time period. The three model tools are discussed below.

3.6.1 Automatic Municipal Intake Elevation

The Municipal Intake TCD, based on data recorded between 2006 and 2011, was generally operated to extract water at approximately 18^{o}C (≤65^{o}F) within the maximum and minimum operating constraints of the TCD (See Attachment C). The capability was built into the CE-QUAL-W2 model to allow the modeler to specify general constraints: (1) automatic target temperature water extraction (65^{o}F, typically); (2) maximum and minimum inlet elevations (see Table 3); and (3) minimum inlet elevation below WSE (8.23 meters, typically).

[3] Data provided by Russell Yaworsky (Reclamation) to Craig Addley (Cardno) by email dated June 20, 2012.

[4] In cases where the subtraction resulted in a negative value, the Municipal Intake flows was reduced that hour by an appropriate amount and mass balance for the day was maintained by adjusting the Municipal Intake flow during other hours of the day.

In addition to these constraints, operation rules were developed in the code including the following:

1. On March 1st of each model year, the elevation of the intake is raised as high as possible given the WSE constraint.
2. If not raised to the maximum on March 1st, the model continues checking on a daily basis until the intake can be raised to maximum elevation possible in a given year.
3. If the temperature criteria are violated, the intake is lowered in one meter increments until water temperature meets the criteria.
4. The model continues lowering the intake elevation as dictated by the temperature criteria until December 1st of each model year, or until the minimum water intake elevation is reached.

3.6.2 Automatic Shutter Operations

A power penstock TCD shutter algorithm and set of operational rules were set up to apportion flow through each of the power generation penstocks and determine when TCD shutters needed to be raised or lowered in order to meet the Folsom Dam release temperature target. The release target is back-calculated using a regression equation (see below) from the ATSP schedule at Watt Avenue (or more generally from any location in the river) (Section 3.6.3 below). The automated code calculates the percent flow for each penstock and the elevation of each shutter given the following constraints:

1. The minimum and maximum flow through each powerhouse; and
2. A minimum shutter elevation of 8.23 meters below the WSE at any time; otherwise the shutter elevation would be lowered to next lowest level.

When all shutters are at their lowest level and the release temperature target is still not being met, the model is set up to allow “coldwater power bypass” flow releases from low level river outlets at the bottom of the dam (i.e., access cold water in the reservoir below the power intake elevation). The “coldwater power bypass” can be constrained to allow operation only after a user-specified date each year and with a user-specified maximum flowrate (i.e., to mimic actual operations as appropriate).

In order to determine the temperature criteria to be met at the dam outflow, a temperature regression was developed to relate outflow temperatures from Folsom Reservoir to downstream river temperatures at Hazel Avenue and Watt Avenue. These regressions were developed on a daily average basis and the parameters included daily average flow, air temperature, and Folsom Dam release temperature. A detailed explanation of the regression techniques can be found in Technical Memorandum 9, entitled Lower American River Water Temperature Regression Relationships. In addition, a general regression equation that works at any location in the river is available (Technical Memorandum 9, Lower American River Water Temperature Regression Relationships).

3.6.3 Automatic Temperature Schedule Selection

An ATSP (Water Forum 2004, Water Forum 2006) algorithm was developed that allowed the model to automatically converge on the coldest ATSP temperature schedule that could be met each year given specified flow releases and MET data. The model user provides 78+ target temperature “schedules” for Folsom Dam releases ranging from coolest (#1) to warmest (#78). These target temperature “schedules” are back-calculated using the previously mentioned regression based on the ATSP temperature schedules at the Watt Avenue (or any other location in the river). Table 12 shows the ATSP schedules (Water Forum 2004, Water Forum 2006) for Watt Avenue (note: the ATSP schedules are expanded to a higher temperature range than in the original documents). The CE-QUAL-W2 model starts with the schedule identified as the “best guess.” The model then proceeds to use either a bisection approach (Method 1) or a 2-step technique (Method 2), according to the modeler user’s preference (Figure 25). Method 1 starts by running the initial best guess temperature schedule. If this schedule is exceeded, the model proceeds to a temperature target that is half way between the original run and the upper confidence bound (also an input set by the modeler). It proceeds upwards or downwards using bisection until a schedule is found that does not exceed the target. The model will check to see if a cooler target exists that has not been attempted before determining the final schedule. Method 2 uses a 2-step method to step up or step down (in the case of a non-exceedance) until it converges on the final schedule. It will then check one schedule higher or lower to guarantee the most efficient schedule has been identified. The decision process for methods 1 and 2 for a hypothetical scenario of a starting guess of 40 and a final solution of 45 is shown in Figure 25. Both methods share the same general logic for running the model, which is shown in Figure 26. Method 1 is the fastest approach if a good guess of the best ATSP schedule is not available. Method 2 is the fastest algorithm if an accurate estimate of the best ATSP schedule is available.

4.0 CE-QUAL-W2 MODEL PERFORMANCE

A calibration process was used to develop the final Folsom Reservoir CE-QUAL-W2 water temperature model. This process included the comparison of modeled flows/reservoir WSEs and water temperature (in-reservoir and lower American River) to measured data for the 2001-2011 time period. Model input parameters were then iteratively adjusted such that the modeled reservoir WSEs and water temperatures matched measured data as closely as possible. The flow/WSE and water temperature calibration process and model results are each discussed in the following sections.

4.1 MODEL CALIBRATION / VALIDATION APPROACH

4.1.1 Flow/Water Surface Elevation

Flow calibration involved matching measured and modeled Folsom Reservoir WSEs throughout the model calibration period. The exact WSE cannot be maintained simply by running the model with the historical inflows and outflows due to various uncertainties or estimations in the data, including ungaged inflows, evaporation, instrument error, interaction with groundwater, and possible leakage.

Folsom Reservoir WSE data were obtained from the CDEC-FOL gage. Inflow and outflow data were obtained from the sources described in the previous sections. In order to determine the Folsom Reservoir unknown volume gain or loss on a daily basis, the model was run with the known boundary conditions and then a water balance was carried out to determine how much water had to be added or subtracted to match the historical WSE. After several iterations of this process, the final WSE was obtained (Figure 27). The water balance flow was then added into the model as a distributed tributary (this is the typical CE-QUAL-W2 water balancing approach).

4.1.2 Water Temperature Calibration Methods

Minimal calibration was necessary in order to achieve tight model versus historical water temperature data agreement. Model uncertainty primarily resulted from the wind data, leakage flow through the powerhouse shutters, and the estimation of the light extinction coefficient. Water temperature calibration comparisons were based on measured and modeled Folsom Reservoir water temperature profiles and lower American River water temperatures throughout the calibration period (2001-2011).

A total of 185 in-reservoir temperature profiles were collected between January 1st, 2001 and December 31st, 2011, in two to four week intervals[5]. A map of the location of the temperature profile sites is shown in Figure 28, with additional site details summarized in Table 13. An example of the temperature profiles collected is shown in Figure 29. These profiles were collected on 7/16/2001 at all six profile measurement sites. Water temperature profiles for the calibration period 2001-2011 are shown in detail in Attachment D.

The USGS-maintained American River below Folsom Dam (AFD) gage (Table 14) is the nearest location for historical water temperature data below Folsom Reservoir. Prior to September 2009, the gage was located immediately below Folsom Dam. In September 2009, the gage was moved 1-mile downstream to its current location as shown in Figure 30. This change in location may have affected temperature recordings sufficiently to make direct comparison to model outflow temperatures less valid. Only data prior to September 2009 were used when calculating model vs. data statistics.

Daily average percent flow through each powerhouse was used for calibration and all powerhouses were assumed to be powered on and off at the same time. Hourly powerhouse flow data were not available to us; therefore, it was not possible to reproduce the hourly downstream temperature pattern during the model calibration period.

Most of the wind data were obtained from MET stations not located on Folsom Reservoir and, therefore, are not completely representative of conditions on the surface of Folsom Reservoir. In order to account for this and to improve the modeled temperature profiles, a wind sheltering coefficient (WSC) of between 1.1 (2001-2003) and 1.2 (2004-2011) was used over the calibration period.

[5] Data provided by Russell Yaworsky (Reclamation) to Craig Addley (Cardno) by email dated June 20, 2012.

Average leakage through the powerhouse shutters was determined to be approximately 35% based on several test model runs that were used to calibrate modeled versus measured downstream water temperatures. In the model, the leakage flow was assumed to be pulled out at the level of the power generation penstocks.

Secchi disk data collected in 1979 were used to estimate the average light extinction coefficient (Shay 1979). Calculations show that the light extinction coefficient varied from 0.3 to 0.7 per meter, with an average value close to the CE-QUAL-W2 default value of 0.45 per meter. The CE-QUAL-W2 default value of 0.45 per meter was used in the modeling.

4.2 MODEL WATER CALIBRATION RESULTS

Model versus measured data comparisons for in-reservoir temperature profiles and the lower American River water temperature were computed. The absolute mean in-reservoir profile error averaged 1^{o}F (0.55^{o}C) with a bias of almost zero for all profile stations. The profile error statistics are summarized in

Table 15. A representative visual comparison of two temperature profiles (August 2002 and October 2007) is shown in Figure 31. A complete record of all calibration period temperature profile data versus model comparisons can be found in Attachment E. A summary comparison of all of the modeled versus empirical measurements over the 10-year calibration period is shown in Figure 32 (R^2 0.996, slope 1.002).

The flow weighted absolute mean error for modeled versus measured water temperature below Folsom Dam was less than 1.08^{o}F (0.6^{o}C) for the calibration period. A time series plot of modeled versus measured water temperature is provided in Figure 33 and error statistics are shown in Table 16.

4.3 MODEL VALIDATION

A model validation period in 2016 was chosen to test the performance of the temperature model outside of the calibration period (2003-2011). Model input and boundary condition data including inflows, inflow water temperature, meteorological data, shutter operations, and outflows were collected from the same sources as were used for the original calibration period. The model was set up and run using the same settings as the original calibration period.

The initial temperature starting condition was set based on a measured reservoir water temperature profile collected on 6/13/2016. Data from 6/13/2016 through 11/10/2016 were then used to validate the model. Temperature data from temperature profiles collected at Folsom Dam, below Folsom Dam in the American River, and downstream at Watt Avenue were all compared to model output for the same period. Although calibration settings remained unchanged, the leakage rate was adjusted through the season as the reservoir elevation declined and shutters were reconfigured. As would be expected, the adjusted leakage rate was higher when the reservoir elevation was high (more shutter sections in place) and lower as the reservoir elevation declined (less shutter sections in place). The adjusted leakage started at 38%, and declined to 30%, and then 20% as additional shutters were removed (Figure 34).

The flow weighted average daily model vs. observed water temperature comparison immediately below Folsom dam had a mean error of -0.17°F (-0.09°C) and an absolute mean error of 0.51°F (0.28°C) A slight cold bias was observed in the fall of 2016. Modeled water temperatures were slightly colder in the modeled hypolimnion than in the measured data in the fall (Figure 35).

4.4 EXAMPLE MODEL OPTIMIZATION

An example of the automated temperature model results for 2008 is compared to actual historical operations in Figure 36. Compared to actual operations, the model code optimized lower American River water temperature at Watt Avenue by releasing slightly warmer water earlier in the summer and maintaining significantly cooler temperatures later season. Generally, when the model is operated in "optimization mode," partly because of perfect foresight, the model produces operations that result in cooler temperatures over historical operations.

5.0 CONCLUSIONS

Using extensive flow, water temperature, and MET empirical data from 2001 to 2011, a fully calibrated CE-QUAL-W2 model of Folsom Reservoir was developed. This model performed very well when compared to historical in-reservoir temperature profile and downstream release temperature time series data, with absolute mean errors of less than 1.08°F (0.6°C) for both metrics. Model validation, using a 2016 data set showed that for a particular year, the assumed shutter leakage (affected potentially by the fit of shutters when placed together or by the configuration of the shutters, i.e., how many shutters are in place) can have an effect on the temperature model accuracy. The best accuracy was obtained by modifying the shutter leakage through the season as shutters were reconfigured.

The calibrated model includes a series of tools developed to allow complete automation of the powerhouse penstock and Municipal Intake TCDs and powerhouse penstock TCDs. These tools allow the model to be used for simulating much longer periods of record than the calibration period (e.g.. 1922-2003 typical CalSim II modeling period) and allow the model to be used to compare different flow scenarios (e.g., historical or future). Specifically, the model is designed to both help guide Folsom Dam water temperature operations (as needed) and to perform impact analyses of alternative hydrologic or dam operations.

6.0 ACKNOWLEDGEMENTS

We appreciate the cooperation and calibration data sets provided by Reclamation. We also were greatly benefitted by Chris Hammersmark, CBEC Inc., sharing Folsom Reservoir modeling knowledge related to his use of the 1D Iterative Coldwater Pool Management Model (iCPMM).

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8.0 TABLES

Table 1. Folsom Reservoir Model Grid Details.

Number of water bodies	1
Number of branches	3
Number of segments	191
Minimum grid elevation	191 ft (58.2 m)
Maximum grid elevation	491.2 ft (149.72 m)
Number of layers	152
Layer thickness	2 ft (0.61 m)
Latitude	38.705
Longitude	-120.0

Table 2. Folsom Reservoir Model Branch Details.

Branch Number	Number of Active Segments	Upstream Active Segment	Downstream Active Segment	Centerline Length of Branch	Average Segment Length
1	104	2	105	16.2 miles (26120 m)	824.0 ft. (251.16 m)
2	71	108	178	10.9 miles (17608 m)	824.8 ft. (251.56 m)
3	10	181	190	1.7 miles (2678 m)	878.6 ft. (267.8 m)

Table 3. Description of Folsom Dam Outlets (Note: mixed units feet and meters are used).

Outlet Description[1]	Shape	Dimension (ft)		Monolith	Horizontal Centerline Coordinates[2] (m)		Elevations[3] (ft)						
							Unshuttered		Shuttered Configurations				
					X	Y	Centerline[4]	Invert	A = All Lowered	U = Upper Raised	M = Middle Raised	L = Lower Raised	O = Unit Offline
Municipal Water Supply Intake													
Municipal	Circle	d = 7.0		7	660264	4285826	317.0	313.5	Max 401 ft - Min 331.5 ft (Gate can be anywhere within this range)				
Power Generation Penstock Outlets													
Power Penstock #1	Circle	d = 15.5		8	660290	4285811	307.0	299.25	401.0	362.0	336.0	284.0	N/A
Power Penstock #2	Circle	d = 15.5		9	660304	4285804	307.0	299.25	401.0	362.0	336.0	284.0	N/A
Power Penstock #3	Circle	d = 15.5		10	660317	4285796	307.0	299.25	401.0	362.0	336.0	284.0	N/A
River Outlet Gates													
Rectangular River #1 (Upper)	Rectangle	w = 5.0	h = 9.0	13	660358	4285771	280.0	275.5	NA				
Rectangular River #1 (Lower)	Rectangle	w = 5.0	h = 9.0	13	660358	4285771	210.0	205.5					
Rectangular River #2 (Upper)	Rectangle	w = 5.0	h = 9.0	14	660370	4285764	280.0	275.5					
Rectangular River #2 (Lower)	Rectangle	w = 5.0	h = 9.0	14	660370	4285764	210.0	205.5					
Rectangular River #3 (Upper)	Rectangle	w = 5.0	h = 9.0	15	660383	4285757	280.0	275.5					
Rectangular River #3 (Lower)	Rectangle	w = 5.0	h = 9.0	15	660383	4285757	210.0	205.5					
Rectangular River #4 (Upper)	Rectangle	w = 5.0	h = 9.0	16	660396	4285750	280.0	275.5					
Rectangular River #4 (Lower)	Rectangle	w = 5.0	h = 9.0	16	660396	4285750	210.0	205.5					
Spillway Gates													
Spillway Gate 1	Radial Gate	w = 42.0	h = 50.0	12-13	660351	4285774	NA	418.0	NA				
Spillway Gate 2	Radial Gate	w = 42.0	h = 50.0	13-14	660364	4285767	NA	418.0					
Spillway Gate 3	Radial Gate	w = 42.0	h = 50.0	14-15	660377	4285760	NA	418.0					
Spillway Gate 4	Radial Gate	w = 42.0	h = 50.0	15-16	660390	4285753	NA	418.0					
Spillway Gate 5	Radial Gate	w = 42.0	h = 50.0	16-17	660402	4285746	NA	418.0					
Spillway Gate 6	Radial Gate	w = 42.0	h = 50.0	17-18	660415	4285739	NA	418.0					
Spillway Gate 7	Radial Gate	w = 42.0	h = 50.0	18-19	660428	4285732	NA	418.0					
Spillway Gate 8	Radial Gate	w = 42.0	h = 50.0	19-20	660441	4285724	NA	418.0					

[1]Outlets are numbered from North to South (Furthest North = 1).
[2]X and Y Coordinates are UTM 10 NAD 27 (meters) and correspond directly with TIN/contour data.
[3]Elevations are UTM NAD 27 (feet) and correspond to engineering drawings.
[4]Municipal water supply outtake at centerline elevation only when water surface elevation is below 351.5 ft, otherwise see range for shutter configurations.

Table 4. Summary Table of Outlet Structure Elevations for Folsom Dam.

Outlet Structure	Position 1	Position 2	Position 3	Position 4[1]
Power Generation Penstock 1	409.8 ft (124.9 m)	371 ft (113.1 m)	344.8 ft (105.1m)	307 ft (93.6 m)
Power Generation Penstock 2	409.8 ft (124.9 m)	371 ft (113.1 m)	344.8 ft (105.1m)	307 ft (93.6 m)
Power Generation Penstock 3	409.8 ft (124.9 m)	371 ft (113.1 m)	344.8 ft (105.1 m)	307 ft (93.6 m)

[1] Note: The elevation of the position 4 powerhouse shutters corresponds to the centerline elevation of the power generation penstocks (307 ft [93.6 m]), not the elevation of the bottom of the lowest shutter (284 ft [86.5 m]).

Table 5. Summary of River Outlet Use (2001-2014)

Parameter/Units		Average	Year							
			2001	**2002**	**2007**	**2008**	**2009**	**2012**	**2013**	**2014**
Start Date		11/01	11/10	10/25	11/09	11/10	11/10	10/22	10/28	10/20
End Date		11/25	11/26	11/19	11/29	11/28	11/25	11/24	11/27	11/25
Total Days		25	17	26	21	19	16	34	31	37
Daily Average	cfs	439.2	507.2	513.8	320.9	478.4	466.3	350.1	422.0	455.1
	TAF	0.871	1.006	1.019	0.637	0.949	0.925	0.694	0.837	0.903
Annual Sum	TAF	21.594	17.104	26.498	13.367	18.030	14.797	23.608	25.948	33.402
Daily Minimum	cfs	171.8	352.0	331.0	94.0	171.0	166.0	171.0	16.0	73.0
	TAF	0.341	0.698	0.657	0.186	0.339	0.329	0.339	0.032	0.145
Daily Maximum	cfs	516.1	522.0	550.0	436.0	554.0	544.0	517.0	508.0	498.0
	TAF	1.024	1.035	1.091	0.865	1.099	1.079	1.025	1.008	0.988

Source: Data provided by Jesse Barker (CBEC) to Vanessa Martinez (Cardno) by email dated 05/26/2015.

Table 6. Summary of Meteorological Stations Used to Compile Calibration Period Met Data.

MET Station and Parameter	Station ID	Location Lat.	Location Long.	Elevation	Distance from Folsom Dam	Frequency of Data Collection	Source Location
Fair Oaks							
• Air temperature • Dew point temperature • Wind speed and direction (only when no other data available) • Solar radiation	CIMIS-131	38.65	121.21	265 ft. (80.8 m)	8 miles (12.7 km)	15-minute	http://mesowest.utah.edu/ (Requires login to access historical data)
Folsom/Dyke 8							
• Wind speed and direction	FSLC1	38.692	121.13	551 ft. (167.9 m)	< 0.5 miles (< 1 km)	15-minute	http://mesowest.utah.edu/ (Requires login to access historical data)
	FLD	38.7	121.16	350 ft. (106.7 m)	0.75 miles (1.24 km)	15-minute	http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=FLD
Mather Air Force Base							
• Wind speed and direction • Cloud cover	KMHR	38.56	-121.3	96 ft. (29.29 m)	14 miles (22.6 km)	Hourly	http://gis.ncdc.noB.gov/map/viewer/#app=cdo

CIMIS: California Irrigation Management Information Center

Table 7. Fair Oaks Wind Speed Multipliers.

Range of Fair Oaks Wind, m/s	Multiplier
0-3	1.92
3-5	1.74
5-6	1.58
> 6	1.41

Table 8. Mather AFB MET Station Cover Code Summary.

Code	Sky Condition	Cloud Cover Value
SKC	Clear	0.0
FEW	Few	1.9
SCT	Scattered	4.4
BKN	Broken	7.5
OVC	Overcast	10.0

Table 9. Data Sources for Summary Folsom Reservoir Inflow and Water Temperature.

Name	Data Collected	Operator	Station No.	Location		Frequency
				Lat.	Long.	
North Fork American River						
NF AMERICAN R A NORTH FORK DAM CA	Flow	USGS	11427000	38.936	121.022	Hourly
NF AMERICAN R AUBURN DAM NR AUBURN	Water Temperature	USGS/CDEC	11433790/ CDEC-NFA	38.883	121.061	Hourly
MF AMERICAN R NR FORESTHILL CA	Flow	USGS	11433300	39.006	120.759	Daily
South Canal						
NEWCASTLE PP NR NEWCASTLE CA	Flow	USGS	11425416	38.835	121.091	Daily
	Water Temperature	PCWA	Various locations			Variable
MORMON RAVINE NR NEWCASTLE CA	Flow	USGS	11433930	38.836	121.093	Daily
South Fork American River						
SF AMERICAN R NR PILOT HILL CA	Water Temperature	USGS	11446030	38.763	121.007	Hourly
SF AMERICAN R NR PLACERVILLE CA	Flow	USGS/CDEC	11444500/ CDEC-CBR	38.771	120.815	Hourly

Table 10. Sources for Model Outflow and Operational Data.

Operator/ Source	Data Type	Gage No.	Data Frequency
Municipal Water Supply Intake			
CDEC	Flow	CDEC-FOL	Hourly
Reclamation	Temperature	Operation Logs	Daily
Low Level River Outlet Gates			
CDEC	Flow	CDEC-FOL (control regulating discharge)	Daily
Spillway Gates			
CDEC	Flow	CDEC-FOL – sensor 71 (spillway)	Daily
Power Generation Penstocks			
CDEC	Flow	CDEC-FOL- sensor 48 (discharge power generation)	Daily
Calculated[1]	Flow (calculated)		Hourly
CDEC	Temperature[2]	CDEC - AFD	Hourly
El Dorado Irrigation District			
EID Water Division Reports	Flow	EID records	Monthly volumes

[1] Hourly flow was calculated from hourly data from below Folsom Dam (CDEC-FOL [reservoir outflow]), daily average pumping data (CDEC-FOL sensor 70 [pumping discharge]), daily average spill data (CDEC-FOL sensor 71 [spillway]) and daily average bypass flow (CDEC-FOL [regulatory control device]).

[2]AFD records temperature of combined outflow from Folsom, including power penstock, spillway, and river outlets flows.

Table 11. Summary of Monthly El Dorado Irrigation District Diversion from Folsom Reservoir.

Month/Year	Monthly Volumes in Acre-Feet										
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
January	236	245	258	252	149	237	325	194	86	0	89
February	195	221	240	224	243	155	283	0	0	0	0
March	293	288	324	436	88	257	406	0	205	0	1
April	381	477	323	687	271	209	683	570	336	90	266
May	800	722	587	985	596	918	947	655	779	444	644
June	982	944	1062	1096	903	1128	1174	950	1009	911	690
July	1026	1156	1275	1230	1271	1298	1357	1114	1312	1288	976
August	1012	1135	1075	1202	1352	1206	1328	1092	1259	1271	1020

September	860	999	948	106 6	108 6	111 4	107 8	780	108 9	107 1	967
October	747	861	811	668	827	891	693	802	599	790	498
November	362	394	360	314	519	451	522	401	17	304	333
December	243	287	265	263	251	326	377	325	0	241	301

Table 12. ATSP Schedules for Water Temperature at Watt Avenue.

Schedule	May	Jun	Jul	Aug	Sep	Oct	Nov
1	63	63	63	63	63	56	56
2	63	63	63	63	63	57	56
3	63	63	63	63	63	58	56
4	63	63	63	63	63	59	56
5	63	63	63	63	63	60	56
6	63	63	63	63	63	60	57
7	63	63	63	63	63	60	58
8	63	63	64	63	63	60	58
9	63	63	64	64	63	60	58
10	63	63	64	64	64	60	58
11	63	64	64	64	64	60	58
12	64	64	64	64	64	60	58
13	64	64	65	64	64	60	58
14	64	64	65	65	64	60	58
15	64	64	65	65	65	60	58
16	64	65	65	65	65	60	58
17	65	65	65	65	65	60	58
18	65	65	65	65	65	61	58
19	65	65	65	65	65	62	58
20	65	65	65	65	65	63	58
21	65	65	65	65	65	64	58
22	65	65	65	65	65	65	58
23	65	65	65	65	65	65	59
24	65	65	66	65	65	65	59
25	65	65	66	66	65	65	59
26	65	65	66	66	66	65	59
27	65	66	66	66	66	65	59
28	66	66	66	66	66	65	59
29	66	66	67	66	66	65	59
30	66	66	67	67	66	65	59
31	66	66	67	67	67	65	59
32	66	67	67	67	67	65	59
33	67	67	67	67	67	65	59
34	67	67	68	67	67	65	59
35	67	67	68	68	67	65	59

36	67	67	68	68	68	65	59
37	67	68	68	68	68	65	59
38	68	68	68	68	68	65	59

Table 12. ATSP Schedules for Water Temperature at Watt Avenue.

Schedule	May	Jun	Jul	Aug	Sep	Oct	Nov
39	68	68	68	68	68	66	59
40	68	68	68	68	68	67	59
41	68	68	68	68	68	68	59
42	68	68	69	68	68	68	59
43	68	68	69	69	68	68	59
44	68	68	69	69	69	68	59
45	68	69	69	69	69	68	59
46	69	69	69	69	69	68	59
47	69	69	69	69	69	69	59
48	69	69	69	69	69	69	60
49	69	69	70	69	69	69	60
50	69	69	70	70	69	69	60
51	69	69	70	70	70	69	60
52	69	70	70	70	70	69	60
53	70	70	70	70	70	69	60
54	70	70	70	70	70	70	60
55	70	70	70	70	70	70	61
56	70	70	71	70	70	70	61
57	70	70	71	71	70	70	61
58	70	70	71	71	71	70	61
59	70	71	71	71	71	70	61
60	71	71	71	71	71	70	61
61	71	71	71	71	71	71	61
62	71	71	71	71	71	71	62
63	71	71	72	71	71	71	62
64	71	71	72	72	71	71	62
65	71	71	72	72	72	71	62
66	71	72	72	72	72	71	62
67	72	72	72	72	72	71	62
68	72	72	72	72	72	72	62
69	72	72	72	72	72	72	63
70	72	72	72	72	72	72	64
71	72	72	72	72	72	72	65
72	72	72	72	72	72	72	66
73	72	72	72	72	72	72	67
74	72	72	72	72	72	72	68
75	72	72	72	72	72	72	69
76	72	72	72	72	72	72	70
77	72	72	72	72	72	72	71
78	72	72	72	72	72	72	72

Table 12. ATSP Schedules for Water Temperature at Watt Avenue.

Schedule	May	Jun	Jul	Aug	Sep	Oct	Nov
79	72	72	73	72	72	72	72
80	72	72	73	73	72	72	72
81	72	72	73	73	73	72	72
82	72	73	73	73	73	72	72
83	73	73	73	73	73	72	72
84	73	73	73	73	73	73	72
85	73	73	73	73	73	73	73
86	73	73	74	73	73	73	73
87	73	73	74	74	73	73	73
88	73	73	74	74	74	73	73
89	73	74	74	74	74	73	73
90	74	74	74	74	74	73	73
91	74	74	74	74	74	74	73
92	74	74	74	74	74	74	74
93	74	74	75	74	74	74	74
94	74	74	75	75	74	74	74
95	74	74	75	75	75	74	74
96	74	75	75	75	75	74	74
97	75	75	75	75	75	74	74
98	75	75	75	75	75	75	74
99	75	75	75	75	75	75	75
100	75	75	76	75	75	75	75
101	75	75	76	76	75	75	75
102	75	75	76	76	76	75	75
103	75	76	76	76	76	75	75
104	76	76	76	76	76	75	75
105	76	76	76	76	76	76	75
106	76	76	76	76	76	76	76
107	76	76	77	76	76	76	76
108	76	76	77	77	76	76	76
109	76	76	77	77	77	76	76
110	76	77	77	77	77	76	76
111	77	77	77	77	77	76	76
112	77	77	77	77	77	77	76
113	77	77	77	77	77	77	77
114	77	77	78	77	77	77	77
115	77	77	78	78	77	77	77
116	77	77	78	78	78	77	77
117	77	78	78	78	78	77	77
118	78	78	78	78	78	77	77

Table 12. ATSP Schedules for Water Temperature at Watt Avenue.

Schedule	May	Jun	Jul	Aug	Sep	Oct	Nov
119	78	78	78	78	78	78	77
120	78	78	78	78	78	78	78
121	78	78	79	78	78	78	78
122	78	78	79	79	78	78	78
123	78	78	79	79	79	78	78
124	78	79	79	79	79	78	78
125	79	79	79	79	79	78	78
126	79	79	79	79	79	79	78
127	79	79	79	79	79	79	79
128	79	79	80	79	79	79	79
129	79	79	80	80	79	79	79
130	79	79	80	80	80	79	79
131	79	80	80	80	80	79	79
132	80	80	80	80	80	79	79
133	80	80	80	80	80	80	79
134	80	80	80	80	80	80	80
135	80	80	81	80	80	80	80
136	80	80	81	81	80	80	80
137	80	80	81	81	81	80	80
138	80	81	81	81	81	80	80
139	81	81	81	81	81	80	80
140	81	81	81	81	81	81	80
141	81	81	81	81	81	81	81

Table 13. Summary of Name and Location of Temperature Profiles Sites on Folsom Reservoir.

Site Name	Latitude	Longitude	Description
Site A	38°47.01' N	121°06.39' W	North Fork arm near Anderson Creek
Site B	38°44.19' N	121°05.63' W	Red Buoy in front of EID's intake, South Fork arm
Site C	38°44.00' N	121°08.69' W	North Fork arm off Mooney Ridge
Site D	38°42.76' N	121°07.31' W	South Fork arm off Mormon Island Dam
Site E	38°46.02' N	121°07.31' W	North Fork arm
Site Dam	38°42.54' N	121°09.32' W	White buoy in front of dam

Table 14. Summary of Name and Location of River Temperature Gages.

CDEC Gage Name	USGS Gage Number	Gage Location	Lat.	Long.
NFA	11433790	N FORK AMERICAN R AT AUBURN DAM	38.852	-121.057
ARP	11446030	SO FRK AMERICAN R NR PILOT HILL	38.763	-121.007
AFD	11446220	AMERICAN R BELOW FOLSOM DAM	38.688	-121.166
AHZ	-	AMERICAN R AT HAZEL AVE BRIDGE	38.636	-121.224
AFO	11446500	AMERICAN R AT FAIR OAKS	38.635	-121.227
AWP	11446700	AMERICAN RIVER AT WILLIAM B POND PARK	38.591	-121.332
AWB	11446980	AMERICAN RIVER BELOW WATT AVE BRIDGE	38.567	-121.387

Table 15. Temperature Profile Model Error Statistics.

Temperature Profile Model Segment	# of Profiles	# of Individual Temperature Observations	Mean Error °C	Absolute Mean Error °C	Root Mean Squared Error °C
TEMP 63	169	4430	0.09°F (-0.050 °C)	1.07°F (0.598 °C)	1.33°F (0.742 °C)
TEMP 72	154	4681	0.149°F (-0.083 °C)	1.084°F (0.602 °C)	1.389°F (0.772 °C)
TEMP 91	154	4873	0.09°F (0.050 °C)	0.983°F (0.546 °C)	1.235°F (0.686 °C)
TEMP 105	178	7191	0.079°F (-0.044 °C)	0.997°F (0.554 °C)	1.273°F (0.707 °C)
TEMP 151	154	4287	0.322°F (0.179 °C)	1.071°F (0.595 °C)	1.325°F (0.736 °C)
TEMP 169	171	5949	0.0594°F (0.033 °C)	0.931°F (0.517 °C)	1.174°F (0.652 °C)
Average overall statistics:			0.027°F (0.015 °C)	1.024°F (0.569 °C)	1.288°F (0.716 °C)

Table 16. Downstream Temperature Time Series Error Statistics.

Mean Error	Absolute Mean Error (AME)	Flow Weighted AME
0.56°F (0.31°C)	1.17°F (0.65°C)	1.04°F (0.58°C)

9.0 FIGURES

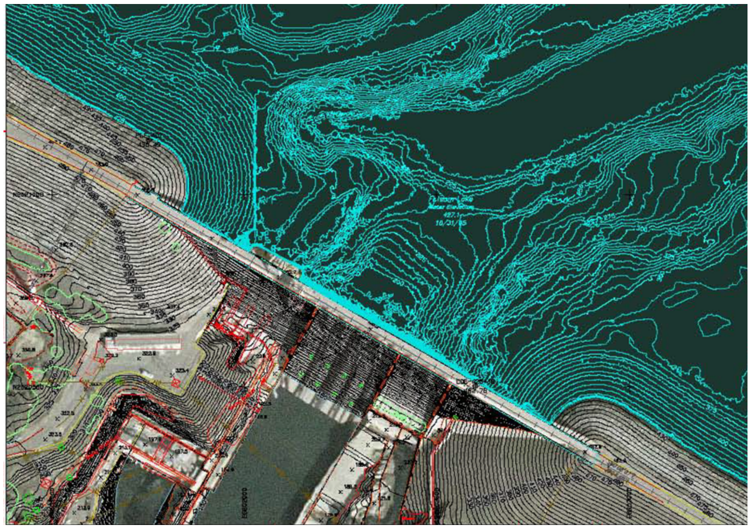


Figure 1. Example of Contour Elevations (Source: Ferrari 2007).

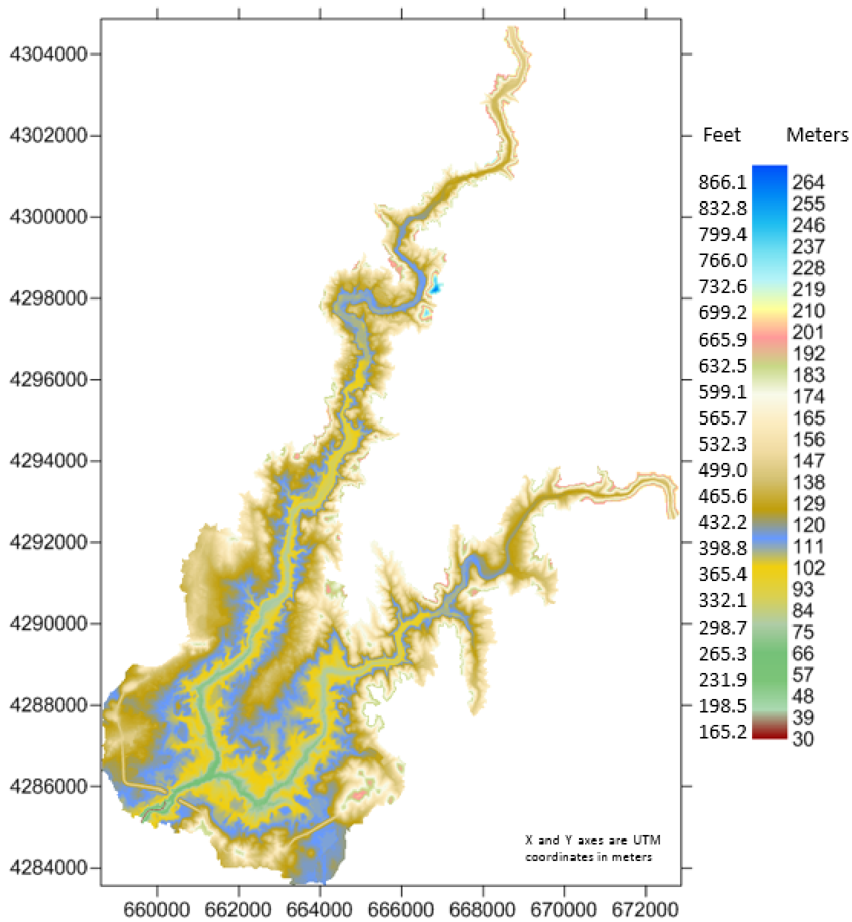


Figure 2. Elevation Contour Map of Folsom Reservoir.

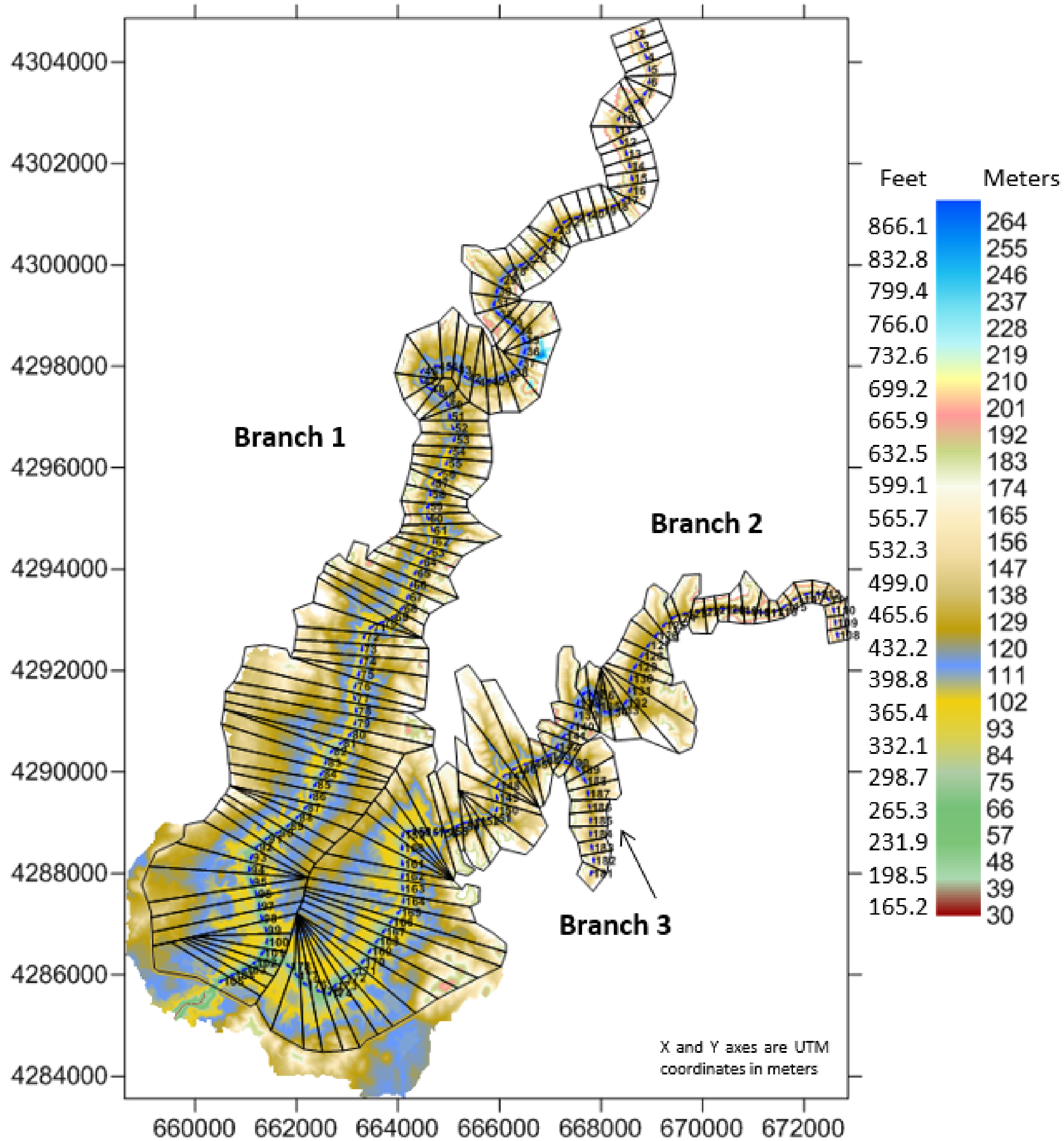


Figure 3. Folsom Reservoir Model Segments, Branches.

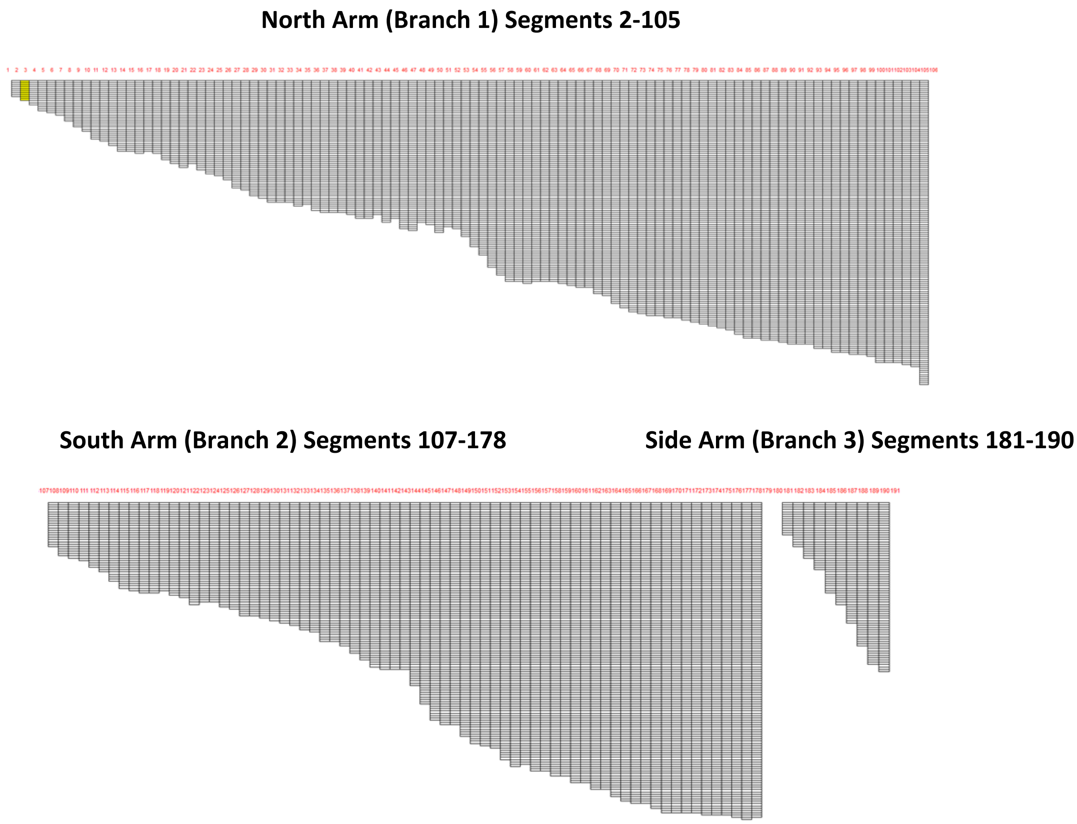


Figure 4. Model Configuration Showing Side-View of Model Grid.

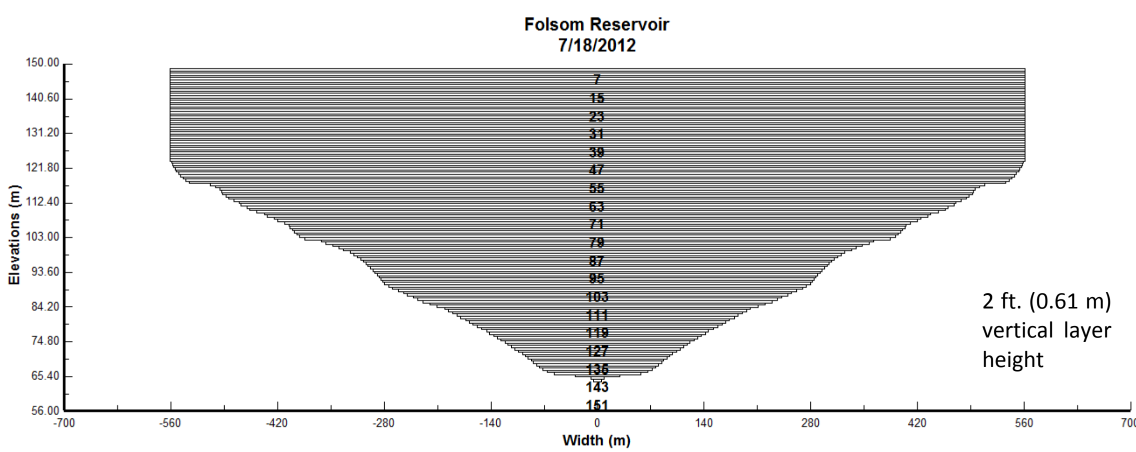


Figure 5. Model Configuration Showing Vertical Grid Layers (Segment 102).

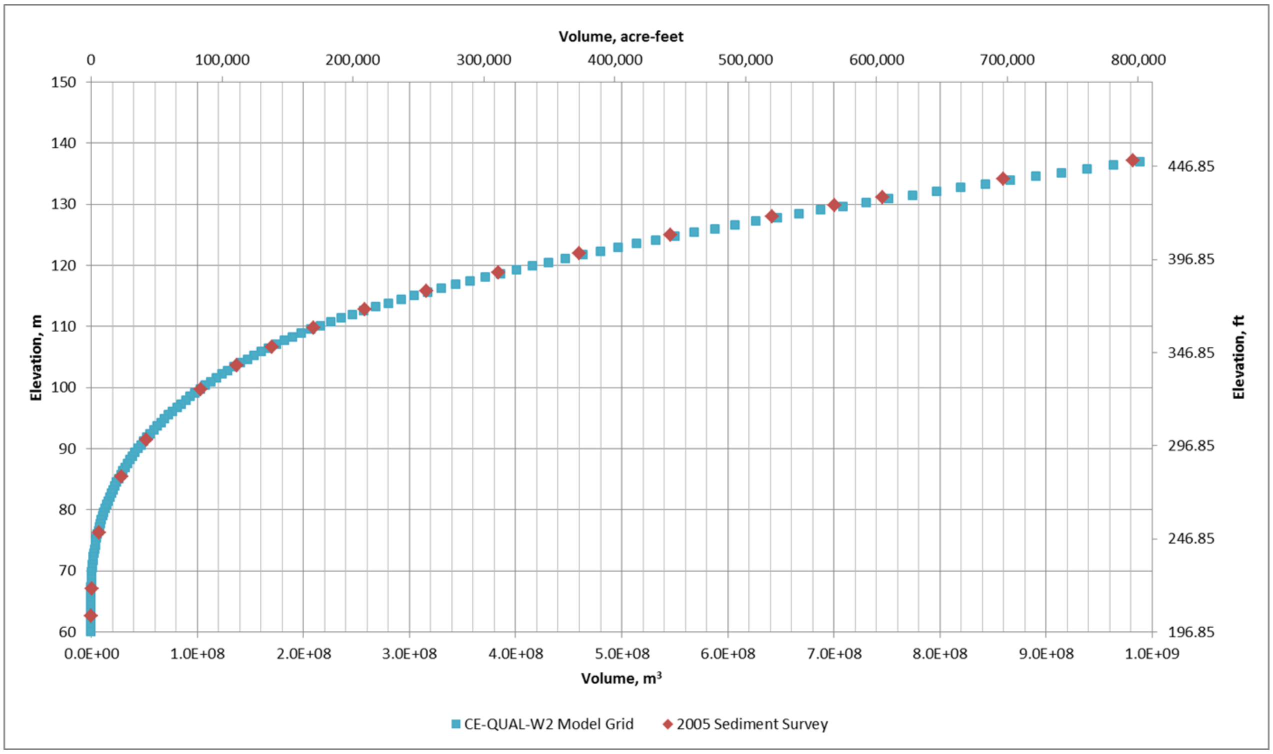


Figure 6. CE-QUAL-W2 Model Volume-Elevation Curve vs. 2005 Sediment Survey.

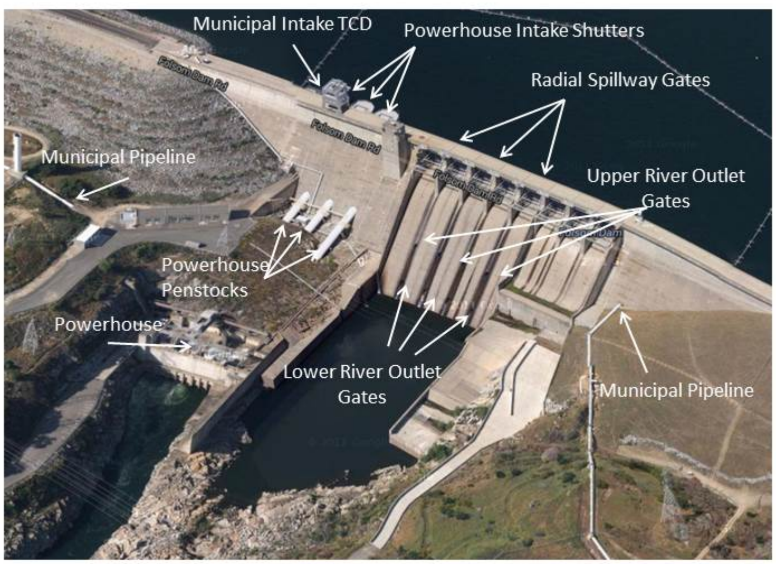


Figure 7. Folsom Dam Outlet Structures.

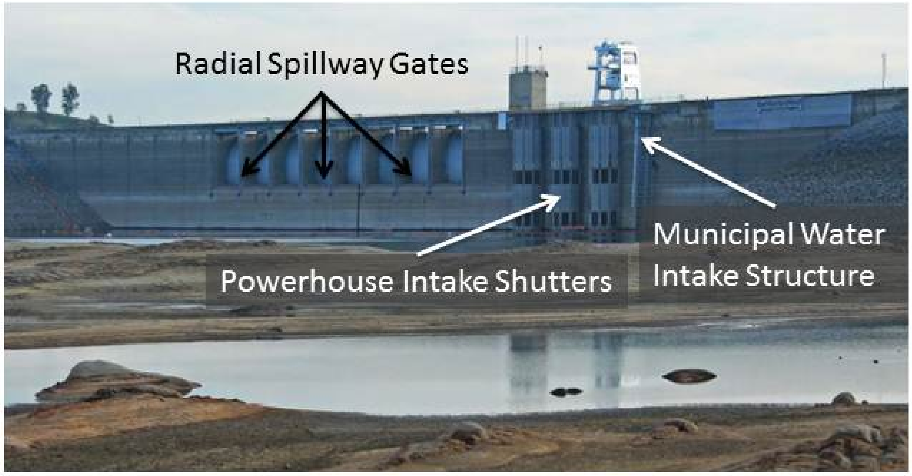


Figure 8. Upstream View of Folsom Reservoir Dam.

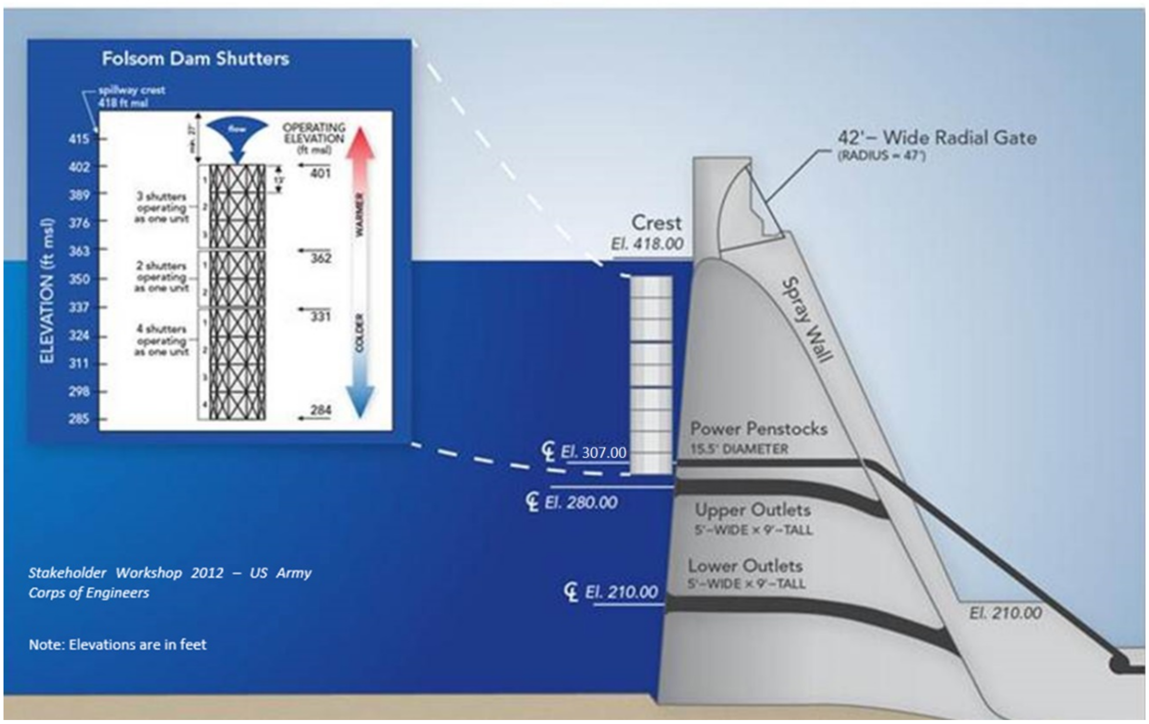


Figure 9. Side View Schematic of Folsom Dam Outlets and Shutters.

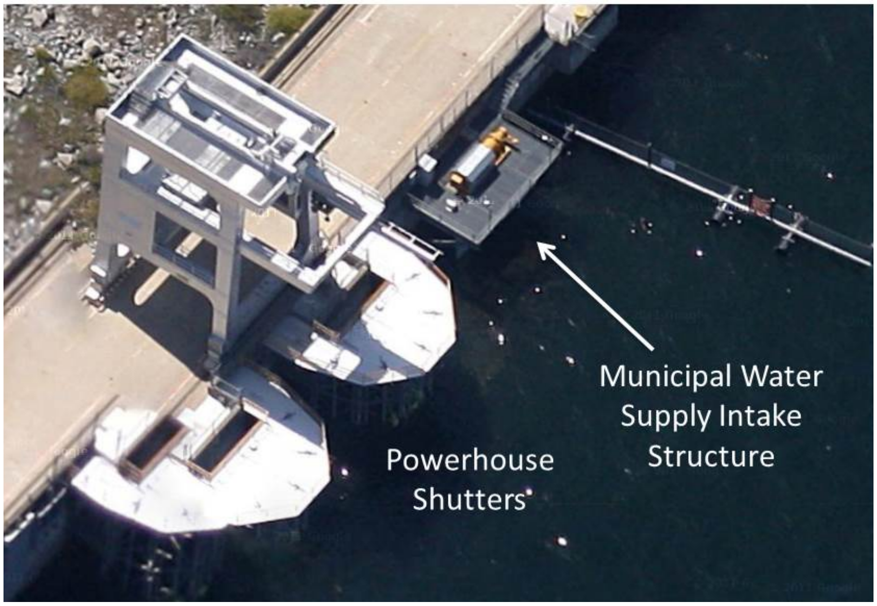


Figure 10. Location of Municipal Water Supply Intake Structure.

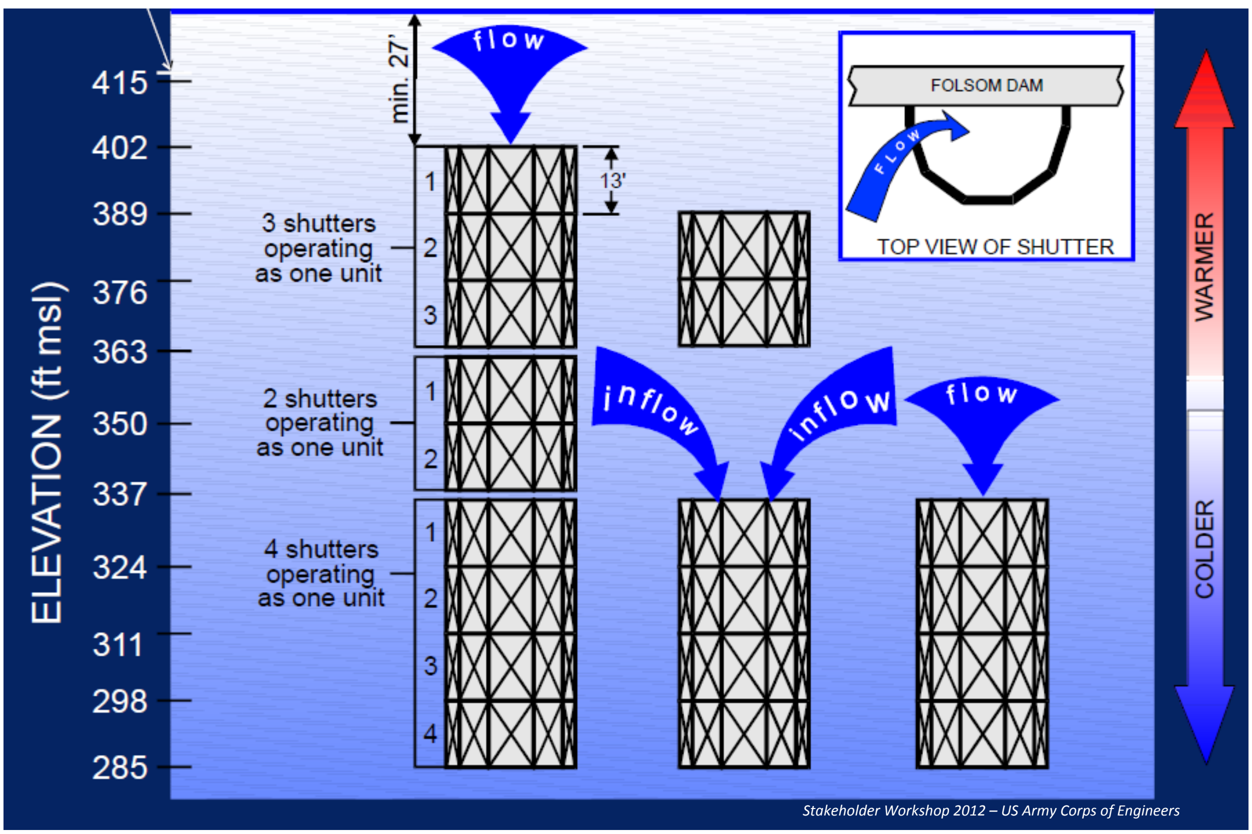


Figure 11. Powerhouse Shutter Schematic.

Figure 12. Powerhouse Intakes – Top of Shutters Showing.

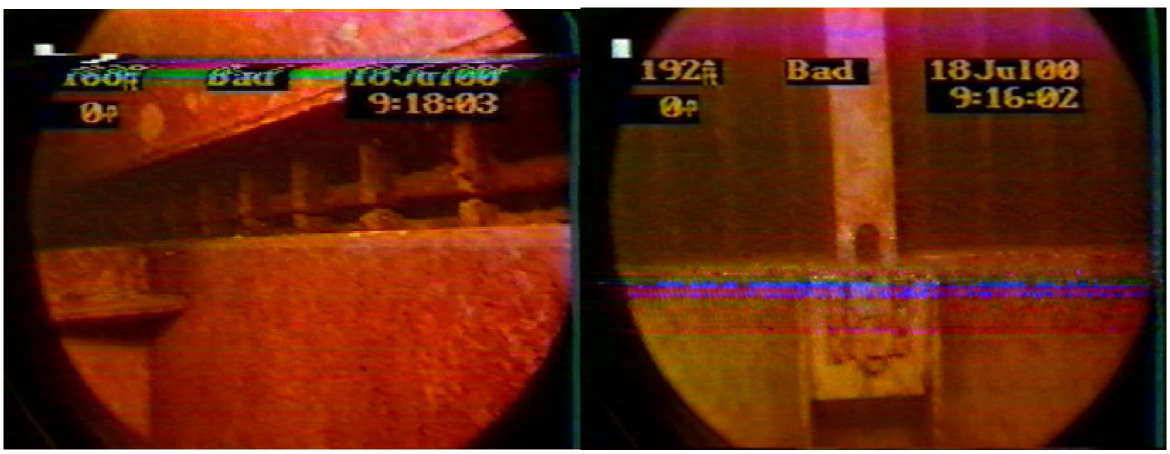


Figure 13. Photograph of Gaps in Submerged Shutters.

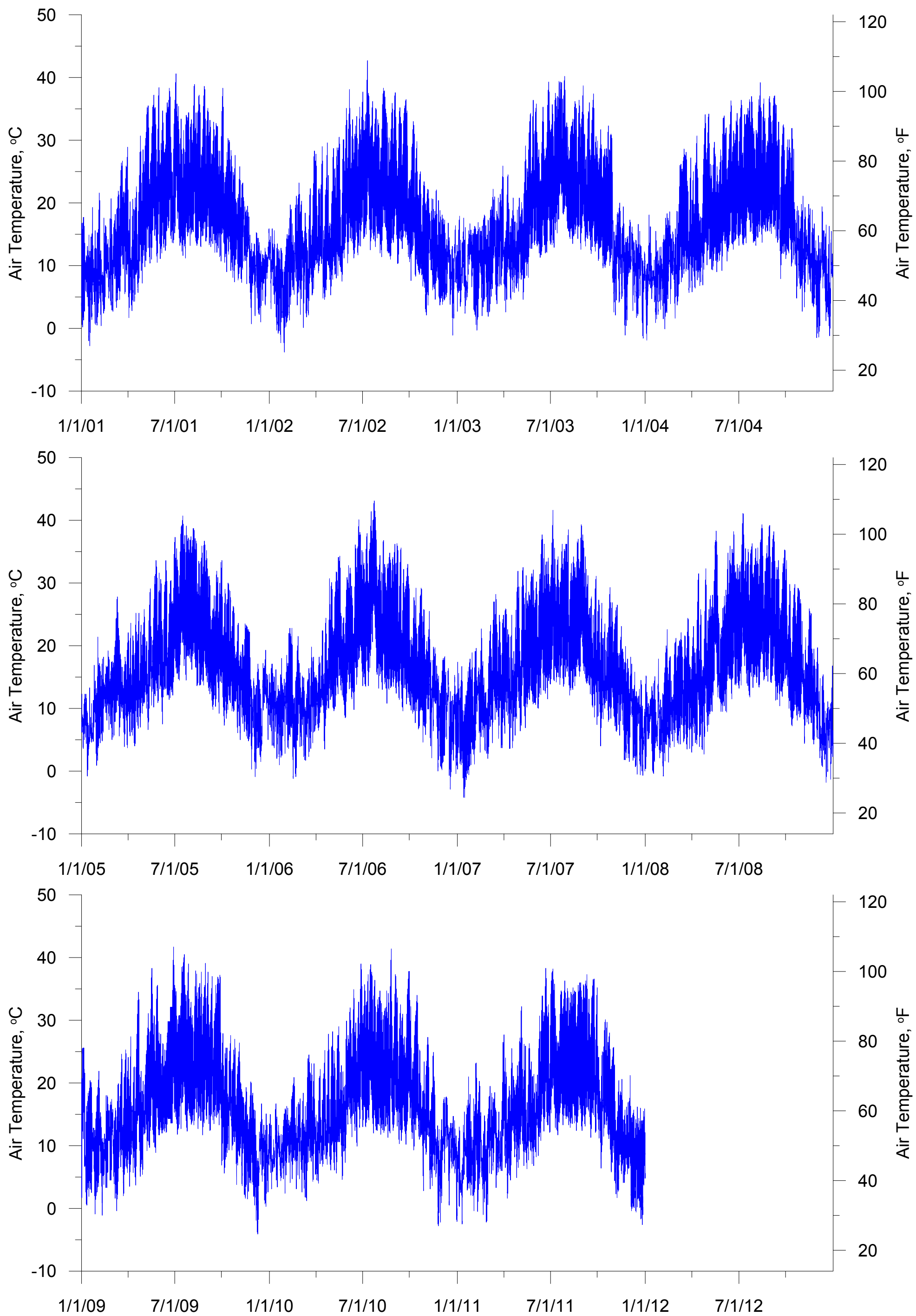


Figure 14. Fair Oaks Air Temperature, 2001-2011 (Station CIMIS-131).

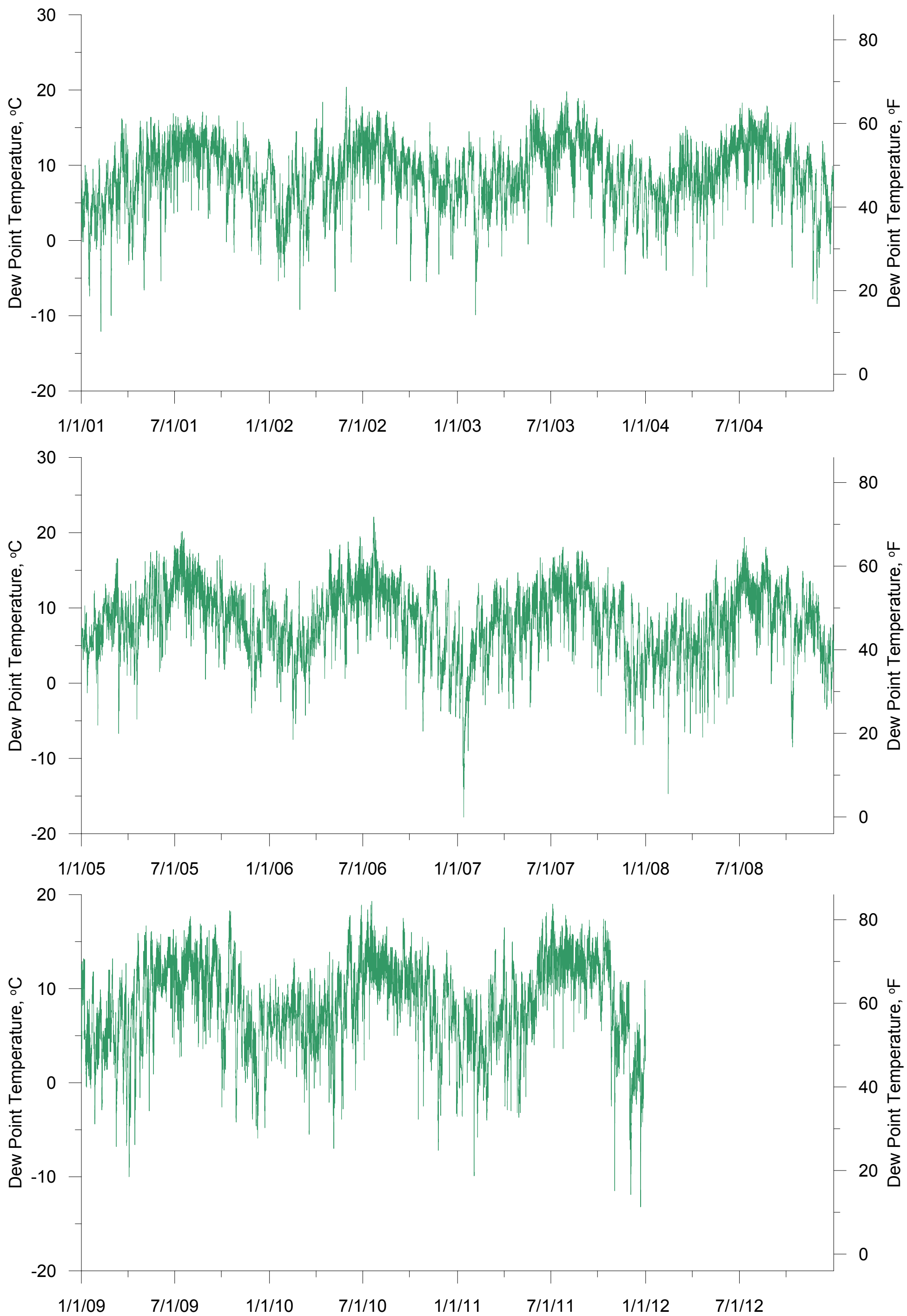


Figure 15. Fair Oaks Dew Point Temperature, 2001-2011 (Station CIMIS-131).

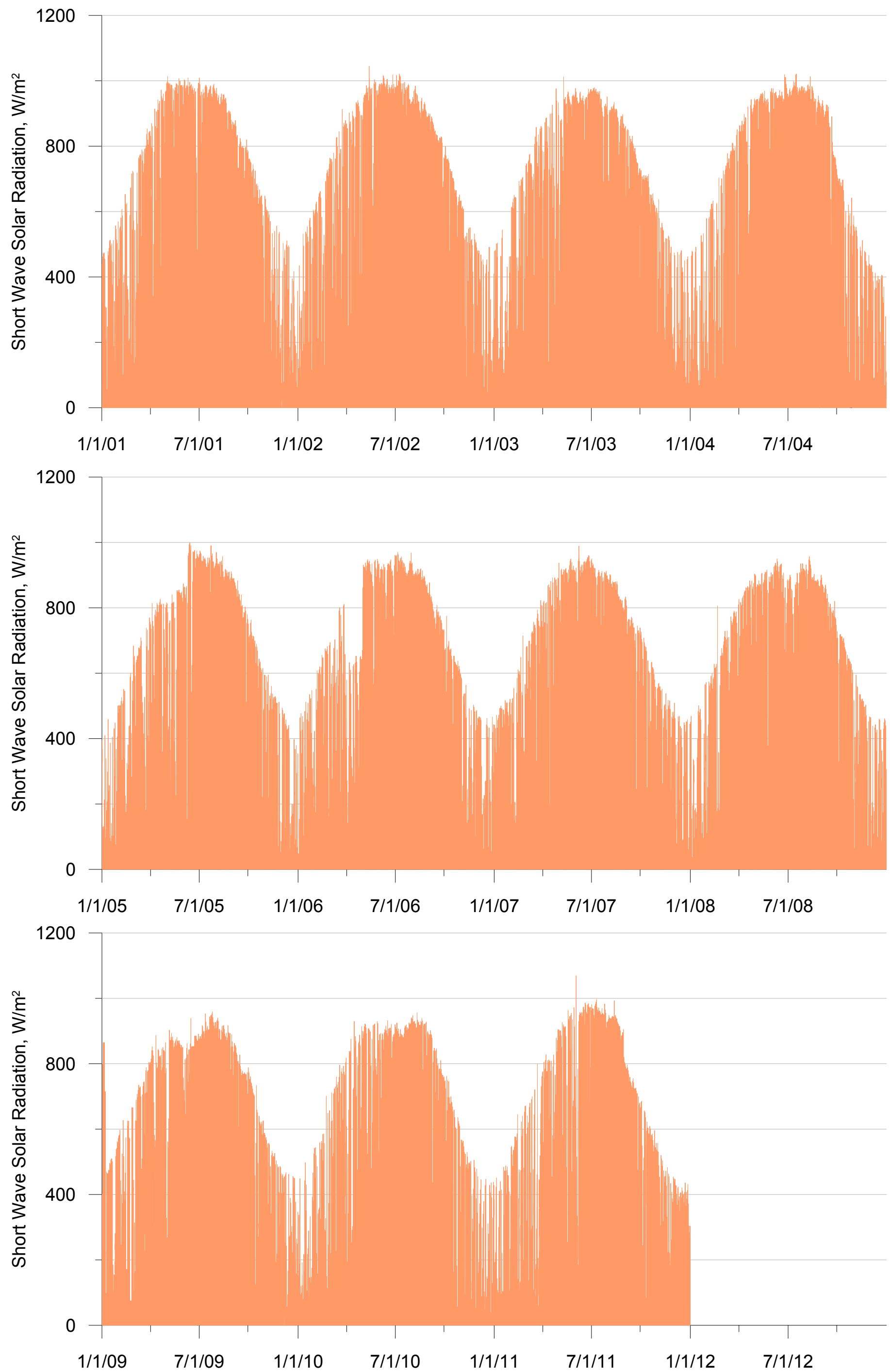


Figure 16. Fair Oaks Solar Radiation Data, 2001-2011 (Station CIMIS-131).

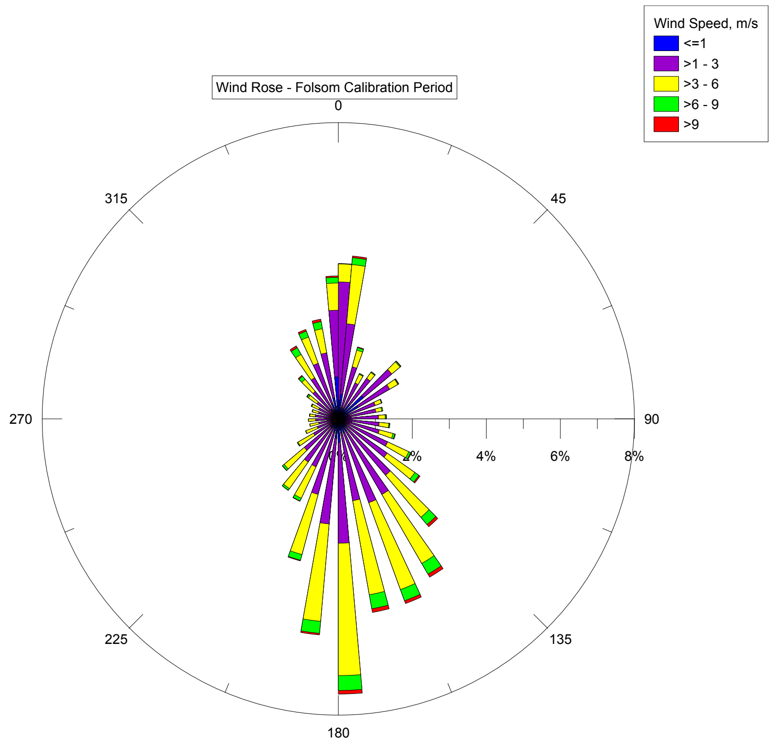


Figure 17. Composite Wind Rose Showing Wind Speed and Duration, 2001-2011 (Multiple Stations).

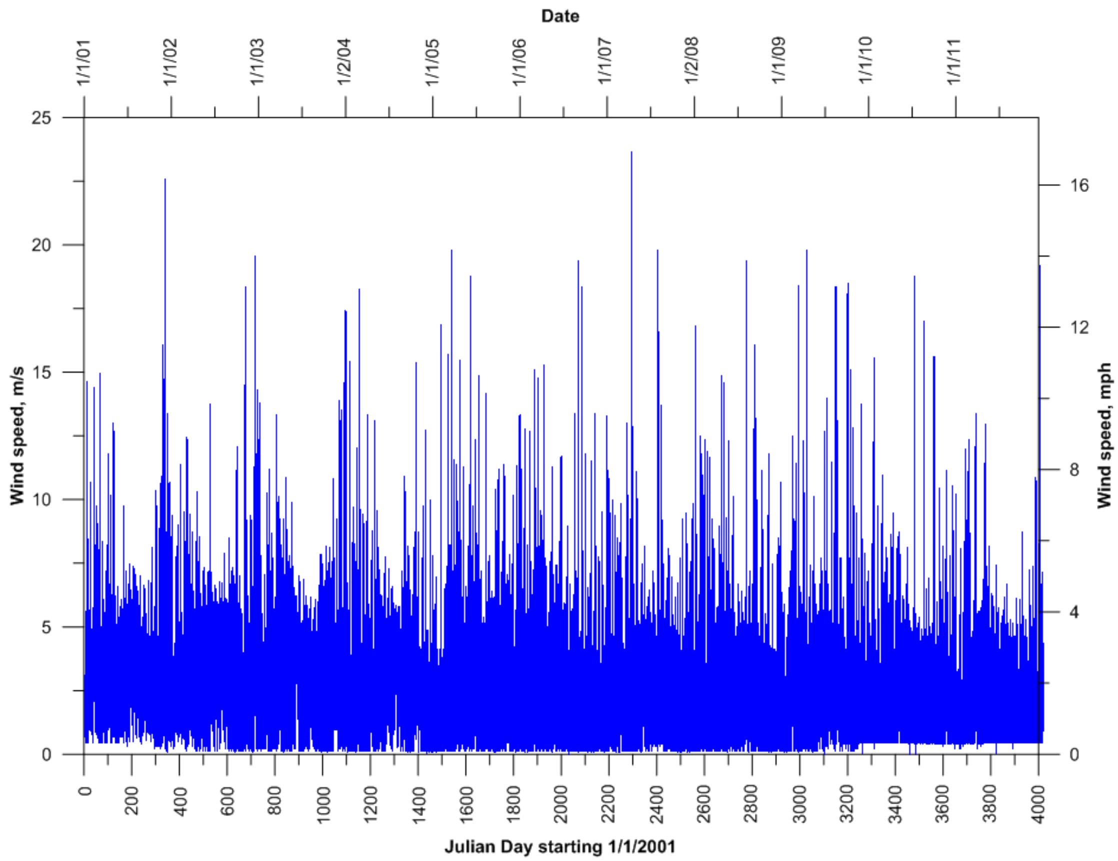


Figure 18. Wind Speed, 2001-2011 (Multiple Stations).

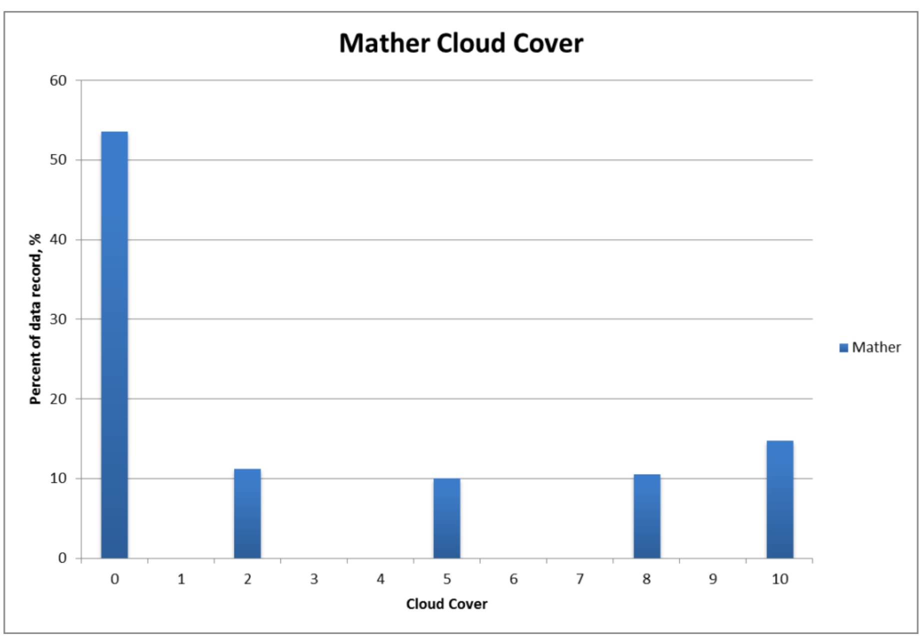


Figure 19. Cloud Cover, 2001-2011 (Mather AFB MET Station).

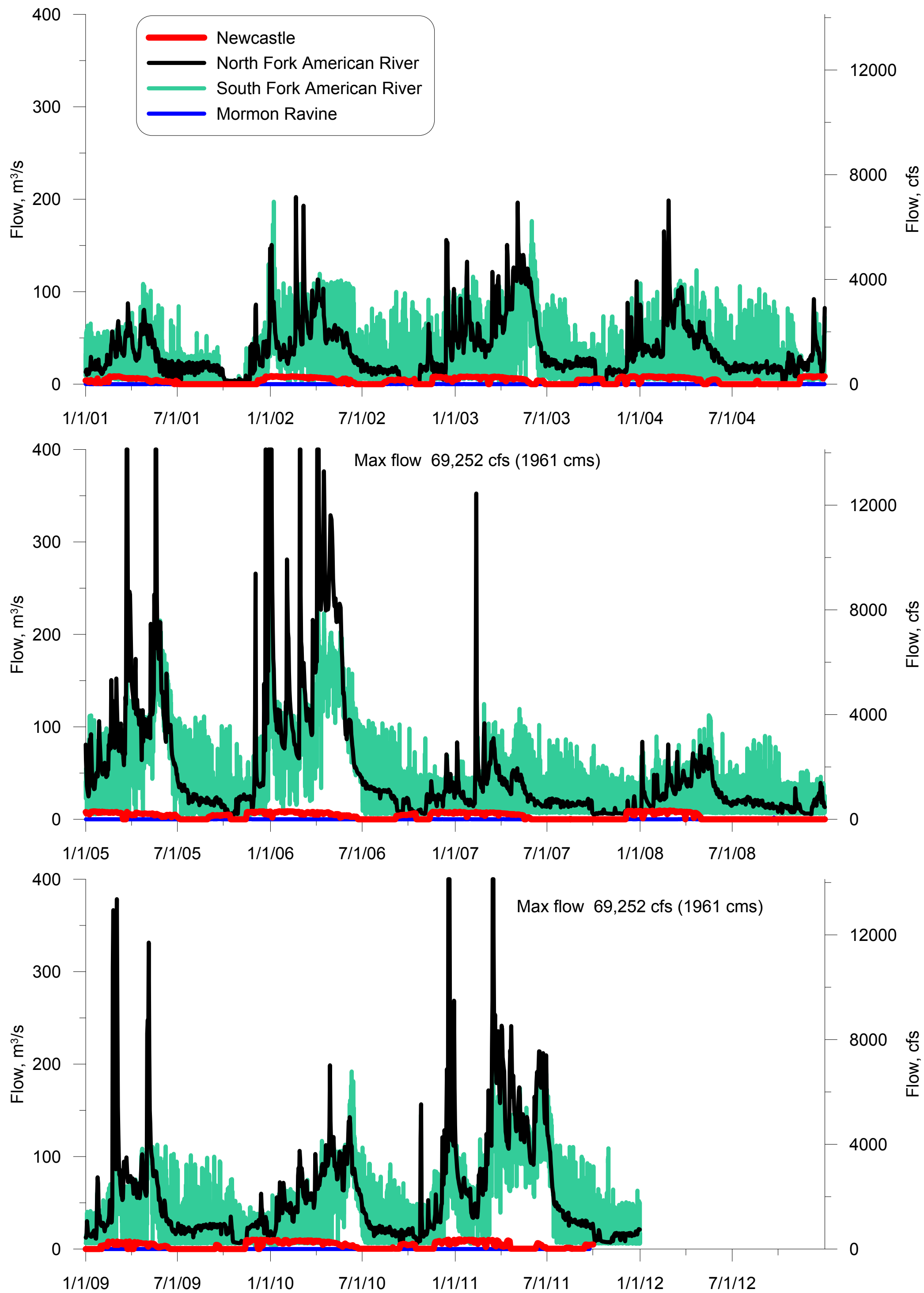


Figure 20. Inflows to Folsom Reservoir, 2001-2011.

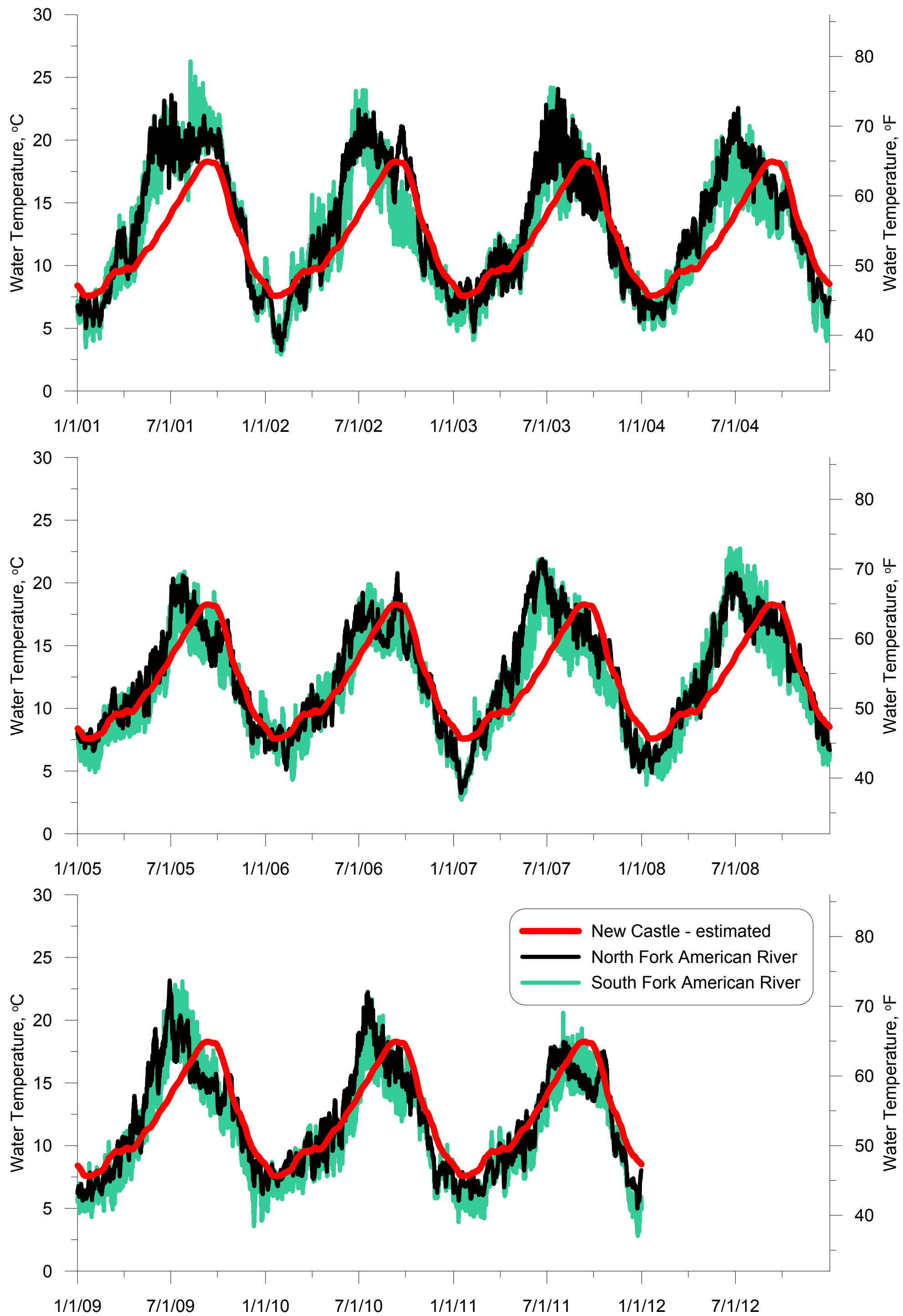
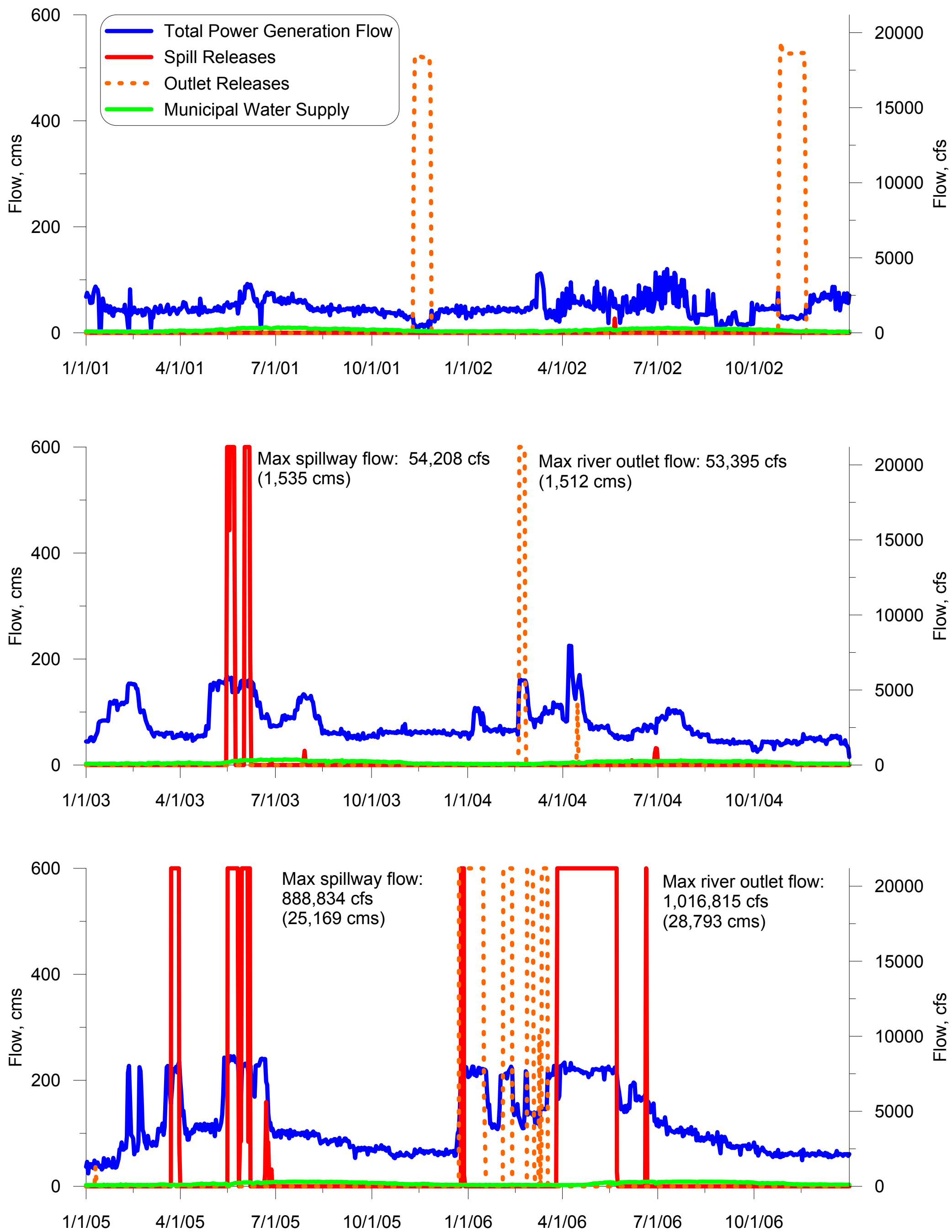


Figure 21. Inflow Water Temperatures to Folsom Reservoir, 2001-2011.


Total Power Generation Flow
Spill Releases
Outlet Releases
Municipal Water Supply
Flow, cms
Flow, cfs
1/1/01
4/1/01
7/1/01
10/1/01
1/1/02
4/1/02
7/1/02
10/1/02
Max spillway flow: 54,208 cfs
(1,535 cms)
Max river outlet flow: 53,395 cfs
(1,512 cms)
1/1/03
4/1/03
7/1/03
10/1/03
1/1/04
4/1/04
7/1/04
10/1/04
Max spillway flow:
888,834 cfs
(25,169 cms)
Max river outlet flow:
1,016,815 cfs
(28,793 cms)
1/1/05
4/1/05
7/1/05
10/1/05
1/1/06
4/1/06
7/1/06
10/1/06

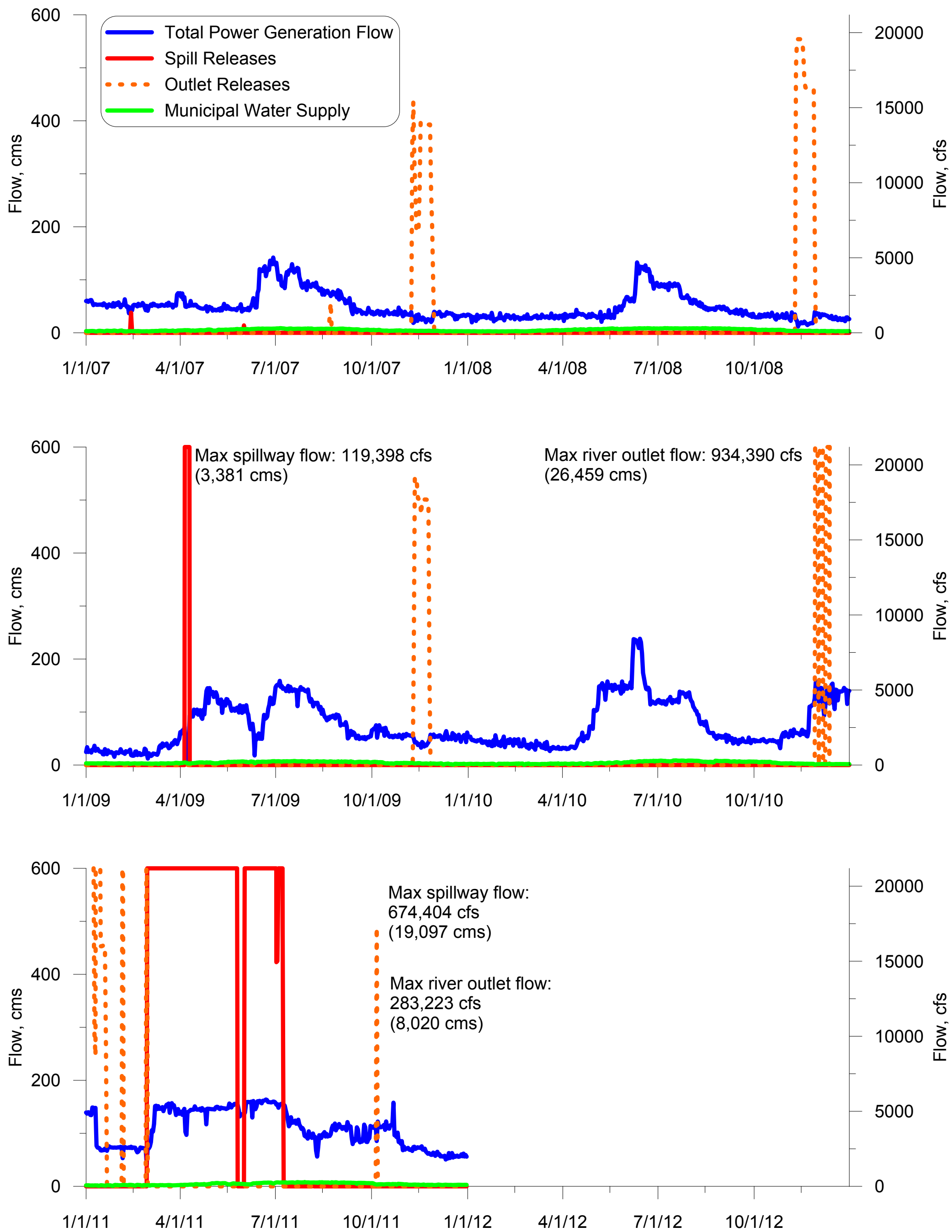


Figure 22. Outflow Summary from Folsom Dam 2001-2011.

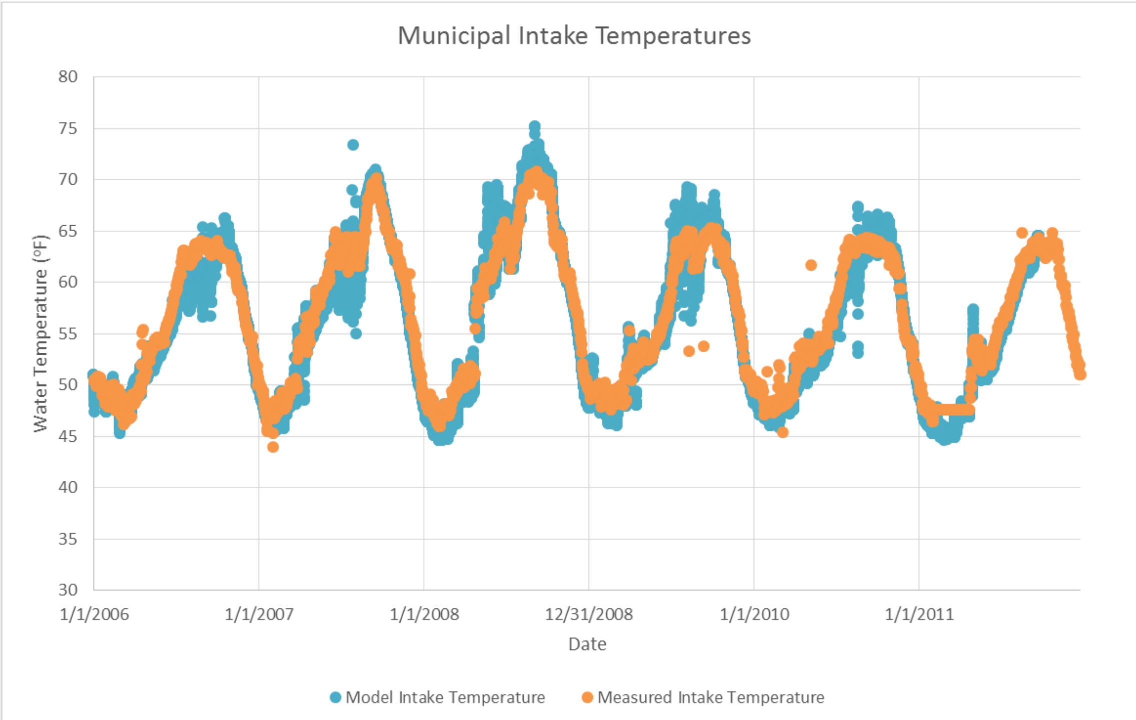


Figure 23. Plot of Municipal Water Supply Intake Modeled vs. Actual Temperature 2006-2011.

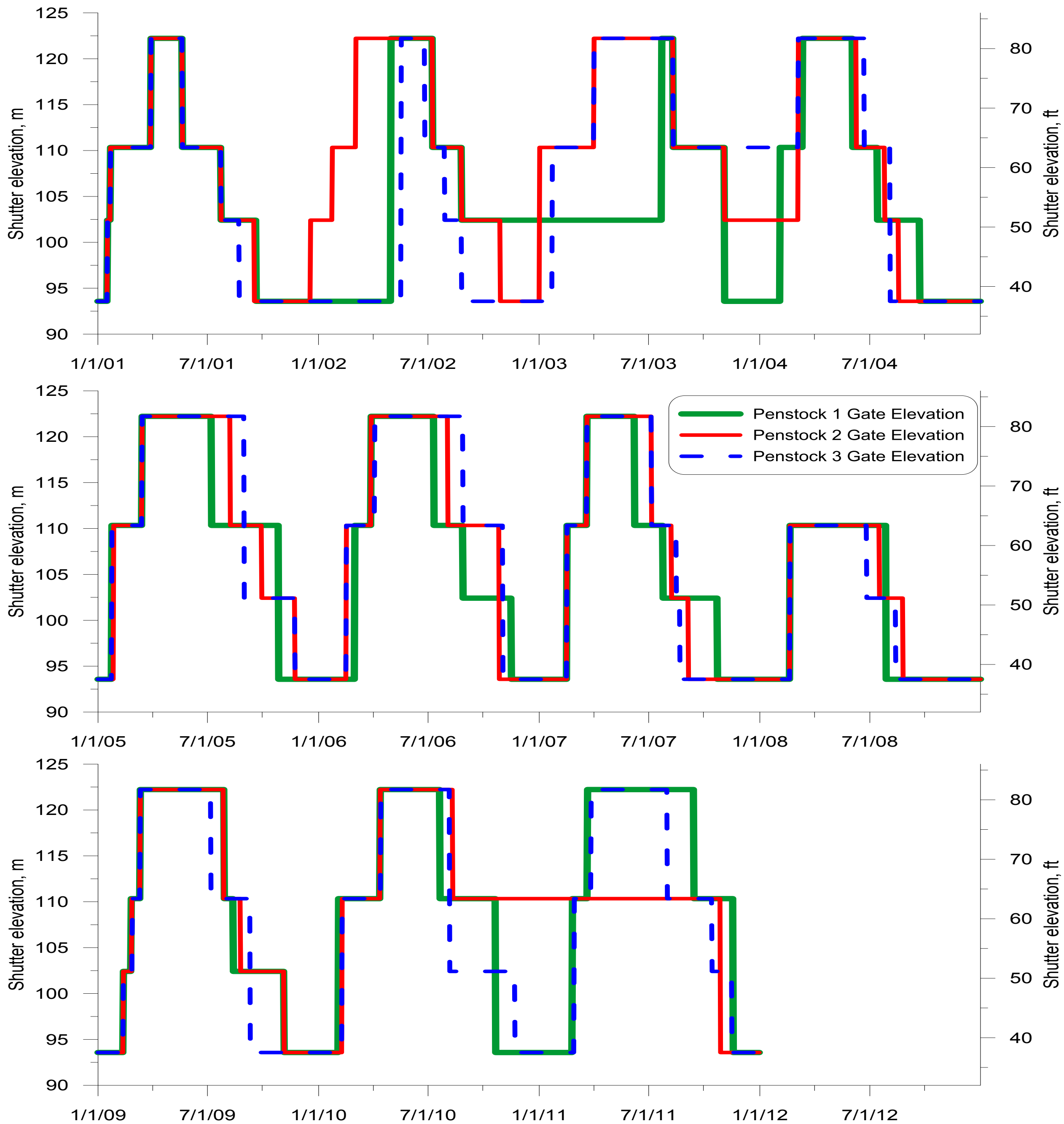


Figure 24. Folsom Dam Powerhouse Shutter Operations, 2001-2011.

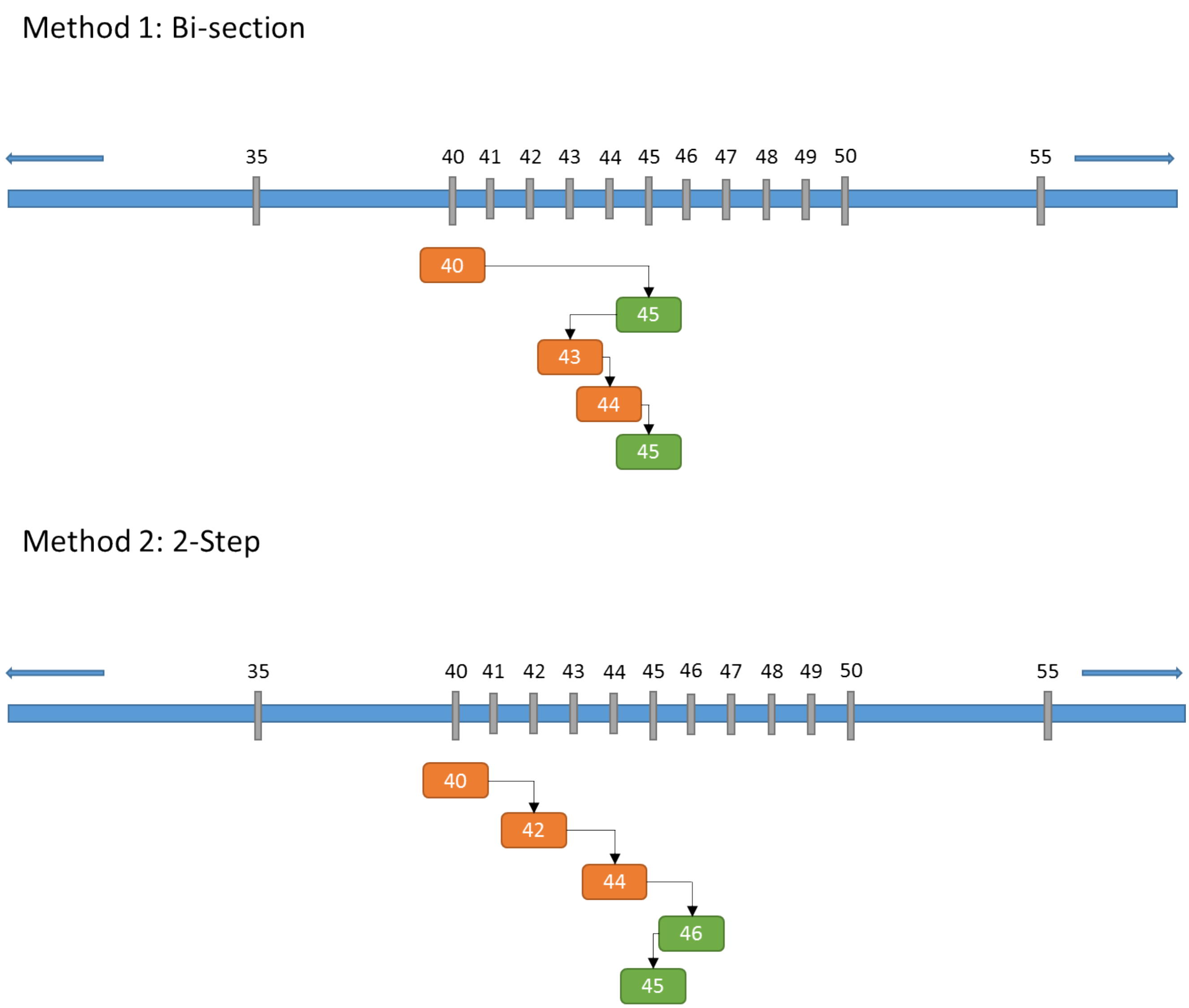


Figure 25. **Diagram of Temperature Target Selection Methods 1 (with a confidence bound of 10) and 2 – Starting Guess 40, Final Schedule 45. Orange Indicates Temperature Schedule was Exceeded, Green indicates Target was Met.**

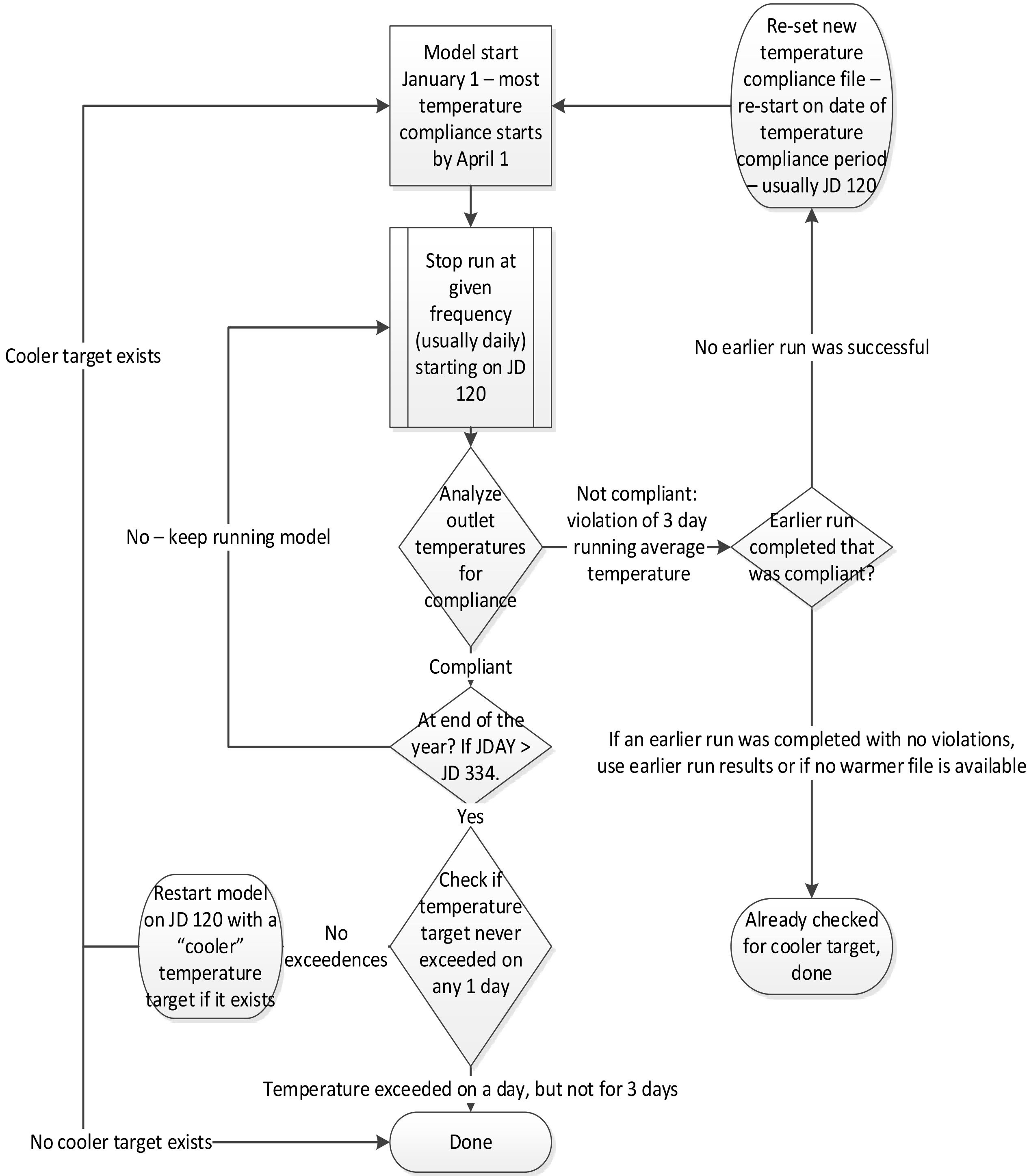


Figure 26. Flow Chart for Automatic Model Selection of Optimal Temperature Schedule.

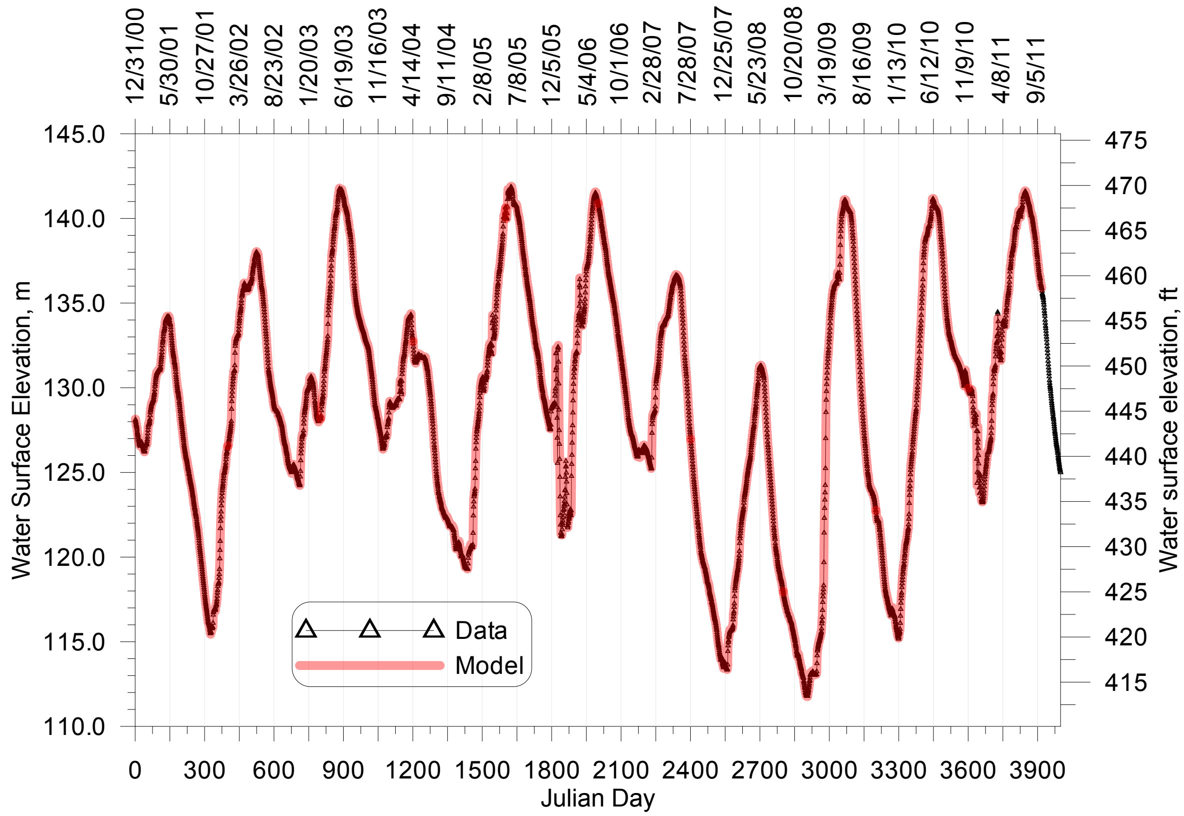


Figure 27. Comparison of Model Water Surface Elevation with Measured Data, 2001-2011.

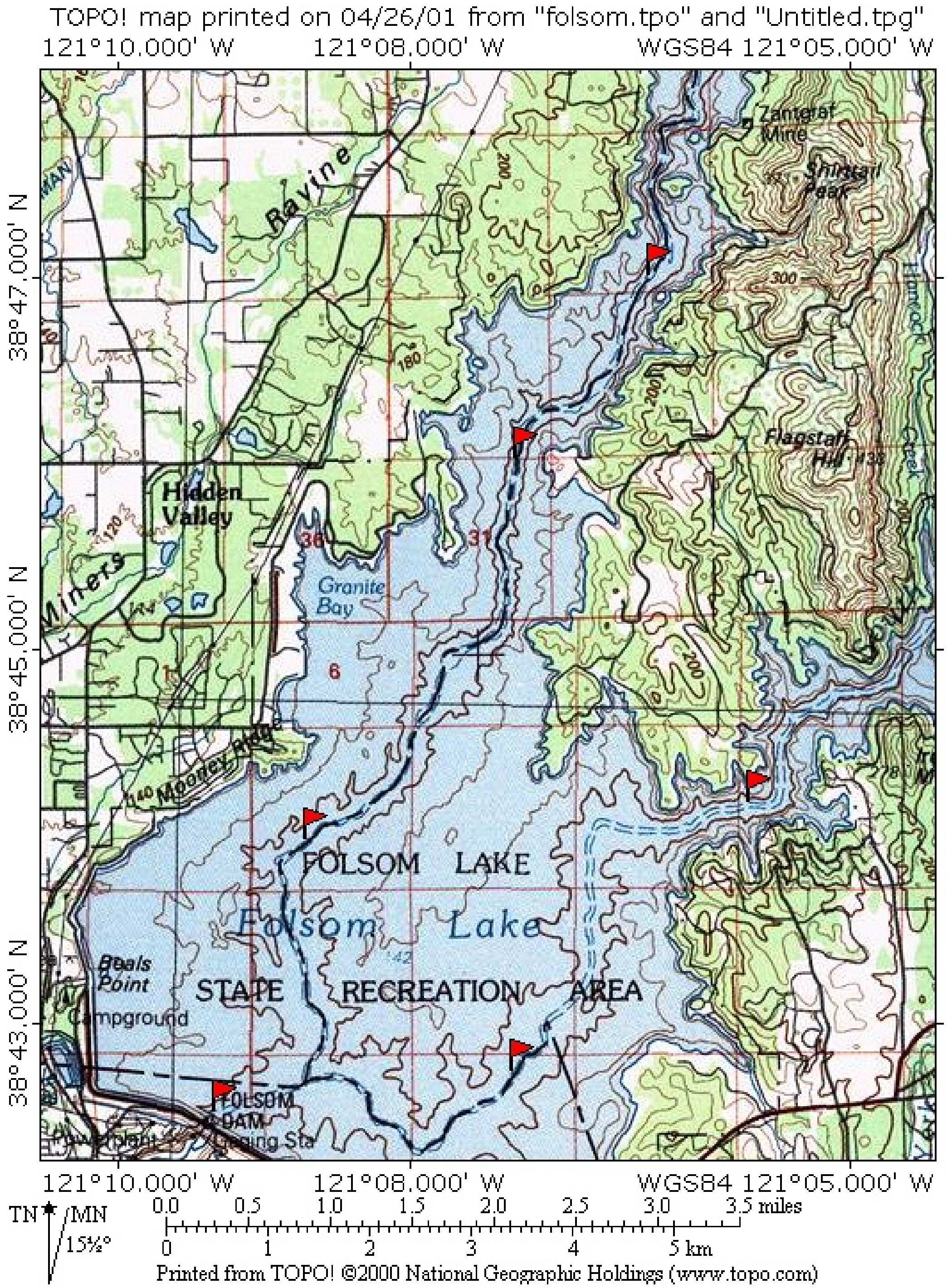


Figure 28. Historic Locations of Temperature Profile Stations.

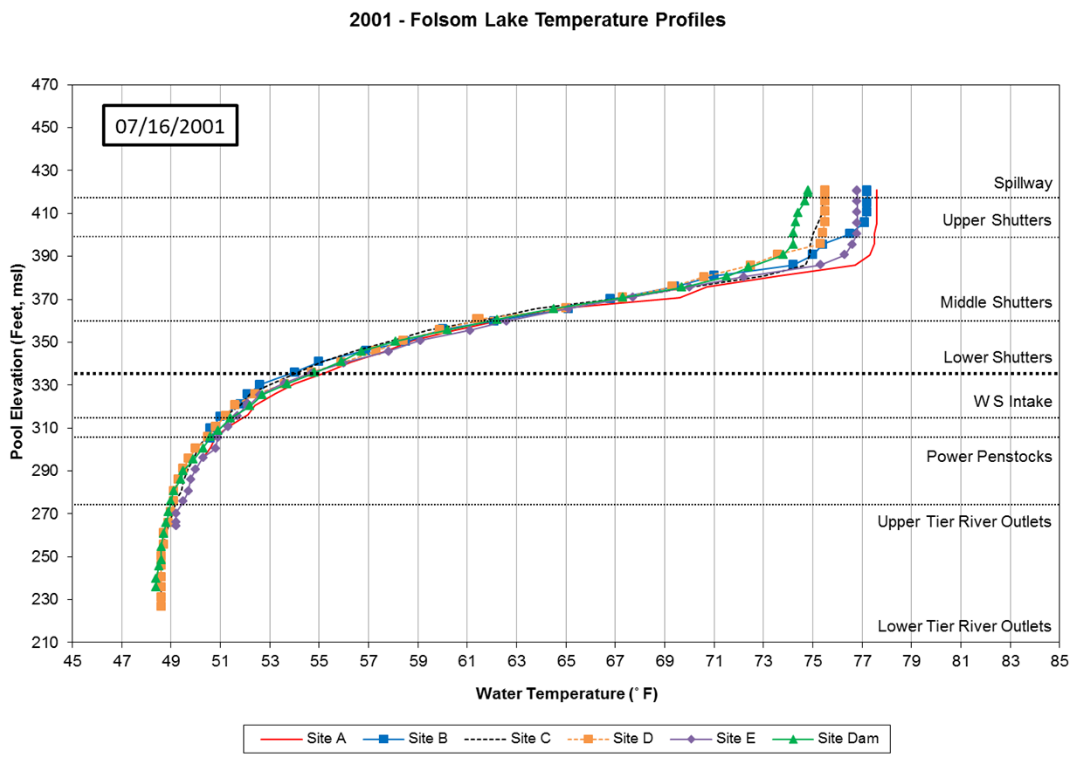


Figure 29. Folsom Reservoir Temperature Profile Collected on 7/16/2001.

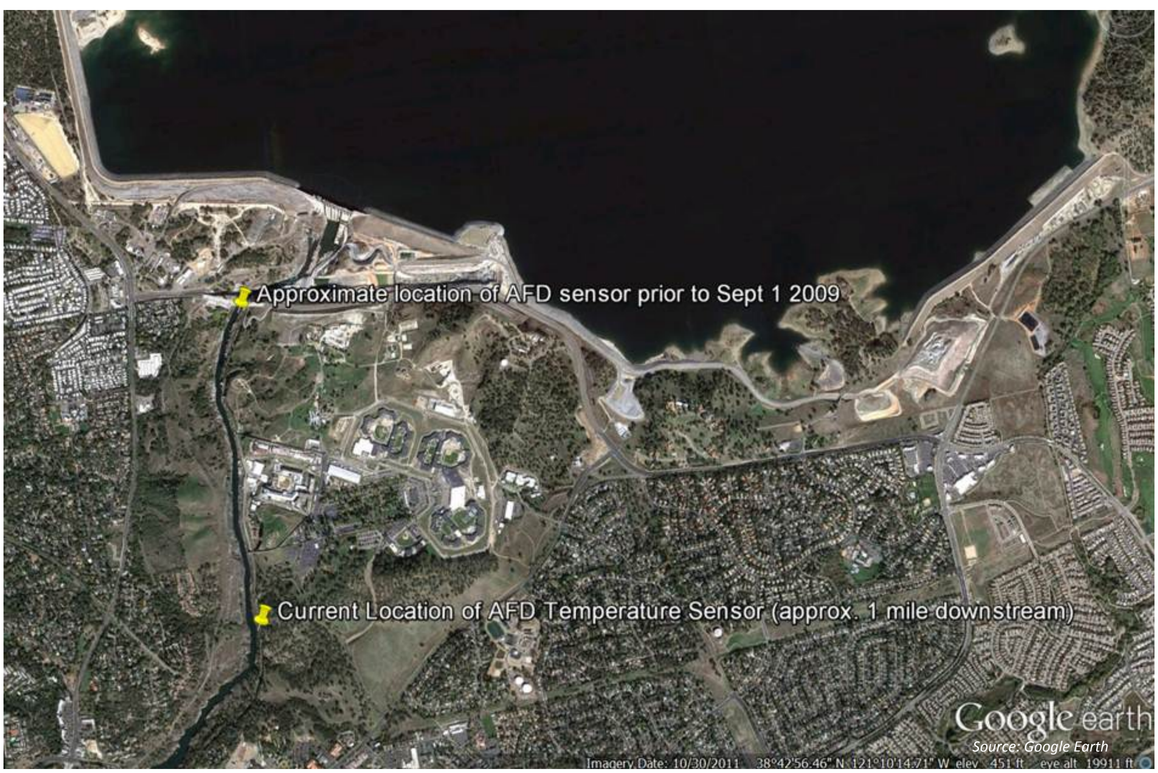


Figure 30. Location of Temperature Probe Downstream of Folsom Dam.

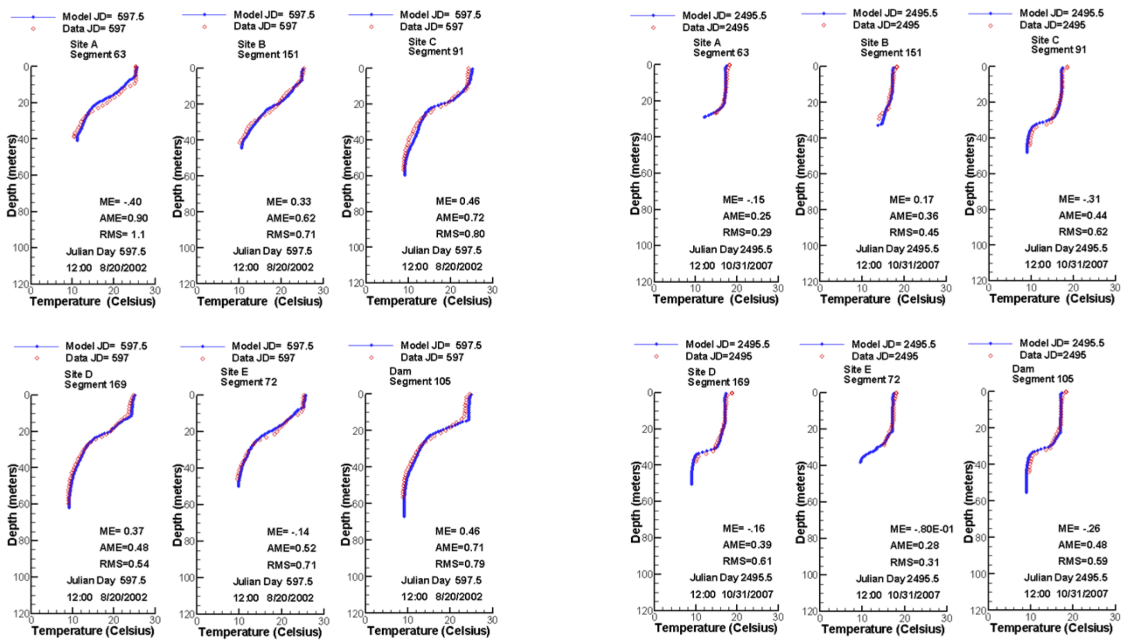


Figure 31. Model Temperatures Compared to Measurements on August 20, 2002 (left) and October 31, 2007 (right) at 6 Different Stations in Folsom Reservoir.

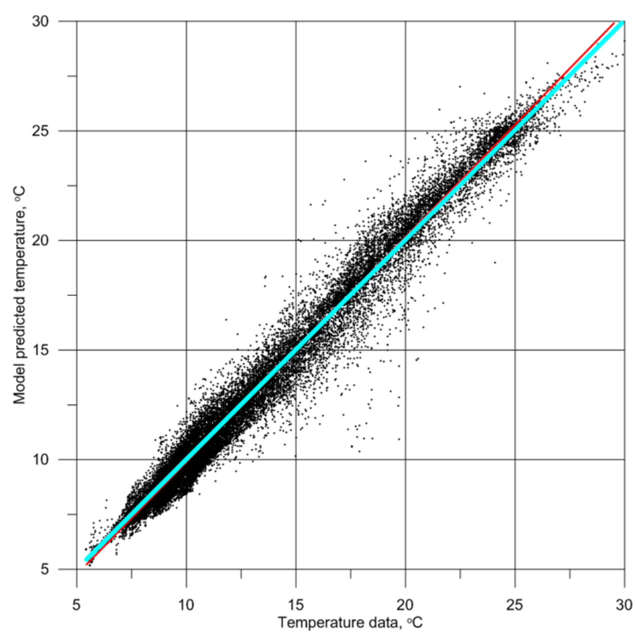


Figure 32. Comparison of Model Predicted in-Reservoir Water Profile Temperatures and Measured Profile Data, 2001-2011.

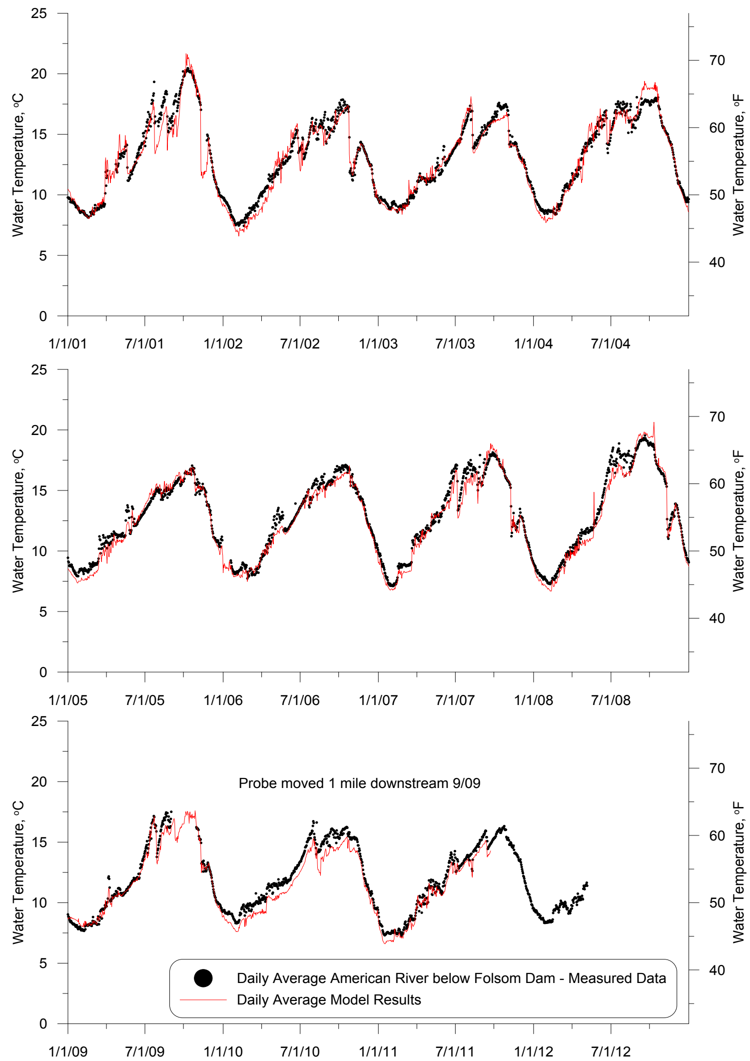


Figure 33. Model Predicted Temperatures Below Folsom Dam Compared to Measured Temperatures Immediately Downstream of Folsom Dam Between 2001 and 2009. For 2010 and 2011, Model Predictions are Compared to Data Collected 1 Mile Downstream of Folsom Dam.

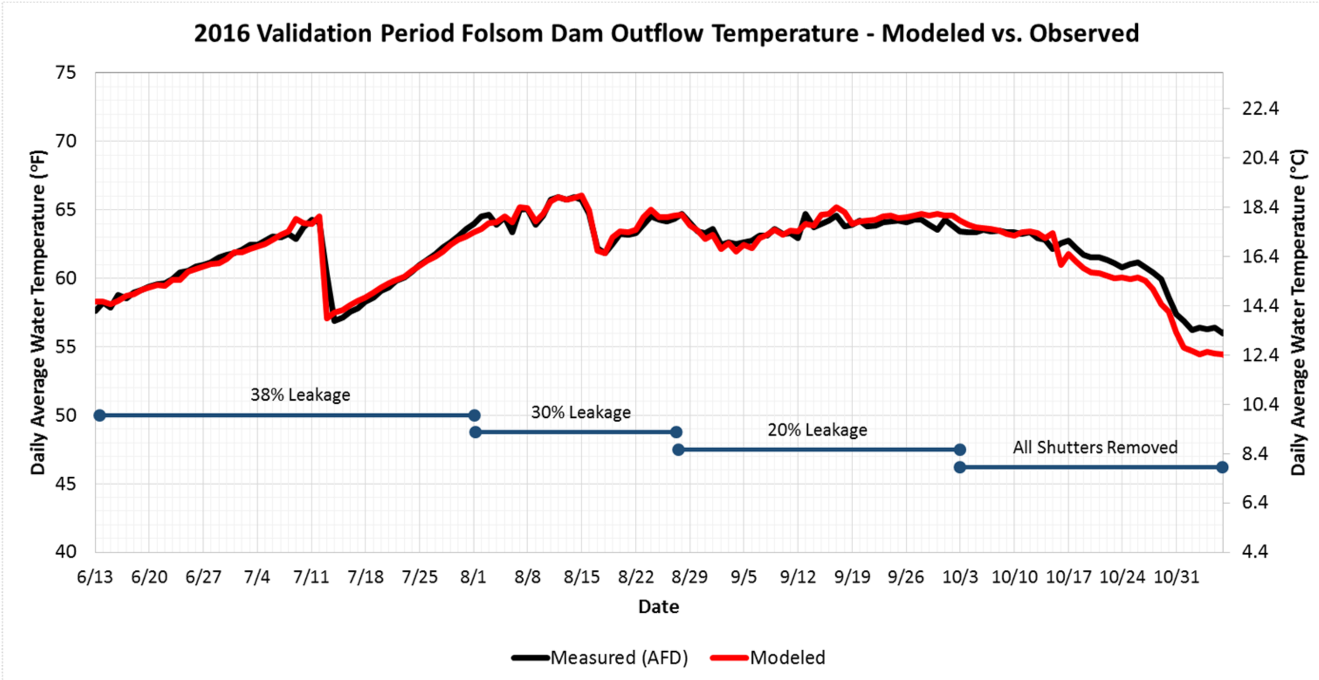


Figure 34. **Daily Average water temperature of outflow from Folsom Reservoir during 2016 temperature model validation period (modeled vs. observed).**

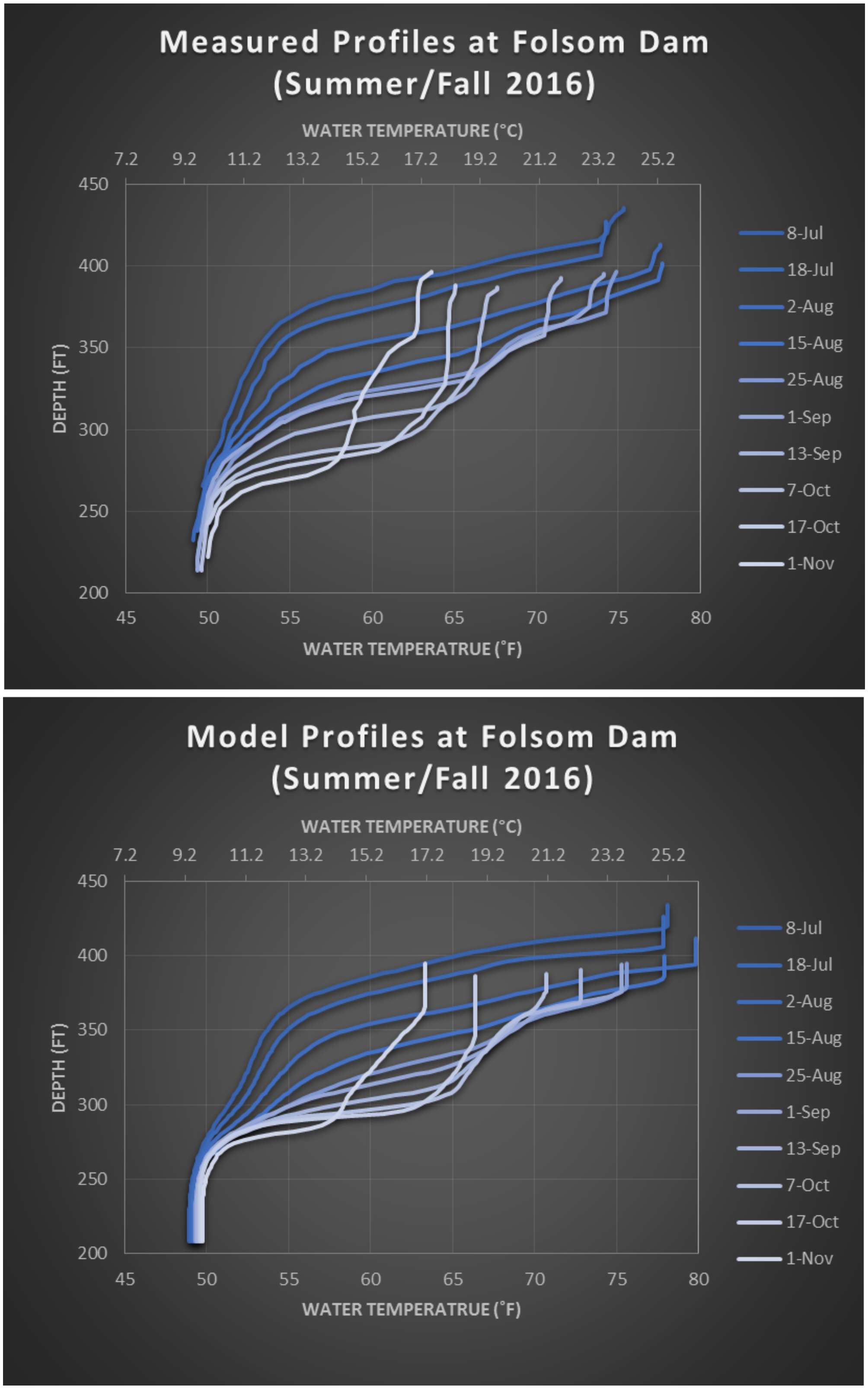


Figure 35. Water temperature profiles near Folsom Dam during 2016 temperature model validation period (model vs. observed).

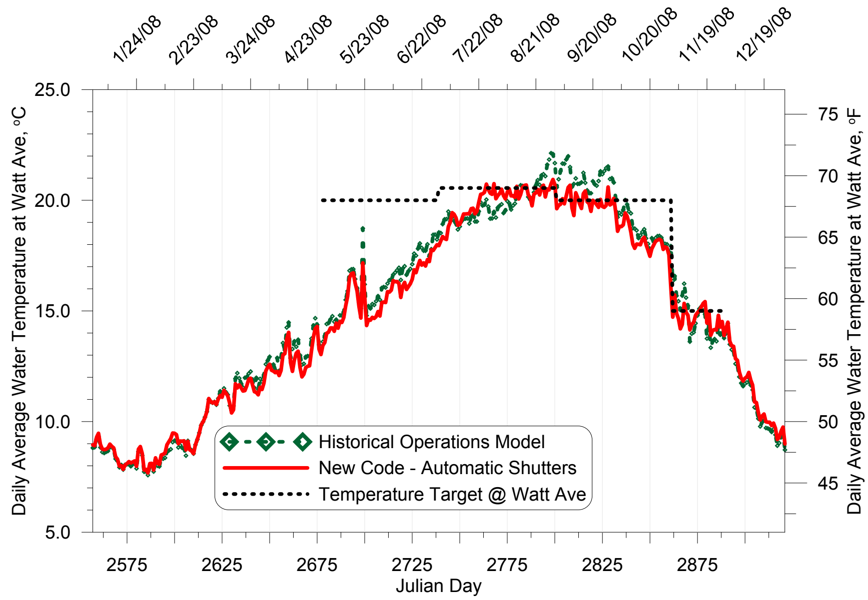


Figure 36. Comparison of Historical vs. Automated Model Scenarios of Watt Avenue Water Temperature, 2008.