

## **Appendix 5B**

# **Folsom Reservoir CE-QUAL-W2 Temperature Model Report**



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## **1.0 INTRODUCTION**

A Folsom Reservoir water temperature modeling tool was developed for Placer County Water Agency's (PCWA) American River Water Rights Extension (ARWRE) Project. The model was developed to test the ability of alternative hydrology and reservoir operations scenarios to meet regulatory water temperature requirements (or targets if the requirement cannot be met) 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 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 modeling tool was developed to automatically determine the best ATSP outflow temperature schedule possible and utilize cold water in the reservoir most effectively. The modeling tool includes automated TCD and powerhouse flow splits 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 modeling tool uses CE-QUAL-W2 (Cole and Wells, 2013), 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 modeling tool 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 BACKGROUND (FOLSOM DAM AND RESERVOIR)**

Folsom Dam and reservoir are located approximately 20 miles northeast of Sacramento, California, on the American River as shown in Appendix 5B 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<sup>1</sup> 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. Three power generation penstocks 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 °F (1°C). The model reportedly calibrated well to downstream temperatures; however no error statistics were provided in the model report.

For the current study (current PCWA 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, 2013) 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 is a 2-dimensional (longitudinal-vertical)

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<sup>1</sup> Threatened under the federal Endangered Species Act of 1973.

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 PCWA 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). Appendix 5B 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 Appendix 5B 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

(Appendix 5B 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 Appendix 5B Table 1. Details regarding the configuration of each individual branch are summarized in Appendix 5B 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 Appendix 5B Figures 4 and 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 Appendix 5B 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 Appendix 5B Table 3. Appendix 5B Figures 7, 8, and 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 Appendix 5B 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). Appendix 5B 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. Appendix 5B Figures 9, 11, and 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 (Appendix 5B 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. 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 Appendix 5B Figure 13. As a result, 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 immediately 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 Appendix 5B 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 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 Appendix 5B 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) (Appendix 5B Table 6). The locations of the stations are shown in Appendix 5B 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 Appendix 5B Figures 14-16.

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 Appendix 5B 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 Appendix 5B Table 7. Wind speed data for the calibration period are shown in Appendix 5B 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 (Appendix 5B Table 8). Each category was assigned a value between zero and ten for use in the CE-QUAL-W2 model. Appendix 5B 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 Appendix 5B Table 9. The location of each of these sites is shown in Appendix 5B Map 1. Appendix 5B Figure 20 shows the inflow rates to Folsom Reservoir for the calibration period 2001-2011. Appendix 5B 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 Appendix 5B Attachment B.

## **3.5.3 Reservoir Outflows and Temperature Control Device Operations**

Appendix 5B 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 Appendix 5B 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<sup>2</sup>. 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 Appendix 5B 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 (2001-2011). The flows were converted to hourly values.

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<sup>2</sup> Data sheets provided by the Folsom Dam operator, Marlon Premo (Reclamation), to Craig Addley (Cardno) July 20, 2012.

### **Spillway Gates - Flows**

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<sup>3</sup> and are shown in Appendix 5B 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<sup>4</sup>. 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 (Appendix 5B 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°C ( $\leq 65^{\circ}\text{F}$ ) within the maximum and minimum operating constraints of the TCD (See Appendix 5B Appendix 5B Attachment C). The capability was built into the CE-QUAL-W2 model to allow the modeler to specify general constraints: (1)

<sup>3</sup> Data provided by Russell Yaworsky (Reclamation) to Craig Addley (Cardno) by email dated June 20, 2012.

<sup>4</sup> 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.

automatic target temperature water extraction (65°F, typically); (2) maximum and minimum inlet elevations (see Appendix 5B Table 3); and (3) minimum inlet elevation below WSE (8.23 meters, typically).

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

1. On March 1<sup>st</sup> 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 1<sup>st</sup>, 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 1<sup>st</sup> 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 use 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 Appendix 5D Lower American River Water Temperature Regression Relationships. In addition, a

general regression equation that works at any location in the river is available (Appendix 5D 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). Appendix 5B Table 12 shows the ATSP schedules (Water Forum 2004, Water Forum 2006) for Watt Avenue. 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 (Appendix 5B 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 Appendix 5B Figure 25. Both methods share the same general logic for running the model which is shown in Appendix 5B 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 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 unengaged 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 (Appendix 5B 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**

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 1<sup>st</sup>, 2001 and December 31<sup>st</sup>, 2011, in two to four week intervals<sup>5</sup>. A map of the location of the temperature profile sites is shown in Appendix 5B Figure 28, with additional site details summarized in Appendix 5B Table 13. An example of the temperature profiles collected is shown in Appendix 5B 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 Appendix 5B Attachment D.

The USGS-maintained American River below Folsom Dam (AFD) gage (Appendix 5B 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 Appendix 5B 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 (Appendix 5B Figure 30).

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.

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<sup>5</sup> Data provided by Russell Yaworsky (Reclamation) to Craig Addley (Cardno) by email dated June 20, 2012.



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.

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 TEMPERATURE 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°F (0.55°C) with a bias of almost zero for all profile stations. The profile error statistics are summarized in Appendix 5B Table 15. A representative visual comparison of two temperature profiles (August 2002 and October 2007) is shown in Appendix 5B Figure 31. A complete record of all calibration period temperature profile data versus model comparisons can be found in Appendix 5B Attachment E. A summary comparison of all of the modeled versus empirical measurements over the 10-year calibration period is shown in Appendix 5B 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°F (0.6°C) for the calibration period. A time series plot of modeled versus measured water temperature is provided in Appendix 5B Figure 33 and error statistics are shown in Appendix 5B Table 16.

#### **4.3 EXAMPLE MODEL OPTIMIZATION**

An example of the automated temperature model results for 2008 is compared to actual historical operations in Appendix 5B Figure 34. 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 improved temperature operations 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. 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/or 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).

## 7.0 REFERENCES

- Bender, M., Kubitschek, J., and T. Vermeyen. 2007. Temperature Modeling of Folsom Lake, Lake Natoma, and the Lower American River, Special Report. Prepared for U. S. Bureau of Reclamation, Sacramento County, California.
- Cole, T. and S.A. Wells. 2013. CE-QUAL-W2: A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.7. Department of Civil and Environmental Engineering, Portland State University, Portland, OR.
- El Dorado Irrigation District (EID). 2005. 2005 Water Diversion Report Years: 2001-2005.
- \_\_\_\_\_. 2007. 2007 Water Diversion Report Years: 2003-2007, as revised 3/27/2008.
- \_\_\_\_\_. 2012. 2012 Water Diversion Report Years: 2008-2012.
- Ferrari, R. L. 2007. Folsom Lake, 2005 sedimentation survey. U.S. Dept. of Interior, Bureau of Reclamation Technical Service Center, Denver Colorado.
- Folsom Lake, CA. May 2013. Google Maps. Google. Retrieved from <https://maps.google.com/maps?q=folsom,ca&hl=en&ll=38.707105,-121.157441>
- Shay, J.M. 1979. Water-quality data for the American River Basin, California February – October 1979. United States Geological Survey. Open-File Report 82-363. 80 pp.
- United States Department of the Interior – Bureau of Reclamation (Reclamation). 2013. Folsom Dam. Retrieved from [http://www.usbr.gov/projects/Facility.jsp?fac\\_Name=Folsom+Dam&groupName=Overview](http://www.usbr.gov/projects/Facility.jsp?fac_Name=Folsom+Dam&groupName=Overview)

Vermeyen, T.B. 1997. Folsom Dam – Selective Withdrawal Analysis for a Proposed Temperature Control Device for the Municipal Water Supply Intake. Prepared for U. S. Bureau of Reclamation, Sacramento County, California. 28 pp.

Water Forum. 2004. Draft Policy Document Lower American River Flow Management Standard. Available at: <http://www.waterforum.org/DraftPolicyDoc-final.pdf>.

\_\_\_\_\_. Lower American River Flow Management Standard. Available at: [http://www.waterforum.org/Technical\\_FMS\\_Report\\_7-31-06.pdf](http://www.waterforum.org/Technical_FMS_Report_7-31-06.pdf).

**TABLES**

**Appendix 5B 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

**Appendix 5B 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)

**Appendix 5B Table 3. Description of Folsom Dam Outlets (Note: mixed units feet and meters are used).**

Outlet Description <sup>1</sup>	Shape	Dimension (ft)		Monolith	Horizontal Centerline Coordinates <sup>2</sup> (m)		Elevations <sup>3</sup> (ft)						
					X	Y	Unshuttered		Shuttered Configurations				
							Centerline <sup>4</sup>	Invert	A = All Lowered	U = Upper Raised	M = Middle Raised	L = Lower Raised	O = Unit Offline
<b>Municipal Water Supply Intake</b>													
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)				
<b>Power Generation Penstock Outlets</b>													
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
<b>River Outlet Gates</b>													
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					
<b>Spillway Gates</b>													
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					

<sup>1</sup>Outlets are numbered from North to South (Furthest North = 1).

<sup>2</sup>X and Y Coordinates are UTM 10 NAD 27 (meters) and correspond directly with TIN/contour data.

<sup>3</sup>Elevations are UTM NAD 27 (feet) and correspond to engineering drawings.

<sup>4</sup>Municipal water supply outtake at centerline elevation only when water surface elevation is below 351.5 ft, otherwise see range for shutter configurations.

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**Appendix 5B Table 4. Summary Table of Outlet Structure Elevations for Folsom Dam.**

Outlet Structure	Position 1	Position 2	Position 3	Position 4 <sup>1</sup>
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)

<sup>1</sup> 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]).

**Appendix 5B 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.

**Appendix 5B Table 6. Summary of Meteorological Stations Used to Compile Calibration Period Met Data.**

MET Station and Parameter	Station ID	Location		Elevation	Distance from Folsom Dam	Frequency of Data Collection	Source Location
		Lat.	Long.				
<b>Fair Oaks</b>							
<ul style="list-style-type: none"> <li>• Air temperature</li> <li>• Dew point temperature</li> <li>• Wind speed and direction (only when no other data available)</li> <li>• Solar radiation</li> </ul>	CIMIS-131	38.65	121.21	265 ft.	8 miles	15-minute	http://mesowest.utah.edu/ (Requires login to access historical data)
				(80.8 m)	(12.7 km)		
<b>Folsom/Dyke 8</b>							
<ul style="list-style-type: none"> <li>• Wind speed and direction</li> </ul>	FSLC1	38.692	121.13	551 ft.	< 0.5 miles	15-minute	http://mesowest.utah.edu/ (Requires login to access historical data)
				(167.9 m)	(< 1 km)		
	FLD	38.7	121.16	350 ft.	0.75 miles	15-minute	http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=FLD
				(106.7 m)	(1.24 km)		
<b>Mather Air Force Base</b>							
<ul style="list-style-type: none"> <li>• Wind speed and direction</li> <li>• Cloud cover</li> </ul>	KMHR	38.56	-121.3	96 ft.	14 miles	Hourly	http://gis.ncdc.noaa.gov/map/viewer/#app=cdo
				(29.29 m)	(22.6 km)		

CIMIS: California Irrigation Management Information Center

**Appendix 5B 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



**Appendix 5B 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

**Appendix 5B Table 9. Data Sources for Summary Folsom Reservoir Inflow and Water Temperature.**

Name	Data Collected	Operator	Station No.	Location		Frequency
				Lat.	Long.	
<b>North Fork American River</b>						
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
<b>South Canal</b>						
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
<b>South Fork American River</b>						
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

**Appendix 5B Table 10. Sources for Model Outflow and Operational Data.**

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

<sup>1</sup> 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]).

<sup>2</sup>AFD records temperature of combined outflow from Folsom, including power penstock, spillway, and river outlets flows.

**Appendix 5B 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	1066	1086	1114	1078	780	1089	1071	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

**Appendix 5B 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

**Appendix 5B 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

**Appendix 5B 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

**Appendix 5B 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

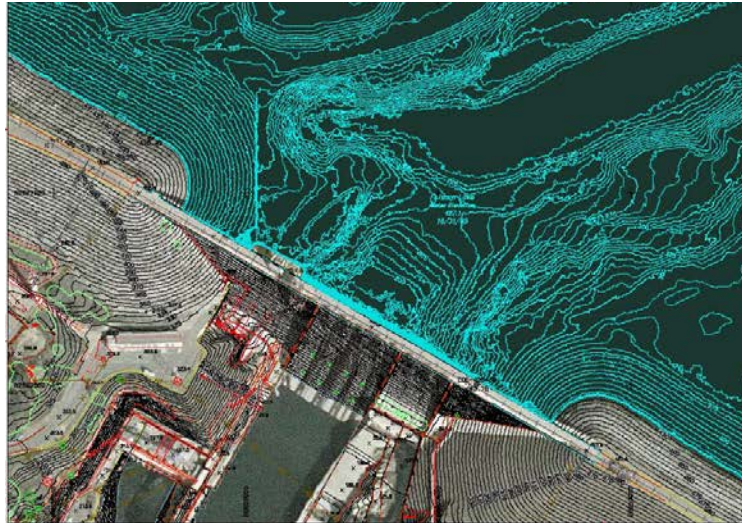
**Appendix 5B Table 15. Temperature Profile Model Error Statistics.**

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)

**Appendix 5B Table 16. Downstream Temperature Time Series Error Statistics.**

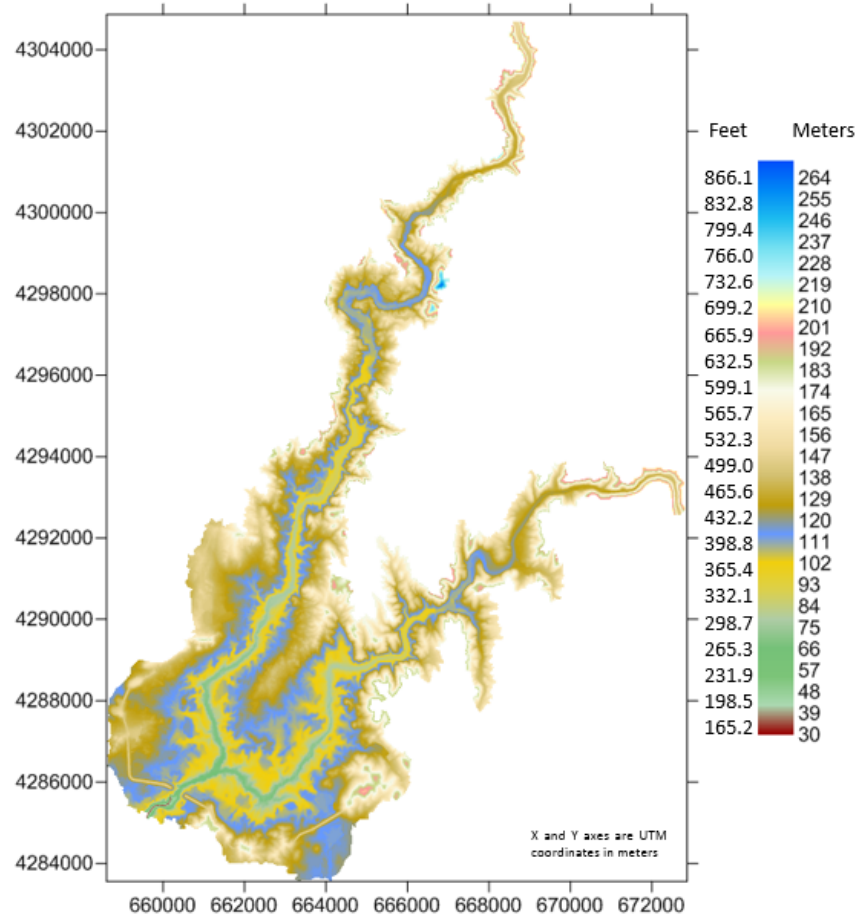
Mean Error	Absolute Mean Error (AME)	Flow Weighted AME
0.56 °F (0.31 °C)	1.17 °F (0.65 °C)	1.04 °F (0.58 °C)

## Figures

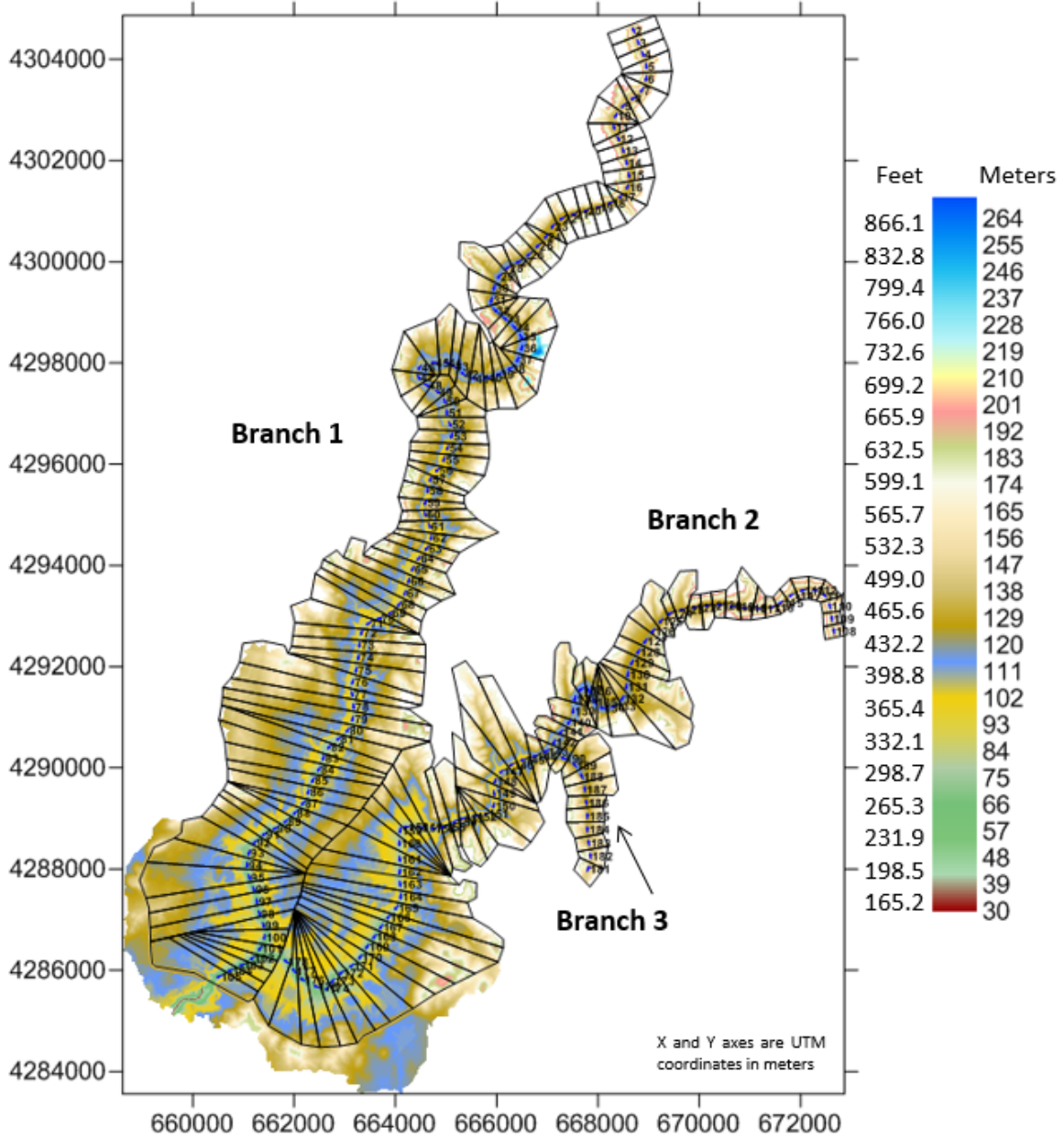


**Appendix 5B Figure 1. Example of Contour Elevations (Source: Ferrari 2007).**



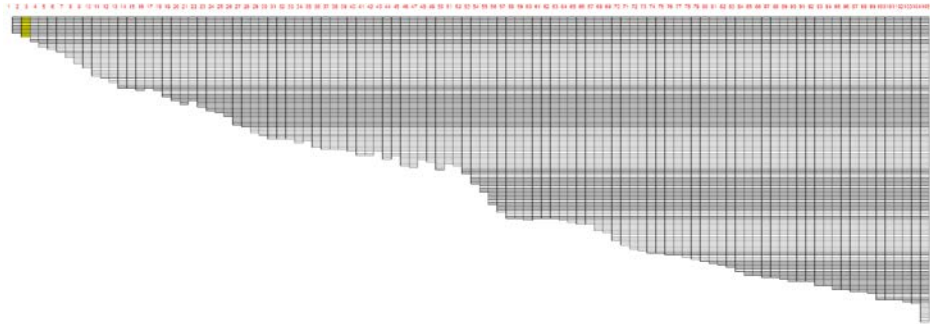


**Appendix 5B Figure 2. Elevation Contour Map of Folsom Reservoir.**

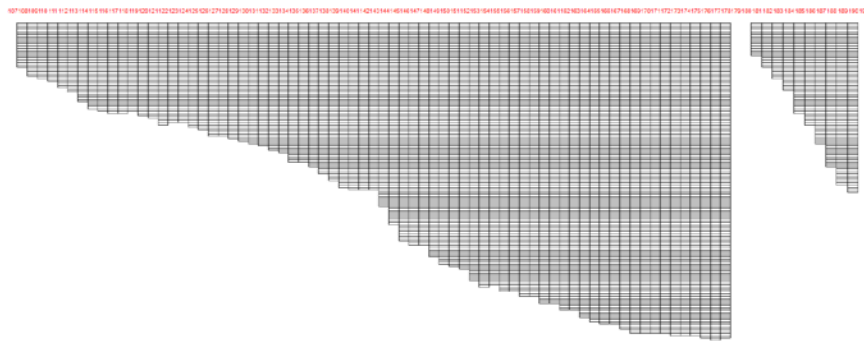


Appendix 5B Figure 3. Folsom Reservoir Model Segments, Branches.

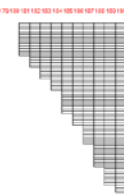
**North Arm (Branch 1) Segments 2-105**



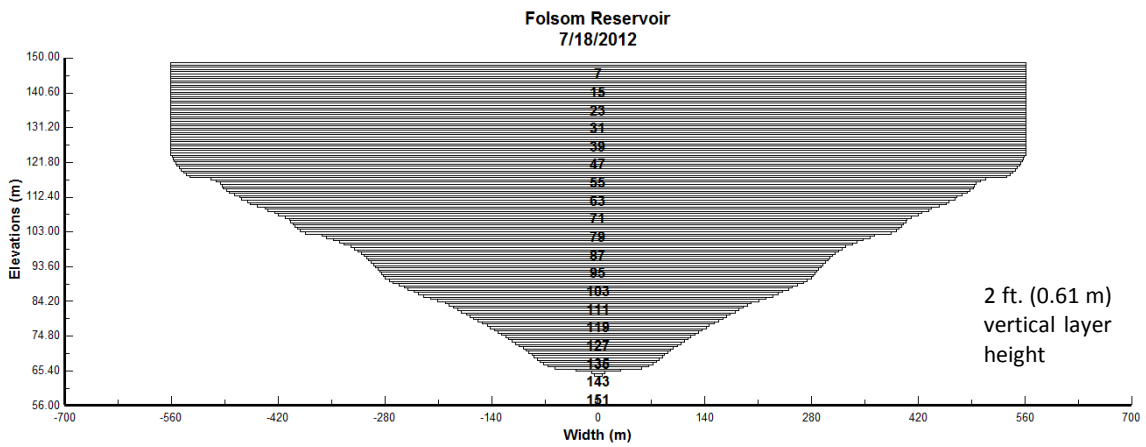
**South Arm (Branch 2) Segments 107-178**



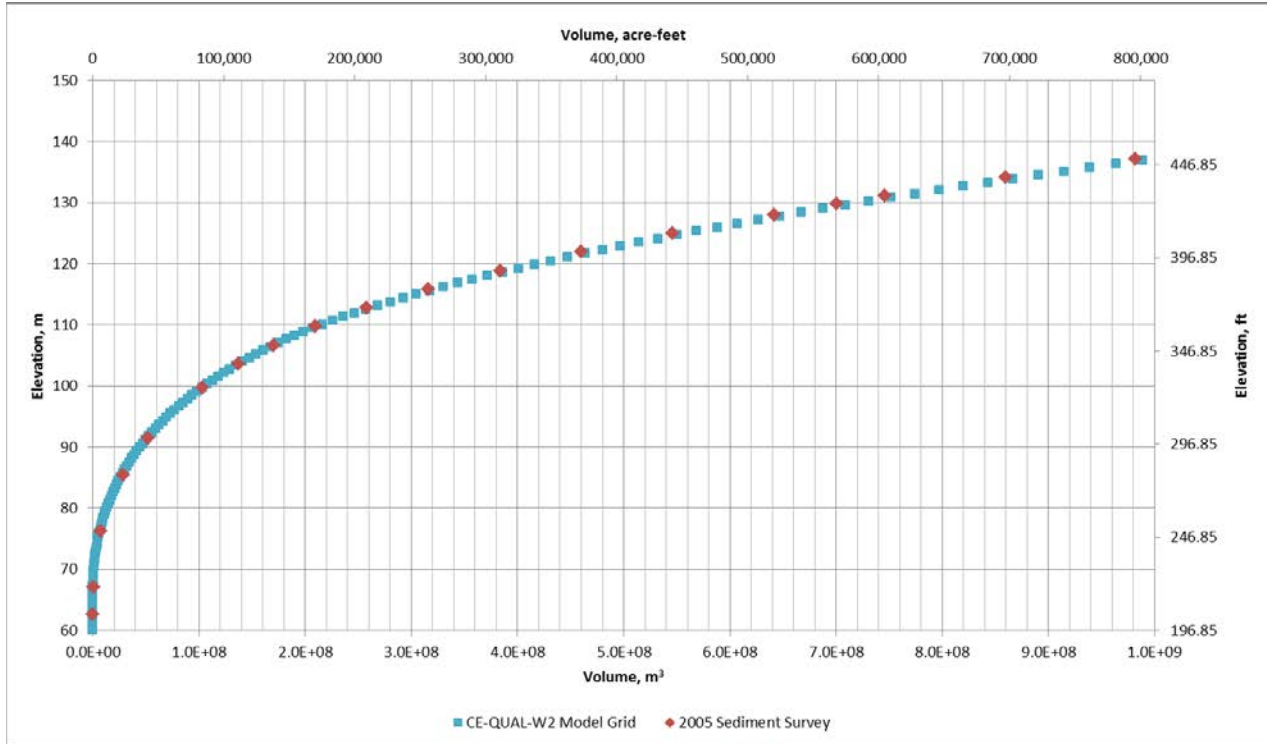
**Side Arm (Branch 3) Segments 181-190**



**Appendix 5B Figure 4. Model Configuration Showing Side-View of Model Grid.**



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



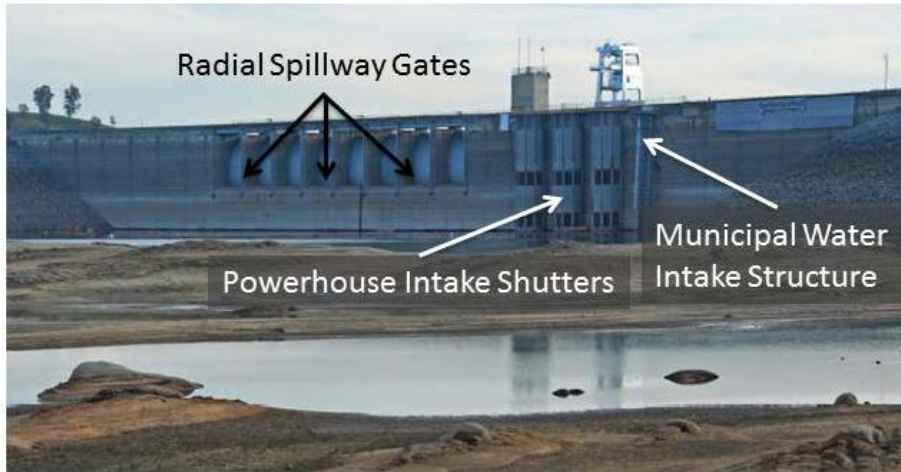
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**Appendix 5B Figure 6. CE-QUAL-W2 Model Volume-Elevation Curve vs. 2005 Sediment Survey.**



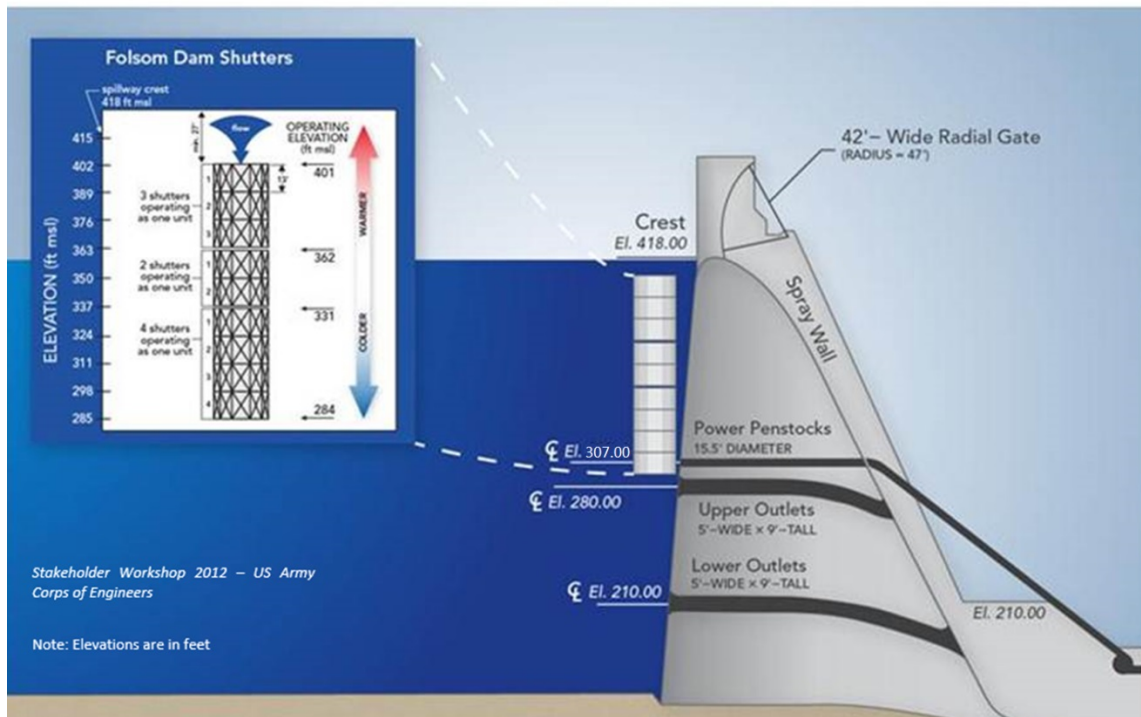
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**Appendix 5B Figure 7. Folsom Dam Outlet Structures.**



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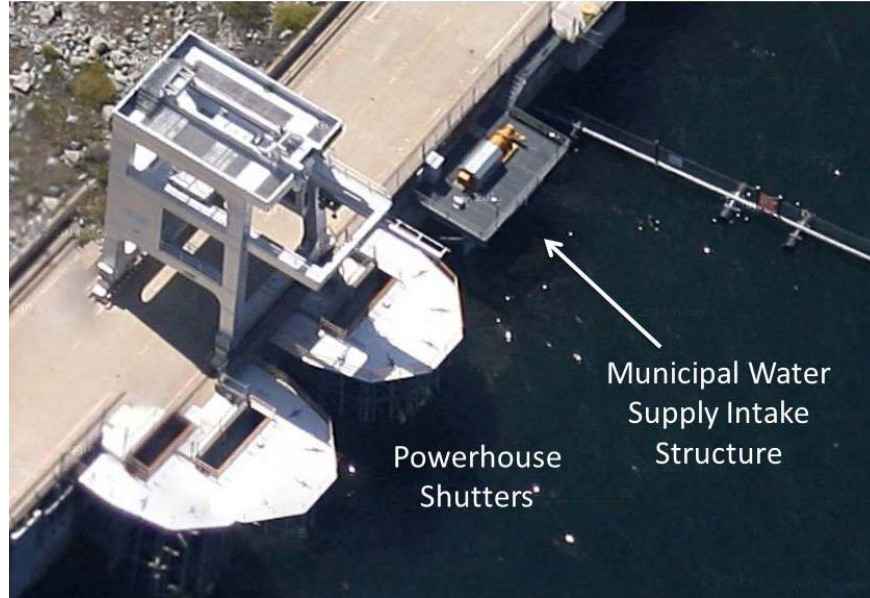
**Appendix 5B Figure 8. Upstream View of Folsom Reservoir Dam.**



S:\PROJECTS\PCWA Water Rights\02\_Technical Appendix\_Hydro\_Temp\05\_Temperature Modeling\05B\_Folsom\00\_Data\Folsom Dam Water Control Manual\_from MFinnegan\FMOS\_2012\_08\_08 Stakeholder Workshop Template-DRAFT DA MV-.pptx

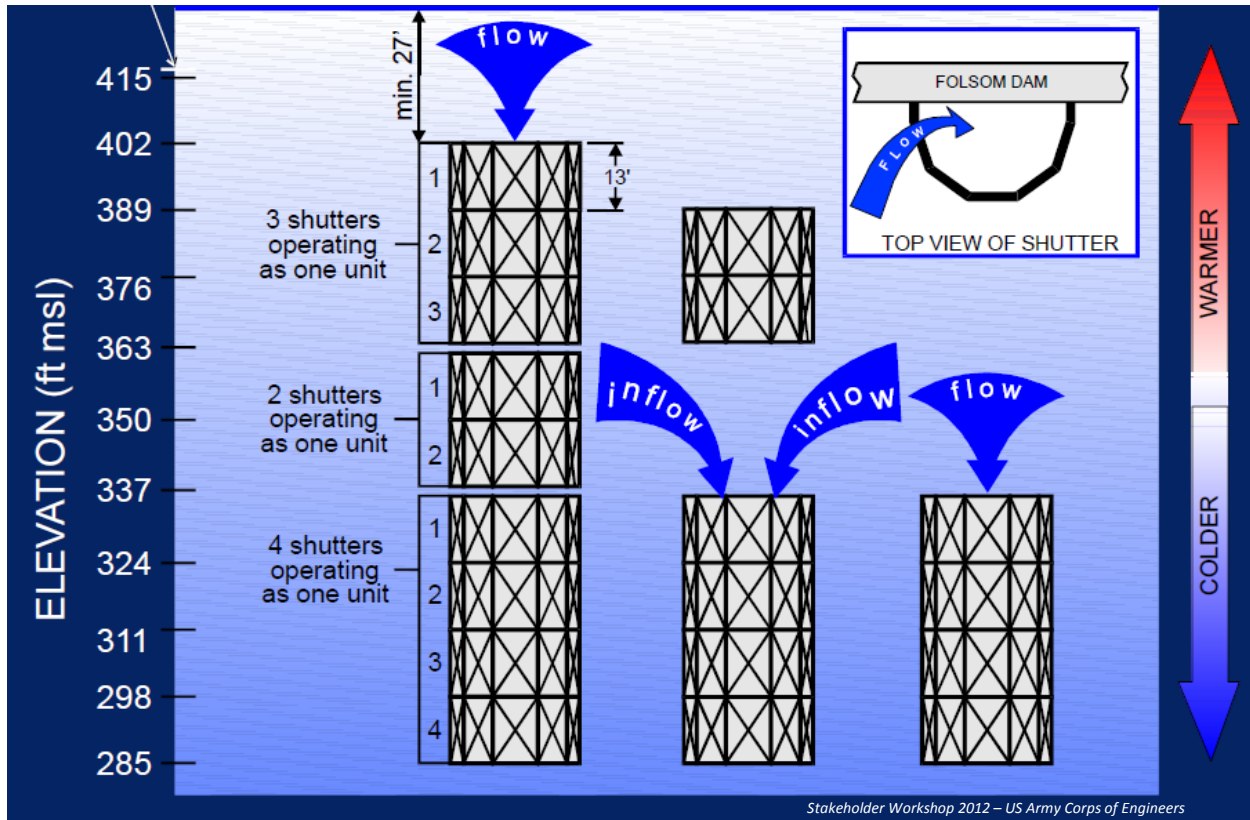
**Appendix 5B Figure 9. Side View Schematic of Folsom Dam Outlets and Shutters.**





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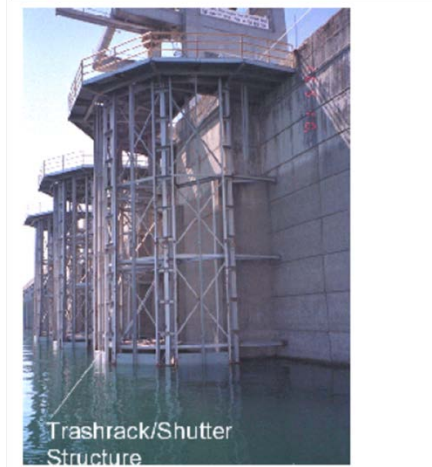
**Appendix 5B Figure 10. Location of Municipal Water Supply Intake Structure.**



Stakeholder Workshop 2012 – US Army Corps of Engineers

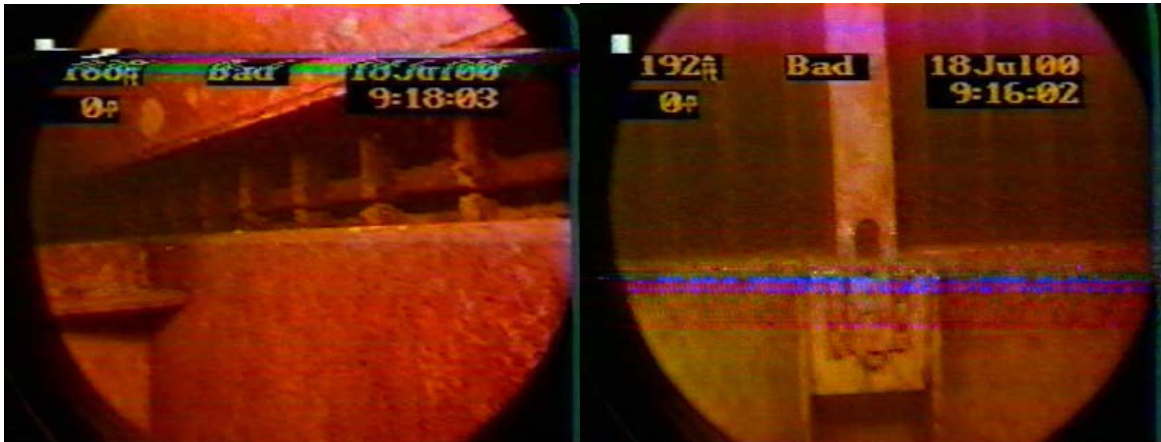
S:\PROJECTS\PCWA Water Rights\02\_Technical Appendix\_Hydro\_Temp\05\_Temperature Modeling\05B\_Folsom\00\_Data\Folsom Dam Water Control Manual\_from MFinnegan\FMOS\_2012\_08\_08 Stakeholder Workshop Template-DRAFT DA MV-.pptx

**Appendix 5B Figure 11. Powerhouse Shutter Schematic.**



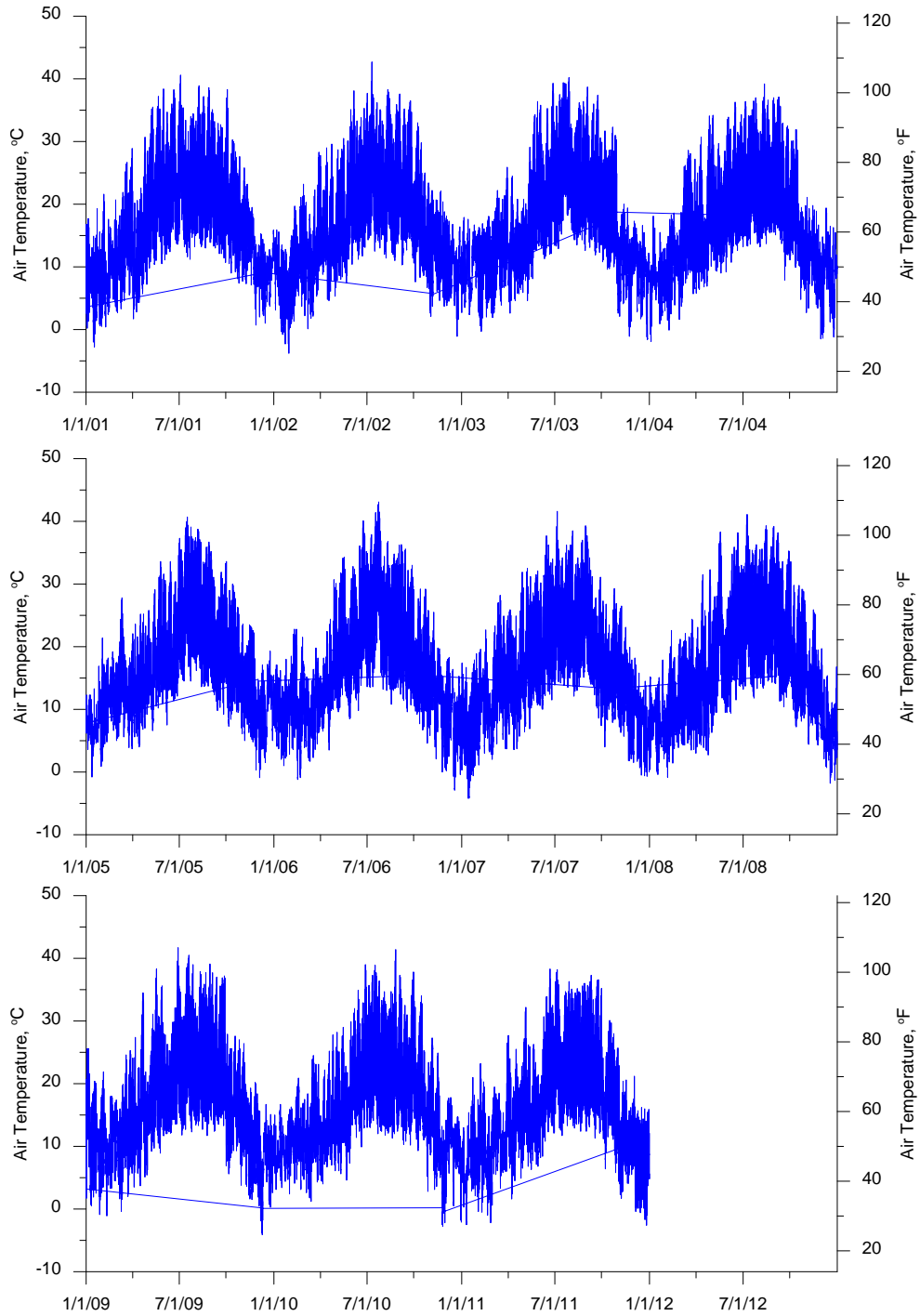
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**Appendix 5B Figure 12. Powerhouse Intakes – Top of Shutters Showing.**



Source: LAR\_Temps\_WF\_Plenary\_011013\_handout.pdf

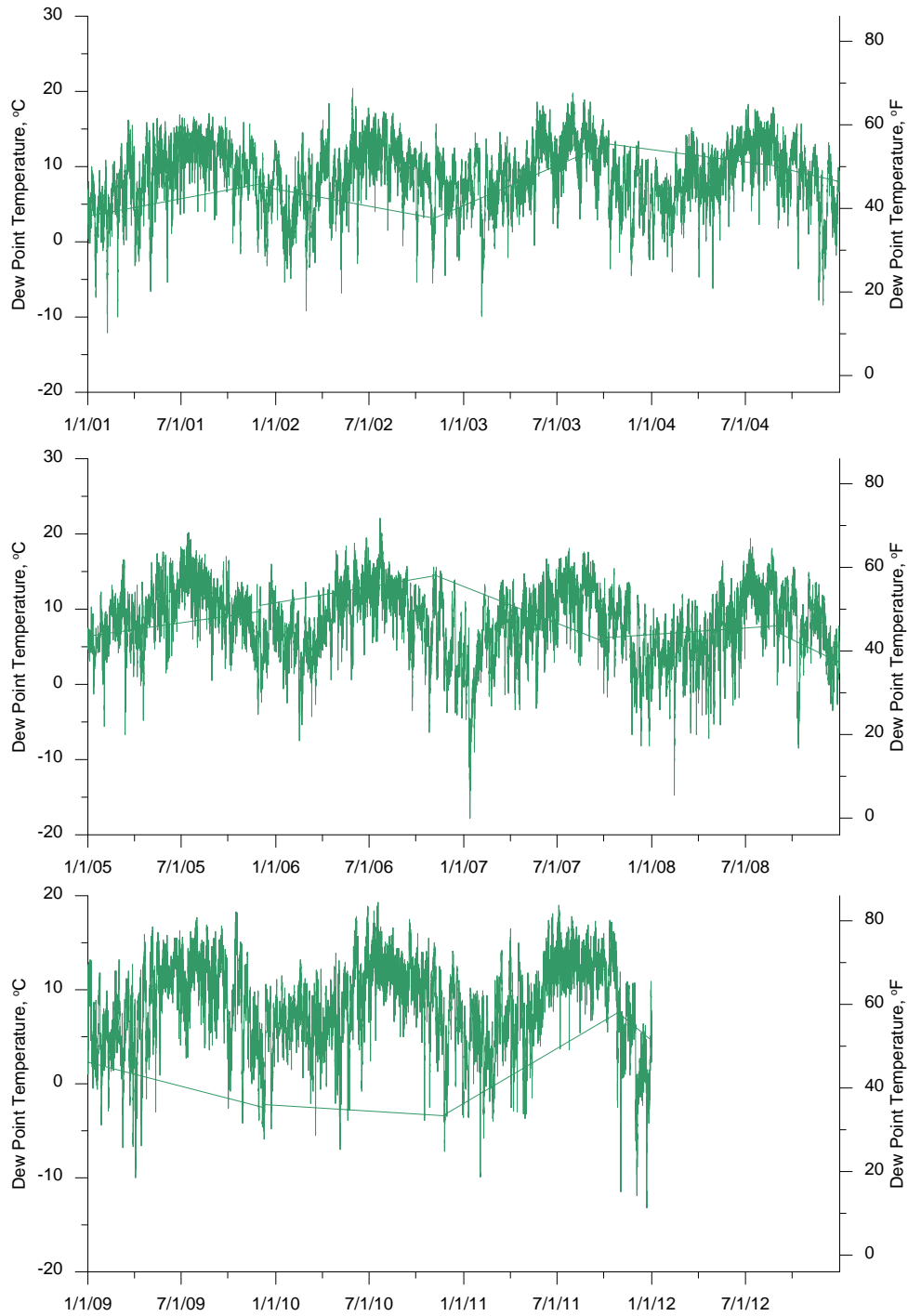
**Appendix 5B Figure 13. Photograph of Gaps in Submerged Shutters.**



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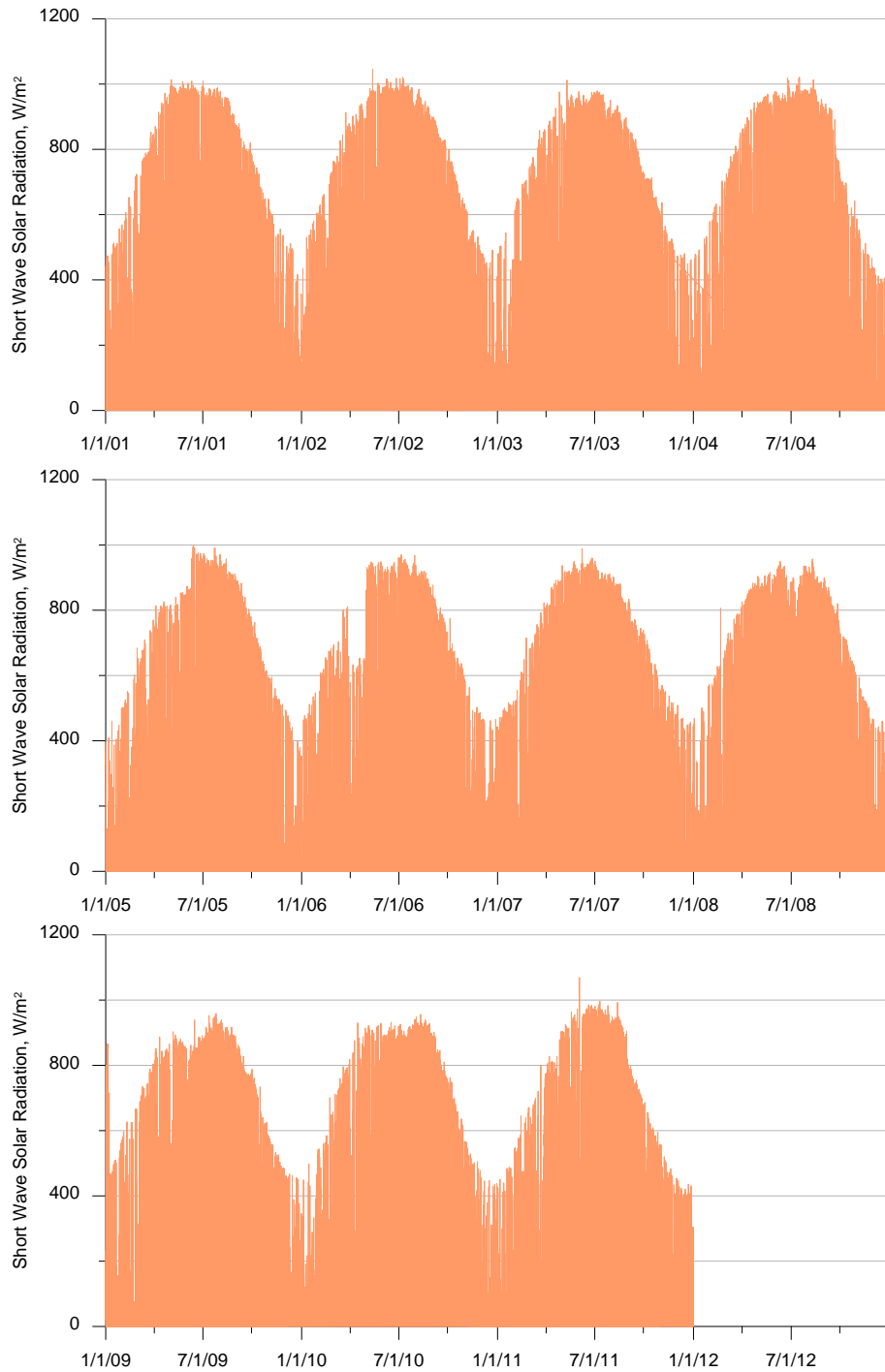
**Appendix 5B Figure 14. Fair Oaks Air Temperature, 2001-2011 (Station CIMIS-131).**





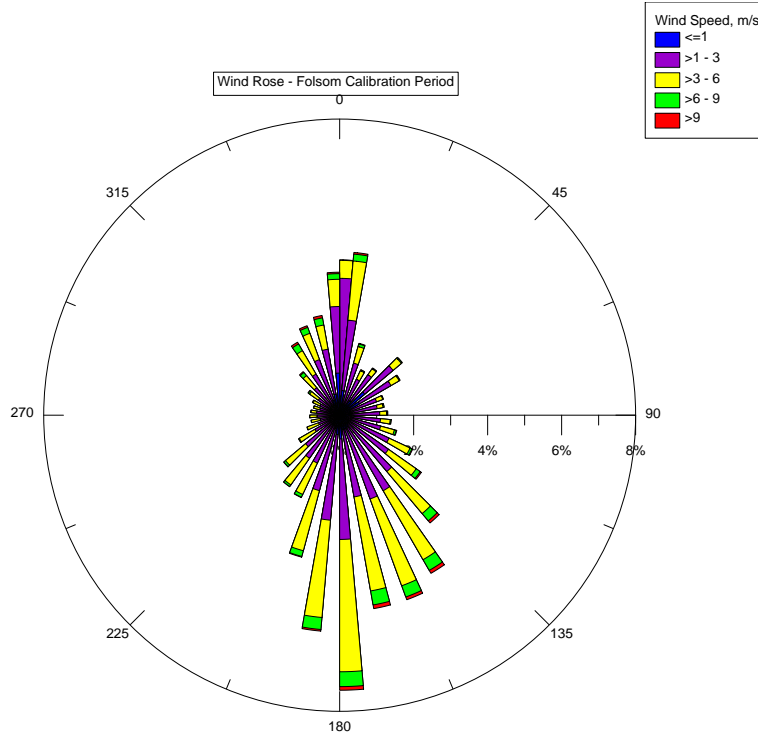
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**Appendix 5B Figure 15. Fair Oaks Dew Point Temperature, 2001-2011 (Station CIMIS-131).**



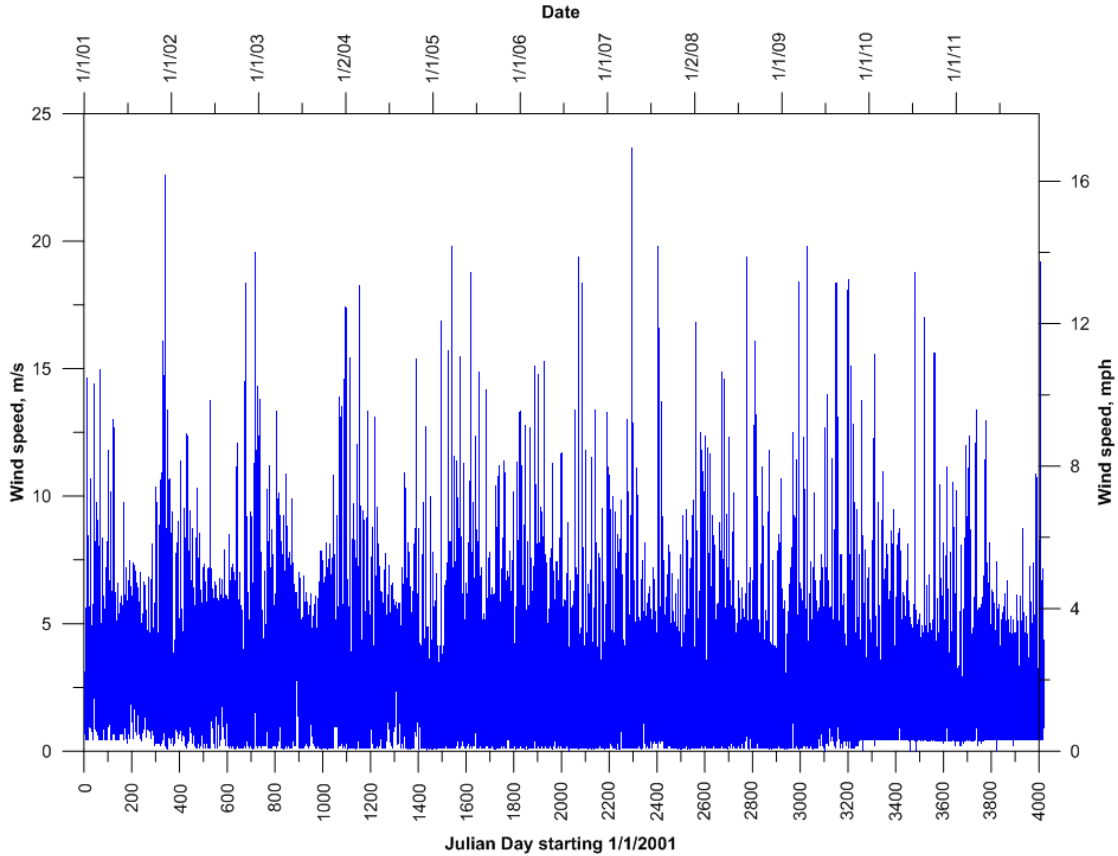
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**Appendix 5B Figure 16. Fair Oaks Solar Radiation Data, 2001-2011 (Station CIMIS-131).**



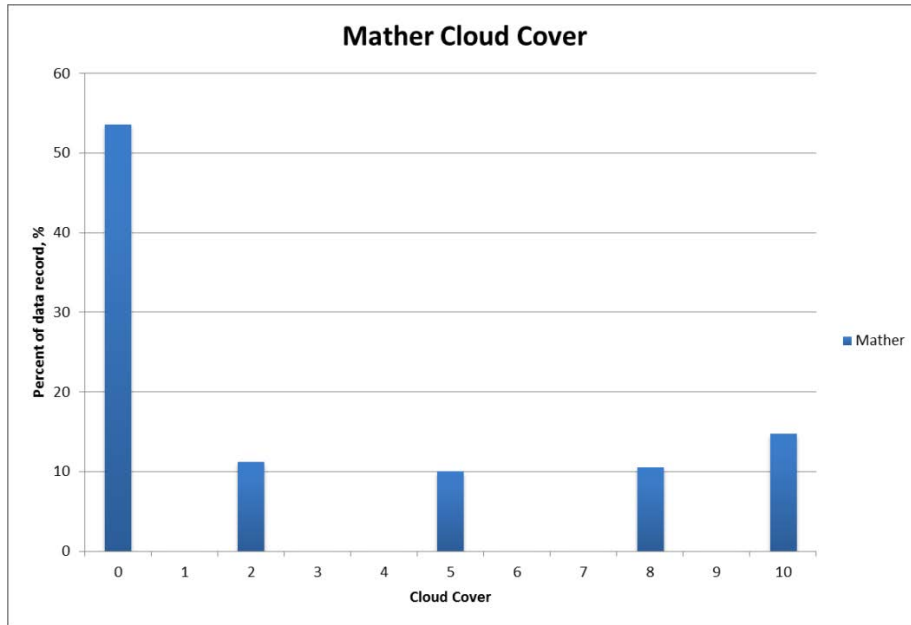
S:\PROJECTS\PCWA Water Rights\02\_Technical Appendix\_Hydro\_Temp\05\_Temperature Modeling\05B\_Folsom\00\_Data\Meteorological Data\ Analysis of Wind Data for Calibration Period.docx

**Appendix 5B Figure 17. Composite Wind Rose Showing Wind Speed and Duration, 2001-2011 (Multiple Stations).**



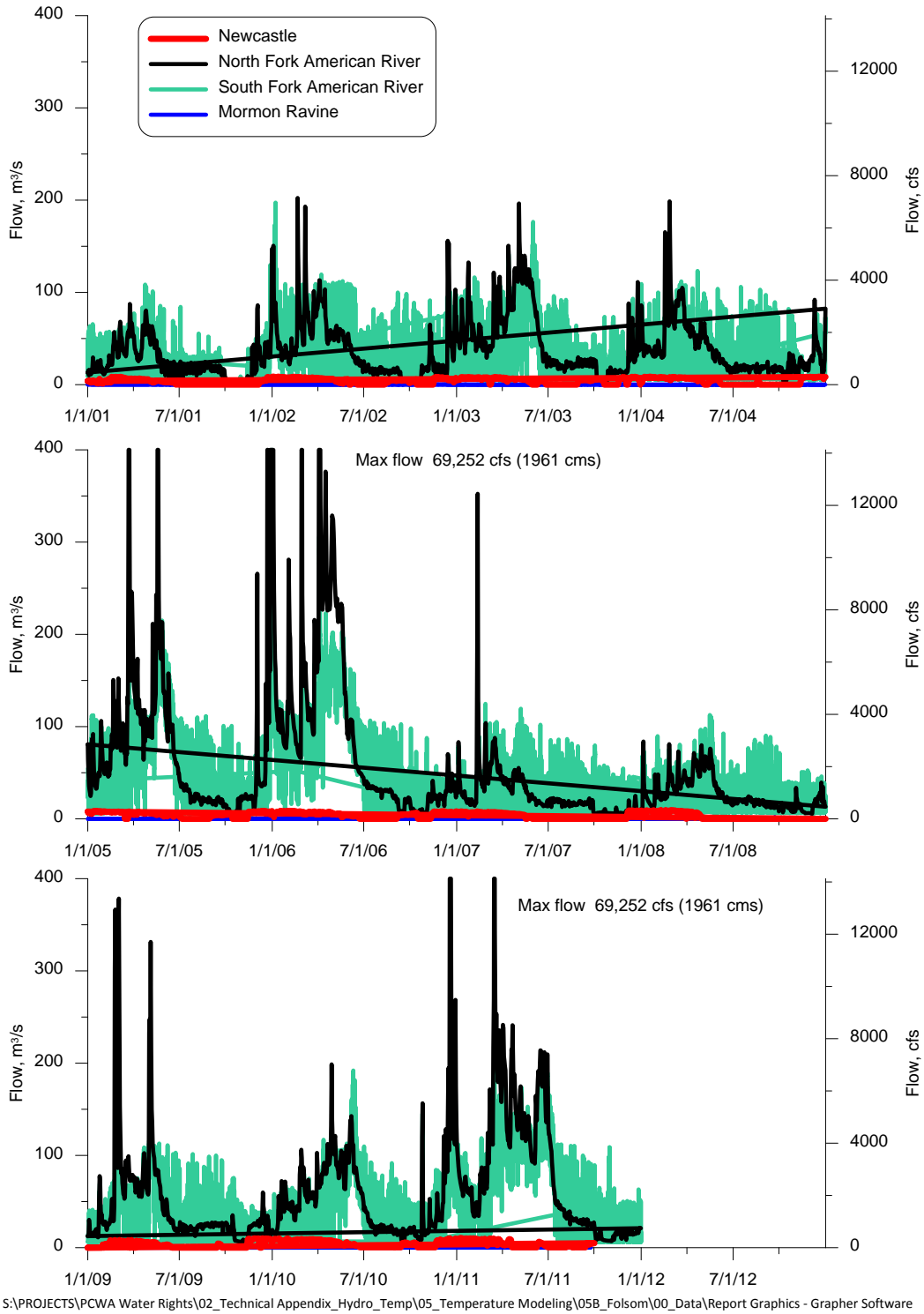
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**Appendix 5B Figure 18. Wind Speed, 2001-2011 (Multiple Stations).**

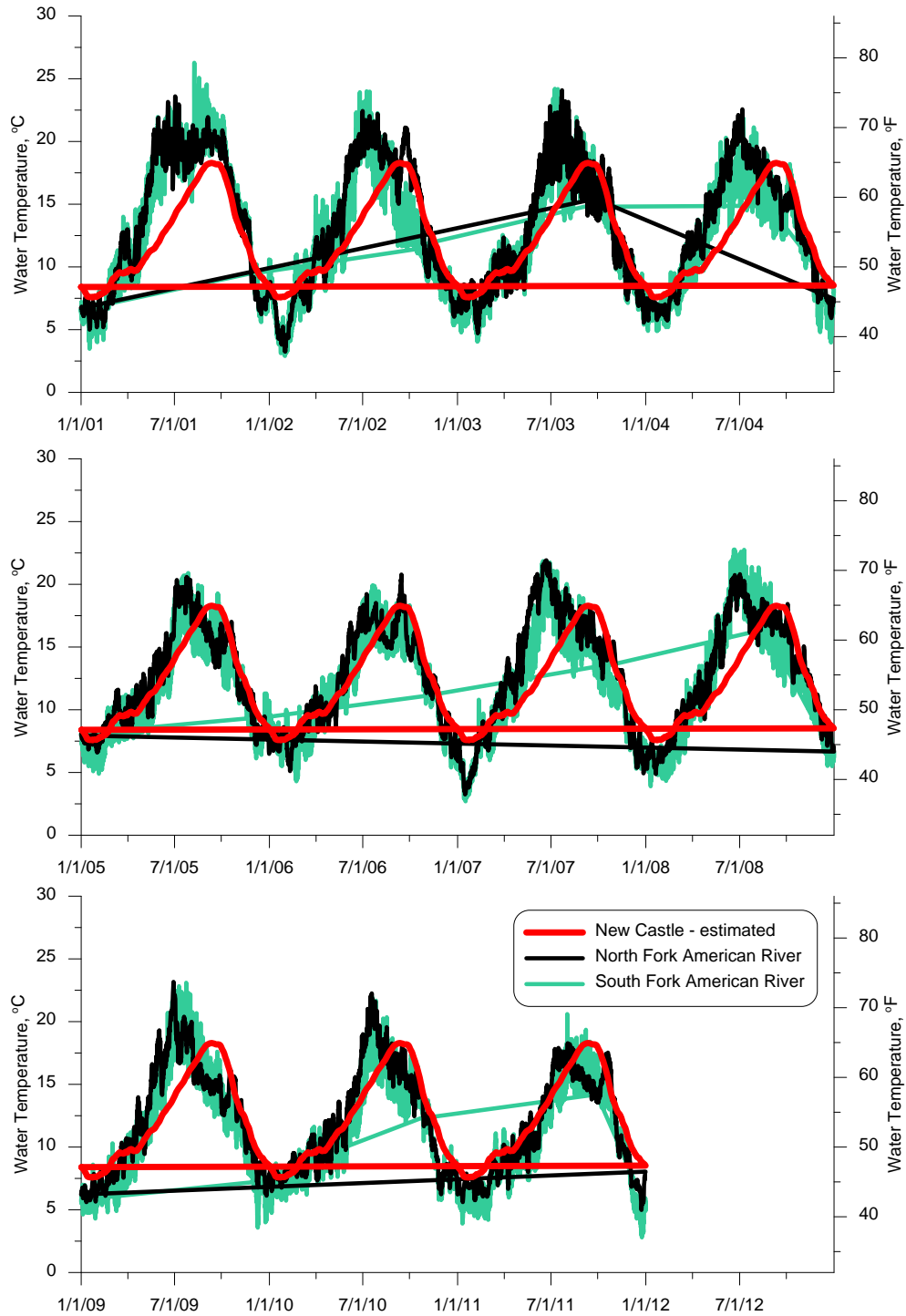


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**Appendix 5B Figure 19. Cloud Cover, 2001-2011 (Mather AFB MET Station).**

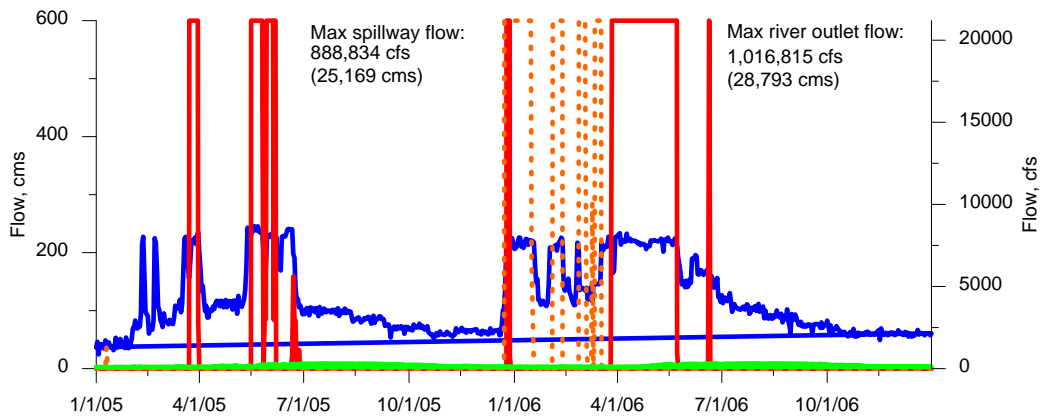
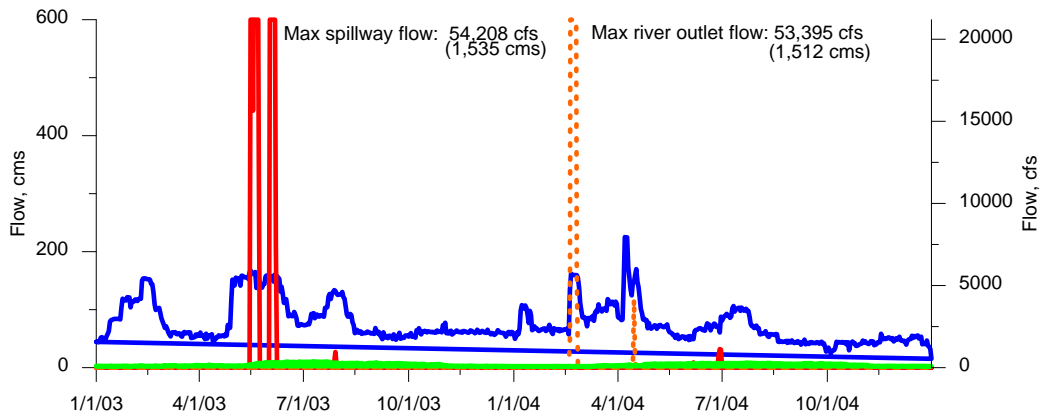
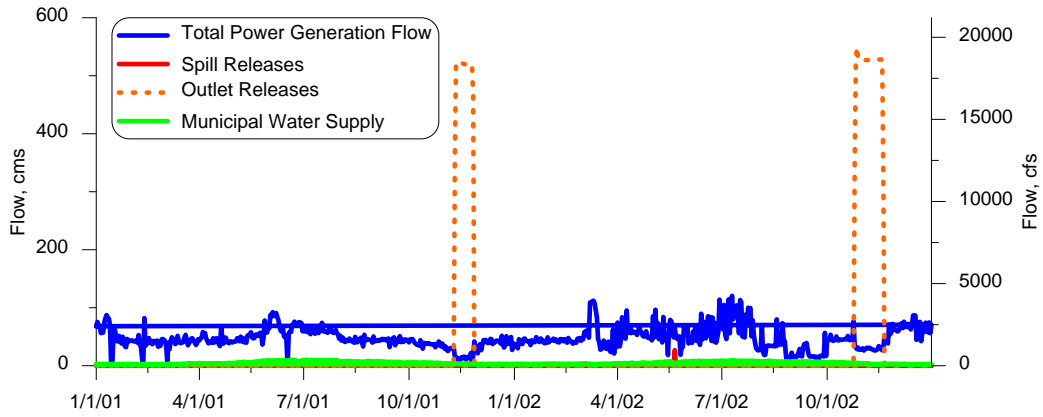


**Appendix 5B Figure 20. Inflows to Folsom Reservoir, 2001-2011.**

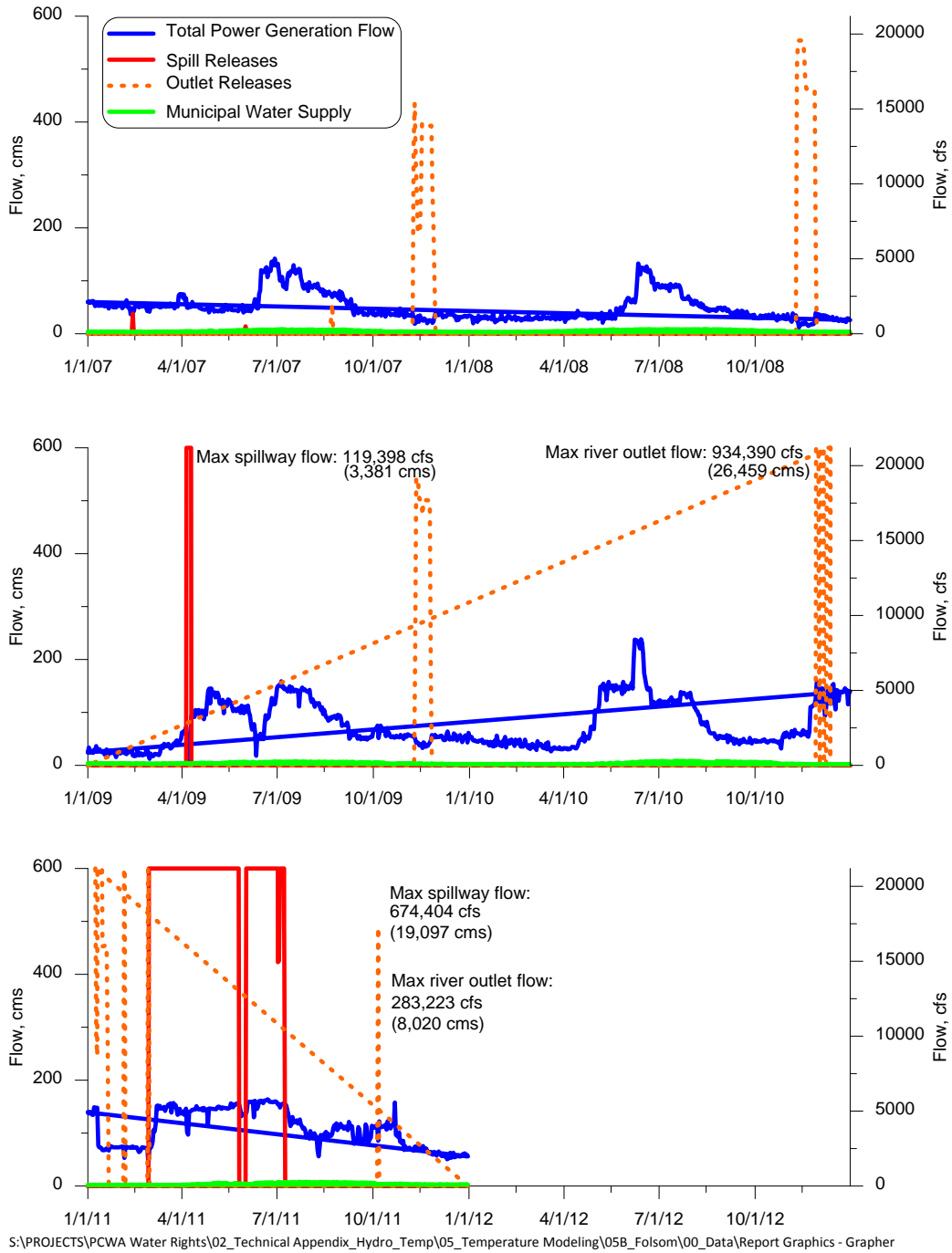


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**Appendix 5B Figure 21. Inflow Water Temperatures to Folsom Reservoir, 2001-2011.**

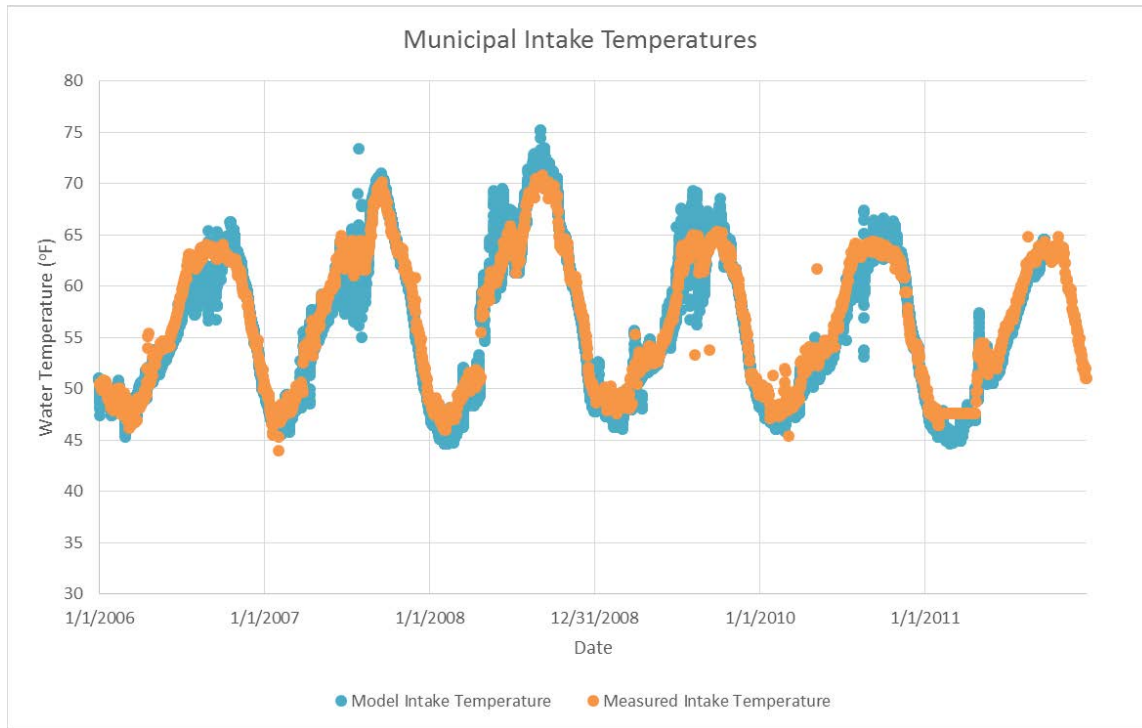


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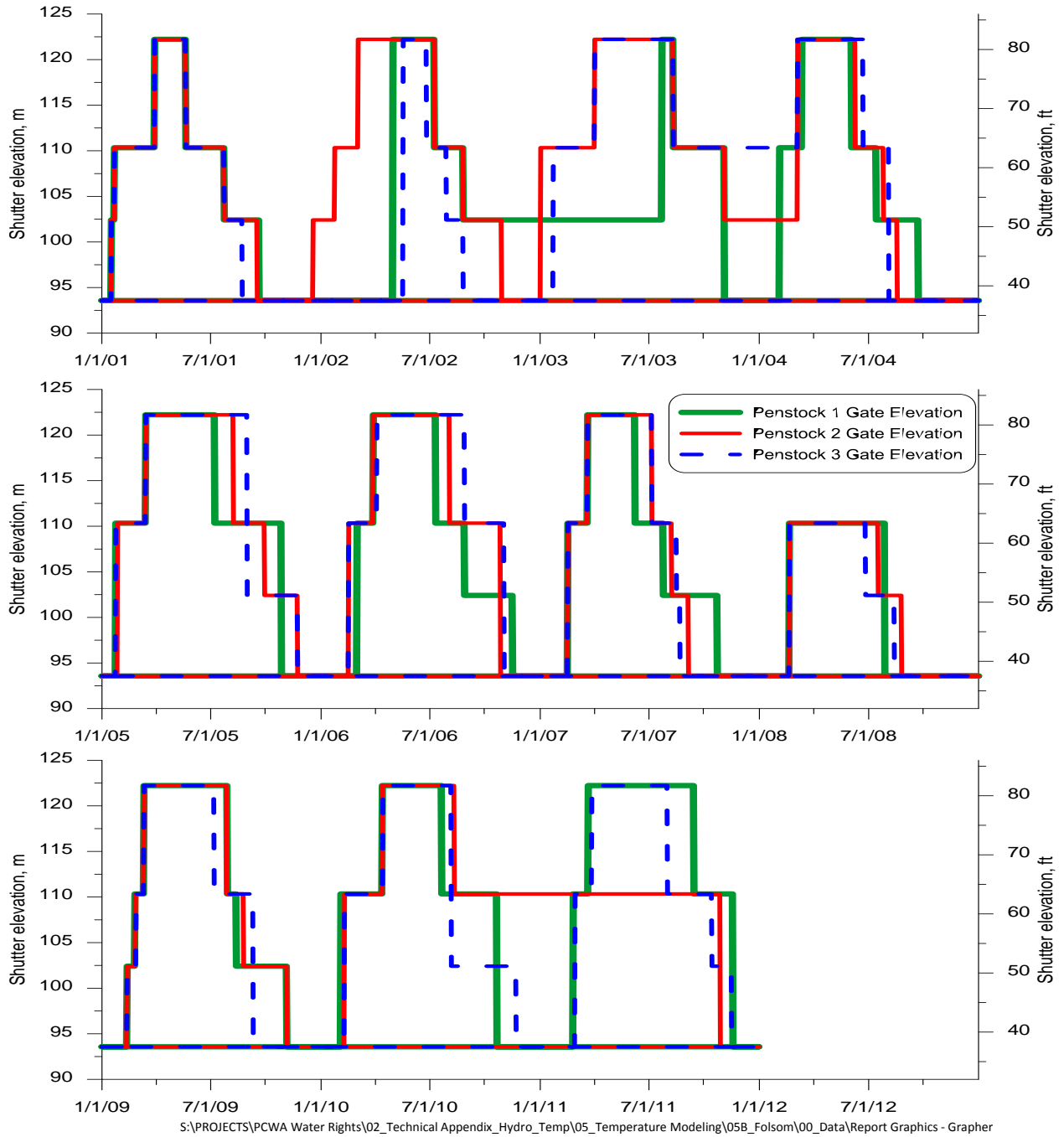


Appendix 5B Figure 22. Outflow Summary from Folsom Dam 2001-2011.



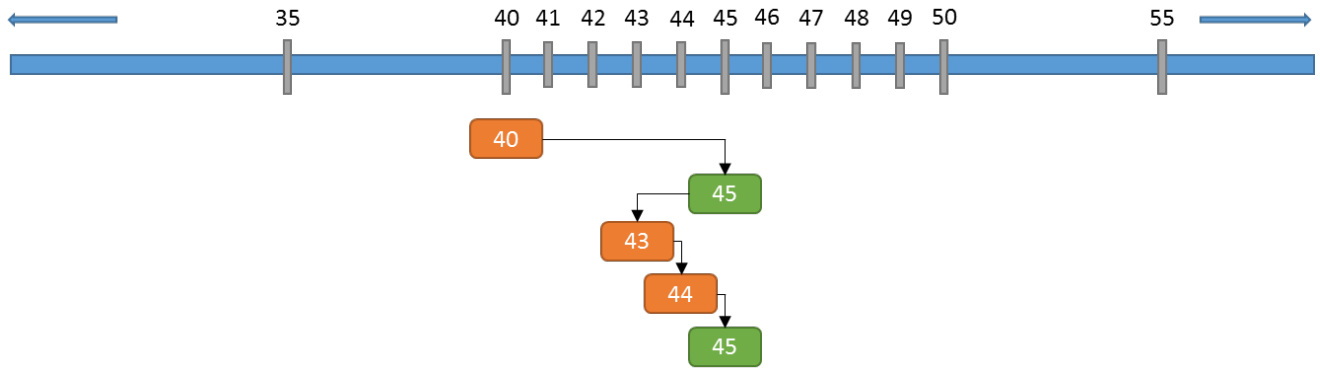


**Appendix 5B Figure 23. Plot of Municipal Water Supply Intake Modeled vs. Actual Temperature 2006-2011.**

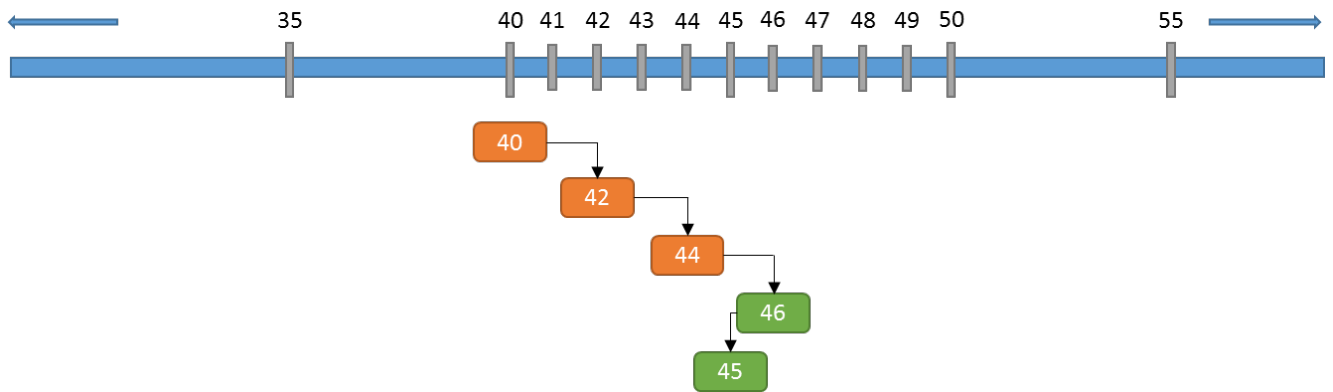


Appendix 5B Figure 24. Folsom Dam Powerhouse Shutter Operations, 2001-2011.

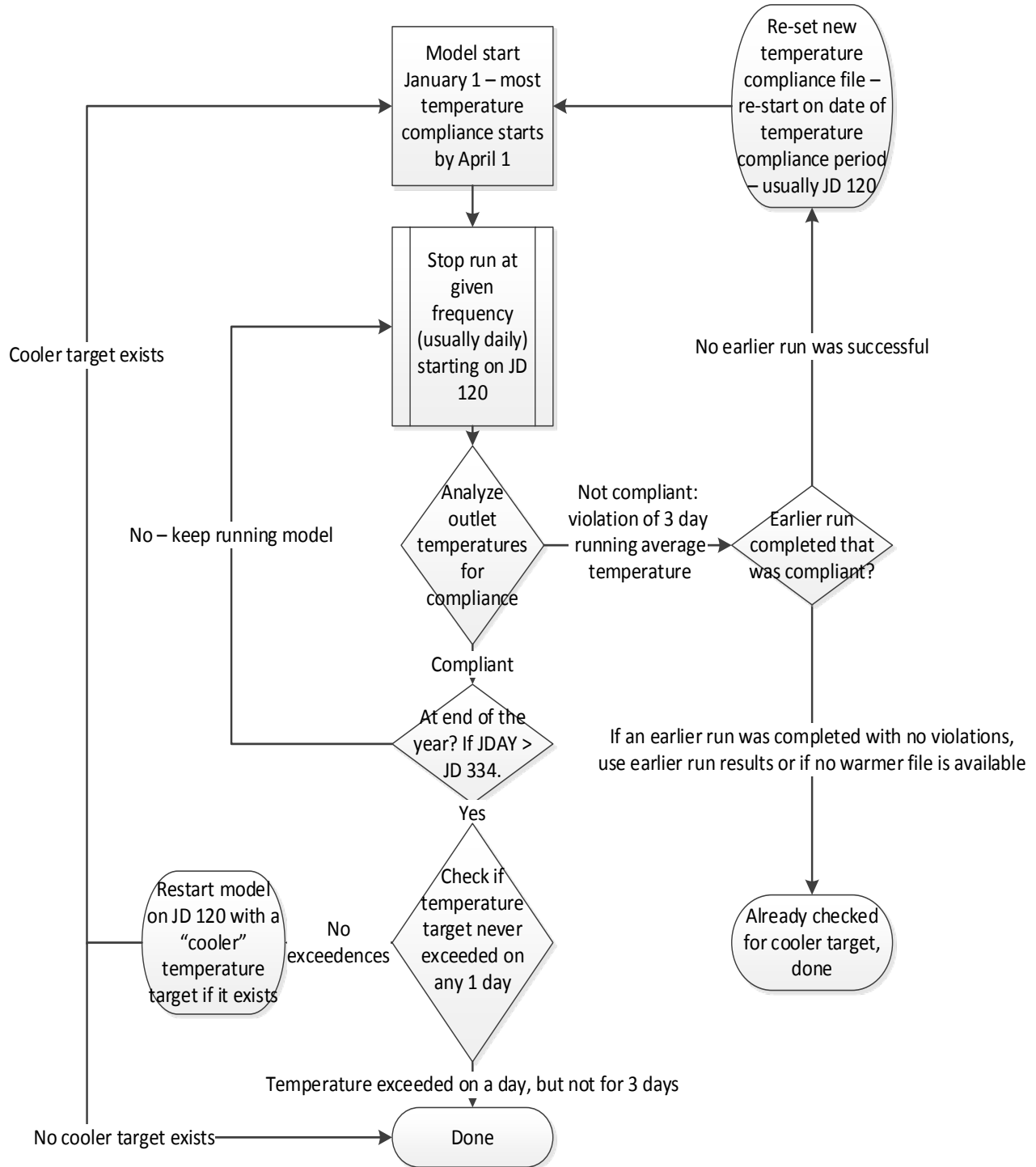
Method 1: Bi-section



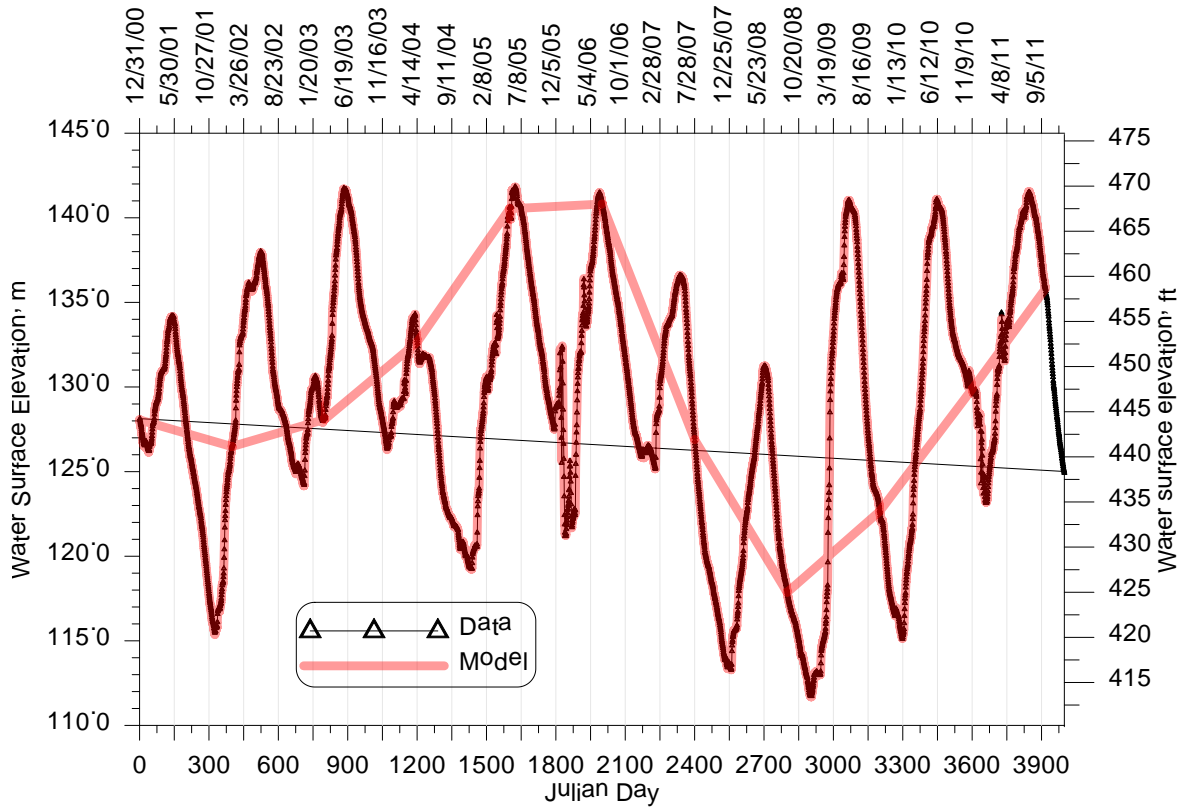
Method 2: 2-Step



**Appendix 5B 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.**



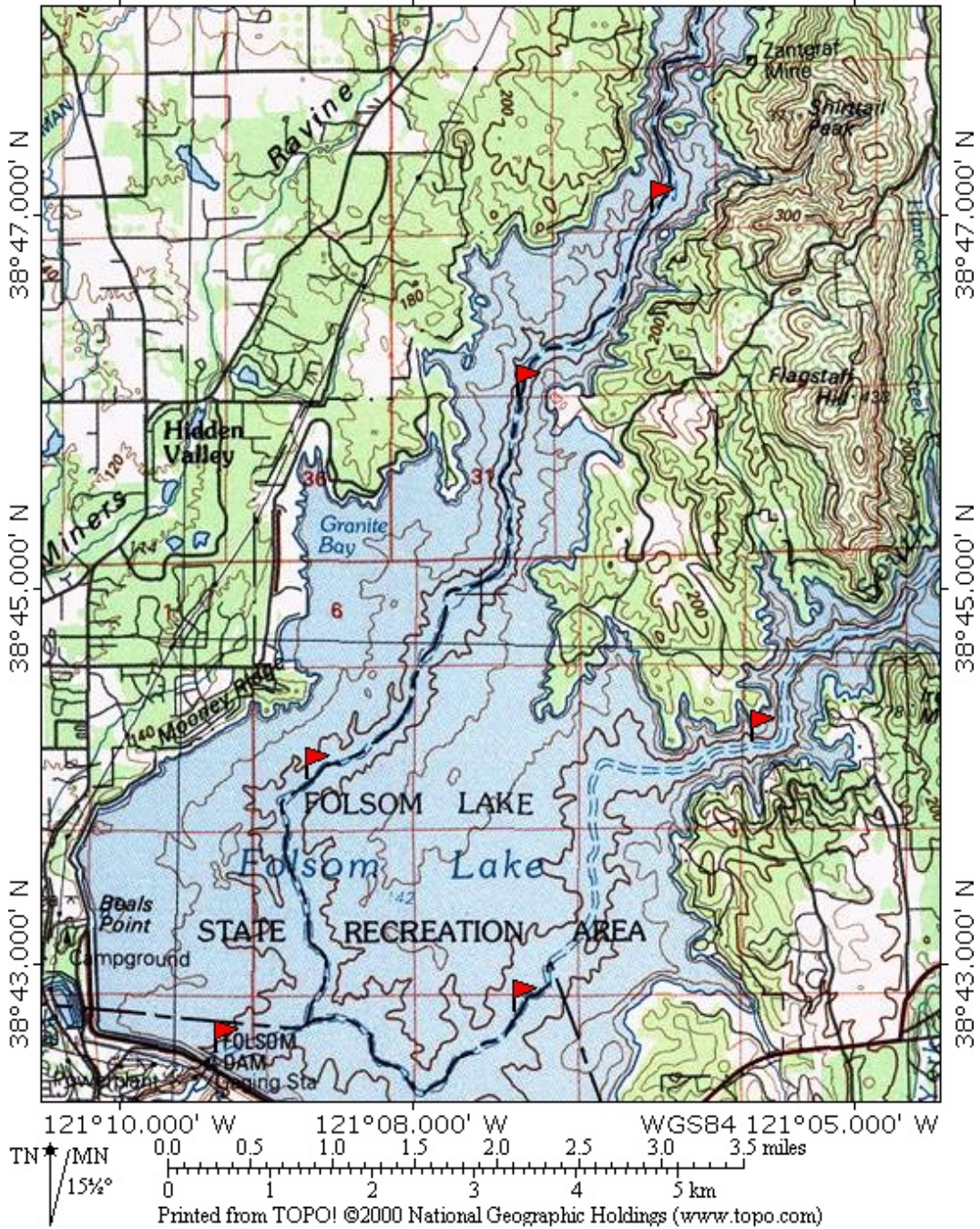
**Appendix 5B Figure 26. Flow Chart for Automatic Model Selection of Optimal Temperature Schedule.**



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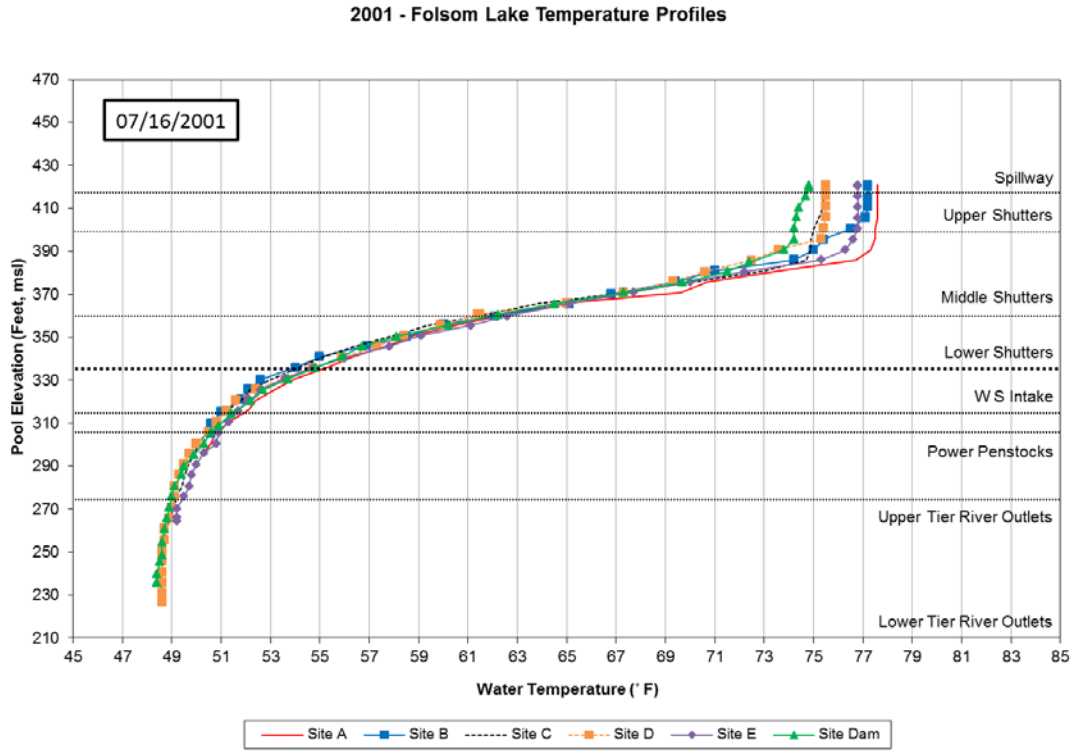
**Appendix 5B Figure 27. Comparison of Model Water Surface Elevation with Measured Data, 2001-2011.**

TOPO! map printed on 04/26/01 from "folsom.tpo" and "Untitled.tpg"  
 121°10.000' W      121°08.000' W      WGS84 121°05.000' W



**Appendix 5B Figure 28. Historic Locations of Temperature Profile Stations.**

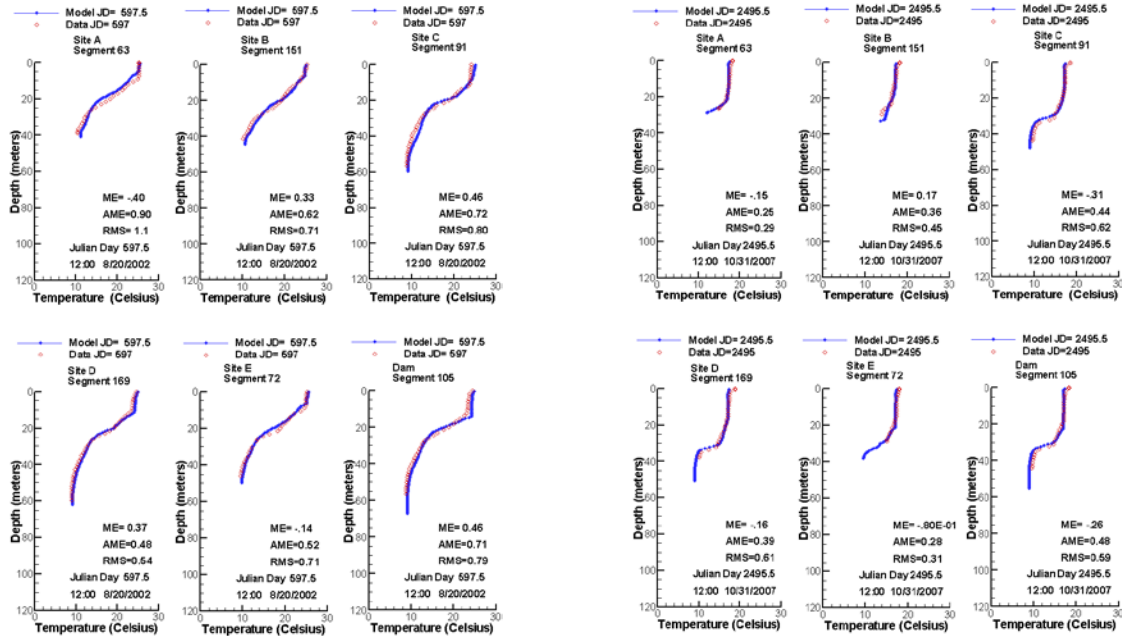




**Appendix 5B Figure 29. Folsom Reservoir Temperature Profile Collected on 7/16/2001.**

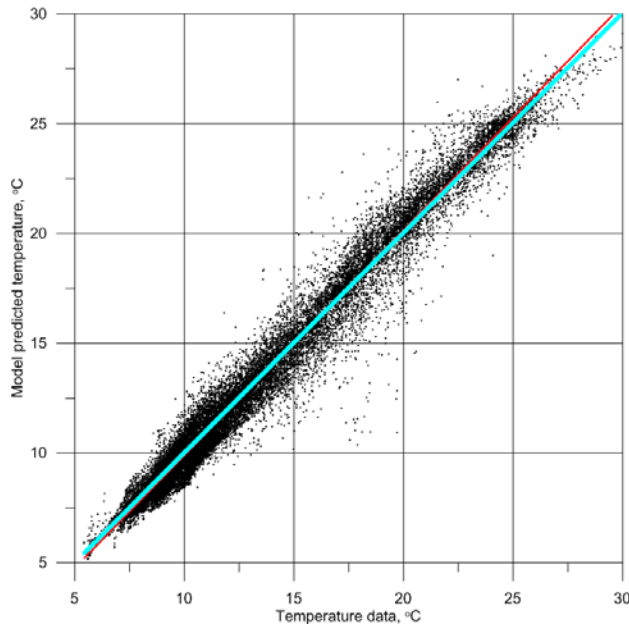


**Appendix 5B Figure 30. Location of Temperature Probe Downstream of Folsom Dam.**



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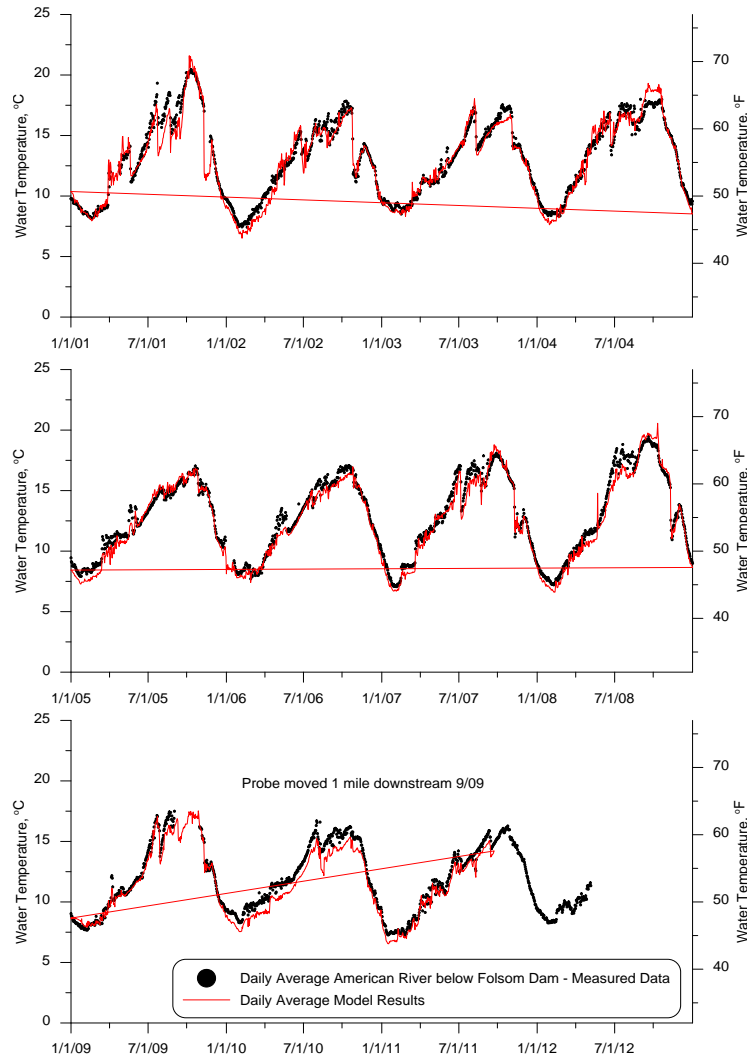
**Appendix 5B Figure 31. Model Temperatures Compared to Measurements on August 20, 2002 (left) and October 31, 2007 (right) at 6 Different Stations in Folsom Reservoir.**



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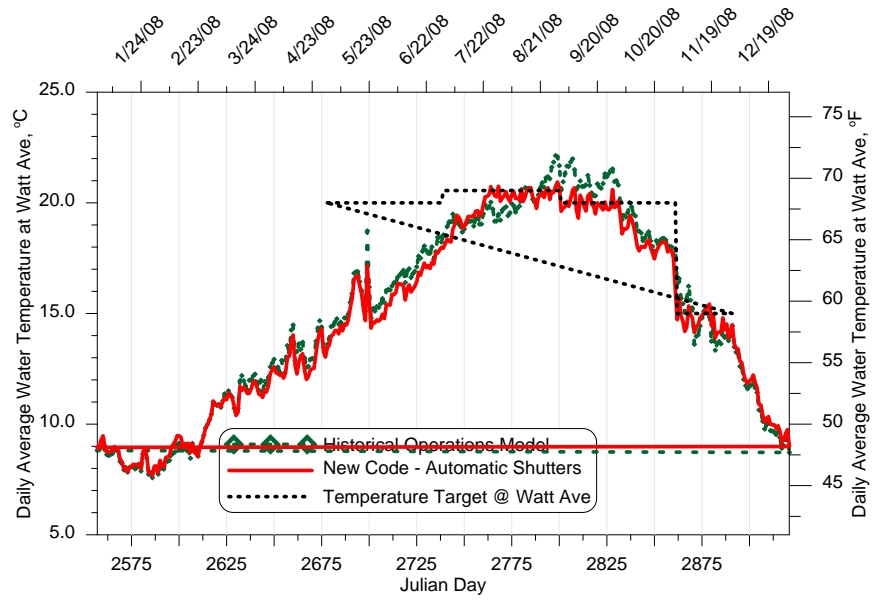
**Appendix 5B Figure 32. Comparison of Model Predicted in-Reservoir Water Profile Temperatures and Measured Profile Data, 2001-2011.**





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**Appendix 5B 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.**



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**Appendix 5B Figure 34. Comparison of Historical vs. Automated Model Scenarios of Watt Avenue Water Temperature, 2008.**