TECHNICAL MEMORANDUM 2-6

Water Temperature Models

Yuba River Development Project

FERC Project No. 2246

October 2013

TECHNICAL MEMORANDUM 2-6

EXECUTIVE SUMMARY

In 2012, Yuba County Water Agency (YCWA) began development of three water temperature models of reservoirs and stream reaches potentially affected by YCWA's Yuba River Development Project (Project). The areas and model platforms used for each were:

- Upper Temp Model. The United States Army Corps of Engineers' (USACE's) HEC-5Q "Alpha" version 8.0 from June 9, 1997 was selected to model Project affected reaches and reservoirs upstream of Englebright Reservoir. These included New Bullards Bar Dam; Our House Diversion Dam; Log Cabin Diversion Dam; Lohman Ridge Diversion Tunnel; Camptonville Diversion Tunnel; Bullards Bar Minimum Flow Powerhouse; New Bullards Bar Reservoir low-level outlet; New Colgate Penstock and Powerhouse; Middle Yuba River below Our House Diversion Dam; Oregon Creek below Log Cabin Diversion Dam; North Yuba River below New Bullards Bar Dam; and the Yuba River between the confluence of the North Yuba River and Middle Yuba River and Englebright Reservoir.
- Englebright Temp Model. USACE's CE-QUAL-W2, version 3.71, was selected to model Englebright Reservoir.
- Lower Temp Model. USACE's HEC-5Q "Alpha" version 8.0 from June 9, 1997, was selected to model the Yuba River downstream from Englebright Dam to the confluence with the Feather River.

In the Upper Temp Model, New Bullards Bar Reservoir was represented as a vertically-stratified reservoir; its water temperature profile was calibrated to match historically-measured profiles near the New Colgate Penstock intake. Our House and Log Cabin diversion dams were represented as longitudinally-stratified reservoirs with no storage capacity. Physical information was incorporated into the model for New Bullards Bar Reservoir and its outlets, Our House and Log Cabin diversion dams and their outlets, and the river reaches between those dams and the upper extent of Englebright Reservoir.

The Englebright Temp Model represents Englebright Reservoir as a two-dimensional reservoir, with vertical stratification represented at many points along the centerline of the reservoir. The CE-QUAL-W2 reservoir temperature model simulates water-surface elevations, velocities, and temperatures for Englebright Reservoir based on inflows and outflows. Detailed bathymetric information was used to develop the Englebright Temp Model, along with physical information about Englebright Dam and its outlets. Englebright Reservoir bathymetric information came from a 2002 USGS bathymetric survey for Englebright Reservoir; information about Englebright Reservoir outlets came from YCWA and Pacific Gas and Electric Company (PG&E). The model was calibrated to match historically-measured water temperature profiles measured near the Narrows 2 Powerhouse intake and water temperatures at the Smartsville gage (USGS 11418000).

In the Lower Temp Model, releases from Englebright Reservoir were combined with inflows from Deer and Dry creeks and diversions at Daguerre Point Dam. Detailed physical geometry was utilized for the Yuba River in the models that include those reaches. The model of the Yuba River below Englebright Dam was calibrated to accurately represent water temperatures at the Marysville gage (USGS 11421000).

Input data for the models, including input water temperatures and meteorology were developed for three simulation modes: 1) calibration; 2) validation; and 3) Base Case simulations. Input water temperatures for the calibration mode were, as much as possible, historical water temperatures from data collected by YCWA to support the model development as part of Study 2-5, *Water Temperature Monitoring*. Both the validation and Base Case simulation modes were run for longer periods of record than was supportable by water temperature data collected by YCWA, so synthetic inflow temperatures were developed by repeating available data based on hydrologic conditions for the desired period of record. Similarly, meteorological data were readily available for the calibration mode from weather stations within close proximity of the model regions. But, both the validation and Base Case simulation modes required an extension of available historical meteorology with synthetic data developed through comparison with meteorological data from a station with full period-of-record data available. Synthetic input temperatures and meteorology were successfully tested in the validation process of the models.

Development of all three models is complete.

This study was conducted in conformance with the FERC-approved Study 2.6, *Water Temperature Model*, with two variances. First, a matrix comparing various model platforms and using an explicit scoring approach to select the model platforms was not used. Instead, YCWA and the Relicensing Participants discussed potential platforms in meetings and agreed on the platform after considering a range of alternatives. Second, the model and documentation were scheduled to have been completed in September 2012, but due to delays in receiving channel geometry information and in challenges associated with resolving the Englebright Reservoir water temperature model water balance, completion of the study was delayed.

The study is complete.

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WATER TEMPERATURE MODELS[1]

Yuba County Water Agency's (YCWA) continued operation and maintenance (O&M) of the Yuba River Development Project, Federal Energy Regulatory Commission (FERC or Commission) Project Number 2246 (Project) will affect water temperatures in stream reaches downstream from the Project.

1.0 Study Goals and Objectives

The goal of the study was to develop one or more water temperature models that could be used to simulate water temperature conditions using historical meteorology and hydrology with current Project operations, and to simulate potential future Project operations.[2]

The objective of the study was to develop a water temperature model that all interested Relicensing Participants agreed is reasonably reliable for the purposes of Relicensing, and also agree to use this water temperature model to make relicensing recommendations. The model objectives included:

- Simulate reservoir and stream water temperatures resulting from historical meteorology, hydrology, and Project operation and maintenance
- Include both Project and non-Project reservoirs and stream reaches below the Project for a period of analysis that covers the range of normal variations in hydrology of the Yuba River
- Accurately reproduce observed reservoir and stream water temperatures, within acceptable calibration standards over a range of hydrologic and meteorological conditions to confidently serve as a modeling platform and tool to simulate potential future operations

2.0 Methods

This study was performed in six parts, each of which is described below.

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1 This technical memorandum presents the results for Study 2.6, *Water Temperature Model*, which was included in YCWA's August 17, 2011 Revised Study Plan for relicensing of the Yuba River Development Project, and approved by FERC in its September 30, 2011 Study Plan Determination. There were no modifications to Study 2.6 subsequent to FERC's September 30, 2011 Study Determination.

2 Model runs beyond those specifically identified in the FERC-approved study were not part of the study. However, after the study is complete, YCWA is willing to make a reasonable number of model runs as collaboratively agreed to between YCWA and Relicensing Participants.

2.1 Study Area

The study area included: 1) the Middle Yuba River from and including Our House Diversion Dam impoundment to the confluence with the North Yuba River; 2) Oregon Creek from and including the Log Cabin Diversion Dam impoundment to the confluence with the Middle Yuba River; 3) the North Yuba River from and including New Bullards Bar Dam Reservoir to the confluence with the Middle Yuba River; and 4) the portion of the Yuba River from the confluence of the North and Middle Yuba rivers to the Feather River, including the United States Army Corps of Engineers' (USACE's) Englebright Reservoir.[3]

2.2 Model Platforms and Time-Step Selections

To select the water temperature model or model platforms, YCWA developed a list of required water temperature model platform attributes necessary to meet the study goal and objectives. The attributes were:

- Produce results such that Relicensing Participants could agree on the validity of the results.
- Simulate water temperatures on an appropriate time-step to capture biologically-appropriate water temperature variability.
- Simulate water temperatures over the full range of historical hydrology and meteorology experienced by Project-affected streams (i.e., the hydrology period of record from Water Year (WY) 1970 through WY 2010).
- Simulate the effects of New Bullards Bar Reservoir releases through New Colgate Powerhouse on downstream water temperatures due to storage changes, flow changes and outlet used (i.e., the New Colgate Power Tunnel Intake includes multiple inlets).
- Simulate the effects of changes in flow from the New Bullards Bar Dam's low-level outlet and New Bullards Bar Dam Minimum Flow Powerhouse on the North Yuba River and Yuba River temperatures upstream from Englebright Reservoir.
- Simulate the effects of operations of Our House and Log Cabin diversion dams and the associated Lohman Ridge and Camptonville diversion tunnels on water temperatures in the Middle Yuba River and Oregon Creek.
- Simulate the effect of Englebright Reservoir releases, including spill, on water temperatures in the Yuba River.

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[3] Englebright Reservoir is formed by Englebright Dam. The dam is about 260 feet high, was constructed by the California Debris Commission in 1941, and is owned by the United States, and the dam and reservoir is not included as a Project facility in FERC's License for the Yuba River Development Project. When the California Debris Commission was decommissioned in 1986, administration of Englebright Dam and Reservoir passed to the USACE. The primary purpose of the dam is to trap and contain sediment derived from extensive historic hydraulic mining operations in the Yuba River watershed. Englebright Reservoir is about 9 miles long with a surface area of 815 acres. When the dam was first constructed in 1941, it had a gross storage capacity of 70,000 ac-ft; however, due to sediment capture, the gross storage capacity today is approximately 50,000 ac-ft (USGS 2003).

- Simulate the effect of Narrows 1 and Narrows 2 powerhouses operations on water temperatures in the Yuba River.
- Simulate the effects on temperatures due to of irrigation diversions to agricultural water users from diversion locations near USACE's Daguerre Point Dam.[4]
- Be able to incorporate the temperature effects of upstream water projects.

Based on the selection attributes, YCWA and Relicensing Participants considered the following water temperature model platforms, which had been previously used in regional FERC relicensings or in the Project Area:[5]

- River Water Temperature Model Platforms:
  - United States Geological Survey's (USGS) Stream Network Temperature Model (SNTEMP)
  - USGS's Stream Segment Temperature Model (SSTEMP)
  - USGS's Hydrological Simulation Program-Fortran (HSPF) model
  - Stockholm Environmental Institute's (SEI) Water Evaluation and Planning (WEAP) system
- Reservoir Water Temperature Model Platforms:
  - USACE's CE-THERM-R1
  - USACE's CE-QUAL-W2
- River and Reservoir Water Temperature Model Platforms:
  - USACE's Hydrologic Engineering Center-5Q (HEC-5Q) model
  - Hydrocomp, Inc.'s HFAM II model
  - Regression-based model using Microsoft® Excel

The benefits and drawbacks of each of the above model platforms are discussed below.

2.2.1 Potential River Water Temperature Model Platforms

The following model platforms were considered for the simulation of river reaches only.

[4] Daguerre Point Dam, which is about 25 feet high and 575 feet wide, was constructed by the California Debris Commission and has no storage capacity. It is not part of the Yuba River Development Project. The dam was constructed in 1906 and rebuilt in 1964, and is owned by the United States. When the California Debris Commission was decommissioned in 1986, administration of Daguerre Point Dam passed to the USACE. The primary purpose of the dam when it was constructed was to serve as a debris barrier and to stabilize the Yuba River channel after it was re-located.

[5] For this technical memorandum, the Project Area is defined as the area within the FERC Project Boundary and the land immediately surrounding the FERC Project Boundary (i.e., within about 0.25 mile of the FERC Project Boundary) and includes Project-affected reaches between facilities and downstream to the next major water controlling feature or structure.

2.2.1.1 SNTEMP

SNTEMP is a mechanistic, one-dimensional heat transport model for branched stream networks that predicts mean-daily and maximum-daily water temperatures as a function of stream distance and environmental heat flux. Typical applications for SNTEMP include predicting the consequences of stream manipulation on water temperatures. Positive attributes of SNTEMP as a model platform include:

- Widely used and well documented.
- Calculates mean-daily temperatures.
- Uses a regression model to fill in missing data.
- Geometry input is simplistic.
- Includes shading of vegetation and topography.

SNTEMP does meet a majority of the selection criteria; however, SNTEMP has limitations that rank it lower in some categories than other model platforms, and therefore, is not the best modeling platform to be used in this study. Some weaknesses in using SNTEMP as a model platform include the following:

- Uses an empirical approach to predict maximum-daily water temperature.
- Temperature prediction is very sensitive to stream width parameter affecting the heat flux calculation.
- Only simulates a single year (366 time periods), which would require iterations to simulate multiple years.
- Does not internally calculate hydraulic conditions, which would require separate hydraulic modeling of all reaches.

2.2.1.2 SSTEMP

SSTEMP, developed by USGS, is a scaled down version of the USGS model SNTEMP. SSTEMP utilizes hydrology, stream geometry, shading information, meteorological data and stream temperature data to evaluate stream water temperatures. Positive attributes of SSTEMP include:

- Analyzes effects of changing riparian shade of physical features of a stream.
- Estimates the combined topographic and vegetative shading and solar radiation penetrating the water.
- Estimates maximum-, minimum-, and mean-daily temperatures at a specified location.
- Simulates steady-state releases from a dam at the upstream end of the system.
- Used satisfactorily for a variety of simple cases.

- Can be run in batch mode, which enables the user to process multiple dates for a stream segment or multiple stream segments in series for the same day, or a combination of the two.

SSTEMP has limitations that rank it low as a modeling platform to be used in this study. Some weaknesses in SSTEMP as a modeling platform include:

- Simulates a single stream segment for a single period of time (e.g., month, week and day).
- Streams through multiple terrain types need to be broken into sub-reaches and cannot be modeled as one continuous reach.
- Incapable of dealing with rapidly fluctuating flows.
- Uses an empirical approach to predicting maximum-daily water temperatures.
- Turbulence is assumed to thoroughly mix the stream vertically and transversely (i.e., no micro-thermal distributions).

2.2.1.3 HSPF

HSPF focuses on the entire hydrologic cycle and is capable of simulating a wide range of water quality constituents. HSPF uses continuous rainfall and metrological data to compute streamflow hydrology graphs and pollutant graphs. The model has many positive attributes including:

- Simulations are made on a watershed scale, including land-surface runoff and one-dimensional stream channels.
- Simulations are made on a sub-daily time step; maximum-daily temperature is implicitly calculated.
- Includes shading of vegetation and topography.
- Capable of simulating multiple years in a single run.

There are some limitations to choosing HSPF as the modeling platform in this study. These limitations include:

- Requires amassing a large amount of data files, which can be difficult to manage.
- Relies on volumetric calculations to determine surface area and depth of flow rather than hydraulic routing, which can limit the accuracy of the heat exchange calculation.
- Cannot simulate reservoirs.

2.2.1.4 WEAP

WEAP is an integrated water resources planning tool designed to simulate river-basin-wide issues including water use, equipment efficiencies, water allocations, stream flow, groundwater resources, reservoir operations, and water transfers. WEAP includes simulation of both natural, including water temperatures, and engineered components of water systems. Positive attributes of WEAP as a modeling platform include the following:

- Simulations are made on a watershed scale, including rainfall runoff, base flow, and groundwater interaction.
- Capable of simulating a broad-range of timesteps, from daily to annual.
- Includes a graphical-user interface (GUI) for data input and model setup.
- Includes linkage to a parameter estimation tool (PEST) to aid in model calibration.

Negative attributes of WEAP as a modeling platform include the following:

- Not designed to be a water temperature model; it is designed for watershed-wide evaluations and is therefore more complicated than necessary for application as a water temperature model.
- Does not have ability to simulate daily reservoir water temperatures.
- Requires compiling a large amount of data files, which can be difficult to manage.
- Requires a flow-stage-width relationship as an input rather than a hydraulic routing computation, which can limit accuracy of the heat exchange calculation.
- Hydraulic calculations are computed at a reach level, precluding calculation of mid-reach temperatures.

2.2.2 Potential Reservoir Water Temperature Models

The following section provides descriptions of model platforms evaluated for simulation of reservoirs only.

2.2.2.1 CE-THERM-R1

CE-THERM-R1, by the Waterways Experiment Station of the USACE, is a dynamic, one-dimensional, horizontally averaged model used to simulate vertical profiles of water temperature in lakes and reservoirs. A CE-THERM-R1 model of New Bullards Bar Reservoir was developed by YCWA in 1991 (Bookman-Edmonston Engineering, Inc. 1992) but it is no longer available. CE-THERM-R1 is the thermal analysis model associated with CE-QUAL-R1, which is capable of simulating a range of water quality components. CE-THERM-R1 is a reservoir model that simulates density- and wind-driven vertical mixing constituents through a series of horizontal layers. Positive attributes of CE-THERM-R1 as a modeling platform include the following:

- Widely used in reservoir simulations.
- Includes shading of vegetation and topography.
- Capable of simulating gate operations and multiple outlets.
- Capable of simulating variable vertical layer thicknesses.
- Calculates solar radiation internally based on input cloud cover and project latitude and longitude.

Negative attributes of CE-THERM-R1 as a modeling platform in this study include the following:

- Legacy software with limited support.
- Substantial pre-processing of inputs, such as light penetration, is needed.
- Cannot simulate rivers.
- Only provides single dimensional, vertical profile for a reservoir.
- Does not use Hydrologic Engineering Center (HEC) Data Storage System (DSS) for data exchange.

2.2.2.2 CE-QUAL-W2

CE-QUAL-W2, by the Waterways Experiment Station of the USACE, is a two-dimensional, laterally averaged, hydrodynamic water quality model for rivers, estuaries, lakes, reservoirs, and river basin system (Cole and Wells 2011). The model is capable of predicting many different variables, including water–surface elevation, velocity, and temperature at longitudinal segments and vertical layers. Positive attributes of CE-QUAL-W2 as a modeling platform include the following:

- Widely used in reservoir simulations
- Well suited for relatively long and narrow waterbodies
- Includes shading of vegetation and topography
- Capable of simulating gate operations and multiple outlets
- Capable of simulating multiple years in a single run

Negative attributes of CE-QUAL-W2 as a modeling platform in this study include the following:

- Relatively calculation intensive, requiring a lot of computer resources and several hours of run time.
- Accurate representation of a reservoir requires detailed input data, including bathymetry and topographic shading.

- Requires sub-daily meteorological data inputs, which a) requires long records of input data that can be hard to manage, and b) may need to be estimated if historical data do not exist.
- Does not use HEC-DSS for data exchange.

2.2.3 Potential River and Reservoir Water Temperature Models

The following section provides descriptions of model platforms capable of simulating both rivers and reservoirs.

2.2.3.1 HEC-5Q

HEC-5Q, by the HEC of the USACE, is a one-dimensional model platform designed to simulate the sequential operation of a reservoir-channel system with branch network configuration. A HEC-5Q model of the Yuba River below Englebright Dam was developed by YCWA in 1991 (YCWA 1992) to simulate Water Years (WYs) 1974 though 1978. However, due to the limited coverage and period of record of the model, that particular application of the model platform is not usable for the FERC Relicensing process. Positive attributes of HEC-5Q as a modeling platform include:

- Capable of simulating gate operations and multiple outlets.
- Contains integrated hydraulic and hydrologic routing calculations.
- Widely used and accepted platform.
- Uses HEC-DSS for easy data exchange between models.
- Uses an equilibrium temperature as an input to simplify meteorological conditions; it can be computed in an external processor.
- Capable of simulating multiple years in a single run.
- Capable of simulating reservoir vertical mixing either as a factor of water column stability or wind.
- Very short processing time; requires limited computing resources.

Negative attributes include:

- Legacy software with limited support.
- Difficult to debug input errors, if any exist.
- Lack of GUI makes visualizing connectivity difficult.

2.2.3.2 HFAM II

HFAM II, developed by Hydrocomp, Inc., is based on the Stanford method and is a continuous simulation model that can do both historical and forecast analysis. The HFAM II stream temperature models simulate flow rates and water temperatures based on upstream initial conditions for the full extent of each reach at nodes at tributary confluences and existing gage locations. The model has many positive attributes including:

- Simulates both rivers and reservoirs.
- Simulates hourly temperatures.
- Simulations can be run as forecast, analysis, probabilistic, or optimization runs.
- Provides statistical summaries of both inputs and outputs.
- Calculates mean- and maximum-daily water temperatures.
- Outputs include flow and storage in physical elements, heat exchange, mass and concentrations for sediment and nutrients.

There are some limitations to choosing HFAM II as the modeling platform in this study. These limitations include:

- Requires amassing a large amount of data files, which can be difficult to manage.
- Exporting of data from the platform is tedious and requires export at each individual location.

2.2.3.3 Regression-Based Model in Microsoft® Excel

Using historically-measured water temperatures throughout the Project, linear regressions relating independent physical parameters such as reservoir water-surface elevation, flow, and air temperature can be used to compute water temperatures at designated locations. Microsoft® Excel can be used with these relationships and time series of the input data as a water temperature model. YCWA has used this methodology twice previously to support analyses (YCWA 2001, YCWA 2007). Positive attributes of a regression-based Microsoft ® Excel model include:

- Capable of simulating both rivers and reservoirs.
- Highly flexible and adaptable as additional information becomes available.
- Easily understood by most Relicensing Participants.
- Microsoft® Excel is a very common program and most potential users already have it.
- Can use HEC-DSS for data storage.
- Capable of simulating any period of record or time-step desired.

Negative attributes include:

- Reliability of the model is limited to the range of historically-measured data used to develop the regressions.
- Lack of ability to compute water temperatures for locations other than those with regressions and historically-measured data.
- Previously developed models are not appropriate since each was developed using monthly data and are not representative of daily water temperatures.

2.2.4 Selection of Model Platforms

Based on the above analysis, YCWA elected to use two model platforms and develop three models:

- Upstream of Englebright Reservoir (i.e., Upper Temp Model). HEC-5Q "Alpha" version 8.0 from June 9, 1997 (HEC 1998) was selected to model New Bullards Bar Reservoir; Our House Diversion Dam; Log Cabin Diversion Dam; Lohman Ridge Diversion Tunnel; Camptonville Diversion Tunnel; Bullards Bar Minimum Flow Powerhouse; New Bullards Bar Reservoir low-level outlet; New Colgate Penstock and Powerhouse; Middle Yuba River below Our House Diversion Dam; Oregon Creek below Log Cabin Diversion Dam; North Yuba River below New Bullards Bar Dam; Yuba River between the confluence of the North Yuba River and Middle Yuba River Englebright Reservoir; and the Yuba River downstream from Englebright Dam. Inflows to the model were the hydrologic outputs from Study 2.2, *Water Balance/Operations Model*. Temperature output from the HEC-5Q model was used as an input to the Englebright Temp Model. Additional information about HEC-5Q can be found in Attachment 2-6A.
- Englebright Reservoir (i.e., Englebright Temp Model). CE-QUAL-W2, version 3.71, was selected to model Englebright Reservoir. The water temperature output from the HEC-5Q model was used as an input to the CE-Qual-W2 model. The CE-QUAL-W2 model simulated Englebright Reservoir water temperatures, including inflows from the Yuba and South Yuba rivers, as well as accretions directly to the reservoir itself. Inflows to the model were the hydrologic outputs from Study 2.2, *Water Balance/Operations Model*. The model included diversions to the Narrows 1 and Narrows 2 powerhouses, as defined by the Water Balance/Operations Model. Other inputs include all physical reservoir information such as the elevation-area-storage relationships. Output from the Englebright Temp Model was used as an input to the Lower Temp Model.
- Downstream from Englebright Dam (i.e., Lower Temp Model). HEC-5Q "Alpha" version 8.0 from June 9, 1997 (HEC 1998), was selected to model the Yuba River downstream from Englebright Dam. Releases from the Narrows 1 and 2 powerhouses and spill from Englebright Dam, and inflows from Deer Creek and Dry Creek were model inputs, as defined by the Water Balance/Operations Model. Agricultural withdrawals at Daguerre Point Dam were included in the HEC-5Q model

Figure 2.2-1 shows the extents of each of the three water temperature models.

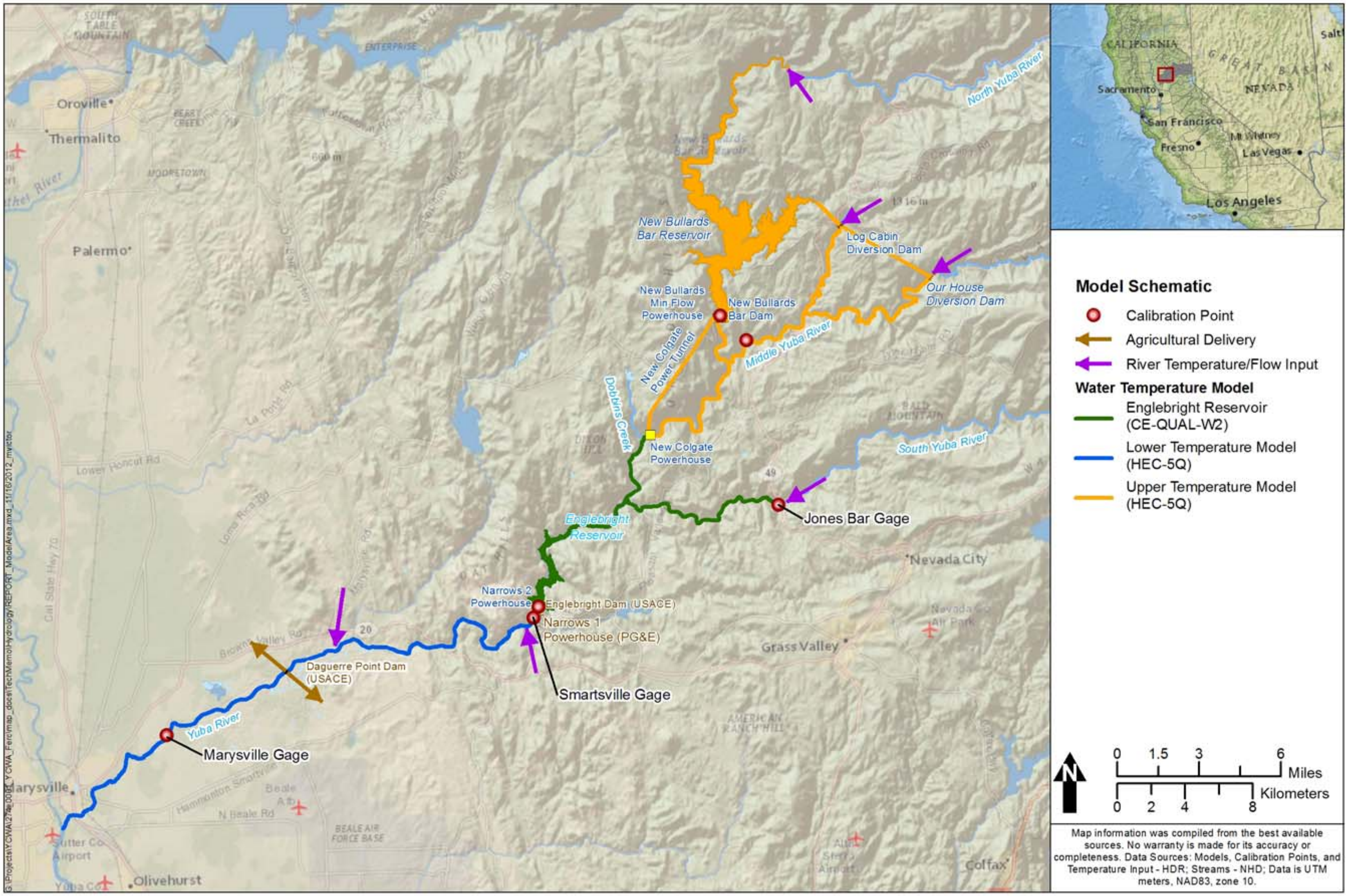

Figure 2.2-1. Extent of Upper Temp Model, Englebright Temp Model and Lower Temp Model.

2.2.5 Selection of Model Time-Step

Through discussions with Relicensing Participants regarding the applicable time-step for simulation, a daily time-step was selected. Relicensing Participants indicated that the mean-daily water temperature[6] and maximum-daily water temperature were the most biologically significant water temperature model outputs, rather than hourly or any other sub-daily time-step.

YCWA developed a methodology to compute maximum-daily water temperature[7] based on mean-daily water temperature, mean-daily air temperature, and mean-daily flow through regressions, with a high level of accuracy compared to historical maximum-daily water temperatures, at key locations. For all locations, using coefficients that varied by season improved the regression.

The equation for computing maximum-daily water temperatures was:

> Maximum-Daily Water Temperature = A*(Mean-Daily Water Temperature) + B*(Mean-Daily Flow) + C*(Mean-Daily Air Temperature)

where the mean-daily water temperature, flow, and air temperature were specified by location.

Table 2.2-1 shows applicable input data locations, and coefficients determined through regression, to compute maximum-daily water temperatures at specific locations, by season.

Table 2.2-1. Regression coefficients to compute maximum-daily water temperatures.

Location	Mean-daily Water Temperature		Mean-daily Flow		Mean-daily Air Temperature	
	Location	Coefficient (A)	Location	Coefficient (B)	Location	Coefficient (C)
Middle Yuba River near its confluence with the North Yuba River	Middle Yuba River near its confluence with the North Yuba River	0.9975 (July - September) 1.0318 (October – June)	Middle Yuba River near its confluence with the North Yuba River	-0.0112 (July – September) 0.0 (October – June)	Browns Valley CIMIS[1] station	0.042 (July-September) 0.0001 (October-June)
Daguerre Point Dam	Daguerre Point Dam	0.9803 (March-October) 1.0259 (November-February)	USGS Smartsville Gage	-0.0002 (March-October) -0.0002 (November-February)	NOAA's Beale AFB station	0.0676 (March-October) 0.0074 (November-February)
Marysville Gage	USGS Marysville Gage	1.0169 (March-October) 1.0016 (November-February)	USGS Marysville Gage	-0.0003 (March-October) -0.0002 (November-February)	NOAA's Beale AFB station	0.0594 (March-October) 0.0434 (November-February)

[1] California Irrigation Management Information System

[6] In this technical memorandum and for the purposes of modeling, "mean-daily water temperature" refers to the mean temperature in any one calendar day calculated by averaging instantaneous water temperature measurements (i.e., often hourly measurements or once every 15-minutes) in that calendar day.

[7] In this technical memorandum, maximum-daily water temperature was calculated as defined above. A maximum-daily water temperature calculated by the models should not be confused with the maximum-daily water temperature measured in the field, which is the maximum (i.e., warmest) water temperature recorded in a calendar day.

After simulating mean-daily water temperatures using the water temperature models, water temperature model output and the equation and coefficients above were used to determine maximum-daily water temperatures at key locations.

2.3 Model Development and Calibration

For the purpose of relicensing, YCWA has compiled three hydrology datasets used for the evaluations in this study and for use in other relicensing studies: 1) Historical Hydrology; 2) Without-Project Hydrology; and 3) With-Project Hydrology. The description of each is provided below.

- Historical Hydrology (i.e., gaged flows). The Historical Hydrology is the measured (i.e., gaged) mean-daily hydrology. This data set is primarily composed of the measured hydrology from start of the Project in Water Year (WY) 1970 through WY 2010 for the geographic area from just upstream from the Project to the United States Geological Survey (USGS) Marysville streamflow gage, which is located on the Yuba River upstream of backwater effects from the Feather River. In addition, this data set includes data from several gages from as early as 1900. The Historical Hydrology data set for locations downstream from Project facilities is representative of Project operations throughout its history.[8]
- Without-Project Hydrology. The Without-Project Hydrology is the mean-daily hydrology as if the Project had not been constructed (i.e., no Project facilities in place), but all other water projects in the basin are operating. This data set is comprised of measured hydrology and synthesized hydrology from WY 1970 through WY 2010 for the geographic area from just upstream from the Project to the USGS Marysville gage. The Without-Project Hydrology for areas upstream from the Project is the measured hydrology from the Historical Hydrology data set (i.e., inflow to the Project). The Without-Project Hydrology downstream from Project facilities is synthesized hydrology that consists of calculated accretions downstream from the inflow measurement locations plus the relevant measured inflow (i.e., in the Project area and downstream).[9]
- With-Project Hydrology. The With-Project Hydrology is current conditions (i.e., with the Project in operation). This data set is comprised of mean-daily hydrology for the geographic area from just upstream from the Project to the USGS Marysville gage for WY 1970 through WY 2010. The measured inflows and synthesized accretions used in

[8] A significant shift in the Historical Hydrology occurred in 2006. From WY 1970 through WY 2005 the Project was operated under either the existing FERC license minimum flow requirements or the California State Water Resource Control Board (SWRCB) Revised Decision 1644 (RD-1644). Beginning in WY 2006, the Project was operated under the Yuba River Accord flow requirements, which are higher than the flow requirements in the existing FERC License.

[9] YCWA has not evaluated a Yuba basin "unimpaired flow" data set for the relicensing because it would have no meaning for the Yuba River Development Project relicensing. Other water projects, including South Feather Water and Power Agency's South Feather Power Project (FERC Project No. 2088), Nevada Irrigation District's Yuba-Bear Hydroelectric Project (FERC Project No. 2266) and Pacific Gas and Electric Company's Drum-Spaulding Project (FERC Project No. 2310) affect flow into YCWA's Yuba River Development Project. These upstream projects are in various stages of relicensing, but new licenses with new flow requirements, have not been issued for those water projects. YCWA used the upstream historic regulated measured flows into the Yuba River Development Project as inputs for Without-Project Hydrology for its relicensing.

the Without-Project Hydrology are used as inputs to YCWA's Relicensing Water Balance/Operations Model. The With-Project Hydrology dataset is the output from the Base Case Scenario of the Water Balance/Operations Model.[10]

Each of the three data sets are included in Attachment 2-2D of YCWA's Relicensing Technical Memorandum 2-2, *Water Balance/Operations Model*.

YCWA has been collecting water temperature data throughout the Project area as part of Study 2-5, *Water Temperature Monitoring*, for use in the relicensing. The calibration of the three water temperature models focused on making adjustments to the models so that simulated water temperatures were as close as possible to historically-measured water temperatures for the calibration period. Each model's calibration period was selected based on the availability of historical input data for the model and was generally between 2008 and 2012. In addition to visual comparison of time series graphs of the simulated and historical data, the calibration used two quantitative methods for assessing the quality of a calibration (Cole and Wells 2011). Those two methods were:

- Minimize the Mean Error (ME). For this method, the error, or difference between historical and simulated data, was averaged for the period of record, which varies by location. The goal of calibration was to have this value as close to 0°F as possible; a value of 0°F would indicate no systematic bias in the prediction. Short of a value of 0°F, the ME should be within +/-0.5°F to indicate any systematic bias was relatively small compared to the range of temperatures being predicted.
- Minimize the Absolute Mean Error (AME). For this method, the absolute error for each day was averaged for the period of record. While a value of 0°F was preferable, short of that, it should be below 1.0°F; an AME within 1.0°F means that the model results was, on the average, within 1.0°F of the measured data.

2.3.1 Upper Temp Model

Figure 2.3-1 shows a schematic of the Upper Temp Model.

[10] Refer to YCWA's Relicensing Technical Memorandum 2-2, *Water Balance/Operations Model*, for a detailed description of the Water Balance/Operations Model and Base Case.

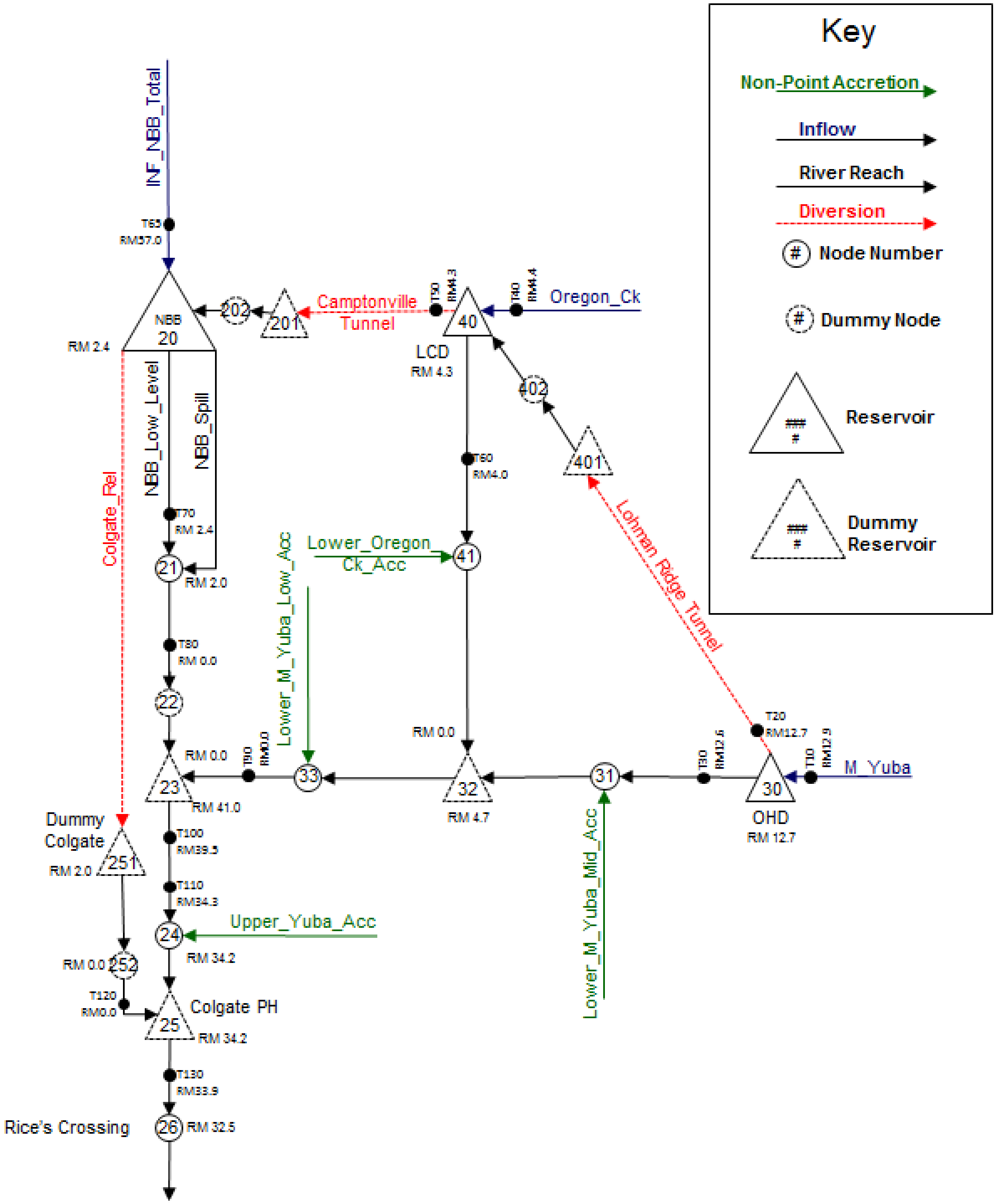

Figure 2.3-1. Upper Temp Model flow schematic.

The Upper Temp Model was constructed so each of three regions of the model could be calibrated independently of the other two. The three regions of the Upper Temp Model are: 1) New Bullards Bar Reservoir; 2) the North Yuba River below New Bullards Bar Dam and the

Yuba River above Englebright Reservoir; and 3) the Middle Yuba River below Our House Dam and Oregon Creek below Log Cabin Dam.

The Upper Temp Model was developed to ensure the best possible calibration of each region, rather than relying on simulated temperatures and flows from the other two regions of the model as inputs, calibration of each region used historical inflows and inflow temperatures as inputs.

Elevation-area-storage relationship and release capacities for New Bullards Bar Reservoir in the HEC-5Q model were taken from values used in the Water Balance/Operations Model. Also, the water balance module of the Upper Temp Model included inflows and diversions to the Lohman Ridge and Camptonville diversion tunnels, New Colgate Powerhouse, and the New Bullards Bar Minimum Flow Powerhouse as determined by the output of the Water Balance/Operations Model. The North Yuba River minimum flow requirement below Log Cabin Diversion Dam was included as a requirement and the water balance module accounted for releases to meet that requirement. Releases to the Middle Yuba River below Our House Diversion Dam and to Oregon Creek below Log Cabin Diversion Dam were determined in the water balance module based on simple mass balance; without any storage in the respective facilities - all water not diverted into the tunnels was released to the tributary below the dam. Spill decisions from New Bullards Bar Dam were made by the water balance module according to the New Bullards Bar Reservoir's flood reservation (USACE 1972).

Each of the three regions in the Upper Temp Model is discussed below.

2.3.1.1 New Bullards Bar Reservoir

New Bullards Bar Reservoir was simulated as a one-dimensional vertically-segmented reservoir, with a profile located near the New Colgate Power Tunnel intake. Hydrologic and water temperature inputs to New Bullards Bar Reservoir included the Camptonville Diversion Tunnel and the North Yuba River. Releases from the reservoir were made through the New Colgate Powerhouse, the combined low-level outlet and New Bullards Bar Minimum Flow Powerhouse, and the New Bullards Bar Dam spillway. The model incorporated the ability to represent operation of two New Bullards Bar Dam inlets in the New Colgate Power Tunnel Intake Tower.[11] Reservoir elevation-area-storage-maximum release relationships and outlet locations were from the USACE New Bullards Bar Reservoir Regulation for Flood Control (USACE 1972). A detailed discussion of the New Bullards Bar Reservoir representation is included in Attachment 2-6C.

[11] In 1993, YCWA convened a Temperature Advisory Committee to obtain more refined recommendations for the operation of New Bullards Bar Reservoir's multilevel outlet. The committee was composed of YCWA, USFWS, and CDFG. After reviewing temperature model data and the operating options, USFWS and CDFG recommended that water releases from New Bullards Bar Reservoir be as cold as possible at all times. YCWA immediately implemented this recommendation and, since 1993, all controlled releases of water from New Bullards Bar Reservoir through New Bullards Bar Minimum Flow Powerhouse into the north Yuba River and through New Colgate Powerhouse into the Yuba River have been from the deepest port of the New Bullards Bar Power Intake.

To calibrate the New Bullards Bar Reservoir portion of the Upper Temp Model, mean-daily historical inflows from the Camptonville Diversion Tunnel and synthesized inflows from the North Yuba River and accretions directly to New Bullards Bar Reservoir along with mean-daily historical inflow temperatures collected as part of Study 2.5, *Water Temperature Monitoring*, from the North Yuba River (YCWA gage T065) and Camptonville Tunnel (YCWA gage T050), were used for the period of November 14, 2009 through April 5, 2012. Similarly, historical releases from New Bullards Bar Reservoir from the New Colgate Powerhouse, the New Bullards Bar Minimum Flow Powerhouse and low-level outlet, or the New Bullards Bar Dam spillway. Daily meteorological data from the New Bullards Bar Dam meteorological station were used as inputs to the model of New Bullards Bar Dam. Water temperatures simulated by the Upper Temp Model were compared to historical reservoir temperature profiles, as measured biweekly by YCWA near the New Colgate Powerhouse intake since 1993. Historical water temperature profiles were reported as part of Study 2.5, *Water Temperature Monitoring.*

The primary parameters adjusted for calibration were physical constants for New Bullards Bar Reservoir. Two methods are available for computing effective diffusion of water temperatures in reservoirs. Effective diffusion represents the combined effects of molecular and turbulent diffusion, and convective mixing or the physical movement of water due to density instability. Wind and flow-induced turbulent diffusion and convective mixing are the dominant components of effective diffusion in the epilimnion of most reservoirs. The “Wind Method” for computing effective diffusion coefficients is appropriate for reservoirs in which wind mixing appears to be the dominant component of turbulent diffusion. This method assumes that wind-induced mixing is greater at the surface and diminishes exponentially with depth. The “Stability Method” for computing effective diffusion coefficients is appropriate for most deep, well-stratified reservoirs and shallower reservoirs where wind mixing is not the dominant turbulent mixing force. This method is based on the assumption that mixing will be at a minimum when the density gradient or water column stability is at a maximum.

Due to the deep, highly-stratified nature of New Bullards Bar Reservoir, the “Stability Method” was used for calibration of the Upper Temp Model. A detailed description of the parameters and the parameter values determined through calibration are included in Attachment 2-6C.

The New Bullards Bar Reservoir calibration also compared historical temperatures to simulated temperatures for New Colgate Powerhouse releases to ensure reasonable temperatures resulted from the reservoir profile. Results from the New Bullards Bar Reservoir model calibration can be found in the Results section and in Attachment 2-6C.

2.3.1.2 North Yuba River Downstream of New Bullards Bar Dam and Yuba River Upstream of Englebright Reservoir

In the Upper Temp Model, the North Yuba River and Yuba River between New Bullards Bar Dam and the normal-maximum water-surface elevation of Englebright Reservoir was simulated as a longitudinally stratified river. In addition to inflows from New Bullards Bar Reservoir and the Middle Yuba River, releases from the New Colgate Powerhouse were the primary water temperature inputs for this reach. A “dummy reservoir,” which existed only for modeling purposes, was used at the confluence of the North Yuba and Middle Yuba rivers to ensure correct mixing of temperatures and correctly distributed flow from the two tributaries.

For calibration, historical flow and temperature inputs were used for the North Yuba River below New Bullards Bar Reservoir, for the Middle Yuba River above its confluence, and for releases from the New Colgate Powerhouse. Historical meteorology from the New Bullards Bar Reservoir weather station was used for the period of November 14, 2009 through April 5, 2012. Channel geometry came from data collected for Study 3.10, *Instream Flow Upstream of Englebright Reservoir*.

Calibration of the reach between New Bullards Bar Dam and Englebright Reservoir was included to ensure inflow water temperatures to the Englebright Reservoir were as accurate as possible. Each of the monitoring stations along this reach was used, and calibration was focused on meeting the full range of water temperatures at each location. A description of model parameters and the parameter values used in calibration can be found in Attachment 2-6C.

2.3.1.3 Middle Yuba River Downstream of Our House Diversion Dam and Oregon Creek Downstream of Log Cabin Diversion Dam

Both Our House and Log Cabin diversion dams were simulated as longitudinally-stratified reservoirs with no storage capacity. Releases from Our House Diversion Dam can be made to either the Middle Yuba River or into the Lohman Ridge Diversion Tunnel. Below Our House Diversion Dam, the Middle Yuba River receives inflows from Oregon Creek and has non-point accretions both above and below Oregon Creek. Releases from Log Cabin Diversion Dam can be made to either Oregon Creek or to the Camptonville Diversion Tunnel. Oregon Creek has non-point accretions below Log Cabin Diversion Dam.

Calibration of the Middle Yuba River below Our House Diversion Dam and Oregon Creek below Log Cabin Diversion Dam utilized historic Middle Yuba River flows below Our House Diversion Dam, as measured by USGS gage 11408880, releases to Oregon Creek from Log Cabin Diversion Dam, as measured by USGS gage 11409400, and synthetic accretions to Oregon Creek, the Middle Yuba River above Oregon Creek, and the Middle Yuba River below Oregon Creek for the period of November 14, 2009 through April 5, 2012. Water temperatures, as measured immediately below Our House Diversion Dam and Log Cabin Diversion Dam were used as upstream boundary conditions. Meteorology data as measured at the New Bullards Bar Dam weather station were used due to its relative proximity and similar elevation.

Stream geometry data used in the Upper Temp Model were collected to support studies on the Middle Yuba River and Oregon Creek for geomorphology and instream flows (i.e., YCWA's Relicensing Study 1.1, *Channel Morphology Upstream of Englebright Reservoir*, and Study 3.10, *Instream Flow Upstream of Englebright Reservoir*). A detailed discussion of the development of the stream geometry data is presented in Attachment 2-6C.

In addition to calibrating the Upper Temp Model for water temperatures on the Middle Yuba River above its confluence with the North Yuba River, historically-measured water temperature monitoring stations along both the Middle Yuba River and Oregon Creek, were used to calibrate reaches above each monitoring location for the period of November 14, 2009 through April 5, 2012. By incrementally calibrating the Middle Yuba River and Oregon Creek, computed intermediate water temperatures along each reach were more representative than if a single calibration location had been used. Model parameter values determined through calibration can be found in Attachment 2-6C.

2.3.2 Englebright Temp Model

To capture travel time for water and temperature transport across Englebright Reservoir, the reservoir was simulated as a two-dimensional, vertically- and longitudinally-stratified reservoir using CE-QUAL-W2 with inputs from the Yuba River and the South Yuba River. The Narrows 1 and 2 powerhouses, and Narrows 2 Full-Flow Bypass were included as outlets; the simulated outflow temperatures were calibrated to match historically-measured water temperatures at the USGS Smartsville gage. Reservoir water temperatures were calibrated to match historically-measured water temperature profiles measured near the Narrows 2 Powerhouse Intake. Englebright Reservoir bathymetry came from a USGS survey conducted in 2002 (USGS 2003).

Figure 2.3-2 shows the layout of the Englebright Temp Model segments.

To calibrate Englebright Reservoir, mean-daily historical inflow temperatures from the Yuba River below the Colgate Powerhouse, and from the South Yuba River at Jones Bar, collected as part of Study 2.5, were used for the period of January 1, 2007 to September 30, 2011. Similarly, historical releases from the Narrows 1 Powerhouse, the Narrows 2 Powerhouse, and spill, and meteorological data from the Browns Valley California Irrigation Management Information System (CIMIS) Station were used as inputs to the model for Englebright Reservoir. Simulated temperatures were compared to historically measured temperatures in the Yuba River at Smartsville and for reservoir profiles, as measured biweekly at two locations: just upstream from the dam at segment 28, and approximately 3.3 miles upstream from the dam at segment 20.

The primary parameters adjusted for calibration were physical constraints for Englebright Reservoir. A description of parameters and parameter values determined through calibration can be found in Attachment 2-6C.

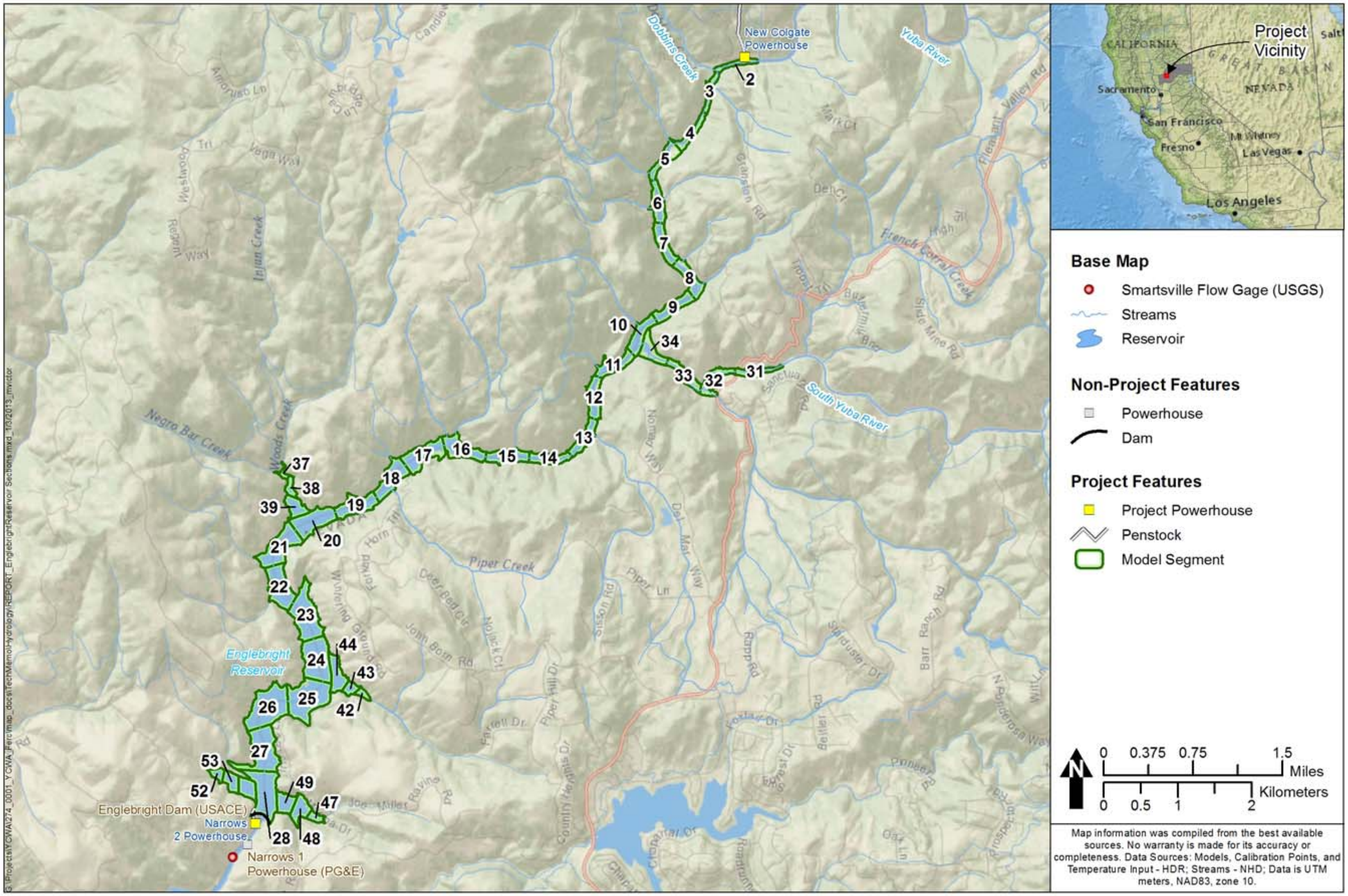

Figure 2.3-2. Englebright Temp Model segments.

2.3.3 Lower Temp Model

The model of the Yuba River below Englebright Reservoir (Lower Temp Model) was simulated as a longitudinally-stratified river using HEC-5Q, with inputs from Deer Creek and Dry Creek in addition to releases from Englebright Reservoir, and agricultural diversions at Daguerre Point Dam. The Lower Temp Model was calibrated to compute water temperatures at the USGS Marysville gage. Figure 2.3-3 shows the Lower Temp Model schematic.

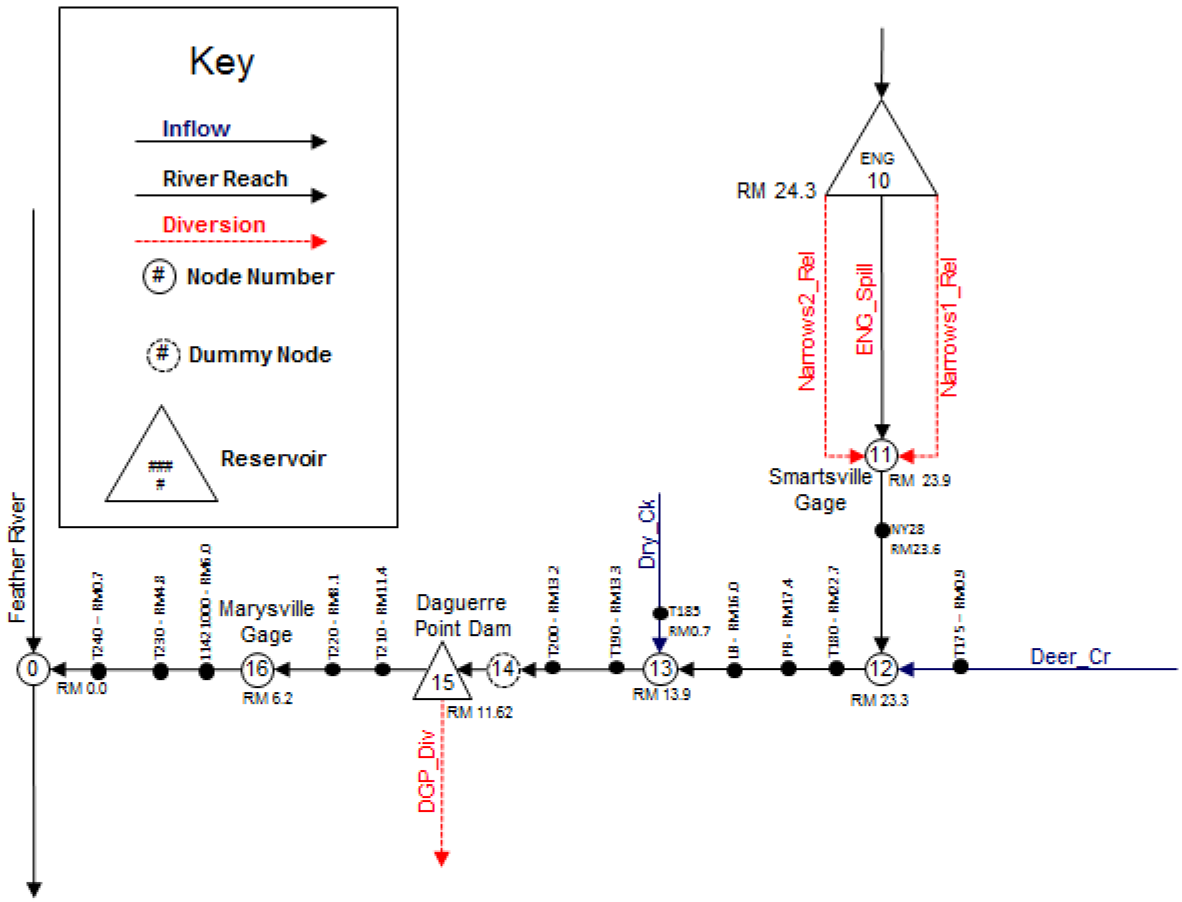

Figure 2.3-3. Lower Temp Model flow schematic.

Unlike the Upper Temp Model, no reservoir release decisions were needed for the Lower Temp Model. The HEC-5Q water balance module was developed to use Narrows 1 and Narrows 2 powerhouse releases and Englebright Reservoir spill aggregated as flow at the Smartsville gage from the Water Balance/Operations Model as inflow. Inflows from Deer and Dry creeks, and Daguerre Point Dam agricultural diversions were also determined in the Water Balance/Operations Model for simulations other than the Calibration and Validation scenarios.

Calibration of the Lower Temp Model used historically-measured mean-daily flows at Smartsville, as measured by the USGS gage 11418000, along with historical water temperatures measured at the Smartsville gage, collected by YCWA for the period from October 1, 2008 through September 30, 2011. Flows and water temperatures at Smartsville were used rather than releases from the Narrows 1 and Narrows 2 powerhouses and Englebright Reservoir spills since Smartsville was the calibration point for the upstream Englebright Temp Model, and ultimately, output from the Englebright Temp Model will be used as an input to the Lower Temp Model. While an extensive period of record of historically-measured mean-daily flows from Deer Creek, as measured by USGS gage 11418500 was available, there was a limited period of record with numerous data gaps for water temperatures in Deer Creek above its confluence with the Yuba River. Missing data within the period of record were filled by historical water temperature data for the same time of year from other, representative years.

Synthetic flow data for Dry Creek, developed for the Water Balance/Operations Model, were used as an inflow to the Yuba River for model calibration, along with available historical water temperature information for Dry Creek above its confluence with the Yuba River. Similar to Deer Creek water temperatures, missing water temperature data were filled with water temperature data for the same time of year from representative years. Dates for missing data for both Dry Creek and Deer Creek can be found in Attachment 2-6C.

Historical daily agricultural diversions from Daguerre Point Dam provided by YCWA were also used for calibration.

Daily meteorology data from the United States Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) Beale Air Force Base (AFB) weather station were used for the simulation due to the weather station’s relative proximity to the lower Yuba River, and similar elevation and exposure as much of the Yuba River below Englebright Dam.

River geometry inputs were taken from the River Management Team (RMT) Sedimentation and River Hydraulics - 2D Version 2.1 (SRH2D) model (Pasternack and Lower Yuba RMT 2012). Figure 2.3-4 shows the locations of the river sections used in the Lower Temp Model.

A detailed discussion of meteorological data development, river geometry, and parameter values used to calibrate the Lower Temp Model can be found in Attachment 2-6C.

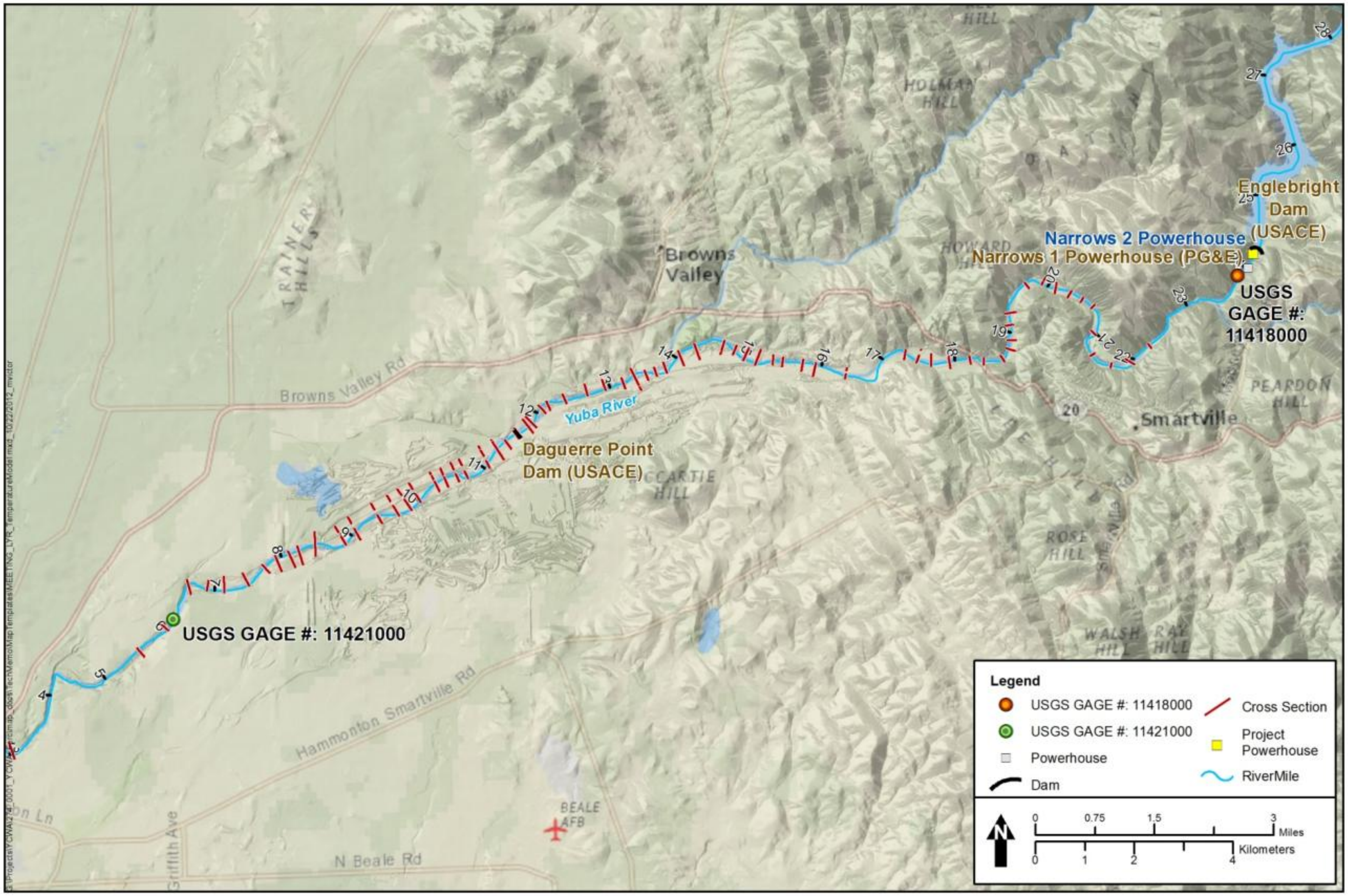

Figure 2.3-4. Location of Lower Temp Model river sections.

2.3.4 Water Temperature Model Output Locations

In addition to previously described output, the model provides output for the locations listed in Table 2.3-8.

Table 2.3-8. Water temperature model output locations.

Node (River Mile)	Location	Hydrologic Reach or Data Source (as listed in Technical Memorandum 2-2, Water Balance/Operations Model)
MIDDLE YUBA RIVER OUR HOUSE DIVERSION DAM REACH[1]		
--	Inflow into Our House Diversion Dam Impoundment	Input Time Series
--	Lohman Ridge Tunnel Intake	Lohman Ridge Tunnel Intake
12.6	Our House Diversion Dam Release to Middle Yuba River	Total Flow Downstream from Our House Diversion Dam
4.7	Middle Yuba River Upstream from Oregon Creek Confluence	Middle Yuba River Upstream from Oregon Creek Confluence
4.7	Middle Yuba River Downstream from Oregon Creek Confluence	Middle Yuba River Downstream from Oregon Creek Confluence
0.1	Middle Yuba River Upstream from North Yuba River Confluence	Middle Yuba River Upstream from North Yuba River Confluence
OREGON CREEK LOG CABIN DIVERSION DAM REACH[2]		
--	Upstream Inflow into Log Cabin Diversion Dam Impoundment	Input Time Series
--	Camptonville Tunnel Intake	Camptonville Tunnel Intake
4.3	Log Cabin Diversion Dam Release to Oregon Creek	Total Flow Downstream from Log Cabin Diversion Dam
0.1	Oregon Creek Upstream from Middle Yuba River Confluence	Oregon Creek Upstream from Middle Yuba River Confluence
NORTH YUBA RIVER NEW BULLARDS BAR DAM REACH[3]		
--	Upstream Inflow into New Bullards Bar Reservoir	Input Time Series
--	New Bullards Bar Reservoir Profile at the New Colgate Powerhouse Intake	Reservoir Simulation
--	Colgate Powerhouse	Colgate Powerhouse
2.4	New Bullards Bar Dam Instream Release (Fish Flow Powerhouse)	New Bullards Bar Dam Instream Release (Fish Flow Powerhouse)
2.4	New Bullards Bar Dam Spill	New Bullards Bar Dam Spill
2.4	Total Flow Downstream from New Bullards Bar Dam	North Yuba River Upstream from Middle Yuba River Confluence
0.1	North Yuba River Upstream from Middle Yuba River Confluence	North Yuba River Upstream from Middle Yuba River Confluence
YUBA RIVER NORTH/MIDDLE YUBA REACH[4]		
40.0	Yuba River at North and Middle Yuba River Confluence	Yuba River at North and Middle Yuba River Confluence
34.2	Yuba River to New Colgate Powerhouse	Yuba River to New Colgate Powerhouse
YUBA RIVER NEW COLGATE POWERHOUSE REACH[5]		
34.0	Yuba River Downstream from New Colgate Powerhouse	Yuba River Downstream from New Colgate Powerhouse
33.6	Yuba River Downstream from Dobbins Creek	Yuba River Downstream from New Colgate Powerhouse
32.5	Inflow into Englebright Reservoir from Middle Yuba River	Yuba River Downstream from New Colgate Powerhouse

Table 2.3-8. (continued)

Node (River Mile)	Location	Hydrologic Reach or Data Source (as listed in Technical Memorandum 2-2, Water Balance/Operations Model)
YUBA RIVER ENGLEBRIGHT DAM REACH[6]		
--	Inflow into Englebright Reservoir from South Yuba River	Input Time Series
--	Englebright Reservoir Profile at Narrows 2 Intake	Reservoir Simulation
24.3	Englebright Dam Spill	Englebright Dam Spill
24.2	Narrows Powerhouse 2 Release	Narrows Powerhouse 2 Release
24.0	Narrows Powerhouse 1 Release	Narrows Powerhouse 1 Release
23.9	Yuba River Near Smartsville	Yuba River Near Smartsville
23.4	Yuba River Upstream from Deer Creek	Yuba River Near Smartsville
23.4	Deer Creek Inflow	Input Time Series
23.1	Yuba River Downstream from Deer Creek Confluence	Yuba River Upstream from Dry Creek
17.7	Yuba River at Parks Bar	Yuba River Upstream from Dry Creek
16.2	Yuba River at Long Bar	Yuba River Upstream from Dry Creek
13.4	Yuba River Upstream from Dry Creek	Yuba River Upstream from Dry Creek
13.4	Dry Creek Inflow	Input Time Series
13.4	Yuba River Downstream from Dry Creek	Yuba River Downstream of Dry Creek
12.4	Yuba River Upstream from Browns Valley Irrigation District’s John L. Nelson Fish Screen Facility	Yuba River Downstream of Dry Creek
12.4	John L. Nelson Fish Screen Facility	Yuba River Downstream from Dry Creek
12.4	Yuba River Downstream from Browns Valley Irrigation District’s John L. Nelson Fish Screen Facility	Yuba River Downstream from Dry Creek
YUBA RIVER DAGUERRE POINT DAM REACH[7]		
11.6	Yuba River Upstream from Daguerre Point Dam	Yuba River Downstream of Dry Creek
11.6	At Daguerre Point Dam	Yuba River below Daguerre Point Dam
11.6	North Canal Diversions	Daguerre Point Dam Diversions
11.6	South Canal Diversions	Daguerre Point Dam Diversions
11.6	Yuba River below Daguerre Point Dam	Yuba River below Daguerre Point Dam
8.3	Yuba River at Walnut Ave (Near Western Extent of Goldfields)	Yuba River below Daguerre Point Dam
6.2	Yuba River near Marysville	Yuba River near Marysville
5.0	Yuba River at Simpson Lane (Between Goldfields and Marysville)	Yuba River near Marysville
0.7	Yuba River at Marysville	Yuba River near Marysville
0.0	Yuba River Upstream from Feather River	Yuba River near Marysville

[1] Our House Diversion Dam Reach - Middle Yuba River from Our House Diversion Dam to immediately upstream from the confluence with the North Yuba River.
[2] Log Cabin Diversion Dam Reach - Oregon Creek from Log Cabin Diversion Dam to immediately upstream from the confluence with the Middle Yuba River.
[3] New Bullards Bar Dam Reach - North Yuba River from New Bullards Bar Dam to immediately upstream from the confluence with the Middle Yuba River.
[4] North and Middle Yuba Rivers Confluence Reach - Yuba River from the confluence of the North Yuba River and the Middle Yuba River to upstream from Colgate Powerhouse.
[5] Colgate Powerhouse Reach - Yuba River from the New Colgate Powerhouse to the normal-maximum water-surface elevation of Englebright Reservoir.
[6] Englebright Dam Reach - Yuba River from and including Englebright Reservoir to Daguerre Point Dam.
[7] Daguerre Point Dam Reach - Yuba River from the Daguerre Point Dam to the Feather River.

2.4 Input Data Development

Input data for the water temperature models took several forms including: 1) meteorological data; 2) physical information; and 3) upstream boundary conditions (i.e., input water temperatures and flows). All meteorological and input water temperature data were read from the input HEC-DSS file. This section describes the development of the input data for each of the three models. Attachment 2-6B includes all time series input data, including hydrology, meteorology, and input water temperatures.

2.4.1 Meteorological Database

As previously described, the water temperature model was broken into three separate models, each representing a different geographic region with unique meteorological conditions. While the Upper Temp Model and Lower Temp Model were both developed in HEC-5Q and have the same data requirements, the Englebright Temp Model was developed in CE-QUAL-W2 and has additional data needs beyond that required by HEC-5Q. This section provides a description of the meteorological data development for each model, available historical data, and methods used to create a full period of record of input meteorology. A detailed description of the meteorological data development is presented in Attachment 2-6C.

2.4.1.1 Data Requirements

The HEC-5Q platform used to develop the Upper Temp Model and Lower Temp Model required daily meteorological input data consisting of the following parameters:

- Coefficient of surface heat exchange, British Thermal Units (BTU)/square-feet (ft^2)/day/degree Fahrenheit (°F)
- Equilibrium temperature (°F)
- Short-wave solar radiation BTU/ft^2/day
- Wind speed, miles per hour (mph)

The coefficient of heat exchange and the equilibrium temperature are not directly recorded meteorological parameters and had to be calculated using the Heat Exchange Program (HEATX) developed by the USACE (USACE 1972). The HEATX model directly calculates the required inputs to the HEC-5Q model as described above. Mean-daily input parameters for HEATX include:

- Cloud cover based on a 0 to 10 scale, with 0 being clear and 10 being completely overcast
- Wind speed (mph)
- Air temperature (°F)
- Dew point temperature (°F)

The Englebright Temp Model developed using CE-QUAL-W2 required hourly meteorological data types as follows:

- Hourly air temperature, degree Celsius (°C)
- Hourly dew point temperature (°C)
- Hourly wind speed, meters per second (m/sec)
- Hourly wind direction, radians
- Hourly cloud cover, 0 (clear) to 10 (cloudy)
- Short wave radiation, Langleys (W) /square meter (m^2) (optional)

Meteorological input data can be input in any frequency and may vary during the simulation. Incidental short-wave radiation is optional and represents only the penetrating short-wave radiation component. CE-QUAL-W2 calculates solar radiation, if not provided, from sun angle relationships and cloud cover. The CE-QUAL-W2 model directly calculates heat transfer parameters.

2.4.1.2 Data Sources

Data from nearby weather stations were obtained from the National Oceanic and Atmospheric Administration (NOAA), the California Data Exchange Center (CDEC), the CIMIS, and the National Renewable Energy Laboratory (NREL). The review of these weather station data took into consideration that a total of nine meteorology data sets would need to be developed for purposes of the water temperature modeling: a Calibration, Validation and Base Case scenario data set for each of the three models: the Upper Temp Model, the Englebright Temp Model, and the Lower Temp Model.

Stations were identified that were the most representative of the meteorology of each model area and having all required data types for either HEATX or CE-QUAL-W2, dependent on the model, as discussed in Section 2.4.1.1. The period of record was considered, resulting in the elimination of some stations while requiring the identification of new stations.

Table 2.4-1 is a summary of the weather stations selected and Figure 2.4-1 shows the geographic location of each gage. Weather station locations are shown in Figure 2.4-1.

Table 2.4-1. Weather stations used in the Upper, Englebright and Lower Temp Models.

Weather Station	Operating Agency	Station ID	Period of Record	Data Type[1]
New Bullards Bar Dam	CDEC[2] (YCWA)[6]	BUD	11/14/2009 to 9/30/2012	Air Temperature Relative Humidity Wind Speed
Nicolaus	CIMIS[3]	030	1/3/1983 to 12/29/2011	Air Temperature Solar Radiation Wind Speed Dew Point

Table 2.4-1. (continued)

Weather Station	Operating Agency	Station ID	Period of Record	Data Type[1]
Browns Valley	CIMIS[3]	084	4/13/1989 to 9/30/2012	Air Temperature Solar Radiation Wind Speed Wind Direction Dew Point Relative Humidity
Beale AFB	NOAA[4], NREL[5]	040584	7/1/1959 to 9/30/2012	Air Temperature Wind Speed Wind Direction Dew Point Solar Radiation Descriptive Weather Observations
Sacramento Executive Airport	NOAA[4], NREL[5]	047630	1/1/1931 to 9/30/2012	Air Temperature Wind Speed Wind Direction Dew Point Solar Radiation Descriptive Weather Observations

1 Only includes weather station data used in the dataset creation.
2 CDEC - **http://cdec.water.ca.gov/**
3 CIMIS - **www.cimis.water.ca.gov/**
4 NOAA - **www.ncdc.noaa.gov/**
5 NREL - **http://www.nrel.gov/rredc/**
6 YCWA collects data at New Bullards Bar Dam, but the data is distributed through CDEC

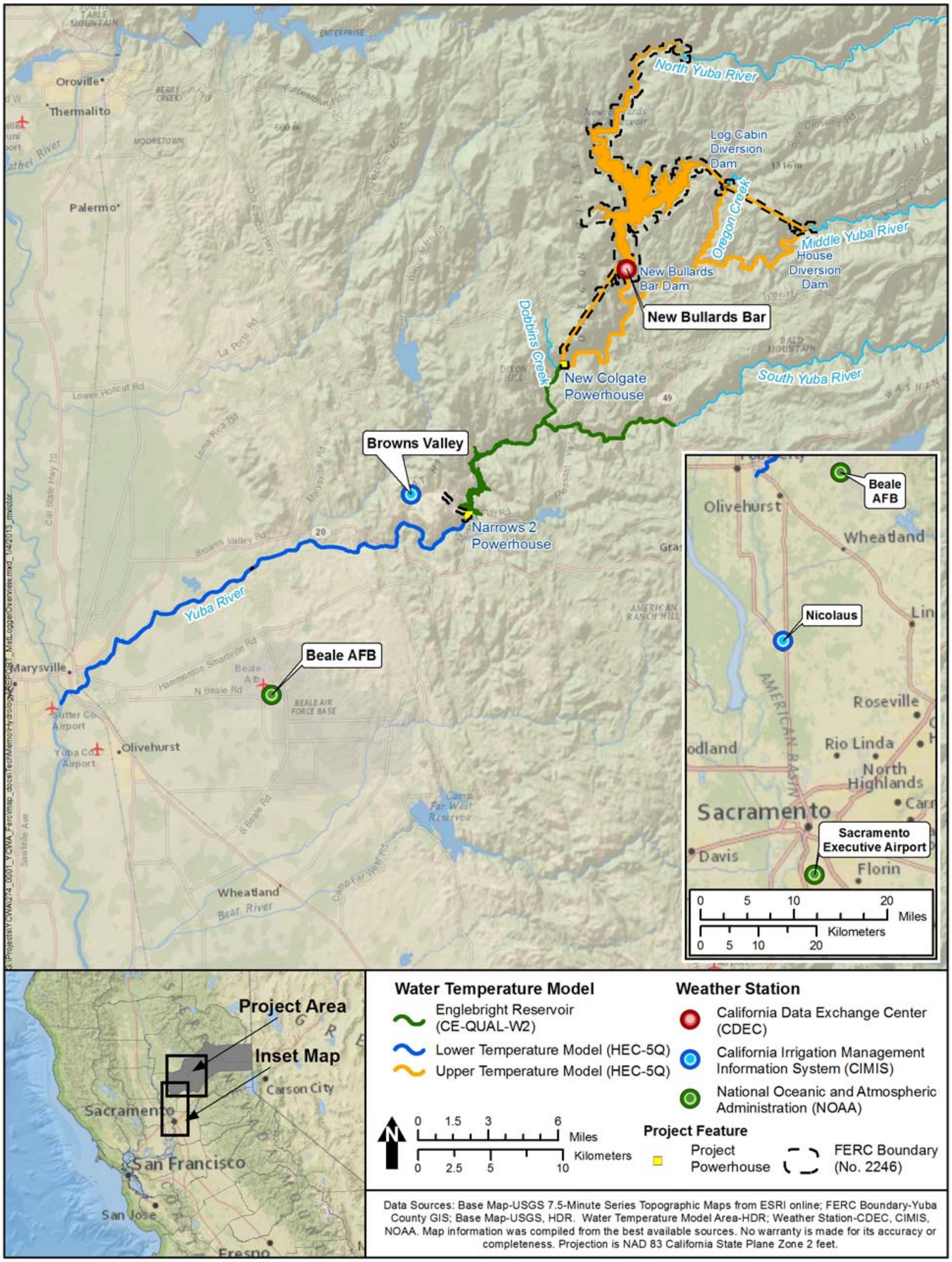

Figure 2.4-1. Location of weather stations used in the study.

2.4.1.3 Dataset Development

Meteorology data sets were developed for the three models: 1) Upper Temp Model; 2) Englebright Temp Model; and 3) Lower Temp Model. For each model, a Calibration, Validation and Base Case scenario data set were created, for a total of nine datasets. A single zone was used for meteorology for each model due to the relative proximity and similarity of meteorology of the various facilities.

While the calibration data sets had different periods of record depending on the availability of historical data, each of the validation data sets had a period of record of January 1, 2000 through September 30, 2011. Similarly, each of the Base Case Scenario data sets had a period of record of October 1, 1969 through September 30, 2010.

Calibration data sets were created using meteorological weather stations in close proximity to the modeled region. Validation data sets were also based on data from meteorological monitoring stations in close proximity to the modeled region, but due to data limitations, the monitoring station may not have been as close to the simulation area as the calibration stations were. Base Case data sets were based on similar stations as the validation data sets, but due to limitations in the period of record, datasets were extended using data from Beale AFB station and Sacramento Executive Airport weather station.

Upper Temp Model

Due to the relative proximity and similarity of meteorological conditions of the various facilities represented in the model, a single zone was used for meteorology. Small variances in climate due to topographic and vegetative shading were accounted for in the calibration process.

The Calibration dataset for the Upper Temp Model was developed using air temperature, wind speed, and relative humidity from the New Bullards Bar Dam weather station. Dew point temperature was approximated using relative humidity data from New Bullards Bar Dam weather station and the following formula:

$$\text{Dew Point Temp} = \text{Air Temp} - (100 - \text{Relative Humidity}) * 9/25$$

Table 2.4-2 lists sources of the air temperature, dew point temperature, and wind speed data for the Upper Temp Model.

Table 2.4-2. Sources of meteorology data for the Upper Temp Model.

Dataset	Period of Record	Data Type	Weather Station
Calibration	11/14/2009 to 09/30/2012	Air Temperature	New Bullards Bar
		Dew Point	New Bullards Bar
		Wind Speed	New Bullards Bar
Validation	1/1/2000 to 09/30/2011	Air Temperature	Browns Valley
		Dew Point	Browns Valley
		Wind Speed	Browns Valley
Base Case Simulation	10/1/1969 to 9/30/2010	Air Temperature	Beale AFB
		Dew Point	Beale AFB
		Wind Speed	Beale AFB

Cloud cover for the Upper Temp Model for the Calibration data set was approximated using Browns Valley weather station solar radiation. Cloud cover was expressed as an integer value ranging from 0, the theoretical clear sky potential solar radiation, to 10, a dark overcast day shielded from much of the solar radiation, based on relating historically-measured radiation to synthetic radiation corresponding to each cloud cover integer, as computed using HEATX. Development of the solar radiation lookup table is discussed in Attachment 2-6C. The relationship between the cloud cover and the resulting percentage of solar radiation expected to that of the theoretical clear sky conditions is shown in Figure 2.4-2.

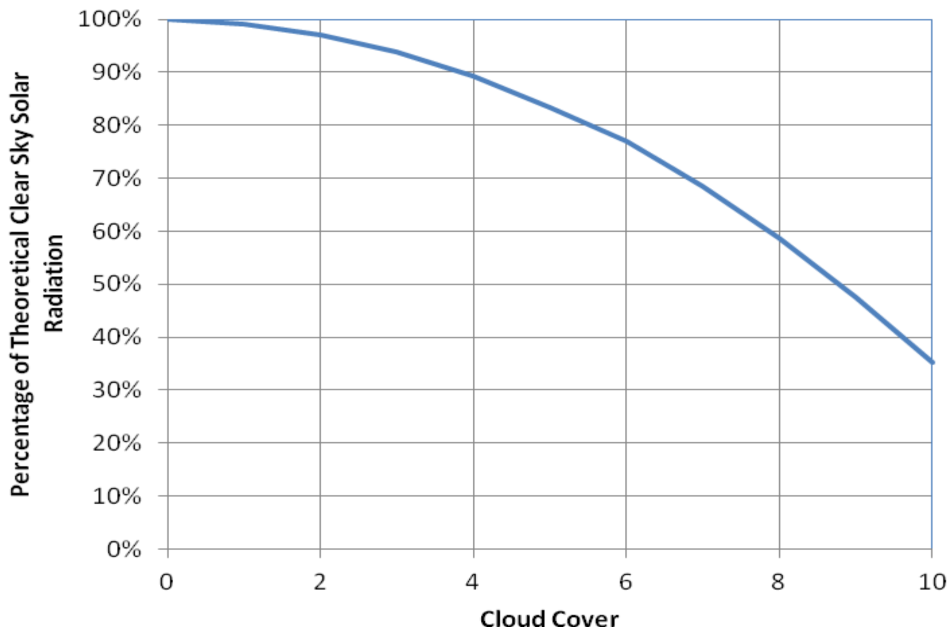

Figure 2.4-2. Relationship of cloud cover number to the theoretical clear sky solar radiation.

The Validation data set was created using the CIMIS weather station at Browns Valley instead of the New Bullards Bar Dam weather station for all meteorological parameters due to the limited period of record at New Bullards Bar. Missing data at the Browns Valley weather station was filled in using data from Beale AFB and the Nicolaus CIMIS weather station data. Linear regression techniques were used to create a data set that was more representative of conditions at the New Bullards Bar Dam weather station. These regressions are discussed in further detail in Attachment 2-6C.

The Base Case Scenario data set was developed primarily from Beale AFB weather station data. Beale AFB was selected as it was the most representative weather station with a sufficiently long period of record. Wind speed, air temperature, and dew point temperature data were available for the majority of the period of record. Large data gaps were filled in using data from the Sacramento Executive Airport weather station. Linear regression techniques were applied to best represent differences between the data at Beale AFB, which is located at a lower elevation in the Central Valley, against conditions at New Bullards Bar Dam, which is located at a higher elevation in the Sierra foothills. Base Case linear regressions and data filling techniques are discussed in further detail in Attachment 2-6C.

Cloud cover for the Base Case Scenario was developed using modeled solar radiation data from the National Solar Radiation Database (NSRDB) developed by the NREL (NREL 2012), a laboratory of the United States Department of Energy. The NRSDB consists of two models; solar radiation from 1961 to 1990, and solar radiation from 1991 to 2010. The 1991 to 2010 database was developed based on updated methods and techniques and benefits from plentiful solar radiation data and was performed on more locations, including Beale AFB. The number of stations modeled in for the 1961 to 1990 data was limited, and Beale AFB was not modeled, but the Sacramento Executive Airport weather station was included. A strong correlation was observed between the Beale AFB solar radiation data and the Sacramento Executive Airport weather station data; Sacramento Executive Airport solar radiation was used for the entire Base Case period of record. Cloud cover was calculated using the solar radiation lookup table. Development of the Base Case Scenario solar radiation data is further discussed in Attachment 2-6C.

Englebright Temp Model

A single zone was used for meteorology for Englebright Reservoir. Small variances in climate due to differences in exposure resulting from topographic shading or tree canopy were accounted for during the calibration process.

The Browns Valley CIMIS station was the primary data source to create the Calibration and Validation data sets. Missing data were filled in using regression techniques and data from the Beale AFB weather station and Nicolaus CIMIS weather stations. The linear regressions and data filling techniques are discussed in further detail in Attachment 2-6C.

The Base Case data set was developed primarily from Beale AFB weather station data with missing data filled in using the same methodology used for the development of the Upper Temp Model Base Case data set. Linear regression techniques were applied to best represent differences between the data at the Beale AFB and Browns Valley. Base Case linear regressions and data filling techniques are discussed in further detail in Attachment 2-6C.

See Table 2.4-3 for sources of air temperature, dew point temperature, and wind speed data used for the Englebright Temp Model.

Table 2.4-3. Sources of meteorological data for the Englebright Temp Model.

Dataset	Period of Record	Data Type	Primary Weather Station
Calibration	1/3/2009-12/31/2011	Air Temperature	Browns Valley
		Dew Point Temperature	Browns Valley
		Wind Speed	Browns Valley
		Wind Direction	Browns Valley

Table 2.4-3. (continued)

Dataset	Period of Record	Data Type	Primary Weather Station
Validation	1/1/2000-09/30/2011	Air Temperature	Browns Valley
		Dew Point Temperature	Browns Valley
		Wind Speed	Browns Valley
		Wind Direction	Browns Valley
Base Case	10/1/1969-9/30/2010	Air Temperature	Beale AFB
		Dew Point Temperature	Beale AFB
		Wind Speed	Beale AFB
		Wind Direction	Beale AFB

For the Englebright Temp model, cloud cover data calculated as described for the Upper Temp Model for all three data sets were converted into hourly cloud cover data under the assumption that cloud cover was consistent throughout the day.

Lower Temp Model

Due to the relative proximity and similarity of meteorological conditions of the various facilities represented in the model, a single zone was used for meteorology. Small variances in climate due to topographic and vegetative shading were accounted for in the calibration process.

Beale AFB weather station data was used for the Calibration, Validation, and Base Case scenarios as the primary data source for wind speed, air temperature, and dew point temperature. For the Calibration and Validation datasets, missing data was filled in using linear regression techniques and data from the Nicolaus and Browns Valley CIMIS weather stations. The Base Case data set was developed using primarily Beale AFB weather station data with missing data filled in using the same methodology used for the development of the Upper Temp Model Base Case data set. Linear regressions and data filling techniques are discussed in further detail in Attachment 2-6C.

Cloud cover data for all scenarios is the same as was developed for the Upper Temp Model.

2.4.2 Model Physical Information

Physical information for a model can take several forms, it can be physical geometry data such as reservoir elevation-volume relationships or river cross-sectional data, or it can be thermodynamic data such as thermal density gradient or stratification.

2.4.2.1 Upper Temp Model

The Upper Temp Model accurately represents New Bullards Bar Reservoir, the North Yuba River below New Bullards Bar Dam and the Yuba River above Englebright Reservoir, and the Middle Yuba River below Our House Diversion Dam and Oregon Creek below Log Cabin Diversion Dam. The following section describes the physical representation of each of these features within the HEC-5Q model.

New Bullards Bar Reservoir

New Bullards Bar Reservoir used the elevation, storage, and area information from the USACE (USACE 1972). The same information was used in both the quantity and quality modules, except the water balance module also includes maximum release capacity by elevation. The quality module also includes the effective reservoir width at the dam to represent the withdrawal area. This information was developed by digitizing pre-New Bullards Bar Dam topographic maps in the area of the dam using geographic information system (GIS) software and linearly interpolating to determine the widths at each elevation. All of these features were defined for the reservoir for elevations ranging from 1,400 ft to 1,965 ft. Linear interpolation was used for elevations between those defined by the GIS exercise. Since they were explicitly defined as an input to the Upper Temp Model, diversions to the New Colgate Powerhouse were not included in the release capacity values in the model. The simulated capacities were representative of the release capacity available for discretionary use by the Upper Temp Model. A detailed description of the New Bullards Bar Reservoir representation in the Upper Temp Model can be found in Attachment 2-6C.

North Yuba River and Yuba River above Englebright Reservoir

Table 2.4-4 shows the location by RM of each feature represented in the Upper Temp Model along the North Yuba River below New Bullards Bar Dam and the Yuba River above Englebright Reservoir. Additional "dummy" nodes were included in the model for simulation purposes, but they were not physical features, and were thus not included in the table.

Table 2.4-4. River mile locations of features along the Yuba River above Englebright Reservoir and the North Yuba River below New Bullards Bar Dam.

Feature	River Mile (mile)[1]
Rice's Crossing	Yuba River RM 32.5
New Colgate Powerhouse	Yuba River RM 34.2
Confluence of Middle Yuba and North Yuba rivers	Yuba River RM 40.0
New Bullards Bar Dam	North Yuba RM 2.4

[1] River miles were measured in GIS from the Yuba River confluence with the Feather River upstream.

Channel geometry for this reach was extrapolated from data collected by Study 3.10, *Instream Flow Upstream of Englebright Reservoir*. Since this geometry was not provided for the entire extent of the reach, available geometry was applied based on the type of habitat represented; habitat data for the entire reach was mapped by helicopter, and it was assumed that similar habitat types had similar geometric characteristics for this reach. The elevation for each section was determined based on available USGS National Elevation Dataset topographic information. A detailed description of the development and application of the North Yuba River channel geometry is included in Attachment 2-6C.

Middle Yuba River below Our House Diversion Dam and Oregon Creek below Log Cabin Diversion Dam

RMs for the Middle Yuba River and Oregon Creek restart at zero at their respective confluences. Table 2.4-5 shows the RMs for features along the Middle Yuba River below Our House Diversion Dam and Oregon Creek below Log Cabin Diversion Dam.

Table 2.4-5. River miles of features along the Middle Yuba River below Our House Diversion Dam and Oregon Creek below Log Cabin Diversion Dam.

Feature	River Mile (mile)[1]
Oregon Creek confluence with Middle Yuba River	Middle Yuba RM 4.7
Our House Diversion Dam	Middle Yuba RM 12.6
Log Cabin Diversion Dam	Oregon Creek RM 4.3

[1] River miles were measured in GIS from the Yuba River confluence with the Feather River upstream.

Channel geometry for these reaches was extrapolated from data collected by Study 3.10, *Instream Flow Upstream of Englebright Reservoir*. Since this geometry was not provided for the entire extent of these reaches, available geometry was applied based on the type of habitat represented; habitat type data for the entire reaches were mapped by helicopter, and it was assumed that similar habitat types had similar geometric characteristics for this reach. The determination of elevation for each section was based on available USGS National Elevation Dataset topographic information. A detailed description of the development and application of the Middle Yuba River and Oregon Creek channel geometry is included in Attachment 2-6C.

2.4.2.2 Englebright Temp Model

The Englebright Temp Model utilized available physical data (e.g., reservoir bathymetry, inflow locations and elevations, and outlet locations and elevations) to represent Englebright Reservoir. The following section describes methods and data sources used to develop the reservoir representation.

Bathymetry

Bathymetric modeling was completed at Englebright Reservoir in 2001 and 2002 by USGS (USGS 2003) as part of the Upper Yuba River Studies Program (UYRSP). Data were converted using GIS software from NAD83 UTM Zone 10N, meters to NAD83 State Plane California Zone II, feet in order to extract the reservoir data for the CE-QUAL-W2 model.

One main branch and five additional side branches were identified for Englebright Reservoir. The centerline of each branch was generated and used to create polygons with equally-spaced segment centers. GIS software was used to generate 3-foot vertical layers within each segment.

In order to check the accuracy of the model grid, model generated volume- and surface-area-elevation curves were compared to the official curves for the reservoir. A summary of the length and segment spacing for each branch can be found in Table 2.4-6.

Table 2.4-6. Englebright Temp Model grid branch summary.

Branch Number	Total Branch Centerline Length (ft)	Average Segment Length (ft)	Number of Active Segments	Designation of Inclusive Upstream Active Segment	Designation of Inclusive Downstream Active Segment
1	52,594	1,948	27	2	28
2	7,305	1,826	4	31	34
3	2,898	966	3	37	39
4	1,958	653	3	42	44
5	2,313	771	3	47	49
6	2,450	817	3	52	54

Each branch is bounded upstream and downstream by an inactive segment. For example, for branch 1, inactive segments are Segment 1 at the upstream end and Segment 29 at the downstream end. Inactive segments do not have volume or surface area. The model was organized this way to impose boundary conditions.[12] A detailed description of the Englebright Temp Model bathymetric representation of Englebright Reservoir can be found in Attachment 2-6C.

Reservoir Physical Characteristics

Englebright Reservoir has a normal-maximum water-surface elevation of 527 ft and a normal-minimum water-surface elevation of 516 ft. The spillway crest is at elevation 527 ft.

The reservoir is impounded by Englebright Dam, a variable radius concrete arch dam. The dam spans 1,142 feet across and is 260 feet high.

Englebright Dam has no low-level outlet. Water from Englebright Reservoir is released for power generation at the Narrows 1 and 2 powerhouses, or spilled over the top of the dam. When water surface elevation is lower than the Engelbright Dam crest, water can also be released through a full flow bypass, which takes water from the same intake as the Narrows 2 Powerhouse. The Narrows 1 Powerhouse has a maximum capacity of 730 cfs, the Narrows 2 Powerhouse has a maximum capacity of 3,400 cfs. Englebright Dam spillway has a maximum capacity of 181,000 cfs at elevation 547 ft. The intake for the Narrows 1 Powerhouse has centerline elevation of 460 ft with intake dimensions of 12 ft by 12 ft. The Narrows 2 Powerhouse intake has a centerline elevation of 448.38 ft. A detailed description of the Englebright Reservoir physical characteristics is presented in Attachment 2-6C.

2.4.2.3 Lower Temp Model

The Lower Temp Model has a relatively simple physical representation. RMs for key features and the river channel geometry is defined. Table 2.4-7 provides the locations, in RMs, for features represented in the Lower Temp Model.

[12] Boundary conditions specify the flow and thermal conditions at the boundaries of the modeled region.

Table 2.4-7. River miles of features along the Yuba River below Englebright Dam.

Feature	River Mile (mile)[1]
Yuba River confluence with the Feather River	0.0
Marysville Gage	6.2
Daguerre Point Dam	11.6
Dry Creek confluence with the Yuba River	13.9
Deer Creek confluence with the Yuba River	23.4
Smartsville Gage	23.9
Narrows 1 Powerhouse	24.0
Narrows 2 Powerhouse	24.2
Englebright Dam	24.3

[1] River miles are measured from the Yuba River confluence with the Feather River upstream.

HEC-5Q computes water-surface area based on its internal hydraulic calculation based on geometric information provided along the river. River geometry came from the RMT SRH2D model (Pasternack and Lower Yuba RMT 2012). River cross-channel geometry was extracted by GIS from the RMT SRH2D model at locations shown in Figure 2.3-4.

Using the water-surface elevation corresponding to 5,000 cfs of flow in the river as a reference elevation to roughly correspond with the combined release capacity of the Narrows 1 and Narrows 2 powerhouses, river geometry was defined at 20 elevations for each cross-section location. To ensure a high resolution for the typical flow range of the river, 15 elevations were defined below the 5,000 cfs elevation at each section, and five elevations were defined between the 5,000 cfs elevation and the 50,000 cfs elevation. A standard Manning's n value of 0.043 for the channel roughness, as used by the RMT SRH2D model, was used throughout the Lower Temp Model. A detailed description of the Lower Temp Model's representation of the Yuba River below Englebright Dam can be found in Attachment 2-6C.

2.4.3 Input Flow and Water Temperature

Simulation of the period of record for each model was dependent on a full period of record of input flows and water temperatures, in addition to the previously described meteorology and physical parameters. This section describes the development of the input flow and water temperature information. All input flows have an associated inflow water temperature file.

2.4.3.1 Upper Temp Model

The Upper Temp Model includes inflows from the North Yuba River above New Bullards Bar Reservoir, the Middle Yuba River above Our House Diversion Dam, Oregon Creek above Log Cabin Diversion Dam, and accretions to the North Yuba, Middle Yuba, and Yuba rivers, and Oregon Creek. The inflows and temperatures for each are described below.

Input Flows

All inflows to the Upper Temp Model come directly from the Water Balance/Operations Model. A complete description of the development of the inflows can be found in Attachment 2-2D. Table 2.4-8 shows the inputs to the model and their respective names in the input HEC-DSS file.

Table 2.4-8. Upper Temp Model input flows and HEC-DSS names.

Location	HEC-DSS Name
North Yuba River inflows above New Bullards Bar Dam	INF_NBB_TOTAL
Oregon Creek above Log Cabin Diversion Dam	INF_OREGONCR
Middle Yuba River above Our House Diversion Dam	INF_MYUBA
Accretions to the Middle Yuba River between Our House Diversion Dam and Oregon Creek	INF_MYUBA_ACC1
Accretions to the Middle Yuba River between Oregon Creek and the North Yuba River	INF_MYUBA_ACC2
Accretions to the North Yuba River below New Bullards Bar Dam and the Yuba River above the New Colgate Powerhouse	INF_UPPERYUBA_ACC

Additionally, the Water Balance/Operations Model provides diversion time series inputs from Our House Diversion Dam to the Lohman Ridge Tunnel; from Log Cabin Diversion Dam to the Camptonville Tunnel; and from New Bullards Bar Reservoir to the New Colgate Powerhouse. Those inputs are named, "LOHMANRIDGE_TUNNEL," "CAMPTONVILLE_TUNNEL," and "COLGATE_RELEASE," respectively, in the input HEC-DSS file.

Input Water Temperatures

Input water temperatures are contained in the same input file as input flows, and have the same names as the input flows. While input flows have a "FLOW" designation, input temperatures have a "TEMP" designation in part C of the HEC-DSS file.

Accretions to the Middle Yuba River, Oregon Creek, and the Yuba River above Englebright Reservoir, developed for the Water Balance/Operations Model, were applied as non-point inflows within the Upper Temp Model. The non-point inflows were distributed evenly across their respective reaches rather than being applied at a specific location.

Historical water temperature information was available for three primary input flows, the North Yuba and Middle Yuba Rivers, and Oregon Creek. However, limited periods of record for the data were available, and within the periods of record, there were large data gaps due to challenges in data collection. For a complete description of the data collection effort, see Study 2.5, *Water Temperature Monitoring*. A detailed description of the development of the Upper Temp Model inflow temperatures can be found in Attachment 2-6C.

2.4.3.2 Englebright Temp Model

The Englebright Temp Model includes inflows from the Yuba River below the New Colgate Powerhouse, the South Yuba River below Jones Bar, and accretions to the South Yuba and Yuba rivers. The inflows and temperatures for each are described below.

Input Flows

All inflows to the Englebright Temp Model come directly from the Water Balance/Operations Model. A complete description of the development of the inflows can be found in Attachment 2-2D. Table 2.4-9 shows inputs to the model and their respective names in the input HEC-DSS file.

Table 2.4-9. Englebright Reservoir water temperature model input flows and HEC-DSS names.

Location	HEC-DSS Name
Yuba River below the New Colgate Powerhouse	YR_BLW_COLGATE
South Yuba River near Jones Bar	INF_SYUBA
Accretions to the South Yuba River below Jones Bar	INF_SYUBA_ACC
Accretions to the Yuba River between Rice's Crossing and Englebright Dam	INF_ENG_ACC

Additionally, the Water Balance/Operations Model provides diversions through the Narrows 1 and Narrows 2 powerhouses and spill over Englebright Reservoir, with the names, "NARROWS1_RELEASE," "NARROWS2_RELEASE," "NARROWS2_BYPASS," and "ENG_SPILL," respectively, in the standard input file.

Input Water Temperatures

Input water temperatures were contained in the same input file as input flows, and have the same names as the input flows. While input flows have a "FLOW" designation, input temperatures have a "TEMP" designation in part C of the HEC-DSS file.

Input water temperatures from the Yuba River below the New Colgate Powerhouse were a direct output from the Upper Temp Model.

Historically-measured water temperature information was available for the South Yuba River at Jones Bar. However, a limited period of record for the data was available, and within the period of record, there were data gaps due to challenges in data collection. For a complete description of the data collection effort, see Study 2.5, *Water Temperature Monitoring*.

Similar to the Upper Temp Model, accretions to Englebright Reservoir and the South Yuba River were treated as non-point inflows and were distributed throughout the reservoir. Temperatures that were assigned to these distributed tributaries were developed using observed data from Dry Creek. A detailed discussion of the development of Englebright Reservoir inflow temperatures is included in Attachment 2-6C.

2.4.3.3 Lower Temp Model

The Lower Temp Model includes inflows from Deer Creek and Dry Creek, as well as releases from Englebright Reservoir. The inflows and water temperatures for each are described below.

Input Flows

All inflows to the Lower Temp Model come directly from the Water Balance/Operations Model. A complete description of the development of the inflows can be found in Attachment 2-2D. Table 2.4-10 shows inputs to the model and their respective names in the input HEC-DSS file.

Table 2.4-10. Lower Temp Model input flows and HEC-DSS names.

Location	HEC-DSS Name
Yuba River near Smartsville	YR_SMARTSVILLE
Deer Creek inflows to the Yuba River	INF_DEERCR
Dry Creek inflows to the Yuba River	INF_DRYCR

Additionally, the Water Balance/Operations Model provides diversions from Daguerre Point Dam with the name "DAGUERRE_DIV" in the standard input file.

Input Water Temperatures

Input water temperatures were contained in the same input file as input flows, and have the same names as the input flows. While input flows have a "FLOW" designation, input temperatures have a "TEMP" designation in part C of the HEC-DSS file.

Input water temperatures at the Yuba River near Smartsville came directly out of the Englebright Temp Model. Output temperatures from Englebright Reservoir were converted to English units and updated into the HEC-DSS input file. A detailed description of the development of the input water temperatures to the Lower Temp Model is included in Attachment 2-6C.

2.5 Model Validation

Water temperature model validation was very similar to calibration, except that differences between simulated output and historically measured temperatures were evaluated qualitatively and differences were explained, and unless there were substantial, unexplainable differences, the model calibration was not changed. If there were substantial, unexplainable differences, the model calibration was adjusted to better reflect the historical measured temperatures. A detailed description of the Validation Scenario can be found in Attachment 2-6C.

2.5.1 Upper Temp Model

Validation of the Upper Temp Model was completed using historical inflow data for the North Yuba River above New Bullards Bar Reservoir, the Middle Yuba River above Our House Dam, and Oregon Creek above Log Cabin Dam, as well as historical diversions to New Bullards Bar Reservoir via Lohman Ridge Diversion Tunnel, and Camptonville Diversion Tunnel from Our House Dam, and Log Cabin Dam, respectively, and diversions to the New Colgate Penstock, from New Bullards Bar Reservoir. Synthetic water temperatures, for all inflow locations for the period of January 1, 2000 through September 30, 2011, as well as synthetic accretion flows on the Middle Yuba River and Oregon Creek, were used in the Validation Scenario. Simulated water temperatures were compared to historical water temperatures on the North Yuba River below New Bullards Bar Dam, on the Middle Yuba River above its confluence with the North Yuba River, and on the Yuba River below the New Colgate Powerhouse. All assumptions for the physical configuration of the reservoir and rivers were identical to those used in calibration.

2.5.2 Englebright Temp Model

Validation of the Englebright Temp Model was completed using historical inflow data in the Yuba and South Yuba Rivers, and synthetic water temperature data for all inflow locations, including simulated Yuba River water temperature below the New Colgate Powerhouse from the Upper Temp Model, for the period of January 1, 2000 through September 30, 2011. Synthetic accretion flows were developed to balance historic inflows, outflows and reservoir storage. Simulated water temperatures were compared to historical water temperatures for the Smartsville gage. All assumptions for physical configuration of the reservoir were identical to those used in calibration.

2.5.3 Lower Temp Model

Validation of the Lower Temp Model was completed using simulated Smartsville water temperatures from the Englebright Temp Model, historically-measured flow at Smartsville, historical meteorology and Daguerre Point Dam irrigation diversions, and synthetic inflows and water temperatures from Deer Creek and Dry Creek for the period of January 1, 2000 through September 30, 2011. Due to a lack of data at other locations along the Yuba River for dates prior to 2008, simulated water temperatures were compared to historical water temperatures at the Marysville gage; YCWA has been collecting water temperature data at the Smartsville and Marysville gage since the mid-1990s and these data were available for validation. All assumptions for the physical configuration of the river were identical to those used in calibration.

2.6 Base Case Development

The Base Case Scenario includes a simulation of the period of record of October 1, 1969 through September 30, 2010. The Base Case Scenario uses hydrologic output from the Water Balance/Operations Model Base Case Scenario. For a complete description of the Base Case Scenario hydrology and operations, see Attachment 2-2C.

The Base Case Scenario uses synthetic input water temperatures for the period of record for the North Yuba River above New Bullards Bar Dam, the Middle Yuba River above Our House Diversion Dam, Oregon Creek above Log Cabin Diversion Dam, the South Yuba River near Jones Bar, Deer Creek near Smartsville, and Dry Creek. These inputs were developed based on repeating available historically-measured data from YCWA water temperature monitoring stations for the period of record. A detailed description of the gages and methodology used to represent the Base Case Scenario inflow water temperatures is presented in Attachment 2-6C.

Meteorology for the Base Case Scenario period of record was different from that used for the validation or calibration phases. Since there was generally limited meteorology data available for the full period of record within the area of interest, available data at locations without a full period of record available were extended by regression comparing locations with the full period available. A detailed description of the meteorological data used in the Base Case Scenario is presented in Attachment 2-6C.

3.0 Results

The following section provides a description of the results from the steps described in Section 2.

3.1 Maximum-Daily Water Temperatures

Through discussion with Relicensing Participants, one of the conditions for use of a daily time-step was the ability to post-process the mean-daily water temperature model output to compute maximum-daily water temperatures at three key locations: 1) Middle Yuba River above its confluence with the North Yuba River; 2) Yuba River near Daguerre Point Dam; and 3) the Yuba River near Marysville. Using regressions based on historical data at each location for flows, air temperatures, and mean-daily water temperatures, relationships for determining maximum-daily water temperatures were developed. Figure 3.1-1 shows a comparison of historical maximum-daily water temperature with computed maximum-daily water temperatures for the Middle Yuba River above its confluence with the North Yuba River. The historical and computed maximum-daily water temperatures were available for the entire period shown in each figure. Where only one is shown for a day, the data were nearly identical and the red line for the Computed Maximum Water Temperature is shown (i.e., the blue line for the Historical Maximum Water Temperature is under the red line).

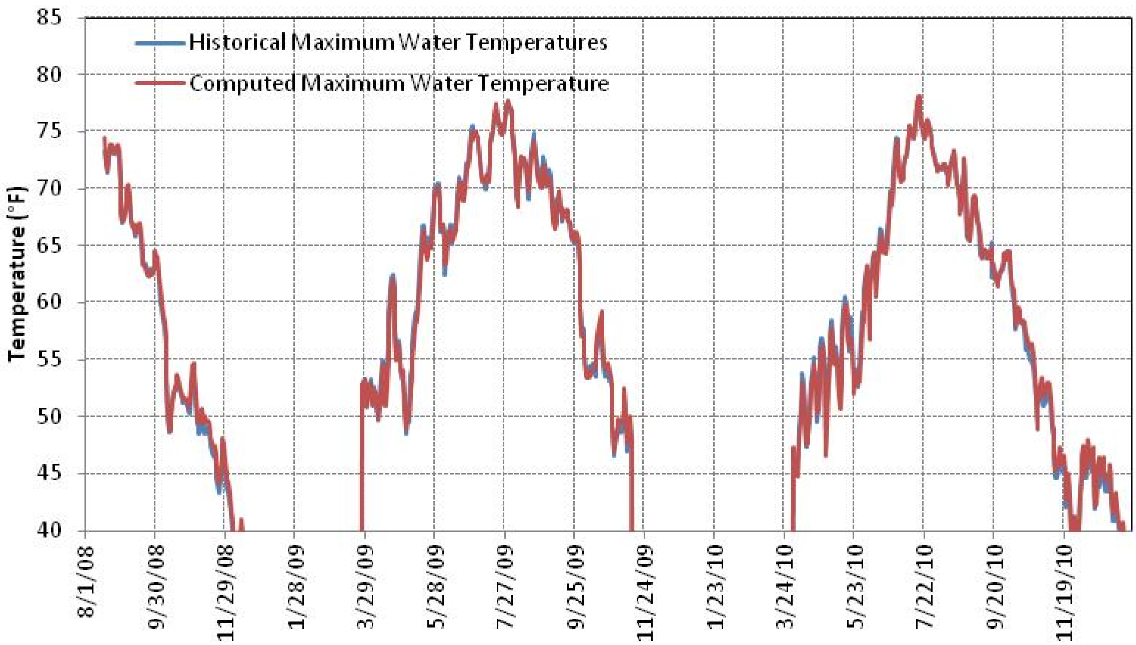

Figure 3.1-1. Comparison of historical and computed maximum-daily water temperatures on the Middle Yuba River above its confluence with the North Yuba River.

Figure 3.1-2 shows a comparison of historical maximum-daily water temperatures with computed maximum-daily water temperatures for the Yuba River near Daguerre Point Dam.

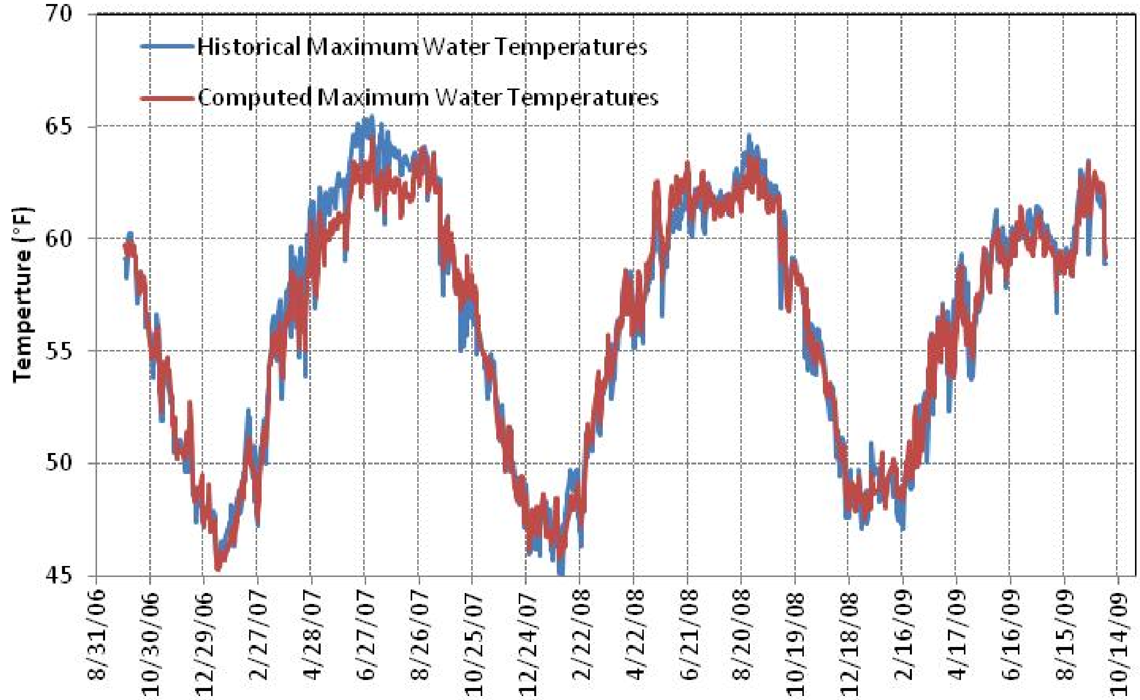

Figure 3.1-2. Comparison of historical and computed maximum-daily water temperatures on the Yuba River near Daguerre Point Dam.

Figure 3.1-3 shows a comparison of historical maximum-daily water temperatures with computed maximum-daily water temperatures for the Yuba River near Marysville.

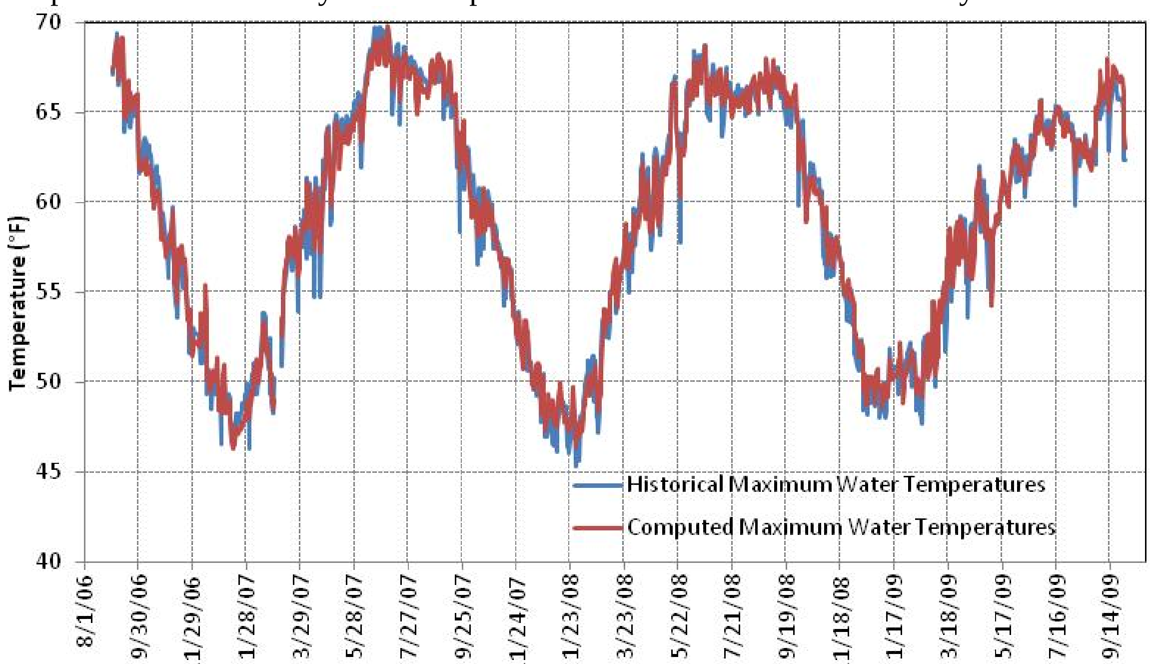

Figure 3.1-3. Comparison of historical and computed maximum-daily water temperatures on the Yuba River near Marysville.

3.2 Model Development and Calibration

The following section provides results of the Model Development and Calibration task of the study.

3.2.1 Upper Temp Model

The Upper Temp Model includes a water balance module to compute flows internal to the model, and a quality module to compute water temperatures. Figure 3.2-1 shows a comparison of simulated New Bullards Bar Reservoir storage from the Water Balance/Operations Model and the Upper Temp Model water balance module.

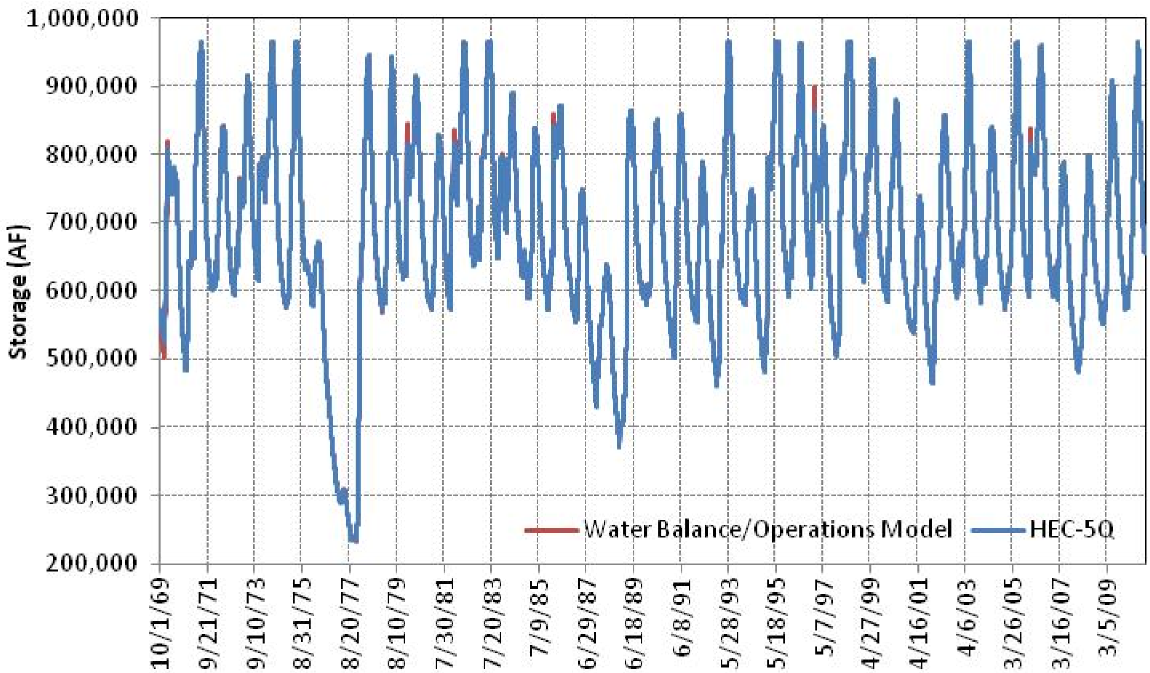

Figure 3.2-1. Comparison of simulated New Bullards Bar Reservoir storage for the Water Balance/Operations Model and the HEC-5Q water balance module.

Figure 3.2-2 shows a comparison of simulated Yuba River flows near Rice's Crossing from the Water Balance/Operations Model and the Upper Temp Model water balance module.

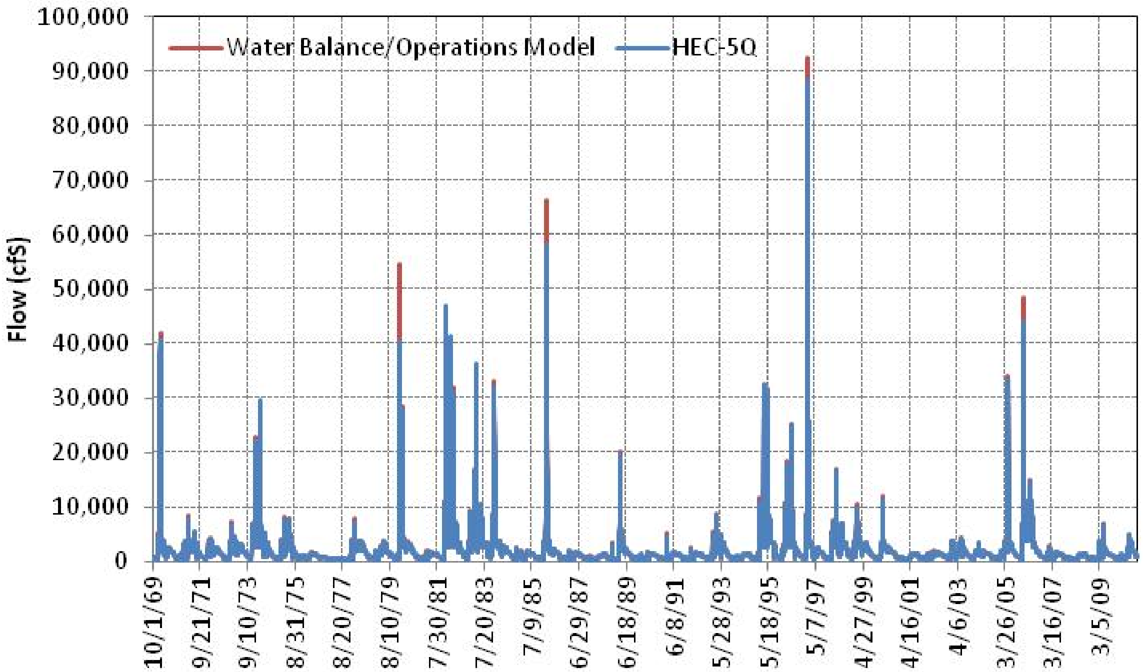

Figure 3.2-2. Comparison of simulated Yuba River flow below the New Colgate Powerhouse for the Water Balance/Operations Model and the HEC-5Q water balance module.

Calibration of the Upper Temp Model focused on both New Bullards Bar Reservoir and the river reaches above Englebright Reservoir. New Bullards Bar Reservoir calibration was completed using historical inflow data from the North Yuba River and the Camptonville Tunnel; historical releases through the New Colgate Powerhouse, the New Bullards Bar Dam spillway, and the New Bullards Bar Dam low-flow powerhouse; and historical meteorological data from the New Bullards Bar Dam weather station for the period of November 14, 2009 through April 9, 2012. This calibration period was chosen due to the availability of meteorological data from the New Bullards Bar Dam weather station for this period of record. New Bullards Bar Reservoir calibration was focused on matching simulated reservoir water temperature profiles with historical profiles that have been measured bi-weekly by YCWA near the New Colgate Powerhouse intake since August 25, 1989. Comparisons of historically-recorded and simulated end-of-month New Bullards Bar Reservoir profiles for the months of June 2010 through May 2011 are shown in Figures 3.2-3 through 3.2-14 for dates with historically-measured profiles nearest the end of each month.[13] This particular sequence was used because it reflects an adequate period for the simulated New Bullards Bar Reservoir profile to stabilize prior to the start of the output period, and it reflects a full year of profiles, demonstrating the model's stability through a full range of hydrological and meteorological conditions. The historical and computed reservoir profiles were available for the date shown in each figure. Where only one is shown for a day, the data were nearly identical and the data series are overlaying one another.

[13] At least one New Bullards Bar Reservoir water temperature profile was taken in each month from June 2010 through May 2011 except in February 2011. So, two profiles in March 2012 (i.e. on March 4 and March 31) are shown (Figures 3.2-11 and 3.2-12, respectively).

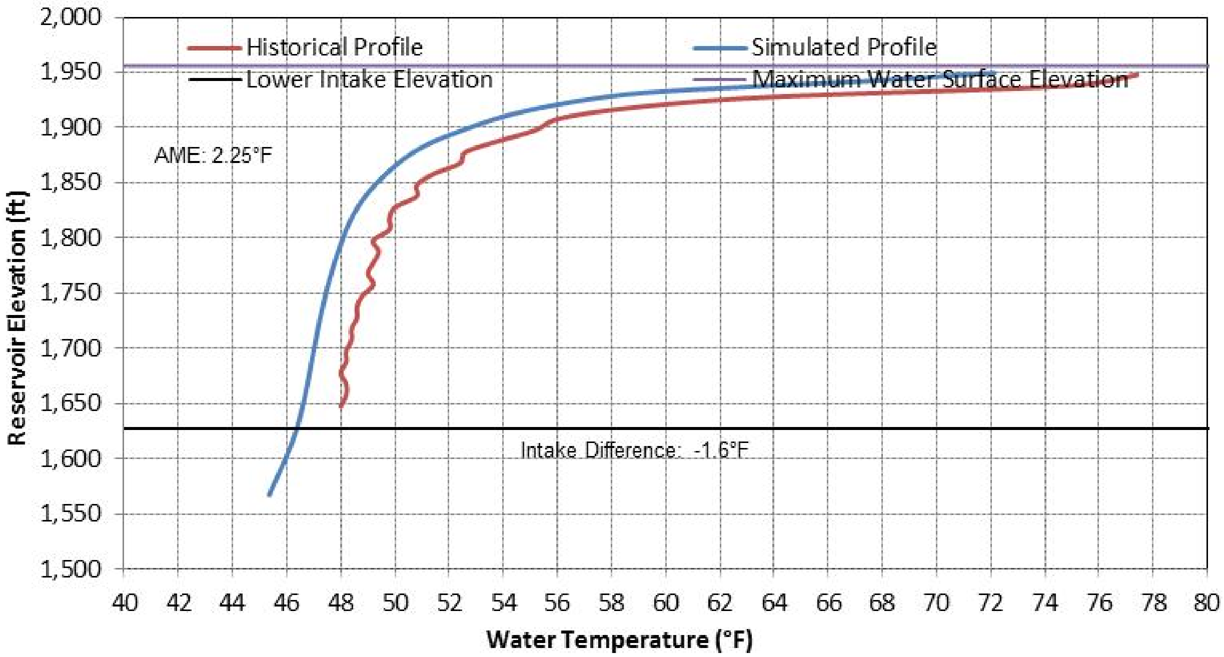

Figure 3.2-3. Comparison of historical and simulated New Bullards Bar Reservoir profiles for June 28, 2010.

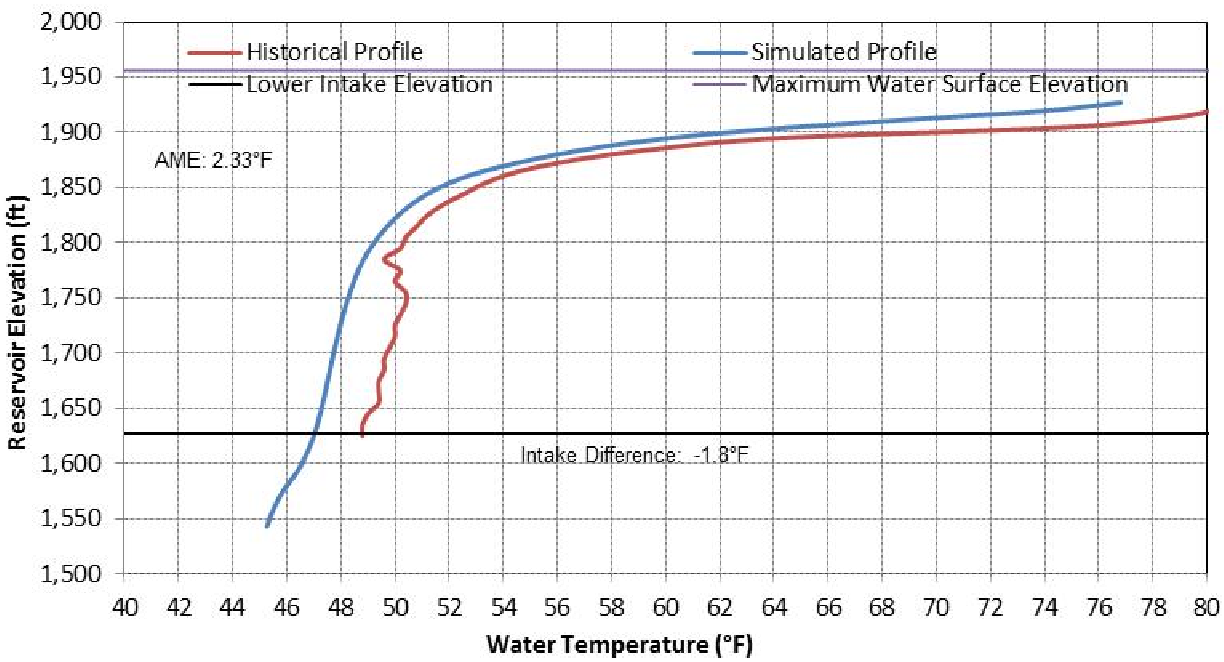

Figure 3.2-4. Comparison of historical and simulated New Bullards Bar Reservoir profiles for July 22, 2010.

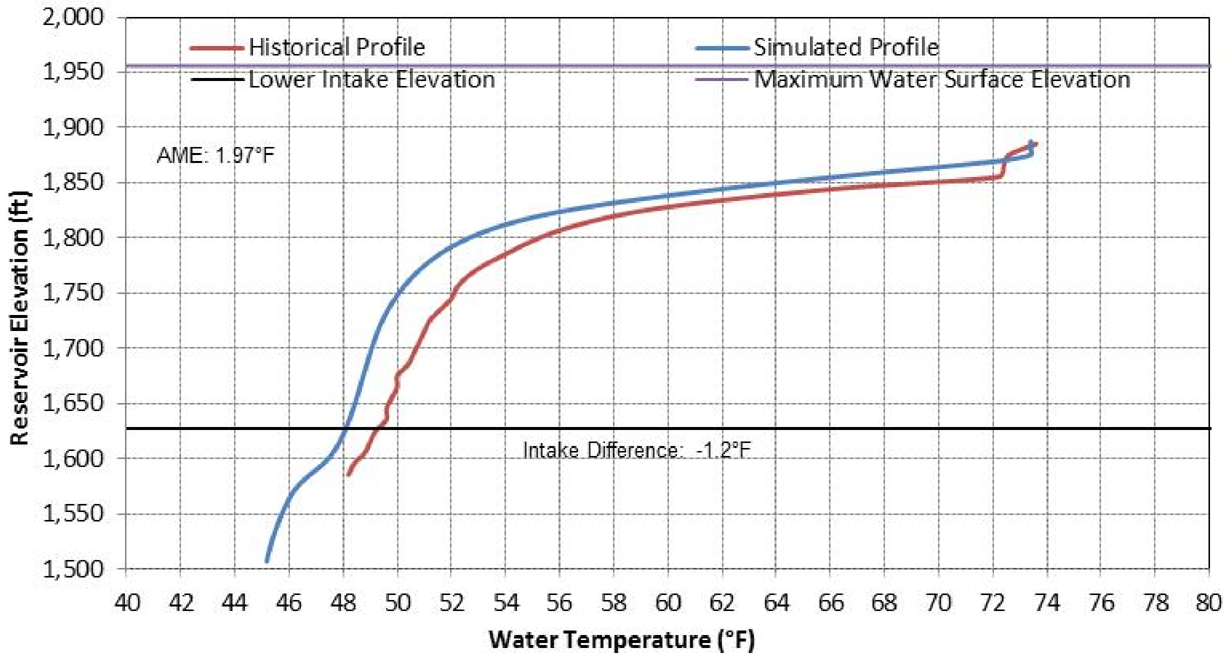

Figure 3.2-5. Comparison of historical and simulated New Bullards Bar Reservoir profiles for August 31, 2010.

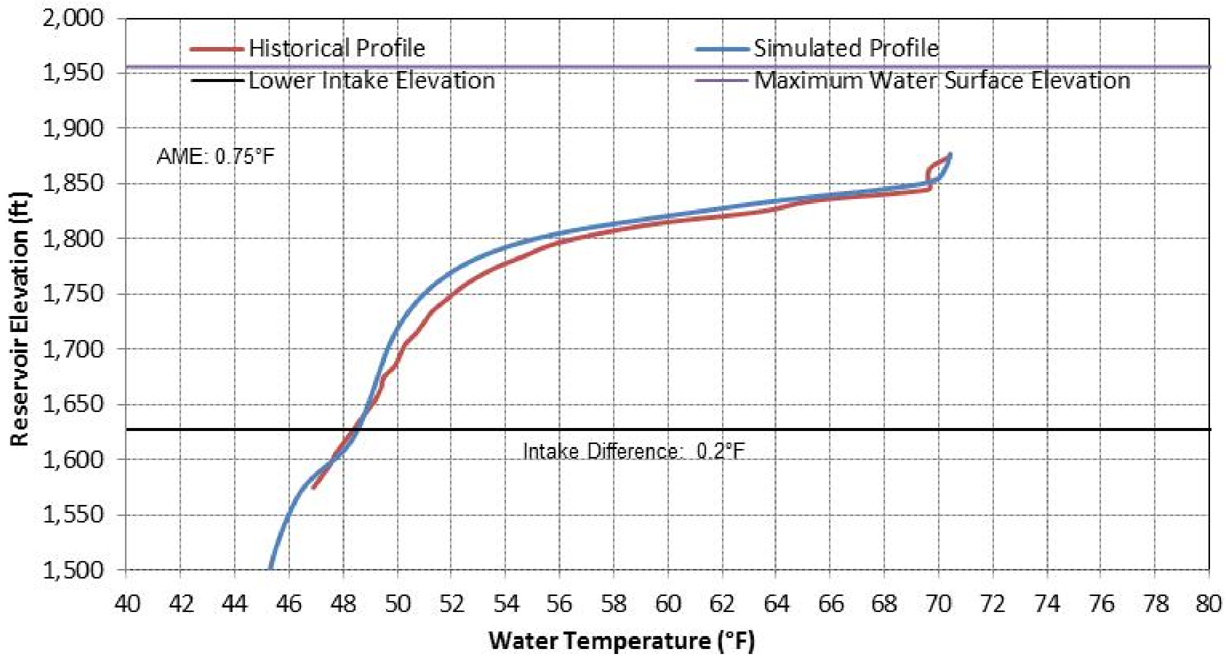

Figure 3.2-6. Comparison of historical and simulated New Bullards Bar Reservoir profiles for September 30, 2010.

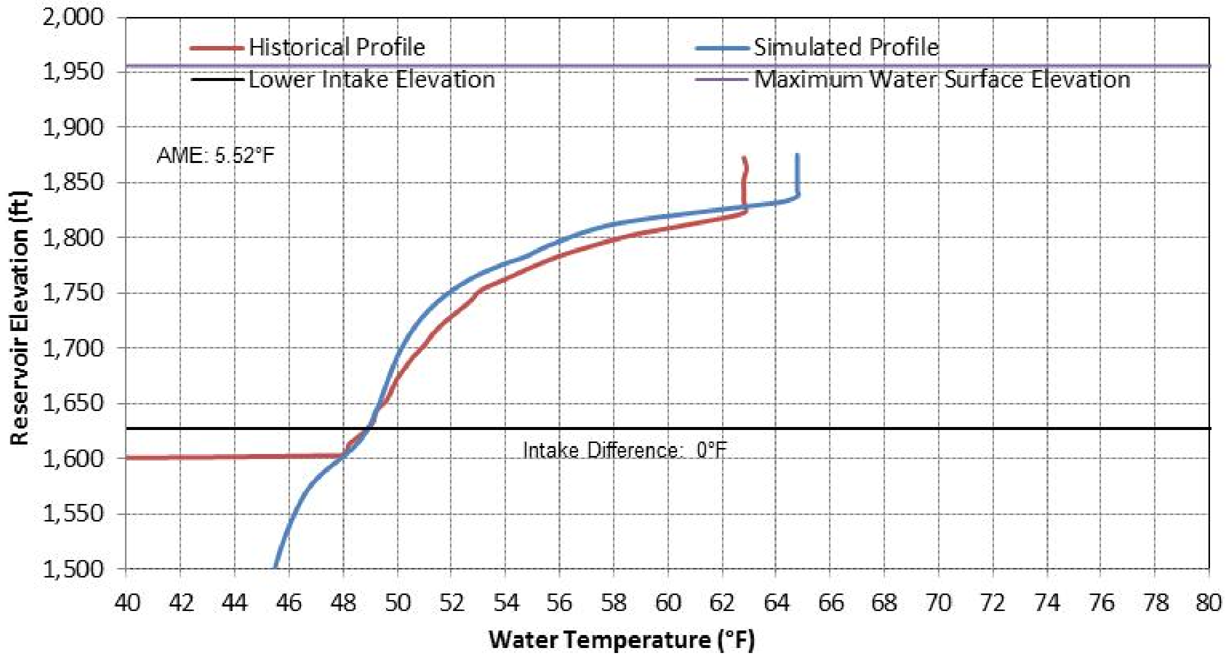

Figure 3.2-7. Comparison of historical and simulated New Bullards Bar Reservoir profiles for October 27, 2010.

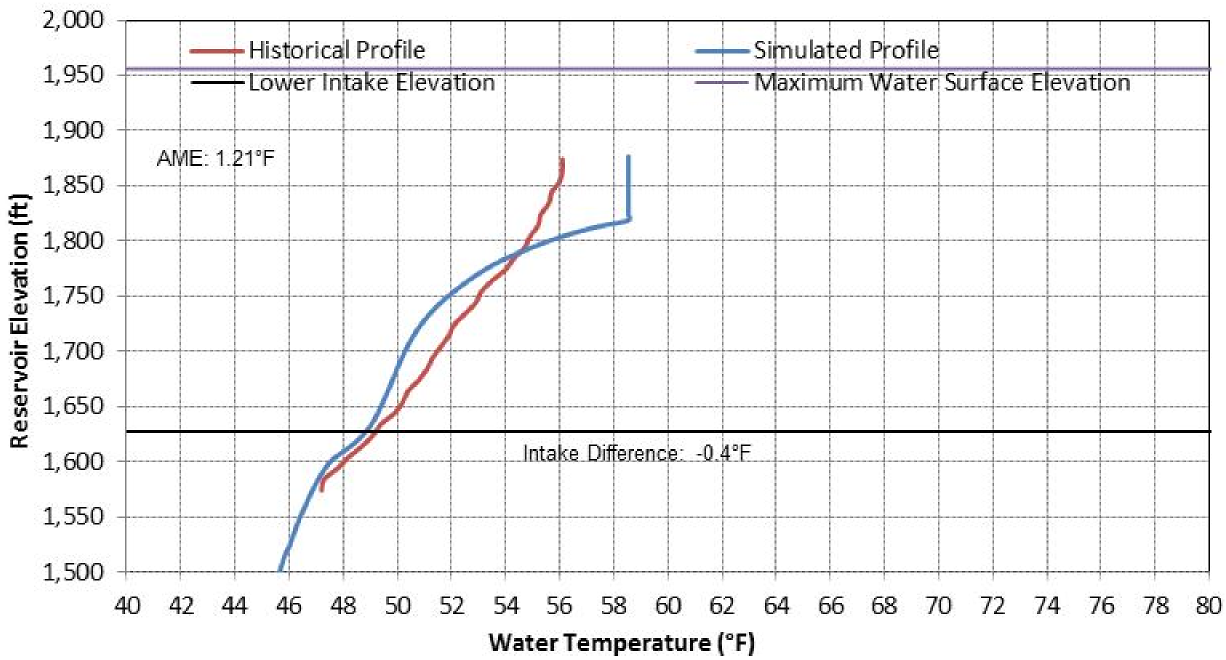

Figure 3.2-8. Comparison of historical and simulated New Bullards Bar Reservoir profiles for November 23, 2010.

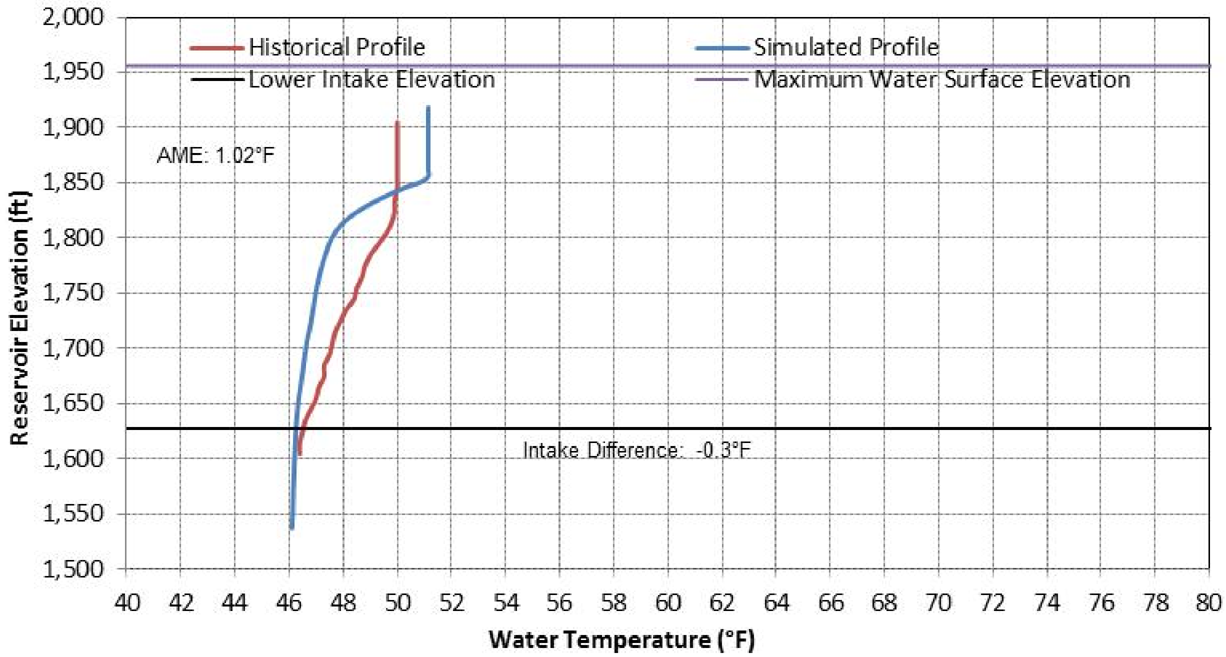

Figure 3.2-9. Comparison of historical and simulated New Bullards Bar Reservoir profiles for December 30, 2010.

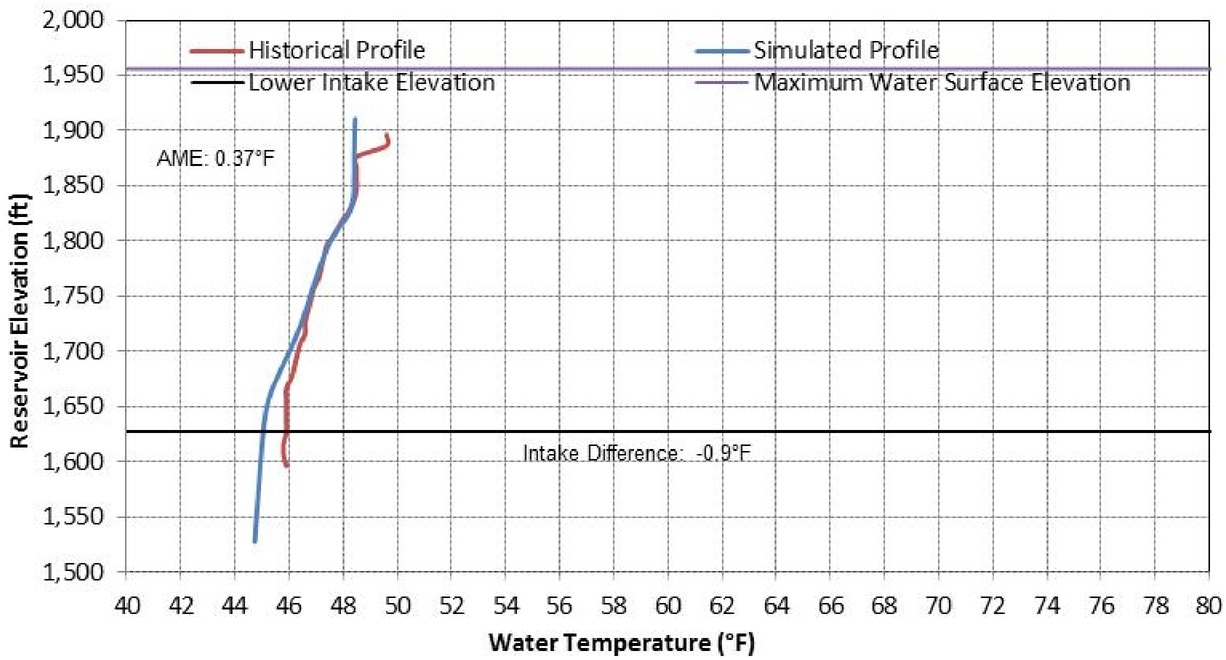

Figure 3.2-10. Comparison of historical and simulated New Bullards Bar Reservoir profiles for January 26, 2011.

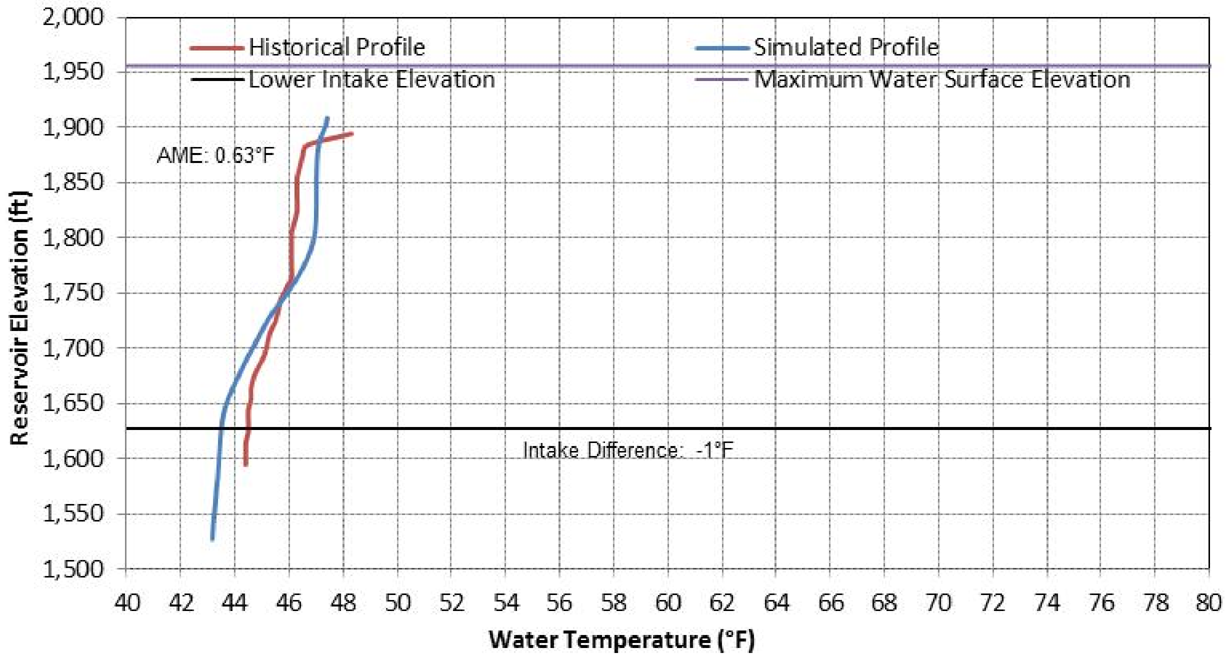

Figure 3.2-11. Comparison of historical and simulated New Bullards Bar Reservoir profiles for March 4, 2011.

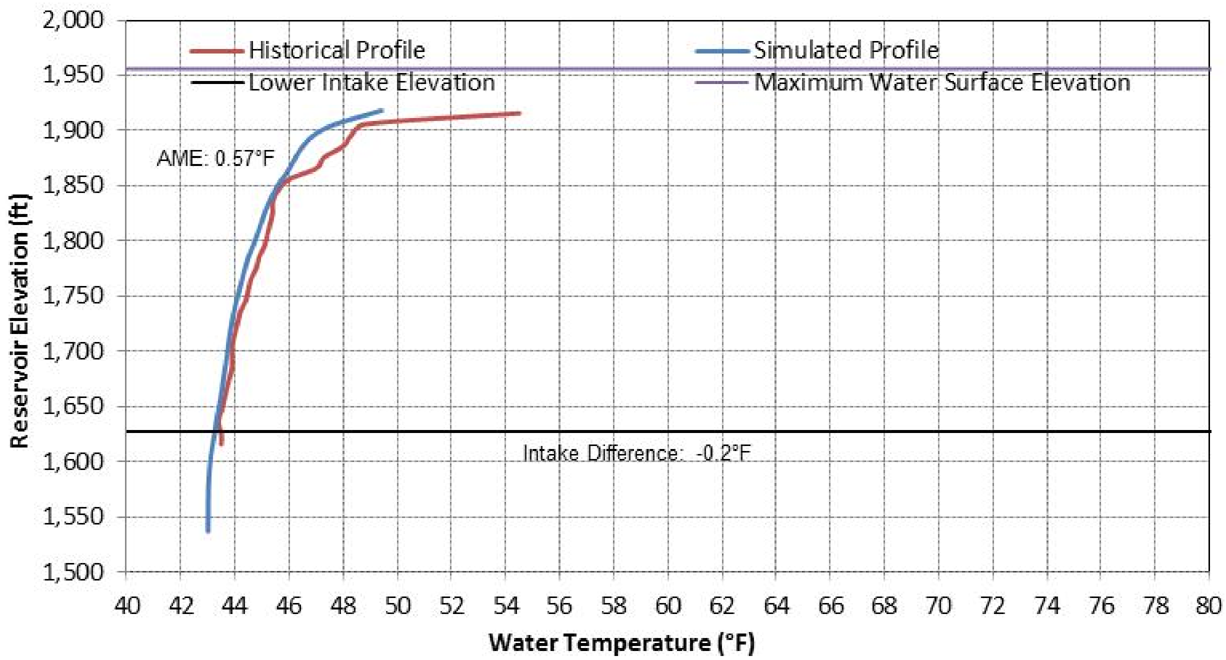

Figure 3.2-12. Comparison of historical and simulated New Bullards Bar Reservoir profiles for March 31, 2011.

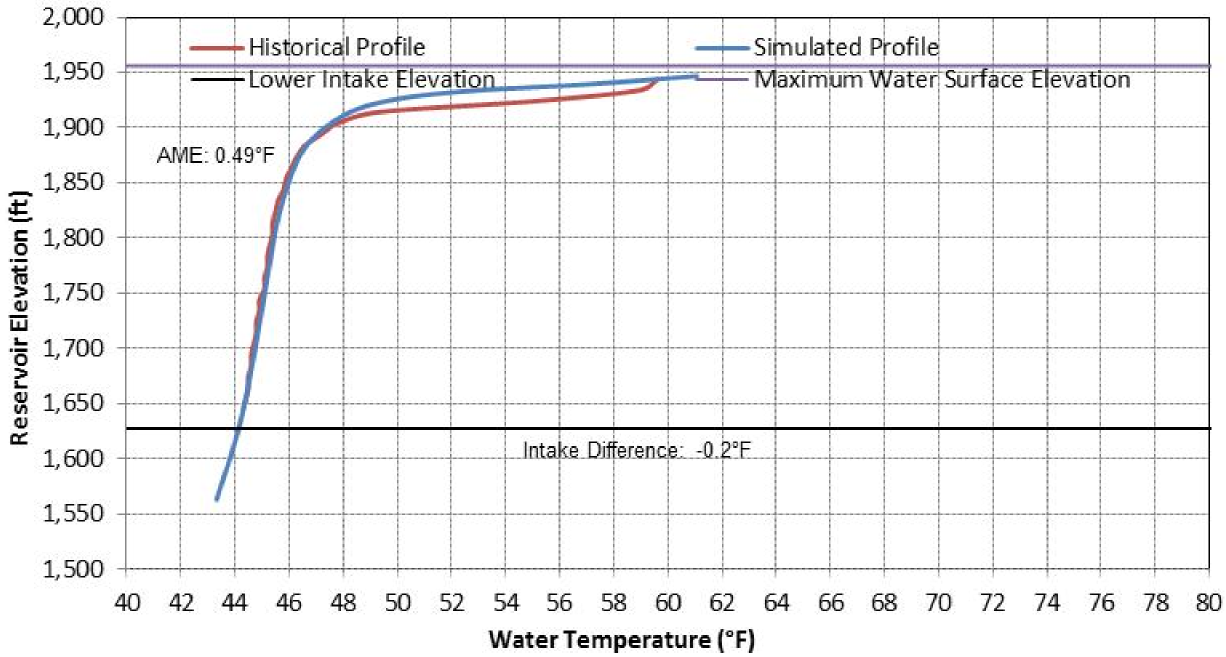

Figure 3.2-13. Comparison of historical and simulated New Bullards Bar Reservoir profiles for May 12, 2011.

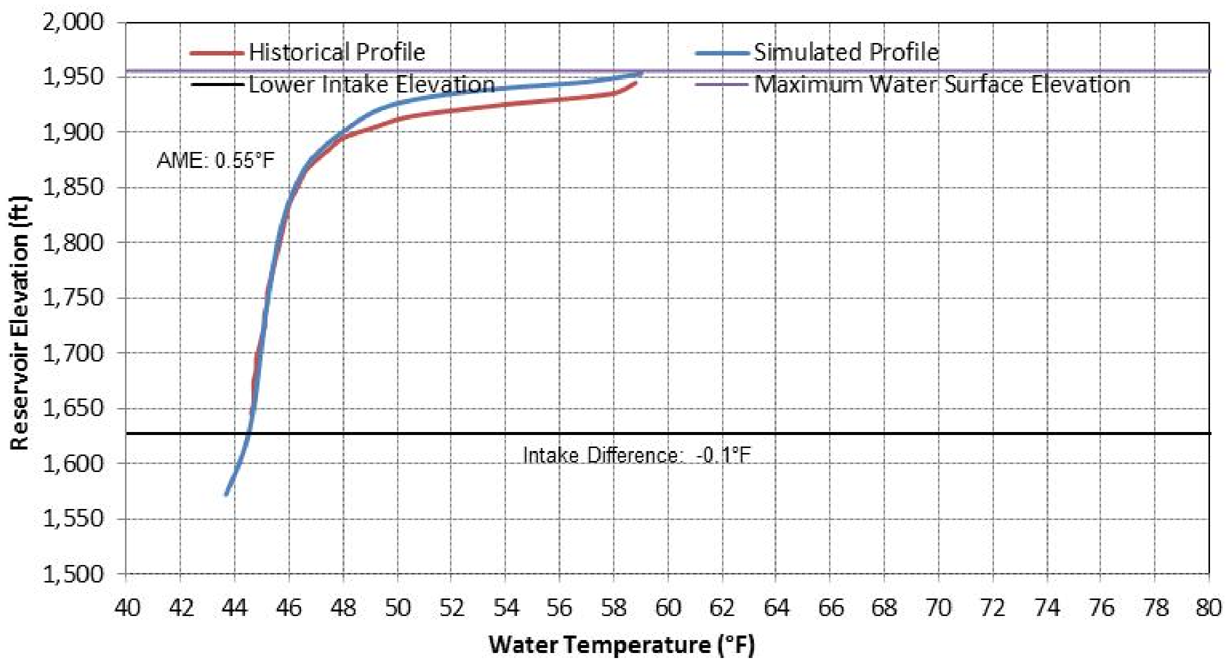

Figure 3.2-14. Comparison of historical and simulated New Bullards Bar Reservoir profiles for May 26, 2011.

Calibration of the Middle Yuba River portion of the Upper Temp Model focused on water temperatures upstream from the Middle Yuba River confluence with the North Yuba River for the period of November 14, 2009 through April 9, 2012.

Historical Middle Yuba River water temperatures were monitored upstream from its confluence with the North Yuba River at RM 0.1. Figure 3.2-15 shows a comparison of the simulated water temperatures with historically-measured water temperatures on the Middle Yuba River upstream from its confluence with the North Yuba River. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Upper Temp Model is under the red line).

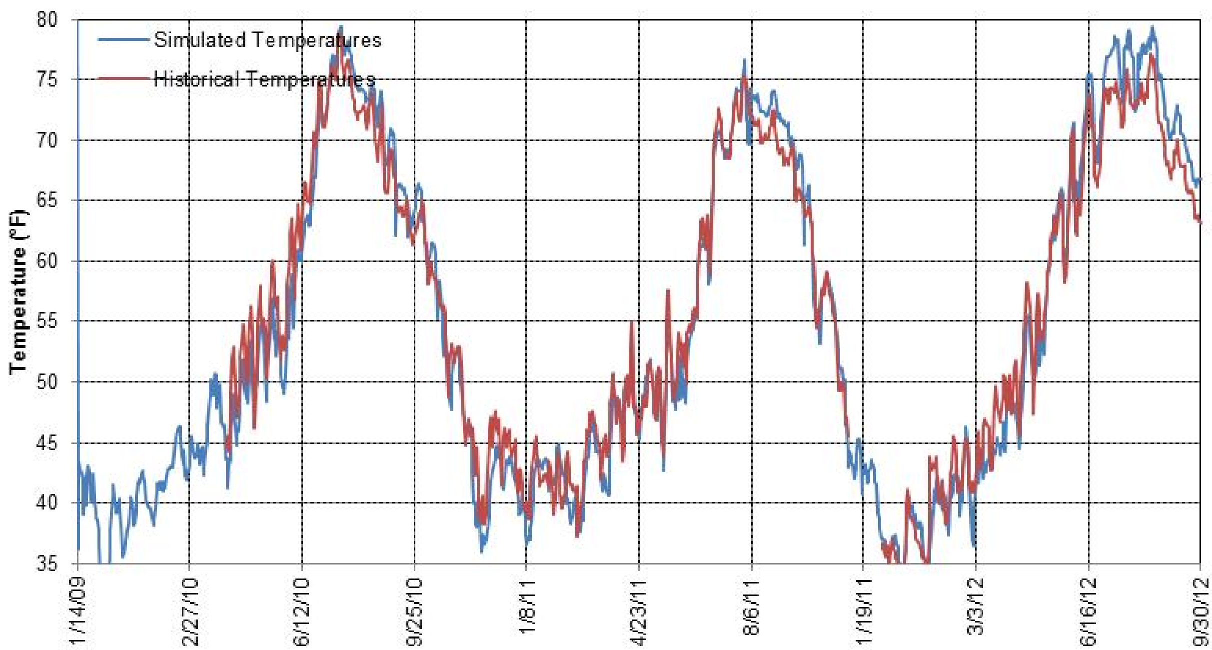

Figure 3.2-15. Comparison of Simulated and Historically-Measured Middle Yuba River (RM 0.1) Water Temperatures upstream from its confluence with the North Yuba River for the Upper Temp Model Calibration Scenario

Figure 3.2-16 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the Middle Yuba River upstream from its confluence with the North Yuba River

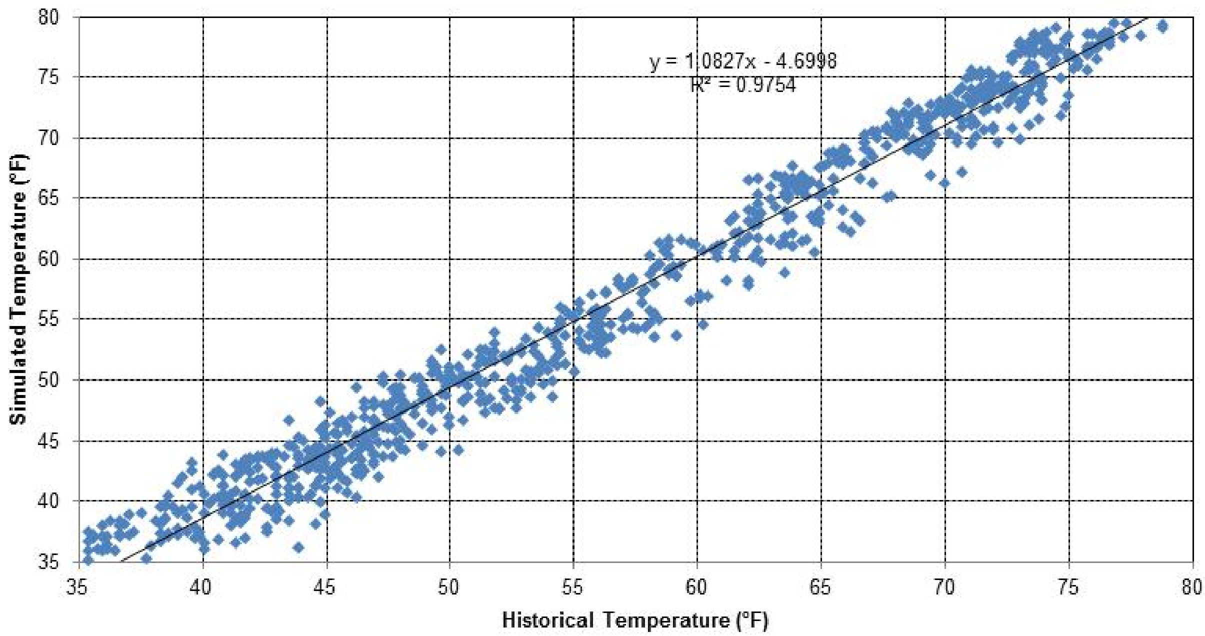

Figure 3.2-16. Scatter Plot Comparison of Simulated and Historically-Measured Middle Yuba River (RM 0.1) Water Temperatures upstream from its confluence with the North Yuba River for the Upper Temp Model Calibration Scenario

Historical North Yuba River water temperatures were monitored upstream from its confluence with the Middle Yuba River at RM 0.1. Figure 3.2-17 shows a comparison of the simulated water temperatures with historically-measured water temperatures on the North Yuba River upstream from its confluence with the Middle Yuba River. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Upper Temp Model is under the red line).

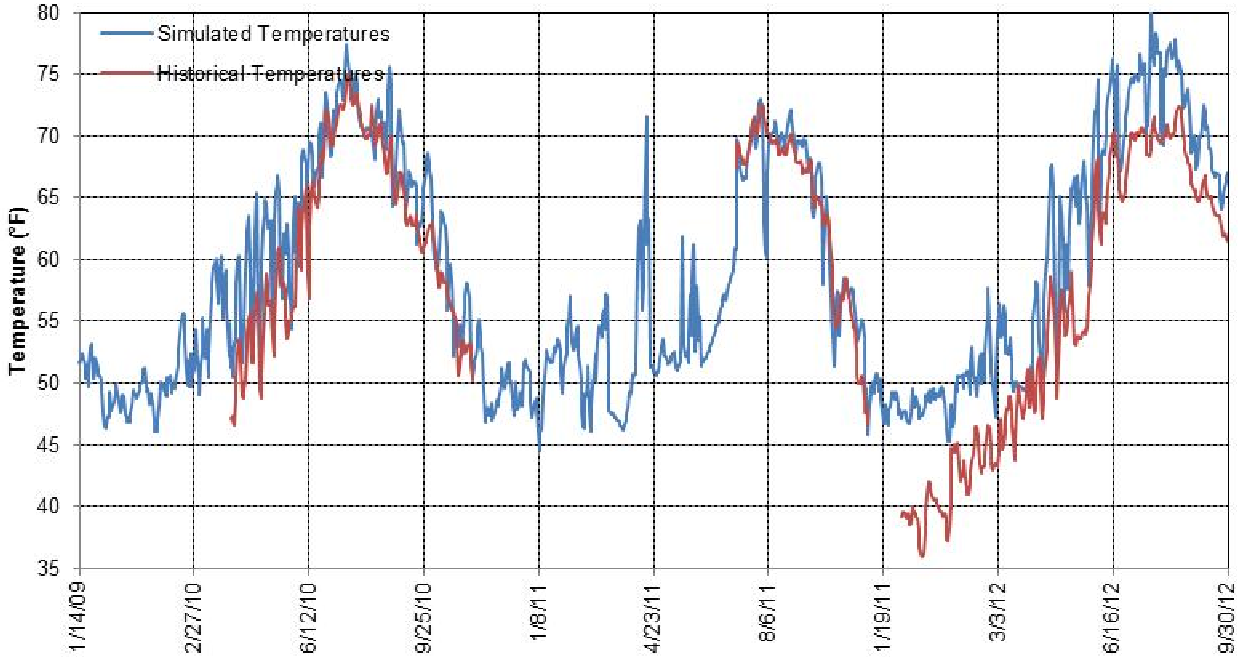

Figure 3.2-17. Comparison of Simulated and Historically-Measured North Yuba River (RM 0.1) Water Temperatures upstream from its confluence with the North Yuba River for the Upper Temp Model Calibration Scenario

Figure 3.2-18 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the North Yuba River upstream from its confluence with the Middle Yuba River.

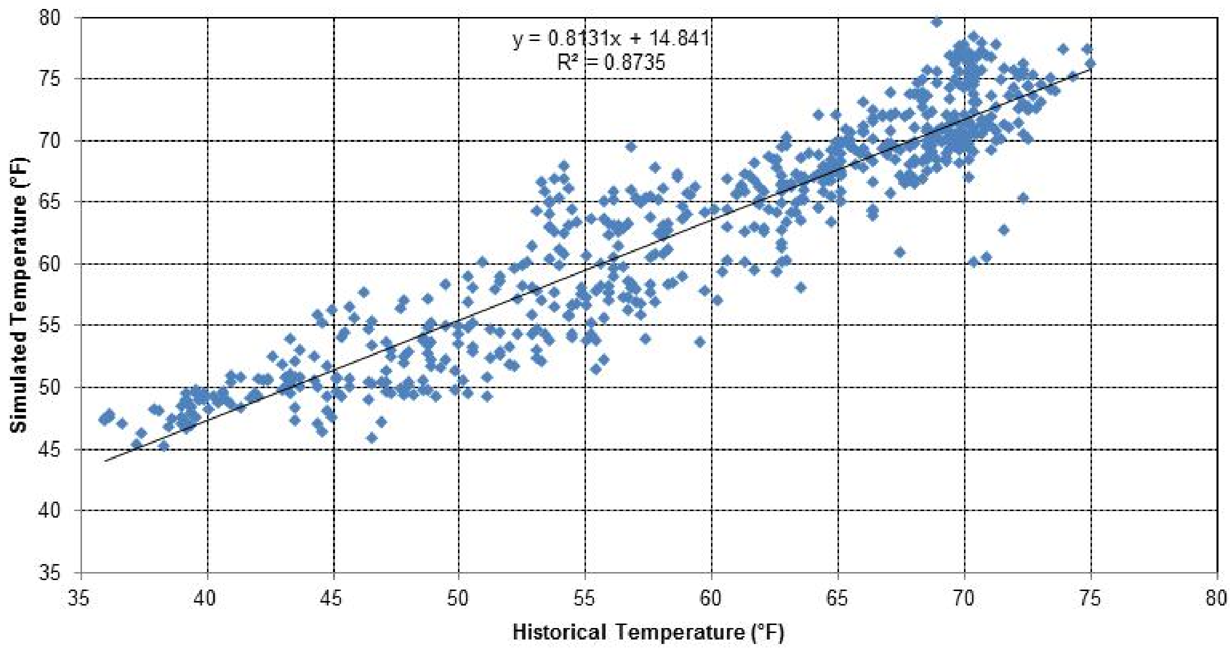

Figure 3.2-18. Scatter Plot Comparison of Simulated and Historically-Measured North Yuba River (RM 0.1) Water Temperatures upstream from its confluence with the North Yuba River for the Upper Temp Model Calibration Scenario

Historical Yuba River water temperatures were monitored downstream from the confluence of the North Yuba and Middle Yuba rivers at Yuba River RM 40.0. Figure 3.2-19 shows a comparison of the simulated water temperatures with historically-measured water temperatures on the Yuba River downstream from the confluence of the North Yuba and Middle Yuba Rivers. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Upper Temp Model is under the red line).

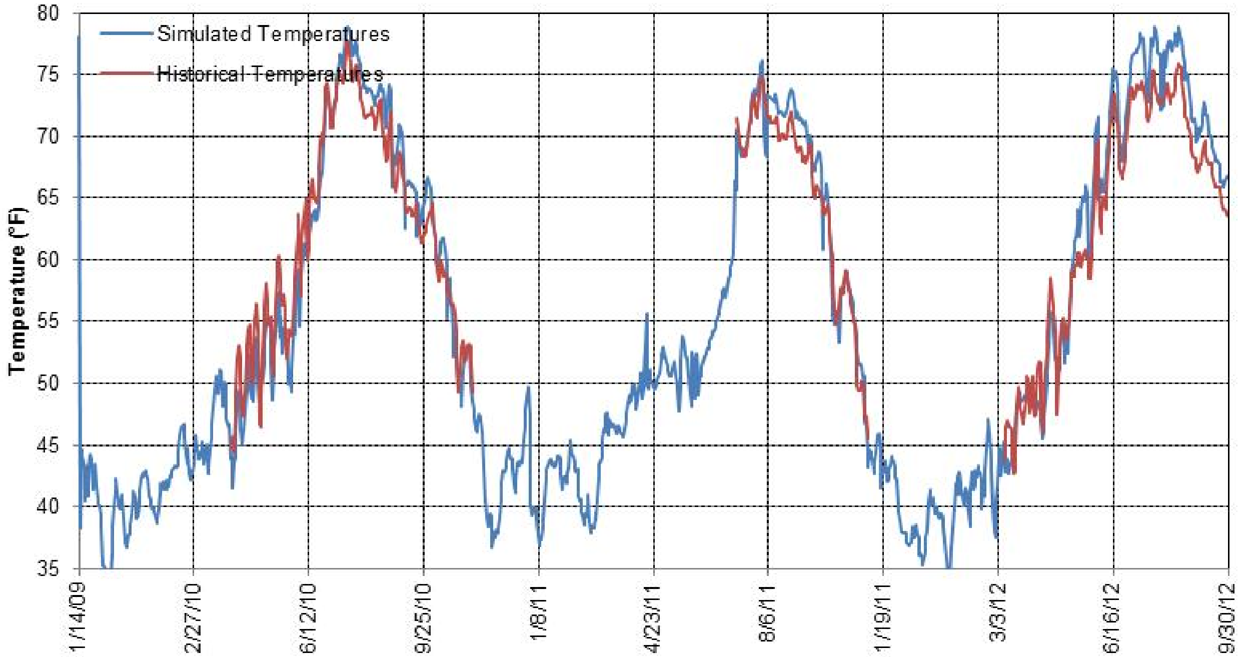

Figure 3.2-19. Comparison of Simulated and Historically-Measured Yuba River (RM 40.0) Water Temperatures downstream from the confluence of the North Yuba and Middle Yuba rivers for the Upper Temp Model Calibration Scenario

Figure 3.2-20 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the Yuba River downstream from the confluence of the Middle Yuba and North Yuba rivers.

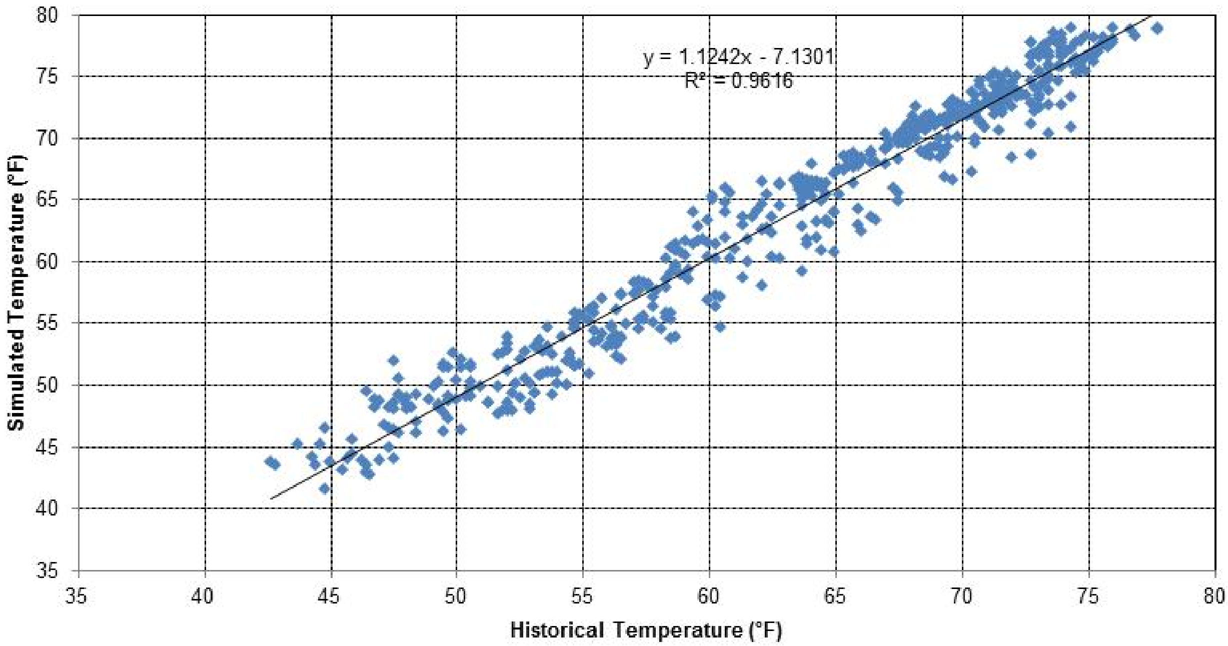

Figure 3.2-20. Scatter Plot Comparison of Simulated and Historically-Measured Yuba River (RM 40.0) Water Temperatures downstream from the confluence of the North Yuba and Middle Yuba rivers for the Upper Temp Model Calibration Scenario

Historical Yuba River water temperatures were monitored upstream from the New Colgate Powerhouse at Yuba River RM 34.4. Figure 3.2-21 shows a comparison of the simulated water temperatures with historically-measured water temperatures on the Yuba River upstream from the New Colgate Powerhouse. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Upper Temp Model is under the red line).

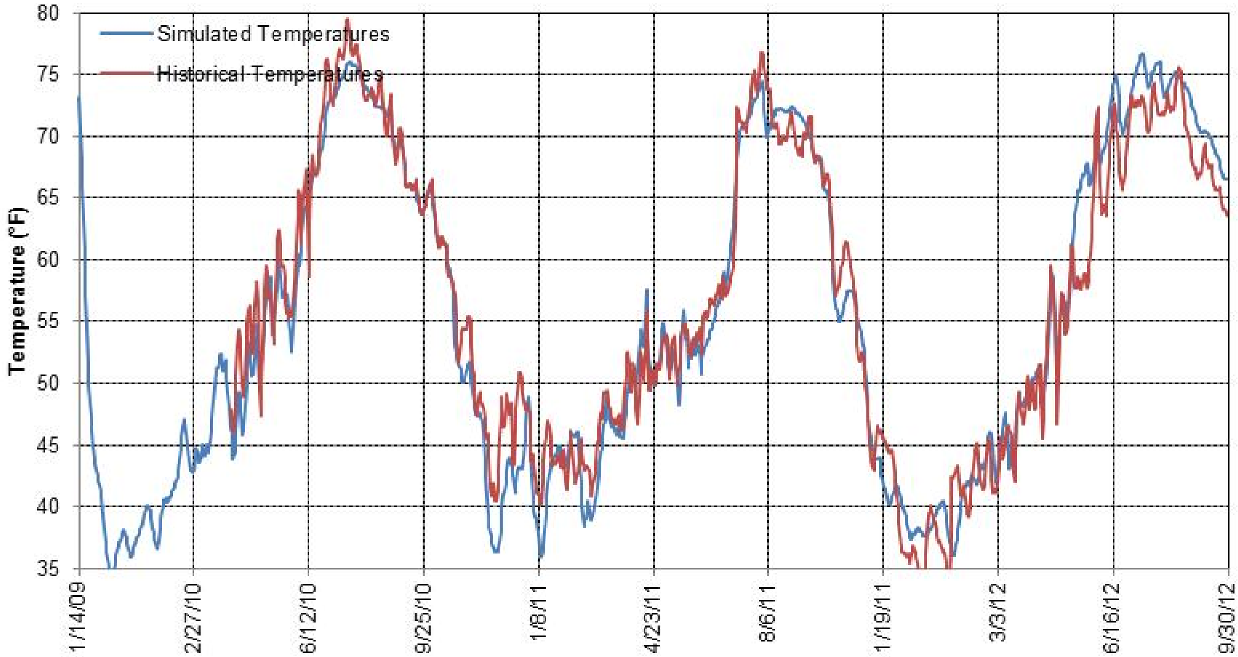

Figure 3.2-21. Comparison of Simulated and Historically-Measured Yuba River (RM 34.4) Water Temperatures upstream from the New Colgate Powerhouse for the Upper Temp Model Calibration Scenario

Figure 3.2-22 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the Yuba River upstream from the New Colgate Powerhouse.

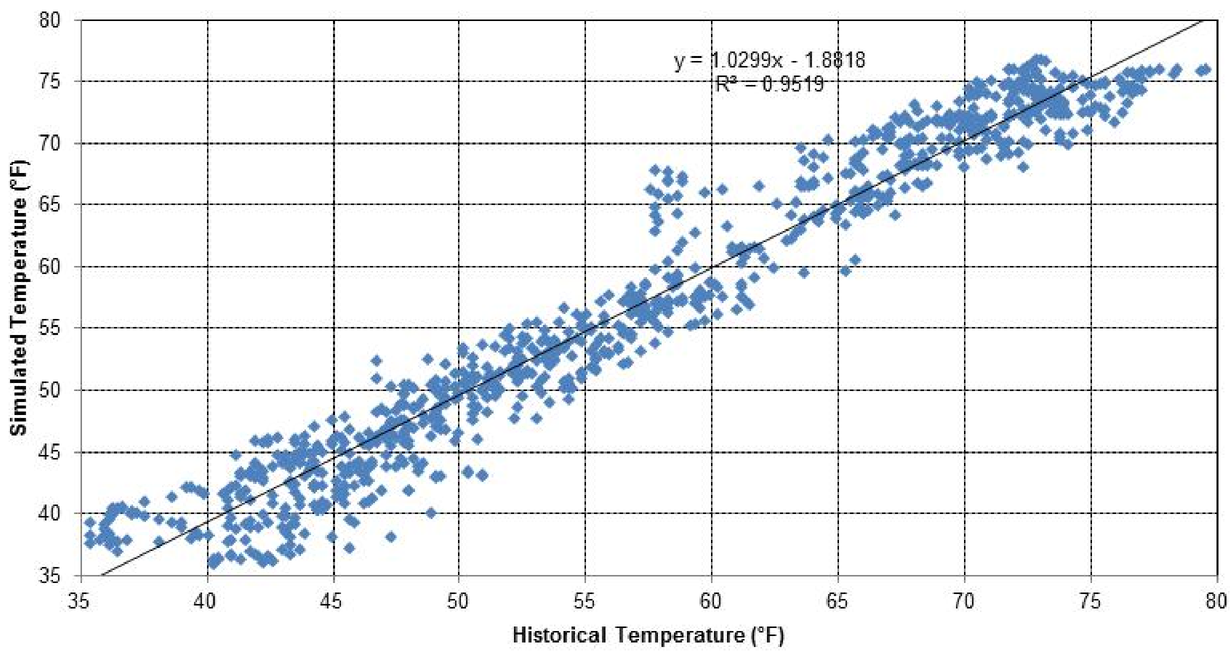

Figure 3.2-22. Scatter Plot Comparison of Simulated and Historically-Measured Yuba River (RM 34.4) Water Temperatures upstream from the New Colgate Powerhouse for the Upper Temp Model Calibration Scenario

Historical Yuba River water temperatures were monitored downstream from the New Colgate Powerhouse at Yuba River RM 34.1. Figure 3.2-23 shows a comparison of the simulated water temperatures with historically-measured water temperatures on the Yuba River downstream from the New Colgate Powerhouse. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Upper Temp Model is under the red line).

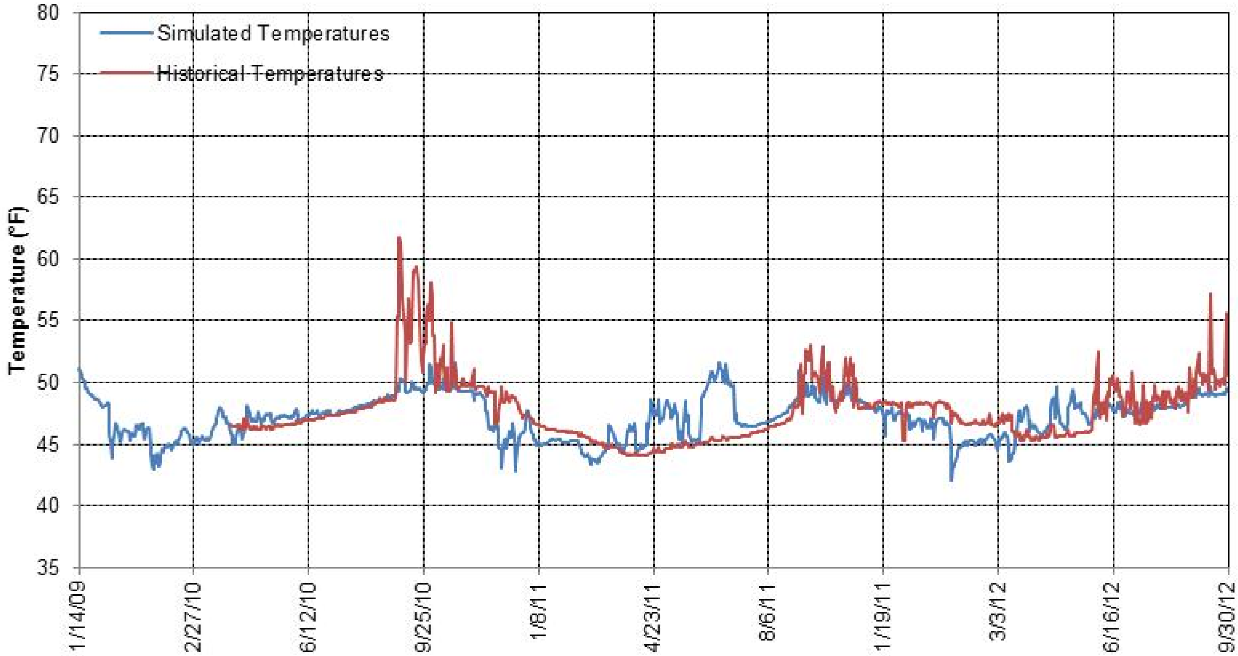

Figure 3.2-23. Comparison of Simulated and Historically-Measured Yuba River (RM 34.1) Water Temperatures downstream from the New Colgate Powerhouse for the Upper Temp Model Calibration Scenario

Figure 3.2-24 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the Yuba River downstream from the New Colgate Powerhouse.

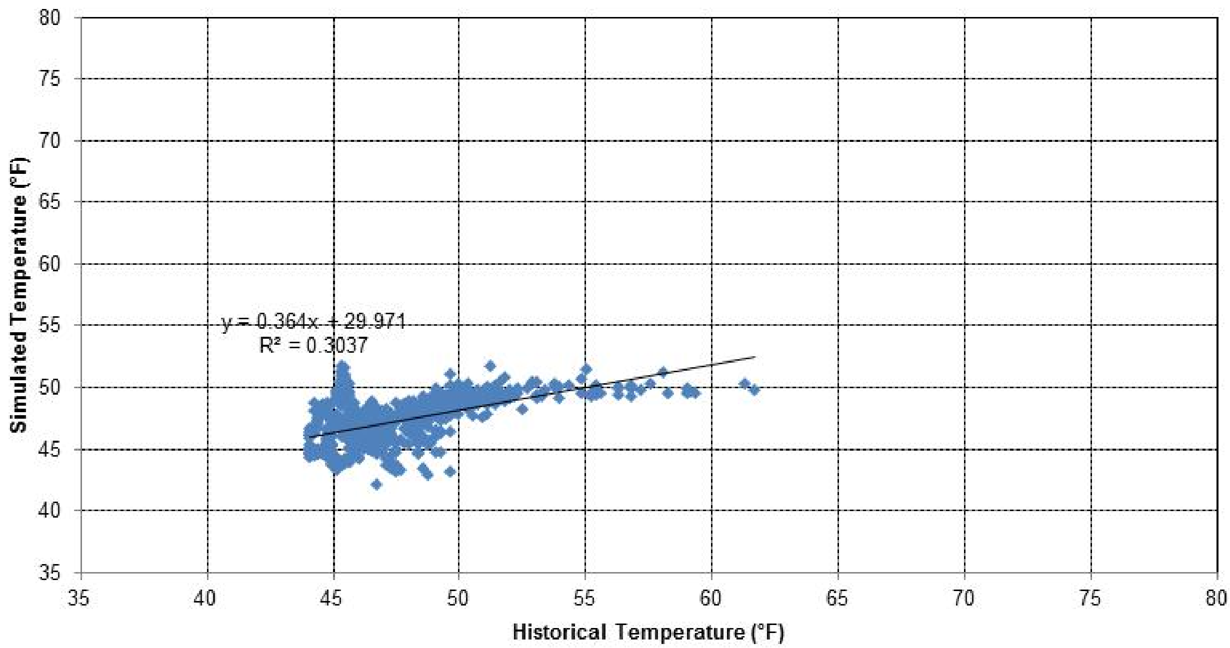

Figure 3.2-24. Scatter Plot Comparison of Simulated and Historically-Measured Yuba River (RM 34.1) Water Temperatures downstream from the New Colgate Powerhouse for the Upper Temp Model Calibration Scenario

The ME and AME were computed for each location for both the full simulation period and the months of July through October; the July through October period was targeted since that period was regarded as being a critical period for water temperatures from a biological perspective. Table 3.2-1 summarizes the ME and AME for the Lower Temp Model at each location for the two time periods.

Table 3.2-1. Summary of Mean Error (ME) and Absolute Mean Error (AME) for the Upper Temp Model at historical measurement locations.

River Mile	Gage ID	Full Period		July-October	
		ME	AME	ME	AME
Middle Yuba 0.1	T90	-0.03	1.93	1.59	2.01
North Yuba 40.1	T80	3.78	4.24	1.94	2.72
Yuba River 40.0	T100	0.72	2.07	1.60	2.03
Yuba River 34.4	T110	-0.18	2.16	0.34	1.70
Yuba River 34.1	T130	-0.34	1.48	-0.87	1.46

3.2.2 Englebright Temp Model

Calibration of the Englebright Temp model focused on the period of April 1, 2009 and September 30, 2012 based on historically-measured water temperature data availability.

Historically-measured water temperatures were available below Englebright Dam at Smartsville. Table 3.2-22 shows the resulting ME and AME for the full period and July through October periods.

Table 3.2-2. Summary of Mean Error (ME) and Absolute Mean Error (AME) for the Englebright Temp Model at Smartsville (April 1, 2009 through September 30, 2012).

Location	Gage ID	Full Period		July-October	
		ME	AME	ME	AME
Smartsville Gage (RM 23.9)	NY28	-0.32	0.64	0.12	0.41

Figure 3.2-25 shows a comparison of the time series for simulated water temperatures and historically measured water temperatures at Smartsville. Figure 3.2-26 shows a comparison of simulated water temperatures versus historically-measured water temperatures, as compared to a one-to-one line.

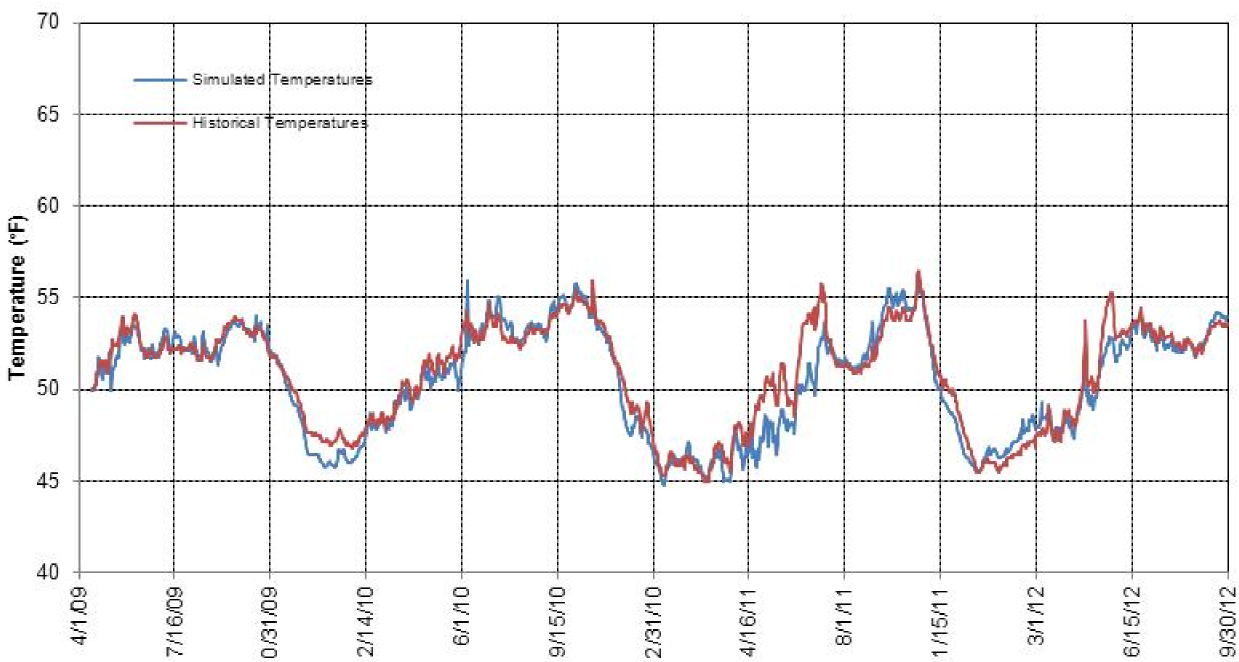

Figure 3.2-25. Comparison of Simulated and Historically-Measured Yuba River (RM 23.9) Water Temperatures at the Smartsville Gage for the Englebright Temp Model Calibration Scenario

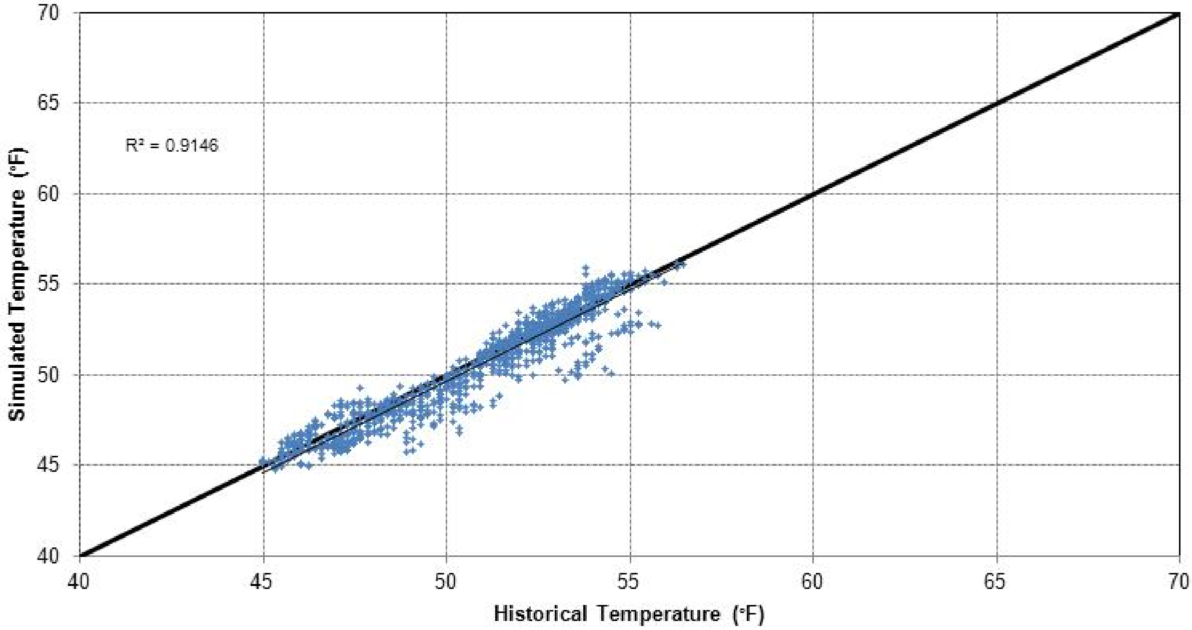

Figure 3.2-26. Comparison of Simulated and Historically-Measured Yuba River (RM 23.9) Water Temperatures at the Smartsville Gage for the Englebright Temp Model Calibration Scenario

3.2.3 Lower Temp Model

Calibration for the Lower Temp Model was completed using historical flow and water temperature data measured at the Smartsville gage, on Deer Creek near its confluence with the Yuba River, and on Dry Creek near its confluence with the Yuba River; meteorology data measured by NOAA at Beale Air Force Base; and river geometry developed for the RMT SRH2D model (Pasternack and Lower Yuba RMT 2012) for the period of January 1, 2008 through December 31, 2011. The Marysville gage was a calibration point for the lower Yuba River, but the model was also calibrated for intermediate locations along the Yuba River to improve the calibration at the Marysville gage. In addition to a qualitative appraisal of the calibration based on visual inspection of the comparisons between simulated and historical water temperatures, a quantitative appraisal was also completed, using the two metrics described in Section 2.3.

Figure 3.2-27 shows a comparison of simulated Yuba River flows at the Marysville gage from the Water Balance/Operations Model and the Lower Temp Model water balance module. The simulated flows from both models were available for the entire period. Where only one line is shown, the data were nearly identical and the blue line for the Lower Temp Model is shown (i.e., the red line for the Water Balance/Operations Model is under the blue line).

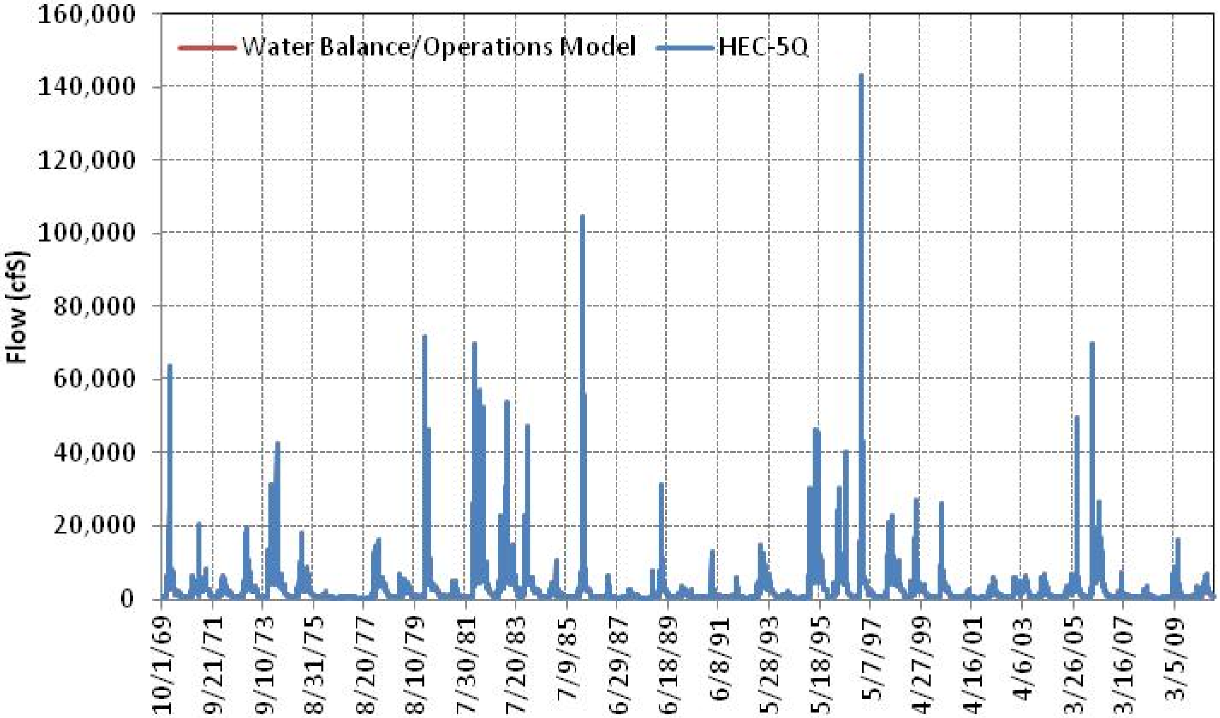

Figure 3.2-27. Comparison of simulated Yuba River flow at the Marysville gage for the Water Balance/Operations Model and the Lower Temp Model water balance module.

Historical Yuba River water temperatures were monitored downstream from Deer Creek at RM 23.1. Figure 3.2-28 shows a comparison of the historical and simulated mean-daily Yuba River water temperatures downstream from Deer Creek after calibration of the Lower Temp Model. Historically-recorded water temperatures were available nearly for the entire calibration period, with the exception of January 1, 2008 through November 8, 2008. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Lower Temp Model is under the red line).

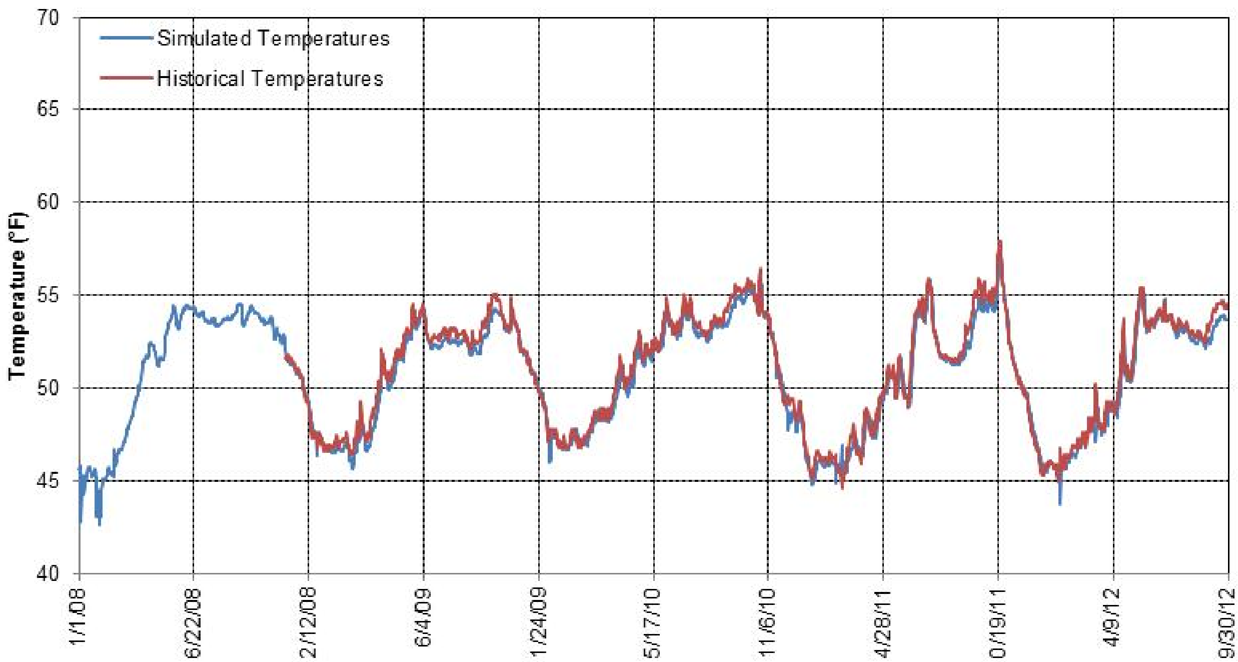

Figure 3.2-28. Comparison of historical and simulated mean-daily water temperatures downstream from Deer Creek (RM 23.1).

Figure 3.2-29 shows a scatter plot comparing historically-measured water temperatures with simulated water temperatures on the Yuba River downstream from Deer Creek.

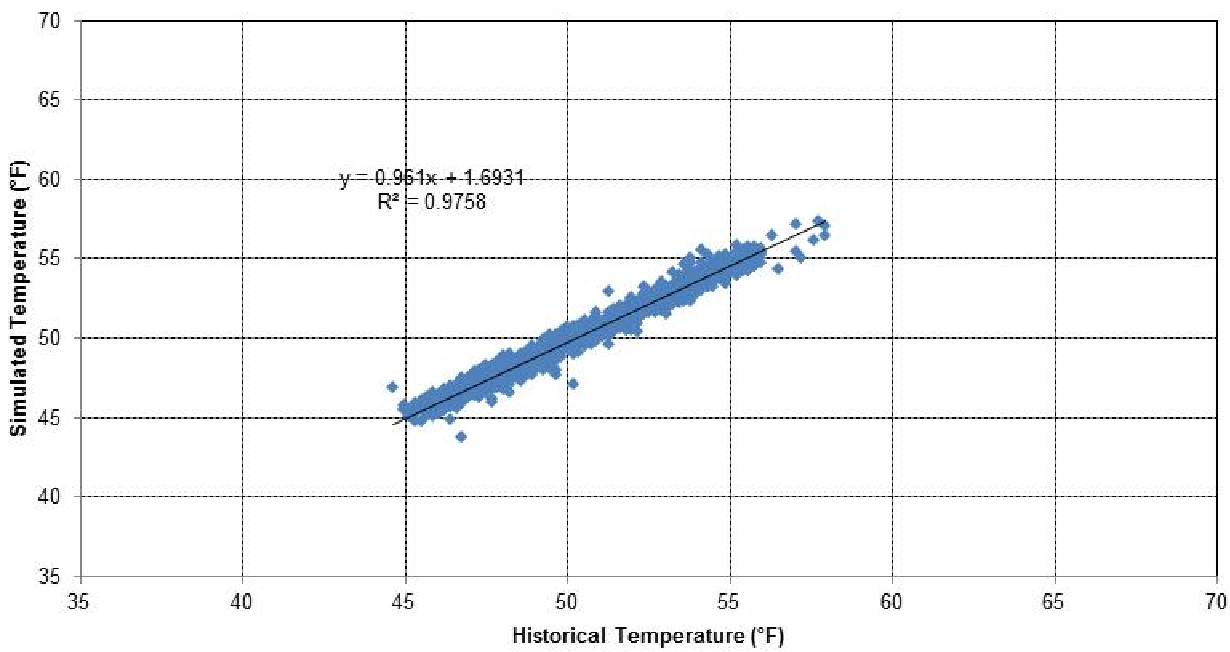

Figure 3.2-29. Scatter Plot Comparison of historical and simulated mean-daily water temperatures downstream from Deer Creek (RM 23.1).

Historical Yuba River water temperatures were monitored at Parks Bar at RM 17.7. Figure 3.2-30 shows a comparison of the historical and simulated mean-daily water temperatures at Parks Bar after calibration of the Lower Temp Model. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Lower Temp Model is under the red line.

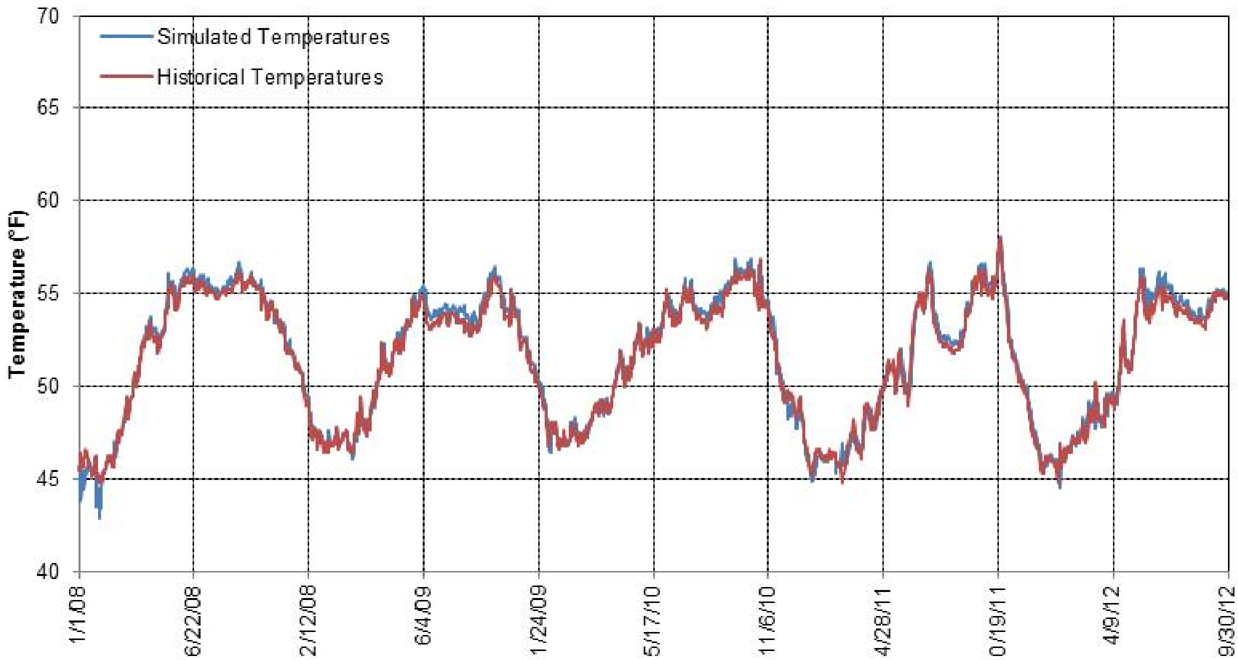

Figure 3.2-30. Comparison of historical and simulated mean-daily water temperatures at Parks Bar (RM 17.7).

Figure 3.2-31 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the Yuba River at Parks Bar.

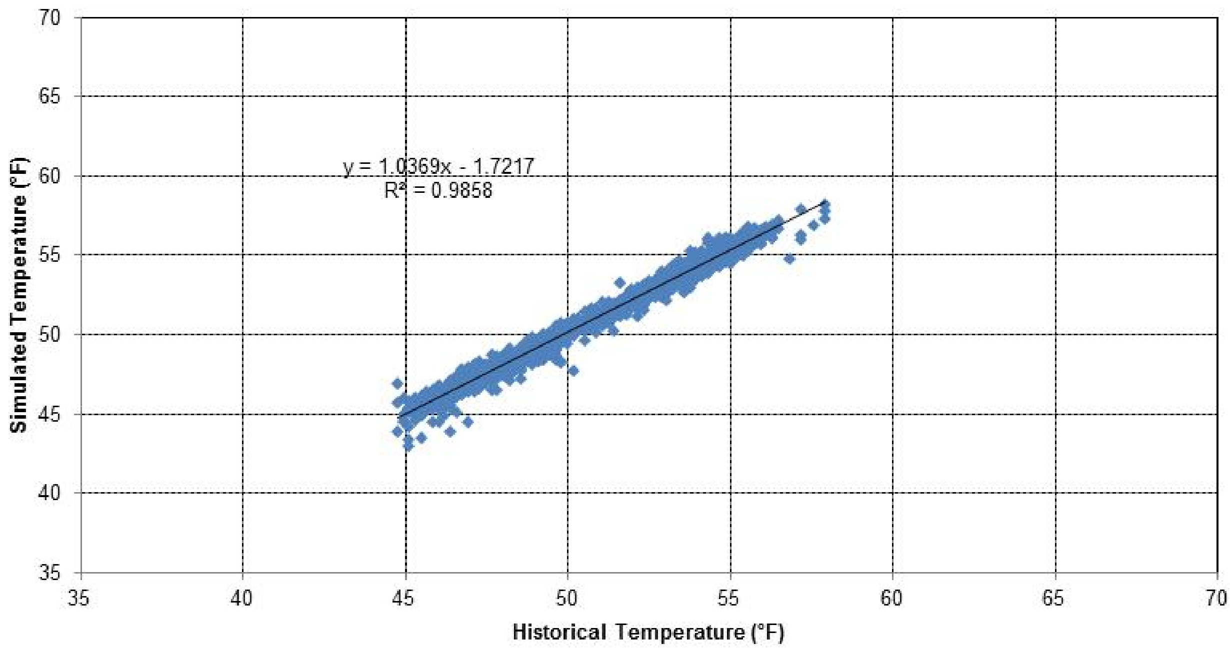

Figure 3.2-31. Scatter Plot Comparison of historical and simulated mean-daily water temperatures at Parks Bar (RM 17.7).

Historical Yuba River water temperatures were monitored at Long Bar at RM 16.2. Figure 3.2-32 shows a comparison of the historical and simulated mean-daily water temperatures at Long Bar after calibration of the Lower Temp Model. Historically-recorded water temperatures were available for the entire calibration period. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Lower Temp Model is under the red line).

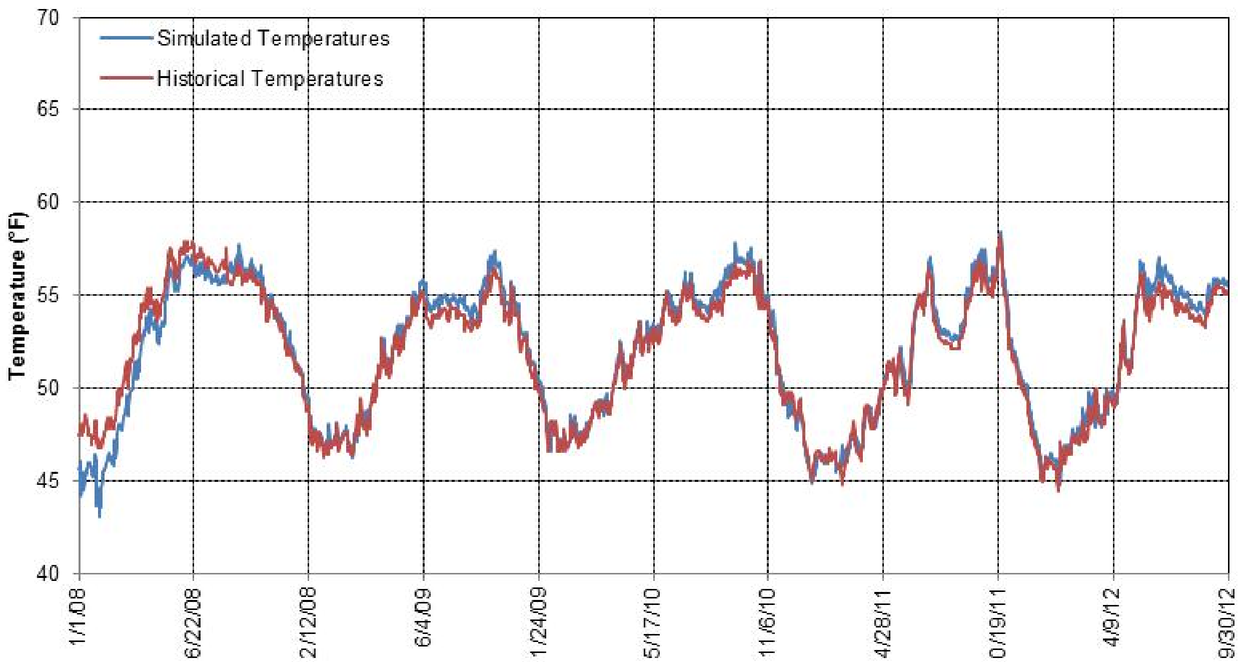

Figure 3.2-32. Comparison of historical and simulated mean-daily water temperatures at Long Bar (RM 16.2).

Figure 3.2-33 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the Yuba River at Long Bar.

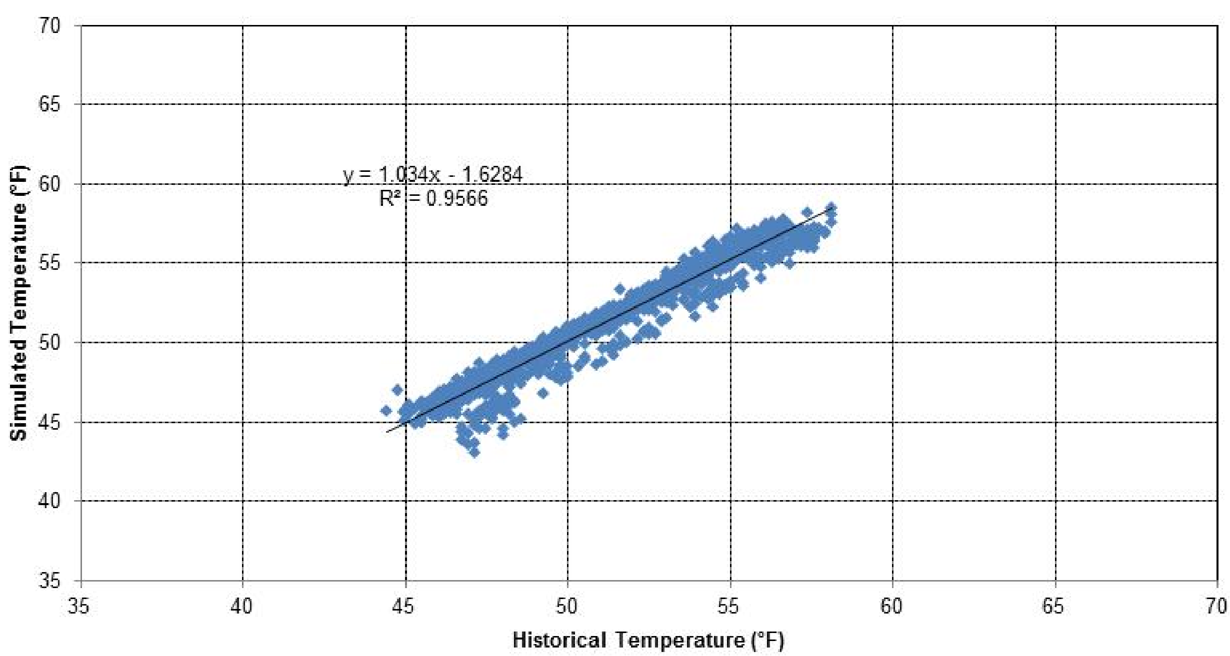

Figure 3.2-33. Scatter plot comparison of historical and simulated mean-daily water temperatures at Long Bar (RM 16.2).

Historical Yuba River water temperatures were monitored upstream from Daguerre Point Dam at RM 11.64. Figure 3.2-34 shows a comparison of the historical and simulated mean-daily water temperatures at upstream from Daguerre Point Dam after calibration of the Lower Temp Model. Historically-recorded water temperatures were available nearly for the entire calibration period with the exception of January 1, 2008 through November 8, 2008. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Lower Temp Model is under the red line).

Figure 3.2-34. Comparison of historical and simulated mean-daily water temperatures upstream from Daguerre Point Dam (RM 11.64).

Figure 3.2-35 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the Yuba River upstream from Daguerre Point Dam.

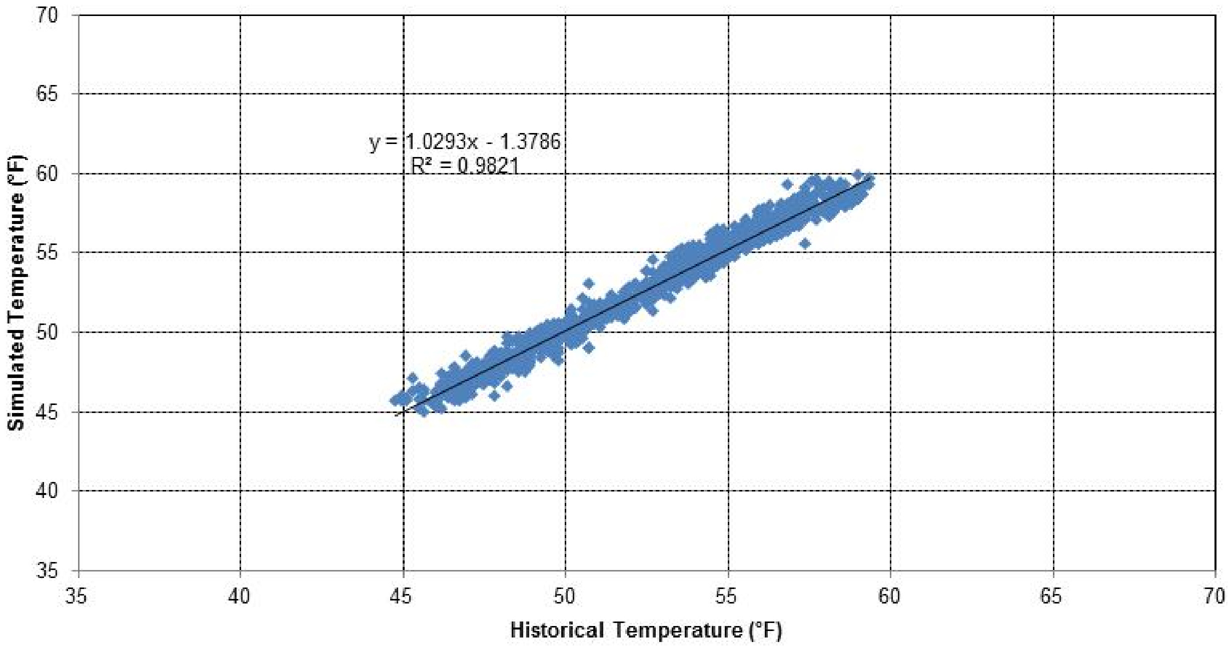

Figure 3.2-35. Scatter plot comparison of historical and simulated mean-daily water temperatures upstream from Daguerre Point Dam (RM 11.64).

Historical Yuba River water temperatures were monitored at the Daguerre Point Dam fish ladders at RM 11.56. Figure 3.2-36 shows a comparison of the historical and simulated mean-daily water temperatures at the Daguerre Point Dam fish ladder after calibration of the Lower Temp Model. Historically-recorded water temperatures were available nearly for the entire calibration period with the exception of January 1, 2008 through November 8, 2008.

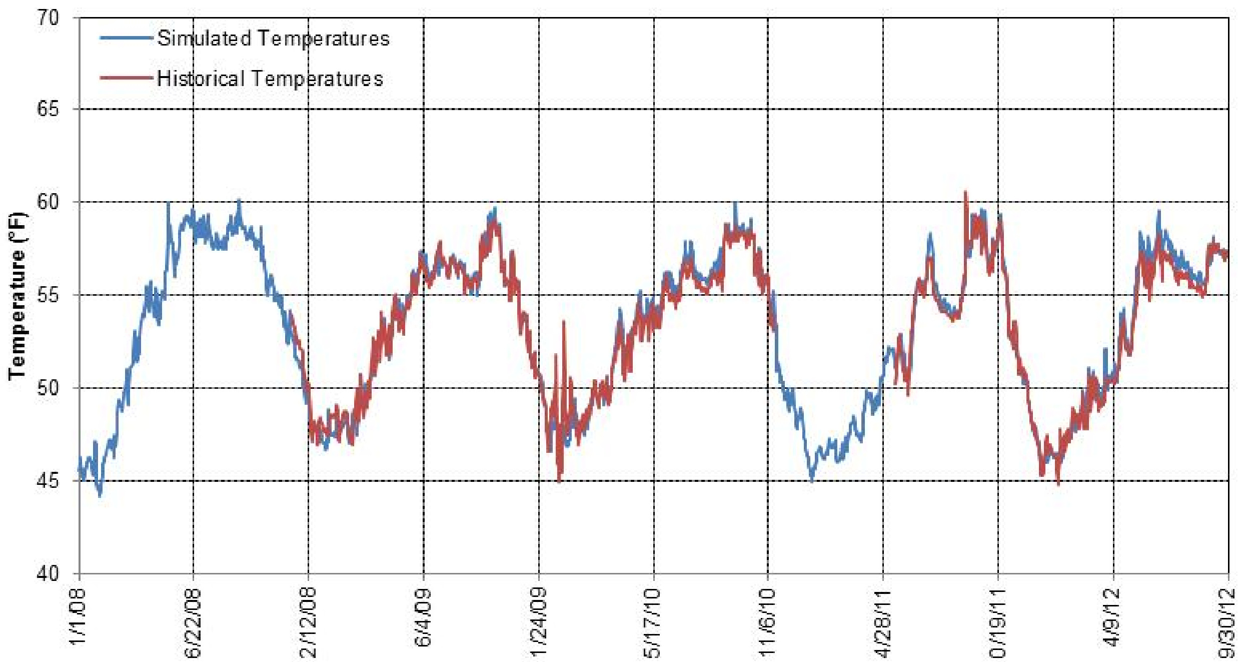

Figure 3.2-36. Comparison of historical and simulated mean-daily water temperatures at the Daguerre Point Dam fish ladder (RM 11.56).

Figure 3.2-37 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the Yuba River at the Daguerre Point Dam fish ladder.

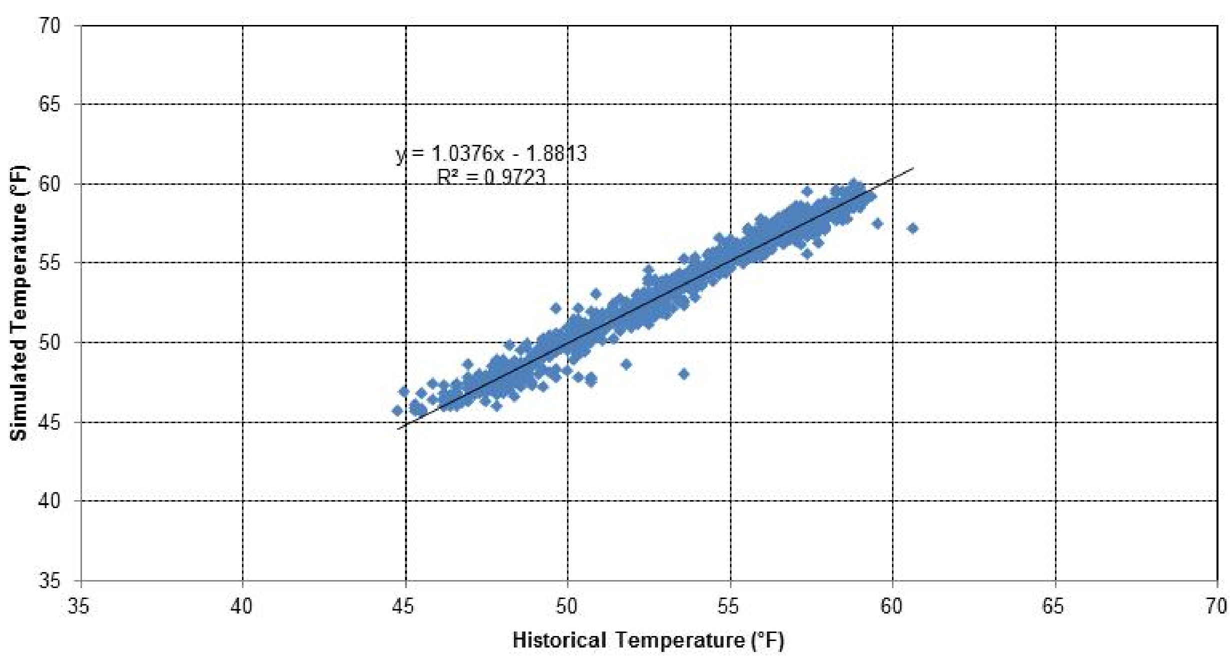

Figure 3.2-37. Scatter plot comparison of historical and simulated mean-daily water temperatures at the Daguerre Point Dam fish ladder (RM 11.56).

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Historical Yuba River water temperatures were monitored near the western extent of the Yuba Goldfields at RM 8.3. Figure 3.2-38 shows a comparison of the historical and simulated mean-daily water temperatures at the western extent of the Yuba Goldfields after calibration of the Lower Temp Model. Historically-recorded water temperatures were available nearly for the entire calibration period, with the exception of January 1, 2008 through August 28, 2008. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Lower Temp Model is under the red line).

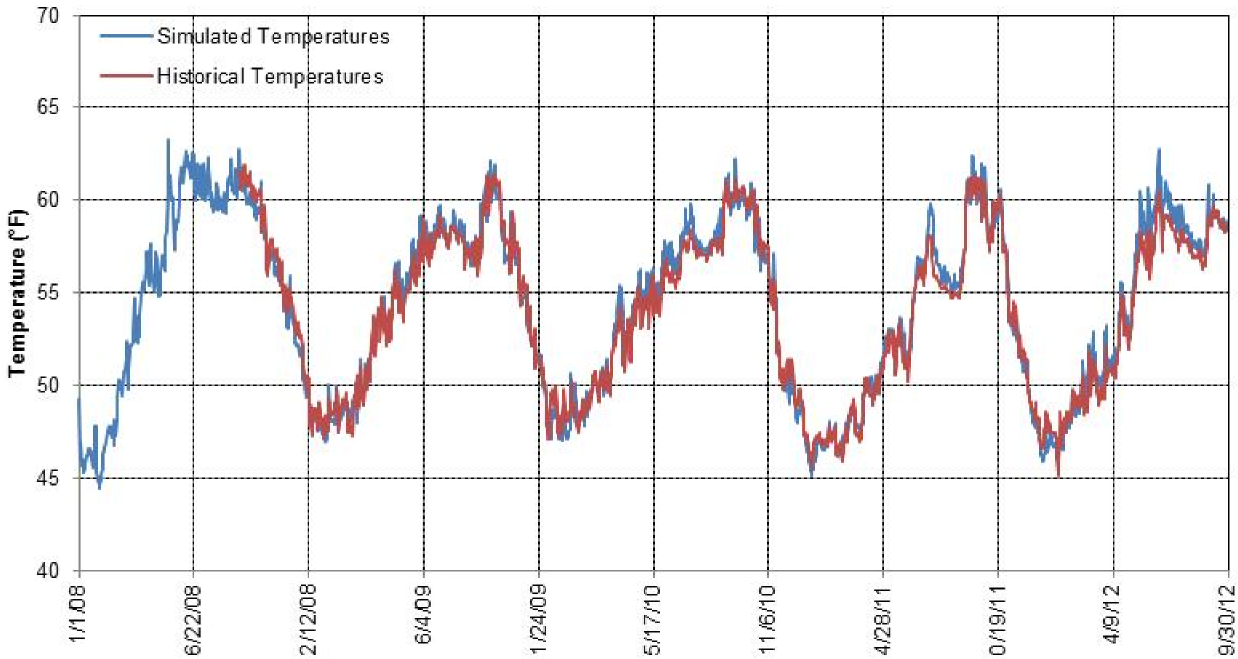

Figure 3.2-38. Comparison of historical and simulated mean-daily water temperatures at the western extents of the Yuba Goldfields (RM 8.3).

Figure 3.2-39 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the Yuba River at the western extents of the Yuba Goldfield.

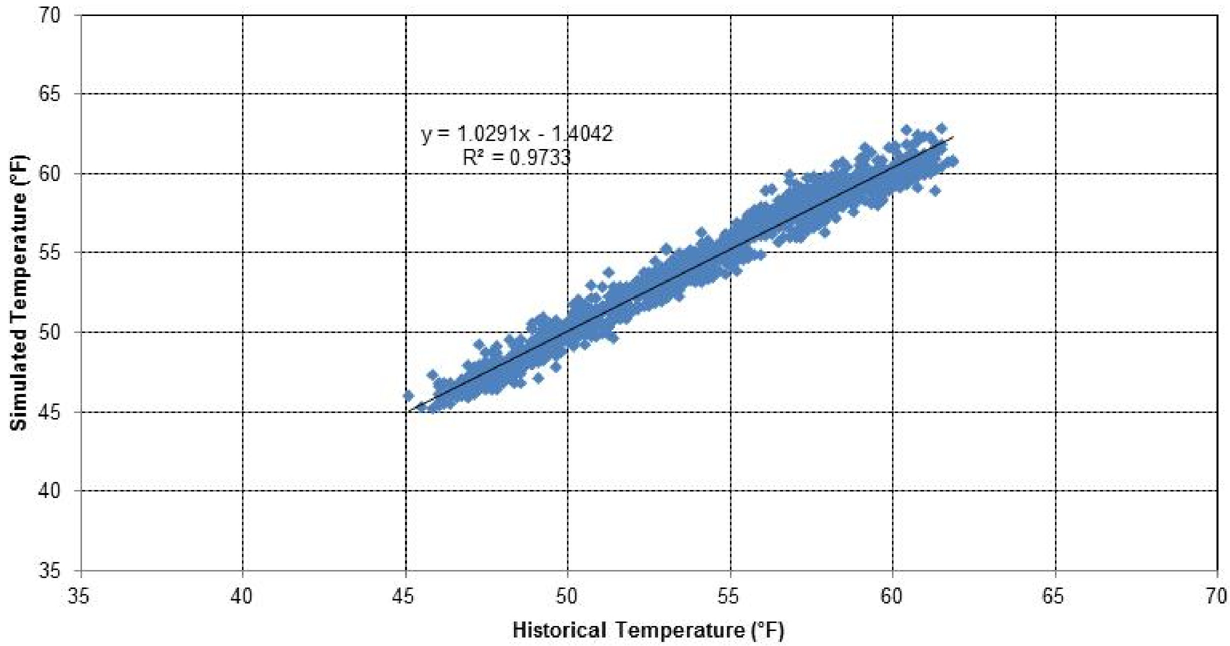

Figure 3.2-39. Scatter plot comparison of historical and simulated mean-daily water temperatures at the western extents of the Yuba Goldfields (RM 8.3).

Historical Yuba River water temperatures were monitored at the Marysville gage at RM 6.2. This location represents the primary calibration point for Lower Temp Model. Figure 3.2-40 shows a comparison of the historical and simulated mean-daily water temperatures at the Marysville gage after calibration of the Lower Temp Model. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Lower Temp Model is under the red line). Historically-recorded water temperatures were available for the entire calibration period.

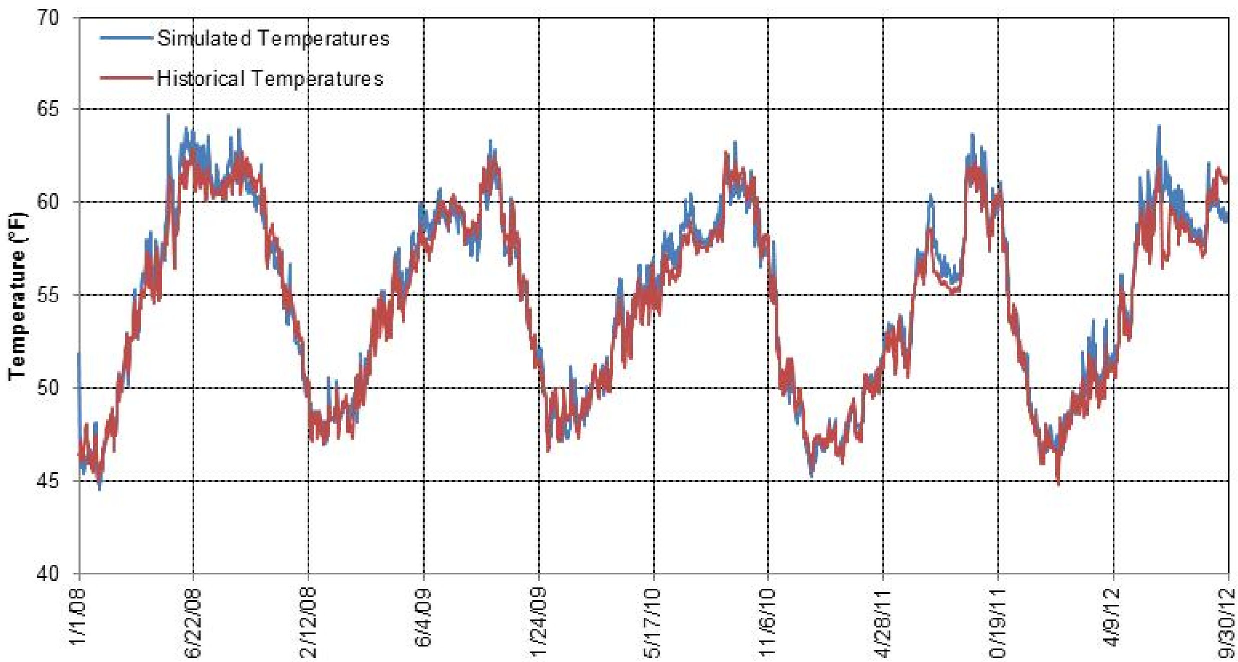

Figure 3.2-40. Comparison of historical and simulated mean-daily water temperatures at the Maryville gage (RM 6.2).

Figure 3.2-41 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the Yuba River at the Marysville gage

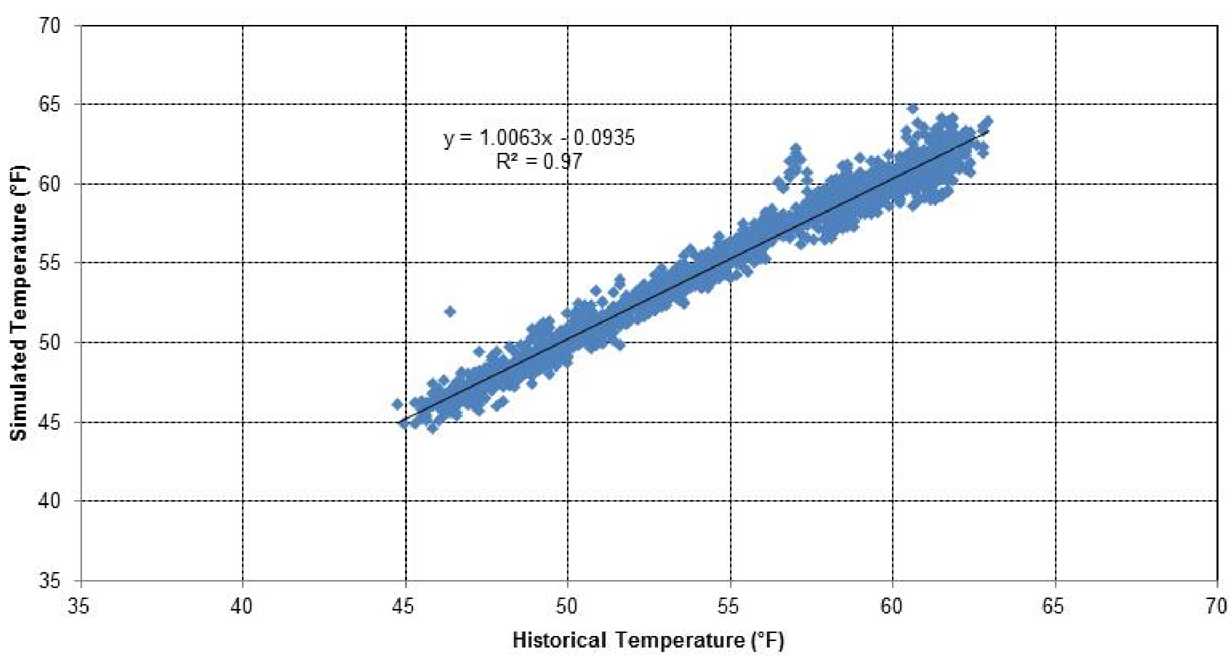

Figure 3.2-41. Scatter plot comparison of historical and simulated mean-daily water temperatures at the Maryville gage (RM 6.2).

Historical Yuba River water temperatures were monitored upstream from Simpson Lane at RM 5.0. Figure 3.2-42 shows a comparison of the historical and simulated mean-daily water temperatures upstream from Simpson Lane after calibration of the Lower Temp Model. Historically-recorded water temperatures were available nearly for the entire calibration period, with the exception of January 1, 2008 through August 28, 2008. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Lower Temp Model is under the red line).

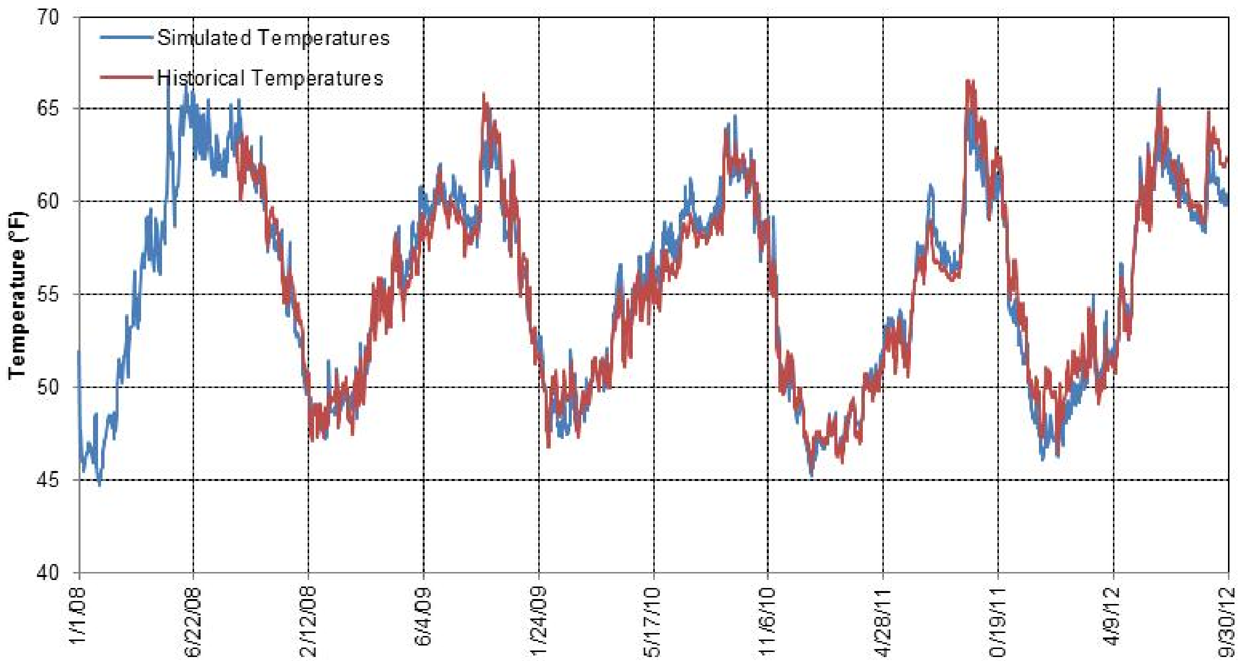

Figure 3.2-42. Comparison of historical and simulated mean-daily water temperatures upstream from Simpson Lane (RM 5.0).

Figure 3.2-43 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the Yuba River upstream from Simpson Lane.

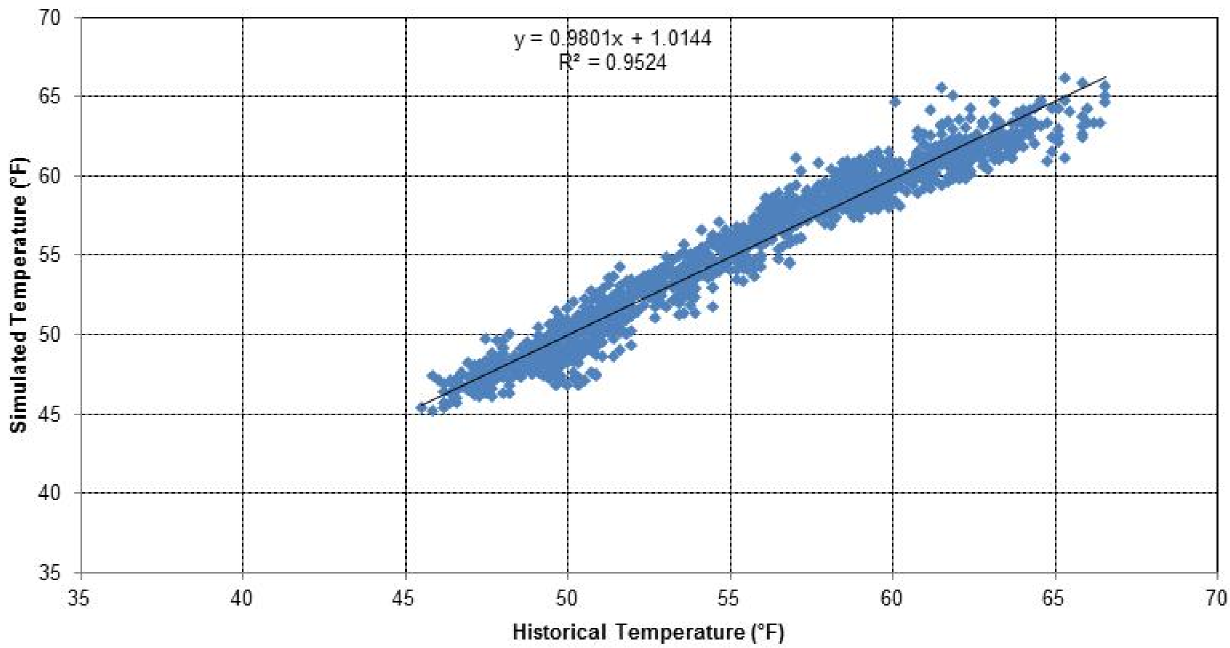

Figure 3.2-43. Scatter plot comparison of historical and simulated mean-daily water temperatures upstream from Simpson Lane (RM 5.0).

Historical Yuba River water temperatures were monitored downstream from Highway 70 at RM 0.7. Figure 3.2-44 shows a comparison of the historical and simulated mean water temperatures downstream from Highway 70 after calibration of the Lower Temp Model. Historically-recorded water temperatures were available nearly for the entire calibration period, with the exception of January 1, 2008 through August 21, 2008. Where only one line is shown, the data were nearly identical and the red line for the historically-recorded water temperatures is shown (i.e., the blue line for the Lower Temp Model is under the red line).

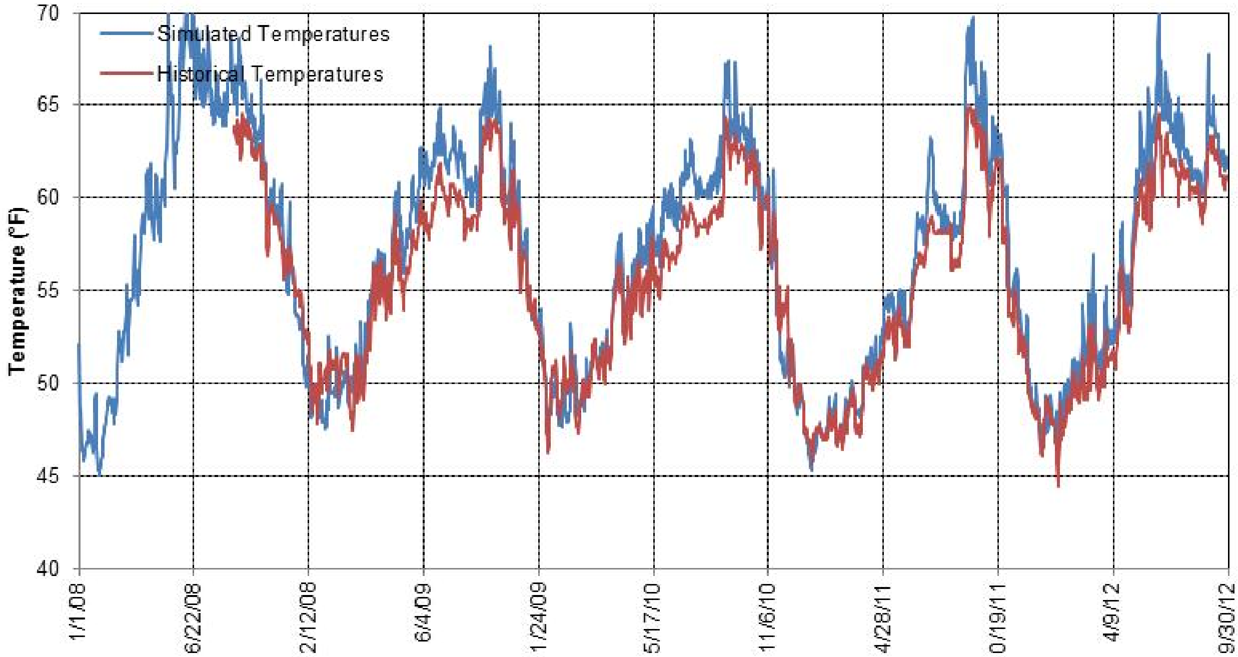

Figure 3.2-44. Comparison of historical and simulated mean-daily water temperatures downstream from Highway 70 (RM 0.7).

Figure 3.2-45 shows a scatter plot comparing historically measured water temperatures with simulated water temperatures on the Yuba River downstream from Highway 70.

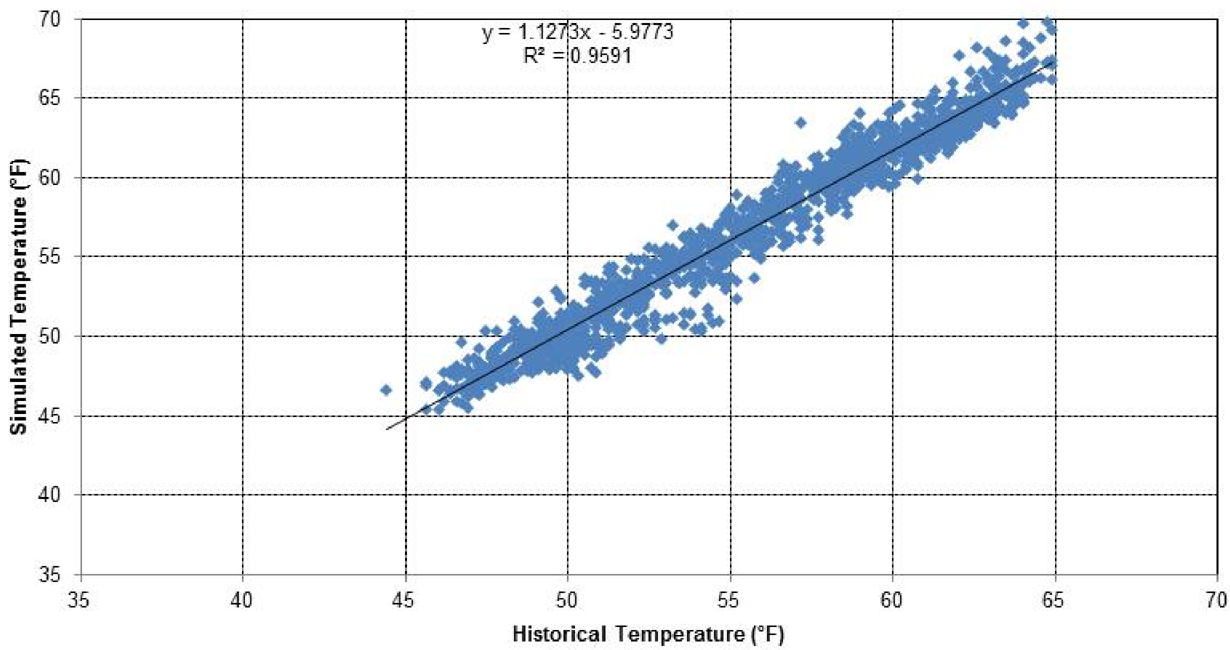

Figure 3.2-45. Scatter plot comparison of historical and simulated mean-daily water temperatures downstream from Highway 70 (RM 0.7).

The ME and AME were computed for each location for both the full simulation period and the months of July through October; the July through October period was targeted, since that period was regarded as being a critical period for water temperatures from a biological perspective. Table 3.2-3 summarizes the ME and AME for the Lower Temp Model at each location for the two time periods.

Table 3.2-3. Summary of Mean Error (ME) and Absolute Mean Error (AME) for the Upper Temp Model at historical measurement locations.

Location (River Mile)	Gage ID	Full Period		July-October	
		ME	AME	ME	AME
Smartsville Gage (RM 23.9)	NY28	-0.01	0.22	0.0	0.18
Above Deer Creek (RM 23.1)	T180	-0.29	0.43	-0.42	0.47
Parks Bar (RM 17.7)	PB	0.18	0.36	0.31	0.36
Long Bar (RM 16.2)	LB	0.14	0.60	0.47	0.59
Above Daguerre Point Dam (RM 11.64)	T200	0.16	0.44	0.33	0.50
Below Daguerre Point Dam (RM 11.56)	T210	0.13	0.48	0.25	0.42
Western Edge of Goldfields (RM8.3)	T220	0.16	0.61	0.16	0.62
Marysville Gage (RM 6.2)	11421000	0.25	0.68	0.05	0.75
Simpson Lane (RM 5.0)	T230	-0.08	0.89	-0.22	1.02
Above Feather River (RM 0.7)	T240	1.10	1.42	1.69	1.70

3.3 Model Input Data Development

Three types of inputs to the water temperature models were developed: 1) meteorological input; 2) physical inputs; and 3) water temperature inputs. A fourth input, hydrology, was defined by the Water Balance/Operations Model and was not developed specifically for this study. For a complete description of the Water Balance/Operations Model, refer to Technical Memorandum 2-2, *Water Balance/Operations Model*. This section describes results of the development of the meteorological, physical, and water temperature inputs to the water temperature model.

3.3.1 Meteorological Input Data

All meteorological data were written to a HEC-DSS file, the Upper Temp Model water temperature model uses meteorological data defined for Zone 3; the Englebright Temp Model uses meteorological data defined for Zone 2; and the Lower Temp Model uses meteorological data defined for Zone 1. The input files, included in Attachment 2-6B, include the meteorological input data for each model and each scenario.

3.3.2 Physical Input Data

The physical input data and configurations defined for each model were consistent for each application of the model. A part of the calibration consisted of ensuring that the physical input data were correct; once calibrated, it is not YCWA's intention that any of the physical input data be changed, since any change could result in an unsatisfactory calibration.

Data describing the physical configuration of New Bullards Bar Reservoir were primarily found in the New Bullards Bar Reservoir Regulation for Flood Control Manual (USACE 1972). Any physical data not found in the New Bullards Bar Reservoir Regulation for Flood Control Manual (USACE 1972) were developed through GIS.

Data for the physical geometry of the Middle Yuba River below the Our House Diversion Dam, Oregon Creek below Log Cabin Diversion Dam, the North Yuba River below New Bullards Bar Dam, and the Yuba River above Englebright Reservoir came from data collected for Study 3-10. The river miles for features and confluences were developed through GIS.

Data for the physical configuration of Englebright Reservoir came primarily from the 2001 USGS bathymetric survey of Englebright Reservoir. Information about the configuration of the intakes to the Narrows 1 Powerhouse came from information provided by PG&E. Information about the physical configuration of the Narrows 2 Powerhouse and Englebright Dam came from information provided by YCWA. Information about the topographic shading for the reservoir was developed through GIS.

Data for the physical geometry of the Yuba River below Englebright Reservoir came from the RMT SRH2D model (Pasternack and Lower Yuba RMT 2012). Locations, in RM, for Project features and confluences were developed through GIS.

3.3.3 Input Water Temperatures

Input temperature needs varied by application of the water temperature models. Generally, the calibration relied upon historical periods of records of data without any modification of data. Validation and Base Case scenario simulation required repetition of available historical data to create the period of record for simulation. Table 3.3-1 shows the input water temperatures developed for the three water temperature models.

Table 3.3-1. Sources of input water temperatures for each of the water temperature models.

Model	Location	Model Process	Source	Treatment	Start of Period of Record Used	End of Period of Record Used
Upper Temp Model	North Yuba River inflow	Calibration	YCWA gage T065	None	11/14/2009	4/9/2012
	Oregon Creek inflow	Calibration	YCWA gage T040	None	11/14/2009	4/9/2012
	Middle Yuba River inflow	Calibration	YCWA gage T030	None	11/14/2009	4/9/2012
	North Yuba River inflow	Validation	YCWA gage T065	Repeated	1/1/2010 (below average years) 1/1/2011 (above average years)	12/31/2010 (below average years) 12/31/2011 (above average years
	Oregon Creek inflow	Validation	YCWA gage T040	Repeated	1/1/2010 (below average years) 1/1/2011 (above average years)	12/31/2010 (below average years) 12/31/2011 (above average years
	Middle Yuba River inflow	Validation	YCWA gage T030	Repeated	1/1/2010 (below average years) 1/1/2011 (above average years)	12/31/2010 (below average years) 12/31/2011 (above average years

Table 3.3-1. (continued)

Model	Location	Model Process	Source	Treatment	Start of Period of Record Used	End of Period of Record Used
Upper Temp Model (continued)	North Yuba River inflow	Base Case	YCWA gage T065	Repeated	1/1/2010 (below average years) 1/1/2011 (above average years)	12/31/2010 (below average years) 12/31/2011 (above average years
	Oregon Creek inflow	Base Case	YCWA gage T040	Repeated	1/1/2010 (below average years) 1/1/2011 (above average years)	12/31/2010 (below average years) 12/31/2011 (above average years
	Middle Yuba River inflow	Base Case	YCWA gage T030	Repeated	1/1/2010 (below average years) 1/1/2011 (above average years)	12/31/2010 (below average years) 12/31/2011 (above average years
Englebright Temp Model	Yuba River below Colgate Powerhouse	Calibration	YCWA gage T130	Data filled in where necessary	8/18/2008	9/30/2012
	South Yuba River near Jones Bar	Calibration	YCWA gage YC6	Data filled in where necessary	7/21/2008	9/30/2012
	Englebright Reservoir Accretions	Calibration	YCWA gage T185	Data filled in where necessary	4/1/2009	9/30/2012
	Yuba River below Colgate Powerhouse	Validation	Upper Temp Model Output	None	1/1/2000	9/30/2010
	South Yuba River near Jones Bar	Validation	YCWA gage YC6	Repeated	1/12010 (below average years) 1/1/2011 (above average years)	12/31/2010 (below average years) 12/31/2011 (above average years
	Englebright Reservoir Accretions	Validation	YCWA gage T185	Averaged and Repeated	04/01/2009	09/30/2012
	Yuba River below Colgate Powerhouse	Base Case	Upper Temp Model Output	None	10/1/1969	9/30/2010
	South Yuba River near Jones Bar	Base Case	YCWA gage YC6	Repeated	1/1/2010 (below average years) 1/1/2011 (above average years)	12/31/2010 (below average years) 12/31/2011 (above average years
	Englebright Reservoir Accretions	Base Case	YCWA gage T185	Averaged and Repeated	04/01/2009	09/30/2012
Lower Temp Model	Englebright Reservoir Releases	Calibration	YCWA Gage NY28	None	1/1/2008	12/31/2011
	Deer Creek inflow	Calibration	YCWA Gage T175	Data filled in where necessary	12/23/2008	9/30/2012
	Dry Creek inflow	Calibration	YCWA gage T185	Data filled in where necessary	1/14/2009	12/14/2011
	Englebright Reservoir Releases	Validation	Englebright Temp Model Output	None	1/1/2000	9/30/2011
	Deer Creek inflow	Validation	YCWA Gage T175	Repeated	1/1/2009	12/31/2009
	Dry Creek inflow	Validation	YCWA gage T185	Repeated	3/1/2010	2/28/2011

Table 3.3-1. (continued)

Model	Location	Model Process	Source	Treatment	Start of Period of Record Used	End of Period of Record Used
Lower Temp Model (continued)	Englebright Reservoir Releases	Base Case	Englebright Temp Model Output	None	10/1/1969	9/30/2010
	Deer Creek inflow	Base Case	YCWA Gage T175	Repeated	1/1/2009	12/31/2009
	Dry Creek inflow	Base Case	YCWA gage T185	Repeated	3/1/2010	2/28/2011

Input temperatures for the Upper Temp Model accretions were assumed to be at Middle Yuba River temperatures. All input water temperature data were written to a HEC-DSS for use in simulation.

3.4 Model Validation

In the model validation process, models were run for a longer period of record, January 1, 2000 through September 30, 2011, than was run in the calibration process. Model validation used historical inflow and meteorology data, and synthetic inflow temperature data. Outflow temperatures from the Upper Temp Model were used as input temperatures to the Englebright Temp Model, and outflow temperatures from the Englebright Temp Model were used as input temperatures to the Lower Temp Model. See Attachment 2-6C for more detail.

3.4.1 Upper Temp Model

There were limited historically-measured water temperature data for the Yuba River watershed for dates prior to 2008. New Bullards Bar Reservoir water temperature profiles have been measured approximately bi-weekly since 1989. Figures 3.4-1 through 3.4-11 show profiles from late-September or early-October for the Validation Scenario simulation period. Late-September or early-October profiles were selected as indicative of the quality of the full-year of simulation, and generally coincide with periods of the greatest amount of thermal stratification in the reservoir. Where only the red series is shown, the data were nearly identical and the historically-recorded water temperatures is shown (i.e., the blue line for the Upper Temp Model is under the red line.

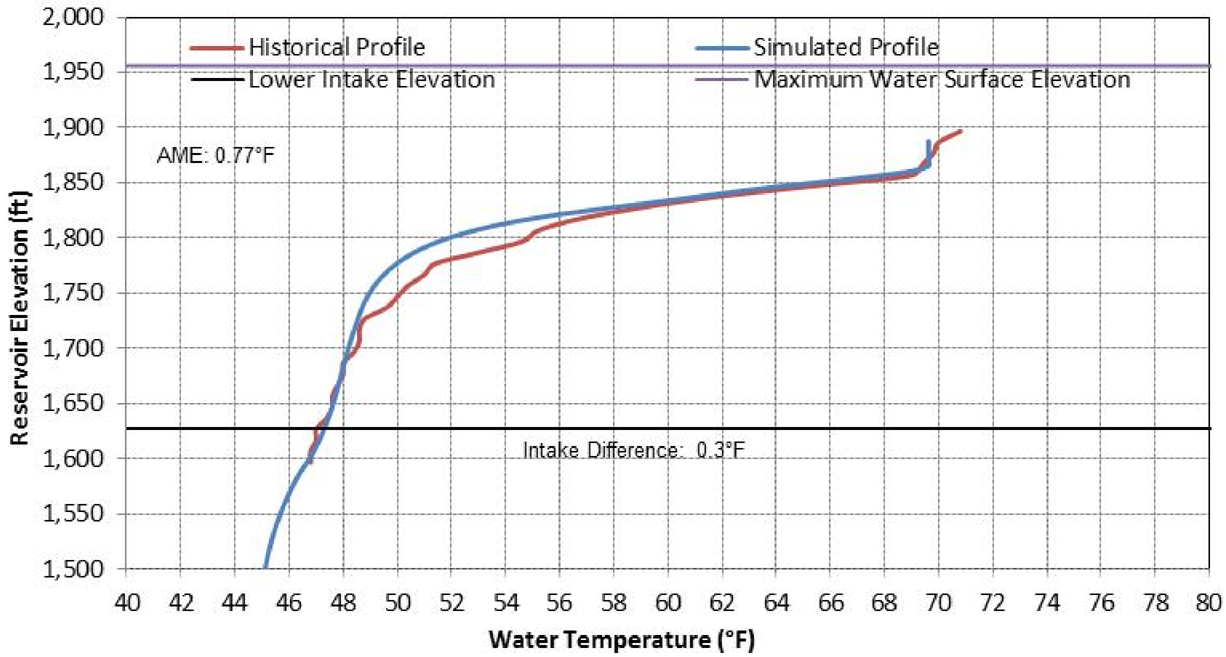

Figure 3.4-1. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 28, 2000

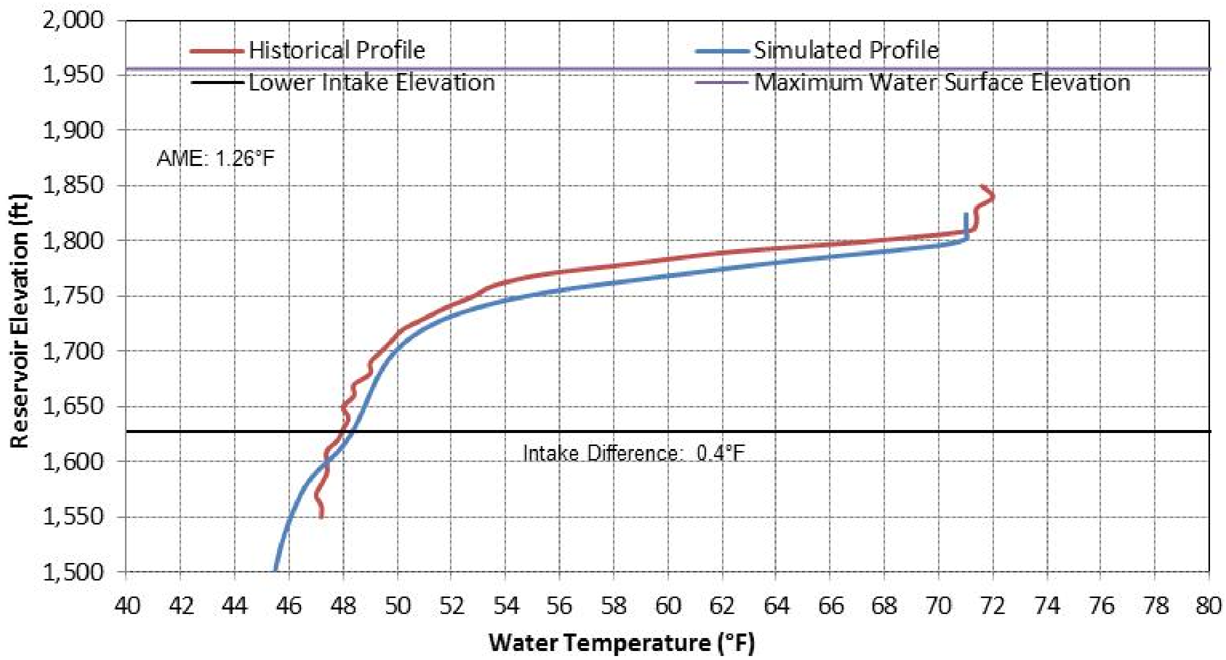

Figure 3.4-2. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 27, 2001

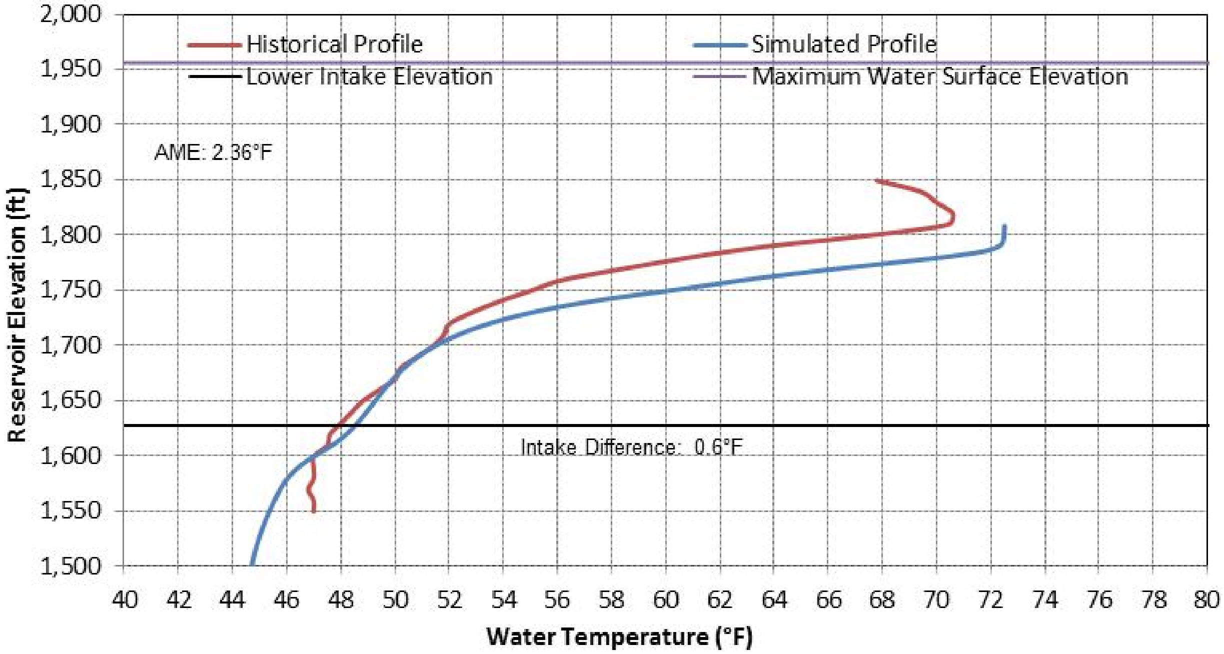

Figure 3.4-3. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 24, 2002

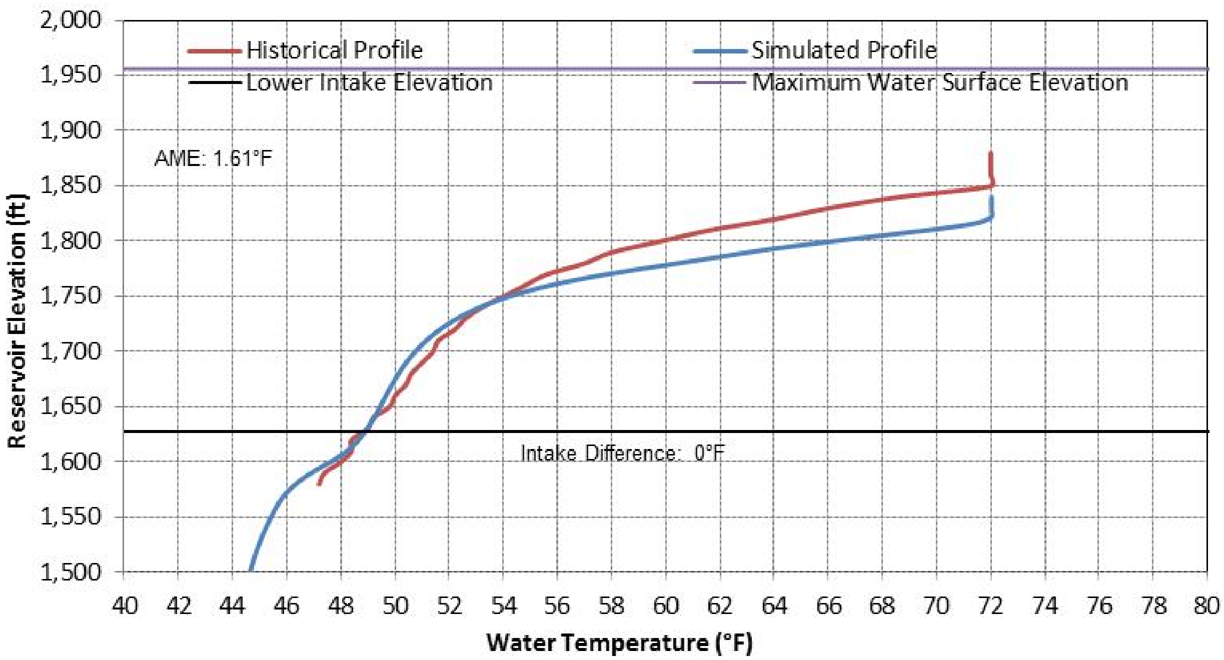

Figure 3.4-4. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 25, 2003

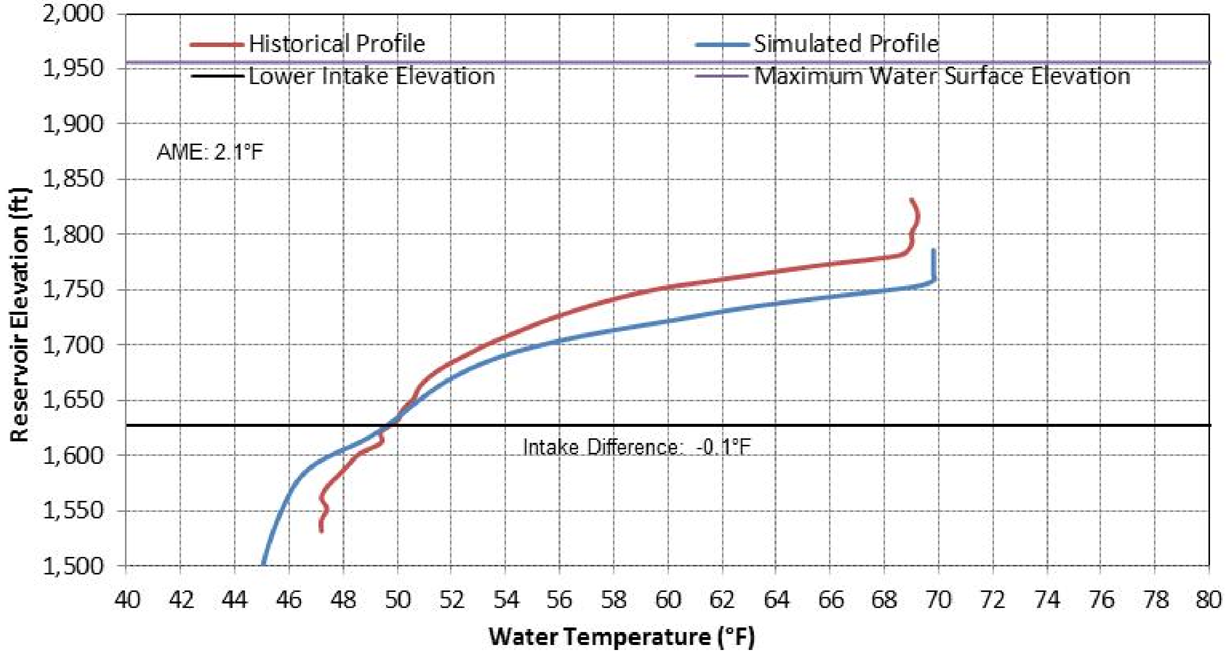

Figure 3.4-5. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for October 5, 2004

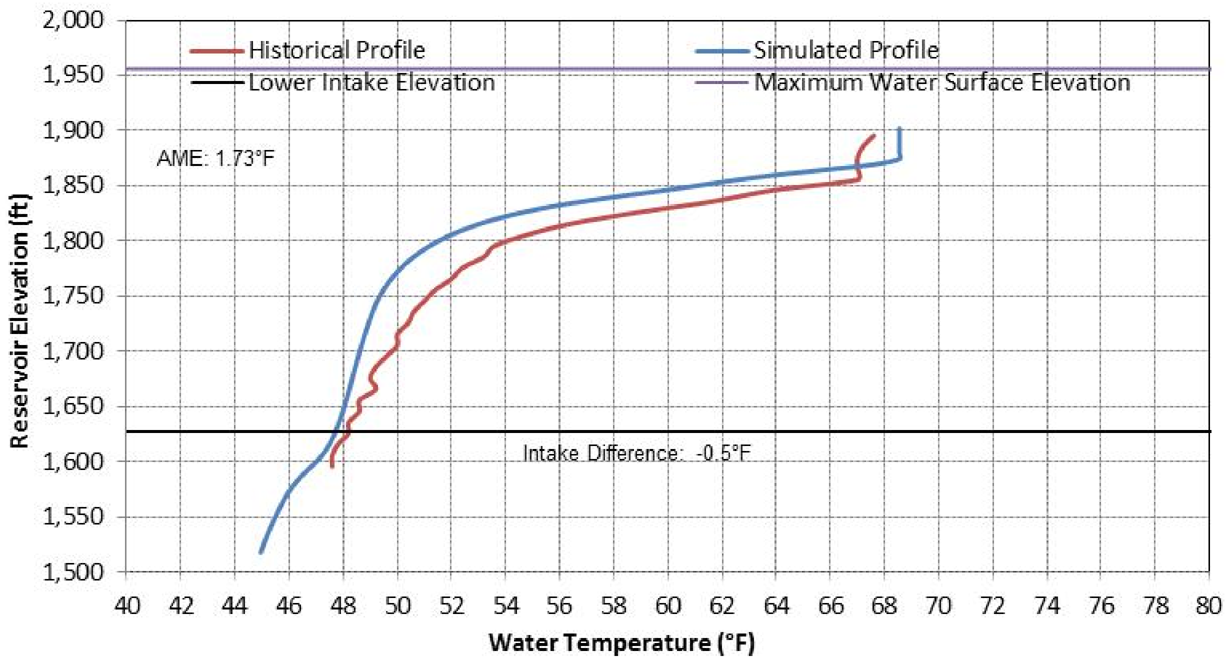

Figure 3.4-6. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for October 6, 2005

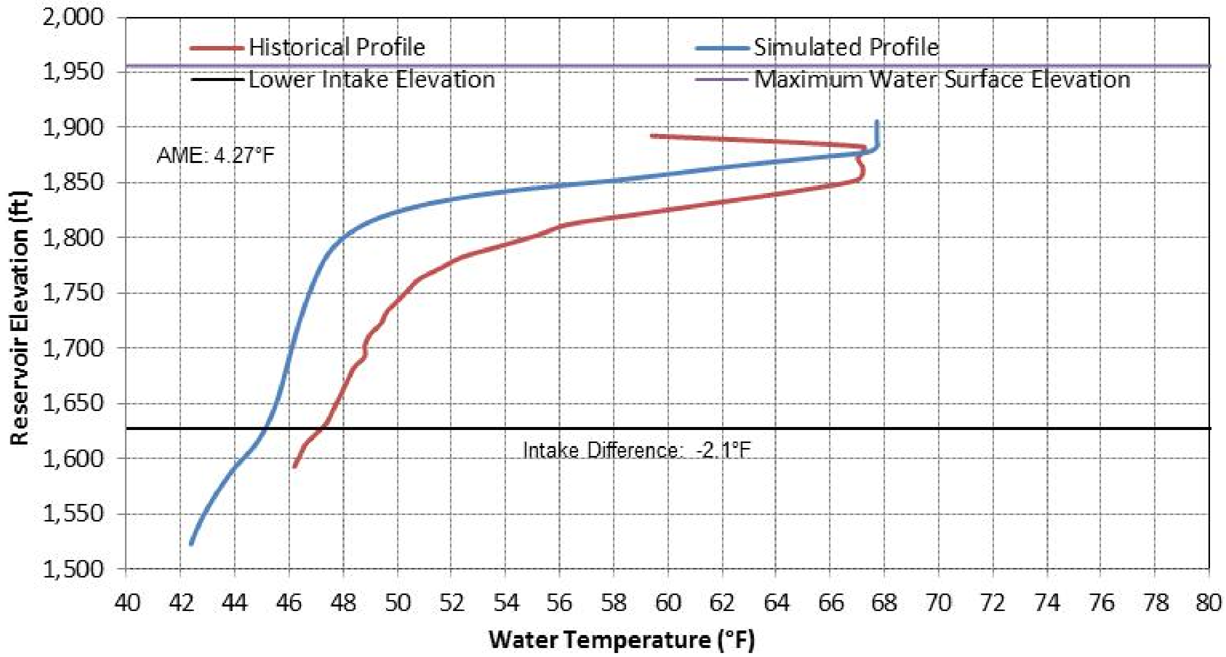

Figure 3.4-7. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for October 5, 2006

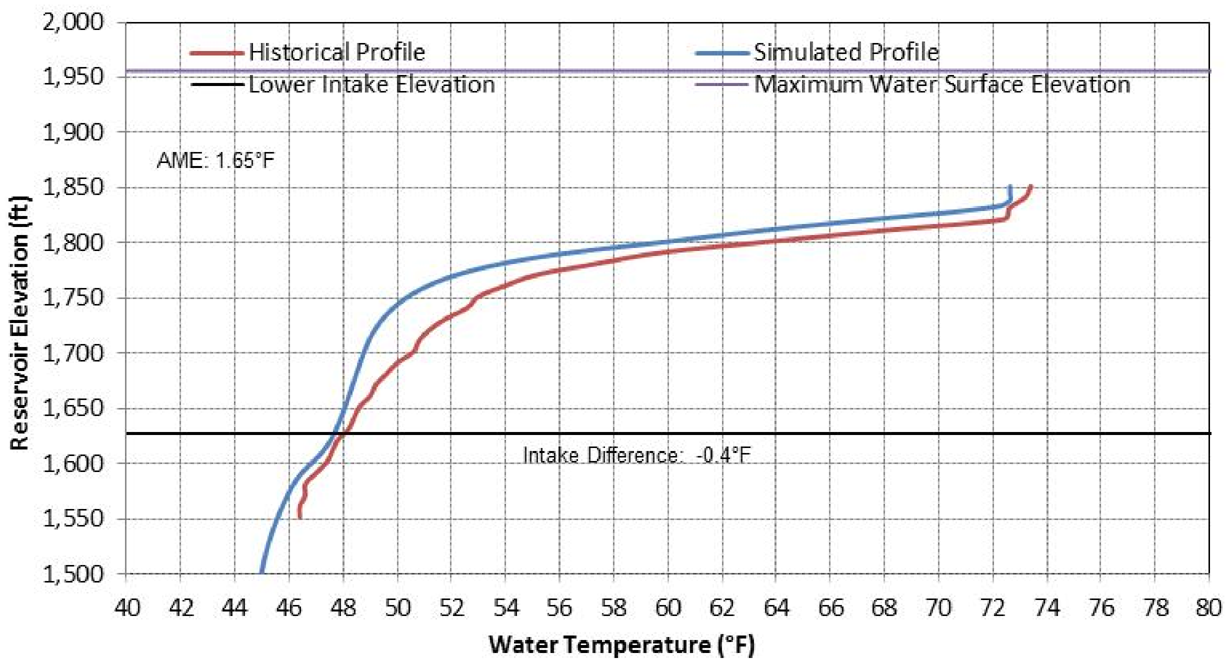

Figure 3.4-8. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 17, 2008

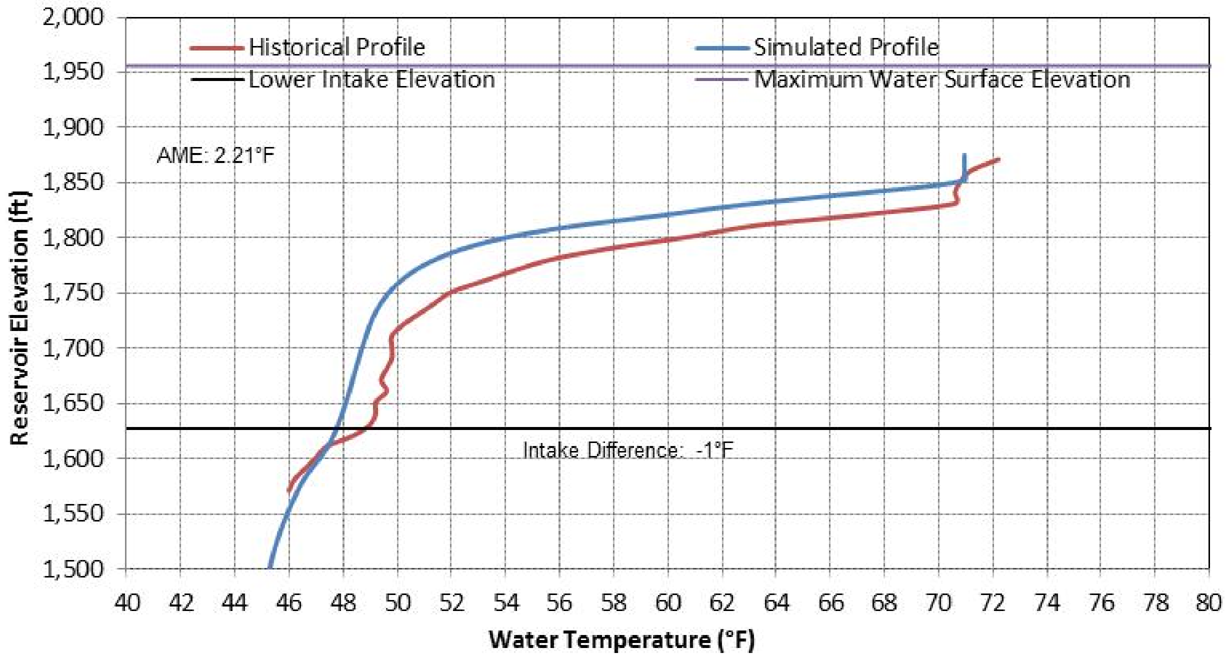

Figure 3.4-9. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for October 1, 2009

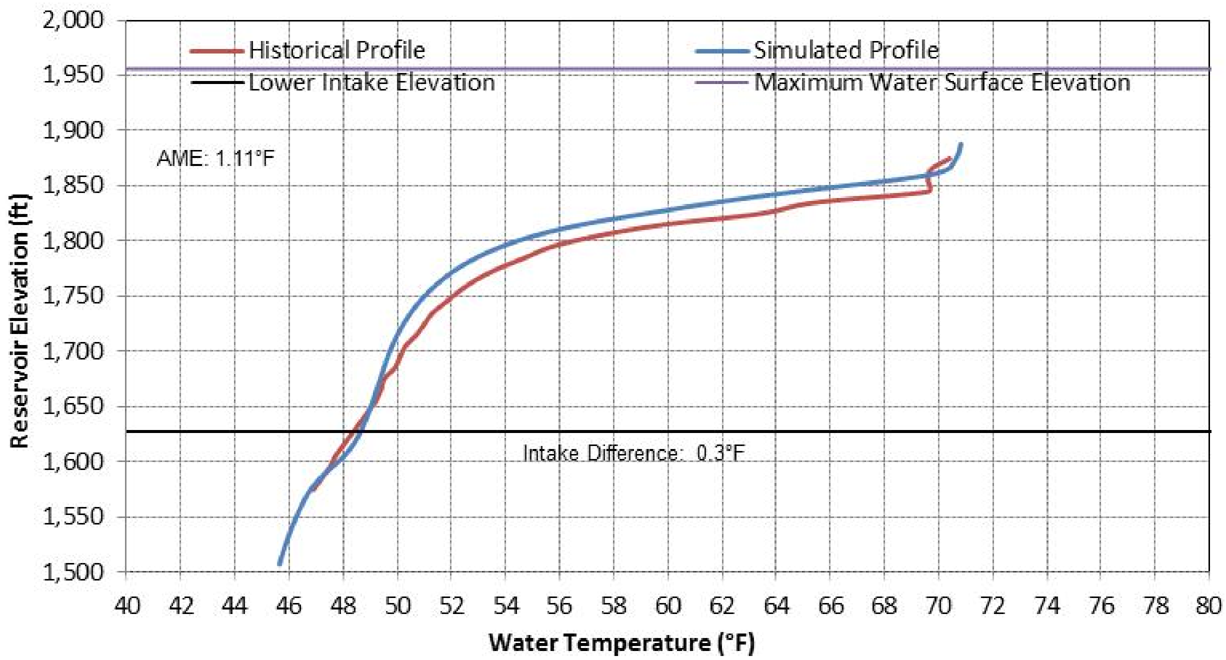

Figure 3.4-10. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 30, 2010

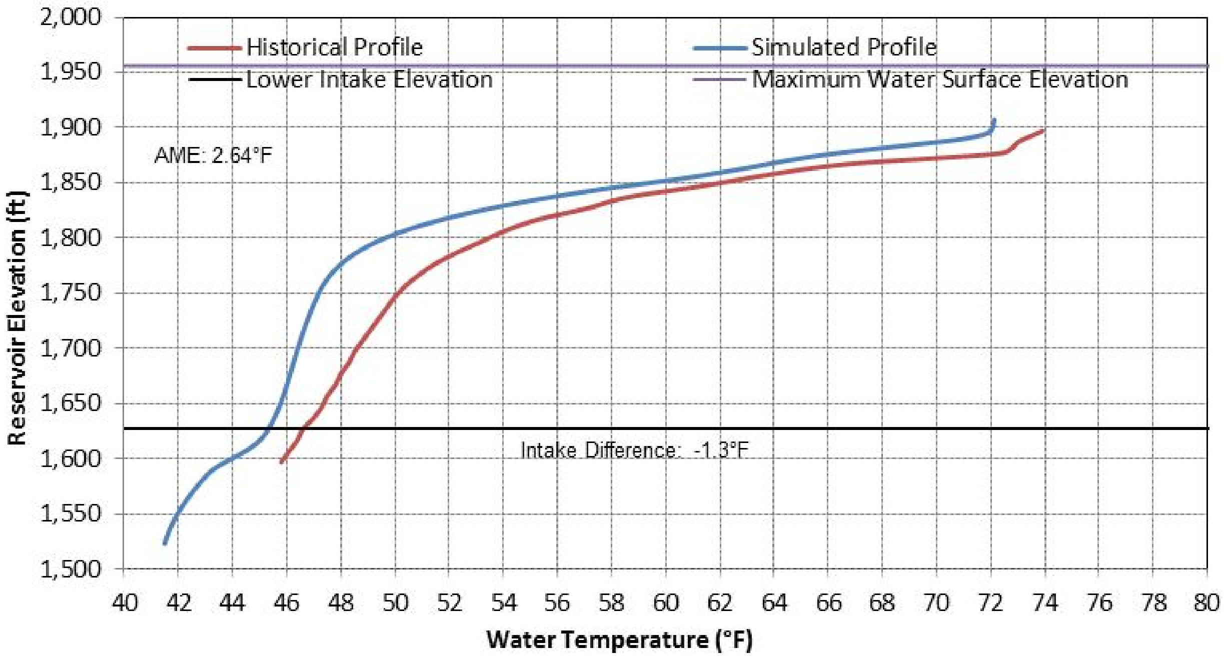

Figure 3.4-11. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 22, 2011

Of particular interest of the Upper Temp Model was the ability of the model to compute water temperatures on the North Yuba River during periods of increased releases from the base of New Bullards Bar Dam. There were no incidences of increased releases, other than spills, from New Bullards Bar Reservoir in the calibration period; however, there were several periods of increased flow in late-2008 and in August and October 2009 that coincided with the validation period. Figure 3.4-12 shows a comparison of historically-measured and simulated water temperatures on the North Yuba River above its confluence with the Middle Yuba River from the Validation Scenario for 2008 and 2009. Where only the red series is shown, the data were nearly identical and the historically-recorded water temperatures is shown (i.e., the blue line for the Upper Temp Model is under the red line).

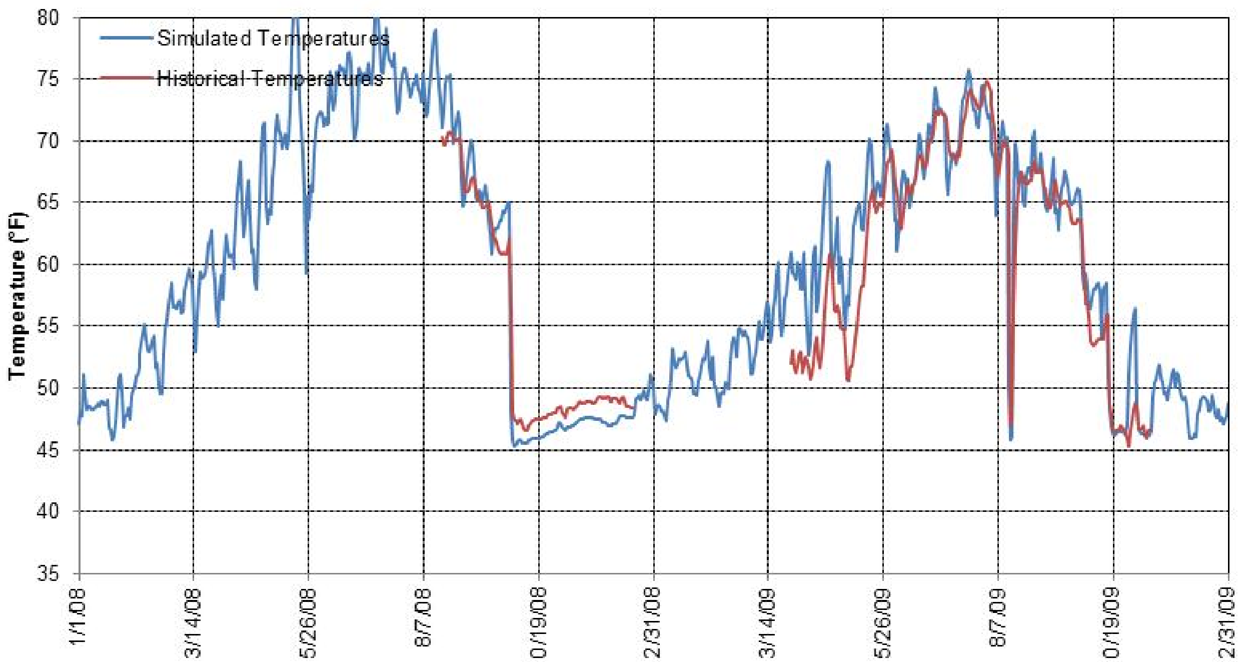

Figure 3.4-12. Comparison of historical and simulated mean-daily water temperatures on the North Yuba River above its confluence with the Middle Yuba River (RM 0.1).

3.4.2 Englebright Temp Model

Water temperature data below Englebright Dam and Smartsville (YCWA gage NY28) were available for the entire validation period. These data were used to compare output from the Englebright Temp Model. Validation output at Smartsville is included in Figure 3.4-13. Where only the red series is shown, the data were nearly identical and the historically-recorded water temperatures is shown (i.e., the blue line for the Englebright Temp Model is under the red line).

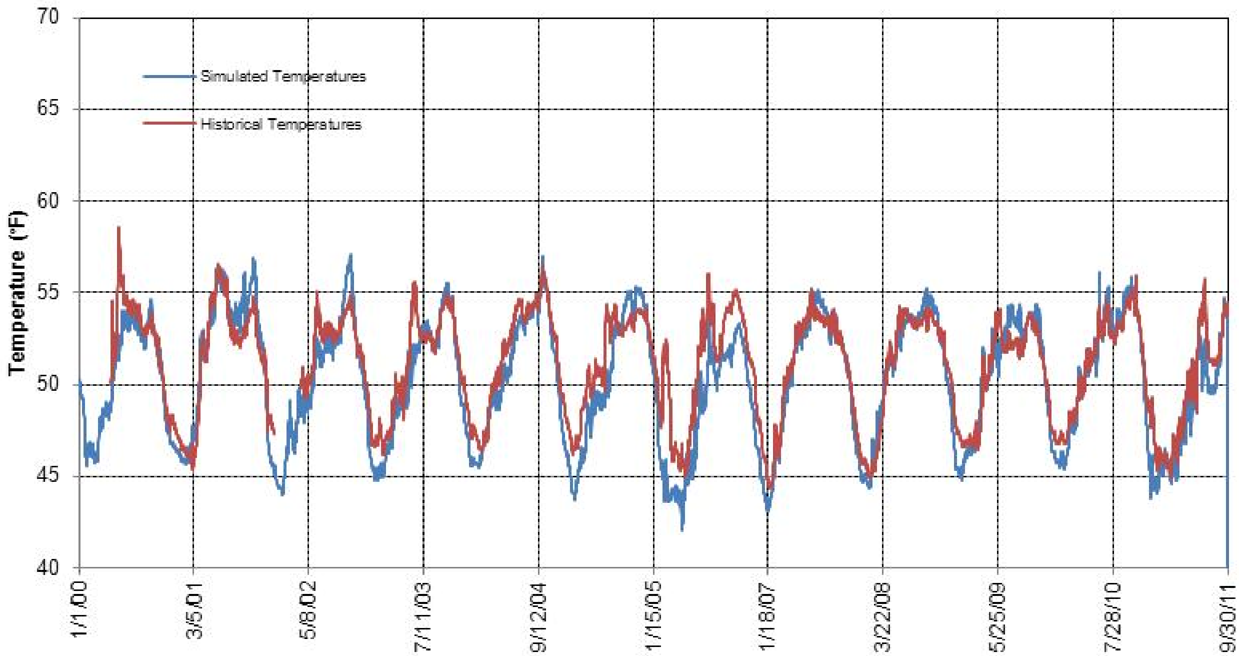

Figure 3.4-13. Comparison of simulated and historical mean-daily water temperatures for the Yuba River near Smartsville (RM 23.9).

Table 3.4-1 summarizes the ME and AME for the Englebright Temp Model.

Table 3.4-1. Summary of Mean Error (ME) and Absolute Mean Error (AME) for the Englebright Temp Model on the Yuba River near Smartsville.

Location (River Mile)	Gage ID	Full Period		July-October	
		ME	AME	ME	AME
Smartsville Gage (RM 23.9)	NY28	-0.65	1.08	0.40	0.87

3.4.3 Lower Temp Model

There were limited water temperature data available on the Yuba River below Englebright Dam for the Validation Scenario period with the exception of water temperatures at Smartsville. There were partial period-of-record data available for Parks Bar and Long Bar; Validation Scenario output at those two locations and Marysville are included below in Figure 3.4-1, Figure 3.4-2, and Figure 3.4-3, respectively. The historically-recorded water temperatures were available nearly for the entire validation period. Where only the red series is shown, the data were nearly identical and the historically-recorded water temperatures is shown (i.e., the blue line for the Lower Temp Model is under the red line).

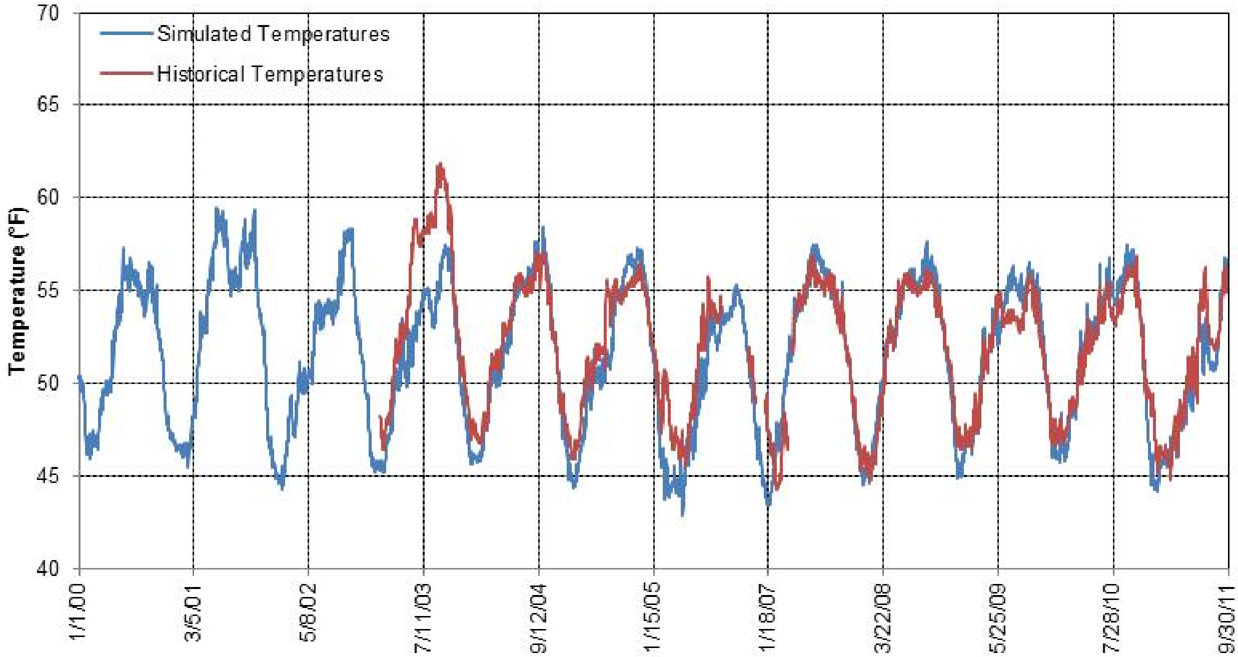

Figure 3.4-1. Comparison of simulated and historical mean-daily water temperatures for the Yuba River near Parks Bar (RM 17.7).

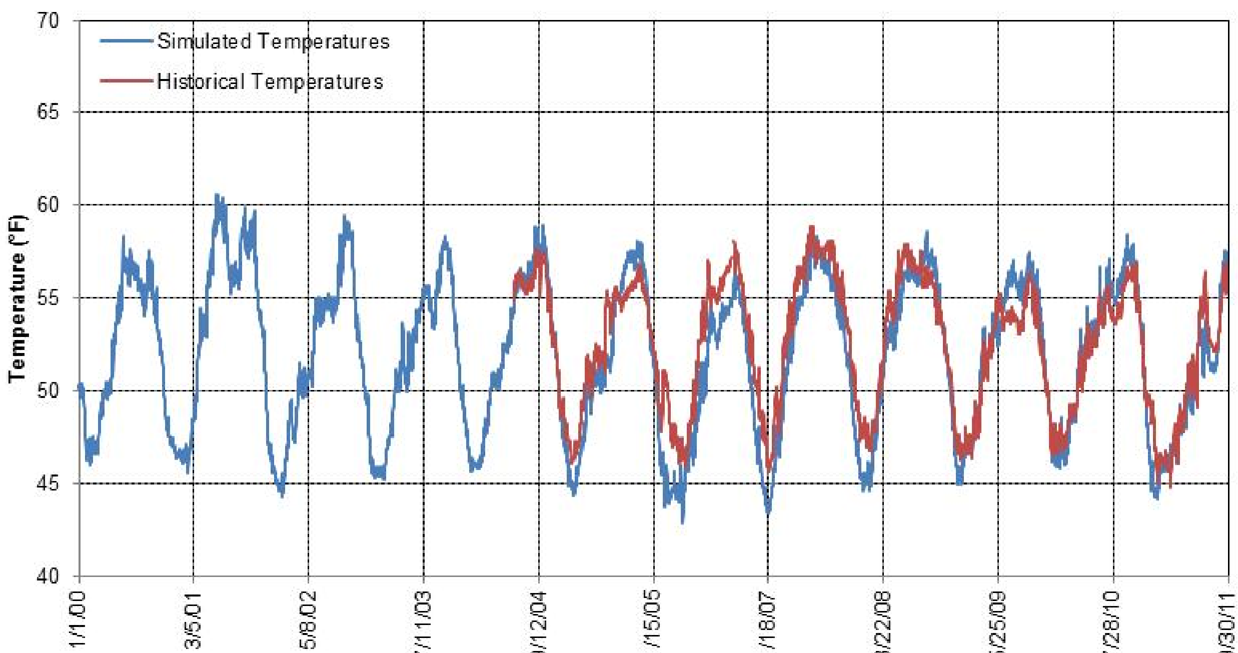

Figure 3.4-2. Comparison of simulated and historical mean-daily water temperatures for the Yuba River near Long Bar (RM 16.2).

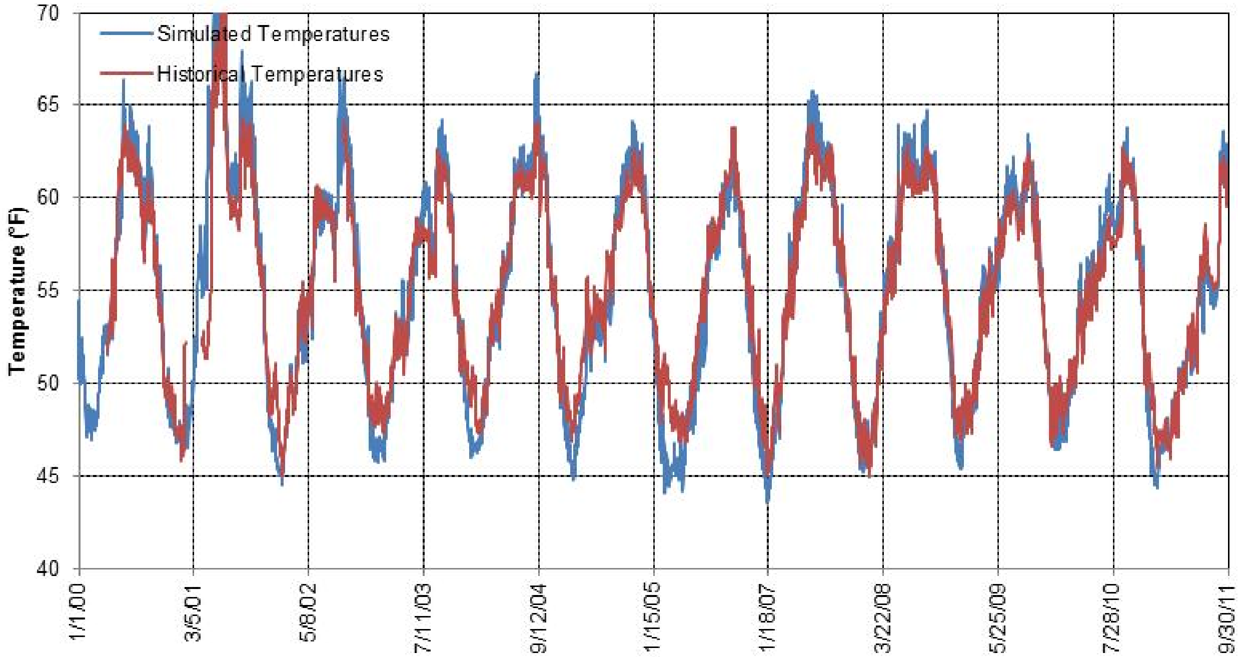

Figure 3.4-3. Comparison of simulated and historical mean-daily water temperatures for the Yuba River near Marysville (RM6.2).

Table 3.4-2 summarizes the ME and AME for the Lower Temp Model at each location.

Table 3.4-2. Summary of Mean Error (ME) and Absolute Mean Error (AME) for the Lower Temp Model at historical measurement locations.

Location (River Mile)	Gage ID	Full Period		July-October	
		ME	AME	ME	AME
Smartsville Gage (RM 23.9)	NY28	-0.95	1.35	0.14	0.81
Parks Bar (RM 17.7)	PB	-0.61	1.23	-0.03	1.25
Long Bar (RM 16.2)	LB	-0.68	1.32	0.26	1.14
Marysville Gage (RM 6.2)	11421000	-0.17	1.10	0.49	0.95

3.5 Base Case Development

For the Base Case, the models were setup and run in series for the entire period of record, October 1, 1969 through September 30, 2010. Output temperatures results from the water temperature models will be presented in two ways: 1) as tables of monthly statistics; and 2) as exceedance plots, for multiple locations. Raw output data can be found in Attachment 2-2B in HEC-DSS format.

3.5.1 Upper Temp Model

The Upper Temp Model simulates water temperatures throughout the Project area above Englebright Dam. Plots for exceedance probability of water temperatures at various locations within the Upper Temp Model area are presented in Figures 3.5-1 through 3.5-12.8. Monthly statistics tables are presented in Tables 3.5-1 to 3.5-18.

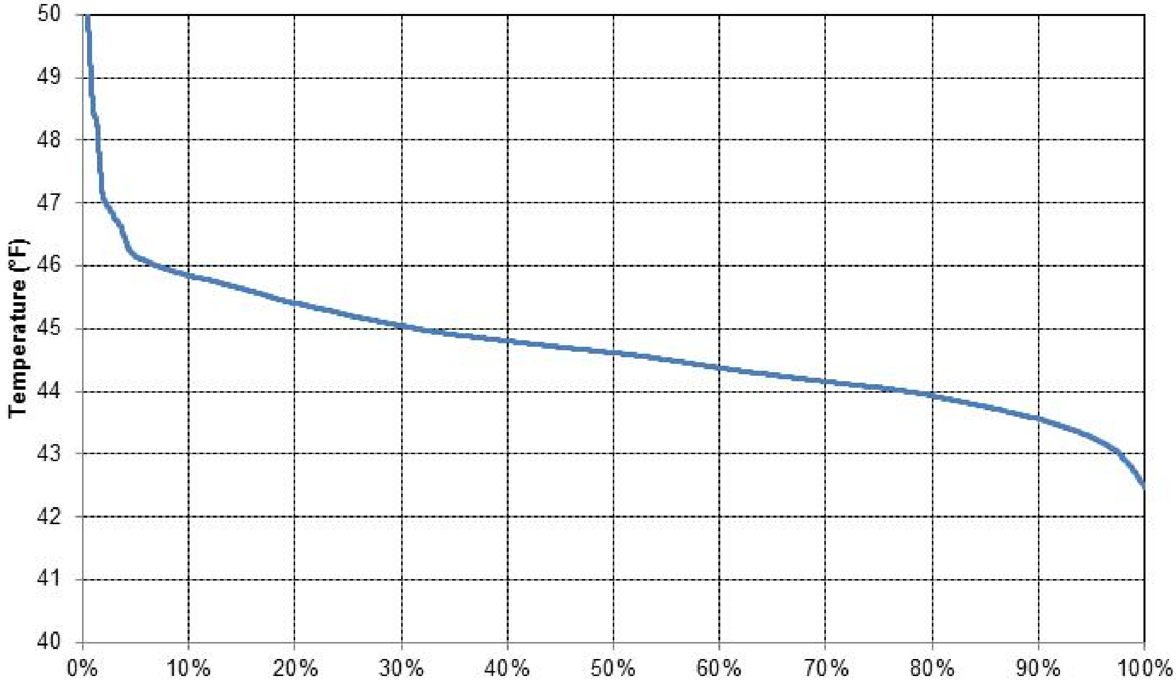

Figure 3.5-1. Exceedance probability of simulated water temperatures on the North Yuba River above its confluence with the Middle Yuba River (RM 0.1).

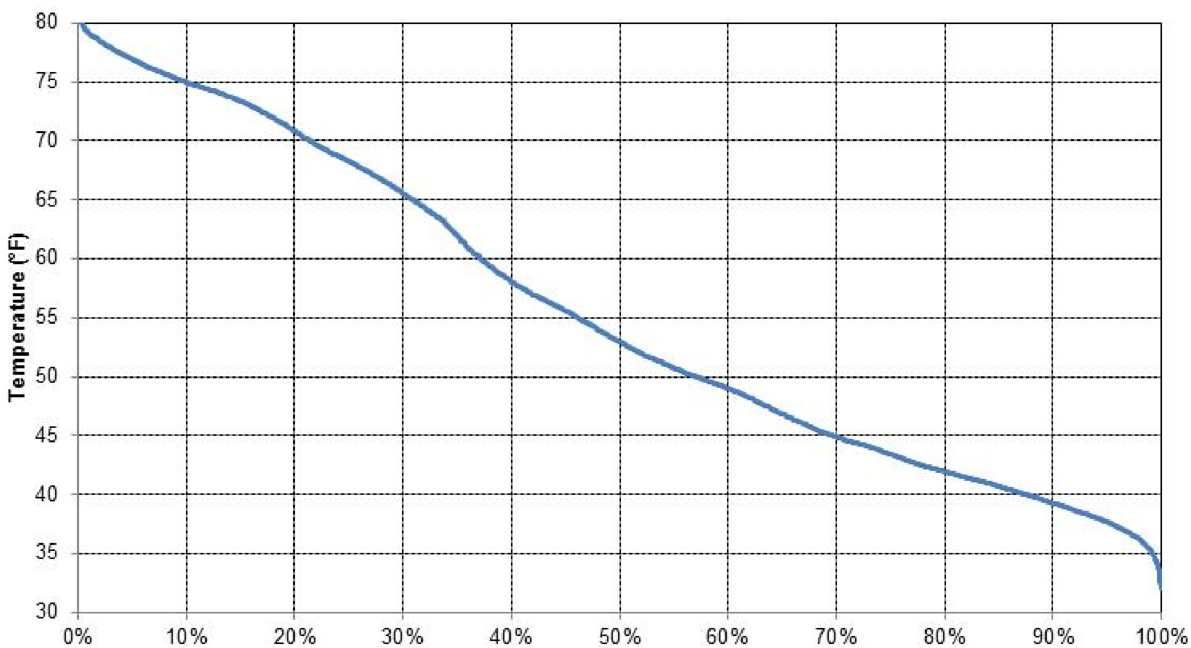

Figure 3.5-2. Exceedance probability of simulated water temperatures on the Middle Yuba River above its confluence with the North Yuba River (RM 0.1).

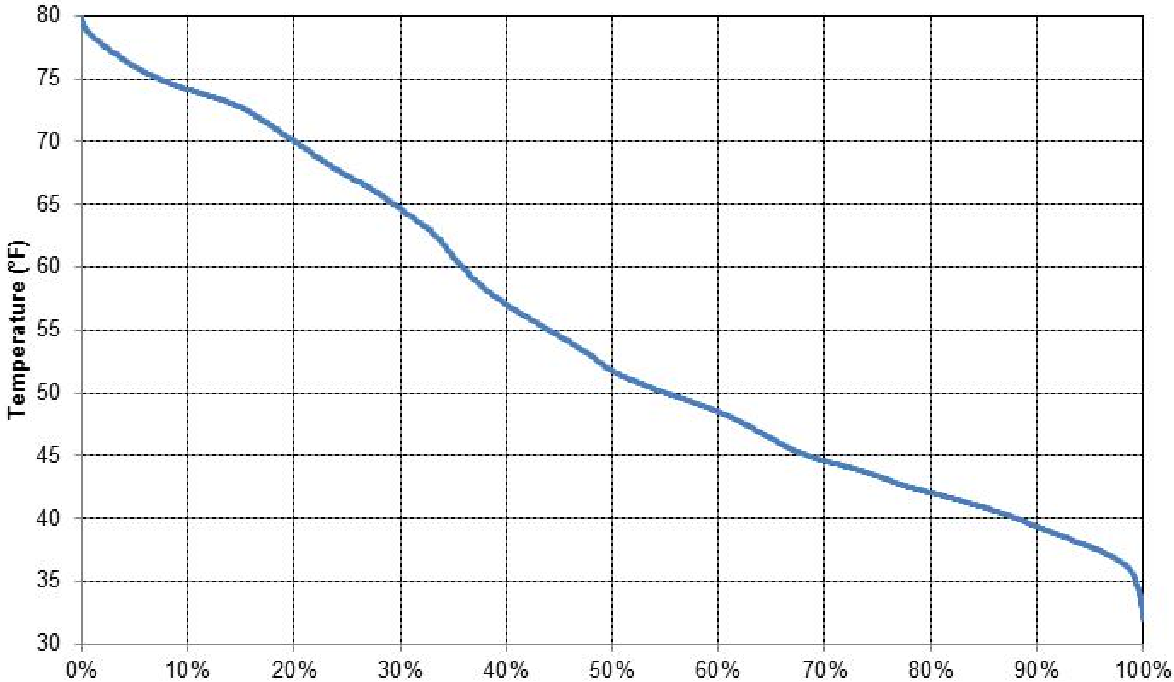

Figure 3.5-3. Exceedance probability of simulated water temperatures on the Middle Yuba River above its confluence with the Oregon Creek (RM 4.8).

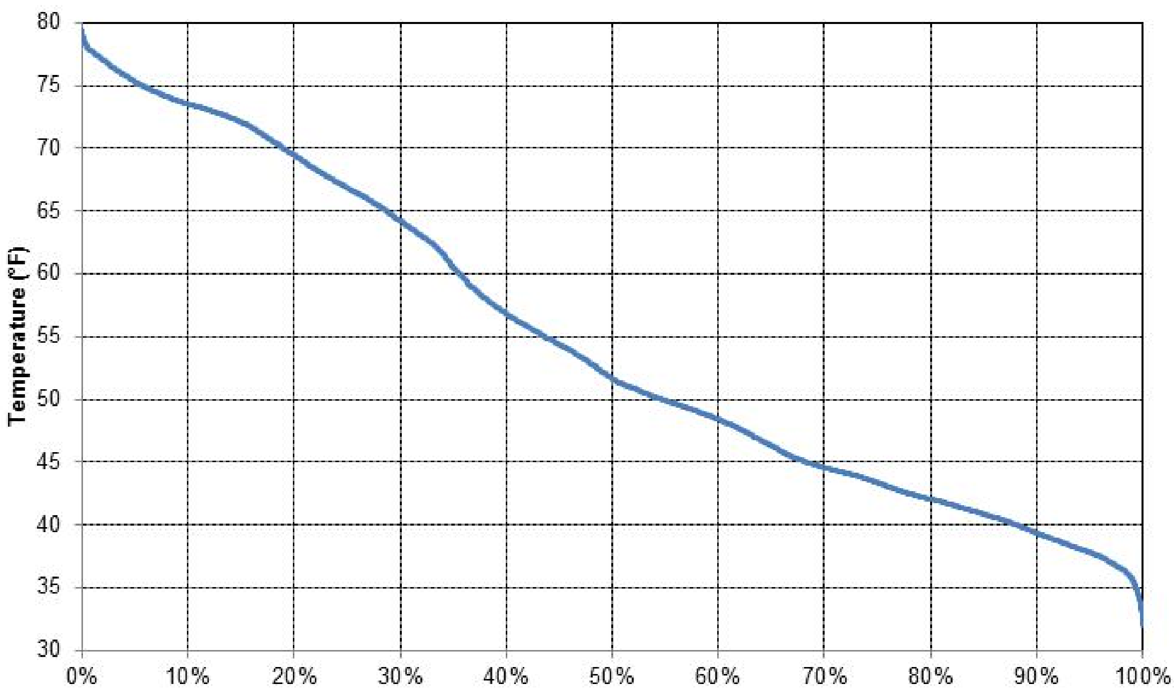

Figure 3.5-4. Exceedance probability of simulated water temperatures on the Middle Yuba River below its confluence with the Oregon Creek (RM 4.4).

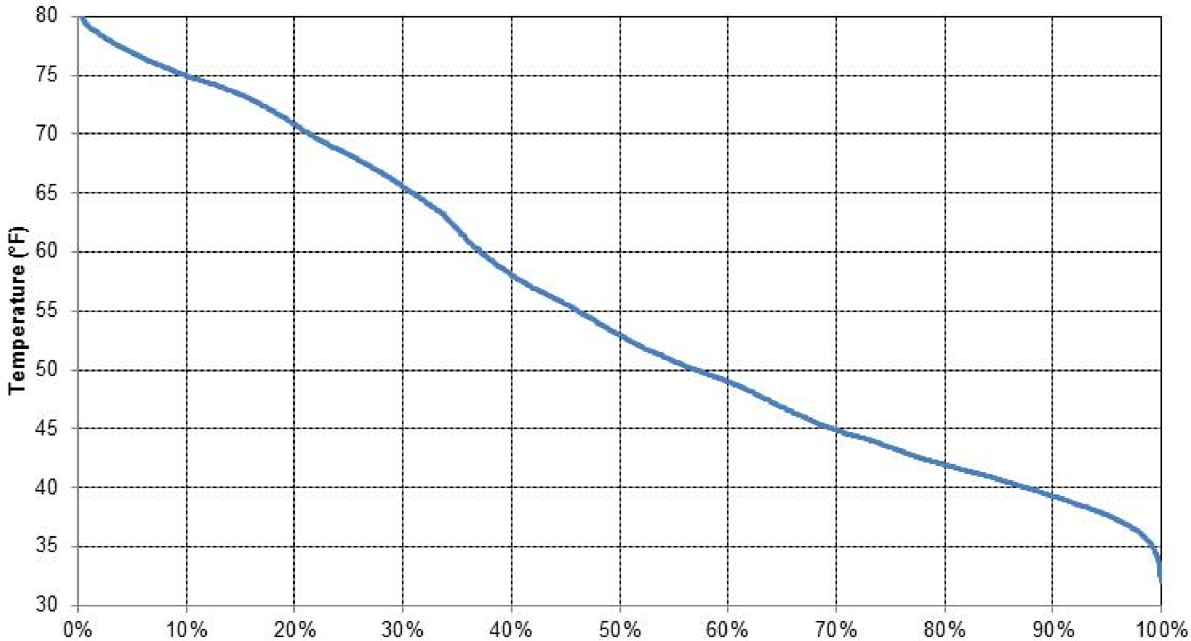

Figure 3.5-5. Exceedance probability of simulated water temperatures on Oregon Creek above its confluence with the Middle Yuba River (RM 0.2).

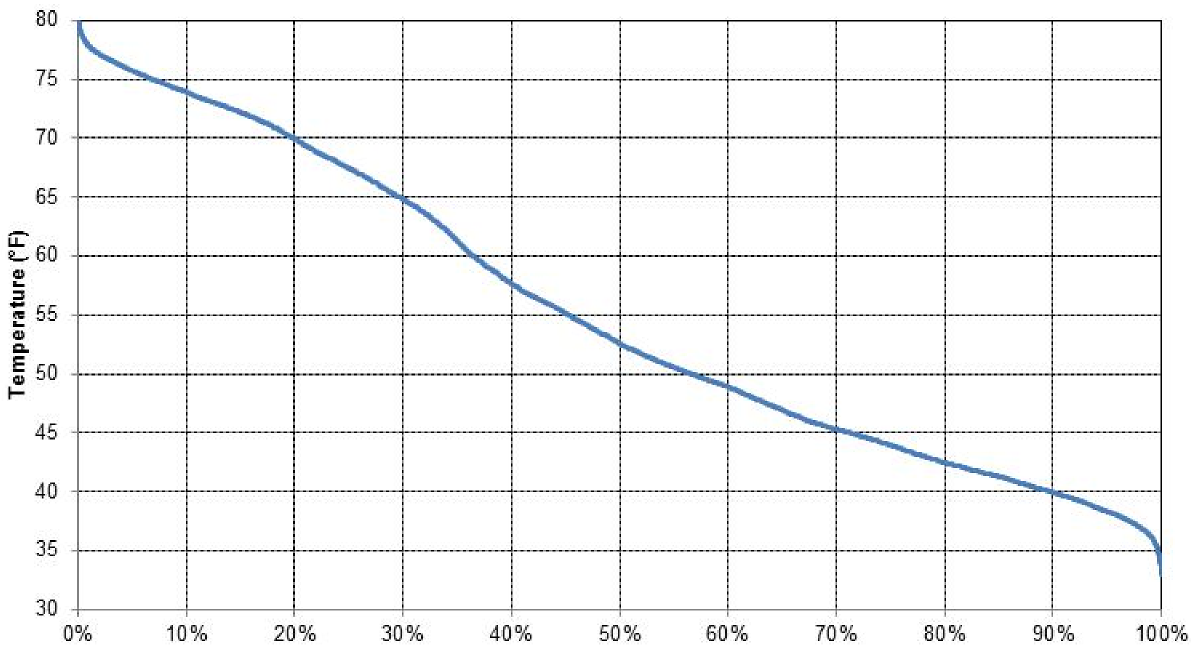

Figure 3.5-6. Exceedance probability of simulated water temperatures on the Yuba River below the confluence of the Middle Yuba and North Yuba rivers (RM 40.0).

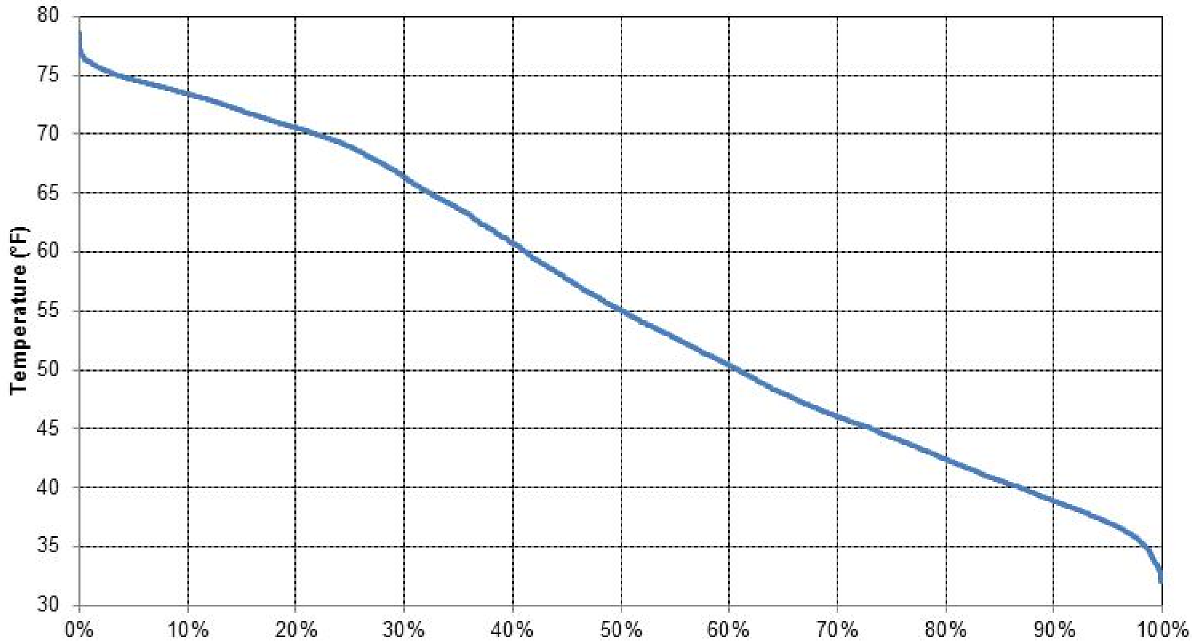

Figure 3.5-7. Exceedance probability of simulated water temperatures on the Yuba River above the New Colgate Powerhouse (RM 34.4).

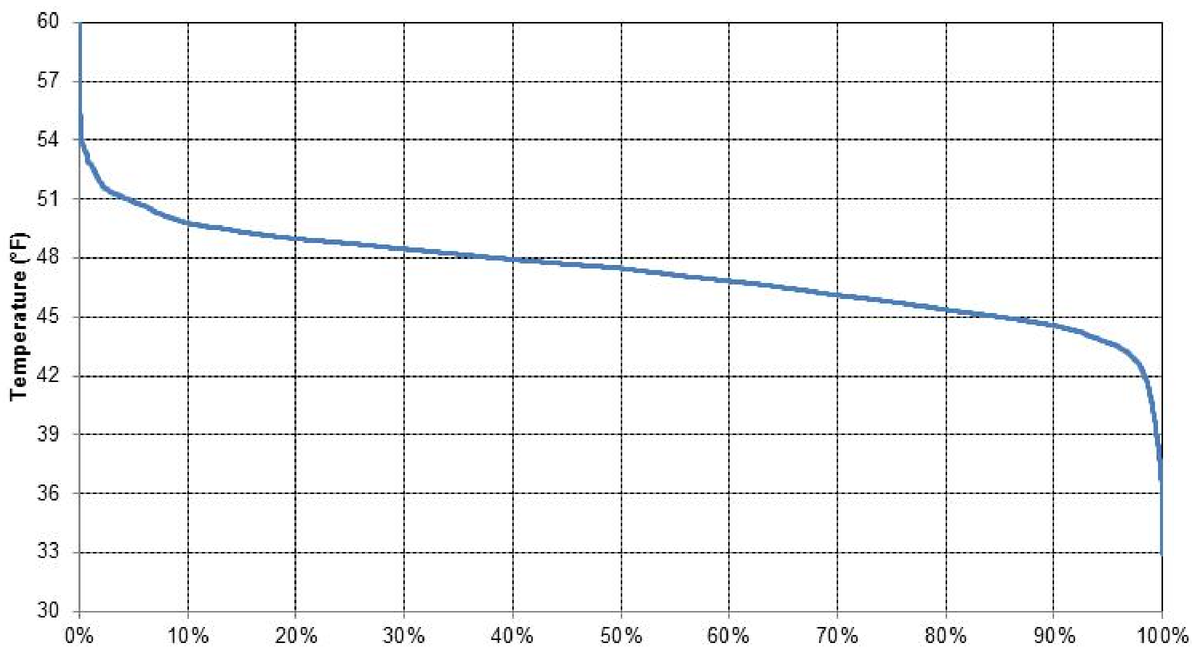

Figure 3.5-8. Exceedance probability of simulated water temperatures on the Yuba River below the New Colgate Powerhouse (RM 34.1).

Table 3.5-1. Base Case monthly water temperature statistics at the Middle Yuba River downstream from Our House Diversion Dam (RM 12.6).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	36.2	44.1	39.9	39.6
February	36.3	44.8	41.5	41.9
March	41.1	47.8	44.2	44.1
April	41.4	53.5	46.9	46.8
May	44.0	62.7	54.3	49.9
June	50.0	71.4	60.3	61.3
July	63.6	77.4	71.8	72.2
August	66.3	78.0	71.9	71.5
September	60.9	72.5	66.7	67.0
October	47.1	65.7	56.6	56.0
November	38.0	51.3	45.4	45.5
December	33.2	45.0	40.3	40.7

Table 3.5-2. Base Case monthly water temperature statistics at the Middle Yuba River upstream from the Oregon Creek confluence (RM 4.8).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	34.7	44.1	39.4	39.2
February	34.4	46.6	42.1	42.4
March	41.8	51.9	46.2	45.9
April	41.9	59.0	50.4	50.5
May	44.3	69.7	59.2	55.0
June	51.4	77.1	65.7	66.4
July	65.3	80.4	75.5	75.8
August	68.1	80.3	73.9	73.8
September	59.7	74.4	67.7	67.8
October	46.8	66.7	57.0	56.7
November	37.3	52.9	45.2	45.2
December	32.0	45.1	39.6	39.8

Table 3.5-3. Base Case monthly water temperature statistics at the Middle Yuba River downstream from the Oregon Creek confluence (RM 4.4).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	34.6	44.0	39.4	39.3
February	34.5	46.5	42.0	42.4
March	41.7	51.7	46.2	45.8
April	42.0	58.8	50.3	50.4
May	44.4	69.5	59.2	54.9
June	51.6	76.5	65.4	66.1
July	65.2	79.5	74.9	75.1
August	67.3	79.3	73.2	73.2
September	59.4	73.8	67.1	67.2
October	46.6	66.0	56.6	56.4
November	37.2	52.5	45.1	45.2
December	32.0	45.1	39.6	39.8

Table 3.5-4. Base Case monthly water temperature statistics at the Middle Yuba River upstream from the North Yuba River confluence (RM 0.1).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	33.5	43.9	39.2	39.2
February	33.9	47.2	42.2	42.5
March	41.9	53.5	46.8	46.5
April	42.2	60.9	51.5	51.6
May	44.6	72.4	61.1	57.2
June	52.4	78.9	67.6	68.2

Table 3.5-4. (continued).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
July	66.0	81.7	76.5	76.8
August	67.4	80.9	74.3	74.3
September	59.2	75.2	67.8	67.9
October	45.7	68.1	57.0	56.8
November	36.7	53.3	45.1	45.1
December	32.0	45.2	39.3	39.5

Table 3.5-5. Base Case monthly water temperature statistics at Oregon Creek downstream from Log Cabin Diversion Dam (RM 4.3).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	32.1	44.1	39.5	39.4
February	34.3	44.7	41.1	41.7
March	40.8	47.5	44.0	44.0
April	41.5	53.4	46.7	46.5
May	43.8	62.2	54.2	49.8
June	50.4	70.5	59.7	60.7
July	62.8	74.5	69.1	69.6
August	60.1	75.5	67.3	67.6
September	55.6	68.8	61.4	61.2
October	46.0	62.9	53.8	53.7
November	37.6	50.9	44.4	44.7
December	32.3	45.0	39.9	40.3

Table 3.5-6. Base Case monthly water temperature statistics at Oregon Creek upstream from Middle Yuba River confluence (RM 0.2).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	33.5	43.9	39.2	39.2
February	33.9	47.2	42.2	42.5
March	41.9	53.5	46.8	46.5
April	42.2	60.9	51.5	51.6
May	44.6	72.4	61.1	57.2
June	52.4	78.9	67.6	68.2
July	66.0	81.7	76.5	76.8
August	67.4	80.9	74.3	74.3
September	59.2	75.2	67.8	67.9
October	45.7	68.1	57.0	56.8
November	36.7	53.3	45.1	45.1
December	32.0	45.2	39.3	39.5

Table 3.5-7. Base Case monthly water temperature statistics at the North Yuba River below New Bullards Bar Dam (RM 2.3).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	42.4	51.6	44.7	44.6
February	42.5	50.6	44.3	44.3
March	42.5	47.8	44.3	44.2
April	42.8	49.2	44.3	44.3
May	42.8	53.0	47.4	44.6
June	42.7	52.1	45.0	44.8
July	43.3	47.2	45.0	44.9
August	43.3	47.1	44.9	44.9
September	43.2	47.0	44.9	44.9
October	43.2	48.6	44.8	44.7
November	43.2	48.4	44.8	44.7
December	43.1	53.6	44.8	44.7

Table 3.5-8. Base Case monthly water temperature statistics at the North Yuba River upstream from the Middle Yuba River confluence (RM 0.1)

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	42.5	51.6	44.7	44.5
February	42.5	50.6	44.3	44.3
March	42.5	47.8	44.2	44.1
April	42.6	49.2	44.3	44.3
May	42.6	53.0	47.4	44.5
June	42.7	52.1	45.0	44.7
July	43.2	47.2	44.9	44.8
August	43.1	47.1	44.9	44.8
September	43.1	47.0	44.8	44.8
October	43.1	48.6	44.8	44.7
November	43.0	48.4	44.8	44.7
December	43.0	53.6	44.8	44.7

Table 3.5-9. Base Case monthly water temperature statistics at the Yuba River downstream from the North and Middle Yuba River confluence (RM 40.0).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	35.0	49.3	40.0	39.8
February	34.4	48.9	42.7	42.9
March	42.0	53.9	46.9	46.5
April	42.7	61.2	51.8	51.9
May	45.7	72.4	61.0	57.5
June	46.7	78.2	66.1	67.9
July	49.0	81.1	75.3	75.7
August	66.5	79.5	73.0	73.0
September	58.3	74.0	66.7	66.8
October	45.7	67.5	56.6	56.5
November	37.7	53.4	45.5	45.6
December	32.9	51.3	40.0	40.1

Table 3.5-10. Base Case monthly water temperature statistics at the Yuba River upstream from the New Colgate Powerhouse (RM 34.4).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	32.4	49.3	38.8	38.4
February	36.3	49.5	43.0	43.1
March	41.7	57.0	48.4	47.8
April	43.1	64.5	54.6	54.8
May	46.9	72.5	64.6	62.0
June	48.5	75.9	68.2	70.3
July	51.3	78.6	74.0	74.4
August	66.7	77.0	72.4	72.4
September	58.5	73.0	67.1	67.4
October	48.5	68.9	58.1	58.1
November	37.1	55.0	46.2	46.5
December	32.0	51.1	38.5	38.5

Table 3.5-11. Base Case monthly water temperature statistics at the Yuba River downstream from the New Colgate Powerhouse (RM 34.1).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	34.7	50.2	44.8	45.1
February	38.0	49.0	44.6	44.6
March	42.8	54.9	45.7	45.4
April	43.2	58.2	46.7	46.4
May	44.4	62.4	49.6	46.7
June	44.8	54.2	47.4	47.3

Table 3.5-11. (continued)

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
July	45.4	54.1	47.9	47.7
August	46.2	53.8	48.6	48.4
September	47.2	58.5	49.6	49.3
October	47.6	54.2	49.6	49.3
November	37.4	52.9	48.9	48.9
December	32.9	51.0	46.2	46.8

3.5.2 Englebright Temp Model

Plots for exceedance probability of simulated water temperatures for the Yuba River near at Smartsville (RM 23.9) from the Englebright Temp Model is presented in Figure 3.5-9, below. Monthly statistics are presented in Table 3.5-12.

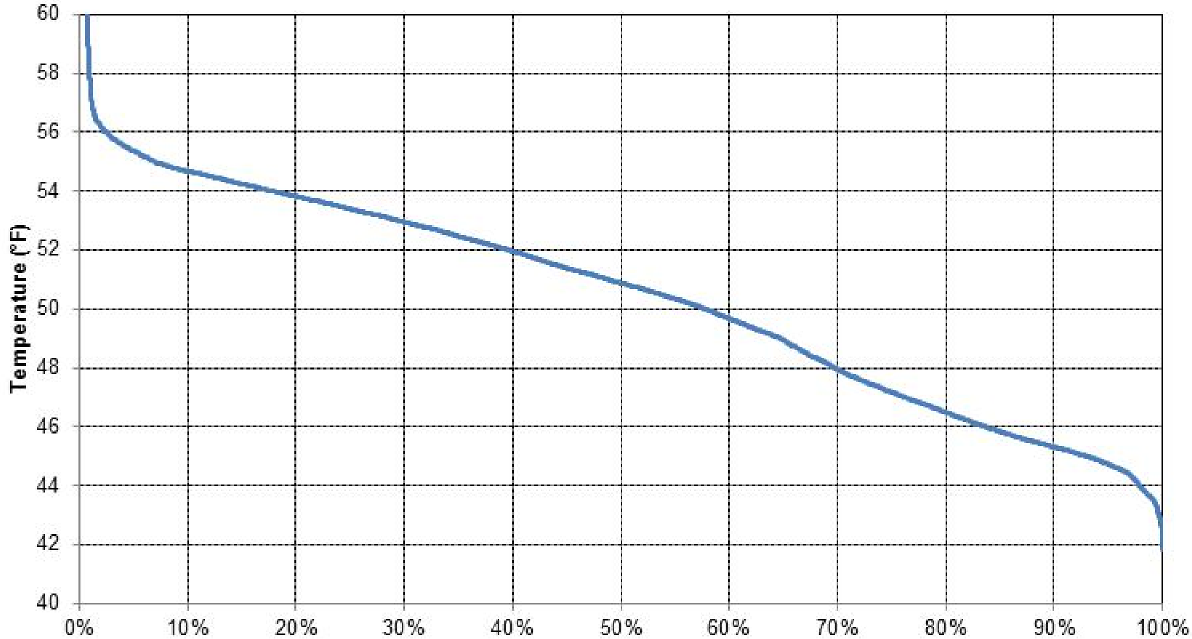

Figure 3.5-9. Exceedance probability of simulated water temperatures on the Yuba River near Smartsville.

Table 3.5-12. Base Case monthly water temperature statistics at the Yuba River near Smartsville (RM 23.9).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	42.3	48.1	45.1	45.2
February	43.0	48.8	45.6	45.5
March	43.6	52.7	47.3	47.1
April	45.0	54.7	49.7	49.7
May	47.5	56.1	53.9	50.7
June	48.4	58.5	52.0	51.7
July	49.0	61.9	53.2	53.2
August	51.5	62.5	54.0	53.8
September	52.1	63.1	54.8	54.6
October	47.5	63.1	54.1	54.0
November	45.9	59.8	51.2	51.2
December	41.9	52.6	47.1	47.0

3.5.3 Lower Temp Model

The Lower Temp Model simulates water temperatures throughout the Project area below Smartsville. Plots for exceedance probability of water temperatures at various locations within the Lower Temp Model area are presented in Figures 3.5-10 through 3.5-17. Monthly statistics tables are presented in Tables 3.5-13 to 3.5-18.

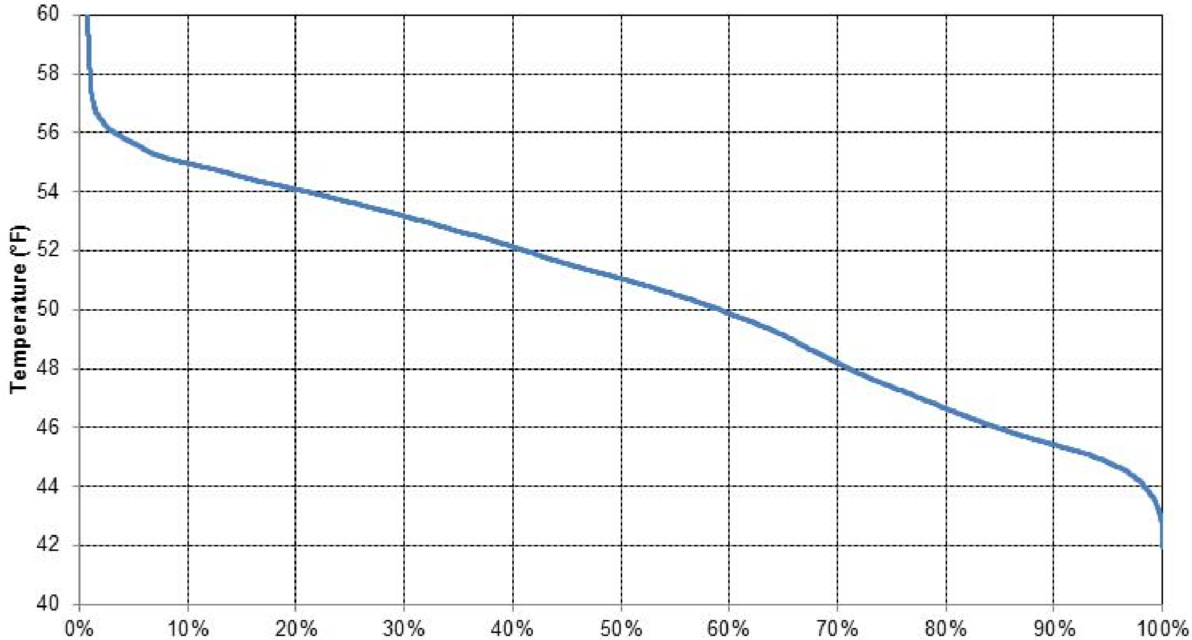

Figure 3.5-10. Exceedance probability of simulated water temperatures on the Yuba River below Deer Creek (RM 23.1).

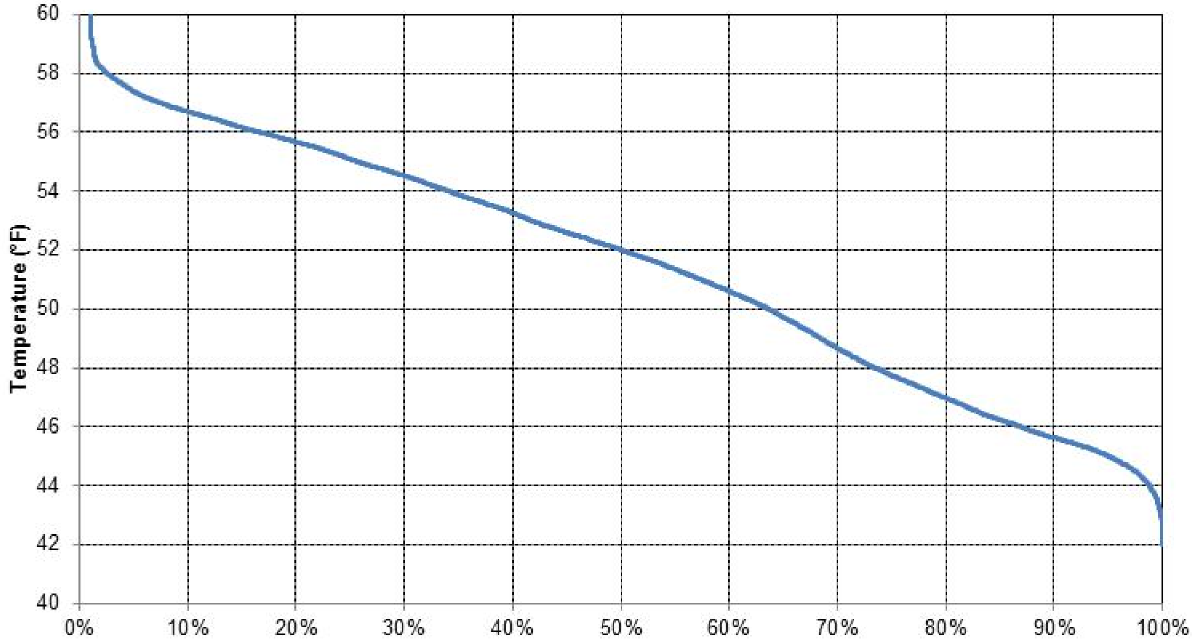

Figure 3.5-11. Exceedance probability of simulated water temperatures on the Yuba River near Parks Bar (RM 17.7).

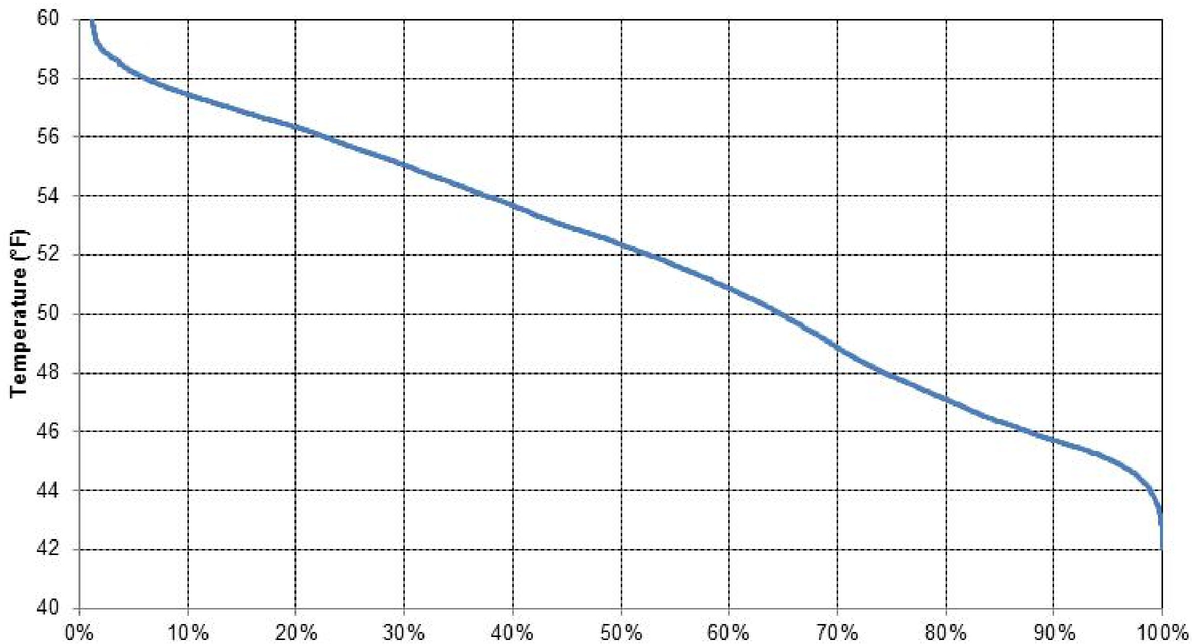

Figure 3.5-12. Exceedance probability of simulated water temperatures on the Yuba River near Long Bar (RM 16.2).

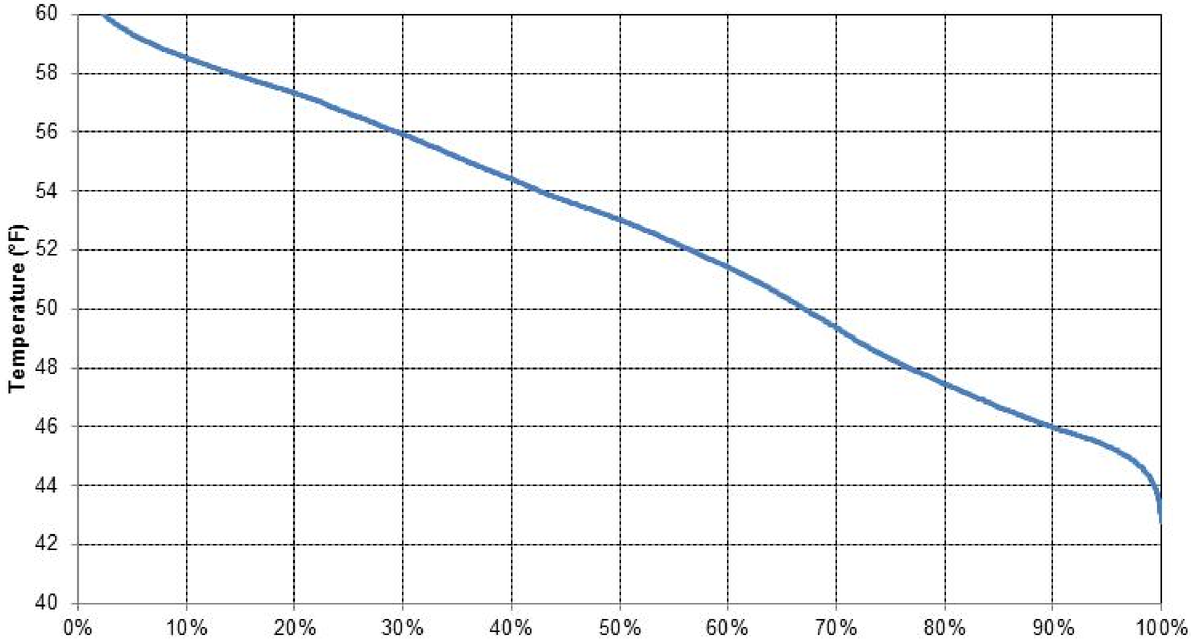

Figure 3.5-13. Exceedance probability of simulated water temperatures on the Yuba River below Dry Creek (RM 13.4).

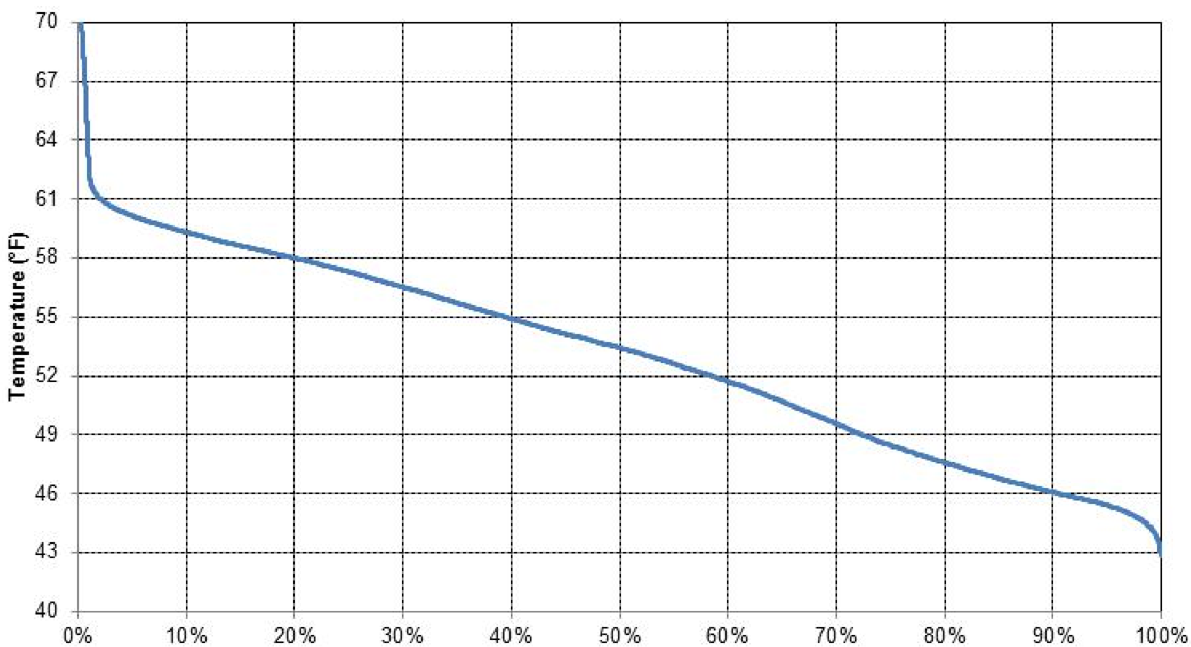

Figure 3.5-14. Exceedance probability of simulated water temperatures on the Yuba River above Daguerre Point Dam (RM 11.6).

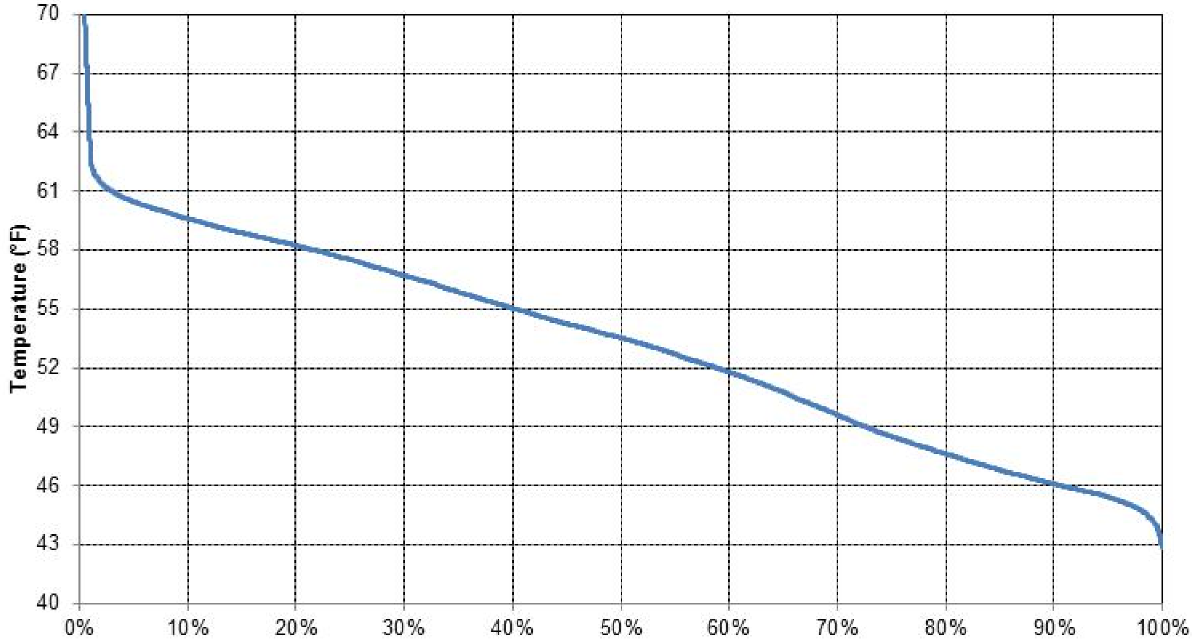

Figure 3.5-15. Exceedance probability of simulated water temperatures on the Yuba River below Daguerre Point Dam (RM 11.6).

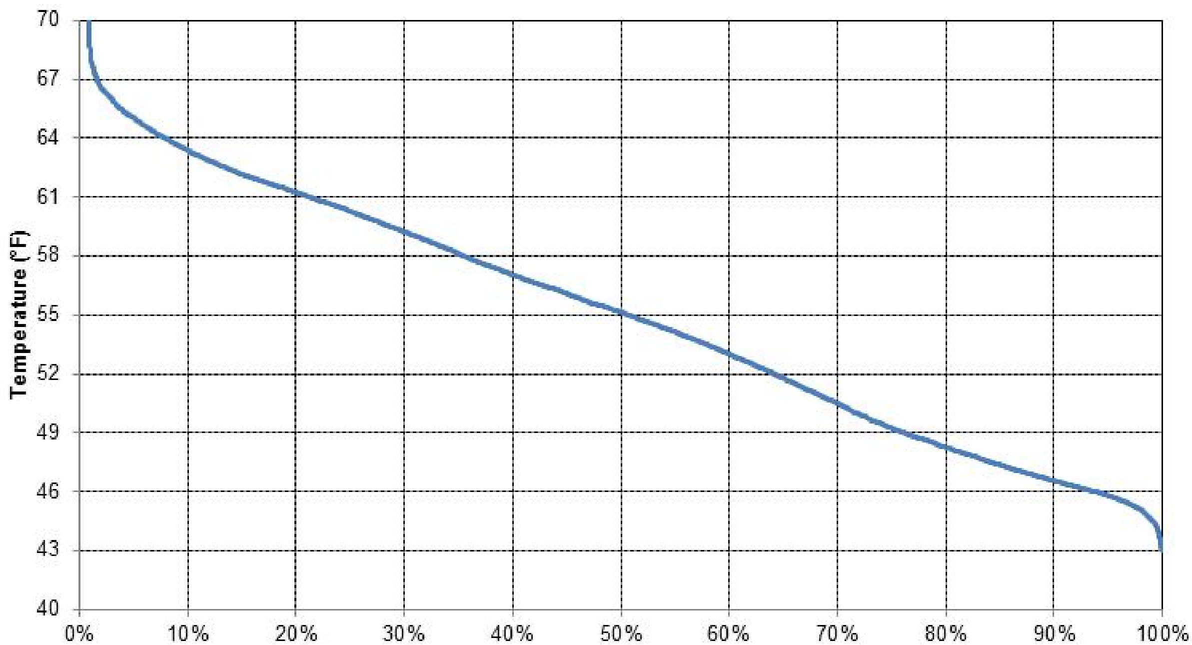

Figure 3.5-16. Exceedance probability of simulated water temperatures on the Yuba River near Marysville (RM 6.2).

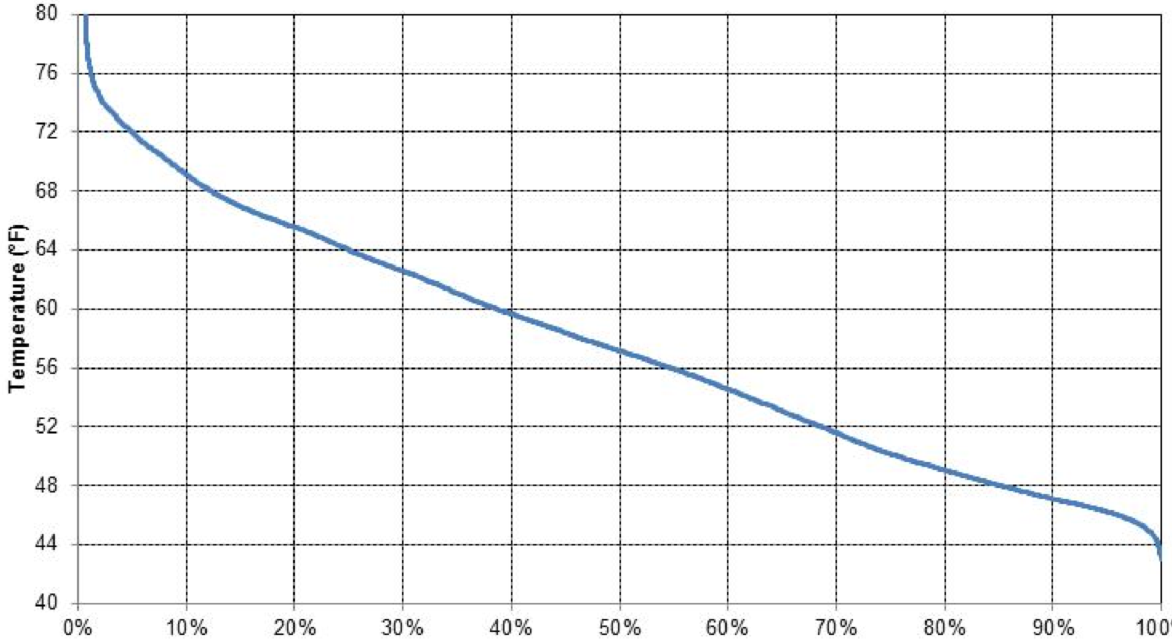

Figure 3.5-17. Exceedance probability of simulated water temperatures on the Yuba River above its confluence with the Feather River (RM 0.7).

Table 3.5-13. Base Case monthly water temperature statistics on the Yuba River below Deer Creek (RM 23.1).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	42.5	48.0	45.2	45.2
February	43.2	48.9	45.7	45.6
March	43.8	53.0	47.7	47.4
April	46.4	55.4	50.2	50.0
May	47.7	56.5	54.0	50.8
June	48.5	59.0	52.2	51.8
July	49.2	62.5	53.4	53.4
August	51.6	63.4	54.3	54.1
September	52.5	64.0	55.1	54.9
October	47.8	63.3	54.3	54.2
November	45.9	59.8	51.2	51.2
December	41.9	52.4	47.0	47.0

Table 3.5-14. Base Case monthly water temperature statistics at the Yuba River at Parks Bar (RM 17.7).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	42.6	48.3	45.4	45.4
February	43.3	49.8	46.1	45.9
March	44.1	54.2	48.3	48.0
April	46.6	56.6	51.1	51.0
May	48.2	59.7	55.2	51.8
June	49.2	62.5	53.6	53.0
July	50.4	65.9	55.2	54.9
August	52.6	68.1	56.0	55.8
September	53.7	68.8	56.9	56.6
October	49.5	65.0	55.3	55.2
November	46.0	61.2	51.6	51.7
December	42.0	52.9	47.2	47.1

Table 3.5-15. Base Case monthly water temperature statistics at the Yuba River at Long Bar (RM 16.2).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	42.6	48.5	45.5	45.5
February	43.4	50.4	46.2	46.1
March	44.2	55.0	48.5	48.2
April	46.7	57.9	51.5	51.4
May	48.4	61.2	55.6	52.2
June	49.5	64.2	54.1	53.4
July	50.7	67.5	55.8	55.5
August	52.9	70.4	56.7	56.4
September	54.1	71.1	57.7	57.4
October	50.2	65.8	55.8	55.7
November	46.1	61.8	51.8	51.8
December	42.0	53.3	47.2	47.2

Table 3.5-16. Base Case monthly water temperature statistics at the Yuba River downstream from Dry Creek (RM 13.4).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	42.8	48.6	45.7	45.6
February	43.6	50.9	46.6	46.4
March	44.8	56.0	49.2	48.8
April	47.8	59.0	52.2	52.1
May	48.8	62.5	56.4	52.9
June	50.1	65.8	55.1	54.3
July	51.5	69.1	56.9	56.6
August	53.5	72.2	57.7	57.5
September	54.7	73.1	58.7	58.4
October	50.9	66.8	56.6	56.5
November	46.0	62.3	52.1	52.1
December	42.9	53.8	47.5	47.5

Table 3.5-17. Base Case monthly water temperature statistics at the Yuba River downstream from Daguerre Point Dam (RM 11.6).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	42.8	48.7	45.8	45.7
February	43.7	51.5	46.8	46.5
March	44.9	56.9	49.5	49.1
April	48.0	60.4	52.7	52.5
May	49.1	64.2	57.1	53.5
June	50.6	67.8	55.9	55.0
July	52.1	72.1	58.0	57.6
August	54.1	75.0	58.7	58.5
September	55.3	75.7	59.7	59.4
October	51.5	68.3	57.1	57.0
November	46.1	62.9	52.3	52.3
December	42.9	54.4	47.6	47.5

Table 3.5-18. Base Case monthly water temperature statistics at the Yuba River near Marysville (RM 6.2).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	43.0	50.0	46.2	46.2
February	44.0	53.3	47.4	47.2
March	45.5	59.2	50.4	50.0
April	48.4	66.2	54.2	53.9
May	49.8	71.0	59.2	55.3

Table 3.5-18. (continued)

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
June	51.8	77.1	58.9	57.3
July	53.6	94.0	62.0	61.3
August	55.7	95.7	62.5	61.8
September	57.0	89.6	62.9	62.3
October	53.2	73.0	59.3	59.2
November	46.4	66.0	53.4	53.5
December	43.0	56.6	48.2	48.0

Table 3.5-19. Base Case monthly water temperature statistics at the Yuba River upstream from the Feather River confluence (RM 0.7).

Month	Minimum (°F)	Maximum (°F)	Mean (°F)	Median (°F)
January	43.2	51.9	46.8	46.7
February	44.4	55.6	48.2	47.9
March	46.1	62.8	51.6	51.0
April	48.7	73.3	56.2	55.6
May	50.4	80.0	61.9	57.2
June	53.0	88.9	62.8	59.9
July	55.0	117.6	67.6	66.6
August	57.4	116.6	67.8	66.6
September	58.9	107.0	67.5	66.6
October	55.5	80.0	62.4	62.2
November	46.7	69.7	55.1	55.1
December	43.1	59.8	48.9	48.8

3.6 Prepare Model and Model Development and Validation Reports

The finalized models can be found in Attachment 2-6B. The model development and validation reports were combined into one report, *Model Development and Validation Report,* located in Attachment 2-6C.

4.0 Discussion

The following section provides a discussion of the various elements of the three water temperature models.

4.1 Model Selection

The selected modeling approach, by constructing the model in three pieces using two platforms, has both simplified the modeling approach by providing for a relatively high level of consistency between models, and it has allowed YCWA to develop a model that meets the needs of the Relicensing process.

The HEC-5Q model has been widely used across many relicensing processes, and was proven to provide consistent and reliable results. By including both a quantity and a quality module, it can compute reservoir storage and flows throughout the system internally; it allows for a straightforward and direct connection to Water Balance/Operations Model output as an input and reproduces flow and storage at key locations. By combining the ability to simulate both a reservoir and riverine system in a single platform, the overall modeling process was simplified, data exchanges between platforms were eliminated, and the potential for error due to user interaction was reduced.

The CE-QUAL-W2 model has also been widely used in many relicensing processes and was recognized as a robust and reliable model. It also meets the needs of YCWA for the relicensing process and was accepted by Relicensing Participants.

There was a fair amount of discussion in the consultation process about other platforms, including SNTEMP for the upper portion of the Yuba River Development Project, and CE-QUAL-W2 for New Bullards Bar Reservoir. Ultimately, in addition to its ability to simulate water temperatures and its generally wide-spread usage in other applications, including relicensings, the ability of HEC-5Q to simulate reservoir and riverine systems as well as using HEC-DSS for data exchange made it the more appealing platform.

4.2 Model Development and Calibration

The following sections provide a discussion about the model development and calibration of each of the temperature models.

4.2.1 Upper Temp Model

The interconnectedness of the Middle Yuba River, Oregon Creek, and North Yuba River made model development substantially more challenging than the Lower Temp Model, and instead of having only two inflows, as the Lower Temp Model did, the Upper Temp Model had three major confluences: where Oregon Creek flowed into the Middle Yuba River, where the Middle Yuba River combined with the North Yuba River, and where the New Colgate Powerhouse discharged into the Yuba River.

Flows in Lohman Ridge and Camptonville tunnels and the Colgate Penstock were defined as inputs to the Upper Temp Model; development of the water balance module of the Upper Temp Model was relatively straightforward, and focused on ensuring New Bullards Bar Reservoir releases from the spillway and the combined New Bullards Bar Dam Minimum Flow Powerhouse and low-level outlet matched the Water Balance/Operations Model. A monthly requirement for minimum flow was specified for the New Bullards Bar Dam Minimum Flow Powerhouse, so matching those releases to the Water Balance/Operations model was simple. Similarly, the monthly evaporation rate, flood reservation volumes, and maximum spillway release curves used in the Water Balance/Operations model were inputs to the water balance module, so New Bullards Bar Reservoir releases matched those from the Water Balance/Operations model. There were very minor differences during high flow events corresponding to differences in interpolation of the flood reservation volume, but these did not affect the computed water temperatures downstream or the New Bullards Bar Reservoir water temperature profile.

Two potential methods of simulating vertical reservoir temperature diffusion are available to HEC-5Q: the stability method, and the wind method. In the stability method, calibration involves modification physical parameters for the water column stability and vertical diffusion of temperatures. The stability method is appropriate for most deep, well stratified reservoirs. This method is based on the assumption that mixing will be at a minimum when the density gradient or water column stability is at a maximum. In the wind method, wind speed is the primary driver for vertical diffusion of temperatures, and calibration focuses on modifying the reservoir's response to the wind. This method assumes that wind-induced mixing is greater at the surface and diminishes exponentially with depth. For deep, strongly stratified reservoirs like New Bullards Bar Reservoir, the stability method was the preferred method for representing vertical diffusion of water temperatures, and was used to calibrate New Bullards Bar Reservoir.

HEC-5Q does not output reservoir profiles for every day of simulation, the user must specify which days are desired for output, and the profiles are written to a Microsoft Excel file, rather than HEC-DSS with the rest of the output. In the calibration mode, water temperature profiles were output for dates YCWA had measured New Bullards Bar Reservoir water temperature profiles. Evaluation of simulated profiles for the calibration period indicated the model required several months to "warm up" at the start of simulation to develop an accurate profile, but once it had warmed up, it accurately simulated water temperature profiles throughout the year. While Upper Temp Model profiles generally had the same shape as the historical profiles, and water temperatures at the surface of the reservoir were generally accurate, the model did an exceptional job of computing water temperatures at the New Colgate Powerhouse intake.

Initial calibration of the North Yuba River below New Bullards Bar Dam relied on a similar methodology as was used in other parts of the system: modification of the meteorological scaling factors. Using coefficients of a similar magnitude as in other reaches, however, resulted in consistently colder temperatures at the lower end of the reach than had been historically measured. A closer examination of the data indicated simulated releases were transiting the reach substantially faster than occurred in nature, and insufficient warming was being applied to the water. To increase the travel time for simulated releases, the roughness coefficient for the reach was increased by an order of magnitude (from 0.039 to 0.4) to represent the boulder-strew, constricted nature of the reach. By increasing the roughness coefficient, simulated temperatures reflected sufficient warming that meteorological scaling factors similar to those in other reaches were used, and a greatly improved calibration was achieved. Through the consultation process, Relicensing Participants indicated a desire to have the model accurately compute water temperatures resulting from flows greater than the minimum in the reach; during the Calibration Scenario period of record, no releases had been made from the New Bullards Bar Dam Minimum Flow Powerhouse or hollow-jet valve above the minimum required flow. However, several periods of increased flow occurred in 2008 and 2009, and were reflected in the Validation Scenario. The Validation Scenario was used to ensure the calibration parameters accurately reflected the effect of increased releases from the base of New Bullards Bar Dam on water temperatures at the downstream end of the North Yuba River. The North Yuba River calibration remained less accurate than that of other reaches for the Upper Temp Model, but it accurately represented effects of increasing releases from the base of the New Bullards Bar Dam and reasonably represented water temperatures during normal operations.

Calibration of the model for the Middle Yuba River and Oregon Creek focused on water temperatures near the confluence of the Middle Yuba River and the North Yuba River. Minimal intermediate water temperature monitoring data was available downstream from Our House and Log Cabin dams other than immediately below Our House and Log Cabin dams, and at the downstream end of the Middle Yuba River. Accordingly, no intermediate calibration was possible, and the two tributaries were essentially calibrated as a single unit. Accordingly, while the model outputs water temperature at multiple nodes along both the Middle Yuba River and Oregon Creek, it is not possible to confirm the accuracy of the simulated water temperatures at locations between the two diversion dams and the downstream end of the Middle Yuba River. However, the model did calibrate very well at the downstream end of the Middle Yuba River, so it is likely intermediate water temperatures were reasonably representative of actual water temperatures.

4.2.2 Englebright Temp Model

The Englebright Temp Model was developed independently from the Upper Temp and Lower Temp models. Grid development was completed using GIS and bathymetric survey data collected by the USGS (2003). Inflows to the Englebright Temp Model were the Yuba River below the New Colgate Powerhouse, the South Yuba River at Jones Bar, and local accretion. Outflows were defined for the Narrows 1 and Narrows 2 powerhouses and for the Englebright Dam spillway. Inflows and outflows were taken directly from the Water Balance/Operations Model. Minor differences in Englebright Temp Model storage occur relative to the Water Balance/Operations model. A water-balance utility was used to true up modeled reservoir storage by adjusting local accretions.

During calibration of the Englebright Temp Model, it was necessary to adjust the representation of the intakes relative to their physical location in the reservoir. It was necessary to split the Narrows 1 intake into two separate intakes to improve the representation of the intake hydraulics. The upper intake elevation was increased to 465.9 ft, from its actual elevation of 460 ft, and received 85% of the total flow to the Narrows 1 Powerhouse. The lower intake elevation was not adjusted from its actual elevation of 442.5 ft, and received 15 percent of the total flow to the Narrows 1 Powerhouse. The Narrows 2 intake elevation was increased to 479 ft, from its actual elevation of 448.38 ft, and inflow to the intake was limited to reservoir elevations of 439 ft and above, representing the shelf in the reservoir shoreline adjacent to the intake. All adjustments were made to minimize the difference between simulated and historically-measured water temperatures for profiles measured in the reservoir and in the Yuba River near Smartsville, downstream of the Narrows 1 and Narrows 2 powerhouse return flows. While the elevation of Narrows 2 Powerhouse Intake was adjusted to minimize error, its elevation is overestimated for low flows into the Narrows 2 Powerhouse and is underestimated for high flows. Current operation of the reservoir keeps the reservoir water-surface elevation relatively constant at approximately 519 ft. If future alternatives cause the water-surface elevation to fluctuate from this elevation, it is not known if the current model calibration would still be representative.

Calibration of the Englebright Temp Model was further refined through modification of wind sheltering coefficients, used to scale wind speed input data. The months of July through October were the primary focus of calibration, since this was the period of highest concern according to relicensing participants. Accordingly, calibration and validation results were better during the July through October months than for the full periods of record. At Smartsville, summer AME was 0.41°F. Summer ME was 0.12°F, indicating temperatures were slightly over calculated on average. These results meet calibration goals outlined in Section 2.3, indicating usability for future simulations.

4.2.3 Lower Temp Model

The Lower Temp Model was developed first, due to its relatively straightforward nature; there were no reservoirs, only a few inflows, plentiful channel geometry available, and an extensive network of monitoring locations covering the Yuba River between Englebright Dam and the Feather River.

The model was capable of running the full period of record for hydrology, representing inflows and diversions identically to the Water Balance/Operations model. The abundance of available channel geometry for the Yuba River below Englebright Dam allowed for a detailed representation.

The calibration version of the Lower Temp Model used historically-measured Smartsville flows and temperatures as the upstream boundary condition to ensure both the hydrologic and temperature inputs were as close to historical conditions as possible. Without modifying any of the calibration parameters, water temperatures at the Marysville gage reflecting the initial setup were fairly close to historical temperatures. The quality of the initial calibration simulation indicated that having high-quality input flows and temperatures and channel geometry were the primary drivers for a high-quality calibration.

The calibration of the Lower Temp Model was refined through modification of meteorological coefficients, specifically an equilibrium temperature offset, an equilibrium temperature scaling factor, and a heat exchange rate scaling factor. The river was broken into five reaches based on physical features: 1) between Englebright Dam and Deer Creek; 2) between Deer Creek and Dry Creek; 3) between Dry Creek and the Daguerre Point Dam; 4) between Daguerre Point Dam and the Marysville gage; and 5) between the Marysville gage and the Feather River. The three meteorological coefficients mentioned above were modified for each reach so that simulated water temperatures were as close as possible to historically-measured water temperatures within the reach. Above the Yuba Goldfields, little modification of the meteorological coefficients were needed, but below the Dry Creek confluence, calibration became more challenging, likely due to the interchange of flow between the Yuba River and the porous Yuba Goldfields.

A comparison of simulated and historical water temperatures at RM 11.64, as measured by the YCWA gage T200, shows the Lower Temp Model under-computes water temperatures in the fall of 2010, but was otherwise relatively accurate. Downstream, in the Daguerre Point Dam fish ladder at RM 11.56, the historical and simulated water temperatures were very close throughout the calibration period. While differences in water temperature were generally propagated downstream, the difference between the quality of the simulated water temperatures at RM 11.64 and RM 11.56 indicates there may be factors not accounted for within the model above Daguerre Point Dam. There is a lot of exchange of flow between the Yuba River and the Yuba Goldfields. It appears return flows from the Yuba Goldfields upstream from Daguerre Point Dam may be a contributor to the warming observed in the fall of 2010. There was a reduction in releases from

Englebright Dam at the end of August and beginning of September of 2010 corresponding with observed water temperature warming upstream from Daguerre Point Dam; it is possible the gage at RM 11.56 reflects a localized temperature effect from an increase in return flows from the Yuba Goldfields due to the drop in river level. The localized effect of the Yuba Goldfields is eliminated as the flow becomes fully mixed downstream.

Daguerre Point Dam was added as a longitudinally-segmented reservoir after a preliminary calibration and validation of the model had been completed in the Base Case Scenario development phase. It was discovered that, under extremely low flow conditions, such as those observed in 1977, a hydraulic instability formed below the agricultural diversion point. By adding Daguerre Point Dam as a reservoir, a form of hydraulic control was added, thus resolving the hydraulic instability in low-flow conditions. The addition of Daguerre Point Dam did not notably affect the calibration of the Lower Temp Model.

Below Daguerre Point Dam, the river geometry flattens out and becomes wider, allowing for increased heat exchange with the atmosphere and additional warming. Both historical and simulated water temperatures reflect greater variations from day to day. Simulated water temperatures at both the western edge of the Yuba Goldfields at RM 8.3, and at the Marysville gage at RM 6.2, were reasonably calibrated according to the quantitative approach discussed in Section 2.3. A visual inspection confirmed a generally good fit between the two time series. Similar to the observed under-calculation of water temperatures in September of 2010 seen at RM 11.6, simulated water temperatures at the Marysville gage in September of 2010 were cooler than the historical temperatures. This is likely due to localized effects since there is not a corresponding under-calculation of water temperatures during this period either upstream at RM 8.3 or downstream at RM 6.2.

Overall, the Lower Temp Model indicates a good calibration and usability for future simulation and analysis throughout the entire reach of the river for the range of flows observed in the Calibration Scenario period of record, but the calibration was best for the reach of the river above Dry Creek. It should be noted that the lowest observed flows at the Marysville gage during the Calibration Scenario period of record were 458 cfs on September 7, 2011; it was not possible to confirm the model calibration for flows lower than the observed flows.

4.3 Model Input Development

Physical input data for each of the three models was developed as part of the model development and is an intrinsic part of the model itself. The development of the meteorological and water temperature inputs was the primary focus of the Model Input Development task.

4.3.1 Input Water Temperatures

Input water temperatures were developed for each of the three simulation modes: 1) calibration; 2) validation; and 3) Base Case. While data were similar for each mode, they were not necessarily identical due to a desire for a consistent methodology throughout the simulation period of record for each mode.

Input temperatures for the Calibration Scenario came as much as possible from historical data. The model calibration periods of records varied slightly between models due to differences in available input data, but were generally the same between 2009 and 2012. For this period, there was generally plentiful input water temperature data for all three temperature models, there were rare instances at each location where several days were missing data; in those instances a linear interpolation between available dates was used to fill any data gaps.

The primary exception to calibration data availability was for Deer Creek water temperatures (T175). In this case, available data were repeated to complete the calibration period of record. The high-quality calibration of Yuba River water temperatures for the reach below Deer Creek indicated the Deer Creek input time series for water temperatures was adequate for calibration.

Input temperatures for the Validation and Base Case scenarios were based on repeating the same year of data for the full period of record. Input temperatures from water year 2010 to represent years with less-than-average annual runoff, and from water year 2011 for years with greater-than-average annual runoff. These two years (e.g. 2010 and 2011) were selected based on a review of available historically-recorded water temperature data, and the observation that historical temperature appeared to follow a hydrologically-related pattern. After validating the approach of using historical water temperatures from 2010 and 2011 throughout the period of record in the Validation Scenario, the identical approach was used to develop the input water temperatures for the Base Case Scenario.

The final developed water temperature input data cover the respective periods of record, and are usable for their intended purposes.

4.3.2 Input Meteorology Data

The greatest challenge for developing input data sets was the development of the meteorological data sets for each mode of each model. While there was an extensive quantity of meteorological data available within the Yuba River watershed, most monitoring stations have been installed within the last ten years and were not useful for long period-of-record simulations. Three meteorological monitoring stations were primarily used for the meteorological input data: 1) the NOAA Beale AFB station: 2) the Browns Valley CIMIS station; and 3) the New Bullards Bar Dam weather station.

Each meteorological station had a period of record that corresponded well to the model within its geographic region for the calibration mode; the Beale AFB station was used for the Lower Temp Model, the Browns Valley station was used for the Englebright model, and the New Bullards Bar Dam station was used for the Upper Temp Model. For the validation mode, the New Bullards Bar Dam station period of record was inadequate, but the other two gages were directly usable. Using a relationship developed by comparing the common period of record between the Browns Valley and New Bullards Bar Dam stations, a full validation period of record was developed for the Upper Temp Model. Neither the New Bullards Bar Dam nor Browns Valley stations' periods of record were adequate for the Base Case simulation; a comparison of the common period of record for the Browns Valley and Beale AFB stations was used to develop a Base Case period of record for the Englebright Model, and the relationship used to create a validation period of record for the Upper Temp Model was used with the Englebright Model Base Case period of record. Through this process, complete and consistent periods of records were developed for each location and for each modeling mode.

There were occasional data gaps for all three locations, and various methodologies were used to fill in gaps. For periods when the period of record overlapped for both locations, data from the Nicolaus CIMIS station was used to supplement missing data at the Beale AFB station. For large periods of missing data at the Beale AFB station, meteorological data from other similar years was used instead. Ultimately, with the exception of the calibration mode, where a precise replication of historical conditions was the goal, the intended use of the synthetic data sets was to provide a reasonable representation of the period of record so simulation of Project operations yielded representative results. An alternative Validation Scenario was developed using meteorology developed for the Base Case Scenario with the inflows and inflow temperatures used in the normal Validation Scenario, and simulated water temperatures from the two models were compared to each other to test the validity of the Base Case Scenario meteorology. Simulated water temperatures from the two data sets were extremely close, particularly for the Upper Temp Model; there were some minor differences in simulated Smartsville water temperatures from the Englebright Temp Model that were perpetuated through the Lower Temp Model (the Lower Temp Model used the same meteorological data for both scenarios).

4.4 Model Validation

The validation process was designed to ensure the models reasonably represent conditions outside of the calibration period, and that significant differences were explainable. The validation period of record for all models was January 1, 2000 through September 30, 2011. This period was chosen because it was long enough to include a wide range of hydrologic conditions and several sets of regulatory requirements for Project operations. It was extended beyond the period of record for the Base Case simulation to take advantage of recent data collection efforts. Since the Validation Scenario relied upon historical hydrology rather than with-project hydrology, there was no need to limit the validation period of record to the Base Case period of record.

4.4.1 Upper Temp Model

New Bullards Bar reservoir validated well. In many cases the profiles matched just as well as in the calibration. The inflow temperatures were synthetic, which indicates that the reservoir profile is dependent more on meteorology than inflow temperatures.

There was some historically-measured water temperature data from prior to the Calibration Scenario period of record on the North Yuba River corresponding to increased releases from the hollow-jet valve and Minimum Flow Powerhouse in 2008 and 2009. Simulated water temperatures during these increased-flow periods were closely examined, and model parameters were adjusted to improve the model's representation of water temperatures during these times. The resulting Validation Scenario indicated an improved calibration of the Upper Temp Model during increased flow events. Changes in North Yuba River calibration to represent increased flow events did not affect the calibration of the Upper Temp Model for water temperatures on the Yuba River below the confluence of the North Yuba and Middle Yuba rivers, nor water temperatures either upstream from or downstream from the New Colgate Powerhouse.

There was very limited availability of historical data for instream temperatures of the Upper Temp Model. For the river reaches, the most downstream node was used for validation – Yuba River above Dobbins Creek (T130). The historical data at this location begins March 28, 2009, but for the period the data can be compared the validation appears to be valid, with 0.38°F and 1.31°F for ME and AME respectively. The July through October ME and AME during this short validation period were 0.12°F and 1.25°F respectively. Fluctuations can be seen in the earlier part of the calibration, and were caused by Colgate Powerhouse flows near zero for some days.

4.4.2 Englebright Temp Model

The Englebright Temp Model validated reasonably well, although deviations between simulated and historical temperatures were noted during periods of high flow through the reservoir.

Validation Scenario results indicate that the Englebright Temp Model was relatively insensitive to input temperatures, except during periods of high flows, particularly during spills, when simulated outflow temperatures were more likely to disagree with historical temperatures. Input temperatures were entirely made of synthetic data for the Validation Scenario. During high flows, residence time in the reservoir is short and thus more sensitive to inflow temperatures. Periods of Spills occurred in spring of 2000, spring of 2005, winter and spring of 2006, and winter and spring of 2011. Spill does not generally occur during the July through October period that relicensing participants have identified as a period of biological concern.

Overall, the Englebright Temp Model validated very well. July-October AME and ME at Smartsville were 0.87°F and 0.40°F, respectively. Similar to calibration results, simulated water temperatures were slightly warmer than historical water temperatures, but on average were less than half a degree different, a statistical goal outlined in section 2.3, above.

4.4.3 Lower Temp Model

The Lower Temp Model also validated reasonably well, but there were some divergences from historical temperatures that required additional review. Similar to the Upper Temp Model, the Lower Temp Model input data consisted of the following:

- Historical flows at the Smartsville gage
- Modeled inflow temperatures from the Englebright Temp Model at the Smartsville gage
- Historical inflows from Deer Creek
- Historical diversions at Daguerre Point Dam
- Historical meteorology from the Beale Point AFB station

- Synthetic inflows from Dry Creek
- Synthetic inflow temperatures for Deer Creek and Dry Creek

A review of the validation model output indicates inconsistency compared to the historical gages; there appears to be a large over-calculation of water temperature at Parks Bar in the fall of 2003, but this same effect was not manifested at the Marysville gage. This difference in calibration quality suggests the potential for poor data quality at the Parks Bar gage during this time period. It is worth noting that there were flood events in May of 2005 and January of 2006 that likely resulted in substantial changes to the river geometry from the geometry used in model calibration. It is likely these large changes in river geometry are most reflected during relatively low-flow periods, and were the best explanation of large divergences in the simulated time series from the historical temperatures observed in winter 2002, and spring 2003. A comparison of the simulated values with the calibration model output indicates the same quality of predicted water temperatures at the Marysville gage relative to the predicted temperatures in the calibration phase for the period of January 1, 2009 through December 31, 2011. The sole difference between the two runs, outside of the period of record simulated, was the input temperatures at Deer and Dry creeks, indicating the switch from historical to synthetic inflow temperatures at these two locations does not substantially affect the calibration during this period.

Overall, the Lower Temp Model validation shows that the model is usable and representative of current river geometry. With this understanding, the model calibration remains valid for an extended period, and for a wide range of flow and meteorological conditions. It should be noted that the lowest observed flow at the Marysville gage during the Validation Scenario period of record was 234 cfs, occurring on June 30, 2001; it was not possible to validate the model calibration for flows lower than the observed flows.

4.5 Base Case Development

The Base Case represents Project conditions under the “No-Action Alternative.” The Base Case period of record for all models was October 1, 1969 through September 30, 2010. As with the Validation Scenario, output from upstream models were used as input to downstream models. Base Case hydrologic inputs were taken from the Base Case version of the Water Balance/Operations Model, as described in Technical Memorandum 2-2, Attachment 2-2C. Boundary condition water temperature inputs are described in Section 3.3.3, above, and in Attachment 2-6C.

4.6 Prepare Model and Model Development and Validation Reports

Water temperature models, input files, and output files can be found in Attachment 2-2B. Calibration, Validation and Base Case scenarios are all included.

Model Development and Validation reports were completed as one document. The Model Development and Validation Report is located in Attachment 2-2C.

5.0 Study-Specific Consultation

The FERC-approved study plan included three study-specific collaborations, each of which is addressed below.

5.1 Modeling Platform Selection

The FERC-approved study stated:

> YCWA will work with Relicensing Participants during the following stages of model development: 1) model selection criteria definition; 2) potential model platform list; 3) potential model scoring against criteria; and 4) ultimate model platform selection (Step 1).

YCWA met with Relicensing Participants on several occasions to discuss model requirements and selection. Table 5.1-1 shows the history of consultation on these topics.

Table 5.1-1. Meetings with Relicensing Participants to discuss model platform selection.

Date	Discussion Topic
1/20/2011	Model selection criteria definition, potential modeling platforms, potential model platform scoring against criteria
3/15/2011	Potential model platforms
4/28/2011	Methodologies used to compute maximum-daily water temperatures, final platform selection.

5.2 Working Meetings to Discuss Calibration and Validation

The FERC-approved study stated:

> YCWA will meet with interested Relicensing Participants (a technical work team) to review calibration of the model moving into model reporting and validation. This will include a meeting to generally introduce the Relicensing Participants to the model and provide Relicensing Participants with the model on CD. YCWA will hold a series of workshops with interested Relicensing Participants to collaboratively review the model and make modifications, as appropriate (Step 2).

YCWA met with Relicensing Participants on five occasions to discuss model calibration and validation. Table 5.2-1 shows the dates and topics of meetings held to date.

Table 5.2-1. Meetings with Relicensing Participants to discuss model calibration and validation.

Meeting Date	Discussion Topic
10/23/2012	Model development status to date. Lower Temp Model calibration, New Bullards Bar Reservoir water temperature model calibration.
11/28/2012	Model development status to date. Lower Temp Model calibration and validation. New Bullards Bar Reservoir water temperature model calibration. Englebright Temp Model calibration
12/11/2012	Model development status to date. Upper Temp Model, Englebright Temp Model, and Lower Temp Model calibration.

Table 5.2-1. (continued)

Meeting Date	Discussion Topic
1/13/2013	Model development status to date. Full validation run.
2/19/2013	Model development status to date. Updated Full validation run. Full Base Case Run.
2/26/2013	Presented results from action items from previous meeting, including meteorological validation, North Yuba calibration, and Daguerre Point Dam hydraulics.
3/13/2013	Model development status to date. Full Base Case Run.

At the February 19, 2013 meeting, Relicensing Participants requested that YCWA perform a simulation using the Base Case Scenario meteorological data instead of the Validation Scenario data, but otherwise using inputs identical to the Validation Scenario inputs, and compare its output to that from the Validation Scenario. The intent of this simulation was to demonstrate the validity of the Base Case Scenario meteorology. YCWA performed the simulation and presented the output to the Relicensing Participants at the February 26, 2013 meeting, and Relicensing Participants were satisfied with the comparison.

At the March 13, 2013 meeting, Relicensing Participants agreed the water temperature models represented operations of the Project and were usable for future evaluations of effects of Project operations on water temperatures, given the existing physical configuration of the Project.[14]

5.3 Working Meetings to Discuss Changes to Model Development and Validation Reports

The FERC-approved study stated:

> YCWA will meet with interested Relicensing Participants to review the model results and discuss any suggested changes to the Model Development Report and the Model Validation Report (Step 4).

YCWA met with Relicensing Participants on 2 occasions to discuss changes to Model Development and Validation Reports. Table 5.3-1 shows the dates and topics of meetings held to date.

Table 5.3-1. Meetings with Relicensing Participants to discuss changes to Model Development and Validation Reports.

Meeting Date	Discussion Topic
2/26/2013	Model development status to date. Updated Full validation run, Model Development and Validation Report
3/13/2013	Model development status to date. Updated Full validation run, full Base Case Run. Model Development and Validation Report

[14] The Relicensing Participants requested that YCWA release test flows in 2013 on the North Yuba River below New Bullards Bar Dam to observe water temperature responses for flows ranging from 20 to 50 cfs. Test flows are not required by the FERC-approved Study 2.6, *Water Temperature Model*. However, YCWA is open to discussing with Relicensing Participants the benefits and costs of performing the test flows, and how the resulting data would be used in relicensing.

6.0 Variances from FERC-Approved Study

The study was performed in conformance with the FERC-approved Study 2.6, *Water Temperature Model*, with two variances. First, a matrix comparing various model platforms and using an explicit scoring approach to select the model platforms was not used. Instead, YCWA and the Relicensing Participants discussed potential platforms in meetings and agreed on the platform after considering a range of alternatives.

Second, the model and documentation were scheduled to have been completed in September 2012, but due to delays in receiving channel geometry information and in challenges associated with resolving the Englebright Reservoir water temperature model water balance, the study completion was delayed.

7.0 Attachments to This Technical Memorandum

Attachment 2-6A Part 1	HEC5 Users Manual [1 Adobe PDF file: 1.5 MB; 370 pages formatted to print double-sided on 8 ½ x 11 paper]
Attachment 2-6A Part 2	HEC5Q Users Manual [1 Adobe PDF file: 784 kB; 180 pages formatted to print double sided on 8 ½ x 11 paper]
Attachment 2-6A Part 3	HEC5Q Exhibit 3: Description of Program Input [1 Adobe PDF file: 415 kB; 94 pages formatted to print double sided on 8 ½ x 11 paper]
Attachment 2-6A Part 4	CE-QUAL-W2 Users Manual [1 Adobe PDF file: 11.9 MB; 779 pages formatted to print double sided on 8 ½ x 11 paper]
Attachment 2-6B	Water Temperature Models and Input Files for the Calibration mode for the New Bullards Bar Reservoir portion of the Upper Temp Model, and Calibration and Validation Modes for the Lower Temp Model [1 DVD containing 13 folders and 195 associated modeling files: 764 MB.]
Attachment 2-6C	Model Development and Validation Report [1 Adobe PDF file: 11 MB; 142 pages formatted to print double-sided on 8 ½ x 11 paper.]

8.0 References

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