Technical Memorandum 2-6

Water Temperature Models

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

Yuba River Development Project

FERC Project No. 2246

October 2013

Attachment 2-6B of Technical Memorandum 2-6 – Water Temperature Models consists of one DVD with 13 file folders containing 195 associated modeling files for YCWA's Yuba River Development Project. Due to the DSS file types, the files on the DVD cannot be uploaded to FERC's e-Library system. YCWA will file a copy of the DVD with FERC.

A copy of the DVD can be obtained by contacting:

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Technical Memorandum 2-6

Water Temperature Model

Attachment 2-6C

Model Development and Validation Report

Yuba River Development Project

FERC Project No. 2246

October 2013

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1.0 Introduction

This report describes the development of Water Temperature Models developed for Yuba County Water Agency's (YCWA) Yuba River Development Project, Federal Energy Regulatory Commission (FERC) Project No. 2246 (Project), Relicensing.

1.1 History of the Yuba River Development Project

YCWA, located in Marysville, California, is a public agency formed in 1959 pursuant to the Yuba County Water Agency Act (West's Water Code App. §§ 84-1 to 84-28). Section 4.1 of this Act (West's Water Code App. § 84-4.1) authorizes YCWA to develop and sell hydroelectric power. Section 5.1 of this Act (West's Water Code App. § 84-5.1) authorizes YCWA to enter into contracts with its member units for various purposes, including the sale of water. Sections 4.3, 4.4 and 4.5 of this Act (West's Water Code App. §§ 84-4.3, 84-4.4 & 84-4.5) authorize YCWA to develop and operate water resource projects.

Besides numerous water delivery conduits, YCWA owns and operates the Project, which is located in Yuba County, California, on the Yuba River and its tributaries including the North and Middle Yuba River and Oregon Creek. A portion of the area within the FERC Project Boundary is located on federally-owned land managed by the United States Department of Agriculture, Forest Service (Forest Service) as part of Plumas and Tahoe national forests.

Project construction started in late 1966 and continued to early 1970 when the New Colgate Powerhouse began producing electricity. At about this time, the Narrows 2 Powerhouse also went on-line and began producing electricity. By the summer of 1970 the Project was operational, YCWA had taken ownership of the Project and it was producing electricity and regulating the flows of the Yuba River.

YCWA holds the initial FERC License for the Project, which was issued to YCWA by the Federal Power Commission (FPC), FERC's predecessor, on May 16, 1963 (FPC 1963). The initial License was effective on May 1, 1963 for a term ending April 30, 2016 (FPC 1966). The Project consists of three developments – New Colgate, New Bullards Bar Minimum Flow, and Narrows No. 2 – which, in total, include: 1 main dam; 2 diversion dams; 4 water tunnels; 3 powerhouses with associated switchyards with a combined capacity of 361.85 megawatts (MW); and appurtenant facilities and structures. Figure 1.2-1 shows the location of the Project facilities.

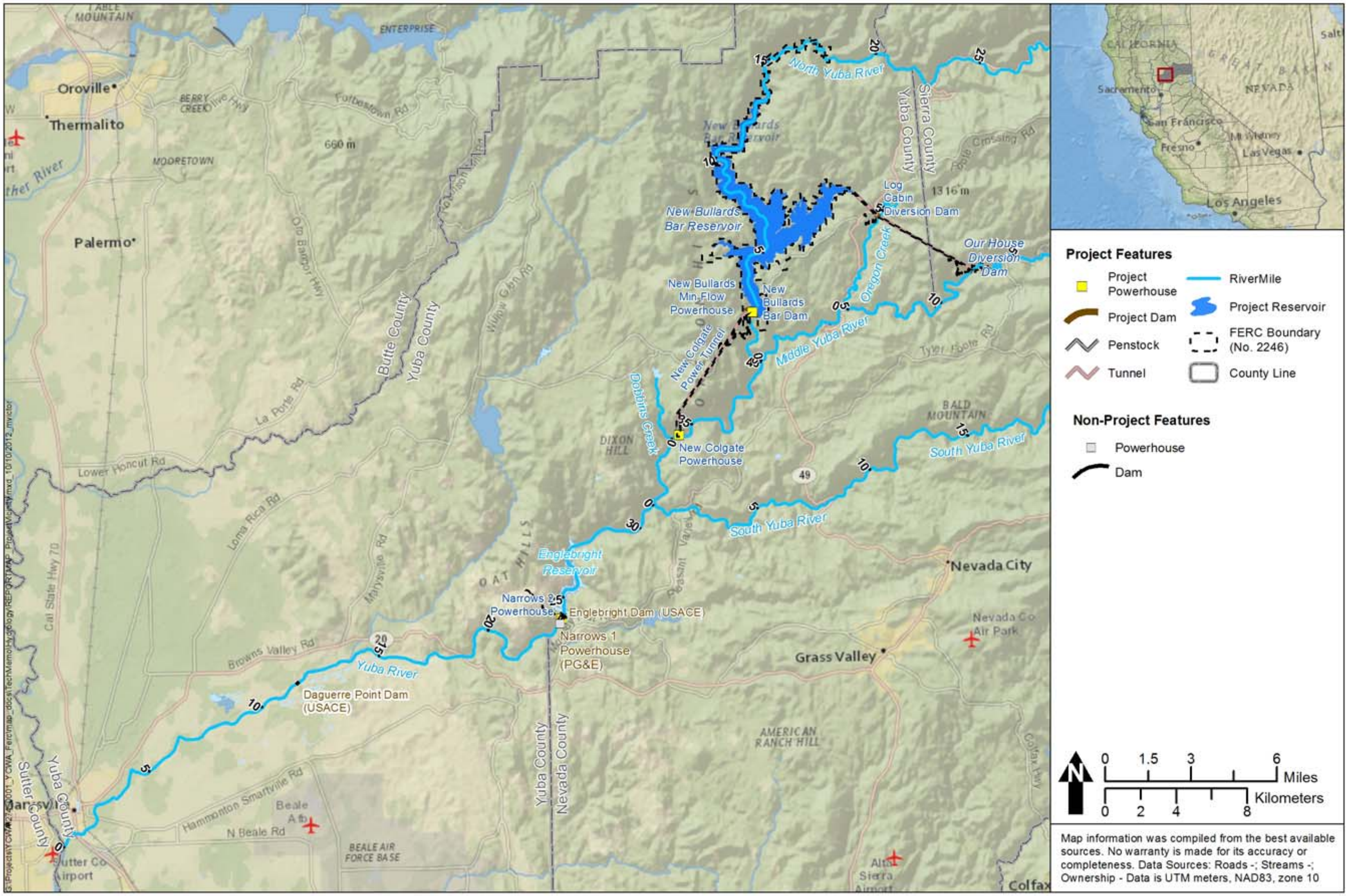

Figure 1.2-1. Yuba River Development Project Facilities Location.

1.2 Need for a Model

A temperature model was needed to simulate the current and potential future water temperature conditions. A primary objective of the study was to develop a water temperature model that all interested Relicensing Participants agree is reasonably reliable for the purposes of Relicensing, and also agree to use this single water temperature model to make Relicensing recommendations. The model accomplished the following:

- Simulated reservoir and stream water temperatures resulting from Project O&M;
- Included 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 reproduced observed reservoir and stream water temperatures, within acceptable calibration standards over a range of hydrologic conditions;
- Was sensitive to both flow and meteorological conditions.

Development of protection, mitigation, and enhancement measures is not part of this study.

1.3 Previous Modeling Efforts

Previous modeling efforts have resulted in several different modeling approaches, as described below:

- In 1991, a water temperature model, the Yuba River Temperature Model (YRTM) (Bookman-Edmonston 1992), was developed by YCWA in response to California Department of Fish and Game (CDFG) proposed flow requirements on the Yuba River below Englebright Dam. This model consisted of the following:
  - A CE-QUAL-R1 1-dimensional model of New Bullards Bar Reservoir.
  - A series of linear regressions to simulate water temperatures in the New Colgate Penstock as a function of water temperature from New Bullards Bar Reservoir, flow through the penstock, and Marysville air temperature.
  - A series of linear regressions to simulate water temperatures in Englebright Reservoir as functions of New Colgate Penstock temperatures; flows through the New Colgate penstock; and Marysville air temperatures.
  - A HEC-5Q 1-dimensional model of the Yuba River below Englebright Dam.

This model operated on a daily basis, and was calibrated for water years 1974, 1976, and 1977, and a portion of June 1991. The model was verified by simulating water temperatures in 1975 and 1978.

While the regression coefficients for the New Colgate Penstock and Englebright Reservoir components and the HEC-5Q model for the lower Yuba River are available, the CE-QUAL-R1 model of New Bullards Bar Reservoir is not available.

- In 2001, a water temperature model of the Yuba River below Englebright Dam was developed by YCWA to support testimony before the California State Water Resources Control Board (SWRCB) (YCWA 2001). This water temperature model consisted of three linear regressions for the following:
  - Narrows 2 Powerhouse temperatures as a function of New Colgate Powerhouse release temperature and Marysville air temperature.
  - Yuba River flow temperature at the Marysville gage as a function of Narrows 2 Powerhouse release temperature, Yuba River flow at Marysville, and Marysville air temperature.
  - Yuba River flow temperature at Daguerre Point Dam as a function of Marysville flow temperature, Yuba River flow at Marysville, and Marysville air temperature.

The model relied on historical average monthly release temperatures from New Colgate Powerhouse rather than simulating New Bullards Bar Reservoir water temperatures. The model operated on a monthly basis, and the regressions were computed based on historical water temperatures from 1989 through 2001.

- In 2006, an expanded regression-based water temperature model was developed by YCWA to support the Yuba River Accord Environmental Impact Report/Environmental Impact Statement (EIR/EIS) (YCWA 2007). This water temperature model included regressions for the following:
  - New Colgate Powerhouse release temperature as a function of month and New Bullards Bar Reservoir storage.
  - Narrows 2 Powerhouse release temperature as a function of New Colgate Powerhouse release temperature, inflow to Englebright Reservoir, and Marysville air temperature.
  - Yuba River at Daguerre Point Dam water temperature as a function of Narrows 2 Powerhouse release temperature, Yuba River flow at Smartsville, and Marysville air temperature.
  - Yuba River at Marysville water temperature as a function of Narrows 2 Powerhouse release temperature, Yuba River flow at Smartsville, Yuba River flow at Marysville, and Marysville air temperature.

Regressions were developed using historical data from 2000 through 2006, and were validated against historical data from 1990 through 2000. The model operated on a monthly time step.

None of these models, as currently developed, adequately addresses the range of operations and geography required as part of Relicensing. Therefore, a new water temperature model is needed for Relicensing.

2.0 Yuba River Watershed

The Yuba River watershed drains approximately 1,339 square miles (sq-mi) (United States Geologic Survey [USGS] 2005) of the western slope of the Sierra Nevada, including portions of Sierra, Placer, Yuba, and Nevada counties, as shown in Figure 1.2-1. The Yuba River is a tributary of the Feather River, which in turn is a tributary of the Sacramento River. The watershed rises from an elevation of about 60 feet (ft) to about 8,590 ft above mean sea level (ft-msl). The annual unimpaired flow below Englebright Dam, as measured by the USGS at the Smartsville Gage (USGS gage 11418000) on the Yuba River has ranged from a high of 4.93 million acre-feet (MAF) in 1982 to a low of 0.37 MAF in 1977, with an average of about 2.36 MAF per year (1901 to 2010).[1] In general, runoff is nearly equally divided between runoff from rainfall during October through March and runoff from snowmelt during April through September. For a detailed description of the watershed, see *Technical Memorandum 2-2, Water Balance/Operations Model, Attachment 2-2D.*

Extensive historical gage data are available for the majority of the Yuba River tributaries. For tributaries and sub-basins without available historical gage data, tributary and sub-basin flows have been synthesized. Figure 2.0-1 shows the hydrologic schematic for the Project, identifying which of the Project inflows are derived from gage data, and which are synthesized data. For a complete description of Project hydrology, see *Technical Memorandum 2-2, Water Balance/Operations Model, Attachment 2-2D.*

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[1] The forecasted seasonal unimpaired flow at Smartsville is estimated each year by DWR and reported monthly in Bulletin 120, *Water Conditions in California*. The unimpaired flow at Smartsville is used in YCWA contracts for water delivery to senior water right holders on the lower Yuba River, and is used in the calculation of the Yuba River Index, a hydrologic water year type index for the Yuba River, defined in State Water Resources Control Board Revised Decision 1644.

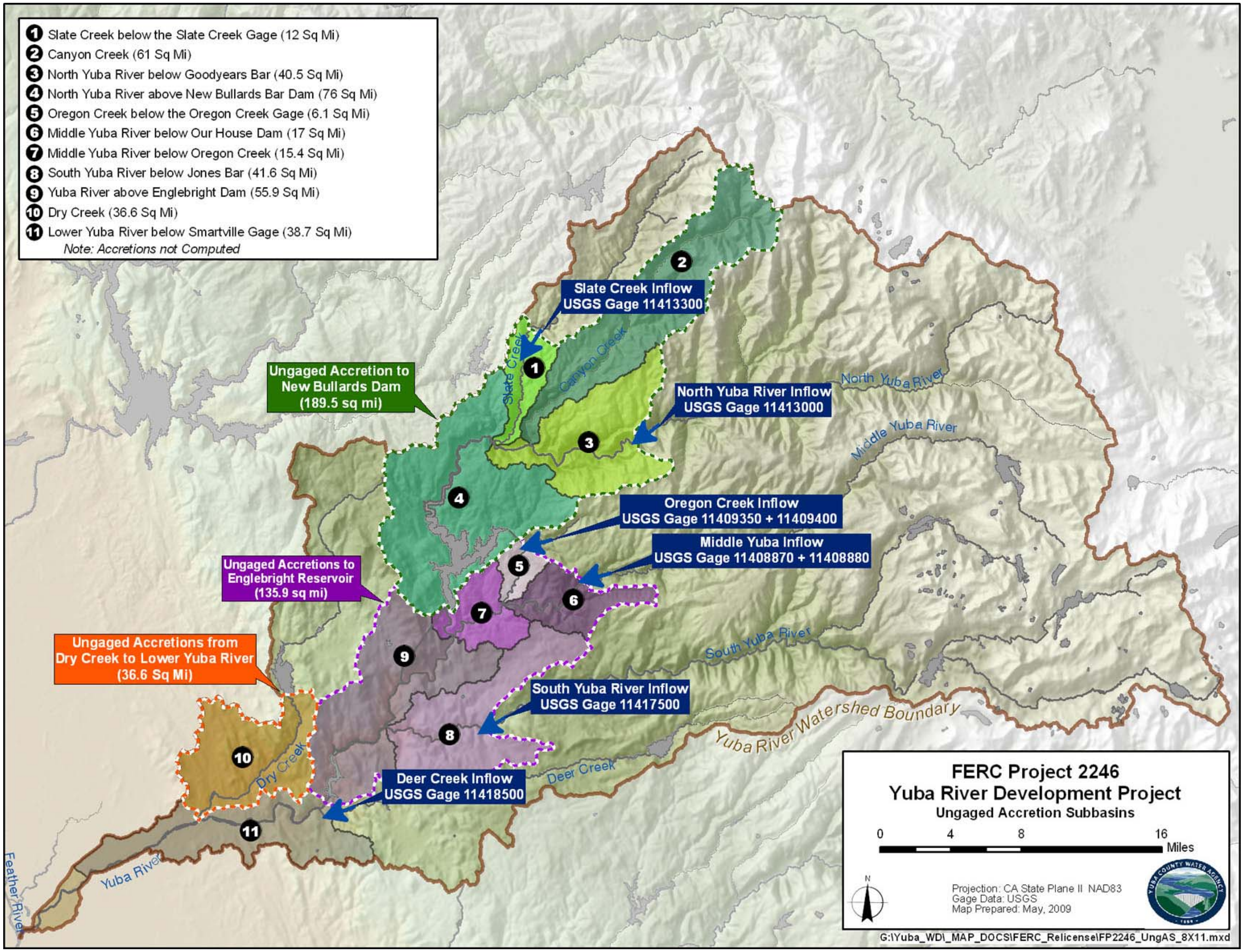

Figure 2.0-1. Sources of Project hydrology.

3.0 Yuba River Development Project Facilities

The Project, constructed in the mid-1960s and put into service in the spring of 1970, ranges in elevation from about 300 ft-msl to 2,050 ft-msl. In total, the Project includes: one dam and associated storage reservoir - New Bullards Bar; two diversion dams - Our House and Log Cabin; two diversion tunnels - Lohman Ridge and Camptonville; two power tunnels - New Colgate and Narrows 2; one penstock – New Colgate; and three powerhouses - New Colgate, New Bullards Bar Minimum-Flow Powerhouse, and Narrows 2.

The Project does not include USACE's Englebright Dam and Reservoir or USACE's Daguerre Point Dam. The Project also does not include the Narrows 1 Powerhouse, which is located near the USACE's Englebright Dam and is part of PG&E's Narrows 1 Project (FERC Project No. 1403).[2] However, since these facilities are integral parts of operations of the Project, these facilities are included in hydrologic and water temperature models.

3.1 New Bullards Bar Dam and Reservoir

New Bullards Bar Dam is a 1,110-ft radius, double curvature, concrete arch dam located on the North Yuba River about 2.4 mi upstream of its confluence with the Middle Yuba River. The dam is 645 ft high with a maximum elevation of 1,965 ft-msl. The dam includes one low-level outlet - a 72 inch Hollow Jet Valve, with an invert elevation of 1,395 ft-msl, has a maximum design capacity of about 3,500 cfs at full reservoir pool, and an actual capacity of 1,250 cfs (the release capacity is limited to 1,250 cfs due to valve vibrations at greater release rates).

New Bullards Bar Reservoir is the principal storage facility of the Project. The North Yuba River inflow to New Bullards Bar Reservoir is augmented by diversions from the Middle Yuba River to Oregon Creek through the Lohman Ridge Tunnel, and by diversions from Oregon Creek into New Bullards Bar Reservoir through the Camptonville Tunnel. The average total inflow to New Bullards Bar Reservoir from the North Yuba River and diversions from the Middle Yuba River and Oregon Creek is about 1.2 MAF per year.

New Bullards Bar Reservoir is deep, thermally-stratified, and has a retention time of about 6 months. The reservoir is psi-shaped ("ψ"). The narrow center arm, which is the longest of the three arms (*i.e.,* about 13 mi), extends up the North Yuba River to just downstream of the Slate Creek confluence. The slightly wider northeast arm extends upstream about 4 mi, and is formed primarily by Willow and Badger creeks. The northwest arm, the shortest of the three (about 1 mi long) is formed by Little Oregon and Burnt Bridge creeks. The portion of reservoir north of New Bullards Bar Dam near Garden Point is the widest portion of the reservoir (about 2 mi wide). Most of the land surrounding New Bullards Bar Reservoir is primitive with no roads or residential communities.

The reservoir has a gross storage capacity of 966,103 ac-ft with a FERC minimum operating storage of 234,000 ac-ft, leaving 732,103 ac-ft of regulated capacity. YCWA typically operates

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[2] The FERC License for PG&E Narrows 1 Project expires on January 31, 2023 (FERC 1993).

New Bullards Bar Reservoir by capturing winter and spring runoff from rain and snowmelt for release later in the year. Consequently, New Bullards Bar Reservoir reaches its peak storage at the end of the spring runoff season, and then is gradually drawn down as storage is released to the Yuba River. Releases are made through both the New Bullards Bar Minimum-Flow Powerhouse at the base of the dam and to the Yuba River through the New Colgate Power Tunnel and New Colgate Powerhouse on the Yuba River. There are two intakes to the New Colgate Powerhouse intake; the upper intake has a centerline elevation of 1,808 ft-msl, and the lower intake has a centerline elevation of 1,627.5 ft-msl. Since 1993, all releases from New Bullards Bar Reservoir to the New Colgate Powerhouse have been made from the lower intake according to an agreement with CDFG to provide cold water temperatures to the Yuba River below the New Colgate Powerhouse. The reservoir usually reaches its lowest elevation in early to mid-winter. The annual drawdown in normal water years is about 90 ft. The reservoir does not undergo significant daily changes in elevation.

New Bullards Bar Reservoir is used to provide irrigation water supply to about 90,000 ac of farmland in western Yuba County. Releases of water from storage are made through the spring and summer to provide flows diverted at USACE's Daguerre Point Dam at RM 11.6 on the Yuba River. Water is released from storage in the fall for diversion at USACE's Daguerre Point Dam for rice stubble decomposition and waterfowl habitat.

New Bullards Bar Reservoir is also the main flood control facility for the Yuba River area. 170,000 ac-ft of storage capacity, or approximately 23 percent of the usable capacity of the reservoir, is reserved from October through May for flood protection purposes.

In addition to providing flood protection, power, and downstream water supply, YCWA pumps water directly from New Bullards Bar Reservoir to supply water to the Cottage Creek Water Treatment Plant for domestic and recreation uses adjacent to the reservoir. Pumping averages approximately 6 ac-ft per year. This relatively small volume of pumping does not affect Project operations.

New Bullards Bar Dam is the fourth dam constructed in the Bullards Bar area. The first dam was a timber crib, rock-filled diversion dam constructed in 1899, and was washed out a year later. In 1900, a 30-ft-tall masonry rock dam was built to replace the washed-out dam. The rock dam is still in place and is located about 1,000 ft downstream of New Bullards Bar Dam. YCWA maintains this dam as a weir for measurement of minimum flow releases from New Bullards Bar Dam. The third dam was a 200-ft-tall concrete-arch dam constructed in 1922 by the Yuba River Power Company, which was acquired by PG&E, and put into operation in 1924. That dam, located about one mile upstream of New Bullards Bar Dam in New Bullards Bar Reservoir, was inundated in 1969 when New Bullards Bar Dam began operation and is not normally exposed.

3.2 New Colgate Powerhouse

The New Colgate Powerhouse is an above-ground, steel-reinforced, concrete powerhouse located adjacent to the Yuba River at RM 34.2. The powerhouse contains two Voith Siemens Pelton-type turbines with a total capacity of 340 MW under a design head of 1,306 ft and a rated flow of

3,430 cfs. The powerhouse receives water from the New Colgate Power Tunnel and Penstock. The New Colgate Power Tunnel and Penstock is 5.2 mi long and composed of four different types of conveyance structures: an unlined horseshoe tunnel 26 ft square; a lined horseshoe tunnel 20 ft wide and 14.5 ft high; a lined circular tunnel 14 ft in diameter; and 2,809 ft of steel penstock with a diameter ranging from 9.0 ft to 14.5 ft. The tunnel and penstock have a maximum capacity of 3,500 cfs.

3.3 Our House Diversion Dam

Our House Diversion Dam is a 130-foot-radius, double curvature, concrete arch dam located on the Middle Yuba River approximately 12.6 mi upstream of its confluence with the North Yuba River. The dam is 70 ft high with a crest length of 368 ft, a crest elevation of 2,049 ft-msl, and a drainage area of 144.8 sq-mi. The dam has an impoundment capacity of 280 ac-ft, but storage and water levels do not fluctuate under Project operations. The diversion dam has two outlets: 1) a 5-foot diameter steel pipe controlled by a slide gate on the upstream face of the dam with a maximum capacity of 800 cfs and a centerline elevation of 1,990 ft; and 2) a 24-inch diameter release pipe, with a maximum capacity of 60 cfs and a centerline elevation of 2,000 ft-msl. The diversion dam has a spillway capacity of 60,000 cfs.

3.4 Lohman Ridge Tunnel

The Lohman Ridge Diversion Tunnel is 12.5-ft high by 12.5-ft wide, and conveys a maximum flow of 860 cfs through its 19,410-ft length (90% unlined and 10% lined) to Oregon Creek.

3.5 Log Cabin Diversion Dam

Log Cabin Diversion Dam is a 105-ft radius, concrete arch dam on Oregon Creek that has a drainage area of 29.1 sq-mi and a maximum spillway capacity of 12,000 cfs. The dam has an impoundment capacity of 90 ac-ft, but storage and water levels do not fluctuate under Project operations. The diversion dam has two outlets: 1) a 5-ft diameter steel pipe controlled by a slide gate on the upstream face of the dam with a maximum capacity is 800 cfs; and 2) an 18-inch diameter release pipe, with a maximum capacity of 13 cfs, located above the low-level outlet and controlled by a downstream gate valve operated by hand.

3.6 Camptonville Tunnel

The Camptonville Diversion Tunnel is 6,107 ft long and has the capacity to convey 1,100 cfs of water to New Bullards Bar Reservoir. The first 4,275 ft of the conduit is an unlined, horseshoe tunnel 14.5-ft wide by 14.5-ft high, becoming a lined, horseshoe tunnel 11.7-ft wide by 13-ft high for the remaining 1,832 ft.

3.7 Englebright Dam and Reservoir

Englebright Dam and Reservoir were constructed in 1941 by the USACE to capture sediment produced by upstream hydraulic mining activities. The reservoir is situated downstream from the New Colgate Powerhouse. The average annual inflow to Englebright Reservoir, excluding releases from New Bullards Bar Reservoir, is approximately 400 thousand acre-feet (TAF). Englebright Reservoir has a total storage capacity of approximately 70 TAF, but provides limited conservation storage because the reservoir is used to attenuate- power -peaking releases from New Colgate Powerhouse. Englebright Reservoir is used extensively for recreation.

Englebright Dam has no low-level outlet. Water from Englebright Reservoir is released for power generation at the Narrows 1 and Narrows 2 powerhouses, or spilled over the top of the dam.

3.8 Narrows 1 and 2 Powerhouses

Narrows 1 Powerhouse, owned by PG&E, is a 12 MW facility, with a discharge capacity of approximately 730 cfs and a bypass flow capacity (when the generator is not operating) of 540 cfs. Narrows 2, which is part of the Project, is a 50 MW facility, with a discharge capacity of approximately 3,400 cfs and a bypass flow capacity of 3,000 cfs. YCWA and PG&E coordinate the operations of Narrows 1 and 2 for hydropower efficiency and to maintain relatively constant flows in the Yuba River below Englebright Dam.

3.9 Daguerre Point Dam

USACE’s Daguerre Point Dam, a weir-type dam, was constructed by the California Debris Commission to prevent hydraulic mining debris from the Yuba River watershed from flowing into the Feather and Sacramento rivers. The dam, which was constructed in 1906 and rebuilt in 1964 following damage from floods, has no appreciable storage capacity. Daguerre Point Dam is used by YCWA to provide for gravity diversion of agricultural water supply to its Member Units. Releases to the Yuba River below the dam are made either through a fish ladder at each end of the dam or over the dam’s crest.

4.0 Model Overview

The following section provides a discussion of the selection of the modeling platforms, the simulation timestep, and an overview of each of the three models.

4.1 Platform Selection

To select the water temperature model or models 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, or 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 spills, on water temperatures in the Yuba River.
- Simulate the effect of Narrows 1 and Narrows 2 powerhouses operations on water temperatures in the Yuba River.
- Simulate the effects on temperature due to of irrigation diversions to YCWA agricultural water users from diversion locations near USACE's Daguerre Point Dam.
- 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:[3]

- River Water Temperature Model Platforms:
    - United States Geological Survey's (USGS) Stream Network Temperature Model (SNTEMP)
    - USGS' Stream Segment Temperature Model (SSTEMP)
    - USGS' 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

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[3] 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.

- 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.

4.1.1 Potential River Water Temperature Model Platforms

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

4.1.1.1 SNTEMP

SNTEMP is a mechanistic, one-dimensional heat transport model for branched stream networks that predicts the 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 water temperatures.
- Uses a regression model to fill in missing data.
- Geometry input is simplistic.
- Includes the affects of shading of vegetation and topography.

SNTEMP does meet a majority of the selection criteria; however, SNTEMP has limitations that ranks 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.

4.1.1.2 SSTEMP

SSTEMP, developed by USGS, is a scaled down version of the USGS model SNTEMP. SSTEMP utilize 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 the daily maximum, minimum, and mean temperatures at a specified location.
- Handles a special case of dam with steady-state release at the upstream end of the system.
- Used satisfactorily for 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, 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).

4.1.1.3 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.

4.1.1.4 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.

4.1.2 Potential Reservoir Water Temperature Models

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

4.1.2.1 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 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.

4.1.2.2 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.
- Wind direction is a required input data parameter; there is generally little historical information available for wind direction.
- Does not use Hydrologic Engineering Center (HEC) Data Storage System (DSS) for data exchange.

4.1.3 Potential River and Reservoir Water Temperature Models

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

4.1.3.1 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 (Bookman-Edmonston 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 DSS for easy data exchange between models.
- Uses an equilibrium temperature as an input to simplify meteorological conditions; it can be computed in external processor (i.e., HEATX).
- 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 and 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.

4.1.3.2 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, probabalistic, or optimization runs.
- Provides statistical summaries of both input and outputs.
- Calculates mean and maximum water temperatures.
- Outputs include flows 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 platform is tedious and requires export at each individual location.

4.1.3.3 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 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.

4.1.4 Selection of Model Platforms

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

4.1.4.1 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 are 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, including the model documentation, can be found in Attachment 2-6A.

4.1.4.2 Englebright Reservoir (i.e., Englebright Temp Model).

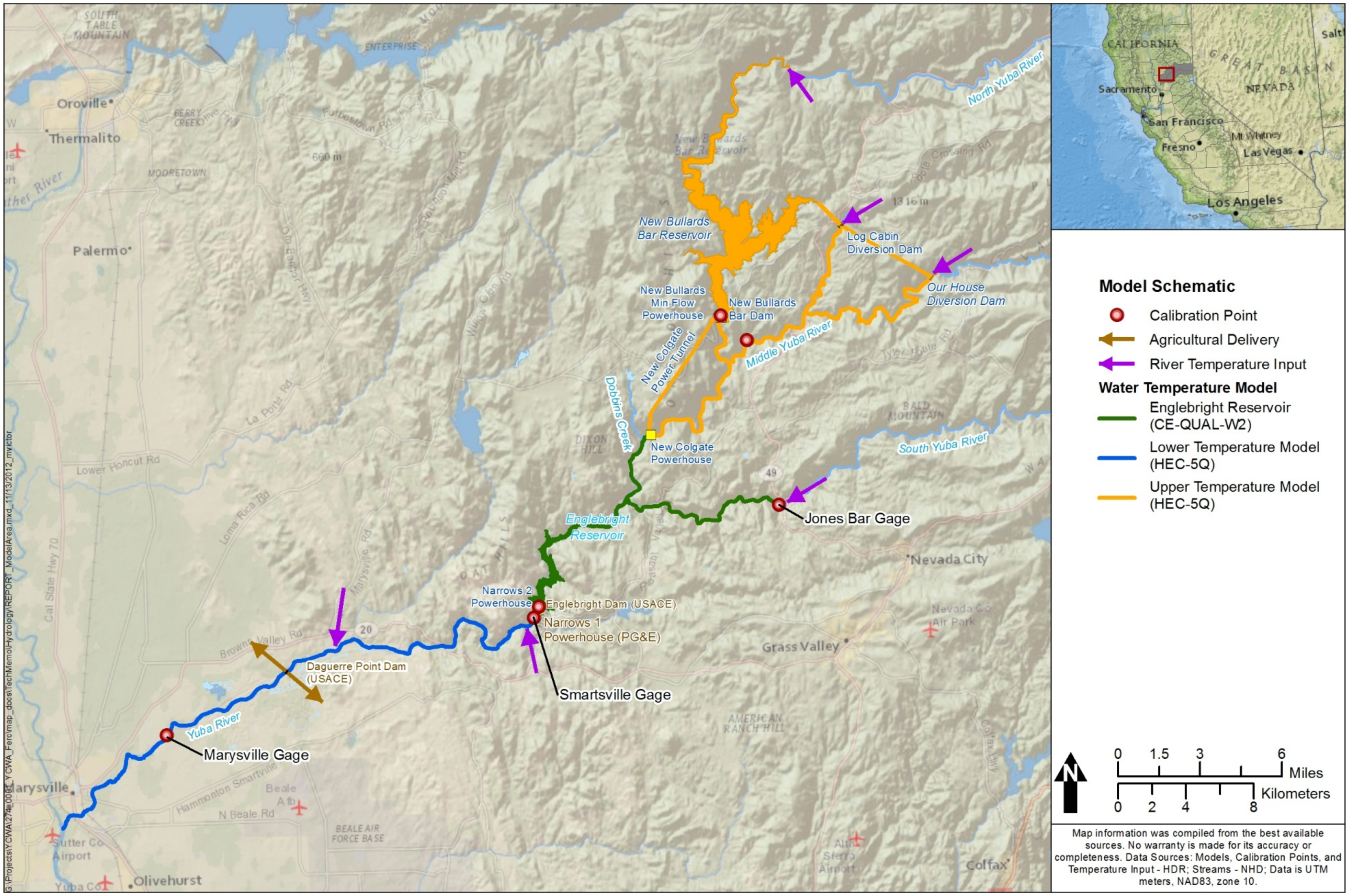
CE-QUAL-W2, version 3.71, was selected to model Englebright Reservoir. The water temperature output from the HEC-5Q model was used as an input to the CE-Qual-W2 model. The CE-QUAL-W2 model simulated Englebright Reservoir water temperatures, including inflows from the Yuba and South Yuba rivers, as well as accretions directly to the reservoir itself. Inflows to the model are 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 is used as an input to the Lower Temp Model. Additional information about CE-QUAL-W2, including the model documentation, can be found in Attachment 2-6A.

4.1.4.3 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, spills 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 4.1-1 shows the extents of the three models used to represent the Project.



Map information was compiled from the best available sources. No warranty is made for its accuracy or completeness. Data Sources: Models, Calibration Points, and Temperature Input - HDR; Streams - NHD; Data is UTM meters, NAD83, zone 10.

Figure 4.1-1. Extent of Upper Temp Model, Englebright Temp Model, and Lower Temp Model.

4.1.5 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[4] and maximum-daily water temperature were the most biologically significant water temperatures to be a model output, rather than hourly or any other sub-daily time step.

YCWA developed a methodology to compute maximum-daily water temperature[5] based on mean-daily water temperature, mean-daily air temperature, and 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 equations 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 are specified by location.

Table 4.1-1 shows applicable input data locations, and coefficients determined through regression, to compute maximum-daily water temperatures at specific locations, by season.

Table 4.1-1. 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

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[4] 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 times measurements once every hour or once every 15-minute) in that calendar day.

[5] 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.

4.2 Model Descriptions

The Yuba County Water Agency water temperature model includes a representation of the Project, including the following features:

- YCWA Facilities
    - New Bullards Bar Reservoir
    - New Colgate Penstock and Powerhouse
    - New Bullards Bar Dam Spillway
    - New Bullards Bar Dam Minimum-Flow Powerhouse
    - Our House Diversion Dam
    - Lohman Ridge Tunnel
    - Log Cabin Diversion Dam
    - Camptonville Tunnel
    - Narrows 2 Powerhouse
- Non-YCWA Facilities
    - Englebright Reservoir
    - Narrows 1 Powerhouse
    - Daguerre Point Dam
- YCWA Non-Project Facilities
    - Agricultural Diversions from Daguerre Point Dam
- River Reaches
    - North Yuba River below New Bullards Bar Dam
    - Middle Yuba River below Our House Diversion Dam
    - Oregon Creek below Log Cabin Diversion Dam
    - Yuba River below Englebright Dam

4.2.1 Upper Temp Model

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 Diversion Dam and Oregon Creek below Log Cabin Diversion 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.

4.2.2 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. In addition to inflow from the Yuba River below the New Colgate Powerhouse, South Yuba River inflow was included as an input to Englebright Reservoir. 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. The reservoir water temperature model for Englebright Reservoir was also calibrated to match historically-measured water-temperature profiles measured near the Narrows 2 Powerhouse Intake.

4.2.3 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.

Unlike the Upper Temp Model, no reservoir release decisions were needed for the Lower Temp Model. The HEC-5Q water balance module used Narrows 1 and Narrows 2 powerhouse releases and Englebright Reservoir spills from the Water Balance/Operations Model as inflows. Inflows from Deer and Dry creeks, and Daguerre Point Dam agricultural diversions were also from the Water Balance/Operations Model.

5.0 Upper Temp Model

The model of the Yuba River above Englebright Reservoir (Upper Temp Model) was simulated as a longitudinally-stratified river using HEC-5Q, with inputs from the Middle Yuba River, Oregon Creek, and the North Yuba River. Additionally, accretions from Oregon Creek below Log Cabin Diversion Dam, the Middle Yuba River below Our House Dam, and the Yuba River above Englebright Reservoir were included as inputs. Camptonville Tunnel, Lohman Ridge Tunnel, and New Colgate Power Tunnel are diversions. Figure 5.0-1 shows the schematic of the Upper Temp Model.

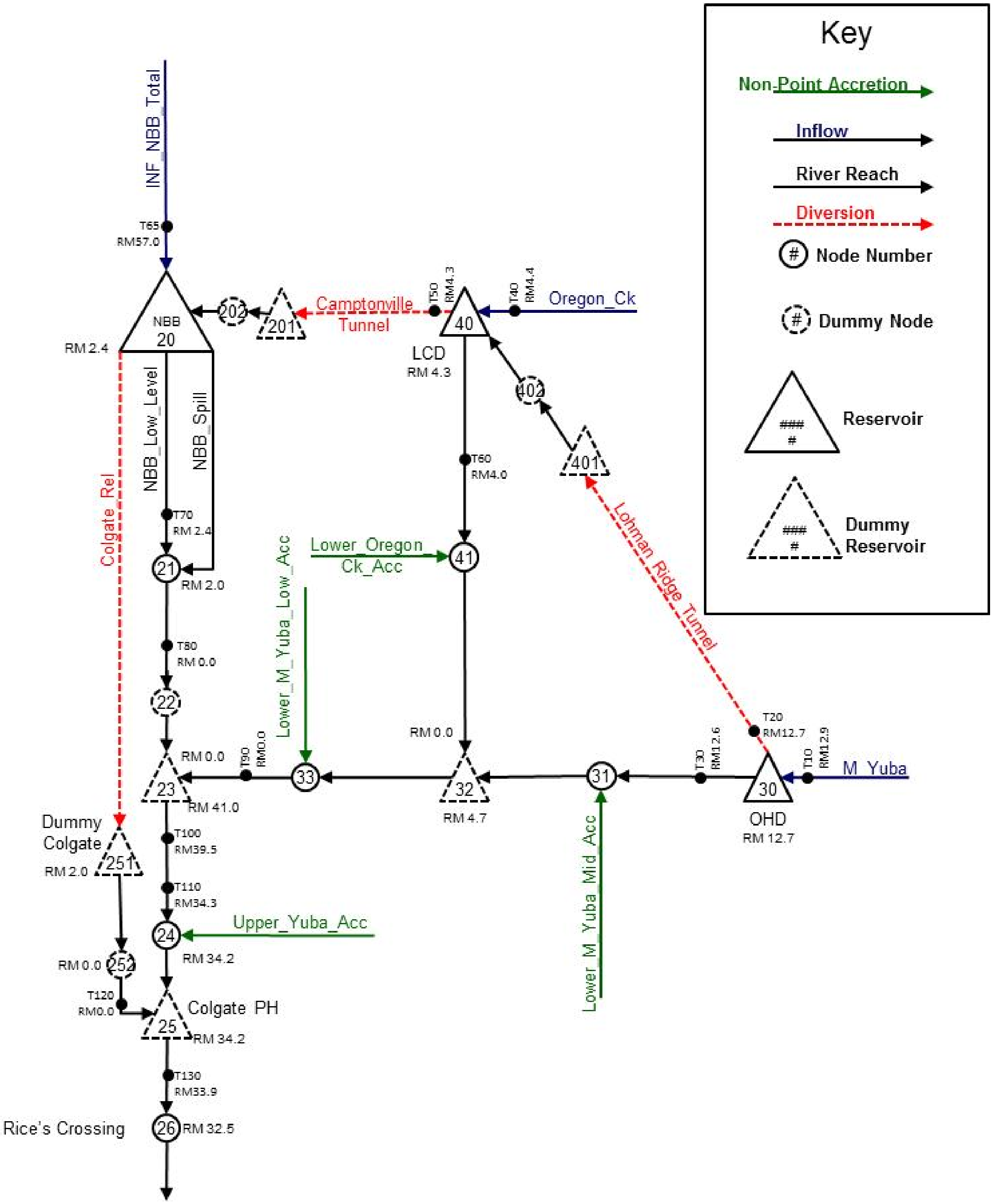

Figure 5.0-1. Upper Temp Model flow schematic.

The Upper Temp Model was calibrated for water-temperature profiles within New Bullards Bar Reservoir, and for Middle Yuba River water temperatures near its confluence with the North Yuba River.

5.1 Input

The following section describes the general input for the Upper Temp Model, the required files for the model, and a description of the representation of each of the components of the Upper Temp Model. Meteorological input data for the Upper Temp Model are described in Section 9.1, and input temperatures for the Upper Temp Model are described in Section 8.1.

5.1.1 General Setup

Upper Temp Model was developed using HEC-5Q "Alpha" Version 8.0 from June 9, 1997. The input structure for HEC-5Q is designed to be flexible with respect to inputs into the system. Each input is described in detail in the HEC-5Q manual (Attachment 2-6A). The types of input records for HEC-5Q are described below in Table 5.1-1.

Table 5.1-1. Input files and descriptions for Upper Temp Model.

File Type	Record Name	Description
Title Information and Job Controls	TI through JZ	Title and simulation controls, including the simulation length and information about the water quality output to the GUI and DSS files
Water-Surface Heat Exchange	EZ and ET	Meteorological data and water-surface heat exchange data
Water Quality Constituents Data	QC and TQ	Water quality constituents
General Reservoir Data	L1 through AC	Reservoir simulation and the physical characteristics of the reservoir
Vertically Segmented Reservoir Data	LR through PL	Additional reservoir and dam geometry, diffusion coefficients and outlet water quality sub-optimization objective functions
Longitudinally Segmented Reservoir Data	LS through LW	Additional reservoir and dam geometry, layering and vertical flow distribution, depth versus elevation relationships, and locations of inflows and outflows
Stream Related Data	S1 through ES	Printout controls, reach limits, local inflow and withdrawal locations, reaeration controls, channel cross section geometry, and energy grade line elevations
Initial Temperature and Water Quality Conditions	L9 through LX	Water quality parameters and uniform initial condition concentration
Local Inflow Temperatures and Water Quality	I1 through E1	Inflow time series
Gate Operations	G1 and G2	Operation schedule for wet wells, flood control outlets, and uncontrolled spillway

The title information and job controls are required to run the HEC-5Q model. HEC-5Q requires three job title records, where both alphabetic and numerical information may be used. The job title information is printed on first pages of the water quality analysis output. Options are available for how the output is written. See Section 5.2 for more information regarding output formats.

Inputs to the Upper Temp Model were developed for three scenarios – (1) the Calibration scenario, (2) the Validation scenario, and (3) the Base Case scenario. The Calibration scenario was run for the period of record of November 14, 2009 to April 30, 2012. The Validation scenario was run for the period of record of January 1, 2000 to September 30, 2011. The Base Case scenario was run for the period of record of October 1, 1969 through September 30, 2010. See Sections 10 (Calibration) and 11 (Validation) for more detailed information regarding each of the Calibration and Validation scenarios; the Base Case Scenario is not included in this report.

Water-surface heat exchange and meteorological data were provided with the EZ and ET Record. EZ records are required for each meteorological zone provided in the model. For the Upper Temp Model, there is only one meteorological zone; therefore, only one EZ Record. A minimum of one ET Record is required for each day of the simulation. Data for these two inputs were read into the model via DSS.

Water quality constituents data is required if a water quality simulation for parameters other than temperature is desired. The water quality constituents data is provided with the QC Record. The QC Record should be provided with the model even if additional water quality simulations are not desired. For the Upper Temp Model, only water temperature is simulated, so no additional water quality data is included.

General reservoir data describe the reservoir simulation and the physical characteristics of the reservoir and define the printout interval, miscellaneous physical constants, and additional reservoir storage, area, and elevation data.

Initial water temperatures for all three models will be based on the specific start date and will either be from simulated data, i.e. the Base Case, or from historical data, i.e. the Calibration and the Validation model. Initial inflow time series will be read into the HEC-5Q model via DSS.

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

Gate operations include operation schedules for wet wells, flood control outlets, and uncontrolled spillways. For the Upper Temp Model, gate operations records were not used.

5.1.2 Files

The files needed to run the Lower Temp Model include the UPPERTM file (UPPERTM.xlsx), HEC-5Q executable (HEC-5Q.exe), and the Input DSS file (Input.dss). This section describes each of these files.

To contain the code from the HEC-5Q model, a Microsoft Excel® spreadsheet titled UPPERTM.xlsx. This file contains all the code used for the Upper Temp Model. There are seven worksheets contained in the UPPERTM excel file. These worksheets are:

- Readme Information (Readme)
- Upper Temp Model schematic (Schematic)
- Batch file info (UPPER)
- HEC-5 data (UPPER5)

- HEC-5Q data (UPPERTM)
- Geometry data (UPTM-S3)
- Tributary data (UPTM-I2)

The first worksheet in the UPPERTM file contains information about the other worksheets, inputs, and outputs. It also contains instructions for running the model, and an execution button to run the model.

The second worksheet in the UPPERTM file contains the schematic shown in Figure 5.0-1, for reference when working with the model.

HEC-5Q is designed to accept certain inputs interactively or from a quasi-batch file. As the program is initiated, a prompt asks for the batch file name or “none” if the interactive input is desired. The third worksheet in the Excel file is the batch file associated with the Lower Temp Model. The batch file for the Lower Temp Model contains the following information:

- Simulation Date
- File name of the HEC-5 data
- File name of the HEC-5Q data
- DSS file name of input data
- DSS file name of output data

The fourth worksheet in the UPPERTM file is for the HEC-5 data. This worksheet contains the code and coefficients for the following data:

- Title and Job Control Information
- Longitudinally Segmented Reservoir Data, including inflows and outflows

The fifth worksheet in the UPPERTM file is for the HEC-5Q data. This worksheet contains the code and coefficients for the following data:

- Title and Job Control Information
- Water-Surface Heat Exchange Data
- Water Quality Constituents Data
- General Reservoir Data
- Longitudinally Segmented Reservoir Data, including inflows and outflows
- Initial Temperature and Water Quality Conditions
- Stream Related Data
- Local Inflow Temperature and Water Quality

The sixth worksheet in the UPPERTM file is for the cross-section data. This worksheet contains the following data:

- Scaling factors for width, areas, and flow rates
- Channel cross section geometry from upstream to downstream
- Manning's "n" data
- Energy grade line

The seventh worksheet in the UPPERTM file is for the tributary data. This worksheet contains the following data:

- Local Inflow Temperatures and Water Quality

An executable files is used to run the HEC-5Q model. This executable file is named HEC-5Q.exe.

Throughout the UPPERTM file, code is written to read the input temperatures, flow, and meteorology from a DSS file. This DSS file is also included in the input files for the Upper Temp Model.

5.1.3 Description of Model Setup

The Upper Temp Model was constructed as three regions, each of which was independently calibrated. 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 Diversion Dam and Oregon Creek below Log Cabin Diversion Dam to New Bullards Bar Reservoir. The following section describes the regional calibrations, and the parameter values determined through calibration.

5.1.3.1 New Bullards Bar Reservoir

New Bullards Bar Reservoir was simulated as a single-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 the two New Bullards Bar Dam inlets in the New Colgate Power Tunnel

Intake Tower.[6] Reservoir elevation-area-storage-maximum release relationships and outlet locations were from the USACE New Bullards Bar Reservoir Regulation for Flood Control (USACE 1972).

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 its representation in the Upper Temp Model. Parameters and the respective model parameter codes used in calibration included the following:

- Fraction of solar radiation absorbed in the upper portion of the reservoir (XQPCT). Nominal values were used for calibration.
- Depth in which the specified percentage of radiation is absorbed (XQDEP). Nominal values were used for calibration.
- Equilibrium temperature offset (SFMET1). This parameter universally offsets the equilibrium temperature for the specified reach. Through iteration, this parameter was found to be an effective parameter for calibration of the water temperature profile.
- Equilibrium temperature scaling factor (SFMET2). This parameter universally scales the equilibrium temperature. Through iteration, this parameter was found to be an effective parameter for calibration of the water temperature profile.
- Heat exchange rate scaling factor (SFMET3). This parameter universally scales the heat exchange rate. Through iteration, this parameter was found to be an effective parameter for calibration of the water temperature profile.
- Water column minimum stability (GMIN). Nominal values were used for calibration.

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[6] 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.

- Water column critical stability (GSWH). Through iteration, this parameter was found to be an effective parameter for calibration of the water temperature profile.
- Diffusion coefficient when the water column stability is less than the specified critical stability (A1). Through iteration, this parameter was found to be an effective parameter for calibration of the water temperature profile.
- Empirical constant for computing diffusion coefficients based on density gradients (A3). Nominal values were used for calibration.
- Empirical constant for adjusting the computing diffusion coefficients for depth (A4). Nominal values were used for calibration.
- Empirical constant for adjusting diffusion coefficients for depth (A5). Nominal values were used for calibration.
- Maximum rate of increase in diffusion with depth and wind speed (A6). Nominal values were used for calibration.
- Lower limit of the withdrawal layer, representing physical obstructions (A7). Nominal values were used for calibration.

Table 5.1-2 shows calibration values for each of the above parameters.

Table 5.1-2. Values of calibration parameters used for New Bullards Bar Reservoir water temperature model calibration.

Parameter	Description	Calibration Value (unit-less, unless provided)
XQPCT	Fraction of solar radiation absorbed in the upper portion of the reservoir	0.3
XQDEP	Depth in which the specified percentage of radiation is absorbed	5 ft
SFMET1	Equilibrium temperature offset	-4.0 °C
SFMET2	Equilibrium temperature scaling factor	0.9
SFMET3	Heat exchange rate scaling factor	1.0
GMIN	Water column minimum stability	-0.9E-6 M^2/sec
GSWH	Water column critical stability	0.55E-6 kg/m^3/m
A1	Diffusion coefficient when the water column stability is less than the specified critical stability	0.25E-4 M^2/sec
A2	Empirical constant for computing diffusion coefficients based on wind speed.	Not used[1]
A3	Empirical constant for computing diffusion coefficients based on density gradients	-0.75
A4	Empirical constant for adjusting the computing diffusion coefficients for depth	-15
A5	Empirical constant for adjusting diffusion coefficients for depth	0.15
A6	Maximum rate of increase in diffusion with depth and wind speed	0
A7	Lower limit of the withdrawal layer, representing physical obstructions	0 ft

[1] Since the “Stability Method” was used for the representation of New Bullards Bar Reservoir, the A2 parameter was not used in the model.

In addition, a time series for Mean Secchi disk reading (EDMAX) was used. Secchi disks measure depth of light transparency of the reservoir, which affects the distribution of light energy with depth and influences the location of the thermocline. YCWA recorded Secchi disk depths bi-weekly for April 12, 2011 through August 8, 2012 as part of Study 2.5, *Water Temperature Monitoring*. Average monthly values applied to the middle of each month were used in calibration. No adjustments were made to monthly values. Table 5.1-3 shows the time series for EDMAX.

Table 5.1-3. Values of the Secchi disk parameter (EDMAX) used for New Bullards Bar Reservoir water temperature model calibration.

Month	Secchi Disk Representative Reading (ft)
January	21.33
February	19.69
March	9.84
April	13.53
May	14.11
June	14.35
July	9.30
August	6.56
September	8.20
October	14.76
November	20.51
December	25.43

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 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 linear interpolating to determine the widths at each elevation. All of these features were defined for the reservoir for elevations ranging from 1,400 ft-msl to 1,965 ft-msl. Linear interpolation was used for elevations between those defined by the GIS exercise. Since they are explicitly defined as an input to the Upper Temp Model, diversions to the New Colgate Powerhouse are not included in the release capacity values in the model. The simulated capacities are representative of the release capacity available for discretionary use by the Upper Temp Model from the low-level outlet and the New Bullards Bar Dam spillway. Table 5.1-4 shows the elevation, storage, water-surface area, and release capacity for the model of New Bullards Bar Reservoir.

Table 5.1-4. New Bullards Bar Reservoir elevation, storage, water-surface area, and maximum-release capacity from HEC-5Q.

Elevation (ft-msl)	Storage (ac-ft)	Water-Surface Area (acres)	Maximum-Release Capacity[1] (cfs)	Effective Reservoir Width (ft)
1,400	1,000	50	1,200	61
1,450	5,600	135	1,200	166
1,500	15,800	275	1,200	326
1,600	64,900	750	1,200	807
1,620	81,300	890	1,200	929
1,630	90,570	965	1,200	993
1,640	100,595	1,040	1,200	1,060
1,650	111,391	1,120	1,200	1,128
1,660	122,993	1,200	1,200	1,199
1,670	135,427	1,287	1,200	1,272
1,680	148,740	1,375	1,200	1,347
1,690	162,933	1,474	1,200	1,424
1,700	178,230	1,575	1,200	1,504
1,710	194,484	1,677	1,200	1,585
1,720	211,768	1,780	1,200	1,669
1,730	230,118	1,890	1,200	1,755
1,740	249,568	2,000	1,200	1,843
1,750	270,110	2,109	1,200	1,867
1,760	291,756	2,220	1,200	1,980
1,770	314,533	2,337	1,200	2,093
1,780	338,489	2,455	1,200	2,207

Table 5.1-4. (continued)

Elevation (ft-msl)	Storage (ac-ft)	Water-Surface Area (acres)	Maximum-Release Capacity[1] (cfs)	Effective Reservoir Width (ft)
1,790	363,628	2,574	1,200	2,320
1,800	389,977	2,695	1,200	2,433
1,810	417,521	2,815	1,200	2,547
1,820	446,271	2,935	1,200	2,660
1,830	476,213	3,054	1,200	2,773
1,840	507,361	3,175	1,200	2,887
1,850	539,748	3,302	1,200	3,000
1,860	573,411	3,430	1,200	3,113
1,870	608,351	3,559	1,200	3,227
1,880	644,595	3,690	1,200	3,340
1,885	663,209	3,757	1,200	3,397
1,890	682,170	3,827	1,200	3,453
1,895	701,477	3,896	1,200	3,510
1,900	721,130	3,965	1,200	3,567
1,905	741,127	4,035	5,000	3,623
1,910	761,482	4,107	9,000	3,680
1,915	782,195	4,178	16,000	3,737
1,920	803,264	4,250	25,000	3,793
1,925	824,693	4,323	35,000	3,850
1,930	846,500	4,399	46,000	3,907
1,935	868,683	4,474	61,000	3,963
1,940	891,244	4,550	76,000	4,020
1,945	914,188	4,630	93,000	4,077
1,950	937,541	4,711	111,000	4,133
1,955	961,302	4,793	129,000	4,190
1,956	966,103	4,809	132,000	4,247
1,960	985,471	4,875	148,000	4,303
1,965	1,010,074	4,965	167,000	4,350

[1] Maximum-release capacity excludes releases through the New Colgate Powerhouse.

Other physical characteristics, such as outlet elevations and sizes, are also included in HEC-5Q. The following is a list of parameters and model parameter codes used to represent New Bullards Bar Reservoir:

- Thickness of vertical layer (SDZ). The thickness of the layer can be varied to achieve the correct representation of stratification. Larger thicknesses can be used if the reservoir is deep and a relatively coarse simulation is acceptable.
- Flood control outlet port area (AOUT1). This parameter value represents the full-open width of the New Bullards Bar Dam spillway gates.
- Maximum-allowable flow rate through the flood control outlet port (QSMAX1). This is the maximum flow rate at the spillway design flood elevation (El. 1,962.5 ft-msl).
- Centerline elevation of the flood control outlet port (ELSP1). This is the elevation of the centerline, halfway between the top and bottom of the spillway gates.
- Area of low-level outlet port (AOUT)
- Maximum discharge through low-level outlet (QWMAX).
- Centerline elevation of the low-level outlet (ELWW)
- Area of the New Colgate Power Tunnel intake (ADV). The lower intake is used.

- Centerline elevation of the New Colgate Power Tunnel intake (EDV). The lower intake is used.

Table 5.1-5 shows parameter values used to physically represent New Bullards Bar Reservoir.

Table 5.1-5. New Bullards Bar Reservoir physical representation parameter values.

Parameter	Description	Value
SDZ	Thickness of vertical layer	5.0 ft
AOUT1	Flood control outlet port area	4,770 sq ft
QSMAX1	Maximum-allowable flow rate through the flood control outlet port	155,000 cfs
ESLP1	Centerline elevation of the flood control outlet port	1,928.5 ft-msl
AOUT	Area of low-level outlet port	28.27 sq ft
QWMAX	Maximum discharge through low-level outlet	1,200 cfs
ELWW	Centerline elevation of the low-level outlet	1,447 ft-msl
ADV	Area of the New Colgate Power Tunnel intake	176.7 sq ft
EDV	Centerline elevation of the New Colgate Power Tunnel intake	1,627.5 ft-msl

Modeled inflows to New Bullards Bar Reservoir from the North Yuba River include local reservoir accretions and flow from Camptonville Tunnel. For both inflows, an effective reservoir length (RLEN) of 71,500 ft and an inflow entrainment factor (TRIBELF) of $0.0175/m^2$ were used. The inflow entrainment factor controls the mixing rate of inflow with the ambient lake water as it sinks/rises to a depth of like density.

A historically-measured New Bullards Bar Reservoir profiles were used for as initial conditions for each of the three scenarios. Table 5.1-6 shows the initial New Bullards Bar Reservoir temperature profile used in the Upper Temp Model for each scenario; normalized elevations are used: 0 corresponds to the bottom of the reservoir, and 1 corresponds to the reservoir surface.

Table 5.1-6. New Bullards Bar Reservoir Initial Condition Reservoir Temperature Profile.

Normalized Elevation	Historical Water Temperature Profile (°C)		
	Calibration (November 18, 2009)	Validation (January 5, 2000)	Base Case (September 27, 2001)
0.338	8.00	8.11	8.92
0.384	8.11	8.44	9.11
0.429	8.67	8.89	9.41
0.475	9.22	10.33	9.50
0.521	9.67	10.89	9.80
0.566	9.89	11.22	10.11
0.612	10.33	11.56	10.72
0.658	10.78	11.78	11.41
0.703	11.33	12.11	12.10
0.749	12.22	12.00	13.89
0.840	13.44	12.00	20.10
0.886	14.78	12.22	21.84
0.932	15.11	12.56	21.89
0.977	15.11	12.44	22.15
1.000	15.33	13.11	22.00

5.1.3.2 North Yuba River below New Bullards Bar Dam and the Yuba River above Englebright Reservoir

The North Yuba River below New Bullards Bar Dam and the Yuba River above Englebright Reservoir region of the Upper Temp Model contains the following:

- North Yuba River below New Bullards Bar Reservoir
- Yuba River above Englebright Reservoir

The Middle Yuba River joins the North Yuba River to form the headwaters of the Yuba River. Additional inflows to this reach include New Bullards Bar Reservoir releases and releases from the New Colgate Powerhouse. Both the North Yuba and Yuba Rivers have non-point accretions.

Table 5.1-7 shows the 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.

Table 5.1-7. River mile locations of features along the Yuba River above Englebright Reservoir and the North Yuba Rive below New Bullards Bar Dam.

Feature	River Mile
Rice’s Crossing	Yuba 32.5
New Colgate Powerhouse	Yuba 34.2
Confluence of Middle Yuba and North Yuba Rivers	Yuba 40.0
New Bullards Bar Dam	North Yuba 2.4

Channel geometry for these reaches was extrapolated from data collected for Study 3.10, *Instream Flow Upstream of Englebright Reservoir*. HEC-5Q uses a generalized version of cross section geometry, by defining cross-sectional area, hydraulic radius, and width as a function of water-surface elevation. Collected channel geometry was converted into this format using an arbitrary vertical datum. These geometric representations were combined into a single representation for each reach by using a habitat weighted average. Each cross section is weighted based on how much its habitat type is in the reach relative to the other habitat types. This is similar to methodology used in Study 3.10 to apply weighted usable habitat area (WUA) to the whole reach.

Cross sections were extracted from USGS National Elevation Dataset (1/3 arc second) every 0.2 river miles. These cross sections were used as a rough template, providing the cross-section elevation and the high-flow widths, up to twenty feet deep. The lower ten feet of each of these cross sections were replaced with the habitat-weighted reach-average geometry. When cross sections were collocated with a measured cross section, the measured cross section geometry was used instead of the habitat weighted reach average geometry.

For calibration, historical flows and temperatures were utilized below New Bullards Bar Reservoir, Middle Yuba River flow and temperatures above its confluence with the North Yuba River, and New Colgate Powerhouse for the period of November 14, 2009 through April 5,

2012. Historical meteorology from the New Bullards Bar Reservoir weather station was also used.

Calibration of the New Bullards Bar Dam to Englebright Reservoir reach was included to ensure inflow water temperatures to the Englebright Reservoir were as accurate as possible. Calibration focused on meeting the full range of water temperatures. Model parameters used for calibration included the following:

- Equilibrium temperature scaling factor to account for environmental factors such as shading by riparian vegetation (HEXF). This value was not used; Heat exchange rate scaling factor (SFMET3) was identified as being more appropriate.
- Diffusion coefficient (DDC). Changed from 0 to 4 with no noticeable effect on simulated water temperatures. A value of 1.0, indicating no change in diffusion, was ultimately selected.
- Thermal conductivity constant for heat transfer to and from the bottom sediments (BEDKC). This parameter is primarily used to account for diurnal variation in water temperatures. Values from 0 to 100 were tested with no differences in simulated water temperatures. A value of 0.0, indicating heat exchange with the bottom is ignored, was ultimately selected.
- Equivalent bed thickness for heat storage (BEDDEP). This parameter is primarily used to account for diurnal variation in water temperatures. Values from 0 to 100 were tested with no differences in simulated water temperatures. With a BEDKC value of 0, the bed thickness is not used, so a value of 0.0 was ultimately selected.
- Equilibrium temperature offset (SFMET1). Through iteration, this parameter was found to be an effective parameter for calibration of river temperatures.
- Equilibrium temperature scaling factor (SFMET2). Through iteration, this parameter was found to be an effective parameter for calibration of river temperatures.
- Heat exchange rate scaling factor (SFMET3). Through iteration, this parameter was found to be an effective parameter for calibration of river temperatures.

Table 5.1-8 shows the preliminary values determined in the calibration process, applied to either all modeled reaches or to individual reaches.

Table 5.1-8. Parameter values used for calibration of the North Yuba River below New Bullards Bar Dam to the Yuba River above Englebright Reservoir reach.

Parameter	**Description**	**Value (unit-less, unless provided)**
PARAMETER VALUES FOR ALL REACHES		
HEXF	Equilibrium temperature scaling factor to account for environmental factors such as shading by riparian vegetation	0
DDC	Diffusion coefficient	1
BEDKC	Thermal conductivity constant for heat transfer to and from the bottom sediments	0.0
BEDDEP	Equivalent bed thickness for heat storage	0.0 ft

Table 5.1-8. (continued)

Parameter	Description	Value (unit-less, unless provided)
PARAMETER VALUES FOR THE NORTH YUBA RIVER BELOW NEW BULLARDS BAR DAM		
SFMET1	Equilibrium temperature offset	3.0
SFMET2	Equilibrium temperature scaling factor	5.5
SFMET3	Heat exchange rate scaling factor	0.25
PARAMETER VALUES FOR THE YUBA RIVER ABOVE NEW COLGATE POWERHOUSE		
SFMET1	Equilibrium temperature offset	-2.0
SFMET2	Equilibrium temperature scaling factor	0.73
SFMET3	Heat exchange rate scaling factor	4.5
PARAMETER VALUES FOR THE YUBA RIVER BETWEEN NEW COLGATE POWERHOUSE AND ENGLEBRIGHT RESERVOIR		
SFMET1	Equilibrium temperature offset	0.0
SFMET2	Equilibrium temperature scaling factor	1.0
SFMET3	Heat exchange rate scaling factor	1.0

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

The Middle Yuba River below Our House Diversion Dam and Oregon Creek below Log Cabin Diversion Dam region of the Upper Temp Model contains the following:

- Our House Diversion Dam
- Log Cabin Diversion Dam
- Lohman Ridge Diversion Tunnel
- Camptonville Diversion Tunnel
- Middle Yuba River below Our House Diversion Dam to the Yuba River confluence
- Oregon Creek below Log Cabin Diversion Dam to New Bullards Bar Reservoir

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.

Table 5.1-9 shows the RMs for features along the Middle Yuba River below Our House Diversion Dam and Oregon Creek below Log Cabin Diversion Dam.

Table 5.1-9. 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
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

Channel geometry for these reaches were developed using methods described in Section 5.1.3.2.

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.

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 temperate from temperature monitoring stations along both the Middle Yuba River and Oregon Creek, were used to calibrate the reaches above each temperature monitoring station location for the period of November 14, 2009 through April 5, 2012. By incrementally calibrating the Middle Yuba River and Oregon Creek, simulated intermediate water temperatures along each reach were more representative than if a single calibration location had been used.

Table 5.1-10 shows preliminary values determined in the calibration process.

Table 5.1-10. Values of parameters used for the calibration of the Middle Yuba River below Our House Diversion Dam and Oregon Creek below Log Cabin Diversion Dam.

Parameter	Description	Value (unit-less, unless provided)
PARAMETER VALUES FOR ALL REACHES		
HEXF	Equilibrium temperature scaling factor to account for environmental factors such as shading by riparian vegetation	0
DDC	Diffusion coefficient	1.0
BEDKC	Thermal conductivity constant for heat transfer to and from the bottom sediments	0.0
BEDDEP	Equivalent bed thickness for heat storage	0.0 ft
PARAMETER VALUES FOR THE MIDDLE YUBA RIVER BETWEEN OUR HOUSE DIVERSION DAM AND OREGON CREEK		
SFMET1	Equilibrium temperature offset	-4.0
SFMET2	Equilibrium temperature scaling factor	1.1
SFMET3	Heat exchange rate scaling factor	2.2
PARAMETER VALUES FOR THE MIDDLE YUBA RIVER BETWEEN OREGON CREEK AND THE NORTH YUBA RIVER		
SFMET1	Equilibrium temperature offset	-4.0
SFMET2	Equilibrium temperature scaling factor	1.1
SFMET3	Heat exchange rate scaling factor	2.2
PARAMETER VALUES FOR OREGON CREEK BELOW LOG CABIN DIVERSION DAM		
SFMET1	Equilibrium temperature offset	-2.0
SFMET2	Equilibrium temperature scaling factor	1.0
SFMET3	Heat exchange rate scaling factor	3.0

5.2 Outputs

Output from the HEC-5Q can be written into several files that are specified by their input controls. The output options for HEC-5Q are:

- ASCII HEC-5Q output file or traditional printer output
- DSS output file in which data is stored in a DSS file

For the Upper Temp Model, river water temperature data is written to a DSS file specified in the batch file, as described in Section 5.1.2, and New Bullards Bar Reservoir profiles are written to an ASCII file with the name NBB_PROFILE.csv.

5.3 Running the Model

Macros are provided in the workbook that assists the user with executing the model. The macro exports all five model worksheets in the workbook as a fixed-width ASCII file with a file extension of h5q. This step could be done manually for each sheet by saving as formatted text (*.prn). After all the files are saved to the same directory as the workbook, the macro will run hec5q.exe, and point to the files that were just created. At this time the Command Prompt will open and you will see each of the days printed as the model runs. When the command prompt closes or stops the model is done running, and the output is ready to view in Output.dss, or in one of the other post-processors provided. Detailed outputs are available in the HEC-5q output files: UPPER5.OUT and UPPERTM.OUT.

6.0 Englebright Temp Model

To capture travel time for water temperatures across Englebright Reservoir, the reservoir was simulated as a two-dimensional, vertically and longitudinally stratified reservoir using CE-QUAL-W2. In addition to inflow from the Yuba River, South Yuba River inflow was included as an input to Englebright Reservoir. The Narrows 1 and 2 Powerhouses were included as outlets; the outflow temperatures from these two powerhouses were calibrated at the USGS Smartsville gage, located approximately 100 yards downstream of the Narrows 1 Powerhouse. Reservoir water temperatures were calibrated using water-temperature profiles measured near the Narrows 2 Powerhouse Intake. Englebright Reservoir bathymetry came from a USGS survey conducted in 2002 (USGS 2002).

Figure 6.0-1 shows the layout of the Englebright Temp Model.

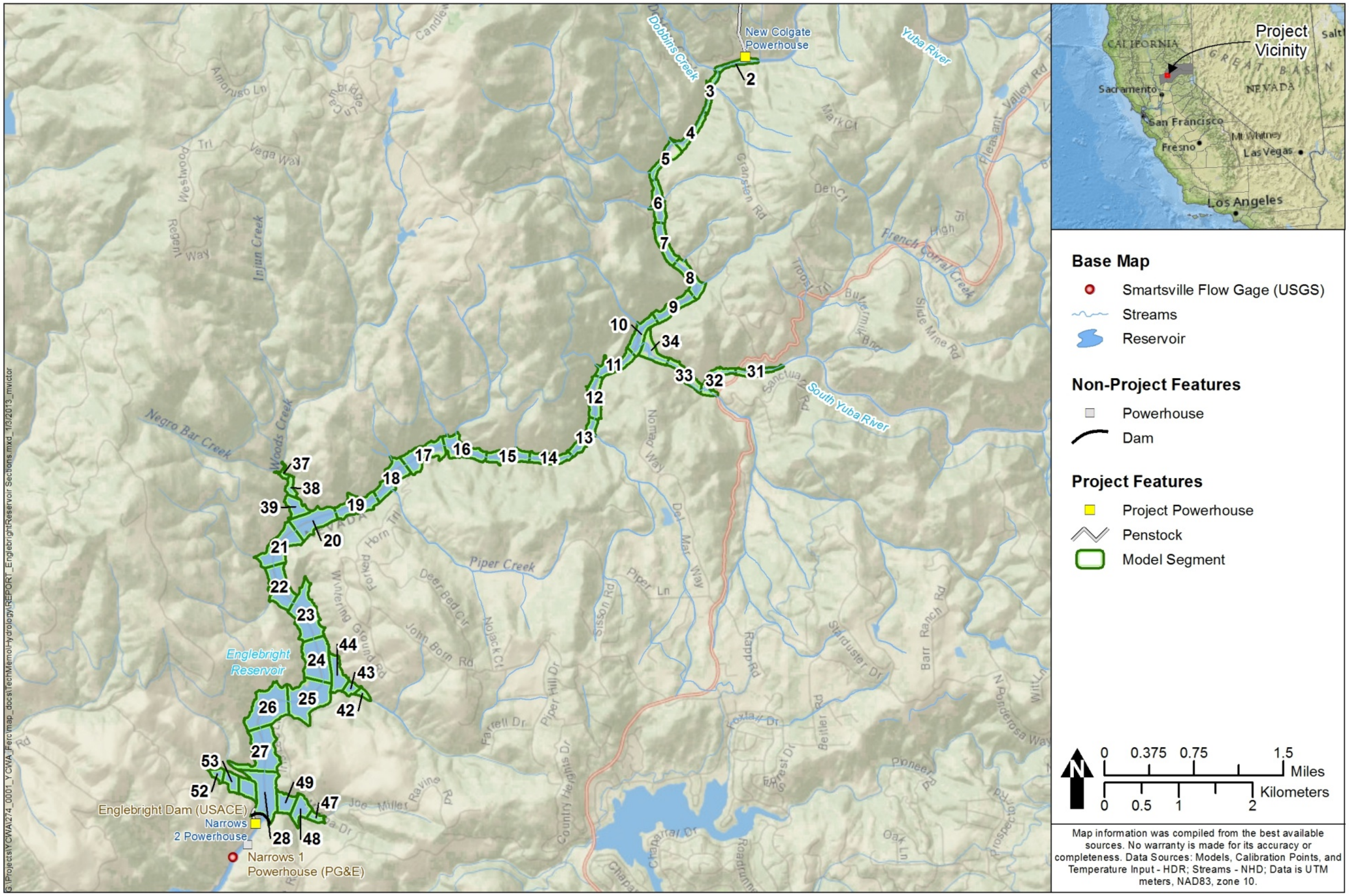

Figure 6.0-1. Englebright Reservoir Water Temperature Model Segments.

6.1 Inputs

The following section describes the general inputs for the Englebright Temp Model, the required files for the model, and a description of each of the components of the Englebright Temp Model. Meteorological input data for the Englebright Temp Model are described in Section 9.2, and input temperatures for the Englebright Temp Model are described in Section 8.2.

6.1.1 General Setup

Englebright Temp Model was developed using CE-QUAL-W2, Version 3.71. The following data are needed to develop a model using CE-QUAL-W2:

- Geometric data,
- Initial conditions,
- Boundary conditions, and
- Hydraulic parameters.

Assembling the geometry data was the first step to creating the Englebright Temp Model. To geometrically represent Englebright Reservoir, the following data were assembled:

- Reservoir bathymetry,
- Inlet locations and elevations, and
- Outlet locations and elevations.

The next step in assembling the Englebright Temp Model was to determine the initial conditions. The initial conditions include:

- Starting and ending time of simulation, and
- Initial water temperatures.

The Englebright Temp Model was initially set up to run three different scenarios: (1) the Calibration Scenario, (2) the Validation Scenario, and (3) the Base Case Scenario. The Calibration Scenario was run for January 1, 2007 through September 30, 2012. The Validation Scenario was run for January 1, 2000 to September 30, 2012. The Base Case Scenario was run for the period of record, October 1, 1969 through September 30, 2010. Inputs for all three models are either from simulated data, as in the Base Case Scenario; from historical data, as in the Calibration Scenario; or from a combination of historical and synthetic data, as in the Validation Scenario. See Sections 10 (Calibration) and 11 (Validation) for more detailed information regarding each of the Calibration and Validation scenarios; the Base Case Scenario is not included in this report.

Boundary conditions to the Englebright Temp Model include the following:

- Inflows and inflow temperatures
  - From the Yuba River below the New Colgate Powerhouse
  - From the South Yuba River at Jones Bar
- Non-point accretion inflows and inflow temperatures
- Downstream outflows
  - Englebright Dam spill
  - Releases through the Narrows 1 Powerhouse intake
  - Releases through the Narrows 2 Powerhouse intake

While the Calibration and Validation scenarios utilize a combination of historical and synthetic flow data, the Base Case Scenario inflows and releases will come from the Water Balance/Operations Model. A complete description of the development of inflows and accretions can be found in Attachment 2-2D to Study 2-2, Water Balance/Operations Model.

The Calibration and Validation scenarios also utilize a combination of historical and synthetic inflow temperatures corresponding to modeled inflows. The Base Case and Validation Scenarios use output temperatures from the Upper Temp Model as input, along with synthetic inflow temperatures for the South Yuba River and accretions. Inflow temperatures for accretions were developed using observed data from Dry Creek.

Evaporation is optional in CE-QUAL-W2 for water balance purposes and is represented by an ON/OFF button in the control file. Note that evaporation is always included in heat transfer calculations, regardless of weather or not it is included in the water balance. Evaporation is calculated by the model from air temperature, dew-point temperature, and wind speed. In the Englebright Temp Model, evaporation is turned OFF. A water-balance utility post processor is run after an initial run of the Englebright Temp Model to true up the water-surface elevations with the Water Balance/Operations model. The Englebright Temp model is then re-run with resulting water-balance flows applied as a distributed tributary (accretion) along the main branch of the reservoir.

Surface boundary conditions include:

- Surface heat exchange,
- Solar radiation absorption, and
- Wind stress.

Surface heat exchange allows the user to specify between two calculation methods. The first method is a term-by-term account of the equilibrium temperature and the second method uses equilibrium temperatures and coefficients of heat exchange to calculate surface heat exchange. For the Englebright Temp Model, the term-by-term approach was selected, as it is a more robust method.

The solar radiation absorption card specifies the short-wave solar radiation coefficients and amount of solar radiation, β, absorbed in the surface layer. For the Englebright Temp Model the default value of 0.45 was selected.

Wind speed and direction are required variables that are supplied to the model via the meteorological data file. Wind stress is required to be used by all CE-QUAL-W2 models. The model allows the user to supply a wind sheltering coefficient (WSC) which, when multiplied by the wind speed, scales the effects of the wind to take into account differences in terrain from the met station and the project location and was used as a calibration variable. The wind sheltering coefficient is supplied in the wind sheltering file (wsc.npt).

Hydraulic parameters include:

- Dispersion/diffusion coefficients, and
- Bottom friction.

Dispersion/diffusion coefficients are specified in the control file for both vertical- and horizontal-eddy viscosity and diffusivity. For the Englebright Temp Model, the default values of 1.0 for horizontal-eddy viscosity and diffusivity were used. The vertical-eddy viscosity and diffusivity the default values of using the CE-QUAL-W2 calculations for vertical turbulence closure and 1.0 for maximum vertical-eddy viscosity are used. Five different vertical-eddy viscosity formulations are available in the model. For the Englebright Temp Model, the W2 method was selected. According to model documentation, W2 is usually used for reservoirs and lakes where wind shear is dominant (Cole and Wells, 2011).

Bottom friction values for the CE-QUAL-W2 model are specified in the bathymetry file. Two methods for computing bottom friction are included in the model: the Manning's method or the Chezy method. The Englebright Temp Model uses the Chezy method and a Chezy coefficient of 70.

6.1.2 Files

A CE-QUAL-W2 model contains executable files, input files, and output files. Table 6.1-1 shows the input files and their descriptions used to create the Englebright Temp Model.

Table 6.1-1. Input files and descriptions for Englebright Temp Model.

File Type	File Name	Description
Control file	w2_con.npt	Model control file containing variables used to run the model
Bathymetry Data File	bth.csv	Bathymetry file containing segment lengths, initial water-surface elevation, segment orientation, layer thickness and cell widths
Meteorological Data File	met_1.npt	Time series file containing air temperature, dew-point temperature, wind speed, wind direction and cloud cover
Branch Inflow Files	qin_br1.npt	Flow rate file for branch 1 inflow - Yuba River
	qin_br2.npt	Flow rate file for branch 2 inflow - South Yuba River
	qin_br3.npt	Flow rate file for branch 3 inflow - no flow (i.e. dummy file)
	qin_br4.npt	Flow rate file for branch 4 inflow - no flow (i.e. dummy file)
	qin_br5.npt	Flow rate file for branch 5 inflow - no flow (i.e. dummy file)
	qin_br6.npt	Flow rate file for branch 6 inflow - no flow (i.e. dummy file)
	tin_br1.npt	Temperature file for branch 1 inflow - Yuba River

Table 6.1-1. Input files and descriptions for Englebright Temp Model.

File Type	File Name	Description
Branch Inflow Files (continued)	tin_br2.npt	Temperature file for branch 2 inflow - South Yuba River
	tin_br3.npt	Temperature file for branch 3 inflow - no temp (i.e. dummy file)
	tin_br4.npt	Temperature file for branch 4 inflow - no temp (i.e. dummy file)
	tin_br5.npt	Temperature file for branch 5 inflow - no temp (i.e. dummy file)
	tin_br6.npt	Temperature file for branch 6 inflow - no temp (i.e. dummy file)
Branch Outflow Files	qot_br1.npt	Flow rate file for branch 1 outflow - Englebright Dam
Distributed Tributary Files	qdt_br1.npt	Flow rate file for branch 1 non-point accretions - Yuba River
	qdt_br2.npt	Flow rate file for branch 2 non-point accretions - South Yuba River
	tdt_br1.npt	Temperature file for branch 1 non-point accretions - Yuba River
	tdt_br2.npt	Temperature file for branch 2 non-point accretions - South Yuba River
Shade File	shade.npt	Shade information for each model segment
Wind Sheltering Coefficient File	wsc.npt	Wind sheltering coefficients for each model segment
Graphing File	graph.npt	Graphing instructions file
Water-Surface Elevation Data File	el_obs.npt	Water-surface elevation data file

The control file contains variables used to run the model. For more detailed information regarding variables included in the control file see CE-QUAL-W2 User's Manual in Attachment 2-6A (Cole and Wells, 2011).

The bathymetry file contains segment lengths, initial water-surface elevation, segment orientation, layer thickness, cell widths, bottom friction, layer heights, and average cell widths for each segment layer. Each branch is surrounded by a non-active boundary segment (segments of zero width and length) on both the upstream and downstream end. Non-active boundary layers are also included at the top and bottom of each segment.

The meteorology file contains the following input data:

- Julian Date;
- Air temperature, °C;
- Dew-point temperature, °C;
- Wind speed, m/sec;
- Wind direction, radians;
- Cloud cover, 0 (clear) to 10 (cloudy); and
- Short-wave radiation, W/m2 (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 can calculate solar radiation if not provided. The CE-QUAL-W2 model directly calculates heat transfer parameters. A complete description of the meteorological input data can be found in Section 9.

Branch inflow files contain data for inflow for a branch with an upstream boundary condition. A separate inflow file is required for each branch. The first field of the branch inflow file is the

Julian Date and then second field in the input file is the inflow rate in m^3/sec. Note that inflow file cannot contain negative values. Negative values can only be present in distributed tributary inflow files.

Branch inflow temperature files contain data for inflow temperatures for an upstream boundary condition. A separate temperature inflow file is required for each branch. Like the branch inflow file, the first field is the Julian Date and the second field is the inflow temperature in °C. A complete description of the input temperature data can be found in Section 8.

Branch outflow files contain data for outflow for a branch with a downstream flow boundary condition. A separate outflow file is required for each branch with a downstream boundary condition. The first field is the Julian Date and the subsequent fields are the outflow rate for individual structures in m^3/sec. For the Englebright Temp Model, the first flow field corresponds to the Narrows 1 Powerhouse upper intake, the second flow field corresponds to the Narrows 1 Powerhouse lower intake, the third flow field corresponds to the Narrows 2 Powerhouse intake, and the fourth flow field corresponds to the spillway.

Branch distributed tributaries are optional. If used, their inflow files contain inflow data for a single branch. The first field in the distributed tributary file is the Julian Date and the second field is the inflow rate at m^3/sec. Distributed tributary inflow values can be negative. For the Englebright Temp Model, distributed tributaries are included for the Yuba and South Yuba River branches.

Branch distributed tributary temperature files contain inflow temperature data for a single branch. The first field in the distributed tributary file is the Julian Date and the second field is the inflow temperature in °C.

The shade input file contains information for computing the vegetative and topographic shading for each model segment. The shade file consists of four types of vegetative information for each bank of the river, topographic information, and the time for leaf growth and leaf fall if the trees are deciduous. If first value of the shade input file, [DYNSH] card, is set from 0 to 1, then static shading is used and the shade factor takes on the specific value. For example if a [DYNSH] value of 0.8 is provided, then CE-QUAL-W2 would allow 80% of the incoming short-wave solar to reach the water surface of the segment or 20% is fully shaded and would apply for all times. If [DYNSH] card is set to a negative value, then the remaining columns in the shade file are read for dynamic shading by segment and time.

The wind sheltering file contains the Julian date and the wind sheltering coefficient for each segment. The wind sheltering coefficient scales the magnitude of the wind speed. This file allows for segment-by-segment wind velocity data, which is preferable if the data are based on one meteorological station. Wind sheltering coefficients are adjusted during model calibration.

The graphing file is a required file for all model simulations of CE-QUAL-W2 on a PC using the downloadable executable. This file controls the input and output format.

The water-surface elevation file is a file containing historical water-surface elevation data to be used by the water-balance utility.

Executable files are used to run the CE-QUAL-W2 model. Table 6.1-2 shows the executable files and their descriptions used to create the Englebright Temp Model. Note that CE-QUAL-W2 can also be run on a 64-bit PC using different preprocessor and executable files.

Table 6.1-2. Executable files and descriptions for Englebright Temp Model.

File Type	File Name	Description
Executable files	preW2-37_32.exe	32-Bit CE-QUAL-W2 Preprocessor
	w2_ivf32.exe	32-Bit CE-QUAL-W2 Executable
	w2Control37.exe	Graphical User Interface (GUI)
	waterbal_ivf37.exe	Water-balance Utility Executable

The preprocessor executable file (preW2-37_32.exe) produces several output files including:

- A file that echoes all the control inputs (pre.opt),
- A file that summarizes any potential problems/warnings with the input data (pre.wrn), and
- A file that summarizes any serious problems with the input data that could prevent the model from running or running incorrectly (pre.err).

If no errors or warning are detected when running the preprocessor file, the warning file (pre.wrn) and the error file (pre.err) are not created.

The CE-QUAL-W2 executable file runs the CE-QUAL-W2 model.

The Graphical User Interface (GUI) executable file is used to view the control file in a user-friendly way. The control file can also be viewed as a text file.

The water-balance utility is used to create a separate outflow file in order to achieve a specific water-surface elevation. To use the water-balance utility, the model must be run first through the entire period of record in order to create the time series output file of modeled water-surface elevations (tsr_1_seg.opt). Historic water-surface elevations must also be available to run this utility. Running the water-balance utility to achieve historic water-surface elevations tends to be an iterative process that requires multiple runs.

6.1.3 Detailed Description

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

6.1.3.1 Bathymetry

Bathymetric modeling was completed at Englebright Reservoir in 2001 and 2002 by the 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 0.91-meter (approximately 3 ft) 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 each reservoir. A summary of the length and segment spacing for each branch can be found in Table 6.1-3.

Table 6.1-3. 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, 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 is organized this way to impose boundary conditions.[7]

A side-view of the model grid is shown in Figures 6.1-1.

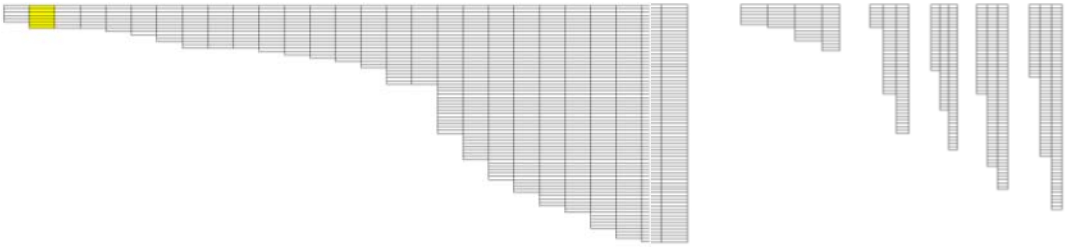

Figure 6.1-1. Englebright Temp Model grid side view.

Table 6.1-4 provides a summary of model grid statistics.

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

Table 6.1-4. Summary of model grid details for Englebright Reservoir.

Parameter (units)	Value
Number of water bodies	1
Number of branches	6
Number of segments	55
Minimum grid elevation (ft-msl)	331
Maximum grid elevation (ft-msl)	546
Number of layers	74
Layer thickness (ft)	3
Latitude (decimal degrees)	39.2585
Longitude (decimal degrees)	-121.2390

Figure 6.1-2 shows the volume-elevation curves for this system.

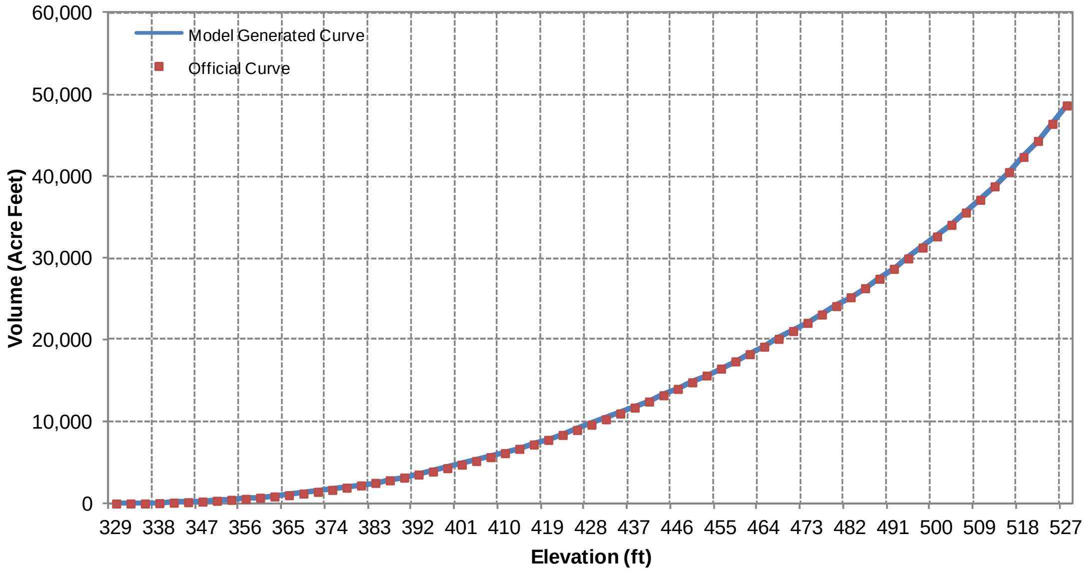


Figure 6.1-2. Englebright Reservoir volume-elevation curve. Official curve is based on 2002 USGS bathymetric survey data.

6.1.3.2 Reservoir Physical Characteristics

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

The reservoir is impounded by Englebright Dam, a variable concrete radius 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 to the Narrows 1 and 2 Powerhouses, or spilled over the top of the dam. The Narrows 1 Powerhouse has a maximum capacity of 730 cfs and 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-msl. The intake for the Narrows 1 Powerhouse has a centerline elevation of 460 ft-msl with intake dimensions of 12 ft by 12 ft. The Narrows 2 Powerhouse intake has a centerline elevation of 448.38 ft-msl. No additional information is available for the Narrows 2 Powerhouse intake.

6.2 Outputs

This section describes the files created when the CE-QUAL-W2 model is run. Table 6.2-1 shows the output files and their descriptions used to create the Englebright Temp Model.

Table 6.2-1. Output files and descriptions for Englebright Temp Model.

File Type	File Name	Description
Output files	qwo_28.opt	Outflow file for segment 28 - Englebright Dam
	two_28.opt	Outflow temperature file for segment 28 - Englebright Dam
	qwo_str1_seg28.opt	Outflow file for segment 28 - Narrows 1 upper intake
	qwo_str2_seg28.opt	Outflow file for segment 28 - Narrows 1 lower intake
	qwo_str3_seg28.opt	Outflow file for segment 28 - Narrows 2 intake
	qwo_str4_seg28.opt	Outflow file for segment 28 - Englebright Dam spillway
	two_str1_seg28.opt	Outflow temperature file for segment 28 - Narrows 1 upper intake
	two_str2_seg28.opt	Outflow temperature file for segment 28 - Narrows 1 lower intake
	two_str3_seg28.opt	Outflow temperature file for segment 28 - Narrows 2 intake
	two_str4_seg28.opt	Outflow temperature file for segment 28 - Englebright Dam spillway
	tsr_1_seg28.opt	Time series output at segment 28 - Englebright Dam
	wl.opt	Water-level output file
	W2Errordump.opt	Error dump file
	w2.err	Run time error file
	w2.wrn	Run time warning file

The outflow files contain release or withdrawal flows and temperatures as a time series. The files contain the Julian Day and outflow temperatures or flows. The segment temperature outflow files (two_28.opt) contain a combined flow-weighted temperature for multiple outlets and then a specific temperature for each of the outlets in °C.

An example of the flow file for a system containing four structures is shown below. The total flow through each of the structures is listed after the Julian Day and the individual flows for each structure shown following the total flow. The same file structure is present for the temperature withdrawal files.

```
Flow file for segment 16
To the right of the sum of flows are individual flows starting with QWD then
QSTR
JDAY QWD
1.002 14.84 0.40 0.00 7.22 7.22
1.200 14.88 0.40 0.00 7.24 7.24
1.400 14.92 0.40 0.00 7.26 7.26
```

Also, when there are multiple outlets, a series of individual files are output for each structure at the withdrawal segment. These files contain the output temperature and flows for each structure. In this case, structure 1 is the Narrows 1 Powerhouse upper intake, structure 2 is the Narrows 1

Powerhouse lower intake, structure 3 is the Narrows 1 Powerhouse intake, and structure 4 is the Englebright dam spillway.

The water-level output file is a summary of water-level variations as a function of time. The water level is written out at every model segment in this file, rather than at a user specified segment as in the time series output file. The file consists of the Julian Day and the water-surface elevation at each model segment, in meters.

The time series output file contains the Julian Date, water-surface elevation, temperature, flow rate (vertically integrated segment flow rate at the specified model segment), short-wave solar radiation (net), light extinction coefficient, (m^{-1}), depth to bottom of channel (m), surface width (m), and shade fraction (1.0 is no shade, 0.0 is 100% reduction in solar radiation). The time series output is also used by the water-balance utility.

Additional files are created if the model is run and errors or warnings are detected. These files are the run-time error files. The run-time files are helpful when the model is being built.

6.3 Running the Model

CE-QUAL-W2 model files can be found on the CE-QUAL-W2 website (http://www.ce.pdx.edu/w2) and in Attachment 2-6B. Directions to installing the modeling software are available on the website, and in the manual, which is included in Attachment 2-6A. To run the CE-QUAL-W2 model, input and executable files should be placed into the same folder on the computer. This folder can be located on a server drive or on your local desktop. Multiple instances of CE-QUAL-W2 can be run at the same time.

The first step in running the CE-QUAL-W2 model is to double click the preprocessor executable to run the preprocessor. After the preprocessor is run, the user must review the output files the preprocessor creates (pre.opt, pre.wrn, and pre.err) to determine if further edits are needed before running the model. If no errors are detected and warnings are reviewed and determined to not to be detrimental to the model, the user then can run the CE-QUAL-W2 model by double click the run executable.

7.0 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 diversions at Daguerre Point Dam. The Lower Temp Model was calibrated to compute water temperatures at the USGS Marysville gage. Figure 7.0-1 shows the Lower Temp Model schematic.

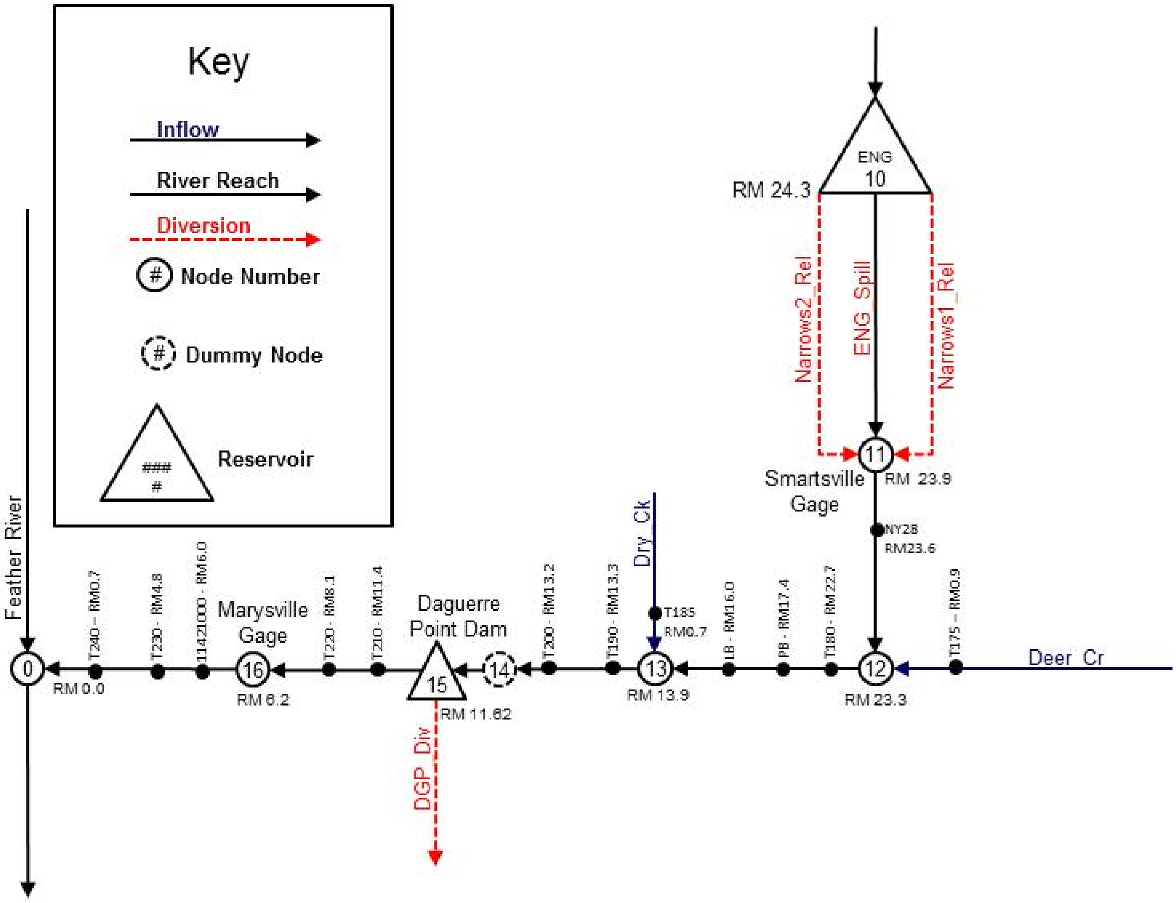


Figure 7.0-1. Lower Temp Model Schematic.

7.1 Input

The following section describes the general input for the Lower Temp Model, required files for the model, and a description of the representation of each of the components of the Lower Temp Model. Meteorological input data for the Lower Temp Model are described in Section 9.3, and input temperatures for the Lower Temp Model are described in Section 8.3.

7.1.1 General Description

Similar to the Upper Temp Model, the Lower Temp Model was developed using HEC-5Q "Alpha" Version 8.0 from June 9, 1997. The input structure for HEC-5Q is designed to be flexible with respect to inputs into the system. Each input is described in detail in the HEC-5Q manual, included in Attachment 2-6A. The types of input records for HEC-5Q are described in Table 5.1-1.

For the Lower Temp Model, there are three different scenarios – the Calibration Scenario, the Validation scenario, and the Base Case scenario. The Calibration scenario was run for the period of record of January 1, 2008 through September 30, 2012. The Validation Scenario was run for the period of record of January 1, 2000 to September 30, 2011. The Base Case scenario was run for the period of record of October 1, 1969 through September 30, 2010. See Sections 10 (Calibration) and 11 (Validation) for more detailed information regarding each of the Calibration and Validation scenarios; the Base Case Scenario is not included in this report.

A general description of the HEC-5Q parameters is provided in Section 5.1.1. Some additional information specific to the Lower Temp Model is provided below.

General reservoir data describe the reservoir simulation and the physical characteristics of the reservoir and define the printout interval, miscellaneous physical constants, and additional reservoir storage, area, and elevation data. For the Lower Temp Model, a “dummy” reservoir representing Englebright Reservoir was used to simulate the outflow from Englebright Reservoir. The “dummy” Englebright Reservoir was set up as a longitudinally segmented reservoir and used only because HEC-5Q requires that the upstream most point of a system be defined by a reservoir. To provide hydraulic control downstream from the agricultural diversions during extremely low flow conditions, Daguerre Point Dam was included as a longitudinally segmented reservoir.

Stream-related data includes printout controls, reach limits, local inflow and withdrawal locations, reaeration controls, channel cross section geometry, and energy grade line elevations. For the Lower Temp Model the geometry were taken from the River Management Team (RMT) Sedimentation and River Hydraulics - 2D Version 2.1 (SRH2D) model (Pasternack and Lower Yuba RMT 2012). The river was broken into five reaches based on physical features: (1) between Englebright and Deer Creek, (2) between Deer Creek and Dry Creek, (3) between Dry Creek and Daguerre Point Dam, (4) between Daguerre Point Dam and Marysville gage, and (5) between Marysville gage and Feather River.

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 5 elevations were defined between the 5,000 cfs elevation and the 50,000 cfs elevation.

Inflow water temperatures for all three models will be based on the specific start date and will either be from simulated data, i.e. the Base Case, or from historical data, i.e. the Calibration and the Validation scenarios. Initial inflow time series will be read into the HEC-5Q model via DSS.

7.1.2 Files

The files needed to run the Lower Temp Model include the Lower Temp Model Microsoft® Excel file (LTM.xlsm) containing the code for the model, HEC-5Q executable (HEC-5Q.exe), the Input DSS file (Input.dss), and two supporting files, an execution script (hec5q.vbs) and a batch file to run the model (run.bat). This section describes each of the primary files; the other two files are included to make running the model easier, but are not critical for model execution.

A Microsoft Excel® spreadsheet titled LTM.xlsm contains all of the HEC-5Q model code. This file contains all the code used for the Lower Temp Model. There are five worksheets contained in the LTM excel file. These worksheets are:

- Batch file info (LOWER),
- HEC-5 data (LOWER5),
- HEC-5Q data (LOWERTM),
- Geometry data (LRY-S3),
- Tributary data (LYR-I2), and
- Energy Lookup

HEC-5Q is designed to accept certain inputs interactively or from a quasi-batch file. As the program is initiated, a prompt asks for the batch file name or "none" if the interactive input is desired. The first worksheet in the excel file is the batch file associated with the Lower Temp Model. The batch file for the Lower Temp Model contains the following information:

- Simulation Date,
- File name of the HEC-5 data,
- File name of the HEC-5Q data,
- DSS file name of input data, and
- DSS file name of output data

The second worksheet in the LTM.xlsm file is for the water balance operations data. This worksheet contains the code and coefficients for the following data:

- Title and Job Control Information and
- Longitudinally Segmented Reservoir Data, including inflows and outflows

The third worksheet in the LTM file is for the water quality modeling data. This worksheet contains the code and coefficients for the following data:

- Title and Job Control Information,
- Water-Surface Heat Exchange Data,
- Water Quality Constituents Data,
- General Reservoir Data,
- Longitudinally Segmented Reservoir Data, including inflows and outflows,
- Initial Temperature and Water Quality Conditions,

- Stream Related Data, and
- Local Inflow Temperature and Water Quality

The fourth worksheet in the LTM.xlsm file is for the cross-section data. This worksheet contains the following data:

- Scaling factors for width, areas, and flow rates,
- Channel cross section geometry from upstream to downstream,
- Manning's "n" data, and
- Energy grade line

The fifth worksheet in the LTM.xlsm file is for the tributary data. This worksheet contains the following data:

- Local Inflow Temperatures and Water Quality

A sixth worksheet in the LTM.xlsm file, Energy Lookup, is included with information about the energy gradeline for the model. This information is referenced by lookup from the cross-section worksheet, but is not an input to the HEC-5Q model.

An executable files is used to run the HEC-5Q model. This executable file is named HEC-5Q.exe.

Throughout the LTM.xlsm file, code is written to read the input temperatures, flow, and meteorology from a DSS file. This DSS file is also included in the input files for the Lower Temp Model.

7.1.3 Description of Model Setup

The 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. The following section describes the parameters used in the quality module described above. A description of the model calibration process and results can be found in Section 10.6.3; however, the parameters determined through calibration are described in this section.

Unlike the Upper Temp Model, no reservoir release decisions were needed for the Lower Temp Model. The HEC-5Q water balance module used Narrows 1 and Narrows 2 powerhouse releases and Englebright Reservoir spills from the Water Balance/Operations Model as inflows. Inflows from Deer and Dry creeks, and Daguerre Point Dam agricultural diversions were also from the Water Balance/Operations Model.

Meteorological scaling factors were the most effective for calibrating the Lower Temp Model. Many parameters modifying meteorological effects are available within HEC-5Q, as described in Section 5.1.3.1. The available parameters and a description of their respective effects are included below:

- KZOPP: Since dissolved oxygen is not simulated in the model, oxygen reaeration is not an issue. A value of 1 is used as a placeholder.
- RK2MI: Since dissolved oxygen is not simulated in the model, oxygen reaeration is not an issue. A value of 0 is used as a placeholder.
- RK2: Since dissolved oxygen is not simulated in the model, oxygen reaeration is not an issue. A value of 0 is used as a placeholder.
- CKL1: Since dissolved oxygen is not simulated in the model, oxygen reaeration is not an issue. A value of 1 is used as a placeholder.
- CKL2: Since dissolved oxygen is not simulated in the model, oxygen reaeration is not an issue. A value of 5 is used as a placeholder.
- DDC: Changed from 0 to 4 with no noticeable effect on simulated water temperatures. A value of 1.0, indicating no change in diffusion, was ultimately selected.
- BEDKC: Changed from 0 to 5 with no noticeable effect on simulated water temperatures. A value of 0.0, indicating heat exchange with the bottom is ignored, was ultimately selected.
- BEDDEP: Set at 3.5 when BEDKC was tested. With a BEDKC value of 0, the bed thickness is not used, so a value of 0.0 was ultimately selected.
- ICEZON: Since ice cover is not an issue on the Yuba River within the Project area, a value of 0.0 was used for this parameter.
- FICEL: Since ice cover is not an issue on the Yuba River within the Project area, a value of 0.0 was used for this parameter.
- SFMET1: This parameter primarily affected the bias of the simulated output as compared to historically-measured data. SFMET1 varies by reach. Increasing the SFMET1 generally resulted in an increase in the average simulated temperature. However, there was a reach-varying value that was the limit of the parameter’s ability to increase or decrease the average temperature. The calibration values of SFMET1 determined for each reach are shown in Table 7.1-1.
- SFMET2: This parameter can have significant effects on model calibration by similarly changing the bias of the simulated output. SFMET2 has the effect of dampening, or exaggerating changes; a smaller value reduces the peaks, a larger value increases the peaks. Low temperatures are not significantly affected by SFMET2. The calibration values of SFMET2 determined for each reach are shown in Table 7.1-1.
- SFMET3: This parameter has a similarly significant effect on model calibration by changing the responsiveness of the simulated temperatures to changes in inputs. The coefficient of heat exchange is multiplied by the difference between the water-surface

temperature and the atmospheric temperature to calculate the quantity of heat exchange; a larger coefficient of heat exchange results in a greater transfer of energy, and a smaller coefficient of heat exchange results in a smaller transfer of energy. Reducing SFMET3 has the effect of reducing the variability of the simulated temperatures, but does not have a significant effect on the overall bias of the simulation. The calibration values of SFMET3 determined for each reach are shown in Table 7.1-1.

Besides the meteorological scaling factors, other parameters are also available for calibration. Other potential parameters for calibration include the following:

- Channel Geometry Scaling Factors: Due to the availability of high quality channel geometry for the Yuba River below Englebright Dam, no channel geometry scaling factors were used for calibration of the Lower Temp Model. Default values were used for the channel geometry scaling factors.
- Wind Speed: As described in Section 9, the HEATX program is used to compute the equilibrium temperature, coefficient of heat exchange, and solar radiation values used as inputs to HEC-5Q. Windspeed, as measured at Beale AFB, was reduced by 50% for use in determining the coefficient of heat exchange and as an input to the Lower Temp Model. This reduction in windspeed was in recognition of the difference in windspeed in the wide-open area of an airport as compared to within the banks of a river channel. The reduction in windspeed had the effect of reducing the coefficient of heat exchange and reducing the sensitivity of the simulated temperatures to changes in equilibrium temperature. A reduction to 25% of the original windspeed was also examined, but it did not improve the calibration of the Lower Temp Model.

Table 7.1-1 shows parameter values used to calibrate the Lower Temp Model.

Table 7.1-1. Parameters values used for the calibration of the Lower Temp Model.

Parameter	Description	Value (unit-less, unless provided)
PARAMETER VALUES FOR ALL REACHES		
HEXF	Equilibrium temperature scaling factor to account for environmental factors such as shading by riparian vegetation	1.0
DDC	Diffusion coefficient	1.0
BEDKC	Thermal conductivity constant for heat transfer to and from the bottom sediments	0.0
BEDDEP	Equivalent bed thickness for heat storage	0.0 ft
PARAMETER VALUES FOR THE YUBA RIVER BETWEEN SMARTSVILLE AND DEER CREEK		
SFMET1	Equilibrium temperature offset	0°C
SFMET2	Equilibrium temperature scaling factor	2.0
SFMET3	Heat exchange rate scaling factor	1.0
PARAMETER VALUES FOR THE YUBA RIVER BETWEEN DEER CREEK AND DRY CREEK		
SFMET1	Equilibrium temperature offset	1.45°C
SFMET2	Equilibrium temperature scaling factor	1.3
SFMET3	Heat exchange rate scaling factor	0.8
PARAMETER VALUES FOR THE YUBA RIVER BETWEEN DRY CREEK AND DAGUERRE POINT DAM		
SFMET1	Equilibrium temperature offset	-1.2°C
SFMET2	Equilibrium temperature scaling factor	0.8
SFMET3	Heat exchange rate scaling factor	0.9

Table 7.1-1. (continued)

Parameter	Description	Value (unit-less, unless provided)
PARAMETER VALUES FOR THE YUBA RIVER BETWEEN DAGUERRE POINT DAM AND MARYSVILLE GAGE		
SFMET1	Equilibrium temperature offset	2.8°C
SFMET2	Equilibrium temperature scaling factor	4.0
SFMET3	Heat exchange rate scaling factor	0.2
PARAMETER VALUES FOR THE YUBA RIVER BETWEEN THE MARYSVILLE GAGE AND THE FEATHER RIVER		
SFMET1	Equilibrium temperature offset	2.1°C
SFMET2	Equilibrium temperature scaling factor	3.0
SFMET3	Heat exchange rate scaling factor	0.4

The Lower Temp Model has a relatively simple physical representation. RMs for key features and the river channel geometry is defined. Table 7.1-2 has the RMs for features represented in the Lower Temp Model.

Table 7.1-2. River miles of features along the Yuba River below Englebright Dam.

Feature	River Mile
Yuba River confluence with the Feather River	Yuba 0.0
Marysville Gage	Yuba 6.2
Daguerre Point Dam	Yuba 11.6
Dry Creek confluence with the Yuba River	Yuba 13.9
Deer Creek confluence with the Yuba River	Yuba 23.4
Smartsville Gage	Yuba 23.9

HEC-5Q computes water-surface area based on its internal hydraulic calculation based on geometric information provided along the river. River geometry was taken from the RMT SRH2D model (Pasternack and Lower Yuba RMT 2012). . River cross-channel geometry was extracted by GIS at the locations shown in Figure 7.1-1.

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 were 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 5 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.

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.

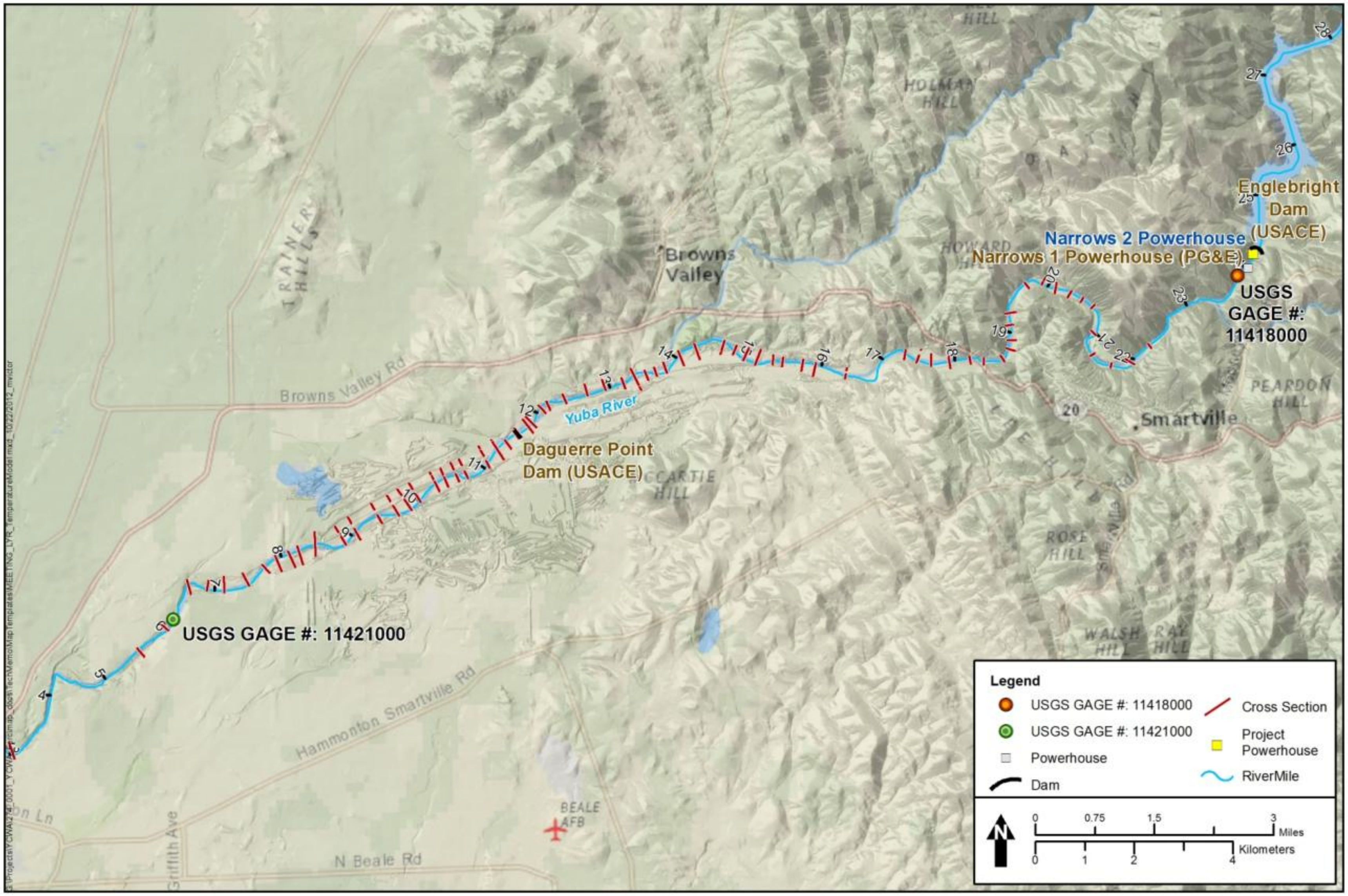


Figure 7.1-1. Location of Lower Temp Model river sections.

7.2 Outputs

Output from the HEC-5Q can be written into several files that are specified by their input controls. The output options for HEC-5Q are:

- ASCII HEC-5Q output fie or traditional printer output
- DSS output file in which data is stored in a DSS file

The output file, "Output.DSS," containing all of the water temperature model output should be in the model folder after successfully executing the model. The model writes its internal water balance model output to the Input.DSS file.

7.3 Running the Model

The five included files must be copied to a folder on the user's C: drive. After opening the LTM.xlsm file, and making any adjustments desired, simply press "cntrl-e" to execute the model. This action will initiate a script exporting the HEC-5Q input files from the Microsoft® Excel file to the model folder, and running the included batch file to execute the model. A Microsoft DOS shell window should open, and the user should see the simulation dates streaming across the screen. Upon completion, the shell window will request the user to "hit any key to continue," closing the shell window.

8.0 Input Water Temperature Development

Simulation of the period of record for each model is dependent on a complete period of record of input flows and water temperatures. Each model requires that all input flows should have an associated water temperature specified. This section describes the development of the input water temperature information. For more information about the inflow hydrology, see Section 2.3.

8.1 Upper Temp Model

Inflows for the Upper Temp Model come directly from the Water Balance/Operations Model. Table 8.1-1 shows the inputs to the model and their respective names in the input DSS file.

Table 8.1-1. Upper Temp Model input flows and 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
Accretions to Oregon Creek between Log Cabin Diversion Dam and the Middle Yuba River	INF_OREGONCR_ACC
Middle Yuba River above Our House Diversion Dam	INF_MYUBA
Accretions to the Middle Yuba River between Our House Diversion Dam and Oregon Cree	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 New Colgate Powerhouse	INF_UPPERYUBA_ACC

Table 8.1-1. (continued)

Location	HEC-DSS Name
Diversions from New Bullards Bar Reservoir to the New Colgate Powerhouse	COLGATE_RELEASE
Diversions from Our House Dam to Oregon Creek	LOHMANRIDGE_TUNNEL
Diversions from Log Cabin Dam to New Bullards Bar Reservoir	CAMPTONVILLE_TUNNEL
Releases from New Bullards Bar Reservoir through the low-level outlet	NBB_LOW_LEVEL

Input water temperatures are contained in the same input file as the input flows, and have the same name as the input flows. The difference between the two is that, while the input flows have a “FLOW” designation, the input temperatures have a “TEMP” designation within the file. While their flows are also determined by the Water Balance/Operations Model, water temperatures of releases from the New Colgate Powerhouse penstock, the Lohman Ridge Tunnel, the Camptonville Tunnel, and the New Bullards Bar Dam low-level outlet are computed as part of the Upper Temp Model simulation.

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

Conversely, historical water temperature information is available for three primary input flows, the North Yuba and Middle Yuba rivers, and Oregon Creek. However, limited period of records for the data is available, and within the period of record, there are 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*.

For the North Yuba River, YCWA’s gage on the North Yuba River upstream from New Bullards Bar Reservoir, T065, was used for input temperatures. For the Middle Yuba River, YCWA gages on the Middle Yuba River above the Our House Diversion Dam impoundment (T010), at the intake to the Lohman Ridge Tunnel (T020), and downstream from Our House Diversion Dam (T030) were essentially identical, so all three were used to create the period of record. On Oregon Creek, the YCWA gage upstream from the Log Cabin Diversion Dam impoundment (T040) was used. Table 8.1-2 shows the earliest and latest dates of available information for the periods of record available for each location.

Table 8.1-2. Earliest and latest dates for available information for input water temperatures to the Upper Temp Model.

Location	Start Date	End Date
North Yuba River (T065)	10/1/2008	10/14/2012
Middle Yuba River (T010)	10/1/2008	10/15/2012
Oregon Creek (T040)	7/8/2008	10/15/2012

Since each of the Upper Temp Model scenarios ran for a different period of record, and each had slightly different requirements for input water temperatures, different water temperature input data sets were developed for each of the Upper Temp Model scenarios The following sections describe the sources of water temperature data used in the Calibration, Validation, and Base Case scenarios.

8.1.1 Calibration Scenario

For the Calibration Scenario, it is preferable that historical data is used as much as possible, since this is modeling phase in which the model is modified to best represent historical data. Where data was missing, it was filled in with data from a different period or location. Table 8.1-3 shows the input data used for the Upper Temp Model Calibration Scenario.

Table 8.1-3. Upper Temp Model Calibration Scenario Input Water Temperature Sources.

Location	Source	Start of Period of Record Used	End of Period of Record Used
North Yuba River inflow	YCWA gage T065	11/14/2009	9/30/2012
Oregon Creek inflow	YCWA gage T040	11/14/2009	9/30/2012
Middle Yuba River inflow	YCWA gage T030	11/14/2009	9/30/2012
Middle Yuba, Oregon Creek, and Yuba River accretions	YCWA gage T040	11/14/2009	9/30/2012

The T065 gage was missing data for the period of June 13, 2011 through June 29, 2011. To ensure relatively smooth transitions of temperatures, water temperatures from the T030 gage was used for North Yuba River inflow temperatures for the period of June 9, 2011 through June 30, 2011.

8.1.2 Validation Scenario

Since historical inflow water temperatures were not available for the full validation period of record, synthetic inflow water temperatures were needed.

Review of the available temperature data for the monitoring three locations indicated little variation from year to year. Of the approximately 5 years of available data, four (WYs 2008 and 2009, 2011 and 2012) were relatively dry and one (WYs 2011) was relatively wet.

For the YCWA gage on the North Yuba River (T065), maximum-annual temperatures ranged from 65.5°F to 74.1°F, and occurred between July 18 and August 18 of each year between WY 2009 and 2012. Minimum-annual temperatures neared freezing (32°F), and occurred between December and February each year. There was some correlation between hydrology and water temperature, but with the volume of New Bullards Bar Reservoir effects of variations in inflow water temperature on downstream reaches are buffered out by the reservoir. Since it was moderately dry year, North Yuba River water temperatures from January 1, 2010 through December 31, 2010 were used as inflow temperatures for all years with below average annual North Yuba River inflow volume. Since it was a relatively wet year, North Yuba River water temperatures from January 1, 2011 through December 31, 2011 were used as inflow temperatures for all years with above average annual North Yuba River inflow volume. Figure 8.1-1 shows a comparison of the historically-measured North Yuba River water temperatures.

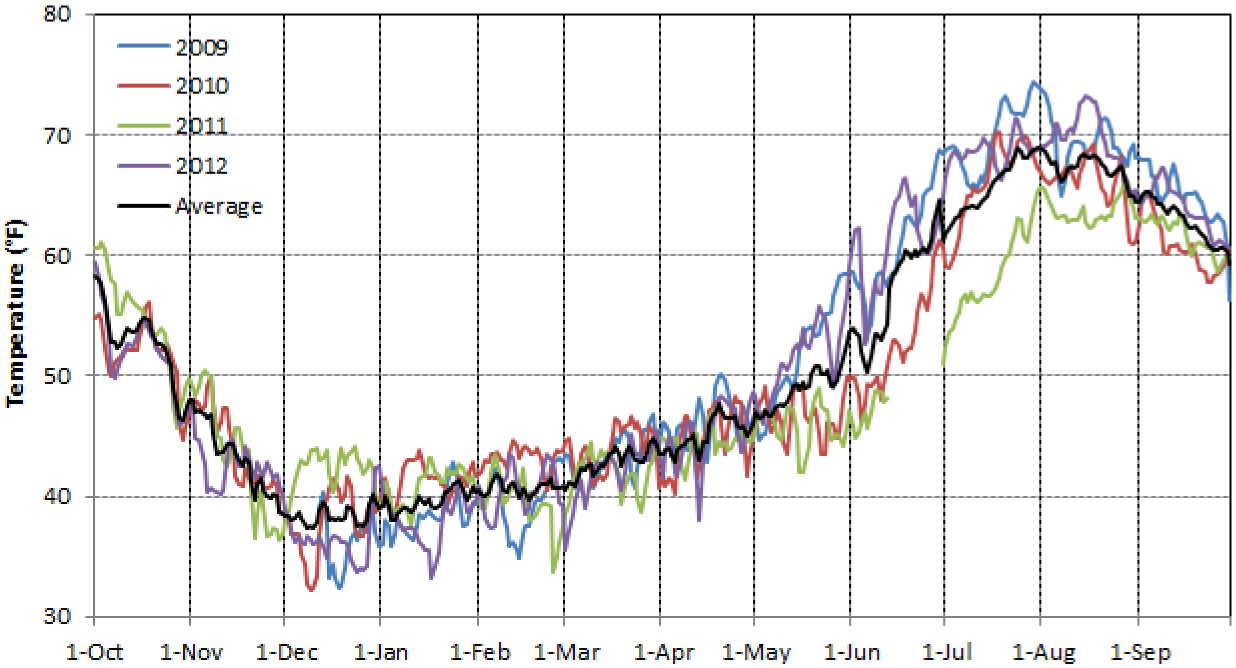


Figure 8.1-1. Comparison of historically-measured mean-daily North Yuba River water temperatures.

On the Middle Yuba River, the YCWA gage downstream from Our House Diversion Dam (T030) had the longest and most complete period of record of the three gage locations around Our House Diversion Dam. Maximum-annual temperatures ranged from 70.9°F to 76.3°F and occurred between July 18 and August 15 each year. Minimum-annual temperatures neared freezing and occurred in December, January, and February of each year. Similar to the North Yuba River, there was some correlation between hydrology and water temperature, but it was relatively weak. With so little variation in temperature from year to year, Middle Yuba River water temperatures from January 1, 2010 through December 31, 2010 were used as inflow temperatures for all years with below average annual Middle Yuba River inflow volume and Middle Yuba River water temperatures from January 1, 2011 through December 31, 2011 were used as inflow temperatures for all years with greater than average annual Middle Yuba River inflow volume. Figure 8.1-2 shows a comparison of historically-measured Middle Yuba River water temperatures.

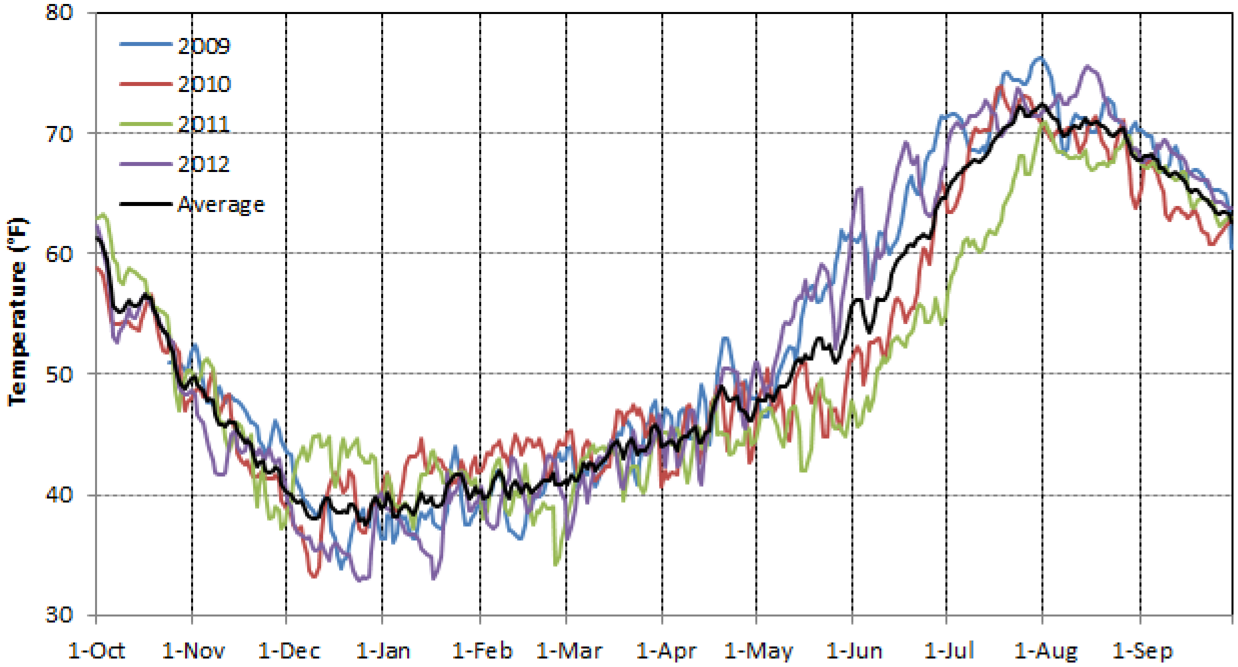


Figure 8.1-2. Comparison of historically-measured Middle Yuba River water temperatures.

On Oregon Creek, the YCWA temperature gage upstream from the Log Cabin Diversion Dam impoundment (T040) was used. Maximum-annual temperatures ranged from 67.3°F to 70.9°F, and occurred between July 18 and August 15 of each year. Minimum-annual temperatures neared freezing and occurred in December, January, and February of each year. Similar to the North Yuba River, there was some correlation between hydrology and water temperature, but it was relatively weak. With so little variation in temperature from year to year, Oregon Creek water temperatures from January 1, 2010 through December 31, 2010 were used as inflow temperatures for all years with below average annual Oregon Creek inflow volume and Oregon Creek water temperatures from January 1, 2011 through December 31, 2011 were used as inflow temperatures for all years with above average annual Oregon Creek inflow volume. Figure 8.1-3 shows a comparison of historically-measured Oregon Creek water temperatures.

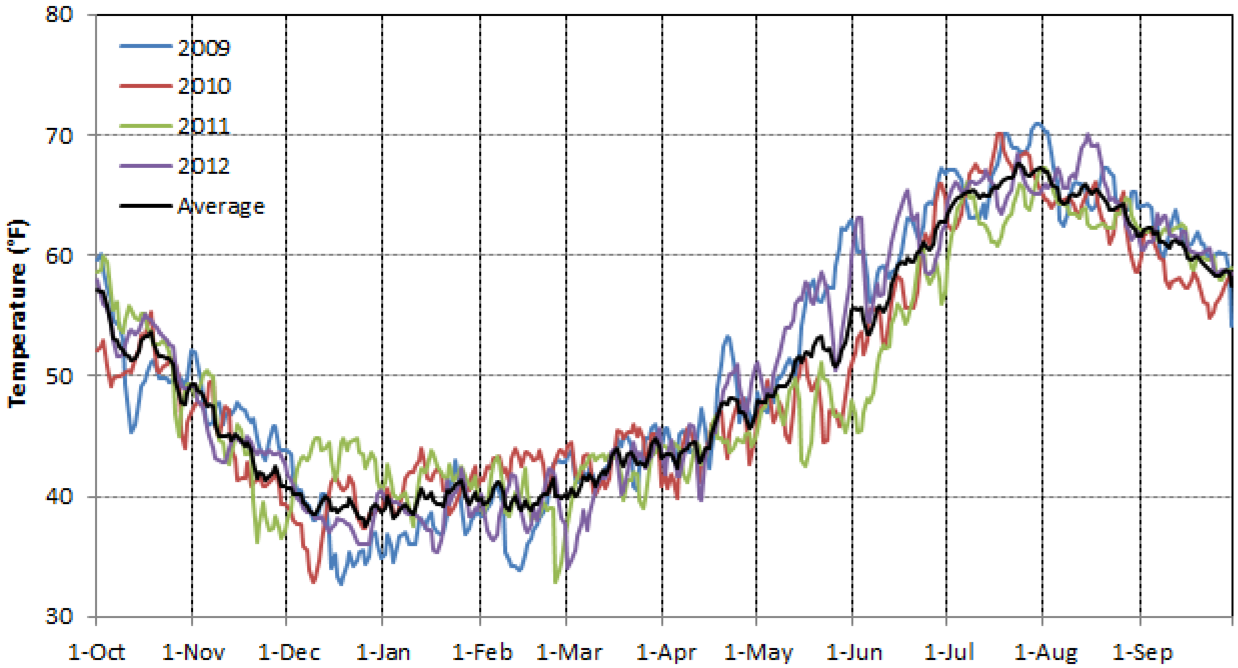


Figure 8.1-3. Comparison of historically-measured Oregon Creek water temperatures.

Table 8.1-4 shows the input data used for the Upper Temp Model Validation Scenario. The classification of years as either below average or above average is shown in Table 8.1-6

Table 8.1-4. Upper Temp Model Validation Scenario Input Water Temperature Sources.

Location	Source	Treatment	Start of Period of Record Used	End of Period of Record Used
North Yuba River inflow	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	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	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
Middle Yuba, Oregon Creek, and Yuba River accretions	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

8.1.3 Base Case Scenario

The Base Case Scenario uses the same methodology as the Validation Scenario; water temperatures for specific years are repeated based on the hydrology of the year. Table 8.1-5 shows the sources of hydrology used for the Upper Temp Model Base Case Scenario.

Table 8.1-5. Upper Temp Model Base Case Scenario Input Water Temperature Sources.

Location	Source	Treatment	Start of Period of Record Used	End of Period of Record Used
North Yuba River inflow	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	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

Table 8.1-5. (continued)

Location	Source	Treatment	Start of Period of Record Used	End of Period of Record Used
Middle Yuba River inflow	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
Middle Yuba, Oregon Creek, and Yuba River accretions	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

Table 8.1-6 shows the years classified as above average or below average, as used to apply the inflow hydrology.

Table 8.1-6. Relative Hydrologic Condition for Upper Temp Model Base Case and Validation Scenario Simulation Years.

Hydrologic Condition	Water Years
Above Average	1969, 1970, 1971, 1973, 1974, 1975, 1978, 1980, 1982, 1983, 1984, 1986, 1993, 1995, 1996, 1997, 1998, 1999, 2006, 2011
Below Average	1972, 1976, 1977, 1979, 1981, 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1994, 2000, 2001, 2002, 2003, 2004, 2005, 2007, 2008, 2009, 2010

8.2 Englebright Temp Model

The Englebright Temp Model was setup to run three different scenarios: Calibration, Validation, and Base Case. Table 8.2-1 summarizes the primary source data, historical or synthetic, for each scenario.

Table 8.2-1. Englebright Temp Model Scenario Input Data Summary.

Input Data	Calibration Model	Validation Model	Base Case
Met	Historical	Historical	Synthetic
Water-Surface Elevation	Historical	Historical	Water Balance/Operations Model Output
River Inflow	Historical	Historical	Water Balance/Operations Model Output
South Yuba River Accretion Flow	(None)	(None)	Water Balance/Operations Model Output
Yuba River Accretion Flow	Water-Balance Utility Output	Water-Balance Utility Output	Water-Balance Utility Output
Spillway outflow	Historical	Historical	Water Balance/Operations Model Output
Powerhouse outflow	Historical	Historical	Water Balance/Operations Model Output
Temperature Input	Historical	Synthetic	Synthetic

Historical inflows to the Englebright Temp Model below the New Colgate Powerhouse for the Calibration and Validation scenarios were computed based on historically-measured flows below Our House and Log Cabin diversion dams and New Bullards Bar Dam, historically-measured releases from the New Colgate Powerhouse, and the intervening synthetic accretions. Calculations of accretions to the Englebright Temp Model are described in Attachment 2-2D. Table 8.2-2 shows the inputs to the Base Case Scenario model and their respective names in the input DSS file.

Table 8.2-2. Englebright Temp Model Base Case Scenario Input Flows and DSS Names.

Location	HEC-DSS Name
Yuba River between New Colgate Powerhouse and Rice's Crossing	YR_34.1_T130
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

Since each scenario of the Englebright Temp model ran for a different periods of record, and each had slightly different requirements for input water temperatures, different water temperature input data sets were developed for each scenario. The following sections describe the sources of water temperature data used.

8.2.1 Calibration Scenario

For the Calibration Scenario, it is preferable that historical data are used as much as possible, since this is modeling phase in which the model is modified to best represent historical data. Where data were missing, gaps were filled with data developed for the validation scenario, as described in Section 8.2.2. Table 8.2-3 shows the input data used for the Englebright Temp Model Calibration Scenario.

Table 8.2-3. Englebright Temp Model Calibration Scenario Input Water Temperature Sources.

Location	Source	Data Treatment	Start of Period of Record Used	End of Period of Record Used
Yuba River below the New Colgate Powerhouse	YCWA gage T130	Data filled in where necessary	08/18/2008	09/30/2012
South Yuba River at Jones Bar	YCWA gage YC6	Data filled in where necessary	07/21/2008	09/30/2012
Englebright Reservoir Accretions	YCWA gage T185	Averaged and Repeated	04/01/2009	09/30/2012

Data were missing in the Yuba River from December 19, 2008 through 26 March, 2009, and from November 9, 2009 through April 1, 2010. Data were missing in the South Yuba River from December 11, 2008 through February 5, 2009.

Englebright Reservoir accretion temperatures are ungaged. Alternatively, accretion temperatures are based on water temperatures measured by YCWA gage T185 on Dry Creek. Daily average water temperatures were calculated for the entire period of record from hourly data. daily average temperatures were again averaged over a calendar year; for example, an average of January 1, 2010, January 1, 2011 and January 1, 2012 values were used to estimate the average temperature for January 1. The resulting year-long records of daily average temperatures are repeated annually for the validation scenario. Figure 8.2-1 shows a comparison of historically-measured Dry Creek water temperatures, and the resulting year-long record of daily average temperatures.

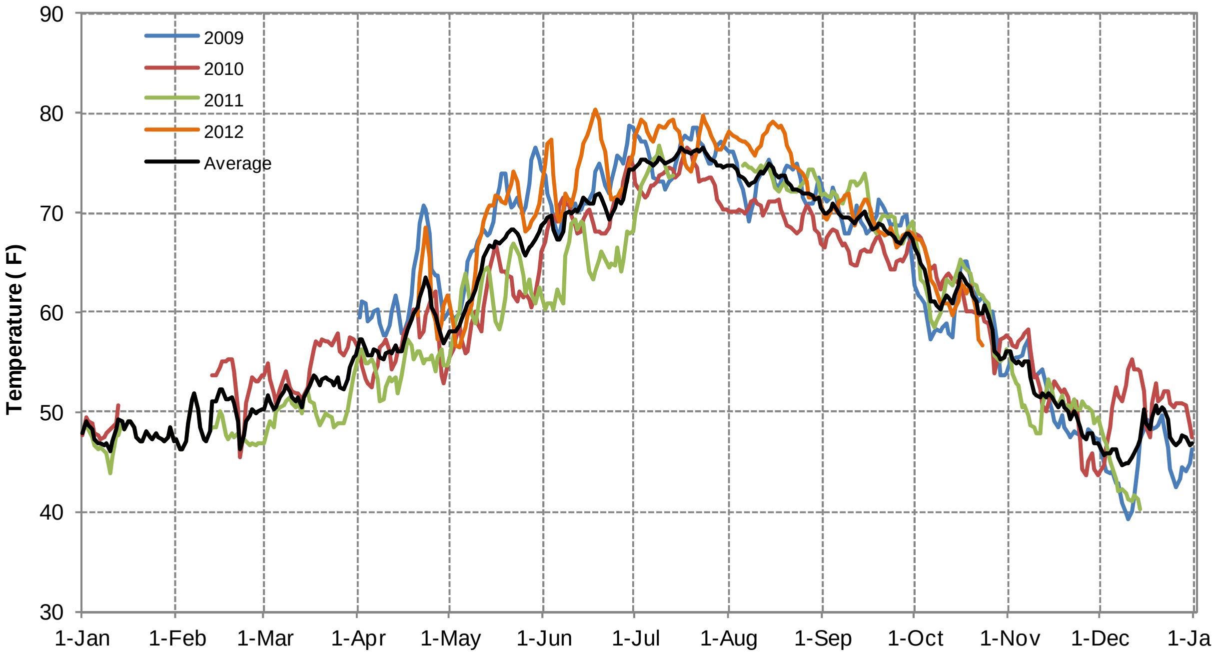


Figure 8.2-1. Comparison of historically-measured Dry Creek water temperatures.

8.2.2 Validation Scenario

For the Validation Scenario, input water temperatures from the Yuba River below the New Colgate Powerhouse are based on output water temperatures from the Upper Temp model Validation Scenario. Input water temperature data from the South Yuba River at Jones Bar are synthesized based on water temperatures measured by YCWA gage YC6. Accretion input water temperature data are synthesized based on YCWA gage T185.

Inflow temperatures from the South Yuba River at Jones Bar are measured by the YCWA gage YC6. Continuous records are available for the period of February 6, 2009 through October 15, 2012. There is similar variability in temperatures on the South Yuba River compared to the North Yuba or Middle Yuba rivers and Oregon Creek. 2011 is exceptionally more wet than the other three years (2009, 2010, and 2012), and its maximum-annual temperature is cooler, at 74.5°F than the other three years, which all have maximum-annual temperatures between 78.1°F and 78.8°F. But while 2010 was a relatively wet year, its maximum-annual water temperature is between that of the much drier 2009 and 2012, indicating moderate hydrology does not strongly affect South Yuba River water temperatures in summer months when peak temperatures generally occur. The South Yuba River is regulated upstream by multiple reservoir releases. There is considerably more variability in daily average temperatures the months of April through July when snowmelt runoff is present. Since it is a wet year, South Yuba River water temperatures from January 1, 2011 through December 31, 2011 are used as inflow temperatures for all years with above average annual South Yuba River inflow volume. Since it was a moderately dry year, South Yuba River water temperatures from January 1, 2010 through December 31, 2010 are used as inflow temperatures for all years with below average annual

South Yuba River inflow volume. Figure 8.2-2 shows a comparison of historically-measured South Yuba River at Jones Bar water temperatures.

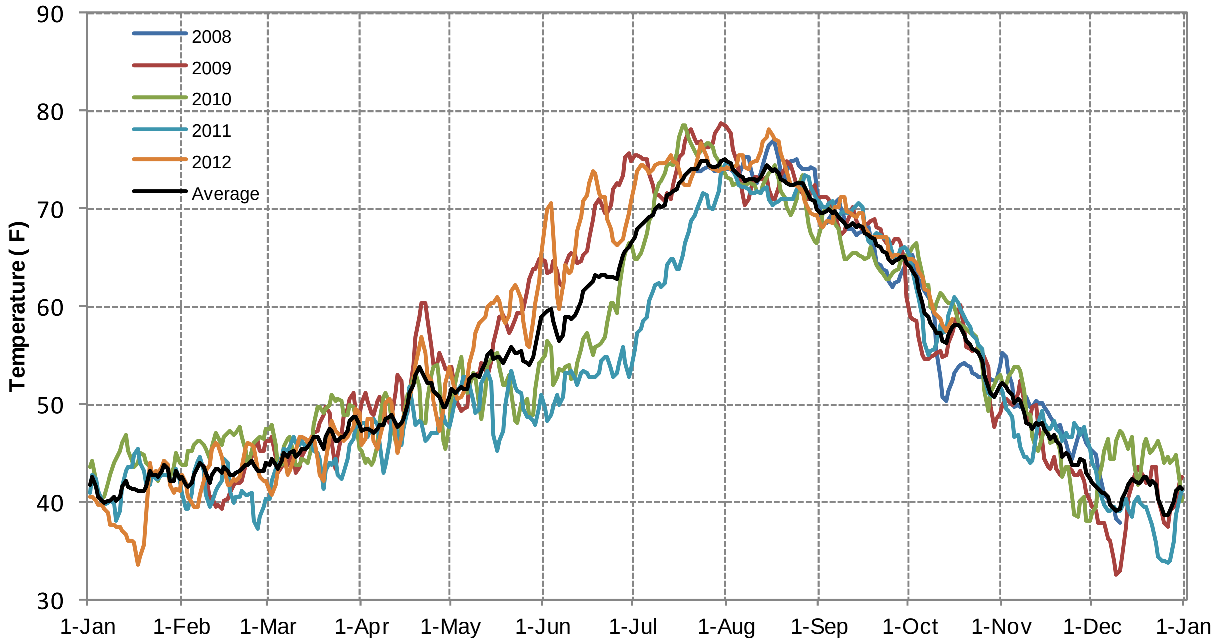


Figure 8.2-2. Comparison of historically-measured South Yuba River at Jones Bar water temperatures.

Similar to accretions in the Upper Temp Model, accretions to Englebright Reservoir and the South Yuba River are treated as non-point inflows, with no distinct inflow location, and are distributed throughout the reservoir. Temperatures assigned to these accretions were developed using observed data from Dry Creek, as described in Section 8.2.1.

Table 8.2-4 shows the input data used for the Upper Temp Model Validation Scenario. The classification of years as either below average or above average is shown in Table 8.1-6

Table 8.2-4. Englebright Temp Model Validation Scenario Input Water Temperature Sources.

Location	Source	Treatment	Start of Period of Record Used	End of Period of Record Used
Yuba River below the New Colgate Powerhouse	Upper Temp Model Output	None	1/1/2000	9/30/2010
South Yuba River at Jones Bar	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	YCWA gage T185	Averaged and Repeated	04/01/2009	09/30/2012

8.2.3 Base Case Scenario

Input water temperature data from the Yuba River below the New Colgate Powerhouse are a direct output from the Upper Temp Model water temperature model. Input water temperature data from the South Yuba River at Jones Bar were developed and applied to the full period, as described in Section 8.2.2.

Similar to accretions in the Upper Temp Model, accretions to Englebright Reservoir and the South Yuba River are treated as non-point inflows, with no distinct inflow location, and are distributed throughout the reservoir. Temperatures assigned to these accretions were developed using observed data from Dry Creek, as described in Section 8.2.1.

Table 8.2-5 shows the input data used for the Upper Temp Model Validation Scenario. The classification of years as either below average or above average is shown in Table 8.1-6

Table 8.2-5. Englebright Temp Model Validation Scenario Input Water Temperature Sources.

Location	Source	Treatment	Start of Period of Record Used	End of Period of Record Used
Yuba River below the New Colgate Powerhouse	Upper Temp Model Output	None	10/1/1969	9/30/2010
South Yuba River at Jones Bar	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	YCWA gage T185	Averaged and Repeated	04/01/2009	09/30/2012

8.3 Lower Temp Model

Inflows to the Lower Temp Model for the Calibration and Validation scenarios come from historical flows at Smartsville and from Deer Creek, and from synthesized flows, as described in Section 2.3, for Dry Creek inflows. Inflows to the Lower Temp Model for the Base Case Scenario come directly from the Water Balance/Operations model. A complete description of the development of the inflows can be found in Attachment 2-2D to Study 2-2, *Water Balance/Operations Model.* Also, simulated releases from Englebright Reservoir are standard outputs from the model. Table 8.3-1 shows the inputs to the Base Case Scenario model and their respective names in the input DSS file.

Table 8.3-1. Lower Temp Model input flows and HEC-DSS names.

Location	DSS Name
Yuba River flow at Smartsville	YR_SMARTSVILLE
Englebright Reservoir spills	ENG_SPILL
Deer Creek inflows to the Yuba River	INF_DEERCR
Dry Creek inflows to the Yuba River	INF_DRYCR
Daguerre Point Dam agricultural diversions	DAGUERRE_DIV

Input water temperatures are contained in the same input file as the input flows, and have the same name as the input flows. The difference between the two is, while the input flows have a “FLOW” designation, the input temperatures have a “TEMP” designation within the file. While its flow is also determined in the Water Balance/Operations model, water temperatures for Daguerre Point Dam agricultural diversions are computed by the model and are not included as an input.

8.3.1 Calibration Scenario

Calibration of the Lower Temp Model uses historical 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 rather than releases and temperatures directly from Englebright Reservoir through the Narrows 1 and Narrows 2 powerhouses. Flows and water temperatures at Smartsville are used since Smartsville is 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.

Historical inflow temperatures from Deer Creek, Dry Creek, and Smartsville, as collected for Study 2.5, *Water Temperature Monitoring* are used as an input to the Lower Temp Model. Table 8.3-2 shows the gages used for the Lower Temp Model Calibration Scenario inputs.

Table 8.3-2. Lower Temp Model Calibration Scenario Input Water Temperature Sources.

Location	Source	Treatment	Start of Period of Record Used	End of Period of Record Used
Englebright Reservoir Releases	YCWA Gage NY28	None	1/1/2008	9/30/2012
Deer Creek inflow	YCWA Gage T175	Data filled in where necessary	12/23/2008	9/30/2012
Dry Creek inflow	YCWA gage T185	Data filled in where necessary	4/1/2009	9/30/2012

While an extensive period of record of historical mean-daily flows from Deer Creek, as measured by USGS gage 11418500 is available, there is a limited period of record with numerous data gaps for water temperature 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. Table 8.3-3 shows dates for missing data for Deer Creek within the calibration period of record and the data used to fill for missing data.

Table 8.3-3. Missing calibration data Deer Creek water temperatures, and replacements data used for missing data.

Dates with Missing Data	Replacement Dates Used
1/1/2008 - 1/3/2008	1/1/2009 - 1/3/2009
1/4/2008	1/4/2010
1/5/2008 - 12/22/2008	1/5/2009 - 12/22/2009
1/4/2009	1/4/2010
11/4/2010 - 1/3/2011	11/4/2009 - 1/3/2010
1/4/2011	1/4/2010
1/5/2011 - 1/24/2011	1/5/2009 - 1/24/2009
2/15/2011 - 8/22/2011	2/15/2009 - 8/22/2009
1/19/2012 - 5/17/2012	1/19/2009 - 5/17/2009
6/19/2012 - 9/19/2012	6/19/2009 - 9/19/2009

Synthetic flow data for Dry Creek, developed for the Water Balance/Operations Model is used as an inflow 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. Table 8.3-4 shows dates for missing data for Dry Creek within the calibration period of record and the data used to fill for missing data.

Table 8.3-4. Missing Calibration Data for Dry Creek Water Temperatures and Replacements Data Used for Missing Data.

Dates with Missing Data	Replacement Dates Used
1/1/2008 - 1/13/2008	1/1/2010 - 1/13/2010
1/14/2008 - 2/12/2008	1/14/2011 - 2/12/2011
2/13/2008 - 12/31/2008	2/13/2010 - 12/31/2010
1/1/2009 - 1/13/2009	1/1/2010 - 1/13/2010
1/14/2009 - 2/12/2009	1/14/2011 - 2/12/2011
2/13/2009 - 3/31/2009	2/13/2010 - 3/31/2010
1/14/2010 - 2/12/2010	1/14/2011 - 2/12/2011
12/15/2011 - 12/31/2011	12/15/2010 - 12/31/2010
1/1/2012 - 1/13/2012	1/1/2010 - 1/13/2010
1/14/2012 - 2/12/2012	1/14/2011 - 2/12/2011
2/13/2012 – 4/19/2012	2/13/2010 – 4/19/2010

8.3.2 Validation Scenario

For the Validation Scenario, input water temperatures at Smartsville come directly out of the Englebright Temp Model. Output are converted to English units and uploaded to the HEC-DSS input file. Input water temperatures from Deer Creek for the Validation Scenario are based on historical water temperatures measured by YCWA gage T175. There is limited available continuous data available for the Deer Creek gage, but it has data primarily for the period of December 23, 2008 through October 17, 2012. Within that date range, the largest block of continuous water temperature data is from December 23, 2008 through November 4, 2010. The nearly two years contained here are almost identical to one another, and since the flow contribution from Deer Creek is negligible compared to releases from Englebright Reservoir, a single year of water temperatures was chosen as representative for all years. Water temperatures for Deer Creek's inflow to the Yuba River for the period of January 1, 2009 through December 31, 2009 were repeated for the full period of record.

There is more available water temperature data for Dry Creek; data is available for the period of April 1, 2009 through September 9, 2012, but the longest period of continuous data within that range is for the period of April 1, 2009 through December 14, 2011. The nearly three years covered by this range are almost identical to one another, so a single year was chosen to represent all inflow from Dry Creek to the Yuba River. The period of March 1, 2010 through February 28, 2011 was repeated for the full period of record.

Table 8.3-5 shows the gages used for the Lower Temp Model Validation Scenario inputs.

Table 8.3-5. Lower Temp Model Validation Scenario Input Water Temperature Sources.

Location	Source	Treatment	Start of Period of Record Used	End of Period of Record Used
Englebright Reservoir Releases	Englebright Temp Model	None	1/1/2000	9/30/2011
Deer Creek inflow	YCWA Gage T175	Repeated	1/1/2009	12/31/2009
Dry Creek inflow	YCWA gage T185	Repeated	3/1/2010	2/28/2011

8.3.3 Base Case Scenario

For the Base Case Scenario, input water temperatures at Smartsville come directly out of the Englebright Temp Model. Output temperatures from Englebright Reservoir are converted to English units and uploaded to the HEC-DSS input file. Inflow temperatures from Deer Creek and Dry Creek are compute using an identical methodology as was used in the Validation Scenario, except for the Base Case Scenario period of record of October 1, 1969 through September 30, 2010. Table 8.3-6 shows the gages used for the Lower Temp Model Base Case Scenario inputs.

Table 8.3-6. Lower Temp Model Base Case Scenario Input Water Temperature Sources.

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

9.0 Meteorological Data

This section describes meteorological data development for each model, including data requirements, available data, and methods used to create full periods of record for three scenarios: (1) Calibration, (2) Validation, and (3) Base Case.

9.1 Meteorological Data Requirements

The Upper Temp Model and Lower Temp Model were both developed in HEC-5Q and have the same input data requirements. The Englebright Temp Model was developed in CE-QUAL-W2 and has additional data requirements.

9.1.1 CE-QUAL-W2 Meteorological Data Requirements

The Englebright Temp Model, developed using CE-QUAL-W2, requires the following meteorological data:

- Air temperature, degree Celsius (°C),
- Dew-point temperature (°C),
- Wind speed, meters per second (m/sec),
- Wind direction, radians
- Cloud cover number, 0 (clear) to 10 (cloudy), and
- Short-wave radiation, Watts (W)/square meter (m^2) (optional)

Meteorological input data can be input in any frequency and may vary during the simulation, but hourly or sub-hourly is preferable. 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.

9.1.2 HEC-5Q Meteorological Data Requirements

HEC-5Q, used to develop the Upper Temp Model and Lower Temp Model, requires 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), and
- Wind speed, (miles per hour [mph])

The coefficient of surface 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). HEATX directly calculates the required inputs to the HEC-5Q model.

9.1.3 HEATX

HEATX calculates the coefficient of surface heat exchange, equilibrium temperature, wind speed, and solar radiation. Results can be exported to HEC-DSS, where it can be used directly as input to HEC-5Q. HEATX requires the following input parameters:

- Daily cloud cover based on a 0 to 10 scale, with 0 being clear and 10 being completely overcast,
- Mean-daily wind speed (mph),
- Mean-daily air temperature (°F), and
- Mean-daily dew-point temperature (°F)

Daily cloud cover number is not a directly measured parameter and is calculated using solar radiation data and methodology discussed in Section 9.3.6.

HEATX input data for wind speed, cloud cover, air temperature, and dew-point temperature can be modified by adding a constant or multiplied by a factor specified by the user in order to produce the most representative HEC-5Q input data.

HEATX only allows for 365 days of input data. Separate single day runs must be run to calculate the HEC-5Q inputs for December 31st for leap years. The results of the leap year calculations were incorporated into the HEC-5Q input DSS records.

9.2 Weather Station Selection

Data from nearby weather stations were obtained from the National Oceanic and Atmospheric Administration (NOAA) (NOAA 2012), the California Data Exchange Center (CDEC) (CDEC 2012), and the California Irrigation Management Information System (CIMIS) (CIMIS 2012). The review of these data considered that a total of nine meteorology data sets would be developed for purposes of the water temperature modeling: a Calibration, Validation and Base Case data set for each of the three models: the Upper Temp Model, the Englebright Temp Model, and the Lower Temp Model.

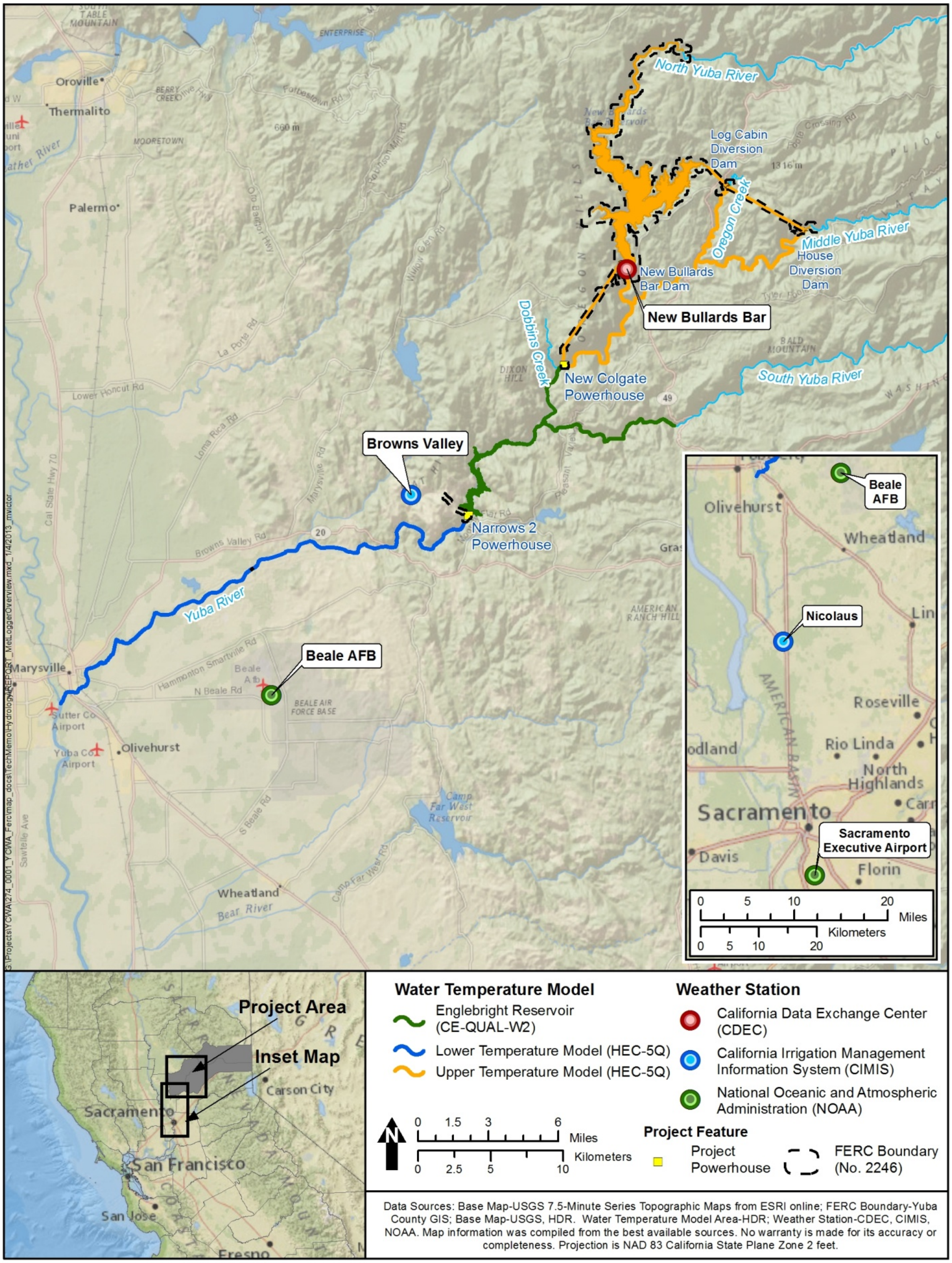
Stations were identified that were representative of the meteorology of each model area and having all required data types, as discussed in Section 9.1. The period of record was considered, resulting in the elimination of some stations while requiring the identification of new stations.

Table 9.2-1 is a summary of the weather stations selected and Figure 9.2-1 shows the geographic location of each gage.

Table 9.2-1. 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 Temperature
Browns Valley	CIMIS[3]	084	4/13/1989 to 9/30/2012	Air Temperature Solar Radiation Wind Speed Wind Direction Dew-Point Temperature Relative Humidity
Beale AFB	NOAA[4], NREL[5]	040584	7/1/1959 to 9/30/2012	Air Temperature Wind Speed Wind Direction Dew-Point Temperature 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 Temperature Solar Radiation Descriptive Weather Observations

[1] Only includes weather station data used in the dataset creation.
[2] CDEC (2012)
[3] CIMIS (2012)
[4] NOAA (2012)
[5] NREL (2012)
[6] YCWA collects data at New Bullards Bar Dam, but the data is distributed through CDEC



Data Sources: Base Map-USGS 7.5-Minute Series Topographic Maps from ESRI online; FERC Boundary-Yuba County GIS; Base Map-USGS, HDR. Water Temperature Model Area-HDR; Weather Station-CDEC, CIMIS, NOAA. Map information was compiled from the best available sources. No warranty is made for its accuracy or completeness. Projection is NAD 83 California State Plane Zone 2 feet.

Figure 9.2-1. Locations of weather stations used in the study.

Review of weather stations in the direct vicinity of the model areas led to the identification of the New Bullards Bar Dam weather station, Browns Valley weather station, and Beale AFB weather station, as the most representative stations for calibration of the Upper Temp Model, the Englebright Reservoir Model, and the Lower Temp Model, respectively. The New Bullards Bar Dam weather station is located near New Bullards Bar Dam, the Browns Valley weather station is located in the foothills near Englebright Reservoir; and Beale AFB, while a few miles south of the Yuba River, is representative of the valley conditions in which the majority of the Lower Temp Model is located.

Browns Valley and Beale AFB had sufficiently long periods of record to be used for both Calibration and Validation, but the New Bullards Bar Dam weather station had a short period of record, beginning in late 2009. Statistical review of the data demonstrated that Browns Valley, also located in the foothills, was well correlated with data from the New Bullards Bar Dam weather station, and was used to extend the New Bullards Bar Dam data record by regression, as described in Section 9.4.2.

Of the three primary weather stations used, only the Beale AFB weather station had a period of record covering the complete Base Case period of record (WY 1970 through 2010). Statistical review of the data demonstrated that the Beale AFB data were reasonably correlated with both Browns Valley and New Bullards Bar Dam weather stations despite being located in the Sacramento Valley, not the Sierra Nevada foothills.

Inspection of data from the three primary gages showed that supplemental weather station data would be needed to fill in missing data. The CIMIS weather station at Nicolaus and the NOAA weather station at the Sacramento Executive Airport were identified as sources for supplemental data based on their relative vicinity to the simulation area, and the quality and length of record.

9.3 Weather Station Data Review and Analysis

This section describes the review and analysis of the hourly raw data for weather stations listed in Table 9.2-1. Hourly and mean-daily datasets were compiled to create model input data sets, as described in Section 9.4. Errors in the data were identified, and fixed or removed, as described below. Single hours of missing or bad data were filled in using an average of the preceding and following values.

9.3.1 New Bullards Bar Dam Weather Station

The period of record for the New Bullards Bar Dam weather station is November 14, 2009 through September 30, 2012. Specific issues for each of the New Bullards Bar Dam Weather Station parameters are described below.

9.3.1.1 Air Temperature

Several individual hours of air temperature data were observed to have excessively high or low or obviously incorrect reported temperature values and were removed.

9.3.1.2 Dew-Point Temperatures

Observed dew-point temperature data were not available for the New Bullards Bar weather station from CDEC, but relative humidity data were available. The dew-point temperature was approximated as a function of air temperature and relative humidity with the formula:

Dew-Point Temperature = Air Temperature – (100 – Relative Humidity) * 9/25

Hours with relative humidity values greater than 100% were removed. Mean-daily dew-point temperatures were calculated as inputs to HEATX. Only days with 24 hours of both air temperature and dew–point temperature data were included.

9.3.1.3 Wind Speed

Several individual hours of wind speed data were observed to have excessively high or negative values and were removed.

9.3.1.4 Solar Radiation

Solar radiation is measured at New Bullards Bar weather station, but upon review, the New Bullards Bar Dam solar radiation was observed to be approximately half the value of the measured solar radiation at the Browns Valley weather station. Upon a visual inspection of the data in DSS, it was observed that from dawn until late morning and again in mid to late afternoon of each day, the solar radiation measurements were consistently low. It is likely that there are obstructions blocking direct sunlight to the gage. Solar radiation data from this weather station were not usable for this analysis.

9.3.2 Browns Valley Weather Station

The period of record for the Browns Valley weather station was April 12, 1989 through September 30, 2012. Specific issues for each of the Browns Valley weather station parameters are described below.

9.3.2.1 Air Temperature

Browns Valley weather station air temperature data were reviewed for completeness, using the methodology described in Section 9.3.1.1.

9.3.2.2 Dew-Point Temperature

Several individual hours of dew-point temperature data were observed to have excessively high or low values and were removed.

9.3.2.3 Wind Speed

Suspect wind speed data were observed for the period between April 28, 2009 and May 10, 2010. Wind speed magnitudes during this period were consistently dampened compared to the rest of the period of record. Browns Valley weather station wind speed data for this period were compared to the wind data for Beale AFB and Nicolaus weather stations. The Browns Valley weather station wind speed followed the general shape of wind speeds recorded at Beale AFB and Nicolaus weather stations, particularly during times of prolonged high wind speeds. This indicated an instrumentation calibration or data recording issue, and with adjustment, the data could be utilized.

Wind speed data from April 28, 2009 through May 10, 2010 were modified using the following equations which are functions of mean-daily wind speed at a given time step (W_t), average of the data set mean-daily wind speeds (μ) and the standard deviation of the data set mean-daily wind speeds (σ).

$$W_{MODIFIED} = A\ W_t + B$$

$$A = \sigma_2 / \sigma_1$$

$$B = \mu_2 - \mu_1 \left(\sigma_2 / \sigma_1 \right)$$

Subscript 1 denotes the data being transformed, which in this case is data for the period from April 28, 2009 through May 10, 2010. Subscript 2 denotes the data to which the modified wind speed data should statistically match, in this case it is all other valid wind speed data for the remaining period of record. The resulting hourly data for April 28, 2009 through May 10, 2010 has the same mean wind speed and standard deviation as the remainder of the period of record. Data were reviewed were consistent with the rest of the remainder of the period of record. This method was considered to be more representative of wind speed at the Browns Valley weather station than replacing the data from another weather station.

9.3.2.4 Wind Direction

Wind direction data were measured as values between 0 and 360 degrees and were converted to radians for use by the Englebright Temp Model.

9.3.2.5 Solar Radiation

Excessively high solar radiation values were identified and removed. Solar radiation data between May 2006 and July 2007 were consistently higher than during the same months of other years. This was confirmed by comparison of recorded Browns Valley weather station solar radiation data to theoretical clear-sky maximum solar radiation calculated using HEATX for the Browns Valley weather station location, as described in Section 9.4.1. Values for solar radiation between May 2006 and July 2007 were reduced by a scaling factor so that peak solar radiation values followed the general shape of the theoretical clear-sky maximum solar radiation curve.

9.3.3 Beale AFB Weather Station

The period of record for the Beale AFB weather station was Oct 1, 1969 through September 30, 2012.

Initial review revealed that daily-peak air temperature and solar radiation were occurring between 10:00 pm and midnight, indicating an error in the reported time of observation. Beale AFB hourly air temperature data were compared to hourly air temperature data from the Browns Valley and Nicolaus weather stations. Hourly air temperature data were selected for the analysis because air temperature data had the greatest observed correlation between the three weather stations. Review of the data indicated the recorded data were eight hours ahead of the actual reported time. An eight-hour time shift yielded the highest coefficient of determination (R^2) when performing a statistical comparison. The time shift was also visually verified by comparing the three air temperature datasets.

Specific issues for each of the Beale AFB weather station parameters are described below.

9.3.3.1 Air Temperature

Beale AFB weather station air temperatures were reviewed for completeness, using the methodology described in Section 9.3.1.1.

9.3.3.2 Dew-Point Temperature

Beale AFB weather station dew-point temperature data were reviewed for completeness, using the methodology described in Section 9.3.2.2

9.3.3.3 Wind Speed

Beale AFB weather station wind speed data were reviewed for completeness, using the methodology described in Section 9.3.1.3.

9.3.3.4 Wind Direction

Beale AFB weather station wind direction data were reviewed for completeness, using the methodology described in Section 9.3.2.4.

9.3.3.5 Solar Radiation

Solar radiation was not measured at Beale AFB. However, solar radiation values were modeled by the National Renewable Energy Laboratory (NREL) using observed meteorological conditions. See Section 9.4.1 for further discussion of the NREL solar radiation data. No modifications to the data were required.

9.3.4 Sacramento Executive Airport Weather Station

The Sacramento Executive Airport weather station was selected as the next closest weather station with all necessary data types for the full Base Case Scenario period of record and covered gaps in Beale AFB data. The weather station had two gages; the primary gage collected data from 1969 to 2012, but was missing data from 1971 to 1972, like the Beale AFB weather station. This gap was filled in from a secondary gage at the Sacramento Executive Airport which provided data from 1969 to 1972 in 3 hour time steps. The 3-hour data were converted to hourly data by linear interpolation.

Sacramento Executive Airport is a primary facility included in the NREL solar radiation database discussed in Section 9.4.1.

The same eight-hour time shift applied to the Beale AFB data as described in Section 9.3.3 was applied to both Sacramento Executive Airport gages. Obviously bad data, based on visual review, were removed from the initial dataset. For the primary gage, the value for single hours of missing data for each data type were calculated as the average of the values for the hour preceding and following the missing hour.

9.3.5 Nicolaus Weather Station

Nicolaus weather station data were used sparingly to fill in missing data in the Browns Valley weather station data. Obviously bad data, based on visual review, were removed.

The Nicolaus weather station was decommissioned at the end of 2011.

9.4 Model Input Meteorological Data Development

This section describes the methodology used to develop complete input datasets as required by Upper Temp, Englebright Temp, and Lower Temp models. Data sets for the Calibration, Validation, and Base Case scenarios were created using hourly or mean-daily data developed as described in Section 9.3. Secondary data were used to fill in missing data, when necessary.

A single zone was used for meteorology for each model due to the relative proximity and similarity of meteorology of the various facilities within each model. Meteorology for the Upper Temp Model was considered Zone 3, the Englebright Temp Model meteorology was Zone 2, and the Lower Temp Model was Zone 1.

To best represent the historic meteorological conditions of each model, long-term regional data records were transformed by means of linear regression to better represent short-term local data records, which were used during calibration of each model. For the Upper Temp Model, data were statistically transformed to best represent the New Bullards Bar Dam weather station. Similarly, the Browns Valley weather station was used for the Englebright Temp Model, and the Beale AFB weather station was used for the Lower Temp Model.

Cloud cover number was calculated independently of the other meteorological data because it is not a measured parameter at any of the weather stations used, and is described in section 9.4.1.

9.4.1 Cloud Cover

All three temp models require an assessment of cloud cover represented as an integer ranging from 0, the theoretical clear-sky potential solar radiation, to 10, a dark overcast day.

Cloud cover number for all three models for the Calibration and Validation scenarios were computed using solar radiation look-up tables developed from Browns Valley weather station. The Browns Valley weather station is the only weather station in the Project vicinity with measured solar radiation data for the Calibration and Validation scenarios' periods of record. Solar radiation data were also available at Nicolaus, but the central location of the Browns Valley weather station made it the preferred source of solar radiation data for this analysis. Missing solar radiation data were filled using measured solar radiation data at the Nicolaus weather station.

HEATX was used to calculate solar radiation associated with a cloud cover number based on a latitude, elevation, and Julian day. HEATX was run for the entire Validation Scenario period of record using Browns Valley weather station mean-daily wind speed, air temperature, and dew-point temperature. A solar radiation lookup table was created containing the average calculated solar radiation associated for each cloud cover number from 0 to 10 for each day of the year. Day 366, during leap years, was calculated as the average of solar radiation from December 31st (day 365) and January 1st (Day 1).

Figure 9.4.1 below shows the non-linear nature of the relationship between cloud cover number and solar radiation.

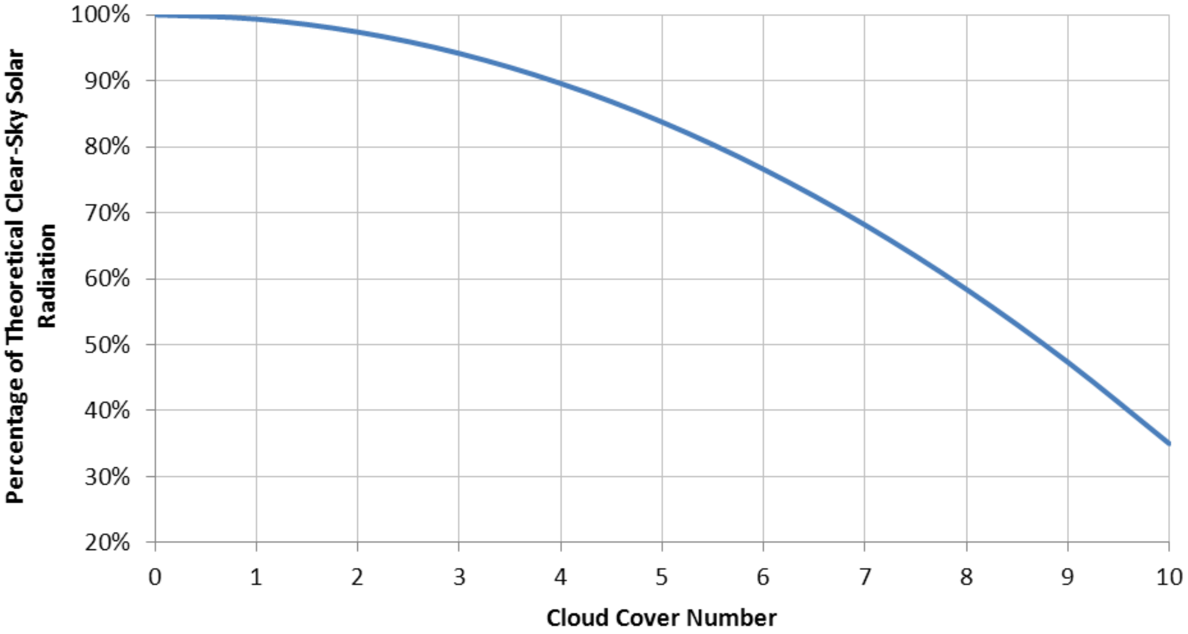


Figure 9.4-1. Relationship of cloud cover number to theoretical clear-sky solar radiation.

Cloud cover numbers for the Base Case Scenario were developed using modeled solar radiation data from the National Solar Radiation Database (NSRDB) developed the National Renewable Energy Laboratory (NREL) (NREL 2012), a laboratory of the U.S. 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 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 included. A strong correlation was observed between the Beale AFB solar radiation data and Sacramento Executive Airport weather station data for periods when data existed for both stations. Accordingly, Sacramento Executive Airport solar radiation data were used for the Base Case period of record. Cloud cover numbers were then calculated using the solar radiation look-up table developed for the Browns Valley Weather Station.

Hourly cloud cover numbers were required for the Englebright Temp Model. Cloud cover data described in this section were developed in daily time-steps. For the Englebright Temp Model, daily cloud cover numbers were applied hourly for the whole day.

9.4.2 Upper Temp Model

Table 9.4-1 shows the primary weather stations used to develop mean-daily HEATX input datasets for air temperature, dew-point temperature, and wind speed for the Upper Temp Model.

Table 9.4-1. Primary 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 Temperature	New Bullards Bar
		Wind Speed	New Bullards Bar
Validation	1/1/2000 to 09/30/2011	Air Temperature	Browns Valley
		Dew-Point Temperature	Browns Valley
		Wind Speed	Browns Valley
Base Case	10/1/1969 to 9/30/2010	Air Temperature	Beale AFB
		Dew-Point Temperature	Beale AFB
		Wind Speed	Beale AFB

For the Calibration and Validation scenarios, model input data sets were developed using mean-daily values calculated from the reviewed weather station data sets as discussed in section 9.3. Only mean-daily data having a full 24 hours of data were included. Additionally, air temperature and dew-point temperature data were only included for days having a full 24 hours of both air temperature and dew-point temperature.

For each scenario, days without 24 hours of data for the primary weather station were replaced using data from secondary weather stations and statistical regression techniques. Linear regression coefficients were used to modify the secondary weather station data to best represent the primary weather station, using an equation of the form:

$$\text{Parameter}_{\text{Primary Weather Station}} = A * \text{Parameter}_{\text{Secondary Weather Station}} + B$$

Values of the A and B coefficients used in meteorological data development are described below.

Statistical analysis of wind speed data generally returned a low value for R^2, indicating a relatively poor correlation between weather station locations. Despite the low R^2 value, it was observed that wind speed at all weather stations followed the same general wind speed pattern. For example, a windy day at the Beale AFB weather station produced a similarly windy day at the Browns Valley weather station, albeit with different magnitudes of wind speed. Regression coefficients for wind speed were developed so that the resulting data set had the same average and standard deviation for the period of record as the primary data set using relationships presented in Section 9.3.2.3. Linear regression coefficients used in the Upper Temp Model are included in Table 9.4-2 below.

Table 9.4-2. Regression coefficients used to modify the secondary weather station data to represent primary weather station data for the Upper Temp Model

Primary Weather Station	Secondary Weather Station	Parameter	Coefficient (A)	Coefficient (B)	R^2
New Bullards Bar Dam	Browns Valley	Wind Speed	0.630	-1.190	0.552
		Air Temperature	1.035	-7.040	0.929
		Dew-Point Temperature	1.040	-5.510	0.800
New Bullards Bar Dam	Beale AFB	Wind Speed	0.222	0.078	0.543
		Air Temperature	1.069	-1.476	0.903
		Dew-Point Temperature	1.088	-7.328	0.728

Table 9.4-2. (continued)

Primary Weather Station	Secondary Weather Station	Parameter	Coefficient (A)	Coefficient (B)	R^2
Beale AFB	Sacramento Executive Airport, Primary Gage	Wind Speed	1.067	-0.461	0.371
		Air Temperature	1.025	0.496	0.937
		Dew-Point Temperature	0.894	4.563	0.752
Beale AFB	Sacramento Executive Airport, Secondary Gage	Wind Speed	1.24	-1.964	0.52
		Air Temperature	1.073	-2.623	0.930
		Dew-Point Temperature	0.817	9.739	0.805

New Bullards Bar Dam weather station meteorological data were used directly as the primary data set for the Calibration Scenario. Missing data were filled using linear regression techniques, and Browns Valley and Beale AFB weather station data. Regression coefficients used are listed in Table 9.4-2.

Dates of missing New Bullards Bar Dam data filled in using secondary weather station data are included below in Table 9.4-3.

Table 9.4-3. Summary of missing calibration scenario weather station data and secondary data sources for the Upper Temp Model.

Data Type	Primary Weather Station	Missing Dates	Secondary Weather Station
Air Temperature/Dew-Point Temperature	New Bullards Bar	12/20/2009	Browns Valley
	New Bullards Bar	8/172010	Browns Valley
	New Bullards Bar	10/16/2010	Browns Valley
	New Bullards Bar	4/5/2011	Browns Valley
	New Bullards Bar	11/26/2011	Browns Valley
	New Bullards Bar	9/27/2012	Browns Valley
Wind Speed	New Bullards Bar	3/10/2010	Browns Valley
	New Bullards Bar	4/4/2012 – 4/5/2012	Browns Valley
	New Bullards Bar	4/9/2010 – 4/22/2010	Browns Valley
	New Bullards Bar	4/23/2010	Beale AFB
	New Bullards Bar	4/24/2010 – 3/31/2011	Browns Valley
	New Bullards Bar	4/5/2011	Browns Valley
	New Bullards Bar	9/27/2012	Browns Valley

The Browns Valley weather station was used as the primary data source for the Validation Scenario. Missing data were replaced using linear regression techniques applied to modify Browns Valley and Beale AFB weather station data using coefficients in Table 9.4-2. Missing data at Browns Valley were filled in with Beale AFB weather station data, when available. For periods of missing data at both Browns Valley and Beale AFB, linear interpolation was applied using the day before and after the missing period.

Dates of missing Browns Valley data are included below in Table 9.4-4.

Table 9.4-4. Summary of missing Validation Scenario weather station data and secondary data sources for the Upper Temp Model.

Data Type	Primary Weather Station	Missing Dates	Secondary Weather Station
Air Temperature/Dew-Point Temperature	Browns Valley	9/12/2001 – 9/13/2001	Beale AFB
	Browns Valley	12/20/2003	Beale AFB
	Browns Valley	12/21/2003	Interpolation
	Browns Valley	9/12/2001 – 9/13/2001	Beale AFB
	Browns Valley	1/12/2004	Interpolation
	Browns Valley	1/13/2004	Beale AFB
	Browns Valley	1/14/04 – 1/15/2004	Interpolation
	Browns Valley	1/4/2008 – 1/10/2008	Interpolation
	Browns Valley	12/21/2009 – 12/22/2009	Beale AFB
	Browns Valley	1/20/2010 – 1/21/2010	Beale AFB
Wind Speed	Browns Valley	12/27/2007 – 1/25/2008	Beale AFB
	Browns Valley	5/19/2008 – 5/20/2008	Beale AFB
	Browns Valley	4/23/2009 – 4/28/2009	Beale AFB
	Browns Valley	12/21/2009 – 12/22/2009	Beale AFB

Beale AFB was the primary weather station used to develop the Base Case Scenario data set. Linear interpolation was used for data gaps of less than 6 hours for air temperature, dew-point temperature, and wind speed data. Remaining Beale AFB data gaps were filled using linear regression techniques and Sacramento Executive Airport weather station data, using coefficients from Table 9.4-2.

Secondary gage data for the Sacramento Executive Airport weather station were used to fill missing Beale AFB data from 1971 to 1972. Linear regression coefficients were developed using the overlapping period of record of Oct 1, 1969 to Dec 31, 1970. The resulting data set was observed to create peak summer air temperatures that were unrealistically high. Visual inspection and statistical analysis determined that linear regressed data fit well for all temperatures up to 95 degrees. No adjustments were applied to air temperatures over 95 degrees.

For the Base Case Scenario, mean-daily values were calculated for air temperature, dew-point temperature, and wind speed from the complete hourly data set representing conditions at Beale AFB. Linear regression and coefficients in Table 9.4-2 were applied to represent conditions at New Bullards Bar for input into the Upper Temp Model.

Periods of at least 5 days (120 hours) of missing Beale AFB weather station data were filled using secondary weather station data, as listed below in Table 9.4-5.

Table 9.4-5. Summary of missing Base Case Scenario weather station data and secondary data sources for the Lower Temp Model.

Data Type	Primary Weather Station	Missing Dates	Secondary Weather Station
Air Temperature/Dew Point	Beale AFB	1/1/1971 – 12/31/1972	Sacramento Executive Airport
	Beale AFB	5/31/1990 – 12/31/1990	Sacramento Executive Airport
	Beale AFB	6/14/2007 – 6/20/2007	Sacramento Executive Airport
Wind Speed	Beale AFB	1/1/1971 – 12/31/1972	Sacramento Executive Airport
	Beale AFB	5/31/1990 – 12/31/1990	Sacramento Executive Airport
	Beale AFB	6/14/2007 – 6/20/2007	Sacramento Executive Airport

HEATX was run using mean-daily Calibration, Validation, and Base Case scenario data for wind speed, air temperature, dew-point temperature and cloud cover number. A factor of 0.87 was applied to wind speed data in HEATX to account for the difference in wind speed between the height of the instrument and the ground. The minimum HEATX wind speed output is 2 mph and is applied even when a user specified factor for wind is specified. No scaling factors were implemented for cloud cover number, air temperature, or dew-point temperature. HEATX output files were exported to DSS for use as an input to the Upper Temp Model.

9.4.3 Englebright Temp Model

Table 9.4-6 shows weather station data used in the development of the Englebright Temp Model hourly input data for air temperature, dew-point temperature, wind speed, and wind direction for each scenario.

Table 9.4-6. Sources of meteorological data the Englebright Reservoir.

Dataset	Period of Record	Data Type	Weather Station
Calibration	01/01/2007-9/30/2012	Air Temperature	Browns Valley
		Dew-Point Temperature	Browns Valley
		Wind Speed	Browns Valley
		Wind Direction	Browns Valley
Validation	01/01/2000-09/30/2011	Air Temperature	Browns Valley
		Dew-Point Temperature	Browns Valley
		Wind Speed	Browns Valley
		Wind Direction	Browns Valley
Base Case	10/01/1969-09/30/2010	Air Temperature	Beale AFB
		Dew-Point Temperature	Beale AFB
		Wind Speed	Beale AFB
		Wind Direction	Beale AFB

Missing hourly air temperature, dew-point temperature, and wind speed data from the applicable weather station were filled from hourly data from Beale AFB and Nicolaus weather stations. All missing data was filled using linear regression techniques, as described in Section 9.4.2, to best match conditions at Browns Valley. Linear regression coefficients used are given in Table 9.4.7. A review of wind direction data from the three sites indicated that the data were statistically independent at the hourly time-step level and linear regression was not applied. Instead, missing wind direction data were replaced with wind direction data measured at secondary sources.

Table 9.4-7. Regression coefficients used to modify secondary weather station data to represent data at the primary weather station for the Englebright Temp Model for the Validation and Calibration scenarios.

Primary Weather Station	Secondary Weather Station	Parameter	Coefficient (A)	Coefficient (B)	R^2
Browns Valley	Beale AFB	Wind Speed	0.846	-1.533	0.331
		Air Temperature	0.915	5.723	0.939
		Dew-Point Temperature	0.937	2.359	0.770
Browns Valley	Nicolaus	Wind Speed	0.696	0.844	0.339
		Air Temperature	0.968	-0.601	0.901
		Dew-Point Temperature	0.869	8.229	0.761

Browns Valley was used as the primary weather station for the Englebright Temp Model Calibration and Validation Scenarios. Missing data were filled using data from the Beale AFB weather station and then the Nicolaus weather station. Small data gaps of 3 hours or less were filled in using linear interpolation. Periods of missing data of at least 24 hours are included below in Table 9.4-8.

Table 9.4-8. Summary of missing Calibration and Validation Scenario weather station data and secondary data sources for the Englebright Temp Model.

Data Type	Primary Weather Station	Missing Dates	Secondary Weather Station
Air Temperature/Dew Point	Browns Valley	9/12/2001 – 9/13/2001	Beale AFB
	Browns Valley	1/14/2004 – 1/15/2004	Beale AFB
	Browns Valley	1/4/2008 – 1/10/2008	Beale AFB
	Browns Valley	12/21/2009 – 12/22/2009	Beale AFB
Wind Speed	Browns Valley	12/27/2007 – 1/26/2008	Beale AFB
	Browns Valley	4/23/2009 – 4/28/2009	Beale AFB
	Browns Valley	12/21/2009 – 12/22/2009	Beale AFB
Wind Direction	Browns Valley	1/4/2008 – 1/10/2008	Beale AFB
	Browns Valley	12/21/2009 – 12/22/2009	Beale AFB

Beale AFB was the primary weather station for the Base Case Scenario. The complete Beale AFB hourly data set, as developed as part of the Upper Temp Model, and described in Section 9.4.2, was modified using linear regression techniques and regression coefficients found in Table 9.4.7 to represent conditions at Browns Valley for air temperature, dew-point temperature, and wind speed.

Base Case wind direction data were developed with Beale AFB weather station data, and supplemented, as required, with data from Sacramento Executive Airport weather station. The following procedures were applied to fill missing wind direction data. For both the Beale AFB and Sacramento Executive Airport weather stations, an average wind direction look-up table was created for each hour by month by using unit vector addition using all available data for the Base Case period of record. For both weather stations it was observed that when the recorded wind speed was less than 3 mph, wind direction was usually not reported. Missing data were filled using hourly values from the wind direction look-up table. No data were missing for the Sacramento Executive Airport secondary gage.

Linear regression was not performed on the wind direction data as wind direction was statistically independent; missing data was filled in from the Sacramento Executive Airport without any modification. Periods of at least 5 days (120 hours) missing data are included below in Table 9.4-9. Periods of missing data for air temperature, dew-point temperature, and wind speed are shown in table 9.4-5.

Table 9.4-9. Summary of missing Base Case Scenario weather station data and secondary wind direction data sources for the Englebright Temp Model.

Data Type	Primary Weather Station	Missing Dates	Secondary Weather Station
Wind Direction	Beale AFB	1/1/1971 – 12/31/1972	Sacramento Executive Airport
	Beale AFB	5/31/1990 – 12/31/1990	Sacramento Executive Airport

Resulting hourly data sets for air temperature, dew-point temperature, wind speed, and wind direction were converted into metric units as required by CE-QUAL-W2. Cloud cover data used for input into CE-QUAL-W2 was developed as described in Section 9.4.1.

9.4.4 Lower Temp Model

Table 9.4-10 shows weather station data used in the creation of the mean-daily HEATX input data set for air temperature, dew-point temperature, and wind speed for the Lower Temp Model.

Table 9.4-10. Sources of meteorological data the Lower Temp Model.

Model Process	Period of Record	Data Type	Weather Station
Calibration	01/01/2008-9/30/2012	Air Temperature	Beale AFB
		Dew-Point Temperature	Beale AFB
		Wind Speed	Beale AFB
Validation	01/01/2000-12/31/2011	Air Temperature	Beale AFB
		Dew-Point Temperature	Beale AFB
		Wind Speed	Beale AFB
Base Case	10/01/1969-12/31/2011	Air Temperature	Beale AFB
		Dew-Point Temperature	Beale AFB
		Wind Speed	Beale AFB

Beale AFB was the primary weather station for all scenarios. Model input data sets developed in this section for the Calibration, Validation, and Base Case scenarios used mean-daily data sets. Calculation of the mean-daily data sets is discussed as part of the Upper Temp Model in Section 9.4.2.

Missing Beale AFB weather station data for the Calibration and Validation scenarios were filled using data from the Nicolaus weather station and then secondly from the Browns Valley weather station. Missing data for the Base Case Scenario were filled using data from the Sacramento Executive Airport. All filled data from the secondary weather stations were modified to represent Beale AFB weather station using linear regression techniques presented in Section 9.4.2 and regression coefficients listed in Table 9.4-11. Periods of two days or more missing data for the Calibration Scenario are included in Table 9.4-12. Periods of at least 5 days missing data for the Validation Scenario are included in Table 9.4-13. The Beale AFB data set described as part of the Upper Temp Model Base Case Scenario in Section 9.4.2 was used for the Lower Temp Model Base Case Scenario.

Table 9.4-11. Regression coefficients used to modify secondary weather Station data to Represent Data at the Primary Weather Station for the Lower Temp Model.

Primary Weather Station	Secondary Weather Station	Parameter	Coefficient (A)	Coefficient (B)	R^2
Beale AFB	Nicolaus	Wind Speed	1.472	-0.629	0.820
		Air Temperature	1.093	-3.403	0.986
		Dew-Point Temperature	0.880	4.31	0.899
Beale AFB	Browns Valley	Wind Speed	2.662	-4.645	0.574
		Air Temperature	0.988	0.195	0.974
		Dew-Point Temperature	0.895	5.454	0.895

Table 9.4-12. Summary of missing Calibration Scenario weather station data and secondary data sources for the Lower Temp Model.

Data Type	Primary Weather Station	Missing Dates	Secondary Weather Station
Air Temperature/Dew-Point Temperature	Beale AFB	2/22/2008 - 2/24/2008	Nicolaus
	Beale AFB	6/21/2008 - 6/22/2008	Nicolaus
	Beale AFB	7/17/2008 - 7/18/2008	Nicolaus
	Beale AFB	8/11/2008 - 8/12/2008	Nicolaus
	Beale AFB	11/7/2008 - 11/8/2008	Nicolaus
	Beale AFB	3/27/2010 - 3/28/2010	Nicolaus
	Beale AFB	7/10/2010 - 7/11/2010	Nicolaus
	Beale AFB	1/30/2011 - 1/31/2011	Nicolaus
	Beale AFB	5/6/2011 - 5/9/2011	Nicolaus
	Beale AFB	10/14/2011 - 10/15/2011	Nicolaus
	Beale AFB	4/20/2012 - 4/21/2012	Browns Valley
	Beale AFB	7/27/2012 - 7/28/2012	Browns Valley
Wind Speed	Beale AFB	2/22/2008 - 2/24/2008	Nicolaus
	Beale AFB	6/21/2008 - 6/22/2008	Nicolaus
	Beale AFB	7/17/2008 - 7/18/2008	Nicolaus
	Beale AFB	8/11/2008 - 8/12/2008	Nicolaus
	Beale AFB	11/7/2008 - 11/8/2008	Nicolaus
	Beale AFB	3/27/2010 - 3/28/2010	Nicolaus
	Beale AFB	7/10/2010 - 7/11/2010	Nicolaus
	Beale AFB	1/30/2011 - 1/31/2011	Nicolaus
	Beale AFB	5/6/2011 - 5/9/2011	Nicolaus
	Beale AFB	10/14/2011 - 10/15/2011	Nicolaus
	Beale AFB	11/30/2011 - 12/31/2011	Browns Valley
	Beale AFB	4/20/2012 - 4/21/2012	Browns Valley
	Beale AFB	7/27/2012 - 7/28/2012	Browns Valley

Table 9.4-13. Summary of missing Validation Scenario weather station data and secondary data sources for the Lower Temp Model.

Data Type	Primary Weather Station	Missing Dates	Secondary Weather Station
Air Temperature/Dew Point	Beale AFB	6/30/2000 - 7/5/2000	Nicolaus
	Beale AFB	9/1/2000 - 9/5/2000	Nicolaus
	Beale AFB	10/6/2000 - 10/10/2000	Nicolaus
	Beale AFB	1/17/2003 - 1/21/2003	Nicolaus
	Beale AFB	1/26/2003 - 2/1/2003	Nicolaus
	Beale AFB	12/1/2005 - 7/21/2006	Nicolaus
	Beale AFB	7/23/2006 - 9/12/2006	Nicolaus
	Beale AFB	9/14/2006 - 10/2/2006	Nicolaus
	Beale AFB	10/4/2006 - 6/9/2007	Nicolaus
	Beale AFB	6/11/2007 - 7/2/2007	Nicolaus
Wind Speed	Beale AFB	3/11/2000 - 3/16/2000	Nicolaus
	Beale AFB	4/17/2000 - 4/26/2000	Nicolaus
	Beale AFB	4/28/2000 - 5/2/2000	Nicolaus
	Beale AFB	5/17/2000 - 5/22/2000	Nicolaus
	Beale AFB	5/26/2000 - 5/30/2000	Nicolaus
	Beale AFB	6/30/2000 - 7/6/2000	Nicolaus
	Beale AFB	7/8/2000 - 7/15/2000	Nicolaus
	Beale AFB	7/22/2000 - 8/2/2000	Nicolaus
	Beale AFB	8/11/2000 - 8/28/2000	Nicolaus
	Beale AFB	9/1/2000 - 9/13/2000	Nicolaus
	Beale AFB	9/16/2000 - 9/20/2000	Nicolaus
	Beale AFB	9/23/2000 - 9/27/2000	Nicolaus
	Beale AFB	10/3/2000 - 10/10/2000	Nicolaus
	Beale AFB	10/12/2000 - 10/19/2000	Nicolaus
	Beale AFB	10/31/2000 - 11/5/2000	Nicolaus
	Beale AFB	11/9/2000 - 11/18/2000	Nicolaus
	Beale AFB	11/20/2000 - 11/28/2000	Nicolaus
	Beale AFB	6/25/2001 - 7/4/2001	Nicolaus
	Beale AFB	8/23/2001 - 8/29/2001	Nicolaus
	Beale AFB	9/3/2001 - 9/8/2001	Nicolaus

Table 9.4-13. (continued)

Data Type	Primary Weather Station	Missing Dates	Secondary Weather Station
Wind Speed (continued)	Beale AFB	9/17/2001 - 9/26/2001	Nicolaus
	Beale AFB	9/28/2001 - 10/3/2001	Nicolaus
	Beale AFB	10/7/2001 - 10/11/2001	Nicolaus
	Beale AFB	10/13/2001 - 10/20/2001	Nicolaus
	Beale AFB	10/28/2001 - 11/10/2001	Nicolaus
	Beale AFB	11/14/2001 - 11/20/2001	Nicolaus
	Beale AFB	11/23/2001 - 11/30/2001	Nicolaus
	Beale AFB	1/3/2002 - 1/12/2002	Nicolaus
	Beale AFB	1/19/2002 - 1/25/2002	Nicolaus
	Beale AFB	1/31/2002 - 2/5/2002	Nicolaus
	Beale AFB	12/1/2005 - 7/21/2006	Nicolaus
	Beale AFB	7/23/2006 - 9/12/2006	Nicolaus
	Beale AFB	9/14/2006 - 10/2/2006	Nicolaus
	Beale AFB	10/4/2006 - 6/9/2007	Nicolaus
	Beale AFB	6/11/2007 - 7/2/2007	Nicolaus
	Beale AFB	11/30/2011 - 12/31/2011	Browns Valley

HEATX was run using mean-daily Calibration, Validation, and Base Case scenario datasets for wind speed, air temperature, dew-point temperature, and for daily cloud cover, as described in Section 9.4.1. A scaling factor of 0.87 was initially applied to the wind data to account for the difference in wind speed between the height of the instrument and the ground. This factor was reduced to half the initial value, 0.43, after it was hypothesized that measured wind speeds are likely to be substantially higher than at the river water surface where topography, trees, and riparian vegetation would dampen the wind speed. This hypothesis was upheld in the Lower Temp Model Calibration Scenario; using 50% of the ground-level wind speed resulted in a substantially improved calibration. HEATX input scaling factors were not used for cloud cover, air temperature, or dew-point temperature. HEATX output files were exported to DSS for use as an input to the Lower Temp Model.

10.0 Calibration

This section provides information about the calibration of the three water temperatures models used to simulate Project water temperatures. A detailed description of the models and model parameters determined through calibration can be found in Section 5.0 for the Upper Temp Model, Section 6.0 for the Englebright Temp Model and Section 7.0 for the Lower Temp Model.

10.1 Purpose

The objective of a calibration model is to determine parameter values for the model so that the model characterizes the behavior of a system, given a set of measured inputs and outputs. The purpose of the calibration model is:

- To ensure that temperature model output are consistent with historical data,
- To determine the accuracy of the model simulation, and
- To establish reliability of the model simulation.

10.2 Calibration Periods of Record

Each of the Project water temperature models was calibrated for a period of record determined based on available historical input information. This section describes the periods of records chosen for calibration of each of the models. Starting and ending simulation periods for the three calibration temperatures models are detailed in Table 10.2-1. See Section 11.0 for more information regarding each of the calibration models.

Table 10.2-1. Starting and ending simulation periods for calibration temperature models.

Temperature Model	Starting Date	Ending Date
Upper Temp Model	November 14, 2009	August 24, 2013
Englebright Temp Model	January 1, 2007	September 30, 2012
Lower Temp Model	January 1, 2008	September 30, 2012

10.2.1 Upper Temp Model

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 August 24, 2013. 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 Bullard Bar Reservoir calibration was focused on matching both simulated reservoir water-temperature profiles with historically-measured profiles in New Bullards Bar Reservoir, and simulated and historically measured Middle Yuba River water temperatures near its confluence with the North Yuba River. 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 Section 10.7.1.1 for dates with historically-measured profiles nearest the end of each month. This particular sequence was used because it reflects an adequate simulation 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 are available for the date shown in each figure.

A series of test flows occurred in the reach below New Bullards Bar Dam from August 12 to August 19, 2013. Flow and temperature data from this period were used to refine calibration parameters in the North Yuba River between New Bullards Bar Dam and the confluence with the Middle Yuba River.

10.2.2 Englebright Temp Model

In-pool data are used to set the model's initial conditions and to evaluate the model's ability to reproduce observed data. Proper application of the CE-QUAL-W2 model requires at least one set of in-pool observed data, with two sets being preferred. For the Englebright Temp Model, historical dam profile data are available bi-weekly for January 27, 1990 through present at YCWA's gage NY14. Historical profile data are also available bi-weekly 3.3 mi upstream of the dam from April 5, 2011 through present at YCWA's gage ENU. Historically-measured inflow water temperatures from the Yuba River and South Yuba River were available for the periods of August 18, 2008 (Yuba River) and December 19, 2003 (South Yuba River) through September 30, 2012. The period of record for calibration was selected to ensure sufficient "warm-up" time for the model prior to the start of historically-measured data. January 1, 2007 was selected as the start date as a winter month, with limited stratification in the reservoir.

Other calibration data included hourly meteorology data available from April 12, 1989 through September 30, 2012 from CIMIS station Browns Valley and daily average water temperature data at YCWA's NY28 gage at Smartsville starting on September 3, 1999 through September 30, 2012.

10.2.3 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 AFB; and river geometry taken from the RMT SRH2D model (Pasternack and Lower Yuba RMT 2012) for the period of January 1, 2008 through September 30, 2012. 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. The period of record for calibration was selected based on the general availability of input water temperatures and flow data; while few locations had data as early as January 1, 2008, a slightly longer period of record was selected due to the availability of water temperature data at Smartsville, at the upstream end of the reach, and Marysville, near the downstream end.

10.3 Calibration Standards

Calibration standards were used to determine how accurate the calibration model was to predicting observed water temperatures. To determine if the calibration was a quality calibration, statistical methods were used. These two statistical methods were the mean error (ME) and the absolute mean error (AME).

$$\textit{Mean Error (ME)} = \frac{\Sigma\ (\textit{Predicted Temperature} - \textit{Observed Temperature})}{\textit{number of observations}}$$

$$\text{Absolute Mean Error (AME)} = \frac{\Sigma\ |\textit{Predicted Temperature} - \textit{Observed Temperature}|}{\textit{number of observations}}$$

By using statistical analysis to determine the quality of the calibration, these two methods provide the best indication of the model performance since it is directly interpretable. The goal of calibration was to have a ME 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. While it was preferable if the AME value was as close to 0°F as possible, short of that, it should be below 1.0°F; an AME greater than 1.0°F implies the average error is either greater than 1.0°F or less than -1.0°F. An average error within 1.0°F represents a reasonable calibration given the range of temperatures being predicted.

10.4 Determination of Calibration Parameter Values

As part of calibration, different calibration parameters were modified to identify which were most applicable for use in calibrating the models. This section describes the determination of the values for the various calibration parameters for each model.

10.4.1 Upper Temp Model

The Upper Temp Model was calibrated in three separate portions. First, New Bullards Bar Reservoir was calibrated for it's observed reservoir profiles, then Oregon Creek below Log Cabin Diversion Dam and the Middle Yuba River from Our House Diversion Dam to the North Yuba River were calibrated, and finally the North Yuba River below New Bullards Bar Dam and the Yuba River down to Rice's Crossing was calibrated.

10.4.1.1 New Bullards Bar Reservoir

After running the Upper Temp Model, New Bullards Bar Reservoir water temperature profiles were compared against historically-measured profiles to determine the overall fit of the calibration parameters. The AME for each profile assisted with this comparison, and special attention was given to the simulated and historically-measured temperatures near the New Colgate Penstock intake elevation. Models runs were repeated and calibration parameters were changed until the historically-measured and simulated profiles matched as closely as possible. Modifications to meteorological scaling factors made the most dramatic improvements in calibration, and the diffusion coefficients were effective for fine adjustments in the overall shape of the profile.

10.4.1.2 Oregon Creek and Middle Yuba River

After running the Upper Temp Model, the ME and AME were determined for all of the locations where temperature data were available. There is one temperature logger on Oregon Creek near Celestial Valley (Oregon Creek, RM 2.3), and another on the Middle Yuba River just above the confluence with the North Yuba River, but otherwise, no historically-measured water temperatures were available downstream from the Our House and Log Cabin diversion dams. Oregon Creek temperatures were calibrated first, to minimize AME and ME, though there is little warming between the input temperature location (Log Cabin Diversion Dam, RM 4.3), and the location of the logger in Celestial Valley (RM 2.3). Since there are no intermediate temperature loggers to check against until the confluence with the North Yuba River, all river reaches below Celestial Valley were calibrated as a single reach,.

10.4.1.3 North Yuba River and Yuba River

North Yuba River and Yuba River above Englebright Reservoir reaches were calibrated in the same way as Oregon Creek and the Middle Yuba River. First the North Yuba River from below New Bullards Bar Dam down to the confluence with the Middle Yuba River was calibrated. While the primary parameters used to calibrate the North Yuba River below New Bullards Bar Dam were the meteorological scaling factors, the river reach is filled with large boulders and multiple pools, limiting the ability of a typical representation using available channel geometry to represent actual hydraulics of the reach. Accordingly, the manning's n, or roughness coefficient, for the reach was modified to better represent the reach and improve the calibration. Once that reach was calibrated to satisfaction, it was followed by a more typical calibration using meteorological scaling factors of the Yuba River from the Middle-North confluence to above New Colgate Powerhouse, and finally from the New Colgate Powerhouse down to RM 33.9. There isn't any observed water temperature data below RM 33.9, so the model cannot be calibrated all the way down to Rice's Crossing. Water temperatures computed at RM 34.1 were used as inputs to the Englebright Temp Model.

10.4.2 Englebright Temp Model

A post-processor comparing simulated and historically-measured water temperature data at Smartsville was used for model calibration. After running the Englebright Temp Model, ME, AME and R^2 parameters were determined both for the full period of record and for the months of July through October. July through October was identified as a period of biological concern, and model calibration for this period was identified by the relicensing participants as more important than for the overall period. Additionally, simulated reservoir water-temperature profiles were compared to historically-measured profiles at two locations within the reservoir, immediately upstream of the dam and 3.3 mi upstream of the dam. AME parameters were calculated for each profile. Model parameters were modified to optimize ME, AME and R^2 parameters.

Primary model parameters used for calibration included the wind sheltering coefficients [WSC], reservoir outlet centerline elevations [ESTR], and selective withdrawal limitations of reservoir outlets [KTSTR AND KBSTR]. Other model parameters considered during calibration included the surface heat exchange method used [SLHTC], the light extinction coefficient for pure water [EXH2O]. Parameters evaluated for calibration capability, and the range of factors used are listed below.

10.4.2.1 Wind Sheltering Coefficients

Wind sheltering coefficients are able to scale the historically-measured wind speed values by model segment and Julian Day. Wind speed impacts mixing and heat exchange in the upper layers of the reservoir model. Calibration resulted in wind sheltering coefficients greater than 1.0, indicating a need for increased wind speeds above gaged values. Predominately east-west oriented segments required higher wind sheltering coefficients than north-south oriented segments. Additionally, the period of synthesized wind speeds from April 28, 2009 through August 10, 2010, as described in Section 9.2, needed an additional increase in the wind sheltering coefficients. Table 10.4-1 summarizes the final calibrated wind sheltering coefficients.

Table 10.4-1. Calibrated Wind Sheltering Coefficients, by Segment and Date, for the Englebright Temp Model.

Date	Wind Sheltering coefficient	
	Segment 9-20	Segments 1-8, and 21-55
January 1, 2007-April 27, 2009	1.50	1.25
April 28, 2009-October 10, 2010	1.80	1.50
October 11, 2010-September 30, 2012	1.50	1.25

10.4.2.2 Reservoir outlet centerline elevations

Both the Narrows 1 and Narrows 2 Powerhouse intakes are configured such that the standard selective withdrawal algorithm included in the model did not strictly apply. It was determined during calibration that both reservoir outlet elevations for the Narrows 1 and Narrows Powerhouse intakes were better represented by adjusting them upwards.

The Narrows 1 intake is vertically-oriented, with a trashrack mounted on top, and a secondary horizontally-oriented inlet along the base of the intake. It is not known if the secondary inlet has been plugged by sediment, as was originally envisioned when the intake was constructed. Through calibration, the centerline intake elevation of the vertically-oriented inlet was increased to 465.9 ft-msl (142 m). It was found during calibrating that both the reservoir profiles and downstream temperatures were improved by splitting flow between the vertically-oriented inlet and the lower horizontally-oriented inlet. Error between simulated temperatures and historically-measured temperatures was minimized with 85% of flow through the vertically-oriented inlet and 15% of flow through the lower horizontally-oriented inlet.

The Narrows 2 intake is inset into the side slope of the reservoir on a ledge with a sloping trashrack across the face of the intake. Through calibration, error between simulated temperatures and historically-measured temperatures was minimized by increasing centerline intake elevation of the inlet to 479 ft-msl (146 m) in combination with selective withdrawal limitations, as discussed in Section 10.4.3. Increasing the centerline elevation improved results on the average, but is generally too low for higher intake flows (underestimates temperatures) and too high for lower intake flows (overestimates temperatures).

10.4.2.3 Selective Withdrawal Limitations

The selective withdrawal algorithm calculates the vertical withdrawal zone limits based on outlet geometry, outflows, and in-pool densities. Selective withdrawal limitations allow the model user to add additional limitations upon the bottom and top elevations for which outflows are calculated. By default, the limits are set at the bottom-most and top-most layer of the model segment. Optimal calibration results were achieved by limiting the Narrows 2 Powerhouse intake withdrawal from the top-most layer down to the 37th layer, approximately equal to the intake invert elevation. This was justified because the intake is located on a shelf inside the reservoir that extends out approximately 80 ft from the intake. No selective withdrawal limitations were imposed on the Narrows 1 Powerhouse or the spillway.

10.4.2.4 Surface Heat Exchange Method

Two surface heat exchange methods are available to the user: term-by-term [TERM] or equilibrium temperature [ET]. Term-by-term is the default method. A sensitivity run using the equilibrium temperature method did not improve results. Term-by-term was chosen.

10.4.2.5 Light Extinction Coefficient for Pure Water

The default range for light extinction in the model is 0.25 to 0.45. The CE-QUAL-W2 user's manual suggests using 0.45 if water quality is not simulated. An empirical relationship was used to estimate light extinction using Secchi depth measurements measured bi-weekly from April 2011 to October 2012. Two runs of the model were made, 1) with a the default 0.45 value and 2) with the empirically-derived, interpolated time series. Results indicated that the model is relatively insensitive to the light extinction coefficient. A value of 0.45 was deemed more appropriate for the Englebright Temp Model because of the limited availability of measured Secchi depth data.

Results of the Englebright Temp Model calibration are shown in Section 10.5.2.

10.4.3 Lower Temp Model

After running the Lower Temp Model, the calibration post-processor read in the water temperatures at selected locations from the output DSS file and also read in historically-measured water temperatures for the same locations from a different DSS file. The ME and AME parameters at each location were determined both for the fully period of record and for the months of July through October. July through October was identified as a period of biological concern, and model calibration for this period was identified by the relicensing participants as more important than for the overall period. The Yuba River below Englebright Dam was broken into five reaches: (1) from Englebright Dam to the Yuba River's confluence with Deer Creek; (2) from the Yuba River's confluence with Deer Creek to the Yuba River's confluence with Dry Creek; (3) from the Yuba River's confluence with Dry Creek to Daguerre Point Dam; (4) from Daguerre Point Dam to the Marysville gage; and (5) from the Marysville gage to the Yuba River's confluence with the Feather River. Parameters for each reach, starting with the upstream reaches, were modified so the ME and AME for monitoring locations within each reach were as close to the desired values, as described in Section 10.3, as possible. After calibrating a reach, the immediately-downstream reach was similarly calibrated.

Among the various parameters available within HEC-5Q for model calibration, the meteorological scaling factors were primarily used for calibration. Parameters evaluated for calibration capability, and the range of factors used are listed in Section 7.1.3.

Results of the Lower Temp Model calibration are shown in Section 10.5.3.

10.5 Results

This section includes the final results from the Calibration Scenario. These simulation results reflect the calibration parameter values determined as described in Section 10.3.

10.5.1 Upper Temp Model

The calibration of the Upper Temp Model was broken into three pieces: (1) New Bullards Bar Reservoir, (2) Middle Yuba River and Oregon Creek, and (3) the North Yuba River and Yuba River. This section provides a description of each.

10.5.1.1 New Bullards Bar Reservoir

Meteorological data and inflow temperatures were examined to see if there was an unusually cold bias in 2010 compared to 2011 and 2012 and all were found to be normal. An investigation into the validity of the observed temperature profiles revealed that, while measuring the profile on September 15th, 2010, the temperature logger became caught on something, could not be recovered, and had to be replaced. The absolute mean errors for the three profiles before September 15th are 2.9°, 2.9°, and 2.5 °F, while the absolute mean errors for the three profiles after September 15th are each 1.3°F. It is believed that the discrepancy is due to the changing of equipment, and the match to the newer equipment lends greater confidence to the calibration profiles. Figures 10.5-1 through 10.5-14 show comparisons of selected historically-measured New Bullards Bar Reservoir water-temperature profiles with simulated New Bullards Bar Reservoir water-temperature profiles for the period of May 12, 2010 through June 30, 2011.

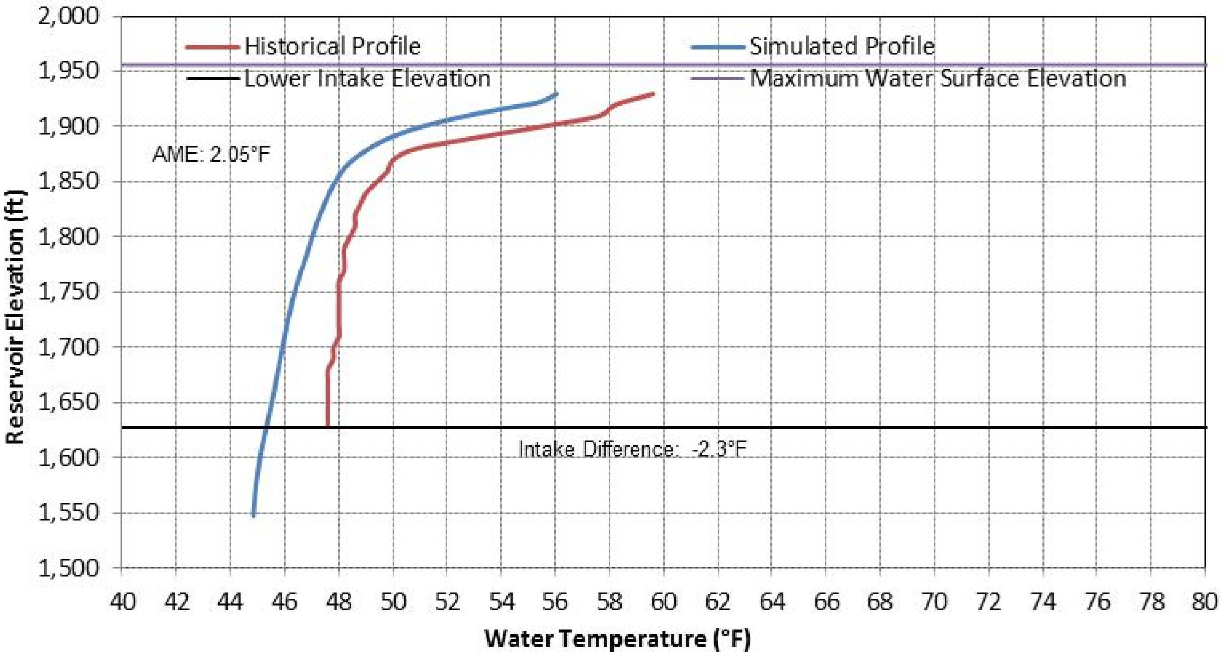


Figure 10.5-1. Comparison of historical and simulated New Bullards Bar Reservoir profiles for May 12, 2010.

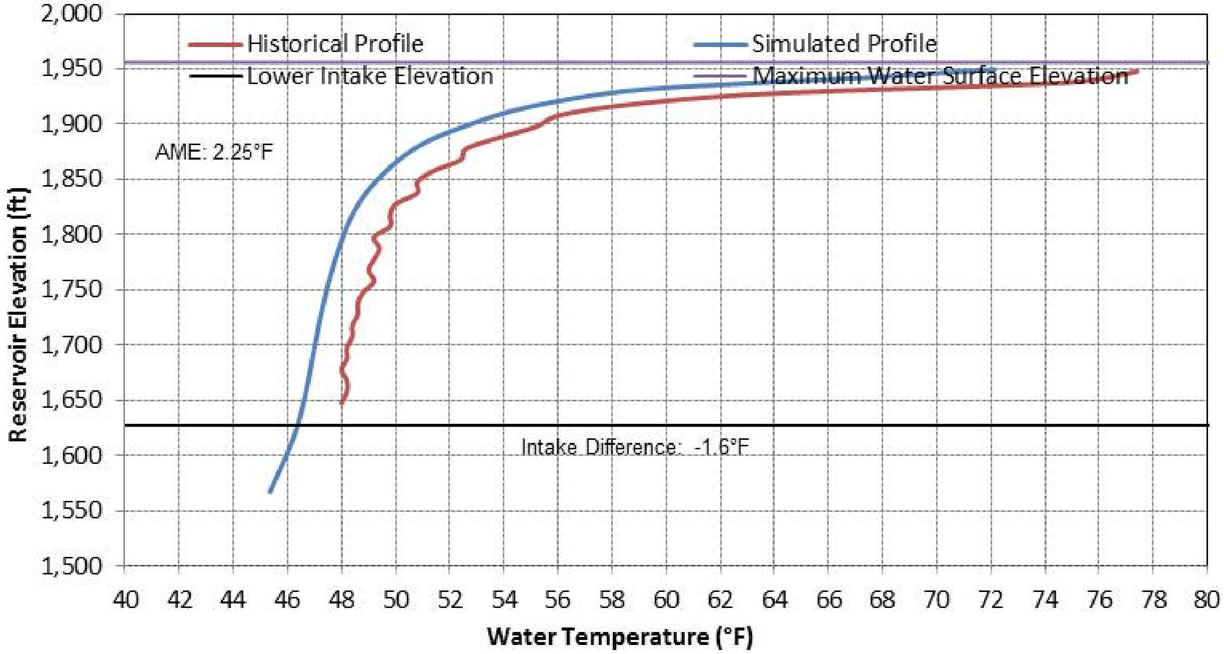


Figure 10.5-2. Comparison of historical and simulated New Bullards Bar Reservoir profiles for June 28, 2010.

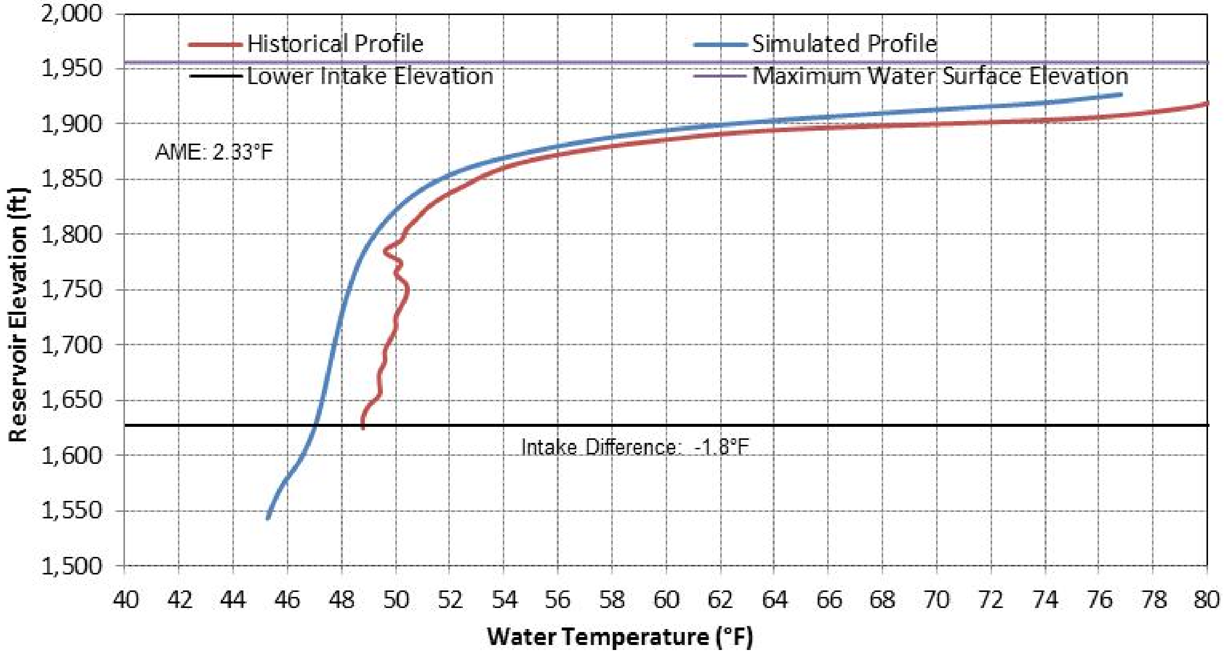


Figure 10.5-3. Comparison of historical and simulated New Bullards Bar Reservoir profiles for July 22, 2010.

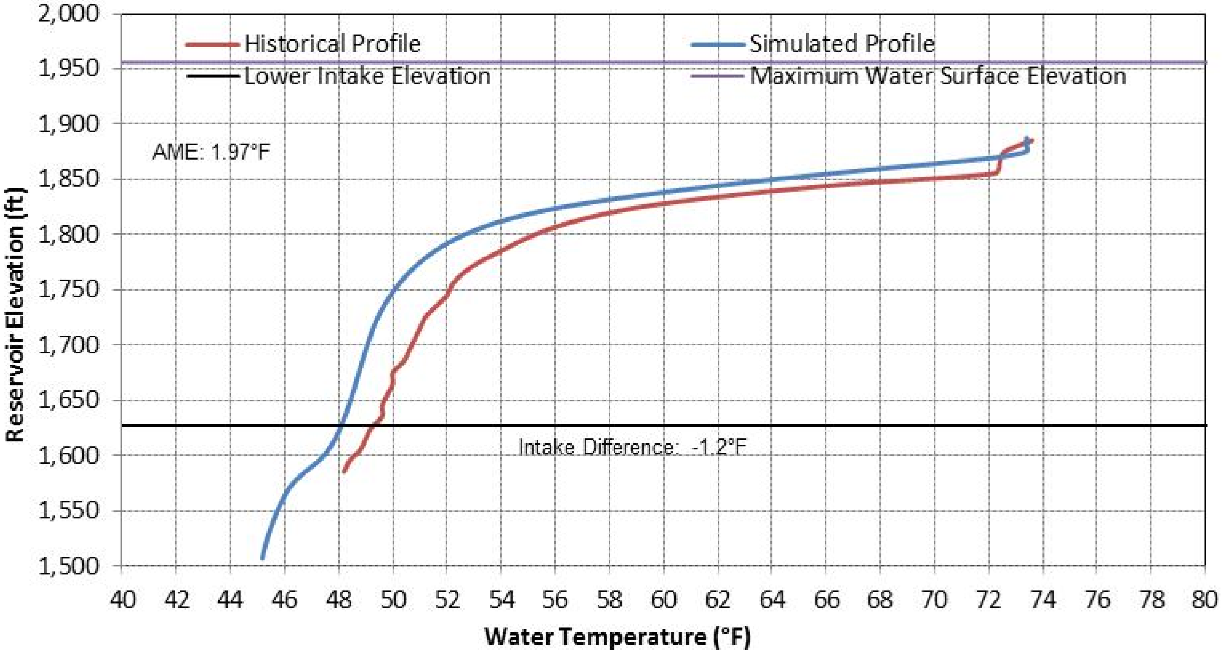


Figure 10.5-4. Comparison of historical and simulated New Bullards Bar Reservoir profiles for August 31, 2010.

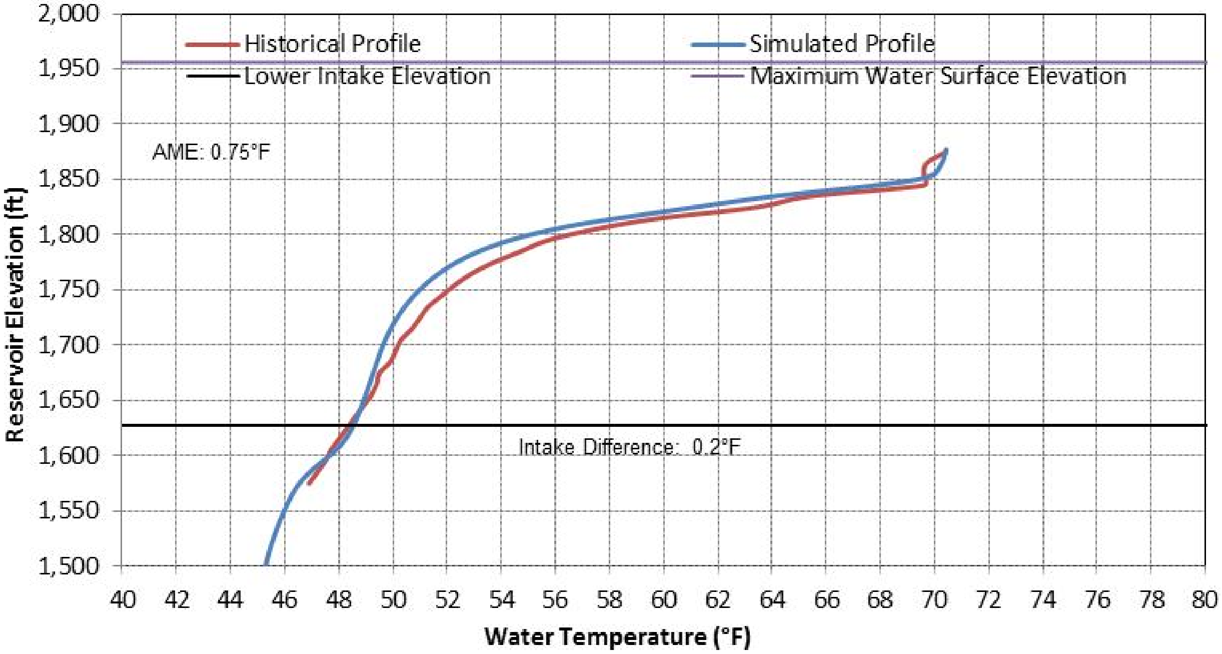


Figure 10.5-5. Comparison of historical and simulated New Bullards Bar Reservoir profiles for September 30, 2010.

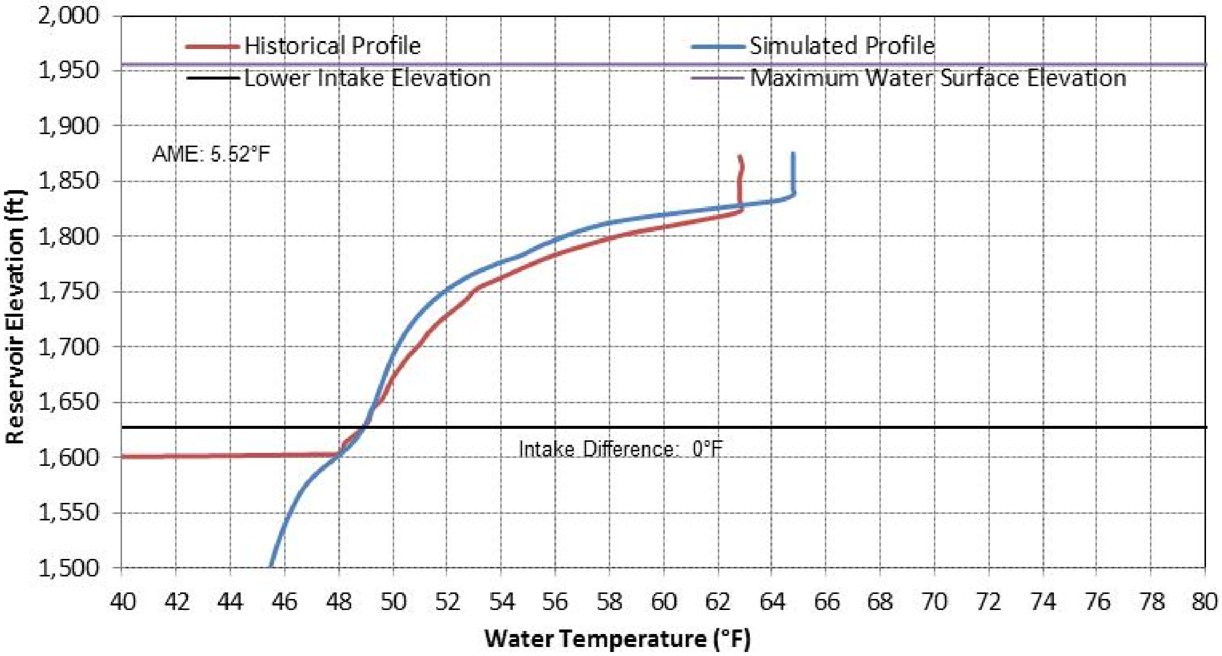


Figure 10.5-6. Comparison of historical and simulated New Bullards Bar Reservoir profiles for October 27, 2010.

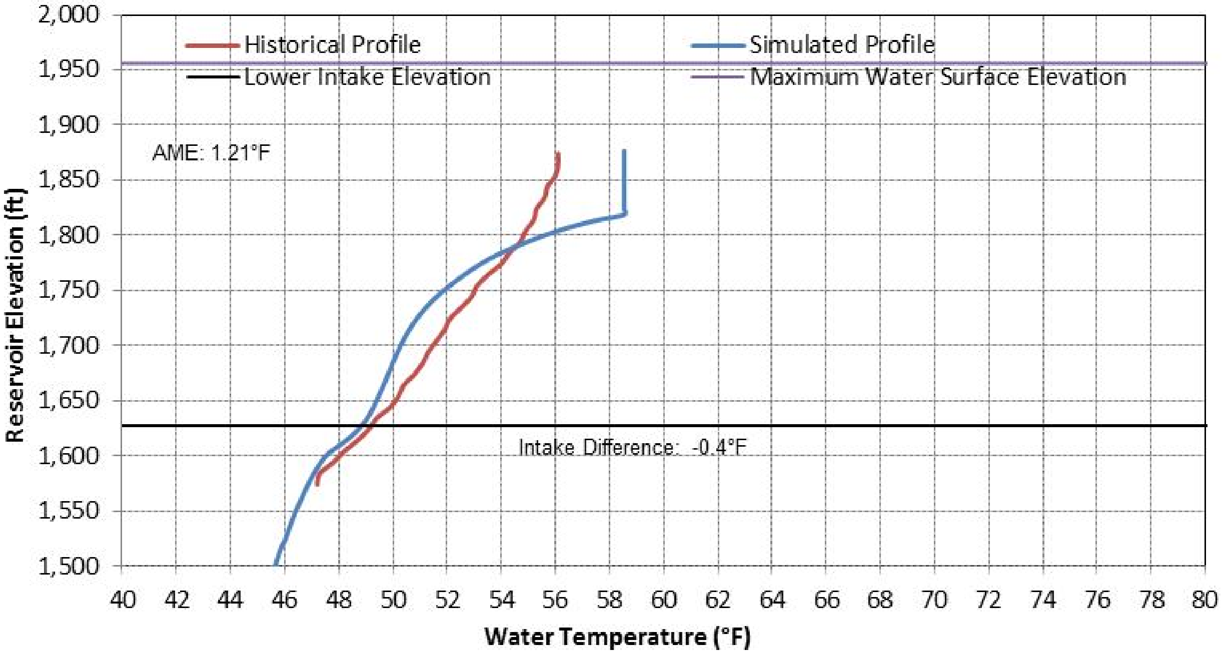


Figure 10.5-7. Comparison of historical and simulated New Bullards Bar Reservoir profiles for November 23, 2010.

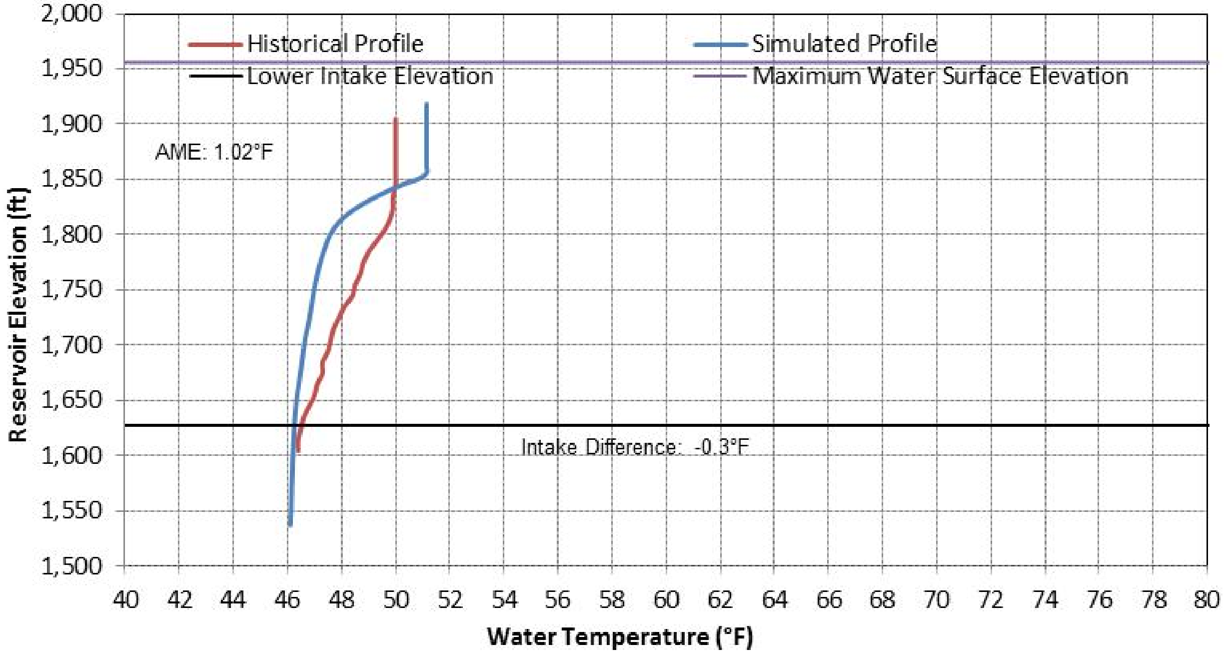


Figure 10.5-8. Comparison of historical and simulated New Bullards Bar Reservoir profiles for December 30, 2010.

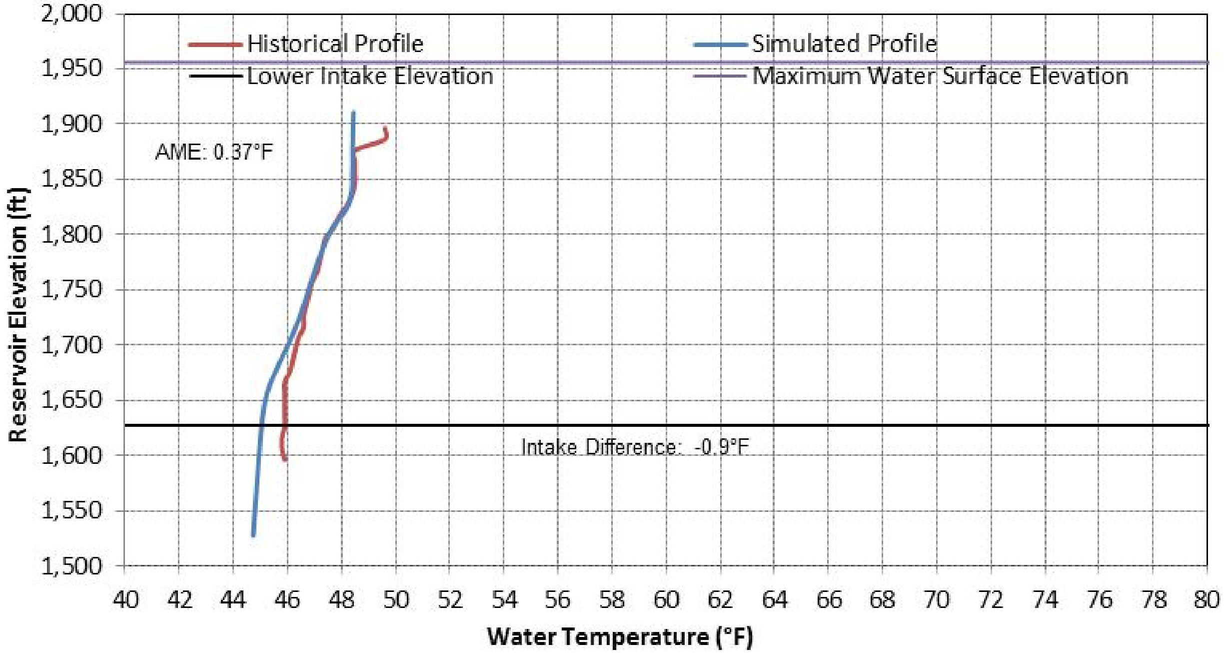


Figure 10.5-9. Comparison of historical and simulated New Bullards Bar Reservoir profiles for January 26, 2011.

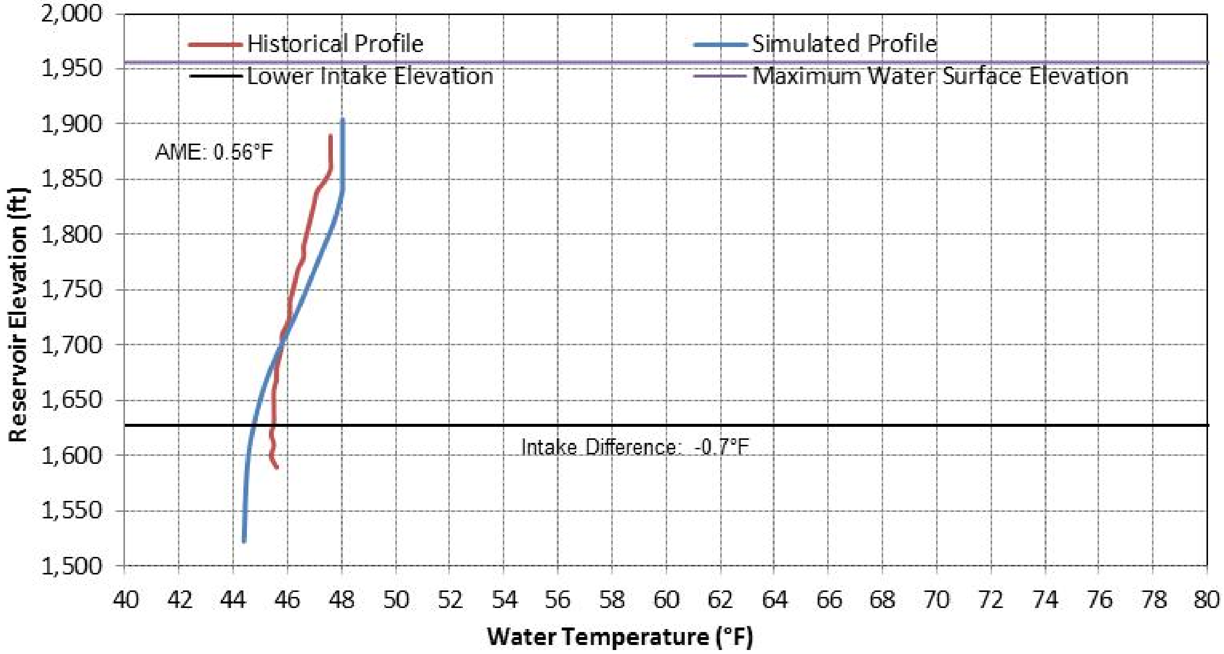


Figure 10.5-10. Comparison of historical and simulated New Bullards Bar Reservoir profiles for February 15, 2011.

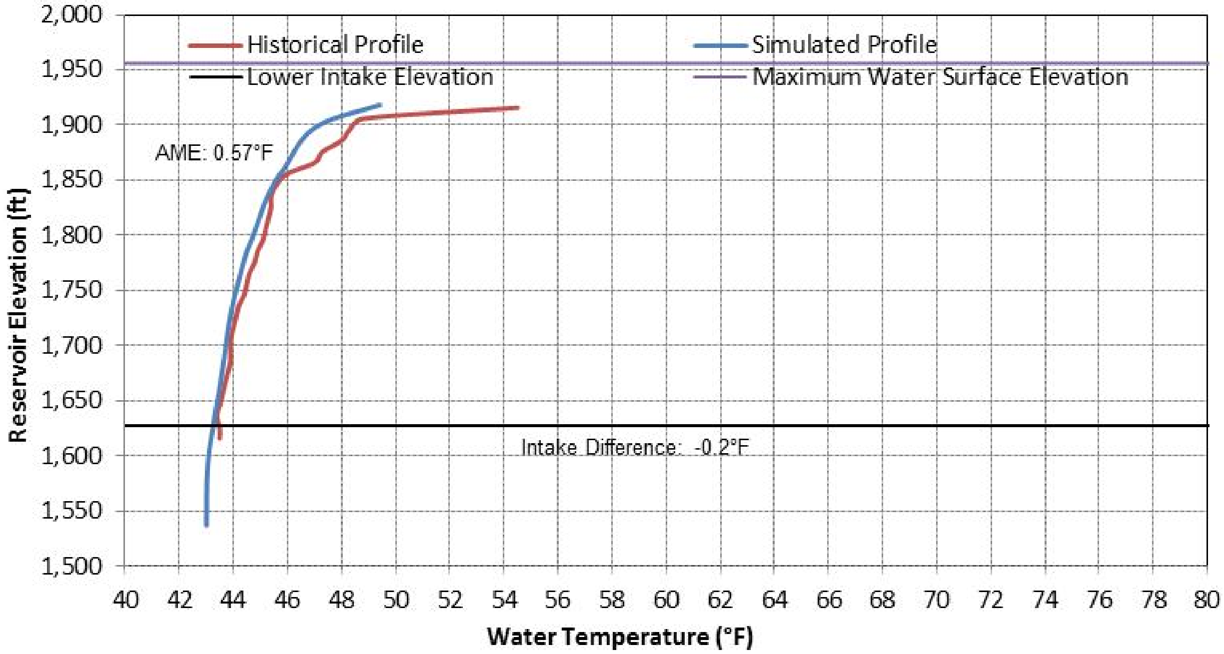


Figure 10.5-11. Comparison of historical and simulated New Bullards Bar Reservoir profiles for March 31, 2011.

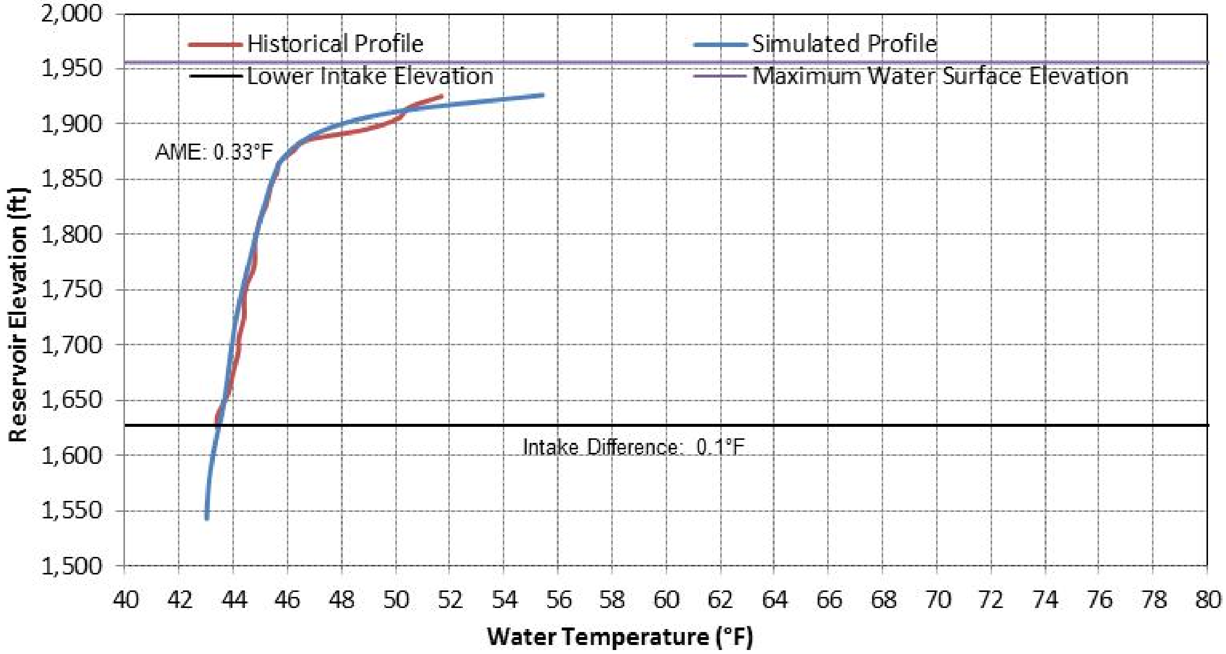


Figure 10.5-12. Comparison of historical and simulated New Bullards Bar Reservoir profiles for April 12, 2011.

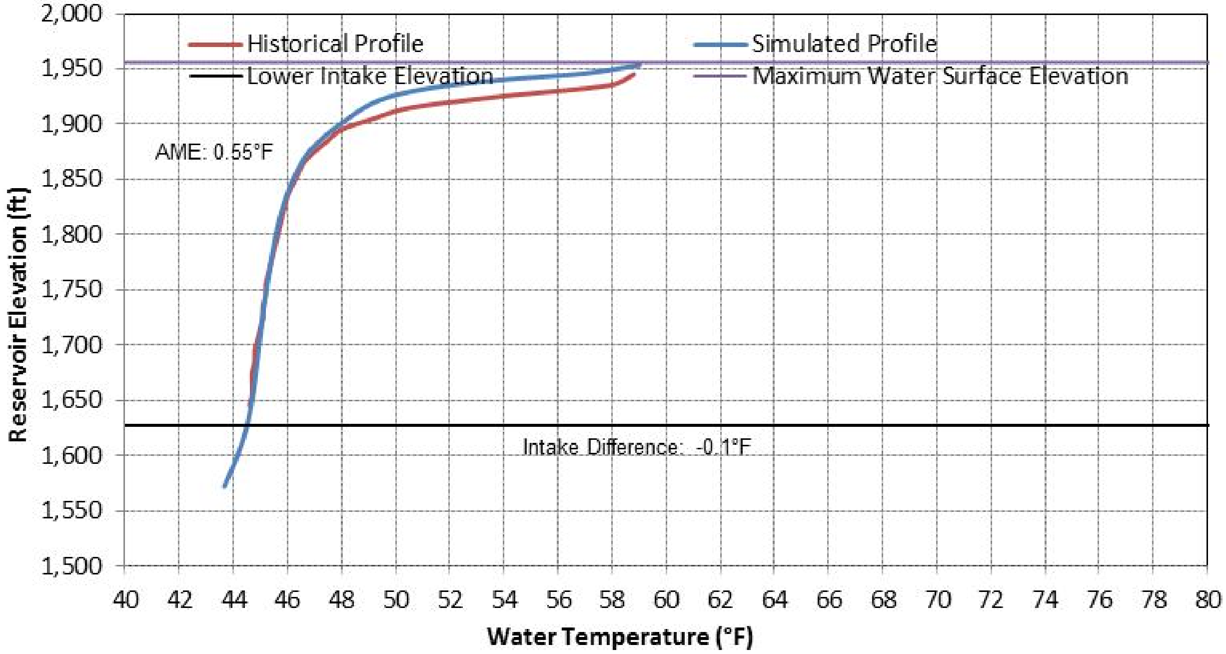


Figure 10.5-13. Comparison of historical and simulated New Bullards Bar Reservoir profiles for May 26, 2011.

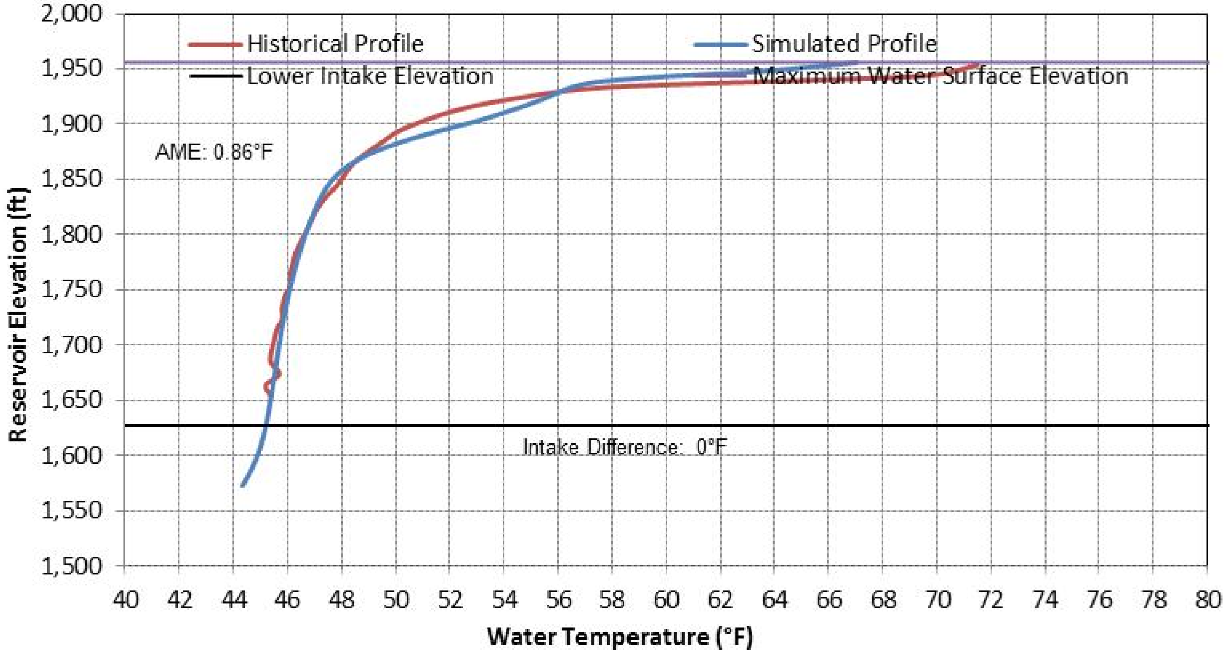


Figure 10.5-14. Comparison of historical and simulated New Bullards Bar Reservoir profiles for June 30, 2011.

10.5.1.2 Middle Yuba River and Oregon Creek

Historically-measured water temperatures are available on a site in Oregon Creek, as well as the Middle Yuba River. Table 10.5-1 shows the resulting ME and AME for the full calibration period and July through October periods.

Table 10.5-1. Summary of Mean Error (ME) and Absolute Mean Error (AME) for the Upper Temp Model at historical measurement locations.

Location	Gage ID	Full Period		July-October	
		ME	AME	ME	AME
Oregon Creek between Log Cabin Diversion Dam and Middle Yuba River					
Celestial Valley (RM 2.3)	T60	-0.88	1.54	-1.58	2.02
Middle Yuba River					
Middle Yuba River upstream of North-Middle Yuba Junction (RM 0.1)	T90	-0.03	1.86	1.56	1.99

Figures 10.5-15 through 10.5-17 show comparisons of timeseries for the simulated water temperatures and the historically measured water temperatures at the locations shown in Table 10.5-1.

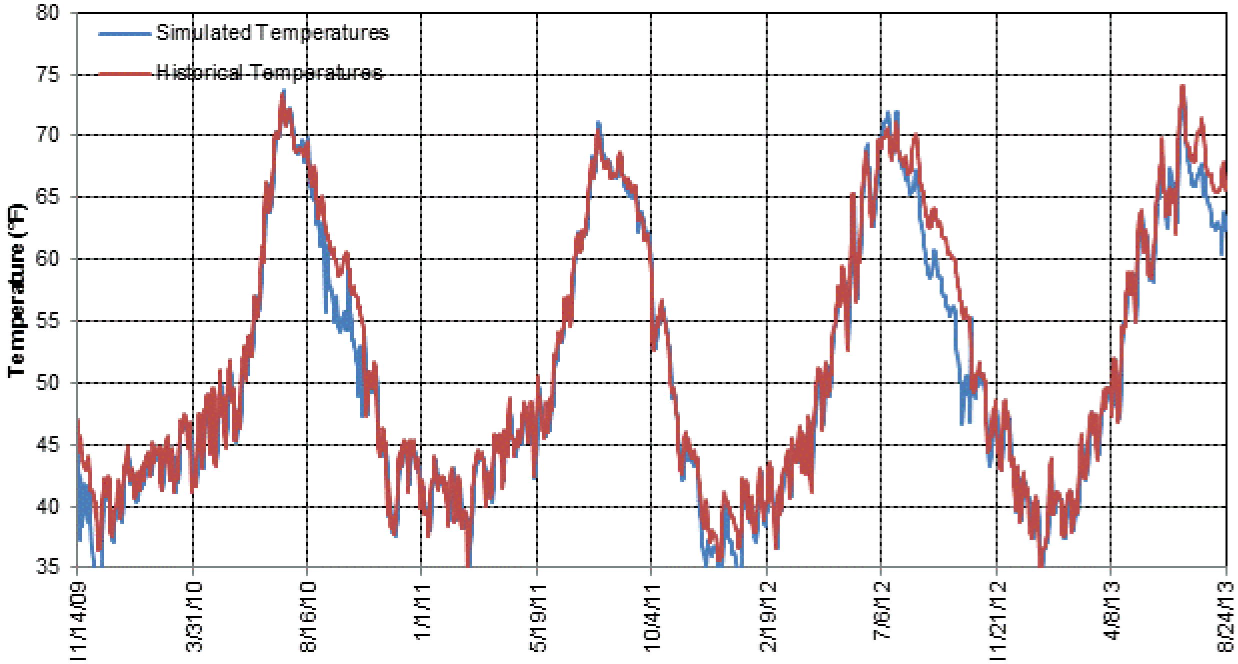


Figure 10.5-15. Comparison of Simulated and Historically Measured Oregon Creek Water Temperatures in Celestial Valley (RM 2.3) for the Calibration Scenario.

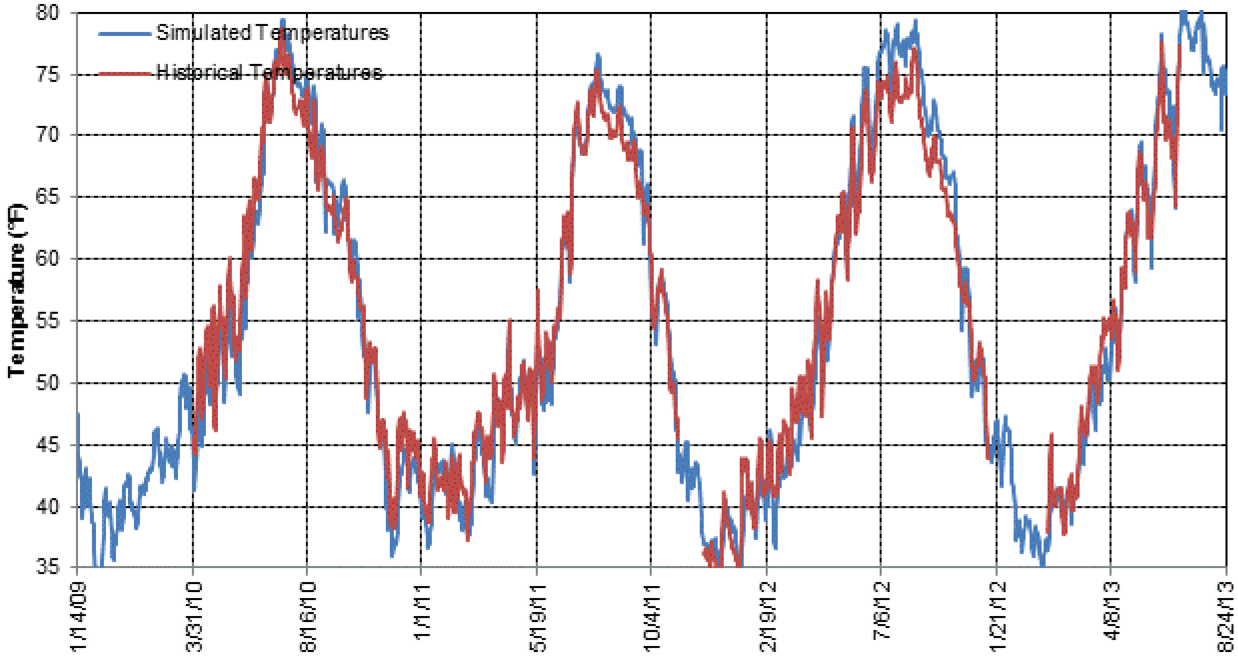


Figure 10.5-16. Comparison of Simulated and Historically-Measured Middle Yuba River (RM 0.1) Water Temperatures upstream from its confluence with the North Yuba River for the Upper Temp Model Calibration Scenario

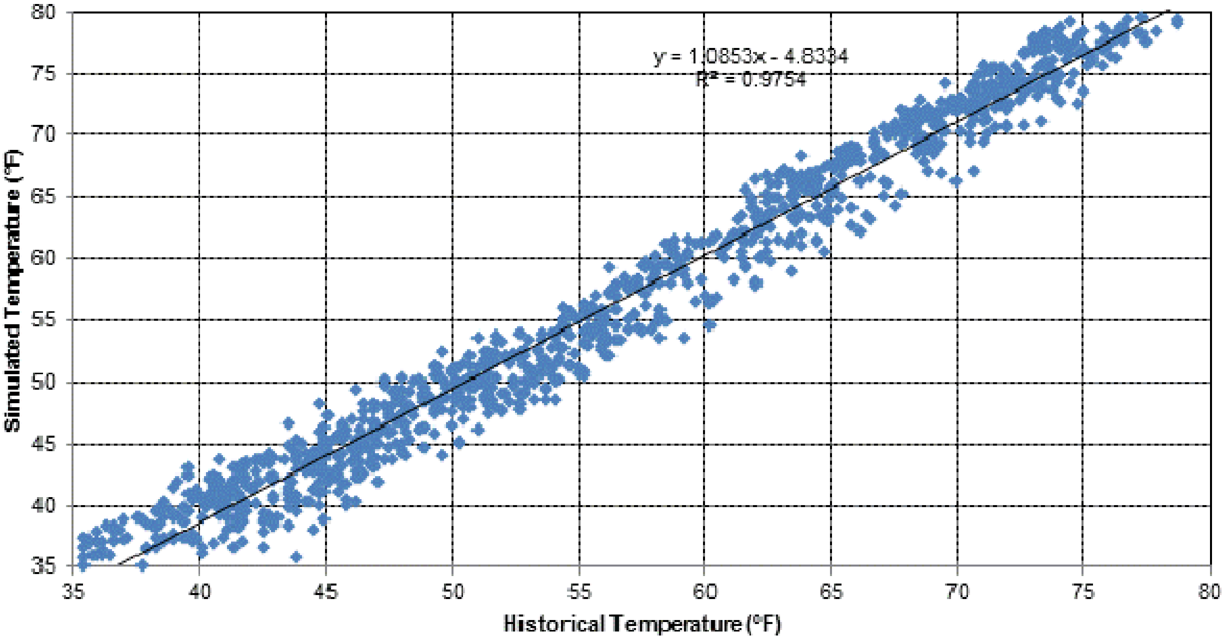


Figure 10.5-17. Scatter Plot Comparison of Simulated and Historically-Measured Middle Yuba River (RM 0.1) Water Temperatures upstream from its confluence with the North Yuba River for the Upper Temp Model Calibration Scenario

10.5.1.3 North Yuba River and Yuba River

Historically-measured water temperatures are available at multiple sites on the Yuba River. Table 10.5-2 shows the resulting ME and AME for the full calibration period and July through October periods.

Table 10.5-2. Summary of Mean Error (ME) and Absolute Mean Error (AME) for the Upper Temp Model at historical measurement locations.

Location	Gage ID	Full Period		July-October	
		ME	AME	ME	AME
North Yuba River					
North Yuba River upstream of North-Middle Yuba Junction (RM 40.1)	T80	2.07	3.39	-0.20	1.73
Yuba River between North-Middle Yuba Junction and New Colgate Powerhouse					
Yuba River downstream of North-Middle Yuba Junction (RM 40.0)	T100	-0.36	2.24	1.24	1.76
Yuba River upstream of New Colgate Powerhouse (RM 34.4)	T110	-0.39	2.39	0.26	1.83
Yuba River between New Colgate Powerhouse and Rice's Crossing					
Yuba River downstream of New Colgate Powerhouse (RM 34.1)	T130	-0.65	1.56	-0.49	1.38

Figures 10.5-18 through 10.5-26 show comparisons of the time series for the simulated water temperatures and the historically measured water temperatures at the locations shown in Table 10.5-2.

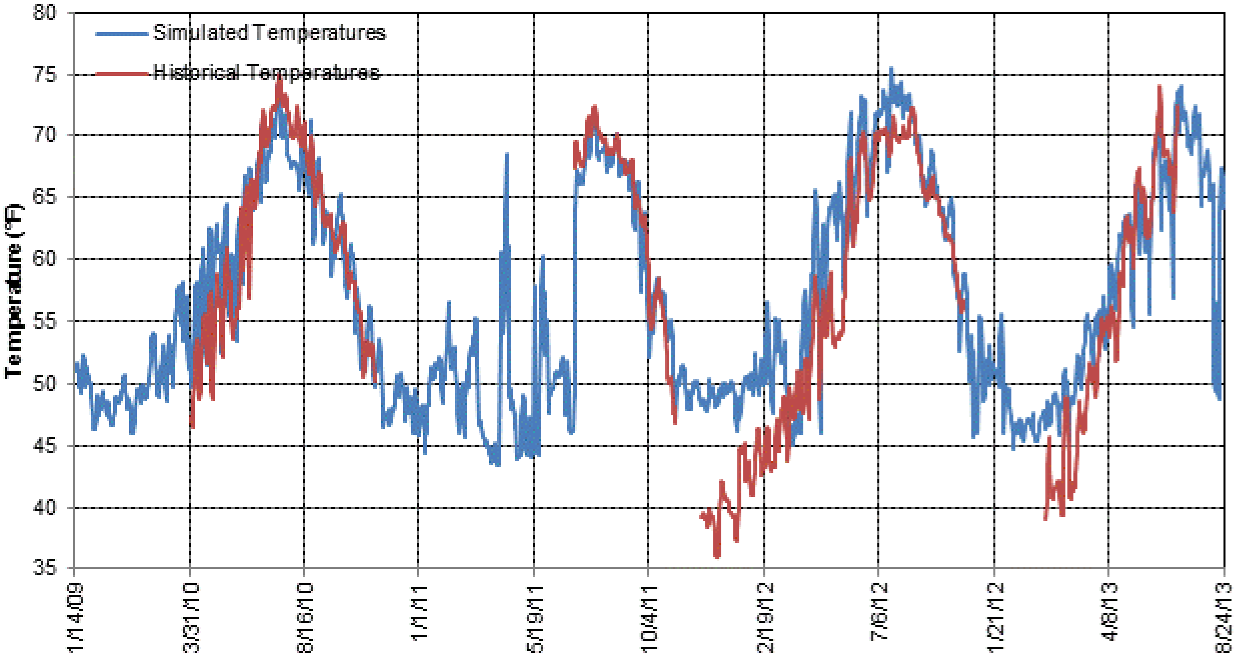


Figure 10.5-18. Comparison of Simulated and Historically-Measured North Yuba River (RM 0.1) Water Temperatures upstream from its confluence with the North Yuba River for the Upper Temp Model Calibration Scenario

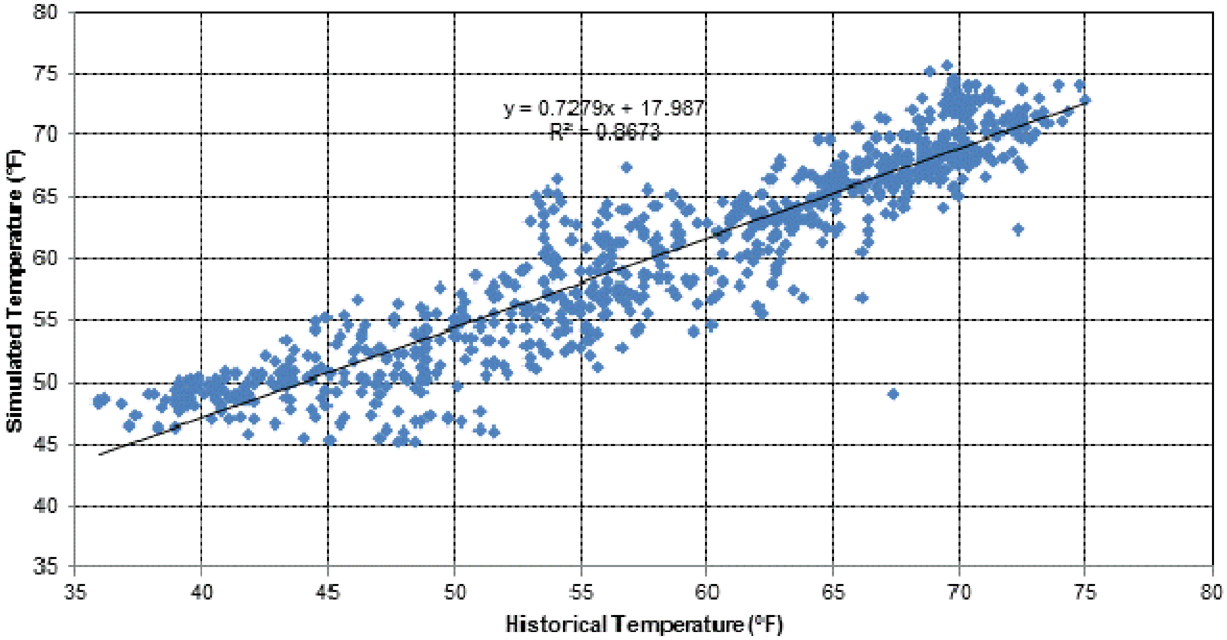


Figure 10.5-19. Scatter Plot Comparison of Simulated and Historically-Measured North Yuba River (RM 0.1) Water Temperatures upstream from its confluence with the North Yuba River for the Upper Temp Model Calibration Scenario

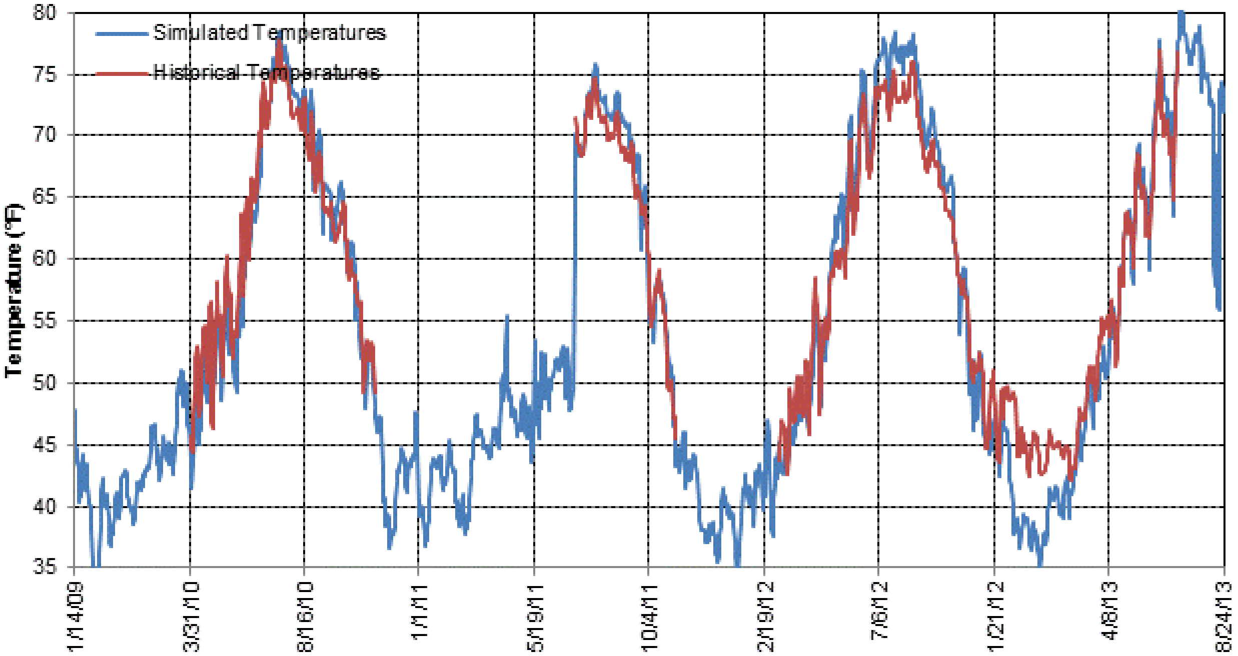


Figure 10.5-20. Comparison of Simulated and Historically-Measured Yuba River (RM 40.0) Water Temperatures downstream from the confluence of the North Yuba and Middle Yuba rivers for the Upper Temp Model Calibration Scenario

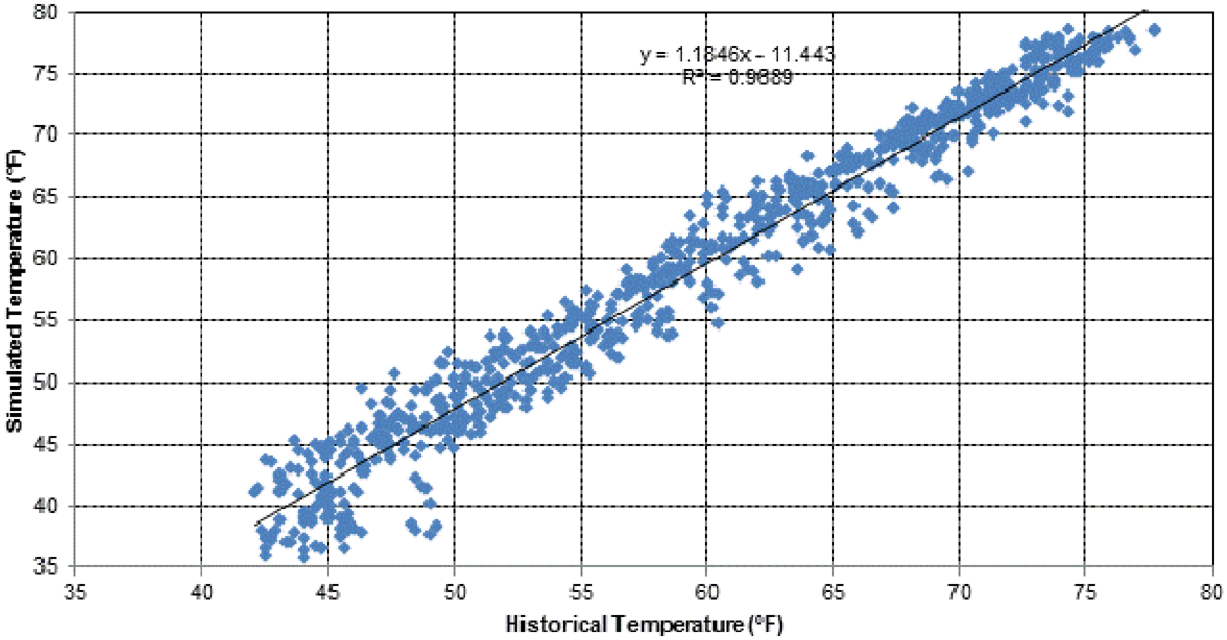


Figure 10.5-21. Scatter Plot Comparison of Simulated and Historically-Measured Yuba River (RM 40.0) Water Temperatures downstream from the confluence of the North Yuba and Middle Yuba rivers for the Upper Temp Model Calibration Scenario

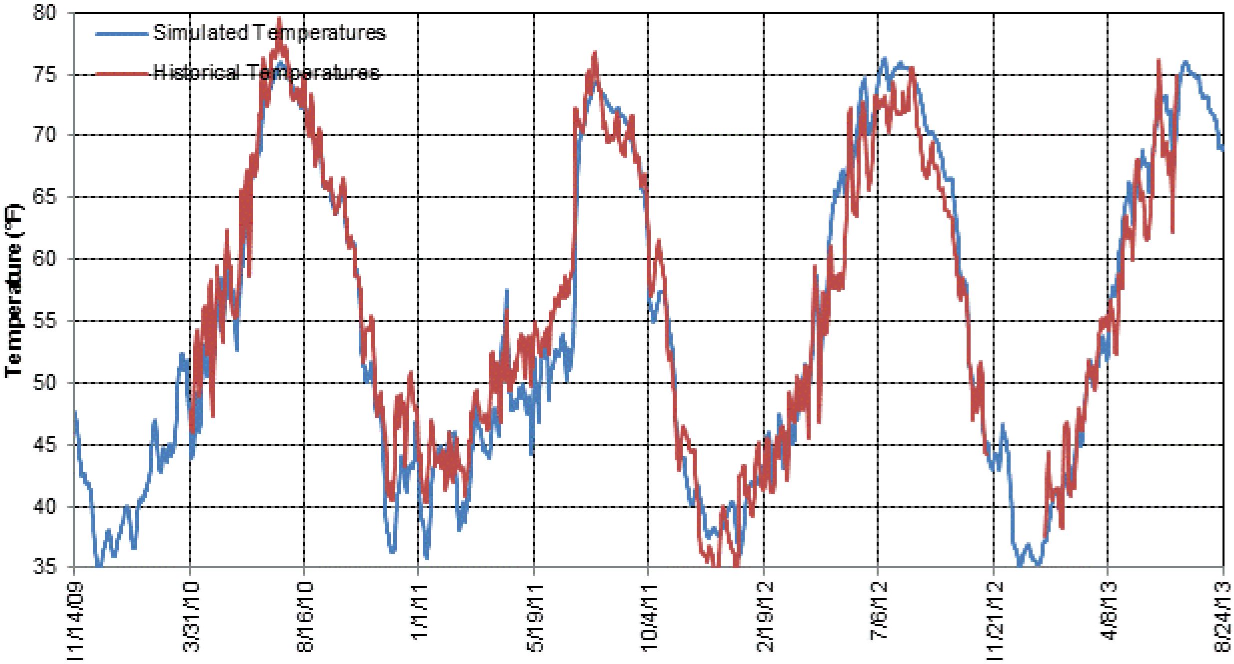


Figure 10.5-22. Comparison of Simulated and Historically-Measured Yuba River (RM 34.4) Water Temperatures upstream from the New Colgate Powerhouse for the Upper Temp Model Calibration Scenario

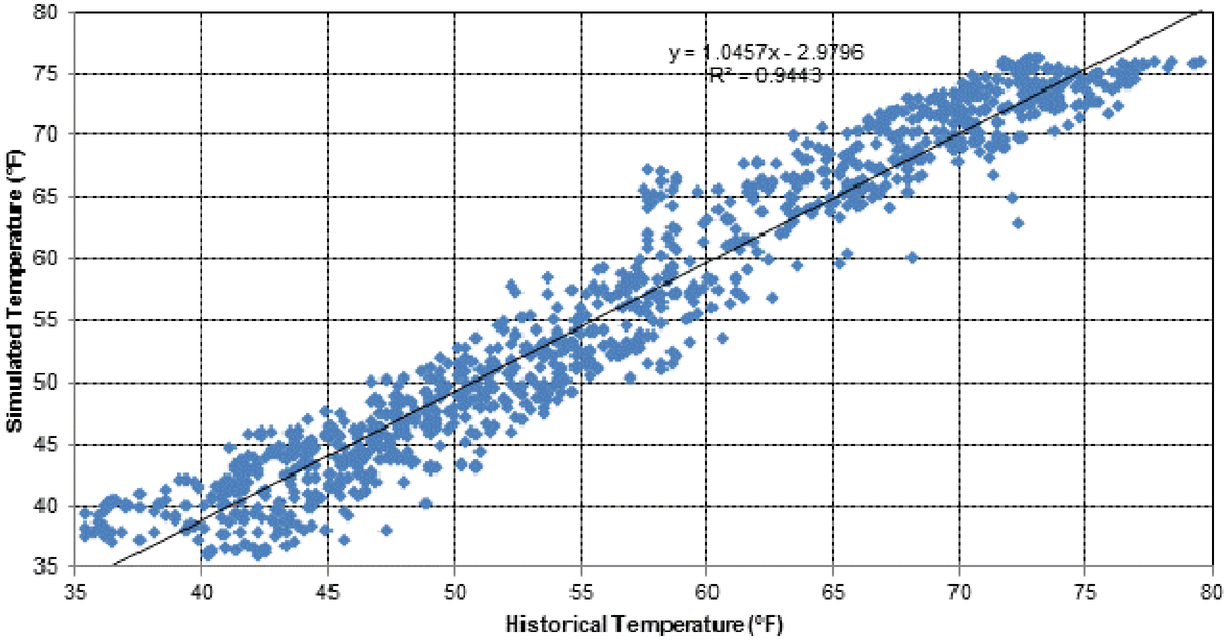


Figure 10.5-23. Scatter Plot Comparison of Simulated and Historically-Measured Yuba River (RM 34.4) Water Temperatures upstream from the New Colgate Powerhouse for the Upper Temp Model Calibration Scenario

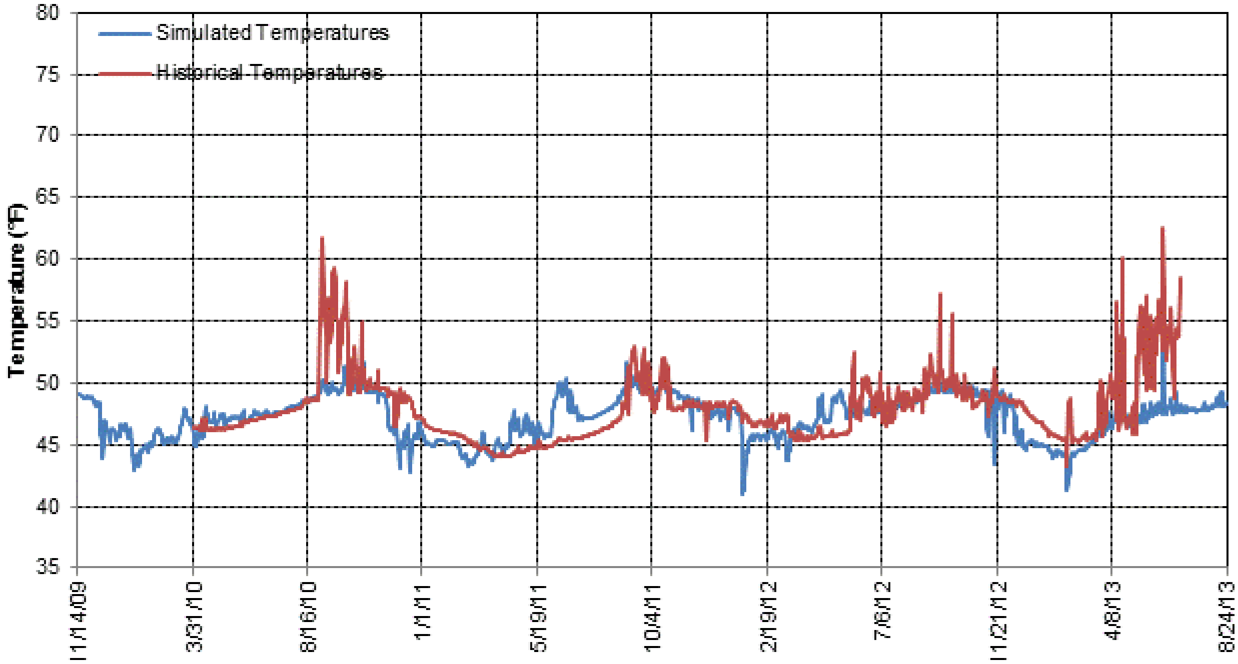


Figure 10.5-24. Comparison of Simulated and Historically-Measured Yuba River (RM 34.1) Water Temperatures downstream from the New Colgate Powerhouse for the Upper Temp Model Calibration Scenario

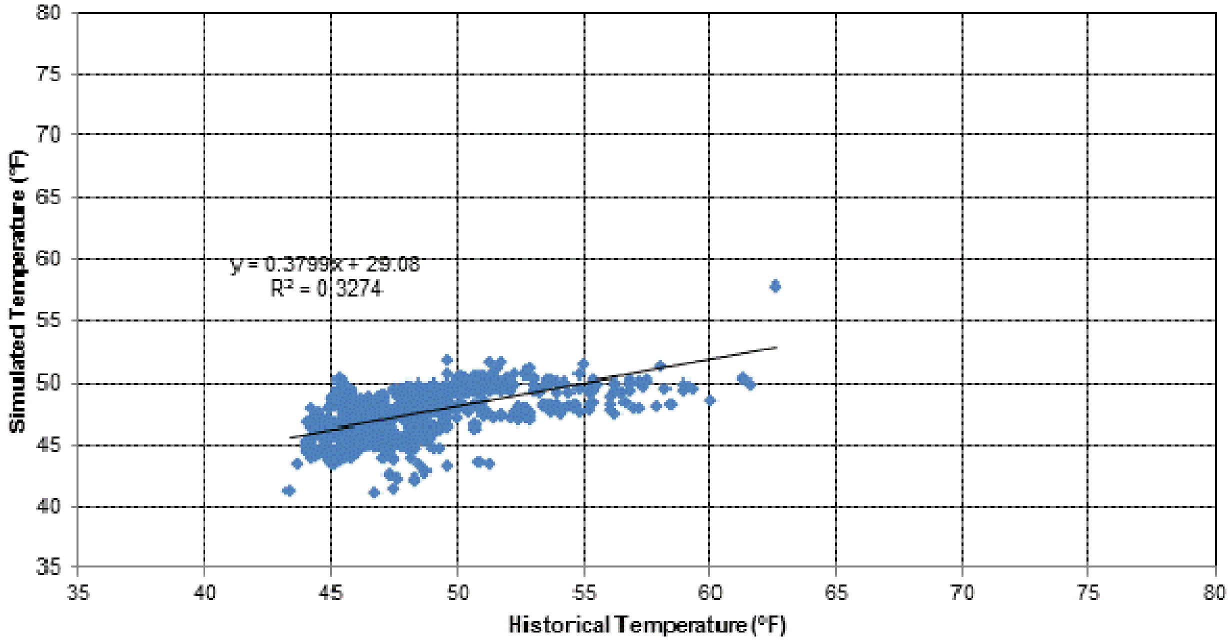


Figure 10.5-26. Scatter Plot Comparison of Simulated and Historically-Measured Yuba River (RM 34.1) Water Temperatures downstream from the New Colgate Powerhouse for the Upper Temp Model Calibration Scenario

Figure 10.5-27 shows the comparison of the time series for the simulated water temperatures and the historically measured water temperatures at the North Yuba River upstream of the North-Middle Yuba Junction (RM40.1) for the test flow period, performed in August 2013.

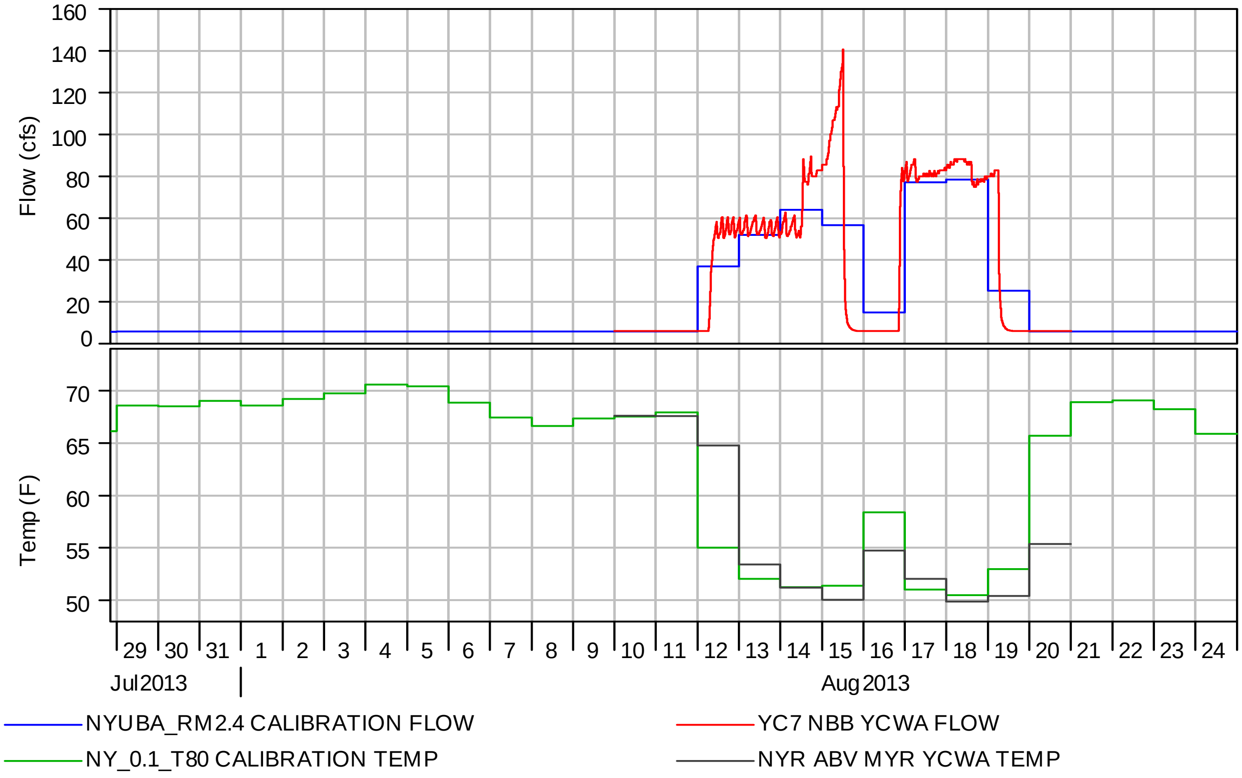


Figure 10.5-27 Comparison of Simulated and Historically-Measured North Yuba River (RM 0.1) Water Temperatures upstream from its confluence with the North Yuba River for the August 2013 test flow period

10.5.2 Englebright Temp Model

Historically-measured water temperatures are available below Englebright Dam at Smartsville. Table 10.5-3 shows the resulting ME and AME for the full period and July through October periods.

Table 10.5-3. Summary of Mean Error (ME) and Absolute Mean Error (AME) for the Englebright Temp Model near Smartsville (April 1, 2009 through September 30, 2012) for the Calibration Scenario.

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 10.5-28 shows a comparison of the timeseries for simulated water temperatures and historically measured water temperatures at Smartsville. Figure 10.5-29 shows a comparison of

simulated water temperatures versus historically-measured water temperatures, as compared to a one-to-one line.

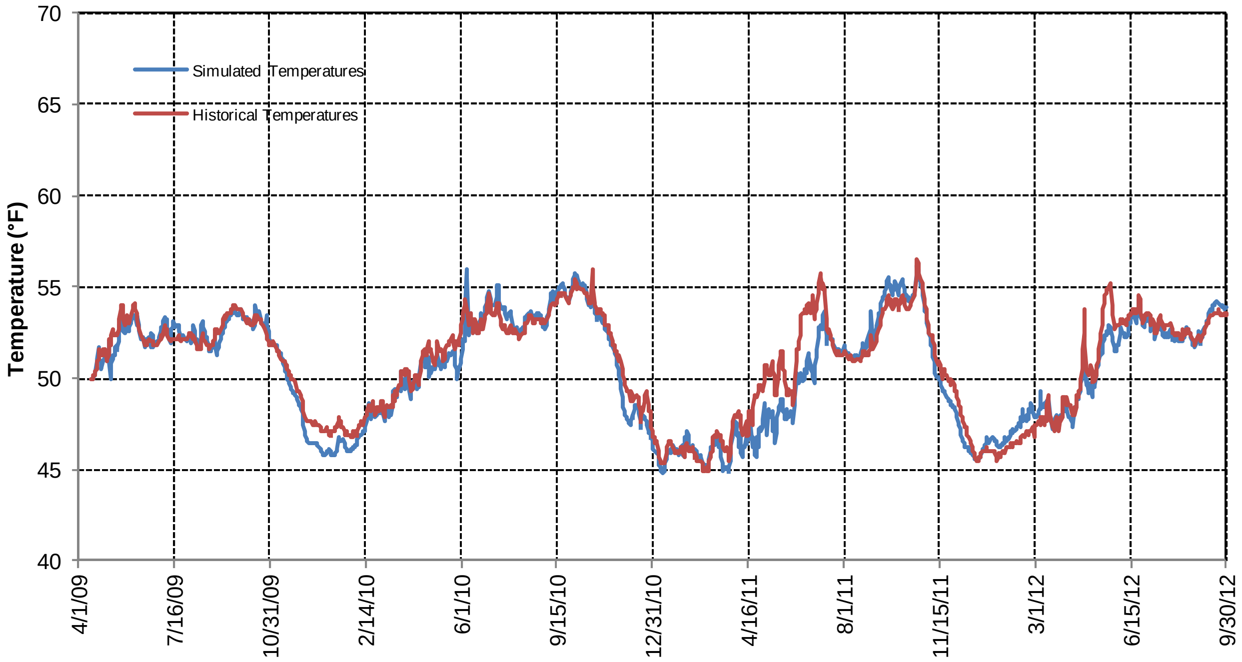


Figure 10.5-28. Comparison of Simulated and Historically-Measured Yuba River Water Temperatures at the Smartsville Gage (RM 23.9) for the Englebright Temp Model Calibration Scenario.

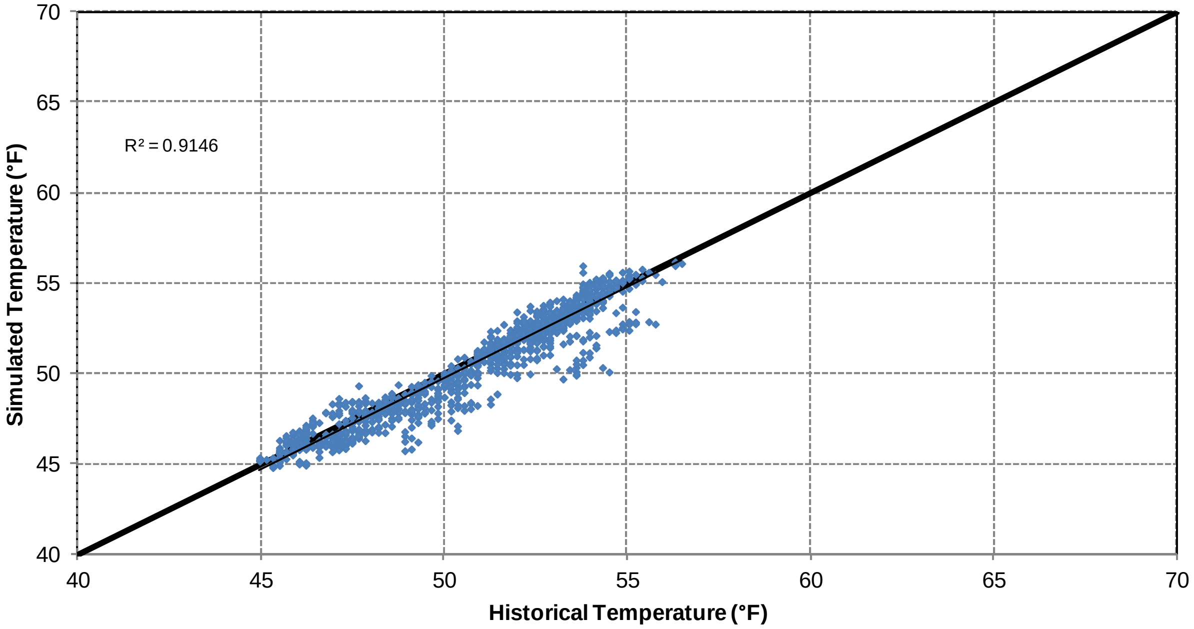


Figure 10.5-29. Comparison of Simulated versus Historically-Measured Yuba River Water Temperatures at the Smartsville Gage (RM 23.9) for the Englebright Temp Model Calibration Scenario.

10.5.3 Lower Temp Model

Historically-measured water temperatures are available a multiple locations along the Yuba River below Englebright Dam. Table 10.5-4 shows locations with historically-measured water temperatures along the Yuba River below Englebright Dam, and the results of the ME and AME for the full period and July through October periods.

Table 10.5-4. Summary of Mean Error (ME) and Absolute Mean Error (AME) for the Lower Temp Model at historical measurement locations.

Location	Gage ID	Full Period		July-October	
		ME	AME	ME	AME
Yuba River between Englebright Dam and Deer Creek					
Smartsville Gage (RM 23.9)	NY28	-0.01	0.22	0.0	0.18
Yuba River between Deer Creek and Dry Creek					
Yuba River downstream from Deer Creek (RM 23.1)	T180	-0.29	0.43	-0.42	0.47
Yuba River at Parks Bar (RM 17.7)	PB	0.18	0.36	0.31	0.36
Yuba River at Long Bar (RM 16.2)	LB	0.14	0.60	0.47	0.59
Yuba River between Dry Creek and Daguerre Point Dam					
Yuba River upstream from Daguerre Point Dam (RM 11.64)	T200	0.16	0.44	0.31	0.49
Yuba River at Daguerre Point Dam Fish Ladder (RM 11.56)	T210	0.26	0.54	0.45	0.53
Yuba River between Daguerre Point Dam and Marysville Gage					
Yuba River near Western Extent of Goldfields (RM 8.3)	T220	0.16	0.61	0.16	0.62
Yuba River at Marysville Gage (RM 6.2)	11421000	0.25	0.68	0.05	0.75

Table 10.5-4. (continued)

Location	Gage ID	Full Period		July-October	
		ME	AME	ME	AME
Yuba River between Marysville Gage and the Feather River					
Yuba River upstream from Simpson Lane Bridge (RM 5.0)	T230	-0.08	0.89	-0.22	1.02
Yuba River downstream from Highway 70 Bridge (RM 0.7)	T240	1.10	1.42	1.69	1.70

Figures 10.5-30 through 10.5-49 show a comparison of the timeseries for the simulated water temperatures and the historically measured water temperatures at the locations shown in Table 10.5-1.

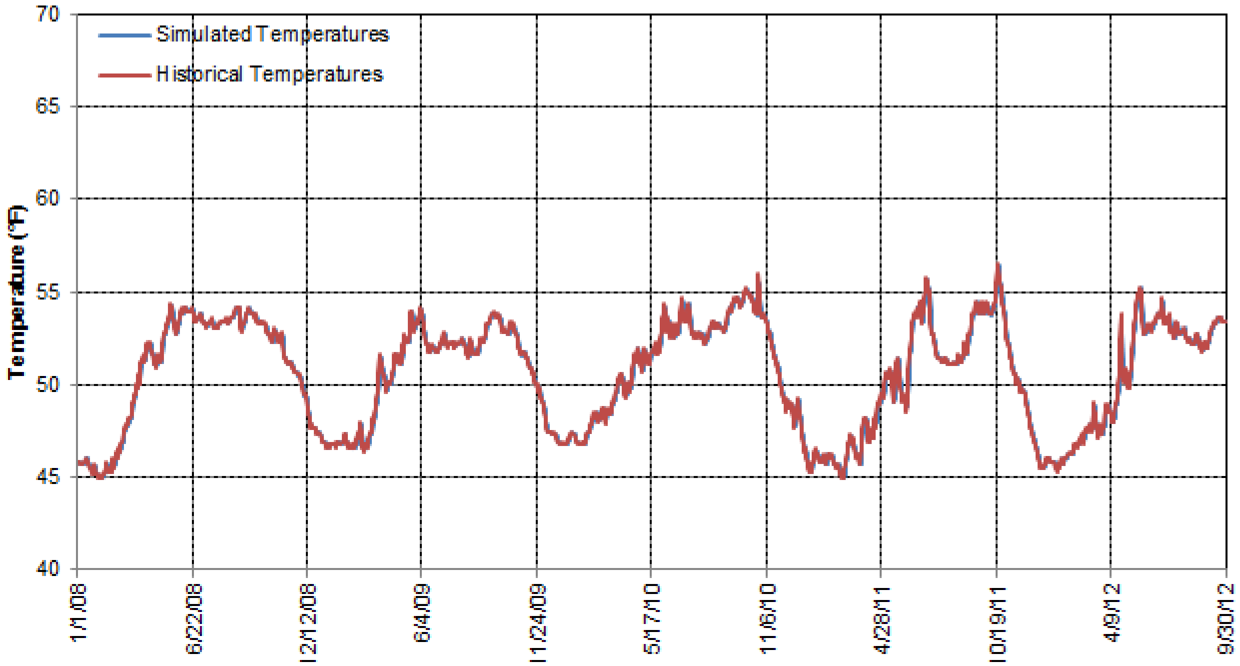


Figure 10.5-30. Comparison of Simulated and Historically Measured Yuba River Water Temperatures at the Smartsville Gage (RM 23.9) for the Calibration Scenario.

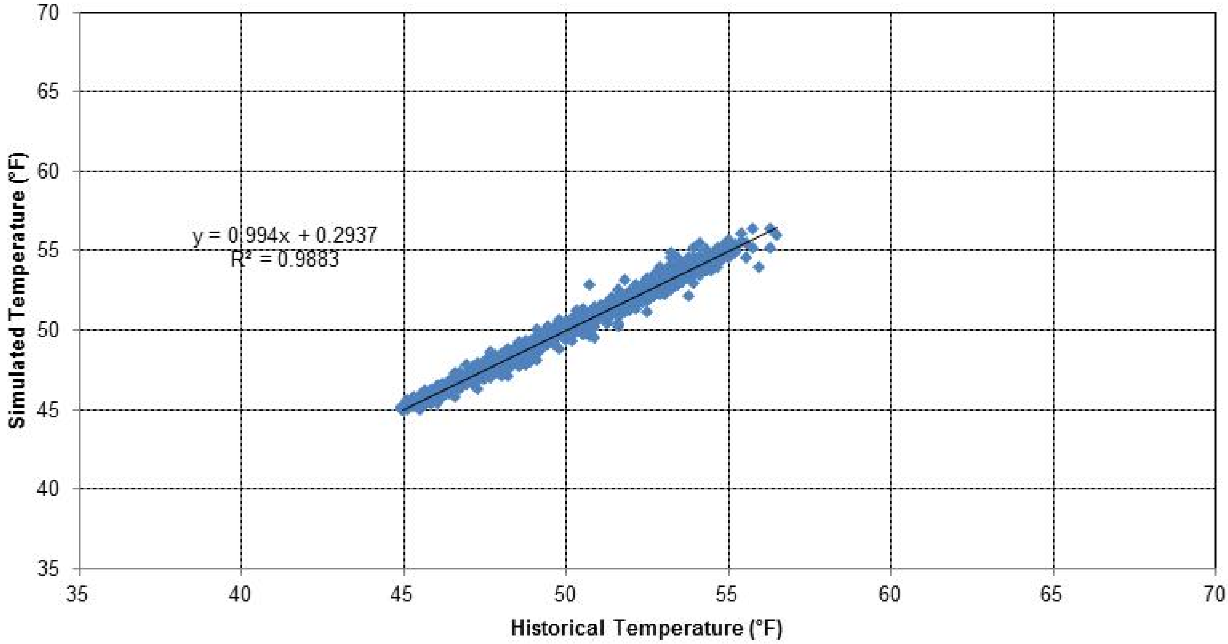


Figure 10.5-31. Scatter plot comparison of Simulated and Historically Measured Yuba River Water Temperatures at the Smartsville Gage (RM 23.9) for the Calibration Scenario.

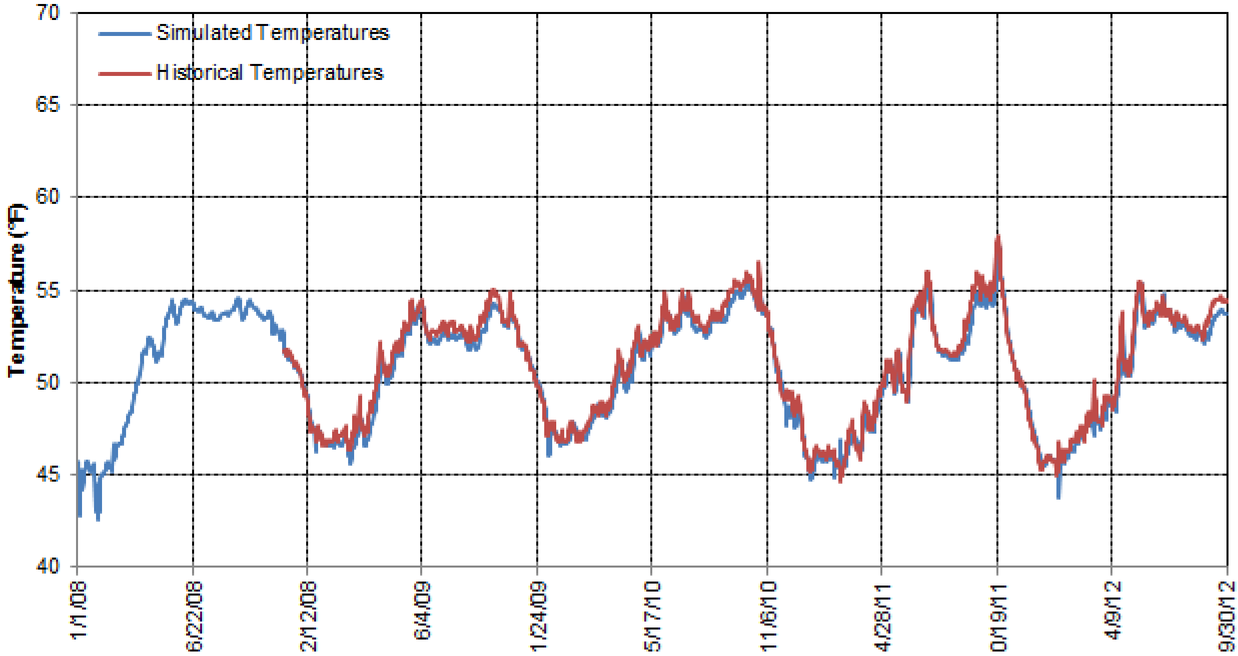


Figure 10.5-32. Comparison of Simulated and Historically Measured Yuba River Water Temperatures Downstream from Deer Creek (RM 23.1) for the Calibration Scenario.

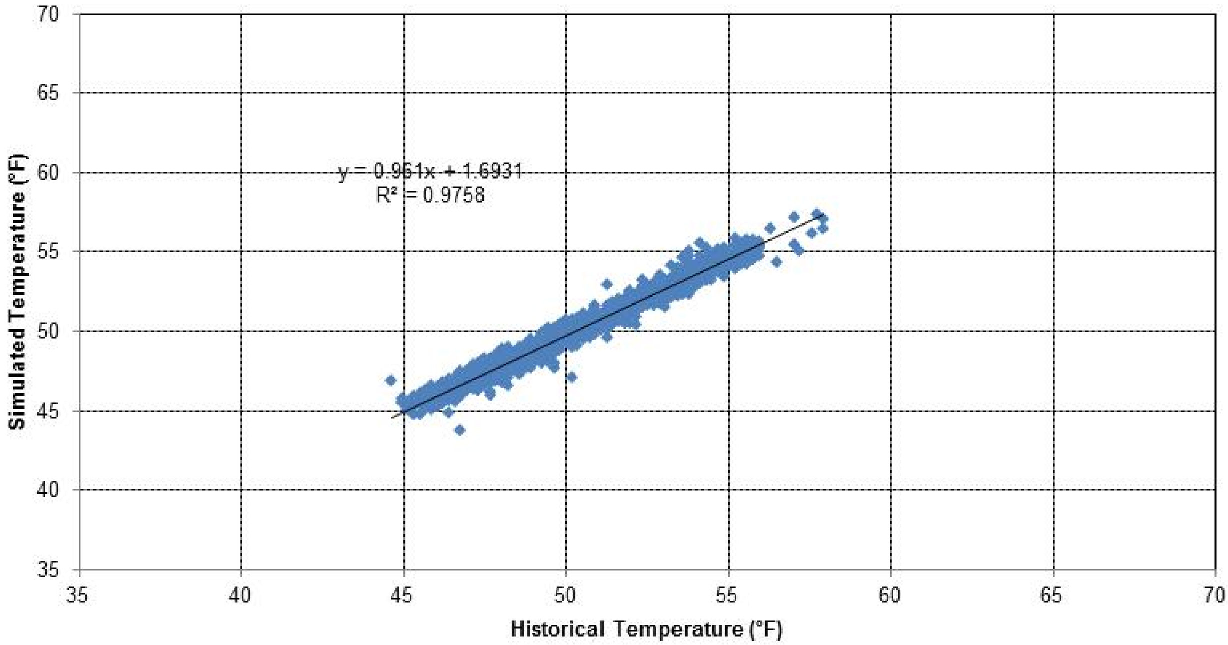


Figure 10.5-33. Scatter Plot Comparison of historical and simulated mean-daily water temperatures downstream from Deer Creek (RM 23.1).

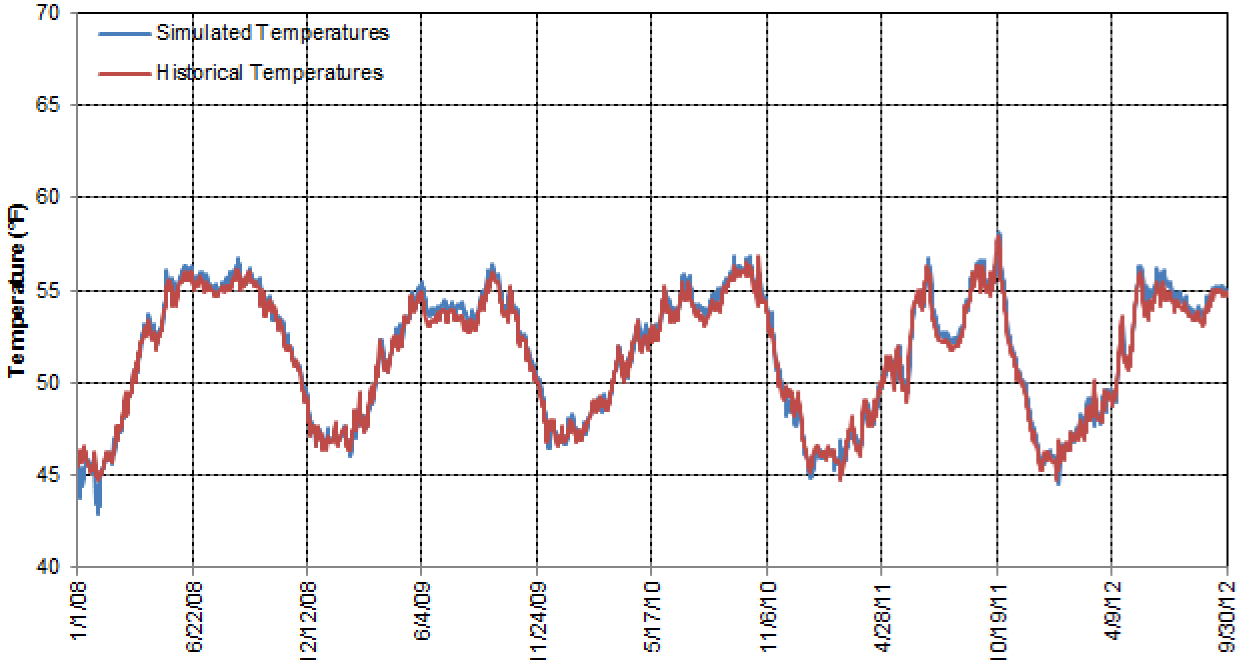


Figure 10.5-34. Comparison of Simulated and Historically Measured Yuba River Water Temperatures near Parks Bar (RM 17.7) for the Calibration Scenario.

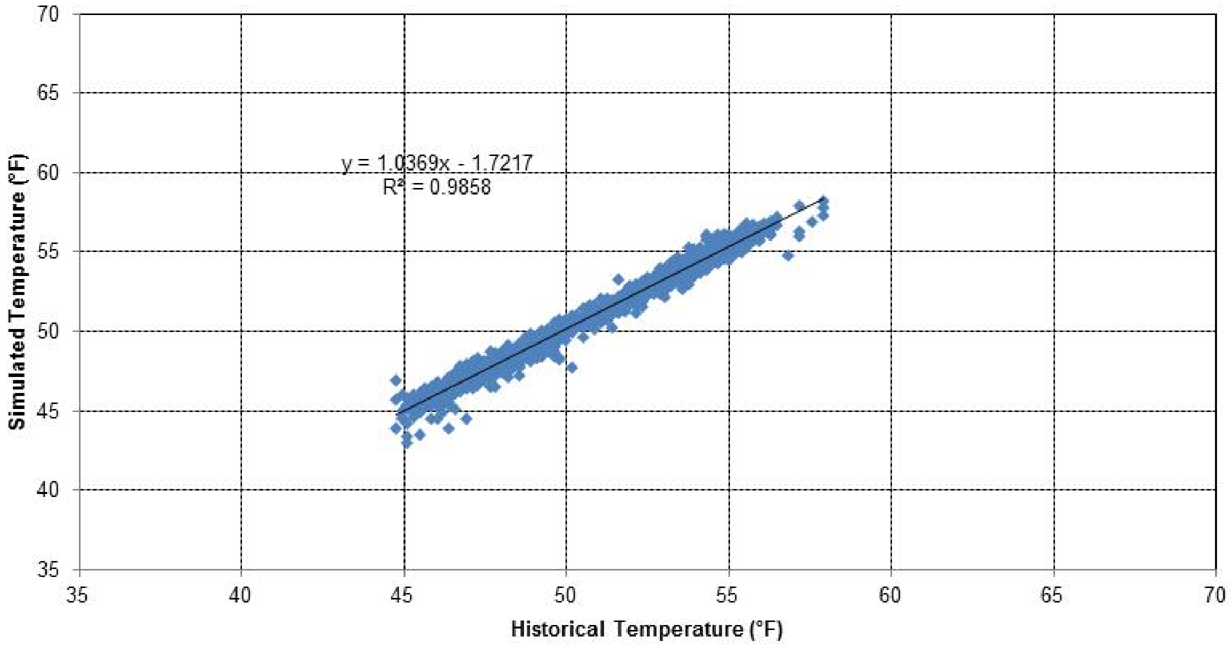


Figure 10.5-35. Scatter Plot comparison of historical and simulated mean-daily water temperatures at Parks Bar (RM 17.7).

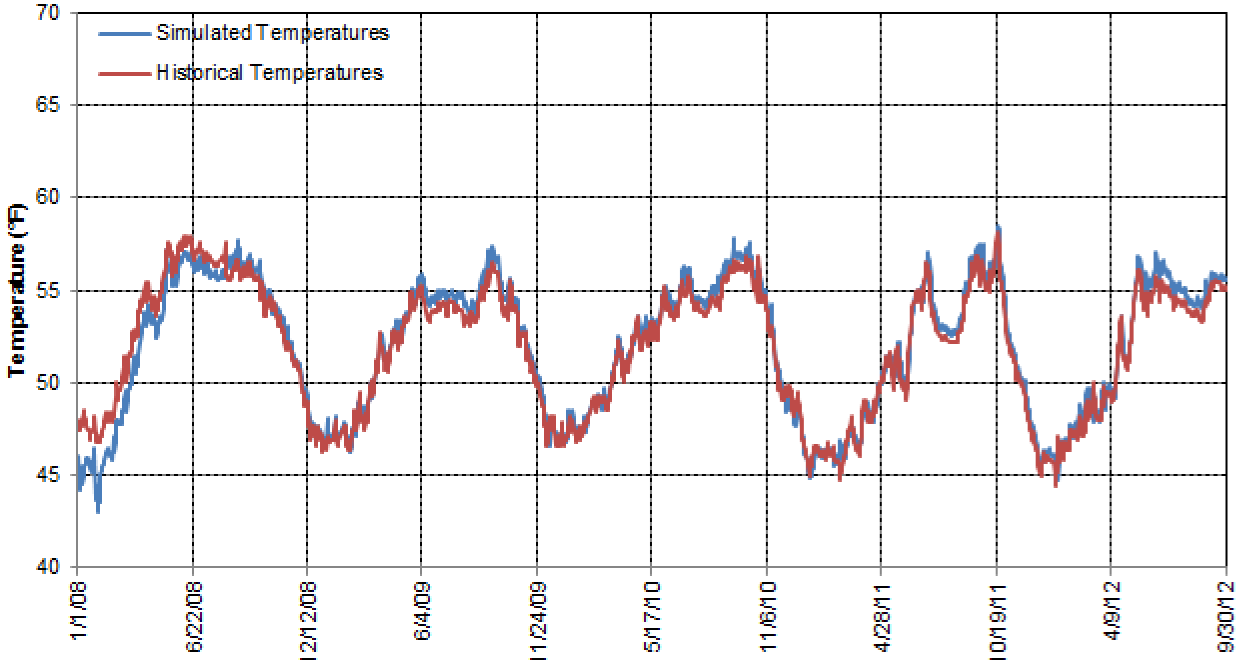


Figure 10.5-36. Comparison of Simulated and Historically Measured Yuba River Water Temperatures near Long Bar (RM 16.2) for the Calibration Scenario.

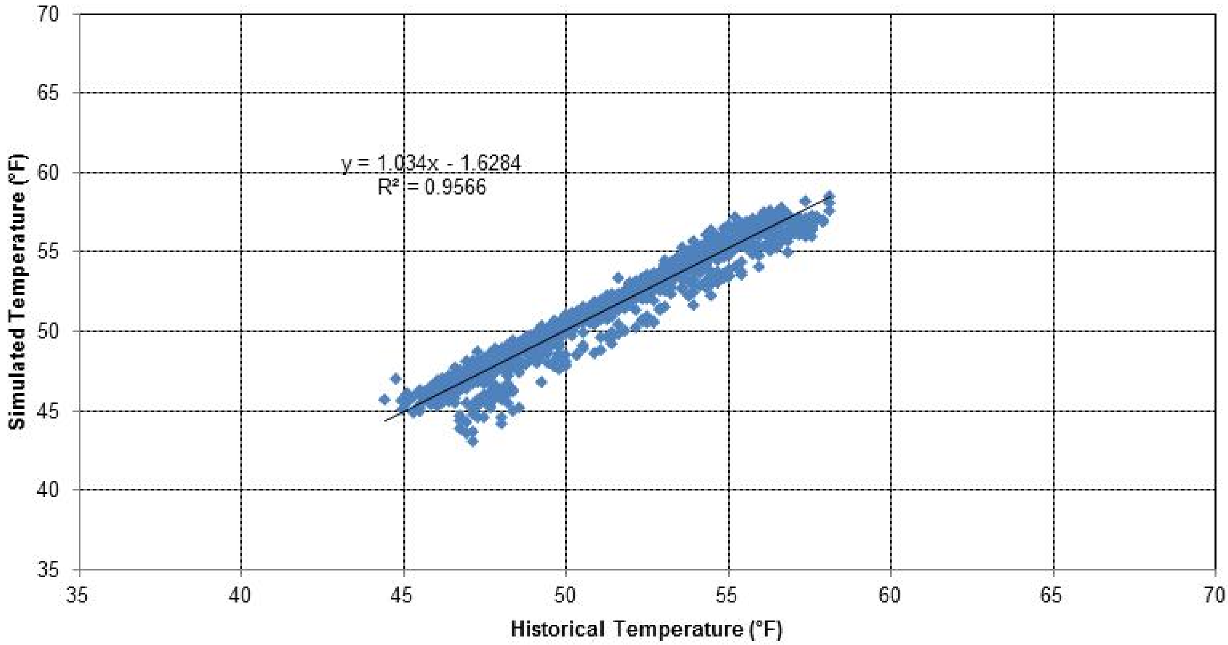


Figure 10.5-37. Scatter plot comparison of historical and simulated mean-daily water temperatures at Long Bar (RM 16.2).

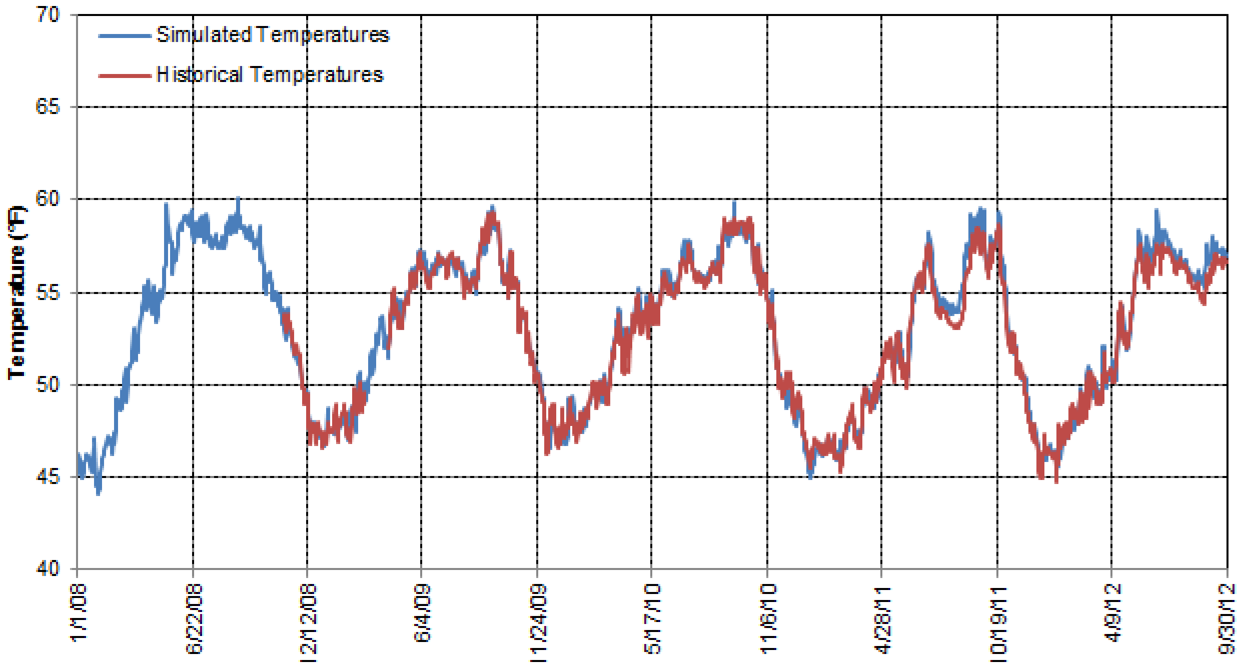


Figure 10.5-38. Comparison of Simulated and Historically Measured Yuba River Water Temperatures Upstream from Daguerre Point Dam RM (11.64) for the Calibration Scenario.

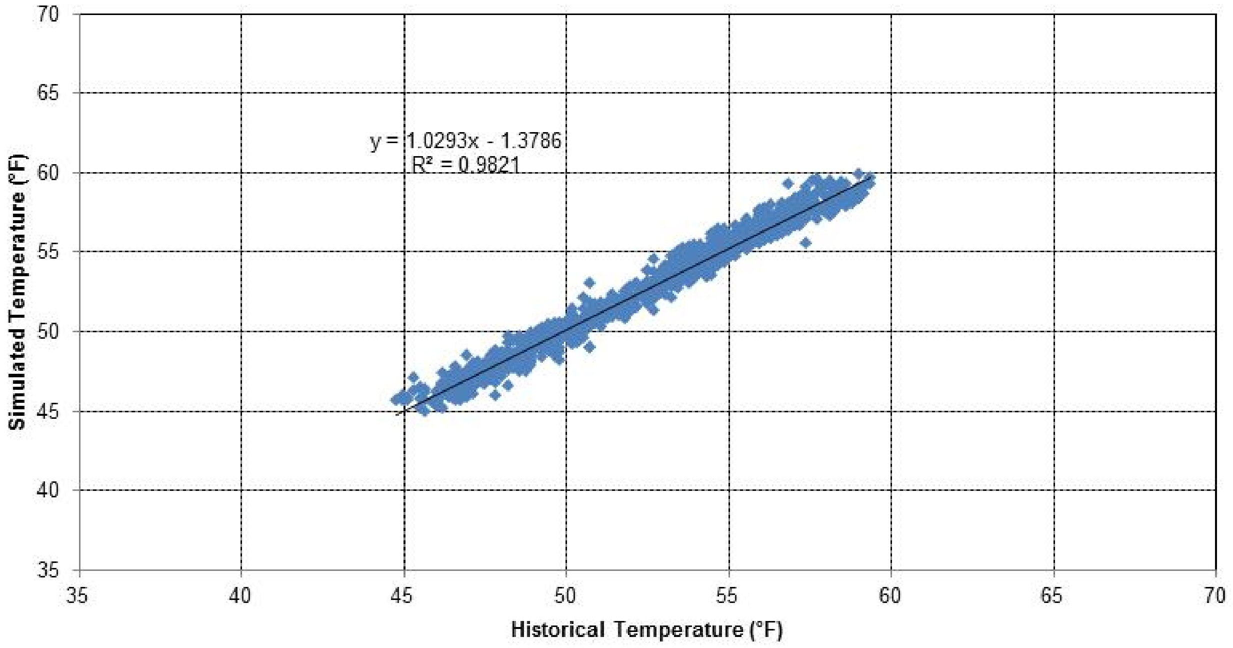


Figure 10.5-39. Scatter plot comparison of historical and simulated mean-daily water temperatures upstream from Daguerre Point Dam (RM 11.64).

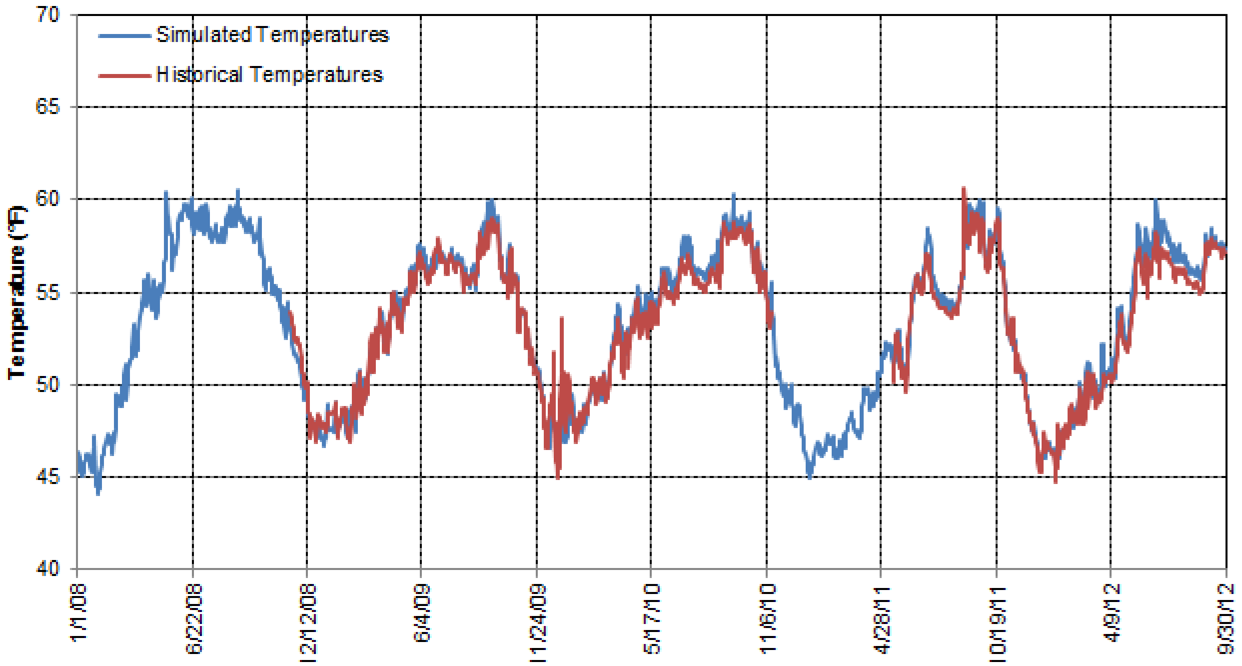


Figure 10.5-40. Comparison of Simulated and Historically Measured Yuba River Water Temperatures at the Daguerre Point Dam Fish Ladder (RM 11.56) for the Calibration Scenario.

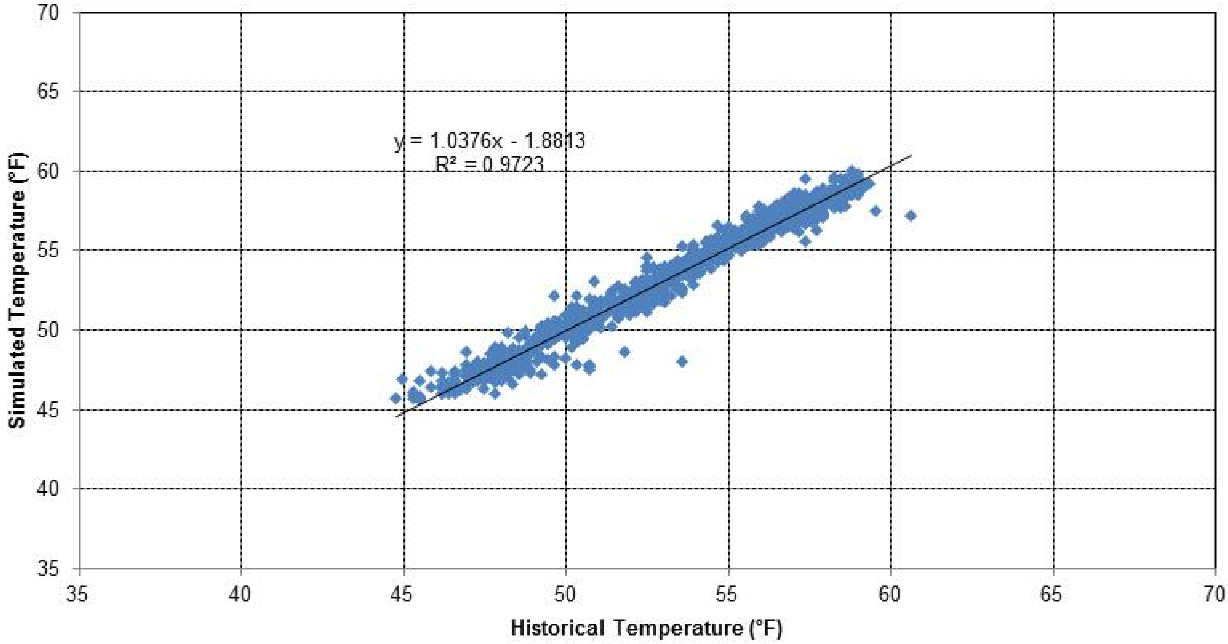


Figure 10.5-41. Scatter plot comparison of historical and simulated mean-daily water temperatures at the Daguerre Point Dam fish ladder (RM 11.56).

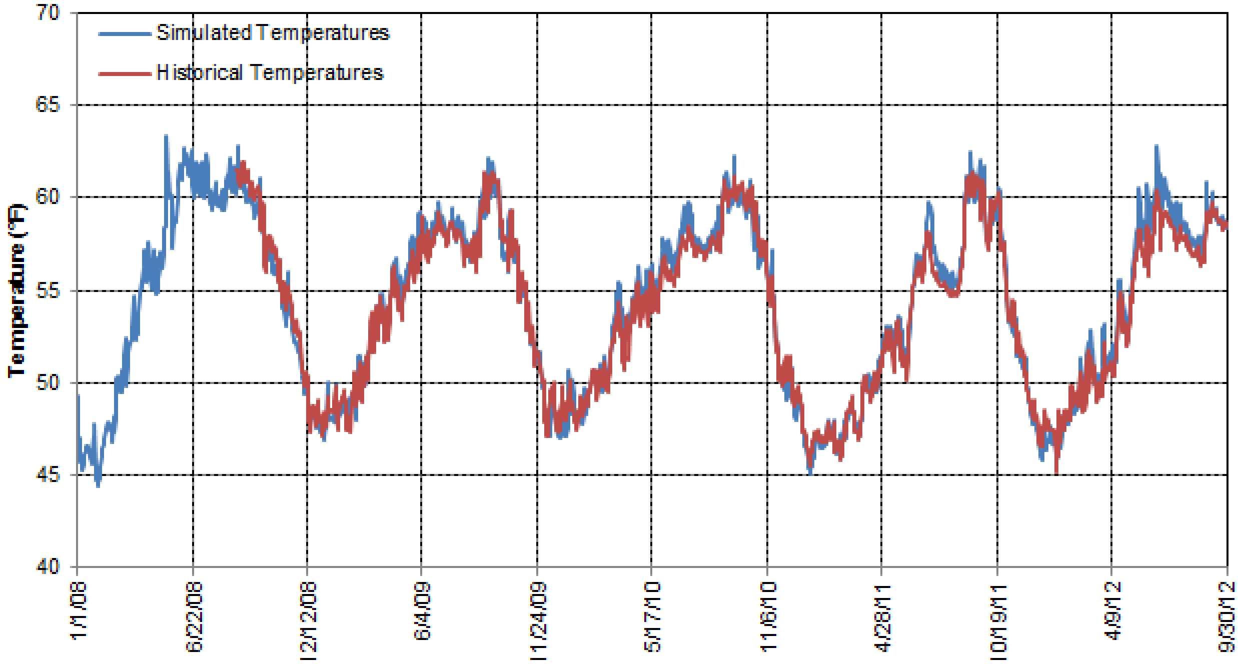


Figure 10.5-42. Comparison of Simulated and Historically Measured Yuba River Water Temperatures near the Western Edge of the Yuba Goldfields (RM 8.3) for the Calibration Scenario.

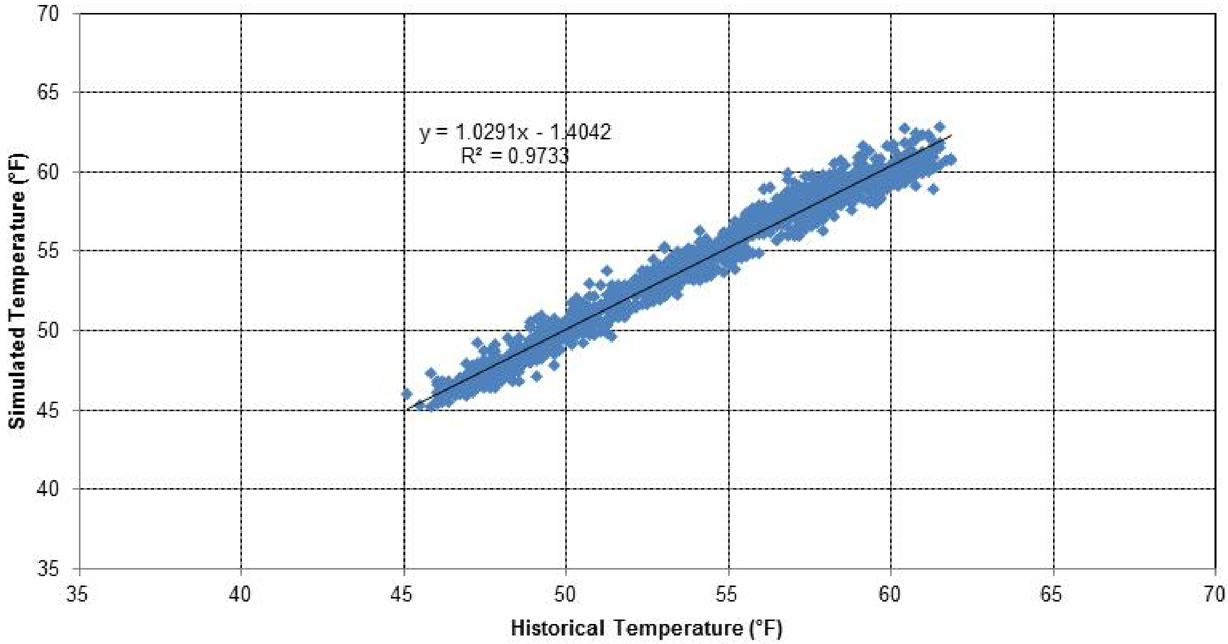


Figure 10.5-43. Scatter plot comparison of historical and simulated mean-daily water temperatures at the western extents of the Yuba Goldfields (RM 8.3).

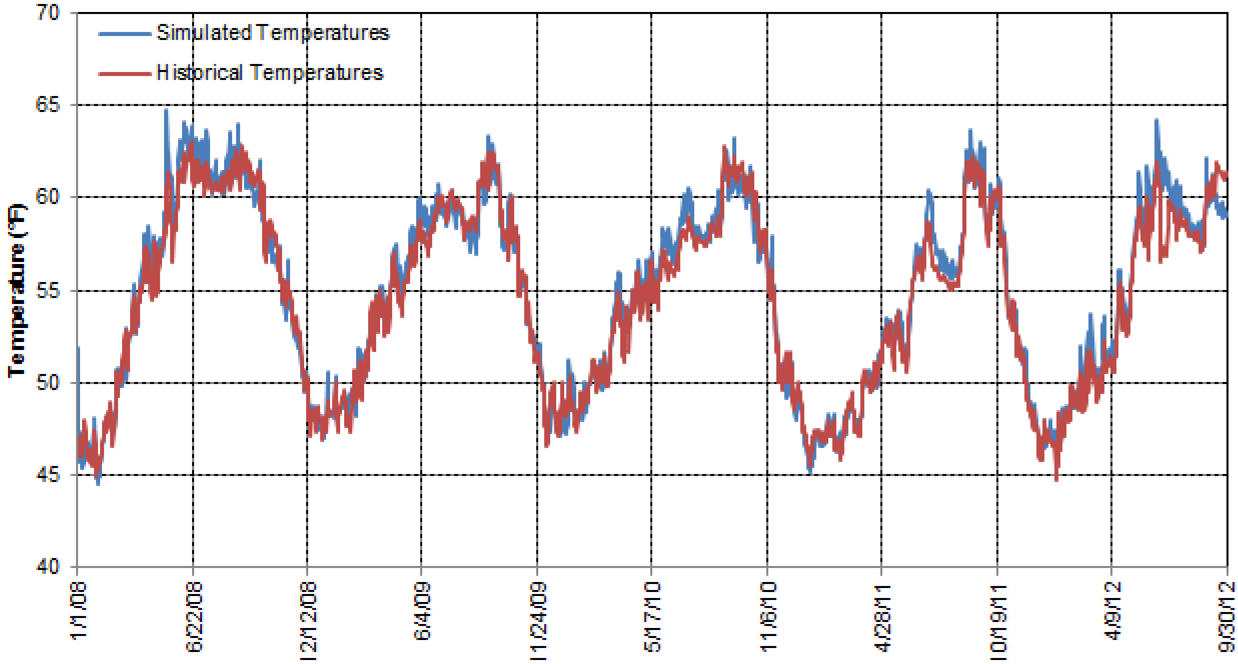


Figure 10.5-44. Comparison of Simulated and Historically Measured Yuba River Water Temperatures near the Marysville Gage (RM 6.2) for the Calibration Scenario.

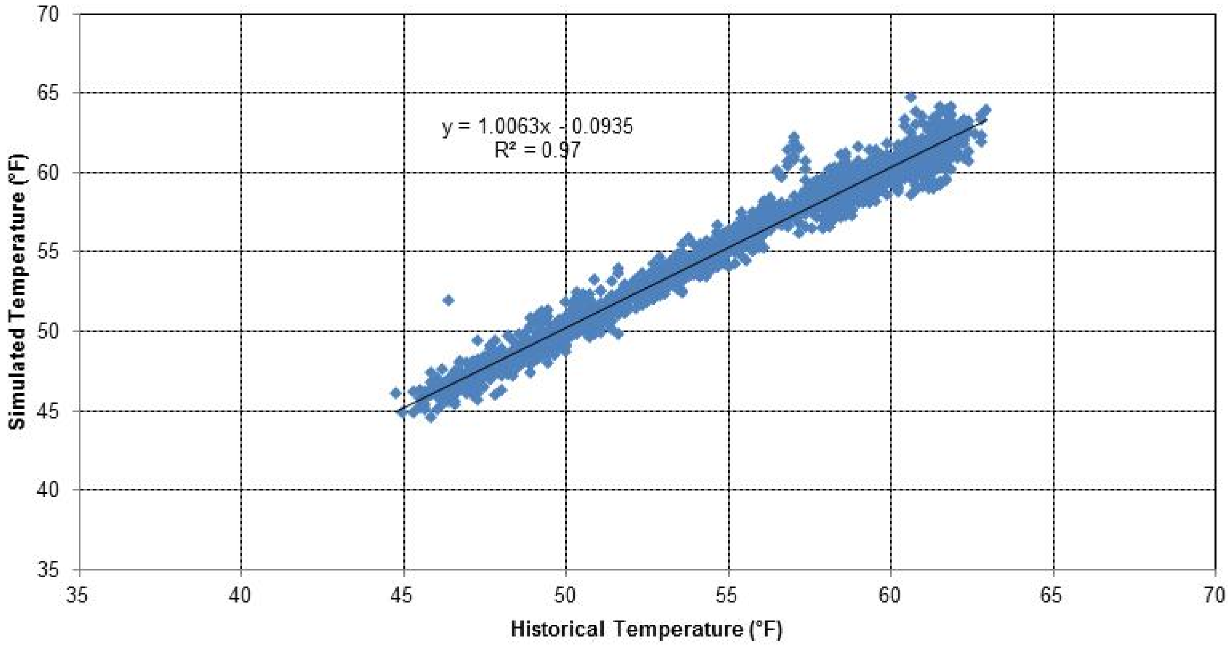


Figure 10.5-45. Scatter plot comparison of historical and simulated mean-daily water temperatures at the Maryville gage (RM 6.2).

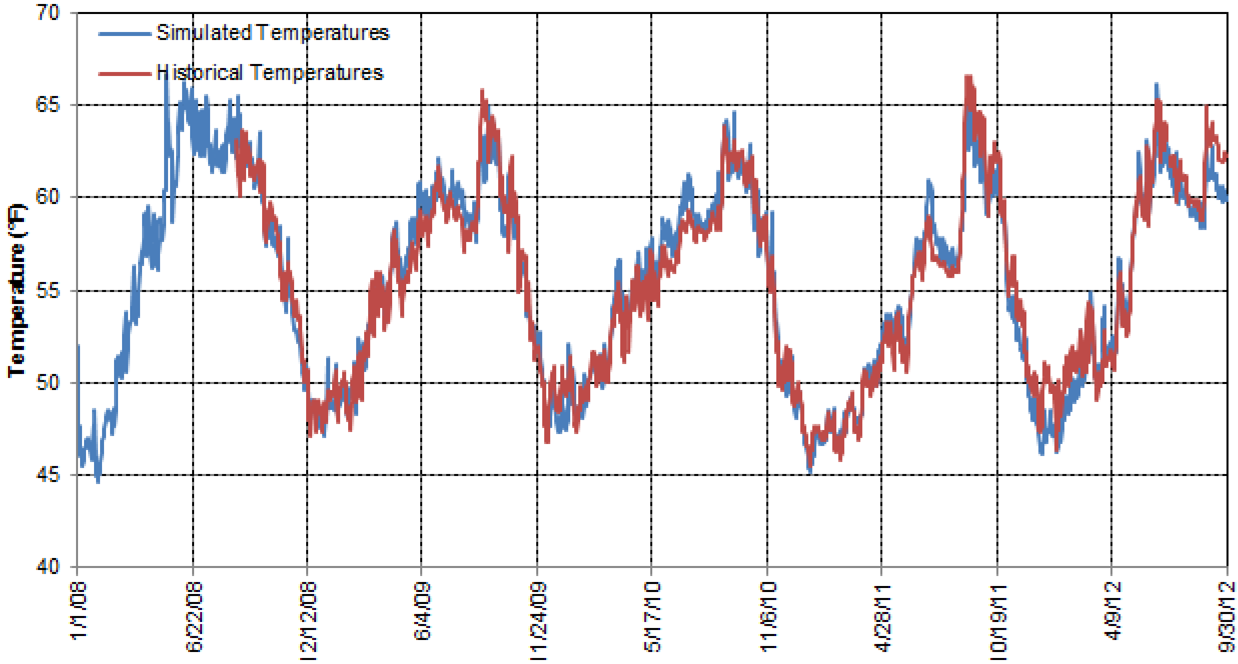


Figure 10.5-46. Comparison of Simulated and Historically Measured Yuba River Water Temperatures Upstream from the Simpson Lane Bridge (RM 5.0) for the Calibration Scenario.

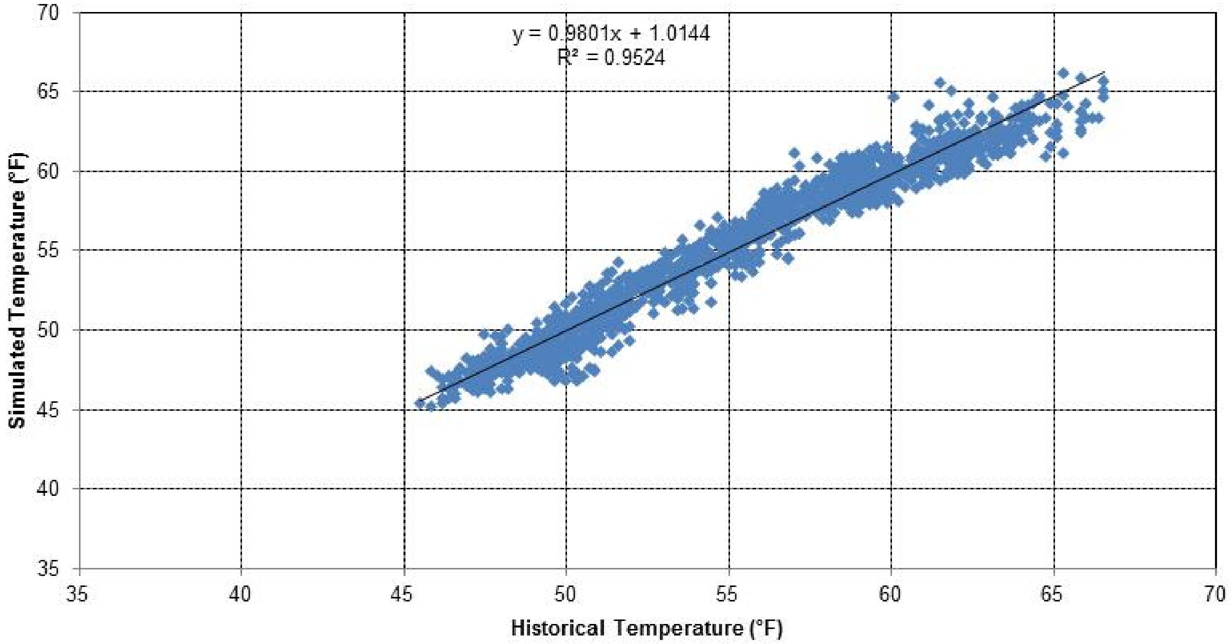


Figure 10.5-47. Scatter plot comparison of historical and simulated mean-daily water temperatures upstream from Simpson Lane (RM 5.0).

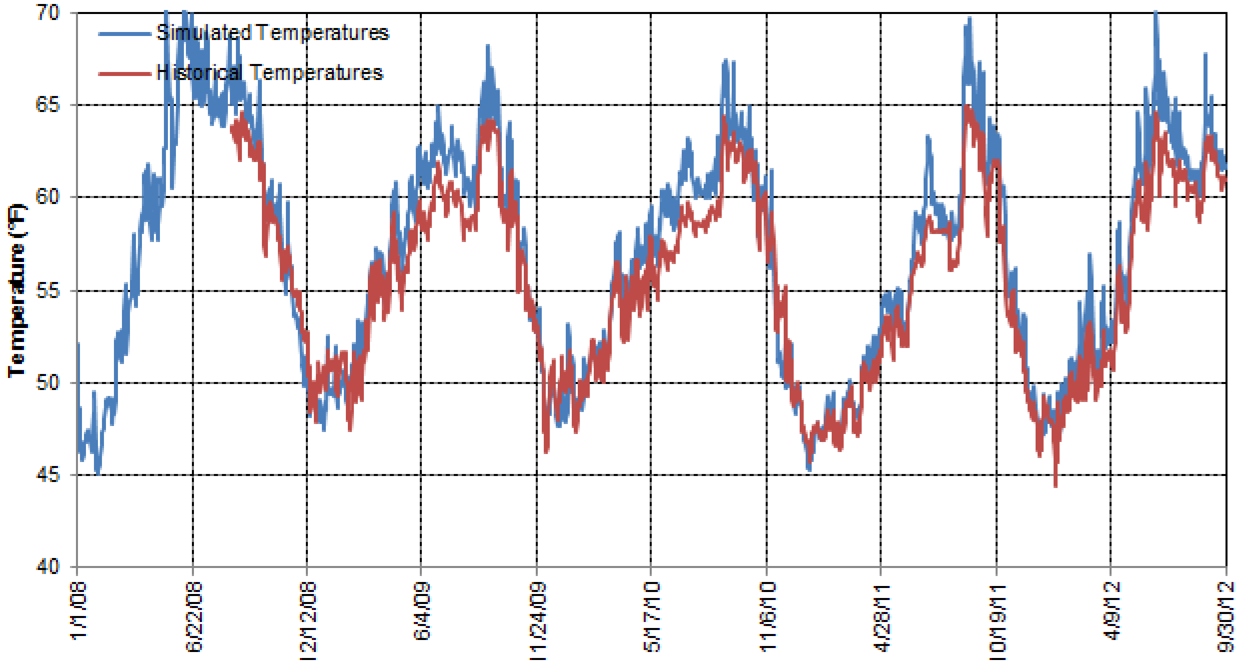


Figure 10.5-48. Comparison of Simulated and Historically Measured Yuba River Water Temperatures Downstream from the Highway 70 Bridge (RM 0.7) for the Calibration Scenario.

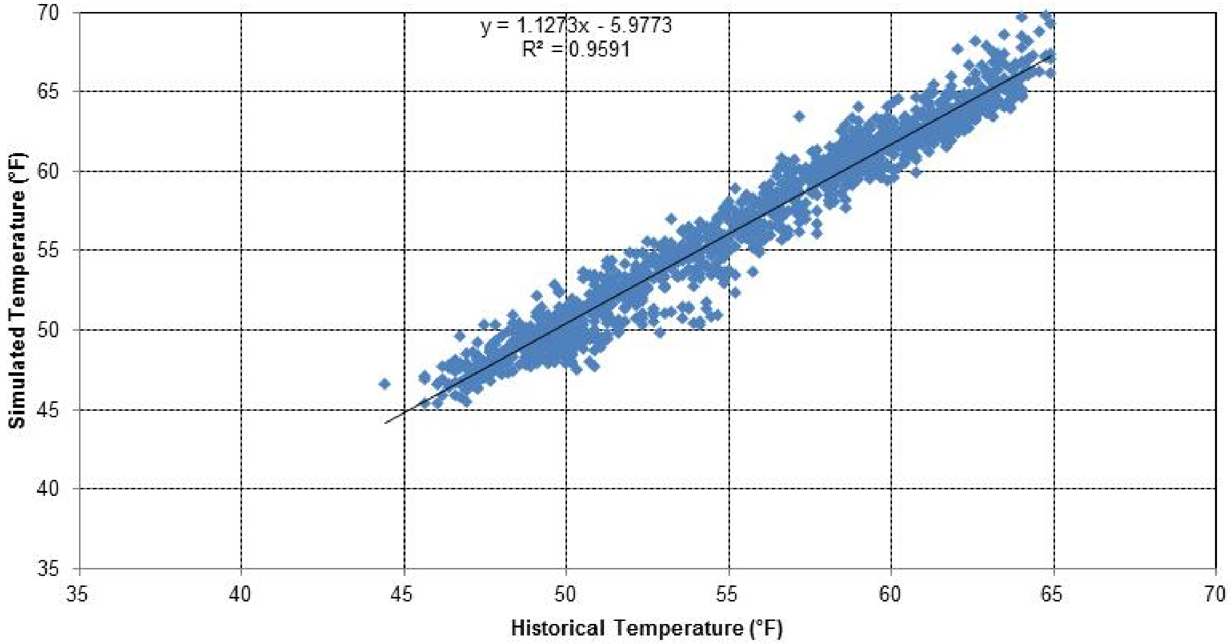


Figure 10.5-. Scatter plot comparison of historical and simulated mean-daily water temperatures downstream from Highway 70 (RM 0.7).

11.0 Validation

This section describes the results of the Validation Scenario simulations of the water temperature models.

11.1 Purpose

The purpose of a validation model is to use an independent data set to verify model predictive ability once the model has been calibrated. The simulation period for the validation models is different than the calibration model to ensure that calibration parameters are appropriate to predict historical values. If there are substantial, unexplainable differences between the historical values and the validation model simulated values, the calibration is adjusted to better reflect the historical conditions. The three validation temperatures models all had a period of record of January 1, 2000 through September 30, 2011.

The primary difference between the calibration and validation process is the quality of the input data used in simulation; for the calibration scenarios, input data was predominantly historical, and synthetic data was used sparingly to fill in gaps in the data. For the validation scenarios, a lack of a complete set of historically-measured input data for the full period of record requires the use a large quantity of synthetic data along with available historically-measured data. Historically-measured data are available for comparison for the validation period of record at key locations for each of the three water temperature models as described below:

- Upper Temp Model – Bi-weekly New Bullards Bar Reservoir water-temperature profiles
- Englebright Temp Model – Daily Smartsville water temperatures
- Lower Temp Model – Daily Marysville water temperatures

Simulated water temperatures for each of the locations described above were compared to the historically-measured temperatures to confirm the models' abilities to reasonably match the historically-measured temperatures given the mix of historically-measured and synthetic input data.

11.2 Results

Key model output indicating each model's ability to compute water temperatures that reasonably match historically-measured water temperatures are included in the sections below. A discussion of causes of differences between historically-measured and computed temperatures follows the presentation of results.

11.2.1 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 are synthetic, which indicates that the reservoir profile is dependent more on meteorology than inflow temperatures. Figures 11.2-1 through 11.2-11 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.

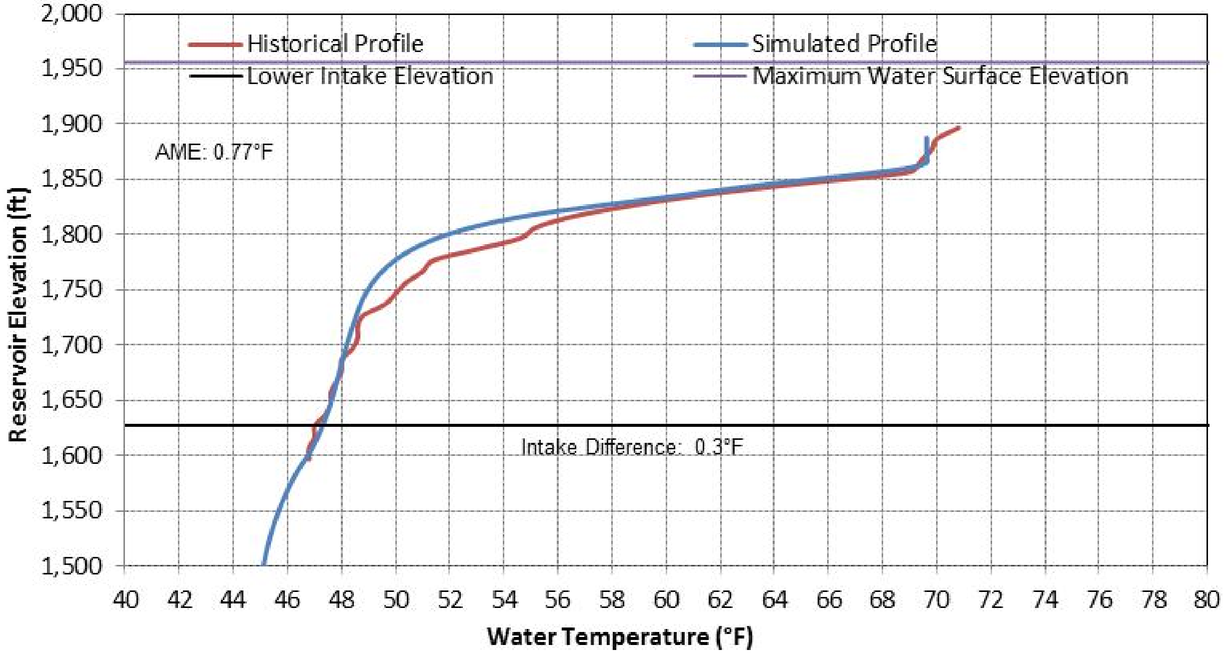


Figure 11.2-1. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 28, 2000

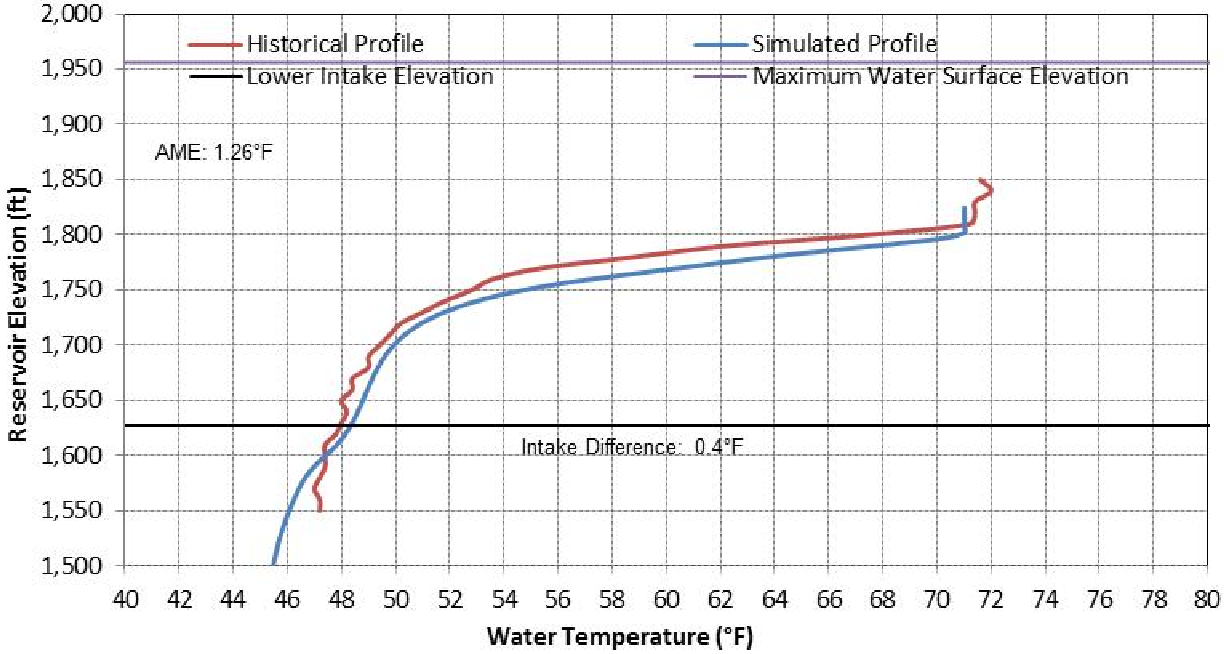


Figure 11.2-2. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 27, 2001

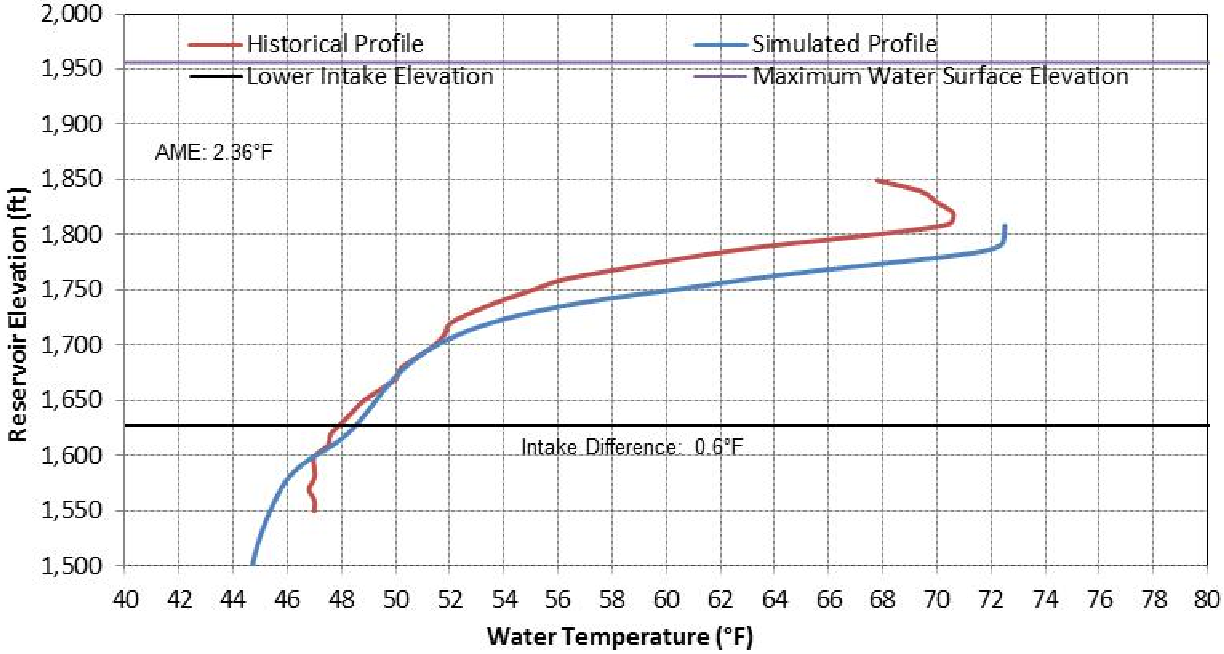


Figure 11.2-3. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 24, 2002

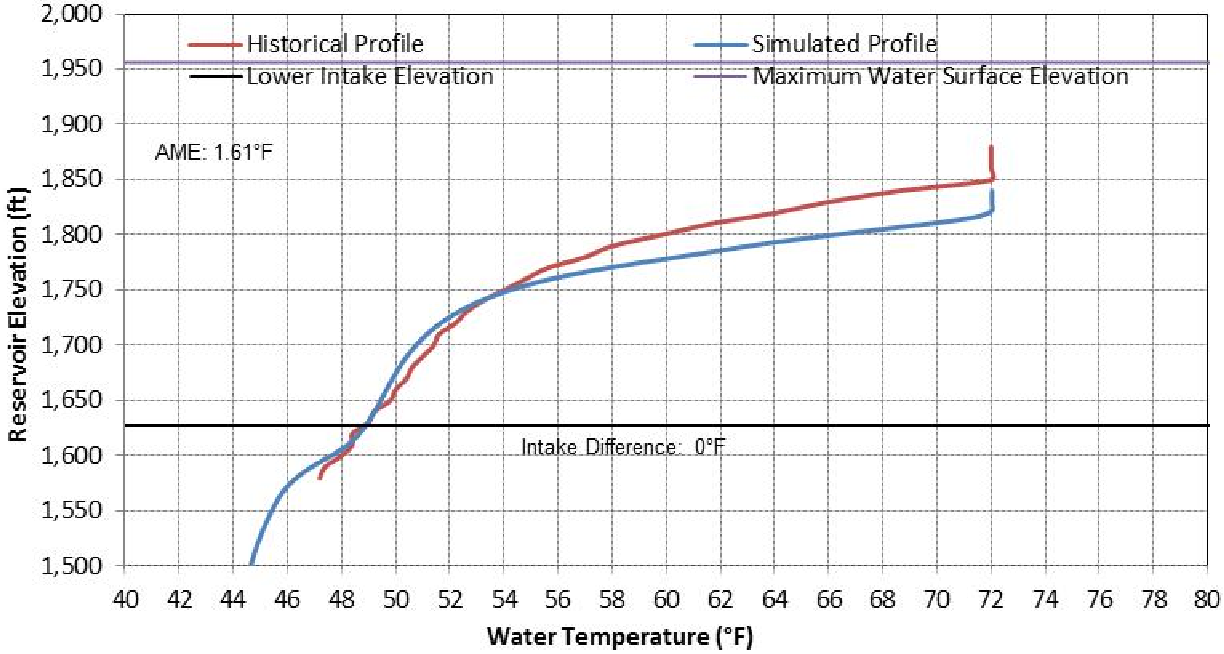


Figure 11.2-4. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 25, 2003

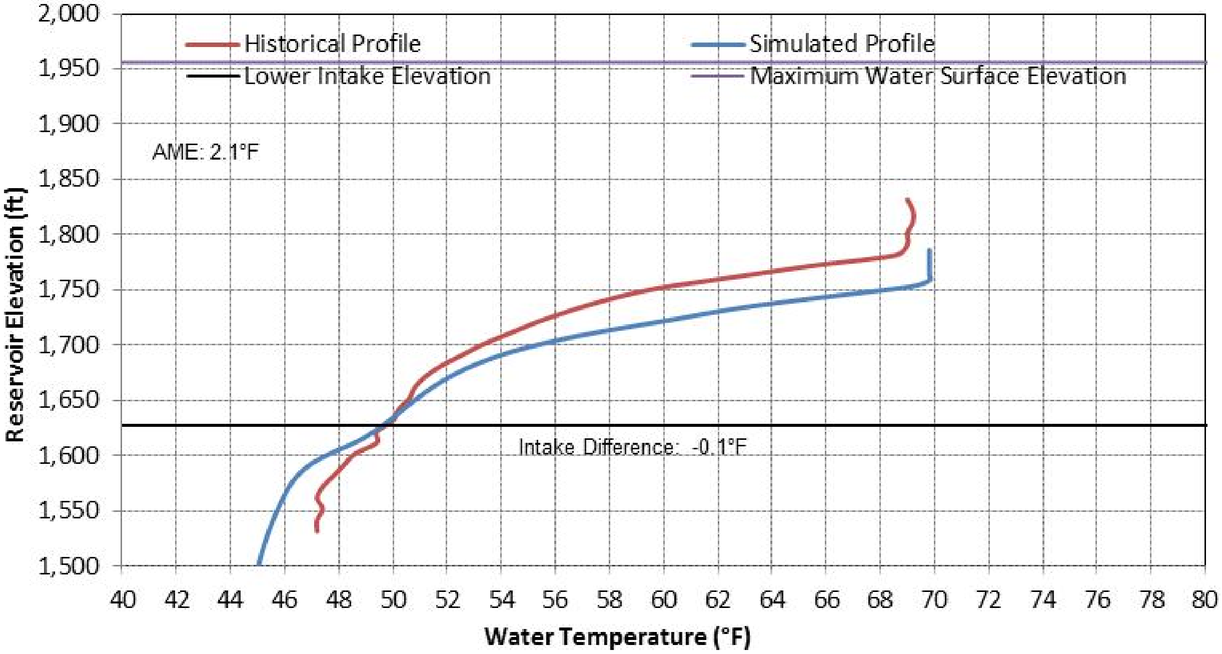


Figure 11.2-5. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for October 5, 2004

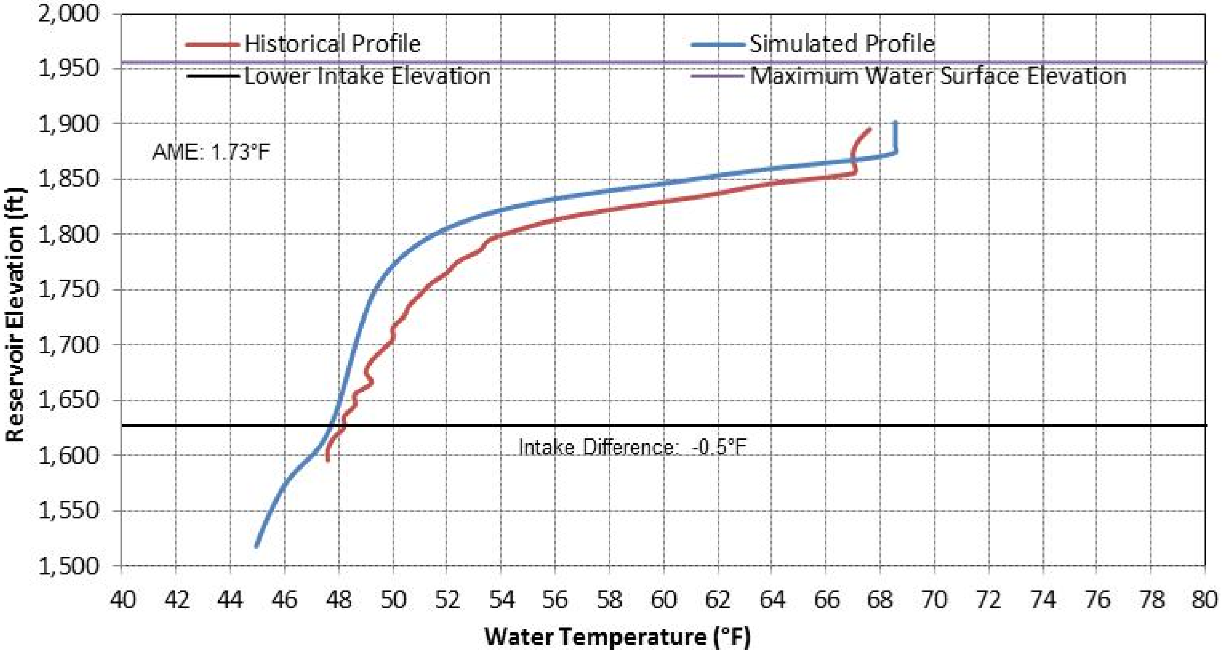


Figure 11.2-6. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for October 6, 2005

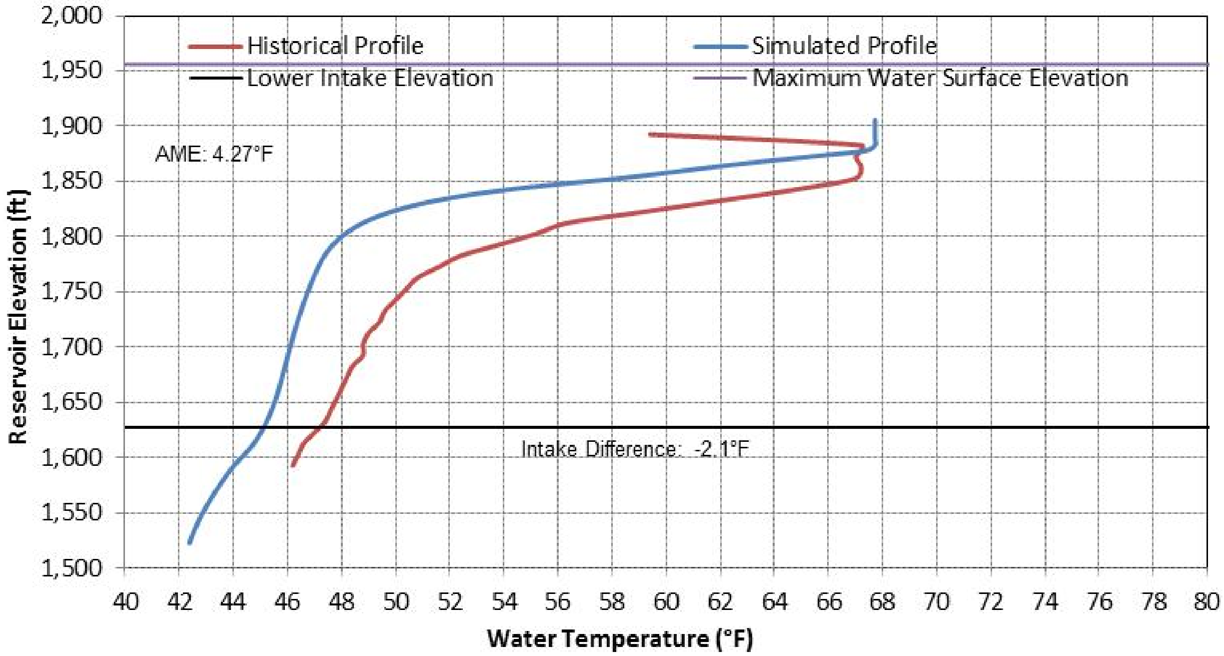


Figure 11.2-7. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for October 5, 2006

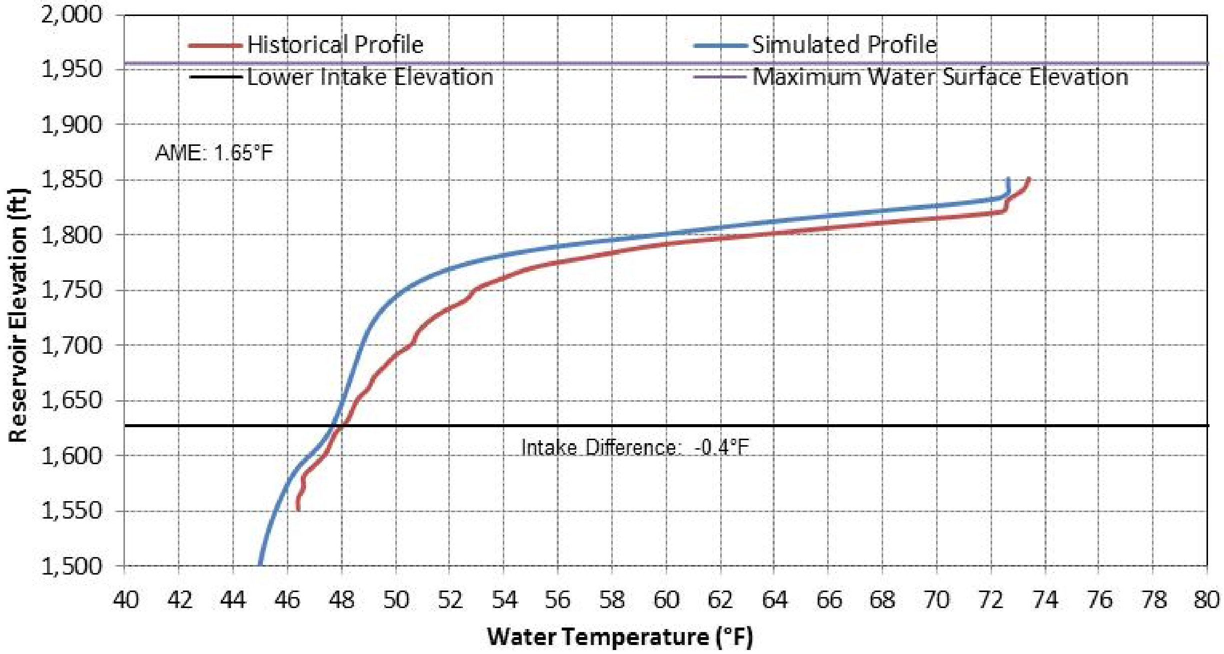


Figure 11.2-8. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 17, 2008

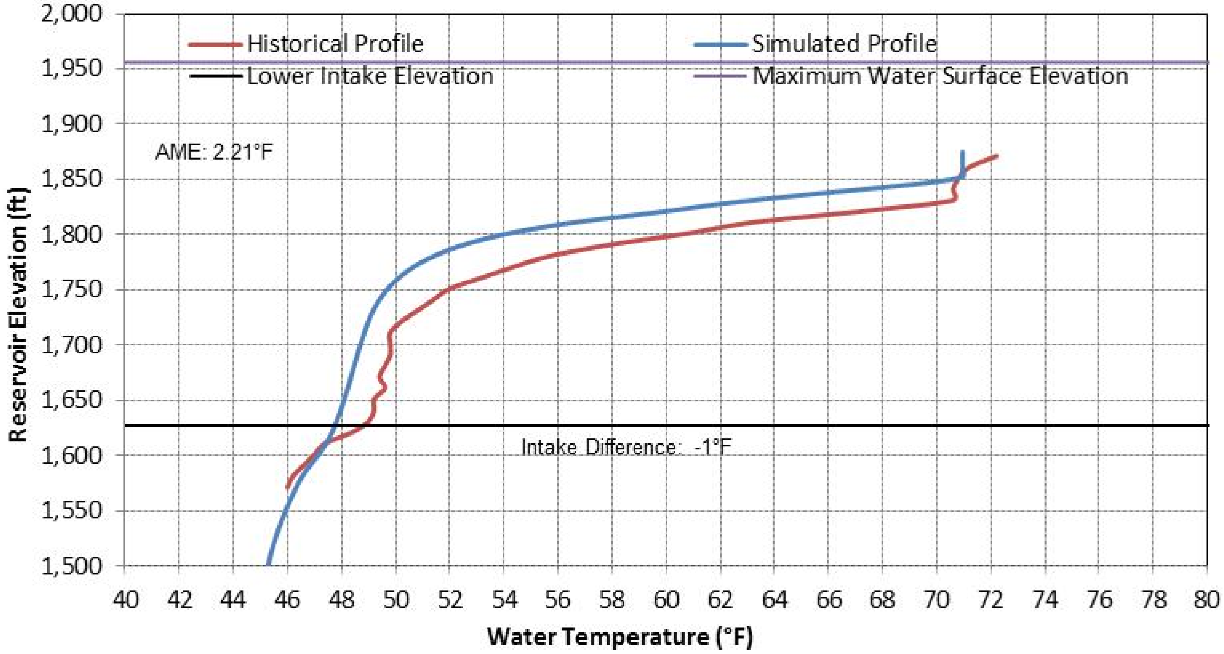


Figure 11.2-9. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for October 1, 2009

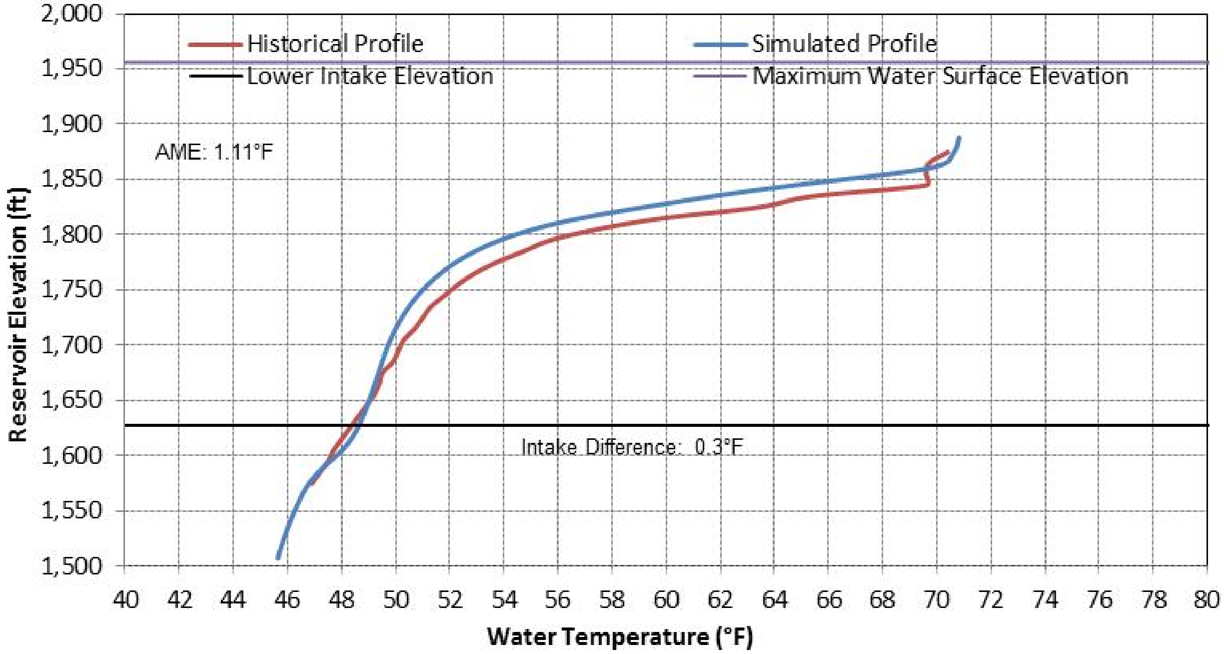


Figure 11.2-10. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 30, 2010

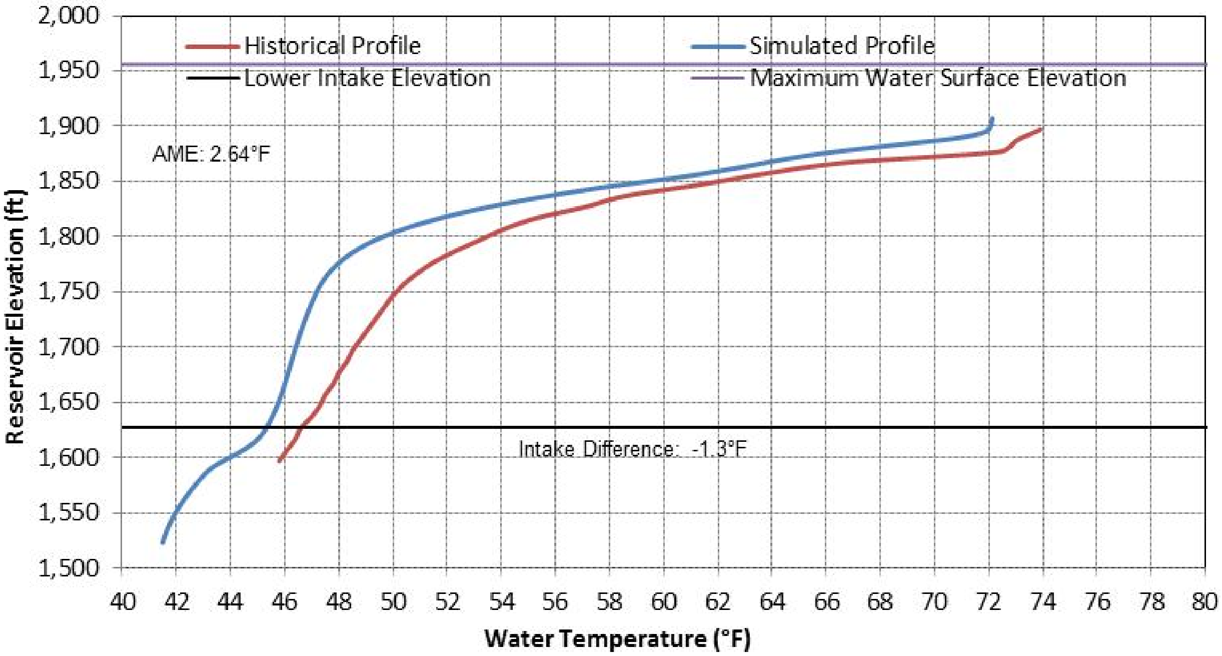


Figure 11.2-11. Comparison of simulated and historically-measured New Bullards Bar Reservoir water temperature profile for September 22, 2011

There is a very limited availability of historical data for instream temperatures of the Upper Temp Model. For the river reaches, the node used as an input to the Englebright Temp Model was used for validation – Yuba River below the New Colgate Powerhouse (T130). The historical data at this location begins August 19, 2009, but for the period the data can be compared the validation appears to be valid, with -0.3736°F and 1.50°F for ME and AME respectively. The July through October ME and AME during this short validation period are -0.73°F and 1.69°F respectively. Fluctuations can be seen in the earlier part of the calibration, and are caused by New Colgate Powerhouse flows near zero for some days. A complete plot of the validation run can be seen in Figure 11.2-12.

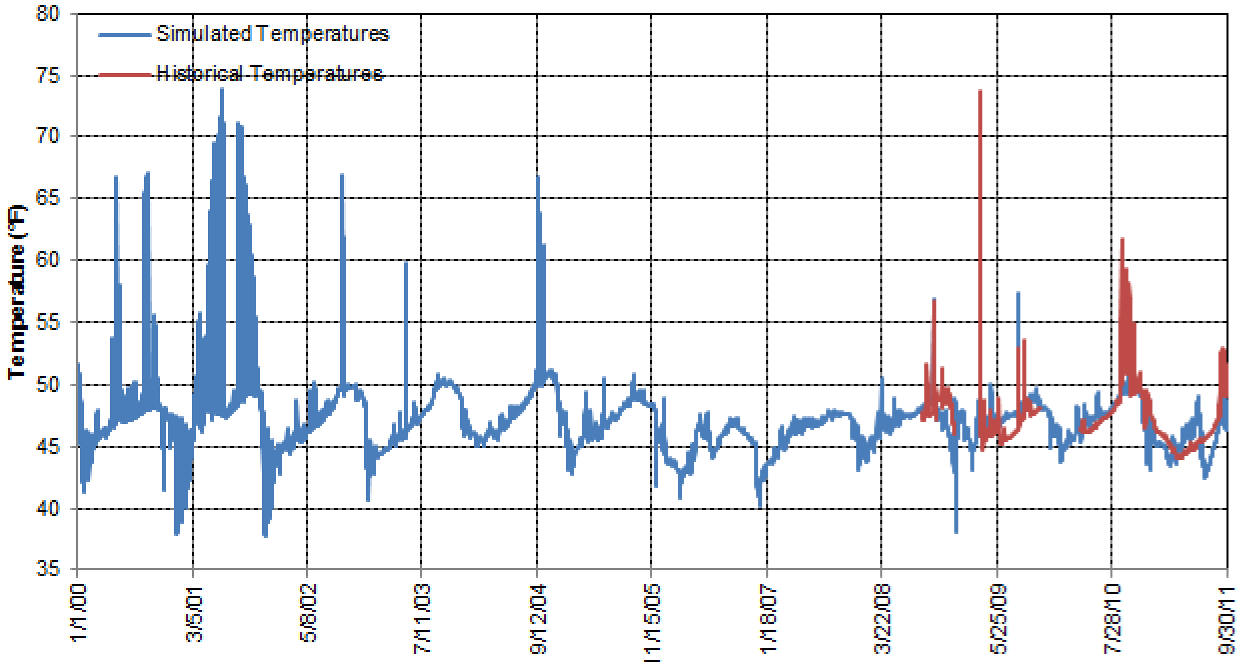


Figure 11.2-12. Comparison of Simulated and Historically-Measured Yuba River Water Temperatures below Dobbins Creek (RM 33.9) for the Validation Scenario.

11.2.2 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. The Englebright Temp Model input data consisted of the following:

- Historical inflows at the Yuba River below the New Colgate Powerhouse
- Modeled inflow temperatures from the Upper Temp Model at the Yuba River below the New Colgate Powerhouse
- Historical inflows at the South Yuba River at Jones Bar
- Synthetic inflow temperatures at the South Yuba River at Jones Bar
- Historical outflows at the Narrows 1 Powerhouse
- Historical outflows at the Narrows 2 Powerhouse
- Historical outflows at the Englebright Dam spillway
- Historical meteorology from the Browns Valley CIMIS station
- Synthetic accretion inflows, calculated by the water-balance utility
- Synthetic accretion inflow temperatures

Section 8 describes of the development of the inflow temperatures, and Section 9 describes the development of the meteorological input data.

Figure 11.2-13 shows a comparison of historically-measured water temperatures with simulated temperatures at Smartsville for the Validation Scenario. Figure 11.2-14 shows a comparison of simulated water temperatures versus historically-measured water temperatures, as compared to a one-to-one line.

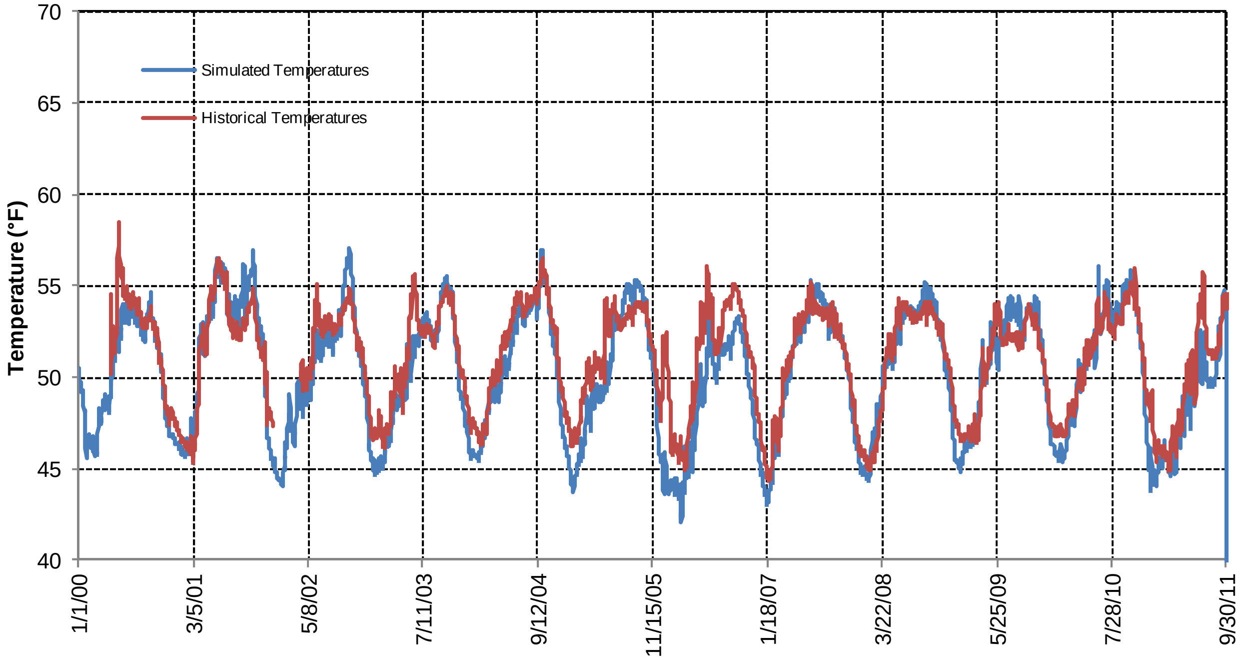


Figure 11.2-13. Comparison of Simulated and Historically-Measured Yuba River Water Temperatures near the Smartsville Gage (RM 23.9) for the Validation Scenario.

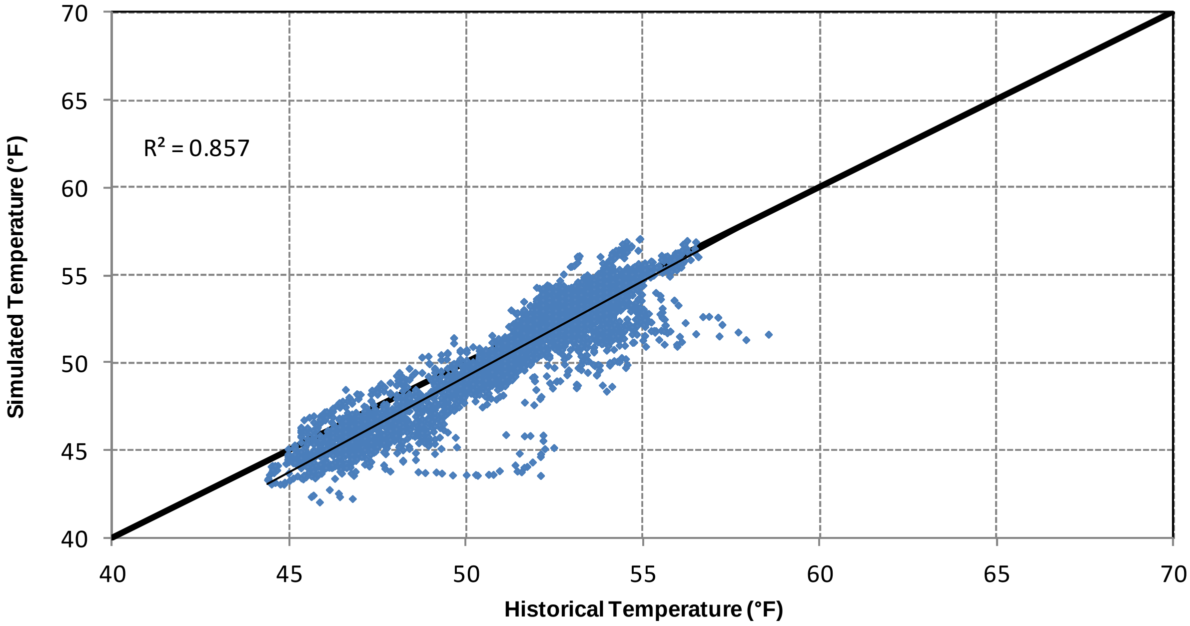


Figure 11.2-14. Comparison of Simulated versus Historically-Measured Yuba River Water Temperatures at the Smartsville Gage (RM 23.9) for the Englebright Temp Model Calibration Scenario.

Table 11.2-1 shows the resulting ME and AME for the full period and July through October periods.

Table 11.2-1. Summary of Mean Error (ME) and Absolute Mean Error (AME) for the Englebright Temp Model near Smartsville (January 1, 2000 through September 30, 2011) for the Validation Scenario.

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

Validation Scenario results indicate that the Englebright Temp Model is relatively insensitive to input temperatures, except during periods of spill. Inputs temperatures are entirely made of synthetic data for the validation scenario. During periods of spill, simulated outflow temperatures are more likely to disagree with historical temperatures, as the residence time in the reservoir is short and thus more sensitive to inflow temperatures. 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.

11.2.3 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 at the Smartsville gage from the Englebright Temp Model
- 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

Section 8 includes a description of the development of the inflow temperatures, and Section 9 describes the development of the meteorological input data.

Figure 11.2-15 shows a comparison of historically-measured water temperatures with simulated temperatures at Marysville.

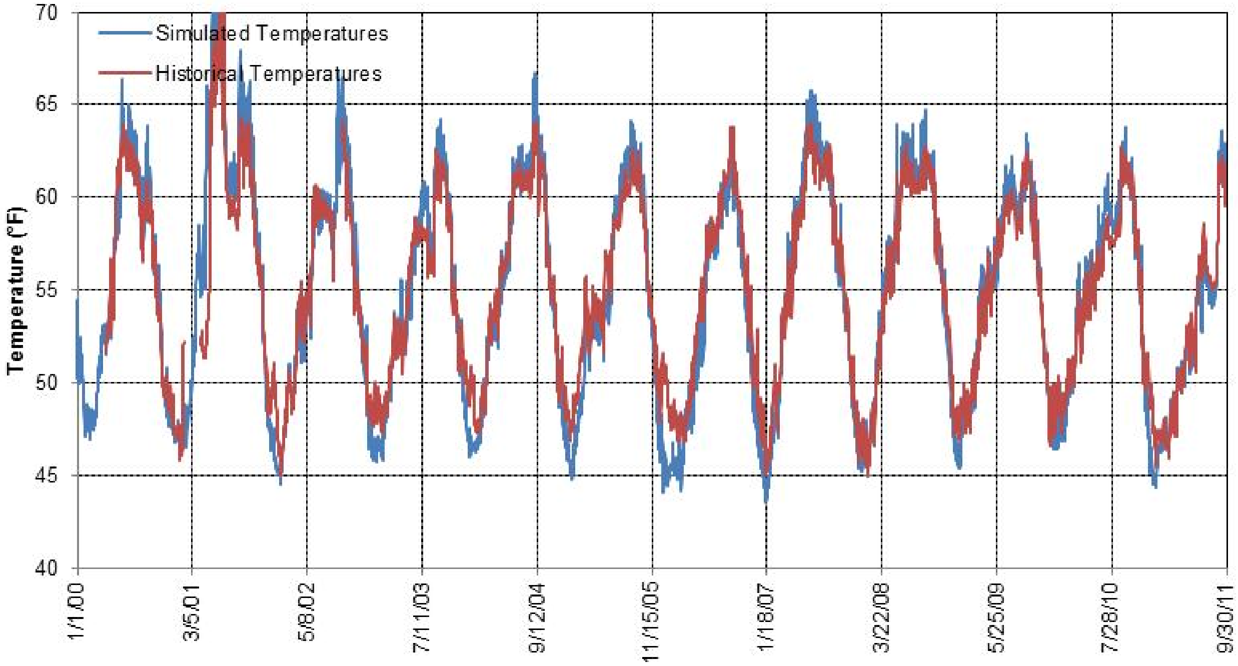


Figure 11.2-15. Comparison of Simulated and Historically-Measured Yuba River Water Temperatures near the Marysville Gage (RM 6.2) for the Validation Scenario.

Table 11.2-2 shows the resulting ME and AME for the full period and July through October periods.

Table 11.2-2. Summary of Mean Error (ME) and Absolute Mean Error (AME) for the Lower Temp Model near Marysville (January 1, 2000 through September 30, 2011) for the Validation Scenario.

Location	Gage ID	Full Period		July-October	
		ME	AME	ME	AME
Yuba River near Marysville (RM 6.2)	11421000	-0.17	1.10	0.49	0.95

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, is 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 Validation Scenario output indicates that water temperatures at Marysville are primarily driven by meteorology, flow, and Smartsville water temperatures; input water temperatures from Deer Creek and Dry Creek have a minor affect on water temperatures, but using a reasonably representative inflow temperatures along with high-quality flow, meteorology, and Smartsville water temperatures allows the model to calculate water temperatures with a reasonable degree of accuracy.

12.0 References

Bookman-Edmonston Engineering, Inc. 1992. Report on Water Temperature Modeling on the Yuba River. January, 1992

California Data Exchange Center (CDEC). 2012. California Department of Water Resources. Data available online: <http://cdec.water.ca.gov/>. Accessed October 2012.

California Irrigation Management Information System (CIMIS). 2012, California Department of Water Resources. Data available online: <www.cimis.water.ca.gov>. Accessed October, 2012.

Cole, T.M., and Wells, S.A. 2011. "CE-QUAL-W2: A two-dimensional, laterally averaged, Hydrodynamic and Water Quality Model, Version 3.7," Department of Civil and Environmental Engineering, Portland State University, Portland, OR

National Oceanic and Atmospheric Administration (NOAA). 2012. US department of Commerce. Data available online: <www.climate.gov>. Accessed October 2012.

National Renewable Energy Laboratory (NREL). 2012. U.S. Department of Energy. Available online: < http://rredc.nrel.gov/solar/old_data/nsrdb/>. Accessed November, 2012.

Pasternack, G.B. and Lower Yuba River Management Team (RMT). 2012. "Lower Yuba River 2D Hydrodynamic Modeling Suite, Release Version 2012.07.17" <www.yubaacordrmt.com>, 2012.

United States Army Corps of Engineers (USACE). 1972. New Bullards Bar Reservoir Regulation for Flood Control. June 1972.

United States Army Corps of Engineers, Hydrologic Engineering Center (HEC). 1998. Users Manual, Simulation of Flood Control and Conservation Systems, Appendix on Water Quality Analysis. August 1998.

United States Federal Energy Regulatory Commission (FERC). 1993. Order Issuing New License. February 1993.

United States Federal Power Commission (FPC). 1963. Order Issuing License and Accepting Surrender of License. May 1963.

_____. 1966. P-2246 35 FPC Order Amending License. FPC, Washington D.C. May 6, 1966.

United States Geological Survey (USGS). 2003. Open-File Report 03-383. Bathymetric and Geophysical Surveys of Englebright Lake, Yuba-Nevada Counties, California, 2003

_____. 2005. Water-Data Report CA-04-4. Water Resources Data, California, Water Year 2004. Volume 4. Northern Central Valley Basins from Honey Lake Basin to Oregon State Line.

_____. 2012. Data available online: <http://waterdata.usgs.gov>. Accessed October 2012.

Yuba County Water Agency (YCWA). 2001. Lower Yuba River: Assessment of Proposed Water Temperature Requirements. October 2001

_____. 2007. Draft Environmental Impact Report/ Environmental Impact Statement for the Proposed Lower Yuba River Accord. June 2007

_____. 2009. Yuba River Development Project FERC Project 2246 Preliminary Information Package. September 2009