Study 2.2

WATER TEMPERATURE MODELING STUDY

December 2015

1.0 Project Nexus

South Sutter Water District's (SSWD) continued operation and maintenance (O&M) of the Camp Far West Hydroelectric Project (Project) may have an effect on water temperature in the Bear River downstream of the Camp Far West Dam.

2.0 Study Goals and Objectives

The goal of the Water Temperature Modeling Study (Study) is to determine if Project O&M adversely affects water temperature in Camp Far West Reservoir and in the Bear River downstream of the Camp Far West Dam.

The objective of the Study is to develop a water temperature model that can be used to address the Study goal. In particular, the model should:

- Reasonably simulate reservoir and stream water temperatures resulting from Project O&M; that is, accurately reproduce observed reservoir and stream water temperatures, within acceptable calibration standards over a range of hydrologic conditions.
- Cover a range of normal variations in hydrology of the Bear River.
- Be sensitive to reservoir operations, upstream/downstream flow and meteorological conditions.

The Study does not include the development of potential requirements in the new license, or runs of the model other than described in this Study.

3.0 Existing Information and Need for Additional Information

Existing, relevant and reasonably available information regarding water temperature in Camp Far West Reservoir and in the Bear River downstream of the reservoir is provided in Section 3.2.2.9.1 of SSWD's Pre-Application Document (PAD). As a summary:

- Stream Temperature Data
    - SSWD-gathered stream temperature data in 2015 – upstream and downstream of Camp Far West Reservoir (see PAD Table 3.2.2-7 for list of locations)

- Reservoir Temperature Data
    - Alpers et al. study (2001-2003) [Alpers et al. 2005]
    - SSWD-gathered reservoir temperature data in 2015 (see PAD Table 3.2.2-8 for list of locations)
- Meteorological Data
    - Publicly available data are available for download on the internet from the California Irrigation Management Information System (CIMIS, www.cimis.water.ca.gov), California Data Exchange Center (CDEC, www.cdec.water.ca.gov), National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI, www.ncdc.noaa.gov)

SSWD did not find an existing model of water temperature in Camp Far West Reservoir of the Bear River downstream of Camp Far West Dam.

Additional information to be provided by the Study is a water temperature model, which is not currently available, for Camp Far West Reservoir and the Bear River downstream of Camp Far West Dam to the confluence with the Feather River.

4.0 Study Methods and Analysis

4.1 Study Area

The Study Area includes Camp Far West Reservoir and the Bear River from Camp Far West Dam downstream to the confluence of the Bear River with the Feather River. Figure 4.1-1 provides a schematic of the Study Area with existing water temperature gage locations. Figure 4.1-2 shows a map of the Study Area.

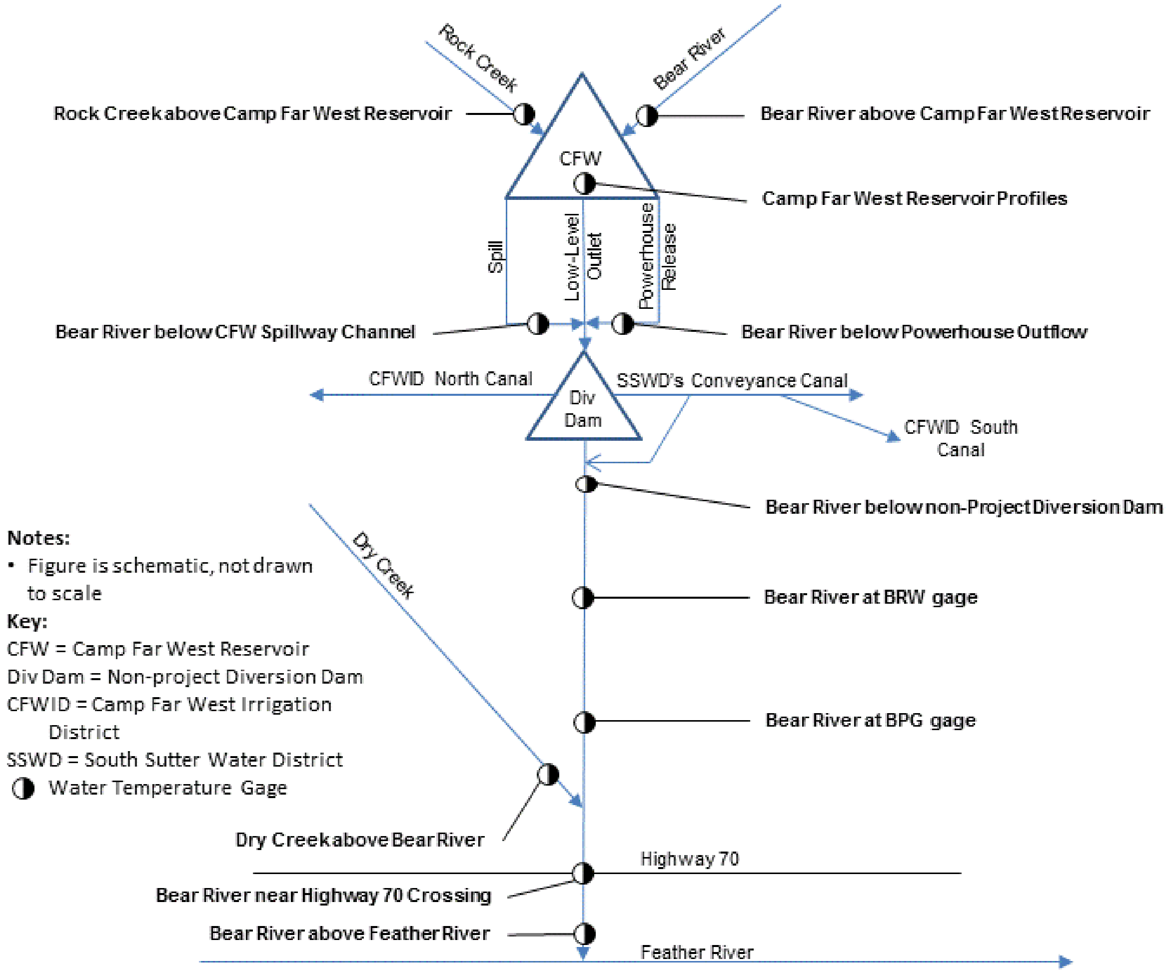

Figure 4.1-1. Water temperature gage locations.

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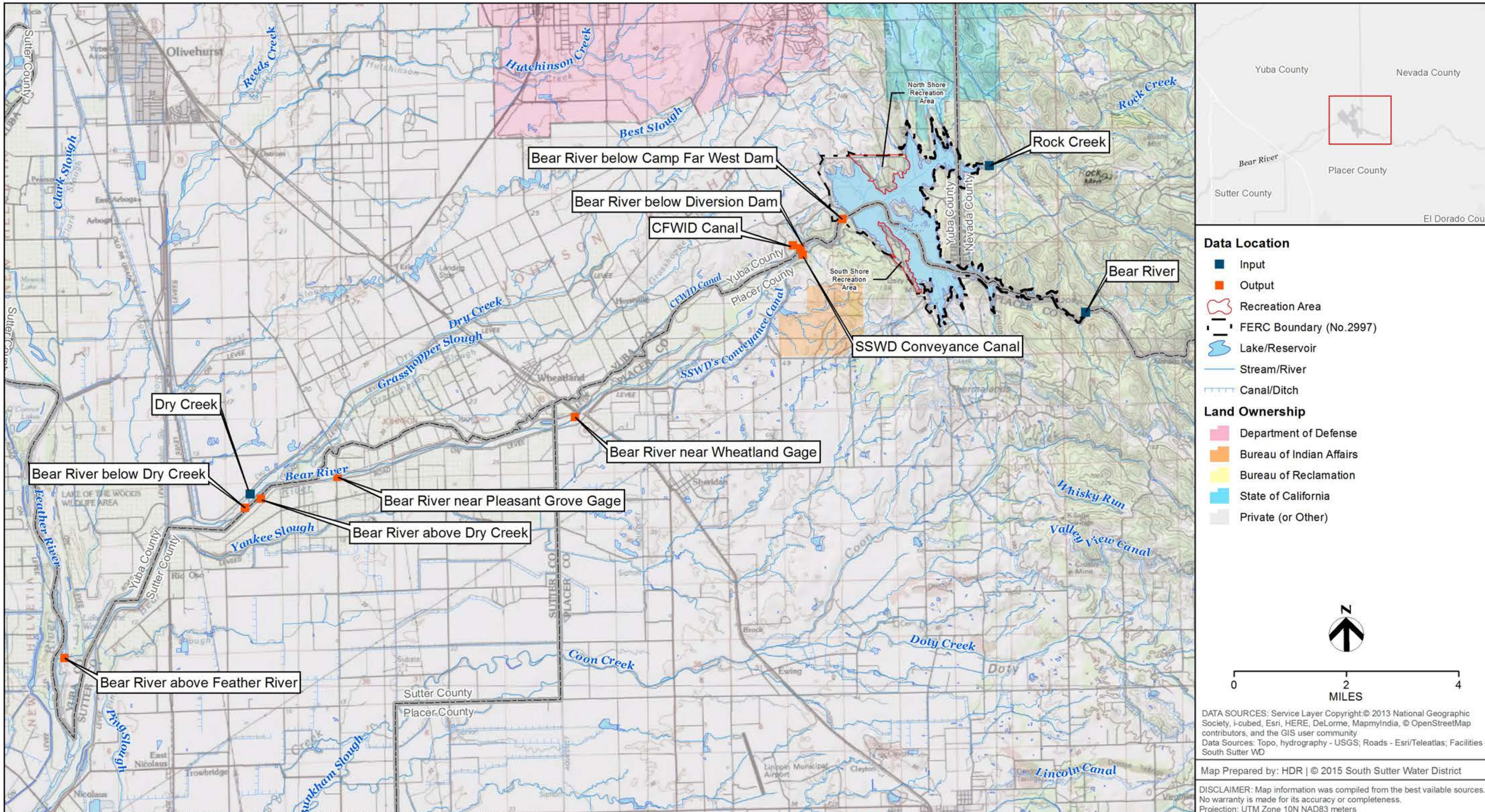

Figure 4.1-2. Study Area of Water Temperature Modeling Study.

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4.2 General Concepts and Procedures

The following general concepts and practices apply to all SSWD relicensing studies:

- Personal safety is the most important consideration of each fieldwork team.
- If required for the performance of the study, SSWD will make a good faith effort to obtain permission to access private property well in advance of initiating the study. SSWD will only enter private property if such permission has been provided by the landowner.
- SSWD will acquire all necessary permits prior to beginning fieldwork for a study that requires them.
- Field crews may make variances to the study plan in the field to accommodate actual field conditions and unforeseen problems. When a variance is made, the field crew will follow to the extent applicable the protocols in the study plan.
- When SSWD becomes aware of a variance to the study plan, SSWD will issue an e-mail to the Federal Energy Regulatory Commission (FERC); National Oceanic and Atmospheric Association, National Marine Fisheries Service; United States Fish and Wildlife Service; California Department of Fish and Wildlife (Cal Fish and Wildlife) and the State Water Resources Control Board describing the variance and reason for the variance. SSWD will summarize in the Application for New License all study plan variances.
- SSWD's performance of the study does not presume that SSWD is responsible in whole or in part for measures that may arise from the study.
- If Global Positioning System (GPS) data are required by a study plan, they will be collected using either a Map Grade Trimble GPS (sub-meter data collection accuracy under ideal conditions), a Recreation Grade Garmin GPS unit (3-meter data collection accuracy under ideal conditions), or similar units. GPS data will be post-processed and exported from the GPS unit into Geographic Information System (GIS) compatible file format in an appropriate coordinate system using desktop software. The resulting GIS file will then be reviewed by both field staff and SSWD's consultant's relicensing GIS analyst. Metadata will be developed for deliverable GIS data sets. Upon request, GIS maps will be provided to National Oceanic and Atmospheric Association, National Marine Fisheries Service; United States Fish and Wildlife Service; Cal Fish and Wildlife or State Water Resources Control Board in a form, such as ESRI Shapefiles, GeoDatabases, or Coverage with appropriate metadata. Metadata will be Federal Geographic Data Committee compliant.
- SSWD's field crews conducting relicensing studies will record incidental records of aquatic and wildlife species observed during the performance of a study. All incidental observations will be reported in Application for New License. The purpose of this effort is not to conduct a focused study (i.e., no effort in addition the specific field tasks identified for the specific study) or to make all field crews experts in identifying all species, but only to opportunistically gather data during the performance of a relicensing

study. Species included for incidental observation will include, but are not limited to: bald eagle (*Haliaeetus leucocephalus*), golden eagle (*Aquila chrysaetos*), osprey (*Pandion haliaetus*), any bats or positive sign of bats; Chinook salmon (*Oncorhynchus tshawytscha*), and steelhead (*O. mykiss*), including redds and carcasses; northern western pond turtle (*Actinemys marmorata*), foothill yellow-legged frog (*Rana boylii*), American bullfrog (*Lithobates catesbeianus*), and aquatic invasive species.

- Field crews will be trained on, provided with, and use materials (e.g., Quat disinfectant) for decontaminating their boots, waders, and other equipment between water-based study sites. Major concerns are amphibian chytrid fungus, and invasive invertebrates (e.g., zebra mussel, *Dreissena polymorpha*).
- If in the performance of a study, SSWD observes an Endangered Species Act-listed or special-status species, within 30 days of the observation SSWD will submit to Cal Fish and Wildlife's California Natural Diversity Database a record, on the appropriate form, of the observation.
- If a study plan requires collection and reporting of time series data, the data will be provided at a minimum in HEC-DSS format. A viewer for these files (HEC-DSSVue) can be obtained from the United States Army Corps of Engineers (USACE) at the following website as of September 2015: http://www.hec.usace.army.mil/software/hec-dssvue/downloads.aspx in both Microsoft® Excel and *.DSS formats.
- If a field crew encounters human remains during field work, all work within a 100-foot radius of the discovery will stop immediately. The field crew will not disturb the remains in any way, secure the area to the best of its ability, mark the location with flagging tape in such a way as to not draw attention to the remains, and record the location using a GPS unit or plot the location by hand on a map if no GPS unit is available. As soon as possible thereafter, the field crew will contact SSWD and the relicensing Cultural Resources Lead to report the discovery. SSWD will report the finding and initiate the appropriate steps required under State of California and federal law to address the discovery. Any human remains encountered will be treated with respect, and the field crew members will keep the location confidential and will not disclose the location of the discovery to the public or to any other study crews. The field crew will keep a log of all calls/contacts it makes regarding the discovery and that details the event. Work will not proceed in the secured area of the discovery until provided clearance by SSWD.

4.3 Methods

The Study will be completed in six steps: 1) select a water temperature model platform; 2) develop and calibrate a CE-QUAL-W2 water temperature model; 3) develop an input data set; 4) validate the water temperature model; 5) develop a base case for the water temperature model; and 6) prepare a final report. Each step is described below.

Information needed to develop the model is either existing or will be developed as part of other SSWD relicensing studies, as discussed below.

Observed water temperature data is a key component in the development of a water temperature model. Little information is available regarding water temperatures in Camp Far West Reservoir and the Bear River downstream of Camp Far West Dam. In April 2015, SSWD began collecting water temperature upstream of Camp Far West Reservoir, within the reservoir, and downstream of Camp Far West Dam. These existing data are summarized in Section 3.2.2.9.1 of the PAD. Through SSWD's proposed relicensing Study 2.1, *Water Temperature Monitoring*, SSWD will continue to monitor water temperature data through December 2016. Table 4.3-1 provides a list of locations where water temperature data have been and will be collected.

Table 4.3-1. SSWD water temperature monitoring locations.

Location	River Mile[1]	Installation Date	Latitude	Longitude
UPSTREAM OF PROJECT AREA				
Bear River above Camp Far West Reservoir	25.1	4/10/15	39.011685	-121.220506
Rock Creek above Camp Far West Reservoir	--	8/6/15	39.063471	-121.263205
DOWNSTREAM OF PROJECT AREA				
Bear River below Powerhouse Outflow	18.0	4/10/15	39.04898	-121.31841
Bear River below CFW Spillway Channel	17.9	9/30/15	39.04719	-121.31969
Bear River below non-Project Diversion Dam	16.9	4/10/15	39.04163	-121.33235
Bear River at BRW[2] gage, Highway 65 Crossing	11.4	4/10/15	38.99901	-121.40810
Bear River at BPG[3] gage, Pleasant Grove Bridge	7.1	4/10/15	38.98561	-121.48329
In Dry Creek above Bear River	--	12/1/15	38.99596	-121.49121
Bear River near Highway 70 Crossing	3.5	4/10/15	38.97249	-121.54343
Bear River above Feather River Confluence	0.1	4/10/15	38.93906	-121.57831
Feather River above Bear River Confluence	--	8/6/15	38.94277	-121.57928
Feather River below Bear River Confluence	--	4/10/15	38.93802	-121.58038

1 River miles are for locations in the Bear River only.
2 BRW – Bear River near Wheatland
3 BPG – Bear River near Pleasant Grove

Another key component for a water temperature model is hydrology. Bear River unimpaired hydrology was developed as part of this relicensing from the headwaters downstream to Camp Far West Dam (see Appendix F of the PAD). Inflow and outflows to Camp Far West Reservoir and the non-Project diversion dam are input to the water temperature model. The majority of the hydrologic input data will come from SSWD's Water Operations Model output, described in Section 2.1.4.6 of the PAD. Additional hydrology input data are needed to characterize accretion data in the lower Bear River, including Dry Creek inflow to the Bear River (RM [River Mile] 5.1), and agricultural deliveries and/or returns downstream of the non-Project diversion dam. Methods developed to estimate unimpaired flow in the Bear River above Camp Far West Dam will be used to estimate historical inflow from Dry Creek.

Meteorological data are also needed to develop a water temperature model. Existing and relevant historical meteorological data are available for the weather stations listed in Table 4.3-2.

Table 4.3-2. Summary of available historical meteorological data in the Project Vicinity.

Weather Station	Operating Agency	Station ID	Period of Record	Data Type[1]
Nicolaus	CIMIS	030	1/3/1983 to 12/29/2011	Air Temperature Solar Radiation Wind Speed Dew-Point Temperature
Bear River at Camp Far West Dam	CDWR	CFW	10/1/2005 to Present	Air Temperature

Table 4.3-2. (continued)

Weather Station	Operating Agency	Station ID	Period of Record	Data Type[1]
Browns Valley	CIMIS	084	4/13/1989 to Present	Air Temperature Solar Radiation Wind Speed Wind Direction Dew-Point Temperature Relative Humidity
Beale AFB[2]	NOAA NCEI	040584	7/1/1959 to Present	Air Temperature Wind Speed Wind Direction Dew-Point Temperature Solar Radiation Descriptive Weather Observations
Sacramento Executive Airport	NOAA NCEI	047630	1/1/1931 to Present	Air Temperature Wind Speed Wind Direction Dew-Point Temperature Solar Radiation Descriptive Weather Observations

1 Only lists available weather station data necessary to develop a water temperature model.
2 Primary station used for development of meteorological dataset.

An estimation of channel form is also necessary to develop a reliable water temperature model. A bathymetric study of Camp Far West Reservoir was performed in 2008, and these data will be used to develop reservoir geometry input data for the water temperature model. Storage and area curves developed from the bathymetric survey are available in Section 3.2.2.4 of the PAD.

Existing information regarding channel morphology in the Bear River downstream of Camp Far West Dam is not available. However, under SSWD's relicensing Study 3.3, *Instream Flow*, SSWD will collect channel geometry data in the Bear River from Camp Far West Dam to the confluence with the Feather River. These data will be available to develop the water temperature model. If additional channel characteristics are required to properly calibrate the model, these data will be collected as part of this Study.

4.3.1 Step 1 – Select Water Temperature Model Platform

To select the water temperature model or model platforms, SSWD 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 FERC and Relicensing Participants can 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 reaches (i.e., the hydrology period of record from Water Year [WY] 1976 through WY 2014).

- Simulate the effects of Camp Far West Reservoir releases through the powerhouse, low-level outlet and spillway on downstream water temperatures due to storage changes, flow changes and outlet used.
- Simulate the effects of changes in flow from SSWD's non-Project diversion dam fish flow release outlet and spill over the diversion dam on downstream Bear River water temperatures.
- Be able to incorporate the temperature effects of upstream water projects.

Based on the selection attributes, SSWD considered the following water temperature model platforms, which had been previously used in regional FERC relicensings:

- River Water Temperature Model Platforms
  - United States Geological Survey's (USGS) Stream Network Temperature Model (SNTEMP) [Barthalow 2010]
  - USGS' Stream Segment Temperature Model (SSTEMP)
  - USGS' Hydrological Simulation Program-Fortran (HSPF) model (Aqua Terra Consultants 2005).
  - Stockholm Environmental Institute's (SEI) Water Evaluation and Planning (WEAP) system (SEI 2015)
  - USACE's Hydrologic Engineering Center RAS (HEC-RAS) model
  - Regression-based model using Microsoft® Excel
- Reservoir Water Temperature Model Platforms
  - USACE's CE-THERM-R1 (Old Dominion University 1993)
  - Danish Hydraulic Institute's (DHI) MIKE3-FM (DHI 2011)
- River and Reservoir Water Temperature Model Platforms
  - USACE's Hydrologic Engineering Center-5Q (HEC-5Q) model
  - Hydrocomp, Inc.'s HFAM II model (Hydrocomp 2012)
  - USACE's CE-QUAL-W2

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

4.3.1.1 Potential River Water Temperature Model Platforms

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

4.3.1.1.1 SNTEMP

SNTEMP is a mechanistic, one-dimensional (1D) heat transport model for branched stream networks that predicts mean-daily and maximum-daily water temperatures as a function of stream distance and environmental heat flux. Typical applications for SNTEMP include predicting the consequences of stream manipulation on water temperatures. Positive attributes of SNTEMP as a model platform include:

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

SNTEMP does meet a majority of the Study selection criteria; however, SNTEMP has limitations that rank it lower in some categories than other model platforms, and therefore, is not the best modeling platform to be used in the 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, which would require iterations to simulate multiple years.
- Does not internally calculate hydraulic conditions, which would require separate hydraulic modeling of all reaches.

4.3.1.1.2 SSTEMP

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

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

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

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

- Simulates a single stream segment for a single period of time (e.g., month, week and day).
- Streams through multiple terrain types need to be broken into sub-reaches and cannot be modeled as one continuous reach.
- 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).

4.3.1.1.3 HSPF

Hydrologic Simulation Program – Fortran (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 1D 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 the 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.

4.3.1.1.4 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.

4.3.1.1.5 HEC-RAS

HEC-RAS is a widely applied hydraulic model for open channel flow in rivers and other water conveyances. A water quality module of the model, including temperature modeling, has been available since the release of HEC-RAS 4.0 in March 2008. The water quality component of HEC-RAS is based on a now defunct model CE-QUAL-RIV1. Positive attributes of HEC-RAS as a modeling platform include the following:

- Wide industry acceptance of HEC-RAS as a hydraulic model.
- Easily interface with HEC-DSSvue databases and model GUI.
- Capable of simulating a broad range of timesteps, from minutes to days.

Negative attributes of HEC-RAS as a modeling platform include the following:

- Not designed to be a water temperature model; it is designed for hydraulic computations and allows for water quality modeling as an add-on component.
- Lack of robust calibration parameters.
- Does not include topographic or vegetative shading.

- In active development, and subject to change with a future release of HEC-RAS.
- Requires hand-off conversion between reservoir temperature model and river model

4.3.1.1.6 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. Positive attributes of a regression-based Microsoft® Excel model include:

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

Negative attributes include:

- Reliability of the model is limited to the range of historically-measured data used to develop the regressions.
- Lack of ability to compute water temperatures for locations other than those with regressions and historically-measured data.

4.3.1.2 Potential Reservoir Water Temperature Models

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

4.3.1.2.1 CE-THERM-R1

CE-THERM-R1, by the Waterways Experiment Station of the USACE, is a dynamic, 1D, horizontally averaged model used to simulate vertical profiles of water temperature in lakes and reservoirs. 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 the 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 1D, vertical profile for a reservoir.
- Does not use HEC-DSS for data exchange.

4.3.1.2.2 MIKE3-FM

MIKE3-FM, by the Danish Hydraulic Institute is a professional engineering software package for 3-D free-surface flows. Positive attributes of MIKE3-FM as a modeling platform include the following:

- Ability to model complex three-dimensional mixing.
- Flexible Mesh allows for detail to be concentrated in areas of interest.
- Graphical User Interface makes model features very accessible.

Negative attributes of MIKE3-FM as a modeling platform in the Study include the following:

- Expensive license with limited virtual machine access for participants.
- Proprietary input and output format requiring conversion for model input and output.
- For 3D simulation, tradeoffs must be made between model simplicity and computation time. May be very slow even for a simple system, if long-period simulations are needed.
- Large data requirements for calibration: temperature profiles and inflow temperatures.
- Used primarily for oceanic and delta modeling.

4.3.1.3 Potential River and Reservoir Water Temperature Models

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

4.3.1.3.1 HEC-5Q

HEC-5Q, by the HEC of the USACE, is a 1D model platform designed to simulate the sequential operation of a reservoir-channel system with branch network configuration. Positive attributes of HEC-5Q as a modeling platform include:

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

Negative attributes include:

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

4.3.1.3.2 HFAM II

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

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

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

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

4.3.1.3.3 CE-QUAL-W2

CE-QUAL-W2, by the Waterways Experiment Station of the USACE, is a two-dimensional (2D), laterally averaged, hydrodynamic water quality model for rivers, estuaries, lakes, reservoirs, and river basin system (Portland State University, 2015). 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 (reservoirs)
- 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 the Study include the following:

- Relatively calculation intensive, requiring a lot of computer resources and several hours of run time.
- Accurate representation of a reservoir requires detailed input data, including bathymetry and topographic shading.
- Requires sub-daily meteorological data inputs, which a) requires long records of input data that can be hard to manage, and b) may need to be estimated if historical data do not exist.
- Does not use HEC-DSS for data exchange.

4.3.1.4 Selection of Model Platforms

SSWD selected CE-QUAL-W2, version 3.72 (Portland State University, 2015) to simulate Camp Far West Reservoir, the non-Project diversion dam and lower Bear River because:

- Of its flexibility to be customized to represent the complexities of the Project, including reservoir outlets at different elevations

- Of its ability to simulate the entire study area (See Section 5.1) using a single model platform
- Of its ability to simulate water temperature at an hourly time step to adequately characterize diurnal water temperature variability.
- Of its ability to simulate the entire period of record
- Relicensing Participants are familiar with this modeling platform, and have agreed on the validity of the model results in other similar studies.

Limitations of CE-QUAL-W2 are:

- Model inputs and outputs are stored as text files, accessible using a text editor or Microsoft® Excel. HEC-DSS is preferred due to its use in hydrology/operations model output viewing.
- Model inputs and outputs are in metric units

Limitations listed above will be overcome by generating a spreadsheet tool that will:

- Export Water Balance/Operation Model output data as a CE-QUAL-W2 input data files in the format required, including conversion from English to metric units for compatibility
- Read in CE-QUAL-W2 output and export it to a HEC-DSS database file, converting from metric units to English units, as necessary

4.3.2 Step 2 – Develop and Calibrate the Model

SSWD will develop and calibrate the water temperature model so that inputs, assumptions, operations, and calibration are consistent with operations and factors governing water temperature in Camp Far West Reservoir and in the Bear River downstream of the reservoir.

The model will simulate Camp Far West Reservoir, Camp Far West Reservoir dam to the non-Project diversion dam below Camp Far West Reservoir, and the lower Bear River reach between the diversion dam and the Bear River confluence with the Feather River. Each will be linked in series as separate water bodies within a single CE-QUAL-W2 model. Model output will be extracted hourly to capture diurnal fluctuations in water temperatures. The model will include input and output for locations listed in Table 4.3-3.

Table 4.3-3. Water temperature model input and output locations.

Node (River Mile)	Location	Input/Output
BEAR RIVER – CAMP FAR WEST DAM REACH[1]		
25.1	Bear River Inflow into Camp Far West	Input
--	Rock Creek Inflow into Camp Far West	Input
18.0	Camp Far West Dam Release	Output
16.9	CFWID[2] North Canal Diversions	Output
16.9	SSWD Main Canal Diversions	Output

Table 4.3-3. (continued)

Node (River Mile)	Location	Input/Output
BEAR RIVER – NON-PROJECT DIVERSION DAM REACH[3]		
16.9	Non-Project Diversion Dam Release	Output
11.5	Bear River near Wheatland Gage	Output
6.8	Bear River near Pleasant Grove Gage	Output
5.2	Bear River Upstream of Dry Creek	Output
--	Dry Creek Inflow	Input
5.1	Bear River Downstream of Dry Creek	Output
0.1	Bear River Upstream of Feather River	Output

[1] Camp Far West Dam Reach – Bear Yuba River from Camp Far West Dam to the non-Project diversion dam.
[2] CFWID – Camp Far West Irrigation District
[3] Non-Project Diversion Dam Reach – Bear Yuba River from below the non-Project diversion dam to immediately upstream from the confluence with the Feather River.

Camp Far West Reservoir will be simulated in CE-QUAL-W2 as a 2D laterally-averaged reservoir. This will allow the water temperature model to capture the variability of release water temperature associated with changing water levels. Hydrologic and water temperature inputs to Camp Far West Reservoir will include the Bear River and Rock Creek. Releases from the reservoir will be modeled through the low-level outlet, the powerhouse, and the spillway. The Camp Far West Reservoir water temperature model will be calibrated for water temperature profiles at three locations in the reservoir: 1) at the dam; 2) in the Bear River arm of the reservoir; and 3) in the Rock Creek arm of the reservoir.

The reach between Camp Far West Reservoir dam and the non-Project diversion dam below Camp Far West Reservoir will be simulated in CE-QUAL-W2 as a 2D laterally-averaged reservoir. Hydrologic and water temperature inputs will include releases from Camp Far West Reservoir. Releases from the diversion dam will be made through SSWD's Conveyance Canal, Camp Far West Irrigation District's canal, or spill over the diversion dam. The diversion dam water temperature model will be calibrated to measured water temperature in the Bear River below the diversion dam (RM 16.9).

The Bear River below the diversion dam will be simulated in CE-QUAL-W2 as a 2D laterally averaged river, with inputs from the non-Project diversion dam and Dry Creek. The Bear River water temperature model will be calibrated to measured water temperature at the following locations:

- Bear River at BRW gage, Highway 65 (RM 11.4)
- Bear River at BPG gage, Pleasant Grove Bridge (RM 7.1)
- Bear River near Highway 70 (RM 3.5)
- Bear River above Feather River Confluence (RM 0.1)[1]

[1] The Bear River above the Feather River Confluence (RM 0.1) stream temperature model node will assume no backwater variability from the Feather River. The model will have limited ability to predict temperatures at this location during high flow periods in the Feather River (i.e. winter and spring months) due to backwater influence.

Available water temperature data (Table 4.3-1); meteorological data, including air temperature, atmospheric pressure, humidity, precipitation, solar radiation, and wind speed (Table 4.3-2); and physical parameters such as reservoir area-storage relationships and river channel geometry will be used for water temperature model calibration. Accretions at multiple locations throughout the Study Area will be included to preserve mass balance throughout the system. Model calibration will use publicly-available historical hydrology data and non-public hydrology data measured by SSWD corresponding to the calibration period, which will be from April 2015 through March 2016.

4.3.3 Step 3 – Develop a Relicensing Period of Record Input Data Set

Concurrent with calibration of the CE-QUAL-W2 models, SSWD will develop both a meteorological and an input-water-temperature data set for the relicensing period of record, which is WY 1976 through WY 2014.

A complete set of hourly meteorological data will be assembled from the gages listed in Table 4.3-2. The primary source gage for the data set will be Beale Air Force Base, which covers the period of record. Other meteorological gages listed in Table 4.3-2 will be used to fill data gaps on an as-needed basis.

Meteorological input data requirements for CE-QUAL-W2 include:

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

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.

Hourly input water temperatures will be determined for the Bear River, as well as Rock Creek and Dry Creek. Since limited historical water temperature data are available for Study Area tributaries for the period of record, it will be necessary to synthesize input water temperatures. Input water temperatures will be synthesized by identifying statistical relationships between available historical water temperature, meteorology and hydrology data. Ungaged accretion water temperatures will be simulated based on data measured in Dry Creek, Rock Creek, or both.

Bear River unimpaired hydrology was developed as part of this relicensing from the headwaters downstream to Camp Far West Dam (see Appendix F of the PAD). Similar methods will be used to estimate unimpaired flow in the Bear River below the non-Project diversion dam, including Dry Creek.

Regulated hydrology data, including inflow and outflow to Camp Far West Reservoir and the diversion dam will come directly from the relicensing Water Operations Model. Outputs from this model are described in Section 2.1.4.6 of the PAD.

4.3.4 Step 4 – Validate the Model

Model validation will occur in three tasks. In the first task, SSWD will evaluate the draft CE-QUAL-W2 models by comparing modeled output to the record from April 2016 through December 2016. Significant differences between historical conditions and modeled output will be examined, and the causes identified and documented. Where substantial differences cannot be explained, the model will be recalibrated. Key validation points will be at the following locations:

- Vertical profile in Camp Far West Reservoir near the dam
- River temperature in the Bear River below the diversion dam
- River temperature at USGS Wheatland gage
- River temperature in the Bear River upstream from its confluence with the Feather River

In the second task, SSWD will meet with interested Relicensing Participates to review the model. This will include a meeting to generally introduce the parties to the model. At that meeting, the parties will be given a compact disc (CD) with the model, a Model Development Report that describes model inputs and logic and general information on running the model, and SSWD's Draft Model Validation Report. After 30 days for review, SSWD will hold a workshop with interested Relicensing Participates to review the model and discuss modifications, as appropriate.

In the last task, SSWD will finalize the model and the Model Development and Validation reports.

4.3.5 Step 5 – Develop Period of Record Base Case Model Scenario

The Base Case water temperature model run will simulate reservoir and stream temperature for the relicensing period of record, which is WY 1976 through WY 2014, under existing Project operations and water deliveries. The underlying assumption is that this Base Case represents the "No-Action Alternative." Meteorological data, boundary condition water temperature data, and hydrologic input data developed in Step 2 will be used to develop the Base Case temperature model scenario. Project operating assumptions for the Base Case are described in Section 2.1.4.6 of the PAD.

4.3.6 Step 6 – Prepare Final Report

At the conclusion of the study, SSWD will prepare a report that includes the following sections: 1) Study Goals and Objectives; 2) Methods; 3) Results; 4) Discussion; and 5) Description of Variances from the study plan, if any. The report will include as attachments the final model configured for the Base Case scenario, and a final Model Validation Report.

6.0 Consistency of Methodology with Generally Accepted Scientific Practices

This Study is consistent with the goals, objectives, and methods outlined for many recent FERC hydroelectric relicensing efforts in California, including the Yuba River Development Project (FERC No. 2246), the Drum-Spaulding Project, (FERC No. 2310) and the Yuba-Bear Hydroelectric Project (FERC No. 2266). Model development, including calibration, verification, and model application will be conducted in accordance with generally accepted scientific practices.

7.0 Schedule

SSWD anticipates the schedule to complete the study as follows:

Develop and Calibrate Model (Step 1) ....February 2016 – August 2016
Develop Input Data Set (Step 2) .... October 2016 – December 2016
Validate Model (Step 3)...January 2017 – March 2017
Develop Base Case (Step 4)...April 2017 – May 2017
Prepare Model and Reports (Step 5)..May 2017 – June 2017

The Study report will be included in SSWD's DLA and FLA. If SSWD completes the Study report before preparation of the DLA, SSWD will post the report on SSWD's Relicensing Website and issue an e-mail to Relicensing Participants advising them that the report is available.

8.0 Level of Effort and Cost

SSWD estimates the cost to complete this study in 2015 dollars is between $100,000 and $125,000.

9.0 References Cited

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