Placer County Water Agency
Middle Fork American River Project
(FERC No. 2079)

FINAL

AQ 4 – WATER TEMPERATURE MODELING TECHNICAL STUDY REPORT

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1.0 INTRODUCTION

This report describes the AQ 4 – Water Temperature Modeling Technical Study conducted by the Placer County Water Agency (PCWA) in accordance with the AQ 4 – Water Temperature Modeling Technical Study Plan (AQ 4 – TSP). The AQ 4 – TSP was included in the Supporting Document (SD) H of the Pre-Application Document (PAD) for the Middle Fork American River Project (MFP or Project) (PCWA 2007a).

The purpose of the study was to characterize water temperature in the MFP reservoirs (French Meadows Reservoir, Hell Hole Reservoir, and Ralston Afterbay) and in the bypass and peaking reaches associated with the MFP as a function of meteorological conditions and Project operations (reservoir storage, bypass, and peaking reach streamflow). The information developed from this study, in combination with other resource studies (e.g., water temperature, geomorphology, fish passage, fish population, special-status amphibian and reptile, bioenergetics, and riparian resources studies), will provide a basis for reservoir and streamflow-related resource management decisions.

The draft report was distributed to the Aquatic Technical Working Group (TWG) on May 27, 2010 for a 60-day comment period. The comment period ended on July 27, 2010, with no comments received.

2.0 STUDY OBJECTIVES

The specific study objectives include the following:

- Characterize the relationship between flow and water temperature in bypass reaches and the peaking reach using an appropriate model supported by existing water temperature data.
- Characterize water temperature conditions in the bypass reaches and the peaking reach for the existing and unimpaired flow regimes.
- Document the availability of cold water thermal refugia in bypass reaches where water temperatures exceed established technical evaluation criteria.
- Assess the potential effects of increased air temperature due to global warming on water temperatures over the term of the new Federal Energy Regulatory Commission (FERC) license.

Figure AQ 4-1 shows the AQ 4 – TSP study objectives and the study elements associated with each objective. It also shows where information developed is documented.

3.0 STUDY IMPLEMENTATION

Study elements described in the AQ 4 – TSP (PCWA 2007a) were initiated in 2007 and will be completed in 2010. A summary of the completed study elements, deviations from the TSP, outstanding study elements, and any proposed modifications to the AQ 4 – TSP are discussed in the following subsections.

3.1. STUDY ELEMENTS COMPLETED

The following water temperature modeling elements were completed:

- Summarize water temperature and meteorological data from the 2005–2006 Water Temperature Study (PCWA 2006a, PCWA 2007b).
- Continue to collect water temperature and meteorological data through the summers of 2007 and 2008.
- Establish a Water Temperature Modeling Subgroup (WTMG) to provide oversight and technical review of modeling procedures/decisions.
- Select and develop appropriate reservoir and river temperature models with seasonal, daily, and sub-daily temperature modeling capability as necessary for specific study reaches.
- Develop models to simulate average, maximum, and minimum daily water temperature during the summer months when water temperature may be of most concern to aquatic species. Modeling development steps completed in collaboration with the WTMG include:
    - Collect/develop model inputs including channel and reservoir geometry data, solar shading data (topographic and riparian), meteorological data (air temperature, wind speed, relative humidity, solar radiation), hydrology data, and boundary condition flow and water temperature data for the modeled river reaches and reservoirs.
    - Calibrate the hydrodynamics water temperature model(s) with empirical water temperature (river reaches and reservoirs) and meteorological data (e.g., use data collected in 2005–2008). Calibrate water travel time in the peaking reach using the flow fluctuation travel times collected in the AQ 1 – Instream Flow TSP.
- Characterize modeled water temperatures for existing, unimpaired, and alternative flow conditions. For alternative flow conditions, model a range of flow releases determined by the WTMG.
- In selected reaches of the lower Rubicon River and the Middle Fork American River, collect water temperature data at tributary inflows and in deep pools to identify the potential availability of water temperature refugia for trout. In particular, review the 2005–2006 Water Temperature Study results (e.g., PCWA 2006A, PCWA 2007b) to identify river reaches with summer temperatures above 20°C. Within these reaches, identify likely tributaries with potential cold water inflows and characterize the extent of the cold water refugia (e.g., amount of tributary habitat, extent of influence in the main channel). Identify two deep pools upstream and two downstream of the tributary and collect water temperature profiles to examine potential thermal stratification.

- In the Project reaches where water temperature was not modeled (e.g., Duncan Creek, North Fork Long Canyon Creek, South Fork Long Canyon Creek, and Long Canyon Creek), use existing water temperature and meteorological data to quantify the relationships between air temperature and water temperature.

3.2. DEVIATIONS FROM TECHNICAL STUDY PLAN

There was one deviation from the AQ 4 – TSP as described below:

- The potential French Meadows – Hell Hole Reservoir Pump Storage Betterment was eliminated from the Project; therefore, the water temperature modeling components in the AQ 4 – TSP (PCWA 2007a) related to potential pump storage betterment were not implemented.

3.3. OUTSTANDING STUDY ELEMENTS

The following outstanding study element will be completed and included in the draft and final license application once proposed instream flows have been identified.

- Incorporate available literature predictions of changes in air temperature as a result of global warming into a limited number of model runs (2–3) to evaluate the resulting effect of global warming on water temperature over the anticipated term of the FERC license period (limited sensitivity analysis).

3.4. PROPOSED MODIFICATION TO TECHNICAL STUDY PLAN

No modifications are proposed to the AQ 4 – TSP.

4.0 EXTENT OF STUDY AREA

The study area for water temperature modeling includes the following (Map AQ 4-1):

- French Meadows Reservoir, Hell Hole Reservoir, and Ralston Afterbay;
- Middle Fork American River between French Meadows Reservoir and the confluence with the North Fork American River;
- North Fork American River between the Middle Fork American River confluence and Folsom Reservoir; and
- Rubicon River between Hell Hole Reservoir and Ralston Afterbay.

Middle Fork Interbay, due to its very small size, was not modeled. It was used as the upstream boundary condition for the river temperature model immediately below Middle Fork Interbay.

The Project small stream bypass reaches, Duncan Creek, North and South Fork Long Canyon creeks, and Long Canyon Creek, were not included in the water temperature modeling study area; however, existing water temperature and meteorological data were used to quantify relationships between air and water temperature in these streams. PCWA has committed to not divert flow from the small streams during the summer, after July 1, in the new license. Because the highest summer water temperatures occur during late July and early August (PCWA 2006A; PCWA 2007b) and because the Project will not divert during this time period, there was no need to model Project operation effects on summer water temperature.

5.0 STUDY APPROACH

The following describes the general approach for: (1) model development; (2) model parameter calibration; (3) model calibration assessment; (4) model sensitivity analysis; (5) unimpaired temperature modeling; (6) alternative flow regime temperature analysis; (7) empirical water temperature characterization in small stream bypass reaches; and (8) cold water thermal refugia assessment in bypass reaches. The WTMG was established to provide oversight and technical review of the modeling procedures and decisions. All Aquatic TWG members were invited to participate in the WTMG.

5.1. MODEL DEVELOPMENT

The process for constructing models of the MFP reservoirs and river reaches began with model selection, followed by model design, implementation, and parameter calibration.

5.1.1. Model Selection

The Project incorporates a wide range of facilities and conditions including large and small reservoirs, rivers with a wide range of flow rates, peaking and non-peaking reaches, and tunnels. To accommodate these diverse characteristics, a combination of discrete river models and reservoir models were selected in collaboration with the WTMG to model flow and water temperatures. The RMA-2 and RMA-11 models were developed by Resource Management Associates (King 2002; King 2003) and were selected to model flow and temperature, respectively, in the river reaches. The CE-QUAL-W2 model was developed by the U.S. Army Corps of Engineers (Cole and Wells 2003) and selected to model reservoir water temperature. Both models can simulate water temperatures on a sub-daily time step. A review of available models and their attributes is provided in Appendix A.

Flow and temperature characteristics of the river reaches were modeled using RMA-2 and RMA-11, respectively. RMA-2 is a finite-element, hydrodynamic model capable of modeling highly dynamic flow regimes in short space and time steps. Output from RMA-2 (including velocity, depth, and representative surface and bed areas) is passed to the water quality model, RMA-11. RMA-11 is a finite-element water quality model that simulates the fate and transport of a wide range of physical, chemical, and biological constituents. These linked river models were applied on hourly or sub-hourly time steps to capture short-term water temperature response (e.g., peak daily temperature). The RMA models were applied in one-dimension and represented variations along the longitudinal axis of the river (i.e., laterally and vertically averaged).

One-dimensional model formulations provide an appropriate representation of water temperature conditions in steep, turbulent river reaches like those in the MFP (Saviz et al. 1995; UC Davis 1998).

The river models were also able to incorporate attributes of the MFP such as topographic shading due to the mountainous terrain; riparian vegetation shading in select reaches; steep riverine reaches; dynamic flow conditions due to hydropower operations and natural fluctuations; variable spatial and temporal meteorology; low summer flows in certain reaches; as well as other features. This flexibility provided a comprehensive analysis of the MFP and its effect on water temperatures on the river and reservoir systems using the selected models.

The MFP reservoirs were modeled with CE-QUAL-W2, a two-dimensional (longitudinal and vertical) hydrodynamic and water quality model. In the MFP reservoirs, thermal stratification exists seasonally, requiring considerations of both the longitudinal and vertical dimensions. The model assumes lateral homogeneity. Lateral variability in water temperatures in the MFP reservoirs can be assumed to be minimal, as the reservoirs are relatively long and narrow due to their canyon locations. The CE-QUAL-W2 model is capable of representing a wide range of physical, chemical, and biological processes that affect water quality. It can simulate thermal stratification, density-dominated inflows, internal weirs and curtains, and other options useful in assessing a wide range of existing and possible future conditions of the system. To interface with the river models, model output at time steps on the same scale as the river models (hourly) was employed.

5.1.2. Model Design Overview

The MFP was modeled as three reservoirs (French Meadows Reservoir, Hell Hole Reservoir, and the Ralston Afterbay) connected to three rivers (the Middle Fork American River, the Rubicon River, and the North Fork American River from its confluence with the Middle Fork American River to Folsom Reservoir). To create a Project-wide simulation, the models were applied along the length of the Project starting at the uppermost reservoirs (French Meadows and Hell Hole) with CE-QUAL-W2 and subsequently in downstream reaches with the RMA-2/RMA-11 river models. CE-QUAL-W2 was also applied for Ralston Afterbay.

The Middle Fork American River, Rubicon River, and North Fork American River were modeled as four river reaches, including: (1) Middle Fork American River from French Meadows Reservoir to Middle Fork Interbay; (2) Middle Fork American River from Middle Fork Interbay to Ralston Afterbay; (3) Middle/North Fork American River from Ralston Afterbay to Folsom Reservoir (Peaking Reach); and (4) Rubicon River from Hell Hole Reservoir to Ralston Afterbay (Map AQ 4-1). These four reaches are bounded by project facilities (e.g., reservoir, diversion, or inflow location).

The Rubicon River model was stratified into three sub-reaches based on channel geomorphology information developed as part of the AQ 1 – Instream Flow Technical Study Report (AQ 1 – TSR) (PCWA 2010): below Hell Hole Dam to Deer Creek, Deer

Creek to the Long Canyon Creek confluence, and the Long Canyon Creek confluence to Ralston Afterbay. The sub-reach strata and the corresponding AQ 1 – TSR instream flow study sites are shown on Map AQ 4-2.

Two MFP system attributes were not explicitly represented in the MFP model – Middle Fork Interbay and the subsurface section of Rubicon River immediately downstream of Hell Hole Reservoir:

- Due to the short length and residence time of Middle Fork Interbay and the large inflow/temperature change at Middle Fork Interbay from the Middle Fork Powerhouse, the river model from French Meadows Reservoir downstream was terminated at Middle Fork Interbay. A new river model was started from Middle Fork Interbay Dam downstream to Ralston Afterbay. The diversion facilities at Middle Fork Interbay were not explicitly modeled, rather, the flow and temperature from Middle Fork Interbay were used as the upstream boundary condition for the Middle Fork Interbay to Ralston Afterbay river temperature model.
- The approximately 1.5–mile reach of the Rubicon River between Hell Hole Dam and RM 28.8 typically consists of subsurface flow through the alluvium (from the historic Hell Hole Dam failure). This reach of river was not explicitly modeled due to the lack of persistent surface flow. The location where persistent flow occurs (RM 28.8) was used as the upstream boundary condition and starting location for the Rubicon River temperature model.

5.1.3. Model Implementation

Once the general structure of the model design was determined, model implementation commenced. The first step was to assemble data describing the project area's geometry, flow, water quality, meteorology, flow travel time, and initial conditions. After the data were formatted for the selected numerical models, general model testing occurred using default model coefficients and parameters specified in model user manuals (e.g., King 2002; King 2003; Cole and Wells 2003). Other model control parameters were also determined, including selection of time step, spatial resolution, and periods of analysis. The result of model implementation was a functioning, but uncalibrated model.

5.1.3.1 Geometry

Reservoir and stream geometry were constructed using bathymetric and topographic surveys of the Project area. The resolution with which streams and reservoirs are best represented can vary depending on relative size of the reservoir (e.g., the volume of the reservoir) or the varying topographic features of the stream channel. A sensitivity analysis was performed to evaluate the effect of different spatial resolutions. Geometry for tunnel and tributary features was not explicitly represented in the models, but rather determined empirically or as boundary condition inflows to the system. Specific geometry details of reservoir and river models are outlined below.

Reservoirs

To model the geometry of each reservoir, bathymetric data and facility information (stage-volume relationships, intake structure configurations, elevations, locations of diversion structures, and return points) were required. Bathymetry maps were developed from digitized pre-dam topography. Facility information is provided in Table AQ 4-1.

Each reservoir was modeled in two dimensions using 1.0 m vertical layers that varied in width and length, depending on the reservoir morphology. The geometry for French Meadows Reservoir is illustrated from its plan, downstream, and profile views in Figure AQ 4-2 a-c, respectively. As a point of reference, the location of the turquoise element is identical in all views. Each segment in the plan view is 304.8 m long; the width varies with each cross-section. Similar information for Hell Hole Reservoir is presented in Figure AQ 4-3 a-c. Segments representing Hell Hole Reservoir were also 304.8 m long with varying widths. Ralston Afterbay was represented with 60.69 m-long segments due to its notably smaller size (Figure AQ 4-4 a-c). A summary of basic reservoir representation information, including the number of segments and layers in each reservoir, is provided in Table AQ 4-2.

Rivers

Geometric data required for each river reach included stream line work with channel elevation, habitat types, channel geometry data by habitat type (e.g., cross-section data), channel roughness, and channel slope.

Stream Line Work – Geographic Information System (GIS) based line work for the river reaches was digitized from orthophotos[1] and the bed elevation data were generated by overlaying the digital line graphs (DLG) onto georeferenced, digital raster graphics (DRGs) of U.S. Geological Survey (USGS) 7.5-minute quadrangle maps and digitizing the contour line intersections. Distance and river miles along the river line were calculated using ArcInfo GIS software.

The stream line work data were then used to develop the initial, one-dimensional numerical grid, which comprised a system of elements. Specifically, each of the river sub-reaches was divided into 50-meter (m) increments called elements. Each element consisted of three discrete points, termed nodes—an upstream, downstream, and mid-element node spaced at 25-m increments (Figure AQ 4-5).

[1]The orthophoto product was obtained from AirPhoto USA. The elevation of the plane was 12,000 feet. Photo scale was 1:2000 and the image was scanned at 2000 dpi, creating a 1 foot pixel. Photos were collected on 9/13 and 9/15, 2005 - 37 N-S flight lines / 11,700' of Gain on each flight line / 35 % forward overlap. Collection time was 10AM – 2PM.

Habitat Types – Once the grid was constructed, habitat types were defined for each element. The proportion of different habitat types in each model sub-reach (Table AQ 4-3) was set based on the proportion of each habitat type mapped in each of the sub-reaches, AQ 1 – TSR (PCWA 2010). Habitat types were categorized as pools, runs, low-gradient riffles (LGR), and high-gradient riffles (HGR).

Transitional elements existed when the end nodes of an element were assigned a different habitat type. Where this occurred, the model used linear interpolation to construct the transitional geometry (see geometry section below) between the different habitat types of the two nodes (Figure AQ 4-6).

Due to hydrodynamic model stability challenges that occurred while simulating low flows (e.g., <10 cfs) for the Middle Fork American River and Rubicon River above Ralston Afterbay, the habitat type elements were arranged in a specific pattern to limit the number of transitional elements, while preserving the proportion of habitat types that occurred in each sub-reach. For every 625 m model segment, the elements were arranged so that similar habitat types were grouped together. For example, all the pool, run, LGR, and HGR type elements were grouped together with a single transition between each habitat type group. At the top of the first 625 m segment, the order began with pool elements followed by run, LGR, and HGR elements. In the next 625 m segment the order was reversed (order went from HGR, LGR, runs, and finally pools). This ordering approach was maintained throughout each sub-reach. Through sensitivity testing, it was determined that the order of habitat types in the temperature model had no appreciable effect on the temperature results as long as the overall proportion of habitat types was maintained. Reordering, however, greatly improved hydrodynamic model stability.

Channel Geometry – Once elements were assigned habitat types, representative stage versus wetted width and stage versus wetted area relationships were applied to the elements (Appendix B). Habitat type specific relationships for each sub-reach were developed using the AQ – 1 TSR (PCWA 2010) hydraulic modeling. As multiple cross-sections were modeled in the AQ – 1 TSR for each habitat type, stage and wetted area relationships were averaged by habitat type. That is, each habitat type in each sub-reach was described by an average stage-wetted width curve and stage-wetted area curve (Figure B-1 a-b through Figure B-6 a-b).

The wetted width and wetted area curves were typically greater than zero at the stage of zero flow for pool habitat types (e.g., no flow in the channel, only standing water). The width/area below the stage of zero flow is considered dead pool volume; only pools had significant dead pool volumes. The amount of dead pool volume affected diurnal variations in temperature and was used as a calibration parameter in selected river reaches.

Habitat Type Channel Roughness and Slope – Specific roughness and slope factors were assigned to each element based on habitat type (Table AQ 4-4). These were initially set using approximate values from the AQ – 1 TSR hydraulic modeling. Subsequently, they were refined by calibration using empirical travel-time data available in each reach. Typically, because travel time data were only available between gages, the channel roughness and slope data were set using different sub-reaches than those used from the habitat mapping. For example, on the Rubicon River the channel roughness and slope was set for the reach from Hell Hole Reservoir to Ellicott Bridge and from Ellicott Bridge to Ralston Afterbay because gage and travel time data were available at the beginning and end of these two reaches.

5.1.3.2 Flow Data

Discharge for the river reaches and tunnels and reservoir elevation information for the reservoirs was obtained from the impaired and unimpaired Project hydrology (PCWA 2006b) and from alternative flow scenarios generated using the PCWA Operations Model. Node locations for the impaired hydrology, unimpaired hydrology, and Operations Model flow data are shown in Map AQ 4-3. Daily average flows were used in all of the bypass reaches for the hourly temperature model (i.e., daily average flows were input as hourly flows). In the peaking reach, hourly flows from the impaired hydrology/Operations Model were available for use in the hourly temperature model.

Impaired hydrology data for the years 2006 and 2007 were used for calibrating the temperature model (Section 5.1.4 Model Parameter Calibration). Unimpaired hydrology data that would have occurred during 2007 were used to model unimpaired stream temperatures (Section 5.4 Unimpaired Temperature Modeling). And, several alternative flow regimes were developed to test the sensitivity of stream temperatures to changes in discharge (Section 5.5 Alternative Flow Regime Temperature Analysis).

Reservoirs

Inflows and outflows for French Meadows Reservoir, Hell Hole Reservoir, and Ralston Afterbay CE-QUAL-W2 applications were provided by the impaired hydrology data set (2006b). The exception was the miscellaneous accretions and depletions for each reservoir, which were calculated based on simulated versus observed reservoir water surface elevations using a processor included in the CE-QUAL-W2 model (http://www.ce.pdx.edu/w2/). These were defined in the reservoir model as a distributed tributary (i.e., the accretions or depletions were distributed equally among all segments as opposed to a point source or sink). The inflows and outflows for each reservoir and the sources of data are provided in Table AQ 4-5.

The elevation at which inflows entered each reservoir was determined by the inflow density, which was a function of inflow temperature. Model simulations account for these inflow elevations (as well as inflow and outflow volume and momentum, reservoir geometry, current storage, and internal reservoir processes such as hydrodynamics and thermal dynamics) while accurately maintaining the thermal profile.

Rivers

A summary of the headwater and downstream boundary conditions, tributary inflows, and accretion inputs for each river reach represented in the model is provided in Table AQ 4-6. The impaired hydrology/Operations Model nodes and RMA-2 element numbers that correspond with the node locations are shown in Table AQ 4-6. In situations where the impaired hydrology/Operations Model combined inflows from two sources into a single node, the flow from each source was determined and the flow from one source was shifted downstream by one element in RMA-2 to clearly identify where all flows originated.

Five tributaries were included as inflow to the temperature models:

- Duncan Creek
- North Fork of the Middle Fork American River
- North Fork American River
- South Fork Rubicon River
- Long Canyon Creek

Flows from each of these tributaries were available as daily data; daily values were used in the hourly temperature model simulations (i.e., input as hourly flows) and they were each input to a single element location in the temperature model.

Accretion flows (average daily flow) were available at specific nodes (point sources) in the impaired flow/Operations Model data. In the temperature models, the accretions inflows were used both as point sources and/or distributed sources. The accretion inflows were considered groundwater or surface water and were either input at one location or distributed at multiple locations along the reach. The decision regarding how to handle accretions in individual river reaches was primarily determined during model calibration (Section 5.1.4 Model Parameter Calibration). Table AQ 4-6 shows how accretion was used as input to the temperature models in each river reach.

A special hydrology analysis was developed for the 2006 and 2007 impaired flow data in the stream reach from Middle Fork Interbay to Ralston Afterbay. The original impaired hydrology data did not accurately represent accretion due to imbalances in historical gage data. Accretion data from the reach above Middle Fork Interbay was scaled by watershed area to represent accretion in the reach below Middle Fork Interbay. The refined impaired hydrology improved the calibration results of the temperature model.

Tunnels

Tunnel flow data was obtained from the impaired hydrology/Operations Model. Four major tunnels in the MFP were included in the models:

- Duncan Creek – Middle Fork Tunnel
- French Meadows – Hell Hole Tunnel
- Hell Hole – Middle Fork Tunnel
- Middle Fork – Ralston Tunnel

Summary statistics and approximate travel times for the tunnels are provided in Table AQ 4-7. The Ralston – Oxbow tunnel was not included due to its short length and transit time.

5.1.3.3 Water Temperature Data

Water temperature data for MFP reach inflows, outflows, and facilities operations were required for RMA-11 modeling. Water temperature data were collected by PCWA as part of the MFP water temperature monitoring program for the river reaches and reservoirs (Map AQ 4-4, Map 4-5 a-c) (PCWA 2006a; PCWA 2007a and b). In addition, data from the United States Geological Survey (USGS) at the Auburn Dam site was used (http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=NFA). A summary of the water temperature data collected from 2005 through 2007 is provided in Appendix C. Water temperatures were monitored through the summer of 2008.

Reservoirs

Water temperature data required for reservoir modeling included boundary condition information for all inflows as well as in-reservoir vertical temperature profiles. Table AQ 4-8 identifies the source of temperature data for reservoir inflows and vertical temperature profiles. Vertical profile data (temperature data collected at multiple depths on a specific day and time) were available at monthly intervals for two locations in French Meadows Reservoir and Hell Hole Reservoir and one location in Ralston Afterbay (Maps AQ 4-5 a-c). These data were used to calibrate the reservoir models. Reservoir outflow temperatures were calculated using CE-QUAL-W2.

Rivers

Water temperature data from water temperature monitoring stations (Map AQ 4-4) were used for river boundary conditions located at each headwater and tributary (Table AQ 4-9). No temperature monitoring stations were directly available for accretions (groundwater, small tributaries, etc.). For these inputs, measured data from a nearby monitoring station was used or estimates of groundwater temperatures were used (Table AQ 4-9). In some cases the estimates of groundwater temperature were adjusted during model calibration.

Tunnels

Tunnel temperatures were determined empirically based the observed rate of heating (temperature change) between the tunnel intake and the tailrace. Data were available for two MFP tunnels: French Meadows – Hell Hole, and Middle Fork – Ralston. An examination of sub-daily time series of water temperatures during July–August 2008 at the upstream and downstream points of French Meadows – Hell Hole tunnel indicated that minor heating occurs in this tunnel system (Figure AQ 4-7). Although there was a fair amount of noise in the data, heating through this tunnel appeared to be on the order of approximately 0.25^{o}C. A similar data set for the Middle Fork – Ralston Tunnel suggested a heat gain of approximately 0.50^{o}C between the tunnel intake and the tailrace (Figure AQ 4-8). One challenge of interpreting these data is that these minor heating rates were near the resolution of the temperature loggers. Nonetheless, the data suggested a modest, but consistent rate of heat gain during the July–August period. Assuming all tunnel systems experienced similar thermal conditions through the simulation period, a linear relationship representing heat gain through the tunnel systems of 0.027^{o}C per kilometer of tunnel length was determined based on these data (Figure AQ 4-9). Because the Duncan Creek – Middle Fork Tunnel is considerably shorter than the other tunnels and minimal diversions occurred during the primary modeling period (June through September), heating was assumed to be negligible (i.e., temperatures in Duncan Creek were applied directly to any diversions into French Meadows Reservoir). During model simulations, boundary conditions for water entering each reservoir outflow tunnel were determined using temperature data from the bottom of the reservoir where the tunnel intake was located.

5.1.3.4 Meteorological Data

Meteorological data, including air temperature, wet bulb temperature (or dew point temperature), solar radiation, cloud cover, wind speed, and barometric pressure were required for heat budget calculations within the numerical models. Meteorological conditions were assigned to each element. Several meteorological stations are located throughout the MFP in various settings (e.g., adjacent to river reaches, atop ridges). These meteorological station data sets were evaluated to ascertain how individual locations represented local river and reservoir reaches. Some parameters, such as solar radiation and atmospheric pressure either did not vary significantly or could readily be calculated based on elevation within the MFP. Other parameters, including air temperature, vapor pressure terms (dew point, wet bulb), and wind, varied spatially throughout the modeling domain. This would be expected due to the large range of elevations and varying topography in the project area (Linacre 1992). Based on the findings from these preliminary analyses, and in collaboration with the WTMG, meteorological data from six full and partial meteorological stations were used. Data from each meteorological station were applied as appropriate to each element within the reaches to capture the meteorological spatial variability over the Project area (Table AQ 4-10). Meteorological stations were selected based on their proximity to the reservoir or river reach being modeled. Data from a nearby meteorological station were used to “fill in” for the reaches where a partial data record was available at the primary meteorological station. The locations of the meteorological stations are shown on Map AQ 4-4. A summary of the meteorological data collected from approximately 2005 through 2008 is provided in Appendix D.

5.1.3.5 Flow Travel Time

Flow travel time information in the river modeling reaches (Middle Fork American River above Ralston Afterbay, Rubicon River, and Peaking Reach) was needed to help calibrate the RMA-2 hydrodynamic model.

Middle Fork American River above Ralston Afterbay and Rubicon River Bypass Reaches

Travel times for the Middle Fork American River reach (French Meadows Reservoir – Ralston Afterbay, Middle Fork Interbay – Ralston Afterbay) and Rubicon River were calculated using empirical gage data from various flow releases. The time the release was made was subtracted from the time the pulse passed selected gage locations along each reach to empirically determine travel time. Table AQ 4-11 shows a summary of these travel times.

Middle Fork American River Peaking Reach

The travel time for the Middle Fork American River peaking reach was calculated using pressure transducers installed at select locations throughout the reach (PCWA 2010). The calculations were made by subtracting the release time of the pulse from the times the pulse passed the different pressure transducer locations. The locations of the pressure transducers are shown in Map AQ 4-6. The approximate peaking flow travel times for the peaking reach are provided in Table AQ 4-12. Actual pressure transducer data were used to calibrate the model.

5.1.3.6 Initial Conditions

Initial conditions are required for most modeling simulations (initial state of the system from which the model progresses). In some situations, such initial conditions are not available or are insufficient to define spatially all conditions throughout the modeling domain. In these instances the model is generally started with a “representative” set of initial conditions. The model is applied for a sufficient period of time prior to the desired analysis period to ensure that the assumed initial condition does not affect model results. This is often termed the “spin-up” period.

In all three reservoirs (i.e., French Meadows, Hell Hole, and Ralston Afterbay), flow and water temperature initial conditions (inflow, outflow, and initial storage) were specified to initiate the reservoir simulations in the absence of measured data. Isothermal initial water temperature data were estimated. To ensure that the reservoir models had achieved accurate thermal profiles, several weeks or months of simulation were completed. During this spin-up period, significant processes such as stratification onset and the effect of meteorological loading prior to the study period are incorporated. Simulations of the isothermal conditions in French Meadows and Hell Hole reservoirs were started on January 1 to develop stratified thermal characteristics prior to the simulated time period of interest (June 1 to September 30). Various January 1 initial condition temperatures were initially evaluated, but the model was insensitive to these variations. For Ralston Afterbay, it was not necessary to assume isothermal initial conditions on January 1 due to its short residence times, and the model was started on May 1.

For the river reach simulations, initial depth and global constant initial water temperature were assumed. Simulations were started several weeks prior to the analysis period to allow the model to achieve depths and water temperatures free from effects of initial conditions.

5.1.4. Model Parameter Calibration

Following model implementation and general model testing, the reservoir and river model parameters were adjusted (calibrated) using the June through September 2006 and 2007 empirical flow and water temperature data. The calibration period was determined in collaboration with the WTMG.

Both reservoir and river models were calibrated for flow and temperature by adjusting a number of default values assigned to model parameters in the implementation stage. For the reservoir simulations, flow accuracy was evaluated by comparing observed and simulated reservoir elevations. Temperature accuracy was evaluated by comparing observed and simulated vertical temperature profile data. Model performance was principally assessed based on representation of hypolimnion temperatures, location of the thermocline, and thermal stratification evolution. For river simulations, flow accuracy was evaluated by comparing observed to simulated travel times. Temperature accuracy was evaluated by comparing modeled and measured hourly temperature time series at multiple locations along the river reach.

5.1.4.1 Flow Calibration Parameters

Reservoirs

Calibration of reservoir flow (hydrodynamic) typically includes adjusting one of several parameter values: Manning's *n*, eddy viscosity, and eddy diffusivity. Default parameter values were used for the reservoir modeling (Table AQ 4-13) (Cole and Wells 2003) because reservoir temperature calibration was insensitive to the parameter values and because reservoir flow is largely a function of the accuracy of the reservoir geometry (bathymetry) and the inflows and outflows specified by the impaired hydrology/Operations Model. The principal metric used to test reservoir model hydrodynamics calibration was stage. Stage results for French Meadows Reservoir, Hell Hole Reservoir, and the Ralston Afterbay (Figures AQ 4-10 to 4-15) illustrate that the models effectively represented flow conditions.

Rivers

Calibration of the RMA-2 river flow models included adjusting the element slope factor and Manning's *n* values (Table AQ 4-14) so the modeled hydrology matched observed river travel times in the bypass reaches and in the peaking reach (Section 5.1.3.1, Tables AQ 4-11 and AQ 4-12). Visual comparison of measured and modeled travel times in the peaking reach are shown in Figures AQ 4-16 through AQ 4-20. These results indicate that the model performed well for flow simulations.

Calibrated roughness and slope factors (Table AQ 4-14) varied depending on habitat type. Roughness values in these steep, mountain reaches were higher than identified in some typical hydrology literature (Chaudry 1993; Chow 1959), but consistent with

Jarrett (1984) who identified a wide range of roughness values for high gradient streams.

5.1.4.2 Water Temperature Calibration Parameters

Reservoirs

There were several parameters used for reservoir water temperature model calibration, including evaporation coefficients "***a***" and "***b***", bed heat transfer coefficient and bed temperature, and wind sheltering in space and time (Table AQ 4-15). A single parameter value was used for all the parameters except the wind sheltering factor, which varied by reservoir surface elevation, time, and water transparency. A review of model results indicated that slightly higher water transparency values (compared to French Meadows Reservoir) improved results for Hell Hole Reservoir. The open environment and more gently sloping shorelines of French Meadows Reservoir may allow shoreline sediments to readily become suspended from wind waves, versus the steep, granite slopes surrounding Hell Hole Reservoir.

A range of wind sheltering coefficient values was calibrated because the reservoir water surface wind speeds can be different from those recorded at the meteorological station, which were located at different elevations than the corresponding reservoir. Wind sheltering factors were identified for each segment in each reservoir over specified time periods to reflect seasonal variations, consistent with Cole and Wells (2003) (Table AQ 4-16 to Table AQ 4-18). The model interpolated the value of the wind sheltering coefficient during time steps in between the dates for which values were specified.

Observed water temperature data from two of the monitoring stations in French Meadows Reservoir (FM1 and FM2) were used for calibration (Map AQ 4-5a). Observed data from one location each in Hell Hole Reservoir and the Ralston Afterbay were used for calibration (Maps AQ 4-5b and AQ 4-5c). In Hell Hole Reservoir, data from one additional location (HH2) was calibrated for one day (May 30, 2007). The calibration dates for each reservoir occurred between May and October in 2006 and 2007 (Table AQ 4-19).

Rivers

The RMA-11 water temperature model was calibrated by adjusting parameters for each river reach including wind speed coefficients (King 2003; Deas and Lowney 2000), topographic shading, dead pool area, topographic emissivity and terrestrial long-wave radiation contribution fraction (Bartholow 1989), bed temperature, and bed heat exchange coefficient (Hauser and Schohl 2003; Meier et al. 2003) (Table AQ 4-20). The monitoring locations where observed data were used to calibrate the model for each reach are listed in Table AQ 4-9 and shown on Map AQ 4-4.

5.2. MODEL CALIBRATION ASSESSMENT

Model calibration results were presented in two ways: graphically and statistically. For reservoirs, simulated monthly vertical thermal profiles were graphically compared with measured data at multiple depths. Statistical assessment included calculation of mean absolute error (MAE, mean of the absolute value of the error [bias]) and root mean squared error (RMSE, square root of the mean squared errors [bias]) (Maidment 1993):

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Xsim_i - Xmeas_i)^2}{n}},$$

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}\left|Xsim_i - Xmeas_i\right|$$

where: Xsim = simulated temperature, Xmeas = measured temperature, and n = number of temperature values.

For rivers, data were similarly assessed both graphically and statistically. The hourly time series data at each location were graphically examined for both the entire summer/early fall (June through September) analysis period as well as shorter time periods. The first three weeks of August was presented graphically to provide a more detailed performance assessment. Statistics were completed for hourly, daily mean, and daily maximum temperatures. Summary statistics were MAE, RMSE and Mean Bias (average simulated minus observed):

$$\text{Mean Bias} = \frac{1}{n}\sum_{i=1}^{n}\left(Xsim_i - Xmeas_i\right)$$

Mean bias was used to indicate the amount the models, on average, over or underestimated temperature. Equal overestimation and underestimation of temperature in a time series, however, could result in a Mean Bias of zero. MAE and RMSE quantify the absolute error (negative and positive errors do not cancel each other in these estimators as in the Mean Bias). Both MAE and RMSE indicate the magnitude of the average error, however, RMSE is more sensitive to outliers in the data than the MAE because the errors are squared and summed (large errors become larger) prior taking the square root. The two error estimates can be used together to diagnose the variation in the errors in a set of simulations. The RMSE will always be larger or equal to the MAE. The greater difference between them, the greater the variance in the individual errors in the sample. If RMSE is approximately equal to MAE, then all the errors are of the same magnitude (low variance).

Reservoir results were also provided in electronic form to the WTMG along with Animation and Graphics Portfolio Manager (AGPM) software. AGPM is post-processing software that graphically displays CE-QUAL-W2 results as well as those of other two-dimensional models. With AGPM the user can explore simulation results using a variety of tools (http://www.loginetics.com/).

The U.S. Army Corps of Engineers' Hydrologic Engineering Center Data Storage System (HEC-DSS) was used to store river modeling results from the entire calibration time period. The HEC-DSS database and associated HEC-DSSVue program are designed to efficiently store and view time series data (http://www.hec.usace.army.mil/software/) (ACOE 2006). These river results were provided to the WTMG for review and are available in .dss format upon request.

5.3. MODEL SENSITIVITY ANALYSIS

A range of values for model parameters was investigated during the calibration process, which provided information on the sensitivity of the temperature models to each parameter. Sensitivity indicates how responsive the models are to changes in a parameter value. A quantitative sensitivity analysis was not conducted, rather a qualitative assessment was completed, wherein assessment of sensitivity was based on findings during model calibration. The parameters that were investigated on the reservoirs and rivers are listed in Table AQ 4-21. These included upstream water temperature boundary conditions, distributed tributary inflow temperatures into the reservoirs, accretion/depletion temperatures in the rivers, various meteorological parameters, evaporative heat flux coefficients for the reservoirs and rivers, bed heat conduction for the reservoirs and rivers, topographic shading, wind sheltering on the reservoirs, terrestrial radiation, and channel width and dead pool area.

5.4. UNIMPAIRED TEMPERATURE MODELING

A simulation of "unimpaired" river temperature in the MFP bypass and peaking reaches was developed for 2007. Unimpaired 2007 hydrology (PCWA 2006b) was used as input to the calibrated temperature models. All facilities were "removed" from the temperature models in the sense that no reservoirs or diversions/tunnels or Project operations were included in the modeling. All tributary and accretion inflows and temperatures were the same as those in the 2007 calibrated temperature model. Similarly, 2007 meteorological data were assumed for the unimpaired simulation to provide a common basis for comparison of impaired versus unimpaired results.

The river models began downstream of French Meadows and Hell Hole reservoirs; no attempt was made to model the unimpaired rivers upstream within the existing footprint of the two reservoirs. However, in the downstream river where Ralston Afterbay exists, river geometry in the Ralston Afterbay footprint was developed from detailed bathymetric data and used to replace the reservoir representation.

The water temperature of inflows into French Meadows and Hell Hole reservoirs (measured in 2007) was used for input (boundary conditions) to the river temperature models. Because the river models start below the reservoirs, the boundary water temperatures are likely cooler than would actually be expected under unimpaired conditions. That is, some warming of the water would occur in the unimpaired channel between the top of the existing reservoirs and the beginning of the river temperature models. In this sense, the modeling represents a conservative assessment of expected warming of the river reaches under unimpaired conditions. Actual unimpaired temperatures in downstream reaches would probably be warmer than the modeled unimpaired temperatures.

The river temperature models routed the unimpaired hydrology and simulated water temperature from one model reach to the next (upstream to downstream) to predict unimpaired water temperature throughout the MFP culminating in river water temperature predictions at the bottom of the system (Folsom Reservoir). An example temperature map for August 2007 average unimpaired temperatures was developed to compare with measured impaired August 2007 average temperatures. In addition, longitudinal comparison plots of August 1, 2007 daily average, minimum, and maximum temperature for unimpaired and impaired conditions. Hourly unimpaired temperature results for each river reach are available as an hourly time series is DSS database format upon request.

5.5. Alternative Flow Regime Temperature Analysis

To help understand the effects of river discharge on water temperature in the bypass reaches and in the peaking reach, a series of alternative flows was run through the 2007 calibrated river temperature models. The existing 2007 flow and temperature model results were compared to decreasing and increasing increments of flow for the same 2007 time period (i.e., 2007 meteorological conditions). Table AQ 4-22 shows the original and alternative flow regime hydrology runs for each of the river reaches. In the bypass reaches, the alternative flow regime runs include: (1) subtracting and adding fixed increments of flow to the 2007 hydrology; and (2) adding a pulse flow in early spring. In the peaking reach the alternative hydrology runs include increasing the minimum flow (reducing flow fluctuations from daily peaking) and running the 2-day average flow.

Comparison plots of water temperature for existing conditions (2007) versus the alternative discharges were developed. Longitudinal plots of maximum daily and average daily temperature were generated for the second week of May and for the first week of June, July and August to compare flow versus water temperature effects within each reach. Time series plots were also developed for specific locations along each river reach (May through September).

5.6. Empirical Water Temperature Characterization in Small Stream Bypass Reaches

In the small Project bypass streams (Duncan Creek, North Fork Long Canyon Creek, South Fork Long Canyon Creek, and Long Canyon Creek), existing water temperature and meteorological data were used to develop regression relationships between air and water temperature both upstream and downstream of the diversions. Specifically, measured average, minimum, and maximum daily summer (June through September) water temperatures were related to average, minimum, and maximum daily air temperatures recorded at a meteorological monitoring station located in the general vicinity of each stream. The water temperature monitoring station locations and the corresponding meteorological station location are listed in Table AQ 4-23 and shown on

Map AQ 4-4. All years with available summer data for both data sets were included in the analyses. Typically, the water and air temperatures were recorded on a sub-daily time step (15 minute to hourly). For streams with a considerable spring water contribution, preliminary analyses indicated a poor relationship between stream water and air temperatures. For these locations, impaired hydrology discharge was also included in the analysis. The types of analyses conducted for each stream are also indicated on Table AQ 4-23. The water and air temperature data are provided in Appendices C and D.

5.7. COLD WATER THERMAL REFUGIA ASSESSMENT IN BYPASS REACHES

A review of the empirical temperature data collected as part of PCWA's temperature monitoring program (Appendix C) indicated that the highest summer temperatures in the MFP (i.e., temperatures that exceed thresholds for coldwater fish) occurred in the lower portion of the Rubicon River. Therefore, it was determined that the greatest likelihood for observing whether cold water refugia in the form of tributary inflows/deep water pools occur within the MFP would be in this reach of river. Long Canyon Creek and Pilot Creek were identified as tributaries with potential cold water inflow.

Two deep pools upstream and two deep pools downstream of Long Canyon Creek (RM 3.5) and Pilot Creek (RM 5.2) were identified and temperatures were measured on August 8, 2008. Temperature was monitored/measured in the tributaries and near the surface/bottom of the upstream/downstream pools at the point of maximum pool depth using a handheld YSI water quality probe. Snorkeling was used to put the probe on the channel bottom and in the water near the surface of the pools. In addition, in two pools immediately upstream and downstream of Pilot Creek, continuous monitoring temperature sensors (Onset Tidbits) were installed on the channel bottom and near the surface of the pools. Stream temperature was monitored through the day and the temperature in the tributaries and near the surface/bottom of the pools was recorded in late afternoon when the water temperature was approximately at the daily maximum.

6.0 RESULTS

6.1. MODEL CALIBRATION ASSESSMENT

This section presents the results of the reservoir and river water temperature model calibration assessment for the 2006 and 2007 summer/early fall time period (Appendices E and F).

6.1.1. Reservoirs

The French Meadows and Hell Hole reservoir models performed well with respect to modeling vertical water temperature profiles at the empirical data collection sites (Tables E-1 and E-2 and Figures E-1 through E-25). Graphical results of modeled and measured temperature profiles indicate that thermal stratification as well as epilimnion and hypolimnion temperatures were effectively represented throughout the simulation period.

Statistical results for French Meadows Reservoir show that the average amount of error was ≤1.08°C (range 0.27 to 1.08°C) and ≤1.67°C (range 0.35 to 1.67°C) for MAE and RMSE, respectively. The results for Hell Hole Reservoir were similar. Average amount of error was ≤1.53°C (range 0.16 to 1.53°C) and ≤1.95°C (range 0.23 to 1.95°C) for MAE and RMSE, respectively.

The Ralston Afterbay reservoir model performed well, but modeled reservoir surface water temperatures were cooler than observed surface water temperatures for some time periods (e.g., June and early July 2007) (Figures E-26 to E-33). The average amount of error was ≤1.77°C (range 0.16 to 1.77°C) and ≤2.75°C (range 0.22 to 2.75°C) for MAE and RMSE, respectively (Table E-3). Modeled reservoir surface water temperatures in June and July 2007 were responsible for higher MAE and RMSE statistics compared to the larger upstream reservoirs (Table E-3). In Ralston Afterbay, surface temperature profiles are sensitive to the timing of daily inflows from Ralston Powerhouse. Some of the error could be a result of differential timing between measured and modeled profiles.

6.1.2. Rivers

The river models generally simulated both hourly and daily summer water temperature accurately (June 1 and September 30 analysis period). Typically, daily temperature simulations were slightly more accurate than hourly water temperature simulations. The individual reaches are discussed below with respect to mean daily and maximum daily temperature. Overall, for the four model reaches, which included 24 individual temperature monitoring locations used to test model calibration, the Mean Bias for simulated average daily temperature was less than ±1.0°C and model errors, MAE and RMSE, were less than or equal to 1.14°C and 1.36°C, respectively. For maximum daily temperature the Mean Bias was ±1.4°C and the model errors, MAE and RMSE, were less than or equal to 1.38°C and 1.61°C, respectively.

Each of the bypass reach models (French Meadows Reservoir – Middle Fork Interbay, Middle Fork Interbay – Ralston Afterbay, and Hell Hole Reservoir – Ralston Afterbay) simulated the magnitude and timing of the maximum daily temperature (magnitude and timing) accurately. The peaking reach model (Ralston Afterbay – Folsom Reservoir) simulated magnitude of mean and maximum daily temperature accurately, but the daily temperature cycle timing was out of phase with the measured daily temperature cycle in 2007 (see below).

6.1.2.1 Middle Fork American River – French Meadows Reservoir to Middle Fork Interbay

Simulated average daily water temperature average mean bias was 0.12°C (range -0.67 to 0.76°C), with errors less than 0.76°C and 0.97°C for MAE and RMSE, respectively (Table F-1). Simulated maximum daily water temperature exhibited an average mean bias of 0.72°C (range -0.06 to 1.38°C) and errors less than 1.38°C and 1.61°C for MAE and RMSE, respectively. The maximum measured daily temperature in 2006/2007 23°C at the most downstream study site, MF36.1. Modeled July/August maximum daily temperatures were similar to measured in 2006 and typically 1–2^{o}C greater than measured in 2007. The model diel variation was typically 3–4^{o}C and there was approximately 1–2^{o}C greater variation in the simulated compared to the observed variation. Simulated and observed hourly water temperatures are compared by location in Figures F-1 through F-8.

6.1.2.2 Middle Fork American River – Middle Fork Interbay to Ralston Afterbay

Simulated average daily water temperature average mean bias was -0.34^{o}C (range -0.7 to 0.23^{o}C), with errors less than 0.77^{o}C and 0.89^{o}C for MAE and RMSE, respectively (Table F-2). Simulated maximum daily water temperature exhibited an average mean bias of -0.15^{o}C (range -1.28 to 1.23^{o}C) and errors less than 1.28^{o}C and 1.36^{o}C for MAE and RMSE, respectively. The maximum measured daily temperature in 2006/2007 was 22.6^{o}C at the most downstream study site, MF26.0. Modeled July/August maximum daily temperatures were slightly lower or higher (1–3 ^{o}C in some cases) than measured, depending on the location. The model diel variation was typically 1.5–4^{o}C and, depending on location, slightly less or greater than the observed (greatest difference about 2.5^{o}C). Simulated and observed hourly water temperatures are compared by location in Figures F-9 through F14.

6.1.2.3 Rubicon River – Hell Hole Reservoir to Ralston Afterbay

Simulated average daily water temperature average mean bias was -0.02^{o}C (range -0.52 to 0.31^{o}C), with errors less than 0.67^{o}C and 0.90^{o}C for MAE and RMSE, respectively (Table F-3). Simulated maximum daily water temperature exhibited an average mean bias of 0.21^{o}C (range -1.17 to 0.74^{o}C) and errors less than 1.35^{o}C and 1.33^{o}C for MAE and RMSE, respectively. The maximum measured daily temperature in 2006/2007 was 26.74^{o}C at the most downstream study site, RR0.7. Modeled July/August maximum daily temperatures were slightly lower or higher (1–2^{o}C in some cases), depending on the location, than observed. The model diel variation was typically 2–5^{o}C and, depending on location, slightly less or greater than the simulated (greatest difference about 2.5^{o}C). Simulated and observed hourly water temperatures are compared by location in Figures F-15 through F30.

6.1.2.4 Middle Fork American River – Ralston Afterbay to Folsom Reservoir

Simulated average daily water temperature average mean bias was -0.09^{o}C (range -0.97 to 0.46^{o}C), with errors less than 1.14^{o}C and 1.30^{o}C for MAE and RMSE, respectively (Table F-4). Simulated maximum daily water temperature exhibited an average mean bias of -0.13^{o}C (range -0.97 to 0.78^{o}C) and errors less than 1.23^{o}C and 1.49^{o}C for MAE and RMSE, respectively. The maximum measured daily temperature in 2006 and 2007 was 22.7^{o}C at the most downstream study site, NF14.3. Modeled July/August maximum daily temperatures were slightly lower or higher than observed (1.5–3^{o}C in some cases), depending on the location. The model diel variation was typically 1–4^{o}C and, depending on location, slightly less or greater than the simulated (greatest difference about 2.5^{o}C). Simulated and observed hourly water temperatures are compared by location in Figures F-31 through F-50.

In the Ralston Afterbay to Folsom Reservoir reach of the Middle/North Fork American River the timing of the daily maximum/minimum temperature signal was accurate in 2006, but there were locations where the simulated thermal signal deviated notably in phase from the field observations in 2007. Between MF14.3 and MF8.9, simulated river temperatures were out of phase, but overall mean daily temperatures were preserved. The peaking pattern was markedly different in 2007 than in 2006, when more water was present in the system (Figures F-33 and F-34). In 2006, peaking generally ranged between approximately 700 and 1000 cfs throughout the summer; in 2007, it ranged between approximately 200 cfs and 1000 cfs for the same period. It is possible that, complicated processes not included in the temperature model, but related to peaking, such as inundation of bars that have warm substrate from solar radiation and/or hyporheic water exchange (Sawyer et al. 2009; Neilson et al. 2009) may be a factor affecting the accuracy of the temperature phase predictions.

6.2. MODEL SENSITIVITY ANALYSIS

Overall, only a few model parameters (Table AQ 4-21) were highly sensitive. For reservoirs, the flow parameters were insensitive and several of the temperature model parameters (evaporative heat flux coefficients, wind sheltering and solar radiation extinction terms) were the most sensitive (Table AQ 4-24). For rivers, flow hydrodynamics were sensitive to channel roughness and slope and no single parameter of the temperature models was highly sensitive; simulated temperatures were moderately sensitive to several parameters (evaporation coefficients, shade, bed temperature, bed heat exchange coefficient) (Table AQ 4-25).

6.3. UNIMPAIRED TEMPERATURE MODELING

Temperature modeling of unimpaired hydrological conditions indicate that summer water temperature in the Project bypass and peaking reaches is warmer for unimpaired conditions than for impaired conditions (Maps 4-7, 4-8, and 4-9; Appendix G; Figures G-1 through G-8). The overall pattern for existing conditions (impaired) was that cold water releases originating from French Meadows and Hell Hole reservoirs (including the tunnels and powerhouses) provided cooler water conditions throughout the bypass and peaking reaches during the summer than would occur for the modeled unimpaired conditions (e.g., see temperatures below French Meadows and Hell Hole reservoirs, Middle Fork Interbay, and Ralston Afterbay). For example, under unimpaired conditions, average August temperature less than 18^{o}C (65^{o}F) would have existed only in the upper portion of the Project area near the two large reservoirs, whereas, with impaired conditions, temperature less than about 18^{o}C (65^{o}F) exists throughout much of the Project area (Maps 4-8 and 4-9).

In addition to the overall cooler water temperature pattern with impaired condition, two sub-patterns are apparent in the impaired and unimpaired temperature data set comparison. In the bypass river reaches immediately downstream of the large reservoirs (French Meadows to Middle Fork Interbay and Hell Hole to Ralston Afterbay), impaired cool water conditions exist at the top of the reaches, but then warm relatively rapidly to an equilibrium temperature near the bottom of the reach that is very similar to unimpaired temperature at the bottom of the reach (Figures G-1, G-2, G-5, and G-6). In the farthest downstream Project river reaches (below Middle Fork Interbay and below Ralston Afterbay), however, the temperature pattern is different. Cooler water temperatures exist both at the top and bottom of these reaches for impaired conditions compared to unimpaired conditions (Figures G-3, G-4, G-7, and G-8).

6.4. ALTERNATIVE FLOW REGIME TEMPERATURE ANALYSIS

The 2007 alternative minimum flow regime temperature analysis results indicate that an increase in discharge in the bypass river reaches would cause a decrease in water temperature (Table AQ 4-22, Appendix H). The greatest effect between flow increments occurs at the lower discharges. At higher discharges the incremental decrease in temperature becomes smaller. For example, there is often approximately 2°C (3.8°F) or more mean daily difference between the two lowest flow increments, but only a very small (<1°C) difference between the two highest flow increments. The longitudinal plots of temperature with increasing increments of discharge in Appendix H can be used to identify how modifications to discharge would extend or contract the length of particular temperature regime. The time series plots at different locations (Appendix H) provide a seasonal view of changes in temperature with different flows. The largest difference in temperature occurs in the summer, smaller differences occur in the spring and fall.

Pulse flow temperature sensitivity tests show that in late April/early May in the lower portion of the Rubicon River (e.g., R3.7) and lower portion of the Middle Fork American River below Interbay (e.g., MF26) (Figures H-27 and H-16, respectively) pulse flows decrease water temperature below a typical foothill yellow-legged frog breeding threshold of approximately 12°C (54°F). After the pulse begins to recede, water temperature quickly increases above the breeding threshold. The pulse flows decrease temperature by about 4°C (7.2°F) during this time period.

6.5. EMPIRICAL WATER TEMPERATURE CHARACTERIZATION IN SMALL STREAM BYPASS REACHES

Relationships were developed between summer stream water and air temperatures for Duncan Creek, Long Canyon Creek, North Fork Long Canyon Creek, and South Fork Long Canyon Creek upstream and downstream from the diversions (Appendix I). In general, average daily stream water temperatures were fairly well-correlated with average daily air temperatures (r-squared values were typically greater than 0.70) (Table AQ 4-26). The relationships for minimum daily and maximum daily water versus air temperature were typically a little weaker (r-squared values between 0.5 and 0.8). The relationships between average, minimum, and maximum daily stream water and air temperatures for each stream are shown in Appendix I (Figures I-1 to I-5). The specific periods of record from which the relationships were developed for each stream are provided in Table AQ 4-25.

Stream water temperatures were only moderately correlated with air temperatures on Duncan Creek (explaining less than 50% of the variability in the data at DC8.8 and

DC8.4). The relationship was a little stronger near the confluence at DC0.1. Along Duncan Creek, springs are common. Spring inflows are cooler than the stream water temperatures. To account for this additional input, a second analysis was conducted that included Duncan Creek stream flow, stream water temperature, and air temperature. The correlation was substantially improved at DC8.4 when stream flow was included, but was only slightly better at DC8.8 upstream of the diversion and at DC0.1 near the confluence with the Middle Fork American River (Table AQ 4-26). The relationships between average, minimum, and maximum daily stream water and air temperatures for Duncan Creek are shown in Appendix I (Figure I-4) and with stream flow included are shown in Appendix I (Figures I-5).

6.6. Cold Water Thermal Refugia Assessment in Bypass Reaches

A very limited amount of temperature stratification was observed in the pools that were selected for testing (Table 4-27, Figure AQ 4-21). The greatest stratification was observed immediately downstream of Pilot Creek. Temperatures measured within Pilot Creek were generally 2–7^{o}C (4–13^{o}F) colder than temperatures in the Rubicon River. In the first pool immediately downstream of the confluence, water temperature near the surface of the pool was generally 1.2^{o}C (2^{o}F) warmer than the temperature near the bottom of the pool (Figure AQ 4-21). The maximum difference in temperature was 1.4^{o}C (2.4^{o}F) and occurred at approximately 3:30 PM. At the other pools above or below Pilot Creek very little stratification occurred.

In the Rubicon River near Long Canyon Creek, no temperature stratification was observed in the pools above or below the confluence. Water temperature in Long Canyon Creek was similar to that measured in the Rubicon River.

Overall, it appears that limited thermal refugia exists in the warmer sections of the Project bypass reaches (e.g., lower Rubicon River). There appears to be limited stratification of pools and few cold water tributaries/groundwater inflows appear to exist. In addition, the tributaries present have barriers near their confluences with the bypass streams (PCWA 2009); therefore, temperature refugia in the tributaries is limited.

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TABLES

Table AQ 4-1. Project Facility Specifications.

DUNCAN CREEK DIVERSION	
DAM	
Material	Concrete
Height of Dam Crest above Streambed	32 ft
Dam Crest Length	165 ft
Elevation of Dam Crest	5,275 ft
Elevation of Streambed	5,243 ft
Elevation of Spillway Crest	5,265 ft
RESERVOIR	
Gross Storage	20 ac-ft
DUNCAN CREEK – MIDDLE FORK TUNNEL	
Length:	
Total	7,864 ft or 1.5 miles
Concrete Lined (Est.)	300 ft
Maximum Discharge	400 cfs
FRENCH MEADOWS DAM (LL ANDERSON DAM) AND FRENCH MEADOWS RESERVOIR	
DAM	
Material	Rock and Gravel Fill
Height of Dam Crest above Streambed	231 ft
Dam Crest Length	2,700 ft
Dam Crest Width	32 ft
Elevation of Dam Crest	5,273 ft
Elevation of Streambed	5,040 ft
Elevation of Spillway Crest	5,244.5 ft
SPILLWAY	
Type	Gated Ogee Crest
Type of Gates	Radial
Number of Gates	2
Size of Gates	20 ft x 18.5 ft
Capacity (Res. Water Surface 5271.0, 2' freeboard)	39,957 cfs
RESERVOIR	
Maximum Operating Water Surface	5,262.0 ft
Minimum Operating Water Surface	5,125 ft
Gross Storage	134,993 ac-ft
Dead Storage (as constructed), at Tunnel Intake lip	7,635 ac-ft
Active Storage (as constructed)	127,358 ac-ft
Area at Maximum Operating Water Surface	1,408 acres
Area at Minimum Operating Water Surface	434 acres
Depth at Minimum Operating Water Surface	77 ft
Shoreline at Maximum Operating Water Surface	9 miles
Low Level Outlet	
Elevation	5056 ft at centerline
Size	60 in
Shape	round
Capacity	1,430 cfs
Stream Maintenance Pipe	
Elevation	5068 ft at shelf
Size	8 in
Shape	round
Capacity	8 cfs

Table AQ 4-1. Project Facility Specifications (continued).

FRENCH MEADOWS — HELL HOLE TUNNEL	
Inlet Elevation	5117 ft at surface
Size	12 ft 4 in
Shape	Horseshoe
Length	
Total	13,694 ft or 2.6 miles
Concrete Lined (Est.)	1,617 ft
Steel Lined (Est.)	317 ft
Maximum Discharge	400 cfs[1]
HELL HOLE DAM AND RESERVOIR	
DAM	
Material	Rockfill
Height of Dam Crest above Streambed	410 ft
Dam Crest Length	1,570 ft
Dam Crest Width	35 ft
Elevation of Dam Crest	4,650 ft
Elevation of Streambed	4,240 ft
SPILLWAY	
Type	Uncontrolled
Elevation of Spillway Crest	4,630 ft
Width at Lip	350 ft
Capacity (Water Surface 4647.1, 2.8' freeboard)	89,500 cfs
RESERVOIR	
Maximum Operating Water Surface	4,630 ft
Minimum Operating Water Surface	4,340 ft
Gross Storage	207,590 ac-ft
Dead Storage (as constructed), at Tunnel Intake lip	2,533 ac-ft
Active Storage (as constructed)	205,057 ac-ft
Area at Maximum Operating Water Surface	1,253 acres
Area at Minimum Operating Water Surface	185 acres
Depth at Minimum Operating Water Surface	88 ft
Shoreline at Maximum Operating Water Surface	11 miles
Low Level Outlet	
Elevation	4288 ft at shelf
Size	48 in
Shape	round
Capacity	852 cfs
Stream Maintenance Pipe	
Elevation	4288 ft at shelf
Size	16 in
Shape	round
Capacity	20 cfs
HELL HOLE — MIDDLE FORK TUNNEL	
Inlet Elevation	4321.9 ft at surface
Size	13 ft 5 in
Shape	Horseshoe
Length	
Total	55,006 ft or 10.4 miles
Concrete Lined (Est.)	6,780 ft
Steel Lined (Est.)	5,180 ft
Maximum Discharge	920 cfs

Table AQ 4-1. Project Facility Specifications (continued).

MIDDLE FORK INTERBAY	
DAM	
Material	Concrete
Height of Dam Crest above Streambed	70.5 ft
Dam Crest Length	233 ft
Elevation of Dam Crest	2,536 ft
Elevation of Streambed	2,465 ft
SPILLWAY	
Type	Gated Ogee Crest
Capacity (Water Surface 2534)	36,506 cfs
Width of Spillway	80 ft Gated, 60 ft Un-controlled
Number of Gates	4
Type of Gates	Radial
Size of Gates	20 ft x 20 ft
Elevation of Top of Gates	2,530 ft
Elevation of Sill of Gates	2,510 ft
IMPOUNDMENT	
Maximum Operating Water Surface	2,529 ft
Minimum Operating Water Surface	2,502 ft
Normal Operating Water Surface	2,527 ft
Gross Storage	175 ac-ft
Dead Storage (as constructed), at Tunnel Intake lip	2 ac-ft
Active Storage (as constructed)	173 ac-ft
Area at Maximum Operating Water Surface	7 acres
Area at Minimum Operating Water Surface	3 acres
Depth at Minimum Operating Water Surface	37 ft
Low Level Outlet	
Elevation	2463 ft at centerline
Size	60 in
Shape	round
Capacity	890 cfs
Stream Maintenance Pipe	
Elevation	2490 ft at centerline
Size	20 in
Shape	round
Capacity	23 cfs
MIDDLE FORK — RALSTON TUNNEL	
Inlet Elevation	2478 ft at invert
Size	13 ft 5 in
Shape	Horseshoe
Length	
Total	35,397 ft or 6.7 miles
Concrete Lined (Est.)	8,245 ft
Steel Lined (Est.)	245 ft
Maximum Discharge	836 cfs

Table AQ 4-1. Project Facility Specifications (continued).

RALSTON AFTERBAY	
DAM	
Material	Concrete
Height of Dam Crest above Streambed	89 ft
Dam Crest Length	560 ft
Elevation of Dam Crest	1,189 ft
Elevation of Streambed	1,100 ft
SPILLWAY	
Type	Gated Ogee Crest
Capacity at Water Surface 1186	171,200 cfs
Elevation of Top of Gates	1,179 ft
Elevation of Sill of Gates	1,149 ft
Crest Length	232 ft
Number of Gates	5
Type of Gates	Radial
Size of Gates	30'x40'
IMPOUNDMENT	
Gross Storage	2,782 ac-ft
Active Storage	1,804 ac-ft
Low Level Outlet	
Elevation	1108 ft at centerline
Size	72 in
Shape	round
Capacity	1,132 cfs
Stream Maintenance Pipe	
Elevation	1139 ft at centerline
Size	30 in
Shape	round
Capacity	155 cfs
RALSTON-OXBOW TUNNEL	
Inlet Elevation	1146 ft at centerline
Size	13 ft 3 in
Shape	Horseshoe
Length:	
Total	403 ft or 0.08 miles
Concrete Lined	343 ft
Steel Lined	60 ft
Maximum Discharge	1,088 cfs

Notes:

cfs = cubic feet per second

ft = feet

in = inch

[1]As constructed tunnel capacity is approximately 800 cfs, maximum discharge is limited to 400 cfs in French Meadows Powerhouse.

Table AQ 4-2. CE-QUAL-W2 Reservoir Model Information.

Model Information	French Meadows Reservoir	Hell Hole Reservoir	Ralston Afterbay
Number of Segments	24	26	49
Segment Length (m)	304.80	304.80	60.69
Layer Thickness (m)	1.0	1.0	1.0
Headwater	MFAR above FM	Rubicon River above HH	Rubicon River
Tributaries	Duncan Creek Tunnel	French Meadows PH	MFAR

MFAR = Middle Fork American River, FM = French Meadows, HH = Hell Hole, PH = Power House, MFP = Middle Fork Project

Table AQ 4-3. Mapped Percentage of Habitat per Reach.

Habitat Type	Middle Fork American River			Rubicon River		
	French Meadows Reservoir Dam to Middle Fork Interbay (%)	Middle Fork Interbay to Ralston Afterbay (%)	Ralston Afterbay to Folsom Reservoir (%)	Hell Hole Reservoir Dam to RM 24.7 (%)	RM 24.7 to RM 3.6 (%)	RM 3.6 to Ralston Afterbay (%)
High Gradient Riffle (HGR)	20.9	19.5	3.8	13.3	22.7	12
Low Gradient Riffle (LGR)	2.9	6.2	9.1	18	3.4	9.2
Run (RUN)	15.6	26.2	29.4	24.6	21.2	30
Pool (POOL)	55.8	42.6	55.8	41.7	40.8	46.3
Cascade[1]	4.8	5.4	1.9	2.4	11.9	2.4

[1]Cascade habitat types were modeled as HGR

Table AQ 4-4. Initial RMA-2 Model Roughness and Slope Factors for Each River Reach by Habitat Type.

RMA-2 Model Factors	Habitat Type[1]	Upper Middle Fork American River		Rubicon River		Middle Fork American River Peaking Reach
		French Meadows Reservoir to Middle Fork Interbay	Middle Fork Interbay to Ralston Afterbay	Hell Hole Reservoir to Ellicott Bridge	Ellicott Bridge to Ralston Afterbay	Ralston Afterbay to Folsom Reservoir
Roughness Factor (Manning's *n*)	POOL	0.035	0.075	0.042	0.037	0.055
	RUN	0.030	0.070	0.040	0.035	0.045
	HGR	0.027	0.060	0.035	0.030	0.035
	LGR	0.030	0.065	0.037	0.032	0.045
Slope Factor	POOL	0.97	0.90	0.97	0.92	0.45
	RUN	0.90	0.85	0.95	0.88	0.40
	HGR	0.85	0.75	0.90	0.75	0.30
	LGR	0.90	0.80	0.92	0.80	0.35

[1]HGR = high gradient riffle, LGR = low gradient riffle

Table AQ 4-5. Inflow and Outflow Information for CE-QUAL-W2 Reservoir Modeling.

French Meadows Reservoir		
Inflows	**Source**	**In-Reservoir Representation**
Middle Fork American River	Operations Model	Determined as a function of density
Duncan Creek-Middle Fork Tunnel	Operations Model	Determined as a function of density
Accretions/Depletion	CE-QUAL-W2 processor	Determined as a function of density
Outflows[1]		
Low-level outlet	Operations Model	Outlet Elevation 5,056.0 ft
Stream maintenance pipe	Operations Model	Outlet Elevation 5,068.0 ft
Spillway	Operations Model	Outlet Elevation 5,244.5 ft
French Meadows-Hell Hole Tunnel	Operations Model	Outlet Elevation 5,117.0 ft
Hell Hole Reservoir		
Inflows	**Source**	**In-Reservoir Representation**
Rubicon River	Operations Model	Determined as a function of density
French Meadows-Hell Hole Tunnel	Operations Model	Determined as a function of density
Accretions/Depletion	CE-QUAL-W2 processor	Determined as a function of density
Outflows[1]		
Low-level outlet	Operations Model	Outlet Elevation 4,288.0 ft
Stream maintenance pipe	Operations Model	Outlet Elevation 4,288.0 ft
Spillway	Operations Model	Outlet Elevation 4,630.0 ft
Hell Hole-Middle Fork Tunnel	Operations Model	Outlet Elevation 4,321.9 ft
Ralston Afterbay		
Inflows	**Source**	**In-Reservoir Representation**
Middle Fork American River	Operations Model	Determined as a function of density
Rubicon River	Operations Model	Determined as a function of density
Middle Fork-Ralston Tunnel	Operations Model	Determined as a function of density
Accretions/Depletion	CE-QUAL-W2 processor	Determined as a function of density
Outflows[1]		
Low-level outlet	Operations Model	Outlet Elevation 1,108.0 ft
Stream maintenance pipe	Operations Model	Outlet Elevation 1,139.0 ft
Spillway	Operations Model	Outlet Elevation 1,179.0 ft
Discharge tunnel to Oxbow Powerhouse	Operations Model	Outlet Elevation 1,146.0 ft

[1]Low level outlet and stream maintenance pipes were simulated at full capacity when they were operated - no ramping.

Table AQ 4-6. RMA-2 Model Summary of River Reaches.

Reach Elements	River Reaches			
	French Meadows Reservoir to Middle Fork Interbay	**Middle Fork Interbay to Ralston Afterbay**	**Hell Hole Reservoir to Ralston Afterbay**	**Ralston Afterbay to Folsom Reservoir**
Length (km)	18.9	16.4	46.3	55.5
Number of Nodes	761	661	1867	2231
Number of Elements	380	330	933	1115
Maximum Elevation (m)	1536.2	756.0	1234.4	318.0
Minimum Elevation (m)	770.3	328.6	350.6	109.7
	Model Elements [#] and Hydrology / Operations Model Nodes <#>			
Headwater Boundary Condition				Ralston Dam (1)[3] <845>
				Oxbow PH (2238) <847>
	French Meadows [1][1] <530>[2]	Middle Fork Interbay [1] <810>	Hell Hole [1] <540>	NF American River (2232) <865>
Tributaries			South Fork Rubicon [202] <834>	
			Pilot Creek [773] <839 to 840>	
			Long Canyon [818] <830 to 842>	
	Duncan Creek [256] <805>	-	Ralston PH [919] <810 to 815>	NF of MFAR [21] <865>
Accretion Inputs[4]	1. [27, 54, 82, 108] <802>	1. [25, 50, 75, 95, 115, 135, 155, 175][5] <812>	1. [131] <832>	1. [22] <855>
	2. [145, 182, 218, 255] <806>	2. [212, 248, 284, 320] <813>	2. [149, 167, 185, 201] <835>	2. [50] <857>
	3. [286, 318, 349] <810>		3. [267, 332, 397, 464] <836>	3. [123] <858>
			4. [503, 542, 581, 620] <838>	4. [123] <859>
			5. [658, 696, 734, 772] <840>	5. [341] <860>
			6. [784, 795, 806, 817] <842>	6. [344] <863>
			7. [843, 868, 893, 918] <815>	7. [444] <864>
				8. [447] <866>
				9. [808] <868>
Downstream Boundary Condition	Stage	Stage	Stage	Stage

[1][Temperature Model Element Assignments]

[2]<Hydrology / Operations Model Node>

[3](Headwater Node Assignments)

[4]Accretion inputs were typically distributed uniformly among river reaches, thus multiple element inflows may be specified based on a single hydrology / operations model accretion location.

[5]One quarter of accretion in Element 75 (Big Mosqito Creek) and 1/4 in Element 175 (Brushy Canyon) and the remainder was distributed evenly among the other elements.

Table AQ 4-7. Middle Fork Project Tunnel Statistics and Travel Times.

Tunnel	Volume (ft^3)	Length (ft)	Maximum Capacity (cfs)	Velocity (ft/s)	Travel Time (min)[1]
Duncan Creek-Middle Fork Tunnel	-[2]	7,700	400	-	-
Hell Hole-Middle Fork Tunnel	8,124,000	55,105	900	6.1	150±15
French Meadows-Hell Hole Tunnel	1,712,000	13,681	400	6.2	71±8
Middle Fork-Ralston Tunnel	5,840,500	35,397	900	5.5	108±11

[1]Travel time range provided at ±10 percent of tunnel volume.

[2]NA = Data not available.

Table AQ 4-8. Temperature Sources for CE-QUAL-W2 Reservoir Modeling.

Inflows	Application	Data Type	Monitoring Location
French Meadows Reservoir			
Middle Fork American River	Boundary Condition	Measured time series	MF 51.9
Duncan Creek-Middle Fork Tunnel	Boundary Condition	Measured time series	DC 8.8
Accretions/Depletions	Boundary Condition	Measured time series	—
In-pool vertical profiles (n = 2)[1]	Calibration	Monthly profile	See Map AQ 4-5a
Hell Hole Reservoir			
Rubicon River	Boundary Condition	Measured time series	RR 35.9
French Meadows-Hell Hole Tunnel	Boundary Condition	Time Series	French Meadows CE-QUAL-W2 simulation[2]
Accretions/Depletions	Boundary Condition	Time Series	—
In-pool vertical profiles (n = 2)[1]	Calibration	Monthly profile	See Map AQ 4-5b
Ralston Afterbay			
Middle Fork American River	Boundary Condition	Measured time series	MF 26.0
Rubicon River[3]	Boundary Condition	Measured time series	RR 0.7
Middle Fork-Ralston Tunnel[3]	Boundary Condition	Measured time series	MF 35.5
Accretions/Depletions	Boundary Condition	Measured time series	—
In-pool vertical profiles (n = 1)[1]	Calibration	Monthly profile	See Map AQ 4-5c

[1]Reservoir profiles measurements completed June through September, but not available in all years at all locations.
[2]Tunnel temperature equation was applied to CE-QUAL-W2 output to account for warming within the tunnel
[3]Rubicon River and Middle Fork-Ralston Tunnel outlet temperatures were mass balanced and represented as a single inflow to Ralston Afterbay.

Table AQ 4-9. Water Temperature Sources for Middle Fork Project RMA-11 River Reach Modeling.

Inflows	Application	Data Type	Monitoring Location/ Data Used
French Meadows Reservoir to Middle Fork Interbay			
French Meadows Reservoir	boundary condition	measured time series	MF 46.6
Duncan Creek	boundary condition	measured time series	DC 8.8
Accretions/Depletions	boundary condition	time series	10^{o} C constant
Middle Fork Interbay to Ralston Afterbay			
Middle Fork Interbay	boundary condition	measured time series	MF 36.1
Accretions/Depletions[1]	boundary condition	calculated time series	01- Apr, 15^{o} C 09 - June, 15^{o} C 29 - June, 25^{o} C 08 - Aug, 25^{o} C 07 - Sep, 15^{o} C 01 - Oct, 15^{o} C
Hell Hole Reservoir to Ralston Afterbay			
Hell Hole Reservoir	boundary condition	measured time series	MF 28.8
South Fork Rubicon River	boundary condition	measured time series	SF 0.1
Pilot Creek	boundary condition	measured time series	PC 0.1
Long Canyon Creek	boundary condition	measured time series	LC 0.1
Ralston Powerhouse	boundary condition	time series	calculated
Accretions/Depletions WSM Node 832	boundary condition	time series	MF 28.8
Accretions/Depletions WSM Node 835	boundary condition	time series	SF 0.1
Accretions/Depletions WSM Node 834	boundary condition	time series	SF 0.1
Accretions/Depletions WSM Node 836	boundary condition	time series	SF 0.1
Accretions/Depletions WSM Node 838	boundary condition	time series	SF 0.1
Accretions/Depletions WSM Node 840	boundary condition	time series	LC 0.1
Accretions/Depletions WSM Node 842	boundary condition	time series	LC 0.1
Accretions/Depletions WSM Node 815	boundary condition	time series	LC 0.1
Ralston Afterbay to Folsom Reservoir			
Ralston Afterbay	boundary condition	measured time series	MF 24.6
North Fork of the Middle Fork American River	boundary condition	measured time series	NM 2.3
Oxbow Powerhouse	boundary condition	measured time series	MF 24.3
North Fork American River	boundary condition	measured time series	NF 21.4
Accretions/Depletions WSM Node 855	boundary condition	time series	NM 2.3
Accretions/Depletions WSM Node 857	boundary condition	time series	NM 2.3
Accretions/Depletions WSM Node 858	boundary condition	time series	NM 2.3
Accretions/Depletions WSM Node 859	boundary condition	time series	NM 2.3
Accretions/Depletions WSM Node 860	boundary condition	time series	OC 0.1
Accretions/Depletions WSM Node 863	boundary condition	time series	OC 0.1
Accretions/Depletions WSM Node 864	boundary condition	time series	OC 0.1
Accretions/Depletions WSM Node 868	boundary condition	time series	NF 20.8

[1]Interpolated water temperature data between the dates given were used.

Table AQ 4-10. Meteorological Stations[1] and Associated Information Used for Each Model Reach.

Meteorological Elements	Reservoirs			River Reaches					
	French Meadows Reservoir	Hell Hole Reservoir	Ralston Afterbay	MFAR French Meadows to Duncan Creek	MFAR Duncan Creek to Middle Fork Interbay	MFAR Middle Fork Interbay to Ralston Afterbay	Rubicon River (Hell Hole to Ellicott Bridge)	Rubicon River (Ellicott Bridge to Ralston Afterbay)	Ralston Afterbay to Folsom Reservoir
Solar radiation	HLL	HLL	RAB	IBR	IBR	IBR	IBR	IBR	RAB
Air temperature	HLL	HLL	RAB	FA1	IBR	IBR	HA1	IBR	NA1
Relative Humidity/Dew Point	HLL	HLL	RAB	FA1	IBR	IBR	HA1	IBR	NA1
Wind speed	HLL	HLL	RAB	IBR	IBR	IBR	IBR	IBR	RAB
Wind direction	HLL	HLL	RAB	-[5]	-	-	-	-	-
Atmospheric pressure[2]	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.
Topographic shading[3]	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.
Wind sheltering[4]	0.5 – 1.2	0.6 – 1.3	0.7 – 1.2	-	-	-	-	-	-

[1]Full Meteorological Stations (air temperature, relative humidity, solar radiation, wind speed, wind direction, precipitation) = HLL, IBR, RAB. Partial Stations (air temperature, relative humidity) = FA1, HA1, NA1.

[2]Atmospheric pressure (P) was calculated based on elevation (E) using P =1013-3.436*(E/100)-0.0029*(E/100)^2+0.0001*(E/100)^3 (Snyder and Shaw, 1984).

[3]Topographic shading reduced incoming solar radiation through reduced day length and was developed using a DEM model (****). For selected reaches, day length was further reduced to accommodate local shade elements and in certain cases riparian vegetation.

[4]Wind sheltering was a calibration term in the CE-QUAL-W2 models to account for local topographic sheltering adjacent to reservoirs (see Cole and Wells, 2003) .

[5]Not applicable.

Table AQ 4-11. Summary of Bypass Reach Flow Travel Times.

Date	Location Name	Location RM	Pulse Flow at Location (cfs)	Distance (miles)	Travel Time For Segments (hr:min) (not cumulative)	Miles Per Hour (MPH)	Cumulative Adjusted Travel Time From Temperature Model Start Location to End Location (hrs)
Rubicon River							
9/28/2007	Below Hell Hole Reservoir	30.3	67.1	0	0		
	Ellicott Bridge	21.2	84.1	9.1	15:45	0.58	15.75
	Above Ralston Afterbay	0.7	96	20.5	12:30	1.64	28.25
12/3/2007	Below Hell Hole Reservoir	30.3	46.8	0	0		
	Ellicott Bridge	21.2	68.8	9.1	15:45	0.58	15.75
	Above Ralston Afterbay	0.7	83	20.5	20:15	1.01	36.00
5/16/2008	Below Hell Hole Reservoir	30.3	29.3	0	0		
	Ellicott Bridge	21.2	65.3	9.1	15:15	0.60	15.25
	Above Ralston Afterbay	0.7	97.3	20.5	20:15	1.01	35.50
6/12/2008	Below Hell Hole Reservoir	30.3	31.9	0	0		
	Ellicott Bridge	21.2	52	9.1	18:30	0.49	18.50
	Above Ralston Afterbay	0.7	71.1	20.5	20:00	1.02	38.50
4/16/2008	Below Hell Hole Reservoir	30.3	70.7	0	0		
	Ellicott Bridge	21.2	138.6	9.1	12:00	0.76	12.00
	Above Ralston Afterbay	0.7	208.9	20.5	13:00	1.58	25.00
10/25/2007	Below Hell Hole Reservoir	30.3	62.9	0	0		
	Ellicott Bridge	21.2	75.7	9.1	11:30	0.79	11.50
	Above Ralston Afterbay	0.7	90.8	20.5	16:30	1.24	28.00
Middle Fork American River (French Meadows Reservoir to Middle Fork Interbay)							
2/9/2007	Below French Meadows Reservoir	47.1	21	0	0		
	Middle Fork Interbay	35.98	266	11.12	4:00	2.78	4.00
10/19/2007	Below French Meadows Reservoir	47.1	14	0	0		
	Middle Fork Interbay	35.98	60	11.12	6:30	1.71	6.50
3/13/2008	Below French Meadows Reservoir	47.1	28	0	0		
	Middle Fork Interbay	35.98	261	11.12	7:45	1.43	7.75
3/19/2008	Below French Meadows Reservoir	47.1	20	0	0		
	Middle Fork Interbay	35.98	179	11.12	6:15	1.78	6.25
5/27/2008	Below French Meadows Reservoir	47.1	42	0	0		
	Middle Fork Interbay	35.98	153	11.12	7:45	1.43	7.75
5/27/2008	Below French Meadows Reservoir	47.1	181	0	0		
	Middle Fork Interbay	35.98	227	11.12	7:45	1.43	7.75
5/4/2008	Middle Fork Interbay	35.6	97	0	0		
	Ralston Afterbay	26	170	9.6	6:15	1.54	6.25
Middle Fork American River (Middle Fork Interbay to Ralston Afterbay)							
5/4/2008	Middle Fork Interbay	35.6	~200	0	0		
	Ralston Afterbay	26	192	9.6	4:00	2.4	4.2

Table AQ 4-12. Middle Fork American River Peaking Reach Approximate Pulse Flow Arrival Time by Location.

Release Time	Indian Bar Rafter Access	USGS Gage No. 11433300	Cache Rock	Fords Bar (IF Site)[1]	Canyon Creek	Ruck-a-Chucky	Poverty Bar	Buckeye Bar (IF Site)	Mammoth Bar	Confluence	Birdsall Access	Oregon Bar Access
12:00 AM	12:00 AM	12:30 AM	2:00 AM	4:04 AM	5:23 AM	6:00 AM	7:13 AM	7:49 AM	8:53 AM	9:44 AM	11:12 AM	11:52 AM
2:00 AM	2:00 AM	2:30 AM	4:00 AM	6:04 AM	7:23 AM	8:00 AM	9:13 AM	9:49 AM	10:53 AM	11:44 AM	1:12 PM	1:52 PM
4:00 AM	4:00 AM	4:30 AM	6:00 AM	8:04 AM	9:23 AM	10:00 AM	11:13 AM	11:49 AM	12:53 PM	1:44 PM	3:12 PM	3:52 PM
6:00 AM	6:00 AM	6:30 AM	8:00 AM	10:04 AM	11:23 AM	12:00 PM	1:13 PM	1:49 PM	2:53 PM	3:44 PM	5:12 PM	5:52 PM
8:00 AM	8:00 AM	8:30 AM	10:00 AM	12:04 PM	1:23 PM	2:00 PM	3:13 PM	3:49 PM	4:53 PM	5:44 PM	7:12 PM	7:52 PM
10:00 AM	10:00 AM	10:30 AM	12:00 PM	2:04 PM	3:23 PM	4:00 PM	5:13 PM	5:49 PM	6:53 PM	7:44 PM	9:12 PM	9:52 PM
11:00 AM	11:00 AM	11:30 AM	1:00 PM	3:04 PM	4:23 PM	5:00 PM	6:13 PM	6:49 PM	7:53 PM	8:44 PM	10:12 PM	10:52 PM
12:00 PM	12:00 PM	12:30 PM	2:00 PM	4:04 PM	5:23 PM	6:00 PM	7:13 PM	7:49 PM	8:53 PM	9:44 PM	11:12 PM	11:52 PM
2:00 PM	2:00 PM	2:30 PM	4:00 PM	6:04 PM	7:23 PM	8:00 PM	9:13 PM	9:49 PM	10:53 PM	11:44 PM	1:12 AM	1:52 AM
4:00 PM	4:00 PM	4:30 PM	6:00 PM	8:04 PM	9:23 PM	10:00 PM	11:13 PM	11:49 PM	12:53 AM	1:44 AM	3:12 AM	3:52 AM
6:00 PM	6:00 PM	6:30 PM	8:00 PM	10:04 PM	11:23 PM	12:00 AM	1:13 AM	1:49 AM	2:53 AM	3:44 AM	5:12 AM	5:52 AM
8:00 PM	8:00 PM	8:30 PM	10:00 PM	12:04 AM	1:23 AM	2:00 AM	3:13 AM	3:49 AM	4:53 AM	5:44 AM	7:12 AM	7:52 AM
10:00 PM	10:00 PM	10:30 PM	12:00 AM	2:04 AM	3:23 AM	4:00 AM	5:13 AM	5:49 AM	6:53 AM	7:44 AM	9:12 AM	9:52 AM
12:00 AM	12:00 AM	12:30 AM	2:00 AM	4:04 AM	5:23 AM	6:00 AM	7:13 AM	7:49 AM	8:53 AM	9:44 AM	11:12 AM	11:52 AM
Distance (miles)	0	1.25	5.05	10.25	13.45	15.13	18.05	19.55	22.20	24.35	28.00	29.65
Travel Time[2] (hrs)	0	0:30	2:00	4:04	5:23	6:00	7:13	7:49	8:53	9:44	11:12	11:52

[1]IF Site = AQ 1 Instream Flow Study Site

[2]Travel time is 2.5 mph and assumes a base flow of 200 cfs and a peak flow of 1,000 cfs. Travel time is faster when either base flow or peak flow increases.

Table AQ 4-13. Calibrated Reservoir Flow Parameters.

Calibration Parameter	French Meadows Reservoir	Hell Hole Reservoir	Ralston Afterbay
Manning's *n*	0.01	0.01	0.01
Longitudinal eddy viscosity (m^2/sec)	1	1	1
Longitudinal eddy diffusivity (m^2/sec)	1	1	1

Table AQ 4-14. Calibrated RMA-2 Model Roughness and Slope Factors for Each River Reach by Habitat Type.

RMA-2 Model Factors	Habitat Type[1]	Upper Middle Fork American River			Rubicon River		Middle Fork American River Peaking Reach
		French Meadows Reservoir to Duncan Creek	Duncan Creek to Middle Fork Interbay	Middle Fork Interbay to Ralston Afterbay	Hell Hole Reservoir to Ellicott Bridge	Ellicott Bridge to Ralston Afterbay	Ralston Afterbay to Folsom Reservoir
Roughness Factor (Manning's *n*)	POOL	0.035	0.035	0.065	0.042	0.037	0.045
	RUN	0.030	0.030	0.060	0.040	0.035	0.040
	HGR	0.030	0.030	0.055	0.037	0.032	0.035
	LGR	0.027	0.027	0.050	0.035	0.030	0.030
Slope Factor	POOL	0.97	0.95	0.90	0.97	0.90	0.05
	RUN	0.90	0.92	0.85	0.95	0.85	0.05
	HGR	0.90	0.90	0.80	0.92	0.80	0.04
	LGR	0.85	0.85	0.75	0.90	0.75	0.04

[1]HGR = high gradient riffle, LGR = low gradient riffle

Table AQ 4-15. CE-QUAL-W2 Reservoir Water Temperature Calibration Parameters.

Calibration Parameter	French Meadows Reservoir	Hell Hole Reservoir	Ralston Afterbay
AFW (wind speed coefficient)	15.5	15.5	15.5
BFW (wind speed coefficient)	0.46	0.46	0.46
EXH2O (light extinction, m^{-1})	0.3	0.25	0.3
BETA (fraction of solar radiation absorbed)	0.3	0.3	0.3
TSED (sediment temperature, ^{o}C)	11	11	11
CBHE (bottom heat exchange, $W\ m^{-2}\ sec^{-1}$)	0.5	0.5	0.5
Wind sheltering	0.4 - 1.2	0.6 - 1.3	0.5 -1.2

Table AQ 4-16. The CE-QUAL-W2 Wind Sheltering Values for French Meadows Reservoir.

Segment Number	Julian Day				
	1.0	130.0	222.0	242.0	366.0
1	0.5	0.5	0.5	0.4	1.0
2	0.5	0.5	0.5	0.4	1.0
3	0.5	0.5	0.5	0.4	1.0
4	0.5	0.5	0.5	0.4	1.0
5	0.5	0.5	0.5	0.4	1.0
6	0.5	0.5	0.5	0.4	1.0
7	0.5	0.5	0.5	0.4	1.0
8	1.2	0.5	1.2	0.4	1.2
9	1.2	0.5	1.2	0.4	1.2
10	1.2	0.5	1.2	0.4	1.2
11	1.2	0.5	1.2	0.4	1.2
12	1.2	0.5	1.2	0.4	1.2
13	1.2	0.5	1.2	0.4	1.2
14	1.2	0.5	1.2	0.4	1.2
15	1.2	0.5	1.2	0.4	1.2
16	1.2	0.5	1.2	0.4	1.2
17	1.0	0.5	1.0	0.4	1.0
18	1.0	0.5	1.0	0.4	1.0
19	1.0	0.5	1.0	0.4	1.0
20	1.0	0.5	1.0	0.4	1.0
21	1.0	0.5	1.0	0.4	1.0
22	1.0	0.5	1.0	0.4	1.0
23	1.0	0.5	1.0	0.4	1.0
24	1.0	0.5	1.0	0.4	1.0

Table AQ 4-17. The CE-QUAL-W2 Wind Sheltering Values for Hell Hole Reservoir.

Segment Number	Julian Day							
	1.0	123.0	222.0	245.0	255.0	285.0	320.0	366.0
1	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
2	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
3	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
8	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
9	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
10	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
11	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
12	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
13	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
14	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
15	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
16	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
17	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
18	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
19	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
20	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
21	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
22	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
23	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
24	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
25	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0
26	1.0	1.3	1.3	0.9	0.6	0.6	0.6	1.0

Table AQ 4-18. The CE-QUAL-W2 Wind Sheltering Values for Ralston Afterbay.

Segment Number	Julian Day				
	1.0	198.0	221.2	280.0	366.0
1	1.2	0.7	1.0	0.5	1.2
2	1.2	0.7	1.0	0.5	1.2
3	1.2	0.7	1.0	0.5	1.2
4	1.2	0.7	1.0	0.5	1.2
5	1.2	0.7	1.0	0.5	1.2
6	1.2	0.7	1.0	0.5	1.2
7	1.2	0.7	1.0	0.5	1.2
8	1.2	0.7	1.0	0.5	1.2
9	1.2	0.7	1.0	0.5	1.2
10	1.2	0.7	1.0	0.5	1.2
11	1.2	0.7	1.0	0.5	1.2
12	1.2	0.7	1.0	0.5	1.2
13	1.2	0.7	1.0	0.5	1.2
14	1.2	0.7	1.0	0.5	1.2
15	1.2	0.7	1.0	0.5	1.2
16	1.2	0.7	1.0	0.5	1.2
17	1.2	0.7	1.0	0.5	1.2
18	1.2	0.7	1.0	0.5	1.2
19	1.2	0.7	1.0	0.5	1.2
20	1.2	0.7	1.0	0.5	1.2
21	1.2	0.7	1.0	0.5	1.2
22	1.2	0.7	1.0	0.5	1.2
23	1.2	0.7	1.0	0.5	1.2
24	1.2	0.7	1.0	0.5	1.2
25	1.2	0.7	1.0	0.5	1.2
26	1.2	0.7	1.0	0.5	1.2
27	1.2	0.7	1.0	0.5	1.2
28	1.2	0.7	1.0	0.5	1.2
29	1.2	0.7	1.0	0.5	1.2
30	1.2	0.7	1.0	0.5	1.2
31	1.2	0.7	1.0	0.5	1.2
32	1.2	0.7	1.0	0.5	1.2
33	1.2	0.7	1.0	0.5	1.2
34	1.2	0.7	1.0	0.5	1.2
35	1.2	0.7	1.0	0.5	1.2

Figure AQ 4-18. The Wind Sheltering Values for Ralston Afterbay (continued).

Segment Number	Julian Day				
	1.0	198.0	221.2	280.0	366.0
36	1.2	0.7	1.0	0.5	1.2
37	1.2	0.7	1.0	0.5	1.2
38	1.2	0.7	1.0	0.5	1.2
39	1.2	0.7	1.0	0.5	1.2
40	1.2	0.7	1.0	0.5	1.2
41	1.2	0.7	1.0	0.5	1.2
42	1.2	0.7	1.0	0.5	1.2
43	1.2	0.7	1.0	0.5	1.2
44	1.2	0.7	1.0	0.5	1.2
45	1.2	0.7	1.0	0.5	1.2
46	1.2	0.7	1.0	0.5	1.2
47	1.2	0.7	1.0	0.5	1.2
48	1.2	0.7	1.0	0.5	1.2
49	1.2	0.7	1.0	0.5	1.2

Table AQ 4-19. Reservoir CE-QUAL-W2 Model Calibration Dates.

Reservoir	Calibration Dates	
	2006	**2007**
French Meadows Reservoir	7/6, 8/9, 9/8, 10/27	5/30, 7/12, 8/2, 8/31
Hell Hole Reservoir	7/6, 8/9, 9/8, 10/27	5/30, 7/12, 8/2, 8/31
Ralston Afterbay	7/6, 8/8, 9/30	6/7, 7/11, 7/31, 9/6, 9/25

Table AQ 4-20. RMA-11 Water Temperature Model Parameter Values for River Reaches.

Calibrated Parameter	Upper Middle Fork American River		Rubicon River		Middle Fork American River Peaking Reach
	French Meadows Reservoir to Middle Fork Interbay	Middle Fork Interbay to Ralston Afterbay	Hell Hole Reservoir to Ellicott Bridge	Ellicott Bridge to Ralston Afterbay	Ralston Afterbay to Folsom Reservoir
a (coefficent in evaporation equation)	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06
b (coefficent in evaporation equation)	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06
Topographic shading	YES	YES	YES	YES	YES
Local shading modified	YES	YES	NO	NO	NO
Dead pool area	Variable[1]	Measured	Variable[1]	Variable[1]	Measured
Topographic emissivity	0.98	0.98	0.98	0.98	0.98
Terrestrial long wave radiation contribution fraction	0.25	0.98	0.25	0.25	0.25
Bed temperature ^oC	15 to 23	18	18	23	20
Bed heat exchange coefficient W m^{-2} $^0C^{-1}$	-22.7	-22.7	-22.7	-22.7	-22.7

[1]Dead pool area was modified during calibration.

Table AQ 4-21. River and Reservoir Model Parameters Tested during the Sensitivity Analysis.

Reach Type	Parameters
River	Manning's n, slope factor, A& B evaporation coefficients, topographic shade, local shade, dead pool area, terrestrial long wave radiation, terrestrial emissivity, bed temperature, bed heat exchange coefficient.
Reservoir	Wind sheltering coefficient, solar radiation absorbed in surface layer, extinction coefficient for pure water, coefficient of bottom heat exchange, bed temperature.

Table AQ 4-22. Summary of Alternative Flow Regime Temperature Analysis.

Site/Baseline for Testing	Existing Minimum Flow for 2007 (Wet Year, Existing FERC License)	Alternative Flow Scenario Description
Middle Fork American River from French Meadows Reservoir to Middle Fork Interbay		
Instream Flow Sensitivity	8 cfs	Existing Flow -5, 0, +5, +10, +15 and +20 cfs
Spring Pulse Flow Sensitivity	NA[1]	400 cfs for ~15 days beginning April 25
Middle Fork American River from Middle Fork Interbay to Ralston Afterbay		
Instream Flow Sensitivity	23 cfs	Existing Flow -10, 0, +10, +20, +30 and +40 cfs
Spring Pulse Flow Sensitivity	NA[1]	550 cfs for ~15 days beginning April 25
Rubicon River below Hell Hole Reservoir		
Instream Flow Sensitivity	20 cfs	Existing Flow -10, 0, +10, +20, +30 and +40 cfs
Spring Pulse Flow Sensitivity	NA[1]	600 cfs for ~15 days beginning April 25
Middle Fork American River below Ralston Afterbay - Peaking Reach		
Minimum Instream Flow	75 cfs	Minimum Flow (cfs) during Peaking Operations (100, 150, 200, 250, 300, 2-Day Smoothed Average)

[1]No pulse flows are in the existing FERC license.

Table AQ 4-23. Data Used for Water Temperature Analyses on Duncan Creek, North Fork Long Canyon Creek, South Fork Long Canyon Creek, and Long Canyon Creek.

Monitoring Stations[1]	Water Temperature	Air Temperature		Flow Node[2]	Analysis[3]
	Period of Record[4]	Meteorological Monitoring Station[1]	Period of Record[4]		
Duncan Creek					
DC8.8	9/24/03 - 12/31/08 Missing: 12/31/05 - 7/12/06	CDEC DUN[5]	9/17/03 - 3/19/08 Missing: 6/1/05 - 8/12/05; 7/11/06 - 7/19/06; 7/25/06 - 7/27/06	800.804 unimpaired	Linear and multiple regressions
DC8.4	9/24/03 - 10/19/07 Missing: 8/27/04 - 6/1/05			804.805 impaired	
DC0.1	6/1/06 - 9/26/08			805.806 impaired	
South Fork Long Canyon Creek					
SL3.4	9/24/03 - 9/23/09 Missing: 5/14/05 - 7/8/05	HLL - near Hell Hole Dam	7/20/05 - 7/10/08	-	Linear regression
SL3.2	10/2/03 - 9/23/09			-	
North Fork Long Canyon Creek					
NL3.2	1/1/05 - 9/23/09 Missing: 10/11/05 - 7/13/06	HLL - near Hell Hole Dam	7/20/05 - 7/10/08	-	Linear regression
NL3.1	9/24/03 - 9/23/09 Missing: 10/11/05 - 8/31/06; 7/13/06 - 9/14/06			-	
Long Canyon Creek					
LC11.0	7/7/05 - 10/30/07 Missing: 2/28/06 - 9/14/06; 7/13/06 - 10/23/06	HLL - near Hell Hole Dam	7/20/05 - 7/10/08	-	Linear regression
LC6.8	7/21/05 - 10/30/07 Missing: 6/22/06 - 7/13/06	RAB - near Ralston Afterbay	6/30/05 - 4/27/09 Missing: 5/25/08 - 7/2/08	-	
LC0.1	7/7/05 - 10/30/08 Missing: 10/27/05 - 7/14/06			-	

[1]See Map AQ 4-4 for temperature and meteorological monitoring station locations.
[2]Flow data was only used for the analysis on Duncan Creek.
[3]Linear Regression: relationship between air temperature and stream water temperatures. Multiple regression: relationship between air temperature and flow with stream water temperatures. Analyses were completed for the summer months (June through September).
[4]Missing data only listed if period of time included summer months (June through September).
[5]CDEC: California Data Exchange Center. Data available at: http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=DUN.

Table AQ 4-24. Sensitivity of Reservoir Model Parameters.

Parameters	Calibration Parameter	Sensitivity	Notes
Flow	Manning's n	Low	Affects velocity, insensitive
	Eddy viscosity	Low	Affects dispersion of momentum, insensitive
Temperature	A & B coefficients in evaporation equation	Medium	Affects evaporative cooling. In this application, these coefficients had a modest impact on temperature
	Wind sheltering coefficient	High	Affects wind speed, which is used in the evaporative heat flux term of the heat budget. For wide, long reservoirs, this parameter was sensitive.
	Solar radiation absorbed in surface layer	High	Affects surface temperatures. Important in simulating epilimnion temperatures and stratification.
	Extinction coefficient for pure water	High	Affects surface temperatures. Important in simulating epilimnion temperatures and stratification.
	Coefficient of bottom heat exchange	Low-Medium	Affects temperature profile in bottom waters
	Bed temperature	Low-Medium	Affects temperature profile in bottom waters

Table AQ 4-25. Sensitivity of River Model Parameters.

Parameters	Calibration Parameter	Sensitivity	Notes
Flow	Manning n	High	Affects travel time, can affect phase of diurnal cycle/variation of water temperature.
	Slope Factor	High	Affects travel time, can affect phase of diurnal cycle/variation of water temperature.
Temperature	A & B coefficients in evaporation equation	Medium	Affects evaporative cooling. In this application, these coefficients had a modest impact on temperature.
	Topographic Shade	Low	Reduces solar radiation, a principal component of the heat budget. The topographic relief was not globally sufficient for this parameter to have a large effect.
	Local Shade	Medium	Reduces solar radiation, a principal component of the heat budget. The local shade had a modest affect in certain reaches above Ralston Afterbay.
	Dead Pool Area (m^2)	Low	Affects diurnal variation of water temperature.
	Terrestrial Long Wave (%)	Low	Contributes slightly to heat budget.
	Terrestrial Emissivity	Low	Contributes slightly to heat budget.
	Bed Temperature (^oC)	Medium	A moderately sensitive parameter that affects both mean temperature and diurnal range. Seasonal values used in several reaches.
	Bed Heat Exchange Coefficient ($W/m^2/^oC$)	Medium	A moderately sensitive parameter that affects both mean temperature and diurnal range. Seasonal values used in several reaches.

Table AQ 4-26. Relationships Between Summer Average Daily, Maximum, and Minimum Air and Water Temperatures (°F) for Duncan Creek, South Fork Long Canyon Creek, North Fork Long Canyon Creek, and Long Canyon Creek[1].

Location	Period of Record[1]	Regression Relationships[2,3]					
		Average Daily Water Temperature	R-squared	Maximum Daily Water Temperature	R-squared	Minimum Daily Water Temperature	R-squared
Duncan Creek							
DC8.8	6/1/04 - 9/30/07	$WT_{avg} = 0.40(AT_{avg}) + 32.66$	0.46	$WT_{max} = 0.40(AT_{max}) + 32.95$	0.41	$WT_{min} = 0.36(AT_{min}) + 34.77$	0.42
		$WT_{avg} = 33.28-0.13(Flow)+0.40(AT_{avg})$	0.47	$WT_{max}=31.92-0.19(Flow)+0.41(AT_{max})$	0.42	$WT_{min} = 36.49-0.37(Flow)+0.35(AT_{min})$	0.47
DC8.4	6/1/04 - 9/30/07	$WT_{avg} = 0.44AT_{avg} + 33.12$	0.44	$WT_{max} = 0.45(AT_{max}) + 33.18$	0.41	$WT_{min} = 0.39AT_{min} + 35.62$	0.37
		$WT_{avg} = 37.54-0.69(Flow)+0.40(AT_{avg})$	0.67	$WT_{max}=39.53-0.85(Flow)+0.40(AT_{max})$	0.66	$WT_{min} = 39.67-0.70(Flow)+0.36(AT_{min})$	0.63
DC0.1	6/1/06 - 9/30/07	$WT_{avg} = 0.28(AT_{avg}) + 40.78$	0.58	$WT_{max} = 0.27(AT_{max}) + 41.38$	0.50	$WT_{min} = 0.26(AT_{min}) + 42.35$	0.51
		$WT_{avg} = 41.76-0.06(Flow)+0.28(AT_{avg})$	0.61	$WT_{max}=42.56-0.06(Flow)+0.26(AT_{max})$	0.53	$WT_{min} = 43.56-0.26(Flow)+0.09(AT_{min})$	0.59
South Fork Long Canyon Creek				r2=0.42			
SL3.4	7/20/05-7/10/08	$WT_{avg} = 0.34(AT_{avg}) + 30.46$	0.76	$WT_{max} = 0.35(AT_{max}) + 31.10$	0.66	$WT_{min} = 0.36(AT_{min}) + 30.33$	0.70
SL3.2	7/20/05-7/10/08	$WT_{avg} = 0.42(AT_{avg}) + 26.86$	0.73	$WT_{max} = 0.46(AT_{max}) + 23.62$	0.61	$WT_{min} = 0.39(AT_{min}) + 29.89$	0.67
North Fork Long Canyon Creek							
NL3.2	7/20/05-7/10/08	$WT_{avg} = 0.53(AT_{avg}) + 22.31$	0.72	$WT_{max} = 0.40(AT_{max}) + 27.25$	0.56	$WT_{min} = 0.59(AT_{min}) + 24.23$	0.74
NL3.1	7/20/05-7/10/08	$WT_{avg} = 0.57(AT_{avg}) + 20.76$	0.74	$WT_{max} = 0.53(AT_{max}) + 23.39$	0.57	$WT_{min} = 0.61(AT_{min}) + 22.80$	0.71
Long Canyon Creek							
LC11.0	7/20/05-9/30/07	$WT_{avg} = 0.51(AT_{avg}) + 24.67$	0.76	$WT_{max} = 0.45(AT_{max}) + 26.21$	0.66	$WT_{min} = 0.54(AT_{min}) + 26.75$	0.75
LC6.8	7/21/05-9/30/07	$WT_{avg} = 0.80(AT_{avg}) + 2.64$	0.82	$WT_{max} = 0.62(AT_{max}) + 8.32$	0.60	$WT_{min} = 0.84(AT_{min}) + 7.67$	0.80
LC0.1	7/7/05-9/30/08	$WT_{avg} = 0.65(AT_{avg}) + 20.99$	0.72	$WT_{max} = 0.47(AT_{max}) + 30.29$	0.52	$WT_{min} = 0.64(AT_{min}) + 26.43$	0.67

[1]Summer Months: June, July, August, and September. See Table AQ 4-25 for time periods with missing data.

[2] WT: Water Temperature (°F); AT: Air Temperature (°F); Flow: Impaired Flow (cfs) at D8.4 and D0.1 and Unimpaired Flow at D8.8; Avg: Daily Average; Max: Maximum Daily; Min: Minimum Daily.

[3]Multiple regression with Flow was only completed for Duncan Creek.

Table AQ 4-27. Water Temperature Measured in the Rubicon River at the Confluences with Long Canyon Creek and Pilot Creek.

Site Location		Time (8/8/2008)	Depth (ft)	Temperature (°C)	Temperature (°F)
Rubicon River Upstream of Long Canyon	Pool A	16:15	0.1	24.7	76.5
		16:15	11.0	24.7	76.5
	Pool B	16:25	0.1	24.8	76.6
		16:25	4.0	24.8	76.6
Long Canyon Creek	Riffle/Run	16:30	~1.0	25.7	78.3
Rubicon River Downstream of Long Canyon	Pool A	16:35	0.1	25.0	77.0
		16:35	6.0	24.9	76.8
	Pool B	16:35	0.1	24.9	76.8
		16:35	8.0	24.8	76.6
Rubicon River Upstream of Pilot Creek	Pool A	16:40	0.1	24.5	76.1
		16:40	6.5	24.5	76.1
	Pool B[1]	16:30	0.5	25.1	77.2
		16:30	11.0	24.8	76.6
Pilot Creek	Run A	16:55	~1.0	19.5	67.1
	Pool A	16:55	0.1	19.2	66.6
		16:55	7.0	19.3	66.7
Rubicon River Downstream of Pilot Creek	Pool A	17:05	0.1	23.5	74.3
		17:05	5.0	23.5	74.3
	Pool B[1]	16:30	1.0	24.5	76.0
		16:30	8.0	23.6	74.5

[1]Temperature monitored continuously with an Onset Tidbit Temperature Datalogger.

FIGURES

Figure AQ 4-1. Water Temperature Modeling Objectives, Related Study Elements, and Reports.

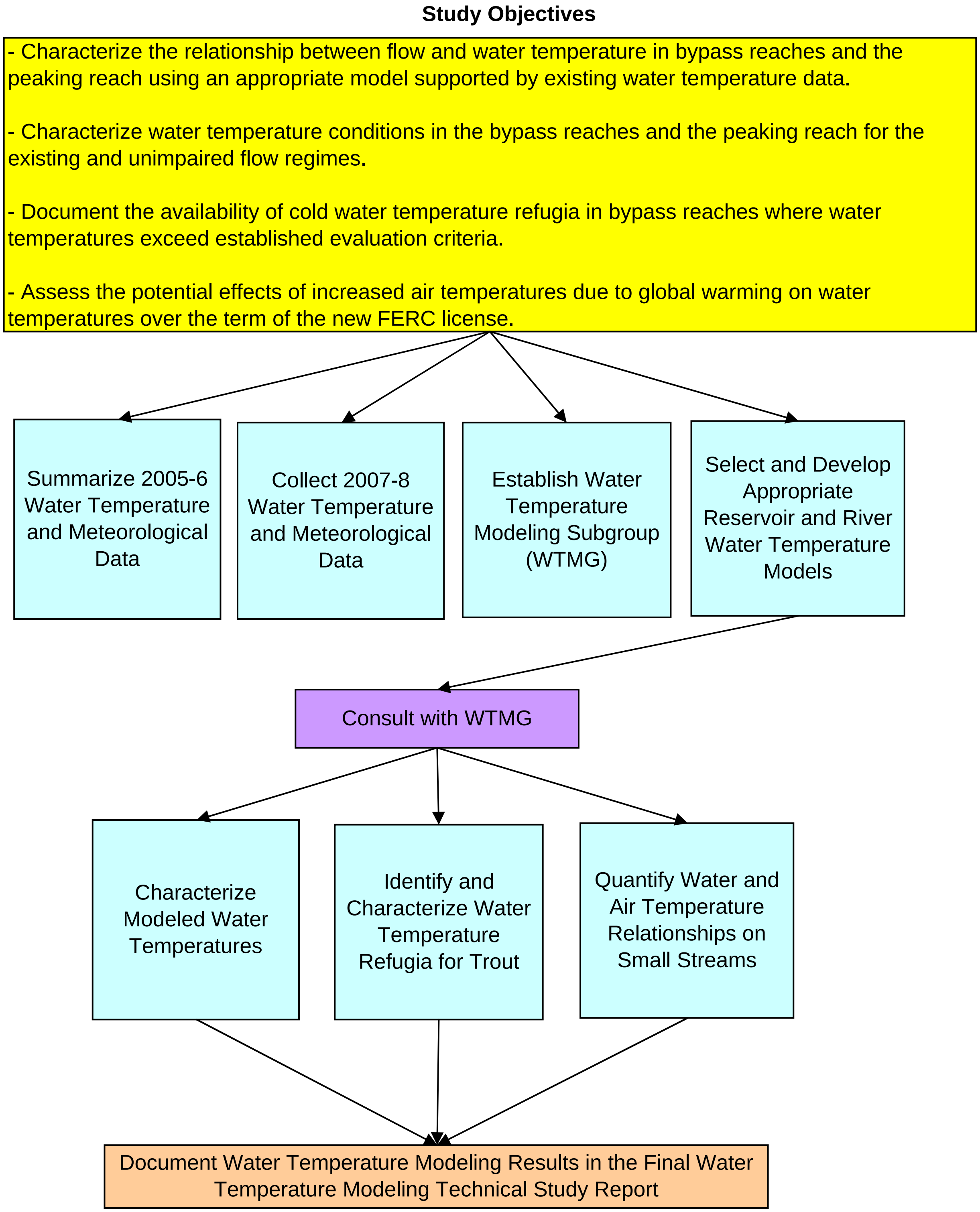


Figure AQ 4-2a. Model Geometry for French Meadows Reservoir - Plan View Showing Segments.

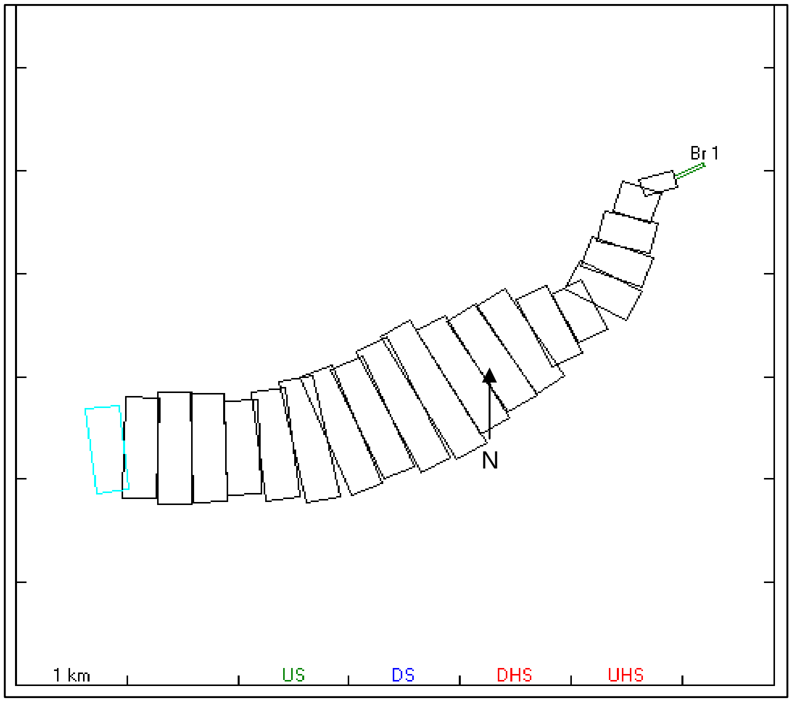


Figure AQ 4-2b. Model Geometry for French Meadows Reservoir - Segment 23 (at dam).

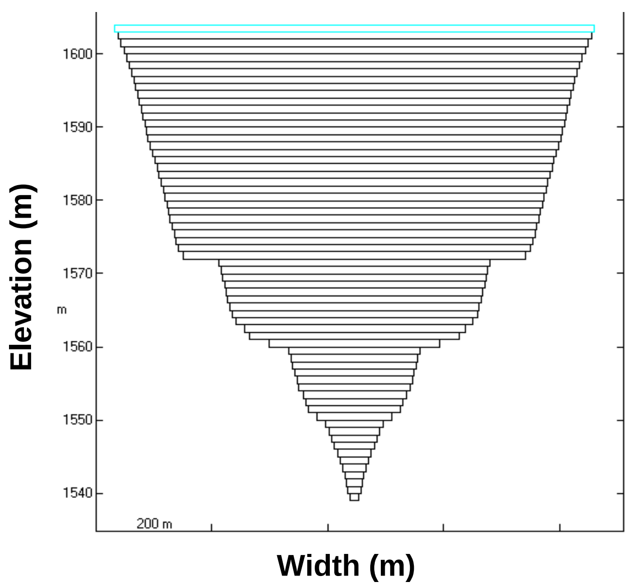


Figure AQ 4-2c. Model Geometry for French Meadows Reservoir - Profile View Showing Segments and Layers.

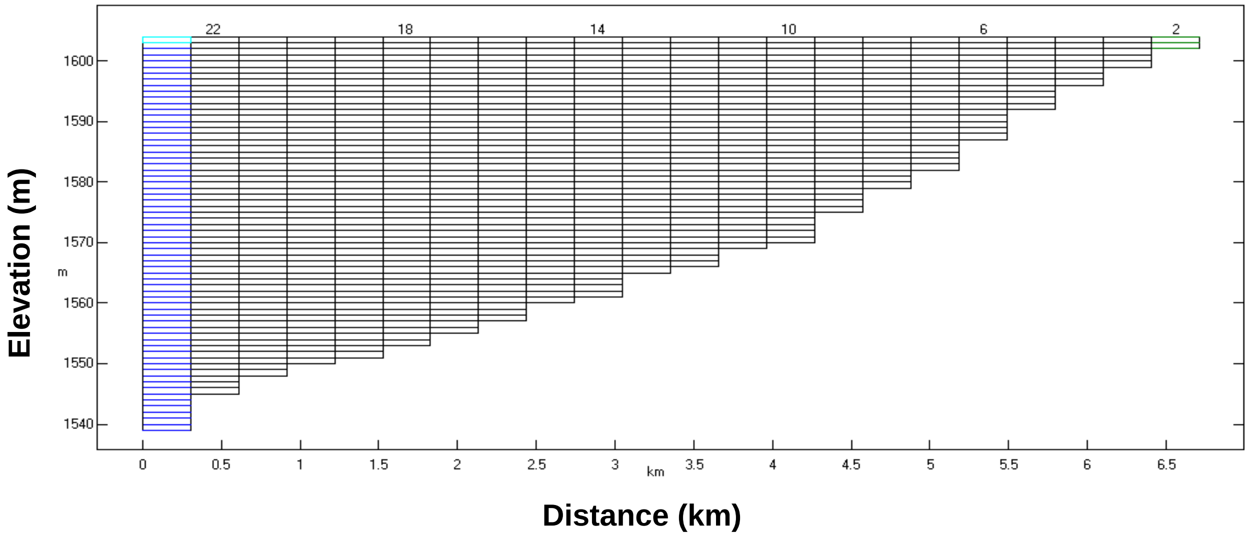


Figure AQ 4-3a. Model Geometry for Hell Hole Reservoir - Plan View Showing Segments.

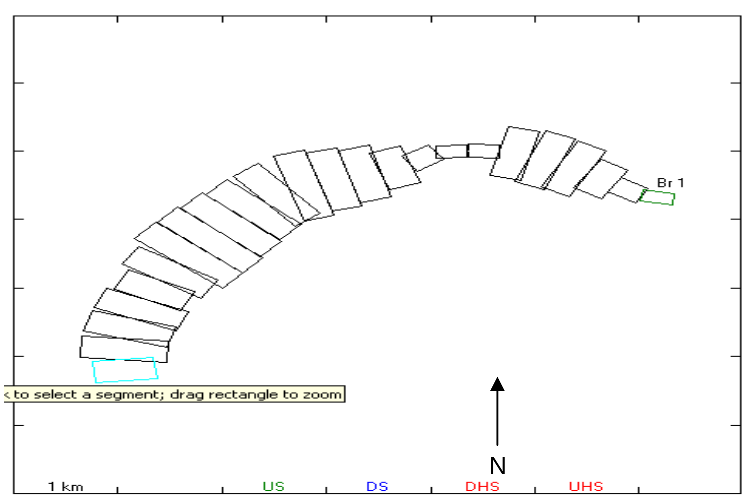


Figure AQ 4-3b. Model Geometry for Hell Hole Reservoir - Segment 23 (at dam).

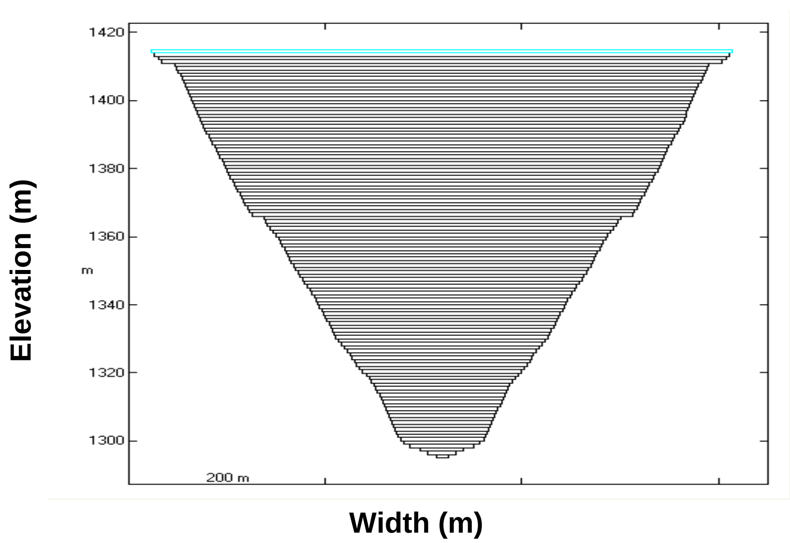


Figure AQ 4-3c. Model Geometry for Hell Hole Reservoir - Profile View Showing Segments and Layers.

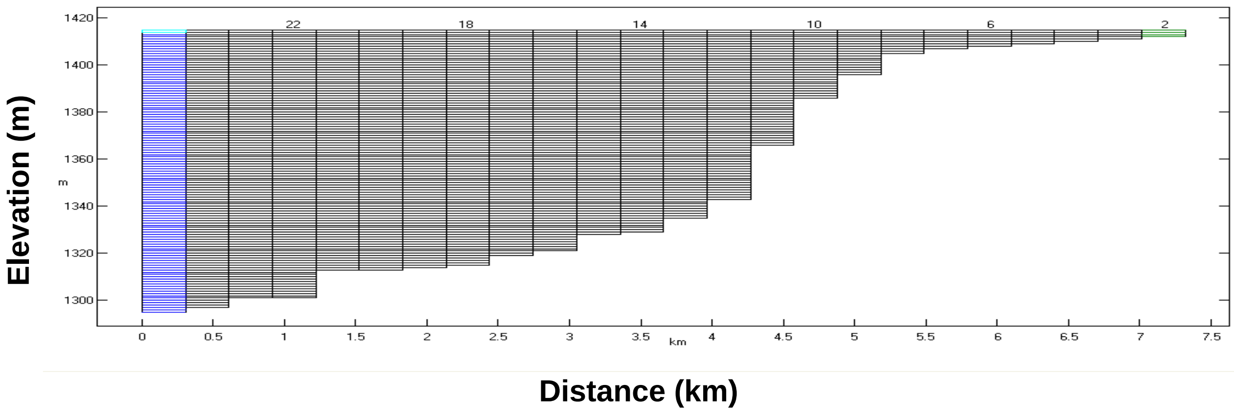


Figure AQ 4-4a. Model Geometry for Ralston Afterbay - Plan View Showing Segments.

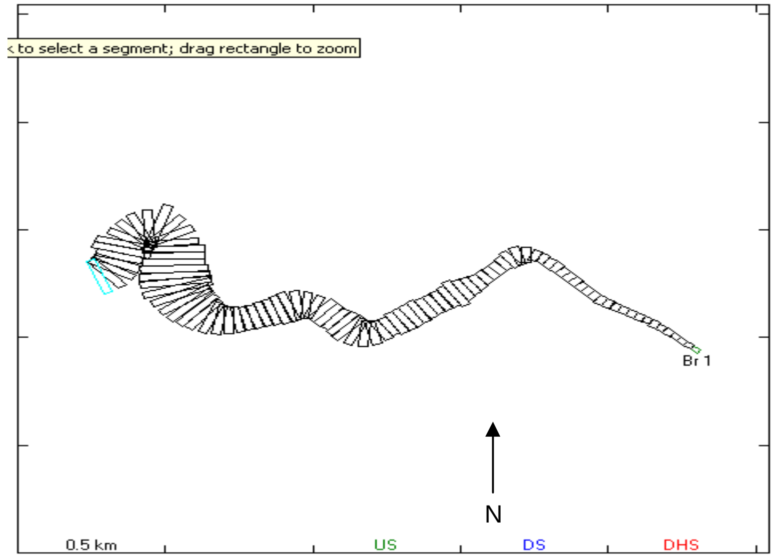


Figure AQ 4-4b. Model Geometry for Ralston Afterbay - Segment 23 (at dam).

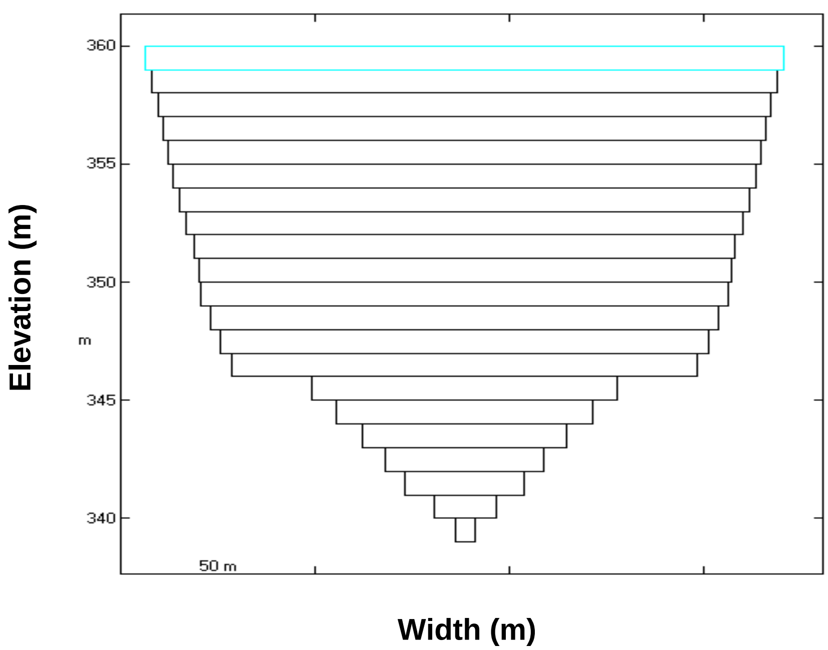


Figure AQ 4-4c. Model Geometry for Ralston Afterbay - Profile View Showing Segments and Layers.

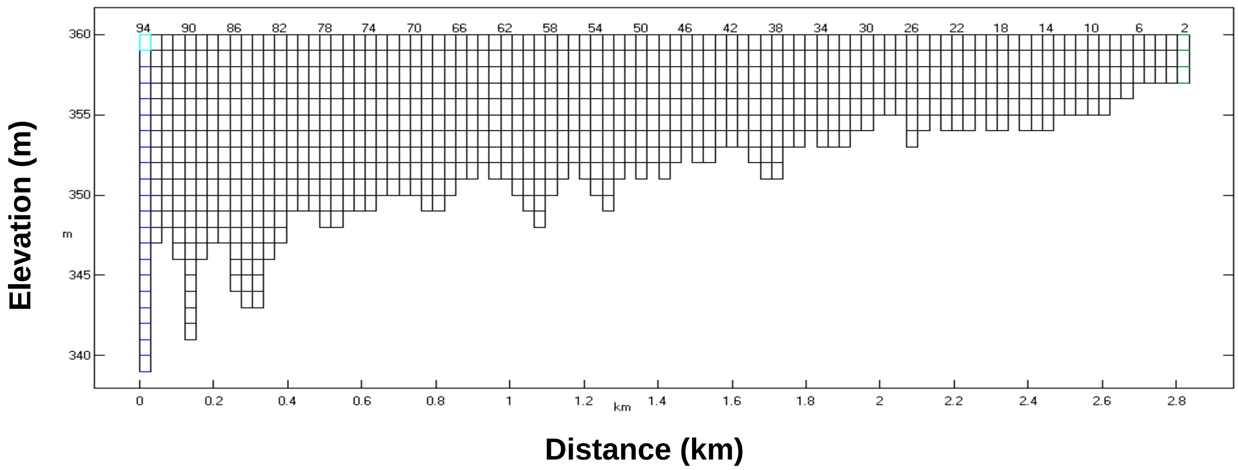


Figure AQ 4-5. RMA-2 and RMA-11 River Geometry Representation Showing Elements (boxes) and Nodes (circles).

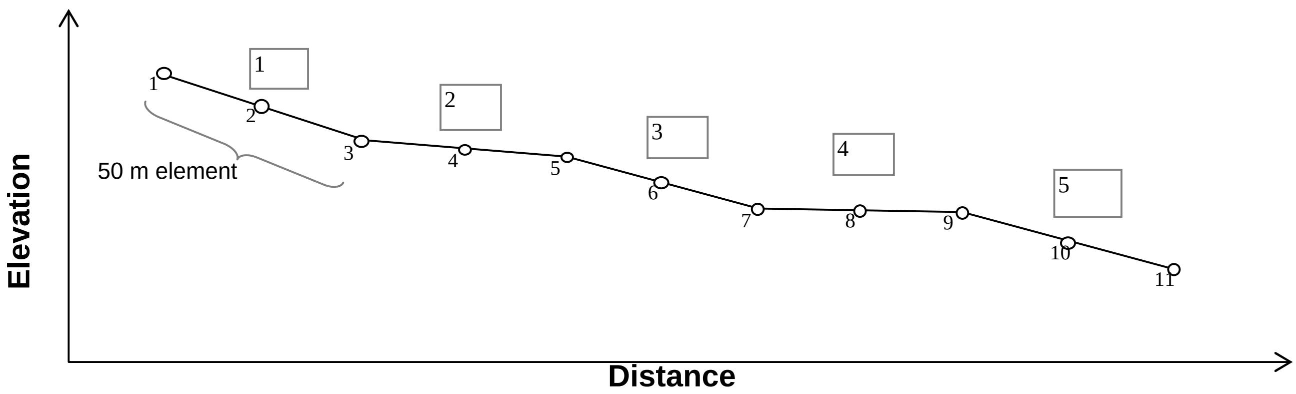


Figure AQ 4-6. Example Computational Mesh for a Representative River Reach, Showing Habitat Types on an Element-by-Element Basis. Node Spacing is 25 m.

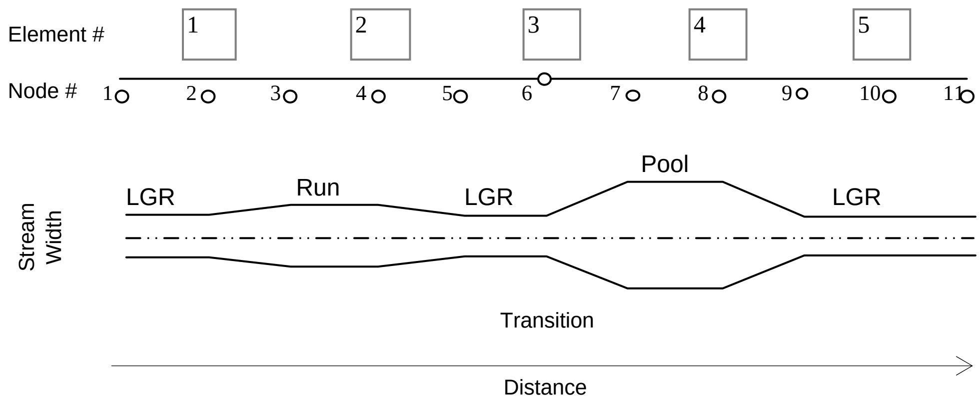
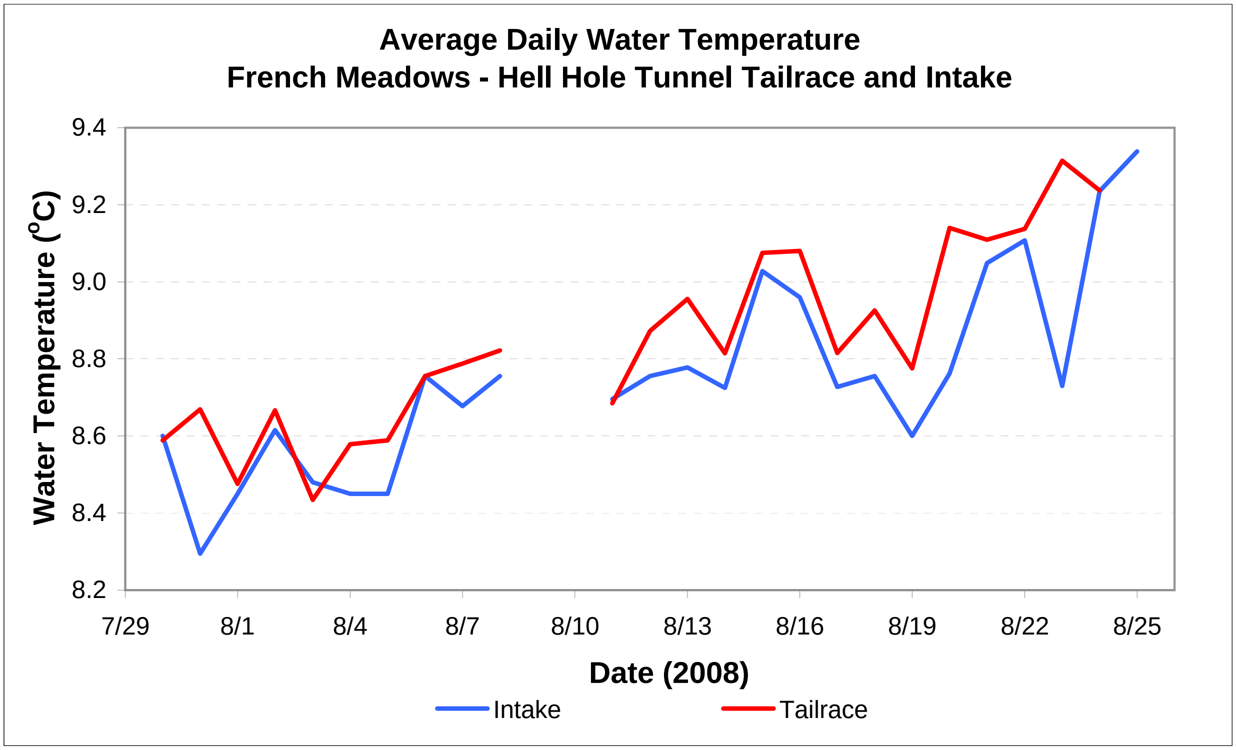
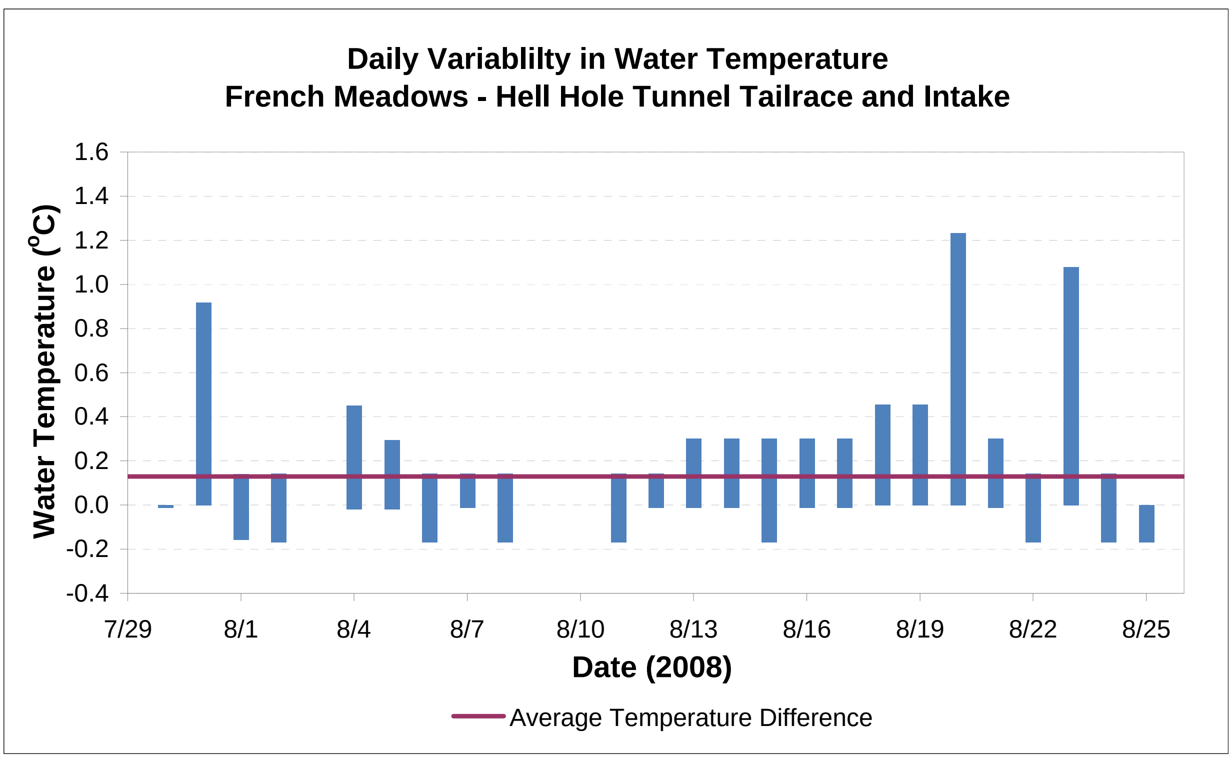


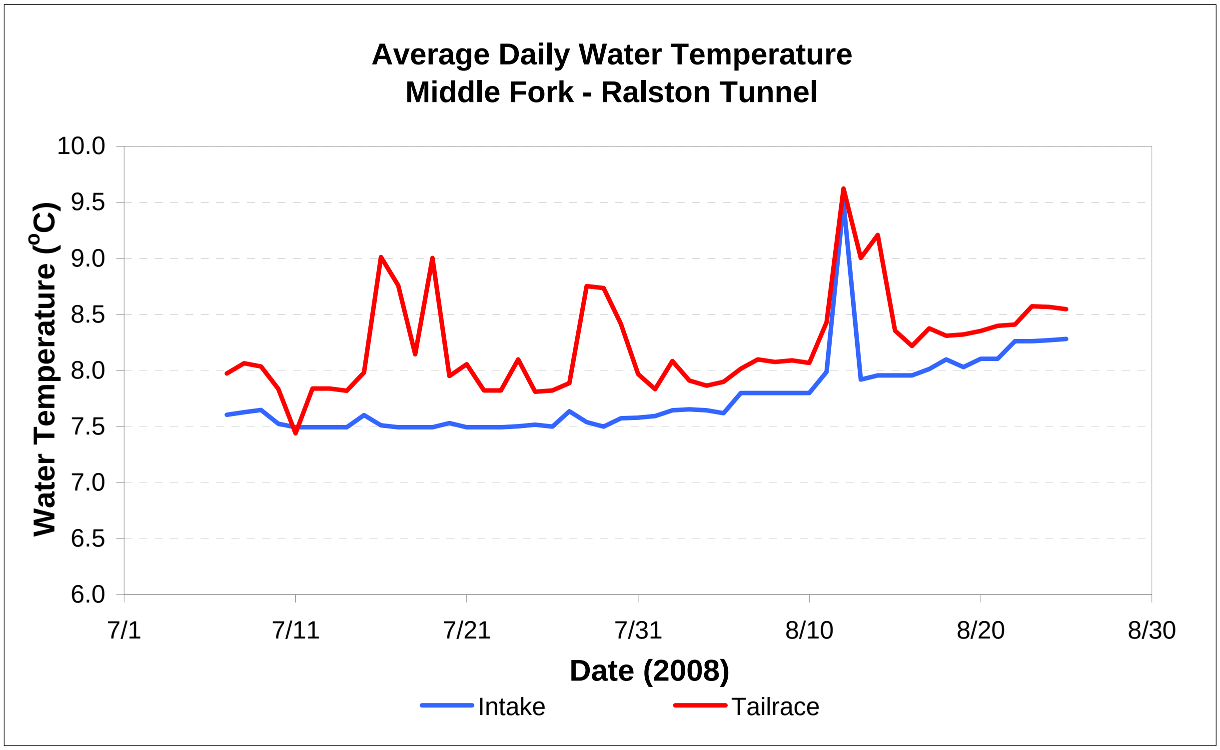
Figure AQ 4-7. Daily Average Intake and Tailrace Water Temperatures (Top) and the Daily Variablity Between Intake and Tailrace Water Temperatures for the French Meadows - Hell Hole Tunnel (Bottom) (July 30 - August 25, 2008[1]).





[1]Data not available August 9 - 10, 2008.

Figure AQ 4-8. Daily Average Intake and Tailrace Water Temperatures (Top) and the Daily Variablity Between Intake and Tailrace Water Temperatures for the Middle Fork - Ralston Tunnel (Bottom) (July 30 - August 25, 2008).



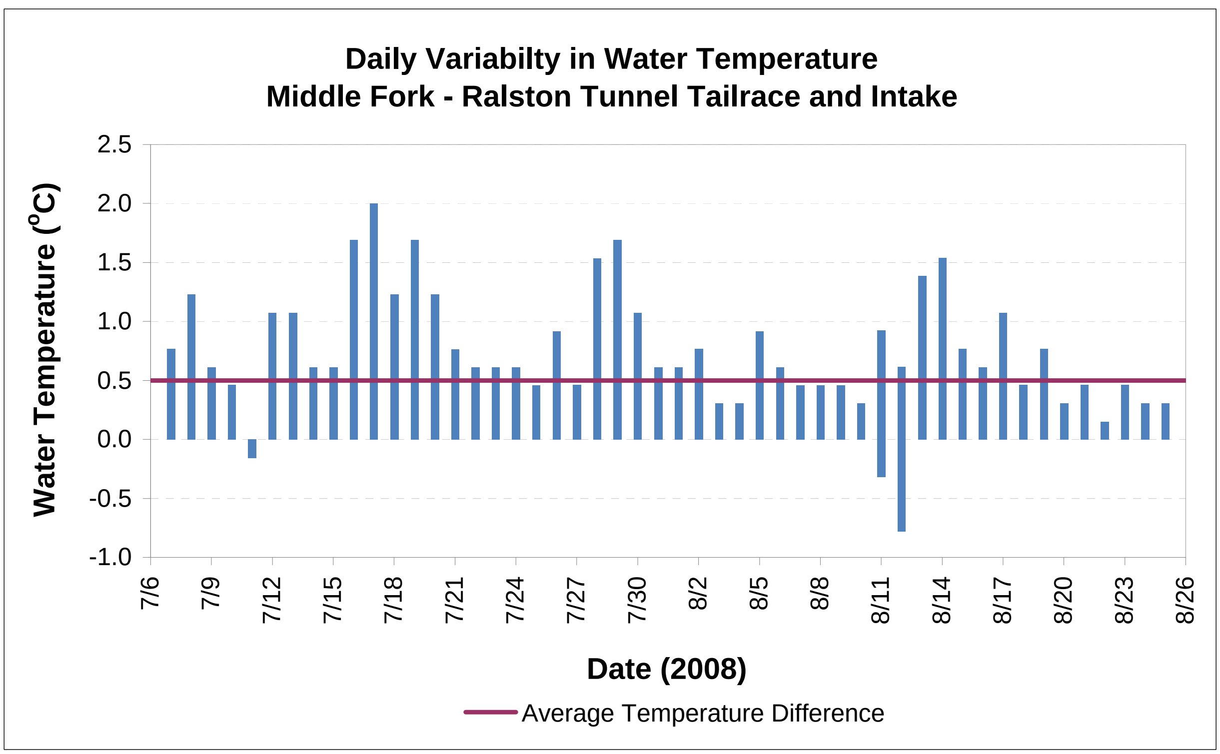


Figure AQ 4-8b. Difference Between Intake and Tailrace Water Temperatures for the Middle Fork Interbay - Ralston Afterbay Tunnel: July-August 2008.

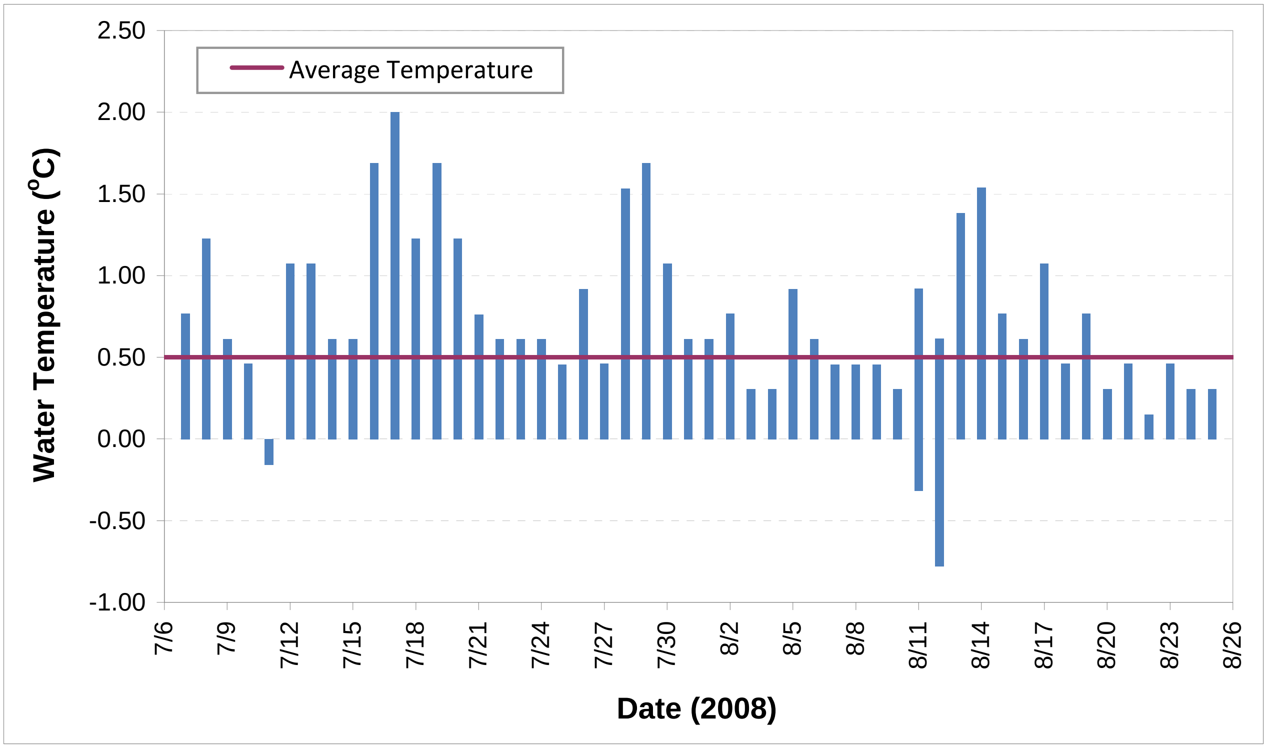


Figure AQ 4-9. Water Temperature and Tunnel Length Heating Relationship.

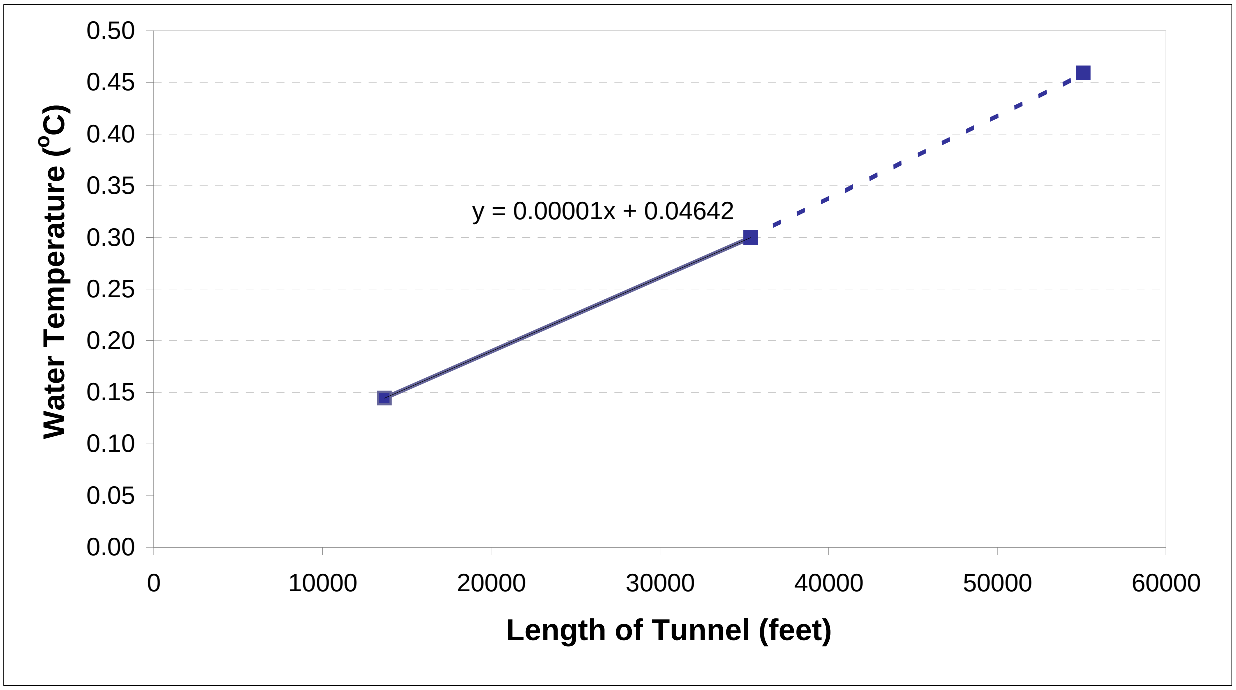


Figure AQ 4-10. Water Surface Elevation Model Calibration Results for French Meadows Reservoir (2006).

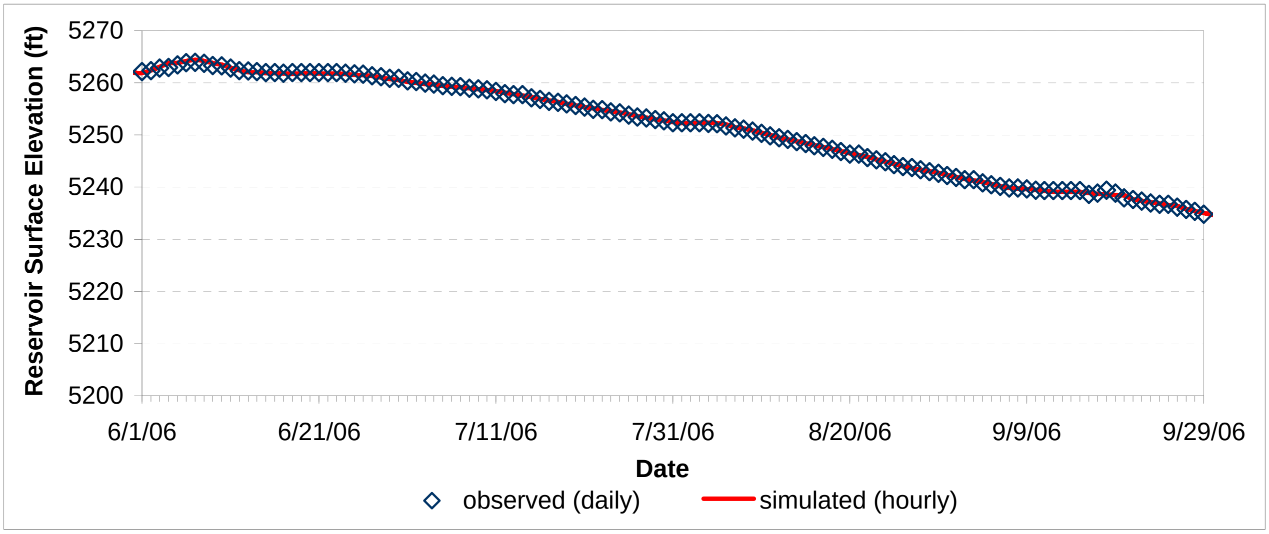


Figure AQ 4-11. Water Surface Elevation Model Calibration Results for French Meadows Reservoir (2007).

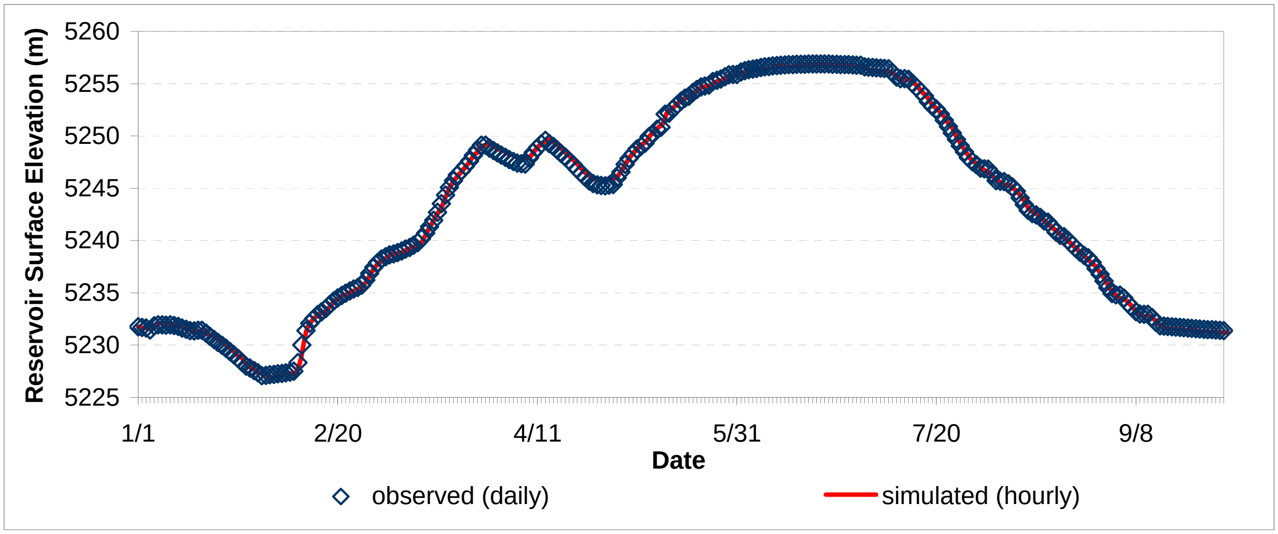


Figure AQ 4-12. Water Surface Elevation Model Calibration Results for Hell Hole Reservoir (2006).

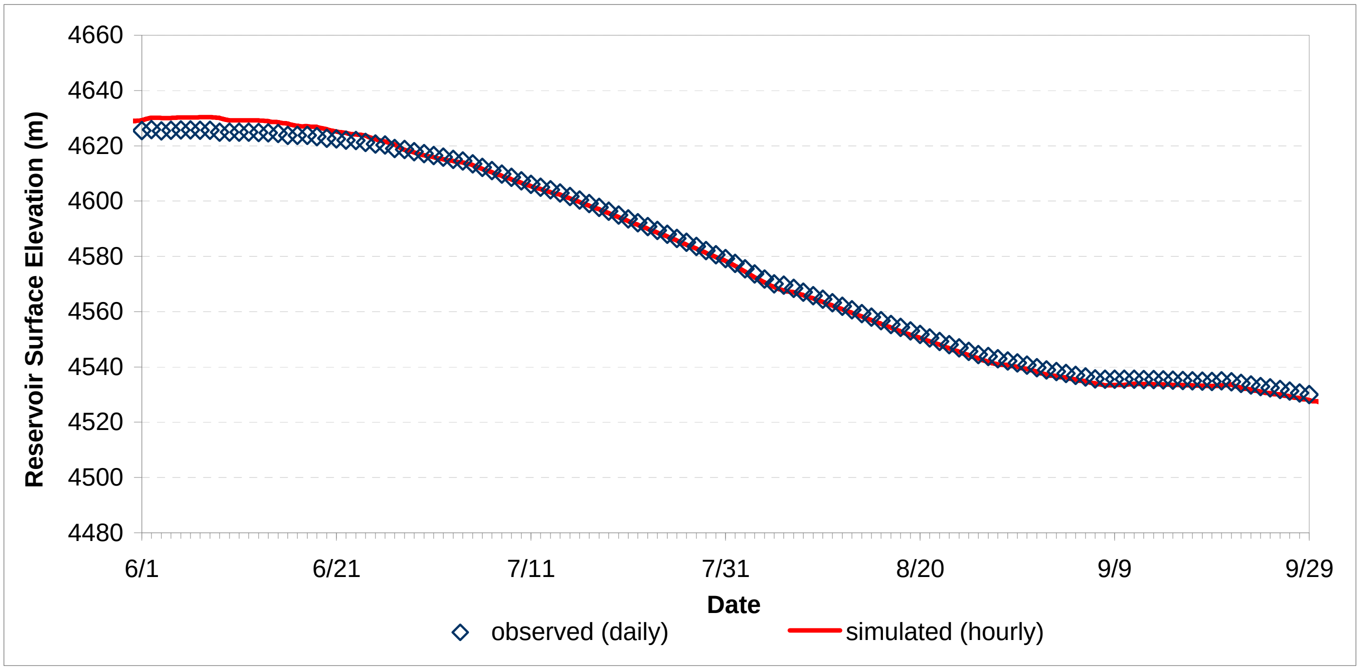


Figure AQ 4-13. Water Surface Elevation Model Calibration Results for Hell Hole Reservoir (2007).

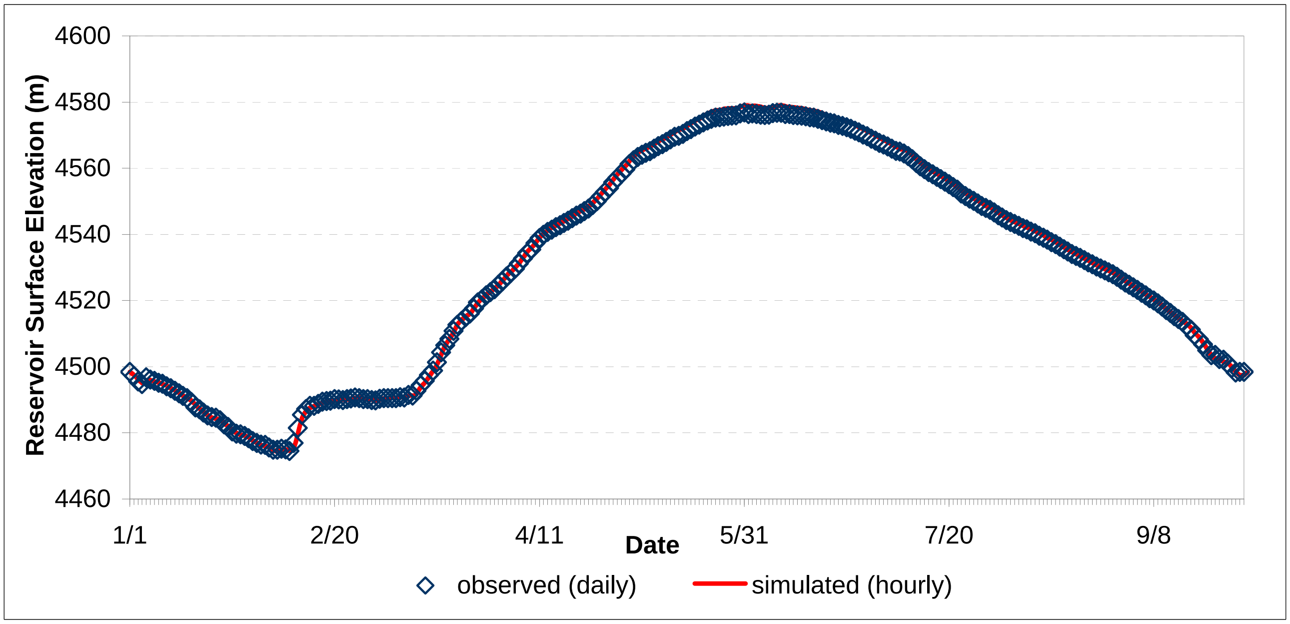


Figure AQ 4-14. Water Surface Elevation Model Calibration Results for Ralston Afterbay (2006).

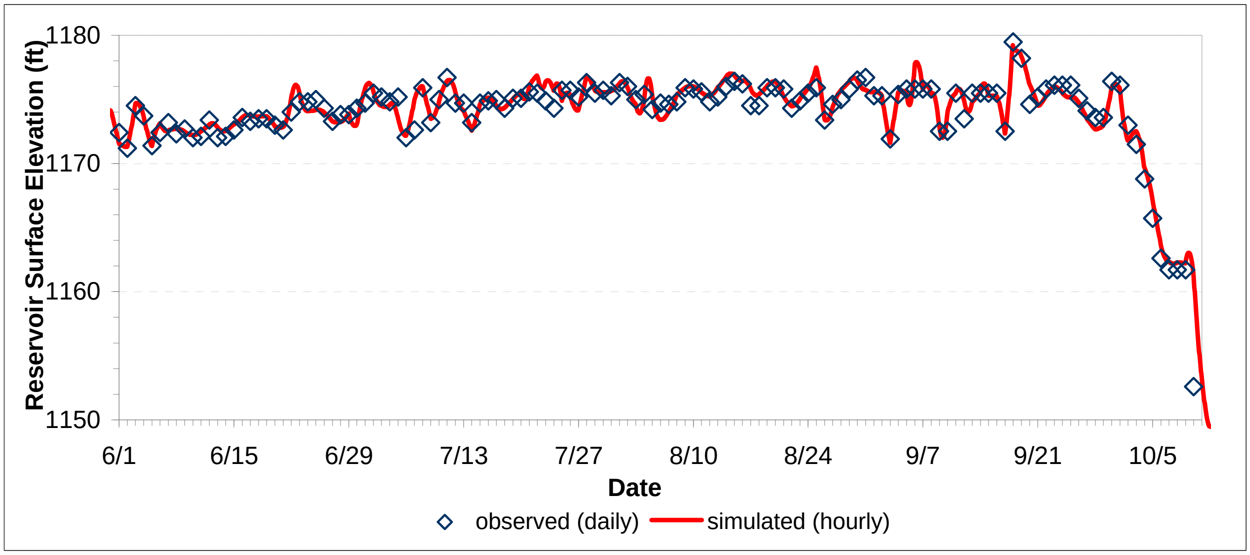


Figure AQ 4-15. Water Surface Elevation Model Calibration Results for Ralston Afterbay (2007).

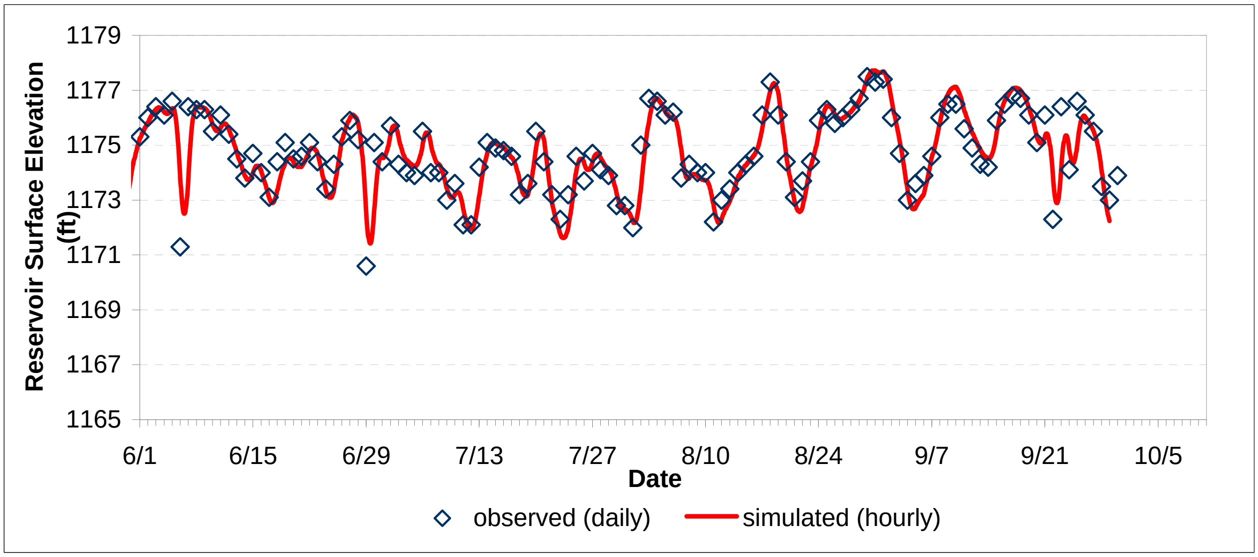
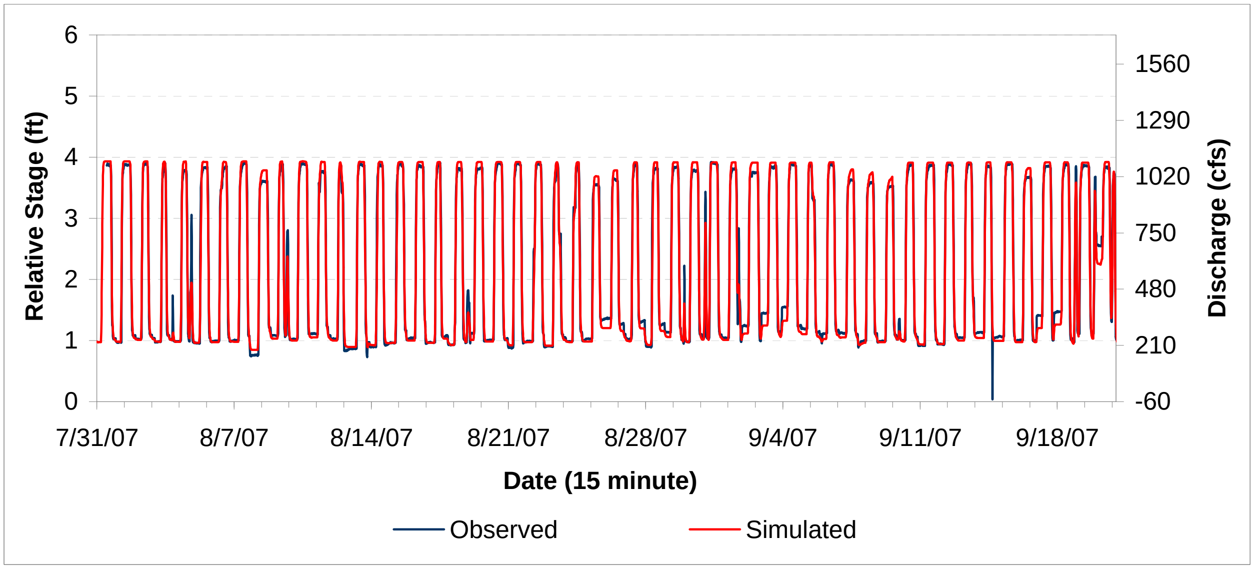


Figure AQ 4-16. RMA-2 Hydrodynamics Calibration Results for the Peaking Reach -- Near Foresthill USGS Gage RM 23.75.



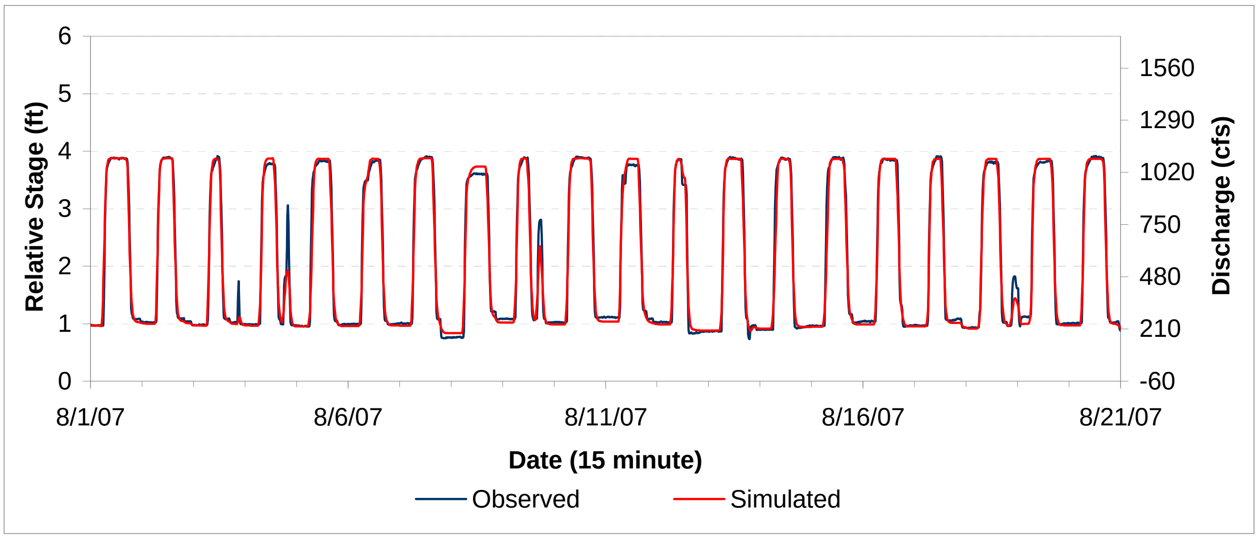
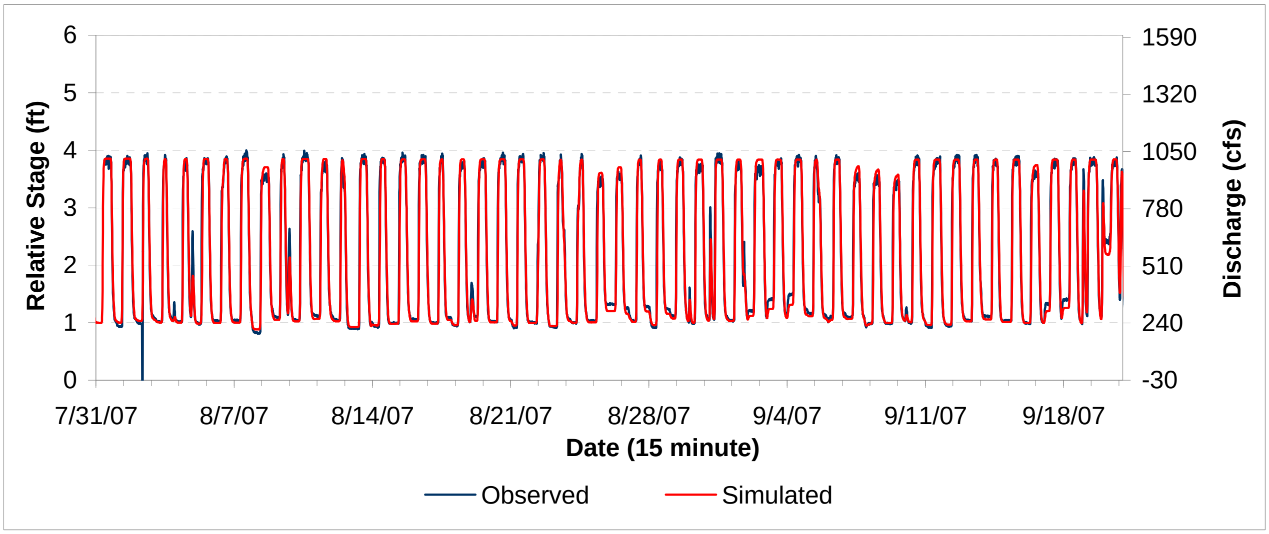


Figure AQ 4-17. RMA-2 Hydrodynamics Calibration Results for the Peaking Reach -- Cache Rock RM 19.3.



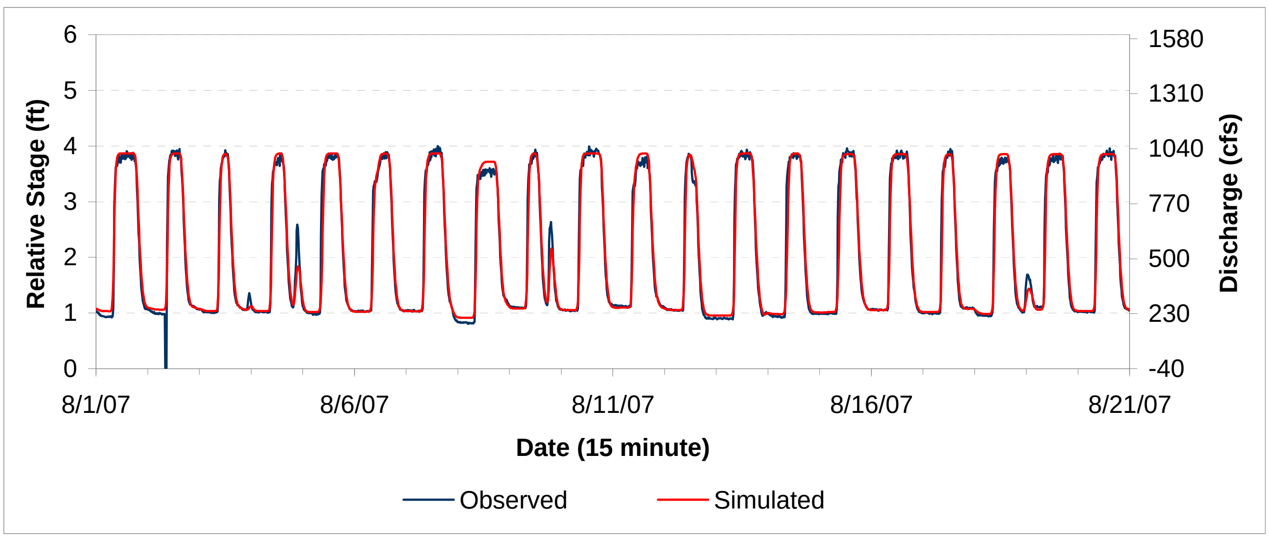
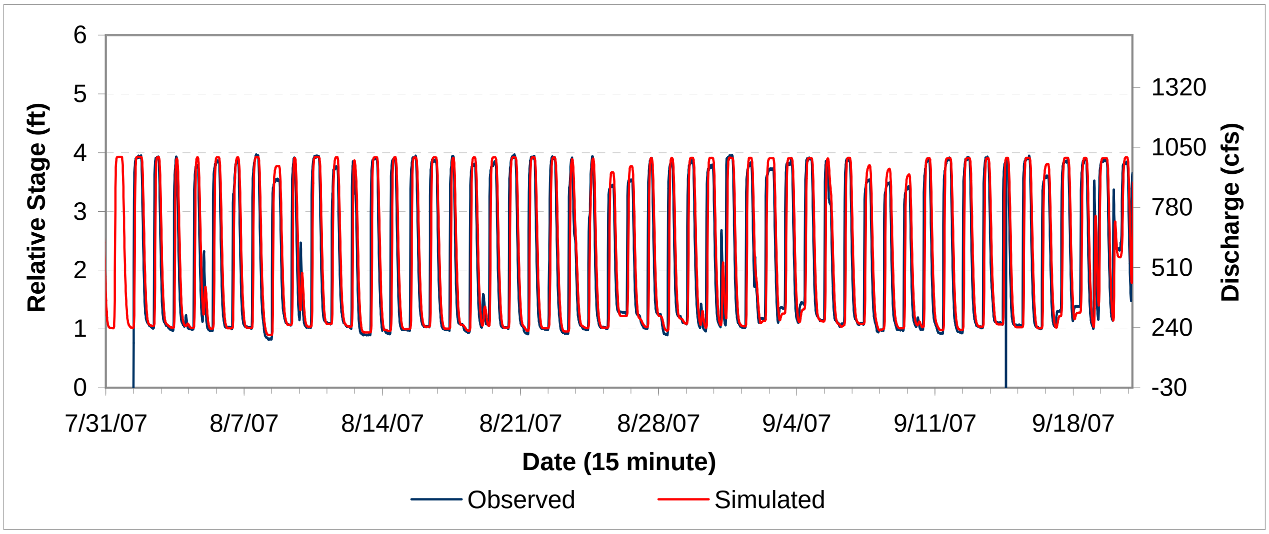


Figure AQ 4-18. RMA-2 Hydrodynamics Calibration Results for the Peaking Reach -- Otter Creek RM 14.5.



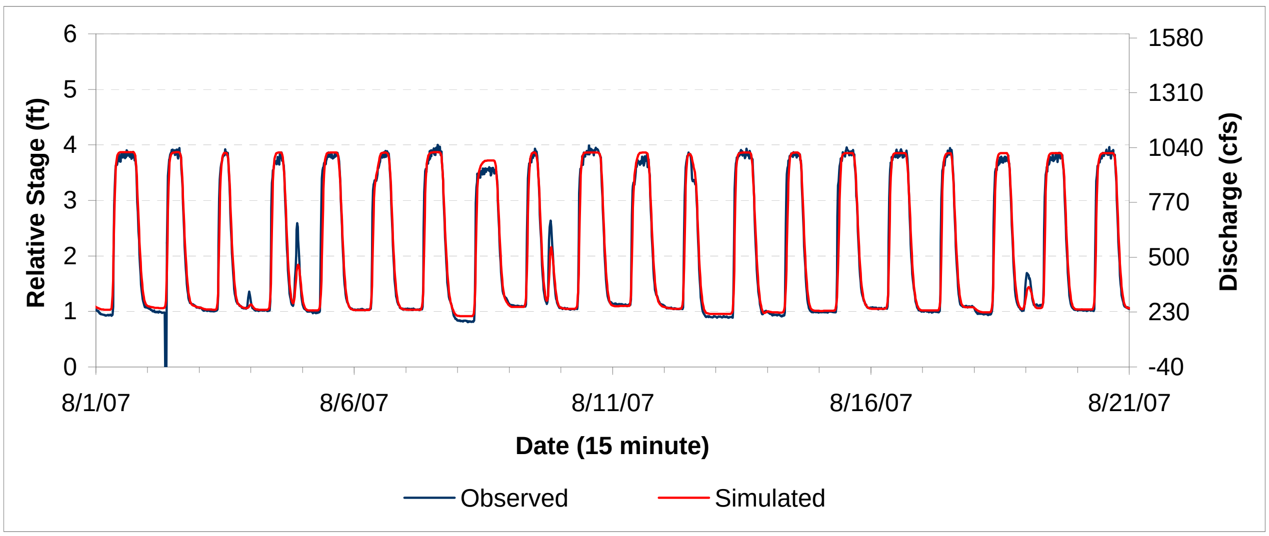
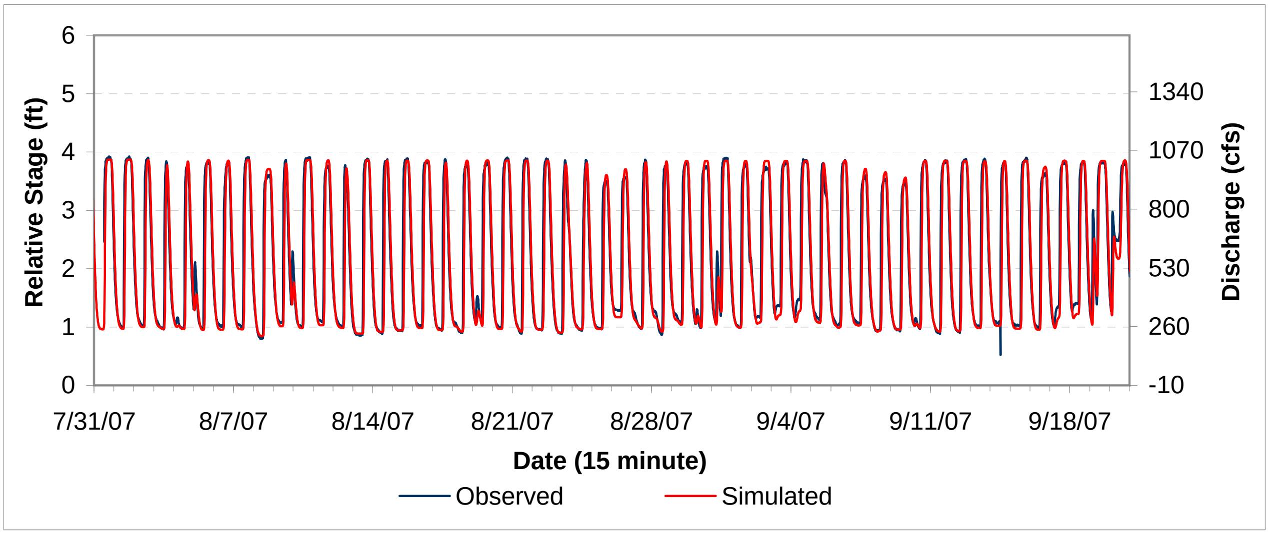


Figure AQ 4-19. RMA-2 Hydrodynamics Calibration Results for the Peaking Reach -- Drivers Flat RM 9.5.



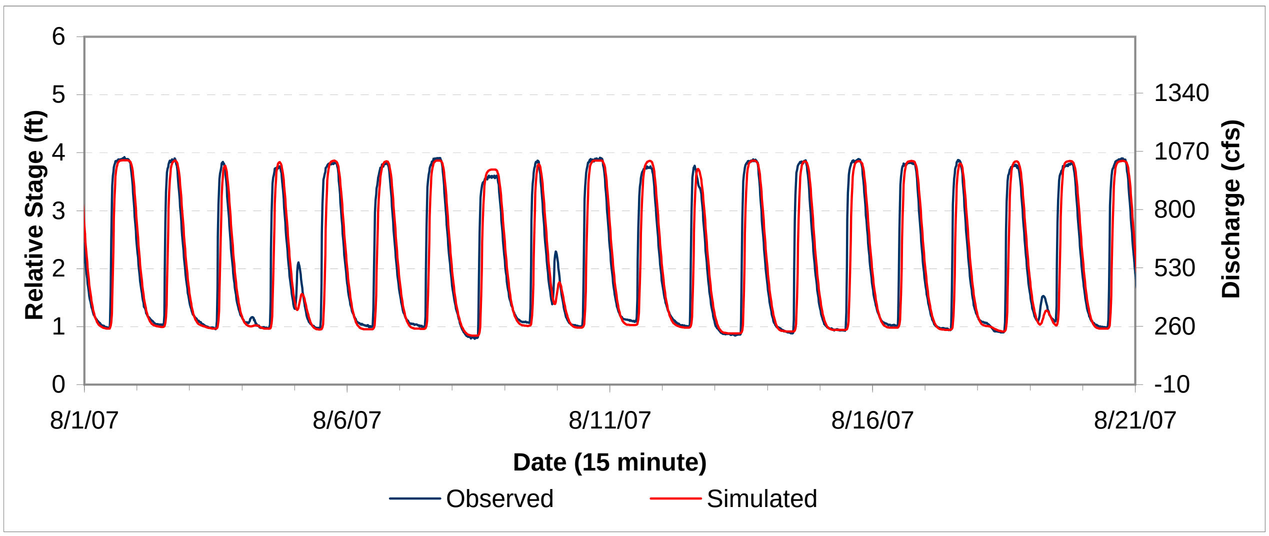
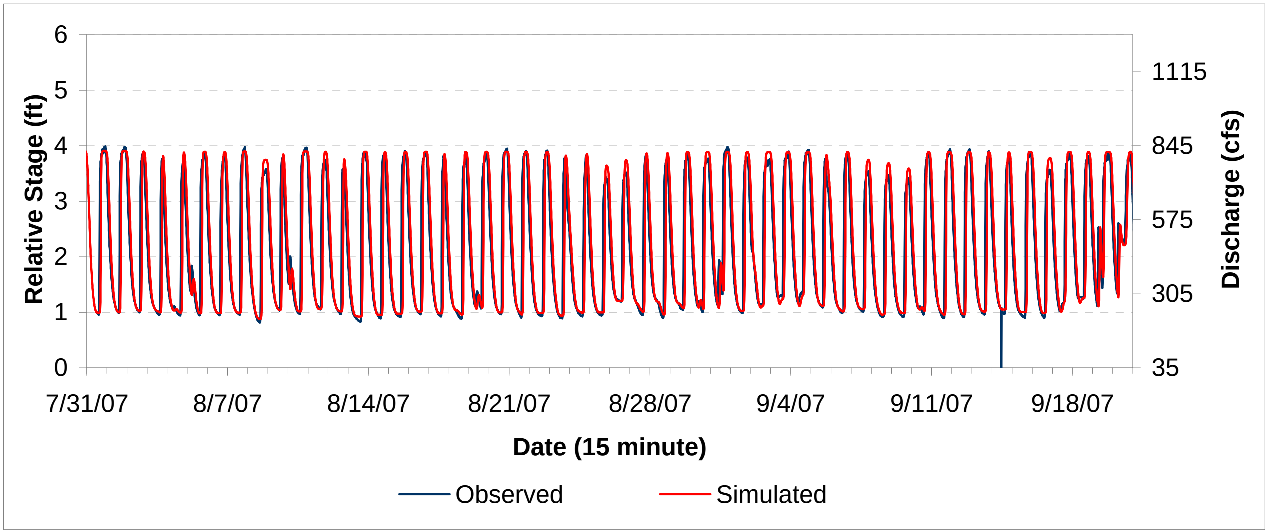


Figure AQ 4-20. RMA-2 Hydrodynamics Calibration Results for the Peaking Reach -- Below Mammoth Bar RM 1.4.



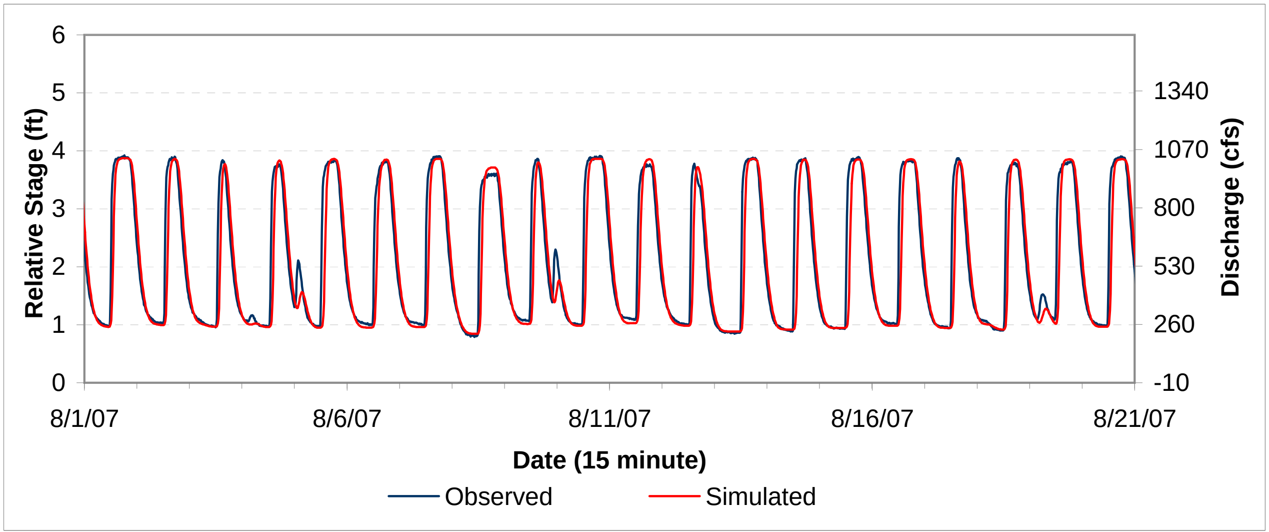
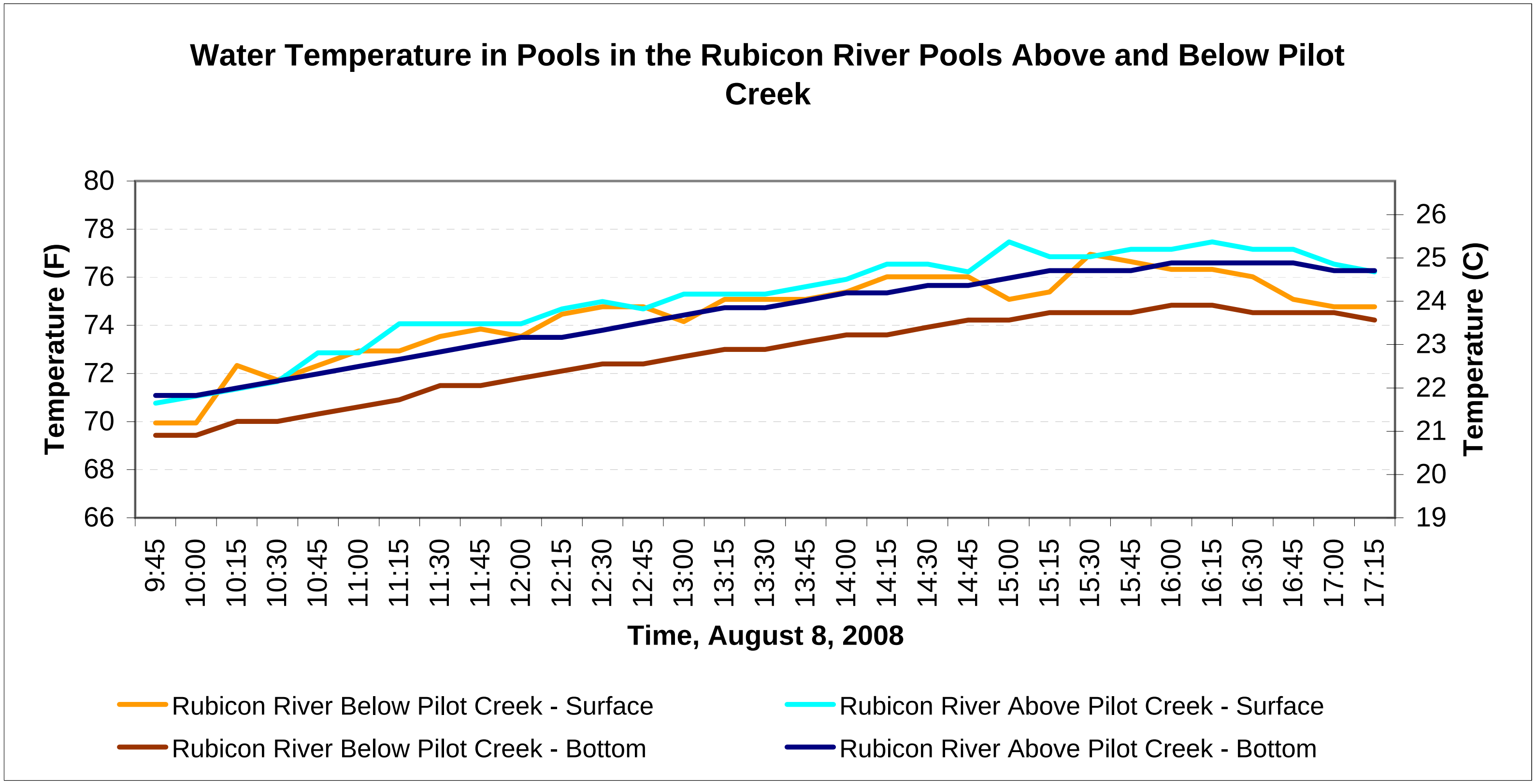


Figure AQ 4-21. Water Temperature in the Rubicon River Measured at the Surface and Bottom of Pools Above and Below the Confluence with Pilot Creek.



MAPS

APPENDIX A

Attributes of Prospective Water Temperature Models

Appendix A

A review of applicable river and reservoir flow and temperature models was completed to aid model selection for the Middle Fork American River Project. A wide range of model attributes was examined for nine river models and two reservoir models (Table A-1). A few critical attributes used to assess the models included documentation, active support, open source codes, and pre-and post-processors. Specific to river models, attributes of particular concern included:

- longitudinal temperature gradients;
- replication of dynamic flow conditions on a short time step (e.g., one-hour) to assess potential implications of hydropower operations, i.e., robust hydrodynamics;
- sub-daily temperatures/maximum daily temperatures;
- topographic and riparian shading; and
- representation of steep river reaches.

For reservoirs the primary attributes included:

- ability to assess multiple level outlets;
- sub-daily simulation time steps; and
- representation of mid-reservoir conditions to assess implications of water transfers from French Meadows Reservoir to Hell Hole Reservoir.

There were several models potentially applicable to the Project. Discussions with the Aquatic TWG, resource availability, schedule, and system attributes were considered when selecting a final model. Ultimately the suite of RMA-2 and RMA-11 for river reaches and CE-QUAL-W2 for the reservoirs was selected.

TABLES

Table A-1. General Model Attributes Considered during Model Selection.

		Model										
		TVA	QUAL-2K	WASP	HEC- RAS (Temp)	HSPF	Heat Source	SNTEMP	RMA2/ RMA11	CE-QUAL-RIV1	CE-QUAL-W2	CE-QUAL-R1
Attribute	**Author/ Sponsor**	**Tennessee Valley Authority**	**EPA[e]**	**EPA**	**U.S. Army Corps**	**USGS[e]**	**Oregon Dept of Envir. Quality**	**USGS**	**RMA[e]**	**U.S. Army Corps**	**U.S. Army Corps**	**U.S. Army Corps**
	System	**River**	**River**	**River**	**River**	**River**	**River**	**River**	**River**	**River**	**River/ Reservoir**	**Reservoir**
	Dimension	1	1	1,2,3	1	1	1	1	1,2	1	1,2	1
	Dynamic Flow Model	Yes	No	Yes[a]	Yes	No	Yes	No	Yes	Yes	Yes	No
	Boundary Condition	P,NP	P,NP	P,NP	P,NP	P,NP	P,NP	P	P,NP	P,NP	P,NP	P
	Topographic Shade	No	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No
	Riparian Shade[b]	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No
	Steep River Logic[c]	No	No	No	No	Yes	No	n/a	Yes	No	n/a	n/a
	Bed Conduction	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	n/a
	Hyporheic Flow	No	No	No	No	No	No	No	No	No	n/a	n/a
	Time Step	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	SD
	Actively Supported	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Pre-Processor	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
	Post Processor	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
	Open Source Code	Yes	Yes	Yes	Yes[d]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Documentation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Boundary Conditions: P – Point, and NP – Nonpoint

Time Step: SD – sub-daily, and D - Daily

[a]Requires a hydrodynamic model (e.g., Dynhyd).

[b]Solar radiation can be pre-processed for all models. There is a version of RMA-11 that includes riparian vegetation shading for the one-dimensional formulation.

[c]Steep river logic in HSPF includes representing reaches as pools with weirs, a cumbersome but potentially viable approach.

[d]HEC_RAS temperature model was in beta version when this process commenced. Status of source code is currently unknown.

[e]EPA = Environmental Protection Agency, USFS = United States Geological Survey, RMA = Resource Management Associates.

APPENDIX B

Channel Geometry

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TABLES

Table B-1a. Middle Fork American River from French Meadows Reservoir to Middle Fork Interbay Pool Habitat Cross-Section Representation.

Calibrated Flow, cfs	Calculated Stage, ft	Wetted Area, ft^2	Wetted Width, ft	Average Depth, ft
0.25	0.42	23.38	21.16	1.09
0.50	0.52	25.60	21.91	1.14
0.75	0.60	27.21	22.44	1.19
1.00	0.65	28.51	23.00	1.21
1.25	0.70	29.64	23.50	1.23
1.50	0.74	30.64	23.85	1.25
1.75	0.78	31.54	24.09	1.28
2.00	0.82	32.37	24.26	1.30
2.25	0.85	33.14	24.41	1.33
2.50	0.88	33.85	24.54	1.35
5.00	1.10	39.34	25.58	1.51
7.50	1.25	43.30	26.38	1.62
10.00	1.38	46.55	27.26	1.68
15.00	1.57	51.86	28.14	1.82
20.00	1.72	56.20	28.61	1.94
30.00	1.96	63.23	29.68	2.11
40.00	2.16	69.00	30.66	2.23
50.00	2.32	74.10	32.82	2.23
60.00	2.46	78.89	34.90	2.23
70.00	2.59	83.38	36.20	2.28
80.00	2.70	87.59	37.23	2.33
90.00	2.81	91.56	38.12	2.38
100.00	2.91	95.33	38.87	2.44
110.00	3.00	98.93	39.80	2.47
120.00	3.08	102.38	40.43	2.52
130.00	3.16	105.69	40.98	2.57
140.00	3.24	108.87	41.45	2.62
150.00	3.32	111.94	41.96	2.67
175.00	3.49	119.18	42.95	2.78
200.00	3.64	125.90	44.00	2.87
225.00	3.78	132.22	44.83	2.97
250.00	3.92	138.30	47.07	2.98
275.00	4.04	144.17	47.80	3.06
300.00	4.16	149.76	48.47	3.14
350.00	4.37	160.27	49.85	3.25
400.00	4.57	170.10	51.11	3.36
450.00	4.75	179.32	51.98	3.47
500.00	4.92	187.99	52.73	3.58
550.00	5.07	196.20	53.33	3.70

Table B-1b. Middle Fork American River from French Meadows Reservoir to Middle Fork Interbay Run Habitat Cross-Section Representation.

Calculated Stage, ft	Wetted Area, ft^2	Wetted Width, ft	Average Depth, ft	Velocity, ft/sec
0.60	7.48	15.94	0.43	0.12
0.73	9.93	19.23	0.49	0.16
0.82	11.75	21.66	0.53	0.18
0.89	13.26	23.32	0.57	0.21
0.98	15.66	25.35	0.62	0.25
1.07	17.84	27.23	0.65	0.28
1.18	21.09	29.10	0.72	0.34
1.27	23.78	30.90	0.77	0.39
1.35	25.97	31.77	0.82	0.44
1.48	30.47	33.04	0.93	0.55
1.66	36.50	36.23	1.02	0.66
1.83	42.96	39.15	1.12	0.80
1.95	47.45	41.32	1.17	0.88
2.05	51.65	42.57	1.23	0.98
2.12	54.72	43.77	1.27	1.04
2.22	59.39	45.15	1.34	1.15
2.26	60.94	45.68	1.36	1.18
2.33	64.03	47.27	1.38	1.23
2.37	66.01	48.09	1.40	1.27
2.58	76.82	54.97	1.41	1.40
2.86	92.10	61.32	1.51	1.66
3.13	108.92	64.91	1.69	2.03
3.13	109.29	64.97	1.70	2.04
3.50	134.79	74.32	1.82	2.46
3.72	151.73	76.13	1.99	2.86
3.95	169.41	81.07	2.09	3.18
4.10	182.53	81.66	2.23	3.53
4.25	194.57	82.14	2.36	3.86
4.38	205.75	82.59	2.48	4.18
4.50	216.22	82.95	2.59	4.48

Table B-1c. Middle Fork American River from French Meadows Reservoir to Middle Fork Interbay Low Gradient Riffle (LGR) Habitat Cross-Section Representation.

Calculated Stage, ft	Wetted Area, ft^2	Wetted Width, ft	Average Depth, ft	Velocity, ft/sec
0.65	5.56	18.38	0.28	0.15
0.75	7.39	21.42	0.33	0.20
0.81	8.71	23.19	0.36	0.23
0.86	9.86	24.37	0.39	0.27
0.93	11.68	26.24	0.44	0.32
0.99	13.16	27.36	0.48	0.37
1.08	15.66	29.41	0.54	0.45
1.15	17.99	32.00	0.58	0.51
1.21	19.91	33.55	0.62	0.57
1.34	24.11	37.10	0.69	0.69
1.47	29.16	39.75	0.78	0.85
1.61	34.84	43.52	0.86	1.02
1.70	38.59	45.17	0.91	1.13
1.79	42.34	46.54	0.97	1.25
1.85	44.91	47.42	1.01	1.34
1.96	50.04	51.29	1.01	1.42
1.99	51.42	51.83	1.02	1.46
2.05	54.91	56.12	1.03	1.51
2.08	56.75	57.11	1.04	1.55
2.24	65.17	62.03	1.09	1.72
2.45	78.15	67.30	1.20	2.06
2.69	94.85	73.61	1.31	2.47
2.69	95.22	73.73	1.32	2.48
2.96	116.05	80.02	1.48	3.05
3.17	133.98	86.45	1.60	3.51
3.36	150.07	91.17	1.68	3.91
3.50	163.46	93.26	1.78	4.30
3.64	176.43	96.20	1.85	4.60
3.75	187.68	97.43	1.94	4.96
3.86	198.29	98.57	2.02	5.30

Table B-1d. Middle Fork American River from French Meadows Reservoir to Middle Fork Interbay High Gradient Riffle (HGR) Habitat Cross-Section Representation.

Calculated Stage, ft	Wetted Area, ft^2	Wetted Width, ft	Average Depth, ft	Velocity, ft/sec
0.58	2.01	6.90	0.31	0.30
0.71	2.90	7.87	0.39	0.39
0.81	3.65	9.02	0.44	0.45
0.90	4.52	10.99	0.44	0.48
1.01	5.80	13.07	0.48	0.55
1.09	6.80	14.11	0.52	0.61
1.21	8.73	16.78	0.58	0.71
1.32	10.44	19.06	0.62	0.78
1.40	11.92	20.49	0.66	0.85
1.56	15.31	23.71	0.72	1.00
1.78	20.75	30.74	0.73	1.10
1.95	25.96	34.70	0.79	1.26
2.06	29.69	37.62	0.83	1.36
2.15	33.30	39.94	0.88	1.47
2.22	35.79	41.40	0.92	1.54
2.31	39.79	43.32	0.98	1.67
2.34	40.97	43.63	1.00	1.72
2.39	43.07	44.12	1.03	1.79
2.43	44.51	44.50	1.06	1.84
2.57	51.00	46.16	1.17	2.07
2.81	62.06	49.10	1.34	2.44
3.12	77.11	53.35	1.51	2.85
3.13	77.43	53.40	1.52	2.86
3.47	95.28	55.61	1.78	3.46
3.73	109.95	57.20	2.00	3.94
3.97	123.25	58.75	2.19	4.36
4.19	135.54	60.15	2.35	4.74
4.40	147.87	62.23	2.46	5.05
4.58	158.83	63.34	2.58	5.37
4.74	169.02	64.16	2.71	5.68

Table B-2a. Middle Fork American River from Middle Fork Interbay to Ralston Afterbay Pool Habitat Cross-Section Representation.

Calculated stage, ft	Wetted Area, ft^2	Wetted Width, ft	Avgerage Depth, ft	Velocity, ft/sec
0.81	62.61	30.21	1.90	0.04
1.02	69.54	33.45	2.03	0.06
1.26	77.90	36.33	2.18	0.09
1.41	83.78	38.53	2.25	0.11
1.53	88.38	40.08	2.28	0.13
1.63	92.28	41.27	2.32	0.15
1.82	100.46	43.66	2.43	0.20
1.97	106.97	45.52	2.50	0.24
2.19	117.16	47.77	2.62	0.31
2.35	125.20	49.46	2.70	0.38
2.49	132.25	51.23	2.75	0.44
2.61	138.35	53.28	2.76	0.49
2.70	143.68	54.51	2.79	0.55
2.79	148.77	55.39	2.85	0.60
2.88	153.45	56.15	2.90	0.65
2.95	157.82	56.94	2.95	0.70
3.14	169.03	58.26	3.09	0.83
3.31	178.70	59.43	3.19	0.96
3.45	187.74	60.41	3.30	1.08
3.54	193.29	61.04	3.36	1.15
3.66	200.64	61.72	3.45	1.26
3.81	210.45	62.48	3.56	1.42
3.98	221.38	64.06	3.66	1.59
4.12	230.76	65.02	3.76	1.74
4.30	243.41	66.14	3.90	1.97
4.46	254.88	67.20	4.02	2.19
4.65	269.01	68.67	4.15	2.46
4.82	280.75	69.18	4.28	2.73
4.96	291.53	69.62	4.41	3.00
5.09	301.33	69.89	4.53	3.25

Table B-2b. Middle Fork American River from Middle Fork Interbay to Ralston Afterbay Run Habitat Cross-Section Representation.

Calculated stage, ft	Wetted Area, ft^2	Wetted Width, ft	Avgerage Depth, ft	Velocity, ft/sec
0.32	9.41	18.96	0.51	0.12
0.48	12.51	21.36	0.60	0.17
0.66	16.56	23.66	0.71	0.26
0.78	19.58	25.14	0.78	0.33
0.88	22.08	26.33	0.84	0.39
0.95	24.24	27.30	0.89	0.44
1.13	29.32	30.81	0.95	0.55
1.25	33.23	32.70	1.02	0.65
1.42	39.17	34.66	1.14	0.83
1.59	45.44	39.04	1.17	0.95
1.70	49.81	40.39	1.24	1.09
1.79	53.35	40.88	1.31	1.22
1.87	56.52	41.25	1.37	1.34
1.94	59.44	41.59	1.43	1.45
2.01	62.16	41.96	1.48	1.56
2.07	64.82	42.47	1.53	1.66
2.29	74.02	47.32	1.56	1.87
2.45	82.21	51.59	1.59	2.06
2.58	88.88	53.98	1.64	2.25
2.65	92.71	54.96	1.68	2.38
2.74	97.92	56.17	1.74	2.57
2.88	105.52	58.43	1.80	2.83
3.02	114.35	62.62	1.82	3.05
3.14	121.45	64.60	1.88	3.29
3.29	131.38	67.46	1.94	3.62
3.42	140.34	69.78	2.01	3.95
3.57	151.25	72.47	2.09	4.35
3.69	160.09	73.55	2.18	4.75
3.80	168.17	74.33	2.27	5.14
3.90	175.93	75.33	2.34	5.50

Table B-2c. Middle Fork American River from Middle Fork Interbay to Ralston Afterbay Low Gradient Riffle (LGR) Habitat Cross-Section Representation.

Calculated stage, ft	Wetted Area, ft^2	Wetted Width, ft	Avgerage Depth, ft	Velocity, ft/sec
0.71	6.07	18.27	0.36	0.18
0.84	8.36	19.71	0.45	0.25
1.02	11.75	22.29	0.56	0.36
1.15	14.53	24.87	0.60	0.43
1.25	17.09	27.90	0.63	0.48
1.33	19.31	30.07	0.66	0.53
1.49	24.72	37.34	0.67	0.62
1.59	28.58	40.18	0.71	0.71
1.75	35.24	45.44	0.78	0.86
1.86	40.53	48.25	0.85	0.99
1.96	45.34	51.40	0.90	1.11
2.03	49.13	52.10	0.97	1.22
2.10	52.58	52.73	1.03	1.33
2.16	55.80	53.31	1.08	1.44
2.22	58.91	54.29	1.12	1.53
2.27	61.84	55.23	1.16	1.62
2.43	70.10	57.69	1.25	1.86
2.55	77.41	59.71	1.33	2.07
2.66	84.05	61.38	1.40	2.27
2.73	88.09	62.26	1.44	2.39
2.83	93.74	63.48	1.51	2.57
3.00	105.44	70.94	1.49	2.72
3.11	113.29	72.05	1.58	2.98
3.21	120.53	73.07	1.66	3.22
3.35	130.51	74.48	1.76	3.55
3.47	139.70	75.75	1.85	3.86
3.61	150.92	77.24	1.96	4.24
3.75	161.17	78.47	2.06	4.59
3.87	170.61	79.55	2.16	4.93
3.98	179.51	80.54	2.24	5.25

Table B-2d. Middle Fork American River from Middle Fork Interbay to Ralston Afterbay High Gradient Riffle (HGR) Habitat Cross-Section Representation.

Calculated stage, ft	Wetted Area, ft^2	Wetted Width, ft	Avgerage Depth, ft	Velocity, ft/sec
1.10	7.06	13.68	0.50	1.12
1.26	8.95	14.55	0.60	1.23
1.47	11.74	16.99	0.68	1.25
1.59	13.72	17.89	0.77	1.31
1.69	15.36	18.61	0.84	1.36
1.78	16.78	19.05	0.90	1.41
1.95	19.91	20.65	0.98	1.50
2.10	22.84	23.13	1.04	1.47
2.32	28.12	26.49	1.16	1.47
2.49	32.59	28.39	1.26	1.55
2.63	36.61	31.01	1.33	1.62
2.76	40.54	34.00	1.40	1.67
2.87	44.31	36.04	1.47	1.72
2.97	47.94	37.02	1.54	1.78
3.06	51.39	37.87	1.60	1.84
3.15	54.79	38.92	1.65	1.91
3.39	64.51	41.99	1.78	2.10
3.58	73.09	43.97	1.89	2.29
3.77	81.56	46.57	1.98	2.46
3.93	87.89	49.44	1.90	2.50
4.07	95.50	52.95	1.94	2.65
4.27	106.90	56.97	2.00	2.85
4.44	117.00	57.93	2.13	3.10
4.60	127.10	59.90	2.23	3.33
4.81	140.83	62.05	2.38	3.65
4.99	153.02	63.32	2.52	3.97
5.21	167.84	64.74	2.68	4.37
5.45	182.70	67.96	2.73	4.66
5.65	196.64	69.67	2.84	4.94
5.82	209.35	70.77	2.96	5.23

Table B-3a. Middle Fork American River from Ralston Afterbay to Folsom Reservoir Pool Habitat Cross-Section Representation.

Calc stage, ft	Wetted Area, ft^2	Wetted Width, ft	Avg. Depth, ft	Velocity, ft/sec
1.549	492.754	122.821	4.176	0.016
1.789	521.752	125.072	4.345	0.028
2.067	556.323	128.752	4.528	0.048
2.249	579.677	130.896	4.652	0.067
2.389	597.777	132.139	4.751	0.085
2.504	612.778	133.088	4.828	0.102
2.603	625.671	133.669	4.906	0.118
2.688	637.029	134.172	4.973	0.134
2.764	647.224	134.629	5.033	0.149
2.835	656.504	135.039	5.087	0.165
2.898	665.035	135.397	5.136	0.180
3.038	683.864	136.179	5.247	0.216
3.158	700.041	136.823	5.339	0.251
3.264	714.307	137.461	5.418	0.284
3.357	727.134	138.144	5.481	0.318
3.443	738.826	138.779	5.532	0.350
3.522	749.602	139.352	5.581	0.382
3.662	768.980	140.396	5.669	0.443
3.782	786.111	141.482	5.746	0.503
3.892	801.553	142.148	5.826	0.561
3.993	815.627	142.748	5.899	0.618
4.082	828.591	143.317	5.962	0.674
4.244	851.892	144.341	6.079	0.782
4.388	872.492	145.219	6.181	0.887
4.515	891.044	146.203	6.268	0.990
4.633	907.992	147.099	6.346	1.089
4.738	923.630	147.775	6.419	1.187
5.172	988.059	150.122	6.744	1.650
5.504	1038.182	151.891	6.990	2.082
5.777	1079.864	153.574	7.184	2.494

Table B-3b. Middle Fork American River from Ralston Afterbay to Folsom Reservoir Run Habitat Cross-Section Representation.

Calc stage, ft	Wetted Area, ft^2	Wetted Width, ft	Avg. Depth, ft	Velocity, ft/sec
1.571	36.157	38.827	0.855	0.571
1.811	46.384	45.239	0.965	0.689
2.066	58.344	49.074	1.141	0.859
2.234	66.634	50.791	1.269	0.990
2.374	73.493	52.470	1.361	1.089
2.494	79.776	54.068	1.429	1.178
2.594	85.014	55.234	1.495	1.255
2.692	90.236	57.041	1.536	1.316
2.774	94.771	58.287	1.581	1.376
2.846	98.924	59.159	1.627	1.437
2.918	102.998	60.278	1.660	1.485
3.078	112.536	62.976	1.731	1.599
3.203	120.426	64.493	1.810	1.709
3.313	127.573	65.826	1.881	1.810
3.411	134.100	66.983	1.942	1.903
3.512	140.746	68.693	1.989	1.985
3.598	146.749	69.984	2.036	2.063
3.749	157.477	71.901	2.129	2.212
3.886	167.553	73.983	2.205	2.345
4.007	176.810	75.804	2.276	2.468
4.115	185.239	77.186	2.346	2.586
4.217	193.152	78.454	2.407	2.696
4.411	208.771	82.176	2.501	2.862
4.578	222.555	84.834	2.589	3.029
4.729	235.612	87.664	2.664	3.175
4.860	247.284	89.494	2.745	3.328
4.986	258.746	91.446	2.818	3.469
5.496	308.729	101.281	3.101	4.065
5.864	346.418	104.571	3.363	4.617
6.174	379.172	107.330	3.584	5.104

Table B-3c. Middle Fork American River from Ralston Afterbay to Folsom Reservoir Low Gradient Riffle (LGR) Habitat Cross-Section Representation.

Calc stage, ft	Wetted Area, ft^2	Wetted Width, ft	Avg. Depth, ft	Velocity, ft/sec
1.018	24.854	44.252	0.513	0.520
1.204	33.982	52.737	0.612	0.633
1.451	49.113	66.073	0.699	0.745
1.592	58.340	69.884	0.794	0.861
1.707	66.350	73.823	0.863	0.951
1.798	72.998	76.097	0.927	1.030
1.883	79.289	79.228	0.978	1.094
1.984	87.031	87.710	0.964	1.092
2.043	92.190	89.124	1.010	1.149
2.099	97.049	90.538	1.047	1.201
2.156	102.183	93.804	1.078	1.240
2.274	113.340	98.052	1.150	1.336
2.374	123.097	100.764	1.220	1.430
2.462	131.994	102.954	1.283	1.516
2.538	140.208	104.844	1.341	1.594
2.616	148.018	106.733	1.393	1.666
2.687	155.474	108.589	1.439	1.732
2.819	170.739	114.272	1.511	1.846
2.926	182.931	116.219	1.596	1.962
3.026	194.668	118.889	1.666	2.059
3.117	205.127	120.119	1.737	2.158
3.200	215.093	121.420	1.804	2.251
3.360	235.106	126.436	1.906	2.397
3.497	251.967	128.071	2.014	2.548
3.621	267.429	129.286	2.113	2.691
3.732	281.746	130.346	2.208	2.825
3.839	295.490	131.144	2.300	2.953
4.288	354.399	134.761	2.672	3.492
4.652	403.664	137.472	2.976	3.938
4.966	446.709	139.552	3.236	4.326

Table B-3d. Middle Fork American River from Ralston Afterbay to Folsom Reservoir High Gradient Riffle (HGR) Habitat Cross-Section Representation.

Calc stage, ft	Wetted Area, ft^2	Wetted Width, ft	Avg. Depth, ft	Velocity, ft/sec
0.755	12.445	35.390	0.370	0.436
0.915	19.125	52.040	0.435	0.536
1.095	27.835	60.475	0.545	0.727
1.215	34.765	66.385	0.625	0.868
1.325	41.435	75.305	0.670	0.967
1.400	46.590	77.225	0.730	1.074
1.470	51.250	78.905	0.770	1.172
1.535	55.790	80.845	0.810	1.256
1.610	60.585	83.665	0.825	1.322
1.675	65.515	87.150	0.835	1.377
1.725	69.740	89.405	0.845	1.438
1.845	79.310	93.740	0.895	1.582
1.935	87.660	96.730	0.950	1.718
2.010	94.630	97.775	1.010	1.855
2.075	101.120	98.700	1.065	1.983
2.140	107.340	99.785	1.115	2.100
2.200	113.485	101.180	1.160	2.207
2.315	124.635	103.160	1.245	2.410
2.415	134.650	104.500	1.320	2.602
2.500	144.010	105.645	1.390	2.779
2.590	152.940	106.985	1.460	2.943
2.665	161.455	108.295	1.520	3.097
2.815	177.855	111.565	1.625	3.374
2.950	192.815	113.930	1.725	3.631
3.075	206.860	116.035	1.810	3.868
3.185	219.805	117.655	1.895	4.097
3.285	232.130	119.175	1.975	4.311
3.730	285.985	124.220	2.320	5.257
4.085	331.230	127.595	2.615	6.063
4.390	370.810	130.080	2.865	6.783

Table B-4a. Upper Rubicon River from RM 28.8 to RM 24.69 Pool Habitat Cross-Section Representation.

Calculated stage, ft	Wetted Area, ft^2	Wetted Width, ft	Average Depth, ft	Velocity, ft/sec
0.28	91.22	44.94	1.99	0.01
0.37	94.84	45.76	2.05	0.02
0.43	97.60	46.74	2.09	0.02
0.48	99.95	47.51	2.12	0.03
0.57	103.78	48.91	2.17	0.04
0.62	106.53	50.42	2.20	0.05
0.71	110.53	51.34	2.26	0.07
0.77	113.55	51.97	2.30	0.10
0.82	116.18	52.48	2.33	0.11
0.93	121.70	53.45	2.40	0.16
1.06	128.73	54.96	2.47	0.22
1.20	136.04	56.05	2.57	0.29
1.29	140.99	56.70	2.63	0.35
1.38	146.09	57.34	2.70	0.40
1.45	149.63	57.73	2.75	0.44
1.55	155.37	58.38	2.83	0.51
1.58	157.23	58.76	2.85	0.53
1.64	160.65	59.84	2.87	0.57
1.69	162.99	60.23	2.90	0.59
1.86	173.17	61.80	3.02	0.70
2.16	190.36	63.81	3.22	0.90
2.52	212.64	66.46	3.45	1.15
2.53	213.16	66.53	3.46	1.16
3.00	243.08	70.23	3.74	1.47
3.37	267.63	73.15	3.97	1.73
3.67	289.09	75.63	4.11	1.97
3.95	309.15	77.18	4.30	2.20
4.21	328.02	78.27	4.50	2.40
4.45	345.80	79.04	4.69	2.59
4.67	362.75	79.85	4.86	2.77

Table B-4b. Upper Rubicon River from RM 28.8 to RM 24.69 Run Habitat Cross-Section Representation.

Calculated stage, ft	Wetted Area, ft^2	Wetted Width, ft	Average Depth, ft	Velocity, ft/sec
0.60	7.48	15.94	0.43	0.12
0.73	9.93	19.23	0.49	0.16
0.82	11.75	21.66	0.53	0.18
0.89	13.26	23.32	0.57	0.21
0.98	15.66	25.35	0.62	0.25
1.07	17.84	27.23	0.65	0.28
1.18	21.09	29.10	0.72	0.34
1.27	23.78	30.90	0.77	0.39
1.35	25.97	31.77	0.82	0.44
1.48	30.47	33.04	0.93	0.55
1.66	36.50	36.23	1.02	0.66
1.83	42.96	39.15	1.12	0.80
1.95	47.45	41.32	1.17	0.88
2.05	51.65	42.57	1.23	0.98
2.12	54.72	43.77	1.27	1.04
2.22	59.39	45.15	1.34	1.15
2.26	60.94	45.68	1.36	1.18
2.33	64.03	47.27	1.38	1.23
2.37	66.01	48.09	1.40	1.27
2.58	76.82	54.97	1.41	1.40
2.86	92.10	61.32	1.51	1.66
3.13	108.92	64.91	1.69	2.03
3.13	109.29	64.97	1.70	2.04
3.50	134.79	74.32	1.82	2.46
3.72	151.73	76.13	1.99	2.86
3.95	169.41	81.07	2.09	3.18
4.10	182.53	81.66	2.23	3.53
4.25	194.57	82.14	2.36	3.86
4.38	205.75	82.59	2.48	4.18
4.50	216.22	82.95	2.59	4.48

Table B-4c. Upper Rubicon River from RM 28.8 to RM 24.69 Low Gradient Riffle (LGR) Habitat Cross-Section Representation.

Calculated stage, ft	Wetted Area, ft^2	Wetted Width, ft	Average Depth, ft	Velocity, ft/sec
1.02	24.85	44.25	0.51	0.52
1.20	33.98	52.74	0.61	0.63
1.45	49.11	66.07	0.70	0.75
1.59	58.34	69.88	0.79	0.86
1.71	66.35	73.82	0.86	0.95
1.80	73.00	76.10	0.93	1.03
1.88	79.29	79.23	0.98	1.09
1.98	87.03	87.71	0.96	1.09
2.04	92.19	89.12	1.01	1.15
2.10	97.05	90.54	1.05	1.20
2.16	102.18	93.80	1.08	1.24
2.27	113.34	98.05	1.15	1.34
2.37	123.10	100.76	1.22	1.43
2.46	131.99	102.95	1.28	1.52
2.54	140.21	104.84	1.34	1.59
2.62	148.02	106.73	1.39	1.67
2.69	155.47	108.59	1.44	1.73
2.82	170.74	114.27	1.51	1.85
2.93	182.93	116.22	1.60	1.96
3.03	194.67	118.89	1.67	2.06
3.12	205.13	120.12	1.74	2.16
3.20	215.09	121.42	1.80	2.25
3.36	235.11	126.44	1.91	2.40
3.50	251.97	128.07	2.01	2.55
3.62	267.43	129.29	2.11	2.69
3.73	281.75	130.35	2.21	2.83
3.84	295.49	131.14	2.30	2.95
4.29	354.40	134.76	2.67	3.49
4.65	403.66	137.47	2.98	3.94
4.97	446.71	139.55	3.24	4.33

Table B-4d. Upper Rubicon River from RM 28.8 to RM 24.69 High Gradient Riffle (HGR) Habitat Cross-Section Representation.

Calculated stage, ft	Wetted Area, ft^2	Wetted Width, ft	Average Depth, ft	Velocity, ft/sec
0.65	5.56	18.38	0.28	0.15
0.75	7.39	21.42	0.33	0.20
0.81	8.71	23.19	0.36	0.23
0.86	9.86	24.37	0.39	0.27
0.93	11.68	26.24	0.44	0.32
0.99	13.16	27.36	0.48	0.37
1.08	15.66	29.41	0.54	0.45
1.15	17.99	32.00	0.58	0.51
1.21	19.91	33.55	0.62	0.57
1.34	24.11	37.10	0.69	0.69
1.47	29.16	39.75	0.78	0.85
1.61	34.84	43.52	0.86	1.02
1.70	38.59	45.17	0.91	1.13
1.79	42.34	46.54	0.97	1.25
1.85	44.91	47.42	1.01	1.34
1.96	50.04	51.29	1.01	1.42
1.99	51.42	51.83	1.02	1.46
2.05	54.91	56.12	1.03	1.51
2.08	56.75	57.11	1.04	1.55
2.24	65.17	62.03	1.09	1.72
2.45	78.15	67.30	1.20	2.06
2.69	94.85	73.61	1.31	2.47
2.69	95.22	73.73	1.32	2.48
2.96	116.05	80.02	1.48	3.05
3.17	133.98	86.45	1.60	3.51
3.36	150.07	91.17	1.68	3.91
3.50	163.46	93.26	1.78	4.30
3.64	176.43	96.20	1.85	4.60
3.75	187.68	97.43	1.94	4.96
3.86	198.29	98.57	2.02	5.30

Table B-5a. Middle Rubicon River from RM 24.69 to RM 3.62 Pool Habitat Cross-Section Representation.

Calc stage, ft	Wetted Area, ft^2	Wetted Width, ft	Avg. Depth, ft	Velocity, ft/sec
0.88	164.92	46.89	3.27	0.01
1.04	172.96	49.67	3.32	0.01
1.14	177.75	50.49	3.38	0.01
1.22	181.74	51.09	3.43	0.02
1.34	187.98	51.91	3.51	0.03
1.43	192.68	52.86	3.56	0.03
1.57	199.89	54.21	3.64	0.05
1.66	205.04	54.96	3.70	0.06
1.74	209.29	55.76	3.74	0.07
1.90	218.46	57.62	3.81	0.10
2.07	228.26	59.02	3.93	0.14
2.24	237.91	60.31	4.03	0.19
2.35	244.30	61.17	4.11	0.22
2.46	251.03	61.74	4.19	0.26
2.58	258.08	62.34	4.27	0.28
2.70	265.51	62.91	4.36	0.33
2.74	267.75	63.09	4.39	0.34
2.80	271.20	63.48	4.42	0.37
2.83	273.46	63.72	4.44	0.39
2.99	283.48	65.00	4.51	0.47
3.13	292.89	66.05	4.59	0.56
3.24	300.04	66.78	4.65	0.62
3.55	320.60	69.02	4.82	0.83
3.92	346.77	71.32	5.05	1.11
4.24	369.97	74.70	5.19	1.34
4.50	389.44	76.53	5.34	1.55
4.73	407.71	78.27	5.47	1.74
4.98	426.55	80.67	5.56	1.91
5.20	444.36	82.12	5.70	2.07
5.40	460.27	83.35	5.81	2.23

Table B-5b. Middle Rubicon River from RM 24.69 to RM 3.62 Run Habitat Cross-Section Representation.

Calc stage, ft	Wetted Area, ft^2	Wetted Width, ft	Avg. Depth, ft	Velocity, ft/sec
0.64	13.59	19.01	0.57	0.10
0.78	16.66	20.55	0.67	0.15
0.88	18.85	21.55	0.74	0.18
0.96	20.64	22.39	0.78	0.21
1.08	23.71	24.39	0.84	0.25
1.18	26.17	25.78	0.88	0.29
1.31	30.05	27.69	0.96	0.36
1.44	33.89	30.88	0.99	0.41
1.53	37.11	33.23	1.02	0.46
1.69	43.53	37.33	1.10	0.56
1.87	50.11	39.99	1.21	0.68
2.05	58.16	44.99	1.28	0.81
2.15	62.95	46.90	1.33	0.91
2.26	67.80	48.74	1.38	1.00
2.32	70.78	49.48	1.42	1.07
2.41	75.42	50.29	1.49	1.19
2.45	76.83	50.52	1.51	1.22
2.50	79.49	51.15	1.55	1.29
2.53	81.17	51.41	1.57	1.34
2.69	89.18	54.11	1.65	1.52
2.82	96.21	55.31	1.74	1.72
2.91	101.45	56.07	1.81	1.87
3.21	119.81	63.62	1.90	2.26
3.50	138.91	67.07	2.09	2.85
3.72	153.98	70.08	2.24	3.34
3.89	166.01	71.19	2.37	3.79
4.04	176.75	72.13	2.49	4.22
4.17	186.33	72.81	2.60	4.62
4.29	195.06	73.29	2.71	5.00
4.40	203.06	73.73	2.80	5.37

Table B-5c. Middle Rubicon River from RM 24.69 to RM 3.62 Low Gradient Riffle (LGR) Habitat Cross-Section Representation.

Calc stage, ft	Wetted Area, ft^2	Wetted Width, ft	Avg. Depth, ft	Velocity, ft/sec
0.69	5.01	17.22	0.29	0.10
0.80	7.22	22.89	0.32	0.14
0.85	8.55	24.05	0.36	0.18
0.90	9.66	24.96	0.39	0.21
0.97	11.42	26.12	0.44	0.26
1.02	12.88	27.06	0.48	0.31
1.11	15.27	28.55	0.53	0.39
1.17	17.21	29.48	0.58	0.46
1.23	18.88	30.20	0.63	0.53
1.34	22.31	31.50	0.71	0.67
1.47	26.39	32.73	0.81	0.86
1.59	30.50	33.54	0.91	1.06
1.69	33.82	35.85	0.94	1.18
1.79	37.74	39.49	0.96	1.29
1.84	39.78	40.17	0.99	1.38
1.93	43.12	41.29	1.04	1.54
1.95	44.11	41.38	1.07	1.59
1.99	45.77	41.53	1.10	1.68
2.02	46.89	41.73	1.12	1.74
2.14	52.05	42.79	1.22	2.02
2.25	56.75	43.40	1.31	2.29
2.33	60.19	43.85	1.37	2.49
2.55	70.19	45.12	1.56	3.11
2.82	82.39	46.59	1.77	3.94
3.02	91.80	47.54	1.93	4.63
3.19	99.99	48.35	2.07	5.25
3.34	107.30	49.07	2.19	5.82
3.47	114.01	49.72	2.29	6.36
3.60	120.21	50.31	2.39	6.86
3.71	125.97	50.85	2.48	7.34

Table B-5d. Middle Rubicon River from RM 24.69 to RM 3.62 High Gradient Riffle (HGR) Habitat Cross-Section Representation.

Calc stage, ft	Wetted Area, ft^2	Wetted Width, ft	Avg. Depth, ft	Velocity, ft/sec
0.70	3.69	11.02	0.31	0.20
0.82	5.18	13.02	0.37	0.26
0.90	6.31	14.18	0.42	0.32
0.96	7.29	15.22	0.46	0.36
1.07	9.01	16.95	0.50	0.43
1.14	10.29	17.57	0.55	0.50
1.26	12.47	18.64	0.64	0.61
1.35	14.32	19.61	0.70	0.70
1.43	15.98	20.61	0.74	0.77
1.60	19.65	22.97	0.83	0.91
1.78	24.10	25.01	0.93	1.10
2.00	29.99	29.82	0.97	1.25
2.11	33.72	32.12	1.02	1.37
2.23	38.13	35.65	1.05	1.49
2.30	40.49	36.47	1.09	1.58
2.40	44.26	37.64	1.15	1.73
2.43	45.47	38.05	1.18	1.77
2.49	47.62	38.76	1.21	1.86
2.52	49.02	39.18	1.23	1.91
2.69	55.32	41.07	1.33	2.15
2.86	63.06	46.74	1.36	2.32
2.98	68.41	49.80	1.38	2.44
3.26	82.51	54.61	1.51	2.87
3.58	100.23	59.29	1.69	3.44
3.81	114.03	62.25	1.83	3.91
4.00	125.82	63.93	1.97	4.35
4.18	137.52	66.95	2.07	4.73
4.33	147.64	68.65	2.17	5.10
4.46	156.51	69.41	2.28	5.46
4.58	164.80	70.06	2.38	5.81

Table B-6a. Lower Rubicon River from RM 3.62 to RM 0.0 Pool Habitat Cross-Section Representation.

Calculated stage, ft	Wetted Area, ft^2	Wetted Width, ft	Average Depth, ft	Velocity, ft/sec
0.13	80.52	36.22	2.07	0.02
0.30	87.24	38.00	2.17	0.02
0.45	93.16	39.89	2.24	0.03
0.59	98.50	41.69	2.31	0.04
0.73	104.82	43.44	2.40	0.05
0.87	110.73	45.35	2.48	0.06
1.07	119.89	48.33	2.60	0.08
1.23	127.65	51.99	2.67	0.09
1.35	133.73	54.31	2.70	0.11
1.52	143.64	56.29	2.81	0.15
1.71	154.59	58.81	2.86	0.20
1.88	164.57	59.65	2.97	0.25
2.00	171.35	60.41	3.04	0.29
2.11	177.86	60.91	3.11	0.34
2.20	182.89	61.33	3.18	0.37
2.31	189.74	61.89	3.26	0.42
2.36	192.49	62.25	3.28	0.44
2.42	196.48	62.63	3.32	0.46
2.48	200.17	62.89	3.37	0.50
2.66	211.24	63.37	3.51	0.60
2.82	221.22	63.84	3.64	0.69
2.97	230.43	64.24	3.76	0.79
3.32	252.63	65.11	4.04	1.04
3.73	279.06	66.50	4.34	1.36
4.05	299.97	67.79	4.56	1.63
4.33	318.46	68.53	4.78	1.87
4.57	334.43	69.27	4.96	2.11
4.79	349.03	69.93	5.12	2.33
4.98	362.56	70.43	5.27	2.54
5.19	385.35	70.96	5.58	2.66

Table B-6b. Lower Rubicon River from RM 3.62 to RM 0.0 Run Habitat Cross-Section Representation.

Calculated stage, ft	Wetted Area, ft^2	Wetted Width, ft	Average Depth, ft	Velocity, ft/sec
0.49	14.45	23.88	0.69	0.06
0.54	19.71	31.68	0.64	0.07
0.64	22.81	33.62	0.71	0.09
0.72	25.37	35.56	0.76	0.11
0.83	29.19	36.92	0.85	0.14
0.93	32.35	38.21	0.90	0.16
1.05	36.79	39.78	0.98	0.20
1.17	41.33	41.65	1.05	0.25
1.28	45.99	44.09	1.10	0.29
1.44	52.44	44.91	1.23	0.37
1.62	59.21	45.70	1.36	0.46
1.82	66.90	47.80	1.43	0.55
1.92	71.36	48.26	1.51	0.62
2.02	76.26	48.78	1.59	0.70
2.09	79.35	49.40	1.62	0.75
2.20	84.19	50.19	1.70	0.83
2.24	86.13	50.77	1.72	0.86
2.32	90.89	52.59	1.75	0.93
2.38	94.07	53.04	1.79	0.99
2.56	103.12	56.13	1.83	1.11
2.73	112.80	57.58	1.95	1.30
2.88	121.70	58.70	2.06	1.49
3.14	137.40	60.48	2.26	1.86
3.44	155.69	62.47	2.49	2.34
3.68	171.35	65.97	2.61	2.71
3.89	185.32	69.46	2.71	3.05
4.05	196.81	71.33	2.82	3.39
4.19	206.88	72.29	2.93	3.72
4.32	207.90	71.77	2.99	4.01
4.44	216.26	72.45	3.09	4.32

Table B-6c. Lower Rubicon River from RM 3.62 to RM 0.0 Low Gradient Riffle (LGR) Habitat Cross-Section Representation.

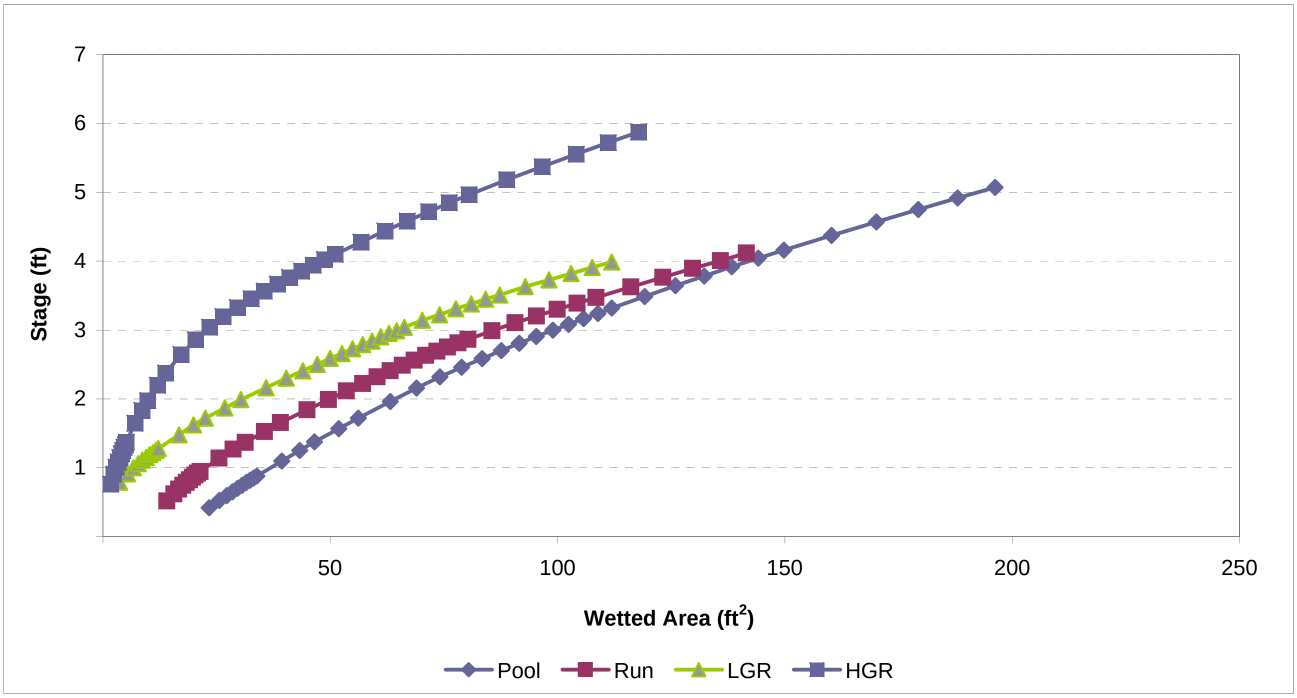
Calculated stage, ft	Wetted Area, ft^2	Wetted Width, ft	Average Depth, ft	Velocity, ft/sec
0.38	2.66	15.77	0.17	0.19
0.45	4.00	18.50	0.22	0.25
0.51	5.15	20.98	0.25	0.29
0.56	6.27	24.08	0.26	0.32
0.63	7.95	26.44	0.30	0.38
0.68	9.62	29.89	0.32	0.42
0.77	12.41	34.36	0.36	0.48
0.84	14.63	36.27	0.41	0.55
0.89	16.72	38.48	0.44	0.60
1.01	21.44	43.24	0.50	0.70
1.15	27.92	50.38	0.56	0.81
1.28	35.06	56.91	0.62	0.93
1.36	39.70	59.71	0.67	1.01
1.44	44.48	62.01	0.72	1.09
1.48	47.60	62.93	0.76	1.16
1.58	53.47	66.65	0.81	1.24
1.63	57.86	76.07	0.76	1.21
1.68	60.83	76.58	0.80	1.26
1.70	62.79	76.92	0.82	1.30
1.83	72.93	81.97	0.89	1.44
1.93	81.41	83.03	0.98	1.60
2.01	87.85	83.84	1.05	1.71
2.23	106.59	85.54	1.25	2.06
2.51	130.84	87.02	1.51	2.50
2.72	150.20	88.19	1.71	2.85
2.94	168.80	90.92	1.86	3.13
3.12	185.96	93.24	2.00	3.38
3.29	201.67	94.89	2.13	3.61
3.45	216.90	96.97	2.24	3.82
3.58	230.23	97.77	2.36	4.04

Table B-6d. Lower Rubicon River from RM 3.62 to RM 0.0 High Gradient Riffle (HGR) Habitat Cross-Section Representation.

Calculated stage, ft	Wetted Area, ft^2	Wetted Width, ft	Average Depth, ft	Velocity, ft/sec
0.66	4.07	10.57	0.36	0.16
0.81	5.76	12.09	0.45	0.22
0.95	8.06	20.50	0.41	0.21
1.04	9.85	24.45	0.41	0.23
1.14	12.40	28.14	0.45	0.27
1.22	14.59	30.83	0.48	0.31
1.33	18.26	34.62	0.54	0.37
1.42	21.47	38.04	0.57	0.41
1.49	24.27	40.60	0.61	0.45
1.63	30.25	45.32	0.68	0.54
1.79	37.87	50.04	0.76	0.66
1.94	45.53	53.43	0.84	0.78
2.03	50.48	54.96	0.92	0.86
2.14	56.31	58.20	0.96	0.94
2.20	60.26	60.37	0.98	0.99
2.30	66.20	62.38	1.05	1.08
2.33	68.15	63.06	1.07	1.11
2.38	71.41	63.98	1.10	1.16
2.41	73.55	64.50	1.12	1.20
2.56	82.90	66.18	1.24	1.36
2.68	91.53	67.33	1.34	1.52
2.79	98.30	68.91	1.41	1.63
3.07	118.67	73.80	1.60	1.93
3.41	144.48	78.06	1.84	2.35
3.67	165.76	82.70	2.01	2.66
3.89	183.83	85.24	2.17	2.95
4.10	202.04	90.17	2.27	3.17
4.28	218.94	93.87	2.36	3.39
4.44	233.46	95.63	2.47	3.61
4.57	246.59	96.74	2.58	3.83

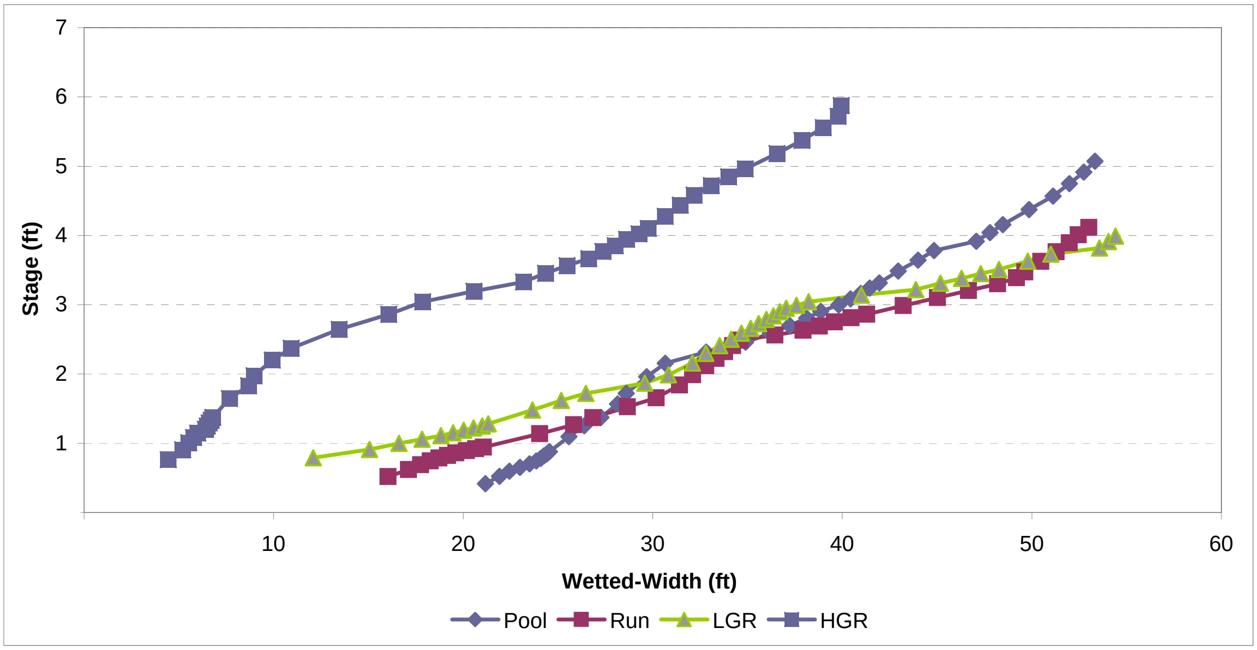
FIGURES

Figure B-1a. Stage-Wetted Area Relationships for Habitat Types in the French Meadows Reservoir to Middle Fork Interbay Reach of the Middle Fork American River.



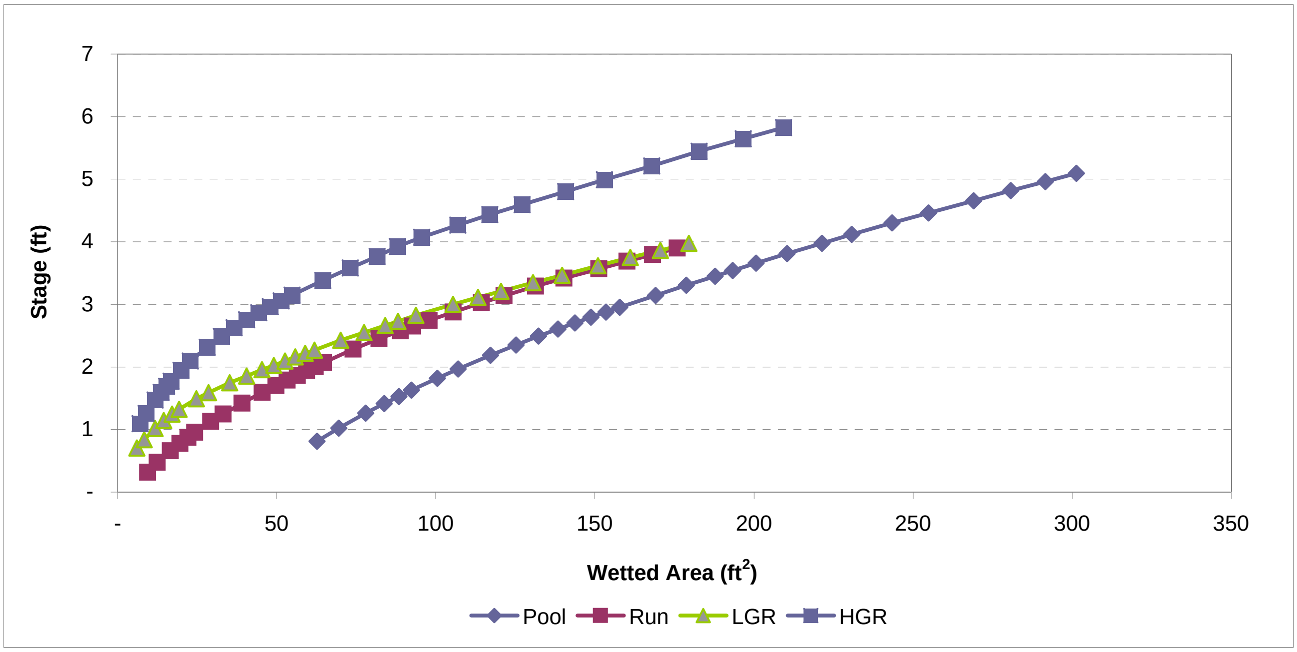
* zero stage occurs at zero flow

Figure B-1b. Stage-Wetted Width Relationships for Habitat Types in the French Meadows Reservoir to Middle Fork Interbay Reach of the Middle Fork American River.



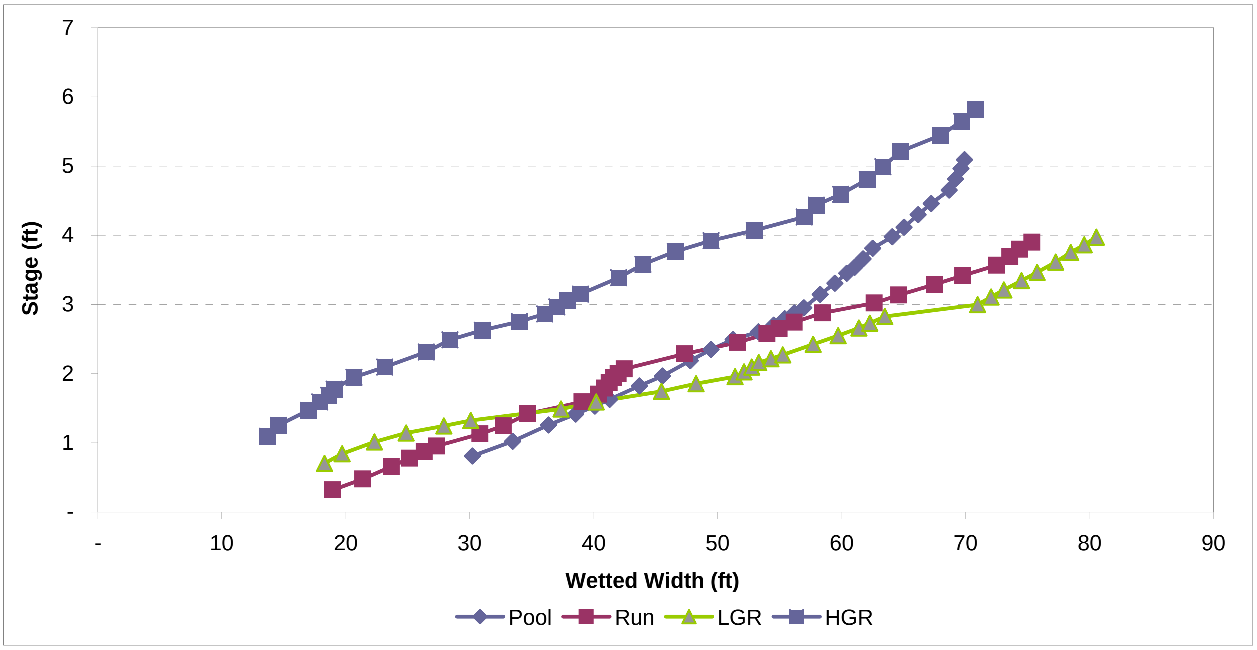
* zero stage occurs at zero flow

Figure B-2a. Stage-Wetted Area Relationships for Habitat Types in the Middle Fork Interbay to Ralston Afterbay Reach of the Middle Fork American River.



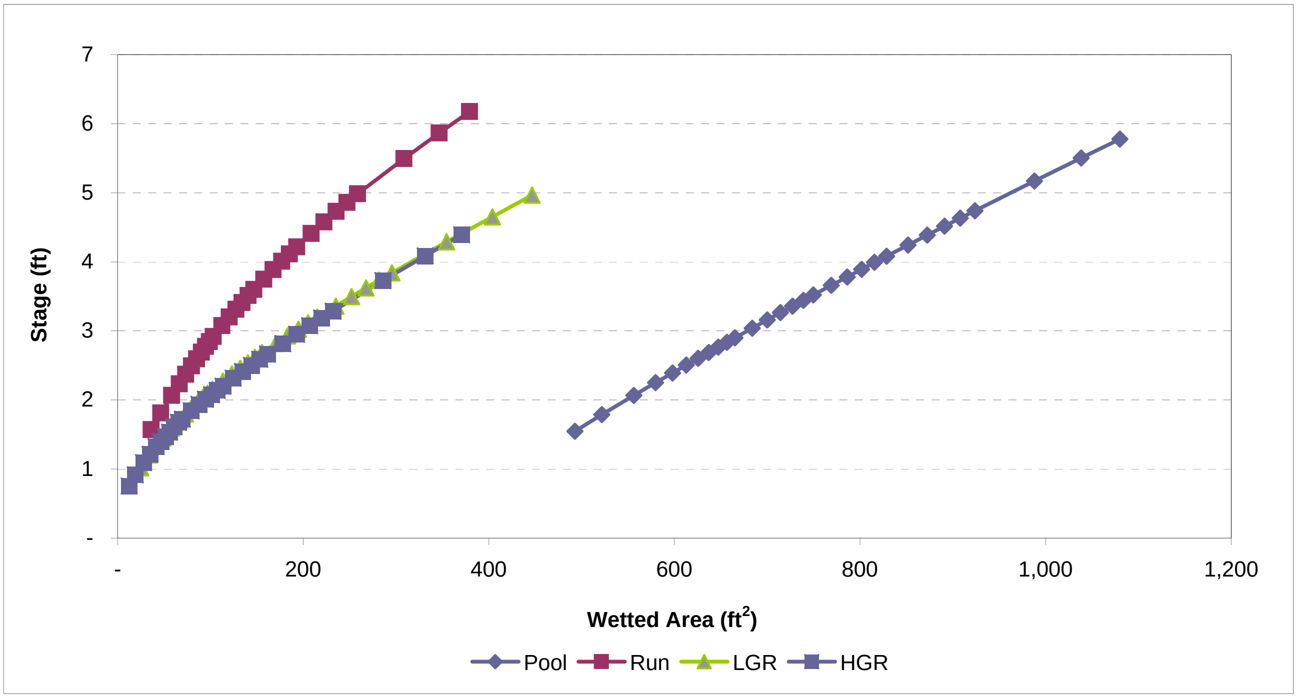
* zero stage occurs at zero flow

Figure B-2b. Stage-Wetted Width Relationships for Habitat Types in the Middle Fork Interbay to Ralston Afterbay Reach of the Middle Fork American River.



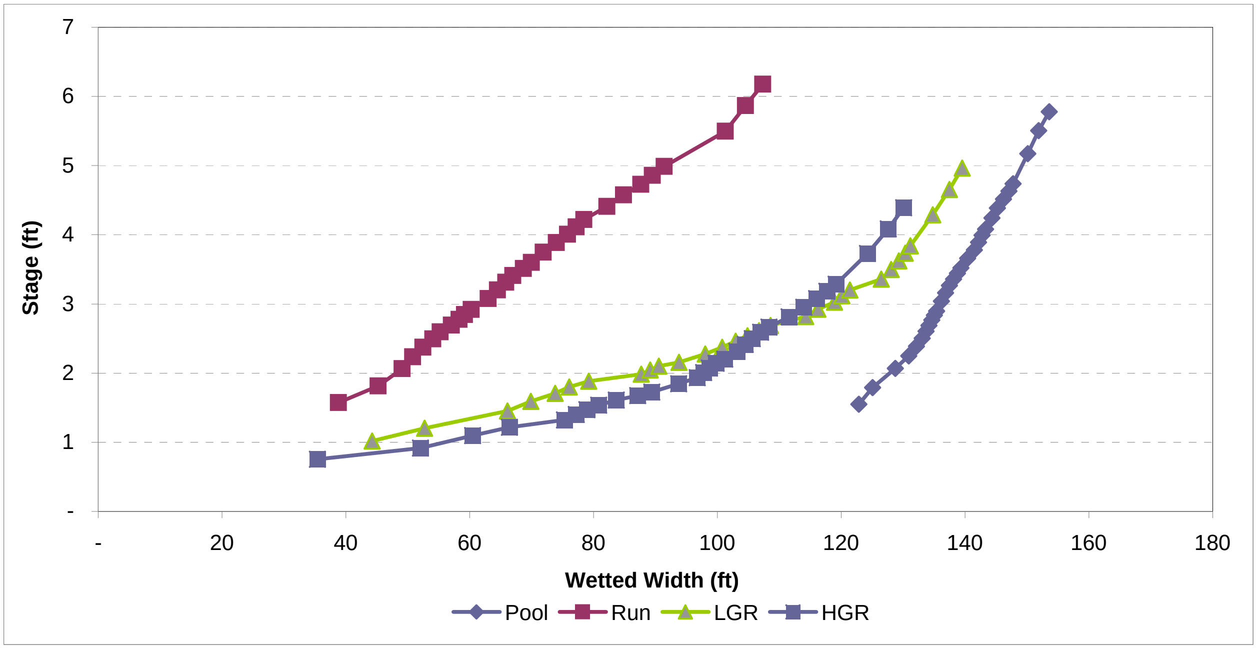
* zero stage occurs at zero flow

Figure B-3a. Stage-Wetted Area Relationships for Habitat Types in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork and the North Fork of the American River.



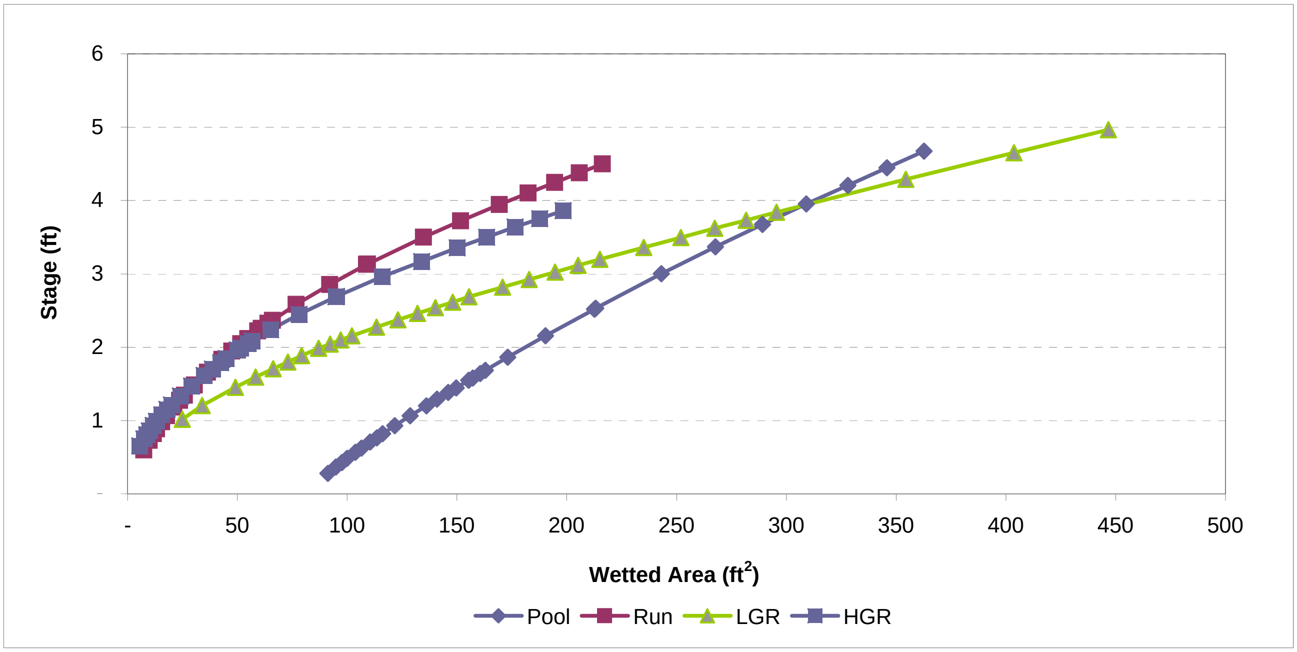
* zero stage occurs at zero flow

Figure B-3b. Stage-Wetted Width Relationships for Habitat Types in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork and the North Fork of the American River.



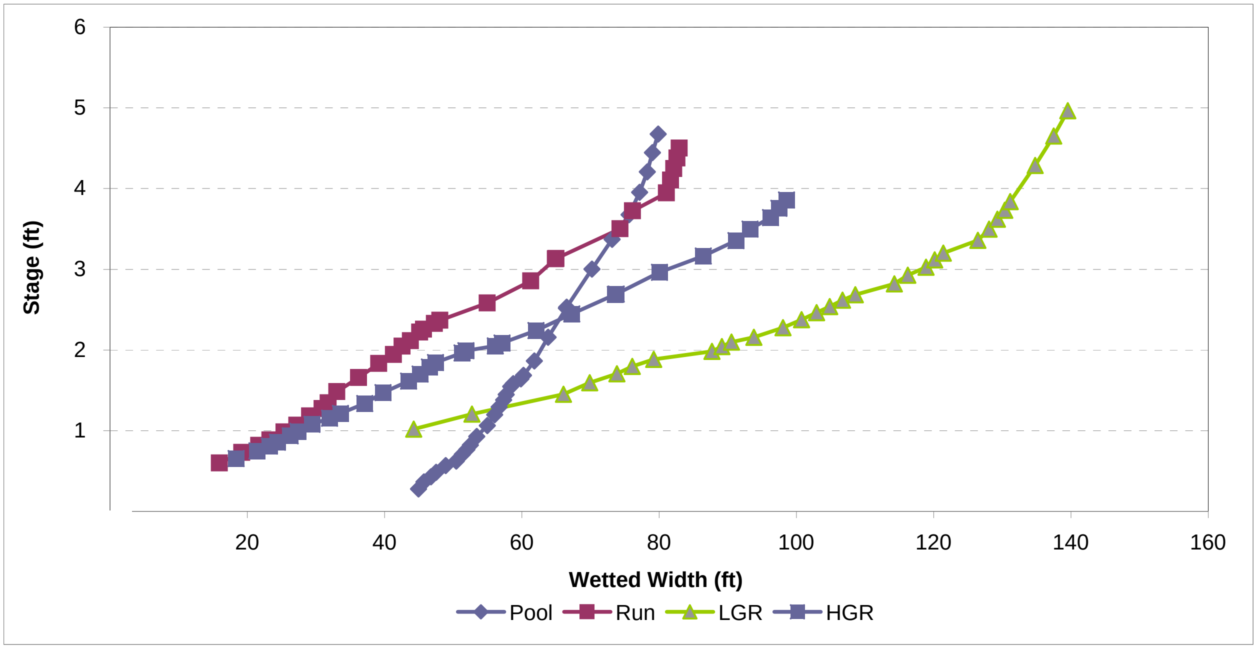
* zero stage occurs at zero flow

Figure B-4a. Stage-Wetted Area Relationships for Habitat Types in the Upper Rubicon River, RM 28.8 to RM 24.69.



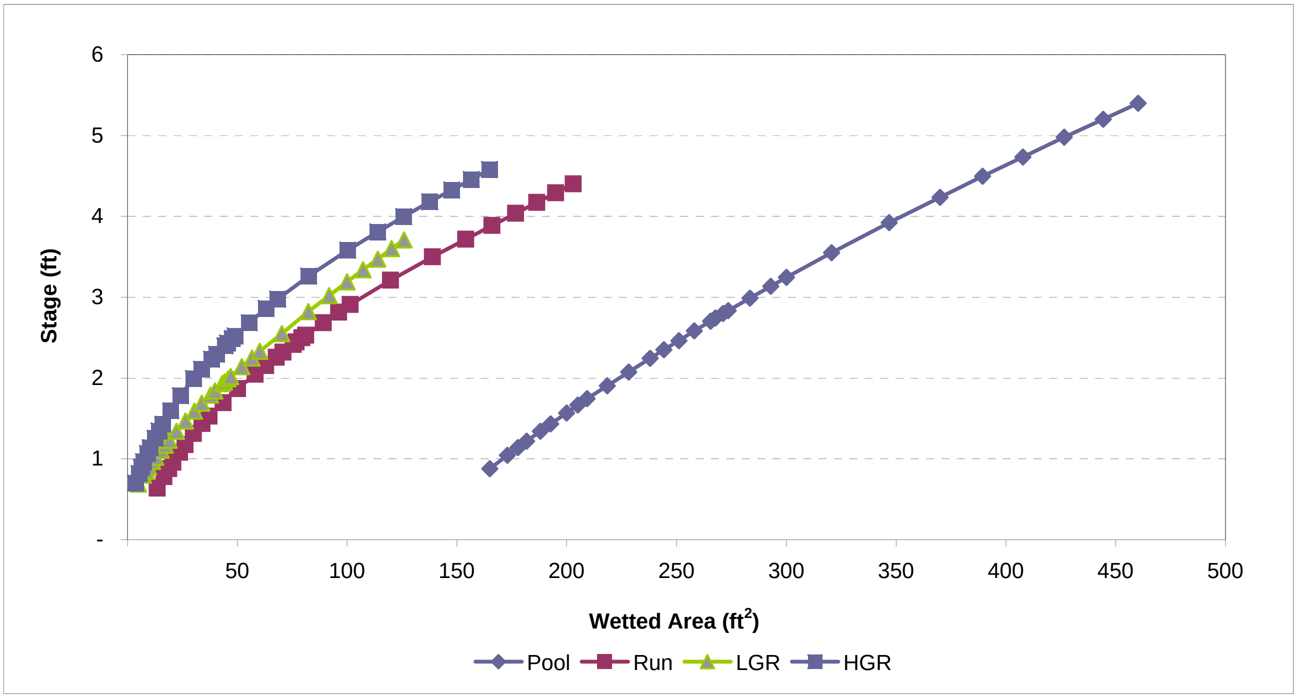
* zero stage occurs at zero flow

Figure B-4b. Stage-Wetted Width Relationships for Habitat Types in the Upper Rubicon River, RM 28.8 to RM 24.69.



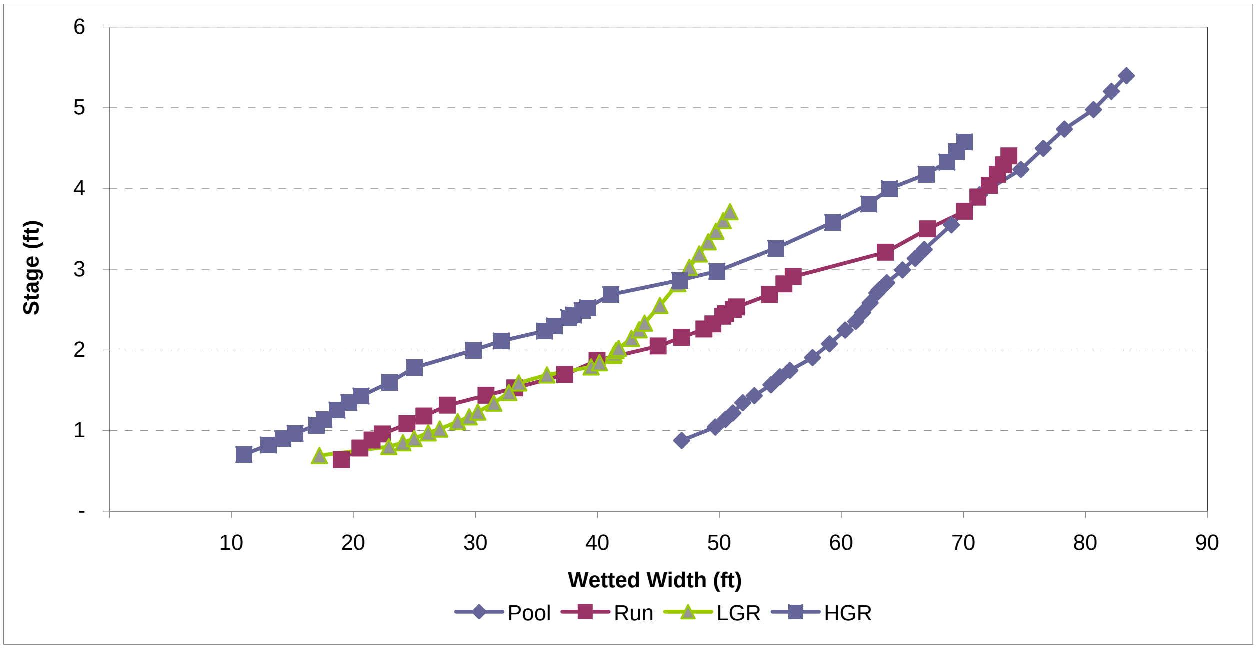
* zero stage occurs at zero flow

Figure B-5a. Stage-Wetted Area Relationships for Habitat Types in the Middle Rubicon River, RM 24.69 to RM 3.62.



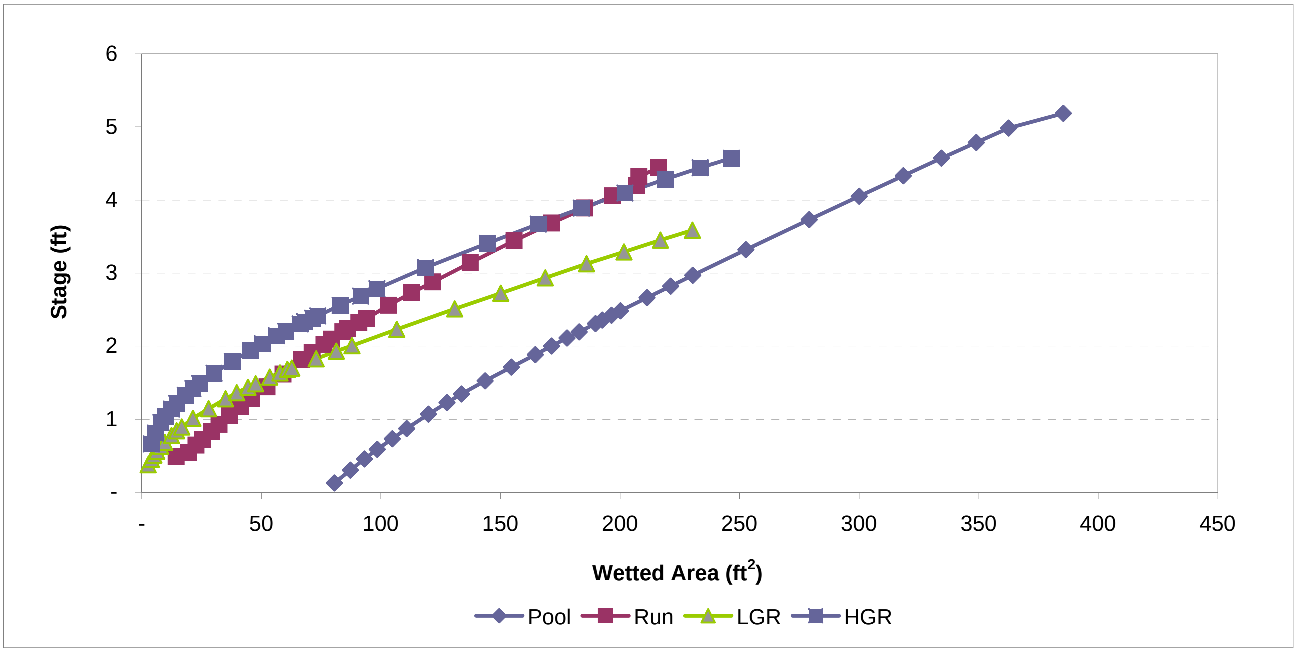
* zero stage occurs at zero flow

Figure B-5b. Stage-Wetted Width Relationships for Habitat Types in the Middle Rubicon River, RM 24.69 to RM 3.62.



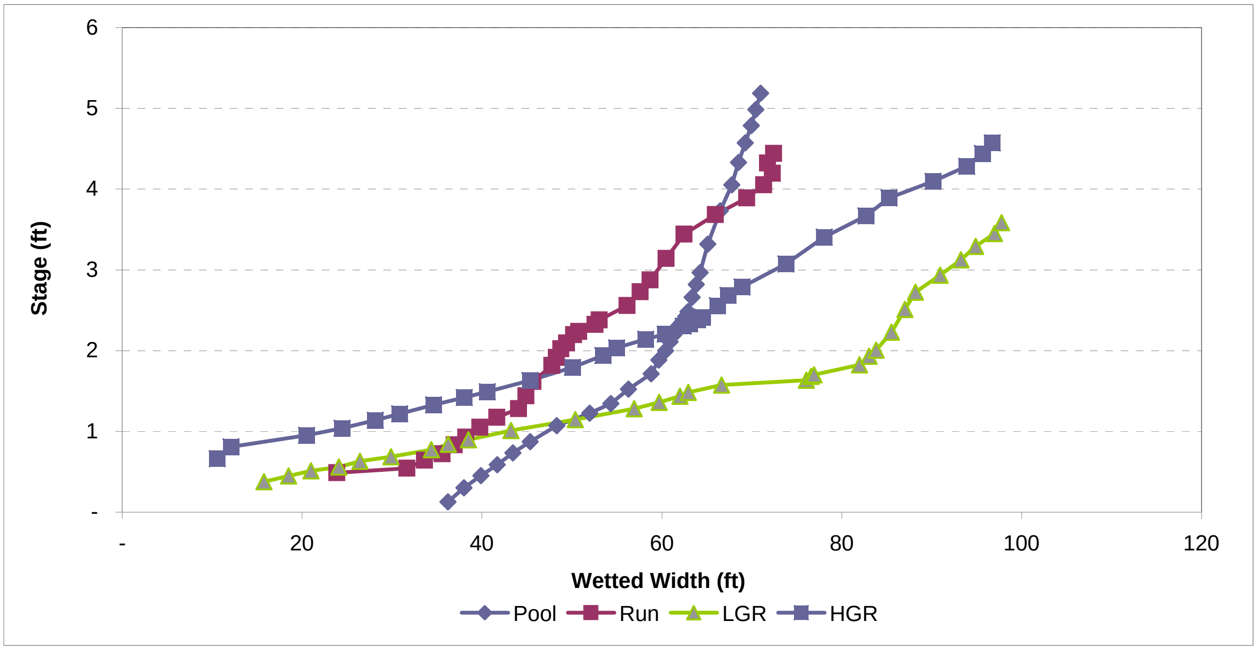
* zero stage occurs at zero flow

Figure B-6a. Stage-Wetted Area Relationships for Habitat Types in the Lower Rubicon River, RM 3.62 to RM 0.0.



* zero stage occurs at zero flow

Figure B-6b. Stage-Wetted Width Relationships for Habitat Types in the Lower Rubicon River, RM 3.62 to RM 0.0.



* zero stage occurs at zero flow

APPENDIX C

Measured Water Temperature Data

(See Attached Electronic Media)

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Databases of Measured Water Temperature by Reach and Monitoring Station (see Map AQ 4-4)

Rubicon River River Above Hell Hole Reservoir

19_RR35.9.xls

Rubicon River River Below Hell Hole Reservoir

20_RR30.2.xls

21_RR28.8.xls

22_RR25.3.xls

23_RR22.7.xls

24_RR22.5.xls

25_RR14.3.xls

26_RR9.5.xls

27_RR5.3.xls

28_RR3.7.xls

29_RR0.7.xls

30_RR0.5.xls

Duncan Creek Above Duncan Creek Diversion

31_DC8.8.xls

Duncan Creek from Duncan Creek Diversion to Middle Fork American River

32_DC8.4.xls

32_DC8.4.xls

North Fork Long Canyon Creek Above North Fork Long Canyon Diversion

34_NL3.2.xls

North Fork Long Canyon Creek Below North Fork Long Canyon Diversion

35_NL3.1.xls

South Fork Long Canyon Creek Above South Fork Long Canyon Diversion

36_SL3.4.xls

South Fork Long Canyon Creek Below South Fork Long Canyon Diversion

37_SL3.2.xls

Long Canyon Creek

38_LC0.1.xls

Reservoir Temperature Profiles

39_2008 Res Prof Temps.xls

Tributaries to the Middle Fork American River

40_NM2.3.xls

41_OC0.1.xls

42_CC0.1.xls

43_NF21.4.xls

44_NF20.8.xls

Tributaries to the Rubicon River

45_FL0.1.xls

46_SF0.1.xls

47_PC0.1.xls

Tributaries to Long Canyon Creek

48_WC1.2.xls

APPENDIX D

Meteorological Data

(See Attached Electronic Media)

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Databases of Meterorlogical Data by Monitoring Station (see Map AQ 4-4)

Full Stations

Capable of measuring six parameters: (1) air temperature, (2) relative humidity, (3) solar radiation, (4) wind speed, (5) wind direction, and (6) precipitation.

PCWA Maintained

Other Agency Maintained

Partial Stations

Capable of measuring two parameters: (1) air temperature, and (2) relative humidity.

PCWA Maintained

Other Agency Maintained

Extra (not in 2005 Water Temp Rpt)

KBLU (not on map)

APPENDIX E

Reservoir Temperature Profile Calibration Results

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Hell Hole Reservoir

Ralston Afterbay

TABLES

Table E-1. Calibration Statistics for the French Meadows Reservoir 2006 and 2007 Simulations.

		French Meadows Reservoir			
		Segment 23/FM1		Segment 17/FM2	
	Date	MAE[1]	RMSE[1]	MAE[1]	RMSE[1]
2006	6-Jul	1.08	1.67	0.61	1.02
	9-Aug	0.86	1.26	0.56	0.77
	8-Sep	0.62	0.78	0.48	0.56
	27-Oct	0.62	0.67	0.51	0.63
2007	30-May	0.97	1.66	1.07	1.50
	12-Jul	0.27	0.41	0.28	0.35
	2-Aug	0.51	0.86	0.51	0.91
	31-Aug	0.75	1.36	0.78	1.36

[1]MAE = mean absolute error, RMSE = Root mean square error.

Table E-2. Calibration Statistics for the Hell Hole Reservoir 2006 and 2007 Simulations.

	Hell Hole Reservoir				
		Segment 24/HH1		Segment 20/HH2[1]	
	Date	MAE[2]	RMSE[2]	MAE[2]	RMSE[2]
2006	6-Jul	0.51	0.64	-	-
	9-Aug	1.34	1.60	-	-
	8-Sep	1.19	1.42	-	-
	27-Oct	0.16	0.23	-	-
2007	30-May	0.64	0.96	0.65	0.92
	12-Jul	0.86	1.05	-	-
	2-Aug	0.96	1.26	-	-
	31-Aug	1.53	1.95	-	-

[1] Data were only collected on May 30, 2007 at this location.

[2] MAE = mean absolute error, RMSE = Root mean square error.

Table E-3. Calibration Statistics for the Ralston Afterbay 2006 and 2007 Simulations.

	Ralston Afterbay		
		Segment 40/RA1	
	Date	MAE[1]	RMSE[1]
2006	6-Jul	1.035	1.085
	8-Aug	1.357	1.618
	30-Sep	0.703	0.719
2007	7-Jun	1.69	2.26
	11-Jul	1.77	2.75
	31-Jul	0.67	0.83
	6-Sep	0.49	0.57
	25-Sep	0.16	0.22

[1]MAE = mean absolute error, RMSE = Root mean square error.

FIGURES

Figure E-1. Calibration Data for French Meadows Reservoir on July 6, 2006 for Segment 23 (Temperature Model) and Vertical Profile Sampling Location FM1.

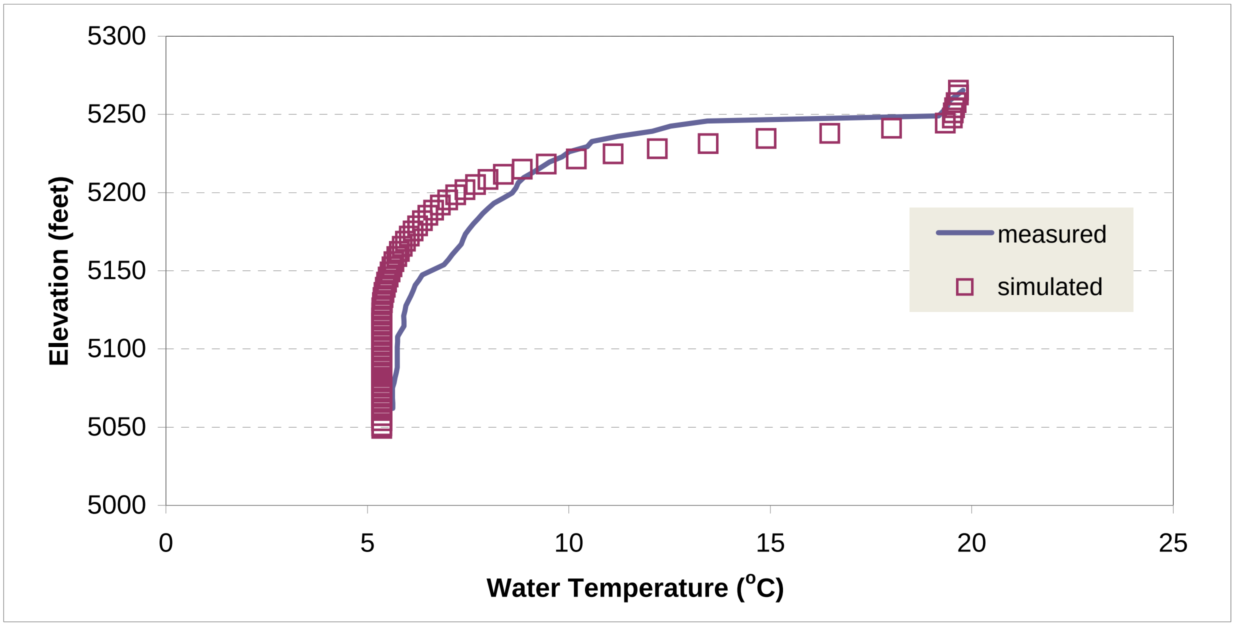


Figure E-2. Calibration Data for French Meadows Reservoir on August 9, 2006 for Segment 23 (Temperature Model) and Vertical Profile Sampling Location FM1.

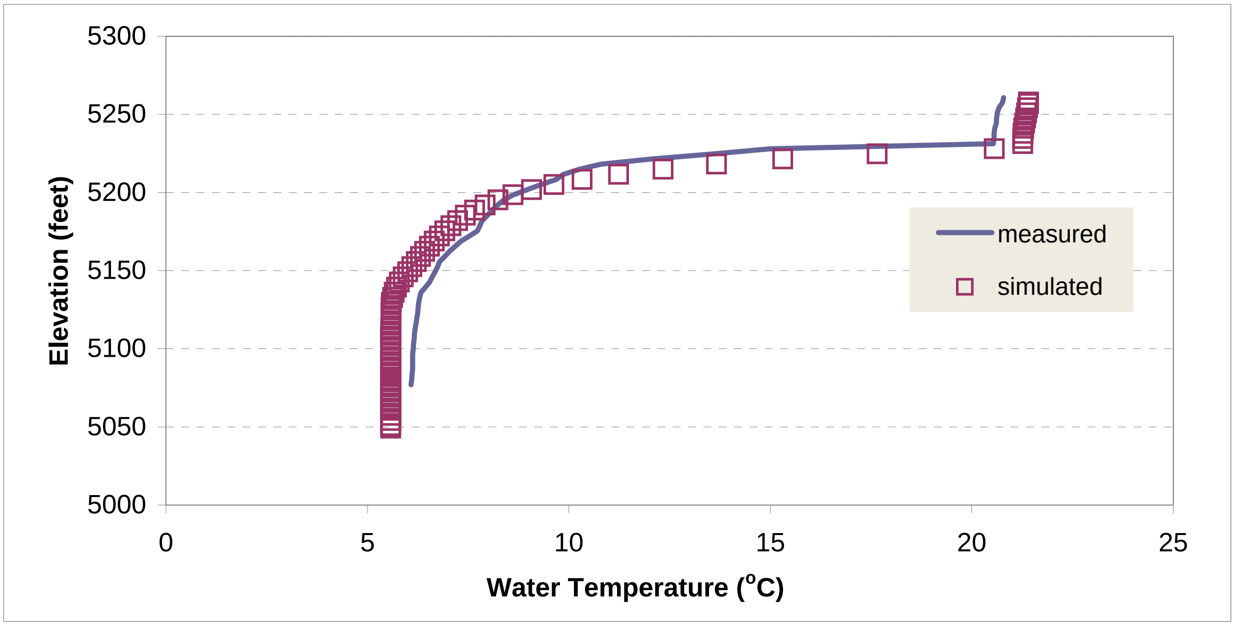


Figure E-3. Calibration Data for French Meadows Reservoir on September 8, 2006 for Segment 23 (Temperature Model) and Vertical Profile Sampling Location FM1.

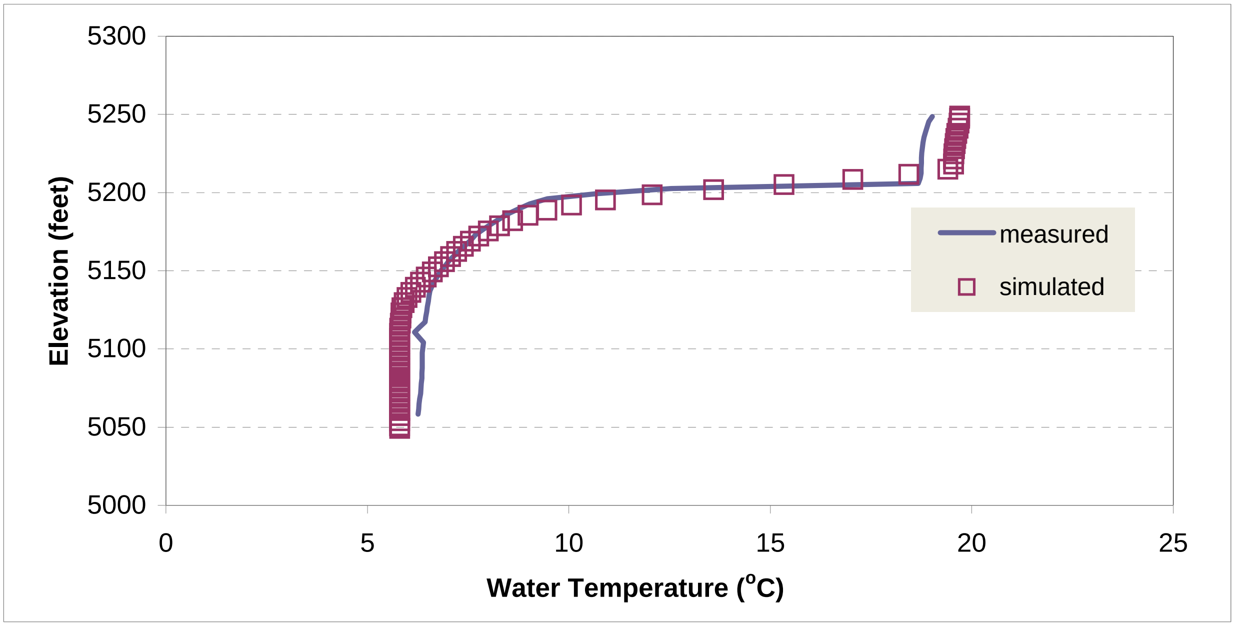


Figure E-4. Calibration Data for French Meadows Reservoir on October 27, 2006 for Segment 23 (Temperature Model) and Vertical Profile Sampling Location FM1.

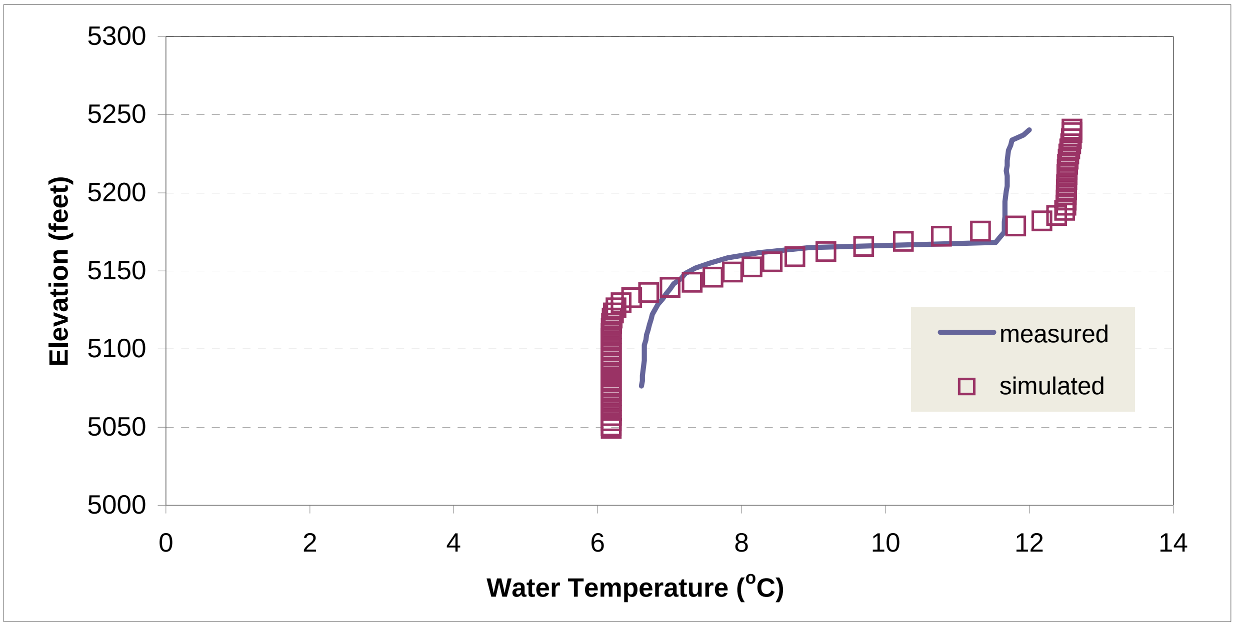


Figure E-5. Calibration Data for French Meadows Reservoir on July 6, 2006 for Segment 17 (Temperature Model) and Vertical Profile Sampling Location FM2.

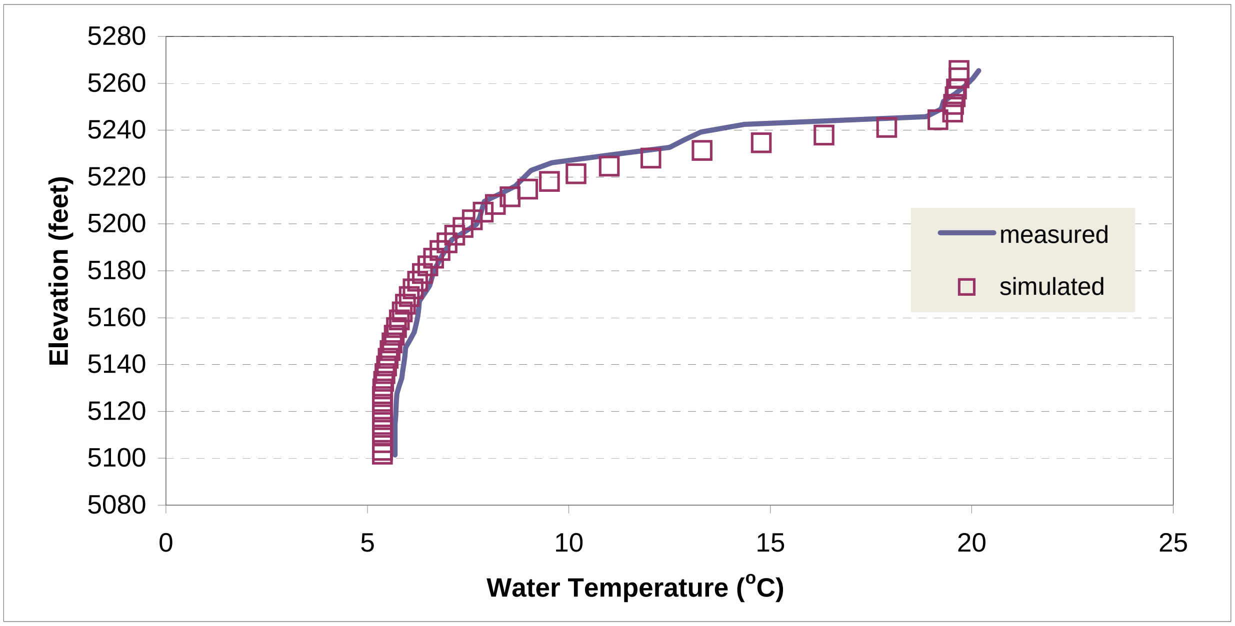


Figure E-6. Calibration Data for French Meadows Reservoir on August 9, 2006 for Segment 17 (Temperature Model) and Vertical Profile Sampling Location FM2.

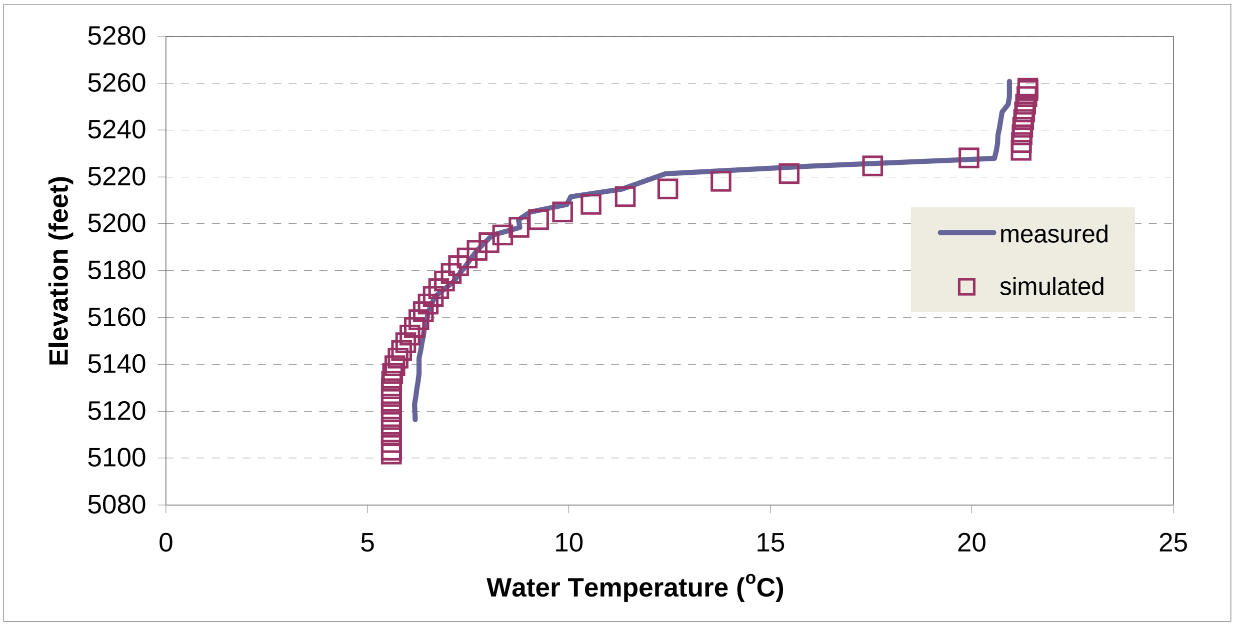


Figure E-7. Calibration Data for French Meadows Reservoir on September 8, 2006 for Segment 17 (Temperature Model) and Vertical Profile Sampling Location FM2.

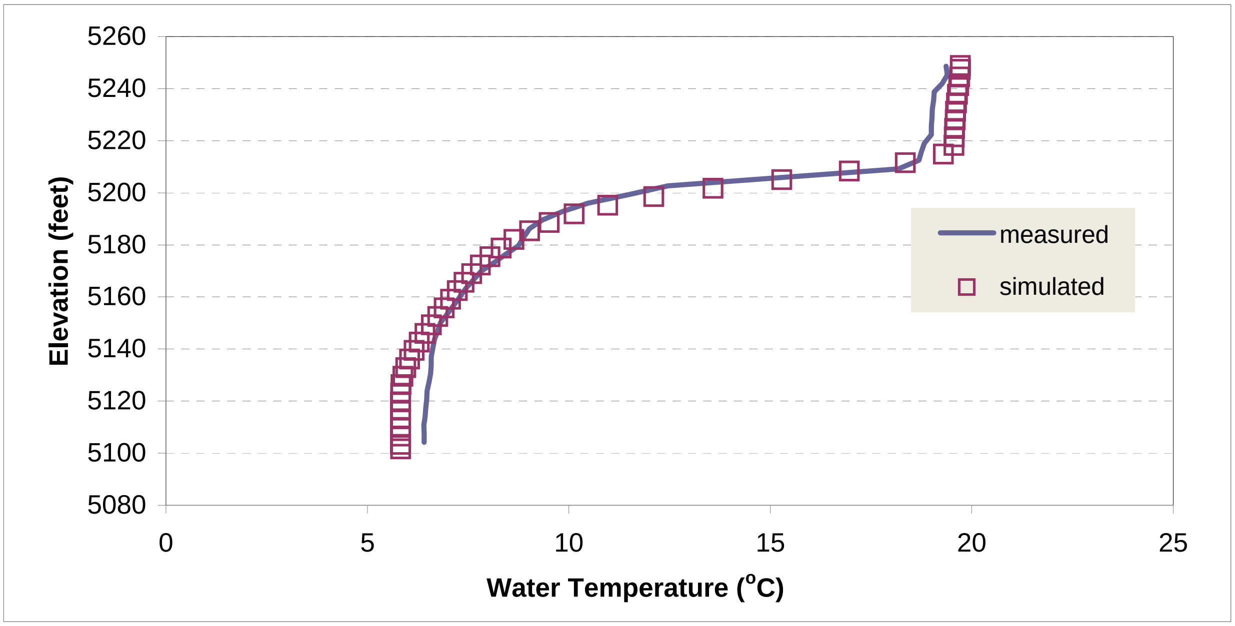


Figure E-8. Calibration Data for French Meadows Reservoir on October 27, 2006 for Segment 17 (Temperature Model) and Vertical Profile Sampling Location FM2.

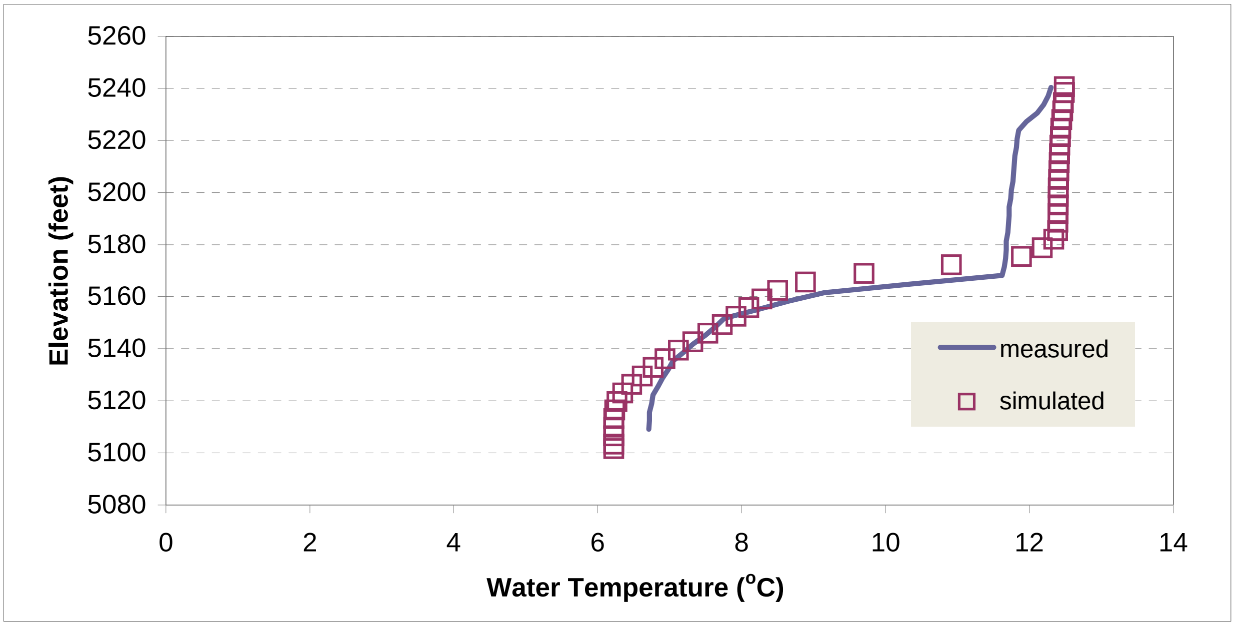


Figure E-9. Calibration Data for French Meadows Reservoir on May 30, 2007 for Segment 23 (Temperature Model) and Vertical Profile Sampling Location FM1.

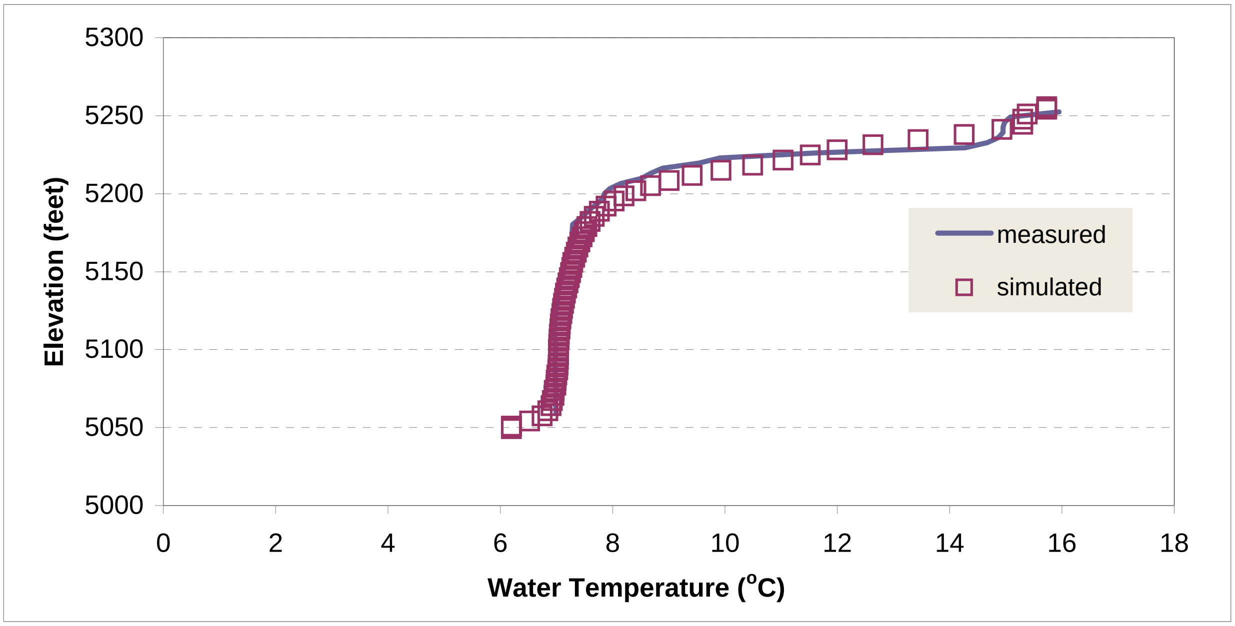


Figure E-10. Calibration Data for French Meadows Reservoir on July 12, 2007 for Segment 23 (Temperature Model) and Vertical Profile Sampling Location FM1.

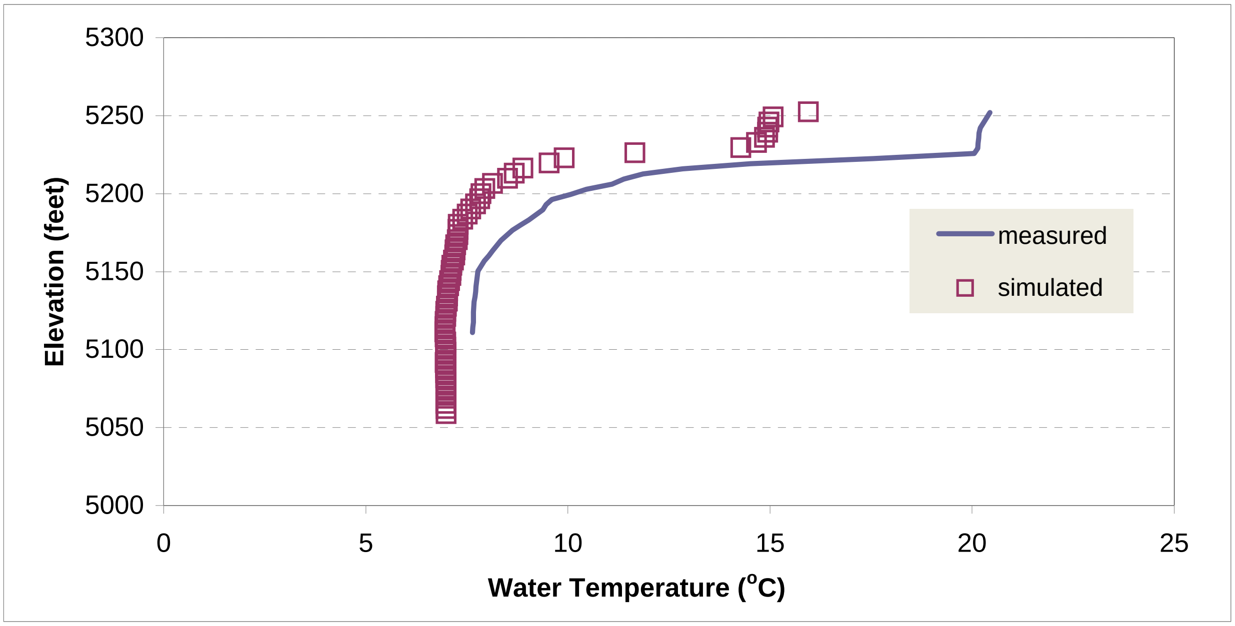


Figure E-11. Calibration Data for French Meadows Reservoir on August 2, 2007 for Segment 23 (Temperature Model) and Vertical Profile Sampling Location FM1.

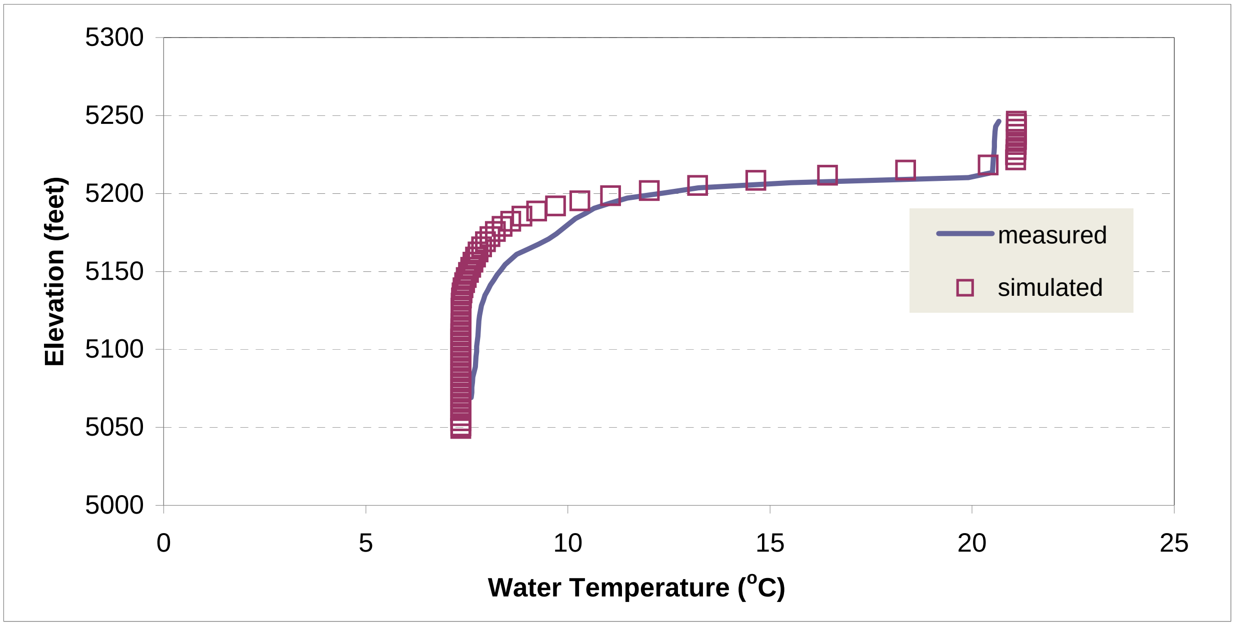


Figure E-12. Calibration Data for French Meadows Reservoir on August 31, 2007 for Segment 23 (Temperature Model) and Vertical Profile Sampling Location FM1.

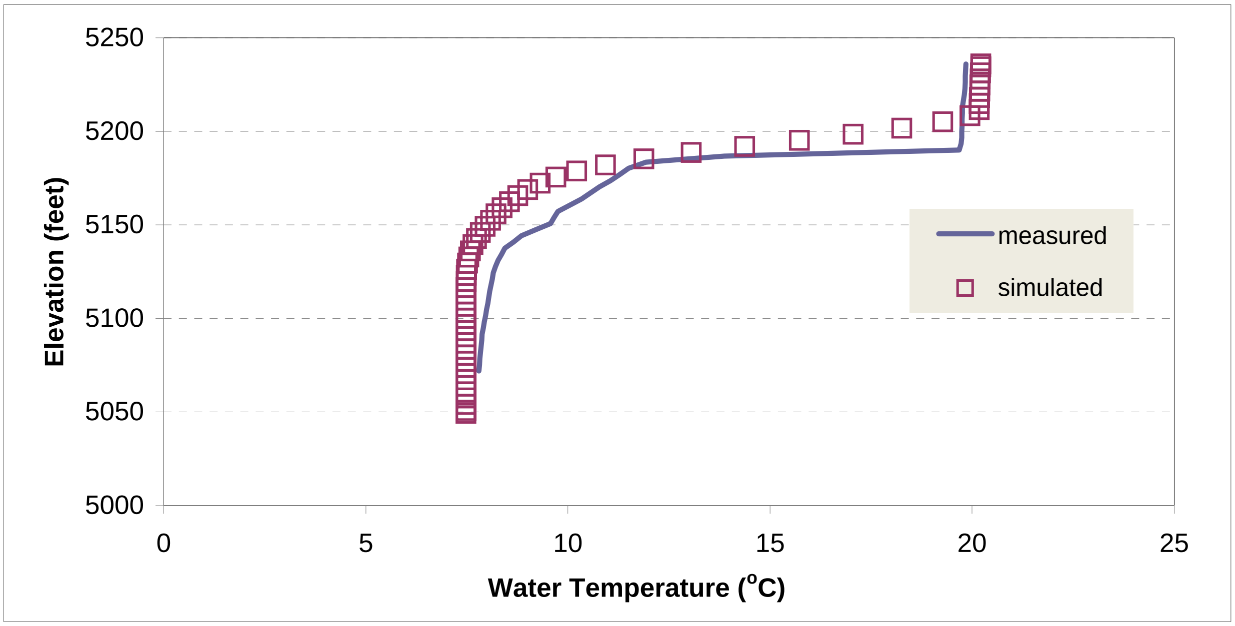


Figure E-13. Calibration Data for French Meadows Reservoir on May 30, 2007 for Segment 17 (Temperature Model) and Vertical Profile Sampling Location FM2.

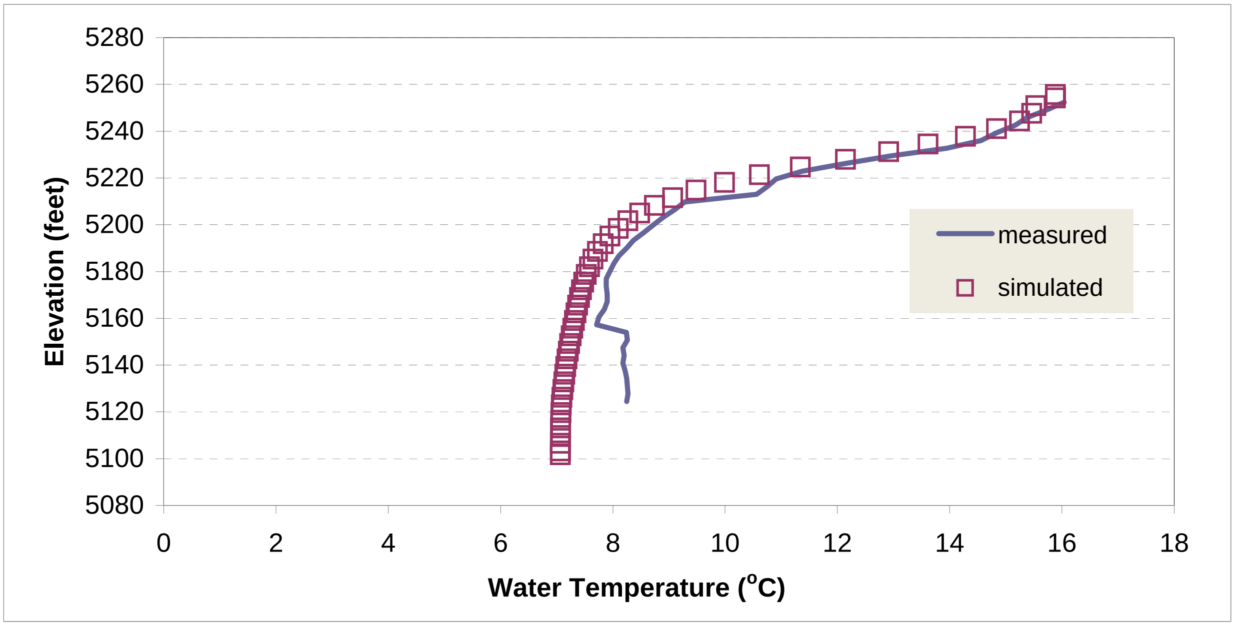


Figure E-14. Calibration Data for French Meadows Reservoir on July 12, 2007 for Segment 17 (Temperature Model) and Vertical Profile Sampling Location FM2.

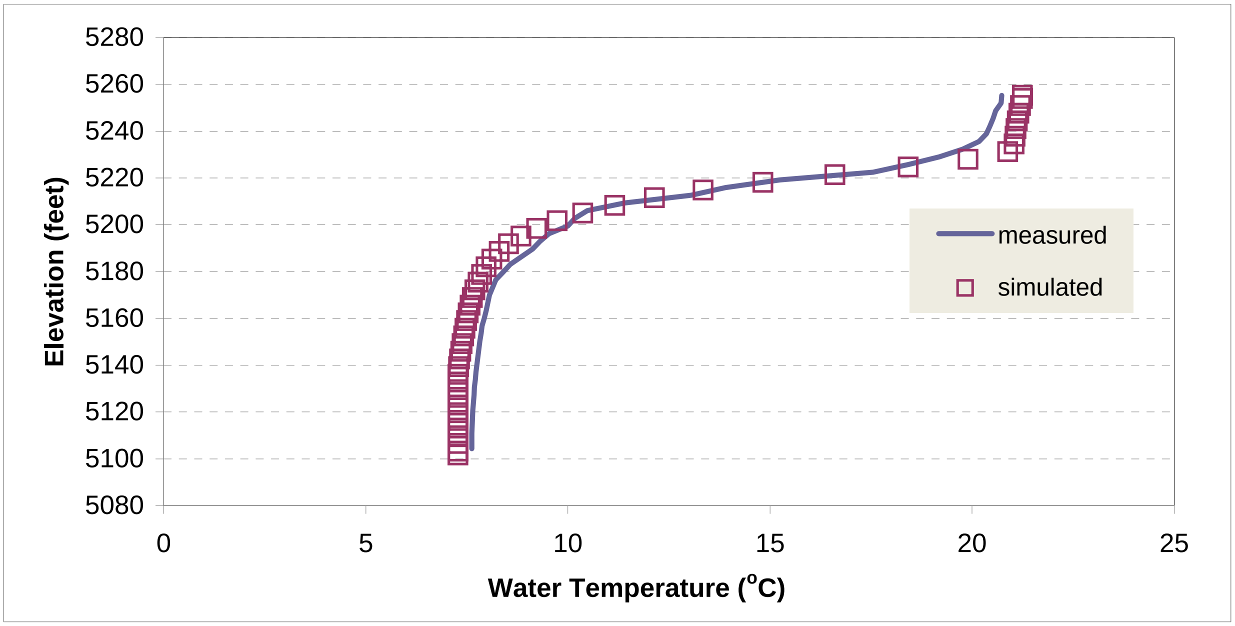


Figure E-15. Calibration Data for French Meadows Reservoir on August 2, 2007 for Segment 17 (Temperature Model) and Vertical Profile Sampling Location FM2.

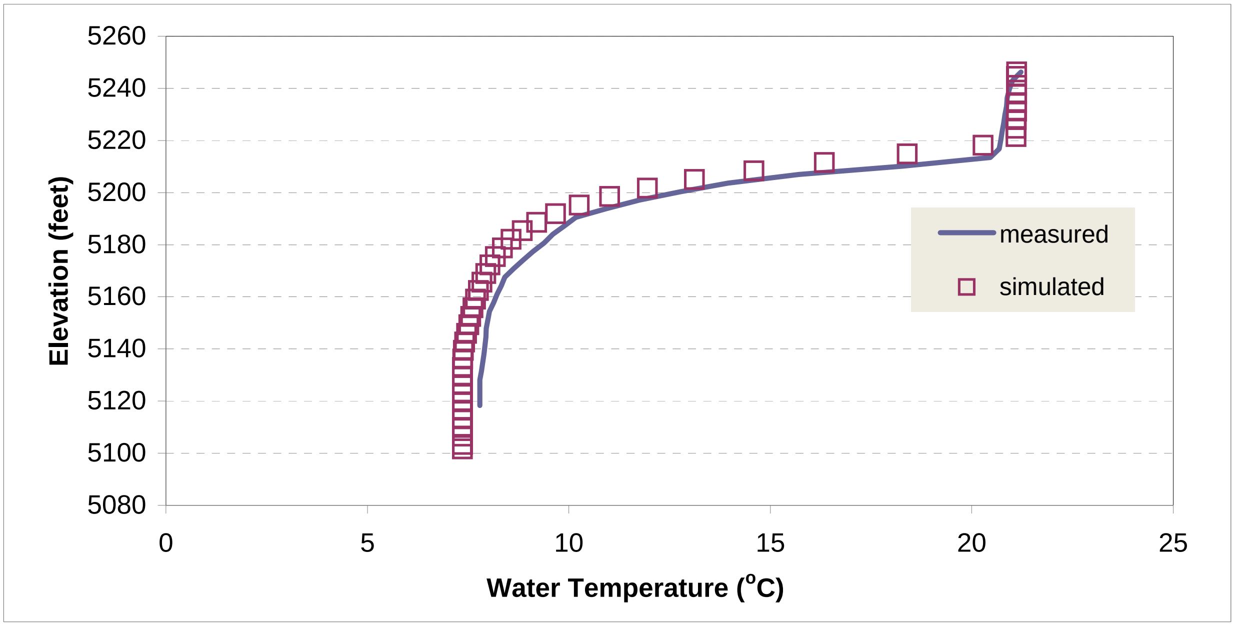


Figure E-16. Calibration Data for French Meadows Reservoir on August 31, 2007 for Segment 17 (Temperature Model) and Vertical Profile Sampling Location FM2.

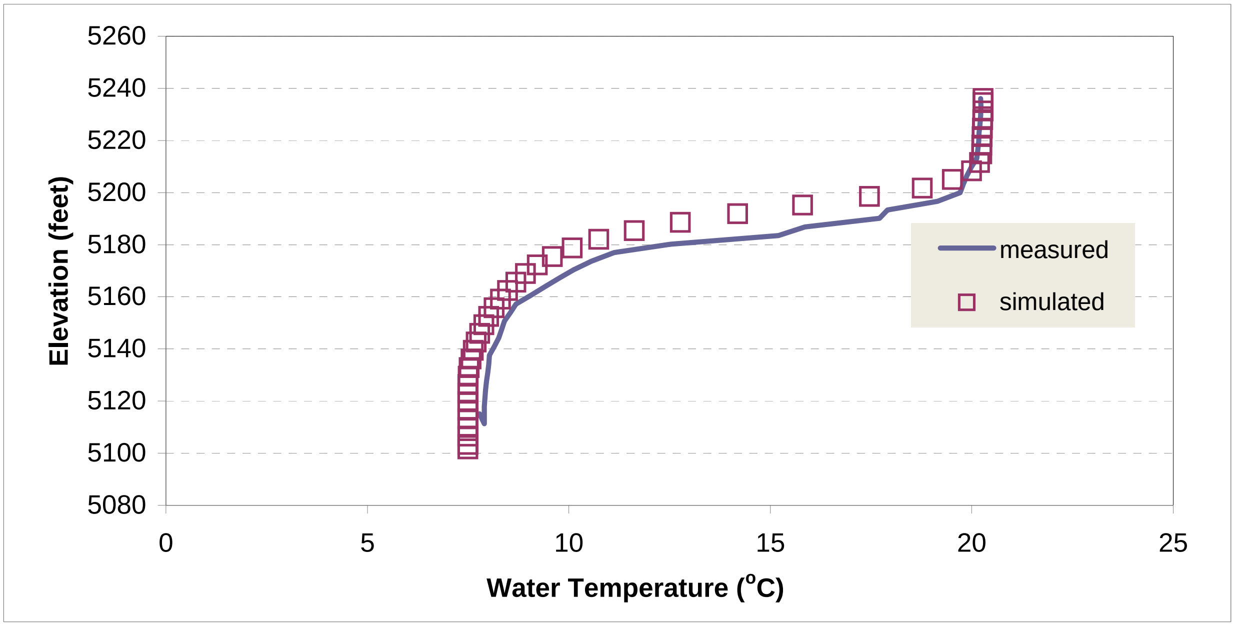


Figure E-17. Calibration Data for Hell Hole Reservoir on July 6, 2006 for Segment 24 (Temperature Model) and Vertical Profile Sampling Location HH1.

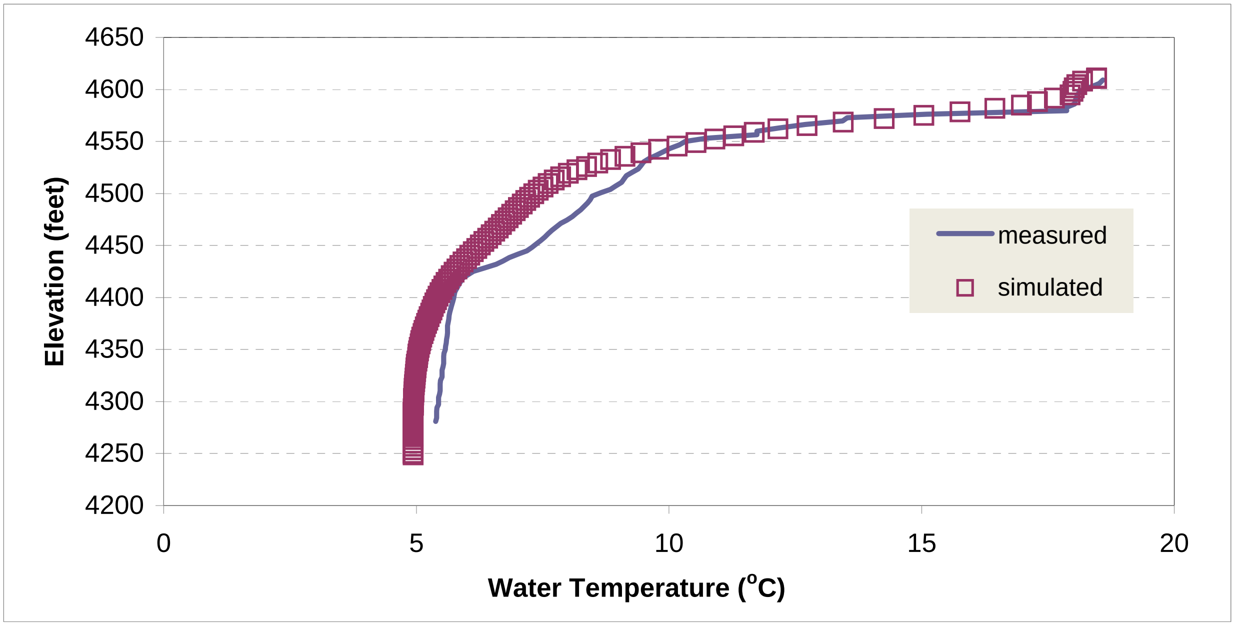


Figure E-18. Calibration Data for Hell Hole Reservoir on August 9, 2006 for Segment 24 (Temperature Model) and Vertical Profile Sampling Location HH1.

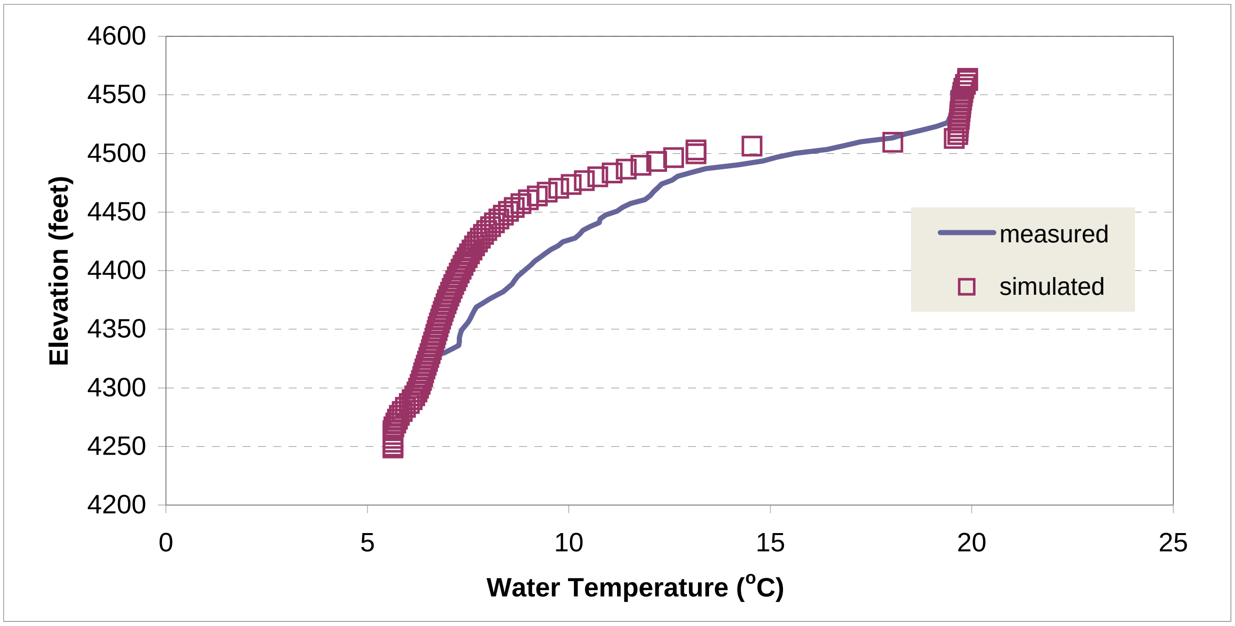


Figure E-19. Calibration Data for Hell Hole Reservoir on September 8, 2006 for Segment 24 (Temperature Model) and Vertical Profile Sampling Location HH1.

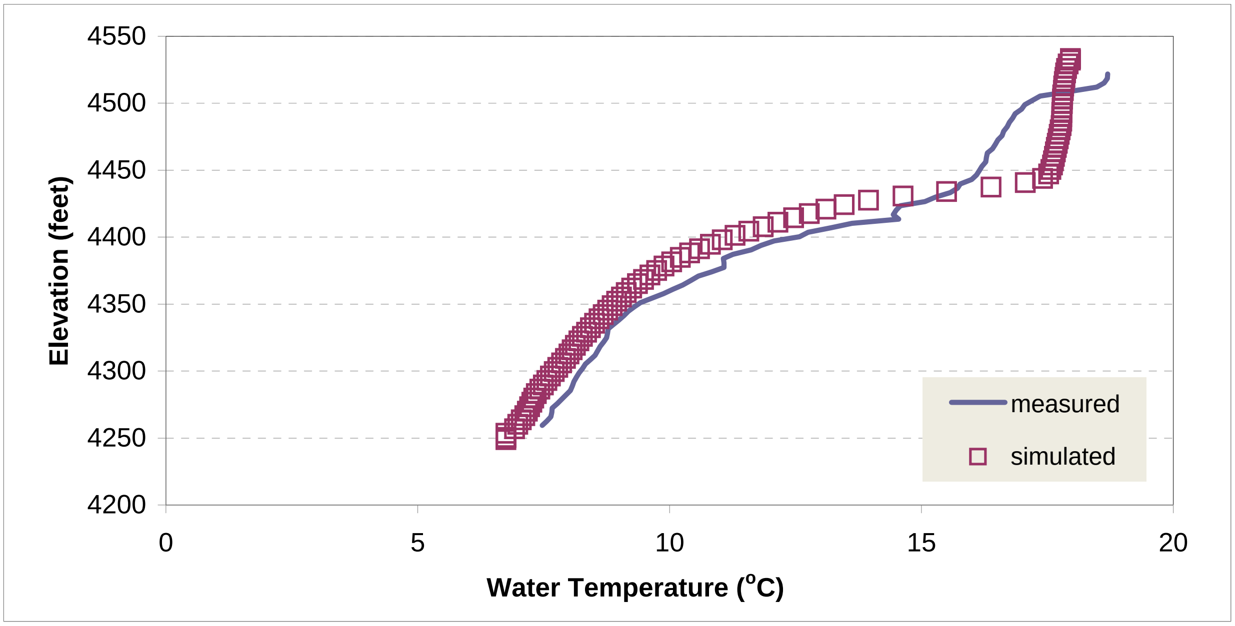


Figure E-20. Calibration Data for Hell Hole Reservoir on October 27, 2006 for Segment 24 (Temperature Model) and Vertical Profile Sampling Location HH1.

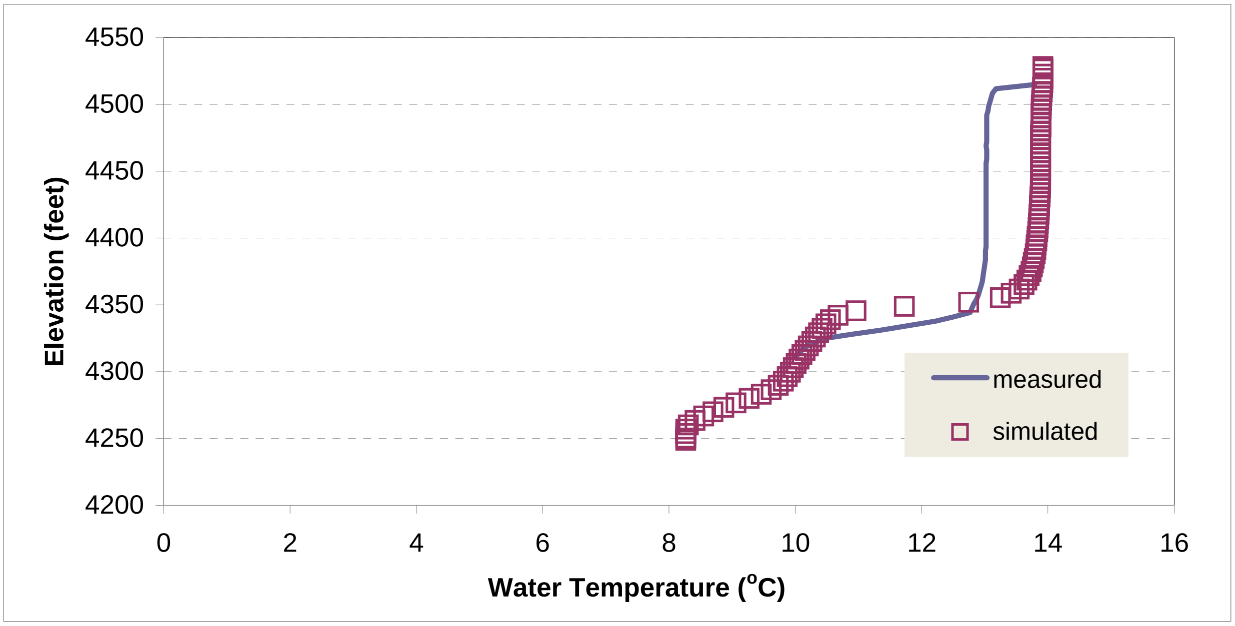


Figure E-21. Calibration Data for Hell Hole Reservoir on May 30, 2007 for Segment 24 (Temperature Model) and Vertical Profile Sampling Location HH1.

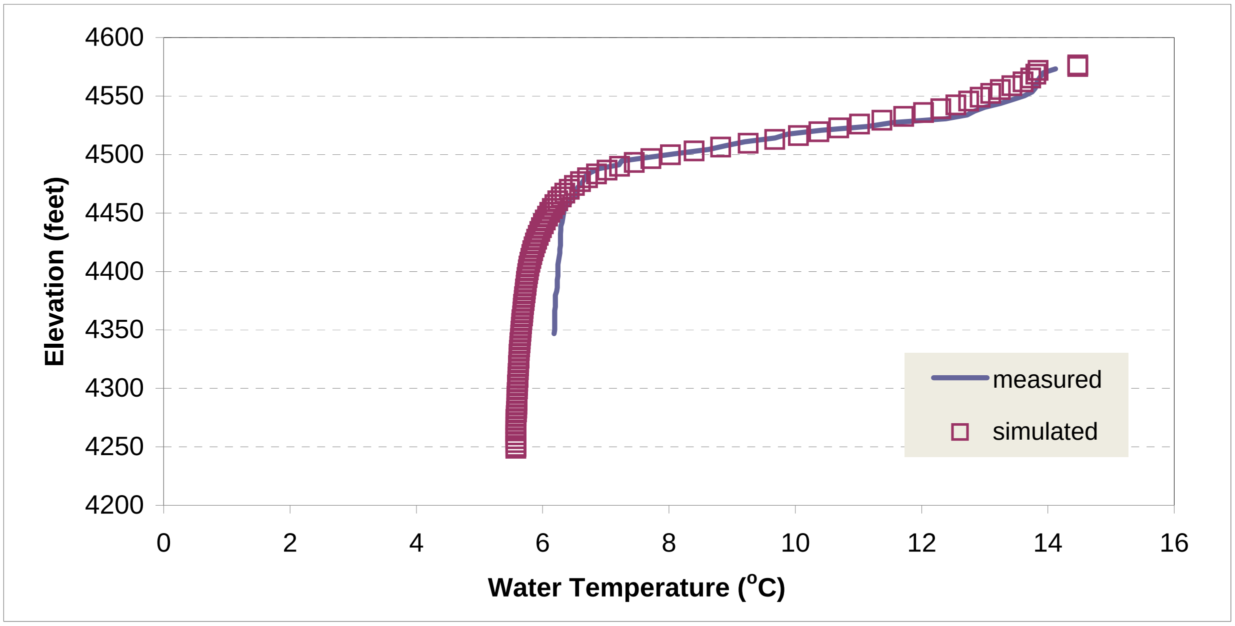


Figure E-22. Calibration Data for Hell Hole Reservoir on July 12, 2007 for Segment 24 (Temperature Model) and Vertical Profile Sampling Location HH1.

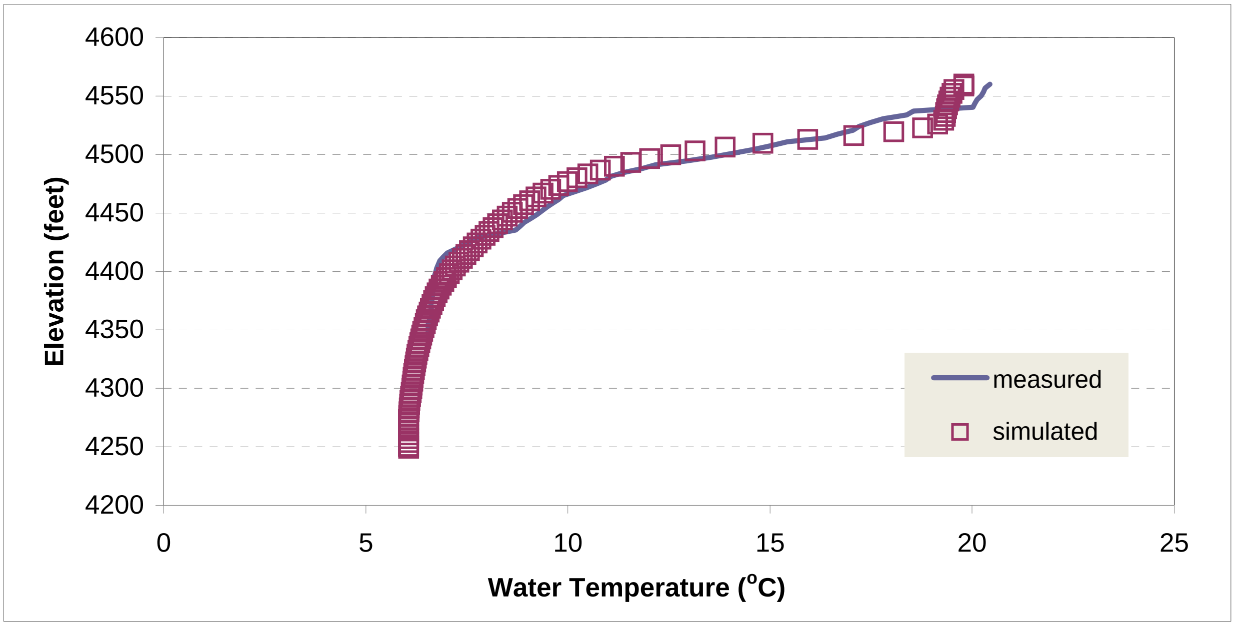


Figure E-23. Calibration Data for Hell Hole Reservoir on August 2, 2007 for Segment 24 (Temperature Model) and Vertical Profile Sampling Location HH1.

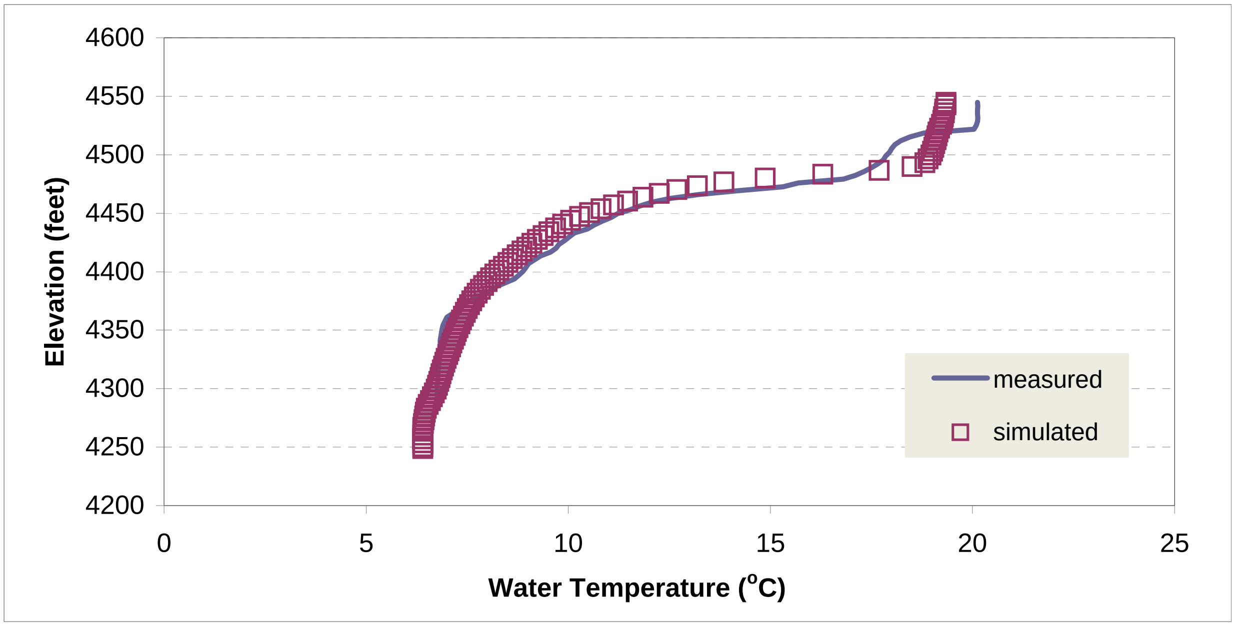


Figure E-24. Calibration Data for Hell Hole Reservoir on August 31, 2007 for Segment 24 (Temperature Model) and Vertical Profile Sampling Location HH1.

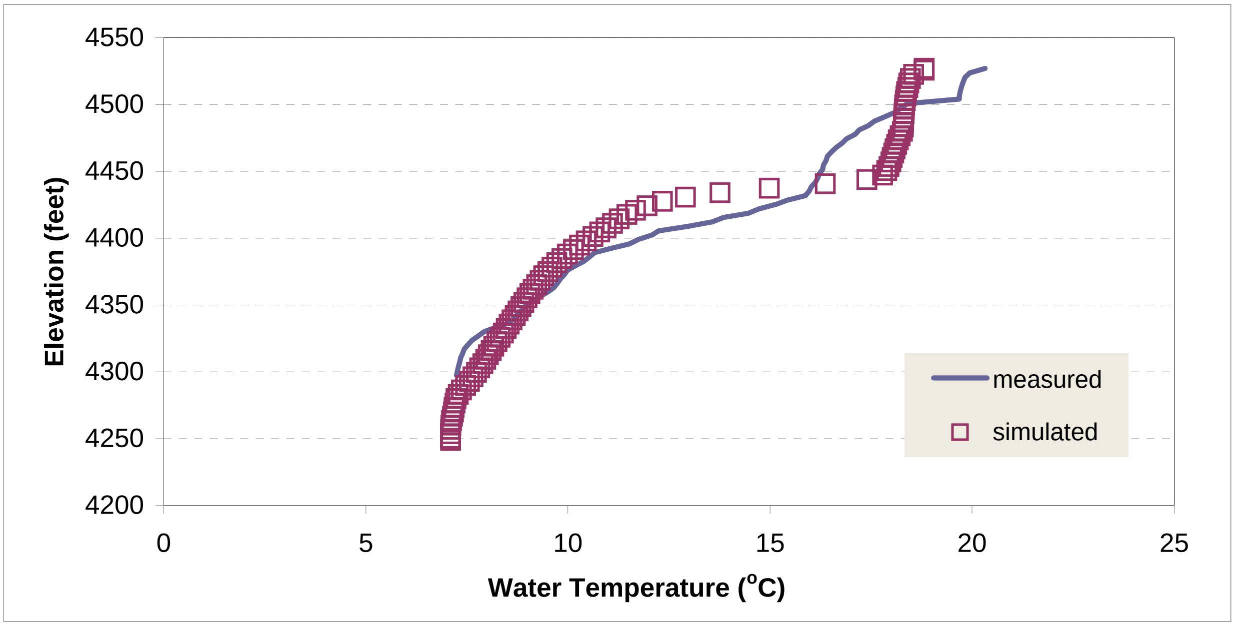


Figure E-25. Calibration Data for Hell Hole Reservoir on May 30, 2007 for Segment 20 (Temperature Model) and Vertical Profile Sampling Location HH2.

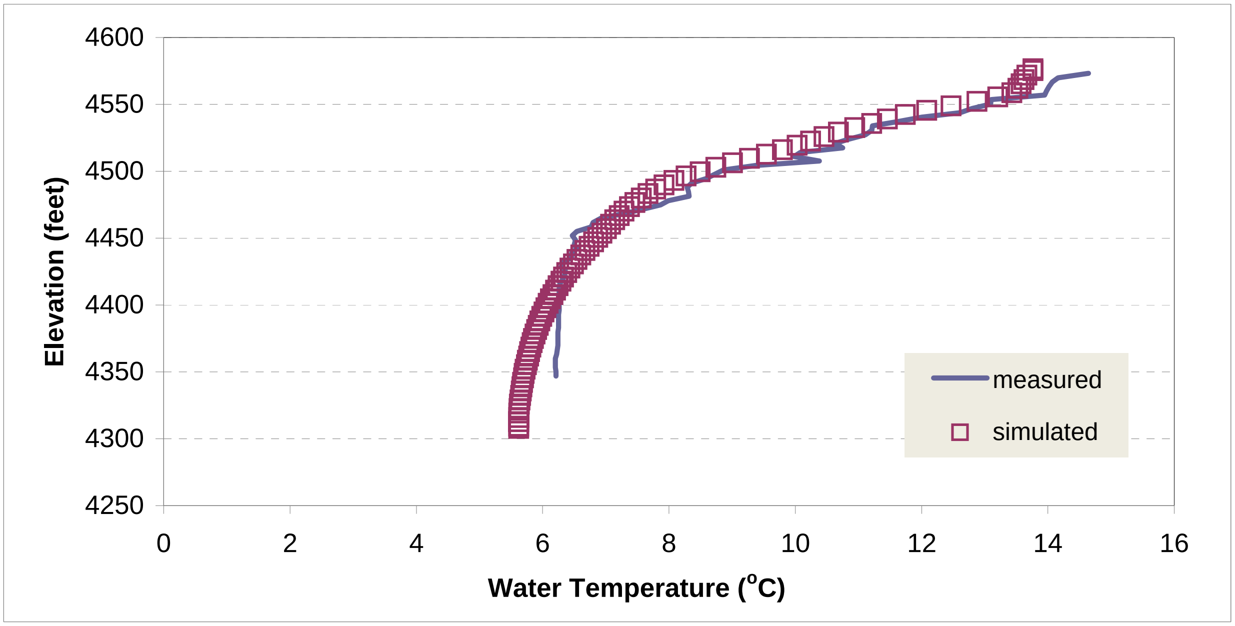


Figure E-26. Calibration Data for Ralston Afterbay on July 6, 2006 for Segment 40 (Temperature Model) and Vertical Profile Sampling Location RA1.

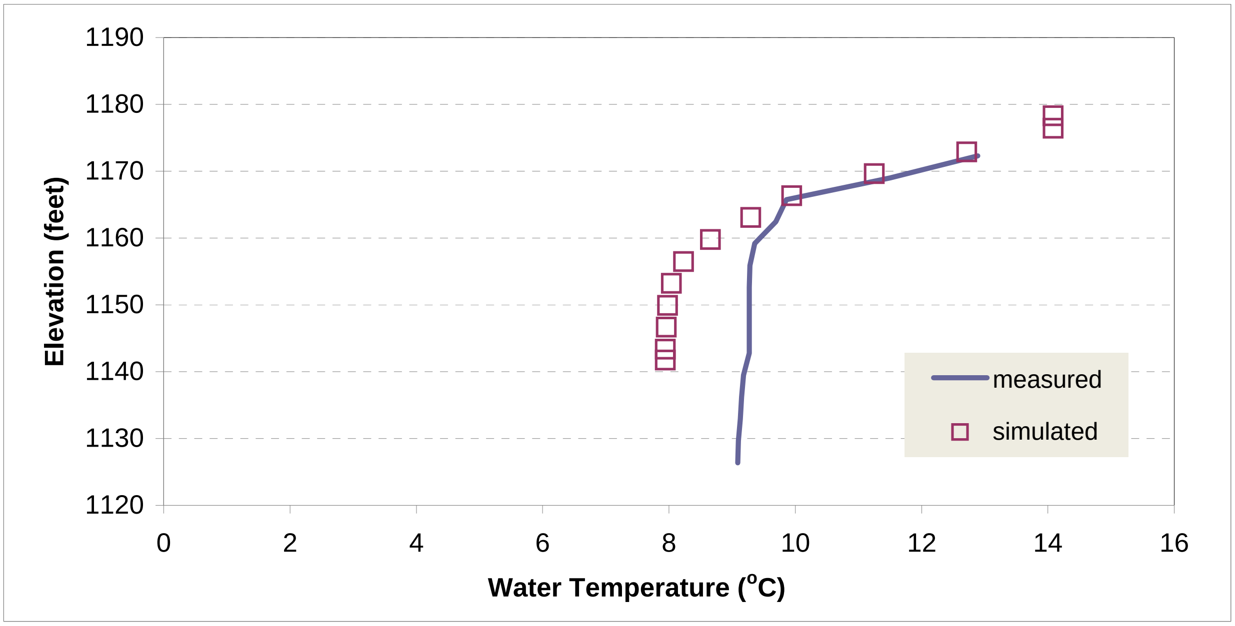


Figure E-27. Calibration Data for Ralston Afterbay on August 8, 2006 for Segment 40 (Temperature Model) and Vertical Profile Sampling Location RA1.

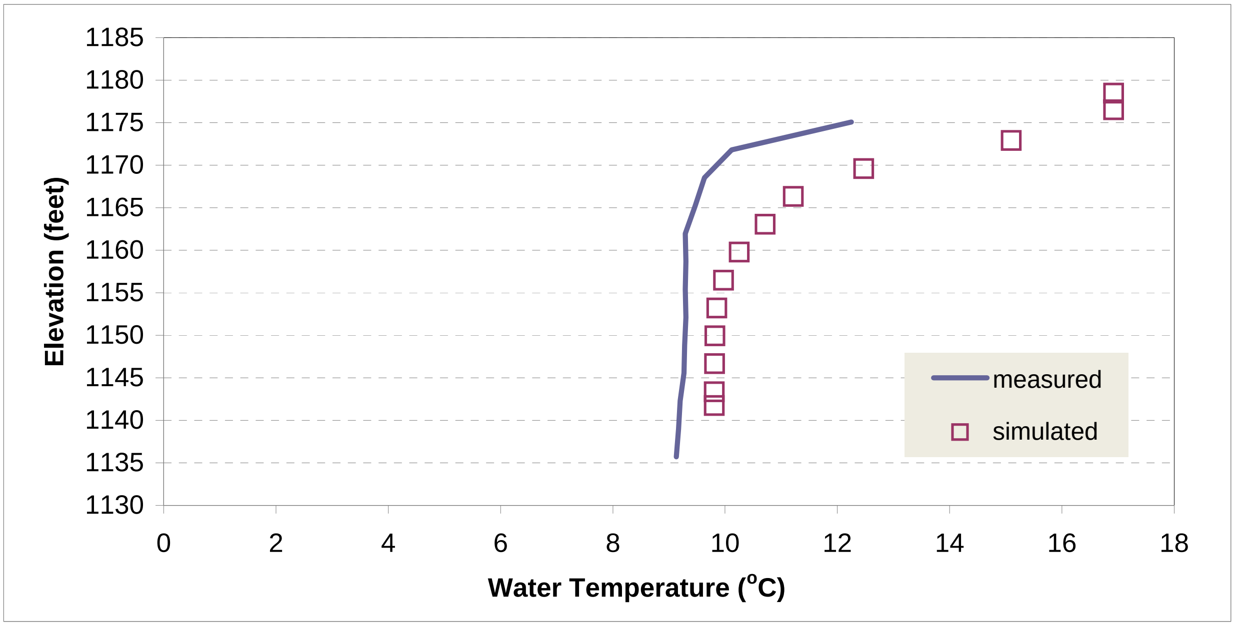


Figure E-28. Calibration Data for Ralston Afterbay on September 30, 2006 for Segment 40 (Temperature Model) and Vertical Profile Sampling Location RA1.

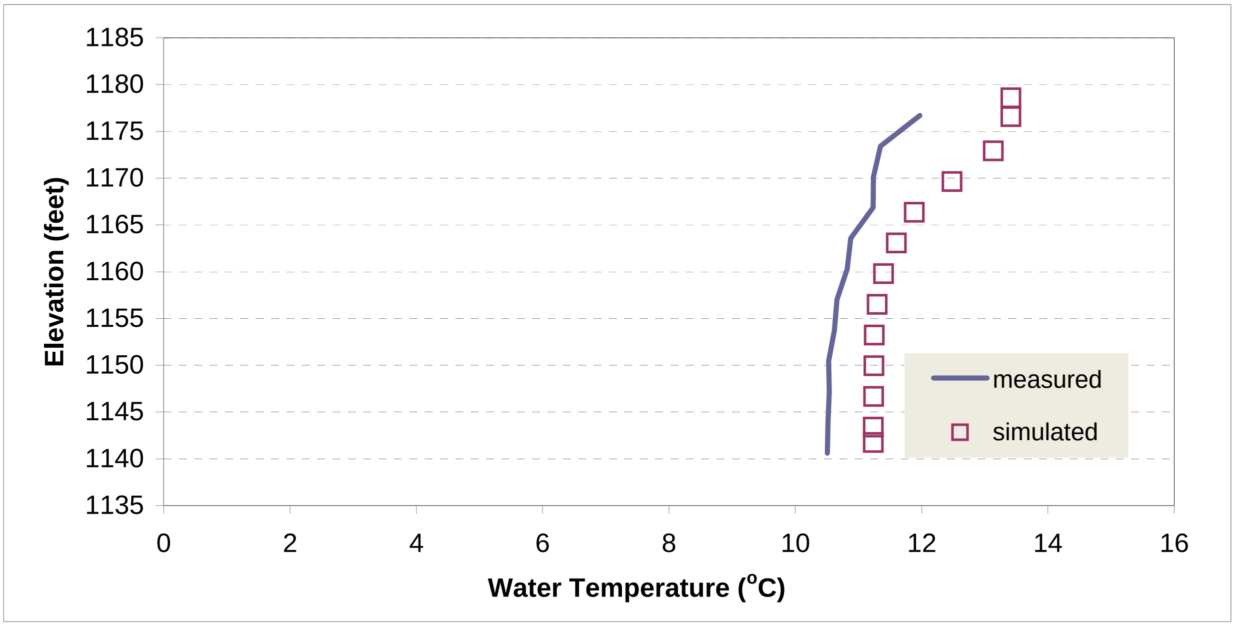


Figure E-29. Calibration Data for Ralston Afterbay on June 7, 2007 for Segment 40 (Temperature Model) and Vertical Profile Sampling Location RA1.

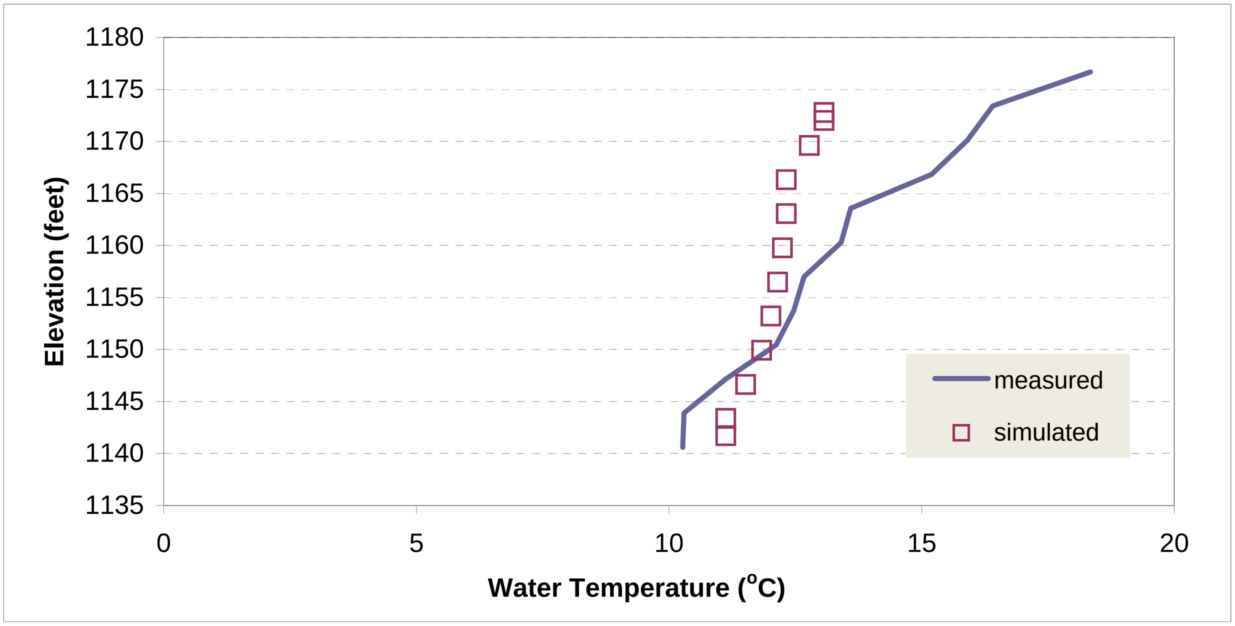


Figure E-30. Calibration Data for Ralston Afterbay on July 11, 2007 for Segment 40 (Temperature Model) and Vertical Profile Sampling Location RA1.

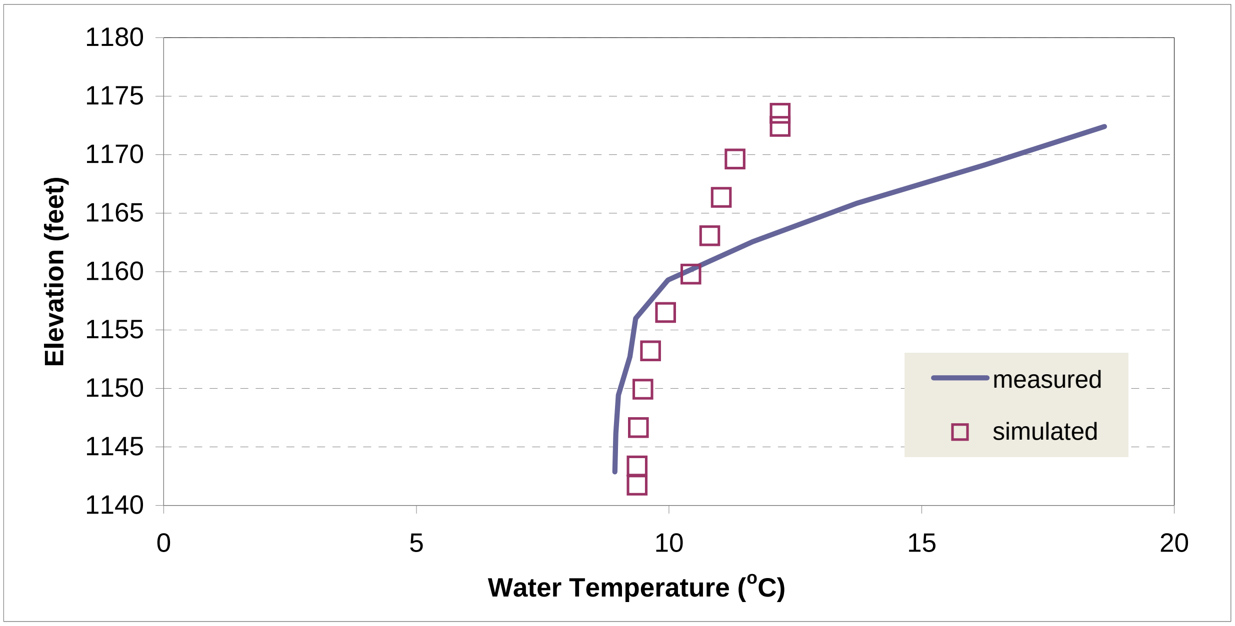


Figure E-31. Calibration Data for Ralston Afterbay on July 31, 2007 for Segment 40 (Temperature Model) and Vertical Profile Sampling Location RA1.

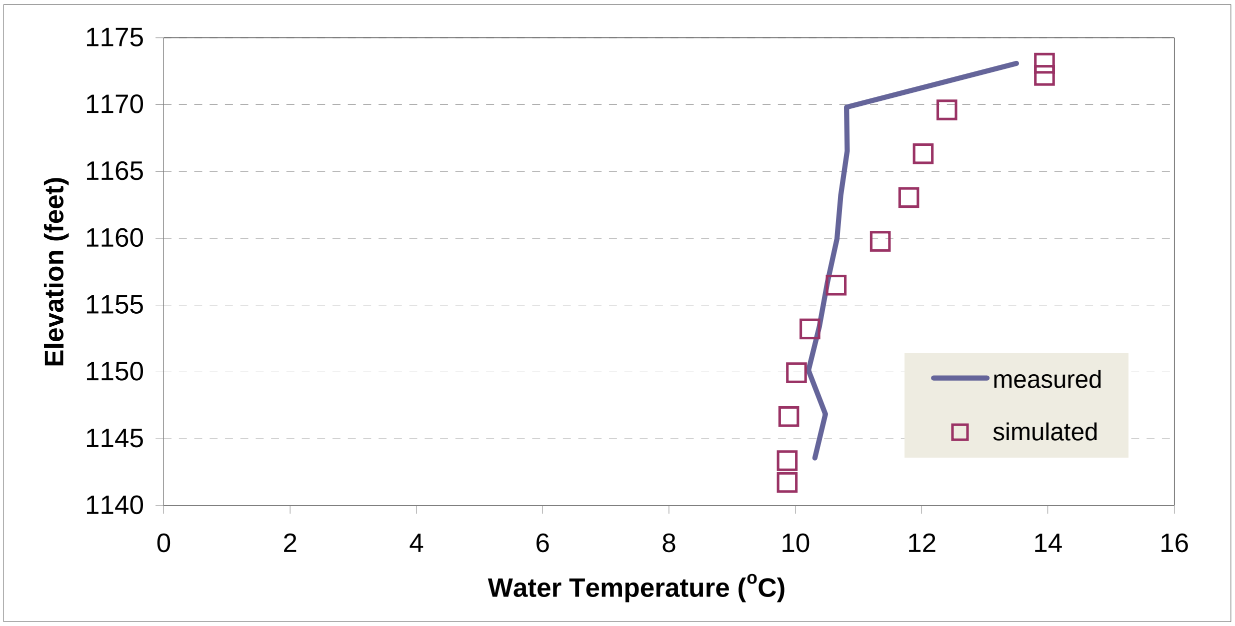


Figure E-32. Calibration Data for Ralston Afterbay on September 6, 2007 for Segment 40 (Temperature Model) and Vertical Profile Sampling Location RA1.

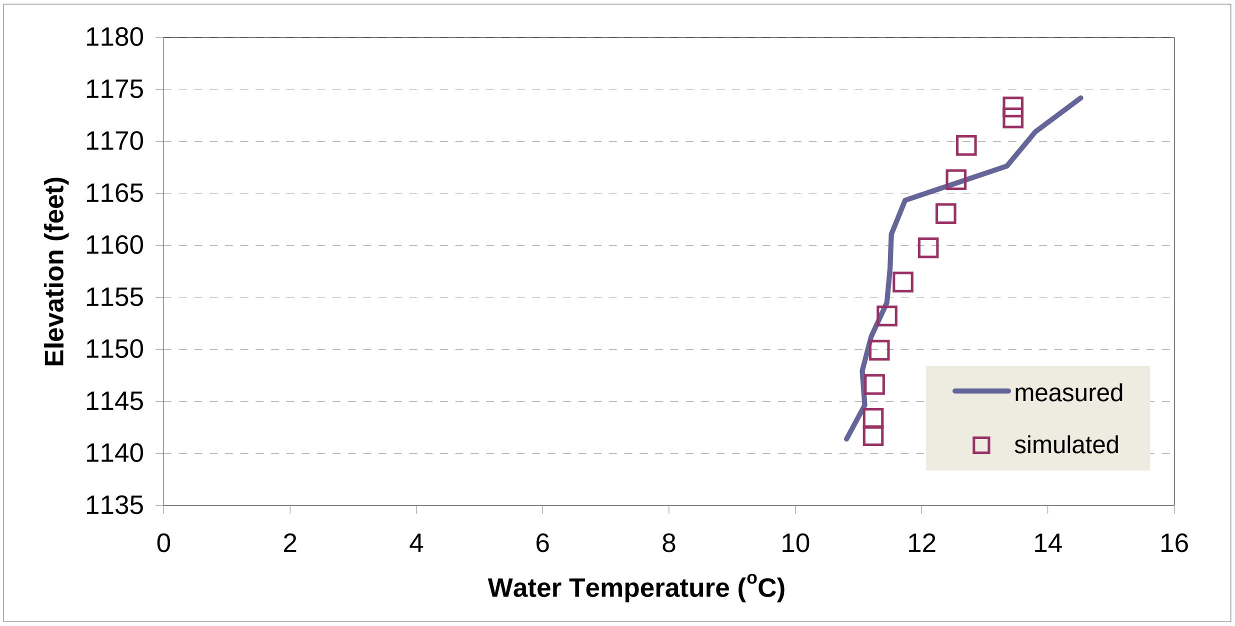
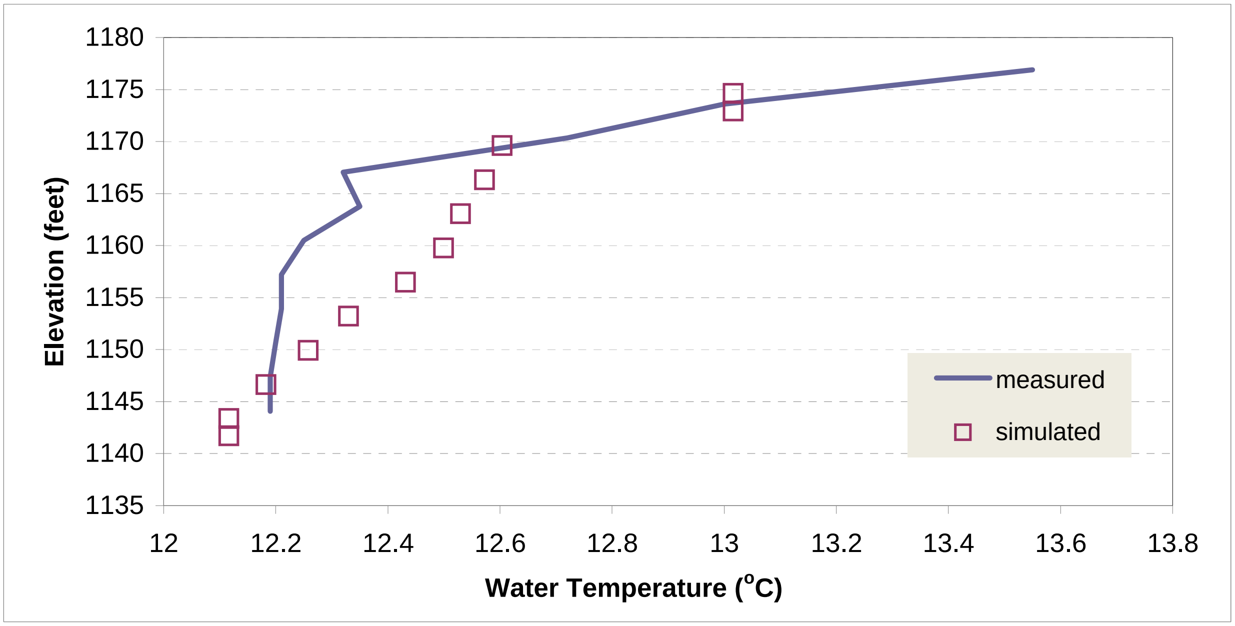


Figure E-33. Calibration Data for Ralston Afterbay on September 25, 2007 for Segment 40 (Temperature Model) and Vertical Profile Sampling Location RA1.



APPENDIX F

River Temperature Calibration Results

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French Meadows Reservoir to Middle Fork Interbay Reach of the Middle Fork American River

Middle Fork Interbay to Ralston Afterbay Reach of the Middle Fork American River

Rubicon River below Hell Hole Reservoir

Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River

TABLES

Table F-1. Calibration Statistics for the 2006 and 2007 Simulations in the French Meadows Reservoir to Middle Fork Interbay Reach of the Middle Fork American River.

	French Meadows Reservoir to Middle Fork Interbay												
	Site	Hourly			Daily Average			Daily Min			Daily Max		
		Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]
2006	**MF 46.6**	0.69	0.71	0.81	0.69	0.69	0.75	0.58	0.58	0.63	0.74	0.74	0.79
	MF 44.6	0.06	0.85	1.01	0.06	0.34	0.47	-0.09	0.34	0.54	0.87	1.15	1.21
	MF 39.4	-0.14	0.83	1.09	-0.14	0.50	0.73	-0.14	0.57	0.85	0.13	0.65	0.87
	MF 36.1	-0.67	0.93	1.18	-0.67	0.73	0.97	-0.78	0.80	1.04	-0.06	0.73	0.92
2007	**MF 46.6**	0.76	0.76	0.86	0.76	0.76	0.78	0.68	0.68	0.70	0.71	0.71	0.74
	MF 44.6	0.02	0.77	0.93	0.02	0.30	0.39	-0.53	0.64	0.73	0.82	0.86	0.93
	MF 39.4	0.23	0.89	1.11	0.23	0.51	0.63	0.06	0.64	0.81	1.13	1.13	1.27
	MF 36.1	0.01	0.92	1.11	0.01	0.41	0.51	-0.60	0.68	0.86	1.38	1.38	1.61

[1]Mean Bias = average of simulated minus observed, MAE = Mean absolute error, RMSE = Root mean square error

Table F-2. Calibration Statistics for the 2006 and 2007 Simulations in the Middle Fork Interbay to Ralston Afterbay Reach of the Middle Fork American River.

	Middle Fork Interbay to Ralston Afterbay												
	Site	Hourly			Daily Average			Daily Min			Daily Max		
		Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]
2006	MF 35.5	-0.66	0.79	1	-0.66	0.77	0.89	-0.57	0.65	0.77	-0.8	1	1.28
	MF 29.4	-0.01	0.69	0.92	-0.01	0.47	0.64	0.48	0.52	0.79	-0.16	0.52	0.78
	MF 26.0	0.23	0.67	0.82	0.23	0.4	0.58	0.06	0.53	0.67	1.23	1.25	1.32
2007	MF 35.5	-0.7	0.75	0.97	-0.7	0.72	0.9	-0.58	0.6	0.81	-1.28	1.28	1.36
	MF 29.4	-0.28	0.86	1.08	-0.28	0.59	0.76	0.26	0.55	0.76	-0.28	0.59	0.78
	MF 26.0	-0.6	0.95	1.13	-0.6	0.76	0.89	-0.81	0.96	1.11	0.4	0.6	0.79

[1]Mean Bias = average of simulated minus observed, MAE = Mean absolute error, RMSE = Root mean square error

Table F-3. Calibration Statistics for the 2006 and 2007 Simulations in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River.

	Hell Hole Reservoir to Ralston Afterbay												
	Site	Hourly			Daily Average			Daily Min			Daily Max		
		Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]
2006	RR 25.3	-0.30	0.68	0.89	-0.30	0.37	0.48	-0.92	0.92	1.05	0.42	0.51	0.60
	RR 22.7	0.03	0.59	0.73	0.03	0.46	0.55	0.14	0.55	0.66	0.31	0.54	0.65
	RR 22.5	0.06	0.44	0.57	0.06	0.32	0.37	0.18	0.39	0.47	0.19	0.38	0.47
	RR 14.3	0.12	0.81	1.00	0.12	0.60	0.72	0.72	0.86	1.04	-0.91	1.35	1.27
	RR 5.3	-0.18	0.76	0.92	-0.19	0.60	0.68	-0.41	0.61	0.72	0.43	0.79	0.94
	RR 3.7	-0.52	0.86	1.03	-0.52	0.67	0.82	-0.79	0.82	1.00	0.29	0.68	0.82
	RR 0.7	-0.19	0.73	0.88	-0.20	0.59	0.68	-0.86	0.88	1.03	0.49	0.83	0.98
2007	RR 25.3	-0.13	0.67	0.84	-0.13	0.28	0.35	-0.92	0.92	0.99	0.72	0.75	0.84
	RR 22.7	0.24	0.54	0.66	0.24	0.43	0.52	0.28	0.47	0.58	0.22	0.40	0.49
	RR 22.5	0.31	0.50	0.61	0.31	0.41	0.50	0.38	0.49	0.58	0.22	0.34	0.42
	RR 14.3	0.22	1.04	1.20	0.22	0.56	0.67	1.20	1.26	1.38	-1.17	1.18	1.33
	RR 5.3	0.00	0.76	1.00	0.00	0.66	0.90	-0.19	0.74	1.04	0.50	0.86	1.00
	RR 3.7	-0.22	0.74	0.93	-0.22	0.57	0.77	-0.46	0.77	0.99	0.46	0.75	0.88
	RR 0.3	0.23	0.76	0.95	0.23	0.65	0.83	-0.12	0.68	0.93	0.74	0.86	1.02

[1]Mean Bias = average of simulated minus observed, MAE = Mean absolute error, RMSE = Root mean square error

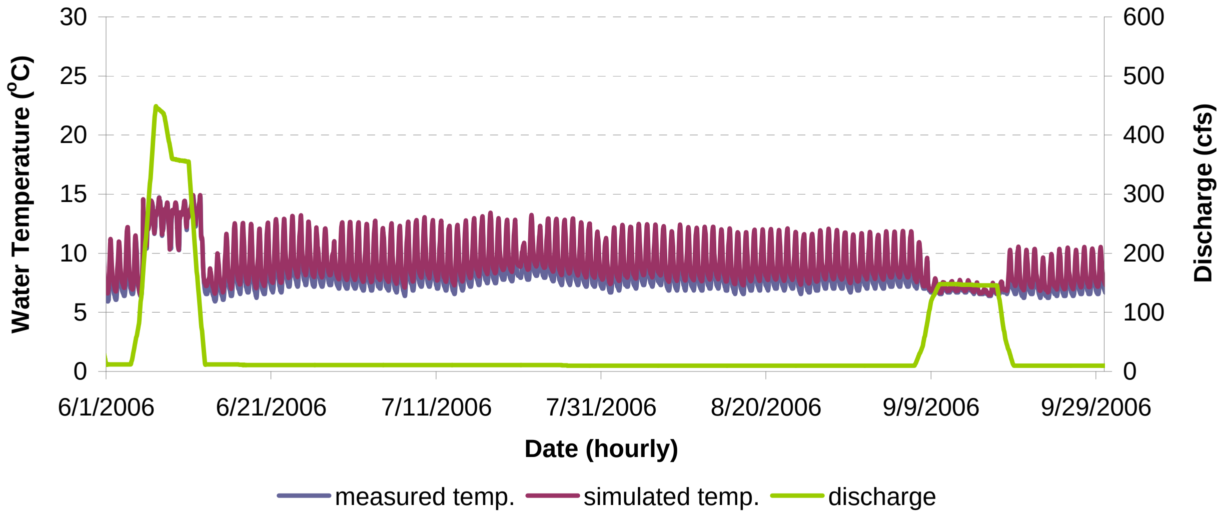
Table F-4. Calibration Statistics for the 2006 and 2007 Simulations in the in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River.

	Ralston Afterbay to Folsom Reservoir												
	Site	Hourly			Daily Average			Daily Min			Daily Max		
		Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]
2006	**MF 24.6**	0.17	0.24	0.36	0.17	0.17	0.2	0.12	0.12	0.15	0.25	0.25	0.3
	MF 24.3	0	0.09	0.14	0	0.02	0.03	-0.01	0.02	0.07	0.01	0.02	0.05
	MF 23.1	-0.11	0.27	0.36	-0.11	0.17	0.18	-0.16	0.25	0.27	-0.12	0.23	0.31
	MF 19.6	-0.29	0.58	0.73	-0.3	0.35	0.41	-0.29	0.37	0.45	-0.69	0.8	0.92
	MF 14.3	-0.09	0.95	1.13	-0.1	0.36	0.41	0.47	0.55	0.63	-0.97	1.05	1.3
	MF 11.0	-0.09	1.01	1.2	-0.1	0.31	0.4	0.58	0.66	0.73	-0.89	1.21	1.38
	MF 8.9	-0.21	0.97	1.17	-0.21	0.37	0.45	0.39	0.52	0.59	-0.74	1.17	1.28
	MF 0.1	-0.35	0.65	0.77	-0.35	0.49	0.57	0.07	0.52	0.65	-0.51	0.57	0.66
	NF 20.8	-0.18	0.47	0.58	-0.18	0.32	0.39	0.04	0.39	0.49	-0.42	0.45	0.54
	NF 14.9	-0.11	0.49	0.61	-0.11	0.33	0.42	-0.4	0.65	0.77	-0.79	0.86	0.98
2007	**MF 24.6**	0.17	0.27	0.47	0.19	0.24	0.34	0.12	0.22	0.31	0.37	0.52	0.73
	MF 24.3	0.05	0.06	0.24	0.06	0.25	0.36	0.02	0.22	0.36	0.1	0.38	0.61
	MF 23.1	0.15	0.29	0.49	0.17	0.27	0.37	-0.06	0.29	0.46	0.54	0.67	0.81
	MF 19.6	-0.07	0.71	0.9	-0.05	0.27	0.37	-0.9	0.94	1.08	0.68	0.75	0.86
	MF 14.3	0.38	1.23	1.47	0.39	0.51	0.61	0.17	0.47	0.63	0.6	0.74	0.92
	MF 11.0	0.45	1.44	1.71	0.46	0.6	0.74	0.52	0.6	0.75	0.78	1.03	1.22
	MF 8.9	-0.18	1.16	1.43	-0.17	0.58	0.72	-0.35	0.58	0.74	0.77	1.06	1.23
	MF 0.1	-0.99	1.24	1.47	-0.97	1.14	1.3	-0.82	1	1.14	-0.97	1.23	1.49
	NF 20.8	0.01	0.76	0.99	0.03	0.66	0.81	-0.22	0.69	0.85	-0.14	0.78	0.96
	NF 14.9	-0.59	0.77	0.92	-0.55	0.7	0.83	-1.05	1.06	1.17	-0.4	0.7	0.84

[1]Mean Bias = average of simulated minus observed, MAE = Mean absolute error, RMSE = Root mean square erroı

FIGURES

Figure F-1. Water Temperature Model Calibration Results for MF 46.6 in the French Meadows Reservoir to Middle Fork Interbay Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



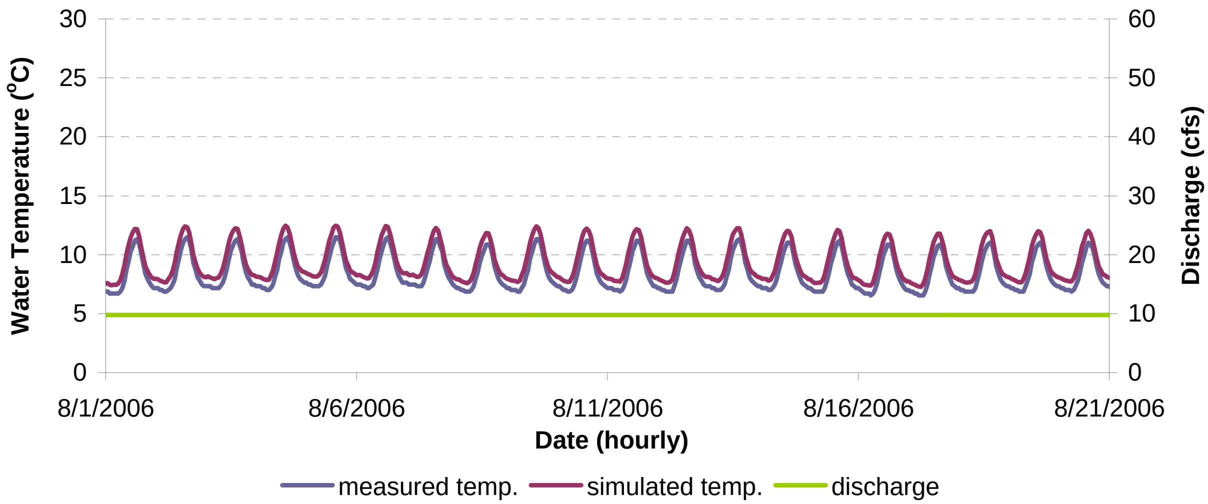
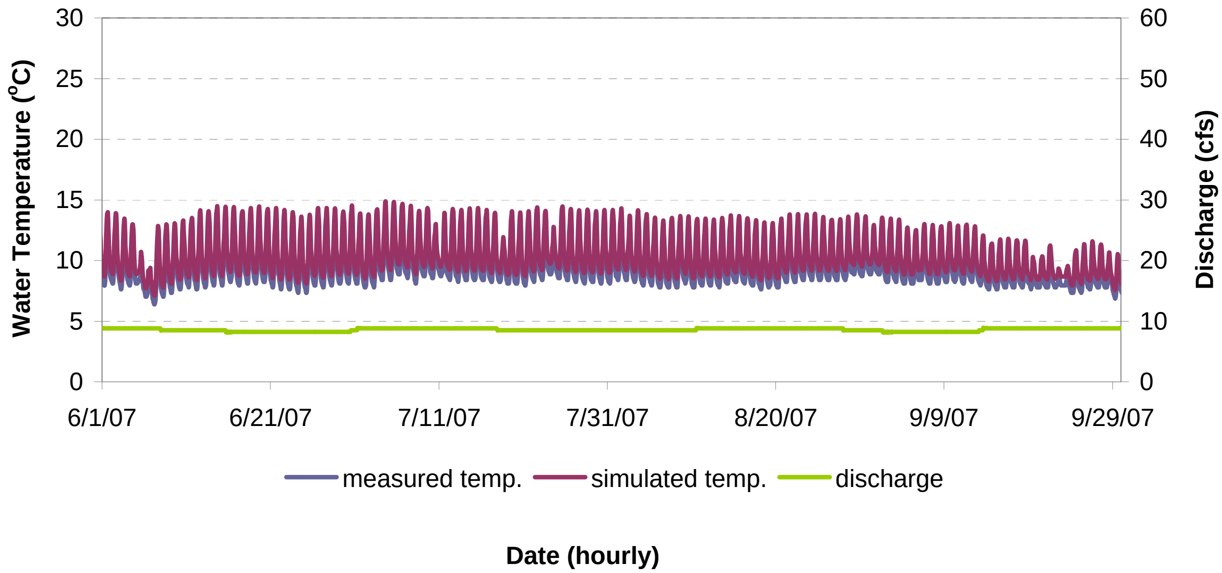


Figure F-2. Water Temperature Model Calibration Results for MF 46.6 in the French Meadows Reservoir to Middle Fork Interbay Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



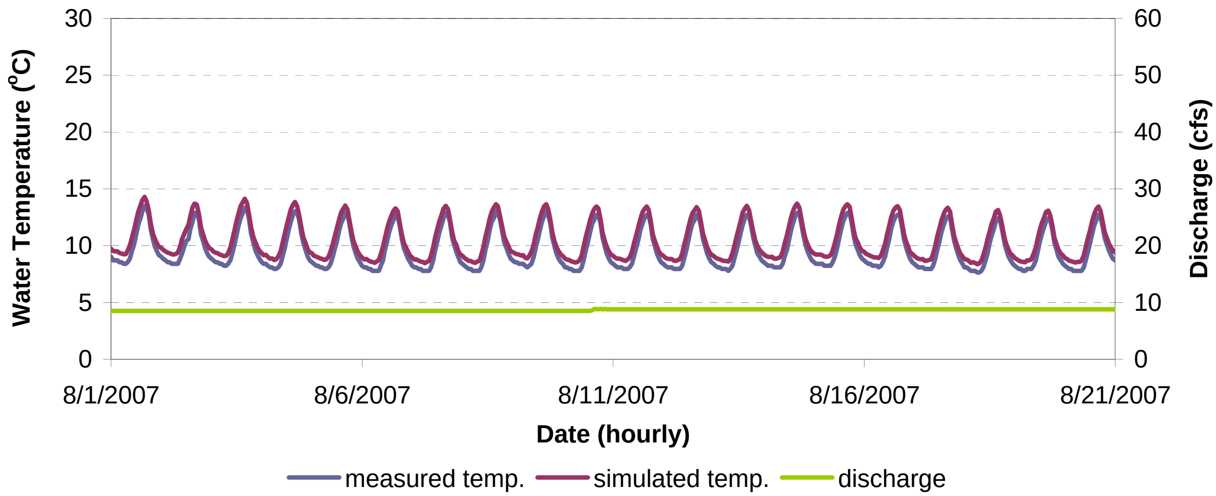
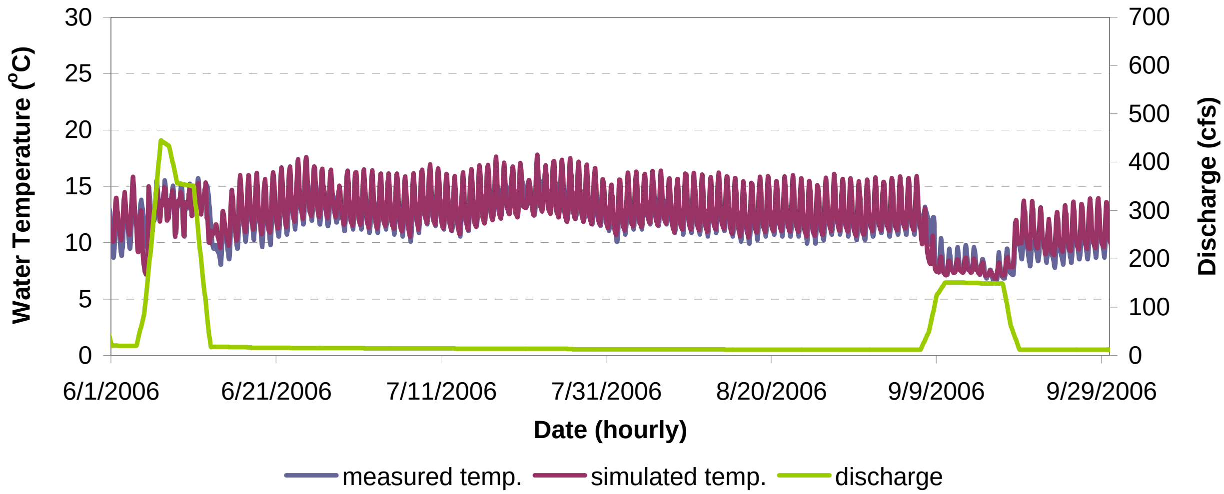


Figure F-3. Water Temperature Model Calibration Results for MF 44.6 in the French Meadows Reservoir to Middle Fork Interbay Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



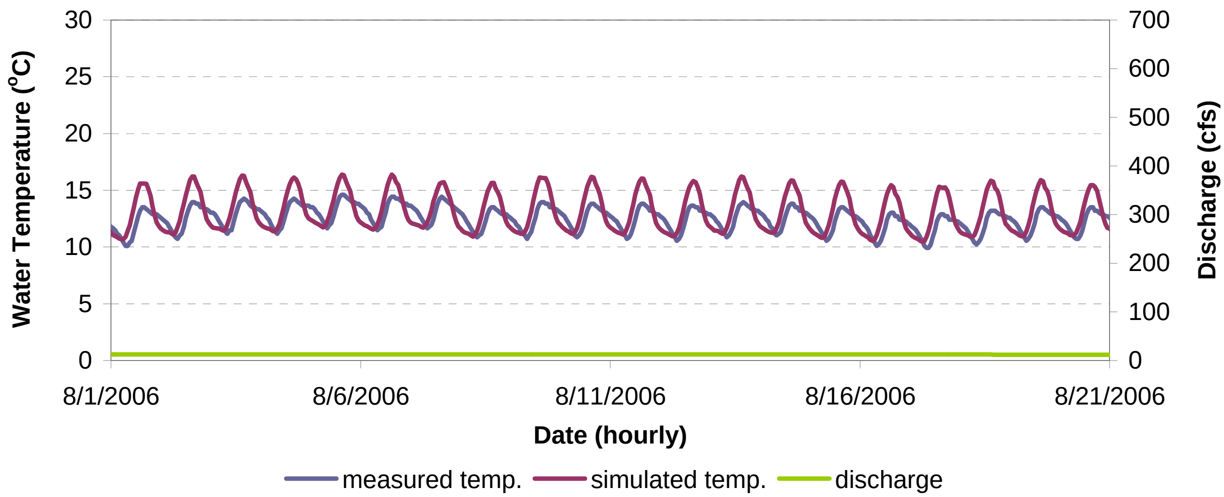
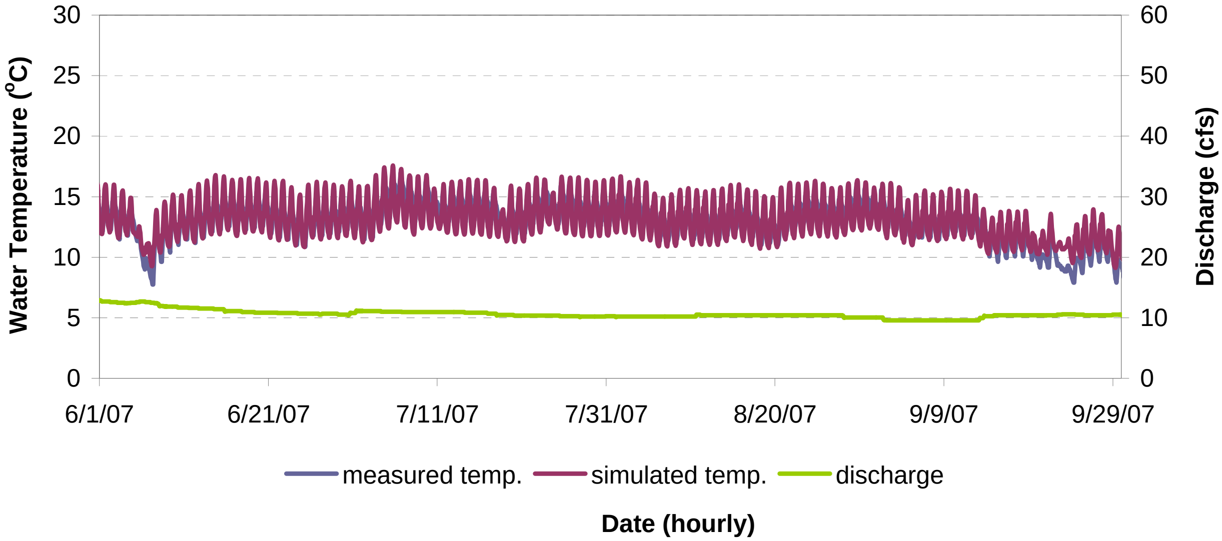


Figure F-4. Water Temperature Model Calibration Results for MF 44.6 in the French Meadows Reservoir to Middle Fork Interbay Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



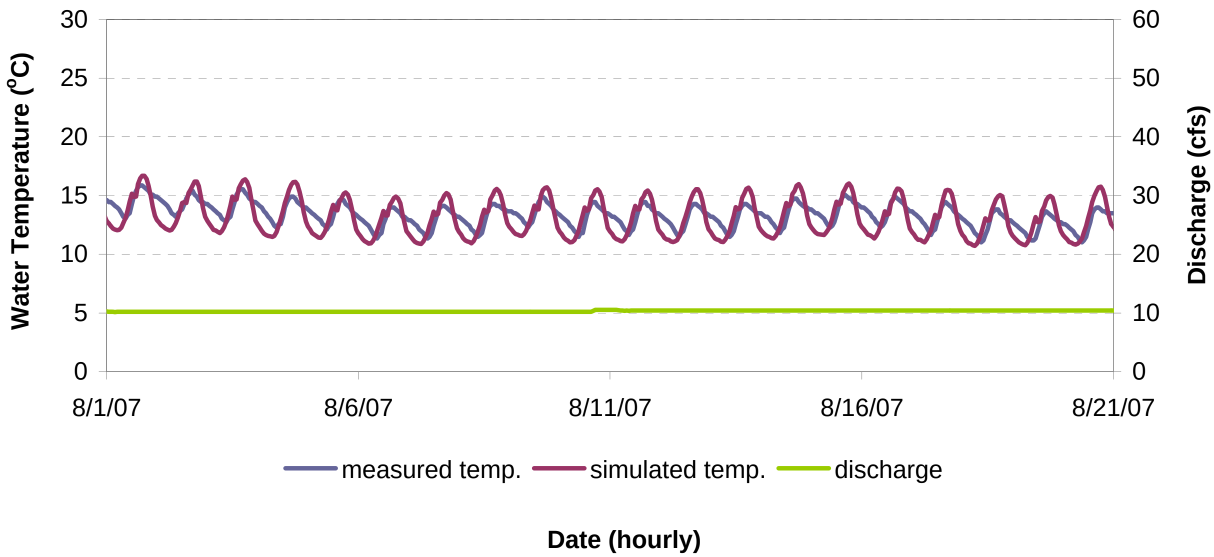
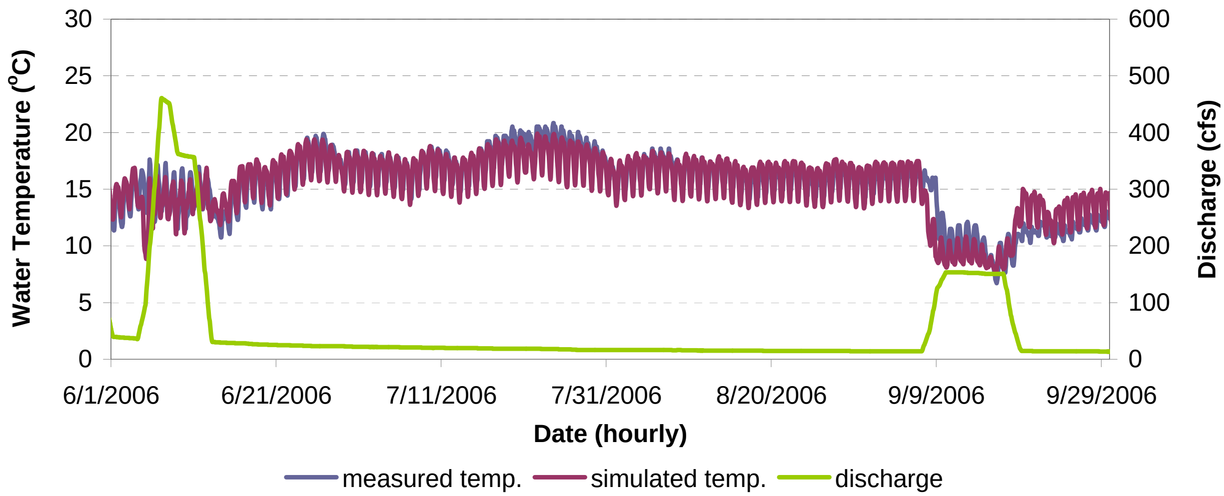


Figure F-5. Water Temperature Model Calibration Results for MF 39.4 in the French Meadows Reservoir to Middle Fork Interbay Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



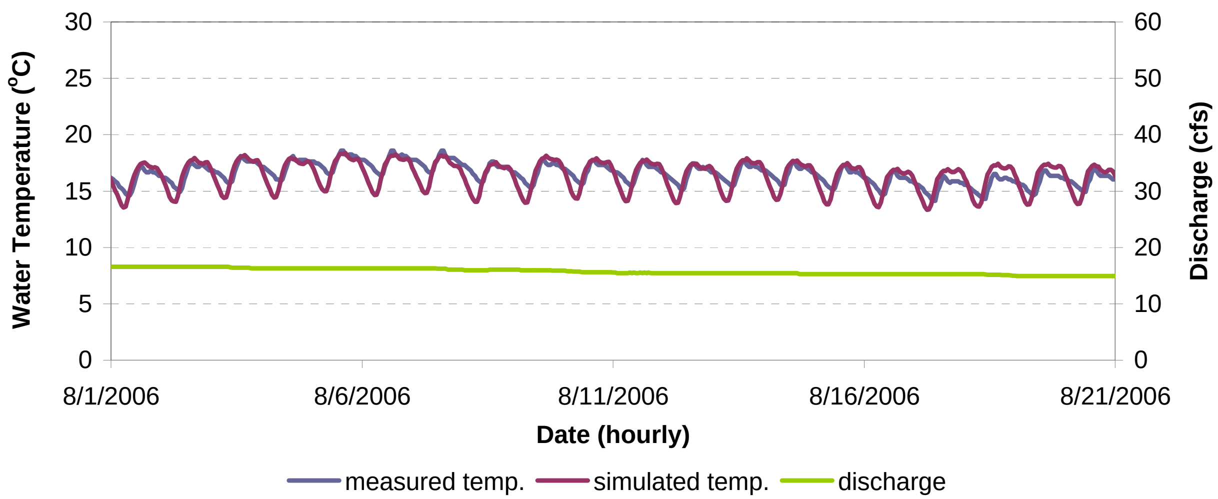
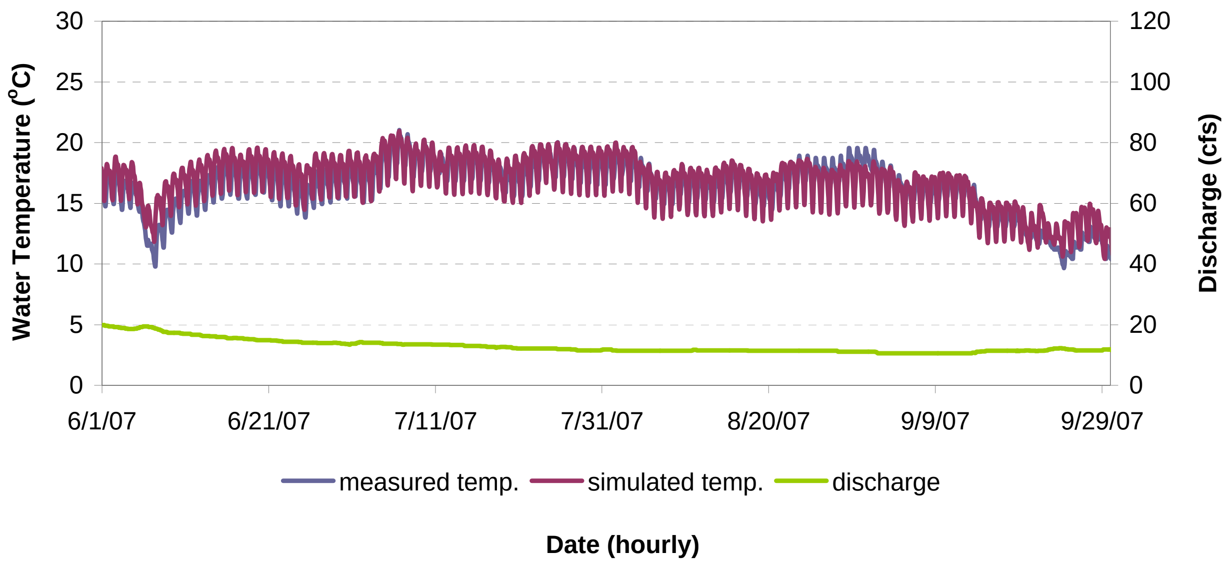


Figure F-6. Water Temperature Model Calibration Results for MF 39.4 in the French Meadows Reservoir to Middle Fork Interbay Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



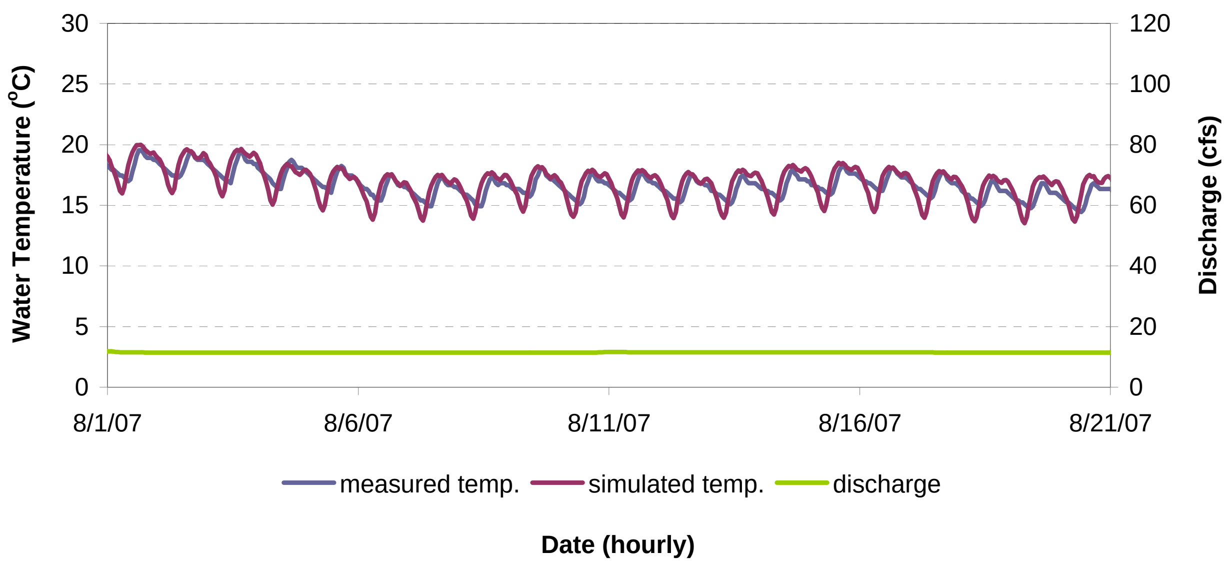
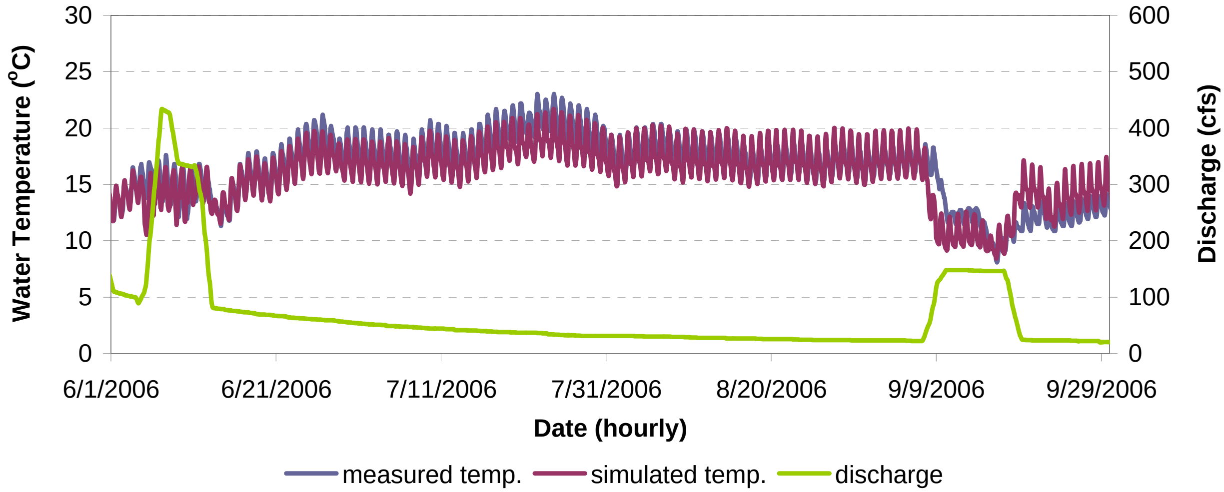


Figure F-7. Water Temperature Model Calibration Results for MF 36.1 in the French Meadows Reservoir to Middle Fork Interbay Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



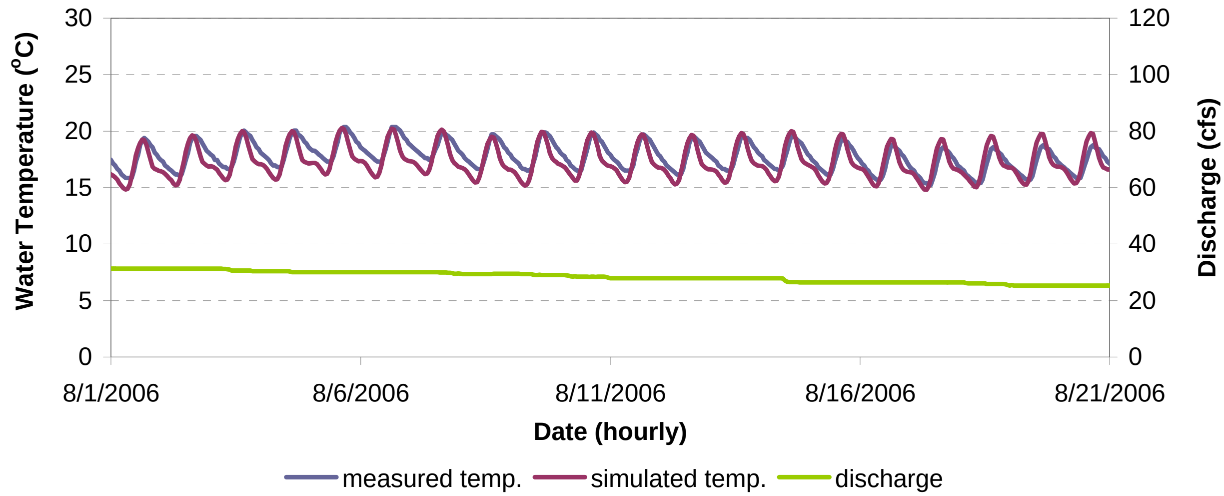
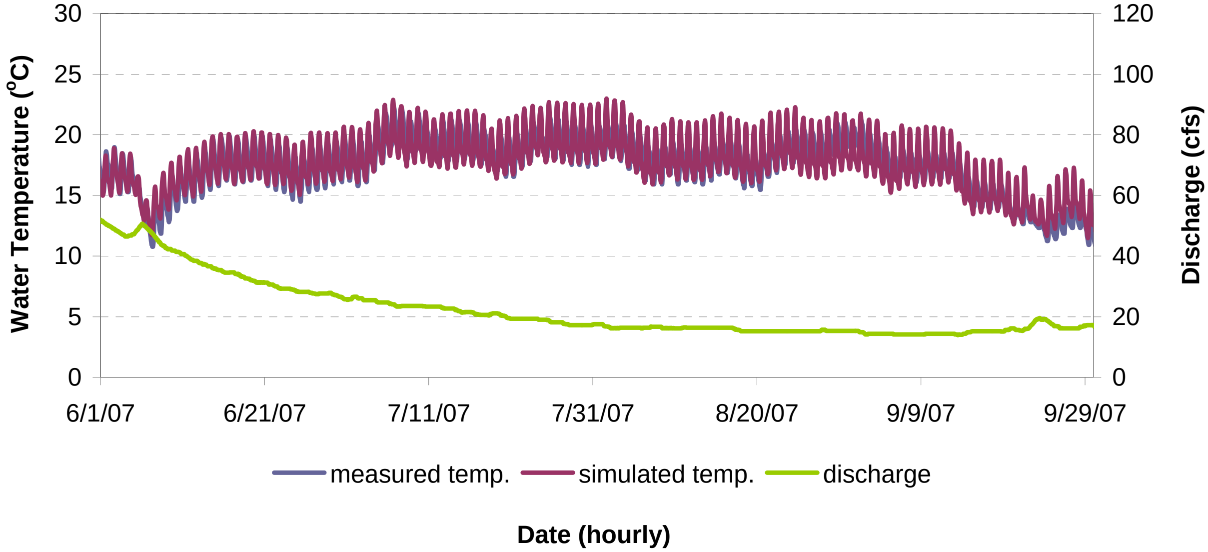


Figure F-8. Water Temperature Model Calibration Results for MF 36.1 in the French Meadows Reservoir to Middle Fork Interbay Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



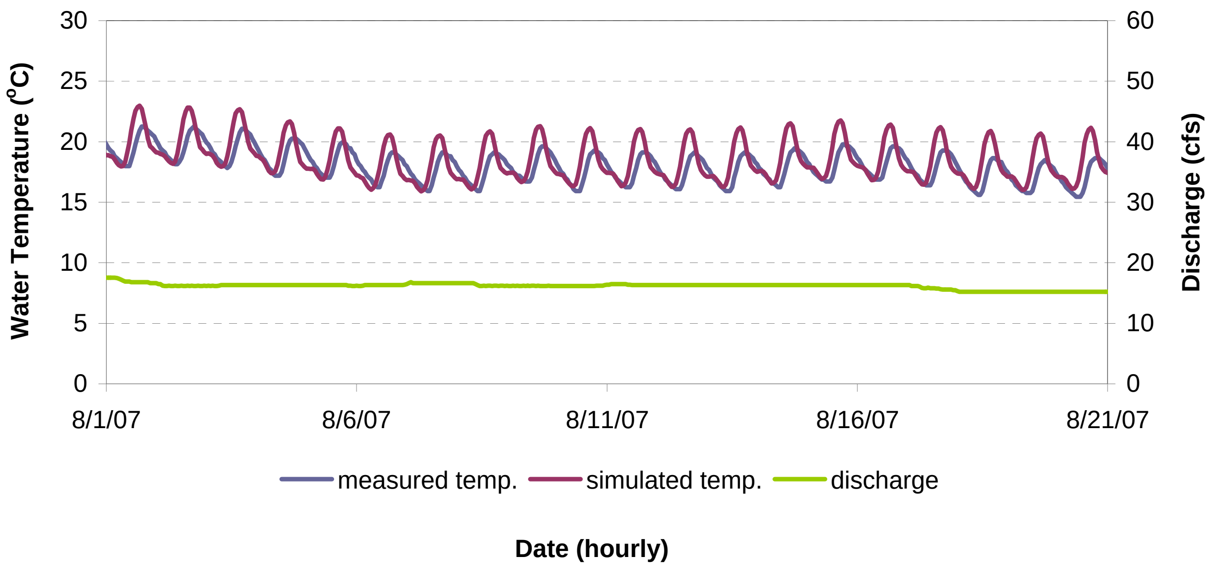
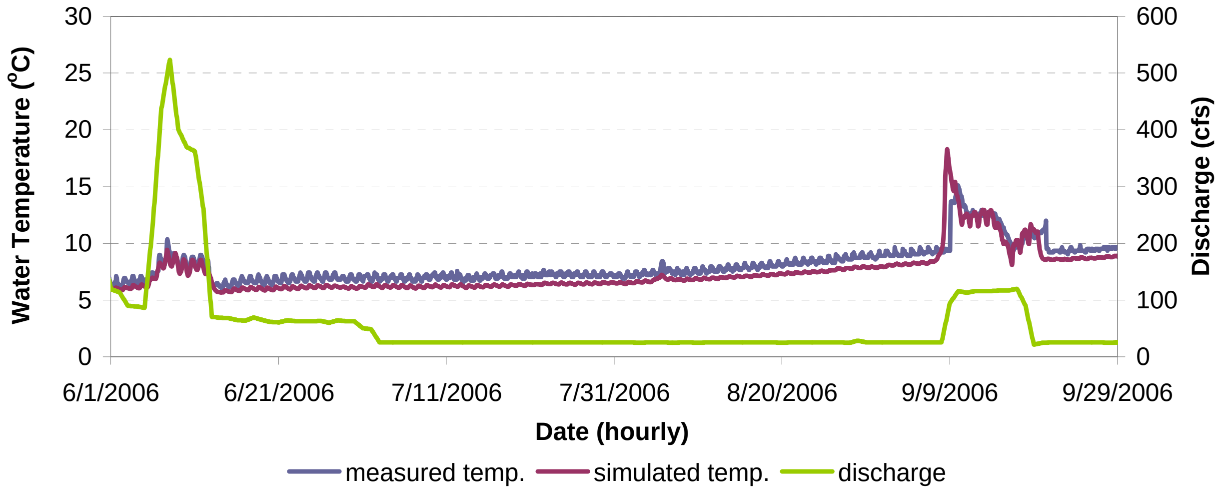


Figure F-9. Water Temperature Model Calibration Results for MF 35.5 in the Middle Fork Interbay to Ralston Afterbay Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



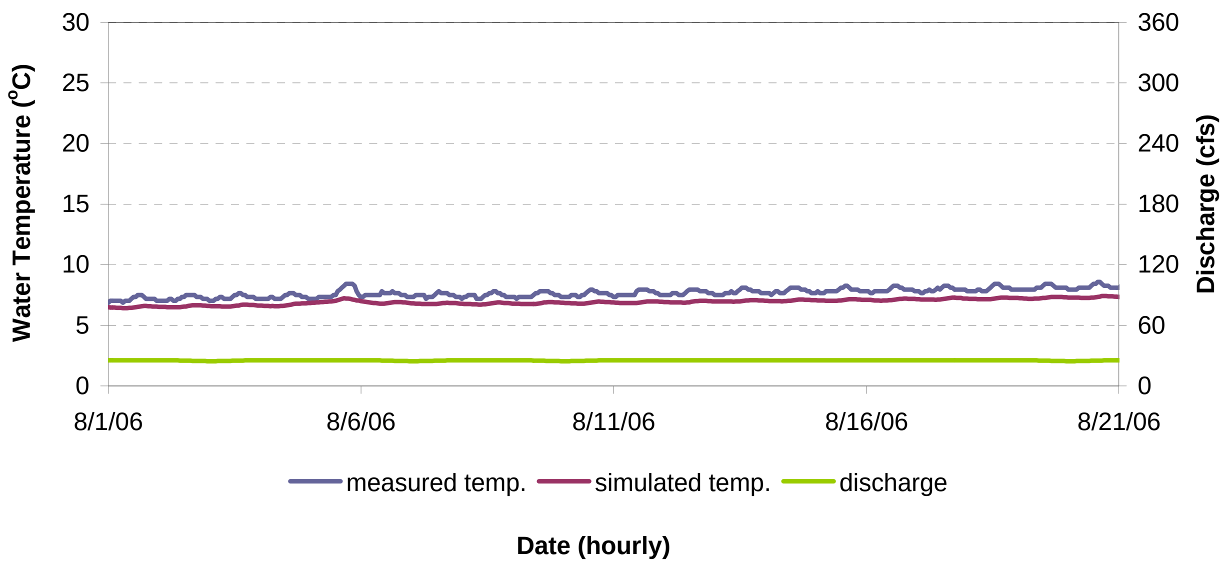
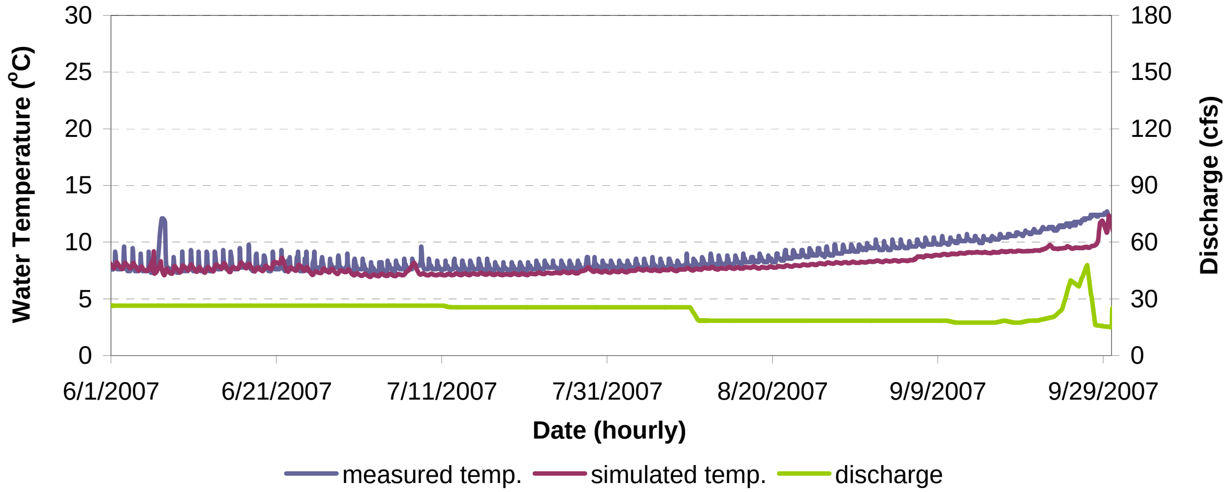


Figure F-10. Water Temperature Model Calibration Results for MF 35.5 in the Middle Fork Interbay to Ralston Afterbay Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



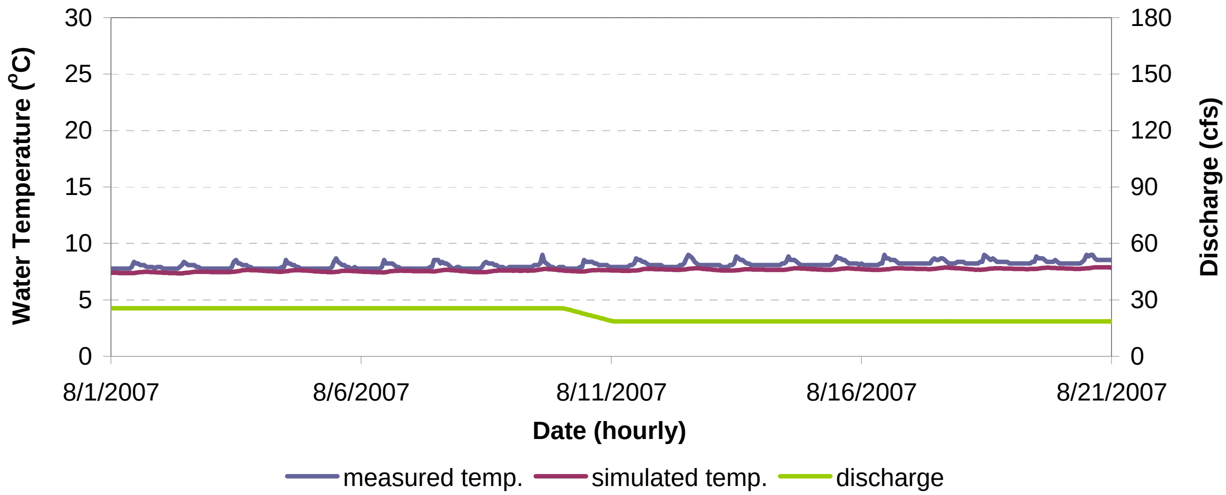
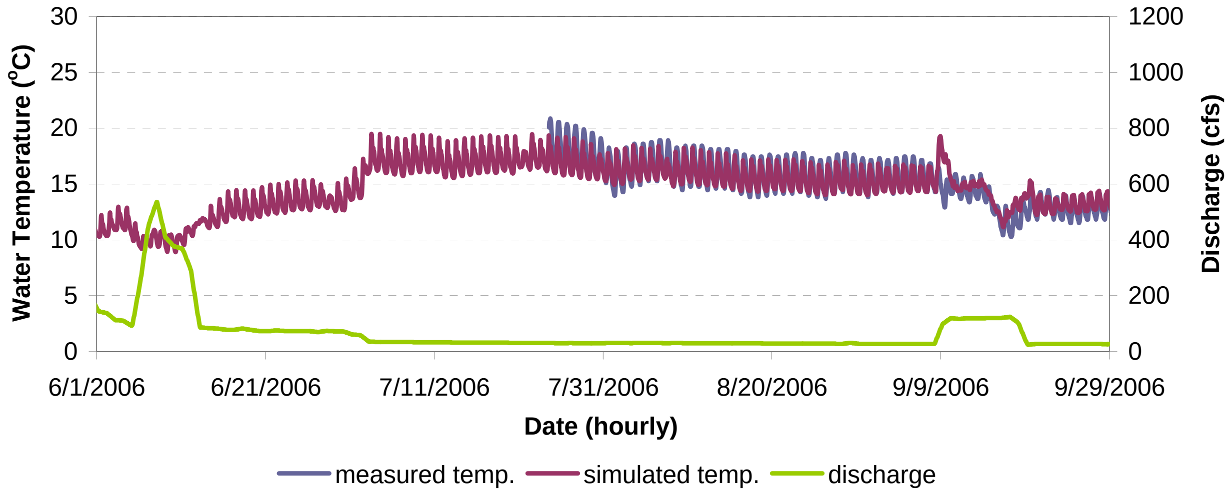


Figure F-11. Water Temperature Model Calibration Results for MF 29.4 in the Middle Fork Interbay to Ralston Afterbay Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



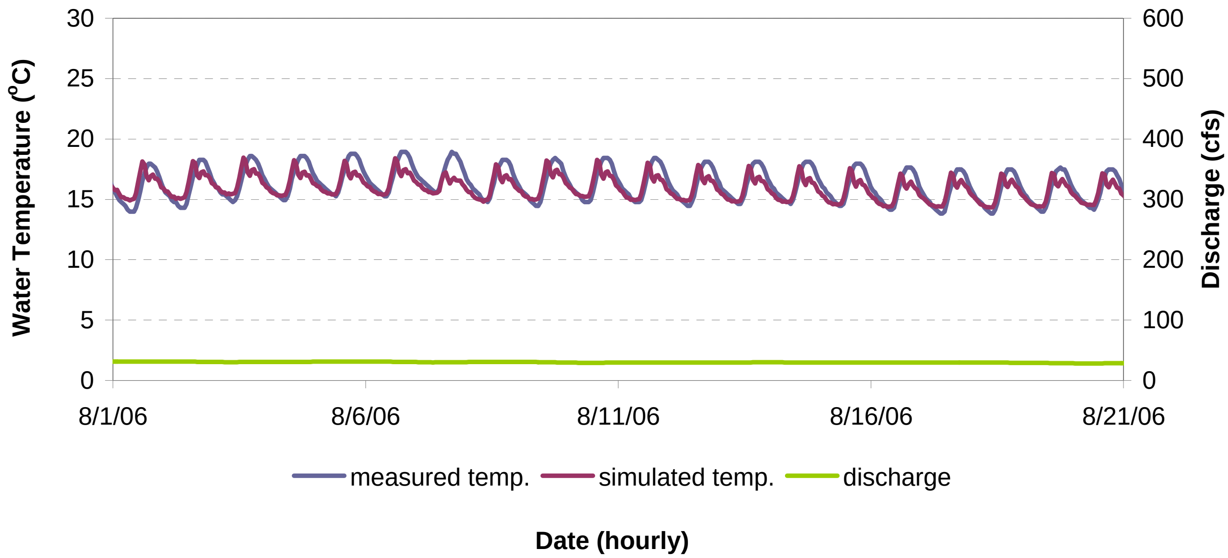
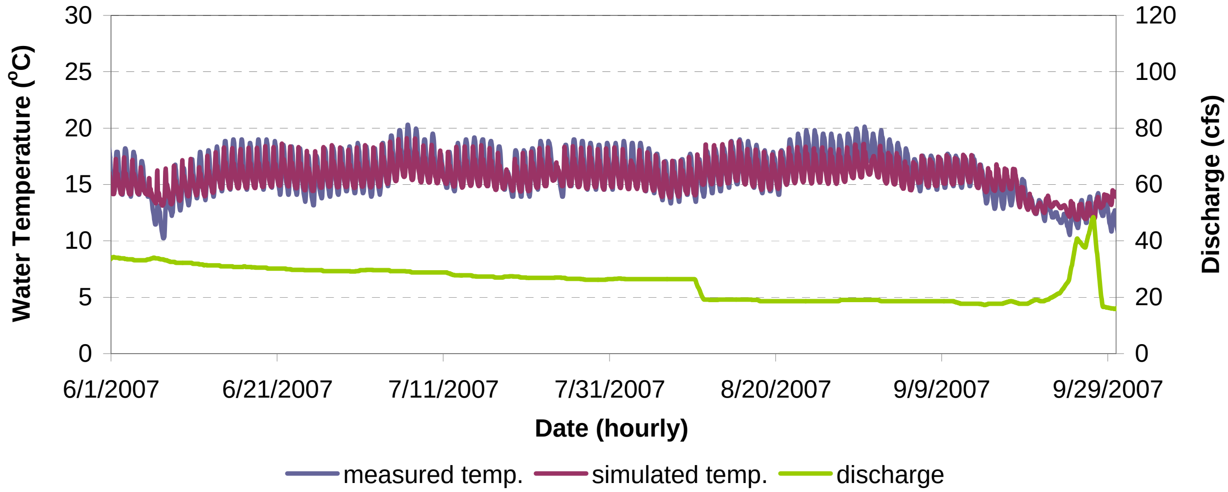


Figure F-12. Water Temperature Model Calibration Results for MF 29.4 in the Middle Fork Interbay to Ralston Afterbay Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



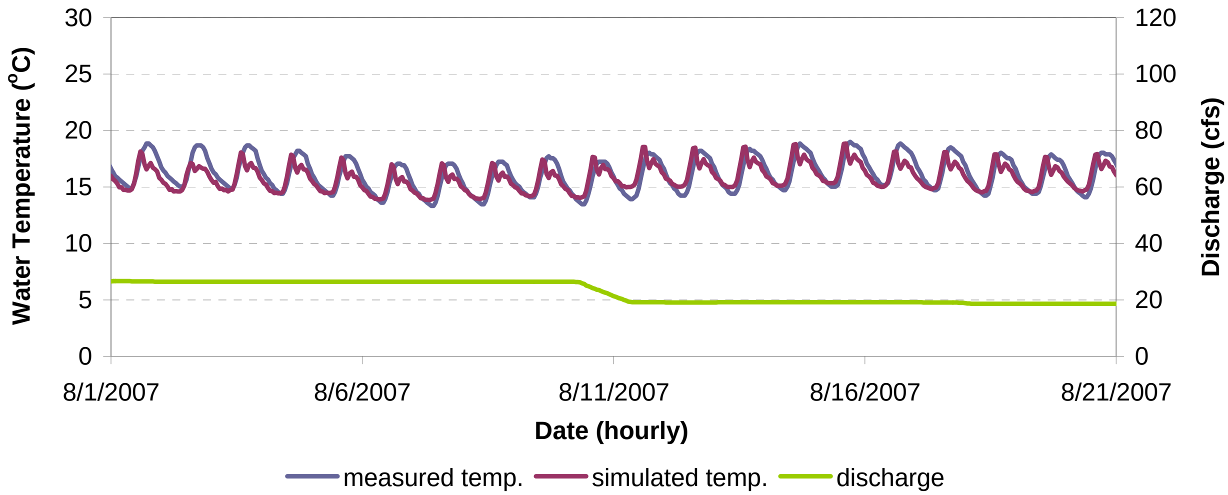
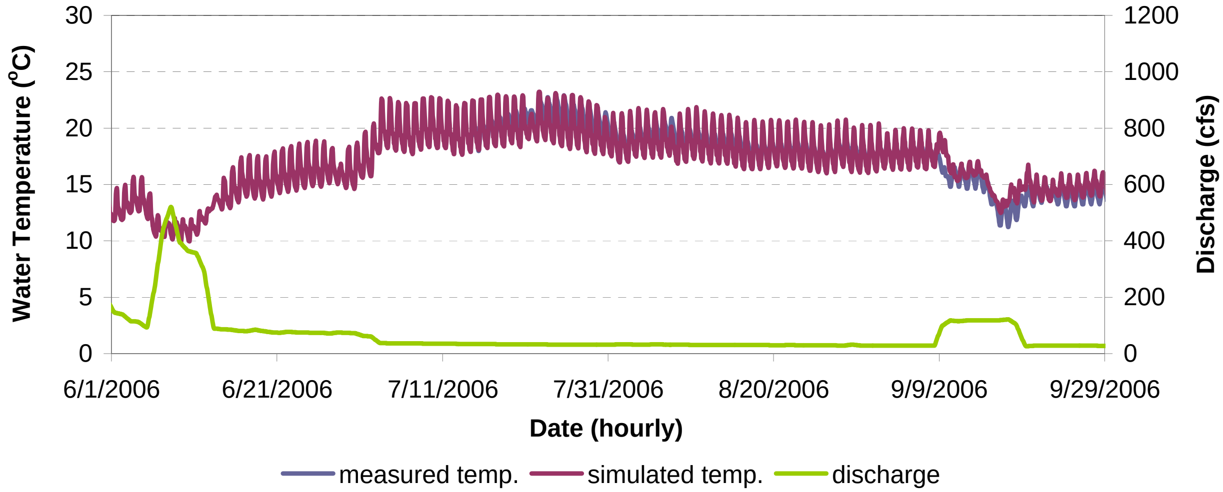


Figure F-13. Water Temperature Model Calibration Results for MF 26.0 in the Middle Fork Interbay to Ralston Afterbay Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



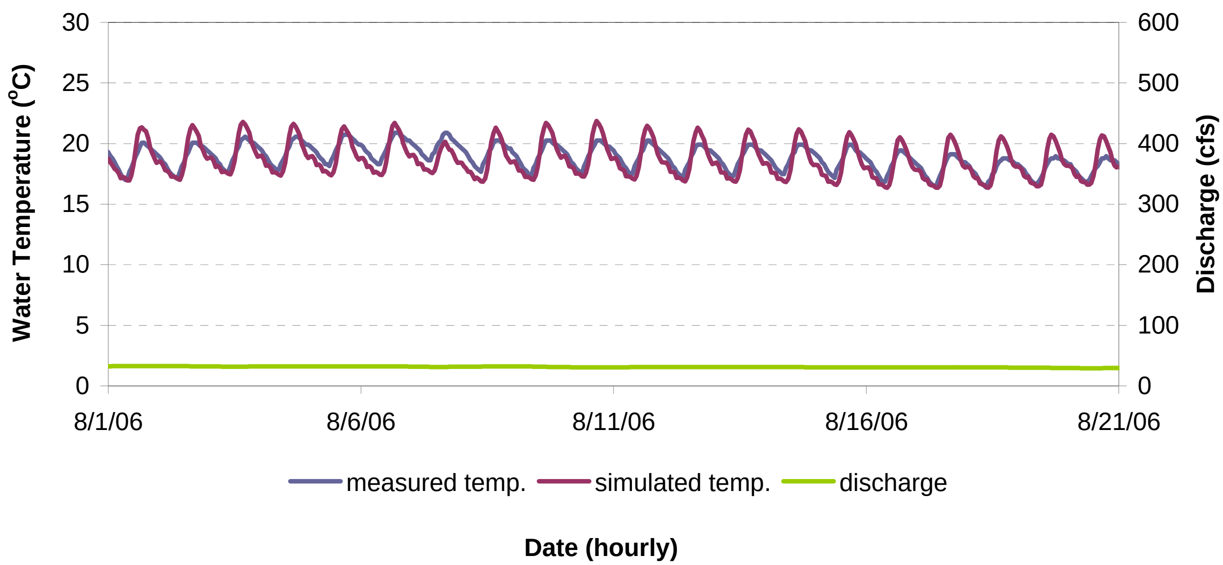
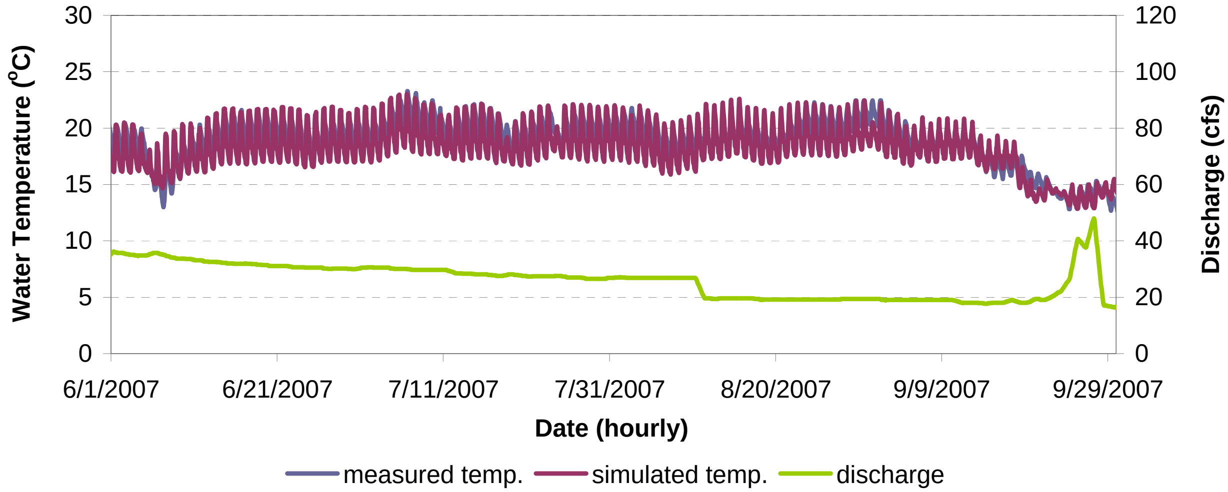


Figure F-14. Water Temperature Model Calibration Results for MF 26.0 in the Middle Fork Interbay to Ralston Afterbay Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



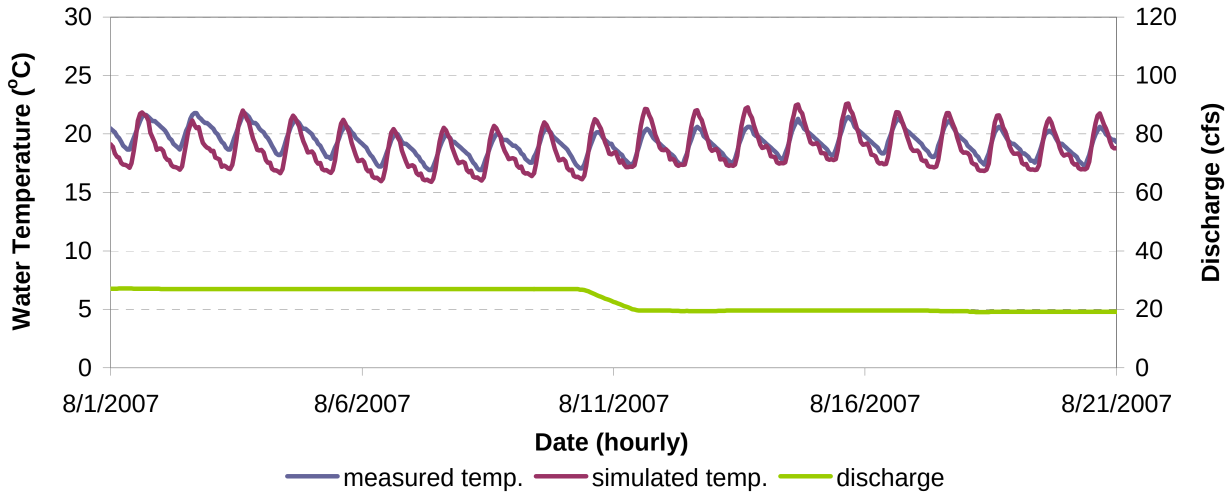
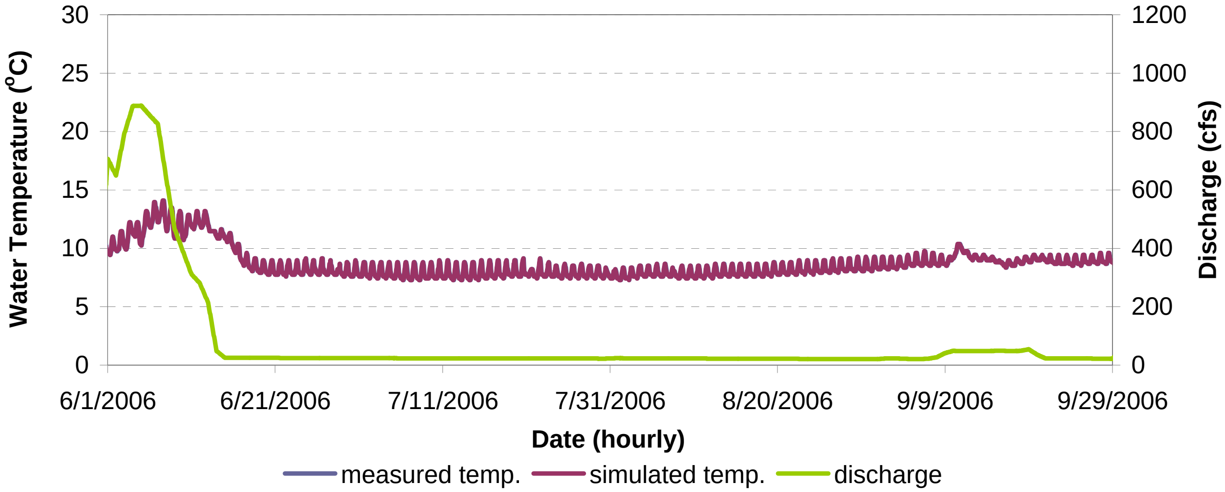


Figure F-15. Water Temperature Model Calibration Results for RR 28.8 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



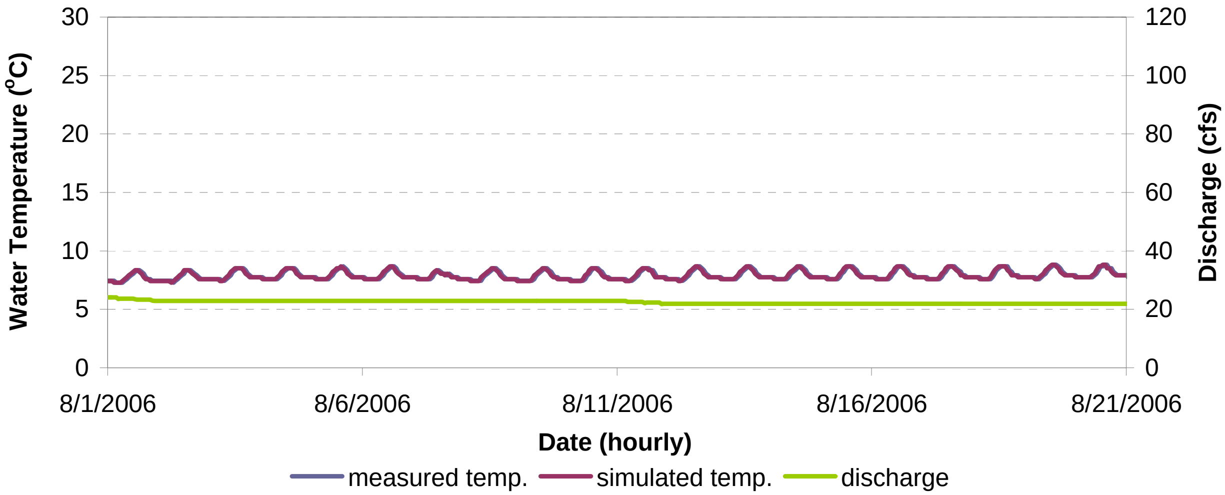
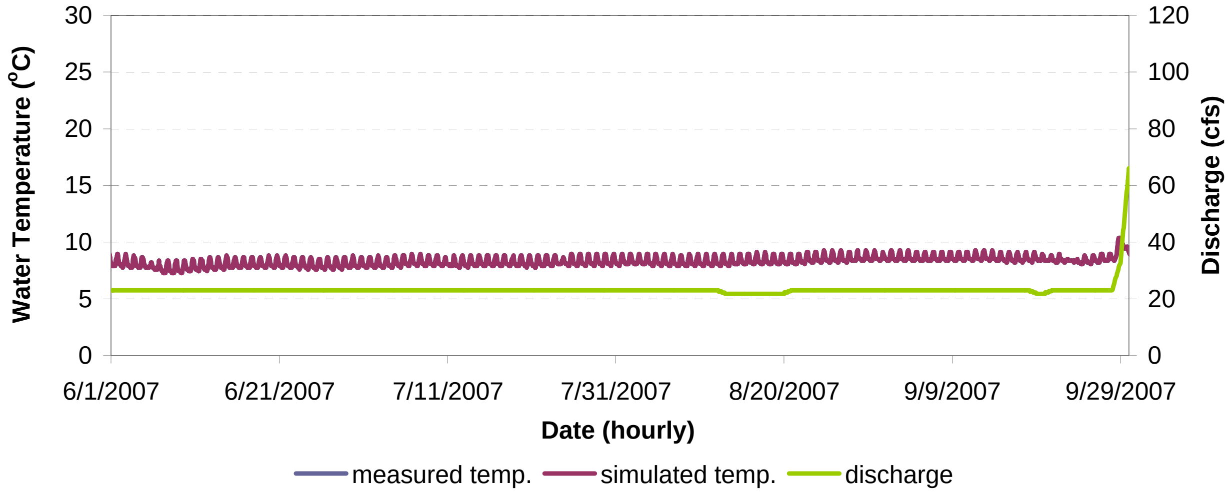


Figure F-16. Water Temperature Model Calibration Results for RR 28.8 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



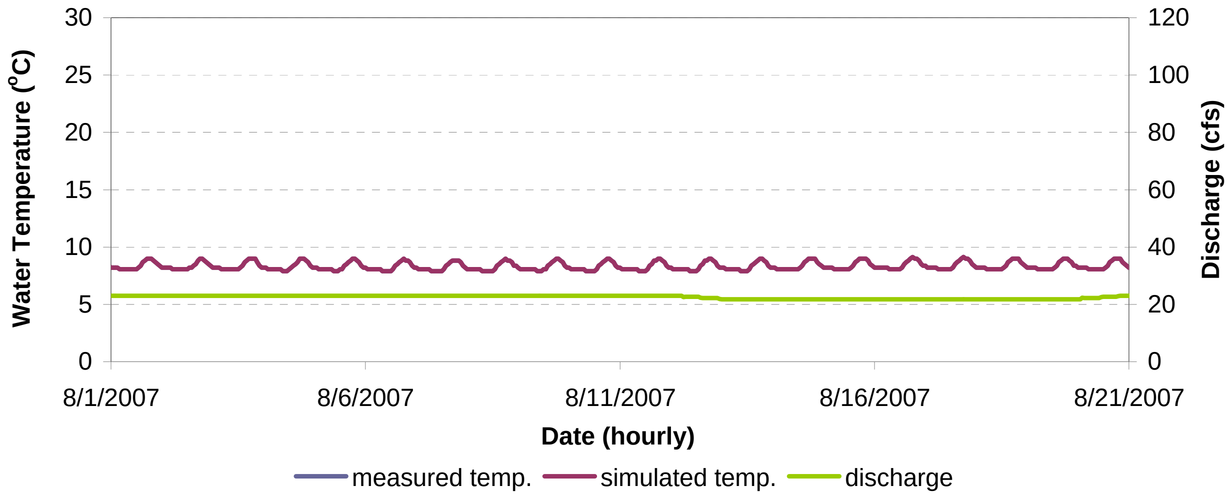
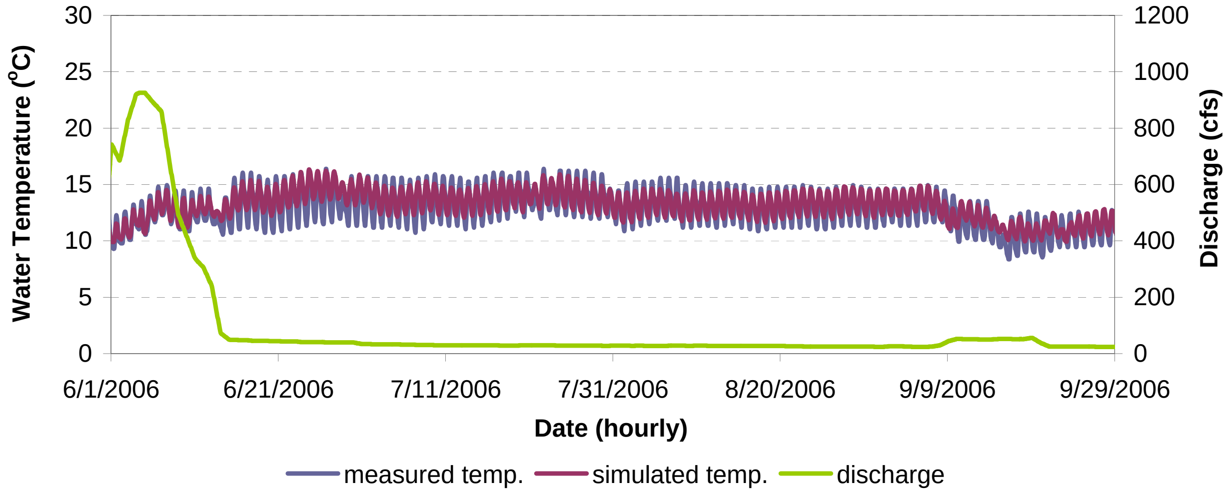


Figure F-17. Water Temperature Model Calibration Results for RR 25.3 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



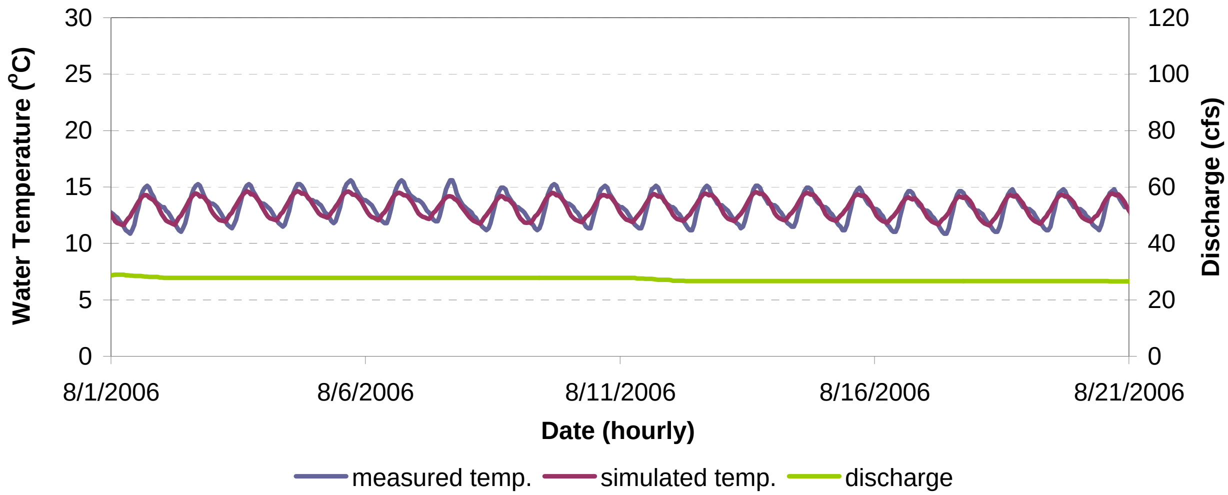
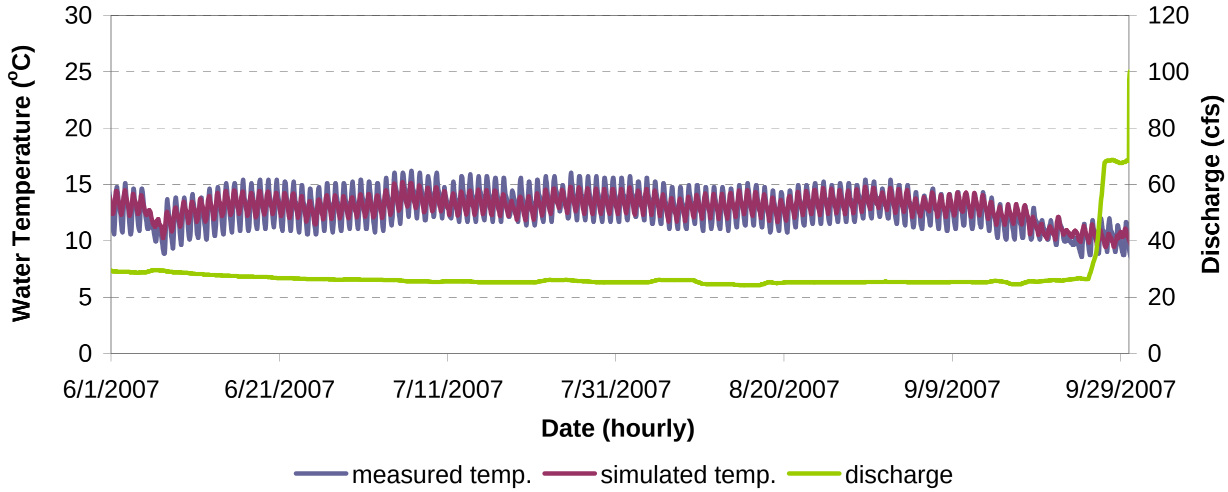


Figure F-18. Water Temperature Model Calibration Results for RR 25.3 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



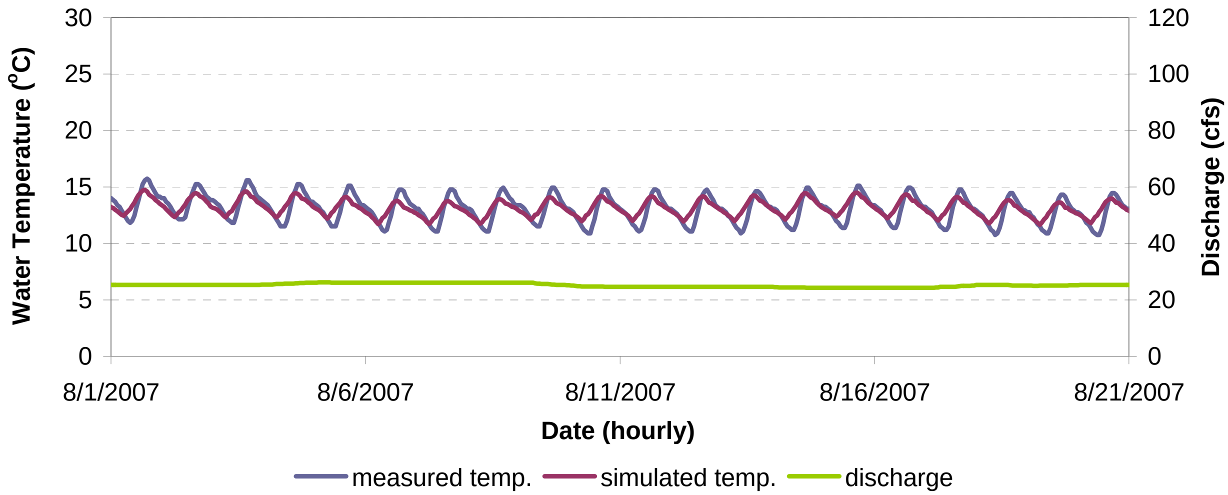
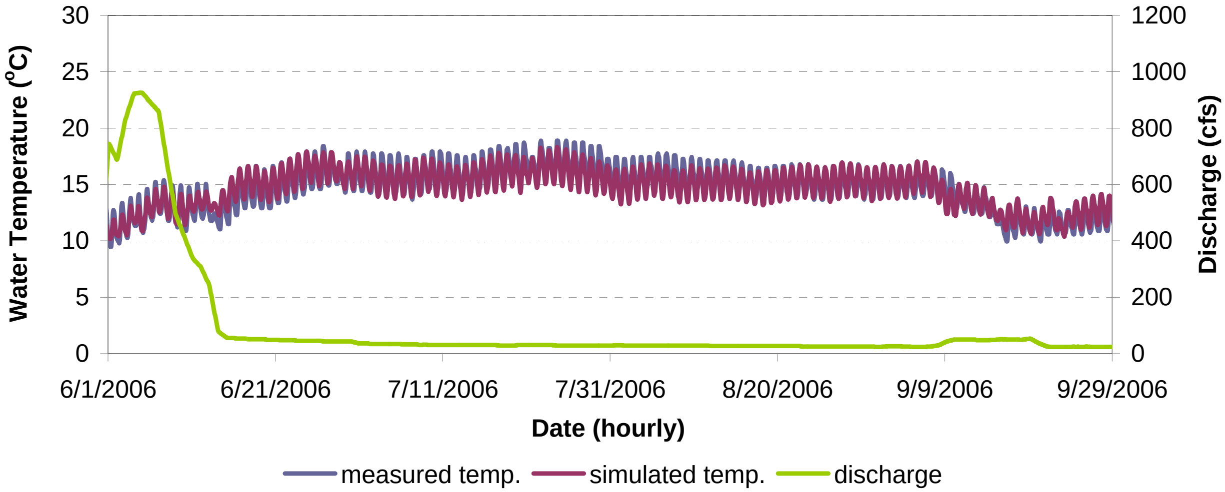


Figure F-19. Water Temperature Model Calibration Results for RR 22.7 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



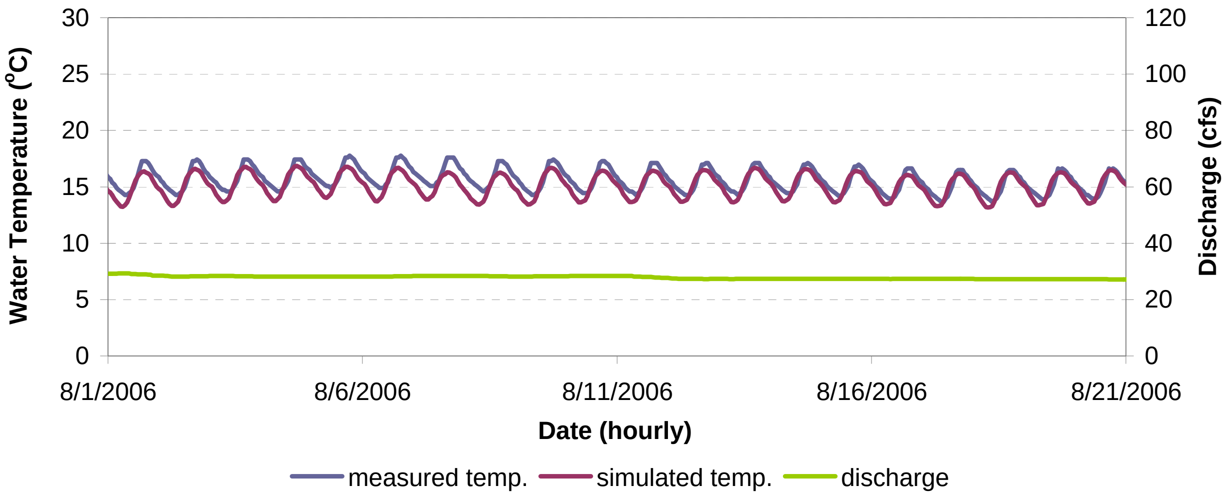
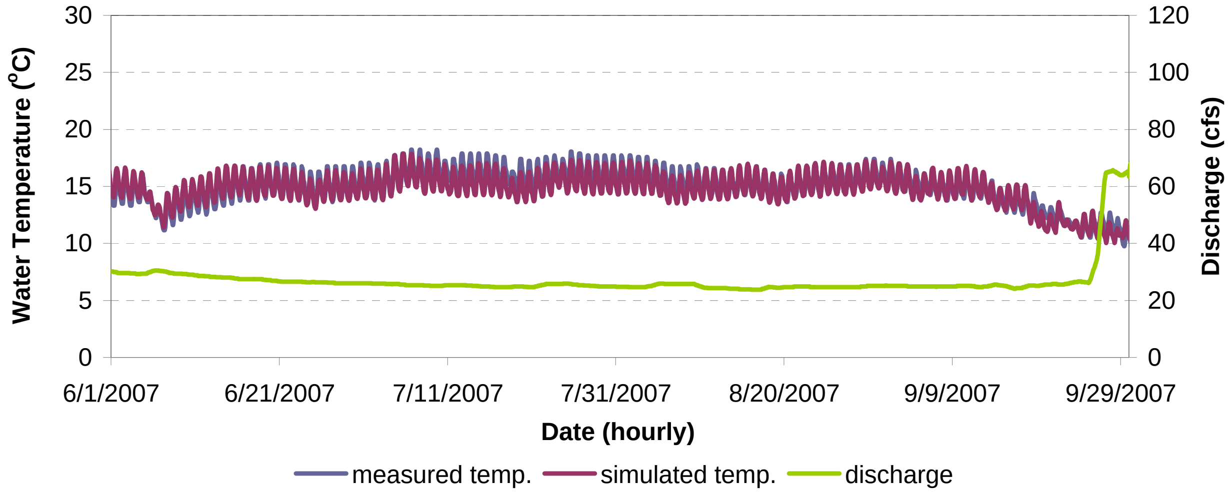


Figure F-20. Water Temperature Model Calibration Results for RR 22.7 in the Hell Hole Reservoir to Ralston Afetrbay Reach of the Rubicon River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



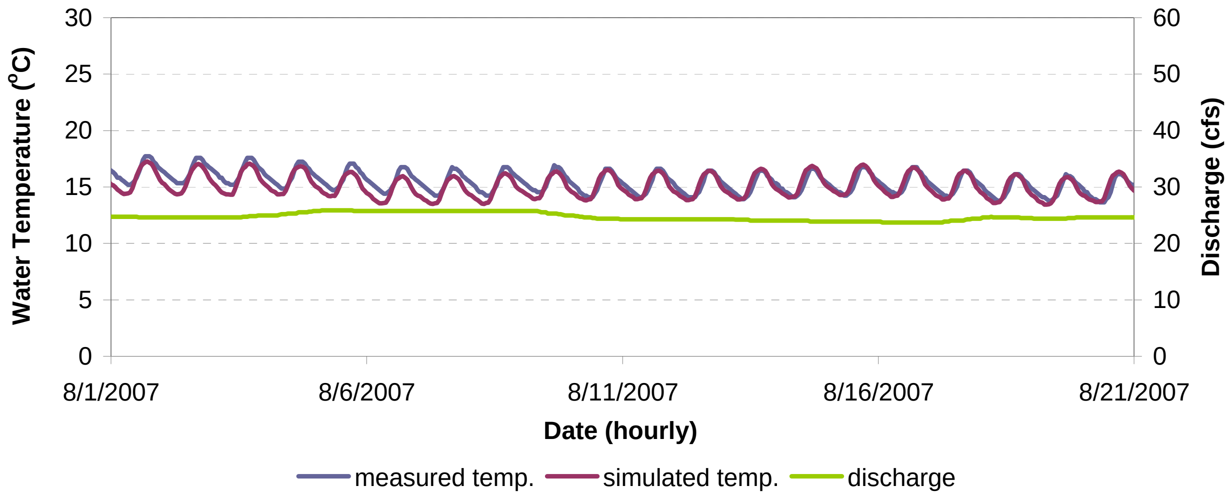
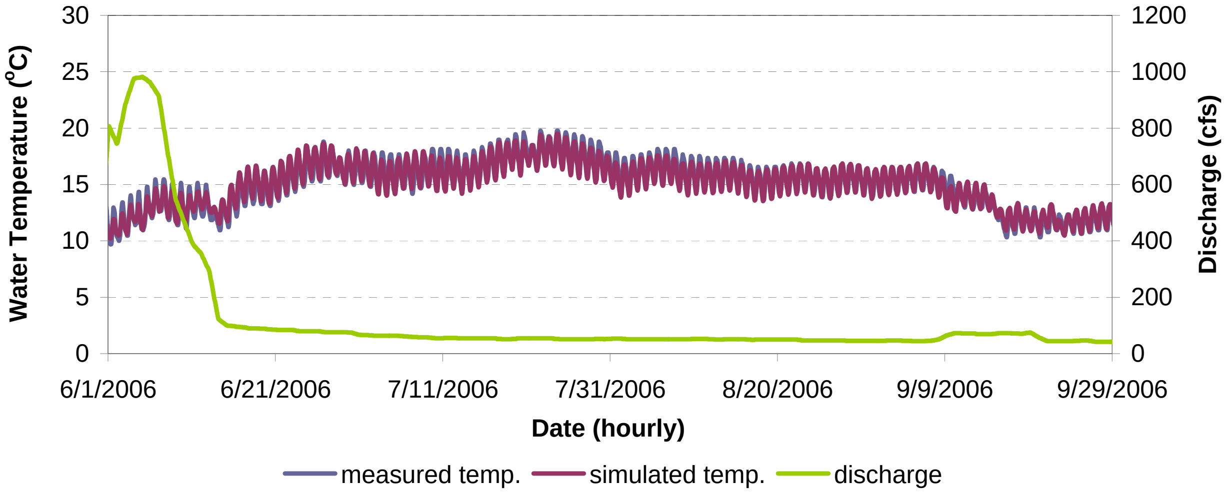


Figure F-21. Water Temperature Model Calibration Results for RR 22.5 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



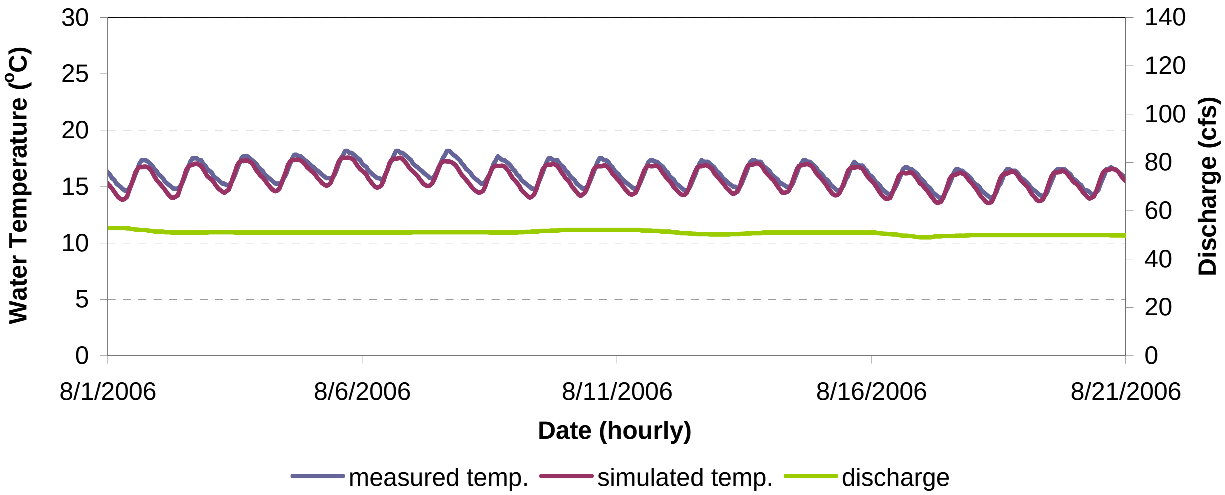
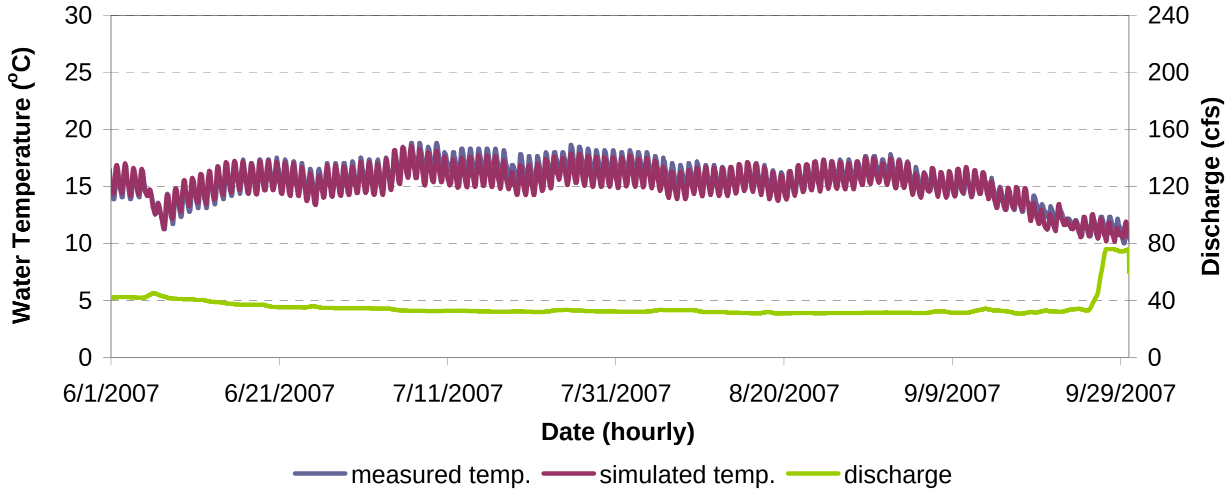


Figure F-22. Water Temperature Model Calibration Results for RR 22.5 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



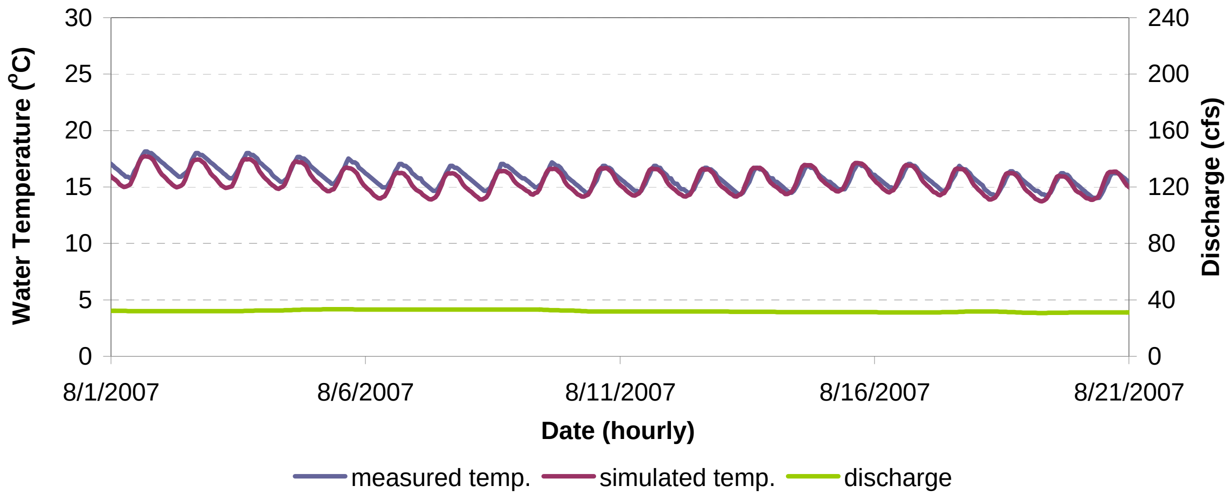
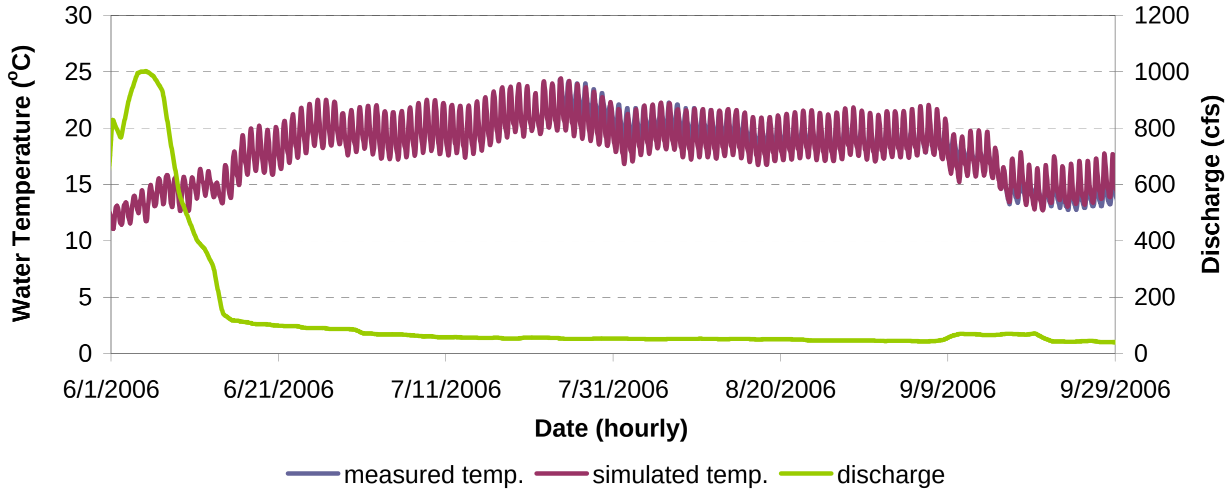


Figure F-23. Water Temperature Model Calibration Results for RR 14.3 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for the June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



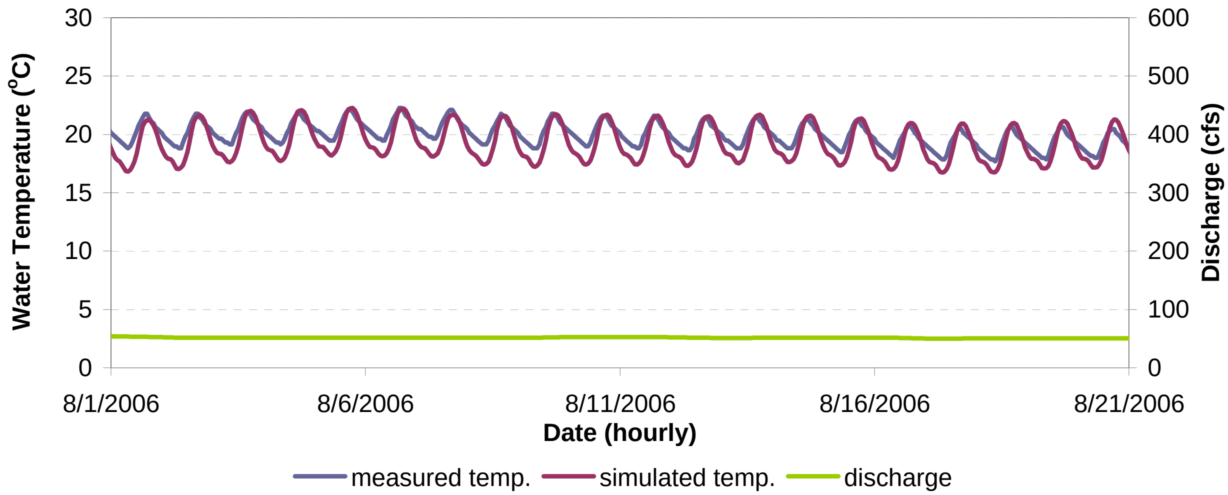
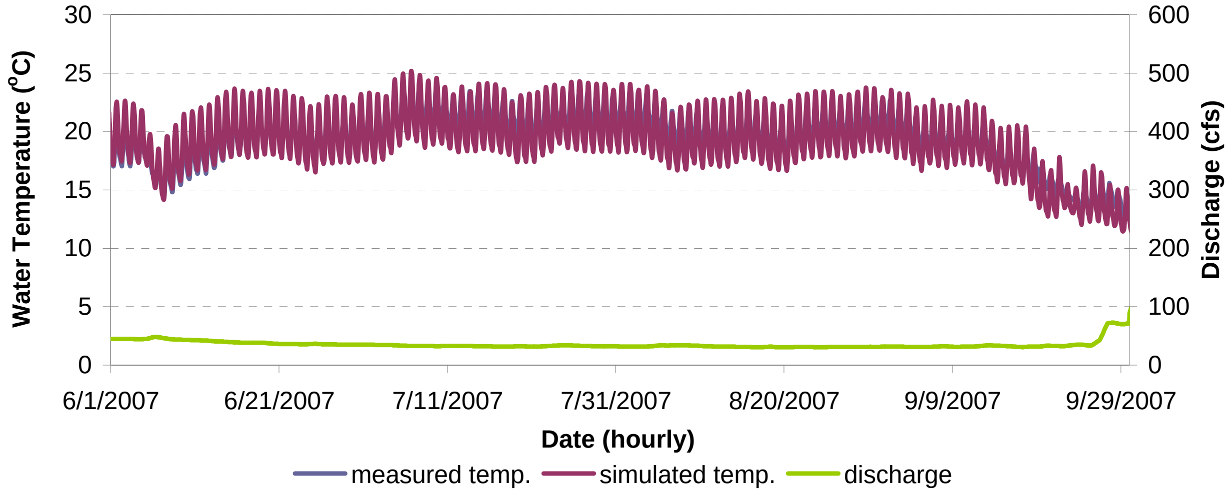


Figure F-24. Water Temperature Model Calibration Results for RR 14.3 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



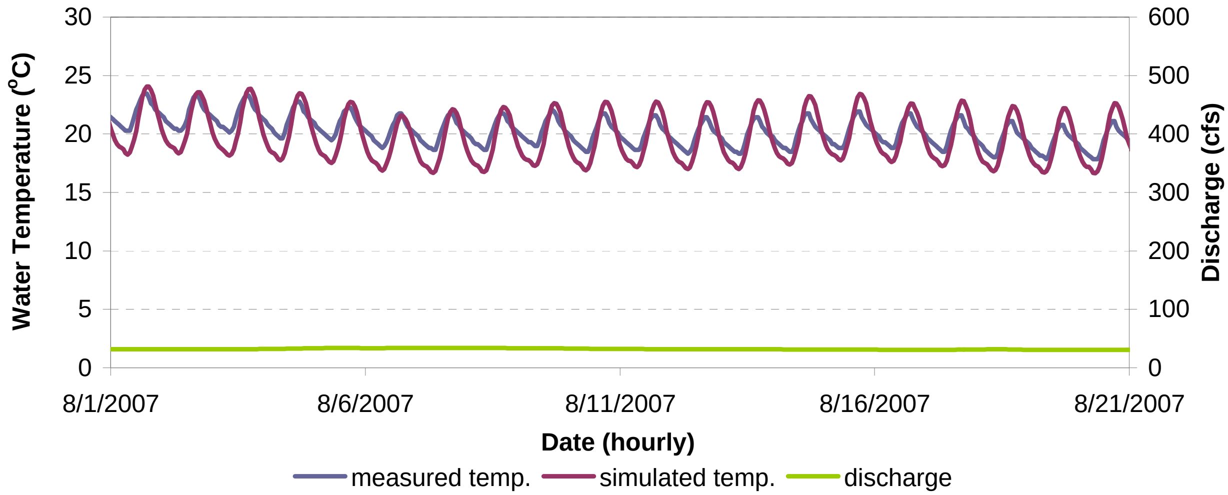
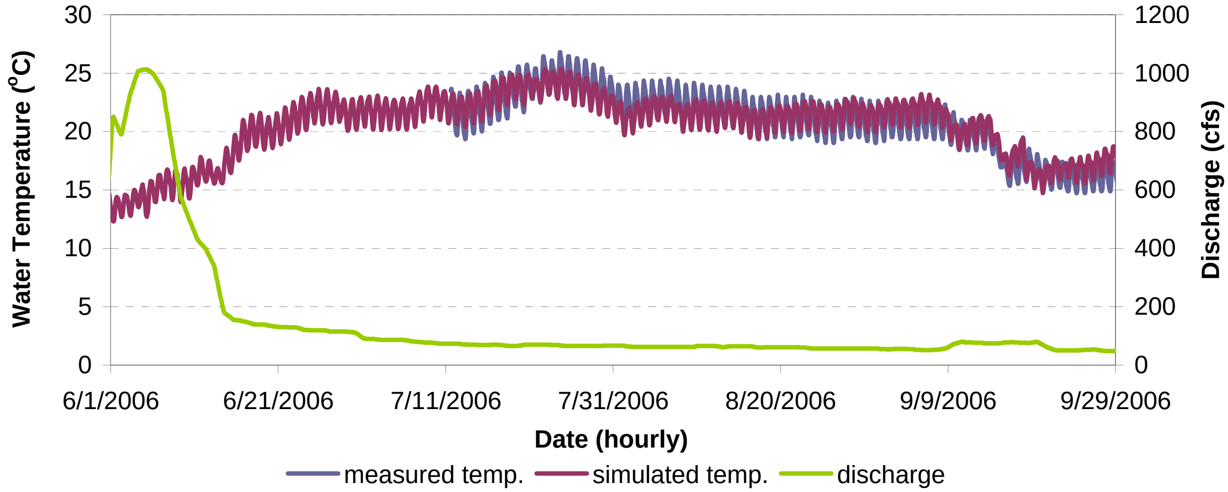


Figure F-25. Water Temperature Model Calibration Results for RR 5.3 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



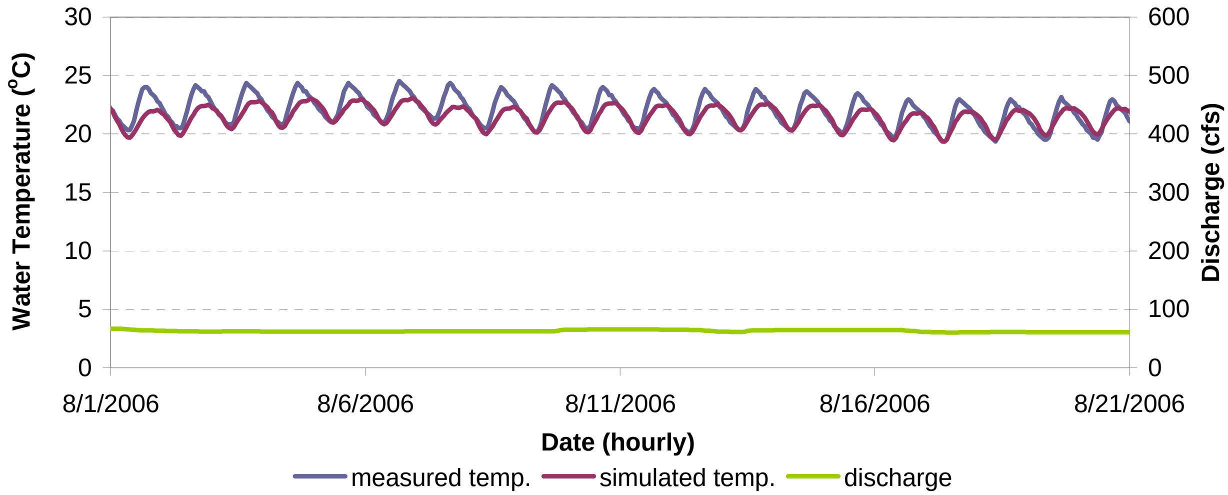
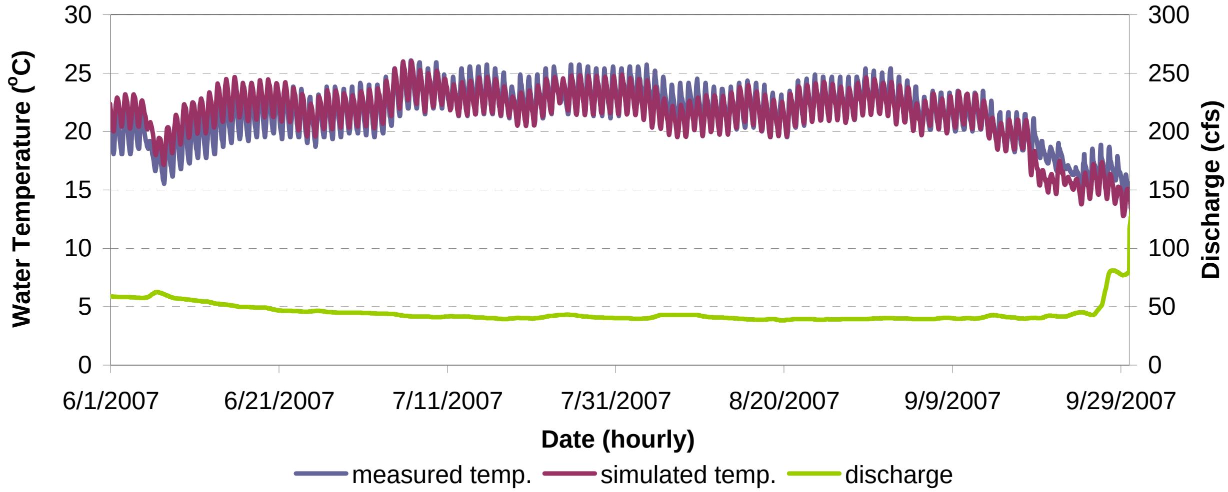


Figure F-26. Water Temperature Model Calibration Results for RR 5.3 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



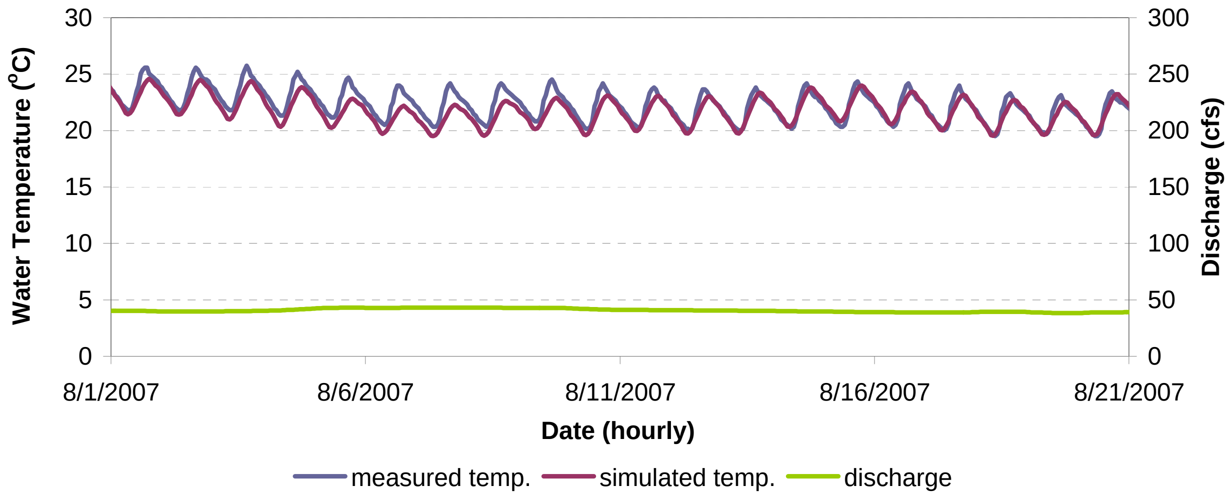
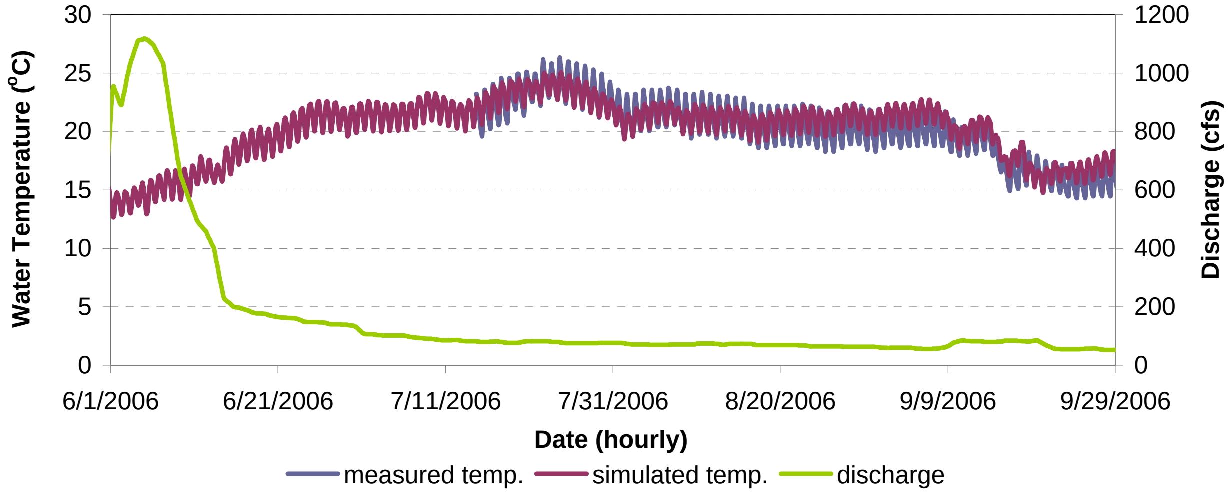


Figure F-27. Water Temperature Model Calibration Results for RR 3.7 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 Simulations (Bottom).



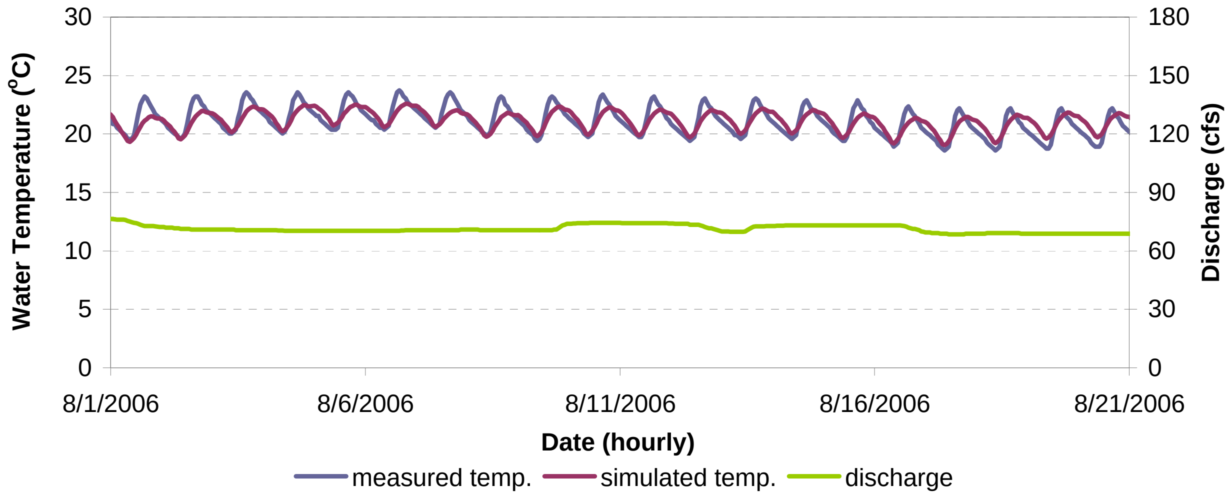
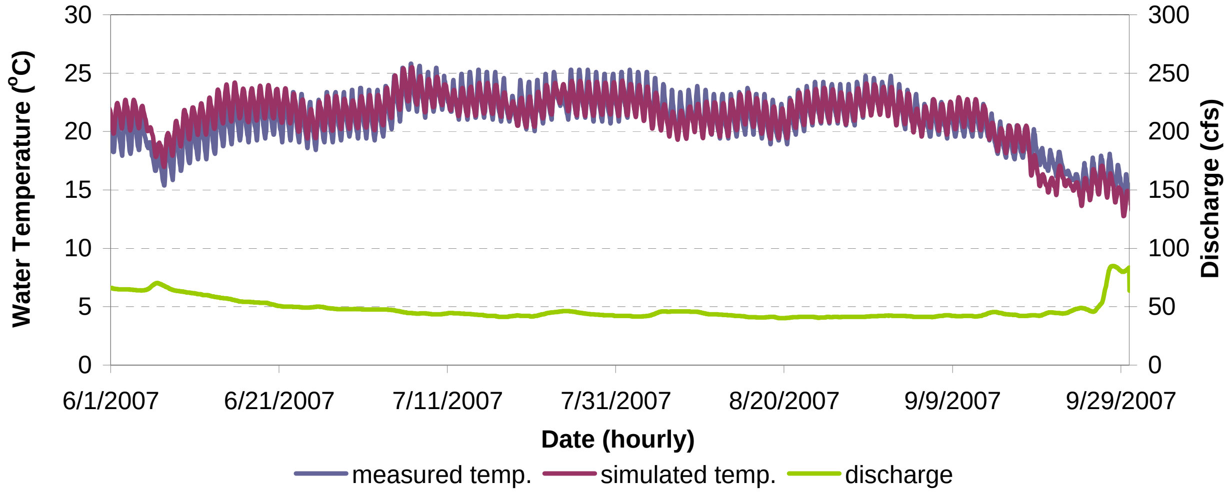


Figure F-28. Water Temperature Model Calibration Results for RR 3.7 in the Hell Hole Reservoir to Ralston Aferbay Reach of the Rubicon River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



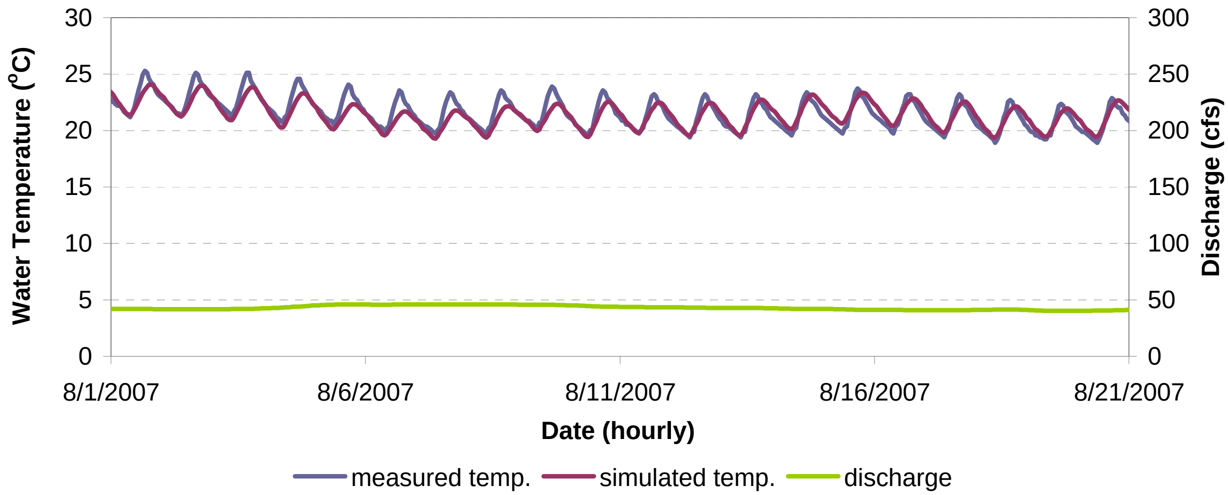
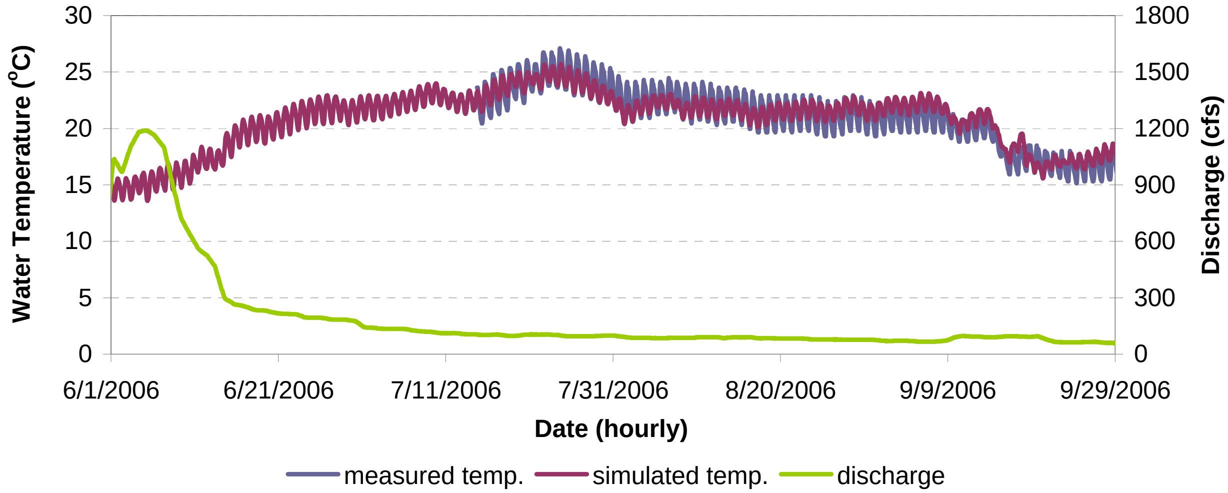


Figure F-29. Water Temperature Model Calibration Results for RR 0.7 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



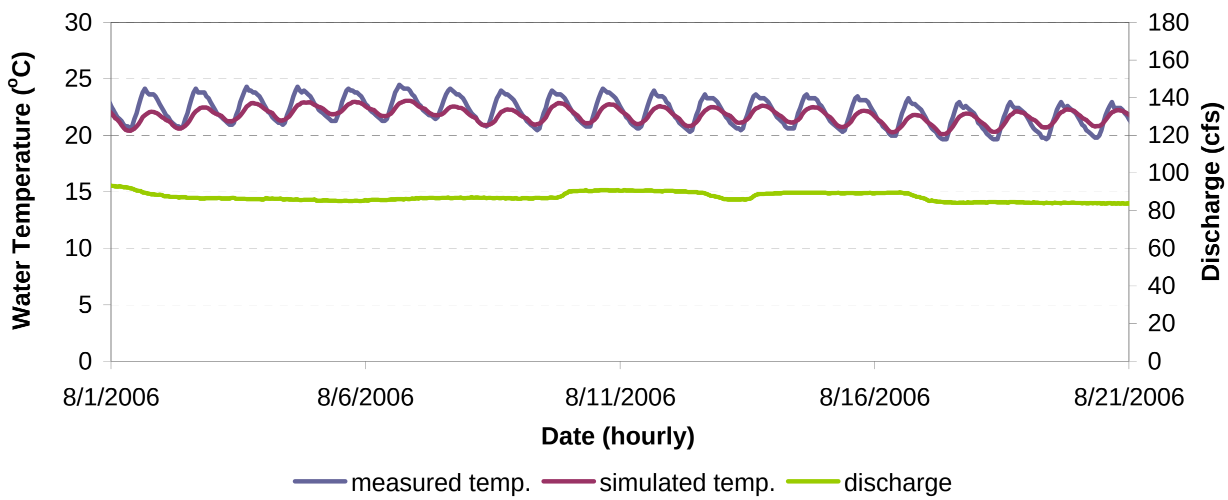
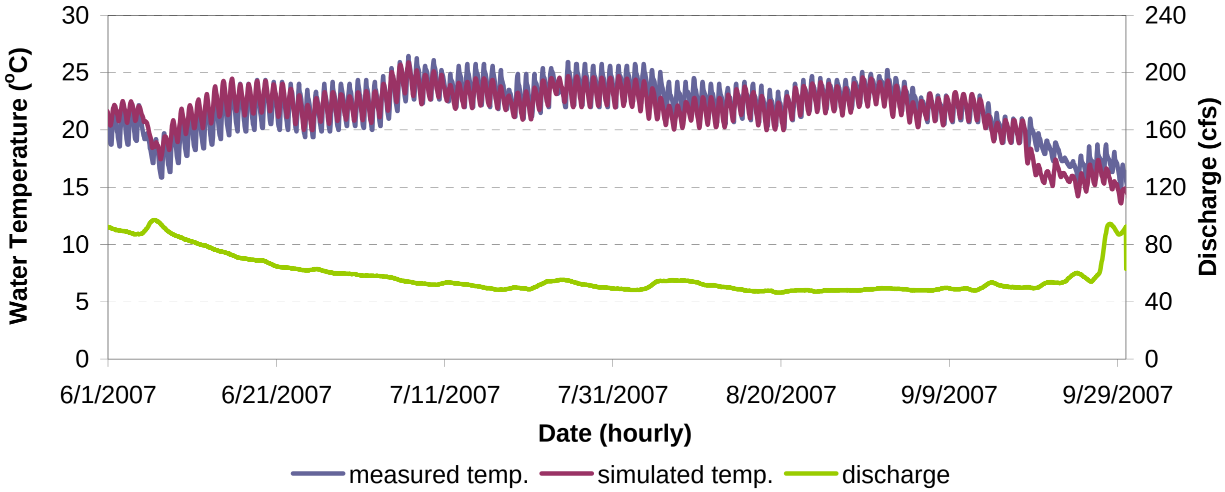


Figure F-30. Water Temperature Model Calibration Results for RR 0.7 in the Hell Hole Reservoir to Ralston Afterbay Reach of the Rubicon River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).



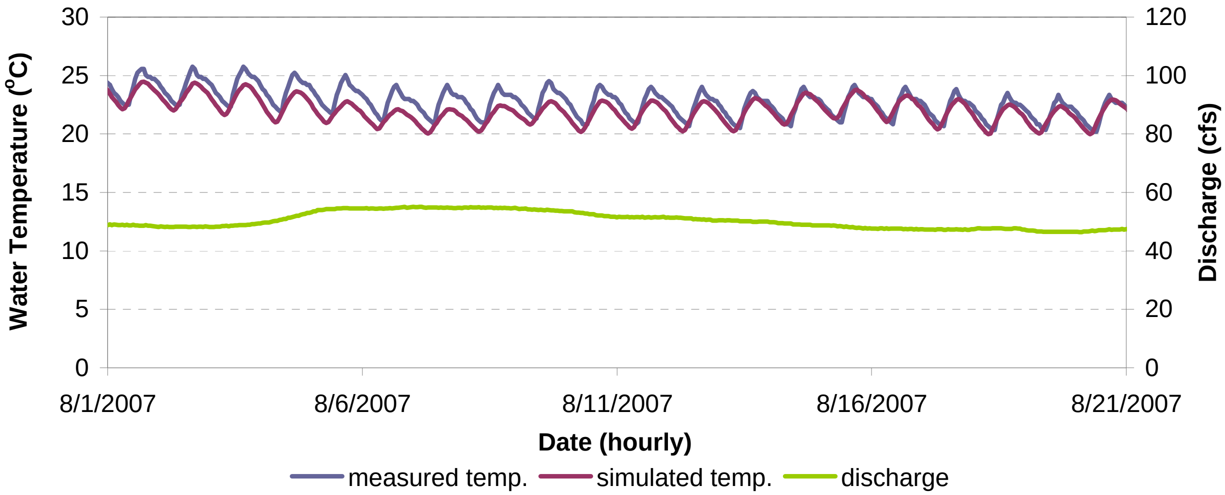
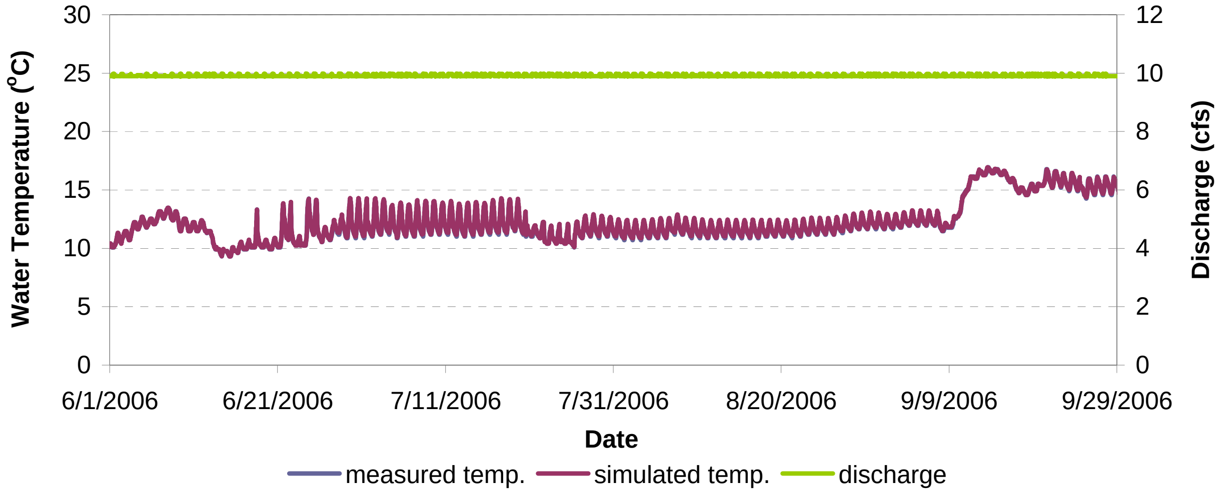
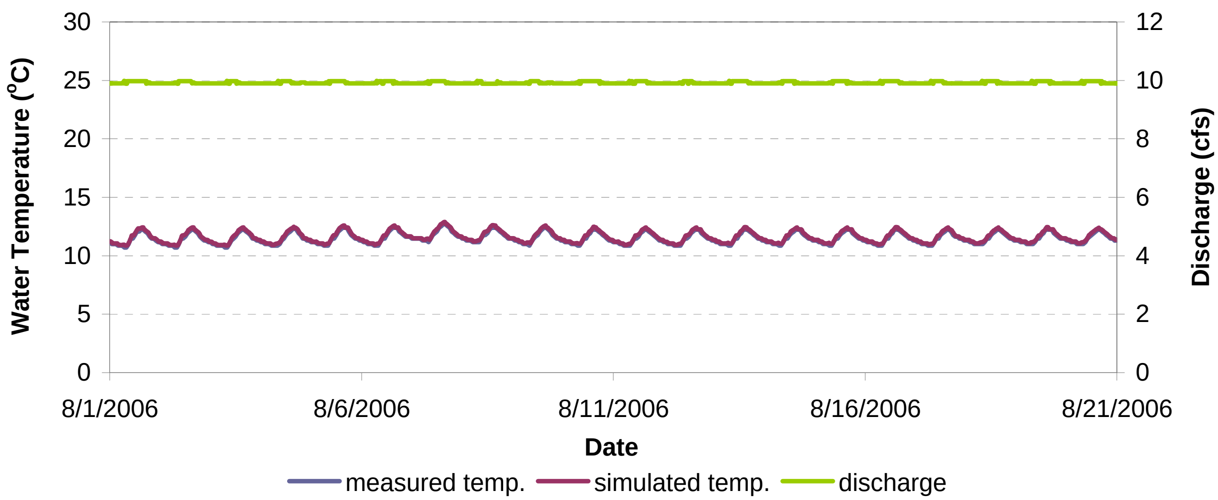


Figure F-31. Water Temperature Model Calibration Results for MF 24.6 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).

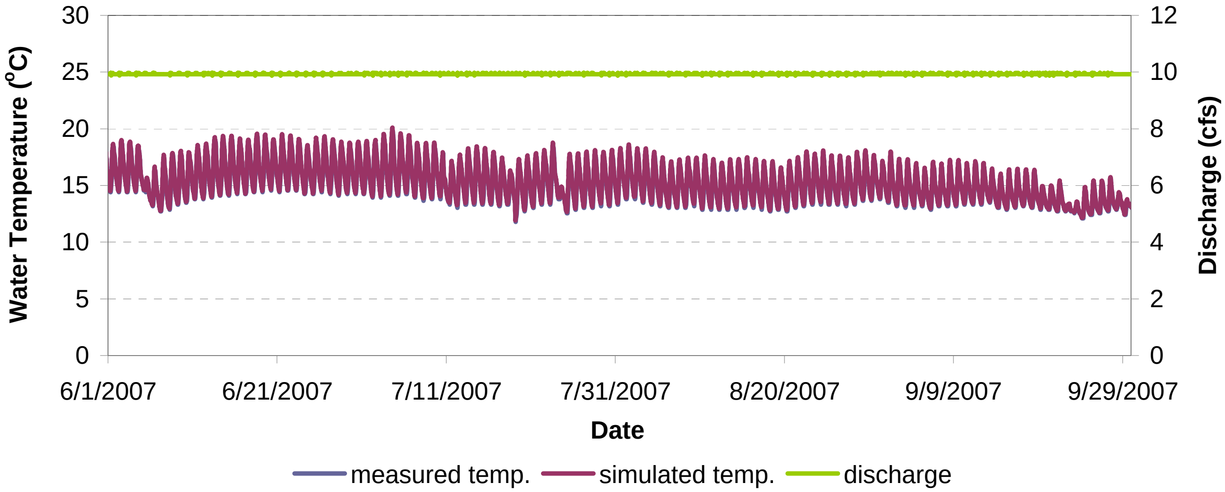


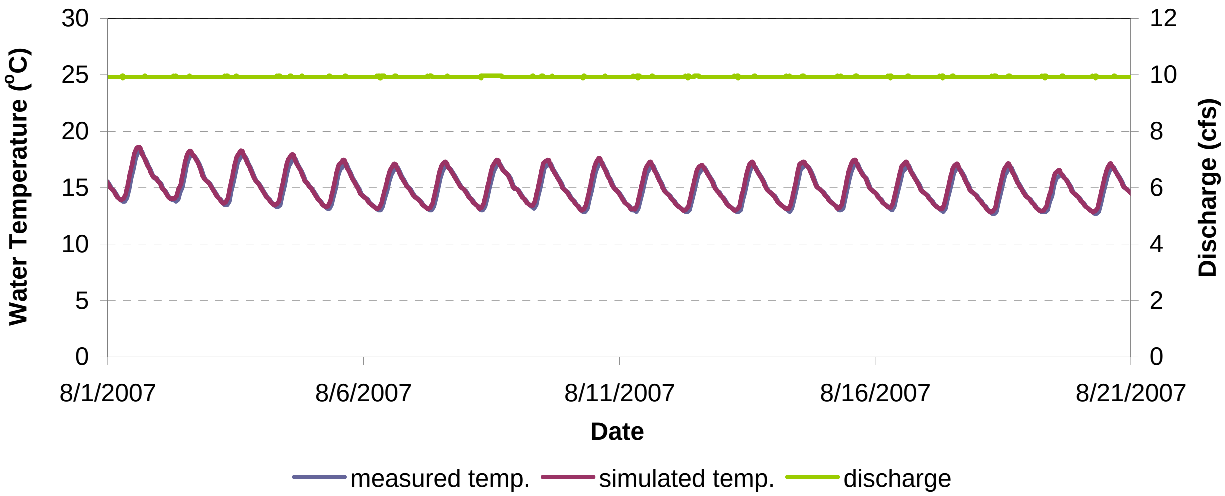
measured temperature in hourly time steps; simulated temperature and discharge in 12 minute time steps



measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps

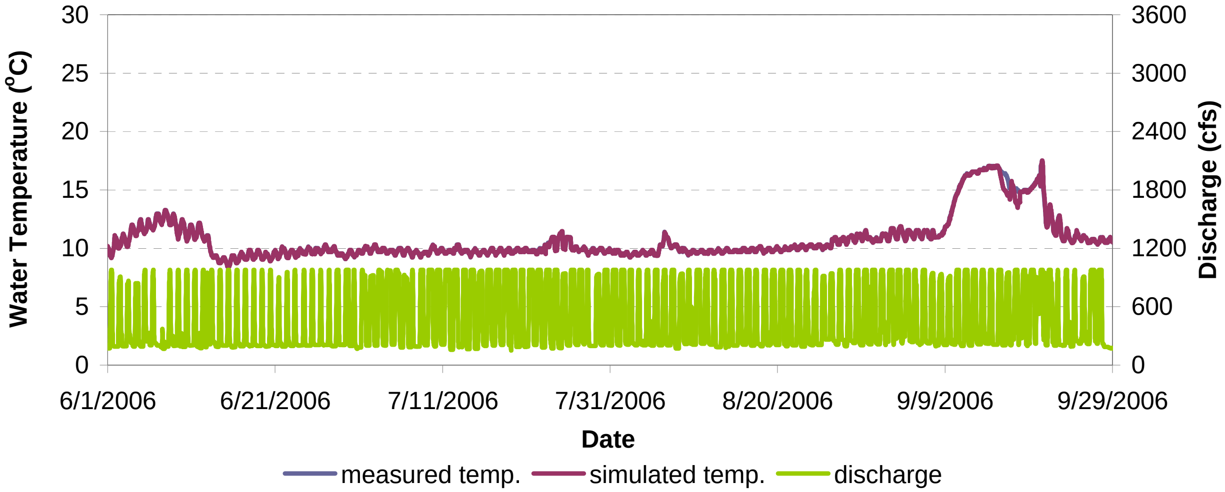
Figure F-32. Water Temperature Model Calibration Results for MF 24.6 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).

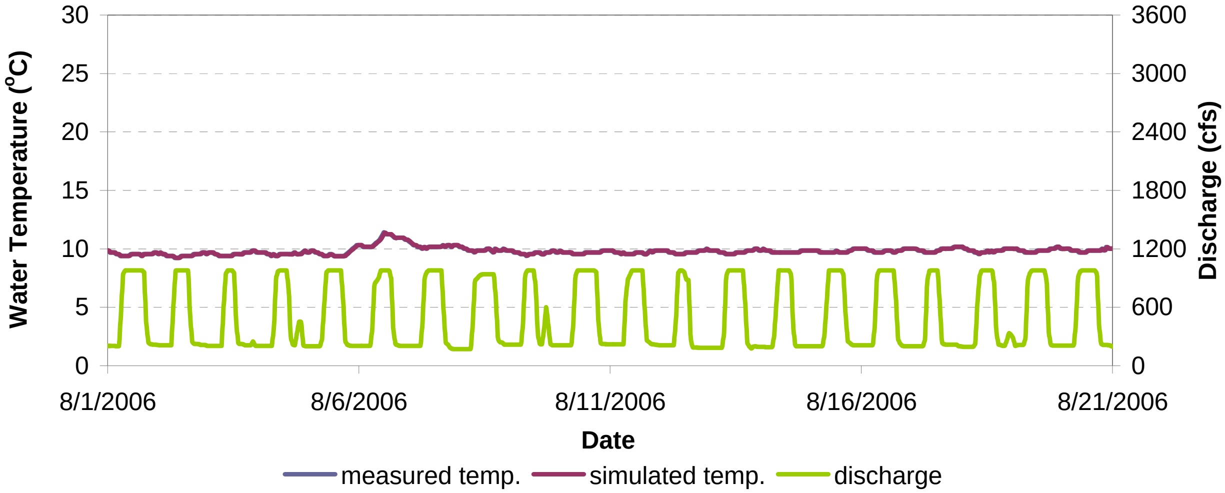




measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps

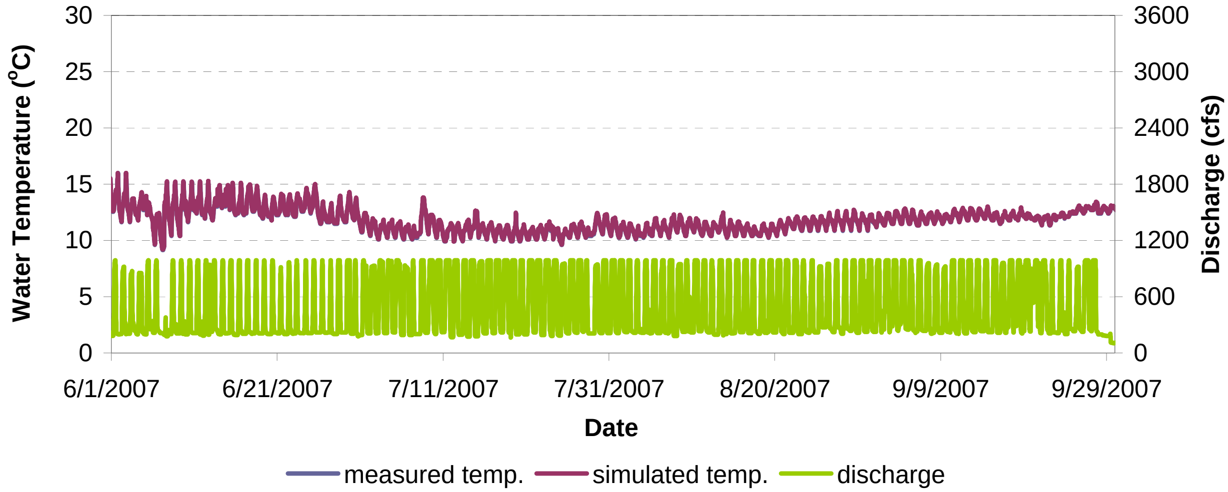
Figure F-33. Water Temperature Model Calibration Results for MF 24.3 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).

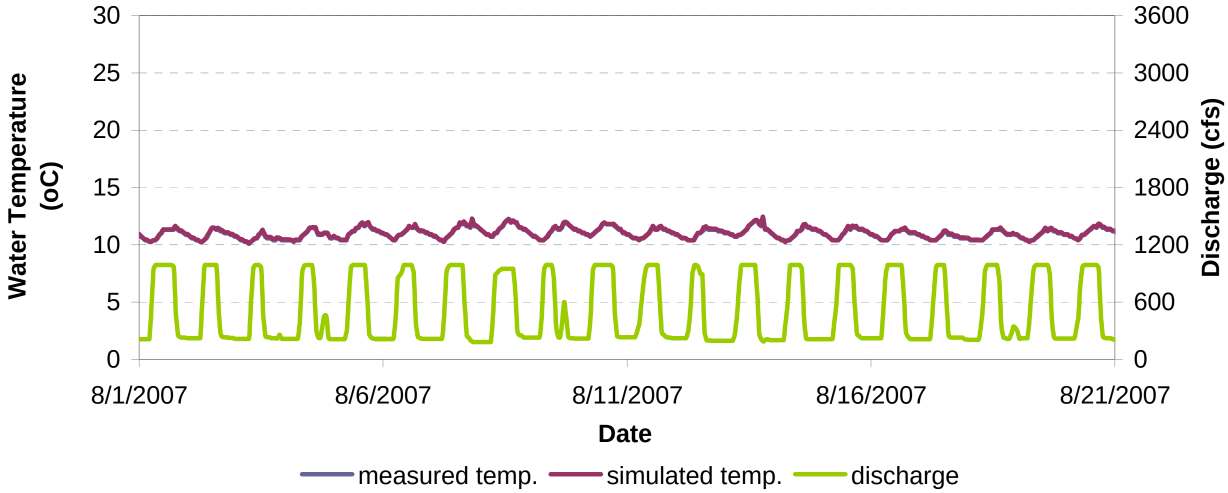




measured temperature in hourly time steps; simulated temperature and discharge in 12 minute time steps

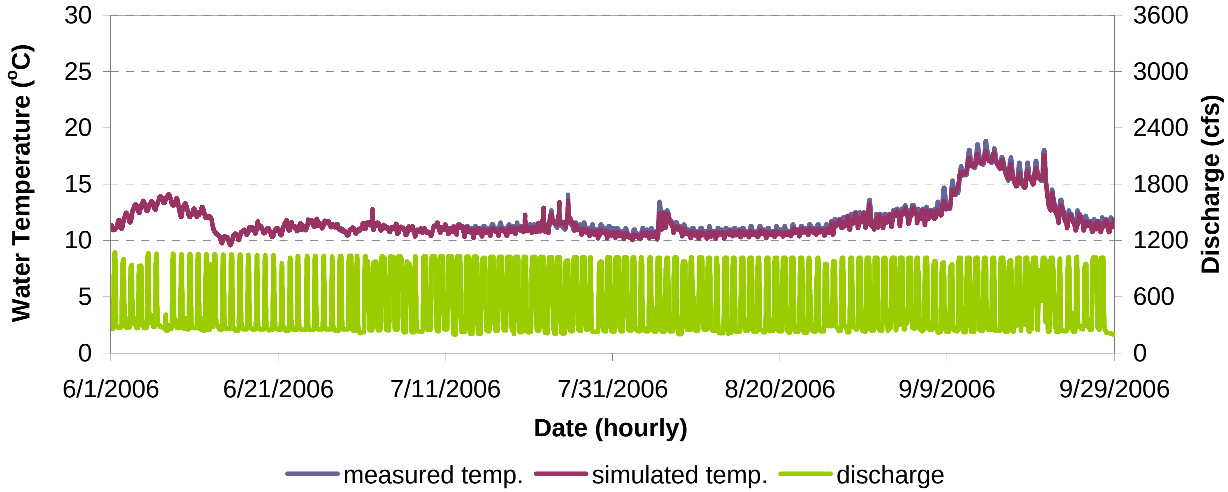
Figure F-34. Water Temperature Model Calibration Results for MF 24.3 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).

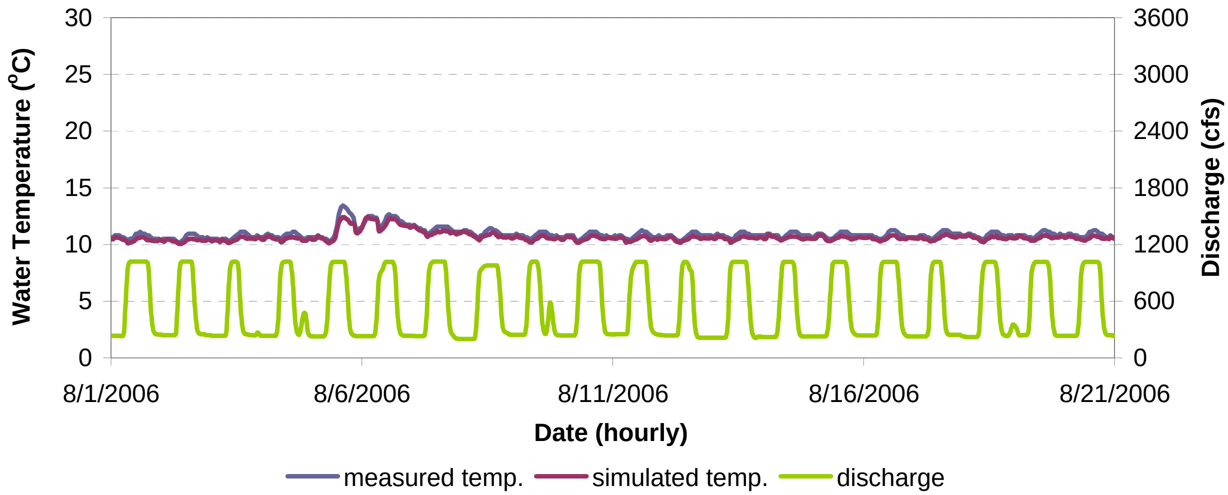




measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps

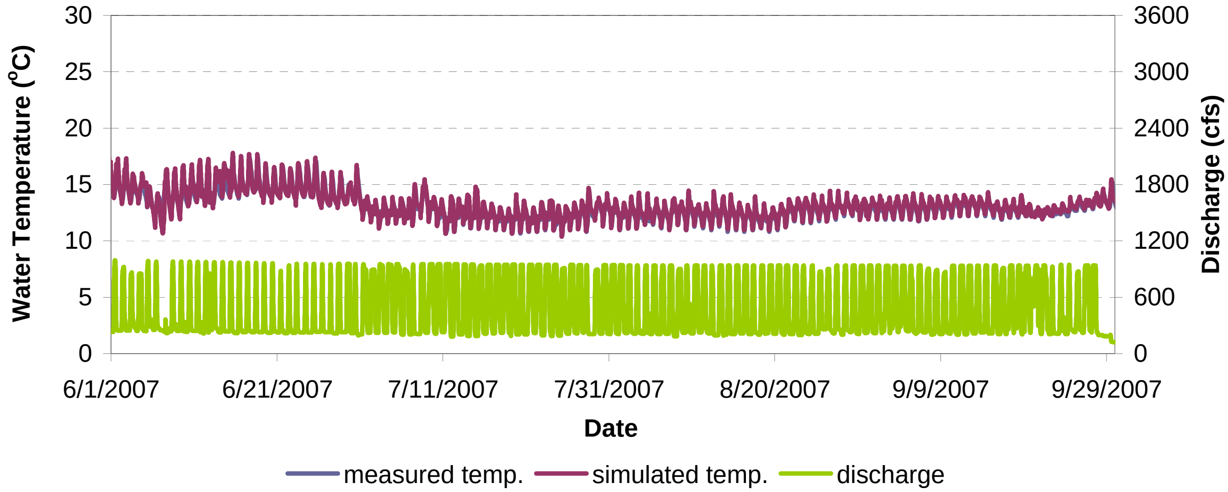
Figure F-35. Water Temperature Model Calibration Results for MF 23.1 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).

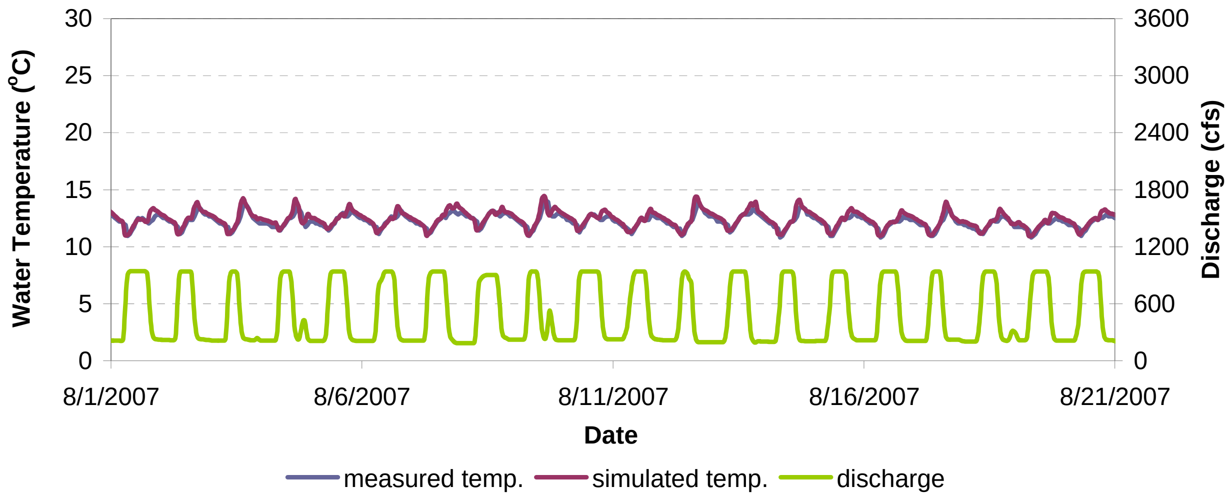




measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps

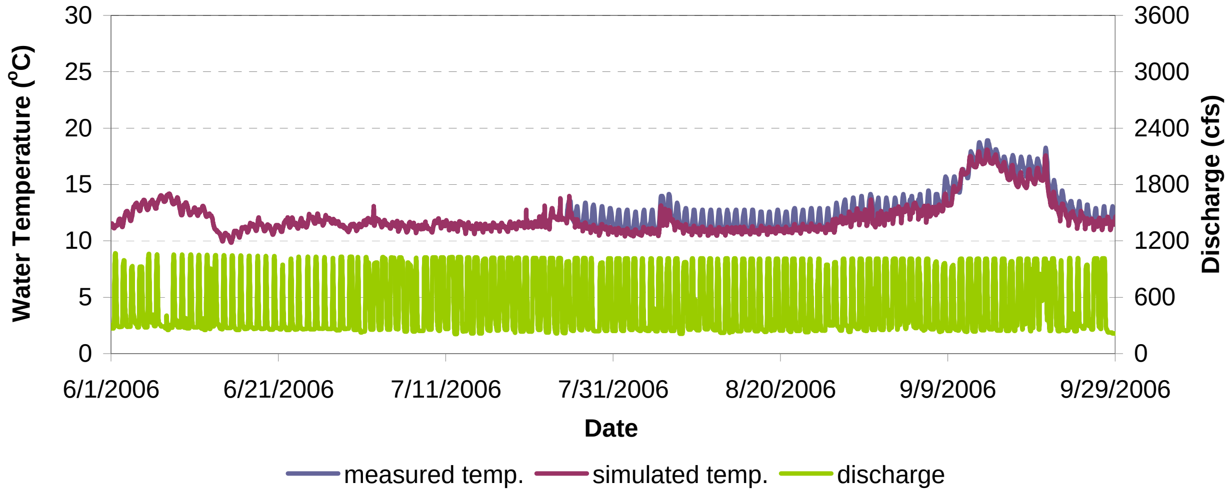
Figure F-36. Water Temperature Model Calibration Results for MF 23.1 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).

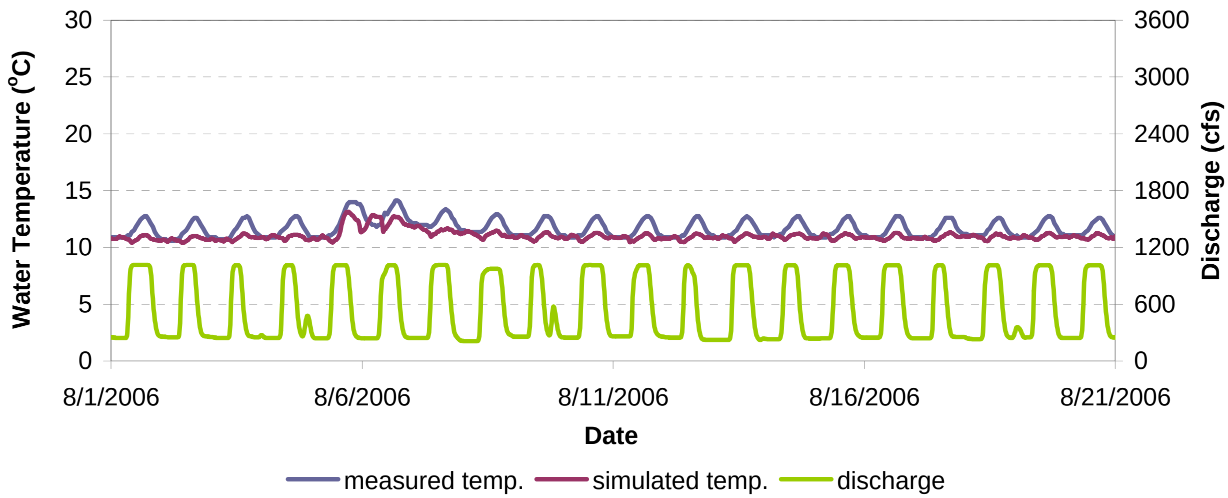




measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps

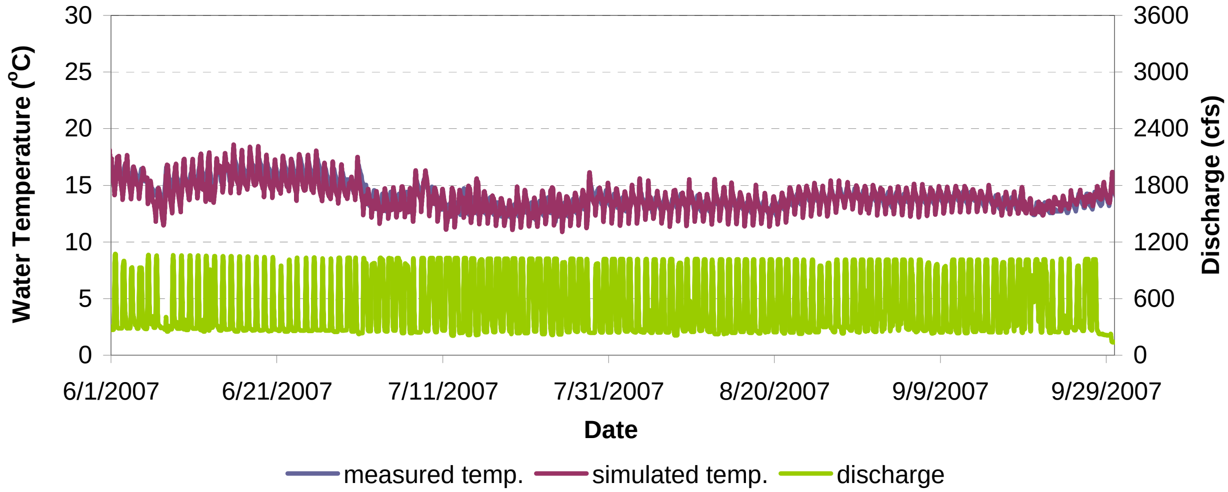
Figure F-37. Water Temperature Model Calibration Results for MF 19.6 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).

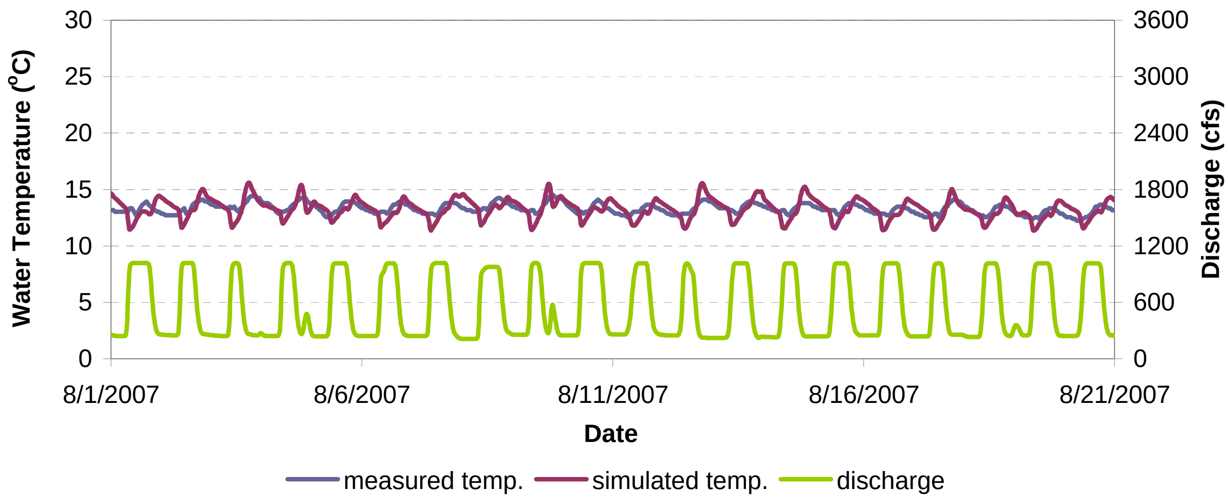




measured temperature in hourly time steps; simulated temperature and discharge in 12 minute time steps

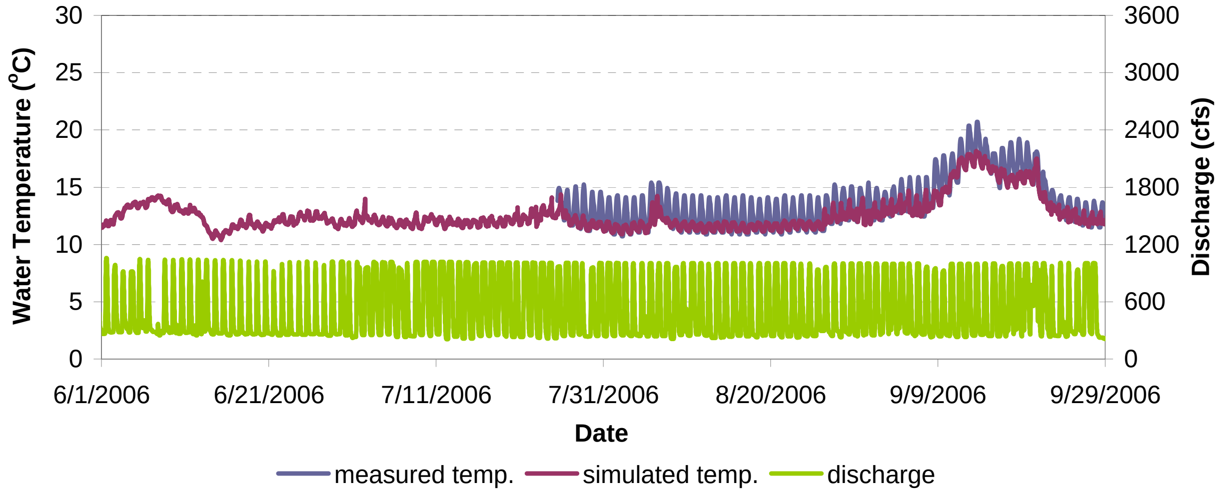
Figure F-38. Water Temperature Model Calibration Results for MF 19.6 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).

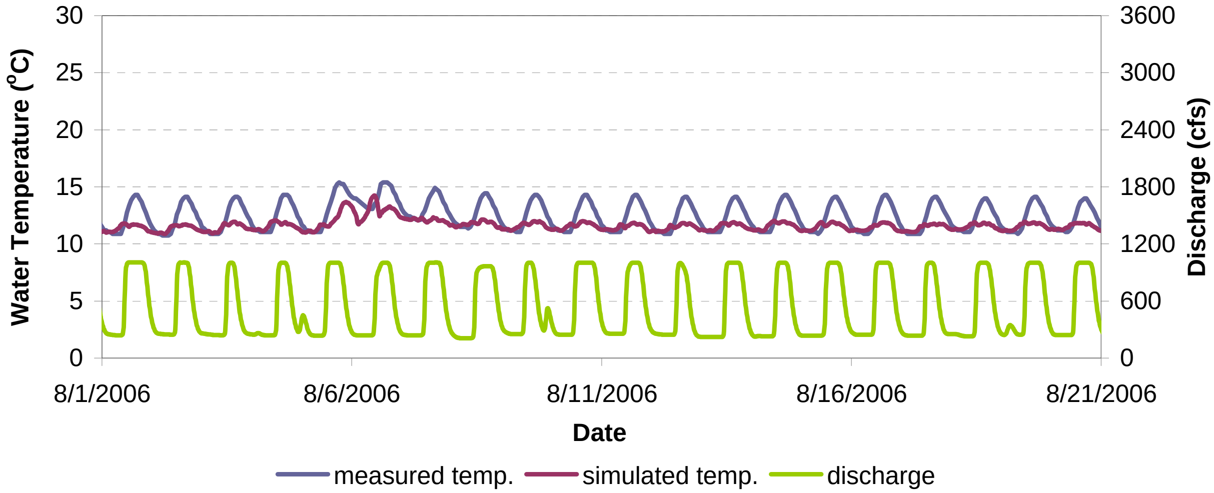




measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps

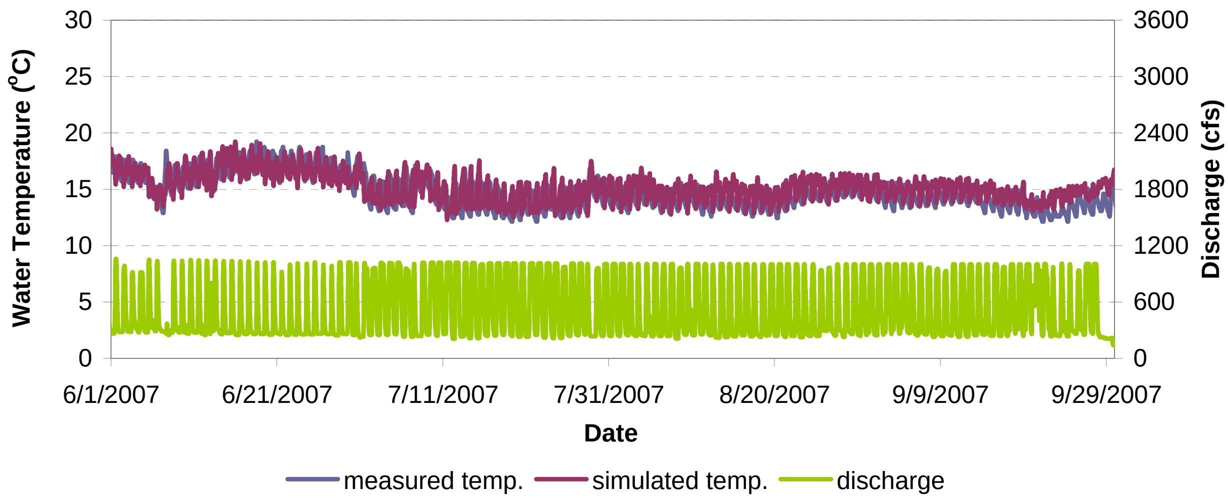
Figure F-39. Water Temperature Model Calibration Results for MF 14.3 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 21, 2006 (Top) and August 1 - August 21, 2006 (Bottom).



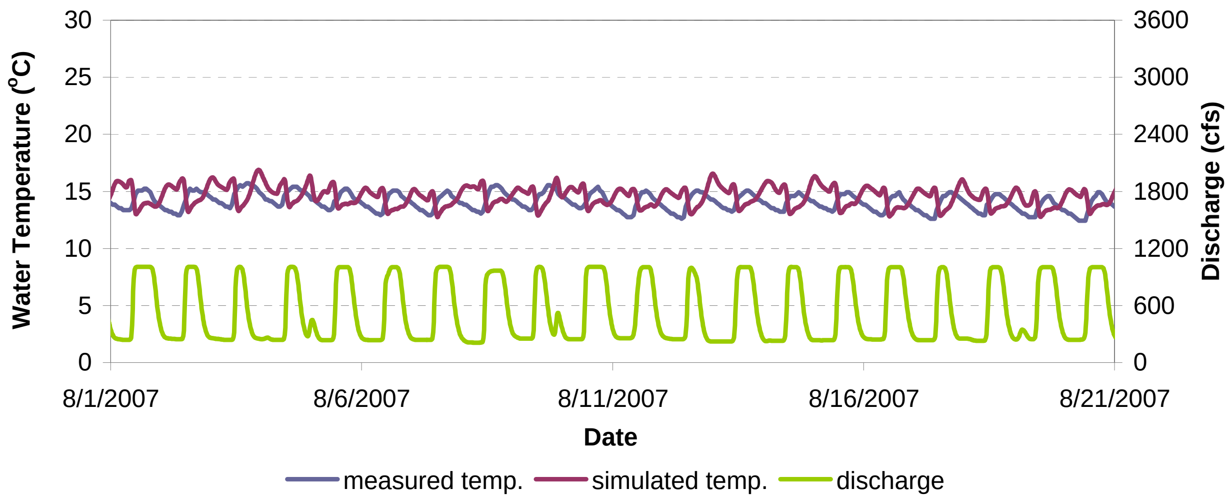


measured temperature in hourly time steps; simulated temperature and discharge in 12 minute time steps

Figure F-40. Water Temperature Model Calibration Results for MF 14.3 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).

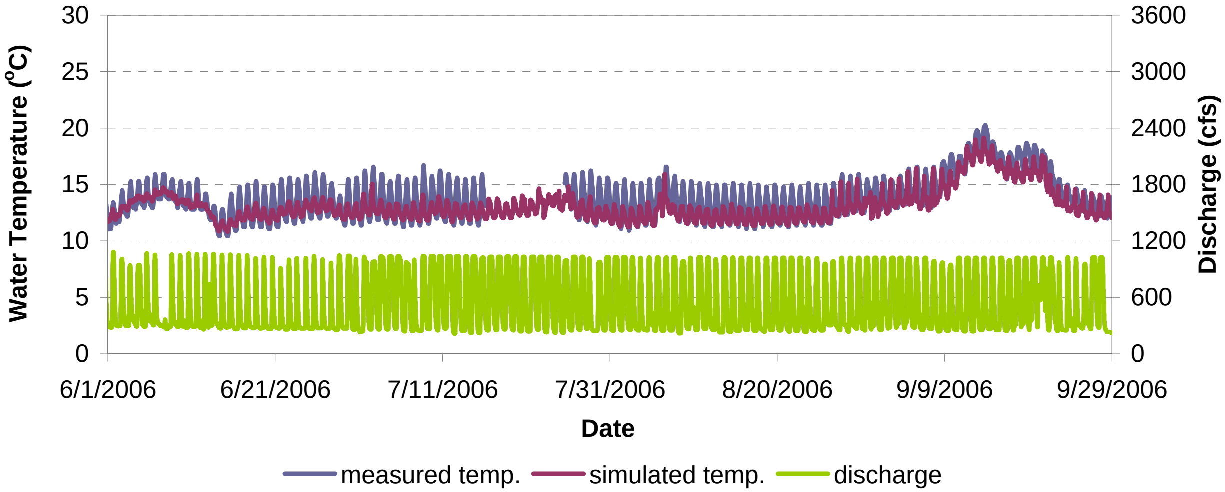


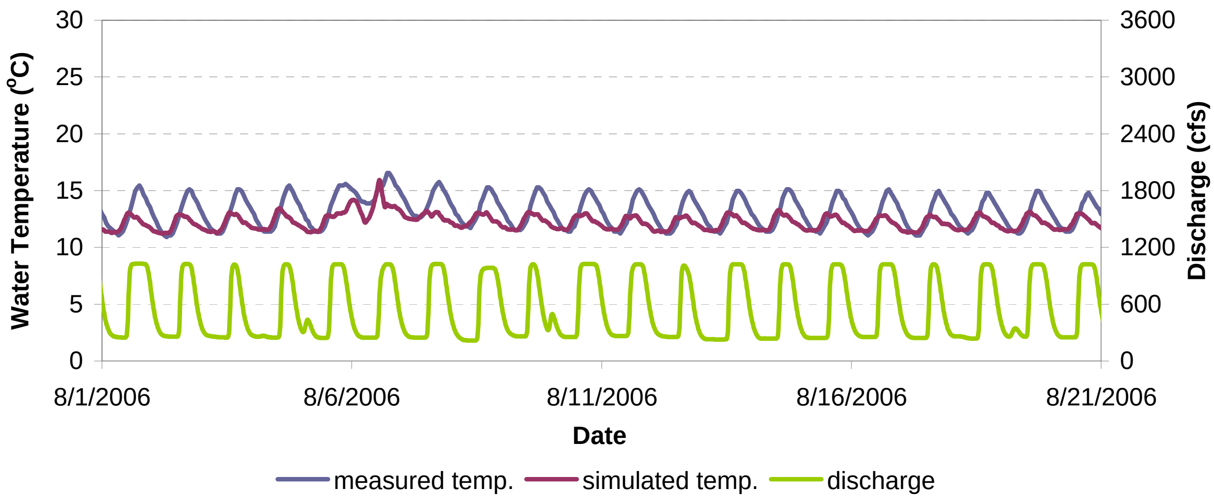
measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps



measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps

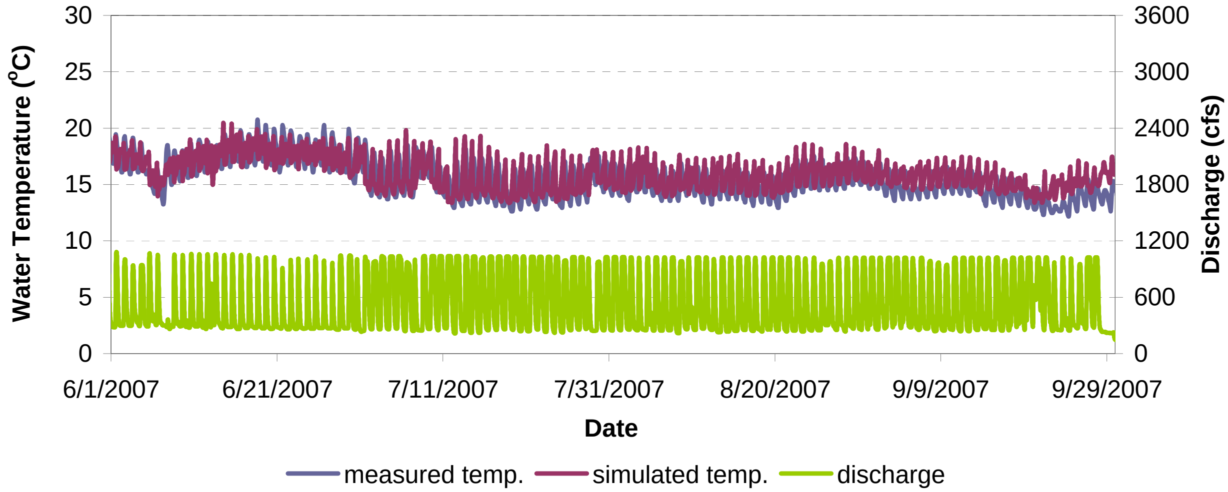
Figure F-41. Water Temperature Model Calibration Results for MF 11.0 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).

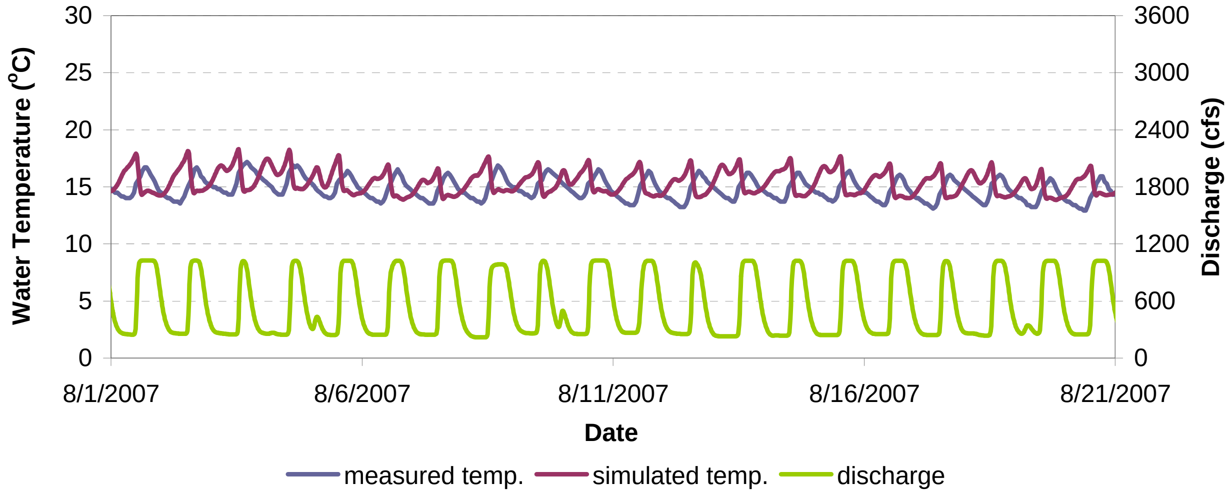




measured temperature in hourly time steps; simulated temperature and discharge in 12 minute time steps

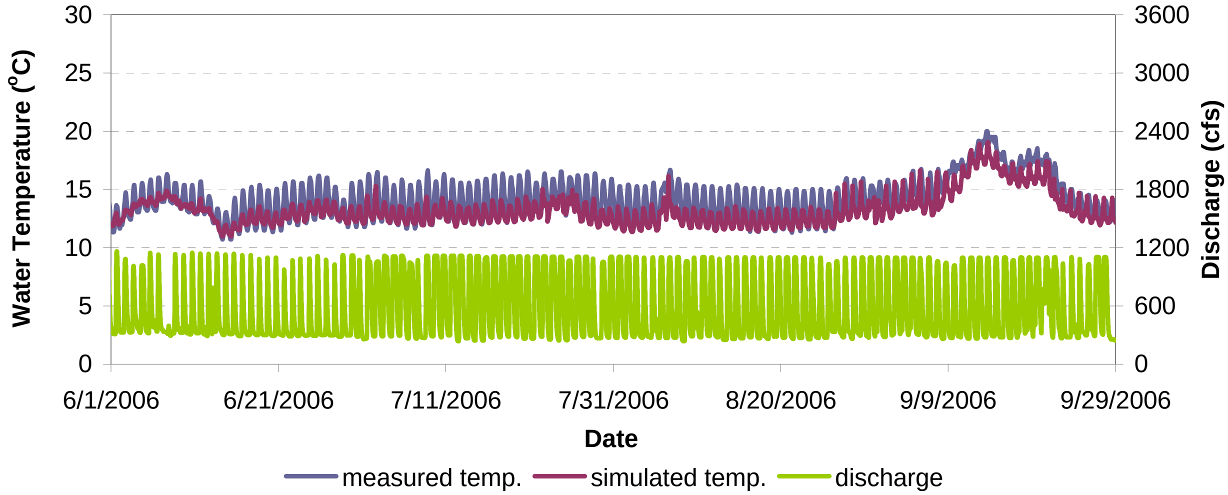
Figure F-42. Water Temperature Model Calibration Results for MF 11.0 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).

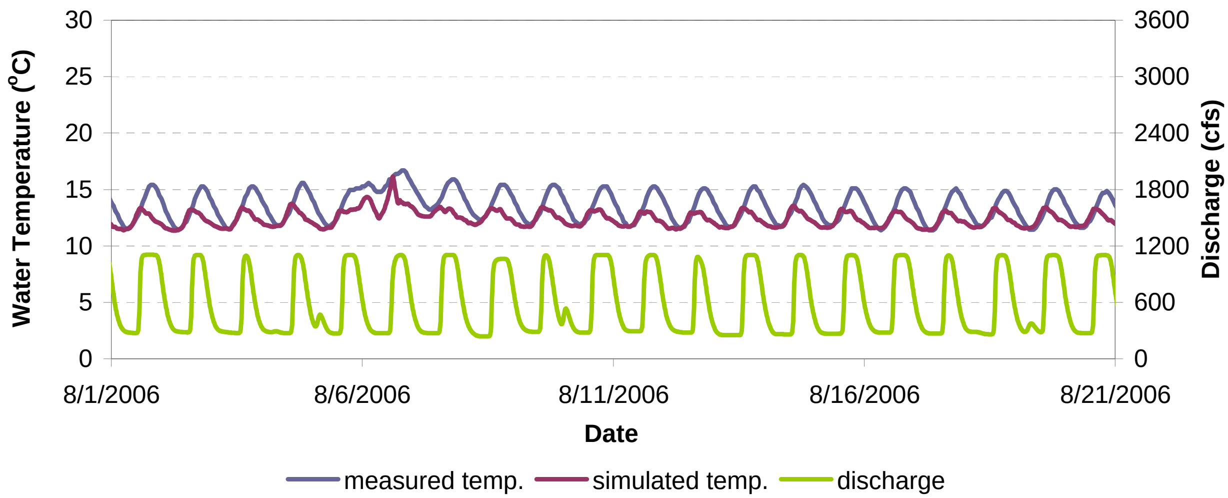




measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps

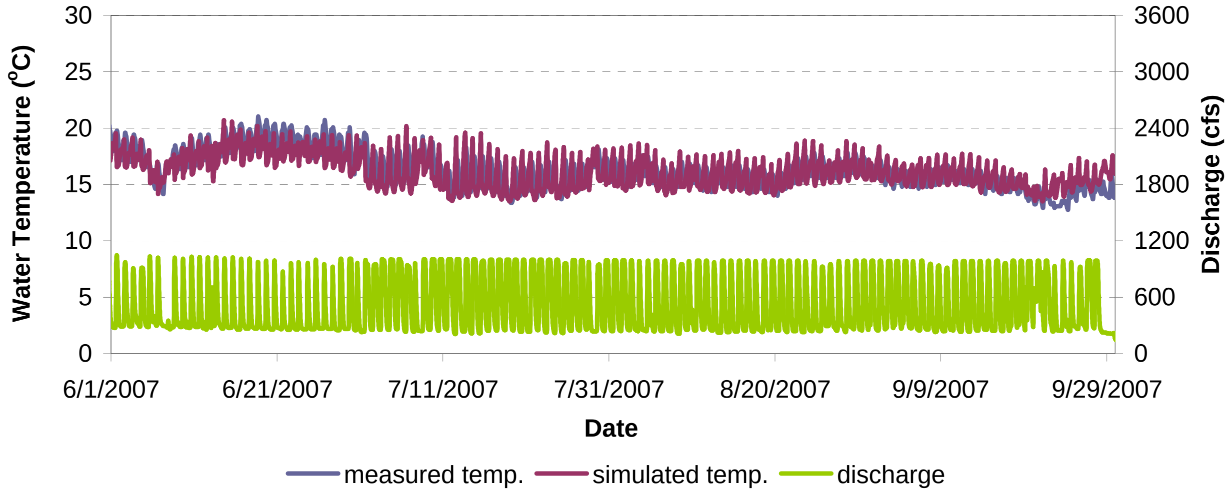
Figure F-43. Water Temperature Model Calibration Results for MF 8.9 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).

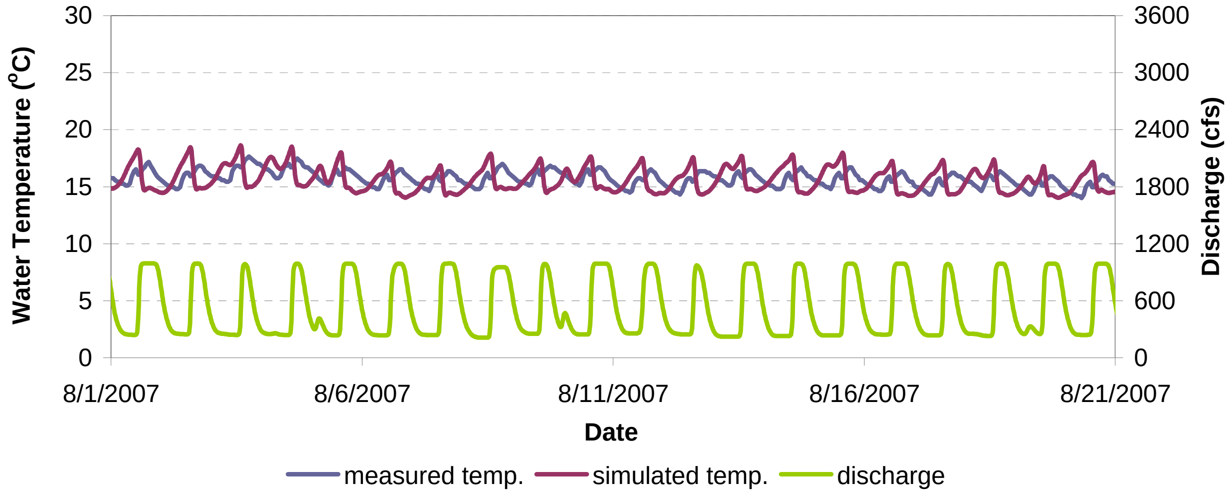




measured temperature in hourly time steps; simulated temperature and discharge in 12 minute time steps

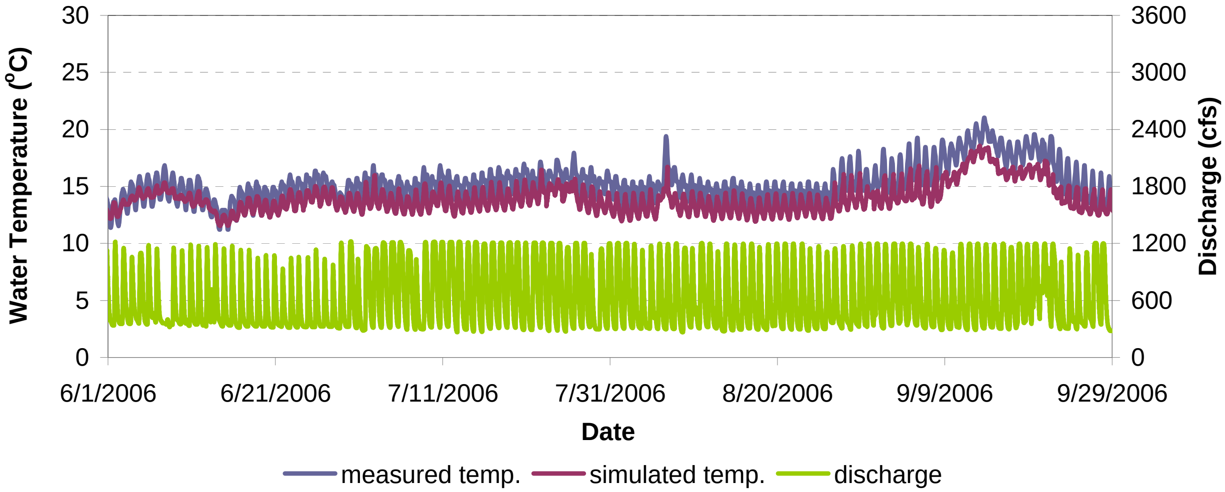
Figure F-44. Water Temperature Model Calibration Results for MF 8.9 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).

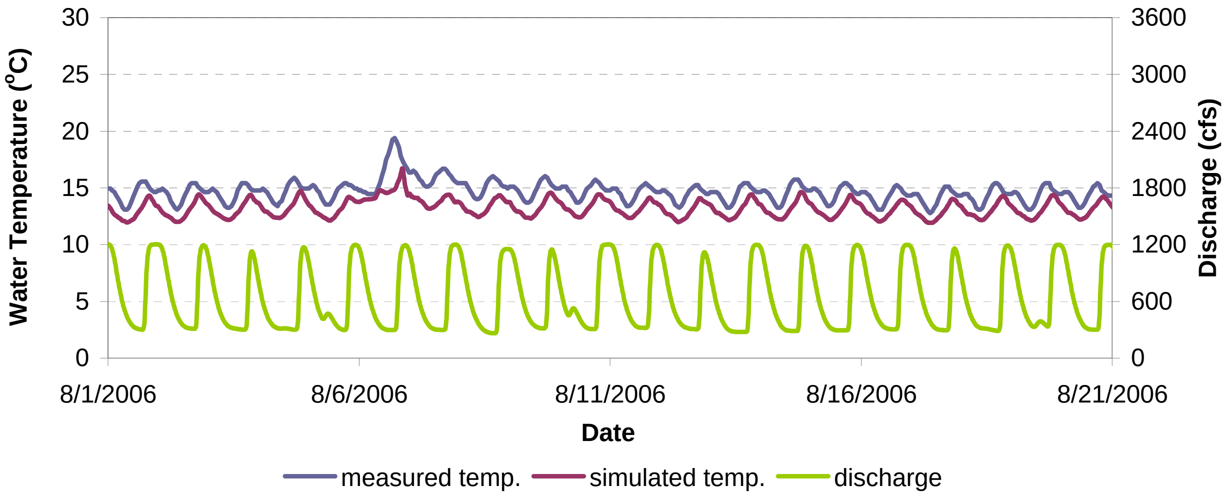




measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps

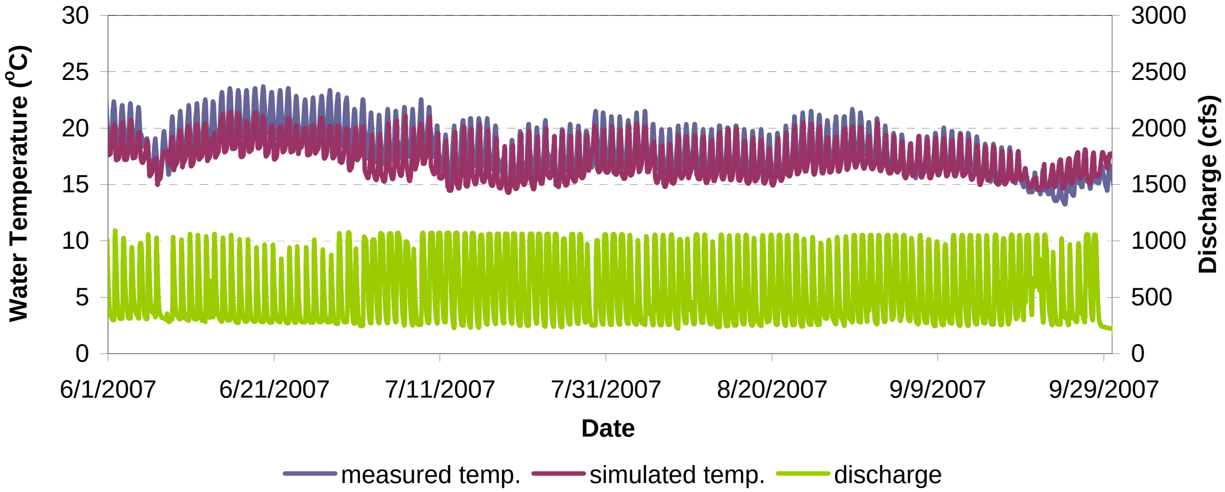
Figure F-45. Water Temperature Model Calibration Results for MF 0.1 in the Ralston Afterbay to Folsom Resrvoir Reach of the Middle Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).

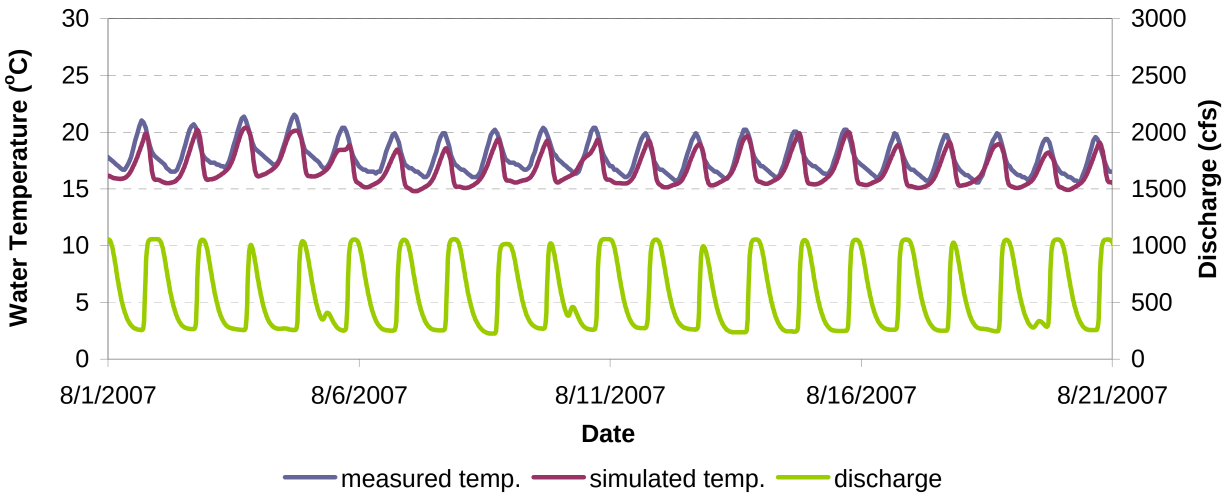




measured temperature in hourly time steps; simulated temperature and discharge in 12 minute time steps

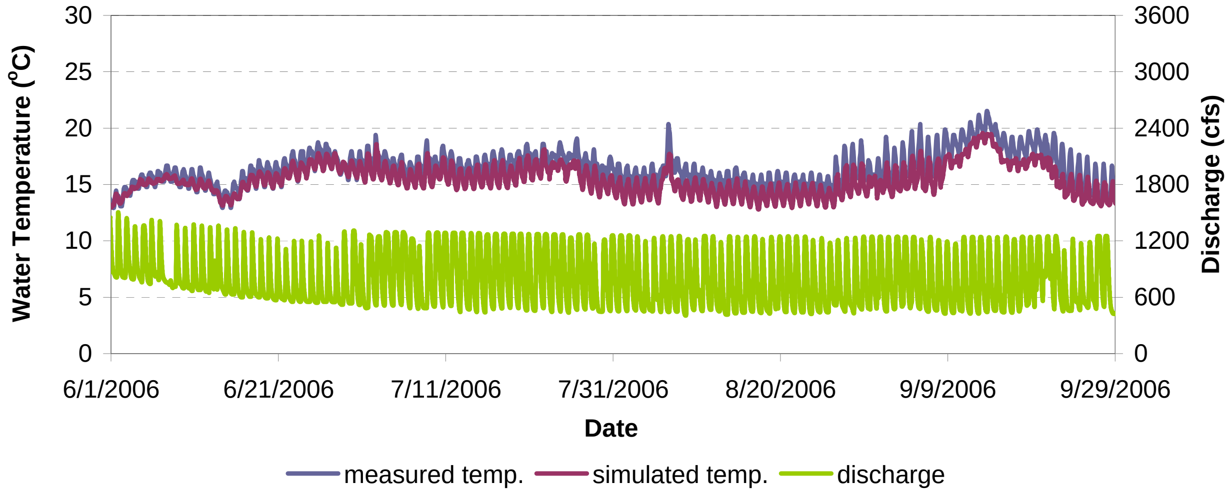
Figure F-46. Water Temperature Model Calibration Results for MF 0.1 in the Ralston Afterbay to Folsom Reservoir Reach of the Middle Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).

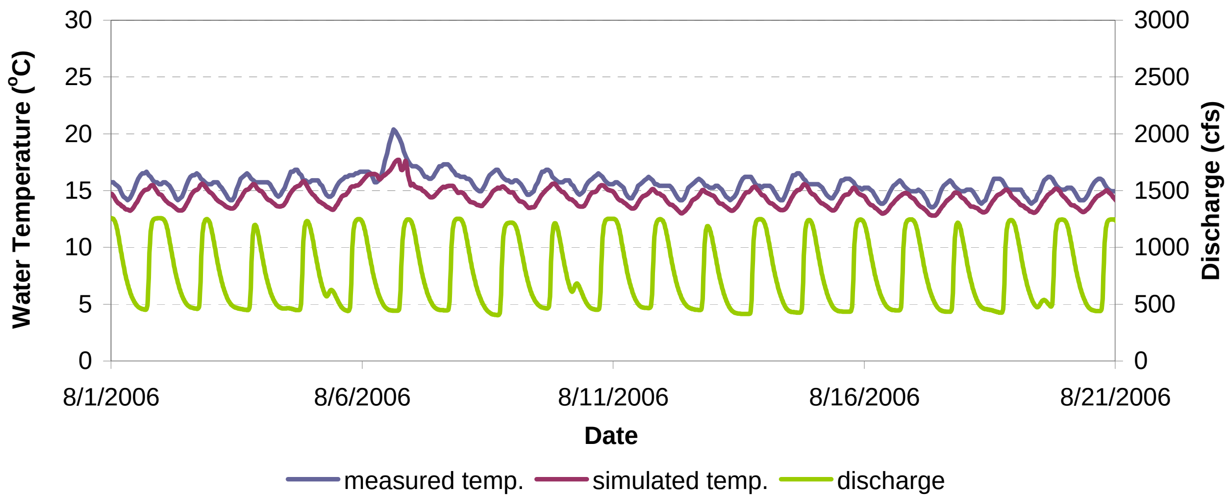




measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps

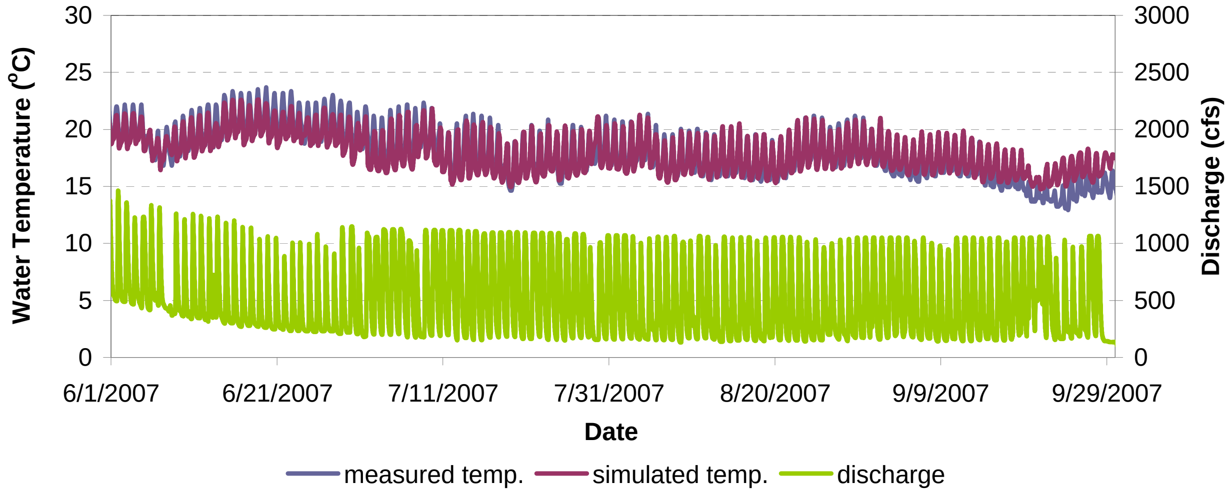
Figure F-47. Water Temperature Model Calibration Results for NF 20.8 in the Ralston Afterbay to Folsom Reservoir Reach of the North Fork American River for June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).

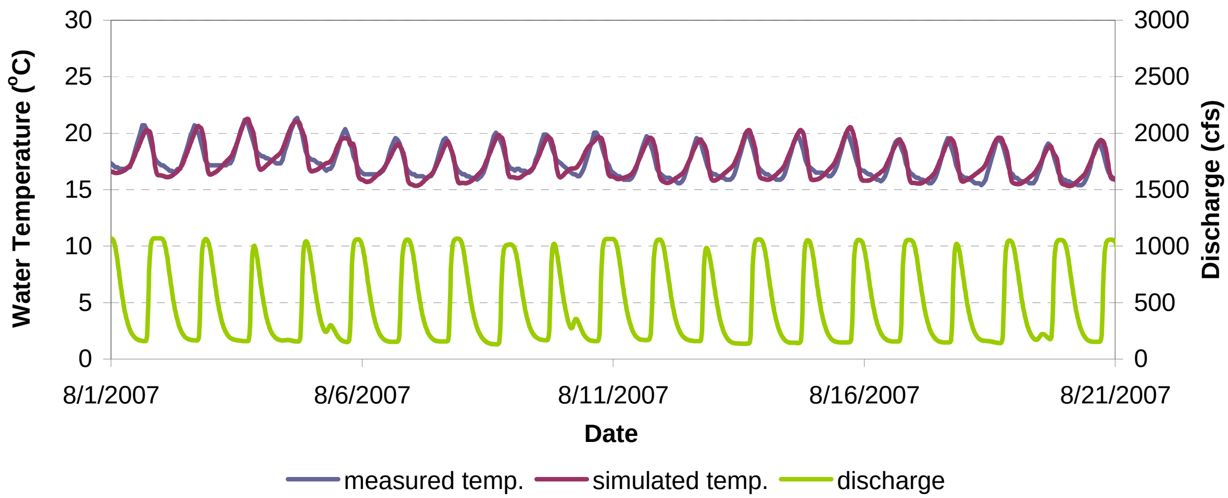




measured temperature in hourly time steps; simulated temperature and discharge in 12 minute time steps

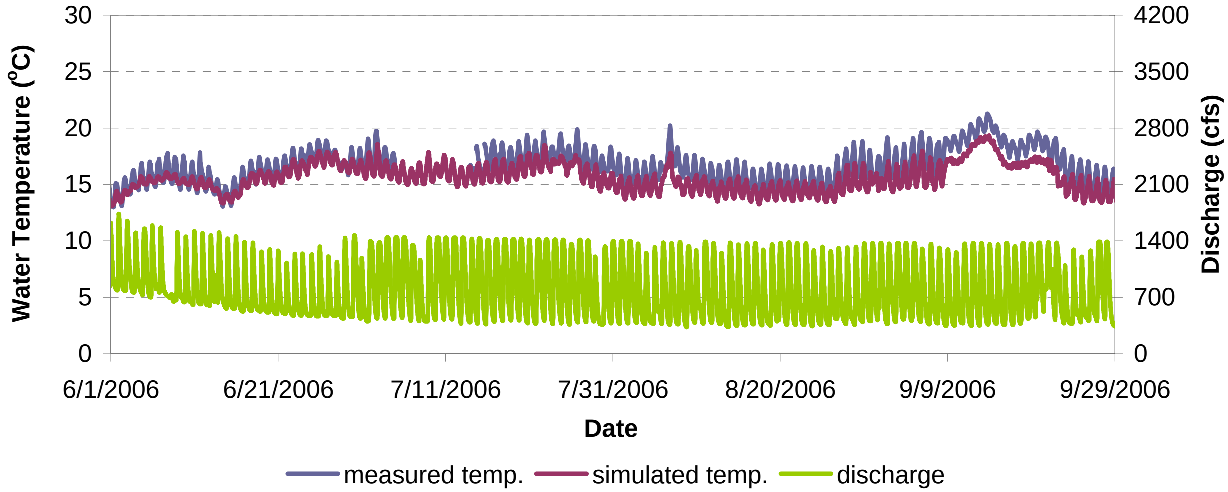
Figure F-48. Water Temperature Model Calibration Results for NF 20.8 in the Ralston Afterbay to Folsom Reservoir Reach of the North Fork American River for June 1 - September 30, 2007 (Top) and August 1 - August 21, 2007 (Bottom).

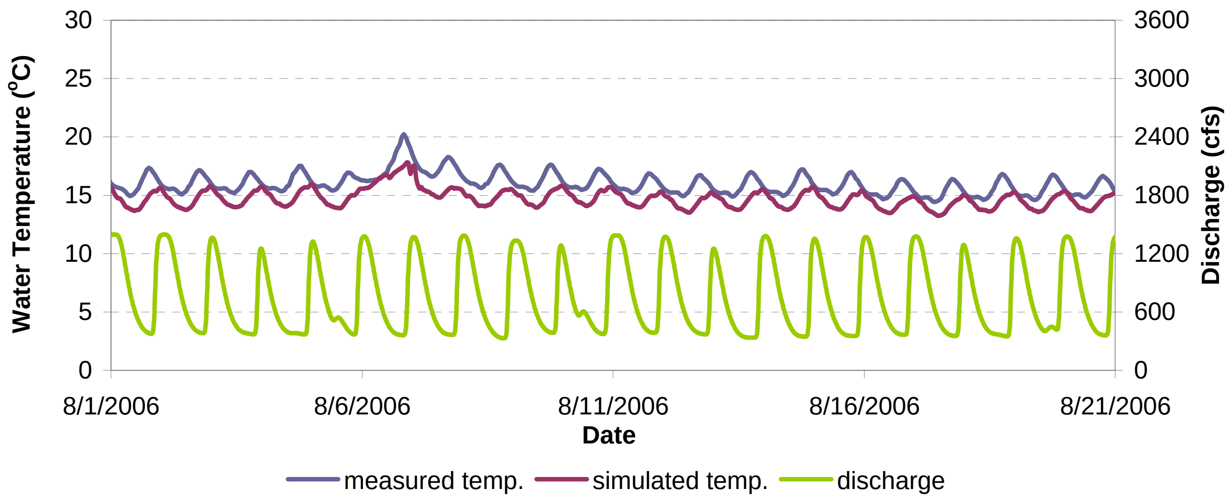




measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps

Figure F-49. Water Temperature Model Calibration Results for NF 14.3 in the Ralston Afterbay to Folsom Reservoir Reach of the North Fork American River for the June 1 - September 30, 2006 (Top) and August 1 - August 21, 2006 (Bottom).





measured temperature in hourly time steps; simulated temperature iand discharge in 12 minute time steps

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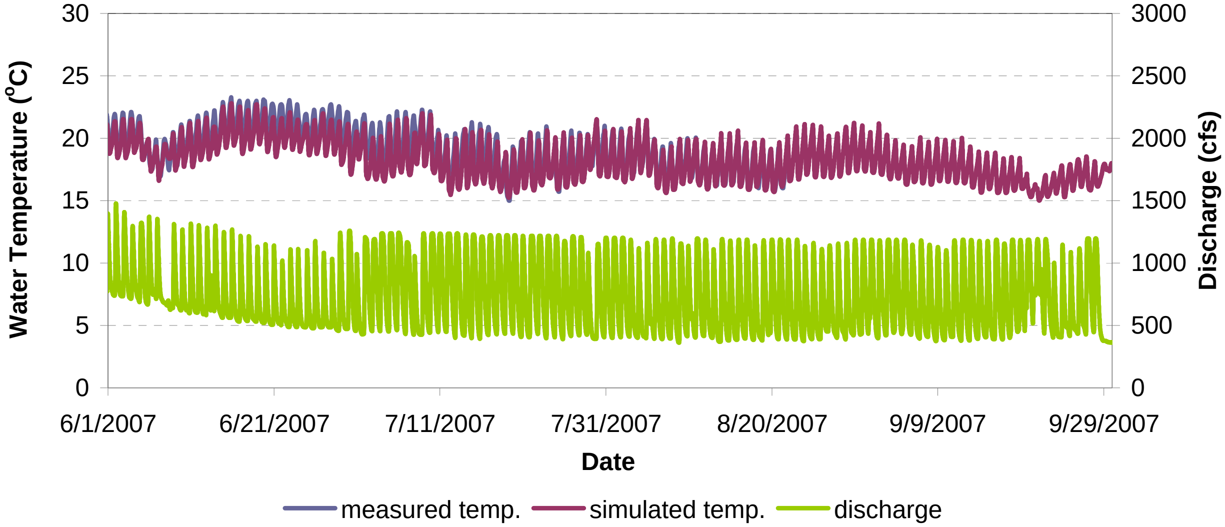
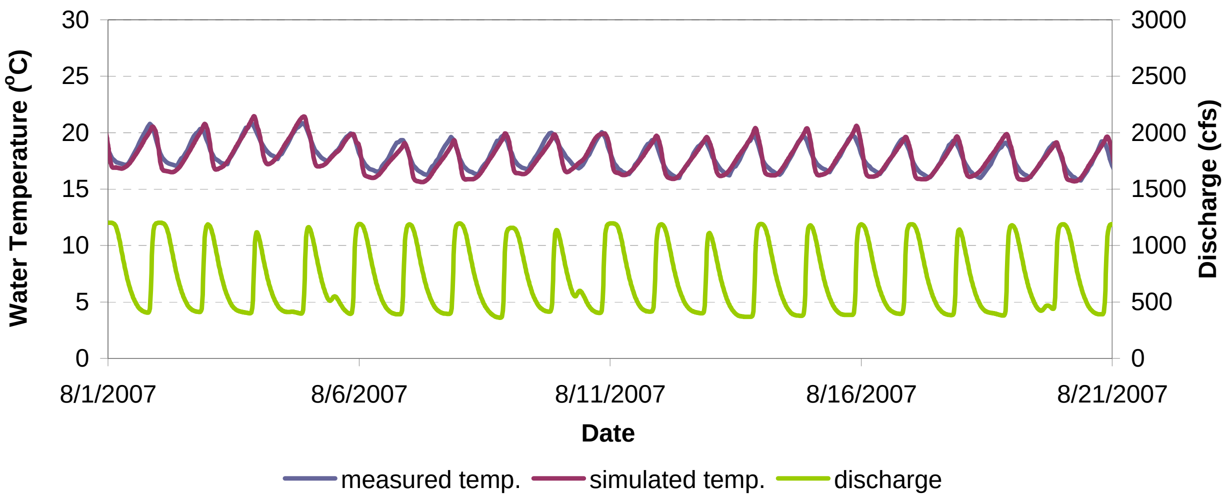


measured temperature in hourly time steps; simulated temperature and discharge in 15 minute time steps



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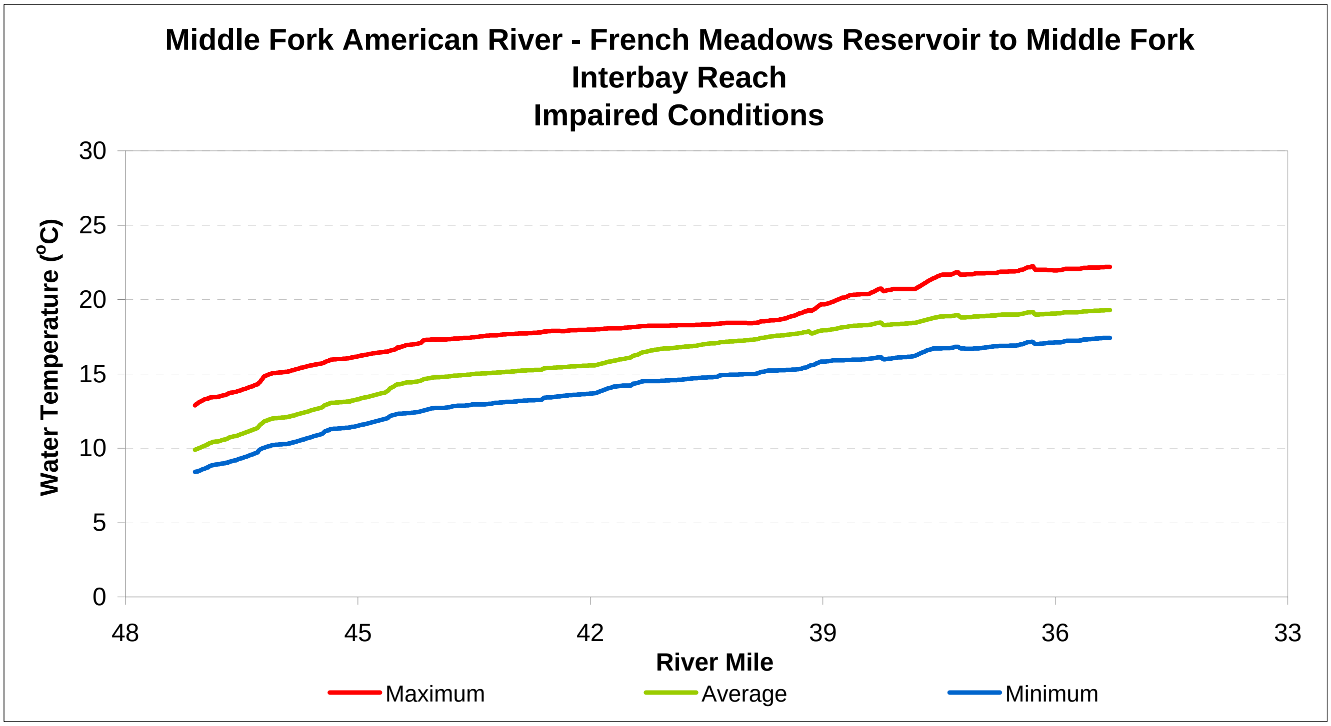

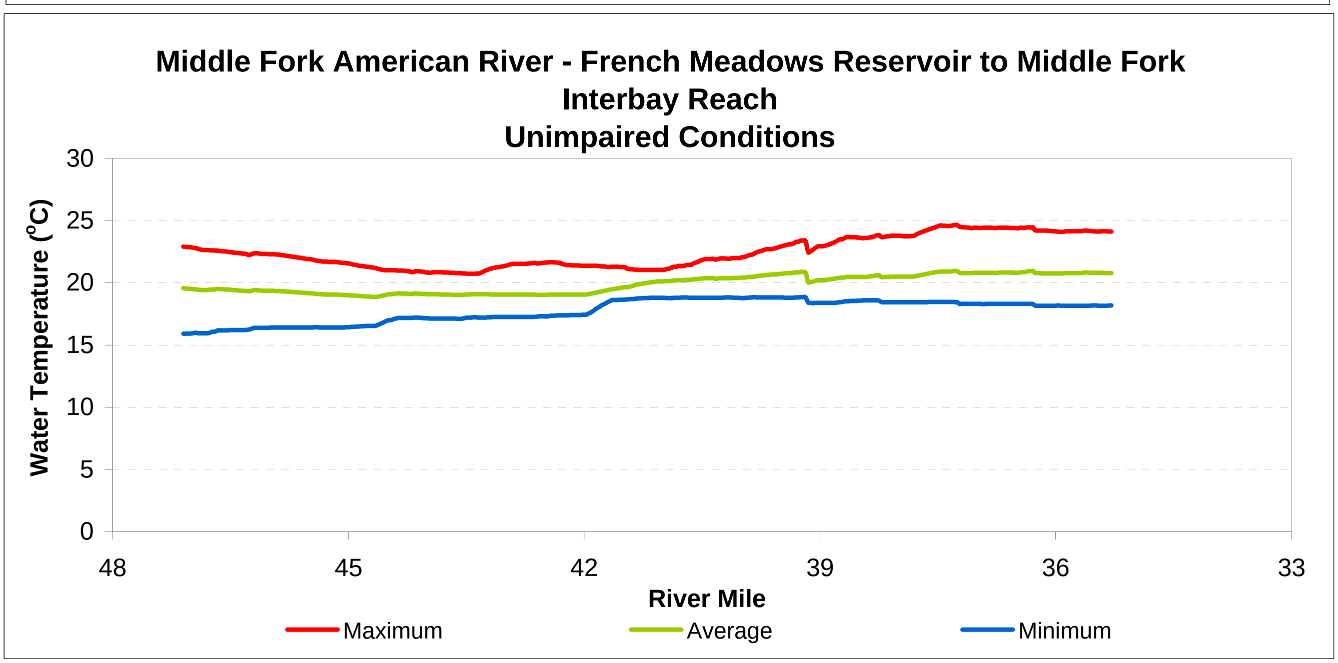

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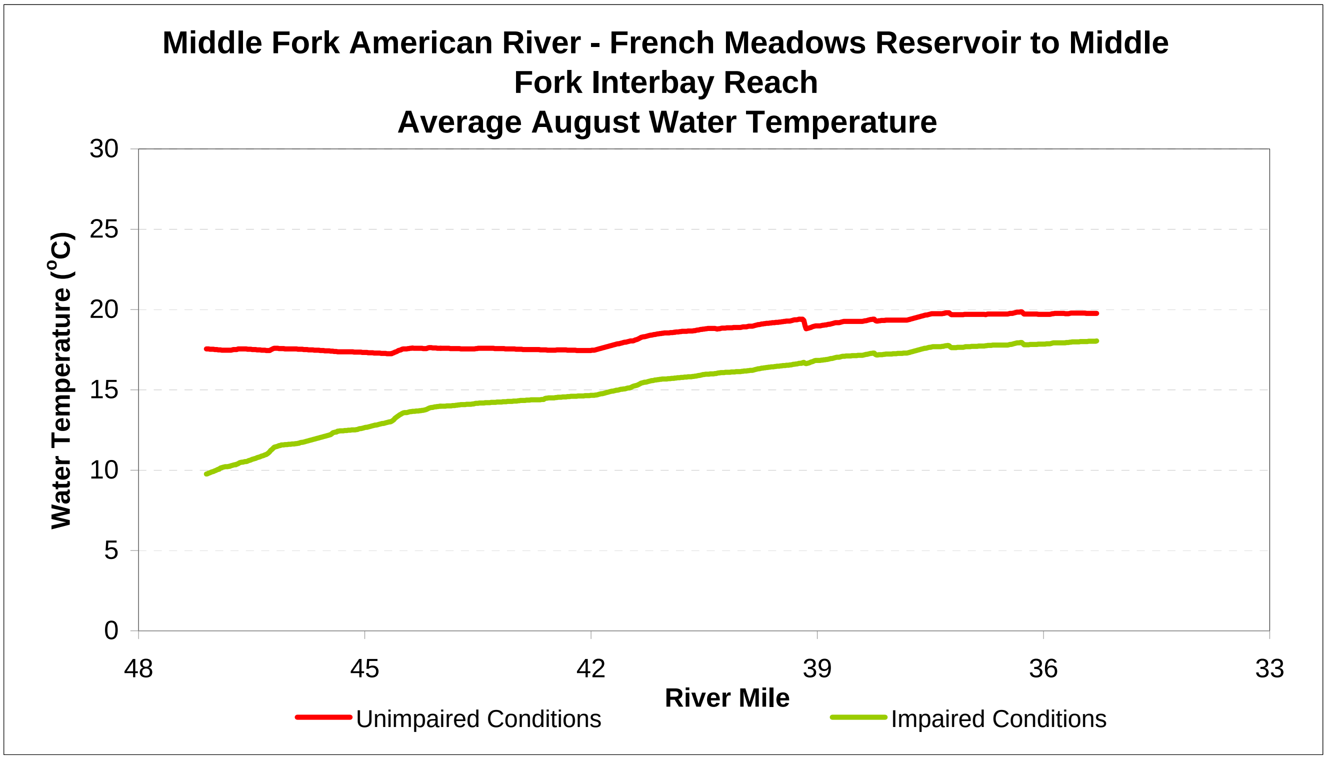

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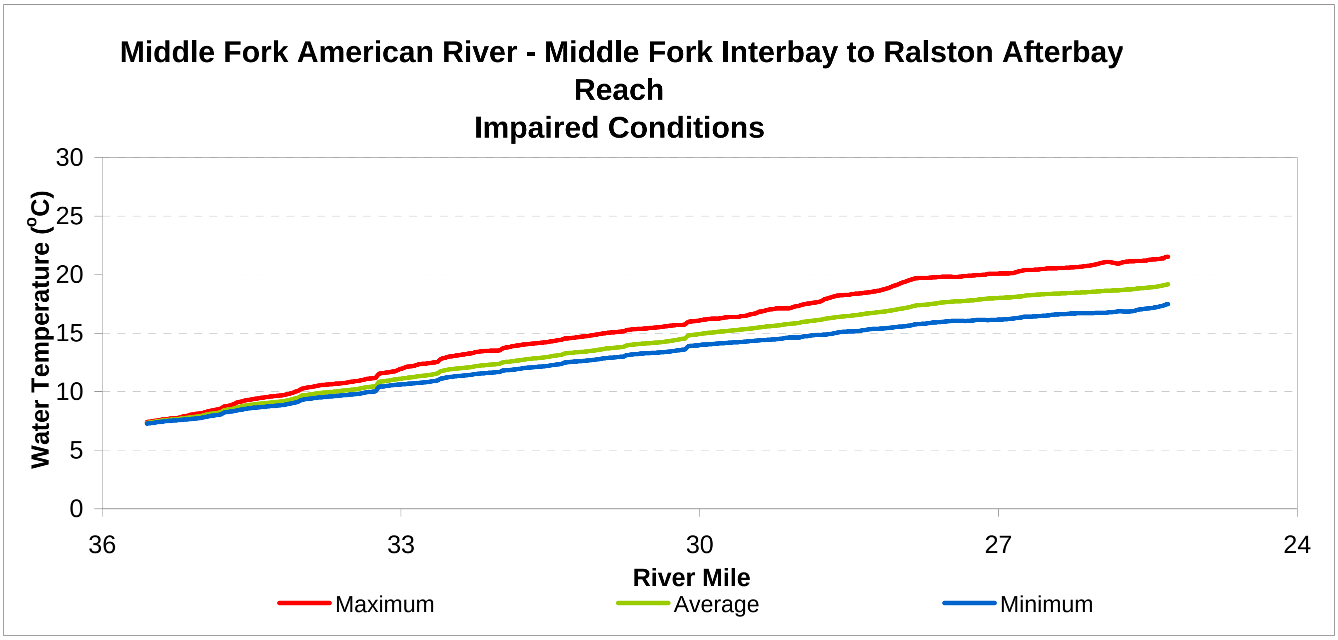

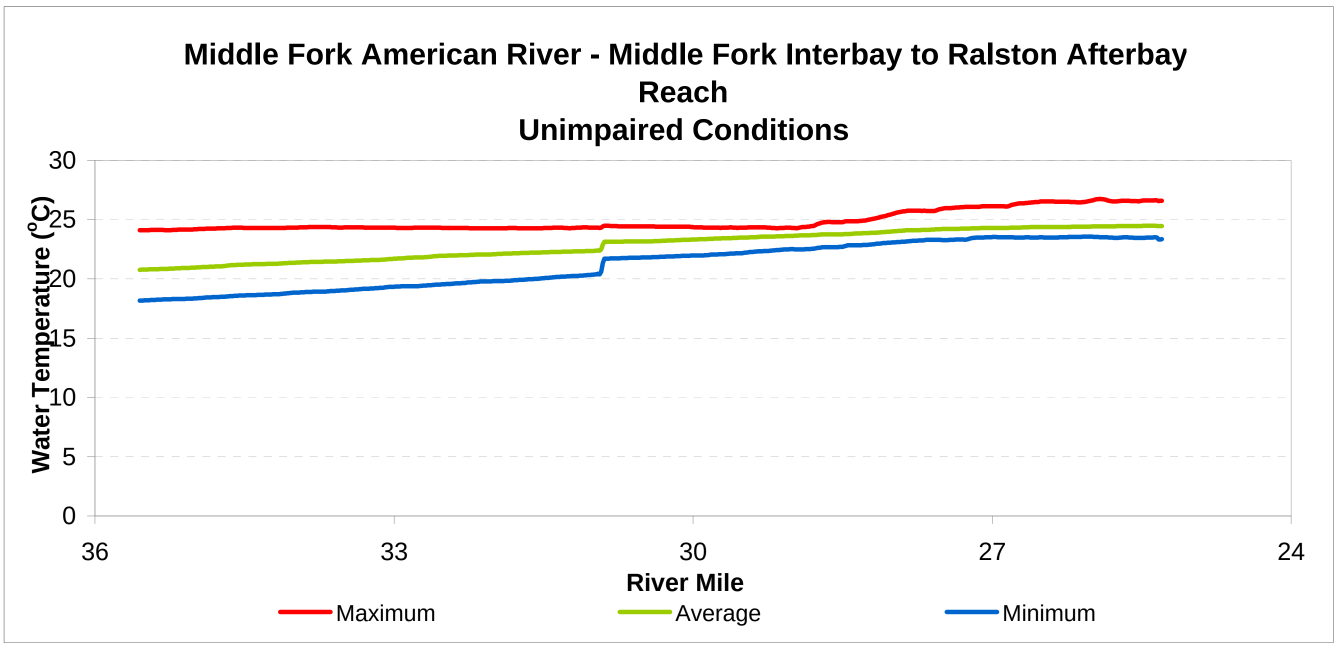

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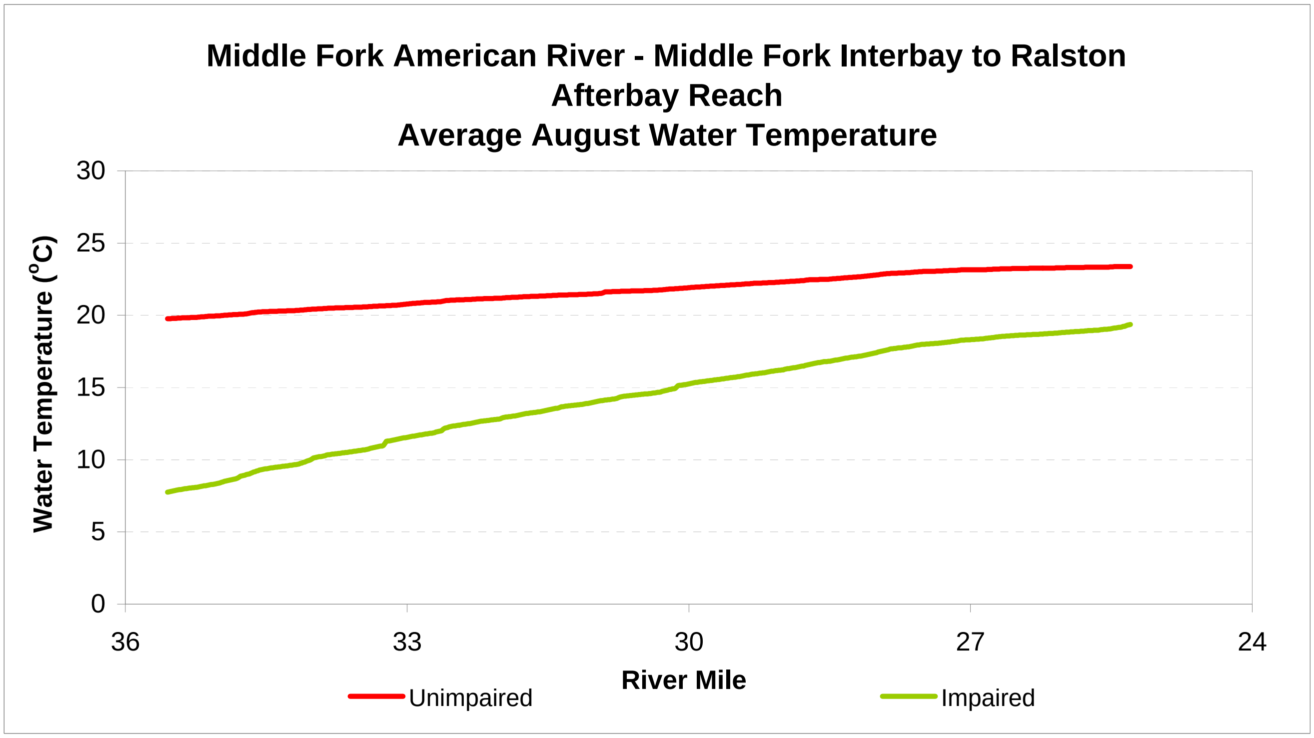

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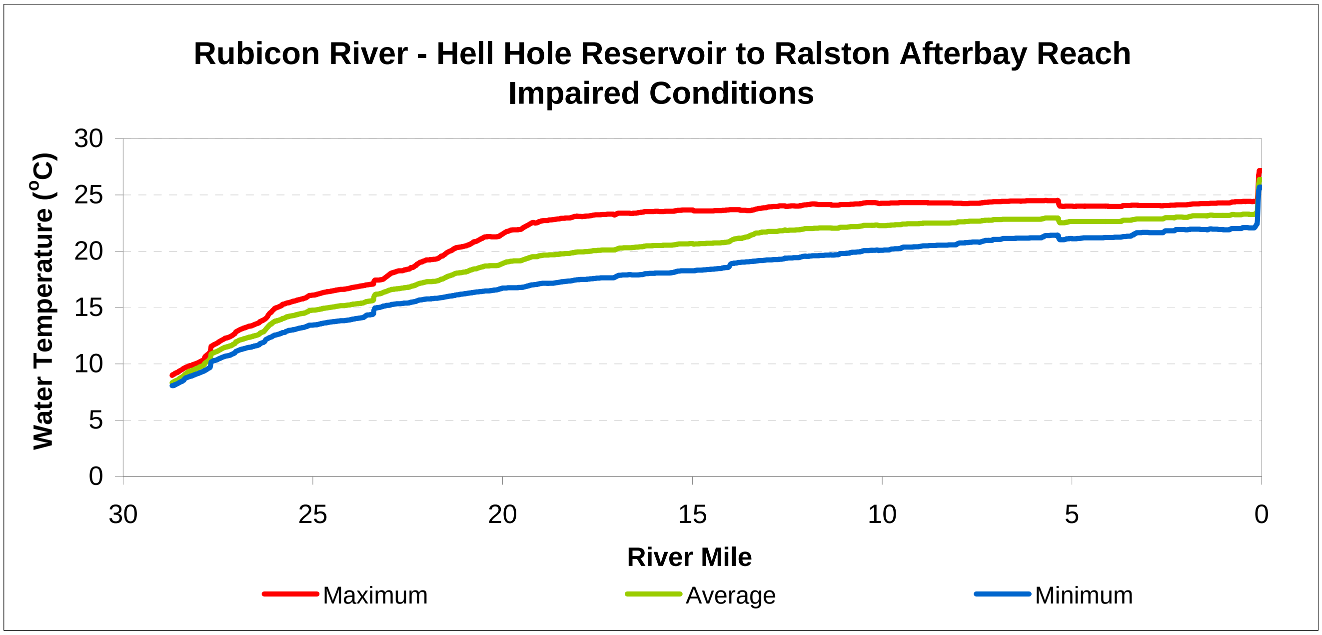

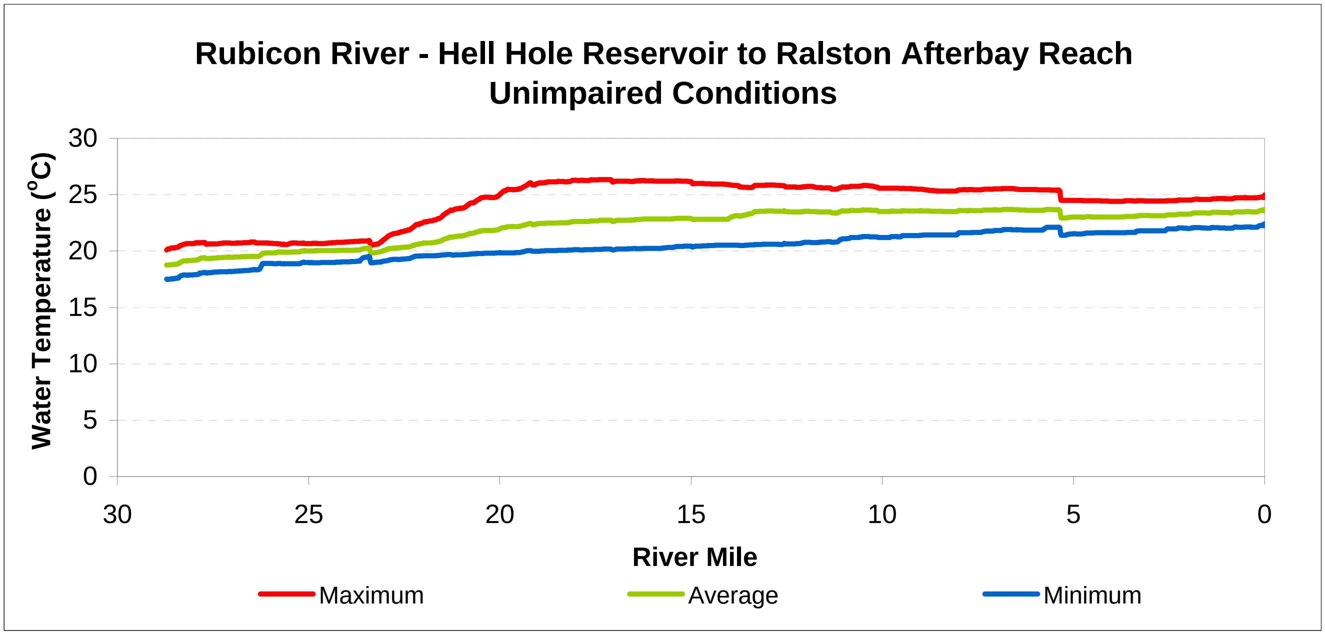

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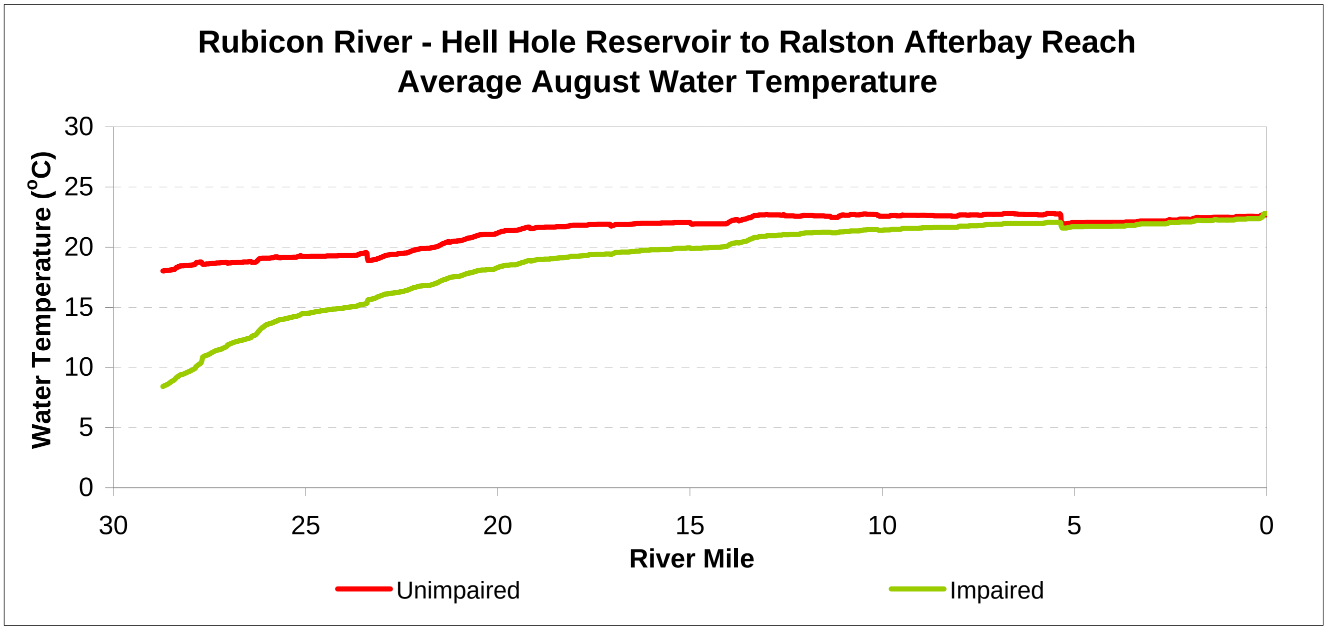

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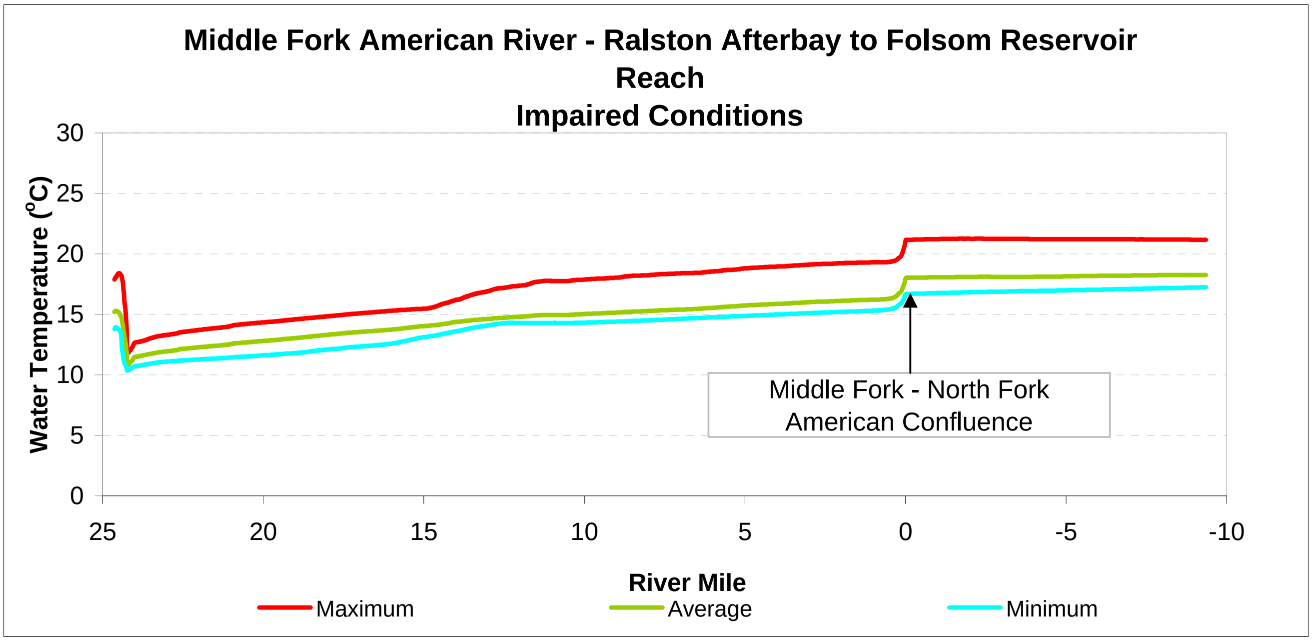

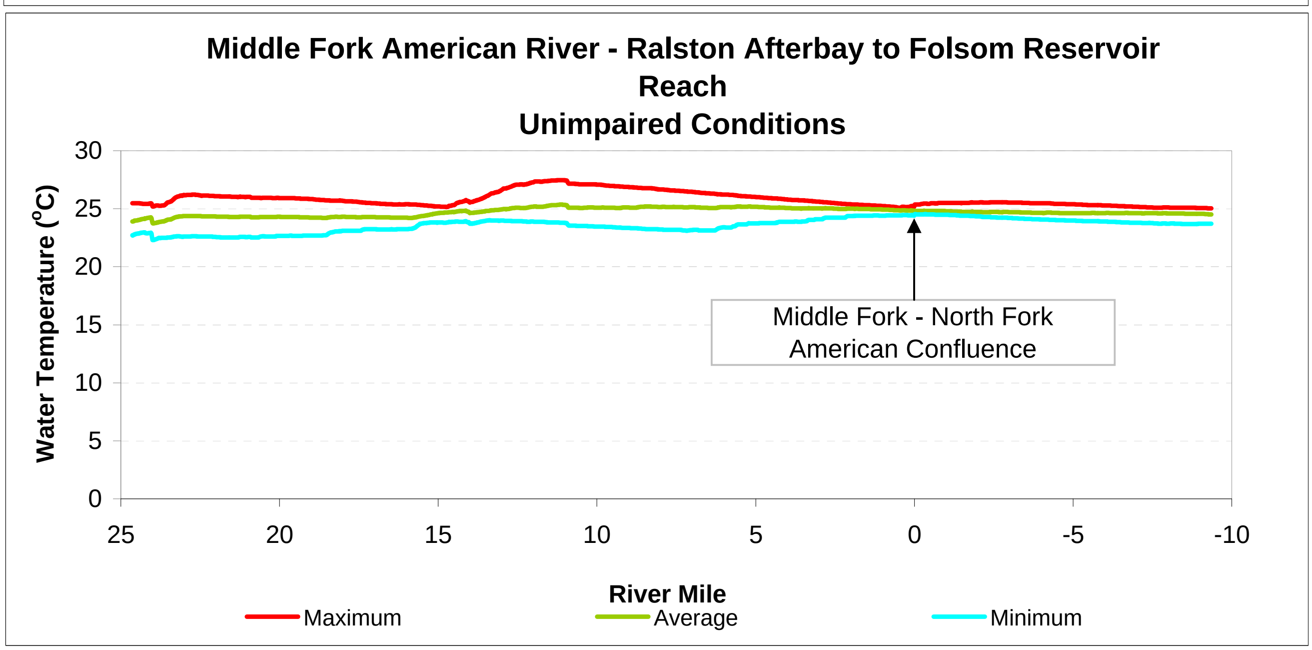

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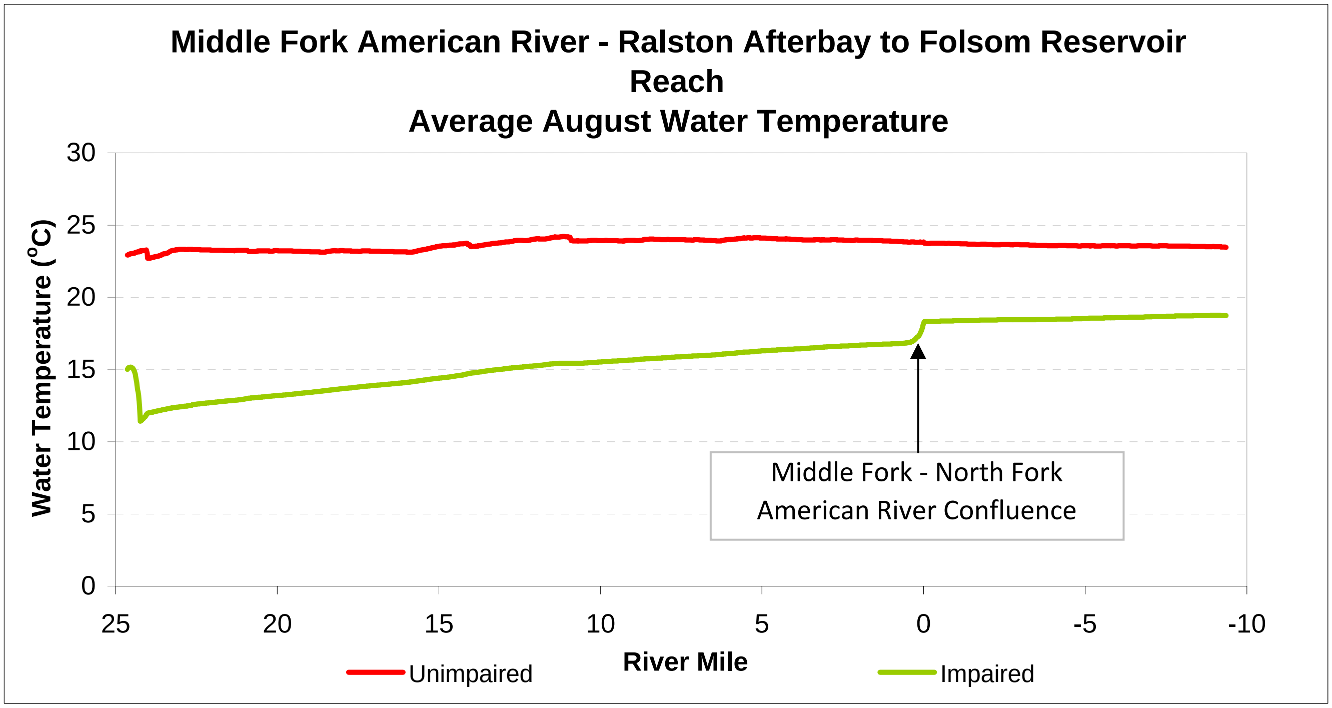

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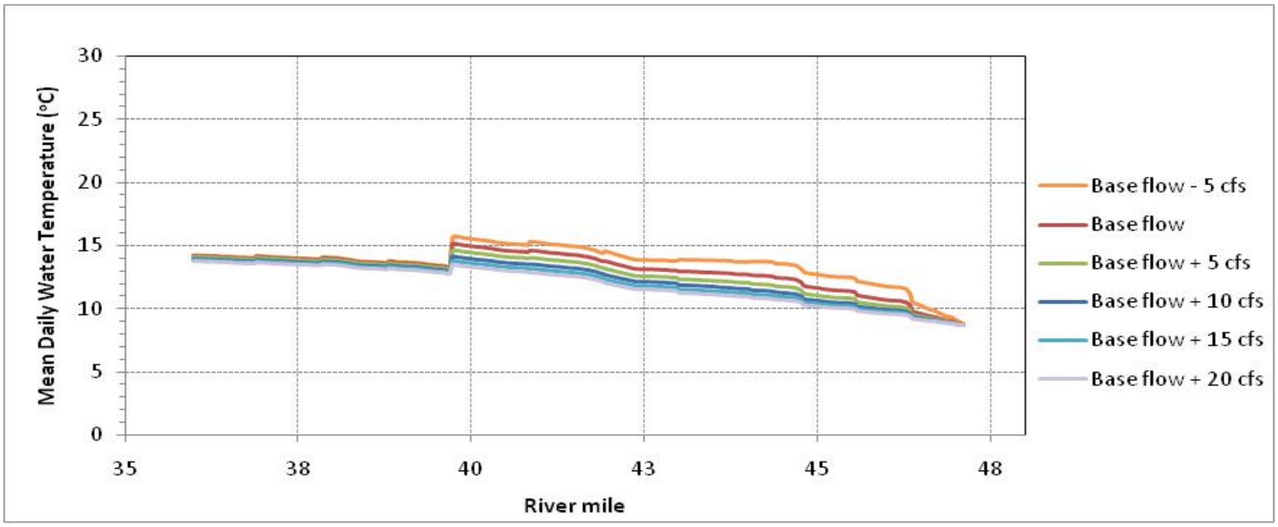

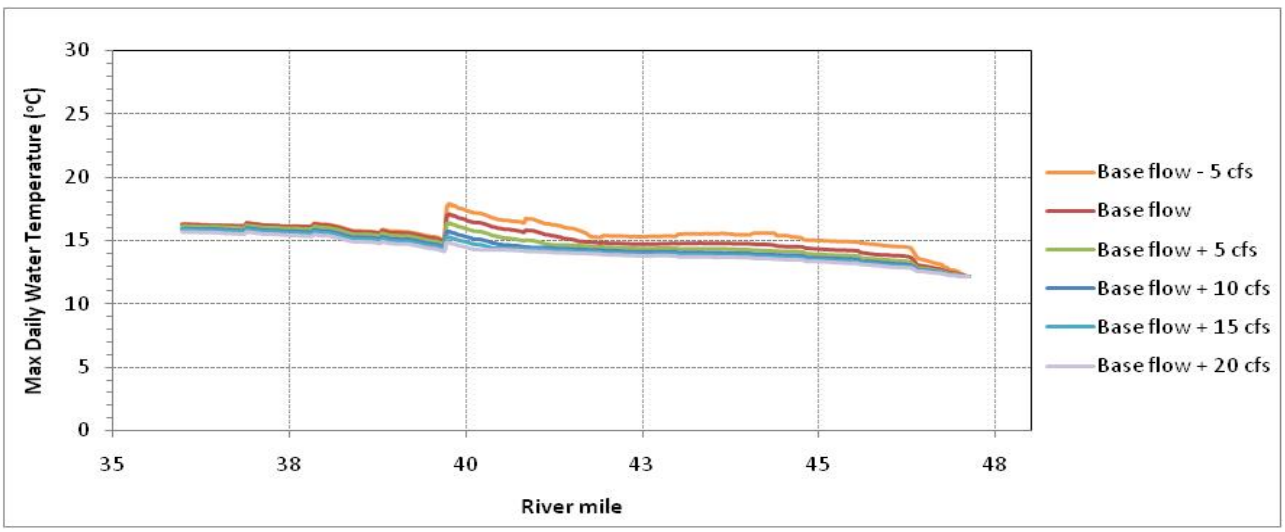

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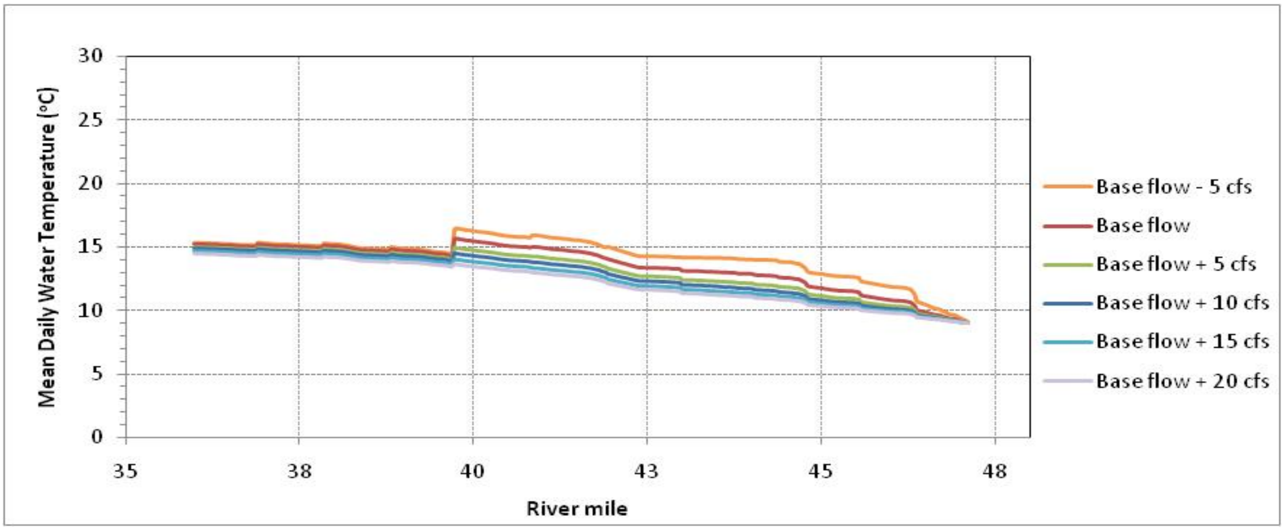

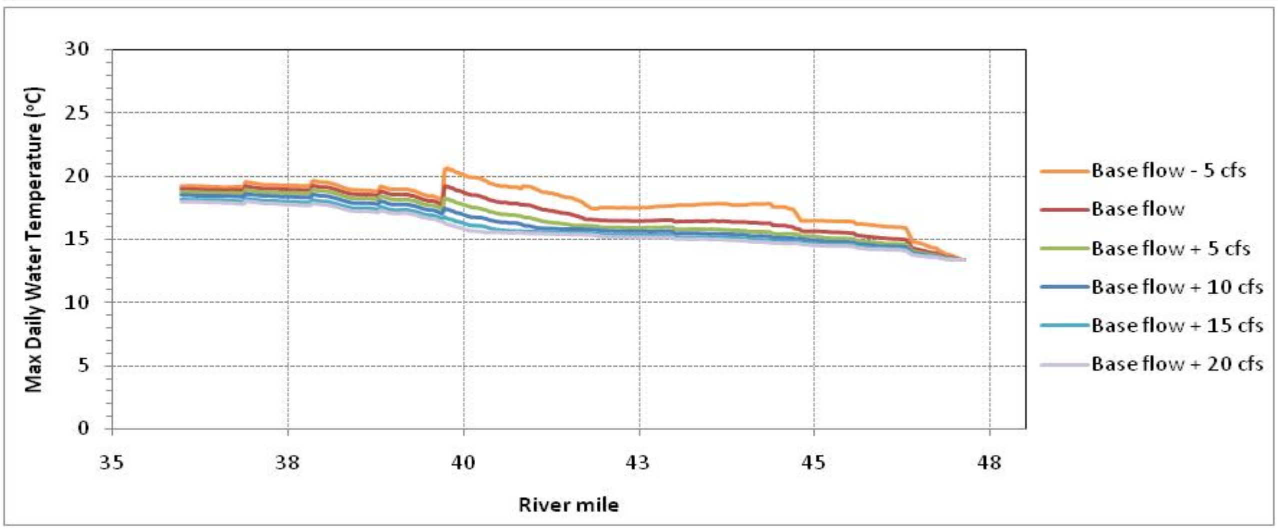

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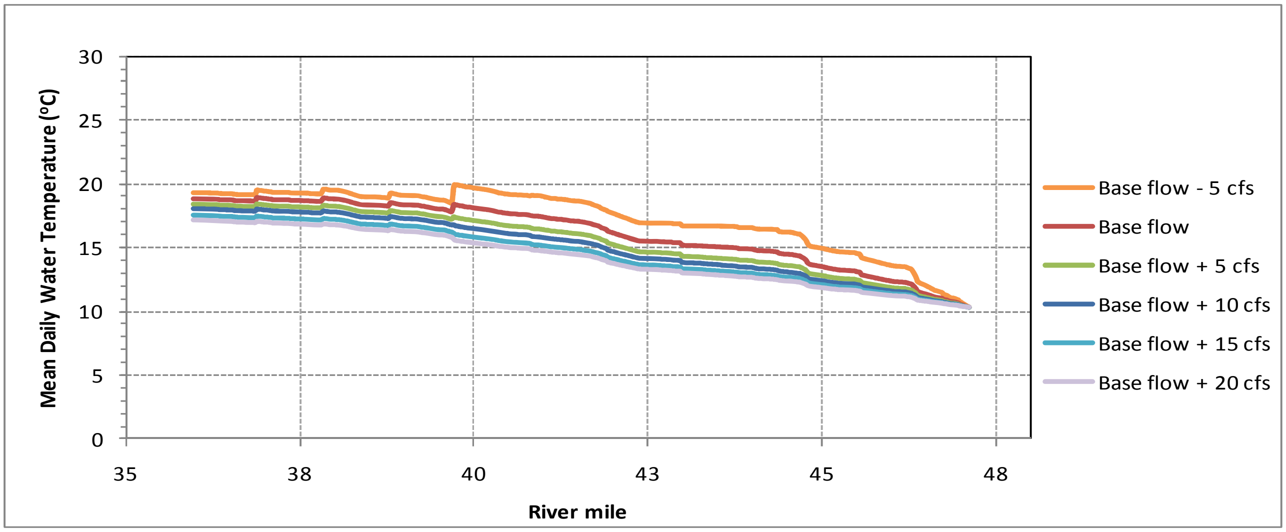

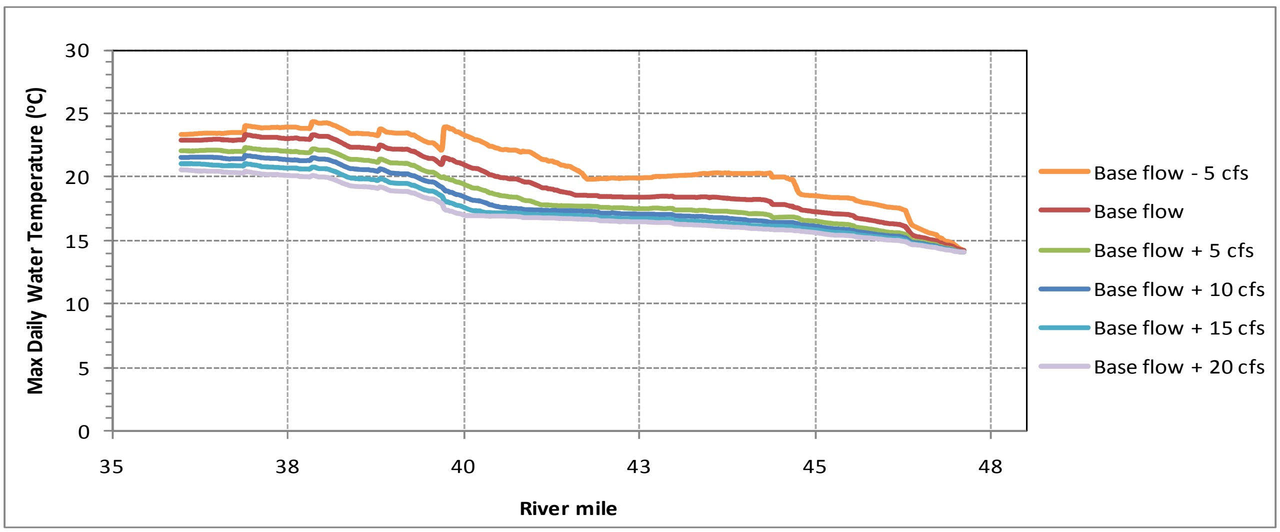

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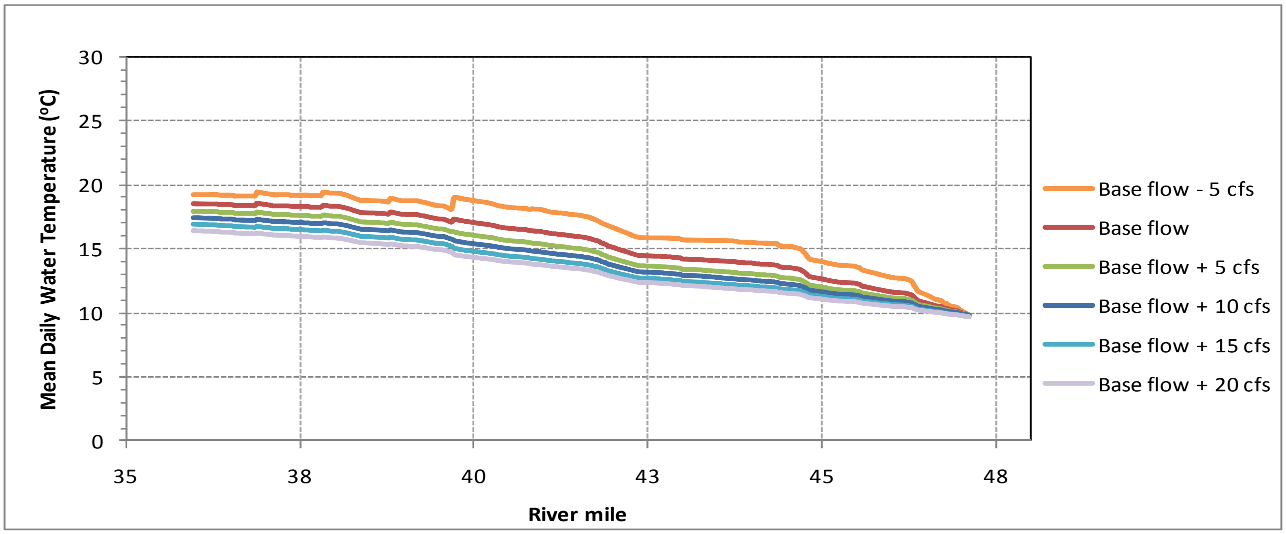

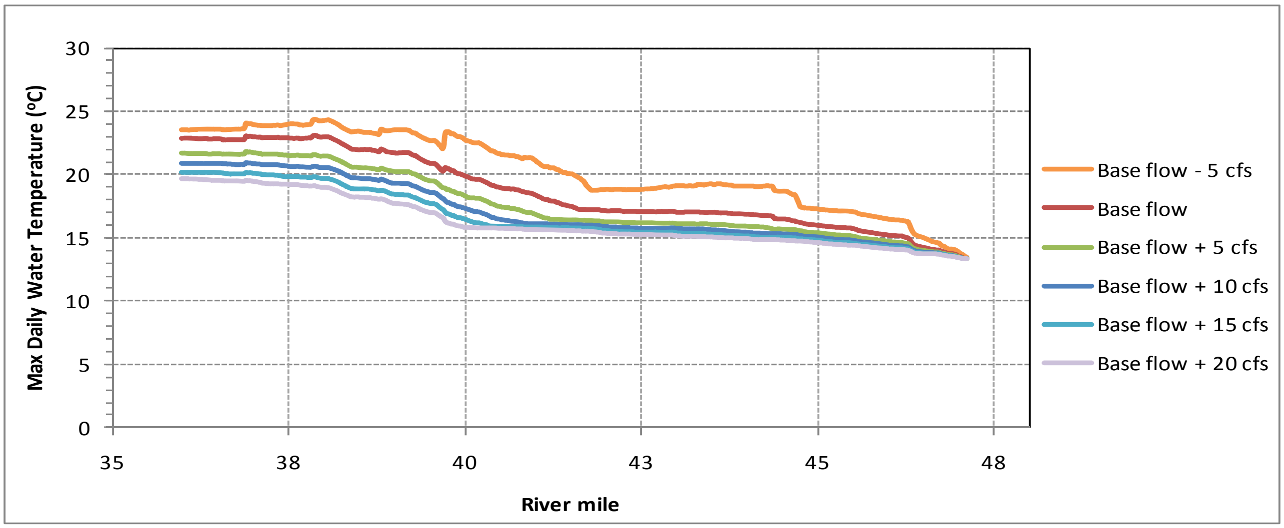

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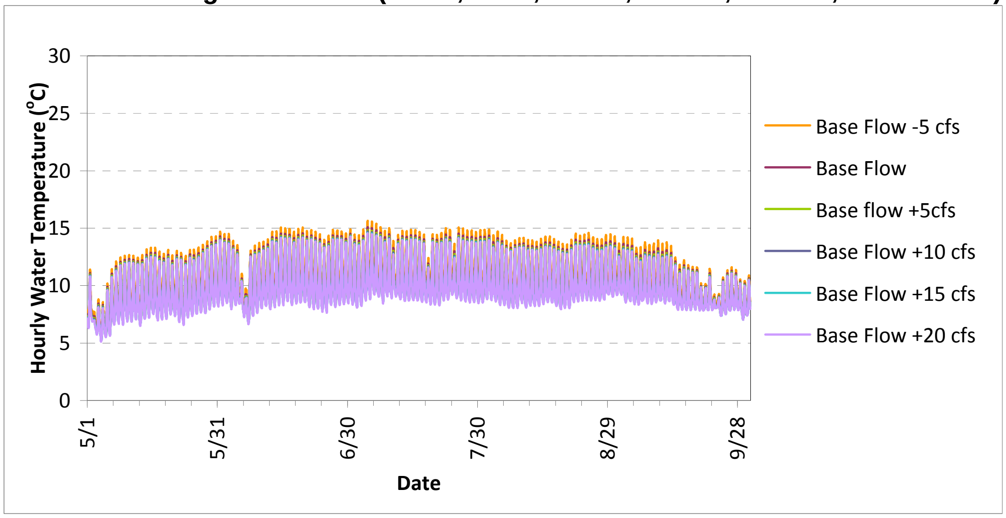

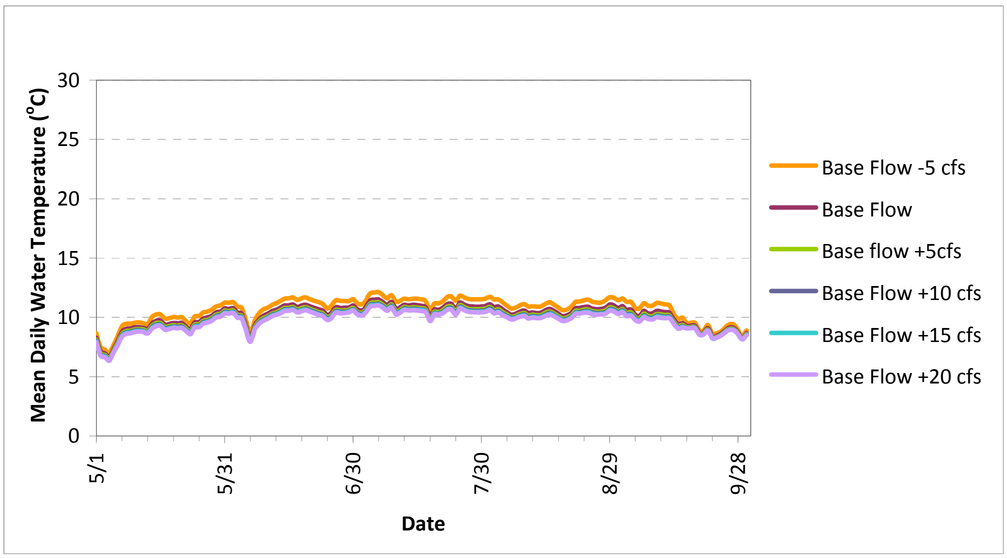

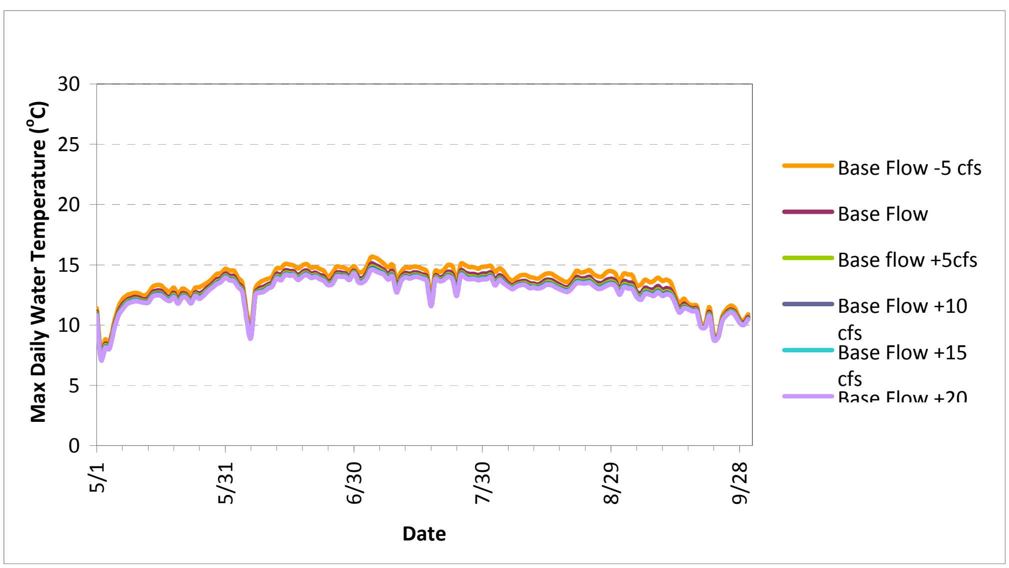

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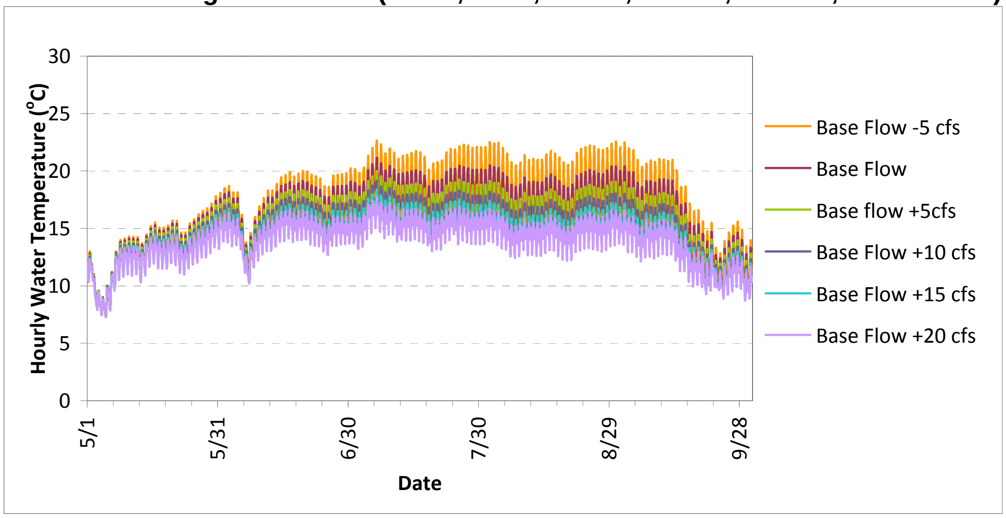

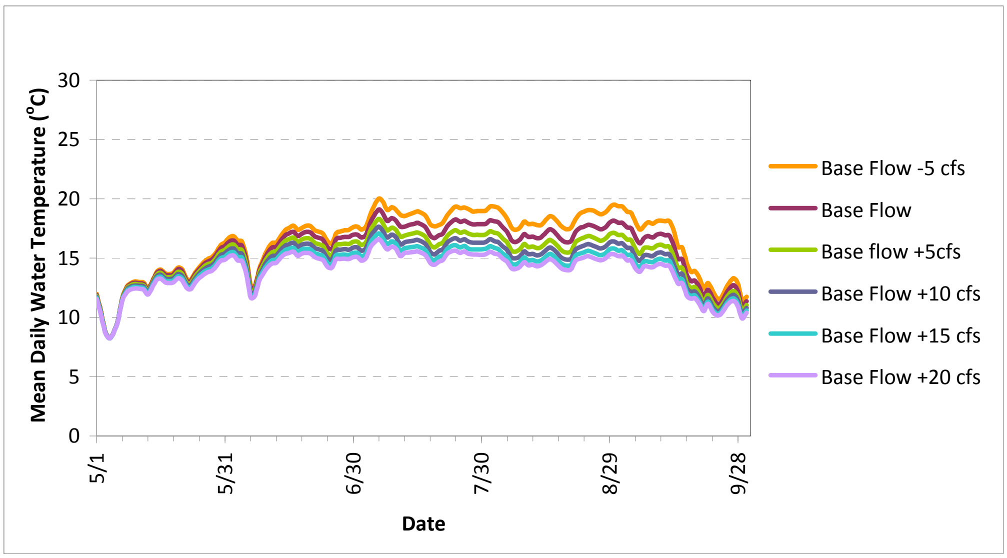

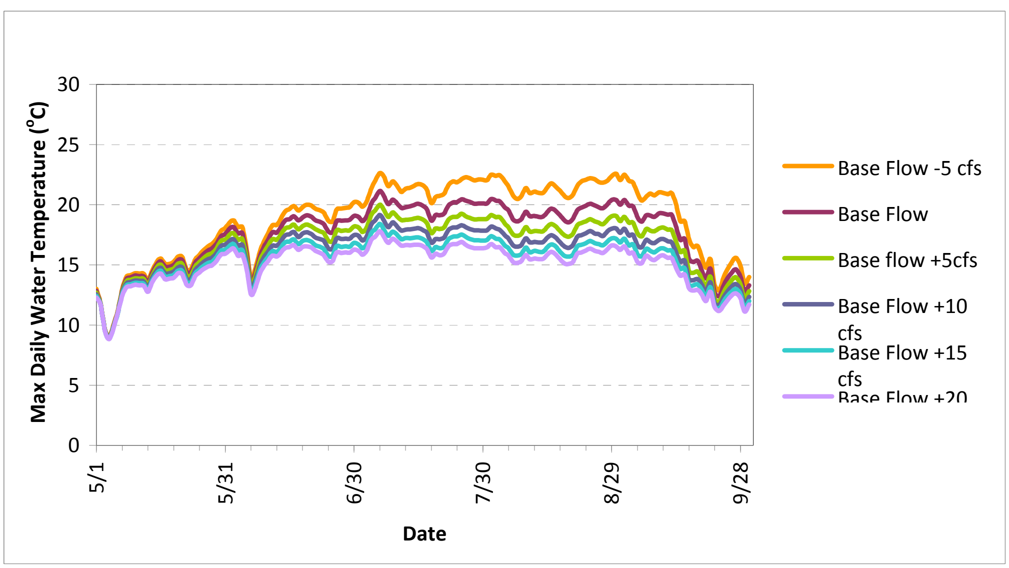

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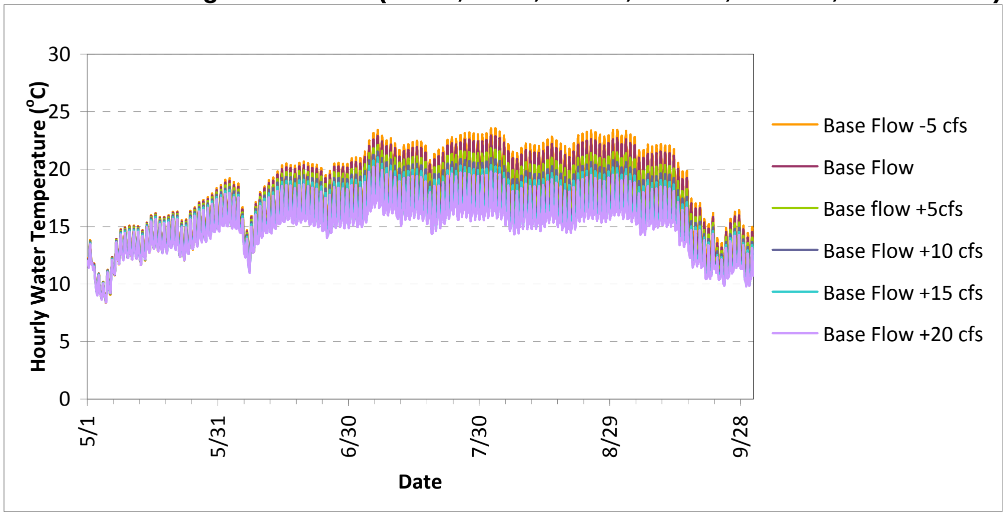

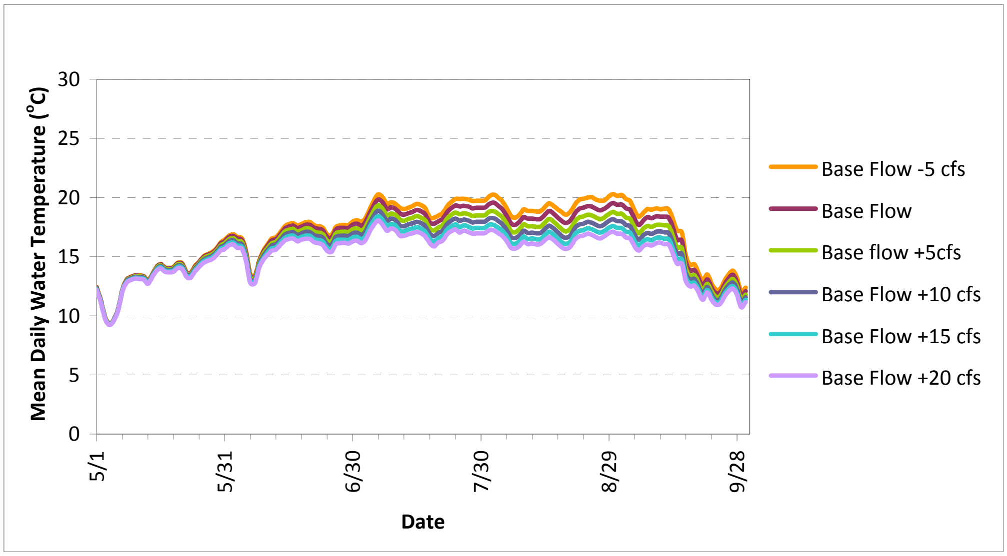

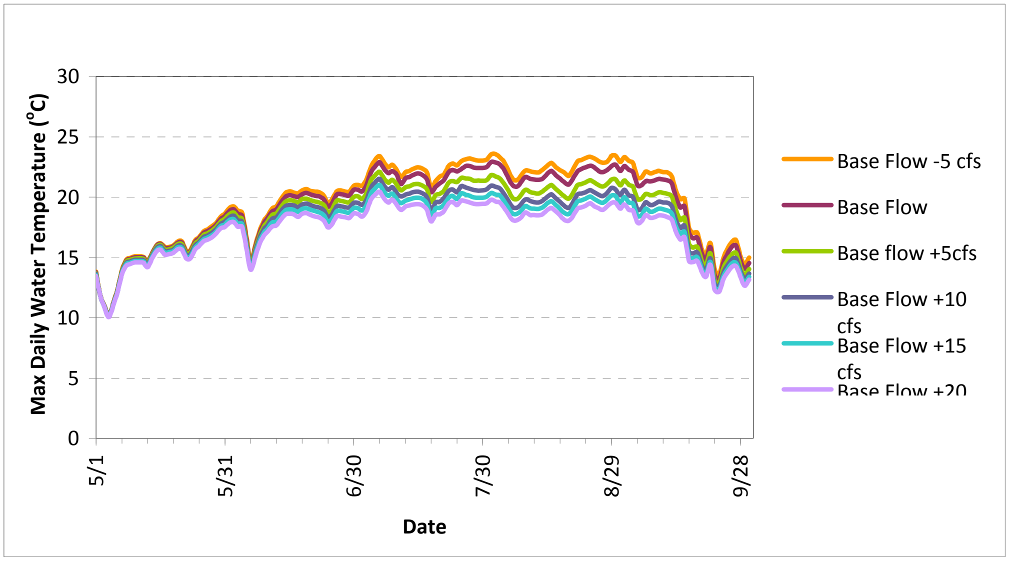

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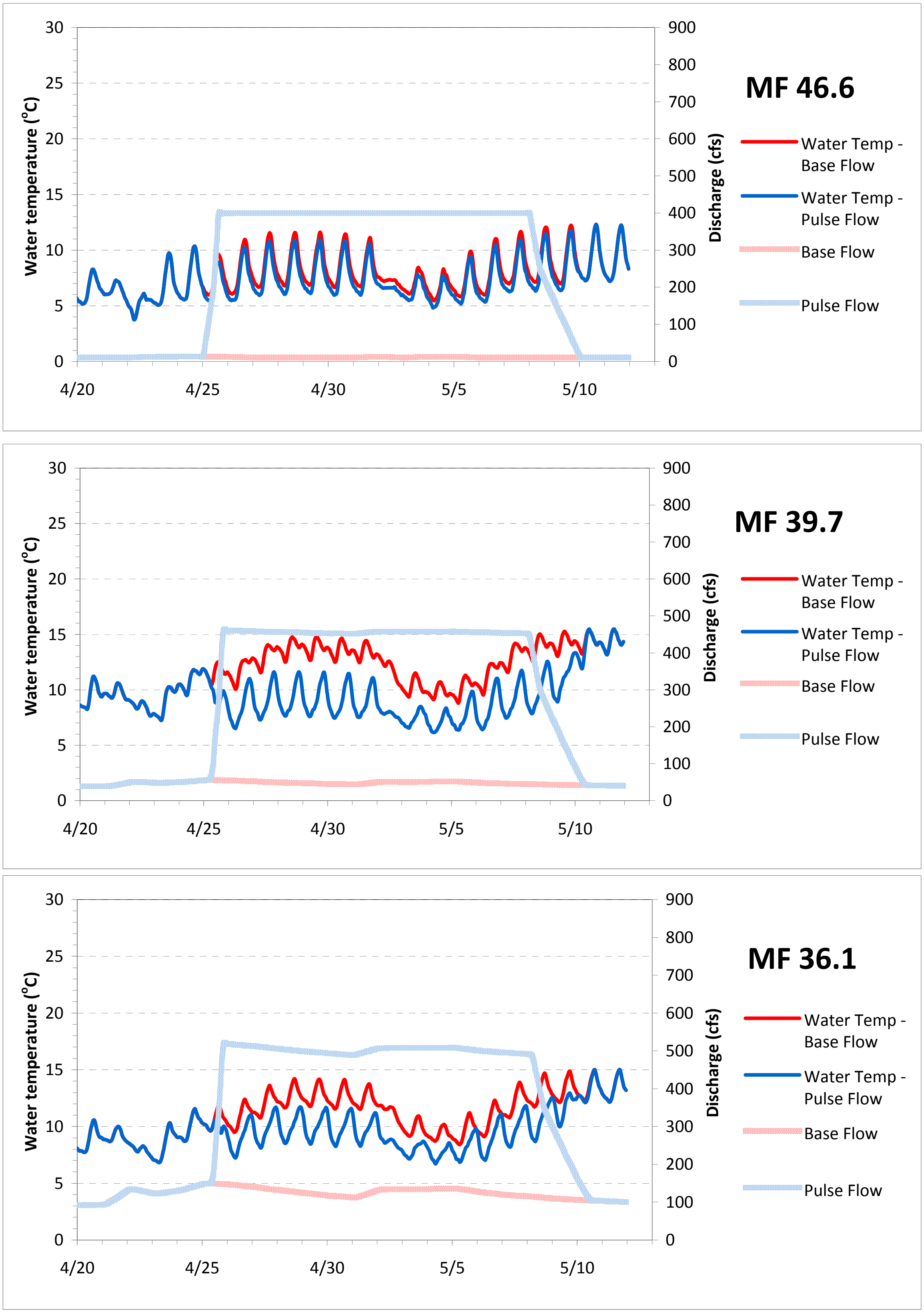

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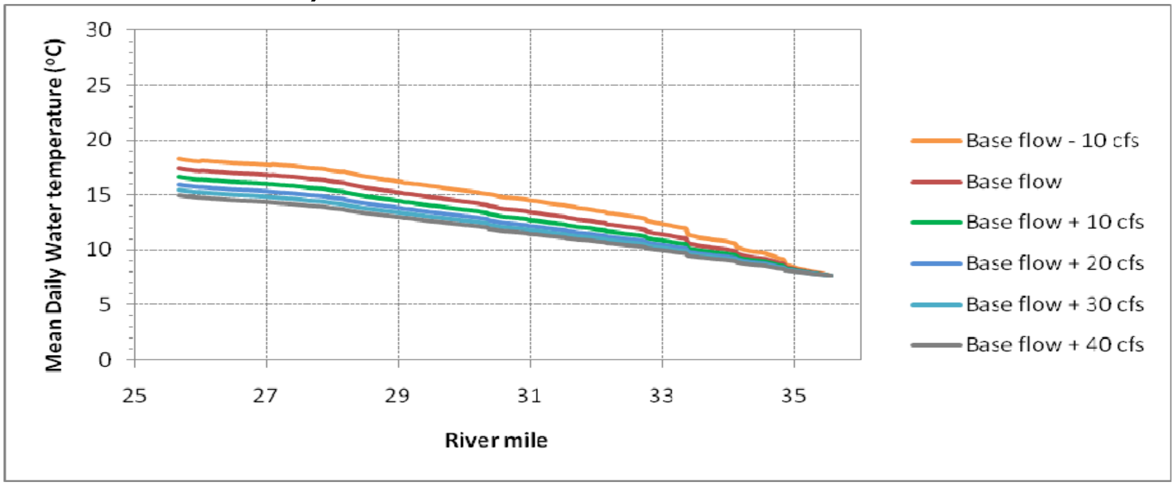

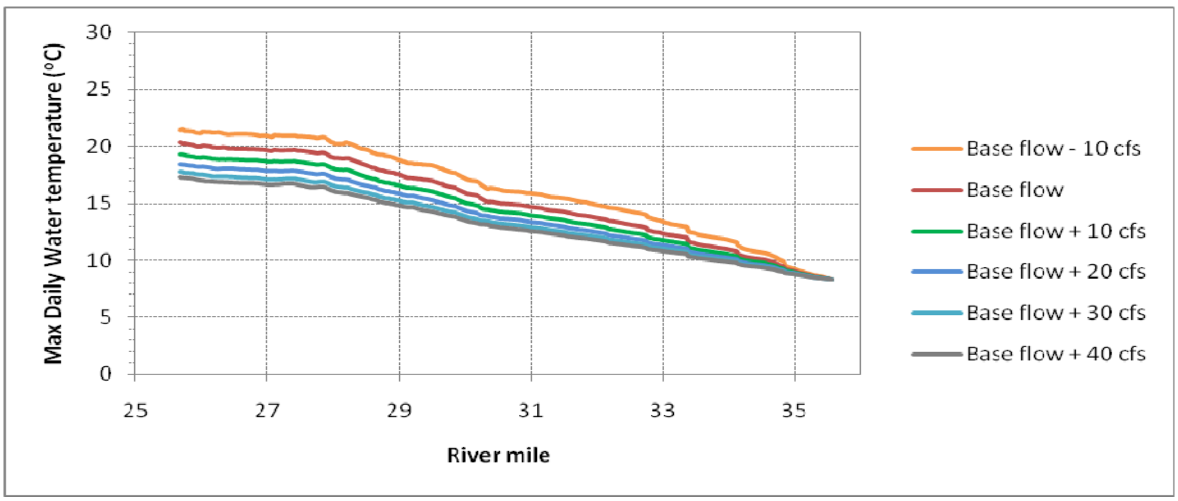

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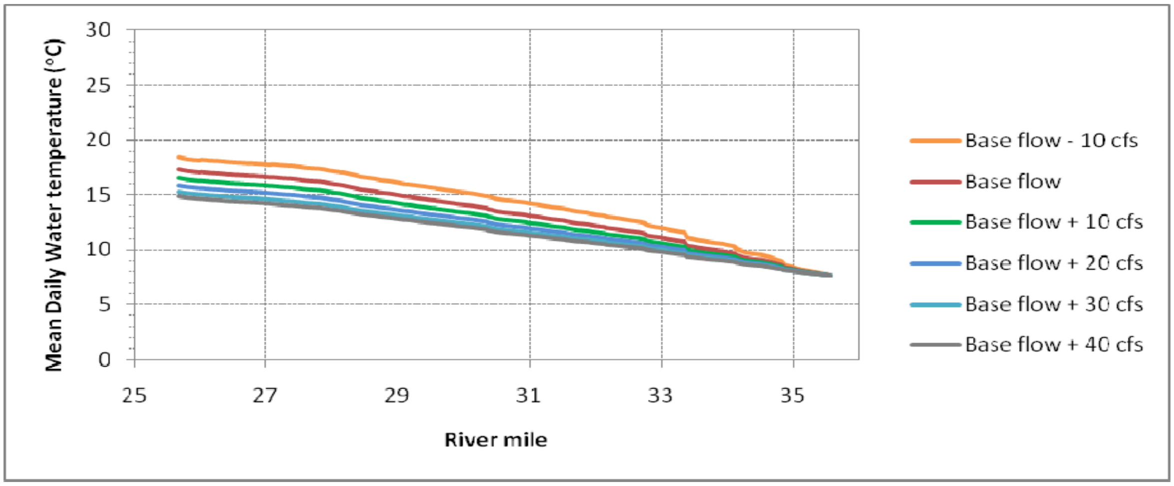

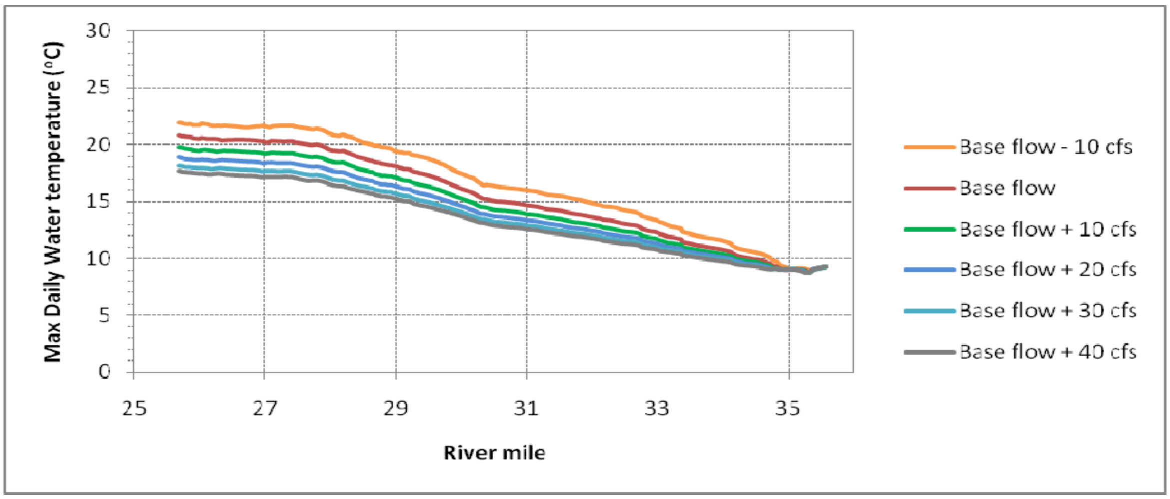

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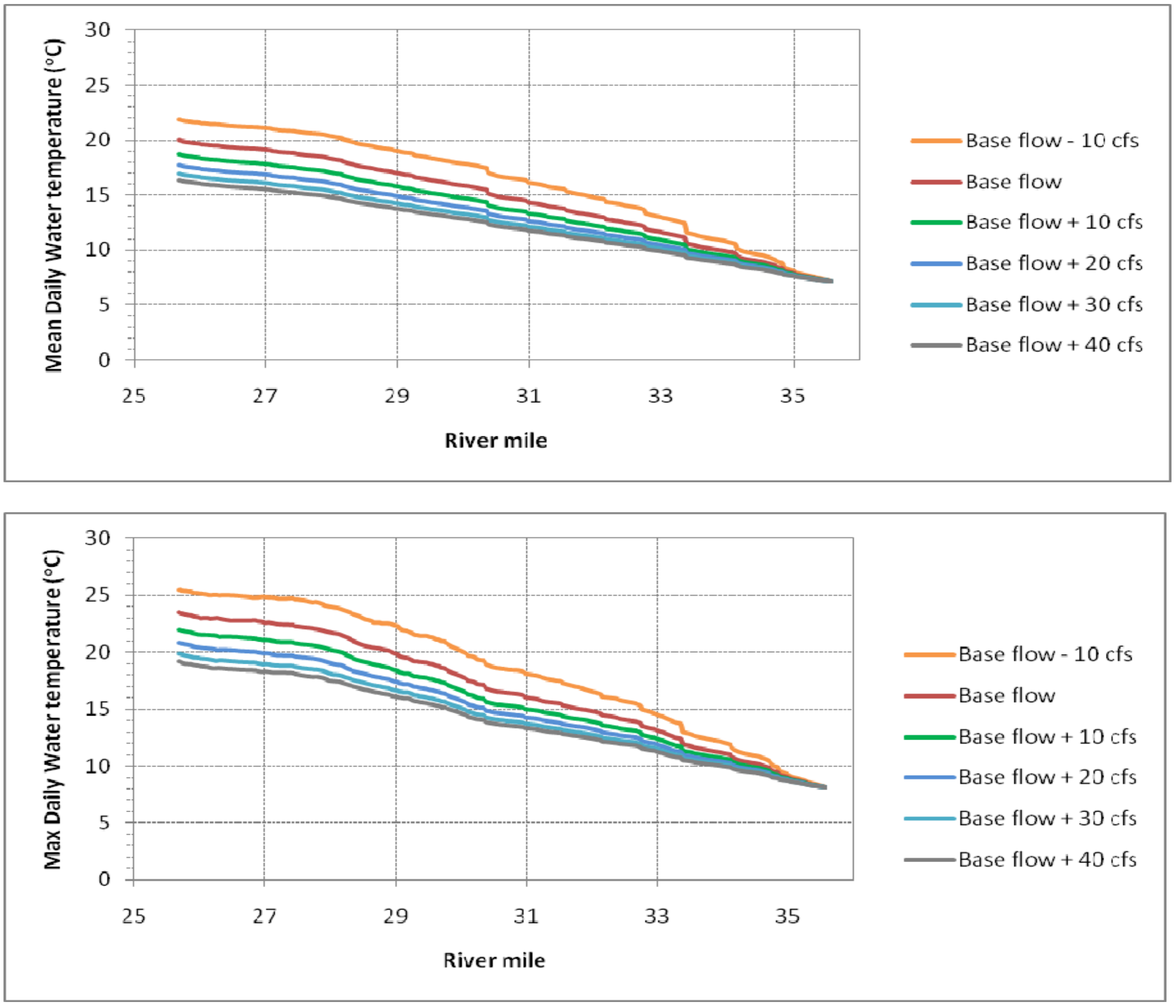

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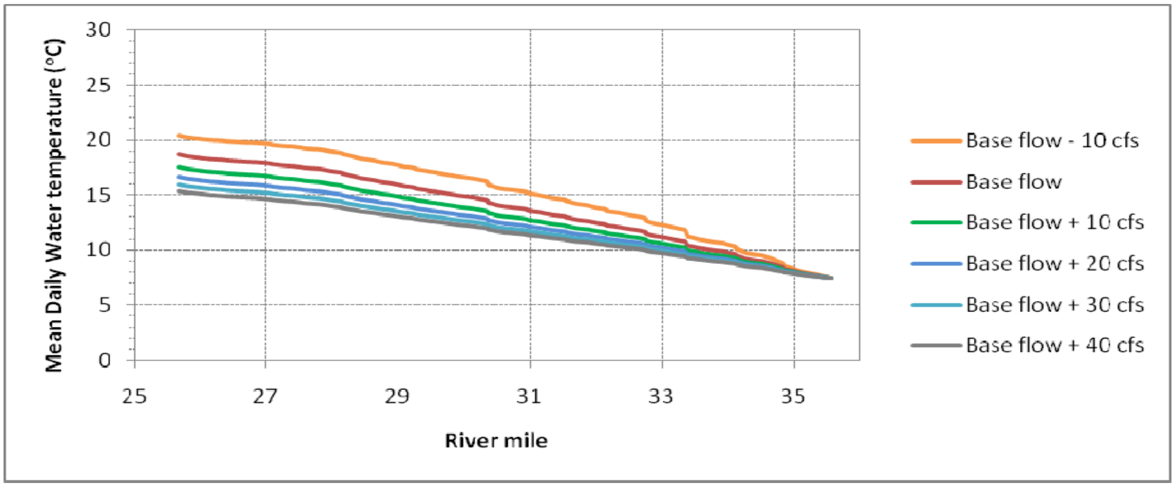

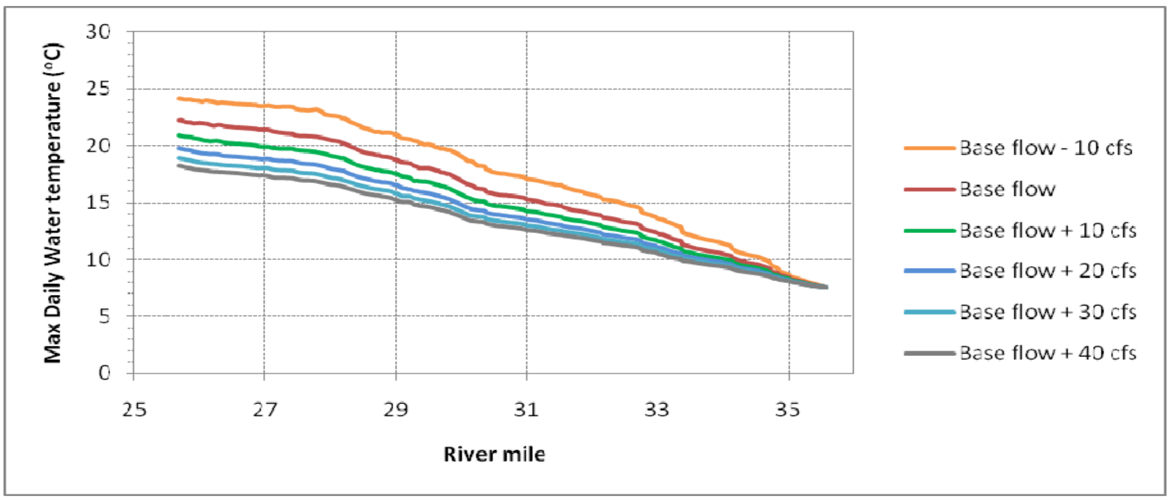

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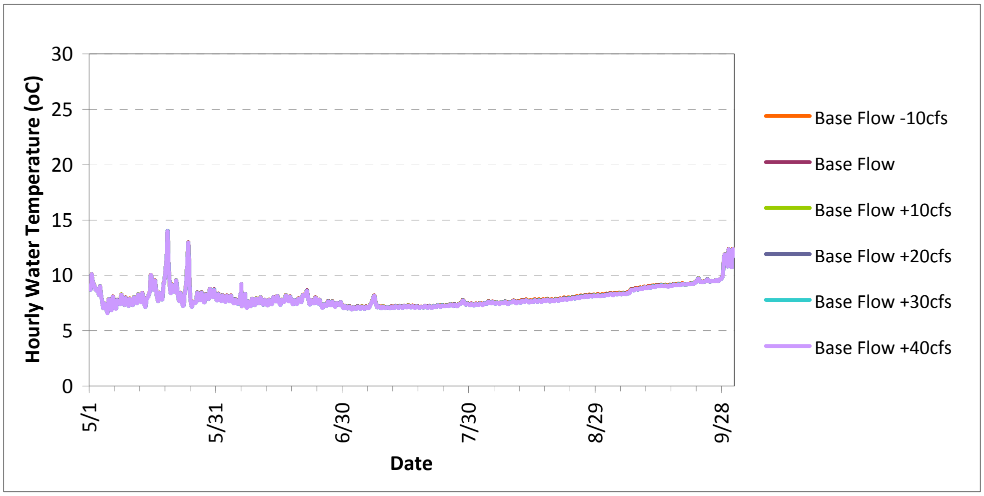

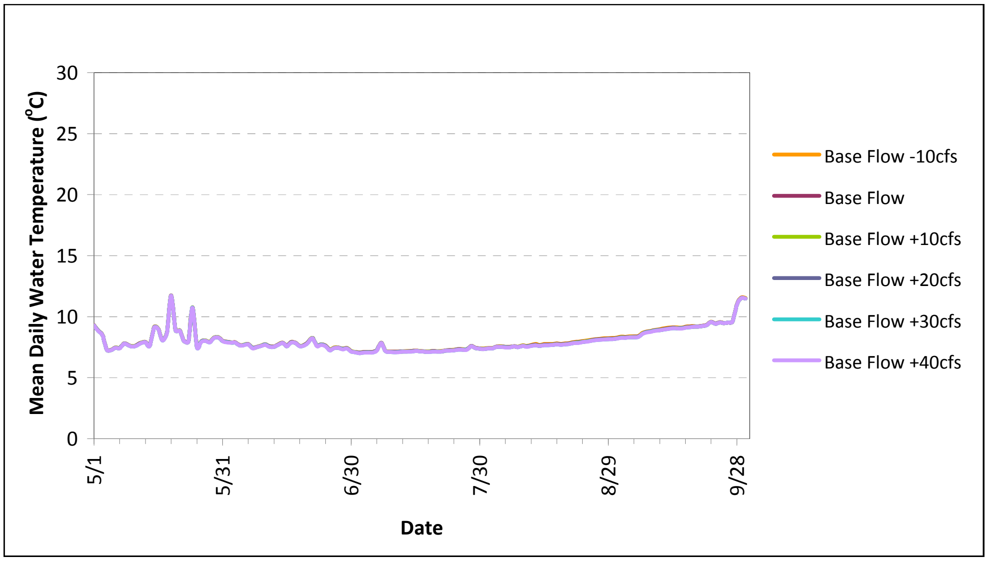

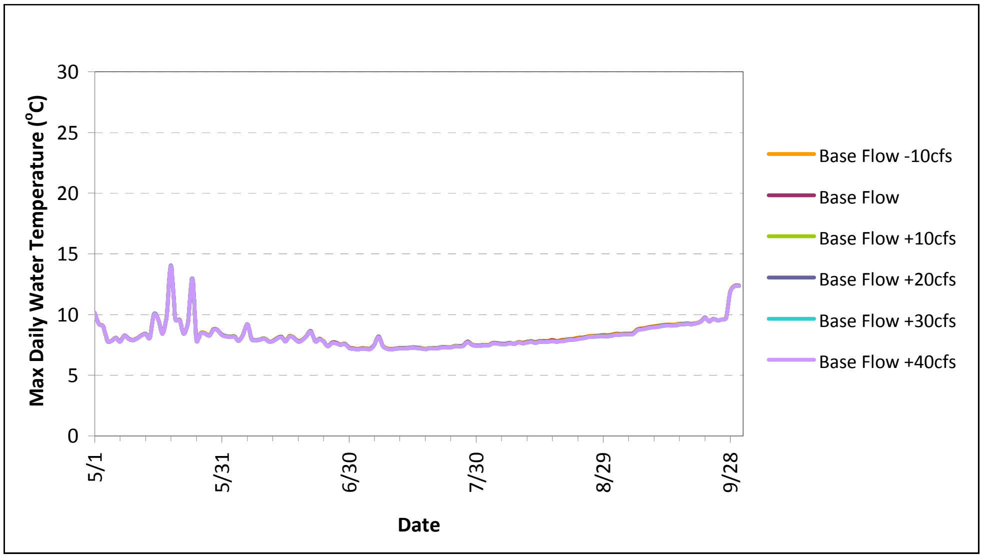

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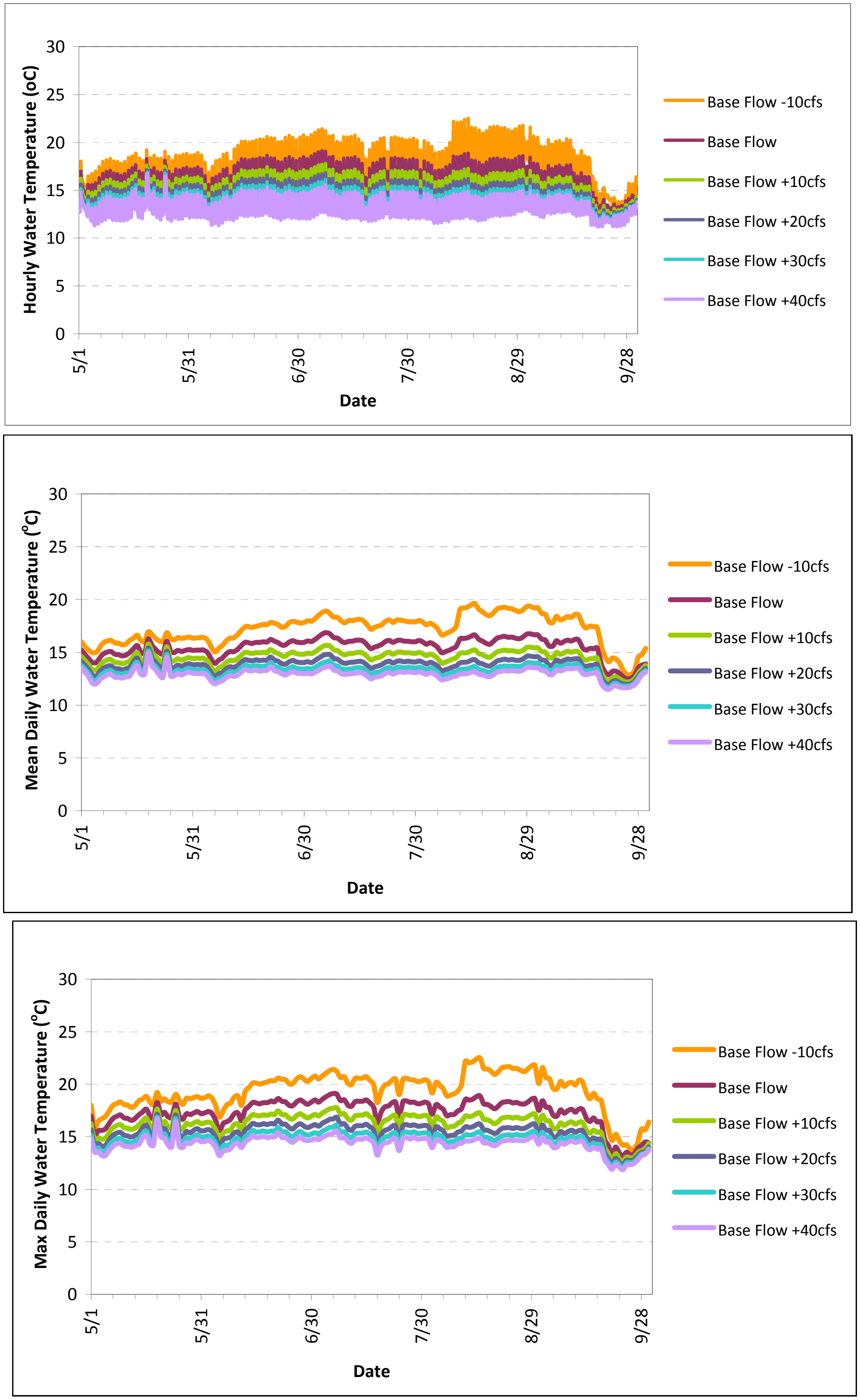

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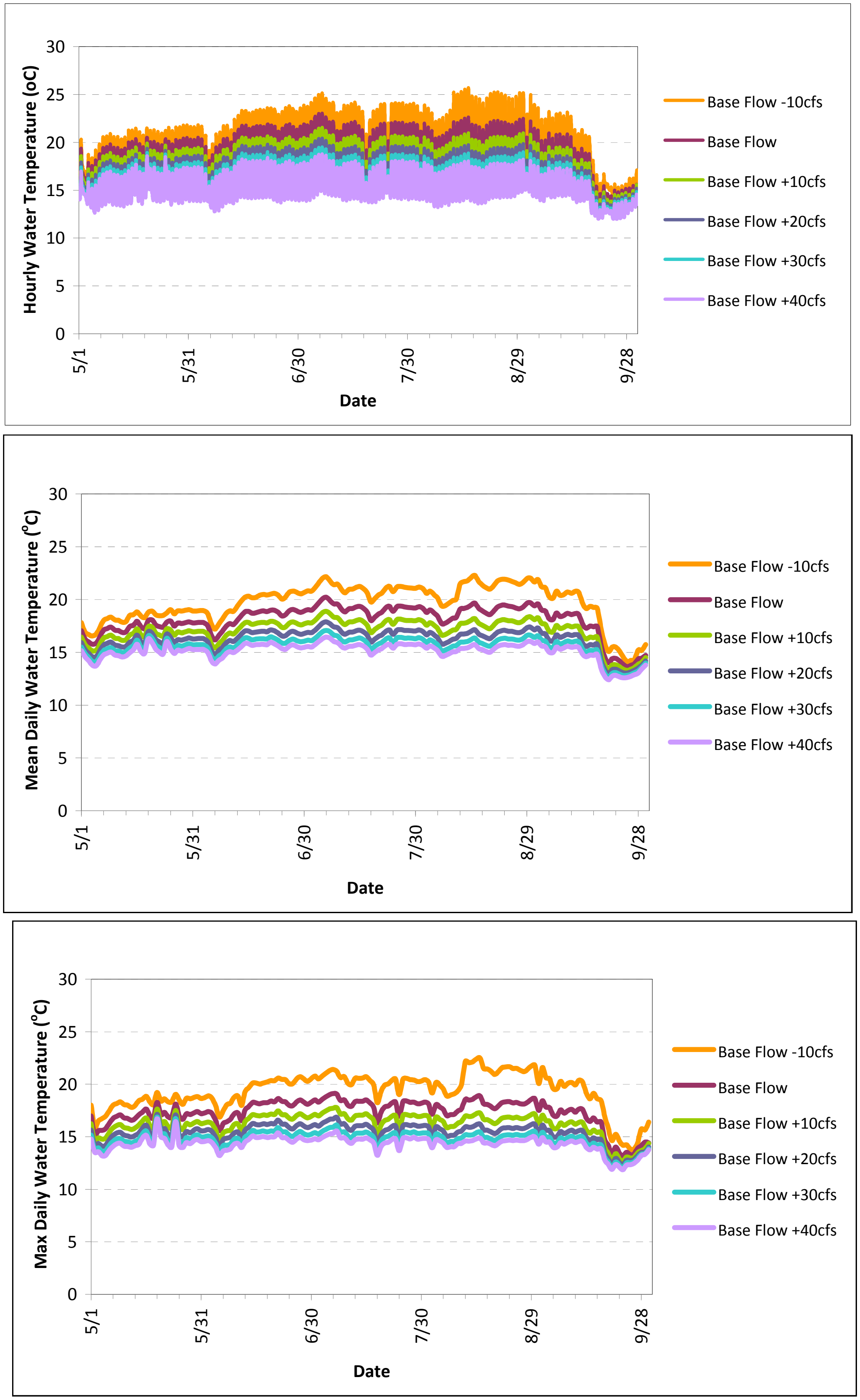

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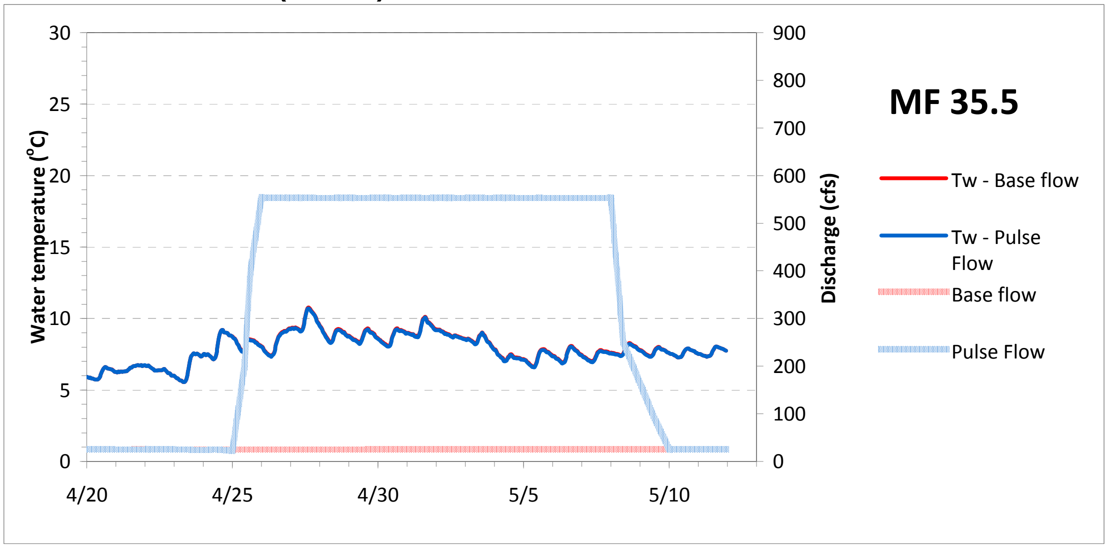

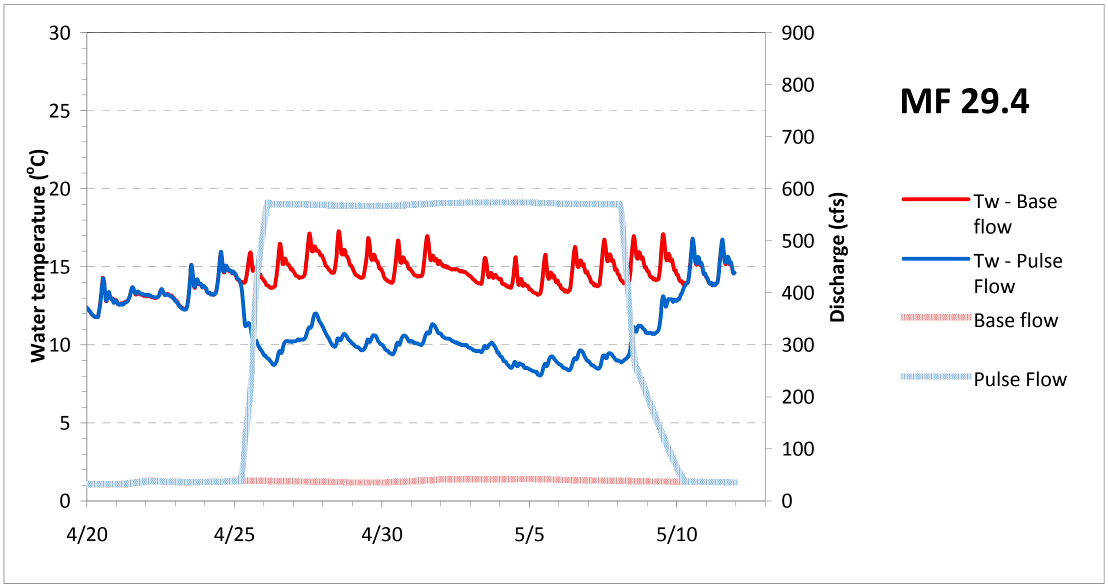

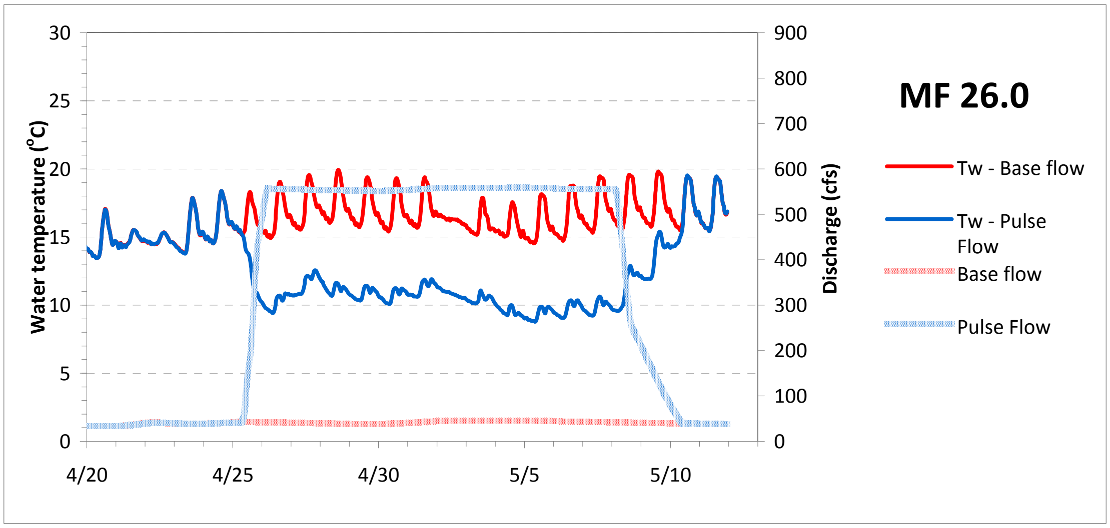

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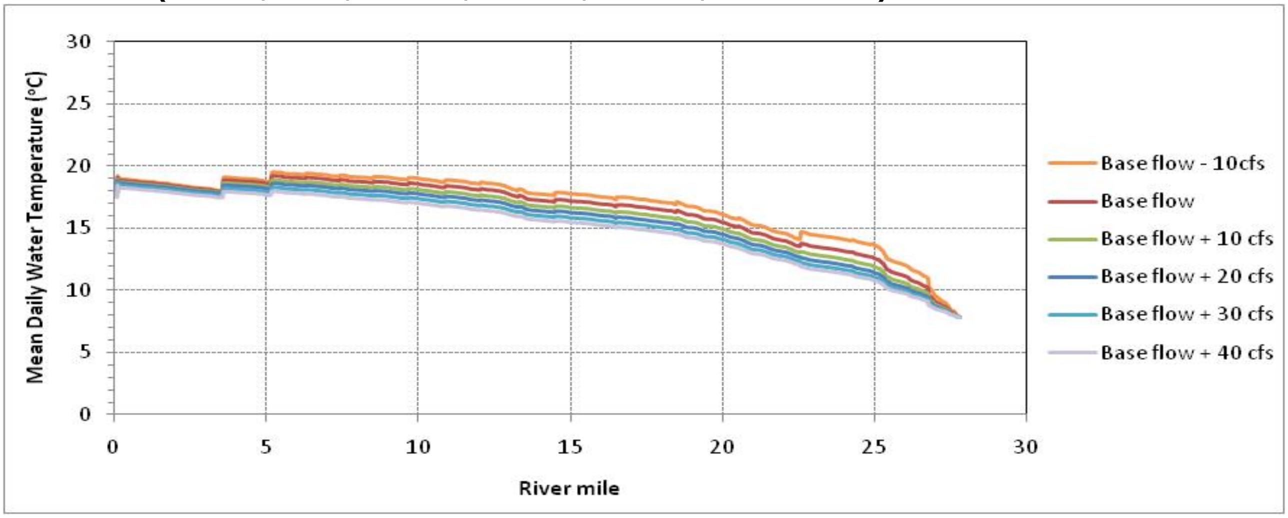

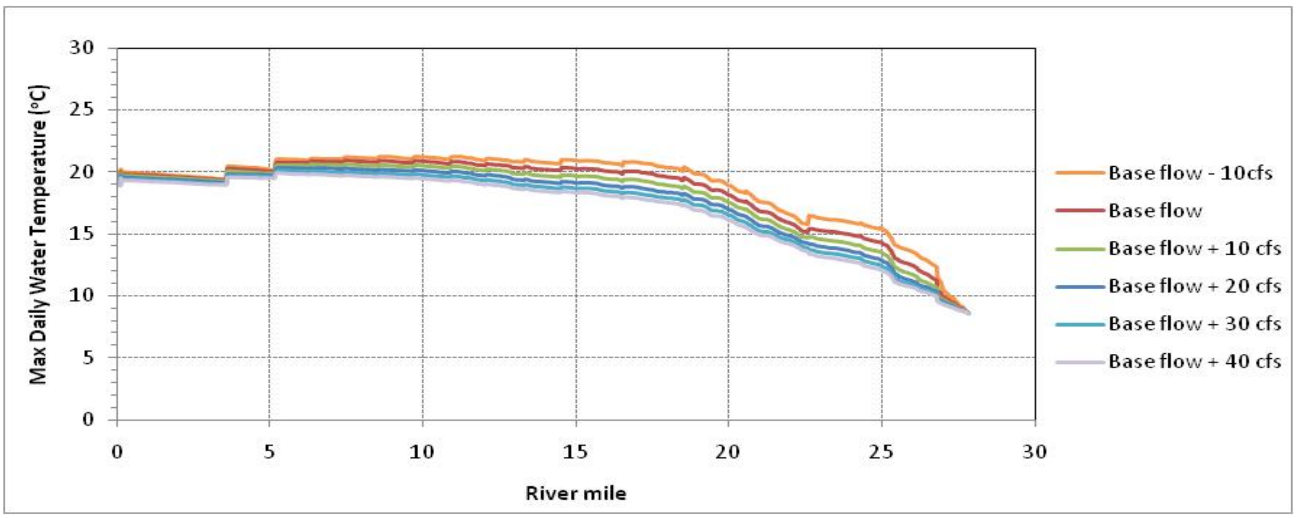

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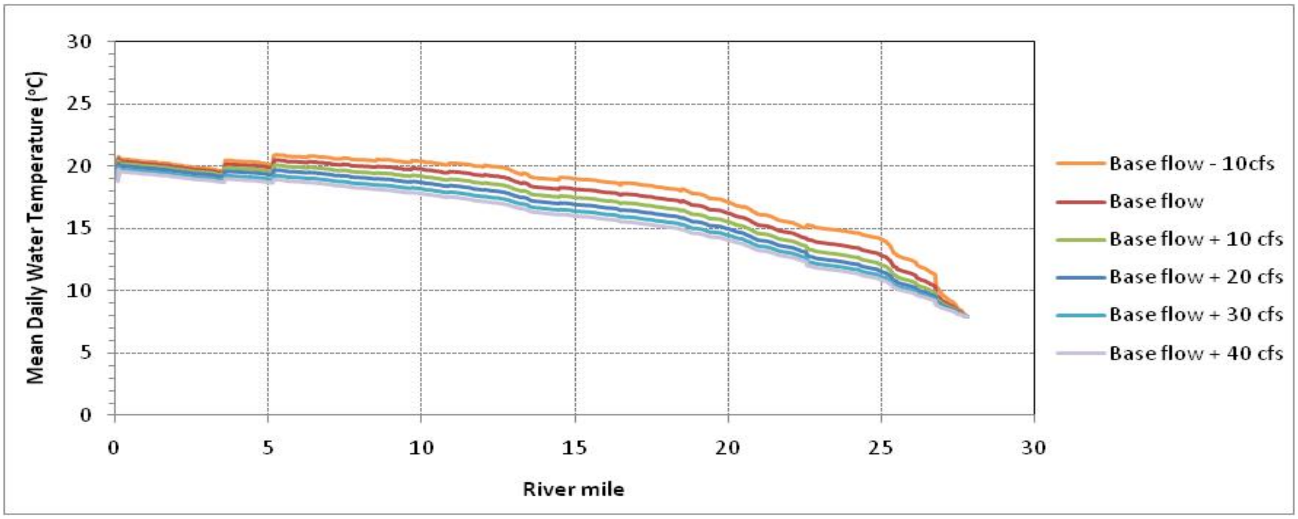

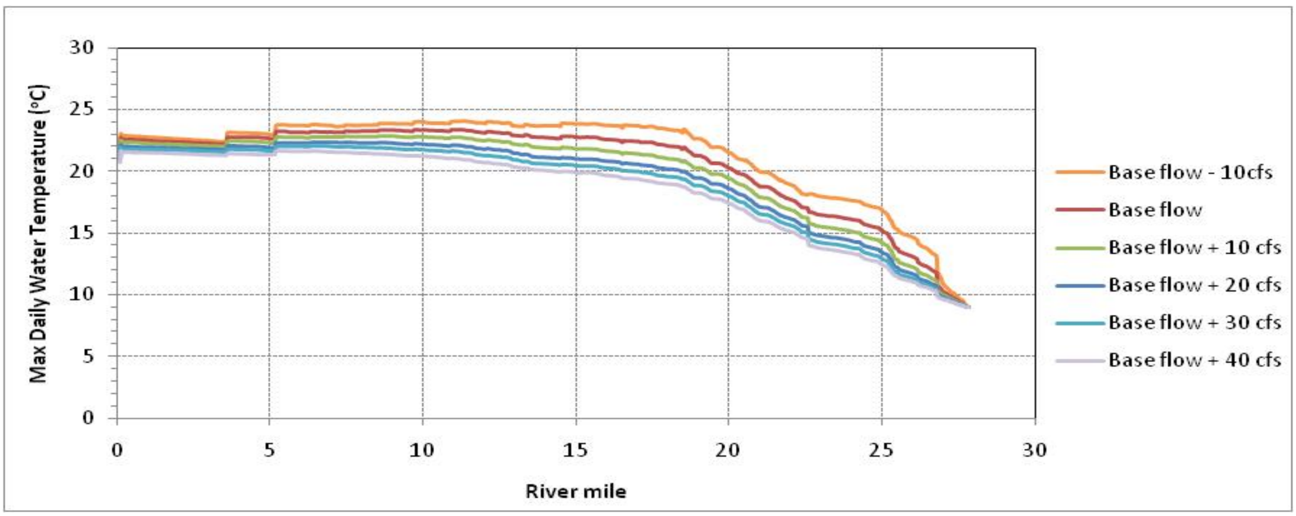

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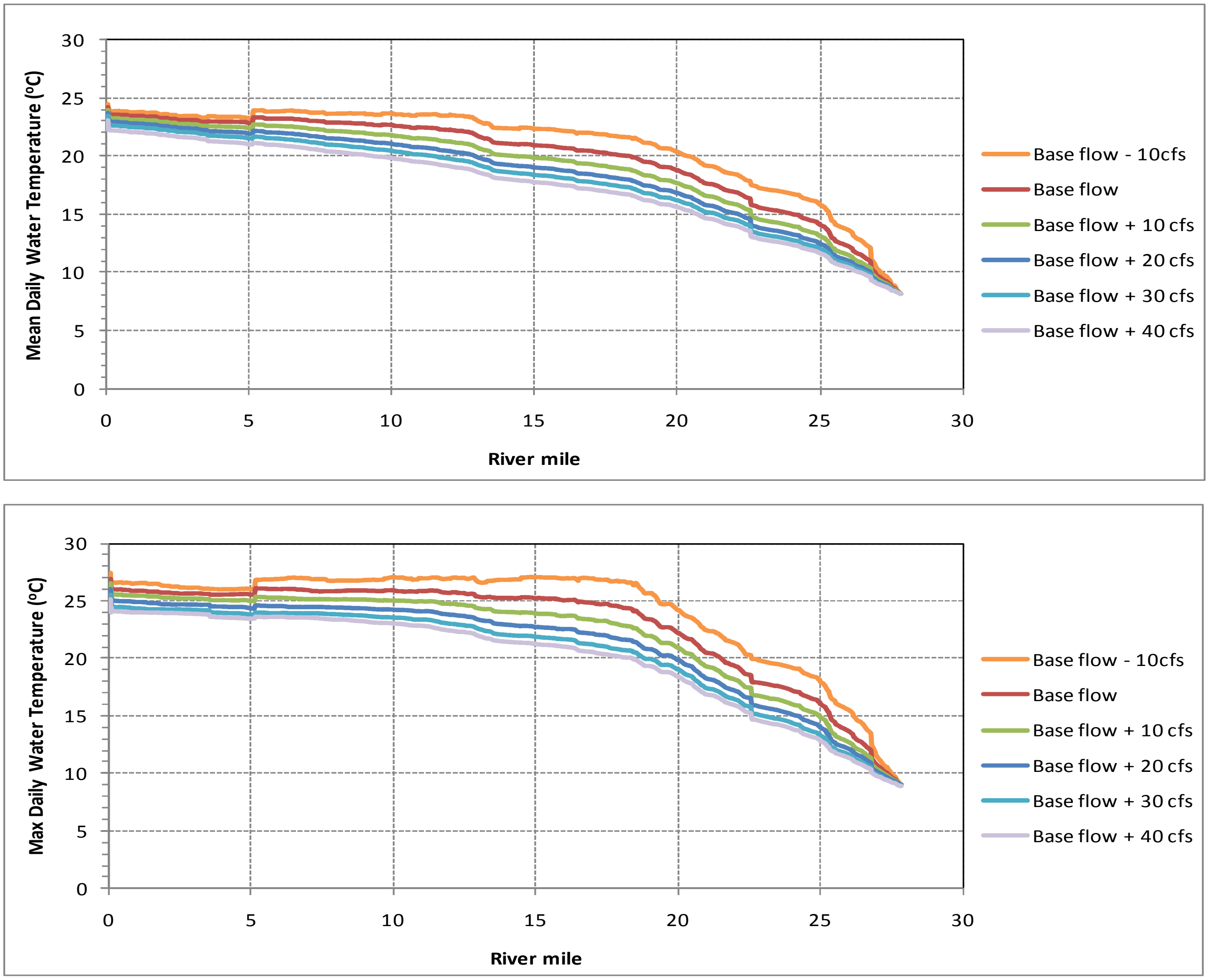

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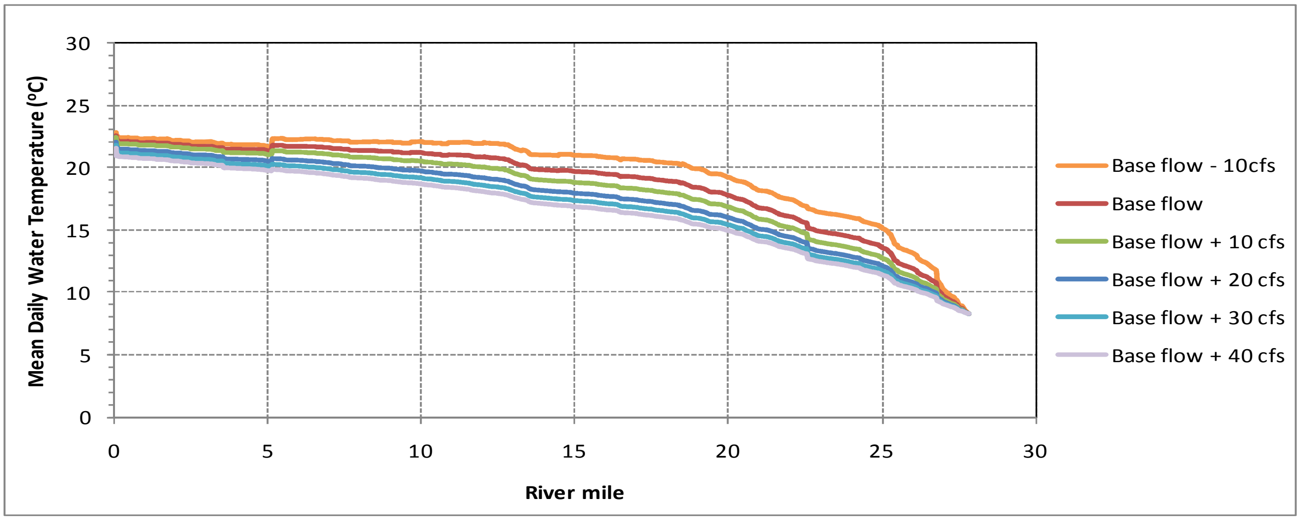


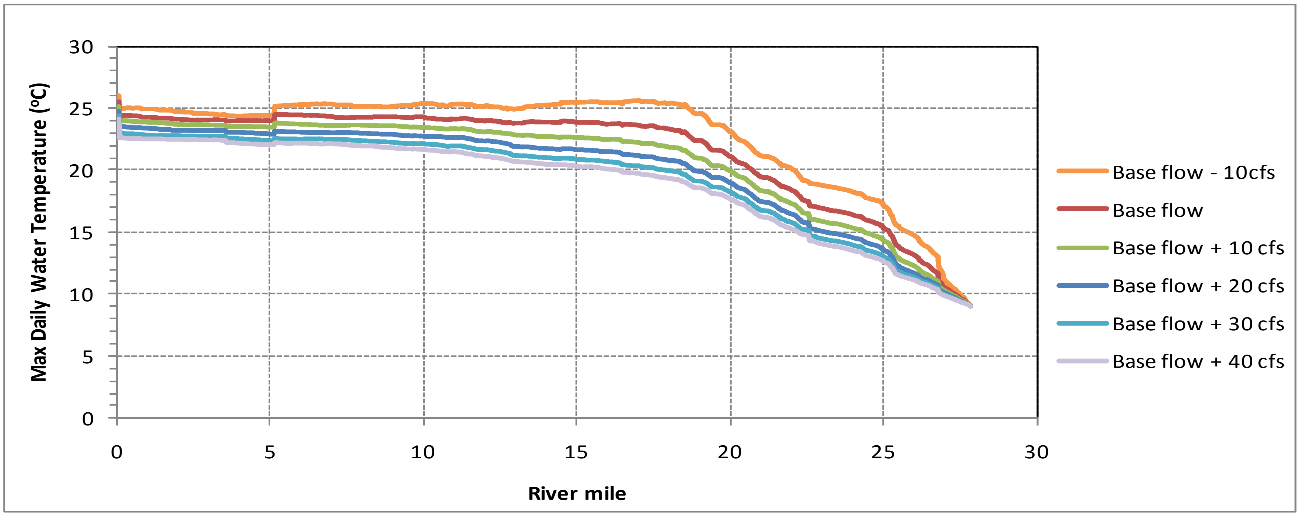
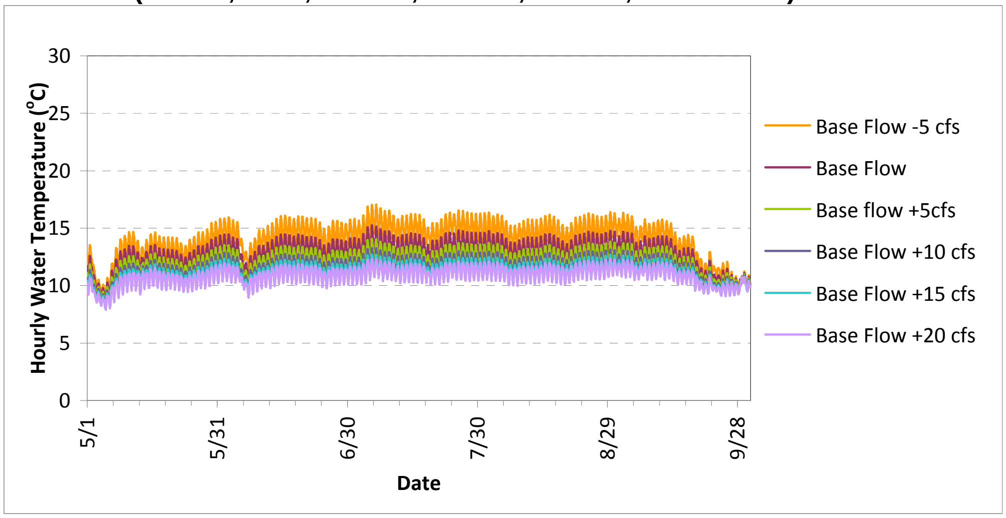
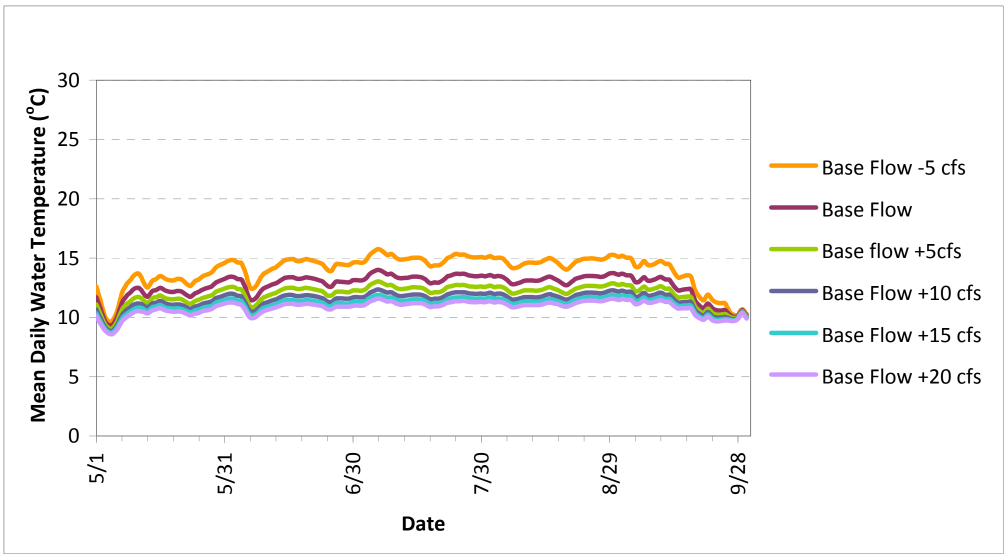


Figure H-21. Rubicon River at River Mile 25.3 Modeled Hourly (Top) Mean Daily (Middle) and Maximum Daily (Bottom) Water Temperature for Various Discharge Scenarios (-10 cfs, 0 cfs, +10 cfs, +20 cfs, +30 cfs, and +40 cfs).





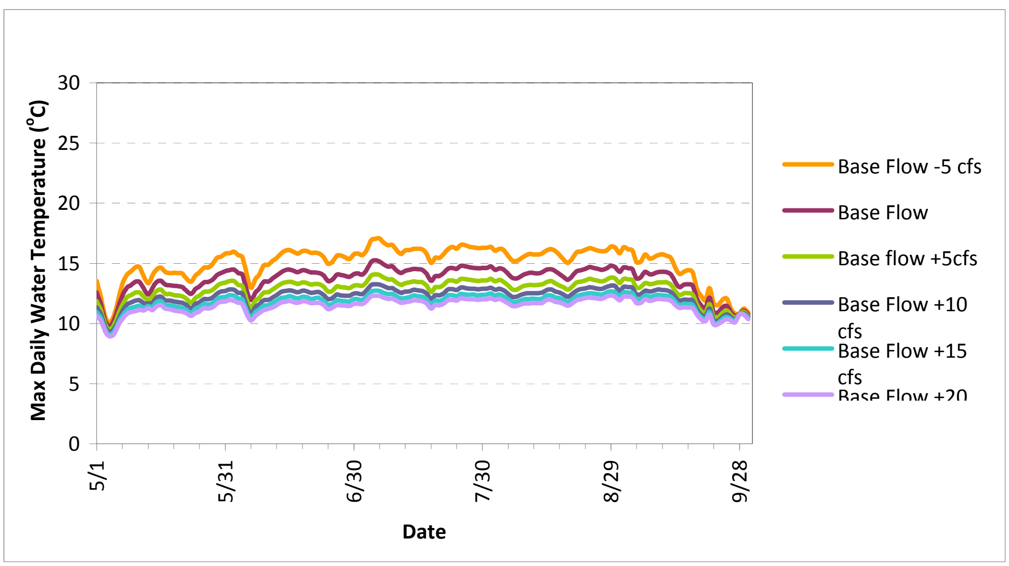
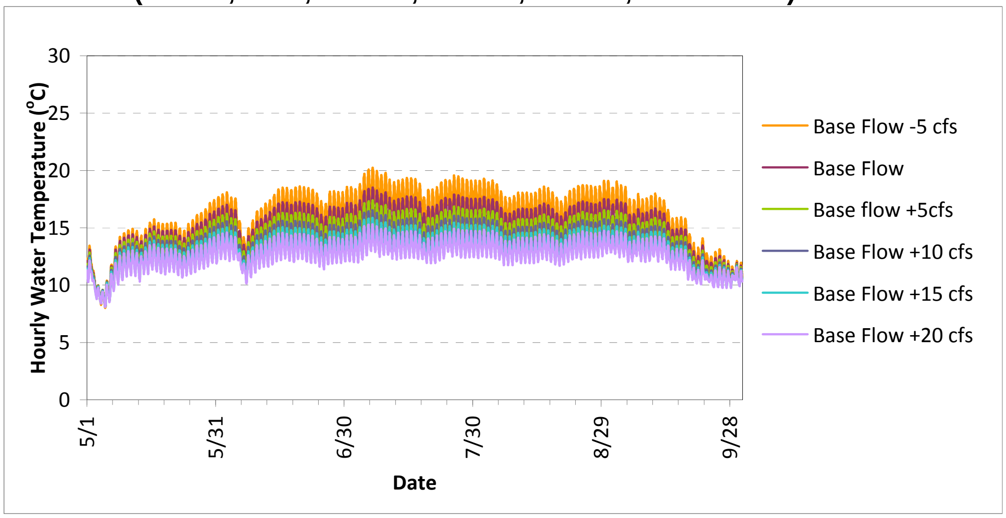
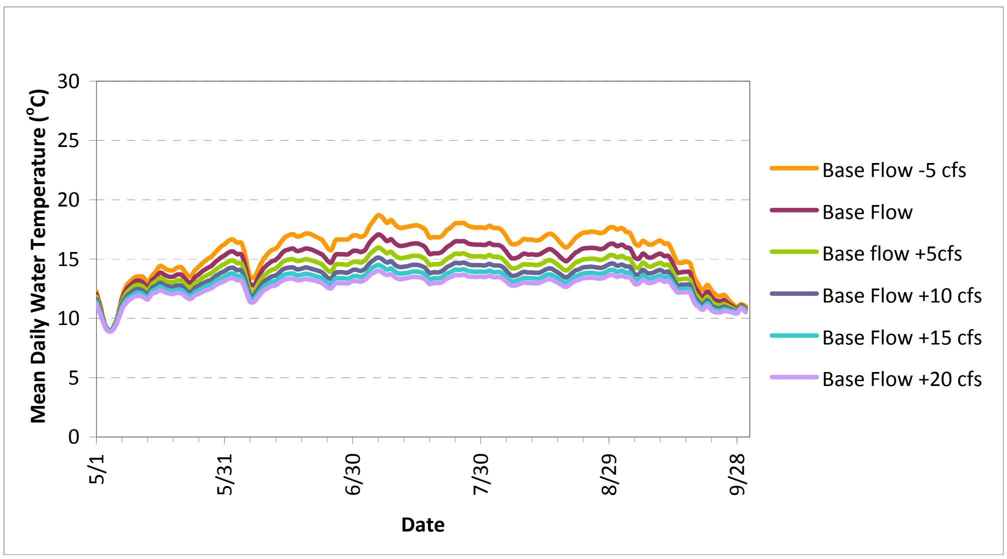


Figure H-22. Rubicon River at River Mile 22.5 Modeled Hourly (Top) Mean Daily (Middle) and Maximum Daily (Bottom) Water Temperature for Various Discharge Scenarios (-10 cfs, 0 cfs, +10 cfs, +20 cfs, +30 cfs, and +40 cfs).





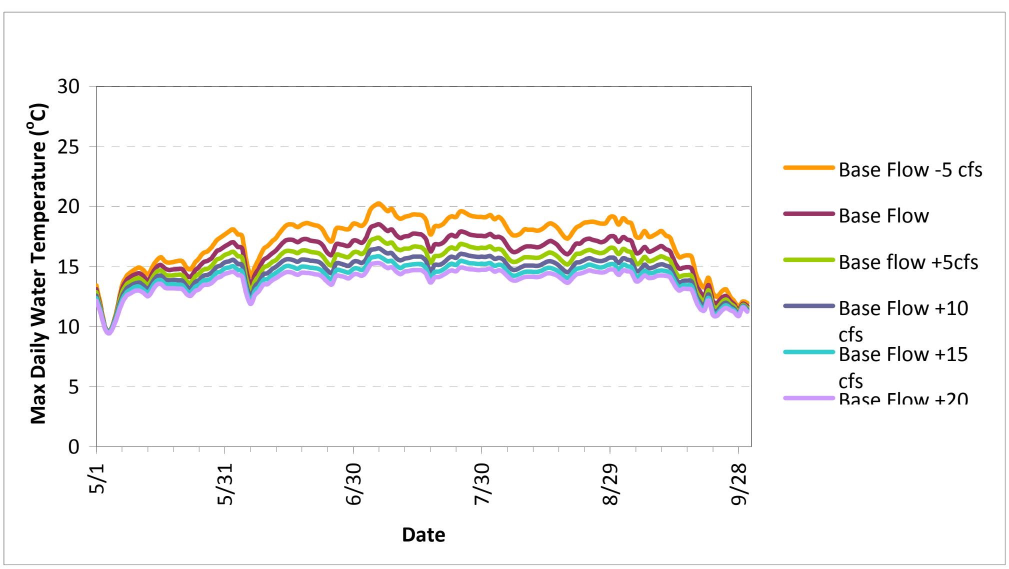


Figure H-23. Rubicon River at River Mile 14.3 Modeled Hourly (Top) Mean Daily (Middle) and Maximum Daily (Bottom) Water Temperature for Various Discharge Scenarios (-10 cfs, 0 cfs, +10 cfs, +20 cfs, +30 cfs, and +40 cfs).

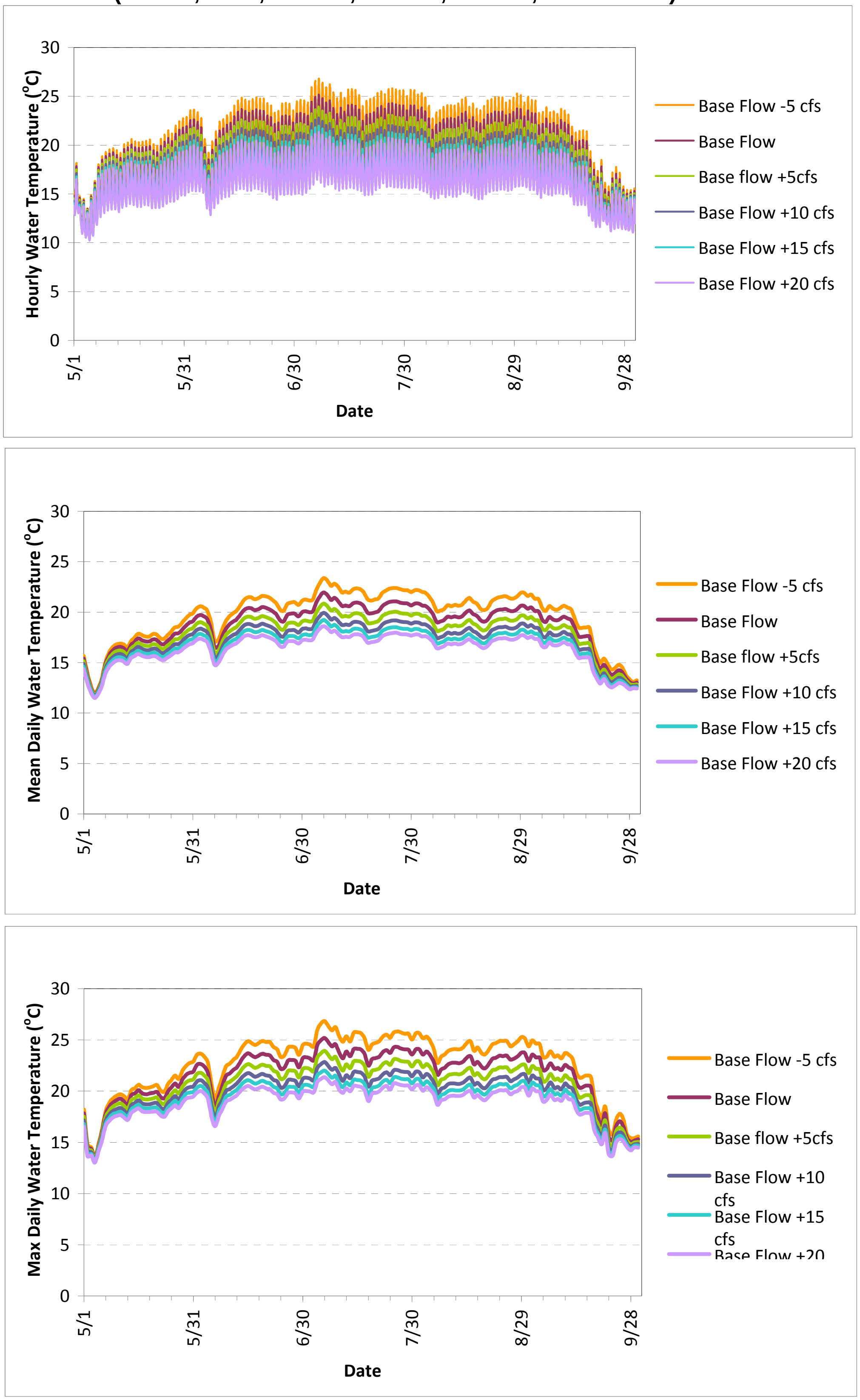


Figure H-24. Rubicon River at River Mile 3.7 Modeled Hourly (Top) Mean Daily (Middle) and Maximum Daily (Bottom) Water Temperature for Various Discharge Scenarios (-10 cfs, 0 cfs, +10 cfs, +20 cfs, +30 cfs, and +40 cfs).

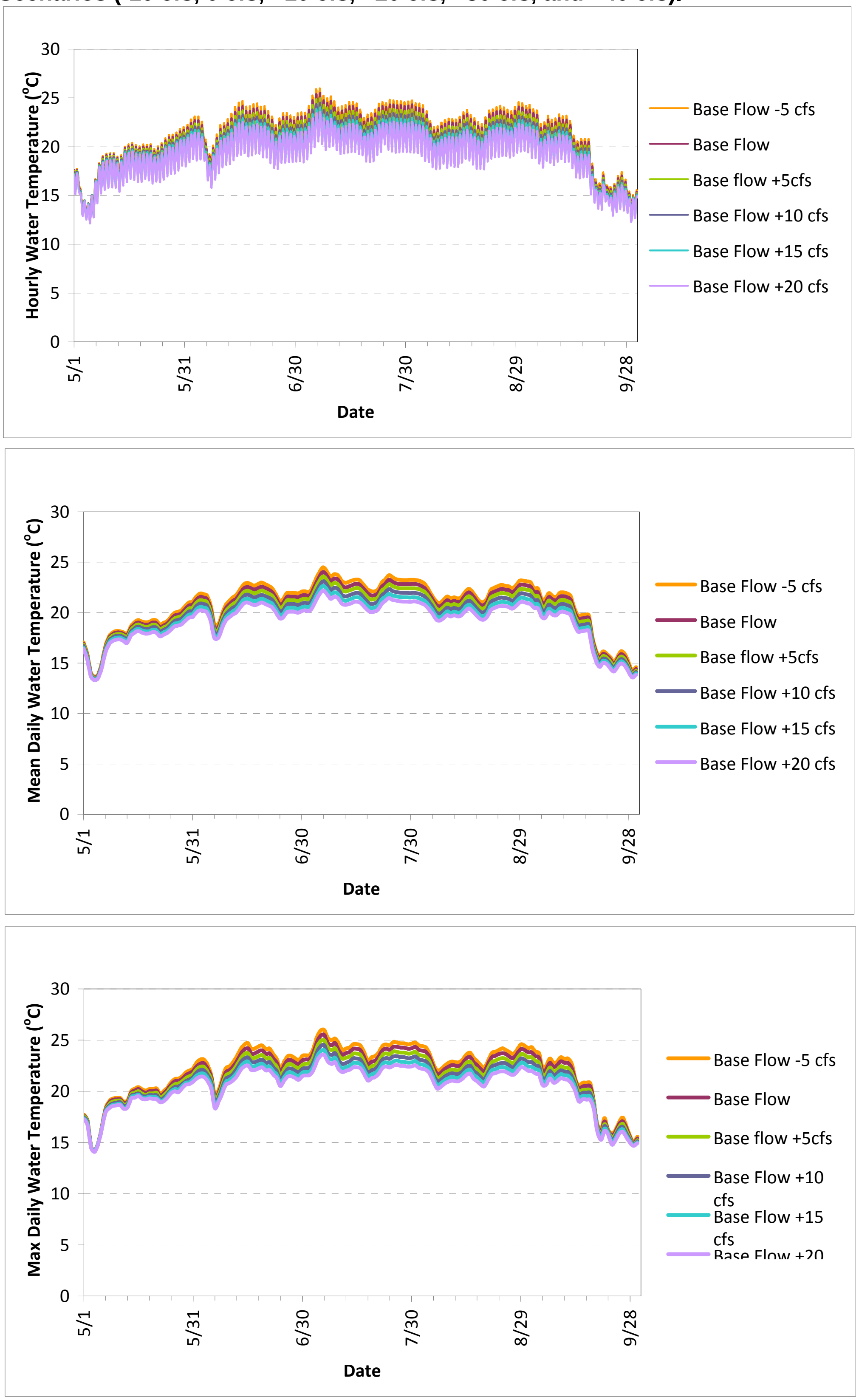


Figure H-25. Rubicon River at River Mile 0.5 Modeled Hourly (Top) Mean Daily (Middle) and Maximum Daily (Bottom) Water Temperature for Various Discharge Scenarios (-10 cfs, 0 cfs, +10 cfs, +20 cfs, +30 cfs, and +40 cfs).

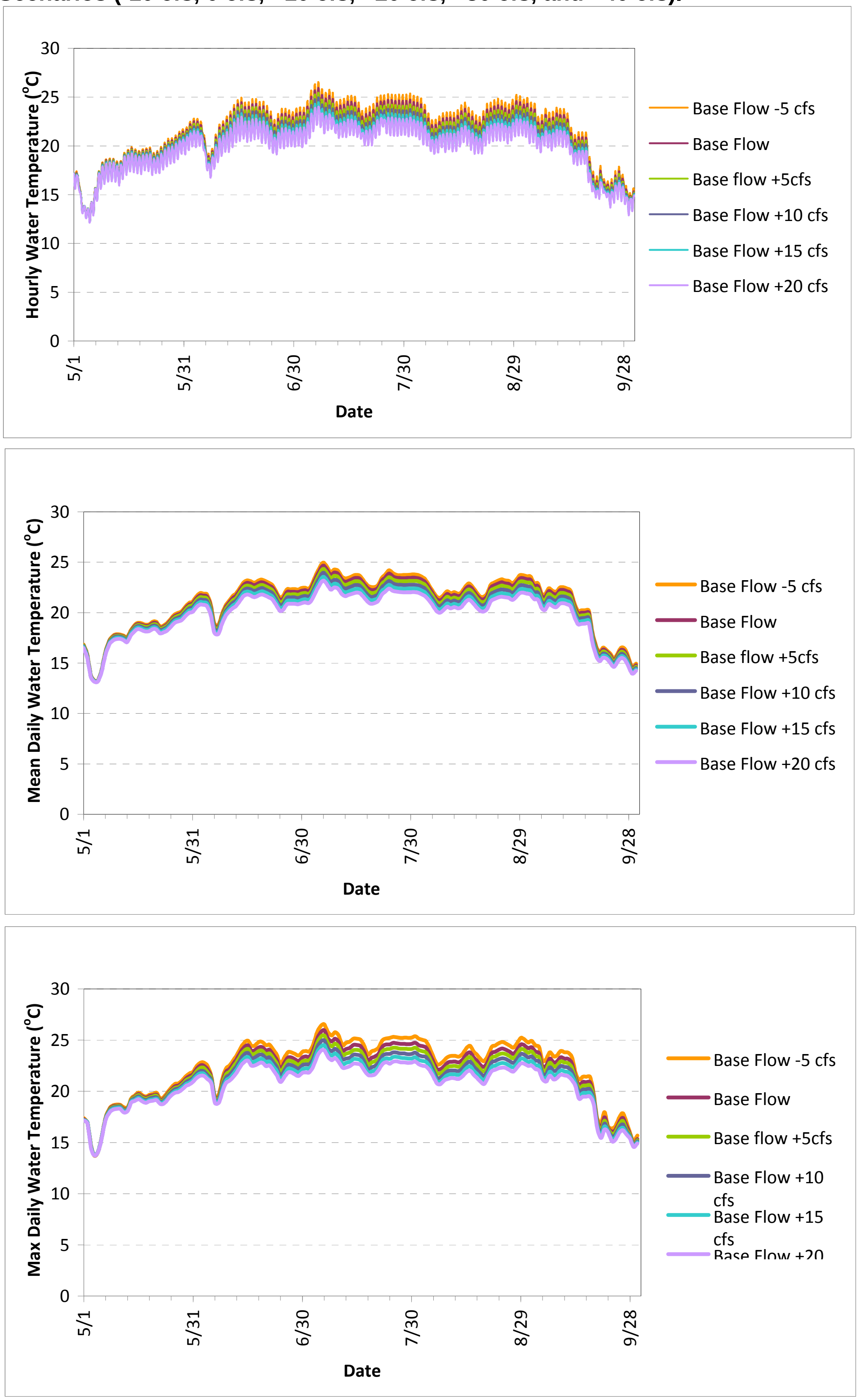
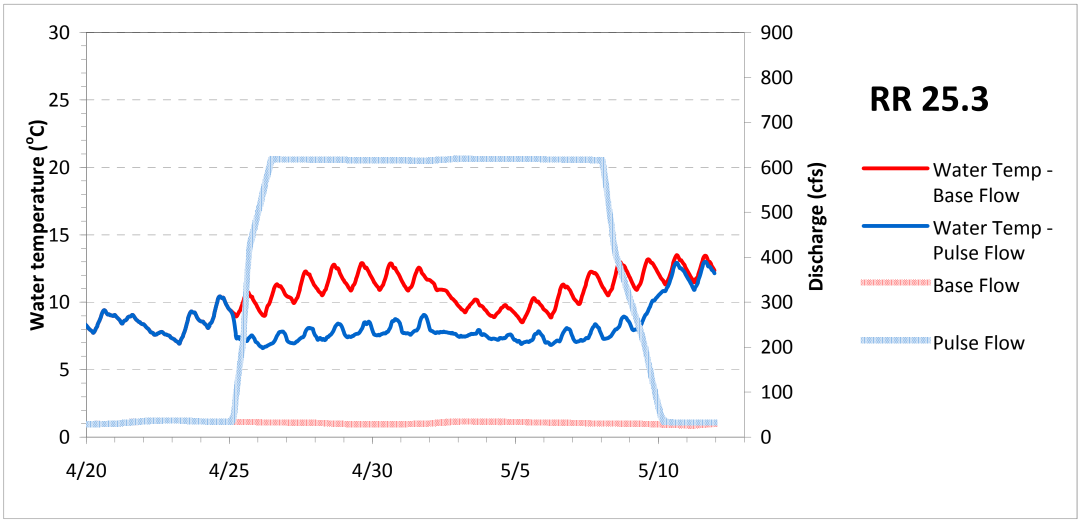
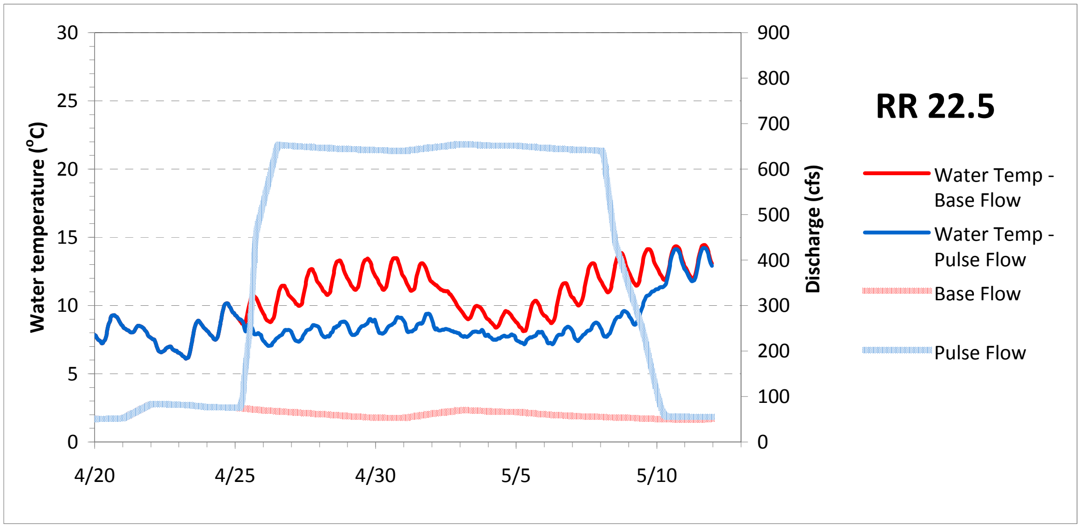


Figure H-26. Rubicon River below Hell Hole Reservoir Spring Pulse Flow Sensitivity Analysis for Top of Reach (Top), Below South Fork Rubicon River Confluence (Middle) and Middle of Reach (Bottom).





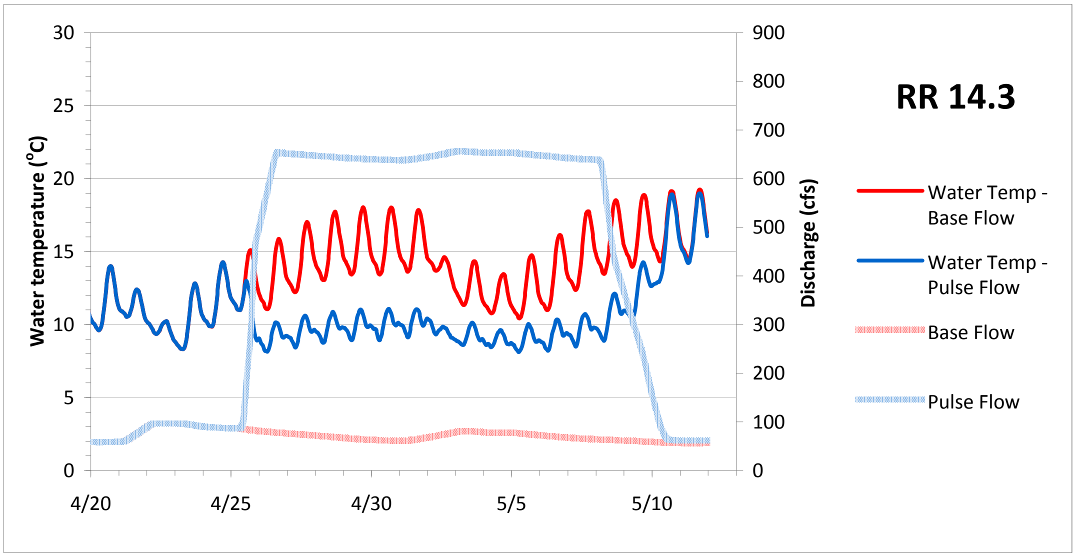
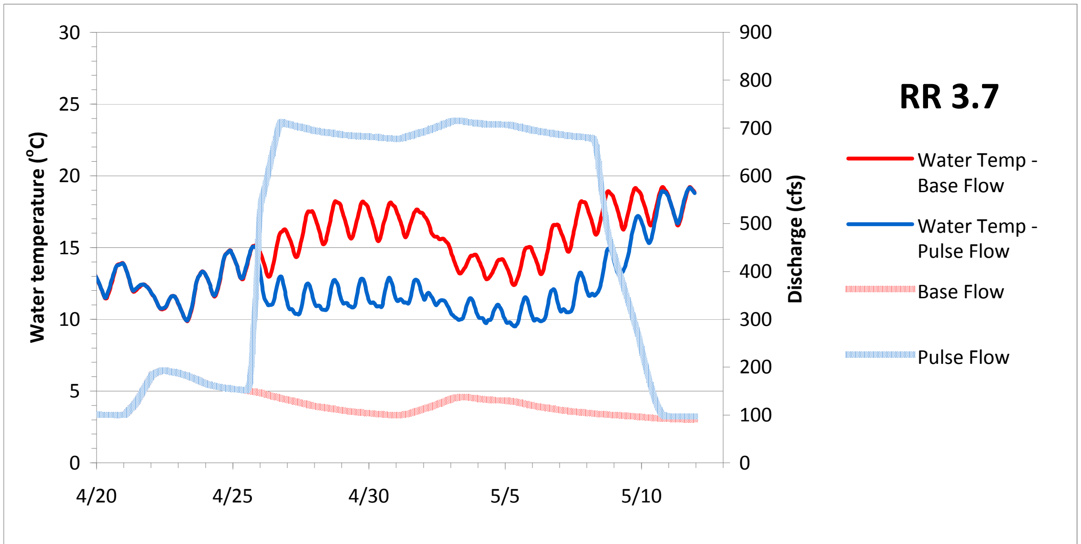


Figure H-27. Rubicon River below Hell Hole Reservoir Spring Pulse Flow Sensitivity Analysis for above Long Canyon Creek Confluence (Top) and Bottom of Reach (Bottom).



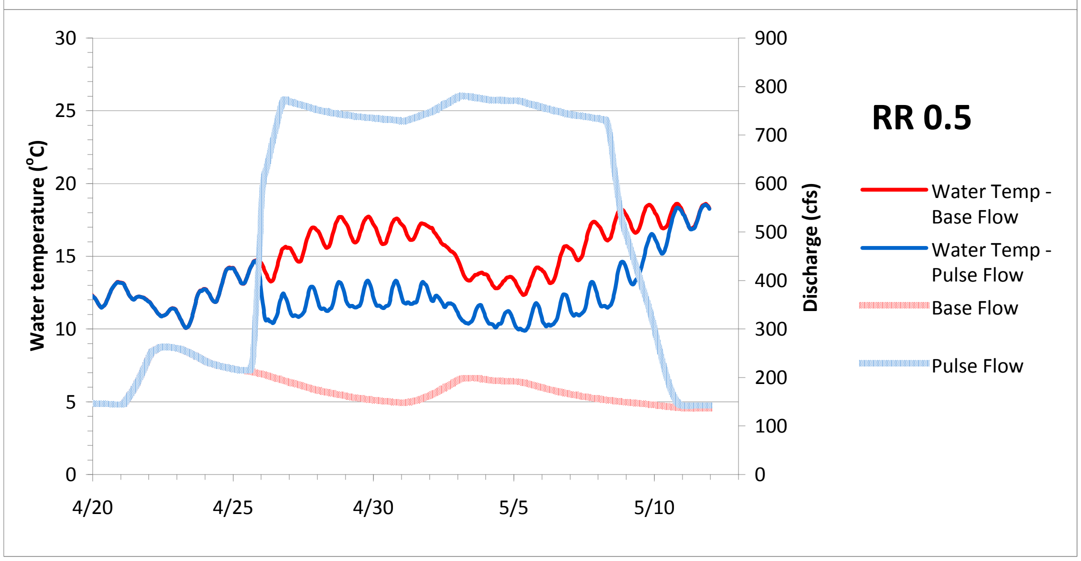
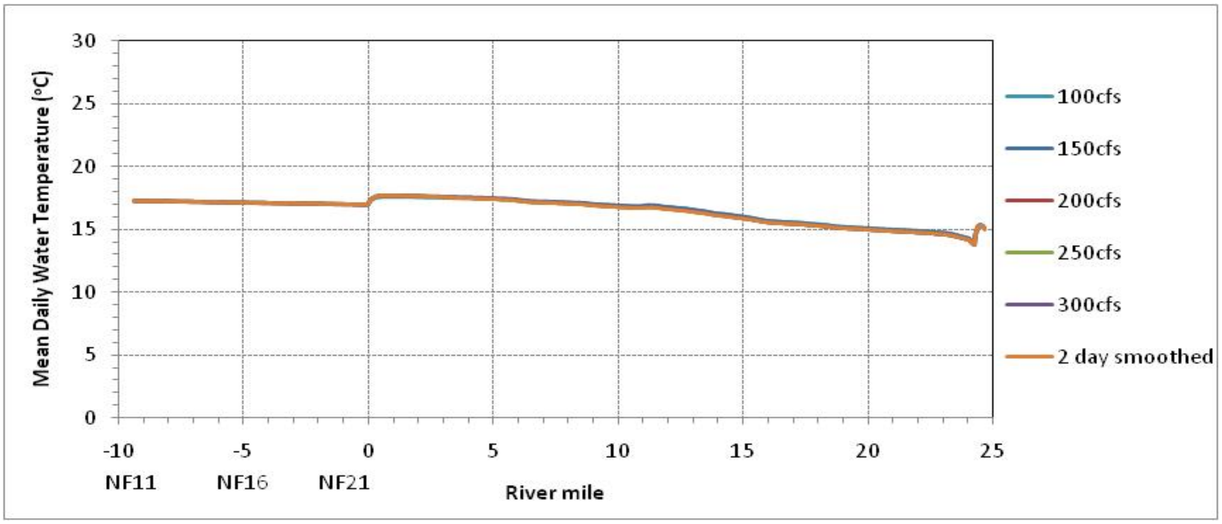


Figure H-28. Middle Fork American River Peaking Reach Longitudinal Profiles of Daily Mean (Top) and Maximum (Bottom) Water Temperature for the Second Week of May, 2007 for Various Discharge Scenarios (100 cfs, 150 cfs, 200 cfs, 250 cfs and 300 cfs Minimum Discharge and 2-Day Average Discharge).



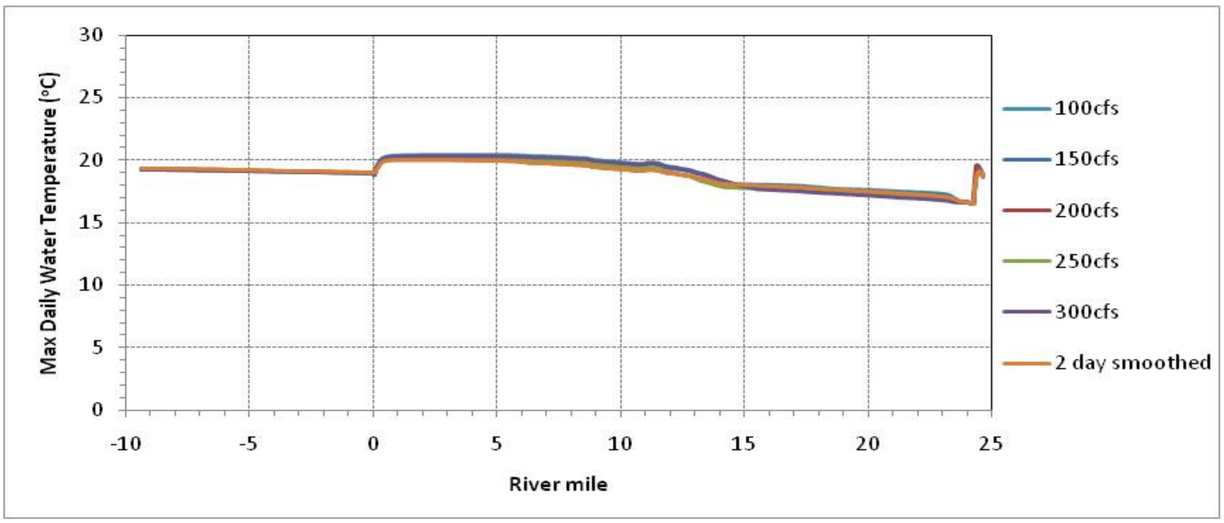


Figure H-29. Middle Fork American River Peaking Reach Longitudinal Profiles of Daily Mean (Top) and Maximum (Bottom) Water Temperature for the First Week of June, 2007 for Various Discharge Scenarios (100 cfs, 150 cfs, 200 cfs, 250 cfs and 300 cfs Minimum Discharge and 2-Day Average Discharge).

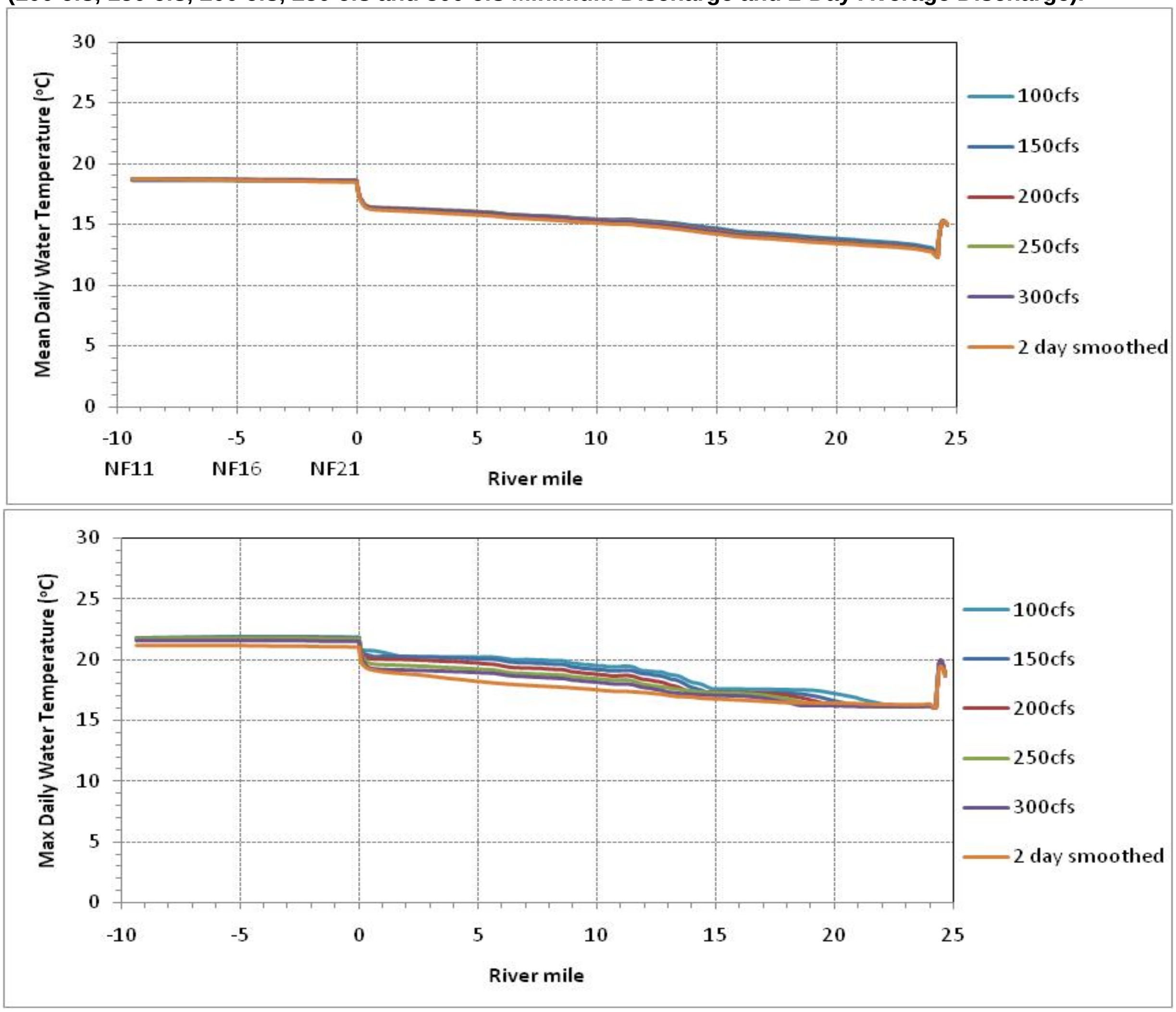
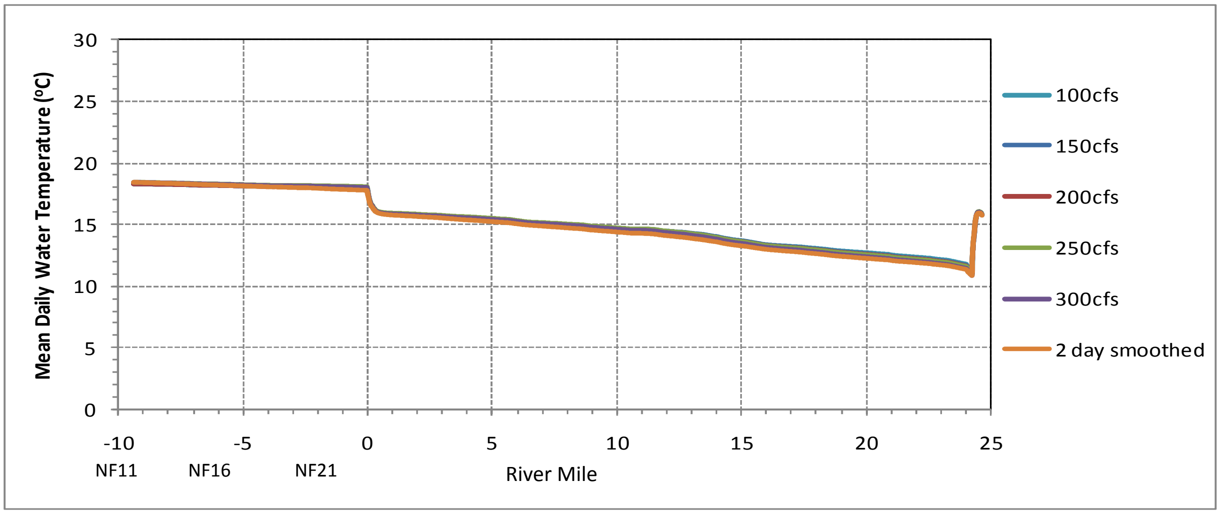
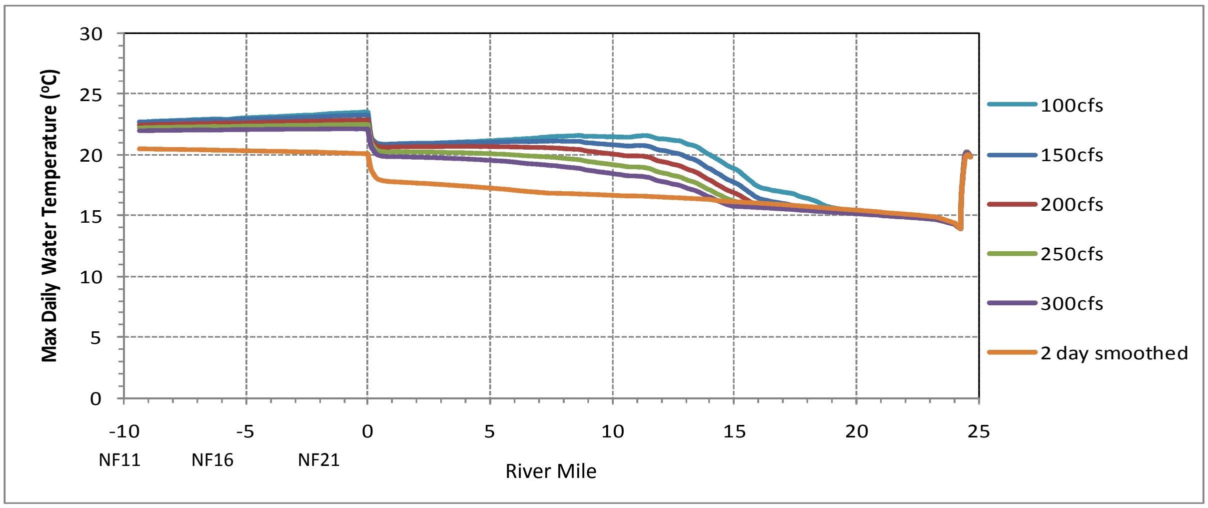


Figure H-30. Middle Fork American River Peaking Reach Longitudinal Profiles of Daily Mean (Top) and Maximum (Bottom) Water Temperature for the First Week of July, 2007 for Various Discharge Scenarios (100 cfs, 150 cfs, 200 cfs, 250 cfs and 300 cfs Minimum Discharge and 2-Day Average Discharge).





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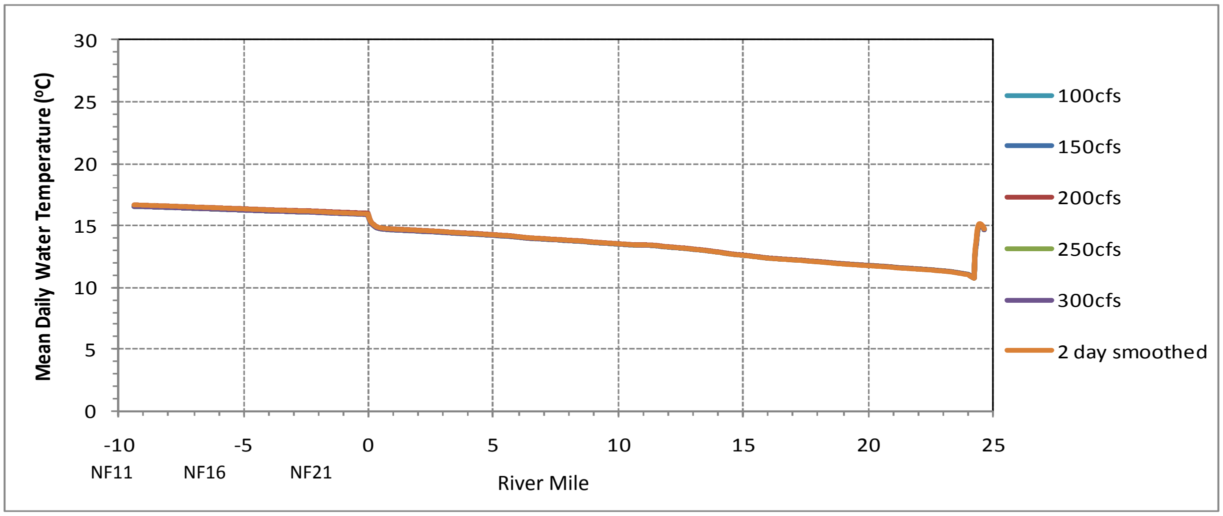


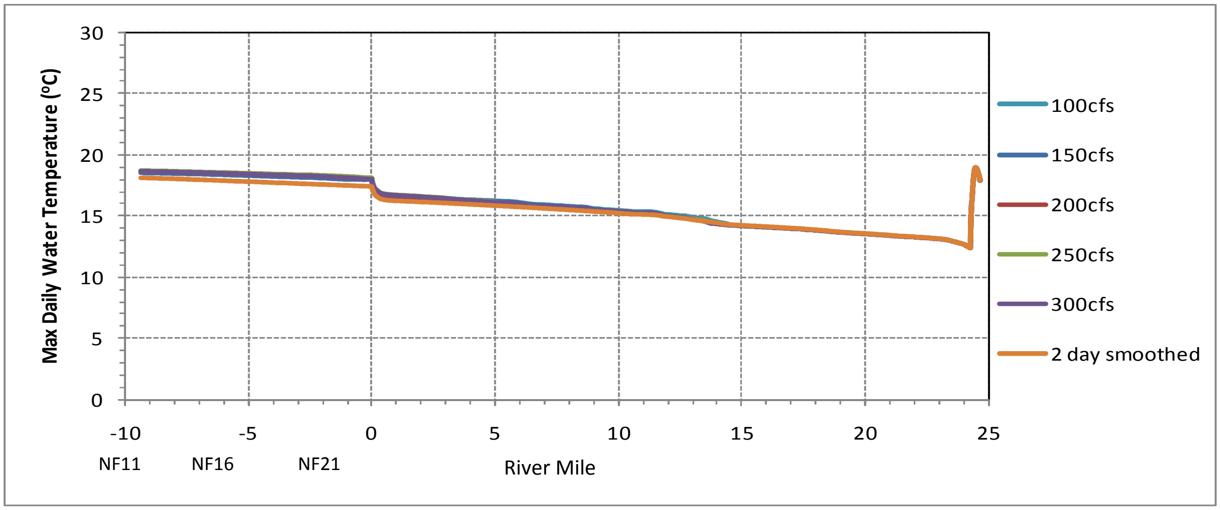


Figure H-32. Middle Fork American River Peaking Reach at River Mile 24.3 Modeled 15-minute Water Temperature (Top), Mean Daily (Middle) and Max Daily (Bottom) for Various Discharge Scenarios (100 cfs, 150 cfs, 200 cfs, 250 cfs and 300 cfs Minimum Discharge and 2-Day Average Discharge).

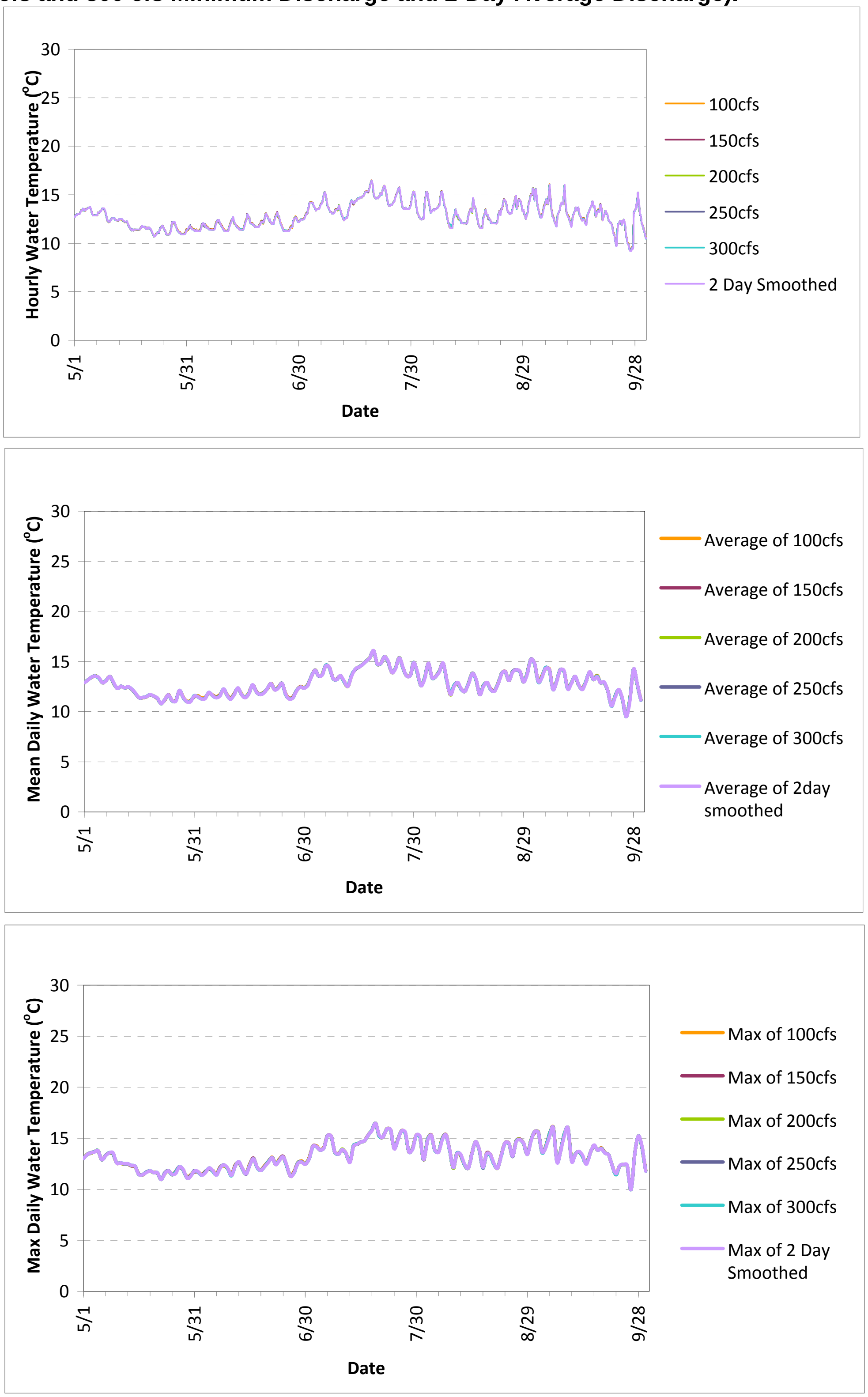
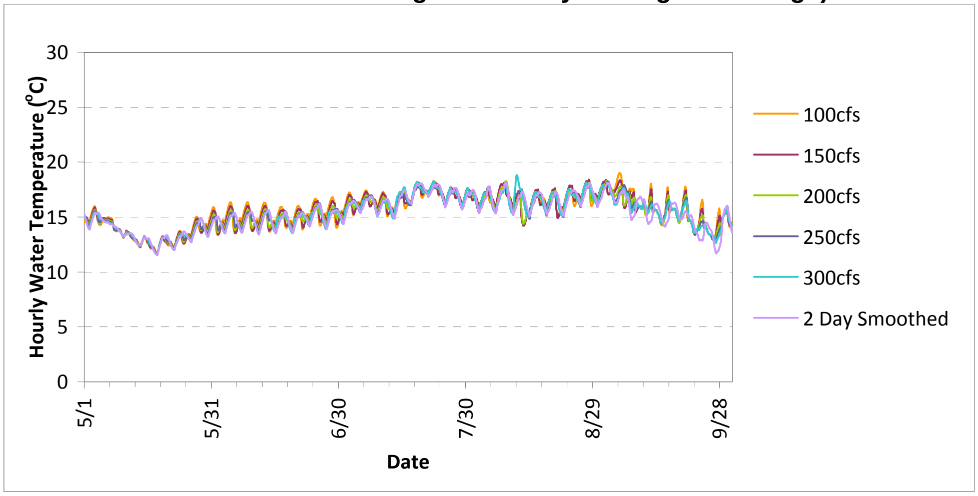
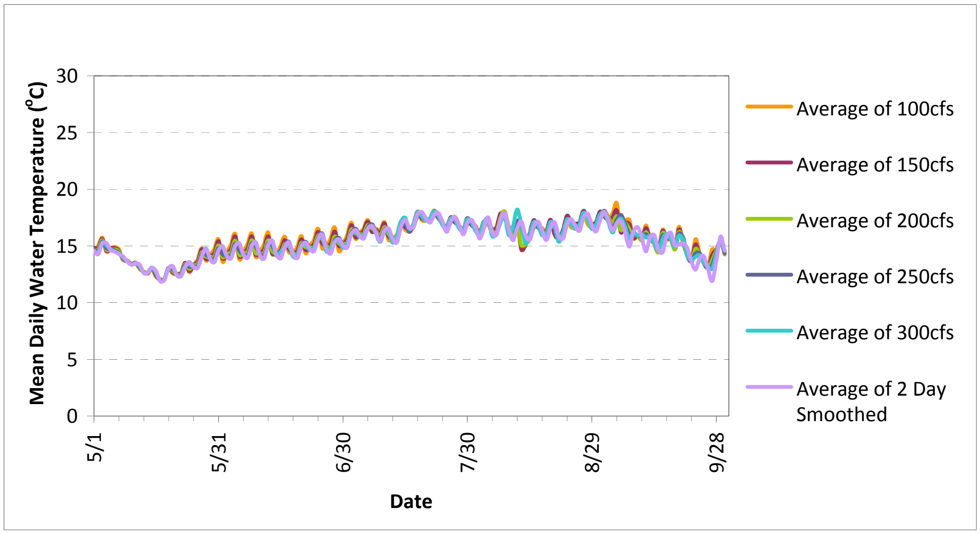


Figure H-33. Middle Fork American River Peaking Reach at River Mile 14.3 Modeled 15-minute Water Temperature (Top), Mean Daily (Middle) and Max Daily (Bottom) for Various Discharge Scenarios (100 cfs, 150 cfs, 200 cfs, 250 cfs and 300 cfs Minimum Discharge and 2-Day Average Discharge).





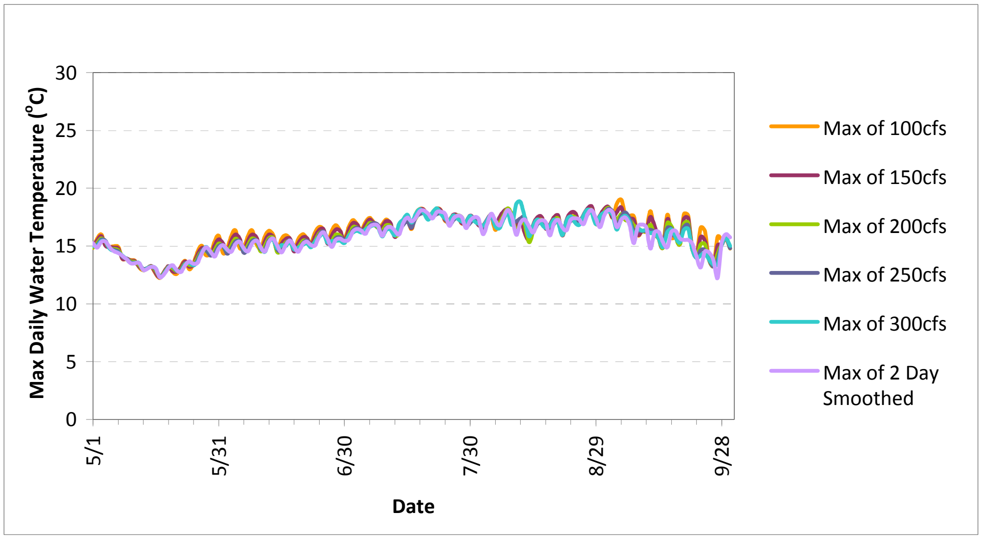
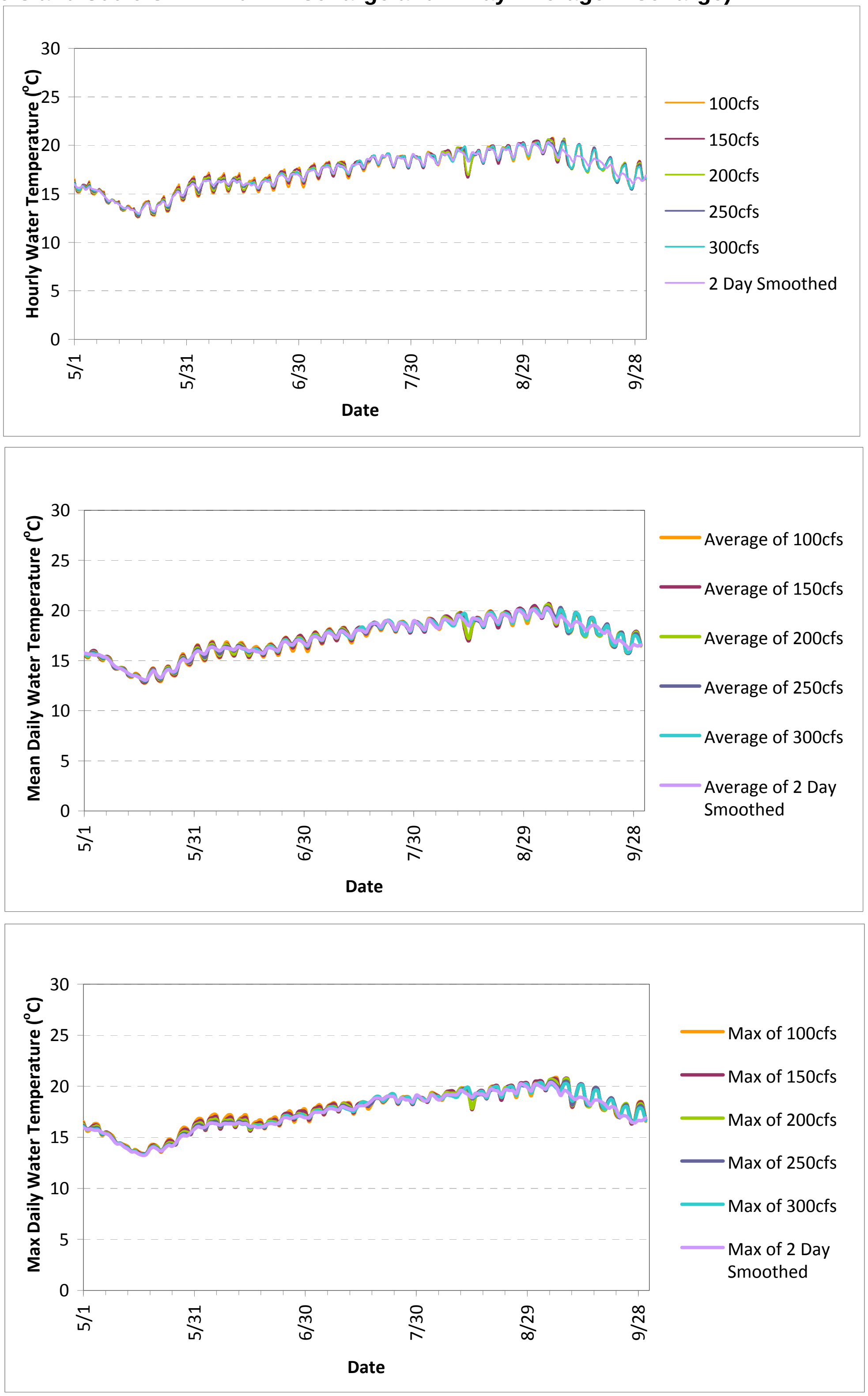


Figure H-34. Middle Fork American River Peaking Reach at River Mile 0.1 Modeled 15-minute Water Temperature (Top), Mean Daily (Middle) and Max Daily (Bottom) for Various Discharge Scenarios (100 cfs, 150 cfs, 200 cfs, 250 cfs and 300 cfs Minimum Discharge and 2-Day Average Discharge).



APPENDIX I

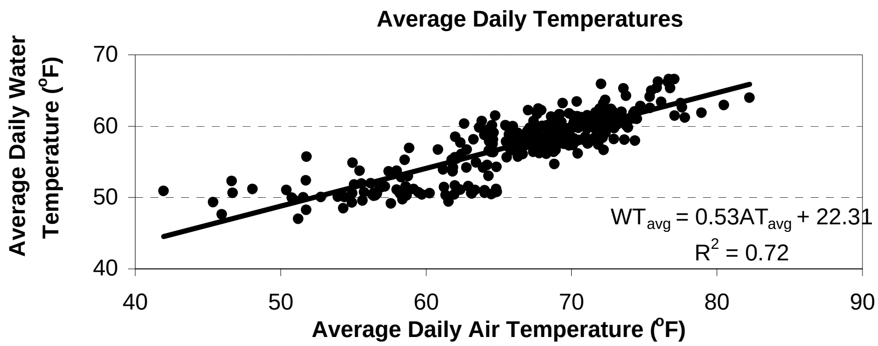
Empirical Water Temperature Characterizations in Small Stream Bypass Reaches

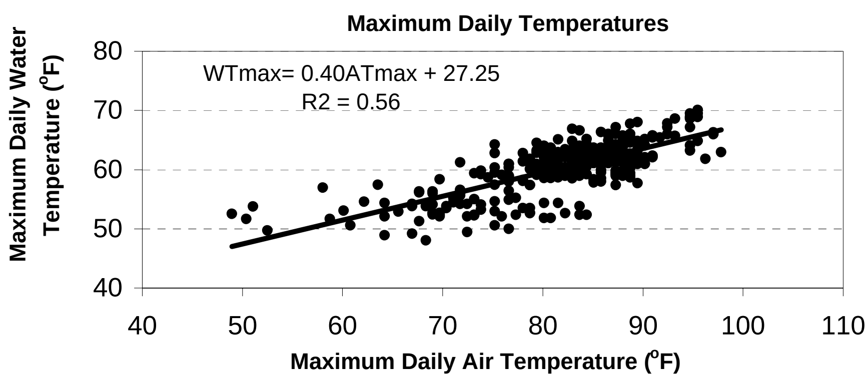
List of Figures

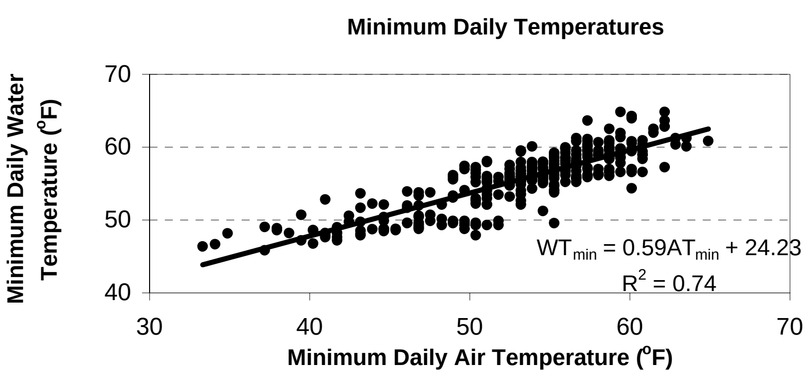
FIGURES

Figure I-1. Relationships Between Summer Mean, Maximum, and Minimum Daily Air and Water Temperatures on North Fork Long Canyon Creek Upstream (NL3.1) and Downstream (NL3.2) of the Diversion[1,2].

North Fork Long Canyon Creek - Upstream of the Diversion (NL3.2)



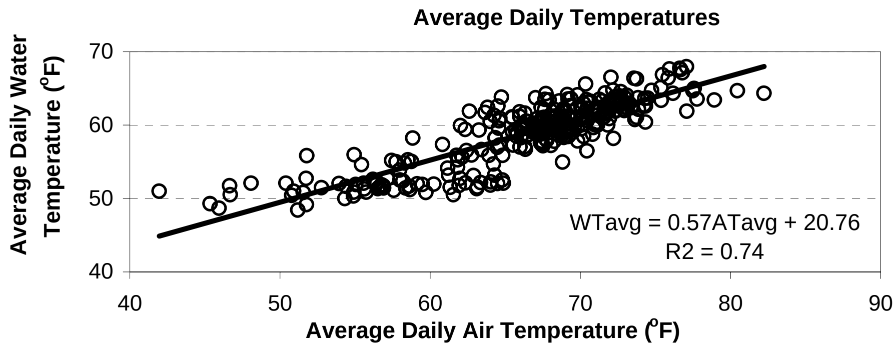


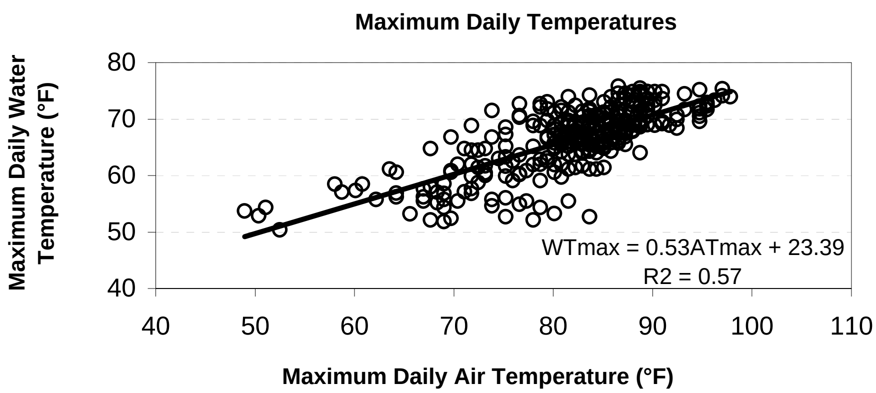


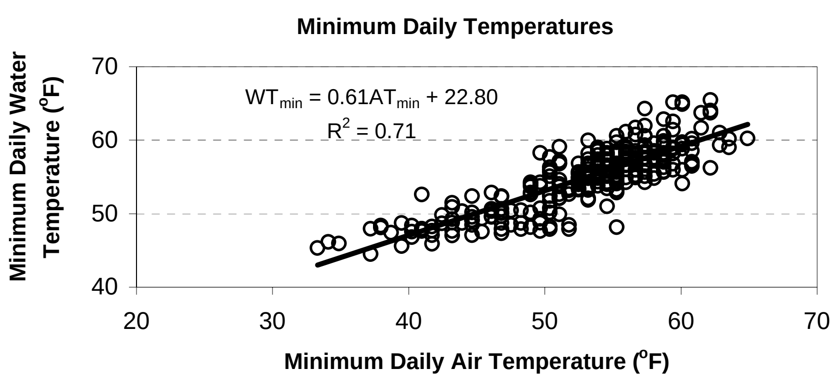
[1] Summer Months: June, July, August, and September.

Figure I-1. Relationships Between Summer Mean, Maximum, and Minimum Daily Air and Water Temperatures on North Fork Long Canyon Creek Upstream (NL3.1) and Downstream (NL3.2) of the Diversion[1,2] (continued).

North Fork Long Canyon Creek - Downstream of the Diversion (NL3.1)





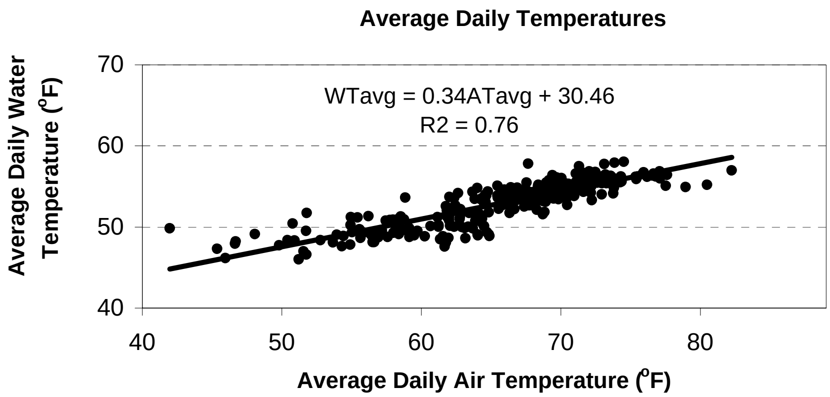


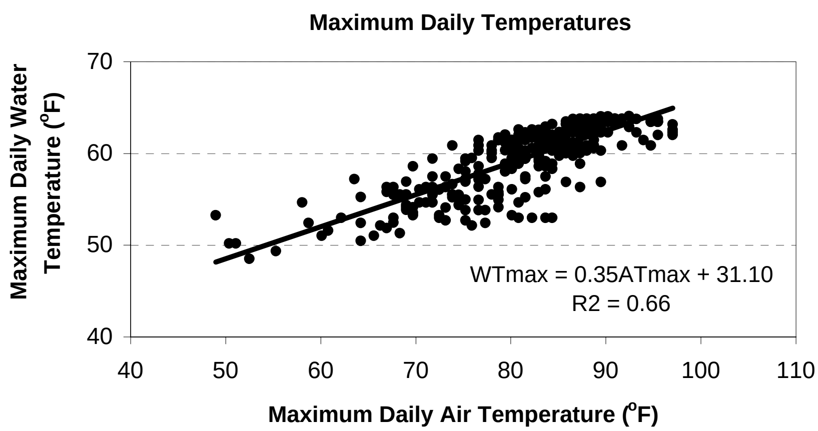
[1] Summer Months: June, July, August, and September.

[2] WT: Water Temperature (°F); AT: Air Temperature (°F); Avg: Daily Average; Max: Maximum Daily; Min: Minimum Daily.

Figure I-2. Relationships Between Summer Mean, Maximum, and Minimum Daily Air and Water Temperatures on South Fork Long Canyon Creek Upstream (SL3.2) and Downstream (SL3.4) of the Diversion[1,2].

South Fork Long Canyon Creek - Upstream of the Diversion (SL3.4)





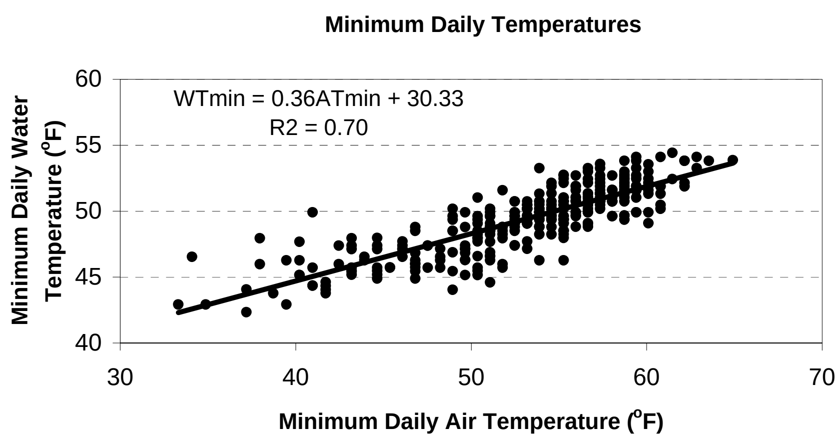
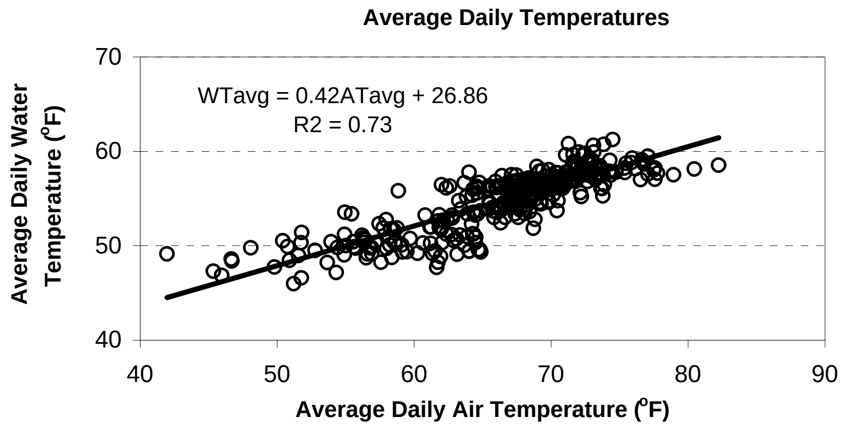
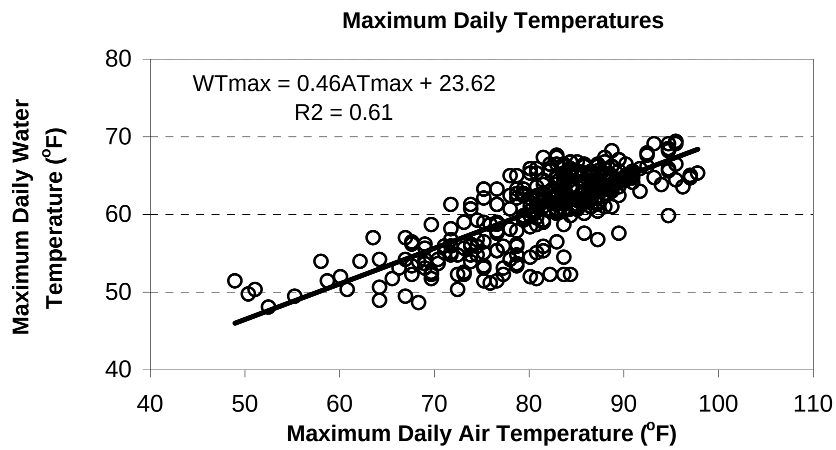
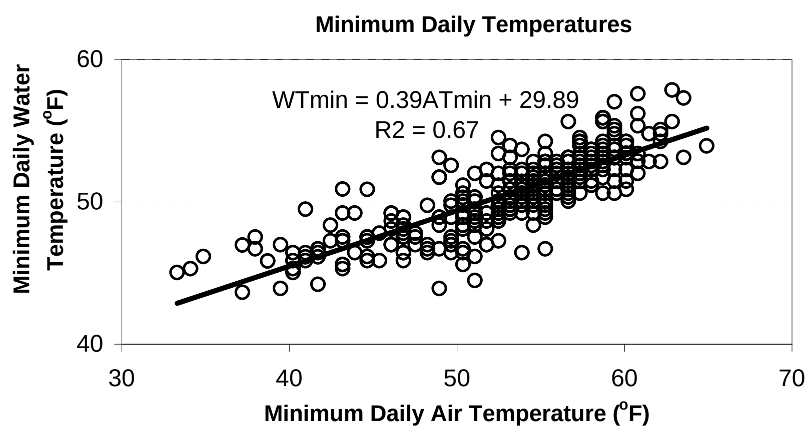


Figure I-2. Relationships Between Summer Mean, Maximum, and Minimum Daily Air and Water Temperatures on South Fork Long Canyon Creek Upstream (SL3.2) and Downstream (SL3.4) of the Diversion[1,2] (continued).

South Fork Long Canyon Creek Downstream of the Diversion (SL3.2)



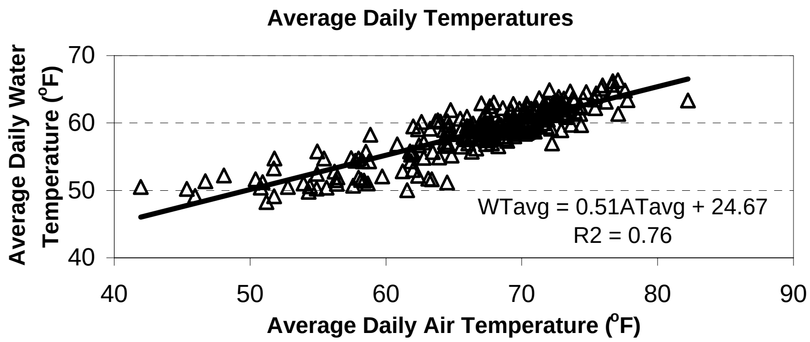


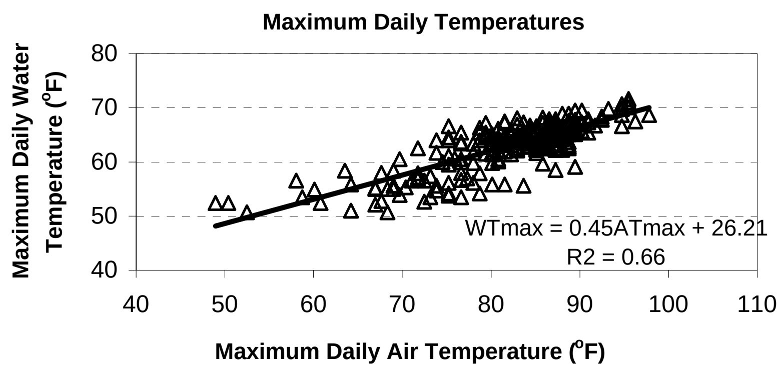


[1] Summer Months: June, July, August, and September.
[2] WT: Water Temperature (°F); AT: Air Temperature (°F); Avg: Daily Average; Max: Maximum Daily; Min: Minimum Daily.

Figure I-3. Relationships Between Summer Mean, Maximum, and Minimum Daily Air and Water Temperatures on Long Canyon Creek (LC11.0, LC6.8, LC.0.1)[1,2].

Long Canyon Creek - LC11.0





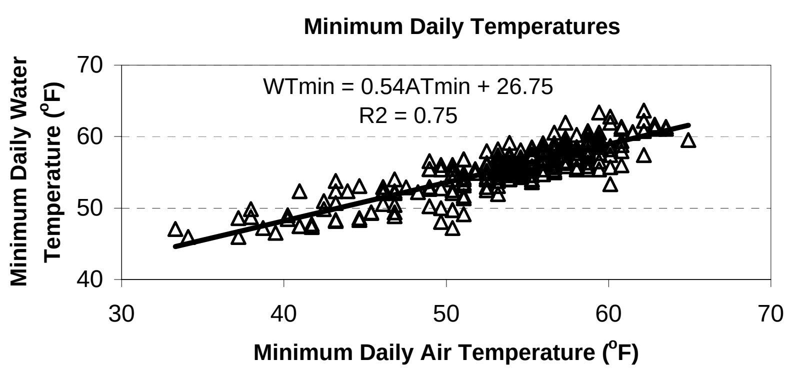
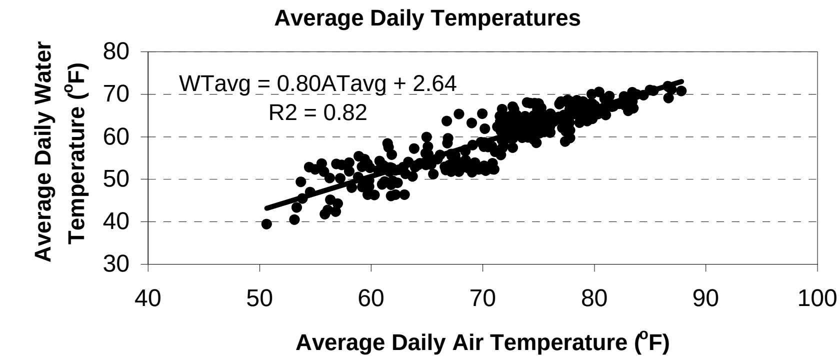
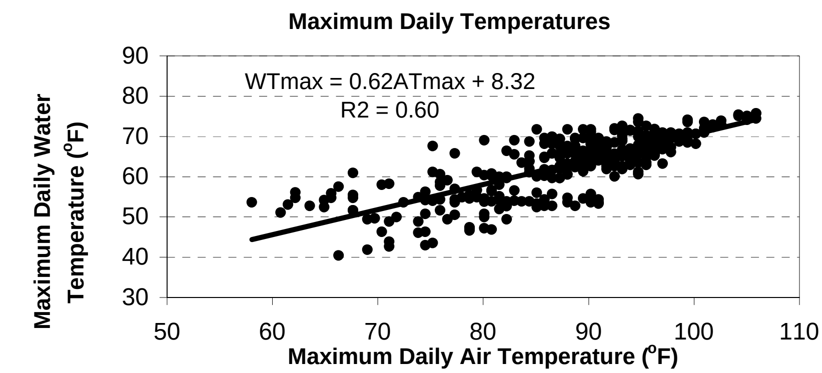
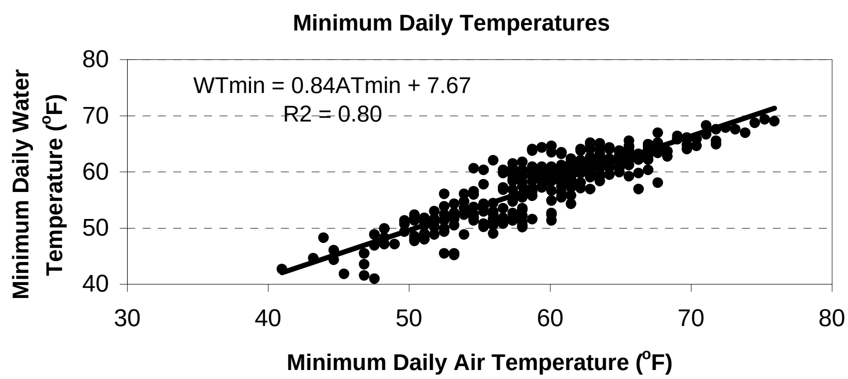


Figure I-3. Relationships Between Summer Mean, Maximum, and Minimum Daily Air and Water Temperatures on Long Canyon Creek[1,2](continued).

Long Canyon Creek - LC6.8



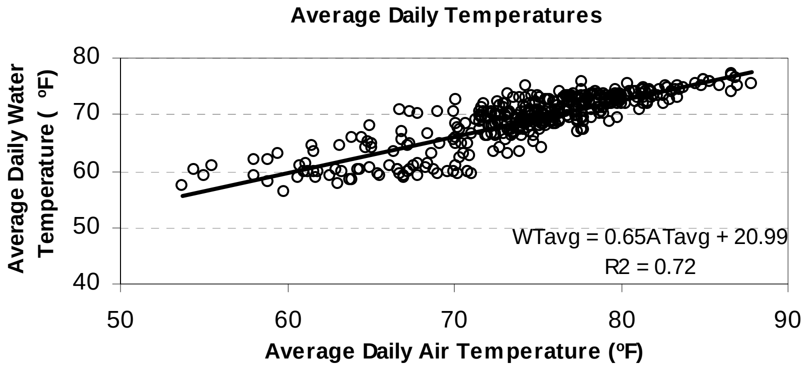


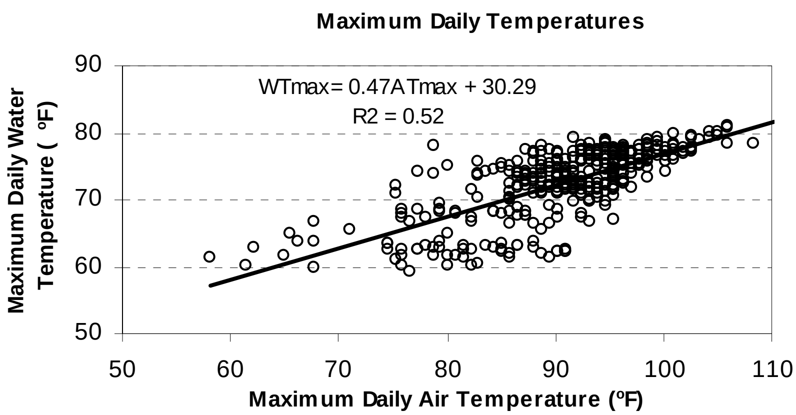


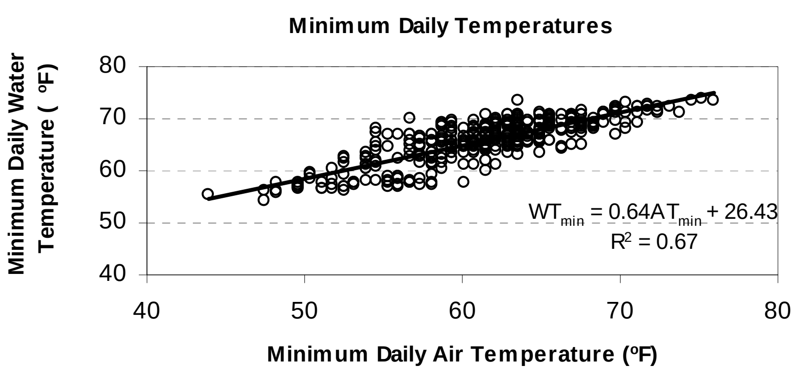
[1] Summer Months: June, July, August, and September.
[2] WT: Water Temperature (°F); AT: Air Temperature (°F); Avg: Daily Average; Max: Maximum Daily; Min: Minimum Daily.

Figure I-3. Relationships Between Summer Mean, Maximum, and Minimum Daily Air and Water Temperatures on Long Canyon Creek[1] (continued).

Long Canyon Creek - LC0.1





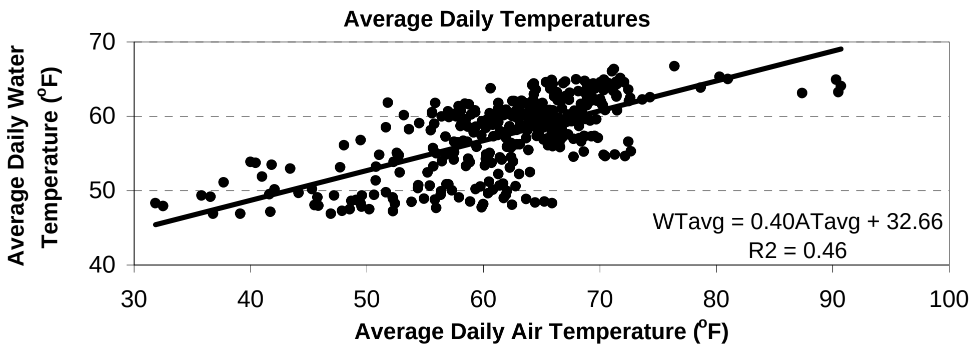


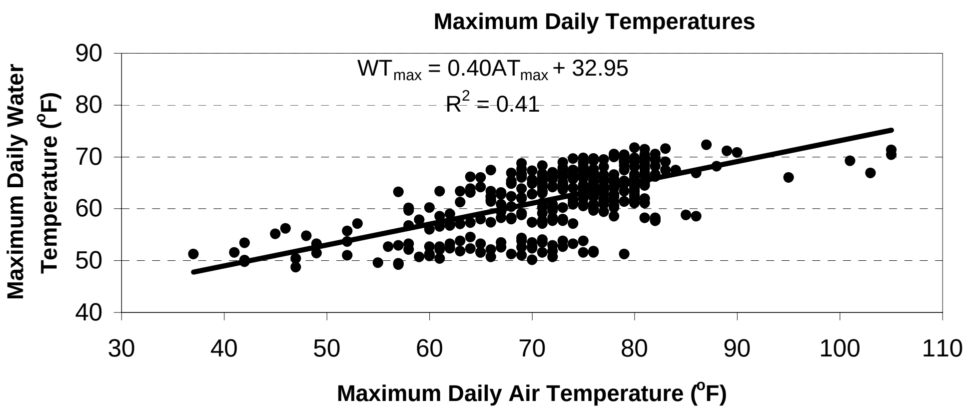
[1] Summer Months: June, July, August, and September.

[2] WT: Water Temperature (°F); AT: Air Temperature (°F); Avg: Daily Average; Max: Maximum Daily; Min: Minimum Daily.

Figure I-4. Relationships Between Summer Mean, Maximum, and Minimum Daily Air and Water Temperatures on Duncan Creek Upstream (DC8.8) and Downstream (DC0.1, DC8.4) of the Diversion[1,2].

Duncan Creek - Upstream of the Diversion (DC8.8)





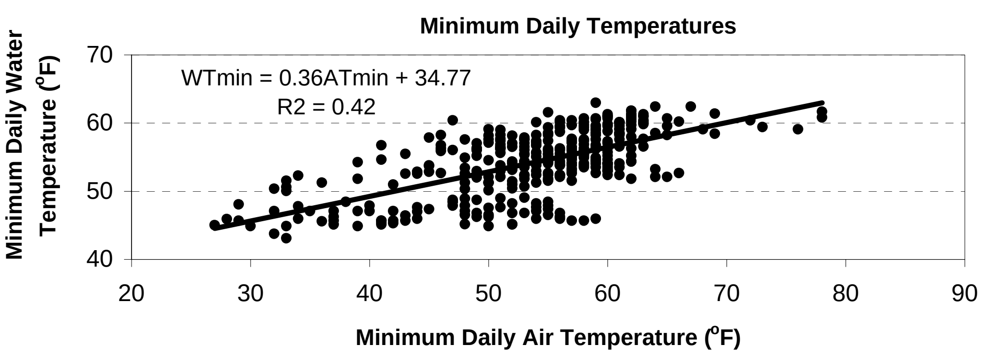
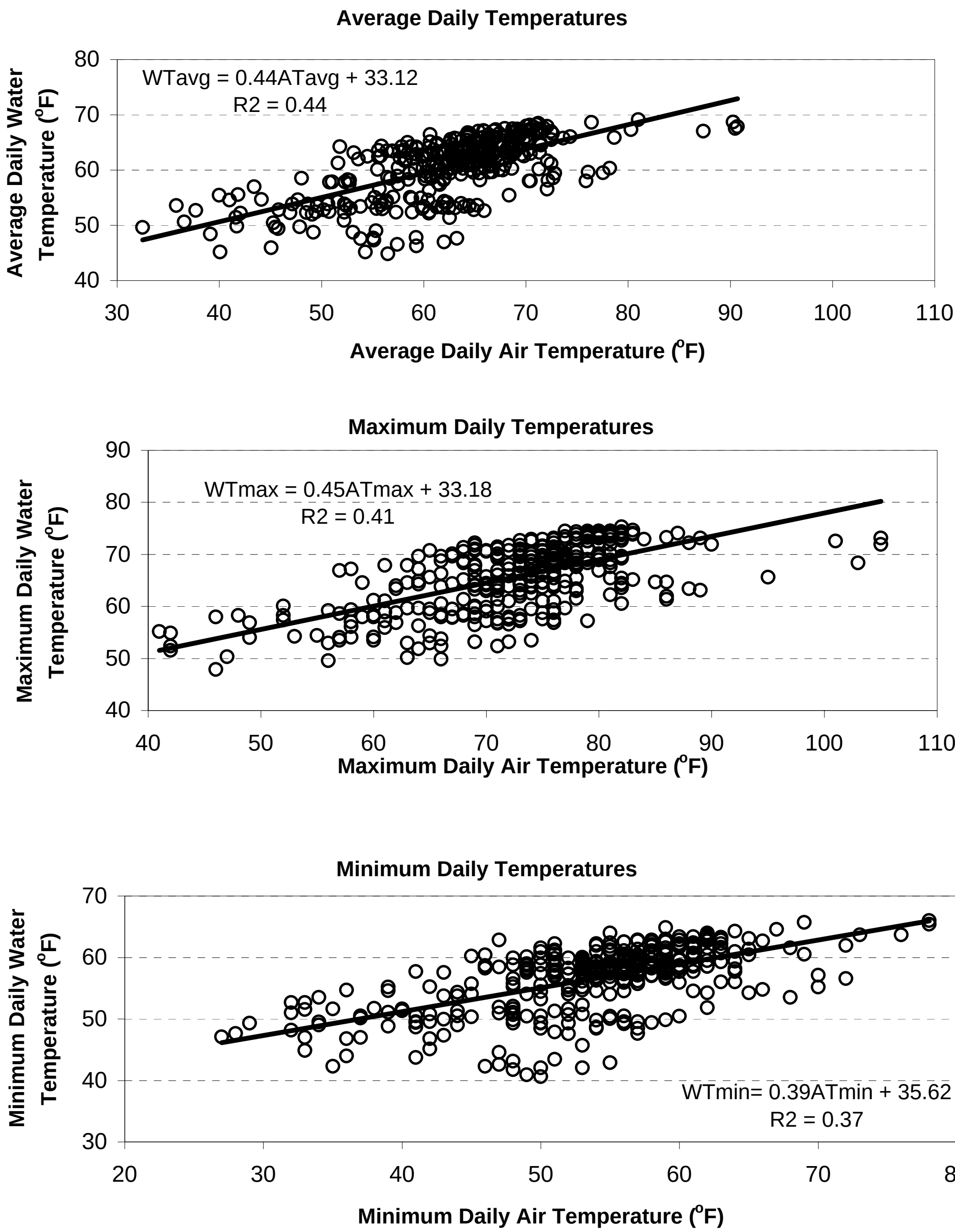


Figure I-4. Relationships Between Summer Mean, Maximum, and Minimum Daily Air and Water Temperatures on Duncan Creek Upstream (DC8.8) and Downstream (DC0.1, DC8.4) of the Diversion[1,2] (continued).

Duncan Creek - Downstream of the Diversion (DC8.4)

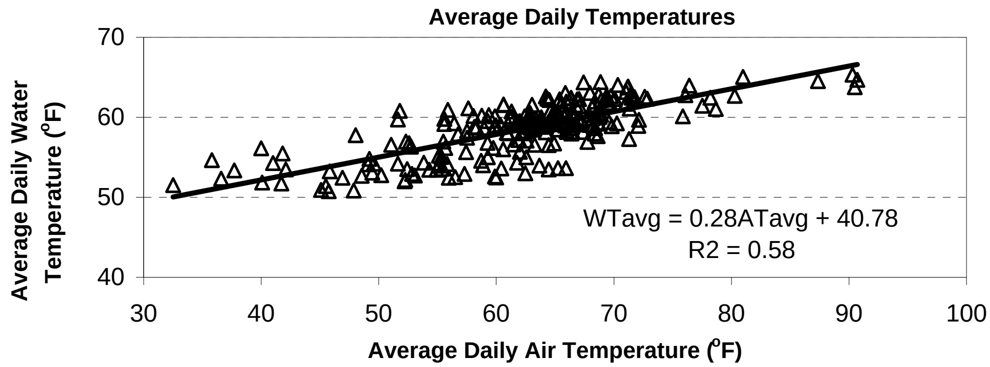


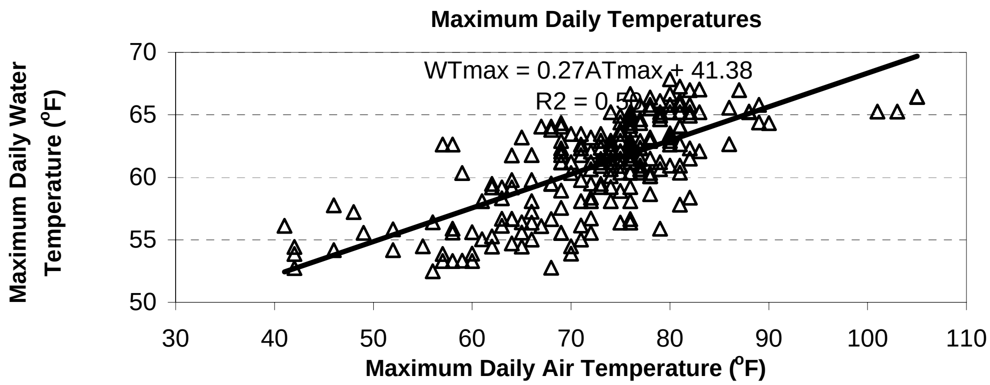
[1] Summer Months: June, July, August, and September.

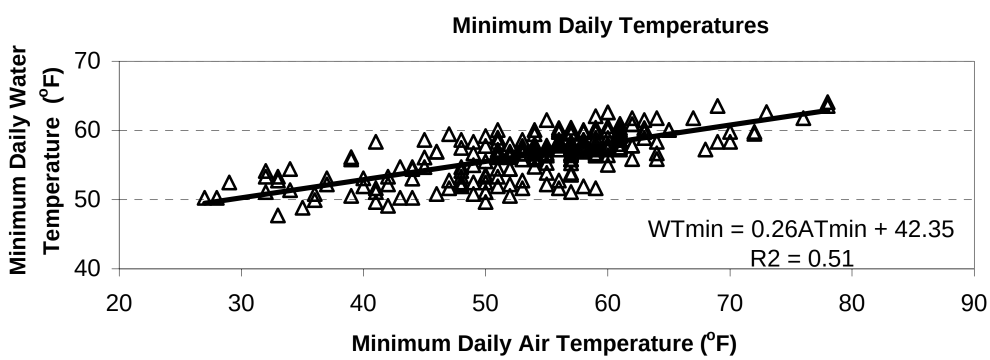
[2] WT: Water Temperature (°F); AT: Air Temperature (°F); Avg: Daily Average; Max: Maximum Daily; Min: Minimum Daily.

Figure I-4. Relationships Between Summer Mean, Maximum, and Minimum Daily Air and Water Temperatures on Duncan Creek Upstream (DC8.8) and Downstream (DC0.1, DC8.4) of the Diversion[1](continued).

Duncan Creek - Downstream of the Diversion near Confluence at Middle Fork American River (DC0.1)





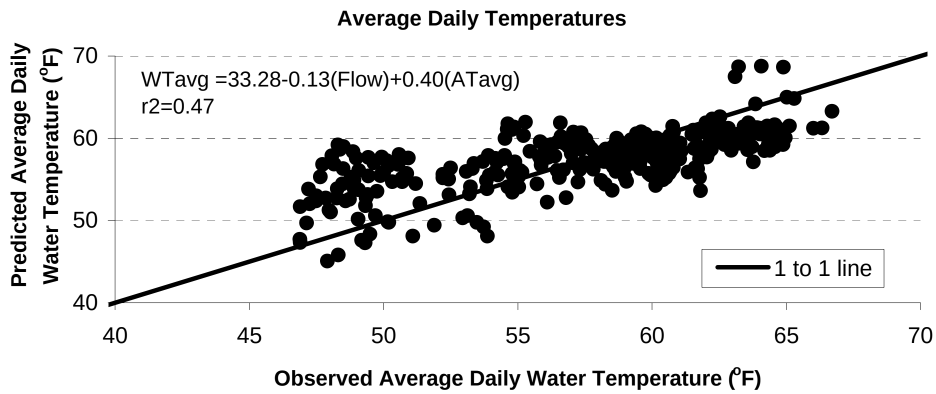


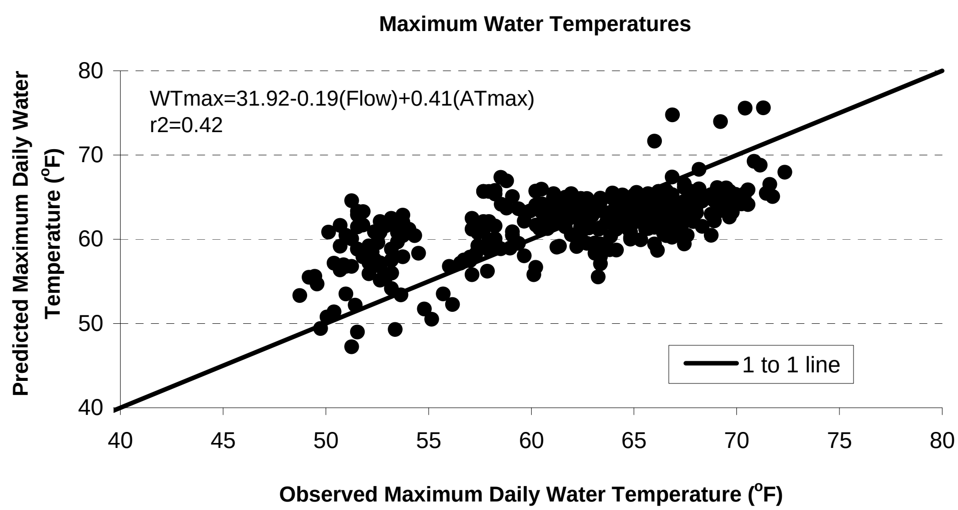
[1] Summer Months: June, July, August, and September.

[2] WT: Water Temperature (°F); AT: Air Temperature (°F); Avg: Daily Average; Max: Maximum Daily; Min: Minimum Daily.

Figure I-5. Relationships Between Summer Mean, Maximum, and Minimum Daily Air, Water Temperatures, and Flow on Duncan Creek Upstream (DC8.8) and Downstream (DC0.1, DC8.4) of the Diversion[1,2].

Duncan Creek - Upstream of the Diversion (DC8.8)





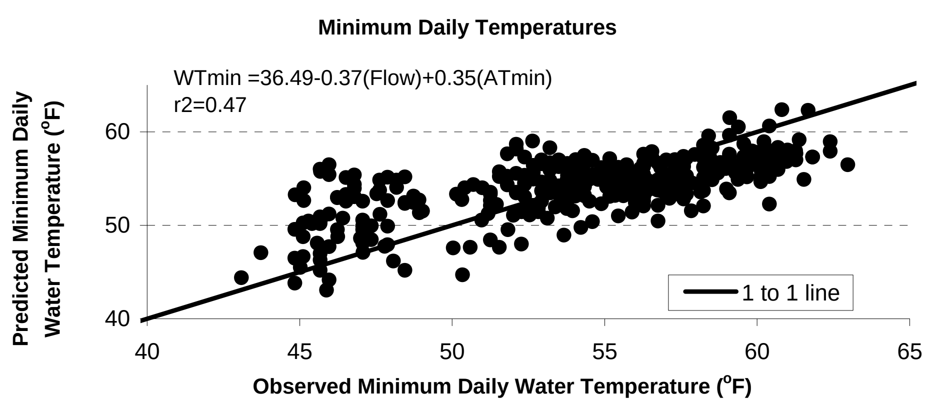
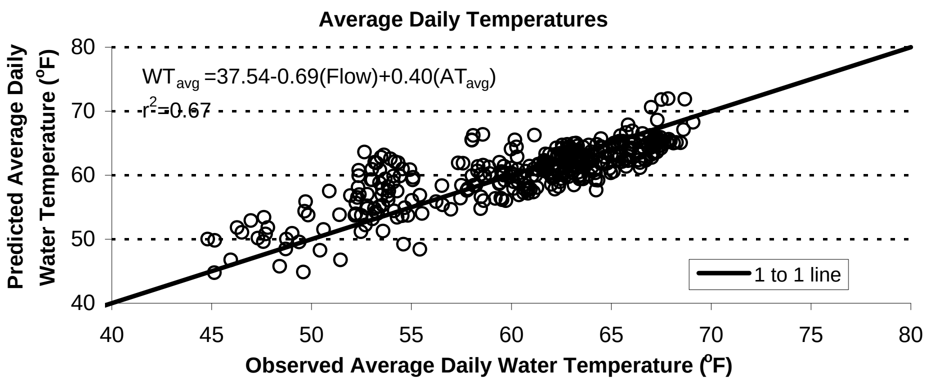
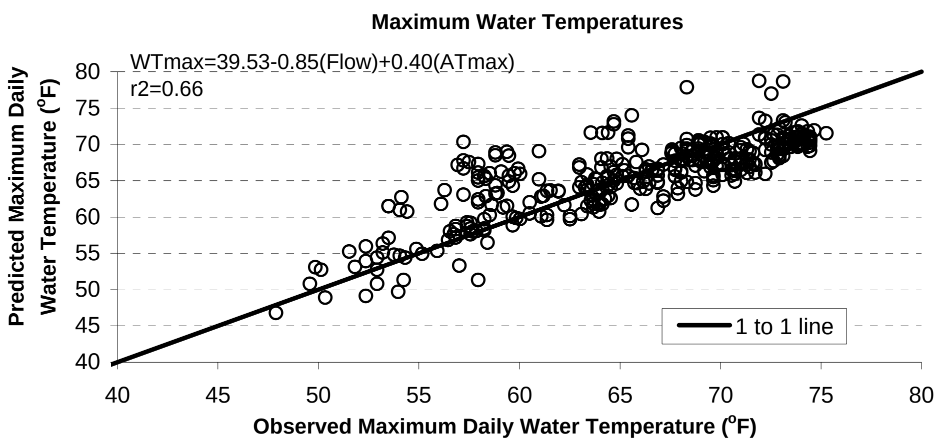
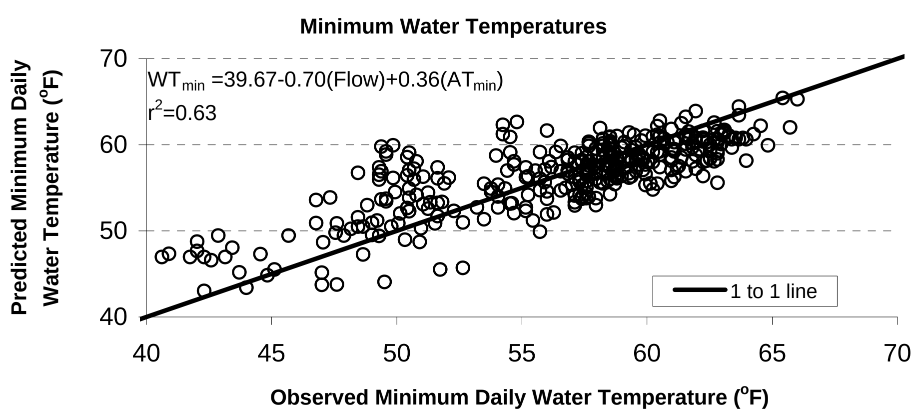


Figure I-5. Relationships Between Summer Mean, Maximum, and Minimum Daily Air, Water Temperatures, and Flow on Duncan Creek Upstream (DC8.8) and Downstream (DC0.1, DC8.4) of the Diversion[1,2](continued).

Duncan Creek - Downstream of the Diversion (DC8.4)





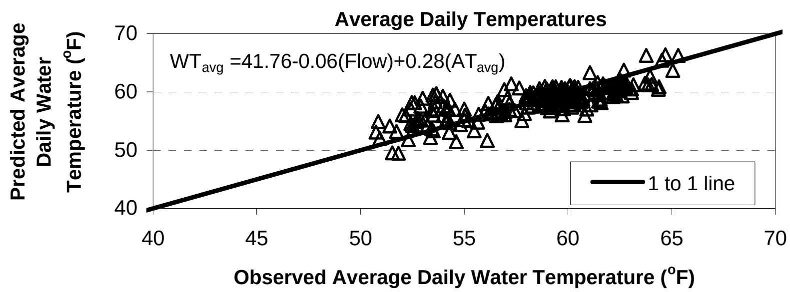


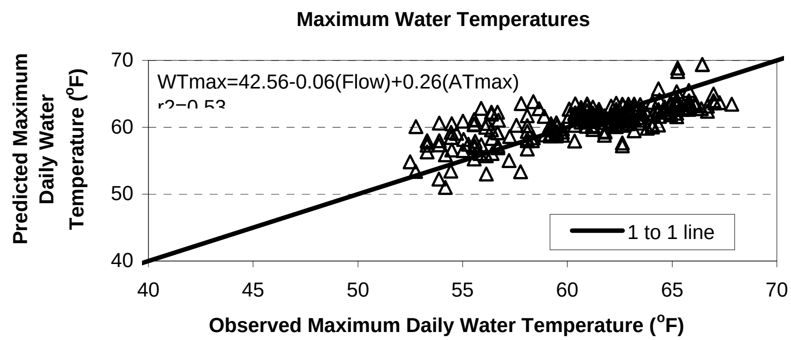
[1] Summer Months: June, July, August, and September.

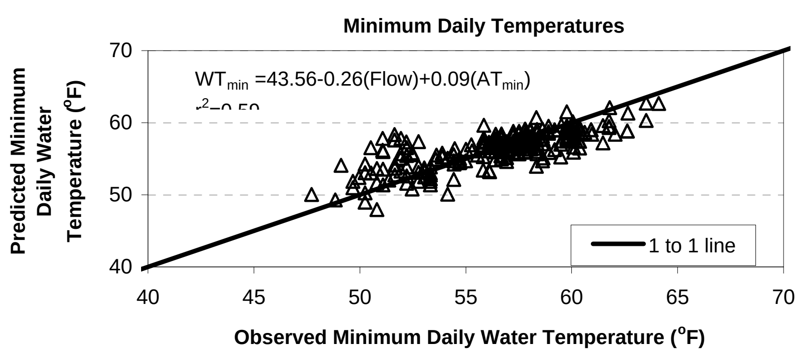
[2] WT: Water Temperature (^{o}F); AT: Air Temperature (^{o}F); Avg: Daily Average; Max: Maximum Daily; Min: Minimum Daily.

Figure I-5. Relationships Between Summer Mean, Maximum, and Minimum Daily Air, Water Temperatures, and Flow on Duncan Creek Upstream (DC8.8) and Downstream (DC0.1, DC8.4) of the Diversion[1,2](continued).

Duncan Creek - Downstream of the Diversion near Confluence at Middle Fork American River (DC0.1)







[1] Summer Months: June, July, August, and September.

[2] WT: Water Temperature (°F); AT: Air Temperature (°F); Avg: Daily Average; Max: Maximum Daily; Min: Minimum Daily.

ADDENDUM 1

Alternative Flow Regime Temperature Analysis

This Addendum was added to the AQ 4 – Water Temperature Modeling Technical Study Report (AQ 4 – TSR) to provide supplemental flow regime temperature sensitivity analyses in the Rubicon River and in the Middle Fork American River below Middle Fork Interbay. Temperature sensitivity tests of various minimum flows using the 2007 calibrated temperature model were used to quantify the effects of the different minimum flows in the drier water year types (below normal, dry, critical). The additional analyses include:

- Middle Fork American River below Middle Fork Interbay – Monthly average temperature profiles for June–September for a series of alternative minimum flows;
- Rubicon River
    - Analysis of potential temperature changes to the South Fork Rubicon River inflows due to increased minimum flows from the Upper American River Project (UARP), FERC Project No. 2101.
    - Rubicon River monthly average temperature profiles for June–September for a series of alternative Rubicon River minimum flows with and without the increased South Fork Rubicon minimum flows.

The general methods for the analysis are the same as described in Section 6.4 Alternative Flow Regime Temperature Analysis of AQ 4 – TSR and Table AQ 4-22. The specifics of the analysis method are provided below:

- Middle Fork American River below Middle Fork Interbay
    - Run four different minimum flow releases from Middle Fork Interbay (13, 23, 33, 43 cfs) (Table AQ 4 – Addendum 1).
    - Plot the Middle Fork American River longitudinal average temperature profile for each of the temperature model runs for the months of June, July, August, and September.
    - Determine the river mile where two temperature transitions occur for each model run during July–August: (1) 17°C—foothill yellow-legged frog lower optimum temperature bound (transition) and (2) 20°C—approximate trout upper temperature bound (transition).
- Rubicon River
    - Develop a lower and upper temperature time series for the South Fork Rubicon River inflow to the Rubicon River.
        - Upper temperature bound is the measured 2007 temperature based on existing South Fork Rubicon River flows.

- Lower temperature bound is an estimate of the temperature when new higher UARP Project minimum flows go into effect. Generate the temperature time series from the source water temperature data at Gerle Creek and Robbs Peak Forebay using the 2001–2004 temperature monitoring data from the UARP Project.

- Run three different minimum flow releases from Hell Hole Reservoir (10, 20, and 30 cfs) in combination with the original South Fork Rubicon River inflows and with the new South Fork Rubicon River critical, dry, and above normal year minimum flow inflows (Table AQ 4 – Addendum 1).

- Use both the upper and lower bound South Fork Rubicon temperature inflow time series for temperature modeling. Average the results for the upper and lower bound model runs to generate the best estimate of future Rubicon River temperatures.

- Plot the Rubicon River longitudinal average temperature profiles for each of the temperature model runs for the months of June, July, August, and September. Compare/contrast the Rubicon River temperatures with the various Rubicon River minimum flows and South Fork Rubicon River inflows.

- Determine the river mile where two temperature transitions occur for each modeling scenario during July–August: (1) 17°C—foothill yellow-legged frog lower optimum temperature bound (transition) and (2) 20°C—approximate trout upper temperature bound (transition).

The changes to the South Fork Rubicon River minimum flows as a result of the new UARP minimum flows are as follows:

Month	Old UARP License Requirement (cfs)		New UARP License Requirement (cfs)		
	Critical – Dry	Bl Normal	Critical	Dry	Bl Normal
June	5	10	13	21	28
Jul	5	10	10	15	19
Aug–Sep	5	10	8	14	18

Results for the South Fork Rubicon River upper and lower inflow temperature bounds estimates for 2007 are shown in Figure AQ 4 – Addendum 1. The upper bound is the measured 2007 South Fork Rubicon River temperature (15 minute). The lower bound was developed by subtracting the “difference” of the source water average daily temperature from the measured 2007 South Fork Rubicon River temperature time series (Figure AQ 4 – Addendum 2). Note that there is a transition near the end of August where increased minimum flows switch from cooling the South Fork Rubicon inflows in the summer to actually warming the South Fork Rubicon inflows in the fall.

Longitudinal temperature profile plots for the sensitivity runs for the Middle Fork American River below Middle Fork Interbay are shown in Figures AQ 4 – Addendum 3a-b. The river mile where the 17 and 20°C temperature transitions occur for each of the sensitivity runs can be determined from the plots. Similar longitudinal temperature profile plots for the Rubicon River sensitivity runs are shown in Figures AQ 4 – Addendum 4a-b, 5a-b, and 6a-b for each of the water year types (critical, dry, and above normal), respectively.

TABLES

Table 1 Summary of Alternative Flow Regime Temperature Analyses for June, July, August, and September.

Site/Year Type Baseline for Testing	Existing Minimum Flow (Existing FERC License)	Sensitivity Minimum Flow Scenario Description[1]	New South Fork Rubicon Minimum Flow[2] (Jun, Jul, Aug, Sept)
Middle Fork American River from Middle Fork Interbay to Ralston Afterbay			
Critical Year Minimum Flows	12 cfs	13, 23, 33, 43 cfs	
Dry Year Minimum Flows	23 cfs		
Above Normal Year Minimum Flows	23 cfs		
Rubicon River below Hell Hole Reservoir			
Critical Year Minimum Flows	20 cfs	10, 20 cfs	13, 10, 8, 8 cfs
Dry Year Minimum Flows	20 cfs	20, 30 cfs	21, 15, 14, 14 cfs
Above Normal Year Minimum Flows	20 cfs	20, 30 cfs	28, 19, 18, 16 cfs

[1]Sensitivity minimum flow scenarios run on the the 2007 year temperature model (2007 accretions and meterological data).

[2]Using minimum flows in the new FERC license for the Upper American River Project, FERC Project 2101.

FIGURES

Figure 1. Estimated Upper and Lower Bounding Temperatures for South Fork Rubicon Inflow to the Rubicon River 2007.

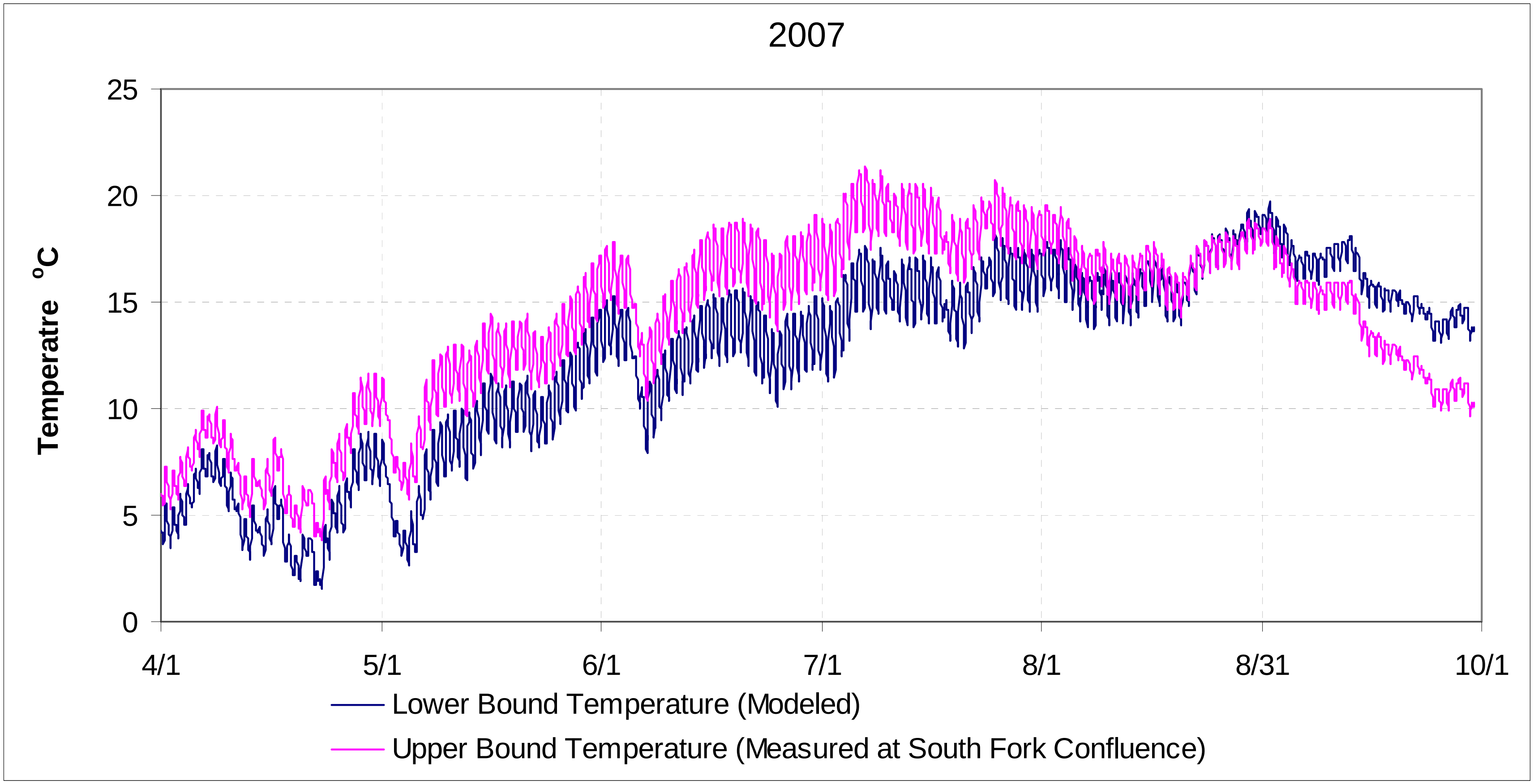


Figure 2. The Average Daily South Fork Rubicon Water Temperature at the Confluence with the Rubicon River (2006–2008) and the Averaged Daily Temperature of the Source Water to the South Fork Rubicon (2001–2004) and the Difference between the Two.

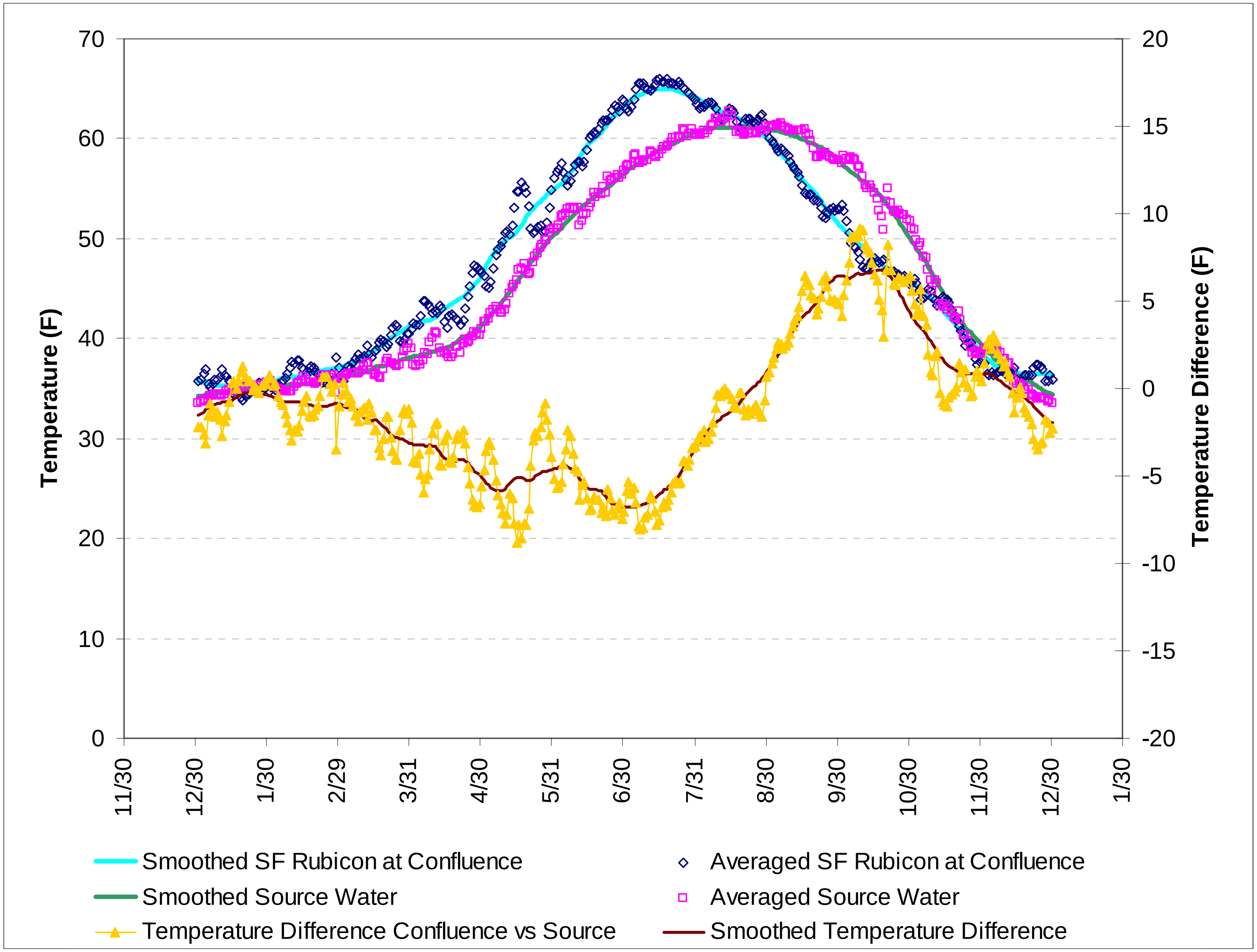
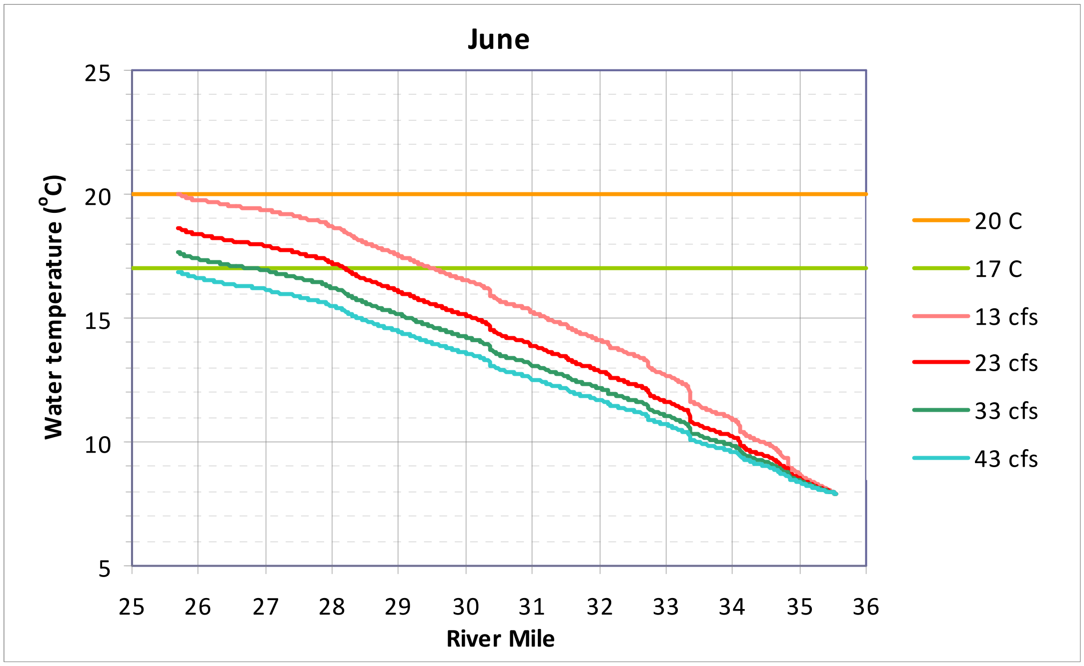


Figure 3a. Middle Fork American River below Middle Fork Interbay Modeled Sensitivity Longitudinal Profiles—June (top) and July (bottom)



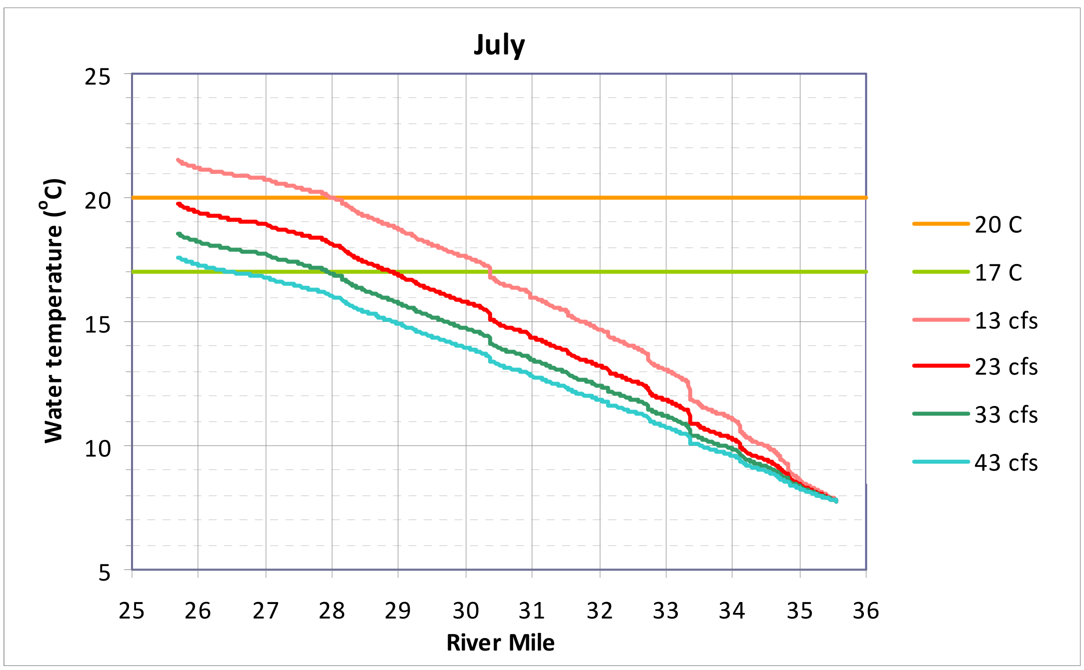
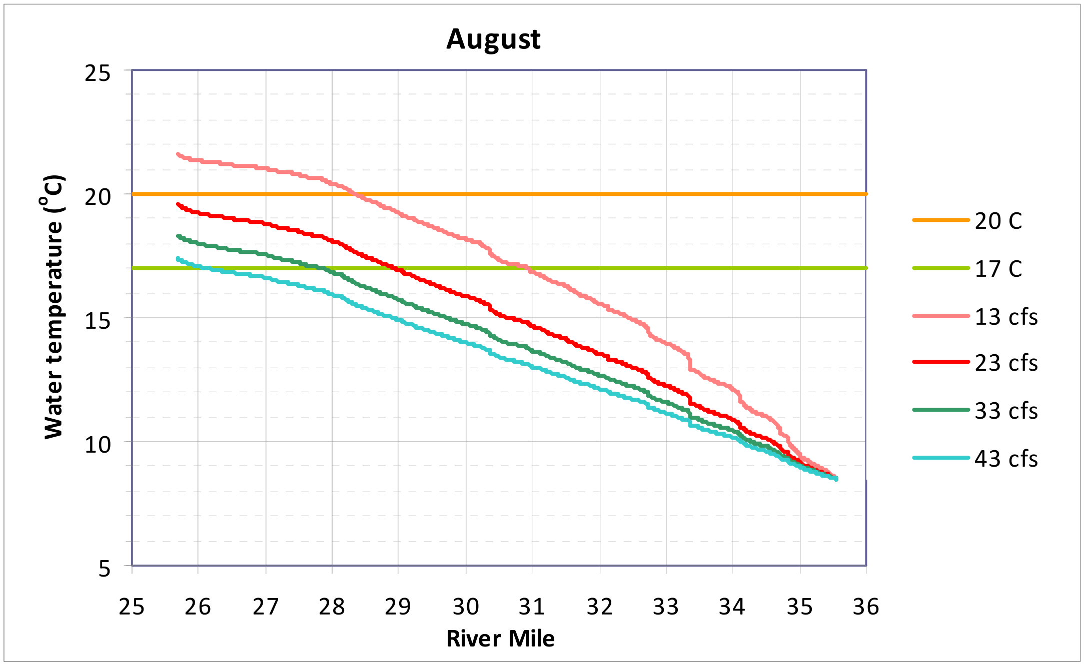


Figure 3b. Middle Fork American River below Middle Fork Interbay Modeled Sensitivity Longitudinal Profiles—August (top) and September (bottom).



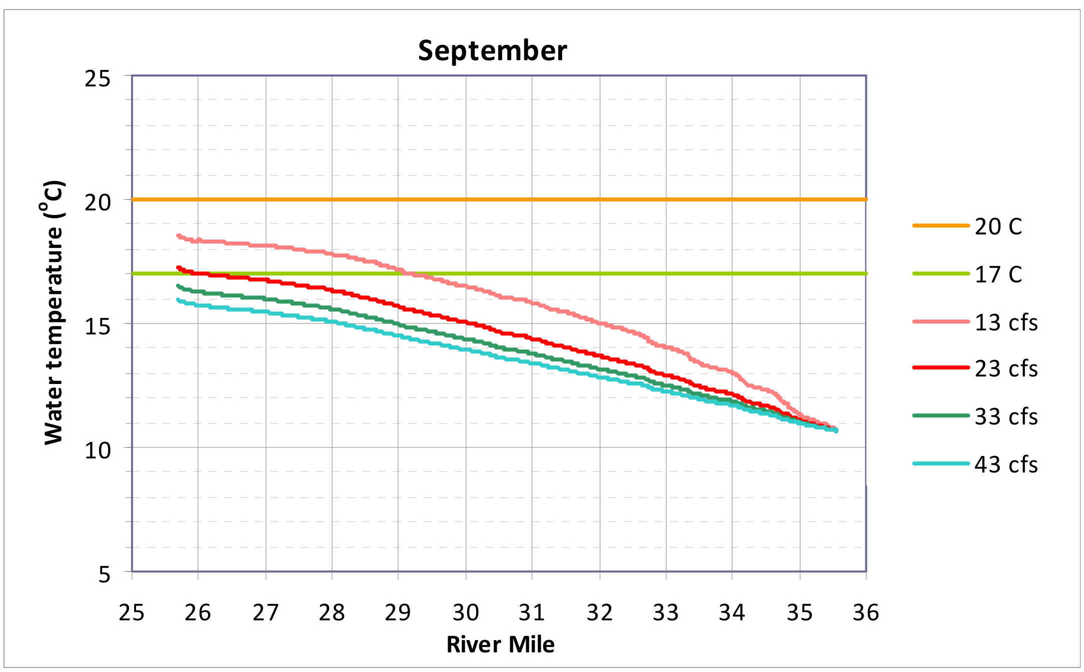
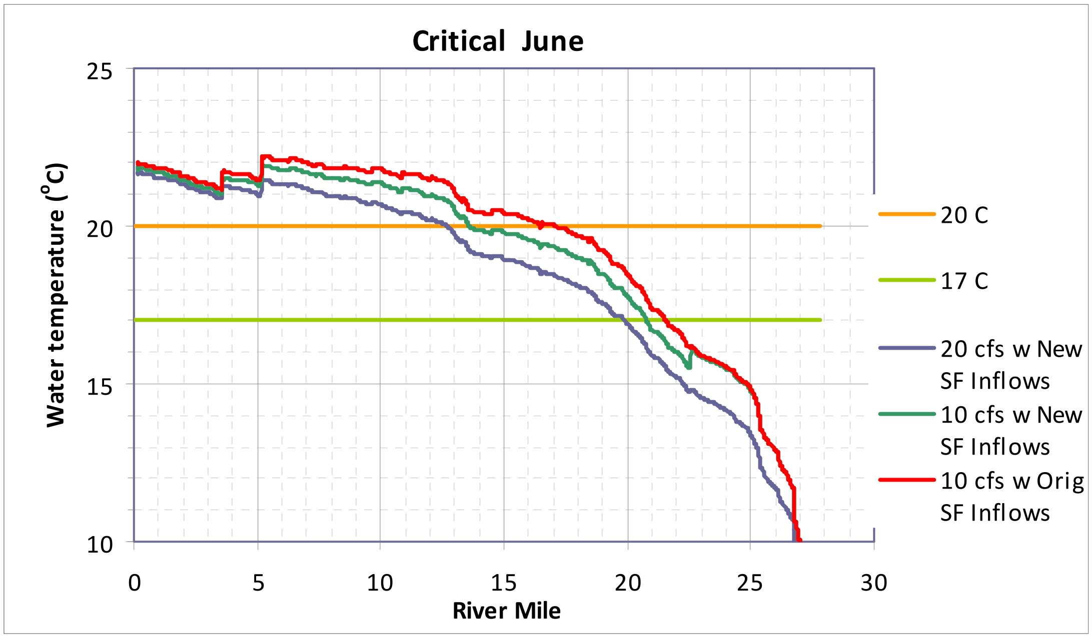


Figure 4a. Rubicon River Critical Water Year Modeled Sensitivity Longitudinal Profiles—June (top) and July (bottom).



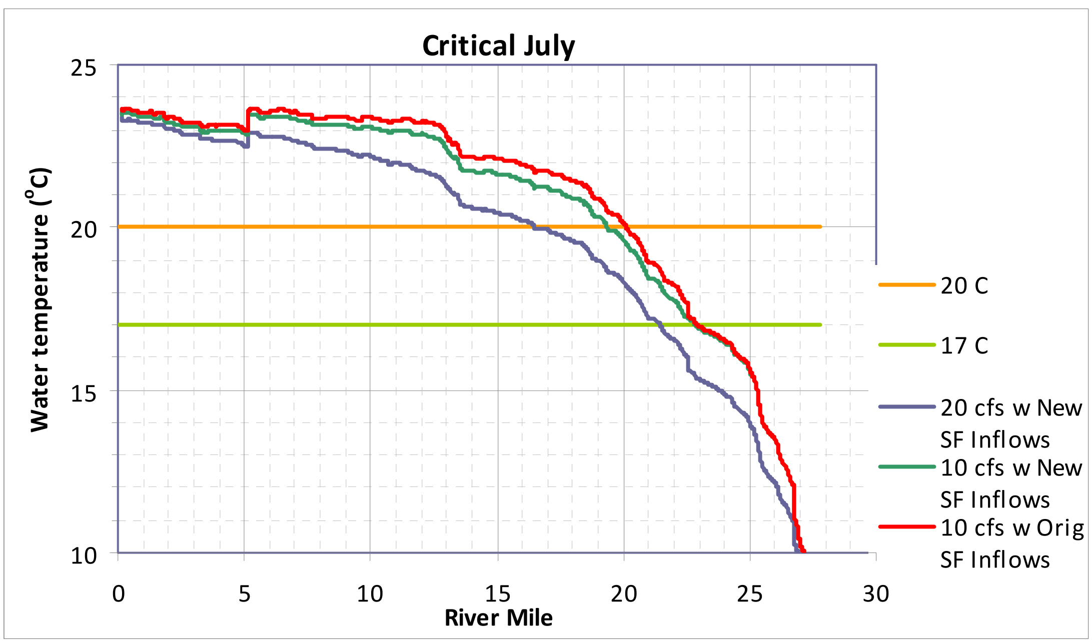
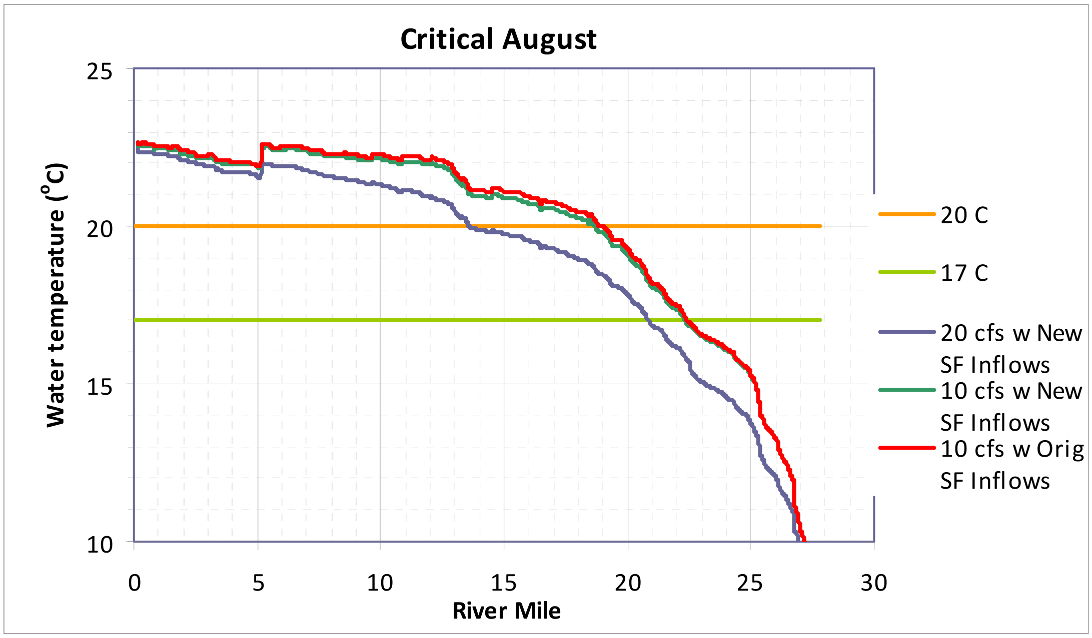


Figure 4b. Rubicon River Critical Water Year Modeled Sensitivity Longitudinal Profiles—August (top) and September (bottom).



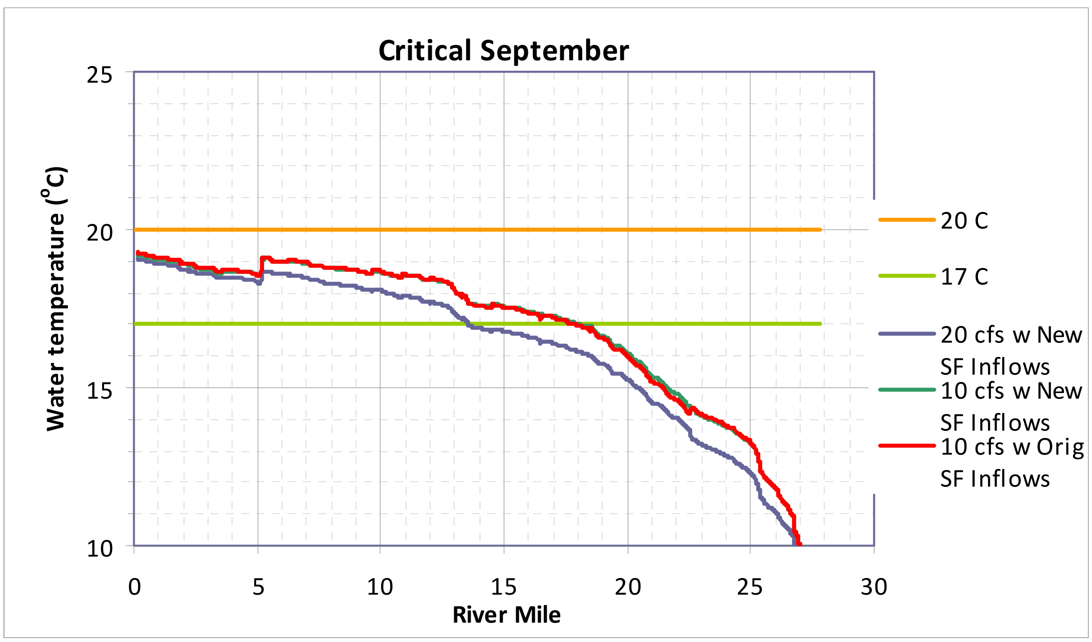
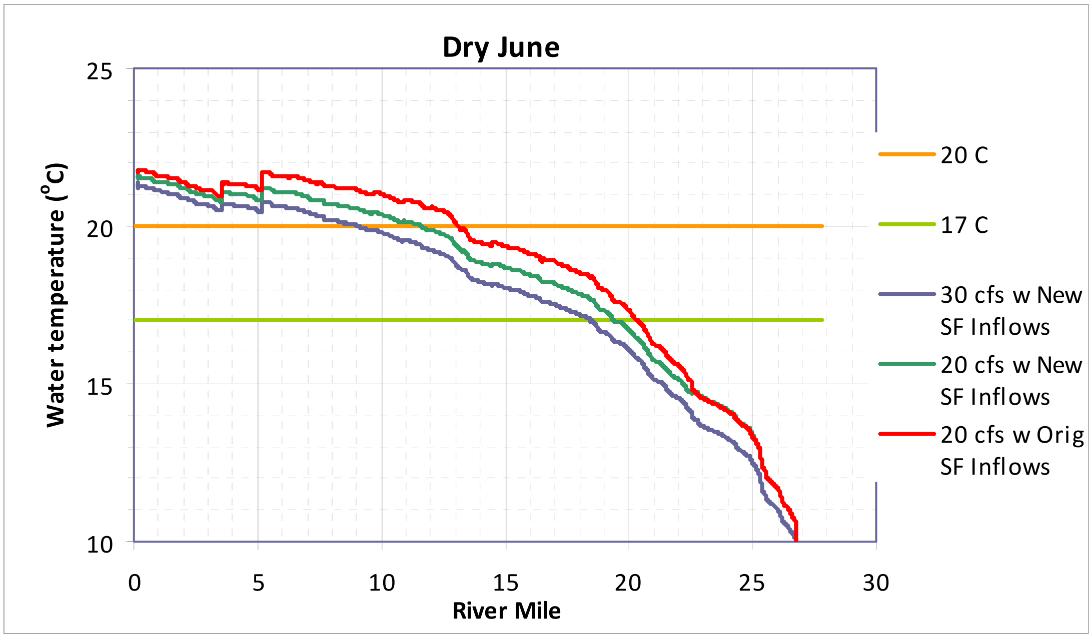


Figure 5a. Rubicon River Dry Water Year Modeled Sensitivity Longitudinal Profiles—June (top) and July (bottom).



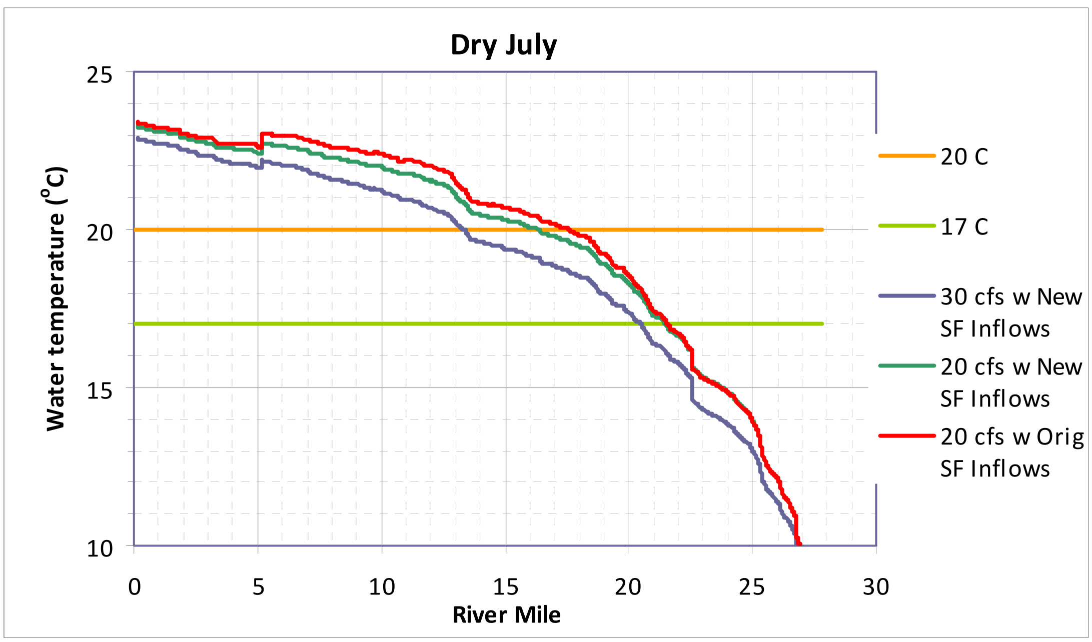
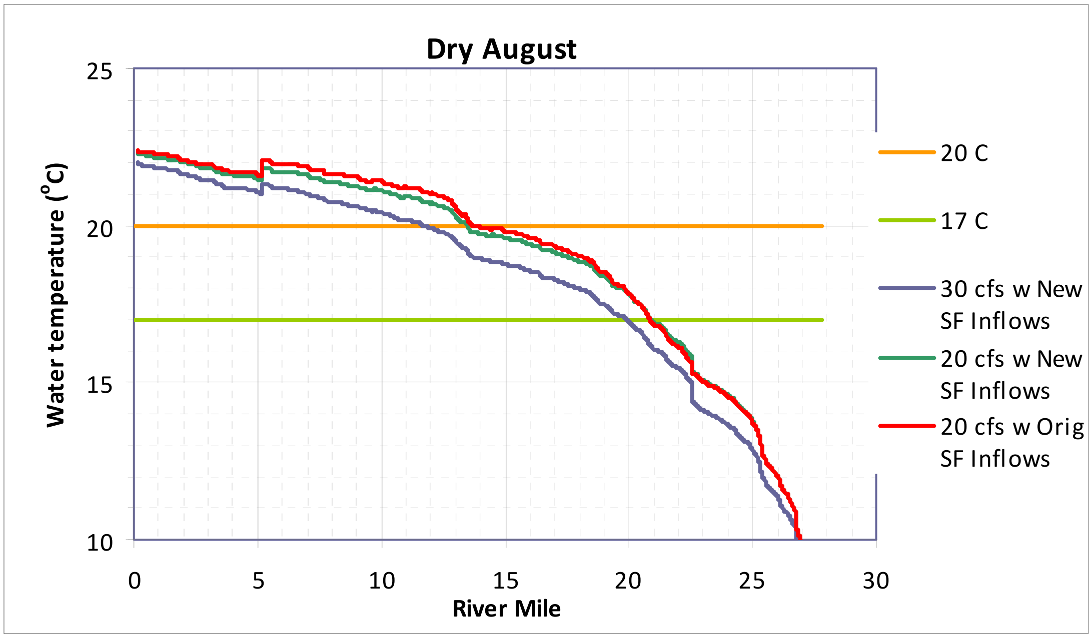


Figure 5b. Rubicon River Dry Water Year Modeled Sensitivity Longitudinal Profiles—August (top) and September (bottom).



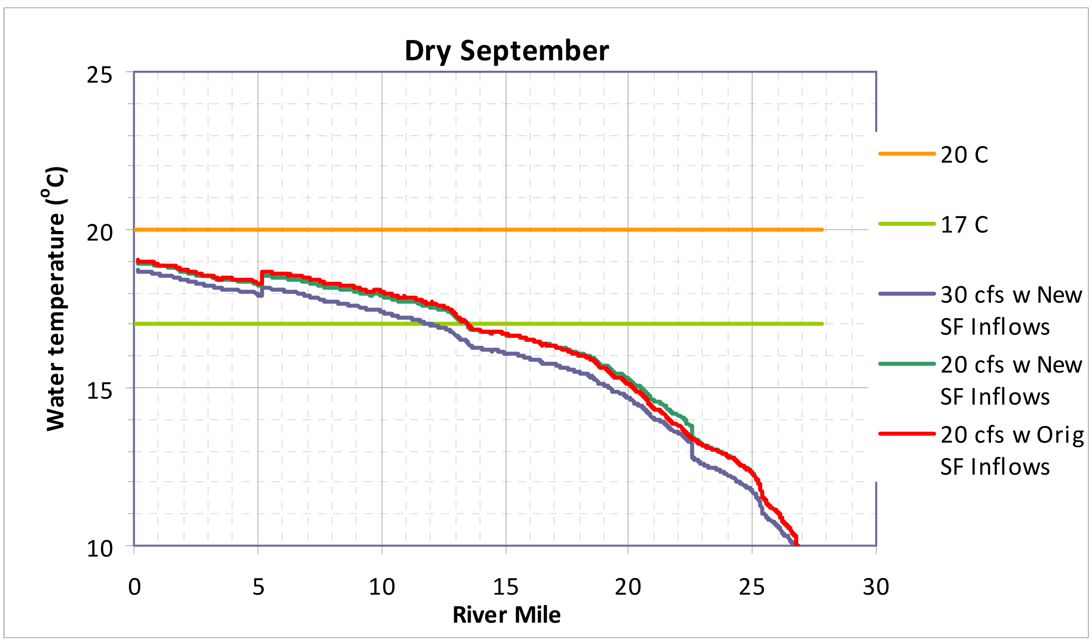
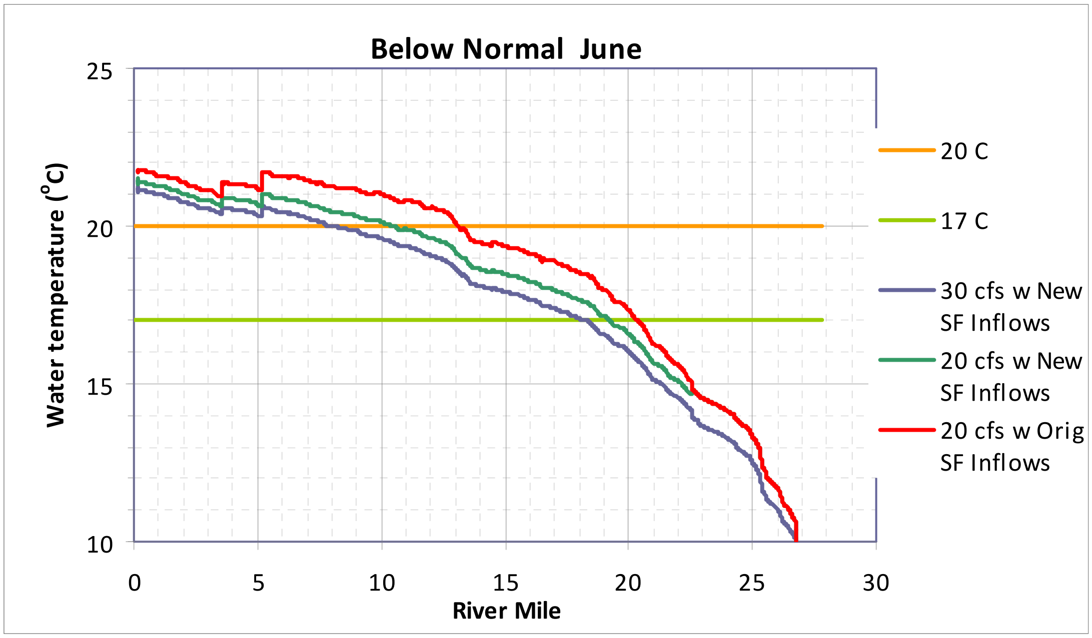


Figure 6a. Rubicon River Below Normal Water Year Modeled Sensitivity Longitudinal Profiles—June (top) and July (bottom).



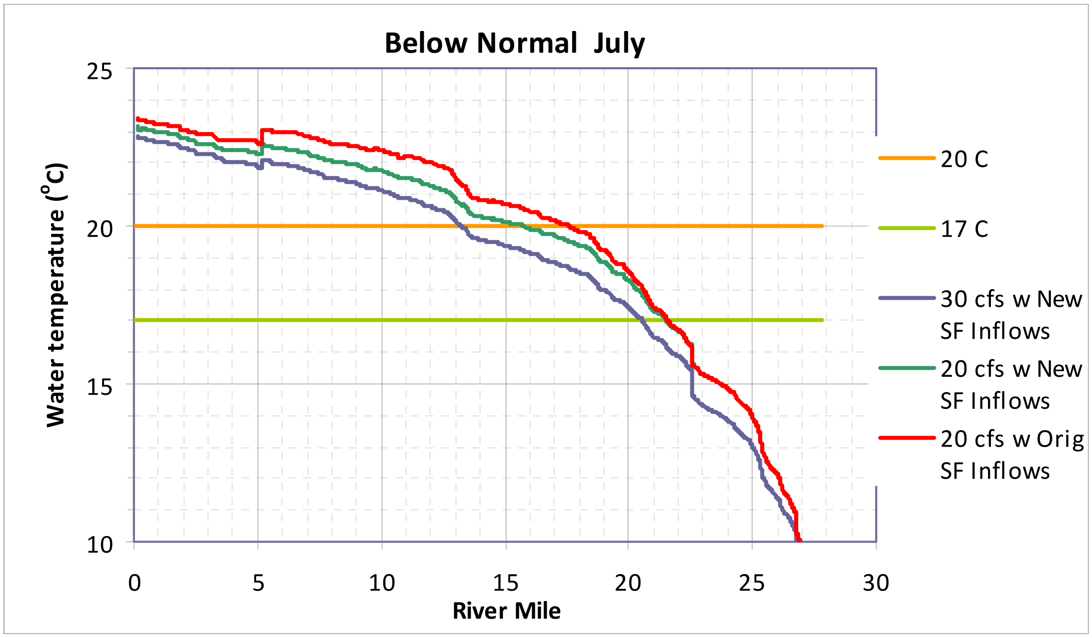


Figure 6b. Rubicon River below Normal Water Year Modeled Sensitivity Longitudinal Profiles—August (top) and September (bottom).