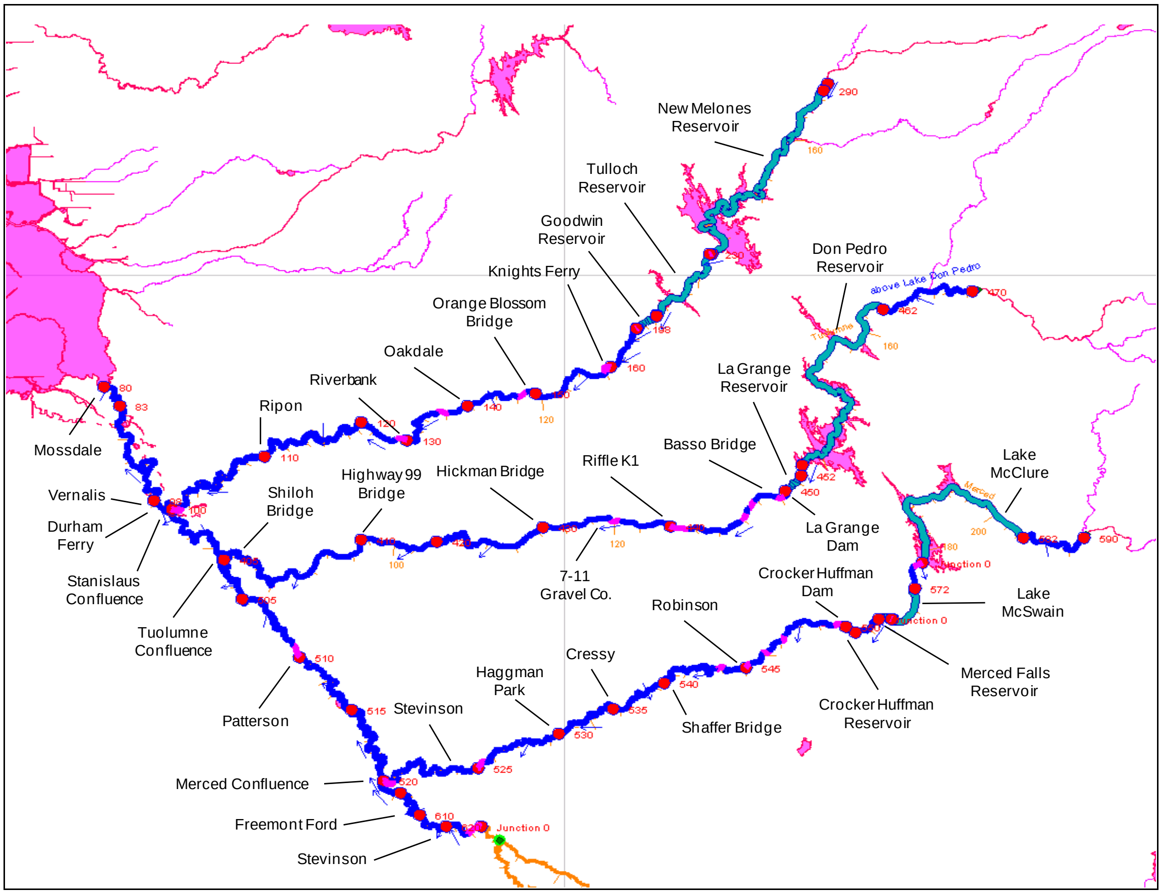
SAN JOAQUIN RIVER BASIN
WATER TEMPERATURE MODELING AND ANALYSIS



Prepared For:

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EXECUTIVE SUMMARY

Background

In the late 1990s a group of stakeholders on the Stanislaus River initiated a cooperative effort to develop a water temperature model for the Stanislaus River having recognized the need to analyze the relationship between operational alternatives, water temperature regimes and fish mortality in the Stanislaus River. These stakeholders included the U.S. Bureau of Reclamation (USBR), Fish and Wildlife Service (USFWS), California Department of Fish & Game (CDFG), Oakdale Irrigation District (OID), South San Joaquin Irrigation District (SSJID), and Stockton East Water District (SEWD).

In December 1999, these partners garnered the necessary funding and, through a cost sharing arrangement, retained AD Consultants in association with its sub-consultant Resource Management Associates to develop the model and perform a preliminary analysis of operational alternatives. In addition, the cost-sharing partners launched an extensive program for water temperature and meteorological data collection throughout the Stanislaus River Basin, in support of the modeling effort.

In 2002, the stakeholders decided unanimously to accept the model and adopt it as the primary water temperature planning tool for the Stanislaus River. Nevertheless, the stakeholders recognized the need to extend the model to the Lower San Joaquin River, thus enabling the stakeholders to study the relationship between Stanislaus operation and the temperature regime in the lower San Joaquin River enroute to the Bay-Delta.

In 2003 the project was extended to include the lower San Joaquin River through a CALFED grant (ERP-02-P28) to Tri-Dam (recipient). The model allowed analysis of temperature response at Vernalis for different operations scenarios using historical flows and water temperature at the Stanislaus - SJR confluence as boundary conditions.

In December 2004, CALFED, decided to extend the Stanislaus – Lower San Joaquin River Water Temperature Model to include the Tuolumne and Merced rivers, and the main-stem San Joaquin River from Stevenson to Mossdale (to be known as the San Joaquin River (SJR) Basin-Wide Water Temperature Model). The work was performed in two stages: 1) Through an amendment to the existing recipient agreement with Tri-Dam (ERP-02-P28), and 2) through a two-year Directed Action (ERP-06D-S20), which is the subject of this report.

Under the Amended scope, the recipient developed a comprehensive SJR Basin-Wide Water Temperature Model. In October 2006, a beta version of the model was presented to CALFED and approved through a CALFED sponsored peer review. Under the Directed Action scope the model was refined and enhanced with new features to allow more capabilities as a short and long-term planning tool as proposed by SJR stakeholders.

In November 2008 the completed model was presented to the SJR stakeholders and a working version became available for the public use.

The Model

The SJR Basin-wide Water Temperature Model is based on the HEC-5Q computer simulation model designed to simulate the thermal regime of mainstem reservoirs and river reaches. The model was designed to provide a SJR basin-wide evaluation of temperature response at 6-hour intervals for alternative conditions such as operational changes, physical changes and combinations of the two.

The extent of the model includes the Merced, Tuolumne, and Stanislaus River systems from their confluences with the San Joaquin River to the head of their mainstem reservoirs (i.e., McClure, Don Pedro, and New Melones, respectively). The upstream extent of the San Joaquin River is the United States Geological Survey (USGS) gage at Stevinson, although the HEC-5Q application has been extended upstream on the mainstem San Joaquin River to Friant Dam (this model is publically available). The downstream extent of the model is Mossdale. A schematic representation of the HEC-5 model of the San Joaquin River basin is shown in Figure 2-1.

Calibration

The model was calibrated using observed data within the period 1999 to 2007. Calibration was based on temperature profiles in the main reservoirs and time series of temperatures recorded in streams at key locations, as shown in Figure 2-1.

Calibration of reservoirs was completed by comparing computed and observed vertical reservoirs temperature profiles both graphically and statistically (e.g., fitting paired simulated and observed data with a regression). The model generally does an excellent job of reproducing the thermal structure in reservoirs and most results are within a few degrees Fahrenheit of observed values.

Calibration of the stream reaches was completed by comparing computed and observed time series temperatures both graphically and statistically (e.g., fitting paired simulated and observed data with a regression and computing model bias). The model generally does an excellent job of reproducing the thermal regime in streams. Results show Coefficient of Determination (R2) to be around 0.93 for the Stanislaus, 0.91 for the Tuolumne, 0.93 for the Merced, and 0.98 for the Main-stem SJR at most locations. The model bias defined as the difference between the average computed and observed temperatures was 0.26, 0.67, 0.32 and 0.31 degrees Fahrenheit for the four rivers, respectively.

Operations Studies

The purpose of the operations study was to demonstrate model capabilities for investigating various mechanisms for water temperature improvements in the river systems through operational and/or structural measures at the reservoirs and lakes. The end result was a fully-tested model of the four river system that stakeholders could use to identify and compare alternative operations to assist in achieving water temperature requirements throughout the system.

The calibrated model was used to perform three broad categories of modeling studies: historical operations, alternative operations, and temperature target specification scenarios.

- *Historical operations scenario – utilized historical hydrology and operations to form a baseline for comparative analysis with the other scenarios.*
- *Alternative operations scenario – focused only on the Stanislaus, where a set of prescriptive operations, such as instream flows, water allocations, and structural and/or operational changes, were implemented into the model following stakeholder development.*
- *Temperature target specification scenarios – applied to the four-river model (all basins); temperature at key locations was specified and the system was re-operated to achieve those values. Note that this model demonstration utilized hypothetical seasonal temperature targets and target location and was intended solely as a demonstration of an approach to quantifying the relationship between temperature operation and reservoir volume impacts.*

Implementation Plan

In the course of this project, the project team identified operations, system elements, and concepts that can be examined to assist resource managers in developing the necessary information to manage water temperature at the basin-scale for anadromous fish. As with previous work completed by the team, this implementation plan does not identify a schedule for completion of activities. Rather, the implementation plan is a road map to provide direction for resource managers to incorporate local knowledge of individual systems and use the tool developed herein to assist in planning and management decisions.

In addition, the team developed a plan for further enhancement of the model by incorporating other water quality parameters that can provide valuable details for water managers in the basin. For example salinity could be added to the model, or more complex water quality processes such as dissolved oxygen and associated controlling factors (e.g., nutrients and primary production).

Another potential implementation of the model is the adaptation of the model as short-term water scheduling support tool. The model contains an algorithm developed during this project that computes the flow rates from reservoirs that would result in meeting temperature objectives downstream. This algorithm could serve as the basis for a user friendly decision support tool for water managers. Using this tool (a sub-model independent of the HEC-5Q), water managers could plug-in forecasted weather, for example, for the upcoming week, water temperature as measured at the release point (below the reservoir) and temperature objectives at a specified point downstream and the model would compute the flow rate needed to meet the temperature objective.

Thermal Criteria Identification (Spreadsheet Tool)

One of several inter-related tasks in the San Joaquin River Basin Water Temperature Modeling and Analysis was the need to review and assess available information to identify water temperature criteria for fall-run Chinook salmon and steelhead. A peer review panel (Panel) was assembled to evaluate the biological merits and application of thermal criteria in assessment of model generated alternatives for the Stanislaus River. Subsequently, the Panel was reconvened and information specific to the Merced, Tuolumne, and mainstem San Joaquin River were reviewed in light of application of identified thermal criteria on the Stanislaus River.

In sum, thermal criteria were developed for various life stages (e.g., adult migration, egg incubation, juvenile rearing) of anadromous fish based on 7-day average of the maximum daily temperatures (7DADM). Panel members identified optimum threshold temperatures after EPA (2003). It should be emphasized that the stakeholders agreed that the Panel criteria should only serve as a means for comparing simulated alternatives and should not be construed as an agreed upon criteria in establishing temperature policy in the basin. Furthermore, the Panel recommended that stakeholders should build upon and/or modify the Panel criteria given their own on-the-ground experience and knowledge of fishery issues related to the Stanislaus and Lower San Joaquin river system.

Summary

The current, expanded, and calibrated model is a powerful long-term and short-term water temperature modeling tool that has been developed with broad stakeholder support. A formal peer review of the expanded model has been completed. Further, the model resides in a graphical user interface that allows stakeholders to use the model and examine output throughout the model domain. Finally, the existing HEC-5Q model can also be adapted to include a wide range of water quality parameters.

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1. Introduction

In the late 1990s a group of stakeholders on the Stanislaus River initiated a cooperative effort to develop a water temperature model for the river having recognized the need to analyze the relationship between operational alternatives, water temperature regimes, and fish mortality. These stakeholders included the U.S. Bureau of Reclamation (USBR), Fish and Wildlife Service (USFWS), California Department of Fish & Game (CDFG), Oakdale Irrigation District (OID), South San Joaquin Irrigation District (SSJID), and Stockton East Water District (SEWD). In December 1999, these partners garnered the necessary funding and, through a cost sharing arrangement, retained AD Consultants (in association with its sub-consultant Research Management Associates) to develop the model and perform a preliminary analysis of operational alternatives. In addition, the cost-sharing partners launched an extensive program for water temperature and meteorological data collection throughout the Stanislaus River Basin in support of the modeling effort.

In 2002, the project team presented to the stakeholders the calibrated model, results for the preliminary alternatives, and a peer review report of the model prepared by Dr. Michael Deas (Deas, 2001), a consultant retained by the stakeholders to evaluate the suitability of the model for its intended purpose. The stakeholders decided unanimously to accept the model and adopt it as the primary water temperature planning tool for the Stanislaus River. Nevertheless, the stakeholders recognized the need to extend the model to the Lower San Joaquin River, thus enabling the study of the relationship between Stanislaus operations and the temperature regime in the lower San Joaquin River as it flows to the Sacramento-San Joaquin Bay-Delta (Bay-Delta). The stakeholders also recommended that newly collected data be used to recalibrate the model. Due to lack of funding, the stakeholders decided to seek the support of CALFED for this effort through its Ecosystem Restoration Program (ERP). The stakeholders nominated Tri-Dam (Oakdale and South San Joaquin Irrigation Districts) to submit a proposal to the ERP for this project on behalf the entire Stanislaus stakeholders group.

In 2003 the project was extended to include the lower San Joaquin River through a CALFED grant (ERP-02-P28) to Tri-Dam (recipient), which is the subject of this report. A principal priority of this CALFED sponsored project was to develop a model capable of evaluating a wide range of alternatives for flow and water temperature management in the Stanislaus River and lower San Joaquin River. The work is also consistent with CALFED's milestone 84 – "to develop water temperature management program [*sic*] for San Joaquin River tributaries" – and milestone 85 – "to identify thermal impacts of irrigation return flows in the San Joaquin River". The project team was expanded to include Watercourse Engineering, Inc. and a peer review panel assigned to assist in developing temperature criteria for the evaluation of model alternatives.

The success of the project generated appreciable attention from stakeholders within other tributary basins of the San Joaquin River, especially the Tuolumne and Merced Rivers, who have been dealing with water temperature related issues similar to those on the Stanislaus River. The primary stakeholders in the Tuolumne River (Turlock Irrigation District and Modesto Irrigation District) and in the Merced River (Merced Irrigation District) basins expressed interest in adopting the same model for their own river system. Further, all the stakeholders recognized the value in combining the individual models for the Stanislaus, Tuolumne, and Merced Rivers into a single, basin-wide model, thus allowing the assessment of overall water operations and water temperature management scenarios in the San Joaquin River basin.

In December 2004, CALFED decided to extend the Stanislaus-Lower San Joaquin River Water Temperature Model to include the Tuolumne and Merced rivers, and the mainstem San Joaquin River from Stevinson to Mossdale (to be known as the San Joaquin River (SJR) Basin-Wide Water Temperature Model). The work was to be performed in two stages: 1) through an amendment to the existing recipient agreement with Tri-Dam (ERP-02-P28), and 2) through a two-year Directed Action. Under the amended scope, a beta-version of the model was developed. This beta-version underwent peer review via a CALFED sponsored process administered by the University of California (separate from the peer review panel assessing thermal criteria). Subsequently, the Directed Action allowed further refinement of the model and investigation, using the model, of various mechanisms for water temperature improvements both through operational and/or structural measures at existing facilities in all three tributaries of the San Joaquin River. This work commenced in October 2006.

The culmination of this work was a series of workshops and stakeholder participation wherein the model was available to interested parties and selected applications were completed to illustrate the efficacy of the tool.

In November 2008 the completed model was presented to the SJR stakeholders and a working version became available for the public use.

1.1. Project Objectives

The primary objective of this project was to develop an effective water temperature modeling tool for the San Joaquin River from Stevinson to Mossdale, including the Merced, Tuolumne, and Stanislaus Rivers and their respective mainstem reservoirs (Figure 1-1). Development of the model allows assessment of alternative water management actions in multiple basins with a single model.

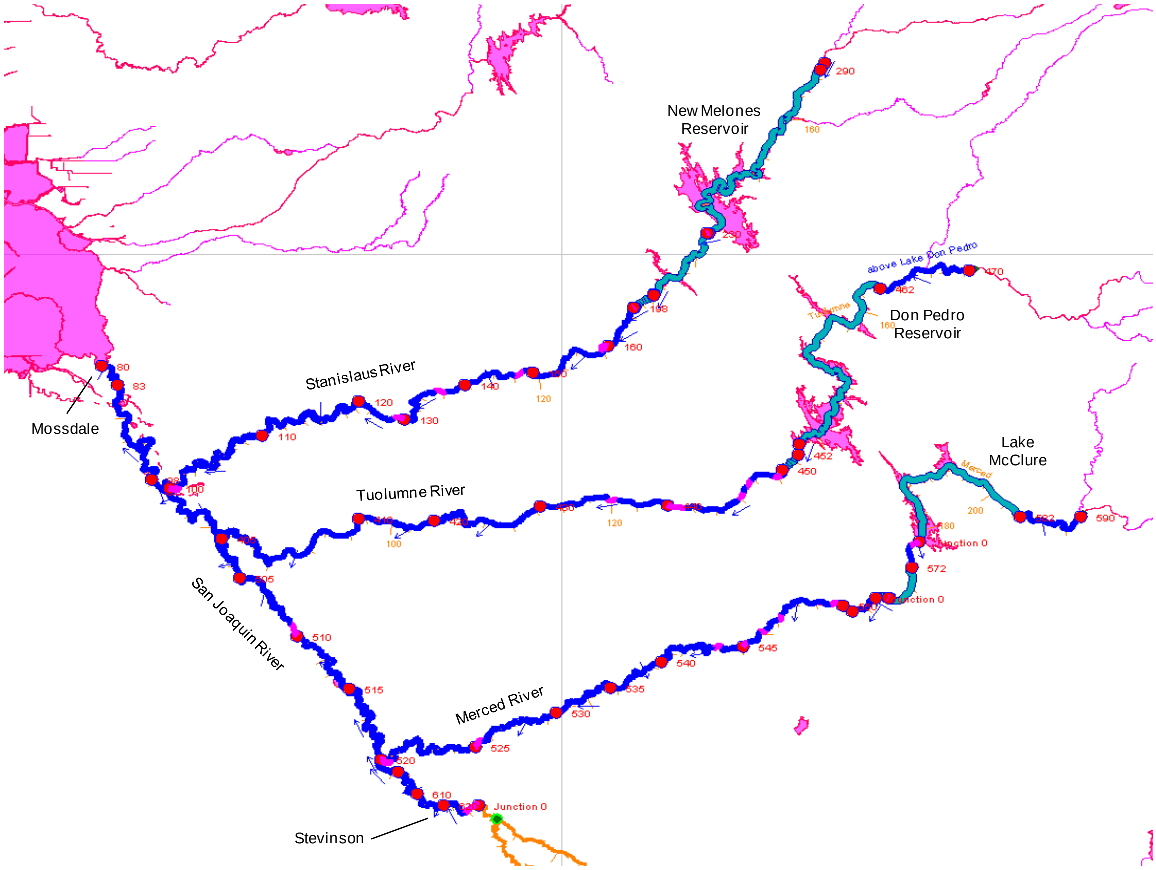

Figure 1-1. The San Joaquin River basin, including the Stanislaus, Tuolumne, and Merced rivers.

The secondary objective was to perform detailed modeling and analysis of various alternatives for water management in the San Joaquin River basin to achieve the following:

1. Determine the relationship between water operations and river temperatures throughout the San Joaquin River basin below Stevinson.
2. Refine and extend current water temperature criteria for anadromous fish to the San Joaquin River below Stevinson and for the Merced, Tuolumne, and Stanislaus Rivers.
3. Explore water operational strategies using the model and assess the potential merit of various water operational alternatives on water temperature.
4. Recommend a course or courses of action.

To achieve the identified objectives, the project team implemented the HEC-5Q model on the San Joaquin river system and major tributaries, calibrated the model, and applied the model to various investigations for water temperature improvements both through operational and/or structural measures. The project team analyzed the merit of those alternatives and developed a preliminary plan for the implementation of selected alternatives.

1.2. Report Organization

The report is designed to provide a description of the overall work conducted under this CALFED contract (ERP-02-P28) and the necessary background needed for potential users before applying the model. The report has been divided into seven sections:

Section 1 provides an overview of the project and its objectives. Section 2 describes the HEC-5Q model and its adaptation to the San Joaquin river system. Section 3 presents model calibration results. Section 4 provides an overview of operations studies performed with the model including temperature objectives and alternatives analyzed. Section 5 introduces a preliminary implementation plan. Section 6 contains the report conclusions and Section 07 contains the references cited in the report. This report also includes three appendices. Appendix A (Section 8) contains the additional calibration and comparison plots. Appendix B (Section 9) contains information for the Thermal Criteria Identification (Spreadsheet Tool). Appendix C (Section 10) contains a list of acronyms used in this document. Appendix D (Section 11) contains links from where the model and supporting files can be downloaded.

2. Model Description

The water quality simulation module (HEC-5Q) was developed to assess temperature and a conservative water quality constituent in basin-scale planning and management decision-making. The application of HEC-5Q to the San Joaquin, Merced, Tuolumne, and Stanislaus Rivers computes the vertical or longitudinal distribution of temperature in the reservoirs and longitudinal temperature distributions in stream reaches based on daily average flows. Reservoirs represented in the model include McClure, McSwain, Merced Falls, and Crocker Huffman on the Merced River; Don Pedro and La Grange on the Tuolumne River; and New Melones, Tulloch, and Goodwin on the Stanislaus River.

HEC-5Q can be used to evaluate options for coordinating reservoir releases among projects to examine the effects on flow and water quality at specified locations in the system. Example applications of the flow simulation model include examination of reservoir capacities for flood control, hydropower, and reservoir release requirements to meet water supply and irrigation demands. The model can be applied to a wide array of applications including evaluation of in-stream temperatures and several water quality constituent concentrations at critical locations in the system, examination of the potential effects of changing reservoir operations, and/or water use patterns on temperature or water quality constituent concentrations. Further, reservoir selective withdrawal operations (either existing or proposed facilities) can be simulated using HEC-5Q to determine necessary operations to meet water quality objectives downstream.

Although a comprehensive water quality model, the HEC-5Q model used in the San Joaquin River basin utilized only temperature and the conservative tracer (for mass continuity checking). A brief description of the processes affecting these two parameters is provided below. Refer to the HEC-5Q users manual (HEC, 1999; 2000) for a more complete description of the water quality relationships included in model.

Temperature

The external heat sources and sinks that were considered in HEC-5Q were assumed to occur at the air-water interface and at the sediment-water interface. Equilibrium temperature and coefficient of surface heat exchange concepts were used to evaluate the net rate of heat transfer. Equilibrium temperature is defined as the water temperature at which the net rate of heat exchange between the water surface and the overlying atmosphere is zero. The coefficient of surface heat exchange is the rate at which the heat transfer process progresses. All heat transfer mechanisms, except short-wave solar radiation, were applied at the water surface. Short-wave radiation penetrates the water surface and may affect water temperatures below the air-water interface. The depth of penetration is a function of adsorption and scattering properties of the water as affected by particulate material (i.e. phytoplankton and suspended solids). The heat exchange with the bottom is a function of conductance and the heat capacity of the bottom sediment.

Conservative Parameter / Tracer

The conservative parameter is unaffected by decay, settling, uptake, or other processes, and thus acts as a tracer – passively transported by advection and diffusion. This parameter was used to check mass continuity by setting the concentration of the tracer in all inflows to a constant value and then checking to ensure simulation results reproduced the specified concentration.

2.1. Model Representation of the Physical System

The San Joaquin River basin model incorporates the Merced, Tuolumne, and Stanislaus River systems from their confluences with the San Joaquin River to the head of their mainstem reservoirs (i.e., McClure, Don Pedro, and New Melones, respectively). The upstream extent of the San Joaquin River is the United States Geological Survey (USGS) gage at Stevinson, although the HEC-5Q application has been extended upstream on the mainstem San Joaquin River to Friant Dam (this model is publically available). The downstream extent of the model is Mossdale. A schematic representation of the HEC-5 model of the San Joaquin River basin is shown in Figure 2-1.

Rivers and reservoirs within the San Joaquin River basin model were represented as a network of discrete sections (reaches and/or layers, respectively) for application of HEC-5 for flow simulation and HEC-5Q for temperature simulation. Within this network, control points (CP) were designated to represent reservoirs and selected stream locations where flow, elevations, and volumes were completed. In HEC-5, flows and other hydraulic information are computed at each control point. Within HEC-5Q, stream reaches and reservoirs were partitioned into computational elements to compute spatial variations in water temperature between control points. Within each element, uniform temperature was assumed; therefore the element size determines the spatial resolution. The model representation of reservoirs and streams is summarized in Sections 2.2 and 2.3.

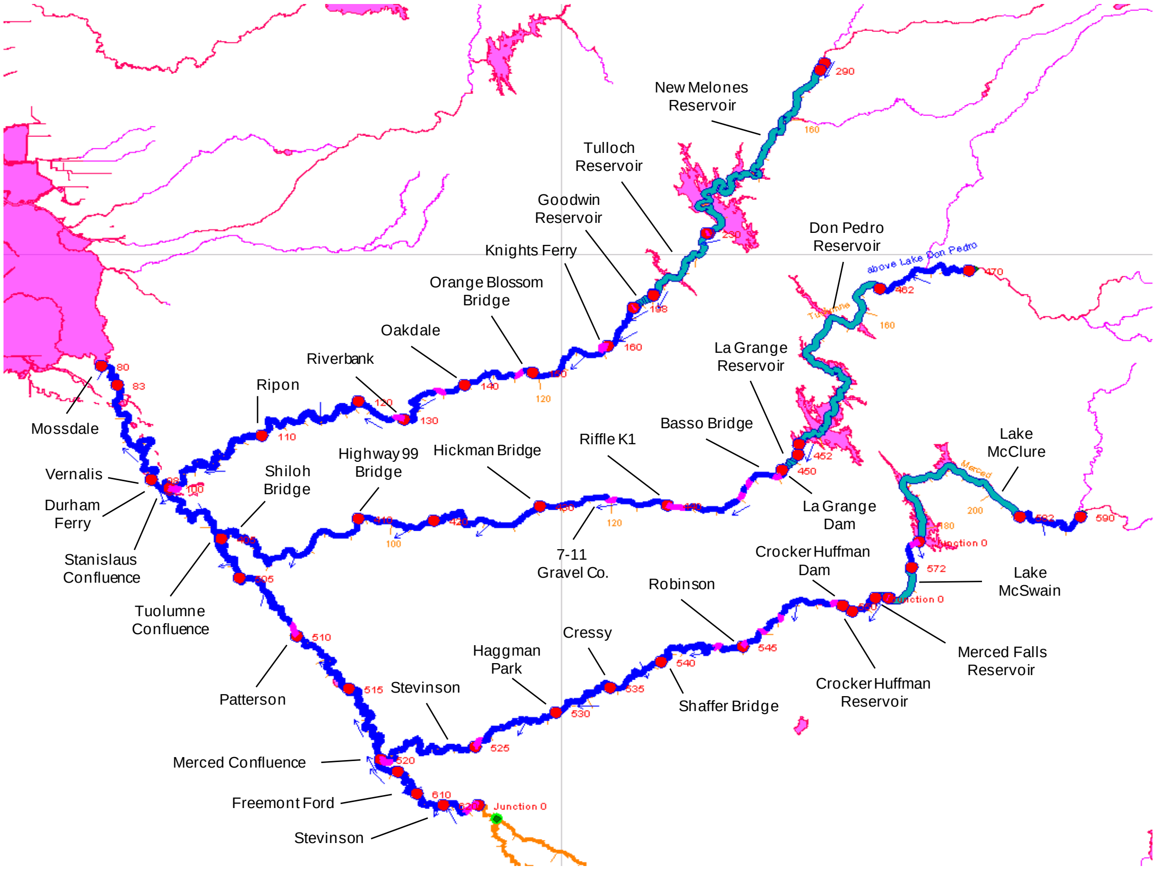

Figure 2-1. The San Joaquin River basin, including the Stanislaus, Tuolumne, and Merced River systems, as represented in the HEC-5 model.

2.2. Model Representation of Reservoirs

Within HEC-5Q, reservoirs can be represented as vertically or longitudinally segmented water bodies. Typically, the vertically segmented representation is applied to reservoirs that are prone to seasonal stratification, while longitudinally segmented representations are applied to impounded waters that retain riverine characteristics (e.g., a short residence time, intermittent/weak, stratification). For water quality simulations, McClure, Don Pedro, New Melones, and Tulloch Reservoirs were geometrically discretized and represented as vertically segmented water bodies with layers approximately 2 feet thick. The smaller reregulating and/or diversion facilities (McSwain, Merced Falls, and Crocker Huffman on the Merced River; LaGrange on the Tuolumne River; and Goodwin Reservoir on the Stanislaus River) were represented as vertically layered and longitudinally segmented water bodies. A 6-hour model time step was used for all reaches. A description of the different types of reservoir representation follows.

2.2.1. Vertically Segmented Reservoirs

Vertically stratified reservoirs are represented conceptually by a series of one-dimensional horizontal slices or layered volume elements, each characterized by an area, thickness, and volume. The aggregate assemblage of layered volume elements is a geometrically discretized representation of the prototype reservoir. The geometric characteristics of each horizontal slice are defined as a function of the reservoir's area-capacity curve. Within each horizontal layer (or 'element') of a vertically segmented reservoir, the water is assumed to be fully mixed with all isopleths parallel to the water surface both laterally and longitudinally. External inflows and withdrawals occur as sources or sinks within each element and are instantaneously dispersed and homogeneously mixed throughout the layer from the headwaters of the impoundment to the dam. Consequently, simulation results are most representative of conditions in the main reservoir body and may not accurately describe flow or quality characteristics in shallow regions or near reservoir banks. It is not possible to model longitudinal variations in water quality constituents using the vertically segmented configuration.

The allocation of the inflow to individual elements is based on the relative densities of the inflow and the reservoir elements. Flow entrainment is considered as the inflowing water seeks a depth or level of similar density.

Vertical advection is one of two transport mechanisms used in HEC-5Q to simulate transport of water quality constituents between elements in a vertically segmented reservoir. Vertical transport is defined as the inter-element flow that results in flow continuity. An additional transport mechanism used to distribute water quality constituents between elements is effective diffusion, representing the combined effects of molecular and turbulent diffusion, and convective mixing or the physical movement of water due to density instability. Wind and flow-induced turbulent diffusion and convective mixing are the dominant components of effective diffusion in the epilimnion of most reservoirs.

The outflow component of the model incorporates a selective withdrawal technique for withdrawal through multiple dam outlet or other submerged orifices or for flow over a weir. The relationships developed for the 'WES Withdrawal Allocation Method' describe the vertical limits of the withdrawal zone and the vertical velocity distribution throughout the water column (HEC, 1986).

For the large, mainstem reservoirs the existing conditions incorporated into HEC-5Q are discussed below.

2.2.1.1. Stanislaus River

The Stanislaus River is represented by two vertically segmented reservoirs: New Melones and Tulloch. New Melones has approximately 2,420 thousand acre-feet (taf[1]) of storage, with a dead pool of 25 taf. There are two elevations from which to withdraw water, in addition to the spillway. The highest outlet works are associated with the power intakes (elevation of 775 feet at the top of the intake pipes), which is always utilized for water surface elevations greater than 786.5 feet. The low-level outlet (two pipes) operates at lake elevations less than 786.5 feet. New Melones spillway has never been used although it would be if releases greater than 7,700 cubic feet per second (cfs) occurred.

Downstream of New Melones is Tulloch Reservoir, which has about 67 taf of storage and

[1] 1 million acre-feet (maf) = 1,000 thousand acre-feet (taf) = 1,000,000 acre-feet (af).

11 taf of dead pool storage. The reservoir has a low-level outlet works associated with its power intake. It is always used except for flows greater than 2,060 cfs, at which point excess flows are passed through the gated spillway.

2.2.1.2. Tuolumne River

The Tuolumne River mainstem reservoir, Don Pedro, has approximately 2,030 taf of storage and a maximum storage elevation of approximately 830 feet. The outlet works are located at 535 feet. Like New Melones (discussed in 2.2.1.1), Don Pedro reservoir was expanded and the original dam was inundated when the newer dam was completed. The old dam had a crest elevation of 607 feet and the spillway was located at 590 feet. The original outlet elevation was approximately 475 feet, but it is only active when the spillway of the old dam is above the water surface elevation. The power outlet for the new dam is below the elevation of the old dam, so all power releases must pass over the old dam which is represented in the model as a submerged weir. The old dam begins to influence temperatures as the storage approaches 500 taf (corresponding to a water surface elevation of about 45 feet above the old dam) and the storage behind old dam is approximately 280 taf.

2.2.1.3. Merced River

The Merced River is represented by two vertically segmented reservoirs: Lake McClure and McSwain. Lake McClure has approximately 1,025 taf of storage. Lake McClure has a single outlet located in the old dam that has been incorporated into the new dam (New Exchequer). The outlet works are located at the bottom of the reservoir; the centerline elevation of the outlet is approximately 490 feet, about 40 feet above the reservoir bottom. Dead pool storage is about 10 taf.

Lake McSwain, downstream of Lake McClure, has approximately 10 taf (9,730 af) of storage. The outlet is located at approximately 370 feet.

2.2.2. Longitudinally Segmented Reservoirs

Longitudinally segmented reservoirs are represented conceptually as a linear network of segments or volume elements. The length of a segment, coupled with an associated stage-width relationship, characterize the geometry of each reservoir segment. Surface areas, volumes and cross-sectional areas are computed from the width relationship.

Additionally, longitudinally segmented reservoirs can be subdivided into vertical elements, with each element assumed fully mixed in the vertical and lateral directions. Branching of reservoirs is allowed. For reservoirs represented as layered and longitudinally segmented, all cross-sections contain the same number of layers and each layer is assigned the same fraction of the reservoir cross-sectional area. Therefore, the thickness of each element varies with the width versus elevation relationship for each element. The model performs a backwater computation to define the water surface profile as a function of the hydraulic gradient based on flow and Manning's equation.

A uniform vertical flow distribution is specified at the upstream end of each reservoir. Velocity profiles within the body of the reservoir may be calculated as flow over a submerged weir or as a function of a downstream density profile. Linear interpolation is performed for reservoir segments without specifically defined flow fields.

External flows, such as withdrawals and tributary inflows, occur as sinks or sources within the segment. Inflows to the upstream ends of reservoir branches are allocated to individual elements in proportion to the fraction of the cross-section assigned to each layer. Other inflows to the reservoir are distributed in proportion to the local reservoir flow distribution. External flows may be allocated along the length of the reservoir to represent dispersed non-point source inflows such as agricultural drainage and groundwater accretions.

Vertical variations in constituent concentrations can be computed for the layered and longitudinally segmented reservoir model. Mass transport between vertical layers is represented by net flow determined by mass balance and by diffusion.

Vertical flow distributions at dams are based on weir or orifice withdrawal. The velocity distribution within the water column is calculated as a function of the water density and depth using the WES weir withdrawal or orifice withdrawal allocation method.

2.2.2.1. Merced River

Downstream of McSwain Reservoir is Merced Fall Reservoir. Merced Falls Dam has a gated spillway that pass all releases to the river. The outlet is represented as a 100-foot wide weir with a crest elevation of 344 feet.

Further downstream is Crocker Huffman Reservoir, formed by Crocker-Huffman Dam that passes flow over the dam crest (elevation 303 feet) over the length of the dam. A weir representation skims the warmer surface waters for discharge to the river although this is only a small vertical temperature variation computed by the model. Dam leakage and flow through the hatchery was ignored.

2.2.2.2. Tuolumne River

Downstream of Don Pedro Reservoir is La Grange Reservoir, which is formed by La Grange Dam. La Grange Dam passes flow over the dam crest (elevation 294 feet) over the length of the dam. However, La Grange Reservoir is silted in to the extent that there is essentially no thermal stratification.

2.2.2.3. Stanislaus River

Downstream of Tulloch Reservoir, Goodwin Reservoir, formed by Goodwin Dam, currently has no low-level outlet. The seasonally warmer surface waters are thus preferentially released to the river (over the spillway, elevation 359 feet) and deeper, cooler water is diverted to the two water districts. The Goodwin retrofit plan, discussed in AD *et al*. (2008), incorporates a low-level siphon to access the deeper, cooler waters for release downstream.

2.2.3. Logic Representing Old Dams

The construction of the large mainstem reservoirs on Tuolumne and Stanislaus rivers have inundated previously constructed smaller dams. A brief discussion of this logic is included herein for each reservoir.

2.2.3.1. New Melones Reservoir

New Melones Reservoir is a large impoundment that is subject to strong seasonal stratification. Of special interest are the representation of New Melones Reservoir and, in particular, the impacts of the old dam on the flow and thermal regime of the reservoir and the reservoir release temperatures. The old dam has a crest elevation of 735 feet and a spillway elevation of 723 feet. The original outlet works are located at approximately 610 feet. The new dam has a crest elevation of 1135 feet and a spillway elevation of 1088 feet. There are two different outlet works for the new dam: the power intakes and the low-elevation outlet. The primary intake for New Melones Dam is at elevation 760 feet (invert elevation) and the top of the intake structure is approximately 775 feet. The lower elevation outlet is at 543 feet.

When water surface elevations are above 785 feet, the power intake is used to generate hydropower. Below that elevation, the lower-elevation outlet is used due to operational constraints. For water levels from 785 feet to 728 feet (five feet above the old dam spillway invert), all water is assumed to pass over the crest and/or the spillway of the old dam. Below 728 feet all flows must pass through the old dam's low elevation outlet.

More details on the calculation methods for flow and temperature in New Melones are available in AD *et al.* (2008).

2.2.3.2. Don Pedro

Similar to New Melones, New Don Pedro dam inundated the old Don Pedro dam when completed in 1971. The old spillway is located at approximately 590 feet, about 17 feet below the top of the old dam. The original low-level outlet is at 475 feet, but it is only active when the water surface elevation in Don Pedro is below the top of the old spillway. The power intakes of the new dam are located at about 535 feet, below the old spillway. For the most part, the old dam acts as a submerged weir, with all power release flowing over the top of the old dam. The old dam begins to influence temperatures as the storage approaches 500,000 af, corresponding to a water surface elevation of about 650 feet.

2.3. Model Representation of Streams

Stream representation in HEC-5Q includes representation of system geometry and flow representations. The representations are briefly outlined below.

2.3.1. Stream Reaches

In HEC-5Q, river or stream reaches are represented conceptually as a linear network of segments or volume elements. The length, width, cross-sectional area and a flow versus depth relationship characterize each element. Cross-sections are defined at all control points and at intermediate locations where data are available. The flow versus depth relation is developed external to HEC-5Q using available cross-section data and appropriate hydraulic computations. Linear interpolation between input cross-section locations is used to define the hydraulic data for each element. Details of each river representations are outlined below.

2.3.1.1. Stanislaus River

For the Stanislaus River, three river reaches are modeled.

- Upstream of New Melones Reservoir,
- Between New Melones Dam and Tulloch Reservoir, and
- From Goodwin Dam to the confluence with the San Joaquin River.

Upstream of New Melones Reservoir, a short river reach is modeled, wherein the modeled length is a function of New Melones elevation. This variable length allows heat exchange in the normally inundated old river channel to be simulated. Downstream of New Melones, United States Army Corps of Engineers' (Corps) cross-sections, field reconnaissance, and aerial photographs were used to define the geometry of the stream reaches. A total of 83 cross sections were utilized to define the river geometry.

2.3.1.2. Tuolumne River

The Tuolumne River is divided into six stream reaches below La Grange Reservoir. A brief description of each reach data source is provided below.

- Confluence (river mile (RM) 0) to RM 23.8 was based on Reach 21 and 23 in the Corps' UNET model.
- RM 23.8 to 24.3, the geometry for this short reach was achieved by interpolating between the upstream and downstream adjacent reaches.
- RM 24.3 to 26.1 is from data developed by HDR for the Tuolumne River restoration program HEC-RAS model (M. Garello, personal communication, October 10, 2005).
- RM 26.1 to 33.6 was based on synthesized data. Cross sections were generated at 500-foot intervals by interpolating between adjacent reaches. To mimic the range of mean channel velocities observed in adjacent reaches, the bottom of approximately 2/3 of the sections were either lowered or raised to achieve a ripple and pool effect.
- RM 33.6 to 37.9 was developed from the Ruddy Segment (RS 177300-21074) data developed by HDR for the Tuolumne River restoration program (geometry data use in supporting this report were used in the current project).
- RM 37.9 to 51.5 was developed from 142 cross sections at 500-foot intervals generated from preliminary Light Detection and Ranging (LIDAR) and bathymetry data provided by McBain & Trust (F. Meyer, personal communication, October 3, 2005).

2.3.1.3. Merced River

The Merced River is divided into five stream reaches below Crocker Huffman Reservoir.

A brief description of each reach data source is provided below.

- Confluence (RM 0) to RM 20.3 was based on Reach 19 in the Corps' UNET model.
- RM 20.3 to 36.4 was from USGS data within the 1968 report "Determination of Channel Capacity of the Merced River Downstream from Merced Falls Dam, Merced County, California" (USGS, 1968). The sections were entered at one mile intervals with intermediate sections interpolated at 1000-foot intervals.[2]
- RM 36.4 to 40.5 did not have any data for this reach. As such, the HEC-RAS cross section were interpolated at 1000-foot intervals.
- RM 40.5 to 44.2 were based on cross sections for the restoration reach. (Some of the sections are primarily channel sections and do not include significant overflow areas).
- RM 45.0 to 51.9 was based on a HEC-2 data set developed from Stillwater Sciences' surveyed cross sections (Stillwater, 2004).

2.3.1.4. San Joaquin River

San Joaquin River was divided into four reaches between Stevinson and Mossdale.

- Stevinson (RM 132) to the Merced River confluence (RM 117),
- Merced River confluence to the Tuolumne River confluence (RM83),
- Tuolumne River confluence to Stanislaus River confluence (RM 74), and
- Stanislaus River confluence to Mossdale (RM57.5).

Including the reach between Stevinson and the Merced confluence allowed for the representation of three independent sources (mainstem at Stevinson, Mud Slough, and Salt Slough) in the CALFED model. All San Joaquin River cross sections were based on the Corps' UNET model cross sections. The general approach to generating the cross section inputs to HEC-5Q is as follows:

- Develop a HEC-RAS model for each river using available cross section data.
- Compute water surface profiles for the anticipated range of flows.
- Develop a curve fit that relates HEC-RAS output (e.g., elevation, area, surface width, etc.) to river mile.
- Integrate the curve so that the HEC-5Q cross sections represent channel

[2] The data is from 1968 and most likely does not represent current channel conditions.

conditions between adjacent elements mid-points.

2.3.2. Flow Representation

All streams in the study region were represented in approximately the same fashion. Flow rates are calculated at stream control points by HEC-5 using one of several available hydrologic routing methods. For this project, all flows were routed using specified routing that explicitly defines travel time between control points. Within HEC-5, incremental local flows (i.e., flow between adjacent control points, such as inflows or withdrawals, may include any point or non-point flow) are assumed to enter at the control point. Within HEC-5Q, incremental local flow for a particular reach may be divided into components and placed at different locations within the stream reach (i.e., that portion of the stream bounded by the two control points). The diversions (demands) are allocated to individual control points within the river reaches or reservoirs. Distributed flows such as groundwater accretions and non-specific agricultural return flows are defined on a rate per mile basis. A flow balance is used to determine the flow rate at element boundaries.

For simulation of water quality (e.g., temperature), the tributary locations and associated water quality are specified (see subsequent section). To allocate components of the diversion flow balance, HEC-5Q performs a calculation using any specified withdrawals, inflows, or return flows, and distributes the balance uniformly along the stream reach. Once inter-element flows are established, the water depth, surface width and cross sectional area are computed at each element boundary, assuming normal flow and downstream control (i.e., backwater). For this study, there were no return flows other than groundwater. Stream elements were approximately one mile long. To be consistent with the reservoir representation, a 6-hour model time step was used.

2.4. Hydrologic & Temperature Boundary Conditions

HEC-5Q requires that flow rates and water quality (temperature) be defined for all inflows.

2.4.1. Hydrology[3]

Daily data from USGS and the California Department of Water Resources (DWR) California Data Exchange Center (CDEC), as well as the United States Bureau of Reclamation (USBR) reservoir operation data provided the daily flow data used to develop all hydrologic boundary flows. Inflow rates may be defined explicitly or as a fraction of the incremental local flow to the control point as defined by HEC-5.

The net incremental inflow to Lake McClure and Don Pedro were represented as a single tributary. The inflow rate was computed by mass balance considering evaporation, outflow, and change in reservoir volume. The fractions of the net incremental inflow to New Melones Reservoir (net inflow equals the total inflow minus Stanislaus and Collierville power house (PH) flows) are shown in Table 2-1. Remaining system inflows are presented in Table 2-2 with the data source or method used for their computation.

[3] All hydrology, meteorology, temperature boundary values and observed temperatures are contained in the DSS file that is a part of the report.

The incremental accretion/depletion to the river system was computed by a mass balance of USGS gauge data and allocated to various locations (Table 2-3).

Table 2-1. Incremental inflow assignment for New Melones Reservoir.

Tributary	Data Source / Computation Method
Stanislaus PH above New Melones	USGS
Collierville PH above New Melones	USGS (synthesized flow for 1980-1993)
Middle & North Forks above New Melones	Computed (69% of net inflow to New Melones*)
South Fork above New Melones	Computed (31% of net inflow to New Melones*)
Inflows to Tulloch	Computed (mass balance on Tulloch)

*Net inflow to New Melones = total inflow – Stanislaus and Collierville PH flows

Table 2-2. Incremental inflows to river reaches.

Tributary	Data Source / Computation Method
San Joaquin at Stevinson	USGS and CDEC
Salt Slough	USGS and mass balance
Mud Slough	CDEC and Fremont Ford USGS data (mass balance)
Dry Creek (Merced-Snelling)	USGS, mass balance, and correlations with other tributaries
Dry Creek (Tuolumne)	CDEC, mass balance, and correlations with other tributaries

Table 2-3. Incremental accretion/depletion.

Tributary	Computation Method
San Joaquin above Newman	San Joaquin at Newman - Merced at Stevinson - Mud and Salt Sloughs -San Joaquin River at Stevinson
Merced above Cressy	Merced at Cressy - Crocker Huffman outflow and correlations with meteorology
Tuolumne above Modesto	Tuolumne at Modesto - Merced Dry Creek - La Grange outflow
San Joaquin above Vernalis	San Joaquin at Vernalis - Stanislaus at Ripon - Tuolumne at Modesto - San Joaquin at Newman

2.4.2. Water Temperature

These data were analyzed and two types of inflow relationships were developed, which were then used to define temperatures for all years at 6-hour intervals.

For the mainstem San Joaquin, Merced, Tuolumne, and Stanislaus River, tributary stream inflow temperature relationships were developed from observed hourly CDEC and project data for the period of 1999 through 2007. For each major inflows, composite relationships were developed that considered meteorology (equilibrium temperature), flow rate, and a seasonal temperature distribution. The seasonal temperatures were defined to represent high flow conditions (e.g., elevated flows due to snow melt). At high flows, there was a seasonal bias. At lower flows, there was an equilibrium temperature bias. Flow rate also influenced the diurnal variation with a large range of inflow temperatures at lower flows and shallower water depths. The temperatures of stream accretions were assumed equal to the ambient stream temperature. Very limited small stream/return flow temperature data suggests that this is a reasonable approximation; however, the current data collection effort may provide sufficient data to further refine this approximation.

2.4.3. Meteorological data

For temperature simulations using HEC-5Q, specification of water surface heat exchange data requires designation of meteorological zones within the study area. Each control point within the system or sub-system used in temperature or water quality simulation must be associated with a defined meteorological zone. Because of the large spatial domain, several meteorological zones were required. The model utilized seven meteorological zones based on Modesto, Merced, and Kesterson California Irrigation Management Information System (CIMIS) data stations and an extrapolation based on 1980 using the correlation with the long-term maximum and minimum temperatures at Modesto. Only one correlation was used so that the same CIMIS day is used for each extrapolated data point (e.g., 5 January 2006 CIMIS data maps to 3 January 1980).

Heat exchange coefficients for each zone were computed to reflect typical environmental conditions. For sheltered stream sections, wind speed was reduced and shading was assumed to reflect riparian canopy conditions. Reduced wind speed decreases the evaporative heat loss and results in higher equilibrium temperatures and lower heat exchange rates. Shading reduces solar radiation resulting in lower equilibrium temperatures and lower heat exchange rates. No riparian shading was assumed for reservoirs and for the lower San Joaquin River. For some reservoirs the wind speed was increased to reflect open water conditions.

Meteorological data for the 1980-1988 period were developed by extrapolation of the CIMIS data based on daily National Weather Service (NWS) maximum and minimum air temperature data for Modesto. The relationship between the maximum and minimum air temperatures of the CIMIS and NWS data were developed by comparing data for each day that air temperatures were available (1989–2002). For each day when CIMIS data were unavailable, the NWS temperature extremes were adjusted using the relationship described above and then the hourly CIMIS data that best replicated the NWS extreme was selected for use in the model. The CIMIS records considered were limited to within 2 days before or after the calendar day; thus up to 5 days from each of the 17 years (1989-2005) of CIMIS data (a maximum of 85 days) were considered.

Hourly air temperature, wind speed, relative humidity, and cloud cover for each day is used to compute the average equilibrium temperature, surface heat exchange rate, solar radiation flux and wind speed at 6-hour intervals for input to HEC-5Q. Solar radiation and wind speed are used in the reservoir simulation to attenuate solar energy below the water surface and to compute wind-induced turbulent mixing parameters.

2.4.3.1. Stanislaus River

For New Melones and Tulloch Reservoirs, the Modesto, Merced, and Kesterson meteorological data, with an increased wind speed to reflect open water conditions, was used. Below Tulloch, a combination of unadjusted and riparian shaded Modesto, Merced, and Kesterson meteorological data was used.

2.4.3.2. Tuolumne River

New Don Pedro reservoir used the Merced meteorological data with a wind speed factor of 1.5 (open water). La Grange reservoir used the Merced meteorological data, with no adjustments. Below La Grange, a combination of unadjusted and riparian shaded Merced and Modesto meteorological data is used.

2.4.3.3. Merced River

Lake McClure and Lake McSwain used Merced meteorological data with a wind speed factor of 1.5 (for open water). For Crocker Huffman and Merced Falls, the Merced meteorological data, with no adjustments, was used. For the Merced River below Crocker Huffman Dam, a combination of unadjusted and riparian shaded Merced meteorological and unadjusted Kesterson meteorological data was used.

It should be noted that minor adjustments to the equilibrium temperature on a river reach and reservoir basis (i.e., intercept and slope) were made. This adjustment is based on the project meteorological data and is used as a calibration knob.

2.4.3.4. San Joaquin River

The San Joaquin River (all reaches) used a combination of unadjusted and riparian shaded Merced, Modesto, and Kesterson meteorological data.

3. Model Calibration

The following section presents the results from the calibration of the HEC-5Q models for the Stanislaus, Tuolumne, Merced, and San Joaquin river systems. The tributary river models were calibrated independently of each other. The calibrated models were then used to calibrate the San Joaquin River model, which includes the San Joaquin's mainstem and three tributary rivers.

3.1. Stanislaus River System

The HEC-5Q model of the Stanislaus River system was previously calibrated to 1990-1999 data. The current effort involves refinement of the initial calibration based on additional data available for the five-year period from 2000 through 2004, including reservoir temperature profile observations in New Melones Reservoir, Tulloch Reservoir, and Goodwin Reservoir, as well as temperature time series observations at several stations in the Stanislaus River and Lower San Joaquin River. Minor adjustments have been made to model coefficients during the current calibration; however, previous calibration results remain relevant representations of model performance.

The following CDFG reservoir profile data sets and CDEC and USGS time series data sets for the 2000-2004 calibration period were utilized. A map of these locations is shown in Figure 3-1.

- Temperature profile data in New Melones Reservoir (CDFG).
- Temperature profile data in Tulloch Reservoir (CDFG).
- Temperature time series data below Goodwin Dam (USGS).
- Temperature time series data at Knights Ferry, Orange Blossom Bridge, Oakdale Recreation Area, Riverbank Bridge, and above the confluence with the San Joaquin River (CDEC).
- Temperature time series data at Ripon (USGS).

The hydrology, meteorology, and inflow water quality conditions described in Chapter 2 were assumed. For a full discussion of the Stanislaus calibration, see AD *et al.* (2008) report. The following sections provide a brief discussion of the calibration results for reservoirs and streams. Station locations for the Stanislaus River are shown in Figure 3-1.

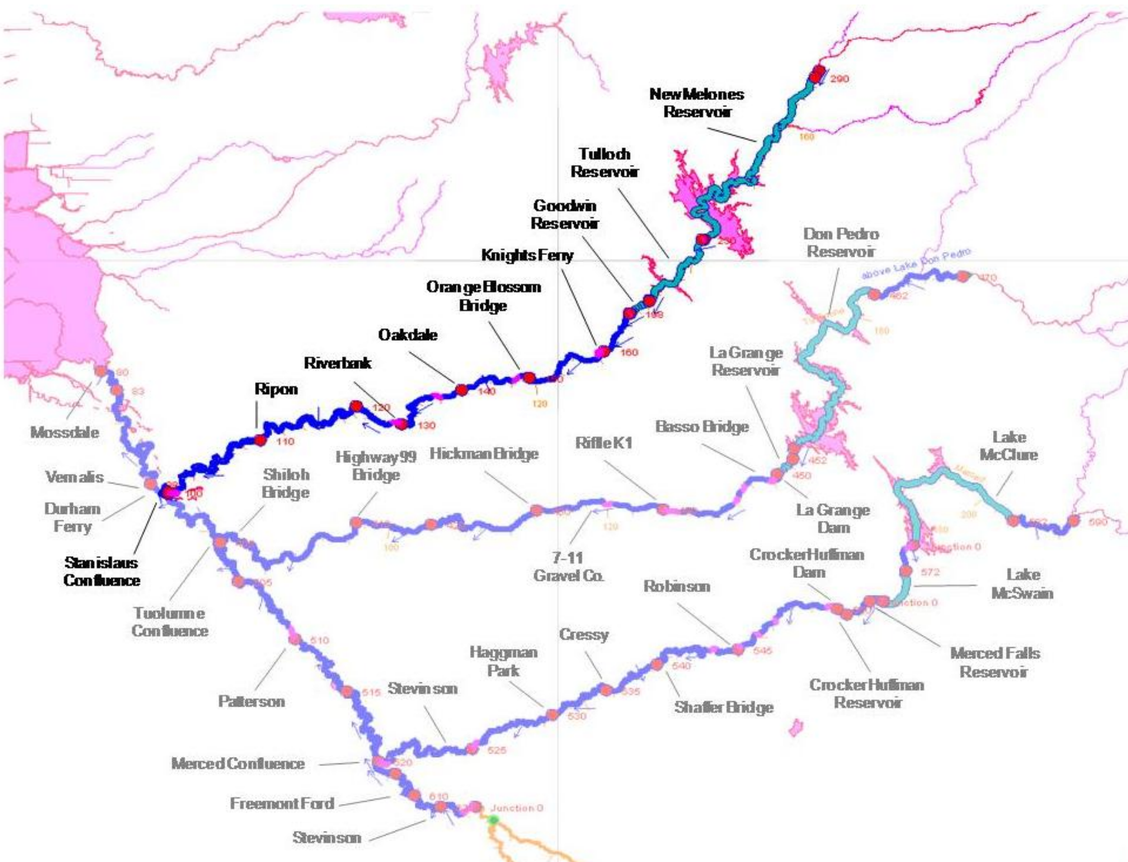

Figure 3-1. Stanislaus River system as represented in the model, with the 2000 through 2004 calibration plots indicated.

3.1.1. Reservoir Temperature Calibration Results

Calibration of New Melones, Tulloch, and Goodwin Reservoirs was completed by comparing computed and observed vertical reservoir temperature profiles both graphically and statistically (e.g., fitting paired simulated and observed data with a regression). Example graphical results are illustrated in Figure 3-2 and Figure 3-3 for New Melones and Tulloch Reservoirs, respectively (see Appendix A, Section 8.1, Figure 8-1 and Figure 8-2 for additional plots). All reservoir elevations are based on mean sea level (msl).

The model generally does an excellent job of reproducing the thermal structure in New Melones Reservoir. Most results are within approximately 1°F to 2°F of observed values. During the late summer and early fall of 2000 and 2003, the computed thermocline gradient is not as steep as observed, resulting in higher than observed temperatures near 1,000 feet elevation. In May and June of 2001 through 2004, surface temperatures are cooler than observed by as much as 5°F. Surface temperature differences are most likely due to assumed meteorological conditions. Near surface temperatures have very little impact on withdrawal temperatures unless the outlet is within epilimnion. The seasonal onset, extent, and breakdown of thermal stratification are well represented.

Likewise, the model generally represented the thermal structure for Tulloch Reservoir well. Most results are within approximately 1°F to 3°F of observed values. In May and October 2000, the computed thermocline is lower than observed, resulting in temperatures in this region that are 4°F to 5°F higher than observed. During April through June 2001, computed surface temperatures are 4°F to 7°F lower than observed. During the spring of 2004, the computed thermocline is lower and less steep than observed. These differences are most likely associated with assumed meteorological conditions. The seasonal onset, extent, and breakdown of thermal stratification are well represented.

Both the model and the ambient data indicate that Goodwin Reservoir has weak thermal stratification (typically less than 3°F). The downstream impacts of thermal stratification can be seen in Figure 3-3. The computed and observed diurnal variation is well represented by the model. Variations in the average temperature below the dam are primarily due to the Tulloch tailwater temperature.

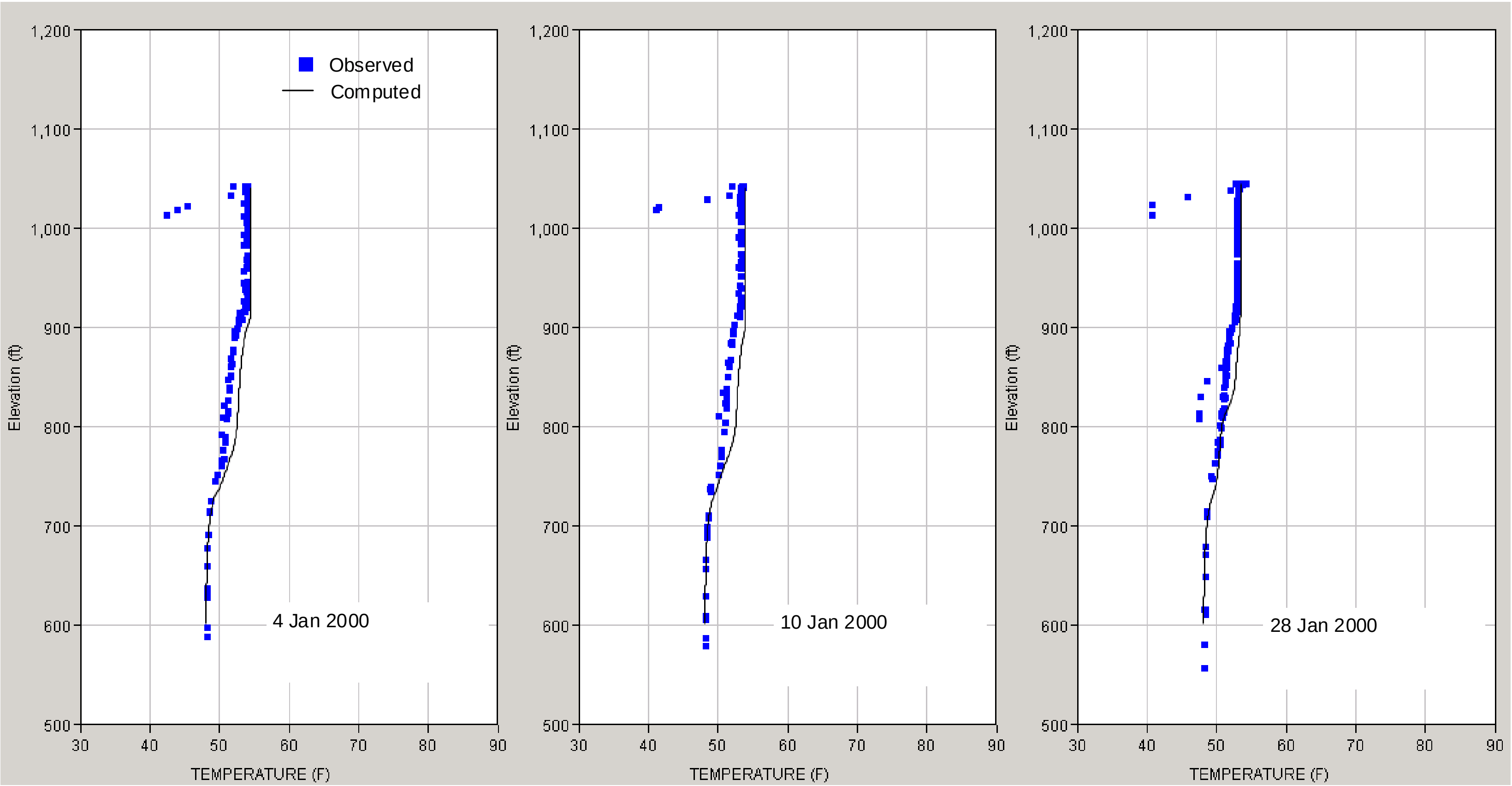

Figure 3-2. Example New Melones Reservoir computed and observed temperature profiles.

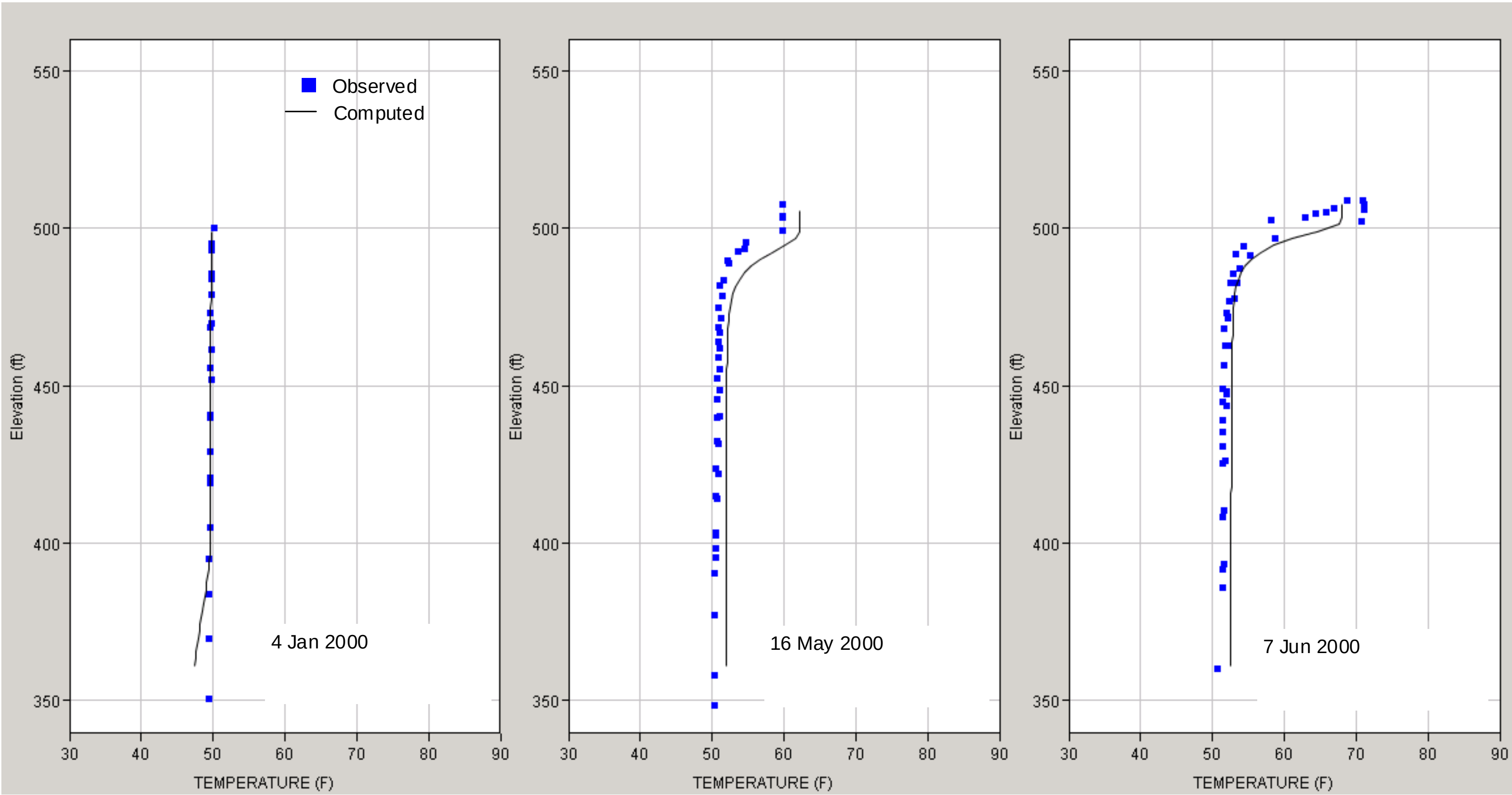

Figure 3-3. Example Tulloch Reservoir computed and observed temperature profiles.

3.1.2. Stream Temperature Calibration Results

Calibration of the Stanislaus River stream reaches was completed by comparing computed and observed time series temperatures both graphically and statistically (e.g., fitting paired simulated and observed data with a regression). Seven locations along the Stanislaus River were employed: Below Goodwin Dam, Knights Ferry, Orange Blossom Bridge, Oakdale Recreation Area, Riverbank Bridge, Ripon, and at the confluence of the Stanislaus and San Joaquin rivers. Example graphical results are illustrated in Figure 3-4 through Figure 3-7 for 1999 through 2007. The time series plots show that an excellent representation of the average temperatures, diurnal variation, and daily and seasonal variation is achieved.

In the computed versus observed temperature plots, an exact match between computed and observed data would result in an equation with a slope of 1 and an intercept of 0 (i.e., $y = 1x + 0$) and an R^2 (coefficient of determination) value of 1. Discrepancies between computed and observed data result in non-zero intercept values and slopes greater than or less than 1. Differences between data points and the line described by the equation result in an R^2 value less than 1. Line equations for the best linear fit to the data are shown on each computed versus observed plot. Mean values for X (computed) and Y (observed) are also shown on these plots.

R^2 values are generally about 0.9 at all locations except below Goodwin Dam (Table 3-1). At this location, overall computed temperatures are lower than observed data as seen in Figure 3-4. The discrepancy between computed and observed data results in an R^2 value of 0.85, and the smallest slope (0.75) and largest intercept (14.4) of all the best linear fit equations. Table 3-1 summarizes the 1999 through 2007 results for each location. The averages of the observed and computed values used in the computed versus observed plots are listed, along with the coefficient of determination (R^2 value).

Table 3-1. Average observed and computed water temperatures, and associated root mean squared error at seven stations on the lower Stanislaus River for 1999 through 2007.

Location	River Mile	Water Temperature (degrees F)		
		Avg. Observed	Avg. Computed	Coefficient of Determination (R^2)
Below Goodwin	58	52.90	53.32	0.855
Knights Ferry	54	53.33	53.72	0.907
Orange Blossom	46	55.29	55.28	0.936
Oakdale Rec.	40	55.88	55.96	0.948
Riverbank	31	57.64	58.07	0.955
Ripon	15	60.49	60.40	0.961
Confluence	0	59.79	60.38	0.961

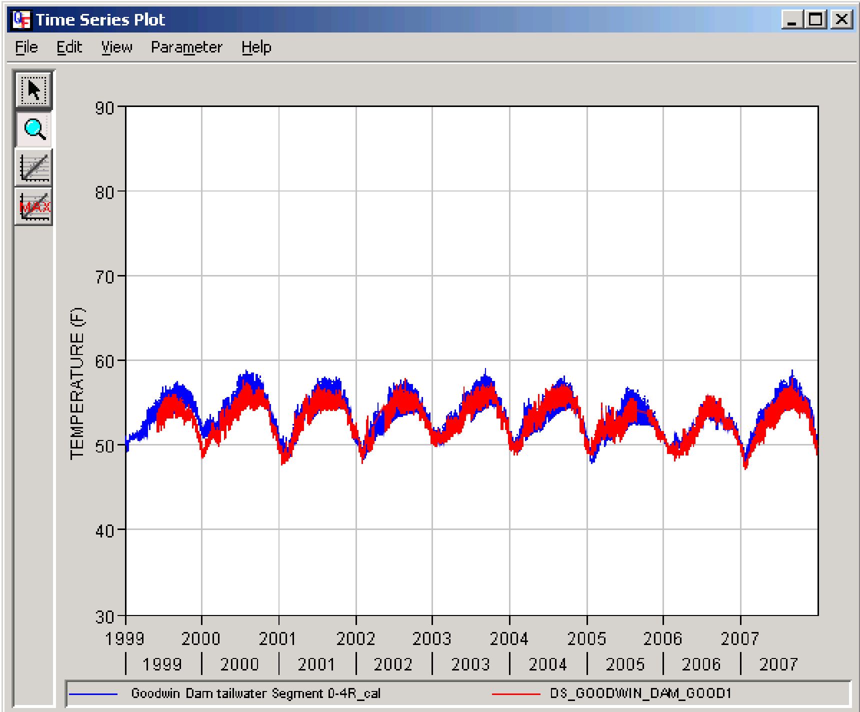

Figure 3-4. Comparison of computed (blue) and observed (red) water temperatures on the Stanislaus River below Goodwin Dam (RM 58).

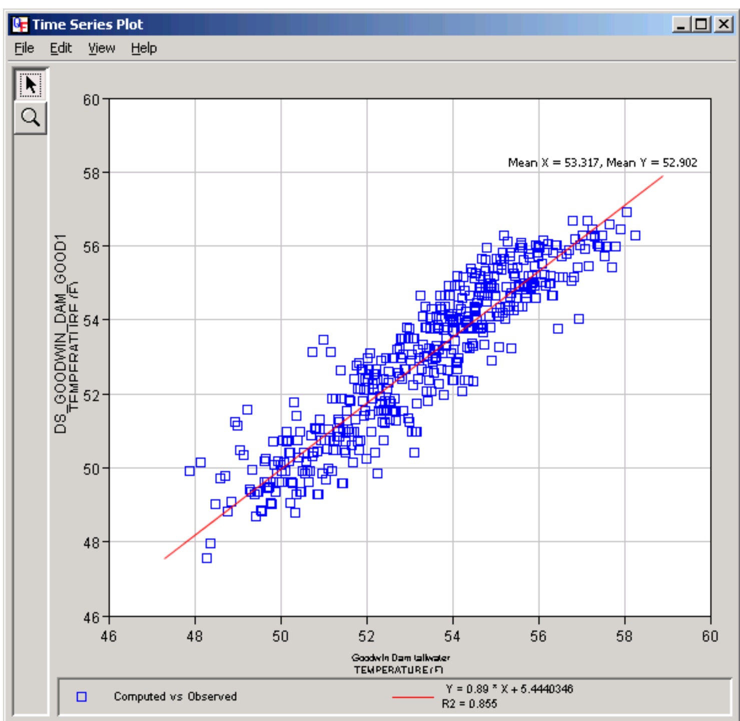

Figure 3-5. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Stanislaus River below Goodwin Dam (RM 58).

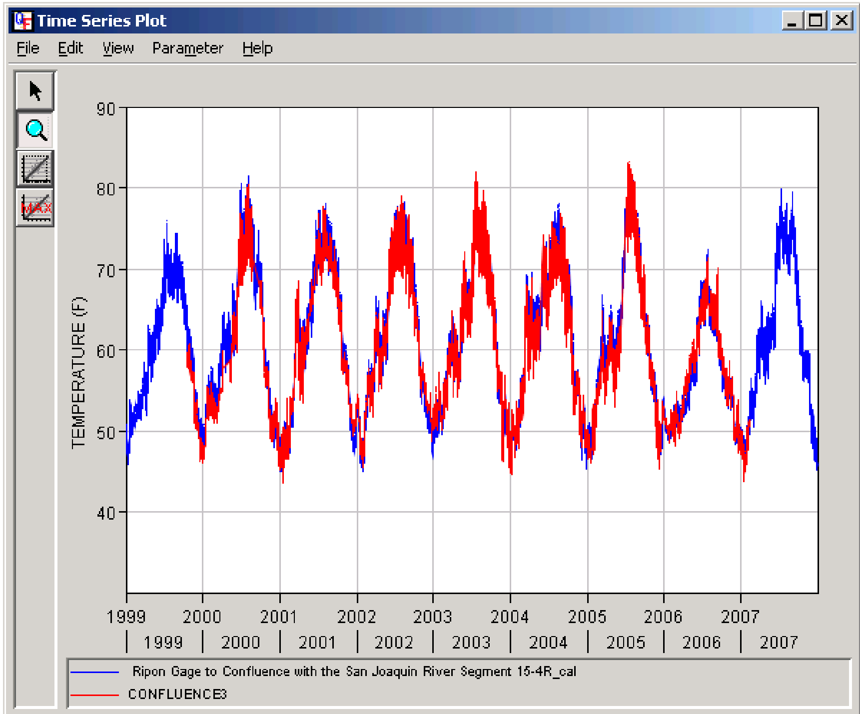

Figure 3-6. Comparison of computed (blue) and observed (red) water temperatures on the Stanislaus River above the confluence with the San Joaquin River (RM 0).

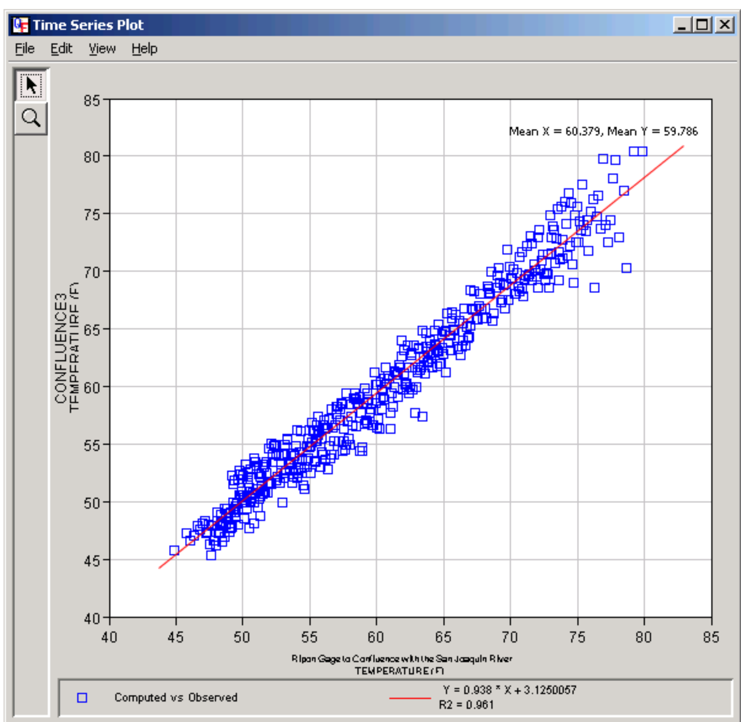

Figure 3-7. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Stanislaus River above the confluence with the San Joaquin River (RM 0).

3.2. Tuolumne River System

The HEC-5Q model of the Tuolumne River system was calibrated to 1999 through 2007 data. The following California Department of Fish and Game (CDFG) reservoir profile data sets, and CDEC and USGS time series data sets for the calibration period were utilized. A map of these locations is shown in Figure 3-8.

- Temperature profile data in Don Pedro Reservoir (CDFG).
- Temperature time series data below La Grange Dam (USGS).
- Temperature time series data at Basso Bridge, Riffle K1, 7-11 Gravel Co., Hickman Bridge, Highway 99 Bridge, and Shiloh Bridge (CDEC).

The hydrology, meteorology, and inflow water quality conditions described in Chapter 2 were assumed.

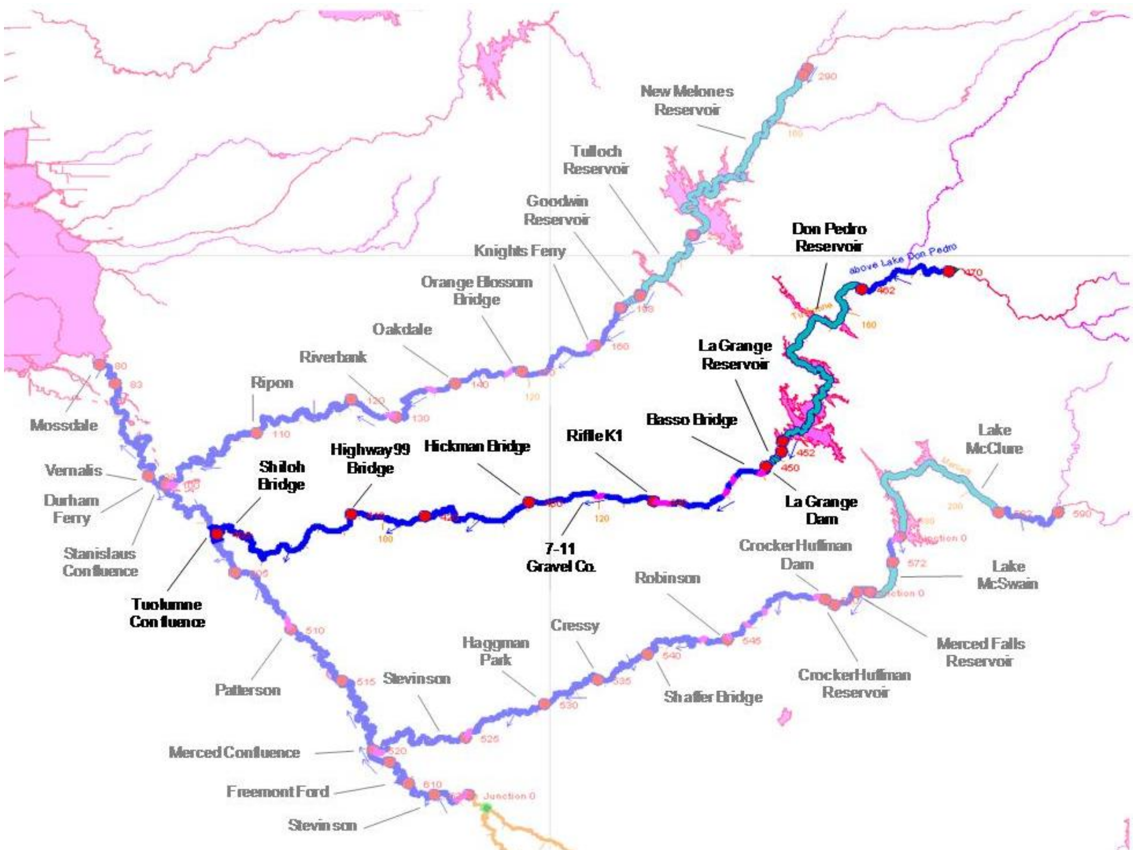

Figure 3-8. Tuolumne River system as represented in the model, with the calibration points and reservoirs indicated.

3.2.1. Reservoir Temperature Calibration Results

Calibration of New Don Pedro Reservoir was completed by comparing computed and observed vertical reservoir temperature profiles both graphically and statistically (e.g., fitting paired simulated and observed data with a regression). Example preliminary calibration results for New Don Pedro are presented in Figure 3-9 (see Appendix A, Section 8.2, Figure 8-13 and Figure 8-14 for additional calibration plots). All reservoir elevations are based on mean sea level (msl).

The model generally does an excellent job of reproducing the thermal structure in New Don Pedro Reservoir. Most results are within a few degrees of observed values. Overall, the surface water temperatures tend to be slightly lower than observed; however, seasonally there is some variability. In the winter months the surface temperatures tend to be slightly cooler than observed, whereas in the summer months the temperatures tend to be slightly warmer.

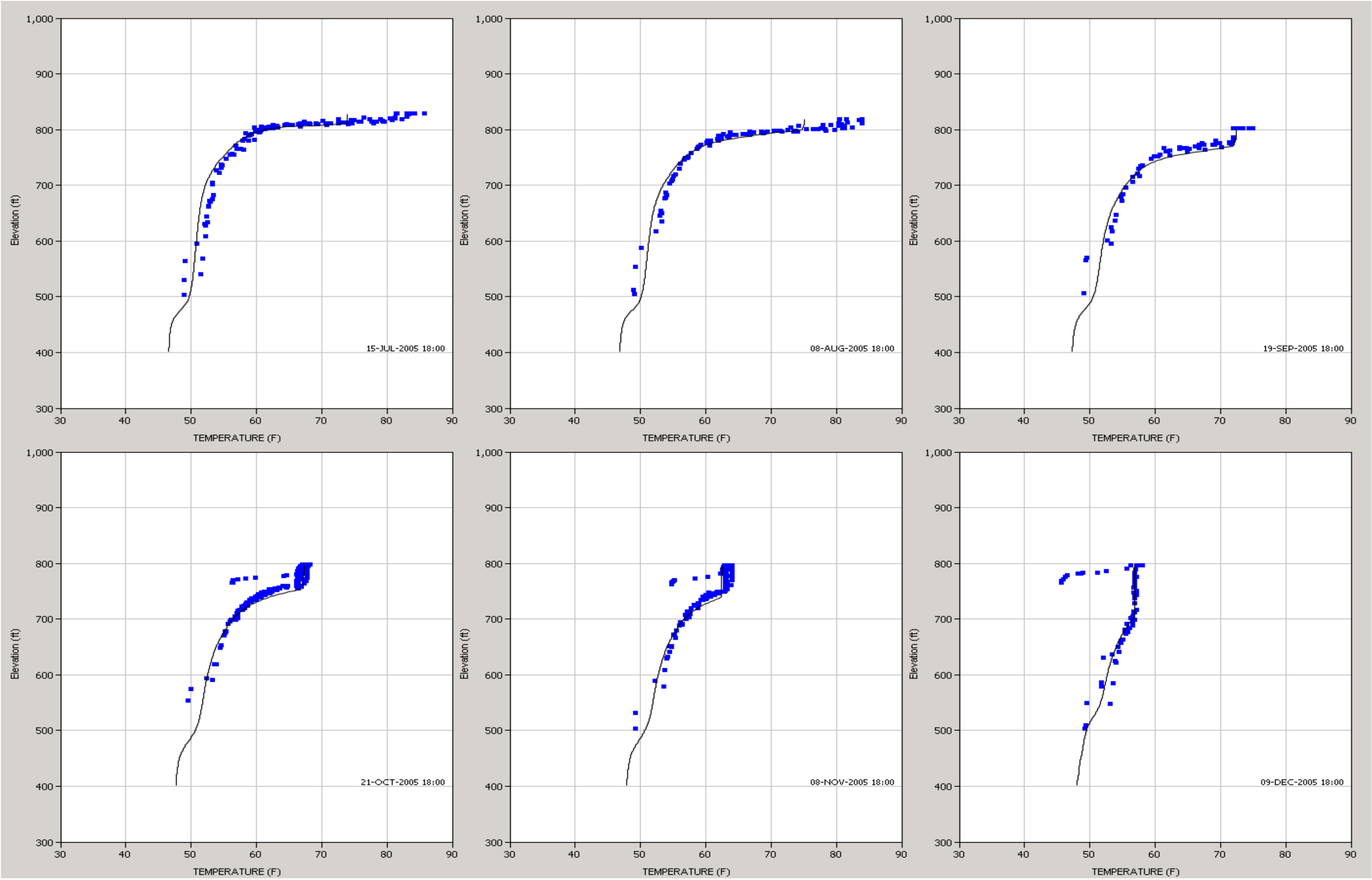

Figure 3-9. Preliminary calibration results for Don Pedro Reservoir from July 2005 through December 2005.

3.2.2. Stream Temperature Calibration Results

Calibration of the Tuolumne River stream reaches was completed by comparing computed and observed time series temperatures both graphically and statistically (e.g., fitting paired simulated and observed data with a regression). Seven locations along the Tuolumne River were employed: Below La Grange Dam, Basso Bridge, Riffle K1, 7-11 Gravel Co., Hickman Bridge, Highway 99 Bridge, and Shiloh Bridge. Example graphical results are illustrated in Figure 3-10 thru Figure 3-13 for 1999 through 2007 (additional figures are presented in Appendix A, Section 8.2, Figure 8-15 thru **Figure 8-24**). The time series plots show that an excellent representation of the average temperatures, diurnal variation, and daily and seasonal variation is achieved.

R^2 values are generally about 0.96 at all locations except below La Grange Dam and Basso Bridge (Table 3-2). Below La Grange Dam, overall computed temperatures are higher than observed data as seen in Figure 3-4 (overall computed temperature are also higher at Basso Bridge). The discrepancy between computed and observed data results in an R^2 value of 0.66, and the smallest slope (0.78) and largest intercept (11.8) of all the best fit linear equations. Table 3-2 summarizes the 1999 through 2007 results for each location. The averages of the observed and computed values used in the computed versus observed plots are listed, along with the coefficient of determination (R^2 value).

Table 3-2. Average observed and computed water temperatures, and associated root mean squared error at four stations on the Tuolumne River for 1999 through 2007.

Location	River Mile	Water Temperature (degrees F)		
		Avg. Observed	Avg. Computed	Coefficient of Determination (R^2)
Below La Grange	52	52.22	51.75	0.664
Basso Bridge	47.5	54.40	54.25	0.854
Riffle K1	42.6	51.57	57.43	0.967
7-11 Gravel Co.	38	59.71	59.39	0.967
Hickman Bridge	31	59.76	59.10	0.968
Highway 99 Bridge	15.5	62.90	62.93	0.974
Shiloh Bridge	3.4	60.02	60.39	0.960

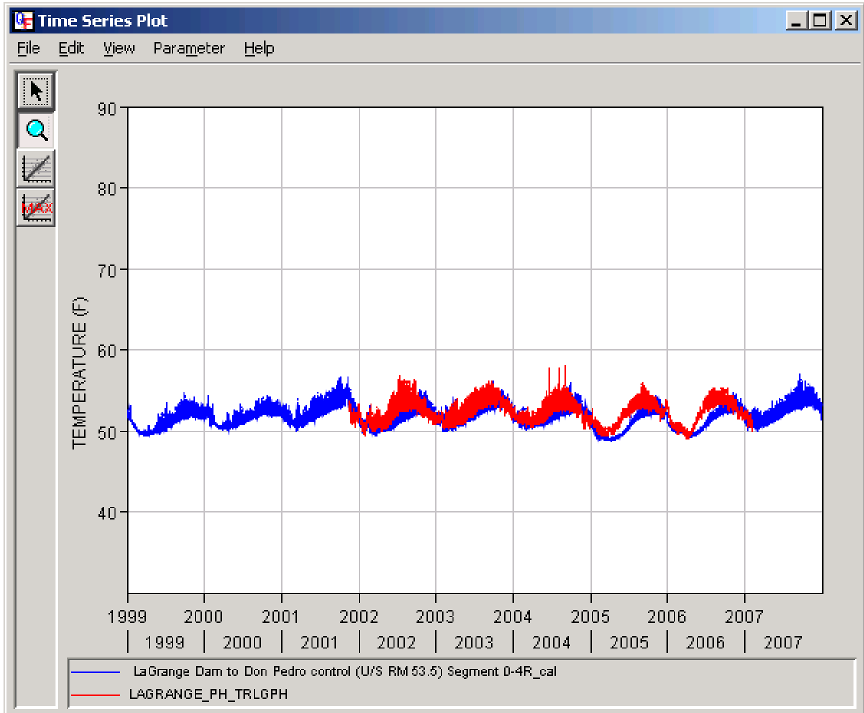

Figure 3-10. Comparison of computed (blue) and observed (red) water temperatures on the Tuolumne River below La Grange Dam (RM 52).

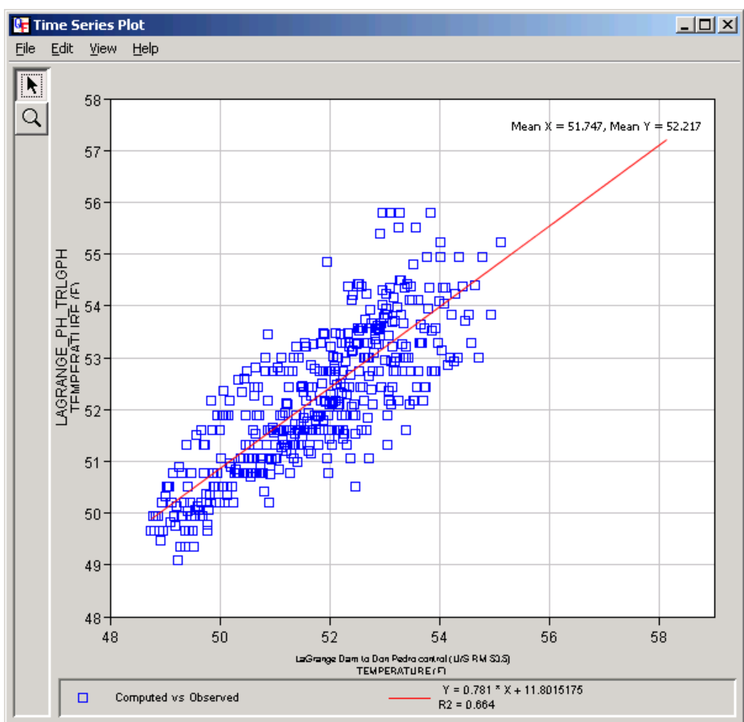

Figure 3-11. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Tuolumne River below La Grange Dam (RM 52).

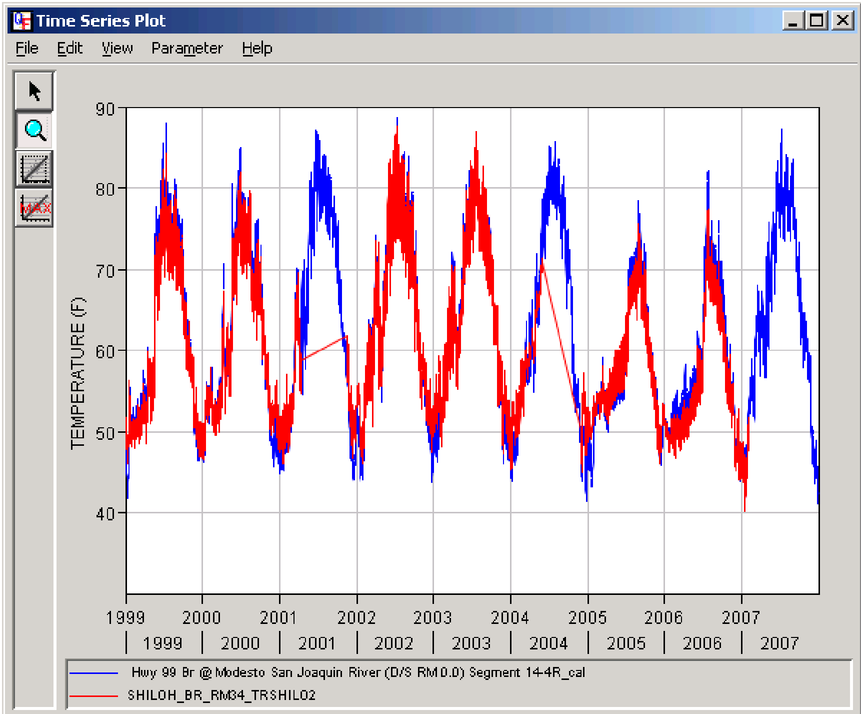

Figure 3-12. Comparison of computed (blue) and observed (red) water temperatures on the Tuolumne River at Shiloh Bridge (RM 3.4).

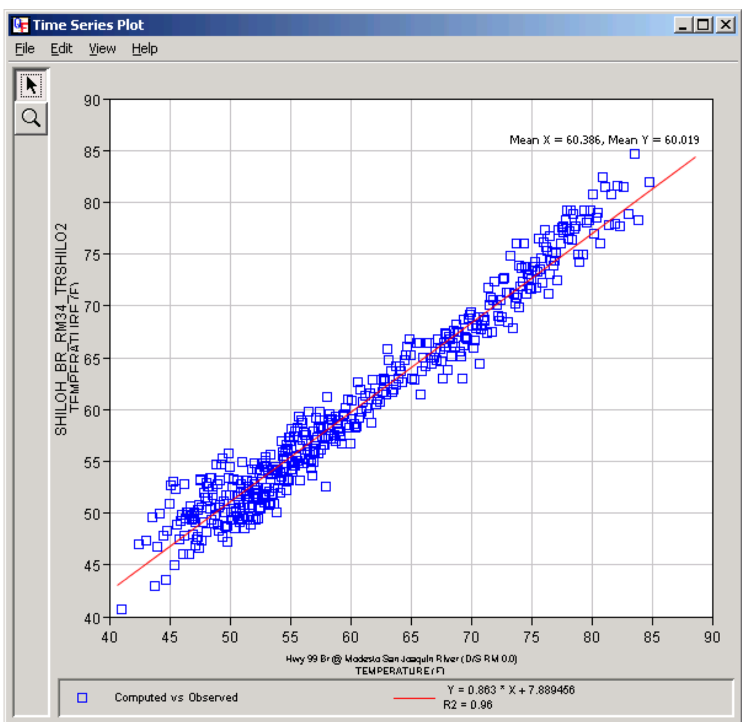

Figure 3-13. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Tuolumne River at Shiloh Bridge (RM 3.4).

3.3. Merced River System

The HEC-5Q model of the Tuolumne River system was calibrated to 1999 through 2007 data. The following California Department of Fish and Game (CDFG) reservoir profile data sets, and CDEC and USGS time series data sets for the calibration period were utilized. A map of these locations is shown in Figure 3-14.

- Temperature profile data in Lake McClure Reservoir (CDFG).
- Temperature profile data in Lake McSwain Reservoir (CDFG).
- Temperature time series data below McSwain Dam, below Crocker-Huffman Dam, Mile 164, Robinson, Mile 158, Shaffer Bridge, Mile 31, Cressy, Haggman Park, Stevinson, and above the confluence with the San Joaquin River (CDEC).

The hydrology, meteorology, and inflow water quality conditions described in Chapter 2 were assumed.

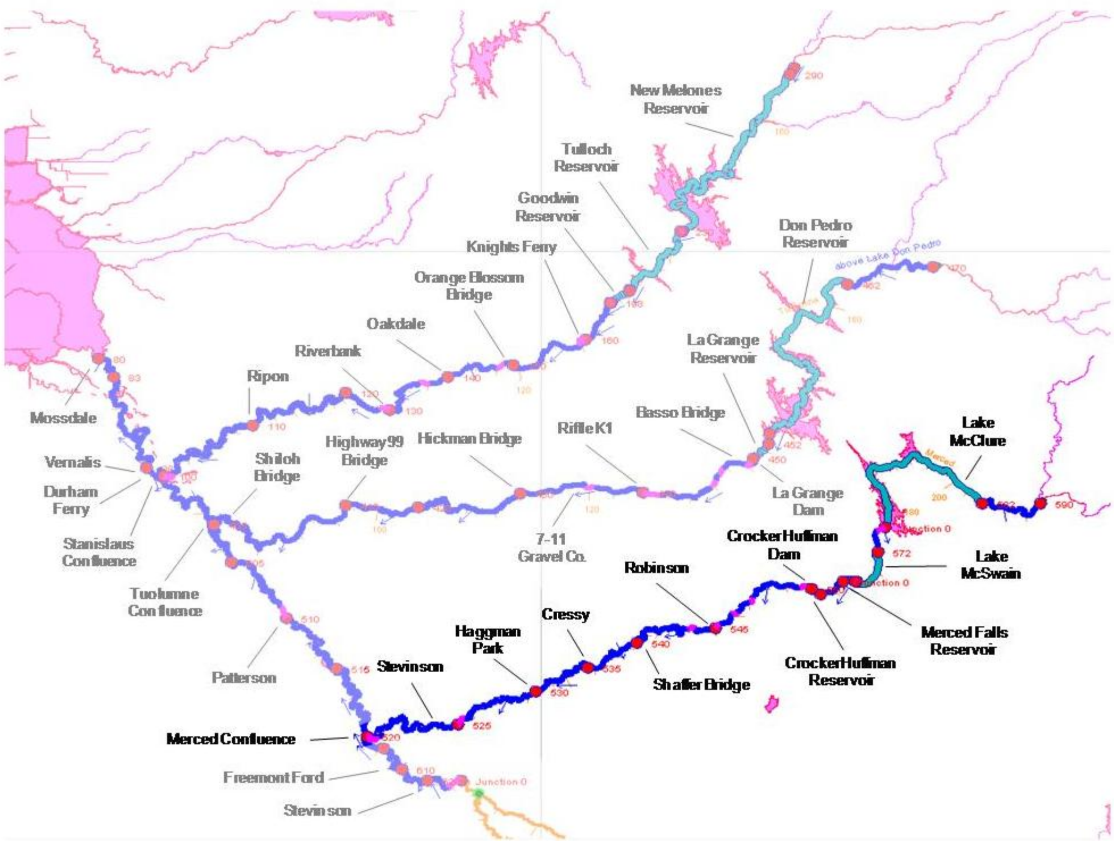

Figure 3-14. Merced River system as represented in the model, with calibration points and reservoirs indicated.

3.3.1. Reservoir Temperature Calibration Results

Calibration of Lake McClure was completed by comparing computed and observed vertical reservoir temperature profiles both graphically and statistically (e.g., fitting paired simulated and observed data with a regression). Example preliminary calibration results for Lake McClure are presented in Figure 3-15 (see Appendix A, Section 8.3,

Figure 8-25 and Figure 8-26 for additional calibration plots). All reservoir elevations are based on mean sea level (msl).

The model generally does an excellent job of reproducing the thermal structure in Lake McClure. Most results are within a few degrees observed values. In general, the surface water temperatures tend to be slightly higher than observed, whereas the sub-surface temperatures tend to be slightly lower.

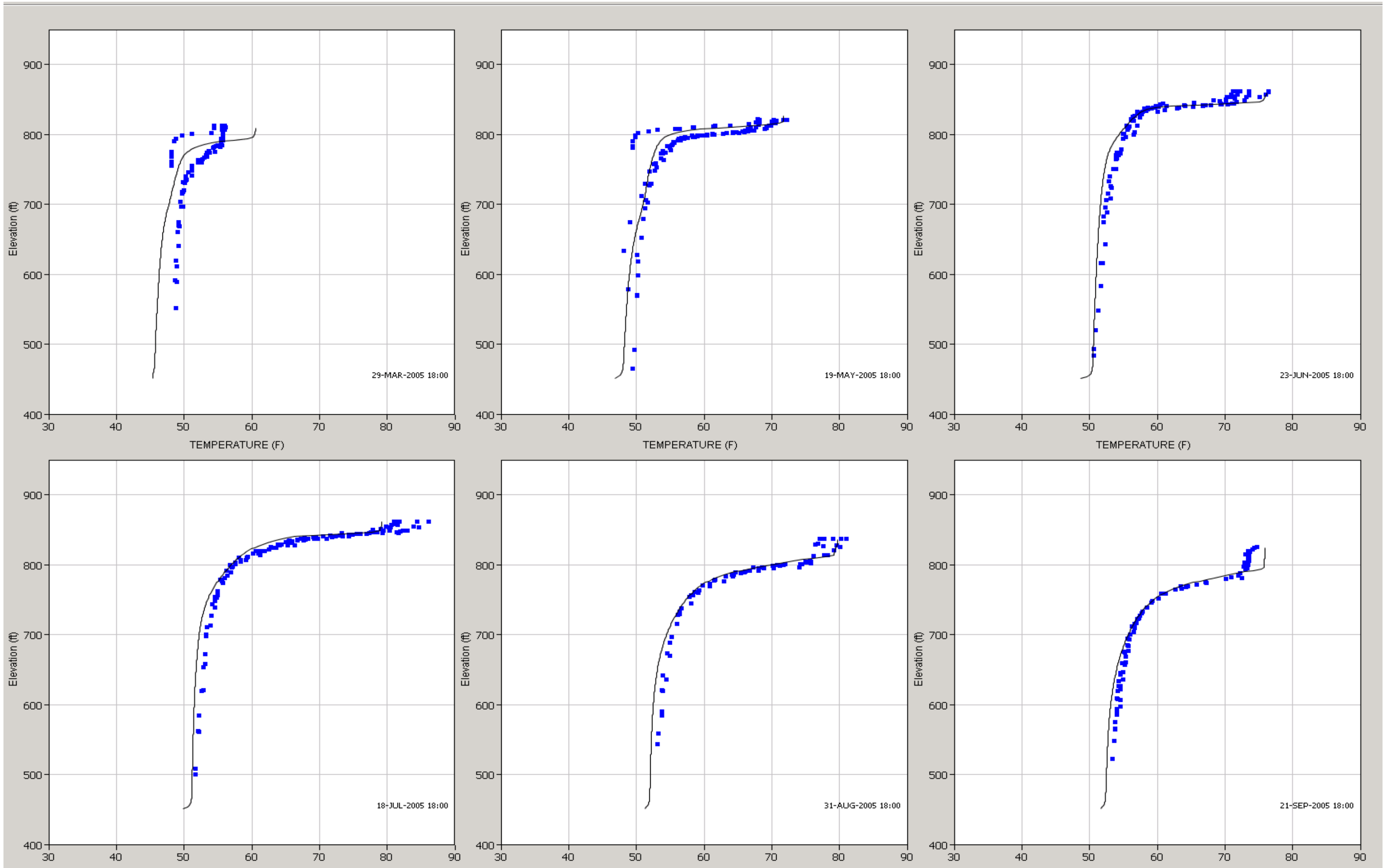

Figure 3-15. Example preliminary calibration results for Lake McClure for March 2005 through September 2005.

3.3.2. Stream Temperature Calibration Results

Calibration of the Merced River stream reaches was completed by comparing computed and observed time series temperatures both graphically and statistically (e.g., fitting paired simulated and observed data with a regression). Eleven locations along the Merced River were employed: below McSwain Dam, below Crocker-Huffman Dam, Mile 164, Robinson, Mile 158, Shaffer Bridge, Mile 31, Cressy, Haggman, Stevinson, and above the confluence with the San Joaquin River. Example graphical results are illustrated in Figure 3-16 thru Figure 3-19 for 1999 through 2007 (additional figures are presented in Appendix A, Section 8.3, Figure 8-27 thru Figure 8-44). The time series plots show that an excellent representation of the average temperatures, diurnal variation, and daily and seasonal variation is achieved.

R^2 values are generally about 0.94 at all locations except below McSwain Dam and below Crocker-Huffman Dam (Table 3-3). Overall the computed temperatures tended to slightly lower than the observed (as seen in Figure 3-16 and Figure 3-18). Table 3-3 summarizes the 1999 through 2007 results for each location. The averages of the observed and computed values used in the computed versus observed plots are listed, along with the coefficient of determination (R^2 value).

Table 3-3. Average observed and computed water temperatures, and associated root mean squared error at four stations on the Merced River for 1999 through 2007.

Location	River Mile	Water Temperature (degrees F)		
		Avg. Observed	Avg. Computed	Coefficient of Determination (R^2)
Below McSwain Dam	56	54.04	54.59	0.858
Below Crocker Huffman Dam	52	55.11	55.31	0.846
Mile 164	48	56.78	56.77	0.883
Robinson	43	58.63	58.89	0.957
Mile 158	41	59.87	59.64	0.947
Shaffer Bridge	33	58.00	58.07	0.919
Mile 31	31	62.90	63.28	0.973
Cressy	27	61.07	61.38	0.974
Haggman Park	13	59.55	60.16	0.974
Stevinson	4	62.99	63.70	0.979
Above the Confluence	0	62.37	63.08	0.966

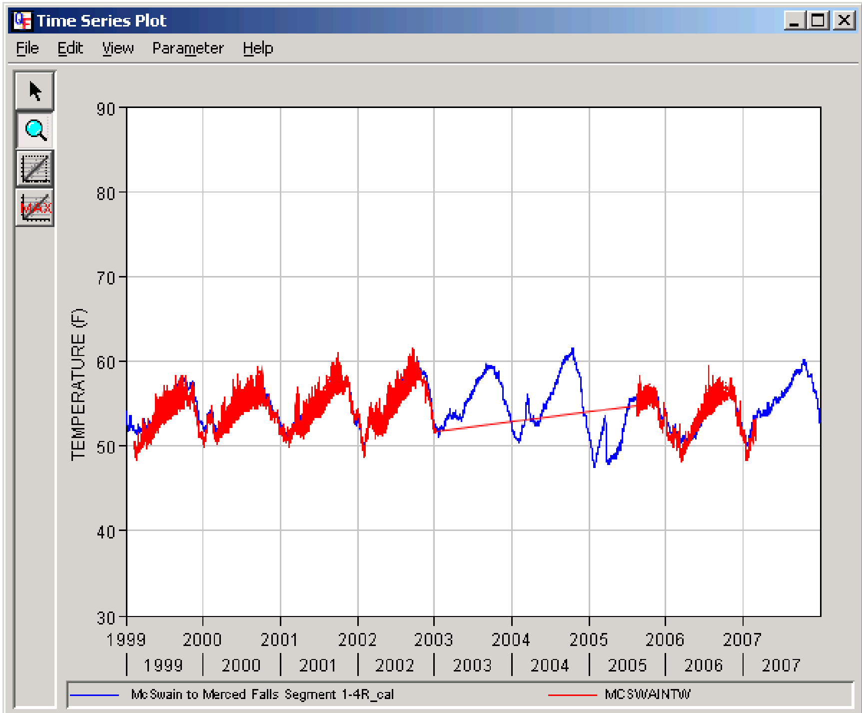

Figure 3-16. Comparison of computed (blue) and observed (red) temperatures in the Merced River below McSwain Dam (RM 56). Observed data was missing for mid-2003 through mid-2005.

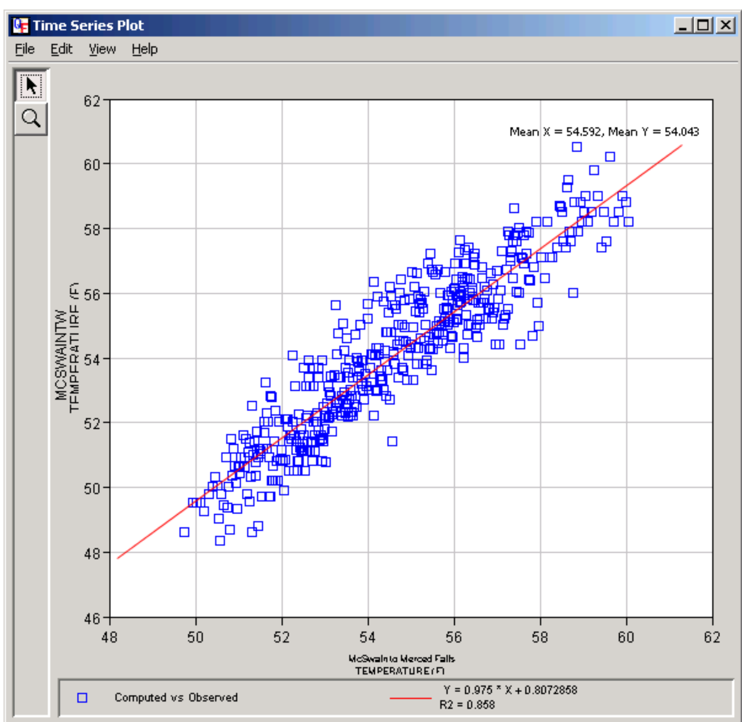

Figure 3-17. Comparison of computed and observed inflow temperatures in the Merced River below McSwain Dam (RM 56).

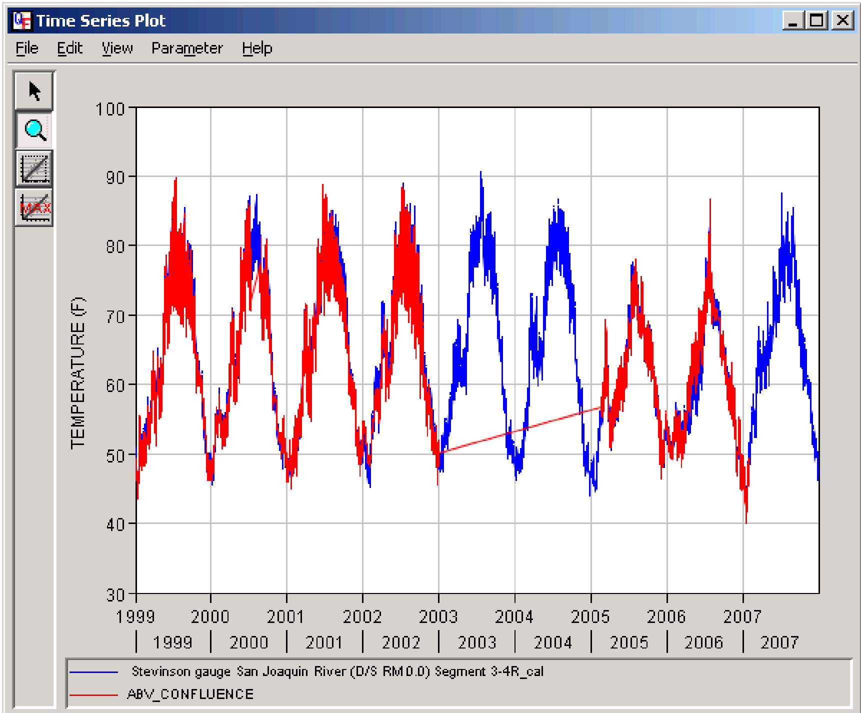

Figure 3-18. Comparison of computed (blue) and observed (red) temperatures in the Merced River above the confluence with the San Joaquin River (RM 0). Observed data was missing for mid-2003 through mid-2005.

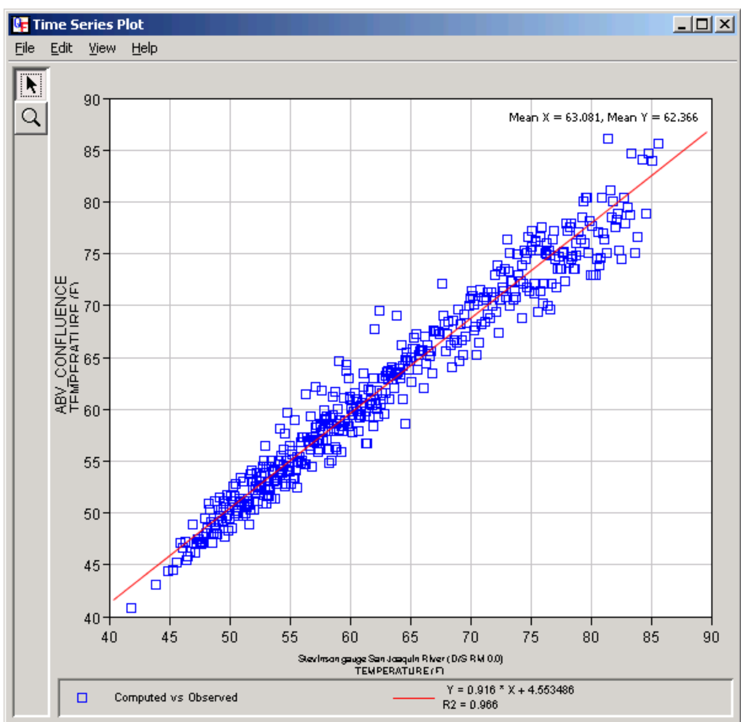

Figure 3-19. Comparison of computed and observed inflow temperatures in the Merced River above the confluence with the San Joaquin River (RM 0).

3.4. San Joaquin River System

The HEC-5Q model of the San Joaquin River system was calibrated to 1999 through 2007 data. There were no reservoirs included in the San Joaquin model. CDEC and USGS time series data sets for the calibration period were utilized. A map of these locations is shown in Figure 3-20.

- Temperature time series data at the confluences with Tuolumne and Stanislaus Rivers and at Mossdale (CDEC).
- Temperature time series data on the San Joaquin River at Patterson, Freemont Ford, Vernalis, and Durham Ferry (CDFG/CDEC).

The hydrology, meteorology, and inflow water quality conditions described in Chapter 2 were assumed.

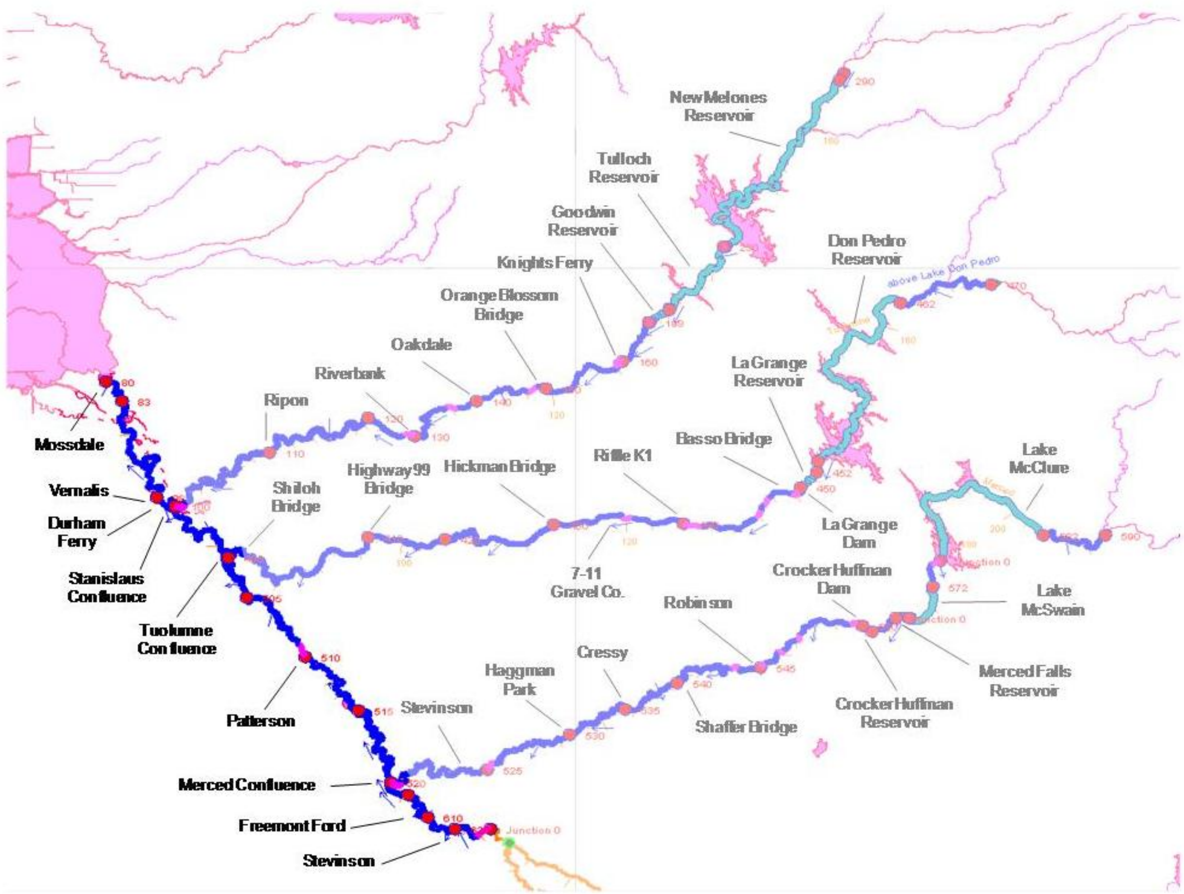

Figure 3-20. San Joaquin River system as represented in the model, with calibration points indicated.

3.4.1. Stream Temperature Calibration Results

Calibration of the San Joaquin River stream reaches was completed by comparing computed and observed time series temperatures both graphically and statistically (e.g., fitting paired simulated and observed data with a regression). Seven locations along the San Joaquin River were employed: Freemont Ford, Patterson, Tuolumne River confluence, Stanislaus River confluence, Vernalis, Durham Ferry, and Mossdale. Example graphical results are illustrated in Figure 3-21 thru Figure 3-24 for 1999 through 2007 (additional figures are presented in Appendix A, Section 8.3, **Figure 8-45** thru Figure 8-56). The time series plots show that an excellent representation of the average temperatures, diurnal variation, and daily and seasonal variation is achieved.

R^2 values are generally about 0.97 (Table 3-4). Overall the computed temperatures tended to slightly lower than the observed (as seen in Figure 3-21 and Figure 3-23). Table 3-4 summarizes the 1999 through 2007 results for each location. The averages of the observed and computed values used in the computed versus observed plots are listed, along with the coefficient of determination (R^2 value).

Table 3-4. Average observed and computed water temperatures, and associated root mean squared error at five stations on the San Joaquin River for 1999 through 2007.

		Water Temperature (degrees F)		
Location	**River Mile**	**Avg. Observed**	**Avg. Computed**	**Coefficient of Determination (R^2)**
Freemont Ford	125	66.55	67.6	0.967
Patterson	97	64.68	65.27	0.981
Confluence with Tuolumne	83	65.25	65.29	0.979
Confluence with Stanislaus	73	62.79	63.01	0.977
Vernalis	72	62.79	63.06	0.978
Durham Ferry	71	61.78	62.02	0.980
Mossdale	57.5	63.74	63.49	0.980

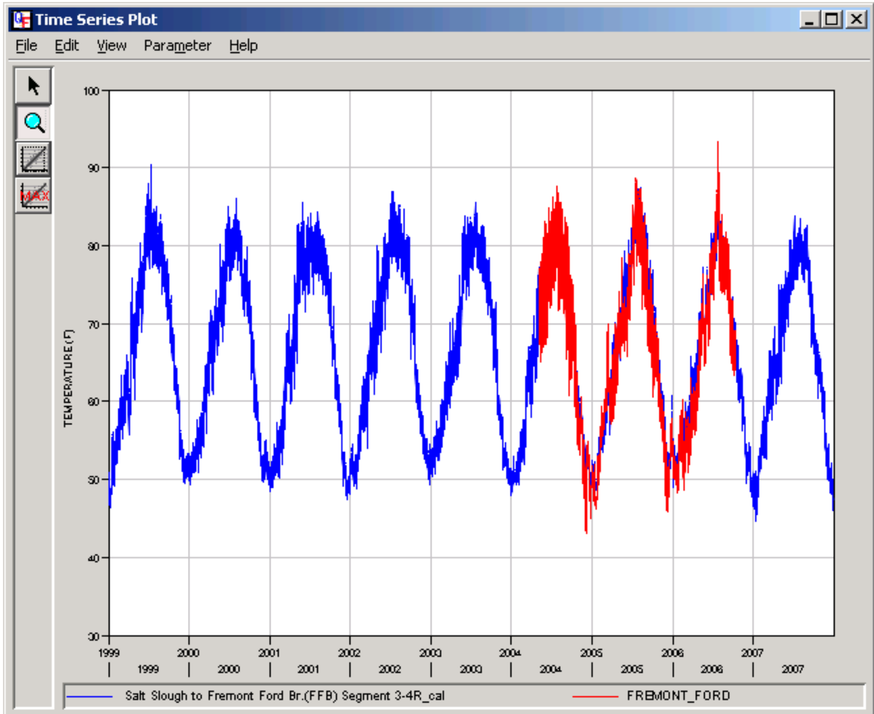

Figure 3-21. Example comparison of computed (blue) and observed (red) temperatures on the San Joaquin River at the Freemont Ford (RM 125). Observed data was not available before mid-2004 and after mid-2006.

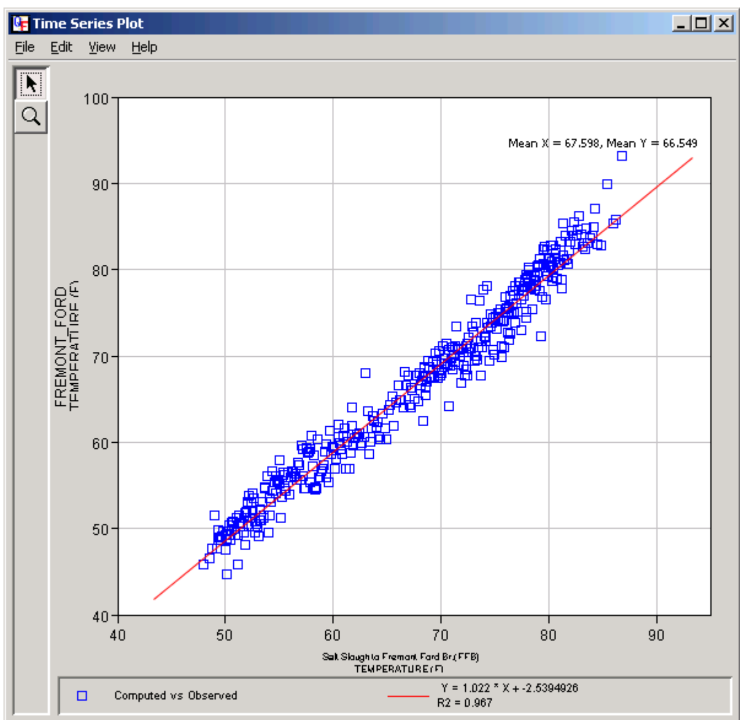

Figure 3-22. Comparison of computed and observed inflow temperatures in the San Joaquin River at the Freemont Ford (RM 125).

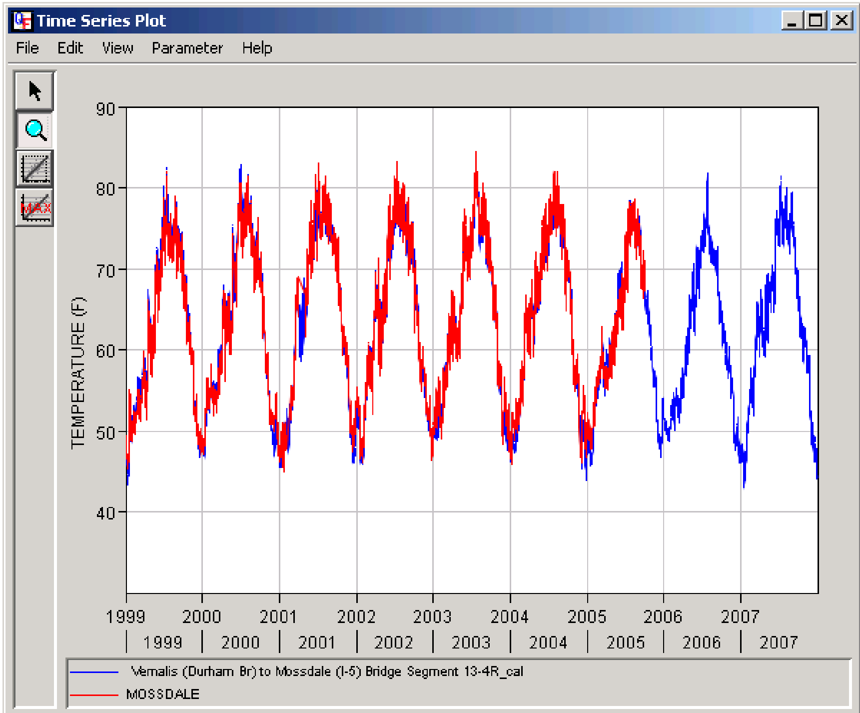

Figure 3-23. Example comparison of computed (blue) and observed (red) temperatures on the San Joaquin River at Mossdale (RM 57.5). Observed data was not available after mid-2005.

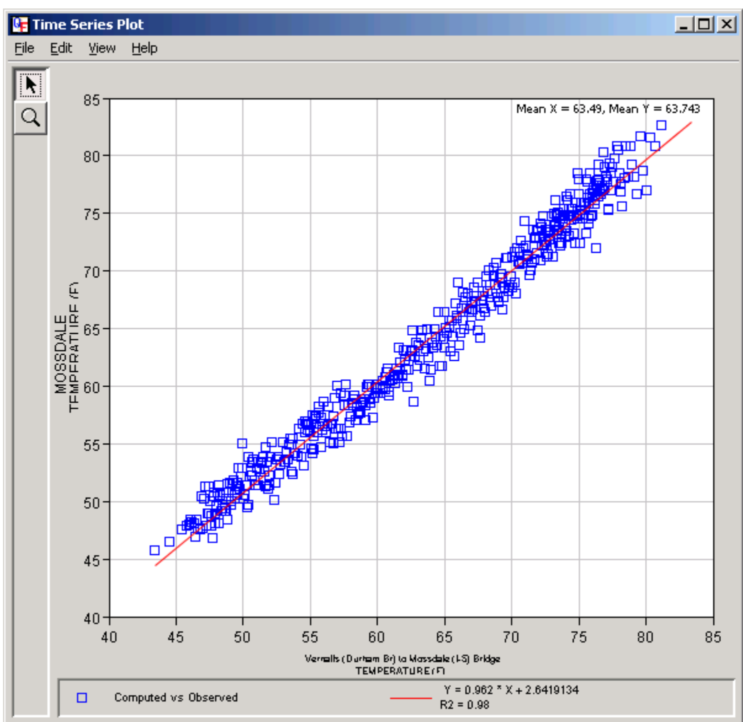

Figure 3-24. Comparison of computed and observed inflow temperatures in the San Joaquin River at Mossdale (RM 57.5).

4. Operations Study

4.1. Introduction

For the purpose of model capability demonstration, the calibrated model was used to perform three broad categories of modeling studies: historical operations, alternative operations, and temperature target specification scenarios.

- Historical operations scenario – utilized historical hydrology and operations to form a baseline for comparative analysis with the other scenarios.

- Alternative operations scenario – focused only on the Stanislaus, where a set of prescriptive operations, such as instream flows, water allocations, and structural and/or operational changes, were implemented into the model following stakeholder development. These alternatives allowed the stakeholders to identify and compare various operational changes.

- Temperature target specification scenarios – applied to the four-river model (all basins); temperature at key locations was specified and the system was re-operated to achieve those values. Additional options and assumptions allowed for the comparison of how various storage and release operations impacted downstream water temperatures and flows.

The purpose of the operations study was to demonstrate model capabilities for investigating various mechanisms for water temperature improvements in the river systems through operational and/or structural measures at the reservoirs and lakes. The end result was a fully-tested model of the four river system that stakeholders could use to identify and compare alternative operations to assist in achieving water temperature requirements throughout the system.

4.2. Historical Operations Scenario

After the separate river models were calibrated and combined, a single four-river model was developed. The historical operations model was run for 2004 through 2007. Two comparison points were located on each tributary and the mainstem of the San Joaquin (Figure 4-1). The model was run with historic hydrology and operations and compared with observed data. Overall, the historical operations model represented the flow and temperature at the key locations fairly well. (See Appendix A, Section 8.5, Figure 8-57 thru Figure 8-64 for comparison plots at the eight locations specified in Figure 4-1.) The historical operations scenario model provides a baseline for comparative analysis with the alternative operations or temperature target specification scenarios.

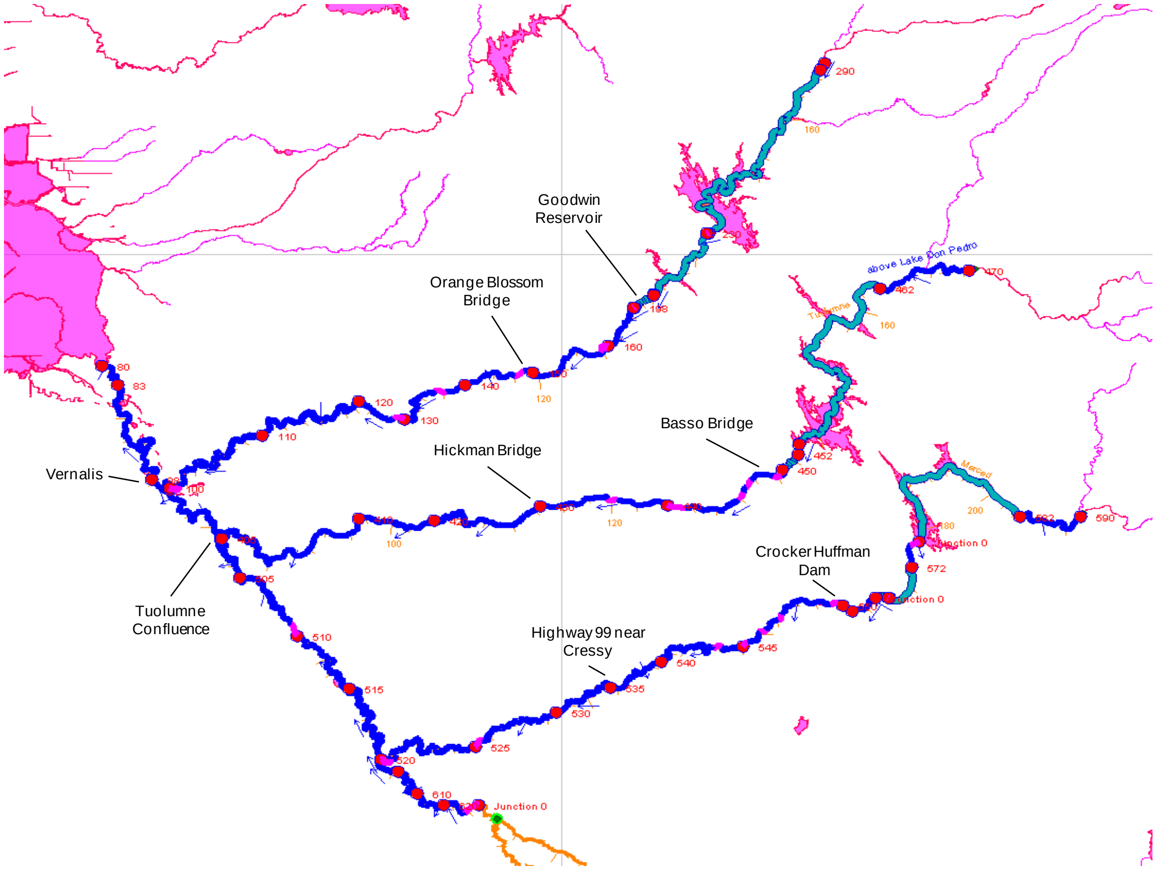

Figure 4-1. Four-river system as represented in the model, with calibration points indicated.

4.3. Alternative Operations Scenarios

The alternative operations scenarios can be divided into three main categories: instream flow, water allocation, and structural and/or operational change scenarios. These scenarios were run for the Stanislaus River model (which included the lower San Joaquin), but were not specifically developed for the Tuolumne or Merced due to complex stakeholder concerns. For the Tuolumne and Merced, the focus shifted to expanding the existing model capabilities into areas of most benefit. Discussions with stakeholders identified priority features that would allow stakeholders to assess their needs, which led to the development of the temperature target specification scenarios (see Section 4.4). As a result, the discussion herein focuses on the results for the Stanislaus River system alternative operations scenarios, which has been abbreviated from the full analysis presented in AD *et al*. (2008), Section 4.

The model simulated various alternatives of Stanislaus River operation. The alternatives consisted of two categories:

1. Water Management Plans for re-operation of New Melones, primarily consisting of diversions and instream flow schedules proposed by the irrigation districts and fishery agencies, and

2. Other Operational and Physical Changes in the system that were developed jointly by the Stanislaus stakeholders and/or initiated by the project team. These concepts are stand-alone options and, if feasible, could be implemented in conjunction with the Water Management Plans.

For the Water Management Plans, the model estimated the temperature response at specified control points on the river and the effect on water supply and storage at New Melones Reservoir. The driving force behind those proposals is the desire to meet water temperature objectives at defined control points in the river system that would enhance habitat conditions for fall-run Chinook salmon and Steelhead rainbow trout.

For the Other Operational and Physical Changes, the model estimated the temperature impact in absolute terms by examining specific time periods and system conditions when those changes are most relevant.

See AD *et al*. (2008) for additional information and comments. Discussion of the temperature criteria and control points are presented in Appendix B (Section 9).

4.3.1. Water Management Plans

The water management options were developed by the Stanislaus stakeholders through a series of workshops with the participation of representatives from irrigation districts (Districts) and fishery agencies (CDFG). Water management plans consisted of three common elements:

1) Proposed diversions schedules.

2) Proposed instream flow schedules.

3) Proposed temperature criteria for evaluation of alternatives. These criteria were developed based on the same principals proposed by the Peer Panel (see Section 4.2 above) with some modifications, as discussed below.

4.3.1.1. Districts Proposal

The Districts proposal was based on a CALSIM II model run. This proposal introduced a concept in which CVP (SEWD & Central San Joaquin Water Conservation District (CSJWCD)) deliveries and instream flow requirements for fish and water quality are triggered by the New Melones Forecast Index, which is similar to the current index being used by the New Melones Interim Operation Plan. The index is based on the sum of end-of-February New Melones storage and projected March through September reservoir inflows. To evaluate modeling results using the Districts temperature criteria, it was necessary to convert the criteria to a form compatible with that used in the Peer Panel Evaluation Model (the details of the conversion are available in AD *et al.* (2008)).

In summary, the Districts Proposal represents CALSIM II simulated deliveries to OID and SSJID and subscribed deliveries to SEWD and CSJWCD, fish flow, and water quality release and a modified temperature criteria in terms of magnitude and location of control points for the various life stages.

4.3.1.2. CDFG Proposal

The CDFG presented two cases for instream flow:

1) Case 1: Fish and water quality schedule with spring flow variation only.

2) Case 2: Fish and water quality schedule with fall/spring/summer flow variation.

The underlying assumptions in CDFG cases are that the release schedule changes depending on year type (wet, above-normal, below-normal, dry, and critically dry) as defined by the SJR Index, and diversions from Goodwin Dam are based on historical values (OID/SSJID and CVP contractors). Additionally, CDFG requested that the temperature analysis be conducted in two ways:

1) Using the proposed Peer Criteria.

2) Using the proposed Peer Criteria, with moving control point locations depending on the year type.

4.3.1.3. Results & Findings

Both the Districts and CDFG proposals were evaluated using the same underlying assumptions, which are detailed in AD *et al.* (2008). The alternative operations cases proposed by the Districts and CDFG were analyzed using the flow and temperature model. The results were subsequently evaluated based on the Peer Criteria, Districts Criteria, and CDFG Criteria.

The main difference between the Districts case and CDFG cases was the assumption regarding diversions. While CDFG uses historical diversion from Goodwin, the Districts case assumed deliveries based on future demands by the irrigation districts subject to the Districts' proposed curtailments based on New Melones Forecast Index.

Water temperature response results differ among the alternatives, but generally late spring and early fall present the most challenging periods for anadromous fish in the river. In the spring period, the Districts case and criteria provided the best performance. During the summer period, the CDFG Case 1, with either the Peer or CDFG Criteria, provided the best performance. In the fall, both the CDFG Case 1 and CDFG Case 2 provided improvement over historic conditions. The Districts case showed reduced penalty, but this reduction varied considerably among the selected criteria and at times accrued more penalty than the historic condition.

In conclusion: these simulations provide potentially useful insight into several facets of flow and temperature management in the Stanislaus River system, including:

- For approximately 8 months of the year, there are low penalties and generally little difference among many of the scenarios and criteria.

- Regardless of the criteria or proposal, spring (smoltification) and fall (early adult immigration and egg incubation) are the most challenging periods in the river.

- The system may be operated in various manners resulting in different benefits or drawbacks.

- The model and peer review criteria spreadsheet can readily identify the impacts of various water management strategies and sensitivity of selected thermal criteria.

4.3.2. Other Operational and Physical Changes

In addition to the operations proposed by the Districts and CDFG, other operational and physical changes were developed through discussions with the stakeholders or initiated by the project team. These concepts are stand-alone options and, if feasible, could be implemented in conjunction with the Water Management Plans proposed by the Districts and CDFG.

To assess potential impacts of operational changes, a base case and seven alternatives were simulated for the 1988 through 1997 period (a time of extended drought and reservoir recovery). The details of the alternatives are presented in AD *et al.* (2008). Presented herein is a list of the alternatives and some generalized findings.

1) Re-operation using Tulloch Rule Curve (base case),

2) Tulloch re-operation (September drawdown and filling),

3) Old Melones Dam removal,

4) New Melones power bypass with and without Old Melones Dam (various dates),

5) Goodwin Dam retrofit (lower level outlet),

6) New Melones selective withdrawal (with and without Old Melones Dam),

7) New Melones power outlet extension (without Old Melones Dam), and

8) Old Melones Dam lowered by 55 feet (partial removal).

4.3.2.1. Summary

Several insights were gained from simulations of a wide range of operational and physical changes, and are summarized below.

- Re-operation of Tulloch has little merit with or without New Melones power plant bypass.

- The Goodwin retrofit option provides a modest reduction of the maximum temperature below Goodwin Dam throughout the spring, summer, and fall months of all years. Implementation decisions should consider temperature benefits versus construction and operations and maintenance costs.

- New Melones power bypass provides cooler temperatures during the fall months without any structural changes, but did result in forgone power production.

Likewise, New Melones selective withdrawal provides greater flexibility for controlling outflow temperatures without foregoing power production. Temperature reductions are of the same magnitude as power bypass, so a selective withdrawal implementation plan should be based on temperature benefits versus construction and operations and maintenance costs.

- Old Melones Dam removal or lowering alone (i.e., no power bypass) has very little impact on New Melones release temperatures when water levels are above approximately 790 feet. Removal or lowering of the old dam does provide more cool water when bypassing the power plant or if a selective withdrawal option is adopted. Considering the effort of total removal of Old Melones Dam versus partial removal, the notched dam provides approximately 75 percent of the benefit with a much lower level of effort.

- Extension of the power intake to 675 feet alone depletes the cold water pool prematurely and compromises the potential for power bypass to control fall temperatures. Such an extension should only be considered as part of the two-port selective withdrawal scheme.

4.4. Temperature Target Specification Scenarios

The four-river model was also run to demonstrate different temperature target specification scenarios with reservoir volume reset options and a reservoir reoperation option, all of which were developed in response to stakeholders needs and suggestions. A total of five volume reset options and a reservoir reoperation option evolved out of stakeholder discussions.

4.4.1. Volume Resets

Five different reservoir volume reset options were added to the model. These options are designed to allow the user to evaluate past or future operation scenarios and their impacts on temperature in an efficient manner using the calibrated model and auxiliary data. Each option specifies reservoir volumes and temperature profiles on the simulation anniversary date of the beginning of simulation.

- Volume Reset 1 – Reset reservoir volume and temperature to a specific storage level at each anniversary date. This alternative can be used to examine the system state and temperature response given today's conditions for the range of historical ambient conditions (hydrology and meteorology) over any simulation period within the 1980 – 2007 period. This option can also evaluate alternative reservoir operation options by utilizing the capabilities of the HEC-5 model (e.g., minimum instream flow flood control requirements).

- Volume Reset 2 – Reset volume only when specific storage level is exceeded on the anniversary date. If storage is below the stated reset volume, then model does not reset and there is penalty for shortfalls. This alternative is similar to Vol_set1, but it can examine cumulative impacts of shortfalls over several years.

- Volume Reset 3 – Reset volume on first year only (i.e., non-varying initial condition). This alternative examines multi-year operation given initial condition (e.g., current conditions).

- Volume Reset 4 – Reset volume is user specified (e.g., historical volumes or user specified alternative volume objectives) for each year. This alternative examines how the system could have operated year-by-year given temperature objectives.

- Volume Reset 5 – Reset volume is user specified for each year unless the end of period storage falls below the stated reset initial storage, then model does not reset and there are penalties for shortfalls. This alternative is similar to Vol_set4, but shortfalls are accumulated. This method allows the user to quickly identify how long after the on-set of a dry period it takes the reservoirs to recover to historic levels.

The volume reset options allow the user to assess how alternative operational conditions and requirements would have impacted the system in any given year. Volume reset option 4 was used to demonstrate how the reservoirs and tributaries would respond to downstream temperature controls with and without the reoperation option.

4.4.2. Reservoir Reoperation

In addition to Volume Reset, a temperature objective option was implemented that determined reservoir releases required by downstream temperature objectives. This option was used in conjunction with either Volume Reset 4 or 5. A variation on the temperature objective option reoperates the reservoir so that the reservoir volume conforms to the volume specified on the anniversary date of the beginning of simulation (e.g. January 1st). The adjustment procedure is predicated on the anniversary volume relative to the prescribed volume. If the volume requires an upward adjustment (reduced reservoir outflow), the flow augmentation requirement computed based on downstream temperature targets flows is reduced by a fraction of the excess above flood control and minimum instream flow requirements. Conversely, if the volume requires a downward adjustment, the augmented flows are increased by a fraction of the differential between the historical and augmented flows when the historical flows exceed the augmented flows. The rational for the distribution of flow increases is that it mimics real-time operator decisions. Flow adjustments are made throughout the year so that the specified anniversary date reservoir volume is achieved. A more detailed description of Reservoir Reoperation is provided in Section 4.4.4.

4.4.3. Flow and Temperature Controls

One means of achieving compliance with temperature requirements is to modify the flow releases from reservoirs. Currently regulatory requirements specify minimum flows, which can be exceeded when there are flood release/spill (these are limited in the model by rule curve restrictions) and/or when flows are deliberately augmented to meet temperature targets downstream. A range of flows were modeled to determine the effect on temperature (i.e., determine the cfs per degree parameter). The initial parameter value is based on historic flows and temperature. Below is a discussion of the basic steps used to determine the target flow needed to meet a temperature requirement at a given control point. This method is based on implementing a minimum and maximum flow decrement (ramping) scheme. HEC-5Q essentially overrides HEC-5 minimum flow requirements under the bottom-up simulations, but channel capacities continue to apply.

- A maximum increment was added to current day flow at midnight. Likewise, a maximum decrement was subtracted from the flow at midnight. (Note that the resulting flow cannot exceed the maximum or minimum flow.) This defines limit of flows for subsequent 24 hours. For example, if the current flow is 300 cfs, the potential operating range available for temperature control is 225 cfs to 425 cfs, assuming a maximum increment of 125 cfs and a maximum decrement of 75 cfs.

- Evaluate the temperature at each control point.

- Estimate travel time based on the reservoir release, tributary contributions, and distance to control point to the determine forecast period.

- Take minimum and maximum range of flows and simulate each into the future (which includes downstream diversions, inputs, and meteorology). Specifically, make repetitive run of the HEC-5 and HEC-5Q models for the minimum flow for the duration of the travel time. If the minimum flow meets the temperature target requirement, apply the minimum flow in the range. If not, repeat the simulation for the maximum flow for the duration of the travel time. If maximum does not meet temperature target, use maximum of range. If the value is not at the extremes (maximum or minimum of range), an interpolation scheme is used (see Figure 4-2).

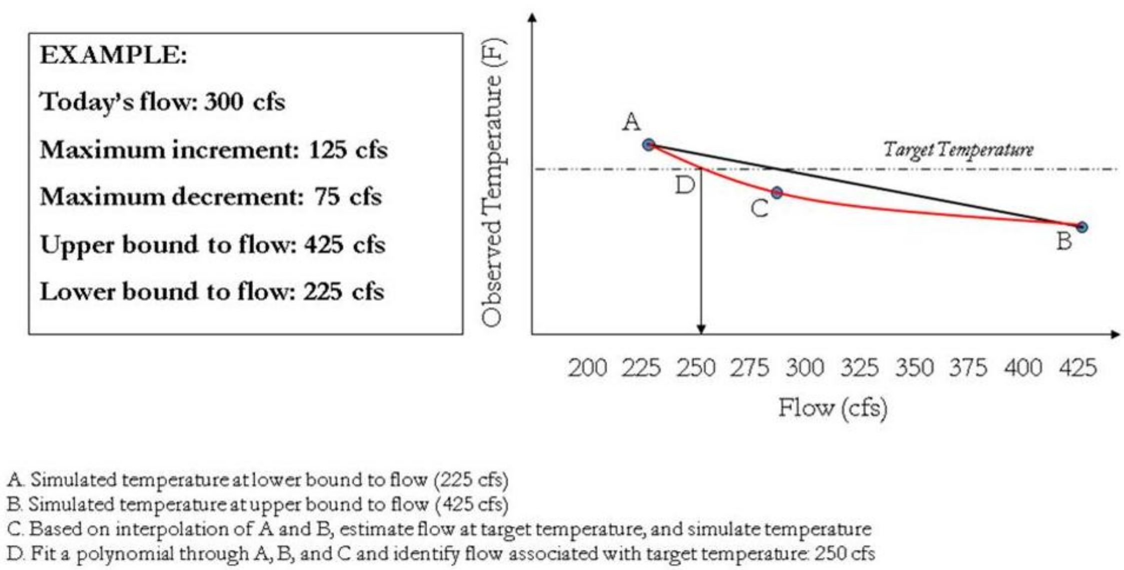

Figure 4-2. Example flow and temperature interpolation scheme.

4.4.4. Reoperation Controls

In addition to modifying the releases from the reservoirs, the models were also run to assess how reoperations would impact water temperatures downstream. A minimum operating storage (e.g., 200,000 acre-feet for Lake McClure) was specified and if storage in the source reservoir dropped below that volume, releases were set to achieve the minimum flow requirements (regulatory requirements) at the specific downstream locations. These control points were at varying distances downstream of the reservoirs on each river.

The minimum flow control points of interest are below Goodwin Dam and La Grange Dams on the Stanislaus and Tuolumne Rivers, respectively. The control point on the Merced River is located at Cressy to accommodate riparian users between Crocker Huffman Dam and Cressy. For these model runs, the minimum flow control point does not change as a function of time[4]; however, the required flow volume can change.[5] Reoperation controls only applies to the Volume Reset 4 and 5 alternatives.

At the end of the year (last day prior to anniversary date) the model compares the simulated volume to the reset volume and determines a scale factor (positive or negative). If the reset option is employed, the model scales the releases to ensure final volume matches the reset point on the anniversary date (increase or decreases flows). This scaling only applies to the incremental increase in flows (those flows that were calculated to meet temperature target above minimum flows). This option allows the comparison of benefits of (1) using all the water available regardless of what is needed to meet temperature requirements, and (2) using only water that is needed for temperature control.

4.4.5. Model Demonstration Results and Findings

The four-river model was run using historical hydrology (diversions and inflows) and meteorology and a combination of hypothetical temperature targets. For this model run, the three major reservoirs (New Melones, Don Pedro, and McClure) were operated to meet temperature objectives at specific downstream locations. The river flow control locations of interest are Cressy on the Merced River, La Grange Dam on the Tuolumne River, and Goodwin Dam on the Stanislaus River. A map of the four-river model with flow and temperature control points is shown in Figure 4-3.

In the first alternative, the reservoir storage volumes were reset to historical volumes on January 1st of each year (Volume Reset 4). The volume reset was achieved by either adding (if storage was below the reset volume on January 1st) or subtracting (if storage was above the reset volume on January 1st) water from storage instantaneously. This reset volume water neither increased nor decreased the total reservoir release volume

[4] The target temperatures (either daily average or daily maximum) and temperature control points can change daily, as can their associated minimum and maximum flows and maximum increments/decrements. **Note that the temperature and minimum flow targets used in these demonstration runs are not reflective of any policies of any stakeholders and are for model demonstration purposes only**.

[5] The maximum and minimum flows can be set equal to restrict flow to a stable regime (e.g., for spawning).

over the model year and does not factor into downstream flow (or temperature) conditions.

For the second alternative, Reservoir Reoperation was used to achieve anniversary date reservoir volume compliance.

4.4.5.1. Tuolumne River – Volume Reset

Figure 4-4 illustrates typical temperature target (daily maximum) operation in Tuolumne River with the Volume Reset option. Augmented La Grange Dam flows are in the upper plot with the 6-hour temperature response at the downstream temperature control points in the lower plot. Temperature targets for each location are also plotted. La Grange Dam flows are based on temperature targets at the three locations. When temperatures fall below the targets, minimum flows are released. When operating for locations furthest downstream, e.g. the confluence, the influence of meteorology becomes important. During these periods, there are greater variations in reservoir releases as the model attempts to meet the target temperature, and more frequent violations of the temperature target.

In Figure 4-5, Don Pedro Reservoir volumes are plotted for the historical simulation and the Volume Reset temperature target operation. The volume resets can be clearly seen by the abrupt changes in storage (near vertical lines) occurring on January 1st of each year. At the end of 2001, 2002, and 2004, the storage was below the historical operations volume and water was added to achieve the desired storage. At the end of 2003, the storage was very close to the anniversary volume, therefore only a small additional volume was needed to reach the required volume. Corresponding La Grange Dam flows are plotted in Figure 4-6.

Computed maximum (hour 18) temperatures for the historical and Volume Reset temperature target operation are plotted along with temperature targets at the three temperature control point locations (Turlock Park, Waterford, and the confluence) in Figure 4-7 through Figure 4-9. As indicated by the volume resets in Figure 4-5, significantly more water was released for the temperature target operation in 2002 and 2004, whereas the increase in release volume in 2003 was small. For this reason, the differences between historical and temperature target operation summertime temperatures are greater in 2002 and 2004 than they are in 2003. At uppermost location, Turlock Park, temperature targets are achieved most of the time. Furthest downstream, at the confluence, there is more variability in temperature and temperature target violations occur more frequently. The maximum flow constraints and ramping rates contribute to the target violations.

4.4.5.2. Tuolumne River – Reservoir Reoperation

In Figure 4-10, Don Pedro Reservoir volumes are plotted for the historical simulation, Volume Reset temperature target operation and temperature target operation with Reservoir Reoperation. While the volume resets cause the abrupt changes in storage on January 1st of each year, the Reservoir Reoperation makes adjustments to flow augmentation throughout the year to achieve the anniversary date volume goal. Corresponding La Grange Dam flows are plotted in Figure 4-11. In 2002, relative to the historical condition, the Reservoir Reoperation reduced releases during the winter, saving water to allow summer releases to be increased by about three times to meet the temperature targets. In 2003, Reservoir Reoperation redistributed the spring flows and increased summer flows. In 2004 there was no available water early in the year to redistribute over time due to volume constraints (extra water could not be saved during the winter due to flood control requirements). Consequently, summertime flows are set at minimum flow requirement for the Reoperation case.

Computed maximum (hour 18) temperatures for the historical, Volume Reset temperature target operation, and temperature target operation with Reservoir Reoperation are plotted along with temperature targets at Turlock State Park in Figure 4-12. During the summer of 2002, Reservoir Reoperation temperatures are about 2° F higher than target temperatures. During 2003, sufficient water is available to maintain temperatures within 1° F of target with Reservoir Reoperation. In 2004, Reoperation reduces summertime temperatures below historical due to higher minimum instream flow requirements, however temperatures are well above targets because the volume constraints discussed above do not allow flexibility in redistributing flows. Similar impacts of Reservoir Reoperation are computed at the downstream locations.

Overall, reoperating the reservoir to redistribute the same annual volume of water released historically results in dramatic improvements in downstream temperatures.

4.4.5.3. Merced River – Volume Reset

Figure 4-13 illustrates typical temperature target (daily maximum) operation in Merced River with the Volume Reset option. Augmented Crocker-Huffman Dam and Cressy flows are in the upper plot with the 6-hour temperature response at the downstream temperature control points in the lower plot. Temperature targets for each location are also plotted. Exchequer Dam is operated to meet flow requirements at Cressy that are based on temperature targets at the three locations. Crocker-Huffman flows are also plotted. The difference between the flows is the net consumptive use between the two locations. When temperatures fall below the targets, minimum flows are released. During November and December, there are no temperature targets and releases are based on a constant flow requirement. The lack of temperature compliance during the summer months results from the maximum flow constraint (600 cfs at Cressy) assumed for this demonstration. This plot illustrates the challenges of meeting this hypothetical temperature objective. The smaller Lake McClure volume (relative to New Melones and Lake Don Pedro) results in a more rapid depletion of the cold water pool resulting in higher release temperatures. Additionally, the three reservoirs and stream reaches between Exchequer Dam and Crocker-Huffman Dam add to travel time and instream heating. The results are typical summertime maximum daily temperatures at Crocker-Huffman Dam of approximately 60^{o} F. At La Grange Dam on the Tuolumne River, the summertime daily maximum temperature is approximately 55^{o} F. The warmer temperatures at Crocker-Huffman reduce the thermal efficiency of the augmentation flow (e.g., 1 unit of flow at 55° F (Tuolumne) has approximately the same cooling effects as 2 units of flow at 60° F (Merced) for a temperature objective of 65° F).

In Figure 4-14, Lake McClure volumes are plotted for the historical simulation and the

Volume Reset temperature target operation. Again, the volume resets can be seen by the abrupt changes in storage (near vertical lines) occurring on January 1st of each year. At the end of each year shown, the storage was below the historical operations volume and water was added to achieve the desired storage. Historical flows at Cressy (flows at Cressy and Highway 59 are essentially the same in the model) and Volume Reset temperature target operation flows at Cressy and Crocker-Huffman Dam are plotted in Figure 4-15. For the temperature target operation, the model operates to the flow at Cressy. The difference between the Crocker-Huffman release flows and the Cressy flows is consumptive use between the two locations. There is very little difference in flow among the three years shown. Flow is constrained at 600 cfs during the summer at Cressy and this constraint is active every year.

Computed maximum (hour 18) temperatures for the historical and Volume Reset temperature target operation are plotted along with temperature targets at the three temperature control point locations (Hwy 59, Cressy, and the confluence) in Figure 4-16 through Figure 4-18. Summertime operations are based on the temperature target at Hwy 59. The maximum flow constraint of 600 cfs prevents temperature compliance at this location in the late summer each year, indicating that the hypothetical temperature targets conflict with the flow constraints and with the realities of the limited Lake McClure volumes and Crocker-Huffman temperature conditions discussed above. A higher temperature target is probably indicated. At Cressy and the confluence, temperature targets are generally met during 2002 and 2003 with small violations. During 2004, there are frequent violations of 1 to 4° F at the confluence during April, May and October. There is a pronounced temperature response at both Cressy and the confluence due to flows that are typically four times the historical rate. The increased flow and shorter stream residence time results in less heating within the river.

4.4.5.4. Merced River – Reservoir Reoperation

In Figure 4-19, Lake McClure volumes are plotted for the historical simulation, Volume Reset temperature target operation, and temperature target operation with Reservoir Reoperation. While the volume resets cause the abrupt changes in storage on January 1st of each year, the Reservoir Reoperation makes adjustments to flow augmentation throughout the year to achieve the anniversary date volume goal. Corresponding Crocker-Huffman Dam flows are plotted in Figure 4-20. For the Reservoir Reoperation case, each year's augmented flows are reduced by about 1/3 relative to the Volume Reset case. Relative to the historical case, the winter and spring flows are redistributed to the summer.

Computed maximum (hour 18) temperatures for the historical, Volume Reset temperature target operation, and temperature target operation with Reservoir Reoperation are plotted along with temperature targets at Hwy 59 in Figure 4-21. Results are similar for each year because the reset volumes are similar for each year. Reservoir Reoperation temperatures are about 2 to 3° F above the target temperature during the summer months.

Overall, reoperating the reservoir to redistribute the same annual volume of water released historically results in substantially cooler downstream temperatures.

4.4.5.5. Model Demonstration Summary

Overall, the model was able to meet temperature targets better when re-operated. There were higher summer flows in the rivers, but lower winter flows. The peak flows in spring tended to be larger than under historic operations. When temperature targets were met easily (i.e., targets were already met under historic operations), more water tended to remain in storage in the reservoir because lower flow required lower releases, whereas when temperature targets were harder to achieve more flow was required and reservoir storage was correspondingly lower. Even with the reservoir reoperation it was not always possible to achieve the temperature targets downstream. The number of occurrences when the targets were violated decreased with the reoperation, but was not eliminated.

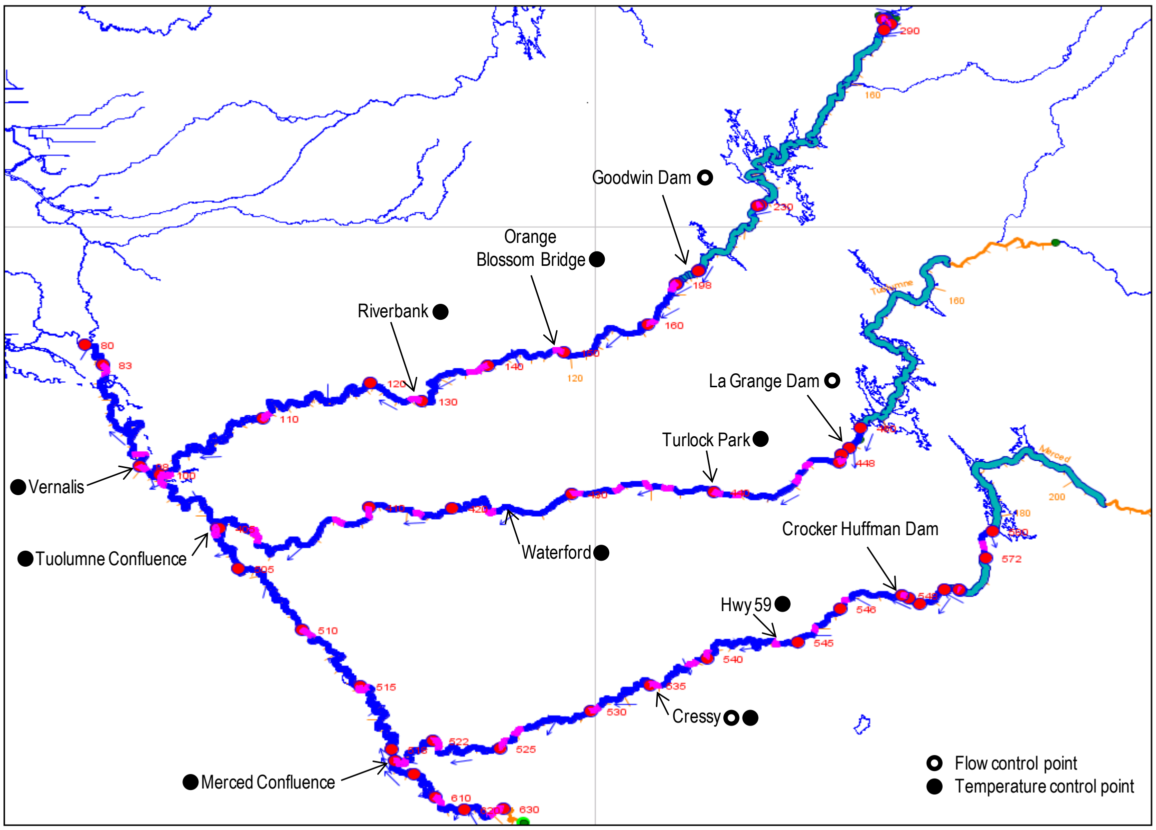

Figure 4-3 Four-river system as represented in the model, with flow and temperature control points indicated.

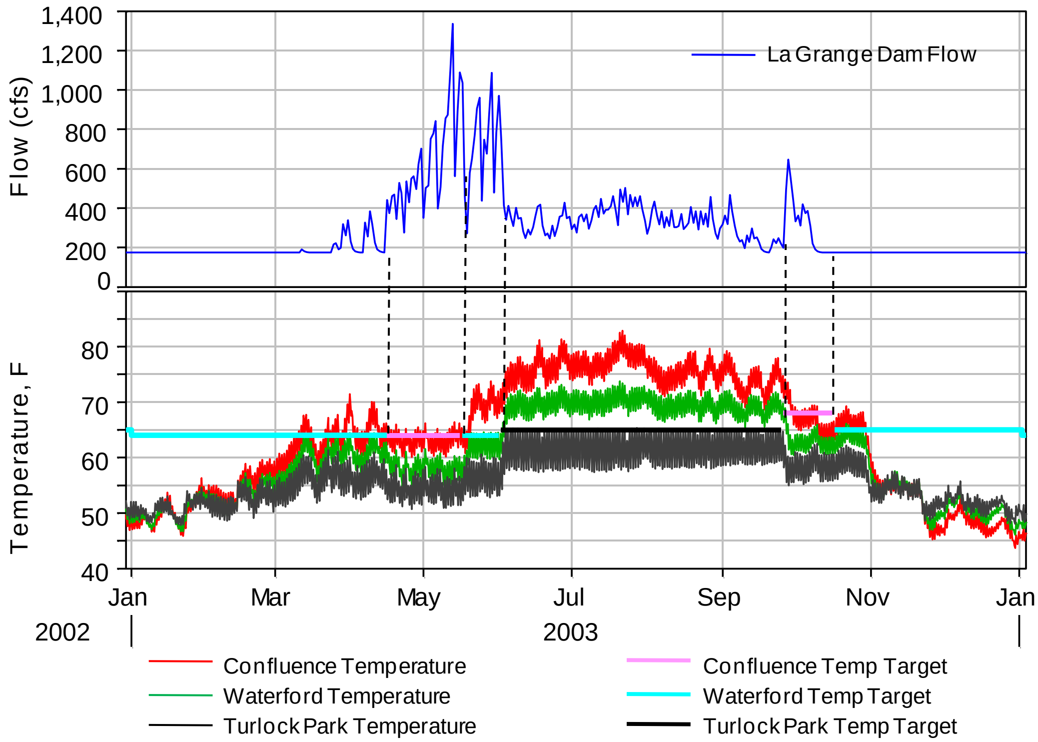

Figure 4-4 Illustration of temperature target operation in Tuolumne River: La Grange Dam flows and downstream temperatures and temperature targets.

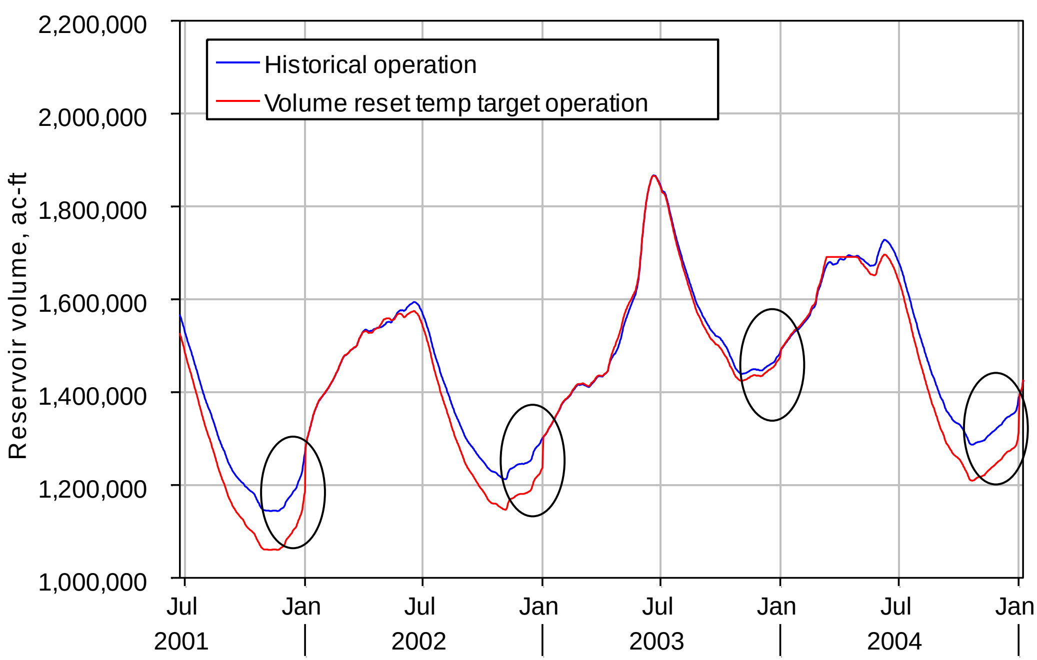

Figure 4-5 Don Pedro storage computed for historic operations and volume reset temperature target operations from 2001 through 2004. The volume reset forced the temperature target storage to equal the historic operations storage on January 1st of each year, indicated by ovals.

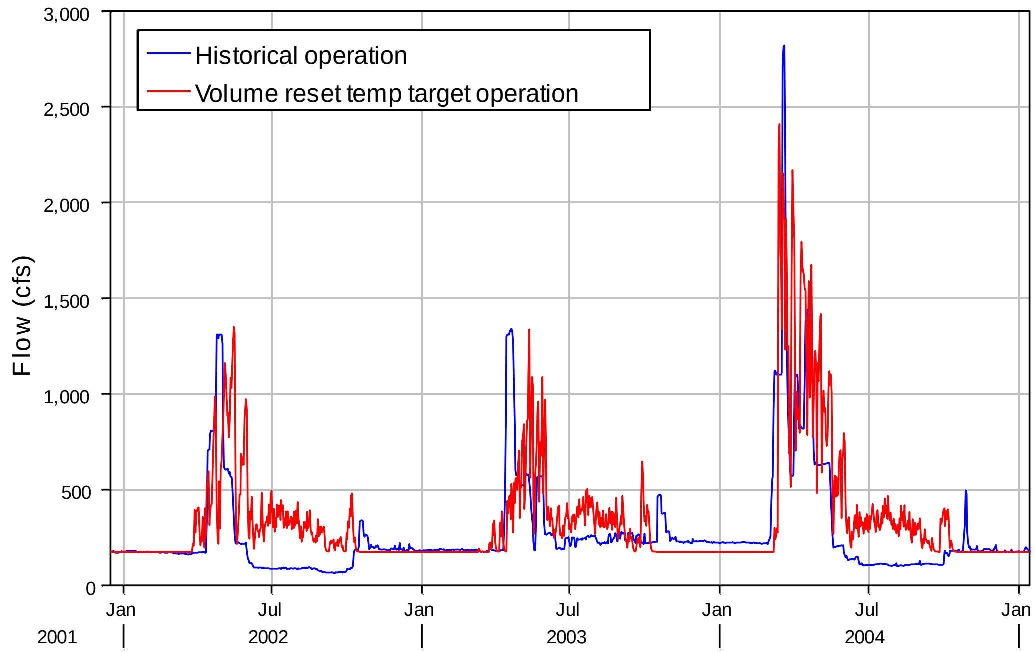

Figure 4-6 La Grange Dam flow (Tuolumne River) computed for historic operations and volume reset temperature target operations from 2002 through 2004.

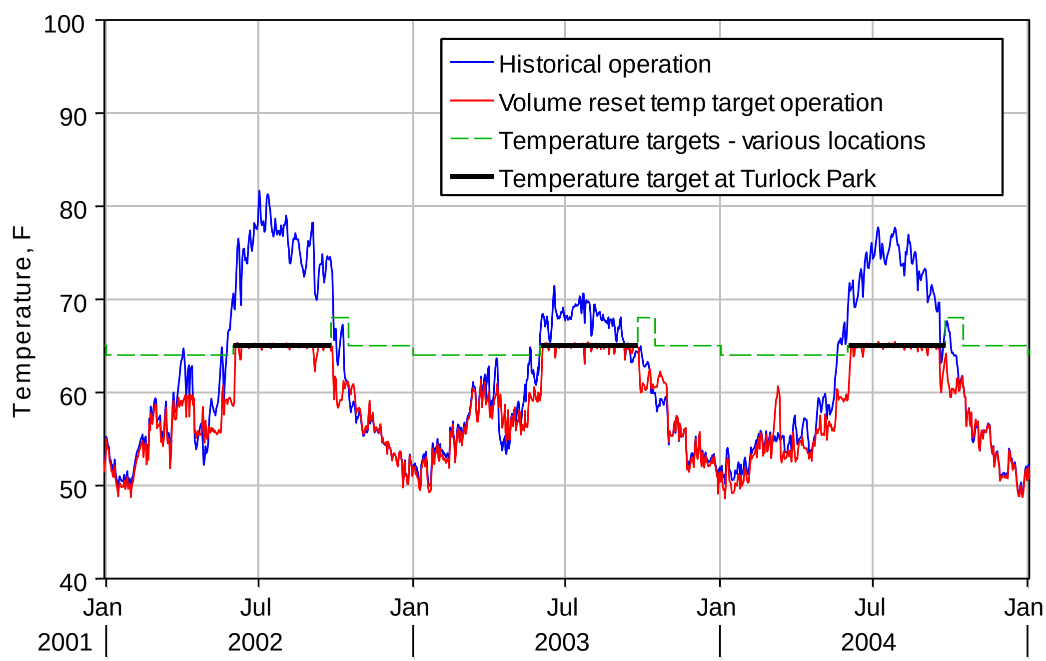

Figure 4-7 Computed daily maximum temperatures (occurring at hour 18) at Turlock State Park for historical operations and volume reset temperature target operations from 2002 through 2004.

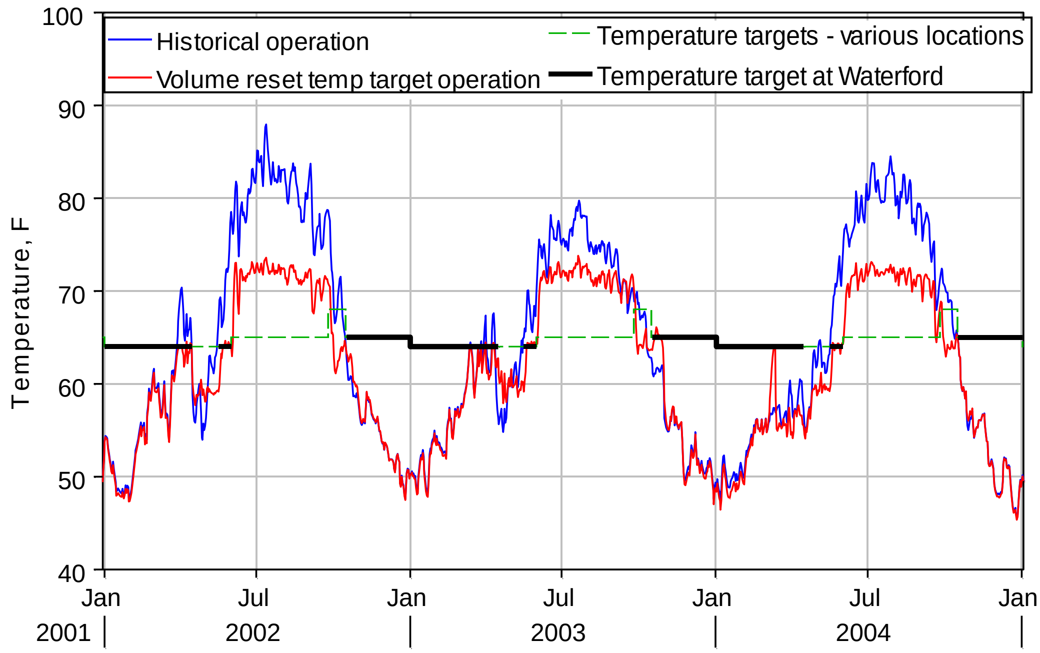

Figure 4-8 Computed daily maximum temperatures (occurring at hour 18) at Waterford for historical operations and volume reset temperature target operations from 2002 through 2004.

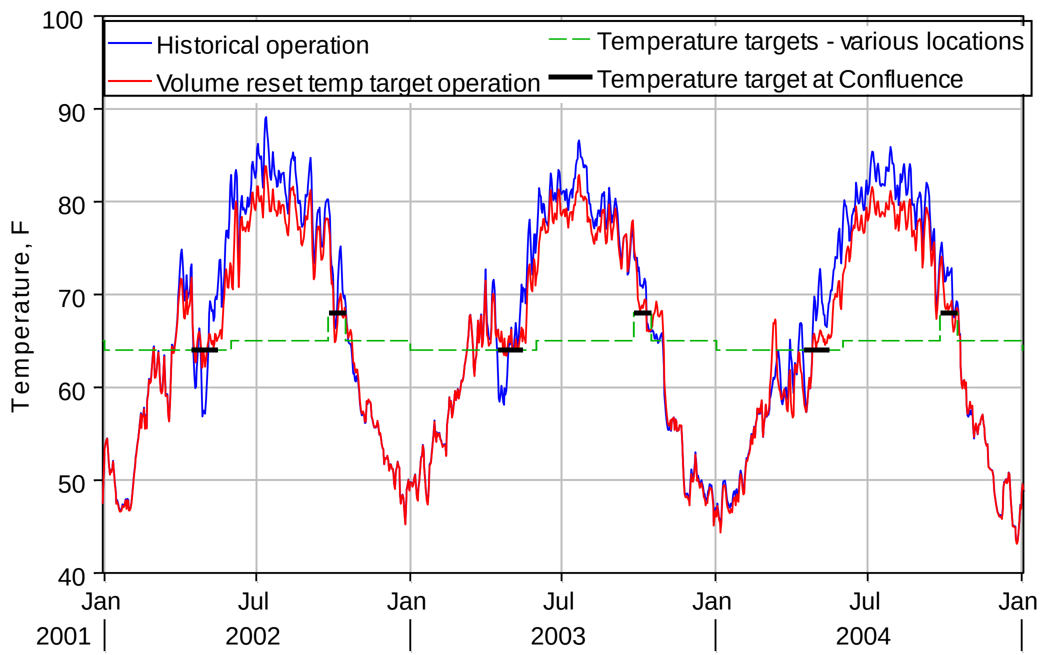

Figure 4-9 Computed daily maximum temperatures (occurring at hour 18) at the Tuolumne confluence for historical operations and volume reset temperature target operations from 2002 through 2004.

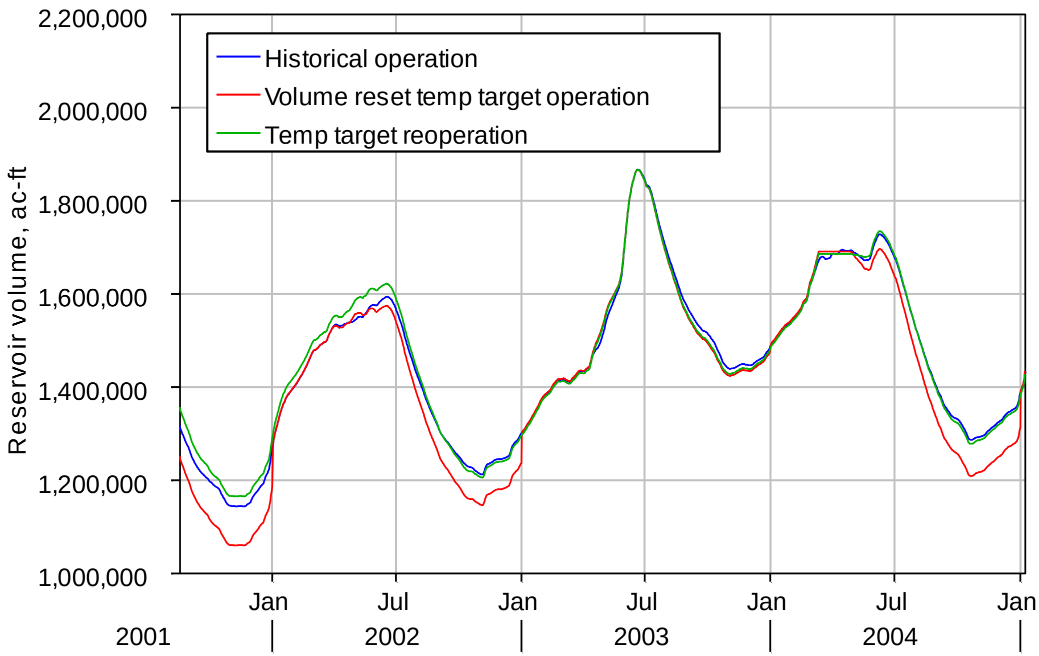

Figure 4-10 Don Pedro storage computed for historic operations, volume reset temperature target operations and temperature target reoperation from 2001 through 2004.

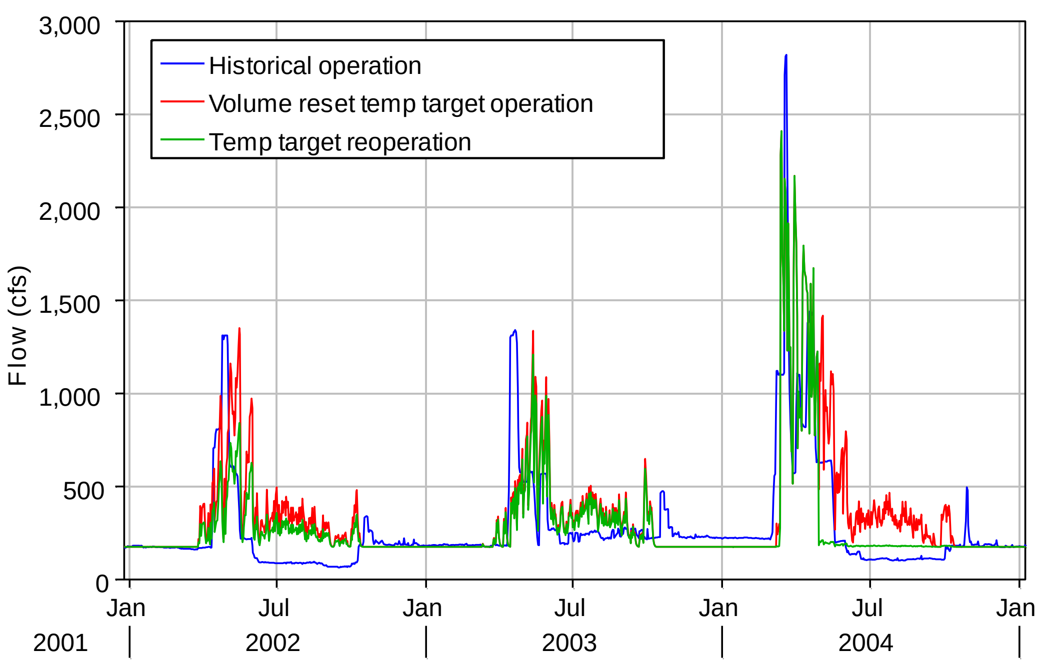

Figure 4-11 La Grange Dam flow computed for historic operations, volume reset temperature target operations and temperature target reoperation from 2002 through 2004.

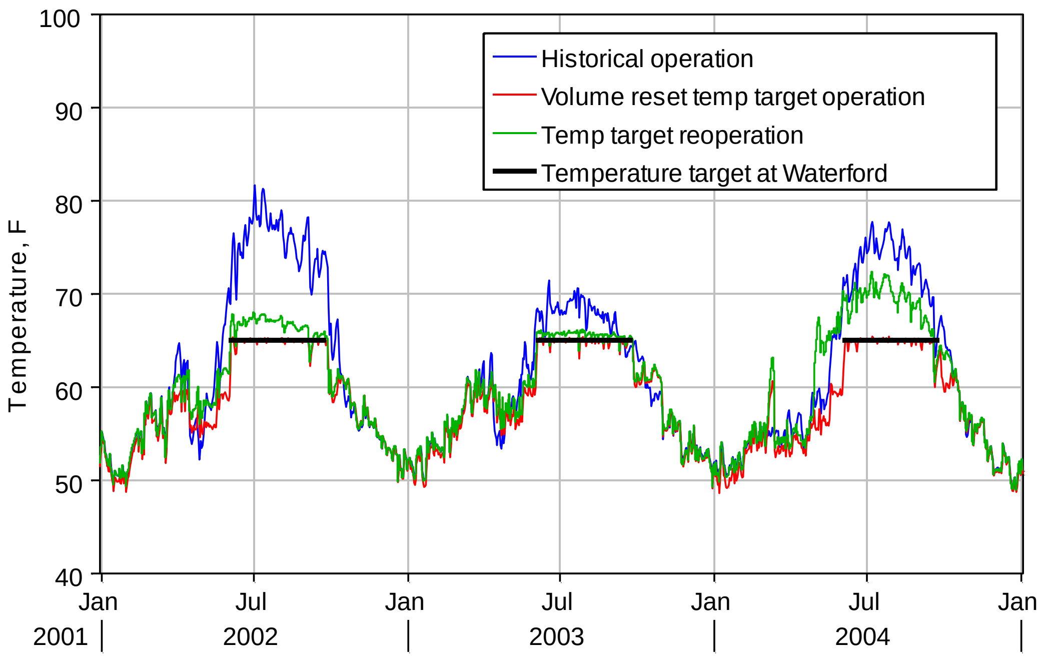

Figure 4-12 Computed daily maximum temperatures (occurring at hour 18) at Turlock State Park for historical operations, volume reset temperature target operations and temperature target reoperation from 2002 through 2004.

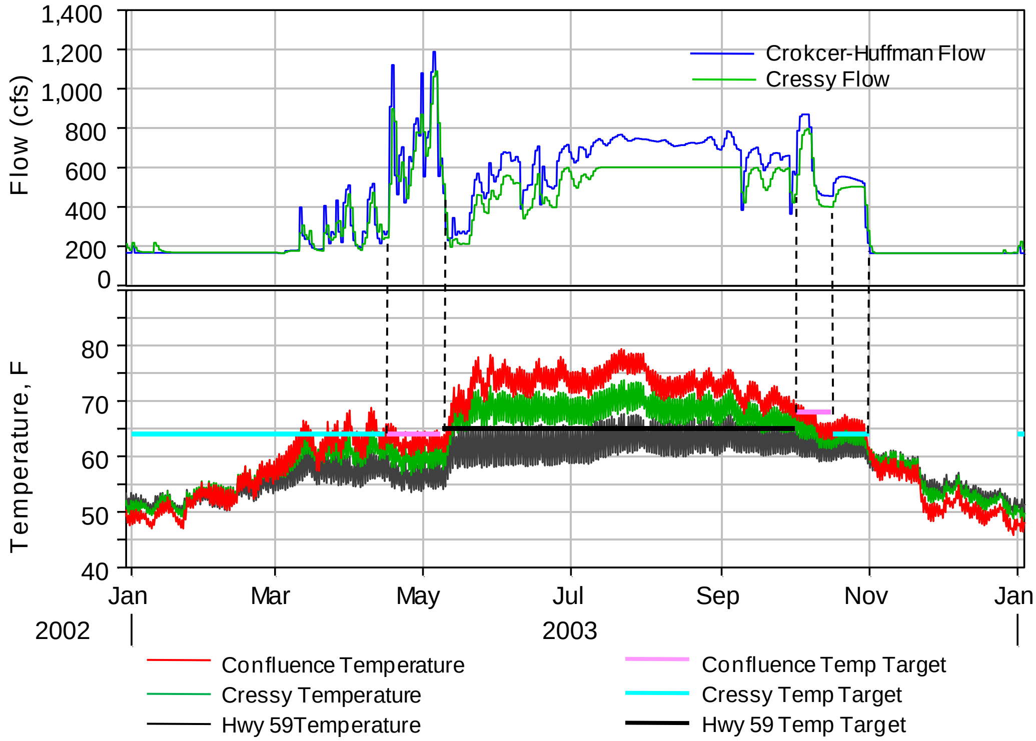

Figure 4-13 Illustration of temperature target operation in Merced River: Crocker-Huffman and Cressy flows, and downstream temperatures and temperature targets.

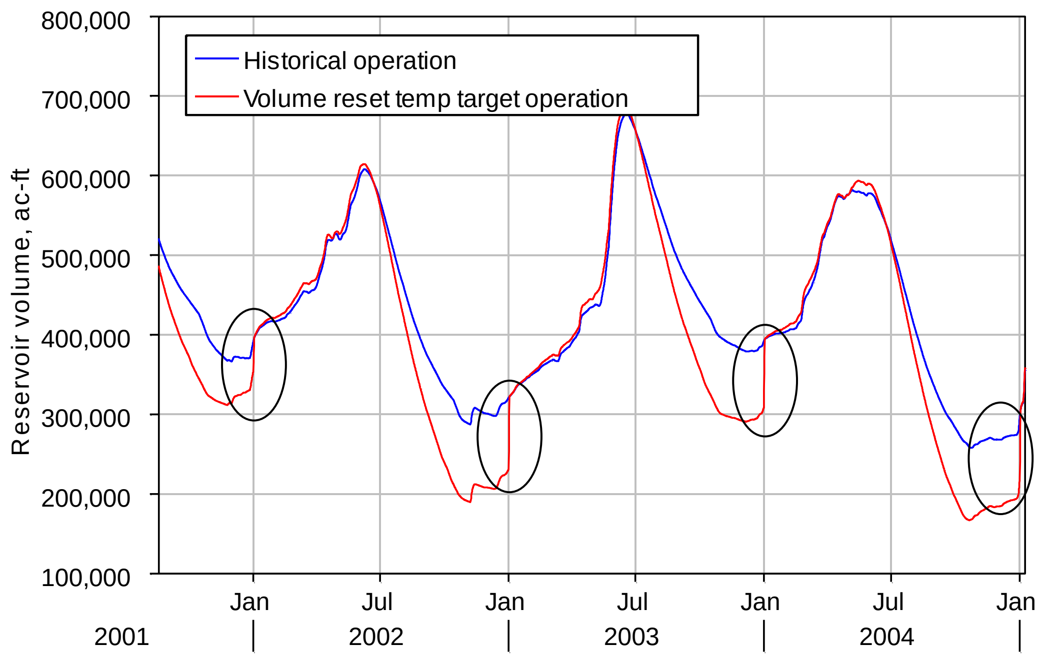

Figure 4-14 Lake McClure storage for historic operations and volume reset temperature target operations from 2001 through 2004. The volume reset forced the temperature target storage to equal the historic operations storage on January 1st of each year.

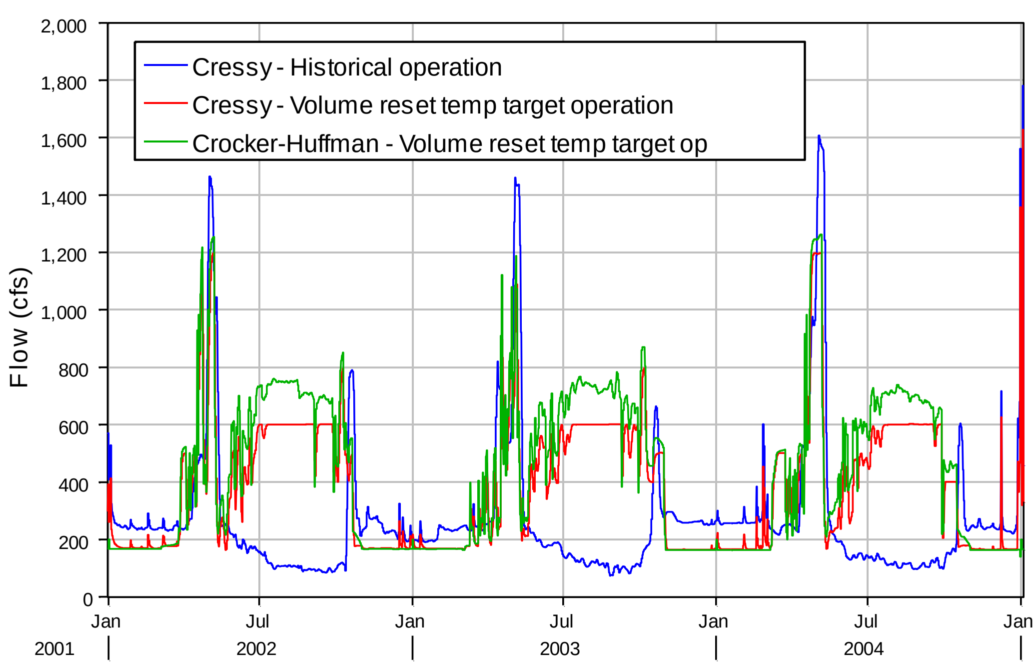

Figure 4-15 Flow computed at Cressy for historic operations and volume reset temperature target operations and at and Crocker-Huffman Dam for volume reset temperature target operations from 2002 through 2004.

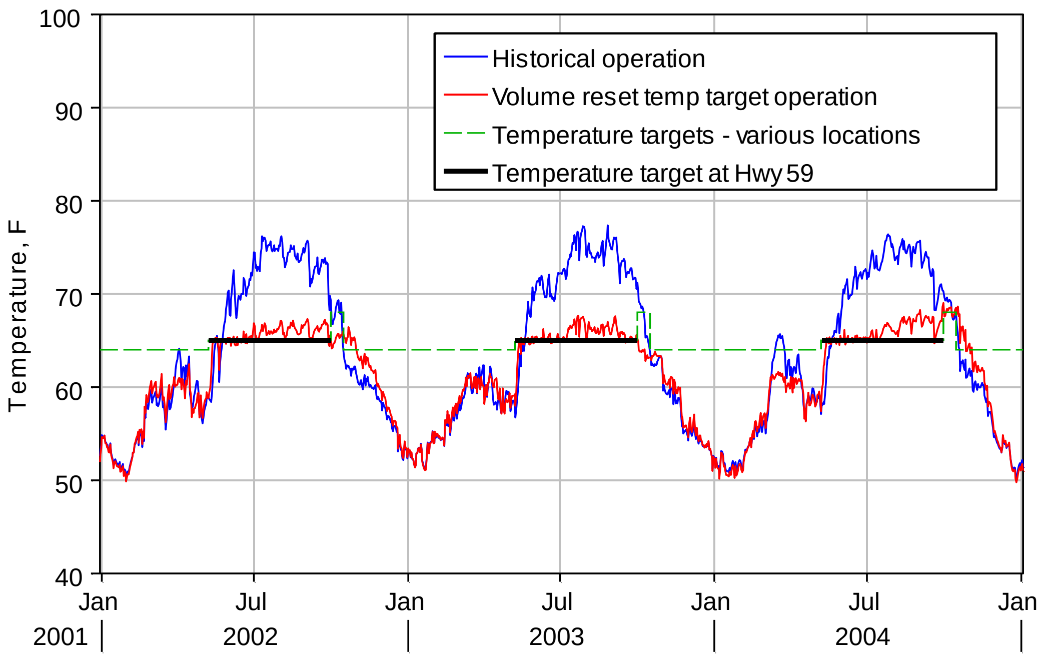

Figure 4-16 Computed daily maximum temperatures (occurring at hour 18) at Hwy 59 for historical operations and volume reset temperature target operations from 2002 through 2004.

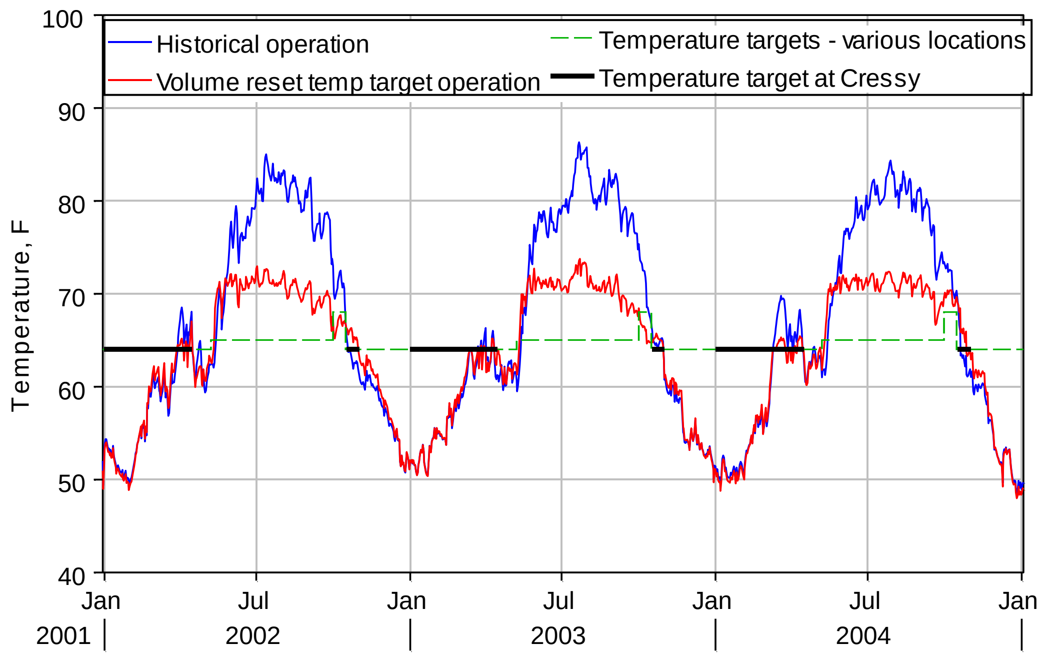

Figure 4-17 Computed daily maximum temperatures (occurring at hour 18) at Cressy for historical operations and volume reset temperature target operations from 2002 through 2004.

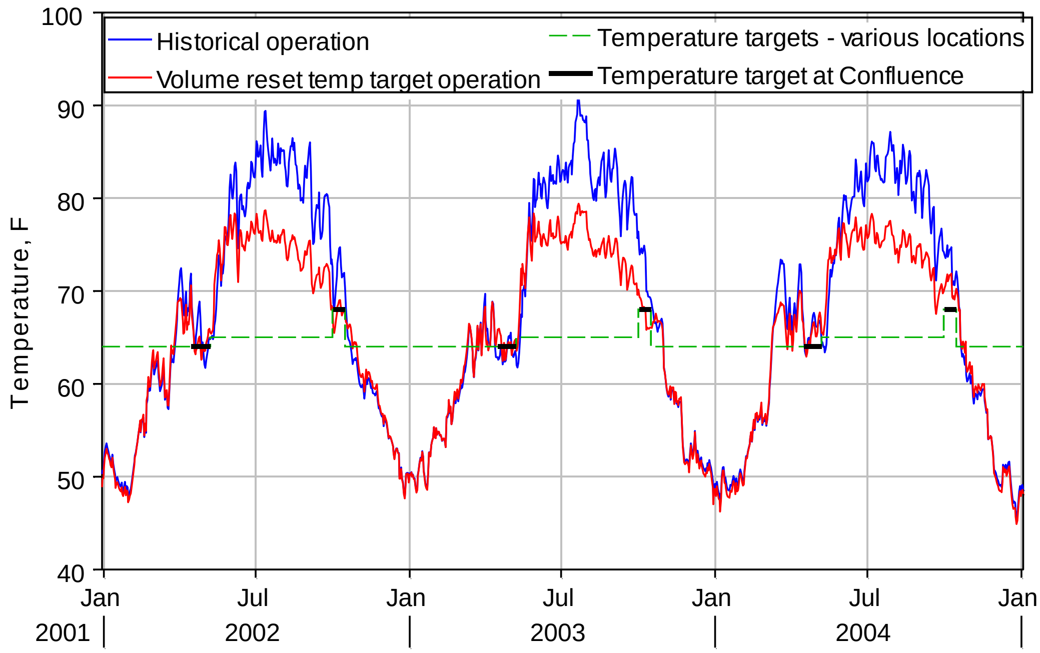

Figure 4-18 Computed daily maximum temperatures (occurring at hour 18) at the Merced confluence for historical operations and volume reset temperature target operations from 2002 through 2004.

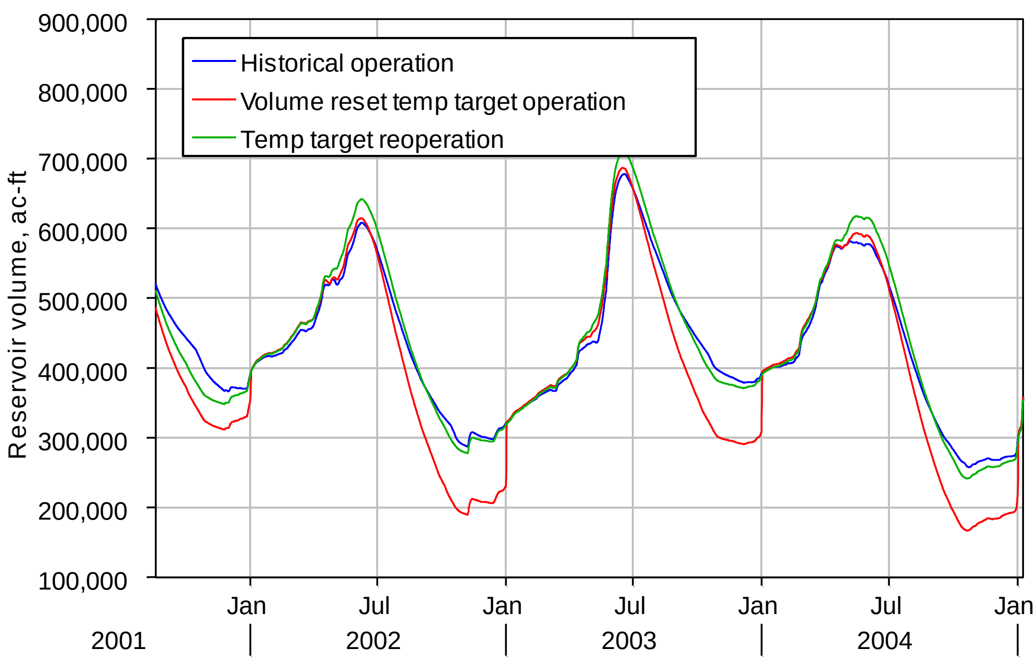

Figure 4-19 Lake McClure storage computed for historic operations, volume reset temperature target operations and temperature target reoperation from 2001 through 2004.

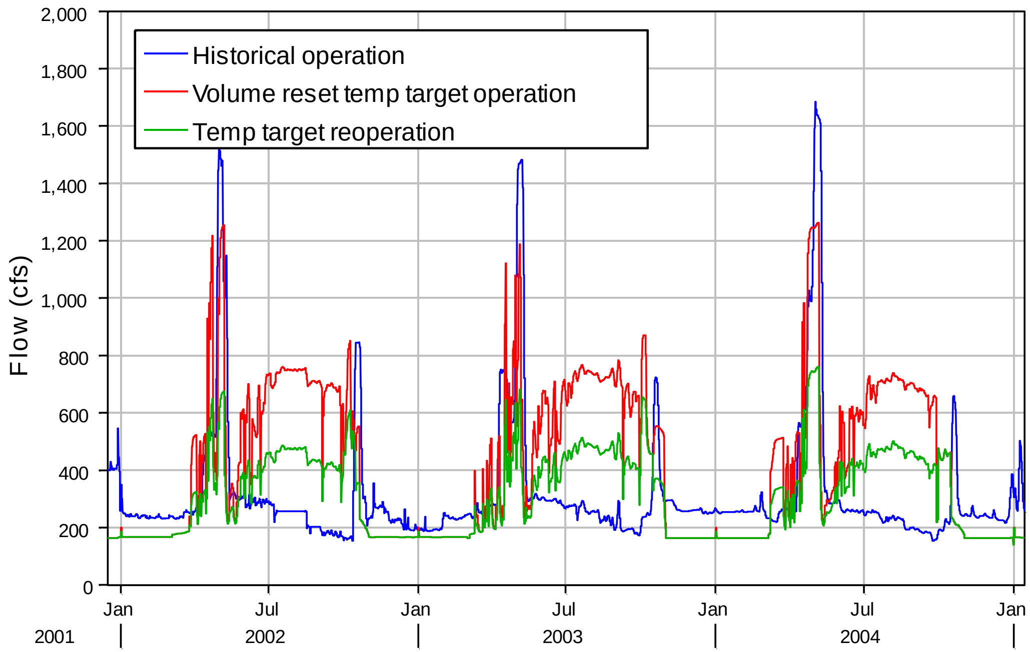

Figure 4-20 Flow computed at Crocker-Huffman for historic operations, volume reset temperature target operations and temperature target reoperation from 2002 through 2004.

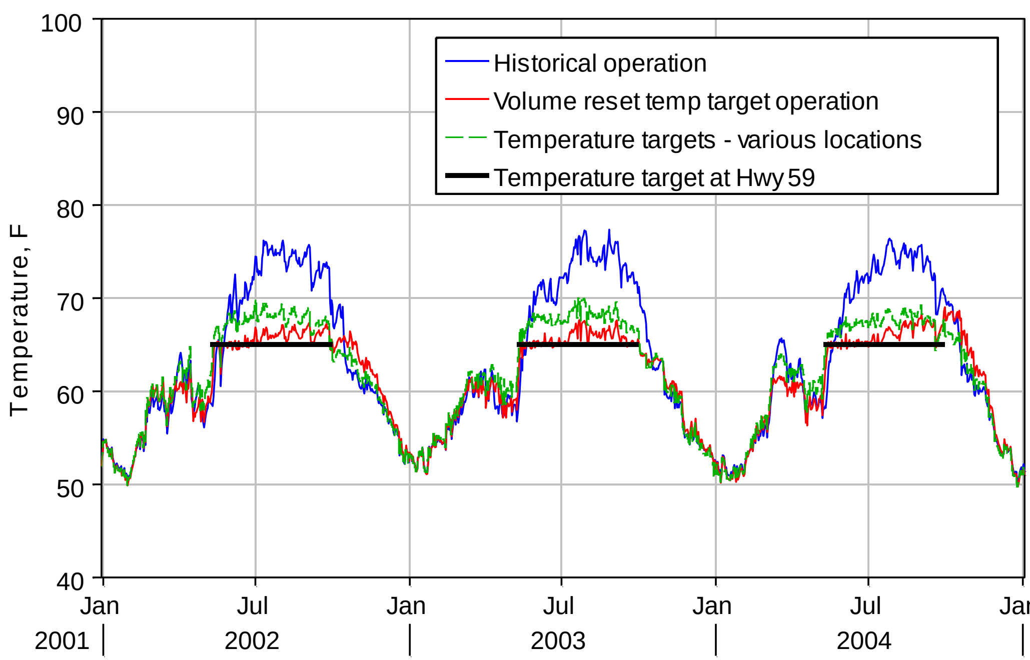

Figure 4-21 Computed daily maximum temperatures (occurring at hour 18) at Hwy 59 for historical operations, volume reset temperature target operations and temperature target reoperation from 2002 through 2004.

5. Implementation Plan

An implementation plan follows the acceptance of an operational philosophy agreed to by the decision makers (stake holders, resource agencies, etc.). It is premature to attempt to define or anticipate a consensus operation approach due to the many conflicting interests. Therefore, this section addresses how the model can contribute to the decision making process that eventually would result in an implementation plan.

Section 4 identifies typical operational, structural, planning, or other activities that could provide insight to decision makers that allow water temperature objectives to be incorporated in the development of water management plans or similar actions. These plans are intended to compliment other activities in the basin.

As such, elements of the plan can take several forms, including identifying operational strategies (storage management, delivery quantity and timing), return flow and tributary impacts, in stream flow conditions to support temperature objectives, downstream and basin-scale interactions, and restoration measures. Because the model provides a detailed representation of the system (spatial scale of approximately a mile or less and sub-daily time step), analyses ranging from general to specific can be completed. Further, the basin-scale extent of the model provides a means to assess concurrent activities throughout the main stem San Joaquin River and its major tributaries.

5.1. Identified Actions

In the course of this and antecedent projects, the project team analyzed operations, system elements, and concepts that can be examined to assist resource managers in developing the necessary information to manage water temperature at the basin-scale for anadromous fish. As with previous work completed by the team, this implementation plan does not identify a schedule for completion of activities. Rather, the implementation plan is a road map to provide direction for resource managers to incorporate local knowledge of individual systems and use the tool developed herein to assist in planning and management decisions. That is, it may be prudent to consider future changes in operations and conditions prior to embarking on certain aspects of this implementation plan. An encouraging aspect of this study is the continued, direct involvement of basin stakeholders in identifying potential actions and participating in the assessment of these actions. With such involvement, it is envisioned that acceptable actions will be appropriately studied and implemented as funding and need arise.

Several examples of this approach are evident in studies completed during the project for the Stanislaus River, including:

- Goodwin Dam Retrofit (lower level outlet)
- Tulloch re-operation (September drawdown and filling)
- New Melones power bypass with and without Old Melones Dam (various dates)
- New Melones selective withdrawal (with and without Old Melones Dam) and power intake extension (without old dam)

- Old Melones Dam removal or modification

Each of these model applications were exploratory and intended as examples of how the model could be utilized to examine specific operational and physical changes. Nonetheless, these model applications clearly illustrate the wide range of alternative actions that can be assessed with the model. As noted above under the operational plans, multiple simulations were completed for each of the major tributaries to assess potential operational conditions. Minimum flow requirements were explored, as were operational constraints to maintain minimum reservoir storage and explore cold water pool implications. Hypothetical temperature targets were set and multiple year-types were examined. These results constrain the range of flows and temperatures that may be expected and the carryover storage impacts and subsequent temperature ramifications of decreased cold water pool volume. This type of information and modeling approach would be useful to stakeholders and resource managers to assess and evaluate water temperature management actions throughout the basin.

5.2. Continued Development of the Model

The HEC-5Q model includes other water quality parameters that can provide valuable details for water managers in the basin. For example salinity could be added to the model, or more complex water quality processes such as dissolved oxygen and associated controlling factors (e.g., nutrients and primary production). Water quality conditions beyond temperature are of concern in portions of the basin, including dissolved oxygen conditions in the Stanislaus River at Ripon, salinity at Mud and Salt Sloughs (and other drains), and potential water quality conditions associated with the upper San Joaquin River restoration activities between the Merced River and Friant Dam. One approach would be to phase in future model modifications with reach specific water quality elements added to the model in order of priority. These model elements would extend the value of the model and would be useful, for example, in developing flow-temperature and flow-salinity relationships for larger scale planning models, such as CALSIM.

Another potential implementation of the model is by the adaptation of the model as short-term water scheduling support tool. For example:

Recently, the National Marine Fisheries Service and U.S. Fish and wildlife Service (collectively, NMFS) issued Interim Measure Elements for temperature control in the lower Tuolumne River. NMFS has identified the need for a “temperature model to predict release flow targets to meet the temperature requirements” in the Tuolumne River on a real time basis.

Currently, the HEC-5Q model has the capability for computing reservoir releases to meet downstream temperature targets using historical hydrology and meteorology. The current model and graphical user interface (GUI) is an ideal starting point for creating a user friendly software package designed to forecast reservoir operation a week or so into the future using anticipated weather conditions (e.g., maximum and minimum air temperature), forecasted demand and ambient conditions. The GUI would be developed to query the required inputs and display the results. The forecast model would utilize selected routines from the current 5Q model and a database to define invariant model data.

The proposed code would be developed for a specific river system (e.g., Tuolumne River and Don Pedro Reservoir) but would be designed to be easily transported to other river basins where a large reservoir provides a cold water pool for temperature management. The model would include river specific data such as:

- Stream and reservoir geometry as a function of flow (e.g., La Grange Reservoir and the Tuolumne and portions of the San Joaquin Rivers)
- Detailed meteorological data and correlations with max/min air temperatures

The interactive program / GUI (residing on a laptop or desktop PC) would only require a small data set reflecting current conditions. For the Tuolumne River example, the following inputs reflecting anticipated conditions would be required for the planning period (normally a few days to a week)

- Don Pedro Dam outflow temperature
- Daily demands (TID and MID)
- Maximum and minimum air temperatures (Modesto or other weather station)
- Temperature target (daily maximum or average) and target location.
- San Joaquin River flow and temperature at Newman (only pertinent if the target is in the San Joaquin River between the Tuolumne and Stanislaus confluences)
- Dry Creek flow and temperature

The primary uncertainty in this forecasting approach is weather. The meteorology preprocessing utility program used to develop meteorological inputs to the HEC-5Q model has demonstrated the good correlation between maximum and minimum air temperature and detailed meteorology. The forecasting model would automatically select appropriate detailed meteorology. To assess uncertainty, several sets of conditions could be evaluated to compute a range of required flows. The appropriate number of meteorological conditions would be assessed during model development. The number of conditions could increase as the analysis time horizon increased.

The goal of this development would be a program that would take minutes to set up and run so that forecasts could be easily updated daily with the most recent conditions.

6. Conclusions

The current, expanded, and calibrated model is a powerful tool that has been developed with broad stakeholder support. A formal peer review of the expanded model has been completed. Further, the model resides in a graphical user interface that allows stakeholders to use the model and examine output throughout the model domain. Finally, the existing HEC-5Q model can also be adapted to include a wide range of water quality parameters.

Another element of the modeling project is the development of temperature objectives for each major tributary and the main stem San Joaquin River. A post-processor spreadsheet tool has been developed to allow stakeholders and agency staff to readily compare and assess the implications of various model output scenarios based on thermal criteria for anadromous fish. The spreadsheet environment is transparent and users can change life stage criteria, location of application, and time of year. This work has been developed in cooperation with stakeholders and agency staff throughout the project.

In sum, a powerful temperature model has been developed at the basin scale for the San Joaquin River. Development of this tool has taken place in an open and inclusive environment with basin stakeholders and agencies. Likewise, scenarios and simulations have been shared with basin stakeholders and agencies. The project team presents this tool to all members of the basin as a calibrated fully developed model to assist stakeholders, resource agencies, and others to incorporate water temperature objectives when developing water management plans.

7. References

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8. Appendix A: Additional Calibration Figures

Included herein are the remaining calibration figures for the Stanislaus, Tuolumne, Merced, and San Joaquin River system models.

8.1. Stanislaus River System

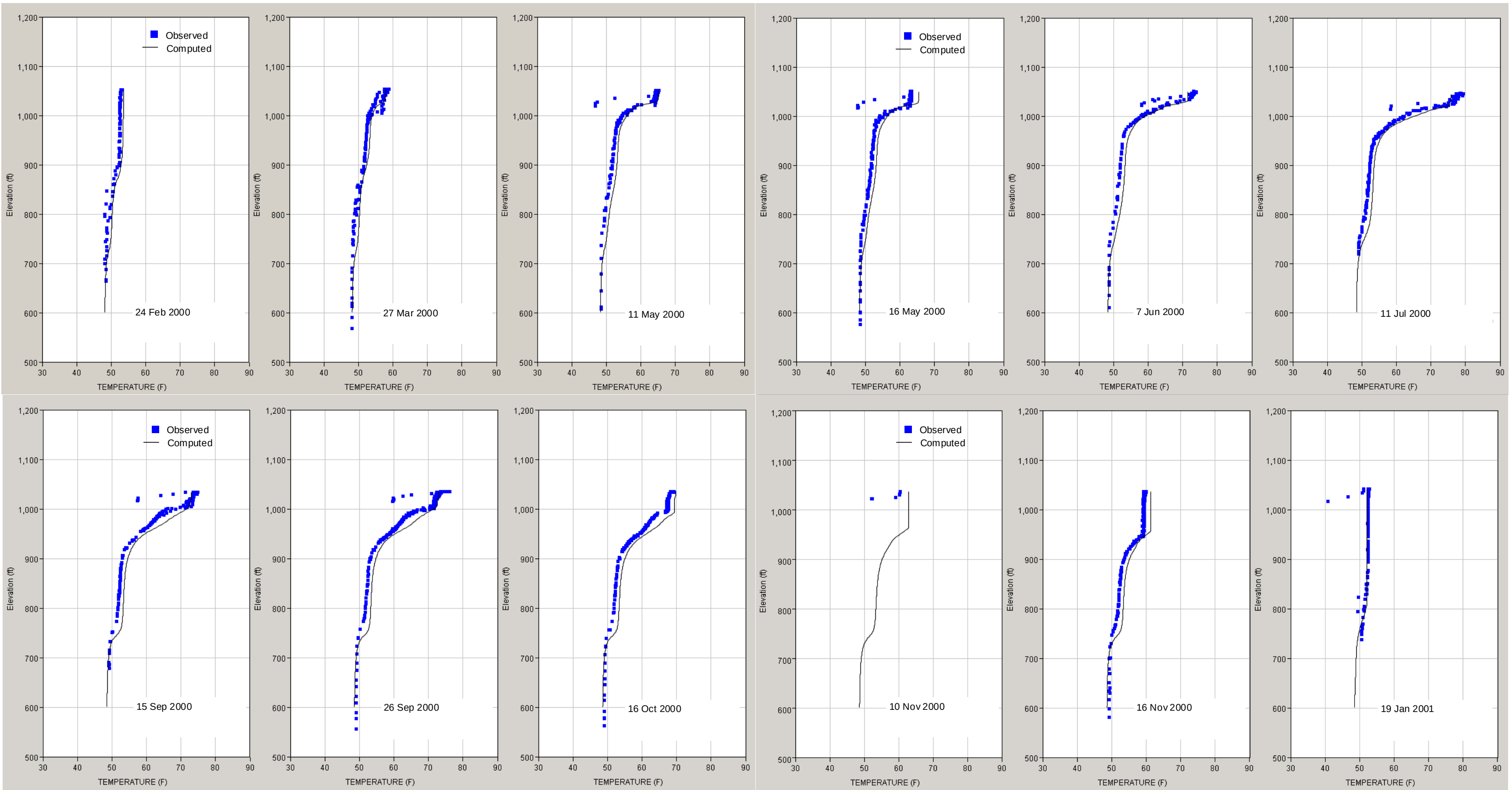

Figure 8-1. New Melones Reservoir computed and observed temperature profiles for February 2000 through January 2001.

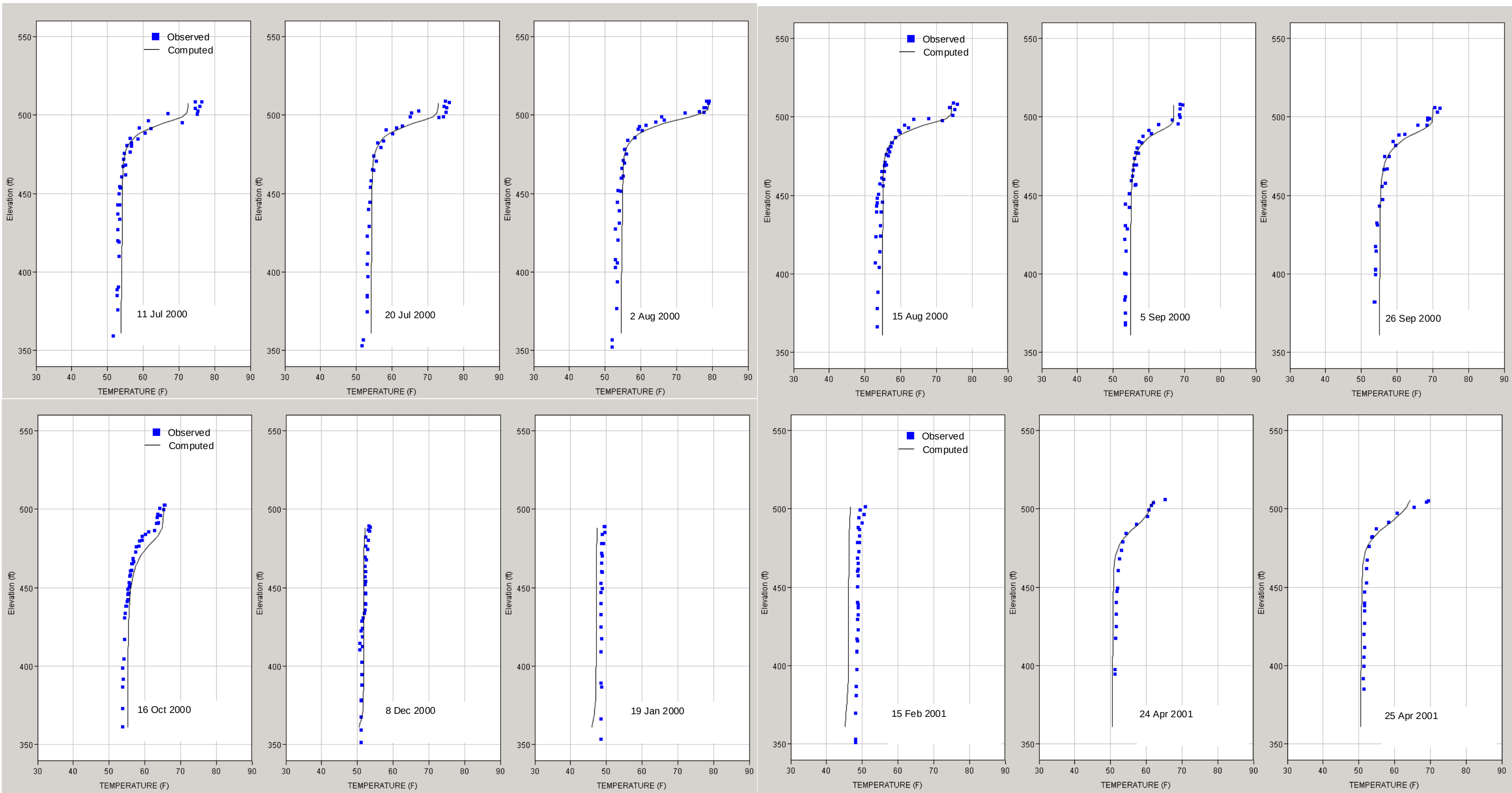

Figure 8-2. Tulloch Reservoir computed and observed temperature profiles for July 2000 through April 2001.

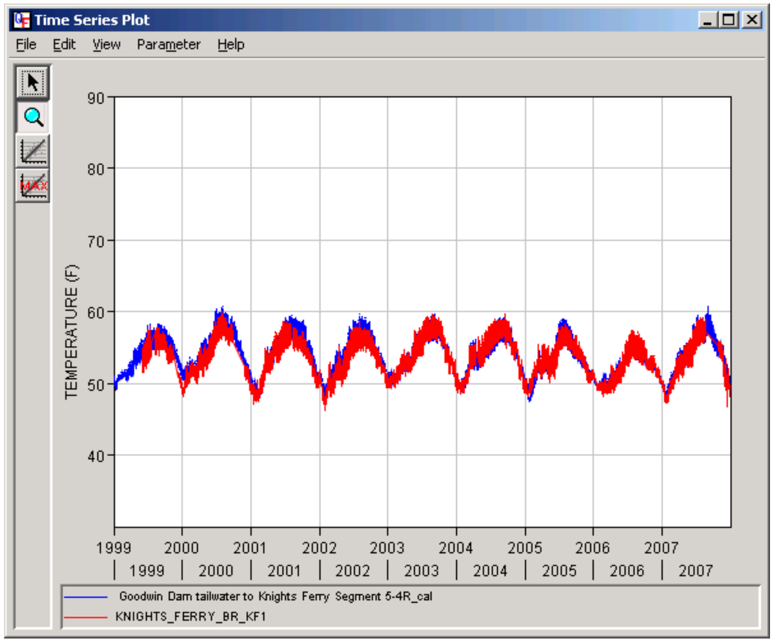

Figure 8-3. Comparison of computed (blue) and observed (red) water temperatures in the Stanislaus River at Knights Ferry (RM 54).

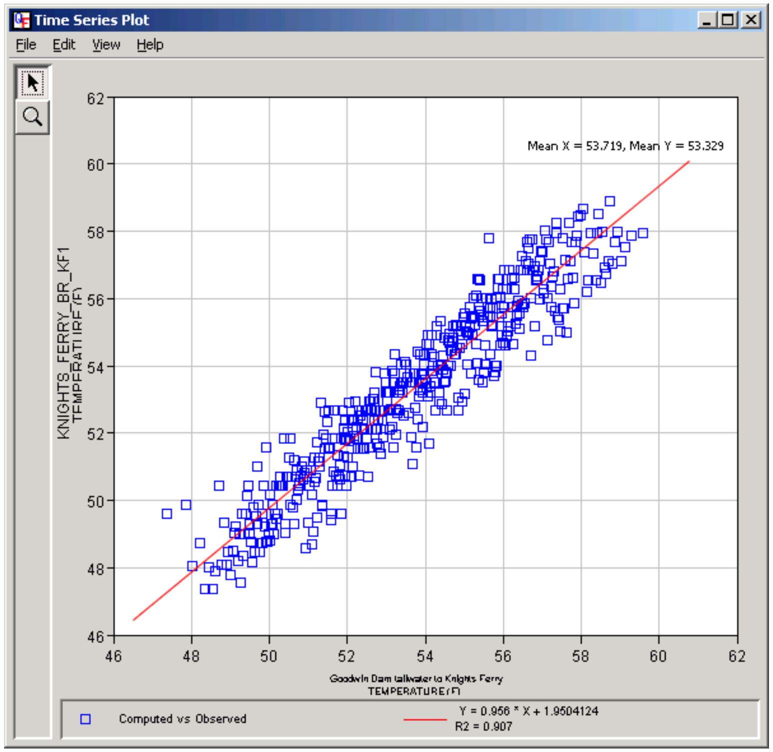

Figure 8-4. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Stanislaus River at Knights Ferry (RM 54) .

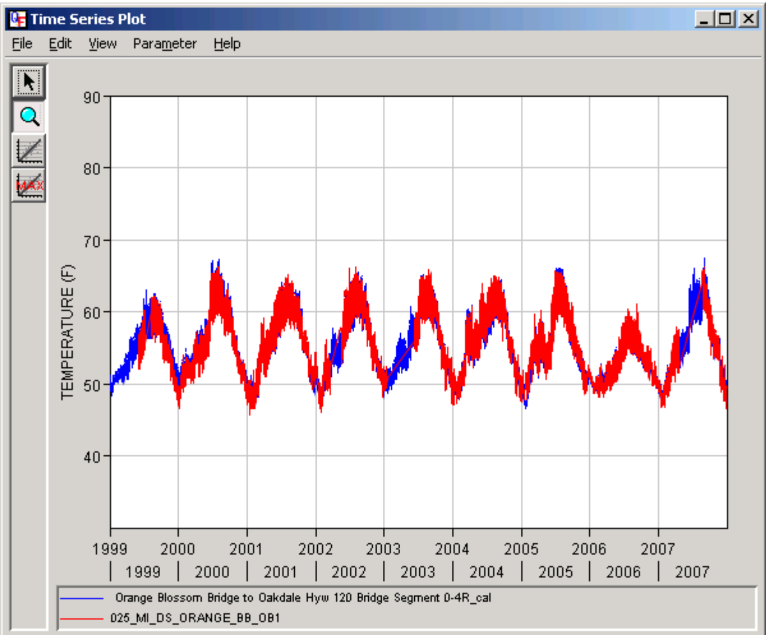

Figure 8-5. Comparison of computed (blue) and observed (red) water temperatures in the Stanislaus River at Orange Blossom Bridge (RM 46).

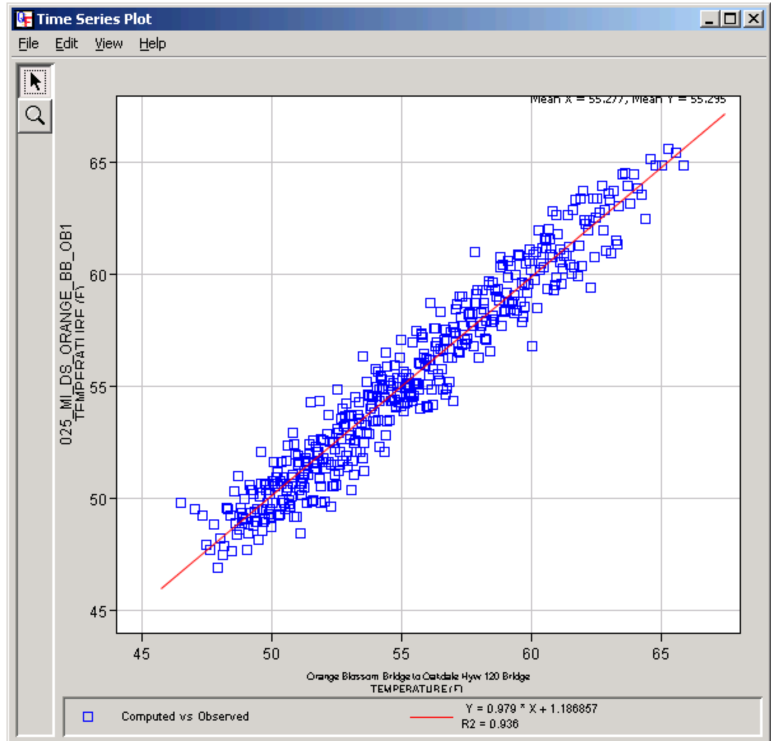

Figure 8-6. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Stanislaus River at Orange Blossom Bridge (RM 46).

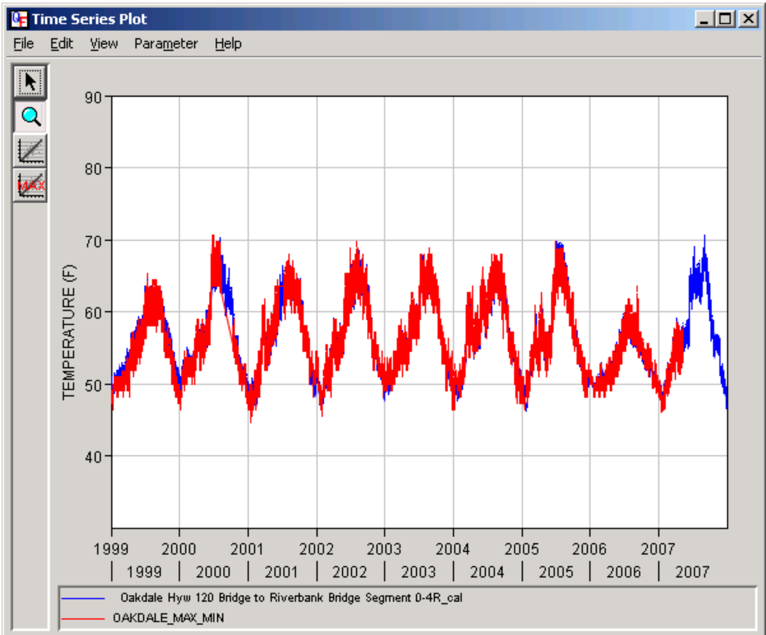

Figure 8-7. Comparison of computed (blue) and observed (red) water temperatures in the Stanislaus River at Oakdale Recreation Area (RM 40).

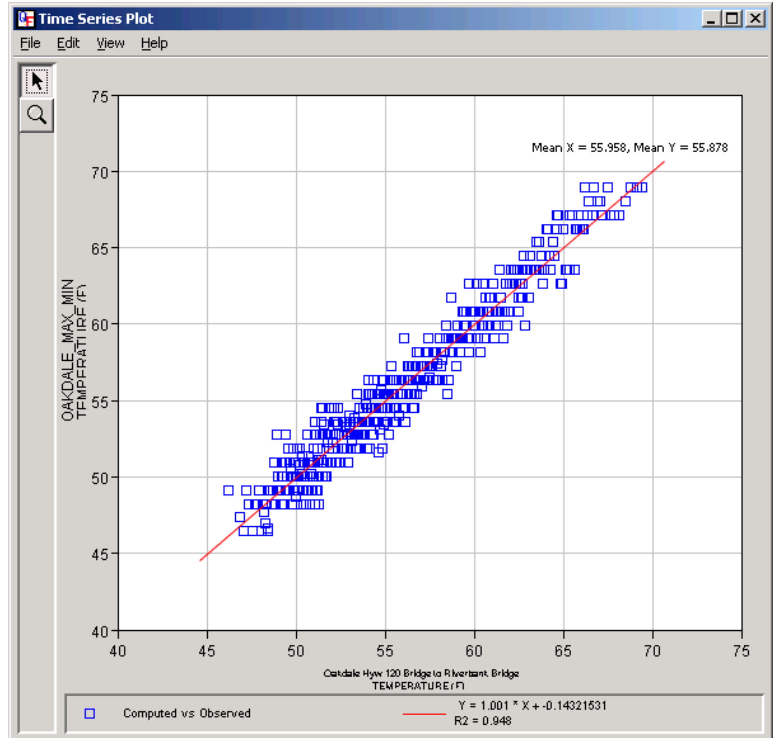

Figure 8-8. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Stanislaus River at Oakdale Recreation Area (RM 40).

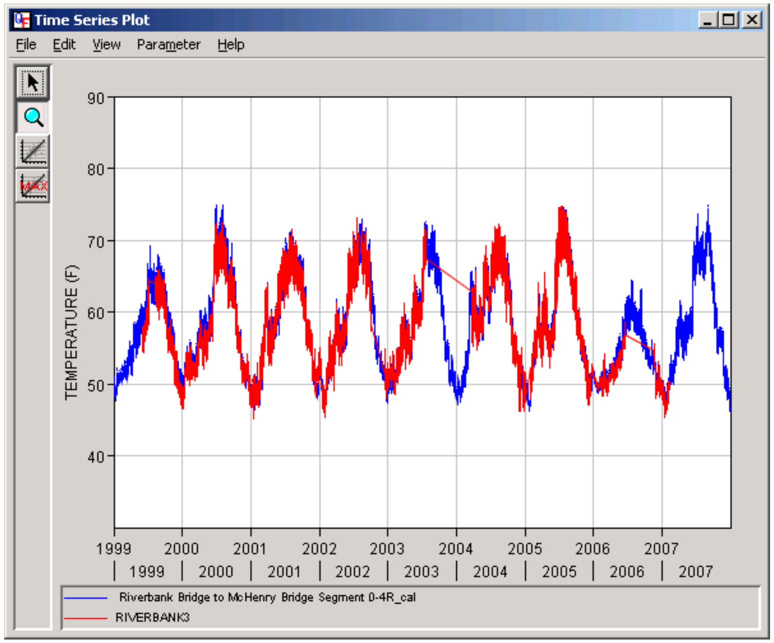

Figure 8-9. Comparison of computed (blue) and observed (red) water temperatures in the Stanislaus River at Riverbank Bridge (RM 31).

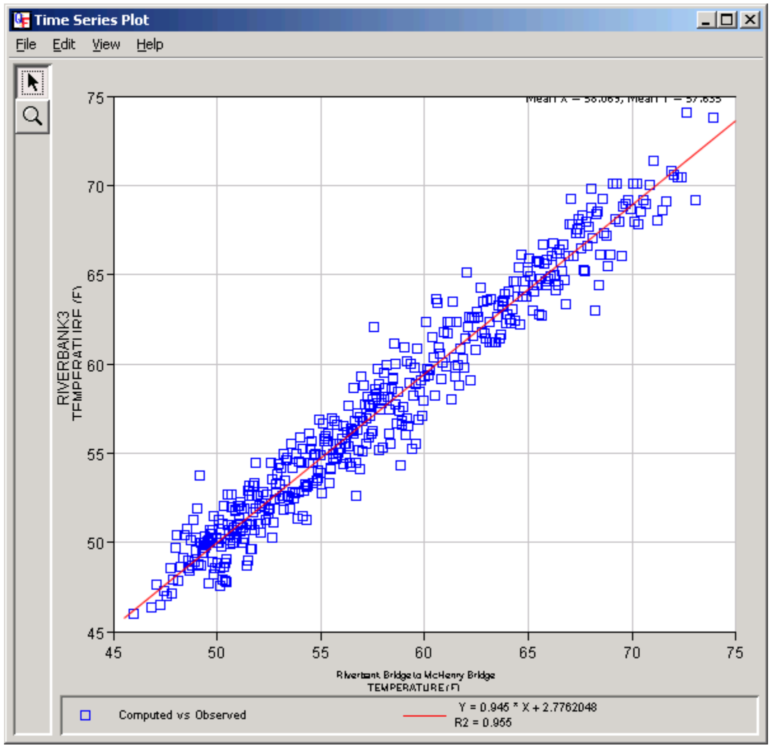

Figure 8-10. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Stanislaus River at Riverbank Bridge (RM 31).

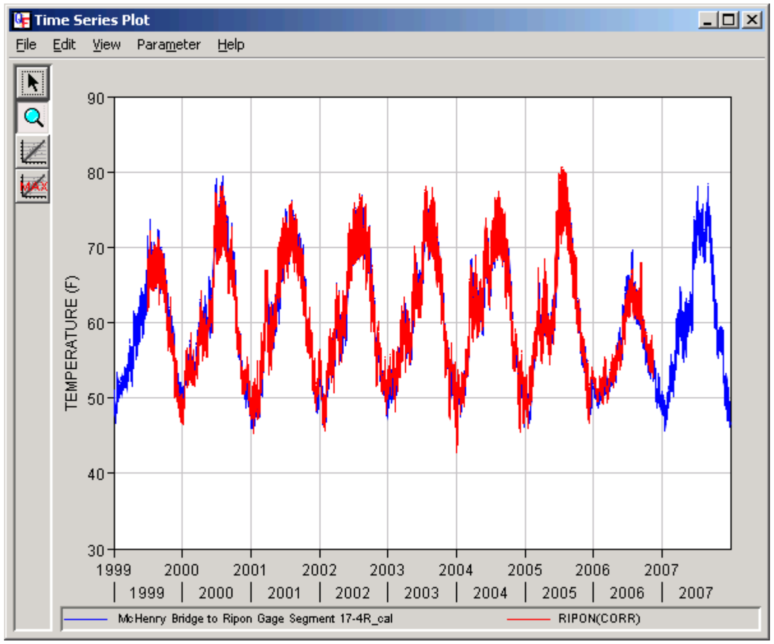

Figure 8-11. Comparison of computed (blue) and observed (red) water temperatures in the Stanislaus River at Ripon (RM 15).

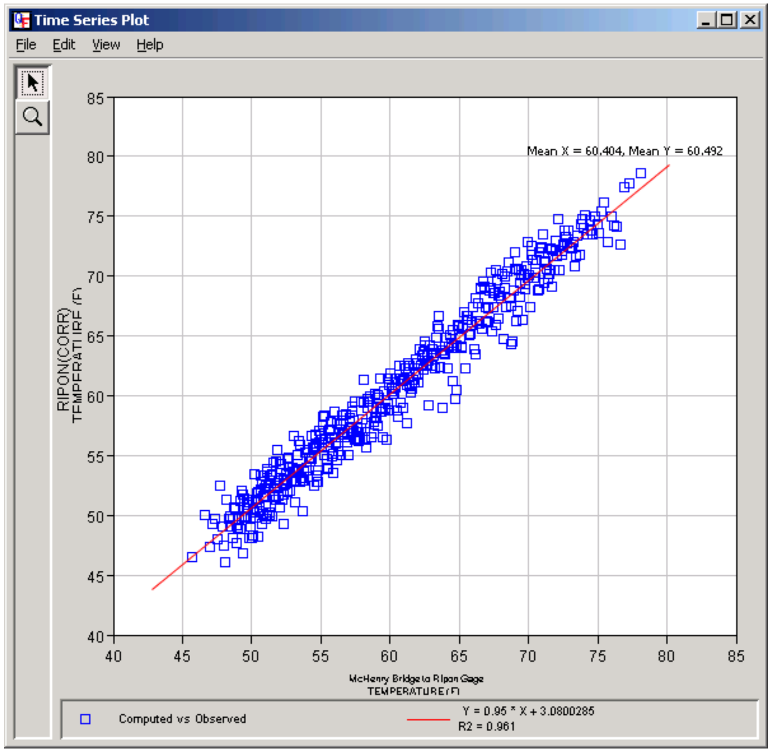

Figure 8-12. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Stanislaus River at Ripon (RM 15).

8.2. Tuolumne River System

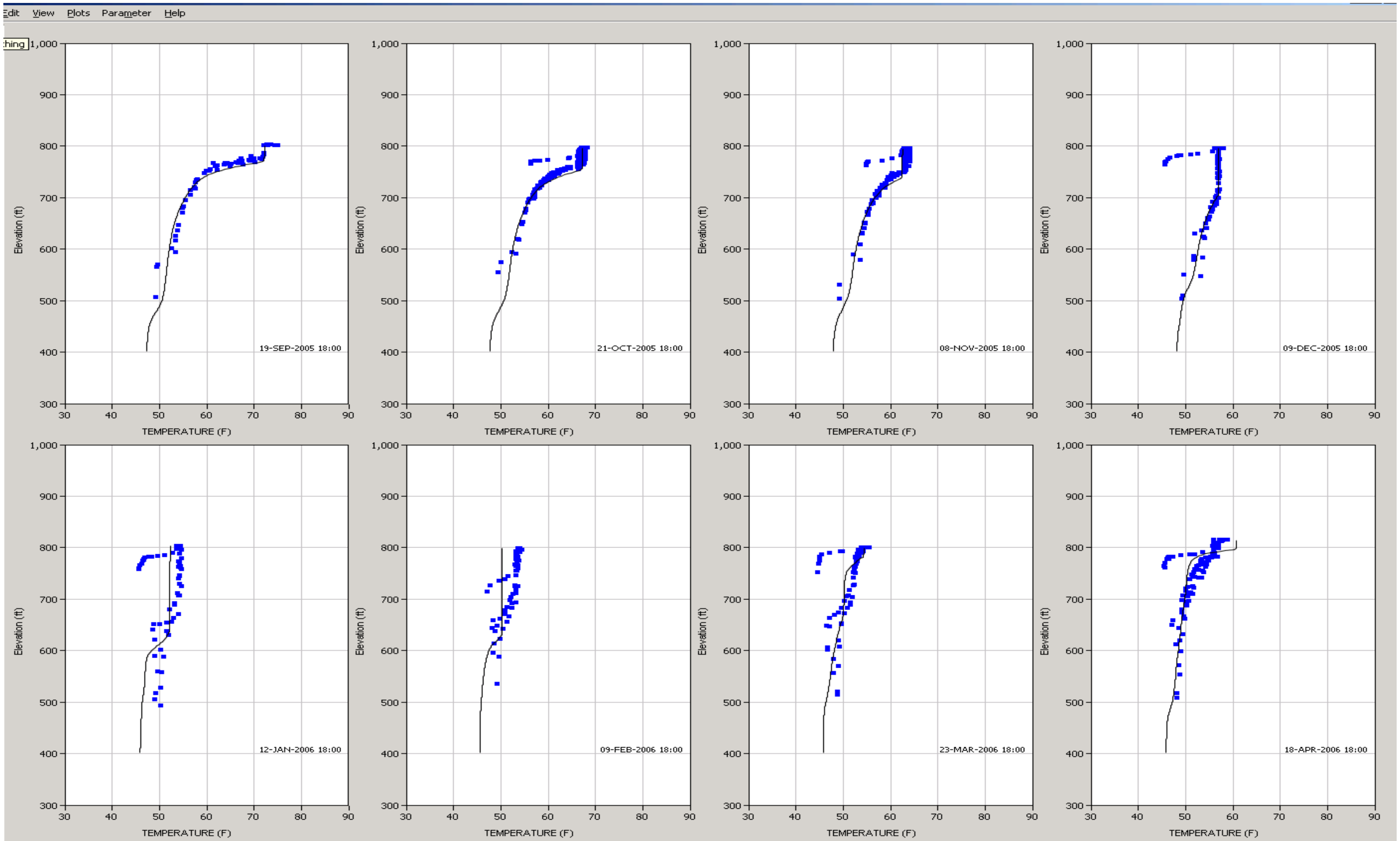

Figure 8-13. Preliminary calibration results for Lake Don Pedro from September 2005 through April 2006.

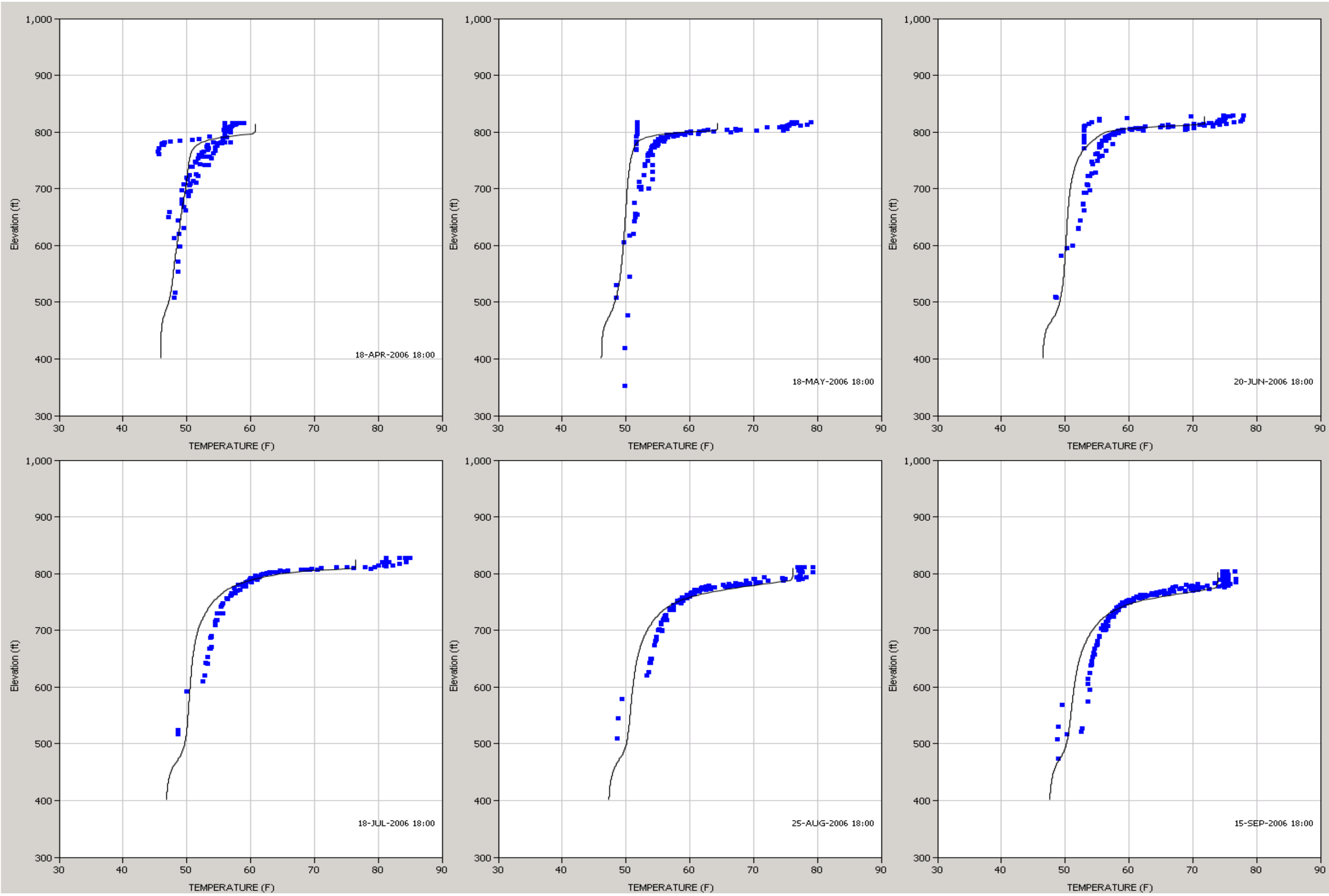

Figure 8-14. Preliminary calibration results for Lake Don Pedro from April 2006 through September 2006.

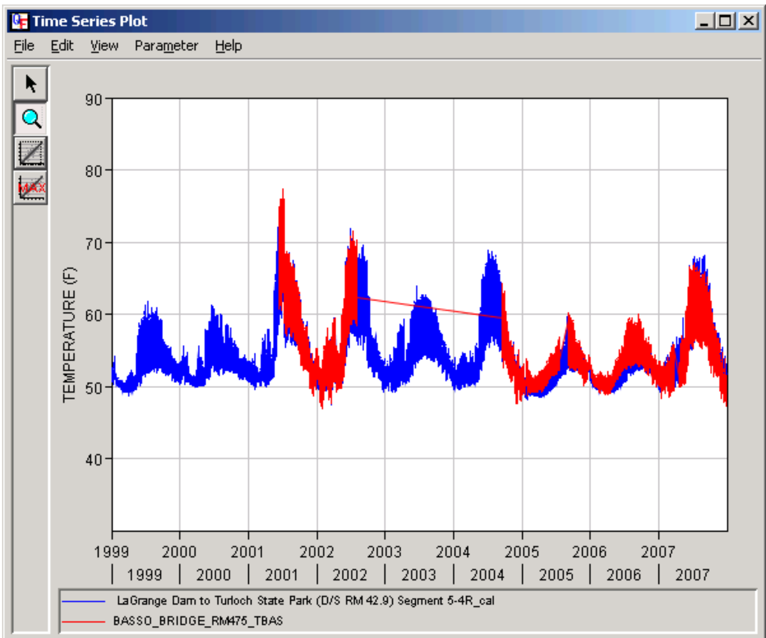

Figure 8-15. Comparison of computed (blue) and observed (red) water temperatures in the Tuolumne River at Basso Bridge (RM 47.5).

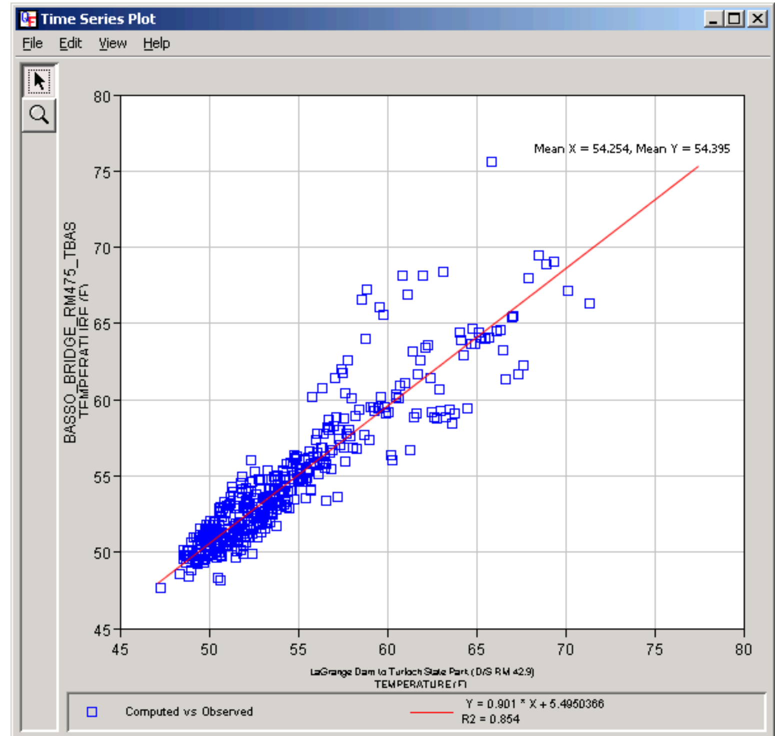

Figure 8-16. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Tuolumne River at Basso Bridge (RM 47.5).

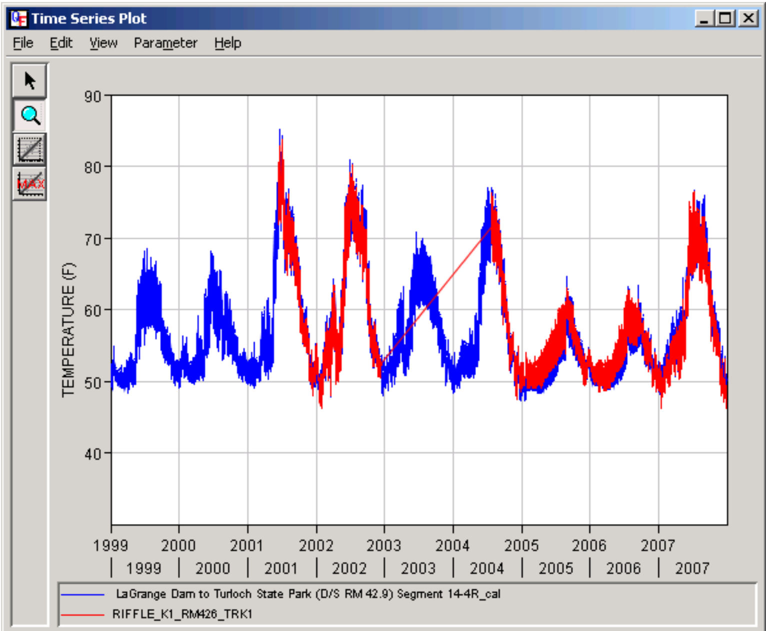

Figure 8-17. Comparison of computed (blue) and observed (red) water temperatures in the Tuolumne River at Riffle K1 (RM 42.6).

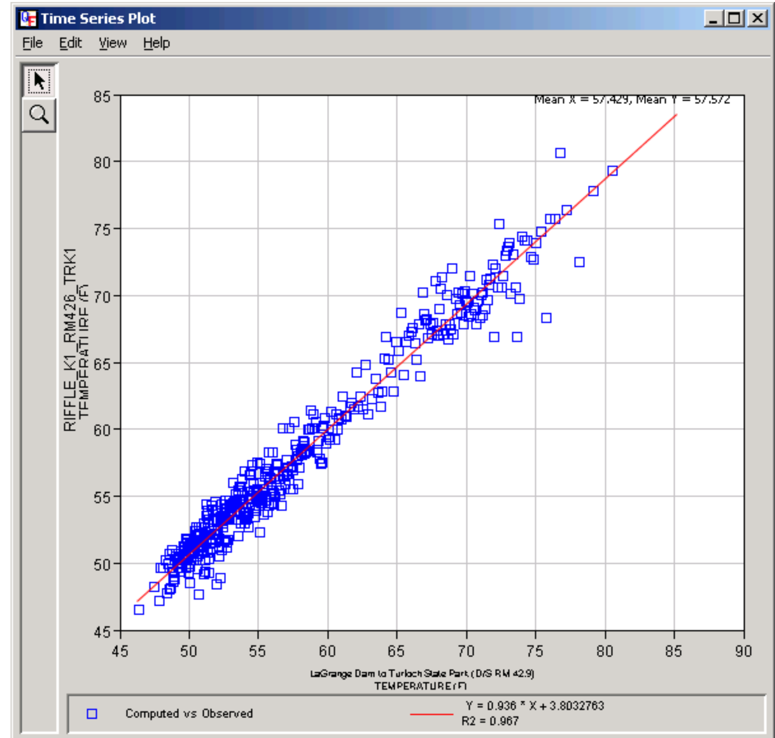

Figure 8-18. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Tuolumne River at Riffle K1 (RM 42.6).

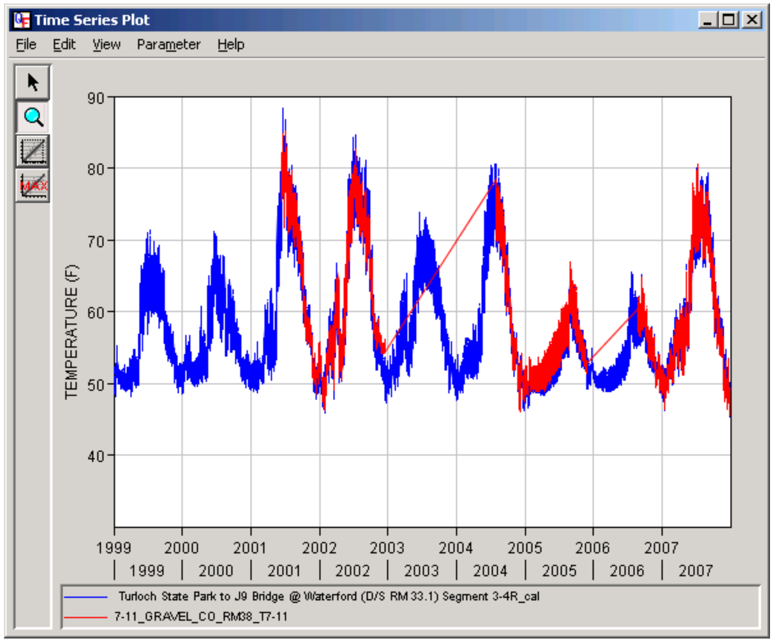

Figure 8-19. Comparison of computed (blue) and observed (red) water temperatures in the Tuolumne River at 7-11 Gravel Co. (RM 38).

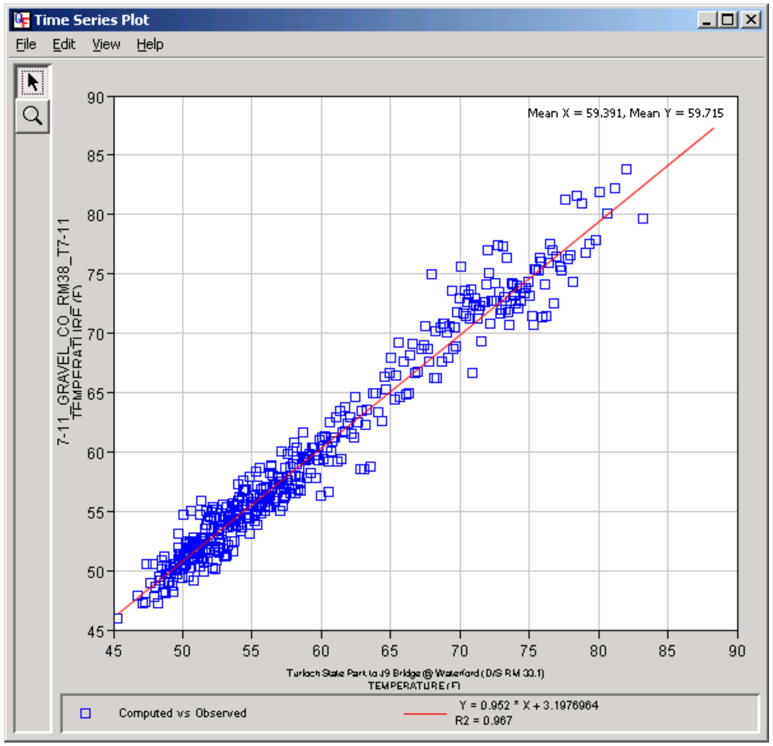

Figure 8-20. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Tuolumne River at 7-11 Gravel Co. (RM 38).

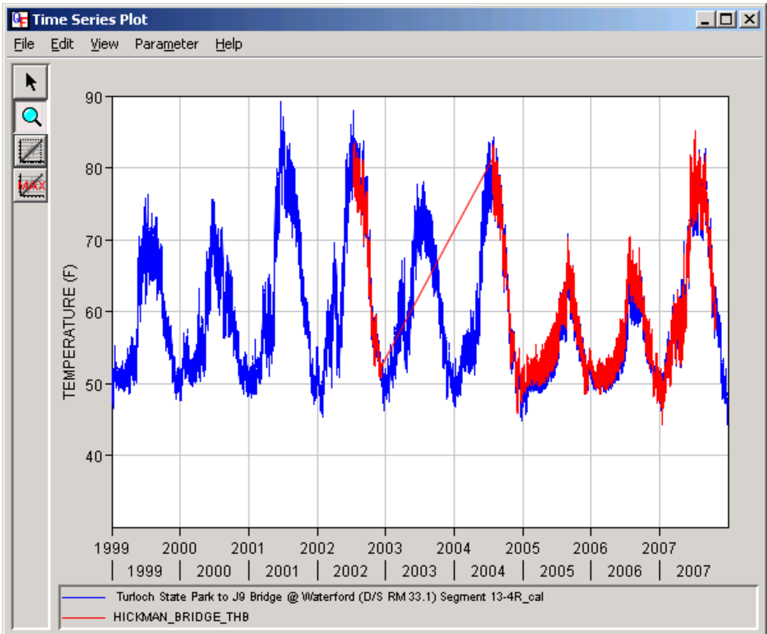

Figure 8-21. Comparison of computed (blue) and observed (red) water temperatures in the Tuolumne River at Hickman Bridge (RM 31).

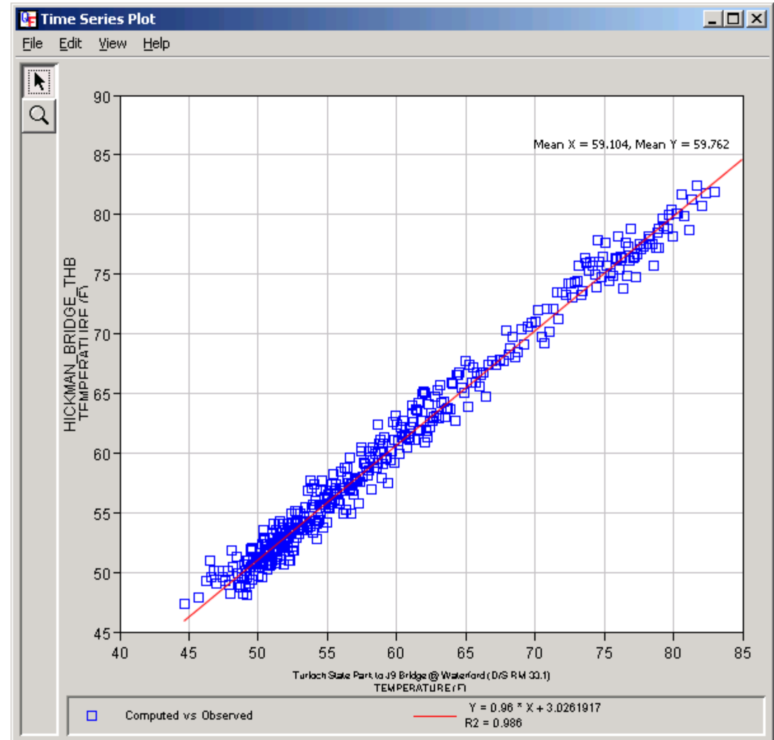

Figure 8-22. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Tuolumne River at Hickman Bridge (RM 31).

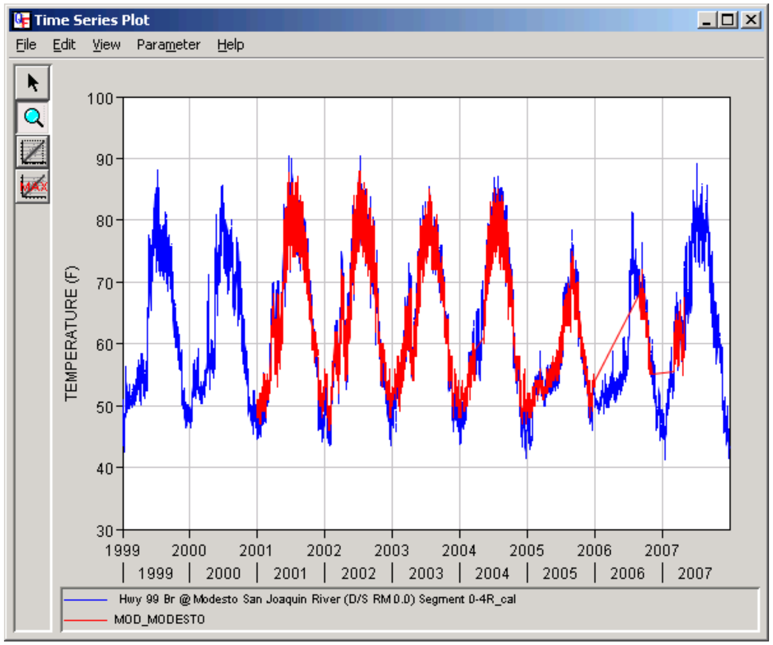

Figure 8-23. Comparison of computed (blue) and observed (red) water temperatures in the Tuolumne River at the Highway 99 Bridge (RM 15.5).

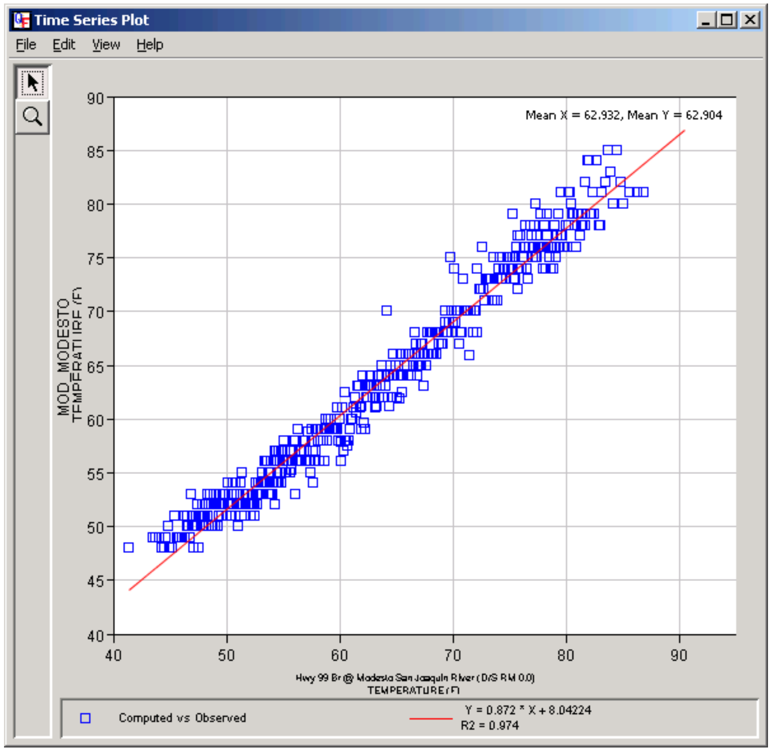

Figure 8-24. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Tuolumne River at the Highway 99 Bridge (RM 15.5).

8.3. Merced River System

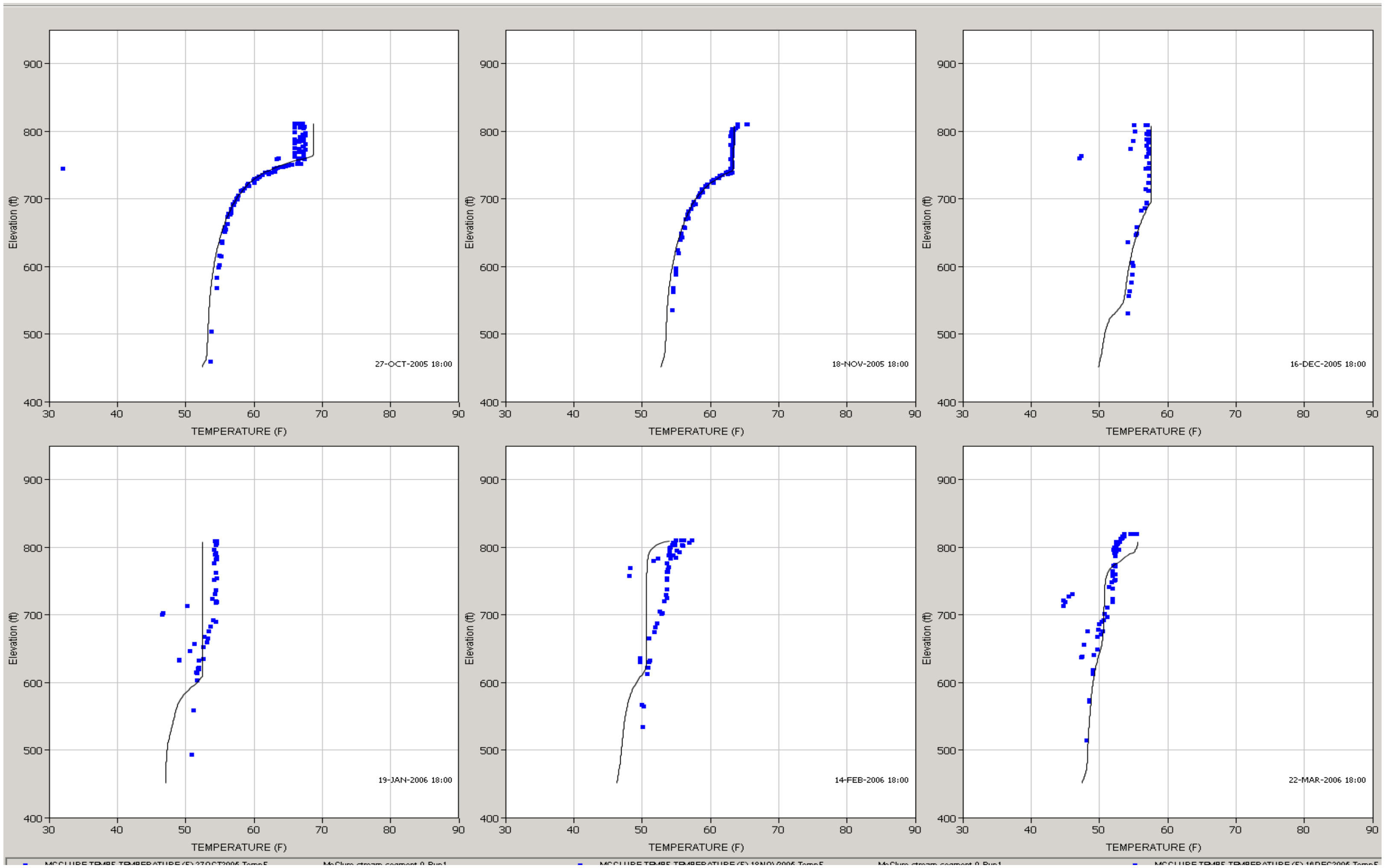

Figure 8-25. Preliminary calibration results for Lake McClure from October 2005 – March of 2006.

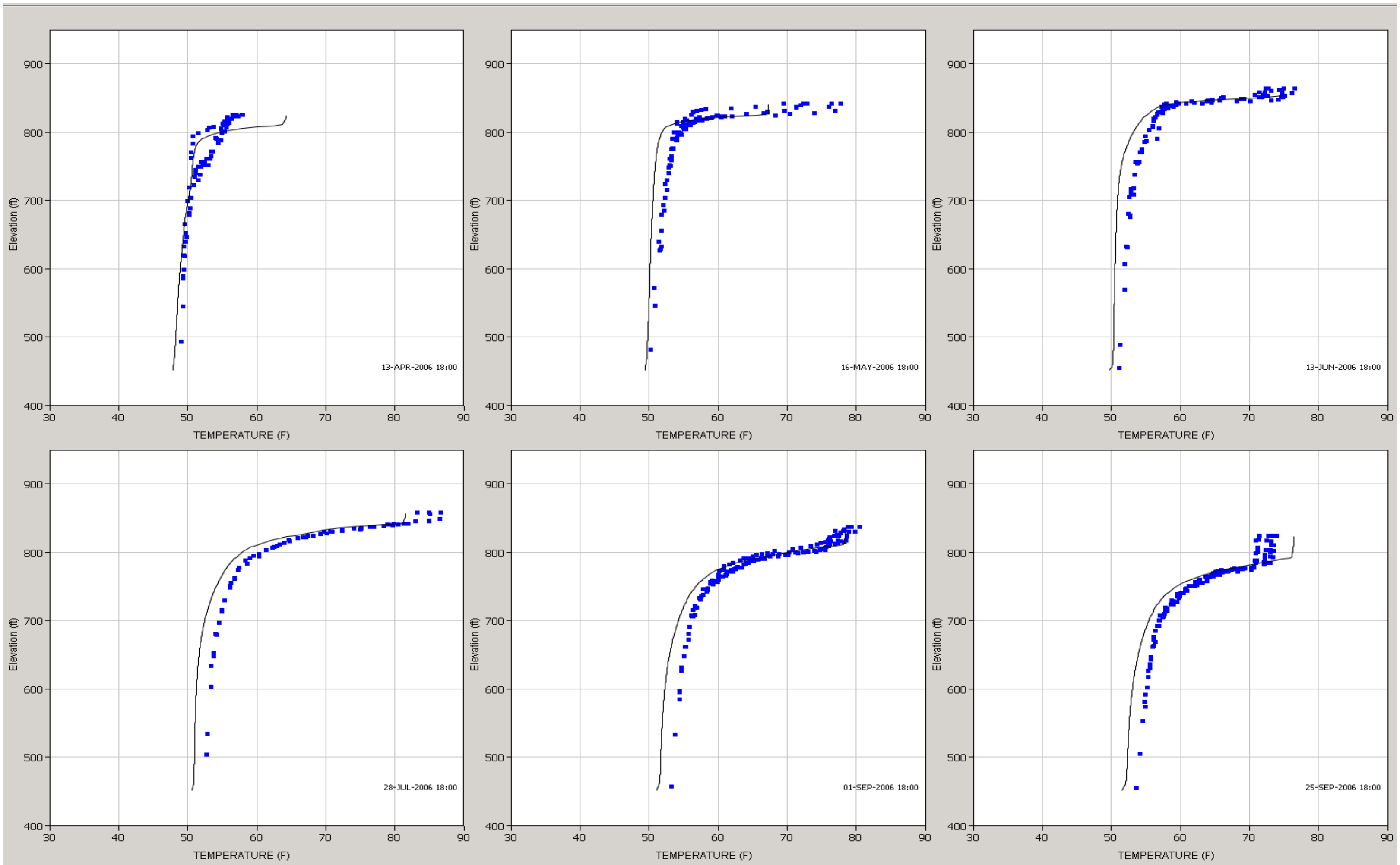

Figure 8-26. Preliminary calibration results for Lake McClure from April – September of 2006.

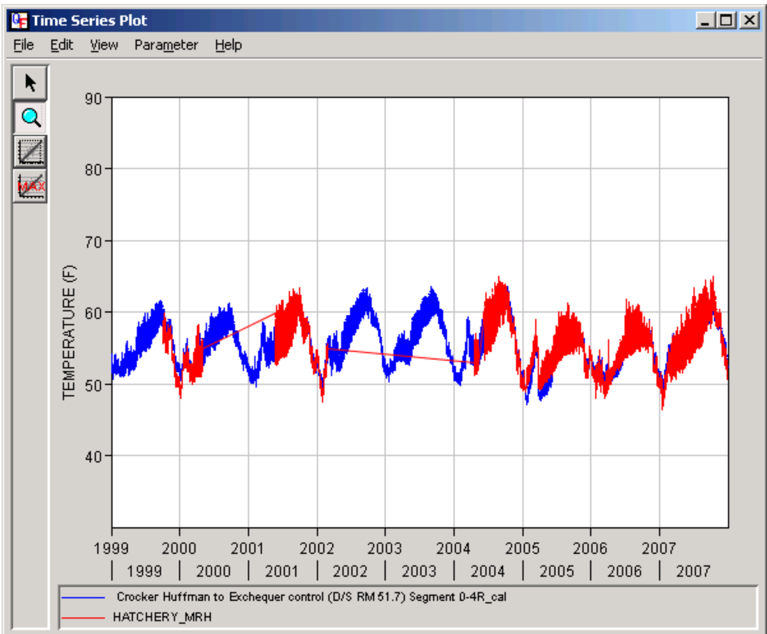

Figure 8-27. Comparison of computed (blue) and observed (red) water temperatures in the Merced River below Crocker-Huffman Dam (RM 52).

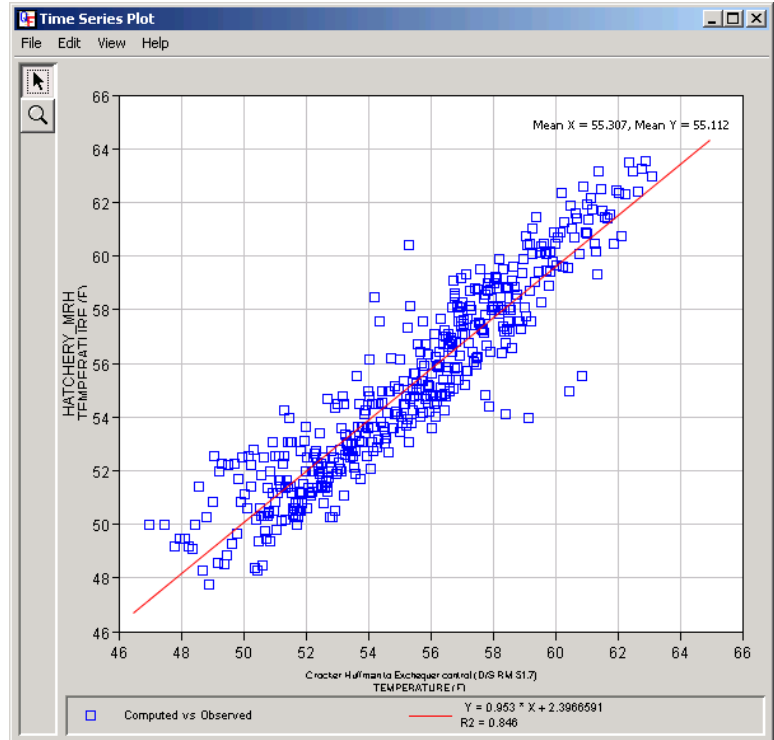

Figure 8-28. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Merced River below Crocker-Huffman Dam (RM 52).

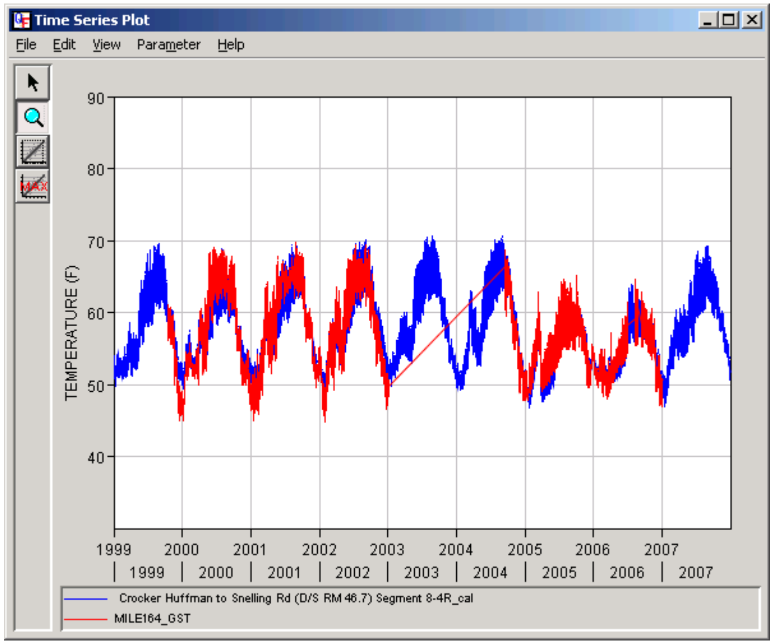

Figure 8-29. Comparison of computed (blue) and observed (red) water temperatures in the Merced River at Mile 164 (RM 48).

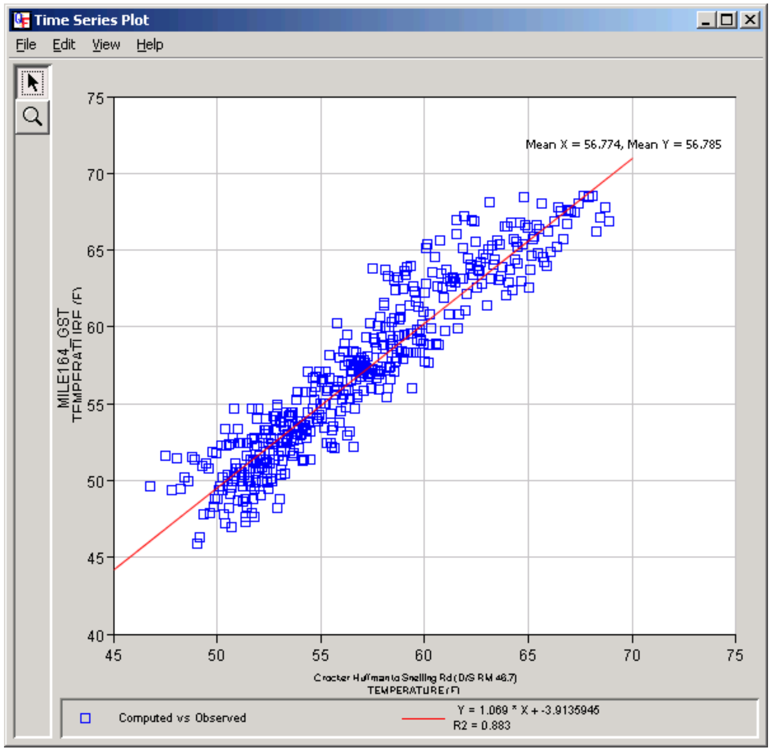

Figure 8-30. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Merced River at Mile 164 (RM 48).

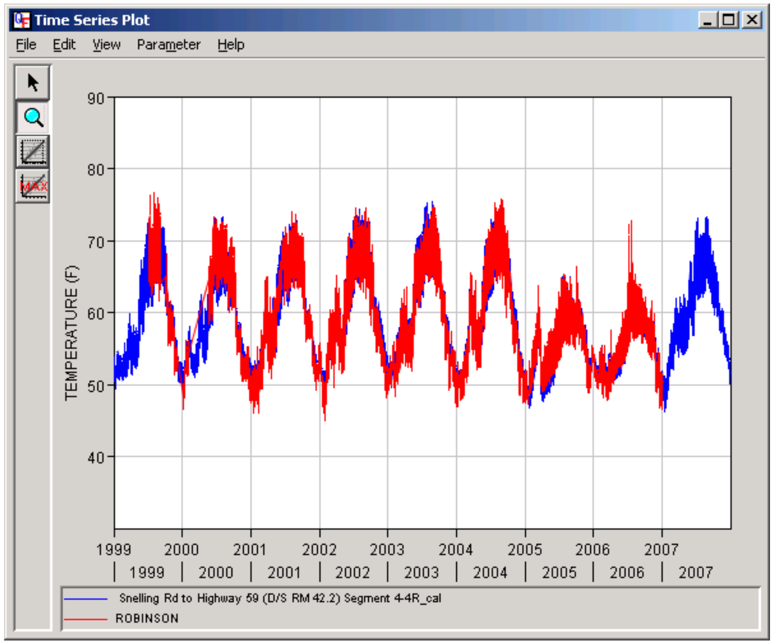

Figure 8-31. Comparison of computed (blue) and observed (red) water temperatures in the Merced River at Robinson (RM 43).

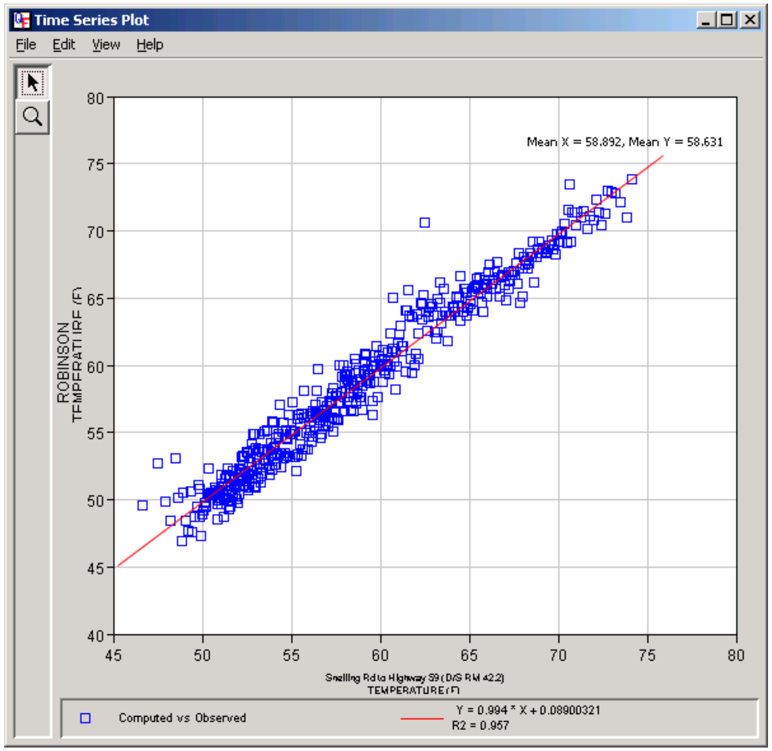

Figure 8-32. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Merced River at Robinson (RM 43).

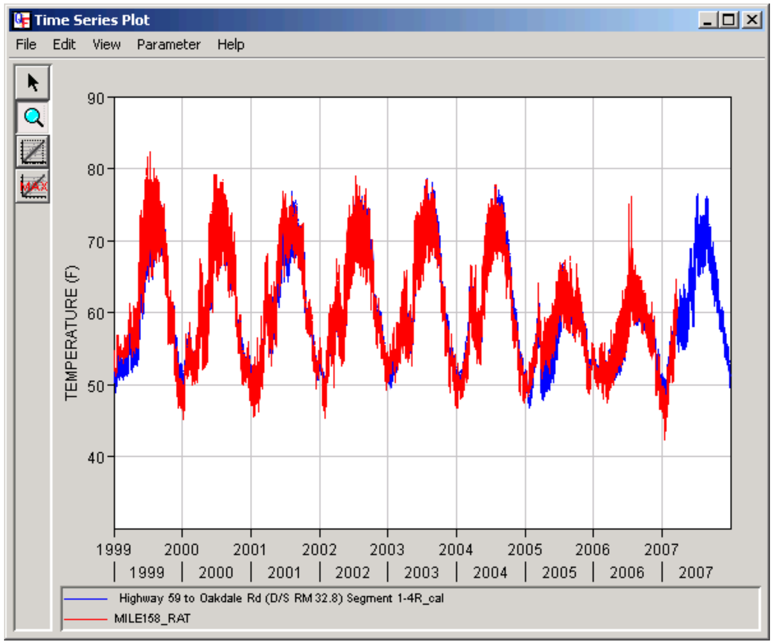

Figure 8-33. Comparison of computed (blue) and observed (red) water temperatures in the Merced River at Mile 157 (RM 41).

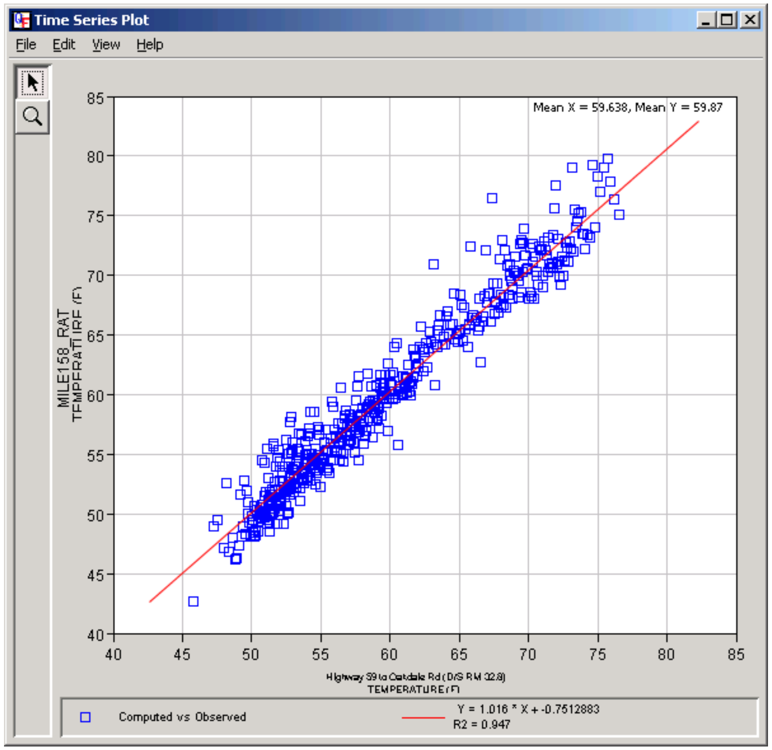

Figure 8-34. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Merced River at Mile 157 (RM 41).

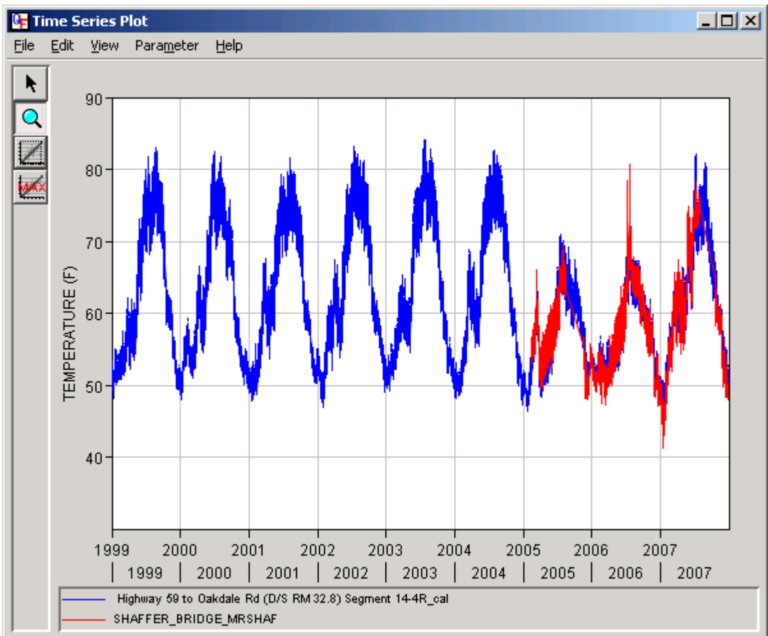

Figure 8-35. Comparison of computed (blue) and observed (red) water temperatures in the Merced River at Shaffer Bridge (RM 31).

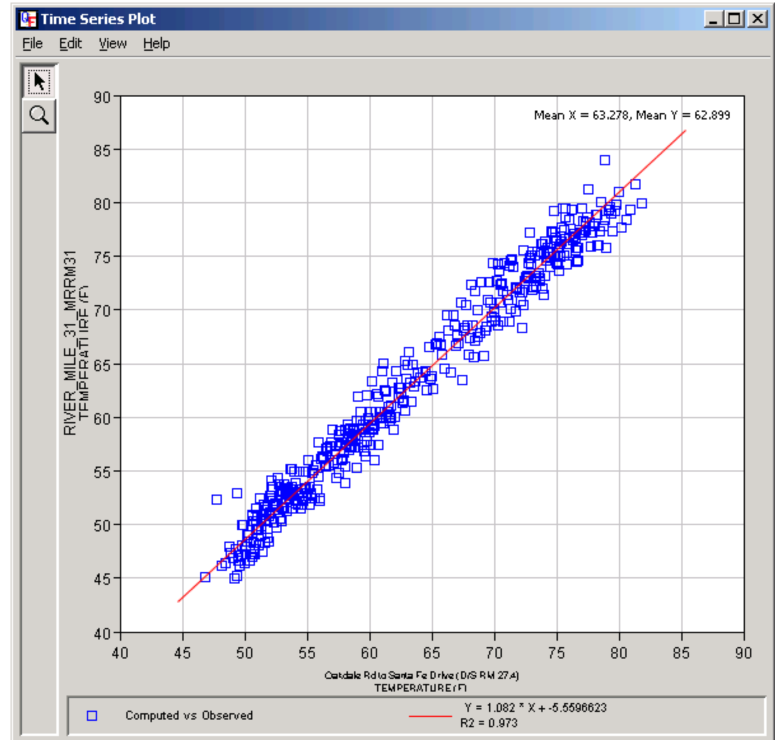

Figure 8-36. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Merced River at Shaffer Bridge (RM 31).

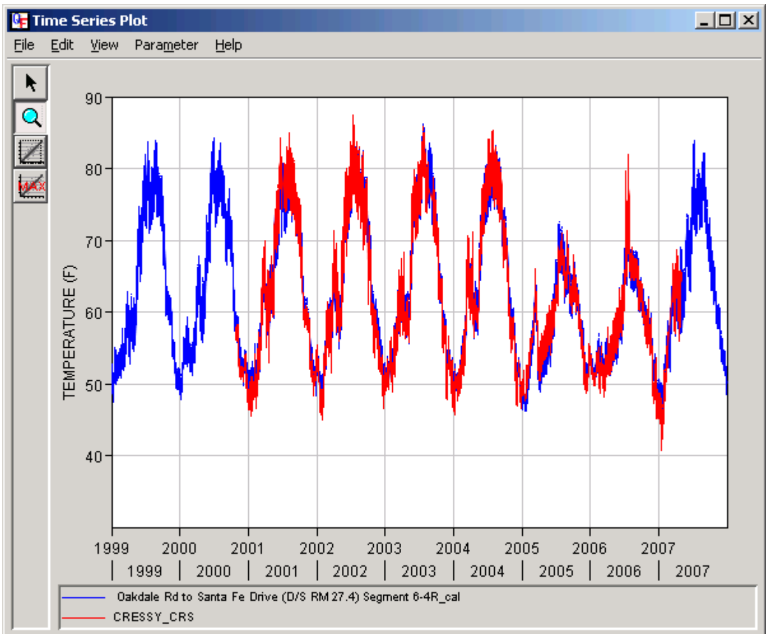

Figure 8-37. Comparison of computed (blue) and observed (red) water temperatures in the Merced River at Mile 31 (RM 31).

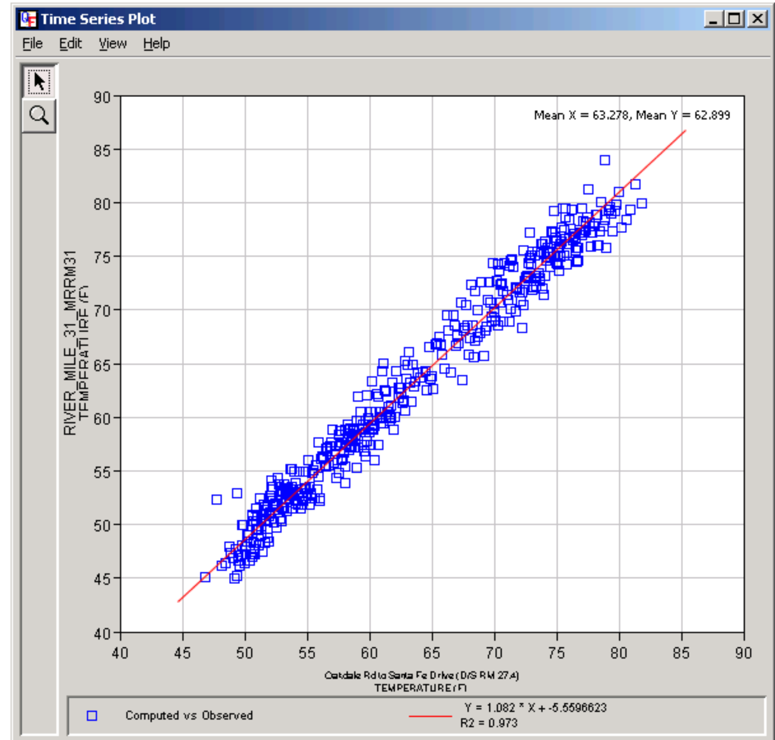

Figure 8-38. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Merced River at Mile 31 (RM 31).

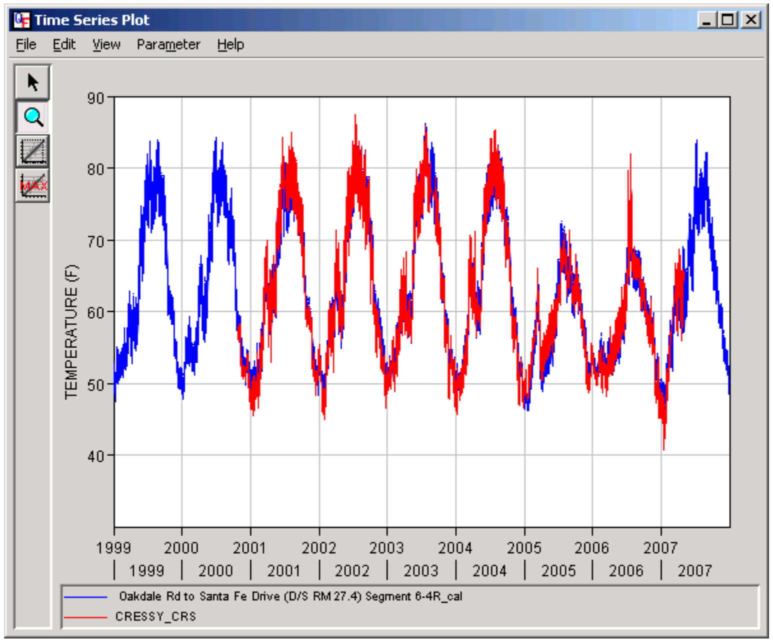

Figure 8-39. Comparison of computed (blue) and observed (red) water temperatures in the Merced River at Cressy (RM 27).

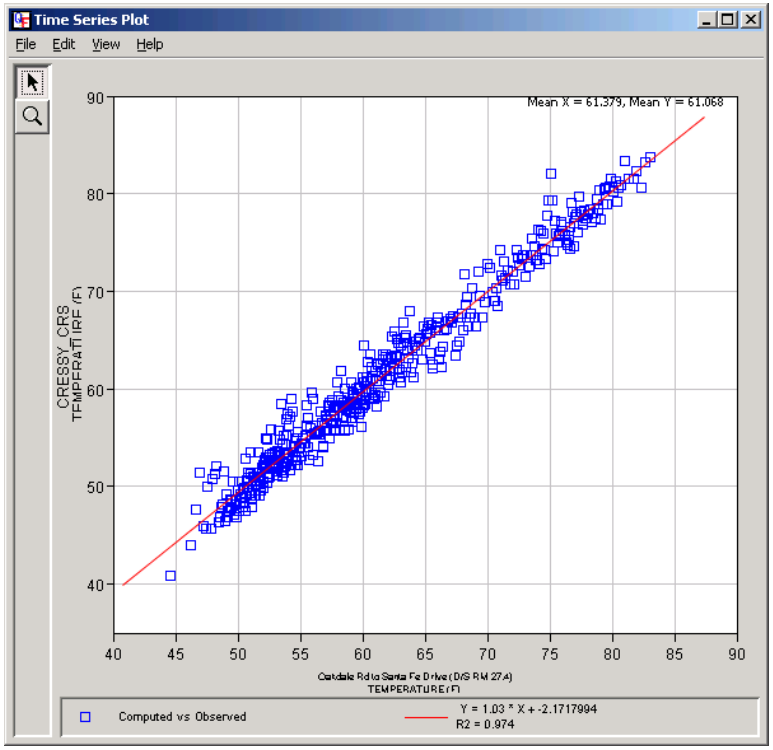

Figure 8-40. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Merced River at Cressy (RM 27).

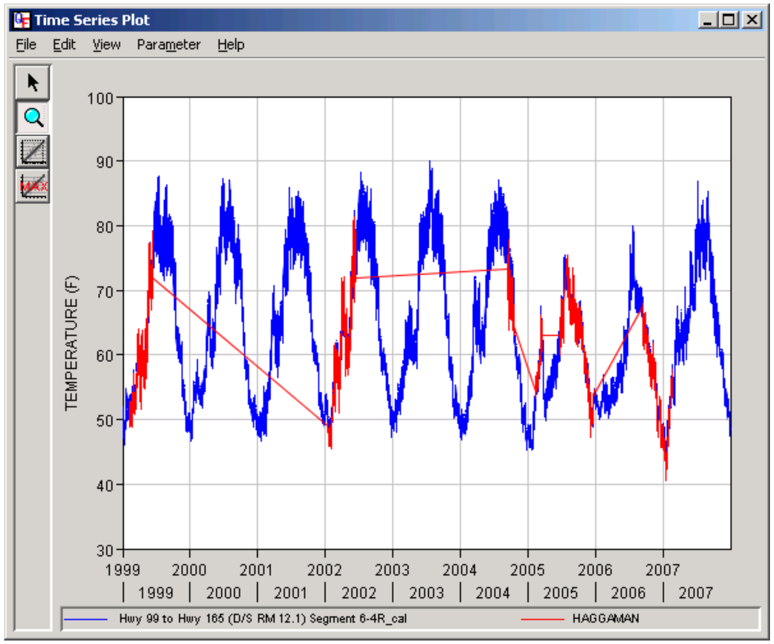

Figure 8-41. Comparison of computed (blue) and observed (red) water temperatures in the Merced River at Haggman Park (RM 13).

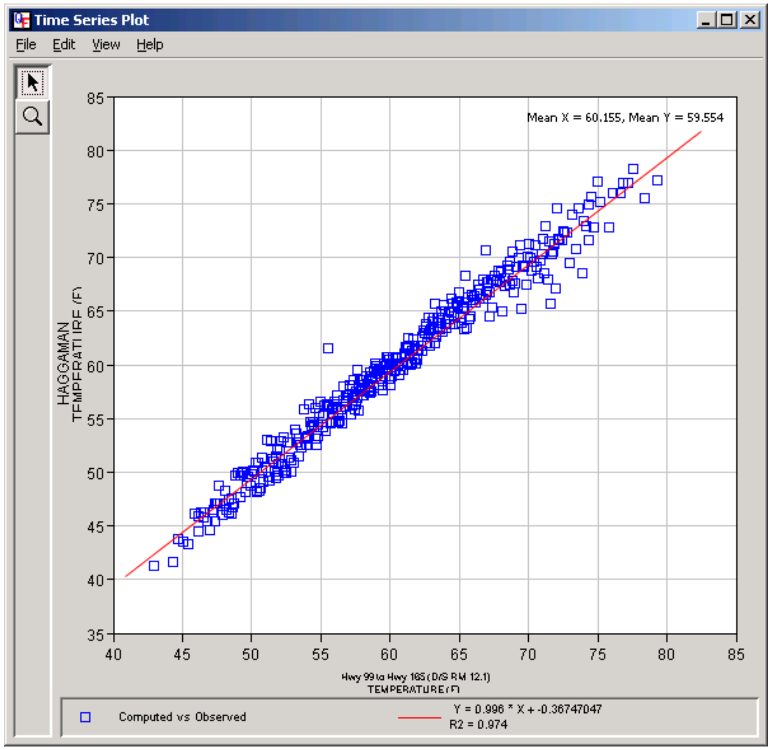

Figure 8-42. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Merced River at Haggman Park (RM 13).

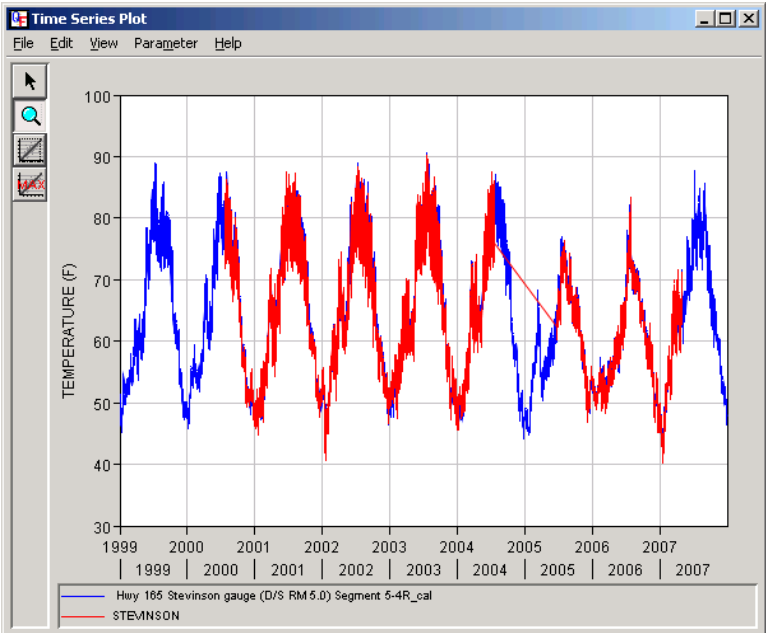

Figure 8-43. Comparison of computed (blue) and observed (red) water temperatures in the Merced River at Stevinson (RM 4).

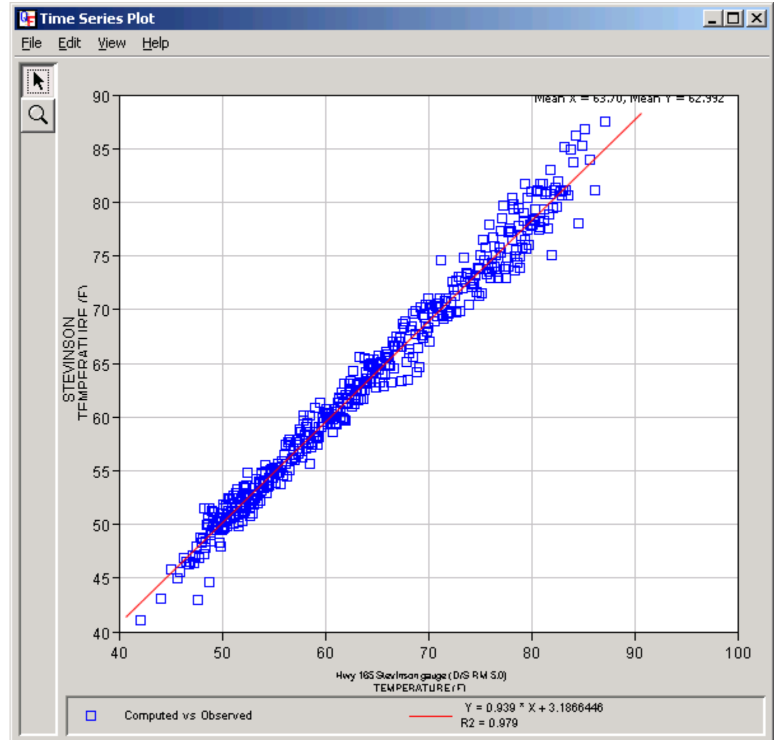

Figure 8-44. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the Merced River at Stevinson (RM 4).

8.4. San Joaquin River System

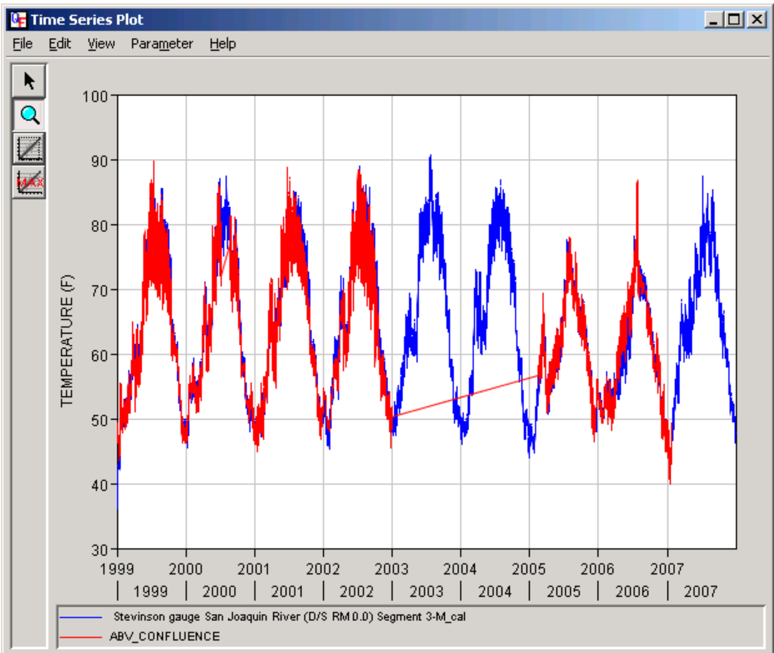

Figure 8-45. Comparison of computed (blue) and observed (red) water temperatures in the San Joaquin River at the Merced River Confluence (RM 117).

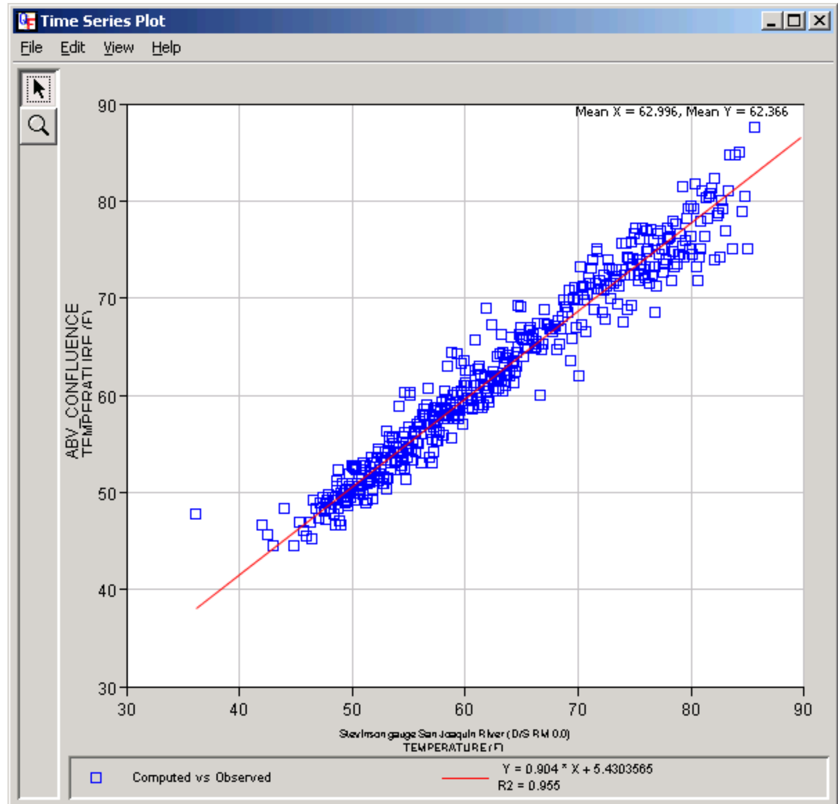

Figure 8-46. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the San Joaquin River at the Merced River Confluence (RM 117).

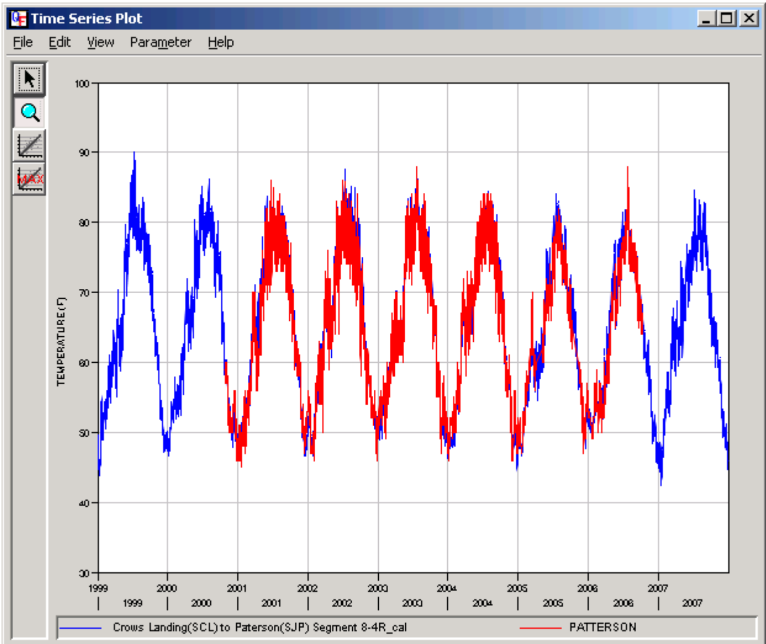

Figure 8-47. Comparison of computed (blue) and observed (red) water temperatures in the San Joaquin River at Patterson (RM 97).

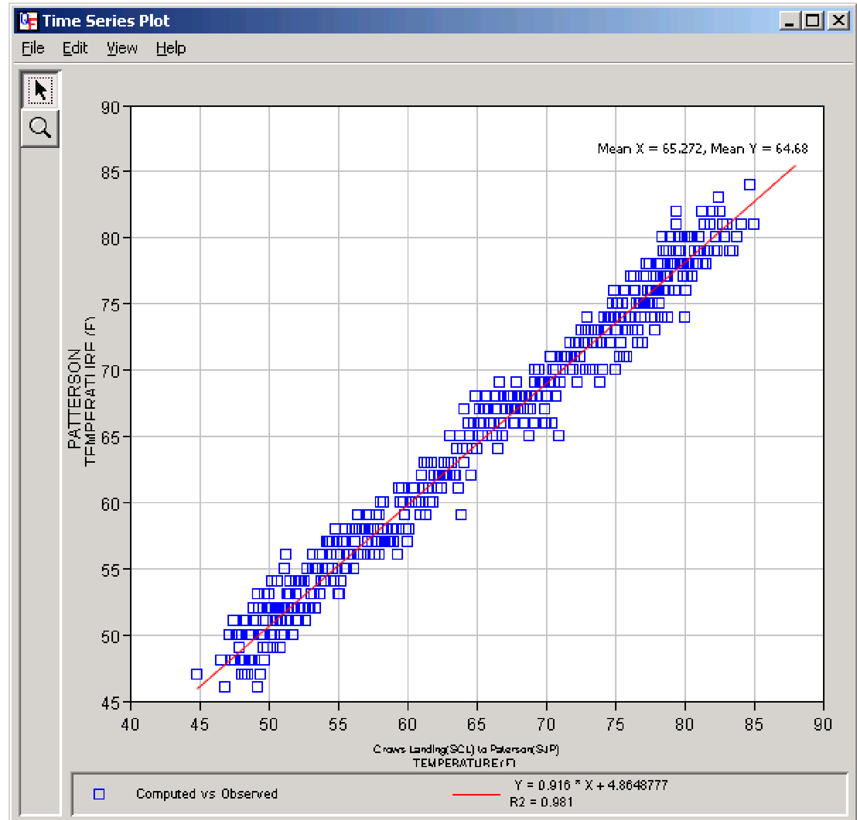

Figure 8-48. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the San Joaquin River at Patterson (RM 97).

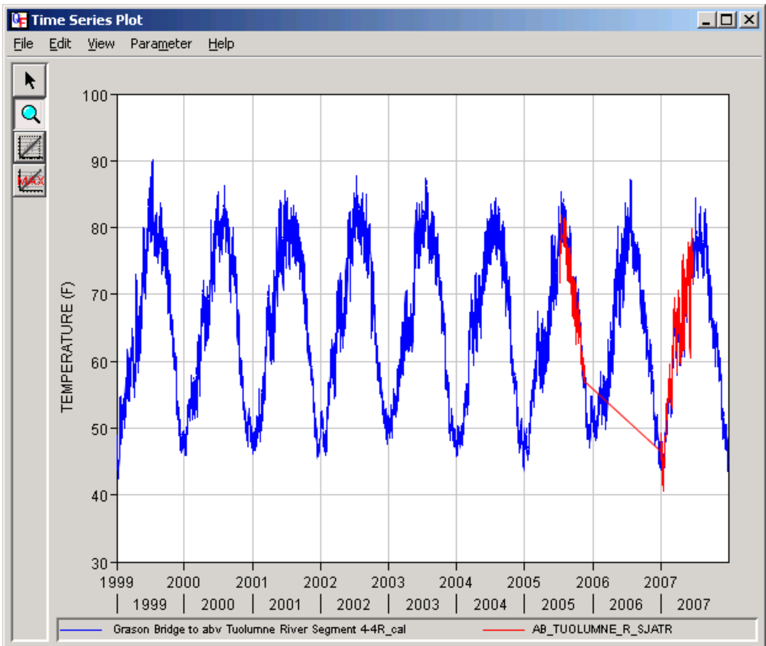

Figure 8-49. Comparison of computed (blue) and observed (red) water temperatures in the San Joaquin River at the Tuolumne River Confluence (RM 83).

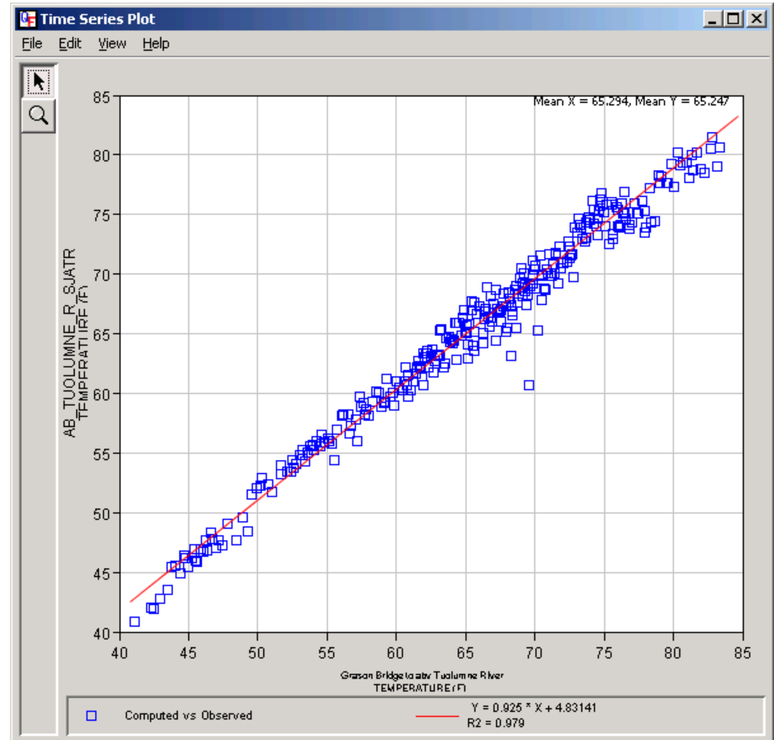

Figure 8-50. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the San Joaquin River at the Tuolumne River Confluence (RM 83).

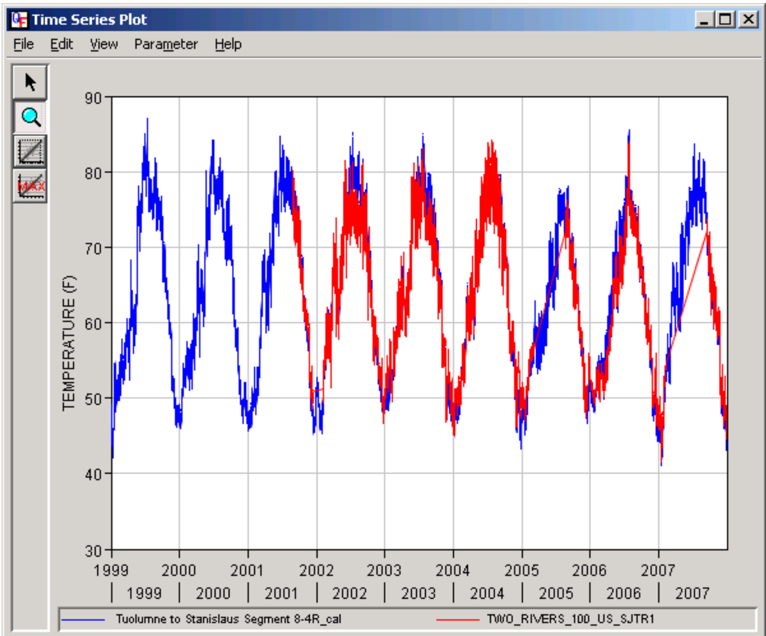

Figure 8-51. Comparison of computed (blue) and observed (red) water temperatures in the San Joaquin River at the Stanislaus River Confluence (RM 73).

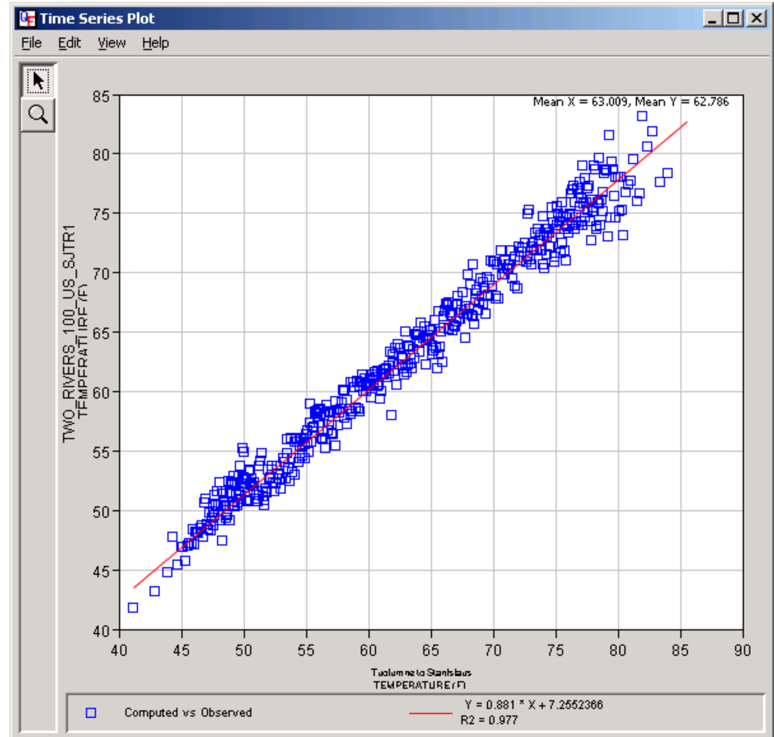

Figure 8-52. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the San Joaquin River at the Stanislaus River Confluence (RM 73).

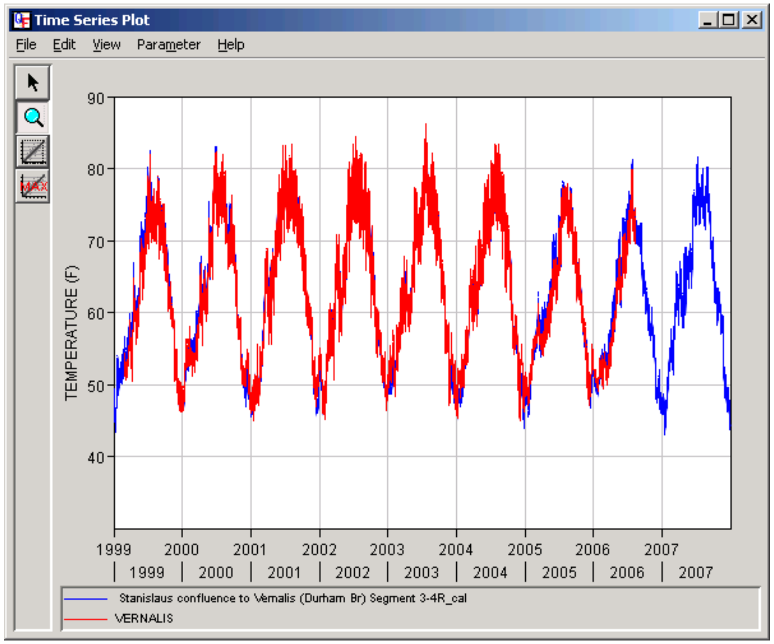

Figure 8-53. Comparison of computed and observed inflow temperatures in the San Joaquin River at Vernalis (RM 72).

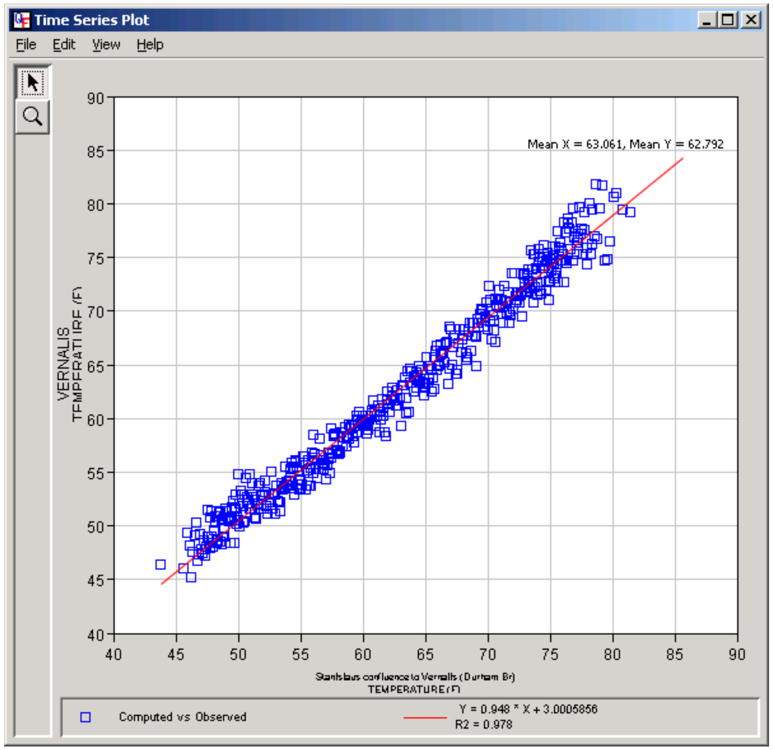

Figure 8-54. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the San Joaquin River at Vernalis (RM 72).

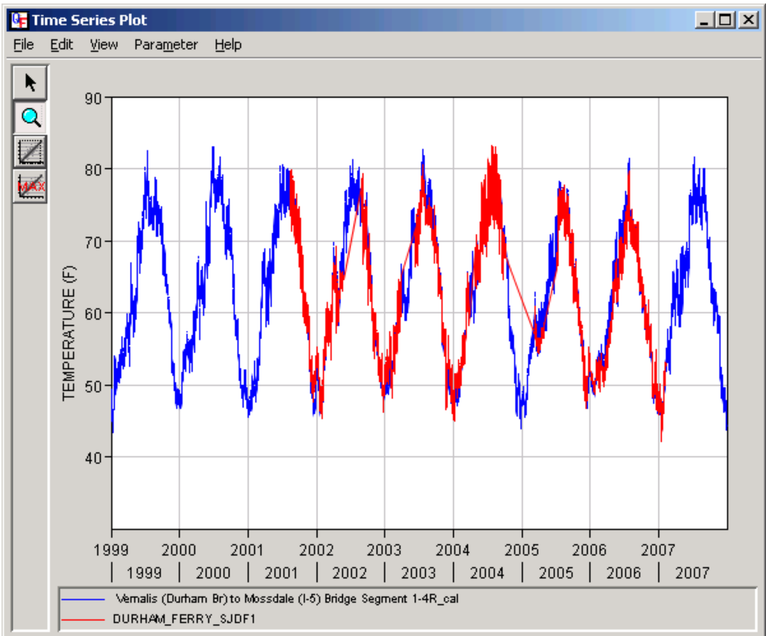

Figure 8-55. Comparison of computed (blue) and observed (red) water temperatures in the San Joaquin River at Durham Ferry (RM 71).

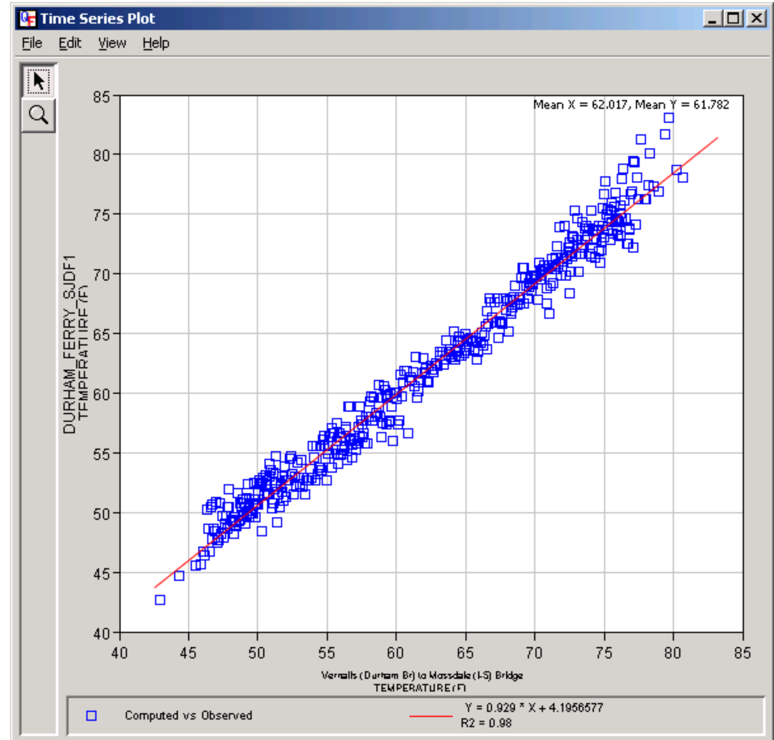

Figure 8-56. Linear regression of computed (x-axis) and observed (y-axis) water temperatures in the San Joaquin River at Durham Ferry (RM 71).

8.5. Four River Model

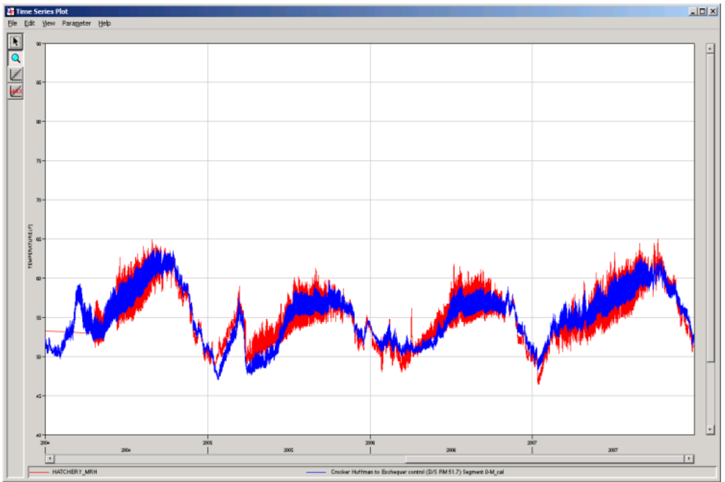

Figure 8-57. Comparison of computed (blue) and observed (red) water temperatures in the Merced River below Crocker-Huffman Dam.

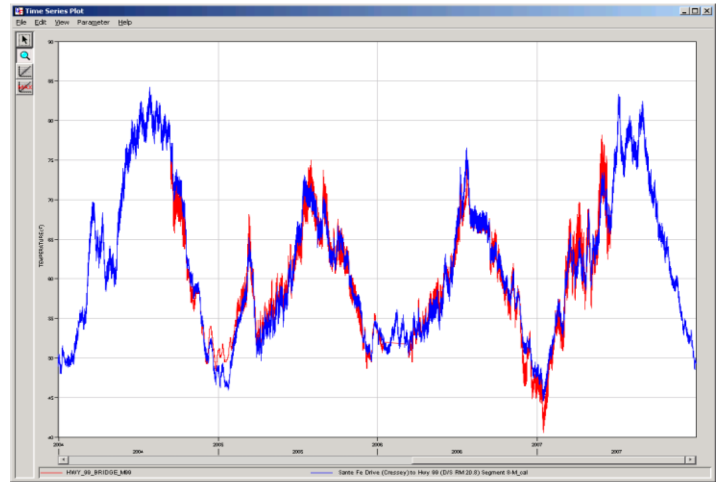

Figure 8-58. Comparison of computed (blue) and observed (red) water temperatures in the Merced River at the Highway 99 Bridge near Cressy.

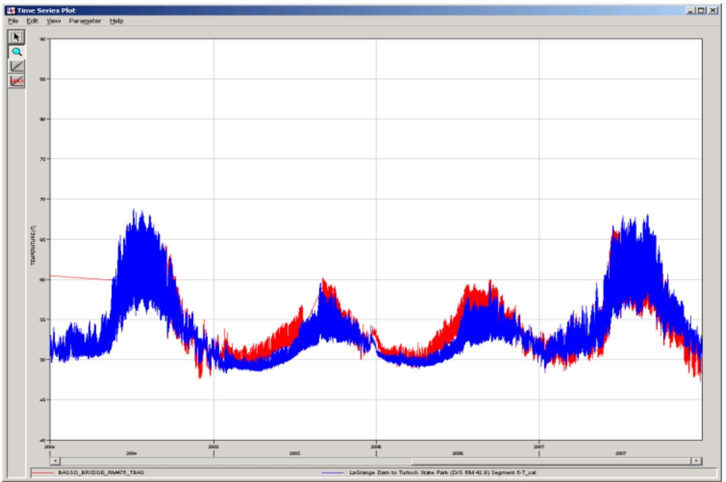

Figure 8-59. Comparison of computed (blue) and observed (red) water temperatures in the Tuolumne River at Basso Bridge.

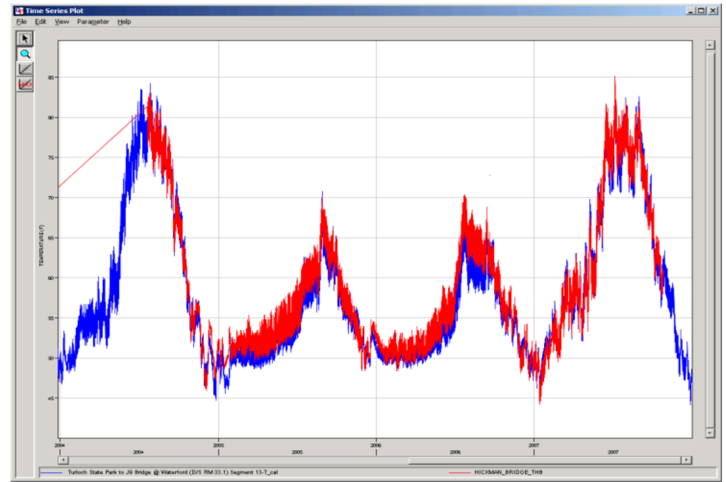

Figure 8-60. Comparison of computed (blue) and observed (red) water temperatures in the Tuolumne River at Hickman Bridge.

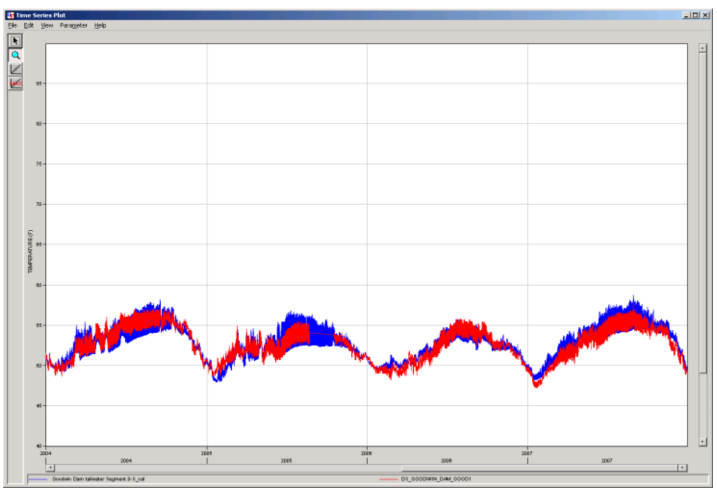

Figure 8-61. Comparison of computed (blue) and observed (red) water temperatures in the Stanislaus River below Goodwin Dam.

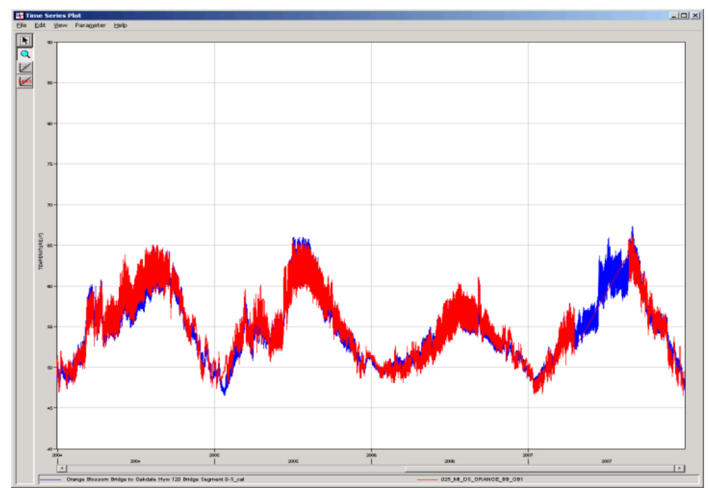

Figure 8-62. Comparison of computed (blue) and observed (red) water temperatures in the Stanislaus River at Orange Blossom Bridge.

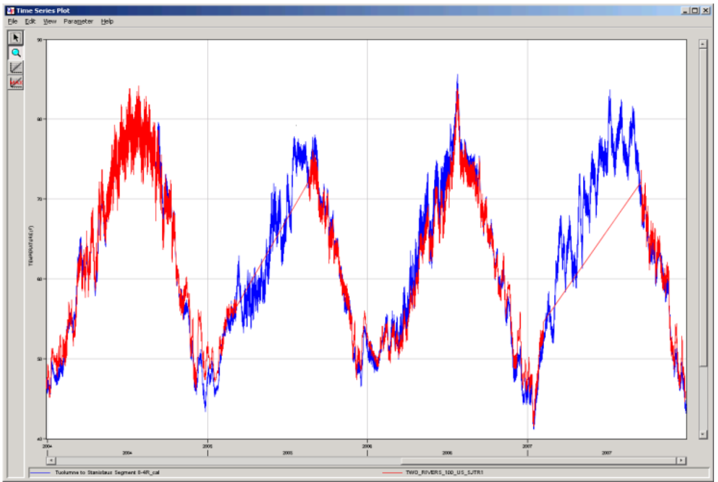

Figure 8-63. Comparison of computed (blue) and observed (red) water temperatures in the San Joaquin River at the Stanislaus River Confluence.

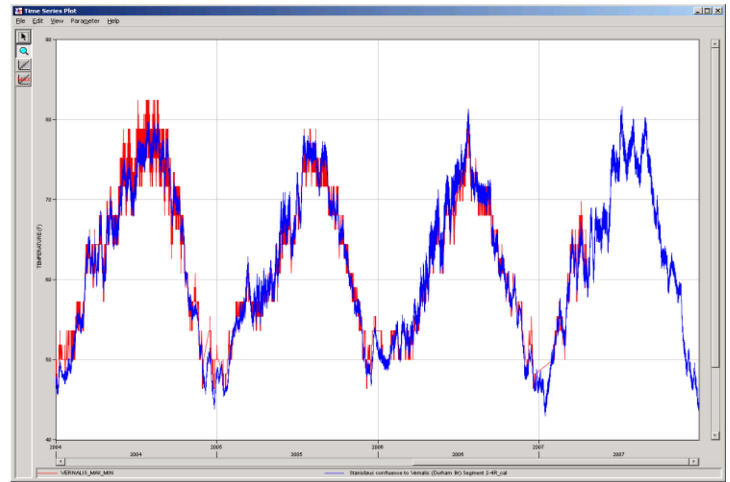

Figure 8-64. Comparison of computed (blue) and observed (red) water temperatures in the San Joaquin River at Vernalis.

9. Appendix B: Thermal Criteria Identification (Spreadsheet Tool)

9.1. Introduction

One of several inter-related tasks in the San Joaquin River Basin Water Temperature Modeling and Analysis was the need to review and assess available information to identify water temperature criteria for fall-run Chinook salmon and steelhead. A peer review panel[6] (Panel) was assembled to evaluate the biological merits and application of thermal criteria in assessment of model generated alternatives for the Stanislaus River. Subsequently, the Peer Review panel was reconvened and information specific to the Merced, Tuolumne, and mainstem San Joaquin River were reviewed in light of application of identified thermal criteria on the Stanislaus River. The Peer Review panel identified that the methodology applied on the Stanislaus River was appropriate for the additional river reaches and thermal criteria for the Tuolumne, Merced, and San Joaquin Rivers were developed. Outlined herein is a brief summary of the Panel findings. Specific details on development of the thermal criteria are presented in Deas *et al*. (2004).

In sum, thermal criteria were developed for various life stages (e.g., adult migration, egg incubation, juvenile rearing) of anadromous fish based on 7-day average of the maximum daily temperatures (7DADM). Panel members identified optimum threshold temperatures after EPA (2003). It should be emphasized that the stakeholders agreed that the Peer criteria should only serve as a means for comparing simulated alternatives and should not be construed as an agreed upon criteria in establishing temperature policy in the basin. Furthermore, the Peer Panel recommended that stakeholders should build upon and/or modify the Peer criteria given their own on-the-ground experience and knowledge of fishery issues related to the Stanislaus and Lower San Joaquin river system.

9.1.1. Framework

A critical Panel conclusion was that a two threshold (e.g., optimal, suboptimal, and lethal ranges) criteria did not necessarily differentiate alternatives on a broad scale. Further, from the outset of this review, the Panel had concerns over the discontinuous format of the two threshold (three-range) criteria - specifically, the inability of the discrete ranges to represent the continuous physiological response of a particular life stage. An example of how discontinuous criteria represent thermal conditions is provided in Figure 9-1. Temperatures T_a, T_b, and T_c, represent conditions in the high sub-optimal range, the low sub-optimal range, and in the optimal range, respectively. Note that in this discrete representation, thermal condition (e.g., stress) is equivalent for T_a and T_b, and markedly greater than T_c even though T_b and T_c are nearly equivalent temperatures.

[6] The panel was composed of John Bartholow (United States Geological Survey), Chuck Hanson (Hanson Environmental), and Chris Myrick (Colorado State University), and chaired by Michael Deas (Watercourse Engineering, Inc.).

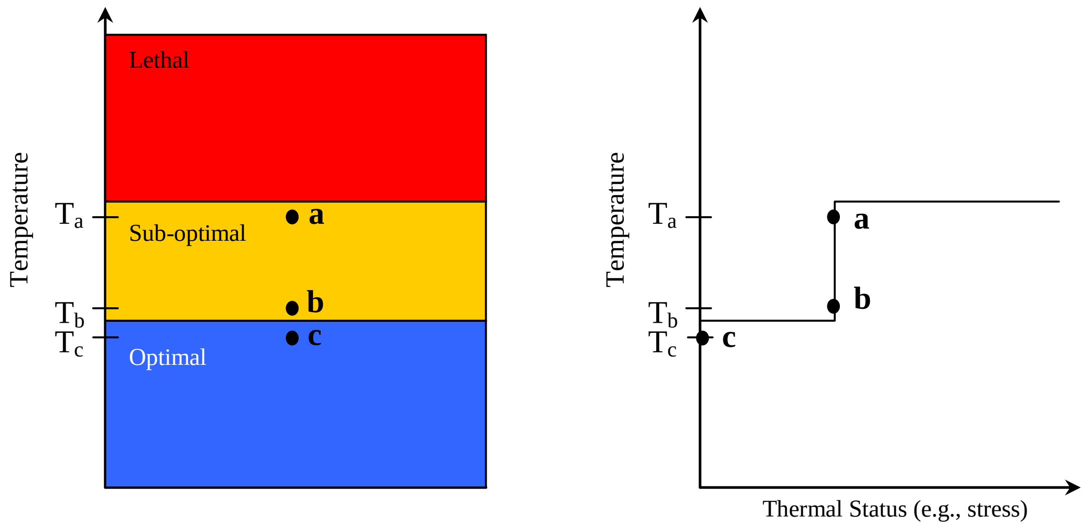

Figure 9-1. Discrete criteria based on two temperatures defining three ranges of thermal conditions and associated thermal status (e.g., stress).

To overcome these discrete ranges the panel elected to modify the two threshold (three range) criteria and adopt a response function that would essentially allow a continuous representation of increasingly adverse thermal conditions (Figure 9-2). In this case thermal status is more representative of a continual, but exponentially increasing function with increasing temperature, with thermal status at T_b markedly lower than at T_a, but only marginally higher than T_c. Construction of the temperature response curves shown above, were identified for each life stage based on an exponential relationship. Complete details are presented in Deas *et al*. (2004).

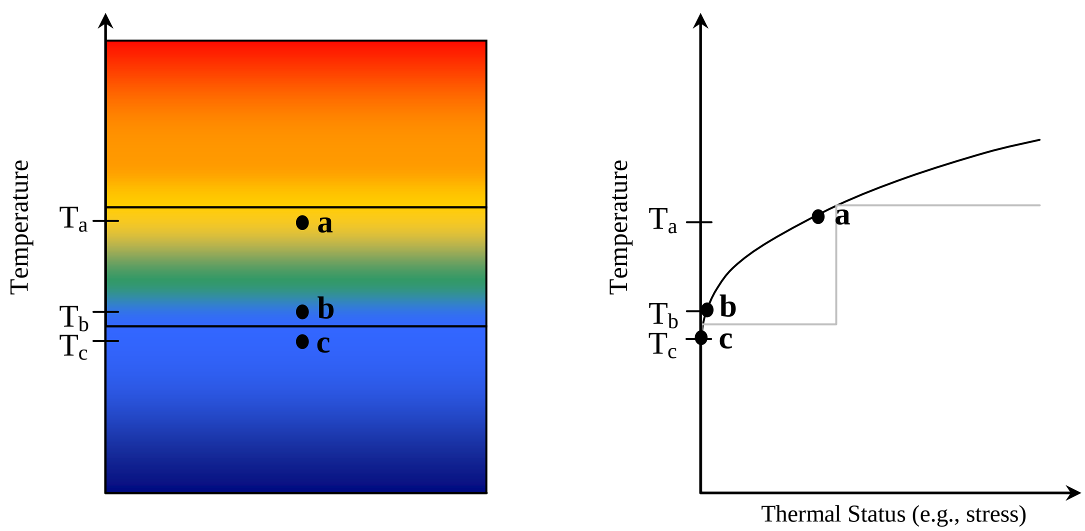

Figure 9-2. Example continuous criteria based on an optimum temperature and an exponential function defining an increasingly degraded thermal condition – discrete criteria shown for comparison.

In addition to the weekly average criteria, single day maximum temperatures were also considered because short duration elevated temperature events (on the order of a few hours) can have profound impacts on anadromous fish populations. Thus, an additional metric representing a one-day instantaneous maximum lethal water temperature was developed based on an upper incipient lethal condition. This criterion defined incipient upper lethal temperatures (IULT) as a thermal condition that would result in severe impairment to the fish when exposed for a short duration (hours). The application of this daily instantaneous maximum criteria/metric was to identify short duration events that are potentially masked by the 7DADM temperature. In the early fall or late spring, when thermal conditions are generally changing most rapidly, sub-weekly conditions may be highly variable and can put fish under stress. A modeled alternative that produced many instantaneous daily maximum temperatures above the selected criteria would indicate potential short-term impacts and the single day maximum criteria may assist in assessing alternatives (i.e., this criterion is intended to raise a "red flag" versus a quantitative measure).

Both the single day and weekly criteria were incorporated into a post-processing module to allow efficient comparison of alternative simulations. An Excel spreadsheet was used to provide a familiar platform for stakeholders and to allow transparency. An example is presented in Figure 9-3.

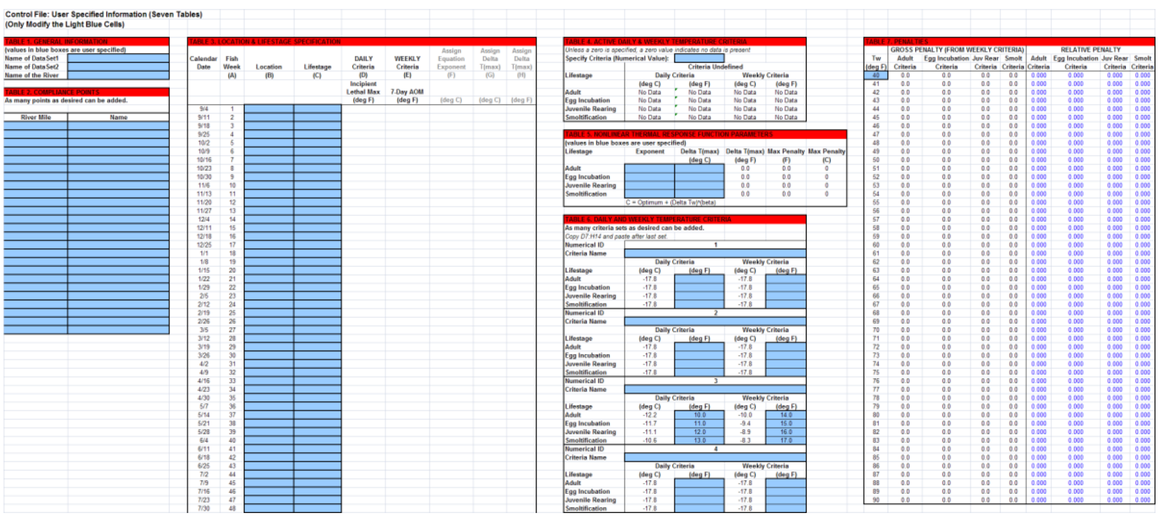

Figure 9-3. Screenshot from control panel worksheet for the Excel spreadsheet model used to assess single day and weekly criteria.

The compliance point locations and single day and 7DADM criteria are included in below for the Tuolumne, Merced, and San Joaquin Rivers.

9.2. Stanislaus River System Operations Study

The temperature objectives (or criteria) were developed by a panel of experts, as discussed previously. Compliance or reference points where the criteria for the various life stages are applied were subsequently identified with Stakeholder input. Compliance points for the Stanislaus River are presented in Table 9-1.

Table 9-1. Stanislaus River compliance points and associated life stages.

Location	River Mile (RM)	Life Stage
Orange Blossom Bridge	RM 46	Summer Juvenile Rearing
Riverbank	RM 33	Juvenile Rearing and Egg Incubation
Confluence with the San Joaquin River	RM 0	Smoltification and Adult Immigration

Additional compliance points of interest included Goodwin Dam (RM 57.9), Knights Ferry (RM 54), Oakdale (RM 40), and Ripon (RM 15). Compliance points may move with season and life stage and may not include all locations listed. These locations are shown Figure 9-4. Single day criteria were applied at the same locations as the 7DADM. An example of the single day and 7DADM criteria by compliance location and life stage for the September through August period is shown in Figure 9-5.

Figure 9-4. Stanislaus River compliance locations for application of thermal criteria.

Date	Fish Week	Location	Lifestage	WEEKLY Criteria 7DADM (deg F)	DAILY Criteria Incipient Lethal Max (deg F)
9/4	1	Confluence	Adult	64.0	69.8
9/11	2	Confluence	Adult	64.0	69.8
9/18	3	Confluence	Adult	64.0	69.8
9/25	4	Confluence	Adult	64.0	69.8
10/2	5	Riverbank	Egg Incubation	55.0	69.8
10/9	6	Riverbank	Egg Incubation	55.0	69.8
10/16	7	Riverbank	Egg Incubation	55.0	62.0
10/23	8	Riverbank	Egg Incubation	55.0	62.0
10/30	9	Riverbank	Egg Incubation	55.0	62.0
11/6	10	Riverbank	Egg Incubation	55.0	62.0
11/13	11	Riverbank	Egg Incubation	55.0	62.0
11/20	12	Riverbank	Egg Incubation	55.0	62.0
11/27	13	Riverbank	Egg Incubation	55.0	62.0
12/4	14	Riverbank	Egg Incubation	55.0	62.0
12/11	15	Riverbank	Egg Incubation	55.0	62.0
12/18	16	Riverbank	Egg Incubation	55.0	62.0
12/25	17	Riverbank	Egg Incubation	55.0	62.0
1/1	18	Riverbank	Juvenile Rearing	61.0	84.2
1/8	19	Riverbank	Juvenile Rearing	61.0	84.2
1/15	20	Riverbank	Juvenile Rearing	61.0	84.2
1/22	21	Riverbank	Juvenile Rearing	61.0	84.2
1/29	22	Riverbank	Juvenile Rearing	61.0	84.2
2/5	23	Riverbank	Juvenile Rearing	61.0	84.2
2/12	24	Riverbank	Juvenile Rearing	61.0	84.2
2/19	25	Riverbank	Juvenile Rearing	61.0	84.2
2/26	26	Riverbank	Juvenile Rearing	61.0	84.2
3/5	27	Riverbank	Juvenile Rearing	61.0	84.2
3/12	28	Riverbank	Juvenile Rearing	61.0	84.2
3/19	29	Riverbank	Juvenile Rearing	61.0	84.2
3/26	30	Riverbank	Juvenile Rearing	61.0	84.2
4/2	31	Riverbank	Juvenile Rearing	61.0	84.2
4/9	32	Riverbank	Juvenile Rearing	61.0	84.2
4/16	33	Confluence	smoltification	57.0	84.2
4/23	34	Confluence	smoltification	57.0	84.2
4/30	35	Confluence	smoltification	57.0	84.2
5/7	36	Confluence	smoltification	57.0	84.2
5/14	37	Confluence	smoltification	57.0	84.2
5/21	38	Confluence	smoltification	57.0	84.2
5/28	39	Confluence	smoltification	57.0	84.2
6/4	40	Orange Blossom	Juvenile Rearing	64.0	84.2
6/11	41	Orange Blossom	Juvenile Rearing	64.0	84.2
6/18	42	Orange Blossom	Juvenile Rearing	64.0	84.2
6/25	43	Orange Blossom	Juvenile Rearing	64.0	84.2
7/2	44	Orange Blossom	Juvenile Rearing	64.0	84.2
7/9	45	Orange Blossom	Juvenile Rearing	64.0	84.2
7/16	46	Orange Blossom	Juvenile Rearing	64.0	84.2
7/23	47	Orange Blossom	Juvenile Rearing	64.0	84.2
7/30	48	Orange Blossom	Juvenile Rearing	64.0	84.2
8/6	49	Orange Blossom	Juvenile Rearing	64.0	84.2
8/13	50	Orange Blossom	Juvenile Rearing	64.0	84.2
8/20	51	Orange Blossom	Juvenile Rearing	64.0	84.2
8/27	52	Orange Blossom	Juvenile Rearing	64.0	84.2

Figure 9-5. Single day and 7DADM criteria by compliance location and life stage for the September through August for the Stanislaus River.

9.3. Tuolumne River

Compliance or reference points where the criteria for the various life stages are applied

were subsequently identified with Stakeholder input. Compliance points for the Tuolumne River are presented in Table 9-2.

Table 9-2. Tuolumne river compliance points and associated life stages.

Location	River Mile (RM)	Life Stage
Below Don Pedro Dam	RM 60	
Below La Grange Dam	RM 52	
New La Grange Bridge	RM 50	
Basso Bridge	RM 47.5	
Bobcat Flat/Turlock State Recreation Area	RM 43	Adult/Egg Incubation/Juvenile Rearing
7-11 Gravel Bridge	RM 38	
Waterford	RM 32	Juvenile Rearing/Smoltification
Geer Road (Fox Grove Bridge)	RM 26	
Below Dry Creek	RM 16	
Confluence with the San Joaquin River	RM 0	Juvenile Rearing

Compliance points may move with season and life stage and may not include all locations listed. These locations are shown in Figure 9-6. Single day criteria were applied at the same locations as the 7DADM. An example of the single day and 7DADM criteria by compliance location and life stage for the September through August period is shown in Figure 9-7.

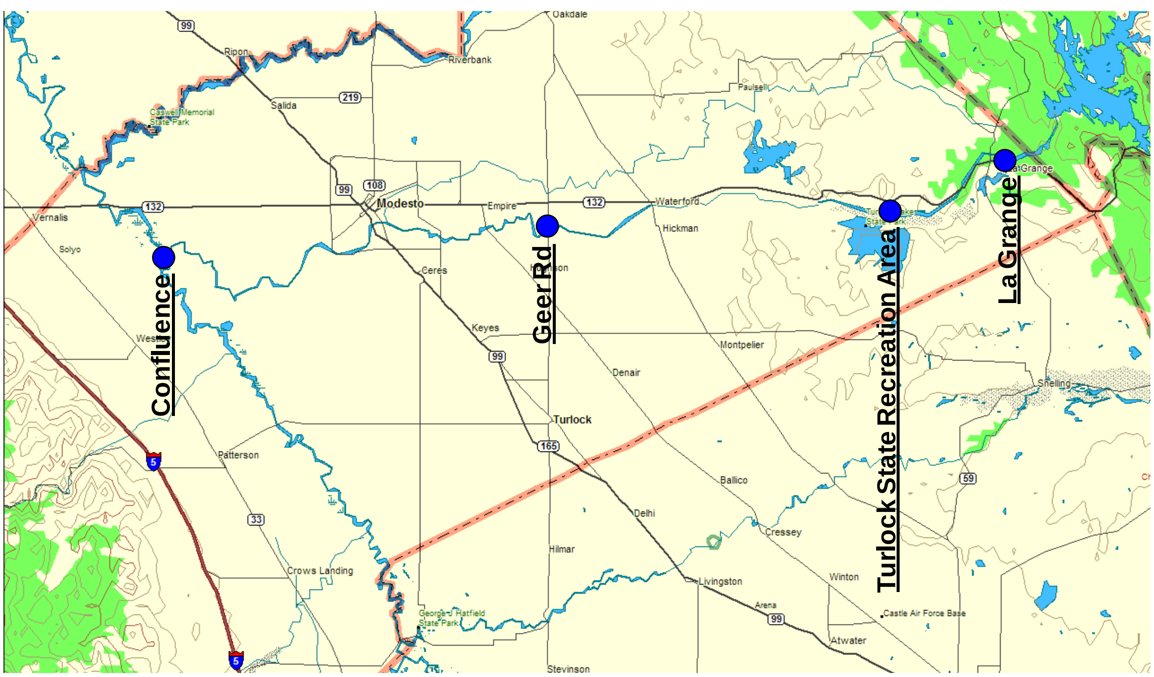

Figure 9-6. Tuolumne River compliance locations for application of thermal criteria.

TABLE 3. LOCATION & LIFESTAGE SPECIFICATION								
Calendar Date	Fish Week (A)	Location (B)	Lifestage (C)	DAILY Criteria (D) Incipient Lethal Max (deg F)	WEEKLY Criteria (E) 7-Day AOM (deg F)	Assign Equation Exponent (F) (deg C)	Assign Delta T(max) (G) (deg C)	Assign Delta T(max) (H) (deg F)
9/4	1	Bobcat Flat	Adult	69.8	64.0	2	10	18.0
9/11	2	Bobcat Flat	Adult	69.8	64.0	2	10	18.0
9/18	3	Bobcat Flat	Adult	69.8	64.0	2	10	18.0
9/25	4	Bobcat Flat	Adult	69.8	64.0	2	10	18.0
10/2	5	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
10/9	6	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
10/16	7	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
10/23	8	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
10/30	9	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
11/6	10	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
11/13	11	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
11/20	12	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
11/27	13	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
12/4	14	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
12/11	15	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
12/18	16	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
12/25	17	Bobcat Flat	Egg Incubation	62.0	55.0	3	4	7.2
1/1	18	Bobcat Flat	Juvenile Rearing	84.2	61.0	2	10	18.0
1/8	19	Bobcat Flat	Juvenile Rearing	84.2	61.0	2	10	18.0
1/15	20	Bobcat Flat	Juvenile Rearing	84.2	61.0	2	10	18.0
1/22	21	Bobcat Flat	Juvenile Rearing	84.2	61.0	2	10	18.0
1/29	22	Bobcat Flat	Juvenile Rearing	84.2	61.0	2	10	18.0
2/5	23	Bobcat Flat	Juvenile Rearing	84.2	61.0	2	10	18.0
2/12	24	Bobcat Flat	Juvenile Rearing	84.2	61.0	2	10	18.0
2/19	25	Bobcat Flat	Juvenile Rearing	84.2	61.0	2	10	18.0
2/26	26	Bobcat Flat	Juvenile Rearing	84.2	61.0	2	10	18.0
3/5	27	Bobcat Flat	Juvenile Rearing	84.2	61.0	2	10	18.0
3/12	28	Waterford	Juvenile Rearing	84.2	61.0	2	10	18.0
3/19	29	Waterford	Juvenile Rearing	84.2	61.0	2	10	18.0
3/26	30	Waterford	Juvenile Rearing	84.2	61.0	2	10	18.0
4/2	31	Waterford	Juvenile Rearing	84.2	61.0	2	10	18.0
4/9	32	Waterford	Juvenile Rearing	84.2	61.0	2	10	18.0
4/16	33	Waterford	Smoltification	84.2	57.0	3	10	18.0
4/23	34	Waterford	Smoltification	84.2	57.0	3	10	18.0
4/30	35	Waterford	Smoltification	84.2	57.0	3	10	18.0
5/7	36	Waterford	Smoltification	84.2	57.0	3	10	18.0
5/14	37	Waterford	Smoltification	84.2	57.0	3	10	18.0
5/21	38	Waterford	Smoltification	84.2	57.0	3	10	18.0
5/28	39	Waterford	Smoltification	84.2	57.0	3	10	18.0
6/4	40	Waterford	Juvenile Rearing	84.2	61.0	2	10	18.0
6/11	41	Waterford	Juvenile Rearing	84.2	61.0	2	10	18.0
6/18	42	Confluence	Juvenile Rearing	84.2	61.0	2	10	18.0
6/25	43	Confluence	Juvenile Rearing	84.2	61.0	2	10	18.0
7/2	44	Confluence	Juvenile Rearing	84.2	61.0	2	10	18.0
7/9	45	Confluence	Juvenile Rearing	84.2	61.0	2	10	18.0
7/16	46	Confluence	Juvenile Rearing	84.2	61.0	2	10	18.0
7/23	47	Confluence	Juvenile Rearing	84.2	61.0	2	10	18.0
7/30	48	Confluence	Juvenile Rearing	84.2	61.0	2	10	18.0
8/6	49	Confluence	Juvenile Rearing	84.2	61.0	2	10	18.0
8/13	50	Confluence	Juvenile Rearing	84.2	61.0	2	10	18.0
8/20	51	Confluence	Juvenile Rearing	84.2	61.0	2	10	18.0
8/27	52	Confluence	Juvenile Rearing	84.2	61.0	2	10	18.0

Figure 9-7. Single day and 7DADM criteria by compliance location and life stage for the September through August for the Tuolumne River.

9.4. Merced River

Compliance or reference points where the criteria for the various life stages are applied

were subsequently identified with Stakeholder input. Compliance points for the Merced River are presented in Table 9-3.

Table 9-3. Merced river compliance points and associated life stages.

Location	River Mile (RM)	Life Stage
Below Exchequer Dam	RM 60	Adult/Egg Incubation/Juvenile Rearing
Below Crocker Huffman Dam	RM 52	Juvenile Rearing/Smoltification
Highway 59	RM 41	Smoltification/Juvenile Rearing
Santa Fe Bridge	RM 28	
Confluence with the San Joaquin River	RM 0	

Compliance points may move with season and life stage and may not include all locations listed. These locations are shown in Figure 9-8. Single day criteria were applied at the same locations as the 7DADM. An example of the single day and 7DADM criteria by compliance location and life stage for the September through August period is shown in Figure 9-9.

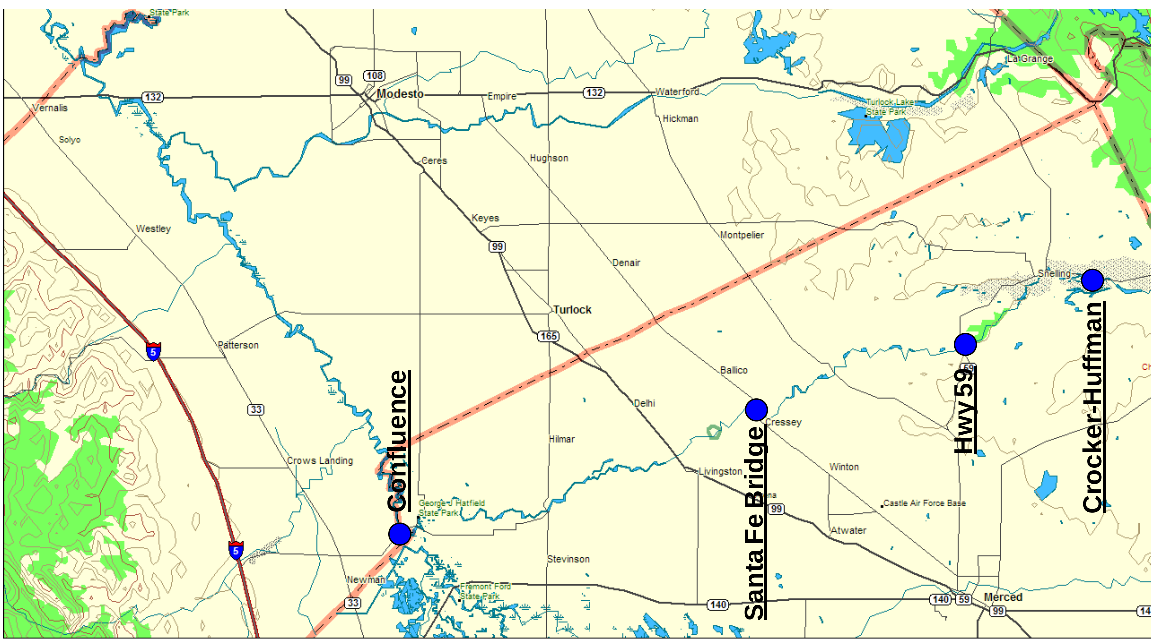

Figure 9-8. Merced River compliance locations for application of thermal criteria.

TABLE 3. LOCATION & LIFESTAGE SPECIFICATION								
Calendar Date	Fish Week (A)	Location (B)	Lifestage (C)	DAILY Criteria (D) Incipient Lethal Max (deg F)	WEEKLY Criteria (E) 7-Day AOM (deg F)	Assign Equation Exponent (F) (deg C)	Assign Delta T(max) (G) (deg C)	Assign Delta T(max) (H) (deg F)
9/4	1	Exchequer Dam	Adult	69.8	64.0	2	10	18.0
9/11	2	Exchequer Dam	Adult	69.8	64.0	2	10	18.0
9/18	3	Exchequer Dam	Adult	69.8	64.0	2	10	18.0
9/25	4	Exchequer Dam	Adult	69.8	64.0	2	10	18.0
10/2	5	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
10/9	6	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
10/16	7	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
10/23	8	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
10/30	9	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
11/6	10	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
11/13	11	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
11/20	12	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
11/27	13	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
12/4	14	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
12/11	15	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
12/18	16	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
12/25	17	Exchequer Dam	Egg Incubation	62.0	55.0	3	4	7.2
1/1	18	Exchequer Dam	Juvenile Rearing	84.2	61.0	2	10	18.0
1/8	19	Exchequer Dam	Juvenile Rearing	84.2	61.0	2	10	18.0
1/15	20	Exchequer Dam	Juvenile Rearing	84.2	61.0	2	10	18.0
1/22	21	Exchequer Dam	Juvenile Rearing	84.2	61.0	2	10	18.0
1/29	22	Exchequer Dam	Juvenile Rearing	84.2	61.0	2	10	18.0
2/5	23	Exchequer Dam	Juvenile Rearing	84.2	61.0	2	10	18.0
2/12	24	Exchequer Dam	Juvenile Rearing	84.2	61.0	2	10	18.0
2/19	25	Crocker Huffman	Juvenile Rearing	84.2	61.0	2	10	18.0
2/26	26	Crocker Huffman	Juvenile Rearing	84.2	61.0	2	10	18.0
3/5	27	Crocker Huffman	Juvenile Rearing	84.2	61.0	2	10	18.0
3/12	28	Crocker Huffman	Juvenile Rearing	84.2	61.0	2	10	18.0
3/19	29	Crocker Huffman	Juvenile Rearing	84.2	61.0	2	10	18.0
3/26	30	Crocker Huffman	Juvenile Rearing	84.2	61.0	2	10	18.0
4/2	31	Crocker Huffman	Juvenile Rearing	84.2	61.0	2	10	18.0
4/9	32	Crocker Huffman	Juvenile Rearing	84.2	61.0	2	10	18.0
4/16	33	Crocker Huffman	Smoltification	84.2	57.0	3	10	18.0
4/23	34	Crocker Huffman	Smoltification	84.2	57.0	3	10	18.0
4/30	35	Crocker Huffman	Smoltification	84.2	57.0	3	10	18.0
5/7	36	Highway 59	Smoltification	84.2	57.0	3	10	18.0
5/14	37	Highway 59	Smoltification	84.2	57.0	3	10	18.0
5/21	38	Highway 59	Smoltification	84.2	57.0	3	10	18.0
5/28	39	Highway 59	Smoltification	84.2	57.0	3	10	18.0
6/4	40	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0
6/11	41	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0
6/18	42	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0
6/25	43	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0
7/2	44	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0
7/9	45	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0
7/16	46	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0
7/23	47	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0
7/30	48	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0
8/6	49	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0
8/13	50	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0
8/20	51	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0
8/27	52	Highway 59	Juvenile Rearing	84.2	61.0	2	10	18.0

Figure 9-9. Single day and 7DADM criteria by compliance location and life stage for the September through August for the Merced River.

9.5. San Joaquin River

Compliance or reference points where the criteria for the various life stages are applied

were subsequently identified with Stakeholder input. Compliance points for the San Joaquin River are presented in Table 9-4.

Table 9-4. San Joaquin river compliance points and associated life stages.

Location	River Mile (RM)	Life Stage
Confluence with the Merced River	RM 117	Adult, Egg Incubation
Confluence with the Tuolumne River	RM 83	Juvenile Rearing
Confluence with the Stanislaus River	RM 74	Juvenile Rearing/Smoltification
Mossdale	RM 56	Juvenile Rearing

Compliance points may move with season and life stage and may not include all locations listed. These locations are shown in Figure 9-10. Single day criteria were applied at the same locations as the 7DADM. An example of the single day and 7DADM criteria by compliance location and life stage for the September through August period is shown in Figure 9-11.

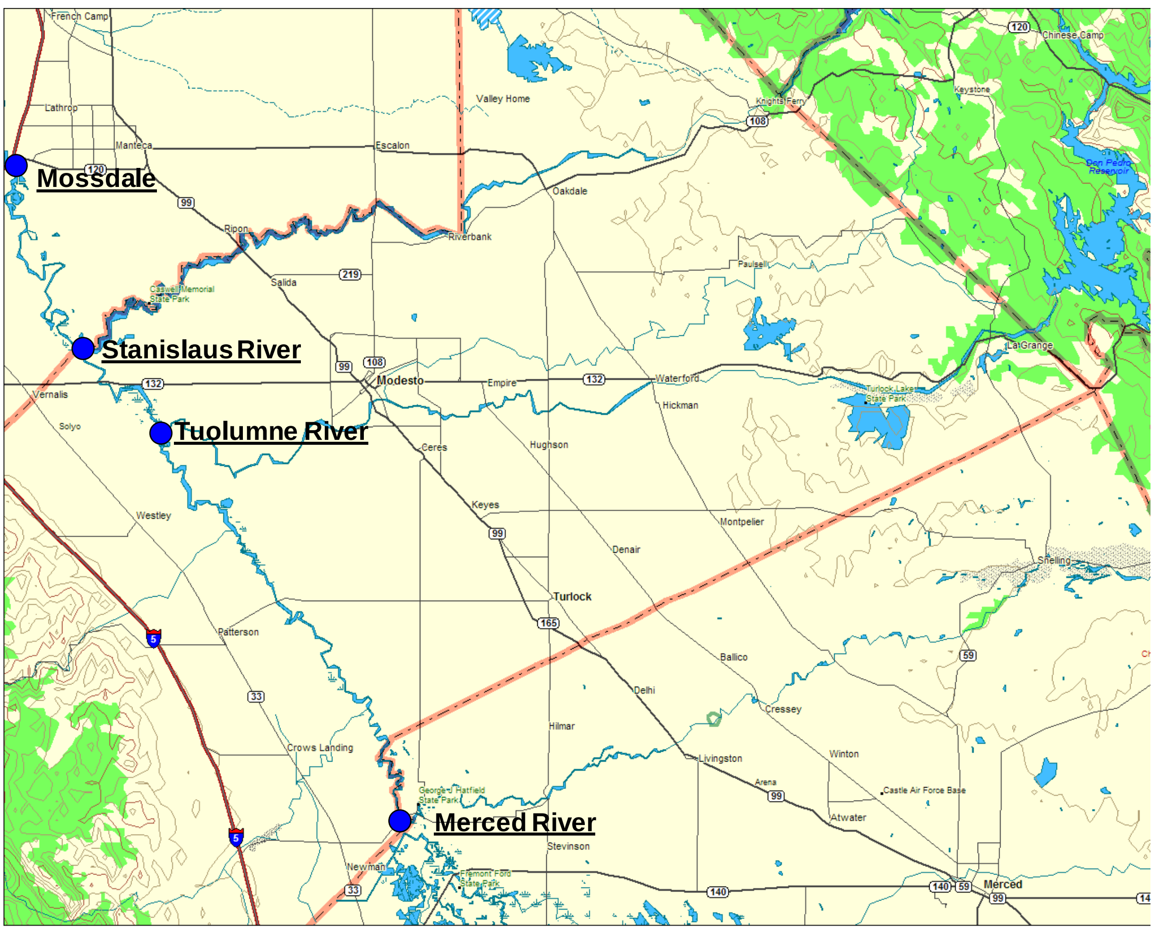

Figure 9-10. San Joaquin River compliance locations for application of thermal criteria.

TABLE 3. LOCATION & LIFESTAGE SPECIFICATION								
Calendar Date	Fish Week (A)	Location (B)	Lifestage (C)	DAILY Criteria (D) Incipient Lethal Max (deg F)	WEEKLY Criteria (E) 7-Day AOM (deg F)	Assign Equation Exponent (F) (deg C)	Assign Delta T(max) (G) (deg C)	Assign Delta T(max) (H) (deg F)
9/4	1	Abv Merced	Adult	69.8	64.0	2	10	18.0
9/11	2	Abv Merced	Adult	69.8	64.0	2	10	18.0
9/18	3	Abv Merced	Adult	69.8	64.0	2	10	18.0
9/25	4	Abv Merced	Adult	69.8	64.0	2	10	18.0
10/2	5	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
10/9	6	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
10/16	7	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
10/23	8	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
10/30	9	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
11/6	10	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
11/13	11	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
11/20	12	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
11/27	13	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
12/4	14	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
12/11	15	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
12/18	16	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
12/25	17	Abv Merced	Egg Incubation	62.0	55.0	3	4	7.2
1/1	18	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
1/8	19	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
1/15	20	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
1/22	21	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
1/29	22	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
2/5	23	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
2/12	24	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
2/19	25	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
2/26	26	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
3/5	27	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
3/12	28	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
3/19	29	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
3/26	30	Abv Tuolumne	Juvenile Rearing	84.2	61.0	2	10	18.0
4/2	31	Abv Stanislaus	Juvenile Rearing	84.2	61.0	2	10	18.0
4/9	32	Abv Stanislaus	Juvenile Rearing	84.2	61.0	2	10	18.0
4/16	33	Abv Stanislaus	Smoltification	84.2	57.0	3	10	18.0
4/23	34	Abv Stanislaus	Smoltification	84.2	57.0	3	10	18.0
4/30	35	Abv Stanislaus	Smoltification	84.2	57.0	3	10	18.0
5/7	36	Abv Stanislaus	Smoltification	84.2	57.0	3	10	18.0
5/14	37	Abv Stanislaus	Smoltification	84.2	57.0	3	10	18.0
5/21	38	Abv Stanislaus	Smoltification	84.2	57.0	3	10	18.0
5/28	39	Abv Stanislaus	Smoltification	84.2	57.0	3	10	18.0
6/4	40	Abv Stanislaus	Juvenile Rearing	84.2	61.0	2	10	18.0
6/11	41	Mossdale	Juvenile Rearing	84.2	61.0	2	10	18.0
6/18	42	Mossdale	Juvenile Rearing	84.2	61.0	2	10	18.0
6/25	43	Mossdale	Juvenile Rearing	84.2	61.0	2	10	18.0
7/2	44	Mossdale	Juvenile Rearing	84.2	61.0	2	10	18.0
7/9	45	Mossdale	Juvenile Rearing	84.2	61.0	2	10	18.0
7/16	46	Mossdale	Juvenile Rearing	84.2	61.0	2	10	18.0
7/23	47	Mossdale	Juvenile Rearing	84.2	61.0	2	10	18.0
7/30	48	Vernalis	Juvenile Rearing	84.2	61.0	2	10	18.0
8/6	49	Vernalis	Juvenile Rearing	84.2	61.0	2	10	18.0
8/13	50	Vernalis	Juvenile Rearing	84.2	61.0	2	10	18.0
8/20	51	Vernalis	Juvenile Rearing	84.2	61.0	2	10	18.0
8/27	52	Vernalis	Juvenile Rearing	84.2	61.0	2	10	18.0

Figure 9-11. Single day and 7DADM criteria by compliance location and life stage for the September through August for the San Joaquin River.

10. Appendix C: Acronyms

This appendix contains a listing of the acronyms referred to in this document.

7DADM	7-Day Average of Maximum Daily Temperature
af	acre-feet
Bay-Delta	Sacramento-San Joaquin Bay Delta
CDEC	California Data Exchange Center
CDFG	California Department of Fish and Game
cfs	cubic feet per second
CIMIS	California Irrigation Management Information System
Corps	United States Army Corps of Engineers
CP	Control Point
CSJWCD	Central San Joaquin Water Conservation District
CVP	Central Valley Project
DWR	California Department of Water Resources
ERP	Ecosystem Restoration Program
GUI	Graphical User Interface
IULT	Incipient Upper Lethal Temperature
NWS	National Weather Service
OID	Oakdale Irrigation District
PH	Power House
R^2	Coefficient of Determination
RM	River Mile
SEWD	Stockton East Water District
SJR	San Joaquin River
SSJID	South San Joaquin Irrigation District
taf	thousand acre-feet
USBR	United States Bureau of Reclamation
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
LIDAR	Light Detection and Ranging

11. Appendix D: Model Installation and Supporting Files

The following are links from where interested parties could download the model and supporting files:

Project Report (current document) - 4.3 mb
http://www.rmanet.com/CalFed_Sep09/ SJRTempModelReport_09.pdf

File description / instructions - 0.6 mb
http://www.rmanet.com/CalFed_Sep09/final_model.ppt

Data files - 351 mb
http://www.rmanet.com/CalFed_Sep09/CalFed.zip

Hec5q executable - 7.5 mb
http://www.rmanet.com/CalFed_Sep09/hec5q.exe

HWMS setup - 26 mb
http://www.rmanet.com/CalFed_Sep09/HWMS_Setup2009.exe

HWMS startup instructions - 0.6 mb
http://www.rmanet.com/CalFed_Sep09/HWMS_StartUp.doc

HWMS users Manual - 1.1 mb
http://www.rmanet.com/CalFed_Sep09/HWMS_Users_Manual.doc

Java installs - 13 mb
http://www.rmanet.com/CalFed_Sep09/jre-6-windows-i586.exe

Thermal Criteria Identification (Spreadsheet Tool)/Stanislaus – 4.5 mb
http://www.rmanet.com/CalFed_Sep09/Stanislaus_6-6-071.zip

Thermal Criteria Identification (Spreadsheet Tool)/Tuolumne – 5.23 mb
http://www.rmanet.com/CalFed_Sep09/Tuolumne_6-6-071.zip

Thermal Criteria Identification (Spreadsheet Tool)/Merced – 3.6 mb
http://www.rmanet.com/CalFed_Sep09/Merced6-6-07.zip

Thermal Criteria Identification (Spreadsheet Tool)/San Joaquin – 3.6 mb
http://www.rmanet.com/CalFed_Sep09/SanJoaquin_6-6-07.zip

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