San-Joaquin Basin
Water Temperature Modeling and Analysis

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SAN JOAQUIN BASIN WATER TEMPERATURE MODELING AND ANALYSIS

EXECUTIVE SUMMARY

INTRODUCTION

This document summarizes the development and application of the HEC-5Q Water Temperature Model for the San Joaquin Basin and provides detailed descriptions of outcomes achieved in modeling the water temperature regime through the improvement of the methodology and by expanding the modeling area.

The overall structure of the document is as follows:

- Chapter 1 provides an introduction and background pertinent to the San Joaquin River water temperature modeling effort and work from related projects;
- Chapter 2 includes the model representation of the physical system, reservoirs, streams, hydrologic and temperature boundary conditions, the meteorological data set up and the temperature model structure;
- Chapter 3 describes the details of the reservoirs and the stream temperature calibration results;
- Chapter 4 depicts the Kondolf Hydrographs model application and how the bypass spring pulse flow was modeled; and
- Chapter 5 provides conclusions and recommendations for future water temperature modeling.

BACKGROUND

The HEC-5Q model was developed to assess temperature in support of basin-scale planning and management decision making. HEC-5Q is designed to evaluate options for coordinating reservoir releases among projects to examine the effects on temperature throughout the system. The model interfaces with a comprehensive graphical user interface to aid in the interpretation of model results. The model computes temperatures on a diurnal time scale over long time planning periods (e.g., 1921 – 1994 for the Upper Sacramento / Sites application coupled with CALSIM).

In the late 1990s, under a collaborative effort proposed by the stakeholders, a Stanislaus Water Temperature Model was developed. This model includes the New Melones Reservoir, Tulloch Reservoir, Goodwin Pool, and approximately 60 miles of the Stanislaus River from Goodwin Dam to the confluence with the San Joaquin River. Beginning in 2002, CALFED sponsored a project to extend the model to include the

Tuolumne and Merced Rivers below Lake Don Pedro and Lake McClure respectively and the San Joaquin River between Stevinson and Mossdale.

In 2005, the San Joaquin River Riparian Habitat Restoration Program (SJRRHRP) recognized the need to develop water temperature models for Millerton Lake and the San Joaquin River. The HEC-5Q model of the San Joaquin River system described in this report was developed to meet this need.

OBJECTIVES

The temperature model development process takes into account the detailed temperature collection effort, the integrated groundwater depletion/accretion knowledge and improved temperature connectivity calculation. The objectives of this model development focused on:

- Increasing resolution in flow and temperature modeling capability in the San Joaquin Basin.
- Improving temperature estimates to provide dynamic and accurate temperature/water quality computation for the fishery restoration objective.
- Applying temperature modeling assumptions using available water quality/temperature information from previous studies and existing models.
- Providing potential operational forecast and criteria for the Friant operations.

SUMMARY OF FINDINGS

The Millerton Lake/Friant Dam model was calibrated using observed temperature profile at multiple locations on the lake for 58 sampling dates between November 2002 and June 2005. Error analysis of the computed and observed temperatures indicated an average negative bias of 0.25^{o} F (0.14^{o} C), mean absolute error (MAE) of 0.94^{o} F (0.52^{o} C) and root mean square error (RMSE) of 1.23^{o} F (0.68^{o} C). The available river temperature data below Friant Dam indicates the lake model computed outflow temperature is accurate to within 1^{o} F.

The accuracy of the temperatures predictions within the lake and good representation of the discharge temperatures dynamics provides strong evidence that the model is potentially a useful tool for evaluating temperature impacts of alternative reservoir operation scenarios. As a minimum, it indicates the model can be used to screen the operation and water management alternatives for future fishery restoration objectives.

River model temperature calibration simulations indicated that the river is heated by warm water re-entering the stream channel as the gravel pits drain during periods of sharply falling Friant Dam releases. Significant impacts on temperature were limited to a few brief periods in 2005, however as a general rule, sharp curtailment of dam releases appear to be problematic and should be avoided to minimize potential adverse thermal impacts.

Calibration of the San Joaquin River model utilized time series temperature data at numerous channel location between Friant Dam and Patterson located approximately 169 miles below Friant Dam. The weighted MAE and RMSE indicate that the model is most accurate in the river segment below Friant Dam. The sample number weighted bias, MAE and RMSE for all locations above Mendota was -0.83° F, 1.73° F and 2.22° F respectively. The negative bias above Mendota is attributed to consistently lower computed temperatures during the summer of 2004 and from ignoring the heating effects of offline storage during spring and summer 2005. The magnitudes of the errors appear slightly more dependant on flow above Mendota than below.

There is a positive bias of 0.99° F (0.55° C) below Mendota that increases with higher flows. The sample number weighted MAE and RMSE for all locations was 2.13° F and 2.61° F respectively. The model generally under predicts diurnal variations below Mendota. Since the calibration emphasized maximum daily temperatures (important for salmonid survival); the positive bias is attributable to computed daily minimum temperatures that are higher than observed. There is very little variation in the MAE and RMSE below Mendota for the various data categories. The uniformity of error statistics below Mendota is to be expected since river temperatures are near equilibrium with the atmosphere and subject of meteorological data approximations. Temperatures below Mendota are also more dependant on inflow temperatures rather than influenced by Friant Dam release flows and temperatures.

The goal of the modeling effort was to develop a system wide engineering modeling tool capable for predicting the thermal responses of the Millerton Lake and the San Joaquin River under a wide range of environmental conditions.

A demonstration analysis of the thermal impacts of settlement flows on river and reservoir temperatures was performed by simulating the 2000 – 2004 period with reservoir release rates that comply with Kondolf hydrograph goals for normal wet, normal dry and dry years. Canal deliveries were downscaled to maintain end-of-year volumes in Millerton Lake. Gravel pit interflow was included to assess impacts of the abrupt changes inherent in the Kondolf hydrographs. Results were presented for the "spring rise and pulse flows", "summer base flow" and "fall run attraction flow" for various year types. A Friant-Kern bypass to the river option was evaluated to evaluate effects of conserving the cold waters of Millerton Lake during the spring pulse flows.

This report documents the level of accuracy of the model which is considered the first step in evaluating this difficult and complex problem. The results presented in this report show that the model has the potential of accomplishing that goal. Issues such as temperature impacts of ground water interflow, ill defined point inflows, accretions and depletions remain to be addressed

RECOMMENDATIONS

Based on the findings of the temperature modeling, the model did provide quantitative results in estimating the flow and temperature relation along the San Joaquin River. However, the model is considered preliminary and further calibration and sensitivity are indicated.

Without temperature objectives and Millerton Lake operation criteria, it will not be easy to characterize the benefits of the temperature model. Some issues to consider regarding future reservoir operational needs are:

- Determining how to balance the spring high flows requirement for migrating adults and juvenile spring run Chinook salmon with the cold water pool maintenance in Millerton Lake for adults that remain in the river during the summer before spawning in the fall.

- Evaluating whether adult fall-run Chinook can migrate upstream to Reach 1 between mid October and mid December under base flow conditions.

- Evaluating how groundwater inflows interact with the stream between Reach 4 and 5.

- Determining water-year types and the timing of the restoration flows consistent with the hydrograph release.

- Determining if the level of flood release meets the restoration flow hydrograph release made in accordance within Settlement flow objectives.

The following efforts are recommended for improving the temperature modeling:

Short-term effort:

- Calibrate model to 2007 data - this task permits the model to have a better hydrologic cycle calibration (2005 and 2006 were wet years).

- Extend the restoration flow period of analysis to 1980 through 2006 to include critical dry through wet years.

- Develop release temperature response algorithm and embed with CALSIM. This task will enhance the temperature/operational modeling capability of the San Joaquin River.

- Evaluate use of the Madera Canal and /or Friant-Kern Canal alternatives of providing spring and summer discharge to conserve cold water pool.

Long-term effort:

- Continue field monitoring program and data collection. This information is of critical necessity to update and improve the model.

- Incorporate groundwater monitoring/modeling information from Reach 4 and 5 into the HEC-5Q model. This effort will help us understand if the pockets of water with suitable temperature can be established throughout the river under base flow conditions, whereas high flow may disrupt those pockets.

- Work with fishery biologists to define the temperature suitability for both the spring and fall-run salmon.

TABLE OF CONTENTS

List of Tables

LIST OF FIGURES

(NOTE: FIGURES ARE LOCATED AT THE END OF EACH SECTION)

1 INTRODUCTION

During the past decade, numerous scientific and technical investigations have been conducted to evaluate potential opportunities and constraints on the San Joaquin River system. In 2005, the San Joaquin River Riparian Habitat Restoration Program (SJRRHRP) recognized the need to develop a water temperature model for Millerton Lake and the San Joaquin River. Initially, two models were developed, the lake model (CE-QUAL-W2) and the river model (HEC-5Q).

These two models were used to evaluate the thermal regime and flow relation of Millerton Lake and the San Joaquin River. This development is noted as the Upper San Joaquin Temperature Model development. The calibration of both models (based on the error statistics presented in Chapter 3) appears to represent the thermal responses of the lake and river during the limited calibration period. The two models were also used to analyze the Kondolf Hydrographs. Two individual expert reports were produced based on the modeling results.

In the 1990s, under a collaborative effort proposed by the stakeholders, a Stanislaus Water Temperature Model was developed. This model included the New Melones Reservoir, Tulloch Reservoir, Goodwin Pool, and approximately 60 miles of the Stanislaus River from Goodwin Dam to the confluence with the San Joaquin River. Beginning in 2002, CALFED sponsored (initial contract and subsequent contract amendments) projects to extend the model to the lower San Joaquin River downstream of Stevinson and north to Mossdale. Currently, the CALFED model includes the Tuolumne and Merced River systems downstream from Lake Don Pedro and Lake McClure, respectively. The CALFED project is ongoing and the model is considered preliminary in that final calibration has not been completed.

The upper San Joaquin HEC-5Q river model only modeled the geographic area from downstream of the Friant Dam to the confluence of the Merced River. In 2006, the SJRRHRP decided to expand its river temperature modeling scope to include the confluence of the Stanislaus River and other tributaries of the San Joaquin Basin. This was done to better understand the temperature and flow relation and the thermal connectivity of the main-stem San Joaquin River and its tributaries. The upper San Joaquin temperature model and the CALFED temperature model use the same HEC-5Q model. Creating a connected San Joaquin River basin-wide temperature model is accomplished by incorporating the existing HEC-5Q CALFED model sections.

1.1 PURPOSE

The Upper San Joaquin and the Lower San Joaquin Temperature Model linkage will provide an opportunity to evaluate the temperature interactions of the various tributaries of the San Joaquin Basin. The objective of the integrated model is to provide a modeling tool to assess thermal impacts of reservoir operations basin-wide and aid in the establishment of temperature objectives.

1.2 SITE DESCRIPTION

The Stanislaus River and the lower San Joaquin River (HEC-5Q) application compute the distribution of temperature in the reservoirs and in the stream reaches. The model's geographical area includes: (1) New Melones Reservoir, Tulloch Reservoir, Goodwin Pool, and approximately 60 miles of the Stanislaus River from Goodwin Dam to the confluence with the San Joaquin River; (2) Lake Don Pedro and La Grange Reservoir and approximately 47 miles of the Tuolumne River from La Grange Dam to the confluence with the San Joaquin River; (3) Lake McClure, Lake McSwain, Merced Falls and Crocker-Huffman Reservoirs and approximately 52 miles of the Merced River from Crocker-Huffman Dam to the confluence with the San Joaquin River; and (4) approximately 78 miles of the San Joaquin River from the Old River bifurcation north of Mossdale to Stevinson located south of the confluence with the Merced River. A schematic representation of the HEC-5Q model of the Lower San Joaquin system is shown in Figure 1-1. An integrated San Joaquin basin-wide model is shown in Figure 1-2.

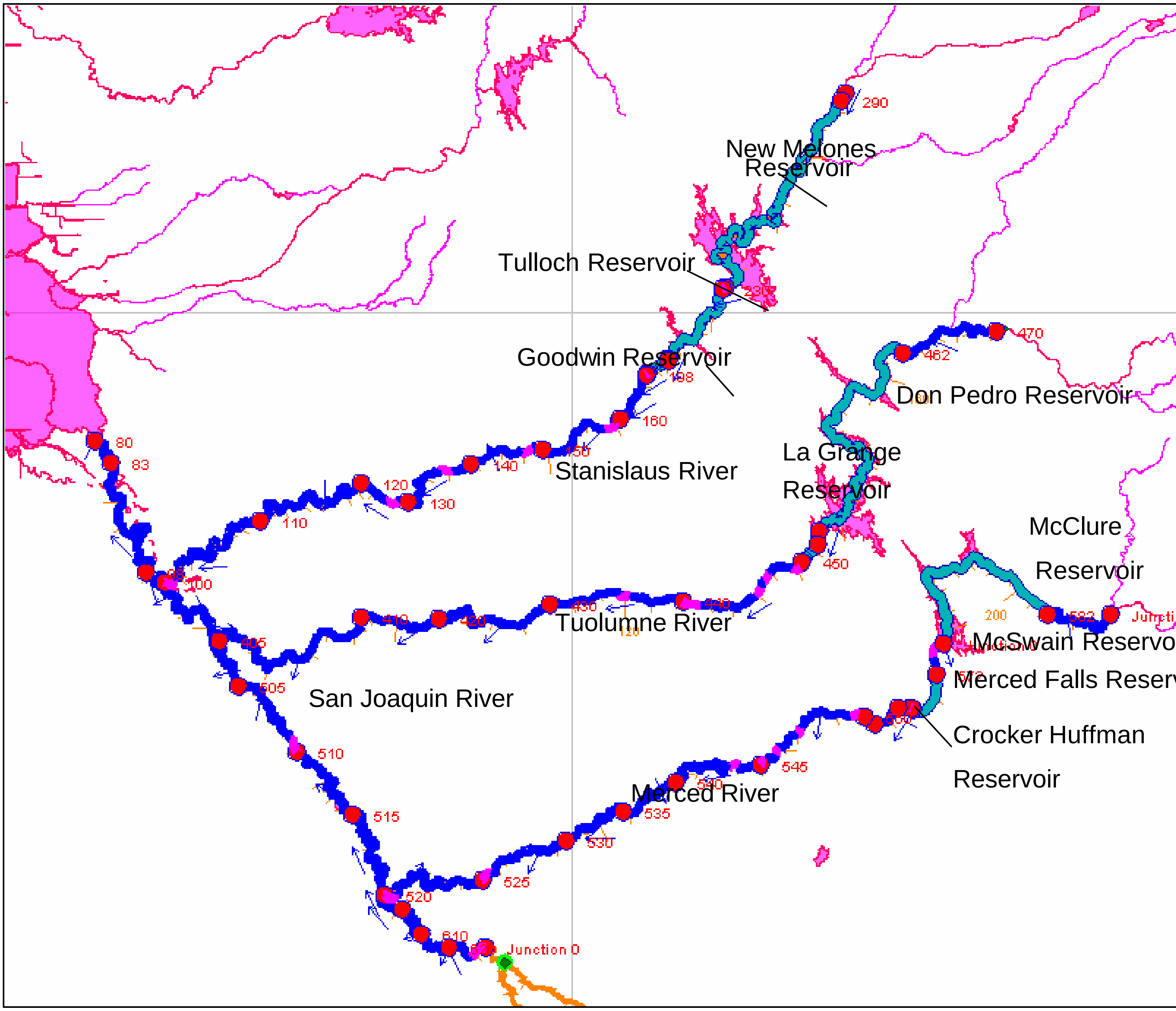

Figure 1-1 Schematic of HEC-5 model of the Stanislaus/Tuolumne/Merced River system

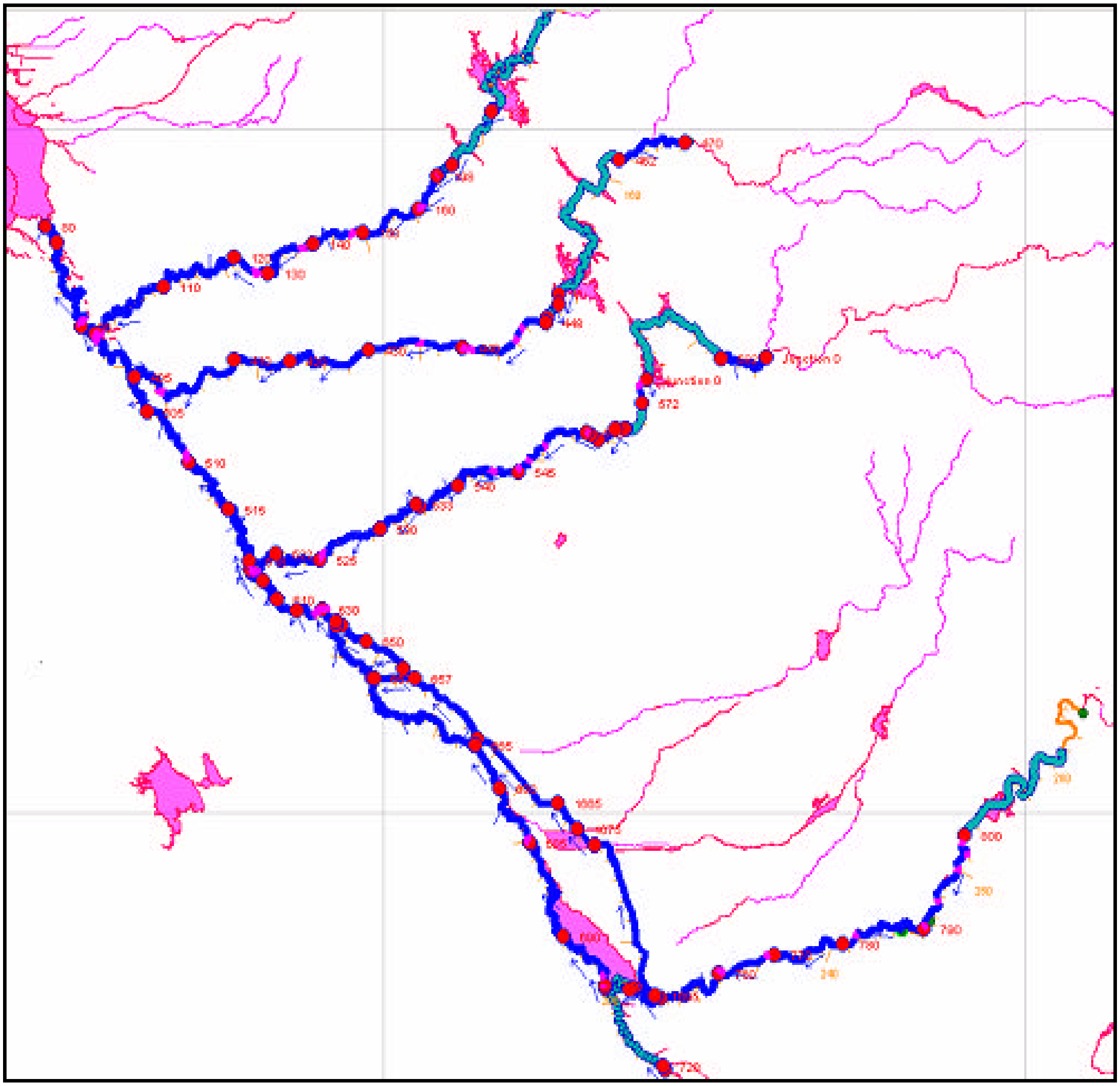

Figure 1-2 Schematic of HEC-5Q San Joaquin Basin-wide model

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 River computes the vertical or longitudinal distribution of temperature in the reservoirs and longitudinal temperature distributions in stream reaches based on daily average flows.

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. 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.

The HEC-5Q model used in the San Joaquin River analysis utilized only temperature and the conservative tracer (for mass continuity checking). A brief description of the processes affecting these two parameters is provided below. The HEC-5Q users manual (HEC, 2001a) provides a more complete description of the water quality relationships included in model.

<u>Temperature</u>

The external heat sources and sinks 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 affects 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.

<u>Conservative parameter/tracer</u>

The conservative parameter is unaffected by decay, settling, uptake, or other processes, and thus can act 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

River sections and reservoirs are represented in the model as a network of discrete segments (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 computed. 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 is 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.

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, Millerton Lake was geometrically discretized and represented as a vertically segmented water body with layers approximately two feet thick. Model time steps were six hours. A description of the different types of reservoir representation follows.

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.

For the San Joaquin River application, the Millerton Lake existing conditions incorporated into HEC-5Q include:

1) The low-level river outlet at elevations 264 feet
2) Madera Canal outlet at elevation 436 feet
3) Friant-Kern Canal outlet at elevation 456 feet
4) The spillway for use at elevations greater than 570 feet

<u>Longitudinally Segmented Reservoirs</u>

Longitudinally segmented reservoirs are represented conceptually as a linear network of a specified number 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. Hence, the thickness of each element varies with the width versus elevation relationship for each element.

In defining the vertical resolution (i.e., the number of layers) one should consider the stratification characteristics of the reservoir; however, this representation is not intended for well stratified reservoirs. 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 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. Mendota Pool is an example of this type of reservoir representation.

2.3 MODEL REPRESENTATION OF STREAMS

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. A cubic polynomial curve fit of all input data provides a continuous relationship between flow and the hydraulic parameter defining each cross section. Cross-sections are defined at all control points and at intermediate locations where data are available. Element lengths typically range from a few hundred feet to several thousand feet.

The flow versus depth relation is developed external to HEC-5Q using available cross-section data and appropriate hydraulic computations. For the San Joaquin River model, hydraulic characteristics were defined at all element boundaries and often represent several measured cross sections. All of the cross section data within the stream reach are considered. The equivalent cross section is developed by integrating a cubic polynomial curve fit of the cross section data for each flow in the rating table over the length of the element.

This process assumes that the input hydraulic characteristics represent the channel over the range of hydraulic conditions. For the San Joaquin River and bypasses, the Corps Comprehensive study data set was used. This detailed data set incorporates all control structures, bridge restrictions and critical sections that control or restrict flow.

2.4 HYDROLOGIC AND TEMPERATURE BOUNDARY CONDITIONS

2.4.1 Hydrologic Conditions

HEC-5Q requires that flow rates and water quality be defined for all inflows. Available data were evaluated and processed to define all hydrologic inputs for an evaluation period of 1980 through 2005. The following flow assumptions were used for both model calibration and alternative evaluation:

Millerton Lake - Observed end-of-day storage, outflow rates (canals, spill and low level) and seasonal evaporation rates (and surface area) were used to compute total net inflow by mass balance.

San Joaquin River above Mendota Pool - Partial flow records for tributary stream Cottonwood and Little Dry Creek) and river gauge locations (Friant Dam, Donny Bridge, Skaggs Bridge and Gravelly Ford) were evaluated to develop estimates of time dependant inflows and seasonal depletions above Gravelly Ford. The total depletion was distributed within the model based on gauge data tendencies. Diversions to the Chowchilla Bypass were computed within the model as a function of river flow.

Mendota Pool to Sack Dam - Seasonal diversions form the Mendota Pool and at Sack Dam (Arroyo Canal) were developed from available flow records (e.g., San Joaquin River at Mendota 1999-2006 USGS). These demand assumptions, plus observed James Bypass (USGS) flows and computed San Joaquin River inflow (model) were used to compute the required Delta Mendota Canal flows by mass balance. The mass balance computation assumed a January 1 - February 15 maintenance drawdown of the Mendota Pool.

San Joaquin River below Sack Dam - Observed data at Stevinson (USGS), partial Bear Creek flow data, computed flow to the Eastside Bypass and below Sac Dam were used to compute net accretions/depletions considering flow attenuation consistent with routing coefficients used in the model.

San Joaquin River between Stevinson and the Merced River - Flow records for San Joaquin River at Stevinson and Newman, Mud and Salt Sloughs and the Merced River at Stevinson were used to compute net accretions and depletions for this section of the river. The flows from the two sloughs and other accretions dominate temperatures in this area during low San Joaquin River (at Stevinson) flows and are an important influence on temperature at moderate river flows.

Stanislaus, Tuolumne and Merced Reservoirs - Observed storage or elevation, seasonal evaporation rates and observed outflow (canals, power, flood control and spills) were used to compute net inflows to each reservoir by mass balance.

San Joaquin River and Tributaries - Major tributaries (Dry Creek on the Tuolumne and Merced) and net accretions and depletions were defined based on available gauge data and flow attenuation consistent with routing coefficients used in the Model.

2.4.2 Temperature Boundary Conditions

For temperature boundary conditions, composite relationships were developed that considered meteorology (equilibrium temperature), flow rate (observed or computed from reservoir and stream gauge mass balances), and a seasonal temperature distribution. The seasonal temperatures are designed to represent high flow conditions that cannot be determined by meteorological conditions (e.g., elevated flows due to snow melt and dam releases).

At high flows, the inflow temperature has a seasonal bias. An example of an inflow with a large potential seasonal bias would be inflow originating in the Sierras. In early spring, the seasonal temperature would represent the temperature of snow melt from lower elevations. Later in the spring, the travel distance and time for higher elevation snowmelt would result in higher seasonal temperature. As air temperatures rise, the rate of snow melt increases with little change in temperature at the inflow location. The seasonal temperature requires the consideration of time in the stream channel and the associated heating. The seasonal temperature distribution may also include effects of upstream storage. In this case, the seasonal temperature should represent high flow releases from those reservoirs. As flow rates decrease, the meteorology (equilibrium temperature) dominates the inflow computation. Flow rate also influenced the diurnal variation with a large range of inflow temperatures at lower flows and shallower water depths.

Limited current temperature data were available for Millerton Lake inflows. The dominant inflow to Millerton Lake is from Kerckhoff Powerhouse, for which temperature and flow data are available from 1960 through 1974. Kerckhoff Powerhouse temperature data for 2005 were influenced by lake back water effects and were judged to not necessarily represent the inflow. Therefore, Millerton Lake inflow temperature relationships were developed using the 1960 through 1974 Kerckhoff Powerhouse data.

For the Millerton Lake inflow relationship, the seasonal distribution represents high flows due to snow melt and upstream system operation. The computed Millerton inflow temperatures for each year during the 2000 through 2005 period and the daily average of the 1960 through 1974 observed Kerckhoff Powerhouse temperatures are shown in Figure 2-1. This approximation of the inflow temperature appears adequate, based on the accuracy of the model predictions of the Lake Millerton thermal regime for the 2003 through 2005 period.

Another example of the utility of this procedure is the computed temperature of the Merced River at Briceburg above Lake McClure. Figure 2-2 shows the correlation between computed and observed temperatures at six-hour intervals. A statistical analysis of the computed versus observed data yields a mean error or bias of -0.30^{o} F (-.17^{o} C), absolute mean error of 1.79^{o} F (1.0^{o} C) and root mean squared error of 2.26^{o} F (1.26^{o} C). A regression of the data computes a slope 0.993 with an R^2 value of 0.994. Each of these measures indicate an accurate representation of the observed temperatures

Similar relationships were developed for each tributary based on available (and limited) data. The temperatures of stream accretions (other than the interflow between the river and gravel pits or alluvial deposits - see chapter 3.2) were assumed equal to the ambient stream temperature.

2.5 METEOROLOGICAL DATA

For temperature simulation 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. Meteorological zones represent hourly data from the Modesto, Fresno and Kesterson California Irrigation Management Information System (CIMIS) stations for the period of 1999 - 2005.

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 six-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.

Six meteorological zones were used in the San Joaquin River model. 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. For reservoirs, wind speed was scaled up for the wide open exposed water surfaces. Reduced wind speed decreases the evaporative heat loss and results in higher equilibrium temperatures and lower heat exchange rates, and vice versa for increased wind speed. Shading reduces solar radiation resulting in lower equilibrium temperatures and lower heat exchange rates.

The meteorological data collected as part of this project were used in determining the heat exchange adjustments to the individual stream sections. Meteorological zones are listed and described in Table 1 and meteorological zones for each location in the model are listed in Table 2.

Table 1 Meteorological zone descriptions

Met Zone	CIMIS station	modifications
1	Fresno	Wind scaled x 1.5
2	Fresno	none
3	Kesterson	none
4	Modesto	none
5	Modesto	Wind scaled x 1.5
6	Modesto	Wind scaled x 0.8, riparian shading

Table 2 Meteorological zones used in the model

Location	Meteorological Zone
Millerton Lake	1
Mendota Pool	3
Lake McClure	5
McSwain Reservoir	5
Merced Falls Reservoir	5
Crocker Huffman Reservoir	4
Lake Don Pedro	5
La Grange Reservoir	5
New Melones Reservoir	5
Tulloch Reservoir	5
Goodwin Reservoir	4
San Joaquin River, Friant Dam to Mendota Pool	2
Bypass system components	2
San Joaquin River, Mendota Pool to Merced confluence	3
Merced River	4
Tuolumne River	4
Stanislaus River above New Melones	4
Stanislaus River below New Melones	6
San Joaquin River, Merced confluence to Old River	4

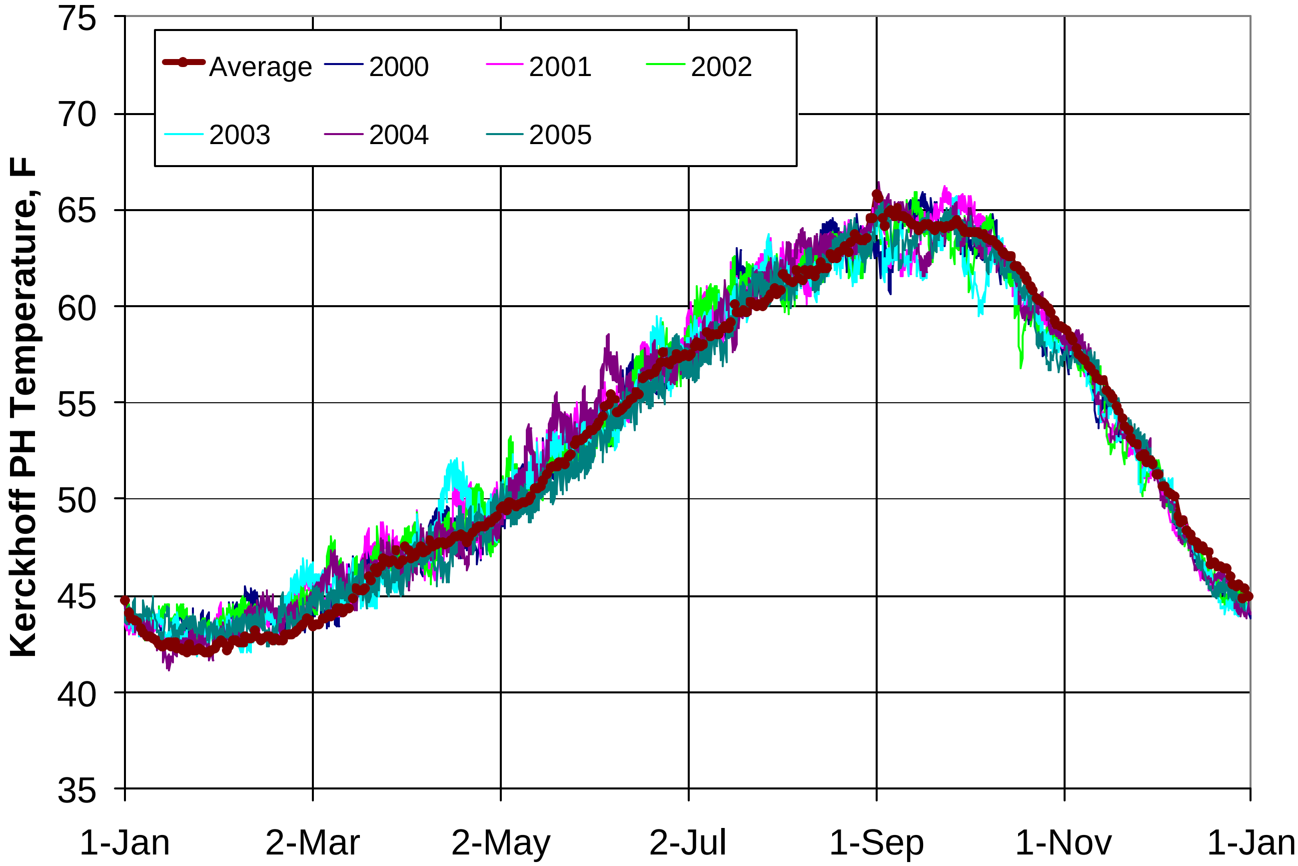

Figure 2-1 Kerckoff Powerhouse temperatures: individual years and overall average

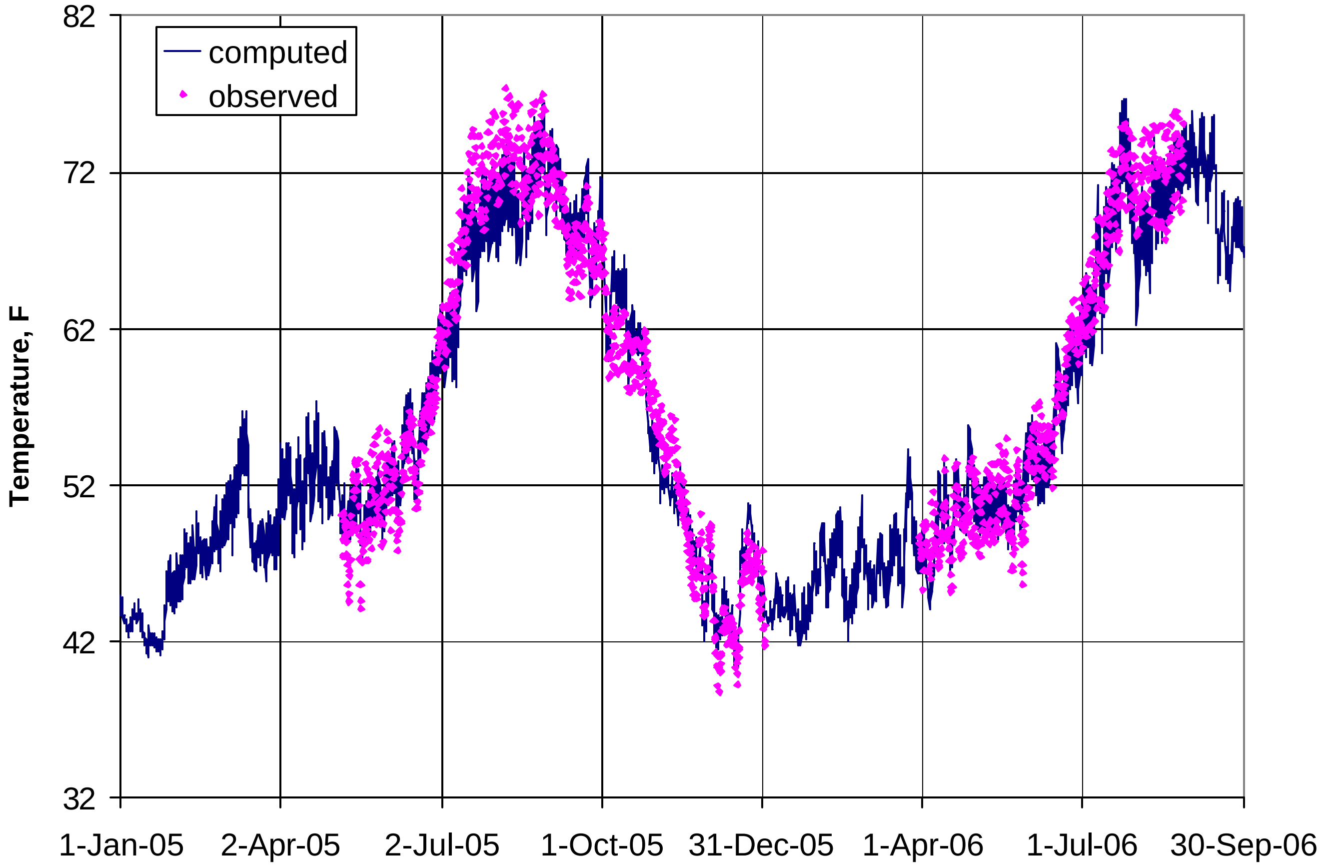

Figure 2-2 Computed and observed temperature in the Merced River at Briceburg (above Lake McClure)

3 MODEL CALIBRATION

The HEC-5Q model of the San Joaquin River system has been calibrated to 1999 through 2005 temperature time series data at numerous stream monitoring locations, and November 2002 through June 2005 Millerton Lake observed temperature profile data. These were the only data provided to date.

Model inputs include:

- 1999 through 2005 Fresno, Kesterson, and Modesto CIMIS meteorology data;
- 1999 through 2005 daily flows (Friant Dam releases to Friant-Kern Canal, Madera Canal and San Joaquin River); and
- 1999 through 2005 tributary stream inflow temperature data (relationships relating six-hour temperatures to flow, meteorology, and seasonal trends as discussed in section 2.4).

Model sensitivity and calibration variables include:

- Wind speed scaling to reflect environmental conditions;
- Riparian shading;
- Substrate interaction coefficients (river bottom heat transfer);
- Gravel pit/alluvial interflow assumptions;
- Groundwater interflow; and
- Scaling of cross section hydrologic parameters (HEC-RAS model based on COE Comprehensive Study data).

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

The intent of the model calibration exercise was to represent the thermal dynamics of the San Joaquin River system by minimizing the differences between the computed and observed data, so as to demonstrate that the model adequately represents the thermal responses of the prototype stream and reservoir system.

The dominant parameters governing the Millerton Lake thermal regime are inflow temperature and the level of withdrawal. Mixing and inflow entrainment coefficients that are related to the density structure within the lake control the internal heat dynamics. These coefficients were typical of those used for other deep well stratified California reservoirs.

For stream sections, parameters governing heat fluxes to the bottom were utilized to dampen diurnal variations. The rate of surface heat exchange was refined by minor adjustments to the equilibrium temperature designed to represent local environmental conditions.

All model representations, data processing procedures, factors and coefficients were held constant during each simulation without regard to water year type.

The results of the calibration effort are presented as tabular error indicators and as plots of computed and observed values using various formats. The final results of the calibration effort may also be viewed using the graphical user interface (GUI). The following sections provide a brief discussion of the calibration results for reservoirs and streams.

3.1 RESERVOIR TEMPERATURE CALIBRATION RESULTS

Calibration of the Millerton Lake model was completed by graphically comparing computed and observed reservoir vertical temperature profiles and by computing the mean error (bias), mean absolute error (MAE) and root mean squared error (RMSE) for each profile. The bias is the average difference between the simulated and observed temperature. A negative bias is an under prediction and a positive is an over prediction. The MAE is the absolute value of the error and determines overall model performance without positive and negative errors canceling. The RMSE is a test for extreme outliers. The results of the error analysis for all 58 profiles are listed by observation date in Table 3 and Table 4.

Table 3 lists the statistics for all measurements recorded during the months of October through March for all years. The separate analysis for the two periods was indicated by the magnitude of the bias which were slightly different between the winter and summer months. The average bias was -0.65^{o} F (0.36 ^{o} C) and appears to be due primarily to a colder computed hypolimnion during the winter of 2002-2003. The absolute bias exceeded 0.9^{o} F (0.5^{o} C) twenty-four percent of the time and exceeded 1.8^{o} F (1.0^{o} C) twice. The RMSE and MAE exceeded 1.8^{o} F sixteen percent and twelve percent of the time, respectively.

Table 4 lists the statistics for all measurements recorded during the months of April through September for all years. The average of the mean errors was 0.05^{o} F showing essentially no bias in the model for the well stratified summer period. The absolute bias exceeded 0.9^{o} F once (three percent of the time) and never exceeded 1.8^{o} F. The MAE exceeded 0.9^{o} F thirty-three percent of the time but never exceed 1.8^{o} F. The RMSE exceeded 1.8^{o} F fifteen percent of the time.

From a dam release perspective, the hypolimnion temperatures is important since the river release port draws from this region except during very low reservoir elevations. The model consistently computes temperatures within 1.8^{o} F (1^{o} C) at the elevation of the river outlet.

The results are illustrated in Figures 3-1 through 3-7 for various dates between November 2002 and June 2005. The simulation period began in January 1999, so there is little likelihood that initial conditions impacted these results. Plot dates were selected at intervals of one month or less to demonstrate the seasonal progression of the thermal structure. All reservoir profile plots elevations are based on sea level datum. The elevation and temperature scale is uniform throughout to aid in comparing model performance on a consistent scale.

Observed profile data represent one or more locations in the reservoir. The largest variations between lake data locations occur during the spring 2005 high runoff period (Figures 3-6 and 3-7) where there are small differences at the surface. The fact that there is essentially no difference at depth confirms that the 1-D approximation used in the model is appropriate for computing river release temperature.

Figures 3-1 and 3-2 show the results for winter 2002-2003. The model initially under predicts the depth of the thermolcline, but accurately computes the observed location by March 28, 2003. The surface temperatures are up to 2^{o} F warmer in November and December but are within 1^{o} F for the remainder of the winter months. The predicted hypolimnion temperatures are uniformly cooler prior March 28, 2003. The March 2003 profile is well represented by the model except for a slightly warmer epolimnion.

Figures 3-3 and 3-4 show the computed and observed temperatures for the remainder of 2003. The model does a reasonable job of reproducing the double thermocline structure resulting from the reservoir release patterns. During April through August 2003, releases totaled 838,000, 219,000 and 71,000 acre-feet for the Friant-Kern Canal (outlet at 456 feet), Madera Canal (outlet at 436 feet), and to the river (outlet at 380 feet) respectively. The average residence time (computed as the average outflow/reservoir capacity) was approximately 56 days. The two canal withdrawals (ninety-three percent of the total outflow) control formation of the lower thermocline. Releases to the river at elevation 380 feet average only 290 cfs. The top of the cold water pool is gradually drawn down throughout the year, but the cold water at the bottom does not get depleted.

Figure 3-5 shows computed and observed temperature profiles for all available dates in 2004. The model reproduces the observed thermal structure in June and July. The computed thermocline is slightly higher than observed in October. In November, the computed profile is in agreement with the data at the reservoir location. The observations labeled “suspect data”. There are no other periods where profiles exhibit such a variation with lake locations. We know of no environmental factor such as hydrology, meteorology or unusual reservoir operation that would explain such a variation and we suspect data error.

Computed and observed temperature profiles are shown in Figures 3-6 and 3-7 for all available dates in 2005. The model reproduces the observed profile data for each of these dates in April, May and June. Variations in the near surface water between profile locations indicate some longitudinal variation. On June 24, 2005, a maximum longitudinal variation of approximately 5^{o} F is observed in the data.

On this date, the Millerton inflow and outflow was approximately 9,000 and 4,000 respectively, which translates to a hydraulic residence time of approximately 25 days. The absence of any significant longitudinal variation in hypolimnion temperature observations ($<1^{o}$ F at the river outlet elevations) indicates the 1-D assumption is consistent with the model objective of computing river discharge temperatures.

A different thermal structure was present during 2005 because it was a very wet year and dominated by large inflows. During April through August 2005, releases totaled 1,172,000 321,000 and 606,000 AF for the Friant-Kern Canal, Madera Canal and to the river, respectively. The average residence was only 30 days. Although the two canal withdrawals accounted for seventy-one percent of the total outflow, river outlet volume exceeded the total capacity of Millerton Lake and rapidly depleted the cold water pool below the canal outlet elevations. The high flow through rate completely eliminated the double thermocline. The thermocline location and hypolimnion temperatures are well represented by the model on each of the sampling dates, indicating the inflow temperature algorithm is accurate under these high runoff conditions.

Table 3 Millerton Lake model calibration accuracy expressed as Mean (Bias), Mean Absolute Error and RMS Error for the 23 sampling events during the months of November through March of all years

Location	Values	Mean error (F)	Mean absolute error (F)	RMS error (F)
1-Nov-02	127	-0.44	1.37	1.59
8-Nov-02	133	-1.43	2.21	2.75
15-Nov-02	128	-0.52	1.29	1.40
22-Nov-02	140	-0.78	1.38	1.59
29-Nov-02	131	0.03	1.35	1.49
6-Dec-02	131	-0.63	1.15	1.34
13-Dec-02	140	-0.36	1.06	1.16
20-Dec-02	140	-1.87	1.87	2.06
27-Dec-02	140	-1.75	1.75	1.93
3-Jan-03	137	-0.61	0.79	1.00
10-Jan-03	140	-0.92	0.92	1.29
17-Jan-03	52	-0.82	0.89	1.11
24-Jan-03	144	-0.87	0.89	1.11
31-Jan-03	143	-0.93	0.93	1.04
7-Feb-03	148	-0.43	0.82	0.97
14-Feb-03	152	-0.58	0.78	0.91
21-Feb-03	160	-0.54	0.85	0.91
28-Feb-03	159	-0.33	0.63	0.65
7-Mar-03	160	-0.24	0.57	0.60
14-Mar-03	156	-0.05	0.67	0.86
21-Mar-03	159	-0.04	0.66	0.85
28-Mar-03	161	-0.03	0.53	0.68
16-Nov-04	28	0.18	0.37	0.51
3-Oct-03	83	-0.43	0.84	1.00
1-Oct-04	58	-1.84	1.84	2.16
Average		-0.65	1.06	1.24

Table 4 Millerton Lake model calibration accuracy expressed as Mean (Bias), Mean Absolute Error and RMS Error for the 35 sampling events during the months of April through October of all years

Location	Values	Mean error (F)	Mean absolute error (F)	RMS error (F)
4-Apr-03	160	-0.19	0.63	0.71
11-Apr-03	160	0.05	0.80	1.08
18-Apr-03	161	0.06	0.76	1.10
25-Apr-03	160	0.08	0.66	0.99
2-May-03	158	0.03	0.66	1.14
9-May-03	139	-0.04	0.57	0.84
16-May-03	161	0.24	0.75	1.01
23-May-03	191	0.21	0.65	0.86
30-May-03	166	0.48	0.73	1.01
6-Jun-03	168	0.23	0.73	0.92
13-Jun-03	178	-0.36	0.77	1.08
20-Jun-03	180	0.14	0.63	0.94
27-Jun-03	177	0.30	0.73	1.13
3-Jul-03	181	0.37	0.84	1.08
11-Jul-03	166	0.69	1.02	1.32
18-Jul-03	154	0.49	1.00	1.35
25-Jul-03	171	0.32	0.87	1.05
1-Aug-03	159	0.96	1.28	1.96
8-Aug-03	150	0.38	0.93	1.13
15-Aug-03	142	-0.51	0.80	1.09
22-Aug-03	133	-0.67	0.87	1.29
29-Aug-03	143	0.00	0.78	0.96
5-Sep-03	117	0.11	0.94	1.32
12-Sep-03	118	-0.78	1.08	1.37
19-Sep-03	110	0.21	1.13	1.51
26-Sep-03	111	-0.39	0.77	0.93
21-Jun-04	178	0.35	0.85	1.17
2-Jul-04	196	-0.25	0.79	1.09
5-Apr-05	78	0.05	0.66	1.08
22-Apr-05	67	-0.33	1.22	2.22
12-May-05	76	0.01	0.96	1.87
3-Jun-05	77	-0.40	1.13	2.11
24-Jun-05	83	-0.02	1.21	1.81
Average		0.05	0.85	1.23

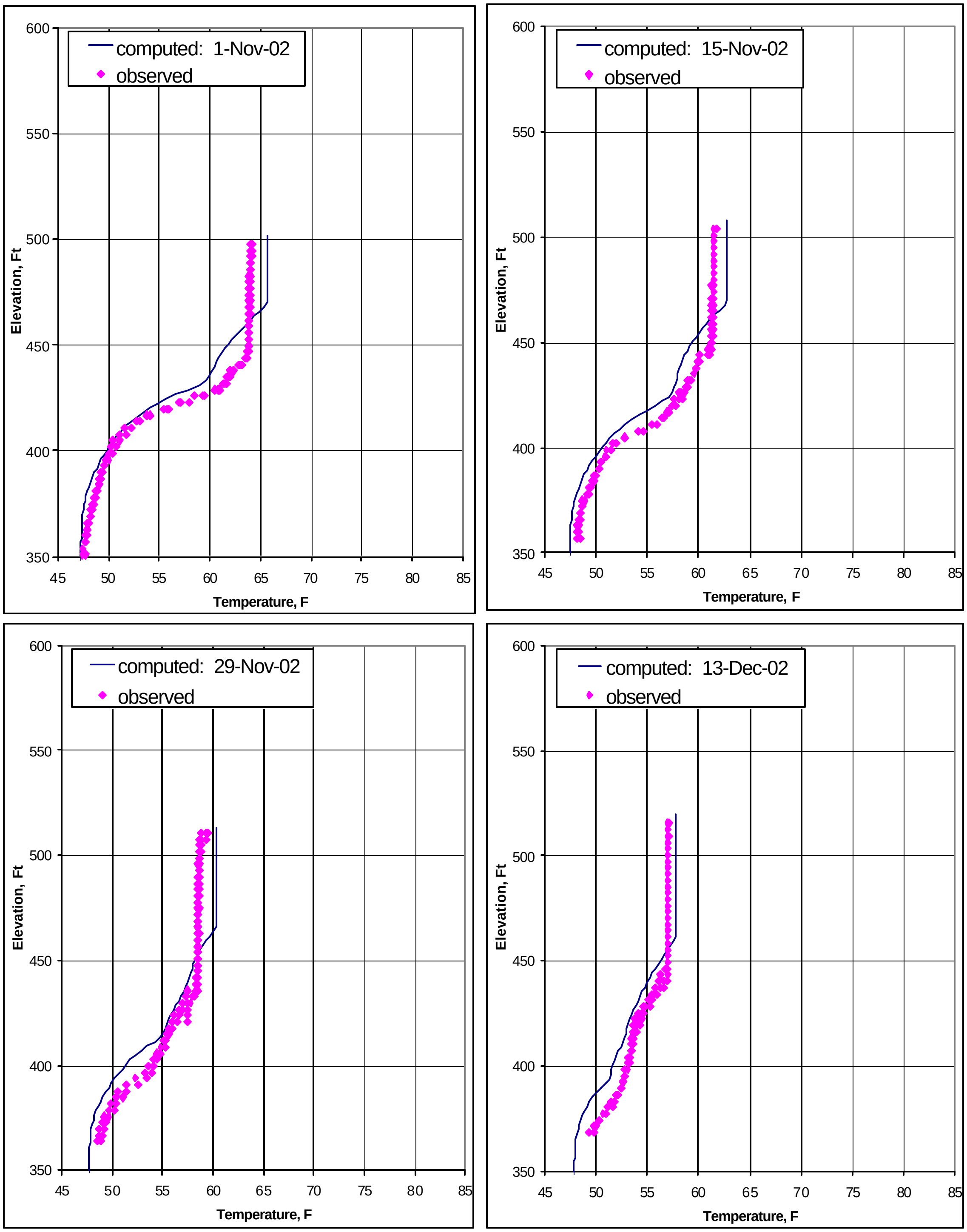

Figure 3-1 Millerton Lake computed and observed temperature profiles for November and December 2002

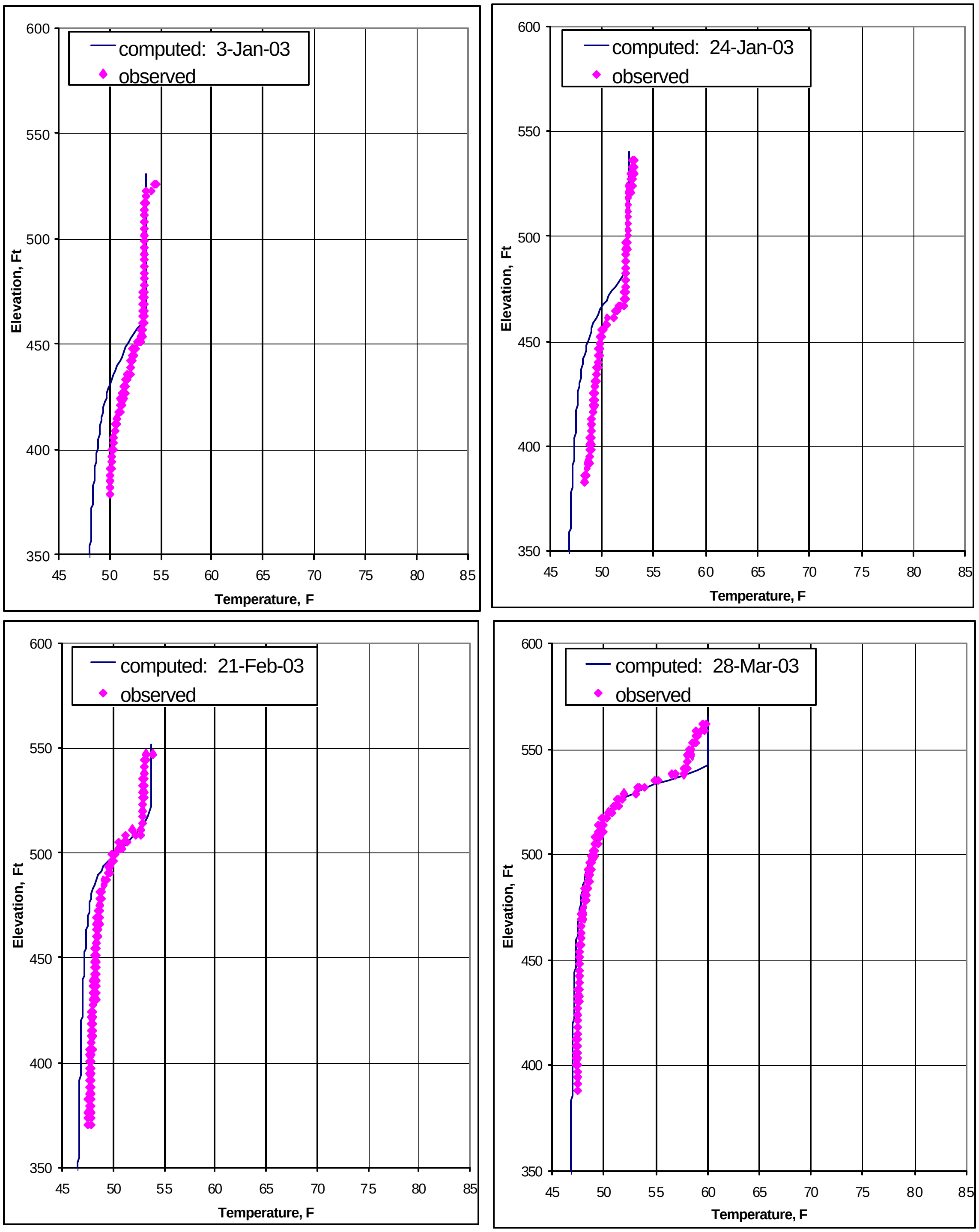

Figure 3-2 Millerton Lake computed and observed temperature profiles during January through March 2003

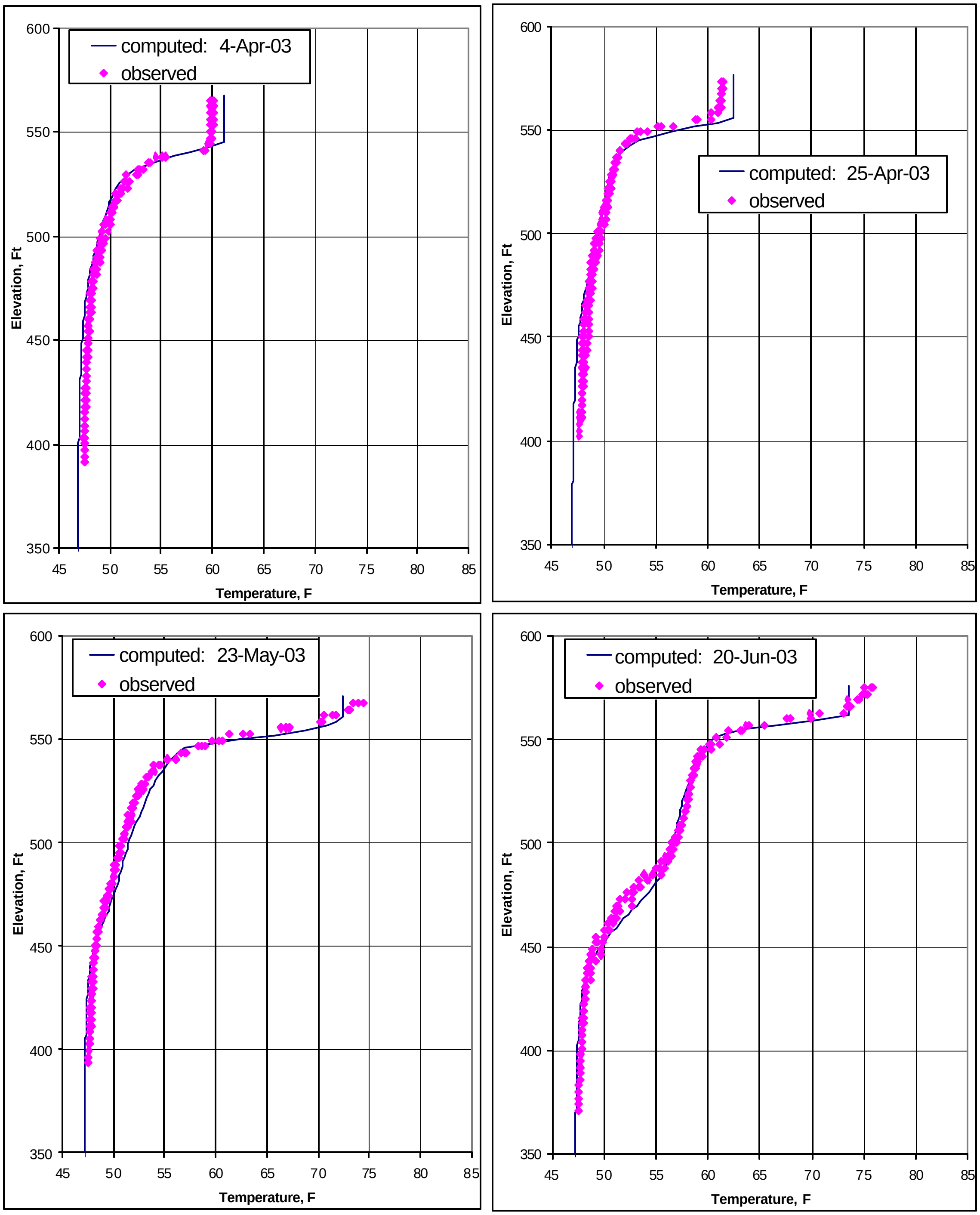

Figure 3-3 Millerton Lake computed and observed temperature profiles during April through June 2003

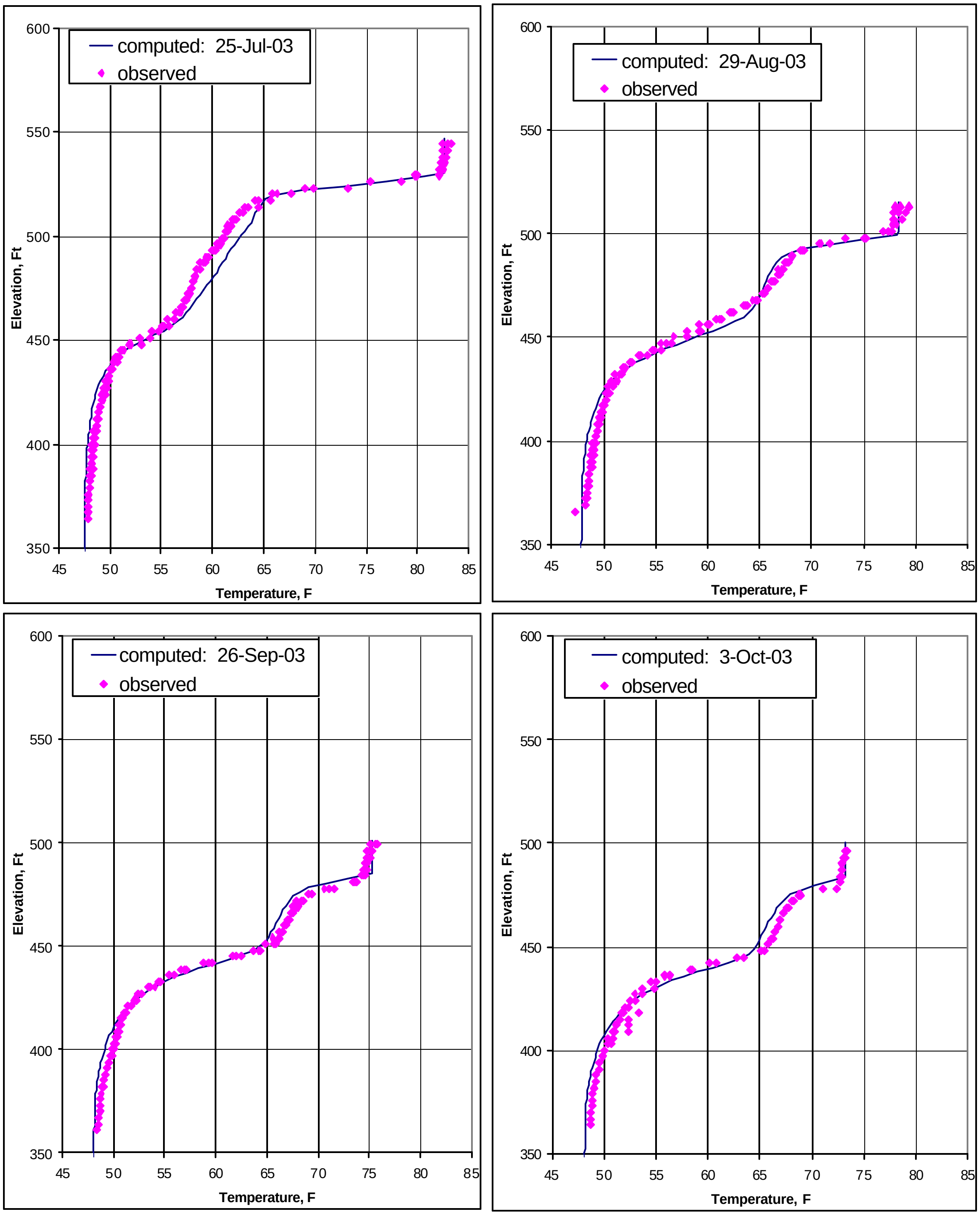

Figure 3-4 Millerton Lake computed and observed temperature profile during July through October 2003

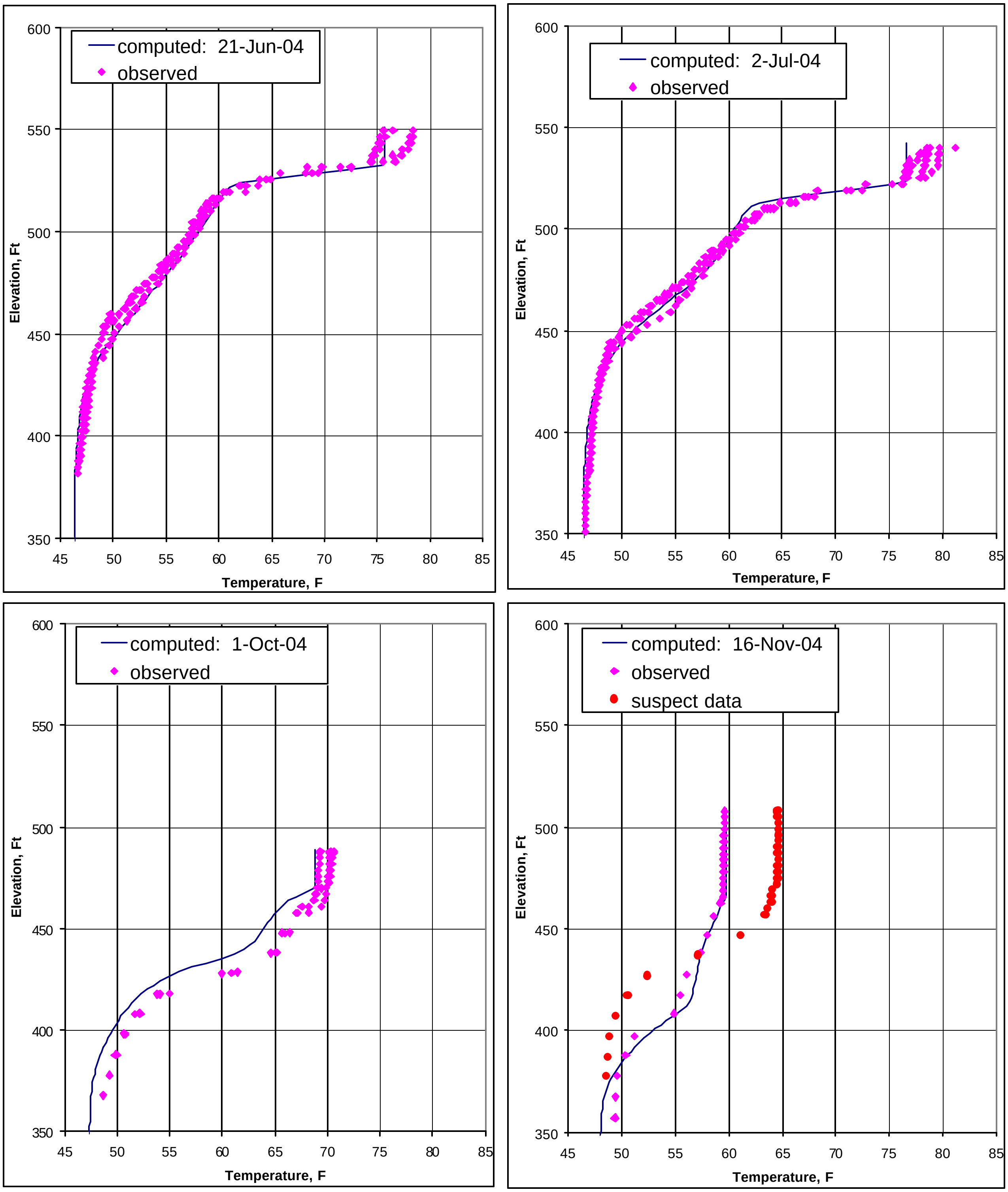

Figure 3-5 Millerton Lake computed and observed temperature profile during 2004

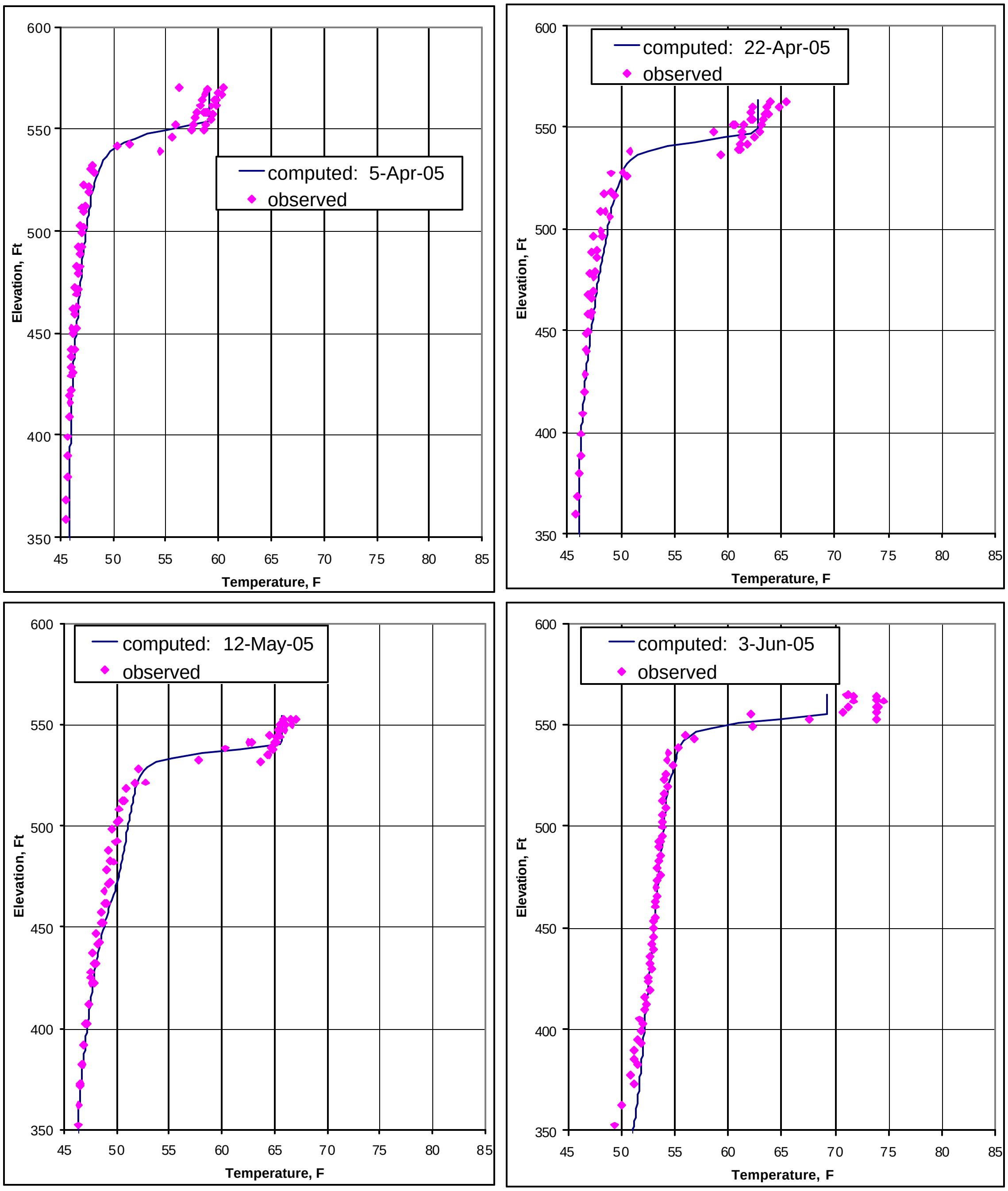

Figure 3-6 Millerton Lake computed and observed temperature profiles during April through June 3, 2005

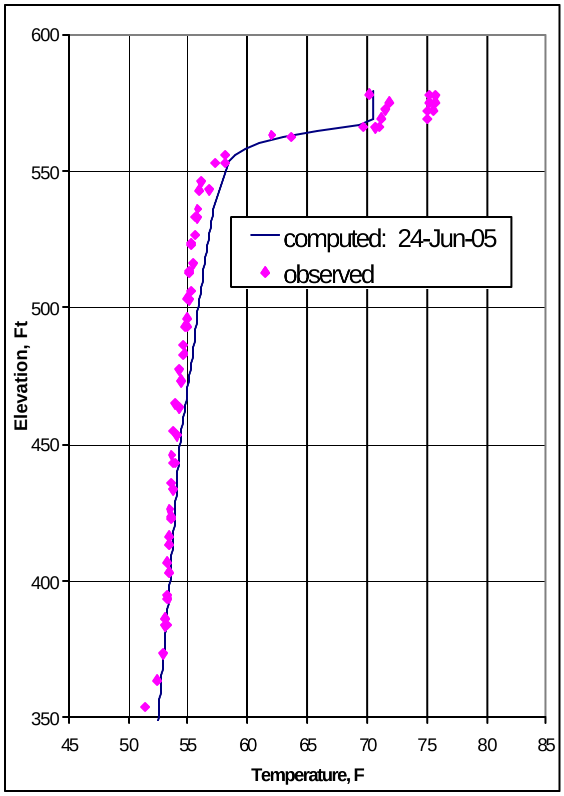

Figure 3-7 Millerton Lake computed and observed temperature profiles for June 24, 2005 (last available profile)

3.2 STREAM TEMPERATURE CALIBRATION RESULTS

Preliminary temperature calibration simulations showed the model was not producing elevated stream temperatures that were observed at some locations on falling hydrographs during June and July of 2005. The rapid flow changes resulted from flood control operation at Friant Dam (see Figure 3-8). The temperature effect was identifiable as the dam release dropped below a few hundred cfs.

It was postulated that these elevated temperatures were the result of interflow between the river and gravel pits and/or alluvial deposits. During periods of high river flow, river water flows into the alluvial deposits and to open gravel pits through pervious levees. As the river water levels fall, water that is stored and heated in the gravel pits and alluvial deposits flows back into the river.

To represent this phenomenon in the model, three square miles of offline storage area was added to the model near Highway 41. The offline storage is in addition to the normal channel area that attenuates flows in a dynamic hydrology environment. Although this approach utilizes a hypothetical offline storage area, there are regions of the river (see Figure 3-9) where lateral interflow is certainly a factor in hydrograph attenuation.

The actual channel and adjacent pit configuration is complex and would be a challenge to model rigorously (e.g., multi-dimensional coupled stream-pond-groundwater model). This model representation is in lieu of the rigorous approach (which is beyond time and budget constraints) and was intended to assess the potential thermal ramifications of offline storage interflow. A plot of the hypothetical interflow is shown in Figure 3-10. The interflow must be pre-computed and would be included in the normal pre-processing of alternative operation scenarios.

The temperature of the returning water was computed by the model using the same heat exchanged parameters that were used in the adjacent stream channel. However, subsequent analysis indicated temperature of the returning water may be adequately approximated based on meteorology and flow using an approach similar to that used to compute point inflows. The return flow would be considered a variable line source distributed based on the physical environment.

To show model sensitivity to interflow, examples of computed San Joaquin River temperatures with and without the interflow are shown in Figure 3-11 at Highway 99 and Figure 3-12 at Gravelly Ford, eight and twenty-four miles downstream of the off line storage return, respectively. The observed data at Gravelly Ford are included to demonstrate that inclusion of model interflow results in improved representation of the temperature spikes that coincide with the abrupt flow decreases that occurred in June and July 2005.

It is important to note that only an off-line storage/interflow module near Highway 41 was included to evaluate sensitivity using this hypothetical model. It is likely that interflow occurs at many locations and could be an important phenomenon impacting temperatures in the lower part of the river. The mid-July Gravelly Ford results suggest that additional offline storage would further improve the calibration.

Calibration of the San Joaquin River model was completed by graphically and statistically comparing computed and observed river temperature time series. Stream calibration data locations are shown in Table 5 along with the number of observed values, Mean Error (bias), MAE and RMSE at each location. The bias is the average difference between the simulated and observed temperature. A negative bias is an under prediction and a positive is an over prediction. The MAE is the absolute value of the bias and determines overall model performance without positive and negative errors canceling out. The RMSR is a test for extreme outliers.

Given that the inclusion of offline storage was not well received by some stakeholders and report reviewers, the decision was made to show results from the calibrated model without offline interflow. However, significant improvement in the error statistics is achieved if interflow is considered. Referring to Table 5, the sample weighted bias for the Gravelly Ford, transect number 10 and the bifurcation during spring and summer 2005 was -1.11^{o} F. With interflow the bias was reduced to -0.61^{o} F or forty-five percent. The MAE and RMSE were reduced twelve percent and sixteen percent respectively.

The top half of Table 5 lists the statistics for the entire simulation period while the bottom half are for the period of March 16 through July 15, 2005 only. The March 16 through July 15, 2005, period is isolated to assess the model performance during periods of higher flow when the outflow from Friant Dam has a greater influence on river temperature.

To further quantify model performance during periods when Friant Dam releases have greater influence on river temperatures, error statistics for days when Friant Dam releases exceed 250 and 300 cfs are listed on Table 6. Minimum Friant Dam release rates under settlement flow conditions is 350 cfs for dry and wetter year hydrology. Therefore, these error statistics are an indicator of model accuracy for alternative operation evaluation.

The largest bias, MAE and RMSE (at flows > 250cfs) are computed for Skaggs Park. Possible reasons for the poor model performance are included with the discussion of Figure 3-30. There is a negative bias in the computed temperatures above Mendota Pool and positive bias below (excluding the bias below Mendota Dam). Table 7 lists the weighted error statistics (weighted by the number of measurement at each location) above and below Mendota Pool for the entire record, spring of 2005 and for Friant Dam flows greater than 250 cfs. Neither the Mendota Dam nor the Skaggs Park data were included in these error statistics.

The sample number weighted MAE and RMSE indicate the model is most accurate in the river segment below Friant Dam. The magnitudes of the errors appear somewhat more dependant on flow above Mendota than below. There is very little variation in the MAE and RMSE below Mendota for the various data categories. The uniformity of error statistics below Mendota is to be expected since river temperatures are near equilibrium with the atmosphere and subject of meteorological data approximations.

Temperatures below Mendota are also more dependant on inflow temperature rather than influenced by Friant Dam release flows and temperatures. The average ratio of the RMSE to the MAE for all stations and periods is approximately 1.25, indicating there are no prolonged periods where the computed temperatures diverge dramatically from the observed.

The graphical results are illustrated in Figures 3-13 through Figure 3-31 for periods during 2000 through 2005 when data are available. Overall, the time series plots show that overall, a resonable representation of the average temperatures, diurnal variation, and daily and seasonal variation is achieved at each location.

Figure 3-13 shows computed and observed temperatures in the San Joaquin River below Friant Dam. Observed temperatures during 2004 are approximately 1º F higher than observed, while 2005 temperatures are nearly identical and confirm that the Millerton Lake/Friant Dam model adequately represents outflow temperatures.

Figures 3-14 and 3-15 illustrate computed and observed temperatures in the San Joaquin River at Friant Bridge, located less than one mile below Friant Dam. Figure 3-15 shows the temperature during the spring and early summer of 2005 to more clearly reveal the inter relationship between flow (see Figure 3-8) and reservoir volume constraints and river temperature dynamics. The observations that correspond to Friant Dam release rates exceeding 250 and 300 cfs are highlighted in Figure 3-14. The model accurately represents the observed temperatures through the spring of 2004. During the summer of 2004, the model computes lower temperatures with less diurnal variation (1 to 2^o F).

The large diurnal variation seen in the observed data suggests that the flow computations (described in section 2.4.1) may produce unrealistically low flows during this period or that there is a bias in the Fresno CIMIS meteorology for 2004 (which is unlikely). The temperature response during 2005 is very well represented. The observed temperature spikes are larger than computed. The interflow phenomenon discussed earlier, which was not represented in the model at this location, is the possible contributor to the under prediction. The temperature spike in June 2003 is also well represented indicating that the Millerton Lake model produces realistic temperatures under spill conditions.

During periods of high reservoir inflow such as spring 2005, water in excess of the lake flood control limits and the Friant-Kern and Madera Canals demands is discharged to the river. The resulting high flow through rate results in shorter residence time in Millerton Lake. Therefore, water temperatures below Friant Dam are a function of Millerton Lake inflow temperatures once the cold water volume below the canal outlets is depleted. The relatively rapid increase in temperature from mid May through mid June of 2005 shows the response of release temperatures due to depletion of the cold water pool within the lake. The response of the reservoir thermal regime to high flow rates can be seen in Figures 3-6 and 3-7 as previously noted.

During this period, the majority of the flow to the river utilized the low level outlet with only short periods of spill. Spills access warmer surface waters and increase river temperatures; however, spill decreases the rate of cold water depletion that resulting from the use of the low level outlet. The effect of spillway usage on river temperature can be seen at other downstream locations (Figures 3-6 through 3-17).

Figure 3-16 shows computed and observed temperatures in the San Joaquin River at Lost Lake. The computed temperature is in agreement with the observed temperature data at this location as evidenced by the MAE and RMSE of 1.49^o F (0.83^o C) and 1.74^o

F (0.97° C) respectively. This June 2003 temperature during spill spike exceeds 70° F and the daily minimum temperature exceeds 65° F. Sixty-five degrees is the highest daily minimum computed or observed temperature during the entire simulation period and shows the potential of detrimental impacts on salmonids associated with spilling during periods of elevated surface temperatures in Millerton Lake.

Computed and observed San Joaquin River temperatures at Willow Unit are shown in Figure 3-17. In general, the model reproduces temperatures at this location that are consistent with the observed data. The maximum daily temperatures are accurately computed but the minimum computed daily temperatures are up to 2° F higher than observed. Since maximum temperatures are of primary concern for salmonid survival, the maximum temperatures were emphasized during calibration. The minimum daily temperature during the June 2003 spill event continue to produce the highest minimum daily temperature during the four year simulation period more than eight miles below Friant Dam.

Figure 3-18 shows computed and observed river temperatures at Sportsman Club. The model represents the observed temperatures throughout the period of available data Summer 2002 and 2003 daily minimums are 1 to 2° F warmer than observed and summer 2003 maximums are up to 2° F warmer for a brief period. The minimum daily temperature during summer 2005 exceeds the June 2003 spill event minimum daily temperature twelve miles below Friant Dam. The high minimum daily temperatures during the summer of 2005 result from a combination of warmer Friant Dam releases and low flow rates and associated river thermal gain. The rate of heat gain within the river during June 2003 spike is less due to the flow rate that approaches 1,000 cfs.

Figure 3-19 shows computed and observed San Joaquin River temperatures at Donny Bridge. Computed daily maximum temperatures are up to 5° below observed data. It is unclear whether this is due to hydrology or meteorology. The uncertainties associated with the hydrology during low flow periods (see Section 2.4) make it difficult to evaluate the model accuracy during very low flow periods. Beginning in the fall of 2004, the model does a better job of representing the thermal response seen in the data.

Computed and observed temperatures for the San Joaquin River at Skaggs Park are shown in Figure 3-20. As seen in Table 5, the representation of temperature during the summer and winter of 2002 accounts for the large error statistics. The temperature measurements at higher flows were identified on the Figure 3-20 to highlight and help assess the error statistics at higher flows presented in Table 6. The errors at this location appear unrelated to flow rate in 2002 and 2003. It is obvious that the model does not represent ambient conditions during 2002 and 2003, regardless of Friant Dam release rates. The large diurnal variation and cold minimum temperatures (<40° F) seen in the data during the fall of 2002 is characteristic of a recorder that is above the water surface and measuring air temperature. The model provided reasonable prediction for spring 2004.

Gravelly Ford computed and observed temperatures are plotted in Figure 3-21. During the summer of 2004, the model under predicts the daily maximum temperatures by up to 5° F. During much of the summer, there is no flow at this location, while the model assumes a minimum flow of several cfs. This assumption may explain some of the differences between the computed and observed temperatures. The gravel pit/alluvial interflow phenomenon appear to be identifiable at this station, and its representation in the model provides acceptable agreement with observed data. In Figure 3-22, the spring and summer of 2005 is plotted for this station to more clearly show the temperature spikes that occur during periods of falling hydrograph when warmer water returns to the river from the gravel pits and alluvial deposits.

A brief period of observed temperature data were available for the San Joaquin River at Transect #10 and below the bifurcation structure, shown in Figures 3-23 and 3-24, respectively. At these locations, the diurnal temperature variations in the model are slightly smaller compared with observed data, but the model response is consistent with that of the observed data.

Computed and observed temperatures below both Mendota and Sack Dam are shown in Figures 3-25 and 3-26 respectively. During low flow Friant Dam release periods, temperatures at these locations are a function of other inflows (e.g. the Delta Mendota Canal (DMC) and occasionally, flow from the Kings River system via the James Bypass) and are almost completely independent of Friant Dam release temperatures. During flood control operation, Friant Dam excess flows are diverted to the Chowchilla Bypass and Mendota Pool temperatures may be influenced only slightly by Friant Dam flows.

Model results show that the seasonal trends are consistent with the observed data throughout much of the year; however, diurnal variations are greater in the observed data below Mendota Dam. The computed diurnal variation is impacted by the model representation of Mendota Pool. During the calibration process, the Mendota Pool was not emphasized due to uncertainty of the James Bypass, DMC inflows and canal demand assumptions. It was also assumed that river restoration will include a bypass of Mendota Pool. The smaller diurnal variation at Sack Dam is due, in part, to the small diurnal variation at Mendota Dam.

Figure 3-27 shows that the model provides a reasonable representation of the observed data during a brief period (spring of 2005) under Bypass operation, although the spike in computed temperature in mid-June is underestimated.

Figure 3-28 shows computed and observed river temperatures at Stevinson. The seasonal trends are well represented by the model; however, the diurnal variations are generally less than observed. The summer 2004 temperatures are well represented by the model suggesting that the meteorological data are representative of local conditions. Both the computed and observed temperatures are similar to the summer period of other years unlike the San Joaquin River section between Friant Dam and Mendota.

At Fremont Ford and Crows Landing, shown in Figures 3-29 and 3-30, respectively, observed temperature data are available for the latter half of 2004 and nearly all of 2005. Except for the spring of 2005, flows in the San Joaquin River at Stevinson are low and the Fremont Ford temperatures are influenced greatly by the temperature of Salt Slough which contributes to the majority of the flow. At Crows Landing, both Mud Slough and the Merced River inflows are a major influence on temperature. Therefore, the accuracy of the model is dominated by the accuracy of the inflow temperature algorithms. During the spring of 2005, bypass and Bear Creek temperatures are more significant. The temperature response during the spring 2005 high flow period is well represented, which is important from the perspective of evaluating river temperatures during the proposed spring pulse flow events.

Computed and observed river temperatures at Patterson are shown in Figure 3-31. The model is in reasonable agreement with observed temperature data. A review of Table 5 indicates the model remains accurate below the Merced River (bias of 0.11° F, MAE of 1.67° F or 0.93° C and RMSE of 2.04° F or 1.13° C). This may be an important factor in evaluating the potential for attracting returning adult salmonids since the temperatures of the two rivers at the Merced confluence may impact fish's migration route decisions.

Table 5 San Joaquin River calibration plot locations, distances below Friant Dam and model accuracy expressed as Mean (Bias), Mean Absolute and RMS Error for the entire simulation period and for the Mid-March through Mid-July 2005 time period

Location	Miles Below Dam	Values	Mean error (F)	Mean absolute error (F)	RMS error (F)
2000 - 2005 period of record					
Friant Dam	0.1	1371	-0.56	0.61	0.73
Friant Bridge	1	4703	-0.81	1.15	1.44
Lost Lake	4	2394	-0.73	1.49	1.74
Willow Unit	8	2300	-1.26	1.98	2.3
Sportsman Club	12	2267	-1.22	1.61	2.02
Downey Bridge	26	1882	-1.26	2.24	2.91
Skaggs Park	33	2077	-0.2	3.34	4.81
Gravelly Ford	39	2188	-0.53	1.98	2.47
Transect #10	47	372	-1.27	1.49	2.19
Bifrucation	51	373	-0.62	1.25	1.94
Mendota Dam	63	1959	-0.23	2.69	3.4
Sac Dam	85	1287	2.03	2.75	3.36
Mariposa Bypass	120	96	1.37	2.24	2.97
Stevinson	134	7456	1.7	2.54	3.1
Fremont Ford	142	2364	0.97	2.09	2.5
Crows Landing	160	2086	0.85	1.9	2.32
Patterson	169	7163	0.11	1.67	2.07
Average			-0.10	1.94	2.49
16-March-2005 through 15-July-2005					
Friant Dam	0.1	250	-0.22	0.24	0.29
Friant Bridge	1	488	-0.58	0.85	1.25
Sportsman Club	12	218	0.33	0.47	0.61
Downey Bridge	26	225	-0.94	1.14	1.33
Gravelly Ford	39	488	-1.35	1.55	2.12
Transect #10	47	372	-1.27	1.49	2.19
Bifrucation	51	373	-0.62	1.25	1.94
Mendota Dam	63	487	-1.11	2.39	2.99
Sac Dam	85	474	1.38	1.85	2.37
Mariposa Bypass	120	96	1.37	2.24	2.97
Stevinson	134	488	3.02	3.07	3.42
Fremont Ford	142	488	2.24	2.3	2.53
Crows Landing	160	488	1.66	1.82	2.2
Patterson	169	353	1.52	1.71	2.02
Average			0.39	1.60	2.02

Table 6 San Joaquin River calibration plot locations, distances below Friant Dam and model accuracy expressed as Mean (Bias), Mean Absolute and RMS Error for days when the Friant Dam release exceeded 250 and 300 cfs during the entire simulation period

Location	Miles Below Dam	Values	Mean error (F)	Mean absolute error (F)	RMS error (F)
2000 - 2005 period of record - Friant Dam flows > 250 cfs at Friant Dam					
Friant Dam	0.1	229	-0.3	0.3	0.38
Friant Bridge	1	580	-0.44	0.89	1.33
Lost Lake	4	93	0.1	1.14	1.52
Willow Unit	8	120	-0.79	2.13	2.5
Sportsman Club	12	338	-0.33	1.07	1.62
Downey Bridge	26	221	-1.76	1.89	2.57
Skaggs Park	33	97	-4.61	4.61	4.98
Gravelly Ford	39	460	-1.62	1.77	2.39
Transect #10	47	354	-1.33	1.51	2.23
Bifrucation	51	355	-0.68	1.25	1.95
Mendota Dam	63	459	-1.31	2.52	3.15
Sac Dam	85	414	1.39	1.86	2.37
Mariposa Bypass	120	92	1.18	2.08	2.77
Stevinson	134	961	2.48	2.66	3.1
Fremont Ford	142	460	2.23	2.31	2.54
Crows Landing	160	460	1.67	1.83	2.18
Patterson	169	761	1.26	1.65	1.99
Average			-0.17	1.85	2.33
2000 - 2005 period of record - Friant Dam flows > 300 cfs at Friant Dam					
Friant Dam	0.1	214	-0.25	0.25	0.29
Friant Bridge	1	448	-0.46	0.78	1.21
Lost Lake	4	24	-0.25	1.6	2.05
Willow Unit	8	24	-1.07	1.68	1.86
Sportsman Club	12	242	0.12	0.67	1.09
Downey Bridge	26	193	-1.17	1.32	1.62
Skaggs Park	33	24	-5.76	5.76	6.24
Gravelly Ford	39	424	-1.48	1.64	2.23
Transect #10	47	346	-1.37	1.52	2.25
Bifrucation	51	347	-0.72	1.24	1.96
Mendota Dam	63	423	-1.44	2.48	3.1
Sac Dam	85	409	1.43	1.86	2.37
Mariposa Bypass	120	92	1.18	2.08	2.77
Stevinson	134	503	2.79	2.95	3.32
Fremont Ford	142	424	2.29	2.35	2.56
Crows Landing	160	424	1.63	1.78	2.14
Patterson	169	369	1.24	1.69	2.03
Average			-0.19	1.86	2.30

Table 7 Model accuracy expressed as weighted (by number of observations) Mean (Bias), Mean Absolute Error and RMS Error by river segment, time period and Friant Dam release threshold

Period / River Segment	Values	Mean error (F)	Mean absolute error (F)	RMS error (F)
Above Mendota With Skaggs Park Data				
Entire Record	19,927	-0.83	1.73	2.22
16-March-2005 through 15-July-2005	2,414	-0.76	1.08	1.53
Friant Dam Flows Exceeding 250 cfs	2,847	-0.99	1.39	1.92
Above Mendota Excluding Skaggs Park Data				
Entire Record	17,850	-0.91	1.55	1.92
16-March-2005 through 15-July-2005	2,414	-0.76	1.08	1.53
Friant Dam Flows Exceeding 250 cfs	2,750	-0.86	1.28	1.82
Below Mendota excluding Mendota Dam Data				
Entire Record	20,452	0.99	2.13	2.61
16-March-2005 through 15-July-2005	2,387	1.97	2.18	2.55
Friant Dam Flows Exceeding 250 cfs	3,148	1.85	2.12	2.51

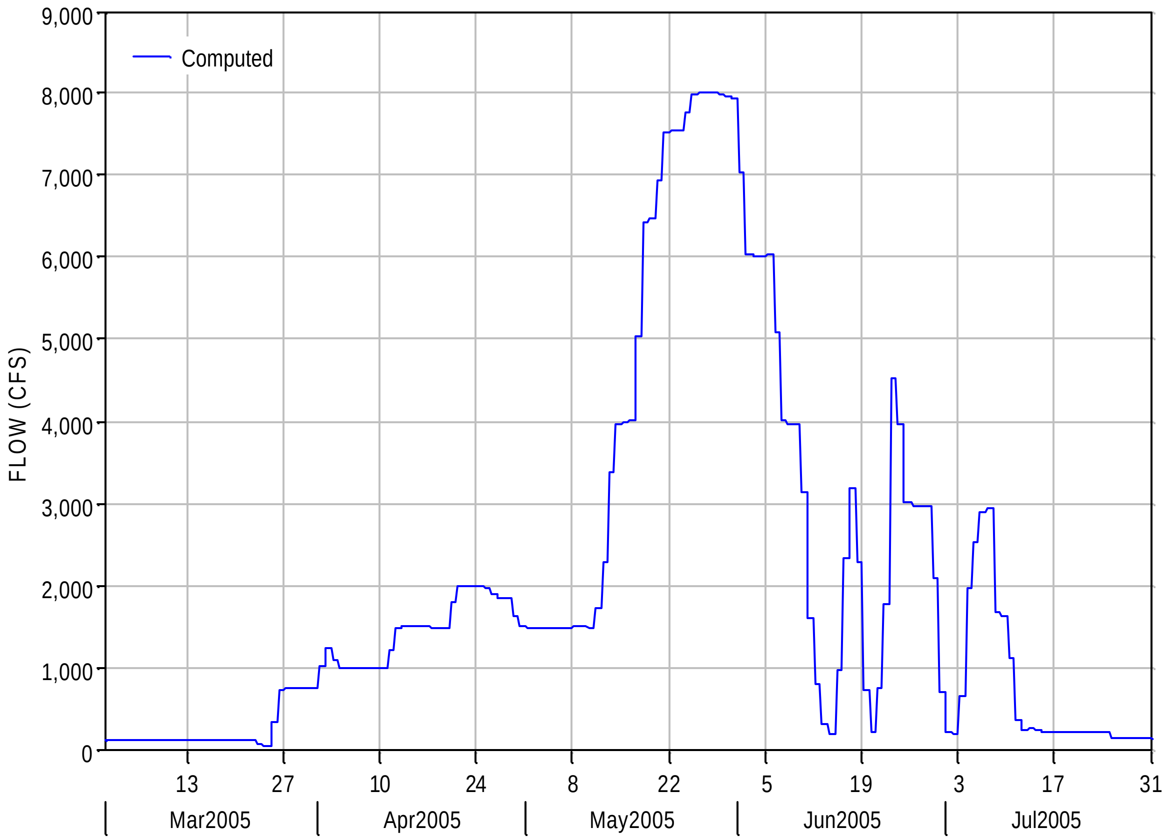

Figure 3-8 Computed flows at Friant Bridge for spring 2005

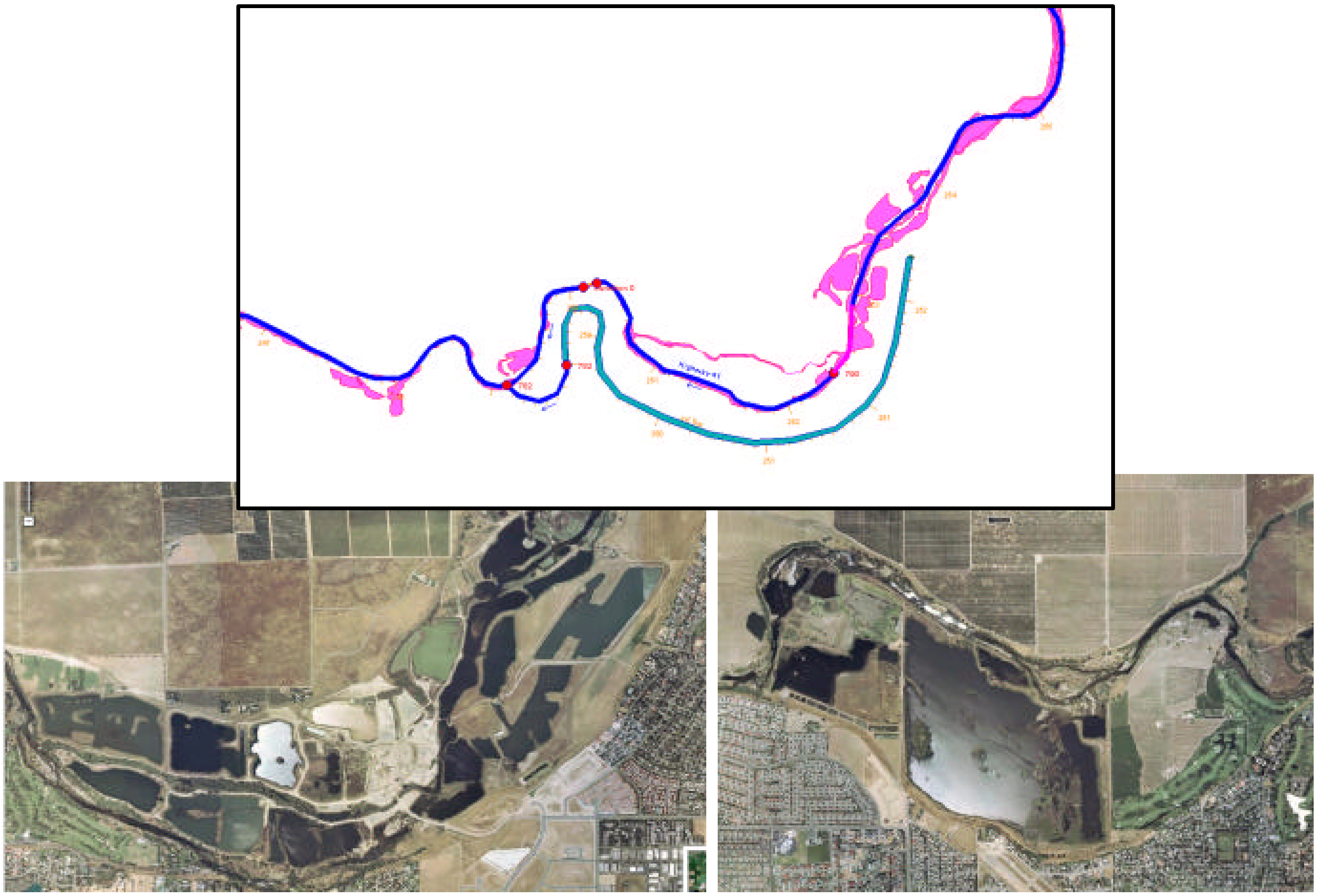

Figure 3-9 Model representation of interflow between river and gravel pits/alluvial deposits, and aerial photos showing gravel pits

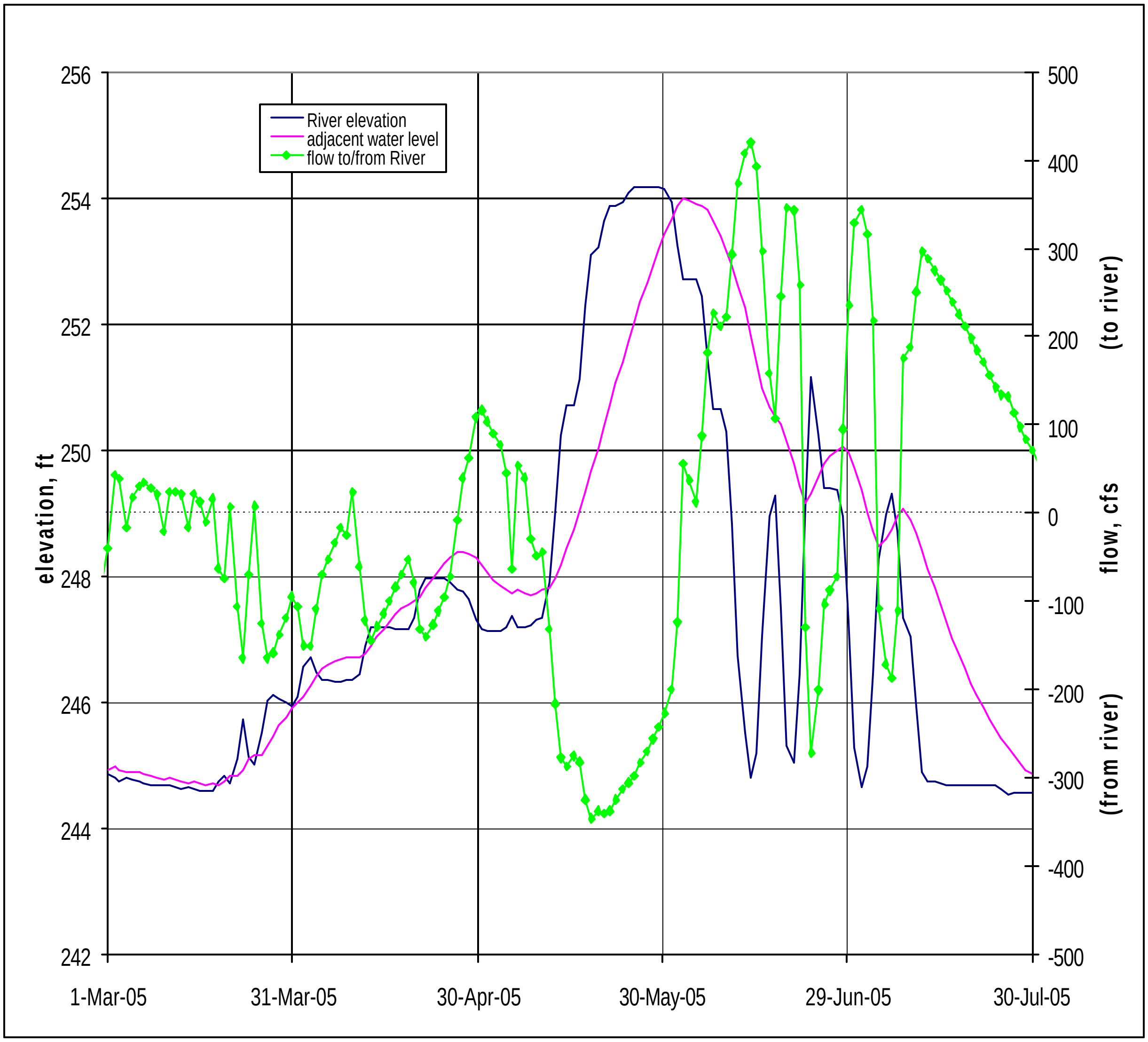

Figure 3-10 Hypothetical interflow between river and gravel pits/alluvial deposits as a function of river elevation

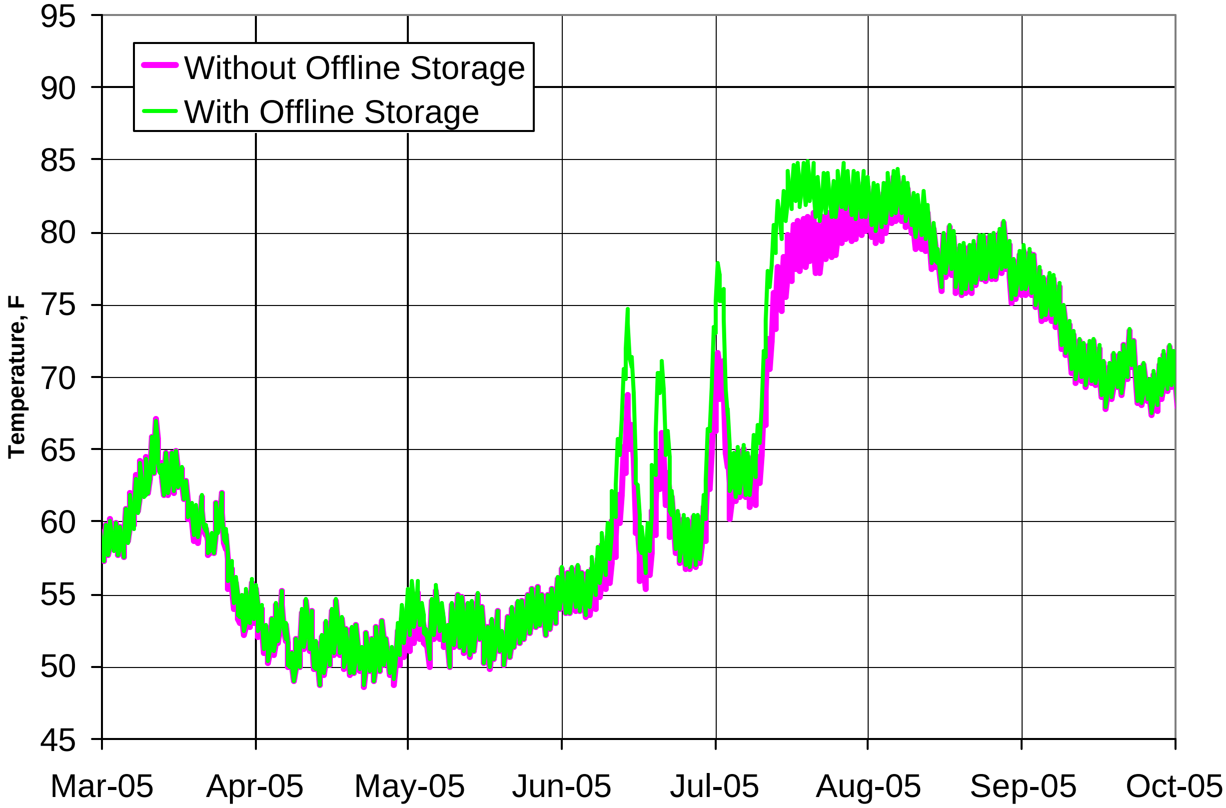

Figure 3-11 Computed San Joaquin River temperatures at Downey Bridge (26 miles D/S) with and without interflow between the river and gravel pits/alluvium

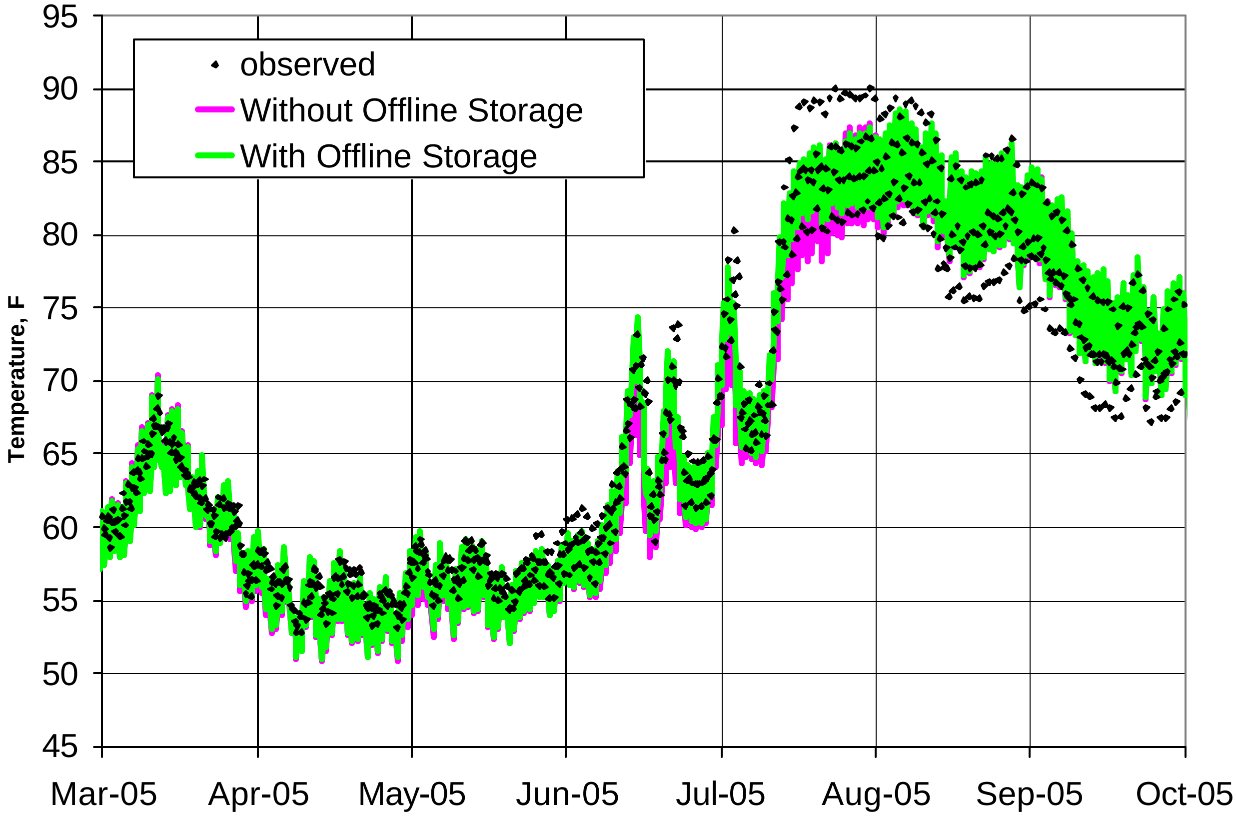

Figure 3-12 Computed San Joaquin River temperatures at Gravelly Ford (39 miles D/S) with and without interflow between the river and gravel pits/alluvium

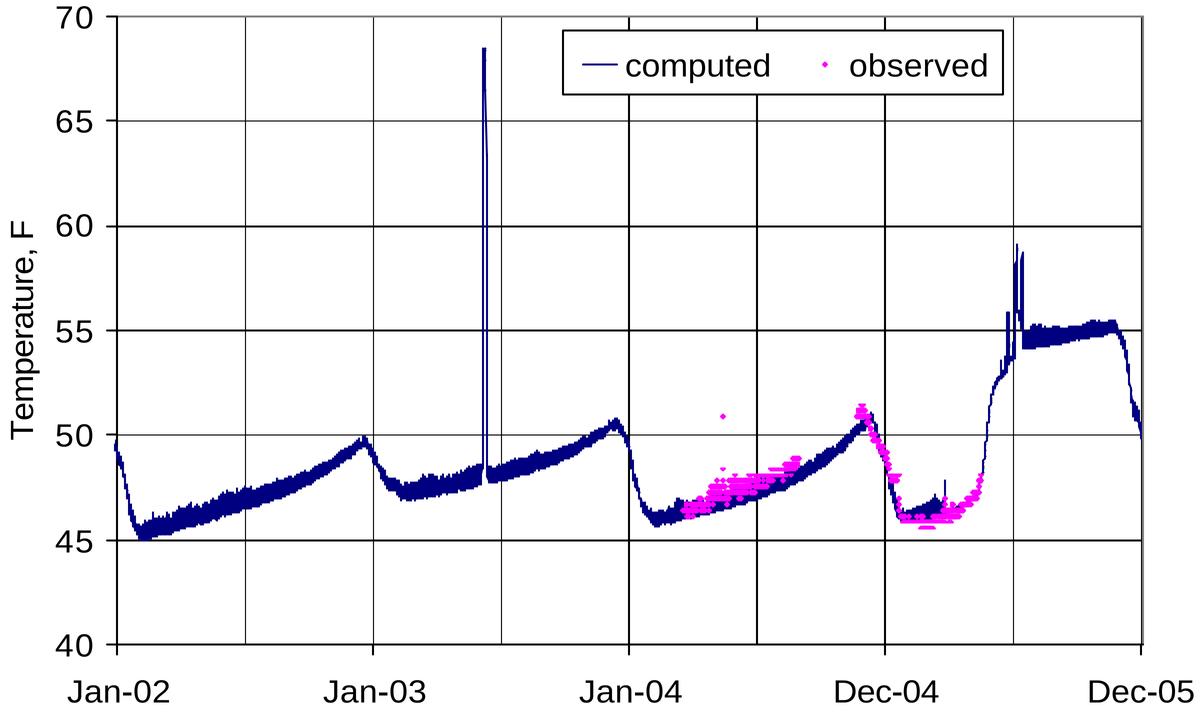

Figure 3-13 Computed and observed temperatures at Friant Dam (0.1 mile D/S)

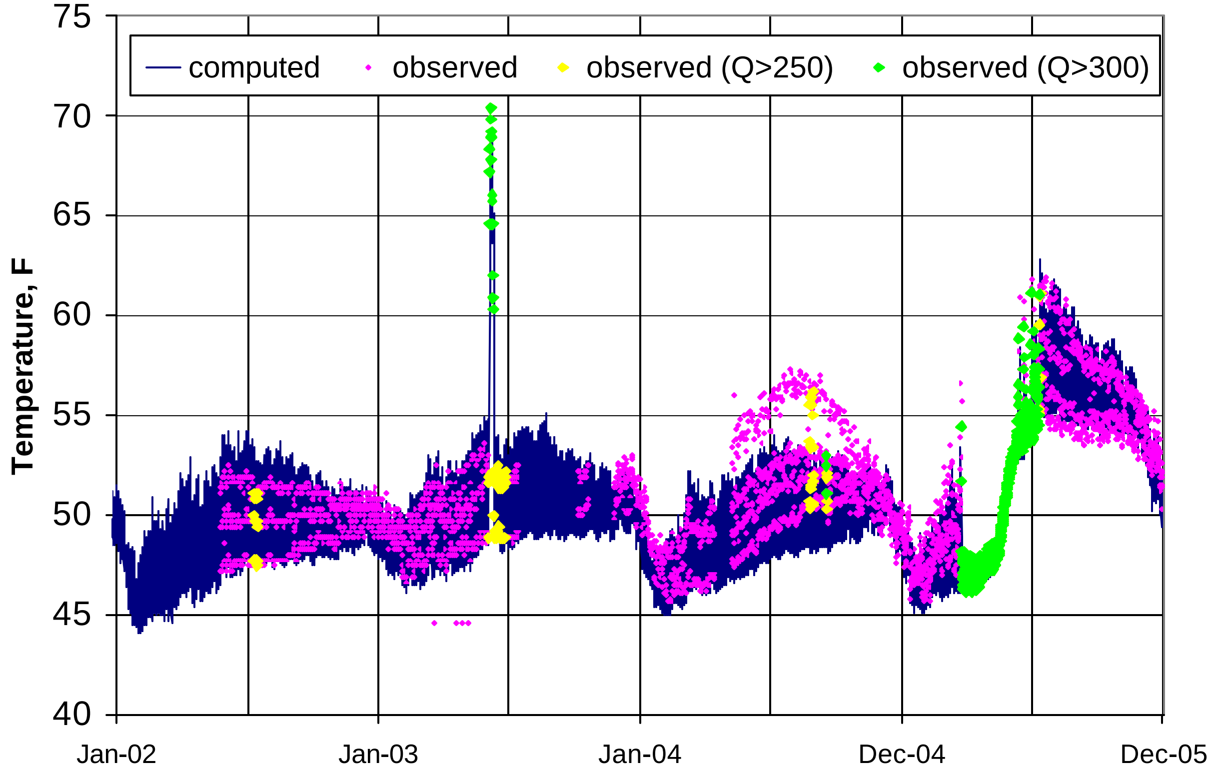

Figure 3-14 Computed and observed temperatures at Friant Bridge (1 miles D/S)

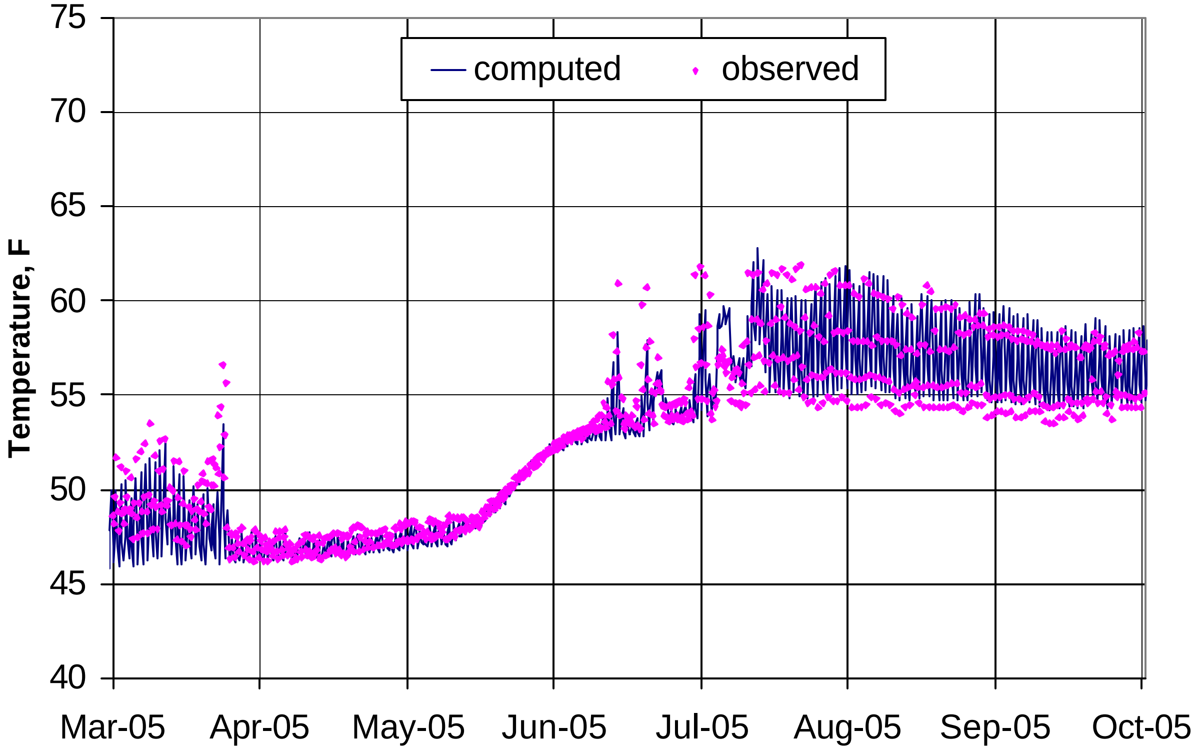

Figure 3-15 Computed and observed temperatures at Friant Bridge for spring and summer 2005

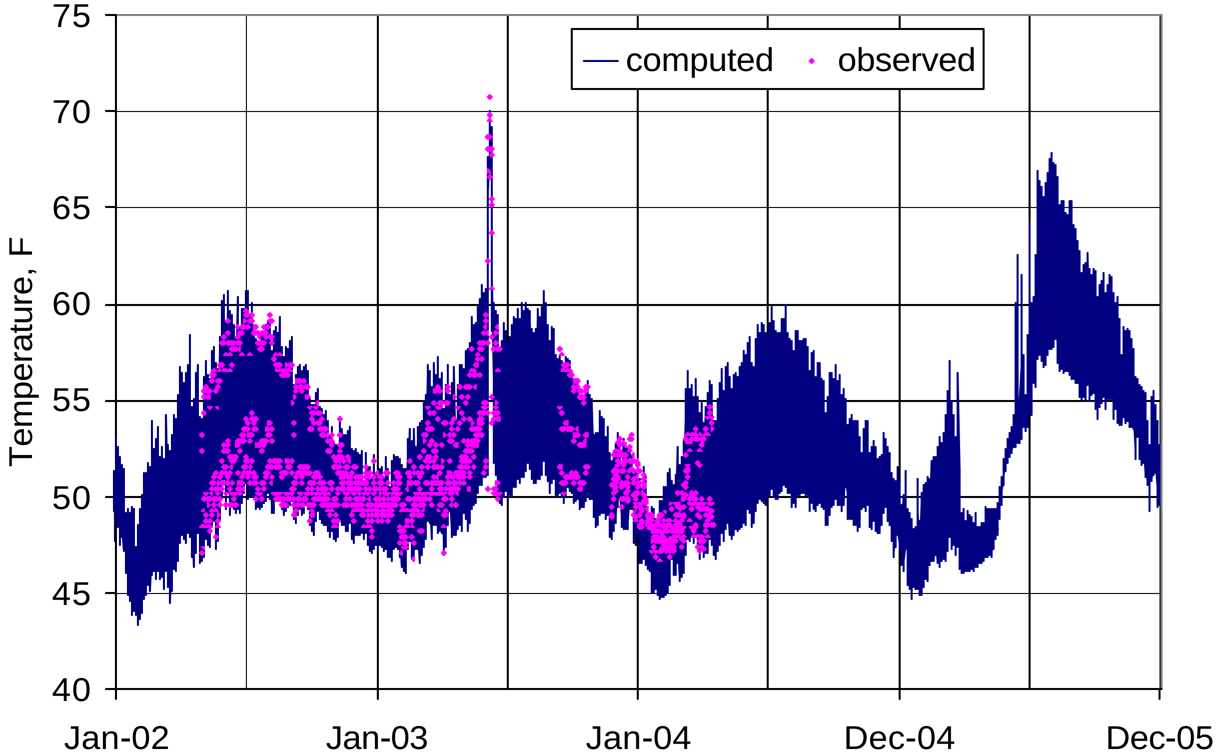

Figure 3-16 Computed and observed temperatures at Lost Lake (4 miles D/S)

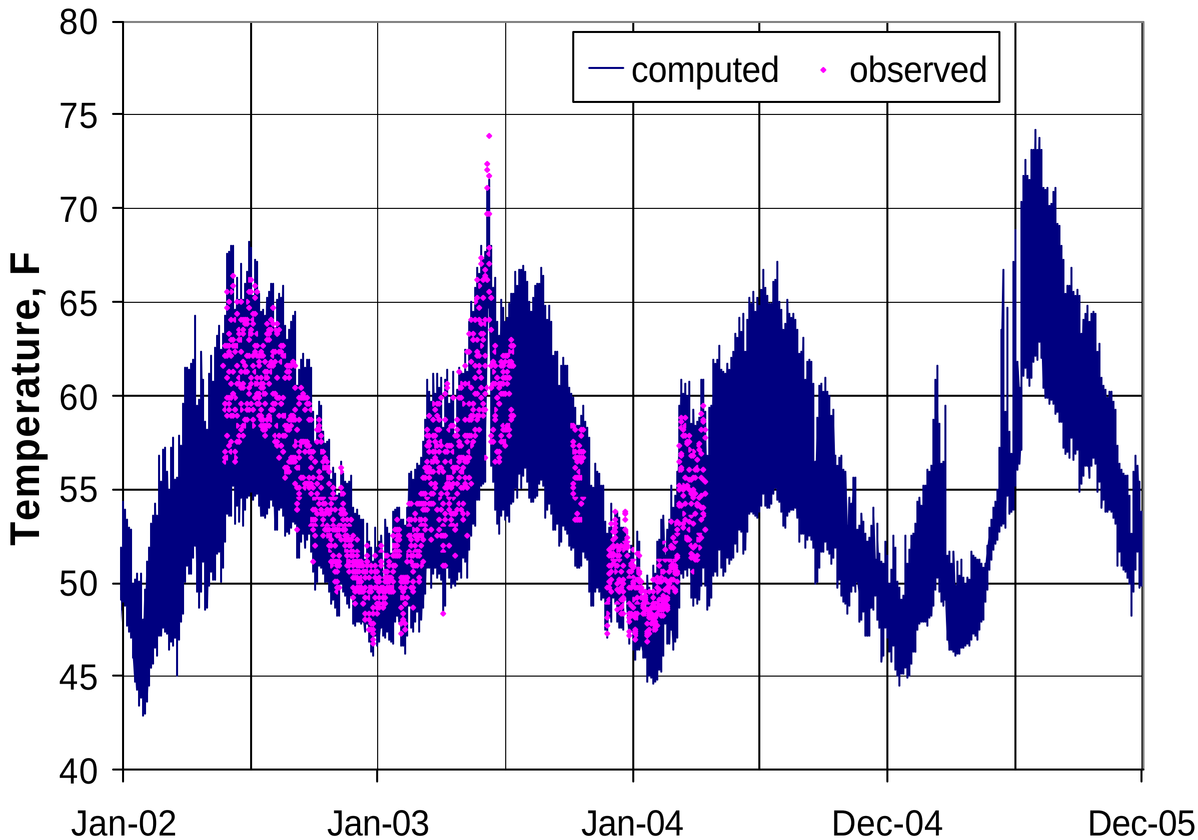

Figure 3-17 Computed and observed temperatures at Willow Unit (8 miles D/S)

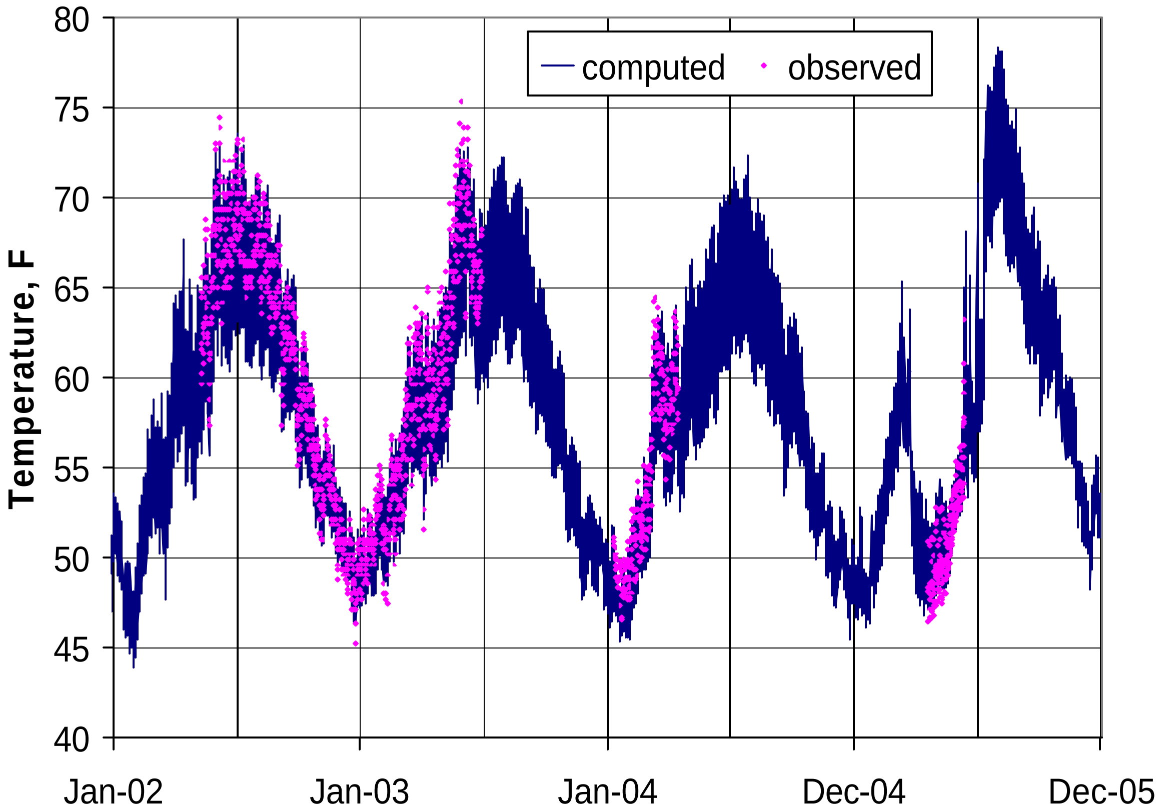

Figure 3-18 Computed and observed temperatures at Sportsman Club (12 miles D/S)

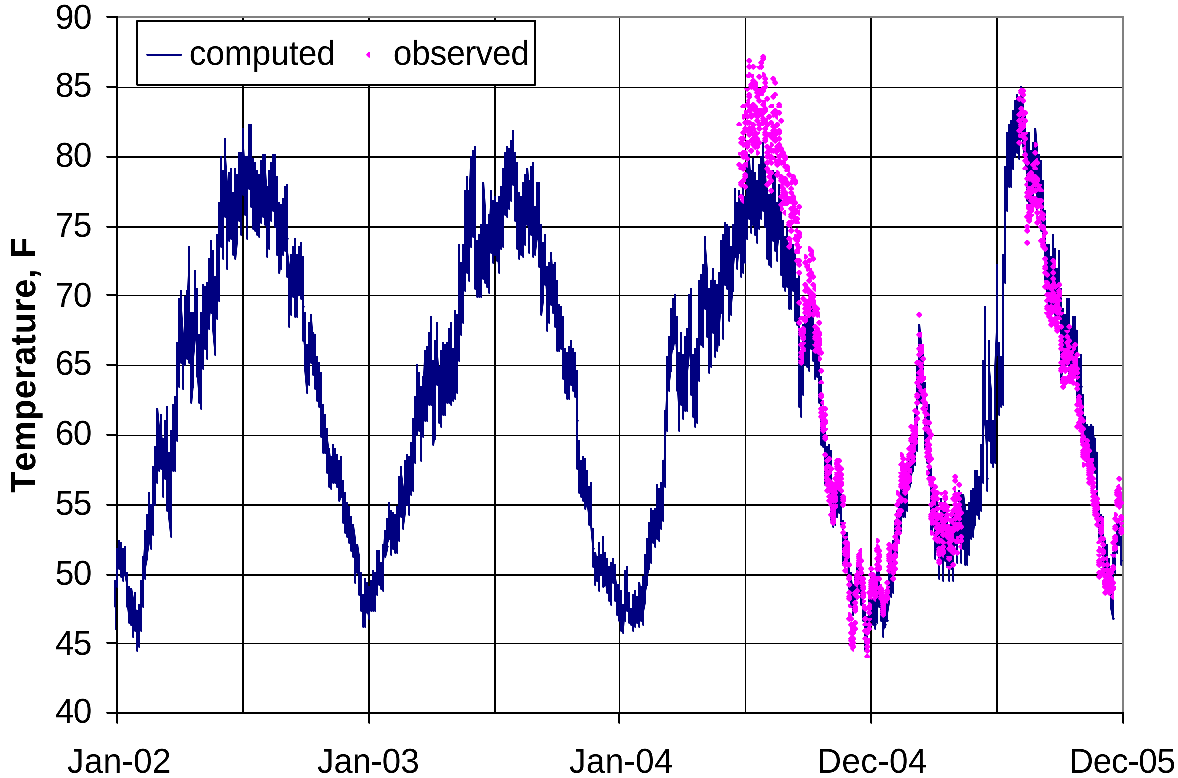

Figure 3-19 Computed and observed temperatures at Downey Bridge (26 miles D/S)

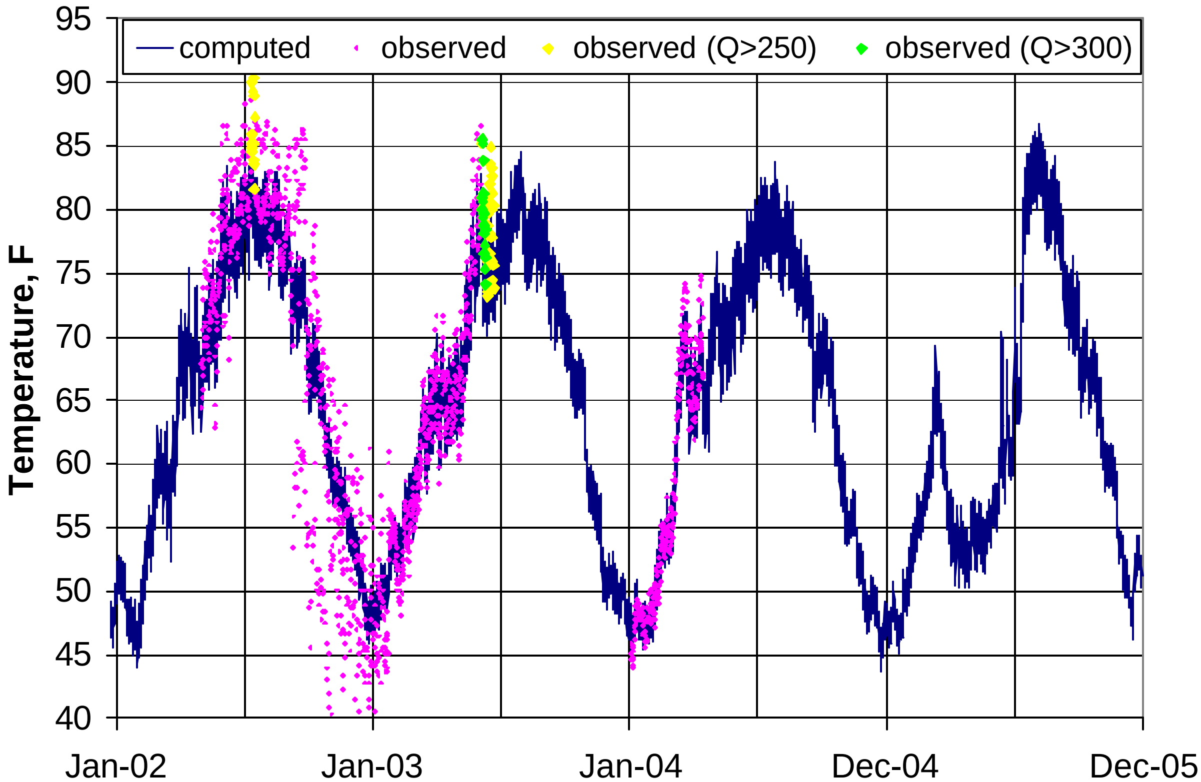

Figure 3-20 Computed and observed temperatures at Skaggs Park (33 miles D/S)

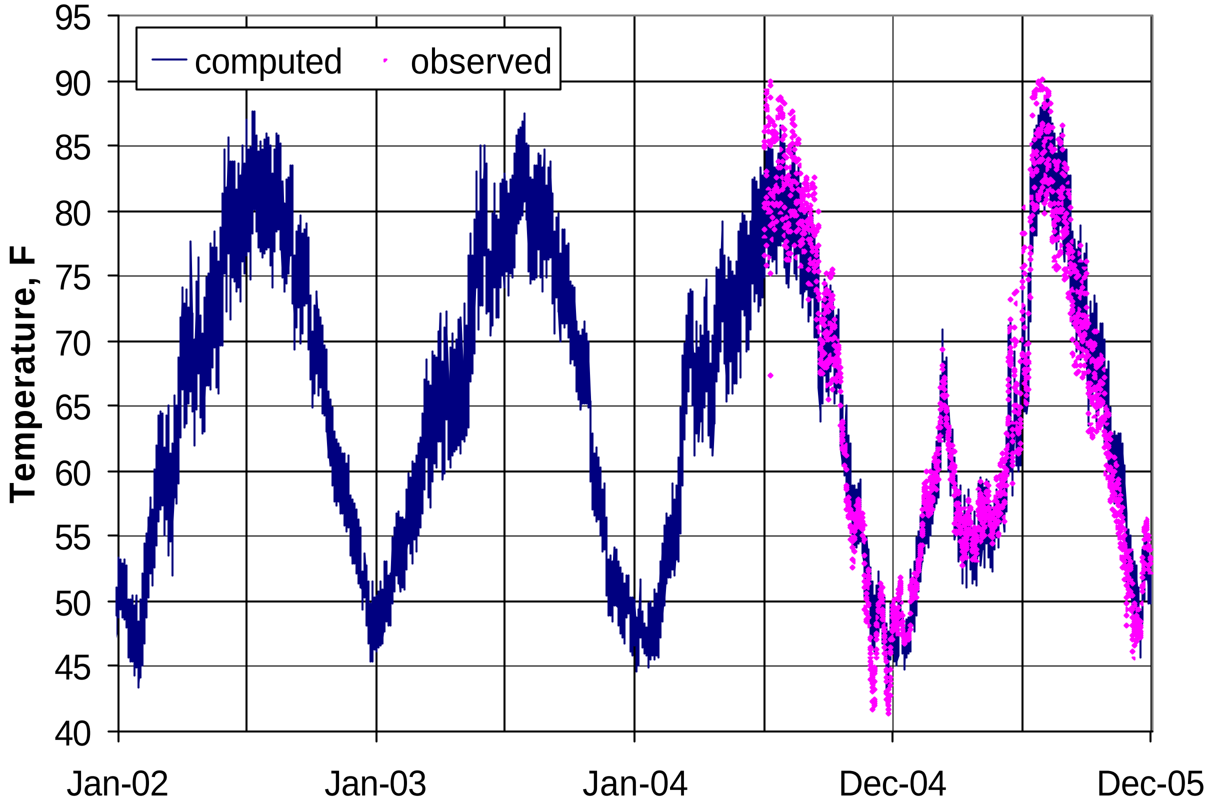

Figure 3-21 Computed and observed temperatures at Gravelly Ford (39 miles D/S)

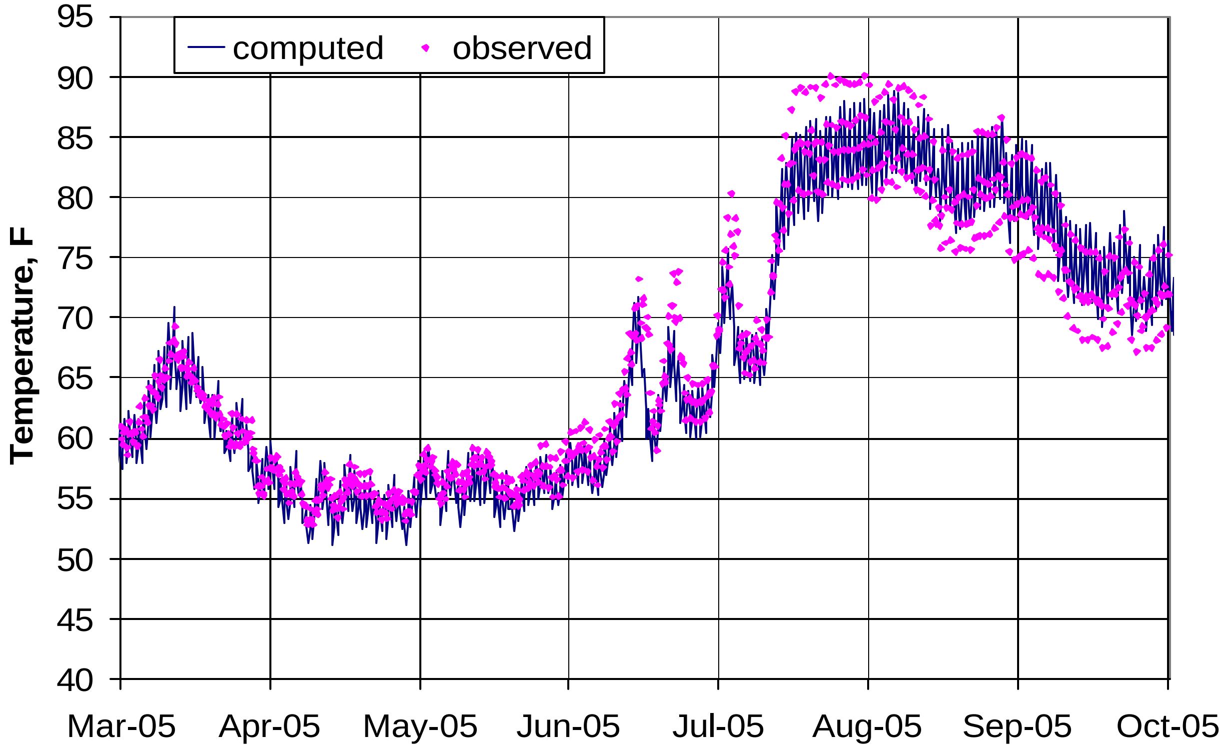

Figure 3-22 Computed and observed temperatures at Gravelly Ford (39 miles D/S), spring and summer 2005

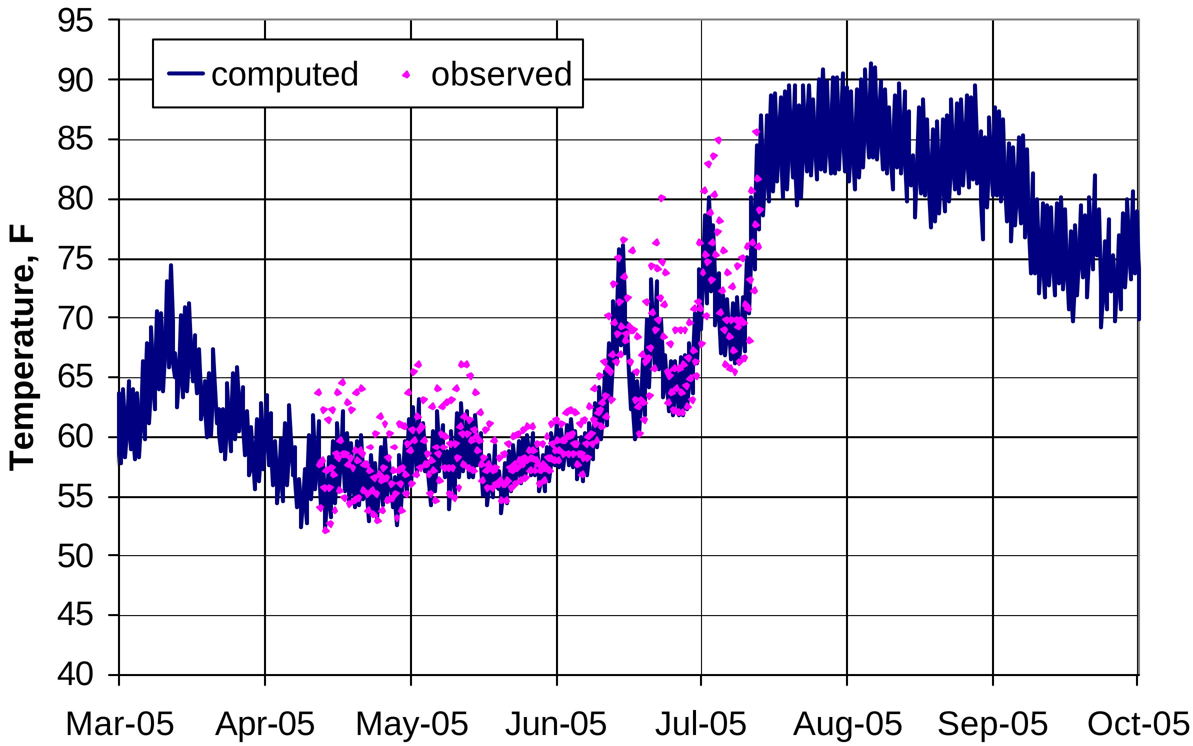

Figure 3-23 Computed and observed temperatures at Transect #10 (47 miles D/S)

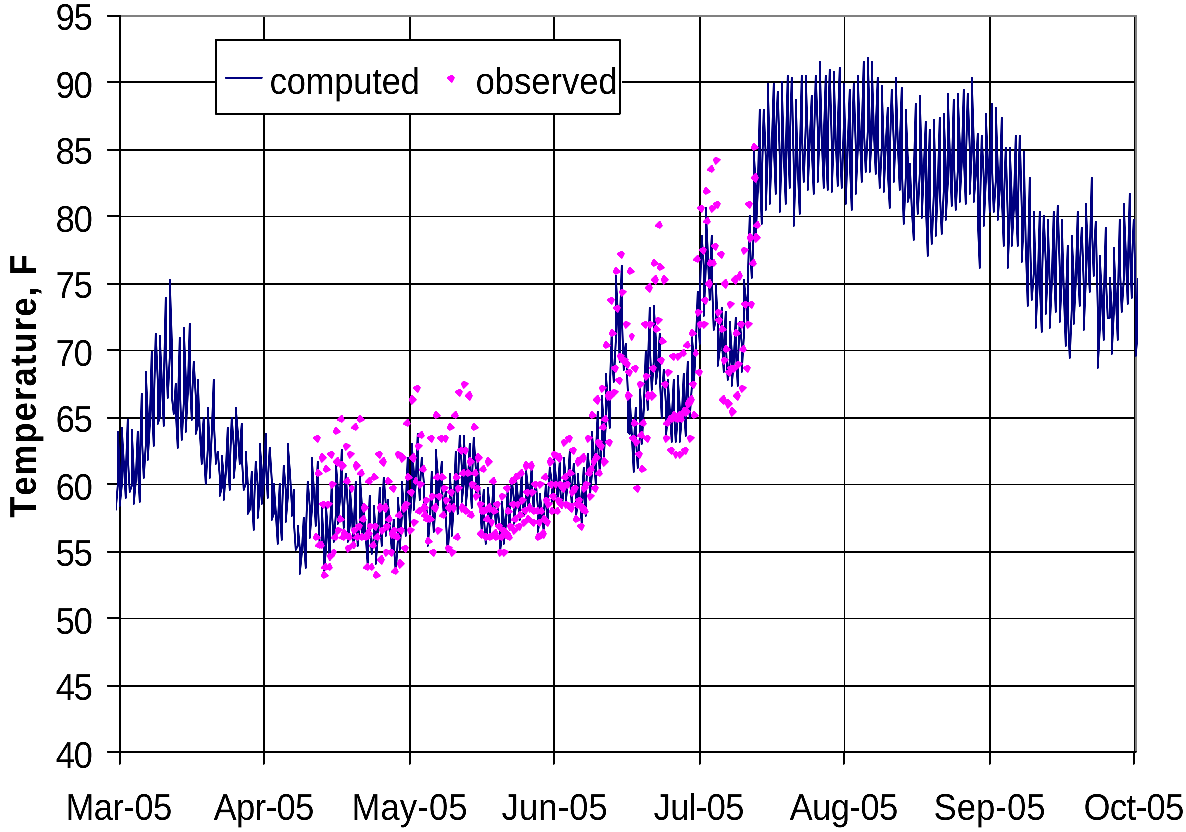

Figure 3-24 Computed and observed temperatures below bifurcation (51 miles D/S)

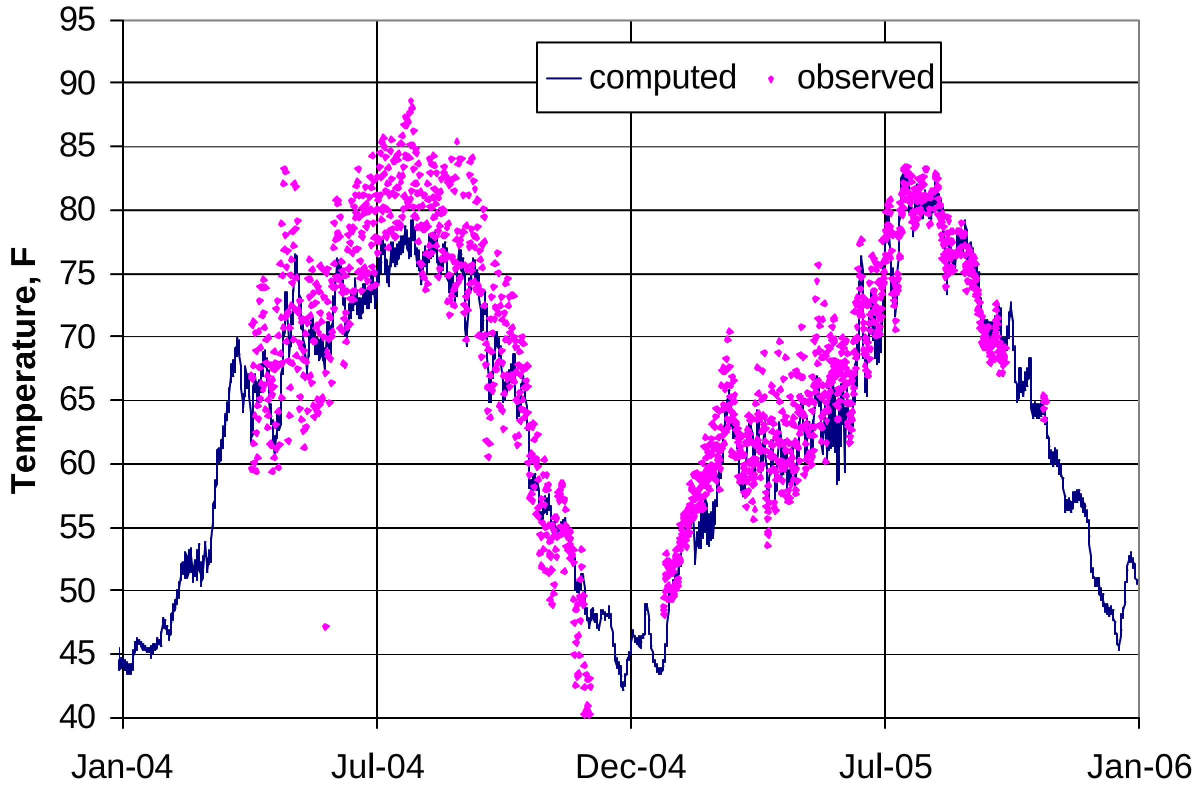

Figure 3-25 Computed and observed temperatures below Mendota Dam (63 miles D/S)

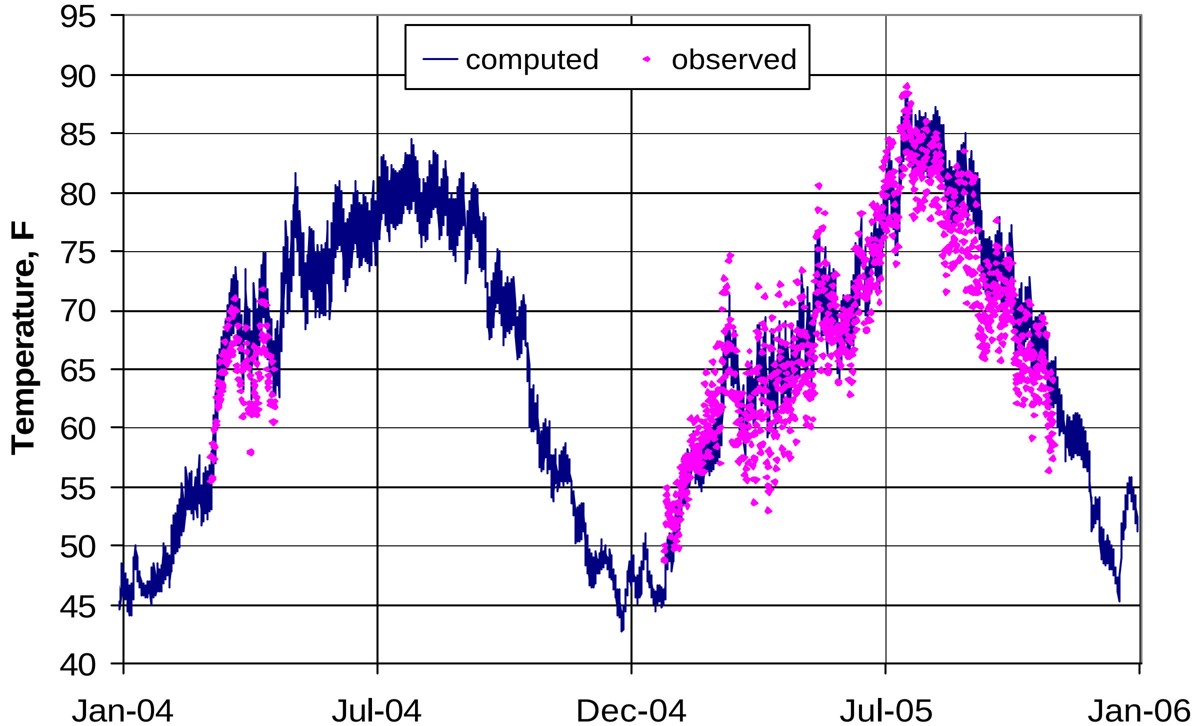

Figure 3-26 Computed and observed temperatures at Sack Dam (85 miles D/S)

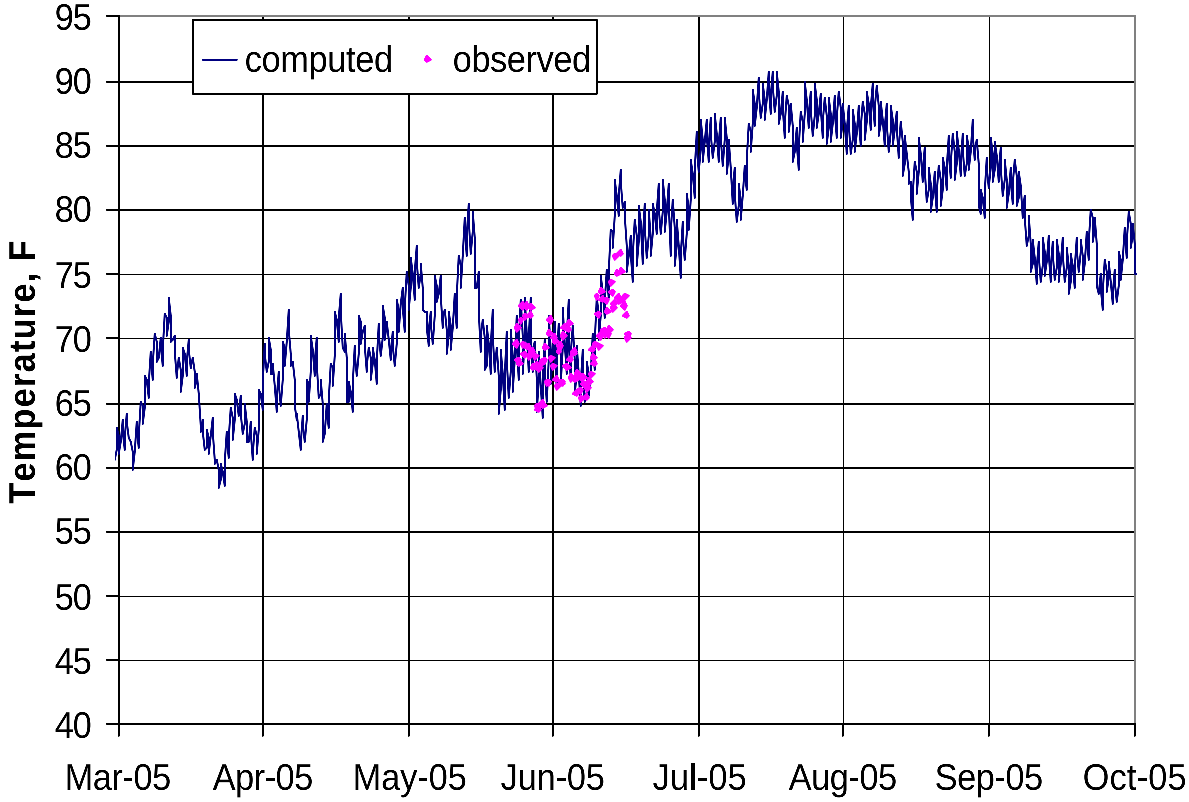

Figure 3-27 Computed and observed temperatures below Mariposa Bypass (119 miles D/S)

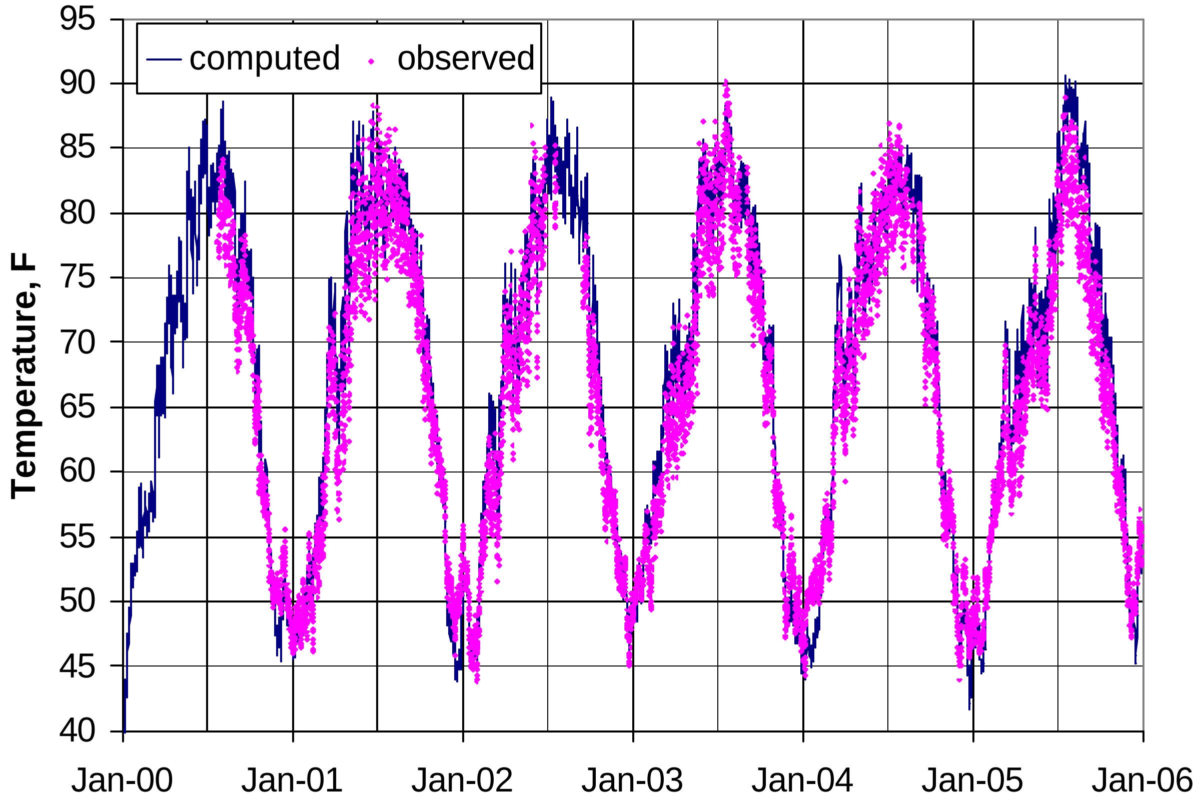

Figure 3-28 Computed and observed temperatures at Stevinson (134 miles D/S)

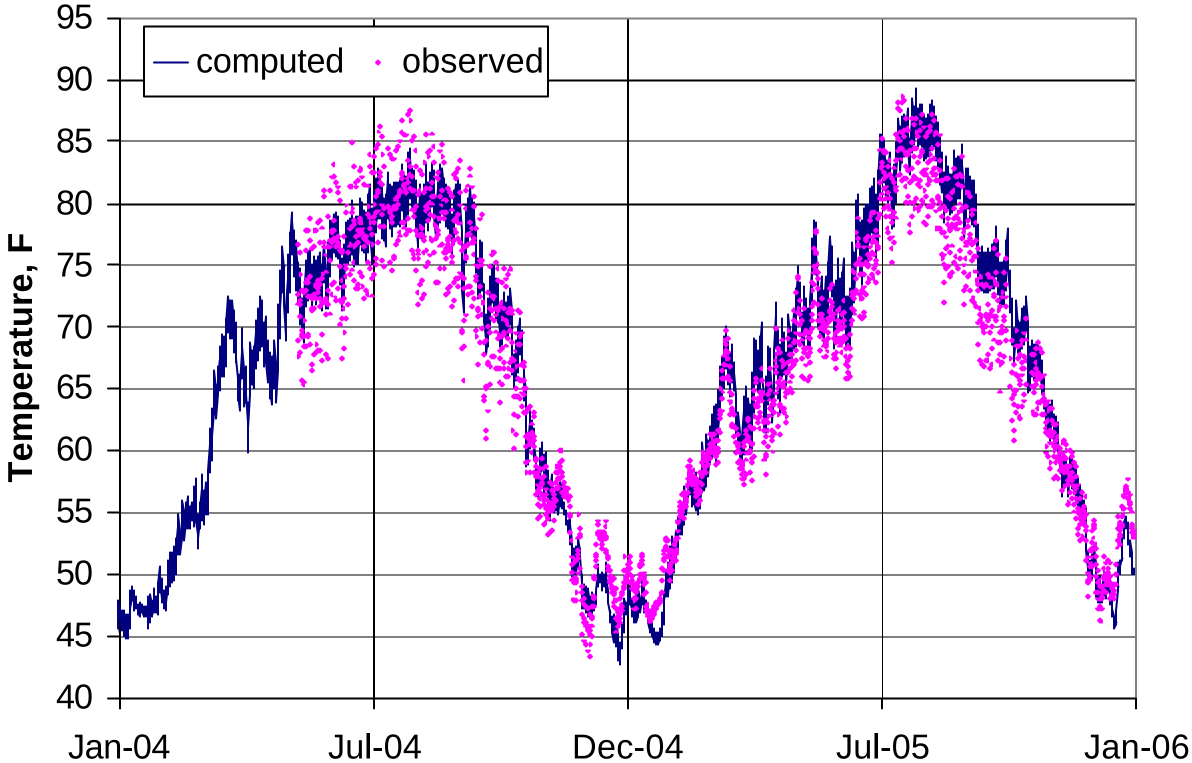

Figure 3-29 Computed and observed temperatures at Freemont Ford (142 miles D/S)

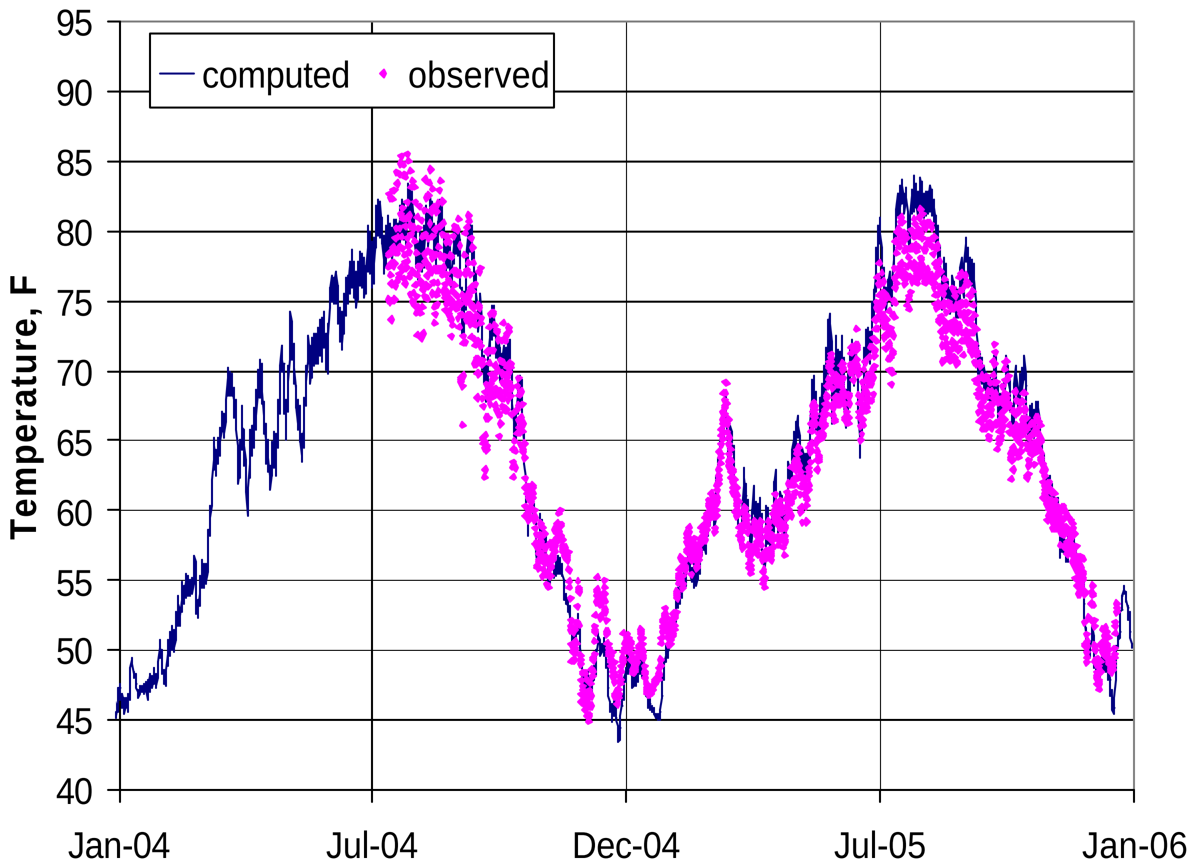

Figure 3-30 Computed and observed temperatures at Crows Landing (160 miles D/S)

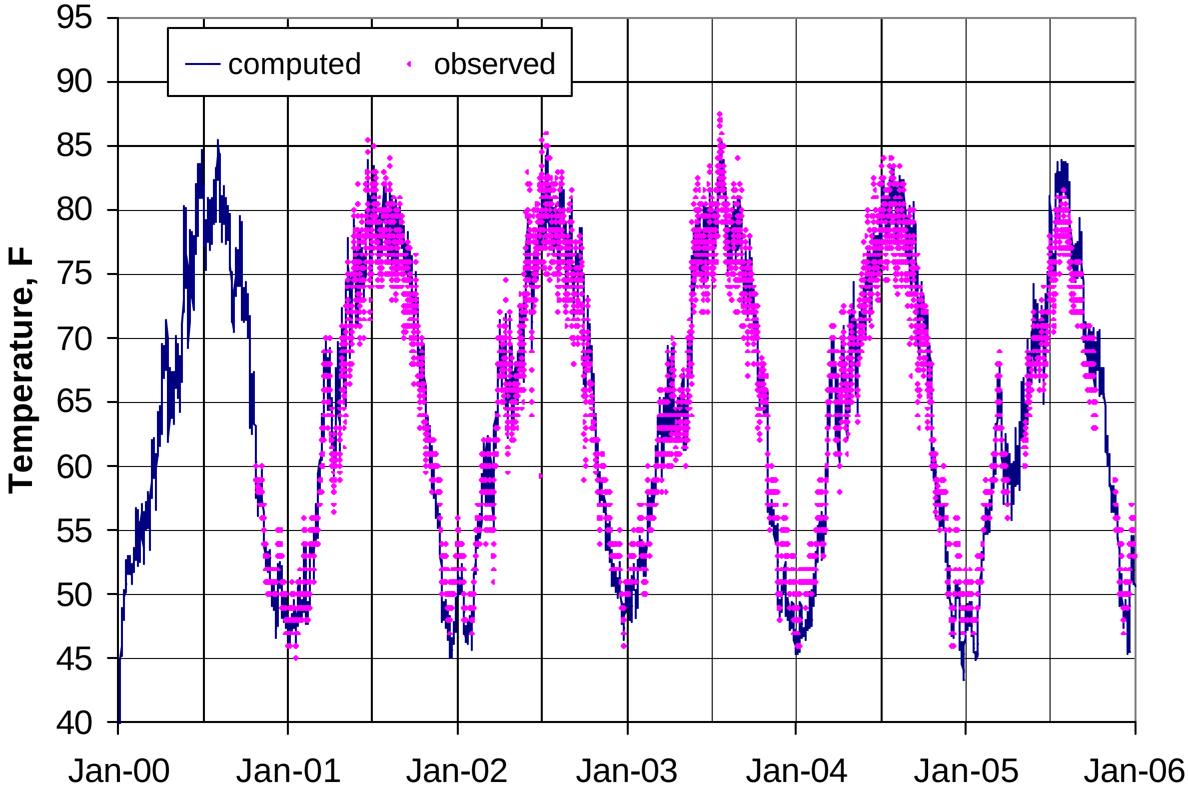

Figure 3-31 Computed and observed temperatures at Patterson (169 miles D/S)

4 SETTLEMENT OPERATION

4.1 KONDOLF HYDROGRAPH

The proposed Kondolf hydrograph was used to evaluate a thermal impacts settlement operation study. Modeling of the Kondolf hydrograph included the following assumptions.

- Friant Dam releases were based on water year type.
- Shortfalls in the minimum flow requirements above the Merced River (resulting from daily inflows, accretions, depletions and flow routing) were ignored.
- Historical canal deliveries were downscaled such that the end-of-year volumes in Millerton Lake were unchanged (without reduced diversions, Millerton Lake would be nearly empty by the end of the simulation period).
- There is no lag in the standard Kondolf hydrograph; however hydrologic flow routing and the resulting flow attenuation was implemented in the HEC-5 model.
- Gravel pit / alluvial deposit interflow was computed using a similar approach to that described in the stream calibration section. Gravel pit interflow was included to include impacts of the abrupt changes inherent in the Kondolf hydrographs.

The settlement operation simulation period was during the period 2000-2004, encompassing normal wet, normal dry and dry years. Figure 4-1 provides an overview of the Kondolf hydrograph and computed river temperatures below Friant Dam, at Highway 41, at Highway 99 and at Gravelly Ford. These four locations in Reach 1 are approximately 1/8, 14, 23 and 39 miles below Friant Dam respectively.

Year 2005 was not evaluated since flood control considerations governed reservoir operation. Nor was a critical dry year included since our analysis was limited to the historical 2000-2004 period. During critical dry years, smaller base and pulse flows would likely result in higher temperatures in the river downstream of the Dam.

Detailed results are presented for the "spring rise and pulse flows", "summer base flow" and "fall run attraction flow" for various year types in Figures 4-2 through 4-6. The Kondolf hydrograph flows are presented at the dam and at Gravelly Ford to show flow attenuation, effects of gravel pit interflow and net depletion above Gravelly Ford. Interflow is computed externally as a function of stream and gravel pit water surface elevation and area. The temperature of the returning water is computed within the model as a function of stream temperature (flow to the pit), meteorology, and residence time within the gravel pit model representation.

Figure 4-2 shows the computed effect of the March 16 through 31 spring rise and pulse flow of 1,500 cfs on river temperatures during March through May 2002. The results for the other dry years within the simulation period were similar. The total dam release volume during the March 16-April 30 period is 68,400 AF. This period encompasses the maximum length of the spring pulse flow for the various year types evaluated. Prior to the pulse, river temperatures are cold due to typical winter weather conditions. The cold temperatures prior to the spring pulse were similar for all years.

Temperatures during the pulse remain cold due to increased flow depths and shorter travel times. Temperatures following the pulse respond to typical spring meteorology. The effects of gravel pit interflow contribute to the raise in temperature during the first few days of April at Highway 99 and Gravelly Ford, but have very minimal impact during the remainder of the simulation. The effects of the pulse flow on dam release temperatures appear minimal due to the downscaling of canal demands.

Figure 4-3 shows the computed impact of the March 16 through April 15 spring rise and pulse flow of 1,500 cfs and 2,500 cfs on river temperatures during March through May 2003. The total dam release volume during the March 16-April 30 period is 132,400 AF. Temperatures during the pulse remain cold due to increased flow depths and shorter travel times. Temperatures following the pulse respond to typical spring meteorology.

The effects of gravel pit interflow appear more dramatic during the first few days in mid April at Highway 99 and Gravelly Ford due the larger drop in flow rate and water elevation. The effects of the pulse flow on dam release temperatures remains small; however, there is an increase of nearly 1^{o} F on June 1 relative to June 1 of the dry year seen in Figure 4-2 due to the addition flow through the river outlet.

Figure 4-4 shows the computed impact of the March 16 through April 30 spring rise and pulse flow of 1,500 cfs, 2,500 cfs and 4,000 cfs on river temperatures during March through May 2003. The total dam release volume during the March 16-April 30 period is 241,000 AF. Temperatures during the pulse remain uniformly cold due to increased flow depths and shorter travel times. Temperatures following the pulse respond to typical spring meteorology.

The effects of gravel pit interflow appear more dramatic during the first few days in May at Highway 99 and Gravelly Ford due the larger drop in flow rate and water elevation. The effects of the pulse flow on dam release temperatures remains small until mid April when a more rapid raise is computed due to more rapid depletion of the cool water volume of Millerton Lake. The increase in the June first Dam discharge temperature is approximately 1.5^{o} F relative to June 1 of the dry year.

Nonetheless, the June 1 difference in temperature for the three pulse flow conditions does not have a major effect on the maximum discharge temperature late in the year (mid November) since the volume of cool water flows into Millerton Lake after June 1 is higher for the wetter years with high pulse flow volumes. Additionally, the 350 cfs base flow following June 1 approaches the upper limits of the available lake cold water volume. The mid November release temperatures likely reflect the temperature of the tributaries to Millerton Lake and fall overturn dynamics of the lake.

The model representation of the gravel pits/alluvium interflow impacts is hypothetical and based on limited data. However, water returning to the river on a falling hydrograph would almost certainly be warmer than the pulse flow river temperatures.

Therefore abrupt decreases in flow such as 4,000 cfs to 350 cfs may create undesirable temperature impacts and such decreases should be avoided.

San Joaquin River temperatures computed using the “summer base flow” Kondolf hydrograph are plotted in Figure 4-5 for the period of June through September 2000. The summer base flow of 350 cfs and computed temperature is typical of each year. Under these conditions, temperatures reach a maximum daily temperature slightly greater than 70º F at Highway 41, suggesting that Highway 41 is the approximate downstream limit of the cold water fishery and spring run adult holding area. There is insufficient cold water storage in the existing Millerton Lake to provide additional base flow to move the cold water reach much father downstream.

Figure 4-6 shows computed temperatures for the “fall run attraction flow” Kondolf hydrograph for the period of October through December 2000. The same fall run attraction flow was assumed for all years. The pulse flow coincides with the time of the year when the dam discharge temperature approaches the equilibrium water temperature. Following the pulse release period, the river temperature decreases with distance downstream.

4.2 BYPASS SPRING PULSE THROUGH FRIANT-KERN CANAL

Friant Dam has the capacity to pass in excess of 4,500 cfs to the Friant-Kern Canal under favorable head conditions. During the spring, this capacity is under utilized due to reduced agricultural demand. The spring pulse bypass option assumes that water could be diverted to the river after passing through the Friant-Kern Canal outlet and powerplant. This option has the potential of conserving the cold water resources of the lake and may be a less expensive alternative to a selective withdrawal structure.

The Kondolf hydrograph spring pulse flows in excess of 350 cfs was assumed to pass through the Friant-Kern Canal outlet for each year. The total flow through the canal outlet was capped at 4,500 cfs. When the 4,500 cfs maximum was reached (this occurred frequently at the 4,000 cfs pulse flow rate), the excess was passed through the low level river outlet to the river. All river releases during the remainder of the year were passed through the low level outlet.

Figure 4-7 shows computed temperatures for 2000 (normal wet year) below Friant Dam and at Highway 41 with and without the hypothetical bypass. That year’s operation resulted in the greatest effect on temperature. The total bypass volume was 190,000 AF. With river pulse flows diverted through the bypass, computed temperatures below the Dam and at Highway 41 were increased as much as 4º F during the bypass period.

Temperatures at both locations, however, remained below 55º for the entire pulse period. During the summer months, the computed temperatures were approximately 2º and 1º F lower below the Dam and at Highway 41, respectively. The summer time reduction resulted for the conservation of cold water during the spring pulse period.

Results for 2002, a dry year, are shown in Figure 4-8. Temperatures are slightly higher during the spring pulse and slightly lower during the summer months. This year’s operation resulted in 68,000 AF of flow being diverted through the canal and in the smallest thermal impact.

The Madera Canal outlet accesses cooler water for a longer period of time since it is located approximately 20 feet lower than the Friant-Kern Canal outlet. During 2004, the Madera Canal outflow temperature remained below 55° F through mid July. Therefore, a modification to the Madera Canal outlet that allows discharge to the river directly below Friant Dam may provide additional flexibility in managing the cold water resources of Millerton Lake.

By passing the entire 350 cfs base flow through the Madera Canal outlet during the first half of the year, the cold waters of Millerton Lake could be conserved for use later in the year. A 350 cfs discharge during the period of July 16 through November 15 represents a volume of 85 TAF which is only slightly larger than the lake volume (85 TAF) below the Madera Canal outlet.

Fine tuning of the discharge rate combined with operation of these two candidate canal outlet river discharge facilities may reduce the elevated river temperatures predicted for mid November and their adverse impact on fisheries.

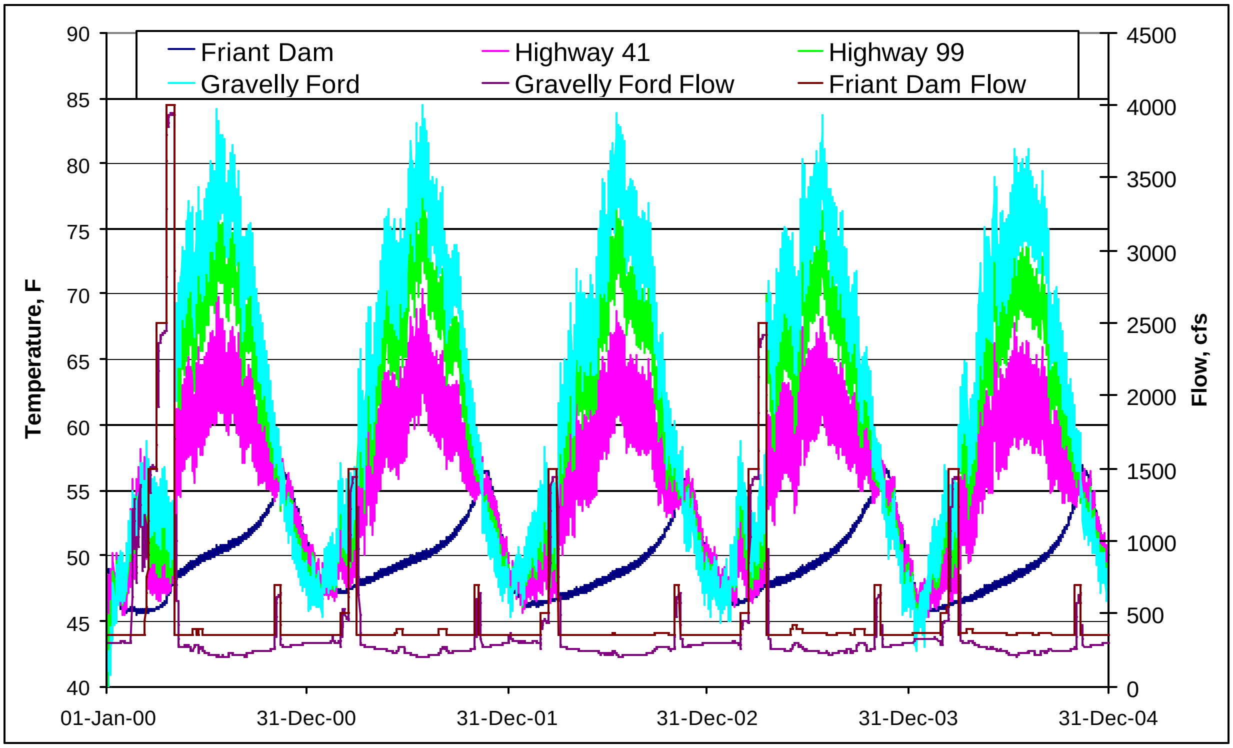

Figure 4-1 Kondolf Hydrographs - Computed Temperatures and Flow during 2000 through 2004

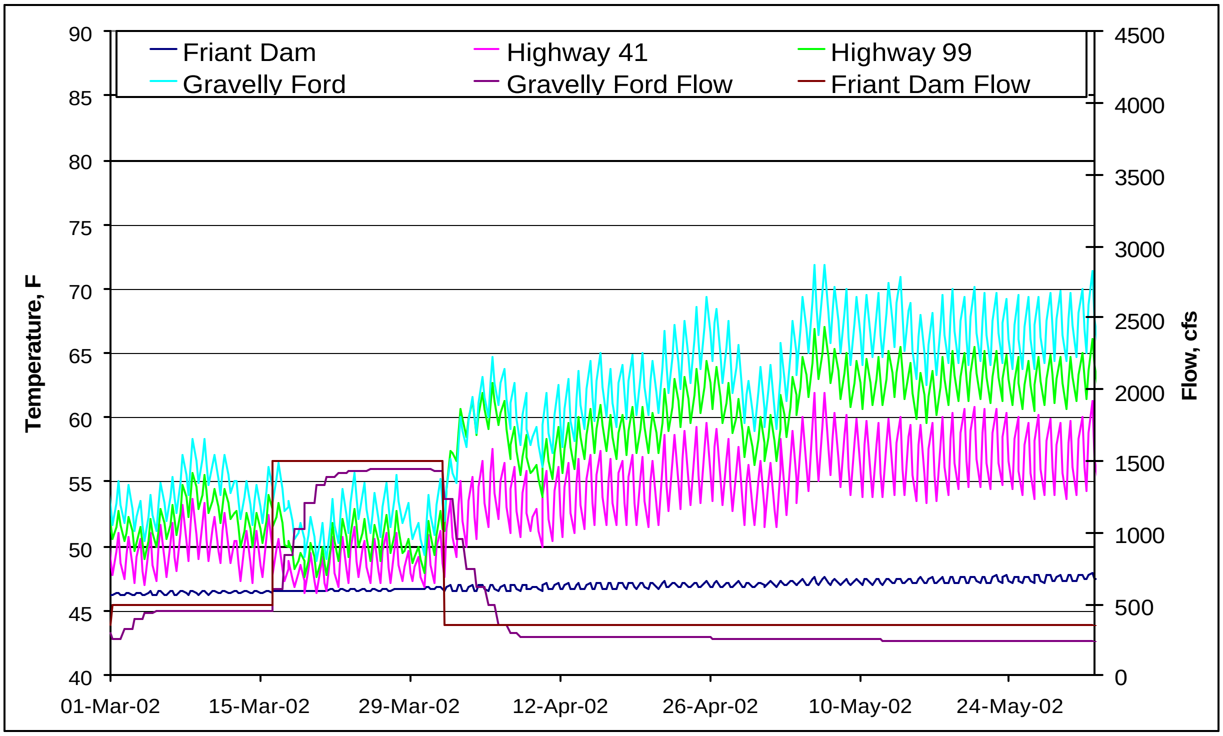

Figure 4-2 Kondolf Hydrographs - Computed Temperatures and Flow during “Spring Rise and Pulse Flows” Year 2002: Dry Year Type

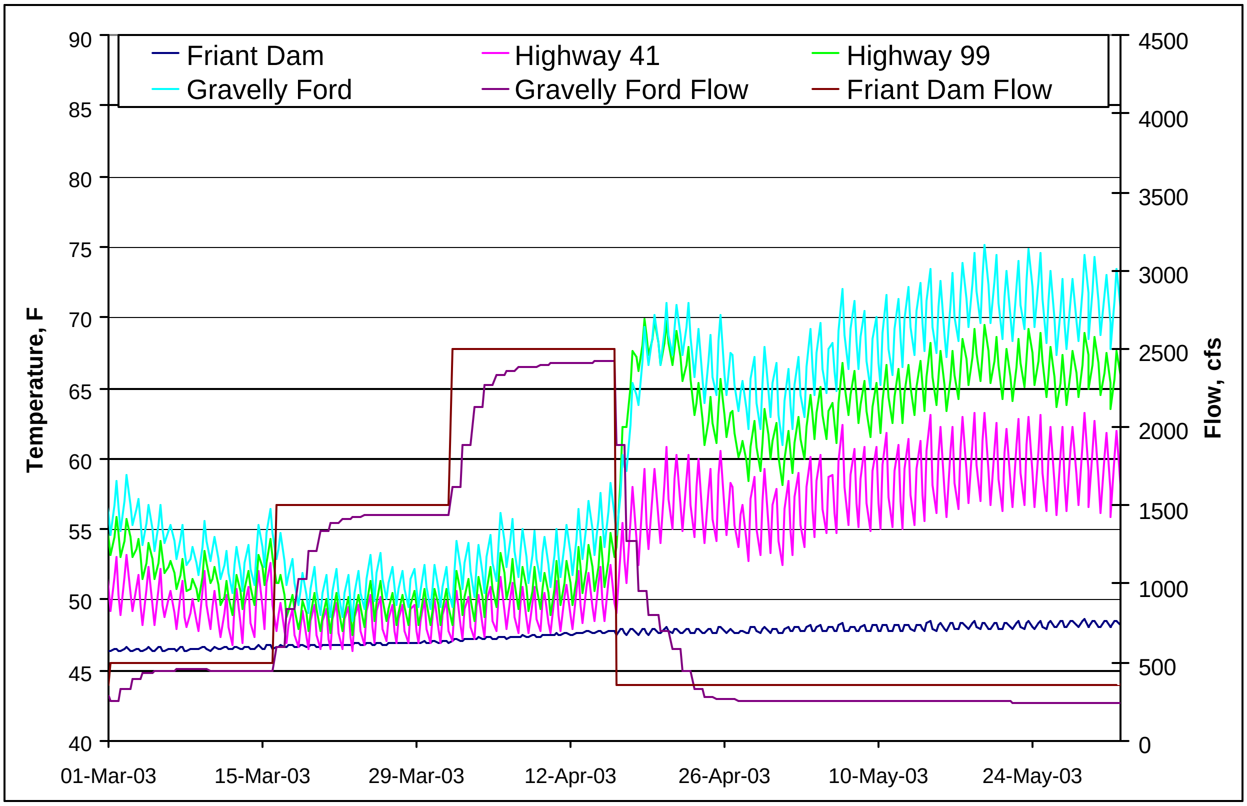

Figure 4-3 Kondolf Hydrographs - Computed Temperatures and Flow during "Spring Rise and Pulse Flows" Year 2003: Normal-Dry Year Type

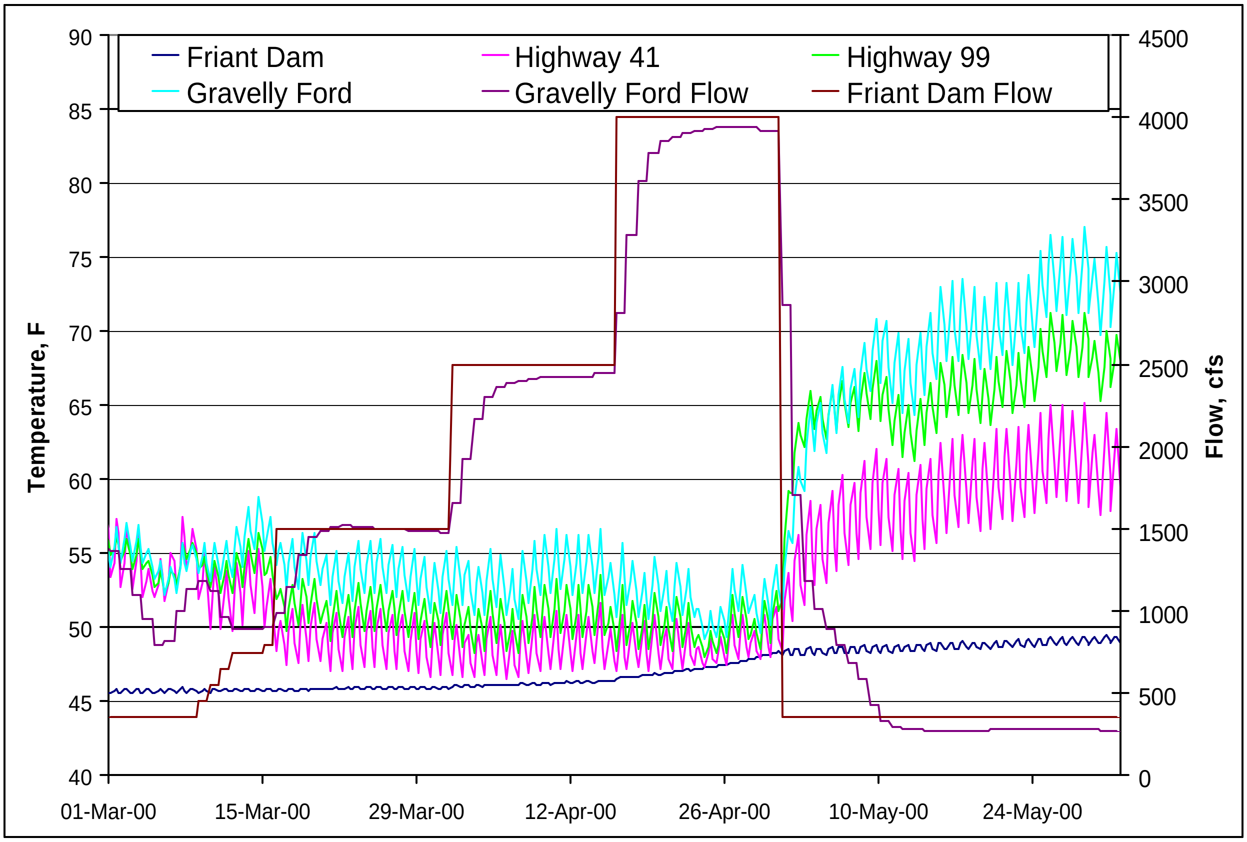

Figure 4-4 Kondolf Hydrographs - Computed Temperatures and Flow during “Spring Rise and Pulse Flows” Year 2000: Normal-Wet Year Type

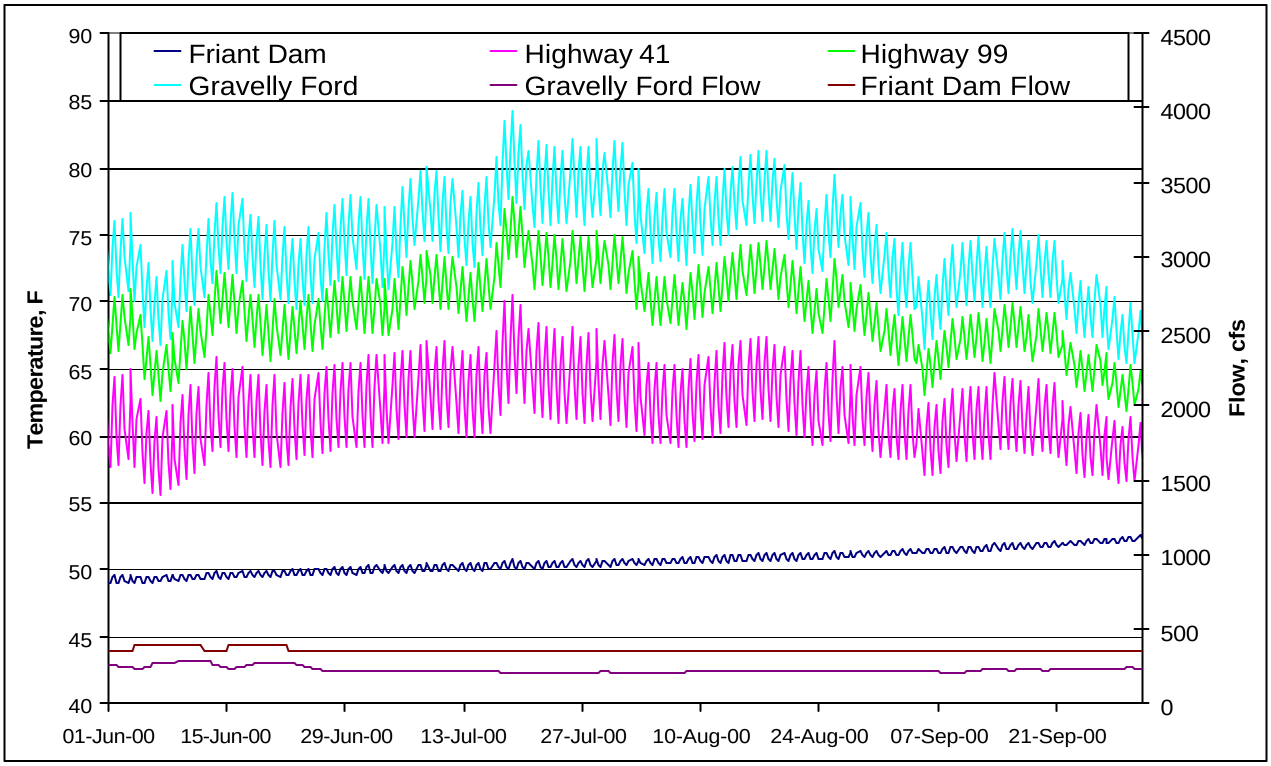

Figure 4-5 Kondolf Hydrographs - Computed Temperatures and Flow during "Summer Base Flows" Year 2000: Normal-Wet Year Type

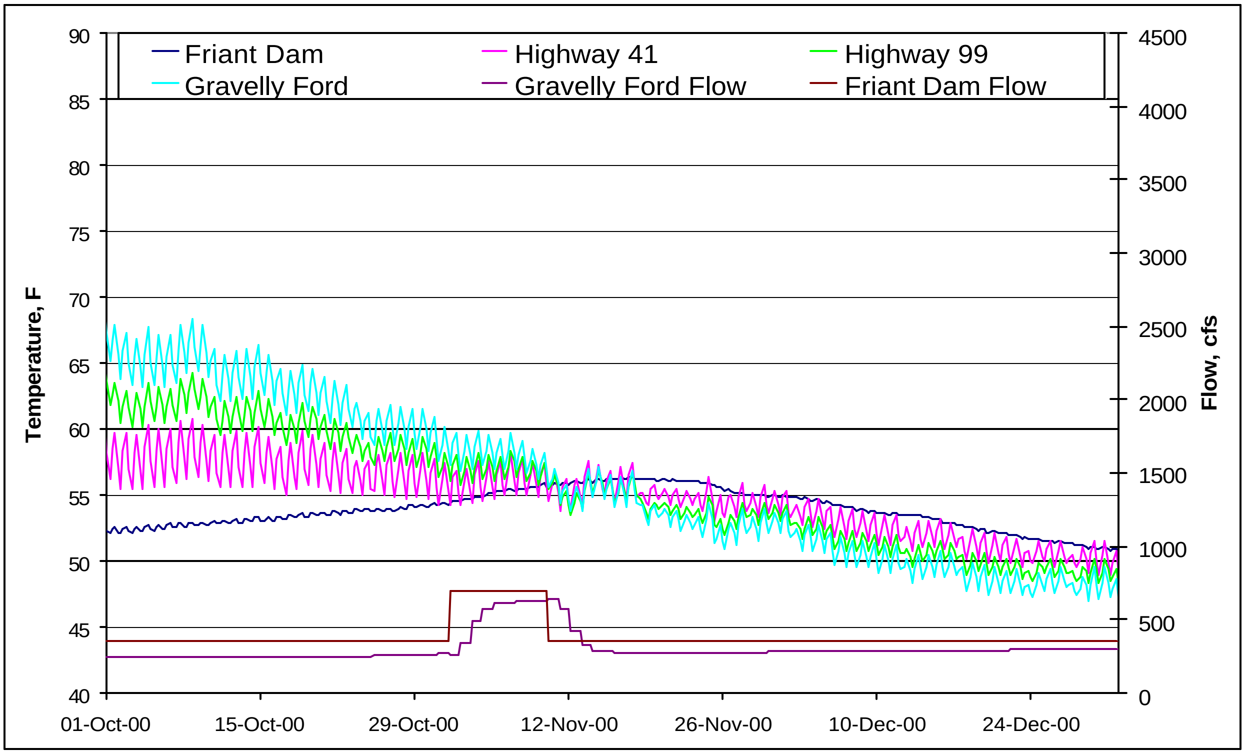

Figure 4-6 Kondolf Hydrographs - Computed Temperatures and Flow during "Fall Run Attraction Flow" Year 2000: (Same Flow for each Year)

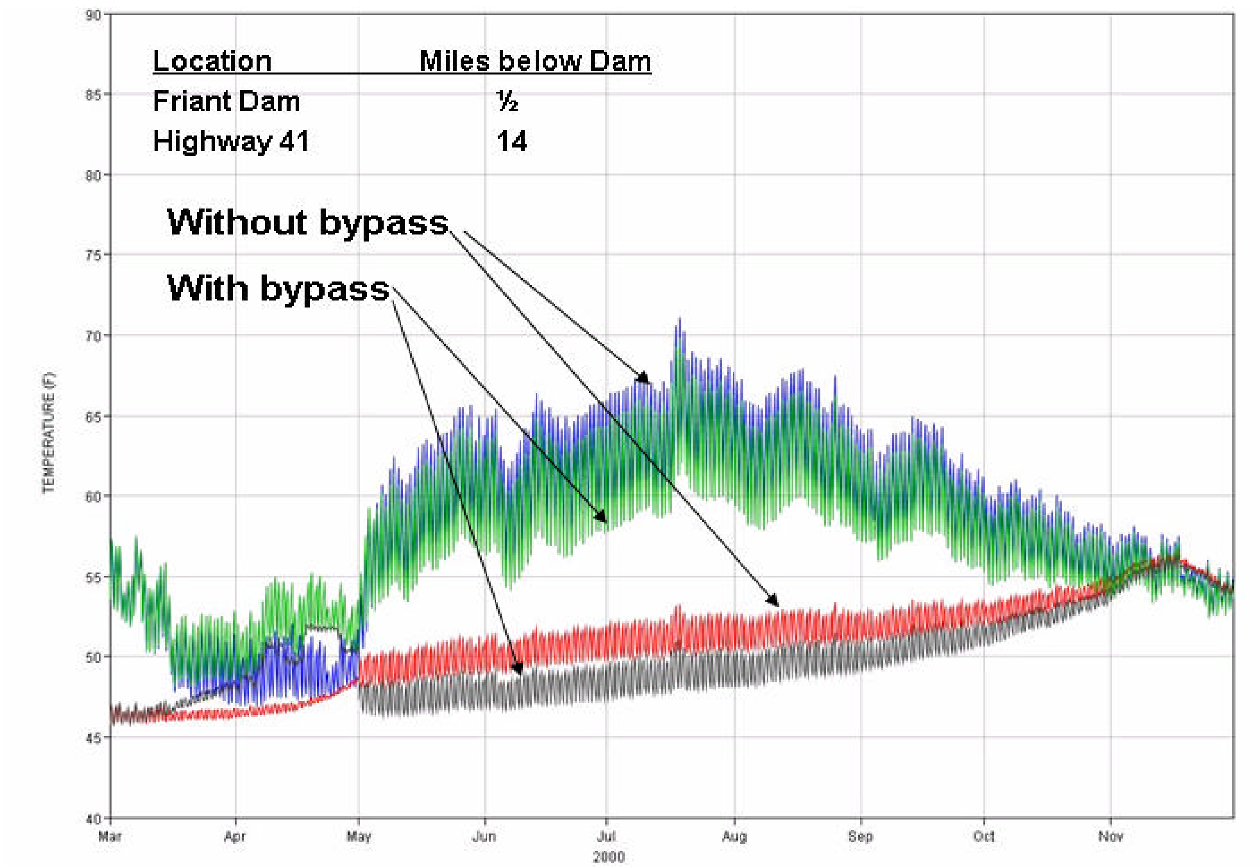

Figure 4-7 Kondolf Hydrographs – Friant-Kern Canal bypass of Spring Pulse flow – normal-wet year - maximum computed thermal impact

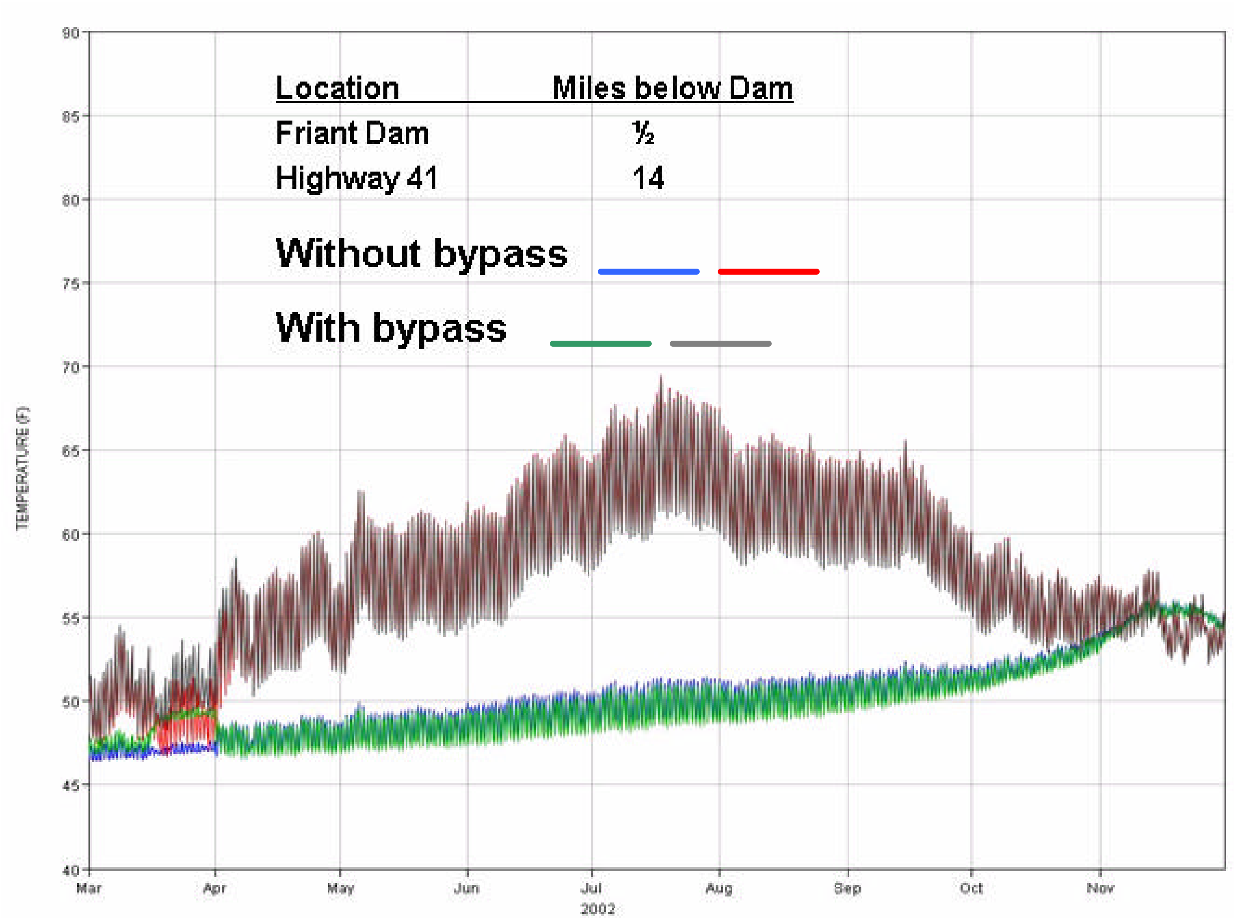

Figure 4-8 Kondolf Hydrographs – Friant-Kern Canal bypass of Spring Pulse flow – Dry year - minimum computed thermal impact

5 CONCLUSIONS AND RECOMMENDATIONS

The Millerton Lake/Friant Dam model was calibrated using observed temperature profile at multiple locations on the lake for 58 sampling dates between November 2002 and June 2005. Error analysis of the computed and observed temperatures indicated a negative bias during the winter months of October through March of -0.65^o F (0.36^o C). The bias in the model results for the remainder of the year was 0.05^o F. The average of the MAE and RMSE for the winter and summer period were similar (1.06^o F or 0.59^o C and 1.24^o F or 0.69^o C, respectively) indicating that the model's accuracy is only slightly seasonally dependant.

During the high runoff period of 2005, there was some variation in the observed epilimnion temperatures (up to 5^o F or 2.8^o C) between sampling locations on the lake. However, the maximum observed temperature variation between profile locations at the river outlet elevation was less than 1^o F for the same high runoff period. The available temperature data below Friant Dam indicates the model is accurate to within 1^o F during the period of observed tailwater temperature data.

The minimal longitudinal variation in observed temperature at the river outlet depth, the accuracy of the hypolimnion temperatures prediction, and reasonable representation of the discharge temperatures dynamics provides strong evidence that the model is a potentially useful tool for evaluating temperature impacts of alternative reservoir operation scenarios. At a minimum, it indicates the model can be used to screen the operation and water management alternatives for future fishery restoration objectives.

Preliminary river model temperature calibration simulations indicated the model was not producing elevated stream temperatures (observed at some locations on falling hydrographs of June and July of 2005) as the dam release dropped below a few hundred cfs. It was postulated that these elevated temperatures were influenced by warm water re-entering the stream channel as the gravel pits/alluvial deposits drained as channel levels dropped.

An offline storage component was installed in the model to quantify potential impacts of temporal storage adjacent to the stream channel. Subsequent analysis indicated the temperature of the returning water may be adequately approximated based on meteorology and flow. Significant impacts on temperature were limited to a few brief periods. However, as a general rule, sharp curtailment of dam releases should be avoided to minimize potential adverse thermal impacts and be considered as a part of reservoir regulation protocol.

Calibration of the San Joaquin River model utilized time series temperature data at numerous channel locations between Friant Dam and Patterson located approximately 169 miles below Friant Dam between the Tuolumne and Merced River confluences. Graphical and statistical comparisons of computed and observed river temperature time series were used to assess model accuracy. The offline storage component was disabled for reporting purposes due to reservations expressed by both the stakeholders and report reviewers. However, the error statistics improve with the inclusion of interflow.

The bias, MAE, and RMSE statistics were computed to quantify accuracy for the entire period of record (spring and summer 2005) and for Friant Dam release rates exceeding 250 and 300 cfs at each location. Minimum Friant Dam release rates under settlement flow conditions are 350 cfs for dry and wetter year hydrology. Therefore, flow related error statistics are an indicator of model accuracy for alternative operation evaluation conditions.

The weighted MAE and RMSE indicate the model is most accurate in the river segment below Friant Dam. The sample number weighted bias, MAE and RMSE for all locations above Mendota was -0.83° F, 1.73° F and 2.22° F, respectively. The negative bias above Mendota is attributed to consistently lower computed temperatures during the summer of 2004 and from ignoring the heating effects of offline storage during spring and summer 2005. The magnitudes of the errors appear slightly more dependant on flow above Mendota than below.

There is a positive bias below Mendota which increases with higher flows. The model generally under predicts diurnal variations below Mendota. The calibration emphasized maximum daily temperatures (important for salmonid survival); therefore, the positive bias is attributable to computed daily minimum temperatures that are too high. There is very little variation in the MAE and RMSE below Mendota for the various data categories. The uniformity of error statistics below Mendota is to be expected since river temperatures are near equilibrium with the atmosphere and subject to meteorological data approximations.

Temperatures below Mendota are also more dependant on inflow temperature rather than influenced by Friant Dam release flows and temperatures. The small computed diurnal variation is due, in part, to the specification of inflow temperatures. The average ratio of the RMSE to the MAE for all stations and periods is approximately 1.25, indicating there are no prolonged periods where the computed temperatures diverge dramatically from the observed.

Simulated temperatures in the river above Mendota during the summer of 2004 were consistently lower than observed and the diurnal variation was smaller than observed. The larger diurnal variation seen in the observed data suggests that the river flow rates were too high in the model. Additionally, locations such as Skaggs Park were poorly represented by the mode. The discrepancies point to the need for further calibration and flow regime refinements.

The intent of this modeling effort was to develop a system-wide engineering modeling tool capable of predicting the thermal responses of Millerton Lake and the San Joaquin River under a wide range of environmental conditions. This report documents the level of accuracy of the model, which is considered the first step in evaluating this difficult and complex problem.

The results presented in this report show that the model has the potential of accomplishing that goal. Issues such as temperature impacts of ground water interflow, ill-defined point inflows, and accretions and depletions need to be refined. Additional temperature profile data beyond June 2005 for Millerton Lake and river temperature data beyond December 2005 would provide the opportunity to further calibrate the model.

The course of further development of this modeling approach and its usage in the San Joaquin River restoration project evaluation is a decision to be made by Reclamation and other stakeholders of the restoration engineering team.

Numerous issues arise when considering future Friant and San Joaquin River operation needs:

- The need to determine how to balance the requirement of high flows in the spring for migrating adults and juvenile spring run Chinook salmon with the maintenance of a cold water pool in Millerton Lake for adults remaining in the river during the summer before fall spawning.

- The need to evaluate whether adult fall-run Chinook can migrate upstream to Reach 1 between mid October and mid December under base flow conditions.

- The need to evaluate how the groundwater inflows interact with the stream between Reach 4 and 5.

- The need to determine water-year types and the timing of the restoration flows consistent with the hydrograph release.

- The need to determine if the level of flood release meets the restoration flow hydrograph release made in accordance within Settlement flow objectives.

The following efforts are recommended for improving the temperature modeling:

Short-term effort:

- Reevaluate hydrology inputs and end extend the calibration/verification period through 2007. This task permits the model to have a better hydrologic cycle calibration (2005 and 2006 were wet years).

- Extend the restoration flow period of analysis to 1980 through 2006 to include critical dry through wet years.

- Develop release temperature response algorithm and embed with CALSIM. This task will enhance the temperature/operational modeling capability of the San Joaquin River.

- Evaluate use of the Madera Canal and/or Friant-Kern Canal alternatives of providing spring and summer discharge to conserve cold water pool.

Long-term effort:

- Continue field monitoring program and data collection. This information can be used to update and improve the model.

- Incorporate groundwater monitoring/modeling information from Reach 4 and 5 into the HEC-5Q model. This effort will help us understand if the pockets of water with suitable temperature can be established throughout the river under base flow conditions, whereas high flow may disrupt those pockets.

- Work with fishery biologists to define the temperature suitability for both the spring-run and fall-run salmon.

6 REFERENCES

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