

Expert Report of Michael L. Deas. Ph.D., P.E.

1. Introduction

I have been asked by the plaintiffs in *NRDC v. Rodgers* to provide an assessment of potential thermal conditions of restored flow in the San Joaquin River from Friant Dam to the confluence with the Merced River. I have also been asked to review the reports of Drs. Moyle and Kondolf and to assess temperatures that could be achieved by the flow regimes proposed in their reports. It is my understanding that their proposed flow regime would allocate seasonal blocks of water to meet requirements of Chinook salmon and that the precise timing of releases from Friant Dam could be adjusted in light of meteorological and other conditions in any given year.

This report sets out my conclusions and methodology. For the reasons explained herein, it is my opinion, based on the available evidence, that the flow schedules proposed by Drs. Moyle and Kondolf will achieve temperatures consistent with the requirements that Dr. Moyle has identified for Chinook salmon. Of course, in any endeavor such as evaluating thermal conditions on a restored river, uncertainties exist, and this report also discusses those uncertainties.

The information used to define and outline the potential for restoring flows sufficient to manage temperature in the San Joaquin River is presented in several sections. The first section introduces thermal concepts useful in understanding reservoir and river thermal regimes. These concepts are presented and supported with conditions on the San Joaquin based on available field data. The second section presents the likely thermal conditions that would result from various flow regimes based on available data and available models. The report concludes with a summary and recommendations. References, figures, tables, as well as qualifications and other miscellaneous matters are included as exhibits.

2. Temperature Considerations for Regulated Rivers and Implications for the San Joaquin River: Conceptual Framework

The thermal regime of rivers that are regulated by large reservoirs plays a critical role in the planning and management of water temperature for restoration and maintenance of anadromous fish as well as other native fishes. Outlined herein are several water temperature concepts that potentially play a role in temperature assessment. The concept of equilibrium temperature is presented first, as a basis for much of the following discussion. Subsequently, several concepts are presented with a specific description of conditions as they pertain to the San Joaquin River. Because the available models for the San Joaquin River are largely untested and, because the river is dewatered, field observations of the river are limited, the information presented herein provides a screening level analysis. In other words, available data and models allow an assessment of feasibility but further studies would be appropriate to determine details, components, and timelines of a long terms restoration plan.

The Concept of Equilibrium Temperature

Background

The exchange between water (i.e., a lake or river) and its surroundings (i.e., the atmosphere and channel bed) may be expressed as conservation of energy,

Change in heat storage = net heat flux = heat energy in – heat energy out

or in terms of heat fluxes

$$q_{net} = q_{sw} + q_{atm} - q_b \pm q_l \pm q_h \pm q_g$$

where q_{sw} is short-wave (or solar) radiation, q_{atm} is down-welling long-wave (or atmospheric) radiation, q_b is upwelling long-wave (back, or water surface) radiation, q_L is latent heat flux, q_h is sensible heat flux, and q_g is conduction between the water and the bed (Martin and McCutcheon, 1999). When energy in exceeds energy out, q_{net} is positive, energy is stored in the water volume with a resulting rise in temperature. When energy out exceeds energy in, q_{net} is negative, and

1 energy is lost from the water volume with a resulting fall in temperature. The relative magnitude
2 throughout a calendar year is presented in **Figure 2**. The fate and transport of heat energy in a
3 river system is typically represented by the advection diffusion equation, i.e., for a one-
4 dimensional simplification (depth and laterally averaged river):

$$\frac{\partial T}{\partial t} + u_x \frac{\partial T}{\partial x} = \frac{\partial}{\partial x} \left(D_x \frac{\partial T}{\partial x} \right) + \frac{q_{net}}{\rho_w C_s} \frac{A}{V}$$

6 The net heat flux, q_{net} , is located in the last term on the right hand side of the equation. Where T
7 is temperature, t is time, x is distance, u_x is velocity in the longitudinal direction, D_x is diffusion
8 in the longitudinal direction, ρ_w is water density, C_s is specific heat of water, A is surface area of
9 a representative reach (across which the heat flux occurs), and V is volume of the representative
10 reach.

11
12 Equilibrium temperature is the unique water temperature for which q_{net} in equation (1) is zero,
13 given a particular set of meteorological conditions. Equilibrium temperature is the temperature
14 that would be reached if all meteorological conditions were to remain constant with respect to
15 both space and time, and water was allowed to reach a steady temperature in response to such
16 static meteorological conditions. In reality, this temperature is rarely achieved because
17 meteorological conditions are never steady. However, equilibrium temperature can be a useful
18 concept when considering thermal conditions in aquatic systems. Streams or lakes may in some
19 circumstances be assumed to be at equilibrium temperature. For example, the surface layer of a
20 lake may be at equilibrium, while temperatures of lower layers are governed by more complex
21 mixing processes. Slow sluggish stream, small tributaries, sloughs, and backwaters are often at
22 or near equilibrium temperature. In contrast, groundwater fed streams and streams controlled by
23 upstream reservoirs that release very cold or warm water may not reach equilibrium temperature
24 for some distance downstream.

25 26 Implications for the San Joaquin River Downstream of Friant Dam

27 Friant Dam impounds the San Joaquin River at approximately river mile (RM) 267, forming
28 Millerton Reservoir with a capacity of approximately 520,500 acre-feet. The San Joaquin River
29 below Friant Dam flows generally westward and then northwest to the confluence with the

1 Merced River at approximately River Mile 120 (**Figure 1**). **Table 1** provides a list of river miles
2 and selected landmarks for the San Joaquin River between Friant Dam and the Merced River.
3 Upstream of Millerton Reservoir are a host of additional reservoirs, primarily used for
4 hydropower operations, with a total storage of approximately 611,688 acre-feet (**Table 2**).

5
6 As a result of the appreciable storage not only in Millerton Reservoir, but in upstream lakes and
7 reservoirs as well, during much of the year releases from the river outlets at Friant Dam are
8 below equilibrium temperature (thermal conditions of Millerton Reservoir are discussed below).
9 That is, the water temperature of cool, deep waters released from Friant Dam are not in
10 equilibrium with meteorological conditions experienced in the downstream river reaches.
11 During periods when release waters are below equilibrium, and the river water temperatures
12 increase with increasing distance from Friant Dam until they reach a point where they are in
13 equilibrium with meteorological conditions. At this point the daily mean temperature does not
14 deviate appreciably with increasing distance from Friant Dam (however, a daily, or diurnal,
15 temperature signal is imposed on the river due to daily variability in conditions primarily
16 associated with solar radiation). The distance downstream where waters attain equilibrium is a
17 function of several factors, including, but not limited to quantity of water released from Friant
18 Dam, temperature of water released from Friant Dam; meteorological conditions; diversions
19 from the river; surface inflows to the river; river exchange with groundwater; channel attributes
20 such as gradient, cross section; and riparian shading. These attributes, and their potential
21 implications in temperature control, are presented below.

22
23 As discussed herein, the flow regime proposed by Drs. Moyle and Kondolf attains desirable
24 temperatures by relying on cool water releases from Friant Dam throughout the year, particularly
25 in the spring, summer, and fall periods. Seasonal increases in flows during certain periods of the
26 late winter and spring to manage water temperatures when meteorological conditions are
27 conducive to only modest heat gain between Friant Dam and the Merced River.

1 *Thermal Regimes of Reservoirs and Lakes*

2 Background

3 The rate of change of heat content in a lake or reservoir is determined by the rate of heat
4 transport into and out of the water body at the air- and bed-water interfaces, as well as transport
5 of heat from inflows and outflows (TVA, 1972). The surface of most large lakes can be assumed
6 to be at or near equilibrium temperature. However, water temperature beneath the surface is not
7 necessarily at equilibrium temperature because it is not in direct contact with the atmosphere.

8
9 While energy flux (i.e., solar radiation, long-wave radiation, latent and sensible heat flux)
10 determines heat load into a lake or reservoir, fluid movement within the water body determine
11 heat distribution within the lake itself. Deep lakes tend to exhibit a characteristic seasonal cycle
12 of vertical stratification, where warm, less dense surface waters “float” on cooler, denser deeper
13 waters. In the winter, reservoirs are typically isothermal throughout (temperature is vertically
14 uniform). During the spring and early summer period surface layers of the reservoir begin to
15 warm in response to increasing intensity of solar radiation, which decreases exponentially with
16 depth. Wind acts to mix water near the top of the lake, gradually mixing warm surface water
17 with layers of cooler water beneath, to distribute heat downward. The result of this combination
18 forces is a layer of warm, less dense water overlying layers of colder, denser water below. The
19 thickness of this zone of mixing is a function of solar intensity and the wind regime, along with
20 other factors that affect mixing (e.g., inflow and outflow dynamics and lake morphology) and
21 solar extinction (e.g., turbidity, primary production, and lake morphology). Throughout the
22 summer, continued input of solar radiation accompanied by wind mixing continue to warm the
23 surface layer, making it increasingly less dense than cool bottom waters. This process results in
24 stratification, a common occurrence in deep temperate lakes during summer months. A sharp
25 temperature gradient called a thermocline forms in the metalimnion, the region that separates the
26 surface layer (epilimnion) from the bottom layer (hypolimnion). Water motion in the epilimnion
27 is dominated by wind mixing, while motion in the hypolimnion, protected from wind induced
28 mixing by the thermocline, tends to be sluggish or quiescent. **Figure 3** shows a representative
29 example of this layer system (Deas and Lowney, 2000).

1 In late summer, the energy balance shifts and surface cooling occurs. As surface waters cool,
2 their density increases, and these cool parcels begin to sink, mixing with water at lower depths
3 and eroding the thermocline – a process termed convective mixing. Surface winds continue to
4 provide mixing energy in the epilimnion and, coupled with convective cooling deepens the
5 epilimnion and the impoundment gradually progresses toward an isothermal condition (Fischer
6 et al, 1979). This mixing process is sometimes called the “fall overturn” even though it may not
7 completely involve all of the water stored within the reservoir, nor does it suggest that the waters
8 of the reservoir are physically turned-over.

9
10 The hypolimnetic waters are often used as a source of cold water to maintain water temperatures
11 in river reaches below large main stem reservoirs during warmer periods of the year. It is
12 important to note that cold water supplies available for release during the spring through fall
13 period in a reservoir are often relic water from the winter period. If it is exhausted during the
14 summer period, there is often no replacement cold water until the subsequent winter. However,
15 in certain reservoirs cold water inflows occur during even during the warmer periods of the year.
16 This cooler, denser water can replenish cold water supplies in the hypolimnion (Fischer et al,
17 1979), and thus provide potential for increased temperature control in river reaches downstream
18 of the dam.

19 20 Implication on the San Joaquin River: Millerton Lake

21 Millerton Lake on the San Joaquin River has a maximum storage of approximately 520,500 acre-
22 feet. During winter periods the reservoir fills with cold water and typically exhibits isothermal
23 or near isothermal conditions. The onset of thermal stratification occurs in March or April, often
24 corresponding with increased storage. The reservoir is sufficiently large and deep to experience
25 seasonal thermal stratification, and by May such conditions are clearly evident in typical years
26 **(Figure 4).**

27
28 Canal operations for the Friant-Kern Canal and Madera Canals are impaired below elevations of
29 approximately 471 ft mean sea level (msl) and 446 ft msl, respectively (URS, 2002). The river

1 outlets are located at about 375 ft msl and the top of the drum-type spillway is 578.0 ft msl
2 (520,500 acre-feet) (USGS, 2001). The river outlets access reservoir elevations where
3 temperatures are typically range from 48 to 52°F (9-11°C) based on vertical profile observations
4 of water temperature in Millerton Reservoir data provided by Reclamation (USBR Reservoir
5 Data) Water temperatures measured approximately 0.75 miles downstream of Friant Dam
6 (**Figure 5**) indicate that these deeper reservoir waters are released to the downstream river reach.
7 Though available information is limited, data suggest that water temperatures are cool
8 throughout the summer period, a conditions supported by the existence of a trout hatchery
9 downstream of the dam.

10
11 Using a stage-volume table based on U.S. Bureau of Reclamation data (USGS, 2001) (**Figure 6**)
12 the hypolimnetic volume is estimated to be approximately 90,000 acre-feet under typical storage
13 conditions. Under the current release rate of approximately 200 -225 cubic feet per second (cfs)
14 (URS, 2002) through the summer period there is sufficient water in the hypolimnion to last for
15 over 200 days; however, there is no shortage of cold water under current operations. In the case
16 of the San Joaquin River inflow to Millerton Reservoir during summer periods, cold waters
17 inflows from upstream (e.g., Kerchoff Powerhouse) appear to replenish a portion of the cold
18 water pool within Millerton Reservoir to some degree and thus extend the cold water available
19 for release below Friant Dam. Limited data available from Ecological Analysts (1980) (**Figure**
20 **7**) suggest that inflow temperatures remain under 60°F (15.6°C) into June. Consistent with these
21 estimates, the reservoir does not currently experience a shortage of cold water for existing
22 downstream uses (e.g., hatchery operations).

23
24 For appreciably larger release volumes during summer periods, the cool water available in the
25 hypolimnion could be exhausted. Further, the influence of a sufficiently large withdrawal in the
26 warmer months from the river outlets – sometimes termed a withdrawal envelop – may lead to
27 warmer temperature conditions for discharges to the San Joaquin River below Friant Dam.
28 Nonetheless, the modest increases in summer flow identified by Drs. Moyle and Kondolf are

1 most likely not sufficiently large to lead to a loss of cold water supplies for downstream reaches.
2 Ongoing summer monitoring of reservoir thermal conditions and operations would provide the
3 necessary information to efficiently and effectively manage temperature below Friant Dam.

4
5 Field observations, in the form of vertical temperature profiles indicate that infrequently the
6 reservoir will fill with slightly warmer water than in typical years.

7
8 Figure 8 illustrates June profiles from 1959-1978, wherein deep waters are less than 50°F (10°C)
9 for all years except 1969 when deeper water temperatures were on the order of 52-53°F (11.1-
10 12.8°C) (USBR Reservoir data)

11
12 Overall, although uncertainty exists as to the degree with which cold water replenishes Millerton
13 Reservoir due to lack of physical measurements and analytical assessment, there is appreciable
14 cold water storage in Millerton Reservoir and cool water inflows through spring. The
15 information and data discussed herein indicates that there is sufficient cold water in storage and
16 from upstream locations (above Millerton Reservoir) to provide the range in release temperatures
17 specified by Dr. Moyle below Friant Dam for the proposed preliminary flow regime presented by
18 Drs. Moyle and Kondolf. Further, until the reservoir experiences appreciable thermal
19 stratification, which typically occurs sometime in mid-April through mid-May, water
20 temperatures throughout the depth of the reservoir are cool (exception being the near-surface
21 waters). Nonetheless, any identified restoration activities would benefit from consideration of
22 the Friant Dam/Millerton Reservoir complex, as well as water resources development in the
23 upper San Joaquin River basin. Further study may show that more cold water could be made
24 available through modified management of upstream sources. Additional reservoir operations
25 features to assist in temperature control that may be considered, should more careful
26 management be desired, include temperature control curtains and selective withdrawal devices
27 (Vermeyen, 1995, 1997, 1999) as well as other physical structures. Such measures can
28 maximize the use of cold water and improve both temperature control and water supply
29 reliability.

Thermal Regimes of Regulated Rivers

Background

Natural streams are often at or near equilibrium temperature; however, this equilibrium assumption may not be appropriate for streams and rivers fed by groundwater, impacted by water resources utilization/development, as well as those regulated by upstream reservoir releases. If a reservoir release water temperature is cooler than equilibrium temperature, the water temperature will rise exponentially toward equilibrium as water travels downstream. Conversely, if the controlling source is below equilibrium, average daily water temperature will fall exponentially toward equilibrium. These two cases are illustrated in **Figure 9** for a release temperature (a) below equilibrium and (b) above equilibrium temperature, respectively.

In a natural stream, not subjected to control by an upstream regulating reservoir, the magnitude of diurnal stream temperature variation is typically inversely proportional to flow rate (Constantz, et al., 1994). Local changes in heat flux through the air-water interface associated with changes in atmospheric conditions due to riparian or topographic shading, or geographic orientation, may also influence the diurnal range. Further, diversion and return flows, groundwater, and tributary contributions may also alter the diurnal temperature regime.

Diurnal variation of stream temperature can be strongly influenced by reservoir management. To maintain cold water downstream of large reservoirs during summer periods, releases are sometimes drawn from the hypolimnion (i.e., beneath the thermocline) where water temperature are cool and exhibit little diurnal variation. Although local changes in heat flux at the air-water and air-ground interfaces may affect diurnal temperature variation, particularly in an unregulated river, the strongest influence on diurnal temperature variation in a river regulated by a large reservoir may be the temporal signature of the reservoir release itself. When an upstream regulating reservoir supplies nearly constant flow and temperature, a unique pattern of diurnal variation may occur downstream of the regulating reservoir. At a location equivalent to one day's travel downstream from the reservoir, diurnal temperature variation diminishes to a minimum, repeating the temporal signal at the release point and forming the first of several nodes of minimum diurnal temperature variation. In addition to nodes of minimum diurnal

1 variation, anti-nodes of maximum diurnal variation are also formed at locations equivalent to odd
2 multiples of 12 hours of travel downstream from the reservoir (**Figure 10**). A principal
3 component of this feature is the high heat capacity of water (e.g., four times that of air) and thus
4 the ability to advect thermal energy downstream in flowing rivers.

5
6 Changes in flow, which affect travel time, can interrupt the formation of nodes and antinodes, as
7 do external sources of heat such as tributary inflows. Nodes and anti-nodes have been observed
8 in the Klamath River (Lowney, et al., 1997) and the Sacramento River (Deas et al., 1997).
9 Similar behavior has been observed in other regulated systems. Field investigation of diurnal
10 temperature variation gives new insight into the velocity regime of regulated rivers.

11 Implication on the San Joaquin River: Friant Dam Releases and Downstream San Joaquin 12 River Temperatures

13
14 Release temperatures in spring through fall from Friant Dam are cooler than meteorological
15 conditions warrant, i.e., the releases are below equilibrium temperature. Thus, the river heats in
16 the downstream direction similar to **Figure 9(a)**, and it is expected that a series of nodes of
17 minimum diurnal variation are expected to occur within the river system. Simulation results
18 from the Jones and Stokes temperature model, which produces daily maximum and minimum
19 temperatures, indicate the potential for such phenomenon on the San Joaquin. It is expected that
20 due to the various return flows and large variation in base flow throughout this long reach that
21 these nodes probably will not persist to the confluence with the Merced River, but their presence
22 (or absence) will be largely dependent on meteorological and flow conditions (discussed below),
23 return flow quantity and temperature, and interaction with groundwater. Such results can greatly
24 facilitate calibration of flow travel times in models with sub-daily time steps (Deas and Orlob,
25 1999).

26 *The Impact of Seasonal Meteorological Conditions and Flow*

27
28 The rate of heating and the ultimate equilibrium temperature of the San Joaquin River is
29 primarily a function of flow rate, meteorological conditions, channel geometry, and riparian
30 shading. (Topographic shading in the reach below Friant Dam is deemed minimal, and the role

1 of bed conduction on overall rate of rise and ultimate equilibrium is not assessed in detail
2 herein.) For the purposes of this discussion flow rate and meteorological conditions are
3 addressed for a fixed geometry and without riparian vegetation restoration. Riparian shading and
4 geometry are discussed separately in subsequent sections.

6 Implications on the San Joaquin River: Meteorological Conditions and Water

7 Temperature Control Strategies

8 In certain respects, the San Joaquin River is similar to other Central Valley streams that support
9 Chinook salmon populations. In these rivers it is typical that in downstream reaches there are
10 temperature control concerns in the late spring and summer periods. Because of the significant
11 distance from Friant Dam to the Merced River, it is expected that it would be challenging to
12 provide temperature control throughout this reach during these warmer periods of the year.

13
14 During the maximum thermal loading months of late spring and early summer the water
15 requirements to attain temperature control to the Merced River (and presumably downstream as
16 well) is uncertain given the level of water resources development (e.g., levees, channel
17 modifications) and variability of meteorological conditions. The ability to control temperatures is
18 expected to be largely dependent on meteorological conditions and later in spring and on into
19 summer these factors become difficult to overcome or control through flow because thermal
20 loading is too great and the distance from Friant Dam is simply too great. However, prior to and
21 following the period of maximum thermal loading there are opportunities to take advantage of
22 meteorological conditions that may provide temperature control alternatives. For example,
23 during the late winter and early spring water temperatures are cooler and thermal loading has not
24 yet peaked, leading to relatively cool water conditions which are more conducive to anadromous
25 fish restoration. Further, there is an appreciable amount of variability in terms of “hot” and
26 “cold” spells during spring. Short-term deviations from seasonal normal meteorological
27 conditions are expected – both warmer and cooler. These meteorological conditions are imposed
28 on the river and water temperatures respond accordingly. **Figure 11** includes daily average air
29 temperature from the Five Points No. 2 CIMIS Station (California Irrigation Management
30 Information System) and **Figure 12** hourly water temperature for the San Joaquin River near
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1 Stevinson (upstream from the Merced Confluence) for January through May, 2001. Flow in the
2 San Joaquin River near Stevinson during this period was less than approximately 500 cfs. Using
3 air temperature as a surrogate for overall meteorological conditions, the relationship between
4 meteorological conditions and water temperatures is apparent for both seasonal and short-term
5 variations.

6
7 The specific implications of meteorological conditions as they relate to water temperatures
8 (diurnal variation and longitudinal distribution) related to flow are discussed in greater detail,
9 below. In addition these concepts are revisited in the modeling analysis section.

10 11 *Role of Riparian Shading on Regulated Rivers*

12 Riparian vegetation (woody vegetation, e.g., trees) shading can play an important role in
13 management of water temperatures in river systems through reduction of incoming solar
14 radiation. The size of the river as well as the stature and status of the riparian vegetation are
15 critical attributes in assessment of riparian vegetation effects. For large rivers, such as the
16 Sacramento River where river widths of greater than 500 feet are not uncommon, the role of
17 riparian vegetation (even mature gallery forests) has only modest effects because the river is
18 simply too wide for shading to have an appreciable impact. However, for smaller rivers riparian
19 vegetation can sufficiently reduce incoming solar radiation to have an impact on water
20 temperatures.

21
22 An important consideration in planning and management of water temperatures through the use
23 of riparian vegetation shading in regulated rivers, beyond river size and existing and/or potential
24 woody vegetation, is in-stream water temperature. As noted previously, in regulated rivers
25 waters may be released at temperatures well below equilibrium and increase in water
26 temperature with distance downstream in response to local meteorological conditions. **Figure 13**
27 illustrates a hypothetical condition with and without shading. The effects of riparian vegetation
28 shading play a larger role in downstream reaches where water temperatures are closer to
29 equilibrium: **Figure 13** illustrates that both with and without shading cases are nearly coincident
30 for some distance below the dam. Even with riparian vegetation shading on the river the

1 equilibrium temperature is well above the dam release temperature, resulting in a relatively rapid
2 rise as water travels downstream. In other words, shading has a modest impact on controlling
3 main stem water temperatures in the reaches immediately below the dam because release
4 temperatures are appreciably cooler than shaded equilibrium temperatures. Such findings were
5 borne out in studies for the Sacramento River where cold water released from Shasta Dam heat
6 toward equilibrium temperature with increasing distance downstream (Deas, et al 1997). This is
7 not to say that riparian vegetation cannot or does not provide benefit in these reaches,
8 particularly in regard to thermal diversity (see below), but that riparian vegetation shading has a
9 potentially larger impact in reaches where water temperatures are approaching equilibrium.

11 Implications on the San Joaquin River: San Joaquin River below Friant Dam

12 No data were reviewed to identify the current extent of woody riparian vegetation below Friant
13 Dam, nor the potential for riparian vegetation in the reach between Friant Dam and the Merced
14 River. Riparian vegetation shading could play an important on the San Joaquin River where
15 temperature management is proposed for roughly 140 river miles below Friant Dam. Potential
16 flow ranges could span several thousand cubic feet per second. At very low flows riparian
17 vegetation could have appreciable local impacts on water temperature. At the higher proposed
18 flows in late winter in spring, riparian vegetation may have variable effects depending on the
19 quantity of flow and whether the vegetation has leafed out to a sufficient degree to provide
20 significant shading. Riparian vegetation can also provide large woody debris to the river which
21 can provide opportunity for thermal diversity within the channel (see below). Additional study
22 would be beneficial to more explicitly quantify the full range of potential impacts associated with
23 riparian shading under a restored condition. In general, increased riparian vegetation would
24 improve the opportunity for cool water refugia and thermal diversity in the system.

26 *Flow Quantity and Water Temperature Control Strategies*

27 Modification to flow rates can affect water temperature in several ways. First, larger flows can
28 lead to increased mean channel velocity and decrease transit time. In regulated rivers where
29 releases from large main stem reservoirs are often below equilibrium in late-winter through fall
30 months, the decrease in transit time leads to a decrease in “exposure” to the thermal loading

1 influences, which can lead to a reduced rate of heating and cooler downstream temperatures.
2 Further, because the specific heat of water is relatively large (e.g., compared to air), larger
3 volumes of water tend to heat (and cool) more slowly than smaller volumes. Thus, higher flow
4 volumes tend to heat less quickly. There are exceptions where field conditions can offset
5 changes in temperature due to increased flow, e.g., geometry or cross section characteristics.

6
7 Because larger volumes of water may heat more slowly than smaller volumes, there is a critical
8 point where the ratio of river width and depth provide a similar benefit. That is, small wide
9 rivers can gain and lose heat more quickly than narrow deep rivers, e.g., water spilled out over
10 flood plains may heat more quickly than that in the main river channel. It is important to assess
11 existing and potential future river geometric configuration to properly represent these conditions
12 in model simulations, particularly at low flow rates/volumes.

13
14 Another consideration in managing temperature with flow is the impact on diurnal temperature
15 range. Both maximum and minimum daily temperature criteria can play a role in determining
16 the appropriateness of thermal regimes for anadromous fish (e.g., daily maximum temperatures
17 up to X °C are acceptable if daily minimum temperatures fall below Y °C). For larger flow
18 volumes the diurnal range is often smaller than for small flow volumes, i.e., smaller volumes can
19 gain and lose heat quickly in response to the differences in meteorological conditions between
20 daytime (solar loading) and nighttime – leading to a larger diurnal range.

21
22 In sum, larger flow rates can decrease the rate of heating due to increased flow volume and
23 decreased transit time; however channel geometry may play a role. Due to the increased volume,
24 the diurnal range is smaller (lower daily maximum and higher daily minimum). The inverse
25 holds for small flow volumes. These attributes of flow-temperature relationships should be
26 considered when assessing flow regimes.

27 28 Implications on the San Joaquin River: San Joaquin River Below Friant Dam

29 Flow management to control water temperature on the San Joaquin River below Friant Dam is an
30 important component of any proposed solution. Issues of transit time, flow volumes,

1 equilibrium, and channel geometry are discussed below with regard to temperature response in
2 the San Joaquin River.

3
4 Based on reach-averaged hydraulic conditions as simulated by Mussetter Engineering (2000a,
5 200b), travel times were estimated for flows ranging from 100 to 8000 cfs. These flows are for
6 the San Joaquin River proper and do not include the bypass. Travel times are appreciable for
7 low flow conditions – on the order of weeks. The longer the travel time and the smaller the flow
8 volume the less conducive to active temperature control through flow management.

9 Expanding on the concept of travel time and the implications that travel time may hold for water
10 temperature management, longitudinal temperature profiles were developed for conditions
11 downstream of Friant Dam, based on simulations performed by Stillwater Sciences (these are
12 employed herein primarily for illustration purposes, with model limitations discussed in the
13 subsequent section). This information, presented in **Figure 14**, illustrates several concepts of
14 heat gain from a cold water release at Friant Dam for different flow rates at different times of the
15 year. These simulated temperatures assume no diversion, return flows, tributary inputs,
16 groundwater exchange, riparian shading, etc. – the results, as presented, are only for the
17 discussion of temperature concepts. Examining the monthly traces indicates several factors:

18 - all traces rise exponentially from the release temperature at Friant Dam at RM 267 (ranging
19 from approximately 48°F to 52°F (9°C to 11°C)), albeit at different rates at different times of the
20 year.

21 - for lower flow rates notably higher water temperatures are experienced in all but winter
22 months.

23 - at 500 cfs most of the months reach equilibrium temperature - where the temperature traces
24 attain a relatively constant temperature.

25 Heating in the downstream direction, including response to flow rates, is evident in the late
26 winter and spring field observations collected in 2005 (**Figure 15**). The river heated in the
27 downstream direction at a modest rate for flows greater than 1000 cfs (see also **Figure 16**) and
28 moderate meteorological conditions of spring 2005. Below the Eastside bypass, where flow
29 drops markedly from over 1000 to less than a few hundred cubic feet per second, the river
30 temperatures rise at a more rapid rate (e.g., Mendota Pool and Sack Dam).

1 Channel geometry also plays a role in the rate of heating associated with flow volumes. In
2 **Figure 14** the perturbations or breaks in the steady rise toward equilibrium, as well as the
3 “noise” in the trace once at equilibrium are associated with variable channel cross section and the
4 impact these variations have on flow depth, surface width, and stream velocity. Channel
5 variability can have an effect on water temperatures, but it appears that meteorological
6 conditions and flow volumes dominate the existing system (JSA, 2002).

7
8 Channel cross section and gradient for channel assessment and flow modeling was determined
9 using measured field data and digital elevation models (Ayers and Assoc. (1998, 1999) and
10 Mussetter 2000a, 2000b). Further issues associated with the geometry are considerations for
11 subsidence. Although corrections for subsidence have been made piecemeal through time (M.
12 Fainter pers. comm.), the existing assessments and models may be inconsistent in the degree to
13 which this information has been incorporated into studies (e.g., models). Such uncertainty aside,
14 the river morphology is highly variable throughout its length, with areas of broad channel forms
15 and areas of significant confinement between levees. Certain reaches are devoid of vegetation,
16 while others have considerable woody riparian vegetations. Further, the channel bed in some
17 areas is sand or gravel with little vegetation, while other reaches crowded with herbaceous
18 vegetation. These features may affect the thermal regime of the San Joaquin River if an
19 increased flow regime is imposed on the river. Although there are potential thermal implications
20 associated with wide shallow reaches, and initially there may be greater thermal loading in these
21 reaches, through time it is envisioned that the river channel will diversify in channel form in
22 response to flows, riparian vegetation, and restoration activities. A restored condition would
23 reduce the potential for greater thermal loading, provide potential for thermal refugia, and
24 contribute to thermal diversity.

25
26 During spring 2005 several temperature recording devices were placed in the Eastside Bypass,
27 Mariposa Bypass, and Bear River (DFG electronic data). These devices recorded water
28 temperature at one-hour intervals and although these data are from late May into June, they
29 provide valuable insight into the thermal regime of the bypass system. **Figure 17** shows water
30 temperatures at several locations along the bypass system. Avenue 9, the most upstream point

1 monitored in the Eastside Bypass, is fairly close to the bifurcation structure, and experiences the
2 coolest water temperatures. Moving downstream in the Eastside Bypass to El Nido, the water
3 temperature has warmed considerably (data only available for comparison after 6/1/05). Waters
4 from the San Joaquin River proper can be diverted back into the bypass system via the Mariposa
5 Bypass. There are periods when San Joaquin River waters diverted into the bypass via the
6 Mariposa Bypass are either cooler or warmer than those in the Eastside Bypass. Limited flow
7 data are available to parse out the details of the thermal regime, but overall, one common theme
8 is that maximum daily water temperatures were in the range of mid-60's to low 70's (°F) well
9 into June, 2005. It is reasonable to assume that under a restored condition, an actively managed
10 flow schedule could provide a desired thermal regime under this type of hydrologic and
11 meteorological condition.

12 13 *Thermal Diversity in Water Temperature in River Systems*

14 Thermal diversity exists in many forms in aquatic systems. Thermal diversity in reservoirs and
15 lakes was introduced through the concepts and processes of thermal stratification. Many of the
16 results addressed above for river reaches have clearly identified thermal diversity in the
17 longitudinal direction for the San Joaquin River downstream of Friant Dam. However, there are
18 addition attributes to thermal diversity that may play a critical role in anadromous fish
19 restoration.

20
21 Bartholow (1999) outlines many biologically relevant phenomenon in aquatic systems,
22 specifically rivers, that contribute to spatially and temporally diverse habitats that can be used by
23 aquatic organism, in some cases anadromous fish, to persist in under thermally compromised
24 conditions. These processes or mechanisms producing heterogeneous thermal conditions include
25 variable velocities and depth; cold water seeps, springs, or tributaries forming cold water refugia
26 adjacent to and in the main stem river; braided channels where smaller channels experiencing
27 lower temperatures than the main channel, presumably due to groundwater inflow; areas of
28 riparian shading; regions below point bars where subsurface flow (hyporheic flow) from
29 upstream reaches re-surfaces cooler than the mainstem, and groundwater inflow. In addition, to
30 cold water influences, the conditions such as gravel bars, macrophyte beds, large woody debris,
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1 and other physical habitat conditions within the stream may increase the benefit by protecting the
2 cold water inflow from mixing into the warmer main stem. Bartholow (1995), Ebersol et al
3 (2003), Gallagher (1999), Lowney (2001), Mosley (1983), Torgerson, et al, (1999), and
4 Watercourse (2004) as well as others provide detailed discussions and investigations of such
5 phenomenon. Although models are useful tools to provide insight into potential system
6 dynamics, there is generally an inability (not only numerically, but also given data
7 considerations) to capture the true variability and dynamic thermal nature of river systems. Such
8 characteristics would potentially provide opportunities to locally meet thermal conditions for
9 anadromous fish as well as other aquatic life in a system such as the San Joaquin River.

11 Implications on the San Joaquin River: San Joaquin River Below Friant Dam

12 Previous discussions have characterized the longitudinal diversity of the San Joaquin River, but
13 detailed studies of the processes outlined above are not well studied in the San Joaquin River
14 below Friant Dam. Because the processes identified above are typical of alluvial river systems,
15 such diversity in downstream river reaches certainly occurs at some level.

16 For example, vertical measurements in reach 4B during June and July of 2005 indicate that there
17 is thermal stratification in certain slow moving locations (**Figure 18**). The existence of relatively
18 cool water temperature may be indicative of interaction with groundwater.

19 Thermal diversity may be important for resource managers and biologist to consider when
20 assessing the viability of the river to meet the requirements of salmon.

22 *Thermal Considerations at Confluences*

23 Where streams converge there are near-field and far-field considerations for temperature
24 impacts. Near field conditions include dynamics at the confluence, while far field effects would
25 extend some distance downstream. If both streams were of the same temperature, the near field
26 effects would be insignificant. However, the far field effects could be notable depending on the
27 size of the two streams. If one is much larger than the other, the impacts to the thermal regime
28 downstream will be minimal. If they are of the same magnitude, the volume of the river below
29 the confluence will approximately double. Under such circumstances it is often valuable to take
30 stock of the channel morphology and any changes in width, depth, and velocity of the

1 downstream reaches and assess the potential impacts on thermal regime. A common impact
2 below the confluence of two large streams is a reduced diurnal range (lower maximum and
3 higher minimum diurnal temperature).

4
5 If one stream is markedly different temperature than the other, there can be both near-field and
6 far-field effects. The near field conditions include considerable temperature gradients over short
7 distances as the two streams mix. The far field implications are based on one's frame of
8 reference. If one is interested in cooler waters, then from the perspective of the cooler stream,
9 the warmer stream may be perceived as detriment, while the inverse is true for the warm stream.
10 The issue can actually be quite complex when considering the magnitude of each stream,
11 whether the stream are or are not at equilibrium temperature, and the downstream conditions.

12 13 Implications on the San Joaquin River: San Joaquin River Below Friant Dam

14 The San Joaquin has few major tributaries, but there are three issues of potential interest: (1) the
15 Kings River flows via the Fresno Slough, (2) return flows from Mud and Salt Sloughs, and (3)
16 the confluence with the Merced River.

17 Flows from the Kings River were not assessed herein. It is recommended that operations on the
18 Kings River be incorporated into any long-term management plan to determine how the
19 operations of each river system can be managed to minimize undesirable conditions, e.g., warm
20 water entering the San Joaquin River at Mendota during a period when it is not preferred. Kings
21 River flows are expected to occur in only the wetter years or under flooding conditions, and if
22 properly managed should not adversely impact the San Joaquin River.

23 Mud and Salt Sloughs by and large consist of local runoff and agricultural return flows. As with
24 other waters in the area, these sloughs are also at equilibrium with meteorological conditions.

25 The data presented in **Figure 19** show that until mid-May Salt and Mud Sloughs are roughly the
26 same temperature as the San Joaquin River at Stevinson under current conditions. The impacts
27 of these sloughs on water temperature during the spring period when flows are proposed for
28 emigrating and immigrating salmon are most likely modest.

1 With regard to conditions at the confluence with the Merced River a comparison of water
2 temperatures at the Merced River near Stevinson and San Joaquin River near Stevinson gages
3 from 2000-2004 suggest that both rivers are approximately the same temperature through mid-
4 April (**Figure 20**). After mid-April, under current conditions, the Merced River typically
5 experiences cooler water temperatures as flows are increased through early- to mid-May. If
6 flows are reinstated in the San Joaquin River to restore Chinook salmon, it is not expected that
7 temperatures will be markedly cooler (e.g., consistent with the Merced) after mid-April due to
8 the travel time from Friant Dam, meteorological conditions notwithstanding. From a
9 temperature management perspective, the impact on the Merced through mid- to late-April
10 should be small because the rivers experience very similar temperatures. Higher flows in wetter
11 years would likewise have similar water temperatures to the Merced due to large volumes and
12 short transit times in the San Joaquin River. If meteorological conditions are mild and flows are
13 extended into late April and May, it is expected that the rivers will likewise experience similar
14 water temperatures. If meteorological conditions are adverse in mid-spring during drier years,
15 the San Joaquin River may be warmer than the Merced River, but by this time, the flows for
16 temperature management will most likely have been reduced to low volumes that would have a
17 negligible impact on temperatures below the Merced River confluence. Flows released for
18 environmental purposes after mid-May would not be expected to have adverse effects on the San
19 Joaquin River downstream of the Merced River because temperatures near their confluences
20 would be similar.

22 **3. Flow-Temperature Relationships**

23 As noted previously, one method of seeking temperature control alternatives for the San Joaquin
24 River is to utilize seasonal meteorological conditions and flow management to achieve desired
25 conditions.

27 *Role of Numerical Models in Flow and Temperature Studies*

28 Numerical models are a natural extension of conceptual models. Numerical models, often
29 termed mathematical models, incorporate a set of mathematical expressions that define the
30 physical processes (and sometimes chemical and biological processes as well) that are assumed

1 to take place in an aquatic system. In most instances these models are based on the conservation
2 laws, including the conservation of mass, conservation of momentum, and conservation of
3 energy. For aquatic systems three phenomena are of interest: the inflows to and outflows from
4 the system; the transport through the system; and the reactions or other processes that lead to a
5 change in conditions within the river system.

6
7 To assess temperature conditions within a river system, the numerical representation of both flow
8 dynamics and heat energy (represented as temperature) must be included. Flow is important
9 because representation of the stream velocity affects travel time, and flow conditions define river
10 depth and width – all of which play a role in the thermal regime of the system.

11 12 Available Computer Models

13 The two models currently available on the San Joaquin are the Jones and Stokes (JSA) model,
14 which resides in a spreadsheet environment, and the Stillwater Sciences model written in the
15 computer language C++. The Stillwater model was adapted from the JSA modeling effort. The
16 modeling task is challenging considering the paucity of data and lack of formal model
17 calibration; limitations that both Stillwater and JSA acknowledge. To the extent that data are
18 available, they do not reflect a restored condition and are of modest use in testing models.
19 Nonetheless, the identified models are valuable tools and a useful first step in assessing
20 restoration options.

21
22 The JSA model is a very transparent model in terms of the inputs and output. The user can
23 readily see the processes that are included in the model and the predicted values are available in
24 both tabular and graphical form. Such models are particularly useful when multiple stakeholders
25 are involved because they are fairly easy to understand. Some specifics that are important
26 include:

- 27 - the flow component of this model is simple. Complex operations and flow changes
28 cannot be effectively modeled with this tool.

- 1 - the model simulates single months at time. Simulating long time periods (e.g., to assess
2 variable hydrologic conditions) requires simulating individual months consecutively and
3 as a result each month presents discrete model output.
- 4 - representation of the river channel using reach averaged cross sections at approximately
5 mile intervals was employed. These averages were derived from the Mussetter
6 Engineering studies (2000a, 2000b).
- 7 - the model utilizes hourly meteorological data and produces a daily average temperature
8 as well as a minimum and maximum, providing useful sub-daily information.
- 9 - the model contains many other features than temperature, and was intended to investigate
10 broader aspects of restoration (e.g., available habitat for anadromous fish) for various
11 flow regimes.
- 12 - the model includes various tributaries and inflows. These inflows are assumed to enter at
13 equilibrium temperature.
- 14 - the model includes diversions and losses, as well as riparian shading and
15 evapotranspiration losses.
- 16 - monthly input files are available for water year 2001.

17
18 The Stillwater adaptation of the JSA model is written in C++ and as such requires a trained
19 analyst that can understand the computer code and assess the logic. Stillwater has simulated
20 multiple years under various flow releases from Friant Dam and placed the results in a set of
21 spreadsheets that allows the analyst to query the output in several ways (note, the spreadsheet is
22 not a model, it is only a post-processor of model results). Some specifics that are important
23 include:

- 24 - the Stillwater model uses the same geometry as the JSA Model – averaged cross-sections
25 from the Mussetter Engineering (2000a, 2000b) hydraulic modeling (which relied on
26 detailed cross sections from a digital elevation model).
- 27 - the results of the model are daily average. The results are broken down into the daily
28 average of the 1990-2002 period to provide the user the maximum, minimum, and mean
29 daily average for the period. Sub-daily results were not provided.

- 1 - the model was not completely tested and downstream of approximately RM 150, there is
2 a lack of confidence in model performance. Stillwater recommends not using the model
3 results below RM 150 at this time (M Fainter, P Baker, pers. comm.).
- 4 - to assess conditions downstream of RM 150, Stillwater relied on limited measured data
5 from the Fremont Ford and Stevinson gages. However, continuous flow conditions and
6 associated water temperature observations in the San Joaquin River from Friant Dam to
7 the Merced River were unavailable until 2005 (after the JSA work was completed.
8 However, even in 2005 it should also be noted that conditions presented (i.e., under the
9 current level of water resources development and management), are most likely not
10 representative of a “restored” flow condition.
- 11 - Stillwater extended their modeling analysis using, SNTEMP model results from the
12 Tuolumne River. Such an extension may not be appropriate for the San Joaquin River:
13 the SNTEMP application on the Tuolumne operates on a 5-day time step (EA, 1999), has
14 no ability to assess dynamic flow regimes, and does not produce sub-daily information
15 (Bartholow, 1989) in a useful manner for regulated rivers.

16 Although both models have strengths and weaknesses, at a feasibility level assessment they are
17 quite useful. The use of the models in this report is by and large to assess the rate of increase in
18 water temperature with increasing distance downstream from Friant Dam for various steady flow
19 rates. This rise towards equilibrium temperature (that water temperature that is in approximate
20 equilibrium with meteorological conditions) with distance downstream is sufficiently represented
21 in the models to provide insight on flow-temperature relationships throughout the year.

22 Selected Model

24 Due to the lack of data, the available models have not been rigorously calibrated – a step that
25 could currently be tested in much greater detail due to the appreciable flow and temperature data
26 collected in 2005. Out of the two models, the JSA model was selected to assist in assessing the
27 impact of flow on river temperature regime. The reasons for this decision included:

- 28 - the JSA model was transparent, i.e., easy to view calculations and results
- 29 - sensitivity analysis had been completed and a memorandum produced (JSA, 2002)

- 1 - there was some level of discussion on the basic assumptions in the available literature
- 2 (JSA, 2002; McBain and Trush, Inc., 2002).
- 3 - the model produces sub-daily information (daily maximum temperature) versus the
- 4 Stillwater version from which only daily average information was available
- 5 - the model included diversions and losses and other useful features.

6

7 Results from both models were examined and although they differed in certain aspects, the

8 results were generally consistent. It is important to reiterate that models are only tools to assist

9 in decision-making. In the case of the San Joaquin River, field observations of flow,

10 temperature, and meteorological conditions were largely sufficient to identify many of the basic

11 aspects of the flow regime. Namely, that water temperatures often remain cool through mid-

12 March and that by late-April meteorological conditions are such that temperature control at the

13 confluence with the Merced River can be challenging under adverse meteorological conditions.

14 Thus, the benefits of seasonal meteorological conditions are used to the extent possible, and as

15 spring time conditions lead to increasing water temperature, additional water is used to maintain

16 desired temperature ranges – to a point. After late-April or early-May meteorological conditions

17 may not conducive to temperature control through flow management from Friant. Given these

18 side-boards, the JSA model and professional judgment were used to assess potential flow-

19 temperature relationships. These flow regimes are preliminary, and a rigorously developed,

20 tested, documented, and peer reviewed numerical flow and temperature model that assesses both

21 reservoir and river dynamics should be used to refine and fully develop final regimes for existing

22 and possible future conditions. Model results at a low release flow rate (500 cfs) were compared

23 with observed values for March and April 2001 to ensure the model produced results that were

24 reasonable (**Figure 21**). Although conditions are not similar between the two conditions

25 (simulated and observed), nor is this test applicable to any type of calibration, the results suggest

26 that the model reproduces approximate temperatures and ranges comparable to field

27 observations.

28

29 It did not appear to be necessary to extensively model water temperature conditions in the fall

30 because by late October water temperatures are rapidly decreasing due to decreased solar

1 radiation (see Figure 2) as a function of both lower solar altitude (the sun is lower in the sky) and
2 decreased day length. Results from the Stillwater model, although subject to limitations
3 discussed elsewhere in this report, suggest that water temperatures decrease rapidly during this
4 time period (Figure 14). Even if there is a spell of Indian summer, minimum daily temperatures
5 are often quite cool due to the longer nights. Upon review of the temperature requirements
6 identified by Dr. Moyle and the flow regimes specified by Drs. Moyle and Kondolf, and
7 considering the evidence presented herein it is my opinion that the temperature requirements can
8 be achieved under the specified flow regimes.

9 10 *Model Results*

11 With temperature criteria identified, the JSA model was then applied with Friant Dam release set
12 to flows of 500, 1000, 1500, 2000, 3000, and 4000 cfs. Channel capacities in Reach 2B and 4B
13 were set to values sufficient to pass all flows, and routing water through the bypass system was
14 not assessed for this exercise. All inflows and operations in the San Joaquin River below Friant
15 Dam that existing the March and April model simulations produced by JSA were retained. To
16 assist in assessing flow regimes to provide desired temperature conditions in these transition
17 months (from cool season to warm season), the JSA model was applied. Specifically, the model
18 was applied for the months of March and April.

19
20 Available hydrology for 2001 was the only data set provided with the JSA model. Thus 2001
21 hydrology was used for all simulations with the exception, as noted above, that Friant Dam
22 releases were varied from 500 to 4000 cfs. To assess the impact of a range of meteorological
23 conditions, meteorological conditions for March and April 2001, 2002, 2003, and 2004, were
24 examined. These data were compared to long-term air temperature statistics presented in JSA
25 (2002), and are presented in **Table 4**. March and April air temperatures are generally close to
26 normal on 2001 through 2004, with the exception of a cool April in 2003, a warm March 2003,
27 and a warm March-April period in 2004. Sub-monthly variability can be considerable.

28
29 The results for simulated water temperatures above the Merced River confluence are shown in
30 **Figure 22** through **Figure 37**. Overall these simulations present conditions consistent with
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1 several of the concepts identified above. Namely, that water temperatures respond strongly to
2 seasonal and short-term variations in meteorological conditions, and conditions are variable not
3 only within a particular time span, but also among years. Further, it is useful to note that the
4 warmest water temperatures in the San Joaquin River between Friant Dam and the confluence of
5 the Merced River during March and April occur immediately above the confluence to the
6 Merced River in all but the lowest flow rate cases (e.g., 500 cfs and occasionally at 1000 cfs).

7
8 In addition, 2001 air temperature was increased 10 percent based on data presented by JSA
9 (2002) to examine the sensitivity of the model to air temperature. This assumption presents a
10 March condition that is outside the range of the historic air temperatures (as presented by JSA,
11 2000), with a percent of normal equal to 116 percent (the maximum average March air
12 temperature for the period of record is approximately 109 percent of the long-term mean). The
13 assumption presents an April condition that is about 106 percent of normal (the maximum
14 average April air temperature for the period of record is approximately 110 percent of the long-
15 term mean). The results of this sensitivity are included in **Figure 38** and **Figure 39** for March
16 and April, respectively. Maximum differences are on the order of 2 °F to 3 °F, and are diminish
17 slightly as flow rate is increased.

18
19 Upon completing the model simulations, these results were reviewed in light of the temperature
20 requirements identified by Dr. Moyle and the flow regimes specified by Drs. Moyle and
21 Kondolf, and considering this information it is my opinion that the temperature requirements can
22 be achieved under the specified flow regimes. In reaching this conclusion I considered the range
23 of meteorological conditions from the months of March and April for the 2001 through 2004
24 period.

26 **4. Summary of Opinion and Recommendations**

27 *Summary*

28 The San Joaquin River travels nearly 150 miles from Friant Dam to the confluence with the
29 Merced River. Direct control of water temperatures over these long distances during the warmer

1 periods of the year can be challenging due the influence of local meteorological conditions. A
2 key factor in the ability to meet water temperatures over the entire reach during critical periods,
3 such as winter and spring outmigration of juvenile salmon, is the ability to take advantage of
4 meteorological conditions that allow some level of temperature relief extending down to the
5 Merced River. After mid-April to early-May this ability is compromised due to seasonal thermal
6 loading conditions associated with meteorological conditions in the San Joaquin Valley, although
7 short-term and seasonal variability may allow for additional flexibility.

8
9 For the reasons explained herein, it is my opinion, based on the available evidence, that the flow
10 schedules proposed by Drs. Moyle and Kondolf will achieve temperatures consistent with the
11 requirements that Dr. Moyle has identified for Chinook salmon. Of course, in any endeavor such
12 as evaluating thermal conditions on a restored river, uncertainties exist, and this report also
13 discusses those uncertainties. Restoration activities would benefit from further studies to help
14 refine the detailed components and timelines for a flow regime to meet the requirements of fish.
15 Some of studies are outlined in the recommendations below.

16
17 Existing information indicates that there is sufficient cold water in storage and from upstream
18 locations (above Millerton Reservoir) to provide the desired range in release temperatures below
19 Friant Dam for the proposed preliminary flow regimes. Further, as the identified flow-
20 temperature relationships indicate, prudent management of water during periods of the year
21 when meteorological conditions are conducive to temperature management provides sufficient
22 flexibility to supply the desired range in temperatures for anadromous fish production from
23 Friant Dam to the Merced River. However, to move forward in practical and efficient manner
24 with regard to assessing flow and temperature conditions in the reservoir and river system,
25 additional information would be advantageous. Prior to implementing a long-term restoration
26 plan, an assessment that builds upon the initial studies on the San Joaquin River would be
27 appropriate to determine the explicit details, components, uncertainties, and timeline necessary
28 for re-introduction of Chinook salmon. Some recommendations on data needs, analyses, and the
29 role of adaptive management are presented below.

1 *Recommendations*

2 Data Needs

3 With regard to data needs to fill existing gaps and provide a better basis for future management,
4 it is recommended that:

- 5 - continuous, sub-daily inflow temperatures to Millerton Reservoir be monitored
- 6 - continue the monitoring of vertical temperatures profiles at monthly intervals in Millerton
7 Reservoir, and possibly sample at two week intervals in spring months should conditions
8 and management activities warrant. These data would assist in cold management
9 associated with reservoir operations.
- 10 - identify appropriate flow, temperature, and meteorological stations (and parameters) and
11 data that are necessary for flow and temperature management.
- 12 - implement a formal water temperature monitoring protocol and set of sampling locations
13 in the San Joaquin River between Friant Dam and the Merced River (including the
14 Merced River and down stream of the Merced River), including tributaries, return flows,
15 and bypass operations. Review existing efforts and produce a uniform protocol to ensure
16 proper location, sampling frequency, periods of the year, and equipment are employed.
17 Create a data sharing framework to ensure information is available to all parties.
- 18 - efforts to quantify the location, timing, duration, and magnitude of surface water
19 diversions be carried out to maintain or improve delivery system reliability and river flow
20 management
- 21 - efforts to quantify the location, timing, duration, and magnitude groundwater-surface
22 water interactions to assist in management of water supplies and river flow management

23 Ongoing Flow and Temperature and Other Analyses
24

25 With regard to flow and temperature analyses to improve understanding and restoration of flow
26 and temperatures it is recommended that:

- 27 - additional data analysis (based on existing data sets) to assist resource managers in
28 refining flow regimes and temperature management strategies under a restored condition.
- 29 - characterization of Millerton Reservoir and the role of upstream storage on the thermal
30 regime both above Millerton, below Millerton, and below Millerton would provide

1 valuable insight into the flexibility of the system to meet water temperature management
2 goals

3 - building on the Jones and Stokes and Stillwater Sciences temperature modeling efforts,
4 benefits would be derived through extending the temperature simulation capability to
5 include

- 6 ▪ reservoir and river operations (extend beyond just assessing the river)
- 7 ▪ dynamic flow modeling (e.g., hydrodynamic) to assess ramping rates, travel
8 times, and other dynamic characteristics of the flow regime.
- 9 ▪ Coupling temperature modeling to the dynamic flow modeling to determine
10 thermal response of flow management
- 11 ▪ Assess geometry for a restored channel conditions to determine added thermal
12 benefits.
- 13 ▪ Ultimately, the San Joaquin River operations at Millerton Reservoir and Friant
14 Dam should be managed in concert with the Merced, Tuolumne, and Stanislaus
15 complexes (rivers and reservoirs) to maximize benefits and reduce uncertainty for
16 all uses. Any flow and modeling work on the San Joaquin should be considered
17 in light of the ongoing development of a basin-scale flow and temperature model
18 for the San Joaquin that includes the Stanislaus, Merced, and Tuolumne Rivers
19 (funded via CALFED).

21 Adaptive Management Considerations


22 Although often an overused term, adaptive management still embodies the necessary approach to
23 restoring and/or managing any aquatic system and those activities that may impact aquatic
24 systems. Although there are many definitions of adaptive management, a practical definition is:

- 25 1. carry out experiments to learn more about the system
- 26 2. actively plan to change in response to the outcomes of the experiments (J. Lund pers.
27 comm.)

28 Should restoration activities occur on the San Joaquin River, at any level, active monitoring of
29 the system would be invaluable, with careful consideration given to seasonal and short-term
30 hydrologic, meteorological, and water temperature conditions, as well as location, status, and

1 activity of fish in the system (particularly in the spring time). A certain level of real time
2 information may be necessary to track the effect of managed flows in response to flow levels
3 (including the impacts of Kings River inflows, bypass operations, return flows and tributaries,
4 diversions, Merced River conditions, etc.), temperature conditions, meteorological conditions,
5 location and status of fish, as well as other factors. Active monitoring, including real time
6 information on other river systems (e.g., Klamath, Trinity, and Sacramento Rivers) have
7 provided such invaluable information to resource managers. These activities would lead to
8 improved water management that would conserve water and improve conditions for fish.
9 Natural systems are marvelously complex, and to do the best job possible adaptive management
10 will be a critical component.

11 Dated: August 15, 2005

12 
13 _____
14 Michael Deas

1
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18 *Other Information Considered*

19 See Exhibit

20
21 Models

- 22 ▪ Jones and Stokes San Joaquin River Model: SJRiver (Input files: 5/03/02; Model:
23 5/24/02)
- 24 ▪ Stillwater Sciences San Joaquin River Model

25 Field Data

- 26 ▪ Thermal Profiles: 1952 through 1978 (records are intermittent) (hardcopy)
- 27 ▪ Thermal Profiles: 2003 (hardcopy)
- 28 ▪ Dissolved Oxygen Profiles: 2003 (hardcopy)
- 29 ▪ California Department of Fish and Game temperature data (DFG, 2005 – electronic: all
30 data are provisional)
- 31 ▪ Field data collected spring 2005

32 Other Data and Information

- 33 ▪ GIS files for the
- 34 ▪ DWR CDEC data (all data are provisional)
 - 35 ▪ Flow, temperature, storage, stage
- 36 ▪ USGS (all data post 9/30/04 are provisional)
 - 37 ▪ <http://waterdata.usgs.gov/nwis/sw>
- 38 ▪ CIMIS meteorological Data
- 39 ▪ USBR Reservoir data (USBR Reservoir data): 1950's through 2003
- 40 ▪ USBR Web Site
- 41 ▪ Friant Dam Statistics: <http://www.usbr.gov/dataweb/dams/ca10154.htm>

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- Daily Operations:
http://www.usbr.gov/mp/cvo/vungvari/sccao_mildop.pdf

Field visits

- California Department of Fish and Game excursion
- Natural Resources Defense Council excursion
- Personal excursions
- Field observations of water temperature

6. Exhibits

6.1. Exhibit A. Figures and Tables

6.1.1. Figures

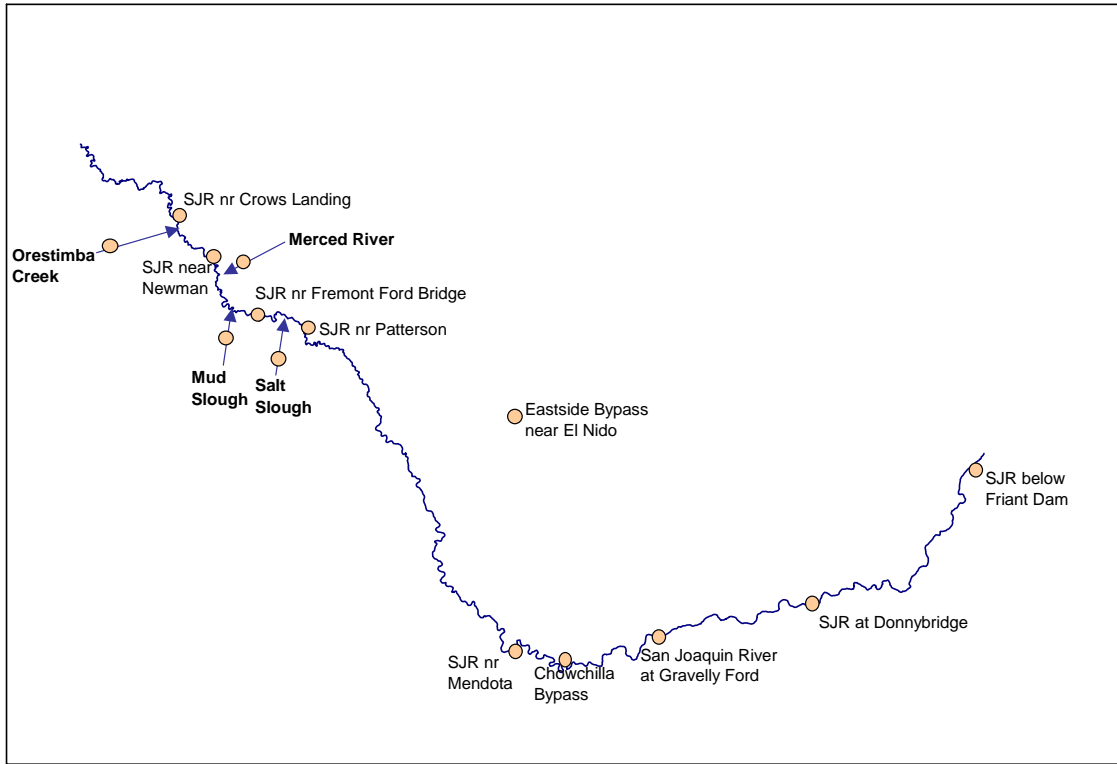


Figure 1. San Joaquin River and Selected Locations

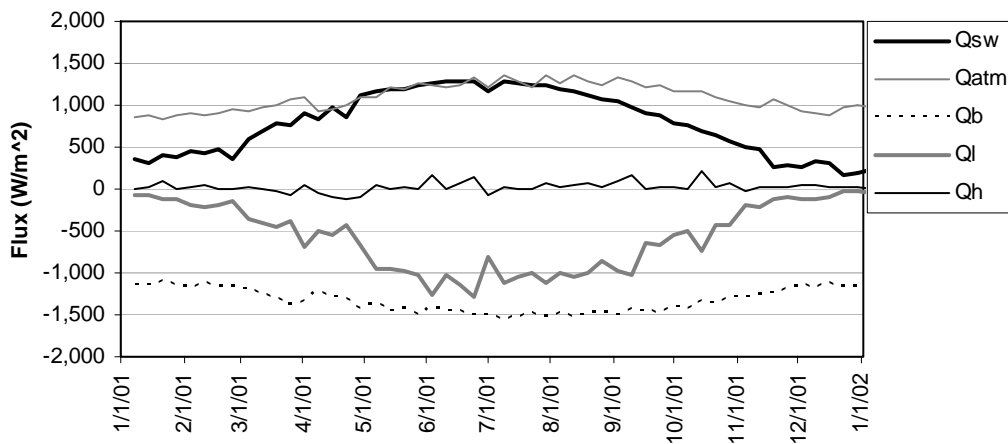


Figure 2. Typical heat flux magnitudes for a calendar year

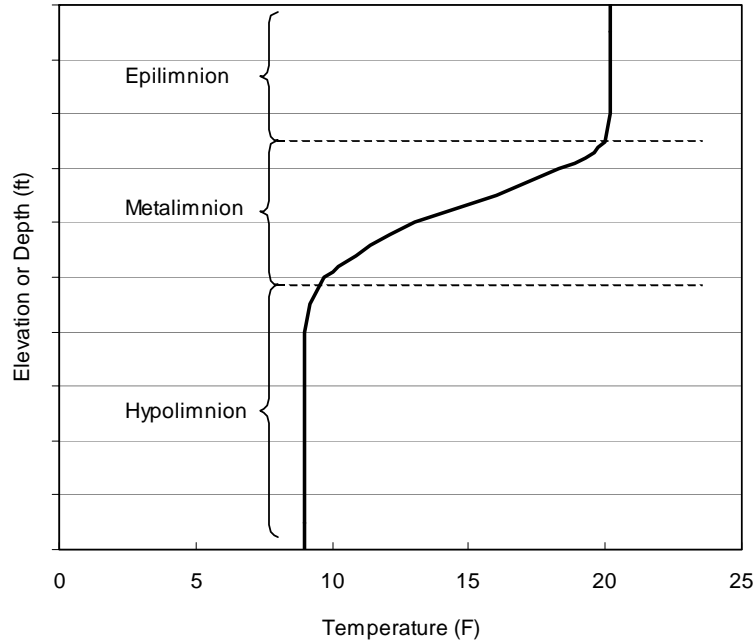


Figure 3. Schematic of summer thermal stratification of a lake showing the epilimnion, metalimnion,

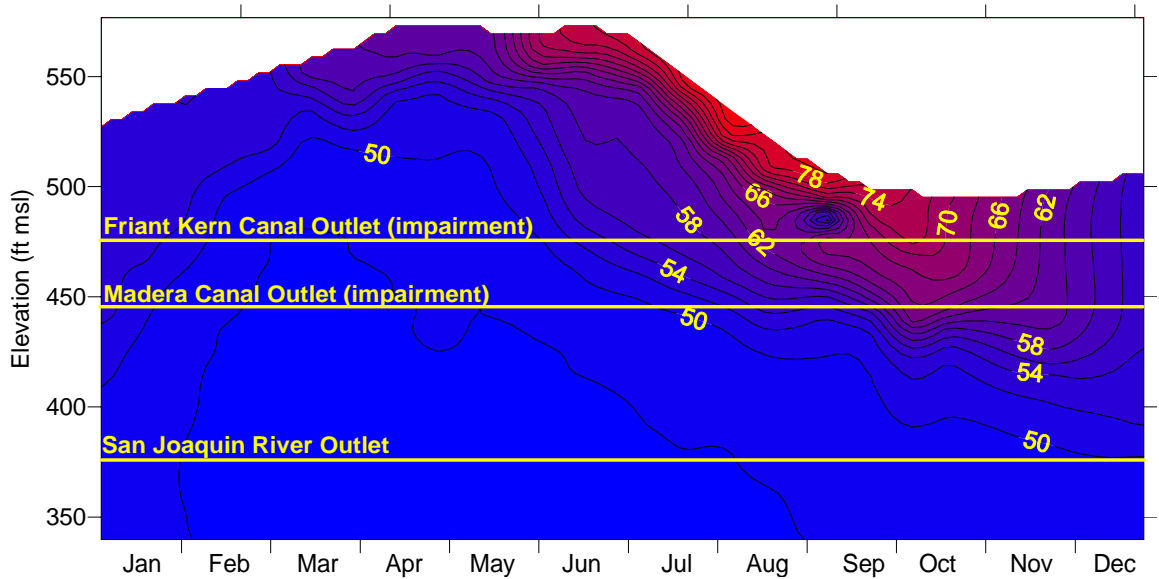


Figure 4. Millerton Reservoir thermal conditions for calendar year 2003 showing isotherms of water temperature as a function of time (x-axis) and elevation (y-axis) (USBR Reservoir Data)

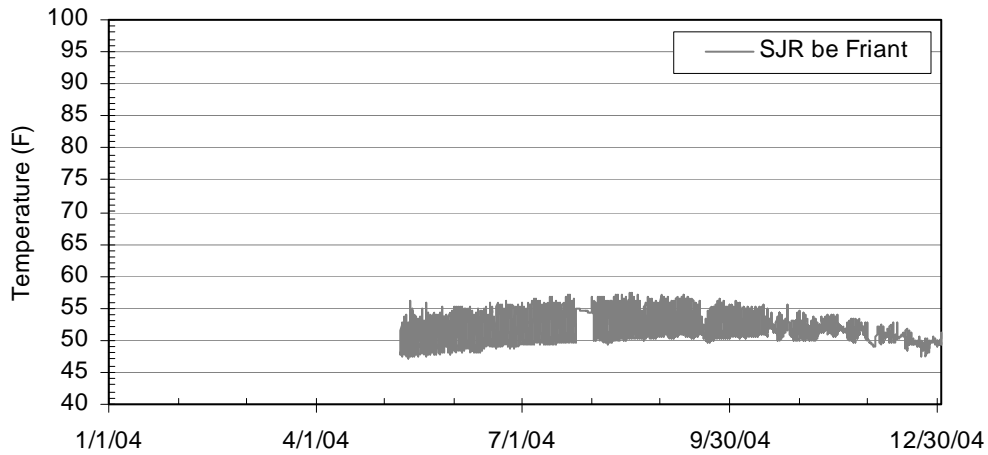


Figure 5. Hourly water temperature observations in the San Joaquin River below Friant Dam from May through December 2004 (California Data Exchange Center)

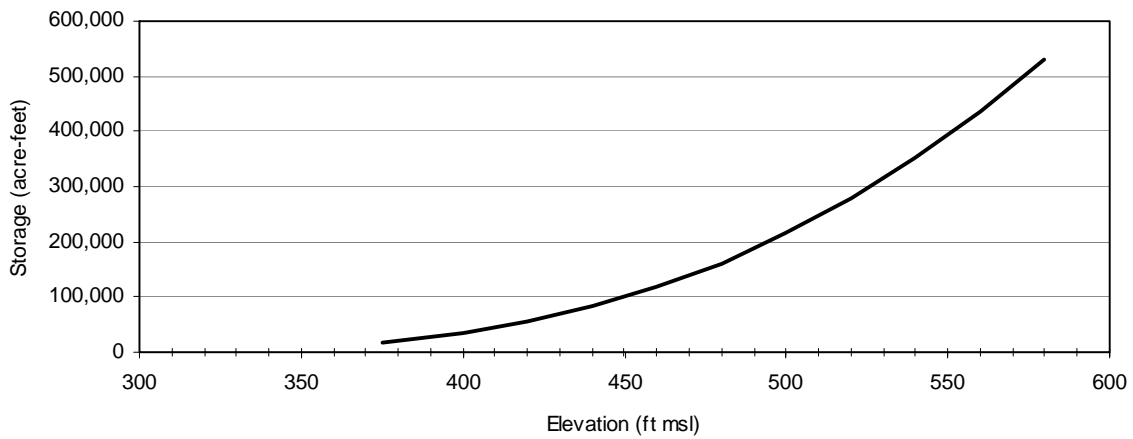


Figure 6. Millerton Reservoir Stage-volume relationship (USGS, 2001)

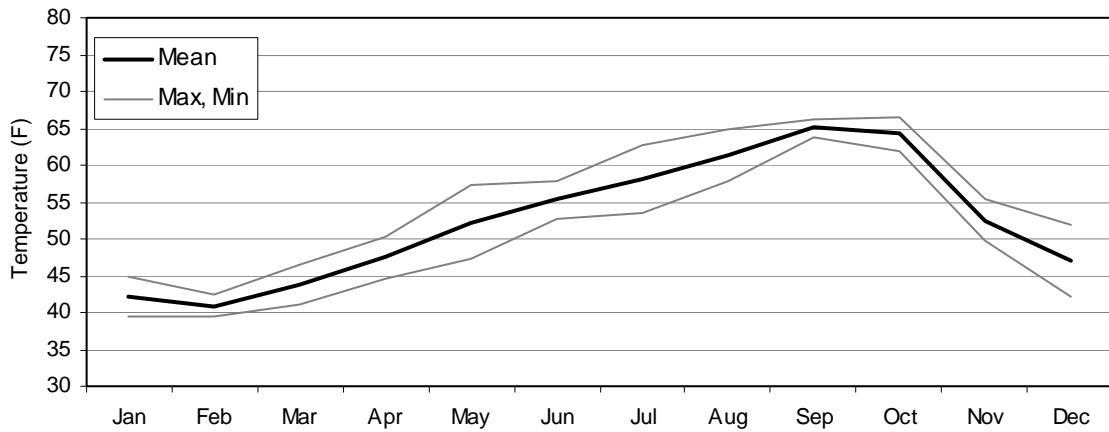


Figure 7. Water temperature below Kerchoff: 1978 and 1979 data (adapted from Ecological Analysts, Inc., 1980)

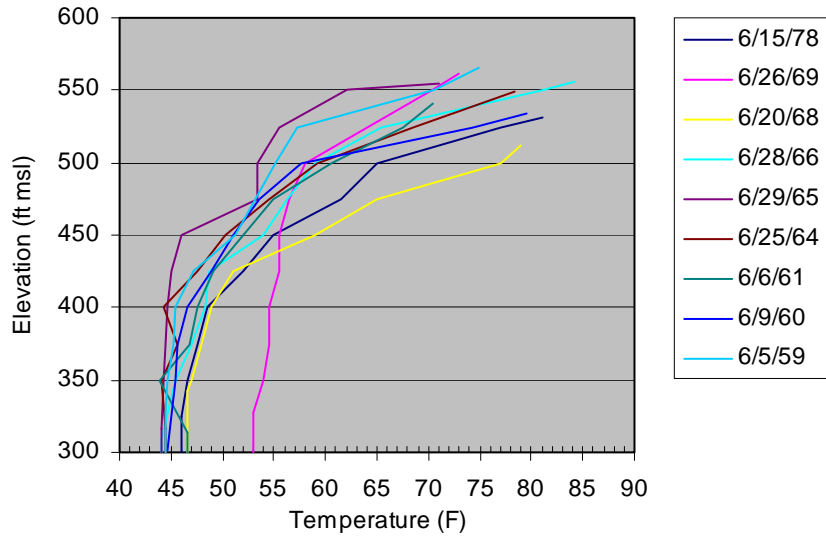
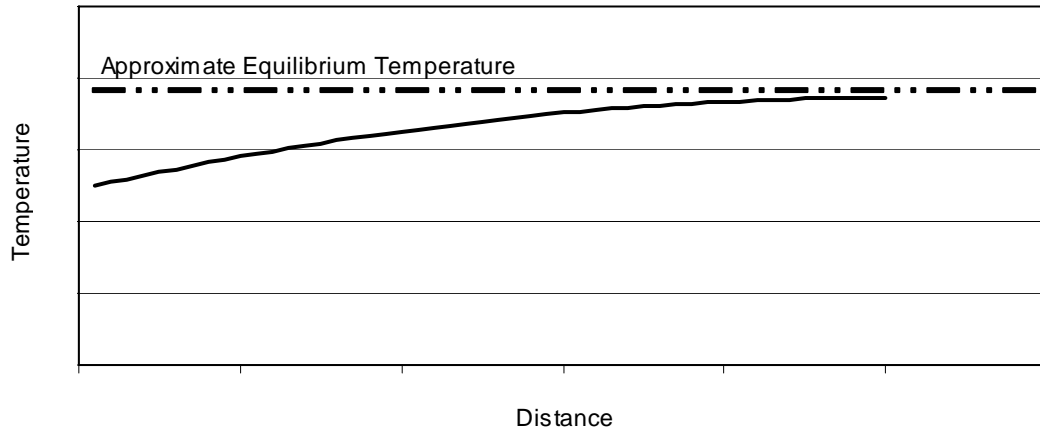
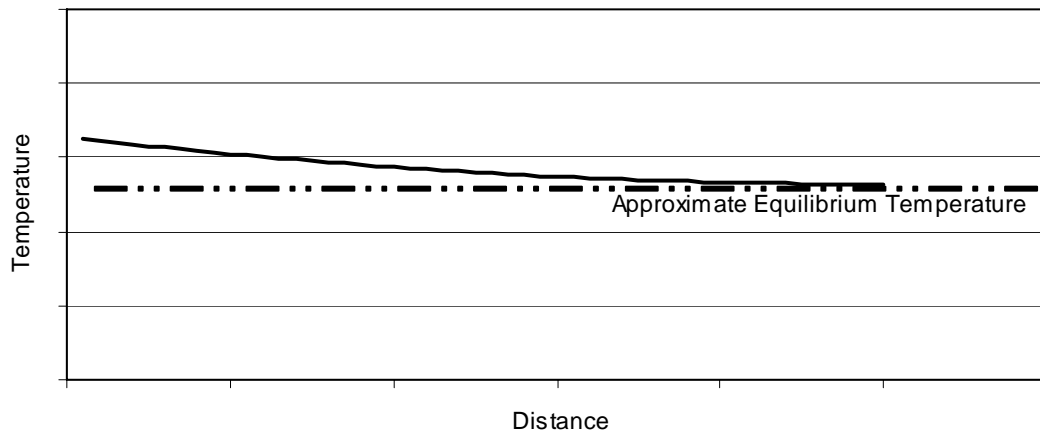


Figure 8. June water temperature profiles for Millerton reservoir: 1959-1978 (USBR Reservoir Data)



(a)



(b)

Figure 9. Illustration of mean daily water temperature approaching equilibrium temperature with increasing distance downstream from a dam for (a) a cold water release, and (b) a warm water release

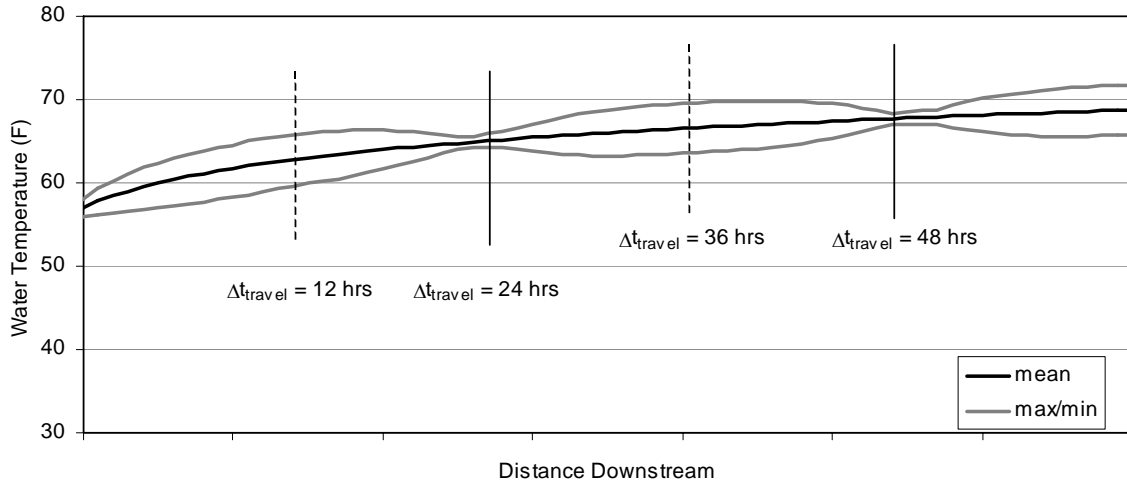


Figure 10. Illustration of nodes of minimum (24 hr, and 48 hr) and maximum (12 hr and 36 hr) diurnal variation

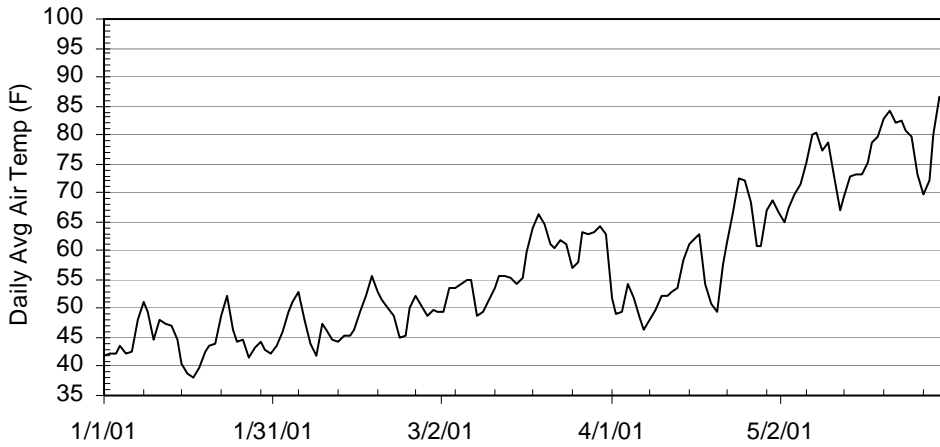


Figure 11. Daily average air temperature at Five Points No. 2 (CIMIS) for January through May, 2001

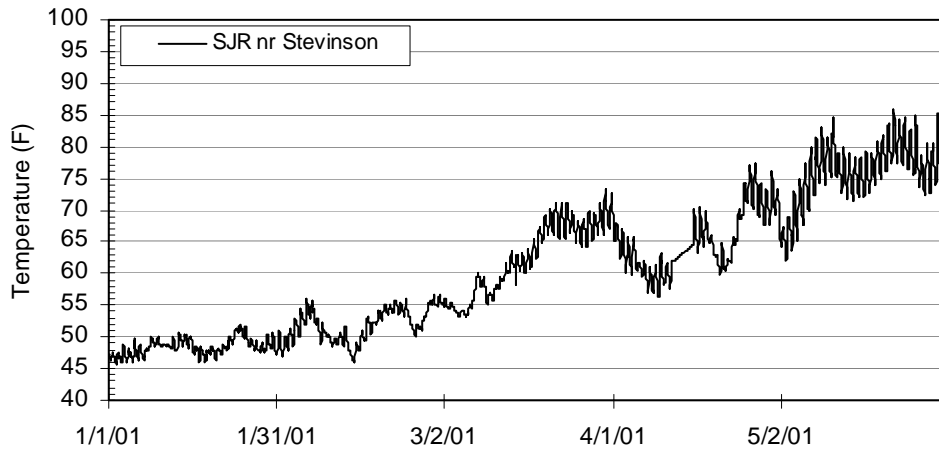


Figure 12. Hourly water temperature for the San Joaquin River near Stevinson (CDEC) for January through May, 2001

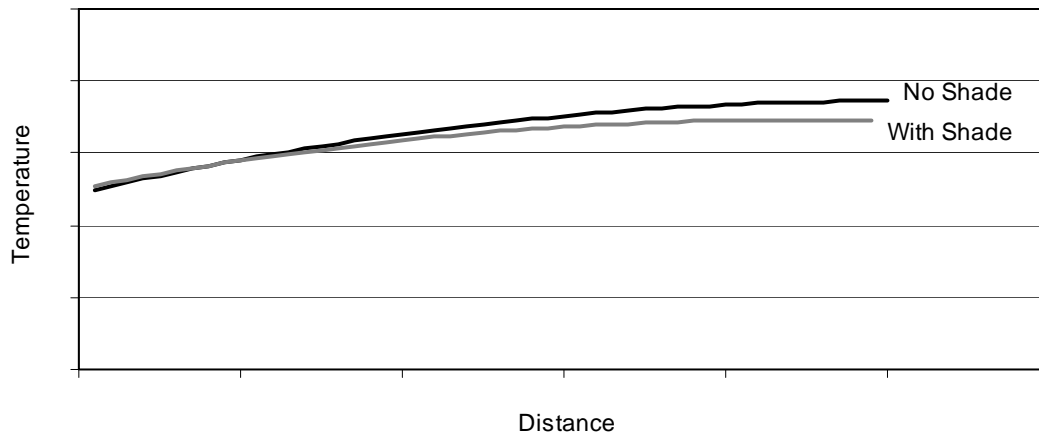
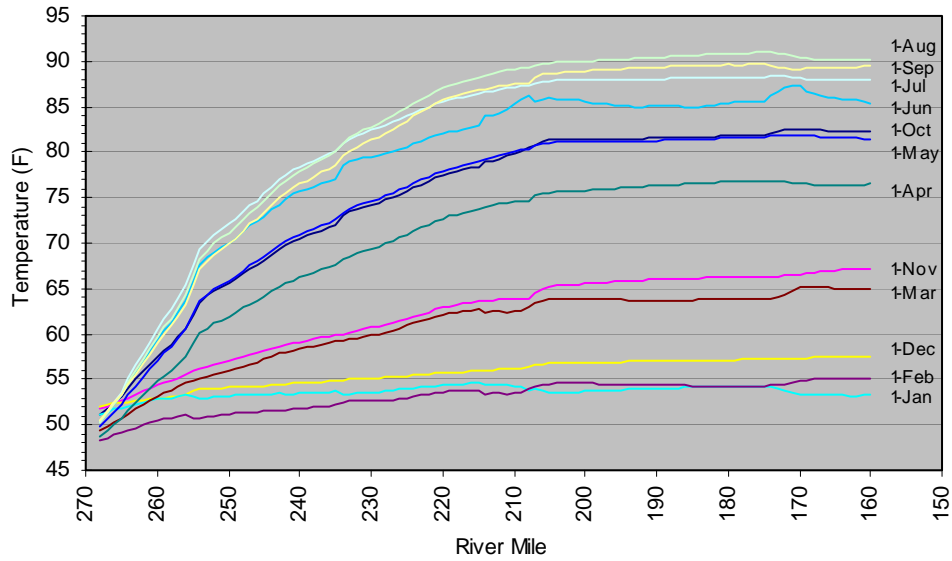
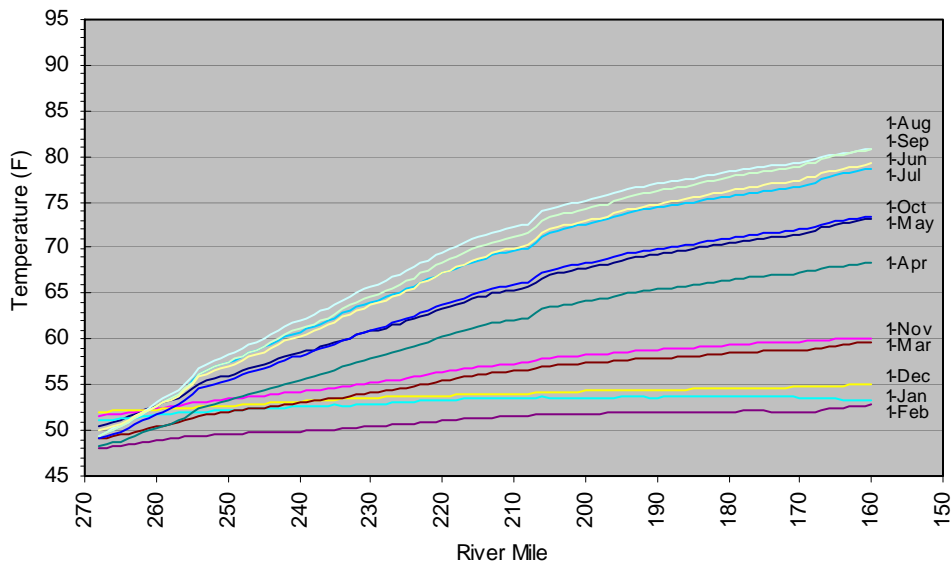


Figure 13. Hypothetical mean daily water temperature rise towards equilibrium with increasing distance downstream from a dam for a with and without shading condition



(a)



(b)

Figure 14. Computed daily average longitudinal temperatures – first of month – derived from the Stillwater Sciences model for a release of (a) 500 cfs and (b) 2,500 cfs (maximum daily average for first of month for 1990-2002 water year simulations)

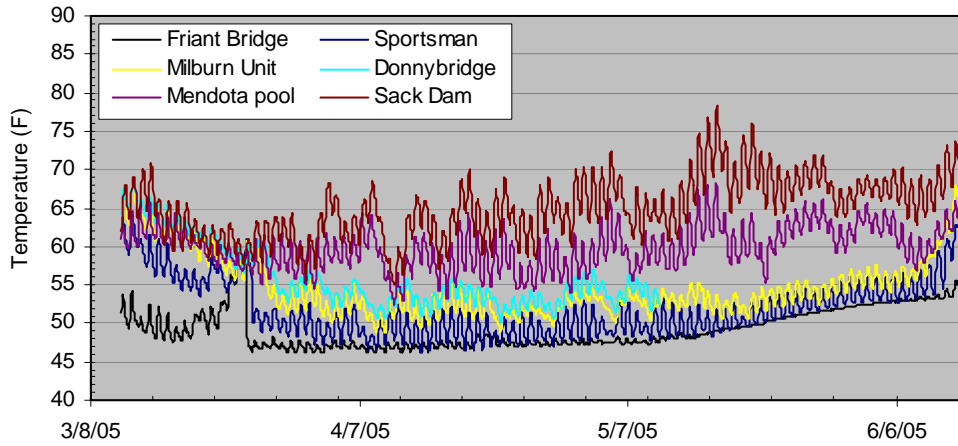


Figure 15. Hourly water temperature data at multiple locations from Friant Dam to Sack Dam (DFG, 2005 - electronic)

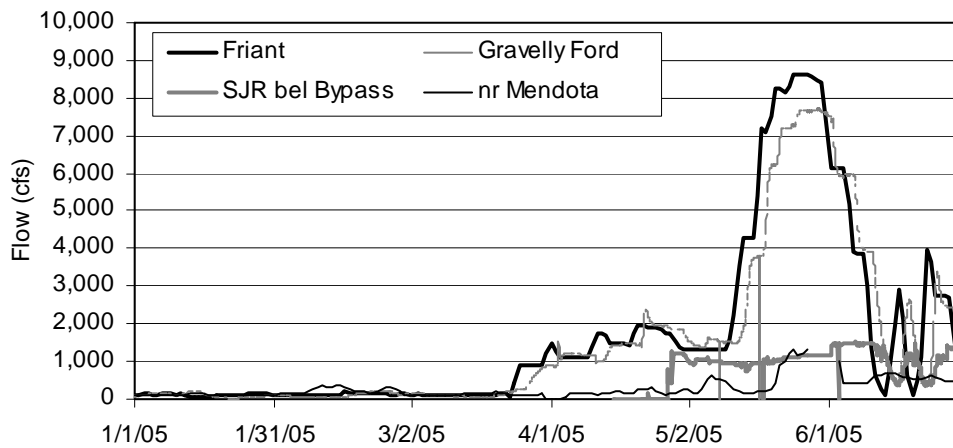


Figure 16. Flow at multiple locations in the San Joaquin River between Friant Dam and Mendota (CDEC)

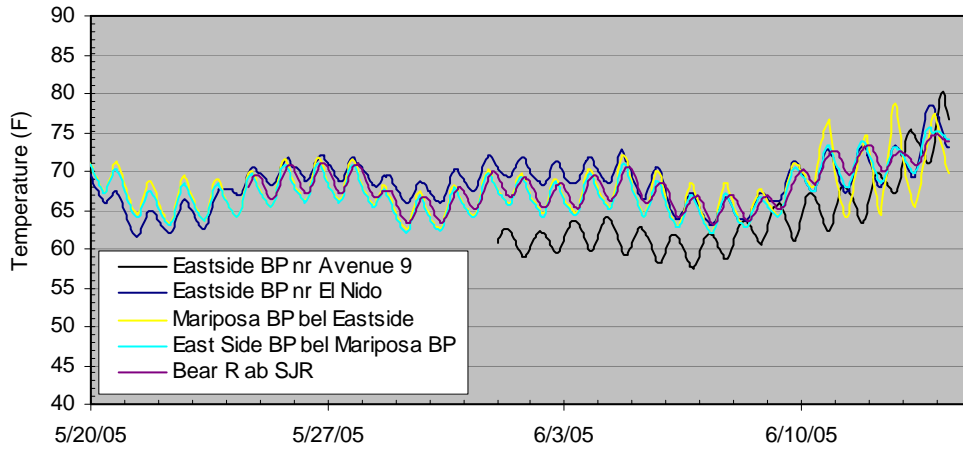


Figure 17. Water temperature at multiple locations in the bypass system: May 20-June 15, 2005 (DFG electronic data)

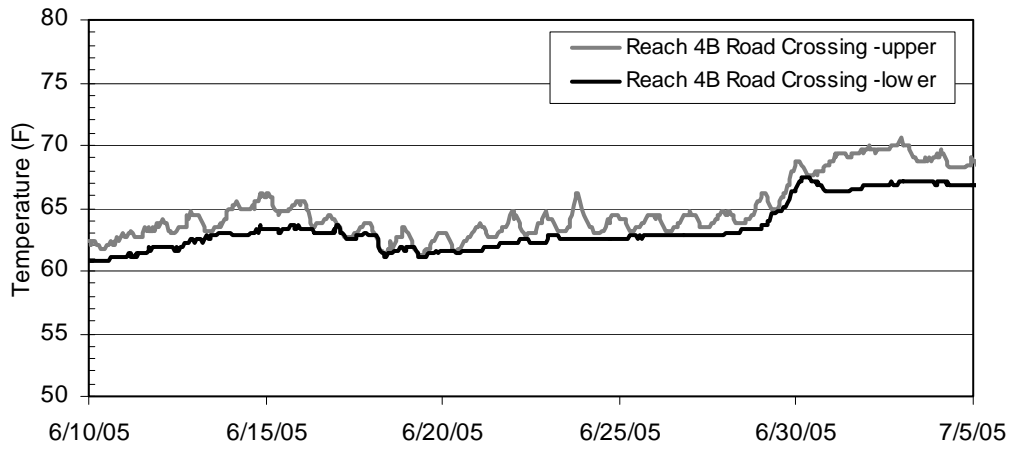
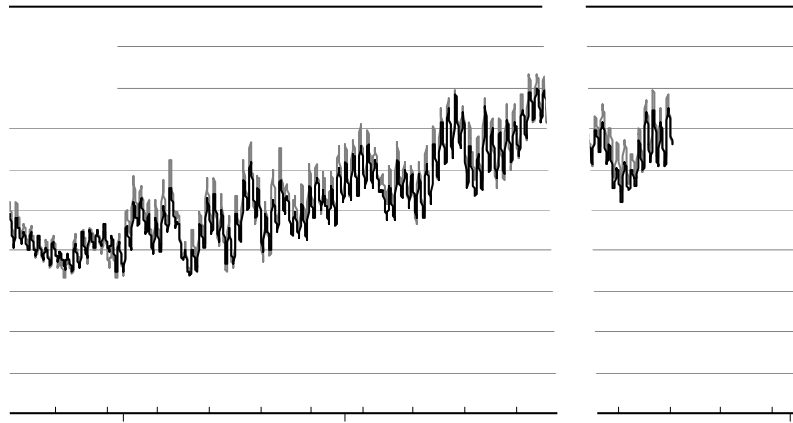


Figure 18. Vertical water column temperatures in Reach 4B for surface (upper) and bottom (lower) for June 10 through July 5, 2005 (field data: M. Deas)



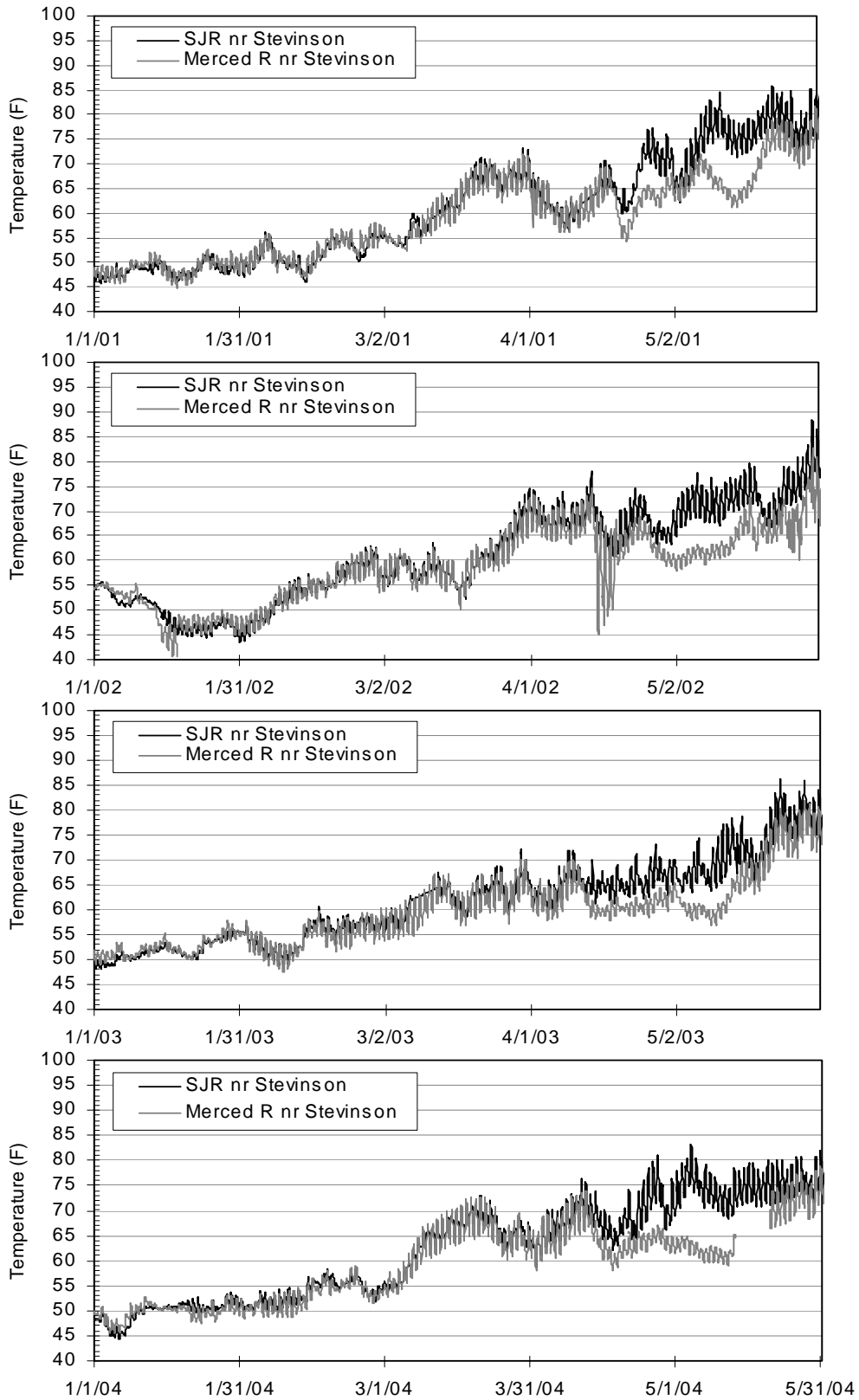
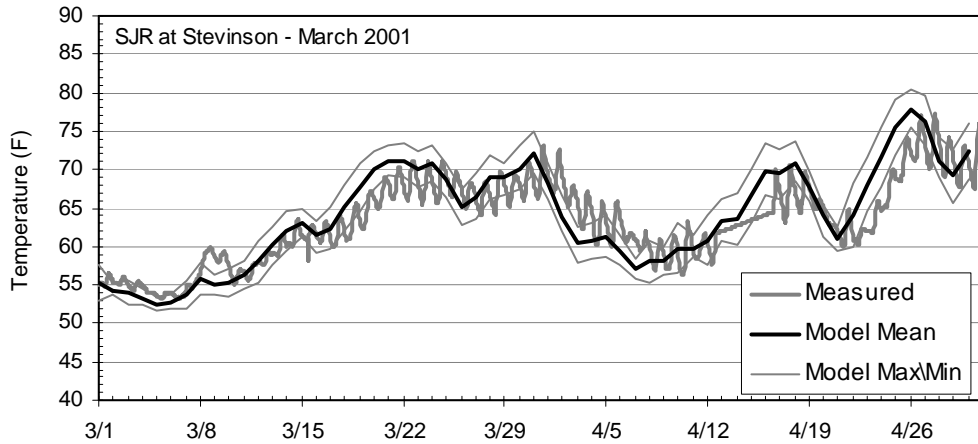
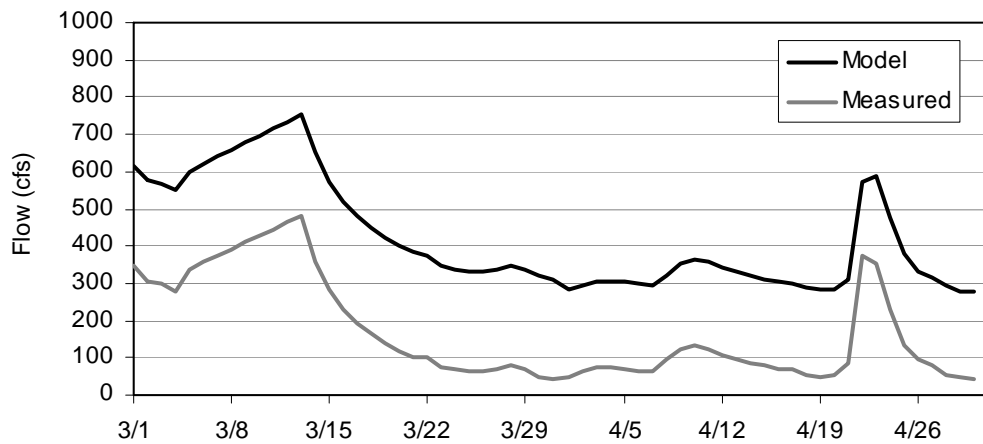


Figure 20. San Joaquin River nr Stevinson and Merced River nr Stevinson water temperatures January 1 through May 31 for 2000-2004 (CDEC)

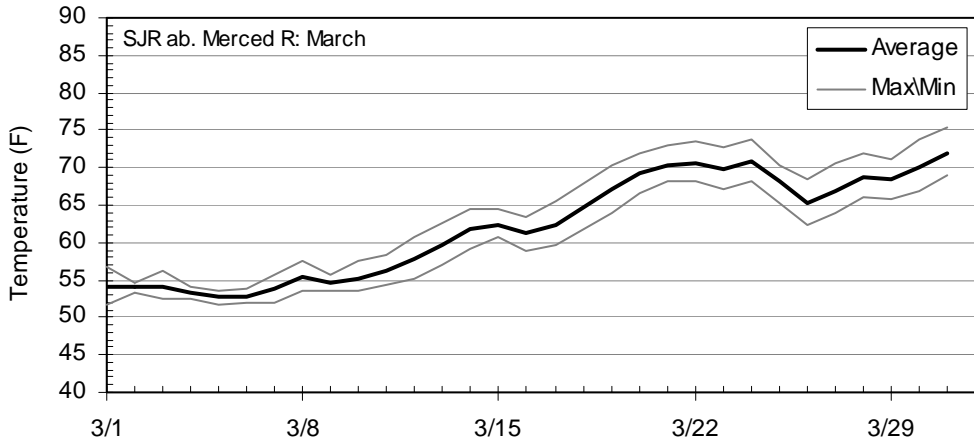


(a)

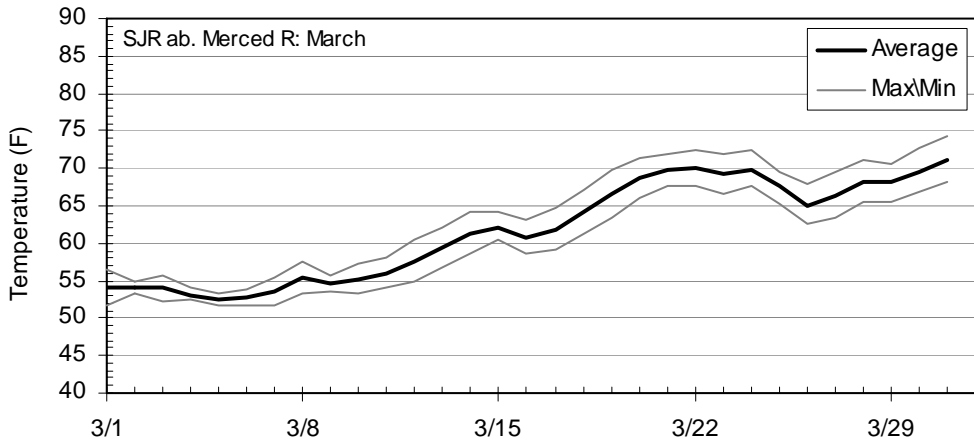


(b)

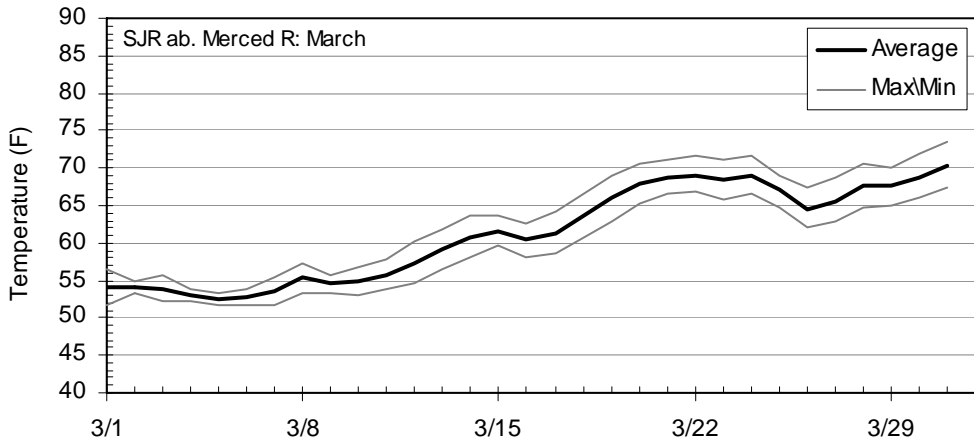
Figure 21. Simulated maximum, mean, and minimum water temperature and flow for the San Joaquin River near Stevinson with a Friant Dam release of 500 cfs compared with field observations (CDEC) for flow and temperature from March 1-31, 2001



(a)

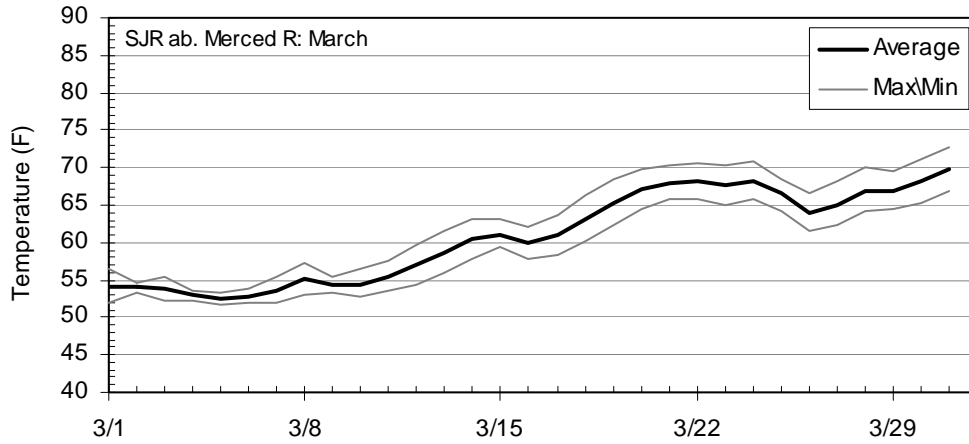


(b)

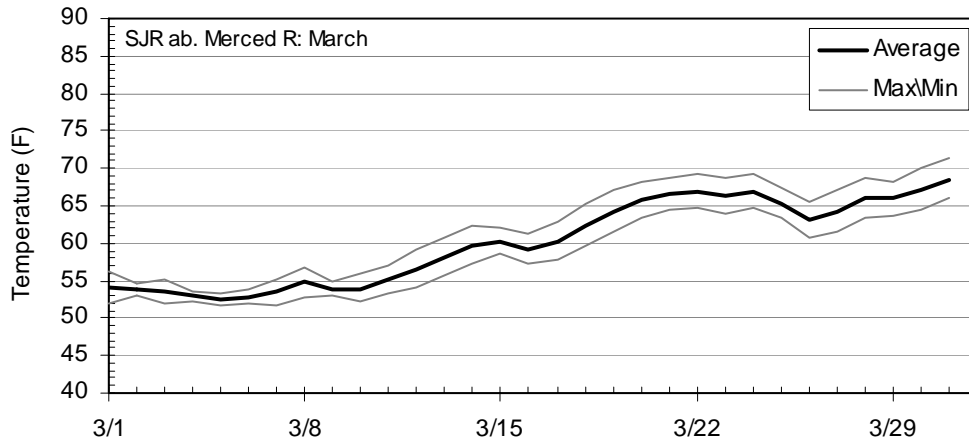


(c)

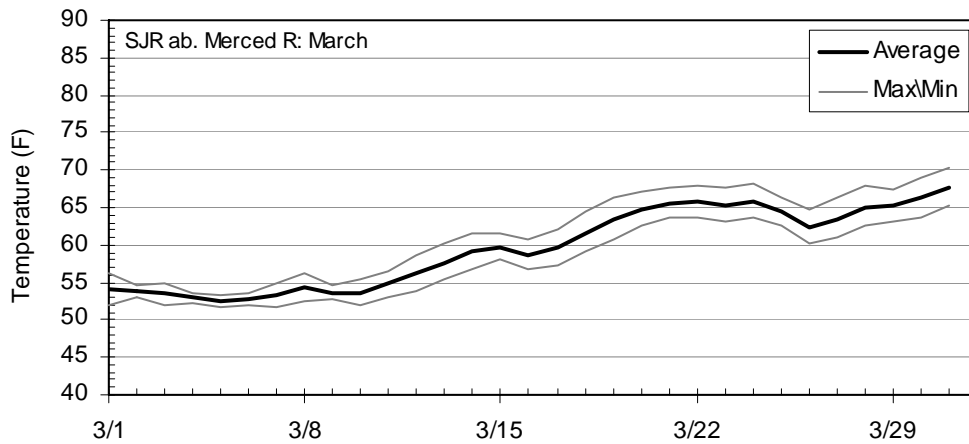
Figure 22. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 500 cfs, (b) 1000 cfs, and (c) 1500 cfs: March 2001



(a)

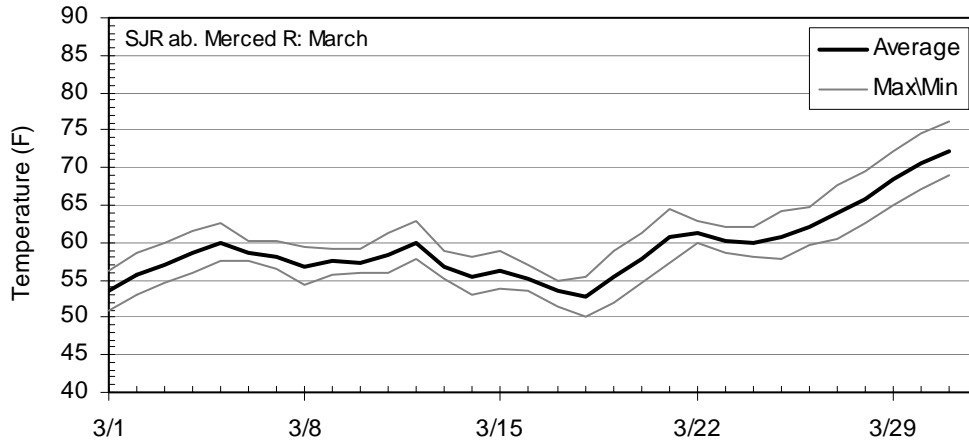


(b)

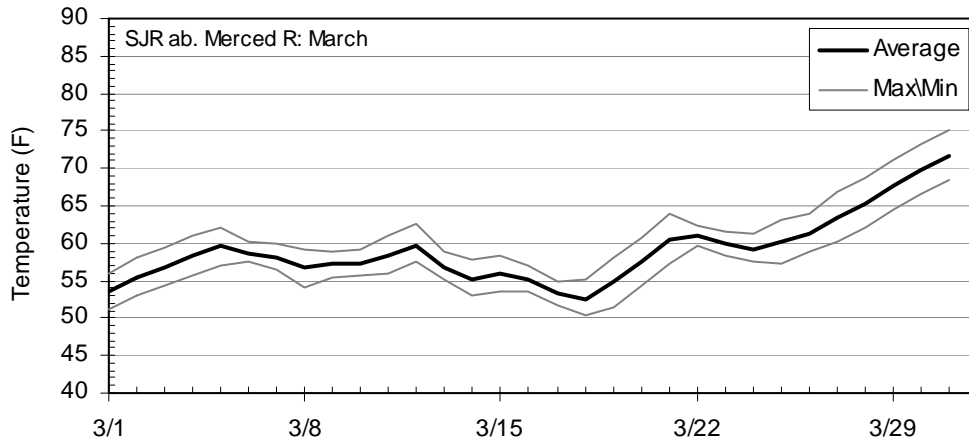


(c)

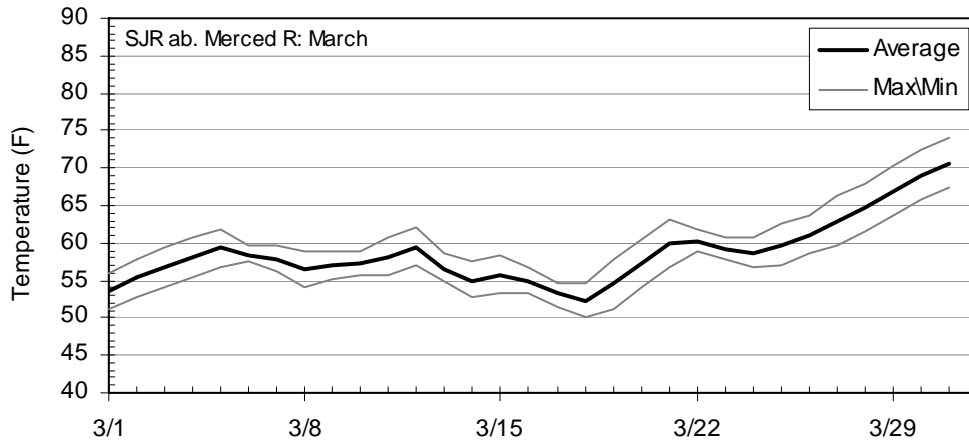
Figure 23. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 2000 cfs, (b) 3000 cfs, and (c) 4000 cfs: March 2001



(a)

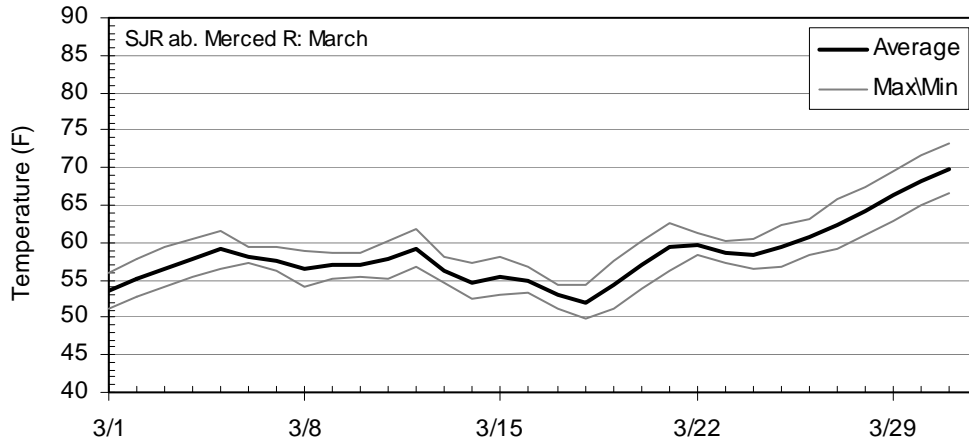


(b)

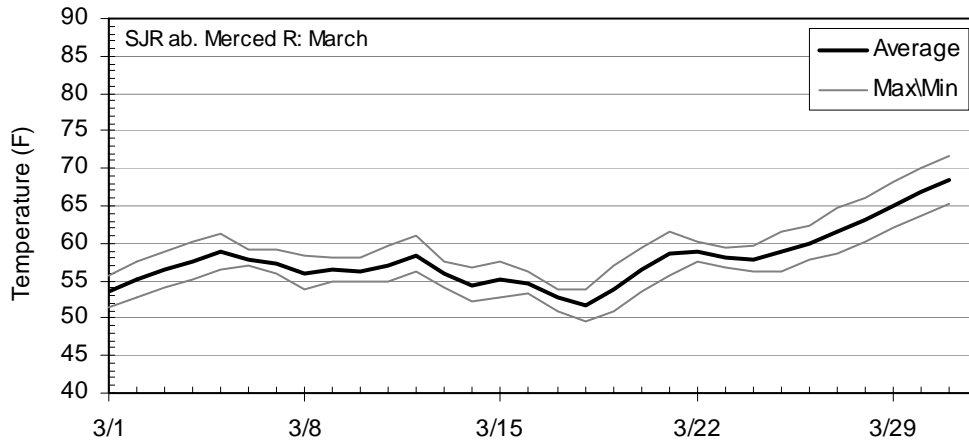


(c)

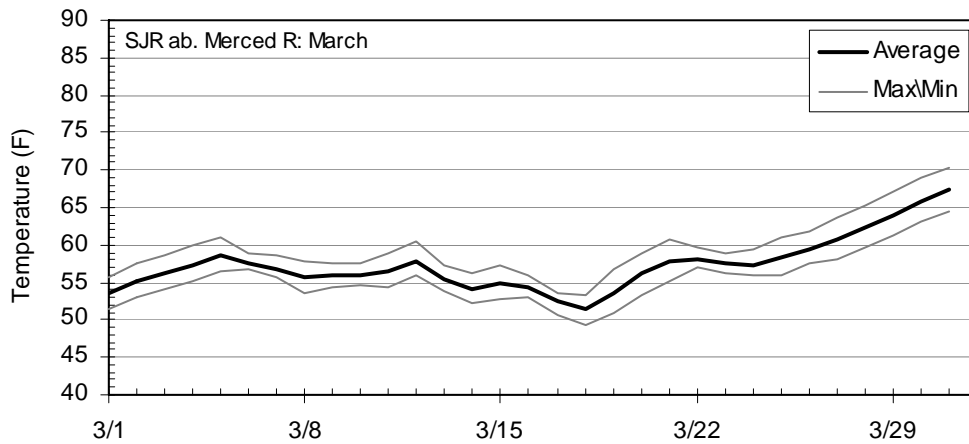
Figure 24. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 500 cfs, (b) 1000 cfs, and (c) 1500 cfs: March 2002



(a)

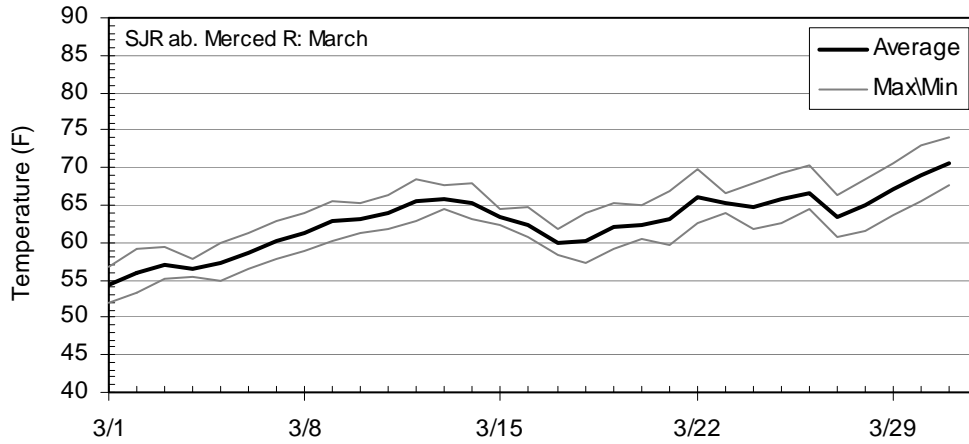


(b)

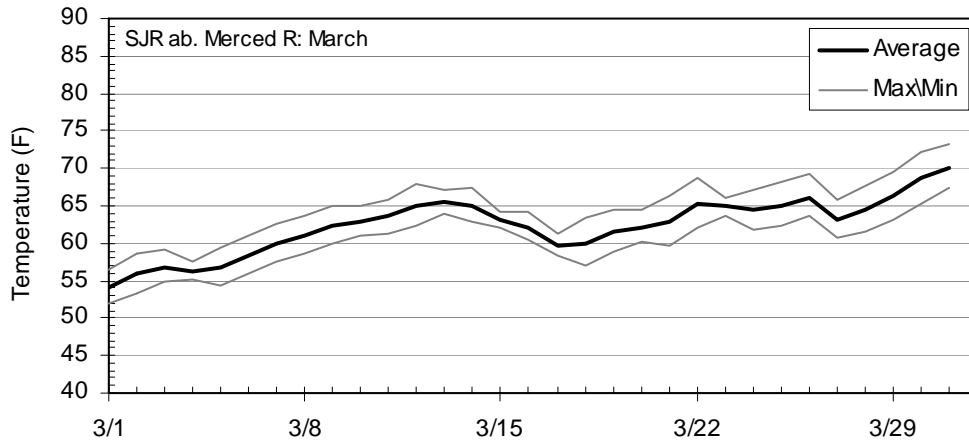


(c)

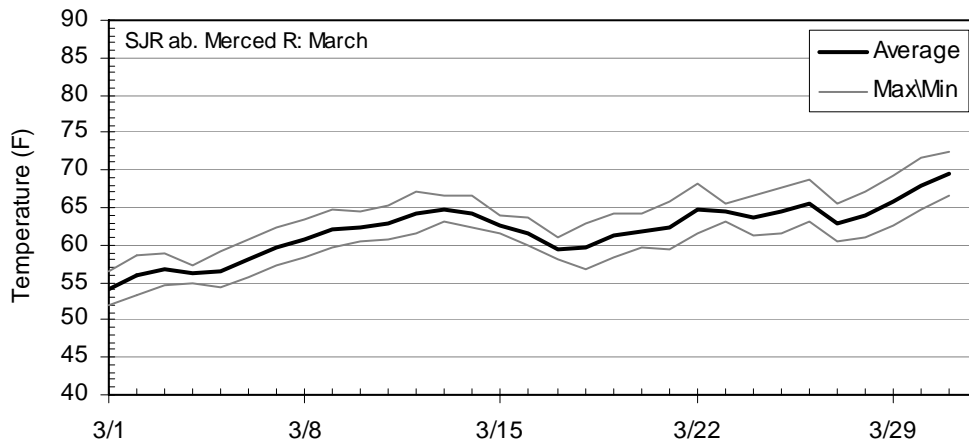
Figure 25. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 2000 cfs, (b) 3000 cfs, and (c) 4000 cfs: March 2002



(a)

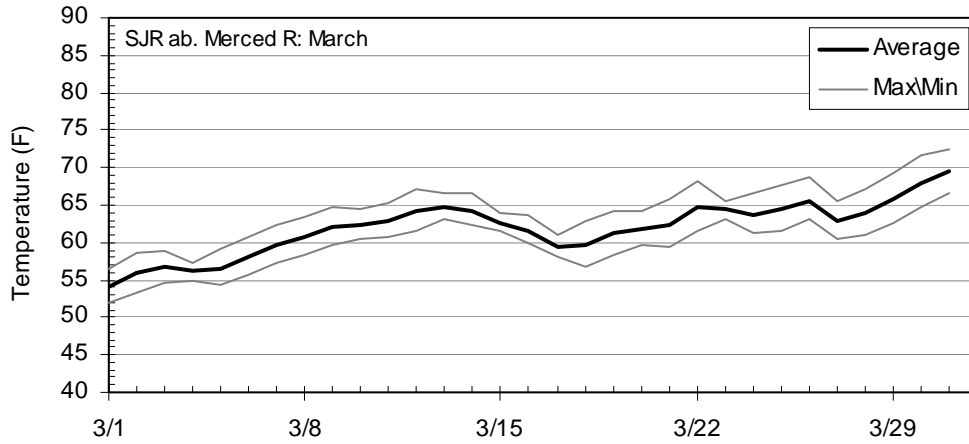


(b)

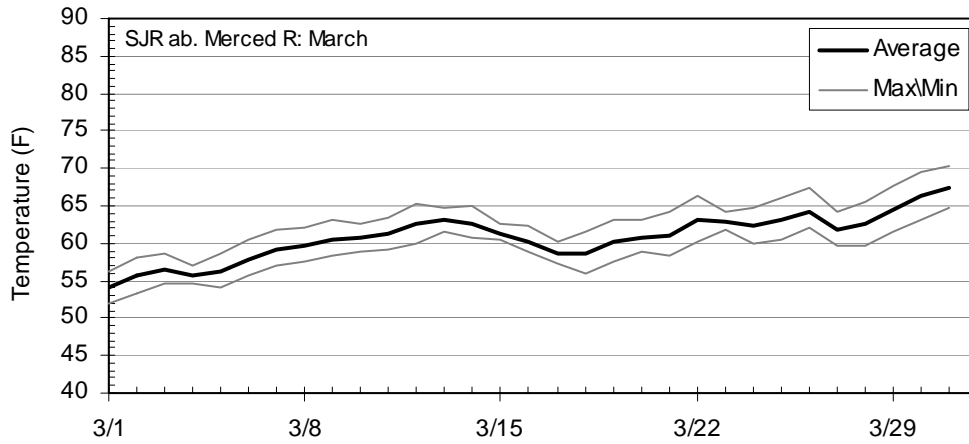


(c)

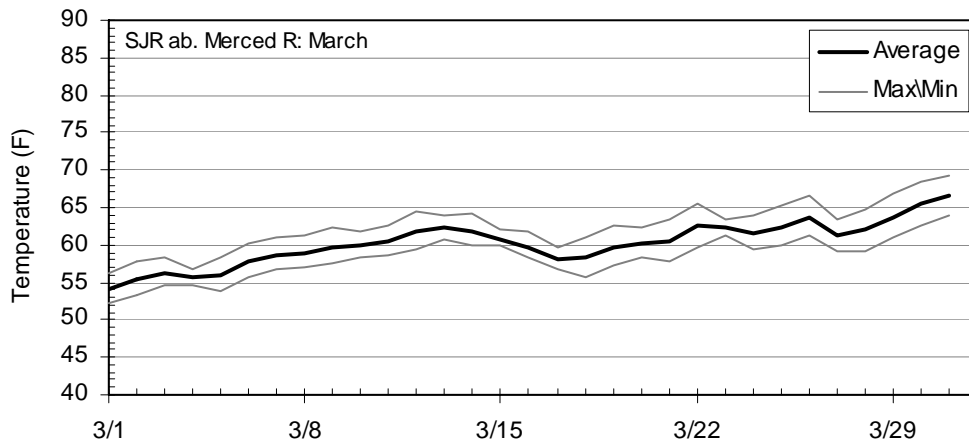
Figure 26. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 500 cfs, (b) 1000 cfs, and (c) 1500 cfs: March 2003



(a)

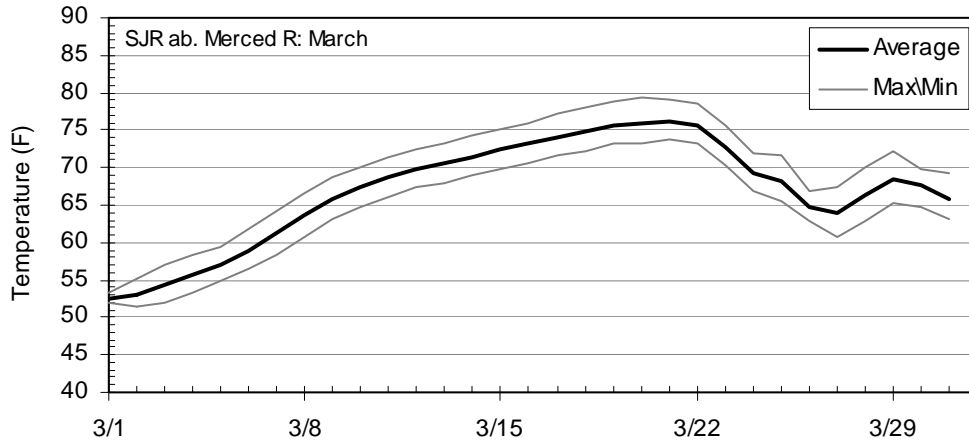


(b)

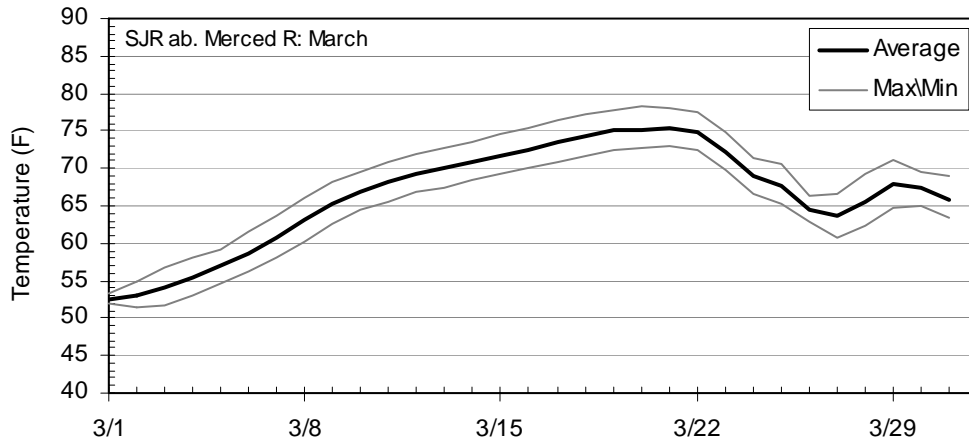


(c)

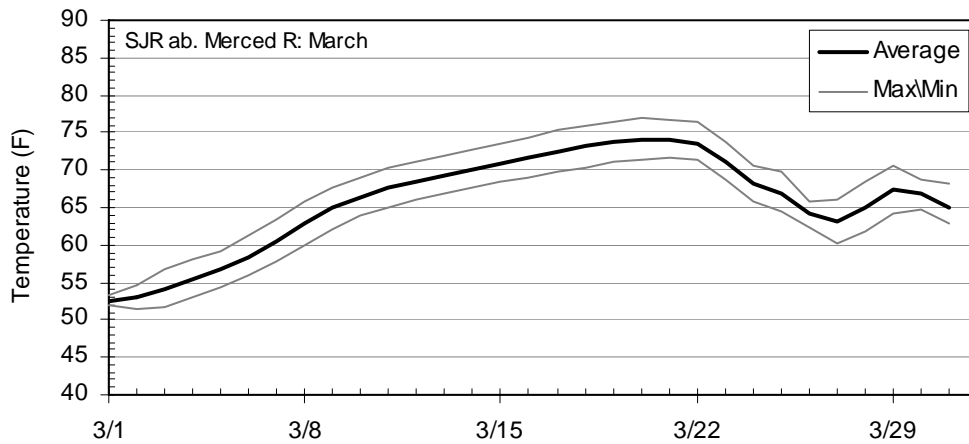
Figure 27. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 2000 cfs, (b) 3000 cfs, and (c) 4000 cfs: March 2003



(a)

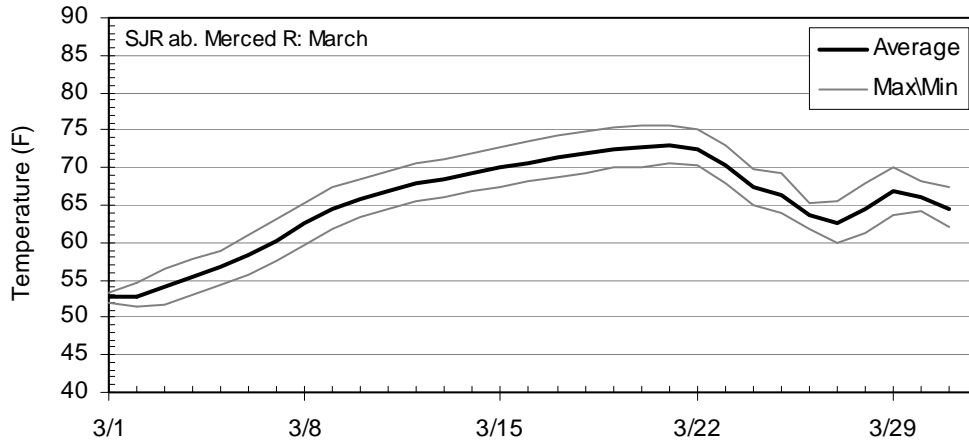


(b)

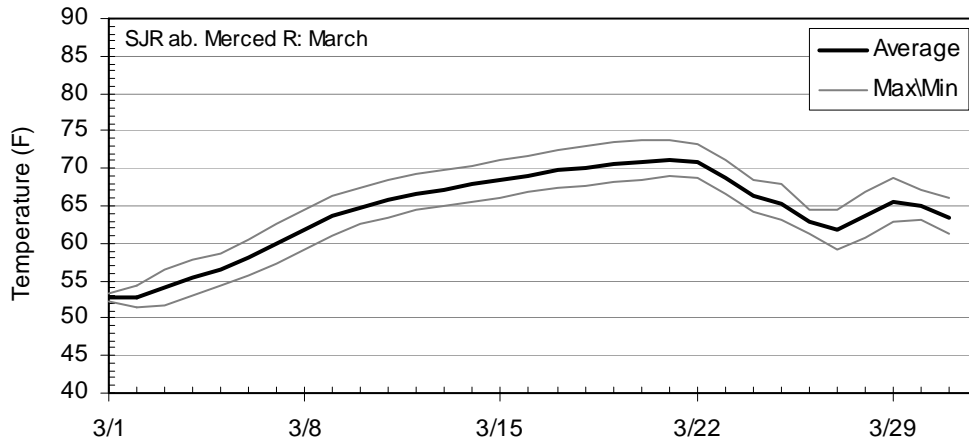


(c)

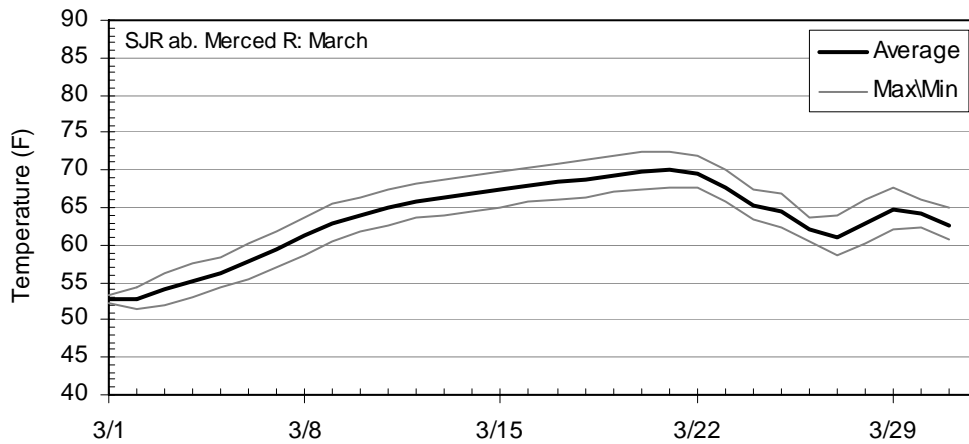
Figure 28. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 500 cfs, (b) 1000 cfs, and (c) 1500 cfs: March 2004



(a)

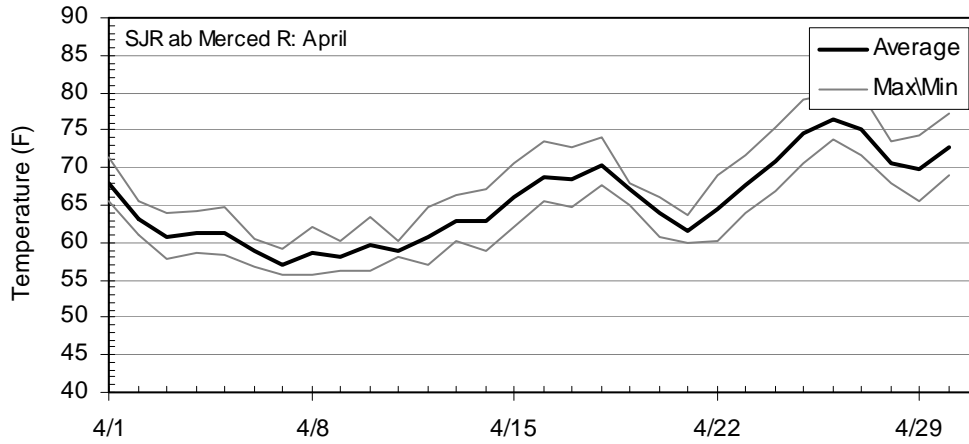


(b)

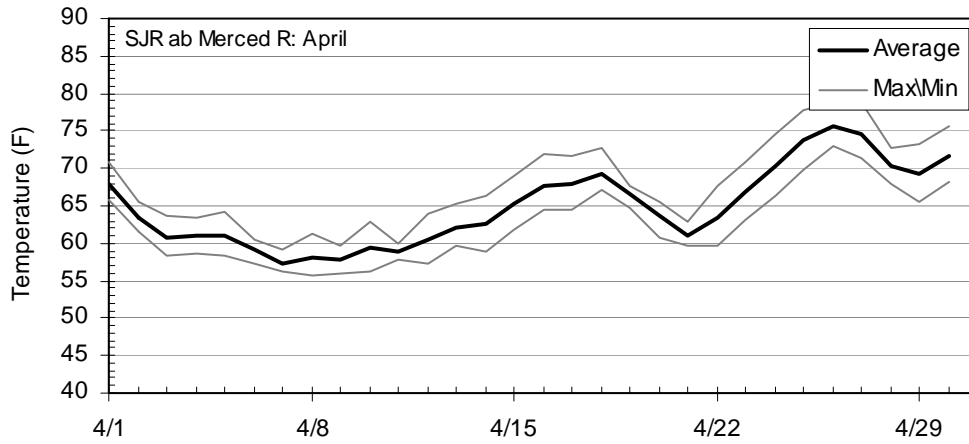


(c)

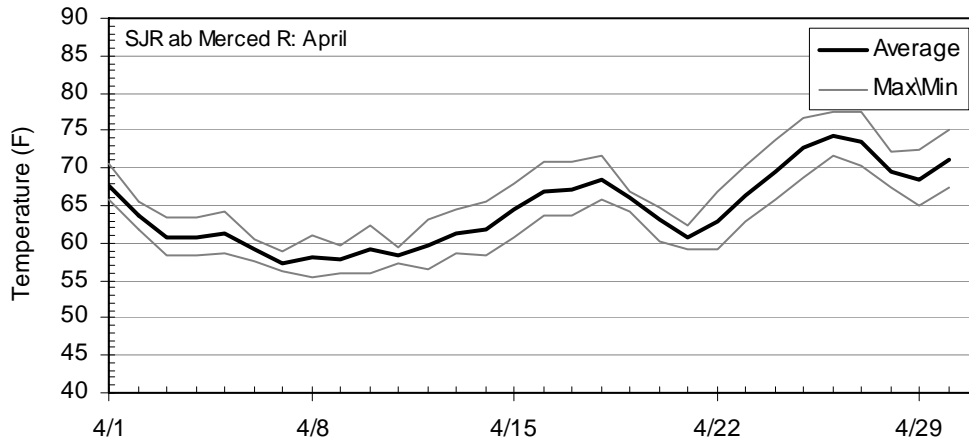
Figure 29. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 2000 cfs, (b) 3000 cfs, and (c) 4000 cfs: March 2001 hydrology (JSA model) March 2004 meteorological conditions



(a)

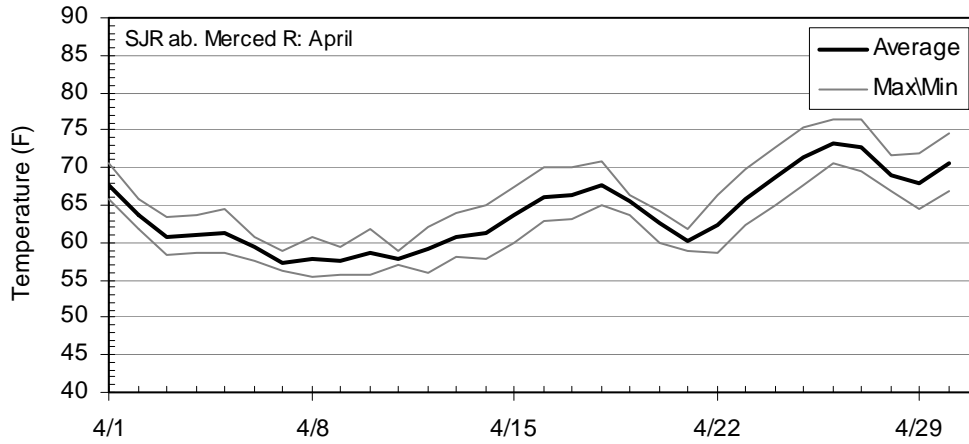


(b)

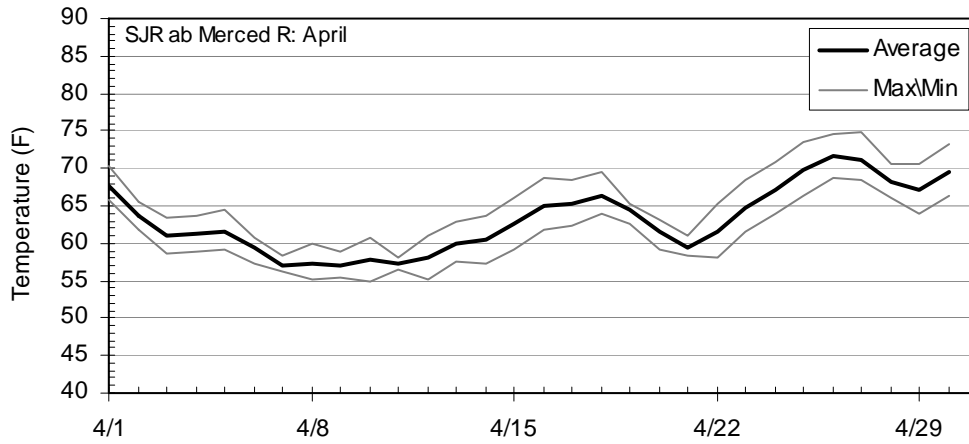


(c)

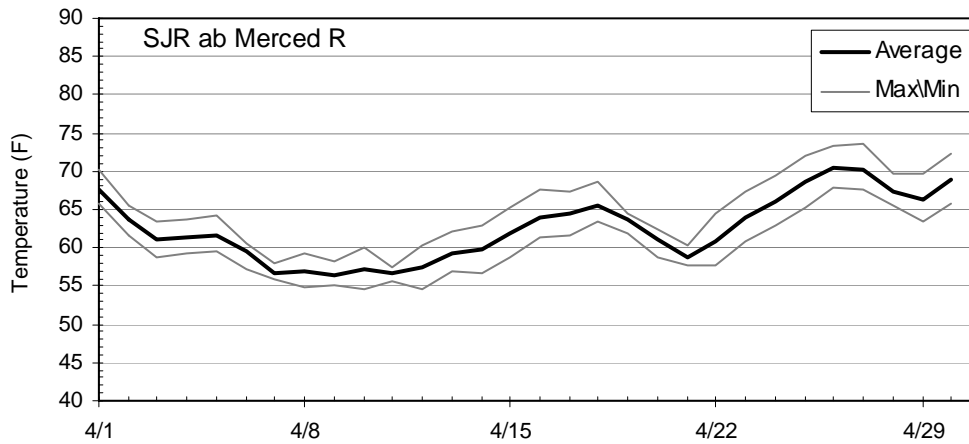
Figure 30. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 500 cfs, (b) 1000 cfs, and (c) 1500 cfs: April 2001 hydrology (JSA model) April 2001 meteorological conditions



(a)

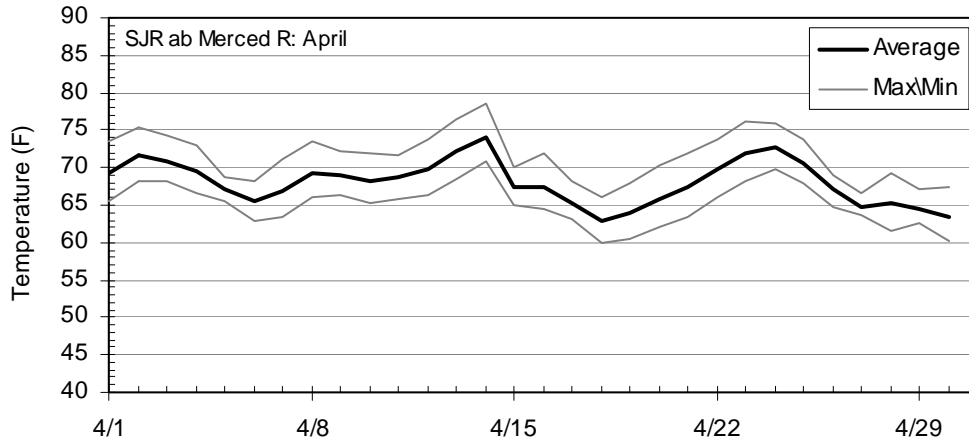


(b)

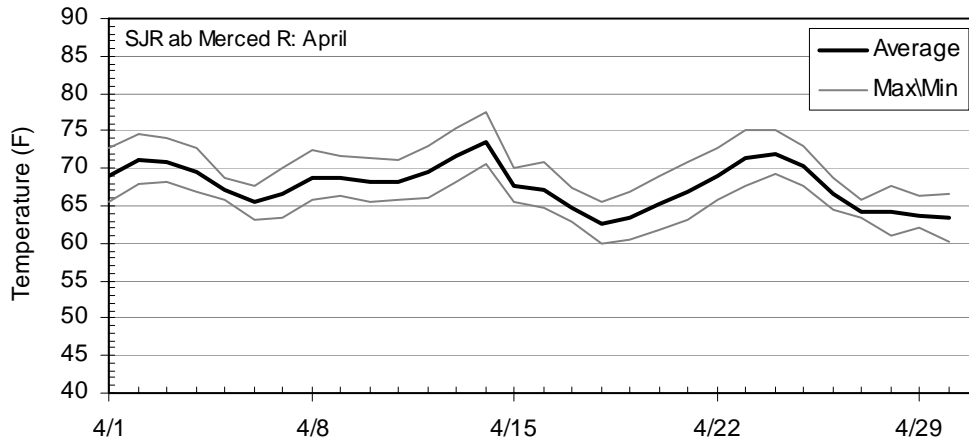


(c)

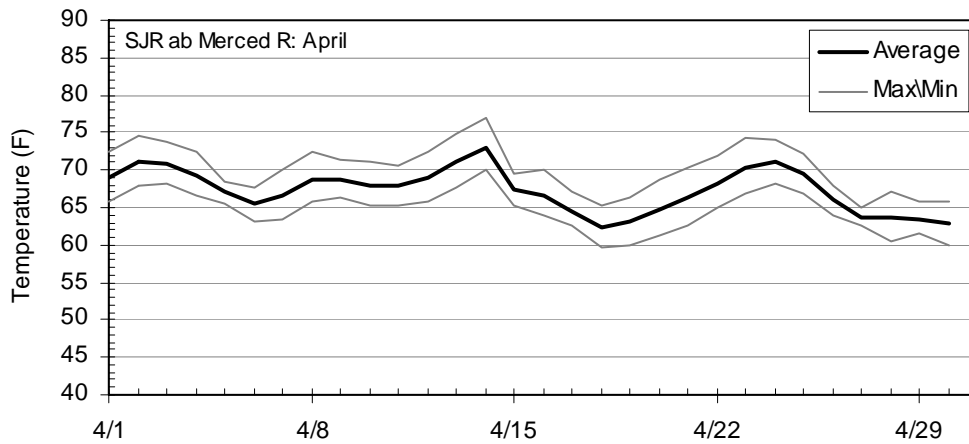
Figure 31. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 2000 cfs, (b) 3000 cfs, and (c) 4000 cfs: April 2001 hydrology (JSA model) April 2001 meteorological conditions



(a)

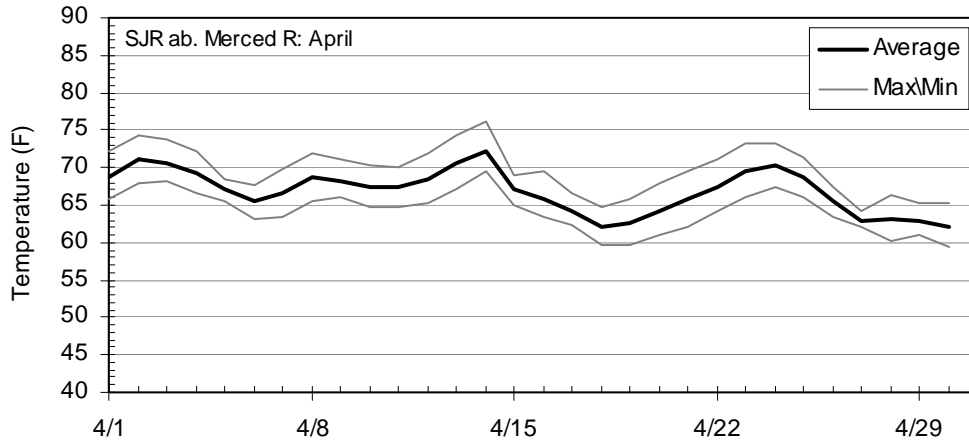


(b)

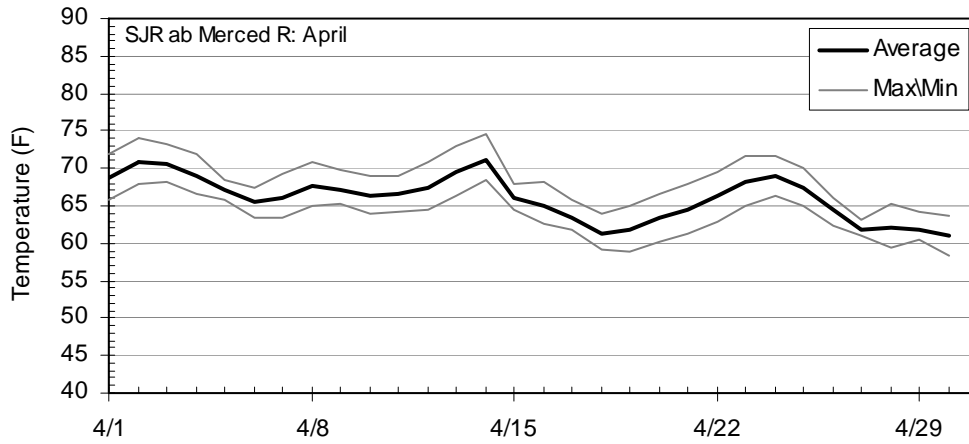


(c)

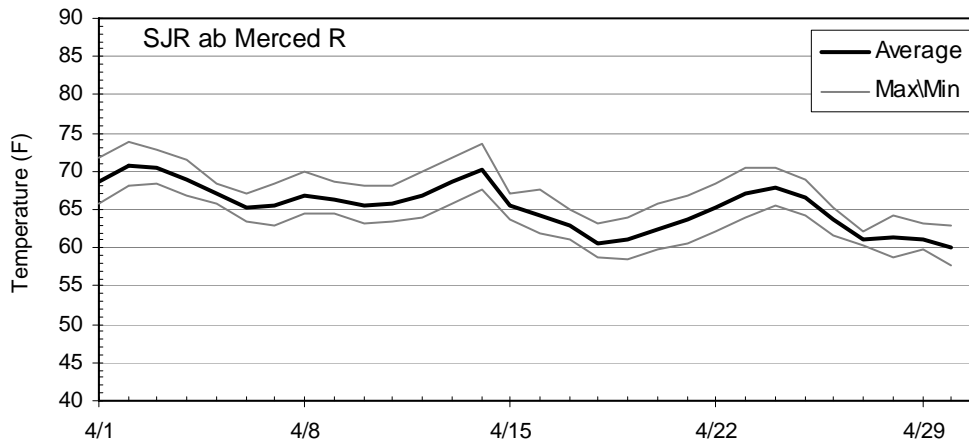
Figure 32. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 500 cfs, (b) 1000 cfs, and (c) 1500 cfs: April 2001 hydrology (JSA model) April 2002 meteorological conditions



(a)

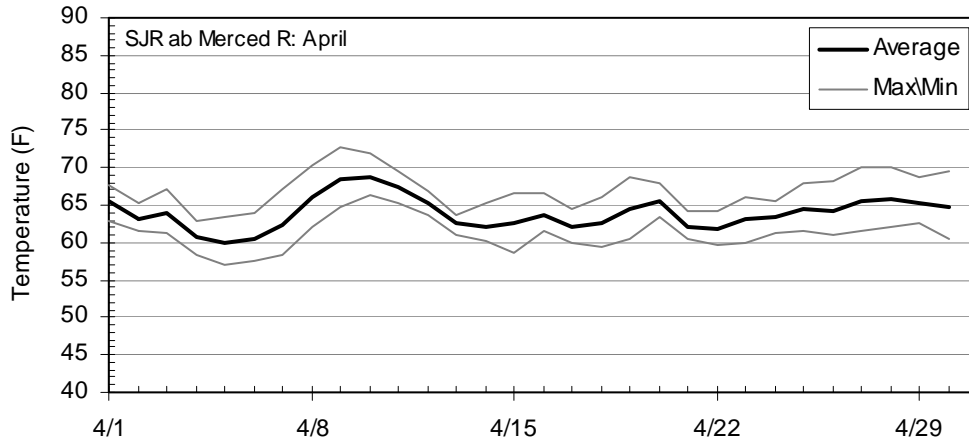


(b)

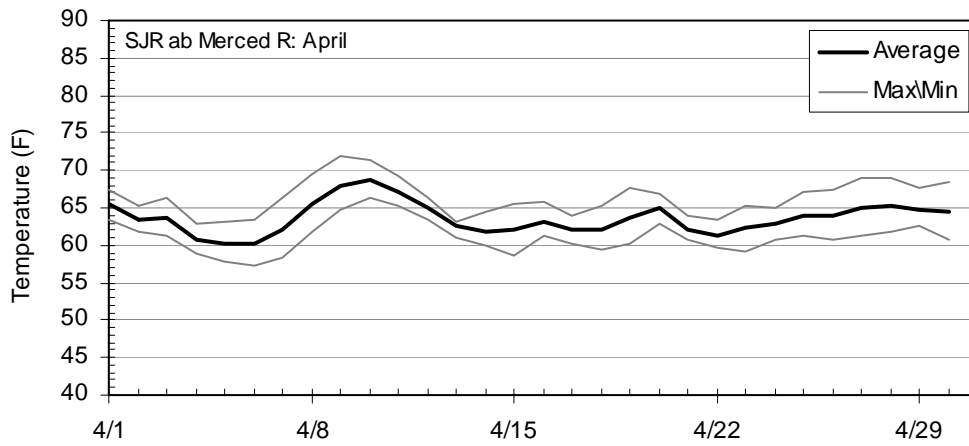


(c)

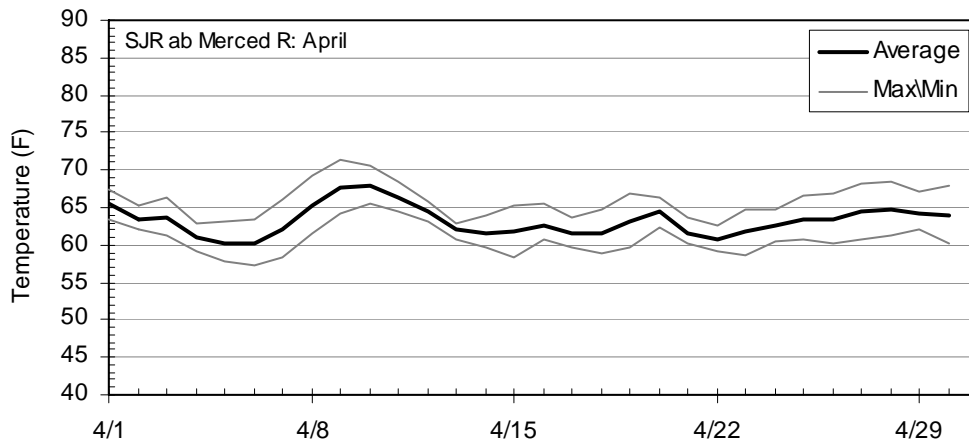
Figure 33. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 2000 cfs, (b) 3000 cfs, and (c) 4000 cfs: April 2001 hydrology (JSA model) April 2002 meteorological conditions



(a)

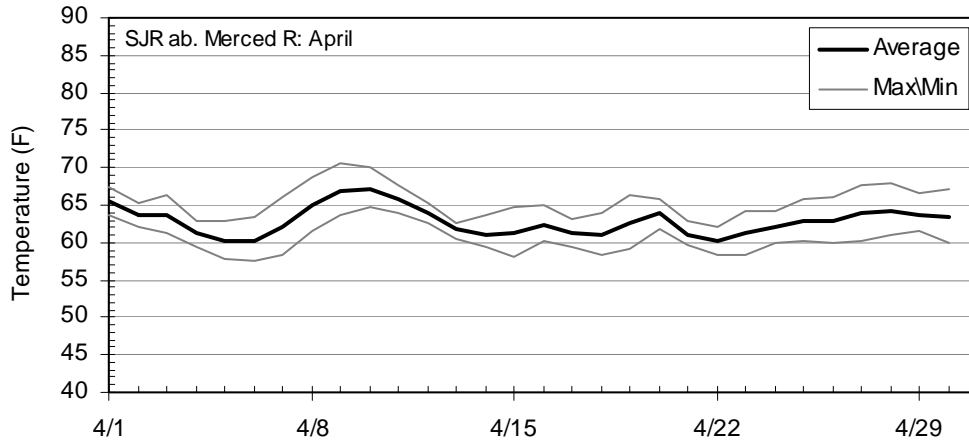


(b)

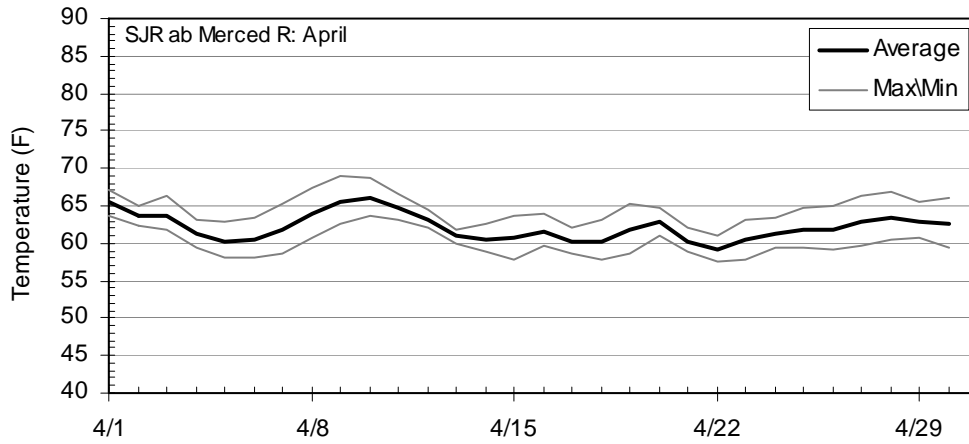


(c)

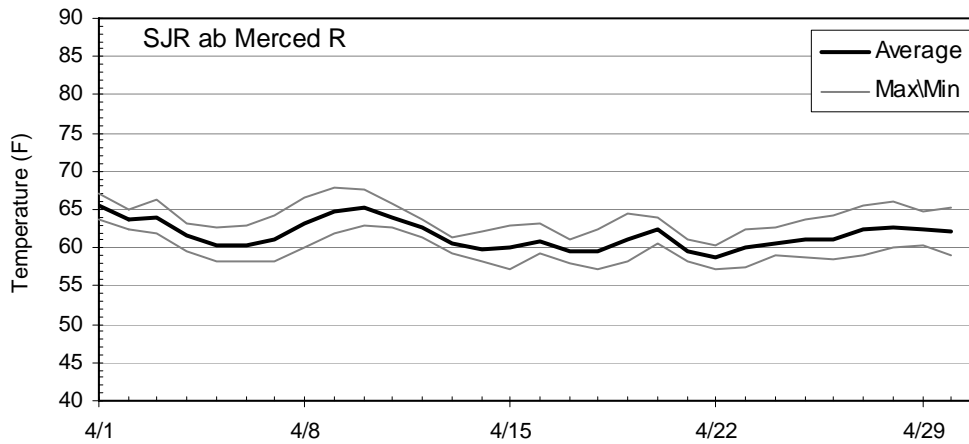
Figure 34. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 500 cfs, (b) 1000 cfs, and (c) 1500 cfs: April 2001 hydrology (JSA model) April 2003 meteorological conditions



(a)

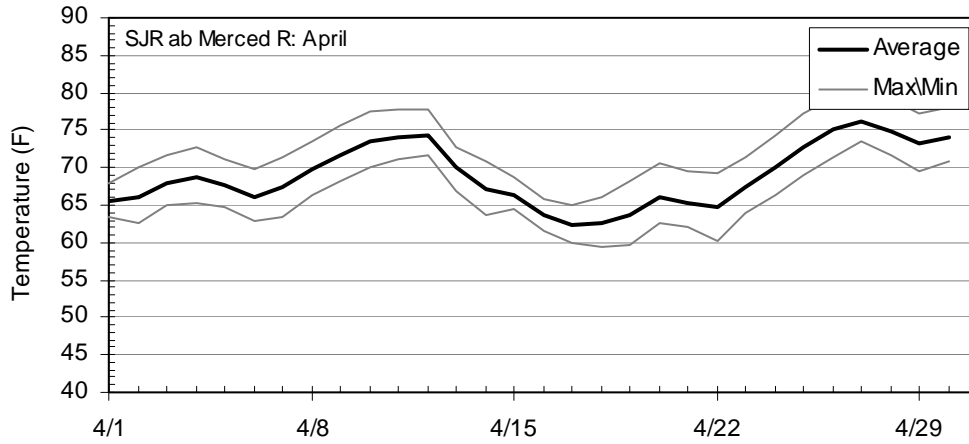


(b)

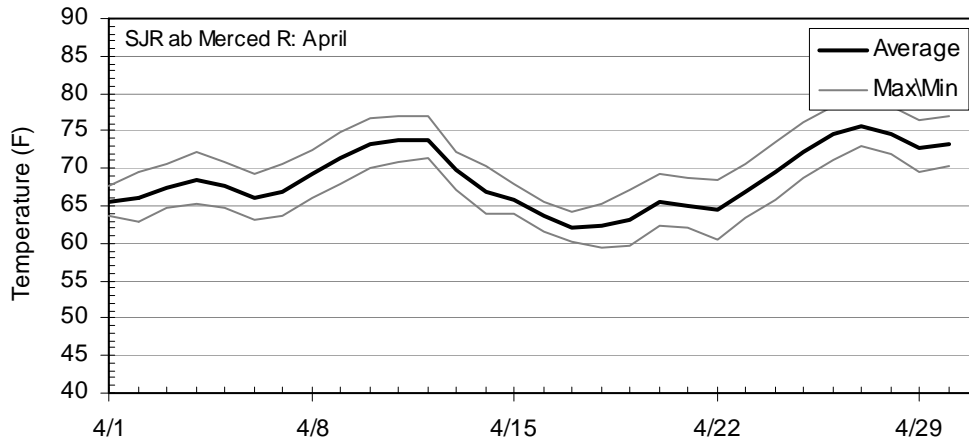


(c)

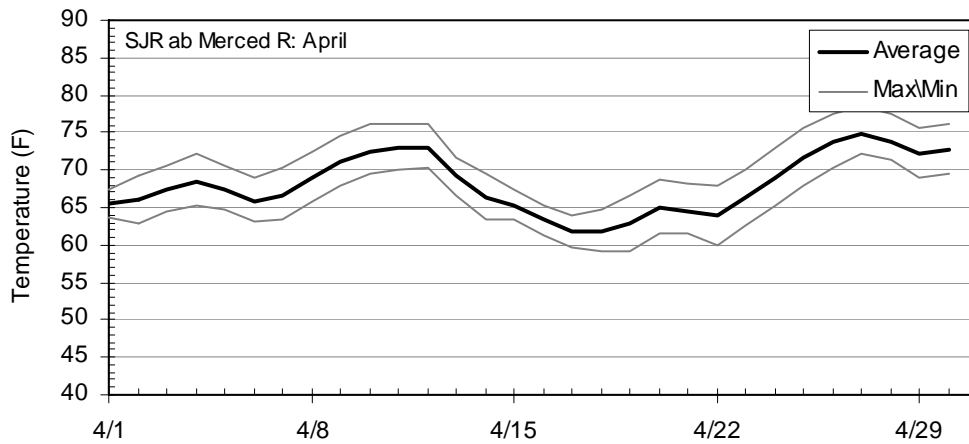
Figure 35. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 2000 cfs, (b) 3000 cfs, and (c) 4000 cfs: April 2001 hydrology (JSA model) April 2003 meteorological conditions



(a)

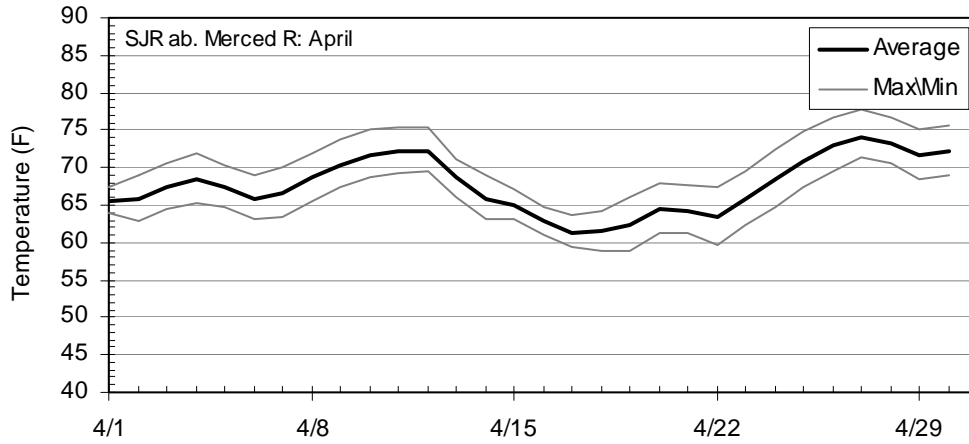


(b)

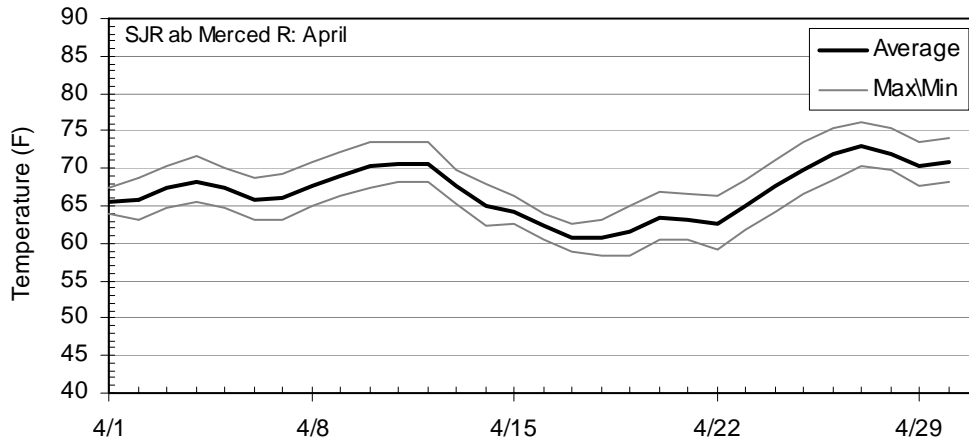


(c)

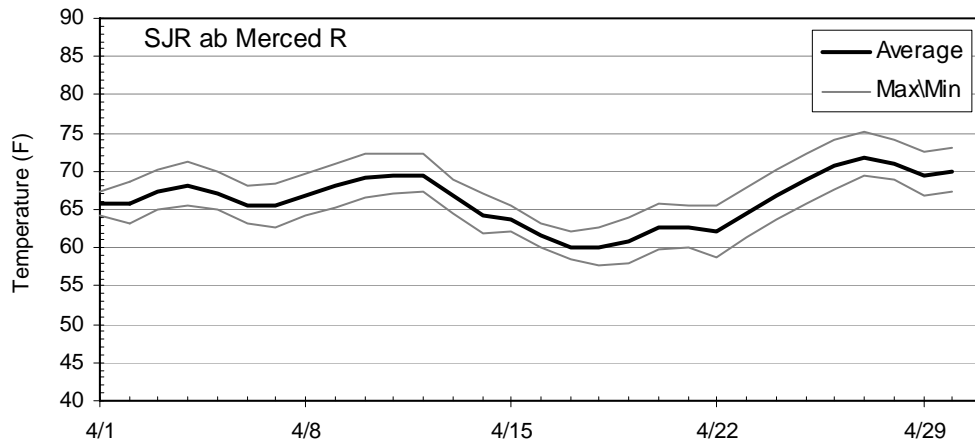
Figure 36. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 500 cfs, (b) 1000 cfs, and (c) 1500 cfs: April 2001 hydrology (JSA model) April 2004 meteorological conditions



(a)



(b)



(c)

Figure 37. Simulated maximum, minimum, and mean water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of (a) 2000 cfs, (b) 3000 cfs, and (c) 4000 cfs: April 2001 hydrology (JSA model) April 2004 meteorological conditions

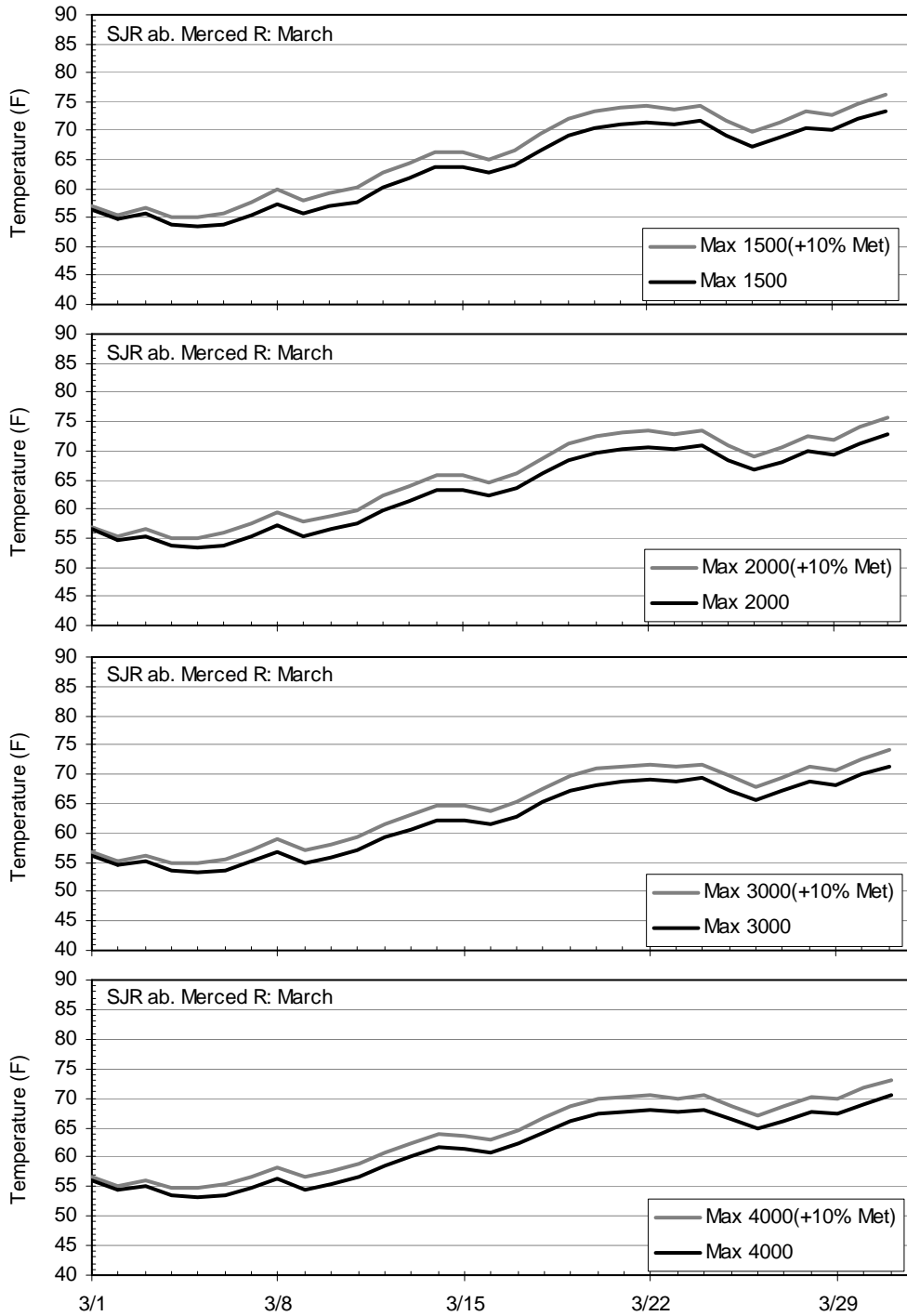


Figure 38. Simulated maximum daily water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of 1,500, 2,000, 3,000, and 4,000 cfs (top to bottom): March 2001 comparison of hydrology (JSA model) with measured air temperature and air temperatures increased by 10 percent (+10% Met)

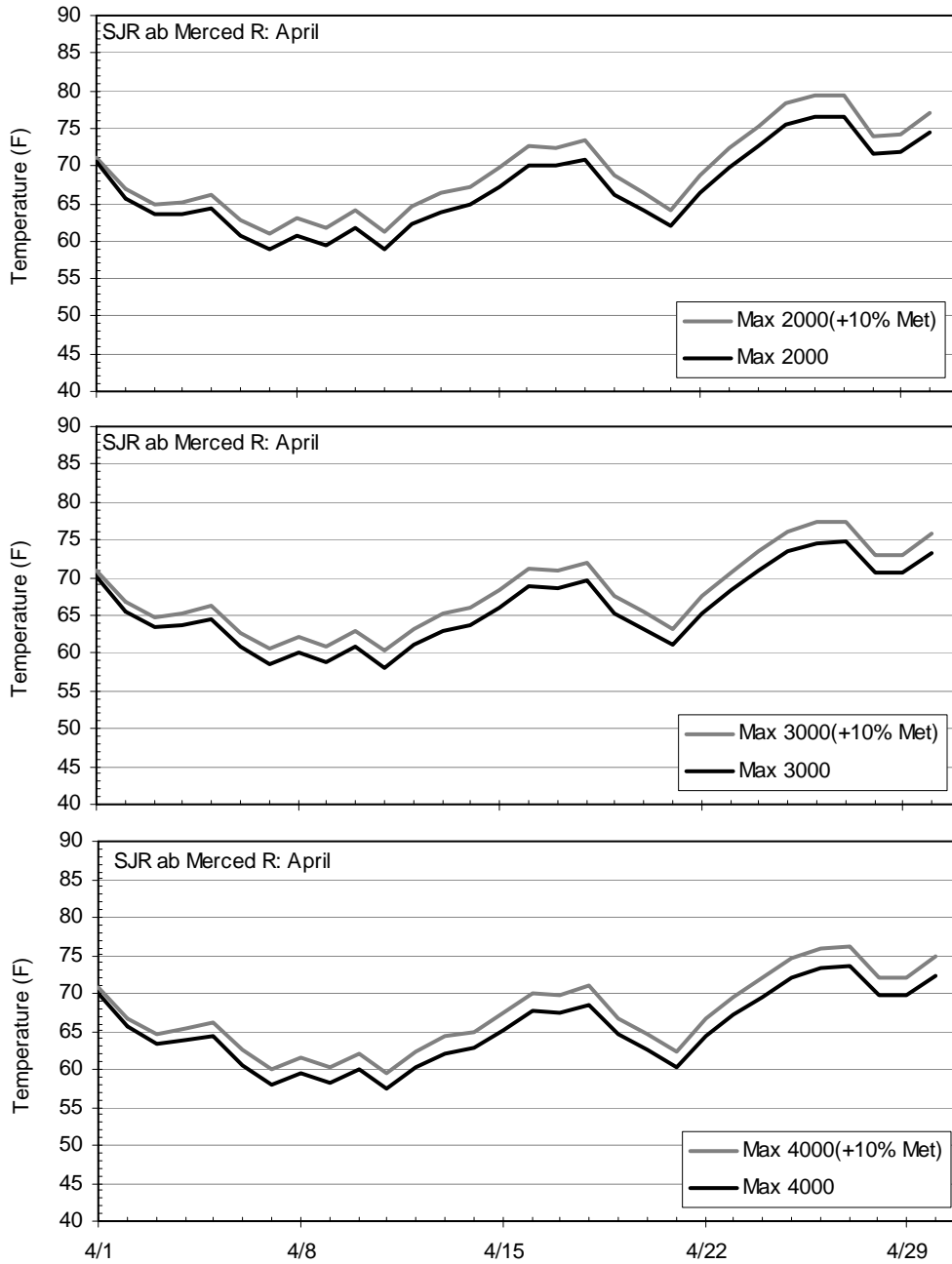


Figure 39. Simulated maximum daily water temperature for the San Joaquin River above the Merced River confluence with a Friant Dam release of 2,000, 3000, and 4000 cfs (top to bottom): April 2001 comparison of hydrology (JSA model) with measured air temperature and air temperatures increased by 10 percent (+10% Met)

6.1.2. Tables

Table 1. Approximate San Joaquin river riles derived from Jones and Stokes Model (2002)

River Mile/ Landmark	Reach Desig. (1-5)	River Mile/ Landmark	Reach Desig. (1-5)	River Mile/ Landmark	Reach Desig. (1-5)	River Mile/ Landmark	Reach Desig. (1-5)
267	1	230	1	190	3	155	4
Hatchery	1	229	1	189	3	154	4
265	1	Gravelly	1	188	3	153	4
264	1	227	1 / 2	187	3	152	4
263	1	226	2	186	3	151	4
262	1	225	2	185	3	150	4
261	1	224	2	184	3	149	4
Donaghy	1	223	2	183	3	Mariposa	4
259	1	222	2	Sack Dam	3 / 4	Mariposa	4
258	1	Napa	2	181	4	146	4
257	1	220	2	180	4	145	4
256	1	Mile 220	2	179	4	144	4
255	1	218	2	178	4	143	4
Hwy 41	1	217	2	177	4	142	4
253	1	216	2	176	4	141	4
252	1	Chowchilla	2	175	4	140	4
251	1	214	2	174	4	139	4
250	1	213	2	173	4	138	4
249	1	212	2	172	4	137	4
Millburn	1	San Mateo	2	171	4	136	4
247	1	210	2	170	4	Bear Crk	4 / 5
246	1	209	2	169	4	134	5
245	1	208	2	Sand	4	Hwy 165*	5
Santa Fe	1	207	2	Sand	4	132	5
243	1	206	2	166	4	131	5
242	1	Mendota	2	165	4	130	5
241	1	Mendota	2 / 3	164	4	129	5
240	1	203	3	163	4	128	5
239	1	202	3	162	4	Salt Sl	5
238	1	201	3	161	4	126	5
237	1	200	3	160	4	125	5
236	1	199	3	159	4	124	5
235	1	198	3	158	4	123	5
Skaggs	1	197	3	157	4	122	5
233	1	196	3	156	4	Mud Sl	5
232	1	195	3			120	5
231	1	Firebaugh	3			Merced R	5
		193	3			Newman	5
		192	3				
		191	3				

River Miles are approximate. From the Jones and Stokes San Joaquin River Restoration Simulations Model SJRiver, 2002

* San Joaquin River near Stevinson: approximate location

Table 2. San Joaquin River storage upstream of Millerton Reservoir

Reservoir/Lake	Capacity (acre-feet)
Thomas A. Edison Lake	125,000
Florence Lake	64,000
Huntington Lake	89,000
Shaver Lake	136,000
Mammoth Pool	122,000
Redinger Lake	26,000
Crane Valley Reservoir	45,500
Kerckhoff Reservoir	<u>4,188</u>
	611,688

Source: U.S. Bureau of Reclamation, Millerton Lake Daily Operations Report
(http://www.usbr.gov/mp/cvo/vungvari/sccao_mildop.pdf)

Table 3. Approximate travel times in the San Joaquin River from Friant Dam to the Merced River (derived from Musseter, 2000a)

Flow Rate (cfs)	Travel time (days)
100	14.7
200	12.3
500	8.7
1,000	6.5
1,500	5.6
2,000	5.1
4,000	4.1
8,000	3.6

Table 4. Air temperature conditions at Fresno (adapted from JSA, 2002)

Month	Coolest Avg Monthly Temperature	Mean Avg Monthly Temperature	Warmest Avg Monthly Temperature	2001 Monthly Avg Temperature	2001 % of Mean Avg Temperature	2002 Monthly Avg Temperature	2002 % of Mean Avg Temperature	2003 Monthly Avg Temperature	2003 % of Mean Avg Temperature	2004 Monthly Avg Temperature	2004 % of Mean Avg Temperature
Jan	40.6	46.0	53.6	46.1	100%	43.9	95%	48.8	106%	45.2	98%
Feb	45.5	50.5	56.4	48.7	96%	49.3	98%	48.7	96%	49.3	98%
Mar	50.1	55.6	60.7	58.7	106%	53.3	96%	55.8	100%	60.2	108%
Apr	52.6	60.9	67.2	58.6	96%	60.4	99%	55.9	92%	63.4	104%
May	61.7	69.3	77.3	77.3	112%	67.4	97%	67.1	97%	68.7	99%
Jun	69.0	76.2	82.8	79.7	105%	75.7	99%	75.8	99%	75	98%
Jul	76.2	81.4	87.0	79.8	98%	81.1	100%	83.4	102%	80.7	99%
Aug	72.7	80.1	84.2	81.0	101%	76.8	96%	78.5	98%	78.4	98%
Sep	68.6	75.0	81.0	76.3	102%	73.6	98%	75.8	101%	72.3	96%
Oct	59.6	65.0	70.5	66.7	103%	61.6	95%	65.3	100%	61.1	94%
Nov	48.1	53.5	58.7	52.8	99%	53.3	100%	49.7	93%	49.7	93%
Dec	40.0	45.3	51.2	44.8	99%	47.5	105%	48.2	106%	44.8	99%

Adapted from JSA (2002) – water year (i.e., Oct. 2000-Sept. 2001)

6.2. Exhibit B. Resume

Michael L. Deas
Watercourse Engineering, Inc.
133 D Street, Suite F
Davis, CA 95616
530-750-3072
mike.deas@watercourseinc.com

QUALIFICATIONS

Michael Deas has over 15 years of problem-solving experience. Dr. Deas analyzes surface water systems, quantifies physical, chemical, and biological processes in aquatic systems as they influence water quality, and evaluates surface water quality for environmental, industrial, and municipal supplies. He is a recognized expert on water quality issues in Northern California and Central Valley systems.

Michael Deas:

- Conducts surface flow and quality assessments.
- Develops conceptual models, identifying the interactions between/among aquatic systems, inputs and outputs, as well as processes taking place within the systems themselves.
- Develops and applies analytical tools as well as complex numerical models to evaluate flow and the fate and transport of physical and chemical constituents in aquatic systems.
- Provides technical presentations, both orally and in writing, for diverse audiences.

EDUCATION

Doctor of Philosophy, Civil Engineering

University of California, Davis

Year Received: March 2000

Major: Environmental Fluid Mechanics

Minor: Water Resources Management

Dissertation: Application of numerical models in ecological assessment

Master of Science

University of California, Davis

Year Received: March 1989

Major: Water Resources Management

Master's Thesis: A finite element model of groundwater flow on shallow layer and perched aquifers

Bachelor of Science

University of California, Davis

Year Received: June, 1986

Major: Civil Engineering

PROFESSIONAL EXPERIENCE

Consulting Engineer, 1/98 – Present

- Provided professional engineering services for water quantity and quality issues associated with river and reservoir systems. Typical tasks include system definition, monitoring (including development and implementation of Quality Assurance Project Plans), numerical model construction and/or application, and analysis of system response to alternative management conditions. Projects include
- Basin-scale flow and water quality modeling for river and reservoir reaches in the Klamath River basin (PacifiCorp)
 - Physical characterization of spatial and temporal variability of flow and temperature within thermal refugia for over-summering anadromous fishes on the Klamath River (U.S. Bureau of Reclamation in cooperation with the Yurok Tribe).
 - Water quality modeling training program (State Water Resources Control Board)
 - Recreation of historic flow and water temperature conditions on the Upper Sacramento River: 1970 to 2001 (United States Geological Survey)
 - Shasta River flow and temperature modeling for anadromous fish restoration (United States Fish and Wildlife Service and California Department of Fish and Game)
 - Water quality model application to assess eutrophication potential within the Crystal Springs Reservoir complex (City of San Francisco for Merritt Smith Consulting)
 - Central Valley water temperature modeling review (Bay Delta Modeling Forum)
 - Review of Truckee River Operations Agreement (G.T. Orlob and Associates for the United States Department of Justice)
 - Klamath River water quality monitoring and modeling for anadromous fish restoration (U.S. Bureau of Reclamation)
 - Trinity Reservoir temperature monitoring/modeling and carry-over studies (Trinity County)
 - Yuba River temperature studies (United States Fish and Wildlife Service)

Senior Engineer, Earth Science Associates, 1992-93.

Designed, constructed, tested, and applied a monthly operations model of the Los Angeles Department of Water and Power Mono Basin – Owens Valley Aqueduct System (Los Angeles Aqueduct Simulation Model). Implemented a long-term computer model maintenance program. Performed water supply analysis for various clients.

Consulting Engineer, Los Angeles Department of Water and Power - 1991, 1993.

Co-managed Mono Basin – Owens Valley computer modeling project. Formulated and implemented system operation model for Los Angeles' eastern Sierra Nevada water gathering facilities. Participated in a UCLA-Mono Basin public policy program mediation effort, and served on technical advisory committees for the State Water Resources Control Board (State Board) water rights re-issuance hearings for

Los Angeles. Testified before the State Board concerning predictive computer models for the Mono Basin and Owens River Basin.

Assistant Engineer, Aqueduct Division, Los Angeles Department of Water and Power, 1989-90.

Revamped and expanded the Mono Basin computer model from a spreadsheet to a FORTRAN program capable of assessing a wide range of scenarios. Conducted various studies examining the impact of alternative operations and hydrologic conditions on Mono Lake surface elevations and water supply to Los Angeles. Reviewed water rights issues and made recommendations to legal staff.

Civil Engineer, Hydrologic Engineering Center, U.S. Army Corps of Engineers, 1987.

Researched and formulated a report on the Corps responsiveness to the 1986 drought in the southeastern United States. The report, titled "Lessons Learned from the 1986 Drought" compiled information learned from the drought and presented specific recommendations for drought contingency planning.

RESEARCH EXPERIENCE

Project Manager, Klamath River water temperature and water quality modeling project.

University of California, Davis. (United States Fish and Wildlife), 6/95 – 12/99. Application of hydrodynamic and water quality models to analyze water quality control alternatives designed to improve anadromous fisheries in the Klamath River downstream of Iron Gate Dam. Simulated dissolved oxygen, temperature, nutrients, and algal dynamics. Alternative included varying timing and quantity of reservoir releases as well as retrofitting outlet works to allow selective withdrawal for downstream temperature control.

Project Manager, Shasta River Flow and Temperature Modeling Project. University of California, Davis. (California State Water Resources Control Board, 205(j) Clean Water Act Grant Program, 3/95 – 6/98.

Project included modeling flow and water temperature on the Shasta River for anadromous fish restoration efforts. Subtasks included hydrology, meteorology, water temperature data inventory and woody riparian vegetation inventory. Modeling included examining the impact of spring flow accretions, diversions, return flow, and riparian shading on this small river system. Designed and implemented temperature monitoring program.

Project Manager, Sacramento River Temperature Modeling Project. University of California, Davis. (California State Water Resources Control Board, 205(j) Clean Water Act Grant Program, 3/95 - 3/97.

Managed a team of engineers to implement and apply computer models to analyze the potential for temperature control in reaches critical for salmon reproduction downstream of Central Valley Project (CVP) reservoirs. Project team completed application of finite difference models of major CVP reservoirs – Lake Shasta and Trinity Lake; and implemented, calibrated, and verified one-dimensional finite element hydrodynamic and water temperature models for Keswick Reservoir, and the Sacramento and Feather Rivers.

Research Engineer, Putah Creek Coarse Sediment Evaluation below Monticello Dam (University of California, Davis Public Service Research Program), 6/95-8/96

Designed and completed field monitoring program to examine morphological changes to Putah Creek. Field work and associated research revealed that direct effects of Monticello Dam include creek aggradation due to tributary sediment contributions, as well as tributary down-cutting due to reduced post-project stream levels.

Project Manager, Willits Bypass Floodplain Study. University of California, Davis. (California Department of Transportation), 4/94 - 6/95.

Applied a two-dimensional finite element hydrodynamic model to an inundated floodplain with coalescing streams in Little Lake Valley near Willits, California. Verified and applied model for 100-year flood event to examine impacts of alternative freeway alignments on floodplain dynamics. Determined over-crossings (bridge) and drainage requirements to maintain backwater effects to less than 1.0 feet, where possible.

TEACHING EXPERIENCE

Associate Instructor, Department of Civil and Environmental Engineering, University of California, Davis, Spring 1999, Spring 2001.

Environmental Quality Modeling (Civil and Environmental Engineering 244) – Instructor for graduate course addressing mathematical modeling of environmental water quality. Subject matter focused on structure, capabilities/limitations, sensitivity and reliability of water quality models as analytical tools.

Lecturer, U.S. Army Corps of Engineers. July 1999, July 2000.

Water and the Watershed – Hydrologic, Environmental, and Ecological Modeling. Provided lecture and materials to Corp of Engineers' planners, economists, and biologists from district offices nationwide. Topics include fundamentals critical to computer modeling at the watershed level as well as case studies.

Associate Instructor, Department of Civil and Environmental Engineering, University of California, Davis, Fall 1997.

Unsteady Flow in Surface Waters (Civil and Environmental Engineering 277) – Instructor for graduate course covering topics of unsteady flow. Subjects included long waves in surface flow, St. Venant equations, method of characteristics, explicit and implicit finite difference methods, stability of numerical schemes, and flood routing techniques.

Teaching Assistant, University of California, Davis, 1986-88, 1993, 1996.

Duties included preparing lectures, designing homework assignments, administering and grading tests, evaluating student performance, and assigning grades. Classes include:

- Engineering 3: Introduction to Engineering (lab)
- Engineering 35: Statics (discussion)
- Civil and Environmental Engineering 10: Introduction to Surveying (lab)
- Civil and Environmental Engineering 141L: Hydraulics (lab)
- Civil and Environmental Engineering 145: Design of Open Channel Structures (class)
- Civil and Environmental Engineering 152: Civil Engineering Planning (class)
- Civil and Environmental Engineering 271: Water Resources Planning Lab (class)

PROFESSIONAL AWARDS AND ACTIVITIES

Chairman: Peer Review Panel for setting temperature objectives for anadromous fish in the Stanislaus River (2003-present)

Member: Levee Risk Assessment Team (CALFED) (2004)

California Water and Environmental Modeling Forum Steering Committee member (2002-present)

Nathaniel Bingham Memorial Award, U.S. Fish and Wildlife (2001)

Causative Factors Analysis ad hoc committee: Shasta River anadromous fisheries restoration (1999)

Water Quality Modeling Panel (1998), Klamath River Technical Working Group
Mono Lake Technical Advisory Group (1992-93), State Water Resources Control Board

Mono Lake Public Policy Program (1991); City of Los Angeles, UCLA.

Peer Reviewer for Professional Journals (ongoing)

- Water Resources Research
- American Society of Civil Engineers: Journal of Water Resources Planning and Management

PROFESSIONAL SOCIETIES, AFFILIATIONS, AND LICENSES:

Sigma Chi – Member

American Society of Civil Engineers

American Water Resources Association

American Geophysical Union

Registered Professional Civil Engineer, State of California (1990)

6.3. Exhibit C. Publications

Michael L. Deas

Principal

(Aug/05)

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PUBLICATIONS

Reports

Tanaka, S.K., M.L. Deas, S. Null. 2005. *STREAM and LAASM: Models for Mono Basin Operations* (Draft). Prepared for the Los Angeles Department of Water and Power. July.

Vaughn, J., and M.L. Deas. 2005. *Shasta River Algae Model*. (Draft) Prepared for the Information Center for the Environment, Department of Environmental Science & Policy, University of California, Davis, and the North Coast Regional Water Quality Control Board. July.

Vignola, A., and M.L. Deas. 2005. *Lake Shastina Limnology*. Prepared for the Information Center for the Environment, Department of Environmental Science & Policy, University of California, Davis, and the North Coast Regional Water Quality Control Board. April.

Deas, M.L. 2005. *Klamath Basin Water Quality Group: Charter* (Draft). Prepared for the Klamath River Water Quality Coordination Group – jointly sponsored by the North Coast Regional Water Quality Control Board and U.S. EPA Region IX, as well as other basin stakeholders. March.

Watercourse Engineering, Inc. 2005. *Trinity River Flow and Temperature Modeling Conceptual Framework*. Prepared for Trinity County Planning Department Natural Resources Division. January.

Deas, M., J. Bartholow, C. Hanson, C. Myrick. 2004. Peer Review of Water Temperature Objectives Used as Evaluation Criteria for the Stanislaus – Lower San Joaquin River Water Temperature Modeling and Analysis. Prepared for AD Consultants under CALFED – CBDA Project Number: ERP-02-P08. June.

Deas, M.L. 2004. Anderson Reservoir Re-operation Study: Water Quality Assessment. Prepared with Merritt Smith Consulting. Submitted to the Santa Clara Valley Water District. March.

Watercourse Engineering, Inc. 2004. *Klamath River Modeling Framework to Support the PacifiCorp Federal Energy Regulatory Commission Hydropower Relicensing Application (including Appendices)*. Prepared for PacifiCorp. March 9.

Deas, M.L., 2004. Technical Memorandum: Review of *Blue River Reservoir Temperature Modeling with HEC-5Q* September 2003 prepared by Resource Management Associates, Inc, for the U.S. Army Corps of Engineers, Portland

- District and the U.S. Army Corps of Engineers, Hydrologic Engineering Center, Sacramento District. February 10.
- San Francisco Public Utilities Commission (SFPUC). 2004. *Preliminary Review Draft: Interim Operations Plan for Calaveras Reservoir*. Prepared with Weiss and Associates, Merritt Smith Consulting, and Entrix.
- Deas, M.L., and S.K. Tanaka. 2003. *Scott River Water Balance Study: Data Analysis and Model Review*. Prepared for the Scott River Watershed Council. June.
- San Francisco Public Utilities Commission (SFPUC). 2003. *Initiative to Raise and Maintain Lake Level and Improve Water Quality, Lake Merced: Task 3 Technical Memorandum - Lake Setting, Alternative Lake Levels and Supplemental Water Requirements, Supplemental Water Sources, Lakeside Vegetation*. Prepared with EDAW, Inc. Talavera and Richardson, Merritt Smith Consulting, Hydroconsult Engineers, Hagar Environmental Science, Ward and Associates, Yuki Kawaguchi. August.
- San Francisco Public Utilities Commission (SFPUC). 2003. *Initiative to Raise and Maintain Lake Level and Improve Water Quality, Lake Merced: Task 4 Technical Memorandum - Impacts to Water Quality, Vegetation, Wildlife, and Beneficial Uses*. Prepared with EDAW, Inc.. Talavera and Richardson, Merritt Smith Consulting, Hydroconsult Engineers, Hagar Environmental Science, Ward and Associates, Yuki Kawaguchi. November.
- San Francisco Public Utilities Commission (SFPUC). 2003. *Initiative to Raise and Maintain Lake Level and Improve Water Quality, Lake Merced: Task 4 Technical Memorandum – Adaptive Management Monitoring Plan*. Prepared with EDAW, Inc.. Talavera and Richardson, Merritt Smith Consulting, Hydroconsult Engineers, Hagar Environmental Science, Ward and Associates, Yuki Kawaguchi. December.
- San Francisco Public Utilities Commission (SFPUC). 2002. *SFPUC Reservoir Water Quality Management Plan*. Prepared with Merritt Smith Consulting. March.
- Watercourse Engineering, Inc. 2003. *Klamath River Water Quality Studies 2000:- Attached Algae Modeling Literature Review*. Sponsored by the U.S. Bureau of Reclamation, Klamath Falls Area Office. January 25.
- Watercourse Engineering, Inc. 2003. *Klamath River Water Quality 2000 Monitoring Program: Project Report*. Sponsored by the U.S. Bureau of Reclamation, Klamath Falls Area Office. January 25.
- Deas, M.L. and A.G. Abbott.2003. *Shasta River Field Monitoring Report*. Prepared for the Klamath River Basin Fisheries Task Force and the United States Fish and Wildlife Service. In draft.
- Deas, M.L. A.G. Abbott, and A.E. Bale. 2003. *Shasta River Flow and Temperature Monitoring Report*. Prepared for the Klamath River Basin Fisheries Task Force and the United States Fish and Wildlife Service. In draft.
- Sutton, R, M.L. Deas, M.R. Belchik, S.M. Turo. 2002. *Klamath River Thermal Refugia Study, Summer 2002*. Prepared for the US Bureau of Reclamation. December 9.

- City of Santa Rosa. 2002. *Technical Memorandum 16: City of Santa Rosa Incremental Recycled Water Program—Water Balance Modeling Summary*. Prepared with Merritt Smith Consulting. December 2.
- Deas, M.L. 2002. *Trinity Reservoir Inflow Temperature Monitoring Study*. Prepared for Trinity County Planning Department. June..
- Watercourse Engineering, Inc. 2002. *Surface Water Quality Modeling: An Introduction*. Prepared for the State of California, State Water Resources Control Board. April.
- Watercourse Engineering, Inc. 2002. *Historic Flow and Temperature Modeling of the Sacramento River Period of Simulation: 1970-2001*. Prepared for United States Geological Survey Biological Resources Division Mid-Continent Ecological Science Center. March 28.
- Deas, M.L. 2001. *Bahia Lagoon Water Quality Assessment (Technical Memorandum)*. Prepared for Northwest Hydraulic Consultants. December 6.
- Deas, M.L. and C.L. Lowney. 2001. *Water Temperature Modeling Review: Focusing on California's Central Valley*. Bay Delta Modeling Forum Technical Publication 01-2.
- San Francisco Public Utilities Commission (SFPUC). 2001. *Water Quality Investigation and Assessment Report: Potential Water Quality Effects in Lake Merced from Enhanced Ammonia Inputs*. Prepared with Merritt Smith Consulting. October.
- San Francisco Public Utilities Commission (SFPUC). 2001. *Phase 2b Report Water Quality Investigation and Assessment: Algal Growth Potential in Lower Crystal Springs Reservoir with Enhanced Ammonia Inputs*. Prepared with Merritt Smith Consulting. March.
- Deas, M.L., 2001. *Technical Memorandum - Washoe Creek Hydraulic Evaluation*. Prepared with Merritt Smith Consulting. October.
- Deas, M.L. and G.T. Orlob. 1999. *Klamath River Modeling Project*. United States Fish and Wildlife Service, Klamath River Basin Fisheries Task Force. Project 96-HP-01. December.
- Deas, M.L. 1999. *Yuba River Temperature Monitoring Project*. Prepared for the United States Fish and Wildlife Service, Sacramento/San Joaquin River Fishery Restoration Office. February.
- Deas, M.L., and G.T. Orlob. 1998. *Shasta River Hydrodynamic and Temperature Modeling Project Report*. Clean Water Act 205(j) Grant Program, California State Water Resources Control Board and the Shasta Valley Resources Conservation District. June.
- Deas, M.L., 1998. *Trinity Reservoir Water Temperature Simulation Model*. Prepared for Trinity County Planning Department, Natural Resources Division. August, 1998.
- Deas, M.L., 1998. *Trinity Reservoir Carryover Analysis*. Prepared for Trinity County Planning Department, Natural Resources Division. August, 1998.

- Deas, M.L. and G.T. Orlob. 1997. *Shasta River Data Inventory*. Clean Water Act 205(j) Grant Program, California State Water Resources Control Board and the Shasta Valley Resources Conservation District. June.
- Deas, M.L., J. Haas, and G.T. Orlob. 1997. *Shasta River Woody Riparian Vegetation Inventory*. Clean Water Act 205(j) Grant Program, California State Water Resources Control Board and the Shasta Valley Resources Conservation District. June.
- Deas, M.L., G. K. Meyer, and C.L. Lowney. 1997. *Sacramento River Temperature Modeling Project*. Clean Water Act 205(j) Grant Program, California State Water Resources Control Board and Trinity County Planning Department. January.
- Deas, M.L., C.L. Lowney, and R.B. Krone. 1996. *Evaluation of Coarse Sediment Sources and Transport in Putah Creek below Monticello Dam - Observations of a Managed Water Resources System*. Public Service Research Program, UC Davis, Bioregion Grant Category A: Natural resources and biological problems in the Putah Creek watershed. August.
- King, I.P. and M.L. Deas. 1995. *Willits Bypass Floodplain Study*. UC Davis for California Department of Transportation, District 1. Grant No. 01E675.
- Los Angeles Aqueduct Simulation Model*. 1993. Prepared in cooperation with the Los Angeles Department of Water and Power, Aqueduct Division - Operations Section. September.
- Coufal, E.L. and M.L. Deas. 1990. *Mono Lake Water Balance Model (LADWP90)*. Los Angeles Department of Water and Power, Aqueduct Division - Hydrology Section. June.
- Johnson, W.K. and M.L. Deas. 1987. "Lessons learned from the 1986 drought." *IWR Policy Study 88-PS-1*, Water Resources Support Center, U.S. Army Corps of Engineers, Fort Belvoir, VA.

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- Deas, M.L. and G.T. Orlob. 1997. Iterative calibration of hydrodynamic and water temperature models – application to the Sacramento River." *Proceedings Water for a Changing Global Community*. 27th Congress of the International Association for Hydraulic Research and hosted by the American Society of Civil Engineers Water Resources Division, August 10-15, San Francisco, CA, 1997.
- Deas, M.L. and J. Schuyler. 1994. "The development and application of a large computer model – an example utilizing the Los Angeles Aqueduct System." *Proceedings, Computers in the Water Industry*, American Water Works Assc., April 10-13, Los Angeles, CA, 1994. pp. 523-534.

Doctoral and Masters Theses

- Deas, M.L. 2000. *Application of numerical models in ecological assessment*. Doctorate of Philosophy Dissertation, UC Davis, March.
- Deas, M.L. 1989. *Finite element model of groundwater flow on shallow layer and perched aquifers*. Master of Science Thesis, UC Davis, March.

PRESENTATIONS AND POSTERS

- Deas, M.L. “Klamath River Flow and Water Quality Modeling Framework.” Poster presented at the California Water and Environmental Modeling Forum, Asilomar, California. March 2005.
- Deas, M.L. “Klamath River Benthic Algae Monitoring Iron Gate Dam to Turwar: 2004.” Presented to the Klamath River Water Quality Coordination Group – jointly sponsored by the North Coast Regional Water Quality Control Board and U.S. EPA Region IX, as well as other basin stakeholders. February 8, 2005.
- Tanaka, S.K. and M.L. Deas. Klamath River Thermal Refugia Study: flow and temperature characterization. Poster presented at the California Water and Environmental Modeling Forum, Asilomar, California. March 2005.
- Deas, M.L. “Historic Temperature Modeling of the Sacramento River: 1970-2001.” Poster presented at the California Water and Environmental Modeling Forum, Asilomar, California. February 2004.
- Deas, M.L., Watercourse Engineering, Inc., J. Bartholow, United States Geological Survey, C. Hanson, Hanson Environmental, C. Myrick, Colorado State University. A. Dotan, Project Manager, AD Consultants (CALFED – CBDA Project Number: ERP-02-P08). “Peer Review of Chinook Salmon Water Temperature Objectives Used as Evaluation Criteria for the Stanislaus – Lower San Joaquin River Water Temperature Modeling and Analysis.” Poster presented at the Third Biennial CALFED Science Conference, Sacramento, CA. October 4-6, 2004
- Deas, M.L. “Sources and Uses of Flow and Water Quality Data from Klamath Reservoirs and River.” Presented at the Lower Klamath Basin Science Conference. U.S. Department of the Interior: U.S. Geological Survey, U.S. Fish and Wildlife Service, Bureau of Reclamation, Klamath River Fisheries Task Force. U.S. Department of Commerce: NOAA Fisheries. Eureka, CA. June 7-10, 2004.
- Deas, M.L. “Overview of the Klamath Basin Physical Environment: Hydrology, Geomorphology, and Water Quality.” Presented at the Lower Klamath Basin Science Conference. U.S. Department of the Interior: U.S. Geological Survey, U.S. Fish and Wildlife Service, Bureau of Reclamation, Klamath River Fisheries Task Force. U.S. Department of Commerce: NOAA Fisheries. Eureka, CA. June 7-10, 2004.
- Deas, M.L. “Klamath River Water Quality: Link Dam to the Pacific Ocean.” Presented at the Presented at the Upper Klamath Basin Science Conference. Hosted by U.S. Department of the Interior: Geological Survey Fish and Wildlife Service Bureau of Reclamation Bureau of Land Management. Klamath Falls, OR. February 3-6, 2004.
- Deas, M.L. “Longitudinal Water Quality Characteristics of the Klamath River from Iron Gate Dam to the Trinity River.” Presented at the American Fisheries Society. Redding, California, April 22-24, 2004.
- Deas, M.L. “Limnology of the Klamath River.” Presented at the American Fisheries Society. San Diego, California, April 14-17, 2003.

- Deas, M.L. and G.T. Orlob. "Application of flow and temperature models to the Shasta River, CA." Presented at the Klamath River Restoration Conference Klamath Falls, OR. March 9-11, 1999.
- Deas, M.L. and G.T. Orlob. "Sacramento River Temperature Modeling Project: Application Hydrodynamic and Temperature Models." Presented at the American Geophysical Union, Fall Meeting, December 8-12, 1997, San Francisco, California. December 10, 1997.
- Deas, M.L. and G.T. Orlob. "Sacramento River Temperature Modeling Project: Challenges in Watershed Modeling." Presented at the State of the Watershed Symposium, Sacramento River Watershed Program, California. October 8, 1997.
- Deas, M.L. C.L. Lowney, and G.T. Orlob. "Sacramento River Temperature Modeling Project." Poster presented at the California Watershed Symposium, Sacramento, California, April 23, 1997.
- Deas, M.L. and G.T. Orlob. "Application of computer models for assessing temperature control alternatives in the Sacramento River system." Poster presented at the Center for Ecological Health Research annual meeting, University of California, Davis. March 17, 1997.
- Deas, M.L. and G.T. Orlob. "Assessment of Alternatives for Flow and Water Quality Control in the Klamath River below Iron Gate Dam." Presented at the Klamath River Restoration Conference, Yreka CA. March 11-13, 1997.
- Haas, J., M.L. Deas, and G.T. Orlob. "Preliminary Riparian Vegetation Evaluation for the Shasta River, California." Presented at the Klamath River Restoration Conference, Yreka CA. March 11-13, 1997.
- Lowney, C.L., M.L. Deas, and G.T. Orlob. "Longitudinal Temperature Characteristics of the Klamath River below Iron Gate Dam." Presented at the Klamath River Restoration Conference, Yreka, CA. March 11-13, 1997.
- Deas, M.L., J.F., DeGeorge, A.E. Bale, and C. Saviz. "Modeling Combined Stresses on Ecosystems." Poster presented at the Center for Ecological Health Research annual meeting, University of California, Davis. March, 1995.
- Deas, M.L., J. Schuyler. "The development and application of a large computer model - an example utilizing the Los Angeles Aqueduct System." Presented at Computers in the Water Industry, American Water Works Association, April 10-13, Los Angeles, CA, 1994.

6.4. – Listing of any other testimony in preceding four years

I have not testified in any proceeding in the last four years

6.5. - Compensation to be paid for Study and Testimony

My compensation for all work completed under this study and for any testimony is provided at a reduced rate that is extended to non-profit organizations on a case-by-case basis. My normal billing rate is \$135.00 per hour, the reduced rate applied herein is \$90.00 hour.