Peer Review of Water Temperature Objectives Used as Evaluation Criteria for the Stanislaus – Lower San Joaquin River Water Temperature Modeling and Analysis

- Task 9 -

CBDA Project No.: ERP-02-P28

Prepared For

AD Consultants
15 Sullivan Drive
Moraga, CA 94556

Panel Chair: Michael Deas

Peer Review Panel: John Bartholow, Chuck Hanson, Chris Myrick

July 29, 2004

Table of Contents

1. Introduction

As part of an evaluation of potential management changes to the instream flows on the Stanislaus River hydrologic and water temperature modeling is being developed to assess the changes in the quality and quantity of habitat for various lifestages of salmonids. One of several inter-related tasks in the Lower San Joaquin River Water Temperature Modeling and Analysis project is the need to review and assess water temperature criteria developed by the California Department of Fish and Game (DFG) for Central Valley fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and Steelhead rainbow trout (*Oncorhynchus tshawytscha*) (Task 9). This task included assembling a peer review panel to evaluate the biological merits of water temperature criteria to be used in evaluating alternative management strategies on the Stanislaus River. Outlined herein are the results of such a peer review.

This report presents the Panel Charge, identifying the objective and scope to provide guidance to the panel members. Based on the task at hand, the Panel identified goals to communicate their interpretation of setting thermal criteria for assessment of model simulated temperatures and scenario/alternative evaluation. Existing thermal refugia are reviewed and discussion presented on the spatial and temporal aspects of thermal criteria for the various life stages of fall-run Chinook salmon and steelhead trout. The strengths and limitations of existing criteria are presented with regard to the ability to differentiate the impact of alternative operations on simulated water temperatures. The panel presents a set of thermal criteria that deviates from the discrete threshold approach commonly used for anadromous fish, presenting the stakeholders with a set of continuous functions as thermal criteria to represent the various life stages on the Stanislaus River.

1.1. Acknowledgements

The Panel acknowledges the support of the Technical Advisory Committee and stakeholders whom assisted in gathering significant amounts of resources for consideration in the Peer review, as well as their active participation in meetings. Further, the presentations of DFG and SP Cramer and Associates at the December workshop were invaluable in communicating fundamental information to the Panel members. The assistance of Avry Dotan of AD Consultants and Don Smith of RMA in providing materials and model simulations for testing various criteria formulations is appreciated. The Panel also wishes to acknowledge CALFED for providing financial support to the peer review process.

2. Panel Charge

Panel charge for the temperature review is to evaluate the biological merits, and application of thermal criteria to the Stanislaus River modeling applications. The review should assess if the identified criteria are suitable to sufficiently differentiate water temperature benefits to the identified species in order to evaluate the various water operation scenarios (model simulations) being considered. The desired result of the larger water temperature project is to select a preferred project alternative for further cost-feasibility analysis.

To fulfill this responsibility, a peer review panel has been assembled consisting of three independent scientific experts who have a history of leadership activities and who have a demonstrated ability to deal with complex issues in a balanced manner. The group includes some scientists with local expertise and some with relevant discipline knowledge but experience outside the Delta or Bay-Delta water issues. A fourth colleague chaired the three-scientist panel.

Peer review is defined for this purpose as exchanging information among panel members and, as necessary, the Technical Advisory Committee and stakeholders with regard to the state of the science that applies to criteria regarding water temperature tolerances for anadromous fish, conditions within the Stanislaus River, and the application of temperature criteria within a numerical modeling framework.

The panel convened in the late fall of 2003, and over the period of approximately three to four months gathered and examined available information specific to the Stanislaus River anadromous fish species, the existing and planned temperature analysis, and restoration objectives to:

- Identify the current state of the science with respect to setting temperature criteria for anadromous fish in the Central Valley of California.
- Describe the approach that is under consideration on the Stanislaus River system with emphasis on using numerical criteria within the framework of a temperature simulation model.
- Assessment of existing Stanislaus River system criteria, and based on available information adopt the existing criteria, adopt a modified set of criteria, or identify an appropriate new set of criteria.
- Recommend performance measures that may assist decision makers and resource managers. For example,
    - Seek to identify methods of incorporating uncertainty/variability into criteria and/or analysis.
    - Establish how the criteria can be used to test key working assumptions.
    - Identify if an adaptive management component is necessary within the criteria, analytical assessment, or both.

This peer review report identifies the state of knowledge that forms the basis for any and all decisions. Points of agreement and points of contradiction among the group have been documented. Likewise, limitations of the criteria are noted.

2.1. Panel Structure

The peer review panel consists of three experts in the field of temperature assessment with respect to anadromous fishes:

Mr. John Bartholow, United States Geological Survey
Dr. Chuck Hanson, Hanson Environmental, Inc., and
Dr. Chris Myrick, Colorado State University.

The panel was chaired by Dr. Michael Deas, Principal at Watercourse Engineering, Inc. who acted as a liaison between stakeholders and the panel members throughout the process, with support from the technical advisory group, scientists, and stakeholders.

2.2. Panel Deliverable

The deliverable from the Peer Review Panel consists of this report.

3. Peer Review Goals

It is apparent from review of available literature as well as stakeholder presentations that the goal is not simply to sustain maintenance populations, but to increase the population of both fall-run Chinook salmon and steelhead. In contrast to Chinook salmon, little is known about steelhead at this time, though they are listed as Threatened under the Federal Endangered Species Act and are thus presumed vulnerable.

The CVPIA-AFRP restoration goal for fall-run Chinook salmon is an escapement of 10,819 fish. This number was derived from the 1967 to 1991 period escapement average, wherein the goal was to double escapement (i.e., from an escapement of 5,410 fish to 10,819 fish). Within the last decade the average fall-run Chinook escapement has been around 3,500, well short of the stated restoration goals (DFG, 2003; see also USFWS, 1995; USFWS-AFRP, 1997; and USFWS, 1998). No specific restoration goals have been set for steelhead on the Stanislaus River due to lack of basin-specific information.

Although restoration goals have been enumerated for fall-run Chinook, specific restoration actions have not been identified or quantified for the various life stages of Chinook salmon to attain such goals. For example, goals have not been specified in terms of life stages that may be a more meaningful metric for recovery. Related to this topic is the issue that although a numeric goal may be identified (and set), there may be considerable year-to-year variation around what can be achieved on average. Escapement is an effective metric, because it is the final integrator of the effects of physical and biological conditions throughout the salmon's life. An acceptable range of escapement numbers for returning adults (or other metric) has not been determined. These issues are outside the purview of the Panel charge.

With lack of guidance in the form of numerical criteria in terms of long-term mean and variability of anadromous fish production, the panel determined that, for the purposes of identifying thermal criteria to assess model alternatives, the goal of restoration on the Stanislaus was at a minimum to maintain the current numbers of returning adult fish (i.e., do not let stocks dwindle further), and if at all possible identify an approach, with regard to thermal conditions, that will favor the rapid attainment of restoration goals. To achieve this latter goal, it is suggested that a more conservative approach with respect to selected temperature criteria be adopted. Review of the literature indicates that there is a range of "acceptable" temperatures for any particular category (e.g., optimal, sub-optimal, etc.), and the intent herein is to hedge toward the lower end of that range to provide the best protection for the resource under the stated desire to double escapement. This interpretation of restoration goals has a direct impact on the developed thermal criteria.

Finally, the Panel is fully aware that temperature is only one of many factors potentially limiting anadromous fish populations in the Stanislaus River. Fish disease, habitat, predation, spawning substrate, water quality conditions, as well as other factors can limit anadromous fish production – there is much to be learned concerning the Stanislaus River stocks, as well as stocks throughout the San Joaquin River drainage. Readers of this report should bear in mind these and other factors when seeking to interpret results of the alternatives assessment for thermal conditions in the Stanislaus River system.

3.1. The Temperature Model

A unique attribute of this review is the intention to identify criteria that can differentiate among various operations scenarios using model simulated water temperature. This is in contrast to the more typical use where thermal criteria become a "target" or "regulatory compliance" point and a system is managed to attain the desired thermal conditions at a location or locations for particular times of the year. Because the intent is to use model output solely in assessment of alternative operations, it is appropriate to introduce the model used to produce simulated temperatures.

The water temperature model that has been applied to the Stanislaus River system is the U.S. Army Corps if Engineers HEC-5Q – River and Reservoir Water Quality Analysis Program. The model represents a short reach of the Stanislaus River above New Melones Reservoir from the Collierville and Stanislaus power plants; New Melones, Tulloch, and Goodwin reservoirs (as well as all free flowing reaches between the reservoirs); the Stanislaus River downstream to the confluence with the San Joaquin; and the San Joaquin River from the Tuolumne River to Vernalis.

Table 1. River miles upstream from the San Joaquin River confluence for selected locations on the Stanislaus River

Location	Approximate River Mile
Goodwin Dam	58
Knights Ferry	54
Orange Blossom Bridge	46.5
Oakdale	40
Riverbank	33
Caswell	5
San Joaquin River	0

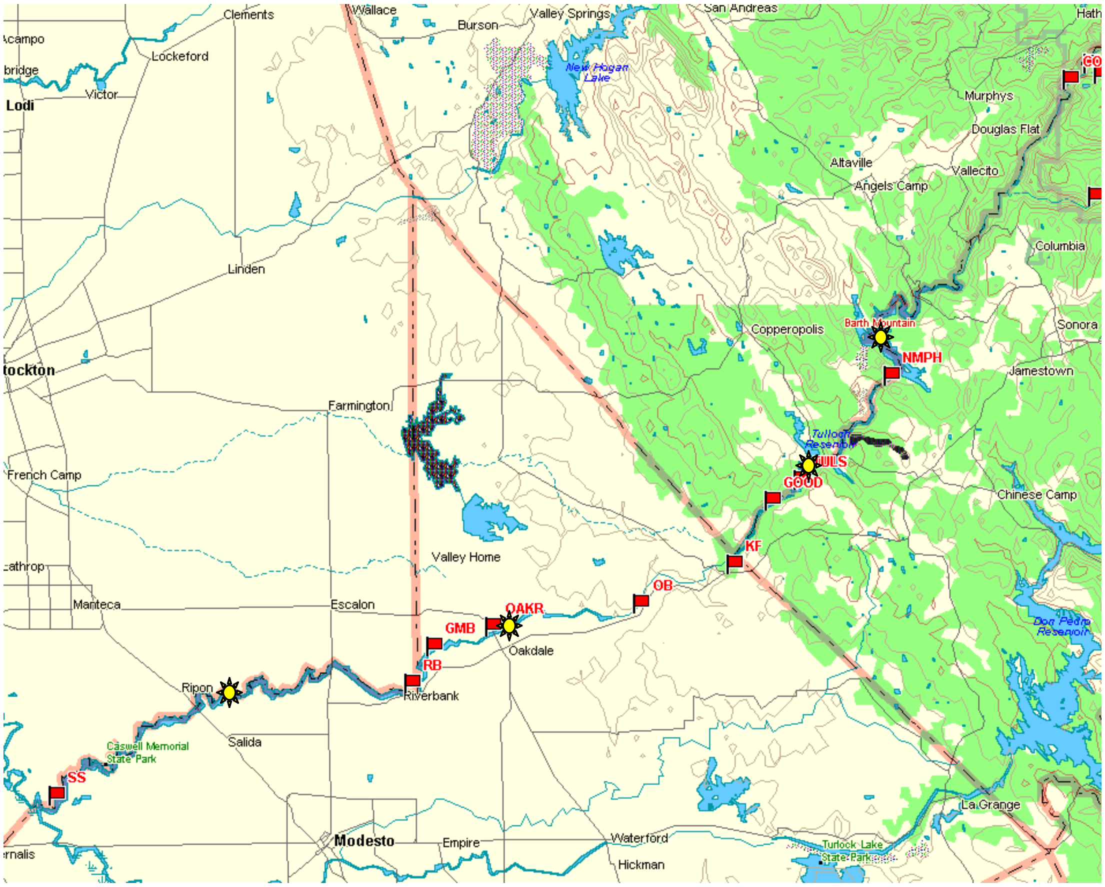


Figure 1. Stanislaus River project area

HEC-5Q represents reservoirs as one-dimensional, vertically stratified impoundments. Lateral and longitudinal variability are not considered and the model replicates conditions that are typical of the main body of the reservoir. River reaches are represented as one-dimensional, longitudinal variable systems, and lateral and vertical variations are not characterized. The model accommodates diverse reservoir-river systems allowing for complete system simulation in a single modeling framework. As such it is an efficient approach for assessing hydrologic and operational conditions in multiple reservoir systems.

The model has variable spatial scales and representations among the reservoir and river reaches, but the free flowing reaches (below Goodwin Dam in the Stanislaus River and the San Joaquin River from the confluence with the Tuolumne River to Vernalis) are represented at a spatial scale of approximately one mile, i.e., there is model output available at approximately one-mile intervals in the river reaches. The model simulates water temperature conditions at 6-hour time steps, thus producing sub-daily information that can be used to identify potential maximum and minimum daily temperatures. Complete details of the simulation model, implementation and calibration, and previous applications are outlined by AD and RMA (2002).

4. Thermal Criteria

4.1. Review of Existing Thermal Criteria in the Central Valley

Exposure to seasonally elevated water temperatures has been identified as a significant factor limiting quality and availability of habitat, and the survival of various lifestages for Chinook salmon and steelhead, within regulated and unregulated Central Valley streams and rivers. Water temperature has also been identified as a significant factor affecting Chinook salmon and steelhead populations within other California river systems. Goals and objectives for water temperature management intended to protect and enhance habitat conditions have been identified in State Water Resources Control Board (SWRCB) water right permits, FERC license terms and conditions, settlement agreements, voluntary fishery management plans, and as part of biological opinions issued under the California and federal Endangered Species Acts. Water temperature management has focused on protecting immigrating adult Chinook salmon and steelhead, adult holding, spawning and egg incubation, juvenile rearing, and smolt emigration. Temperature goals and objectives have been developed for a number of river systems, which in addition to the Stanislaus River, include the mainstem Sacramento River, Feather River, American River, Mokelumne River, Tuolumne River, Merced River, and the Trinity and Klamath Rivers. Water temperature goals and objectives are typically designed to include consideration of both the seasonal timing of various life stages of Chinook salmon and steelhead, in addition to the geographic distribution of each life stage within the river. Temperature goals and objectives developed for many of the Central Valley rivers have identified both an optimum temperature criterion and a temperature criterion above which habitat conditions for a particular species and life stage are characterize as stressful or unsuitable. Water temperature targets for the Feather River (low flow channel downstream of Oroville Dam) are summarized below as an example of Central Valley temperature goals and objectives for Chinook salmon and steelhead.

Table 2. Feather River temperature goals and objectives for Chinook salmon and steelhead

Life Stage	Steelhead		Chinook Salmon	
	Primary Target (°F)	Secondary Target (°F)	Primary Target (°F)	Secondary Target (°F)
Adult Immigration and Holding	52	56	60	64
Spawning and Egg Incubation	52	54	56	58
Juvenile Rearing	65	68	60	65
Smolt Emigration	52	55	60	63

Although the example of water temperature criteria developed for the Feather River system is typical, specific temperature targets, seasonal time periods, and geographic distributions vary among river systems based on site-specific information and conditions.

4.2. Review of Existing Thermal Criteria on the Stanislaus River

4.2.1. Background[1]

In late 1999, the California Department of Fish and Game (DFG) was asked by the other members of the Stanislaus River Stakeholders to develop water temperature criteria for fall-run Chinook salmon and steelhead/rainbow trout. In response, DFG initiated a literature review to develop water temperature criteria for fall-run Chinook salmon and steelhead rainbow trout in the Stanislaus River (Guignard, 2001). The intent of these criteria was to provide a screening tool to assist in identifying viable and non-viable solution alternatives. Thus, narrowly focused optimal water temperature levels were identified for fall-run Chinook salmon and steelhead to determine if such criteria would be effective in separating various scenarios assessed using the water temperature model. Using daily mean water temperature (Guignard (2001) provides details about the spatial and temporal aspects of life stage history and the determination of this initial set of criteria, presented in Table 1 and Table 2 for Chinook salmon and steelhead, respectively.

Table 3. Chinook salmon water temperature criteria (^{o}F) by month and reach/location (Guignard, 2001)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Location	RB	RB	CON	CON	CON	CON	KF	KF	CON	RB	RB	RB
Criteria	54	54	55	55	55	55	60	60	54	54	54	54
KF – Knights Ferry (RM 54): Juvenile rearing in July and August RB – Riverbank (RM 33): Spawning and egg incubation in October – February CON – confluence (RM 0): Juvenile rearing/emigration/smoltification in March-June; Adult immigration in September												

Table 4. Steelhead trout water temperature criteria (^{o}F) by month and reach/location (Guignard, 2001)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Location	OAK	OAK	OAK	OAK	OAK	OAK	OAK	OAK	OAK	OAK	OAK	OAK
Criteria	52	52	52	52	52	52	52	52	52	52	52	52
Oak – Oakdale (RM 40):												

The application of these criteria utilized "Fahrenheit Degree Day Violations," defined as the total number of degree-day units that simulated mean daily water temperatures exceeded the criteria based on model simulations. Assessment of the application of this single threshold criteria illustrated that identified scenarios produced similar results, i.e., the criteria did not provide sufficient resolution to differentiate among scenarios.

Based upon these findings, Stakeholders requested refined water temperature criteria. DFG subsequently produced a two threshold criteria, wherein two temperatures define three ranges: optimal, sub-optimal, and acute. These criteria are likewise based on mean daily temperature. The revised DFG criteria are presented in Tables 3 and 4 for Chinook salmon and steelhead, respectively

[1] This information is largely drawn from DFG/Marston (2003), and the DFG and SP Kramer presentations during the December workshop

Table 5. Chinook salmon water temperature criteria (^{o}F) by month and reach/location (AD and RMA, 2002)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temperature Classification	RB	RB	CON	CON	CON	CON	KF	KF	CON	RB	RB	RB
Optimum	54	54	55	55	55	55	60	60	54	54	54	54
Sub-lethal	>54<62	>54<62	>55<65	>55<65	>55<65	>55<65	>60<65	>60<65	>54<65	>54<65	>54<62	>54<62
Critical (lethal)	62	62	65	65	65	65	65	65	65	65	62	62

KF – Knights Ferry (RM 54): Juvenile rearing in July and August

RB – Riverbank (RM 33): Spawning and egg incubation in October – February

CON – confluence (RM 0): Juvenile rearing/emigration/smoltification in March-June; Adult immigration in September

Table 6. Steelhead Trout water temperature criteria (^{o}F) by month and reach/location (AD and RMA, 2002)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temperature Classification	KF	KF	OAK	OAK	OAK	OAK	OAK	OAK	OAK	OAK	OAK	KF
Optimum	52	52	56	56	56	60	60	60	60	56	56	52
Sub-lethal	>52<56	>52<56	>56<66	>56<66	>56<66	>60<66	>60<66	>60<66	>60<66	>56<66	>56<66	>52<66
Critical (lethal)	56	56	66	66	66	66	66	66	66	66	66	56

KF – Knights Ferry (RM 54): Spawning and egg incubation in December – February

Oak – Oakdale (RM 40): Juvenile rearing emigration/smoltification in March-November

Application of these criteria included identifying appropriate temperatures for each life stage. Life stages were implicitly represented by applying the criteria at different locations along the river, where each location represents "breakpoints" for suitable habitat and thermal conditions.

The criteria were applied in AD and RMA (2002) to assess a wide range of conditions and alternatives. The two threshold (three-range) criteria provided additional information, such as the number of days that fell into each category, which assisted in differentiating between alternatives; however, many alternatives were still similar.

During the inception of the latest project work regarding temperature modeling on the Stanislaus River, it was determined that the two threshold (three-range) criteria of thermal criteria should undergo a peer review. In preparation for review of the Peer Review Panel, DFG and SP Cramer and Associates developed refined thermal criteria. These criteria were formally presented at the Peer Review Panel workshop in Oakdale on December 9, 2003. Both parties presented composite criteria – a single set of criteria for both Chinook salmon and steelhead trout – for the annual period September 1 through August 31. The criteria are based on the 7-day average of the daily maximum temperature (7DADM). These DFG and SP Cramer and Associates proposed criteria are presented in Figure 1 and Figure 2. The Peer Review Panel used these proposed criteria as a starting point for this project.

Table 7. Composite water temperature criteria (°F) for Chinook salmon and steelhead trout by month and reach/location (DFG, 2003)

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
Temperature Classification	CON	RB	RB	RB	RB	RB	RB	CON	CON	OAK	OAK	OAK
Optimum	55	54	54	54	54	54	54	50	50	61	61	61
Sub-lethal	>55<63	>54<59	>54<59	>54<59	>54<59	>54<59	>54<59	>50<59	>50<59	>61<73	>61<73	>61<73
Critical (lethal)	63	59	59	59	59	59	59	59	59	73	73	73

Oak – Oakdale (RM 40): Summer juvenile rearing in June – August
RB – Riverbank (RM 33): Spawning and egg incubation in October – February; Juvenile rearing in February – March
CON – confluence (RM 0): Juvenile rearing/emigration/smoltification in April – May; Adult immigration in September

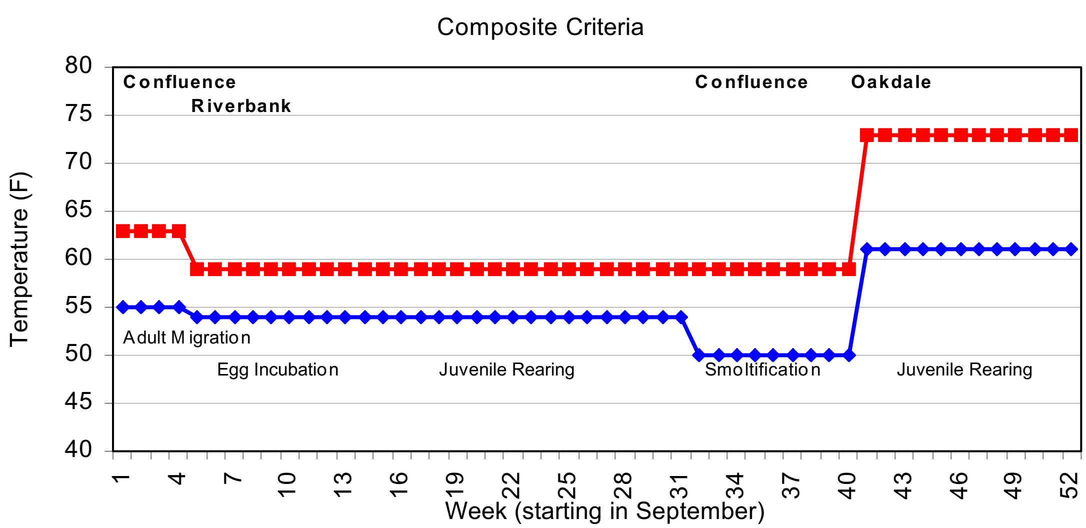


Figure 2. Proposed DFG composite temperature criteria (°F) for Chinook salmon and steelhead trout on the Stanislaus River

Table 8. Composite water temperature criteria (^oF) for Chinook salmon and steelhead trout by month and reach/location (SP Cramer and Associates, Panel Presentation 12-9-04)

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
Temperature Classification	CON	RB	RB	RB	RB	RB	RB	CON	CON	OAK	OAK	OAK
Optimum	60	54	54	54	54	54	54	56/59	59	61	61	61
Sub-lethal	>60<65	>54<65	>54<62	>54<62	>54<62	>54<62	>54<62	>56<63 >59<68	>59<68	>61<73	>61<73	>61<73
Critical (lethal)	65	65	62	62	62	62	62	63/68	68	65	65	65
Oak – Oakdale (RM 40): Summer juvenile rearing in June – August												
RB – Riverbank (RM 33): Spawning and egg incubation in October – February; Juvenile rearing in February – March												
CON – confluence (RM 0): Juvenile rearing/emigration/smoltification in April – May; Adult immigration in September												

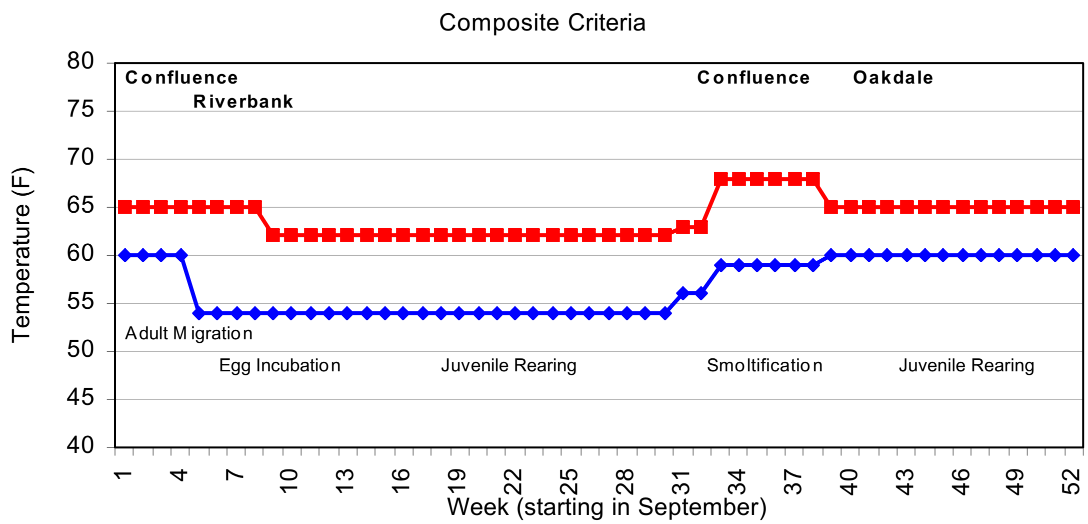


Figure 3. Proposed SP Cramer and Associates composite temperature criteria (^oF) for Chinook salmon and steelhead trout on the Stanislaus River (SP Cramer and Associates, Panel Presentation 12-9-04)

The panel very much appreciated the introduction given to them by both DFG and SP Cramer and Associates. They agreed that multiple perspectives are always possible on these issues. Readers of the extensive literature on salmonid thermal tolerance can be led to multiple conclusions depending on the literature reviewed, the relative emphasis that authors have placed on field versus laboratory findings, thermal preference versus mortality, chronic versus acute exposure time frames, variation among species or stocks, the perceived applicability to the problem(s) at hand, and other factors.

Rather than provide a 'verdict' on the merits of any of the stakeholders proposed criteria, the Panel decided to review and “test” the proposed criteria as well as further examining the literature, all the while attempting to anticipate how criteria might profitably be employed to screen the various water management alternatives for the lower Stanislaus River. These steps are outlined below.

4.2.2. Assessment of Existing Criteria

A primary charge of the panel was to review the current criteria on the Stanislaus River. As noted in the previous section, two sets of thermal criteria have been recently presented for potential frameworks to assess alternative operations on the Stanislaus River system based on a two threshold (three-range) method of assessing simulated temperatures and their impacts on anadromous fishes among various operational alternatives. The basic metric is the seven day average of the daily maximum (7DADM) temperatures. The framework for evaluating water temperature effects on Chinook salmon and steelhead includes, in addition to the temperature thresholds, the seasonal timing of various lifestages (and consideration of the response of each lifestage to water temperature exposure) and the location within the river where water temperature would affect a given lifestage. Information on the general seasonal timing and geographic distribution of habitat used by different lifestages are briefly discussed below.

4.2.3. Timing and Life Stage

The panel appreciates the challenges of identifying the temporal and spatial distribution of anadromous fish in the Stanislaus River. Timing and distribution of particular lifestages (e.g., adult immigration or juvenile emigration) varies from year-to-year. It can be argued that the best survival and production is achieved through protecting the majority of the distribution for a particular lifestage (e.g., 80 percent). However, there are arguments that there is valuable genetic information in the "tails" of the distribution and truncating the distribution may result in the loss of some of the genetic variability. Within river systems where significant water resources development has occurred there is often a trade-off between water supply for developed uses and in-river needs (e.g., fishery requirements). Careful characterization and management of the resource is required to avoid undesired consequences (e.g., exhausting water supplies, leaving insufficient cold water to support over-summering juveniles). It is not the charge of the panel to explore all of these potential outcomes, but rather to identify criteria that will assist resource managers and stakeholders in assessing alternatives.

Panel members caution that screening criteria based on the timing and life stage utilization of *current* runs (both in- and out-migrants) should not in any way set a precedent for future *potential* runs if larger population goals are indeed achieved. Larger populations would likely entail a wider range of life history timing variability and, potentially, spatial access.

The general temporal distribution of anadromous fall-run Chinook salmon and steelhead is briefly discussed below.

Fall-Run Chinook Salmon

Adult Migration and Spawning

Adult migration data is limited on the Stanislaus River to weir data from the 2003 and 2004 seasons (SP Kramer unpublished data). Data to date are insufficient to draw conclusions on run timing by themselves but can be used in combination with information from other sources to characterize general patterns in adult run timing. Earlier data, based predominately on carcass surveys (normally completed once a week), do not provide clear run-timing information because of the limitations of carcass surveys. Typical carcass survey techniques can be useful in developing an estimate of how many adults came back into the river, but it is difficult to discern when fish entered the system, when they spawned, or when they died. Limitations include a count that includes a mix of fresh fish and some with decay, there are problems with scavengers removing fish, and during winter variable flows can wash fish into deeper pools and turbidity can limit recovery and observations.

As an alternative to working with the short record of weir counts and the available carcass surveys, data from the East Bay Municipal Utility District (EBMUD) on the Mokelumne River was examined. This data has the advantage that there is a dam and fish ladder facility equipped with video monitoring and traps that allow trapping for physical inspections. The facility is operated daily throughout the migration season and has been in place since the early 1990's. Results of this monitoring provide a significant body of daily data on adult fall-run Chinook salmon migration. Although the information is potentially skewed from Woodbridge Irrigation District Dam (WIDD) operations, this bias is assumed to be short-term, i.e., daily, with general seasonal patterns being well represented, particularly seasonal timing of upstream movement. EBMUD also conducts detailed redd surveys where field crews routinely monitor the river for construction of redds. Both trapping and redd surveys date back to1993. These Mokelumne River data, coupled with the weir data from the Stanislaus River, were used to identify upstream migration and spawning periods within approximately 2-week intervals.

Although the seasonal timing of adult upstream Chinook salmon migration various within and among years in response to a variety of factors including, but not limited to, seasonal attraction and instream flows, migration impediments, seasonal water temperatures, and other factors, a generalized distribution of adult run timing can be developed. The general seasonal period of adult Chinook salmon immigration extends from approximately mid- to late-September through early January with the peak period of migration typically occurring in November. A generalized seasonal distribution for adult immigration, based upon adult weir counts from the Stanislaus River, in combination with information from the Mokelumne River is shown below:

Table 9. Generalized seasonal distribution for adult fall-run Chinook salmon immigration, based upon adult weir counts from the Stanislaus River, in combination with information from the Mokelumne River

Period	Percentage of Adult Fall-run Chinook Salmon Immigration
Sept 1-15	<1
Sept 16-30	5
Oct 1-15	20
Oct 16-31	20
Nov 1-15	30
Nov 16-30	15
Dec 1-15	5
Dec 16-31	3
Jan 1-15	<1

Egg Incubation

Information is available from fishery surveys conducted on the Mokelumne River by the East Bay Municipal Utility District (EBMUD) on the seasonal timing of Chinook salmon spawning and redd construction. Results of these redd surveys show that spawning activity occurs from early-October through early-January with the peak of spawning occurring in mid- to late-November. The seasonal distribution of spawning activity (redd construction) is summarized below:

Table 10. Seasonal distribution of spawning activity (redd construction)

Period	Percentage of Fall-run Chinook Salmon Redd Construction
Oct 1-5	2
Oct 16-31	5
Nov 1-15	20
Nov 16-30	56
Dec 1-15	13
Dec 16-31	4
Jan 1-15	1
Jan 16-31	<1

The duration of egg incubation prior to hatching is typically several months but varies substantially in response to water temperature.

Juvenile Rearing and Smoltification

Juvenile rearing and emigration time periods were derived from the SP Cramer and Associates rotary screw trap (RST). These data provide site-specific information for a period of approximately 5 years on the Stanislaus River. Two screw traps are operated at Oakdale (RM 40) and Caswell (RM 5) (Figure 1). There are two different life history traits for fall-run Chinook juveniles. One life history type consists of fry emerging from the gravels (≈1.5") immediately moving downstream to rear and undergo smoltification in lower San Joaquin River and delta. The other life history type emerges from the gravel at the same time, but rear in the Stanislaus River, growing to about 3" in length, which are refered to as smolts. These fish undergo smoltification in April-June and move out of the Stanislaus River and into the ocean in a fairly quick emigration.

Temperature may not be a critical factor in the Stanislaus River for the fry life history trait of rearing in the lower San Joaquin River and Delta, but for the smolt life history trait temperatures may be an issue in April, May and particularly June when water temperatures can reach stressful levels and may be limiting. An additional complicating element is the survival rate of fry versus smolts: there are many fry but with low natural survival rates, compared with relatively few smolts with substantially higher survival.

Information is available on downstream migration to juvenile fall-run Chinook salmon from the Stanislaus River based on results of RST collections. RST data is most complete for collections at Oakdale, showing that the general period of juvenile salmon outmigration extends from approximately mid-December through early July with the greatest proportion of juvenile salmon outmigrating during late-January and February. A generalized seasonal distribution of juvenile fall-run Chinook salmon outmigration for the Stanislaus River has been developed from the RST collections as shown below:

Table 11. Generalized seasonal distribution of juvenile fall-run Chinook salmon outmigration for the Stanislaus River has been developed from the rotary screw trap collections

Period	Percentage of Juvenile Fall-run Chinook Salmon Emigrating
Dec 1-15	<1
Dec 16-31	<1
Jan 1-15	2
Jan 16-31	20
Feb 1-15	30
Feb 16-28	18
Mar 1-15	7
Mar 16-31	4
Apr 1-15	3
Apr 16-30	4
May 1-15	7
May 16-31	5
Jun 1-15	2
Jun 16-30	<1
Jul 1-15	<1

Steelhead

Adult Migration and Spawning

Adult steelhead migrate upstream into Central Valley river systems typically during the winter and early spring (approximately December through March). Unlike Chinook salmon, adult steelhead do not necessarily die after spawning and a portion of the spawning adults may successfully migrate back downstream. Downstream migration of adult steelhead typically occurs during February and March but may extend into April. As a result of the difficulty in monitoring both adult upstream and downstream steelhead migration the available information on the seasonal timing of migration, variability in migration within and among years, and the influence of various environmental factors on adult migration timing are not well documented. In addition, the numbers of adult steelhead migrating into many of the Central Valley river systems, including those within the San Joaquin River drainage, have been extremely low in recent years which further contributes to the general lack of information on the dynamics and life history characteristics of steelhead.

Egg Incubation

As noted above, there is relatively little information on the seasonal timing of adult steelhead spawning within most of the Central Valley river systems, including those within the San Joaquin River drainage. Information is available on steelhead spawning within the lower Mokelumne River based on redd surveys conducted by EBMUD. Results of redd surveys conducted during 2001-2002, for example, showed that steelhead spawning and redd construction occurred between late-January, and extended through February and March, with the greatest spawning activity occurring in late-February.

Juvenile Rearing and Smoltification

Juvenile steelhead rear within the Central Valley river systems throughout the year, in contrast to fall-run Chinook salmon that rear within the river systems for only several months. The duration of juvenile steelhead rearing within a river system may extend from 1 to 2 years, or potentially longer, based on juvenile growth rates, physiological condition of the fish (smolting), and potentially other factors. Prior to moving downstream from the juvenile rearing areas steelhead undergo a physiological transformation referred to as smolting which allows the fish make the transition from a freshwater to a marine environment. Smolting and downstream migration typically occurs during the late winter and spring extending from approximately January through April or early May. The peak period of juvenile steelhead emigration, based upon results of fishery monitoring at the SWP and CVP export salvage facilities, typically occurs in late-February, March, and early-April.

4.2.4. Application to the Stanislaus River Temperature Assessment

The Panel examined the existing thermal criteria in terms of timing and various life stages. The DFG and SP Cramer and Associates criteria were reviewed by the Panel to identify areas where the criteria deviated appreciably from one another, as well as areas where there was potential for modification. Several of these areas are outlined below based on the annual period from September through August.

Week 1 – 4 (September): both DFG and SP Cramer and Associates maintain constant water temperature criteria through the month of September for adult fall-run Chinook migration. Two-week criteria may be better during this period of potentially rapidly changing conditions. It is recommended that the temperature criteria be decreased through the month, e.g., in two-week periods.

Week 5 – 31 (September to April): Although the two sets of criteria differ slightly here, with the SP Cramer and Associates sub-optimal to lethal criteria 3°F greater than the DFG criteria, water temperatures are generally low and problems, if they occur, are probably short duration in nature.

Week 33 – 39 (April and May): SB Kramer Associates and DFG diverge considerably during the smoltification phase. DFG bases their optimal temperature criteria (53.6°F) on McCoullough (1997), while it appears that SP Kramer and Associates is the altered impaired smoltification criteria from Keith Marine (1997), plus Clarke and Shelbourn (1985) for saltwater survival. The physical condition of outmigrants is poorly understood and the Panel chose to assume that smoltification could be accomplished in the Delta. Further, the Panel felt that the 68°F criterion (presumably based on Marine (1997, 2004)) was too high for this critical life stage.

Week 40-52 (June through August). The 73°F criteria identified as the upper temperature criterion for juvenile rearing appeared to be too high. Panel members felt that it was not appropriate to challenge the fish at this level. One concern was "squeezing" rainbow trout and over-summering anadromous steelhead into limited reaches of the river where larger rainbow trout might out-compete the other fish. SP Kramer and Associates identified Orange Blossom Bridge as the downstream extent of juvenile rearing while DFG identified Oakdale as a break point. Food availability during these months for the reaches in question is not well quantified. The Panel recommends 65°F or below for the criteria to define the sub-optimal to lethal criteria for juvenile rearing during summer months.

4.2.5. Location (Reach Designations) and Life Stage

The Panel also considered the existing thermal criteria in terms of location and life stage. There are several locations along the river that have been associated with particular reaches and life stages. By-and-large Stanislaus River reaches are designated according to geographic landmarks, including Goodwin Canyon, Knights Ferry, Orange Blossom Bridge, Oakdale, Riverbank, and Caswell. These reaches roughly represent physical differences in terms of hydrology, channel morphology, geology, riparian vegetation, and slope and define whether or not fall-run Chinook salmon and steelhead/rainbow trout are present, and where the individual components of their respective life history stages (e.g., eggs, fry, smolts, etc.) are typically found (Marston, 2003). General reach designations for different lifestages of the target species are shown below:

Fall-Run Chinook
Adult Migration – mouth
Spawning – above Oakdale
Egg Incubation – above Oakdale
Juvenile Rearing (late emigration life history trait) - mouth
Smoltification (both life history traits)– mouth

Steelhead
Adult Migration – mouth
Spawning – above Oakdale
Egg Incubation – above Oakdale
Juvenile Rearing - mouth
Smoltification - mouth

The Panel identified these as useful, well-established points of reference, but recommends that reach delineation be reviewed based on biologically significant features or conditions within a given reach or reaches. From a management perspective, the existing reach designations are well established and particularly useful in terms of access to the river. However, such existing designations should not restrict assessment of model alternatives because flow and water temperature conditions can be simulated at a fine spatial and temporal scale throughout the Stanislaus River system, i.e., there is a considerable amount of flow and temperature information available to the analyst. The Panel recommends that stakeholders, managers, and analysts explore more fully the temporal and spatial information available from the model and seek to utilize the information from this powerful tool. For example, exploring longitudinal variation in thermal conditions within the river system under various year hydrologic and meteorological conditions, and/or operational scenarios (flow rate and storage/cold water volume). Coupling this information with known habitat types and life stages could result in different reach designations, e.g., for juvenile rearing the target temperature may shift up and downstream based on hydrology, temperature, and operations. Such information would lend insight into drought year management strategies, such as relaxation of thermal criteria to avoid exhausting cold water supplies in upstream reservoirs.

4.2.6. A Note on Composite Criteria

A potential limitation of composite criteria – addressing both fall-run Chinook salmon and steelhead trout with a single set of criteria – is the inability to identify if an individual species is in trouble either spatially or temporally. Composite criteria are acceptable as a first layer screen, but it is wise to retain the ability to use separate criteria if problems arise, i.e., review the individual criteria to identify the problem. For example, if two alternatives showed vastly different conditions for a particular life stage, then one may wish to re-assess the criteria and determine if there are differences between the species. In addition, it is useful to watch for conflict of species-specific temperature criteria: e.g., if criteria were favoring steelhead that could retard growth in salmon, although conditions where water temperatures are too cold are generally not deemed a problem.

On the other hand, McCullough et al. (2001) investigated the issue of similarities and differences between thermal thresholds among salmonid species. They examined the thermal tolerance range for Salmonidae accounting for the response of Chinook, coho, sockeye, chum, and pink salmon; steelhead; Atlantic salmon; and brown, brook, and lake trout. That synthesis revealed very little variation in the Ultimate Upper Incipient Lethal Threshold (UUILT) among species in family groups, except for a higher lethal limit for redband trout and a lower one for bull trout. Thus, McCullough et al. (2001) provides a reasonable justification for applying composite criteria as a screening tool.

The proposed thermal criteria structure and framework for assessment of alternatives grew out of a review of existing thermal criteria. The structure of existing criteria values for identifying the various ranges, and the evolution to the final criteria are outlined below.

For the purposes of this report, the examples generally address a single species (e.g., fall-run Chinook salmon), but numbers for both steelhead and fall-run Chinook are provided.

4.3. Proposed Thermal Criteria

Throughout the review process the Panel members identified issues that were pertinent to the general topic of temperature criteria goals. Review of EPA (2003) identifies several of the same goals, some of which are summarized below

- Provide thermal habitat capable of supporting viable populations (including a surplus for human harvest) of all native salmonids
- Protect high quality thermal habitat while minimizing circumstances where compliance would require remediation beyond a system's thermal potential
- Promote a population size large enough to maintain genetic and phenotypic diversity over the long-term; survive environmental variation and catastrophic disturbance; and provide ecological functions
- Support a positive population growth rate
- Support population distributions that are well connected and extensive within and across sub-basins; allow full utilization of habitat potential (temporally and spatially) of sub-basins, which allows natural expression of multiple life history strategies.

Specific to the large rivers in the Central Valley of California, anadromous fish populations are often restricted to reaches below sizeable mainstem reservoirs. These reservoirs typically have large storage volumes and can provide cool water releases to downstream river reaches. As such, whether planned or not, these storage facilities result in temperature conditions that often deviate from conditions under which these species evolved. To ameliorate these conditions and better mimic pre-development watershed conditions, both of natural and managed temperature regimes should be considered, along with storage volume, reservoir operations, and flow conditions all must be considered. For example, providing temperature gradients through the river system, versus abrupt changes in water temperature, may play an important role to cue juvenile fish to leave the system and acclimate to conditions downstream in the San Joaquin River. The intent of the proposed criteria is to support these goals.

Outlined below are the three-range temperature framework, single day maximum temperature criteria, and introduction of the continuous thermal criteria approach.

4.3.1. Two Threshold (three-range) Temperature Criteria

The panel reviewed the two threshold (three-range) criteria as a basic method of assessing simulated temperatures among various operational alternatives. The basic metric, as outlined above, is the 7DADM temperatures. Two temperatures are assigned; one differentiating the optimal from the sub-optimal range, and one differentiating the sub-optimal range form the acute range. The definitions of the three ranges, which are all life stage dependent, generally represent:

- Optimal conditions – no adverse impacts on anadromous fish,
- Sub-optimal conditions – generally a stressful condition imposed on the fish. Conditions may not be continuously stressful, but fish cannot put all their energy to successful life function. As water temperatures approach the upper end of this range impacts become more severe,
- Lethal conditions – at times termed chronic or acute, lead to increasingly stressful conditions that result in various impacts, but not necessarily death. However, long-term exposure to such conditions is assumed to limit survival, reproduction, and or long-term success of the particular life stage.

These criteria are applied at selected locations that represent the species, life stage, duration of exposure, magnitude of exposure, and biological/physiological response. Early in the review process the Panel discussed the option of a single threshold (two-range) criteria. Below the criteria would be termed "optimum," while above the criteria was "not optimum" (combining sub-optimal, and lethal/acute conditions). A single threshold (two-range) criteria has been effective at separating alternatives in other basins (USFWS and Hoopa Valley Tribe 1999; Hendrick and Monahan 2003; Bartholow et al. In press), and its simplicity is a benefit.

The Panel, as a starting point, retained the two threshold (three-range) criteria based on the 7DADM temperatures, coupled with the instantaneous daily maximum statistic as well. Reasons for starting with this framework included:

- The TAC had started with a single threshold (two-range) criteria and found that a two threshold (three-range) criteria provided more opportunity to separate alternatives,
- A single threshold criteria can potentially suggest (correctly or not) an interpretation of a "good" or "bad" outcome,
- The temperature model is producing sub-daily information that can be advantageous for both short-duration (instantaneous daily max temperature) and longer-duration (7DADM temperatures) conditions.

The Panel felt that the Stanislaus River is a thermally marginal habitat, and the use of three ranges, or some variation thereof, would potentially provide better results because many fish will be surviving above the optimal criteria (but below some acute/lethal range).

4.3.2. Single Day Maximum Temperature Criteria

Because short duration elevated temperature events (on the order of a few hours) can have profound impacts on anadromous fish populations, one of the first steps the Panel took was to provide an additional metric of one-day instantaneous maximum lethal water temperature. This instantaneous daily maximum criterion represents an upper incipient lethal condition and is not equal to the 7DADM temperature that separates the sub-optimal from the lethal range in the three-range framework. Rather, this criterion defines incipient upper lethal temperatures (IULT) as a thermal condition, that when the fish is exposed for a short duration (hours) would result in severe impairment to the fish. For those stages that are mobile (e.g., adult, juvenile rearing) the impact would be manifest as impairment of natural function (e.g., swimming impairment). If temperature returned to more suitable conditions the fish would recover, if not, death would be the most probable outcome. Eggs are an immobile and sensitive life stage, and the literature does not readily distinguish between IULT and critical thermal maximum (CTMax)[2] for eggs, so temperatures that are listed in the literature as the maximum for eggs tend to be those where eggs start dying, i.e., as temperatures approach these maximum values increased egg mortality is expected.

The application of this daily instantaneous maximum criteria/metric is to identify short duration events (e.g., upper incipient lethal temperatures) that are masked by the 7DADM temperature. In the early fall or late spring, when thermal conditions are generally changing most rapidly, sub-weekly conditions may be highly variable and can put fish under stress. An alternative that produces many instantaneous daily maximum temperatures above the selected criteria indicates potential short-term impacts and the single day maximum criteria may assist in assessing alternatives, i.e., this criterion is intended to raise a "red flag" versus a quantitative measure.

4.3.3. Selecting Temperature "Breakpoints"

Two Threshold (three-range) Criteria

Selecting water temperature breakpoints for the two threshold (three-range) criteria to define the three ranges of optimal, sub-optimal and lethal is a considerable task. There is a large amount of literature presenting a wide range of conditions (field and laboratory) concerning the potential response of anadromous fish at various life stages to thermal conditions. The challenge facing resource managers, biologists, and others is to wade through this daunting amount of information and arrive at criteria that are meaningful for the river system of interest. Further, because of the inherent variability in fish response to thermal conditions, as well as variability among methodologies, settings, and analysts, the interpretation of literature values can result in diverging views of appropriate thermal

[2] The incipient upper lethal temperature (IULT) and critical thermal maximum (CTMax) are experimental laboratory approaches that generate temperature tolerances of fishes that are quantitatively expressed as a temperature. The approaches generate valuable, albeit different, information concerning the temperature tolerance of a species (Beitenger et al., 2000).

criteria. A clear example is the Panel identifying areas when modification of the existing thermal criteria should be considered (Section 4.2.3).

The Panel initially turned to the EPA document *Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* (EPA, 2003) to set the breakpoint temperature defining the optimal and sub-optimal thermal conditions. Although EPA's temperature guidance is not without its detractors, there is a wide range of published reports and EPA has taken many studies into account when setting their criteria.   The Panel feels the EPA approach and criteria can be used to address Stanislaus River goals. That is, if the identified EPA criteria (Panel's interpretation shown in Table 12) are plotted along with the information presented by DFG and SP Kramer and Associates, the criteria alternately hover near the upper breakpoint for adult migration, near the lower breakpoint for egg incubation and early rearing, near the lower breakpoint for smoltification under the SP Kramer and Associates criteria and near the upper breakpoint under the DFG criteria, and near the middle of the sub-optimal range late-season for juvenile rearing (Figure 4 and Figure 5).

Panel members identified that the values presented in Table 12 are a starting point. EPA (2003) is a well-documented source, with specific identified processes and procedures, and extensive peer review – intended to be a common starting point for assessment of thermal criteria.   The Panel felt that local resource managers should adapt the criteria as necessary when assessing model-simulated alternatives if there was supporting evidence to refine these for the Stanislaus River.

Table 12. Temperature criteria/goal for identified species and lifestages in the Stanislaus River (after EPA, 2003[3])

Stanislaus R. Terminology	EPA-based Recommended Temperature Criteria/Goals to Protect Salmon and Trout (Criteria are based on the 7-day average of the daily maximum values)
Adult migration	<64°F (<18°C) for salmon and trout migration
	<68°F (<20°C) for salmon and trout migration - generally in the lower part of river basins that likely reach this temperature naturally, <u>if</u> there are cold-water refugia available [but no evidence of such refugia are available for the Stanislaus River]
Incubation	<55°F (<13°C) for salmon and trout spawning, egg incubation, and fry emergence
Juvenile rearing (early year)	<61°F (<16°C) for salmon "core" juvenile rearing - generally in the mid- to upper part of river basins
Smoltification	<59°F (<15°C) for salmon smoltification <57°F (<14°C) for steelhead smoltification (for composite criteria steelhead conditions are applied)
Juvenile rearing (late year)	<64°F (<18°C) for salmon and steelhead migration plus non-Core Juvenile Rearing - generally in the lower part of river basins

[3] The reader is encouraged to review EPA (2003) for a full discussion of the development of numeric criteria, a portion of which is reproduced herein to indicate the general approach: "[N]umeric criteria that apply to uses that occur during the summer maximum period are intended to apply to the warmest times of the summer, the warmest years (except for extreme conditions), and the lowest downstream extent of use. Because of the conservative nature of this application, EPA believes that it is appropriate to recommend numeric criteria near the warmer end of the optimal range for uses intended to protect high quality bull trout and salmon/trout rearing. EPA expects that adopting a numeric criterion near the warmer end of the optimal range that is applied to the above conditions is likely to result in temperatures near the middle of the optimal range for most of the spring through fall period in the segments where most of the rearing use occurs. EPA has identified two reasons for this. First, if the criterion is met at the summer maximum, then temperatures will be lower than the criterion during most of the year. Second, because the criterion would apply at the furthest point downstream where the use is designated, temperatures will generally be colder across the full range of the designated use."

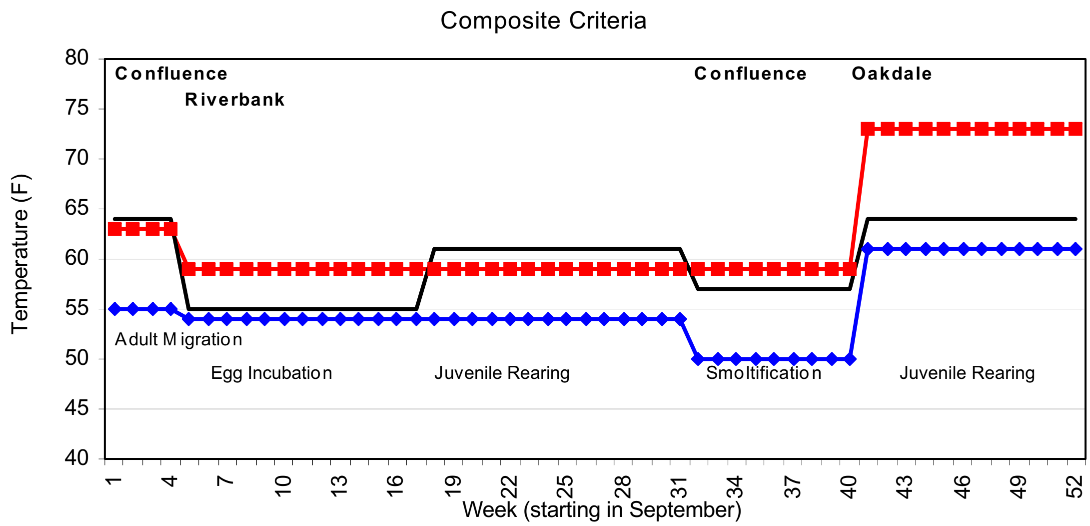


Figure 4. Proposed DFG composite temperature criteria (°F) for Chinook salmon and steelhead trout on the Stanislaus River compared with EPA criteria for optimal temperature criteria (solid black line)

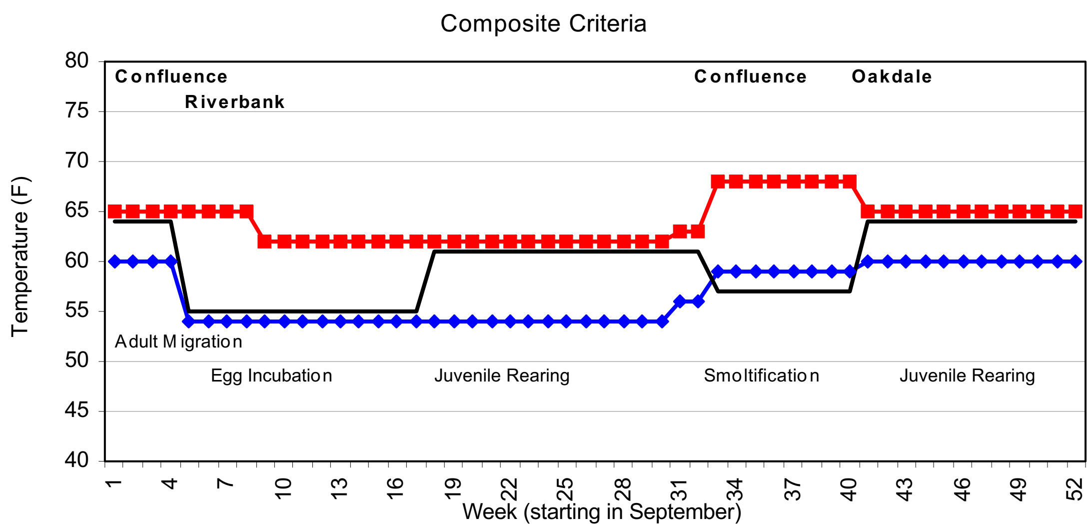


Figure 5. Proposed SP Cramer and Associates composite temperature criteria (°F) for Chinook salmon and steelhead trout on the Stanislaus River compared with EPA criteria for optimal temperature criteria (solid black line)

Setting the upper breakpoint in the three-range framework – between sub-optimal and lethal conditions – was a more challenging task. EPA (2003) provides no formal criteria and little guidance on the specific issue because the overall EPA approach is conservative. One approach was to simply rely on the literature and recommend modest changes to the existing criteria as identified in Section 4.2.3. However, there was considerable discussion on this point among Panel members. After some debate it was suggested that a fixed increment (e.g., 3°C (5.4°F)) above the lower breakpoint be explored. A starting point was based on Coutant (1972):

"Because the equations based on research on thermal tolerance predict 50% mortality, a safety factor is needed to assure no mortality. Several studies have indicated that a 2°C (3.8°F) reduction of an upper stress temperature results in no mortalities within an equivalent exposure duration (Fry at al. 1942; Black 1953). The validity of a 2°C (3.8°F) safety factor was strengthened by the results of Coutant (1970). He showed that about 15 to 20 percent of the exposure time, for median mortality and a given high temperature, induced selective predation on thermally shocked salmon and trout. (This also amounted to reduction of the effective stress temperature by about 2°C (3.8°F).). Unpublished data from subsequent predation experiments showed that this reduction of about 2°C (3.8°F) also applied to the incipient lethal temperature. The level at which there is no increased vulnerability to predation is the best estimate of a no-stress temperature that is currently available. No similar safety factor has been explored for tolerance of low temperatures. Further research may determine that safety factors as well as tolerance limits, have to be decided independently for each species, life stage, and water quality situation."

This approach was further supported by EPA (2001):

"Temperature-dependent life stages for salmonids include spawning, egg incubation, emergence, rearing, smoltification, migration, and pre-spawn holding. Any of these salmonid life stages can be present (depending on species and location) during summer months when streams in Pacific Northwest are warmest. Scientific evidence suggests that small increases in temperatures (e.g., 2-3°C (3.8 to 5.4°F) above biologically optimal ranges can begin to reduce salmonid fitness in some of these life stages."

Application of such a simple criteria has benefits, but Panel members felt that a simple across-the-board increase, for all life stages, was not realistic. Nonetheless, they felt that assessment of such a set of criteria should be tested, along with existing criteria. To complete this task, a straw man analysis was set up using simulations from previous work on the Stanislaus River (AD and RMA, 2002) to test various proposed criteria. Generally, comparison of alternatives using the two threshold (three range) criteria indicated they were not sufficiently sensitive to differentiate alternatives, leading the Panel to explore other options that are discussed below. The results of comparison of the two threshold (three range) criteria are outlined below.

Single Day Maximum Temperature Criteria

Only a single value was selected (versus multiple ranges) for the single day maximum temperature criteria because hourly data for lethal conditions can be derived from lab tolerance studies for shorter duration studies with some confidence, while chronic or sub-optimal impacts for these short duration events are not well documented. On a technical note, the model output at 6 p.m. is an acceptable representation of the daily maximum temperature and allows one to capture more of the information the model is generating, i.e., taking full advantage of this sub-daily modeling tool that has been developed for the

Stanislaus River (output at 6 hour intervals). Although the 6 p.m. time does not represent maximum daily temperature conditions in late fall through the early spring period, these cooler periods of the year are generally not of concern for thermal conditions.

Table 13. Upper incipient lethal temperature ranges for identified species and life stages in the Stanislaus River

Species	Life-stage	Acutely Lethal Temperature Range
Chinook salmon	Eggs	>16.7°C [1]
	Juveniles (parr)	> 29°C [2]
	Juveniles (smolts)	> 29°C [2]
	Adults	> 21°C (?)*
Steelhead (anadromous rainbow trout)	Eggs	> 15°C (?)*
	Juveniles (parr)	> 28°C [2]
	Juveniles (smolts)	> 28°C [2]
	Adults	> 26°C [2]

[1] Hinze, J.A., *Annual report Nimbus Salmon and Steelhead Hatchery fiscal year of 1957-58.* 1959, California Department of Fish and Game: Sacramento. p. 21.

[2] Cech, J.J., Jr. and C.A. Myrick, *Steelhead and Chinook salmon bioenergetics: temperature, ration, and genetic effects.* 1999, University of California Water Resources Center: Davis, CA.

[3] Bidgood, B.F., *Temperature tolerance of hatchery reared rainbow trout Salmo gairdneri, Richardson.* 1980, Fisheries Research Section, Fish and Wildlife Division, Alberta Energy and Natural Resources.

* Acutely lethal temperatures are unknown. Those values presented represent chronically lethal conditions and the value for steelhead egg incubation is an estimate

To assess these criteria a straw man analysis was set up using simulations from previous work on the Stanislaus River (AD and RMA, 2002). These comparisons are outlined below.

4.3.4. Continuous Thermal Criteria: The Proposition to Replace the Two Threshold Criteria

As noted above, the Panel discovered that the two threshold (three range) criteria did not successfully differentiate alternatives on a broad scale. However, it was possible to identify temperature criteria that differentiated alternatives, but these criteria were selected based on simulated temperatures were known *a priori*. The Panel was seeking robust criteria that could be applied without such foresight. Further, from the outset of this review the Panel had concerns over the discontinuous format of the two threshold (three-range) criteria - specifically, the inability of the discrete ranges to represent the continuous physiological response of a particular life stage. One example is the inability to effectively differentiate between conditions that are marginally sub-optimal (point "a" in Figure 6) versus those that are bordering on lethal (point "b" in Figure 6), i.e., both conditions are defined as sub-optimal but the physiological response of the life stage may be markedly different. In previous work (AD and RMA, 2002), several valuable methods were identified for examination of the output from the model including temperature duration information for species and life stage by locations and period of year (Figure 7). Also, degree-day violations within particular ranges were accumulated to quantify total thermal exposure over the optimum or sub-optimum temperature ranges. These are, and continue to be, useful measures for assessing alternatives. However, the Panel struggled with the linear representation of accumulated degree-day violations within any one category. Not only is the physiological response non-linear, but also in the discrete framework there is still a potential discontinuity between the sub-optimal and lethal ranges. This concern can be summed up by the statement that four days at one degree over the threshold is not biologically equivalent to one day at four degrees over the threshold.

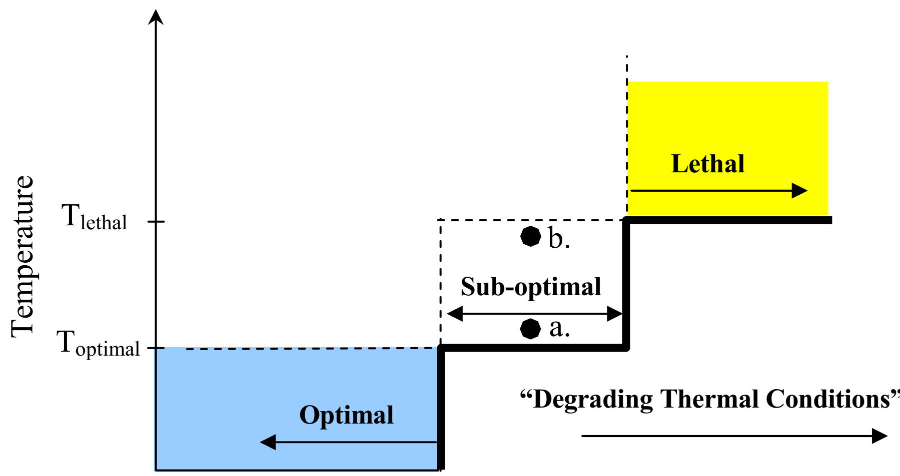


Figure 6. Discrete criteria based on two temperatures defining three ranges of thermal conditions. Point "a" represents thermal conditions that are merely somewhat sub-optimal as distinct from point "b" that are nearly lethal.

Table 1: Temperature Duration Table for Steelhead Trout

% of time Temp. is equaled to or less	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
5%	44.9	45.7	48.4	50.5	52.4	54.3	56.0	56.1	54.0	52.5	46.7	45.2
10%	45.3	46.4	49.6	51.2	53.2	54.9	56.9	56.8	56.8	53.4	48.0	45.7
15%	45.6	46.8	50.3	52.1	53.5	55.3	58.2	57.5	57.6	53.9	49.7	45.9
20%	45.8	47.2	50.6	52.6	53.7	55.7	59.1	58.0	58.2	54.5	50.7	46.4
25%	45.9	47.7	50.8	53.1	54.0	56.1	59.7	59.1	59.0	55.0	51.4	46.8
30%	46.0	48.0	51.0	53.4	54.4	56.6	60.2	61.1	59.8	55.6	52.2	47.4
35%	46.2	48.3	51.2	53.7	54.7	57.7	60.5	61.8	60.5	56.2	52.9	47.9
40%	46.4	48.5	51.5	54.1	55.1	58.6	60.8	62.4	61.1	56.7	53.3	48.2
45%	46.6	48.8	51.7	54.4	55.8	59.2	61.2	62.9	61.5	57.5	53.6	48.9
50%	46.9	49.1	52.0	54.8	56.3	59.7	61.6	63.3	61.9	58.4	53.8	49.4
55%	47.1	49.4	52.3	55.1	56.7	60.1	62.1	63.7	62.7	59.2	54.1	49.9
60%	47.4	49.7	52.6	55.5	57.4	61.1	62.6	64.1	64.4	59.8	54.3	50.3
65%	47.7	49.8	52.8	55.8	57.7	62.4	63.3	64.9	65.2	60.5	54.7	50.7
70%	47.9	50.0	53.1	56.2	58.3	63.5	64.4	65.6	66.2	61.0	55.6	51.0
75%	48.4	50.2	53.5	56.5	58.9	64.8	65.0	66.5	66.9	62.0	56.2	51.3
80%	48.9	50.3	54.0	57.0	59.8	65.5	66.1	67.0	67.5	63.0	56.5	51.6
85%	49.3	50.6	54.7	57.7	61.2	66.5	68.3	69.7	68.8	64.1	57.1	52.1
90%	49.7	50.9	55.7	58.2	63.0	68.2	69.2	71.4	69.6	65.5	57.9	52.5
95%	50.1	51.7	56.9	58.8	64.6	69.8	70.2	72.7	72.8	66.5	58.9	53.1
100%	52.6	56.2	58.3	60.4	69.1	72.6	71.8	73.8	74.9	73.9	61.8	54.6
Temp. Criteria/location	KF	KF	OAK	OAK	OAK	OAK	OAK	OAK	OAK	OAK	OAK	KF
Optimal -Max	52	52	56	56	56	60	60	60	60	56	56	52
Sub-Lethal	52-56	52-56	56-66	56-66	56-66	60-66	60-66	60-66	60-66	56-66	56-66	52-56
Critical	56	56	66	66	66	66	66	66	66	66	66	56
Optimal (%)	100%	95%	90%	65%	45%	50%	25%	25%	30%	30%	70%	80%
Sub-Lethal (%)	0%	0%	10%	35%	50%	30%	50%	45%	35%	60%	30%	20%
Critical (%)	0%	5%	0%	0%	5%	20%	25%	30%	35%	10%	0%	0%

Figure 7. Temperature duration table (AD Consultants and RMA, 2002)

The Panel elected to modify the two threshold (three range) criteria and adopt a response function that would essentially allow a continuous representation of increasingly adverse conditions. Discussion focused around constructing appropriate response curves for temperatures above the identified optimum temperature for each life stage: an example is shown in Figure 8.

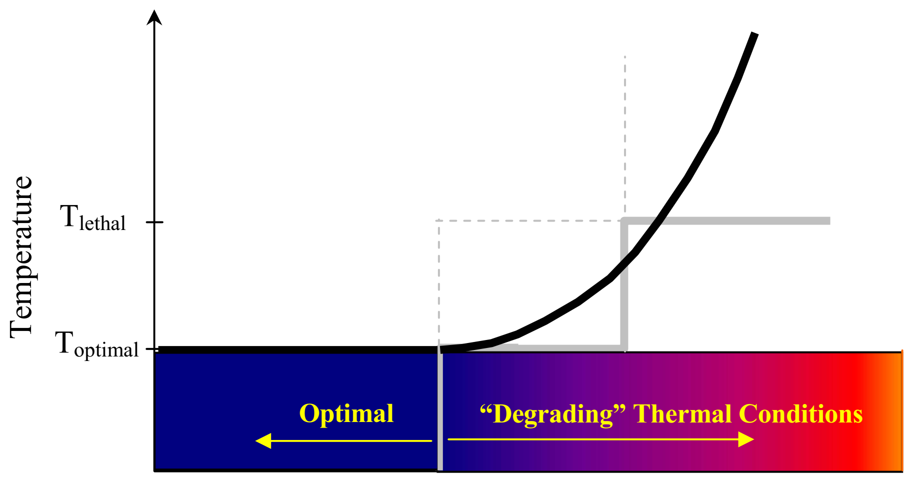


Figure 8. Example continuous criteria based on an optimum temperature and an exponential function defining an increasingly degraded thermal condition – discrete criteria shown for comparison

The Panel explored a non-linear response curve to identify a continuum of impact and quantify the level of degradation. For temperatures minimally greater than the optimum, a weight or penalty would theoretically be modest. As temperatures increasingly deviated from the optimum, the weight or penalty would increase exponentially. The desired form of the equation was

$$W = (\Delta T)^a$$

where

- W = estimated weighting factor or penalty (akin to degree days)
- ΔT = $T_w - T_o$
- T_w = water temperature, where $T_w \geq T_o$
- T_o = optimum water temperature
- a = exponent defining the shape of the response curve

for
a = 0, W would equal 1 for all values of
a = 1, W is represented as a linear response function
a = 2, W is represented as a quadratic response function
a = 3, W is represented as a cubic response function

As shown in Figure 9, the higher the exponent the more quickly the weighting factor increases, representing ever more severe thermal conditions. These weighting factors (or penalty) can then be compared among alternatives and those scenarios with the lower accumulated weighting factor are presumably more desirable. However, careful evaluation of the results should still be carried out to ensure that one life stage does not perform poorly at the expense of another.

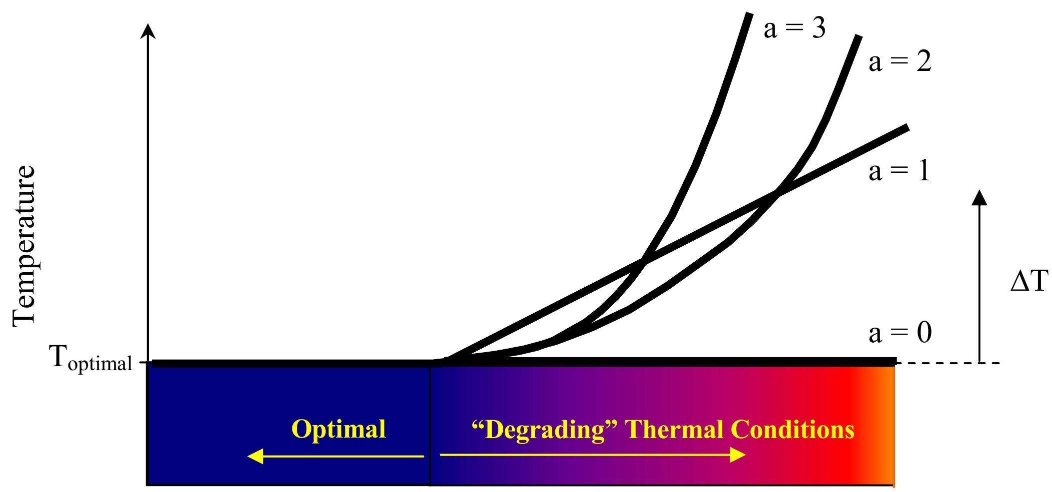


Figure 9. Representative continuous criteria exponential function for integer values of a ranging from 0 to 3

To estimate the appropriate value of the functions exponent "a", the Panel started with Baker et al. (1995). Using juvenile survival for outmigrants from this study an estimate of mortality was determined. Baker et al. reported that juvenile survival in the Sacramento River could be estimated as

$$S = 1/(1+e^{(-\beta 1 - \beta 2\ Tw)})$$

where

S = survival fraction (i.e., 1.0 is 100 percent survival, 0.0 is 100 percent mortality) for temperatures up to 24°C
T_w = mean weekly water temperature (°C)
β_1 = 15.56
β_2 = -0.6765

Representing mortality (M) as

$$M = 1-S$$

a temperature-mortality relationship can be developed using 16°C (60.8°F) as the optimum temperature for juvenile rearing (Table 12) as shown in Table 14 and Figure 10.

Because the Baker et al. (1995) formula was developed for water temperatures below 24°C, weekly mortality for temperatures over 24°C are highlighted as extrapolated.

Table 14. Juvenile Chinook survival and mortality (after Baker et al., 1995)

Temperature (°C)	Temperature (°F)	Juvenile Survival (fraction)	Juvenile Mortality (fraction)
16	60.8	0.991	0.009
17	62.6	0.983	0.017
18	64.4	0.967	0.033
19	66.2	0.937	0.063
20	68.0	0.884	0.116
21	69.8	0.795	0.205
22	71.6	0.663	0.337
23	73.4	0.500	0.500
24	75.2	0.337	0.663
25	77.0	0.205	0.795
26	78.8	0.116	0.884
27	80.6	0.063	0.937
28	82.4	0.033	0.967
29	84.2	0.017	0.983
30	86.0	0.009	0.991

Shaded cells are extrapolated above 24°C

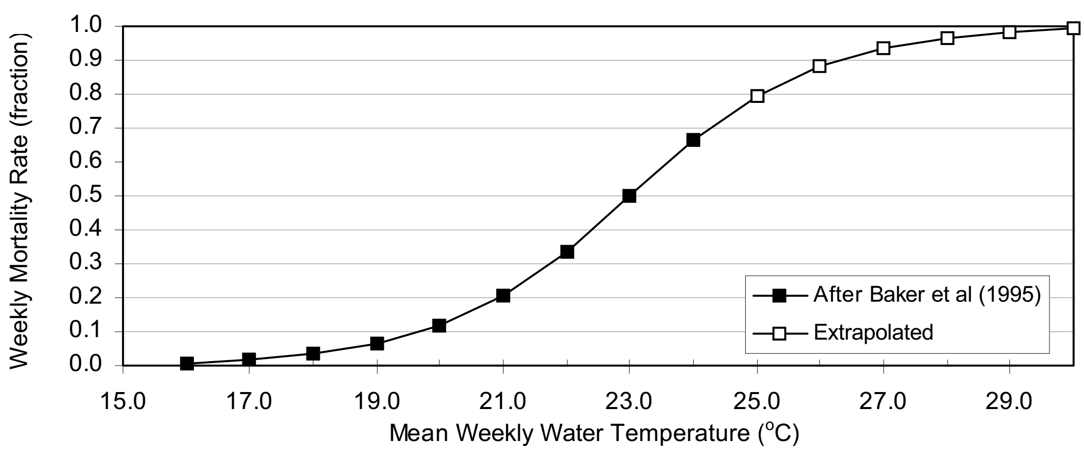


Figure 10. Juvenile Chinook thermal mortality (after Baker et al., 1995)

Further, defining a relative weighting factor (W_R) that describes mortality above the optimum temperature as

$$W_R = M_{Tw}/M_{To}$$

where

M_{Tw} = mortality at water temperature T_w, where $T_w \geq T_o$
M_{To} = mortality at the optimum water temperature T_o
provides a metric akin to degree days, but as a surrogate for mortality incurred above the optimum water temperature represented by $\Delta T = T_w - T_o$ (Figure 11).

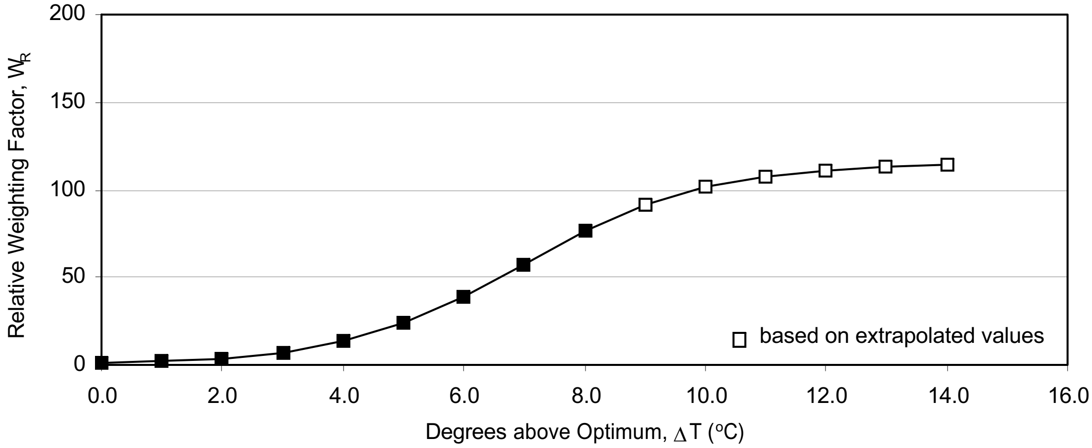


Figure 11. Relative weighting factor for juvenile Chinook salmon

Subsequently, a suite of curves for various values of a (exponent) in the estimated weighting factor equation

$$W = (\Delta T)^a$$

were assessed. A value of a = 2 approximately represented the field observations (with the exception of extrapolated values) for juvenile Chinook salmon from Baker et al., as shown in Figure 12.

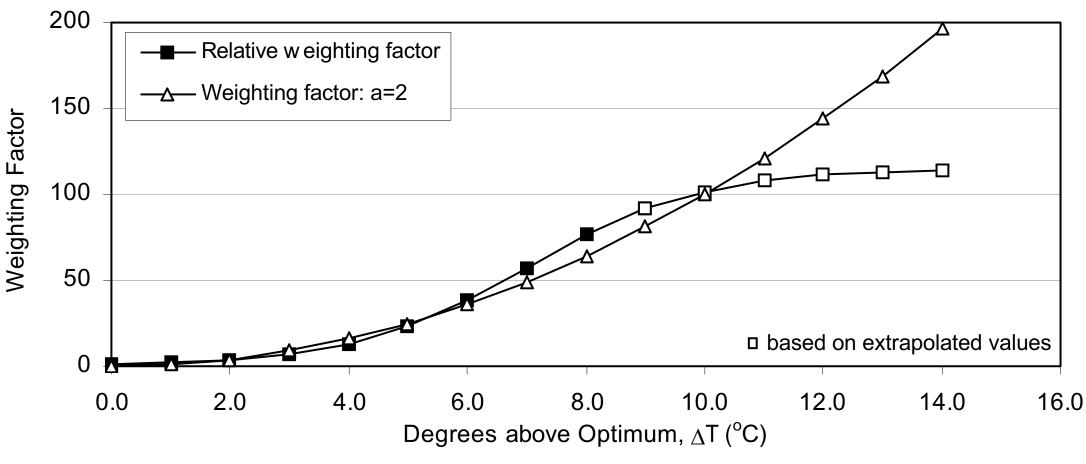


Figure 12. Relative weighting factor (W_R) and estimated weighting factor (W) for juvenile Chinook salmon

Limited quantitative data were available for other life stages: adult migration, egg incubation, and smoltification. Based on professional judgment and literature on the sensitivity of various life stages, the Panel set exponent values for adult migration, egg incubation, and smoltification at 2, 3, and 3, respectively. The higher exponent values for egg incubation and smoltification indicate the relative sensitivity of these life stages.

In addition to defining the exponent for each life stage, a maximum ΔT was specified to ensure that very high values would not skew the results, i.e., do not continue to increase the weighting factor (e.g., accrue penalty) when the life stage experiences almost complete mortality and the simplified, artificial function begins to deviate substantially from the literature-derived function. The low value for egg incubation indicates that the life stage is highly sensitive to increases in water temperature above the optimum. Finally, all calculated weighting factors (W) based on model data are scaled (normalized) to 100 to weight each life stage equally, identifying that all life stages are equally important in maintenance and restoration of anadromous fish populations. The results, including optimum water temperatures are summarized in Table 15.

Table 15. Optimum water temperature, weighting function exponent and maximum ΔT for each life stage of Chinook salmon

Life stage	Optimum Water Temperature		Exponent, a	ΔT_{max}	
	(°C)	(°F)		(°C)	(°F)
Adult	18	64	2	10.0	18
Egg Incubation	13	55	3	4.0	7.2
Juvenile Rearing	18	64	2	10.0	18
Smoltification	14	57	3	10.0	18

Figure 13 illustrates the values of the smoltification weighting function for a range of temperatures, as per Table 15. Weighting function values for all life stages are presented in Figure 14. Note the weighting factor for smoltification is an order of magnitude larger than the other life stages. This is because the exponent for this life stage is three, leading to a cubic function. Coupled with the ΔT_{max} of 18°F, the result is potentially large weighting factors. To place the various life stages on an equal scale, regardless of the choice of exponent or ΔT_{max}, the weightings are normalized for all life stages on a scale of 0 to 100 (Figure 15).

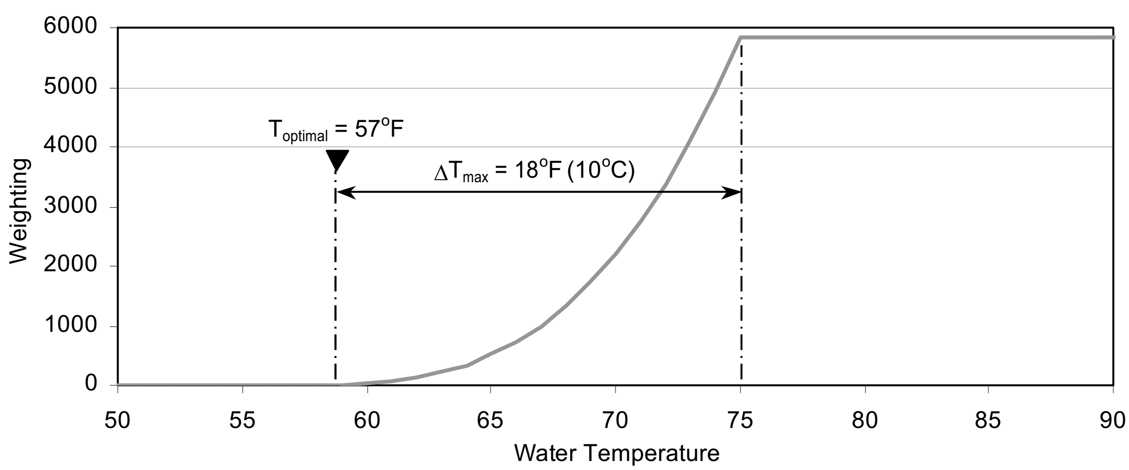


Figure 13. Weighting function versus temperature for smoltification

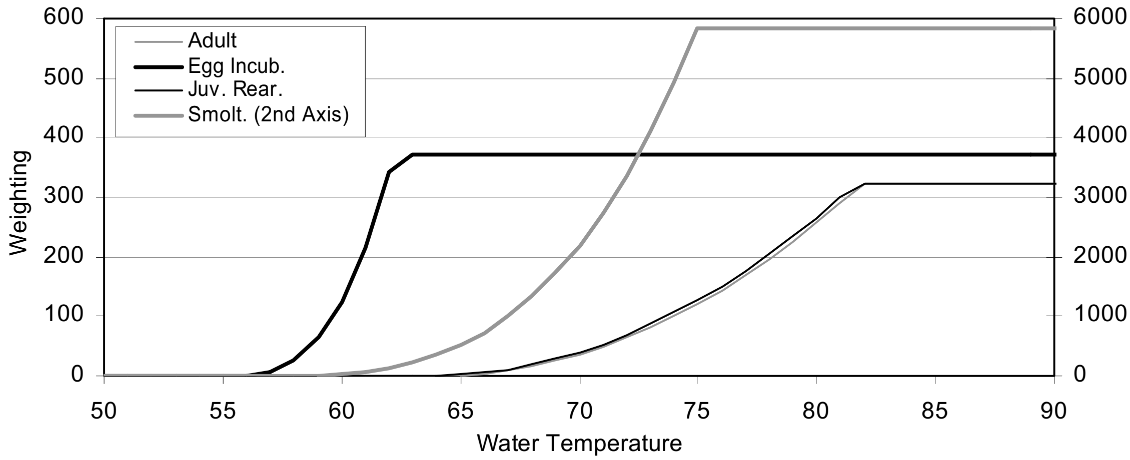


Figure 14. Weighting function versus temperature for all life stages

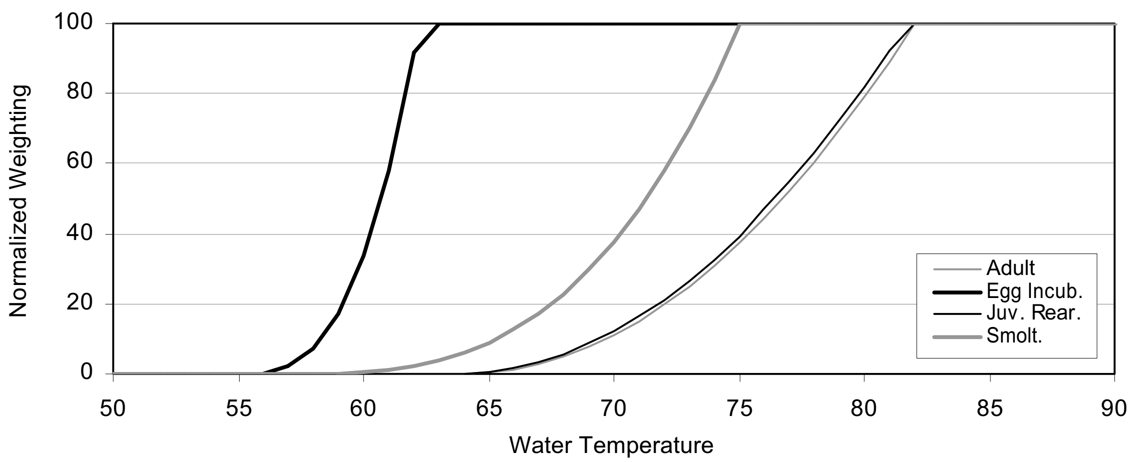


Figure 15. Normalized weighting function versus temperature for all life stages

Review of Figure 15 illustrates that egg incubation has a lower optimum temperature than the other life stages and is the most sensitive life stage as indicated by the steep rise in weighting function as ΔT increases. The next most sensitive life stage is smoltification, followed by both juvenile rearing and adult migration.

Modification of the optimum temperature, exponent, and ΔT_{max} parameters results in functions of different shapes, which can directly impact weighting function values. The impact of modifying these parameters is described below and shown graphically in Figure 16. Modifying the optimum temperature (e.g., from Table 12) results in a shift of the curve left to right (increasing $T_{optimum}$) or vice versa (decreasing $T_{optimum}$) as shown in Figure 16[a]. Setting the exponent to 1.0 results in a linear relationship between the optimum temperature and ΔT_{max}; as exponent values increase or decrease, the function approaches a step at either $T_{optimal}$ or $T_{optimal}+\Delta T$. Finally, if ΔT is decreased, the function becomes steeper, while if it is increased the function becomes flatter.

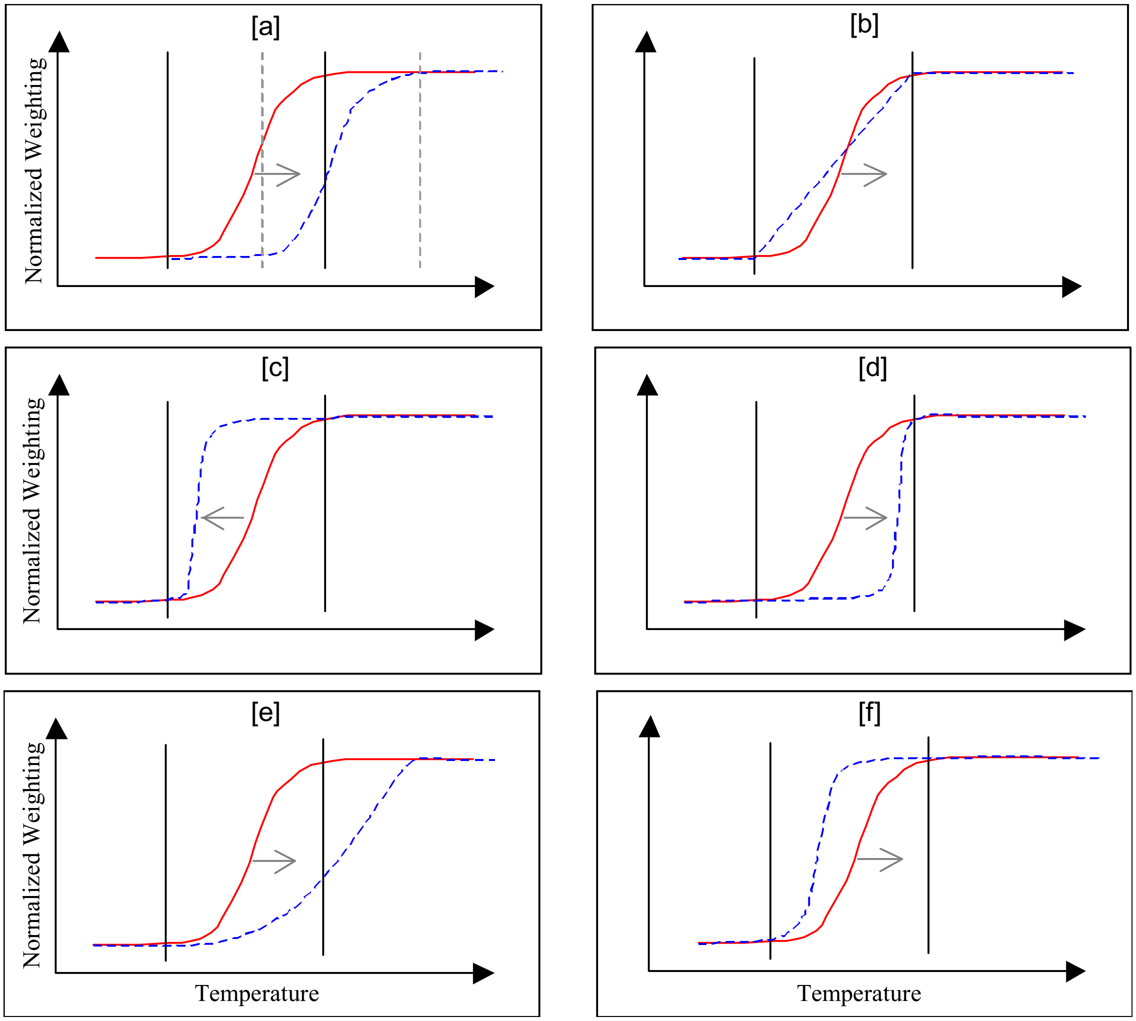


Figure 16. Effects of [a] increasing $T_{optimum}$; modifying exponent [b] a = 1.0, [c] a → 0, [d] a → ∞; modifying ΔT_{max} [e] increasing ΔT_{max}, [f] decreasing ΔT_{max} (red line represents original condition, blue line represents impact of modifying stated parameter)

4.3.5. Limitations of the Continuous Thermal Criteria

As noted previously, application of a single-threshold criterion can be interpreted as "good" or "bad" when temperatures are below or above the criteria, respectively. Similar interpretation, albeit with slightly more resolution, can be applied to the two threshold criteria. Further, both the single- and two threshold criteria provide discrete values that may not reflect the continuous nature of biological responses to thermal conditions.

Although the continuous thermal criteria provide appreciable flexibility in representing the potential continuous thermal response of anadromous fish for the various life stages (e.g., Figure 16), there are limitations to this method as well. Probably the most significant limitation is the lack of available information on the response of the various life stages to thermal conditions, which presents a challenge to constructing the various continuous functions, as well as identifying the maximum threshold (ΔT_{max}).

Another limitation is identifying the importance of relative weighting values. Although all values are normalized on a scale of 0 to 100, some experience may be required to evaluate the impacts of the continuous metric. In some cases, consideration of the two-range criteria may prove useful in initial assessment and interpretation of results.

Nonetheless, the Panel identifies these limitations not as barriers to advancing the proposed method, which is a logical extension of the discrete threshold criteria (i.e., adding resolution by increasing the number of discrete threshold criteria until a continuous function is attained), but as opportunities to improve thermal management of anadromous fish stocks. In fact, these limitations also plague the discrete criteria as well.

4.3.6. Other Considerations

Arguments for Retaining the Two Threshold (three-range) Criteria

Although the three-range framework does not completely represent the non-linear physiological response of the fish as temperatures rise above the optimum level, the approach has been applied in other river basins with varying levels success (USFWS and Hoopa Valley Tribe, 1999; Hendrick and Monahan, 2003; Bartholow et al., in press). Further, AD Consultants (undated draft) identify conditions where such an approach proved useful in the Stanislaus River. However, in review of the alternatives presented in AD Consultants and RMA (2002), it appears that in its most basic form, the three-range method is not providing an ability to differentiate among alternatives – or the alternatives are not very different. The Panel does not feel that the two threshold criteria necessarily provides sufficient detail to differentiate among alternatives on a broad scale, but does not want to preclude its use if it provides additional insight. In fact, as noted above, the two threshold criteria may assist managers in interpreting the continuous criteria. Although there are limitations, as noted previously, the three-range approach may still play a role in anadromous fish management at the planning level. The Panel did not arrive at an upper breakpoint for all life stages, but did recommend modification to the existing composite criteria that could be used as a starting point for resource managers.

Conditions for the lower San Joaquin River

Although the Panel discussed conditions in the San Joaquin River, this review focused primarily on the Stanislaus River. Little information on water temperatures in the lower San Joaquin is available. More information will be available once the updated model is calibrated for this lower reach. It is generally assumed that the Stanislaus River thermal conditions are more conducive to anadromous fish than the San Joaquin. Thus, adult migrating Chinook salmon may move into the river to seek relief from the San Joaquin River. With regard to juvenile outmigration, the Panel identified a goal to have emigrating fish in the best possible fitness upon leaving the Stanislaus River to improve their chances of survival through the San Joaquin River and Delta.

Further, there is limited information available with regard to anadromous fish behavior and condition within the lower San Joaquin. Finally, other factors that may play an important role - disease, predation, cover, food availability, etc. - in the health of anadromous fish (either adult migration, juvenile rearing, or smoltification life stages) are largely unknown. Due to this paucity of critical information on the San Joaquin River, the Panel recommends ongoing study in this reach to improve the physical and biological information necessary to manage anadromous fish, as well as other aquatic ecosystem functions.

4.3.7. Conclusion

By employing two criteria, it is more likely that two "levels" of assessment can be characterized (short- and long-term system response). The continuous criteria provide a unique approach to managing fish stocks, with a theoretical basis of increasing impact as temperatures rise above optimal thresholds. Based on the 7DADM these criteria provide a week-to-week assessment of habitat conditions within various management reaches of the river. Because the daily instantaneous maximum temperature criteria are largely derived from laboratory studies, they may not translate effectively to field situations. However, it can still be a useful metric in comparing alternatives on a day-to-day basis, e.g., this additional metric may assist a biologist in separating alternatives that did not indicate significant differences using the continuous criteria or two threshold criteria.

5. Criteria Assessment

The Panel identified the need to assess developed thermal criteria to determine their efficacy, e.g., a straw man assessment. AD Consultants provided the results of several alternatives. The two threshold criteria and continuous criteria were assessed, as well as the single day maximum water temperature criteria. Two sets of alternatives were supplied:

- Set 1: Runs #2 and #4 from AD and RMA (2002) and
- Set 2. Base case and IFIM case from AD Consultants (undated draft)

Each set of simulations retains different assumptions and thus, for example, run #2 from Set 1 cannot be compared with the IFIM Case from Set 2. These alternatives, their assumptions, and reasons for selection are outlined below.

5.1. Set 1: Runs #2 and #4

Set 1 consisted of two simulations selected from a suite of 11 operating cases presented in AD and RMA (2002). The Panel requested a set of runs that would show sufficient variability in results and would make likely candidates for testing the various criteria.

Run #2 was termed a simulated "baseline case" wherein daily flow, meteorology, volumes, inflow temperatures, and adjustments are as described in AD and RMA (2002) for simulated conditions. All subsequent runs in AD and RMA (2002) used these base assumptions, modified for a particular operational condition.

Run #4 modified the hydrology for the baseline case (Run #2) to maintain a minimum pool of 350 TAF in New Melones. These required reducing Goodwin Dam diversions (deliveries) by 20 % during 1990 – 1992 to meet a minimum pool of 350 TAF on Oct. 30, 1992 and as described in AD and RMA (2002).

Simulated conditions for the period 1983 to 1996 were utilized. The period 1983 to 1996 was selected because it represents the most recent storage cycle in New Melones where the reservoir reached a full capacity, reduced to almost dead storage, and then recovered. The simulated conditions were based on monthly results of the CALSIM II model.

The CALSIM II model simulated future operation of the Stanislaus River including
- the allocation of water to irrigation and reclamation districts,
- water sales by districts,
- obligations of Oakdale Irrigation District (OID) and South San Joaquin Irrigation District (SSJID) for the Vernalis Adaptive Management Plan (VAMP) and the San Joaquin River Agreement (SJRA),
- fish release requirements per the Interim Operations Plan (IOP) between the U.S. Bureau of Reclamation (USBR), the California Department of Fish and the U.S. Fish and Wildlife Service, and.
- other release requirements for water quality, Bay-Delta and flood control.

Because of input data limitations, the CALSIM II model results were available only for the period WY 1922 through 1994, but was extended through 1996 to allow the simulation of New Melones storage recovery.

Other assumptions related to the use of CALSIM II data were:
- The monthly flow data were distributed evenly throughout the month to derive the daily values.
- New Melones withdrawals were adjusted such that Tulloch Storage volume ranges between 57 and 67 TAF, in accordance with the flood control requirements.

5.2. Set 2: Base Case and IFIM Case

Two additional simulations were used to test the temperature criteria: a "base" case and an "IFIM" case. These simulations were part of a separate analysis to test the hypothesis that water temperature objectives cannot be met due to diminished pool of cool water in New Melones as a result of prolonged drought and depressed storage. More specifically, to assess if it is possible to improve water temperatures in critically dry years by conserving water in normal and wet years to increase carryover storage into drought years. The two simulations are outlined below: additional detailed can be found in AD Consultants (undated draft)

The base case represents the historical operation of New Melones in the period 1983-1999. The period of record was 1983-1999. This period was selected because it represents a full cycle of New Melones storage: the reservoir started full in the 1980's, reached almost dead storage in the 1992 drought and then recovered. For these two cases the inflows to the system (i.e. reservoir inflow and accretions) were based on the historical daily data. Diversions at Goodwin Dam were combined to be a single delivery and were also based on historical data. Under the Base Case, the release was based on the historical operations. It should be noted that no other release requirements were prescribed for other purposes, such as, meeting water quality standards at Vernalis, dissolved oxygen (DO) requirements, Bay-Delta exports, etc.

The IFIM case represents the operations of New Melones given historical inflows to New Melones in the period 1983-1999, but assuming that the instream flows are based on the

IFIM study conducted for the Stanislaus River in 1993. The hydrology was the same as the base case except under the IFIM case, instream flow releases were based on the IFIM schedule presented in AD Consultants (undated draft).

5.3. Assessment of Simulated Alternatives

Assessment of alternatives was completed with the two threshold (three-range) and the composite criteria initially – prior to the inception of the continuous criteria. Similar information can be compiled for fall-run Chinook salmon or steelhead trout as species-specific criteria. Several simulations were assessed including identifying the two threshold criteria as described in Table 16.

Table 16. Trials assessed using the two threshold criteria

Trial	Lower Threshold*	Upper threshold
1	Optimum (Table 12)	Optimum plus 2°C (3.8°F)
2	Optimum (Table 12)	Optimum plus 3°C (5.4°F)
3	Optimum (Table 12)	Optimum plus 4°C (7.2°F)
4	Optimum (Table 12)	Optimum plus 3°C (5.4°F) – by year type
5	Optimum (Table 12)	Optimum plus 4°C (7.2°F)) – by year type

* Life stage and species dependent

By and large, the first three trials, assessed with Set #1, resulted in minimal differences between the two alternatives (Run 2 and Run 4), e.g., reduction in lethal or sub-optimal conditions on the order of three percent. The Panel members concluded that the proposed operations identified in Run #4 did not differ significantly from the baseline case (Run #2). Additional trials were completed by examining individual year-types based on the unimpaired flow regime (full natural flow) as reported by the California Department of Water Resources. This breakdown, although not accounting for seasonal or carryover storage in New Melones Reservoir, identified that in the 1991 and 1992 period there were differences between the two simulations. However, these were modest differences primarily because most of the7DADM temperatures during the critical summer and fall periods were generally above the upper threshold.

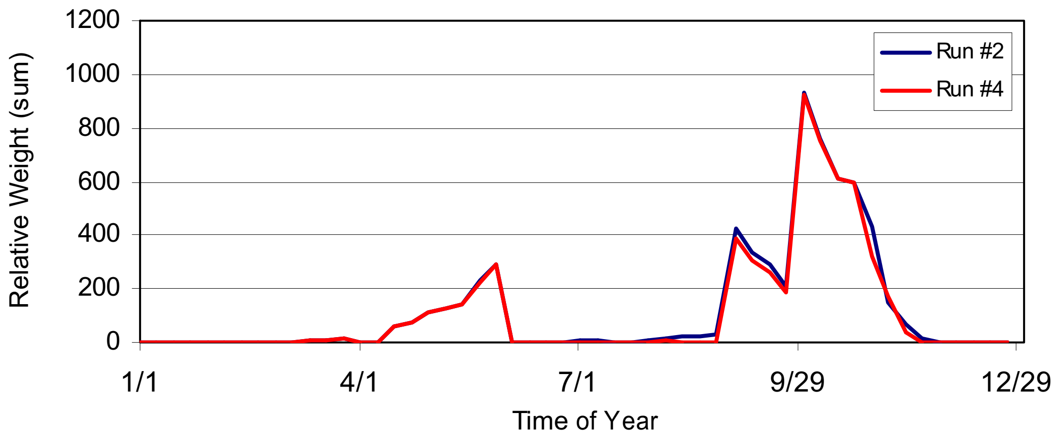
One critical issue the Panel avoided was “reverse engineering” the criteria, that is, using the simulations to create a set of criteria that “worked” for the Stanislaus River. Instead, the Panel identified the criteria and the chairman completed the screening process independently. This approach led to biologically relevant criteria versus criteria that “fit” the data.

Additional simulations were obtained from AD Consultants (Set #2) to further assess the criteria. Although these simulations showed additional differences, for the identified criteria the simulations were not significantly different. Specifically, the Panel felt that the alternative simulations did not deviate sufficiently from the base case(s) to provide a robust restoration strategy. For example, although a particular proposed operation would result in a 5 or 10 percent reduction in lethal or sub-optimal conditions, Panel members felt that such modest improvement was within the natural variability of system conditions, and thus would not result in successful restoration of salmon and steelhead.

Panel members felt that reductions of greater than 20 percent would be required to indicate a reasonable potential for long-term success. Further, though particular years such as 1991 and 1992, proposed operations might show such improvement, the remaining years showed no improvement or performed worse. Panel members felt that improving conditions in 2 of 17 years, while retaining baseline (existing) conditions in the remaining 15 years, was not amenable to increasing production on a long-term basis.

5.3.1. Continuous Thermal Criteria

Application of the continuous composite criteria to simulation Set #1 and Set #2 did not provide clear distinction in all cases. Figure 17 indicates that for Set #1 differences were minimal, adding further credence to the Panel's conclusion that Run #4 is not substantially different than Run #2 (baseline). However, application of the continuous criteria to Set #2 presents a richer response. The shoulder seasons – April and May, and October – show improvement, while certain intermediate periods indicate degradation of conditions.



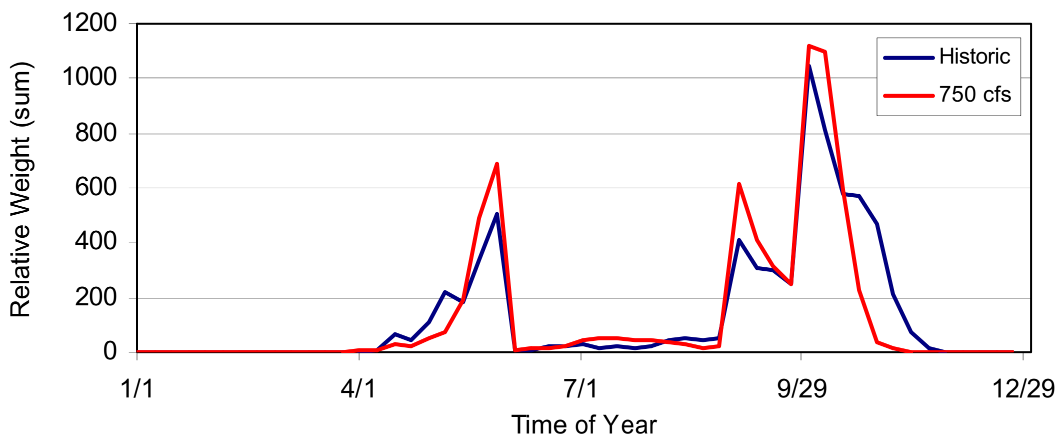


Figure 17. Relative weight determined by continuous criteria for Set #1 (top) and Set #2 (bottom)

Although results and comparisons can be examined in many ways, providing detailed information throughout the simulation period (in space and time) yielded the best opportunity to assess model output. Figure 18 and Figure 19 tabulate weekly relative weight (penalty) data by calendar date, fish week, and location (life stage) for fall-run Chinook salmon during the entire analysis period for simulation Set #1.

Using tabulated results, year-type conditions can readily be assessed (e.g., drought conditions of the late 1980's through early 1990's). Further, critical periods of the year can be examined to determine if there are limiting conditions – "bottlenecks" – for a particular life stage (represented by location). Both sets of simulations indicate that conditions from mid-April through May and September through mid- to late-October are adverse for salmon and steelhead. Winter and summer periods do not present major problems for the identified compliance points and life stage periodicity. Figure 20 shows differences between Run #2 and Run #4 in simulation Set #1, wherein blue values (negative) indicate improvement over the baseline case, while red value (positive) indicate degradation over the baseline case. Although Run #4 indicates some improvement over Run #2, the improvements are modest.

Calendar Date	Fish Week (A)	Location (B)	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Sum	Average
1/1	18	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/8	19	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/15	20	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/22	21	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/29	22	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/5	23	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/12	24	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/19	25	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/26	26	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
3/5	27	Riverbank	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1	0.1
3/12	28	Riverbank	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	1.1	1.0	0.0	0.0	4	0.3
3/19	29	Riverbank	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	4	0.3
3/26	30	Riverbank	0.0	0.0	0.0	0.0	5.0	1.0	1.0	1.0	0.0	2.4	0.0	1.0	0.0	0.0	11	0.8
4/2	31	Riverbank	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	2	0.1
4/9	32	Riverbank	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2	0.1
4/16	33	Confluence	0.0	0.1	0.3	0.1	6.1	15.5	9.4	7.5	0.8	9.5	3.5	6.2	0.0	0.1	59	4.2
4/23	34	Confluence	0.0	0.3	1.7	0.3	2.6	25.2	1.9	12.5	1.3	14.3	9.5	1.1	0.1	1.1	72	5.1
4/30	35	Confluence	0.0	0.3	2.7	0.1	10.0	17.4	8.4	21.3	1.8	28.7	13.7	4.9	0.1	1.4	111	7.9
5/7	36	Confluence	0.1	2.6	0.7	0.3	17.6	8.9	10.2	20.8	2.1	32.8	12.1	15.4	0.1	1.6	125	9.0
5/14	37	Confluence	2.3	3.2	2.0	3.9	9.0	40.3	10.7	14.9	1.8	25.9	20.2	5.9	0.2	0.8	141	10.1
5/21	38	Confluence	9.9	8.1	3.9	3.4	18.2	71.7	7.5	10.9	9.5	35.9	25.5	21.5	0.8	0.8	228	16.3
5/28	39	Confluence	3.4	25.9	1.2	11.8	14.6	75.5	9.9	13.2	11.5	61.6	23.1	32.9	2.6	5.2	292	20.9
6/4	40	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
6/11	41	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
6/18	42	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1	0.1
6/25	43	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	2	0.1
7/2	44	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	7.0	1.0	0.0	0.0	0.0	9	0.6
7/9	45	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	1.0	0.0	0.0	0.0	4	0.3
7/16	46	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1	0.1
7/23	47	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	3	0.2
7/30	48	Orange Blossom	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	2.4	1.0	0.0	0.0	0.0	4	0.3
8/6	49	Orange Blossom	0.0	0.0	0.0	0.0	0.0	1.5	0.0	3.0	1.0	8.3	0.0	0.0	0.0	0.0	14	1.0
8/13	50	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.2	20.0	0.0	0.0	0.0	0.0	22	1.6
8/20	51	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	19.8	0.0	0.0	0.0	0.0	22	1.6
8/27	52	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	5.2	19.0	1.0	0.0	0.0	0.0	26	1.9
9/4	1	Confluence	4.3	55.9	4.2	4.9	26.7	26.2	30.1	42.1	62.8	42.9	50.9	32.1	16.5	24.4	424	30.3
9/11	2	Confluence	6.8	55.9	1.3	2.0	15.2	17.1	23.4	35.7	57.1	34.1	30.5	26.9	16.7	10.7	333	23.8
9/18	3	Confluence	1.7	45.2	3.0	1.0	5.2	17.7	14.5	30.1	61.3	36.4	20.1	29.0	15.4	10.8	292	20.8
9/25	4	Confluence	0.0	22.1	3.3	0.0	1.0	3.5	11.8	26.4	54.2	28.6	22.7	25.0	4.8	8.9	212	15.2
10/2	5	Riverbank	1.6	100.0	100.0	4.4	2.5	17.4	100.0	100.0	100.0	100.0	100.0	100.0	2.4	100.0	928	66.3
10/9	6	Riverbank	0.0	56.3	27.1	1.6	1.6	3.0	100.0	100.0	100.0	100.0	100.0	100.0	1.6	72.2	763	54.5
10/16	7	Riverbank	0.0	3.2	6.1	1.6	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	1.6	1.9	614	43.9
10/23	8	Riverbank	0.0	3.9	1.9	0.0	0.0	0.0	89.3	100.0	100.0	100.0	100.0	100.0	0.0	1.6	597	42.6
10/30	9	Riverbank	0.0	1.7	1.6	0.0	0.0	0.0	35.5	69.3	100.0	92.9	100.0	28.2	1.6	0.0	431	30.8
11/6	10	Riverbank	0.0	1.6	1.6	0.0	0.0	0.0	4.2	8.5	100.0	6.7	26.4	2.2	1.6	0.0	153	10.9
11/13	11	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	1.6	5.0	56.2	1.6	1.6	0.0	2.1	1.6	70	5.0
11/20	12	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	10.4	0.0	0.0	0.0	1.6	1.6	15	1.1
11/27	13	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/4	14	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/11	15	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/18	16	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/25	17	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
		Sum	30	386	162	35	141	346	569	726	943	940	768	633	70	245	5994	
		Average	0.6	7.4	3.1	0.7	2.7	6.7	11.0	14.0	18.1	18.1	14.8	12.2	1.3	4.7		

Figure 18. Cumulative relative weight (penalty), composite criteria, for Run #2 (baseline) for weekly conditions throughout the simulation period 1988-98

Calendar Date	Fish Week (A)	Location (B)	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Sum	Average
1/1	18	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/8	19	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/15	20	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/22	21	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/29	22	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/5	23	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/12	24	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/19	25	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/26	26	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
3/5	27	Riverbank	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1	0.1
3/12	28	Riverbank	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	1.2	1.0	0.0	0.0	4	0.3
3/19	29	Riverbank	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	1.0	1.1	0.0	0.0	0.0	4	0.3
3/26	30	Riverbank	0.0	0.0	0.0	0.0	5.0	1.0	1.0	1.0	0.0	2.5	1.0	1.0	0.0	0.0	13	0.9
4/2	31	Riverbank	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	2	0.1
4/9	32	Riverbank	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2	0.1
4/16	33	Confluence	0.0	0.1	0.3	0.1	6.1	15.5	9.4	7.4	0.8	9.8	3.5	6.0	0.0	0.1	59	4.2
4/23	34	Confluence	0.0	0.3	1.7	0.3	2.6	25.2	1.9	12.5	1.3	14.8	9.4	1.0	0.1	1.2	72	5.2
4/30	35	Confluence	0.0	0.3	2.7	0.1	10.0	17.4	8.4	21.4	1.8	29.5	13.6	4.7	0.1	1.5	111	8.0
5/7	36	Confluence	0.1	2.6	0.7	0.3	17.6	8.9	10.2	20.9	2.1	33.5	11.8	14.9	0.1	1.7	125	9.0
5/14	37	Confluence	2.3	3.2	2.0	3.9	9.0	40.3	10.7	15.0	1.8	26.1	19.6	5.6	0.3	0.8	141	10.0
5/21	38	Confluence	9.9	8.1	3.9	3.4	18.2	71.7	7.5	11.0	9.5	35.3	24.7	20.7	0.9	0.8	226	16.1
5/28	39	Confluence	3.4	25.9	1.2	11.8	14.6	75.5	9.9	13.4	11.5	58.7	22.2	31.7	2.8	5.3	288	20.6
6/4	40	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
6/11	41	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
6/18	42	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
6/25	43	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
7/2	44	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	2	0.1
7/9	45	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
7/16	46	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
7/23	47	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1	0.1
7/30	48	Orange Blossom	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1	0.1
8/6	49	Orange Blossom	0.0	0.0	0.0	0.0	0.0	1.5	0.0	3.0	0.0	1.0	0.0	0.0	0.0	0.0	5	0.4
8/13	50	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	2.7	0.0	0.0	0.0	0.0	4	0.3
8/20	51	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1	0.1
8/27	52	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1	0.1
9/4	1	Confluence	4.3	55.9	4.2	4.9	26.7	26.2	30.1	40.6	49.2	30.9	47.0	28.7	15.8	23.9	388	27.7
9/11	2	Confluence	6.8	55.9	1.3	2.0	15.2	17.1	23.4	34.0	44.1	25.5	27.2	23.4	15.9	10.4	302	21.6
9/18	3	Confluence	1.7	45.2	3.0	1.0	5.2	17.7	14.5	28.1	46.0	29.7	16.9	24.7	14.5	10.5	259	18.5
9/25	4	Confluence	0.0	22.1	3.3	0.0	1.0	3.5	11.8	24.0	39.6	28.0	18.8	20.5	4.3	8.5	185	13.2
10/2	5	Riverbank	1.6	100.0	100.0	4.4	2.5	17.4	100.0	100.0	100.0	100.0	100.0	100.0	1.6	100.0	927	66.2
10/9	6	Riverbank	0.0	56.3	27.1	1.6	1.6	3.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	63.4	753	53.8
10/16	7	Riverbank	0.0	3.2	6.1	1.6	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	1.6	612	43.7
10/23	8	Riverbank	0.0	3.9	1.9	0.0	0.0	0.0	89.3	100.0	100.0	100.0	100.0	100.0	0.0	0.0	595	42.5
10/30	9	Riverbank	0.0	1.7	1.6	0.0	0.0	0.0	35.5	36.2	61.8	100.0	73.1	8.6	0.0	0.0	318	22.7
11/6	10	Riverbank	0.0	1.6	1.6	0.0	0.0	0.0	4.2	1.6	82.7	69.9	4.9	1.6	1.6	0.0	169	12.1
11/13	11	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	1.6	1.6	10.6	21.7	0.0	0.0	1.6	0.0	37	2.6
11/20	12	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	1.6	0.0	0.0	0.0	0.0	3	0.2
11/27	13	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/4	14	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/11	15	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/18	16	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/25	17	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
		Sum	**30**	**386**	**162**	**35**	**141**	**346**	**569**	**673**	**765**	**925**	**698**	**594**	**60**	**230**	**5615**	
		Average	**0.6**	**7.4**	**3.1**	**0.7**	**2.7**	**6.7**	**11.0**	**12.9**	**14.7**	**17.8**	**13.4**	**11.4**	**1.1**	**4.4**		

Figure 19. Cumulative relative weight (penalty), composite criteria, for Run #2 (baseline) for weekly conditions throughout the simulation period 1988-98

Calendar Date	Fish Week (A)	Location (B)	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Sum	Avg.
1/1	18	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/8	19	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/15	20	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/22	21	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/29	22	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/5	23	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/12	24	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/19	25	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/26	26	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
3/5	27	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
3/12	28	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0	0.0
3/19	29	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0	0.0
3/26	30	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.0	0.0	0.0	0.0	1	0.1
4/2	31	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
4/9	32	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
4/16	33	Confluence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.3	0.0	-0.2	0.0	0.0	0	0.0
4/23	34	Confluence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	-0.1	-0.1	0.0	0.1	0	0.0
4/30	35	Confluence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.8	-0.2	-0.2	0.0	0.1	1	0.1
5/7	36	Confluence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.7	-0.3	-0.5	0.0	0.1	0	0.0
5/14	37	Confluence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	-0.6	-0.3	0.0	0.0	-1	0.0
5/21	38	Confluence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	-0.7	-0.8	-0.8	0.1	0.0	-2	-0.1
5/28	39	Confluence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	-2.8	-0.9	-1.2	0.2	0.1	-4	-0.3
6/4	40	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
6/11	41	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
6/18	42	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	0.0	-1	-0.1
6/25	43	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0	0.0	0.0	0.0	-2	-0.1
7/2	44	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-7.0	0.0	0.0	0.0	0.0	-7	-0.5
7/9	45	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.0	-1.0	0.0	0.0	0.0	-4	-0.3
7/16	46	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	0.0	-1	-0.1
7/23	47	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0	0.0	0.0	0.0	0.0	-2	-0.1
7/30	48	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.4	-1.0	0.0	0.0	0.0	-3	-0.2
8/6	49	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-7.3	0.0	0.0	0.0	0.0	-8	-0.6
8/13	50	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.2	-17.3	0.0	0.0	0.0	0.0	-19	-1.3
8/20	51	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.3	-18.8	0.0	0.0	0.0	0.0	-21	-1.5
8/27	52	Orange Blossom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-5.2	-18.0	-1.0	0.0	0.0	0.0	-25	-1.8
9/4	1	Confluence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.5	-13.6	-12.1	-3.9	-3.3	-0.8	-0.5	-36	-2.5
9/11	2	Confluence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.7	-13.0	-8.6	-3.2	-3.5	-0.8	-0.3	-31	-2.2
9/18	3	Confluence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.0	-15.3	-6.7	-3.1	-4.2	-0.9	-0.4	-33	-2.3
9/25	4	Confluence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.4	-14.6	-0.6	-3.8	-4.5	-0.5	-0.4	-27	-1.9
10/2	5	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.8	0.0	-1	-0.1
10/9	6	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.6	-8.8	-10	-0.7
10/16	7	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.6	-0.3	-2	-0.1
10/23	8	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.6	-2	-0.1
10/30	9	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-33.1	-38.2	7.1	-26.9	-19.7	-1.6	0.0	-112	-8.0
11/6	10	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-7.0	-17.3	63.2	-21.5	-0.7	0.0	0.0	17	1.2
11/13	11	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.4	-45.6	20.2	-1.6	0.0	-0.5	-1.6	-33	-2.3
11/20	12	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.6	-8.8	1.6	0.0	0.0	-1.6	-1.6	-12	-0.9
11/27	13	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/4	14	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/11	15	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/18	16	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/25	17	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
		Sum	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-53**	**-177**	**-15**	**-70**	**-39**	**-10**	**-15**	**-379**	
		Average	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-1.0**	**-3.4**	**-0.3**	**-1.3**	**-0.8**	**-0.2**	**-0.3**		

Figure 20. Comparison of Set #1 for composite criteria: difference in relative weighting (penalty) for weekly conditions throughout the simulation period 1988-98. Values in blue denote decreases in penalty (i.e., negative values represent improved conditions over baseline) and values in red denote increases in penalty (i.e., positive values represent degraded conditions over baseline)

Similar tabulated output for the Historic and 750 cfs runs for simulation Set #2 are shown in Figure 21 through Figure 23. As with the previous set of simulations, these simulations indicate that conditions from mid-April through May and September through mid- to late-October are less than optimal. Winter and summer periods do not present major problems for the identified compliance points and life stage periodicity. Although fall conditions are somewhat ameliorated in the 750 cfs case, summer conditions degrade in many years, although relative weighting are low. Exceptions include the summer of the drought years 1991 and 1992 when conditions are improved under the 750 cfs alternative (Figure 23).

Calendar Date	Fish Week (A)	Location (B)	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Sum	Average
1/1	18	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/8	19	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/15	20	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/22	21	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/29	22	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/5	23	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/12	24	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/19	25	Riverbank	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1	0.1
2/26	26	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
3/5	27	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
3/12	28	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1	0.1
3/19	29	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
3/26	30	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
4/2	31	Riverbank	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	2	0.1
4/9	32	Riverbank	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	4	0.3
4/16	33	Confluence	0.0	1.9	1.5	0.2	7.9	7.4	1.0	9.4	6.6	2.6	5.2	20.8	0.1	0.1	65	4.6
4/23	34	Confluence	0.0	3.1	4.7	1.9	5.8	11.4	0.1	6.7	4.6	4.3	2.1	1.3	0.1	0.6	47	3.3
4/30	35	Confluence	0.0	3.2	10.8	0.6	18.4	4.6	1.5	17.8	2.2	39.6	1.1	8.3	0.4	0.7	109	7.8
5/7	36	Confluence	0.0	12.4	8.4	1.4	32.8	3.1	1.4	16.7	7.4	84.4	0.5	49.7	0.1	0.8	219	15.7
5/14	37	Confluence	0.1	19.0	31.6	8.2	22.9	21.5	2.5	13.1	4.9	37.0	4.6	19.4	0.8	0.5	186	13.3
5/21	38	Confluence	1.0	48.3	67.3	8.0	38.2	39.1	1.1	14.4	16.3	79.9	2.2	16.4	1.4	1.6	335	23.9
5/28	39	Confluence	0.3	100.0	37.3	17.8	37.9	40.3	2.2	32.4	38.8	100.0	0.7	79.7	4.2	11.8	504	36.0
6/4	40	Orange Blossom	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	4.4	0.0	0.0	0.0	0.0	6	0.5
6/11	41	Orange Blossom	0.0	1.2	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	5	0.4
6/18	42	Orange Blossom	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.4	1.0	0.0	0.0	0.0	20	1.5
6/25	43	Orange Blossom	0.0	9.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.1	1.0	0.0	0.0	0.0	25	1.8
7/2	44	Orange Blossom	0.0	8.9	0.0	0.0	0.0	0.0	0.0	0.0	1.7	14.9	1.0	0.0	0.0	0.0	26	1.9
7/9	45	Orange Blossom	0.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0	6.4	0.0	0.0	0.0	0.0	15	1.1
7/16	46	Orange Blossom	0.0	9.8	0.0	0.0	0.0	0.0	0.0	0.0	2.8	6.6	0.0	0.0	0.0	0.0	19	1.4
7/23	47	Orange Blossom	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	5.6	6.2	1.0	0.0	1.0	0.0	17	1.2
7/30	48	Orange Blossom	0.0	5.6	0.0	0.0	1.0	0.0	0.0	1.0	5.7	7.2	1.0	1.0	1.5	0.0	24	1.7
8/6	49	Orange Blossom	0.0	14.2	0.0	0.0	0.0	0.0	1.0	1.0	12.6	10.5	1.3	0.0	0.0	0.0	41	2.9
8/13	50	Orange Blossom	0.0	11.6	0.0	0.0	0.0	0.0	0.0	0.0	20.1	18.1	1.0	0.0	0.0	0.0	51	3.6
8/20	51	Orange Blossom	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	22.1	20.4	1.0	1.0	0.0	0.0	47	3.3
8/27	52	Orange Blossom	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.3	23.1	19.8	1.6	1.0	0.0	0.0	48	3.4
9/4	1	Confluence	1.7	49.5	15.8	0.0	20.2	1.1	20.8	37.1	90.1	42.4	51.0	31.5	27.8	19.2	408	29.1
9/11	2	Confluence	3.6	43.4	10.1	0.0	5.2	1.0	13.5	34.9	75.8	33.7	31.8	24.5	24.8	7.0	309	22.1
9/18	3	Confluence	1.0	34.4	14.3	0.0	1.3	1.0	12.9	34.2	79.4	36.4	22.5	30.3	26.3	7.9	302	21.6
9/25	4	Confluence	0.0	16.2	15.5	0.0	1.0	0.0	12.2	35.0	68.7	26.1	26.0	30.2	14.2	7.1	252	18.0
10/2	5	Riverbank	4.4	100.0	100.0	1.6	38.3	1.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1046	74.7
10/9	6	Riverbank	3.8	56.4	100.0	1.6	14.0	1.6	100.0	100.0	100.0	100.0	65.0	100.0	43.8	25.7	812	58.0
10/16	7	Riverbank	1.6	1.6	31.8	1.6	1.6	0.0	84.5	100.0	100.0	100.0	55.0	100.0	2.5	1.6	582	41.5
10/23	8	Riverbank	11.3	9.2	13.9	0.0	0.0	0.0	30.7	100.0	100.0	100.0	100.0	100.0	3.3	0.0	568	40.6
10/30	9	Riverbank	9.7	6.8	9.3	0.0	0.0	0.0	31.2	100.0	100.0	100.0	74.8	35.5	1.6	0.0	469	33.5
11/6	10	Riverbank	1.6	1.6	1.6	0.0	0.0	0.0	10.2	27.0	100.0	31.9	25.9	9.4	1.6	0.0	211	15.0
11/13	11	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	1.8	15.5	44.2	8.7	1.6	1.6	1.6	0.0	75	5.4
11/20	12	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	1.6	1.6	7.8	1.6	0.0	0.0	0.0	0.0	13	0.9
11/27	13	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/4	14	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/11	15	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/18	16	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/25	17	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
		Sum	40	588	476	43	247	135	430	801	1144	1173	582	763	258	185	$\boxed{6863}$	
		Average	0.8	11.3	9.2	0.8	4.8	2.6	8.3	15.4	22.0	22.5	11.2	14.7	5.0	3.6		

Figure 21. Cumulative relative weight (penalty), composite criteria, for Historic Run (Set #2) for weekly conditions throughout the simulation period 1988-98

Calendar Date	Fish Week (A)	Location (B)	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Sum	Average
1/1	18	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/8	19	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/15	20	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/22	21	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/29	22	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/5	23	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/12	24	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/19	25	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/26	26	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
3/5	27	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
3/12	28	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1	0.1
3/19	29	Riverbank	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	2	0.1
3/26	30	Riverbank	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	2	0.2
4/2	31	Riverbank	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	4	0.3
4/9	32	Riverbank	0.0	0.0	1.0	0.0	1.0	1.4	1.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	6	0.5
4/16	33	Confluence	0.0	0.5	2.3	0.0	6.5	1.3	3.6	2.6	0.1	4.6	0.9	6.3	0.3	0.8	30	2.1
4/23	34	Confluence	0.0	2.3	1.9	0.1	7.5	0.5	0.2	3.1	0.1	2.6	1.4	0.2	1.6	3.2	25	1.8
4/30	35	Confluence	0.1	3.5	5.4	0.1	7.9	1.3	3.1	7.0	0.2	8.9	4.4	2.7	2.0	7.1	54	3.8
5/7	36	Confluence	1.2	9.6	4.2	0.1	16.9	3.3	3.9	6.7	0.4	14.3	3.5	7.0	1.3	4.1	77	5.5
5/14	37	Confluence	13.3	22.8	15.7	0.6	35.0	15.3	11.8	13.0	1.6	19.6	15.8	8.3	8.6	11.9	193	13.8
5/21	38	Confluence	40.0	55.5	44.4	0.6	40.5	59.1	17.6	22.6	15.6	57.1	46.9	36.3	34.3	20.9	491	35.1
5/28	39	Confluence	3.4	95.5	39.8	2.5	58.6	60.6	26.8	35.2	24.5	100.0	47.0	78.8	67.1	47.8	688	49.1
6/4	40	Orange Blossom	0.0	0.0	1.0	0.0	1.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	2.3	6	0.4
6/11	41	Orange Blossom	0.0	1.0	3.9	0.0	1.2	1.0	0.0	1.0	1.0	0.0	1.0	1.0	0.0	1.0	12	0.9
6/18	42	Orange Blossom	0.0	2.3	1.6	0.0	1.0	2.1	0.0	1.7	0.0	1.0	1.5	1.0	0.0	1.0	13	0.9
6/25	43	Orange Blossom	0.0	4.9	2.6	0.0	2.3	3.7	0.0	1.3	0.0	1.0	2.5	1.7	0.0	0.0	20	1.4
7/2	44	Orange Blossom	0.0	9.9	5.4	1.0	1.7	3.6	0.0	1.7	6.7	1.0	3.3	3.7	0.0	2.4	40	2.9
7/9	45	Orange Blossom	0.0	7.9	5.2	1.0	3.7	4.8	1.0	8.8	2.3	1.0	3.0	6.3	0.0	3.3	48	3.5
7/16	46	Orange Blossom	0.0	8.8	3.3	1.0	1.6	9.9	4.4	8.6	1.7	3.3	1.0	2.5	0.0	2.1	48	3.4
7/23	47	Orange Blossom	0.0	3.7	3.8	1.0	1.4	10.2	2.9	4.4	3.1	2.0	3.4	1.9	0.0	3.3	41	2.9
7/30	48	Orange Blossom	0.0	4.9	1.1	1.2	3.7	6.3	1.0	6.3	3.2	2.2	3.3	1.6	0.0	5.4	40	2.9
8/6	49	Orange Blossom	0.0	5.1	1.0	1.0	2.9	2.2	1.6	11.6	2.5	1.9	1.0	1.2	0.0	2.8	35	2.5
8/13	50	Orange Blossom	0.0	5.5	1.0	1.0	1.1	1.4	1.2	2.4	2.3	3.7	1.0	1.4	0.0	4.1	26	1.9
8/20	51	Orange Blossom	0.0	2.4	1.0	1.0	1.0	3.1	1.0	1.0	1.1	1.0	1.0	1.0	0.0	1.0	16	1.1
8/27	52	Orange Blossom	0.0	1.6	1.0	1.0	3.3	5.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0	19	1.4
9/4	1	Confluence	1.0	54.0	29.7	54.7	54.8	89.2	40.3	48.0	69.1	35.2	50.0	44.7	0.0	41.4	612	43.7
9/11	2	Confluence	0.0	44.6	22.1	29.0	30.2	53.1	27.4	38.0	53.6	25.8	30.5	30.2	0.0	22.7	407	29.1
9/18	3	Confluence	0.0	35.8	20.3	10.6	24.1	32.8	14.9	29.6	51.1	28.7	17.4	29.0	0.0	17.2	311	22.2
9/25	4	Confluence	0.0	23.3	18.1	2.6	21.2	18.0	12.4	25.8	42.3	22.6	17.3	26.2	0.0	15.4	245	17.5
10/2	5	Riverbank	1.6	100.0	100.0	21.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	100.0	1123	80.2
10/9	6	Riverbank	1.6	100.0	100.0	1.6	100.0	100.0	100.0	100.0	100.0	100.0	97.6	100.0	0.0	100.0	1101	78.6
10/16	7	Riverbank	0.0	15.9	18.0	0.0	100.0	100.0	75.1	26.6	100.0	99.8	30.7	26.2	0.0	1.6	594	42.4
10/23	8	Riverbank	0.0	5.4	6.4	0.0	46.1	44.0	6.1	17.6	19.7	34.7	23.2	27.2	0.0	0.0	230	16.4
10/30	9	Riverbank	0.0	1.6	1.6	0.0	1.6	3.9	2.4	1.6	3.0	15.0	7.3	1.6	0.0	0.0	39	2.8
11/6	10	Riverbank	0.0	0.0	0.0	0.0	0.0	1.6	1.6	0.0	10.9	1.6	1.6	0.0	0.0	0.0	17	1.2
11/13	11	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	2	0.1
11/20	12	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
11/27	13	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/4	14	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/11	15	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/18	16	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/25	17	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
		Sum	62	628	464	133	678	742	462	529	619	694	520	549	116	424	6620	
		Average	1.2	12.1	8.9	2.6	13.0	14.3	8.9	10.2	11.9	13.3	10.0	10.6	2.2	8.1		

Figure 22. Cumulative relative weight (penalty), composite criteria, for 750 cfs Run (Set #2) for weekly conditions throughout the simulation period 1988-98

Calendar Date	Fish Week (A)	Location (B)	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Sum	Average
1/1	18	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/8	19	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/15	20	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/22	21	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
1/29	22	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/5	23	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/12	24	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
2/19	25	Riverbank	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1	-0.1
2/26	26	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
3/5	27	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
3/12	28	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	1.0	0.0	0.0	0.0	0	0.0
3/19	29	Riverbank	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	2	0.1
3/26	30	Riverbank	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	2	0.2
4/2	31	Riverbank	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	2	0.1
4/9	32	Riverbank	0.0	0.0	1.0	0.0	0.0	1.4	1.0	0.0	0.0	1.0	-1.0	-1.0	0.0	0.0	2	0.2
4/16	33	Confluence	0.0	-1.4	0.8	-0.2	-1.5	-6.2	2.6	-6.8	-6.5	2.1	-4.2	-14.5	0.2	0.7	-35	-2.5
4/23	34	Confluence	0.0	-0.9	-2.8	-1.8	1.7	-10.9	0.1	-3.6	-4.5	-1.7	-0.7	-1.1	1.5	2.5	-22	-1.6
4/30	35	Confluence	0.1	0.3	-5.4	-0.5	-10.5	-3.3	1.6	-10.8	-2.0	-30.7	3.3	-5.6	1.6	6.4	-55	-4.0
5/7	36	Confluence	1.2	-2.8	-4.2	-1.3	-15.9	0.2	2.5	-10.0	-7.0	-70.2	3.0	-42.7	1.2	3.3	-143	-10.2
5/14	37	Confluence	13.2	3.9	-15.9	-7.6	12.1	-6.2	9.2	0.0	-3.3	-17.4	11.2	-11.1	7.8	11.4	7	0.5
5/21	38	Confluence	39.0	7.2	-22.8	-7.4	2.4	19.9	16.4	8.2	-0.7	-22.8	44.7	19.9	32.8	19.3	156	11.1
5/28	39	Confluence	3.0	-4.5	2.5	-15.3	20.7	20.3	24.7	2.8	-14.3	0.0	46.3	-0.9	63.0	36.0	184	13.2
6/4	40	Orange Blossom	0.0	-1.0	1.0	0.0	1.0	0.0	0.0	1.0	-1.0	-3.4	0.0	0.0	0.0	2.3	0	0.0
6/11	41	Orange Blossom	0.0	-0.2	2.9	0.0	1.2	1.0	0.0	1.0	0.0	-1.0	0.0	1.0	0.0	1.0	7	0.5
6/18	42	Orange Blossom	0.0	-3.7	1.6	0.0	1.0	2.1	0.0	1.7	0.0	-12.4	0.5	1.0	0.0	1.0	-7	-0.5
6/25	43	Orange Blossom	0.0	-4.8	2.6	0.0	2.3	3.7	0.0	1.3	0.0	-13.1	1.5	1.7	0.0	0.0	-5	-0.3
7/2	44	Orange Blossom	0.0	1.1	5.4	1.0	1.7	3.6	0.0	1.7	5.0	-13.9	2.3	3.7	0.0	2.4	14	1.0
7/9	45	Orange Blossom	0.0	0.6	5.2	1.0	3.7	4.8	1.0	8.8	1.3	-5.4	3.0	6.3	0.0	3.3	34	2.4
7/16	46	Orange Blossom	0.0	-1.0	3.3	1.0	1.6	9.9	4.4	8.6	-1.1	-3.4	1.0	2.5	0.0	2.1	29	2.1
7/23	47	Orange Blossom	0.0	0.2	3.8	1.0	1.4	10.2	2.9	4.4	-2.5	-4.2	2.4	1.9	-1.0	3.3	24	1.7
7/30	48	Orange Blossom	0.0	-0.7	1.1	1.2	2.7	6.3	1.0	5.3	-2.5	-5.0	2.3	0.6	-1.5	5.4	16	1.2
8/6	49	Orange Blossom	0.0	-9.1	1.0	1.0	2.9	2.2	0.6	10.6	-10.2	-8.6	-0.2	1.2	0.0	2.8	-6	-0.4
8/13	50	Orange Blossom	0.0	-6.1	1.0	1.0	1.1	1.4	1.2	2.4	-17.8	-14.3	0.0	1.4	0.0	4.1	-25	-1.8
8/20	51	Orange Blossom	0.0	1.4	1.0	1.0	1.0	3.1	1.0	0.0	-21.0	-19.4	0.0	0.0	0.0	1.0	-31	-2.2
8/27	52	Orange Blossom	0.0	0.6	1.0	1.0	3.3	5.0	1.0	-0.3	-22.1	-18.8	-0.6	0.0	0.0	1.0	-29	-2.1
9/4	1	Confluence	-0.7	4.5	13.9	54.7	34.7	88.1	19.5	10.9	-21.0	-7.1	-1.0	13.2	-27.8	22.2	204	14.6
9/11	2	Confluence	-3.6	1.2	12.1	29.0	25.0	52.1	13.8	3.1	-22.2	-7.9	-1.2	5.7	-24.8	15.6	98	7.0
9/18	3	Confluence	-1.0	1.5	6.0	10.6	22.8	31.8	2.0	-4.6	-28.3	-7.7	-5.1	-1.3	-26.3	9.2	10	0.7
9/25	4	Confluence	0.0	7.1	2.6	2.6	20.2	18.0	0.2	-9.1	-26.4	-3.5	-8.7	-4.0	-14.2	8.3	-7	-0.5
10/2	5	Riverbank	-2.8	0.0	0.0	19.5	61.7	98.4	0.0	0.0	0.0	0.0	0.0	0.0	-100.0	0.0	77	5.5
10/9	6	Riverbank	-2.2	43.6	0.0	0.0	86.0	98.4	0.0	0.0	0.0	0.0	32.6	0.0	-43.8	74.3	289	20.6
10/16	7	Riverbank	-1.6	14.4	-13.8	-1.6	98.4	100.0	-9.4	-73.4	0.0	-0.2	-24.3	-73.8	-2.5	0.0	12	0.9
10/23	8	Riverbank	-11.3	-3.8	-7.6	0.0	46.1	44.0	-24.5	-82.4	-80.3	-65.3	-76.8	-72.8	-3.3	0.0	-338	-24.1
10/30	9	Riverbank	-9.7	-5.3	-7.7	0.0	1.6	3.9	-28.8	-98.4	-97.0	-85.0	-67.5	-33.9	-1.6	0.0	-429	-30.7
11/6	10	Riverbank	-1.6	-1.6	-1.6	0.0	0.0	1.6	-8.6	-27.0	-89.1	-30.3	-24.3	-9.4	-1.6	0.0	-193	-13.8
11/13	11	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	-1.8	-15.5	-42.6	-8.7	-1.6	-1.6	-1.6	0.0	-73	-5.2
11/20	12	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	-1.6	-1.6	-7.8	-1.6	0.0	0.0	0.0	0.0	-13	-0.9
11/27	13	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/4	14	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/11	15	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/18	16	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
12/25	17	Riverbank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
		Sum	22	41	-12	90	430	607	32	-272	-525	-479	-61	-213	-142	239	-243	
		Average	0.4	0.8	-0.2	1.7	8.3	11.7	0.6	-5.2	-10.1	-9.2	-1.2	-4.1	-2.7	4.6		

Figure 23. Comparison of Set #2 for composite criteria: difference in relative weighting (penalty) for weekly conditions throughout the simulation period 1988-98. Values in blue denote decreases in penalty (i.e., negative values represent improved conditions over baseline) and values in red denote increases in penalty (i.e., positive values represent degraded conditions over baseline)

5.3.2. Single Daily Maximum Criteria

The results of applying the single daily maximum criteria as a method to identify short-duration outliers of elevated temperature was modestly successful. For Set #1, the differences were minimal, indicating an approximately 5 percent reduction in simulated temperatures exceeding the single day maximum criteria for Run #4 (minimum New Melones Reservoir storage) versus Run #2 (baseline). These reductions in the total number of temperatures above the IULT criteria occurred primarily in October. Comparison of simulation Set #2 indicated that there are larger differences; however, results suggest that improved conditions in the fall may potentially come at the sacrifice of condition in the late summer and early fall. Results are presented for Set#1 and Set #2 in Figure 24.

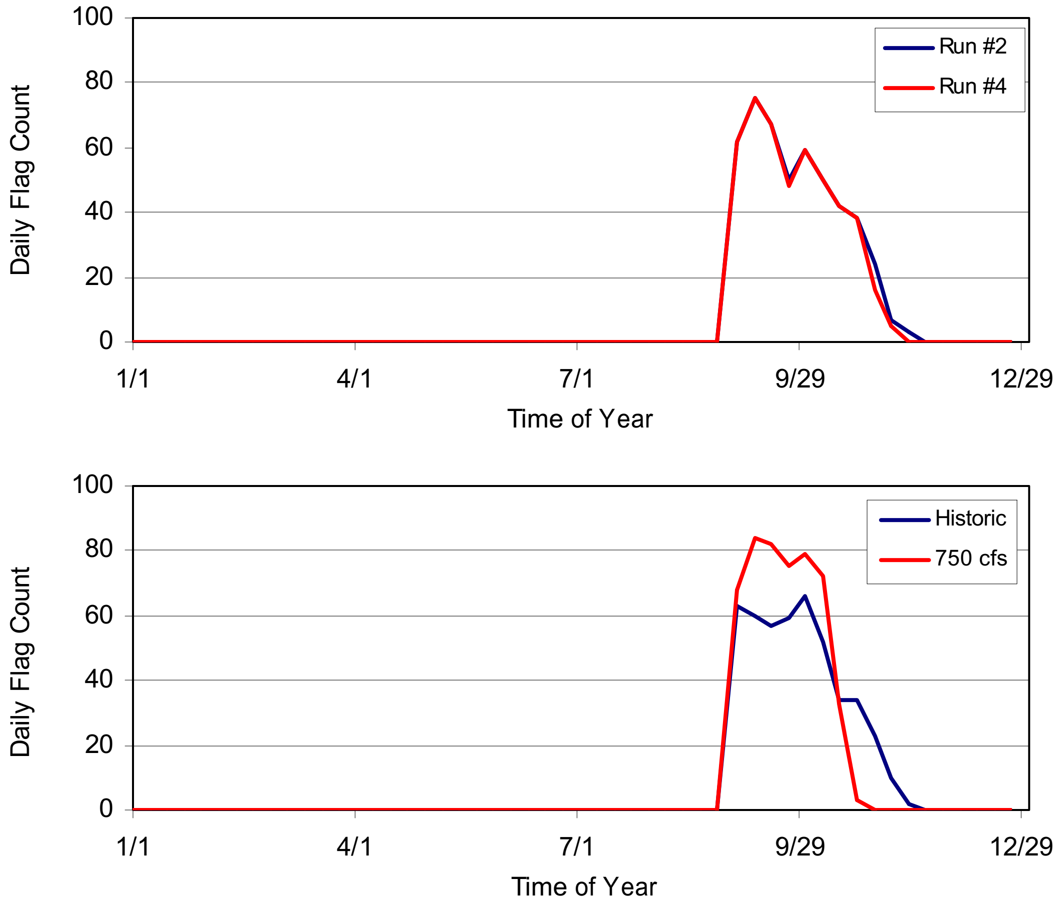


Figure 24. Total number of days where simulated water temperatures exceeded the single day maximum criteria for Set #1 (top) and Set #2 (bottom)

5.4. Additional Assessment Options

Throughout the peer review process Panel members identified issues that may require additional data, information, and/or research to provide more detailed assessment options. The Panel took the opportunity to recommend additional screening tools, analysis, and techniques, as well as studies to improve the understanding of the system. The more pertinent issues are presented below:

- Maintain existing anadromous fish runs as a minimum goal. Specifically, maintain spawning from Goodwin to Oakdale, over-summering habitat from Goodwin to Knights Ferry for steelhead, and consider providing sufficient conditions for rearing and emigration to the confluence for both fall-run Chinook and steelhead.
- Quantify existing populations and goals for fall-run Chinook and steelhead (e.g., over-summer juvenile rearing populations of steelhead) based on carrying capacity for the various life stages in appropriate reaches. It is difficult to provide guidance on criteria when such targets have not been determined.
- Design and implement studies to further characterize components of the proposed thermal criteria for the Stanislaus River, e.g., identify the shape (exponent values)

of the non-linear continuous functions for the various life stages, define ΔT_{max}, define life stage periodicity, location of criteria application, etc.

- Further explore particular year types when assessing alternatives to determine variations in spatial and temporal extent of available habitat. Seek to improve (fine tune) management as additional data is collected at the weir, RST, and other field surveys (e.g., redd surveys), e.g., look for inter-annual variability.
- Consider examining temperature data (e.g., with single day maximum criteria) from multiple, consecutive days to determine if there are persistent events that may prove limiting to anadromous fish. Further consider matching this with the spatial distribution of conditions as well (i.e., assess persistence of thermal conditions in time and space).
- Beyond short-term persistence of thermal conditions, the Panel noted the need to look at long-term relationships through time and space. For example, examine conditions over multiple weeks and multiple miles of river. One method of assessing such information is to examine the frequency of excursion above an identified threshold. Such assessments could include examining sub-daily data, e.g., 12 a.m. to 6 a.m., 6 a.m. to 12 p.m., 12 p.m. to 6 pm, 6 p.m. to 12 a.m., to explore the issue of dose response, or using daily or weekly data to assess conditions, e.g., comparing longitudinal temperature profiles on a daily or weekly basis.
- The proposed approach by Dean Marston (DFG) laid out at the December workshop was an integration of degree-days and river miles. This approach has merit because it takes the estimation of the non-linear thermal penalty function a step further than what has been proposed in this report. Alternately, a more comprehensive salmon mortality model (e.g., Salmod [Bartholow et al. 1993]) could be applied to serve the same purpose.
- Though the Panel did not discuss the longitudinal issues to consensus, they agreed that the concept of "compliance points" is tricky. The further downstream they are located, the more water must be released with no guaranteed increase in salmon production. On the other hand, since the thermal attributes of the river are so dependent on water quantity, it is important to consider the other potential benefits improved water quantity may have on the productivity of the habitat. Recent literature supports this linkage below a dam on the Snake River (Connor et al., 2003). VAMP experiments may eventually lead to further development of these inter-relationships.
- Stakeholders on the Stanislaus may wish to investigate structural changes to the lower river aimed at increasing velocities to speed outmigration through presumably "hostile" waters resulting in exposure to both seasonally elevated temperature and predators. Such changes might pay off more handsomely than improved spawning grounds.
- Other points of interest, queries, and identified needs:
  - Dual species management presents challenges: is a composite criterion for steelhead and salmon acceptable – especially in light of the tenuous status of steelhead?
  - Little is known about juvenile rearing and outmigration/smoltification between Oakdale and Caswell

- Little is known about juvenile rearing and outmigration/smoltification in the San Joaquin River and delta downstream of the Stanislaus River
- Is the Stanislaus River a thermal improvement over the San Joaquin for adult in-migrating fall-run Chinook salmon?
- Can management of cold water be used to modify run timing and growth rates?

6. Summary and Conclusions

The determination of thermal criteria for anadromous fish has been, and continues to be, an important aspect of the restoration and maintenance of these resources. A component of the Lower San Joaquin River Water Temperature Modeling and Analysis project included a peer review of existing water temperature criteria for assessment and comparison of simulated temperatures for various alternative operations/scenarios. A peer review panel was assembled to complete the task.

The criteria presented to the Panel by the Technical Advisory Committee (TAC) and stakeholders were two threshold (three-range) criteria, wherein two temperatures defined three ranges representing optimum, sub-optimal and lethal conditions. The basic metric used in the criteria was the seven day average of the daily maximum (7DADM). Although this approach has been successfully applied in other river systems, the approach was relatively insensitive in the Stanislaus River because during many periods of the year water temperature conditions are marginal and it can be difficult to manage water to control water temperatures in this system. Although criteria could be selected that would differential among alternatives, the biological support for such criteria values was lacking, i.e., generally the threshold criteria, particularly for the criteria defining the sub-optimal to lethal threshold, were deemed too high.

To overcome this issue, as well as the discrete nature of the two threshold criteria, a nonlinear continuous criterion was developed. This criterion utilized the 7DADM values developed by EPA (2001) to identify optimal conditions for each life stage. For temperatures greater than the optimum conditions an exponential relationship was used to represent increasingly adverse thermal conditions. The concept of a nonlinear function was based on the survival and mortality of juvenile Chinook salmon response to thermal conditions presented by Baker et al. (1995). A weight or penalty is assigned for temperatures above optimal according to the exponential function. Life stages vary in their sensitivity to water temperature, thus leading to higher order exponents (e.g., cubic) for egg incubation and smoltification, than for adult migration and juvenile rearing (e.g., quadratic). Further, certain life stages, such as egg incubation, have a notably smaller tolerance for variations in temperatures than other life stages. The weights are normalized on a scale of 0 (no impact) to 100 (severe impact) for all life stages.

The Panel recognizes that the proposed approach is a deviation from past practices; however, the move to continuous criteria is a logical extension of multiple threshold criteria. Further, the Panel acknowledges that the biological responses, represented by various parameters, are not completely defined at this time. Nonetheless, the Panel members believe this is an appropriate approach with sufficient flexibility to not only address current problems on the Stanislaus River, but to expand as additional information comes available (on this river or other rivers).

This approach provides an important component of adaptive management to further improve management strategies through direct experimentation and modification of thermal criteria, if applicable.

7. Materials Reviewed

California Department of Fish and Game (DFG). 2003. *Stanislaus River Water Temperature Criteria Development and Application for Chinook Salmon and Steelhead*. Prepared by Dean Marston. December 1 (Final Draft).

California Department of Fish and Game (DFG). 2003. Presentation (Power Point and associated materials), December 9, 2003 Oakdale Irrigation District Office

United States Fish and Wildlife Service – Anadromous Fish Restoration Program. Oakdale and Caswell Rotary Screw Trap Outmigration Data (1996-2003) and Stanislaus River Weir Upstream and Downstream Counts (2003)

Review of Temperature Criteria Proposed for the Stanislaus River. 2003. Prepared for the Oakdale Irrigation District and South San Joaquin Irrigation District by S.P. Cramer and Assoc. December 2 (including appendix) (Draft).

S.P. Cramer and Assoc. 2003. Presentation (Power Point), December 9, 2003 Oakdale Irrigation District Office

8. References

AD Consultants. (___). Development of Instream Flows Driven by Water Temperature Requirements in the Lower Stanislaus River. Draft. 9 pp.

AD Consultants and RMA (AD and RMA). 2002. Stanislaus River Water Temperature Model. Prepared for the U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, California Department of Fish & Game, Oakdale Irrigation District, South San Joaquin Irrigation District, and Stockton East Water District. March.

Adams, B.L., Zaugg, W. S., and L. R.McLain. 1975. Inhibition of salt water survival and Na-K-ATPase elevation in steelhead trout (*Salmo gairdneri*) by moderate water temperatures. Transactions of the American Fisheries Society. 104(4): p. 766 - 769.

Adams, B.L., W.S. Zaugg, and L.R. McLain. 1973. Temperature effect on parr–smolt transformation in steelhead trout (*Salmo gairdneri*) as measured by gill sodium–potassium stimulated adenosine triphosphatase. Comparative Biochemistry and Physiology. 44A: p. 1333 – 1339.

Baker, P.F., T.P. Speed, and F.K. Ligon. 1995. Estimating the influence of temperature on the survival of Chinook salmon smolts migrating through the Sacramento-San Joaquin River Delta of California. Can. J. Fish. Aquat. Sci. 52:855-863.

Bartholow, J. M. 2003. Modeling Chinook Salmon with SALMOD on the Sacramento River. Chapter 14 in B.L. Lamb, D. Garcia de Jalon, C. Sabaton, Y. Souchon, N. Tamai, H.R. Robinette, T.J. Waddle, and A. Brinson, Editors. *Proceedings of the International IFIM Users' Workshop*. Fort Collins, Colorado, USA: Colorado State University, Office of Conference Services. Available on the Internet at http://www.fort.usgs.gov/products/publications/21009/21009.asp. Bartholow, J.M., J.L. Laake, C.B. Stalnaker, and S.C. Williamson. 1993. A salmonid population model with emphasis on habitat limitations. Rivers 4(4):265-279.

Bartholow, J. M., S. Campbell, and M. Flug. In press. Predicting the thermal effects of dam removal on the Klamath River. Environmental Management.

Beitinger, T.L., W.A. Bennett, R.W. McCauley. 2000. Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. Environmental Biology of Fishes 58 (3): 237-275, July.

Bidgood, B.F., 1980. Temperature tolerance of hatchery reared rainbow trout *Salmo gairdneri*, Richardson. 1980, Fisheries Research Section, Fish and Wildlife Division, Alberta Energy and Natural Resources.

Bidgood, B.F. and A.H. Berst. 1969. Lethal temperatures for Great Lakes rainbow trout. Journal of the Fisheries Research Board of Canada. 26(2): p. 456 - 459.

Boles, G. 1988. Water temperature effects on Chinook salmon (*Oncorhynchus tshawytscha*) with emphasis on the Sacramento River: A literature review. California Department of Water Resources, Northern District. 42 pp.

Brett, J.R., W.C. Clarke, and J.E. Shelbourn. 1982. Experiments on thermal requirements for growth and food conversion efficiency of juvenile Chinook salmon. Department of Fisheries and Oceans, Fisheries Research Branch: Nanaimo, B.C.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus.* Journal of the Fisheries Research Board of Canada 9(6): p. 265-323.

California Department of Fish and Game (DFG). 2003. Stanislaus River Water Temperature Criteria Development and Application for Chinook Salmon and Steelhead. Prepared by Dean Marston. December 1.

Cech, J.J., Jr. and C.A. Myrick. 1999. Steelhead and Chinook salmon bioenergetics: temperature, ration, and genetic effects. University of California Water Resources Center: Davis, CA.

Clarke, W. C. and J. E. Shelbourn. 1985. Growth and development of seawater adaptability by juvenile fall Chinook salmon in relation to temperature. Aquaculture 45: p. 21-31.

Clarke, W.C., J.E. Shelbourn, and J. Brett, R. 1981. Effect of artificial photoperiod cycles, temperature, and salinity on growth and smolting in underyearling coho

(Oncorhynchus kisutch), Chinook *(O. tshawytscha)* and sockeye *(O. nerka)* salmon. Aquaculture, 1981. 22(1-2): p. 105-116.

Connor, W.P., H.L Burge, J.R. Yearsley, and T.C. Bjornn. 2003. Influence of flow and temperature on survival of wild subyearling fall Chinook salmon in the Snake River. NAJFM 23:362-375.

Coutant, C.C. 1972. Water quality criteria. A report of the Committee on Water Quality Criteria, Environmental Studies Board. Page 161 in National Academy of Sciences, National Academy of Engineers, Washington, DC.

Embody, G.C. 1934Relation of temperature to the incubation periods of eggs of four species of trout. Transactions of the American Fisheries Society. 64: p. 281 - 291.

Guinard, J. 2001. Stanislaus River Temperature Monitoring/Modeling Project Water Temperature Criteria Development. California Department of Fish and Game, Fresno.

Hanson, C.R. 1991. Acute temperature tolerance of juvenile Chinook salmon from the Mokelumne River. Hanson Environmental, Inc.: Walnut Creek, CA. p. 15.

Healey, T. P. 1979. *The effect of high temperature on the survival of Sacramento River chinook (king) salmon, Oncorhynchus tshawytscha, eggs and fry*. California Department of Fish and Game, Anadromous Fisheries Branch Administrative Report No. 79-10. 7 pp.

Hendrick, R., and J. Monahan. 2003. An assessment of water temperatures of the Entiat River, Washington using the Stream Network Temperature Model (SNTEMP) (draft). Washington Department of Ecology and the Entiat WRIA Planning Unit, Water Quality Sub-Committee. Yakima and Entiat, WA. 85 p. Available on the Internet at http://www.chelancd.org/WRIA46Plan/Reports/SNTEMP/Entiat_SNTEMP.pdf

Hinze, J.A. 1959. Annual report Nimbus Salmon and Steelhead Hatchery fiscal year of 1957-58. California Department of Fish and Game: Sacramento. p. 21.

Marine, K.R., Cech, J.J., Jr., 2004. Effects of high water temperature on growth, smoltification, and predator avoidance in juvenile Sacramento River Chinook salmon. N. Am. J. Fish. Manage. 24, 198–210.

Marine, K. M. 1997. Effects of elevated water temperature on some aspects of the physiological and ecological performance of juvenile Chinook salmon (*Oncorhynchus tshawytscha*): implications for management of California's Central Valley salmon stocks. Master's Thesis, University of California, Davis.

Marine, K.R. 1992. A background investigation and review of the effects of elevated water temperature on reproductive performance of adult Chinook salmon

(*Oncorhynchus tshawytscha*). Department of Wildlife and Fisheries Biology, Univ. Calif., Davis. October 1992. 30 pp plus appendices.

McCullough, D. A. 1999. A Review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon. Prepared by Dale A. McCullough, PhD, Columbia Inter-tribal Fish Commission, Portland, Oregon. Prepared for EPA, Region 10, Seattle, Washington. 95p.

McCullough, D.A., S. Spalding, D. Sturdevant, M. Hicks. 2001. Issue Paper 5: Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids, Prepared as Part of EPA Region 10 Temperature Water Quality Criteria Guidance Development Project. U.S. Environmental Protection Agency Report EPA-910-D-01-005. 114 pp. Available on the Internet at http://yosemite.epa.gov/R10/water.nsf/6cb1a1df2c49e4968825688200712cb7/5eb9e547ee9e111f88256a03005bd665/$FILE/Paper%205-Phys%205-9-dm.pdfhttp://yosemite.epa.gov/R10/water.nsf/6cb1a1df2c49e4968825688200712cb7/5eb9e547ee9e111f88256a03005bd665/$FILE/Paper%205-Phys%205-9-dm.pdf

Myrick, C.A., and J.J. Cech, Jr. 2001. Temperature Effects on Chinook Salmon and Steelhead: A Review Focusing on California's Central Valley Populations. Bay-Delta Modeling Forum Technical Publication 01-1. http://www.cwemf.org/Pubs/TempReview.pdf. 57 pp.

Slater, D.W. 1963. Winter–run Chinook salmon in the Sacramento River, California with notes on water temperature requirements at spawning. U.S. Fish and Wildlife Service: Washington, D.C.

Threader, R.W. and A.H. Houston.1983. Heat tolerance and resistance in juvenile rainbow trout acclimated to diurnally cycling temperatures. Comparative Biochemistry and Physiology. 75A(2): p. 153-155.

United States Bureau of Reclamation (USBR). 1991. *Appendixes to Shasta outflow temperature control: Planning Report/ Environmental Statement. Appendix A*. USBR Mid-Pacific Region. 176 pp. Originally issued in November 1990, Revised May 1991.

United States Environmental Protection Agency (EPA). 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. 49 pp. April.

United States Environmental Protection Agency (EPA). 2001. Technical Synthesis Scientific Issues Relating to Temperature Criteria for Salmon, Trout, and Char Native to the Pacific Northwest. EPA 910-R-01-007. 21 pp. August

United States Fish and Wildlife Service (USFWS). 1999. Effect of temperature on early–life survival of Sacramento River fall– and winter–run Chinook salmon., Northern Central Valley Fish and Wildlife Office: Red Bluff, CA.

United States Fish and Wildlife Service (USFWS). 1998. Central Valley Project Improvement Act Tributary Production Enhancement Report.

United States Fish and Wildlife Service (USFWS). 1995. Working Paper in Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California. Volumes 1-3.

United States Fish and Wildlife Service – Anadromous Fisheries Restoration Program (USFWS-AFPR). 1997. Revised Draft Anadromous Fish Restoration Plan.

United States Fish and Wildlife Service (USFWS) and Hoopa Valley Tribe. 1999. Trinity River Flow Evaluation, Final Report. 307 pp plus appendices.