Upper Yuba River
Water Temperature Criteria for Chinook Salmon and Steelhead

Technical Appendix

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Table of Contents

Tables

Figures

1 INTRODUCTION AND BACKGROUND

The Upper Yuba River Studies Program (UYRSP) seeks to determine the feasibility of introducing wild Chinook salmon and steelhead into the upper Yuba River upstream of Engelbright Dam. One objective of the UYRSP feasibility evaluation is to determine the suitability of aquatic habitat in the upper watershed and its ability to support salmon and steelhead under current operations and under other potential operation scenarios. Water temperature will be an important factor in that evaluation. Water temperature may determine the spatial extent and seasonal timing of suitable habitat for Chinook salmon and steelhead in the upper Yuba River watershed, but it is only one of several factors evaluated in determining the biological feasibility of introducing these species into the upper watershed. The objective of this report is to describe the recommended water temperature criteria for use in evaluating the suitability of habitat in the upper Yuba River watershed and the technical basis for those recommendations.

For the purposes of this evaluation, “suitability” refers to the environmental conditions that enable Chinook salmon and steelhead to persist (i.e., that support these species) without causing or contributing to stresses that would significantly reduce the probability of survival, reproduction, or the viability of gametes. Suitable water temperatures, then, are those which do not cause or contribute to acute or chronic stresses that would significantly reduce survival or reproductive success of these species in the upper Yuba River watershed.

Most fish maintain body temperatures that closely match their environment (Moyle 1993). As a result, water temperature has a strong influence on almost every salmonid life history stage (Berman 1998), including metabolism, growth and development, timing of life history events such as adult migration and emergence from the redd, and susceptibility to disease (Groot et al. 1995). Temperature also influences the ecology of many amphibians, aquatic macroinvertebrates, and other stream organisms.

Exposure to high temperatures can have a variety of adverse effects on the physiology and physical performance of salmonids (Figure 1). Temperature can affect growth, behavior, competitive interactions, habitat requirements, and susceptibility to disease. These effects may vary depending on a fish’s prior thermal history (i.e., acclimation).

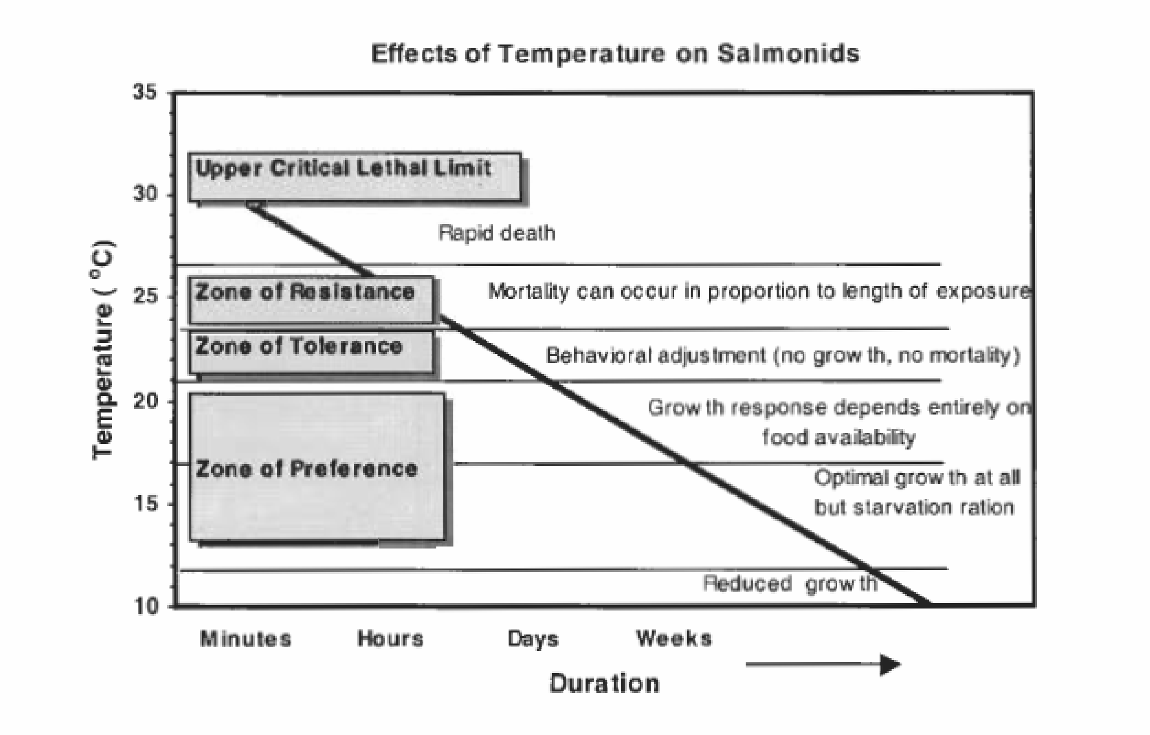

Figure 1. General biological effects of temperature on salmonids, as influenced by duration of exposure (from Sullivan et al. 2000).

Temperature effects on salmonids include both lethal and sublethal effects, depending on the magnitude and duration of exposure (Sullivan et al. 2000). Short-term (minutes to days) lethal effects are referred to as acute temperature effects, whereas long-term (weeks to months) thermal stresses are termed chronic effects (Sullivan et al. 2000). Numerous studies (e.g., Elliott 1976, Brett et al. 1982, Thomas et al. 1986) have shown that fish respond to water temperature with behavioral and physiological adjustments that depend on the magnitude and duration of exposure (Sullivan et al. 2000). Indirect effects of temperature can also influence growth and survival of salmonids. Elevated water temperature can increase the infectiousness and virulence of waterborne pathogens, and may also increase vulnerability to predation (Myrick and Cech 2001).

Water temperature can effectively determine the amount and location of suitable habitat available for a given salmonid freshwater life stage. This effect varies seasonally, and is influenced by latitude, elevation, and other factors. Spatial variation in temperature-driven habitat suitability is closely tied to seasonal effects, which in California's Mediterranean climate are typically associated with unsuitably high temperatures. Stream habitat that would otherwise support salmonids may be rendered unsuitable (i.e., too warm) for periods ranging from days to the entire summer season. In addition to temporal variations in habitat suitability, patterns of temperature-related habitat suitability may often be spatially patchy. This is typically due to cold water inputs such as springs, tributaries, or groundwater that provide cold water refugia. In watersheds such as the upper Yuba River watershed that experience wide fluctuations in annual air and water temperature, an understanding of stream temperature is a key requirement for assessing habitat suitability for salmonids.

2 REVIEW OF WATER TEMPERATURE TOLERANCES OF CHINOOK SALMON AND STEELHEAD

As a first step in identifying temperature tolerances for Chinook salmon and steelhead, we reviewed published literature and unpublished reports, focusing on temperature tolerances of spring-run Chinook salmon and winter steelhead in the Sacramento River basin. Temperature tolerances compiled from the literature are summarized by life stage for Chinook salmon in Table 1 and for steelhead in Table 2. Although it is unclear what ecotype (run) of each species might have existed historically in the Upper Yuba River basin and how the runs may have been spatially distributed, spring-run Chinook salmon and winter steelhead were chosen because (1) these ecotypes currently occur in the lower Yuba River and other Sacramento River tributaries, and (2) they are the species identified for possible introduction into the upper Yuba River watershed through the UYRSP.

In preparing these summaries we reviewed pertinent information from laboratory studies and field investigations of water temperatures used by wild fish during each freshwater life stage. A considerable body of information is available on temperature tolerances, preferences, thresholds, and recommendations for Chinook salmon and steelhead. We report temperature thresholds or ranges as given in the literature we reviewed (Tables 1 and 2). Descriptors of the temperatures reported in the literature are many and varied, and include “optimum” (or “optimal”), “preferred,” “suitable,” “stressful,” “maximum,” “lethal” (often as the upper incipient lethal temperature, or UILT), and various observed averages and ranges. Very few studies use comparable evaluation methods or produce equivalent standards or recommendations. Even fewer studies have been conducted with a focus on Sacramento River spring-run Chinook salmon and winter steelhead. Therefore, while every attempt was made to preferentially report regionally- and population-specific data, general information was reported when it was the only information available.

It is well known that thermal tolerance is dependent on acclimation temperature and exposure time (Myrick and Cech 2001). Fishes acclimated to higher temperatures generally have a higher temperature tolerance than fish acclimated to lower temperatures (Becker and Genoway 1979; Threader and Houston 1983, as cited in Myrick and Cech 2001). However, this information is not consistently reported in the literature sources we reviewed. For laboratory studies, we report acclimation temperatures if the information is available. Susceptibility to disease is another temperature-related variable that was rarely addressed in the literature we reviewed. Although elevated water temperature is known to be positively correlated with disease susceptibility of salmon and steelhead, the information summarized in Tables 1 and 2 does not specifically consider this effect. However, some studies for which lethal temperature effects are reported herein may include disease as a mortality component.

3 WATER TEMPERATURE INDICES, THRESHOLDS, AND STANDARDS

For the purposes of our temperature analyses in the Upper Yuba River watershed we define an **index** as a means of summarizing temperature data (measured or modeled) over specific time periods of interest (i.e., a life stage). We define a **threshold** as the value of an index that temperature must remain below to avoid specified (i.e., adverse) impacts. **Standards** are defined as a combination of an index and threshold(s), which are used to determine the suitability of observed (or modeled) temperatures within identified river reaches.

3.1 Indices

Commonly encountered temperature indices are summarized below.

Daily average temperature is the average temperature for a single 24-hour period based on regular and periodic measurements.

Daily maximum temperature is the maximum instantaneous temperature in a single 24-hour period based on regular and periodic measurements.

Seasonal average temperature is the average temperature for the entirety of a designated seasonal period. An alternative time period of concern (e.g., the duration of a fish life stage) may often be used in place of season.

Annual maximum temperature is the maximum daily temperature that occurs each year. The annual maximum temperature index is typically used to develop temperature standards to protect against short-term temperature increases that can result in direct mortality.

Weekly average temperature, or ***7-day mean of the daily average temperatures (7DMAVG)***, is the moving (running) 7-day average of the daily average temperatures. This index reflects the average temperatures that an organism experiences during a 7-day period, but may not account for short-term maxima that may approach or exceed lethal limits. The 7DMAVG is commonly confused with MWAT, which uses the maximum value of the 7DMAVG over a defined time period to set an upper protective limit (i.e., standard). Use of the MWAT standard is described in more detail in Section 3.3 below.

Weekly average maximum temperature, or ***7-day mean of the daily maximum temperatures (7DMMax)***, is the moving (running) 7-day average of the daily maximum temperatures. This index reflects a stream's maximum temperatures without undue bias by the temperature of a single day (USEPA 2003). This index, however, due to its emphasis on maximum temperatures that often occur only for short periods, may not accurately characterize chronic temperature conditions that affect growth. Therefore, the 7DMMax is best suited for use as part of a temperature standard that protects against acute (i.e., lethal) effects.

3.2 Thresholds

Based on a review of available information (Tables 1 and 2), we developed recommended water temperature criteria (thresholds) for each life stage of Chinook salmon and steelhead in the upper Yuba River watershed (Table 3). The review-based criteria listed in Table 3 are in most cases composites of multiple values reported by various sources. As such, the criteria were derived using various methods, including laboratory experiments and observations of temperatures experienced by wild fish in their natural environment. We attempted to focus our review on wild fish of Sacramento River basin origin, and whenever possible derived our recommendations accordingly. Recommended ranges, and the resultant threshold values, were initially chosen using a weight-of-evidence approach with the final selection based on review and consensus among the UYRSP Habitat Team and technical committee members. In cases where multiple studies reported similar or identical values as defining a suitability category (e.g., optimal) for a given life stage, we used this value as the recommended threshold. If no single value was reported by more than one source, the threshold value was chosen from the study deemed to be most applicable from a regional, ecological, and methodological perspective. For example, temperature tolerances or preferences from investigations of wild spring-run Chinook salmon from the Sacramento River basin were chosen over values reported for Chinook salmon from hatchery stock, other major drainage basins, or other runs. Whenever possible, preference was also given to the use of temperature values reported by foundational laboratory or field studies rather than literature reviews.

The expected timing of each life stage in the Yuba River watershed is also included in Table 3 to indicate the duration for which recommended temperature thresholds are applicable. Life stage timing was determined by iterative review and consensus among the UYRSP Habitat Team and technical committee members, based on information initially compiled from published and unpublished sources for each species, run, and life stage in nearby (Sacramento River basin) streams that support these species and runs.

Based on the available information, we define three thermal zones, which correspond to expected physiological responses of each species and life stage: Optimal, Suboptimal, and Chronic to Acute Stress (Table 3). The use of these thermal zones helps ameliorate the unrealistic limitations of a single, rigid temperature threshold around which the suitability of habitat drastically changes (e.g., "suitable" versus "unsuitable" in response to a small temperature change), and reflects the knowledge that physiological response occurs along a continuum of broader temperature ranges, each of which can generally be characterized by a related set of physiological responses. The three thermal zones are described below.

Optimal: At optimal temperatures, feeding and growth occur, with growth generally dependent on food availability. Temperatures in this zone are within the range reported in the literature to include the physiological optimum, but do not account for potential confounding factors such as disease or habitat variability. No lethal or sublethal temperature effects occur in this zone.

Suboptimal: Exposure to suboptimal temperatures does not cause direct mortality, but may result in a higher probability of diminished success of a particular life stage due to sublethal effects (e.g., reduced fitness, viability, competitive ability or growth, and increased susceptibility to disease) (Sullivan et al. 2000). This probability increases with increasing duration of exposure, particularly to temperatures at the high end of the range. Conversely, the probability of success is increased, up to a point, with increased acclimation time at temperatures in this zone.

Temperatures at the high end of this range may result in behavioral adjustments (i.e., behavioral thermoregulation) that are determined by the magnitude and duration of temperature exposure.

Chronic to Acute Stress: In contrast to the Suboptimal zone, in which the likelihood of stress depends on which end of the range is encountered by a fish, all temperatures in the Chronic to Acute Stress zone are expected to result in stress. Exposure to temperatures at the low end of this range typically leads to sublethal (i.e., chronic) effects similar to those that may occur near the upper end of the Suboptimal zone. At higher temperatures in the Chronic to Acute Stress zone, exposure can result in acute (i.e., lethal) effects. Exposure to temperatures in this zone would require behavioral thermoregulation to avoid sublethal or lethal effects. Although acclimation to temperatures at the low end of this range can reduce the probability of sublethal or lethal effects, this range includes the chronic upper lethal limit (approximately 25°C [77°F] for Central Valley Chinook salmon and steelhead [Myrick and Cech 2001]), at which prolonged exposure results in mortality.

The water temperatures identified as the upper limits of the Optimal range are intended to be used as threshold values that will avoid potential sublethal temperature effects such as reduced fitness, reduced gamete viability, reduced growth, and increased susceptibility to disease. The upper limits of the Suboptimal range are intended to be used as threshold values that will avoid chronic or acute temperature stresses that would be expected to severely reduce success of a particular life stage, potentially including mortality. Although it is recognized that the temperature zone (i.e., threshold) approach has inherent drawbacks, especially given the often undistinguishable effects at the upper and lower ends of adjacent zones, this approach was chosen by the UYRSP Habitat Team and technical committee as the most appropriate means of identifying biologically meaningful temperature ranges that could be used to identify suitable habitat for Chinook salmon and steelhead in the upper Yuba River watershed.

3.3 Standards

Temperature standards can be categorized according to their objectives. Short-term temperature standards are generally developed to protect against acute effects (i.e., mortality), whereas long-term standards address chronic, sublethal effects such as reduced growth or reduced gamete viability. The most commonly used temperature thresholds used in setting short-term standards are the incipient lethal temperature (ILT): upper incipient lethal temperature (UILT) and lower incipient lethal temperature (LILT) (e.g., Armour 1991, Myrick and Cech 2001). The UILT and LILT can also be referred to as the short-term maximum survival temperature (STM) (Armour 1991). For temperatures above the UILT, sometimes referred to as the “zone of resistance” (Figure 1) (Armour 1991, Sullivan et al. 2000), mortality is a function of exposure time. Therefore, standards for maximum temperatures should address the duration of exposure.

Perhaps the most widely used and commonly accepted long-term water temperature standard is the ***maximum weekly average temperature, or MWAT***. The use of MWAT was first proposed by the National Academy of Sciences (NAS and NAE) in 1972 (NAS and NAE 1973) as a long-term standard for preventing chronic sublethal effects for a variety of fish species. MWAT is currently a convenient way to compare the results of researchers, and is the threshold most commonly used for establishing temperature standards for salmonids (e.g., Armour 1991, NMFS and USFWS 1997, Sullivan et al. 2000). The objective of the MWAT is to provide an upper temperature threshold that is protective of a particular salmonid life stage, typically during the summer season.

The scientific rationale for using MWAT as a temperature standard is based on experimental observations that fish can tolerate moderate temperature fluctuations as long as the ILT is not exceeded for prolonged periods (Sullivan et al. 2000). The use of MWAT also assumes that optimal temperatures are not necessary or realistic at all times to sustain viable fish populations (NAS and NAE 1973), and thus allows some environmental variability around any daily threshold value.

MWAT is calculated as the maximum 7-day running average of the daily mean temperatures for the period of record or a time period of concern (e.g., a salmonid life stage) (Brungs and Jones 1977). The date of the 7-day averaging period may be any day in the period, but is typically the midpoint or end of the period. This threshold reflects the average temperatures that an organism experiences over the course of any 7-day period during the time period of concern, but may not account for short-term maxima that may approach or exceed lethal limits. Although fish can generally tolerate short-term exposure to critically high temperatures, repeated or prolonged exposure may negatively affect growth, fitness, or survival.

4 WATER TEMPERATURE STANDARDS FOR DETERMINING SUITABILITY FOR CHINOOK SALMON AND STEELHEAD IN THE UPPER YUBA RIVER BASIN

Daily and seasonal variability in stream water temperatures, and changing responses at different stages of development, make it difficult to define water temperature standards that are fully protective of salmonids. It is even more difficult to identify temperature standards that protect against sublethal effects on salmonids, such as reduced growth (which is dependent on food availability). Although setting maximum temperature standards is crucial to protect against potential lethal temperature effects, the results of laboratory-based studies may not apply to site-specific situations in the natural environment. The temperatures at which fish in streams become susceptible to sublethal or lethal effects can be influenced by local genetic or physiological adaptations, food availability, acclimation temperatures, behavioral adaptations, or access to cool water refugia.

The 7DMAVG is the recommended temperature index and MWAT is the water temperature standard we recommend for evaluation of water temperature data to determine the quantity, distribution, and seasonal availability of suitable habitat for Chinook salmon and steelhead in the upper Yuba River watershed. Comparison of water temperature data collected in the field and derived from water temperature modeling (7DMAVG) with the thresholds (Table 3) for each species and life stage will help determine the potential for the Middle Yuba and South Yuba rivers to support these species. If the maximum 7DMAVG (MWAT) water temperature exceeds the identified thresholds at any time during the time period a particular life stage would occupy the river, then it is assumed that water temperatures would have an adverse effect on that particular life stage. Exceeding an *Optimal* threshold would not necessarily indicate unsuitability, but would imply that there could be water temperature effects that could adversely affect the success of Chinook salmon or steelhead into the upper Yuba River watershed. If a *Suboptimal* upper threshold is exceeded, then it is assumed that water temperatures would have chronic or acute effects which would significantly impair the success of Chinook salmon or steelhead given current habitat conditions.

The water temperature recommendations in this report are intended to be used as one of several factors weighed in the decision-making process to determine the feasibility of introducing Chinook salmon and steelhead into the upper Yuba River watershed. The information and recommendations presented here will primarily be useful in identifying the spatial extent and seasonal timing of suitable habitat for these species in the upper watershed. These recommendations, in and of themselves, are not sufficient to provide the basis for determining the feasibility of introduction. Additional information, including water temperature modeling under conditions of increased flows, will be necessary to inform the feasibility decision.

Table 1. Summary of Chinook salmon temperature tolerance by life stage.

Life Stage	Water Temperature °C (°F)	Descriptor	Source	Notes
Upstream Migration	3.3–13.3°C (38–56°F)	observed range	Bell (1986)	spring-run Chinook: location not specified
	6–14°C (43–57°F)	optimal	Marine (1992)	migration and pre-spawning survival: American River fall-run Chinook
Adult Holding	16–20°C (61–68°F)	observed average	Moyle et al. (1995)	1986 average daily holding temperatures for Deer (16°C) and Mill Creek (20°C) spring-run Chinook
	<16°C (<60.8°F)	optimum	Ward and Kier (1999)	used as thermal criterion for Battle Creek spring Chinook; criteria taken from Berman (1990, as cited in USFWS 1996), Armour (1991), and CDFG (1998)
	15.6°C (60°F)	upper optimal limit	NMFS (1997), NMFS (2000)	for holding adults while eggs are maturing; Sacramento River winter-run Chinook
	19°C (66°F)	upper limit of successful spawning/ low end of range associated with pre-spawning mortality	Ward and Kier (1999), Ward et al. (2003)	upper limit for successful spawning in Battle Creek spring Chinook restoration plan (Ward and Kier 1999). Reported approximate low end of range associated with significant pre-spawning mortality of spring Chinook in Butte Creek in 2002 and 2003 (Ward et al. 2003).
	21–25°C (70–77°F)	maximum	Moyle et al. (1995)	range of max temps for holding pools used by spring-run Chinook in Sacramento-San Joaquin system
	>27°C (>80.6°F)	lethal	Cramer and Hammack (1952), as cited in Moyle et al. (1995)	upper limit for spring-run Chinook holding in Deer Creek
Spawning	5.6–13.9°C (42–57°F)	recommended range	Bell (1986)	same for all Chinook runs
	10°C (50°F)	optimum	FERC (1993)	from undocumented literature review, with emphasis on American River: run not specified
	13.3°C (56°F)	upper limit of suitability	NOAA (2002), as cited in CDWR (2004)	Sacramento River spring-run Chinook
	>15.6°C (>60°F)	stressful	FERC (1993)	from undocumented literature review, with emphasis on American River: run not specified
	>21.1°C (>70°F)	lethal	FERC (1993)	same comment as above
Incubation	5–14.4°C (41–58°F)	recommended range to minimize mortality	Bell (1986)	spring-run Chinook: location not specified
	11.7–14.4°C (53–58°F)	preferred	NOAA (2002), as cited in CDWR (2004)	Central Valley spring-run Chinook
	5.8–14.2°C (42–58°F)	minimal mortality	Combs and Burrows (1957),	eggs from Entiat and Skagit rivers, Washington

Life Stage	Water Temperature °C (°F)	Descriptor	Source	Notes
			as cited in Myrick and Cech (2001)	
	4–12°C (39–54°F)	highest egg survival rates	Myrick and Cech (2001)	run or location not specified
	10°C (50°F)	optimum	FERC (1993)	from undocumented literature review, with emphasis on American River: run not specified
	>13.3°C (>56°F)	stressful	FERC (1993)	from undocumented literature review, with emphasis on American River: run not specified
	>15.6°C (>60°F)	lethal	FERC (1993)	from undocumented literature review, with emphasis on American River: run not specified
	>16.7°C (>62°F)	lethal (UILT)	Hinze (1959), as cited in Myrick and Cech (2001); USFWS (1999)	100% mortality of American River Chinook eggs incubated in water >16.7°C (Hinze 1959; run not specified); 16.7°C is upper survival temp. for Sac. R. winter- and fall-run Chinook eggs (USFWS 1999)
Fry & Juvenile	18.3–21.1°C (65–70°F)	optimum growth	Clarke and Shelbourn (1985), Brett et al. (1982)	British Columbia; with unlimited food
	19°C (66°F)	maximum growth	Cech and Myrick (1999)	American River (Nimbus Hatchery) fish with unlimited food
	13.2–15.3°C (56–59.5°F)	maximum growth	Rich (1987)	American River fall-run Chinook; does not account for increased susceptibility to pathogens
	14.4°C (58°F)	optimum	FERC (1993)	from undocumented literature review, with emphasis on American River: run not specified
	15.6°C (60°F)	preferred	NOAA (2002), as cited in CDWR (2004)	Central Valley spring-run Chinook
	>18.3°C (>65°F)	stressful	FERC (1993)	from undocumented literature review, with emphasis on American River: run not specified
	24°C (75°F)	lethal	Rich (1987)	chronically lethal temperature for American River (Nimbus Hatchery) fish reared in river water for 8+ days
	25°C (77°F)	lethal	Myrick and Cech (2001)	run or location not specified
	26°C (79°F)	lethal (UILT)	Hanson (1991)	Feather River fish acclimated to 13°C (55°F) at Mokelumne hatchery

Life Stage	Water Temperature °C (°F)	Descriptor	Source	Notes
	28.8°C (84°F)	lethal (UILT)	Cech and Myrick (1999)	American River (Nimbus Hatchery) fish acclimated to 19°C (66°F)
Smolt	10–17.5°C (50–64°F)	optimum	Clarke and Shelbourn (1985), Clarke et al. (1992)	optimal adaptation for marine survival
	20°C (68°F)	maximum	Marine (1997)	maximum smolting temperature for Sacramento River fall-run Chinook

Table 2. Summary of steelhead temperature tolerance by life stage.

Life Stage	Water Temperature °C (°F)	Descriptor	Source	Notes
Upstream Migration	7.8–11.1°C (46–52°F)	Preferred	NMFS (2000), McEwan and Jackson (1996)	Central Valley winter-run steelhead
	>21°C (>70°F)	Stressful	Lantz (1971), as cited in Beschta et al. (1987)	Columbia River steelhead
Adult Holding (freshwater residence)	10–15°C (50–59°F)	Preferred	Moyle et al. (1995)	California summer steelhead
	>16.1°C (>61°F)	Chronic high stress	USFWS (1995)	Central Valley winter-run steelhead
	23–24°C (73–75°F)	Lethal	Moyle (2002)	run or location not specified
Spawning	3.9–11.1°C (39–52°F)	Preferred	McEwan and Jackson (1996), IEP Steelhead Project Work Team (no date)	Central Valley winter-run steelhead
	7.2–10°C (45–50°F)	Optimum	FERC (1993)	Based on undocumented literature review
	20°C (68°F)	Stressful	FERC (1993)	Based on undocumented literature review
	>22°C (>72°F)	Lethal	FERC (1993)	Based on undocumented literature review
Incubation (eggs)	8.9–11.1°C (48–52°F)	Optimum/preferred	NMFS (2000), McEwan and Jackson (1996), FERC (1993), Bell (1986)	Bell (1986) gives 50°F as preferred
	>12.8°C (>55°F)	Stressful	FERC (1993)	Based on undocumented literature review
	>15°C (>59°F)	Lethal	Myrick and Cech (2001)	

Life Stage	Water Temperature °C (°F)	Descriptor	Source	Notes
Juvenile (fry, parr)	7.2–18.3°C (45–65°F)	Preferred for growth and development	NMFS (2000)	Sacramento River and American River fish
	15–19°C (59–66°F)	Optimum for growth	Myrick and Cech (2001)	Based on laboratory studies
	17°C (63°F)	Preferred – wild	Myrick and Cech (2000) as cited in Myrick and Cech (2001)	Feather River wild fish
	18–19°C (64–66°F)	Preferred – hatchery	Myrick and Cech (2000) as cited in Myrick and Cech (2001)	Feather River hatchery fish
	20°C (68°F)	Stressful	FERC (1993)	Based on undocumented literature review
	>25°C (>77°F)	Lethal	Myrick and Cech (2001), FERC (1993)	Significant mortality at temps. >25°C
Smolt	6–10°C (43–50°F)	Physiological optimum	Myrick and Cech (2001)	Temps. needed during parr-smolt transformation to maximize saltwater survival
	>15°C (>59°F)	Unsuitable	Myrick and Cech (2001)	Little seawater adaptation at temps. >15°C
	25°C (77°F)	Lethal	FERC (1993)	Based on undocumented literature review

Table 3. Recommended temperatures for spring-run Chinook salmon and steelhead in the Upper Yuba River basin.

Species and life stage	Primary Time Period	Temperature			Notes	Source(s) for Temperature Information
		Optimal[1]	Suboptimal[2]	Chronic to Acute Stress[3]		
Spring-run Chinook salmon						
Upstream migration	Apr–Jun	<13.3°C (<56°F)	13.3–18.3°C (56–65°F)	>18.3°C (>65°F)	Possible blockage or delay of upstream migration at temps > 13.3°C	Bell (1986); Hallock et al. (1970), Bumgarner et al. (1997), both as cited in McCullough (1999).
Adult holding	mid Apr–late Sep	<16°C (<60.8°F)	16–19°C (60.8–66.2°F)	>19°C (>66.2°F)	thermal criteria are those used for Battle Creek spring Chinook	Ward and Kier (1999): taken from Berman (1990, as cited in USFWS 1996), Armour (1991), and CDFG (1998); Ward et al. (2003)
Spawning	Sep–Oct	<13.3°C (<56°F)	13.3–15.6°C (56–60°F)	>15.6°C (>60°F)		NOAA (2002, as cited in CDWR 2004), FERC (1993)
Egg incubation	late Sep–Jan	<12°C (<54°F)	12–14.4°C (54–58°F)	>14.4°C (>58°F)		Myrick and Cech (2001), Bell (1986), NOAA (2002, as cited in CDWR 2004)
Fry & juvenile rearing and outmigration	mid Nov–Apr[4]	<15.6°C (<60°F)	15.6–18.3°C (60–65°F)	>18.3°C (>65°F)		Rich (1987), NOAA (2002, as cited in CDWR 2004), FERC (1993)
Winter steelhead						
Upstream migration/ adult residence	Aug–Mar	<11.1°C (<52°F)	11.1–21°C (52–70°F)	>21°C (>70°F)		NMFS (2000), McEwan and Jackson (1996), Lantz (1971, as cited in Beschta et al. 1987)
Spawning	Jan–Apr	<11.1°C (<52°F)	11.1–12.8°C (52–55°F)	>12.8°C (>55°F)	Temperatures inferred from incubation temps	NMFS (2000), McEwan and Jackson (1996), FERC (1993), Bell (1986)
Egg incubation	Jan–early Jun	<11.1°C (<52°F)	11.1–12.8°C (52–55°F)	>12.8°C (>55°F)		NMFS (2000), McEwan and Jackson (1996), FERC (1993), Bell (1986)
Fry & juvenile rearing and outmigration	Jan–Dec	<18.3°C (<65°F)	18.3–20°C (65–68°F)	>20°C (>68°F)		NMFS (2000), FERC (1993)

[1] Feeding and growth occur; growth dependent on food availability. No sublethal or lethal effects.

[2] No direct mortality, but may result in a higher probability of diminished success (i.e., sublethal effects), especially at high end of range.

[3] Chronic exposure at the low end of the range results in sublethal effects, including reduced growth, reduced competitive ability, behavioral alterations, and increased susceptibility to disease. At higher temperatures in this zone, short-term exposure (minutes to days) results in death.

[4] Presumes that spring-run Chinook salmon in the Upper Yuba River basin would follow an “ocean-type” life history pattern, similar to the population in Butte Creek, and juveniles would not typically over-summer due to excessively high summer water temperatures.

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