Water Temperature Considerations
for
Yuba River Basin
Anadromous Salmonid Reintroduction Evaluations

Prepared for:

Yuba Salmon Forum Technical Working Group

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Table of Contents

List of Appendices

1 INTRODUCTION

The Yuba Salmon Forum (YSF) is a multi-stakeholder group addressing the opportunities for reintroducing anadromous salmonids (i.e., spring-run Chinook salmon and steelhead) in the Upper Yuba River Basin upstream of Englebright Dam.

The YSF stakeholder group is comprised of representatives from National Marine Fisheries Service (NMFS), U.S. Forest Service (USFS), California Department of Fish and Game (CDFG), the Yuba County Water Agency (YCWA), Placer County Water Agency (PCWA) and a group of the non-governmental organizations (NGOs) including Trout Unlimited, American Rivers, The Bay Institute, Sierra Club, California Sport Fishing Protection Alliance, and South Yuba River Citizens League. The YSF is comprised of a Plenary Group and a Technical Working Group (TWG). The purpose of the TWG is to address technical issues associated with anadromous salmonid reintroduction. One of the technical issues addressed by the TWG includes water temperature considerations for the reintroduction of anadromous salmonids into the Upper Yuba River Basin.

2 TECHNICAL MEMORANDUM PURPOSE AND OBJECTIVES

The overall purpose of this Technical Memorandum is to establish the technical basis to evaluate water temperature regimes for spring-run Chinook salmon and steelhead reintroduction in the various rivers and reaches of the Upper Yuba River Basin (North Yuba River upstream of New Bullards Bar Reservoir, North Yuba River downstream of New Bullards Bar Dam to the high water mark of Englebright Reservoir, Middle Yuba River, and South Yuba River) **(Figure 1)**.

Specific objectives are to: (1) conduct a comprehensive literature review of lifestage-specific water temperature relationships; (2) identify a suite of water temperature index (WTI) values representing a summarization of the literature review; (3) select water temperature criteria for each species-specific lifestage for reintroduction evaluation; and (4) identify the water temperature evaluation methodological approach (water temperature metrics and metric application to water temperature monitoring and/or modeling data).

NMFS commented (NOAA Memorandum dated January 18, 2012) on the November 2011 version of this technical memorandum, stating that it should demonstrate the need for new criteria in consideration of criteria previously developed by Stillwater Sciences (2006). In summary, this technical memorandum differs from Stillwater Sciences (2006) in some lifestage periodicities (e.g., spring-run Chinook salmon spawning (Sep – mid Nov vs. Sep – Oct), and embryo incubation (Sep – Feb vs. late Sep – Jan). Notably, Stillwater Sciences (2006) assumed that juvenile spring-run Chinook salmon in the Upper Yuba River Basin "*…would not typically over-summer due to excessively high summer water temperatures*." By contrast, this technical memorandum assumes that juvenile rearing in the Upper Yuba River Basin could occur year-round. In addition, this technical memorandum identifies spring-run Chinook salmon smolt emigration potentially occurring from November through mid-May, whereas Stillwater Sciences (2006) did not identify spring-run Chinook salmon smolt emigration as a lifestage to be addressed. Similarly, Stillwater Sciences (2006) did not identify smolt emigration as a steelhead lifestage to be addressed. In addition to lifestage periodicities, this technical memorandum identifies upper optimum and upper tolerance water temperature index values to be used in the evaluation of water temperature suitability for reintroduction of spring-run Chinook salmon and steelhead into the Upper Yuba River Basin, whereas Stillwater Sciences (2006) identified optimal, suboptimal, and chronic-to-acute stress water temperature index values. These categories are not directly comparable, and the actual values also differ between the two reports.

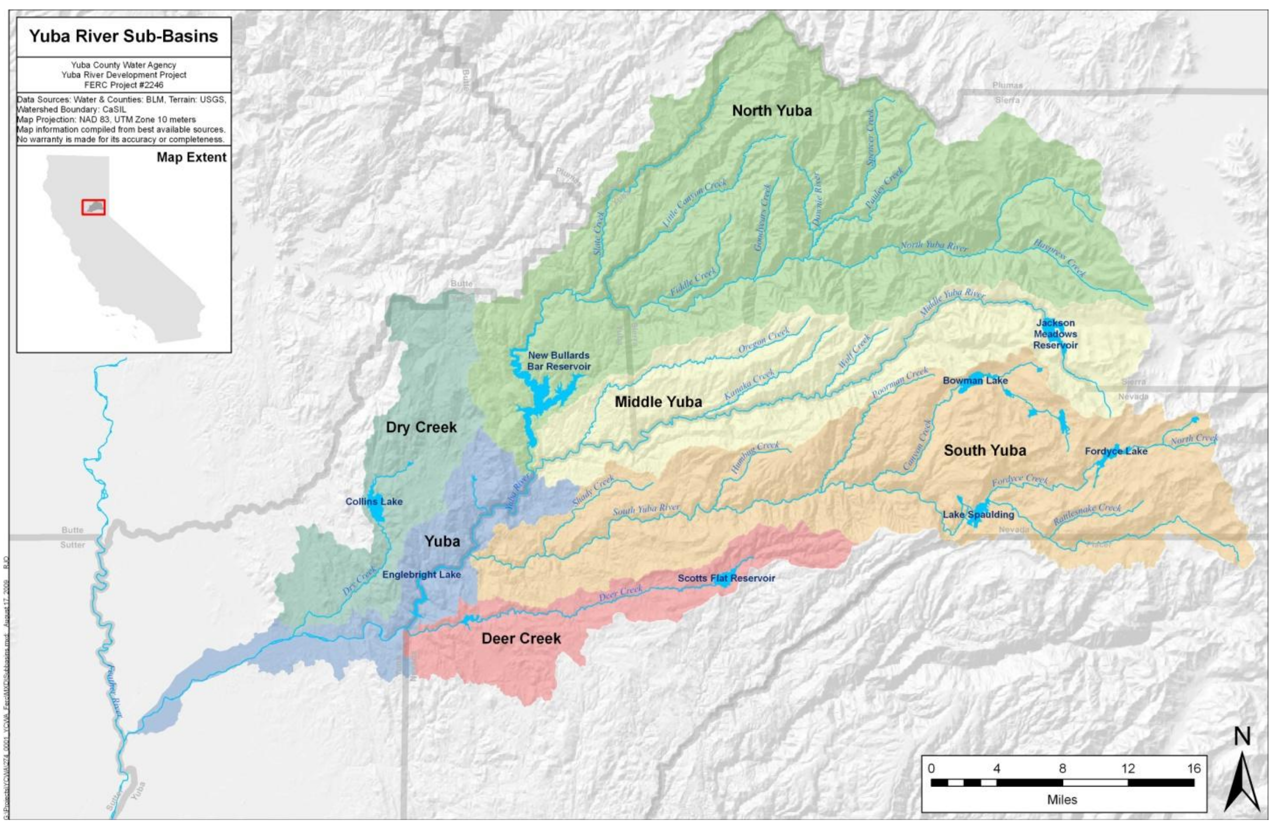

Figure 1. Sub-basins of the Yuba River Basin (source: Yuba County Water Agency 2010).

3 LIFESTAGE PERIODICITIES OF ANADROMOUS SALMONIDS

Lifestage-specific water temperature considerations for spring-run Chinook salmon and steelhead were addressed by the TWG in the evaluation of anadromous reintroduction in the Upper Yuba River Basin. A review of previously conducted studies, as well as recent and currently ongoing data collection activities by the Yuba Accord Monitoring and Evaluation Program (M&E Program) in the lower Yuba River was conducted to identify species- and lifestage-specific temporal periodicities for water temperature considerations. The TWG agreed on the spring-run Chinook salmon and steelhead lifestage periodicities presented in **Table 1** for reintroduction consideration in the Upper Yuba River Basin during a meeting held May 20, 2011. However, it was noted that these periodicities reflect existing conditions in the lower Yuba River, and that lifestage periodicities may change in response to local adaptation over time. It was further noted that although some lifestages may occur concurrently, the periodicities presented in Table 1 reflect specific consideration for water temperature evaluation for reintroduction. For example, spring-run Chinook salmon holding continues to occur during September, even though spawning activity begins during that month.

Table 1. Lifestage-Specific Periodicities for Spring-run Chinook Salmon and Steelhead in the Lower Yuba River.

Lifestage	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Spring-Run Chinook Salmon																								
Adult Immig. & Holding							■	■	■	■	■	■	■	■	■	■								
Spawning																	■	■	■	■	■			
Embryo Incubation	■	■	■	■													■	■	■	■	■	■	■	■
Juv. Rearing & Outmig.	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Yearling+ Smolt Emig.	■	■	■	■	■	■	■	■	■												■	■	■	■
Steelhead																								
Adult Immig. & Holding	■	■	■	■	■	■									■	■	■	■	■	■	■	■	■	■
Spawning	■	■	■	■	■	■	■	■																
Embryo Incubation	■	■	■	■	■	■	■	■	■	■														
Juv. Rearing & Outmig.	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Yearling+ Smolt Emig.	■	■	■	■	■	■	■												■	■	■	■	■	■

4 LITERATURE REVIEW OF WATER TEMPERATURE RELATIONSHIPS FOR STEELHEAD AND CHINOOK SALMON

A comprehensive review and compilation of available literature was conducted to identify the range of acceptable water temperatures for reintroduction evaluation of Chinook salmon and steelhead, by lifestage, in the Upper Yuba River Basin. The thermal requirements of Chinook salmon and steelhead have been extensively studied in California and elsewhere. The literature review informed the selection of a range of WTI values to be used in the TWG's evaluation of the water temperature-related reintroduction potential in the Upper Yuba River Basin. The information presented herein is largely based on information provided in Appendix E2 to the Public Draft EIR/EIS for the Yuba Accord (YCWA *et al.* 2007), Appendix B (Stillwater Sciences 2006) to the Upper Yuba River Studies Program (UYRSP) Technical Report (DWR 2007), and the Yuba Accord River Management Team Water Temperature Objectives Technical Memorandum (RMT 2010).

WTI values were identified from laboratory experiments and field studies that examined how water temperature affects Central Valley Chinook salmon and steelhead. WTI values were also identified from regulatory documents such as biological opinions from NMFS. Results of the literature review are presented in **Appendix A**. Specific temperature index values were then selected by the TWG to evaluate temperature-related reintroduction potential in the Upper Yuba River Basin.

Studies on fish from outside the Central Valley were used to establish WTI values when local studies were unavailable. To avoid unwarranted specificity, only whole integers were selected as WTI values. In some cases, whole integer WTI values were partially derived from literature results that varied from the index value by several tenths of a degree. For example, Combs and Burrows (1957) reported that constant incubation temperatures up to 57.5°F resulted in normal development of Chinook salmon eggs, and their report was referenced as support for a rounded[1] WTI value of 58°F.

The WTI values presented herein represent a gradation of potential biological effects from optimal to lethal water temperatures for each lifestage. Literature on salmonid water temperature requirements generally reports water temperature thresholds using various descriptive terms including "optimal", "preferred", "suitable", "suboptimal", "tolerable", "stressful – chronic and acute", "sublethal", "incipient lethal", and "lethal". Water temperature effects on salmonids are often discussed in terms of "lethal" and "sublethal" effects, and depend on the both the magnitude and the duration of exposure (Sullivan *et al.* 2000), as well as acclimation water temperature. Exposure to adverse water temperatures can result in adverse effects on the biological functions, feeding activity, lifestage timing, growth, reproduction, competitive interactions, susceptibility to disease, growth and development and ultimately probability of survival (McCullough 1999).

[1] Rounding for the purposes of selecting index values is appropriate because the daily variation of experimental treatment temperatures is often high. For example, temperature treatments in Marine (1997) consisted of control (55.4°F to 60.8°F), intermediate (62.6°F to 68.0°F) and extreme (69.8°F to 75.2°F) treatments that varied daily by several degrees.

There are inherent limitations associated with the development and application of WTI values. Some of the limitations are summarized by McEwan (2001). Namely, that WTI values serve as general guidelines, originally developed by researchers on specific streams or under laboratory conditions. Also, research under controlled laboratory conditions does not take into account ecological considerations associated with water temperature regimes, such as predation risk, inter- and intra-specific competition, long-term survival and local adaptation.

5 LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

Lifestage-specific WTI summary tables derived from the literature review are provided for steelhead and Chinook salmon: (1) adult immigration and holding; (2) spawning and embryo incubation; (3) juvenile rearing and downstream movement; and (4) yearling + smolt emigration in **Tables 2 - 9** (see below). A written discussion of the literature used to create the summary tables is provided in Appendix A. A short discussion of acute versus chronic temperature tolerance also is provided.

5.1 Steelhead and Chinook Salmon Acute Versus Chronic Temperature Tolerance (Juveniles and Adults)

Lifestage-specific WTI values (Sections 5.2 and 5.3 below) were based on long-term (≥ 7 days) chronic temperature exposure rather than acute temperature exposure (< 7 days). The boundary between the upper end of the chronic exposure range and the lower end of the acute exposure range is typically measured as the upper incipient lethal temperature (UILT) where 50% mortality occurs after 7 days (Elliott 1981)[2].

The UILT for both juvenile steelhead and Chinook salmon is very similar and is between 75-79°F (24-26°C) depending on the study (McCullough 1999; Sullivan et al. 2000; McCullough et al. 2001). The UILT for adult steelhead and Chinook salmon is 70-72°F (21-22°C) (Coutant 1970; Becker 1973; McCullough et al. 2001), which is much lower than that for juveniles and is approximately the same temperature that has been identified as an upstream migration barrier for Chinook salmon (McCullough 1999).

Acute temperature response (< 7 days) is strongly dependent on duration of exposure. **Figure 2** shows some example acute exposure relationships for juvenile salmonids. The hourly (60 minute) acute temperature is 5.4 – 9.0°F (3-5°C) higher than the 7-day (10,000 minute) chronic temperature. Because the acute temperature for juvenile salmonids, approximately 82.4°F (28.4°C) is relatively high, it rarely becomes a factor affecting

[2] Note that some authors have measured the UILT using shorter duration exposure than 7 days (e.g., 1,000 mins or 24 hrs). UILT values based on a shorter duration exposure than 7 days will be higher than the UILT values based on a 7 day exposure.

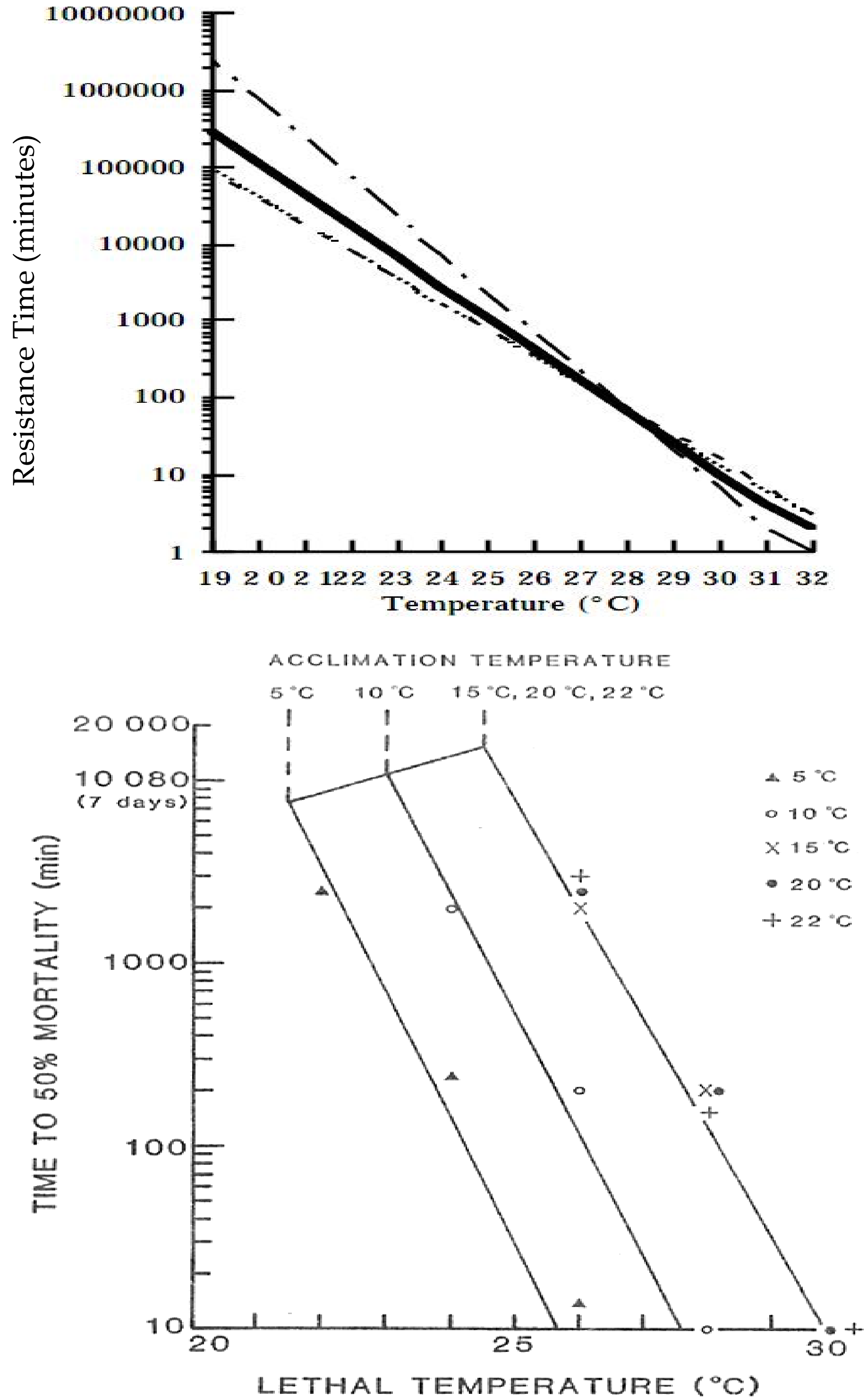

Figure 2. Relationship Between the Time (Minutes) to Mortality and the Lethal Temperature for Rainbow Trout (Top) (Bidgood 1969) and Brown Trout (Bottom) (Elliott 1981). Note the Effect of Acclimation Temperature in the Bottom Figure.

survival in natural streams (Sullivan et al. 2000). However, the acute temperature for adult salmonids is lower – it could become a survival factor particularly for adult spring-run Chinook salmon holding through the summer.

The temperature range between the UILT (7 days) and very short duration mortality (minutes) (e.g., critical thermal maximum) is called the zone of resistance. Below the UILT is a zone of tolerance where fish can tolerate the temperature for an extended period of time (> 7 days). At the higher temperatures in the tolerance zone fish may not feed, grow, or reproduce and they may have modified behavior (e.g., holding in temperature refugia locations). An important point to note is that the effects of water temperature are associated with duration of exposure and, depending upon the actual water temperature value, short duration exposure to relatively high temperatures may not result in sustained adverse effects if temperatures quickly decrease to non-impactive levels.

At lower temperatures in the tolerance zone, denoted "tolerable" in this report, growth and/or reproduction occur, but are reduced from optimal due to temperature effects. The zone of temperature where fish processes (growth, reproduction, behavior) are not affected appreciably by temperature is denoted as the "optimum" temperature range in this report (**Figure 3**).

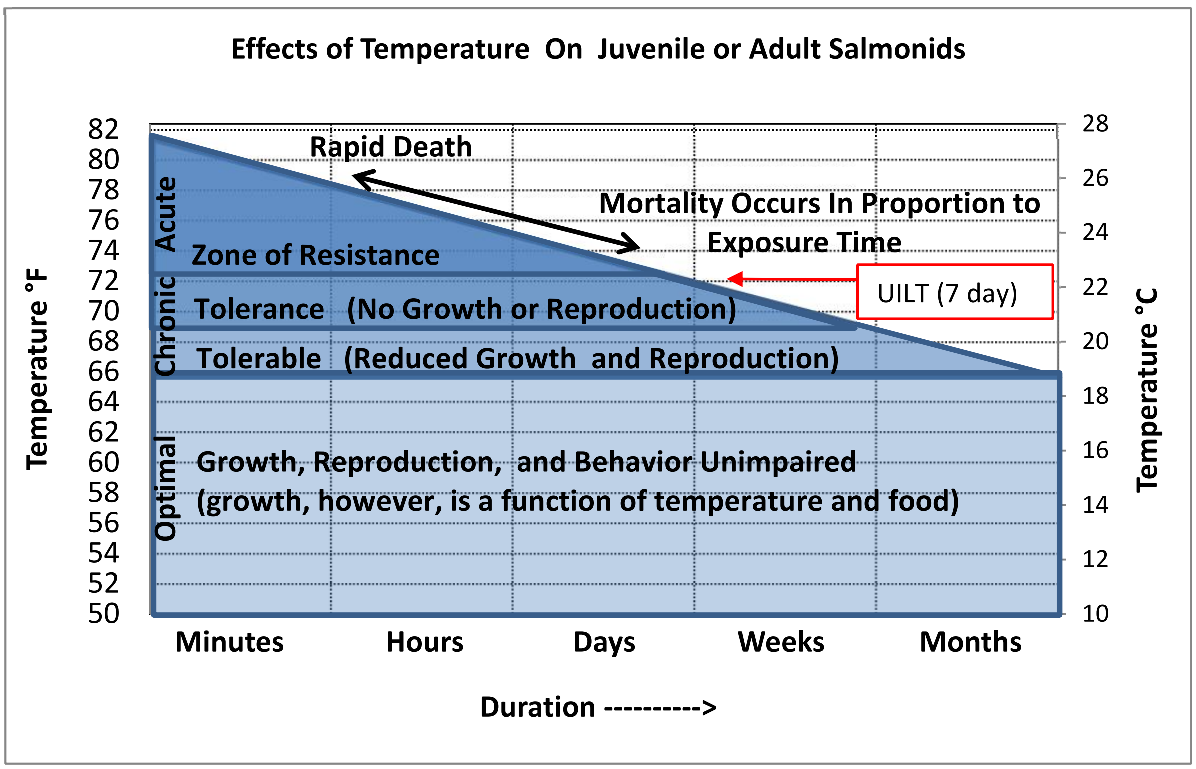

Figure 3. Illustration of Acute, Chronic, and Optimum Temperature Zones.

5.2 Steelhead Lifestage-specific Water Temperature Index Values

5.2.1 Adult Immigration and Holding

Table 2. Steelhead Adult Immigration and Holding Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
52°F	Preferred range for adult steelhead immigration of 46.0°F to 52.0°F (NMFS 2000; NMFS 2001a; SWRCB 2003). Optimum range for adult steelhead immigration of 46.0°F to 52.1°F (Reclamation 1997a). Recommended adult steelhead immigration temperature range of 46.0°F to 52.0°F (Reclamation 2003).
56°F	To produce rainbow trout eggs of good quality, brood fish must be held at water temperatures not exceeding 56.0°F (Leitritz and Lewis 1980). Rainbow trout brood fish must be held at water temperatures not exceeding 56°F for a period of 2 to 6 months before spawning to produce eggs of good quality (Bruin and Waldsdorf 1975). Holding migratory fish at constant water temperatures above 55.4°F to 60.1°F may impede spawning success (McCullough *et al.* 2001).
61°F	Water temperatures greater than 61°F may result in "chronic high stress" of holding Central Valley winter-run steelhead (USFWS 1995a). Preferred range of water temperature for holding Caliifornia summer steelhead occurs between 50-59°F (Moyle 1995).
64°F	Steelhead (and fall-run Chinook salmon) encounter potentially stressful temperatures between 64.4-73.4°F (Richter and Kolmes 2005). Over 93% of steelhead detections occurred in the 65.3-71.6°F, although this may be above the temperature for optimal immigration (Salinger and Anderson 2006).
70°F	Migration barriers have frequently been reported for pacific salmonids when water temperatures reach 69.8°F to 71.6°F (McCullough *et al.* 2001). Snake River adult steelhead immigration was blocked when water temperatures reached 69.8 (McCullough *et al.* 2001). A water temperature of 68°F was found to drop egg fertility in vivo to 5 percent after 4.5 days (McCullough *et al.* 2001). The UILT for adult steelhead was determined to be 69.8°F (Coutant 1972).

5.2.2 Spawning and Embryo Incubation

Table 3. Steelhead Spawning and Embryo Incubation Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
46°F	Orcutt et al. (1968) reported that steelhead spawning in late spring in the Clearwater and Salmon Rivers, Idaho, occurred at temperatures between 35.6 and 46.4°F.
52°F	Rainbow trout from Mattighofen (Austria) had highest egg survival at 52.0°F compared to 45.0°F, 59.4°F, and 66.0°F (Humpesch 1985). Water temperatures from 48.0°F to 52.0°F are suitable for steelhead incubation and emergence in the American River and Clear Creek (NMFS 2000; NMFS 2001a; NMFS 2002a). Optimum water temperature range of 46.0°F to 52.0°F for steelhead spawning in the Central Valley (USFWS 1995b). Optimum water temperature range of 46.0°F to 52.1°F for steelhead spawning and 48.0°F to 52.1°F for steelhead egg incubation (Reclamation 1997a). Upper limit of preferred water temperature of 52.0°F for steelhead spawning and egg incubation (SWRCB 2003).
54°F	Big Qualicum River steelhead eggs had 96.6 percent survival to hatch at 53.6°F (Rombough 1988). Highest survival from fertilization to hatch for *Salmo gairdneri* incubated at 53.6°F (Kamler and Kato 1983). Emergent fry were larger when North Santiam River (Oregon) winter steelhead eggs were incubated at 53.6°F than at 60.8°F (Redding and Schreck 1979). The upper optimal water temperature regime based on constant or acclimation water temperatures necessary to achieve full protection of steelhead is 51.8°F to 53.6°F (EPA 2001). From fertilization to hatch, rainbow trout eggs and larvae had 47.3 percent mortality (Timoshina 1972). Survival of rainbow trout eggs declined at water temperatures between 52.0 and 59.4°F (Humpesch 1985). The optimal constant incubation water temperature for steelhead occurs below 53.6°F (McCullough *et al.* 2001).

Index Value	Supporting Literature
57°F	From fertilization to 50 percent hatch, Big Qualicum River steelhead had 93 percent mortality at 60.8°F, 7.7 percent mortality at 57.2°F, and 1 percent mortality at 47.3°F and 39.2°F (Velsen 1987). A sharp decrease in survival was observed for rainbow trout embryos incubated above 57.2°F (Kamler and Kato 1983).
60°F	Water temperatures >59°F are described as "lethal" to incubating steelhead embryos (Myrick and Cech 2001), From fertilization to 50 percent hatch, Big Qualicum River steelhead had 93 percent mortality at 60.8°F, 7.7 percent mortality at 57.2°F, and 1 percent mortality at 47.3°F and 39.2°F (Velsen 1987). From fertilization to 50 percent hatch, rainbow trout eggs from Ontario Provincial Normendale Hatchery had 56 percent survival when incubated at 59.0°F (Kwain 1975).

5.2.3 Juvenile Rearing and Downstream Movement

Table 4. Steelhead Juvenile Rearing and Downstream Movement Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
63°F	Preferred water temperature for wild juvenile steelhead is reportedly 63°F, whereas preferred water temperatures for juvenile hatchery steelhead reportedly range between 64-66°F. Myrick and Cech (2001)
65°F	Upper limit of 65°F preferred for growth and development of Sacramento River and American River juvenile steelhead (NMFS 2002a). Nimbus juvenile steelhead growth showed an increasing trend with water temperature to 66.2°F, irrespective of ration level or rearing temperature (Cech and Myrick 1999). The final preferred water temperature for rainbow fingerlings was between 66.2 and 68°F (Cherry *et al.* 1977). Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). Rainbow trout fingerlings preferred or selected water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971).
68°F	Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). The final preferred water temperature for rainbow trout fingerlings was between 66.2°F and 68°F (Cherry *et al.* 1977). Rainbow trout fingerlings preferred or selected water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya et al. 1977). FERC (1993) referred to 68°F as "stressful" to juvenile steelhead. Empirical fish population and water temperature data in the North Yuba, Middle Yuba, South Yuba, Middle Fork American, and Rubicon Rivers (**Figure 4**) indicate a sharp reduction in O. *mykiss* population densities when temperatures exceed 68°F for greater than one week. Bioenergetics modeling of growth based on consumption (P value = 0.5) in the Middle Fork American River watershed (adjacent watershed) indicates that growth likely does not occur above 68°F (**Figure 5**).
72°F	Increased physiological stress, increased agonistic activity, and a decrease in forage activity in juvenile steelhead occur after ambient stream temperatures exceed 71.6°F (Nielsen *et al.* 1994). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya *et al.* 1977). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6°F to 79.9°F (Ebersole *et al.* 2001).
75°F	The maximum weekly average water temperature for survival of juvenile and adult rainbow trout is 75.2°F (EPA 2002). Rearing steelhead juveniles have an upper lethal limit of 75.0°F (NMFS 2001a). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6 to 79.9°F (Ebersole *et al.* 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan et al. 2000; McCullough 2001).

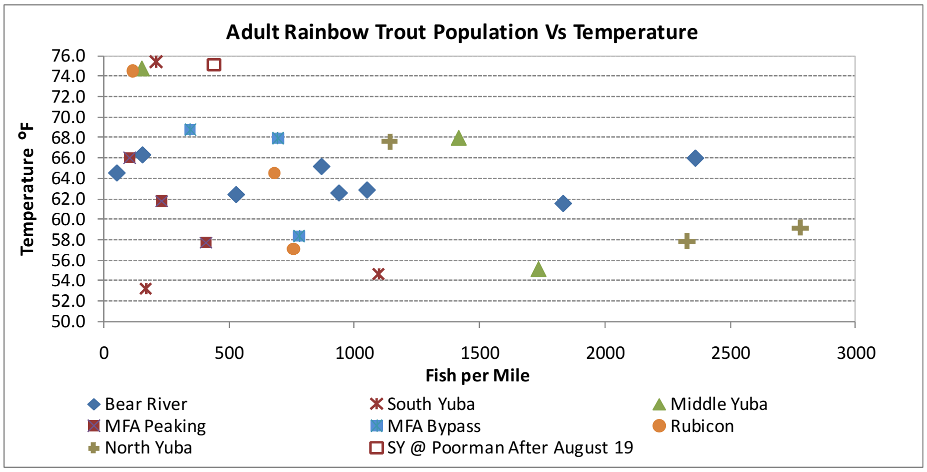

Figure 4. Empirical Adult Fish Population Data in the Middle Fork American and Yuba River Rivers Compared to the Maximum Temperature Exceeded Less Than 7 Days.

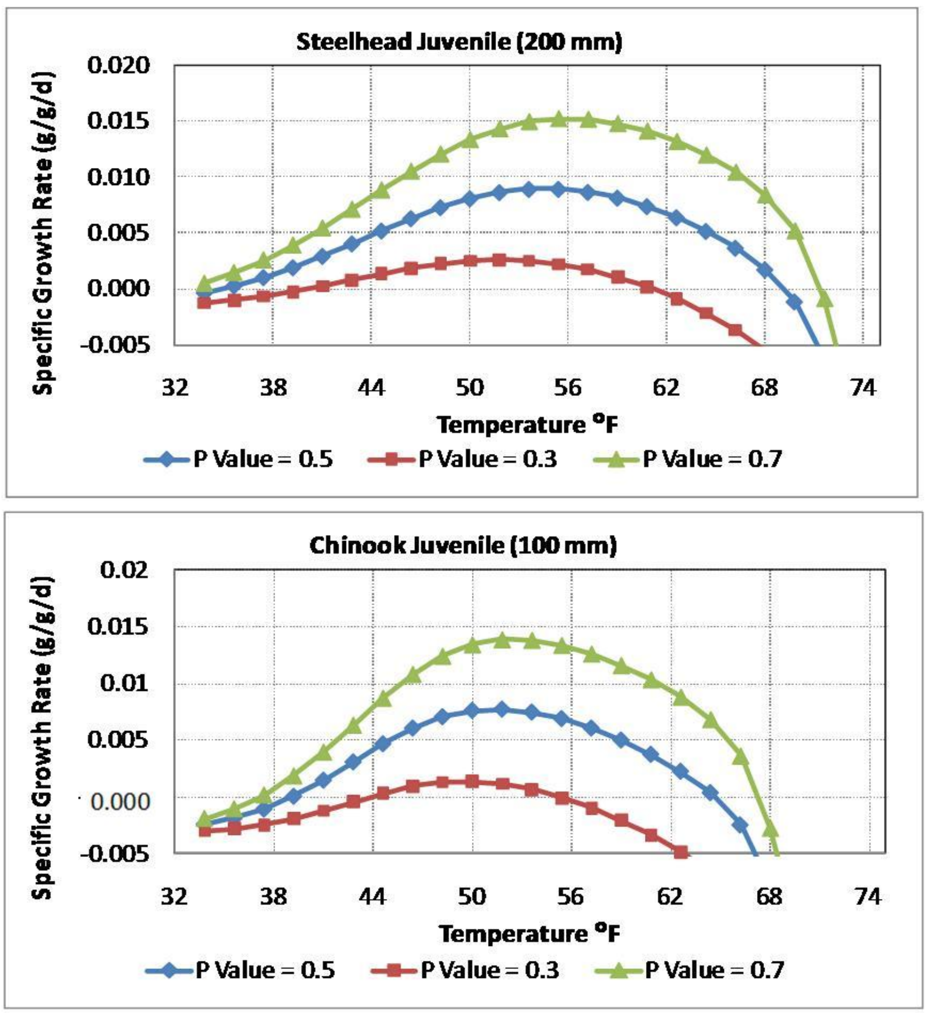

Figure 5. Bioenergetics Growth Rate Modeling For Steelhead and Chinook Salmon Juveniles Over a Range of Temperatures.

5.2.4 Yearling + Smolt Emigration

Table 5. Steelhead Smolt Emigration Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
52°F	Steelhead successfully smolt at water temperatures in the 43.7°F to 52.3°F range (Myrick and Cech 2001). Steelhead undergo the smolt transformation when reared in water temperatures below 52.3°F, but not at higher water temperatures (Adams *et al.* 1975). Optimum water temperature range for successful smoltification in young steelhead is 44.0°F to 52.3°F (Rich 1987a).
55°F	ATPase activity was decreased and migration reduced for steelhead at water temperatures greater than or equal to 55.4°F (Zaugg and Wagner 1973). Water temperatures should be below 55.4°F at least 60 days prior to release of hatchery steelhead to prevent premature smolting and desmoltification (Wedemeyer *et al.* 1980). In winter steelhead, a temperature of 54.1°F is nearly the upper limit for smolting (McCullough *et al.* 2001; Zaugg and Wagner 1973). Water temperatures less than or equal to 54.5°F are suitable for emigrating juvenile steelhead (EPA 2003b). Water temperatures greater than 55°F prevent increases in ATPase activity in steelhead juveniles (Hoar 1988). Water temperatures greater than 56°F do not permit smoltification in summer steelhead (Zaugg *et al.* 1972)
59°F	Yearling steelhead held at 43.7°F and transferred to 59°F had a substantial reduction in gill ATPase activity, indicating that physiological changes associated with smoltification were reversed (Wedemeyer *et al.* 1980).

5.3 Chinook Salmon Lifestage-Specific Water Temperature Index Values

5.3.1 Adult Immigration and Holding

Table 6. Chinook Salmon Adult Immigration and Holding Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
60°F	Maximum water temperature for adults holding, while eggs are maturing, is approximately 59°F to 60°F (NMFS 1997b). Acceptable water temperatures for adults migrating upstream range from 57°F to 67°F (NMFS 1997b). Upper limit of the optimal water temperature range for adults holding while eggs are maturing is 59°F to 60°F (NMFS 2000). Many of the diseases that commonly affect Chinook salmon become highly infectious and virulent above 60°F (ODEQ 1995). Mature females subjected to prolonged exposure to water temperatures above 60°F have poor survival rates and produce less viable eggs than females exposed to lower water temperatures (USFWS 1995b). Ward and Kier (1999) designated temperatures <60.8°F as an "optimum" water temperature threshold for holding Battle Creek spring-run Chinook salmon.
65°F	Acceptable range for adults migrating upstream is from 57°F to 67°F (NMFS 1997b). Disease risk becomes high at water temperatures above 64.4°F (EPA 2003b). Latent embryonic mortalities and abnormalities associated with water temperature exposure to pre-spawning adults occur at 63.5°F to 66.2°F (Berman 1990). During each of the years when Chinook salmon temperature mortality was not observed at Butte Creek (2001, 2004-2007), on average, daily temperature did not exceed 65.8°F for more than 7 days (**Figure 6**).
68°F	Acceptable range for adults migrating upstream range from 57°F to 67°F (NMFS 1997b). For chronic exposures, an incipient upper lethal water temperature limit for pre-spawning adult salmon probably falls within the range of 62.6°F to 68.0°F (Marine 1992). Spring-run Chinook salmon embryos from adults held at 63.5°F to 66.2°F had greater numbers of pre-hatch mortalities and developmental abnormalities than embryos from adults held at 57.2°F to 59.9°F (Berman 1990). Water temperatures of 68°F resulted in nearly 100 percent mortality of Chinook salmon during columnaris outbreaks (Ordal and Pacha 1963). In Butte Creek a period of average daily temperatures above 67°F (11-16 days) preceded the onset of significant pre-spawn mortalities. In

	years when 67°F was exceeded only a few days, pre-spawn mortality was minimal (Ward et al. 2004). Adult Chinook salmon migration rates through the lower Columbia River were slowed significantly when water temperatures exceeded 68°F (Goniea et al. 2006).
70°F	Migration blockage occurs for Chinook salmon at temperatures from 70-71+°F (McCollough 1999; McCullough *et al.* 2001; EPA 2003b). Strange (2010) found that the mean average body temperature during the first week of Chinook salmon migration on the Klamath River was 71.4°F. The UILT for Chinook salmon jacks is 69.8-71.6°F (McCullough 1999).

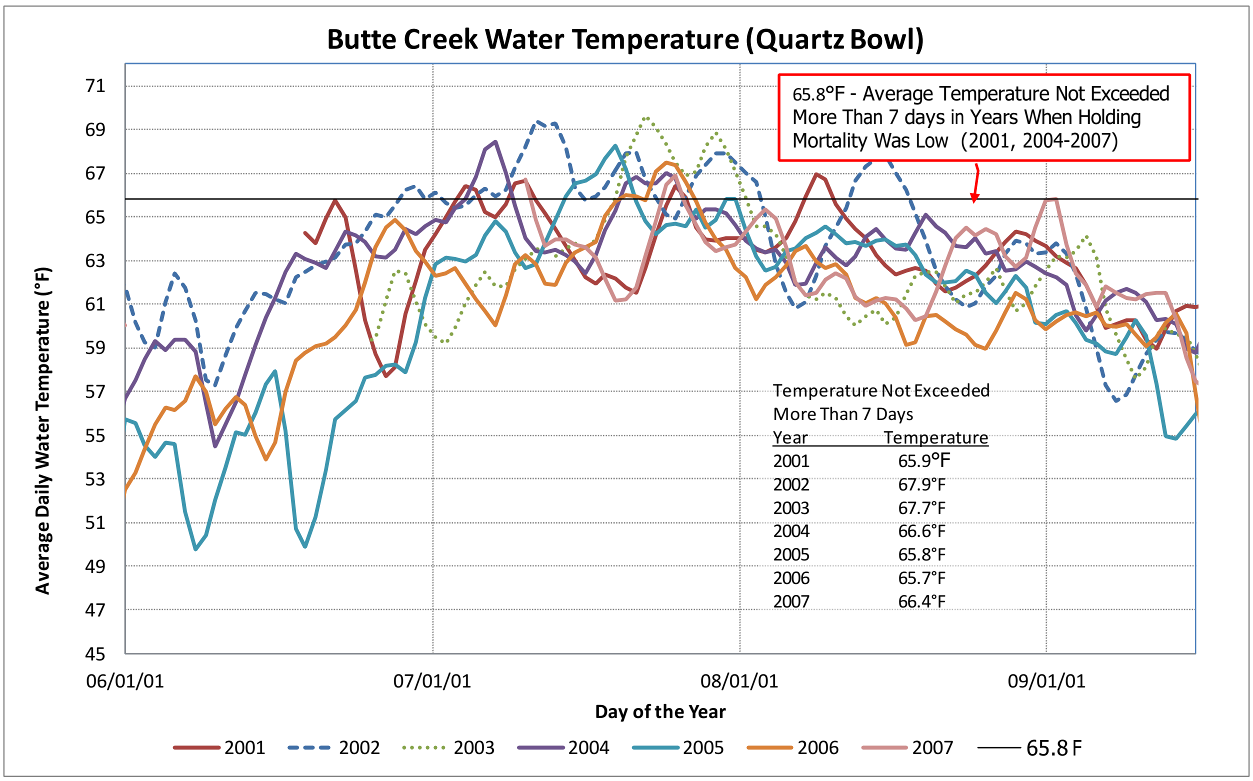

Figure 6. Water Temperature in Butte Creek at Quartz Bowl (2001-2007).

5.3.2 Spawning and Embryo Incubation

Table 7. Chinook Salmon Spawning and Embryo Incubation Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
56°F	Less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs (Reclamation Unpublished Work). Optimum water temperatures for egg development are between 43°F and 56°F (NMFS 1993b). Upper value of the water temperature range (i.e., 41.0°F to 56.0°F) suggested for maximum survival of eggs and yolk-sac larvae in the Central Valley of California (USFWS 1995b). Upper value of the range (i.e., 42.0°F to 56.0°F) given for the preferred water temperature for Chinook salmon egg incubation in the Sacramento River (NMFS 1997a). Incubation temperatures above 56°F result in significantly higher alevin mortality (USFWS 1999). 56.0°F is the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River (NMFS 2002a). Water temperatures averaged 56.5°F during the week of fall-run Chinook salmon spawning initiation on the Snake River (Groves and Chandler 1999).
58°F	Upper value of the range given for preferred water temperatures (i.e., 53.0°F to 58.0°F) for eggs and fry (NMFS 2002a). Constant egg incubation temperatures between 42.5°F and 57.5°F resulted in normal development (Combs and Burrows 1957). The natural rate of mortality for alevins occurs at 58°F or less (Reclamation Unpublished Work).
60°F	100 percent mortality can occur to late incubating Chinook salmon embryos (yolk-sac stage) if temperatures are 60°F or greater (Seymour 1956). An October 1 to October 31 water temperature criterion of less than or equal to 60°F in the Sacramento River from Keswick Dam to Bend Bridge has been determined for protection of late incubating larvae and newly emerged fry (NMFS 1993b). Mean weekly water temperature at first observed Chinook salmon spawning in the Columbia River was 59.5°F (Dauble and Watson 1997). Consistently higher egg losses resulted at water temperatures above 60.0°F than at lower temperatures (Johnson and Brice 1953). For Chinook Salmon eggs incubated at constant temperatures, mortality increases rapidly at temperatures greater than about 59-60°F (see data plots in Myrick and Cech 2001). Olsen and Foster (1957) found high survival of Chinook salmon eggs and fry (89.6%) when incubation temperatures started at 60.9°F and declined naturally for the Columbia River (about 7°F / month). Geist et al. (2006) found high (93.8%) Chinook salmon incubation survival through emergence for naturally declining temperatures (0.36°F/day) starting as high as 61.7°F; however, a significant reduction in survival occurred above this temperature.
62°F	100 percent mortality of fertilized Chinook salmon eggs after 12 days at 62°F (Reclamation Unpublished Work). Incubation temperatures of 62ºF to 64°F appear to be the physiological limit for embryo development resulting in 80 to 100 percent mortality prior to emergence (USFWS 1999). 100 percent loss of eggs incubated at water temperatures above 62°F (Hinze 1959). 100 percent mortality occurs during yolk-sac stage when embryos are incubated at 62.5°F (Seymour 1956). Approximately 80% or greater mortality of eggs incubated at constant temperatures of 63°F or greater (see data plots in Myrick and Cech 2001). Olsen and Foster (1957) found high mortality of Chinook salmon eggs and fry (79%) when incubation temperatures started at 65.2°F and declined naturally for the Columbia River (about 7°F / month). Geist et al. (2006) found low Chinook salmon incubation survival (1.7%) for naturally declining temperatures (0.36°F/day) when temperatures started at 62.6°F.

5.3.3 Juvenile Rearing and Downstream Movement

Table 8. Chinook Salmon Juvenile Rearing and Downstream Movement Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
60°F	Optimum water temperature for Chinook salmon fry growth is between 55.0°F and 60°F (Seymour 1956). Water temperature range that produced optimum growth in juvenile Chinook salmon was between 54.0°F and 60.0°F (Rich 1987b). Water temperature criterion of less than or equal to 60.0°F for the protection of Sacramento River winter-run Chinook salmon from Keswick Dam to Bend Bridge (NMFS 1993b). Upper optimal water temperature limit of 61°F for Sacramento River fall-run Chinook salmon juvenile rearing (Marine 1997; Marine and Cech 2004). Upper water temperature limit of 60.0°F preferred for growth and development of spring-run Chinook salmon fry and fingerlings (NMFS 2000; NMFS 2002a). To protect salmon fry and juvenile Chinook salmon in the upper Sacramento River, daily average water temperatures should not exceed 60°F after September 30 (NMFS 1997b). A water temperature of 60°F appeared closest to the optimum for growth of fingerlings (Banks *et al.* 1971). Optimum growth of Nechako River Chinook salmon juveniles would occur at 59°F at a feeding level that is 60 percent of that required to satiate them (Brett *et al.* 1982). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).
65°F	Water temperatures between 45°F to 65°F are preferred for growth and development of fry and juvenile spring-run Chinook salmon in the Feather River (NMFS 2002a). Recommended summer maximum water temperature of 64.4°F for migration and non-core rearing (EPA 2003b). Water temperatures greater than 64.0°F are considered not "properly functioning" by NMFS in Amendment 14 to the Pacific Coast Salmon Plan (NMFS 1995). Fatal infection rates caused by *C. columnaris* are high at temperatures greater than or equal to 64.0°F (EPA 2001). Disease mortalities diminish at water temperatures below 65.0°F (Ordal and Pacha 1963). Fingerling Chinook salmon reared in water greater than 65.0°F contracted *C. columnaris* and exhibited high mortality (Johnson and Brice 1953). Water temperatures greater than 64.9°F identified as being stressful in the Columbia River Ecosystem (Independent Scientific Group 1996). Juvenile Chinook salmon have an optimum temperature for growth that appears to occur at about 66.2°F (Brett *et al.* 1982). Juvenile Chinook salmon reached a growth maximum at 66.2°F (Cech and Myrick 1999). Optimal range for Chinook salmon survival and growth from 53.0°F to 64.0°F (USFWS 1995b). Survival of Central Valley juvenile Chinook salmon declines at temperatures greater than 64.4°F (Myrick and Cech 2001). Increased incidence of disease, reduced appetite, and reduced growth rates at 66.2±1.4 °F (Rich 1987b). Bioenergetics modeling of growth based on consumption of rainbow trout (P value = 0.5) in the Middle Fork American River watershed (adjacent watershed) indicates that growth likely does not occur above about 65°F (Figure 5)
68°F	Sacramento River juvenile Chinook salmon reared at water temperatures greater than or equal to 68.0°F suffer reductions in appetite and growth (Marine 1997; Marine and Cech 2004). Significant reductions in growth rates may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997).
70°F	No growth at all would occur for Nechako River juvenile Chinook salmon at 70.5°F (Brett *et al.* 1982; Zedonis and Newcomb 1997). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997). Increased incidence of disease, hyperactivity, reduced appetite, and reduced growth rates at 69.8 ±1.8 °F (Rich 1987b). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).

75°F	For juvenile Chinook salmon in the lower American River fed maximum rations under laboratory conditions, 75.2°F was determined to be 100 percent lethal due to hyperactivity and disease (Rich 1987b; Zedonis and Newcomb 1997). Lethal temperature threshold for fall-run juvenile Chinook salmon between 74.3 and 76.1°F (McCullough 1999). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004). The juvenile Chinook Salmon UILT based on numerous studies is 75-77°F (Sullivan et al. 2000; McCullough et al. 2001; Myrick and Cech 2001)

5.3.4 Yearling + Smolt Emigration

Table 9. Chinook Salmon Yearling + Smolt Emigration Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
63°F	Acceleration and inhibition of Sacramento River Chinook salmon smolt development reportedly may occur at water temperatures above 63°F (Marine 1997; Marine and Cech 2004). Laboratory evidence suggest that survival and smoltification become compromised at water temperatures above 62.6°F (Zedonis and Newcomb 1997). Juvenile Chinook salmon growth was highest at 62.6°F (Clarke and Shelbourn 1985).
68°F	Significant inhibition of gill sodium ATPase activity and associated reductions of hyposmoregulatory capacity, and significant reductions in growth rates, may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Water temperatures supporting smoltification of fall-run Chinook salmon range between 50°F to 68°F, the colder temperatures represent more optimal conditions (50°F to 62.6°F), and the warmer conditions (62.6°F to 68°F) represent marginal conditions (Zedonis and Newcomb 1997).
72°F	In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004). Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989).

5.4 Upstream Migration Behavioral Effects Due to River Temperature Gradients

If volitional upstream passage was provided past Englebright Reservoir (e.g., ladder, dam removal), the potential exists for upstream migrating adult salmonids to have to volitionally pass through significant water temperature differentials from the Lower Yuba River into the South or Middle Yuba rivers (Upper Yuba River) due to cold water releases from New Bullards Bar Reservoir into the Yuba River (via Colgate Powerhouse). **Figure 7** shows an example of water temperature in the Yuba River below Colgate Powerhouse and the South and Middle Fork Yuba rivers near their confluence with the Yuba River. It is possible to modify the temperature differentials by selective withdrawal of water from New Bullards Bar Reservoir (Colgate Powerhouse temperature) or by modifying flows in the South or Middle Yuba rivers; nevertheless, the temperature differentials could be large. For example, during the May-June migration period for spring-run Chinook salmon or the late summer/fall migration period for steelhead, Middle and South Yuba river temperatures are much warmer than the downstream Yuba River temperatures (e.g., > 7°F or > 4°C).

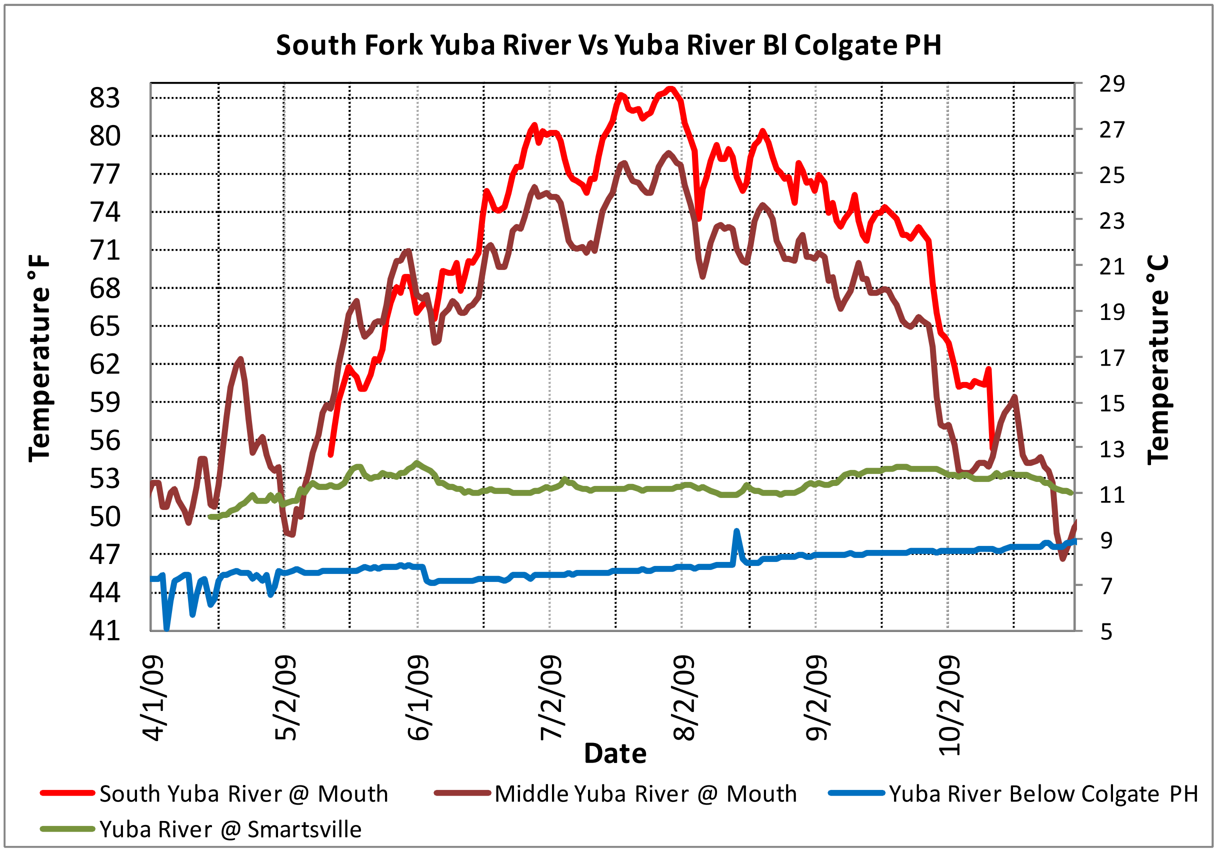

Figure 7. Water Temperature Differentials Between the South and Middle Yuba Rivers, and the Yuba River Below Colgate and at Smartsville.

To date, we have only identified limited information in the literature regarding the effect of temperature differentials on volitional upstream migration of Chinook salmon or steelhead. Typically, as fish migrate upstream in rivers the water temperature becomes cooler. Migrating fish may move from cooler ocean/estuary temperatures (Strange 2010) into warmer river temperatures, but as fish move upstream in rivers, the temperature typically gets cooler. In the case of migration from the Yuba River to the South and Middle Yuba rivers, fish could be faced with moving in a reverse temperature gradient from cooler downstream water, into warmer upstream water.

In the Columbia River both migrating Chinook salmon and steelhead use coolwater tributaries as thermal refugia during warm summer conditions. Staging in coolwater tributaries significantly slows and affects the migratory behavior of the fish (High et al.

2006; Goniea et al. 2006). Also temperature differentials at Columbia River ladders (e.g., colder water at the entrance to the ladder versus warmer water in the ladder), even relatively small temperature differentials, can slow migration rates through the ladders. Caudill et al. (2005) found that few fish passed the ladders when temperature differentials were > 7°F (> 4°C) and that passage times increased with increased temperature differential (e.g., > 2°F).

In the Snake River/Clearwater River system a somewhat analogous temperature situation exists compared to that which may occur in the Yuba River system. During the summer (July-August) cold water is released from Dworshak Reservoir on the North Fork Clearwater River into the Clearwater River. As a result, the Clearwater River becomes colder than the Snake River where they meet near Lewiston, Idaho. Spring-run Chinook salmon are generally not affected because by July, most spring-run Chinook salmon moving up the Clearwater River are already past the mouth of the North Fork Clearwater River, and are up close to or in their higher elevation natal streams getting ready to spawn. It does appear, however, that some later returning spring-run Chinook salmon do hold longer than they would have normally, near or in the North Fork Clearwater River, because of the colder water coming out of Dworshak Reservoir. As a result, there is spawning activity that occurs in the lower North Fork Clearwater River (it is possible that some of these fish may be hatchery fish shunted off from entering Dworshak Hatchery).

The cooling effect of Dworshak Reservoir releases to the Clearwater River does modify the behavior of returning steelhead and fall-run Chinook salmon at the confluence with the Snake River. The cooler water in the Clearwater River draws fish destined for the Snake River into the Clearwater River and they hold in the mouth of the Clearwater River until the Snake River cools down (Personal Communication, Bill Arnsberg, Nez Perce Tribal Biologist).

Our recommendation is that additional literature and data should be obtained and summarized regarding the effect of water temperature differentials on volitional migration (if such information exists). In addition, based on the limited information available, a temperature differential of 7°F (4°C) should precautionarily be viewed as a potential thermal barrier to adult upstream migration. It is possible that even lower temperature differentials (< 7°F) could result in migrating fish holding downstream and not migrating, or significantly delaying migration.

6 TEMPORAL TEMPERATURE PATTERNS RELATED TO WATER TEMPERATURE INDEX VALUES AND METRICS

Typical water temperature patterns in the Yuba River system exhibit a week or two of high temperatures and a much broader range of temperatures that are lower. For example, **Figure 8** shows historical water temperature in the section of the Middle Yuba River near Wolf Creek in 2008. This site is used below to briefly discuss temporal temperature patterns and their relationship to critical WTI values and some typical water temperature metrics used in the literature to summarize water temperature.

Historical daily average water temperatures at the Middle Yuba River site were near the temperature that has been observed to cause mortality to Chinook Salmon in Butte Creek (e.g., 67°F or greater) (Ward et al. 2004). Most of the summer, daily average water temperatures at the Middle Yuba River site were at or below 67°F, but there were a couple of weeks that the average daily water temperature exceeded 67°F (similar to conditions that caused mortality in Butte Creek). Maximum daily water temperatures at the site during much of the summer were near the 7-day UILT[3] for Chinook salmon adults of 69.8-71.6°F (McCullough 1999). However, the duration of time within a day that the water temperature was near the 7-day UILT was short and is not available from the plot nor from typical maximum temperature metrics (see below).

Some typical temperature metrics are shown on Figure 8. The 7-day moving average temperature (7DMA) also exceeded 67°F for the same two time periods that the average daily temperature exceeded 67°F. The maximum weekly average temperature (MWAT) (average of the daily mean temperature of the 7 warmest days) occurred in mid-July and was 67.9°F. The maximum daily temperatures, 7-day moving average daily maximum (7DMADM), were about 4°F greater than the mean daily temperature during the warmest months, and the 7-day average daily maximum temperature (7DADM) occurred at the same time as the MWAT (67.9 °F versus 71.7°F).

Historically in Butte Creek, when average daily water temperature was 67°F for more than about a week (11 and 16 days in 2002 and 2003, respectively) significant adult Chinook salmon mortality occurred. However, if water temperature exceeded 67°F for a relatively short number of days (e.g., < 7 days), significant mortality did not occur (Ward et al. 2004).

An analogous approach for analyzing the Yuba River water temperatures could be used. This could be done by using WTI values, where exceeding the WTI temperature criteria for less than 7 days would not be expected to affect each lifestage, but exceeding the WTI for more than 7 days would be detrimental.

[3] Note, however, the UILT is 7 continuous days exposure and is not comparable to a daily maximum temperature.

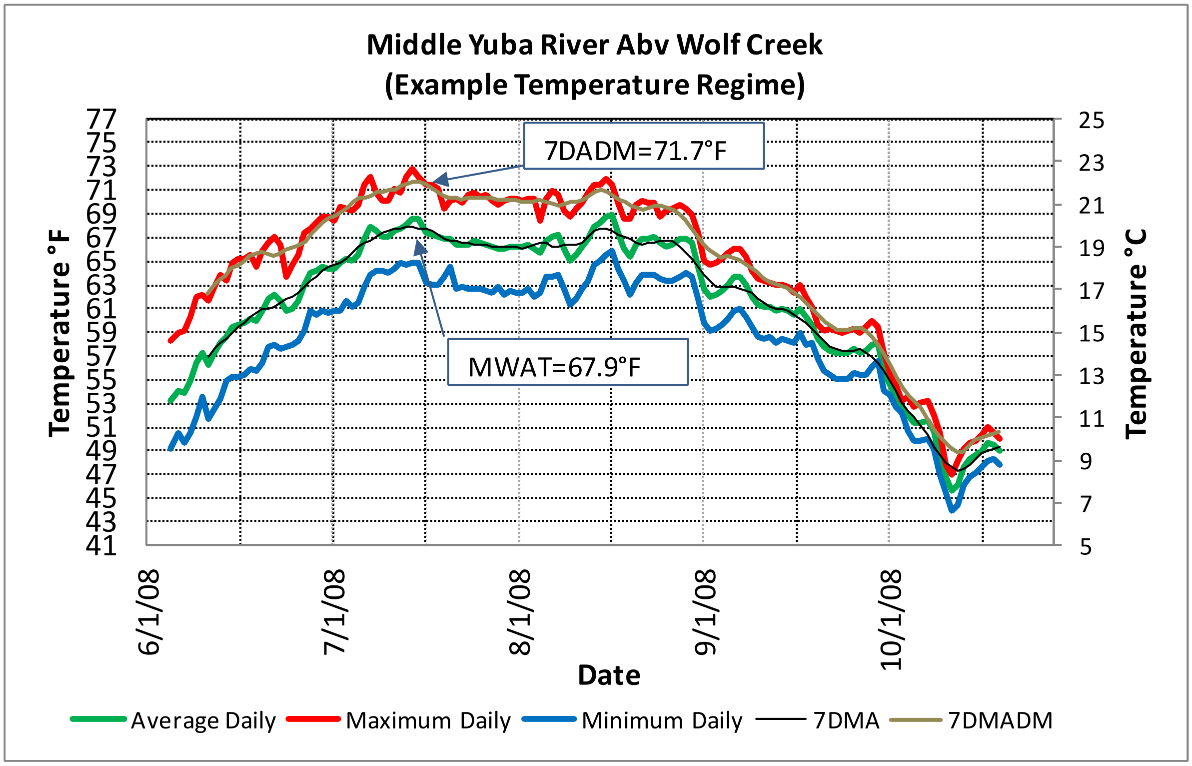

Figure 8. Middle Fork Yuba River Water Temperature Including 7 Day Moving Averages of the Average Daily Temperature and the Maximum Daily Temperature. Also Included Are the Maximum Weekly Average Temperature (MWAT) and the 7 Day Average Daily Maximum Temperature (7DADM).

Quantifying the number of average daily water temperature values that exceed a WTI threshold would be a direct approach to quantifying habitat suitability. The MWAT and/or the moving average (7DMA) identify a maximum average weekly water temperature value, but do not indicate the duration of time that this occurred. Similarly, if acute temperature was a concern, the individual water temperature measurements (e.g., hourly) could be used to identify the number of hours (duration) that a maximum WTI value was exceeded (e.g., tally the number of days and hours). Conversely, the 7DADM and/or the moving average (7DMADM) identify a maximum average weekly maximum temperature value, but do not indicate the duration of time that it occurred.

7 SPECIES- AND LIFESTAGE-SPECIFIC WATER TEMPERATURE RANGE ACCEPTABLE FOR REINTRODUCTION EVALUATION

The goal of the temperature analysis is twofold: (1) to identify the high temperature WTI value(s) that clearly demarcate the spatial/temperature boundary between where steelhead and Chinook salmon lifestages can and cannot exist (even though temperature is a stressor) (upper tolerable WTI); and (2) to determine within the "can exist" boundary, if there is a core area where they can thrive without temperature as a stressor (upper optimal WTI). The upper tolerable temperature represents the upper boundary of the range of acceptable water temperatures for reintroduction evaluation. It represents a water temperature at which fish can survive indefinitely, without experiencing substantial detrimental effects to physiological and biological functions such that survival occurs, but growth and reproduction success are reduced below optimal. The upper optimal temperature represents the upper boundary of the optimum range and represents a temperature below which growth, reproduction, and/or behavior are not affected by temperature. Below, we discuss: (1) existing regulatory water temperature standards or guidelines that could be used as index values; and (2) specific water temperature index values that have been derived based on the literature review in this report.

7.1 Existing Water Temperature Standards/Guidelines

Several different water temperature standards are used currently by states for salmonids (e.g., California, Oregon, and Washington water temperature standards). California's Basin Plan is largely based on not altering the temperature of intrastate waters unless alterations can be shown to not have an effect on beneficial uses for cold freshwater habitat, migration, and/or spawning (**Table 10**). The beneficial uses of the Yuba River are listed in **Table 11**. Specific temperature criteria for species/lifestages are not identified in the Basin Plan nor are there specific temperature objectives for the Yuba River system. However, for the Sacramento River, seasonal temperature criteria have been developed (Table 10). These temperature objectives, while not directly applicable to the Yuba River, give an indication of temperature objectives that have been set for anadromous fish in the basin.

Table 10. Basin Plan Temperature Standards Including Specific Standards for the Sacramento River.

Temperature

The natural receiving water temperature of intrastate waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Water Board that such alteration in temperature does not adversely affect beneficial uses.

Temperature objectives for COLD interstate waters, WARM interstate waters, and Enclosed Bays and Estuaries are as specified in the *Water Quality Control Plan for Control of Temperature in the Coastal and Interstate Waters and Enclosed Bays of California* including any revisions. There are also temperature objectives for the Delta in the State Water Board's May 1991 *Water Quality Control Plan for Salinity*.

At no time or place shall the temperature of COLD or WARM intrastate waters be increased more than 5°F above natural receiving water temperature. Temperature changes due to controllable factors shall be limited for the water bodies specified as described in Table III-4. To the extent of any conflict with the above, the more stringent objective applies.

In determining compliance with the water quality objectives for temperature, appropriate averaging periods may be applied provided that beneficial uses will be fully protected.

TABLE III-4
SPECIFIC TEMPERATURE OBJECTIVES

DATES	APPLICABLE WATER BODY
From 1 December to 15 March, the maximum temperature shall be 55°F. From 16 March to 15 April, the maximum temperature shall be 60°F. From 16 April to 15 May, the maximum temperature shall be 65°F. From 16 May to 15 October, the maximum temperature shall be 70°F. From 16 October to 15 November, the maximum temperature shall be 65°F. From 16 November to 30 November, the maximum temperature shall be 60°F.	Sacramento River from its source to Box Canyon Reservoir (9); Sacramento River from Box Canyon Dam to Shasta Lake (11)
The temperature in the epilimnion shall be less than or equal to 75°F or mean daily ambient air temperature, whichever is greater.	Lake Siskiyou (10)
The temperature shall not be elevated above 56°F in the reach from Keswick Dam to Hamilton City nor above 68°F in the reach from Hamilton City to the I Street Bridge during periods when temperature increases will be detrimental to the fishery.	Sacramento River from Shasta Dam to I Street Bridge (13, 30)

Table 11. Basin Plan Beneficial Uses for the Yuba River.

TABLE II-1

SURFACE WATER BODIES AND BENEFICIAL USES

	SURFACE WATER BODIES (1)	HYDRO UNIT NUMBER	MUN	AGRI-CULTURE AGR		INDUSTRY PROC	IND	POW	RECREATION REC-1		REC-2	FRESHWATER HABITAT (2) WARM	COLD	MIGRATION MIGR		SPAWNING SPWN		WILD	NAV
			MUNICIPAL AND DOMESTIC SUPPLY	IRRIGATION	STOCK WATERING	PROCESS	SERVICE SUPPLY	POWER	CONTACT	CANOEING AND RAFTING (1)	OTHER NONCONTACT	WARM	COLD	WARM (3)	COLD (4)	WARM (3)	COLD (4)	WILDLIFE HABITAT	NAVIGATION
	YUBA RIVER																		
41	SOURCES TO ENGLEBRIGHT RESERVOIR	517.	E	E	E			E	E	E	E		E				E	E	
42	ENGLEBRIGHT DAM TO FEATHER RIVER	515.3		E	E			E	E	E	E	E	E	E	E	E	E	E	

LEGEND
E = EXISTING BENEFICIAL USES
P = POTENTIAL BENEFICIAL USES
L = EXISTING LIMITED BENEFICIAL USE

The EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) provides water temperature recommendations regarding coldwater salmonid uses and numeric criteria to protect those uses for the following:

Salmonid Uses	Criteria
Salmon/trout core juvenile rearing	61°F (16°C) 7DADM
Salmon/trout migration plus non-core juvenile rearing	64°F (18°C) 7DADM
Salmon/trout migration	68°F (20°C) 7DADM
Salmon/trout spawning, egg incubation, and fry emergence	55°F (13°C) 7DADM
Steelhead smoltification	57°F (14°C) 7DADM

These temperature criteria are developed for summer water temperatures, except for the spawning and smolting lifestages which occur earlier in the year. The criteria are intended to represent the upper end of the optimal temperature range for each lifestage. It is important to note that the criteria are based on 7DADM (daily maximum temperatures), while the data used to generate the criteria were primarily based on daily average or continuous temperature field/laboratory data sets (**Table 12**). Several general assumptions were applied by EPA (2003b) to the data to make a connection between 7DADM temperature and the field/laboratory data (Section 8.1).

Table 12. EPA (2003b) Laboratory and Field Data Summary for Generating Water Temperature Criteria.

Life Stage	Temperature Consideration	Temperature & Unit	Reference
Spawning and Egg Incubation	*Temp. Range at which Spawning is Most Frequently Observed in the Field	4 - 14°C (daily avg)	Issue Paper 1; pp 17-18 Issue Paper 5; p 81
	* Egg Incubation Studies - Results in Good Survival -Optimal Range	 4 - 12°C (constant) 6 - 10°C (constant)	 Issue Paper 5; p 16
	*Reduced Viability of Gametes in Holding Adults	> 13°C (constant)	Issue Paper 5; pp 16 and 75
Juvenile Rearing	*Lethal Temp. (1 Week Exposure)	23 - 26°C (constant)	Issue Paper 5; pp 12, 14 (Table 4), 17, and 83-84
	*Optimal Growth - unlimited food - limited food	 13 - 20°C (constant) 10 - 16°C (constant)	 Issue Paper 5; pp 3-6 (Table 1), and 38-56
	*Rearing Preference Temp. in Lab and Field Studies	10 - 17°C (constant) < 18°C (7DADM)	Issue Paper 1; p 4 (Table 2). Welsh et al. 2001.
	*Impairment to Smoltification	12 - 15°C (constant)	Issue Paper 5; pp 7 and 57-65 Issue Paper 5; pp 7 and 57-65
	*Impairment to Steelhead Smoltification	> 12°C (constant)	
	*Disease Risk (lab studies) -High - Elevated - Minimized	 > 18 - 20°C (constant) 14 - 17°C (constant) 12 - 13°C (constant)	Issue Paper 4, pp 12 - 23
Adult Migration	*Lethal Temp. (1 Week Exposure)	21- 22°C (constant)	Issue Paper 5; pp 17, 83 - 87
	*Migration Blockage and Migration Delay	21 - 22°C (average)	Issue Paper 5; pp 9, 10, 72-74. Issue Paper 1; pp 15 - 16
	*Disease Risk (lab studies) - High - Elevated - Minimized	 > 18 - 20°C (constant) 14 - 17°C (constant) 12- 13°C (constant)	 Issue Paper 4; pp 12 - 23
	*Adult Swimming Performance - Reduced - Optimal	 > 20°C (constant) 15 - 19°C (constant)	 Issue Paper 5; pp 8, 9, 13, 65 - 71
	* Overall Reduction in Migration Fitness due to Cumulative Stresses	> 17-18°C (prolonged exposures)	Issue Paper 5; p 74

In addition to the numeric temperature criteria, there are a number of other factors (e.g., site specific issues, background temperatures) that EPA (2003b) considered in recommending coldwater salmonid uses and water quality standards (WQS) to protect those uses. These factors and the EPA's recommended approach for establishing WQS are described in EPA (2003b).

EPA (2003b) recognized that salmonids will use waters that are warmer than their optimal thermal range and further recognizes that some portions of rivers and streams naturally (i.e., absent human impacts) were warmer than the salmonid optimal range. They also recognized that some streams have unique diurnal temperature patterns, which may necessitate modified WQS. To account for these issues, the EPA identified three alternate salmonid temperature standard approaches. These include identifying the natural background temperature of the water body, creating site-specific temperature criteria, and/or identifying that a criterion is "unattainable" and altering the use designation to a use designation that has a criterion that is obtainable.

The EPA's water temperature recommendations are intended to assist States and Tribes to adopt temperature WQS that the EPA can approve consistent with its obligations under the Clean Water Act and the Endangered Species Act. States and Tribes that adopt temperature WQS consistent with these recommendations can expect an expedited review by EPA and the Services, subject to new data and information that might be available to during that review (EPA 2003b). In some cases, the criteria seem to be conservative and may exclude habitat that is currently used and/or demonstrably usable by salmonid lifestages. Section 8.1 has a brief discussion of issues related to the EPA (2003b) numerical criteria based on 7DADM temperatures and the needs of the Yuba Salmon Forum.

7.2 Site Specific Water Temperature Index Values

In addition to the EPA (2003b) numeric temperature criteria (Section 7.1) it also seems appropriate to develop Yuba Salmon Forum water temperature index values that are specific to the purposes of the Yuba Salmon Forum and the Yuba River. Below, for each species/lifestage, we provide: (1) an upper tolerance WTI (UTWTI) that identifies the sustained (chronic) tolerance/no tolerance boundary; and (2) the upper optimal WTI (UOWTI) where physiological processes (growth, disease resistance, normal development of embryos) are not stressed by temperature.

The lifestage-specific WTI values are not intended to represent significance thresholds, but instead provide criteria to evaluate reintroduction of anadromous salmonids. Moreover, as suggested by DWR (2007), the use of temperature "boundaries" has inherent drawbacks associated with the often indistinguishable effects at the upper and lower ends of an identified range and attributing undue specificity to values slightly exceeding an identified range. Nonetheless, WTI values, as defined, are used for evaluation of water temperature considerations regarding the reintroduction of steelhead (**Table 13**) and spring-run Chinook salmon (**Table 14**) in the Upper Yuba River Basin.

7.2.1 Steelhead

Table 13. Lifestage-Specific Upper Optimal Water Temperature Index (UOWTI) Values and Upper Tolerance Water Temperature Index (UTWTI) Values Identified as Defining the Range of Acceptable Water Temperatures for Evaluation of the Reintroduction of Steelhead in the Upper Yuba River Basin.

Lifestage	Upper Optimum WTI[1]	Upper Tolerance WTI[1]	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Adult Migration	64°F	68°F	■■	■■	■■					■■	■■	■■	■■	■■
Adult Holding	61°F	65°F	■■	■■	■■					■■	■■	■■	■■	■■
Spawning	54°F	57°F	■■	■■	■■	■■								
Embryo Incubation	54°F	57°F	■■	■■	■■	■■	■■							
Juv. Rearing & Downstream Mvmt.	65°F	68°F	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■
Smolt Emigration	52°F	55°F	■■	■■	■■	■□						■■	■■	■■

[1] The WTI values are to be applied to the water temperature metrics recommended in Section 8, below.

7.2.2 Spring-run Chinook Salmon

Table 14. Lifestage-Specific Upper Optimal Water Temperature Index (UOWTI) Values and Upper Tolerance Water Temperature Index (UTWTI) Values Identified as Defining the Upper Acceptable Water Temperatures for Evaluation of the Reintroduction of Spring-Run Chinook Salmon in the Upper Yuba River Basin.

Lifestage	Upper Optimum WTI[1]	Upper Tolerance WTI[1]	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Adult Migration	64°F	68°F				■■	■■	■■	■■	■■				
Adult Holding	61°F	65°F				■■	■■	■■	■■	■■				
Spawning	56°F	58°F									■■	■■	■□	
Embryo Incubation	56°F	58°F	■■	■■							■■	■■	■■	■■
Juv. Rearing & Downstream Mvmt.	61°F	65°F	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■
Smolt Emigration	63°F	68°F	■■	■■	■■	■■	■□					■■	■■	■■

[1] The WTI values are to be applied to the water temperature metrics recommended in Section 8, below.

8 WATER TEMPERATURE METRICS

Water temperature metrics (e.g., MWAT, 7DADM) are typically designed to provide a reproducible index of temperature over a period of time that can be used in combination with temperature standards (numeric criteria values) to determine if a water temperature body is impaired. Water temperature metrics are by definition an index of the complete temperature time series. As such, they do not completely represent the temperature time series nor are they always the most accurate way to represent the biological response of various lifestages. Water temperature metrics for potential application to the Yuba Salmon Forum specific criteria (UOWTI and UTWTI) are described below.

8.1 7DADM

The EPA (2003a) recommends the 7DADM (maximum 7-day average of the daily maxima) as a water temperature metric for all of the numeric criteria that is applied to a specific species and lifestage. The 7DADM is similar to the maximum weekly average temperature metric that was previously used by the EPA for its national temperature criteria recommendations (EPA 1977). However, in 2003, the EPA initiated use of the 7DADM metric "because it describes the maximum temperatures in a stream, but is not overly influenced by the maximum temperature of a single day."

A 7DADM value is calculated by adding the daily maximum temperatures recorded at a site on seven consecutive days and dividing by seven. Thus, it reflects an average of daily maximum temperatures that fish are exposed to over a week-long period. EPA (2003b) states that because this metric "is oriented to daily maximum temperatures, it can be used to protect against acute effects, such as lethality and migration blockage conditions." This statement illustrates two shortcomings of the EPA (2003a) use of the 7DADM metric. The 7DADM: (1) includes no duration information, which is critical to understanding acute (zone of resistance) temperature analysis – rather, it is an index of maximum temperature that occurs for a short time each day and, most importantly; (2) the numeric criteria that are identified by EPA (2003b) are not acute criteria nor derived from acute criteria data, but are chronic temperature criteria.

The EPA (2003b) numeric criteria were derived from chronic field or laboratory studies (e.g., > 7 day continuous or average daily temperatures), including the migratory blockage data (see Section 5.1; Table 12). A couple of simple examples illustrate this concept. The EPA (2003b) juvenile core rearing criteria is 61°F 7DADM and is the same temperature value as the upper optimal growth temperature under limited food (Table 12, 16°C), but the optimal growth temperature was derived from constant temperature laboratory studies. This temperature is much lower than the temperature where acute temperature affects occur. The UILT (7 day) from literature studies is 72 - 79°F (e.g., Table 12) and for shorter duration exposure is even much higher 80 - 88°F (e.g., see Table TT2 in Myrick and Cech 2001). Another example is the migration criteria. The migration blockage source data is based on observations in natural rivers, and is based on daily average or weekly field temperatures (70 – 72°F) (Table 12; McCullough 1999).

A daily maximum temperature equivalent of this temperature (70°F) is approximately 75°F [4], but the EPA (2003b) 7DADM numeric criterion for migration was set at 68°F.

EPA (2003b) states that the 7DADM metric can also can be used to protect against sub-lethal or chronic effects (e.g., temperature effects on growth, disease, smoltification, and competition), but the resultant cumulative thermal exposure fish experience over the course of a week or more needs to be considered when selecting a 7DADM value to protect against these effects. The EPA's general conclusion from studies on fluctuating water temperature regimes (which is what fish generally experience in rivers) is that fluctuating temperatures increase juvenile growth rates when mean temperatures are colder than the optimal growth temperature derived from constant temperature studies, but will reduce growth when the mean temperature exceeds the optimal growth temperature (see Issues Paper 5, pages 51-56). When the mean temperature is above the optimal growth temperature, the "mid-point" temperature between the mean and the maximum is the "equivalent" constant temperature. This "equivalent" constant temperature then can be directly compared to laboratory studies done at constant temperatures. For example, a river with a 7DADM value of 64°F and a 58°F weekly mean temperature (i.e., diurnal variation of ± 5.4°F) will be roughly equivalent to a constant laboratory study temperature of 61.7°F (mid-point between 58°F and 65°F). Thus, both maximum and mean temperatures are important when determining a 7DADM value that is protective against sub-lethal/chronic temperature effects.

To account for using the 7DADM metric based on constant temperature laboratory data, EPA (2003a) assumed an average diel temperature difference between the mean and daily maximum temperature of 5.4°F, although the EPA appears to have decreased the temperature in the laboratory data down by 2.7°F (equivalently added 2.7°F to the criteria). It is completely unclear, however, if or how EPA then also accounted for the fact that 7DADM temperature is on average also 5.4°F greater than the average daily temperature (i.e., was this accounted for or not).

It also is unclear if the "midpoint of the maximum and average temperature" correction was applied for all lifestages. If so, this would be inappropriate based on the data available. The "midpoint" correction literature is only applicable to juvenile growth. There is no evidence presented that it is applicable to other lifestages. Also, the juvenile growth "midpoint" temperature correction is somewhat mis-represented in EPA (2003b). The main study relied on by EPA (2003b) is Hokanson et al. (1977), and that study states that the difference in growth between constant and diel fluctuating temperatures was 39% (1.5°C in a ±3.8C fluctuating range) of the difference between the

[4] Maximum daily temperatures are typically 5.4°F higher than average daily temperature (EPA 2003b).

average and maximum temperature (not 50% or the midpoint) and, perhaps more importantly, most of the studies reviewed by EPA indicate that growth in constant temperature was essentially equivalent to growth in fluctuating temperatures. Elliott (1975), for example, found that a growth model developed from constant temperature experimental data predicted brown trout growth in daily fluctuating temperature environments accurately when the mean daily value of the fluctuating temperature was used as input to the growth model.

For the evaluation of potential water temperature-related impacts associated with the reintroduction of anadromous salmonids into the Upper Yuba River Basin, 7DADM values could be calculated for species-specific lifestage periods on an annual basis over the simulation or empirical data period, and the occurrences when that 7DADM values exceed the EPA (2003b) numeric values could be compared among rivers/reaches in the Upper Yuba River Basin.

8.2 ADT

The average daily temperature (ADT) should be considered for application to the Yuba Salmon Forum specific criteria (WTI values) because nearly all of the data in the literature review were either based on ADT or on continuous temperature (also see Table 12). For juvenile growth, the data from Hokanson et al. (1977) can be directly applied to the constant temperature data to provide a correction, if deemed appropriate. The average daily temperature also can be used to determine the number of days (duration) that a WTI is exceeded, and duration of exceedance can be compared among specific geographic areas.

8.3 MWAT

The Maximum Weekly Average Temperature (MWAT) is a metric used by the California RWQCB that is commonly applied to water temperature numeric objectives. Generally, the MWAT serves as a summary measurement of instream water temperature variation that may occur on a daily or seasonal basis, and is used to evaluate chronic (sub-lethal) water temperature impacts (SWRCB website).

The MWAT is found by calculating the mathematical mean of multiple, equally spaced, daily water temperatures over a 7-day consecutive period. The MWAT is defined as the highest value calculated for all possible 7-day periods over a given time period, which usually extends over the summer or is commensurate to the duration of a salmonid lifestage. In order to determine whether the maximum weekly temperature standard is attained, the mathematical mean of multiple, equally spaced, daily temperatures over a seven-day consecutive period is compared to the criterion.

For the evaluation of acceptable water temperature-related reintroduction potential associated with spring-run Chinook salmon and steelhead in the Upper Yuba River Basin, MWAT values should be calculated for species-specific lifestage periods, on an annual basis over the monitoring or simulation period, and the probability that MWAT values exceed specified water temperature index values will be compared among rivers/reaches in the Upper Yuba River Basin.

The use of a single temperature measurement such as MWAT is convenient from a monitoring and regulatory standpoint, but oversimplifies the complex interactions between water temperature regimes and fish health which are affected by the duration of peak and daily average temperatures. Therefore, for the evaluation of acceptable water temperature-related reintroduction potential associated with spring-run Chinook salmon and steelhead in the Upper Yuba River Basin, it is recommended that both the MWAT, and ADT lifestage-specific exceedance durations, be compared with the UOWTI and UTWTI values.

8.4 7DMAVG

The 7-day moving average of maximum daily temperature (7DMAVG) serves as the basis for instream water temperature standards, including those of the Oregon Department of Environmental Quality (ODEQ). The reason for using the 7DMAVG is to decrease the effect of a single peak temperature on data interpretation. Aquatic organisms are affected more by exposure to high temperature over an extended period than to a single exceedance of the criteria. The ODEQ recognizes that not only summer maximum temperatures are of importance to aquatic biota. The intent is to protect the temperature regime through the year. Built into the ODEQ 7DMAVG standard is the assumption that if stream and riparian conditions are managed such that they meet the summer maximum criteria, those same conditions will protect the temperature regime of the stream through the year.

The 7DMAVG standard is based not on directly lethal temperatures (usually above 70°F), but on sub-lethal effects, which are numerous. Sub-lethal effects can lead to death indirectly, or they may reduce the ability of the fish to successfully reproduce and for their offspring to survive and grow. These sub-lethal effects include an increase in the incidence of disease, an inability to spawn, a reduced survival rate of eggs, a reduced growth and survival rate of juveniles, increased competition for limited habitat and food, reduced ability to compete with other species that are better adapted to higher temperatures (many of these are introduced species) and other adverse effects. Sub-lethal effects of temperature on salmonids occur gradually as stream temperatures increase.

In California, the 7DMAVG has been applied in effectiveness monitoring protocols (e.g. 2006 Green Diamond Resource Company Aquatic Habitat Conservation Plan/Candidate Conservation Agreement and Assurances) and other monitoring efforts (e.g., Upper Yuba River Studies Program 2006 Upper Yuba River Water Temperature Criteria for Chinook salmon and Steelhead). However, for the evaluation of water temperature-related reintroduction potential associated with spring-run Chinook salmon and steelhead in the Upper Yuba River Basin, 7DMAVG is not recommended as a metric.

9 WATER TEMPERATURE EVALUATION CONSIDERATIONS

For the evaluation of water temperatures acceptable for reintroduction of salmonids in the Upper Yuba River Basin, it is anticipated that water temperature modeling and/or monitoring will be applied for a comparison among rivers and reaches in the Upper Yuba River Basin. In addition to the application of the criteria and metrics as described in the preceding sections, it may be appropriate to consider other specific evaluation methodologies.

9.1 Water Year Type

Model output and/or monitoring data could be summarized by water year type. Comparisons of the water temperature-related potential among rivers and reaches in the Upper Yuba River Basin could include water year types. This would help identify reaches/lengths of river that would be suitable in all conditions (e.g., critically dry to wet years) as well as the lengths of river that would be suitable under more favorable conditions (e.g., wet water year types only).

9.2 Water Temperature Exceedance Curves

Model output and/or monitoring data also could be summarized by the calculation of water temperature exceedance curves, by month, occurring over the period of evaluation for each of the rivers and reaches. Exceedance curves are particularly useful for examining the probability of occurrence/duration of water temperatures. The evaluation approach could specifically evaluate the probabilities/duration of time that each of the identified lifestage-specific water temperature index values would be exceeded over the period of evaluation. Comparisons of the water temperature-related potential among rivers and reaches in the Upper Yuba River Basin could be made by presentation of monthly cumulative water temperature exceedance distribution probabilities (using average daily water temperatures) relative to specified water temperature index values corresponding to the appropriate months for each lifestage of spring-run Chinook salmon and steelhead.

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APPENDIX A

LIFESTAGE-SPECIFIC WATER TEMPERATURE
BIOLOGICAL EFFECTS AND INDEX TEMPERATURE VALUES

STEELHEAD LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

Adult Immigration and Holding

Water temperatures can control the timing of adult spawning migrations and can affect the viability of eggs in holding females. YCWA et al. (2007) suggests that few studies have been published examining the effects of water temperature on either steelhead immigration or steelhead holding, and none of the available studies were recent (Bruin and Waldsdorf 1975; McCullough *et al.* 2001). The available studies suggest that adverse effects occur to immigrating and holding steelhead at water temperatures exceeding the mid 50°F range, and that immigration will be delayed if water temperatures approach approximately 70°F (**Table 2**). Water temperature index values of 52°F, 56°F, 61°F, 65°F and 70°F were chosen because they provide a gradation of potential water temperature effects, and the available literature provided the strongest support for these values.

Because of the paucity of literature pertaining to steelhead adult immigration and holding, an evenly spaced range of water temperature index values could not be achieved. We also used some pertinent information related to other salmonids (e.g., Chinook salmon). 52°F was selected as a water temperature index value because it has been referred to as a "recommended" (Reclamation 2003), "preferred" (McEwan and Jackson 1996; NMFS 2000; NMFS 2002a), and "optimum" (Reclamation 1997a) water temperature for steelhead adult immigration. Increasing levels of thermal stress to this life stage may reportedly occur above the 52°F water temperature index value. 56°F was selected as a water temperature index value because 56°F represents a water temperature above which adverse effects to migratory and holding steelhead begin to arise (Bruin and Waldsdorf 1975; Leitritz and Lewis 1980; McCullough *et al.* 2001; Smith *et al.* 1983). 50-59°F is referred to as the "preferred" range of water temperatures for California summer steelhead holding (Moyle 1995). Whereas, water temperatures greater than 61°F may result in "chronic high stress" of holding Central Valley winter-run steelhead (USFWS 1995). 65°F was selected as a water temperature index value because steelhead (and fall-run Chinook salmon) encounter potentially stressful temperatures between 64.4-73.4°F (Richter and Kolmes 2005). Additionally, over 93% of steelhead detections occurred in the 65.3-71.6°F range, although this may be above the temperature for optimal immigration (Salinger and Anderson 2006) and/or may modify migration timing due to holding in coldwater refugia (High et al. 2006). 70°F was selected as the highest water temperature index value because the literature suggests that water temperatures near and above 70.0°F may result in a thermal barrier to adult steelhead migrating upstream (McCullough *et al.* 2001) and are water temperatures referred to as "stressful" to upstream migrating steelhead in the Columbia River (Lantz

1971 as cited in Beschta et al 1987). Further, Coutant (1972) found that the UILT for adult steelhead was 69.8°F and temperatures between 73-75°F are described as "lethal" to holding adult steelhead in Moyle (2002).

Spawning and Embryo Incubation

Relatively few studies have been published directly addressing the effects of water temperature on steelhead spawning and embryo incubation (Redding and Schreck 1979; Rombough 1988). Because anadromous steelhead and non-anadromous rainbow trout are genetically and physiologically similar, studies on non-anadromous rainbow trout also were considered in the development of water temperature index values for steelhead spawning and embryo incubation (Moyle 2002; McEwan 2001). From the available literature, water temperatures in the low 50°F range appear to support high embryo survival, with substantial mortality to steelhead eggs reportedly occurring at water temperatures in the high 50°F range and above (**Table 3**). Water temperatures in the 45-50°F range have been referred to as the "optimum" for spawning steelhead (FERC 1993).

Water temperature index values of 46°F , 52°F, 54°F, 57°F, and 60°F were selected for two reasons. First, the available literature provided the strongest support for water temperature index values at or near 46°F, 52°F, 54°F, 57°F, and 60°F. Second, the index values reflect a gradation of potential water temperature effects ranging between optimal to lethal conditions for steelhead spawning and embryo incubation. Some literature suggests water temperatures ≤ 50°F are when steelhead spawn (Orcutt et al. 1968) and/or are optimal for steelhead spawning and embryo survival (FERC 1993; Myrick and Cech 2001; Timoshina 1972) and temperatures between 39-52°F are "preferred" by spawning steelhead (IEP Steelhead Project Work Team (no date); McEwan and Jackson 1996), a larger body of literature suggests optimal conditions occur at water temperatures ≤ 52°F (Humpesch 1985; NMFS 2000; NMFS 2001a; NMFS 2002a; Reclamation 1997b; SWRCB 2003; USFWS 1995a). Further, water temperatures between 48-52°F were referred to as "optimal" (FERC 1993; McEwan and Jackson 1996; NMFS 2000) and "preferred" (Bell 1986) for steelhead embryo incubation. Therefore, 52°F was selected as the lowest water temperature index value. Increasing levels of thermal stress to the steelhead spawning and embryo incubation life stage may reportedly occur above the 52°F water temperature index value.

54°F was selected as the next index value, because although most of the studies conducted at or near 54.0°F report high survival and normal development (Kamler and Kato 1983; Redding and Schreck 1979; Rombough 1988), some evidence suggests that symptoms of thermal stress arise at or near 54.0°F (Humpesch 1985; Timoshina 1972). Thus, water temperatures near 54°F may represent an inflection point between properly functioning water temperature conditions, and conditions that cause negative effects to steelhead spawning and embryo incubation. Further, water temperatures greater than 55°F were referred to as "stressful" for incubating steelhead embryos (FERC 1993). 57°F was selected as an index value because embryonic mortality increases sharply and development becomes retarded at incubation temperatures greater than or equal to 57.0°F. Velsen (1987) provided a compilation of data on rainbow trout and steelhead embryo mortality to 50% hatch under incubation temperatures ranging from 33.8°F to 60.8°F that demonstrated a two-fold increase in mortality for embryos incubated at 57.2°F, compared to embryos incubated at 53.6°F. In a laboratory study using gametes from Big Qualicum River, Vancouver Island, steelhead mortality increased to 15% at a constant temperature of 59.0°F, compared to less than 4% mortality at constant temperatures of 42.8°F, 48.2°F, and 53.6°F (Rombough 1988). Also, alevins hatching at 59.0°F were considerably smaller and appeared less well developed than those incubated at the lower temperature treatments. From fertilization to 50% hatch, Big Qualicum River steelhead had 93% mortality at 60.8°F, 7.7% mortality at 57.2°F, and 1% mortality at 47.3°F and 39.2°F (Velsen 1987). Myrick and Cech (2001) similarly described water temperatures >59°F as "lethal" to incubating steelhead embryos, although FERC (1993) suggested that water temperatures exceeding 68°F were "stressful" to spawning steelhead and "lethal" when greater than 72°F.

Juvenile Rearing & Downstream Movement

Water temperature index values were developed to evaluate the combined steelhead rearing (fry and juvenile) and juvenile downstream movement lifestages. Some steelhead may rear in freshwater for up to three years before emigrating as yearling+ smolts, whereas other individuals move downstream shortly after emergence as post-emergent fry, or rear in the river for several months and move downstream as juveniles without exhibiting the ontogenetic characteristics of smolts. Presumably, these individuals continue to rear and grow in downstream areas (e.g., lower Feather River, Sacramento River, and Upper Delta) and undergo the smoltification process prior to entry into saline environments. Thus, fry and juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement and are assessed in this Technical Memorandum using the fry and juvenile rearing water temperature index values.

The growth, survival, and successful smoltification of juvenile steelhead are controlled largely by water temperature. The duration of freshwater residence for juvenile steelhead is long relative to that of Chinook salmon, making the juvenile life stage of steelhead more susceptible to the influences of water temperature, particularly during the over-summer rearing period. Central Valley juvenile steelhead have high growth rates at water temperatures in the mid 60°F range, but reportedly require lower water temperatures to successfully undergo the transformation to the smolt stage.

Water temperature index values of 63°F, 65°F, 68°F, 72°F, and 75°F were selected to represent a gradation of potential water temperature effects ranging between optimal to lethal conditions for steelhead juvenile rearing (Table 4). The lowest water temperature index value of 63°F was established because Myrick and Cech (2001) describe 63°F as the "preferred" water temperature for wild juvenile steelhead, whereas "preferred" water temperatures for juvenile hatchery steelhead reportedly range between 64-66°F. 65°F was also identified as a water temperature index value because NMFS (2000; 2002a) reported 65°F as the upper limit preferred for growth and development of Sacramento and American River juvenile steelhead. Also, 65°F was found to be within the optimum water temperature range for juvenile growth (i.e., 59-66°F) (Myrick and Cech 2001), and supported high growth of Nimbus strain juvenile steelhead (Cech and Myrick 1999).

Increasing levels of thermal stress to this life stage may reportedly occur above the 65°F water temperature index value. For example, Kaya *et al.* (1977) reported that the upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F. Cherry *et al.* (1977) observed an upper preference water temperature near 68.0°F for juvenile rainbow trout, duplicating the upper preferred limit for juvenile steelhead observed in Cech and Myrick (1999) and FERC (1993). Empirical adult *O. mykiss* population data from the North Yuba, Middle Yuba, South Yuba, Middle Fork American, and Rubicon rivers collected in 2007-2009 are plotted against temperature in Figure 4. The temperature used was the 8th largest average daily temperature during the summer (i.e., up to seven days had higher daily average temperatures). The data show a population density break at about 68.0°F. Although smaller population densities occurred at higher temperatures, the largest population densities occurred at temperatures near 68.0°F or less. In addition Figure 5 shows growth for a 200 mm juvenile O. mykiss versus temperature for three food levels (percent of maximum consumption = 30%, 50%, and 70%). The average empirically derived percent of maximum consumption in an adjacent watershed (Middle Fork American Fork River) was 50% (Hanson et al. 1997). Positive growth only occurs up to approximately 68°F. Because of the literature describing 68.0°F as both an upper preferred and an avoidance limit for juvenile *Oncorhynchus mykiss*, and because of the empirical fish population data and bioenergetics growth data, 68°F was established as a upper tolerable water temperature index value.

A water temperature index value of 72°F was established because symptoms of thermal stress in juvenile steelhead have been reported to arise at water temperatures approaching 72°F. For example, physiological stress to juvenile steelhead in Northern

California streams was demonstrated by increased gill flare rates, decreased foraging activity, and increased agonistic activity as stream temperatures rose above 71.6°F (Nielsen *et al.* 1994). Also, 72°F was selected as a water temperature index value because 71.6°F has been reported as an upper avoidance water temperature (Kaya *et al.* 1977) and an upper thermal tolerance water temperature (Ebersole *et al.* 2001) for juvenile rainbow trout. The highest water temperature index value of 75°F was established because NMFS and EPA report that direct mortality to rearing juvenile steelhead results when stream temperatures reach 75.0°F (EPA 2002; NMFS 2001b). Water temperatures >77°F have been referred to as "lethal" to juvenile steelhead (FERC 1993; Myrick and Cech 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan et al. 2000; McCullough 2001).

Yearling + Smolt Emigration

Laboratory data suggest that smoltification, and therefore successful emigration of steelhead smolts, is directly controlled by water temperature (Adams *et al.* 1975) (**Table 5**). Water temperature index values of 52°F and 55°F were selected to evaluate the steelhead smolt emigration life stage, because most literature on water temperature effects on steelhead smolting suggest that water temperatures less than 52°F (Adams *et al.* 1975; Myrick and Cech 2001; Rich 1987a) or less than 55°F (EPA 2003a; McCullough *et al.* 2001; Wedemeyer *et al.* 1980; Zaugg and Wagner 1973) are required for successful smoltification to occur. (Adams *et al.* 1973) tested the effect of water temperature (43.7°F, 50.0°F, 59.0°F or 68.0°F) on the increase of gill microsomal Na^+-, K^+-stimulated ATPase activity associated with parr-smolt transformation in steelhead and found a two-fold increase in Na^+-, K^+-ATPase at 43.7 and 50.0°C, but no increase at 59.0°F or 68.0°F. In a subsequent study, the highest water temperature where a parr-smolt transformation occurred was at 52.3°F (Adams *et al.* 1975). The results of Adams *et al.* (1975) were reviewed in Myrick and Cech (2001) and Rich (1987b), which both recommended that water temperatures below 52.3°F are required to successfully complete the parr-smolt transformation. Further, Myrick and Cech (2001) suggest that water temperatures between 43-50°F are the "physiologically optimal" temperatures required during the parr-smolt transformation and necessary to maximize saltwater survival. The 52°F water temperature index value established for the steelhead smolt emigration life stage is the index value generally reported in the literature as the upper limit of the water temperature range that provides successful smolt transformation thermal conditions. Increasing levels of thermal stress to this life stage may reportedly occur above the 52°F water temperature index value.

Zaugg and Wagner (1973) examined the influence of water temperature on gill ATPase activity related to parr-smolt transformation and migration in steelhead. They found ATPase activity was decreased and migration reduced when juveniles were exposed to water temperatures of 55.4°F or greater. In a technical document prepared by the EPA to provide temperature water quality standards for the protection of Northwest native salmon and trout, water temperatures less than or equal to 54.5°F were recommended for emigrating juvenile steelhead (EPA 2003b). Water temperatures are considered "unsuitable" for steelhead smolts at >59°F (Myrick and Cech 2001) and "lethal" at 77°F (FERC 1993).

CHINOOK SALMON LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

It has been suggested that separate water temperatures standards should be developed for each run-type of Chinook salmon. For example, McCullough (1999) states that spring-run Chinook salmon immigrate in spring and spawn in 3rd to 5th order streams and, therefore, face different migration and adult holding temperature regimes than do summer- or fall-run Chinook salmon, which spawn in streams of 5th order or greater. However, to meet the objectives of the current literature review, run-types are not separated because: (1) there is a paucity of literature specific to each life stage of each run-type; (2) there is an insufficient amount of data available in the literature suggesting that Chinook salmon run-types respond to water temperatures differently; (3) the WTI values derived from all the literature pertaining to Chinook salmon for a particular life stage will be sufficiently protective of that life stage for each run-type; and (4) all run-types overlap in timing of adult immigration and holding and in some cases are not easily distinguished (Healey 1991). Nonetheless, water temperature relationships for each lifestage of spring-run Chinook salmon available in the literature are emphasized in the consideration and identification of WTI values for evaluation of reintroduction of spring-run Chinook salmon in the Upper Yuba River Basin.

Adult Immigration and Holding

The adult immigration and adult holding life stages are evaluated together, because it is difficult to determine the thermal regime that Chinook salmon have been exposed to in the river prior to spawning and in order to be sufficiently protective of pre-spawning fish, water temperatures that provide high adult survival and high egg viability must be available throughout the entire pre-spawning freshwater period. Although studies examining the effects of thermal stress on immigrating Chinook salmon are generally lacking, it has been demonstrated that thermal stress during the upstream spawning migration of sockeye salmon negatively affected the secretion of hormones controlling sexual maturation causing numerous reproductive impairment problems (McCullough *et al.* 2001).

The water temperature index values reflect a gradation of potential water temperature effects that range between those reported as "optimal" to those reported as "lethal" for adult Chinook salmon during upstream spawning migrations and holding. The water temperature index values established for the Chinook salmon adult immigration and holding lifestage are 61°F, 65°F, and 68°F (**Table 6)**. Although 56°F is referenced in the literature frequently as the upper "optimal" water temperature limit for upstream migration and holding, the references are not foundational studies and often are inappropriate citations. For example, Boles *et al.* (1988), Marine (1992), and NMFS (1997b) all cite Hinze (1959) in support of recommendations for a water temperature of 56°F for adult Chinook salmon immigration. However, Hinze (1959) is a study examining the effects of water temperature on incubating Chinook salmon eggs in the American River Basin. Further, water temperatures between 38-56°F are considered to represent the "observed range" for upstream migrating spring-run Chinook salmon (Bell 1986).

The lowest water temperature index value established was 61°F, because in the NMFS biological opinion for the proposed operation of the Central Valley Project (CVP) and State Water Project (SWP), 59°F to 60°F is reported as…"*The upper limit of the optimal temperature range for adults holding while eggs are maturing*" (NMFS 2000). Also, NMFS (1997b) states…"*Generally, the maximum temperature of adults holding, while eggs are maturing, is about 59°F to 60°F*" …and… "*Acceptable range for adults migrating upstream range from 57°F to 67°F*." ODEQ (1995) reports that "…*many of the diseases that commonly affect Chinook become highly infectious and virulent above 60°F*." Study summaries in EPA (2003) indicate disease risk is high at 62.6°F. Additionally, Ward and Kier (1999) designated temperatures <60.8°F as an "optimum" water temperature threshold for holding Battle Creek spring-run Chinook salmon. EPA (2003) chose a holding value of 61°F (7DADM) based on laboratory data various assumptions regarding diel temperature fluctuations. 61°F is also a holding temperature index value for steelhead (see above). The 61°F water temperature index value established for the Chinook salmon adult immigration and holding life stage is the index value generally reported in the literature as the upper limit of the optimal range, and is within the reported acceptable range. Increasing levels of thermal stress to this life stage may reportedly occur above the 61°F water temperature index value.

An index value of 65°F was established because Berman (1990) suggests effects of thermal stress to pre-spawning adults are evident at water temperatures near 65°F. Berman (1990) conducted a laboratory study to determine if pre-spawning water temperatures experienced by adult Chinook salmon influenced reproductive success, and found evidence suggesting latent embryonic abnormalities associated with water temperature exposure to pre-spawning adults that ranged from 63.5°F to 66.2°F. Ward et al. (2003; 2004) identified an extended period of average daily temperatures above 67°F during July as measured at the Quartz Bowl that preceded the onset of significant pre-spawn mortalities. During 2002, temperatures exceeded 67°F a total of 16 days with a maximum of 20.8°C on July 12. During 2003, temperatures exceed 67°F a total of 11 days with a maximum of 20.9°C on July 23. However during other years when there were minimal pre-spawn mortalities, maximum daily average water temperature at Quartz Bowl never exceeded 67°F more than an few days (Ward et al. 2004; Ward et al. 2006; Ward et al. 2007; McReynolds and Garman 2008; McReynolds and Garman 2010). During each of the years when Chinook salmon temperature mortality was not observed at Butte Creek (2001, 2004-2007), on average, daily temperature did not exceed 65.8°F for more than 7 days (Figure 6). Tracy McReynolds (Pers. Comm. October 2011) indicated that an upper tolerable holding temperature of 65°F was reasonable based on her experience.

An index value of 68°F was established because the Butte Creek data and the literature suggests that thermal stress at water temperatures greater than 68°F is pronounced, and severe adverse effects to immigrating and holding pre-spawning adults, including mortality, can be expected (Berman 1990; Marine 1997; NMFS 1997b; Ward et al. 2004).

Water temperatures between 70-77°F are reported as the range of maximum temperatures for holding pool conditions used by spring-run Chinook salmon in the Sacramento-San Joaquin system (Moyle et al. 1995). Migration blockage occurs for Chinook salmon at temperatures from 70-71+°F (McCollough 1999; McCullough et al. 2001; EPA 2003b). Strange (2010) found that the mean average body temperature during the first week of Chinook salmon migration on the Klamath River was 71.4°F. The UILT for Chinook salmon jacks is 69.8-71.6°F (McCullough 1999). The upper limit for spring-run Chinook salmon holding in Deer Creek is reportedly 80.6°F, at which point temperatures exceeding this value become "lethal" (Cramer and Hammack (1952), as cited in Moyle et al. (1995). As a result of the potential effects to immigrating and holding adult Chinook salmon that reportedly occur at water temperatures greater than or equal to 68°F, index values higher than 68°F were not established.

Spawning and Embryo Incubation

The adult spawning and embryo (i.e., eggs and alevins) incubation life stage includes redd construction, egg deposition, and embryo incubation. Potential effects to the adult spawning and embryo incubation life stages are evaluated together using one set of water temperature index values because it is difficult to separate the effects of water temperature between lifestages that are closely linked temporally, especially considering that studies describing how water temperature affects embryonic survival and development have included a pre-spawning or spawning adult component in the reporting of water temperature experiments conducted on fertilized eggs (Marine 1992; McCullough 1999; Seymour 1956).

The water temperature index values selected for the Chinook salmon spawning and embryo incubation life stages are 56°F, 58°F, 60°F, and 62°F (**Table 7**). Anomalously, FERC (1993) refers to 50°F as the "optimum" water temperature for spawning and incubating Chinook salmon. Additionally, for the adult spawning lifestage, FERC (1993) reports "stressful" and "lethal" water temperatures occuring at >60°F and >70°F, respectively, whereas for incubating Chinook salmon embryos, water temperatures are considered to be "stressful" at <56°F or "lethal" at >60°F. Much literature suggests that water temperatures must be less than or equal to 56°F for maximum survival of Chinook salmon embryos (i.e., eggs and alevins) during spawning and incubation. NMFS (1993b) reported that optimum water temperatures for egg development are between 43°F and 56°F. Similarly, Myrick and Cech (2001) reported the highest egg survival rates occur between water temperatures of 39-54°F. Reclamation (unpublished work) reports that water temperatures less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs. Bell (1986) recommends water temperatures ranging between 42-57°F for spawning Chinook salmon, and water temperatures between 41-58°F for incubating embryos. USFWS (1995a) reported a water temperature range of 41.0°F to 56.0°F for maximum survival of eggs and yolk-sac larvae in the Central Valley of California. The preferred water temperature range for Chinook salmon egg incubation in the Sacramento River was suggested as 42.0°F to 56.0°F (NMFS 1997a). Alevin mortality is reportedly significantly higher when Chinook salmon embryos are incubated at water temperatures above 56°F (USFWS 1999). NMFS (2002a) reported 56.0°F as the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River. The 56°F water temperature index value established for the Chinook salmon spawning and embryo incubation life stage is the index value generally reported in the literature as the upper limit of the optimal range for egg development and the upper limit of the range reported to provide maximum survival of eggs and yolk-sac larvae in the Central Valley of California. Increasing levels of thermal stress to this life stage may reportedly occur above the 56°F water temperature index value.

High survival of Chinook salmon embryos also has been suggested to occur at incubation temperatures at or near 58.0°F. For example, (Reclamation Unpublished Work) reported that the natural rate of mortality for alevins occurs at 58°F or less. Combs (1957) concluded constant incubation temperatures between 42.5°F and 57.5°F resulted in normal development of Chinook salmon eggs, and NMFS (2002a) suggests 53.0°F to 58.0°F is the preferred water temperature range for Chinook salmon eggs and fry.

Johnson (1953) found consistently higher Chinook salmon egg losses resulted at water temperatures above 60.0°F than at lower temperatures. In order to protect late incubating Chinook salmon embryos and newly emerged fry NMFS (1993a) has determined a water temperature criterion of less than or equal to 60.0°F be maintained in the Sacramento River from Keswick Dam to Bend Bridge from October 1 to October 31. Seymour (1956) provides evidence that 100% mortality occurs to late incubating Chinook salmon embryos when held at a constant water temperature greater than or equal to 60.0°F. For Chinook salmon eggs incubated at constant temperatures, mortality increases rapidly at temperatures greater than about 59-60°F (see data plots in Myrick and Cech 2001). Olsen and Foster (1957), however, found high survival of Chinook salmon eggs and fry (89.6%) when incubation temperatures started at 60.9°F and declined naturally for the Columbia River (about 7°F / month). Geist et al. (2006) found high (93.8%) Chinook salmon incubation survival through emergence for naturally declining temperatures (0.36°F/day) starting as high as 61.7°F; however, a significant reduction in survival occurred above this temperature.

The literature largely agrees that 100% mortality will result to Chinook salmon embryos incubated at water temperatures greater than or equal to 62.0°F (Hinze 1959; Myrick and Cech 2003; Seymour 1956; USFWS 1999). Approximately 80% or greater mortality of eggs incubated at constant temperatures of 63°F or greater (see data plots in Myrick and Cech 2001). Olsen and Foster (1957) found high mortality of Chinook salmon eggs and fry (79%) when incubation temperatures started at 65.2°F and declined naturally for the Columbia River (about 7°F / month). Geist et al. (2006) found low Chinook salmon incubation survival (1.7%) for naturally declining temperatures (0.36°F/day) when temperatures started at 62.6°F

Juvenile Rearing & Downstream Movement

Water temperature index values were identified for the combined spring-run Chinook salmon rearing (fry and juvenile) and juvenile downstream movement lifestages, for the reasons previously described regarding steelhead. Fry and juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement, and are assessed in this Technical Memorandum using the fry and juvenile rearing water temperature index values.

The water temperature index values of 60°F, 65°F, 68°F, 70°F and 75°F were identified for the spring-run Chinook salmon juvenile rearing and downstream movement lifestage. The lowest index value of 60°F was chosen because regulatory documents as well as several source studies, including ones recently conducted on Central Valley Chinook salmon fry and juveniles report 60°F as an optimal water temperature for growth (Banks *et al.* 1971; Brett *et al.* 1982; Marine 1997; NMFS 1997b; NMFS 2000;

NMFS 2001a; NMFS 2002a; Rich 1987b) (**Table 8**). Water temperatures below 60°F also have been reported as providing conditions optimal for fry and fingerling growth, but were not selected as index values, because the studies were conducted on fish from outside of the Central Valley (Brett 1952; Seymour 1956). Studies conducted using local fish may be particularly important because *Oncorhynchus* species show considerable variation in morphology, behavior, and physiology along latitudinal gradients (Myrick 1998; Taylor 1990b; Taylor 1990a). More specifically, it has been suggested that salmonid populations in the Central Valley prefer higher water temperatures than those from more northern latitudes (Myrick and Cech 2000).

The 60°F water temperature index value established for the Chinook salmon juvenile rearing and downstream movement life stage is the index value generally reported in the literature as the upper limit of the optimal range for fry and juvenile growth and the upper limit of the preferred range for growth and development of spring-run Chinook salmon fry and fingerlings. FERC (1993) referred to 58°F as an "optimum" water temperature for juvenile Chinook salmon in the American River. NMFS (2002a) identified 60°F as the "preferred" water temperature for juvenile spring-run Chinook salmon in the Central Valley. Increasing levels of thermal stress to this life stage may reportedly occur above the 60°F water temperature index value.

The index value of 65°F was selected because it represents an intermediate value between 64.0°F and 66.2°F, at which both adverse and beneficial effects to juvenile salmonids have been reported to occur. For example, at temperatures approaching and beyond 65°F, sub-lethal effects associated with increased incidence of disease reportedly become severe for juvenile Chinook salmon (EPA 2003a; Johnson and Brice 1953; Ordal and Pacha 1963; Rich 1987a). Conversely, numerous studies report that temperatures between 64.0°F and 66.2°F provide conditions ranging from suitable to optimal for juvenile Chinook salmon growth (Brett *et al.* 1982; Cech and Myrick 1999; Clarke and Shelbourn 1985; EPA 2003a; Myrick and Cech 2001; NMFS 2002a; USFWS 1995a). Maximum growth of juvenile fall-run Chinook salmon has been reported to occur in the American River at water temperatures between 56-59°F (Rich 1987) and in Nimbus Hatchery spring-run Chinook salmon at 66°F (Cech and Myrick 1999). Figure 5 shows growth for a 100 mm juvenile Chinook salmon versus temperature for three food levels (percent of maximum consumption = 30%, 50%, and 70%). The average percent of maximum consumption in an adjacent watershed (Middle Fork American Fork River) for O. *mykiss* was 50% (Hanson et al. 1997). Positive growth only occurs up to approximately 64°F for food levels expected in the wild (e.g., 50% maximum consumption).

A water temperature index value of 68°F was selected because, at water temperatures above 68°F, sub-lethal effects become severe such as reductions in appetite and growth of juveniles (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Chronic stress associated with water temperature can be expected when conditions reach the index value of 70°F. For example, growth becomes drastically reduced at temperatures close to 70.0°F and has been reported to be completely prohibited at 70.5°F (Brett *et al.* 1982; Marine 1997). 75°F was chosen as the highest water temperature index value because high levels of direct mortality to juvenile Chinook salmon reportedly result at this water temperature (Cech and Myrick 1999; Hanson 1991; Myrick and Cech 2001; Rich 1987b). Other studies have suggested higher upper lethal water temperature levels (Brett 1952; Orsi 1971), but 75°F was chosen because it was derived from experiments using Central Valley Chinook salmon and it is a more rigorous index value representing a more protective upper lethal water temperature level. Furthermore, the lethal level determined in Rich (1987b) was derived using slow rates of water temperature change and, thus, is ecologically relevant. The juvenile Chinook Salmon UILT based on numerous studies is 75-77°F (Sullivan et al. 2000; McCullough et al. 2001; Myrick and Cech 2001)

Yearling + Smolt Emigration

Juvenile Chinook salmon that exhibit extended rearing in the lower Yuba River are assumed to undergo the smoltification process and volitionally emigrate from the river as yearling+ individuals. Water temperature index values of 63°F, 68°F and 72°F were selected for the spring-run Chinook yearling+ emigration lifestage (**Table 9)**.

A water temperature index value of 63°F was selected because water temperatures at or below this value allow for successful transformation to the smolt stage, and water temperatures above this value may result in impaired smoltification indices, inhibition of smolt development, and decreased survival and successful smoltification of juvenile spring-run Chinook salmon. Laboratory experiments suggest that water temperatures at or below 62.6°F provide conditions that allow for successful transformation to the smolt stage (Clarke and Shelbourn 1985; Marine 1997; Zedonis and Newcomb 1997). 62.6°F was rounded and used to support an index value of 63°F. Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989). A water temperature index value of 68°F was selected because water temperatures above 68°F prohibit successful smoltification (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Support for an index value of 72°F is provided from a study conducted by (Baker *et al.* 1995) in which a statistical model is presented that treats survival of Chinook salmon smolts fitted with coded wire tags in the Sacramento River as a logistic function of water temperature. Using data obtained from mark-recapture surveys, the statistical model suggests a 95% confidence interval for the upper incipient lethal water temperature for Chinook salmon smolts as 71.5°F to 75.4°F.