ATTACHMENT 7.2A

LOWER YUBA RIVER
WATER TEMPERATURE OBJECTIVES

Technical Memorandum

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Technical Memorandum

Lower Yuba River Accord
River Management Team
Planning Group

DRAFT

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1 INTRODUCTION

Flows in the lower Yuba River, extending from Englebright Dam downstream to the river's confluence with the Feather River near Marysville (**Figure 1**) are released in accordance with the Lower Yuba River Accord (Yuba Accord). The flow schedules that are included in the Yuba Accord were developed by the Lower Yuba River Accord Technical Team (TT), a technical working group including representatives from the Yuba County Water Agency (YCWA), National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), California Department of Fish and Game (CDFG), and a group of the non-governmental organizations (NGOs) including Trout Unlimited, American Rivers, The Bay Institute, and South Yuba River Citizens League. The Yuba Accord flow schedules were developed between 2001 and 2004, and formalized in a set of agreements in 2005. The Yuba Accord, including the flow schedules, underwent CEQA/NEPA evaluation in 2006/2007, and in 2008 the State Water Resources Control Board (SWRCB) approved petitions to change the water right permits of YCWA that were necessary to implement the Yuba Accord.

The initial efforts of the TT during 2001-2003 included conducting a review of water temperature conditions in the lower Yuba River. The TT developed the Yuba Accord flow regime to achieve several objectives, one of which included providing appropriate water temperatures for target species and lifestages, focusing on Chinook salmon and steelhead immigration and holding, spawning, embryo incubation, rearing and emigration. The Yuba Accord flow schedules (and associated water temperatures) were implemented on a pilot program basis during 2006 and 2007, and have been implemented on a long-term basis since approval of the Yuba Accord petitions by the SWRCB in 2008.

One of the provisions of the Yuba Accord was the establishment of the Yuba Accord River Management Team (RMT). The RMT includes representatives of YCWA, NMFS, USFWS, CDFG, Pacific Gas and Electric Company (PG&E), California Department of Water Resources (DWR) and the NGOs that are parties to the Fisheries Agreement of the Yuba Accord. Since the Yuba Accord was formalized in 2008, the RMT has been tasked with oversight of the monitoring and evaluation program for the lower Yuba River.

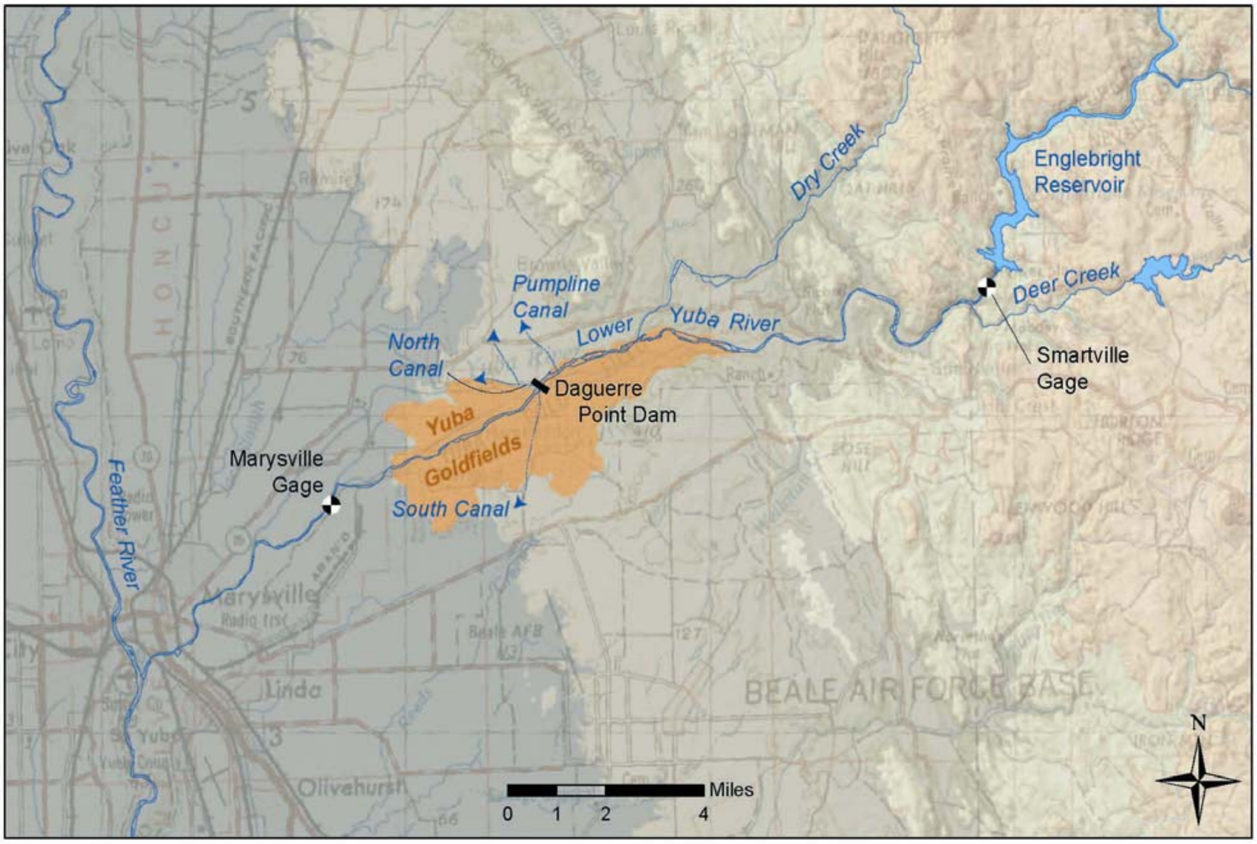

Figure 1. Map of the lower Yuba River

1.1 Technical Memorandum Purpose and Objectives

The RMT's purpose for this Technical Memorandum is to review the appropriateness of the water temperature regime associated with implementation of the Yuba Accord using previously available data and information, updated in consideration of recent and ongoing monitoring activities conducted by the RMT since the pilot programs were initiated in 2006. The RMT's objectives for this memorandum are to review and update the lifestage periodicities of target species in the lower Yuba River, identify the appropriate thermal regime for target fish species taking into account individual species and lifestage water temperature requirements, identify water temperature index values (described in Section 2.2.1), assess the probability of occurrence that those water temperature index values would be achieved with implementation of the Yuba Accord, and to evaluate whether alternative water temperature regimes are warranted.

This Technical Memorandum presents the methodological approach used to address the above stated objectives, summarizes the results and the RMT's conclusions regarding the appropriateness of the current Yuba Accord operational thermal regime, and suggests future water temperature evaluation considerations for the lower Yuba River.

1.2 Background

Environmental parameters such as water temperature affect the distribution, growth and survival of fish populations. Water temperature regimes occurring in regulated rivers are controlled by climatologic and meteorologic conditions, the physical characteristics of the regulating dams and reservoirs, the volume, timing, and temperature of inflows to the reservoirs, and the release schedules associated with dam and reservoir operations. Water temperatures in the lower Yuba River downstream of Englebright Dam are influenced by the temperature of the water released from New Bullards Bar Reservoir to Englebright Reservoir, releases from Englebright Reservoir to the lower Yuba River, operations under the Yuba Accord Fisheries Agreement (magnitude, frequency, and duration of water releases), and natural mechanisms of heat transfer associated with characteristics of the physical environment (e.g., river geometry) and climate (e.g., ambient air temperatures).

1.2.1 Facilities, Operations, and Water Temperature Considerations

The construction of the Yuba River Development Project, and specifically New Bullards Bar Dam and Reservoir in 1970, has played a significant role in lowering water temperatures in the lower Yuba River during the spring, summer, and fall (YCWA *et al.* 2007) by incorporating a large, deep reservoir with a large cold water pool into the Yuba River system. Flows released from New Bullards Bar Reservoir intermix with flows from the Middle Fork and South Fork Yuba rivers, interact with ambient air temperatures, and are impacted by residence time to create the water temperature profile of Englebright Reservoir. Because Englebright Reservoir has a relatively small water storage capacity, the coldwater pool volume in Englebright Reservoir is minimal and, prior to the construction of New Bullards Bar Dam and the release of cold water from New Bullards Bar Reservoir, a limited amount of cold water was available for release from Englebright Dam into the lower Yuba River (YCWA *et al.* 2007). The existing facilities, and their interaction, are described in the following sections.

New Bullards Bar Dam and Reservoir

New Bullards Bar Reservoir, located on the North Fork Yuba River, has a total storage capacity of 966 TAF with a minimum pool of 234 TAF (as required by YCWA's FERC license), thus leaving 732 TAF of capacity that can be regulated. A portion of this regulated capacity, 170 TAF, normally must be held empty from September through April for flood control (YCWA *et al.* 2007).

New Bullards Bar Reservoir is a deep, steep-sloped reservoir that persistently contains a large volume of coldwater pool storage. The primary release of water from New Bullards Bar Reservoir is via a tunnel to Colgate powerhouse, located on the North Fork Yuba River just above the upper extent of Englebright Reservoir. The intake structure for the tunnel and powerhouse includes a multi-level inlet system in New Bullards Bar Reservoir.

Throughout the period of operations of New Bullards Bar Reservoir (1970 through present), which encompasses the most extreme critically dry year on record (1977), the coldwater pool in New Bullards Bar Reservoir has not been depleted (DWR and PG&E 2009). In 1993, YCWA convened a water temperature advisory committee comprised of representatives from CDFG and USFWS. Pursuant to input provided by this committee, the low-level outlet has been used for all controlled releases from New Bullards Bar Dam since September 1993. The coldwater pool availability in New Bullards Bar Reservoir has been sufficient to accommodate year-round utilization of the lower river outlet to provide cold water into Englebright Reservoir, and subsequently into the lower Yuba River.

Englebright Dam and Reservoir

Englebright Dam and Reservoir are located downstream of New Bullards Bar Dam at the confluence of the Middle Fork and South Fork Yuba rivers. Englebright Dam was constructed by the United States Army Corps of Engineers (USACE) in 1941 to trap sediment originating in upstream areas (YCWA 2003). The storage capacity of Englebright Reservoir was 69,700 acre-feet (AF) at the time of construction, as estimated by the U.S. Geological Survey (USGS) using a pre-dam elevation model (Childs *et al.* 2003). Bathymetric and geophysical survey results of the quantity and nature of sediment behind Englebright Dam indicate that at the time of the surveys, Englebright Reservoir contained 17,750 AF of sediment which has reduced the storage capacity by 25.5% (Childs *et al.* 2003). Because of recreation and power generation needs, the storage level within Englebright Reservoir is seldom below 50 TAF (YCWA *et al.* 2007).

Because Englebright Dam was constructed as a sediment retention facility, it does not contain a low-level outlet. Following construction of Englebright Dam in 1941 and extending until approximately 1970, controlled flow releases from Englebright Dam were made through the PG&E Narrows 1 Project facilities. Since about 1970 to the present, controlled flow releases from Englebright Dam into the lower Yuba River have been made from the PG&E Narrows 1 and the YCWA Narrows 2 powerplants, and unregulated flood flows spill over Englebright Dam.

Narrows 1 and Narrows 2 Facilities

Both the Narrows 1 and Narrows 2 facilities have intake structures that draw water from Englebright Reservoir. The intake for the Narrows 2 Powerplant is a tower structure located on the west side of Englebright Reservoir adjacent to Englebright Dam. The intake tower draws water from the surface of Englebright Reservoir down approximately 80 to 85 feet below the normal maximum water surface elevation of Englebright Reservoir, and approximately 100 feet above the bottom of the reservoir (YCWA 2003).

From 1941 through about 1970, flows greater than PG&E Narrows 1 facility's maximum flow capacity of about 740 cfs overflowed Englebright Dam. Since about 1970, operation of the Narrows 2 facility by YCWA has greatly increased the capability for controlling flows released from Englebright Reservoir. YCWA and PG&E coordinate the operations of Narrows 1 and 2 for hydropower efficiency and to maintain relatively constant flows in the lower Yuba River. The Narrows 1 Powerplant typically is used for low-flow reservoir releases, or to supplement the Narrows 2 Powerplant capacity during high flow reservoir releases. The Narrows 1 Powerplant is usually operated when total releases from Englebright Dam are about 730 cfs or less. When releases range from about 730 to 2,560 cfs, the Narrows 2 Powerplant normally is operated. When releases exceed about 2,560 cfs, both powerplants normally operate. The combined release capacity of Narrows 1 and Narrows 2 is about 4,200 cfs (YCWA 2003).

The Narrows 2 Powerplant and outfall is located approximately 400 feet downstream of Englebright Dam on the north bank of the lower Yuba River. The Narrows 1 Powerplant and outfall is located approximately 1,500 feet downstream of the Narrows 2 facility on the south bank of the river.

1.2.2 Lower Yuba River Water Temperature Considerations

Operational releases from Englebright Dam at RM 24 provide the base flow and water temperature boundary conditions in the upper reaches of the lower Yuba River. Further downstream (RM 22.7 and below), lower Yuba River flows and water temperatures during certain periods of the year are affected by inflows from Deer Creek (RM 22.7) and Dry Creek (RM 13.6), and by irrigation diversions at Daguerre Point Dam (DPD) (RM 11.6). Additionally, substantial heat transfer into the lower Yuba River occurs as a result of surface water-air interaction and solar radiant heating. The river channel is generally wide and flat (except in the Narrows Reach) with little or no bank shading from riparian vegetation which promotes significant heat transfer at the water-air interface (YCWA *et al.* 2007). These high surface width-to-flow ratios also facilitate solar radiant heating. A longitudinal temperature gradient may be observed within the lower Yuba River; as illustrated in **Figures 2 & 3**, water temperatures in the lower Yuba River may increase up to 7°F or more between Englebright Dam and Marysville (YCWA *et al.* 2007).

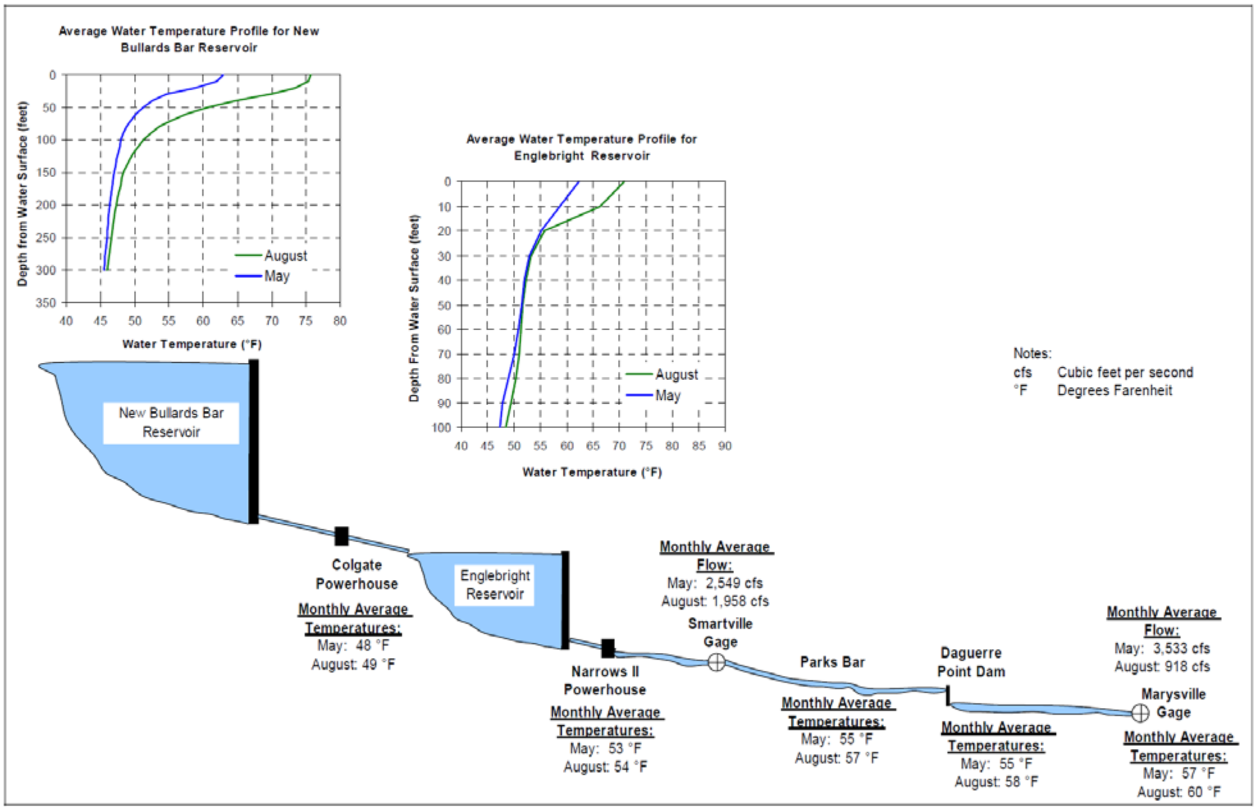

Figure 2. Average monthly water temperature profile in New Bullards Bar and Englebright Reservoirs, and lower Yuba River longitudinal water temperature gradient for the months of May and August during the period extending from 1999 to 2004 (YCWA *et al.* 2007).

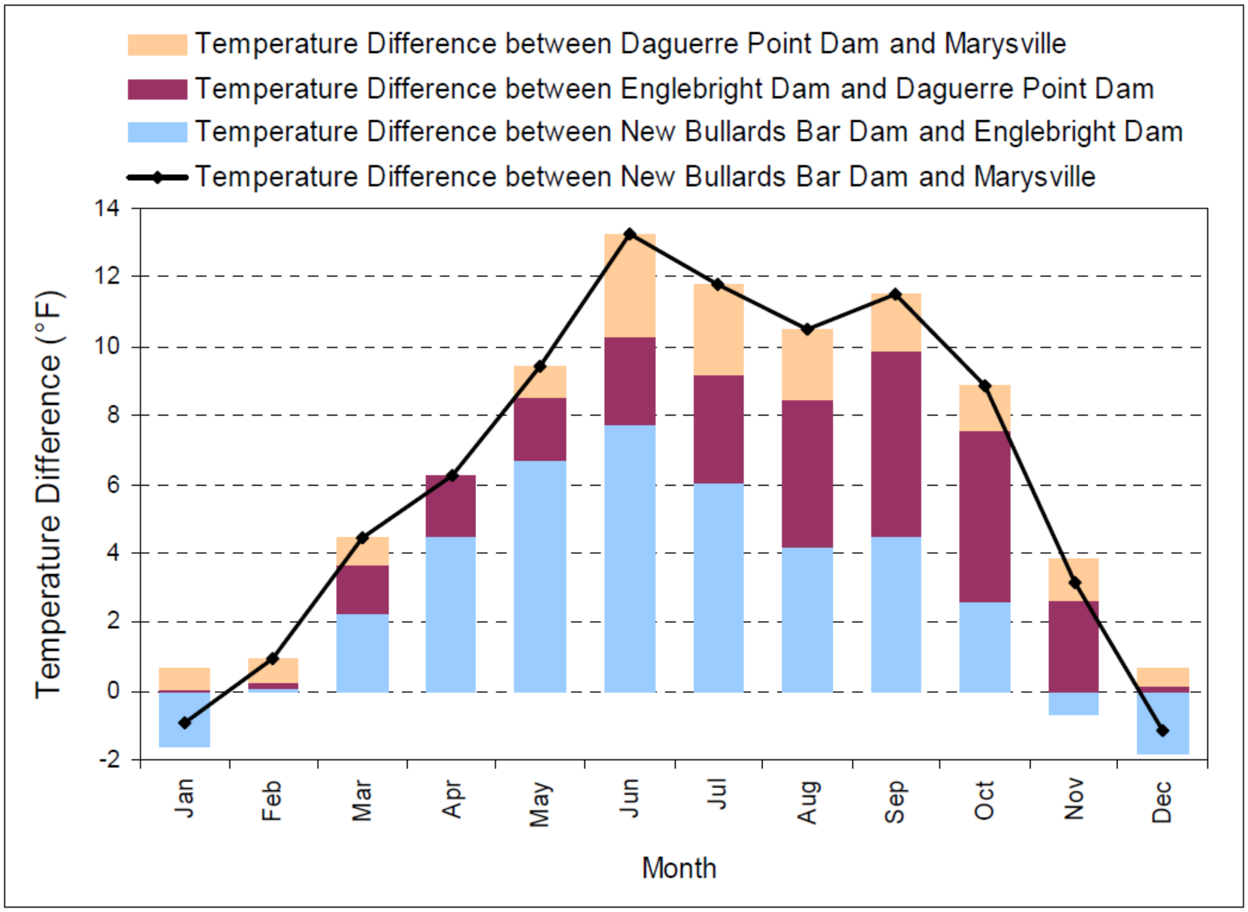

Figure 3. Average monthly water temperature differences in the lower Yuba River between 1990 and 2005 (YCWA *et al.* 2007).

Water temperature modeling conducted as part of the Yuba Accord EIR/EIS (YCWA *et al.* 2007) indicated that temperatures in the lower Yuba River during summer and fall months would generally be colder by 1°F to 5°F (depending on hydrologic conditions and release schedule) under Yuba Accord operations compared to No Project conditions. The Yuba Accord EIR/EIS also indicated that the long-term average water temperatures in most water year types, including Dry and Critical water years, would be lower than the CDFG (1991) suggested temperatures that initially prompted the consideration of a new intake structure for Narrows 2.

In 2000, the SWRCB held an administrative hearing regarding YCWA's water right permits for the Yuba River Development Project. In July 2003, the SWRCB issued Revised Decision 1644 (RD-1644) which included the requirement that YCWA "diligently pursue" funding for a Narrows 2 intake extension that would provide access to colder, deeper water in Englebright Reservoir. YCWA has pursued grant funding from CALFED and other sources for design and installation of an intake device, but funding has not been obtained.

In this Technical Memorandum, the RMT not only addresses whether implementation of the Yuba Accord provides a suitable thermal regime for target species in the lower Yuba River, but also whether water temperature-related operational or infrastructure modifications are warranted.

2 METHODS

2.1 Target Species

Fish surveys indicate that at least 22 native and introduced fish species, including resident and anadromous fish, utilize the lower Yuba River (CDFG 1991; Kozlowski 2004; Massa and McKibbin 2005; YCWA *et al*. 2007). Of these 22 fish species, 3 are listed as "threatened" under the federal Endangered Species Act (ESA) and/or the California Endangered Species Act (CESA): the Central Valley Distinct Population Segment (DPS) of steelhead[1], the Central Valley Evolutionarily Significant Unit (ESU) of spring-run Chinook salmon (*Oncorhynchus tshawytscha)*[2], and the Southern DPS of the North American green sturgeon (*Acipenser medirostrus*)[3].

The lower Yuba River is utilized by two principal Chinook salmon runs (i.e., fall-run and spring-run Chinook salmon). Although late fall-run Chinook salmon populations occur primarily in the Sacramento River (CDFG Website 2007), incidental observations of late fall-run Chinook salmon have been reported to occur in the lower Yuba River (D. Massa, CDFG, pers. comm. 2009; M. Tucker, NMFS, pers. comm. 2009). NMFS has designated one ESU that contains both fall-run and late fall-run Central Valley Chinook salmon. Fall-run/late fall-run Central Valley Chinook salmon are listed as a federal Species of Concern and a state Species of Special Concern.

The RMT placed special emphasis on steelhead, spring-run and fall-run Chinook salmon as target species for evaluation in this Technical Memorandum. The RMT also

[1] The Central Valley DPS of steelhead was listed as a federally threatened species on January 5, 2006 (71 FR 834). Critical habitat was designated on September 2, 2005 including the lower Yuba River (70 FR 52488) from its confluence with the lower Feather River upstream to Englebright Dam.

[2] The Central Valley ESU of spring-run Chinook salmon was listed as a federally threatened species on June 28, 2005 (70 FR 37160). Critical habitat was designated on September 2, 2005 (70 FR 52488) including the Yuba River from its confluence with the Feather River upstream to Englebright Dam. Spring-run Chinook salmon in the Sacramento River Drainage, including the Yuba River, was listed as a threatened species under CESA on February 2, 1999. The genetic integrity of the fish expressing the phenotypic characteristics of spring-run Chinook salmon is presently uncertain.

[3] The Southern DPS of the North American green sturgeon was listed as a federally threatened species on April 7, 2006 (71 FR 17757). Critical habitat was designated on October 9, 2009 (74 FR 52300), including the lower Yuba River from its confluence with the lower Feather River upstream to Daguerre Point Dam.

included North American green sturgeon as a target species. These species were identified as target fish species because of their listing status under the federal and state ESA's, and to be consistent with state and federal restoration/recovery plans and NMFS Biological Opinions (BOs).

2.1.1 Spatial and Temporal Distributions

The RMT has developed representative temporal distributions for specific lifestages of target species through review of previously conducted studies, as well as recent and currently ongoing data collection activities of the Yuba Accord M&E Program. The resultant lifestage periodicities encompass the majority of activity for a particular lifestage, and are not intended to be inclusive of every individual in the population. The lifestage-specific periodicities developed by the RMT for steelhead, spring-run Chinook salmon, and fall-run Chinook salmon are presented in **Figure 4**, the bases for which are presented in the following sections.

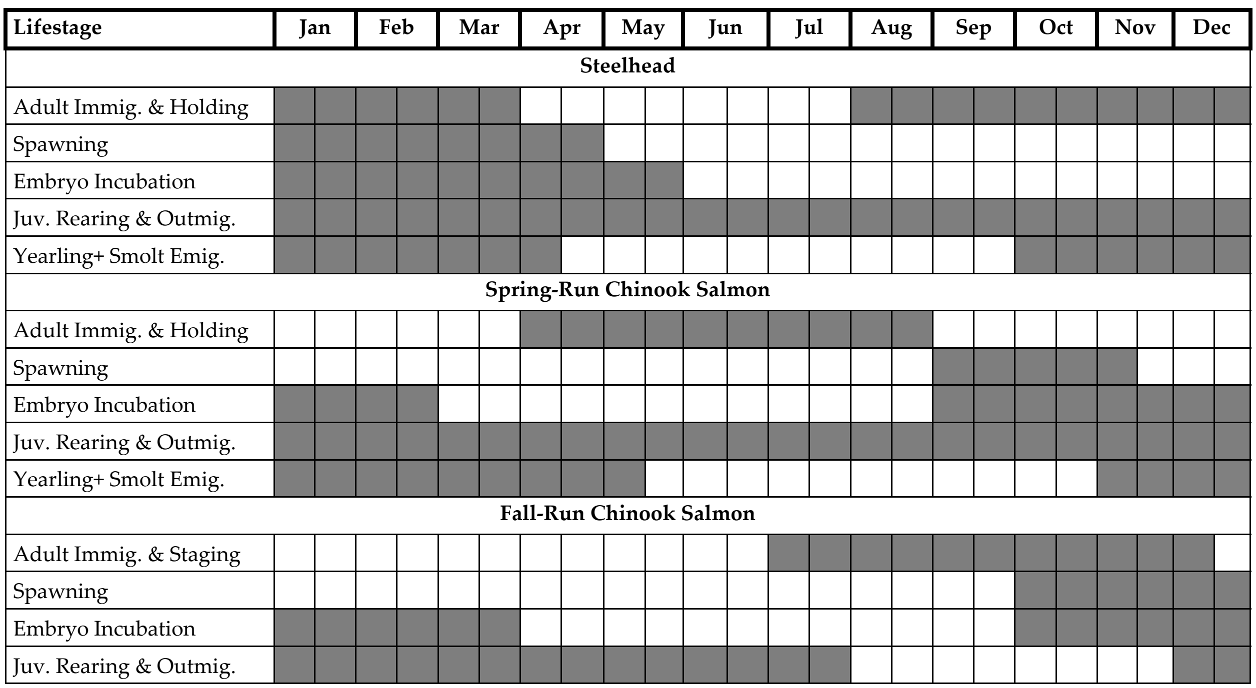

Figure 4. Lifestage-Specific Periodicities for Steelhead, Spring-run Chinook salmon and Fall-run Chinook salmon in the lower Yuba River.

Steelhead

Adult Immigration and Holding

The immigration of adult steelhead in the lower Yuba River has been reported to occur from August through March, with peak immigration occurring from October through February (CDFG 1991; CALFED and YCWA 2005; McEwan and Jackson 1996). In addition, CDFG (1991) report that a run of "half-pounder" steelhead reported occurred from late-June through the winter months.

The RMT's examination of preliminary data identified variable annual timing of *O. mykiss* ascending the fish ladders at DPD since the Vaki Riverwatcher infrared and videographic sampling system began operations in 2003. For example, Massa *et al.* (2010) state that peak passage of steelhead at DPD occurred from April through June during 2007. They also suggest that the apparent disparity between the preliminary data and other reports of steelhead adult immigration periodicity may be explained by the previously reported (Zimmerman *et al.* 2009; Mitchell 2010) relatively high proportion of resident (vs. anadromous) *O. mykiss* occurring in the lower Yuba River, because the Vaki Riverwatcher system did document larger (> 40.6 cm) *O. mykiss* ascending the fish ladders at DPD during the winter months (December through February). The observed timing of larger *O. mykiss* ascending the fish ladders at DPD more closely corresponds with previously reported adult steelhead immigration periodicities.

Spawning

Steelhead spawning has been reported to generally extend from January through April in the lower Yuba River (CALFED and YCWA 2005; CDFG 1991; YCWA *et al.* 2007). The RMT conducted a pilot redd survey from September 2008 through April 2009 (Yuba Accord RMT 2010). Surveys were not conducted during March, which is a known time for steelhead spawning in other Central Valley rivers, due to high flows and turbidity. An extensive area redd survey was conducted by surveyors kayaking from the downstream end of the Narrows pool to the Simpson Lane Bridge. During the extensive area redd survey, redds that were categorized as steelhead based on redd size criteria were observed from October through April, with peaks in spawning activity occurring during fall (October) and spring (February and April). However, some of those redds categorized as steelhead, particularly during October, may actually have been small Chinook salmon redds because the size criteria used to identify steelhead redds was found to be 53% accurate for identifying steelhead redds in the Feather River (USFWS 2008).

Steelhead spawning has been reported to primarily occur in the lower Yuba River upstream of DPD (SWRI *et al.* 2000; Kozlowski 2004; YCWA *et al.* 2007). USFWS (2007) data were collected on *O. mykiss* redds in the lower Yuba River during 2002, 2003, and 2004, with approximately 98% of the redds located upstream of DPD. During the pilot redd survey conducted from the fall of 2008 through spring of 2009, the Yuba Accord RMT (2010) report that most (65%) of the steelhead redds were observed upstream of DPD.

Embryo Incubation

Steelhead eggs incubate in redds for 3 to 14 weeks prior to hatching, depending on water temperatures (Shapovalov and Taft 1954; Barnhart 1991). After hatching, alevins remain in the gravel for an additional 2 to 5 weeks while absorbing their yolk sacs prior to emergence (Barnhart 1991). The entire egg incubation life stage encompasses the time adult steelhead select a spawning site through the time when emergent fry exit the gravel (CALFED and YCWA 2005). In the lower Yuba River, steelhead embryo incubation generally occurs from January through May (CALFED and YCWA 2005; SWRI 2002).

Juvenile Rearing and Outmigration

Juvenile steelhead exhibit variable durations of rearing in the lower Yuba River. The RMT distinguished fry, juvenile, and yearling+ lifestages through evaluation of bi-weekly length-frequency distributions of *O. mykiss* captured in rotary screw traps in the lower Yuba River, and other studies that report length-frequency estimates (Mitchell 2010; CDFG 1984). The steelhead fry (individuals less than about 45mm in length) lifestage periodicity was estimated to extend from the time of initial emergence (based upon consideration of accumulated thermal units from the time of egg deposition through hatching and alevin incubation) until three months following the end of the spawning period. Some juvenile *O. mykiss* may rear in the lower Yuba River for a short periods (up to a few months) and others may spend from one to three years rearing in the river.

The RMT's review of available data found that some juvenile *O. mykiss* are captured in Rotary Screw Traps (RSTs) located downstream of DPD during late-spring and summer, indicating movement downstream. However, at least some of this downstream movement may be associated with the pattern of flows in the river (YCWA *et al.* 2007). Some age-0 *O. mykiss* disperse downstream soon after emergence and this dispersion continues throughout the year.

Most juvenile steelhead rearing has been reported to occur above DPD (CDFG 1991; SWRI *et al.* 2000). Kozlowski (2004) observed age-0 *O. mykiss* throughout the entire study area, with highest densities in upstream habitats and declining densities with increasing distance downstream from the Narrows. Approximately 82% of juvenile *O. mykiss* were observed upstream of DPD. Kozlowski (2004) suggested that the distribution of age-0 *O. mykiss* appeared to be related to the distribution of spawning adults.

Yearling+ Smolt Emigration

CDFG (1991) report that juvenile steelhead may spend from one to three years in the lower Yuba River before emigrating primarily from March to June. Scale analysis conducted by Mitchell (2010) indicates the presence of at least four age categories for *O. mykiss* in the lower Yuba River that spent 1, 2, or 3 years in freshwater and 1 year at sea before returning to the lower Yuba River to spawn.

The steelhead smolt emigration period in the lower Yuba River has been reported to extend from October through May (CALFED and YCWA 2005; SWRI 2002; YCWA *et al.* 2007). The RMT's review of all available data indicate that yearling+ steelhead smolt emigration may extend from October through mid-April.

Spring-run Chinook salmon

Adult Immigration and Holding

The primary characteristic distinguishing spring-run Chinook salmon from the other runs of Chinook salmon is that adult spring-run Chinook salmon enter their natal streams during the spring, and hold in areas downstream of spawning grounds during the summer months until their eggs fully develop and become ready for spawning.

In the lower Yuba River, adult spring-run Chinook salmon immigration and holding has previously been reported to primarily occur from March through October (Vogel and Marine 1991; YCWA *et al.* 2007), with upstream migration generally peaking in May (SWRI 2002). The RMT's examination of preliminary data obtained since the Vaki Riverwatcher infrared and videographic sampling system has been operated (2003 – present) found variable temporal modalities of Chinook salmon ascending the fish ladders at DPD. However, a general mode of Chinook salmon ascending the fish ladders at DPD has been identified as primarily extending from April through June, with few observations during April and peak observations during May or June.

Spring-run Chinook salmon in the lower Yuba River have been reported to hold over during the summer in the deep pools and cool water downstream of the Narrows 1 and Narrows 2 powerplants, or further downstream in the Narrows Reach (CDFG 1991; SWRCB 2003), where water depths can exceed 40 feet (YCWA and USBR 2007). At the Yuba River Symposium held on June 29, 2010, L. Albers (PSMFC) presented preliminary results obtained by the RMT (http://www.yubaaccordrmt.com). Thirty adult Chinook salmon collected between May 12 and May 26, 2009, in the lower Yuba River downstream from DPD were affixed with acoustic tags and tracked through the fall. These fish demonstrated variable patterns of upstream migration and holding, with some fish remaining for several weeks below DPD, and others holding and/or moving among various locations above and below the dam, prior to moving into upstream areas to spawn during early fall.

Spawning

In the lower Yuba River, the spring-run Chinook salmon spawning period has been reported to extend from September through November (CDFG 1991; YCWA *et al.* 2007). Limited reconnaissance-level redd surveys conducted by CDFG since 2000 during late August and September have detected spawning activities beginning during the first or second week of September. They have not detected a bimodal distribution of spawning activities (i.e., a distinct spring-run spawning period followed by a distinct fall-run Chinook salmon spawning period) but instead have detected a slow build-up of spawning activities starting in early September and transitioning into the main fall-run spawning period.

The earliest spawning (presumed to be spring-run Chinook salmon) generally occurs in the upper reaches of the highest quality spawning habitat (i.e., below the Narrows pool) and progressively moves downstream throughout the fall-run Chinook salmon spawning season (NMFS 2007). Spring-run Chinook salmon spawning in the lower Yuba River is believed to occur upstream of DPD. USFWS (2007) collected data from 168 Chinook salmon redds in the lower Yuba River on September 16-17, 2002 and September 23-26, 2002, considered to be spring-run Chinook salmon redds. The redds were all located above DPD. During the pilot redd survey conducted from the fall of 2008 through spring of 2009, the Yuba Accord RMT (2010) report that the vast majority (96%) of fresh Chinook salmon redds constructed by the first week of October 2008, potentially representing spring-run Chinook salmon, were observed upstream of DPD.

Embryo Incubation

The spring-run Chinook salmon embryo incubation period encompasses the time period from egg deposition through hatching, as well as the additional time while alevins remain in the gravel while absorbing their yolk sacs prior to emergence. In well-oxygenated intragravel environs where water temperatures range from about 41 to 55.4°F embryos hatch in 40 to 60 days and remain in the gravel as alevins for another 4 to 6 weeks, usually after the yolk sac is fully absorbed (NMFS 2009). The RMT concluded that the lower Yuba River spring-run Chinook salmon spawning and embryo incubation period generally extends from September through February.

Juvenile Rearing and Outmigration

Spring-run juveniles may move downstream as fry soon after emergence, rear in their natal streams for several months prior to emigration as young-of-the-year, or remain in their natal streams for extended periods and emigrate as yearling+ individuals. CDFG has conducted juvenile salmonid outmigration monitoring by operating rotary screw traps (RSTs) in the lower Yuba River near Hallwood Boulevard, located approximately 6 RM upstream from the city of Marysville. CDFG's RST monitoring efforts generally extended from fall (October or November) through winter, and either into spring (June) or through the summer (September) annually from 1999 to 2006. The Yuba Accord RMT conducted additional RST sampling from 2006 to 2009. Data from CDFG RST monitoring are available from 1999 to 2005, and a Yuba Accord RMT report (Campos and Massa 2010) has been prepared for the sampling period extending from October 1, 2007 to September 30, 2008.

The RMT's examination of CDFG RST data found that most Chinook salmon juveniles move downstream past the Hallwood Boulevard location prior to May of each year. For the 5 years of data included in the analyses, 97.5 to 99.2 percent of the total numbers of juvenile Chinook salmon were captured by May 1 of each year. The percentage of the total juvenile Chinook salmon catch moving downstream past the Hallwood Boulevard location each year ranged from 0.4 to 1.3 percent during May, and 0 to 1.2 percent during June (YCWA *et al.* 2007). During the 2007/2008 sampling period, 95% of all juvenile Chinook salmon were captured by June 2, 2008 (Campos and Massa 2010).

Yearling+ Smolt Emigration

Overall, most (about 84%) of the juvenile Chinook salmon were captured at the Hallwood Boulevard RSTs soon after emergence from November through February, with relatively small numbers continuing to be captured through June. Although not numerous, captures of (over-summer) holdover juvenile Chinook salmon ranging from about 70 to 140 mm FL, primarily occurred from October through January with a few individuals captured into March (Massa 2005; Massa and McKibbin 2006). These fish likely reared in the river over the previous summer, representing an extended juvenile rearing strategy characteristic of spring-run Chinook salmon. During the 2007/2008 sampling period, 33 Chinook salmon that met this criterion were observed at the Hallwood Boulevard RST site from mid-December through January. Juvenile Chinook salmon captured during the fall and early winter (October-January) larger than 70 mm are likely exhibiting an extended rearing strategy in the lower Yuba River (Campos and Massa 2010).

For the sampling periods extending from 2001 to 2005, CDFG identified specific runs based on sub-samples of lengths of all juvenile Chinook salmon captured in the RSTs by using the length-at-time tables developed by Fisher (1992), as modified by S. Green (CDWR). Although the veracity of utilization of the length-at-time tables in the Yuba River has not been ascertained, based on the examination of run-specific determinations, the vast majority (approximately 94%) of spring-run Chinook salmon were captured in the lower Yuba River as post-emergent fry during November and December, with a relatively small percentage (nearly 6%) of individuals remaining in the lower Yuba River and captured as juveniles from January through March. Only 0.6% of the juvenile Chinook salmon identified as spring-run was captured during April, 0.1% during May, and none were captured during June (YCWA *et al.* 2007). The RMT's review of all available data indicate that yearling+ spring-run Chinook salmon smolt emigration may extend from November through mid-May.

Fall-run Chinook salmon

Adult Immigration and Staging

Unlike spring-run Chinook salmon, adult fall-run Chinook salmon do not exhibit an extended over-summer holding period. Rather, they stage for a relatively short period of time prior to spawning. Adult fall-run Chinook salmon immigration and staging have been reported to generally occur in the lower Yuba River from August through November (CALFED and YCWA 2005), and immigration generally peaks in November, with typically greater than 90% of the run having entered the river by the end of November (CDFG 1992; CDFG 1995). The RMT's review of all available data indicate that fall-run Chinook salmon immigration generally extends from July through mid-December.

Spawning

The RMT's examination of preliminary data obtained from the carcass surveys does not indicate a distinct bimodal distribution of spawning activities (i.e., a distinct spring-run spawning period followed by a distinct fall-run Chinook salmon spawning period) but instead demonstrates a slow build-up of spawning activities starting in early September and transitioning into the main fall-run spawning period. The lower Yuba River fall-run Chinook salmon spawning period has been reported to extend from October through December (CALFED and YCWA 2005). Preliminary data from the recently conducted redd surveys, and back-calculations from previous and recent carcass surveys generally confirm this temporal distribution.

Embryo Incubation

Fall-run Chinook salmon embryo incubation in the lower Yuba River extends from the time of egg deposition through alevin emergence from the gravel. The fall-run Chinook salmon embryo incubation period has been reported to extend from October through March (YCWA *et al.* 2007). Based upon consideration of accumulated thermal units from the time of egg deposition through hatching and alevin incubation, the RMT considered the fall-run Chinook salmon embryo incubation period to extend from

October through March. This time period is consistent with observed trends in Chinook salmon fry captures in the RSTs.

Juvenile Rearing and Outmigration

Fall-run Chinook salmon juvenile rearing and outmigration in the lower Yuba River has been reported to primarily occur from December through June (CALFED and YCWA 2005; SWRI 2002). In the lower Yuba River, most fall-run Chinook salmon exhibit downstream movement as fry shortly after emergence from gravels, although some individuals rear in the river for a period up to several months and move downstream as juveniles.

CDFG employed the run identification methodology to identify fall-run Chinook salmon juveniles captured in the RSTs (described above). Based on the examination of run-specific determinations, in the lower Yuba River the majority (81.1%) of fall-run Chinook salmon move past the Hallwood Boulevard RST from December through March, with decreasing numbers captured during April (8.9%), May (6.6%), June (3.2%), and July (0.2%). Most of the fish captured from December through March were post-emergent fry (< 50 mm FL), while nearly all juvenile fall-run Chinook salmon captured from May through July were larger (≥ 50 mm FL) (YCWA *et al.* 2007). Thus, the fry rearing lifestage is considered to extend from December through April, and the juvenile rearing lifestage from March through June. The RMT's review of all available data indicates that the fall-run Chinook salmon juvenile rearing and outmigration lifestage extends from December through July.

North American green sturgeon

Unconfirmed accounts of sturgeon in the lower Yuba River have been reported by anglers, but these accounts do not specify whether the fish were white or green sturgeon (Beamesderfer *et al.* 2004). Since the 1970s, numerous surveys of the Yuba River downstream of Englebright Dam have been conducted including annual salmon carcass surveys, snorkel surveys, beach seining, electrofishing, rotary screw trapping, redd surveys, and other monitoring and evaluation activities. Over the many years of these surveys and monitoring of the lower Yuba River, only one confirmed observation of an adult North American green sturgeon has occurred. The NMFS September 2008 *Draft Biological Report, Proposed Designation of Critical Habitat for the Southern Distinct Population Segment of North American Green Sturgeon* (NMFS 2008a) states that of the three adult or sub-adult sturgeon observed in the Yuba River below DPD during 2006, only one was confirmed to be a North American green sturgeon, and that *"Spawning is possible in the river, but has not been confirmed and is less likely to occur in the Yuba River than* *in the Feather River. No green sturgeon juveniles, larvae, or eggs have been observed in the lower Yuba River to date."*

Because of the paucity of data regarding North American green sturgeon on the lower Yuba River, information from other river systems, specifically the lower Feather River and the Sacramento River, is used to characterize North American green sturgeon lifestage periodicities. However, only limited information regarding green sturgeon distribution, movement, behavioral patterns and lifestage-specific habitat utilization preferences is available for the Sacramento and Feather rivers. North American green sturgeon in the Sacramento River have been documented and studied more widely than the Feather River.

In the lower Feather River, adult North American green sturgeon have intermittently been observed (Beamesderfer *et al.* 2007), although spawning has not been documented (NMFS 2008b). Larval and juvenile North American green sturgeon have not been collected in the lower Feather River despite attempts to collect these lifestages during early spring through summer using rotary screw traps, artificial substrates, and larval nets deployed at multiple locations (Seesholtz 2003).

North American green sturgeon adults in the Sacramento River are reported to begin their upstream spawning migrations into freshwater during late February, prior to spawning between March and July, with peak spawning believed to occur between April and June (Adams *et al.* 2002).

Heublein *et al.* (2009) observed that North American green sturgeon enter San Francisco Bay in March and April and migrate rapidly up the Sacramento River to the region between the Glenn-Colusa Irrigation District (GCID) diversion and Cow Creek. The fish lingered at these regions at the apex of their migration for 14–51 days, presumably engaging in spawning behavior, before moving back downriver (Heublein *et al.* 2009). The apex detections of individual fish indicate reaches and dates when spawning might have occurred during the study conducted by Heublein *et al.* (2009). They reported that spawning may have occurred between May and July.

Adult North American green sturgeon are believed to spawn every 3 to 5 years and reach sexual maturity only after several years of growth (i.e., 10 to 15 years based on sympatric white sturgeon sexual maturity) (CDFG 2002b). Brown (2007) suggested that spawning in the Sacramento River may occur from April to June, and that the potential spawning period may extend from late April through July as indicated by the rotary screw trap data at the Red Bluff Diversion Dam (RBDD) from 1994 to 2000.

After spawning, adult North American green sturgeon have been reported to hold over in the upper Sacramento River between RBDD and the GCID diversion until November (Klimley 2007). Heublein *et al.* (2006, 2009) reported the presence of adults in the Sacramento River during the spring through the fall into the early winter months, holding in upstream locations prior to their emigration from the system later in the year. Some adult North American green sturgeon rapidly leave the system following their suspected spawning activity and re-enter the ocean in early summer (Heublein *et al.* 2006). NMFS (2009d) states that North American green sturgeon larvae and juveniles are routinely observed in rotary screw traps at RBDD and GCID, indicating that spawning occurs upstream of both these sites.

The Sacramento River adjacent to the GCID pumping plant routinely holds a large aggregation of North American green sturgeon during summer and fall months, although the GCID aggregation site is atypical of oversummering habitats in other systems, being an area of high water velocity (Heublein *et al.* 2009).

Heublein *et al.* (2009) stated that in contrast to the behavior of North American green sturgeon observed during 2004–2005, the majority of out-migrants detected in 2006 displayed an entirely different movement strategy. Nine of the ten tagged fish detected that year exited the system with no extended hold-over period and with no apparent relation to flow increases, eight leaving before 4 July and the last on 22 August. Heublein *et al.* (2009) suggested that the rapid out-migration of North American green sturgeon in 2006, and the reduced aggregation period at the GCID site could be a result of consistently higher flows and lower temperatures than during previous study years. Alternatively, this could be an unusual behavior, related to unknown cues, that has not been documented in North American green sturgeon prior to this study (Heublein *et al.* 2009).

Newly hatched North American green sturgeon are approximately 12.5 to 14.5 mm in length. After approximately 10 days, larvae begin feeding and growing rapidly. After 6 days, the larvae exhibit nocturnal swim-up activity (Deng *et al.* 2002) and nocturnal downstream migrational movements (Kynard *et al.* 2005).

Juvenile North American green sturgeon continue to exhibit nocturnal behavior beyond the metamorphosis from larvae to juvenile stages. Exogenous feeding starts at approximately 14 days (23 to 25 mm) (Van Eenennaam *et al.* 2001). Laboratory studies indicate that juvenile fish continued to migrate downstream at night for the first 6 months of life (Kynard *et al.* 2005). When ambient water temperatures reached 46° F, downstream migrational behavior diminished and holding behavior increased. These data suggest that 9 to 10 month old fish would hold over in their natal rivers during the ensuing winter following hatching, but at a location downstream of their spawning grounds. Within the Klamath River, juvenile green sturgeon emigration reportedly occurs from late May through July (Environmental Protection Information Center *et al.* 2001). Within the Trinity River, juvenile green sturgeon emigration reportedly occurs from early June through September (Environmental Protection Information Center *et al.* 2001).

Although there are no data regarding lifestage periodicities of North American green sturgeon in the lower Yuba River because there has been only one confirmed sighting, for the purposes of this Technical Memorandum the RMT characterized the potential periodicities (and primary evaluation locations) as those presented below in Section 2.1.2.

2.1.2 Species Specific Lifestage Periodicities and Primary Evaluation Locations

Through review of previously conducted studies, as well as recent and currently ongoing data collection activities of the Yuba Accord M&E Program, the RMT has developed the following representative lifestage-specific periodicities and primary locations for water temperature suitability evaluations for the target species. The locations used for water temperature evaluations correspond to Smartsville, DPD, and Marysville.

Steelhead

- Adult immigration and holding (August through March) – Smartsville, DPD, and Marysville
- Spawning (January through April) – Smartsville and DPD
- Embryo incubation (January through May) – Smartsville and DPD
- Juvenile rearing and outmigration (Year-round) – DPD and Marysville
- Yearling+ smolt emigration (October through mid-April) – DPD and Marysville

Spring-run Chinook Salmon

- Adult immigration and holding (April through August) – Smartsville, DPD, and Marysville
- Spawning (September through mid-November) – Smartsville
- Embryo incubation (September through February) – Smartsville
- Juvenile rearing and outmigration (Year-round) – DPD and Marysville

- Yearling+ smolt emigration (November through mid-May) – DPD and Marysville

Fall-run Chinook Salmon

- Adult immigration and staging (July through mid-December) – DPD and Marysville
- Spawning (October through December) – Smartsville and DPD
- Embryo incubation (October through March) – Smartsville and DPD
- Juvenile rearing and outmigration (December through July) – DPD and Marysville

North American green sturgeon

- Adult immigration (late February through April) – DPD and Marysville
- Adult spawning and embryo incubation (March through July) – DPD and Marysville
- Post-spawning holding (March through November) – DPD and Marysville
- Juvenile rearing (Year-round) – DPD and Marysville
- Juvenile outmigration (late-May through September) – DPD and Marysville

2.2 Water Temperature Evaluations

The RMT water temperature suitability evaluation is conducted in two general phases. The initial and most comprehensive phase of the evaluation focuses on steelhead and Chinook salmon. The thermal requirements of steelhead and Chinook salmon have been extensively studied in California and elsewhere and, therefore, allow a detailed and specific determination of desired water temperature index values for each lifestage. For Chinook salmon and steelhead, water temperature index values have been developed in greater detail than for North American green sturgeon, because of the greater availability of existing information regarding the effects of water temperature on salmonid lifestages.

The second general phase of the RMT water temperature suitability evaluation is to examine the thermal regime associated with implementation of the Yuba Accord relative to the more general water temperature information for North American green sturgeon.

2.2.1 Water Temperature Index Value Development

Anadromous Salmonids

Lifestage-specific water temperature index values used as evaluation guidelines for steelhead and Chinook salmon are developed based on the information described in Attachment A to this Technical Memorandum. Attachment A draws largely on the information presented in Appendix E2 of the Yuba Accord EIR/EIS, and presents the results of a literature review that was conducted to: (1) interpret the literature on the effects of water temperature on the various life stages of Chinook salmon and steelhead; (2) consider the effects of short-term and long-term exposure to constant or fluctuating temperatures; and (3) establish water temperature index values to be used as guidelines for evaluation in this Technical Memorandum. Attachment A presents detailed information regarding the rationale supporting the development and selection of water temperature index values, including literature citations.

The RMT acknowledges and adopts the limitations associated with the development and application of water temperature index values well summarized by McEwan (2001) addressing steelhead. Namely, the water temperature index values serve as general guidelines, and the data supporting them were originally developed by researchers on specific streams or under laboratory conditions that oftentimes focused on temperature maxima that cause lethal and sublethal effects. 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.

The water temperature index values are not meant to be significance thresholds, but instead provide a mechanism by which to compare the suitability of the water temperature regimes associated with implementation of the Yuba Accord. The water temperature index values presented in Attachment A represent a gradation of potential effects, from reported optimal water temperatures increasing through the range of represented index values for each life stage.

Steelhead

Water temperature index values for the adult immigration and adult holding lifestages are developed together, because it is difficult to determine the thermal regime that steelhead 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.

A review of the literature summaries in Attachment A suggested a wide range of water temperature index values (52°F, 56°F, 70°F) for the steelhead immigration and holding lifestage. The RMT selected the water temperature index value of 56°F because this value represents a water temperature above which adverse effects to steelhead adult immigration and adult holding lifestages, and egg viability begin to arise. The RMT conducted an independent literature review to identify an intermediate value between 56°F and 70°F, which may impede upstream migration. Salinger and Anderson (2006) reported that over 93% of steelhead detections occurred in the 65.3-71.6°F, but that this was "probably above the temperature for optimal migration". Similar findings were reflected in a study conducted by Richter and Kolmes (2005) suggesting that fall-run Chinook and steelhead encounter potentially stressful temperatures between 64.4-73.4°F. The RMT therefore identified the two water temperature index values of 56°F and 64°F for the evaluation of the steelhead immigration and holding lifestage.

Because the spawning and embryo incubation lifestage periodicities overlap and occur concurrently, water temperature index values are developed to evaluate both the spawning and embryo incubation lifestages. The water temperature index value of 54°F was selected by the RMT because studies conducted at or near 54.0°F report high survival and normal development, and that symptoms of thermal stress arise at or near 54.0°F. The RMT selected the water temperature index value of 57.0°F because relatively low mortality of incubating steelhead is reported to occur at 57.2°F, and a sharp decrease in survival was observed for *O. mykiss* embryos incubated above 57.2°F.

A water temperature index value was developed by the RMT to apply to the rearing (fry and juvenile) and juvenile outmigration lifestages. As previously described, 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 water temperature index value of 65°F was selected by the RMT because: (1) it has been reported that this value is the upper limit preferred for growth and development of Sacramento and American River juvenile steelhead; (2) it is within the preferred water temperature range (i.e., 62.6°F to 68.0°F); (3) supports high growth rates of

Nimbus strain juvenile steelhead; and (4) increasing levels of thermal stress to this life stage may reportedly occur above the 65°F water temperature index value.

Separate water temperature index values were developed by the RMT for the yearling+ smolt emigration lifestages for the purposes of this Technical Memorandum. Juvenile steelhead 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 52°F and 55°F were selected to evaluate the steelhead yearling+ emigration lifestage, because most literature on water temperature effects on steelhead smolting suggest that water temperatures less than 52°F, or less than 55°F, are required for successful parr-smolt transformation.

Chinook Salmon

Development of water temperature index values separately for spring-run and fall-run Chinook salmon in this Technical Memorandum was considered. 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, for this Technical Memorandum, water temperature index values for most lifestages of spring-run and fall-run Chinook salmon were not separated because: (1) both spring-run and fall-run Chinook salmon are restricted to spawning in the lower Yuba River below Englebright Dam, and are not spatially segregated in different order streams; (2) there is a paucity of literature specific to each lifestage for each run-type; (3) there is an insufficient amount of data available in the literature suggesting that Chinook salmon run-types respond to water temperatures differently; (4) the water temperature index values derived from the literature generally pertain to both spring-run and fall-run Chinook salmon; and (5) the temporal distribution of the various lifestages of spring-run and fall-run Chinook salmon overlap and the two runs are not readily distinguishable in the lower Yuba River. Where distinct water temperature index values are warranted for the same lifestage of spring-run and fall-run Chinook salmon, they are specified in this Technical Memorandum.

For Chinook salmon adult immigration and holding, the RMT selected the water temperature index values of 60°F and 64°F. The 60°F water temperature index value was selected because it is generally reported in the literature as the upper limit of the optimal range. The index value of 64°F was selected because the effects of thermal stress to pre-spawning adults are evident at water temperatures near 64°F, and latent embryonic abnormalities associated with water temperature exposure of pre-spawning adults to temperatures of 63.5°F to 66.2°F have been suggested.

A water temperature index value was developed by the RMT to evaluate both the spawning and embryo incubation lifestages for Chinook salmon because these lifestages are closely linked temporally, and studies describing how water temperature affects embryonic survival and development based on varying water temperature treatments on holding adults often report similar results to water temperature experiments conducted on fertilized eggs. A water temperature index value of 56°F was selected because water temperatures at or below this value: (1) promote maximum survival of Chinook salmon embryos; (2) alevin mortality is reportedly significantly higher when Chinook salmon embryos are incubated at water temperatures above 56°F; and (3) increasing levels of thermal stress to this lifestage may reportedly occur above 56°F.

A water temperature index value was developed by the RMT to apply to both the 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 value of 65°F was selected by the RMT because, in addition to being specifically referenced in the literature, it represented an intermediate value between 64.0°F and 66.2°F, values which also are often referenced in the literature. Justification for the 65°F water temperature index value includes: (1) preferred for growth and development of fry and juvenile spring-run Chinook salmon in the Feather River; (2) disease outbreaks and mortalities increase at water temperatures above 65.0°F; (3) optimum temperature for growth appears to occur at about 66.2°F; (4) optimal range for Chinook salmon survival and growth from 53.0°F to 64.0°F; and (5) survival of Central Valley juvenile Chinook salmon declines at temperatures greater than 64.4°F.

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. A water temperature index value of 63°F was selected by the RMT to evaluate the spring-run Chinook yearling+ emigration lifestage, 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.

North American green sturgeon

The habitat requirements of North American green sturgeon are not well known. In the Klamath River, the water temperature tolerance of immigrating adult green sturgeon reportedly ranges from 44.4°F to 60.8°F. Reportedly, no green sturgeon were found in areas of the river outside this surface water temperature range (USFWS 1995d)

Green sturgeon reportedly tolerate spawning water temperatures ranging from 50°F to 70°F (CDFG 2001). Water temperatures tolerances for green sturgeon during spawning and egg incubation also have been reported to range between 46° to 57°F (NMFS 74 FR 52300), although eggs have been artificially incubated at temperatures as high as 60°F (Deng 2000 as cited in 74 FR 52300). However, suitable water temperatures for egg incubation in green sturgeon reportedly ranges between 52°F and 63°F (optimally between 57-61°F) with lethal temperatures approaching 73°F (Van Eenennaam *et al.* 2005). Water temperatures above 68°F are reportedly lethal to North American green sturgeon embryos (Cech *et al.* 2000; Beamesderfer and Webb 2002).

Water temperatures not exceeding 62.6°F have been reported to permit normal North American green sturgeon larval development (Van Eenennaam *et al.* 2005 as cited in Heublein *et al.* 2009). Werner *et al.* (2007) suggests temperatures remain below 68 °F for larval development. Temperatures of about 59°F are believed to be optimal for larval growth, whereas temperatures below about 52°F or above about 66°F may be detrimental for growth (Cech *et al*. 2000).

NMFS (74 FR 52300) reports optimal water temperatures for the development of green sturgeon egg, larval, and juvenile lifestages ranging between 52°F and 66°F. Growth of juvenile green sturgeon is reportedly optimal at 59°F and reduced at both 51.8°F and 66.2°F (Cech *et al.* 2000). According to NMFS (74 FR 52300) suitable water temperatures for juvenile green sturgeon should be below about 75°F. At temperatures above about 75°F, juvenile green sturgeon exhibit decreased swimming performance (Mayfield and Cech 2004) and increased cellular stress (Allen *et al*. 2006).

The RMT water temperature evaluation for North American green sturgeon is to evaluate the probability of occurrence that water temperatures in the lower Yuba River are within reported suitable ranges for each of the lifestages as follows:

- Adult immigration/holding/post-spawning holding (44°F to 61°F)
- Adult spawning and embryo incubation (46°F to 63°F)
- Juvenile rearing/outmigration (52°F to 66°F)

2.3 Water Temperature Model Application

2.3.1 Water Temperature Model Simulations

Species- and lifestage-specific target water temperature index values were initially evaluated by the RMT using the monthly time-step statistical water temperature model results used in the Yuba Accord EIR/EIS (YCWA *et al.* 2007). The statistical model consists of sub-models that are used to predict water temperatures at various locations in the Yuba River system. Descriptions of the model and its application are found in Appendix D (including Attachment B) to the Yuba Accord EIR/EIS (YCWA *et al.* 2007).

Output from this model is comprised of monthly average water temperatures occurring over a 72-year simulation period (1922 – 1994). For this Technical Memorandum, simulated average monthly water temperatures were used for the following locations: (1) the Smartsville Gage; (2) DPD; and (3) the Marysville Gage. Although a monthly water temperature model is not able to assess day-to-day water temperature variability or diurnal water temperature fluctuations, a more discrete time-step water temperature model is not presently available for the lower Yuba River.

2.3.2 Water Temperature Exceedance Curves

Water temperature cumulative probability distributions have been developed for each month over the 72–year simulation period. Monthly water temperature cumulative probability distributions represent the probability, as a percent of time, that modeled water temperature values would be met or exceeded at an indicator location. These distributions are commonly referred to as exceedance curves.

For this Technical Memorandum, the RMT utilized the monthly cumulative probability distributions to examine the probability that the water temperature index values would be exceeded for the individual months within the identified lifestages, at the specified locations, for the target species.

2.3.3 Water Temperature Suitability Matrix

The RMT recognized that the multiple species and lifestages present in the lower Yuba River may require different environmental conditions, and that it would be possible to have conflicts among the needs of these species and lifestages for a given month. Thus, the RMT developed three comprehensive water temperature suitability matrices which contain the following information: (1) target species; (2) species-specific lifestages; (3) temporal periodicities specific to the lower Yuba River in consideration of species- and lifestage-specific periodicities; (4) species- and lifestage-specific locations (above, below, and at DPD) for evaluation; (5) species- and lifestage-specific water temperature index values; and (6) the probability of exceeding established water temperature index values under Yuba Accord operations. The water temperature suitability matrices are used by the RMT to organize and synthesize evaluation of the water temperature regime associated with implementation of the Yuba Accord.

2.3.4 Recent Water Temperature Monitoring

Recent water temperature monitoring data in the lower Yuba River are available for the period extending from 2006 to the present, during which time operations have complied with the Yuba Accord. The RMT separately evaluated trends in mean daily water temperatures for the lower Yuba River (at Smartsville, DPD, and Marysville), for the 2006 to the present-day period. The RMT derived mean daily water temperatures for the Yuba River from real-time (hourly) temperature data to evaluate observed temperatures in the lower Yuba River, and to determine the extent of conformance of the monitoring data with output from the Yuba Accord Water Temperature Model.

The primary purpose for examining recent water temperature monitoring data was to compare water temperatures in the lower Yuba River with those in the lower Feather River. The RMT derived mean daily water temperatures from real-time (hourly) temperature data for the concurrent 2006 – present time period in lower Feather River upstream of the confluence with the Yuba River (at Gridley). The resultant mean daily water temperatures were used to identify the magnitude of the differences in water temperature between the lower Yuba River and the lower Feather River to assess between-river water temperature disparities during the target species immigration and outmigration lifestages.

3 RESULTS

3.1 Water Temperature Model Results

Simulated average monthly water temperature model output exhibit distinct seasonal and longitudinal trends in water temperature in the lower Yuba River. Irrespective of location, generally the lowest water temperatures occur during January and February, steadily increase until mid-June or July, remain at relatively high values through September and steadily decrease thereafter. In general, the coldest water temperatures occur upstream at the Smartsville gage, intermediate temperatures occur at DPD, and the warmest temperatures are observed downstream at the Marysville gage for most months of the year. The least amount of spatial variation in water temperature is occurs during late fall through winter months (i.e., late November through February), when simulated average monthly water temperatures are similar among the three monitoring locations. By contrast, relative to the Smartsville gage, average monthly water temperatures during the summer can be up to approximately 4°F warmer at DPD and 7°F warmer at the Marysville gage. The range of temperatures simulated at Marysville is seasonally dependent because the rate of warming in the lower Yuba River, and is greatly influenced by air temperature, solar radiation, and volume of flow in the river (YCWA *et al.* 2007 Attachment B to Appendix D).

3.2 Water Temperature Monitoring Results

Monitoring water temperature data illustrate similar seasonal and longitudinal trends in water temperature in the lower Yuba River **(Figure 4)** to those simulated with the water temperature model. The lowest water temperatures are observed during January and February, and water temperatures steadily increase until mid-June or July, remain at relatively high values through September and steadily decrease thereafter. The coldest water temperatures are observed upstream at the Smartsville gage, intermediate water temperatures occur at DPD, and the warmest temperatures are observed downstream at the Marysville gage for most months of the year. The least amount of spatial variation in water temperature is observed during late fall through winter months (i.e., late November through February), when water temperatures are similar at the three monitoring locations.

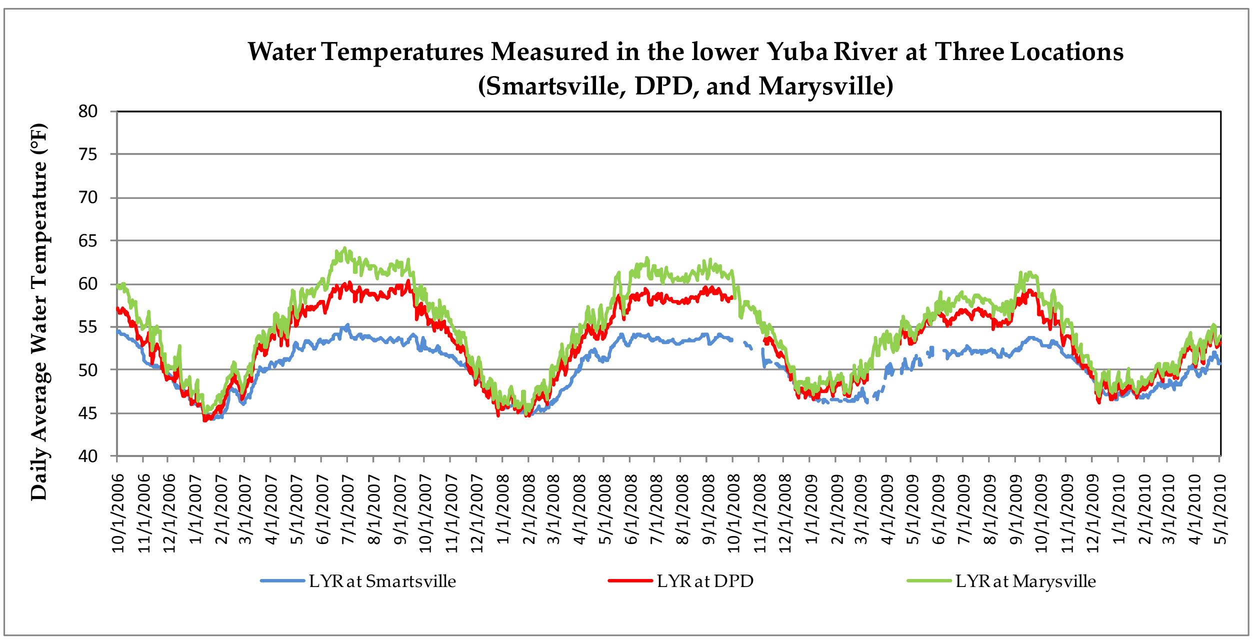

Figure 4. Water temperatures measured in the lower Yuba River at Smartsville, DPD, and Marysville monitoring locations.

Relative to the Smartsville gage, average daily water temperatures during the summer can be up to approximately 5°F warmer at DPD and 8°F warmer at the Marysville gage.

Because the model represents a range of meteorologic and hydrologic conditions over the simulation period extending from 1922 – 1994 it encompasses a range of hydrologic and meteorologic conditions. The monitoring data are for the specific conditions that occurred during 2006 – 2010, therefore it is not reasonable to expect that the long-term model averages would conform to the monitoring data for these specific years. Nonetheless, monitoring water temperature data illustrate similar seasonal and longitudinal trends and approximate magnitude in differences in the lower Yuba River to those simulated with the water temperature model.

Average daily water temperatures for the period from 2006 to the present in the lower Yuba River at Marysville and in the lower Feather River at Gridley are presented in **Figure 5.** Although the lower Feather River water temperature monitoring data contained periods of missing data, seasonal trends are evident from the available data. Similar to the lower Yuba River at Marysville, the lowest water temperatures in the lower Feather River at Gridley are observed during January and February, water temperatures steadily increase until mid-June or July, remain at relatively high values through September and steadily decrease thereafter. The least amount of spatial variation in water temperature is observed during late fall through winter months (i.e., late November through February), when water temperatures are relatively similar in the lower Yuba River at Marysville and in the lower Feather River at Gridley.

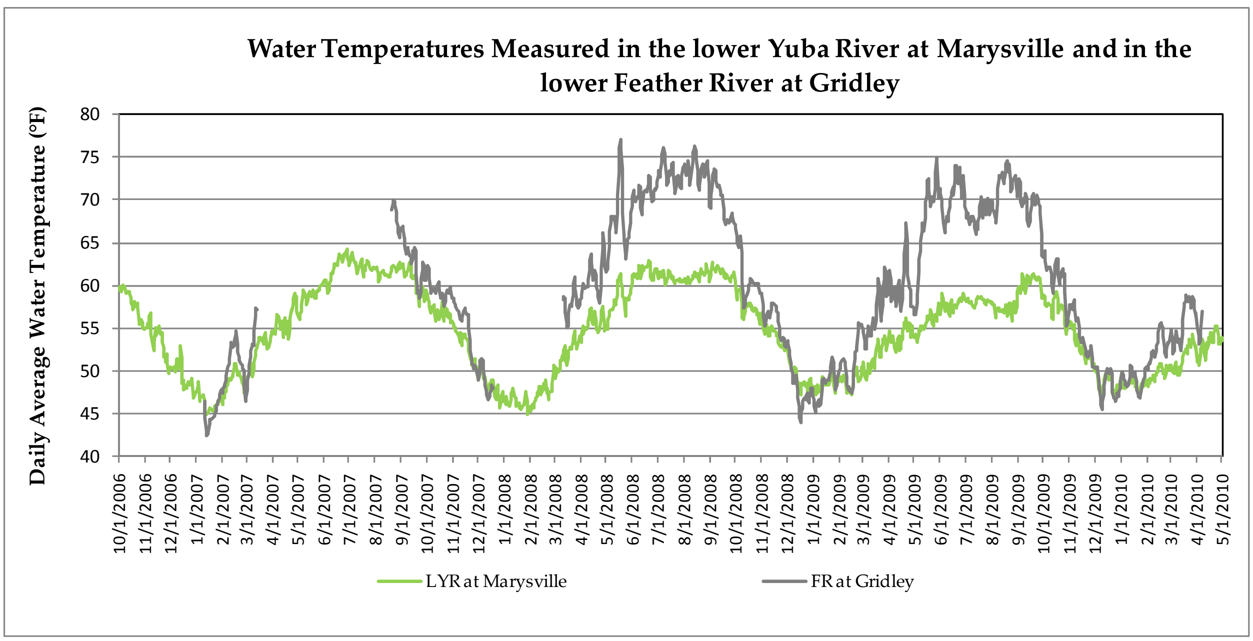

Figure 5. Water temperatures measured in the lower Yuba River at Marysville and in the lower Feather River at Gridley monitoring locations.

In general, water temperatures measured at these two locations diverge beginning in March and extending through October. During 2008, average daily water temperatures at Marysville did not exceed about 62°F from May through September, and the monthly averages ranged from 58.3°F during May to 61.6°F during June. By contrast, average daily water temperatures measured in the lower Feather River at Gridley exceeded 65°F by early May, reached 70°F by mid-May, generally remained at or above 70°F through mid-September, and remained above 65°F through early October. Monthly average water temperatures at Gridley ranged from 67.6°F during May to 73.7°F during August.

Water temperatures during 2009 were slightly cooler than those observed during 2008. During 2009, average daily water temperatures at Marysville did not exceed about 61°F from May through September, and the monthly averages ranged from 55.6°F during May to 60.3°F during September. By contrast, average daily water temperatures measured in the lower Feather River at Gridley exceeded 65°F by early May, reached 70°F by mid-May and generally remained at or above 70°F through late-September, and remained above 65°F through September. Monthly average water temperatures at Gridley ranged from 67.3°F during May to 71.7°F during August.

During summer (i.e., June through August) average daily water temperatures in the lower Feather River at Gridley can be as much as 16°F warmer than in the lower Yuba River at Marysville.

3.3 Lifestage-Specific Water Temperature Suitabilities

The RMT's technical evaluation of the appropriateness of water temperatures in the lower Yuba River primarily focuses on the identification of those months during which the Yuba Accord water temperature model results estimate a probability of exceeding the species- and lifestage-specific water temperature index values of at least 10%. The following sections discuss specific species/ lifestages/ months where model results indicate that water temperatures could exceed the water temperature index values by 10% or more. The 10% exceedance value is used as an indicator of potentially impactive conditions warranting further evaluation and consideration.

3.3.1 Steelhead

Adult Immigration and Holding

Over the August through March adult immigration and holding lifestage period, the water temperature index value of 64°F is not exceeded with a 10% or greater probability at the Smartsville, DPD, or Marysville locations (**Table 1**). The 56°F water temperature index value is not exceeded with a 10% or greater probability at the Smartsville location, although it is exceeded with 81 to 100% probabilities during August, September, and October at DPD and Marysville. Observed mean daily water temperatures at DPD during August, September, and October over the 2006 to 2009 monitoring period were predominantly below 60°F. In fact, the mean monthly DPD average daily water temperatures were 55.8°F, 58.4°F, and 55.5°F during August, September and October, respectively, during 2009. Additionally, immigrating adult steelhead are generally transient, able to seek thermal refuge and therefore may only experience short-term exposure to temperatures greater than 56°F. Also, the highest densities of steelhead in the lower Yuba River reportedly occur above DPD.

Table 1. Modeled Water Temperature Exceedances[1] for Steelhead Lifestage- and Location-Specific Periodicities in the lower Yuba River at Smartsville (SMRT), Daguerre Point Dam (DPD), and Marysville (MRY).

Lifestage	Gage	WTI[2]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult Immigration & Holding	SMRT	56°F	0%	0%	0%					7%	7%	1.4%	0%	0%
	DPD	56°F	0%	0%	0%					81%	100%	93%	0%	0%
	MRY	56°F	0%	0%	0%					97%	100%	97%	0%	0%
	SMRT	64°F	0%	0%	0%					0%	0%	0%	0%	0%
	DPD	64°F	0%	0%	0%					2%	2%	0%	0%	0%
	MRY	64°F	0%	0%	0%					4%	2%	0%	0%	0%
Spawning	SMRT	54°F	0%	0%	0%	0%								
	DPD	54°F	0%	0%	0%	35%								
	SMRT	57°F	0%	0%	0%	0%								
	DPD	57°F	0%	0%	0%	0%								
Embryo Incubation	SMRT	54°F	0%	0%	0%	0%	0%							
	DPD	54°F	0%	0%	0%	35%	74%							
	SMRT	57°F	0%	0%	0%	0%	0%							
	DPD	57°F	0%	0%	0%	0%	4%							
Juvenile Rearing & Downstream Movement	DPD	65°F	0%	0%	0%	0%	0%	0%	2%	1.4%	0%	0%	0%	0%
	MRY	65°F	0%	0%	0%	0%	0%	6%	4%	3%	2%	0%	0%	0%
Yearling+ Smolt Emigration	DPD	52°F	0%	0%	23%	72%						98%	13%	0%
	MRY	52°F	0%	0%	47%	98%						98%	46%	0%
	DPD	55°F	0%	0%	0%	2%						97%	0%	0%
	MRY	55°F	0%	0%	0%	2%						97%	2%	0%

[1] % probability of average monthly temperature exceeding specified water temperature index values as estimated by the Yuba Accord Water Temperature Model.
[2] Water Temperature Index Value established for target species and specific lifestages

Spawning

Over the January through April spawning lifestage period, the water temperature index value of 57°F is not exceeded at the Smartsville or DPD locations (Table 1). Over the January through April spawning lifestage period, the water temperature index value of 54°F is not exceeded at the Smartsville location. The 54°F water temperature index value also is not exceeded at the DPD location with the exception of April, when it is exceeded with a 35% probability. However, observed mean daily water temperatures at DPD during April over the 2007 to 2010 monitoring period were predominantly below 55°F. In fact, the mean monthly DPD average daily water temperatures were 54.9 °F, 54.2°F, 53.7°F, and 52.7°F during April 2007, 2008, 2009 and 2010, respectively. Moreover, most steelhead spawning occurs prior to April, and occurs at locations upstream of DPD.

Embryo Incubation

Over the January through May embryo incubation lifestage period, the water temperature index value of 57°F is not exceeded at the Smartsville location, and is not exceeded with a 10% or greater probability at the DPD location (Table 1). Over the January through May embryo incubation lifestage period, the water temperature index value of 54°F is not exceeded at the Smartsville location. The 54°F water temperature index value also is not exceeded at the DPD location with the exception of April and May, when it is exceeded with a 35% and 74% probability, respectively. However, observed mean daily water temperatures at DPD during April over the 2007 to 2010 monitoring period were predominantly below 55°F. In fact, the mean monthly DPD average daily water temperatures were 54.9 °F, 54.2°F, 53.7°F, and 52.7°F during April 2007, 2008, 2009 and 2010, respectively. Moreover, most steelhead embryo incubation is complete prior to May, and occurs at locations upstream of DPD.

Juvenile Rearing and Downstream Movement

Over the year-round juvenile rearing and downstream movement lifestage period, the water temperature index value of 65°F is not exceeded at either the DPD or Marysville locations during most months of the year, and is not exceeded with a 10% or greater probability during any month of the year (Table 1).

Yearling+ Smolt Emigration

Over the October through mid-April yearling+ smolt emigration lifestage period, the water temperature index value of 55°F is exceeded with a 10% or greater probability during the month of October at both the DPD and Marysville locations, when it is exceeded with a 97% probability (Table 1). The water temperature index value of 52°F is exceeded during the months of October, November, March, and April at both the DPD and Marysville locations, with exceedance probabilities ranging from 13% to 98%. Observed mean daily water temperatures at DPD over the 2006 to 2010 monitoring period were predominantly below 56°F during October, 53°F during November, 53°F during March, and 55°F during April. In fact, the mean monthly DPD average daily water temperatures ranged from 55.4°F to 55.6°F during October, 51.7°F to 52.7°F during November, 50.7°F to 51.1°F during March, and 52.7°F to 54.9°F during April. Additionally, emigrating yearling+ smolts may only experience short-term exposure to temperatures greater than the water temperature index values during these months, which represent the beginning and end of the yearling+ smolt emigration period.

Monitoring data indicate that water temperatures generally observed during the first half of October in the Feather River at Gridley during 2008 are 4°F to 7°F warmer than those observed in the lower Yuba River at Marysville, and ranged from 64°F to 67°F. Therefore, the potential benefits of reducing temperatures in the lower Yuba River to increase suitability during the first half of October are questionable in consideration of the higher water temperatures in the lower Feather River. A similar situation occurs during the months of March and April.

3.3.2 Spring-run Chinook Salmon

Adult Immigration and Holding

Over the April through August adult immigration and holding lifestage period, the water temperature index value of 64°F is not exceeded with a 10% or greater probability at both the Smartsville and DPD locations, and is only exceeded at Marysville with an 11% probability during July (**Table 2**). The 60°F water temperature index value is not exceeded with a 10% or greater probability at either the Smartsville or DPD location, although it is exceeded with a 10% probability during May, 45% during June, 67% during July, and 16% during August. Observed mean daily water temperatures at Marysville were predominantly below 60°F during May, below 63°F during June and July, and below 62°F during August during 2007 and 2008 monitoring periods. Water temperatures were generally cooler during the 2009 monitoring period, with observed mean daily water temperatures at Marysville predominantly below 56°F during May, below 59°F during June and July, and below 58°F during August.

Additionally, preliminary acoustic tagging and tracking data indicate that immigrating adult spring-run Chinook salmon do not spend extended periods of time at downstream (e.g., Marysville) locations. Spring-run Chinook salmon primarily exhibit holding behavior during July and August near or upstream of DPD in the lower Yuba

River following the period of immigration during April, May, and June, in preparation for spawning above DPD, and water temperatures remain below the most rigorous 60°F water temperature index value for the adult immigration and holding lifestage.

Table 2. Modeled Water Temperature Exceedances[1] for Spring-Run Chinook Salmon Lifestage- and Location-Specific Periodicities in the lower Yuba River at Smartsville (SMRT), Daguerre Point Dam (DPD), and Marysville (MRY).

Lifestage	Gage	WTI[2]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult Immigration & Holding	SMRT	60°F				0%	0%	0%	0%	0%				
	DPD	60°F				0%	1.4%	3%	2%	2%				
	MRY	60°F				0%	10%	45%	67%	26%				
	SMRT	64°F				0%	0%	0%	0%	0%				
	DPD	64°F				0%	0%	0%	2%	2%				
	MRY	64°F				0%	0%	8%	11%	4%				
Spawning	SMRT	56°F									7%	1.4%	0%	
Embryo Incubation	SMRT	56°F	0%	0%							7%	1.4%	0%	0%
Juvenile Rearing & Downstream Movement	DPD	65°F	0%	0%	0%	0%	0%	0%	2%	1.4%	1.4%	0%	0%	0%
	MRY	65°F												
Yearling+ Smolt Emigration	DPD	63°F	0%	0%	0%	0%	0%						0%	0%
	MRY	63°F	0%	0%	0%	0%	0%						0%	0%

[1] % probability of average monthly temperature exceeding specified water temperature index values as estimated by the Yuba Accord Water Temperature Model.
[2] Water Temperature Index Value established for target species and specific lifestages

Monitoring data indicate that water temperatures observed in the lower Feather River at Gridley are warmer than those observed in the lower Yuba River at Marysville by 7°F to 16°F during June, 9°F to 14°F during July, and 11°F to 16°F during August for the 2008 and 2009 monitoring period. Reducing lower Yuba River water temperatures during June, July, and August would further exacerbate the substantial water temperature difference between the lower Yuba River at Marysville and the lower Feather River at Gridley, which could potentially increase out-of-basin effects by increasing the rate of straying and associated hybridization and the loss of potential genetic integrity of spring-run Chinook salmon in the lower Yuba River.

Spawning

Over the September through mid-November spawning lifestage period, the water temperature index value of 56°F is not exceeded at the Smartsville location with a 10% or greater probability (Table 2).

Embryo Incubation

Over the September through February embryo incubation lifestage period, the water temperature index value of 56°F is not exceeded at the Smartsville location with a 10% or greater probability (Table 2).

Juvenile Rearing and Downstream Movement

Over the year-round juvenile rearing and downstream movement lifestage period, the water temperature index value of 65°F is not exceeded at either the DPD or Marysville locations during most months of the year, and is not exceeded with a 10% or greater probability during any month of the year (Table 2).

Yearling+ Smolt Emigration

Over the November through mid-May yearling+ smolt emigration lifestage period, the water temperature index value of 63°F is not exceeded at either the DPD or Marysville locations (Table 2).

3.3.3 Fall-run Chinook Salmon

Adult Immigration and Staging

Over the July through mid-December adult immigration and staging lifestage period, the water temperature index value of 64°F is not exceeded with a 10% or greater probability at the DPD location, although it is exceeded with an 11% probability at the Marysville location during July (**Table 3**). The 60°F water temperature index value is exceeded with a 10% or greater probability at the DPD location only during the month of September (12%), and during July (67%), August (26%), and September (93%) at the Marysville location.

Observed mean daily water temperatures at Marysville were predominantly below 62°F during July, August and September during the 2007 and 2008 monitoring periods. Water temperatures were generally cooler during the 2009 monitoring period, with observed mean daily water temperatures at Marysville predominantly below 59°F during July, below 58°F during August, and below 61°F during September. Additionally, immigrating adult fall-run Chinook salmon are generally transient, and therefore may only experience short-term exposure to temperatures greater than 60°F at downstream locations (e.g., Marysville) during July through September.

Table 3. Modeled Water Temperature Exceedances[1] for Fall-Run Chinook Salmon Lifestage- and Location-Specific Periodicities in the lower Yuba River at Smartsville (SMRT), Daguerre Point Dam (DPD), and Marysville (MRY).

Lifestage	Gage	WTI[2]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult Immigration & Staging	DPD	60°F							2%	2%	12%	1.4%	0%	0%
	MRY	60°F							67%	26%	93%	8%	0%	0%
	DPD	64°F							2%	2%	2%	0%	0%	0%
	MRY	64°F							11%	4%	2%	0%	0%	0%
Spawning	SMRT	56°F										1.4%	0%	0%
	DPD	56°F										93%	0%	0%
Embryo Incubation	SMRT	56°F	0%	0%	0%							1.4%	0%	0%
	DPD	56°F	0%	0%	0%							93%	0%	0%
Juvenile Rearing & Downstream Movement	DPD	65°F	0%	0%	0%	0%	0%	0%	2%					0%
	MRY	65°F	0%	0%	0%	0%	0%	6%	4%					0%

[1] % probability of average monthly temperature exceeding specified water temperature index values as estimated by the Yuba Accord Water Temperature Model.
[2] Water Temperature Index Value established for target species and specific lifestages

Spawning

Over the October through December spawning lifestage period, the water temperature index value of 56°F is not exceeded with a 10% or greater probability at the Smartsville location, although it is exceeded with a 93% probability at the DPD location during October (Table 3). Fall-run Chinook salmon are primarily observed spawning during October in the upper reaches upstream of DPD in the lower Yuba River. The Yuba Accord Water Temperature model estimated no probability of exceeding the water temperature index value of 56°F during October at Smartsville. Spawning fall-run Chinook salmon begin expanding their spatial distribution further downstream in later fall months as suitable temperatures become available near or downstream of DPD.

Embryo Incubation

Over the October through March embryo incubation lifestage period, the water temperature index value of 56°F is not exceeded with a 10% or greater probability at the Smartsville location, although it is exceeded with a 93% probability at the DPD location during October (Table 3). Because fall-run Chinook salmon are primarily observed spawning during October in the upper reaches upstream of DPD in the lower Yuba River, that is also where incubation would occur. The Yuba Accord Water Temperature model indicated no probability of exceeding the water temperature index value of 56°F during October at Smartsville. As described above for the spawning lifestage, applicable to the embryo incubation lifestage, spawning fall-run Chinook salmon begin expanding their spatial distribution further downstream in later fall months as suitable temperatures become available near or downstream of DPD.

Juvenile Rearing and Downstream Movement

Over the December through July juvenile rearing and downstream movement lifestage period, the water temperature index value of 65°F is not exceeded at either the DPD or Marysville locations during most months of the year, and is not exceeded with a 10% or greater probability during any month of the year (Table 3).

3.3.4 North American Green Sturgeon Lifestage-Specific Water Temperature Exceedances

The RMT water temperature evaluation for North American green sturgeon is to evaluate the probability of occurrence that water temperatures in the lower Yuba River are within reported suitable ranges for each of the lifestages as described in Sections 2.1.1 and 2.2.1.

Adult Immigration, Holding, And Post-Spawning Holding

Water temperatures from 44°F to 61°F were used by the RMT to represent the suitable range for the adult immigration, holding, and post-spawning holding lifestages. The combination of these lifestages encompasses late February through November. At DPD, water temperatures remain within this range with 100% probability during most months excluding June through September, when they remain within this water temperature range with a 97% probability. At Marysville, water temperatures remain within this range with a 97 to 100% probability from February through May and during October and November, nearly 80% during August, about 50% during June and July, and 20% during September.

Spawning and Embryo Incubation

Water temperatures from 46°F to 63°F were used by the RMT to represent the suitable range for the spawning and embryo incubation lifestages, which occur from March through July. At DPD, water temperatures remain within this range with 100% probability during most months excluding July, when they remain within this water temperature range with a 98% probability. At Marysville, water temperatures remain within this range with a 97 – 100% probability from March through May, and about an 80% probability during June and July.

Juvenile Rearing

Water temperatures from 52°F to 66°F were used by the RMT to represent the suitable range for the juvenile rearing lifestage, which occurs year-round. At DPD, water temperatures remain within this range with a 98 to 100% probability from June through October. During November, water temperatures remain within this range with only a 14% probability because most (86%) of the time water temperatures are below the lower value of 52°F. Water temperatures are always below the 52°F value during December through February, and below this value with a 77% probability during March. During April and May, water temperatures remain within the suitable range with a 72% and 95% probability, respectively, and are below this range the remainder of the time.

At Marysville, water temperatures remain within this range with about 95 to 100% probability from April through October. During November, water temperatures remain within this range with a 47% probability because the rest (53%) of the time water temperatures are below the lower value of 52°F. Water temperatures are always below the 52°F value during December through February, and below this value with a 53% probability during March.

Juvenile Outmigration

Water temperatures from 52°F to 66°F were used by the RMT to represent the suitable range for the juvenile outmigration lifestage, which occurs May through September. At both DPD and Marysville, water temperatures remain within this range with about 95 to 100% probability.

4 DISCUSSION

4.1 Cold Water Considerations Regarding Adult Spring-run Chinook Salmon Immigration

The RMT acknowledged that water temperature concerns in the Central Valley are generally related to temperatures exceeding “upper” tolerance limits rather than “lower” limits. However, the potential exists for water temperatures in the lower Yuba River to be lower than the “lower” salmonid tolerance limits in the Englebright Dam and Narrows reaches. Available scientific literature concerning “lower” water temperature tolerance values was found to be limited. It was recently suggested that raising the water temperature from 50°F to 53°F on the south fork of the McKenzie River in Oregon may have attracted spring-run Chinook salmon to migrate further upstream. This suggested the need to examine the possibility that cold water temperatures in the uppermost reach of the lower Yuba River during the spring and summer may potentially influence the volitional upstream movement and holding of spring-run Chinook salmon. Therefore, the RMT also examined the probability of occurrence of water temperatures less than 53°F at the Smartsville location for the spring-run Chinook salmon adult immigration and holding lifestage.

Over the April through August adult immigration and holding lifestage period, the water temperature model indicates that water temperatures at Smartsville are below 53°F with a 100% probability during April (48.2 to 52.1°F), 97% during May (50.2 to 52.9°F), 18% during June (52.7 to 52.9°F), and nearly 0% during July and August. Water temperatures at DPD are below 53°F with about 50% probability during April (49.9 to 52.9°F), 13% during May (51.1 to 52.9°F), and remain at or above 53°F with a 100% probability from June through August. Therefore, if water temperatures lower than 53°F impede upstream migration, then movement of fish above DPD may be affected about 50% of the time during April.

As previously discussed, the RMT's examination of preliminary data obtained since the Vaki Riverwatcher infrared and videographic sampling system has been operated (2003 – present) indicated a general mode of Chinook salmon ascending the fish ladders at DPD from April through June, with few observations during April and peak observations during May or June. Also, 30 adult Chinook salmon acoustically tagged during May 2009 and tracked through the fall demonstrated variable patterns of upstream migration and holding, with some fish remaining for several weeks below DPD, and others holding and/or moving among various locations above and below the dam, prior to moving into upstream areas to spawn during early fall. Further examination of previously collected and on-going acoustic tagging and tracking and water temperature monitoring data may yield additional insights as to whether cold water temperatures may potentially influence the volitional upstream movement and holding of spring-run Chinook salmon.

In consideration of whether it may be appropriate to provide warmer temperatures during April and May in the upper reaches of the lower Yuba River, the RMT took into account the spatial and temporal distribution of other species and lifestages during these months, and whether water temperature index values are exceeded. Steelhead spawning and embryo incubation is occurring during April and May, associated with water temperature index values of 54°F and 57°F. At DPD the water temperature index value of 54°F is exceeded with a 35% probability during April, and a 74% probability during May. At DPD the water temperature index value of 57°F is not exceeded during April, but is exceeded with a 4% probability during May.

To consistently achieve 53°F at Smartsville, then water temperatures would need to increase approximately 5°F during April and 3°F during May. Based on the water temperature model, these increases would result in exceeding the 54°F water temperature index value with about a 100% probability during both April and May at DPD. Also, these increases would result in exceeding the 57°F water temperature index value with about a 70% probability during April, and with a 75% probability during May at DPD.

Given the low numbers of Chinook salmon ascending the fish ladders at DPD during April, the present uncertainty regarding whether low water temperatures influence the immigration and holding of adult spring-run Chinook salmon in the upper reaches of the lower Yuba River, the recent observations of spatial and temporal distributions of adult spring-run Chinook salmon, and potential adverse impacts on other species and lifestages, the RMT concludes that providing warmer water temperatures during April and May is not recommended at this time.

4.2 *O. mykiss* Anadromy vs. Residency

The issue has been raised at the RMT that providing relatively cold water temperatures below Englebright Dam year-round may favor residency over anadromy in lower Yuba River *O. mykiss*, and that it may be possible to manage the lower Yuba River water temperature regime to promote anadromy in *O. mykiss*.

Englebright Dam and Reservoir are located downstream of New Bullards Bar Dam. Operational releases from Englebright Dam provide the base flow and water temperature boundary conditions in the upper reaches of the lower Yuba River. Since September 1993, the low-level outlet has been used for all controlled releases from New Bullards Bar Dam pursuant to input provided by CDFG and USFWS. The coldwater pool availability in New Bullards Bar Reservoir has been sufficient to accommodate year-round utilization of the lower river outlets in order to provide cold water into Englebright Reservoir, and subsequently into the lower Yuba River.

Although few baseline data are available, it has been suggested that Central Valley *O. mykiss* have apparently shifted from a historic preponderance of anadromy to a greater proportion of fish with a resident life history (maturity in freshwater with no time spent in the ocean) (Lindley *et al*. 2007; Satterthwaite *et al*. 2010). McClure et al. (2008) state that some Central Valley populations below barriers appear to have a higher than expected proportion of resident *O. mykiss*. Zimmerman et al. (2009) analyzed otolith strontium:calcium (Sr:Ca) ratios to determine maternal origin (anadromous vs. non-anadromous) and migratory history (anadromous vs. non-anadromous) of *O. mykiss* collected in Central Valley rivers between 2001 and 2007, including the lower Yuba River. The proportion of steelhead progeny in the lower Yuba River (about 13%) was intermediate to the other rivers examined (Sacramento, Deer Creek, Calaveras, Stanislaus, Tuolumne, and Merced), which ranged from 4% in the Merced River to 74% in Deer Creek (Zimmerman et al. 2009).

Lindley *et al*. (2007), referencing McEwan (2001), suggested that the apparent shift toward the resident life history strategy of *O. mykiss* in the Central Valley is likely partly a response to hypolimnetic releases from reservoirs. Payne and Cramer (2005) suggest that water temperature regimes were the most consistent feature that distinguished the main production areas for anadromous or resident *O. mykiss* in the Yakima, Deschutes, and Willamette river basins in Washington and Oregon. They also suggest that streams with temperatures below 16°C (about 61°F) during summer and capable of producing 12-14 inch trout at first maturity offer a selective advantage for residency, whereas streams where growth opportunities during summer are constrained either by temperature or space likely provide a selective advantage for anadromy. Courter et al. (2009) reported that *O. mykiss* anadromy was dominant in tributary sites in the lower Yakima River Basin where summer flows were relatively low and stream temperatures were comparatively warm, and that residency was the predominate life history form in the upper Yakima River Basin and other mainstem locations where stream channels generally maintained higher summer flows and cooler temperatures.

Lindley *et al*. (2007) suggest that *O. mykiss* may take up residency in dam tailwaters experiencing hypolimnetic releases due to their phenotypic plasticity, or the fitness of *O. mykiss* using these areas may exceed the fitness of anadromous fish, which would drive an evolutionary (i.e., genetic) change if life history strategy is heritable. As stated by McClure *et al.* (2008), the associations of salmonid life histories with environmental characteristics can result from either genetically-based adaptive evolution, or from individual phenotypic plasticity. In phenotypically plastic traits, environment trait associations reflect immediate environmental responses rather than local genetic adaptation, and selective change might be buffered in complex ways (Sultan 2007 as cited in McClure *et al.* 2008). It is unclear the extent to which *O. mykiss* current life histories on Central Valley streams are best explained by a plastic response or a genetic change (Satterthwaite *et al.* 2010).

Some *O. mykiss* individuals complete their entire life history in freshwater whereas others, sympatric at birth, spend variable amounts of time in freshwater, estuaries, and the ocean before returning to freshwater to reproduce (Satterthwaite *et al.* 2010). Also, the progeny of one life-history form of *O. mykiss* can assume a life-history strategy different from that of their parents (McEwan 2001). In the Central Valley, naturallyspawning stocks of rainbow trout that support anadromy are known to occur in the upper Sacramento River and tributaries, Mill, Deer, and Butte creeks, and the Feather, Yuba, American, Mokelumne, Calaveras, and Stanislaus rivers (McEwan 2001).

A polymorphic *O. mykiss* population structure may be necessary for the long-term persistence in highly variable environments such as the Central Valley (McEwan 2001). Resident fish may reduce extinction risk through the production of anadromous individuals that can enhance weak steelhead populations (Lindley *et al.* 2007).

Habitats in tailwater area below dams have changed to become more conducive to the resident life history even though ocean migration is possible (McClure *et al.* 2008). They suggest that migration to the ocean with its superior growth opportunity is presumably necessary when freshwater food supplies are relatively low. However, fish that can grow rapidly in fresh water avoid the risks associated with migration, and in such a situation, anadromy would be expected to be selected against (McClure *et al.* 2008).

In the lower Yuba River, a broad range of *O. mykiss* size classes have been during spring and summer snorkeling, electrofishing, and angling surveys (SWRI *et al.* 2000). Juvenile *O. mykiss* ranging in size from 40-150 mm are commonly observed upstream of DPD. Numerous larger juveniles and resident trout up to 18 inches long also are commonly observed in the mainstem upstream and downstream of DPD (SWRI *et al.* 2000).

Mitchell (2010) reports that analysis of scale growth patterns of juvenile *O. mykiss* in the lower Yuba River indicates a period of accelerated growth during spring, peaking during the summer, followed by decelerated growth during the fall and winter. Following the second winter, juvenile *O. mykiss* in the lower Yuba River exhibit reduced annual growth in length with continued growth in mass until reaching reproductive age. Additionally, more rapid *O. mykiss* growth occurred in the lower Yuba River compared to the lower Sacramento River and Klamath River *O. mykiss*, with comparable growth rates to *O. mykiss* in the upper Sacramento River (Mitchell 2010).

However, Satterthwaite *et al.* (2010) caution against making overly simplistic statements such as the fastest growing parr are expected to mature, the next fastest growing to smolt as young fish, and the remainder to smolt as older fish. They also state that sometimes the fastest growing fish are predicted to smolt immediately, slightly slower growing fish are predicted to mature as parr, and even slower growing fish are predicted to smolt at older ages, with the result that residency is associated with intermediate rather than fast or slow growth. Instead of a dichotomy between residency and anadromy, *O. mykiss* express a multitude of different, independent life histories, including sexual maturity as a resident at a variety of different ages, or smolting at a variety of different ages (Satterthwaite *et al.* 2010).

In general, Satterthwaite *et al.* (2010) do not predict that a warm summer with low food availability will strongly favor anadromy relative to a baseline condition, nor do they predict that a cool summer with high flow will strongly favor residency.

Satterthwaite *et al.* (2010) concluded that the single most important factor in preserving the anadromous life history of *O. mykiss* is survival during the period between emigration to the ocean and returning to spawn, although large changes in freshwater survival or growth rates are potentially also important. Lindley *et al.* (2007) suggest that life history diversity also confers risk spreading, in that individuals are spread among habitats that are subject to independent sources of disturbance. For instance, fish in the ocean are unaffected by flooding, while fish in rivers are immune to poor feeding conditions in the ocean (Lindley *et al.* 2007).

O. mykiss life history evolution is driven by an interacting network of growth rates, freshwater survival, and emigrant survival, along with limits on the asymptotic sizes achievable in freshwater (Satterthwaite *et al.* 2010). They state that it is difficult and perhaps misleading to try to summarize the effects of any one of multiple variables in isolation on predicted changes in steelhead life history in response to management actions.

In the Central Valley, a primary issue of management concern is that releases from dams do not provide sufficient cold water suitable for the continuum of lifestages of *O. mykiss*. McEwan (2001) reports that some dams in the Central Valley were constructed with inadequate release structures that make it difficult to optimize releases from the hypolimnion, or other reservoirs may not have adequate minimum pool storage requirements. Consequently, many reservoirs currently are not able to provide releases necessary to maintain suitable temperatures for steelhead rearing through the critical summer and fall periods, especially during dry and critically-dry years (McEwan 2001). Such is generally not the case regarding water temperatures in the lower Yuba River. Ironically, the issue regarding *O. mykiss* anadromy versus residency in the lower Yuba River centers upon whether it would be advisable to intentionally release warmer waters to promote anadromy. Given the suite of considerations presented in this section, the previously described multi-species/lifestage water temperature suitability evaluations in this Technical Memorandum, and potential adverse impacts on other species and lifestages that could result from the intentional provision of warmer water temperatures, the RMT concludes that providing warmer water temperatures to promote *O. mykiss* anadromy is not recommended at this time.

5 CONCLUSIONS AND RECOMMENDATIONS

The Yuba Accord River Management Team (RMT), comprised of representatives of NMFS, USFWS, CDFG, DWR, YCWA, PG&E and NGOs, used previously available data and information, updated with recent biologic and abiotic monitoring, to review the appropriateness of the water temperature regime in the lower Yuba River associated with implementation of the Yuba Accord. The RMT updated the lifestage periodicities of target species in the lower Yuba River, identified suitable thermal regimes for target fish species taking into account individual species and lifestage water temperature requirements, identified species and lifestage-specific water temperature index values, assessed the probability of occurrence that those water temperature index values would be achieved with implementation of the Yuba Accord, and evaluated whether alternative water temperature regimes are warranted. The RMT also addressed the issue regarding the potential that cold water conditions could affect adult spring-run Chinook salmon immigration and holding, and the issue of *O. mykiss* anadromy versus residency.

Given the entire suite of considerations in this Technical Memorandum, the RMT concludes that implementation of the Yuba Accord provides a suitable thermal regime for target species in the lower Yuba River, and does not recommend water temperature-related operational or infrastructure modifications at this time.

Further, the RMT recommends that this Technical Memorandum be supplemented by incorporating additional data and information obtained from ongoing monitoring and evaluation activities, and by the application of a daily time-step water temperature model, when such a model becomes available, to provide greater resolution and to validate the exceedance estimates of the Yuba Accord Water Temperature Model. It is presently anticipated that the supplemental evaluation would be conducted by fall of 2012.

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ATTACHMENT A

WATER TEMPERATURE INDEX VALUES FOR TECHNICAL EVALUATION GUIDELINES

Attachment A

Water Temperature Index Values for Technical Evaluation Guidelines

INTRODUCTION

This attachment (Attachment A) to the Yuba Accord River Management Team (RMT) Technical Memorandum titled *Lower Yuba River Water Temperature Objectives* serves as a literature review and reference compilation from which the RMT selected water temperature index values to evaluate the thermal regime in the lower Yuba River for Chinook salmon and steelhead. The information presented herein is largely based on excerpts from Appendix E2 to the Public Draft EIR/EIS for the Yuba Accord (YCWA *et al*. 2007).

Water temperature index values were established from a comprehensive literature review to reflect an evenly spaced range of water temperatures, from reported "optimal" to "lethal" water temperatures, for each life stage of Chinook salmon and steelhead. Types of literature examined include scientific journals, Master's theses and Ph.D. dissertations, literature reviews, and agency publications (see Section 4.0, References). Water temperature index values were determined by placing emphasis on the results of laboratory experiments that examined how water temperature affects Central Valley Chinook salmon and steelhead, as well as by considering regulatory documents such as biological opinions from NMFS. Studies on fish from outside the Central Valley were used to establish index values when local studies were unavailable. To avoid unwarranted specificity, only whole integers were selected as index values, thus support for index values was, in some cases, partially derived from literature supporting a water temperature that varied from the resultant index value by several tenths of a degree. For example, Combs and Burrows (1957) reported that constant incubation temperatures between 42.5°F and 57.5°F resulted in normal development of Chinook salmon eggs, and their report was referenced as support for a water temperature index value of 58°F. 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.

Most of the literature on salmonid water temperature requirements refers to "stressful," "tolerable," "preferred," or "optimal" water temperatures or water temperature ranges. (Spence *et al*. 1996) defined the tolerable water temperature range as the range at which fish can survive indefinitely. Thermal stress to fish is any water temperature change that alters the biological functions of the fish and which decreases probability of survival (McCullough 1999). Optimal water temperatures provide for feeding activity, normal physiological response, and behavior void of thermal stress symptoms (McCullough 1999). Preferred water temperature ranges are those that are most frequently selected by fish when allowed to freely choose locations along a thermal gradient (McCullough 1999). Properly functioning condition (PFC) is an additional term that will be used in the present document as defined by NMFS in (McElhany *et al.* 2000). McElhany *et al.* (2000) suggests that defining PFC is an ongoing process and the term will undergo further revision, but based on currently available knowledge, PFC defines the "…freshwater spawning and rearing conditions necessary for the long-term survival of Pacific salmon populations."

The RMT acknowledges and adopts the limitations associated with the development and application of water temperature index values well summarized by McEwan (2001) addressing steelhead. Namely, that they serve as general guidelines, originally developed by researchers on specific streams or under laboratory conditions that oftentimes focused on temperature maxima that cause lethal and sublethal effects. 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. The water temperature index values are not meant to be significance thresholds, but instead provide a mechanism by which to compare the suitability of the water temperature regimes associated with implementation of the Yuba Accord. The water temperature index values presented herein represent a gradation of potential effects, from reported optimal water temperatures increasing through the range of represented index values for each life stage.

1 CHINOOK SALMON

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 will not be 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 water temperature index values derived from all the literature pertaining to Chinook salmon that provide PFC 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).

1.1 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).

One set of adult immigration and holding water temperature index values was established for all Chinook salmon run-types. The water temperature index values are evenly spaced across the range of conditions from 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 to evaluate the Chinook salmon adult immigration and holding lifestage are 60°F, 64°F, and 68°F (**Table A-1**). 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, many of the references to 56°F are based on Hinze (1959), which is a study examining the effects of water temperature on incubating Chinook salmon eggs. 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. Because 56°F is not strongly supported in the literature for adult Chinook salmon immigration and holding, it was not established as an index value.

The lowest water temperature index value established was 60°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*." The 60°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 60°F water temperature index value.

Table A-1. Chinook Salmon Adult Immigration and Holding Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
60°F [a]	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).
64°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).
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).

[a] The 60°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 60°F water temperature index value.

An index value of 64°F was established because Berman (1990) suggests effects of thermal stress to pre-spawning adults are evident at water temperatures near 64°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 occurs at 63.5°F to 66.2°F. Also, 64°F represents a mid-point value between the water temperature index values of 60°F and 68°F. An index value of 68°F was established because the literature suggests that thermal stress at water temperatures greater than or equal to 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). Because potential effects to immigrating and holding adult Chinook salmon reportedly occur at water temperatures greater than or equal to 68°F, index values higher than 68°F were not established.

1.2 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 life stages that are closely linked temporally, especially considering that studies describing how water temperature affects embryonic survival and development based on varying water temperature treatments on holding adults often report similar results to water temperature experiments conducted on fertilized eggs (Marine 1992; McCullough 1999; Seymour 1956).

Water temperature index values were selected from a comprehensive literature review for Chinook salmon eggs during spawning and incubation (**Table A-2**). Relative to the large body of literature pertaining to water temperature effects on Chinook salmon embryos, few laboratory experiments specifically examine Chinook salmon embryo survival under different constant or fluctuating water temperature treatments, only one of which is recent (Combs and Burrows 1957; Hinze 1959; Johnson and Brice 1953; Seymour 1956; USFWS *et al.* 1999). In large part, supporting evidence for index value selections was derived from the aforementioned laboratory studies and from regulatory documents (NMFS 1993b; NMFS 1997b; NMFS 2002a). Field studies reporting river water temperatures during spawning also were considered (Dauble and Watson 1997; Groves and Chandler 1999).

The water temperature index values selected to evaluate the Chinook salmon spawning and embryo incubation life stages are 56ºF, 58ºF, 60ºF, and 62ºF. Some 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. Reclamation (unpublished work) reports that water temperatures less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs. USFWS (1995a) reported a water temperature range of 41.0ºF to 56.0°F for maximum survival of eggs and yolk-sac larvae in the Central Valley of California. 42.0ºF to 56.0°F was suggested as the preferred water temperature for Chinook salmon egg incubation in the Sacramento River (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.

Table A-2. Chinook Salmon Spawning and Embryo Incubation Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
56°F [a]	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 occurs during yolk-sac stage when embryos are incubated at 60°F (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).
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)

[a] 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. However, 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. 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; Seymour 1956; USFWS 1999), therefore, it was not necessary to select index values above 62°F. Similarly, mortality to spawning adult Chinook salmon prior to egg deposition (Berman 1990; Marine 1992) reportedly occurs at water temperatures above those at which embryo mortality results (i.e., 62°F) (Hinze 1959; Reclamation 2003; Seymour 1956; USFWS 1999); therefore, an index value above 62°F was not required.

1.3 Juvenile Rearing and Smolt Emigration

Water temperature index values were selected from a comprehensive literature review for juvenile rearing and smolt emigration (**Table A-3**). 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, fingerlings, and smolts, 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). 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 smolt emigration 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. Increasing levels of thermal stress to this life stage may reportedly occur above the 60°F water temperature index value.

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. 65°F was selected as an index value 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

Table A-3. Chinook Salmon Juvenile Rearing and Smolt Emigration Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
60°F [a]	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, 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).
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).
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 (Rich 1987b)
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 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). 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 (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, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).

Index Value	Supporting Literature
75°F	For juvenile Chinook salmon in the lower American River fed maximum rations under laboratory conditions, 75.2ºF 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, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).
[a] The 60°F water temperature index value established for the Chinook salmon juvenile rearing and smolt emigration 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 juvenile Chinook salmon. Increasing levels of thermal stress to this life stage may reportedly occur above the 60°F water temperature index value.	

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; EPA 2003a; Myrick and Cech 2001; NMFS 2002a; USFWS 1995a). 68°F was selected as an index value because, at water temperatures above 68°F, sub-lethal effects become severe such as reductions in appetite and growth of juveniles, as well as prohibiting successful smoltification (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 (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 (Rich 1987b) was derived using slow rates of water temperature change and, thus, is ecologically relevant. Additional support for an index value of 75°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.

2 STEELHEAD

2.1 Adult Immigration and Holding

Water temperatures can control the timing of adult spawning migrations and can affect the viability of eggs in holding females. Few studies have been published that examine the effects of water temperature on either steelhead immigration or holding, and none have been 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 A-4**). Water temperature index values of 52°F, 56°F, and 70°F were chosen because: (1) they incorporate a range of values that provide PFC to conditions that are highly adverse; and (2) 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. 52°F was selected as a water temperature index value because it has been referred to as a "recommended" (Reclamation 2003), "preferred" (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 (Leitritz and Lewis 1980; McCullough *et al.* 2001; Smith *et al.* 1983). 70°F was selected as the highest water temperature index value because the literature suggests that water temperatures near and above 70.0°F present a thermal barrier to adult steelhead migrating upstream (McCullough *et al.* 2001).

Table A-4. Steelhead Adult Immigration and Holding Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
52°F [a]	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).
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).

[a] The 52°F water temperature index value established for the steelhead adult immigration and holding life stage is the index value generally reported in the literature as the upper limit of either the recommended, preferred, or optimum range for steelhead immigration. Increasing levels of thermal stress to this life stage may reportedly occur above the 52°F water temperature index value.

2.2 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 A-5**).

Table A-5. Steelhead Spawning and Embryo Incubation Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
52°F [a]	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).
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	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).

[a] The 52°F water temperature index value established for the steelhead spawning and embryo incubation life stage is the index value generally reported in the literature as the upper limit of the optimal range for steelhead spawning, embryo incubation, and fry emergence. Increasing levels of thermal stress to this life stage may reportedly occur above the 52°F water temperature index value.

Water temperature index values of 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 52°F, 54°F, 57°F, and 60°F. Second, the index values reflect an evenly distributed range representing reported optimal to lethal conditions for steelhead spawning and embryo incubation. Although some literature suggests water temperatures ≤ 50°F are optimal for steelhead spawning and embryo survival (Myrick and Cech 2001; Timoshina 1972), 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). 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. 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).

2.3 Juvenile Rearing

Like other salmonids, 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 65°F, 68°F, 72°F, and 75°F were selected to represent an evenly distributed range of index values for steelhead juvenile rearing (**Table A-6**). The lowest water temperature index value of 65°F was established because

NMFS (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 preferred water temperature range (i.e., 62.6°F to 68.0°F) 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 (1999). Because of the literature describing 68.0°F as both an upper preferred and an avoidance limit for juvenile *Oncorhynchus mykiss*, 68°F was established as a water temperature index value.

Table A-6. Steelhead Juvenile Rearing Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
65°F [a]	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 [a]	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).
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).

[a] The 65°F and 68°F water temperature index values established for the steelhead juvenile rearing life stage are the index values generally reported in the literature as the upper limits of the preferred range for juvenile steelhead. However, because 68°F also has been reported as an avoidance temperature for juvenile rainbow trout, 65°F may provide more suitable conditions for steelhead juvenile rearing than 68°F. Therefore, increasing levels of thermal stress to this life stage may reportedly occur above the 65°F 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).

2.4 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 A-7**). 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. 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 and 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).

Table A-7. Steelhead Smolt Emigration Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
52°F [a]	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).

[a] 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.

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