Appendix 12D
Water Temperature Index Value Selection Rationale

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APPENDIX 12D
Water Temperature Index Value Selection Rationale

12D.1 Introduction

Water temperature is one of the most important environmental parameters affecting the distribution, growth, and survival of fish populations. Lethal water temperatures control fish populations by directly reducing population size, while sub-lethal water temperatures affect fish populations via indirect physiologic influences. Water temperatures may particularly regulate fish populations that are near their latitudinal distributional extremes, because environmental conditions (e.g., water temperature) at distributional extremes also may be near the boundaries of conditions that allow the populations to persist. For example, California's Central Valley is at the southern limit of Chinook salmon distribution, and studies have demonstrated that direct effects of high water temperatures are an important source of juvenile Chinook salmon mortality in the Central Valley (Baker et al., 1995).

Myrick and Cech (2001) suggested that the primary cause for declines in Central Valley salmon and steelhead populations is the extensive construction of dams on rivers and streams used by salmonids for spawning and freshwater rearing. Dam construction has restricted Central Valley salmonids to less than 80 percent of their historical spawning habitat (Moyle, 2002), and has altered the natural flow and water temperature regimes in the river sections that remain available to spawning and rearing salmonids.

Technical evaluation guidelines have been developed to assess potential impacts of water diversion and water use projects in a consistent and effective manner. In order to successfully evaluate the effects of water temperature regimes on a given salmonid life stage or the entire life cycle, it is necessary to gain a broad understanding of how salmonids respond to water temperature regimes. This appendix presents the results of a literature review that was conducted to: (1) interpret the available 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 biologically defensible water temperature index values to be used as guidelines for impact assessment.

12D.2 Methodology

To the extent that literature describing thermal tolerances for each species was available, 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. Types of literature examined include scientific journals, Master's theses and Ph.D. dissertations, literature reviews, and agency publications. With respect to water temperature, the primary concern in the Central Valley relates to water temperatures that may exceed upper salmonid tolerance limits rather than lower limits; therefore, index values were only established for water temperatures at and above the warmer tolerance zone for salmonids. For non-salmonid and warmwater species, it was assumed that sufficient warmwater habitat is available in Central Valley water bodies such that impacts resulting from exposure to cold water likely would not occur (e.g., warmwater game fishes do not typically occur in the uppermost reaches of Central Valley rivers where cold water is released from terminal dams, but instead, tend to occur farther downstream where water temperatures are generally warmer).

In the 2001 USEPA document, *Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids*, the case is made that there is not enough significant genetic variation among stocks or among species of salmonids to warrant geographically specific water temperature standards (Carter, 2008). However, because this DEIR/EIS focuses on issues in Central Valley watersheds where large bodies of literature are available for some species (e.g., Chinook salmon), water temperature index values were determined by placing emphasis on the results of laboratory experiments that examined how water temperature affects fishes in Central Valley watersheds being evaluated, as well as by considering field studies documenting habitat use and regulatory documents such as biological opinions from the National Marine Fisheries Service (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 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 to 60.8°F), intermediate (62.6 to 68.0°F), and extreme (69.8 to 75.2°F) treatments that varied daily by whole degrees.

Inspection of the available literature on the effects of water temperature on salmonids revealed the need to interpret each document with caution and to verify the appropriateness of statements supported by references to other literature. Often source studies are cited incorrectly, and sometimes repeatedly.

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 defined as any water temperature change that alters the biological functions of the fish and which decreases probability of survival (McCullough, 1999). Optimal water temperatures are defined as those that provide for feeding activity, normal physiological response, and behavior void of thermal stress symptoms (McCullough, 1999). Preferred water temperature ranges are defined as those that are most frequently selected by fish when allowed to freely choose locations along a thermal gradient (McCullough, 1999).

Finally, as a comparative tool, life stage-specific water temperature impact indicator values have been developed for the species evaluated in this DEIR/EIS to be used as evaluation guidelines, the basis of which are described herein. The water temperature index values are not meant to serve as significance thresholds, but instead serve as a mechanism by which to compare the Sites Reservoir Project (Project) action alternatives (alternatives) to the Existing Conditions/No Project/No Action Condition. Thus, water temperature index values represent a gradation of potential effects, from reported optimal water temperatures increasing through the range of represented index values for each life stage. Differences in the frequency of exceeding a particular water temperature index value between an alternative and the baseline do not necessarily constitute an impact. Impact determinations are based on consideration of all evaluated impact indicators for all life stages for a particular species.

12D.3 Water Temperature Indices

12D.3.1 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 were not separated because: (1) there is a paucity of literature specific to each life stage of each run-type; (2) there is an insufficient amount of data available in the literature suggesting that Chinook salmon run-types respond to water temperatures differently; (3) the water temperature index values derived from all the literature pertaining to Chinook salmon that provide suitable habitat conditions 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).

12D.3.1.1 Adult Immigration and Holding

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

The water temperature index values 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 life stage are 60, 64, and 68°F (Table 12D-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. 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 (1997a) 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.*” The Oregon Department of Environmental Quality (ODEQ, 1995) reports that “*...many of the diseases that commonly affect Chinook become highly infectious and virulent above 60°F.*” Study summaries in USEPA (2003) indicate disease risk is high at 62.6°F. Additionally, Ward and Kier (1999) designated temperatures <60.8°F as an “optimum” water temperature threshold for holding Battle Creek spring-run Chinook salmon. USEPA (2003) chose a holding value of 61°F (7DADM[1]) based on laboratory data and various assumptions regarding diel temperature fluctuations. 61°F is also a holding temperature index value for steelhead (see above). 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 12D-1
Chinook Salmon Adult Immigration and Holding Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
60°F*	Maximum water temperature for adults holding, while eggs are maturing, is approximately 59ºF to 60ºF (NMFS, 1997a). Acceptable water temperatures for adults migrating upstream range from 57ºF to 67ºF (NMFS, 1997a). Upper limit of the optimal water temperature range for adults holding while eggs are maturing is 59 to 60°F (NMFS, 2000). Many of the diseases that commonly affect Chinook salmon become highly infectious and virulent above 60ºF (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, 1995).
64°F	Acceptable range for adults migrating upstream is from 57ºF to 67ºF (NMFS, 1997a). Disease risk becomes high at water temperatures above 64.4°F (USEPA, 2003). Latent embryonic mortalities and abnormalities associated with water temperature exposure to pre-spawning adults occur at 63.5 to 66.2°F (Berman, 1990).
68°F	Acceptable range for adults migrating upstream range from 57 to 67ºF (NMFS, 1997a). For chronic exposures, an incipient upper lethal water temperature limit for pre-spawning adult salmon probably falls within the range of 62.6 to 68.0°F (Marine, 1992). Spring-run Chinook salmon embryos from adults held at 63.5 to 66.2°F had greater numbers of pre-hatch mortalities and developmental abnormalities than embryos from adults held at 57.2 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).

*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 to 66.2°F. Also, 64°F represents a mid-point value between the water temperature index values of 60 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, 1992; NMFS, 1997a). Because significant impacts 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.

12D.3.1.2 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

[1] 7DADM = seven day average of the daily maximum

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

Water temperature index values were selected from a comprehensive literature review for Chinook salmon eggs during spawning and incubation (Table 12D-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 (Combs and Burrows, 1957; Hinze, 1959; Johnson and Brice, 1953; Seymour, 1956; USFWS, 1999). In large part, supporting evidence for index value selections was derived from the aforementioned laboratory studies and from regulatory documents (NMFS, 1993; NMFS, 1997a; NMFS, 2002a). Field studies reporting river water temperatures during spawning also were considered (Dauble and Watson, 1997; Groves and Chandler, 1999).

Table 12D-2
Chinook Salmon Spawning and Embryo Incubation Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
56°F*	Less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs (Reclamation, 2003a). Optimum water temperatures for egg development are between 43 and 56°F (NMFS, 1993). Upper value of the water temperature range (i.e., 41.0 to 56.0°F) suggested for maximum survival of eggs and yolk-sac larvae in the Central Valley of California (USFWS, 1995). Upper value of the range (i.e., 42.0 to 56.0°F) given for the preferred water temperature for Chinook salmon egg incubation in the Sacramento River (NMFS, 1997b). 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 to 58.0°F) for eggs and fry (NMFS, 2002a). Constant egg incubation temperatures between 42.5 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, 1993). 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 62 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)

*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.

The water temperature index values selected to evaluate the Chinook salmon spawning and embryo incubation life stages are 56, 58, 60, 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 (1993) reported that optimum water temperatures for egg development are between 43 and 56°F. Similarly, Myrick and Cech (2001) reported the highest egg survival rates occur between water temperatures of 39 to 54°F. Reclamation (unpublished work) reports that water temperatures less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs. Bell (1986) recommends water temperatures ranging between 42 to 57°F for spawning Chinook salmon, and water temperatures between 41 to 58°F for incubating embryos. USFWS (1995) reported a water temperature range of 41.0 to 56.0°F for maximum survival of eggs and yolk-sac larvae in the Central Valley of California. The preferred water temperature range for Chinook salmon egg incubation in the Sacramento River was suggested as 42.0 to 56.0°F (NMFS, 1997b). Alevin mortality is reportedly significantly higher when Chinook salmon embryos are incubated at water temperatures above 56°F (USFWS, 1999). NMFS (2002b) reported 56.0°F as the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River. The 56°F water temperature index value established for the Chinook salmon spawning and embryo incubation life stage is the index value generally reported in the literature as the upper limit of the optimal range for egg development and the upper limit of the range reported to provide maximum survival of eggs and yolk-sac larvae in the Central Valley of California. Increasing levels of thermal stress to this life stage may reportedly occur above the 56°F water temperature index value.

High survival of Chinook salmon embryos also has been suggested to occur at incubation temperatures at or near 58.0°F. For example, Reclamation (unpublished work) reported that the natural rate of mortality for alevins occurs at 58°F or less. Combs and Burrows (1957) concluded constant incubation temperatures between 42.5 and 57.5°F resulted in normal development of Chinook salmon eggs, and NMFS (2002b) suggests 53.0 to 58.0°F is the preferred water temperature range for Chinook salmon eggs and fry. Johnson and Brice (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 (1993) 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 percent mortality occurs to late incubating Chinook salmon embryos when held at a constant water temperature greater than or equal to 60.0°F. For Chinook salmon eggs incubated at constant temperatures, mortality increases rapidly at temperatures greater than about 59-60°F (see data plots in Myrick and Cech, 2001). Olsen and Foster (1955), however, found high survival of Chinook salmon eggs and fry (89.6%) when incubation temperatures started at 60.9°F and declined naturally for the Columbia River (about 7°F / month). Geist et al. (2006) found high (93.8%) Chinook salmon incubation survival through emergence for naturally declining temperatures (0.36°F/day) starting as high as 61.7°F; however, a significant reduction in survival occurred above this temperature.

The literature largely agrees that 100 percent mortality will result to Chinook salmon embryos incubated at water temperatures greater than or equal to 62.0°F (Hinze, 1959; Seymour, 1956; Reclamation, 2003a; 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; Seymour, 1956; Reclamation, 2003a; USFWS, 1999); therefore, an index value above 62°F was not required.

12D.3.1.3 Juvenile Rearing and Emigration

Water temperature index values were selected from a comprehensive literature review for juvenile rearing and emigration, including spring-run Chinook salmon smolt emigration (Table 12D-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, 1997a; NMFS, 2000; NMFS, 2001a; NMFS, 2002a; Rich, 1987a; 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, 1990a; Taylor, 1990b). 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).

Table 12D-3
Chinook Salmon Juvenile Rearing and Smolt Emigration Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
60°F*	Optimum water temperature for Chinook salmon fry growth is between 55.0 and 60°F (Seymour, 1956). Water temperature range that produced optimum growth in juvenile Chinook salmon was between 54.0 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, 1993). 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, 1997a). 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 and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55 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 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 suggests 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).

Index Value	Supporting Literature
65°F	Water temperatures between 45 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 (USEPA, 2003). 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 (USEPA, 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 Jr. and Myrick, 1999). Optimal range for Chinook salmon survival and growth from 53.0 to 64.0°F (USFWS, 1995). 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 to 68°F, the colder temperatures represent more optimal conditions (50 to 62.6°F), and the warmer conditions (62.6 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 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 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 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 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, 1987a). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70 and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55 and 61°F (Marine, 1997; Marine and Cech, 2004).
75°F	For juvenile Chinook salmon in the lower American River fed maximum rations under laboratory conditions, 75.2ºF 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 (NAS, 1972 as cited in 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).

*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.

The 60°F water temperature index value established for the Chinook salmon juvenile rearing and 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. FERC (1993) referred to 58°F as an "optimum" water temperature for juvenile Chinook salmon in the American River. NMFS (2002a) identified 60°F as the "preferred" water temperature for juvenile spring-run Chinook salmon in the Central Valley. Increasing levels of thermal stress to this life stage may reportedly occur above the 60°F water temperature index value.

A water temperature index value of 63°F was selected because water temperatures at or below this value allow for successful transformation to the smolt stage, and water temperatures above this value may result in impaired smoltification indices, inhibition of smolt development, and decreased survival and successful smoltification of juvenile spring-run Chinook salmon. Laboratory experiments suggest that water temperatures at or below 62.6°F provide conditions that allow for successful transformation to the smolt stage (Clarke and Shelbourn, 1985; Zedonis and Newcome, 1997; Marine, 1997). The reported temperature of 62.6ºF was rounded and used to support an index value of 63ºF.

An index value of 65°F was selected because it represents an intermediate value between 64.0°F and 66.2°F, at which both adverse and beneficial effects to juvenile salmonids have been reported to occur. For example, at temperatures approaching and beyond 65°F, sub-lethal effects associated with increased incidence of disease reportedly become severe for juvenile Chinook salmon (Johnson and Brice, 1953; Ordal and Pacha, 1963; Rich, 1987b; USEPA, 2003). Conversely, numerous studies report that temperatures between 64.0 and 66.2°F provide conditions ranging from suitable to optimal for juvenile Chinook salmon growth (Brett et al., 1982; USFWS, 1995; Myrick and Cech, 2001; USEPA, 2003; NMFS, 2002a; Cech and Myrick, 1999). Maximum growth of juvenile fall-run Chinook salmon has been reported to occur in the American River at water temperatures between 56 to 59°F (Rich, 1987a) and in Nimbus Hatchery spring-run Chinook salmon at 66°F (Cech and Myrick, 1999).

An index value of 68°F was selected because, at water temperatures above 68°F, sub-lethal effects become severe such as reductions in appetite and growth of juveniles, 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).

The 75°F index value 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, 1987a). 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 (1987a) 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 percent confidence interval for the upper incipient lethal water temperature for Chinook salmon smolts as 71.5 to 75.4°F. Additionally, the juvenile Chinook salmon upper incipient lethal temperature (UILT) based on numerous studies is 75-77°F (Sullivan et al., 2000; McCullough et al., 2001; Myrick and Cech, 2001).

12D.3.2 Steelhead

12D.3.2.1 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 (Billard and Breton, 1977 and Billard and Gillet, 1981 as cited in McCullough et al., 2001; Bruin and Waldsdorf, 1975). 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 12D-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 suitable habitat 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. A water temperature index value of 52°F was selected because it has been referred to as a "recommended" (Reclamation, 2003b), "preferred" (NMFS, 2002b), and "optimum" (Reclamation, 1997) 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.

Table 12D-4
Steelhead Adult Immigration and Holding Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
52°F*	Preferred range for adult steelhead immigration of 46.0 to 52.0°F (NMFS, 2000; NMFS, 2002a; SWRCB, 2003). Optimum range for adult steelhead immigration of 46.0 to 52.1°F (Reclamation, 1997). Recommended adult steelhead immigration temperature range of 46.0 to 52.0°F (Reclamation, 2003b).
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 two to six months before spawning to produce eggs of good quality (Bruin and Waldsdorf, 1975). Holding migratory fish at constant water temperatures above 55.4 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 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 five percent after 4.5 days (Billard and Breton, 1977 as cited in McCullough et al., 2001).

*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.

A water temperature index value of 56°F was selected 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). A range of 50-59°F is referred to as the "preferred" range of water temperatures for California summer steelhead holding (Moyle et al., 1995). Whereas, water temperatures greater than 61°F may result in "chronic high stress" of holding Central Valley winter-run steelhead (USFWS, 1995). The highest water temperature index value selected was 70°F 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) and are water temperatures referred to as “stressful” to upstream migrating steelhead in the Columbia River (McCullough, 1999). Further, Coutant (1972) found that the UILT for adult steelhead was 69.8°F and temperatures between 73 and 75°F are described as “lethal” to holding adult steelhead.

12D.3.2.2 Spawning and Embryo Incubation

Relatively few studies have been published regarding 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 12D-5). Water temperatures in the 45 to 50°F range have been referred to as the “optimum” for spawning steelhead (FERC, 1993).

Table 12D-5
Steelhead Spawning and Embryo Incubation Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
52°F*	Rainbow trout from Mattighofen (Austria) had highest egg survival at 52.0°F compared to 45.0, 59.4, and 66.0°F (Humpesch, 1985). Water temperatures from 48.0 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 to 52.0°F for steelhead spawning in the Central Valley (USFWS, 1995). Optimum water temperature range of 46.0 to 52.1°F for steelhead spawning and 48.0 to 52.1°F for steelhead egg incubation (Reclamation, 1997). 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 to 53.6°F (USEPA, 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 one percent mortality at 47.3 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 one percent mortality at 47.3 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).

*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, 54, 57, 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, 54, 57, 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 (FERC, 1993; 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; SWRCB, 2003; Reclamation, 1997; USFWS, 1995). Further, water temperatures between 48 to 52°F were referred to as "optimal" (FERC, 1993; McEwan and Jackson, 1996; NMFS, 2000) and "preferred" (Bell, 1986) for steelhead embryo incubation. Therefore, 52°F was selected as the lowest water temperature index value. Increasing levels of thermal stress to the steelhead spawning and embryo incubation life stage may reportedly occur above the 52°F water temperature index value.

An index value of 54°F was selected 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 (Timoshina, 1972; Humpesch, 1985). Thus, water temperatures near 54°F may represent an inflection point between properly functioning water temperature conditions, and conditions that cause negative effects to steelhead spawning and embryo incubation. Further, water temperatures greater than 55°F were referred to as "stressful" for incubating steelhead embryos (FERC, 1993). An index value of 57°F was selected 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 percent hatch under incubation temperatures ranging from 33.8 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 percent at a constant temperature of 59.0°F, compared to less than four percent mortality at constant temperatures of 42.8, 48.2, 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 percent hatch, Big Qualicum River steelhead had 93 percent mortality at 60.8°F, 7.7 percent mortality at 57.2°F, and one percent mortality at 47.3 and 39.2°F (Velsen, 1987). Myrick and Cech (2001) similarly described water temperatures >59°F as "lethal" to incubating steelhead embryos, although FERC (1993) suggested that water temperatures exceeding 68°F were "stressful" to spawning steelhead and "lethal" when greater than 72°F.

12D.3.2.3 Juvenile Rearing and Emigration

Water temperature index values were developed to evaluate the combined steelhead rearing (fry and juvenile) and juvenile downstream movement lifestages. Some steelhead may rear in freshwater for up to three years before emigrating as yearling smolts, whereas other individuals move downstream shortly after emergence as post-emergent fry, or rear in the river for several months and move downstream as juveniles without exhibiting the ontogenetic[2] 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

[2] Ontogeny is the origin and development of an individual organism from embryo to adult.

juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement and are assessed in this EIR/EIS using the fry and juvenile rearing water temperature index values.

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 (Tables 12D-6 and 2D-7).

Table 12D-6
Steelhead Juvenile Rearing Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
63°F*	Nimbus juvenile steelhead preferred water temperatures between 62.6 and 68.0°F (Cech Jr. and Myrick, 1999). Rainbow trout fingerlings preferred or selected water temperatures in the 62.6 to 68.0°F range (McCauley and Pond, 1971).
65°F*	Upper limit of 65°F preferred for growth and development of Sacramento River and American River juvenile steelhead (NMFS, 2002a). Nimbus juvenile steelhead growth showed an increasing trend with water temperature to 66.2°F, irrespective of ration level or rearing temperature (Cech Jr. and Myrick, 1999). Nimbus juvenile steelhead preferred water temperatures between 62.6 and 68.0°F (Cech Jr. and Myrick, 1999). Rainbow trout fingerlings preferred or selected water temperatures in the 62.6 to 68.0°F range (McCauley and Pond, 1971).
68°F*	Nimbus juvenile steelhead preferred water temperatures between 62.6 and 68.0°F (Cech and Myrick, 1999). The final preferred water temperature for rainbow trout fingerlings was between 66.2 and 68°F (Cherry et al., 1977). Rainbow trout fingerlings preferred or selected water temperatures in the 62.6 to 68.0°F range (McCauley and Pond, 1971). The upper avoidance water temperature for juvenile rainbow trout was measured at 68 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 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 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 (USEPA, 2002). Rearing steelhead juveniles have an upper lethal limit of 75.0°F (NMFS, 2001b). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6 to 79.9°F (Ebersole et al., 2001).

*The 65 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.

Table 12D-7
Steelhead Smolt Emigration Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
52°F*	Steelhead successfully smolt at water temperatures in the 43.7 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 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 (USEPA, 2003). 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).

*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.

Water temperature index values of 63, 65, 68, 72, and 75°F were selected to represent an evenly distributed range of index values for steelhead juvenile rearing. The lowest water temperature index value of 63°F was established because Myrick and Cech (2001) describe 63°F as the “preferred” water temperature for wild juvenile steelhead, whereas “preferred” water temperatures for juvenile hatchery steelhead reportedly range between 64 to 66°F. A water temperature index value of 65°F was also identified because NMFS (2000; 2002a) reported 65°F as the upper limit preferred for growth and development of Sacramento River and American River juvenile steelhead. Also, 65°F was found to be within the optimum water temperature range for juvenile growth (i.e., 59 to 66°F) (Myrick and Cech, 2001), and supported high growth of Nimbus strain juvenile steelhead (Cech and Myrick, 1999). Increasing levels of thermal stress to this life stage may reportedly occur above the 65°F water temperature index value. For example, Kaya et al. (1977) reported that the upper avoidance water temperature for juvenile rainbow trout was measured at 68 to 71.6°F. Cherry et al. (1977) observed an upper preference water temperature near 68.0°F for juvenile rainbow trout, duplicating the upper preferred limit for juvenile steelhead observed in Cech and Myrick (1999) and FERC (1993). 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.

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 USEPA report that direct mortality to rearing juvenile steelhead results when stream temperatures reach 75.0°F (USEPA, 2002; NMFS, 2001b). Water temperatures >77°F have been referred to as “lethal” to juvenile steelhead (FERC, 1993; Myrick and Cech, 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan et al., 2000; McCullough et al., 2001).

12D.3.2.4 Smolt Emigration

Laboratory data suggest that smoltification, and therefore successful emigration of juvenile steelhead is directly controlled by water temperature (Adams et al., 1975). Water temperature index values of 52 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, 1987b); or less than 55°F (USEPA, 2003; 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, 50.0, 59.0 or 68.0°F) on the increase of gill microsomal sodium (Na+)-, potassium (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°F, but no increase at 59.0 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 U.S. Environmental Protection Agency (USEPA) 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 (USEPA, 2003). A water temperature index value of 59°F was chosen because water temperatures are considered “unsuitable” for steelhead smolts at >59°F (Myrick and Cech, 2001) and “lethal” at 77°F (FERC, 1993).

12D.3.3 Coho Salmon

12D.3.3.1 Adult Immigration and Holding

Like other salmonids, Coho salmon prefer cool, well-oxygenated water (Giannico and Heider, 2001). It is recommended that the seven day moving average of the daily maximum water temperature (7DADM) should not exceed 18°C (64.4°F) in waters where both adult salmonid migration and “non-core” juvenile rearing occur during the period of summer maximum temperatures (Carter, 2008). USEPA (2003) indicated that this temperature recommendation would protect against lethal conditions, prevent migration blockage, provide optimal or near optimal juvenile growth conditions, and prevent high disease risk by minimizing the exposure time to temperatures which can lead to elevated disease rates.

A 7DADM temperature of 20°C (68°F) is recommended by USEPA (2003) for water bodies that are used almost exclusively for migration during the period of summer maximum temperatures. Further, Table 1 in USEPA (2003) indicates that disease risks for juvenile rearing and adult migration associated with exposure to constant water temperatures are minimized at temperatures from 12 to 13°C (53.6 to 55.4°F), elevated from 14 to 17°C (57.2 to 62.6°F), and high at temperatures from >18 to 20°C (64.4 to 68°F).

In a study of both laboratory and field studies of temperature effects on salmonids and related species, USEPA (1999, 2001 as cited in Carter, 2008) concluded that temperatures of approximately 22 -24°C (71.6 to 75.2°F) limit salmonid distribution (i.e., they totally eliminate salmonids from a location). USEPA (1999 as cited in Carter, 2008) also notes that changes in competitive interactions between fish species can lead to a transition in dominance from salmonids to other species at temperatures 2 to 4°C (3.6 to 7.2°F) lower than the range of total elimination.

Although USEPA (1999, 2001 as cited in Carter, 2008; USEPA, 2003) provides water temperature recommendations for anadromous salmonids that were presumably developed, in part, based on studies of Coho salmon, the recommendations are not specific to Coho salmon. Migration for Coho salmon reportedly is delayed when water temperatures reach 21.1°C (~70°F), while the preferred water temperatures for Coho salmon reportedly range from 11.7 to 14.5°C (53.1 to 58.1°F) (Bell, 1986 as cited in Carter, 2008). In California Coho salmon reportedly typically migrate upstream when water temperatures range from 4 to 14°C (39.2 to 57.2°F) (Carter, 2008). The Washington Department of Ecology (WDOE) reviewed various studies and concluded that to be protective of adult Coho salmon migration, maximum weekly maximum temperatures (MWMT) should not exceed 16.5°C (61.7°F) (Carter, 2008). A report prepared for The North Coast Regional Water Quality Control Board, shows acute lethal water temperature thresholds for Coho salmon based upon "best professional judgment of the literature." The threshold for adult migration and holding is reported to be 25°C (77°F) (Carter, 2008). Additionally, NMFS (2012) reported that a study of Coho salmon occurrence in tributaries of the Mattole River suggested that a maximum weekly maximum temperature (MWMT) greater than 18.1°C (64.6°F) or a maximum weekly average temperature (MWAT) greater than 16.8°C (62.2°F) would preclude the occurrence of Coho salmon.

Based on the water temperature thresholds and recommendations for the protection of anadromous salmon, and specifically Coho salmon, a range of water temperature index values was selected for evaluation purposes in this DEIR/EIS. These water temperature index values are 40, 52, 57, 60, 70, and 77°F.

12D.3.3.2 Spawning and Embryo Incubation

USEPA (2003) recommends that the 7DADM temperatures should not exceed 13°C (55.4°F) for salmonid spawning, egg incubation, and fry emergence.

Carter (2008) reviewed various literature sources and reported the results for the North Coast Regional Water Quality Control Board. As part of the review, Carter (2008) indicated that, in 2002, WDOE reported the results of several studies and literature reviews, which suggested that spawning activity in Coho salmon may typically occur in the range of 4.4 to 13.3°C (39.9 to 55.9°F). Additionally, Carter (2008) reported that according to a review by Bell (1986), preferred spawning temperatures range from 4.5 to 9.4°C (40.1 to 48.9°F). Brungs and Jones (1977 as cited in Carter, 2008) used existing data on the optimum and range of temperatures for Coho salmon spawning and embryo survival to create criteria using protocols from the National Academy of Sciences and National Academy of Engineering. The resultant criteria were that the MWAT should not exceed 10°C (50°F) and the daily maximum temperature should not exceed 13°C (55.4°F) to be protective of Coho salmon (Brungs and Jones, 1977 as cited in Carter, 2008). Further, in a discussion paper and literature summary, WDOE reviewed studies that assessed the survival of embryos and alevin at various temperatures (Carter, 2008). Based on the findings of these studies, WDOE determined that the average daily temperature during the incubation period should be at or below 8 to 10°C (46.4 to 50°F) to fully support this Coho salmon life stage (Carter, 2008). According to a review of various literature sources by Bell (1986 as cited in Carter, 2008), the preferred emergence temperatures for Coho salmon range from 4.5 to 13.3°C (40.1 to 55.9°F). Optimum temperatures for salmonid egg survival are reported to range from 6 to 10°C (42.8 to 50°F) (USEPA, 2001 as cited in Carter, 2008). Additionally, USEPA (2001 as cited in Carter, 2008) concluded that, to fully support pre-emergent stages of Coho salmon development MWMTs should not exceed 9 to 12°C (48.2 to 53.6°F).

One study incubated five species of Pacific salmon, including Coho salmon, at five temperatures (2, 5, 8, 11, and 14°C) (35.6, 41, 46.4, 51.8, and 57.2°F) to determine embryo survival at various temperatures (Carter, 2008). Coho salmon embryos were reported to have suffered increased mortality above 11°C (51.8°F), although survival was still high. According to Carter (2008), they concluded that the upper limit for normal Coho salmon embryo development is 14°C (57.2°F). Based on this review, Carter (2008) shows acute lethal water temperature thresholds for Coho salmon based upon “best professional judgment of the literature.” The threshold for fry emergence is reported to be 20°C (68°F) (Carter, 2008).

Based on the water temperature thresholds and recommendations for the protection of anadromous salmon, and specifically Coho salmon, for evaluation purposes in this DEIR/EIS a range of water temperature index values was selected that encompasses the range described in the literature. These water temperature index values are 40, 43, 48, 50, 56, and 68°F.

12D.3.3.3 Juvenile Rearing and Emigration

USEPA (2003) recommends a 7DADM temperature of 16°C (60.8°F) for salmon and trout “core” juvenile rearing. Core rearing areas include areas with moderate to high densities of summertime salmonid juvenile rearing. USEPA (2003) further recommends a 7DADM temperature of 16°C (60.8°F) to: (1) protect juvenile salmon and trout from lethal temperatures; (2) provide optimal to upper optimal conditions for juvenile growth under limited food conditions; (3) provide optimal growth during other conditions; (4) avoid temperatures where salmonids are at a competitive disadvantage with other fish species; (5) protect against increased disease rates caused by elevated temperatures and; (6) provide temperatures reported in various literature sources that salmon and trout prefer under high rearing densities. USEPA (2003) also indicates that disease risks for juvenile salmon and trout rearing and adult migration are minimized at temperatures from 12 to 13°C (53.6 to 55.4°F), elevated from 14 to 17°C (57.2 to 62.6°F), and high at temperatures from 18 to 20°C (64.4 to 68°F).

In a study of both laboratory and field studies of temperature effects on salmonids and related species, USEPA (1999, 2001 as cited in Carter, 2008) concluded that temperatures of approximately 22 to 24°C (71.6 to 75.2°F) limit salmonid distribution (i.e., they totally eliminate salmonids from a location). USEPA (1999 as cited in Carter, 2008) also notes that changes in competitive interactions between fish species can lead to a transition in dominance from salmonids to other species at temperatures 2 to 4°C (3.6 to 7.2°F) lower than the range of total elimination.

In a study of juvenile Coho salmon presence and absence in the Mattole watershed, logistic regression was used to determine that an MWAT greater than 16.8°C (62.2°F) or a MWMT greater than 18.1°C (64.6°F) may preclude the presence of juvenile Coho salmon in the stream (Carter, 2008). The study also reported that juvenile Coho salmon were found in all streams with an MWAT less than 14.5°C (58.1°F), or a MWMT less than 16.3°C (61.3°F) (NMFS, 2012, Carter, 2008, and Giannico and Hieder, 2001). Another study found juvenile Coho salmon to be absent or rare in stream segments where temperatures exceeded 21°C (69.8°F) in the Sixes River in southern Oregon (Lestelle, 2007).

Sullivan et al. (2000 as cited in Carter, 2008) reviewed sub-lethal and acute temperature thresholds from a wide range of studies, incorporating information from laboratory-based research, field observations, and risk assessment approaches. Using a risk assessment approach based on "realistic food estimates", Sullivan et al. (2000 as cited in Carter, 2008) suggest that MWATs ranging from 12.5 to 14.5°C (54.5 to 58.1°F) for Coho salmon will result in no more than a 10 percent reduction from maximum growth, and that a range for the MWAT of 9 to 18.5°C (48.2 to 65.3°F) will reduce growth no more than 20 percent from maximum. Sullivan et al. (2000 as cited in Carter, 2008) also calculated temperature ranges for MWMT (13 to 16.5°C [55.4 to 61.7°F]) and the annual maximum temperature (13 to 17.5°C [55.4 to 63.5°F]) that will result in no more than a 10 percent reduction in maximum growth. They further calculated ranges for MWMT (9 to 22.5°C [48.2 to 72.5°F]) and the annual maximum temperature (9.5 to 23°C [49.1 to 73.4°F]) that will result in no more than a 20 percent growth loss.

In an attempt to determine the water temperature that will allow for maximum growth of Coho salmon, WDOE reviewed literature on laboratory studies conducted at constant and fluctuating temperatures, as well as field studies (Carter, 2008). The two laboratory studies reviewed were conducted under satiated feeding conditions. One study found that maximum growth occurred at a constant temperature of 17°C (62.6°F), while the other tested fish at different temperatures and determined that Coho salmon had the greatest growth at the temperature test regime from 12.1 to 20.8°C (median 16.5°C) (53.8 to 69.4°F [median 61.7°F]) (Carter, 2008). WDOE also concluded that weekly average temperatures of 14 to 15°C (57.2 to 59°F) were more beneficial to growth than lower temperature regimes, while daily maximum temperatures of 21 to 26°C (69.8 to 78.8°F) were detrimental to growth (Carter, 2008).

Brett (1952 as cited in Giannico and Heider, 2001) found that Coho salmon showed the greatest preference for temperatures between 12 to 14°C (53.6 to 57.2°F), and showed a general avoidance of temperatures above 15°C (59°F). Carter (2008) also reviewed Brett (1952) and concurs with the characterization of Brett's results as described in Giannico and Heider (2001). Additionally, Giannico and Heider (2001) reported that although fish may survive near the extremes of the tolerance range (1.7 to 28.8°C, 35.1 to 83.8°F) (Giannico and Heider, 2001), growth is reduced at both low and high temperatures (Giannico and Heider, 2001).

One study raised two groups of juvenile Coho salmon under identical regimes to test the hypothesis that the group from a stream with lower and less variable temperature would have lower and less variable temperature preferences than the group from a stream with warmer and more variable temperatures. The study concluded that the temperature preference of juvenile Coho salmon in their study was 10 to 12°C (53.6°F) (Carter, 2008).

During the summer (between June and September) of 2001, USFWS conducted several snorkeling surveys of the Klamath River and several tributary creeks, during which juvenile Coho salmon were observed in areas with temperatures ranging from 12.8 to 24.5°C (55 to 76.1°F). However, during one survey Coho salmon were observed in tributary-influenced water that was 24.6°C (76.3°F), while the mainstem Klamath River water temperature was reported to be 20.5°C (68.9°F) (Giannico and Heider, 2001).

Using an extensive database of primarily large stream and river data, one study estimated that the maximum temperature that juvenile Coho salmon tolerate is 23.4°C (74.1°F) (Giannico and Heider, 2001 and Lestelle, 2007). Brett (1952 as cited in Carter, 2008) concluded that the ultimate upper lethal temperature of juvenile Coho salmon was 25.0°C (77°F) (temperature at which 50 percent of the population is dead after infinite exposure). Another study determined that upper lethal temperature for fish acclimated to a 10 to 13°C (50 to 55.4°F) cycle was 26°C (78.8°F) for presmolts (age-2 fish), and 28°C (82.4°F) for age-0 fish (Carter, 2008). One study reported that mortality increased progressively from two percent at 9.4°C (48.9°F) to 22 percent at 15.0°C (59°F) to 84 percent at 20.5°C (68.9°F). No deaths occurred in Coho salmon maintained at 3.9 and 6.7°C (39 and 44°F) (Carter, 2008). Another study reported a lethal temperature limit of 28.8°C (83.8°F) when they gradually exposed fish to increasingly warmer waters (Giannico and Heider, 2001).

Researchers performed a study on the relationship between water temperature and Columnaris in juvenile steelhead, Coho salmon, and spring-run Chinook salmon (Carter, 2008). Juvenile Coho salmon reportedly had 100 percent mortality at 20.5°C (68.9°F), 99 percent at 17.8°C (64°F), and 51 percent at 15.0°C (59°F) (Carter, 2008).

A report prepared for The North Coast Regional Water Quality Control Board that relied on much of the literature reported above shows acute lethal water temperature thresholds for Coho salmon based upon "best professional judgment of the literature." The threshold for juvenile growth and rearing reportedly is 25°C (77°F) (Carter, 2008).

One study found neither evidence of mortality nor lethargic behavior in juvenile Coho salmon when stream temperatures exceeded 24.5°C (76.1°F) during extended periods, and even when they peaked at 29.5°C (85.1°F) for three consecutive days in two Mount St. Helens streams (Washington) (Giannico and Heider, 2001 and Lestelle, 2007). Relatively similar tolerance limits were reported by another study (Giannico and Heider, 2001), which tested the critical maximum temperature for wild juvenile Coho salmon from three streams in Washington. Researchers found consistently high thermal tolerance levels that ranged from mean maximum temperatures of 28.21°C (82.8°F) for one population to 29.23°C (84.6°F) for another (Giannico and Heider, 2001).

These results suggest that juvenile Coho salmon are able to tolerate different critical maximum temperatures, depending on stream channel size, acclimation period, food abundance, competition, predation, body size, and condition (Giannico and Heider, 2001).

Based on the water temperature thresholds and recommendations for the protection of anadromous salmon, and specifically Coho salmon, for evaluation purposes in this DEIR/EIS a range of water temperature index values was selected that encompasses the range described in the literature. These water temperature index values are 41, 48, 54, 57, 60, 64, 70, and 77°F.

12D.3.3.4 Smolt Emigration

NMFS (2012) reported that, because most juveniles rear in tributaries (Lestelle, 2007 as cited in NMFS, 2012) the greatest potential impacts to smolts are those that could occur during emigration. Potential impacts of elevated water temperature on smolts include the inability to maintain osmoregulatory capacity potentially resulting in the inability to properly feed and avoid predators, or in smolts reverting back to parr (McCullough, 1999). Coho salmon have a low tolerance for elevated water temperatures (McCullough, 1999 as cited in NMFS, 2012) and this factor consequently poses a very high level of stress (NMFS, 2012).

NMFS (2012) reported that average mortality is estimated to be approximately 50 percent at 17°C (62.6°F) and approximately 12 percent at 15°C (59°F) in the Upper Klamath River watershed. The ODEQ (NMFS, 2012) limit for MWMT is 64°F (17.8°C), which is compatible with Coho salmon recovery. Laboratory tests clearly showed that a high constant temperature regime (20°C [68°F]) during the emigration period of Coho salmon caused a very restricted peak in gill ATPase activity compared to a normal (10°C [50°F]) temperature regime. Under the elevated temperature regime, ATPase activity plummeted prior to ocean entry (McCullough, 1999).

Transformation from parr to smolt during seaward migration can be blocked by temperatures in the range 15 to 20°C (59 to 68°F) (Adams et al., 1973 as cited in McCullough, 1999). Temperatures of >17 to 20°C (62.6 to 68°F) place smolts under either lethal or loading stresses that can impair metabolic activity, reduce swimming performance, or lead to death (McCullough, 1999). It is recommended for Chinook and Coho salmon that a maximum temperature of approximately 12°C (53.6°F) exist to maintain the migratory response and seawater adaptation in juveniles (Wedemeyer et al., 1980 as cited in McCullough, 1999).

Temperatures must be maintained at <12°C (53.6°F) to prevent premature smolting (Hoar, 1988, Wedemeyer et al., 1980 both as cited in McCullough, 1999). An apparent exception to this rule is that temperatures as high as 15°C (59°F) have been used to increase growth rate and onset of smolting in Coho salmon. However, the rate of desmoltification is also high in this temperature range (McCullough, 1999).

Sockeye salmon terminate their downstream migration if water temperature exceeds 12 to 14°C (53.6 to 57.2°F), although Coho salmon are able to withstand some further increases before impeding migration. The influence on the smoltification process, though, may be common to both species (McCullough, 1999). One study found that Coho salmon smolt size and condition factor was greater in years in which stream temperatures fluctuated annually from four to 13.5°C (39.2 to 56.3°F) than in years with temperatures of near zero to 11 to 12°C (32 to 51.8 to 53.6°F) (McCullough, 1999).

Based on data taken from several studies, Table 9 in McCullough (1999) shows a dramatic decrease in survival of juvenile Coho salmon exposed to various diseases between 15 and 17.8°C (59 and 64.4°F).

Relative to other life stages of Coho salmon, there is a paucity of information that describes water temperature effects on smolt emigration. However, based on the water temperature thresholds and recommendations for the protection of anadromous salmon, and specifically Coho salmon, for juvenile growth, rearing, emigration, and smolt emigration a range of water temperature index values was selected for evaluation purposes in this DEIR/EIS that encompasses the range described in the literature. These water temperature index values are 50, 59, 62, and 70°F.

12D.3.4 Delta Smelt

Water temperature reportedly is an important factor in the development of eggs and newly hatched delta smelt (Swanson and Cech, 1995; Bennett, 2005). Recent studies show that optimal delta smelt hatching success and larval survival in aquaculture occurs at 15°C to 17°C (Bennett, 2005). While incubation temperatures below 15°C have generally lower hatching success, water temperatures exceeding 20°C decrease the egg incubation period, mean hatch length, time to first-feeding, as well as larval feeding success, resulting in higher mortality (Bennett, 2005). Therefore, delta smelt spawning success may be variable when temperatures fall below 15°C, but may be more sharply limited by water temperatures that are above 20°C (Bennett, 2005). Temperatures above 20°C during spring can also lead to higher mortality of newly spawned larvae (Bennett, 2005).

Similar to the egg and embryo life stage, delta smelt larval survival reportedly is optimized when water temperatures are within the range of approximately 15°C to 20°C (Bennett, 2005), and decreases when temperatures rise above 20°C (Swanson and Cech, 1995; Bennett, 2005). Water temperature tolerance thresholds for juvenile delta smelt are not commonly reported in readily available literature. Delta smelt of all sizes are found in the main channels of the Delta and Suisun Marsh and the open waters of Suisun Bay, where the waters are well oxygenated and temperatures are relatively cool, usually lower than 20°C to 22°C in summer. Specifically, over 90 percent of juvenile and pre-adult delta smelt caught in the CDFG Summer Townet Survey and CDFG Fall Mid-Water Trawl Survey were collected at water temperatures lower than 20°C (Bennett, 2005). Additionally, water temperatures over approximately 25°C are reportedly lethal for delta smelt, and can constrain delta smelt habitat, particularly during summer and early fall (Bennett 2005).

Based on the water temperature ranges for adult, spawning, and egg and larval life stages of Delta smelt, a range of 59°F to 68°F was selected for evaluation purposes in this DEIR/EIS.

12D.3.5 North American Green Sturgeon

12D.3.5.1 Adult Immigration and Holding

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 to 60.8°F. Reportedly, no green sturgeon were found in areas of the river outside this surface water temperature range (USFWS, 1995). However, the critical temperature for adult mortality has been reported to be 81°F (Erickson et al., 2002, Heublein et al., 2009). Additionally, Suitable water temperatures for green sturgeon adult immigration range from 52 to 59°F, while water temperatures ranging from 61 to 66°F are reportedly tolerable (NMFS, 2009a). Therefore, water temperature index values of 61 and 66°F were chosen for evaluation purposes in this DEIR/EIS.

12D.3.5.2 Spawning and Egg Incubation

Green sturgeon reportedly tolerate spawning water temperatures ranging from 50 to 70°F (CDFG, 2001). Water temperature affects the following critical processes: 1) hatching rates, 2) rate and type of embryonic development, and 3) survival (Van Eenennaam et al., 2005, Werner et al., 2007). Water temperatures tolerances for green sturgeon during spawning and egg incubation also have been reported to range between 46° to 57°F (NMFS, 2009b), although eggs have been artificially incubated at temperatures as high as 60°F (Deng, 2000 as cited in NMFS, 2009b). However, suitable water temperatures for egg incubation in green sturgeon were reported by Van Eenennaam et al. (2005) to be between 52 and 63°F, with the upper limit of optimal water temperatures ranging from 63 to 64°F. Further, Van Eenennaam et al. (2005) reported that water temperatures greater than approximately 73°F led to complete mortality of embryos prior to hatching. Suitable water temperatures for green sturgeon spawning and egg incubation reportedly range from 46 to 57°F, while water temperatures ranging from 57 to 65°F are reported as tolerable (NMFS, 2009a).

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). Water temperatures above 68°F are reportedly lethal to North American green sturgeon embryos (Cech et al., 2000; Beamesderfer and Webb, 2002).

In addition to available literature evaluating empirical studies, the Sacramento River Ecological Flow Tool (SacEFT) Record of Design (v.2.00) (ESSA Technologies Ltd., 2011) was reviewed to identify water temperature thresholds used by DWR, The Nature Conservancy, and others for evaluating effects on green sturgeon eggs in the Sacramento River. The SacEFT Record of Design states, *"The best information we were able to use is based on in vitro studies (Cech et al., 2000) of larval development, which we adapted to create a quasi-mortality model in which larvae experience no mortality at temperatures below 17°C and complete mortality at temperatures at and above 20°C."* These temperatures correspond to 62.6 and 68°F, respectively.

Because available literature is not entirely in agreement regarding appropriate thermal tolerances for North American green sturgeon a bulk of evidence approach was utilized to identify an appropriate index value to be used for evaluating water temperature effects on green sturgeon spawning and embryo incubation. Based on Werner et al. (2007), Cech et al. (2000), Beamesderfer and Webb (2002), and the use of the SacEFT, index values of 64°F and 68°F were selected for evaluation purposes in this DEIR/EIS analysis.

12D.3.5.3 Juvenile Rearing and Emigration

NMFS (2009b) reports optimal water temperatures for the development of green sturgeon egg, larval, and juvenile life stages ranging between 52 and 66°F. Growth of juvenile green sturgeon is reportedly optimal at 59°F and reduced at both 51.8 and 66.2°F (Cech et al., 2000). According to NMFS (2009b) 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). Optimum water temperatures for green sturgeon larvae reportedly are less than approximately 63°F (Israel and Klimley, 2008). Reproductive success and young-of-year recruitment may be negatively impacted when larvae are exposed to water temperatures greater than 68°F (Israel and Klimley, 2008). Optimal juvenile green sturgeon water temperatures reportedly range from 59 to 66°F (Israel and Klimley, 2008). Because several sources report that optimal green sturgeon larvae and juvenile growth occurs below approximately 66°F, water temperature index values of 64°F and 66°F for juvenile rearing and emigration were selected for evaluation purposes in this DEIR/EIS analysis.

12D.3.6 White Sturgeon

12D.3.6.1 Adult Immigration and Holding

Similar to North American green sturgeon, little detailed information exists regarding white sturgeon thermal tolerances. In fact, very little is known about adult white sturgeon habitat in the Sacramento River or Sacramento-San Joaquin Delta, though they are present throughout the river and Delta during the spring, fall, and winter (Israel et al., 2011). However, publication of the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) conceptual model for white sturgeon indicated that although adult white sturgeon begin to show signs of stress at temperatures above 68°F (20°C), the upper limit of suitable water temperatures for adult white sturgeon is reportedly 25°C (77°F) (Israel et al., 2011). Therefore, an index value of 77°F was used for evaluation purposes in this DEIR/EIS analysis.

12D.3.6.2 Spawning and Egg Incubation

White sturgeon spawning occurs from mid-February to late May when water temperatures are between 46 and 72°F, with peak spawning activity occurring during March and April (Israel et al., 2011).

Incubation length and success in white sturgeon is largely temperature dependent. Field studies have found eggs when water temperatures appear optimal for egg incubation on the Sacramento River (14°-16°C, (Israel et al., 2011). Additionally, white sturgeon egg incubation occurs between 11 and 20°C (~52 to 68°F), with optimal egg incubation occurring at water temperatures ranging from 14 to 16°C (~57 to 61°F) (Israel et al., 2011). Incubation water temperatures above 17°C (~63°F) reportedly result in premature hatching and higher mortality (Israel et al., 2011). Experiments showed the size of a white sturgeon larva was inversely related to water temperature during egg incubation (Israel et al., 2011). In experiments, incubation temperatures above 17°C resulted in premature hatching with higher mortality and no hatching at temperatures above 20°C (Israel et al., 2011).

Index values of 61°F and 68°F was selected for this life stage for evaluation purposes in this DEIR/EIS analysis because optimal egg incubation occurring at water temperatures ranging from 57 to 61°F and white sturgeon embryo hatching reportedly does not occur above 68°F (20°C) (Israel et al., 2011).

12D.3.6.3 Juvenile Rearing and Emigration

White sturgeon are sensitive to temperature at early life stages. Slow growth and some mortality in juvenile white sturgeon kept in water temperatures above 20°C (68°F) has been observed, while larger juveniles were reported to show signs of stress above 19°C (~66°F). Additionally, young juvenile white sturgeon (0.5 to 0.6 g) grew significantly greater at 20 than 15°C. However, no growth difference was observed between 20 and 25°C, though increased temperatures led to increased activity in juvenile white sturgeon. Temperatures higher than 25°C are not tolerated by juvenile white sturgeon, and stress is observed near 20°C (Israel et al., 2011).

Because stress is observed in white sturgeon juveniles above approximately 66°F (19°C), it was selected as an index value for evaluation purposes in this DEIR/EIS.

12D.3.7 Pacific Lamprey and River Lamprey

Generally, lamprey biology is less well studied and understood than that of other fishes in the Central Valley and other California rivers (i.e., the Trinity River system). However, where literature is available, and specifically is available for California streams and rivers, the majority of information available seems to discuss Pacific lamprey. Specifically, Moyle (2002) stated that the biology of river lamprey has not been studied in California. However, Pacific and river lamprey overlap in habitat utilization for spawning and ammocoete rearing in the Sacramento River system with life history periodicity overlapping partially for spawning and completely for ammocoete rearing, indicating that habitat requirements likely are similar. Therefore, for purposes of evaluating potential water temperature effects on Pacific and river lamprey, one set of water temperature index values were used.

12D.3.7.1 Adult Spawning and Egg Incubation

River lamprey are reported to spawn at water temperatures ranging from 55.4 to 56.3°F (Wang, 1986). However, it is not likely that the species requires a water temperature range of 1.1°F. Therefore, these water temperatures were not relied upon for evaluation in this DEIR/EIS.

Pacific lamprey reportedly spawn where water temperatures are typically 12 to 18°C (53.6 to 64.4°F) (Moyle, 2002). Additionally, Moyle (2002) reported that Pacific lamprey embryos hatch in approximately 19 days at 15°C (59°F). Pacific lamprey laboratory studies and analyses in the Columbia River basin suggest that consistently high survival and low occurrence of embryonic developmental abnormalities occur as water temperatures increase from 10 to 18°C (50 to 64.4°F), with a significant decrease in survival and increase in developmental abnormalities at 22°C (~72 °F) (Meeuwig et al., 2002, Meeuwig et al., 2005).

Therefore, for purposes of evaluating potential water temperature impacts in this DEIR/EIS, a range of 50 to 64°F was utilized.

12D.3.7.2 Ammocoete Rearing and Emigration

Meeuwig et al. (2002) and Meeuwig et al. (2005) found a significant decrease in survival and increase in developmental abnormalities of Pacific lamprey larvae at 22°C (71.6°F) in a laboratory setting.

Laboratory studies and analyses suggest that consistently high survival and low occurrence of embryonic developmental abnormalities occur in Pacific lamprey and western brook lamprey at water temperatures ranging from 50 to 64.4°F, with a significant decrease in survival and increase in developmental abnormalities at 71.6°F (Meeuwig et al., 2002, Meeuwig et al., 2005), potentially indicating similar water temperature effects on river lamprey. Meeuwig et al. (2002) Meeuwig et al. (2005) identified 64.4 °F as the most beneficial temperature for survival of Pacific and western brook lampreys, which is similar to the thermal optima reported for survival of sea lampreys (Meeuwig et al., 2002, Meeuwig et al., 2005).

Moyle et al. (1995) indicate that river lamprey eggs and ammocoetes may require water temperatures that do not exceed 25°C (77°F). However, the effect of temperatures exceeding this threshold on river lamprey eggs is unknown. The effects on this species are likely similar to and, for purposes of evaluation in this DEIR/EIS, are assumed to be similar to those for Pacific lamprey when water temperatures exceed 22°C (71.6°F) as described by Meeuwig et al. (2002); Meeuwig et al. (2005).

Therefore, in consideration of available information, an index value of 72°F was utilized to evaluate potential effects on Pacific and river lamprey.

12D.3.8 Hardhead

12D.3.8.1 Adult Spawning

Little is known about life stage-specific water temperature requirements of hardhead. Hardhead spawning has not been documented, and documentation regarding water temperatures associated with hardhead spawning is not widely available. However, Wang (1986) reported that temperatures for hardhead spawning range from 59 to 64.4°F.

Therefore, for purposes of this DEIR/EIS, a range of 59 to 64°F was utilized to evaluate hardhead spawning.

12D.3.8.2 Adults and Other Life Stages

Using samples of hardhead taken at 10 locations within water bodies of the San Joaquin drainage, it was determined that adults prefer water temperatures of 68°F (Moyle, 2002). Hardhead are reportedly found in streams with summer water temperatures above 20°C (68°F) (Moyle, 2002), while water temperatures ranging from 65°F (~18°C) to 75°F (~24°C) are believed to be suitable (Cech et al., 1990). Preliminary work suggests that adult hardhead acclimated to water temperatures below 20°C (68°F) prefer water temperatures at or above 20°C (68°F) (Southern California Edison Company, 2007). Under laboratory conditions, juvenile hardhead preferred water temperatures ranging from 75.2 to 82.4°F (24 to 28°C) (Moyle, 2002). Research indicates that hardhead generally selected water temperatures of 17 to 21°C (62.6 to 69.8°F) in a thermal plume in the Pit River (Moyle, 2002).

Based on the lowest and highest water temperatures reported in the body of literature related to hardhead, a water temperature range of 65 to 82°F was used to evaluate hardhead adults and other life stages.

12D.3.9 Sacramento Splittail

12D.3.9.1 Adult Spawning

Floodplain inundation during March and April appears to be the primary factor contributing to Sacramento splittail abundance (DWR, 2004). Moyle et al. (2003) reports that moderate to strong year classes of Sacramento splittail develop when floodplains are inundated for six to ten weeks between late February and late April.

Although floodplain inundation is the dominant factor in Sacramento splittail spawning success, a literature review of thermal tolerance studies and field observations conducted by DWR (2004), water temperatures between 45 and 75°F were considered to constitute the range of suitable Sacramento splittail spawning water temperatures.

Thus, for purposes of evaluation in this DEIR/EIS, the range of water temperatures from 45 to 75°F was used as an index of potential impact on Sacramento splittail.

12D.3.10 American Shad

12D.3.10.1 Adult Spawning, Embryo Incubation, and Initial Rearing

Water temperature is an important factor influencing the timing of spawning. American shad are reported to spawn at water temperatures ranging from approximately 46 to 79°F (7.8 to 26.1°C) (USFWS, 1967), although optimal spawning temperatures are reported to range from about 60 to 70°F (15.6 to 21.1°C) (Bell, 1986; CDFG, 1980; Leggett and Whitney, 1972; Painter et al., 1979; Rich, 1987a). The optimal water temperature for egg development is reported to occur at 62°F (16.7°C). At this temperature, eggs hatch in six to eight days; at water temperatures near 75°F (23.9°C), eggs would hatch in three days (Moyle, 2002).

Based on available information, a water temperature range of 60 to 70°F was utilized in this DEIR/EIS to evaluate potential effects on American shad adult spawning, embryo incubation, and initial rearing.

12D.3.10.2 Larvae, Fry, and Juvenile Rearing and Emigration

American shad migration into the Sacramento River occurs when water temperatures exceed 14°C. Peak American shad runs in the Sacramento River are reported to occur when water temperatures are between 17 and 24°C (62.6 and 75.2°F) (Moyle, 2002). Although these water temperature ranges are reported for American shad upmigrating adults, they are indicative of water temperatures suitable for larvae, fry, and juvenile American shad because spawning occurs shortly after immigration and incubation occurs relatively quickly. Therefore, juveniles are present when river temperatures are within those ranges reported for adults. Additionally, in the Sacramento River, juvenile American shad reportedly prefer water temperatures between 62.6 and 77°F (17 and 25°C) (Moyle, 2002).

Based on available information, a water temperature range of 63 to 77°F was utilized in this DEIR/EIS to evaluate potential effects on American shad larvae, fry, and juvenile rearing and emigration.

12D.3.11 Striped Bass

12D.3.11.1 Adult Spawning, Embryo Incubation, and Initial Rearing

Adult striped bass are present in Central Valley rivers throughout the year, with peak abundance occurring during the spring months. Adult and juvenile striped bass can survive temperatures as high as 34°C (93.2°F) for short periods of time. They are under stress after temperatures exceed 25°C (77°F), and temperatures over 30°C (86°F) are usually lethal (Moyle, 2002). Spawning reportedly does not occur until water temperatures reach 14°C (57.2°F), while optimal water temperatures for striped bass adult spawning, embryo incubation, and initial rearing are reported to range from approximately 15 to 20°C (59 to 68°F). Spawning ceases above 21°C (69.8°F) (Moyle, 2002).

Based on available information, a water temperature range of 59 to 68°F was utilized in this DEIR/EIS to evaluate potential effects on striped bass adult spawning, embryo incubation, and initial rearing.

12D.3.11.2 Larvae, Fry, and Juvenile Rearing and Emigration

One study reported that striped bass larvae can tolerate water temperatures from 12 to 23°C (53.6 to 73.4°F), while optimum water temperatures range from 16 to 19°C (60.8 to 66.2°F). Another study reported that striped bass larvae can tolerate water temperatures from 10 to 25°C (50 to 77°F), while optimum water temperatures range from 15 to 22°C (59 to 71.6°F). A third study also reported a larval striped bass tolerance range of 10 to 25°C (50 to 77°F), but an optimum water temperature tolerance range of 18 to 21°C (64.4 to 69.8°F). A fourth study reported that juvenile striped bass can tolerate water temperatures from 10 to 27°C (50 to 80.6°F), while optimum water temperatures range from 16 to 19°C (60.8 to 66.2°F). Optimal water temperatures for juvenile striped bass rearing have been reported to range from approximately 16 to 22°C (61 to 71°F) (Fay et al., 1983).

Based on available information, a water temperature range of 61 to 71°F was utilized in this DEIR/EIS to evaluate potential effects on striped bass adult spawning, embryo incubation, and initial rearing.

12D.3.12 Largemouth Bass

Juvenile and adult largemouth bass are generally tolerant of elevated water temperatures. For example, the upper optimal water temperature for adult and juvenile largemouth bass growth is reportedly approximately 86°F, while adult and juvenile largemouth bass can possibly tolerate water temperatures as high as or greater than 95°F (Moyle, 2002). Because simulated water temperatures under the influence of CVP and SWP reservoir operations would not be anticipated to reach or exceed the upper water temperature thresholds for warmwater game fishes, no evaluation of potential water temperature-related impacts was conducted. However, because water temperatures preferred during spawning are substantially lower than adult and juvenile water temperature thresholds, an evaluation of water temperature-related impacts on spawning largemouth bass was conducted.

12D.3.12.1 Adult Spawning

Some researchers report that largemouth bass spawning typically begins in the spring when the water temperature reaches 12.0 to 15.5°C (53.6 to 59.9°F) (Stuber et al., 1982). Others report that spawning has been recorded between 11.5 and 29.0° C (52.7 and 68°F), but most occurs between 16 and 22°C (60.8 and 71.6°F) (Stuber et al., 1982). Optimal temperatures for successful spawning and incubation are 20 to 21°C (68 to 69.8°F), with a range of 13 to 26°C (55.4 to 78.8°F) (Stuber et al., 1982). Literature from California, Arizona, and Nevada indicate that largemouth bass nest building begins at water temperatures of 15 to 16°C (59 to 60.8°F), while spawning may continue until water temperatures reach approximately 24°C (75.2°F) (Moyle, 2002).

Therefore, in consideration of available information, a range of 59 to 75°F was selected for use in this DEIR/EIS to evaluate potential effects on largemouth bass.

12D.4 References

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