APPENDIX E

FISHERIES RESOURCES ANALYTICAL APPROACH AND ANALYSES

Appendix E1:	**Anadromous Salmonid Spawning Habitat – Flow Analyses**
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APPENDIX E1

ANADROMOUS SALMONID SPAWNING HABITAT – FLOW ANALYSES

Appendix E1

Anadromous Salmonid Spawning Habitat – Flow Analyses

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Anadromous Salmonid Spawning Habitat – Flow Analyses

1.0 INTRODUCTION

The potential flow-related effects of the Proposed Project/Action, relative to the Environmental Baseline, on the adult spawning life stage of anadromous salmonids in the lower Yuba River and the lower Feather River are evaluated through the analysis of spawning habitat available to each run/species throughout their spawning seasons.

Available spawning habitat for fall-run Chinook salmon in the lower Yuba River is expressed as a scaled composite weighted usable area that corresponds to the particular species available spawning habitat under the monthly flows throughout the spawning season. The scaled composite weighted usable area (i.e., $\widehat{CWUA}_Y$) is calculated as the sum of the weighted usable areas that correspond to the monthly flows during the species spawning season within various reaches, multiplied by a spatial weighting coefficient that represents the average relative spawning intensity in a particular reach, and by a temporal weighting coefficient that represents the average relative spawning intensity in a particular month, divided by the sum of the maximum weighted usable area (WUA) of each reach multiplied by their corresponding spatial and temporal weighting coefficients.

For a hypothetical salmonid run that spawns within 3 distinct reaches, during 4 months of a particular year or season Y, the scaled composite weighted usable area (i.e., $\widehat{CWUA}_Y$) is expressed by the following formula:

$$\widehat{CWUA}_Y = \frac{\sum_{m=1}^{4}\sum_{k=1}^{3} WUA_k\left(Q_{m,Y}\right) \times w_k \times w_m}{\sum_{m=1}^{4}\sum_{k=1}^{3} \max\left(WUA_k\right) \times w_k \times w_m} \qquad \textbf{(1)}$$

where $WUA_k\left(Q_{m,Y}\right)$ is the weighted usable area (WUA) of reach k at the monthly flow $Q_{m,Y}$ obtained from the WUA-flow relationships developed by the most recent IFIM studies performed in the spawning areas of the particular species. The maximum weighted usable area of reach k over the flow range for which the WUA-flow relationships were developed is expressed as $\max\left(WUA_k\right)$, and w_k and w_m are the spatial and temporal weighting coefficients for the species being analyzed.

For anadromous salmonids in the lower Feather River, and for spring-run Chinook salmon and steelhead in the lower Yuba River, available spawning habitat is expressed by a scaled weighted usable area that corresponds to the species particular available spawning habitat under the monthly flows during the spawning season. The scaled weighted usable area (i.e., $\widehat{WUA}_Y$) is calculated as the sum of the weighted usable areas that correspond to the monthly flows during the species spawning season within various reaches divided by the sum of the maximum WUA of each reach.

For a hypothetical salmonid run that spawns within 3 distinct reaches, during 4 months of a particular year or season *Y*, the scaled weighted usable area (i.e., $\widehat{WUA}_Y$) is expressed by the following formula:

$$\widehat{WUA}_Y = \frac{\sum_{m=1}^{4}\sum_{k=1}^{3} WUA_k\left(Q_{m,Y}\right)}{\sum_{m=1}^{4}\sum_{k=1}^{3} \max\left(WUA_k\right)} \qquad \textbf{(2)}$$

The scaled composite weighted usable area (equation 1) is utilized in the lower Yuba River for fall-run Chinook salmon, but not on the Feather River, or for steelhead or spring-run Chinook salmon in the lower Yuba River, for the following reasons. First, because the Proposed Project/Action includes implementing the lower Yuba River Accord flow schedules, there is a greater emphasis regarding potential changes to salmonid spawning habitat availability in the lower Yuba River than in the Feather River. Thus, an examination of salmonid spawning habitat availability that incorporates species/run-specific spatial and temporal distributions of spawning is assumed to be appropriate for application on the lower Yuba River. Second, data describing run-specific spatial and temporal distributions for steelhead in the lower Yuba River, and for steelhead and Chinook salmon in the Feather River, are somewhat limited relative to the data available for fall-run Chinook salmon in the lower Yuba River. For example, in the Feather River, only four years (i.e., 2000-2003) of fall-run Chinook salmon escapement survey data are available to develop temporal weighting coefficients, compared to 14 years (i.e., 1991-2004) of Chinook salmon escapement data available on the lower Yuba River (YCWA 1992; YCWA 1994; YCWA 1995; YCWA 1996; YCWA 1997; YCWA 1998; YCWA 1999; YCWA 2000; YCWA 2001; YCWA 2002; YCWA 2003; YCWA 2006a; YCWA 2006b).

Table 1-1 summarizes the use of $\widehat{CWUA}_Y$ (equation 1) and $\widehat{WUA}_Y$ (equation 2) in the calculation of annual spawning habitat availability by river and species, specifying the months (*m*) and river reaches (*k*) over which the summations are performed.

The following sections describe the data and calculations utilized to develop the main components of $\widehat{CWUA}_Y$ (equation 1) and $\widehat{WUA}_Y$ (equation 2):

1) WUA-flow relationships per river and species/run ($WUA_k\left(Q\right)$);

2) Spatial weighting coefficients (W_k); and

3) Temporal weighting coefficients (W_m).

Table 1-1. Summary of Calculations of Annual Spawning Habitat Availability Indexes by River and Species

River	Species	WUA Equation	Months (m)	Reaches (k)
Feather	Chinook salmon (Spring- + Fall-run)	2	4 (Sep - Dec)	2 (Upstream and downstream Thermalito Afterbay Outlet)
	Steelhead		5 (Dec – Apr)	
Yuba	Spring-run Chinook salmon	2	3 (Sep - Nov)	1 (Upstream Daguerre Point Dam)
	Fall-run Chinook salmon	1	4 (Oct – Jan)	2 (Upstream and Downstream Daguerre Point Dam)
	Steelhead	2	4 (Jan – Apr)	1 (Upstream Daguerre Point Dam)

2.0 WUA-FLOW RELATIONSHIPS

The weighted usable area of a given reach *k* at a monthly flow $Q_{m,Y}$ (i.e., $WUA_k\left(Q_{m,Y}\right)$ in equations 1 and 2) is obtained from the WUA-flow relationships developed by the most recent IFIM studies performed in the spawning grounds of the particular species/run being analyzed. For each species/run spawning in a particular river, the monthly flow is developed from the modeled monthly flows for the upper boundary of a reach *k* for which there is a WUA-flow relationship and is used to ascertain the corresponding weighted usable area value $\left(WUA_k\left(Q_{m,Y}\right)\right)$.

Because the WUA-flow relationships developed by the most recent IFIM studies present WUA values within particular flow ranges at particular variable steps (e.g., in the lower Yuba River the WUA-flow relationships were developed for a flow range of 100 – 2,500 cfs, with flow increasing steps of 50 cfs, 100 cfs, 250 cfs and 500 cfs), it is often the case that the monthly flow $Q_{m,Y}$ for a particular reach *k* falls between two flows for which there are WUA values. In these cases, the $WUA_k\left(Q_{m,Y}\right)$ value is determined by linear interpolation between the available WUA values for the flows immediately below and above the target flow $Q_{m,Y}$. If $Q_{m,Y}$ is lower than the lowest flow value on the WUA-flow relationship, $WUA_k\left(Q_{m,Y}\right)$ is determined by linear interpolation between the origin (i.e., zero flow and zero WUA) and the WUA at the lowest flow on the WUA-flow relationship. Conversely, the WUA for the highest flow value on the WUA-flow relationship is assigned for all $Q_{m,Y}$ values higher than the highest flow value on the WUA-flow relationship.

2.1 LOWER FEATHER RIVER

The WUA-flow relationships developed for salmonids spawning in the lower Feather River were obtained from DWR (DWR 2004). This recent IFIM study for the lower Feather River generated WUA-flow relationships for two reaches: reach 1, referred to as the Low Flow Channel (LFC); and reach 2, referred to as the High Flow Channel (HFC), as shown in **Table 2-1**.

Table 2-1. Locations of Lower Feather River Reaches with WUA-Flow Relationships Developed by DWR (2004)

Reach *k*	Upstream Limit	RM	Downstream Limit	RM	CALSIM Model Channel
1	Fish Barrier Dam	67.25	Thermalito Afterbay Outlet	59	C200-A
2	Thermalito Afterbay Outlet	59	Honcut Creek	44	C203

The WUA-flow relationships developed by DWR (2004) are based upon the merging of IFIM data collected by DWR in 1992 and reviewed by DWR (DWR 2002), with new depth, velocity, substrate and cover data collected along supplemental PHABSIM cross-section transects in 2002 and 2003.

2.1.1 CHINOOK SALMON

The WUA-flow relationships developed for spawning Chinook salmon (**Figure 2-1)** were based on habitat suitability index (HSI) curves obtained from depth and velocity data collected on 212 Chinook salmon redds measured in October 1991, and on 205 Chinook salmon redds measured in the fall of 1995. In addition to these data, 200 measurements of depth and velocity at "unoccupied" locations within the search area were taken to represent the "availability" of habitat conditions that were not selected by spawners for redd construction. Substrate habitat suitability criteria for the analysis were created from the October 1991 data.

2.1.2 STEELHEAD

The WUA-flow relationships developed for spawning steelhead (**Figure 2-2**) were based on habitat suitability index (HSI) curves obtained from depth, velocity and substrate data collected on 76 steelhead redds in late winter 2002 (DWR 2003).

2.2 LOWER YUBA RIVER

The analysis for the lower Yuba River utilized the WUA-flow relationships developed by a CDFG IFIM study (CDFG 1991) to describe the habitat available for fall-run Chinook salmon spawning. CDFG (1991) divided the lower Yuba River into four study reaches (**Table 2-2**).

Reach 1, also termed the Narrows reach, consists of 11,400 feet of river with steep-walled canyon topography, dominated by deep pools, and bedrock and large boulder substrate. This reach is believed to be an important site for spring-run Chinook salmon holding during late spring, summer, and fall. This reach has never been sampled for Chinook salmon redds or carcasses. The spawning WUA-flow relationships developed for Chinook salmon and steelhead at this uppermost reach showed zero WUA values for flows between 100 cfs and 2,500 cfs. The 56,400-foot long reach 2, known as the Garcia Gravel Pit reach, and the 41,400-ft reach 3, known as the Daguerre Point Dam reach, are believed to have good spawning potential for Chinook salmon.

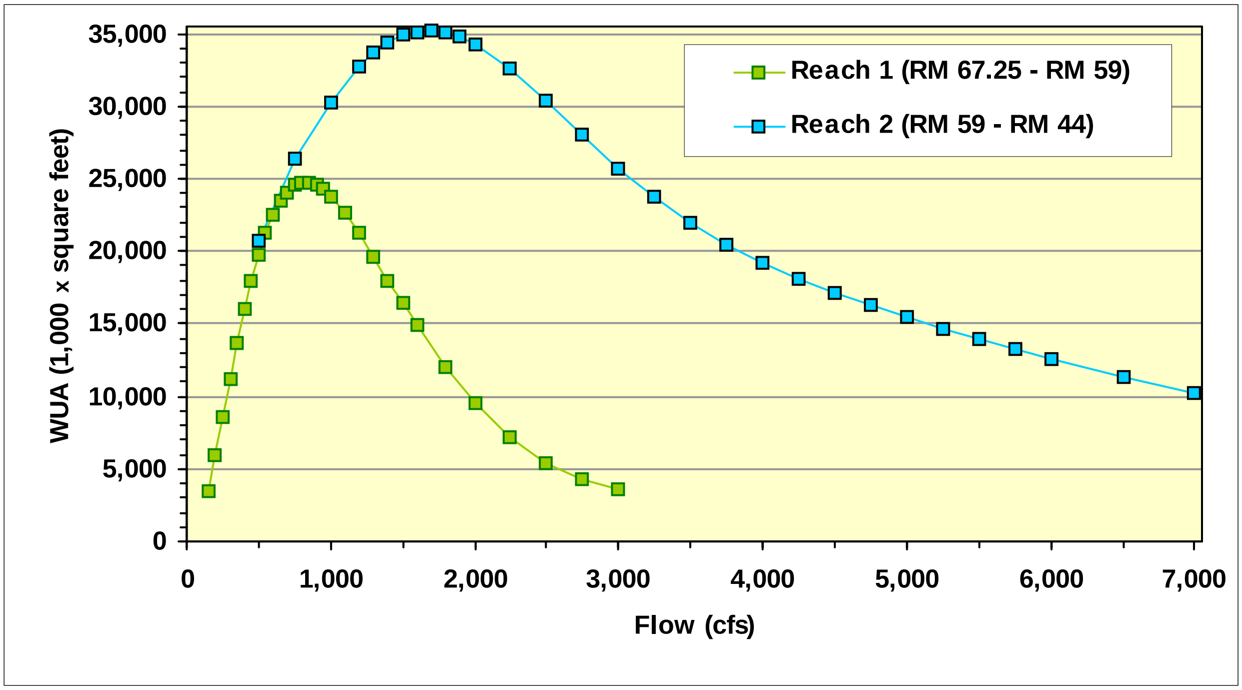

Figure 2-1. Relationship Between Spawning Habitat Availability (Expressed as WUA) and Flow for Lower Feather River Chinook Salmon

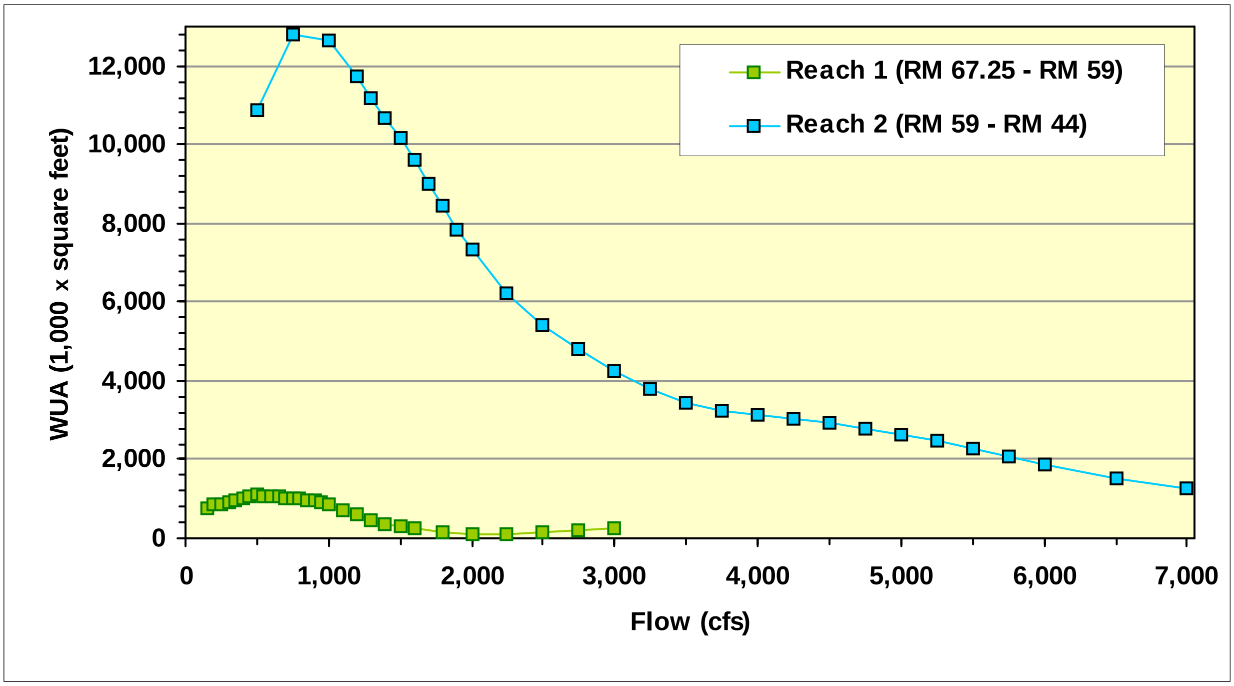

Figure 2-2. Relationship Between Spawning Habitat Availability (Expressed as WUA) and Flow for Lower Feather River Steelhead

Table 2-2. Locations of Lower Yuba River Reaches with WUA-Flow Relationships Developed by CDFG (1991)

Reach *k*	Upstream Limit	RM	Downstream Limit	RM
1	Englebright Dam	23.9	Terminus of the Narrows	21.5
2	Terminus of the Narrows	21.5	Daguerre Point Dam	11.4
3	Daguerre Point Dam	11.4	Terminus of Feather River Backwater Influence	3.5
4	Terminus of Feather River Backwater Influence	3.5	Feather River Confluence	0

Both reaches, which have been customarily sampled during the annual fall-run Chinook salmon carcass surveys performed by CDFG and YCWA, consist of repeating segments of long, deep pools, shallow pools, run/glide, and long low-gradient riffles, with fewer riffles and more pools in reach 3. Finally, reach 4, named the Simpson Lane reach, consists of 18,500 feet of river with low gradient and water velocities, characterized by deep pools under the influence of Feather River waters. This reach has been normally sampled, but not differentiated from reach 3, during the CDFG and YCWA fall-run Chinook salmon carcass surveys, and is believed to have limited potential for Chinook salmon spawning.

2.2.1 CHINOOK SALMON

The fall-run Chinook salmon spawning habitat use data were collected November 17-22, 1986 at three locations:

1) Below and near Highway 20 Bridge crossing (i.e., at RM 18 in reach 2);
2) Below and within one-quarter mile of Daguerre Point Dam (i.e., approximately at RM 11.4 at the upstream end of reach 3); and
3) Near Plantz Road (i.e., at RM 5.3 in reach 3).

A total of 154 redds were observed at these three sites. At each redd location, measurements of mean column water velocity, total depth, and substrate were conducted to provide the basic habitat data used to build the HSI curves. These HSI curves were incorporated into PHABSIM to generate reach-specific WUA-flow relationships for spawning fall-run Chinook salmon (**Figure 2-3)**.

Because spring-run Chinook salmon that spawn in the lower Yuba River are not differentiated from fall-run Chinook salmon during annual carcass surveys, and spring-run Chinook salmon redds cannot be separated from those built by fall-run Chinook salmon during redd surveys, the WUA-flow relationship developed for fall-run Chinook salmon spawning is assumed to reasonably represent the WUA-flow relationship for spring-run Chinook salmon spawning. The WUA-flow relationships in Figure 2-3 were used to calculate the scaled composite weighted usable area (i.e., $\widehat{CWUA}_Y$) for the fall-run Chinook salmon spawning period extending from October into January.

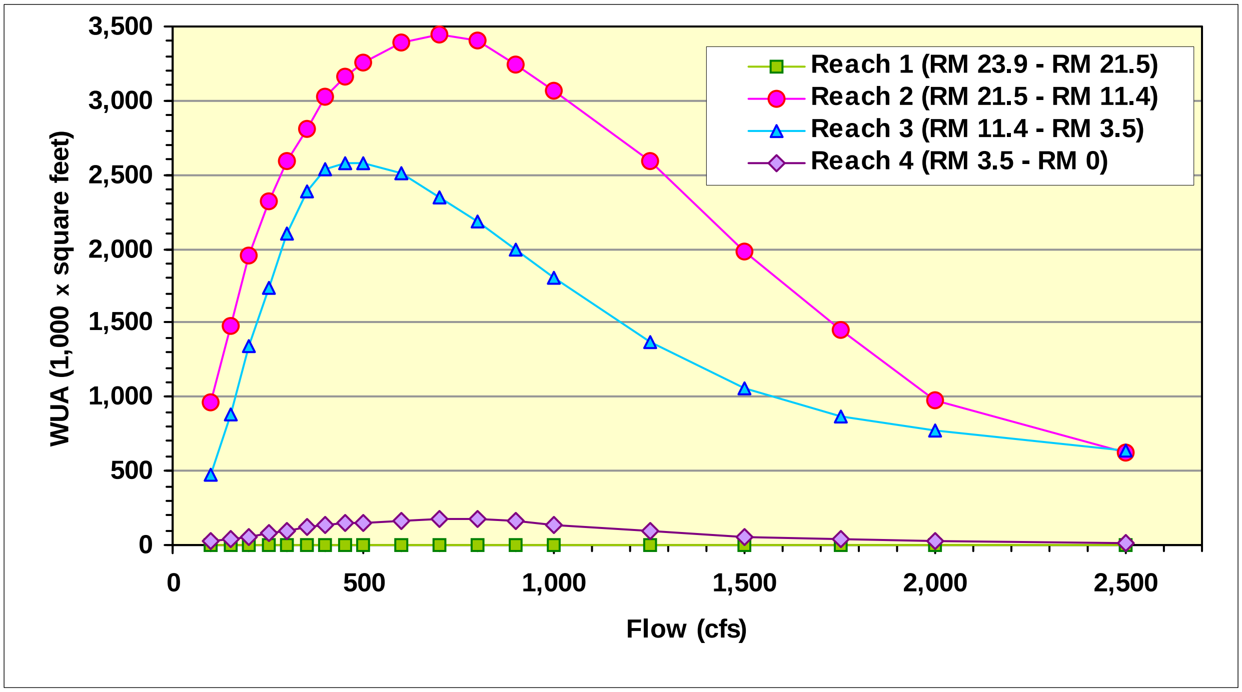

Figure 2-3. Relationship Between Spawning Habitat Availability (Expressed as WUA) and Flow for Lower Yuba River Chinook Salmon

For spring-run Chinook salmon, the annual scaled weighted usable area (i.e., $\widehat{WUA}_Y$) was calculated over a spawning period extending from September through November. For analytical purposes, September through November was assumed to represent the period of spring-run Chinook salmon spawning, although considerable temporal and spatial overlap in spawning occurs between spring-run and fall-run Chinook salmon. Because lower Yuba River spring-run Chinook salmon primarily spawn above Daguerre Point Dam (CALFED and YCWA 2005), the WUA-flow analysis for spring-run Chinook salmon was restricted to those reaches above Daguerre Point Dam (reaches 1 and 2, in Figure 2-3). Additionally, the scaled weighted usable area for the month of September of each year is calculated to compare the potential impacts of the Proposed Project/Action, relative to the Environmental Baseline, on the only month of the spring-run Chinook salmon spawning period that is assumed to not temporally overlap with fall-run Chinook salmon spawning (CDFG 1991).

2.2.2 STEELHEAD

CDFG (1991) steelhead WUA-flow relationships (**Figure 2-4**) were developed from suitability habitat criteria recommended by Bovee (1978). Although the criteria are not specific to the lower Yuba River, the steelhead spawning WUA-flow relationship described in CDFG (1991) is used for this analysis because it is the best available tool for evaluating how flow changes may affect steelhead spawning in the lower Yuba River. The USFWS is in the process of developing a new WUA-flow relationship for steelhead spawning in the lower Yuba River, but this relationship was not finalized or available at the time of the preparation of this BE.

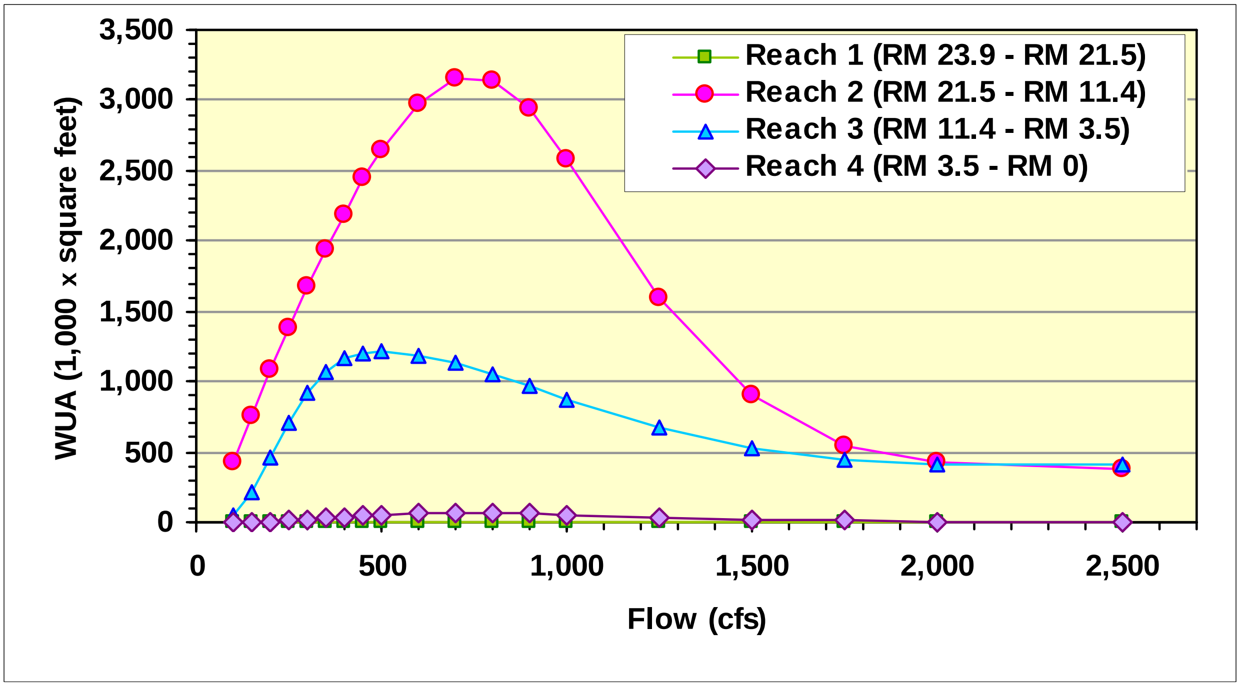

Figure 2-4. Relationship Between Spawning Habitat Availability (Expressed as WUA) and Flow for Lower Yuba River Steelhead

Because the steelhead spawning period in the Yuba River generally extends from January through April, and most of steelhead spawning activity is believed to take place in the lower Yuba River upstream of Daguerre Point Dam, the annual scaled composite weighted usable area for steelhead spawning utilized only the WUA-flow relationship developed for the reaches upstream of Daguerre Point Dam (Reaches 1 and 2, in Figure 2-4), applied to the months of January through April.

3.0 SPATIAL WEIGHTING COEFFICIENTS

Because $\widehat{CWUA}_Y$ is a scaled composite weighted usable area for a species' spawning area that may be comprised of more than one IFIM river reach, and because not all the IFIM reaches may be equally used by the species during its spawning period, the spatial weighting coefficients w_k were incorporated into equation 1 to account for the average relative spawning intensity in particular reaches k. The coefficients w_k of a particular species were developed from in-river Schaefer escapement estimates. Each w_k is a proportion with a value between 0 and 1, so that for a given species and river their sum over all studied IFIM river reaches is equal to 1.

3.1 LOWER YUBA RIVER

Ten years of Schaefer spawning escapement estimates (i.e., 1994 and 1996 to 2004) were utilized in the calculations of spatial weighting coefficients, because only in those ten years was reach 2 sampled to its maximum extent by including Rose Bar (YCWA 1992; YCWA 1994; YCWA 1995; YCWA 1996; YCWA 1997; YCWA 1998; YCWA 1999; YCWA 2000; YCWA 2001; YCWA 2002; YCWA 2003; YCWA 2006a; YCWA 2006b). Because the estimation of fall-run Chinook salmon escapement to the lower Yuba River are based upon two carcass-survey reaches, one extending from Rose Bar, 0.1 river miles downstream of the mouth of the Narrows to Daguerre Point Dam, and another extending from Daguerre Point Dam to Marysville E street bridge (RM 1), spatial weighting coefficients were developed only for IFIM reaches 2, and 3 + 4 (**Table 3-1**). IFIM reach 1, extending from Englebright Dam to the terminus of the Narrows, displayed 0 WUA values for fall-run Chinook spawning, and was never sampled for fall-run Chinook salmon redds or carcasses. Consequently, it was not considered in the calculations of $\widehat{CWUA}_Y$ for fall-run Chinook salmon spawning in the lower Yuba River. The spatial weighting coefficients used for Chinook salmon spawning in the lower Yuba River at IFIM reaches 2, and 3 + 4 are displayed in Table 3-1.

Table 3-1. Spatial Weighting Coefficients Used for Chinook Salmon Spawning in the Lower Yuba River IFIM Reaches 2 and 3+4

Year	IFIM Reach *k*	Upstream Limit	RM	Downstream Limit	RM	Schaefer Escapement	Spawning (%)
1994	2	Rose Bar	21.4	Daguerre Point Dam	11.4	8,801	82.32%
	3 + 4	Daguerre Point Dam	11.4	E Street Bridge	1	1,890	17.68%
1996	2	Rose Bar	21.4	Daguerre Point Dam	11.4	18,892	68.65%
	3 + 4	Daguerre Point Dam	11.4	E Street Bridge	1	8,628	31.35%
1997	2	Rose Bar	21.4	Daguerre Point Dam	11.4	16,951	65.76%
	3 + 4	Daguerre Point Dam	11.4	E Street Bridge	1	8,827	34.24%
1998	2	Rose Bar	21.4	Daguerre Point Dam	11.4	18,306	59.43%
	3 + 4	Daguerre Point Dam	11.4	E Street Bridge	1	12,496	40.57%
1999	2	Rose Bar	21.4	Daguerre Point Dam	11.4	12,392	53.72%
	3 + 4	Daguerre Point Dam	11.4	E Street Bridge	1	10,675	46.28%
2000	2	Rose Bar	21.4	Daguerre Point Dam	11.4	10,435	70.26%
	3 + 4	Daguerre Point Dam	11.4	E Street Bridge	1	4,417	29.74%
2001	2	Rose Bar	21.4	Daguerre Point Dam	11.4	17,059	76.21%
	3 + 4	Daguerre Point Dam	11.4	E Street Bridge	1	5,325	23.79%
2002	2	Rose Bar	21.4	Daguerre Point Dam	11.4	16,838	72.57%
	3 + 4	Daguerre Point Dam	11.4	E Street Bridge	1	6,364	27.43%
2003	2	Rose Bar	21.4	Daguerre Point Dam	11.4	20,924	72.41%
	3 + 4	Daguerre Point Dam	11.4	E Street Bridge	1	7,973	27.59%
2004	2	Rose Bar	21.4	Daguerre Point Dam	11.4	9,477	64.97%
	3 + 4	Daguerre Point Dam	11.4	E Street Bridge	1	5,109	35.03%
Spatial Weighting Coefficients							
2		Rose Bar	21.4	Daguerre Point Dam	11.4	68.63%	
3 + 4		Daguerre Point Dam	11.4	E Street Bridge	1	31.37%	
					Totals	100%	

4.0 TEMPORAL WEIGHTING COEFFICIENTS

Because $\widehat{CWUA}_Y$ in equation 1 is a scaled composite weighted usable area for a species spawning over various months of its spawning season, and because the species' spawning intensity does not remain constant throughout the spawning season, the temporal weighting coefficients w_m were incorporated into equation 1 to account for the average relative spawning intensity in a particular month. Each w_m is a proportion with a value between 0 and 1, so that for a given species and river their sum over the commonly accepted spawning period of the species is equal to 1.

The daily cumulative proportions of fresh carcasses reported in available annual surveys were fitted to a common asymmetric logistic function through non-linear least squares. The asymmetric logistic function has the following expression:

$$Y_D = \left(\frac{1}{1 + \exp(\alpha + \beta \times D)} \right)^{1/\delta}, \qquad \textbf{(3)}$$

where Y_D is the expected cumulative proportion of fresh carcasses through day D, and α, β and δ are parameters that determine the shape of the curve. The variable D is a continuous variable that indicates the day number at which new fresh carcasses were observed during a particular annual survey, counting from a particular starting date. Once equation 3 was fitted to the data available for a particular species, the fitted curve was rescaled to the commonly accepted spawning period of the species, and the monthly temporal weighting coefficients w_m were calculated by subtraction. For example, if $\hat{Y}_D$ is the value of the fitted asymmetric logistic curve at a given day D, for a species that spawns from April through August, the temporal weighting coefficient for May (i.e., w_{May}) is calculated as $w_{\mathrm{May}} = \left(\hat{Y}_{6/01} - \hat{Y}_{5/01}\right) / \left(\hat{Y}_{9/01} - \hat{Y}_{4/01}\right)$. The following sections present the fitted asymmetric curves and the temporal weighting coefficients for lower Yuba River fall-run Chinook salmon.

4.1 LOWER YUBA RIVER

The temporal weighting coefficients used for fall-run Chinook salmon spawning in the lower Yuba River are derived from the latest 14 fall-run Chinook carcass survey reports (YCWA 1992; YCWA 1994; YCWA 1995; YCWA 1996; YCWA 1997; YCWA 1998; YCWA 1999; YCWA 2000; YCWA 2001; YCWA 2002; YCWA 2003; YCWA 2006a; YCWA 2006b). Different common asymmetric curves were fitted to the annual cumulative carcass proportions obtained from the fresh carcasses observed from RM 21.4 through RM 11.4 (i.e., IFIM reach 2), and to those obtained from the fresh carcasses observed from RM 11.4 through RM 1 (i.e., roughly IFIM reaches 3 + 4).

In the lower Yuba River, extending from RM 21.4 through RM 11.4, the 1991-2004 Chinook salmon carcass surveys produced a total of 231 daily cumulative proportions for the fitting of the common asymmetric logistic function (**Figure 4-1**). The resulting fitted curve had the following expression:

$$\hat{Y}_D = \left(\frac{1}{1 + \exp(7.0720 - 0.1113 \times D)} \right)^{1/1.2444}, \qquad \textbf{(4)}$$

where D is the day number at which new fresh carcasses were observed during a particular annual survey, counted from midnight of August 31 of each year. The mean square error of this fit was 0.1044. Fitted equation 4 was rescaled to the spawning period of Chinook salmon in the lower Yuba River (i.e., September into January) to obtain the final monthly weighting coefficients displayed in **Table 4-1**.

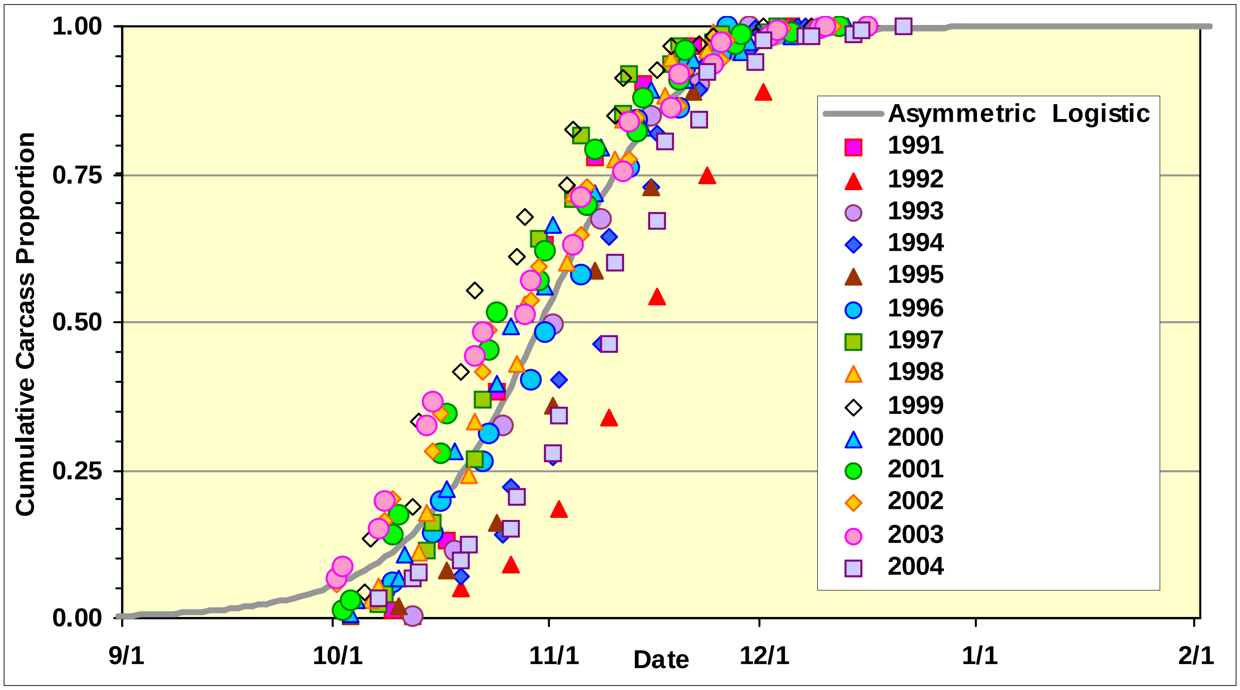

Figure 4-1. Cumulative Proportions of Fresh Chinook Salmon Carcasses in the Lower Yuba River Reach Extending from RM 21.4 Through RM 11.4, during the 1991-2004 Spawning Seasons, and Fitted Asymmetric Logistic Curve

Table 4-1. Temporal Weighting Coefficients Used for Chinook Salmon Spawning in the Lower Yuba River IFIM Reach 2

Month	Asymmetric Logistic	Temporal Weighting Coefficient
October	48.41%	0.513423
November	42.70%	0.452845
December	3.08%	0.032657
January	0.10%	0.001075
Totals	94.28%	1

In the lower Yuba River reach extending from RM 11.4 through RM 1, the 1991-2004 Chinook salmon carcass surveys produced a total of 124 daily cumulative proportions for the fitting of the common asymmetric logistic function (**Figure 4-2**). The resulting fitted curve had the following expression:

$$\hat{Y}_D = \left(\frac{1}{1+\exp\left(10.2105-0.1356\times D\right)}\right)^{1/1.7495}, \qquad (5)$$

where D is the day number at which new fresh carcasses were observed during a particular annual survey, counted from midnight of August 31 of each year. The mean square error of this fit was 0.1687. Fitted equation 5 was rescaled to the spawning period of Chinook salmon in the lower Yuba River (i.e., September into January) to obtain the final monthly weighting coefficients displayed in **Table 4-2**.

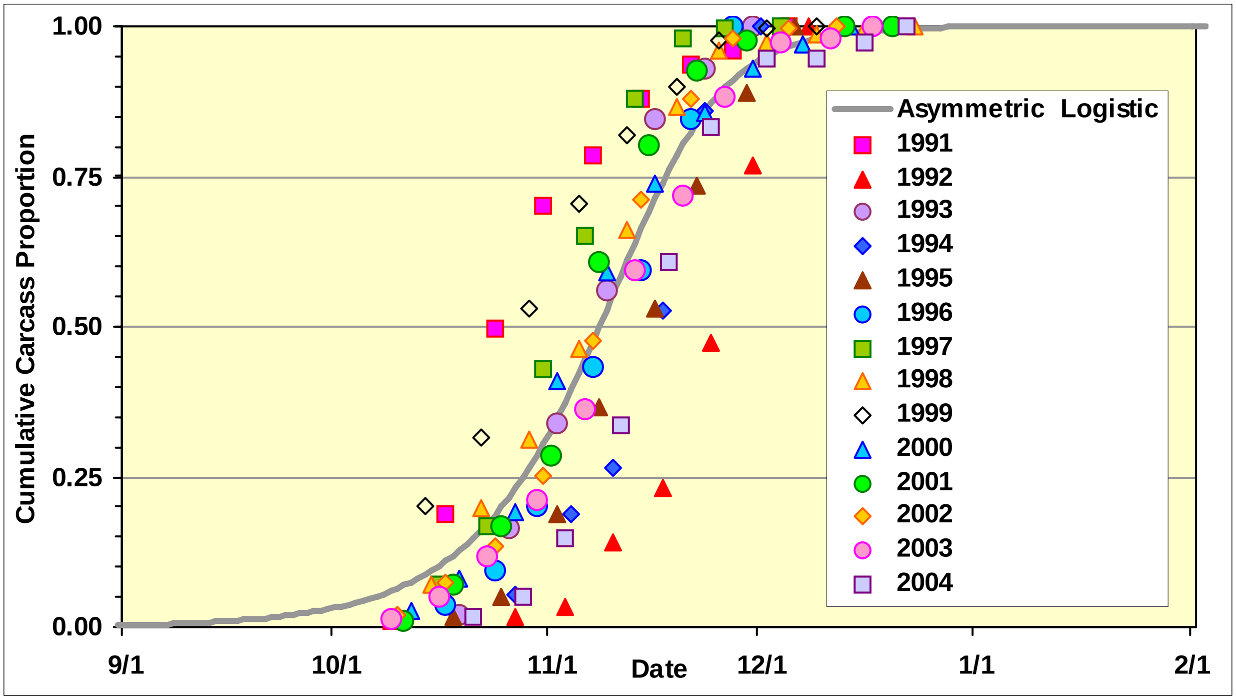

Figure 4-2. Cumulative Proportions of Fresh Chinook Salmon Carcasses in the Lower Yuba River Reach Extending from RM 11.4 Through RM 1, during the 1991-2004 Spawning Seasons, and Fitted Asymmetric Logistic Curve

Table 4-2. Temporal Weighting Coefficients Used for Chinook Salmon Spawning in the Lower Yuba River IFIM Reaches 3+4

Month	Asymmetric Logistic	Temporal Weighting Coefficient
October	29.45%	0.304355
November	61.82%	0.638822
December	5.41%	0.055919
January	0.09%	0.000904
Totals	96.78%	1

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YCWA. 2006b. 2004 Fall-Run Chinook Salmon Spawning Escapement in the Yuba River. Prepared by Jones & Stokes Associates, Inc.

APPENDIX E2

WATER TEMPERATURE INDEX VALUES FOR TECHNICAL EVALUATION GUIDELINES

Appendix E2

Water Temperature Index Values for Technical Evaluation Guidelines

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Appendix E2

Water Temperature Index Values for Technical Evaluation Guidelines

1.0 INTRODUCTION

Water temperature is one of the most important environmental parameters affecting the distribution, growth, and survival of fish populations. Lethal water temperatures affect 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, Jr. (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.

State and federal protection of salmonid resources requires effects assessment for projects that could potentially affect species listed as threatened or endangered under the federal ESA, as well as species managed under the MSA. Technical evaluation guidelines have been developed to assess potential effects of water diversion and water use projects in a consistent and effective manner. Specifically, salmonid life stages have been explicitly defined, and life stage specific water temperature index values derived from comprehensive literature reviews have been established. 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 Technical Appendix presents the results of a literature review that was conducted to: (1) clearly define each salmonid life stage; (2) provide logical and biologically sound rationale for each life stage definition and/or combination of life stages; (3) interpret the literature on the effects of water temperature on the various life stages of Chinook salmon and steelhead; (4) consider the effects of short-term and long-term exposure to constant or fluctuating temperatures; and (5) establish biologically defensible water temperature index values to be used as guidelines for effects assessment.

2.0 METHODS

Water temperature index values were established from a comprehensive literature review to reflect an evenly spaced range of water temperatures, from reported "optimal" to "lethal" water temperatures, for each life stage of Chinook salmon and steelhead. Types of literature examined include scientific journals, Master's theses and Ph.D. dissertations, literature reviews, and agency publications (see Section 4.0, References). 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. Water temperature index values were determined by placing emphasis on the results of laboratory experiments that examined how water temperature affects Central Valley Chinook salmon and steelhead, as well as by considering regulatory documents such as biological opinions from NMFS. Studies on fish from outside the Central Valley were used to establish index values when local studies were unavailable. To avoid unwarranted specificity, only whole integers were selected as index values, thus support for index values was, in some cases, partially derived from literature supporting a water temperature that varied from the resultant index value by several tenths of a degree. For example, Combs and Burrows (1957) reported that constant incubation temperatures between 42.5°F and 57.5°F resulted in normal development of Chinook salmon eggs, and their report was referenced as support for a water temperature index value of 58°F. Rounding for the purposes of selecting index values is appropriate because the daily variation of experimental treatment temperatures is often high. For example, temperature treatments in Marine (1997) consisted of control (55.4°F to 60.8°F), intermediate (62.6°F to 68.0°F), and extreme (69.8°F to 75.2°F) treatments that varied daily by several degrees.

For Chinook salmon, water temperature index values were developed to separately evaluate the following life stages or, where appropriate, combinations of life stages: (1) adult immigration and holding; (2) adult spawning and embryo incubation; and (3) juvenile rearing and smolt emigration. For steelhead, water temperature index values were developed to separately evaluate the following life stages, or where appropriate, combinations of life stages: (1) adult immigration and holding; (2) adult spawning and embryo incubation; (3) juvenile rearing; and (4) smolt emigration.

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. For example, Hinze (1959) actually examines the effects of water temperature on incubating Chinook salmon eggs, yet Hinze (1959); Marine (1992); and NMFS (1997b) in statements regarding the effects of water temperature on holding Chinook salmon adults. Boles *et al.* (1988) and Marine (1992) were then further cited by McCullough *et al.* (2001) in support of a section detailing how water temperature affects the viability of gametes developing in adults.

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

Finally, as a comparative tool, life stage-specific water temperature effects indicator values to be used as evaluation guidelines have been developed for Chinook salmon and steelhead, 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 Proposed Action to an Environmental Baseline. 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 the Proposed Action and Environmental Baseline will not necessarily constitute an effect. Effects determinations will be based on consideration of all evaluated impact indicators for all life stages for a particular species.

3.0 RESULTS

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 will not be separated because: (1) there is a paucity of literature specific to each life stage of each run-type; (2) there is an insufficient amount of data available in the literature suggesting that Chinook salmon run-types respond to water temperatures differently; (3) the water temperature index values derived from all the literature pertaining to Chinook salmon that provide PFC for a particular life stage will be sufficiently protective of that life stage for each run-type; and (4) all run-types overlap in timing of adult immigration and holding and in some cases are not easily distinguished (Healey 1991).

3.1.1 ADULT IMMIGRATION AND HOLDING

3.1.1.1 LIFE STAGE DESCRIPTION

After spending three to four years in the ocean, Chinook salmon begin their return to freshwaters to spawn (Moyle 2002). Chinook salmon show considerable temporal variation in the timing of their spawning migrations, which is evident in the classification of Chinook salmon by run-type (i.e., fall-run, late fall-run, winter-run, and spring-run). In the Central Valley, the upstream migration of adult Chinook salmon generally occurs from October to April for the late fall-run, from December to July for the winter-run, from March to September for the spring-run, and from June to December for the fall-run (Fisher 1994). The holding period extends from the time that adult Chinook salmon enter their natal stream until the onset of spawning site selection. In the Sacramento River, the adult immigration and holding life stage for Chinook salmon generally lasts from December through July for the winter-run (Moyle 2002; USFWS 1995b), from February through September for the spring-run (time period derived from (Moyle 2002; CDFG 1998; Lindley *et al.* 2004; Vogel and Marine 1991), from August through November for the fall-run (time period derived from (Snider *et al.* 1999; Vogel and Marine 1991)), and from October through April for late fall-run (Moyle 2002). In the Feather River, the adult immigration and holding period generally lasts from March through October for spring-run Chinook salmon, and from mid-July through December for fall-run Chinook salmon (Moyle 2002; DWR 2003a; Eaves 1982; 64 FR 50394 (1999); Sommer *et al.* 2001). In the American River, the adult immigration and holding period for fall-run Chinook salmon generally lasts from September through November (time period derived from (CDFG 1995; Snider and McKewan 1992).

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

3.1.1.2 INDEX VALUE SELECTION RATIONALE

One set of adult immigration and holding water temperature index values was established for all Chinook salmon run-types. The water temperature index values are evenly spaced across the range of conditions from those reported as "optimal" to those reported as "lethal" for adult Chinook salmon during upstream spawning migrations and holding. The water temperature index values established to evaluate the Chinook salmon adult immigration and holding life stage are 60°F, 64°F, and 68°F (**Table 3-1**). Although 56°F is referenced in the literature frequently as the upper "optimal" water temperature limit for upstream migration and holding, the references are not foundational studies and often are inappropriate citations. For example, many of the references to 56°F are based on Hinze (1959), which is a study examining the effects of water temperature on incubating Chinook salmon eggs. Boles *et al.* (1988), Marine (1992), and NMFS (1997b) all cite Hinze (1959) in support of recommendations for a water temperature of 56°F for adult Chinook salmon immigration. Because 56°F is not strongly supported in the literature for adult Chinook salmon immigration and holding, it was not established as an index value.

The lowest water temperature index value established was 60°F, because in the NMFS biological opinion for the proposed operation of the Central Valley Project (CVP) and State Water Project (SWP), 59°F to 60°F is reported as…"*The upper limit of the optimal temperature range for adults holding while eggs are maturing*" (NMFS 2000). Also, NMFS (1997b) states…"*Generally, the maximum temperature of adults holding, while eggs are maturing, is about 59°F to 60°F*" …and… "*Acceptable range for adults migrating upstream range from 57°F to 67°F.*" ODEQ (1995) reports that "*…many of the diseases that commonly affect Chinook become highly infectious and virulent above 60°F.*" The 60°F water temperature index value established for the Chinook salmon adult immigration and holding life stage is the index value generally reported in the literature as the upper limit of the optimal range, and is within the reported acceptable range. Increasing levels of thermal stress to this life stage may reportedly occur above the 60°F water temperature index value.

Table 3-1. Chinook Salmon Adult Immigration and Holding Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
60°F [a]	Maximum water temperature for adults holding, while eggs are maturing, is approximately 59ºF to 60ºF (NMFS 1997b). Acceptable water temperatures for adults migrating upstream range from 57ºF to 67ºF (NMFS 1997b). Upper limit of the optimal water temperature range for adults holding while eggs are maturing is 59°F to 60°F (NMFS 2000). Many of the diseases that commonly affect Chinook salmon become highly infectious and virulent above 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 1995b).
64°F	Acceptable range for adults migrating upstream is from 57ºF to 67ºF (NMFS 1997b). Disease risk becomes high at water temperatures above 64.4°F (EPA 2003b). Latent embryonic mortalities and abnormalities associated with water temperature exposure to pre-spawning adults occur at 63.5ºF to 66.2°F (Berman 1990).
68°F	Acceptable range for adults migrating upstream range from 57°F to 67ºF (NMFS 1997b). For chronic exposures, an incipient upper lethal water temperature limit for pre-spawning adult salmon probably falls within the range of 62.6°F to 68.0°F (Marine 1992). Spring-run Chinook salmon embryos from adults held at 63.5ºF to 66.2°F had greater numbers of pre-hatch mortalities and developmental abnormalities than embryos from adults held at 57.2ºF to 59.9°F (Berman 1990). Water temperatures of 68°F resulted in nearly 100 percent mortality of Chinook salmon during columnaris outbreaks (Ordal and Pacha 1963).

[a] The 60°F water temperature index value established for the Chinook salmon adult immigration and holding life stage is the index value generally reported in the literature as the upper limit of the optimal range, and is within the reported acceptable range. Increasing levels of thermal stress to this life stage may reportedly occur above the 60°F water temperature index value.

An index value of 64°F was established because Berman (1990) suggests effects of thermal stress to pre-spawning adults are evident at water temperatures near 64°F. Berman (1990) conducted a laboratory study to determine if pre-spawning water temperatures experienced by adult Chinook salmon influenced reproductive success, and found evidence suggesting latent embryonic abnormalities associated with water temperature exposure to pre-spawning adults occurs at 63.5°F to 66.2°F. Also, 64°F represents a mid-point value between the water temperature index values of 60°F and 68°F. An index value of 68°F was established because the literature suggests that thermal stress at water temperatures greater than or equal to 68°F is pronounced, and severe adverse effects to immigrating and holding pre-spawning adults, including mortality, can be expected (Berman 1990; Marine 1997; NMFS 1997b). Because potential effects to immigrating and holding adult Chinook salmon reportedly occur at water temperatures greater than or equal to 68°F, index values higher than 68°F were not established.

3.1.2 SPAWNING AND EMBRYO INCUBATION

3.1.2.1 LIFE STAGE DESCRIPTION

In the Sacramento River, Chinook salmon spawning and embryo incubation generally occurs from April through October for the winter run (Vogel and Marine 1991), from September through February for both the spring-run (Moyle 2002; DWR 2004) and the fall-run (time period derived from (Moyle 2002; Snider *et al.* 1999; Vogel and Marine 1991)), and from December through June for late fall-run (time period derived from (Reclamation 1991; Vogel and Marine 1991)). In the Feather River, adult spawning and embryo incubation reportedly occurs from September through February for both spring-run and fall-run Chinook salmon (DWR 2004). In the lower American River, fall-run Chinook salmon spawning and embryo incubation generally occurs from October through February (SWRI 2001).

The duration of embryo incubation is dependent on water temperature and can be variable (NMFS 2002a). In Butte and Big Chico creeks, emergence of spring-run Chinook salmon generally occurs from November through January (NMFS 2002b). In Mill and Deer creeks, colder water temperatures delay emergence to January through March (CDFG 1998).

The adult spawning and embryo (i.e., eggs and alevins) incubation life stage includes redd construction, egg deposition, and embryo incubation. Potential effects to the adult spawning and embryo incubation life stages will be evaluated together using one set of water temperature index values because it is difficult to separate the effects of water temperature between life stages that are closely linked temporally, especially considering that studies describing how water temperature affects embryonic survival and development based on varying water temperature treatments on holding adults often report similar results to water temperature experiments conducted on fertilized eggs (Marine 1992; McCullough 1999; Seymour 1956).

3.1.2.2 INDEX VALUE SELECTION RATIONALE

Water temperature index values were selected from a comprehensive literature review for Chinook salmon eggs during spawning and incubation (**Table 3-2**). Relative to the large body of literature pertaining to water temperature effects on Chinook salmon embryos, few laboratory experiments specifically examine Chinook salmon embryo survival under different constant or fluctuating water temperature treatments, only one of which is recent (Combs and Burrows 1957; Hinze 1959; Johnson and Brice 1953; Seymour 1956; USFWS *et al.* 1999). In large part, supporting evidence for index value selections was derived from the aforementioned laboratory studies and from regulatory documents (NMFS 1993b; NMFS 1997b; NMFS 2002a). Field studies reporting river water temperatures during spawning also were considered (Dauble and Watson 1997; Groves and Chandler 1999).

Table 3-2. Chinook Salmon Spawning and Embryo Incubation Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
56°F [a]	Less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs (Reclamation Unpublished Work). Optimum water temperatures for egg development are between 43°F and 56°F (NMFS 1993b). Upper value of the water temperature range (i.e., 41.0ºF to 56.0°F) suggested for maximum survival of eggs and yolk-sac larvae in the Central Valley of California (USFWS 1995b). Upper value of the range (i.e., 42.0ºF to 56.0°F) given for the preferred water temperature for Chinook salmon egg incubation in the Sacramento River (NMFS 1997a). Incubation temperatures above 56°F result in significantly higher alevin mortality (USFWS 1999). 56.0°F is the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River (NMFS 2002a). Water temperatures averaged 56.5°F during the week of fall-run Chinook salmon spawning initiation on the Snake River (Groves and Chandler 1999).
58°F	Upper value of the range given for preferred water temperatures (i.e., 53.0ºF to 58.0°F) for eggs and fry (NMFS 2002a). Constant egg incubation temperatures between 42.5°F and 57.5°F resulted in normal development (Combs and Burrows 1957). The natural rate of mortality for alevins occurs at 58°F or less (Reclamation Unpublished Work).
60°F	100 percent mortality occurs during yolk-sac stage when embryos are incubated at 60°F (Seymour 1956). An October 1 to October 31 water temperature criterion of less than or equal to 60°F in the Sacramento River from Keswick Dam to Bend Bridge has been determined for protection of late incubating larvae and newly emerged fry (NMFS 1993b). Mean weekly water temperature at first observed Chinook salmon spawning in the Columbia River was 59.5°F (Dauble and Watson 1997). Consistently higher egg losses resulted at water temperatures above 60.0°F than at lower temperatures (Johnson and Brice 1953).
62°F	100 percent mortality of fertilized Chinook salmon eggs after 12 days at 62°F (Reclamation Unpublished Work). Incubation temperatures of 62ºF to 64°F appear to be the physiological limit for embryo development resulting in 80 to 100 percent mortality prior to emergence (USFWS 1999). 100 percent loss of eggs incubated at water temperatures above 62°F (Hinze 1959). 100 percent mortality occurs during yolk-sac stage when embryos are incubated at 62.5°F (Seymour 1956)

[a] The 56°F water temperature index value established for the Chinook salmon spawning and embryo incubation life stage is the index value generally reported in the literature as the upper limit of the optimal range for egg development and the upper limit of the range reported to provide maximum survival of eggs and yolk-sac larvae in the Central Valley of California. Increasing levels of thermal stress to this life stage may reportedly occur above the 56°F water temperature index value.

The water temperature index values selected to evaluate the Chinook salmon spawning and embryo incubation life stages are 56ºF, 58ºF, 60ºF, and 62ºF. Some literature suggests that water temperatures must be less than or equal to 56°F for maximum survival of Chinook salmon embryos (i.e., eggs and alevins) during spawning and incubation. (NMFS 1993b) reported that optimum water temperatures for egg development are between 43°F and 56°F. Reclamation (unpublished work) reports that water temperatures less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs. USFWS (1995a) reported a water temperature range of 41.0ºF to 56.0°F for maximum survival of eggs and yolk-sac larvae in the Central Valley of California. 42.0ºF to 56.0°F was suggested as the preferred water temperature for Chinook salmon egg incubation in the Sacramento River (NMFS 1997a). Alevin mortality is reportedly significantly higher when Chinook salmon embryos are incubated at water temperatures above 56°F (USFWS 1999). NMFS (2002a) reported 56.0°F as the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River. The 56°F water temperature index value established for the Chinook salmon spawning and embryo incubation life stage is the index value generally reported in the literature as the upper limit of the optimal range for egg development and the upper limit of the range reported to provide maximum survival of eggs and yolk-sac larvae in the Central Valley of California. Increasing levels of thermal stress to this life stage may reportedly occur above the 56°F water temperature index value.

High survival of Chinook salmon embryos also has been suggested to occur at incubation temperatures at or near 58.0°F. For example, (Reclamation Unpublished Work) reported that the natural rate of mortality for alevins occurs at 58°F or less. Combs (1957) concluded constant incubation temperatures between 42.5°F and 57.5°F resulted in normal development of Chinook salmon eggs, and NMFS (2002a) suggests 53.0°F to 58.0°F is the preferred water temperature range for Chinook salmon eggs and fry. Johnson (1953) found consistently higher Chinook salmon egg losses resulted at water temperatures above 60.0°F than at lower temperatures. In order to protect late incubating Chinook salmon embryos and newly emerged fry NMFS (1993a) has determined a water temperature criterion of less than or equal to 60.0°F be maintained in the Sacramento River from Keswick Dam to Bend Bridge from October 1 to October 31. However, Seymour (1956) provides evidence that 100 percent mortality occurs to late incubating Chinook salmon embryos when held at a constant water temperature greater than or equal to 60.0°F. The literature largely agrees that 100 percent mortality will result to Chinook salmon embryos incubated at water temperatures greater than or equal to 62.0°F (Hinze 1959; Seymour 1956; USFWS 1999), therefore, it was not necessary to select index values above 62°F. Similarly, mortality to spawning adult Chinook salmon prior to egg deposition (Berman 1990; Marine 1992) reportedly occurs at water temperatures above those at which embryo mortality results (i.e., 62°F) (Hinze 1959; Reclamation 2003; Seymour 1956; USFWS 1999); therefore, an index value above 62°F was not required.

3.1.3 JUVENILE REARING AND SMOLT EMIGRATION

3.1.3.1 LIFE STAGE DESCRIPTION

The juvenile life stage is comprised of fry, fingerlings, and smolts; the parr stage is included in the fingerling category. Chinook salmon are considered to be fry from the time when they leave the gravel of the spawning redd to swim up into the water column as a free-swimming fish, until skeletal development is complete, at which point it reaches the fingerling stage (Bovee *et* *al.* 1998). Chinook salmon fry transition to the fingerling stage at approximately 45 to 60 mm (DWR 2003b; NMFS 1997b; NMFS 2003). Fingerling Chinook salmon become smolts when physiological changes occur that allow the juvenile to survive the transition from freshwater to saltwater during seaward migration. In addition to physiological changes, morphological changes also take place during smolting (Hoar 1988). Salmonid smolts can be distinguished from pre-smolts by their silvery appearance and relatively slim, streamlined body (Hoar 1988).

In the Sacramento River Basin, the duration that juvenile Chinook salmon rear in natal streams varies according to run-type. Winter-run juveniles reportedly emerge from the spawning substrate as free-swimming fry from July to October and rear for 5 to 10 months (Fisher 1994). Spring-run juveniles emerge from the spawning substrate as free-swimming fry from November to March and rear for 3 to 15 months (Fisher 1994). Fall-run juveniles emerge from the spawning substrate as free-swimming fry from December to March and rear for 1 to 7 months (Fisher 1994). Late fall-run juveniles emerge from the spawning substrate as free-swimming fry from April to June and rear in their natal stream for 7 to 13 months (Fisher 1994). Recent studies from the American and Feather rivers indicate that most juvenile Chinook salmon move downstream as fry shortly after they emerge from the spawning gravel (DWR 2002; Snider and Titus 2000). In the Sacramento River, juvenile Chinook salmon move downstream during all months, as both fry and smolts (Moyle 2002).

Water temperature is a major limiting factor for juvenile Chinook salmon, as it strongly affects survival and growth. Water temperatures that are too high can be lethal or cause sub-lethal effects such as reduced appetite and growth, increased incidence of disease, increased metabolic costs, and decreased ability for predator avoidance. The scientific literature indicates that a similar range of water temperatures provides positive growth and high survival for Chinook salmon fry, fingerlings, and smolts. Because Chinook salmon juveniles can be found in their natal stream rearing and moving downstream year-round as fry, fingerlings, or smolts, and the scientific literature indicates that a similar range of water temperatures that are important for fry also are important for fingerlings and smolts, potential effects to each phase of the juvenile life stage can be evaluated using a single set of water temperature index values.

3.1.3.2 INDEX VALUE SELECTION RATIONALE

Water temperature index values were selected from a comprehensive literature review for juvenile rearing and smolt emigration (**Table 3-3**). The lowest index value of 60°F was chosen because regulatory documents as well as several source studies, including ones recently conducted on Central Valley Chinook salmon fry, fingerlings, and smolts, report 60°F as an optimal water temperature for growth (Banks *et al.* 1971; Brett *et al.* 1982; Marine 1997; NMFS 1997b; NMFS 2000; NMFS 2001a; NMFS 2002a; Rich 1987b). Water temperatures below 60°F also have been reported as providing conditions optimal for fry and fingerling growth, but were not selected as index values, because the studies were conducted on fish from outside of the Central Valley (Brett 1952; Seymour 1956). Studies conducted using local fish may be particularly important because *Oncorhynchus* species show considerable variation in morphology, behavior, and physiology along latitudinal gradients (Myrick 1998; Taylor 1990b; Taylor 1990a). More specifically, it has been suggested that salmonid populations in the Central Valley prefer higher water temperatures than those from more northern latitudes (Myrick and Cech 2000).

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

Index Value	Supporting Literature
60°F [a]	Optimum water temperature for Chinook salmon fry growth is between 55.0°F and 60°F (Seymour 1956). Water temperature range that produced optimum growth in juvenile Chinook salmon was between 54.0°F and 60.0°F (Rich 1987b). Water temperature criterion of less than or equal to 60.0°F for the protection of Sacramento River winter-run Chinook salmon from Keswick Dam to Bend Bridge (NMFS 1993b). Upper optimal water temperature limit of 61°F for Sacramento River fall-run Chinook salmon juvenile rearing (Marine 1997; Marine and Cech 2004). Upper water temperature limit of 60.0°F preferred for growth and development of spring-run Chinook salmon fry and fingerlings (NMFS 2000; NMFS 2002a). To protect salmon fry and juvenile Chinook salmon in the upper Sacramento River, daily average water temperatures should not exceed 60°F after September 30 (NMFS 1997b). A water temperature of 60°F appeared closest to the optimum for growth of fingerlings (Banks *et al.* 1971). Optimum growth of Nechako River Chinook salmon juveniles would occur at 59°F at a feeding level that is 60 percent of that required to satiate them (Brett *et al.* 1982). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004). Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989).
63°F	Acceleration and inhibition of Sacramento River Chinook salmon smolt development reportedly may occur at water temperatures above 63°F (Marine 1997; Marine and Cech 2004). Laboratory evidence suggest that survival and smoltification become compromised at water temperatures above 62.6°F (Zedonis and Newcomb 1997). Juvenile Chinook salmon growth was highest at 62.6°F (Clarke and Shelbourn 1985).
65°F	Water temperatures between 45°F to 65°F are preferred for growth and development of fry and juvenile spring-run Chinook salmon in the Feather River (NMFS 2002a). Recommended summer maximum water temperature of 64.4°F for migration and non-core rearing (EPA 2003b). Water temperatures greater than 64.0°F are considered not "properly functioning" by NMFS in Amendment 14 to the Pacific Coast Salmon Plan (NMFS 1995). Fatal infection rates caused by *C. columnaris* are high at temperatures greater than or equal to 64.0°F (EPA 2001). Disease mortalities diminish at water temperatures below 65.0°F (Ordal and Pacha 1963). Fingerling Chinook salmon reared in water greater than 65.0°F contracted *C. columnaris* and exhibited high mortality (Johnson and Brice 1953). Water temperatures greater than 64.9°F identified as being stressful in the Columbia River Ecosystem (Independent Scientific Group 1996). Juvenile Chinook salmon have an optimum temperature for growth that appears to occur at about 66.2°F (Brett *et al.* 1982). Juvenile Chinook salmon reached a growth maximum at 66.2°F (Cech and Myrick 1999). Optimal range for Chinook salmon survival and growth from 53.0°F to 64.0°F (USFWS 1995b). Survival of Central Valley juvenile Chinook salmon declines at temperatures greater than 64.4°F (Myrick and Cech 2001). Increased incidence of disease, reduced appetite, and reduced growth rates at 66.2 ± 1.4 (Rich 1987b)
68°F	Sacramento River juvenile Chinook salmon reared at water temperatures greater than or equal to 68.0°F suffer reductions in appetite and growth (Marine 1997; Marine and Cech 2004). Significant inhibition of gill sodium ATPase activity and associated reductions of hyposmoregulatory capacity, and significant reductions in growth rates, may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Water temperatures supporting smoltification of fall-run Chinook salmon range between 50°F to 68°F, the colder temperatures represent more optimal conditions (50°F to 62.6°F), and the warmer conditions (62.6°F to 68°F) represent marginal conditions (Zedonis and Newcomb 1997). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997).
70°F	No growth at all would occur for Nechako River juvenile Chinook salmon at 70.5°F (Brett *et al.* 1982; Zedonis and Newcomb 1997). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997). Increased incidence of disease, hyperactivity, reduced appetite, and reduced growth rates at 69.8 ±1.8 (Rich 1987b). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).

Table 3-3. (continued)

Index Value	Supporting Literature
75°F	For juvenile Chinook salmon in the lower American River fed maximum rations under laboratory conditions, 75.2ºF was determined to be 100 percent lethal due to hyperactivity and disease (Rich 1987b; Zedonis and Newcomb 1997). Lethal temperature threshold for fall-run juvenile Chinook salmon between 74.3 and 76.1°F (McCullough 1999). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).

[a] The 60°F water temperature index value established for the Chinook salmon juvenile rearing and smolt emigration life stage is the index value generally reported in the literature as the upper limit of the optimal range for fry and juvenile growth and the upper limit of the preferred range for growth and development of juvenile Chinook salmon. Increasing levels of thermal stress to this life stage may reportedly occur above the 60°F water temperature index value.

The 60°F water temperature index value established for the Chinook salmon juvenile rearing and smolt emigration life stage is the index value generally reported in the literature as the upper limit of the optimal range for fry and juvenile growth and the upper limit of the preferred range for growth and development of spring-run Chinook salmon fry and fingerlings. Increasing levels of thermal stress to this life stage may reportedly occur above the 60°F water temperature index value.

Laboratory experiments suggest that water temperatures at or below 62.6°F provide conditions that allow for successful transformation to the smolt stage (Clarke and Shelbourn 1985; Marine 1997; Zedonis and Newcomb 1997). 62.6ºF was rounded and used to support an index value of 63ºF. 65°F was selected as an index value because it represents an intermediate value between 64.0°F and 66.2°F, at which both adverse and beneficial effects to juvenile salmonids have been reported to occur. For example, at temperatures approaching and beyond 65°F, sub-lethal effects associated with increased incidence of disease reportedly become severe for juvenile Chinook salmon (EPA 2003a; Johnson and Brice 1953; Ordal and Pacha 1963; Rich 1987a). Conversely, numerous studies report that temperatures between 64.0°F and 66.2°F provide conditions ranging from suitable to optimal for juvenile Chinook salmon growth (Brett *et al.* 1982; Cech and Myrick 1999; EPA 2003a; Myrick and Cech 2001; NMFS 2002a; USFWS 1995a). 68°F was selected as an index value because, at water temperatures above 68°F, sub-lethal effects become severe such as reductions in appetite and growth of juveniles, as well as prohibiting successful smoltification (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Chronic stress associated with water temperature can be expected when conditions reach the index value of 70°F. For example, growth becomes drastically reduced at temperatures close to 70.0°F and has been reported to be completely prohibited at 70.5°F (Brett *et al.* 1982; Marine 1997). 75°F was chosen as the highest water temperature index value because high levels of direct mortality to juvenile Chinook salmon reportedly result at this water temperature (Rich 1987b). Other studies have suggested higher upper lethal water temperature levels (Brett 1952; Orsi 1971), but 75°F was chosen because it was derived from experiments using Central Valley Chinook salmon and it is a more rigorous index value representing a more protective upper lethal water temperature level. Furthermore, the lethal level determined in Rich (Rich 1987b) was derived using slow rates of water temperature change and, thus, is ecologically relevant. Additional support for an index value of 75°F is provided from a study conducted by (Baker *et al.* 1995) in which a statistical model is presented that treats survival of Chinook salmon smolts fitted with coded wire tags in the Sacramento River as a logistic function of water temperature. Using data obtained from mark-recapture surveys, the statistical model suggests a 95 percent confidence interval for the upper incipient lethal water temperature for Chinook salmon smolts as 71.5°F to 75.4°F.

3.2 STEELHEAD

3.2.1 ADULT IMMIGRATION AND HOLDING

3.2.1.1 LIFE STAGE DESCRIPTION

Most Central Valley steelhead spend 1 to 2 years in the ocean before entering freshwater in August, with an immigration peak from early fall (i.e., September) to early winter (i.e., December). Movements of adult steelhead from freshwater holding areas to spawning grounds can occur any time from December to March, with peak activities reportedly occurring in January and February (Moyle 2002). In the Sacramento River, the adult immigration and holding time period for steelhead generally lasts from September through March (McEwan 2001). In the Feather River, the adult immigration and holding time period for steelhead generally lasts from September through mid-April, with peak migration extending from October through November (Moyle 2002; pers. comm., Cavallo 2004; McEwan 2001; S.P. Cramer & Associates 1995). In the American River, steelhead adult immigration and holding reportedly occurs from November through March (SWRI 2001).

The adult immigration and adult holding life stages will be evaluated together, because it is difficult to determine the thermal regime that steelhead have been exposed to in the river prior to spawning and in order to be sufficiently protective of pre-spawning fish, water temperatures that provide high adult survival and high egg viability must be available throughout the entire pre-spawning freshwater period. Although studies examining the effects of thermal stress on immigrating steelhead are 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).

3.2.1.2 INDEX VALUE SELECTION RATIONALE

Water temperatures can control the timing of adult spawning migrations and can affect the viability of eggs in holding females. Few studies have been published that examine the effects of water temperature on either steelhead immigration or holding, and none have been recent (Bruin and Waldsdorf 1975; McCullough *et al.* 2001). The available studies suggest that adverse effects occur to immigrating and holding steelhead at water temperatures exceeding the mid 50°F range, and that immigration will be delayed if water temperatures approach approximately 70°F (**Table 3-4**). Water temperature index values of 52°F, 56°F, and 70°F were chosen because: (1) they incorporate a range of values that provide PFC to conditions that are highly adverse; and (2) the available literature provided the strongest support for these values. Because of the paucity of literature pertaining to steelhead adult immigration and holding, an evenly spaced range of water temperature index values could not be achieved. 52°F was selected as a water temperature index value because it has been referred to as a "recommended" (Reclamation 2003), "preferred" (NMFS 2002a), and "optimum" (Reclamation 1997a) water temperature for steelhead adult immigration. Increasing levels of thermal stress to this life stage may reportedly occur above the 52°F water temperature index value.

Table 3-4. Steelhead Adult Immigration and Holding Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
52°F [a]	Preferred range for adult steelhead immigration of 46.0°F to 52.0°F (NMFS 2000; NMFS 2001a; SWRCB 2003). Optimum range for adult steelhead immigration of 46.0°F to 52.1°F (Reclamation 1997a). Recommended adult steelhead immigration temperature range of 46.0°F to 52.0°F (Reclamation 2003).
56°F	To produce rainbow trout eggs of good quality, brood fish must be held at water temperatures not exceeding 56.0°F (Leitritz and Lewis 1980). Rainbow trout brood fish must be held at water temperatures not exceeding 56°F for a period of 2 to 6 months before spawning to produce eggs of good quality (Bruin and Waldsdorf 1975). Holding migratory fish at constant water temperatures above 55.4°F to 60.1°F may impede spawning success (McCullough *et al.* 2001).
70°F	Migration barriers have frequently been reported for pacific salmonids when water temperatures reach 69.8°F to 71.6°F (McCullough *et al.* 2001). Snake River adult steelhead immigration was blocked when water temperatures reached 69.8 (McCullough *et al.* 2001). A water temperature of 68°F was found to drop egg fertility in vivo to 5 percent after 4.5 days (McCullough *et al.* 2001).

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

56°F was selected as a water temperature index value because 56°F represents a water temperature above which adverse effects to migratory and holding steelhead begin to arise (Leitritz and Lewis 1980; McCullough *et al.* 2001; Smith *et al.* 1983). 70°F was selected as the highest water temperature index value because the literature suggests that water temperatures near and above 70.0°F present a thermal barrier to adult steelhead migrating upstream (McCullough *et al.* 2001).

3.2.2 SPAWNING AND EMBRYO INCUBATION

3.2.2.1 LIFE STAGE DESCRIPTION

Steelhead spawning includes the time period from redd construction until spawning is completed with the deposition and fertilization of eggs. The embryo incubation period extends from egg deposition until emergence from the substrate as a free-swimming fry. In the Central Valley, steelhead spawning reportedly occurs from October through June (McEwan 2001) and embryo (i.e., eggs and alevins) incubation generally lasts 2 to 3 months after deposition (Moyle 2002; McEwan 2001; Myrick and Cech 2001). The steelhead spawning and embryo incubation life stage generally occurs from December through May in the Sacramento River (time period derived from McEwan (2001) and Busby (1996), in the Feather River (Moyle 2002; Busby *et al.* 1996; pers. comm., Cavallo 2004; Interagency Ecological Program Steelhead Project Work Team 1998), and in the American River (time period derived from McEwan (2001) and Busby (1996)).

Like Chinook salmon, the steelhead embryo life stage is highly vulnerable to water temperature. Because the initial embryo incubation water temperatures are a function of spawning water temperatures, one set of water temperature index values was established to evaluate spawning adults and incubating embryos.

3.2.2.2 INDEX VALUE SELECTION RATIONALE

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 3-5**).

Table 3-5. Steelhead Spawning and Embryo Incubation Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
52°F [a]	Rainbow trout from Mattighofen (Austria) had highest egg survival at 52.0°F compared to 45.0°F, 59.4°F, and 66.0°F (Humpesch 1985). Water temperatures from 48.0°F to 52.0°F are suitable for steelhead incubation and emergence in the American River and Clear Creek (NMFS 2000; NMFS 2001a; NMFS 2002a). Optimum water temperature range of 46.0°F to 52.0°F for steelhead spawning in the Central Valley (USFWS 1995b). Optimum water temperature range of 46.0°F to 52.1°F for steelhead spawning and 48.0°F to 52.1°F for steelhead egg incubation (Reclamation 1997a). Upper limit of preferred water temperature of 52.0°F for steelhead spawning and egg incubation (SWRCB 2003).
54°F	Big Qualicum River steelhead eggs had 96.6 percent survival to hatch at 53.6°F (Rombough 1988). Highest survival from fertilization to hatch for *Salmo gairdneri* incubated at 53.6°F (Kamler and Kato 1983). Emergent fry were larger when North Santiam River (Oregon) winter steelhead eggs were incubated at 53.6°F than at 60.8°F (Redding and Schreck 1979). The upper optimal water temperature regime based on constant or acclimation water temperatures necessary to achieve full protection of steelhead is 51.8°F to 53.6°F (EPA 2001). From fertilization to hatch, rainbow trout eggs and larvae had 47.3 percent mortality (Timoshina 1972). Survival of rainbow trout eggs declined at water temperatures between 52.0 and 59.4°F (Humpesch 1985). The optimal constant incubation water temperature for steelhead occurs below 53.6°F (McCullough *et al.* 2001).
57°F	From fertilization to 50 percent hatch, Big Qualicum River steelhead had 93 percent mortality at 60.8°F, 7.7 percent mortality at 57.2°F, and 1 percent mortality at 47.3°F and 39.2°F (Velsen 1987). A sharp decrease in survival was observed for rainbow trout embryos incubated above 57.2°F (Kamler and Kato 1983).
60°F	From fertilization to 50 percent hatch, Big Qualicum River steelhead had 93 percent mortality at 60.8°F, 7.7 percent mortality at 57.2°F, and 1 percent mortality at 47.3°F and 39.2°F (Velsen 1987). From fertilization to 50 percent hatch, rainbow trout eggs from Ontario Provincial Normendale Hatchery had 56 percent survival when incubated at 59.0°F (Kwain 1975).

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

Water temperature index values of 52°F, 54°F, 57°F, and 60°F were selected for two reasons. First, the available literature provided the strongest support for water temperature index values at or near 52°F, 54°F, 57°F, and 60°F. Second, the index values reflect an evenly distributed range representing reported optimal to lethal conditions for steelhead spawning and embryo incubation. Although some literature suggests water temperatures ≤ 50°F are optimal for steelhead spawning and embryo survival (Myrick and Cech 2001; Timoshina 1972), a larger body of literature suggests optimal conditions occur at water temperatures ≤ 52°F (Humpesch 1985; NMFS 2000; NMFS 2001a; NMFS 2002a; Reclamation 1997b; SWRCB 2003; USFWS 1995a). Therefore, 52°F was selected as the lowest water temperature index value. Increasing levels of thermal stress to the steelhead spawning and embryo incubation life stage may reportedly occur above the 52°F water temperature index value.

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

3.2.3 JUVENILE REARING

3.2.3.1 LIFE STAGE DESCRIPTION

The juvenile life stage is comprised of fry, fingerlings, and smolts. Steelhead are considered to be fry from the time they emerge from the gravel of the spawning redd to swim up into the water column as a free swimming fish until skeletal development is complete, at which point it reaches the fingerling stage (Bovee *et al.* 1998). Steelhead fry transition to the fingerling stage at approximately 45 to 60 mm (Moyle 2002; Bovee *et al.* 1998; DWR 2003b; NMFS 1997b). After Central Valley steelhead emerge from the gravel, juveniles remain in freshwater for 1 to 3 years before smolting and migrating to saltwater (Myrick and Cech 2001). Shapovalov (Shapovalov and Taft 1954) suggest that most Waddell Creek, California, steelhead rear in freshwater for two years.

3.2.3.2 INDEX VALUE SELECTION RATIONALE

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 (**Table 3-6** and **Table 3-7**). Water temperature index values of 65°F, 68°F, 72°F, and 75°F were selected to represent an evenly distributed range of index values for steelhead juvenile rearing. The lowest water temperature index value of 65°F was established because NMFS (2002a) reported 65°F as the upper limit preferred for growth and development of Sacramento and American River juvenile steelhead. Also, 65°F was found to be within the preferred water temperature range (i.e., 62.6°F to 68.0°F) and supported high growth of Nimbus strain juvenile steelhead (Cech and Myrick 1999). Increasing levels of thermal stress to this life stage may reportedly occur above the 65°F water temperature index value. For example, Kaya *et al.* (1977) reported that the upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F. Cherry *et al.* (1977) observed an upper preference water temperature near 68.0°F for juvenile rainbow trout, duplicating the upper preferred limit for juvenile steelhead observed in Cech (1999). Because of the literature describing 68.0°F as both an upper preferred and an avoidance limit for juvenile *Oncorhynchus mykiss*, 68°F was established as a water temperature index value.

Table 3-6. Steelhead Juvenile Rearing Water Temperature Index Values and the Literature Supporting Each Value

Index Value	Supporting Literature
65°F [a]	Upper limit of 65°F preferred for growth and development of Sacramento River and American River juvenile steelhead (NMFS 2002a). Nimbus juvenile steelhead growth showed an increasing trend with water temperature to 66.2°F, irrespective of ration level or rearing temperature (Cech and Myrick 1999). The final preferred water temperature for rainbow fingerlings was between 66.2 and 68°F (Cherry *et al.* 1977). Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). Rainbow trout fingerlings preferred or selected water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971).
68°F [a]	Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). The final preferred water temperature for rainbow trout fingerlings was between 66.2°F and 68°F (Cherry *et al.* 1977). Rainbow trout fingerlings preferred or selected water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya *et al.* 1977).
72°F	Increased physiological stress, increased agonistic activity, and a decrease in forage activity in juvenile steelhead occur after ambient stream temperatures exceed 71.6°F (Nielsen *et al.* 1994). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya *et al.* 1977). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6°F to 79.9°F (Ebersole *et al.* 2001).
75°F	The maximum weekly average water temperature for survival of juvenile and adult rainbow trout is 75.2°F (EPA 2002). Rearing steelhead juveniles have an upper lethal limit of 75.0°F (NMFS 2001a). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6 to 79.9°F (Ebersole *et al.* 2001).

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

Table 3-7. Steelhead Smolt Emigration Water Temperature Index Values and the Literature Supporting Each Value

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

[a] The 52°F water temperature index value established for the steelhead smolt emigration life stage is the index value generally reported in the literature as the upper limit of the water temperature range that provides successful smolt transformation thermal conditions. Increasing levels of thermal stress to this life stage may reportedly occur above the 52°F water temperature index value.

A water temperature index value of 72°F was established because symptoms of thermal stress in juvenile steelhead have been reported to arise at water temperatures approaching 72°F. For example, physiological stress to juvenile steelhead in Northern California streams was demonstrated by increased gill flare rates, decreased foraging activity, and increased agonistic activity as stream temperatures rose above 71.6°F (Nielsen *et al.* 1994). Also, 72°F was selected as a water temperature index value because 71.6°F has been reported as an upper avoidance water temperature (Kaya *et al.* 1977) and an upper thermal tolerance water temperature (Ebersole *et al.* 2001) for juvenile rainbow trout. The highest water temperature index value of 75°F was established because NMFS and EPA report that direct mortality to rearing juvenile steelhead results when stream temperatures reach 75.0°F (EPA 2002; NMFS 2001b).

3.2.4 SMOLT EMIGRATION

3.2.4.1 LIFE STAGE DESCRIPTION

Fingerling steelhead become smolts when physiological changes occur that allow the juvenile to survive the transition from freshwater to saltwater during seaward migration. In addition to physiological changes, morphological changes also take place during smolting (Hoar 1988). Salmonid smolts can be distinguished from pre-smolts by their silvery appearance and relatively slim, streamlined body (Hoar 1988). Steelhead smolts migrate out to sea at 1 to 3 years of age, at 10 to 25 cm FL (Moyle 2002). Steelhead smolt emigration generally occurs from January through June in the Sacramento River (time period derived from (USFWS 1999); (Snider and Titus 2000); (McEwan 2001); and Newcomb (2001)), the Feather River, (pers. comm., Cavallo 2004) (Newcomb and Coon 2001); (Snider and Titus 2000); (USFWS 1995a)), and the American River (McEwan 2001; Newcomb and Coon 2001; Snider and Titus 2000; USFWS 1995a).

3.2.4.2 INDEX VALUE SELECTION RATIONALE

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

Zaugg and Wagner (1973) examined the influence of water temperature on gill ATPase activity related to parr-smolt transformation and migration in steelhead and found ATPase activity was decreased and migration reduced when juveniles were exposed to water temperatures of 55.4°F or greater. In a technical document prepared by the EPA to provide temperature water quality standards for the protection of Northwest native salmon and trout, water temperatures less than or equal to 54.5°F were recommended for emigrating juvenile steelhead (EPA 2003b).

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