EXHIBIT ARWA-702

Lower American River

Biological Rationale, Development and Performance of the Modified Flow Management Standard

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Biological Rationale, Development and Performance of the Modified Flow Management Standard

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Biological Rationale, Development and Performance of the Modified Flow Management Standard

The lower American River supports populations of both steelhead and fall-run Chinook salmon. Designed to protect the fishery resources of the lower American River, the existing minimum instream flow requirements for the lower American River are those in the 2006 lower American River flow management standard (2006 FMS), which was developed jointly by the U.S. Bureau of Reclamation (Reclamation), the National Marine Fisheries Service (NMFS), the U.S. Department of Interior, Fish and Wildlife Service (USFWS), California Department of Fish and Wildlife (CDFW), and the Water Forum. Implemented beginning in 2006, the 2006 FMS prescribes minimum release requirements (MRRs) at Nimbus Dam.

Recent developments have demonstrated the need for an improved streamflow standard for Folsom and Nimbus dams and the lower American River (See **Technical Memorandum 1,** Project Description - Lower American River Modified Flow Management Standard). The goals of the Modified Flow Management Standard (Modified FMS) include the protection of anadromous salmonids in the lower American River and avoidance of catastrophic water shortages in the American River Basin, particularly low storage in Folsom Reservoir, without redirecting negative environmental effects to sensitive fish in the Sacramento River.

1.0 APPROACH TO MODIFIED FMS DEVELOPMENT AND PERFORMANCE ASSESSMENT

The Modified FMS has been developed to address the ecology (biology and habitat needs) of steelhead and fall-run Chinook salmon during each lifestage. Updated lifestage-specific periodicities, spatial and temporal distributions, habitat availabilities and utilizations, and habitat-flow relationships, as well as water temperature suitability, for anadromous salmonids in the lower American River were used to support the development, refinement and performance evaluation of the Modified FMS. General lifestage periodicities for steelhead and fall-run Chinook salmon in the lower American River are presented in **Figure 1**. The lifestage periodicities encompass the majority of activity for a particular lifestage, and are not intended to be inclusive of every individual in the population.

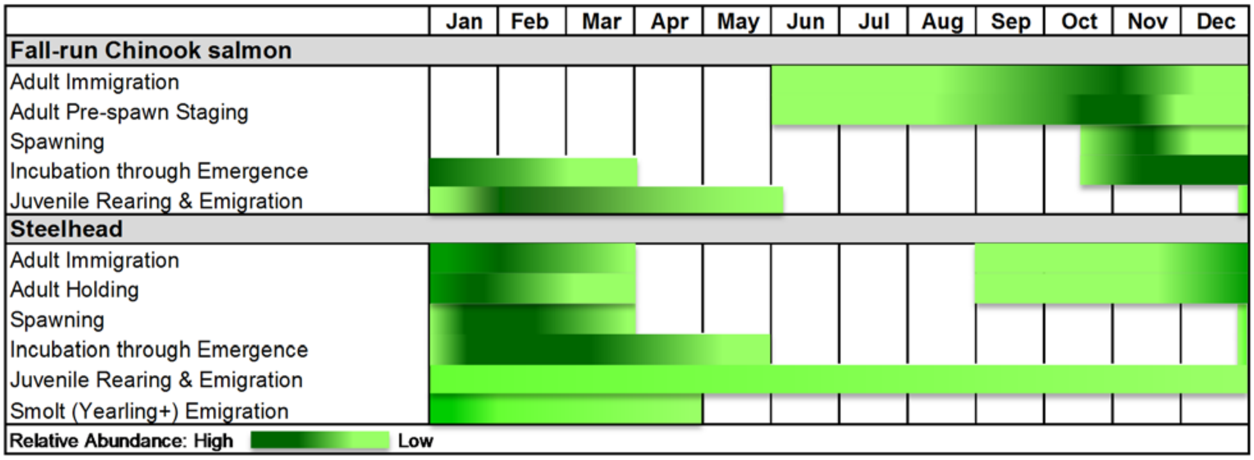

Figure 1. Lifestage periodicities for fall-run Chinook salmon and steelhead in the lower American River. Shading indicates intensity of the particular lifestage.

1.1 Fall-run Chinook Salmon Lifestage Periodicities

1.1.1 Adult Upstream Migration and Staging

The majority of the fall-run Chinook salmon adult immigration into the lower American River has previously been reported to occur from September through November, peaking in November with typically greater than 90% of the run having entered the river by the end of November (SWRI 2001). The temporal distribution of pre-spawning adult fall-run Chinook salmon in the lower American River was re-analyzed using CDFW creel censuses data that provide estimates of the fall-run Chinook salmon monthly catch (see Attachment A). Because fall-run Chinook salmon arrival exhibited extended tails in the temporal distribution, analyses were conducted on the middle 99% of the distribution to capture the vast majority of this lifestage.

Results of these analyses (Figure 2) demonstrate that although the majority (86%) of fall-run Chinook salmon adults immigrate into the lower American River from September through November as previously reported, an estimated 9% of the annual run enter the river prior to September. Adult fall-run Chinook salmon begin entering the lower American River as early as June, continuing through the summer prior to spawning from mid-October through late December. Late (i.e., December) immigrating fall-run Chinook salmon do not exhibit an extended holding period – rather, they spawn shortly after arrival in the spawning areas.

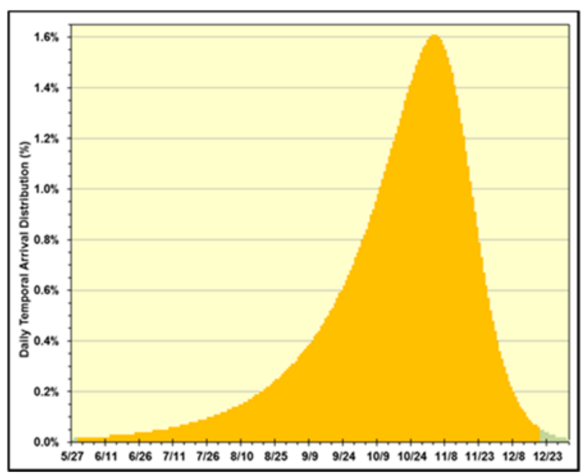

Figure 2. Daily percentage of adult fall-run Chinook salmon arrival in the lower American River. The middle 99% of the distribution is emphasized (orange shading).

We used the fall-run Chinook salmon adult arrival temporal distribution to develop the Modified FMS, and to determine the timeframe to assess the performance of the Modified FMS by comparing water temperature suitablities during the adult immigration and pre-spawn staging lifestages, under the Modified FMS relative to the 2006 FMS.

1.1.2 Spawning

Fall-run Chinook salmon spawning typically begins during mid-October and ends by late December. We used 24 years of fall-run Chinook salmon carcass surveys (from 1992/93 through the 2015/16 seasons) to estimate the lag period between spawning and appearance in the carcass surveys, and thereby the timing of spawning in the lower American River (see **Attachment B**).

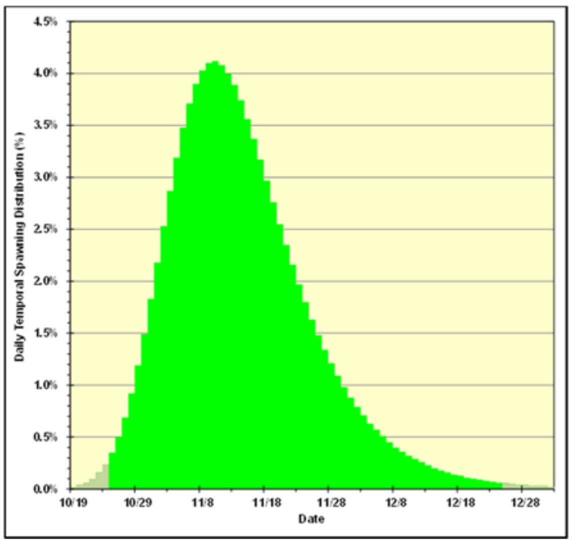

Figure 3. Daily percentage of fall-run Chinook salmon spawning in the lower American River. The middle 99% of the distribution is emphasized (green shading).

In general, most (about 84%) fall-run Chinook salmon spawning in the lower American River occurs during November, with about 8% occurring during both October and December, although a very small amount of spawning (0.2%) is estimated to occur during January (Figure 3). The middle 99% of the fall-run Chinook salmon spawning temporal distribution extends from October 25 through December 24 annually.

We used the fall-run Chinook salmon adult spawning temporal distribution to develop temporal weighting coefficients in the estimation of spawning habitat availability in the lower American River. Spawning habitat availability was iteratively examined as input in the development of MRRs during the fall time period.

Additionally, the performance of the Modified FMS was assessed by comparing spawning habitat availability and water temperature suitablities during the adult spawning lifestage, under the Modified FMS relative to the 2006 FMS.

1.1.3 Incubation through Emergence

Fall-run Chinook salmon eggs deposited in redds incubate until hatching, at which time they are referred to as alevins. The intragravel residence period of incubating eggs and alevins is highly dependent upon water temperature.

The rate of embryonic (egg and alevins) development depends upon both the magnitude and duration of water temperature exposure. Because water temperatures vary on a given day based upon longitudinal distribution in the lower American River (i.e., from Nimbus Dam to the mouth), water temperature exposure is influenced by spatial distribution of spawning and subsequent embryo incubation. In general, the embryonic incubation period can extend for 71 – 97 days for the upstream spawning location during a wetter year (WY 1998). For comparison, incubation can be completed in 70 – 88 days for the downstream spawning location during a drier year (WY 1992). A detailed description of the manner in which these durations were estimated, as well as the overall approach to evaluate embryo incubation, is provided in **Attachment C**.

We used the fall-run Chinook salmon embryo incubation through emergence temporal distribution to evaluate potential redd dewatering, as input to the redd dewatering protective adjustments to the MRRs of the Modified FMS. An annual redd dewatering index was calculated (see Attachment C) to assess the potential effects of flow fluctuations on fall-run Chinook salmon redd dewatering in the lower American River by incorporating information on the spatial and temporal distributions of spawning activity, redd depth distribution, duration of embryo incubation through fry emergence, and maximum reduction in river stage throughout the incubation periods. The performance of the Modified FMS was assessed by comparing potential redd dewatering, and water temperature suitablities, during the embryo incubation through emergence lifestage under the Modified FMS relative to the 2006 FMS.

1.1.4 Juvenile Rearing and Emigration

After alevins emerge from the gravel they are referred to as "post-emergent fry" and begin the rearing and emigration stages of their life histories (SWRI 2001). In general, juvenile Chinook salmon spend relatively little time in the lower American River for rearing. According to Moyle (1976), juvenile fall-run Chinook salmon in California seldom spend more than 30 days in freshwater. This general trend has been observed in the lower American River. Most juvenile fall-run Chinook salmon in the lower American River emigrate shortly after emergence, although some extended rearing also occurs.

The juvenile downstream movement (emigration) period in the lower American River is coincident with the rearing period. Recent (2013 – 2015) rotary screw trap (RST) survey data are summarized below.

During 2013, juvenile Chinook salmon catches generally peaked between mid- to late February, with fry passing Watt Avenue generally during late January (when field sampling was initiated) through early April, parr passing generally during mid-March through mid-May, silvery parr passing generally during mid-April through May. Although only one Chinook salmon smolt was reported emigrating during the 2013 sampling season based on morphology and general appearance (PSMFC 2014a), numerous individuals classified as smolts by length during subsequent years (2014 and 2015) appeared to be observed passing Watt Avenue generally from mid-April through May (PSMFC 2014b; Silva and Bouton 2015).

During 2014, juvenile Chinook salmon catches generally peaked between mid- to late February, and peaked between mid-February and early March during 2015. During both 2014 and 2015, similar emigration patterns were observed, with fry passing Watt Avenue generally during January through mid-March, parr passing generally during mid-February through mid-April (2014) and mid-March through April (2015), silvery parr passing generally during mid-March through mid-May, and smolts passing generally late March through mid-May (PSMFC 2014b; Silva and Bouton 2015). Water years 2013 – 2015 represent drought conditions, and the timing of juvenile rearing and emigration lifestages may not be consistent over a broader range of hydrologic conditions. For example, NMFS (2017) considered the fall-run Chinook salmon juvenile rearing and emigration lifestage to extend from December through June. Overall, the juvenile rearing and emigration period for this analysis extends from late December into June.

We used the fall-run Chinook salmon juvenile rearing and emigration periodicity in the development of the pulse flow component of the Modified FMS, and to determine the timeframe for analyzing water temperature suitablities during this lifestage, under the Modified FMS relative to the 2006 FMS.

1.2 Steelhead Lifestage Periodicities

1.2.1 Adult Upstream Migration and Holding

Adult steelhead immigration and holding in the lower American River has previously been reported to begin as early as late spring or early summer, but primarily beginning in November and continuing into April (SWRI 2001). Steelhead immigration has been reported to generally peak during January (CDFW 1986; SWRI 2001). Temporal distribution of pre-spawning adult steelhead in the lower American River was analyzed using CDFW creel censuses in the lower American River that provide estimates of the steelhead monthly catch (see Attachment A).

Results of these analyses (**Figure 4**) demonstrate that adult steelhead exhibit an extended arrival distribution, with some individuals arriving during nearly all months of the year. The middle 99% of the steelhead arrival temporal distribution occurs from April 18 through March 25, reflecting this extended arrival. Of this representative range of the distribution, 95% of steelhead arrival occurs on or after August 28, 90% occurs on or after October 13, and 80% occurs on or after November 26 in the lower American River.

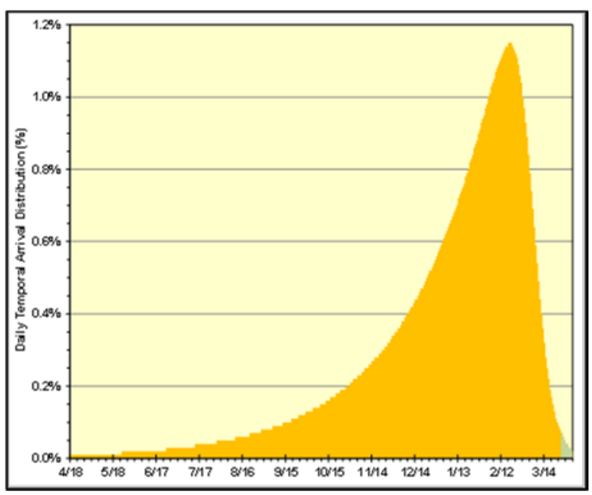

Figure 4. Daily percentage of adult steelhead arrival in the lower American River. The middle 99% of the distribution is emphasized (orange shading).

Most (about 30%) steelhead immigration into the lower American River occurs during February, with about 24% occurring during January, and 14% occurring during December.

The steelhead adult arrival and holding temporal distributions extending from September through March, encompassing approximately 95% of the distributions, was used to determine the timeframe to develop, and to assess the performance of, the Modified FMS by comparing water temperature suitablities under the Modified FMS relative to the 2006 FMS.

1.2.2 Spawning

Steelhead redd surveys conducted by Reclamation during survey years from 2001/02 – 2015/16[1] (see Attachment B) indicate that spawning in the lower American River generally extends from mid-December through March, with the majority of spawning (about 58%) occurring during February, with about 28% during January and 11% during March (**Figure 5**). Hannon and Deason (2008) reported that peak spawning occurs from February through early March, which is generally consistent with more recent steelhead spawning surveys.

The steelhead adult spawning temporal distribution was used to develop temporal weighting coefficients in the estimation of spawning habitat availability in the lower American River.

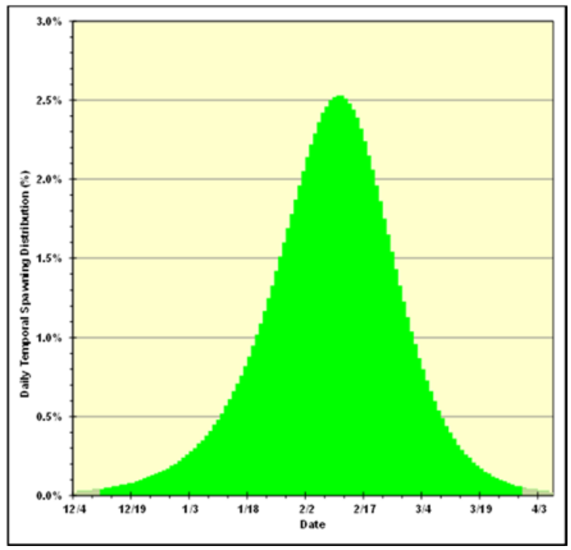

Figure 5. Daily percentage of steelhead spawning in the lower American River. The middle 99% of the distribution is emphasized (green shading).

It also was used to determine the timeframe to assess the performance of the Modified FMS by comparing water temperature suitablities during the adult spawning period under the Modified FMS relative to the 2006 FMS.

[1] - Steelhead redd surveys were not conducted during 2005/06 and 2007/08 seasons due to high flows and low water clarity. During the 2001/02, the 2008/09 and the 2014/15 survey seasons, surveys did not start until 2/7/02, 2/11/09 and 1/23/15, respectively, when steelhead spawning was already in progress. Consequently, these surveys were not used in the estimation of spawning temporal distribution.

1.2.3 Incubation through Emergence

Steelhead eggs deposited in redds incubate until hatching, at which time they are referred to as alevins. The embryo incubation period previously has been estimated to generally extend from late-December through late-May in the lower American River (Hannon and Deason 2008, 2005, 2004; Hannon et al. 2003). As with fall-run Chinook salmon, the rate of embryonic (egg and alevins) development and intragravel residence period depends upon water temperature exposure, which in turn is influenced by the spatial distribution and by the annual variation in water temperature regime (see Attachment C).

The steelhead embryonic incubation period can extend for 55 – 65 days for the upstream spawning location during a wetter year (WY 1998). For comparison, incubation can be completed in 41 – 61 days for the downstream spawning location during a drier year (WY 1992) (see Attachment C).

We used the steelhead embryo incubation through emergence temporal distribution to evaluate potential redd dewatering as input to the redd dewatering protective adjustments to the MRRs. An annual redd dewatering index, incorporating information on the spatial and temporal distributions of spawning activity, redd depth distribution, duration of embryo incubation through fry emergence, and maximum reduction in river stage throughout the incubation period, was used to assess the potential effects of flow reductions on steelhead redd dewatering in the lower American River (see Attachment C). Additionally, the performance of the Modified FMS was assessed by comparing potential redd dewatering and water temperature suitablities during the embryo incubation through emergence lifestage under the Modified FMS relative to the 2006 FMS.

1.2.4 Juvenile Rearing/Emigration, and Smolt Emigration

Rotary screw trap, seine and snorkel surveys conducted in the lower American River suggest that steelhead exhibit a variety of juvenile rearing periodicities in the lower American River. These studies indicate that juvenile steelhead may rear in the lower American River for relatively short periods of time after emergence, or for several months, or even up to a year or more before moving downstream out of the lower American River. Young-of-Year (YOY) steelhead rearing and emigration occur concurrently, and generally extends from February through early June. Some juvenile steelhead rear over the summer up to a year or more (SWRI 2001). Smolts (yearling+) reportedly emigrate from January through April (R. Titus, CDFW, pers. comm., 2013, as cited in Reclamation and NMFS 2014).

We used the steelhead juvenile rearing and emigration periodicity, and the steelhead smolt emigration periodicity, in the development of the pulse flow component of the Modified FMS, and to determine the timeframe for analyzing water temperature suitablities during these lifestages, under the Modified FMS relative to the 2006 FMS.

1.3 Spawning Habitat Suitability and Availability

For the fall-run Chinook salmon and steelhead adult spawning lifestages, flow dependent habitat availability refers to the amount of spawning habitat, including the suitable water depths, velocities and substrate, for spawning. Stream flow directly affects the suitability and availability of spawning habitat.

The physical habitat simulation (PHABSIM) system is a commonly used method to express indices of the quantity and quality of habitat associated with specific flows. PHABSIM is the combination of hydraulic and habitat models, the output of which is expressed as weighted usable area (WUA), and is used to predict the relationship between flow and the quantity and quality of habitat for various lifestages – in this instance, for fall-run Chinook salmon and steelhead spawning in the lower American River.

1.3.1 Fall-run Chinook Salmon

1.3.1.1 Habitat Suitability Criteria

The WUA-flow relationships were developed for spawning fall-run Chinook salmon using two dimensional (2-D) river hydrodynamics modeling and empirically-derived habitat suitability curves (HSC). The HSC were obtained from depth, velocity, and substrate data collected during surveys for fall-run Chinook salmon redds on the American River and other California rivers (also one survey on the Snake River, Idaho, for substrate). Depth, velocity, and/or substrate utilization were compiled from 10 different chinook salmon redd surveys (See Attachment B).

Based on examination of the 10 data sets, including the lower American River, and development of scaling factors to compare habitat utilization frequency between the data sets and conduct visual trend analyses, HSC curves for depth and velocity, scaled between zero and one, were developed to represent the suitability of depth and velocity for spawning (1.0 = completely suitable and 0.0 = not suitable). Details regarding depth and velocity HSC development are provided in Attachment B. The final depth and velocity HSC curves are presented in **Figure 6**.

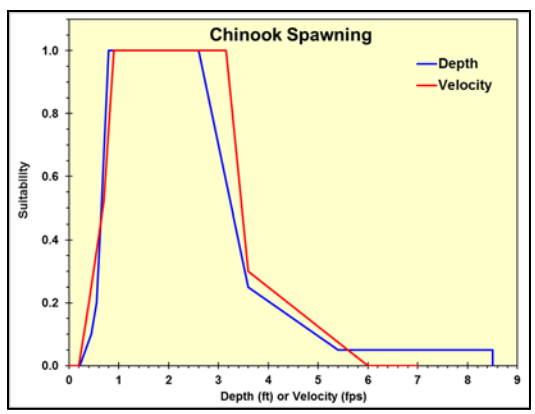

Figure 6. Chinook salmon depth and velocity HSCs.

As with depth and velocity HSC development, substrate utilization frequency data was examined and available from five of the 10 Chinook redd survey data sets. An HSC curve scaled between zero and one was developed to represent the suitability of substrate for spawning (1 = completely suitable and 0 = not suitable) (**Figure 7**). The substrate HSC are generally consistent with substrate composition used for habitat restoration actions on the lower American River.

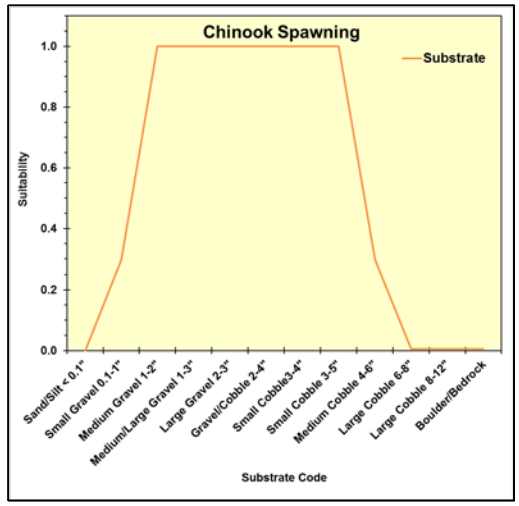

Figure 7. Chinook salmon substrate HSC.

1.3.1.2 Weighted Usable Area (WUA) – Flow Relationships

To describe the habitat available to fall-run Chinook salmon spawning at different flow levels, the analysis uses WUA-flow relationships developed using the most recent 2-D modeling PHABSIM datasets available for the lower American river. The data sets consist of three-dimensional river topography, substrate mapping, and hydrodynamics modeling (depth and velocity) at spawning sites on the American River. Five of the data sets are from Gard (2003), two are additional data sets collected more recently by Gard (USFWS, pers comm and data transfer, 2016), and three data sets are from river restoration/gravel augmentation sites modeled by cbec, Inc. (cbec, unpublished data, 2016) (**Figure 8 and Table 1**). For the purposes of this evaluation, the three Sailor Bar locations were combined, resulting in eight study reaches.

Figure 8. Location of modeled reaches in the lower American River.

Table 1. Modeled river reach summary table.

River Reach	River Mile (downstream boundary)	Length (ft.)	Channel Type		Source
			Main	Side	
Nimbus Basin	23.0	800	x	x	cbec 2016
Sailor Bar Upper	22.6	377	x		Mark Gard 2016
Sailor Bar	22.0	1553	x	x	Mark Gard 2003
Sailor Bar Lower	19.8	522	x		Mark Gard 2003
Above Sunrise 2012	20.7	3142	x	x	Mark Gard 2016
At Sunrise	19.6	3103	x		Mark Gard 2003
Lower Sunrise Side Channel	19.5	1000		x	cbec 2016
El Manto	18.9	754	x		Mark Gard 2003
Rossmoor	16.3	3442	x		Mark Gard 2003
Riverbend Side Channel	13.2	1500		x	cbec 2016

The Gard (2003, 2016) sites were initially modeled using the River2D hydraulic model (http://www.river2d.ualberta.ca/) and those sites were remodeled for this analysis again using River2D. The cbec sites (two specifically for side channel habitat) were modeled using SRH-2D (https://www.usbr.gov/tsc/techreferences/computer%20software/models/srh2d/index.html). All sites were modeled over a range of flows from 500 cfs to 11,000 cfs.

WUA values for each of the eight study reaches at a particular flow were obtained from the WUA-flow relationships developed by the 2-D PHABSIM study, and summed to calculate a composite WUA value for a given flow (Nimbus Dam release).

Figure 9 shows the WUA-flow relationships separately for the eight reaches, and the composite WUA-flow relationship resulting from the sum of the reach-specific relationships. Of the four largest sites with the most WUA, two sites have relatively "flat" habitat versus flow, relationships that show that maximum habitat occurs over a wide flow range from 1,800-2,600 cfs (Sunrise and Sailor Bar) and two have more "peaked" habitat versus flow relationships that reach maximum habitat at 1,400 cfs (Rossmoor and Above Sunrise). The channel topography (e.g., narrow versus wider channel) in these reaches affects the habitat versus flow relationships.

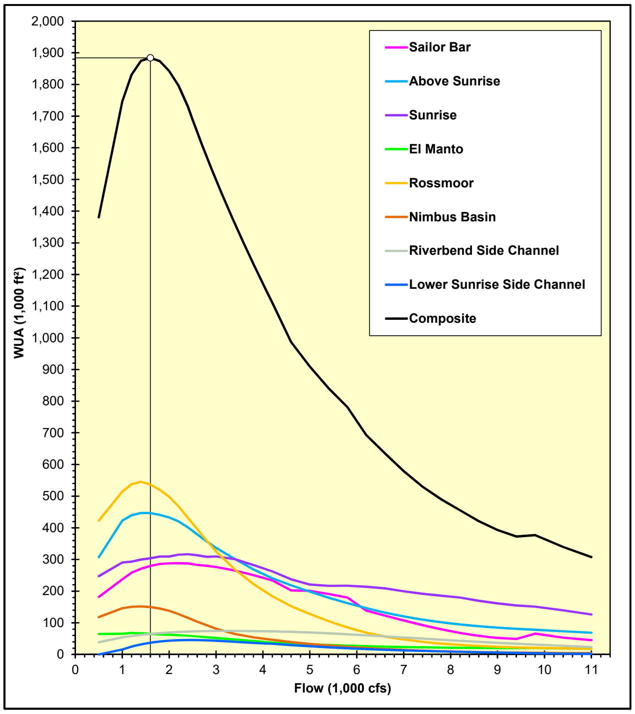

Figure 9. Relationship between Chinook salmon spawning habitat availability (expressed as WUA) and flow for the eight lower American River study reaches, and for the composite of the eight study reaches.

The maximum fall-run Chinook salmon spawning WUA for all eight reaches combined occurs at about 1,600 cfs, and corresponds to the maximum value that was used to scale the composite WUA to a "percent of maximum" value for all flows. The composite WUA curve has 31 data points corresponding to flows ranging from 500 cfs through 11,000 cfs (average daily Nimbus Dam release).

WUA-Flow Relationship Application

Interpolation

Because the WUA-flow relationships developed by the most recent PHABSIM studies present WUA values at discrete flow values, it is often the case that daily flow for which the composite WUA needs to be computed falls between two flows for which there are WUA values in the WUA-flow relationships. In these cases, the composite WUA value was determined by linear interpolation between the available WUA values for the flows immediately below and above the target flow.

Extrapolation

When the target flow was lower than the lowest flow value in the WUA-flow relationship (i.e., 500 cfs) or higher than the highest flow value in the WUA-flow relationship (i.e., 11,000 cfs), two series of extrapolated WUA values were generated.

To extrapolate habitat values for daily flows below 500 cfs, seven extrapolated WUA values were generated by fitting a polynomial function to the WUA values for the seven lower flows in the available WUA-flow relationship. To extrapolate habitat values for daily flows above 11,000 cfs, a power function was fitted to the WUA values for the ten highest flows in the available WUA-flow relationships. The WUA–flow relationship including extrapolated values is presented in **Table 2**. Note that WUA-flow values were determined for flows up to the highest average value of 141,000 cfs over the 82-year evaluation period but, for presentation purposes, Table 2 displays WUA values corresponding to flows less than or equal to 28,000 cfs because this range represents approximately 99.5% of the flows modeled during the simulation period.

Table 2. Composite WUA values for fall-run Chinook salmon spawning in the lower American River used as look-up table for linear interpolation of WUA values for Nimbus daily flows.

Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)
0	0	2,200	1,795,973	7,000	578,846	16,000	186,808
50	213,899	2,400	1,730,322	7,400	529,805	17,000	172,190
100	407,129	2,600	1,650,341	7,800	490,093	18,000	159,457
150	581,175	2,800	1,569,993	8,200	455,519	19,000	148,280
200	737,464	3,000	1,499,420	8,600	421,156	20,000	138,402
300	1,002,199	3,400	1,362,842	9,000	393,293	21,000	129,617
400	1,211,600	3,800	1,230,533	9,400	372,380	22,000	121,761
500	1,380,535	4,200	1,111,178	9,800	377,188	23,000	114,699
1,000	1,746,319	4,600	986,267	10,400	339,853	24,000	108,322
1,200	1,830,899	5,000	909,508	11,000	307,436	25,000	102,539
1,400	1,874,802	5,400	840,726	12,000	274,993	26,000	97,273
1,600	1,884,001	5,800	780,997	13,000	246,944	27,000	92,462
1,800	1,873,823	6,200	692,874	14,000	223,532	28,000	88,051
2,000	1,842,271	6,600	635,208	15,000	203,736		

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using a power function (see text for details).

1.3.1.3 Temporal Weighting Coefficients

Because the scaled composite WUA is for a species spawning over numerous days in the spawning season, and because the species' spawning intensity does not remain constant throughout the spawning season, temporal weighting coefficients were incorporated into the spawning habitat analysis to account for the average relative spawning intensity on a particular day. The temporal weighting coefficients and spawning period used for fall-run Chinook salmon spawning in the lower American River were derived from data collected by both redd surveys and carcass surveys.

Redd surveys performed by CDFW during the 1991/92 through the 1995/96 fall-run Chinook salmon spawning seasons, and by Cramer Fish Sciences during the 2009/10 through the 2015/16 fall-run Chinook salmon spawning seasons, were used to develop a cumulative distribution of redds versus time. Fall-run Chinook salmon carcass surveys also were used in the spawning timing analysis by incorporating the lag time elapsing between spawning and the appearance of fresh carcasses in the carcass surveys (see Attachment B).

The resulting daily temporal weighting coefficients for fall-run Chinook salmon spawning are proportions with a value between 0 and 1, such that the sum for the middle 99% of the daily spawning distribution is equal to 1 (**Table 3**). In general, to calculate the temporal weighting coefficients, spawning timing is described as an asymmetric logistic function of time. Details regarding development of Chinook salmon temporal weighting coefficients are provided in Attachment B.

Table 3. Temporal weighting coefficients used for fall-run Chinook salmon spawning in the lower American River.

Date	Temporal Weighting Coefficient	Date	Temporal Weighting Coefficient	Date	Temporal Weighting Coefficient	Date	Temporal Weighting Coefficient
10/25	0.003540	**11/10**	0.041627	**11/26**	0.014961	**12/12**	0.002580
10/26	0.005034	**11/11**	0.041283	**11/27**	0.013531	**12/13**	0.002298
10/27	0.006933	**11/12**	0.040486	**11/28**	0.012214	**12/14**	0.002046
10/28	0.009256	**11/13**	0.039302	**11/29**	0.011006	**12/15**	0.001822
10/29	0.011991	**11/14**	0.037802	**11/30**	0.009901	**12/16**	0.001621
10/30	0.015089	**11/15**	0.036059	**12/1**	0.008895	**12/17**	0.001443
10/31	0.018468	**11/16**	0.034139	**12/2**	0.007981	**12/18**	0.001283
11/1	0.022016	**11/17**	0.032103	**12/3**	0.007153	**12/19**	0.001141
11/2	0.025599	**11/18**	0.030005	**12/4**	0.006404	**12/20**	0.001015
11/3	0.029076	**11/19**	0.027893	**12/5**	0.005729	**12/21**	0.000903
11/4	0.032309	**11/20**	0.025802	**12/6**	0.005121	**12/22**	0.000803
11/5	0.035174	**11/21**	0.023763	**12/7**	0.004574	**12/23**	0.000713
11/6	0.037574	**11/22**	0.021800	**12/8**	0.004083	**12/24**	0.000634
11/7	0.039440	**11/23**	0.019929	**12/9**	0.003643		
11/8	0.040737	**11/24**	0.018161	**12/10**	0.003249		
11/9	0.041459	**11/25**	0.016504	**12/11**	0.002896	**Total**	1

1.3.1.4 Scaled Composite WUA Annual Index

In the lower American River, spawning habitat for fall-run Chinook salmon is expressed by a scaled composite WUA annual index that corresponds to the spawning habitat available under the daily flows occurring during the spawning season. The scaled composite WUA annual index is calculated as the sum of the WUAs that correspond to the daily flows during the spawning season at the eight indicator reaches within the species' spawning area, multiplied by a temporal weighting coefficient that represents the average relative spawning intensity on that particular day of the spawning season, divided by the maximum possible WUA for the sum of the eight spawning reaches. Thus, an annual index of percent of maximum spawning habitat (e.g., WUA) was developed for each year of the 82-year hydrologic period of evaluation. These annual indices were used as input in the development of the MRRs during the fall period, and were used to evaluate the performance of the Modified FMS relative to the 2006 FMS (see section 2.3.3).

1.3.2 Steelhead

1.3.2.1 Habitat Suitability Criteria

Steelhead HSC were obtained from depth, velocity, and substrate data collected during surveys for steelhead redds on the American River and other California rivers. Steelhead redd surveys with either depth, velocity, and/or substrate utilization data were compiled from five different datasets (see Attachment B).

Based on examination of the five data sets, including the lower American River, and development of scaling factors to compare habitat utilization frequency between the data sets and to conduct trend analyses, HSC curves for depth and velocity, scaled between zero and one, were developed to represent the suitability of depth and velocity for steelhead spawning (1.0 = completely suitable and 0.0 = not suitable). The final depth and velocity HSC curves are presented in **Figure 10**.

Substrate use frequency data from the lower American River steelhead redd survey data set was used to develop a final substrate HSC curve scaled between zero and one to represent the suitability of substrate for spawning (1 = completely suitable and 0 = not suitable) (**Figure 11**).

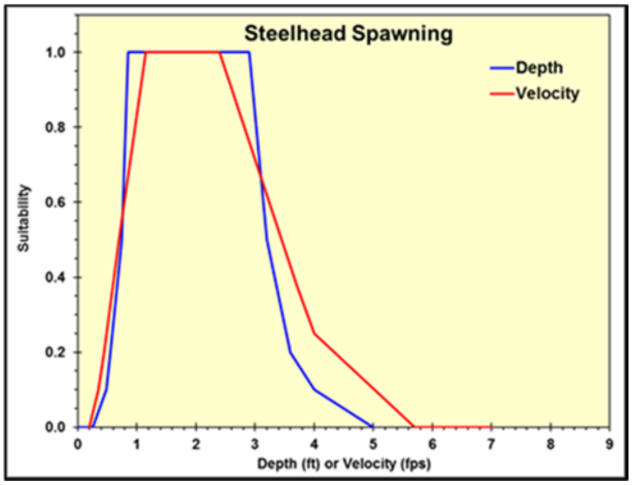

Figure 10. Steelhead depth and velocity HSCs for application to the lower American River.

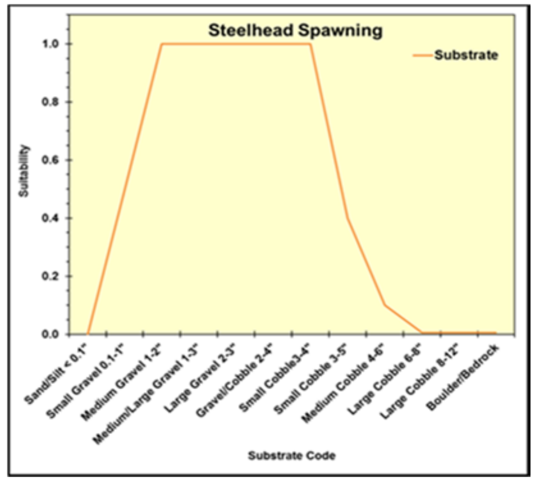

Figure 11. Steelhead substrate HSC for application to the lower American River.

1.3.2.2 Weighted Usable Area (WUA) – Flow Relationships

WUA for steelhead was developed using the same approach as discussed for fall-run Chinook salmon (above). **Figure 12** shows the WUA-flow relationships for each of the eight study reaches (See Attachment B). Figure 12 also shows the composite WUA-flow relationship for the river, resulting from summing the reach-specific relationships. The maximum steelhead salmon spawning WUA for all eight reaches combined occurs at about 1,400 cfs. Of the four largest sites with the most WUA, two sites have relatively “flat” habitat versus flow relationships that show that maximum habitat occurs over a wide flow range from 1,000-3,400 cfs (Sunrise and Sailor Bar) and two have more “peaked” habitat versus flow relationships that reach maximum habitat at 1,400 cfs (Rossmoor and Above Sunrise). The channel topography (e.g., narrow versus wider channel) in these reaches affects the habitat versus flow relationships.

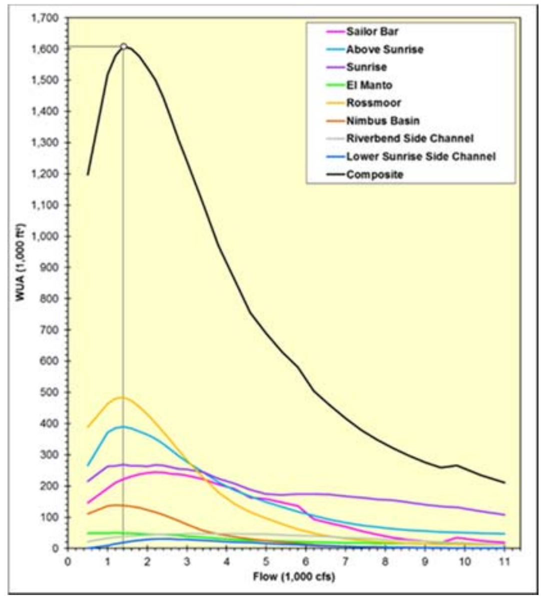

Figure 12. Relationship between steelhead spawning habitat (expressed as WUA) and flow for the eight lower American River study reaches, and for the composite of the eight study reaches.

WUA-Flow Relationship Application

Extrapolation

As was done for fall-run Chinook salmon, when the target flow was lower than the lowest flow value in the WUA-flow relationship (i.e., 500 cfs) or higher than the highest flow value in the WUA-flow relationship (i.e., 11,000 cfs), two series of extrapolated WUA values were generated.

To extrapolate habitat values for daily flows below 500 cfs, a fitted polynomial function was used, and to extrapolate habitat values for daily flows above 11,000 cfs, a power function was used. The WUA–flow relationship including extrapolated values is presented in **Table 4**.

1.3.2.3 Temporal Weighting Coefficients

As for fall-run Chinook salmon, temporal weighting coefficients were incorporated into the spawning habitat analysis. Because steelhead spawning occurs over several months, and because spawning intensity does not remain constant throughout the spawning season, temporal weighting coefficients were developed to account for the relative spawning intensity on a particular day (**Table 5**). The resulting daily temporal weighting coefficients for steelhead spawning are proportions with a value between 0 and 1, such that the sum for the middle 99% of the daily spawning distribution is equal to 1. Details regarding development of steelhead temporal weighting coefficients are provided in Attachment B.

Table 4. Composite WUA values for steelhead spawning in the lower American River used as look-up table for linear interpolation of WUA values for Nimbus daily flows.

Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)
0	0	2,200	1,501,947	7,000	416,957	16,000	123,994
50	183,496	2,400	1,444,590	7,400	379,330	17,000	113,630
100	349,780	2,600	1,375,498	7,800	347,267	18,000	104,654
150	500,035	2,800	1,304,585	8,200	321,000	19,000	96,817
200	635,397	3,000	1,239,775	8,600	296,359	20,000	89,925
300	865,776	3,400	1,105,253	9,000	275,327	21,000	83,825
400	1,049,135	3,800	969,789	9,400	259,147	22,000	78,395
500	1,197,366	4,200	863,117	9,800	265,853	23,000	73,535
1,000	1,518,614	4,600	755,166	10,400	234,702	24,000	69,165
1,200	1,578,917	5,000	689,540	11,000	210,915	25,000	65,217
1,400	1,608,390	5,400	630,272	12,000	187,617	26,000	61,636
1,600	1,600,465	5,800	580,652	13,000	167,196	27,000	58,377
1,800	1,576,700	6,200	503,577	14,000	150,276	28,000	55,399
2,000	1,540,319	6,600	459,308	15,000	136,067		

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using a power function (see text for details).

1.3.2.4 Scaled Composite WUA Annual Index

As for fall-run Chinook salmon, available spawning habitat for steelhead was expressed by scaled composite WUA indices that correspond to the spawning habitat available under the daily flows occurring during the spawning season. An annual index of percent of maximum spawning habitat (i.e., WUA) was developed for each year of the 82-year hydrologic period of evaluation. These annual indices were used as input in the development of the MRRs during the fall period, and were used to evaluate the performance of the Modified FMS relative to the 2006 FMS.

1.4 Hydrologic and Water Temperature Model Applications

We used the annual fall-run Chinook salmon and steelhead spawning habitat availability indices as input to develop the MRRs during the fall (fall-run Chinook salmon) and winter (steelhead) periods by iteratively comparing the amounts of spawning habitat provided under sequential renditions of the Modified FMS, to that provided under the 2006 FMS. The calculation of these indices was based on estimating the amount of habitat associated with a given flow.

Table 5. Temporal weighting coefficients used for steelhead spawning in the lower American River.

Day	Temporal Weighting Coefficient	Day	Temporal Weighting Coefficient	Day	Temporal Weighting Coefficient
12/11	0.000440	1/17	0.008304	2/23	0.016618
12/12	0.000478	1/18	0.008928	2/24	0.015538
12/13	0.000518	1/19	0.009589	2/25	0.014472
12/14	0.000562	1/20	0.010287	2/26	0.013430
12/15	0.000610	1/21	0.011023	2/27	0.012421
12/16	0.000661	1/22	0.011794	2/28	0.011451
12/17	0.000717	1/23	0.012601	3/1	0.010526
12/18	0.000778	1/24	0.013439	3/2	0.009649
12/19	0.000843	1/25	0.014308	3/3	0.008824
12/20	0.000914	1/26	0.015202	3/4	0.008050
12/21	0.000992	1/27	0.016116	3/5	0.007329
12/22	0.001075	1/28	0.017044	3/6	0.006660
12/23	0.001166	1/29	0.017979	3/7	0.006041
12/24	0.001264	1/30	0.018911	3/8	0.005471
12/25	0.001370	1/31	0.019830	3/9	0.004948
12/26	0.001486	2/1	0.020726	3/10	0.004469
12/27	0.001610	2/2	0.021586	3/11	0.004031
12/28	0.001745	2/3	0.022396	3/12	0.003632
12/29	0.001892	2/4	0.023144	3/13	0.003270
12/30	0.002050	2/5	0.023816	3/14	0.002941
12/31	0.002221	2/6	0.024397	3/15	0.002644
1/1	0.002406	2/7	0.024876	3/16	0.002374
1/2	0.002606	2/8	0.025240	3/17	0.002131
1/3	0.002822	2/9	0.025480	3/18	0.001912
1/4	0.003056	2/10	0.025588	3/19	0.001714
1/5	0.003308	2/11	0.025560	3/20	0.001536
1/6	0.003580	2/12	0.025393	3/21	0.001376
1/7	0.003874	2/13	0.025089	3/22	0.001232
1/8	0.004190	2/14	0.024653	3/23	0.001103
1/9	0.004530	2/15	0.024090	3/24	0.000987
1/10	0.004896	2/16	0.023412	3/25	0.000883
1/11	0.005289	2/17	0.022631	3/26	0.000790
1/12	0.005711	2/18	0.021760	3/27	0.000706
1/13	0.006163	2/19	0.020816	3/28	0.000632
1/14	0.006648	2/20	0.019814	3/29	0.000565
1/15	0.007165	2/21	0.018770		
1/16	0.007717	2/22	0.017700	**Total**	1

Both flow and water temperature modeling was conducted to simulate Central Valley Project (CVP) operations, including operations of Folsom and Nimbus dams and releases into the lower American River. Both flow and water temperatures in the lower American River were simulated on a daily time-step. Flow-dependent habitat assessments (including fall-run Chinook salmon and steelhead spawning habitat availability, as well as potential redd dewatering) were based on simulated daily flows over the 82-year period extending from WY 1922 through 2003. Daily water temperatures (both average daily and maximum daily) also were simulated for the lower American River over the same time period, although water temperature simulations were conducted on a calendar year, rather than a water year, basis. For detailed descriptions of the models, see the following Technical Memoranda.

- **Technical Memorandum 2** - Lower American River Modified Flow Management Standard - CalSim II Assumptions
- **Technical Memorandum 3** - Sacramento River Water Temperature Model Assumptions
- **Technical Memorandum 4** - Folsom Reservoir Inflow Water Temperature Relationships
- **Technical Memorandum 5** - Folsom Reservoir CE-QUAL-W2 Water Temperature Model
- **Technical Memorandum 6** - Lake Natoma CE-QUAL-W2 Water Temperature Model and Calibration
- **Technical Memorandum 7** - Folsom Reservoir Inflow and Upstream Reservoir Storage for the 1922-2003 Period of Record
- **Technical Memorandum 8** - Historical 1922-2003 Meteorological Dataset (Folsom Reservoir, Lake Natoma and Lower American River)
- **Technical Memorandum 9** - LAR Water Temperature Regression
- **Technical Memorandum 10** - Daily Flow and Temperature Disaggregator for the Lower American River

After calculating the scaled composite WUAs for Chinook salmon and steelhead spawning habitat availability over the entire 82-year simulation period, habitat duration analyses (or probability of exceedance distributions) were conducted. A habitat duration curve is constructed in the same way as a flow duration curve, but uses habitat values instead of flow as the ordered data. A habitat duration curve is computed simply by obtaining the WUA value (for each species/lifestage) that corresponds to the mean daily flow for each day in the spawning season in the 82-year hydrologic simulation period. These daily WUA data are then ordered into what is referred to as a habitat duration (or probability of exceedance) curve showing the probability (oftentimes referred to as percent of time) that a particular habitat value is equaled or exceeded. Spawning habitat duration analyses were conducted for the period extending from October 25 through December 24 for fall-run Chinook salmon spawning, and from December 11 through March 29 for steelhead spawning in the lower American River.

Performance evaluation was conducted by comparison of the spawning habitat exceedance distributions between the Modified FMS and the 2006 FMS scenarios to estimate the differences in fall-run Chinook salmon and steelhead spawning habitat availability due to the Modified FMS.

1.5 Potential Redd Dewatering

Flow fluctuations during the fall-run Chinook salmon and steelhead embryo incubation periods are of importance to fisheries management because reductions in flow may cause water surface elevations to decrease below the depth at which the redds were built. Dewatered redds may result in desiccation and the loss of developing embryos (fertilized eggs and alevins).

To develop, refine and evaluate the performance of the Modified FMS, a model was developed to address the potential for fall-run Chinook salmon and steelhead redd dewatering due to daily flow fluctuations in the lower American River (see Attachment C). The output of the model is an annual redd dewatering index for fall-run Chinook salmon, and separately for steelhead.

In the annual redd dewatering index, the potential for redd dewatering due to changes in daily flows and corresponding changes in river stage are weighted by the temporal and spatial distributions of Chinook salmon and steelhead spawning activity in the lower American River. Additionally, the index incorporates the redd depth probability distributions of Chinook salmon and steelhead redds, the duration of embryo incubation based on simulated water temperatures, and the maximum river stage reduction from the time of spawning through fry emergence experienced by redds of the same cohort (i.e., redds built on the same day of a spawning season).

1.5.1 Fall-run Chinook Salmon

1.5.1.1 Temporal Weighting Coefficients

The annual redd dewatering index utilizes temporal weighting coefficients to indicate the proportion of redds expected to be built on each day of the spawning period, based on the middle 99% of the daily spawning distribution for fall-run Chinook salmon in the lower American River (see Table 3).

1.5.1.2 Spatial Weighting Coefficients

The spatial weighting coefficients indicate the relative importance of particular spawning areas with respect to the entire spawning area of the lower American River. The spatial weighting coefficients for fall-run Chinook salmon were calculated from redd observations by river mile collected by CDFW during the 1991/92 through the 1995/96 fall-run Chinook salmon spawning seasons (Snider and McEwan 1992; Snider et al. 1993 and 1996; Snider and Vyverberg 1995 and 1996), and from annual redd counts based on interpretation of 3-to-1 USBR aerial redd surveys per year conducted during the 2003 through the 2015 fall-run Chinook salmon spawning seasons.

For the 2003-2015 spawning seasons, the spatial distribution for Chinook salmon spawning was developed through examination of aerial imagery collected by Reclamation. Aerial images were acquired on multiple dates during the Chinook salmon spawning period, ranging from 1-3 flights per year. Data from 27 aerial surveys spanning the 13 years were available for this analysis. Aerial images were analyzed by Reclamation by physically marking the locations of new redds on the original images.

The values of the spatial weighting coefficients for fall-run Chinook spawning in the lower American River were obtained by summing the redd observations from available redd survey data for each 1-mile reach, and then dividing the overall number within each reach by the total number of redds observed along the entire river. **Table 6** displays the redd data and the resulting spatial weighting coefficients for fall-run Chinook salmon spawning in the lower American River based on observations conducted during the 1991 through the 1995 spawning seasons, and during the 2003 through the 2015 spawning seasons.

Table 6. Distribution of observed fall-run Chinook salmon redds by river mile in the lower American River from 1991 through 1995, and from 2003 through 2015, and derived spatial weighting coefficients by each 1-mile reach.

RM	Number of redds by river mile in survey year										
	1991	1992	1993	1994	1995	2003	2004	2005	2006	2007	2008
22 - 23	121	369	1,277	418	560	148	923	1,129	236	0	222
21 - 22	191	2	1,322	280	561	177	1,683	1,257	1,032	766	185
20 - 21	427	266	1,587	572	1,054	8	343	258	191	86	15
19 -20	314	220	663	391	595	48	670	581	388	179	77
18 - 19	154	96	164	297	115	4	533	342	111	25	9
17 - 18	189	9	787	424	601	9	491	777	170	54	16
16 - 17	86	123	13	83	63	8	229	210	148	56	16
15 -16	11	0	177	58	66	0	66	13	8	2	0
14 - 15	33	38	49	56	115	4	133	66	41	15	0
13 - 14	20	0	20	59	87	1	104	30	5	0	10
12 - 13	30	1	0	15	45	0	22	67	34	17	1
11 - 12	0	1	30	0	1	0	29	16	10	4	0
10 - 11	6	0	4	61	39	0	38	17	0	0	0
9 - 10	32	6	71	12	12	0	23	52	41	0	0
8 - 9	0	0	0	1	17	0	4	2	1	0	0
7 - 8	0	0	21	14	28	0	0	0	0	0	0
6 - 7	12	7	20	18	15	0	0	0	0	0	0
5 - 6	0	0	0	6	2	0	18	15	18	2	0
Totals	**1,626**	**1,138**	**6,205**	**2,765**	**3,976**	**407**	**5,309**	**4,832**	**2,434**	**1,206**	**551**

RM	Number of redds by river mile in survey year							Total Redds	Spatial Weighting Coefficients	
	2009	2010	2011	2012	2013	2014	2015			
22 - 23	189	169	1,000	1,133	598	1,189	970	10,651	0.2122	(21.22%)
21 - 22	33	177	1,014	1,877	625	629	99	11,910	0.2373	(23.73%)
20 - 21	3	28	553	441	359	519	522	7,232	0.1441	(14.41%)
19 -20	23	68	809	1,166	531	756	231	7,710	0.1536	(15.36%)
18 - 19	0	3	254	467	247	273	37	3,131	0.0624	(6.24%)
17 - 18	6	2	200	213	138	233	43	4,362	0.0869	(8.69%)
16 - 17	4	14	102	213	130	253	44	1,795	0.0358	(3.58%)
15 -16	0	0	30	24	24	12	0	491	0.0098	(0.98%)
14 - 15	0	1	12	56	32	42	8	701	0.0140	(1.4%)
13 - 14	1	1	6	26	50	187	53	660	0.0132	(1.32%)
12 - 13	2	0	20	122	49	58	40	523	0.0104	(1.04%)
11 - 12	0	0	3	14	7	25	3	143	0.0028	(0.28%)
10 - 11	0	1	11	24	11	3	4	219	0.0044	(0.44%)
9 - 10	1	8	14	25	23	27	1	348	0.0069	(0.69%)
8 - 9	0	0	0	2	0	0	0	27	0.0005	(0.05%)
7 - 8	0	0	0	15	1	0	0	79	0.0016	(0.16%)
6 - 7	0	0	5	4	5	5	0	91	0.0018	(0.18%)
5 - 6	0	0	4	25	10	13	0	113	0.0023	(0.23%)
Totals	**262**	**472**	**4,037**	**5,847**	**2,840**	**4,224**	**2,055**	**50,186**	1	(100%)

1.5.1.3 Water Temperatures and Duration of Embryo Incubation

The annual redd dewatering index requires the calculation of the estimated duration of embryo incubation, in days, corresponding to each daily redd cohort being evaluated. The embryo incubation period for each fall-run Chinook salmon redd cohort is based on lower American River daily water temperatures modeled at each 1-mile reach during the day of redd construction through fry emergence, expressed as Accumulated Thermal Units (ATUs) (see Attachment C for details).

1.5.1.4 Depth-Frequency Distribution of Redds

The annual redd dewatering index uses the cumulative frequency distribution of the water depths at which redds were constructed to estimate the probability that redds were constructed at a given depth, expressed in tenths of a foot.

As described in Attachment C, the cumulative frequency distribution of fall-run Chinook salmon redd depths was the result of fitting an asymmetric logistic function to seven combined annual datasets of Chinook salmon redd depths (**Figure 13**) obtained during 1996, 1998, and 2011 through 2015 spawning seasons. The combined data set resulted in 920 redd depths for fall-run Chinook salmon. The shallowest fall-run Chinook salmon redd depth in the final database was 0.3 ft., while the deepest redd was observed at a depth of 6 ft.

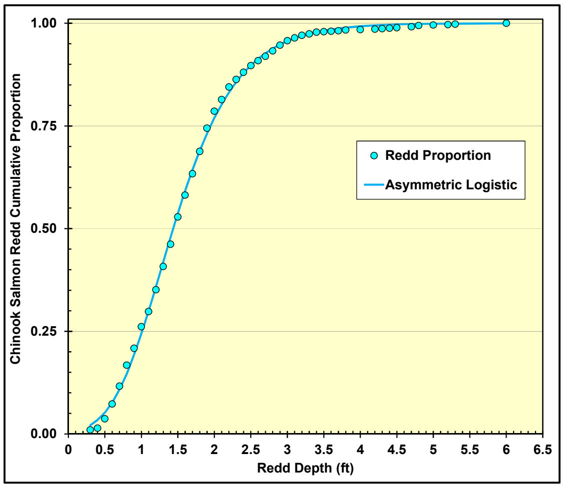

Figure 13. Cumulative proportions of 920 fall-run Chinook salmon redd depths measured in the lower American River during 1996, 1998 and during the 2011 through the 2015 fall-run Chinook salmon spawning seasons, and the fitted asymmetric logistic curve.

1.5.1.5 Stage-Flow Relationships

Eighteen reach-specific stage-flow relationships, each reach representing a 1-mile long section of the lower American River covering the longitudinal expanse of spawning, were used to interpolate daily stage or water surface elevation that corresponds to the simulated average daily flow output. The reach-specific stage-flow relationships were constructed by first developing individual stage-flow relationships for each of the available measured cross sections spaced 0.25 miles apart, and then averaging the resulting stage-flow relationships into 1-mile sections (See Attachment C). Daily changes in stage were estimated for each of the 18 reaches over the course of the embryo incubation period to estimate the probability of redd dewatering.

1.5.1.6 Annual Redd Dewatering Index Calculation

For each daily spawning cohort, the single largest stage reduction, from the day of spawning throughout the incubation period, was identified and applied to the redd depth probability distribution to estimate the percent of redds potentially dewatered for at least one day. Annual indices of potential dewatering were calculated by summing the potential probability of redd dewatering for each of the daily spawning cohorts (i.e., equivalent to the number of days in the spawning season, which is 61 days for fall-run Chinook salmon) for each of the 18 reaches for that year. The resulting annual indices were averaged over the entire simulation period, and by water year type (WYT[2]). These indices and metrics were used as input into the development of the MRRs and in the performance evaluation of the Modified FMS relative to the 2006 FMS. Because Folsom Reservoir operations include flood protection, potential redd dewatering performance evaluations were conducted for those portions of the fall-run Chinook salmon spawning season when redd construction did not coincide with periods of flood control releases.

1.5.2 Steelhead

1.5.2.1 Temporal Weighting Coefficients

The annual redd dewatering index utilizes temporal weighting coefficients to indicate the proportion of redds expected to be built on each day of the spawning period, based on the middle 99% of the daily spawning distribution for steelhead in the lower American River (see Table 5).

1.5.2.2 Spatial Weighting Coefficients

The spatial distribution for steelhead spawning was developed though examination of steelhead redd location data collected by Reclamation and their consultants during the 2002 through the 2005 survey seasons, the 2007 and 2009 seasons, and during the 2011 through 2016 spawning seasons. Each annual data set was reviewed, and potentially erroneous entries were culled (e.g. unknown species listed, possibly Chinook, duplicate entries, etc.) from the data set. Then data from each survey year were analyzed using GIS to determine which river mile each individual redd fell within. As with fall-run Chinook salmon, the values of the spatial weighting coefficients for steelhead spawning in the lower American River were obtained by summing the redd observations from available redd survey data for each 1-mile reach, and then dividing the overall number within each RM reach by the total number of redds observed along the entire river. **Table 7** displays the redd data and the resulting spatial weighting coefficients for steelhead spawning in the lower American River.

[2] For the analyses presented in this document, WYT classifications are in accordance with the Sacramento Valley Index for the 82-year period of simulation and evaluation.

Table 7. Distribution of observed steelhead redds by river mile in the lower American River from 2002 through 2016, and derived spatial weighting coefficients by each 1-mile reach.

RM	Number of redds in survey year							
	2002	2003	2004	2005	2007	2009	2011	2012
22 - 23	21	16	17	34	26	74	26	34
21 - 22	19	16	21	10	22	1	1	3
20 - 21	26	22	16	11	9	0	13	19
19 - 20	15	13	25	6	23	20	2	8
18 - 19	2	5	2	0	6	0	0	0
17 - 18	5	3	6	0	11	0	1	1
16 -17	1	6	5	2	19	0	9	1
15 - 16	0	3	9	8	0	0	6	0
14 -15	0	3	12	6	10	0	1	0
13 - 14	12	20	15	2	1	0	4	0
12 - 13	3	1	9	0	7	1	6	0
11 - 12	1	2	1	3	1	0	0	0
10 - 11	0	3	0	0	12	0	0	0
9 - 10	7	4	8	3	3	3	0	0
8 - 9	0	0	0	0	0	0	0	0
7 - 8	0	0	0	0	0	0	0	0
6 - 7	6	0	0	9	0	0	1	0
5 - 6	6	0	0	5	0	0	0	1
Totals	124	117	146	99	150	99	70	67

RM	Number of redds in survey year				Total Redds	Spatial Weighting Coefficients	
	2013	2014	2015	2016			
22 - 23	47	22	14	11	342	0.2450	(24.50%)
21 - 22	86	4	1	2	186	0.1332	(13.32%)
20 - 21	60	13	5	13	207	0.1483	(14.83%)
19 - 20	38	4	9	6	169	0.1211	(12.11%)
18 - 19	3	2	0	1	21	0.0150	(1.50%)
17 - 18	5	8	16	0	56	0.0401	(4.01%)
16 -17	29	1	11	2	86	0.0616	(6.16%)
15 - 16	0	0	0	1	27	0.0193	(1.93%)
14 -15	4	0	2	0	38	0.0272	(2.72%)
13 - 14	2	32	8	10	106	0.0759	(7.59%)
12 - 13	22	12	3	4	68	0.0487	(4.87%)
11 - 12	0	0	1	0	9	0.0064	(0.64%)
10 - 11	0	1	0	1	17	0.0122	(1.22%)
9 - 10	7	0	0	1	36	0.0258	(2.58%)
8 - 9	0	0	0	0	0	0.0000	(0.00%)
7 - 8	0	0	0	0	0	0.0000	(0.00%)
6 - 7	0	0	0	0	16	0.0115	(1.15%)
5 - 6	0	0	0	0	12	0.0086	(0.86%)
Totals	303	99	70	52	1,396	1	(100%)

1.5.2.3 Water Temperatures and Duration of Embryo Incubation

The approach to calculate the embryo incubation period for each steelhead redd cohort is the same as described for fall-run Chinook salmon, and is based on lower American River daily water temperatures modeled at each 1-mile reach during the day of redd construction and all subsequent days until fry emergence, expressed as ATUs (see Attachment C for details).

1.5.2.4 Depth-Frequency Distribution of Redds

The cumulative frequency distribution of steelhead redd depths was the result of fitting an asymmetric logistic function to 13 combined annual datasets of steelhead redd depths (**Figure 14**). Steelhead redd depth data were collected by Reclamation and USFWS during annual steelhead redd surveys during 2002 through 2005, 2007, and during 2009 through 2016 (See Attachment C). The combined data set resulted in 841 redd depths for steelhead. The shallowest steelhead redd depth in the final database was 0.4 ft., while the deepest redd was observed at a depth of 4.6 ft.

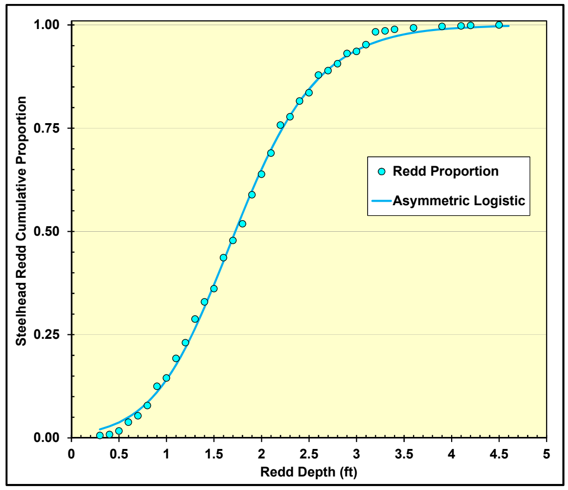

Figure 14. Cumulative proportions of 841 steelhead redd depths measured in the lower American River during the during 2002 through 2005, 2007, and the 2009 through 2016 steelhead spawning survey seasons, and the fitted asymmetric logistic curve.

1.5.2.5 Stage-Flow Relationships

As described above for fall-run Chinook salmon, reach-specific stage-flow relationships were used to interpolate daily stages (water surface elevations) that correspond to the simulated average daily flow output. Daily changes in stage were estimated for each of the 18 reaches over the course of the embryo incubation period to estimate the probability of redd dewatering (See Attachment C).

1.5.2.6 Annual Redd Dewatering Index Calculation

The annual redd dewatering index provides an annual estimate of the expected maximum proportion of redds, relative to the total number of redds built during the spawning period, that were potentially dewatered for at least one day due to reductions in flow and associated decreases in water surface elevations during the embryo incubation period. The reductions in water surface elevations are compared to the steelhead redd depth distributions in the lower American River. The procedure is the same as described for fall-run Chinook salmon, and the step-by-step calculations are described in Attachment C. As previously described for fall-run Chinook salmon, potential redd dewatering indices and metrics were used as input into the development of the MRRs and in the performance evaluation of the Modified FMS relative to the 2006 FMS.

1.6 Water Temperature Suitability

Water temperature is perhaps the physical factor with the greatest influence on American River steelhead (NMFS 2009). High water temperatures are a stressor to juvenile rearing steelhead in the lower American River, particularly during the summer and early fall (NMFS 2009). Water temperatures also are a stressor to fall-run Chinook salmon spawning during early fall, and juvenile rearing and emigration during late spring. Consequently, extensive water temperature evaluations were conducted as part of the development, and performance evaluation, of the Modified FMS.

Modeled average daily water temperatures were used in conjunction with species and lifestage-specific water temperature index (WTI) values to assess lifestage-specific water temperature suitability, under the Modified FMS and under the 2006 FMS. Average daily water temperature outputs were expressed as cumulative probability exceedance distributions on a monthly basis. Development of the Modified FMS included iterative examination of the full range of daily water temperature exceedances, presented by month.

The NMFS 2017 biological opinion for California WaterFix (NMFS 2017 BO) used the water temperature metrics identified in the Biological Assessment (BA) for California WaterFix produced by Reclamation and DWR (Reclamation 2016) to evaluate water temperature effects of the WaterFix for both fall-run Chinook salmon and steelhead in the lower American River. According to the BA (Reclamation 2016, p. 5.D-276), the water temperature analyses determined the frequency and magnitude of exceedance above one or more water temperature criteria obtained from the scientific literature and USEPA guidance for each race/species and life stage at multiple locations within the lower American River (Table 5.D-50). Additional criteria presented in the BA and used by NMFS in the 2017 BO used the metric of estimated mean monthly water temperatures.

For Modified FMS performance evaluation, the same water temperature index values used for evaluation in the NMFS 2017 BO also were used for comparative consistency. The USEPA criteria were evaluated by the metric expressed as a running seven-day average of the daily maximum water temperatures (7DADM). The 7DADM was calculated for each day of the 82-year simulation period using the maximum water temperature for that day and the preceding six days. Water temperature index values, referred to as criteria, and metrics calculated for evaluation of the effects of the Modified FMS for various lifestages are presented in **Table 8** for fall-run Chinook salmon and in **Table 9** for steelhead. Daily water temperature exceedances, by month, are presented in **Attachment D**, followed by 7DADM water temperature exceedances applying the index values identified in the NMFS 2017 BO for the various lifestages of fall-run Chinook salmon, and then followed by 7DADM and daily average water temperature exceedances applying the index values identified in the NMFS 2017 BO for the various lifestages of steelhead in the lower American River.

Table 8. Lifestage-specific periodicities and water temperature index values used to evaluate water temperature suitabilities for fall-run Chinook salmon in the lower American River[1].

Lifestage	Location	Criterion (°F) 7DADM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult Immigration	Hazel Ave Watt Ave Paradise[2]	68°F												
Adult Pre-spawn Staging	Hazel Ave Watt Ave Paradise[2]	61°F												
Spawning	Hazel Ave Watt Ave[3]	55.4°F												
Incubation through Emergence	Hazel Ave Watt Ave	55.4°F												
Juvenile Rearing & Emigration	Hazel Ave Watt Ave Paradise[2]	61°F 64°F 64°F												

[1] – Water temperature index values and metrics (i.e., 7DADM) are those presented in the NMFS 2017 BO, and are repeated here for comparative consistency. Location of assessment and lifestage periodicities reflect those established in this document.

[2] – Although the NMFS 2017 BO did not evaluate water temperatures downstream of Watt Avenue, we included a downstream location (Paradise Beach – RM 5.4) as an evaluation location in this document for migration and staging lifestages.

[3] – Watt Avenue was the downstream location used to assess spawning water temperatures because 99% of all fall-run Chinook salmon redds are located at or upstream of that location.

2.0 BIOLOGICAL ELEMENTS OF THE MODIFIED FMS

Development of the Modified FMS considered both physical habitat and water temperature conditions affecting fall-run Chinook salmon and steelhead in the lower American River. For each species, the Modified FMS was designed to provide similar or improved habitat conditions relative to the 2006 FMS, and to provide more suitable conditions for a primary stressor to anadromous salmonids in the lower American River – water temperatures.

Biological elements of the Modified FMS and their biological rationale are presented below.

2.1 Redd Dewatering Protective Adjustments

Redd dewatering protective adjustments (RDPAs) were developed for the Modified FMS in order to restrict the minimum release requirements (MRR) to limit potential redd dewatering due to reductions in the MRR during the January through May period. Two RDPAs were included: (1) the Chinook salmon RDPA in January and February; and (2) the steelhead RDPA in February through May.

Table 9. Lifestage-specific periodicities and water temperature index values used to evaluate water temperature suitabilities for steelhead in the lower American River[1].

Lifestage	Location	Criterion (°F) Mean Monthly	Criterion (°F) 7DADM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult Immigration	Hazel Ave Watt Ave Paradise[2]	70°F	68°F	■■	■■	■■	□□	□□	□□	□□	□□	■■	■■	■■	■■
Adult Holding	Hazel Ave Watt Ave Paradise[2]	NA	61°F	■■	■■	■■	□□	□□	□□	□□	□□	■■	■■	■■	■■
Spawning	Hazel Ave Watt Ave[3]	53°F	NA	■■	■■	■■	□□	□□	□□	□□	□□	□□	□□	□□	□■
Incubation through Emergence	Hazel Ave Watt Ave	53°F	NA	■■	■■	■■	■■	■■	□□	□□	□□	□□	□□	□□	□■
Juvenile Rearing & Emigration	Hazel Ave Watt Ave Paradise[2]	63°F	69°F	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■
Smolt (Yearling+) Emigration	Hazel Ave Watt Ave Paradise[2]	NA NA NA	61°F 64°F 64°F	■■	■■	■■	■■	□□	□□	□□	□□	□□	□□	□□	□□

[1] – Water temperature index values and metrics (i.e., mean monthly or 7DADM) are those presented in the NMFS 2017 BO, and are repeated here for comparative consistency. Location of assessment and lifestage periodicities reflect those established in this document.

[2] – Although the NMFS 2017 BO did not evaluate water temperatures downstream of Watt Avenue, we included a downstream location (Paradise Beach – RM 5.4) as an evaluation location in this document for migration and holding lifestages.

[3] – Watt Avenue was the downstream location used to assess spawning water temperatures because 98% of all steelhead redds are located at or upstream of that location.

2.1.1 Fall-run Chinook Salmon

The fall-run Chinook salmon RDPA would limit the potential dewatering of fall-run Chinook salmon redds due to a reduction of the MRR from December to January or February. The fall-run Chinook salmon RDPA-based MRR is computed by multiplying the December hydrologic index-based MRR by 0.70, representing a maximum 30% reduction in MRR from December to both January and February. The higher of the two values (the hydrologic index-based MRR or the RDPA-based MRR) are used to set the minimum requirements for January and February.

2.1.2 Steelhead

The steelhead RDPA would limit the potential dewatering of steelhead redds due to a reduction of the MRR during February through May. The January MRR would be used to set the minimum allowable MRR in February through May based upon **Table 10**. In some instances, the MRR may increase from January to February. If the February MRR is higher than the January MRR, then the February MRR would be used to set the minimum MRR for March through May based upon Table 10. The higher of the two values (the hydrologic index-based MRR or the RDPA-based MRR) are used to set the minimum requirements. If the January or February MRR are in between the values provided in Table 10, then the steelhead RDPA-based MRR would be interpolated between the nearest values.

Table 10. Steelhead RDPA-based MRR for February through May.

MRR_{Jan} or MRR_{Feb} (cfs)	Steelhead RDPA-Based MRR for February-May (cfs)
≤700	500
800	520
900	580
1,000	640
1,100	710
1,200	780
1,300	840
1,400	950
1,500	1,030
1,600	1,100
1,700	1,180
1,800	1,250

2.2 Pulse Flow

The Modified FMS includes provision of a pulse flow event in the lower American River under certain circumstances. The purpose of providing pulse flows in the lower American River would be to provide a juvenile salmonid (fall-run Chinook salmon and steelhead) emigration cue during drier years (typically below normal and dry water years), before unsuitable thermal conditions occur later in the spring and summer in the river, and downstream in the lower Sacramento River.

The Modified FMS would provide a pulse flow event at some time during the period extending from March 15 to April 15 by supplementing normal operational releases from Folsom Dam when no pulse flow event otherwise has occurred between the preceding February 1 and March 1 time frame.

The pulse flow event would be provided only when the MRR from March 1 through March 31 ranges from 1,000 cfs to 1,500 cfs. This range of MRRs during this time period generally corresponds to dry and below normal water year types. The peak magnitude of the pulse flow would be three times the MRR base flows (pre-pulse flows), not to exceed a peak magnitude of 4,000 cfs.

The pulse flow event would range in duration from 6 to 7.5 days, depending upon the initial MRR base flows (pre-pulse flows). There are no assumed restrictions on the rate of ramp-up from base flows to the peak of the pulse flow, which would last for 2 days. Pursuant to the ramp-down restrictions provided in the NMFS 2009 biological opinion that applies to CVP operations, flow reductions after the 2-day peak pulse flow will not exceed more than 500 cfs per day and not more than 100 cfs per hour.

The maximum pulse flow limit of 4,000 cfs was established to minimize stranding of juvenile salmonids. Reclamation attempts to avoid flow fluctuations during non-flood control events that raise flows above 4,000 cfs and then drop them back below 4,000 cfs, as recommended by Snider et al. (2001) and NMFS (2009).

Restriction of implementation of this action to situations when MRR base flows (pre-pulse flows) are equal to or more than 1,000 cfs (i.e., 1,000 - 1,500 cfs) also is to avoid, to the extent possible, juvenile stranding, particularly in side-channel habitats in the lower American River. Side-channels in the lower American River, including those recently constructed as habitat improvement measures through the Anadromous Fish Restoration Program, have been designed to generally maintain hydraulic continuity at flows roughly equal to about 800 cfs (C. Hammersmark, cbec, pers. comm. 2017). Thus, only implementing the pulse flow event when base flows equal or exceed 1,000 cfs avoids the situation in which a pulse flow event associated with relatively low (e.g., ≤ 800 cfs) base flows could strand juveniles in side channels when pulse flows return to base flow levels.

The timing of the pulse flow event was based upon timing and magnitude of occurrence of the various lifestages of fall-run Chinook salmon and steelhead in the lower American River.

- Although dependent on water temperatures, typically during dry and below normal water years, fall-run Chinook salmon embryo incubation is complete by late March (see Attachment C). Thus, the pulse flow event would not be expected to dewater or otherwise affect incubating fall-run Chinook salmon redds.
- Because fall-run Chinook salmon embryo incubation is completed, and fry emergence from the redds occurs from early January to late March, the timing of the pulse flow event between mid-March and mid-April is intended to provide an emigration cue to fall-run Chinook salmon juveniles (see Attachment C).
- The pulse flow event would occur during the steelhead spawning and embryo incubation period. However, by having the peak flow only last for 2 days, there would not be sufficient time for steelhead to create redds at the peak flow, because steelhead in the lower American River are reported to require 3 days to build a redd and spawn (Hannon and Deason 2005). Hence, steelhead redd dewatering also would be expected to be avoided/minimized.

- Most steelhead smolts reportedly emigrate from January through April (R. Titus, CDFW, pers. comm., 2013, as cited in Reclamation and NMFS 2014). If no storm event has occurred prior to mid-March, providing such an event at that time is intended to assist in steelhead smolts (yearling+) emigration.

A full description of the pulse flow component of the Modified FMS is provided in **Attachment E**.

2.3 Determination of the Monthly Minimum Release Requirements (Implementation Curves)

The Modified FMS relies on MRRs (from Nimbus Dam) that are based on indices of water availability. To implement the Modified FMS, Reclamation would compute the MRR each month as new hydrology data become available and would compute a seasonal release allocation for each month to achieve target End-of-May (EOM) and End-of-December (EOD) storage levels in Folsom Reservoir. At no time, however, would the MRR result in flows less than those ordered by the State Water Resources Control Board (SWRCB) in Decision-893.

2.3.1 Iterative Analytic Process for MRR Implementation Curve Development

The relationship between instream flow and the quantity and quality of spawning habitat (i.e., WUA) for fall-run Chinook salmon and steelhead in the lower American River, together with hydrologic modeling for the period of evaluation (82 years), was used to identify the inflection points and "plateaus" in the MRR implementation curves. The shapes of the implementation curves were determined by iterative modeling in an effort to achieve the highest amounts of suitable spawning habitat (WUA) that could be achieved each year in consideration of the constraints associated with estimated water availabilities and biologic objectives throughout the year, and in consideration of target storage levels in Folsom Reservoir.

2.3.2 October - December

The MRR implementation curves for the time period extending from October through December are presented separately for the month of October (**Figure 15**) and November and December (**Figure 16**) due to variations in the curves and inflection points.

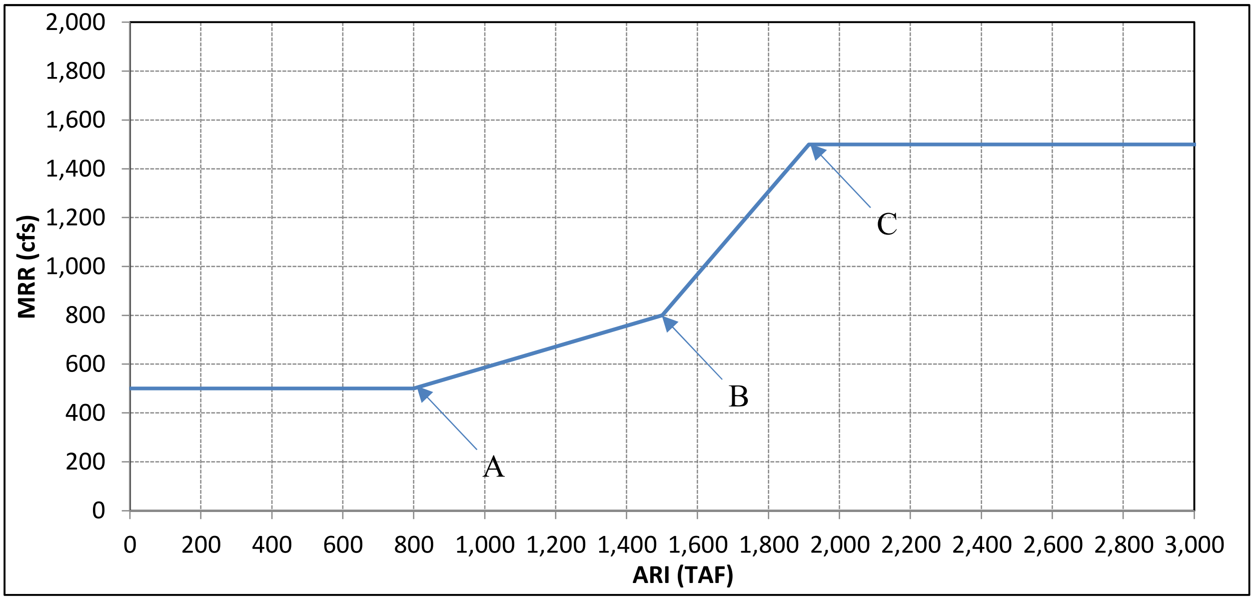

Figure 15. Relationship between the American River Index (ARI) and monthly Minimum Release Requirements (MRRs) for October.

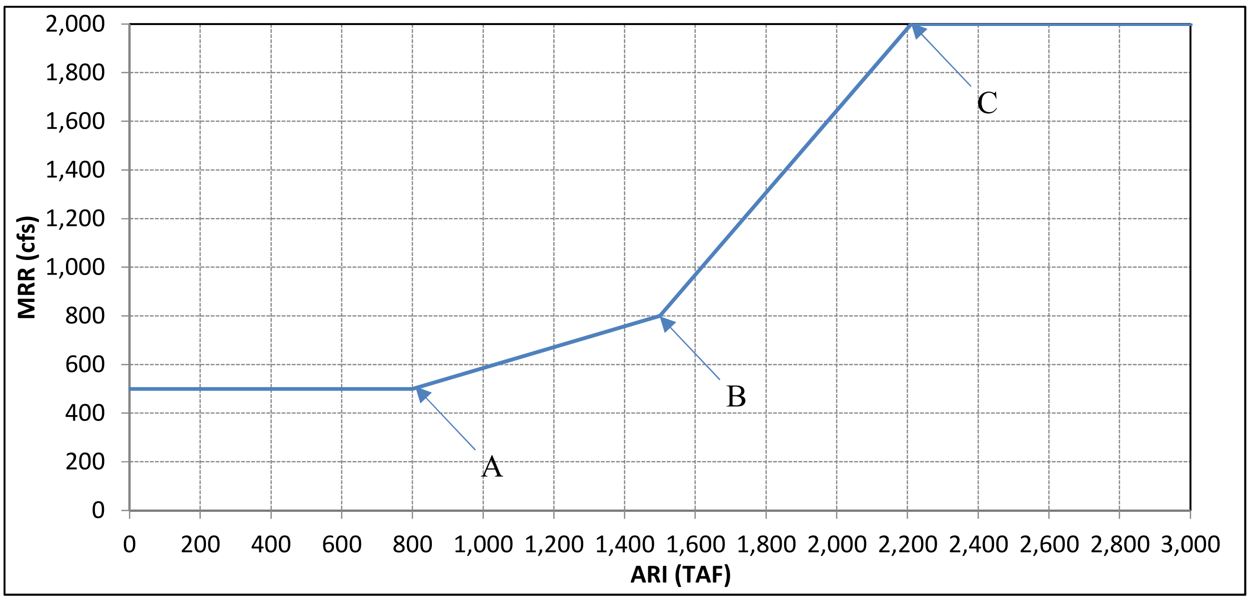

Figure 16. Relationship between the American River Index (ARI) and monthly Minimum Release Requirements (MRRs) for November and December.

2.3.2.1 Biological/Habitat Objectives and Rationale

During the October through December period, the implementation curves were developed to: (1) maximize the frequency of suitable and near optimal spawning habitat availability for Chinook salmon; (2) reduce redd superimposition; and (3) effectively use available water supply.

The October implementation curve is intended to: (1) provide suitable spawning habitat in consideration of the timing and amount of fall-run Chinook salmon spawning; (2) retain storage (and coldwater pool) in Folsom Reservoir for release in subsequent months; (3) provide a spawning flow progression to potentially reduce redd superimposition. It is recognized that fall-run Chinook salmon spawning in the lower American River does not begin until after mid-October, with the majority of spawning occurring during November. Thus, setting the maximum MRR at 1,500 cfs (Point C on Figure 15) during October (when less spawning occurs relative to November) is intended to preserve the Folsom Reservoir coldwater pool for use during subsequent months when greater spawning activity occurs, and also to minimize redd superimposition when the maximum MRR is increased from 1,500 cfs during October to 2,000 cfs during November and December.

Development of the 2006 FMS, as well as initial development of the Modified FMS, utilized the previously identified fall-run Chinook salmon spawning WUA-flow relationship. That relationship indicated a maximum fall-run Chinook salmon spawning WUA value at 2,000 cfs. The updated analyses using more, and more recent information (described above) resulted in a WUA-flow relationship where maximum fall-run Chinook salmon spawning WUA is obtained at about 1,600 cfs. Nonetheless, the Modified FMS retained the 2,000 cfs flow level (Point C on Figure 16) during November and December as the highest MRR because:

- CDFW expressed concern that higher flow values are more desirable in order to spatially distribute spawning and redd construction and reduce the potential for superimposition.
- A flow of 2,000 cfs still provides 98% of maximum WUA.

The inflection point at 800 cfs (Point B on Figure 15 and Figure 16) provides about 85% of maximum Chinook salmon spawning habitat. Moreover, a flow of 800 cfs maintains the hydraulic continuity of side channels and therefore the potential use of side channels for fall-run Chinook salmon spawning.

During mid-October through December, an MRR of 500 cfs represents the Chinook salmon spawning period requirement in Decision-893, and is expected to be implemented with a very low probability[2]. Also, the lowest MRR of 500 cfs (Point A on Figure 15 and Figure 16) still provides approximately 73% of maximum fall-run Chinook salmon spawning habitat availability.

2.3.3 January - March

The monthly MRRs for Nimbus Dam releases are determined using the Sacramento River Index values (for January) and American River Index (ARI) values (for February and March). Although the inflection points (A, B, C) for these two different time periods result in the same MRRs, the shapes of the curves are different, as presented in **Figure 17** and **Figure 18**.

[2] Over the 82-year simulation period, an MRR of 500 cfs is expected to be prescribed about 4% of the days during the October through December time period, based upon the iterative modeling used in the MRR development process.

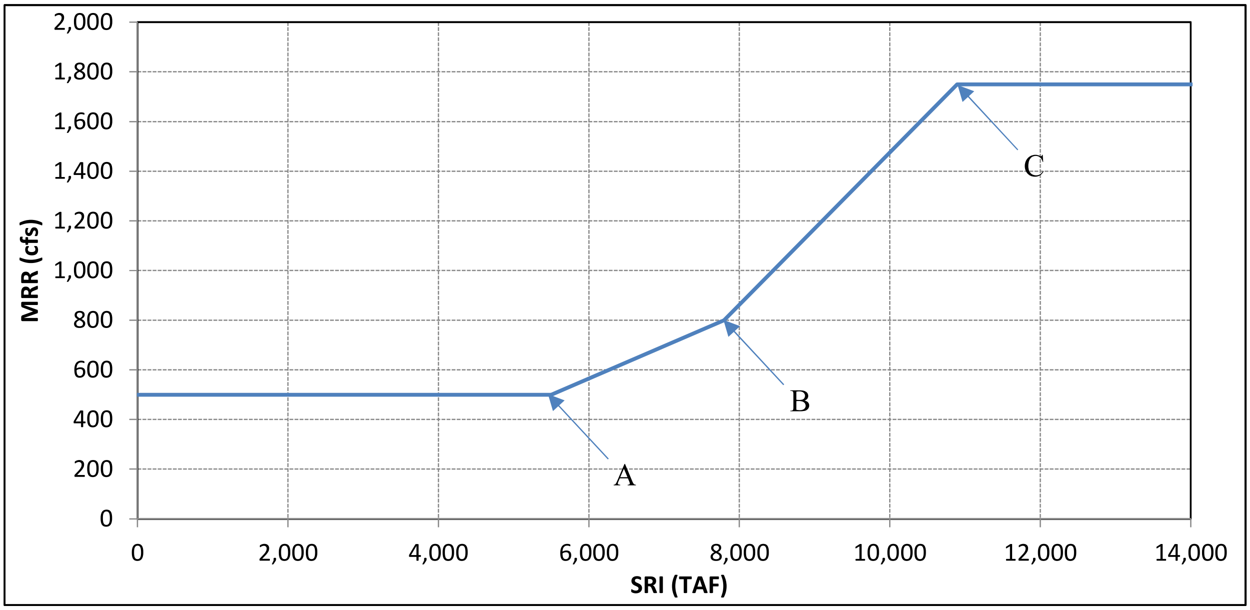

Figure 17. Relationship between the Sacramento River Index (SRI) and monthly Minimum Release Requirements (MRRs) for January.

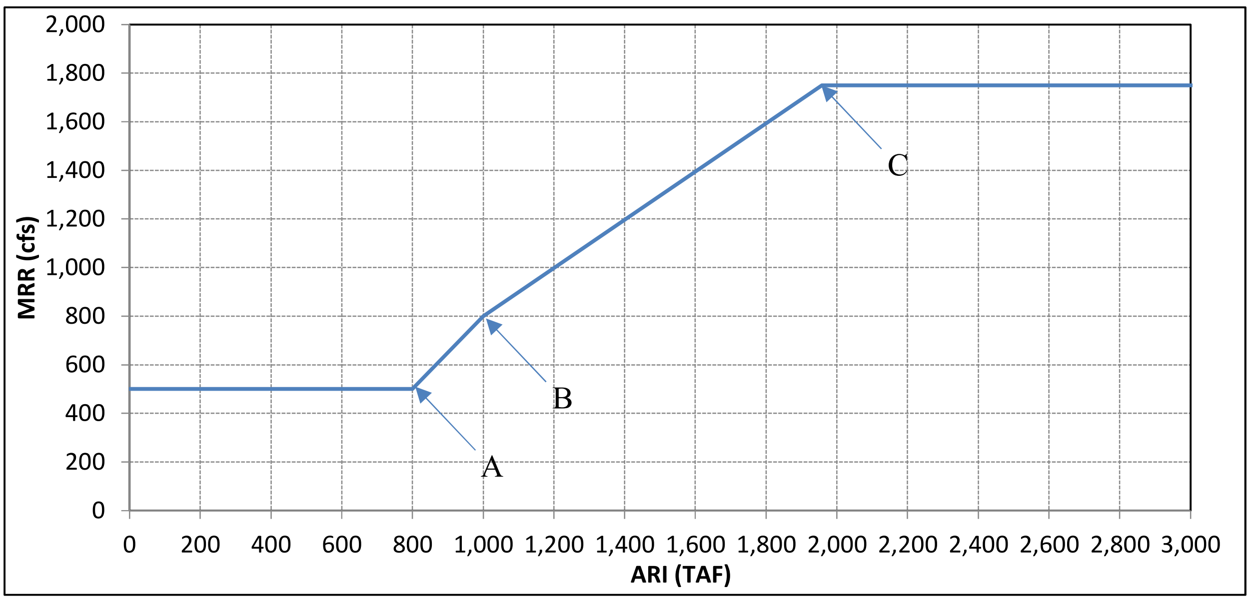

Figure 18. Relationship between the American River Index (ARI) and monthly Minimum Release Requirements (MRRs) for February and March.

2.3.3.1 Biological/Habitat Objectives and Rationale

During the January through March period, the implementation curves were developed to provide suitable spawning habitat availability for steelhead. Additional objectives include limiting month-to-month flow reductions to reduce fall-run Chinook salmon and steelhead potential redd dewatering, minimize juvenile salmonid stranding and isolation, and preserve the coldwater pool in Folsom Reservoir. Flows during this period also provide rearing habitat for post-emergent juvenile fall-run Chinook salmon.

The maximum MRR value of 1,750 cfs (Point C on Figure 17 and Figure 18) was chosen because it represents about 98% of maximum steelhead spawning habitat availability. The maximum MRR value of 1,750 cfs also was chosen because it is consistent with the maximum MRR value specified in the 2006 FMS, and it represents a mid-point between maximum MRRs during December and April. As such, the intent is to provide month-to-month flow sequencing to help minimize steelhead redd dewatering and juvenile salmonid stranding.

For steelhead spawning, 800 cfs (Point B on Figure 17 and Figure 18) provides approximately 86% of maximum steelhead spawning habitat. Moreover, a flow of 800 cfs maintains the hydraulic continuity of side channels and therefore the potential use of side channels for steelhead spawning, as well as minimizing stranding of fall-run Chinook salmon and steelhead juveniles.

The inflection point of 500 cfs (Point A on Figure 17 and Figure 18) provides about 74% of maximum steelhead spawning habitat. During January through March, an MRR of 500 cfs is expected to be implemented with a very low probability[3].

2.3.4 April - June

The MRR implementation curve for the time period extending from April through June is presented in **Figure 19**.

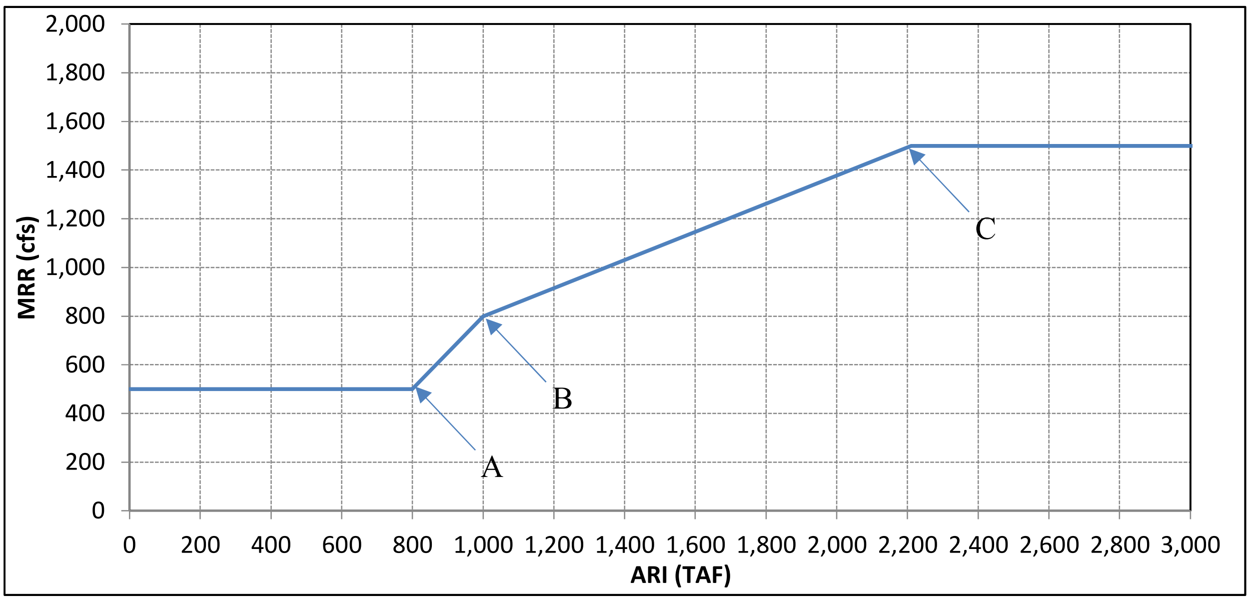

Figure 19. Relationship between the American River Index (ARI) and monthly Minimum Release Requirements (MRRs) for April through June.

2.3.4.1 Biological/Habitat Objectives and Rationale

During the April through June period, the implementation curve was developed to accomplish several objectives: (1) provide rearing habitat for post-emergent juvenile fall-run Chinook salmon;

[3] Over the 82-year simulation period, an MRR of 500 cfs is expected to be prescribed about 3% of the days during the January through March time period, based upon the iterative modeling used in the MRR development process.

(2) preserve the coldwater pool and maximize the amount of storage in Folsom Reservoir for water temperature management in subsequent months; and (3) avoid redirected water temperature-related impacts to the Sacramento River fishery resources.

The maximum MRR value of 1,500 cfs (Point C on Figure 19) was chosen because, during the iterative examination and adjustment of the implementation curves for April through June, it was recognized that Nimbus Dam release flows would exceed the maximum MRR of 1,500 cfs more than 65%, 60% and 70% of the time during April, May and June, respectively (see associated *Rationale, Objectives, and Assessment Methodology for Water and Power Resources for the Modified Flow Management Standard*). It was further recognized that the MRRs would, therefore, actually be "controlling" only during drier conditions, when an important objective is to preserve the coldwater pool and maximize the amount of storage in Folsom Reservoir for water temperature management in subsequent months.

During the April through June time period, 800 cfs (Point B on Figure 19) was chosen because a flow of 800 cfs maintains the hydraulic continuity of side channels and therefore minimizes the potential stranding of juvenile salmonids.

An inflection point of 500 cfs (Point A on Figure 19) during April through June was chosen because, as the absolute minimum MRR, it is consistent with the minimum MRRs corresponding with other months under the driest of conditions, and is expected to be implemented with a very low probability[4].

2.3.5 July - September

The MRR implementation curve for the time period extending from July through September is presented in **Figure 20**.

2.3.5.1 Biological/Habitat Objectives and Rationale

During the July through September period, MRRs were developed to: (1) provide thermally suitable habitat conditions for over-summer rearing steelhead; (2) effectively utilize the available coldwater pool in Folsom Reservoir; (3) provide water temperatures for fall-run Chinook salmon immigration and staging; and (4) avoid redirected water temperature-related impacts to the Sacramento River fishery resources.

[4] Over the 82-year simulation period, an MRR of 500 cfs is expected to be prescribed about 3% of the days during the April through June time period, based upon the iterative modeling used in the MRR development process.

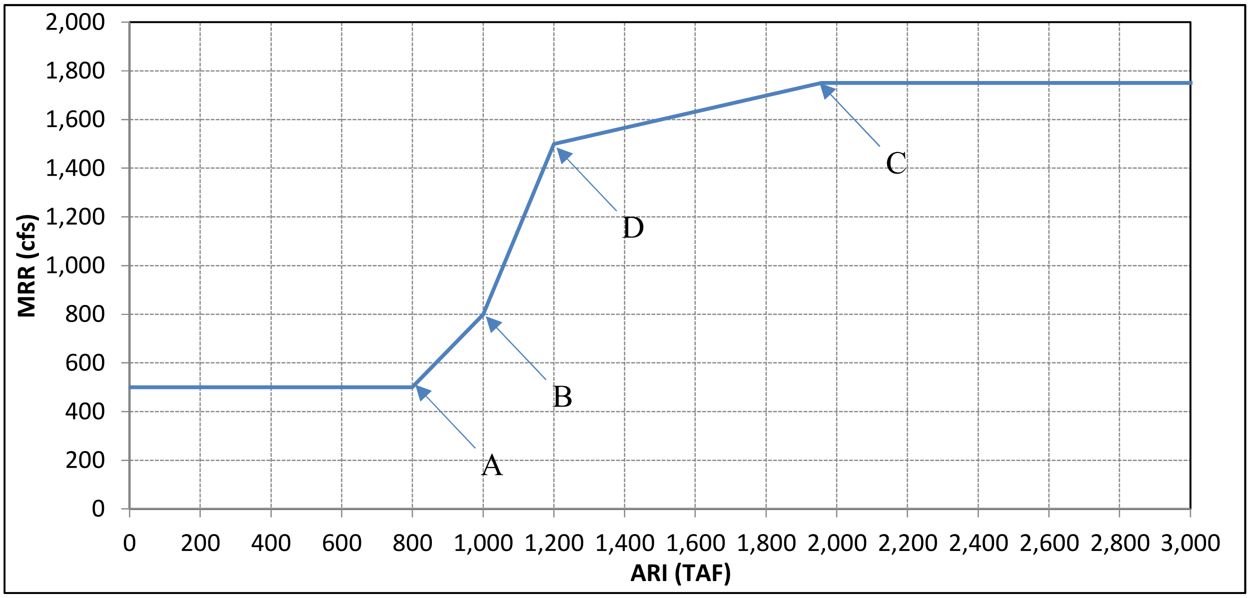

Figure 20. Relationship between the American River Index (ARI) and monthly Minimum Release Requirements (MRRs) for July through September.

It was recognized that the primary factor during the summer period was water temperature for over-summer rearing of juvenile steelhead, in addition to fall-run Chinook salmon immigration and staging. An MRR of 1,750 cfs (Point C on Figure 20) occurs during "wetter" conditions. Actual releases typically exceed the MRR under such conditions. During summer (i.e., July through September) of the wetter years (i.e., wet and above normal), which represent nearly 50% of the time, daily average water temperatures at Watt Avenue typically (50% of the time) would be at or below 65°F (see Attachment D). The maximum MRR value of 1,750 cfs also was chosen because it is consistent with the maximum MRR value specified in the 2006 FMS. Additionally, the MRR of 1,750 cfs was selected because it was identified as a flow to meet recreation interests on the lower American River (Alameda County Superior Court 1990).

An additional inflection point at 1,500 cfs (Point D on Figure 20) was identified for the July through September time period. This point was identified to be consistent with the April through June maximum MRR, as well as the October MRR. Flows at and above the inflection point of 800 cfs (Point B on Figure 20) maintain the hydraulic continuity of side channels and therefore avoids isolation stranding of over-summer rearing steelhead juveniles. During July through September, a MRR of 500 cfs (Point A on Figure 20) serves as the floor of all MRRs, and is expected to be implemented with a very low probability[5].

[5] Over the 82-year simulation period, an MRR of 500 cfs is expected to be prescribed about 4% of the days during the July through September time period, based upon the iterative modeling used in the MRR development process.

2.4 Folsom Reservoir Storage Requirements

The Modified FMS includes both an End-of-May (EOM) storage requirement and an End-of-December (EOD) storage requirement for Folsom Reservoir. The Folsom Reservoir EOM and EOD storage requirements, and biological and habitat objectives and rationale are described below.

2.4.1 End-of-May Storage Requirement

With the publication of the DWR's February Bulletin 120 (B120) and the subsequent determination of the ARI, an initial Folsom Reservoir EOM storage requirement is computed. The Folsom Reservoir EOM storage requirement will then be updated with subsequent B120 publications and ARI calculations, using the March, April, and May forecasts and subsequent updates. **Figure 21** shows the relationship between ARI and the Folsom Reservoir EOM storage requirement.

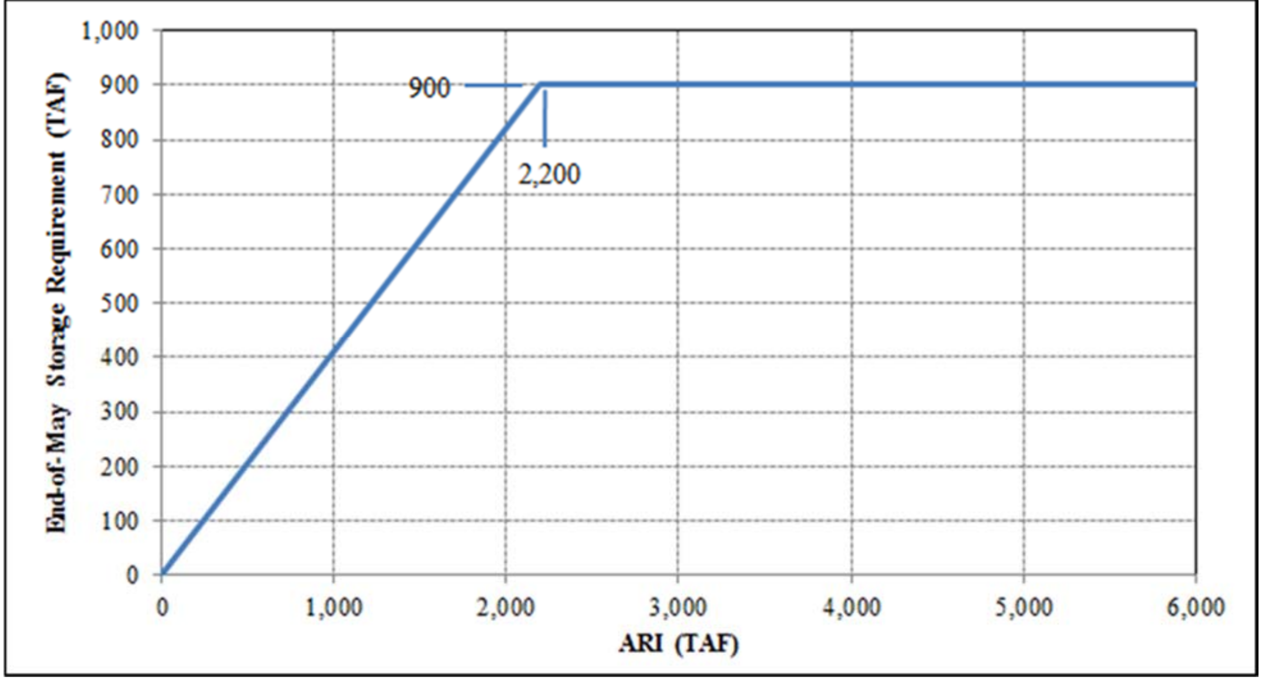

Figure 21. Relationship between ARI and End-of-May Folsom Reservoir storage requirement.

2.4.1.1 Biological/Habitat Objectives and Rationale

The minimum EOM storage requirement was included in the Modified FMS in an effort to acheieve a hypolimnetic cold water pool (after the reservoir stratifies) in Folsom Reservoir by the end of May to maintain suitable summer/fall water temperatures in the lower American River. EOM Folsom Reservoir storage, and subsequent July and August storage, is a primary determinant of summer/fall water temperature in the lower American River. Higher storage, and the associated larger cold water pool volume, results in colder summer/fall river temperatures. **Figure 22** shows an example of the 2011 to 2016 time period, when maximum Folsom Reservoir storage declined annually and summer/fall water temperatures in the lower American River at Watt Avenue increased annually (river water temperature is inversely related to Folsom Reservoir storage). The relationship between Folsom Reservoir EOM storage (and storage in subsequent months) and the annual maximum average weekly water temperature (MWAT) at Watt Avenue is shown in **Figure 23**.

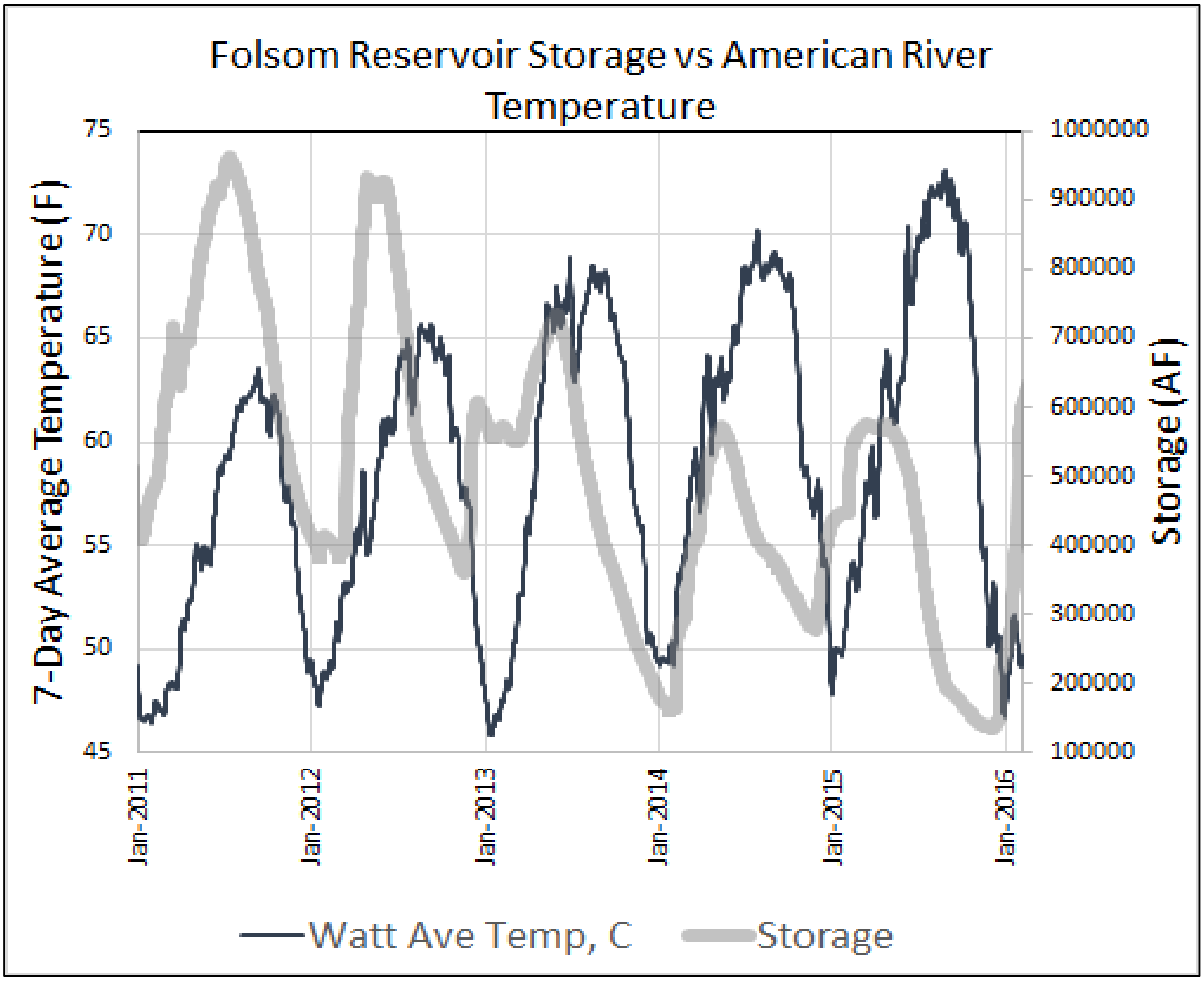

Figure 22. Annually declining Folsom Reservoir storage over the 2011 to 2016 time period and corresponding increases in summer/fall water temperature in the lower American River at Watt Avenue (source: Cardno ENTRIX).

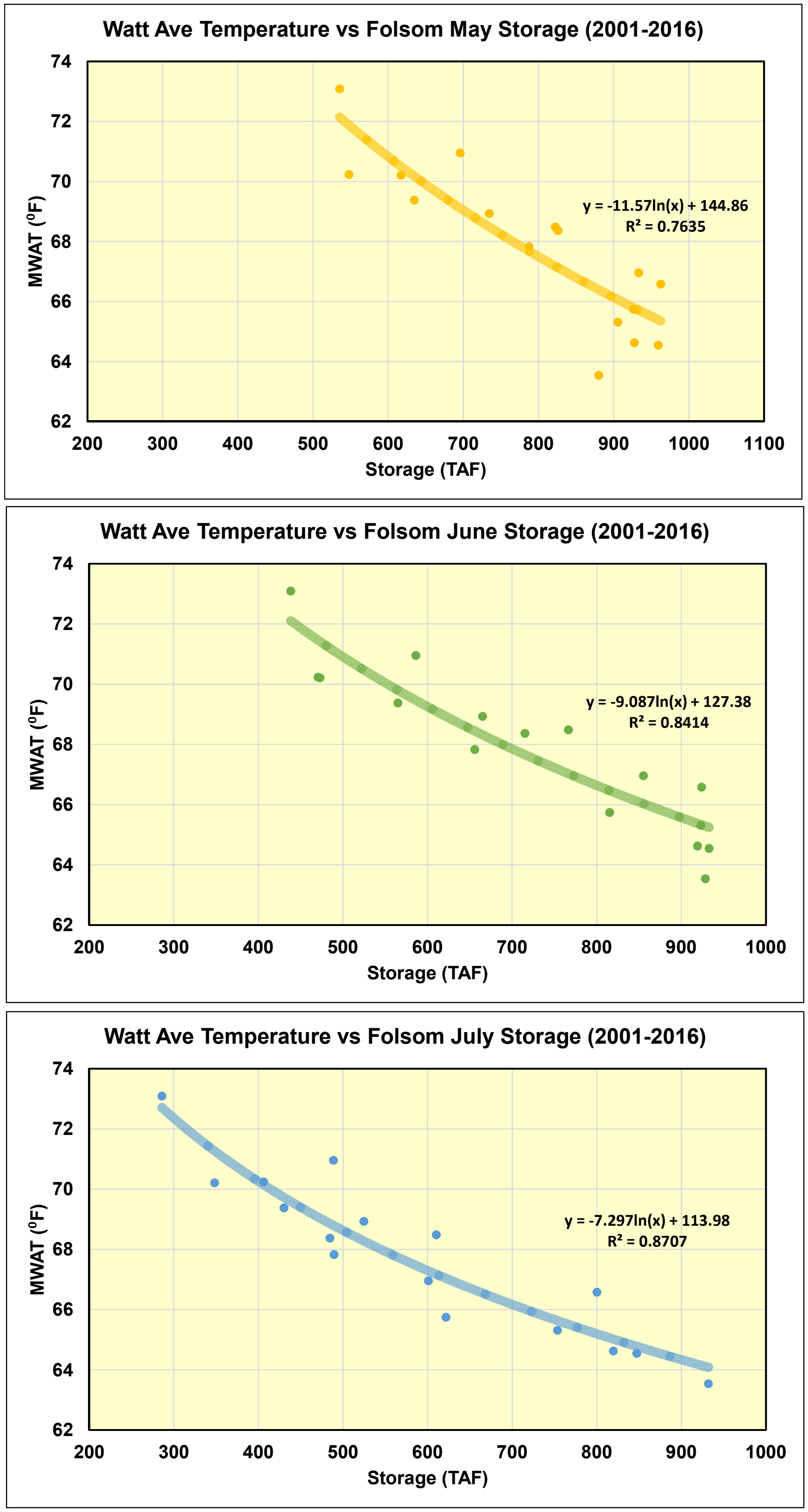

Figure 23. Relationship between Folsom Reservoir End-of-May storage (top) and June and July storage (middle and bottom, respectively) and the annual maximum weekly average temperature in the American River at Watt Avenue (source: Cardno ENTRIX).

The minimum EOM storage requirement was developed to provide suitable summer/fall water temperatures for: (1) juvenile steelhead over-summer rearing; (2) adult fall-run Chinook salmon and steelhead immigration and staging/holding; and (3) fall-run Chinook salmon spawning.

2.4.2 End-of-December Storage Requirement

The integration of Folsom Reservoir operations with other CVP operations requires releases from Folsom Reservoir above the MRR during certain times of the year. The EOD storage requirement for Folsom Reservoir was selected to balance four potentially conflicting objectives:

1) Providing adequate reservoir storage for sufficient diversions through the Folsom Dam M&I intake to meet lower American River Basin demands throughout the year during hydrologic conditions similar to the driest year of record (1977).
2) Maintaining adequate reservoir storage and cold water pool in consideration of thermal habitat suitability for salmonids in the lower American River during hydrologic conditions similar to the driest year of record (1977).
3) Allowing Reclamation the operational flexibility to avoid redirected impacts to the Sacramento River downstream from Keswick Dam.
4) Preserving Reclamation's operational flexibility for integrated CVP and State Water Project (SWP) operations.

The Water Forum performed numerous sensitivity evaluations to maximize benefits and avoid or minimize negative water temperature-related impacts on both the Sacramento and American rivers. An EOD storage requirement of 300 thousand acre-feet (TAF) in Folsom Reservoir was determined to represent the value at which lower American River Basin benefits were maximized without causing adverse water temperature-related impacts to Sacramento River threatened and endangered fish species. Exceptions to the 300 TAF EOD storage requirement are described in **Technical Memorandum 1**, Project Description - Lower American River Modified Flow Management Standard.

2.4.2.1 Biological/Habitat Objectives and Rationale

The minimum EOD storage requirement was included in the Modified FMS to achieve adequate carry-over storage in Folsom Reservoir to maintain flow and water temperature in the lower American River during drought years. Coincident with maintaining Folsom Reservoir storage during drought years, water temperature in the lower American River is directly related to storage, and at low storages water temperatures can become elevated during summer, potentially affecting rearing juvenile steelhead. The EOD storage requirement was designed to maintain water temperatures in the upper portion of the lower American River that would sustain steelhead. **Figure 24** shows an example of modeled water temperatures during 1977, the driest year on record, under the Modified FMS and the 2006 FMS. The Modified FMS (with EOD storage requirements) generally maintains water temperatures at Hazel Avenue (below Nimbus Dam) below 70°F, whereas water temperatures under the 2006 FMS are up to nearly 3°F higher. Similar reductions in water temperatures would occur at Watt Avenue. While water temperatures during 1977 under the Modified FMS are not ideal, under the 2006 FMS water temperatures could be lethal for juvenile steelhead rearing[6] in the lower American River.

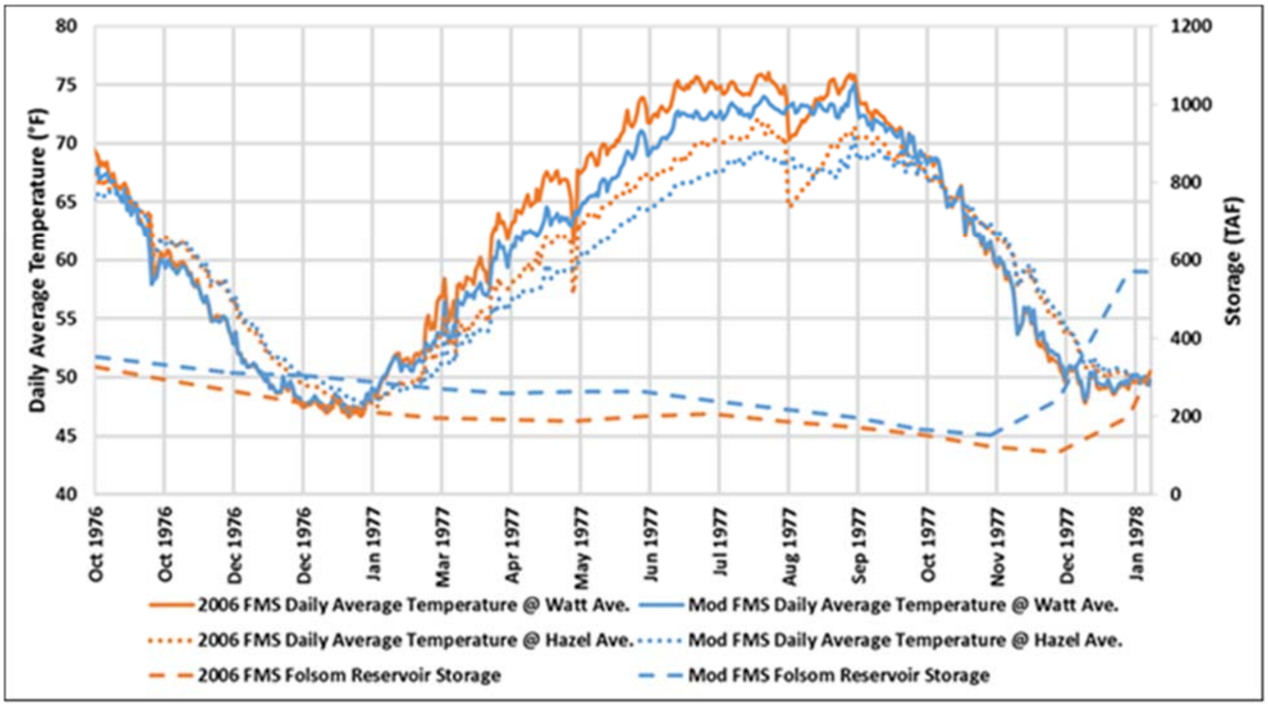

Figure 24. Modeled Folsom Reservoir storage and lower American River water temperature at Watt Avenue and Hazel Avenue during 1977 under the Modified FMS (with EOD storage requirements) and under the 2006 FMS (without EOD storage requirements) (source: Cardno ENTRIX).

2.5 Sacramento River Re-directed Impact Avoidance

The 300 TAF EOD Folsom Reservoir storage requirement was the result of modeling iterations to balance water temperature and flow benefits on the lower American River with effects on Shasta Reservoir storage and resulting Sacramento River water temperatures. A range of EOD Folsom Reservoir storages between 230 TAF and 360 TAF were evaluated, and a 300 TAF EOD storage requirement was identified as the most efficacious level providing environmental benefits on the lower American River, without redirecting adverse environmental effects to the Sacramento River. Further evaluation showed that the 300 TAF EOD storage requirement provided sufficient storage in Folsom Reservoir to allow for water supply diversions from Folsom Reservoir throughout 1977, the driest year in the hydrological period of evaluation.

The Modified FMS was designed to provide beneficial environmental effects on aquatic habitat in the lower American River, while avoiding adverse environmental effects on aquatic habitat outside

[6] NMFS and EPA report that direct mortality to rearing juvenile steelhead results when stream temperatures reach 75°F (EPA 2002; NMFS 2001b). Water temperatures >77°F have been referred to as "lethal" to juvenile steelhead (FERC 1993; Myrick and Cech 2001).

of the American River Basin. The CVP and SWP generally operate as integrated projects, and the effects of CVP project operations in the American River could potentially affect operation of other CVP or SWP project facilities (e.g., Shasta Reservoir, Keswick Dam and the Sacramento River). Development of the Modified FMS was an iterative process that consisted of reviewing the potential effects of the Modified FMS on potential effects outside of the American River Basin. In particular, the Modified FMS was designed to avoid redirected adverse effects on Shasta Reservoir storage and Sacramento River flows and water temperatures.

Storage in Shasta Reservoir during late spring/early summer, when thermal stratification occurs, determines the amount of cold water pool available for release downstream into Keswick Reservoir and the Sacramento River during the summer and fall. In turn, the amount of cold water pool available each year determines (in part) the water temperature that can be achieved, and the distance downstream that cold water can be maintained in the Sacramento River. The Modified FMS CalSim II model runs were reviewed and MRRs iteratively adjusted to avoid reductions in storage in Shasta Reservoir that could lead to increased water temperatures in the Sacramento River (See **Figure F-1 of Attachment F**). Examination of Figure F-1 demonstrates that relative to the 2006 FMS, the Modified FMS would result in a nearly identical end-of-May storage exceedance distribution. In addition, Reclamation's HEC-5Q Sacramento River water temperature model simulations were reviewed to ascertain that operations associated with the Modified FMS avoided redirected adverse effects on Sacramento River water temperatures (See **Technical Memorandum 3 -** Sacramento River Water Temperature Model Assumptions).

As indicated in the WaterFix BA (Reclamation 2016), winter-run Chinook salmon spawning and embryo incubation was evaluated throughout the extent of its spawning habitat. Water temperature suitability was evaluated at several locations including, from upstream to downstream, Keswick, Clear Creek, Balls Ferry, Bend Bridge and Red Bluff. NMFS's 2017 biological opinion for California WaterFix used a threshold value of 55.4°F in water temperature evaluations during the time that winter-run Chinook salmon eggs and alevins occur in the Sacramento River, which is April through October.

In order to evaluate the potential for redirected adverse impacts resulting from implemention of the Modified FMS, we examined water temperature exceedance distributions encompassing the geographic range (and an approximate mid-point) identified in the WaterFix BA – namely, Keswick, Balls Ferry and Red Bluff, from April through October. Comparison of water temperature exceedance distributions that would occur with implementation of the Modified FMS, relative to baseline conditions represented by the 2006 FMS, are presented by month in Attachment F. For comparative consistency with evaluation of water temperature effects associated with implementation of the WaterFix on lower American River water temperatures (Exhibit ARWA-703), water temperature exceedance distributions also are presented by month, by water year type.

Examination of the water temperature exceedance distribution comparisons (**Figures F-2 through F-22**) demonstrate that very similar water temperature exceedance distributions would occur between the Modified FMS and the 2006 FMS during all months evaluated at all three locations for most water year types. Potentially discernable water temperature differences (i.e., differences exceeding 0.5°F when water temperatures exceed the NMFS identified threshold of 55.4°F[7]) were only observed during critical water years, with the exceptions of August (+2.2% of the time during dry years) and September (-0.2% of the time during dry years) at Red Bluff. Under current conditions, critical water years represent about 15% of the 82-year evaluation period.

The majority of potentially discernable water temperature differences (under the Modified FMS relative to the 2006 FMS) during critical years were represented by water temperature improvements (cooler) (up to 25.5% of the time, during October at Balls Ferry). Potentially discernable water temperature increases during critical years occurred infrequently and with relatively low probability of occurrence, with maximum occurrence of 7.5% during August at Keswick. An occurrence of 7.5% of the time during August of critical years would represent a 1.1% probability of occurrence over the entire exceedance distribution during that month.

By comparison, none of the water temperature increases between the Modified FMS and 2006 FMS by month and water year type in the Sacramento River approach the magnitude of water temperature increases in the lower American River under the WaterFix project relative to the analytical baseline identified in the NMFS 2017 BO and the WaterFix BA (Reclamation 2016). Those substantial, discernable water temperature increases by month and water year type range from nearly 25% up to nearly 80% (Exhibit ARWA-703). Relative to those water temperature increases, and in consideration of the magnitude and frequency of occurrence of the observed differences, the infrequent differences in water temperatures between the Modified FMS and the 2006 FMS observed by month and water year type in the Sacramento River are not substantial.

In consideration of the foregoing, implementation of the Modified FMS would avoid redirected adverse effects to water temperature conditions in the Sacramento River.

3.0 MODIFIED FMS PERFORMANCE

Performance of the Modified FMS is evaluated by comparison of habitat conditions to those under the 2006 FMS. Where applicable, physical habitat condition results (e.g., spawning habitat availability, potential redd dewatering) figures and tables are presented in this section.

[7] Adjusted by appropriate month and location conversion factors identified in Table 5.D-51 in Appendix 5.D of the WaterFix BA (Reclamation 2016).

Daily water temperature exceedance probabilities for each month of the year, at each of three locations (Hazel Ave. – RM 22.3, Watt Ave – RM 9.2, and Paradise Beach – RM 5.4) are presented in Attachment D, **Figures D-1** through **D-12**. These figures display the difference in average daily water temperatures, by month, between the Modified FMS and the 2006 FMS.

Daily water temperature exceedance distributions also are presented by month, separately for fall-run Chinook salmon and steelhead, because the WTI values differ between species, and among lifestages. For each month, the WTI thresholds presented in the NMFS 2017 BO for lifestages occuring during that month are overlain on the distributions, for comparative consistency. Water temperature exceedance distributions for fall-run Chinook salmon are presented in **Figures D-13** through **D-24**. Two sets of water temperature exceedance distributions are presented for steelhead, because the NMFS 2017 BO used two different sets of criteria for steelhead water temperature suitability evaluations. Water temperature exceedance distributions for steelhead using average daily exceedance distributions are presented in **Figures D-25** through **D-36**, and distributions using the 7DADM metric are presented in **Figures D-37** through **D-48**.

3.1 Water Temperature Results

Examination of average daily water temperature exceedance distributions, by month, demonstrate the following overall general trends in temperatures resulting from the Modified FMS, relative to the 2006 FMS.

- October – slightly cooler (up to about 0.5°F) varying by location, with cooler water temperatures over about 40% of the distribution at Watt Avenue. Water temperatures typically (more than 80% of the time) would remain at or below 64°F at Hazel Avenue and Watt Avenue.
- November – slightly warmer (up to about 0.5°F) water temperatures over the lowest (warmest) 15% of the distribution at Hazel Avenue, but very similar water temperatures over the entire exceedance distribution at Watt Avenue. Water temperatures typically (more than 80% of the time) would remain below about 59°F at Hazel Avenue and 58°F at Watt Avenue.
- December through February – very similar water temperatures over the entire distributions, with water temperatures nearly always remaining at or below 56°F, 52°F, and 56°F, respectively, at Hazel Avenue and Watt Avenue.
- March – cooler (up to about 2°F) over about the lowest (warmest) 25% portion of the distribution at Watt Avenue. Water temperatures typically (more than 80% of the time) would remain at or below 52.5°F at Hazel Avenue and 55°F at Watt Avenue.
- April – cooler (up to about 2.5°F) over about the lowest (warmest) 15% of the distributions at Hazel Avenue and Paradise Beach, with up to about 3°F cooler water temperatures over the lowest 15% of the distribution at Watt Avenue. Water

temperatures typically (more than 80% of the time) would remain at or below 55.5°F at Hazel Avenue, and below about 59°F at Watt Avenue and Paradise Beach.

- May – cooler (up to about 2°F) over about the lowest (warmest) 20 – 35% of the distributions, varying by location. Water temperatures typically (more than 80% of the time) would remain below about 58°F, 62°F, and 62.5°F at Hazel Avenue, Watt Avenue, and Paradise Beach, respectively.
- June – cooler (up to about 1°F) over more than 35% of the lowest (warmest) portions of the distributions at all locations. Water temperatures typically (more than 80% of the time) would remain at or below 60.5°F at Hazel Avenue, and 65°F at Watt Avenue and Paradise Beach.
- July – cooler over about 25% of the lowest (warmest) portions of the distributions, by up to about 1.5°F at Hazel Avenue, and about 2°F at Watt Avenue and Paradise Beach. Water temperatures typically (more than 80% of the time) would remain below about 63.5°F at Hazel Avenue, 66.5°F at Watt Avenue, and 67°F at Paradise Beach.
- August – cooler (up to about 2.5°F) over the lowest (warmest) about 30 – 40% of the distributions, varying by location, at Hazel Avenue, Watt Avenue, and Paradise Beach, Water temperatures typically (more than 80% of the time) would remain below about 63.5°F at Hazel Avenue, 67.5°F at Watt Avenue, and 68°F at Paradise Beach.
- September – cooler (up to about 1.5°F) over about the lowest (warmest) 30% of the distributions at Hazel Avenue, Watt Avenue, and Paradise Beach. Water temperatures typically (more than 80% of the time) would remain at or below about 64°F at Hazel Avenue, 67°F at Watt Avenue and 67.5°F at Paradise Beach.

3.2 Fall-run Chinook Salmon

3.2.1 Spawning Habitat Availability

Habitat duration for fall-run Chinook salmon spawning under the Modified FMS and the 2006 FMS scenarios are presented in **Figure 25**. The Modified FMS and the 2006 FMS scenarios both provide 80 percent or more of maximum spawning WUA with about an 80 percent probability. The Modified FMS provides somewhat lesser amounts of spawning habitat when both the Modified FMS and the 2006 FMS provide 80% or more of maximum spawning habitat. However, these differences are not biologically meaningful.

The use of 80% of maximum spawning WUA as a benchmark was established in the NMFS and USFWS Klamath Project Operations BO (NMFS and USFWS 2013). In that BO, NMFS reports that available instream habitat of 80% of maximum (WUA) has been used as a guideline to develop minimum flow needs for the conservation of anadromous salmonids, and that: (1) NMFS assumes that at least 80% of maximum WUA provides a wide range of conditions and habitat abundance in which populations can grow and recover; (2) where habitat availability is 80 percent of maximum WUA or greater, habitat is not expected to limit individual fitness or population productivity or distribution, nor adversely affect the function of essential features of [coho] salmon critical habitat. In fact, NMFS excludes flows that provide at least 80 percent of maximum WUA from the analysis, and highlights the time periods and flow exceedances when the proposed action will reduce habitat availability below 80% of maximum WUA (NMFS and USFWS 2013).

The Modified FMS and 2006 FMS would provide very similar amounts of spawning habitat when both the Modified FMS and 2006 FMS provide less than 80% of maximum WUA.

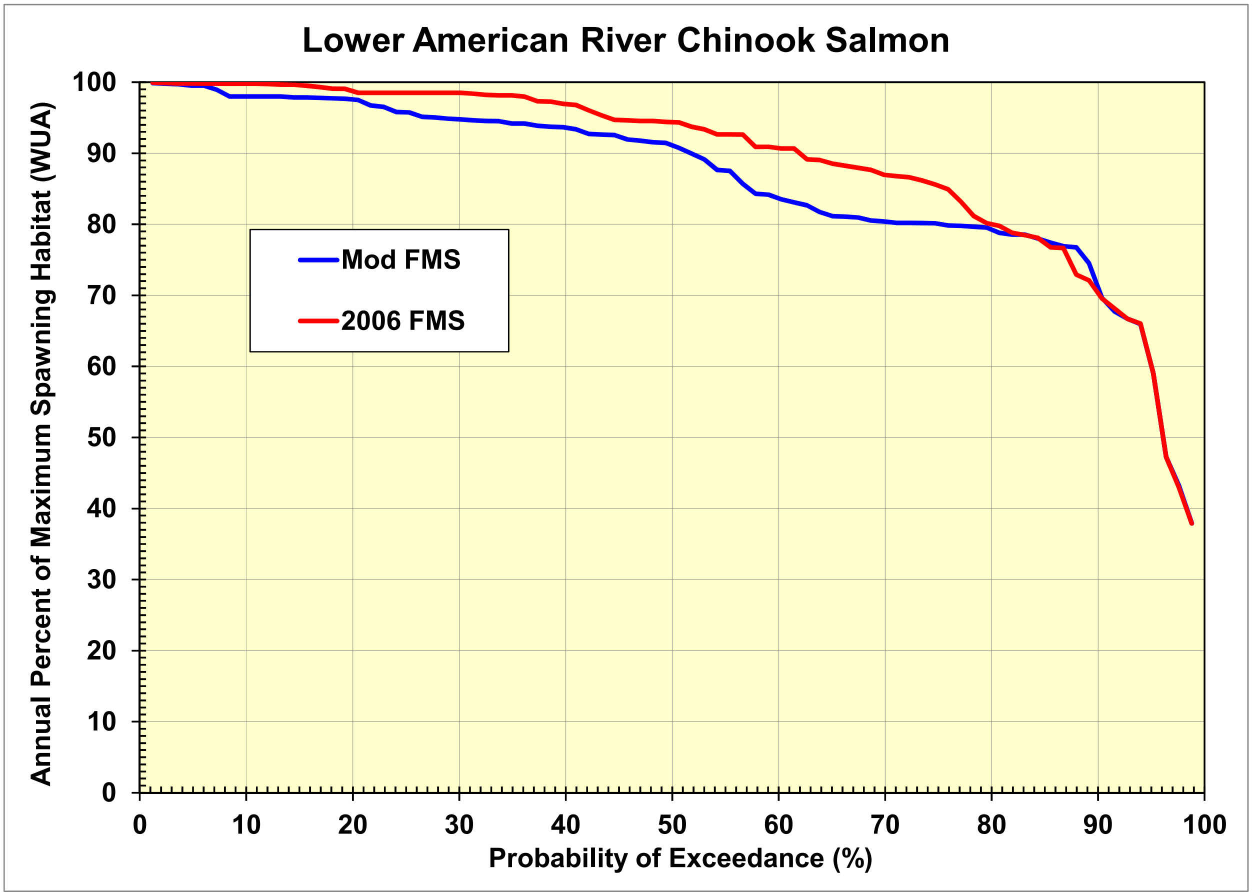

Figure 25. Comparison of fall-run Chinook salmon spawning habitat duration over the 82-year hydrologic simulation period for the Modified FMS and 2006 FMS scenarios.

3.2.2 Potential Redd Dewatering

During the days over the 82-year simulation period when spawning occurred when flows were not under flood control operations, the long-term annual averages and the averages by water year types of the percentages of fall-run Chinook salmon redds potentially dewatered for at least one day under the Modified FMS and 2006 FMS are presented in **Table 11**. The long-term average percentage of fall-run Chinook salmon redds potentially dewatered would be 6.9% under the

Modified FMS, relative to 6.1% under the 2006 FMS. Thus, the difference in the long-term average of potential fall-run Chinook salmon redd dewatering is less than 1% between the Modified FMS and the 2006 FMS. With the exception of above normal years, the estimated potential annual percentage of redds dewatered increases as the water year types go from wet to critical for both the Modified FMS and the 2006 FMS. During critical years, when conditions could be expected to be most stressful for fall-run Chinook salmon, the Modified FMS would reduce potential redd dewatering by 1.9%.

Table 11. Long-term average and average by water year type potential fall-run Chinook salmon redd dewatering, under the Modified FMS relative to the 2006 FMS.

Scenario	Long-term Full Simulation Period[2]	WYTs[1]				
		Wet	Above Normal	Below Normal	Dry	Critical
Mod FMS	6.9	2.7	12.3	5.7	5.9	14.0
2006 FMS	6.1	2.3	11.0	2.9	4.6	15.9
Difference	0.8	0.4	1.3	2.8	1.3	-1.9

[1] As defined by the Sacramento Valley Index (SVI) WY Hydrologic Classification.
[2] Based on the WY 1923-2003 simulation period.

3.2.3 Pulse Flow Events

As previously described, the pulse flow event would only be provided when the MRR for the period extending from February through June (pursuant to the implementation curves for the Modified FMS) range from 1,000 to 1,500 cfs as measured at the USGS Fair Oaks Gage. This range of MRRs during this time period generally corresponds to dry and below normal water year types.

Model simulation results (**Table 12**) indicate that there would be an additional 13 years when a pulse flow event would occur under the Modified FMS, relative to the 2006 FMS, over the 1922 through 2003 model simulation period. Additional pulse flow events under the Modified FMS would occur during 2 above normal water years (1926, 1955), 5 below normal years (1933, 1944, 1955, 1966 and 1968), and 6 dry water years (1930, 1947, 1959, 1964, 1981 and 1985). As shown in Table 12, the magnitude of additional pulse flow events under the Modified FMS would range from 3,072 cfs up to 4,000 cfs.

Table 12. Additional pulse flow events that would occur under the Modified FMS, relative to the 2006 FMS.

Water Year	Water Year Type	Pulse Flow (cfs)
1926	Above Normal	3,551
1930	Dry	4,000
1933	Below Normal	3,200
1944	Below Normal	3,774
1947	Dry	3,641
1955	Above Normal	4,000
1959	Dry	3,072
1960	Below Normal	4,000
1964	Dry	4,000
1966	Below Normal	3,566
1968	Below Normal	4,000
1981	Dry	3,533
1985	Dry	4,000

3.2.4 Water Temperature Suitability

Figures D-13 through D-24 in Attachment D display the daily water temperature exceedance probabilities, by month, during each of the fall-run Chinook salmon adult lifestages under the Modified FMS and 2006 FMS. Water temperature index values are overlain on the exceedance plots. Water temperature index values and metrics (i.e., 7DADM) are those presented in the NMFS 2017 BO, and are repeated here for comparative consistency. Although the NMFS 2017 BO did not evaluate water temperatures downstream of Watt Avenue, a downstream location (Paradise Beach – RM 5.4) was used as an evaluation location in this document for migration and staging lifestages. Also, Watt Avenue was the downstream location used to assess spawning water temperatures because 99% of all fall-run Chinook salmon redds are located at or upstream of that location (See Attachment C).

3.2.4.1 Adult Immigration

Relative to the 2006 FMS, overall the Modified FMS would result in more suitable water temperature conditions during the fall-run Chinook salmon adult immigration period. The Modified FMS would provide more suitable water temperatures, typically up to about 1°F cooler than the 2006 FMS, about 30% of the time when the water temperatures under the 2006 FMS exceed the 68°F 7DADM NMFS threshold at Paradise Beach and at Watt Avenue during June, July, August and September. At Hazel Avenue, water temperatures would remain below the 68°F 7DADM NMFS threshold more than 90% of the time under both the Modified FMS and 2006 FMS scenarios over the entire June through December period.

During October, water temperatures would remain below the 68°F 7DADM NMFS threshold nearly all of the time at Hazel Avenue, more than 90% of the time at Watt Avenue, and about 90%

of the time at Paradise Beach. Water temperatures would remain below the 68°F 7DADM NMFS threshold all of the time during November and December at all locations under both the Modified FMS and 2006 FMS scenarios.

3.2.4.2 Adult Pre-spawning Staging

The Modified FMS would result in more suitable water temperature conditions than the 2006 FMS during the fall-run Chinook salmon adult pre-spawn staging period. The Modified FMS would provide more suitable (typically up to about 1°F cooler) water temperatures than the 2006 FMS about 30% of the time during July, August and September, and nearly 40% of the time during June when the water temperatures under the 2006 FMS exceed the 61°F 7DADM NMFS threshold at Paradise Beach and at Watt Ave.

Additionally, the Modified FMS would provide more suitable water temperatures, typically up to about 1°F cooler than the 2006 FMS, when the water temperatures under the 2006 FMS exceed the 61°F 7DADM NMFS threshold at Hazel Avenue during June (nearly 30% of the time) and July (about 40% of the time). During August, cooler water temperatures would be provided by the Modified FMS at Hazel Avenue over the lower (warmest) 40% of the distribution, and 30% of the distribution during September. During these conditions, water temperatures under the Modified FMS would be up to about 1.0°F to 2.5°F cooler over the lowest (warmest) 10% of the distribution during August and September.

During October, water temperatures under the Modified FMS would be slightly cooler than the 2006 FMS (up to about 15% of the time) when water temperatures exceed the 61°F 7DADM NMFS threshold at Hazel Avenue, nearly 70% of the time at Watt Avenue, and nearly 30% of the time at Paradise Beach. During November, water temperatures are similar and slightly warmer under the Modified FMS, and both the Modified FMS and the 2006 FMS exceed the 61°F 7DADM NMFS threshold about 5 – 20% of the time at all three locations. During December, water temperatures would remain below the 61°F 7DADM NMFS threshold all of the time under both the Modified FMS and 2006 FMS scenarios.

3.2.4.3 Adult Spawning

During October, water temperatures under the Modified FMS would be slightly cooler than the 2006 FMS (about 40% of the time) when water temperatures exceed the 55.4°F 7DADM threshold identified by NMFS in their 2017 BO at Hazel Avenue and at Watt Avenue. Water temperatures during October exceed the 55.4°F 7DADM NMFS threshold all of the time at both locations under both the Modified FMS and 2006 FMS scenarios. Water temperatures are very similar between the Modified FMS and the 2006 FMS during November and exceed the 55.4°F 7DADM NMFS threshold about 90-95% of the time at both locations. At Hazel Avenue, the Modified FMS would be slightly warmer (generally ranging from 0.1°F to 0.3°F, but up to 0.5°F) than the 2006 FMS about 25% of the time during November when water temperatures exceed the 55.4°F 7DADM NMFS threshold. Water temperatures also are very similar between the Modified FMS and the

2006 FMS during December and exceed the 55.4°F 7DADM NMFS threshold over 15% of the time at Hazel Avenue, and about 10% of the time at Watt Avenue.

3.2.4.4 Incubation through Emergence

Because the same water temperature index values and metrics, as well as locations, are applied to the embryo incubation through emergence lifestage as to the spawning lifestage, the immediately preceeding results also pertain to embryo incubation through emergence from October through December. In addition, during January water temperatures would remain below the 55.4°F 7DADM NMFS threshold all of the time at both locations under both the Modified FMS and 2006 FMS scenarios, and nearly 100% of the time during February. During March, water temperatures under the Modified FMS would be below the 55.4°F 7DADM NMFS threshold about 3% more often relative to the 2006 FMS at Hazel Avenue, and would be slightly cooler (up to about 1.5°F) about 25% of the time at Watt Avenue when water temperatures would exceed the 55.4°F 7DADM NMFS threshold.

3.2.4.5 Juvenile Rearing and Emigration

For fall-run Chinook salmon, the NMFS 2017 BO applied the 61°F 7DADM NMFS threshold at Hazel Avenue because they considered that location as "core rearing," representing moderate to high fish density, whereas they applied the 64°F 7DADM NMFS threshold at Watt Avenue because they considered that location as "non-core rearing," representing low to moderate to fish density.

At Hazel Avenue, water temperatures would remain below the 61°F 7DADM NMFS threshold 100% of the time from December through March, and nearly 100% of the time during April under both the Modified FMS and the 2006 FMS. During May, water temperatures under the Modified FMS would be cooler nearly 10% of the time when water temperatures under the 2006 FMS exceed the 61°F 7DADM NMFS threshold. During June, water temperatures under the Modified FMS would be cooler (up to 1°F) about 40% of the time when water temperatures under the 2006 FMS exceed the 61°F 7DADM NMFS threshold.

At Watt Avenue, water temperatures would remain below the 64°F 7DADM NMFS threshold 100% of the time from December through March, and about 95% of the time during April, under both the Modified FMS and the 2006 FMS. During May, water temperatures under the Modified FMS would be cooler about 15% of the time when water temperatures under the 2006 FMS exceed the 64°F 7DADM NMFS threshold. During June, water temperatures under the Modified FMS would be cooler (up to 1°F) about 40% of the time when water temperatures under the 2006 FMS exceed the 64°F 7DADM NMFS threshold.

At Paradise Beach, water temperatures would remain below the 64°F 7DADM NMFS threshold 100% of the time from December through March, and about 95% of the time during April, under both the Modified FMS and the 2006 FMS. During May, water temperatures under the Modified FMS would be cooler about 25% of the time when water temperatures under the 2006 FMS exceed the 64°F 7DADM NMFS threshold. During June, water temperatures under the Modified FMS would be cooler (up to 1°F) nearly 40% of the time when water temperatures under the 2006 FMS exceed the 64°F 7DADM NMFS threshold.

3.3 Steelhead

3.3.1 Spawning Habitat Availability

Habitat duration for steelhead spawning under the Modified FMS and the 2006 FMS scenarios are presented in **Figure 26**. The Modified FMS and the 2006 FMS scenarios provide 80% or more of maximum spawning WUA with similar probabilities (about 47 and 49%, respectively). The Modified FMS provides somewhat lesser amounts of spawning habitat when both the Modified FMS and the 2006 FMS provide 80% or more of maximum spawning habitat, although these slight differences are not biologically meaningful (see previous discussion for fall-run Chinook salmon).

The Modified FMS and 2006 FMS would provide similar amounts of spawning habitat when both the Modified FMS and 2006 FMS would provide less than 80% of maximum habitat.

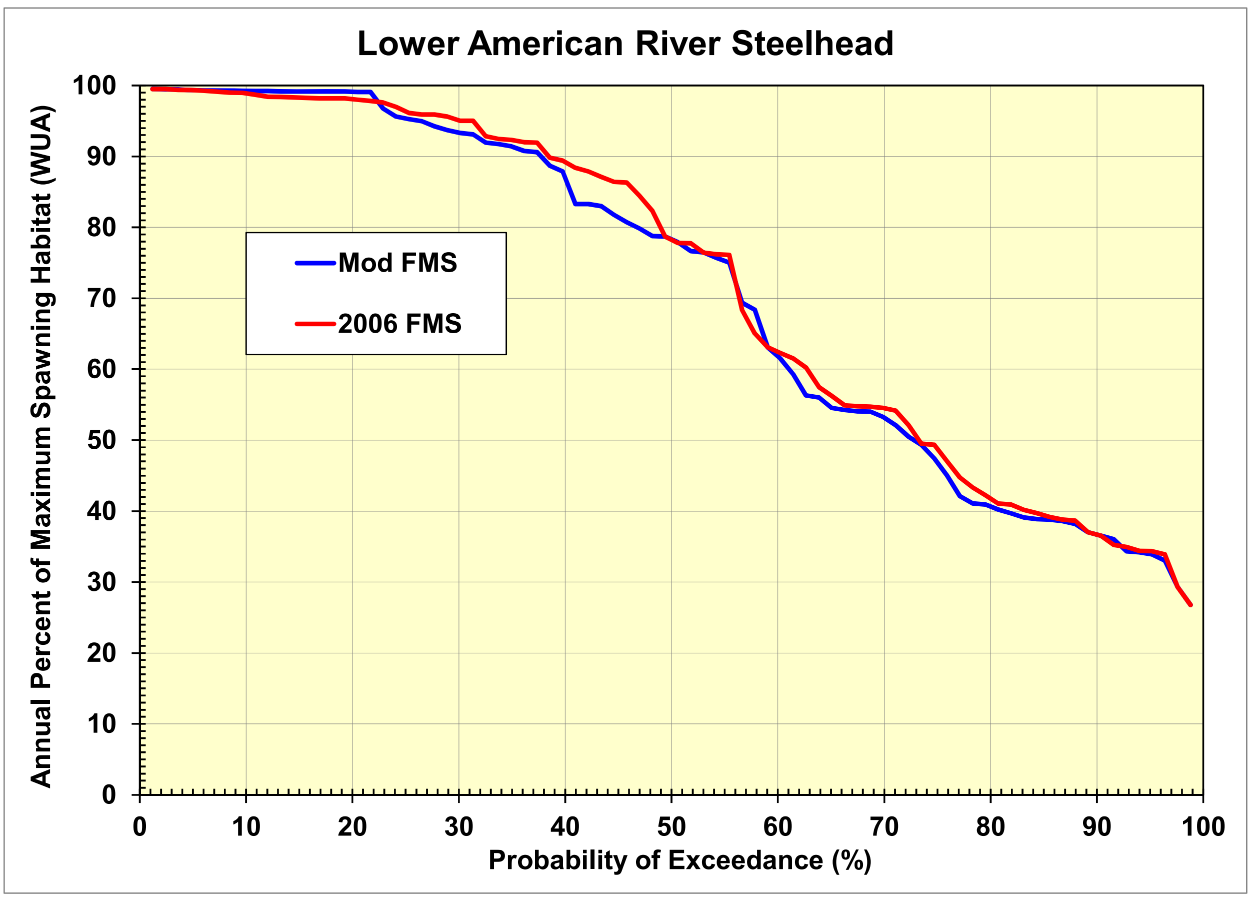

Figure 26. Comparison of steelhead spawning habitat duration over the 82-year hydrologic simulation period for the Modified FMS and 2006 FMS scenarios.

3.3.2 Potential Redd Dewatering

During the days over the 82-year simulation period when spawning occurred when flows were not under flood control operations, the long-term annual averages and the averages by water year types of the percentages of steelhead redds potentially dewatered for at least one day under the Modified FMS and 2006 FMS are presented in **Table 13**. Very little steelhead redd dewatering would be expected to occur under these conditions, with even less potential redd dewatering under the Modified FMS than under the 2006 FMS. The long-term average percentage of steelhead redds potentially dewatered would be only 0.7% under the Modified FMS, relative to 1.8% under the 2006 FMS. Thus, the Modified FMS would provide an estimated -1.1% long-term average reduction in potential redd dewatering relative to the 2006 FMS. No redd dewatering would be expected to occur under either the Modified FMS or the 2006 FMS under wet or above normal water years. Relative to the 2006 FMS, less potential redd dewatering would occur under the Modified FMS relative to the 2006 FMS during below normal, dry, and critical years. During critical years, when conditions could be expected to be most stressful for steelhead, the Modified FMS would reduce potential redd dewatering by 5.1%.

Table 13. Long-term average and average by water year type potential steelhead redd dewatering, under the Modified FMS relative to the 2006 FMS.

Scenario	Long-term Full Simulation Period[2]	WYTs[1]				
		Wet	Above Normal	Below Normal	Dry	Critical
Mod FMS	0.7	0.0	0.0	2.1	0.9	1.2
2006 FMS	1.8	0.0	0.0	2.5	1.9	6.3
Difference	-1.1	0.0	0.0	-0.4	-1.0	-5.1

[1] As defined by the Sacramento Valley Index (SVI) WY Hydrologic Classification.
[2] Based on the WY 1923-2003 simulation period.

3.3.3 Pulse Flow Events

As described in Section 3.2.3, model simulation results indicate that there would be an additional 13 years when a pulse flow event would occur under the Modified FMS, relative to the 2006 FMS, ranging from 3,072 cfs up to 4,000 cfs.

3.3.4 Water Temperature Suitability

Figures D-25 through D-48 in Attachment D display the daily water temperature exceedance probabilities, by month, during each of the steelhead adult lifestages under the Modified FMS and 2006 FMS. Water temperature index values are overlain on the exceedance plots. Water temperature index values and metrics (i.e., 7DADM) are those presented in the NMFS 2017 BO, and are repeated here for comparative consistency. Because the NMFS 2017 BO stated that both the 7DADM and average daily metrics were used, the first set of Figures (D-25 through D-36) in Attachment D display the water temperature exceedance probabilities, by month, with the 7DADM metric and criteria overlain on the plots, and Figures D-37 through D-48 display the average daily metric and criteria overlain on the plots. Although the NMFS 2017 BO did not evaluate water temperatures downstream of Watt Avenue, a downstream location (Paradise Beach – RM 5.4) was used as an evaluation location in this document for migration and holding lifestages. Also, Watt Avenue was the downstream location used to assess spawning water temperatures because 98% of all steelhead redds are located at or upstream of that location (See Attachment C).

3.3.4.1 Adult Immigration

Relative to the 2006 FMS, overall, the Modified FMS would result in more suitable water temperature conditions during the steelhead adult immigration period. The Modified FMS would provide more suitable water temperatures, typically up to about 1°F cooler than the 2006 FMS, when the water temperatures under the 2006 FMS exceed the 68°F 7DADM NMFS threshold at Paradise Beach (about 30% of the time) and at Watt Avenue (about 25% of the time) during September). At Hazel Avenue during September, water temperatures under the Modified FMS would be up to about 1.5°F cooler (about 5% of the time) than the 2006 FMS, when the water temperatures under the 2006 FMS exceed the 68°F 7DADM NMFS threshold.

During October, water temperatures would remain below the 68°F 7DADM NMFS threshold nearly all of the time at Hazel Avenue and more than 90% of the time at Watt Avenue under both the Modified FMS and the 2006 FMS. At Paradise Beach, water temperatures under the Modified FMS would be similar to the 2006 FMS, and both scenarios would exceed the 68°F 7DADM NMFS threshold over 10% of the time. Water temperatures would remain below the 68°F 7DADM NMFS threshold all of the time from November through March at all locations under both the Modified FMS and 2006 FMS scenarios.

The NMFS 2017 BO also used the average daily water temperature metric and the threshold of 70°F to assess adult steelhead immigration. During September, water temperatures would remain below the 70°F average daily NMFS threshold nearly all of the time at Hazel Avenue under both the Modified FMS and the 2006 FMS. At Watt Avenue and Paradise Beach, water temperatures under the Modified FMS would be about 1°F cooler (over 5% of the time) than the 2006 FMS, when the water temperatures under the 2006 FMS exceed the 70°F NMFS threshold during September. Water temperatures would remain below the 70°F average daily NMFS threshold all of the time from October through March at all locations under both the Modified FMS and 2006 FMS scenarios.

3.3.4.2 Adult Holding

The Modified FMS would result in more suitable water temperature conditions than the 2006 FMS during the fall portion of the adult holding period. The Modified FMS would provide more suitable (up to about 1.5°F cooler) water temperatures than the 2006 FMS about 30% and 25% of the time during September when the water temperatures under the 2006 FMS exceed the 61°F 7DADM NMFS threshold at Paradise Beach and at Watt Avenue, respectively. Also during September, cooler water temperatures would be provided over the lower (warmest) 30% of the distribution at Hazel Avenue, when the Modified FMS would provide water temperatures up to about 1.5°F cooler than the 2006 FMS.

During October, water temperatures under the Modified FMS would be slightly cooler than the 2006 FMS (about 20% of the time) when water temperatures exceed the 61°F 7DADM NMFS threshold at Hazel Avenue, nearly 70% of the time at Watt Avenue, and about 35% of the time at Paradise Beach. During November, water temperatures are similar under both the Modified FMS and the 2006 FMS and exceed the 61°F 7DADM NMFS threshold about 5-20% of the time at all three locations. From December through March, water temperatures would remain below the 61°F 7DADM NMFS threshold 100% of the time at Hazel Avenue, and nearly 100% of the time at Watt Avenue and Paradise Beach, under both the Modified FMS and the 2006 FMS.

3.3.4.3 Adult Spawning

Water temperatures are very similar between the Modified FMS and the 2006 FMS during December and exceed the 53°F average daily NMFS threshold about 30% of the time at Hazel Avenue, and nearly 15% of the time at Watt Avenue. During January, water temperatures would remain below the 53°F average daily NMFS threshold all of the time at both locations under both the Modified FMS and 2006 FMS scenarios, and about 95% of the time at Watt Avenue during February. During March, water temperatures under the Modified FMS would be slightly cooler (up to about 1°F) about 15% of the time at Hazel Avenue and about 25% of the time at Watt Avenue when water temperatures would exceed the 53°F average daily NMFS threshold.

3.3.4.4 Incubation through Emergence

Because the same water temperature index values and metrics, as well as locations, are applied to the embryo incubation through emergence lifestage as to the spawning lifestage, the immediately preceeding results also pertain to embryo incubation theough emergence from December through March. During April, water temperatures under the Modified FMS would be slightly cooler about 15% of the time at Hazel Avenue and over 15% of the time at Watt Avenue when water temperatures would exceed the 53°F average daily NMFS threshold. Water temperatures during May would exceed the 53°F average daily NMFS threshold under both the Modified FMS and the 2006 FMS over 85% of the time at Hazel Avenue and nearly 95% of the time at Watt Avenue, but the Modified FMS would be cooler (up to nearly 2°F) than the 2006 FMS over 30% of the time at Hazel Avenue and about 20% of the time at Watt Avenue.

3.3.4.5 Juvenile Rearing and Emigration

At Hazel Avenue, water temperatures would remain below the 63°F average daily NMFS threshold 100% of the time from November through April, and nearly 100% of the time during May, under both the Modified FMS and the 2006 FMS. During June, water temperatures under the Modified FMS would be cooler (up to 1°F) over 10% of the time when water temperatures under the 2006

FMS exceed the 63°F NMFS threshold. Water temperatures under the Modified FMS would be cooler (up to 1°F) during July about 25% of the time, during August about 25% of the time, and during September about 30% of the time when water temperatures under the 2006 FMS exceed the 63°F average daily NMFS threshold. During October, water temperatures under both the Modified FMS and the 2006 FMS would be similar, exceeding the 63°F NMFS threshold about 25% of the time.

At Watt Avenue, water temperatures would remain below the 63°F average daily NMFS threshold 100% of the time from November through March, and nearly 100% of the time during April, under both the Modified FMS and the 2006 FMS. During May, water temperatures under the Modified FMS would be cooler over 15% of the time when water temperatures under the 2006 FMS exceed the 63°F NMFS threshold. During June, water temperatures under the Modified FMS would be cooler (up to 1°F) over 35% of the time when water temperatures under the 2006 FMS exceed the 63°F NMFS threshold. Water temperatures under the Modified FMS would be cooler (up to 1°F) during July about 25% of the time, during August about 35% of the time, and during September about 30% of the time when water temperatures under the 2006 FMS exceed the 63°F NMFS threshold. During October, water temperatures under both the Modified FMS and the 2006 FMS would be similar, exceeding the 63°F NMFS threshold about 25% of the time.

At Paradise Beach, water temperatures would remain below the 63°F average daily NMFS threshold 100% of the time from November through March, and nearly 100% of the time during April, under both the Modified FMS and the 2006 FMS. During May, water temperatures under the Modified FMS would be cooler about 20% of the time when water temperatures under the 2006 FMS exceed the 63°F NMFS threshold. During June, water temperatures under the Modified FMS would be cooler (up to 1°F) nearly 40% of the time when water temperatures under the 2006 FMS exceed the 63°F NMFS threshold. Water temperatures under the Modified FMS would be cooler (up to 1°F) during July about 25% of the time, and during August and September over 30% of the time, when water temperatures under the 2006 FMS exceed the 63°F NMFS threshold. During October, water temperatures under both the Modified FMS and the 2006 FMS would be similar, exceeding the 63°F NMFS threshold about 35% of the time.

3.3.4.6 Smolt (Yearling+) Emigration

At Hazel Avenue, water temperatures under both the Modified FMS and the 2006 FMS would remain below the 61°F 7DADM NMFS threshold 100% of the time from January through March, and nearly 100% of the time during April. At Watt Avenue, water temperatures would remain below the 64°F 7DADM NMFS threshold 100% of the time from January through March under both the Modified FMS and the 2006 FMS. During April, water temperatures under the Modified FMS would be cooler about 5% of the time at Watt Aveune when water temperatures exceed the 64°F 7DADM NMFS threshold. At Paradise Beach, water temperatures under the Modified FMS and the 2006 FMS would remain below the 64°F 7DADM NMFS threshold 100% of the time from January through March. During April, water temperatures under the Modified FMS would be cooler about 5% of the time at Paradise Beach when water temperatures exceed the 64°F 7DADM NMFS threshold.

4.0 CONCLUSIONS

4.1 Fall-run Chinook Salmon

Based on spawning habitat availability, potential redd dewatering, pulse flow occurrences and water temperature suitability evaluations in the lower American River, it is concluded that, relative to the 2006 FMS, the Modified FMS would be expected to provide:

- More suitable adult immigration conditions, because of improved water temperature conditions particularly during June, July, August and September.
- More suitable adult pre-spawn staging conditions, because of improved water temperature conditions particularly during June, July, August and September.
- Generally similar adult spawning conditions, because of similar amounts of spawning habitat when both the Modified FMS and 2006 FMS provide less than 80% of maximum WUA, and because of slightly cooler water temperatures during October, and slightly warmer water temperatures during November.
- Generally similar embryo incubation through emergence conditions because: (1) the difference in the long-term average of potential fall-run Chinook salmon redd dewatering is less than 1% and, during critical years, when conditions could be expected to be most stressful for fall-run Chinook salmon, the Modified FMS would reduce potential redd dewatering by 1.9%; and (2) of slightly cooler water temperatures during October and March, and slightly warmer water temperatures during November.
- More suitable juvenile rearing and emigration conditions, because of an increased occurrence of pulse flows generally corresponding to dry and below normal water year types, and improved water temperature conditions particularly during May and June.

In conclusion, in consideration of potential effects to fall-run Chinook salmon, the Modified FMS, relative to the 2006 FMS, would result in an equivalent or increased level of protection for fall-run Chinook salmon in the lower American River.

4.2 Steelhead

Based on spawning habitat availability, potential redd dewatering, pulse flow occurrences and water temperature suitability evaluations in the lower American River, it is concluded that, relative to the 2006 FMS, the Modified FMS would be expected to provide:

- More suitable adult immigration conditions, because of improved water temperature conditions particularly during September.

- More suitable adult holding conditions, because of improved water temperature conditions particularly during September and October.
- Generally similar adult spawning conditions, because of similar amounts of spawning habitat when both the Modified FMS and 2006 FMS provide less than 80% of maximum WUA, and because of slightly cooler water temperatures during March.
- More suitable embryo incubation through emergence conditions because of: (1) an estimated 1.1% long-term average reduction in potential steelhead redd dewatering relative to the 2006 FMS and, during critical years, when conditions could be expected to be most stressful for steelhead, the Modified FMS would reduce potential redd dewatering by 5.1%; and (2) improved water temperature conditions particularly during March, April and May.
- More suitable juvenile rearing and emigration conditions, because of an increased occurrence of pulse flows generally corresponding to dry and below normal water year types, and improved water temperature conditions during May through September.
- More suitable smolt emigration conditions, because of an increased occurrence of pulse flows generally corresponding to dry and below normal water year types, and generally similar water temperature conditions.

In conclusion, in consideration of potential effects to steelhead, the Modified FMS, relative to the 2006 FMS, would result in an increased level of protection for steelhead in the lower American River.

5.0 REFERENCES

Alameda County Superior Court. 1990. Statement of Decision. Environmental Defense Fund, Inc., et al. (Plaintiff) v. East Bay Municipal Utility District, et al. (Defendants), County of Sacramento, et al. (Intervenors). No. 425955.

Bratovich, P., C. Addley, D. Simodynes, and H. Bowen. 2012. Water Temperature Considerations for Yuba River Basin Anadromous Salmonid Reintroduction Evaluations. Prepared for: Yuba Salmon Forum Technical Working Group. October 2012.

CBEC 2014. 2013 Chinook Salmon Potential Redd Dewatering Estimate. CBEC Technical Memorandum, Project 13-1042 – Lower American River Redd Dewatering Analysis, January 16, 2014, 4 pp.

CDFG. 1986. Instream Flow Requirements of the Fish and Wildlife Resources of the Lower American River, Sacramento County, California. Department of Fish and Game Stream Evaluation Report No. 86-1.

California Department of Fish and Game (CDFG). 1991. Steelhead Restoration Plan for the American River. State of California Department of Fish and Game. 1991.

CDFG. 1998. A Status Review of the Spring-Run Chinook Salmon (*Oncorhynchus Tshawytscha*) in the Sacramento River Drainage. Candidate Species Status Report 98-01. Sacramento, CA: Department of Fish and Game.

CDFG. 2000. Fall-run Chinook Salmon Weekly Catch Distribution. Preliminary Data Obtained from Bill Snider on July 10, 2000.

Crisp, D.T. 1981. A Desk Study of the Relationship between Temperature and Hatching Time for the Eggs of Five Species of Salmonid Fishes. Freshwater Biology 11:361-368.

Crisp, D.T. 1988. Prediction, from Temperature, of Eyeing, Hatching and 'Swim-up' Times for Salmonid Embryos. Freshwater Biology 19:41-48.

FERC (Federal Energy Regulatory Commission). 1993. Proposed modifications to the Lower Mokelumne River Project, California: FERC Project No. 2916-004 (Licensee: East Bay Municipal Utility District). FERC, Division of Project Compliance and Administration, Washington, D. C., Final Environmental Impact Statement.

Gard, M. 2003. Comparison of PHABSIM and 2-D Modeling of Habitat for Steelhead and Fall-run Chinook Salmon Spawning in the Lower American River.

Gerstung, E.R. 1971. Fish and Wildlife Resources of the American River. Department of Fish and Game, Technical Report.

Hannon, J. and B. Deason. 2005. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001-2005. US Bureau of Reclamation, Central Valley Project, American River, California, Mid-Pacific Region. October 2005.

Hannon, J. and B. Deason. 2008. American River Steelhead (*Oncorhynchus mykiss)* Spawning 2001-2007. U.S. Bureau of Reclamation, Central Valley Project, American River, California Mid-Pacific Region.

Hannon, J., M. Healey, and B. Deason. 2003. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001-2003. US Bureau of Reclamation, Central Valley Project, American River, California, Mid-Pacific Region. October 2005.

Humpesch, V. H. 1985. Inter- and intra-specific variation in hatching success and embryonic development of five species of salmonids and *Thymallus thymallus*. Arch. Hydrobiol. 104, 129–144.

Kamler, E. and T. Kato. 1983. Efficiency of Yolk Utilization by *Salmo gairdneri* in Relation to Incubation Temperature and Egg Size. Polskie Archiwum Hydrobiologii 30:271-306.

McEwan, D. 2001. Central Valley Steelhead in Contributions to the Biology of Central Valley Salmonids. Brown, R. L. (ed.), Sacramento, CA: California Department of Fish and Game, pp 1-43.

McEwan, D. and T. Jackson. 1996. Steelhead Restoration and Management Plan for California. California Department of Fish and Game, Sacramento, California.

Moyle, P.B. 1976. Inland Fishes of California. University of California Press. Berkeley.

Murray, C. B., and J. McPhail. 1988. Effect of Incubation Temperature on the Development of Five Species of Pacific Salmon (*Oncorhynchus*) Embryos and Alevins. Canadian Journal of Zoology 66: 266-273.

Myrick, C.A., and J. Cech. 2001. Temperature Effects on Chinook Salmon and Steelhead: A Review Focusing on California's Central Valley Populations. Bay-Delta Modeling Forum, Technical Publication 01-1.

NMFS. 2000. Biological Opinion in October 2000 to evaluate the Preferred Alternative described in the 1999 FEIS/EIR.

NMFS. 2001. Final Biological Opinion Concerning the Effects of Operations of Englebright Dam and Daguerre Point Dam on the Yuba River, California, the Threatened Central Valley Spring-Run Chinook Salmon (Oncorhynchus tshawytscha), the Central Valley Steelhead (O. mykiss), and Their Respective Designated Critical Habitats. SWR-01-SA-6020:MET. U.S. Department of Commerce.

NMFS. 2002. Biological Opinion on Interim Operations of the Central Valley Project and State Water Project Between April 1, 2002 and March 31, 2004, on Federally Listed Threatened Central Valley Spring-Run Chinook Salmon and Threatened Central Valley Steelhead in Accordance With Section 7 of the Endangered Species Act of 1973, As Amended. Long Beach: National Marine Fisheries Service, Southwest Region.

NMFS. 2009. Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project.

NMFS. 2017. Endangered Species Act Section 7(a)(2) Biological Opinion, Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Response, and Fish and Wildlife Coordination Act Recommendations for the California WaterFix Project in Central Valley, California. NMFS Consultation Number: WCR-2016-5506

NMFS and USFWS. 2013. Biological Opinions on the Effects of Proposed Klamath Project Operations from May 31, 2013, through March 31, 2023, on Five Federally Listed Threatened and Endangered Species. May 2013.

Newcomb T.J. and T.G. Coon. 2001. Evaluation of three methods for estimating numbers of steelhead smolts emigrating from Great Lakes tributaries. North American Journal of Fisheries Management 21(3):548-560.

Pacific States Marine Fisheries Commission (PSMFC). 2014a. Juvenile Salmonid Emigration Monitoring in the Lower American River, California January – June 2013. Unpublished report prepared for the U.S. Fish and Wildlife Service and California Department of Fish and Wildlife, Sacramento, California. 54 pp.

PSMFC. 2014b. Juvenile Salmonid Emigration Monitoring in the Lower American River, California January – May 2014. Unpublished report prepared for the U.S. Fish and Wildlife Service and California Department of Fish and Wildlife, Sacramento, California. 112 pp.

Redding, J. M. and C. B. Schreck. 1979. Possible Adaptive Significance of Certain Enzyme Polymorphisms in Steelhead Trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 36:544-551.

Rich, A.A. 1987. Water Temperatures Which Optimize Growth and Survival of the Anadromous Fishery Resources of the Lower American River.

Rombough, P. J. 1988. Growth, Aerobic Metabolism, and Dissolved Oxygen Requirements of Embryos and Alevins of Steelhead, *Salmo gairdneri*. Canadian Journal of Zoology 66:651-660.

Seymour, A. H. 1956. Effects of Temperature on Young Chinook Salmon. 915, 1001. University of Washington, Seattle, WA.

Silva, J., and K. Bouton. 2015. Juvenile Salmonid Emigration Monitoring in the Lower American River, California January – May 2015. Unpublished report prepared for the U.S. Fish and Wildlife Service and California Department of Fish and Wildlife, Sacramento, California.

Snider, B. and N. Keenan. 1994. Fish Community Survey, Lower American River, January through June 1993. Final Report. California Department of Fish and Game. May 1994.

Snider, B. and D. McEwan. 1992. Chinook Salmon and Steelhead Trout Redd Survey, Lower American River, 1991-1992. California Department of Fish and Wildlife, Environmental Services Division, 94 p.

Snider, B. and McEwan, D. 1993. Fish Community Survey, Lower American River, February-July 1992. Department of Fish and Game, Stream Evaluation Program, Environmental Services Division. 94 pp. January 1993.

Snider, B. and R. Titus. 1995. Lower American River Emigration Survey: November 1993-July 1994. California Department of Fish and Game, Environmental Sciences Division, Stream Flow and Habitat Evaluation Program. August 1995.

Snider, B. and R. Titus. 1996. Fish Community Survey, Lower American River, January through June 1995. California Department of Fish and Game, Environmental Services Division. April 1996.

Snider, B., R. Titus, and B. Payne. 1997. Lower American River Emigration Survey: November 1994 September 1995. Draft Report. California Department of Fish and Game, Environmental Sciences Division, Stream Evaluation Program. July 1997.

Snider, B., R. Titus, and B. Payne. 1998. Lower American River Emigration Survey: October 1995–September 1996. California Department of Fish and Game, Environmental Sciences Division, Stream Evaluation Program. September 1998.

Snider, B., B. Reavis, and J. Hill. 2001. Upper Sacramento River Fall-Run Chinook Salmon Escapement Survey: September-December 2000. California Department of Fish and Game, Environmental Sciences Division, Stream Habitat Evaluation Program.

Surface Water Resources, Inc. (SWRI). 2001. Aquatic Resources of the Lower American River: Baseline Report. Prepared for the Lower American River Fisheries and lnstream Habitat (FISH) Working Group.

Timoshina, L. A. 1972. Embryonic Development of the Rainbow Trout (*Salmo gairdneri irideus* (Gibb.)) at Different Temperatures. Journal of Ichthyology 12:425-432.

Titus, R.G. and M. Brown. 2006. Juvenile Steelhead Response to Summer Habitat Conditions on the Lower American River. Presentation at American River Watershed Conference 2005.

United States Bureau of Reclamation (Reclamation). 1991. Appendixes to Shasta Outflow Temperature Control Planning Report/Environmental Statement. (Appendix A: Modeling; Appendix B: part I – Fisheries, Part II – Recreation, Part III – Cultural Resources; Appendix C: Design and Cost Estimates). United States Department of Interior, Bureau of Reclamation, Mid-Pacific Region. November 1990, Revised May 1991.

Reclamation. 1997. Central Valley Improvement Act, Draft Programmatic Environmental Impact Statement: Technical Appendix, Volume III. Sacramento, CA: U.S. Bureau of Reclamation.

Reclamation. 2016. Biological Assessment for the California WaterFix. July 2016.

Reclamation and NMFS. 2014. Water Temperature Evaluation Methodology Technical Memorandum. Structural Improvements for Lower American River Water Temperature Management. Value Planning Workshop. Prepared by HDR and cbec.

United States Environmental Protection Agency (EPA). 2002. National Recommended Water Quality Criteria: 2002. Report No. EPA-822-R-02-047.

United States Fish and Wildlife Service (USFWS). 1995. Working Paper on Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California. Vol. 2. Stockton, CA: U.S. Fish and Wildlife Service.

Velsen, F. P. 1987. Temperature and Incubation in Pacific Salmon and Rainbow Trout: Compilation of Data on Median Hatching Time, Mortality and Embryonic Staging. Canadian Data Report of Fisheries and Aquatic Sciences 626. Nanaimo, BC: Department of Fisheries and Oceans, Fisheries Research Branch.

Water Forum. 2005. Impacts on Lower American River Salmonids and Recommendations Associated with Folsom Reservoir Operations to Meet Delta Water Quality Objectives and Demands (Draft Report). Prepared by Surface Water Resources, Inc. January. Available at www.waterforum.org.

YCWA, DWR, and Reclamation. 2007. Draft Environmental Impact Report/ Environmental Impact Statement for the Proposed Lower Yuba River Accord. Prepared by HDR|Surface Water Resources, Inc. June 2007.

Yoshiyama, R.M., E. Gerstung, F. Fisher, P. Moyle. 1996. Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California. *Sierra Nevada Ecosystem Project: Final report to Congress,* vol. III, *Assessments, Commissioned Reports, and Background Information.* Davis: University of California, Centers for Water and Wildland Resources, 1996.

Zedonis, P. A. and T. J. Newcomb. 1997. An Evaluation of Flow and Water Temperatures During the Spring for Protection of Salmon and Steelhead Smolts in the Trinity River, California. Arcata, CA: U.S. Fish and Wildlife Service, Coastal California Fish and Wildlife Office.

Zeug, S. C., K. Sellheim, C. Watry, B. Rook, J. Hannon, J. Zimmerman, D. Cox, and J. Merz. 2013. Gravel Augmentation Increases Spawning Utilization by Anadromous Salmonids: A Case Study from California, USA. River Research and Applications.

Biological Rationale, Development and Performance of the Modified Flow Management Standard

Attachment A

Lower American River Adult Anadromous Salmonid Immigration Temporal Distribution

November 29, 2017

1.0 Fall-run Chinook Salmon

In the Central Valley, adult fall-run Chinook salmon are reported to generally begin migrating upstream annually in July, with immigration continuing through December in most years (Vogel and Marine 1991). It has been reported that adult fall-run Chinook salmon typically begin entering the lower American River in September and October, and continue through January (SWRI 2001). Both historic (fish passage at Old Folsom Dam, 1944-1946) and recent survey data indicate that adult Chinook salmon arrivals in the lower American River peak in November.

It has generally been reported in the literature that fall-run Chinook salmon spend a variable, but relatively short, amount of time in their natal rivers prior to the onset of spawning activity. For example, Moyle (2002) states that, in California, fall-run Chinook salmon typically spawn within a few days or weeks of arriving on the spawning grounds. The lifestage of adult fall-run Chinook salmon in a river prior to spawning is referred to as “staging”, by contrast to other runs (i.e., spring-run) which typically migrate to their natal streams during spring and “hold” over summer until spawning during early fall.

Estimates of the time spent staging by fall-run Chinook salmon prior to spawning are typically based upon enumeration of immigrating adult fall-run Chinook salmon through a weir located in the lower reaches of a river, electronic and/or photogrammetric recording devices, or through monitoring surveys of live fish concurrently with redd surveys. Such data have not been collected in the lower American River. However, as part of a study to evaluate angler effort and harvest of anadromous fishes in the Central Valley recreational river fishery, CDFW has performed periodic creel censuses in the lower American River that provide estimates of the fall-run Chinook salmon monthly catch, both retained and released, that can be used to assess the temporal distribution of pre-spawning adult fall-run Chinook salmon in the lower American River.

The lower American River Chinook salmon pre-spawn arrival temporal distributions have the potential to be influenced by the straying of late fall-run Chinook salmon into the lower American River, as was particularly evidenced during the 2008/09 spawning season. Chinook salmon have been encountered in the CDFG carcass surveys (Vincik and Kirsch 2009; Healey and Redding 2008; Healey and Fresz 2007; Healey 2005, 2004) through the month of January, although a low percentage of fresh carcasses have been encountered after the first week of January (generally 0.2 to 3%). The highest number of fresh Chinook salmon carcasses encountered after the first week of January was observed during the 2008/2009 survey season, when 12% of all fresh carcasses were observed after the first week of January 2009 (Vincik and Kirsch 2009). Spawning during the latter part of January is somewhat atypical of fall-run, but is phenotypically consistent with late fall-run Chinook salmon. During the 2008/2009 surveys, recovery and analysis of 53 coded-wire tagged (CWT) carcasses obtained throughout the month of January 2009 documented that all of them were late fall-run Chinook salmon strays originating from the Coleman National Fish Hatchery on

Battle Creek. In addition to adipose fin-clipped (i.e., hatchery) carcasses, non-adipose fin-clipped carcasses also were encountered during January. Vincik and Kirsch (2009) speculated that the late spawning Chinook salmon in the lower American River may be attributable to the straying of hatchery-origin fish as well as presumed wild Chinook salmon from other systems, and is not likely a self-sustaining run within the lower American River. However, they recognize the need to further explore this issue in future monitoring efforts. More recently, Kormos et al. (2012) found that relative to the total of 23,945 Chinook salmon carcasses sampled during 2010/2011, 162 (less than 1% of all Chinook salmon) were classified as late fall-run Chinook salmon, of which approximately 23% (37 fish) were of hatchery origin.

1.1 Methods

1.1.1 CDFW Angler Surveys

During each annual angler survey, the number of anglers and the number of fish caught and retained, and caught and released, were sampled by CDFW over 3 sections of the lower American River extending from Discovery Park to Nimbus Dam, on 8 randomly selected days (4 weekend, 4 weekday) per month and river section. Three primary statistical descriptors were calculated for each month and river section: (1) angling effort in terms of angler-hours; (2) catch-per-unit-effort (CPUE) in terms of fish per angler-hour for each target species; and (3) catch for each target species. For each species, results were presented in tables displaying the total number of angler-hours targeting the species, the estimated catch (kept and released), by month and river section.

The estimated monthly catches of adult fall-run Chinook salmon in the lower American River obtained from available CDFW angler survey reports[1] (e.g., Wixom et al. 1995; Murphy et al. 1999; Murphy et al. 2001a and 2001b; Schroyer et al. 2002; Massa and Schroyer 2003; and Titus et al. 2008, 2009 and 2010) were used to obtain the temporal distribution of in-river adult fall-run Chinook salmon prior to spawning.

1.1.2 Temporal Distribution Estimation

The temporal distribution of adult fall-run Chinook salmon arrival in the lower American River prior to spawning was estimated by applying the following steps:

1) The monthly catches of adult Chinook salmon kept and released from available annual angler survey reports were summed over the three river sections and organized annually over the period extending from June 1 through May 31 of the following calendar year (**Table A-1**).

[1] Brown and Titus (2007) also was available, although no survey information was reported for the period extending from June through October and, therefore, was not included in the dataset used to develop the cumulative temporal distribution.

2) The monthly catches (of both kept and released fish) each year were divided by that year's annual total catch to obtain relative monthly catch proportions, which were summed and plotted against time (days extending from June 1 through May 31) by allocating each monthly proportion to the last day of the sampled month.

3) An asymmetric logistic function was fitted to all of the monthly cumulative proportions of fish caught during all of the ten years of available data. The resulting curve (**Figure A-1**) was used to represent the temporal distribution of adult Chinook salmon arriving in the lower American River prior to and during the fall-run Chinook salmon spawning season. Because CDFW's angler surveys report the catch on a monthly basis, the catch data was represented for the last day of each month. Because fish could have been captured any day during a month, and June was the first month during which Chinook salmon were reported in the catch data, the asymmetric logistic function was extended to June 1.

   The fitting of the asymmetric logistic function was performed in Excel using the Solver function with a weighted non-linear least squares procedure. The weights were calculated as the ratio of the annual estimated total of Chinook salmon caught for a given year relative to the total number of Chinook salmon caught over the 10 years (i.e., 233,098 fish). For example, the 7 monthly proportions for the 1992/93 analytic year that had a total annual catch of 6,960 fish were multiplied by a weight of 0.029859 (i.e., 6,960 / 233,098 = 0.029859). The weighting procedure was applied to avoid the disproportionate influence of individual monthly proportions relative to all monthly proportions in the estimation of the parameters of the asymmetric logistic function.

Table A-1. Estimated angler's monthly catch of Chinook salmon (both retained and released) in the lower American River, organized by analytic years[1] that extend from June 1 through May 31 of the following calendar year.

Year	Estimated Chinook Salmon Angler's Retained and Released Catch (No. of Fish)													Source
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total	
1991/92	0	1,056	5,999	1,567	2,450	3,906	49	0	0	0	0	0	15,027	Wixon *et al.* (1995)
1992/93	438	503	1,164	219	816	2,461	1,359	0	0	0	0	0	6,960	Wixon *et al.* (1995)
1993/94	73	455	796	2,061	4,685	12,219	211	131	0	0	0	0	20,631	Wixon *et al.* (1995)
1998/99	120	---	933	4,744	16,824	14,697	943	228	0	0	0	0	38,489	Murphy *et al.* (1999, 2001a)
1999/00	707	1,452	1,976	4,840	17,962	20,697	2,728	60	0	0	0	0	50,422	Murphy *et al.* (2001a, 2001b)
2000/01	1,109	693	582	2,020	25,806	10,294	2,559	57	---	0	0	0	43,120	Murphy *et al.* (2001b); Schroyer *et al.* (2002)
2002/03	491	1,330	7,375	4,604	22,136	12,547	258	---	---	---	---	---	48,741	Massa and Schroyer (2003)
2007/08	0	0	464	238	618	1,310	483	524	127	36	0	0	3,800	Titus *et al.* (2008)
2008/09	28	165	295	432	311	1,678	592	451	67	0	0	0	4,019	Titus *et al.* (2009)
2009/10	0	41	0	78	746	547	306	81	90	0	0	0	1,889	Titus *et al.* (2010)
Total													233,098	

1 – Analytic years were established to evaluate the temporal distribution of adult Chinook salmon arrival, extending from June through the following May. June was selected as the initiation of the analytic year because for each of the data sets the first catches were recorded during the month of June.

CDFW does not make any distinction by run assignation to the Chinook salmon in the creel survey reports, and it is not possible to know which fish caught during January (or later) are fall-run or late fall-run Chinook salmon, or a mixed stock.

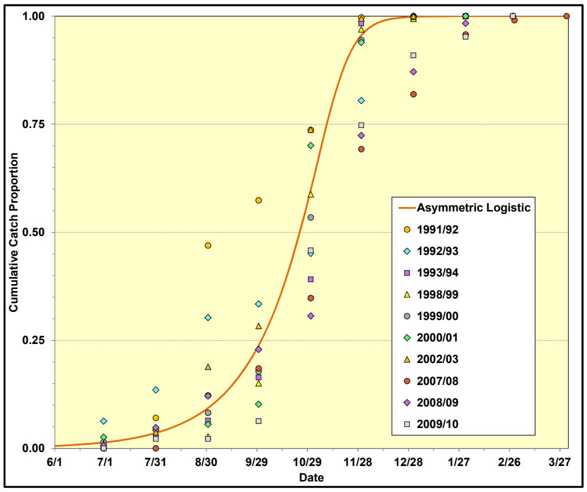

Figure A-1. Chinook salmon monthly proportions of estimated angler's catch in the lower American River, during the 1991/92 – 1993/94, 1998/99 – 2000/01, 2002/03, and 2007/08 – 2009/10 analytic years, and the common fitted asymmetric logistic curve representing the cumulative temporal distribution for all years.

Because there is no dependable quantitative basis to rely upon to exclude data in the analysis, all CDFW Chinook salmon catch data were included in the temporal weighting procedure. In addition, because fish typically exhibit life history periodicities and behaviors that vary somewhat from the anthropogenic characterization of the species/run as a whole, it is possible that some fish spawning later in the season (i.e., January) are fall-run Chinook salmon. However, relatively few adult Chinook salmon are caught after January, representing only about 0.1% of the total number of fish caught included in the CDFW dataset.

The asymmetric logistic function resulting from the weighted least squares fit to the cumulative catch proportions in Figure A-1 had the following expression (Equation 1):

$$Y_D = \left(\frac{1}{1 + \exp(19.1926 - 0.1142 \times D)} \right)^{1/3.6638} \quad \textbf{(1)}$$

where D is the day number, with day 1 starting June 1[2]. The mean square error of the fitted common asymmetric logistic function was 0.0250 (indicating a relatively minor amount of variability in the data set not accounted for by the fitted model). The asymmetric logistic curve of Equation 1 was used to calculate the expected daily proportions of Chinook salmon arriving in the lower American River by subtracting the previous day's value from the cumulative distribution. The final daily proportions of adult fall-run Chinook salmon arriving in the lower American River are presented in **Figure A-2**.

[2] For the adult Chinook salmon arrival temporal distribution analysis, arrival day is the explanatory variable in the asymmetric logistic equation. For this analysis, day 1 was established as June 1 because June represented the first month during which Chinook salmon were reported caught in the angler surveys. Because fish could have been captured any day during June, the asymmetric logistic function was extended to June 1 which represented day 1 in the analyses.

1.2 Comparison of Chinook Salmon Pre-Spawn Arrival and Spawning Temporal Distributions

Figure A-3 compares the middle 99% of the cumulative distribution of fall-run Chinook salmon spawning (green curve (October 25 – December 24), see **Attachment B**) with the middle 99% of the cumulative distribution of fall-run Chinook salmon arrival (orange curve (May 30 – December 19)) in the lower American River in order to estimate staging duration. Because both temporal distributions exhibit extended tails, analyses were conducted on the middle 99% of the distributions to capture the majority of activity, and are not intended to be inclusive of every individual in the population. The red arrows indicate the time (in days) to the onset of spawning associated with particular cumulative proportions of arriving fish. As can be seen from the figure, the duration of staging decreases as the season progresses.

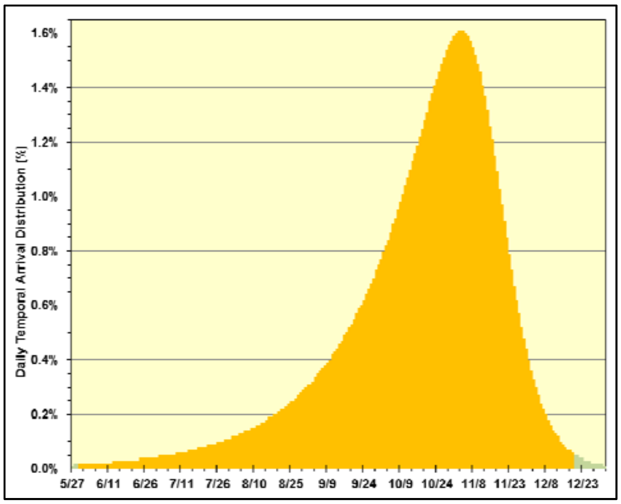

Figure A-2. Daily proportions of adult fall-run Chinook salmon arrival in the lower American River corresponding to the asymmetric logistic function, fitted to CDFW catch data. The middle 99% of the asymmetric logistic function is emphasized (orange shading).

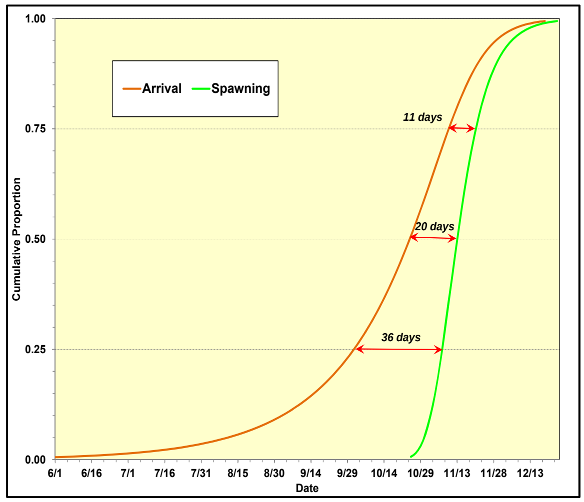

Figure A-3. Comparison of the estimated cumulative temporal distributions developed for pre-spawning arrival and spawning fall-run Chinook salmon in the lower American River.

2.0 Steelhead

Adult steelhead immigration into Central Valley streams typically begins in August and continues into March or April (McEwan 2001; NMFS 2014), and generally peaks during January and February (Moyle 2002). Adult steelhead immigration and holding in the lower American River has previously been reported to begin as early as late spring or early summer, but primarily beginning in November and continuing into April (SWRI 2001). Steelhead immigration has been reported to generally peak during January (CDFG 1986; CDFG unpublished data; SWRI 2001).

Steelhead redd surveys conducted during most survey years from 2002/2003 – 2012/2013 indicate that spawning in the lower American River can begin as early as late-December, but generally extends from January through mid-April, with the vast majority of spawning (nearly 80%) occurring from mid-January through February. Hannon and Deason (2008) reported that peak spawning varies annually, but most frequently occurs during mid-February. Thus, steelhead holding in the lower American River extends from the time of immigration to spawning, which can extend for several months.

As described previously for fall-run Chinook salmon, CDFW has performed periodic creel censuses in the lower American River that provide estimates of the steelhead monthly catch, both retained and released, that can be used to assess the temporal distribution of pre-spawning steelhead in the lower American River.

2.1 Methods

2.1.1 CDFW Angler Surveys

The description of the CDFW angler surveys in the lower American River provided for fall-run Chinook salmon also applies to steelhead. The estimated monthly catches of adult steelhead in the lower American River obtained from available CDFW angler survey reports[3] (e.g., Wixom et al. 1995; Murphy et al. 1999; Murphy et al. 2001a and 2001b; Schroyer et al. 2002; Massa and Schroyer 2003; and Titus et al. 2008, 2009 and 2010) were used to obtain the temporal distribution of in-river adult steelhead prior to spawning. However, the available creel surveys did not provide complete series of anglers' retained and released steelhead catch for the analytic years 1994/95, 2001/02 and 2002/03. These three analytic years were not included in the analysis of steelhead arrival in the lower American River.

2.1.2 Temporal Distribution Estimation

The temporal distribution of adult steelhead arrival in the lower American River prior to spawning was estimated by applying the following steps:

1) The monthly catches of adult steelhead kept and released from available annual angler survey reports were organized annually over the period extending from June 1 through May 31 of the following calendar year (**Table A-2**).

2) The monthly catches (of both kept and released fish) each year were divided by that year's annual total catch to obtain relative monthly catch proportions, which were summed and plotted against time (days extending from June 1 through May 31) by allocating each monthly proportion to the last day of the sampled month.

[3] Brown and Titus (2007) was available, but no survey information was reported for the period extending from June through October and, therefore, was not included in the dataset used to develop the cumulative temporal distribution.

3) An asymmetric logistic function was fitted to the monthly cumulative proportions of fish caught during the nine years of usable data. The fitting of the asymmetric logistic function was performed in Excel using the Solver function with a weighted non-linear least squares procedure, as described previously for fall-run Chinook salmon.

4) It was necessary for the asymmetric logistic function characterizing the arrival distribution not to overlap with the asymmetric logistic function describing the temporal distribution of steelhead spawning. The right-hand tail of the resultant steelhead pre-spawn arrival temporal distribution was constrained to not extend beyond the completion of the estimated steelhead spawning period, as described in **Attachment B**. The dates on which equivalent proportions of the cumulative temporal distributions (i.e., 99.5%, 99.0%, 90%) for both spawning and arrival were examined. The arrival fitted distribution was constrained such that the dates associated with those specified cumulative proportions (i.e., 99.5%, 99.0%, 90%) occur earlier or on the same date as the dates for the corresponding specified cumulative proportions for the spawning distribution.

5) The resulting curve from implementation of the preceding steps was used to represent the temporal distribution of adult steelhead arriving in the lower American River prior to and during the steelhead spawning season (**Figure A-4**).

Table A-2. Estimated anglers' monthly catch of steelhead (both retained and released) in the lower American River, organized by analytic years[1] that extend from June 1 through May 31 of the following calendar year.

Year	Estimated Steelhead Angler's Retained and Released Catch (No. of Fish)													Source
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total	
1991/92	0	0	0	0	0	362	1,987	273	1,294	26	0	0	3,942	Wixon *et al.* (1995)
1992/93	0	0	0	73	26	29	363	65	125	11	55	0	747	Wixon *et al.* (1995)
1993/94	0	0	0	0	85	77	476	515	646	88	32	30	1,949	Wixon *et al.* (1995)
1994/95[2]	0	0	0	0	0	81	546	---	---	---	---	---	627	Wixon *et al.* (1995)
1998/99	0	---	0	0	0	364	635	1,266	630	1,077	711	50	4,733	Murphy *et al.* (1999, 2001a)
1999/00	0	34	583	367	535	865	1,153	1,218	1,331	738	185	0	7,009	Murphy *et al.* (2001a, 2001b)
2000/01	39	0	0	232	0	691	227	1,986	---	1,221	391	0	4,787	Murphy *et al.* (2001b); Schroyer *et al.* (2002)
2001/02[2]	0	---	---	---	---	---	---	---	2,507	1,407	82	46	4,042	Massa and Schroyer (2003)
2002/03[2]	0	0	0	714	595	942	678	---	---	---	---	---	2,929	Massa and Schroyer (2003)
2007/08	68	86	260	995	1,105	806	1,466	1,903	1,863	995	347	0	9,894	Titus *et al.* (2008)
2008/09	0	0	0	201	929	913	809	1,578	2,419	971	586	48	8,454	Titus *et al.* (2009)
2009/10	152	61	350	225	1,155	467	237	744	5,001	2,825	552	171	11,940	Titus *et al.* (2010)
Total													53,455	

1 – Analytic years were established to evaluate the temporal distribution of adult steelhead arrival, extending from June through the following May, to be consistent with the analysis for fall-run Chinook salmon.

2 – The available creel surveys did not provide complete series of angler's steelhead catch for the biological years 1994/95, 2001/02 and 2002/03. These three biological years were not included in the analysis of steelhead arrival.

The asymmetric logistic function resulting from the constrained weighted least squares fit to the cumulative catch proportions in Figure A-4 had the following expression (Equation **Error! Reference source not found.**):

$$Y_D = \left(\frac{1}{1 + \exp(41.3137 - 0.1486 \times D)} \right)^{1/9.0229} \quad \textbf{(2)}$$

where *D* is the day number, with day 1 starting June 1. The mean square error of the fitted common asymmetric logistic function was 0.0526 (indicating a relatively minor amount of variability in the data set not accounted for by the fitted model). The asymmetric logistic curve of Equation 2 was used to calculate the expected daily proportions of steelhead arriving in the lower American River by subtracting the previous day's value from the cumulative distribution. The final daily proportions of the middle 99% of adult steelhead arriving in the lower American River are presented in **Figure A-5**.

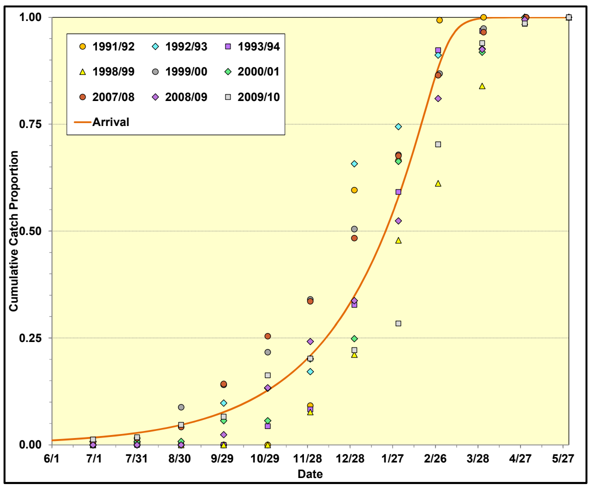

Figure A-4. Steelhead monthly proportions of estimated angler's catch in the lower American River, during the 1991/92–1993/94, 1998/99–2000/01, and 2007/08–2009/10 analytic years, and the common fitted asymmetric logistic curve representing the cumulative temporal distribution for all years.

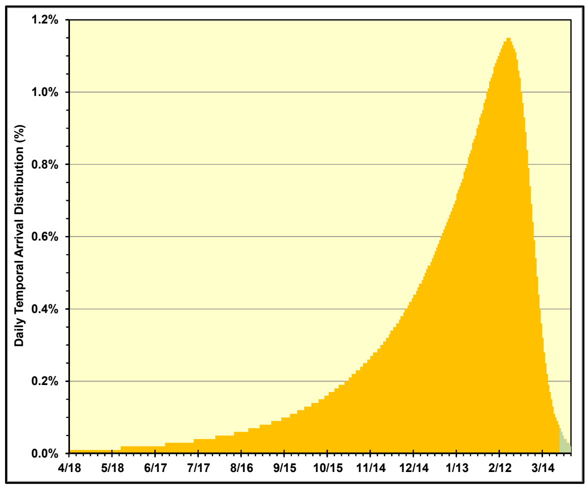

Figure A-5. Daily proportions of adult steelhead arrival in the lower American River corresponding to the asymmetric logistic function, fitted to CDFW catch data. The middle 99% of the asymmetric logistic function is emphasized (orange shading).

2.2 Comparison of Steelhead Pre-Spawn Arrival and Spawning Temporal Distributions

Figure A-6 compares the middle 99% of the cumulative distribution of steelhead spawning (green curve (December 11 – March 29), see Attachment B) with the middle 99% of the cumulative distribution of steelhead arrival (orange curve (April 18 – March 25[4])) in the lower American River in order to estimate holding duration. The red arrows indicate the time (in days) to the onset of spawning associated with particular cumulative proportions of arriving fish. As can be seen from the figure, the duration of holding can be quite extensive, lasting several months, and decreases as the season progresses.

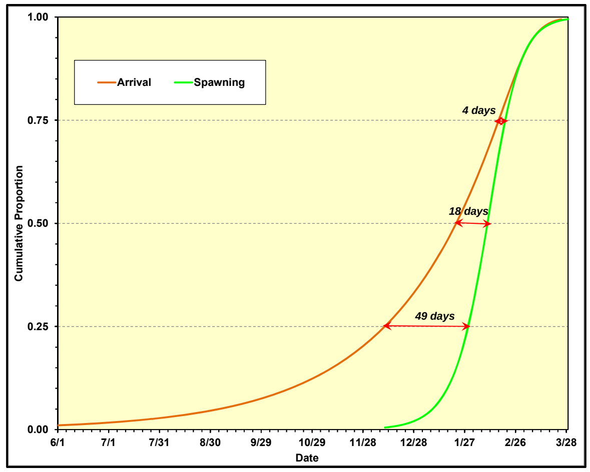

Figure A-6. Comparison of the estimated cumulative temporal distributions developed for pre-spawning arrival and spawning steelhead in the lower American River.

[4] The middle 99% of the steelhead arrival temporal distribution extends from April 18 through March 25, although the graphical depiction extends from June 1 through March 29 for illustrative purposes.

3.0 References

Brown, M. S., and R. G. Titus. 2007. Angler Effort and Harvest of Anadromous Fishes in the Central Valley River Recreational Fishery, 2006 – 2007. California Department of Fish and Game, Inland Fisheries Administrative Report.

CDFG 1986. Instream Flow Requirements of the Fish and Wildlife Resources of the Lower American River, Sacramento County, California. Department of Fish and Game Stream Evaluation Report No. 86-1.

Hannon, J., and B. Deason. 2008. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001 – 2007. Central Valley Project, American River, California, Mid-Pacific Region.

Healey, M. 2004. Lower American River Chinook Salmon Escapement Survey October 2003–January 2004. California Department of Fish and Game, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 15 p.

Healey, M. 2005. Lower American River Chinook Salmon Escapement Survey October 2004 – January 2005. California Department of Fish and Game, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 15 p.

Healey, M. and S. Fresz. 2007. Lower American River Chinook Salmon Escapement Survey, October 2006- December 2007. California Department of Fish and Game, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 14 p.

Healey, M. and J. Redding. 2008. Lower American River Chinook Salmon Escapement Survey October 2007 – January 2008. California Department of Fish and Game, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 14 p.

Kormos, B., M. Palmer-Zwahlen, and A. Low. 2012. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement and Ocean Harvest in 2010. Fisheries Branch Administrative Report 2012-02. California Department of Fish and Game. March 2012.

Massa, D. A. and T. Schroyer. 2003. Central Valley Salmon and Steelhead Harvest Monitoring Project, 2002 Angler Survey. California Department of Fish and Game, Sacramento Valley – Central Sierra Region, CA, 48 p.

McEwan, D. 2001. Central Valley Steelhead in Contributions to the Biology of Central Valley Salmonids. Brown, R. L. (ed.), Sacramento, CA: California Department of Fish and Game, pp 1-43.

Moyle, P.B. 2002. Inland Fishes of California, University of California Press, Ltd., London, England, 502 p.

Murphy, K., L. Hanson, M. Harris and T. Schroyer. 1999. Central Valley Salmon and Steelhead Harvest Monitoring Project, 1998 Angler Survey. California Department of Fish and

Game, Sacramento Valley – Central Sierra Region, CA, 28 p.

Murphy, K., L. Hanson, M. Harris and T. Schroyer. 2001a. Central Valley Salmon and Steelhead Harvest Monitoring Project, 1999 Angler Survey. California Department of Fish and Game, Sacramento Valley – Central Sierra Region, CA, 29 p.

Murphy, K., T. Schroyer, M. Harris and D. Massa. 2001b. Central Valley Salmon and Steelhead Harvest Monitoring Project, 2000 Angler Survey. California Department of Fish and Game, Sacramento Valley – Central Sierra Region, CA, 29 p.

NMFS 2014. Recovery Plan for the ESUs of Sacramento River winter-run Chinook Salmon and central valley spring-run Chinook Salmon and the DPS of California central valley Steelhead.

Schroyer, T., D. Massa and K. Murphy. 2002. Central Valley Salmon and Steelhead Harvest Monitoring Project, 2001 Angler Survey. California Department of Fish and Game, Sacramento Valley – Central Sierra Region, CA, 25 p.

SWRI (Surface Water Resources, Inc.). 2001. Aquatic Resources of the Lower American River: Baseline Report. Prepared for the Lower American River Fisheries and Instream Habitat (FISH) Working Group. March.

Titus, R. G., M. S. Brown and J. Phillips. 2008. Angler Effort and Harvest of Anadromous Fishes in the Central Valley River Recreational Fishery, 2007-2008. California Department of Fish and Game, Inland Fisheries Administrative Report, 21 p.

Titus, R. G., M. S. Brown, J. Phillips, J. Lyons, and E. Collins. 2009. Angler Effort and Harvest of Anadromous Fishes in the Central Valley River Recreational Fishery, 2008-2009. California Department of Fish and Game, Inland Fisheries Administrative Report, 21 p.

Titus, R. G., M. S. Brown, J. Lyons, E. Collins, and L. Koerber. 2010. Angler Effort and Harvest of Anadromous Fishes in the Central Valley River Recreational Fishery, 2009-2010. California Department of Fish and Game, Inland Fisheries Administrative Report, 23 p.

Vincik, R. and J. Kirsch. 2009. Lower American River Chinook Salmon Escapement Survey October 2008 – January 2009. California Department of Fish and Game, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 18 p.

Vogel, D. A. and K. R. Marine. 1991. Guide to Upper Sacramento River Chinook Salmon Life History. U.S. Bureau of Reclamation Central Valley Project. July 1991.

Wixom, L. H., J. Pisciotto and C. Lake. 1995. Sacramento River System Sport Fish Catch Inventory (Estimated Harvest and Angler Use). California Department of Fish and Game, Inland Fisheries Division, CA, 75 p.

Biological Rationale, Development and Performance of the Modified Flow Management Standard

Attachment B

Lower American River Anadromous Salmonid Spawning Habitat – Flow Relationships

November 29, 2017

1.0 ANALYSIS OF WEIGHTED USABLE AREA FOR LOWER AMERICAN RIVER SALMONIDS

Flow-dependent habitat availability refers to the quantity and quality of habitat available to individual species and lifestages for a particular instream flow. The physical habitat simulation (PHABSIM) system is a commonly used method to express indices of the quantity and quality of habitat associated with specific flows. PHABSIM is the combination of hydraulic and habitat models, the output of which is expressed as weighted usable area (WUA), and is used to predict the relationship between instream flow and the quantity and quality of habitat for various lifestages of one or more species of fish.

1.1 OVERVIEW - COMPOSITE WUA ANNUAL INDEX

In the lower American River, available spawning habitat for fall-run Chinook salmon and steelhead is expressed by composite WUA indices that correspond to the spawning habitat available to the species under the daily flows occurring during their spawning seasons. The scaled composite WUA annual index (*i.e.*, $CWUA_Y$) is calculated as the sum of the WUAs that correspond to the daily flows during the species' spawning season at sampled reaches, multiplied by a temporal weighting coefficient that represents the average relative spawning intensity on a particular day of the spawning season, divided by the maximum WUA for the sum of the spawning reaches, over the flow range for which the WUA-flow relationship was developed.

For both fall-run Chinook salmon and steelhead, for the eight[1] distinct spawning reaches (h) within the lower American River during a period of K consecutive days of a particular year Y, the scaled composite WUA annual index (*i.e.*, $CWUA_Y$) is expressed as percent of maximum WUA by the following formula:

$$CWUA_Y = \frac{\sum_{d=1}^{K} w_d \times \left(\sum_{h=1}^{8} WUA_h \left(Q_{d,Y} \right) \right)}{\max \left(\sum_{h=1}^{8} WUA_h \left(Q \right) \right)} \times 100 \qquad \textbf{(1)}$$

$WUA_h\ (Q_{d,Y})$ is the WUA of reach h at the daily flow $Q_{d,Y}$ obtained from the WUA-flow relationships for the eight sampled reaches. The denominator of the equation is the maximum

[1] Overall, a total of 10 sample reaches were included in the analyses. However, three of the reaches were located in the Sailor Bar area and were combined for analytic purposes, resulting in a total of eight study reaches.

achievable WUA for all eight spawning reaches combined over the flow range for which the WUA-flow relationships were developed. Finally, w_d are the temporal weighting coefficients for fall-run Chinook salmon or steelhead for each of the days in the *K*-day spawning periods of fall-run Chinook salmon or steelhead.

1.2 WUA - FLOW RELATIONSHIPS

1.2.1 Fall-run Chinook Salmon

1.2.1.1 Habitat Suitability Criteria

AVAILABLE DATA

WUA-flow relationships were developed for spawning fall-run Chinook salmon using two dimensional (2-D) river hydrodynamics modeling and empirically derived habitat suitability curves (HSC). The HSC were obtained from depth, velocity, and substrate data collected during surveys for fall-run Chinook salmon redds on the American River and other California rivers (also one survey on the Snake River, Idaho, for substrate). Chinook redd surveys with either depth, velocity, and/or substrate utilization data were compiled from 10 different datasets (**Table B-1**).

DATA REDUCTION

Chinook redd utilization data were generally obtained from final reports, but utilization data from the American River for the years 2009 and 2011-2016 were obtained from "raw" data provided by Joe Merz (pers. comm., 2016). The American River data set was carefully processed to remove questionable data including: 1) unknown species; 2) duplicate/multiple redds at one location; 3) redd observations with a zero depth or velocity measurement; and 4) redd observations that were surveyed immediately after a major change in flow that would affect the accuracy of the depth and velocity measurement.

DEPTH

Depth measurements for each Chinook redd data set were plotted as frequency histograms on a single graph to visually compare the various datasets. An individual scaling factor was applied to each of the frequency histograms in order for each data set to plot with a similar magnitude. The scaling factors for each data set are provided in **Table B-2**. A horizontal line representing the center 50% of the depth observations was also included on the plot. An HSC curve scaled between zero and one was developed to represent the suitability of depth for spawning (1.0 = completely suitable and 0.0 = not suitable) (**Figure B-1**).

Table B-1. Fall-run Chinook salmon data sets used to develop habitat suitability criteria.

Dataset Name	River	Report/File Name	Years of Observation	# of Fish Observed (depth/velocity/ substrate)	Depth	Velocity	Substrate
American River 2009-2016 - Merz pers. comm. 2016	American River	GIS Shape Files. Cramer Fish Sciences Redd Utilization Monitoring performed for USBR. (monitoring reports available)	2009, 2011-2016	514/505/692	x	x	x
American River - Gard 1998	American River	Excel File: "Chinook salmon redd data from M Gard.xlsx"	1998	189	x	x	x
American River - USFWS 1996	American River	Excel File: "Chinook salmon redd data from M Gard.xlsx"	1996	218	x	x	x
Yuba River - Gard 2010	Yuba River	Flow-Habitat Relationships for Spring and Fall-run Chinook Salmon and Steelhead/Rainbow Trout Spawning in the Yuba River	2000-2002	877/870	x	x	NA
Yuba River - Beak 1989	Lower Yuba River	Yuba River Fisheries Investigations, 1986-88, Summary Report of Technical Studies on the Lower Yuba River, California	1988	154/154/158	x	x	x
Clear Creek - Gard 2011	Clear Creek	Flow-Habitat Relationships for Fall-Run Chinook Salmon and Steelhead/Rainbow Trout Spawning in Clear Creek between Clear Creek Road and the Sacramento River	2000-2005	759/763	x	x	NA
Klamath River - Hardy et al. 2006	Lower Klamath River	Evaluation of Instream Flow Needs in the Lower Klamath River Phase II	1998, 1999	290	x	x	NA
Trinity River - Hampton et al. 1997	Trinity River	Microhabitat Suitability Criteria for Anadromous Salmonids of the Trinity River	1985-1992	311	x	x	NA
Sacramento River - Gard 2003	Sacramento River	Flow-Habitat Relationships for Steelhead and Fall, Late-Fall and Winter-Run Chinook Salmon Spawning in the Sacramento River between Keswick Dam and Battle Creek	1995, 1996, 1997, 1999	451/440	x	x	NA
Snake River - Groves and Chandler 1999	Snake River	Spawning Habitat Used by Fall Chinook Salmon in the Snake River	1993-1995	103	-	-	x

NA -- *Use frequency data not available for substrate for these sites.*

Table B-2. Scaling factors for each Chinook salmon habitat utilization data set.

Dataset Name	Scaling Factors		
	Depth	Velocity	Substrate
Yuba River - Beak 1989	6	7	3.5
Klamath River - Hardy et al. 2006	2.5	1.5	--
Trinity River - Hampton et al. 1997	3	3	--
Clear Creek - Gard 2011	1.5	1.5	--
Sacramento River - Gard 2003	2.5	2.3	--
Snake River - Groves and Chandler 1999	--	--	4.6
American River 2009-2016 - Merz pers. comm. 2016	2	2	1.7
American River - Gard 1996	6	4.5	1.6
American River - Gard 1998	10	3.5	1.2
Yuba River - Gard 2010	1.2	1.2	--

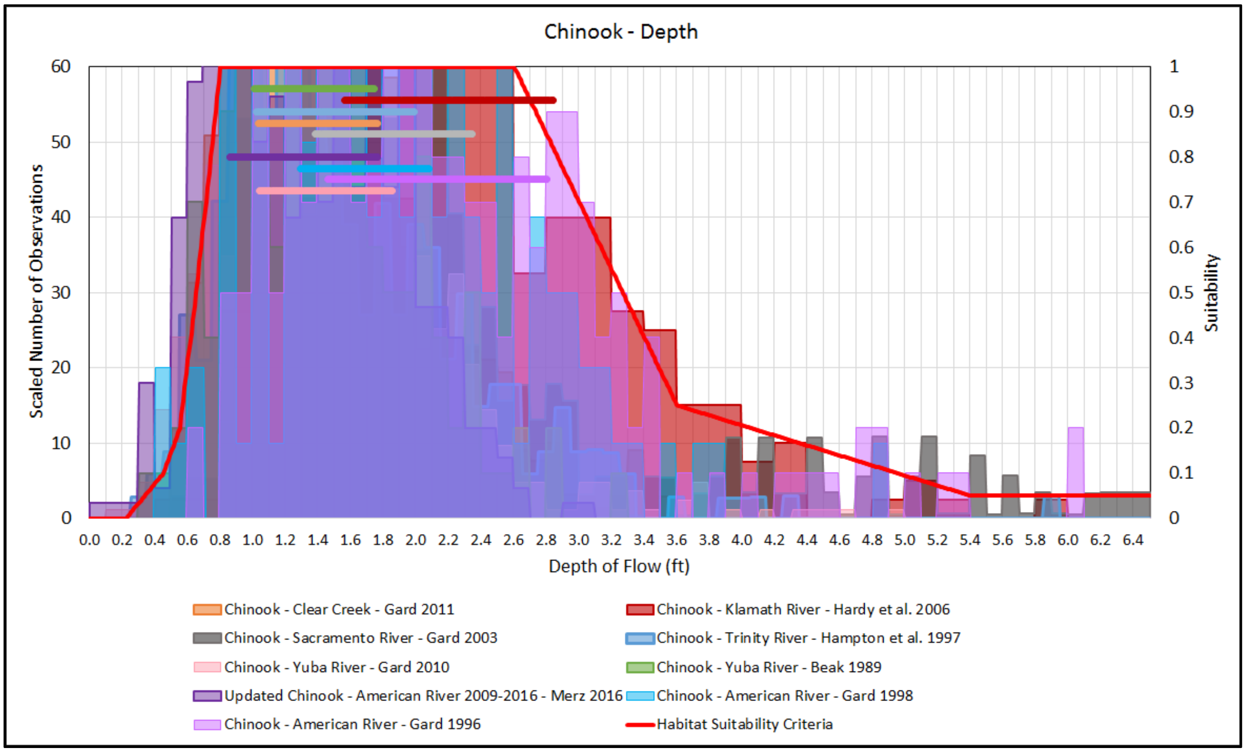

Figure B-1. Chinook redd depth observations (left vertical axis) and habitat suitability criteria (right vertical axis).

VELOCITY

Similar to the depth HSC methods, mean column velocity measurements for each Chinook redd data set were plotted as frequency histograms on a single graph to visually compare the various datasets (**Figure B-2**). An individual scaling factor was applied to each of the frequency histograms in order for each to plot with a similar magnitude. The scaling factors for each data set are provided in Table B-2. A horizontal line representing the center 50% of the depth observations was also included on the plot. An HSC curve scaled between zero and one was developed to represent the suitability of velocity for spawning (1.0 = completely suitable and 0.0 = not suitable).

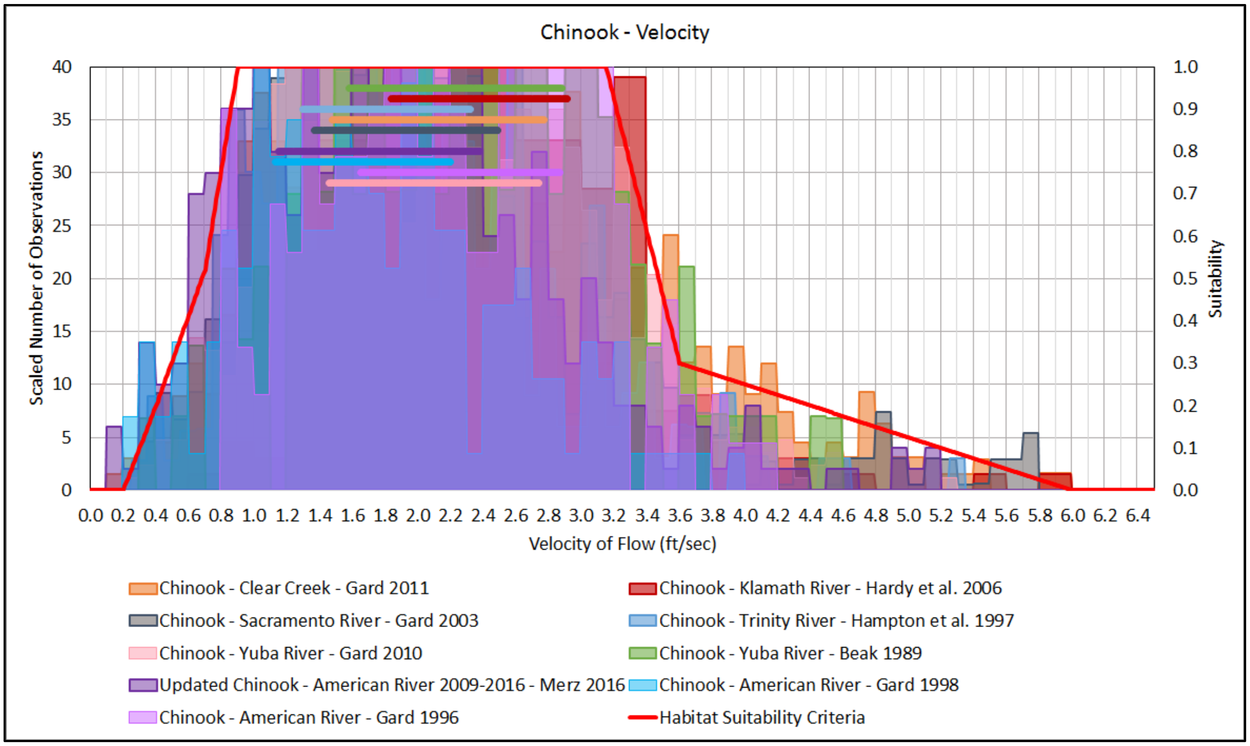

Figure B-2. Chinook redd mean column velocity observations (left vertical axis) and habitat suitability criteria (right vertical axis).

SUBSTRATE

Substrate use frequency data were available from five of the 10 Chinook redd survey data sets used for this analysis. The datasets were plotted together as frequency histograms on a single graph. An individual scaling factor was applied to each of the frequency histograms in order for each to plot with a similar magnitude. The scaling factors for each data set are provided in Table B-2. An HSC curve scaled between zero and one was developed to represent the suitability of substrate for spawning (1 = completely suitable and 0 = not suitable) (**Figure B-3**). The hatched histogram bars for the medium and large cobble substrate sizes in Figure B-3 included a large subdominant component of substrate in the next smaller substrate size class that was factored into the development of the HSC curve.

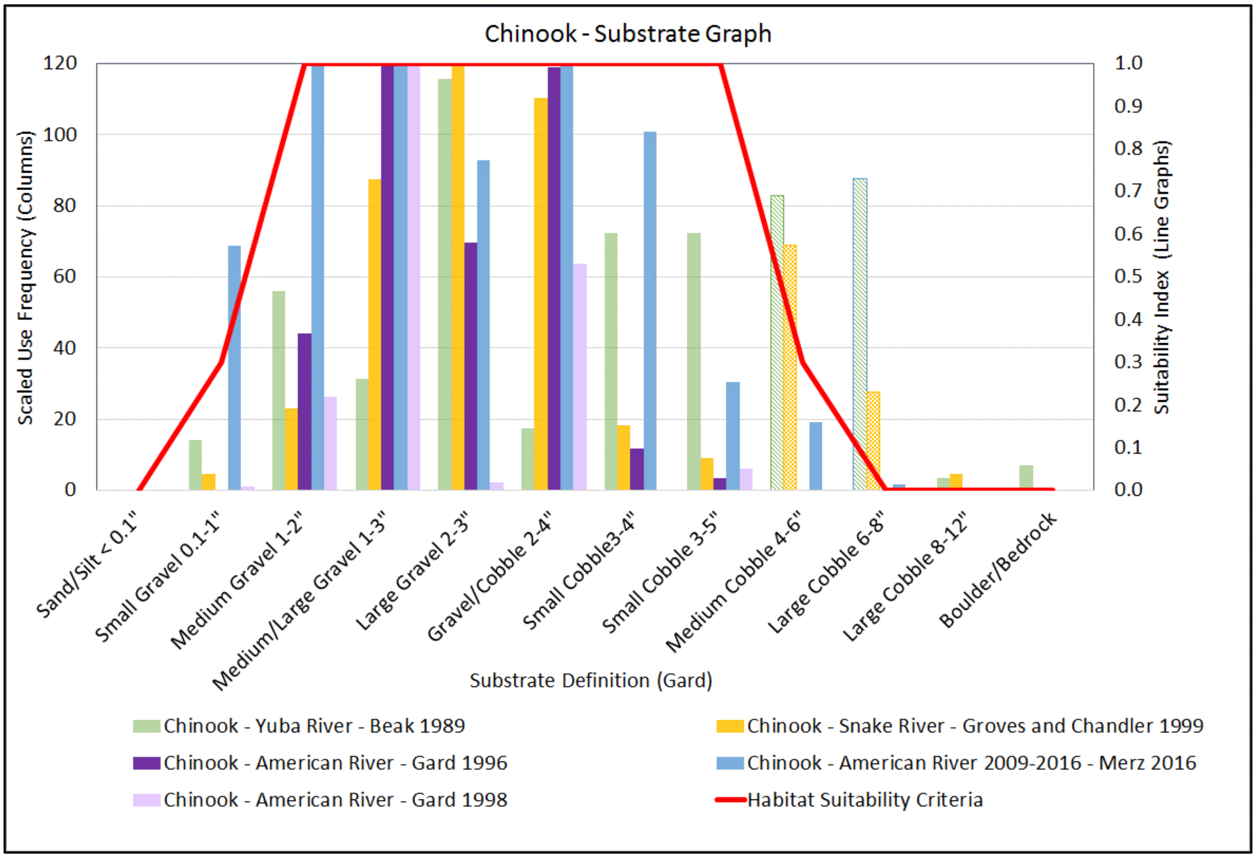

Figure B-3. Chinook redd observations and habitat suitability criteria by substrate type (note the hatched bars include a large percentage of sub-dominant substrate in the next smaller size category and the habitat suitability criteria were adjusted accordingly).

Final Depth and Velocity HSCs

Based on examination of the 10 data sets, including the lower American River, and development of scaling factors and modality and trend visual analyses, HSC curves for depth and velocity, scaled between zero and one, were developed to represent the suitability of depth and velocity for fall-run Chinook salmon spawning (1.0 = completely suitable and 0.0 = not suitable). The final depth and velocity HSC curves are presented in **Figure B-4**.

Final Substrate HSC

Substrate use frequency data from five of the 10 Chinook salmon redd survey data sets was used to develop a final substrate HSC curve scaled between zero and one to represent the suitability of substrate for spawning (1 = completely suitable and 0 = not suitable) (**Figure B-5**).

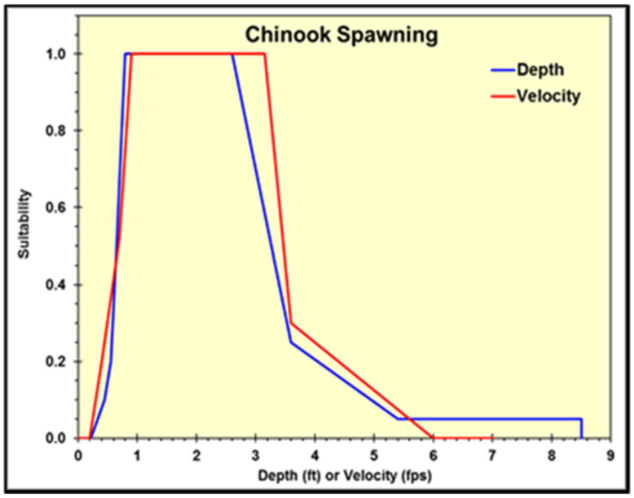

Figure B-4. Fall-run Chinook salmon depth and velocity HSCs for application to the lower American River.

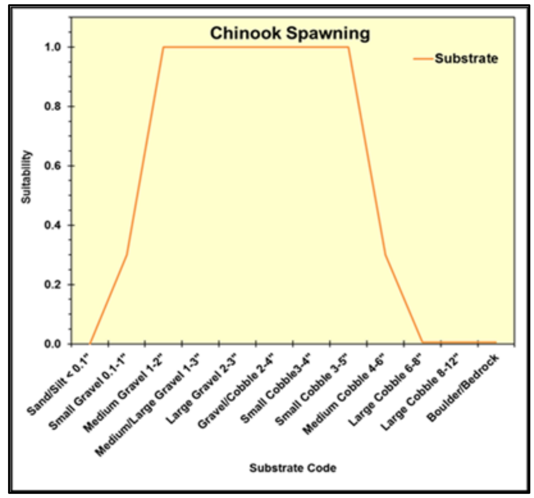

Figure B-5. Fall-run Chinook salmon substrate HSC for application to the lower American River.

1.2.1.2 Reach-specific and Composite WUA – Flow Relationships

To describe the habitat available to fall-run Chinook salmon spawning at different lower American River flows, the analysis uses the WUA-flow relationships that were developed using the most recent 2-D modeling PHABSIM datasets available for the river. The data sets consist of three-dimensional river topography, substrate mapping, and hydrodynamics modeling (depth and velocity) at spawning sites on the lower American River. Five of the data sets are from Gard (2003), two are additional data sets collected more recently by Gard (USFWS, pers comm and data transfer, 2016) and three data sets are from river restoration/gravel augmentation sites modeled by cbec, Inc. (cbec, unpublished data, 2016) (**Figure B-6** and **Table B-3**). The Gard (2003) sites were selected specifically to represent the river sites with the most fall-run Chinook salmon spawning based on fall 1997 aerial photographs of Chinook salmon redds in the lower American River (Gard 2003). The two other Gard (2016) sites were added to augment the initial representation of spawning. The Gard (2016) sites were initially modeled using River2D (http://www.river2d.ualberta.ca/), and the remodeling conducted for this effort also used River2D for these sites. The cbec sites (two specifically for side channel habitat) were modeled using SRH-2D[2]. All sites were modeled over a range of Nimbus Dam release flows from 500 cfs to 11,000 cfs. Available WUA for each of the study reaches at a particular flow was calculated by multiplying the depth, velocity, and substrate habitat suitability in each grid cell by the cell area and then summing the resulting areas to calculate a composite WUA for a given flow (Nimbus Dam release).

[2] https://www.usbr.gov/tsc/techreferences/computer%20software/models/srh2d/index.html

Figure B-6. Location of modeled reaches in the lower American River.

Table B-3. Modeled river reach summary table.

River Reach	River Mile (downstream boundary)	Length (ft.)	Channel Type		Source
			Main	Side	
Nimbus Basin	23.0	800	x	x	CBEC 2016
Sailor Bar Upper	22.6	377	x		Mark Gard 2016
Sailor Bar	22.0	1553	x	x	Mark Gard 2003
Sailor Bar Lower	19.8	522	x		Mark Gard 2003
Above Sunrise 2012	20.7	3142	x	x	Mark Gard 2016
At Sunrise	19.6	3103	x		Mark Gard 2003
Lower Sunrise Side Channel	19.5	1000		x	CBEC 2016
El Manto	18.9	754	x		Mark Gard 2003
Rossmoor	16.3	3442	x		Mark Gard 2003
Riverbend Side Channel	13.2	1500		x	CBEC 2016

Figure B-7 shows the WUA-flow relationships separately for the eight reaches, and the composite WUA-flow relationship resulting from the sum of the reach-specific relationships. Of the four largest sites with the most WUA, two sites have relatively "flat" habitat versus flow, relationships that show that maximum habitat occurs over a wide flow range from 1,800-2,600 cfs (Sunrise and Sailor Bar) and two have more "peaked" habitat versus flow relationships that reach maximum habitat at 1,400 cfs (Rossmoor and Above Sunrise). The channel topography (*e.g.*, narrow versus wider channel) in these reaches affects the habitat versus flow relationships.

The maximum fall-run Chinook salmon spawning WUA for all eight reaches combined occurs at about 1,600 cfs, and corresponds to the denominator $\max\left(\sum_{h=1}^{8} WUA_h\left(Q\right)\right)$ in equation (1) and is used to scale the composite WUA annual index. The composite WUA curve has 31 data points corresponding to flows ranging from 500 cfs through 11,000 cfs (average daily Nimbus Dam release). The composite WUA curve was used for the direct linear interpolation of habitat (WUA) associated with average daily Nimbus Dam release flows ($Q_{d,Y}$).

Because the WUA-flow relationships present WUA values within particular flow ranges at particular variable steps (*e.g.*, in the lower American River the WUA-flow relationships were developed for a flow range of 500 cfs to 11,000 cfs, with variable incremental steps ranging from 200 to 600 cfs), it is often the case that daily flow $Q_{d,Y}$ for which the composite WUA needs to be computed falls between two flows for which there are WUA values in the WUA-flow relationships. In these cases, the composite WUA value was determined by linear interpolation between the available WUA values for the flows immediately below and above the target flow $Q_{d,Y}$.

In those cases when the target flow $Q_{d,Y}$ was lower than the lowest flow value in the WUA-flow relationship (*i.e.*, 500 cfs) or higher than the highest flow value in the WUA-flow relationship (*i.e.*, 11,000 cfs), two series of extrapolated WUA values were generated from fitting a polynomial and a power function to the closest WUA and flow values in the available WUA-flow relationships.

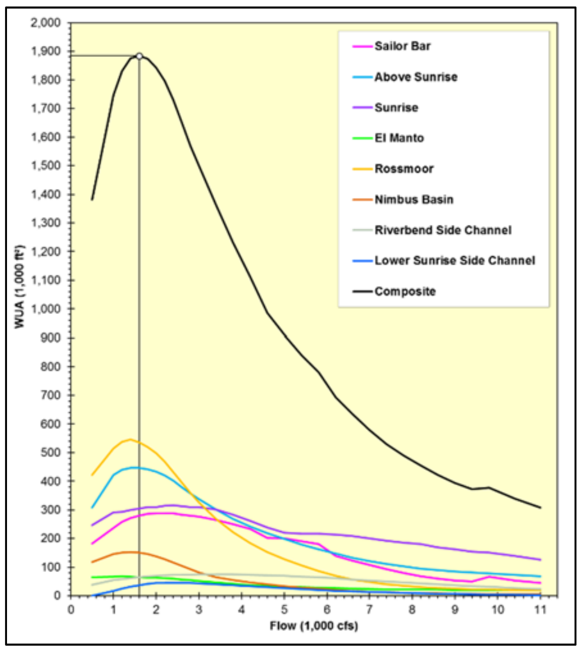

Figure B-7. Relationship between Chinook salmon spawning habitat availability (expressed as WUA) and flow for the eight lower American River study reaches, and for the composite of the eight study reaches.

To interpolate WUA values for average daily flows lower than 500 cfs, a polynomial function was first fitted to the WUA values for the seven lowest flows in the composite WUA-flow relationship (*i.e.*, Q = 500 cfs, 1,000 cfs, 1,200 cfs, 1,400 cfs, 1,600 cfs, 1,800 cfs and 2,000 cfs). The equation of the fitted polynomial was $WUA = 4{,}494.865 \times Q - 4.441539 \times Q^2 + 0.002096 \times Q^3 - 3.85 \times 10^{-7} \times Q^4$ and had a coefficient of determination R^2 =0.99.

The polynomial equation was used to generate seven extrapolated WUA values for Q = 0 cfs, 50 cfs, 100 cfs, 150 cfs, 200 cfs, 300 cfs and 400 cfs.

To interpolate WUA values for average daily flows higher than 11,000 cfs, a power function was fitted to the WUA values for the ten higher flows in the composite WUA-flow relationship (*i.e.*, Q ranging from 7,000 cfs through 11,000 cfs). The equation of the fitted power function was $\ln(WUA) = 25.148863 - 1.344067 \times \ln(Q)$, and had a coefficient of determination R^2 = 0.99. The regression equation was used to generate extrapolated WUA values for Q ranging from 12,000 through 141,000 cfs (the highest daily flow in the evaluation period) in increasing steps of 1,000 cfs.

The seven WUA values extrapolated from the fitted polynomial and WUA values at 1,000 cfs increments out to 141,000 cfs extrapolated from the fitted power function were combined with the 31 values of the original composite WUA-flow relationship into a look-up table used for the linear interpolation of WUA values for all Nimbus Dam average daily flows generated under the 2006 FMS and the Modified FMS over the 82-year simulation period. **Table B-4** displays WUA values corresponding to flows less than or equal to 28,000 cfs because this range represents approximately 99.5% of the flows modeled during the simulation period.

Table B-4. Composite WUA values for fall-run Chinook salmon spawning in the lower American River used as look-up table for linear interpolation of WUA values for Nimbus daily flows.

Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)
0	0	2,200	1,795,973	7,000	578,846	16,000	186,808
50	213,899	2,400	1,730,322	7,400	529,805	17,000	172,190
100	407,129	2,600	1,650,341	7,800	490,093	18,000	159,457
150	581,175	2,800	1,569,993	8,200	455,519	19,000	148,280
200	737,464	3,000	1,499,420	8,600	421,156	20,000	138,402
300	1,002,199	3,400	1,362,842	9,000	393,293	21,000	129,617
400	1,211,600	3,800	1,230,533	9,400	372,380	22,000	121,761
500	1,380,535	4,200	1,111,178	9,800	377,188	23,000	114,699
1,000	1,746,319	4,600	986,267	10,400	339,853	24,000	108,322
1,200	1,830,899	5,000	909,508	11,000	307,436	25,000	102,539
1,400	1,874,802	5,400	840,726	12,000	274,993	26,000	97,273
1,600	1,884,001	5,800	780,997	13,000	246,944	27,000	92,462
1,800	1,873,823	6,200	692,874	14,000	223,532	28,000	88,051
2,000	1,842,271	6,600	635,208	15,000	203,736		

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using a power function (see text for details).

The composite WUA values in Table B-4 were plotted in **Figure B-8** for a visual representation of the final composite WUA-flow relationship. The WUA-discharge relationship extending higher than 28,000 cfs demonstrates a continuously diminishing incremental slope up to the highest flow value of 141,000 cfs.

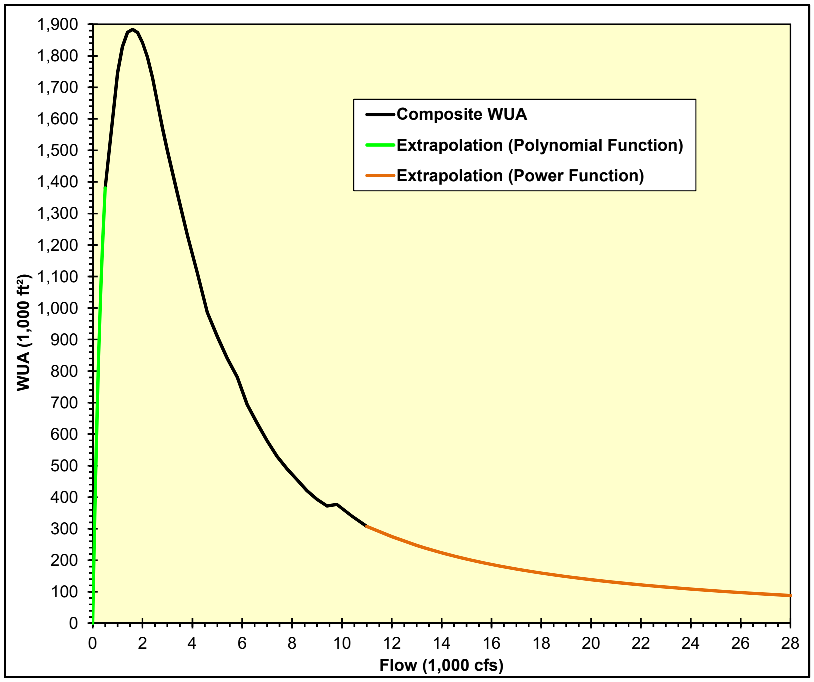

Figure B-8. Final relationship between the composite WUA and flow for fall-run Chinook salmon spawning in the lower American River.

1.2.1.3 Temporal Weighting Coefficients

Because $CWUA_Y$ in equation 1 is a scaled composite WUA for a species spawning over numerous days in the spawning season, and because the species' spawning intensity does not remain constant throughout the spawning season, the temporal weighting coefficients w_d were incorporated into equation 1 to account for the average relative spawning intensity on a particular day. Each w_d is a proportion with a value between 0 and 1, so that for a given species the sum over the middle 99% of the spawning period of the species is equal to 1. Because fall-run Chinook salmon spawning exhibited extended tails in the temporal distribution, analyses were conducted on the middle 99% of the distribution to capture the majority of spawning, and are not intended to be inclusive of every individual in the population.

In general, to calculate the temporal weighting coefficients, spawning timing is described as an asymmetric logistic function of time. The asymmetric logistic function, also known as Richards sigmoidal curve (Ratkowsky 1983), has the following expression:

$$Y_D = \left(\frac{1}{1 + \exp\left(\alpha + \beta \times D\right)} \right)^{1/\delta} \qquad \textbf{(2)}$$

Y_D is the expected cumulative proportion of spawning through day D, and α, β and δ are parameters that determine the shape of the cumulative curve. The variable D is a continuous variable that indicates the day number during a spawning season, counting from a particular starting date. Day 1 was established as June 1 for the spawning temporal distribution to facilitate comparative examination with the arrival temporal distribution. In order to estimate the values of α, β and δ, the daily cumulative proportions of newly built redds, derived from redd observations in available annual redd survey data and reports, were used as a proxy for Y_D, and fitted to the asymmetric logistic model through nonlinear least squares. In the case of fall-run Chinook salmon spawning in the lower American River, the data describing Y_D arose from combining information contained in available carcass and redd survey annual data and reports. Once equation 2 was fitted to the available data, the daily temporal weighting coefficients w_d were calculated by subtracting the fitted cumulative proportions of two consecutive dates for the middle 99% of the temporal distribution, then re-scaled such that the daily proportions summed to 1.

Redd surveys that provide the cumulative distribution of newly built redds over time were performed by the CDFW during the 1991/92 through the 1995/96 fall-run Chinook salmon spawning seasons (Snider and McEwan 1992; Snider et al. 1993; Snider et al. 1996; Snider and Vyverberg 1995 and 1996), and by Cramer Fish Sciences during the 2009/10 through the 2015/16 fall-run Chinook salmon spawning seasons.

The 1991/92 through 1995/96 redd surveys were conducted by aerial photography on a nearly weekly basis. The data collected during the 2009/10 through the 2015/16 fall-run Chinook salmon spawning seasons was collected by ground-based redd surveys. These data were reviewed by representatives of the Water Forum and Cramer Fish Sciences staff as a quality control measure. All redds that were not identified in the field as being a Chinook salmon redd with a redd age classified as “new still clear” or with “fish on”, except for redds observed prior to December 25 that were identified as redd of “unknown species” with those redd age classifications.

Fall-run Chinook salmon carcass surveys have been performed annually since the late 1960’s, and data or reports are available for all surveys performed during the 1992/93 through 2015/16 spawning seasons (*e.g.*, Snider and Bandner 1996; Snider and Reavis 1996; Snider et al. 1993; Snider et al. 1995; Healey 2002, 2003, 2004, 2005 and 2006; Healey and Fresz 2007; Healey and Redding 2008; Vincik and Kirsch 2009; Vincik and Mamola 2010; Maher et al. 2012; Phillips and Maher 2013; and Phillips and Helstab 2013; Cramer Fish Sciences, unpublished data). The temporal distributions of fresh carcasses described in these reports was used to estimate an overall cumulative distribution of fresh carcasses over time that describe when fresh carcasses appear in the surveys, a time that closely follows the actual time of spawning. When appropriately lagged by the time elapsing between spawning and appearance of fresh carcasses in the surveys, the carcass surveys also describe spawning timing. The time elapsing between spawning and redd-construction and post-spawning mortality, or life expectancy after spawning, has been reported to be between 2 and 4 weeks (Briggs 1953).

To take advantage of the potential information on fall-run Chinook salmon spawning timing in the lower American River contained in the available redd and carcass surveys, a five-step procedure was developed to estimate the sigmoidal curve describing fall-run Chinook salmon spawning timing in the lower American River. The five-step procedure consists of the following steps.

1) Fit an asymmetric logistic function to the daily cumulative proportions of newly built redds obtained from the four annual photogrammetric redd surveys performed by CDFW during the 1992/93 through the 1995/96 fall-run Chinook salmon spawning seasons, and the seven redd surveys performed by Cramer Fish Sciences during the 2009/10 through the 2015/16 fall-run Chinook salmon spawning seasons.

2) Fit an asymmetric logistic function to the daily cumulative proportions of fresh carcasses obtained from the eleven carcass surveys performed by CDFW during the 1992/93 through the 1995/96 and the 2009/10 through the 2015/16 fall-run Chinook salmon spawning seasons.

3) Calculate the lag times between the fitted redd and fresh-carcass cumulative distributions (*i.e.*, the number of days separating similar cumulative proportions under the asymmetric logistic functions fitted in steps 1 and 2).

4) Fit an asymmetric logistic function to the daily cumulative proportions of fresh carcasses obtained from the available 24 carcass surveys performed during the 1992/93 through the 2015/16 fall-run Chinook salmon spawning seasons.

5) Apply the lag times calculated in step 3 to the curve fitted in step 4 by subtracting the corresponding lag times from the days for particular cumulative proportions of fresh carcasses expected under the curve obtained in step 4. The resulting lagged asymmetric logistic function was used to describe fall-run Chinook salmon spawning timing based on carcass surveys from 1992/93 through 2015/16, and to calculate the daily temporal weighting coefficients.

During the four CDFW redd surveys performed from late September or October through early January during the 1992/93 through the 1995/96 fall-run Chinook salmon spawning seasons, and the seven redd surveys performed by Cramer Fish Sciences during the 2009/10 through the 2015/16 fall-run Chinook salmon spawning seasons, a total of 21,664 newly-built redds were counted, ranging from a low of 39 redds during the 2010/11 spawning season to a high of 6,205 redds during the 1993/94 spawning season. Given the variation in total number of redds counted each season, as well as the number of weekly redd surveys performed during each spawning season, a weighted nonlinear least squares procedure was used to fit the common asymmetric logistic function (equation 2) to the 11 sets of daily cumulative proportions of newly built redds. The weights were calculated as the ratio of the annually counted redds to the overall total number of counted redds (*i.e.*, 21,664 newly-built redds). For example, the 13 daily cumulative proportions of redds built during the 1992/93 spawning season each received a weight of 0.0525 (*i.e.*, 1,138/21,664 = 0.0525), while the seven daily cumulative proportions of redds built during the 1995/96 spawning season received each a weight of 0.1835 (*i.e.*, 3,976/21,664 = 0.1835). The common asymmetric logistic function fitted to the redd data had the following expression:

$$Y_D = \left(\frac{1}{1 + \exp\left(21.1886 - 0.1353 \times D\right)} \right)^{1/0.3529} \qquad \textbf{(3)}$$

where D is the day number at which new redds were observed during a particular annual survey, counted from June 1 of each year. The mean square error of this fit was 0.0368. **Figure B-9** displays the 11 sets of daily cumulative proportions and the fitted curve of equation 3.

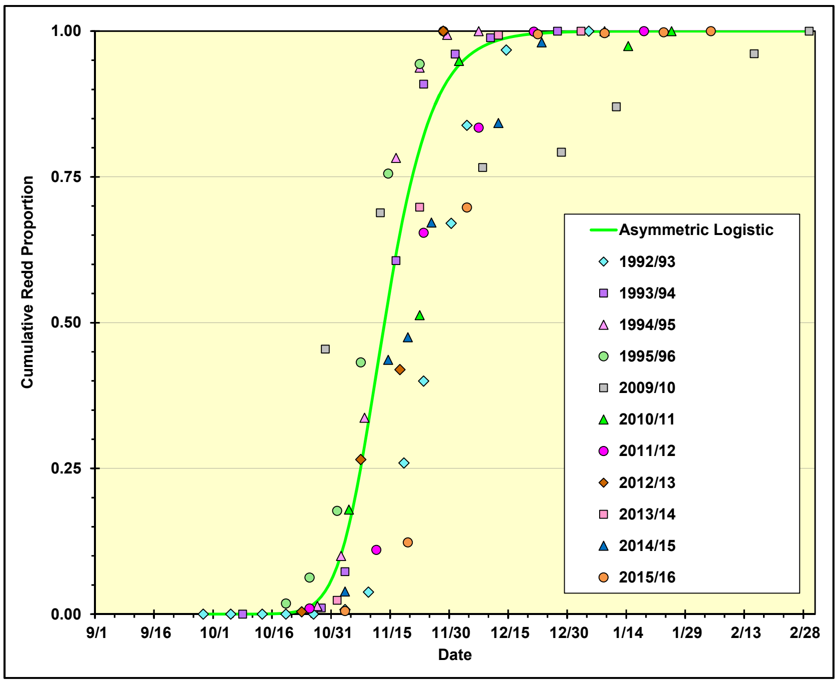

Figure B-9. Fall-run Chinook salmon cumulative proportions of redds in the lower American River, during the 1992/93 – 1995/96 and the 2009/10 – 2015/16 spawning seasons, and fitted asymmetric logistic curve.

During the four carcass surveys performed from October through mid-January during the 1992/93 through the 1995/96 and the seven carcass surveys during the 2009/10 through 2015/16 fall-run Chinook salmon spawning seasons, a total of 15,748 fresh carcasses were counted, ranging from a low of 223 fresh carcasses during the 2009/10 spawning season to a high of 3,344 fresh carcasses during the 2013/14 spawning season. A weighted nonlinear least squares procedure was used to fit the common asymmetric logistic function (equation 2) to the eleven sets of daily cumulative proportions of fresh carcasses. The weights were calculated as the ratio of the annually counted fresh carcasses to the overall number of counted fresh carcasses (*i.e.*, 15,748 carcasses). For example, the 18 daily cumulative proportions of fresh carcasses of the 1992/93 spawning season received each a weight of 0.0229 (*i.e.*, 360/15,748 = 0.0229), while the 11 daily cumulative proportions of fresh carcasses of the 1995/96 spawning season received each a weight of 0.1257 (*i.e.*, 1,980/15,748 = 0.1257). **Figure B-10** displays the 11 annual sets of daily cumulative proportions and the fitted asymmetric logistic curve of equation 4.

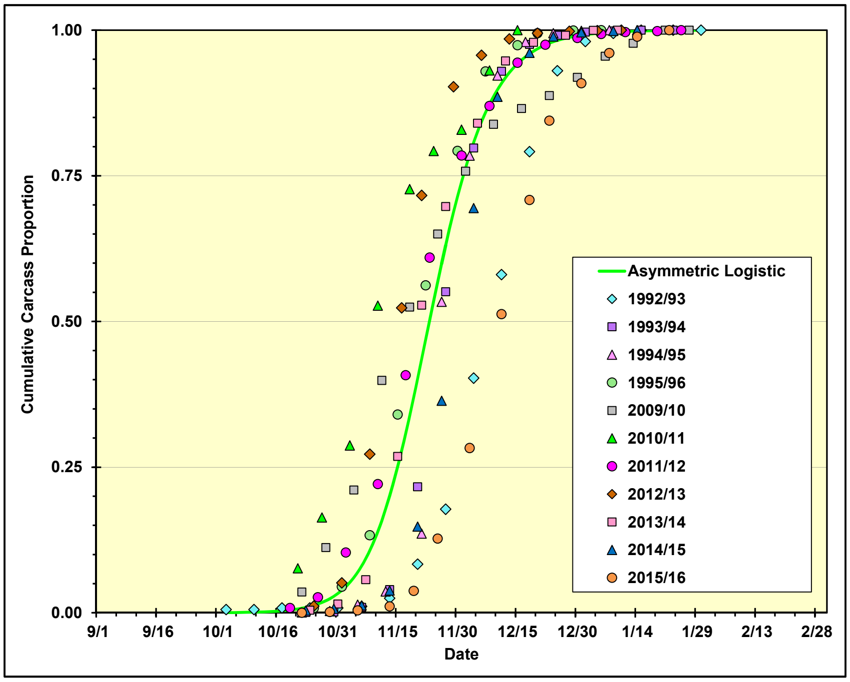

Figure B-10. Fall-run Chinook salmon cumulative proportions of fresh carcasses in the lower American River, during the 1992/93 – 1995/96 and the 2009/10 – 2015/16 spawning seasons, and fitted asymmetric logistic curve.

The common asymmetric logistic function fitted to the fresh carcass data had the following expression:

$$Y_D = \left(\frac{1}{1 + \exp\left(21.0633 - 0.1222 \times D\right)} \right)^{1/0.7209} \qquad \textbf{(4)}$$

The mean square error of this fit was 0.0324.

As part of the third procedural step where the lag times between the fitted redd and fresh-carcass cumulative distributions are computed, the parameter values of equations 3 and 4 are applied to the following equation:

$$D_{Y'} = \frac{\ln\left[\left(\frac{1}{Y'} \right)^{\hat{\delta}} - 1 \right] - \hat{\alpha}}{\hat{\beta}} \qquad \textbf{(5)}$$

where Y' are particular expected cumulative proportions under fitted equations 3 and 4 (*e.g.*, 0.05, 0.15, 0.25, 0.5, etc), $D_{Y'}$ are the days at which those proportions are achieved, and $\hat{\alpha}$, $\hat{\beta}$ and $\hat{\delta}$ are the parameter values in equations 3 and 4. After calculating equation 5 with both set of parameter estimates, there are two $D_{Y'}$ values for each particular expected cumulative proportion Y', one for the fitted redd cumulative distribution (equation 3) and the other for the fitted fresh-carcass cumulative distribution (equation 4). The lag times between the fitted redd and fresh-carcass cumulative distributions are then calculated as the differences between the pairs of $D_{Y'}$ values (**Table B-5**).

Table B-5. Lag times between cumulative proportions (Y'%) of the redd and fresh-carcass cumulative distributions fitted to data for the 1992/93 – 1995/96 and the 2009/10 – 2015/16 Chinook salmon spawning seasons.

Cumulative Proportion (Y'%)	Day under Fitted Redd Cumulative Curve ($D_{Y'}$)	Day under Fitted Carcass Cumulative Curve ($D_{Y'}$)	Lag Time (days)
2%	148.53	149.82	1.28
5%	151.94	155.72	3.79
15%	156.95	163.61	6.66
25%	160.00	167.97	7.98
50%	166.08	175.94	9.86
75%	173.12	184.41	11.29
85%	177.51	189.46	11.95
95%	186.18	199.23	13.06
99%	198.28	212.69	14.42

$D_{Y'}$ and lag times are expressed in decimal days counted from June 1 ($D_{Y'}$ = 1)

As part of the fourth procedural step, a new asymmetric logistic function was fitted to the daily cumulative proportions of fresh carcasses obtained from the available 24 carcass surveys performed during the 1992/93 through the 2015/16 fall-run Chinook salmon spawning seasons to incorporate any additional information on spawning timing not present in the shorter data sets used in steps 1 and 2. As with previous fits, a weighted least square procedure was used. These weights were also calculated as the ratios of the annually counted fresh carcasses of a season to the overall number of counted fresh carcasses (*i.e.*, 43,990 carcasses). Thus, for example the weight for the 18 daily cumulative proportions of fresh carcasses of the 1992/93 spawning season became 0.0082 (*i.e.*, 360/43,990 = 0.0082).

Equation 6 and **Figure B-11** display the results of this new fitted asymmetric logistic function.

$$Y_D = \left(\frac{1}{1 + \exp(18.4127 - 0.1095 \times D)} \right)^{1/0.5155} \quad \textbf{(6)}$$

The mean square error of this fit was 0.0196.

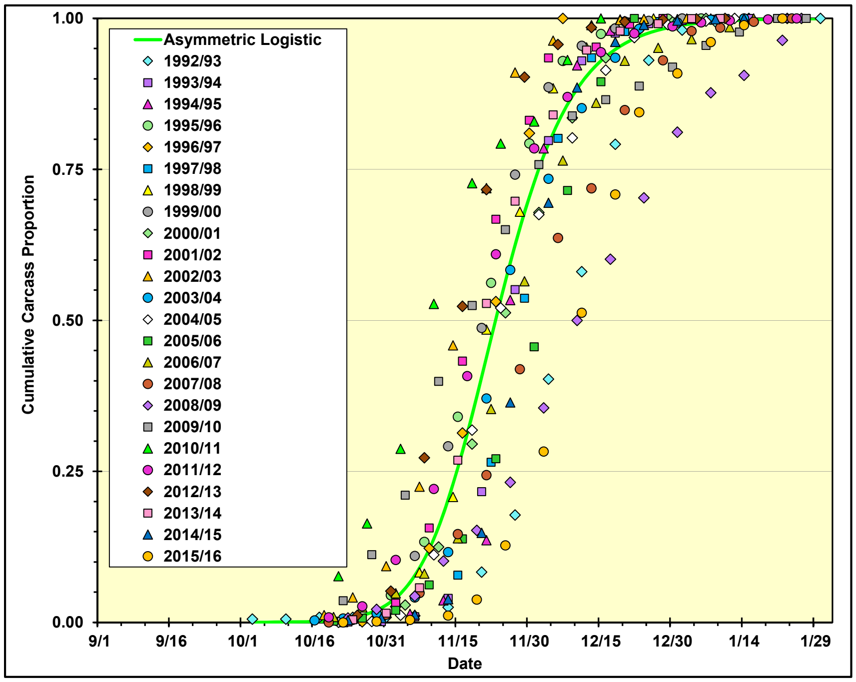

Figure B-11. Fall-run Chinook salmon cumulative proportions of fresh carcasses in the lower American River, during the 1992/93 – 2015/16 spawning seasons, and fitted asymmetric logistic curve.

Finally, as part of the fifth procedural step, the parameter values of equation 6 were applied to equation 5 to calculate new $D_{Y'}$ values (*i.e.*, days at particular cumulative proportions of the new fitted curve), and the lag times in Table B-5 are subtracted from the new $D_{Y'}$ values. The resulting lagged asymmetric logistic curve had the following expression:

$$Y_D = \left(\frac{1}{1 + \exp\left(17.2146 - 0.1185 \times D\right)} \right)^{1/0.1181} \qquad \textbf{(7)}$$

Figure B-12 displays the four asymmetric logistic curves obtained from the five-step procedure used to describe fall-run Chinook salmon spawning timing in the lower American River.

The lagged asymmetric logistic curve of equation 7 was used to calculate expected daily spawning proportions by subtraction. Finally, the daily temporal coefficients for fall-run Chinook salmon were obtained by rescaling the sum of the daily proportions for the middle 99% of the temporal distribution such that they sum to 1. **Figure B-13** and **Table B-6** display the final daily weighting coefficients for fall-run Chinook salmon spawning in the lower American River, and the resulting spawning period used in the calculation of the scaled composite WUA annual index (*i.e.*, $CWUA_Y$) for fall-run Chinook salmon. The resulting spawning period extends from October 25 through December 24, a period consisting of $K = 61$ days.

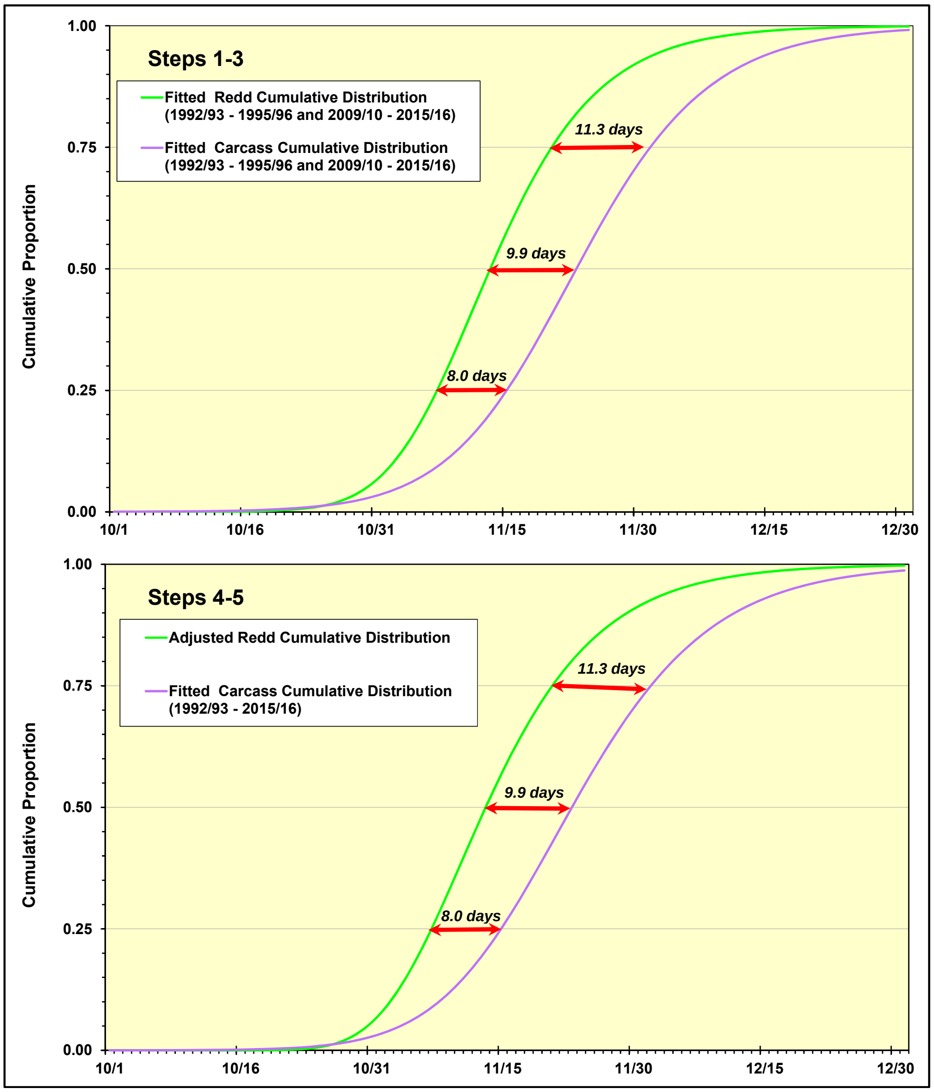

Figure B-12. Asymmetric logistic curves obtained from the 5-step procedure used to describe fall-run Chinook salmon spawning timing in the lower American River during the 1992/93 - 2015/16 spawning seasons.

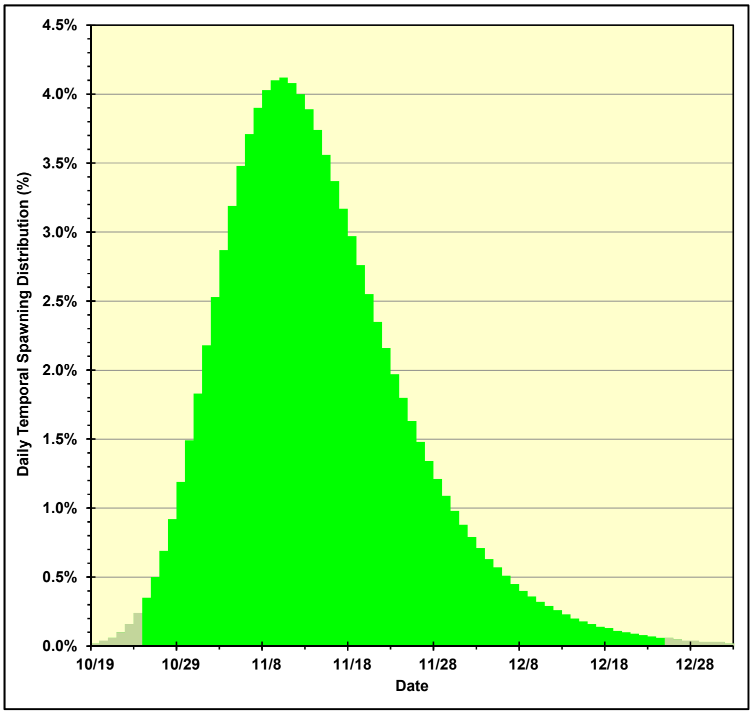

Figure B-13. Daily proportions of fall-run Chinook salmon spawning in the lower American River corresponding to the asymmetric logistic function, fitted to redd data from the 2002/03-2015/16 spawning seasons. The middle 99% of the asymmetric logistic function is emphasized (green shading).

Table B-6. Temporal weighting coefficients used in the calculation of the scaled composite WUA annual index for fall-run Chinook salmon spawning in the lower American River.

Date	Temporal Weighting Coefficient	Date	Temporal Weighting Coefficient	Date	Temporal Weighting Coefficient	Date	Temporal Weighting Coefficient
10/25	0.003540	11/10	0.041627	11/26	0.014961	12/12	0.002580
10/26	0.005034	11/11	0.041283	11/27	0.013531	12/13	0.002298
10/27	0.006933	11/12	0.040486	11/28	0.012214	12/14	0.002046
10/28	0.009256	11/13	0.039302	11/29	0.011006	12/15	0.001822
10/29	0.011991	11/14	0.037802	11/30	0.009901	12/16	0.001621
10/30	0.015089	11/15	0.036059	12/1	0.008895	12/17	0.001443
10/31	0.018468	11/16	0.034139	12/2	0.007981	12/18	0.001283
11/1	0.022016	11/17	0.032103	12/3	0.007153	12/19	0.001141
11/2	0.025599	11/18	0.030005	12/4	0.006404	12/20	0.001015
11/3	0.029076	11/19	0.027893	12/5	0.005729	12/21	0.000903
11/4	0.032309	11/20	0.025802	12/6	0.005121	12/22	0.000803
11/5	0.035174	11/21	0.023763	12/7	0.004574	12/23	0.000713
11/6	0.037574	11/22	0.021800	12/8	0.004083	12/24	0.000634
11/7	0.039440	11/23	0.019929	12/9	0.003643		
11/8	0.040737	11/24	0.018161	12/10	0.003249		
11/9	0.041459	11/25	0.016504	12/11	0.002896	**Total**	1

1.2.2 Steelhead

1.2.2.1 Habitat Suitability Criteria

Available Data

The steelhead HSC were obtained from depth, velocity, and substrate data collected during surveys for steelhead redds on the American River and other California rivers. Steelhead redd surveys with either depth, velocity, and/or substrate utilization data were compiled from five different datasets (**Table B-7**).

Data Reduction

Steelhead redd utilization data were generally obtained from final reports, but utilization data from the American River for the years 2002-2016 were obtained from "raw" data provided by John Hannon (pers. comm., 2016). The American River data set was carefully processed to remove questionable data including: 1) unknown species, 2) duplicate/multiple redds at one location, 3) redd observations with a zero depth or velocity measurement, and 4) redd observations that were surveyed immediately after a major change in flow that would affect the accuracy of the depth and velocity measurement. The data sets obtained from final reports (Table B-7) were assumed to have been processed for quality control by the authors prior to publication.

Depth

Depth measurements for each steelhead redd data set were plotted as frequency histograms on a single graph to visually compare the various datasets. An individual scaling factor was applied to each of the frequency histograms in order for each data set to plot with a similar magnitude. The scaling factors for each data set are provided in **Table B-8**. A horizontal line representing the center 50% of the depth observations was also included on the plot. An HSC curve scaled between zero and one was developed using professional judgment to represent the suitability of depth for spawning (1.0 = completely suitable and 0.0 = not suitable) (**Figure B-14**).

Velocity

Similar to the depth HSC methods, mean column velocity measurements for each steelhead redd data set were plotted as frequency histograms on a single graph to visually compare the various datasets (**Figure B-15**). An individual scaling factor was applied to each of the frequency histograms in order for each to plot with a similar magnitude. The scaling factors for each data set are provided in Table B-7. A horizontal line representing the center 50% of the depth observations was also included on the plot. An HSC curve scaled between zero and one was developed using professional judgment to represent the suitability of velocity for spawning (1.0 = completely suitable and 0.0 = not suitable).

Table B-7. Steelhead data sets used to develop habitat suitability criteria.

Dataset Name	River	Report/File Name	Years of Observation	# of Fish Observed (depth/velocity/ substrate)	Depth	Velocity	Substrate
Trinity River - Hampton et al. 1997	Trinity River	Microhabitat Suitability Criteria for Anadromous Salmonids of the Trinity River	1985-1992	88	x	x	NA
Yuba River - YCWA 2013	Yuba River	Technical Memorandum 7-10 Instream Flow Downstream of Englebright Dam	2012	242/236	x	x	NA
American River 2002-2016-Hannon 2016	American River	GIS Shape Files. USBR John Hannon data. 2013 monitoring report from John Hannon sent by Chris Hammersmark	2002- 2005, 2007, 2009-2016	1105/739/975	x	x	x
Clear Creek – Gard 2007	Clear Creek	Flow-Habitat Relationships for Spring-run Chinook Salmon and Steelhead/Rainbow Trout Spawning in Clear Creek between Whiskeytown Dam and Clear Creek Road	2000-2005	250/226	x	x	NA
Yuba River - Gard 2010	Yuba River	Flow-Habitat Relationships for Spring and Fall-run Chinook Salmon and Steelhead/Rainbow Trout Spawning in the Yuba River	2000-2002	160/157	x	x	NA

NA -- *Use frequency data not available for substrate for these sites.*

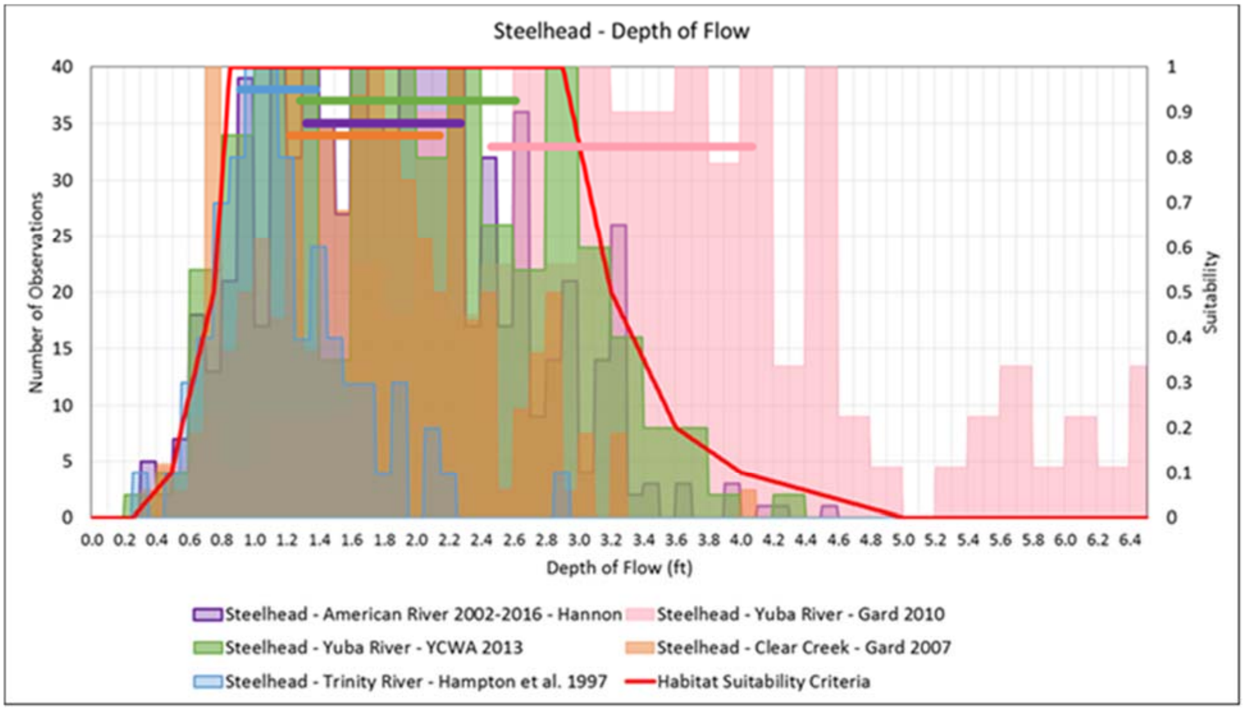

Figure B-14. Steelhead redd depth observations (left vertical axis) and habitat suitability criteria (right vertical axis).

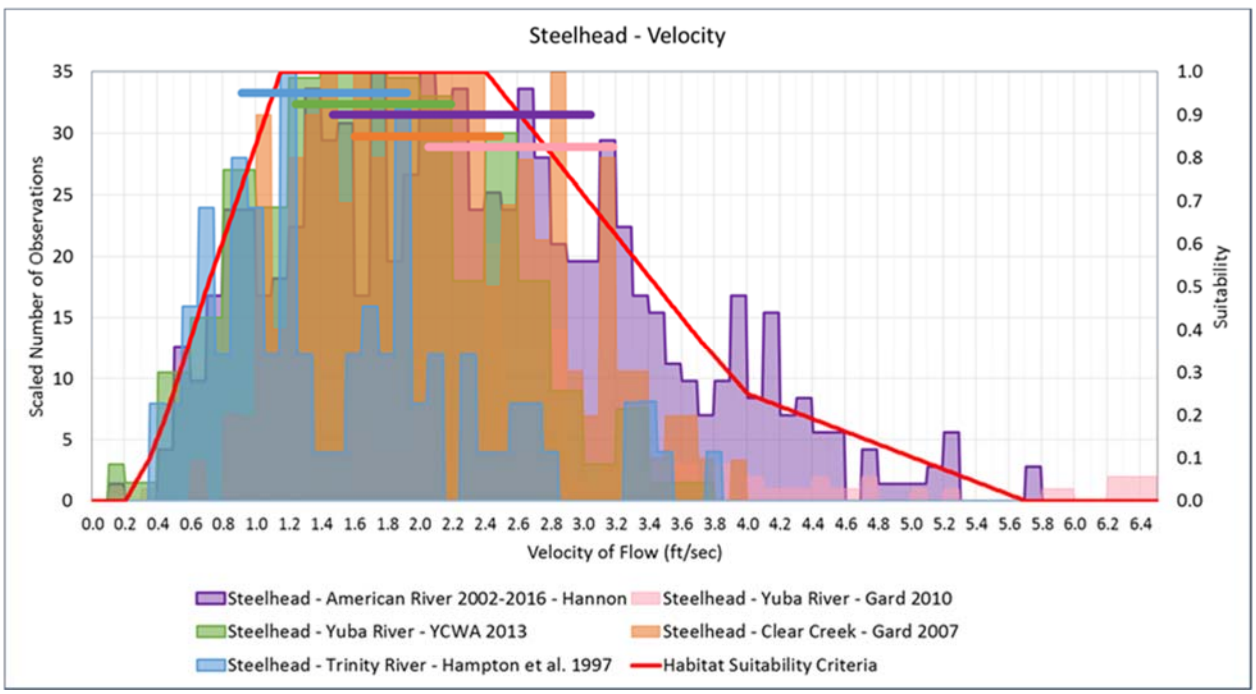

Figure B-15. Steelhead redd mean column velocity observations (left vertical axis) and habitat suitability criteria (right vertical axis).

Table B-8. Scaling factors for each steelhead habitat utilization data set.

Dataset Name	Scaling Factors		
	Depth	Velocity	Substrate
Trinity River – Hampton et al. 1997	4	4	-
Yuba River – YCWA 2013	2	1.5	-
American River 2002-2016 – Hannon	1	1.4	1
Clear Creek – Gard 2007	2.5	3.5	-
Yuba River – Gard 2010	4.5	1	-

SUBSTRATE

Substrate use frequency data were available from only one of the five steelhead redd survey data sets used for this analysis (Table B-7). Steelhead substrate use data were plotted as a frequency histogram from surveys of the American River (2002-2016). An HSC curve scaled between zero and one was developed using professional judgment to represent the suitability of substrate for spawning (1.0 = completely suitable and 0.0 = not suitable) (**Figure B-16**).

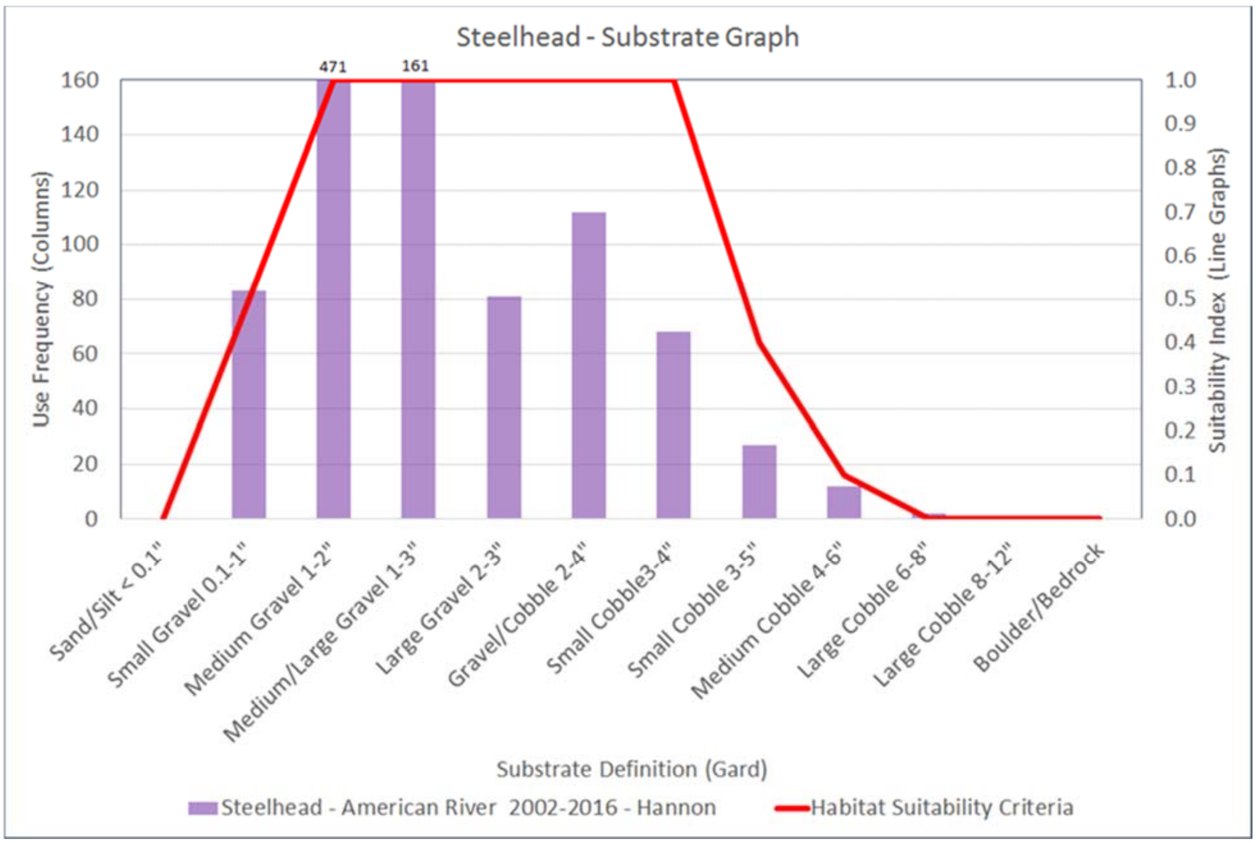

Figure B-16. Steelhead redd observations and habitat suitability criteria by substrate type.

FINAL DEPTH AND VELOCITY HSCS

Based on examination of the five data sets, including the lower American River, and development of scaling factors and modality and trend visual analyses, HSC curves for depth and velocity, scaled between zero and one, were developed using professional judgment to represent the suitability of depth and velocity for steelhead spawning (1.0 = completely suitable and 0.0 = not suitable). The final depth and velocity HSC curves are presented in **Figure B-17**.

FINAL SUBSTRATE HSC

Substrate use frequency data from the lower American River steelhead redd survey data set was used to develop a final substrate HSC curve scaled between zero and one to represent the suitability of substrate for spawning (1 = completely suitable and 0 = not suitable) (**Figure B-18**).

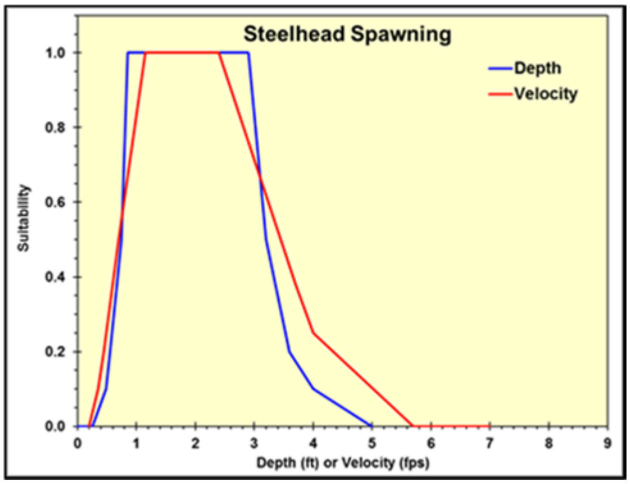

Figure B-17. Steelhead depth and velocity HSCs for application to the lower American River.

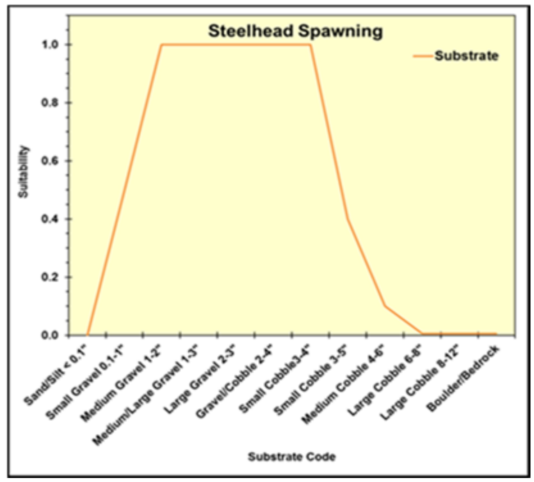

Figure B-18. Steelhead substrate HSC for application to the lower American River.

1.2.2.2 Reach-specific and Composite WUA – Flow Relationships

Spawning habitat (WUA) – flow relationships for steelhead were developed using the same approach as discussed in Section 1.2.1.2 for fall-run Chinook salmon.

Figure B-19 shows the WUA-flow relationships separately for the eight reaches, and the composite WUA-flow relationship resulting from the sum of the reach-specific relationships. Of the four largest sites with the most WUA, two sites have relatively "flat" habitat versus flow relationships that show that maximum habitat occurs over a wide flow range from 1,000-3,400 cfs (Sunrise and Sailor Bar) and two have more "peaked" habitat versus flow relationships that reach maximum habitat at 1,400 cfs (Rossmoor and Above Sunrise). The channel topography (e.g., narrow versus wider channel) in these reaches affects the habitat versus flow relationships.

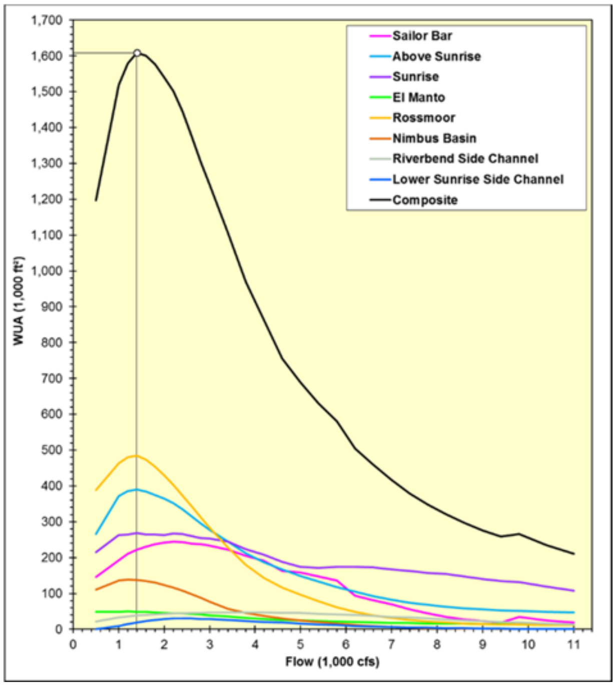

Figure B-19. Relationship between steelhead spawning habitat availability (expressed as WUA) and flow for the eight lower American River study reaches, and for the composite of the eight study reaches.

The maximum fall-run Chinook salmon spawning WUA for all eight reaches combined occurs at about 1,400 cfs, and corresponds to the denominator $\max\left(\sum_{h=1}^{8} WUA_h(Q)\right)$ in equation (1) and is used to scale the composite WUA annual index. As with the composite WUA curve for fall-run Chinook salmon, the steelhead composite WUA curve also has 31 data points corresponding to flows ranging from 500 cfs through 11,000 cfs (average daily Nimbus Dam release). The steelhead composite WUA curve also required extrapolations to account for flows outside of the 500 - 11,000 cfs range.

To interpolate target daily flows lower than 500 cfs, a polynomial function was fitted to the WUA values for the seven lowest flows in the composite WUA-flow relationship (*i.e.*, Q = 500 cfs; 1,000 cfs; 1,200 cfs; 1,400 cfs; 1,600 cfs; 1,800 cfs and 2,000 cfs).

The equation of the fitted polynomial was $WUA = 3{,}850.160 \times Q - 3.687159 \times Q^2 + 0.001666 \times Q^3 - 2.96 \times 10^{-7} \times Q^4$, and had a coefficient of determination $R^2 = 0.99$. The polynomial equation was used to generate seven extrapolated WUA values for Q = 0 cfs, 50 cfs, 100 cfs, 150 cfs, 200 cfs, 300 cfs, and 400 cfs.

To extrapolate habitat values for daily flows higher than 11,000 cfs, a power function was fitted to the WUA values for the ten higher flows in the composite WUA-flow relationship (*i.e.*, Q ranging from 7,000 cfs through 11,000 cfs). The equation of the fitted power function was $\ln(WUA) = 25.664611 - 1.439683 \times \ln(Q)$, and had a coefficient of determination $R^2 = 0.98$. The regression equation was used to generate extrapolated WUA values for Q ranging from 12,000 cfs through 141,000 in increasing steps of 1,000 cfs. The seven WUA values extrapolated from the fitted polynomial and the WUA values extrapolated from the fitted power function were combined with the 31 values of the original composite WUA-flow relationship into a look-up table used for the linear interpolation of WUA values for all Nimbus daily flows generated under the 2006 FMS and the Modified FMS over the 82-year simulation period (**Table B-9**).

Table B-9. Composite WUA values for steelhead spawning in the lower American River used as look-up table for linear interpolation of WUA values for Nimbus daily flows.

Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)
0	0	2,200	1,501,947	7,000	416,957	16,000	123,994
50	183,496	2,400	1,444,590	7,400	379,330	17,000	113,630
100	349,780	2,600	1,375,498	7,800	347,267	18,000	104,654
150	500,035	2,800	1,304,585	8,200	321,000	19,000	96,817
200	635,397	3,000	1,239,775	8,600	296,359	20,000	89,925
300	865,776	3,400	1,105,253	9,000	275,327	21,000	83,825
400	1,049,135	3,800	969,789	9,400	259,147	22,000	78,395
500	1,197,366	4,200	863,117	9,800	265,853	23,000	73,535
1,000	1,518,614	4,600	755,166	10,400	234,702	24,000	69,165
1,200	1,578,917	5,000	689,540	11,000	210,915	25,000	65,217
1,400	1,608,390	5,400	630,272	12,000	187,617	26,000	61,636
1,600	1,600,465	5,800	580,652	13,000	167,196	27,000	58,377
1,800	1,576,700	6,200	503,577	14,000	150,276	28,000	55,399
2,000	1,540,319	6,600	459,308	15,000	136,067		

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using a power function (see text for details).

Table B-9 displays WUA values corresponding to flows less than or equal to 28,000 cfs because this range represents approximately 99.5% of the flows modeled during the simulation period. The composite WUA values in Table B-9 were plotted in **Figure B-20** for a visual representation of the final composite WUA-flow relationship.

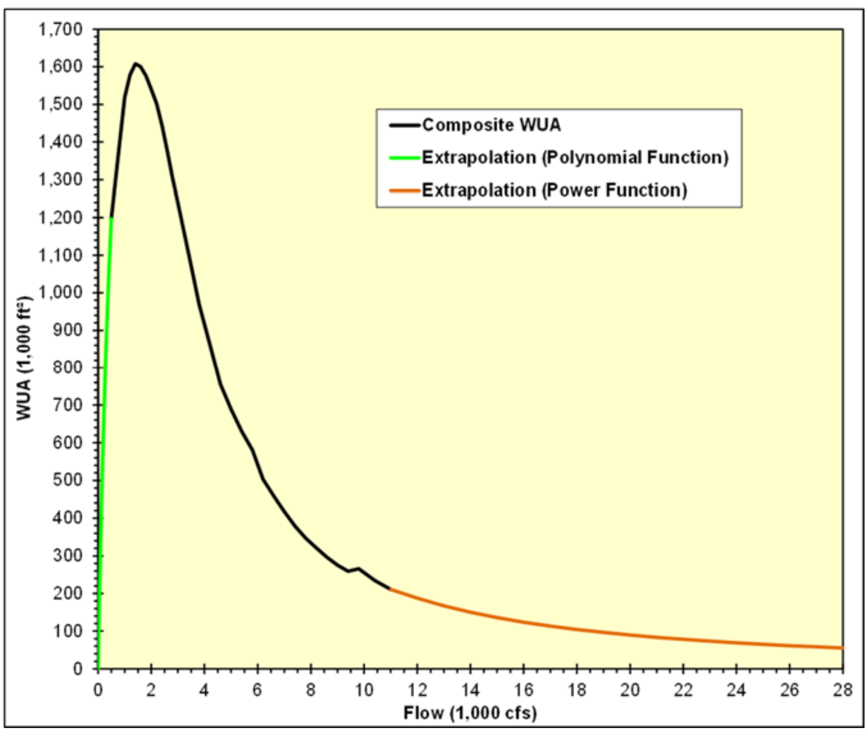

Figure B-20. Final relationship between the composite WUA and flow for steelhead spawning in the lower American River.

1.2.2.3 Temporal Weighting Coefficients

The temporal weighting coefficients used for steelhead spawning in the lower American River were derived from the steelhead redd surveys performed by Reclamation and CDFW from February 2002 through March 2016 (Chase 2010; Hannon 2011, 2012 and 2013; Hannon and Healey 2002; Hannon et al. 2003; Hannon and Deason 2004, 2005 and 2007; and See and Chase 2009). Because steelhead redd surveys have been conducted in the lower American River starting as early as mid-December of one calendar year through as late as mid-June of the following year, the available data are presented as 13 spawning survey seasons over the course of two calendar years as follows: 2001/02, 2002/03, 2003/04, 2004/05, 2006/07, 2008/09, 2009/10, 2010/11, 2011/12, 2012/13, 2013/14, 2014/15 and 2015/16. No redd surveys were conducted during the 2005/2006 and 2007/08 spawning seasons due to high flows and low water clarity.

Sampling was conducted early enough in the year in an effort to observe the initiation of spawning, with redd surveys typically beginning in mid- to late December. However, the surveys conducted during the 2001/02, the 2008/09 and the 2014/15 seasons did not start until 2/7/02, 2/11/09 and 1/23/15, respectively, when steelhead spawning was already in progress. To avoid potential bias introduced by the data in these incomplete surveys, the steelhead cumulative proportions of newly constructed redds derived from these three surveys were not included in the fitting of the asymmetric logistic function (equation 2) that produced the temporal weighting coefficients for steelhead spawning in the lower American River.

Figure B-21 displays the ten sets of daily cumulative proportions used in the fitting of the common asymmetric logistic function. To fit equation 2, the variable *D* (*i.e.*, the days within each spawning season) was counted from June 1 of each year (*D* = 1) through July 31 of the following year. During the 10 spawning seasons the total number of new redds observed per season was variable (*i.e.*, 117 in 2002/03, 129 in 2003/04, 91 in 2004/05, 152 in 2006/07, 45 in 2009/10, 52 in 2010/11, 64 in 2011/12, 286 in 2012/13, 93 in 2013/14 and 52 in 2015/16). The number of weekly surveys performed during each spawning season, ranged from six weekly surveys during the 2013/14 and 2015/16 seasons to 11 weekly surveys during the 2003/04 season. Given the variation among each spawning season, a weighted nonlinear least squares procedure was used to fit the common asymmetric logistic function (equation 2) to the 10 sets of daily cumulative proportions of newly built redds. The weights were calculated as the ratio of the annually counted redds to the overall total number of counted redds over the 10 sampled seasons (*i.e.*, 1,081 newly-built redds). For example, the 11 daily cumulative proportions of redds built during the 2003/04 spawning season each received a weight of 0.1193 (*i.e.*, 129/1,081 = 0.1193), while the eight daily cumulative proportions of redds built during the 2011/12 spawning season received each a weight of 0.0592 (*i.e.*, 64/1,081 = 0.0592), and the nine daily cumulative proportions of redds built during the 2012/13 spawning season received each a weight of 0.2646 (*i.e.*, 286/1,081 = 0.2646).

The resulting fitted curve had the following expression:

$$Y_D = \left(\frac{1}{1 + \exp\left(29.3739 - 0.1135 \times D\right)} \right)^{1/1.3946} \quad \textbf{(8)}$$

where D is the day number at which new steelhead redds were observed during a particular annual survey, counted from June 1 of each year. The mean square error of this fit was 0.0299.

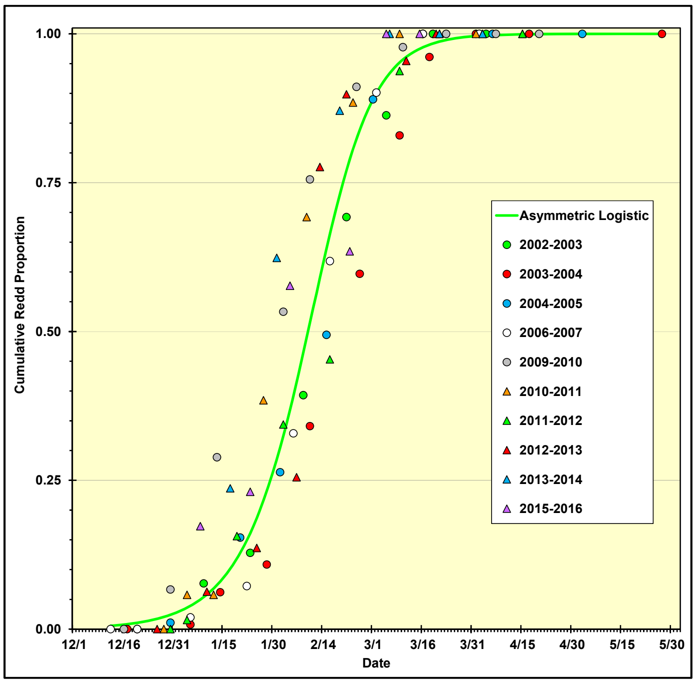

Figure B-21. Steelhead cumulative proportions of newly constructed redds in the lower American River during the 2002/03-2015/16 spawning seasons, and the fitted asymmetric logistic curve.

The cumulative distribution from equation 8 was first restricted to daily cumulative values within the middle 99% of the distribution, and the remaining daily cumulative values were used to calculate the expected daily spawning proportions by subtraction. Finally, the daily temporal coefficients for steelhead were obtained by rescaling each daily proportion such that they summed to 1. The daily temporal distribution of steelhead spawning is displayed in **Figure B-22**. **Table B-10** displays the final daily weighting coefficients for steelhead spawning, and the resulting spawning period used in the calculation of the scaled composite WUA annual index ($CWUA_Y$). The resulting spawning period representing the middle 99% of the distribution extends from December 11 through March 29 (or March 28 in leap years), a period consisting of K = 109 days.

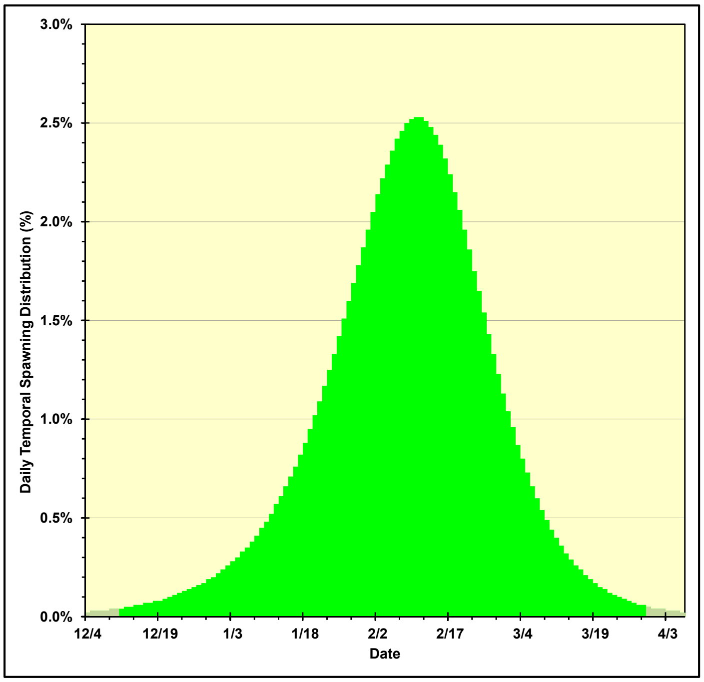

Figure B-22. Daily proportions of steelhead spawning in the lower American River corresponding to the asymmetric logistic function, fitted to redd data from the 2002/03-2015/16 spawning seasons. The middle 99% of the asymmetric logistic function is emphasized (green shading).

1.3 APPLICATION OF COMPOSITE WUA ANNUAL INDICES

The average daily flows below Nimbus Dam, as output of the HEC-RAS Model, and equation (1) were used to calculate the scaled composite WUA annual indices for fall-run Chinook salmon and steelhead spawning in the lower American River for each of the 82 years (1922-2003) simulated under the 2006 FMS and the Modified FMS scenarios. For Modified FMS development and performance evaluation purposes, the resulting annual indices under each of the two scenarios were averaged over the entire 82-year simulation period and by water year type. Additionally, the resulting annual indices were used to develop habitat duration curves, expressed as cumulative probability exceedance curves, for fall-run Chinook salmon and steelhead spawning habitat availability.

Table B-10. Temporal weighting coefficients used for steelhead spawning in the lower American River.

Day	Temporal Weighting Coefficient	Day	Temporal Weighting Coefficient	Day	Temporal Weighting Coefficient
12/11	0.000440	**1/17**	0.008304	**2/23**	0.016618
12/12	0.000478	**1/18**	0.008928	**2/24**	0.015538
12/13	0.000518	**1/19**	0.009589	**2/25**	0.014472
12/14	0.000562	**1/20**	0.010287	**2/26**	0.013430
12/15	0.000610	**1/21**	0.011023	**2/27**	0.012421
12/16	0.000661	**1/22**	0.011794	**2/28**	0.011451
12/17	0.000717	**1/23**	0.012600	**3/1**	0.010526
12/18	0.000778	**1/24**	0.013439	**3/2**	0.009649
12/19	0.000843	**1/25**	0.014308	**3/3**	0.008824
12/20	0.000914	**1/26**	0.015202	**3/4**	0.008050
12/21	0.000992	**1/27**	0.016116	**3/5**	0.007329
12/22	0.001075	**1/28**	0.017044	**3/6**	0.006660
12/23	0.001166	**1/29**	0.017979	**3/7**	0.006041
12/24	0.001264	**1/30**	0.018911	**3/8**	0.005471
12/25	0.001370	**1/31**	0.019830	**3/9**	0.004948
12/26	0.001486	**2/1**	0.020726	**3/10**	0.004468
12/27	0.001610	**2/2**	0.021586	**3/11**	0.004031
12/28	0.001745	**2/3**	0.022397	**3/12**	0.003632
12/29	0.001892	**2/4**	0.023144	**3/13**	0.003270
12/30	0.002050	**2/5**	0.023816	**3/14**	0.002941
12/31	0.002221	**2/6**	0.024397	**3/15**	0.002643
1/1	0.002406	**2/7**	0.024876	**3/16**	0.002374
1/2	0.002606	**2/8**	0.025240	**3/17**	0.002131
1/3	0.002822	**2/9**	0.025480	**3/18**	0.001912
1/4	0.003056	**2/10**	0.025588	**3/19**	0.001714
1/5	0.003308	**2/11**	0.025560	**3/20**	0.001536
1/6	0.003580	**2/12**	0.025393	**3/21**	0.001376
1/7	0.003874	**2/13**	0.025090	**3/22**	0.001232
1/8	0.004190	**2/14**	0.024653	**3/23**	0.001103
1/9	0.004530	**2/15**	0.024090	**3/24**	0.000987
1/10	0.004896	**2/16**	0.023412	**3/25**	0.000883
1/11	0.005289	**2/17**	0.022631	**3/26**	0.000790
1/12	0.005711	**2/18**	0.021760	**3/27**	0.000706
1/13	0.006163	**2/19**	0.020816	**3/28**	0.000632
1/14	0.006647	**2/20**	0.019814	**3/29**	0.000565
1/15	0.007165	**2/21**	0.018770		
1/16	0.007717	**2/22**	0.017700	**Total**	1

2.0 REFERENCES

Beak Consultants, Inc. 1989. Yuba River Fisheries Investigation, 1986-1988. Summary Report of Technical Studies on the Lower Yuba River, California. Prepared for State of California Resources Agency, Department of Fish and Game.

Briggs, J.C. 1953. The Behavior and Reproduction of Salmonid Fishes in a Small Coastal Stream. California Department of Fish and Wildlife. Fish Bulletin 94, 62 p.

Chase, R. 2010. American River Steelhead (*Oncorhynchus mykiss*) Spawning Surveys 2010. U.S. Bureau of Reclamation. Sacramento, 15 p.

Gard, M. 2011. Flow-Habitat Relationships for Fall-Run Chinook Salmon and Steelhead/Rainbow Trout Spawning in Clear Creek between Clear Creek Road and the Sacramento River. January 21, 2011.

Gard, M. 2010. Flow-Habitat Relationships for Spring and Fall-run Chinook Salmon and Steelhead/Rainbow Trout Spawning in the Yuba River.

Gard, M. 2007. CVPIA Instream Flow Investigations Clear Creek Spring-run Chinook Salmon and Steelhead/Rainbow Trout Spawning. August 15, 2007.

Gard, M. 2003. Flow-Habitat Relationships for Steelhead and Fall, Late-Fall and Winter-Run Chinook Salmon Spawning in the Sacramento River between Keswick Dam and Battle Creek. February 4, 2003.

Groves, P. A., and J. A. Chandler. 1999. Spawning Habitat Used by Fall Chinook Salmon in the Snake River. North American Journal of Fisheries Management. Volume 19, 1999 – Issue 4, pg. 912-922.

Hampton, M., T. Payne, and J. A. Thomas. 1997. Microhabitat Suitability Criteria for Anadromous Salmonids of the Trinity River. December 15, 1997.

Hannon, J. 2013. American River Steelhead (*Oncorhynchus mykiss*) Spawning -2013, with Comparison to Prior Years. U.S. Bureau of Reclamation. Sacramento, 32 p.

Hannon, J. 2012. American River Steelhead (*Oncorhynchus mykiss*) Spawning -2012, with Comparison to Prior Years. U.S. Bureau of Reclamation. Sacramento, 30 p.

Hannon, J. 2011. American River Steelhead (*Oncorhynchus mykiss*) Spawning Surveys 2011, with Comparisons to Prior Years. U.S. Bureau of Reclamation. Sacramento, 27 p.

Hannon, J., and B. Deason, 2007. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001-2007. U.S. Bureau of Reclamation. Sacramento, 53 p.

Hannon, J., and B. Deason, 2005. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001-2005. U.S. Bureau of Reclamation. Sacramento, 48 p.

Hannon, J., and B. Deason, 2004. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001-2004. U.S. Bureau of Reclamation. Sacramento, 43 p.

Hannon, J., and M. Healey, 2002. American River Steelhead Redd Surveys, 2001-2002. U.S. Bureau of Reclamation. Sacramento, 19 p.

Hannon, J., M. Healey, and B. Deason, 2003. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001-2003. U.S. Bureau of Reclamation. Sacramento, 36 p.

Hardy, T. B., C. Addley, E. Saraeva. 2006. Evaluation of Instream Flow Needs in the Lower Klamath River Phase II Final Report. Prepared for the U.S. Department of the Interior. July 31, 2006.

Healey, M. 2006. Lower American River Chinook Salmon Escapement Survey October – December 2005. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 14 p.

Healey, M. 2005. Lower American River Chinook Salmon Escapement Survey October 2004 – January 2005. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 15 p.

Healey, M. 2004. Lower American River Chinook Salmon Escapement Survey October 2003– January 2004. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 15 p.

Healey, M. 2003. Lower American River Chinook Salmon Escapement Survey October 2002– January 2003. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 18 p.

Healey, M. 2002. Lower American River Chinook Salmon Escapement Survey, October - December 2001. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, 17 p.

Healey, M. and S. Fresz. 2007. Lower American River Chinook Salmon Escapement Survey, October 2006- December 2007. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 14 p.

Healey, M. and J. Redding. 2008. Lower American River Chinook Salmon Escapement Survey October 2007 – January 2008. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 14 p.

Maher, M., R. Vincik and J. Phillips. 2012. Lower American River Fall-run Chinook Salmon Escapement Survey, 19 October - 15 December 2010. California Department of Fish and Wildlife, North Central Region, Rancho Cordova, CA, 25 p.

Phillips, J. and J. M. Helstab. 2013. Lower American River Fall-run Chinook Salmon Escapement Survey, October 2012- January 2013. California Department of Fish and Wildlife, North Central Region, Rancho Cordova, CA, 30 p.

Phillips, J. and M. Maher. 2013. Lower American River Fall-run Chinook Salmon Escapement Survey, October 2011- January 2012. California Department of Fish and Wildlife, North Central Region, Rancho Cordova, CA, 30 p.

Ratkowsky, D.A. 1983. Nonlinear Regression Modeling. A Unified Practical Approach. Marcel Dekker, Inc., New York, 575 p.

See, M., and R. Chase. 2009. American River Steelhead (*Oncorhynchus mykiss*) Spawning Surveys 2009. U.S. Bureau of Reclamation. Sacramento, 15 p.

Snider, B., and K. Bandner. 1996. Lower American River Chinook Salmon Escapement Survey, October 1994-January 1995. California Department of Fish and Wildlife, Environmental Service Division, 38 p.

Snider, B. and D. McEwan. 1992 Chinook Salmon and Steelhead Trout Redd Survey, Lower American River, 1991-1992. California Department of Fish and Wildlife, Environmental Services Division, 94 p.

Snider, B., and B. Reavis. 1996. Lower American River Chinook Salmon Escapement Survey, October 1995-January 1996. California Department of Fish and Wildlife, Environmental Service Division, 31 p.

Snider B. and K. Vyverberg. 1996. Chinook Salmon Redd Survey, Lower American River, Fall 1995. California Department of Fish and Wildlife, Environmental Services Division, Stream Flow and Habitat Evaluation Program. May 1996.

Snider B. and K. Vyverberg. 1995. Chinook Salmon Redd Survey, Lower American River, Fall 1993. California Department of Fish and Wildlife, Environmental Services Division, 47 p.

Snider, B., A.J. Chappelle, and N. Villa. 1995. Lower American River Chinook Salmon Escapement Survey, October 1993-January 1994. California Department of Fish and Wildlife, Environmental Service Division, 21 p.

Snider, B., N. Keenan, and M. Muños. 1993. Lower American River Chinook Salmon Escapement Survey, September 1992-January 1993. California Department of Fish and Wildlife, Environmental Service Division, 20 p.

Snider, B., K. Urquhart, D. McEwan, and M. Muños. 1993. Chinook Salmon Redd Survey, Lower American River, Fall 1992. California Department of Fish and Wildlife, Environmental Service Division, 30 p.

Snider B., K. Vyverberg, and S. Whiteman. 1996. Chinook Salmon Redd Survey, Lower American River, Fall 1994. California Department of Fish and Wildlife, Environmental Services Division, 54 p.

USFWS. 1996. Identification of the Instream Flow Requirements for Steelhead and Fall-Run Chinook Salmon Spawning in the Lower American River. Sacramento, California: The Instream Flow Assessment Branch.

Vincick, R. and J. Kirsch. 2009. Lower American River Chinook Salmon Escapement Survey October 2008 – January 2009. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 18 p.

Vincick, R. and M. Mamola. 2010. Lower American River Chinook Salmon Escapement Survey, October 2009- January 2010. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 15 p.

Yuba County Water Agency (YCWA). 2013. Technical Memorandum 7-10 Instream Flow Downstream of Englebright Dam. Yuba River Development Project. FERC Project No. 2246.

BIOLOGICAL RATIONALE, DEVELOPMENT AND PERFORMANCE OF THE MODIFIED FLOW MANAGEMENT STANDARD

Attachment C

Lower American River
Potential Redd Dewatering Analyses

November 29, 2017

1.0 POTENTIAL REDD DEWATERING OF LOWER AMERICAN RIVER SALMONIDS

Flow fluctuations during the fall-run Chinook salmon and steelhead embryo incubation periods are of importance to fisheries management because reductions in flow may cause water surface elevations to decrease below the depth at which the redds were built. Dewatered redds may result in desiccation and the loss of eggs and developing embryos. The biological impact of redd dewatering is determined by both the timing and duration of the desiccation and by the magnitude of the decrease in water surface elevation.

In consideration of the potential importance of redd dewatering, the development of redd dewatering protective adjustments was included in the Modified FMS.

2.0 PROTECTIVE ADJUSTMENTS

Redd dewatering protective adjustments (RDPAs) were developed for the Modified FMS in order to restrict the minimum release requirements (MRR) to limit potential redd dewatering due to reductions in the MRR during the January through May period. Two RDPAs were included: (1) the Chinook salmon RDPA in January and February; and (2) the steelhead RDPA in February through May.

2.1 FALL-RUN CHINOOK SALMON

The fall-run Chinook salmon RDPA would limit the potential dewatering of fall-run Chinook salmon redds due to a reduction of the MRR from December to January or February. The fall-run Chinook salmon RDPA-based MRR is computed by multiplying the December hydrologic index-based MRR by 0.70, representing a maximum 30% reduction in MRR from December to both January and February. The higher of the two values (the hydrologic index-based MRR or the RDPA-based MRR) are used to set the minimum requirements for January and February.

2.2 STEELHEAD

The steelhead RDPA would limit the potential dewatering of steelhead redds due to a reduction of the MRR during February through May. The January MRR would be used to set the minimum allowable MRR in February through May based upon **Table C-1**. In some instances, the MRR may increase from January to February. If the February MRR is higher than the January MRR, then the February MRR would be used to set the minimum MRR for March through May based upon Table C-1. The higher of the two values (the hydrologic index-based MRR or the RDPA-based MRR) are used to set the minimum requirements. If the January or February MRR are in between the values provided in Table C-1, then the steelhead RDPA-based MRR would be interpolated between the nearest values.

Table C-1. Steelhead RDPA-based MRR for February through May.

MRR_{Jan} or MRR_{Feb} (cfs)	Steelhead RDPA-Based MRR for February-May (cfs)
≤700	500
800	520
900	580
1,000	640
1,100	710
1,200	780
1,300	840
1,400	950
1,500	1,030
1,600	1,100
1,700	1,180
1,800	1,250

3.0 ANNUAL REDD DEWATERING INDEX

An evaluation of the potential redd dewatering effects of flow fluctuations on spawning salmonids typically involves calculating flow (or river stage) reductions between consecutive days along the spawning area during the spawning and embryo incubation season, and expressing the number of stage reductions of a given magnitude that occurred during the spawning and embryo incubation period. Interpretations of results using this approach are often limited because information concerning the percentage of the spawning population potentially affected by the stage reductions occurring during the spawning and embryo incubation season is not incorporated. In general, most redds are constructed during identifiable peaks of fall-run Chinook salmon and steelhead spawning activity, with variable overall temporal and spatial distributions.

For the purposes of this redd dewatering analysis, the potential for fall-run Chinook salmon and steelhead redd dewatering due to daily flow fluctuations in the lower American River under the Modified FMS and the 2006 FMS is analyzed through an annual weighted redd dewatering index. In this index, the potential for redd dewatering due to changes in daily flows and corresponding changes in river stage are weighted by the expected temporal and spatial distributions of fall-run Chinook salmon and steelhead spawning activity in the lower American River. In addition to the information on the expected temporal and spatial distributions of spawning activity, the index incorporates information on the expected depth distributions of fall-run Chinook salmon and steelhead redds, on the duration of embryo incubation based on simulated water temperatures, and on the maximum river stage reduction through fry emergence experienced by redds of a same cohort (*i.e.*, redds built on the same day and within the same spawning area or reach during a spawning season).

The annual weighted redd dewatering index provides annual estimates of the maximum proportions of redds, relative to the total number of redds built during the species spawning periods, that were potentially dewatered at least once due to decreases in flow and associated drops in water surface elevation occurring from the date of redd construction through the corresponding date of expected fry emergence. The changes in water surface elevation are evaluated against the overall distributions of fall-run Chinook salmon and steelhead redd depths in the lower American River measured at the level of the undisturbed bed surface of the redd.

The annual weighted redd dewatering index (WRD_Y) provides an annual estimate of the expected maximum proportion of redds, relative to the total number of redds built during the species' spawning periods, that were potentially dewatered at least once due to decreases in flow and associated decreases in water surface elevation occurring from the date of redd construction through the corresponding date of fry emergence. The equation describing the annual weighted redd dewatering index is:

$$WRD_Y = \sum_{d=1}^{k} w_d \times \left\{ \sum_{h=1}^{18} w_h \times \left[\Pr\left(Redd\ Depth \leq \max_{i=d+1 \to ED_{d,h,Y}} \left(Stage_{d,h,Y} - Stage_{i,h,Y} \right) \right) \right] \right\}. \qquad \textbf{(1)}$$

The primary components of equation (1) are described below.

- The factor w_d is a temporal weighting coefficient that indicates the proportion of redds built on a particular day (d) relative to all the redds expected to be built during the k days of the fall-run Chinook salmon or steelhead spawning periods over the species' entire spawning grounds. The sum of the daily temporal weighting coefficients over the entire spawning season equals to one (*i.e.*, $\sum_{d=1}^{k} w_d = 1$).

- The factor w_h is a spatial weighting coefficient that indicates the proportion of redds built on a particular area (h) relative to all the redds expected to be built on any given day of the spawning season over the 18 areas in which the lower American River spawning grounds of fall-run Chinook salmon and steelhead are divided. For any given day of the species' spawning season, the sum of the spatial weighting coefficients over the entire spawning ground equals to one (*i.e.*, $\sum_{h=1}^{18} w_h = 1$).

- The variable $ED_{d,h,Y}$ indicates the duration (in number of days) of the embryo incubation for redds built on day d of year Y, in spawning area h. The values of the variables are derived from the time series of daily water temperatures derived from the CE-QUAL-W2 model of Folsom Reservoir and the associated multivariate regression river temperature models for each of the simulated years, under the Modified FMS and the 2006 FMS.

- The variable $Stage_{d,h,Y}$ indicates the mean daily river stage in spawning area h on redd construction day d of year Y. The variable $Stage_{i,h,Y}$ indicates the mean daily river stage in the same spawning area, on any day i subsequent to the date of redd construction, until the last day of the calculated embryo incubation period for the redds built on day d (*i.e.*, $ED_{d,h,Y}$). For each redd cohort (*i.e.*, the group of redds built on the same day d and in the same spawning area h), the positive river-stage differences between $Stage_{d,h,Y}$ and $Stage_{i,h,Y}$ are evaluated for each day within the period d+1 through $ED_{d,h,Y}$ to determine the maximum river-stage difference: $\underset{i=d+1 \rightarrow ED_{d,h,Y}}{\mathrm{Max}} \left(Stage_{d,h,Y} - Stage_{i,h,Y} \right)$. This value is equivalent to the maximum drop in water surface elevation experienced by redds built on day d in spawning area h during year Y.

- The expression $\Pr\left(Redd\ Depth \leq \underset{i=d+1 \rightarrow ED_{d,h,Y}}{\mathrm{Max}} \left(Stage_{d,h,Y} - Stage_{i,h,Y} \right) \right)$ indicates the expected probability of redds being constructed at depths less or equal to the maximum river stage difference experienced by redds built in spawning zone h on day d throughout their embryo incubation periods. These probabilities were obtained from cumulative distributions of redd depths, measured at the level of the undisturbed bed surface of the redds that were developed for fall-run Chinook salmon and steelhead spawning in the lower American River.

Once the annual index (*i.e.*, WRD_Y) for fall-run Chinook salmon and steelhead spawning in the lower American River is calculated using average daily flows (and associated river stages) and average daily water temperatures modeled under the Modified FMS and the 2006 FMS during each of the years simulated, the resulting annual indices were averaged over the entire simulation period and by water year type for comparison under the Modified FMS and 2006 FMS.

3.1 TEMPORAL WEIGHTING COEFFICIENTS

The annual weighted redd dewatering index utilizes temporal weighting coefficients to indicate the proportion of redds expected to be built on each day of the assumed spawning periods, based on the expected spawning temporal distributions for fall-run Chinook salmon and steelhead.

In general, to calculate the temporal weighting coefficients, spawning timing is described as an asymmetric logistic function of time. The asymmetric logistic function, also known as Richards sigmoidal curve (Ratkowsky 1983), has the following expression:

$$Y_D = \left(\frac{1}{1 + \exp\left(\alpha + \beta \times D\right)} \right)^{1/\delta} \qquad \textbf{(2)}$$

where Y_D is the expected cumulative proportion of spawning through day D, and α, β and δ are parameters that determine the shape of the cumulative curve. The variable D is a continuous variable that indicates the day number at which new spawning occurs during a particular spawning season, counting from a particular starting date. In order to estimate the values of α, β and δ, the daily cumulative proportions of newly built redds, reported in available annual redd survey reports, were normally used as a proxy for Y_D, and fitted to the asymmetric logistic model through a nonlinear least squares procedure. In the case of fall-run Chinook salmon spawning in the lower American River, the data describing Y_D arose from combining information contained in available carcass and redd survey annual reports. Once equation (2) was fitted to the data available for the species, the daily temporal weighting coefficients w_d were calculated by subtracting the fitted cumulative proportions of two consecutive dates, rescaled to the middle 99% of the observed spawning period of the species.

3.1.1 Fall-run Chinook Salmon

The temporal weighting coefficients and spawning period used for fall-run Chinook salmon spawning in the lower American River were derived from data collected by both redd surveys and carcass surveys. Redd surveys that provide the cumulative distribution of newly built redds over time, which is a better descriptor of spawning timing, were performed by the California Department of Fish and Wildlife (CDFW) during the 1991/92 through the 1995/96 fall-run Chinook salmon spawning seasons (Snider and McEwan 1992; Snider et al. 1993 and 1996; Snider and Vyverberg 1995 and 1996), and by Cramer Fish Sciences during the 2009/10 through the 2015/16 fall-run Chinook salmon spawning seasons. Fall-run Chinook salmon carcass surveys have been performed annually since the late 1960’s, and data or reports are available for all surveys performed during the 1992/93 through 2015/16 spawning seasons (e.g., Snider and Bandner 1996; Snider and Reavis 1996; Snider et al. 1993 and 1995; Healey 2002, 2003, 2004, 2005 and 2006;

Healey and Fresz 2007; Healey and Redding 2008; Vincik and Kirsch 2009; Vincik and Mamola 2010; Maher *et al.* 2012; Phillips and Maher 2013; and Phillips and Helstab 2013; Cramer Fish Sciences, unpublished data). The temporal distributions of fresh carcasses described in these reports can be used to estimate an overall cumulative distribution of fresh carcasses over time that describe when fresh carcasses appear in the surveys, a time that closely follows the actual time of spawning. When appropriately lagged by the time elapsing between spawning and appearance of fresh carcasses in the surveys, the carcass surveys also describe spawning timing. Normally, the time elapsing between spawning and redd-construction and post-spawning mortality, or life expectancy after spawning, has been reported to be between 2 and 4 weeks (Briggs 1953). To take advantage of the potential information on fall-run Chinook salmon spawning timing in the lower American River contained in the available redd and carcass surveys, a five-step procedure was developed to estimate the sigmoidal curve describing fall-run Chinook salmon spawning timing in the lower American River.

The lagged asymmetric logistic curve resulting from the 5-step procedure was used to calculate expected daily spawning proportions by subtraction (see Attachment B). **Table C-2** display the final daily weighting coefficients for fall-run Chinook salmon spawning in the lower American River, and the resulting spawning period used in the calculation of the scaled composite WUA annual index (*i.e.*, $CWUA_Y$) for fall-run Chinook salmon. The resulting spawning period representing the middle 99% of the distribution extends from October 25 through December 24, a period consisting of $K = 61$ days.

Table C-2. Temporal weighting coefficients used in the calculation of the scaled composite WUA annual index for fall-run Chinook salmon spawning in the lower American River.

Date	Temporal Weighting Coefficient	Date	Temporal Weighting Coefficient	Date	Temporal Weighting Coefficient	Date	Temporal Weighting Coefficient
10/25	0.003540	11/10	0.041627	11/26	0.014961	12/12	0.002580
10/26	0.005034	11/11	0.041283	11/27	0.013531	12/13	0.002298
10/27	0.006933	11/12	0.040486	11/28	0.012214	12/14	0.002046
10/28	0.009256	11/13	0.039302	11/29	0.011006	12/15	0.001822
10/29	0.011991	11/14	0.037802	11/30	0.009901	12/16	0.001621
10/30	0.015089	11/15	0.036059	12/1	0.008895	12/17	0.001443
10/31	0.018468	11/16	0.034139	12/2	0.007981	12/18	0.001283
11/1	0.022016	11/17	0.032103	12/3	0.007153	12/19	0.001141
11/2	0.025599	11/18	0.030005	12/4	0.006404	12/20	0.001015
11/3	0.029076	11/19	0.027893	12/5	0.005729	12/21	0.000903
11/4	0.032309	11/20	0.025802	12/6	0.005121	12/22	0.000803
11/5	0.035174	11/21	0.023763	12/7	0.004574	12/23	0.000713
11/6	0.037574	11/22	0.021800	12/8	0.004083	12/24	0.000634
11/7	0.039440	11/23	0.019929	12/9	0.003643		
11/8	0.040737	11/24	0.018161	12/10	0.003249		
11/9	0.041459	11/25	0.016504	12/11	0.002896	Total	1

3.1.2 Steelhead

The temporal weighting coefficients used for steelhead spawning in the lower American River were derived from the steelhead redd surveys performed by Reclamation and CDFW from February 2002 through March 2016 (Chase 2010; Hannon 2011, 2012 and 2013; Hannon and Healey 2002; Hannon et al. 2003; Hannon and Deason 2004, 2005 and 2007; and See and Chase 2009). Data from ten annual steelhead redd surveys (2002/03, 2003/04, 2004/05, 2006/07, 2009/10, 2010/11, 2011/12, 2012/13, 2013/14 and 2015/16) were used in the fitting of the asymmetric logistic function.

The cumulative distribution resulting from the fit of equation (2) was used to calculate expected daily spawning proportions by subtraction. **Table C-3** displays the final daily weighting coefficients for steelhead spawning, and the resulting spawning period used in the calculation of the scaled composite WUA annual index ($CWUA_Y$). The resulting spawning period representing the middle 99% of the distribution extends from December 11 through March 29 (or March 28 in leap years), a period consisting of $K = 109$ days.

3.2 SPATIAL WEIGHTING COEFFICIENTS

The spatial weighting coefficients (*i.e.*, w_h) indicate the relative importance of particular spawning areas h with respect to the entire spawning grounds, as represented by the proportions of redds built in a particular reach relative to all of the redds expected to be built over the entirety of the fall-run Chinook salmon and steelhead spawning grounds in the lower American River.

The numbers of observed newly built redds in the lower American River obtained from available fall-run Chinook salmon and steelhead redd surveys were categorized into 18 reaches or spawning areas, by each river mile (RM), to obtain a longitudinal spatial distribution of spawning activity for both species in the lower American River. The values of the spatial weighting coefficients were obtained by summing the redd observations from available redd survey data within each reach, and dividing by the total number of redds observed along the entirety of the spawning grounds for both fall-run Chinook salmon, and for steelhead, in the lower American River.

3.2.1 Fall-run Chinook Salmon

The spatial weighting coefficients indicate the relative importance of particular spawning areas with respect to the entire spawning area the lower American River. The spatial weighting coefficients for fall-run Chinook salmon were calculated from redd observations by river mile collected by the CDFW during the 1991/92 through the 1995/96 fall-run Chinook salmon spawning seasons (Snider and McEwan 1992; Snider et al. 1993 and 1996; Snider and Vyverberg 1995 and 1996), and from annual redd counts based on interpretation of 3-to-1 USBR aerial redd surveys per year conducted during the 2003 through the 2015 fall-run Chinook salmon spawning seasons.

Table C-3. Temporal weighting coefficients used for steelhead spawning in the lower American River.

Day	Temporal Weighting Coefficient	Day	Temporal Weighting Coefficient	Day	Temporal Weighting Coefficient
12/11	0.000440	1/17	0.008304	2/23	0.016618
12/12	0.000478	1/18	0.008928	2/24	0.015538
12/13	0.000518	1/19	0.009589	2/25	0.014472
12/14	0.000562	1/20	0.010287	2/26	0.013430
12/15	0.000610	1/21	0.011023	2/27	0.012421
12/16	0.000661	1/22	0.011794	2/28	0.011451
12/17	0.000717	1/23	0.012600	3/1	0.010526
12/18	0.000778	1/24	0.013439	3/2	0.009649
12/19	0.000843	1/25	0.014308	3/3	0.008824
12/20	0.000914	1/26	0.015202	3/4	0.008050
12/21	0.000992	1/27	0.016116	3/5	0.007329
12/22	0.001075	1/28	0.017044	3/6	0.006660
12/23	0.001166	1/29	0.017979	3/7	0.006041
12/24	0.001264	1/30	0.018911	3/8	0.005471
12/25	0.001370	1/31	0.019830	3/9	0.004948
12/26	0.001486	2/1	0.020726	3/10	0.004468
12/27	0.001610	2/2	0.021586	3/11	0.004031
12/28	0.001745	2/3	0.022397	3/12	0.003632
12/29	0.001892	2/4	0.023144	3/13	0.003270
12/30	0.002050	2/5	0.023816	3/14	0.002941
12/31	0.002221	2/6	0.024397	3/15	0.002643
1/1	0.002406	2/7	0.024876	3/16	0.002374
1/2	0.002606	2/8	0.025240	3/17	0.002131
1/3	0.002822	2/9	0.025480	3/18	0.001912
1/4	0.003056	2/10	0.025588	3/19	0.001714
1/5	0.003308	2/11	0.025560	3/20	0.001536
1/6	0.003580	2/12	0.025393	3/21	0.001376
1/7	0.003874	2/13	0.025090	3/22	0.001232
1/8	0.004190	2/14	0.024653	3/23	0.001103
1/9	0.004530	2/15	0.024090	3/24	0.000987
1/10	0.004896	2/16	0.023412	3/25	0.000883
1/11	0.005289	2/17	0.022631	3/26	0.000790
1/12	0.005711	2/18	0.021760	3/27	0.000706
1/13	0.006163	2/19	0.020816	3/28	0.000632
1/14	0.006647	2/20	0.019814	3/29	0.000565
1/15	0.007165	2/21	0.018770		
1/16	0.007717	2/22	0.017700	**Total**	1

For the 2003-2015 spawning seasons, the spatial distribution for Chinook salmon spawning was developed through examination of aerial imagery collected by Reclamation. Aerial images were acquired on multiple dates during the Chinook salmon spawning period, ranging from 1-3 flights per year. Data from 27 aerial surveys spanning the 13 years were available for this analysis. Aerial images were analyzed by Reclamation by physically marking the locations of new redds on the original images.

The values of the spatial weighting coefficients for fall-run Chinook spawning in the lower American River were obtained by summing the redd observations from available redd survey data for each 1-mile reach, and then dividing the overall number within each reach by the total number of redds observed along the entire river. **Table C-4** displays the redd data and the resulting spatial weighting coefficients for fall-run Chinook salmon spawning in the lower American River based on observations conducted during the 1991 through the 1995 spawning seasons, and during the 2003 through the 2015 spawning seasons.

3.2.2 Steelhead

The spatial distribution for steelhead spawning was developed though examination of steelhead redd location data collected by Reclamation and their consultants during the 2002 through the 2005 survey seasons, the 2007 and 2009 seasons, and during the 2011 through 2016 spawning seasons. Each annual data set was reviewed, and potentially erroneous entries were culled (e.g. unknown species listed, possibly Chinook, duplicate entries, etc.) from the data set. Then data from each survey year were analyzed using GIS to determine which river mile each individual redd fell within. As with fall-run Chinook salmon, the values of the spatial weighting coefficients for steelhead spawning in the lower American River were obtained by summing the redd observations from available redd survey data for each 1-mile reach, and then dividing the overall number within each RM reach by the total number of redds observed along the entire river. **Table C-5** displays the redd data and the resulting spatial weighting coefficients for steelhead spawning in the lower American River.

3.3 DURATION OF EMBRYO INCUBATION

The annual dewatering index requires the calculation of the estimated duration of embryo incubation, in days, corresponding to each daily redd cohort (*i.e.*, $ED_{d,h,Y}$ for the proportion of redds built on day d of year Y at spawning area h). Calculation the embryo incubation period for each fall-run Chinook salmon or steelhead redd cohort is based on:

- Lower American River daily water temperatures modeled at location h during the day of redd construction (d) and all subsequent days until fry emergence.
- Duration and magnitude of thermal exposure, expressed as Accumulated Thermal Units (ATUs).

Table C-4. Distribution of observed redds by river mile for fall-run Chinook salmon in the lower American River from 1991 through 1995 and from 2003 through 2015, and derived spatial weighting coefficients by spawning reach.

RM	Number of redds by river mile in survey year										
	1991	1992	1993	1994	1995	2003	2004	2005	2006	2007	2008
22 - 23	121	369	1,277	418	560	148	923	1,129	236	0	222
21 - 22	191	2	1,322	280	561	177	1,683	1,257	1,032	766	185
20 - 21	427	266	1,587	572	1,054	8	343	258	191	86	15
19 -20	314	220	663	391	595	48	670	581	388	179	77
18 - 19	154	96	164	297	115	4	533	342	111	25	9
17 - 18	189	9	787	424	601	9	491	777	170	54	16
16 - 17	86	123	13	83	63	8	229	210	148	56	16
15 -16	11	0	177	58	66	0	66	13	8	2	0
14 - 15	33	38	49	56	115	4	133	66	41	15	0
13 - 14	20	0	20	59	87	1	104	30	5	0	10
12 - 13	30	1	0	15	45	0	22	67	34	17	1
11 - 12	0	1	30	0	1	0	29	16	10	4	0
10 - 11	6	0	4	61	39	0	38	17	0	0	0
9 - 10	32	6	71	12	12	0	23	52	41	0	0
8 - 9	0	0	0	1	17	0	4	2	1	0	0
7 - 8	0	0	21	14	28	0	0	0	0	0	0
6 - 7	12	7	20	18	15	0	0	0	0	0	0
5 - 6	0	0	0	6	2	0	18	15	18	2	0
Totals	**1,626**	**1,138**	**6,205**	**2,765**	**3,976**	**407**	**5,309**	**4,832**	**2,434**	**1,206**	**551**

RM	Number of redds by river mile in survey year							Total Redds	Spatial Weighting Coefficients	
	2009	2010	2011	2012	2013	2014	2015			
22 - 23	189	169	1,000	1,133	598	1,189	970	10,651	0.2122	(21.22%)
21 - 22	33	177	1,014	1,877	625	629	99	11,910	0.2373	(23.73%)
20 - 21	3	28	553	441	359	519	522	7,232	0.1441	(14.41%)
19 -20	23	68	809	1,166	531	756	231	7,710	0.1536	(15.36%)
18 - 19	0	3	254	467	247	273	37	3,131	0.0624	(6.24%)
17 - 18	6	2	200	213	138	233	43	4,362	0.0869	(8.69%)
16 - 17	4	14	102	213	130	253	44	1,795	0.0358	(3.58%)
15 -16	0	0	30	24	24	12	0	491	0.0098	(0.98%)
14 - 15	0	1	12	56	32	42	8	701	0.0140	(1.4%)
13 - 14	1	1	6	26	50	187	53	660	0.0132	(1.32%)
12 - 13	2	0	20	122	49	58	40	523	0.0104	(1.04%)
11 - 12	0	0	3	14	7	25	3	143	0.0028	(0.28%)
10 - 11	0	1	11	24	11	3	4	219	0.0044	(0.44%)
9 - 10	1	8	14	25	23	27	1	348	0.0069	(0.69%)
8 - 9	0	0	0	2	0	0	0	27	0.0005	(0.05%)
7 - 8	0	0	0	15	1	0	0	79	0.0016	(0.16%)
6 - 7	0	0	5	4	5	5	0	91	0.0018	(0.18%)
5 - 6	0	0	4	25	10	13	0	113	0.0023	(0.23%)
Totals	**262**	**472**	**4,037**	**5,847**	**2,840**	**4,224**	**2,055**	**50,186**	1	(100%)

An ATU is defined as degrees Fahrenheit above 32°F, accumulated during a 24-hour period (CDFW 1998). Starting on the day of a given redd's construction, modeled daily average water temperatures for a given simulated year are used to calculate the number of days required to reach the species-specific threshold ATUs (in °F) for egg incubation through fry emergence. The calculations of the duration of embryo incubation are based on the ATUs derived from the annual series of daily water temperatures modeled under the Modified FMS and the 2006 FMS, at locations corresponding to the 18 spawning reaches (*h*). The following sections provide details on how the ATU thresholds used in the calculations of the duration of embryo incubation for fall-run Chinook salmon and steelhead in the lower American River were obtained.

Table C-5. Distribution of observed redds by river mile for steelhead in the lower American River from 2002 through 2016, and derived spatial weighting coefficients by spawning reach.

RM	Number of redds in survey year							
	2002	2003	2004	2005	2007	2009	2011	2012
22 - 23	21	16	17	34	26	74	26	34
21 - 22	19	16	21	10	22	1	1	3
20 - 21	26	22	16	11	9	0	13	19
19 - 20	15	13	25	6	23	20	2	8
18 - 19	2	5	2	0	6	0	0	0
17 - 18	5	3	6	0	11	0	1	1
16 -17	1	6	5	2	19	0	9	1
15 - 16	0	3	9	8	0	0	6	0
14 -15	0	3	12	6	10	0	1	0
13 - 14	12	20	15	2	1	0	4	0
12 - 13	3	1	9	0	7	1	6	0
11 - 12	1	2	1	3	1	0	0	0
10 - 11	0	3	0	0	12	0	0	0
9 - 10	7	4	8	3	3	3	0	0
8 - 9	0	0	0	0	0	0	0	0
7 - 8	0	0	0	0	0	0	0	0
6 - 7	6	0	0	9	0	0	1	0
5 - 6	6	0	0	5	0	0	0	1
Totals	**124**	**117**	**146**	**99**	**150**	**99**	**70**	**67**

RM	Number of redds in survey year				Total Redds	Spatial Weighting Coefficients	
	2013	2014	2015	2016			
22 - 23	47	22	14	11	342	0.2450	(24.50%)
21 - 22	86	4	1	2	186	0.1332	(13.32%)
20 - 21	60	13	5	13	207	0.1483	(14.83%)
19 - 20	38	4	9	6	169	0.1211	(12.11%)
18 - 19	3	2	0	1	21	0.0150	(1.50%)
17 - 18	5	8	16	0	56	0.0401	(4.01%)
16 -17	29	1	11	2	86	0.0616	(6.16%)
15 - 16	0	0	0	1	27	0.0193	(1.93%)
14 -15	4	0	2	0	38	0.0272	(2.72%)
13 - 14	2	32	8	10	106	0.0759	(7.59%)
12 - 13	22	12	3	4	68	0.0487	(4.87%)
11 - 12	0	0	1	0	9	0.0064	(0.64%)
10 - 11	0	1	0	1	17	0.0122	(1.22%)
9 - 10	7	0	0	1	36	0.0258	(2.58%)
8 - 9	0	0	0	0	0	0.0000	(0.00%)
7 - 8	0	0	0	0	0	0.0000	(0.00%)
6 - 7	0	0	0	0	16	0.0115	(1.15%)
5 - 6	0	0	0	0	12	0.0086	(0.86%)
Totals	**303**	**99**	**70**	**52**	**1,396**	1	(100%)

3.3.1 Fall-run Chinook Salmon Embryo Incubation

Several ATU thresholds have been identified in the literature for the development of Chinook salmon eggs from fertilization to hatching, and from hatching through fry emergence. In its status review of spring-run Chinook salmon in the Sacramento River drainage, CDFW (1998), referring to Armour (1991), stated that the required number of ATUs from the time of egg fertilization to fry emergence was 1,550°F. Moreover, Amour (1991) stated that the development from fertilization to hatching required 850°F daily temperature units, and that the development from hatching to fry emergence required an additional 700°F units. In a paper evaluating the development and applicability of an early version of the Chinook Salmon Early Lifestage Mortality Model, HCI (1996) stated that key model assumptions were the requirements of 750°F temperature units for the development from fertilized egg to hatching, and of another 750°F temperature units for the development from hatching to emergent fry (i.e., a total of 1,500°F from fertilized egg to fry emergence).

In a technical memorandum literature review (Bedore et al. 2015), the duration (days) to median hatch (50% hatch) and to median emergence (50% emergence) for fertilized eggs and pre-emergent fry reported in Seymour (1956), Beacham and Murray (1989), Murray and McPhail (1988), and Jensen and Groot (1991) were reviewed and used to calculate the ATUs to 50% hatch and 50% fry emergence. These calculated ATUs together with the ATUs to 50% hatch and 50% emergence for Chinook salmon eggs and pre-emergent fry from variable temperature incubations reported in Geist *et al*. (2011) were combined in plots to calculate the average ATU to 50% hatch (936°F) and the average ATU from 50% hatch to 50% emergence (713°F). These calculations were conducted for water temperatures greater than 45°F, the minimum temperature that has historically occurred in the lower American River during the egg incubation and pre-emergent fry development periods of the year (Figures 20 and 21 in Bedore et al. 2015). Therefore, the annual dewatering index used an ATU threshold of 1,649°F (*i.e*., 936°F + 713°F) to calculate the duration of embryo incubation through fry emergence (*i.e*., $ED_{d,h,Y}$) for all fall-run Chinook salmon redd cohorts. For each redd cohort represented by the proportion of fall-run Chinook salmon redds built on day (*d*) of year (*Y*) at spawning area *h* (*i.e*., $w_d \times w_h$), the daily thermal units of day *d* (*i.e*., daily water temperature - 32°F) and subsequent days measured at location *h* are summed. Consecutive days are added to the embryo incubation period of the redd cohort under consideration until the sum of the daily ATUs remain under the threshold of 1,649°F.

For illustrative purposes, the duration of embryo incubation based upon ATUs was calculated for relatively recent wet (1998) and critical (1992) water years for the 1922 – 2003 simulation period, and at different longitudinally distributed locations (RM 22 for an upper location, RM 16 for a middle location, and RM 9 for a lower location). **Figure C-3** illustrates the modeled daily water temperatures and the corresponding durations of embryo incubation calculated for the Chinook salmon redd daily cohorts of the 1991/92 spawning and embryo incubation season. **Figure C-4** illustrates the daily water temperatures and durations of embryo incubation for Chinook salmon spawning during the wet 1998 water year.

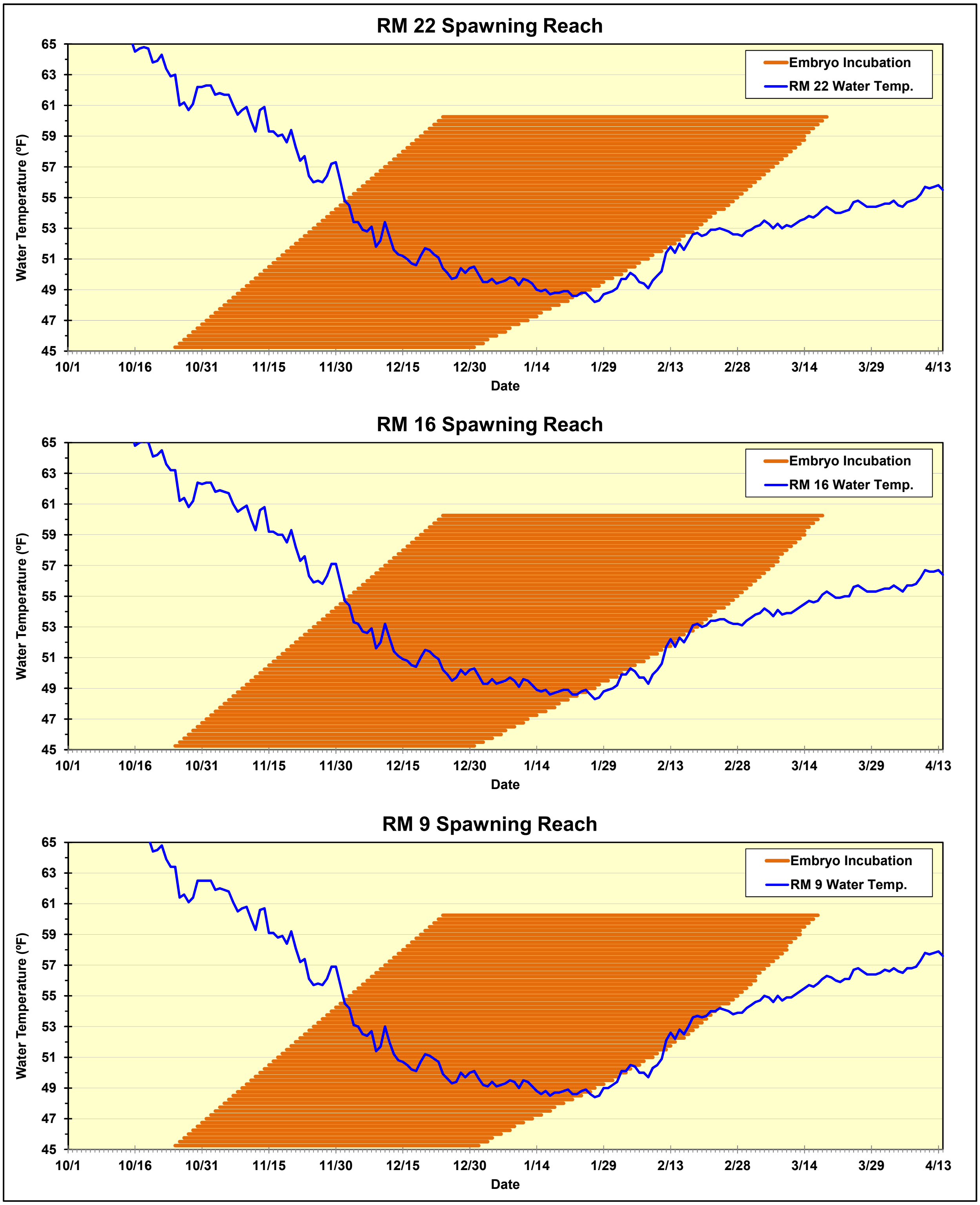

Figure C-1. Daily water temperature (ºF) and expected duration of embryo incubation (days) for fall-run Chinook salmon spawning in three RM reaches of the lower American River during the critical 1992 water year.

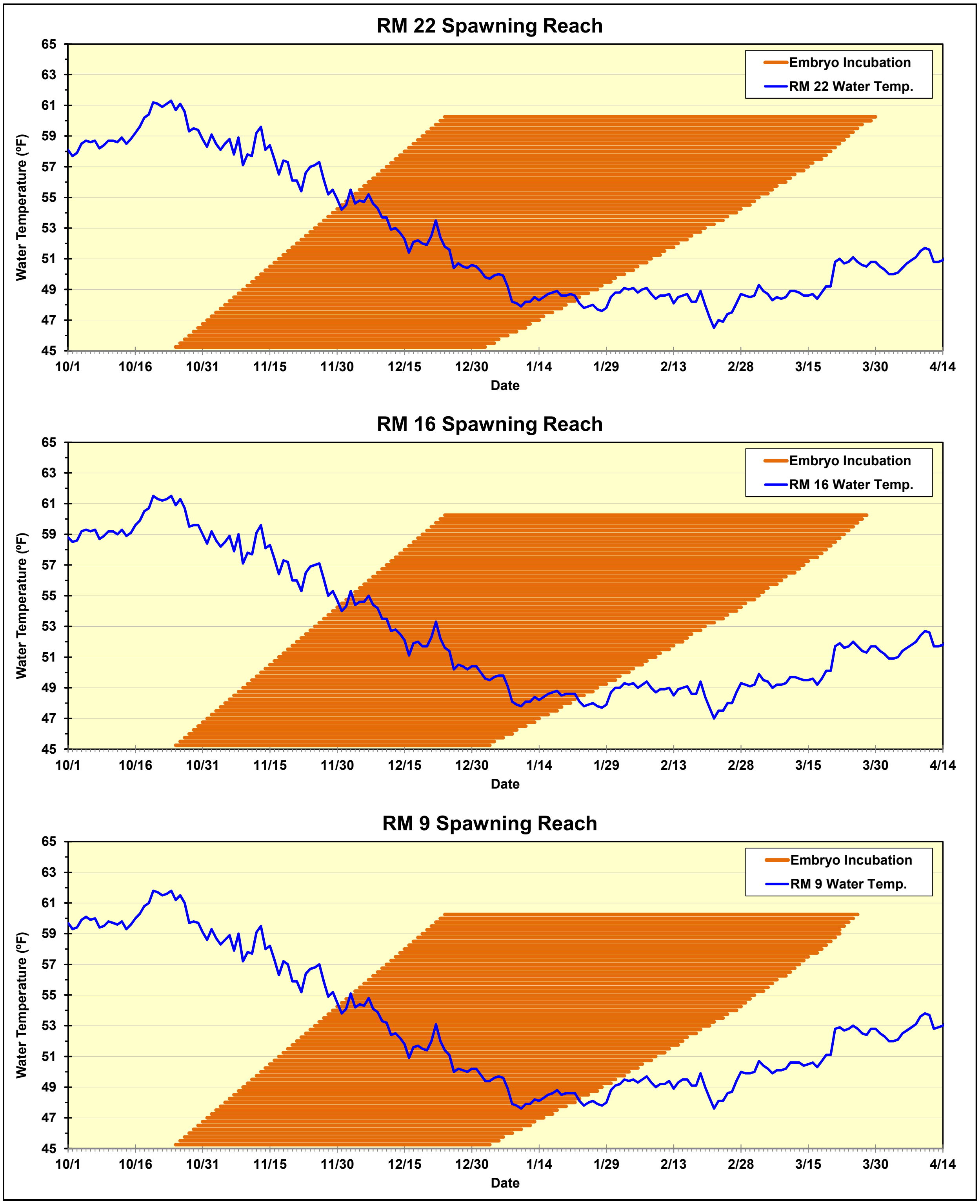

Figure C-2. Daily water temperature (ºF) and expected duration of embryo incubation (days) for fall-run Chinook salmon spawning in three reaches of the lower American River during the wet 1998 water year.

The embryonic incubation period can extend for 70 – 97 days for the upstream spawning location during a wetter year (WY 1998). For comparison, incubation can be completed in 69 – 88 days for the downstream spawning location during a drier year (WY 1992).

1.2.3.2 Steelhead Embryo Incubation

Several ATU thresholds corresponding to the duration of embryo incubation through 50% hatch and fry emergence for steelhead have been reported in the literature. CDFW's restoration and management plan for California steelhead (McEwan and Jackson 1996) reported that steelhead preferred water temperatures for embryo incubation and fry emergence ranging from 48°F to 52°F. Additionally, they stated:

"*The length of time it takes for eggs to hatch depends mostly on water temperature. Hatching of steelhead eggs in hatcheries takes about 30 days at 51°F (Leitritz and Lewis 1980). Fry emerge from the gravel usually about four to six weeks after hatching, but factors such as redd depth, gravel size, siltation, and temperature can speed or retard this time (Shapovalov and Taft 1954).*"

In a manual of hatchery methods for salmon and trout culture, Leitritz (1959) published a table indicating the number of days and ATUs required for development of eggs of various trout species, including *O. mykiss*, to hatch when incubating at constant temperatures ranging from 40°F to 60°F. In a more recent study on steelhead supplementation in rivers in Idaho, Byrne (1996) reported that Thurow (Intermountain Research Station, Boise, Idaho, unpublished data) estimated that 556°C (1,001°F) ATUs were needed for fry emergence to begin and 722°C (1,300°F) ATUs were needed for 95% emergence of hatchery steelhead that spawned naturally in the upper Salmon River, and utilized Thurow's estimated ATUs to predict the date of first fry emergence and the date that 95% of the fry had emerged in Beaver and Frenchman creeks. Kraus (1999) in a guide to classroom egg incubation in Alaska, indicated that spring-run steelhead eggs require 360°C (648°F) ATUs to hatch and 600°C (1,080°F) ATUs to reach fry emergence. Hannon *et al.* (2003) utilized the same requirement of 600°C (1,080°F) ATUs to estimate the time to fry emergence in the report on American River steelhead spawning for 2001-2003.

For many salmonids, including steelhead, various models have been developed in recent decades to calculate the incubation and emergence times, expressed in days or hours, by fitting various functions of constant water temperatures to experimental embryo development data. For example, Crisp (1981) presented four models using a desktop study of the relationship between temperature and hatching time for the eggs of five species of salmonids, including *O. mykiss*. The equations of the four models presented for *O. mykiss* were obtained by fitting the models to 23 pairs of data points, each pair consisting of the water temperatures (T in °C) at which a batch of fertilized eggs is incubated and the corresponding time from egg fertilization to 50% hatch, expressed as days (D).

The equations of the four *O. mykiss* models were:

- ***Model 1a***: $\log(D) = 2.6638 - 1.1623 \times \log(T)$ with $r^2 = 0.978$;
- ***Model 1b***: $\log(D) = 4.0313 - 2.0961 \times \log(T+6)$ with $r^2 = 0.982$;
- ***Model 2***: $\ln(D) = 4.9023 - 0.1384 \times T$ with $r^2 = 0.960$; and
- ***Model 3b***: $\log(D) = 2.3475 - 0.1123 \times T + 0.00278 \times T^2$ with $r^2 = 0.976$.

Recognizing the limited data available to develop species-specific equations relating water temperatures (T in °C) at which a batch of fertilized eggs is incubated and the corresponding time from egg fertilization to 50% fry emergence, Crisp (1988) collected data on time to 50% hatch and corresponding time to 50% fry emergence, both expressed in days, obtained from embryo incubation experiments conducted at various constant temperatures ranging from 2.8°C to 12°C (*i.e.*, 37.0°F – 53.6°F). The data consisted of 60 pairs of duration data encompassing six salmonid species (*Salmo salar*, *S. trutta*, *O. keta*, *O. kisutch*, *O. tshawytscha* and *O. gorbuscha*). Disregarding the individual species, Crisp (1988) used the data for all species to fit a common linear relationship that would allow the prediction of time to 50% fry emergence ($D_{50\%E}$, days) based on the more abundant data on time to 50% hatch ($D_{50\%H}$, days). The fitted equation, $D_{50\%E} = 5.367 + 1.660 \times D_{50\%H}$, was statistically significant ($P << 0.001$) with an $r^2 = 0.947$.

More recently, in the program IncubWin (Jensen and Jensen 1999) and in its updated version WinSIRP (Jensen *et al.* 2009), the time to 50% hatch of steelhead eggs was derived from a set of two equations resulting from fitting Schnute's Growth Model to water temperatures (T in °C) and developmental time expressed in hours (D). The two equations describing the time to 50% hatch are:

$D = 24 \times \left(139.2562^{2.3613821} + \left(139.2562^{2.3613821} - 18.3476^{2.3613821}\right) \times Z\right)^{1/2.3613821}$ with Z expressed as $Z = \dfrac{\left(1 - \exp\left(-1 \times 0.408414 \times (T-1)\right)\right)}{\left(1 - \exp\left(-1 \times 0.408414 \times (19)\right)\right)}$.

In the same programs, the time to steelhead fry emergence expressed in hours was described by a modified Bělehrádek model, with a fitted equation of $D = \dfrac{22{,}129{,}193.76}{(T + 14.1975994)^{3.00725581}}$.

The above information on steelhead time to 50% hatch and time to fry emergence expressed in days is summarized in **Table C-6** and is used to calculate steelhead ATUs (in °F-day) to 50% hatch and fry emergence. The equations reported in Crisp (1981 and 1988), Jensen and Jensen (1999) and Jensen *et al*. (2009) are used to provide estimates of time to 50% hatch ($D_{50\%H}$) and time to fry emergence (D_E) for temperatures (T) within the 48°F - 52°F range reported by McEwan and Jackson (1996) as preferred temperatures for steelhead embryo incubation and fry emergence. The corresponding ATU's were then calculated as the products of $D_{50\%H}$ and T - 32°F, and D_E and T - 32°F.

Table C-6. Estimated times (in days) and accumulated thermal units (ATUs) from fertilization to 50% hatch, and from fertilization to fry emergence for steelhead embryos incubating at temperatures ranging from 40°F to 52°F.

Water Temperature (°F)	Time to 50% Hatch (days)	ATU to 50% Hatch (°F-days)	Reference
40.0	80.0	640	Table 4 in Leitritz (1959)
45.0	48.0	624	
50.0	31.0	558	
55.0	24.0	552	
60.0	19.0	532	
51.0	30.0	570	Leitritz and Lewis (1980)
48.0	36.4	582	Crisp (1981) model 1a
49.0	33.9	577	
50.0	31.7	571	
51.0	29.8	566	
52.0	28.1	561	
48.0	37.4	598	Crisp (1981) model 1b
49.0	34.6	589	
50.0	32.2	579	
51.0	29.9	569	
52.0	27.9	559	
48.0	39.3	629	Crisp (1981) model 2
49.0	36.4	619	
50.0	33.7	607	
51.0	31.2	593	
52.0	28.9	578	
48.0	37.1	593	Crisp (1981) model 3b
49.0	34.3	583	
50.0	31.8	572	
51.0	29.6	563	
52.0	27.7	555	
48.0	38.3	613	Jensen and Jensen (1999) Schnute's growth model
49.0	35.4	602	
50.0	32.9	592	
51.0	30.6	582	
52.0	28.6	573	
---	---	648	Kraus (1999)
Average ATU to 50% hatch:		**585 (°F-days)**	

Water Temperature (°F)	Time to Fry Emergence (days)	ATU to Fry Emergence (°F-days)	Reference
40.0	138.2	1,105	Table 4 in Leitritz (1959) and Crisp (1988) equation
45.0	85.0	1,106	
50.0	56.8	1,023	
55.0	45.2	1,040	
60.0	36.9	1,033	
51.0	55.2	1,048	Leitritz and Lewis (1980) and Crisp (1988) equation
48.0	65.8	1,052	Crisp (1981) model 1a and Crisp (1988) equation
49.0	61.7	1,048	
50.0	58.0	1,045	
51.0	54.8	1,042	
52.0	52.0	1,039	
48.0	67.4	1,079	Crisp (1981) model 1b and Crisp (1988) equation
49.0	62.9	1,069	
50.0	58.8	1,058	
51.0	55.1	1,046	
52.0	51.7	1,035	
48.0	70.7	1,131	Crisp (1981) model 2 and Crisp (1988) equation
49.0	65.8	1,119	
50.0	61.4	1,104	
51.0	57.2	1,087	
52.0	53.4	1,067	
48.0	66.9	1,070	Crisp (1981) model 3b and Crisp (1988) equation
49.0	62.2	1,058	
50.0	58.2	1,047	
51.0	54.6	1,037	
52.0	51.4	1,028	
48.0	73.2	1,172	Jensen and Jensen (1999) modified Beleradek model
49.0	68.2	1,159	
50.0	63.6	1,145	
51.0	59.4	1,129	
52.0	55.6	1,111	
---	---	1,001	Byme (1993)
---	---	1,300	
---	---	1,080	Kraus (1999)
---	---	1,080	Hannon *et al*. (2003)
Average ATU to fry emergence:		**1,080 (°F-days)**	

The analysis of redd dewatering for American River steelhead uses an ATU threshold of 1,080°F (*i.e.*, the average ATU to fry emergence displayed in Table C-3) to evaluate the duration of embryo incubation through fry emergence (*i.e.*, $ED_{d,h,Y}$) for all steelhead redd cohorts in the calculations of the annual dewatering index. For each redd cohort represented by the proportion of steelhead redds built on day *d* of year *Y* at spawning area *h* (*i.e.*, $w_d \times w_h$ with *d* ranging from 1 through 108 and *h* from 1 through 18), the daily thermal units of day *d* (*i.e.*, daily water temperature - 32°F) and subsequent days measured at location *h* are summed. A day is added to the embryo incubation period of the redd cohort while the sum of daily thermal units remain below or equal to 1,080°F.

Consistent with that which was presented for fall-run Chinook salmon, the duration of steelhead embryo incubation based upon ATUs was calculated for relatively recent wet (1998) and critical (1992) water years for the 1922 – 2003 simulation period, and at different longitudinally distributed locations (RM 22 for an upper location, RM 16 for a middle location, and RM 9 for a lower location). **Figure C-5** illustrates the modeled daily water temperatures and the corresponding durations of embryo incubation calculated for the steelhead redd daily cohorts of the 1991/92 spawning and embryo incubation season. **Figure C-6** illustrates the daily water temperatures and durations of embryo incubation for steelhead spawning during the wet 1998 water year.

The steelhead embryonic incubation period can extend for 56 – 65 days for the upstream spawning location during a wetter year (WY 1998). For comparison, incubation can be completed in 41 – 61 days for the downstream spawning location during a drier year (WY 1992).

3.4 DEPTH-FREQUENCY DISTRIBUTIONS OF REDDS

The annual dewatering indices require the use of relative cumulative frequency distributions of the redd water depths of fall-run Chinook salmon and steelhead spawning in the lower American River to evaluate the probability that the redds built on spawning day *d* in reach *h* have of being constructed at particular depths, expressed in tenths of a foot.

Specifically, the annual dewatering indices use the relative cumulative frequency distributions of the depths of redds to calculate the expected proportions of redds of each cohort that were constructed at depths less or equal to the maximum river stage difference experienced by redds built in spawning reach *h* on day *d* throughout their corresponding embryo incubation periods. The proportions are described as $\Pr\left(Redd\ Depth \leq \underset{i=d+1 \rightarrow ED_{d,h,Y}}{\mathrm{Max}} \left(Stage_{d,h,Y} - Stage_{i,h,Y} \right) \right)$ in equation (1).

In general, the relative cumulative frequency distributions of the redd depths were obtained by fitting available redd depth data to asymmetric logistic functions (equation (2)), as described in the following sections.

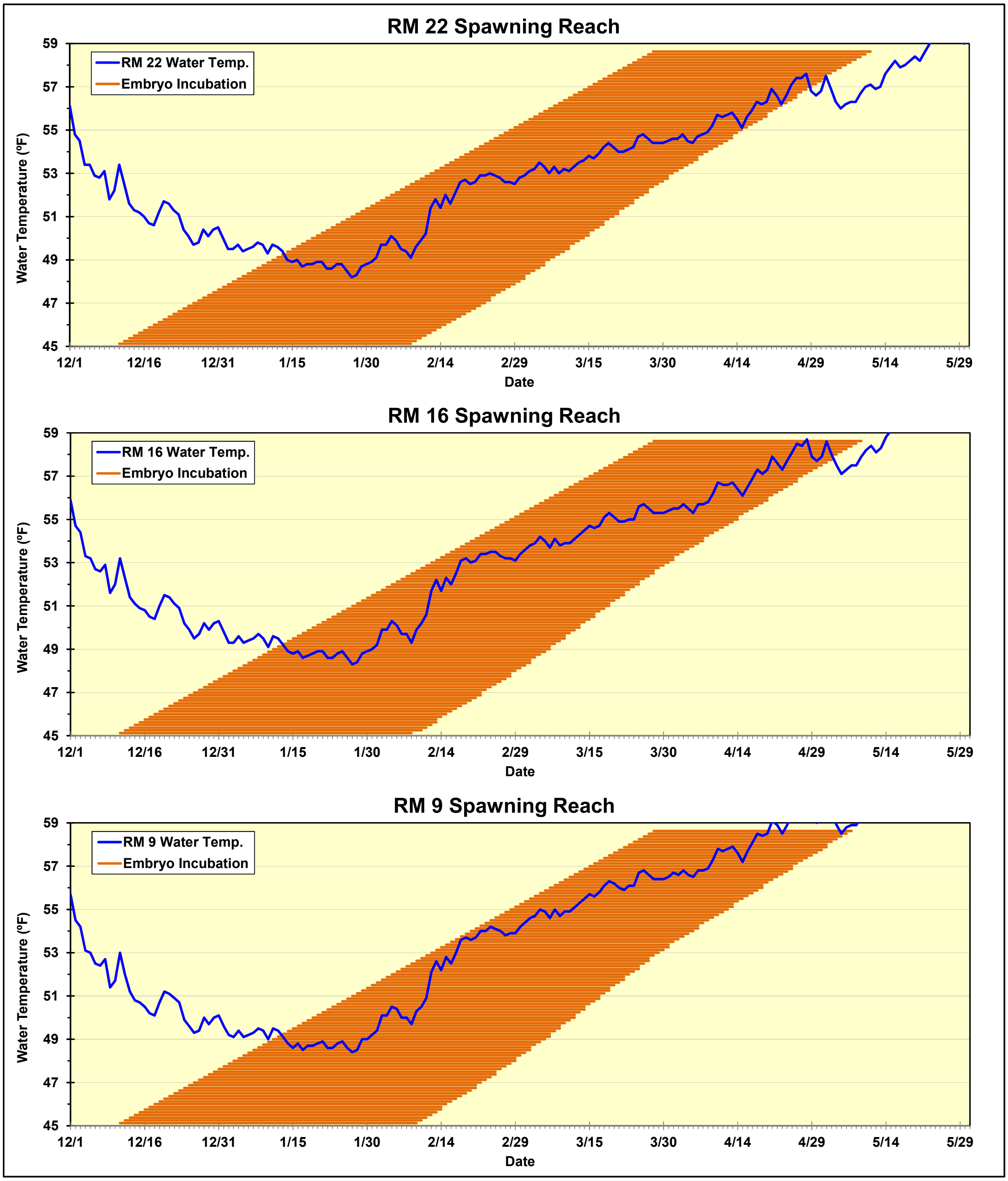

Figure C-5. Daily water temperature (ºF) and expected duration of embryo incubation (days) for steelhead spawning in three RM reaches of the lower American River during the critical 1992 water year.

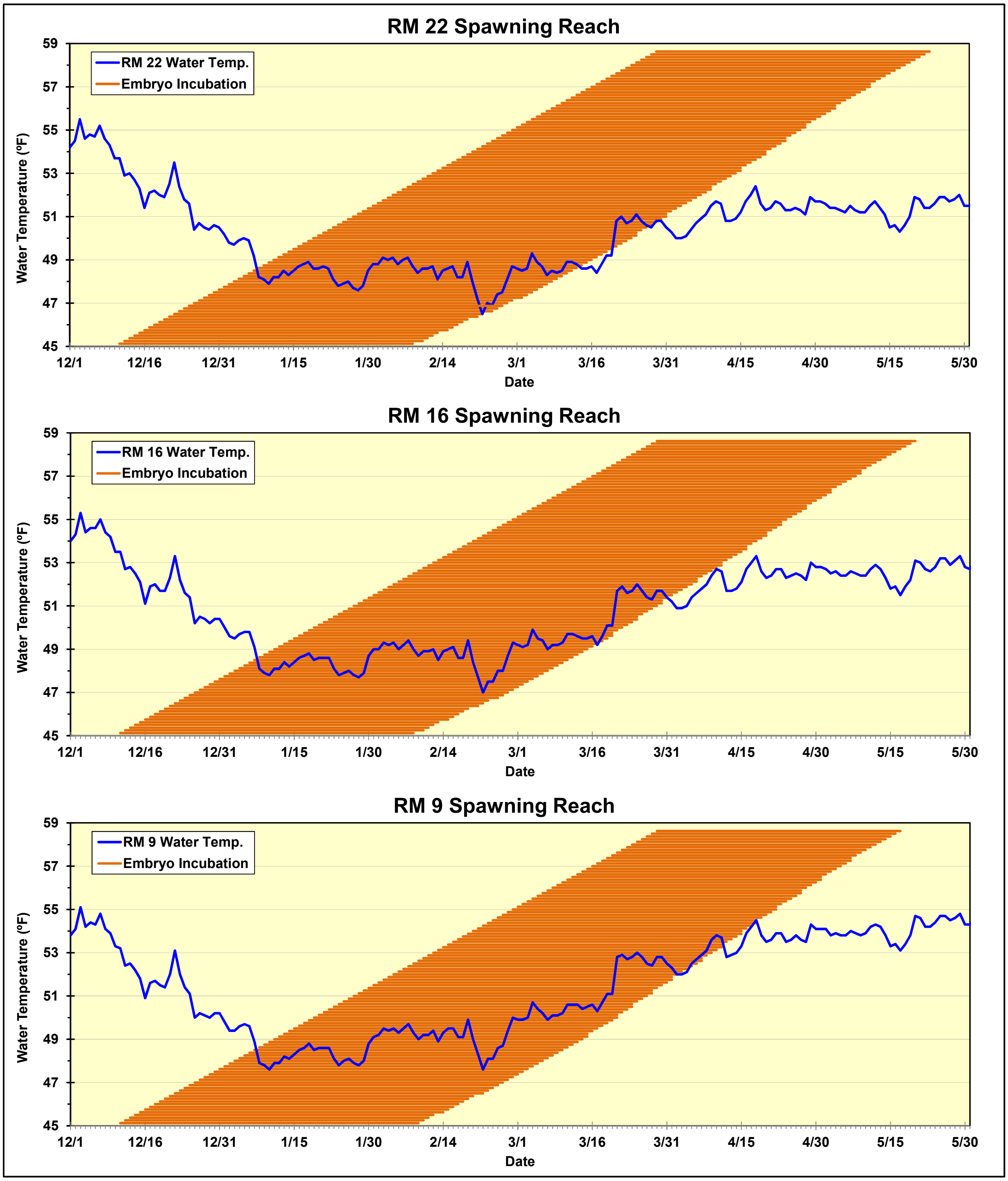

Figure C-6. Daily water temperature (ºF) and expected duration of embryo incubation (days) for steelhead spawning in three reaches of the lower American River during the wet 1998 water year.

3.4.1 Fall-run Chinook Salmon

The relative cumulative frequency distribution of fall-run Chinook salmon redd depths was the result of fitting an asymmetric logistic function to seven combined annual series of Chinook salmon redd depths. The data for 1996 and 1998, provided by Mark Gard (USFWS, pers comm and data transfer) was collected by CDFW during 1996 (N = 218 redd depths) and during 1998 (N = 189 redd depths). The remaining data correspond to redd depths collected by Cramer Fish Sciences (unpublished data) during the 2011 through the 2015 fall-run Chinook salmon spawning seasons. In order to reduce the possibility of introducing error in the calculation of the relative cumulative frequency distribution of fall-run Chinook salmon redd depths, on January 19, 2017 representatives of the Water Forum met with Cramer Fish Sciences staff to review and discuss the quality of the Chinook salmon redd survey data collected in the lower American River. As a result of this meeting the raw data was culled to the data summarized in **Table C-7**. In general, it was agreed that redd depths for which the species could not be unquestionably assigned to fall-run Chinook salmon (e.g., redds observed after December 25 of a survey year and with species catalogued as “unknown” and redds observed from mid- and late March and with species catalogued in the field as “Chinook” that could have been early steelhead redds or late-fall Chinook redds) or were considered not fresh (e.g., redds whose age was catalogued as “older some algae” or whose field comments suggest as potential test redds) would not be included in the calculation of the relative cumulative frequency distribution of fall-run Chinook salmon redd depths.

Additionally, the daily flows and stages at the Fair Oaks gage on the dates and on the weeks prior to the dates of redd depth observations were contrasted. It was decided that whenever there was a change in flow greater than about 100 cfs resulting in a stage change greater or equal than 0.2 ft since the prior survey, the observed redd depths would be excluded from the analysis. Finally, the raw data contained reports of from two to 44 redds for the same recorded redd depth, location and date. For these cases, the meeting participants decided that if the number of redds identified was "2", then the recorded depth would remain in the dataset and be included in the analysis. If the number of redds was greater “2”, the group agreed that it would be appropriate to remove those redds from the dataset and the analysis of redd depths. Finally, three additional redd depths were not included in the analysis because the depths were judged unusually shallow with respect to the average height of a spawning Chinook salmon female. These depths were recorded as 2 cm (0.07 ft), 6 cm (0.20 ft) and 8 cm (0.26 ft) and observed on 11/27/12, 11/27/12 and 12/2/15, respectively, and catalogued in the field as fresh Chinook redds.

The shallowest fall-run Chinook salmon redd depth in the final database was 0.3 ft., while the deepest redd was observed at a depth of 6 ft.

Table C-7. Frequency distribution of redd depths by 0.1-ft depth bins for Chinook salmon redds collected in the American River during 1996 and 1998, and from 2011 – 2015.

Depth (ft)	Annual number of redds by 0.1-ft depth bin							Combined Redds	Cumulative proportion
	1996	1998	2011	2012	2013	2014	2015		
0									
0.1									
0.2									
0.3				4		3	2	9	0.009783
0.4		2				1	1	4	0.014130
0.5		1	2	6		5	7	21	0.036957
0.6	2	2	4	7	2	6	10	33	0.072826
0.7			4	10	1	8	17	40	0.116304
0.8	5	9	4	7	1	12	9	47	0.167391
0.9	5	1	7	9	4	5	7	38	0.208696
1	10	13	3	4	2	4	12	48	0.260870
1.1	5	1	11	4	2	5	6	34	0.297826
1.2	11	18	6	1	5	5	3	49	0.351087
1.3	7	5	9	11	3	7	10	52	0.407609
1.4	12	17	6	5	4	4	2	50	0.461957
1.5	11	14	11	9	3	6	7	61	0.528261
1.6	7	20	3	8	5	4	2	49	0.581522
1.7	8	4	8	7	15	2	4	48	0.633696
1.8	10	18	4	7	3	4	4	50	0.688043
1.9	10	4	9	11	9	8	1	52	0.744565
2	11	13	4	4	5	1		38	0.785870
2.1	8	4	1	7	2	1	3	26	0.814130
2.2	8	8	1	7	3		1	28	0.844565
2.3	7	4	1	2	1		2	17	0.863043
2.4	7	3		4	2			16	0.880435
2.5	4	7		1			3	15	0.896739
2.6	8	1	1				1	11	0.908696
2.7	6	4						10	0.919565
2.8	9	3						12	0.932609
2.9	9	3	1					13	0.946739
3	7	2			1			10	0.957609
3.1	4	2						6	0.964130
3.2	5	1						6	0.970652
3.3	2	1						3	0.973913
3.4	4							4	0.978261
3.5		1						1	0.979348
3.6	1							1	0.980435
3.7		1						1	0.981522
3.8	1	1						2	0.983696
3.9									
4	1							1	0.984783
4.1									
4.2	1							1	0.985870
4.3	1							1	0.986957
4.4	1							1	0.988043
4.5	1							1	0.989130
4.6									
4.7	2							2	0.991304
4.8	2	1						3	0.994565
4.9									
5	1							1	0.995652
5.1									
5.2	1							1	0.996739
5.3	1							1	0.997826
5.4									
5.5									
5.6									
5.7									
5.8									
5.9									
6	2							2	1
Totals	**218**	**189**	**100**	**135**	**73**	**91**	**114**	**920**	

The asymmetric logistic function fitted to the data (**Figure C-7**) had the following expression:

$$\Pr(D) = \left(\frac{1}{1 + \exp(0.6270 - 1.7956 \times D)} \right)^{1/0.1917}, \quad \textbf{(3)}$$

where D is the redd depth in feet. The mean square error of this fit was 0.00009.

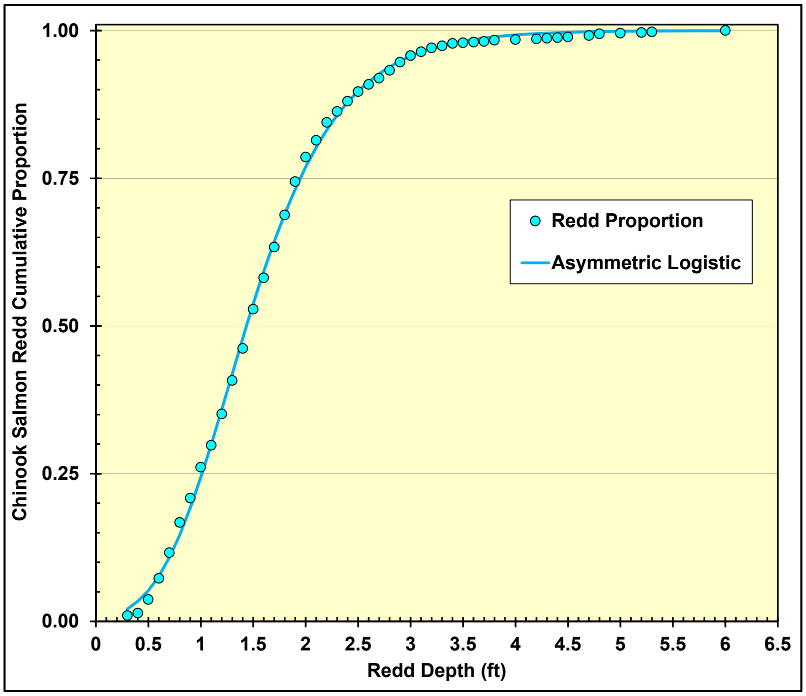

Figure C-7. Cumulative proportions of 920 fall-run Chinook salmon redd depths measured in the lower American River in November 1996, December 1998 and during the 2011 through the 2015 fall-run Chinook salmon spawning seasons, and fitted asymmetric logistic curve.

The asymmetric logistic function in equation (3) was re-scaled to the observed range of fall-run Chinook salmon redd depths (i.e., 0.3 ft. through 6 ft.) and used to build a look-up table providing the expected cumulative proportions of redd depths at every hundredth of a foot (**Table C-8**).

3.4.2 Steelhead

The relative cumulative frequency distribution of steelhead redd depths was the result of fitting an asymmetric logistic function to thirteen annual series of steelhead redd depths combined. The raw data, collected by Reclamation and USFW during their annual steelhead redd surveys during 2002 through 2005, 2007, and during 2009 through 2016, was provided by John Hannon (Reclamation, pers comm and data transfer, 2016). In order to reduce the possibility of introducing error in the calculation of the relative cumulative frequency distribution of steelhead redd depths, on December 16, 2016 representatives of the Water Forum met with John Hannon to review and discuss the quality of the steelhead redd survey data collected in the lower American River from

2002 through 2016. As a result of this meeting the raw data was culled to the data summarized in **Table C-9**.

Table C-8. Re-scaled cumulative proportions of fall-run Chinook salmon redd depths used in the analysis of potential redd dewatering for the lower American River.

Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion
0.29	0	**0.73**	0.103381	**1.17**	0.332839	**1.61**	0.593701	**2.05**	0.785157
0.30	0.001083	**0.74**	0.107301	**1.18**	0.338946	**1.62**	0.599021	**2.06**	0.788482
0.31	0.002211	**0.75**	0.111295	**1.19**	0.345067	**1.63**	0.604300	**2.07**	0.791764
0.32	0.003383	**0.76**	0.115363	**1.20**	0.351200	**1.64**	0.609537	**2.08**	0.795003
0.33	0.004603	**0.77**	0.119503	**1.21**	0.357343	**1.65**	0.614731	**2.09**	0.798199
0.34	0.005869	**0.78**	0.123715	**1.22**	0.363494	**1.66**	0.619883	**2.10**	0.801353
0.35	0.007185	**0.79**	0.127999	**1.23**	0.369652	**1.67**	0.624992	**2.11**	0.804465
0.36	0.008550	**0.80**	0.132354	**1.24**	0.375815	**1.68**	0.630056	**2.12**	0.807535
0.37	0.009967	**0.81**	0.136779	**1.25**	0.381981	**1.69**	0.635077	**2.13**	0.810564
0.38	0.011436	**0.82**	0.141274	**1.26**	0.388149	**1.70**	0.640054	**2.14**	0.813551
0.39	0.012959	**0.83**	0.145837	**1.27**	0.394317	**1.71**	0.644986	**2.15**	0.816498
0.40	0.014536	**0.84**	0.150468	**1.28**	0.400482	**1.72**	0.649872	**2.16**	0.819405
0.41	0.016169	**0.85**	0.155166	**1.29**	0.406645	**1.73**	0.654713	**2.17**	0.822271
0.42	0.017860	**0.86**	0.159929	**1.30**	0.412802	**1.74**	0.659509	**2.18**	0.825098
0.43	0.019608	**0.87**	0.164758	**1.31**	0.418953	**1.75**	0.664259	**2.19**	0.827886
0.44	0.021416	**0.88**	0.169650	**1.32**	0.425095	**1.76**	0.668963	**2.20**	0.830634
0.45	0.023284	**0.89**	0.174605	**1.33**	0.431228	**1.77**	0.673620	**2.21**	0.833344
0.46	0.025213	**0.90**	0.179621	**1.34**	0.437349	**1.78**	0.678231	**2.22**	0.836016
0.47	0.027205	**0.91**	0.184697	**1.35**	0.443458	**1.79**	0.682796	**2.23**	0.838650
0.48	0.029260	**0.92**	0.189832	**1.36**	0.449553	**1.80**	0.687314	**2.24**	0.841246
0.49	0.031380	**0.93**	0.195024	**1.37**	0.455632	**1.81**	0.691785	**2.25**	0.843805
0.50	0.033565	**0.94**	0.200273	**1.38**	0.461694	**1.82**	0.696209	**2.26**	0.846328
0.51	0.035816	**0.95**	0.205576	**1.39**	0.467738	**1.83**	0.700587	**2.27**	0.848814
0.52	0.038134	**0.96**	0.210933	**1.40**	0.473761	**1.84**	0.704917	**2.28**	0.851264
0.53	0.040520	**0.97**	0.216341	**1.41**	0.479764	**1.85**	0.709201	**2.29**	0.853679
0.54	0.042975	**0.98**	0.221800	**1.42**	0.485745	**1.86**	0.713438	**2.30**	0.856058
0.55	0.045499	**0.99**	0.227307	**1.43**	0.491702	**1.87**	0.717628	**2.31**	0.858403
0.56	0.048093	**1.00**	0.232861	**1.44**	0.497635	**1.88**	0.721771	**2.32**	0.860713
0.57	0.050759	**1.01**	0.238461	**1.45**	0.503541	**1.89**	0.725867	**2.33**	0.862989
0.58	0.053495	**1.02**	0.244104	**1.46**	0.509421	**1.90**	0.729917	**2.34**	0.865232
0.59	0.056304	**1.03**	0.249790	**1.47**	0.515272	**1.91**	0.733920	**2.35**	0.867441
0.60	0.059185	**1.04**	0.255516	**1.48**	0.521095	**1.92**	0.737876	**2.36**	0.869617
0.61	0.062139	**1.05**	0.261281	**1.49**	0.526887	**1.93**	0.741786	**2.37**	0.871760
0.62	0.065167	**1.06**	0.267083	**1.50**	0.532647	**1.94**	0.745650	**2.38**	0.873872
0.63	0.068269	**1.07**	0.272920	**1.51**	0.538376	**1.95**	0.749468	**2.39**	0.875951
0.64	0.071444	**1.08**	0.278791	**1.52**	0.544071	**1.96**	0.753240	**2.40**	0.878000
0.65	0.074694	**1.09**	0.284694	**1.53**	0.549733	**1.97**	0.756966	**2.41**	0.880017
0.66	0.078019	**1.10**	0.290626	**1.54**	0.555359	**1.98**	0.760647	**2.42**	0.882003
0.67	0.081418	**1.11**	0.296586	**1.55**	0.560950	**1.99**	0.764283	**2.43**	0.883960
0.68	0.084891	**1.12**	0.302573	**1.56**	0.566504	**2.00**	0.767873	**2.44**	0.885886
0.69	0.088440	**1.13**	0.308585	**1.57**	0.572021	**2.01**	0.771419	**2.45**	0.887783
0.70	0.092063	**1.14**	0.314619	**1.58**	0.577500	**2.02**	0.774919	**2.46**	0.889651
0.71	0.095761	**1.15**	0.320674	**1.59**	0.582940	**2.03**	0.778376	**2.47**	0.891489
0.72	0.099534	**1.16**	0.326748	**1.60**	0.588340	**2.04**	0.781789	**2.48**	0.893300

Table C-8. Continued.

Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion
2.49	0.895082	**2.93**	0.950810	**3.37**	0.977427	**3.81**	0.989792	**4.25**	0.995464
2.50	0.896837	**2.94**	0.951664	**3.38**	0.977827	**3.82**	0.989977	**4.26**	0.995548
2.51	0.898565	**2.95**	0.952504	**3.39**	0.978220	**3.83**	0.990158	**4.27**	0.995631
2.52	0.900265	**2.96**	0.953329	**3.40**	0.978607	**3.84**	0.990335	**4.28**	0.995712
2.53	0.901939	**2.97**	0.954140	**3.41**	0.978986	**3.85**	0.990510	**4.29**	0.995792
2.54	0.903586	**2.98**	0.954938	**3.42**	0.979359	**3.86**	0.990682	**4.30**	0.995870
2.55	0.905208	**2.99**	0.955723	**3.43**	0.979726	**3.87**	0.990850	**4.31**	0.995947
2.56	0.906804	**3.00**	0.956494	**3.44**	0.980086	**3.88**	0.991016	**4.32**	0.996023
2.57	0.908375	**3.01**	0.957252	**3.45**	0.980440	**3.89**	0.991178	**4.33**	0.996097
2.58	0.909921	**3.02**	0.957997	**3.46**	0.980788	**3.90**	0.991338	**4.34**	0.996170
2.59	0.911443	**3.03**	0.958730	**3.47**	0.981129	**3.91**	0.991495	**4.35**	0.996242
2.60	0.912940	**3.04**	0.959451	**3.48**	0.981465	**3.92**	0.991649	**4.36**	0.996312
2.61	0.914413	**3.05**	0.960159	**3.49**	0.981795	**3.93**	0.991801	**4.37**	0.996381
2.62	0.915863	**3.06**	0.960855	**3.50**	0.982119	**3.94**	0.991950	**4.38**	0.996449
2.63	0.917290	**3.07**	0.961539	**3.51**	0.982438	**3.95**	0.992096	**4.39**	0.996516
2.64	0.918694	**3.08**	0.962212	**3.52**	0.982751	**3.96**	0.992240	**4.40**	0.996581
2.65	0.920075	**3.09**	0.962873	**3.53**	0.983058	**3.97**	0.992381	**4.41**	0.996646
2.66	0.921434	**3.10**	0.963523	**3.54**	0.983360	**3.98**	0.992519	**4.42**	0.996709
2.67	0.922771	**3.11**	0.964162	**3.55**	0.983657	**3.99**	0.992656	**4.43**	0.996771
2.68	0.924087	**3.12**	0.964790	**3.56**	0.983949	**4.00**	0.992789	**4.44**	0.996832
2.69	0.925381	**3.13**	0.965407	**3.57**	0.984235	**4.01**	0.992921	**4.45**	0.996892
2.70	0.926654	**3.14**	0.966014	**3.58**	0.984517	**4.02**	0.993050	**4.46**	0.996951
2.71	0.927907	**3.15**	0.966611	**3.59**	0.984794	**4.03**	0.993177	**4.47**	0.997008
2.72	0.929139	**3.16**	0.967197	**3.60**	0.985065	**4.04**	0.993301	**4.48**	0.997065
2.73	0.930351	**3.17**	0.967773	**3.61**	0.985333	**4.05**	0.993424	**4.49**	0.997121
2.74	0.931544	**3.18**	0.968339	**3.62**	0.985595	**4.06**	0.993544	**4.50**	0.997176
2.75	0.932717	**3.19**	0.968896	**3.63**	0.985853	**4.07**	0.993662	**4.51**	0.997230
2.76	0.933870	**3.20**	0.969443	**3.64**	0.986106	**4.08**	0.993778	**4.52**	0.997282
2.77	0.935005	**3.21**	0.969981	**3.65**	0.986355	**4.09**	0.993892	**4.53**	0.997334
2.78	0.936121	**3.22**	0.970509	**3.66**	0.986599	**4.10**	0.994004	**4.54**	0.997385
2.79	0.937219	**3.23**	0.971029	**3.67**	0.986840	**4.11**	0.994114	**4.55**	0.997435
2.80	0.938299	**3.24**	0.971539	**3.68**	0.987076	**4.12**	0.994222	**4.56**	0.997485
2.81	0.939361	**3.25**	0.972041	**3.69**	0.987308	**4.13**	0.994328	**4.57**	0.997533
2.82	0.940405	**3.26**	0.972534	**3.70**	0.987535	**4.14**	0.994432	**4.58**	0.997581
2.83	0.941432	**3.27**	0.973019	**3.71**	0.987759	**4.15**	0.994535	**4.59**	0.997627
2.84	0.942443	**3.28**	0.973495	**3.72**	0.987979	**4.16**	0.994635	**4.60**	0.997673
2.85	0.943436	**3.29**	0.973963	**3.73**	0.988195	**4.17**	0.994734	**4.61**	0.997718
2.86	0.944413	**3.30**	0.974423	**3.74**	0.988407	**4.18**	0.994831	**4.62**	0.997762
2.87	0.945374	**3.31**	0.974875	**3.75**	0.988616	**4.19**	0.994926	**4.63**	0.997806
2.88	0.946318	**3.32**	0.975319	**3.76**	0.988821	**4.20**	0.995020	**4.64**	0.997848
2.89	0.947247	**3.33**	0.975755	**3.77**	0.989022	**4.21**	0.995112	**4.65**	0.997890
2.90	0.948161	**3.34**	0.976184	**3.78**	0.989220	**4.22**	0.995202	**4.66**	0.997931
2.91	0.949059	**3.35**	0.976606	**3.79**	0.989414	**4.23**	0.995291	**4.67**	0.997972
2.92	0.949942	**3.36**	0.977020	**3.80**	0.989605	**4.24**	0.995378	**4.68**	0.998011

Table C-8 Continued.

Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion
4.69	0.998050	**4.96**	0.998878	**5.23**	0.999387	**5.50**	0.999702	**5.77**	0.999895
4.70	0.998089	**4.97**	0.998901	**5.24**	0.999402	**5.51**	0.999711	**5.78**	0.999901
4.71	0.998126	**4.98**	0.998924	**5.25**	0.999416	**5.52**	0.999719	**5.79**	0.999906
4.72	0.998163	**4.99**	0.998947	**5.26**	0.999430	**5.53**	0.999728	**5.80**	0.999911
4.73	0.998200	**5.00**	0.998970	**5.27**	0.999444	**5.54**	0.999736	**5.81**	0.999917
4.74	0.998235	**5.01**	0.998992	**5.28**	0.999458	**5.55**	0.999745	**5.82**	0.999922
4.75	0.998270	**5.02**	0.999013	**5.29**	0.999471	**5.56**	0.999753	**5.83**	0.999927
4.76	0.998305	**5.03**	0.999034	**5.30**	0.999484	**5.57**	0.999761	**5.84**	0.999932
4.77	0.998338	**5.04**	0.999055	**5.31**	0.999497	**5.58**	0.999769	**5.85**	0.999937
4.78	0.998372	**5.05**	0.999076	**5.32**	0.999509	**5.59**	0.999777	**5.86**	0.999941
4.79	0.998404	**5.06**	0.999096	**5.33**	0.999522	**5.60**	0.999784	**5.87**	0.999946
4.80	0.998436	**5.07**	0.999115	**5.34**	0.999534	**5.61**	0.999792	**5.88**	0.999951
4.81	0.998468	**5.08**	0.999135	**5.35**	0.999546	**5.62**	0.999799	**5.89**	0.999955
4.82	0.998499	**5.09**	0.999154	**5.36**	0.999558	**5.63**	0.999806	**5.90**	0.999960
4.83	0.998529	**5.10**	0.999173	**5.37**	0.999569	**5.64**	0.999814	**5.91**	0.999964
4.84	0.998559	**5.11**	0.999191	**5.38**	0.999580	**5.65**	0.999820	**5.92**	0.999968
4.85	0.998588	**5.12**	0.999209	**5.39**	0.999592	**5.66**	0.999827	**5.93**	0.999973
4.86	0.998617	**5.13**	0.999227	**5.40**	0.999603	**5.67**	0.999834	**5.94**	0.999977
4.87	0.998645	**5.14**	0.999244	**5.41**	0.999613	**5.68**	0.999841	**5.95**	0.999981
4.88	0.998673	**5.15**	0.999261	**5.42**	0.999624	**5.69**	0.999847	**5.96**	0.999985
4.89	0.998700	**5.16**	0.999278	**5.43**	0.999634	**5.70**	0.999854	**5.97**	0.999989
4.90	0.998727	**5.17**	0.999294	**5.44**	0.999644	**5.71**	0.999860	**5.98**	0.9999925
4.91	0.998753	**5.18**	0.999311	**5.45**	0.999654	**5.72**	0.999866	**5.99**	0.999996
4.92	0.998779	**5.19**	0.999327	**5.46**	0.999664	**5.73**	0.999872	**6.00**	1
4.93	0.998804	**5.20**	0.999342	**5.47**	0.999674	**5.74**	0.999878		
4.94	0.998829	**5.21**	0.999358	**5.48**	0.999683	**5.75**	0.999884		
4.95	0.998854	**5.22**	0.999373	**5.49**	0.999692	**5.76**	0.999889		

It was agreed that redd depths of redds that were considered not fresh (e.g., redds whose age was catalogued as “older some algae” and “old obscure”, or whose field comments suggest as potential test redds) or that were catalogued as “test redds” would not be included in the calculation of the relative cumulative frequency distribution of steelhead redd depths. Finally, as done for the raw redd-depth database for Chinook salmon, the daily flows and stages at the Fair Oaks gage on the dates and on the weeks prior to the dates of all redd depth observations were contrasted. It was decided that whenever, there was a change in flow greater than 100 cfs resulting in a stage change greater or equal than 0.2 ft., the observed redd depths would be excluded from the analysis.

The shallowest redd depth in the resulting trimmed database was 0.4 ft., while the deepest steelhead redd was observed at 4.6 ft. The asymmetric logistic function fitted to the cumulative proportions in Table C-6, displayed in **Figure C-8**, has the following expression:

$$\Pr(D) = \left(\frac{1}{1 + \exp(2.8584 - 2.0340 \times D)} \right)^{1/0.6066} \qquad \textbf{(4)}$$

where D is the redd depth in feet. The mean square error of this fit was 0.00017.

Table C-9. Frequency distribution of redd depths by 0.1-ft depth bins for steelhead redds collected in the American River from 2002 through 2016. No redd surveys were conducted in 2006 and 2008.

Depth (ft)	Annual number of redds by 0.1-ft depth bin													Combined Redds	Cumulative proportion
	2002	2003	2004	2005	2007	2009	2010	2011	2012	2013	2014	2015	2016		
0															
0.1															
0.2															
0.3								4	1					5	0.005945
0.4									1	1				2	0.008323
0.5			1			2	1		1	1	1			7	0.016647
0.6	2		2			1		2	2	2	4		3	18	0.038050
0.7			1	1	1	3			3		3	1		13	0.053508
0.8			5	1	3	1				2	8		1	21	0.078478
0.9	3	1	3	3			3	1	6	8	9		2	39	0.124851
1		1	5		3	1			3		2		2	17	0.145065
1.1	3	1	7	2	5	2	2	2	1	2	7	1	5	40	0.192628
1.2		1	8		5		2		1	6	6		3	32	0.230678
1.3	11	3		1	8	2	1	4		8	7	1	2	48	0.287753
1.4	2	1	3	3	10	1	2	1	2	4	2	1	3	35	0.329370
1.5		3	3	2	4	1	2	3		5	3		1	27	0.361474
1.6	16	3	4		8	1	3	1	3	13	9	2		63	0.436385
1.7		3	4	1	10	1	2	2	1	3	7		1	35	0.478002
1.8	3	3	5	2	10	1	3		3	2	1	1		34	0.518430
1.9	22	5	3	4	4	1	4	5	2	3	5	1		59	0.588585
2		4	10		12		3	2	3	3		2	3	42	0.638526
2.1	2	9	7	1	10		4	1	2	2	1	2	2	43	0.689655
2.2	15	10	4	1	12		2	4	4	3	1	1		57	0.757432
2.3		3	2	4	5		1		1			1		17	0.777646
2.4	3	5	5		8		4	3	2	2				32	0.815696
2.5		3	4	1	4		1		2	2				17	0.835910
2.6	9	3	11		2		5		4	1	1			36	0.878716
2.7	1	1	3		1				1	2				9	0.889417
2.8		2	4		4		1	2		1				14	0.906064
2.9	3	1	6	1	1		1	3	3		1	1		21	0.931034
3			2	1				1						4	0.935791
3.1	1	6	2	1	3				1					14	0.952438
3.2	10	7	4				1	1	1	2				26	0.983353
3.3								1			1			2	0.985731
3.4			1	1				1						3	0.989298
3.5															
3.6		2						1						3	0.992866
3.7															
3.8															
3.9		1	1					1						3	
4															0.996433
4.1								1						1	
4.2							1							1	0.998811
4.3															
4.4															
4.5		1												1	1
Totals	**106**	**83**	**120**	**31**	**133**	**18**	**49**	**47**	**54**	**78**	**79**	**15**	**28**	**841**	

The asymmetric logistic function in equation (4) was re-scaled to the observed range of steelhead redd depths and used to build a look-up table providing the expected cumulative proportions of redd depths for every hundredth of a foot (**Table C-10**).

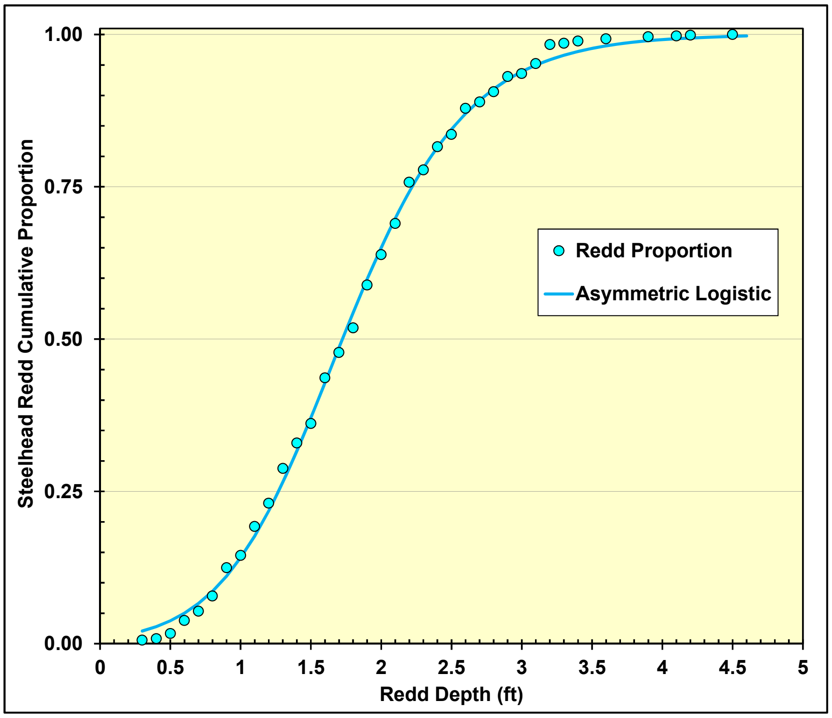

Figure C-8. Cumulative proportions of 841 steelhead redd depths measured in the lower American River from 2002 through 2016 (no redd surveys were conducted in 2006 and 2008), and fitted asymmetric logistic curve.

3.5 STAGE - FLOW RELATIONSHIPS

The calculation of the annual weighted redd dewatering index (WRD_Y) requires estimates of the mean daily stages or water surface elevations at each spawning reach *h* during each redd construction day *d* of the evaluated year *Y*, as well as during any subsequent day until the last day of the corresponding embryo incubation period (*i.e.*, $ED_{d,h,Y}$).

Table C-10. Re-scaled cumulative proportions of steelhead redd depths used in the analysis of potential redd dewatering for the lower American River.

Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion
0.30	0	**0.74**	0.052006	**1.18**	0.194138	**1.62**	0.432372	**2.06**	0.677968
0.31	0	**0.75**	0.054090	**1.19**	0.198645	**1.63**	0.438327	**2.07**	0.682795
0.32	0	**0.76**	0.056220	**1.20**	0.203207	**1.64**	0.444285	**2.08**	0.687577
0.33	0	**0.77**	0.058398	**1.21**	0.207824	**1.65**	0.450242	**2.09**	0.692313
0.34	0	**0.78**	0.060623	**1.22**	0.212494	**1.66**	0.456199	**2.10**	0.697003
0.35	0	**0.79**	0.062897	**1.23**	0.217218	**1.67**	0.462152	**2.11**	0.701646
0.36	0.000779	**0.80**	0.065220	**1.24**	0.221994	**1.68**	0.468101	**2.12**	0.706242
0.37	0.001580	**0.81**	0.067593	**1.25**	0.226823	**1.69**	0.474044	**2.13**	0.710791
0.38	0.002404	**0.82**	0.070016	**1.26**	0.231702	**1.70**	0.479980	**2.14**	0.715293
0.39	0.003250	**0.83**	0.072490	**1.27**	0.236632	**1.71**	0.485906	**2.15**	0.719747
0.40	0.004120	**0.84**	0.075015	**1.28**	0.241612	**1.72**	0.491823	**2.16**	0.724154
0.41	0.005014	**0.85**	0.077592	**1.29**	0.246640	**1.73**	0.497728	**2.17**	0.728512
0.42	0.005933	**0.86**	0.080222	**1.30**	0.251716	**1.74**	0.503619	**2.18**	0.732823
0.43	0.006877	**0.87**	0.082904	**1.31**	0.256839	**1.75**	0.509496	**2.19**	0.737085
0.44	0.007846	**0.88**	0.085641	**1.32**	0.262008	**1.76**	0.515357	**2.20**	0.741299
0.45	0.008842	**0.89**	0.088431	**1.33**	0.267222	**1.77**	0.521201	**2.21**	0.745464
0.46	0.009864	**0.90**	0.091276	**1.34**	0.272480	**1.78**	0.527026	**2.22**	0.749581
0.47	0.010915	**0.91**	0.094175	**1.35**	0.277781	**1.79**	0.532831	**2.23**	0.753649
0.48	0.011993	**0.92**	0.097130	**1.36**	0.283123	**1.80**	0.538615	**2.24**	0.757669
0.49	0.013100	**0.93**	0.100141	**1.37**	0.288506	**1.81**	0.544376	**2.25**	0.761640
0.50	0.014236	**0.94**	0.103208	**1.38**	0.293928	**1.82**	0.550113	**2.26**	0.765562
0.51	0.015403	**0.95**	0.106332	**1.39**	0.299389	**1.83**	0.555826	**2.27**	0.769437
0.52	0.016599	**0.96**	0.109512	**1.40**	0.304886	**1.84**	0.561512	**2.28**	0.773262
0.53	0.017828	**0.97**	0.112749	**1.41**	0.310419	**1.85**	0.567171	**2.29**	0.777040
0.54	0.019088	**0.98**	0.116044	**1.42**	0.315986	**1.86**	0.572801	**2.30**	0.780770
0.55	0.020380	**0.99**	0.119396	**1.43**	0.321587	**1.87**	0.578402	**2.31**	0.784451
0.56	0.021706	**1.00**	0.122806	**1.44**	0.327219	**1.88**	0.583973	**2.32**	0.788085
0.57	0.023065	**1.01**	0.126274	**1.45**	0.332881	**1.89**	0.589511	**2.33**	0.791671
0.58	0.024459	**1.02**	0.129801	**1.46**	0.338573	**1.90**	0.595017	**2.34**	0.795209
0.59	0.025889	**1.03**	0.133385	**1.47**	0.344292	**1.91**	0.600489	**2.35**	0.798700
0.60	0.027354	**1.04**	0.137029	**1.48**	0.350037	**1.92**	0.605927	**2.36**	0.802144
0.61	0.028855	**1.05**	0.140730	**1.49**	0.355807	**1.93**	0.611329	**2.37**	0.805541
0.62	0.030394	**1.06**	0.144490	**1.50**	0.361600	**1.94**	0.616695	**2.38**	0.808892
0.63	0.031971	**1.07**	0.148309	**1.51**	0.367414	**1.95**	0.622024	**2.39**	0.812196
0.64	0.033586	**1.08**	0.152186	**1.52**	0.373249	**1.96**	0.627314	**2.40**	0.815454
0.65	0.035240	**1.09**	0.156122	**1.53**	0.379103	**1.97**	0.632566	**2.41**	0.818666
0.66	0.036934	**1.10**	0.160115	**1.54**	0.384973	**1.98**	0.637778	**2.42**	0.821833
0.67	0.038669	**1.11**	0.164167	**1.55**	0.390860	**1.99**	0.642949	**2.43**	0.824954
0.68	0.040445	**1.12**	0.168277	**1.56**	0.396760	**2.00**	0.648080	**2.44**	0.828031
0.69	0.042264	**1.13**	0.172445	**1.57**	0.402673	**2.01**	0.653169	**2.45**	0.831063
0.70	0.044124	**1.14**	0.176670	**1.58**	0.408597	**2.02**	0.658216	**2.46**	0.834051
0.71	0.046028	**1.15**	0.180952	**1.59**	0.414530	**2.03**	0.663220	**2.47**	0.836995
0.72	0.047976	**1.16**	0.185291	**1.60**	0.420472	**2.04**	0.668180	**2.48**	0.839895
0.73	0.049969	**1.17**	0.189687	**1.61**	0.426419	**2.05**	0.673096	**2.49**	0.842752

Table C-10. Continued.

Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion
2.50	0.845567	**2.94**	0.933304	**3.38**	0.973312	**3.82**	0.990438	**4.26**	0.997572
2.51	0.848339	**2.95**	0.934623	**3.39**	0.973888	**3.83**	0.990679	**4.27**	0.997672
2.52	0.851069	**2.96**	0.935919	**3.40**	0.974452	**3.84**	0.990916	**4.28**	0.997769
2.53	0.853757	**2.97**	0.937192	**3.41**	0.975005	**3.85**	0.991148	**4.29**	0.997865
2.54	0.856404	**2.98**	0.938441	**3.42**	0.975548	**3.86**	0.991376	**4.30**	0.997959
2.55	0.859010	**2.99**	0.939668	**3.43**	0.976081	**3.87**	0.991599	**4.31**	0.998051
2.56	0.861576	**3.00**	0.940872	**3.44**	0.976603	**3.88**	0.991817	**4.32**	0.998142
2.57	0.864101	**3.01**	0.942055	**3.45**	0.977115	**3.89**	0.992032	**4.33**	0.998230
2.58	0.866588	**3.02**	0.943216	**3.46**	0.977617	**3.90**	0.992242	**4.34**	0.998317
2.59	0.869034	**3.03**	0.944356	**3.47**	0.978109	**3.91**	0.992448	**4.35**	0.998402
2.60	0.871442	**3.04**	0.945475	**3.48**	0.978592	**3.92**	0.992649	**4.36**	0.998485
2.61	0.873812	**3.05**	0.946574	**3.49**	0.979065	**3.93**	0.992847	**4.37**	0.998566
2.62	0.876144	**3.06**	0.947652	**3.50**	0.979530	**3.94**	0.993041	**4.38**	0.998646
2.63	0.878438	**3.07**	0.948711	**3.51**	0.979985	**3.95**	0.993231	**4.39**	0.998725
2.64	0.880695	**3.08**	0.949750	**3.52**	0.980431	**3.96**	0.993417	**4.40**	0.998801
2.65	0.882916	**3.09**	0.950769	**3.53**	0.980869	**3.97**	0.993600	**4.41**	0.998877
2.66	0.885100	**3.10**	0.951770	**3.54**	0.981298	**3.98**	0.993779	**4.42**	0.998950
2.67	0.887248	**3.11**	0.952753	**3.55**	0.981719	**3.99**	0.993954	**4.43**	0.999023
2.68	0.889361	**3.12**	0.953717	**3.56**	0.982132	**4.00**	0.994126	**4.44**	0.999093
2.69	0.891440	**3.13**	0.954663	**3.57**	0.982537	**4.01**	0.994295	**4.45**	0.999163
2.70	0.893483	**3.14**	0.955592	**3.58**	0.982933	**4.02**	0.994460	**4.46**	0.999231
2.71	0.895493	**3.15**	0.956503	**3.59**	0.983322	**4.03**	0.994622	**4.47**	0.999297
2.72	0.897469	**3.16**	0.957397	**3.60**	0.983704	**4.04**	0.994780	**4.48**	0.999363
2.73	0.899412	**3.17**	0.958274	**3.61**	0.984078	**4.05**	0.994936	**4.49**	0.999427
2.74	0.901322	**3.18**	0.959135	**3.62**	0.984444	**4.06**	0.995088	**4.50**	0.999489
2.75	0.903200	**3.19**	0.959980	**3.63**	0.984804	**4.07**	0.995237	**4.51**	0.999551
2.76	0.905046	**3.20**	0.960809	**3.64**	0.985156	**4.08**	0.995384	**4.52**	0.999611
2.77	0.906861	**3.21**	0.961623	**3.65**	0.985502	**4.09**	0.995527	**4.53**	0.999670
2.78	0.908644	**3.22**	0.962421	**3.66**	0.985840	**4.10**	0.995668	**4.54**	0.999728
2.79	0.910397	**3.23**	0.963204	**3.67**	0.986173	**4.11**	0.995806	**4.55**	0.999784
2.80	0.912120	**3.24**	0.963972	**3.68**	0.986498	**4.12**	0.995941	**4.56**	0.999840
2.81	0.913813	**3.25**	0.964726	**3.69**	0.986817	**4.13**	0.996073	**4.57**	0.999894
2.82	0.915477	**3.26**	0.965465	**3.70**	0.987130	**4.14**	0.996203	**4.58**	0.999948
2.83	0.917111	**3.27**	0.966190	**3.71**	0.987437	**4.15**	0.996330	**4.59**	1
2.84	0.918718	**3.28**	0.966902	**3.72**	0.987738	**4.16**	0.996455		
2.85	0.920296	**3.29**	0.967600	**3.73**	0.988033	**4.17**	0.996577		
2.86	0.921847	**3.30**	0.968285	**3.74**	0.988322	**4.18**	0.996696		
2.87	0.923370	**3.31**	0.968956	**3.75**	0.988605	**4.19**	0.996814		
2.88	0.924866	**3.32**	0.969615	**3.76**	0.988883	**4.20**	0.996929		
2.89	0.926337	**3.33**	0.970262	**3.77**	0.989155	**4.21**	0.997041		
2.90	0.927780	**3.34**	0.970896	**3.78**	0.989422	**4.22**	0.997152		
2.91	0.929199	**3.35**	0.971517	**3.79**	0.989683	**4.23**	0.997260		
2.92	0.930592	**3.36**	0.972127	**3.80**	0.989940	**4.24**	0.997366		
2.93	0.931960	**3.37**	0.972725	**3.81**	0.990191	**4.25**	0.997470		

In equation (1), the variable $Stage_{d,h,Y}$ indicates the mean daily river stage in spawning reach *h* on redd construction day *d* of year *Y*, and the variable $Stage_{i,h,Y}$ indicates the mean daily river stage in the same spawning area, on any day *i* subsequent to the date of redd construction, until the last day of the embryo incubation period for the redds built on day *d*. Eighteen reach-specific stage-flow relationships were used to interpolate daily stage or water surface elevation that corresponds to the simulated average daily flow output.

The 18 reach-specific stage-flow relationships used (**Figure C-9**) were developed by cbec for this analysis of potential redd dewatering in the lower American River under the Modified FMS and the 2006 FMS. The reach-specific stage-flow relationships were constructed by first developing individual stage-flow relationships for each of the available measured cross sections spaced 0.25 miles apart, and then averaging the resulting stage-flow relationships into 1-mile sections. Each of the resulting 18 reach-specific stage-flow relationships provides water surface elevations expressed in feet for 139 flows ranging from 200 cfs to 180,000 cfs, in increasing steps of 100 cfs (19 values), 500 cfs (12 values), 1,000 cfs (92 values) and 5,000 cfs (16 values).

Because the calculation of the annual weighted redd dewatering index (WRD_Y) requires the derivation of mean daily stages from simulated mean daily flows under the Modified FMS and the 2006 FMS for each spawning reach *h* during each redd construction day *d* of the evaluated year *Y*, as well as during any subsequent day until the last day of the corresponding embryo incubation period (*i.e.*, $ED_{d,h,Y}$), and because the 18 reach-specific stage-flow relationships provide stage values for only 139 flows, daily stages were determined by linear interpolation between the available stage values for the flows immediately below and above the target flow $Q_{d,Y}$.

3.6 ANNUAL WEIGHTED REDD DEWATERING INDEX CALCULATION

The calculations of the annual weighted redd dewatering indices (*i.e.*, WRD_Y) for fall-run Chinook salmon and steelhead spawning in the lower American River for the simulated daily flows and water temperatures under the Modified FMS and the 2006 FMS during each of the simulation years were performed using Excel© templates and macros. The step-by-step calculations included in these templates and macros are summarily described in the following paragraphs.

Step 1. For the first spawning reach (*i.e.*, *h* = RM 22) and the first day of the spawning period (*i.e.*, *d* = October 17 for fall-run Chinook salmon and *d* = December 11 for steelhead) during the first year *Y* of the entire simulation period, count the number of days while the daily ATUs remain below a target of 1,649°F for Chinook salmon and 1,080°F for steelhead. The resulting counts ($ED_{d,h,Y}$) are the durations of fall-run Chinook salmon and steelhead embryo incubation for redds built on day *d* of year *Y*, in spawning area *h*.

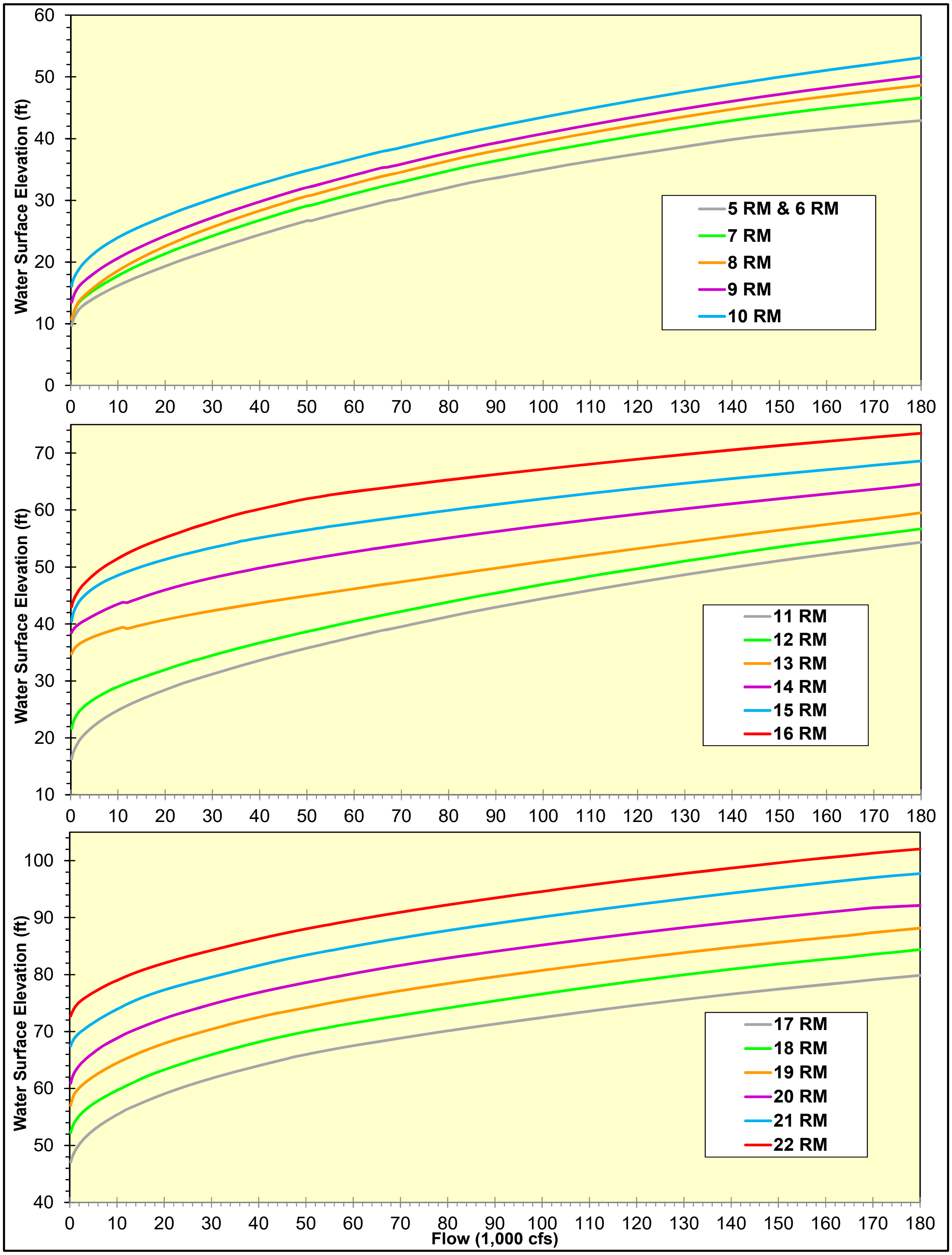

Figure C-9. Relationships between water surface elevation (ft) and flow (thousand cfs) developed by cbec for each of the 18 spawning reaches used in the redd-dewatering analyses for Chinook salmon and steelhead in the lower American River.

Step 2. For the same year *Y*, spawning reach *h* and spawning day *d*, calculate the daily flow at which the fall-run Chinook salmon or steelhead redds are built utilizing the simulated average daily flows.

Step 3. Utilizing the stage-flow relationship for spawning reach *h*, calculate the stage or water surface elevation (*i.e.*, $Stage_{d,h,Y}$) that corresponds to the spawning flow ($Q_{h,d,Y}$) calculated in the previous step, using linear interpolation if needed.

Step 4. Utilizing the stage-flow relationship for spawning reach *h*, calculate the stages or water surface elevations (*i.e.*, $Stage_{i,h,Y}$) that correspond to the simulated daily average flows for all days within the range $i = d + 1$ through $i = d + ED_{d,h,Y}$.

Step 5. Calculate the maximum positive difference between the spawning-day stage (*i.e.*, $Stage_{d,h,Y}$) and the stages on subsequent days (from Step 4). This value represents the maximum drop in water elevation experienced by redds built in spawning area *h* on day *d* of year *Y* throughout their embryo incubation period.

Step 6. Compute the proportion of the redds built in spawning reach *h* on day *d* of year *Y* potentially dewatered by the maximum drop in water elevation calculated in Step 5 by using Excel© function VLOOKUP with the value from Step 5 rounded to two decimal places, and Table C-5 for fall-run Chinook salmon or Table C-7 for steelhead.

Step 7. Multiply the proportions derived from Step 6 by the temporal weighting coefficient corresponding to spawning day *d* (w_d) from Figures C-3 and C-4, and by the spatial weighting coefficient corresponding to spawning reach *h* (w_h) in Tables C-1 and C-2. The result of this step (*i.e.*, $WRD_{d,h,Y}$) represents the maximum proportion of the redds built on spawning day *d* of year *Y* in reach *h* that are potentially exposed to at least one day of dewatering during their embryo incubation period, weighted over all redds built in year *Y*.

Step 8. For spawning day *d* and year *Y*, repeat Steps 1 through 7 with each of the 17 remaining spawning reaches (*i.e.*, *h* = RM 21 through *h* = RM 5), and save the resulting partial dewatering proportions $WRD_{d,h,Y}$.

Step 9. Repeat Steps 1 through 8 for each of the remaining 90 Chinook salmon spawning days (*i.e.*, *d* = October 17 through January 14) and 108 steelhead spawning days (*i.e.*, *d* = December 11 through March 28), and save the resulting partial dewatering proportions $WRD_{d,h,Y}$.

Step 10. Sum the partial dewatering proportions $WRD_{d,h,Y}$ from steps 7, 8 and 9 to obtain WRD_Y - the annual weighted redd dewatering index for year Y.

Step 11. Repeat Steps 1 through 10 for the remaining years of the simulation period.

Once all of the annual weighted redd dewatering indices for fall-run Chinook salmon and steelhead in the lower American River are calculated using simulated daily flows and associated river stages, and simulated daily water temperatures under the Modified FMS and the 2006 FMS, the resulting annual indices are averaged over the entire simulation period, and by water year type, for comparison of the redd dewatering indices under the Modified FMS and the 2006 FMS.

4.0 REFERENCES

Armour, C. L. 1991. Guidance for Evaluating and Recommending Temperature Regimes to Protect Fish. U.S. Fish Wildl. Serv., Biol. Rep. 90(22). 13 p.

Beacham, T.D. and C.B. Murray. 1989. Variation in developmental biology of sockeye salmon (*Oncorhynchus nerka*) and Chinook salmon (*O. tshawytscha*) in British Columbia. Canadian Journal of Zoology, 67:2081-2089.

Bedore, P., M. Bryan, P. Bratovich, J. Perez-Comas, M. Neal, C. Hammersmark, J. Barker and C. Addley. 2015. Lower American River Chinook Salmon Early Lifestage Mortality Model: Updates and Refinements. Prepared for Sacramento Water Forum and U.S. Army Corps of Engineers, Sacramento District. Draft, November 2015. 99 p.

Byrne, A. 1996. Steelhead Supplementation Studies in Idaho Rivers to Evaluate the Feasibility of Using Artificial Production to Increase Natural Steelhead Populations and to Collect Baseline Life History, Genetic, and Disease Data from Natural Steelhead Populations. 1993 Annual Report for Activities Completed January 1, 1993 through December 31, 1993. Idaho Department of Fish and Game. Prepared for U.S. Department of Energy, Bonneville Power Administration, Environment, Fish and Wildlife. IDFG 96-01 Project No. DE-BI79-89BPO1466. January 1996.

Briggs, J.C. 1953. The behavior and reproduction of salmonid fishes in a small coastal stream. California Department of Fish and Wildlife. Fish Bulletin 94, 62 p.

CDFW 1998. A Status Review of the Spring-Run Chinook Salmon (*Oncorhynchus tshawytscha*) in the Sacramento River Drainage. Candidate Species Status Report 98-01. Sacramento, CA: Department of Fish and Game

Chase, R. 2010. American River Steelhead (*Oncorhynchus mykiss*) Spawning Surveys 2010. U.S. Bureau of Reclamation. Sacramento , 15 p.

Crisp, D. T. 1988. Prediction, from temperature, of eyeing, hatching, and ‘swim-up’ times for salmonid embryos. Freshwater Biology 19: 41 – 48.

Crisp, D. T. 1981. A desk study of the relationship between temperature and hatching time for the eggs of five species of salmonid fishes. Freshwater Biology 11: 361 – 368.

Geist, D.R., C.S. Abernethy, K.D. Hand, V.I. Cullinan, J.A. Chandler and P.A. Groves. 2011. Survival, development, and growth of fall Chinook salmon embryos, alevins, and fry exposed to variable thermal and dissolved oxygen regimes. Transactions of the American Fisheries Society, 135:1462-1477.

Hannon, J. 2013. American River Steelhead (*Oncorhynchus mykiss*) Spawning -2013, with comparison to prior years. U.S. Bureau of Reclamation. Sacramento , 32 p.

Hannon, J. 2012. American River Steelhead (*Oncorhynchus mykiss*) Spawning -2012, with comparison to prior years. U.S. Bureau of Reclamation. Sacramento , 30 p.

Hannon, J. 2011. American River Steelhead (*Oncorhynchus mykiss*) Spawning Surveys 2011, with comparisons to prior years. U.S. Bureau of Reclamation. Sacramento, 27 p.

Hannon, J., and B. Deason, 2004. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001-2004. U.S. Bureau of Reclamation. Sacramento , 43 p.

Hannon, J., and B. Deason, 2005. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001-2005. U.S. Bureau of Reclamation. Sacramento , 48 p.

Hannon, J., and B. Deason, 2007. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001-2007. U.S. Bureau of Reclamation. Sacramento , 53 p.

Hannon, J., and M. Healey, 2002. American River steelhead redd surveys, 2001-2002. U.S. Bureau of Reclamation. Sacramento , 19 p.

Hannon, J., M. Healey, and B. Deason, 2003. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001-2003. U.S. Bureau of Reclamation. Sacramento , 36 p.

HCI. 1996. Water Forum Issue Paper. Chinook Salmon Mortality Model: Development, evaluation, and application as one tool to assess the relative effects of alternative flow and diversion scenarios on the lower American River. Prepared for: Sacramento Area Water Plan Forum.

Healey, M. 2002. Lower American River Chinook salmon escapement survey, October - December 2001. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, 17 p.

Healey, M. 2003. Lower American River Chinook Salmon Escapement Survey October 2002–January 2003. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 18 p.

Healey, M. 2004. Lower American River Chinook Salmon Escapement Survey October 2003–January 2004. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 15 p.

Healey, M. 2005. Lower American River Chinook Salmon Escapement Survey October 2004 – January 2005. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 15 p.

Healey, M. 2006. Lower American River Chinook Salmon Escapement Survey October – December 2005. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 14 p.

Healey, M. and S. Fresz. 2007. Lower American River Chinook salmon escapement survey, October 2006- December 2007. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 14 p.

Healey, M. and J. Redding. 2008. Lower American River Chinook Salmon Escapement Survey October 2007 – January 2008. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 14 p.

Jensen, J.O.T., and E. P. Groot. 1991. The effect of moist air incubation conditions and temperature on Chinook salmon egg survival. Am. Fish. Soc. Symposium 10: 529-538.

Jensen, J. O. T. and M. E. Jensen 1999. IncubWin: A new Windows 95/98, NT computer program for predicting embryonic stages in Pacific salmon and steelhead trout. Bull. Aquacult. Assoc. Canada 99-4: 28-30.

Jensen, J.O.T., McLean, W.E., Jensen, M.E., Sweeten, T., and Damon, W. 2009. WinSIRP version 2.0 User Manual: Microsoft Windows®-based salmonid incubation and rearing programs, designed for Microsoft Excel®. Can. Tech. Rep. Fish. Aquat. Sci. 2839: vii + 49 p.

Kraus, F. 1999. A guide to classroom egg incubation in Alaska. Alaska Department of Fish and Game, Special Publication No. 99-2, Anchorage, 45 p.

Leitritz, E. 1959. Trout and salmon culture (hatchery methods). California Department of Fish and Wildlife, Fish Bulletin no. 107. Univ. of Calif.

Leitritz, E. and R.C. Lewis. 1980. Trout and salmon culture (hatchery methods). California Department of Fish and Wildlife, Fish Bulletin no. 164. Univ. of Calif.

McEwan, D. and T. A. Jackson. 1996. Steelhead restoration and management plan for California. February 1996, California Department of Fish and Wildlife, 246 p.

Maher, M., R. Vincik and J. Phillips. 2012. Lower American River fall-run Chinook salmon escapement survey, 19 October - 15 December 2010. California Department of Fish and Wildlife, North Central Region, Rancho Cordova, CA, 25 p.

Murray, C.B. and J.D. McPhail. 1988. Effect of incubation temperature on the development of five species of Pacific salmon (*Oncorhynchus*) embryos and alevins. Canadian Journal of Zoology, 66:266-273.

Phillips, J. and J. M. Helstab. 2013. Lower American River fall-run Chinook salmon escapement survey, October 2012- January 2013. California Department of Fish and Wildlife, North Central Region, Rancho Cordova, CA, 30 p.

Phillips, J. and M. Maher. 2013. Lower American River fall-run Chinook salmon escapement survey, October 2011- January 2012. California Department of Fish and Wildlife, North Central Region, Rancho Cordova, CA, 30 p.

Ratkowsky, D.A. 1983. Nonlinear Regression Modeling. A Unified Practical Approach. Marcel Dekker, Inc., New York, 575 p.

See, M., and R. Chase, 2009. American River Steelhead (*Oncorhynchus mykiss*) Spawning Surveys 2009. U.S. Bureau of Reclamation. Sacramento , 15 p.

Seymour, A.L. 1956. Effects of temperature upon young Chinook salmon. Ph.D. dissertation. University of Washington, Seattle, 127 p.

Shapovalov, L. and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. California Department of Fish and Wildlife, Fish Bull. No. 98. 373 p.

Snider, B., and K. Bandner. 1996. Lower American River Chinook salmon escapement survey, October 1994-January 1995. California Department of Fish and Wildlife, Environmental Service Division, 38 p.

Snider, B., A.J. Chappelle, and N. Villa. 1995. Lower American River Chinook salmon escapement survey, October 1993-January 1994. California Department of Fish and Wildlife, Environmental Service Division, 21 p.

Snider, B., N. Keenan, and M. Muños. 1993. Lower American River Chinook salmon escapement survey, September 1992-January 1993. California Department of Fish and Wildlife, Environmental Service Division, 20 p.

Snider, B. and D. McEwan. 1992. Chinook salmon and steelhead trout redd survey, lower American River, 1991-1992. California Department of Fish and Wildlife, Environmental Services Division, 94 p.

Snider, B., and B. Reavis. 1996. Lower American River Chinook salmon escapement survey, October 1995-January 1996. California Department of Fish and Wildlife, Environmental Service Division, 31 p.

Snider, B., K. Urquhart, D. McEwan, and M. Muños. 1993. Chinook salmon redd survey, lower American River, Fall 1992. California Department of Fish and Wildlife, Environmental Service Division, 30 p.

Snider B. and K. Vyverberg. 1995. Chinook salmon redd survey, Lower American River, Fall 1993. California Department of Fish and Wildlife, Environmental Services Division, 47 p.

Snider B. and K. Vyverberg. 1996. Chinook salmon redd survey, Lower American River, Fall 1995. California Department of Fish and Wildlife, Environmental Services Division, Stream Flow and Habitat Evaluation Program. May 1996.

Snider B., K. Vyverberg, and S. Whiteman. 1996. Chinook salmon redd survey, Lower American River, Fall 1994. California Department of Fish and Wildlife, Environmental Services Division, 54 p.

Vincik, R. and J. Kirsch. 2009. Lower American River Chinook Salmon Escapement Survey October 2008 – January 2009. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 18 p.

Vincik, R. and M. Mamola. 2010. Lower American River Chinook salmon escapement survey, October 2009- January 2010. California Department of Fish and Wildlife, Sacramento Valley-Central Sierra Region, Rancho Cordova, CA, 15 p.

Biological Rationale, Development and Performance of the Modified Flow Management Standard

Attachment D

Lower American River Water Temperature Suitability for Fall-run Chinook Salmon and Steelhead

November 29, 2017

Lower American River
Average Daily Water Temperature
Exceedances

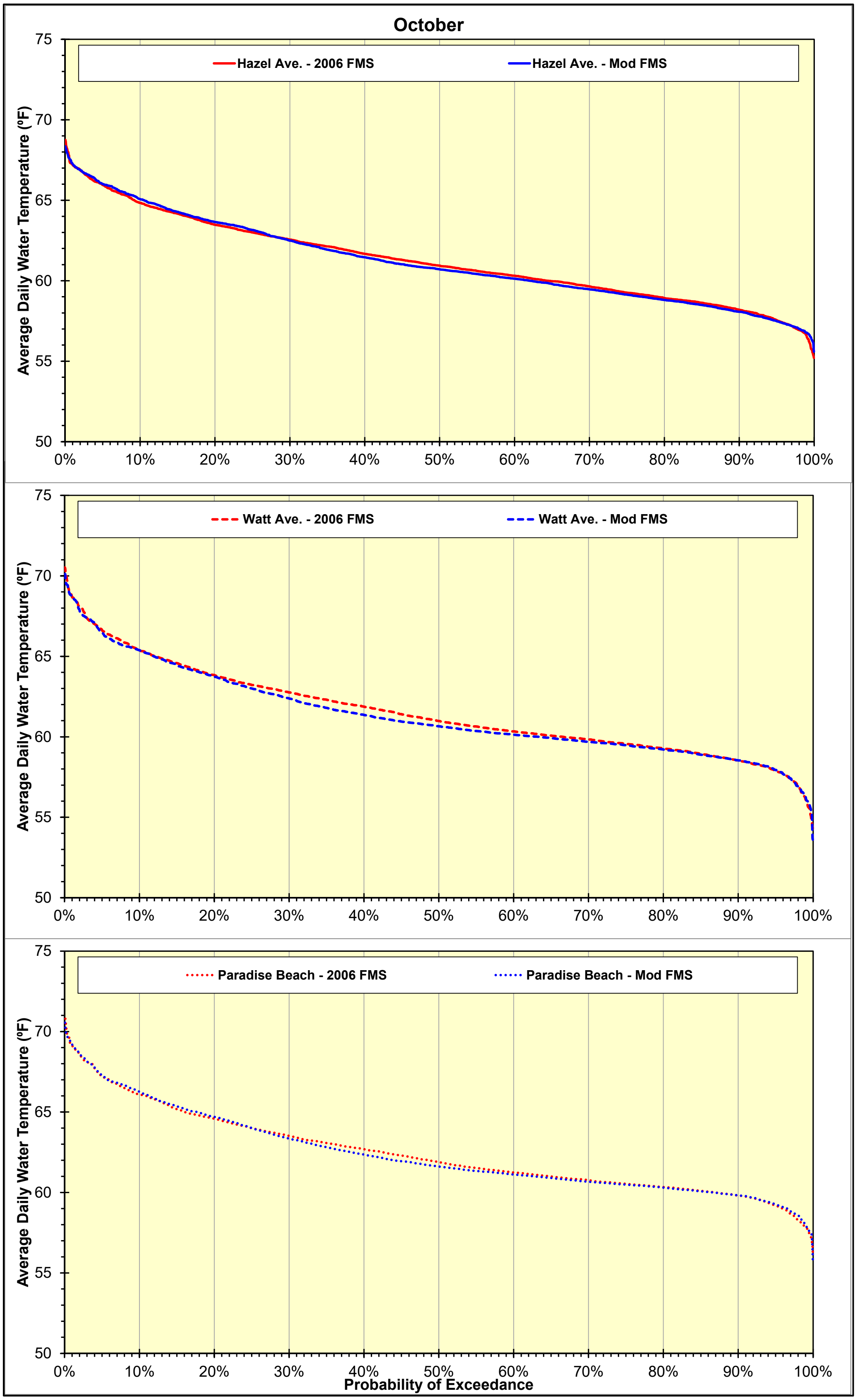

Figure D-1. Daily water temperature exceedance distributions during October at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

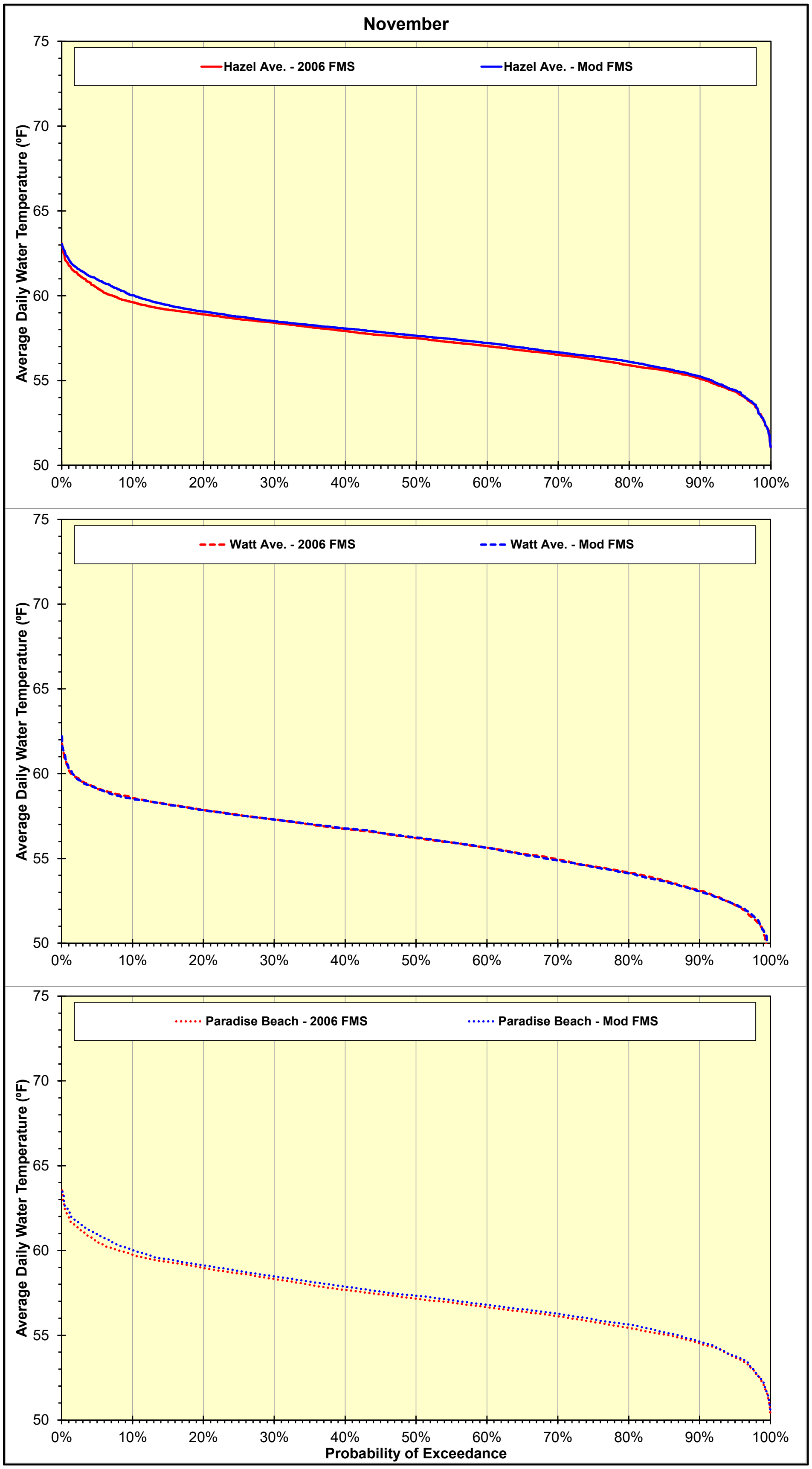

Figure D-2. Daily water temperature exceedance distributions during November at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

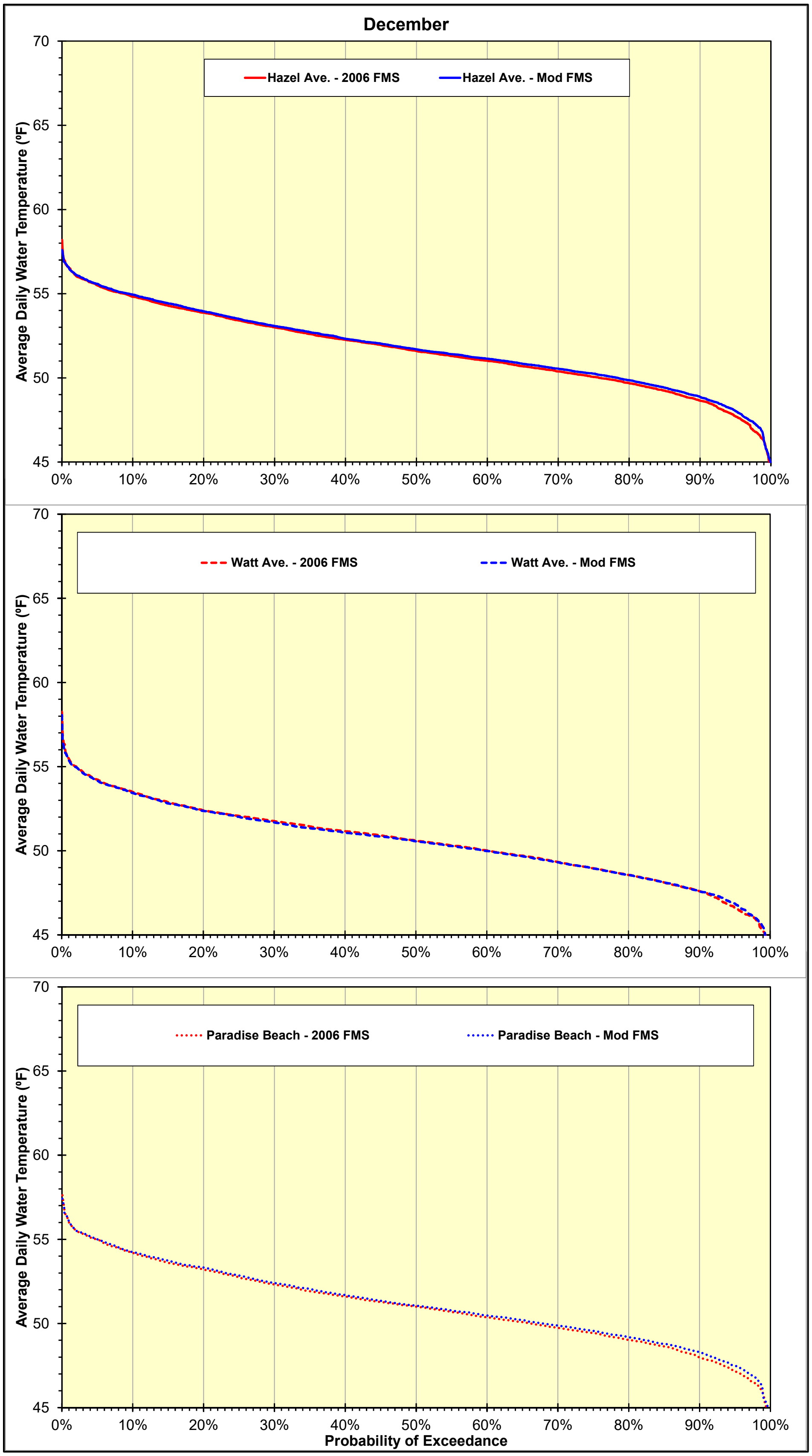

Figure D-3. Daily water temperature exceedance distributions during December at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

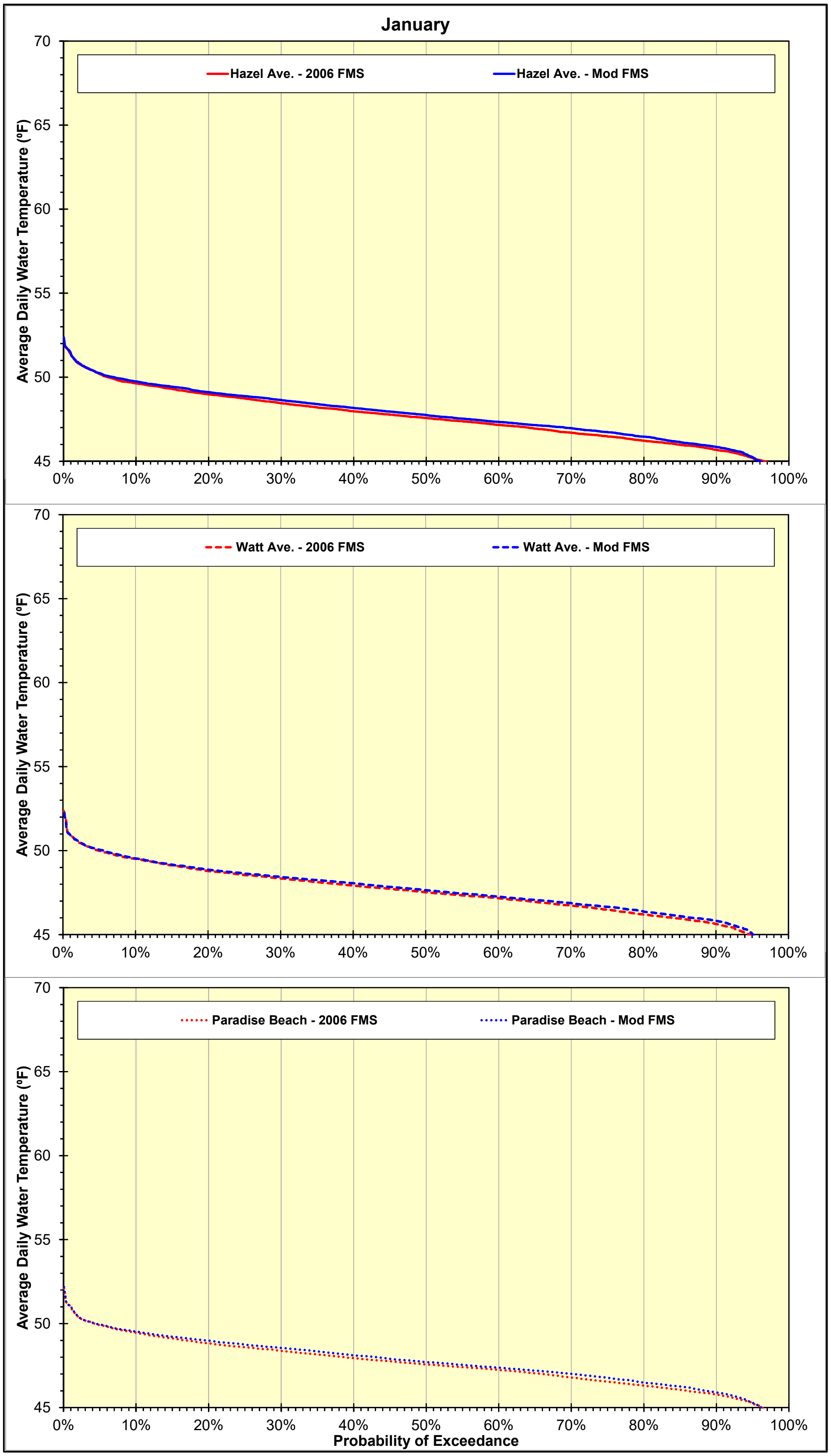

Figure D-4. Daily water temperature exceedance distributions during January at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

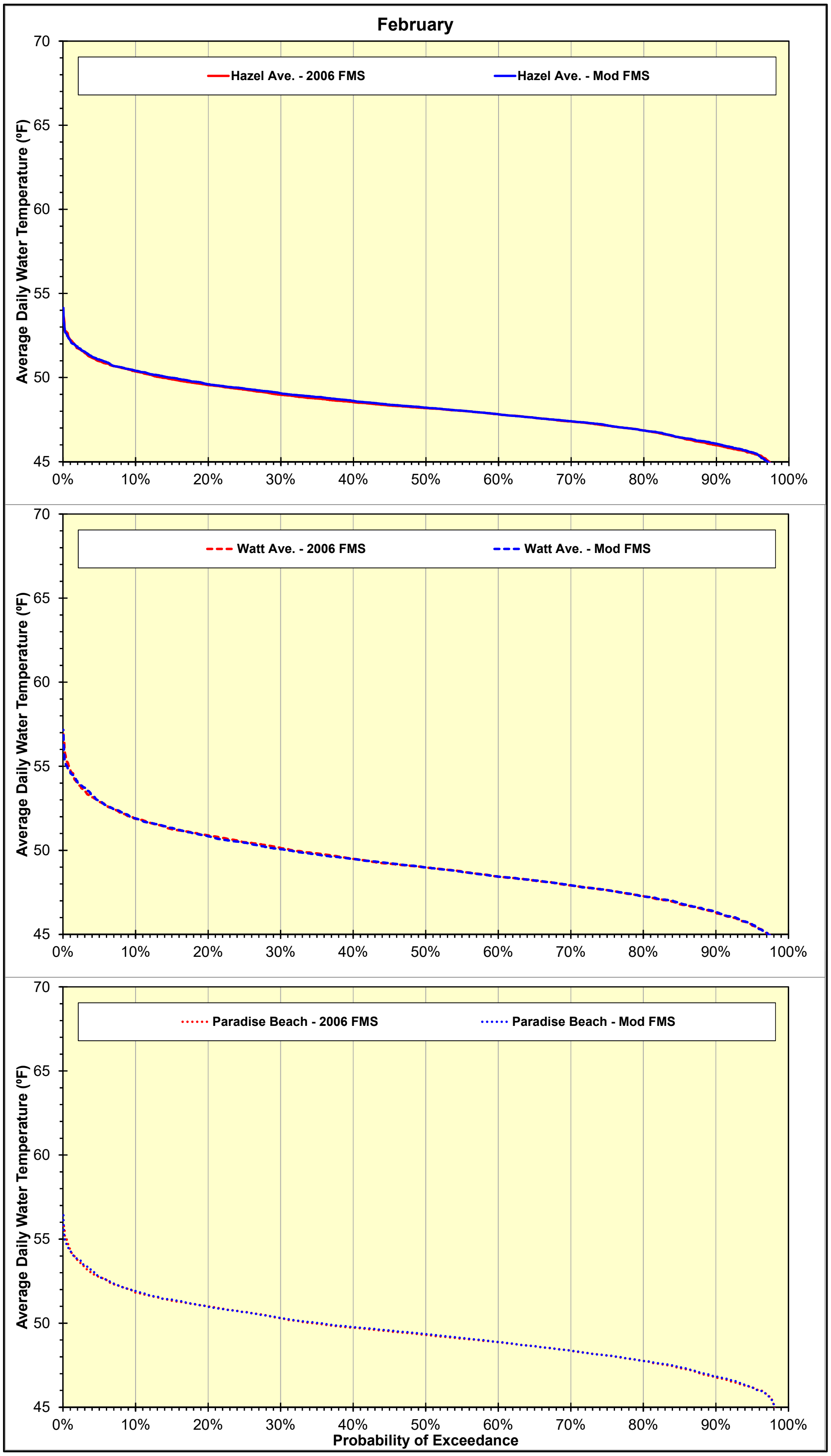

Figure D-5. Daily water temperature exceedance distributions during February at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

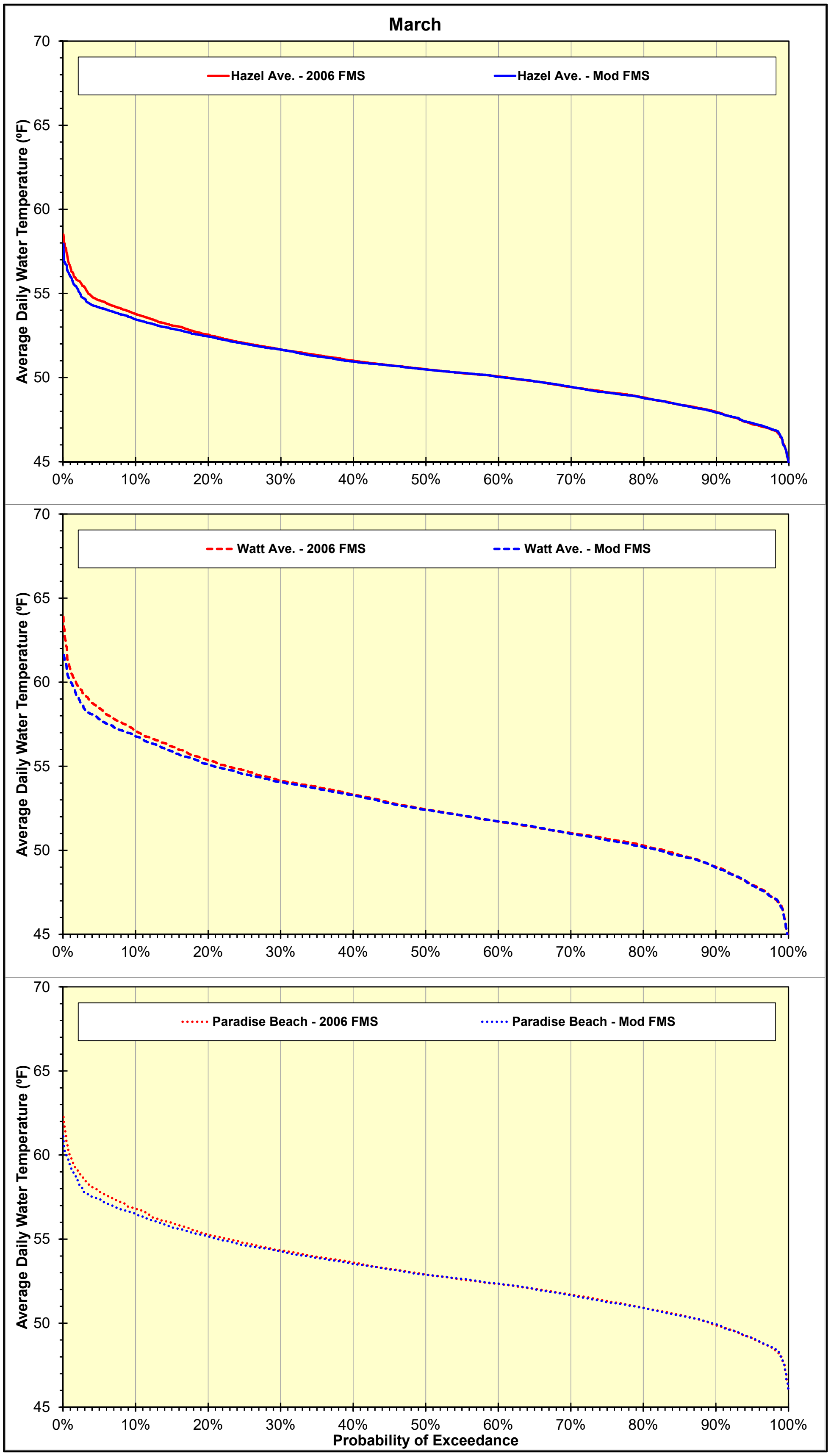

Figure D-6. Daily water temperature exceedance distributions during March at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

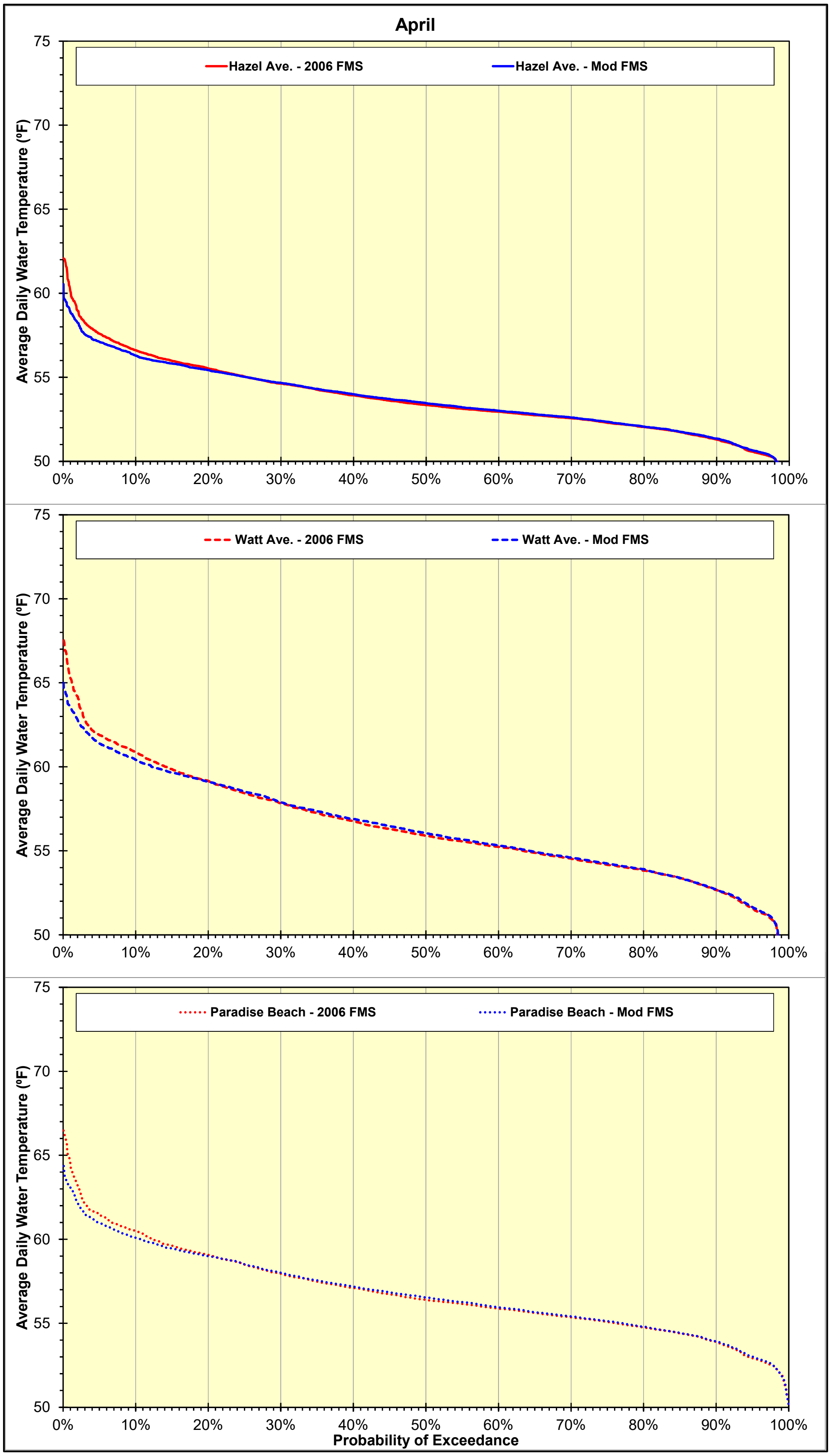

Figure D-7. Daily water temperature exceedance distributions during April at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

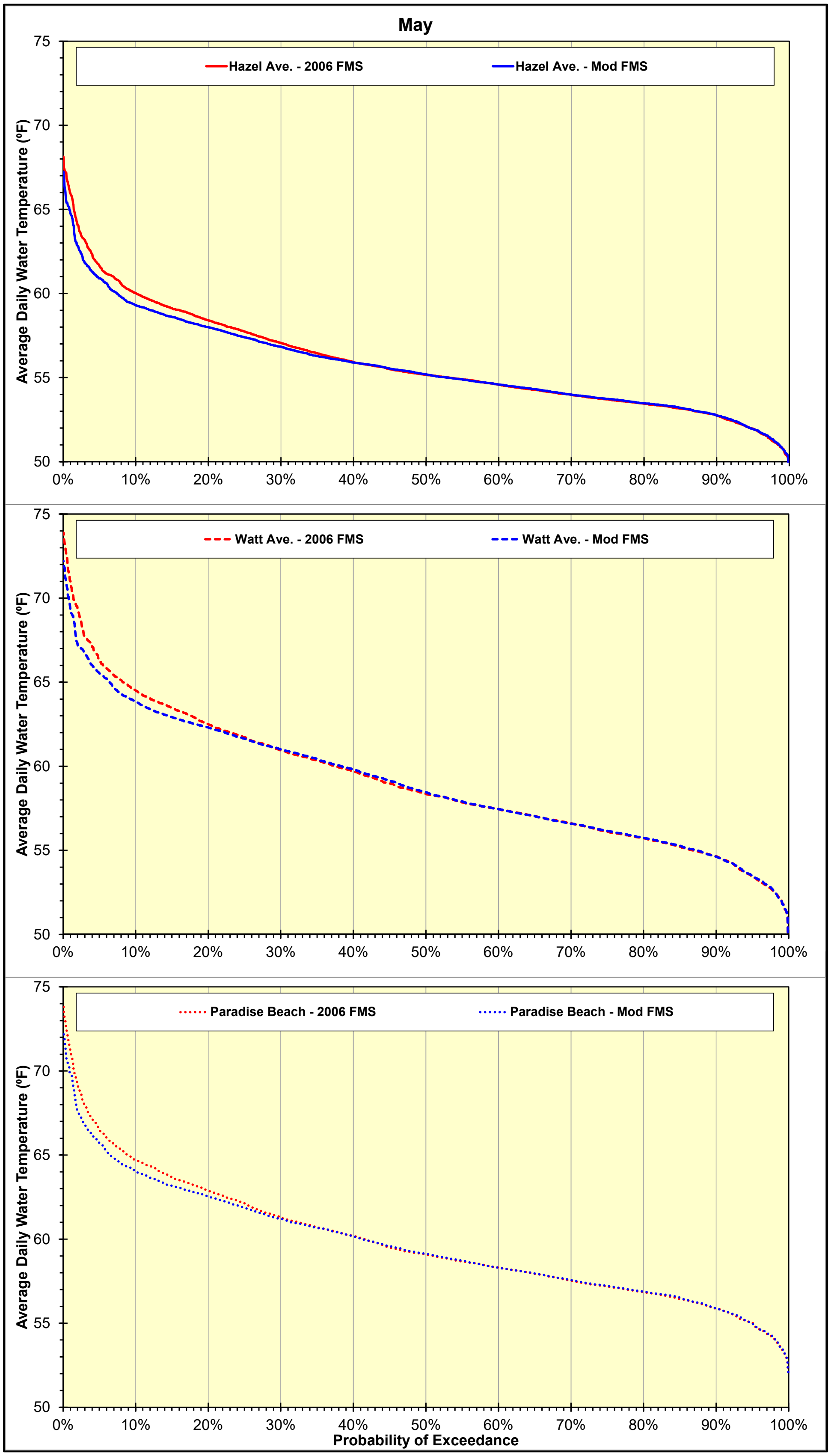

Figure D-8. Daily water temperature exceedance distributions during May at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

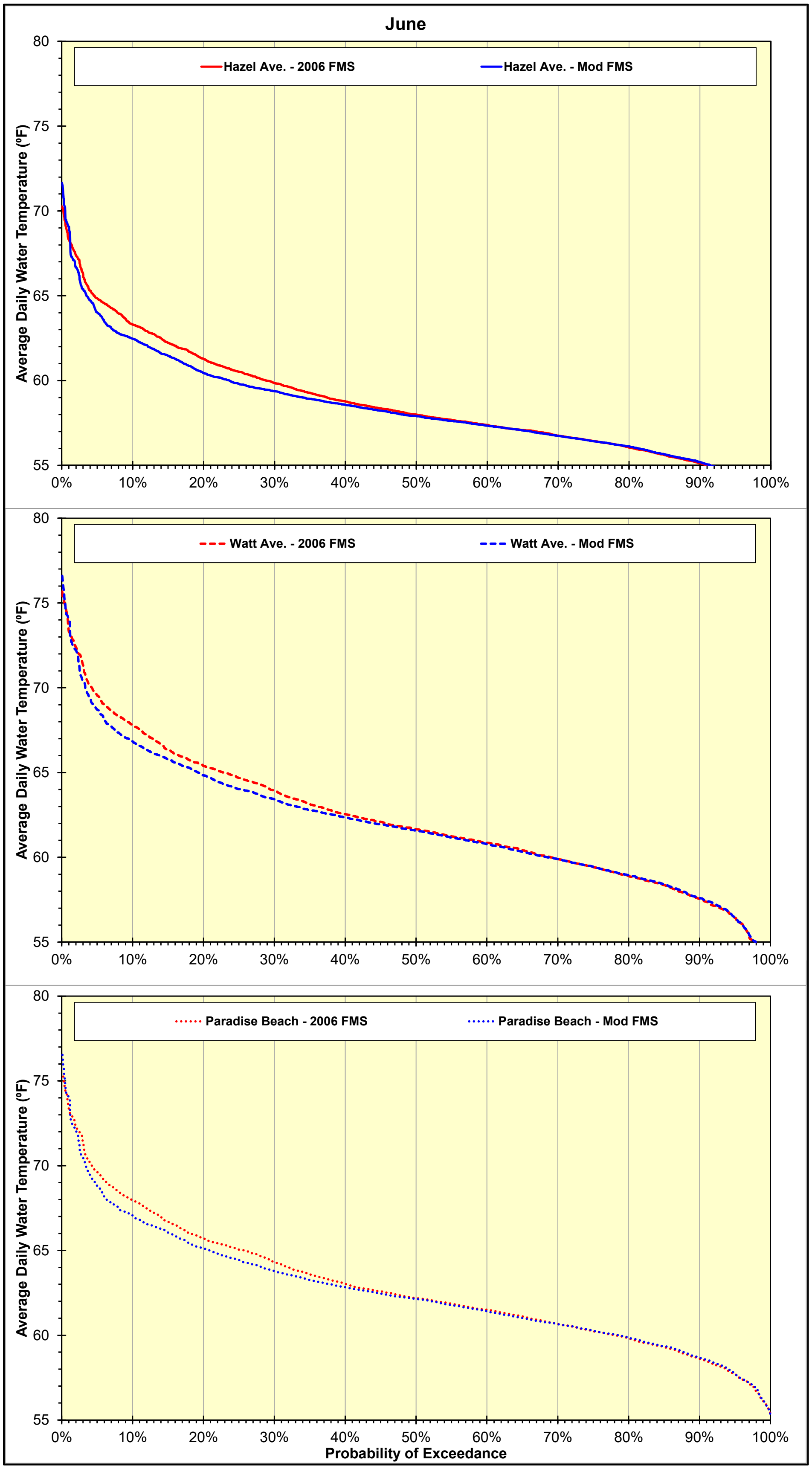

Figure D-9. Daily water temperature exceedance distributions during June at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

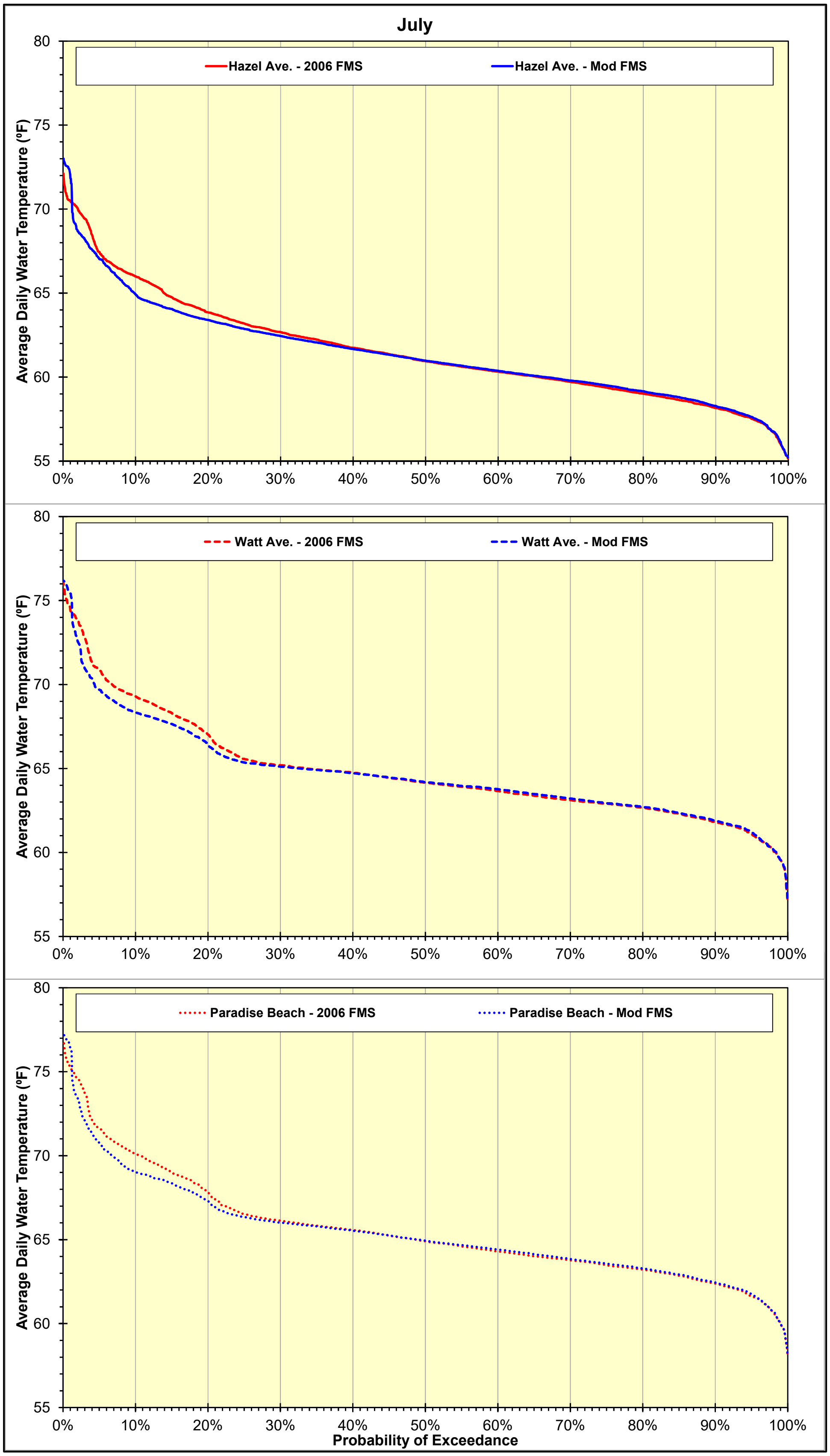

Figure D-10. Daily water temperature exceedance distributions during July at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

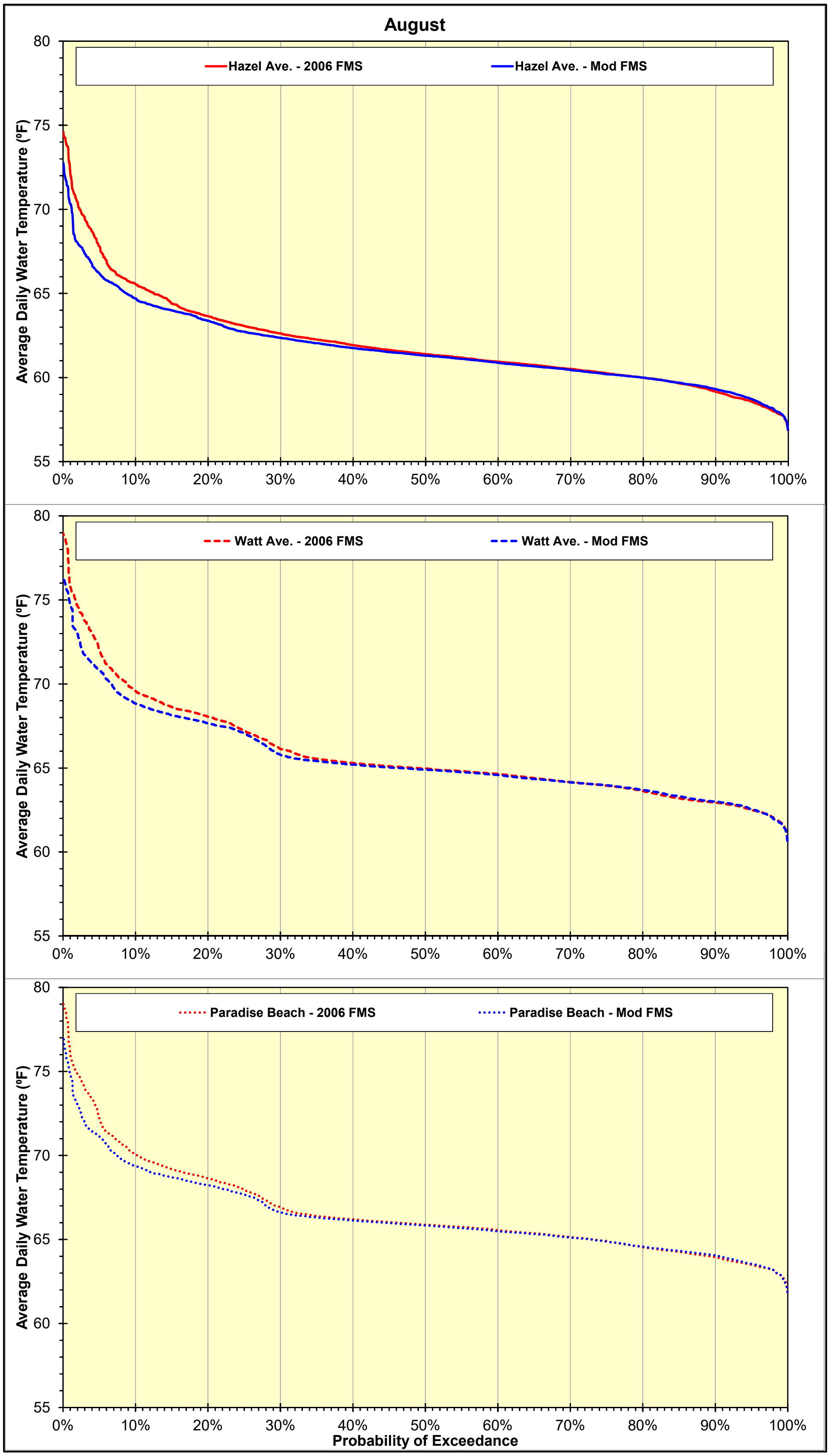

Figure D-11. Daily water temperature exceedance distributions during August at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

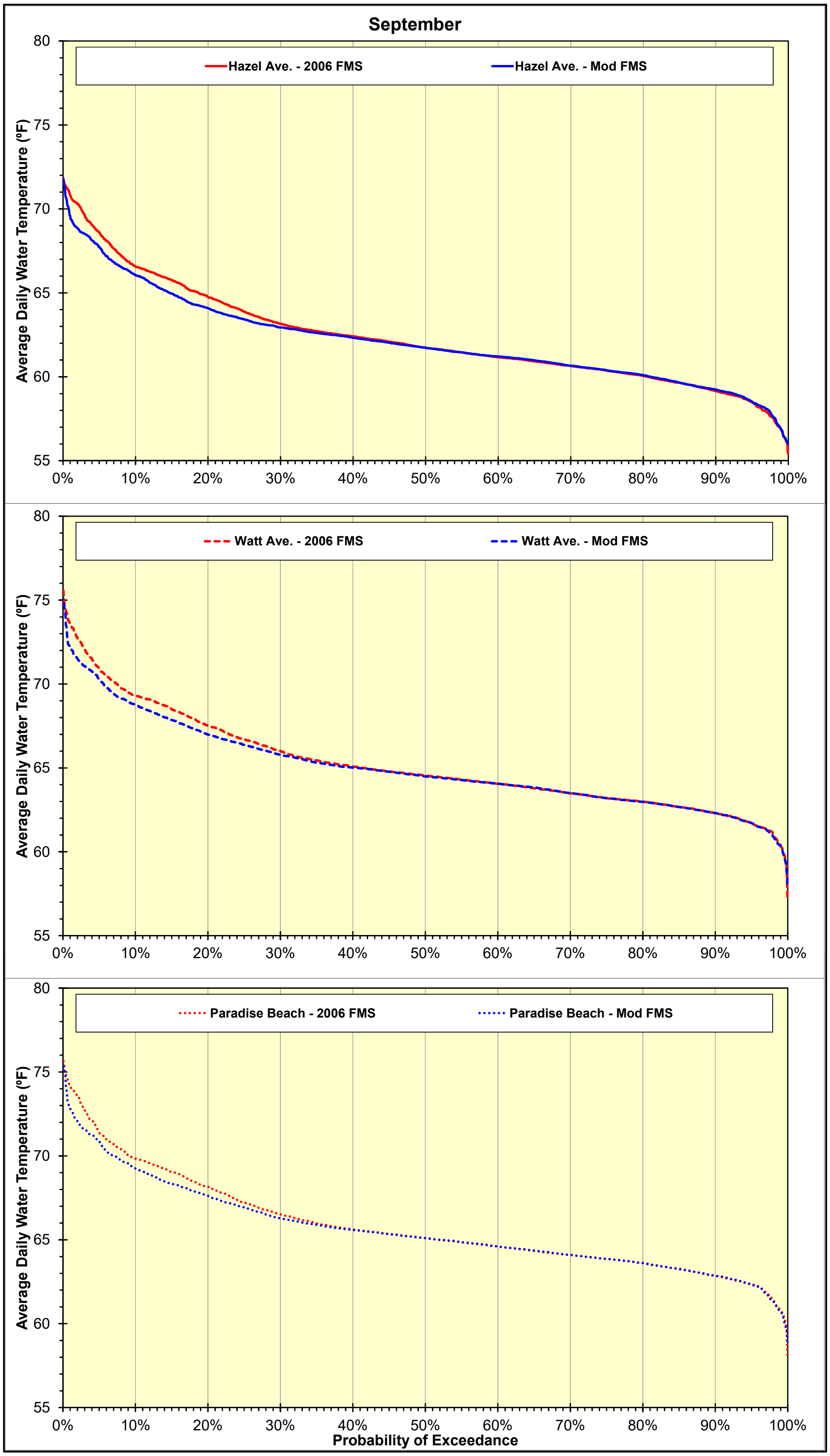

Figure D-12. Daily water temperature exceedance distributions during September at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

Lower American River 7DADM Water Temperature Exceedances

Fall-run Chinook Salmon

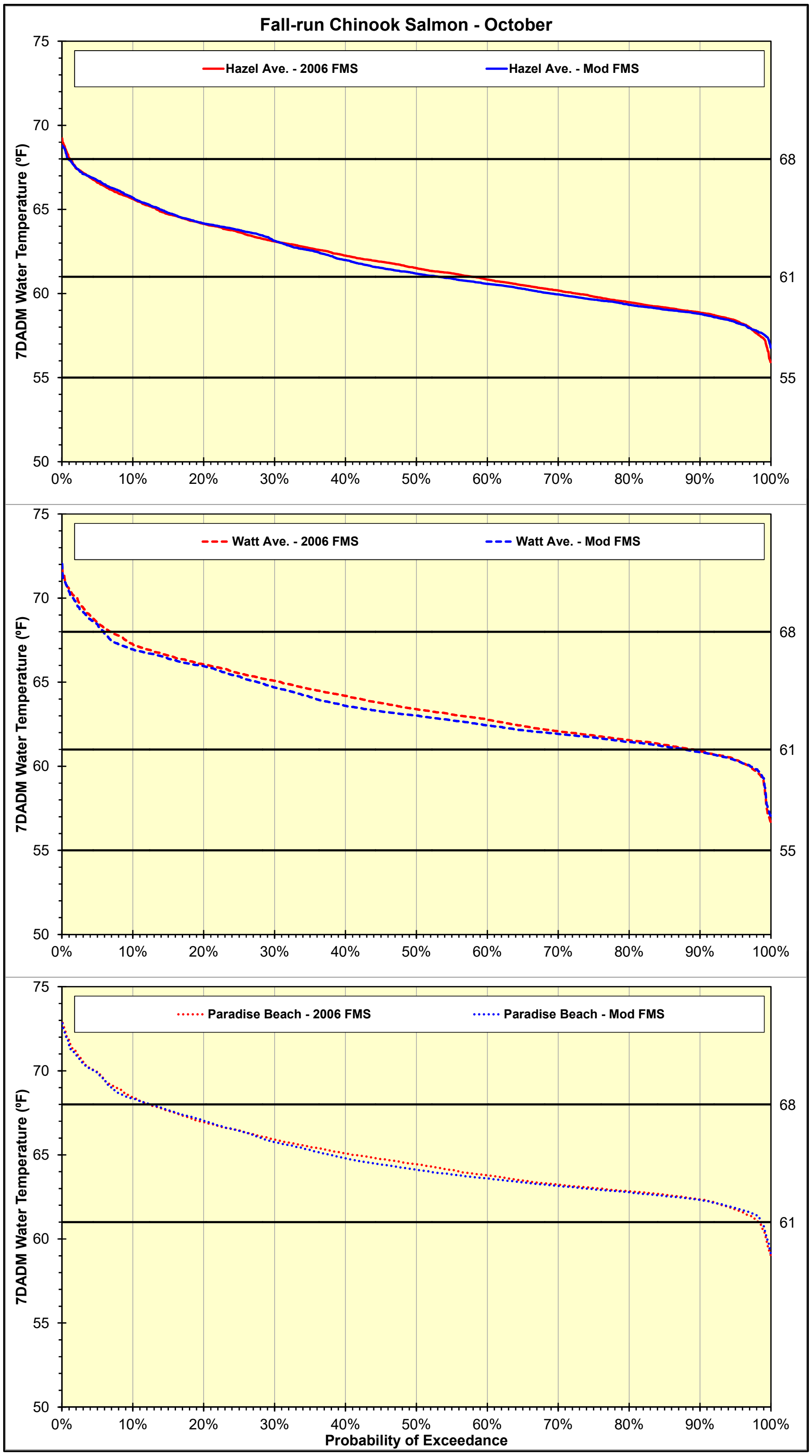

Figure D-13. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for fall-run Chinook salmon, during October at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

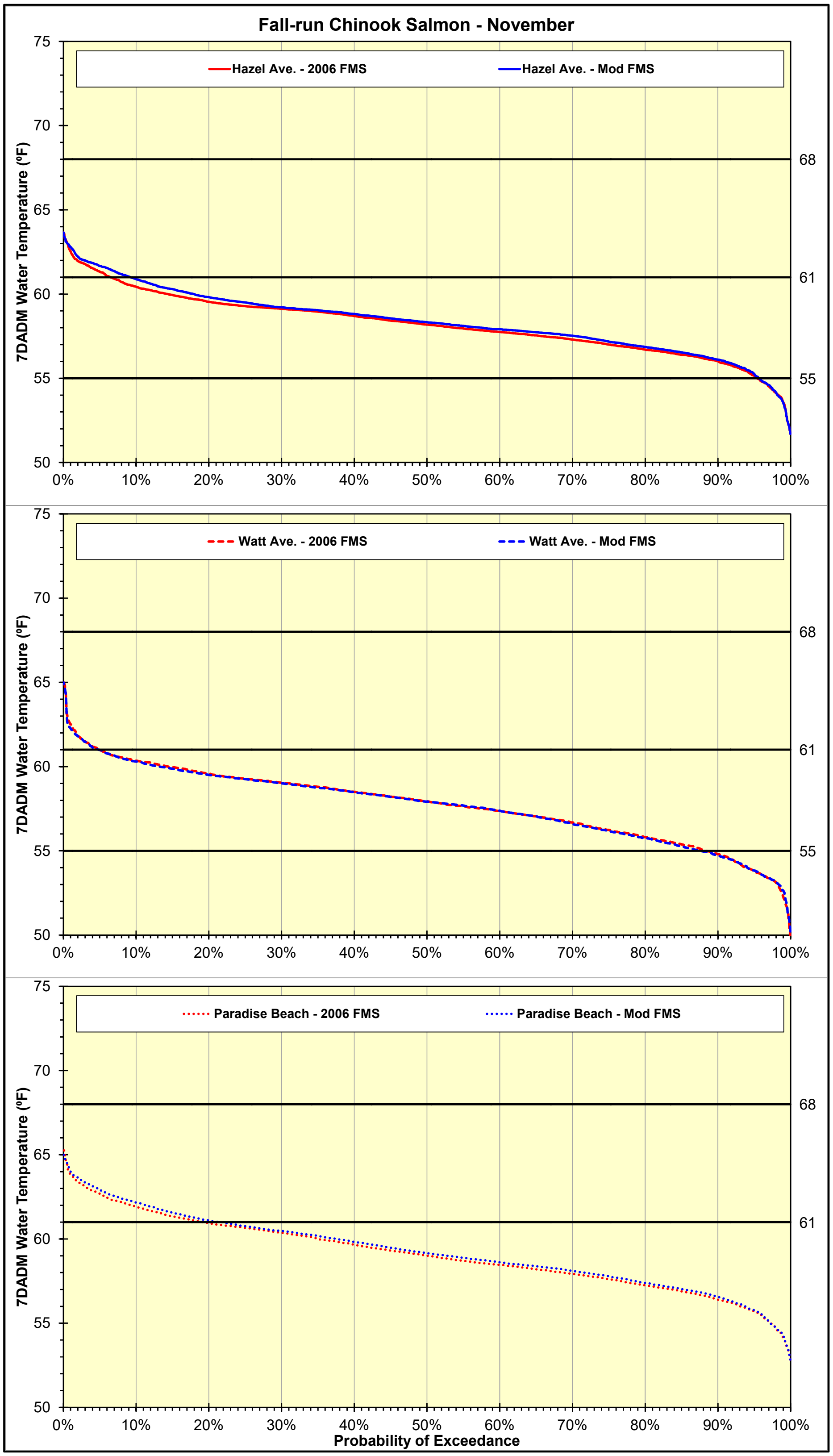

Figure D-14. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for fall-run Chinook salmon, during November at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

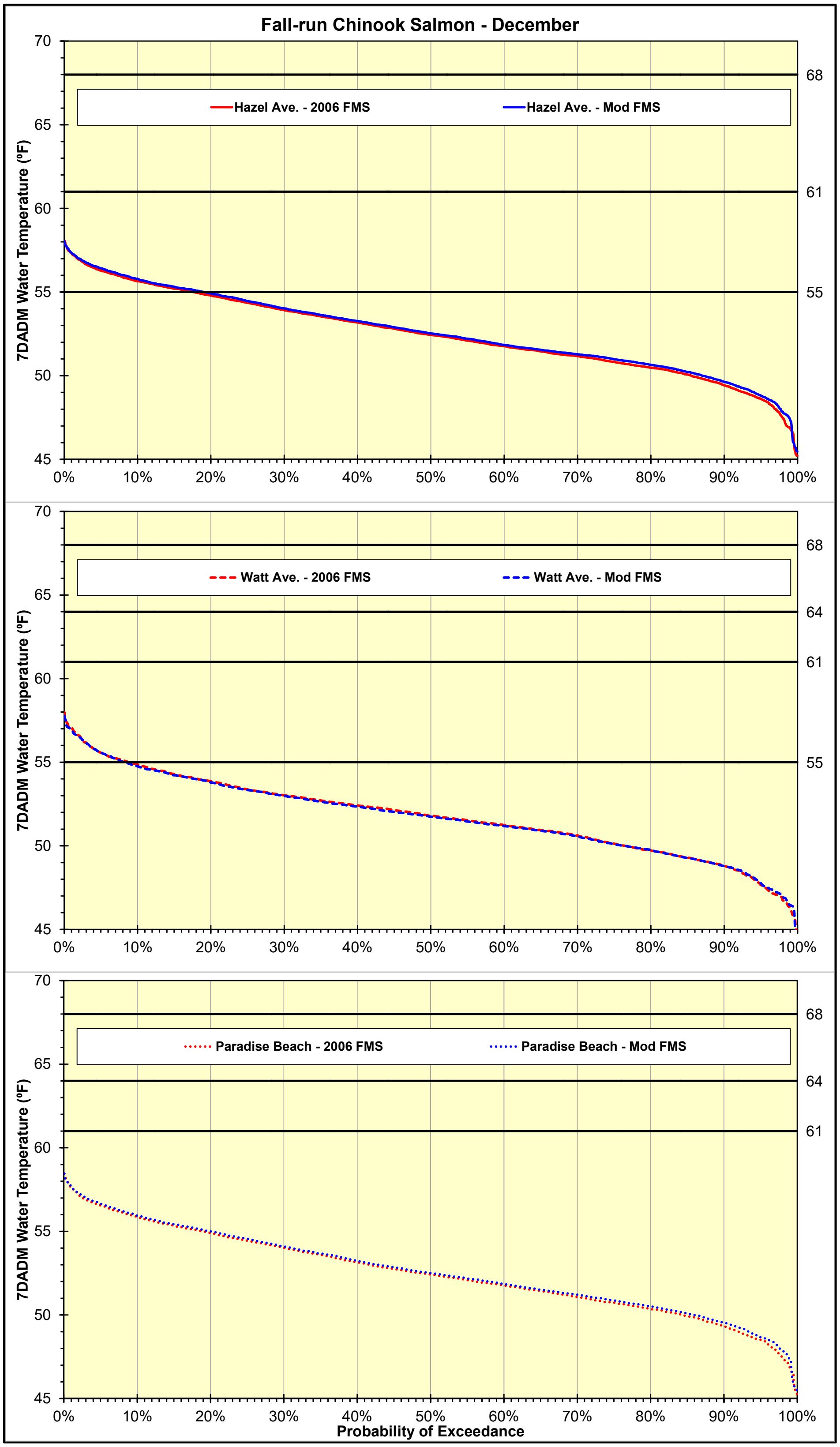

Figure D-15. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for fall-run Chinook salmon, during December at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

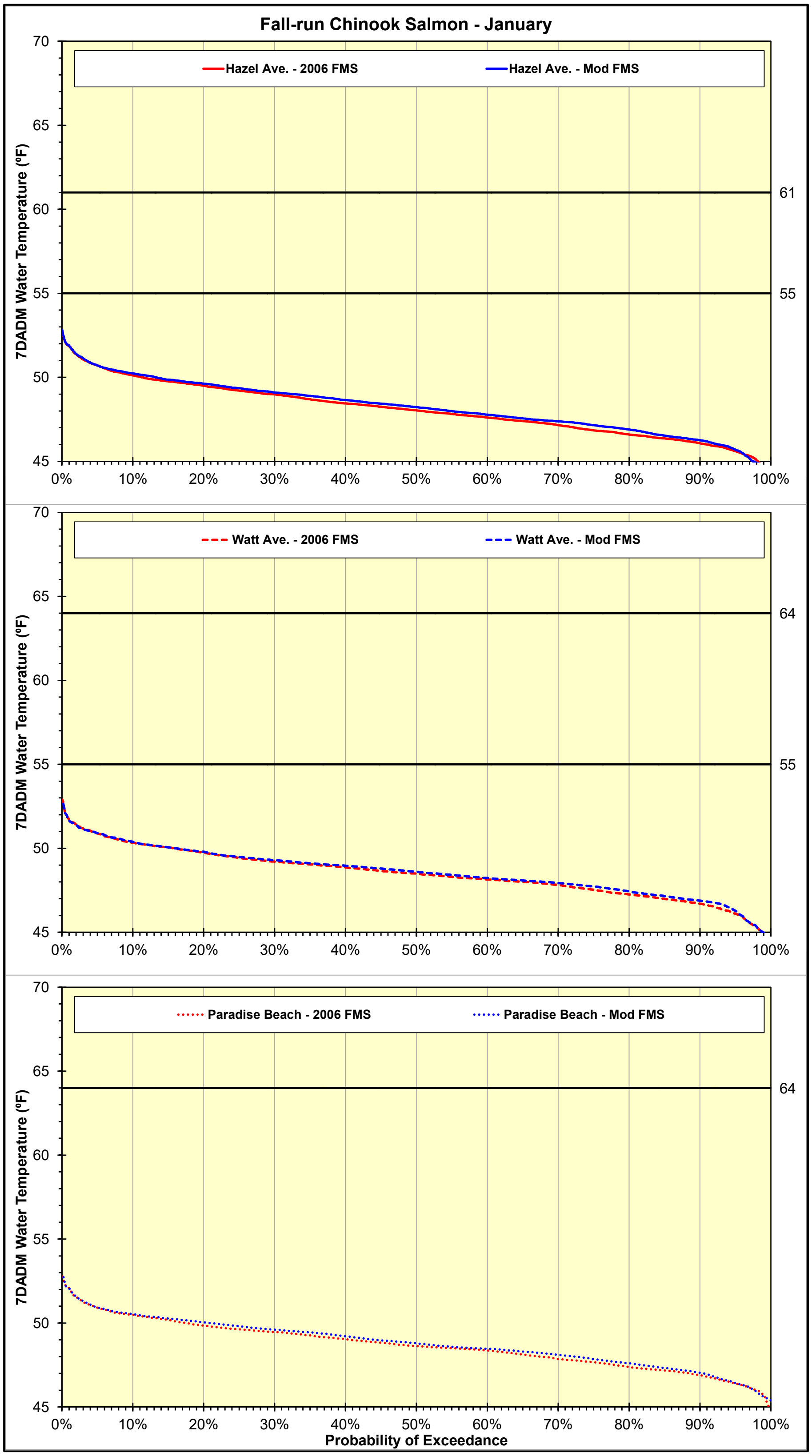

Figure D-16. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for fall-run Chinook salmon, during January at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

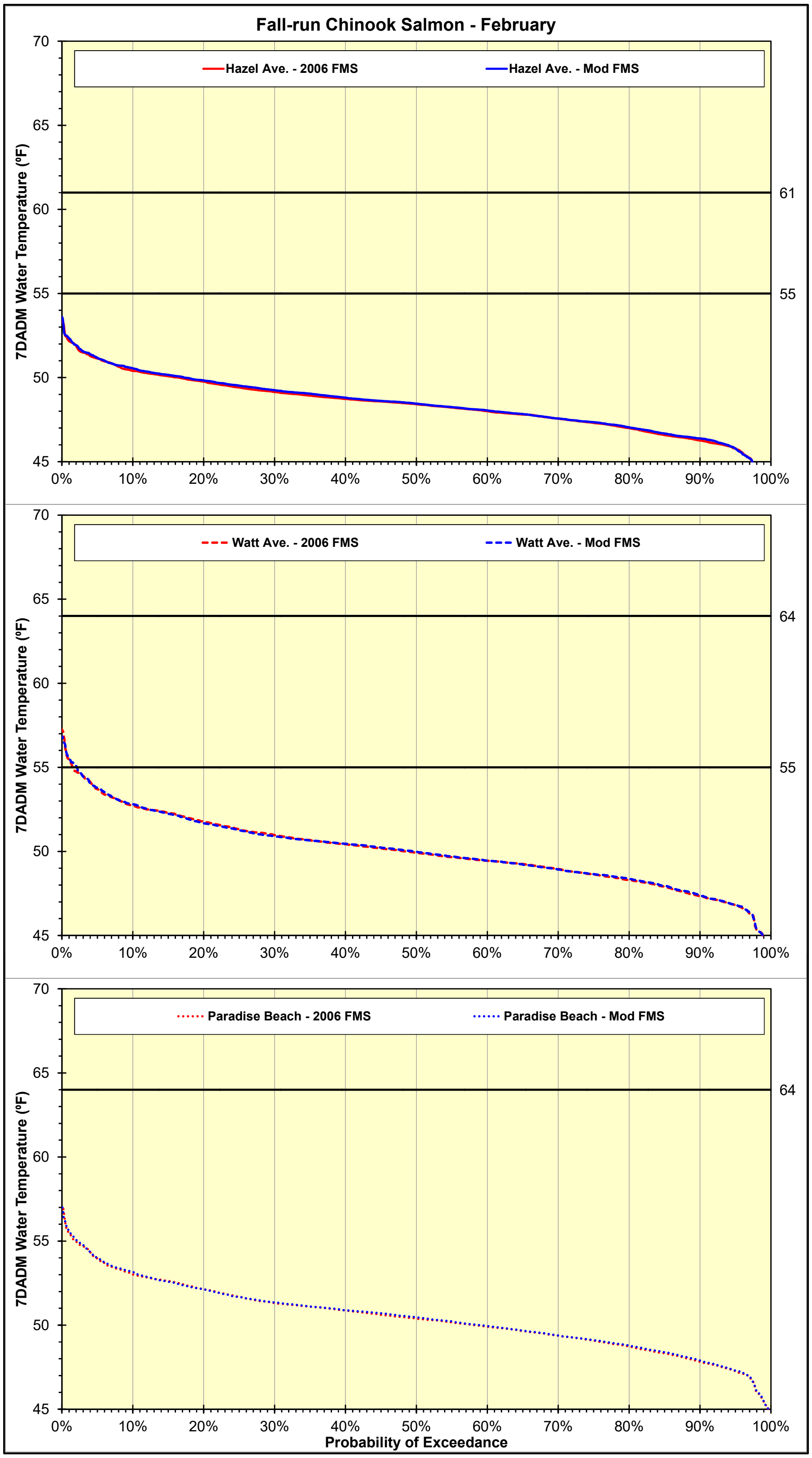

Figure D-17. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for fall-run Chinook salmon, during February at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

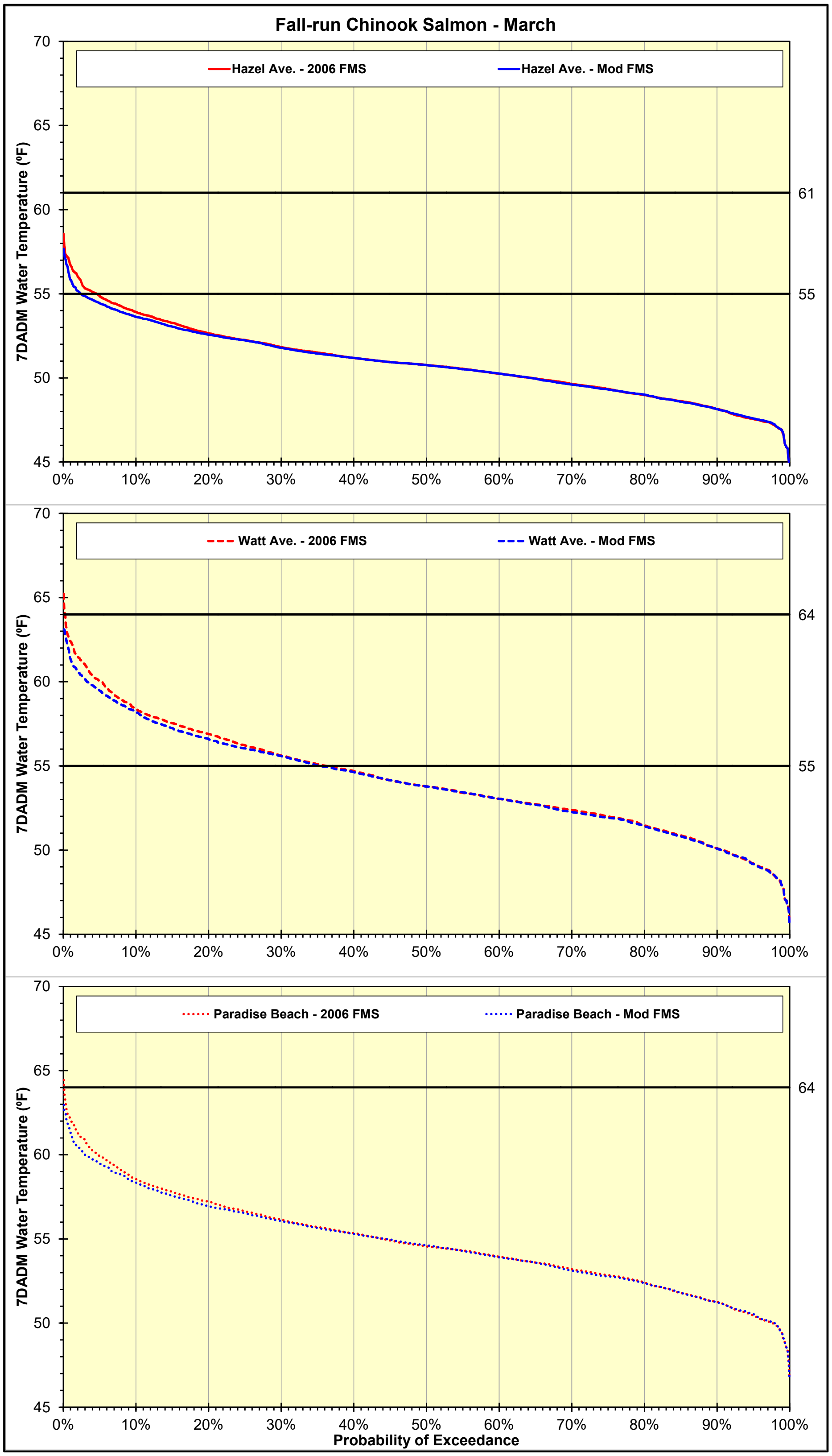

Figure D-18. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for fall-run Chinook salmon, during March at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

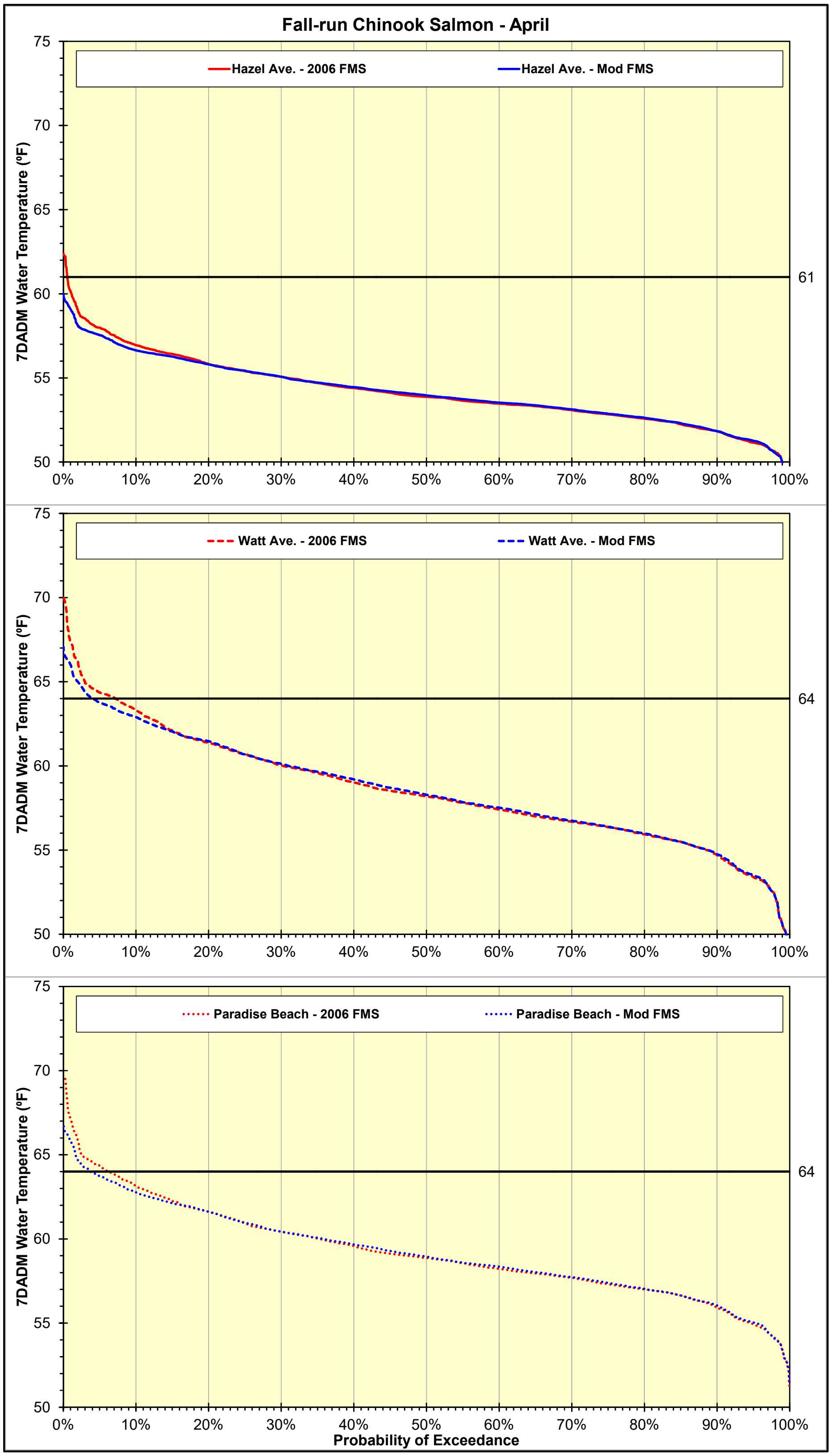

Figure D-19. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for fall-run Chinook salmon, during April at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

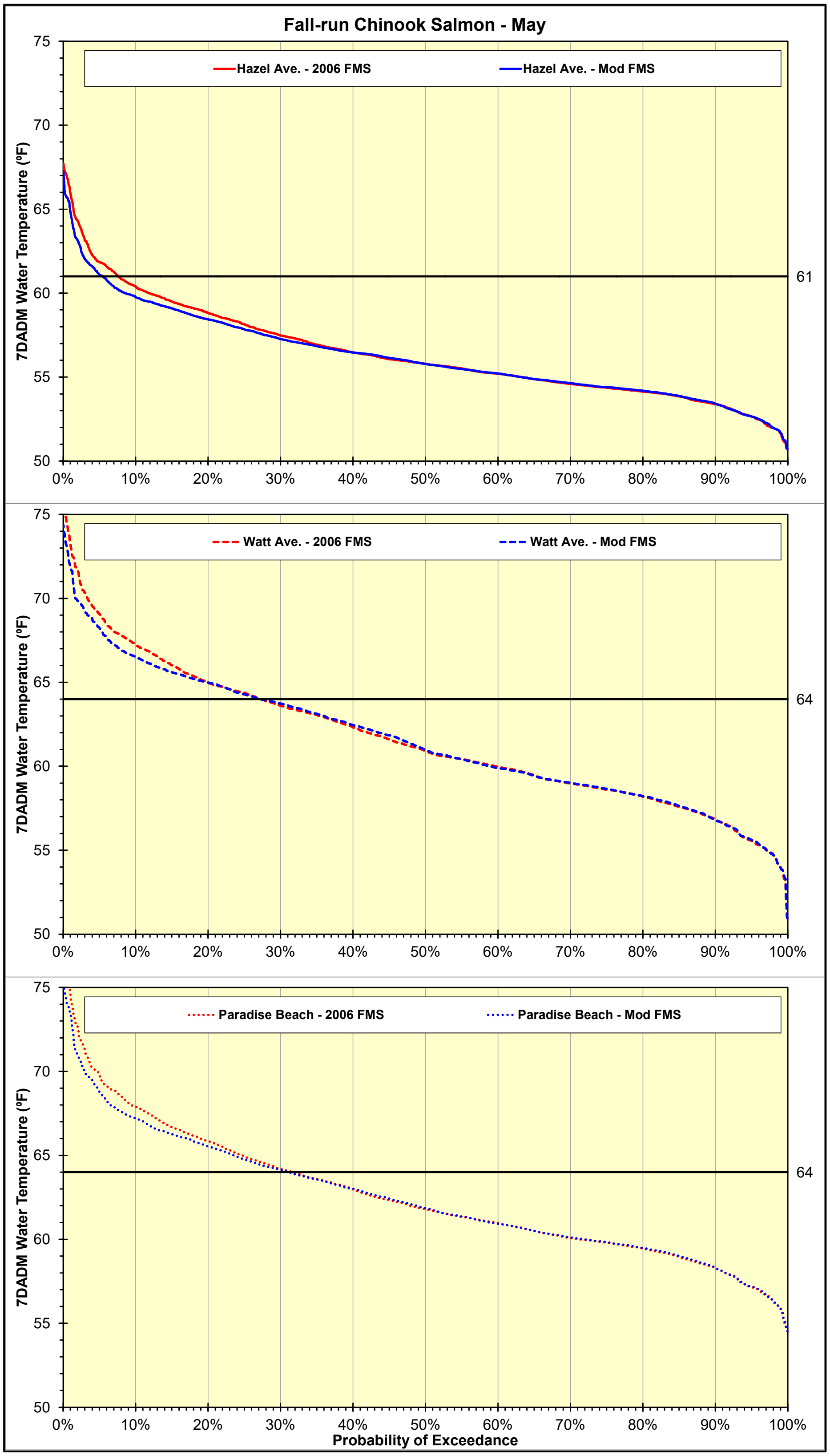

Figure D-20. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for fall-run Chinook salmon, during May at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

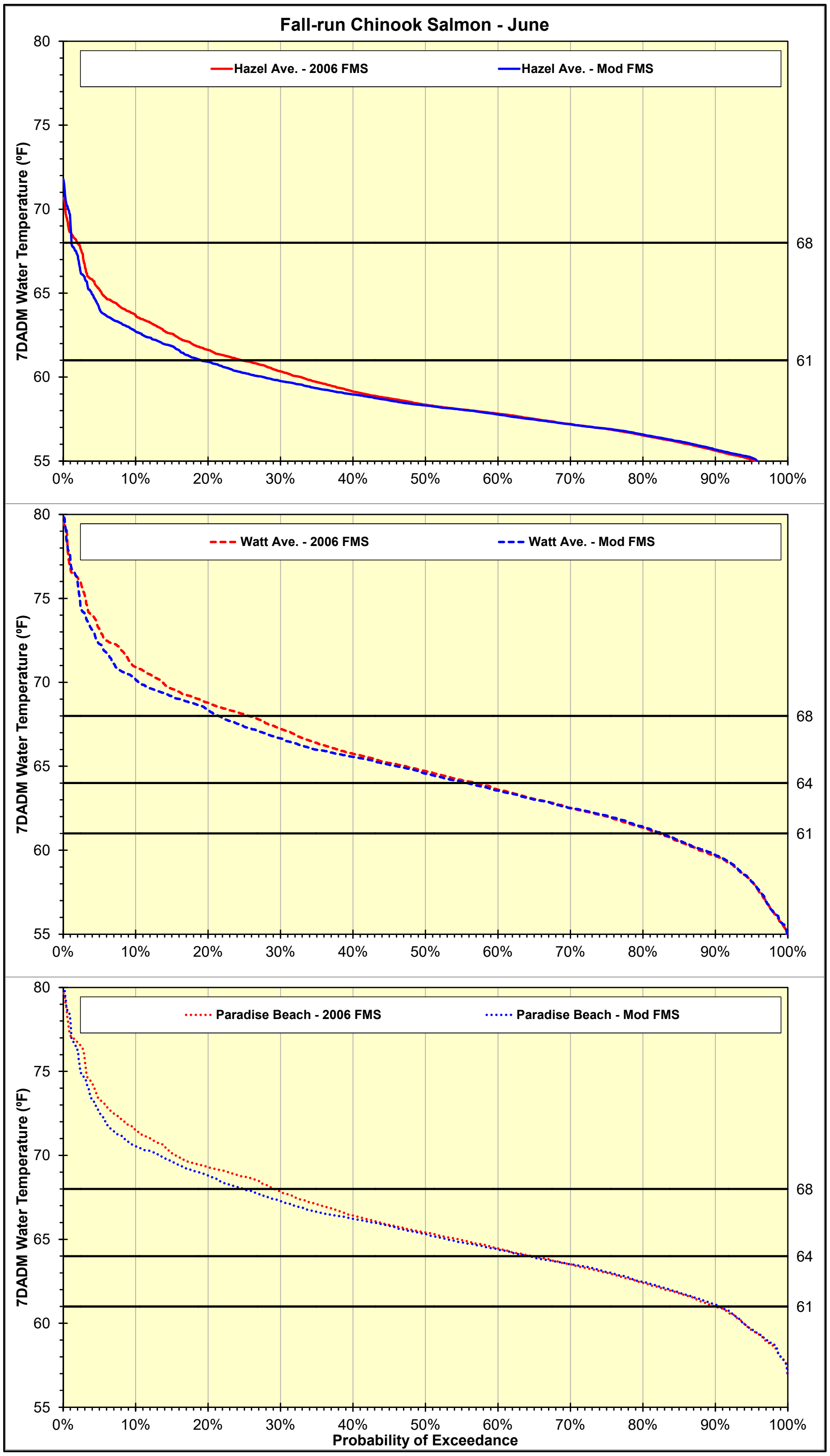

Figure D-21. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for fall-run Chinook salmon, during June at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

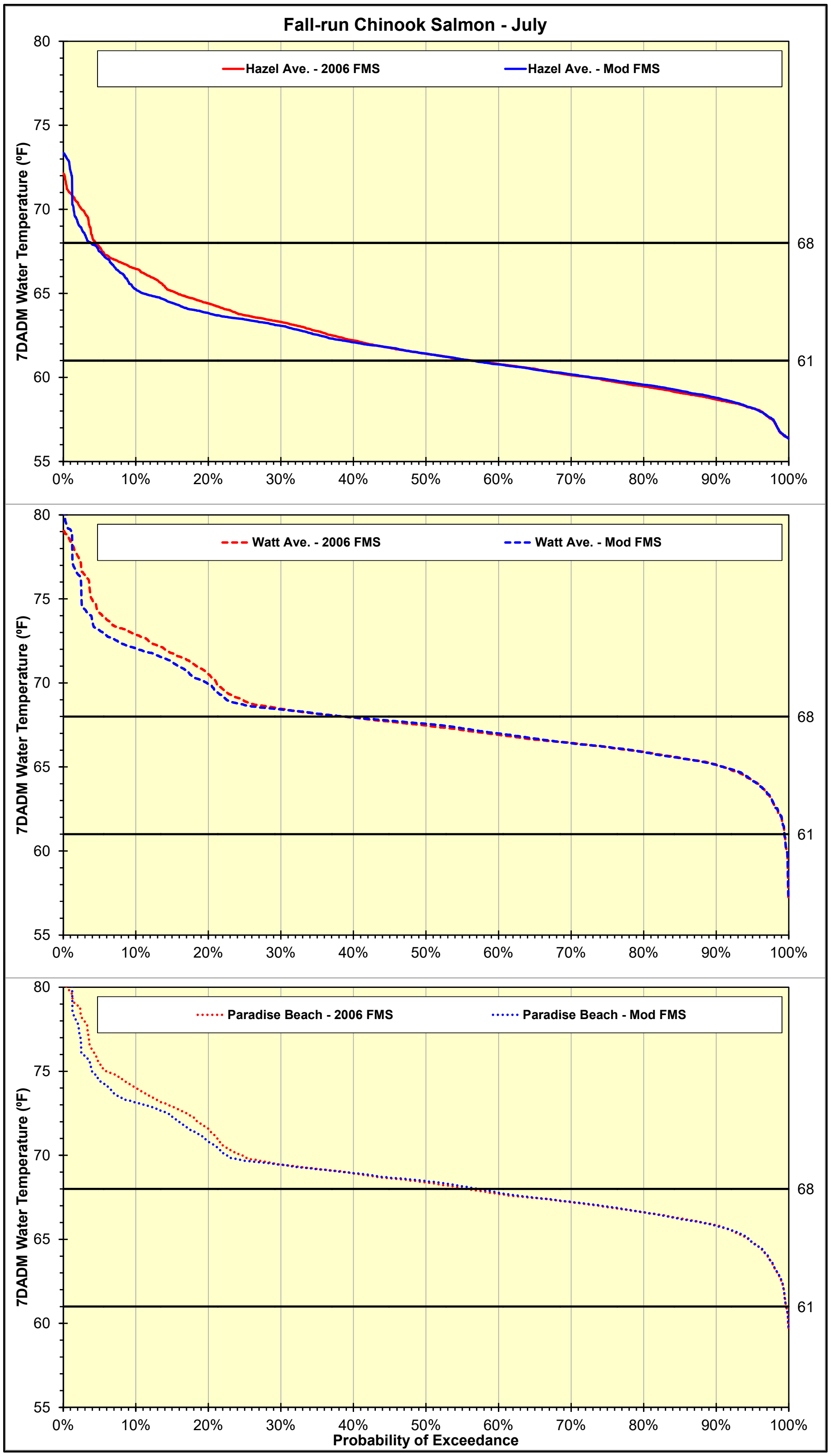

Figure D-22. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for fall-run Chinook salmon, during July at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

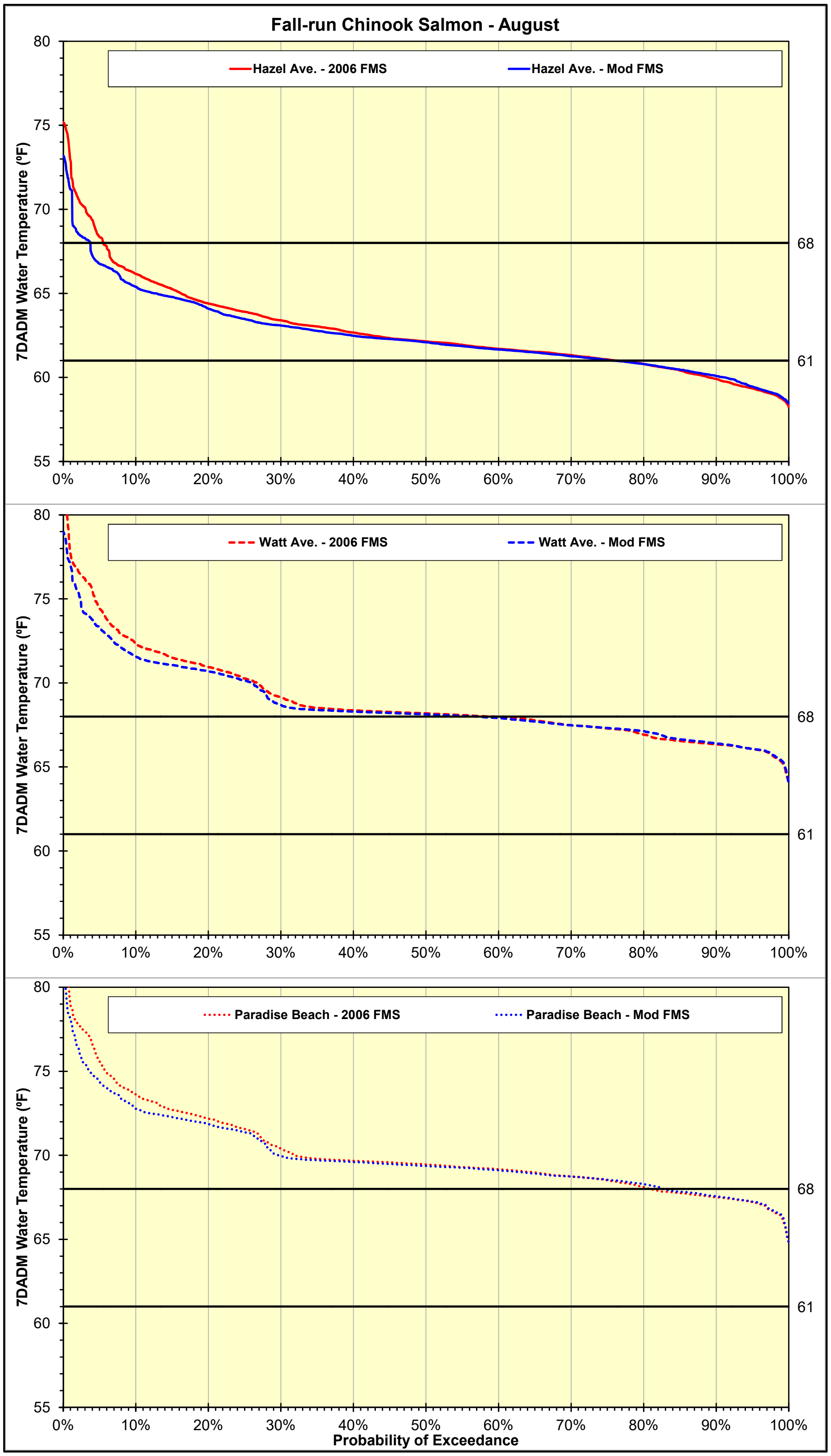

Figure D-23. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for fall-run Chinook salmon, during August at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

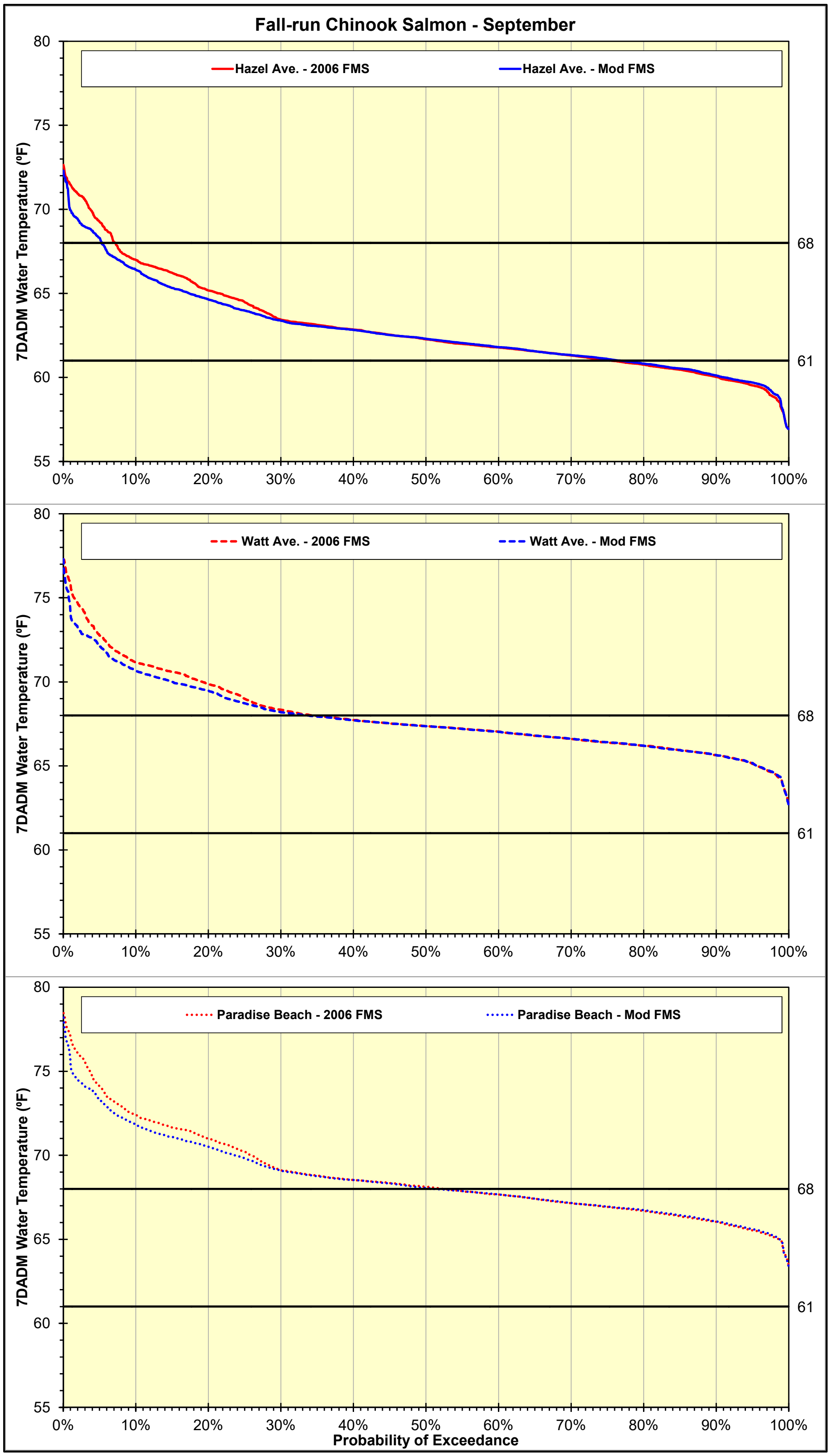

Figure D-24. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for fall-run Chinook salmon, during September at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

Lower American River Average Daily Water Temperature Exceedances

Steelhead

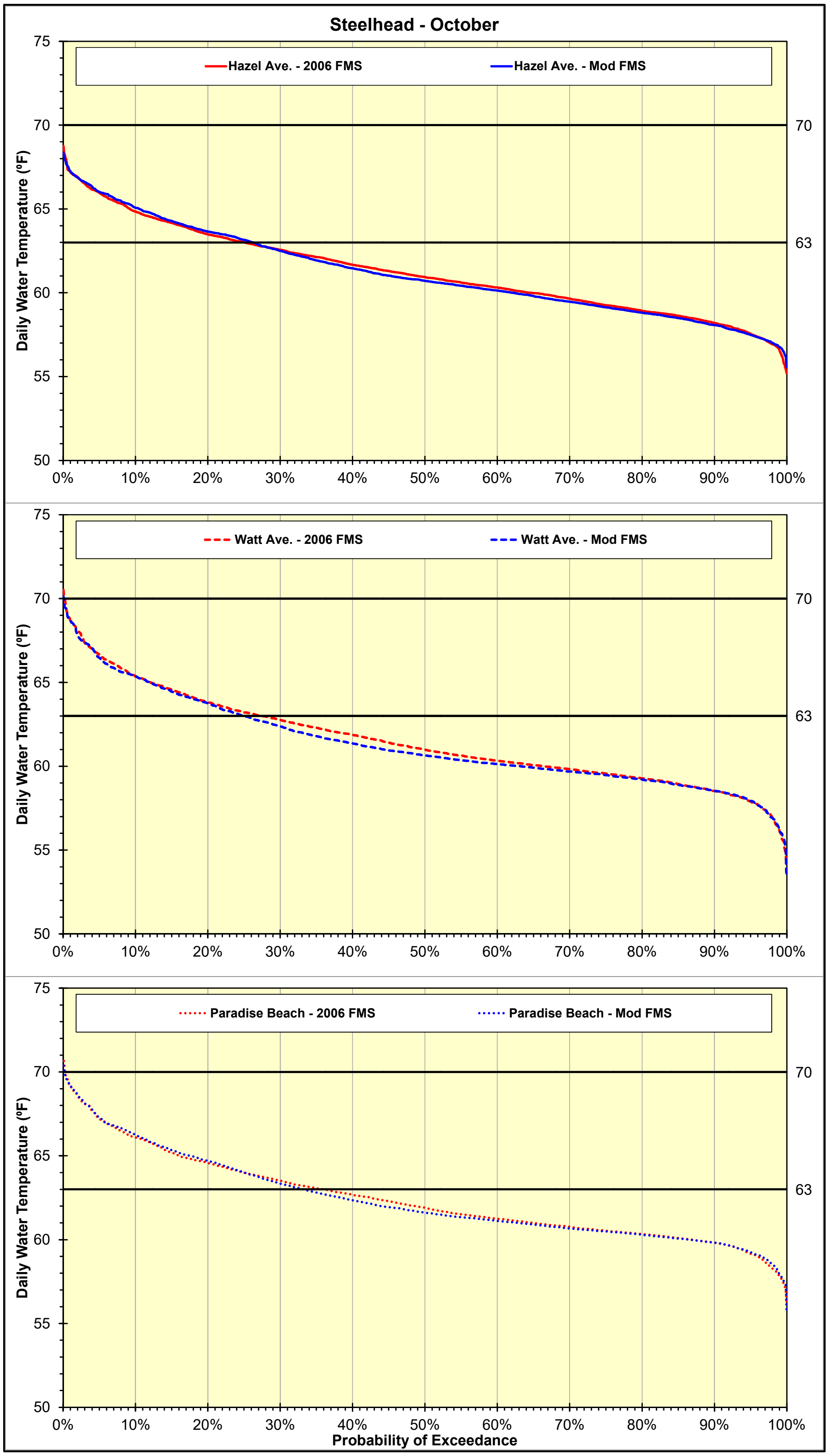

Figure D-25. Daily water temperature exceedance distributions, with the NMFS (2017) identified lifestage-specific WTI values for steelhead, during October at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

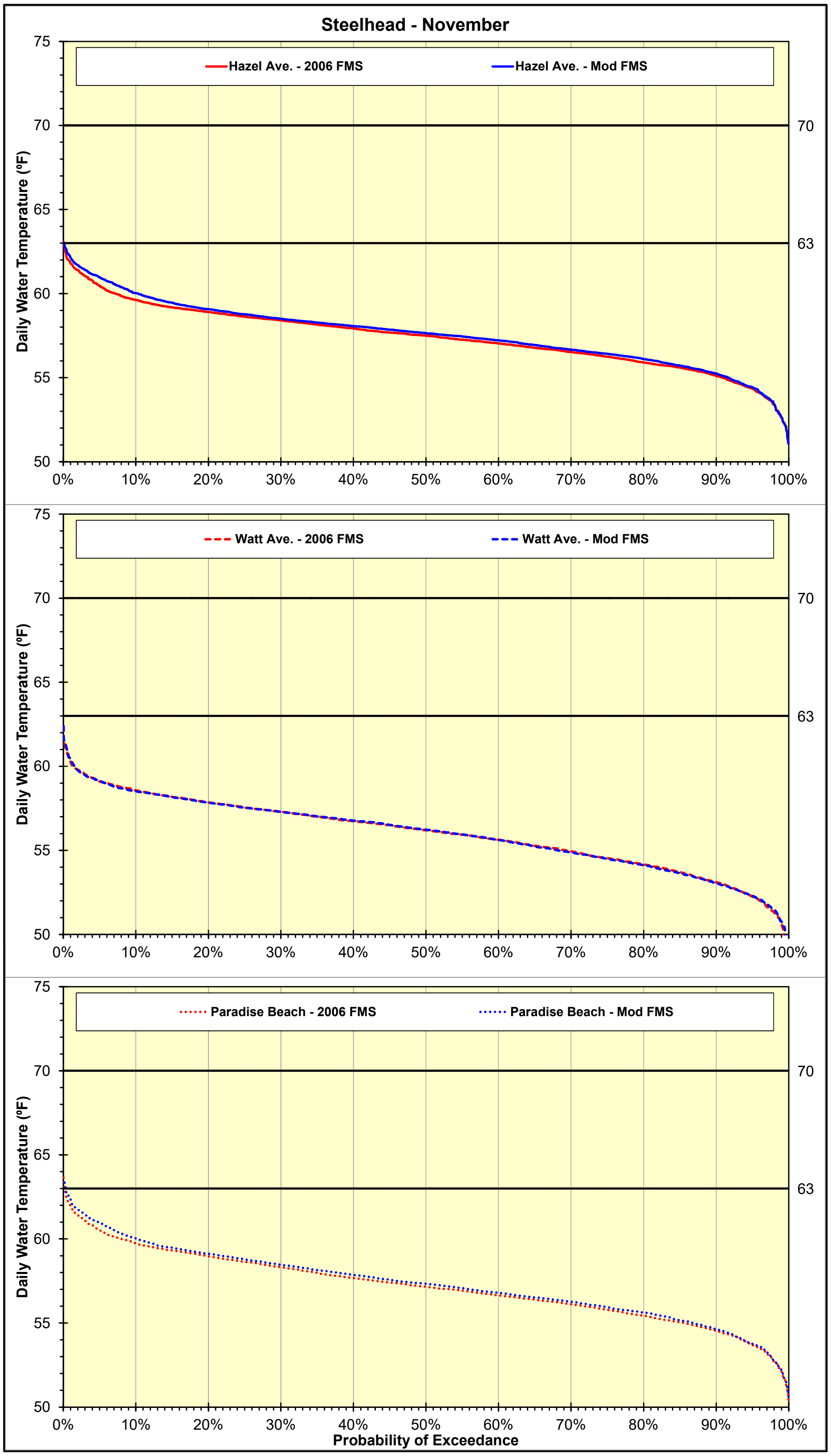

Figure D-26. Daily water temperature exceedance distributions, with the NMFS (2017) identified lifestage-specific WTI values for steelhead, during November at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

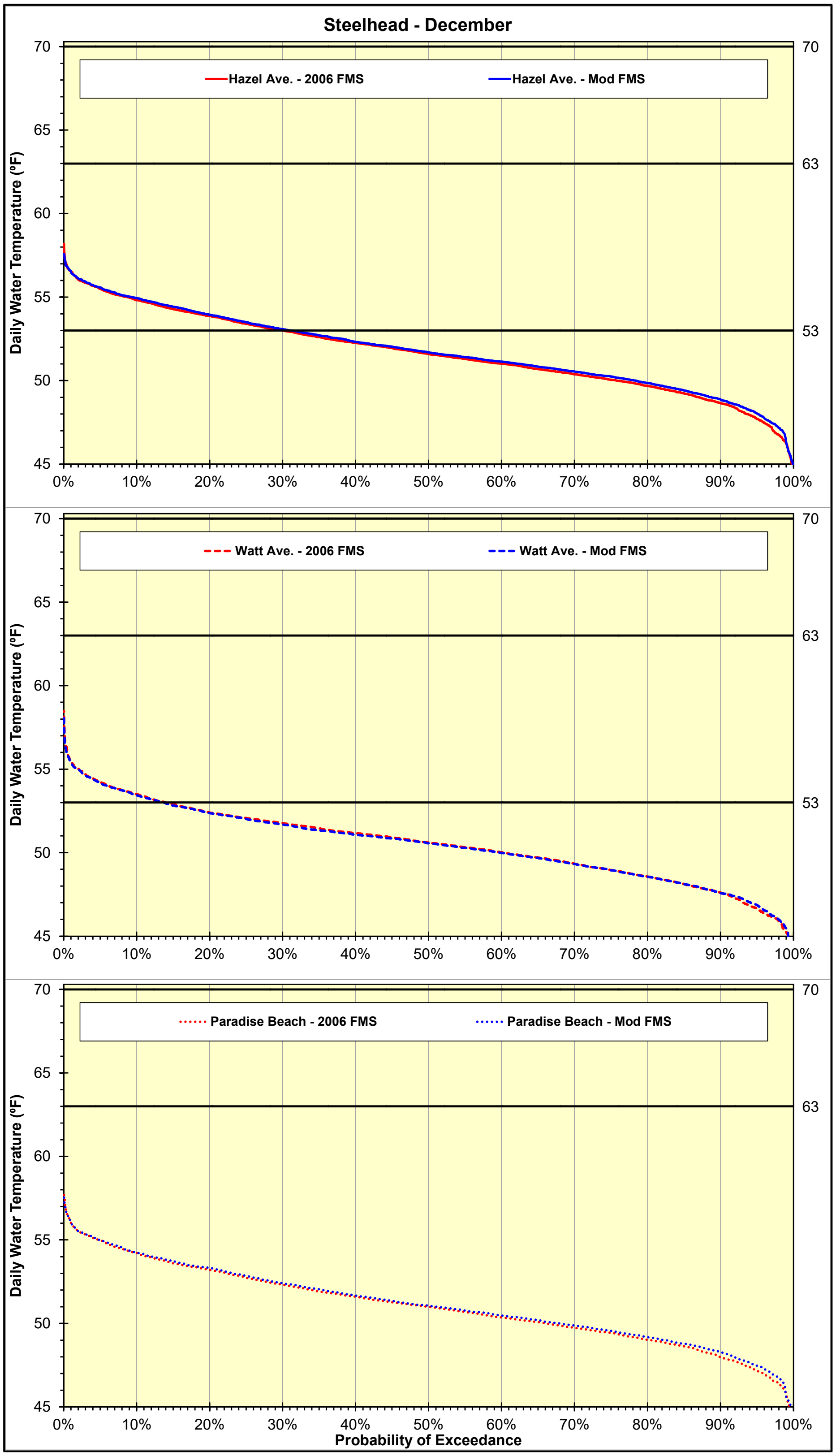

Figure D-27. Daily water temperature exceedance distributions, with the NMFS (2017) identified lifestage-specific WTI values for steelhead, during December at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

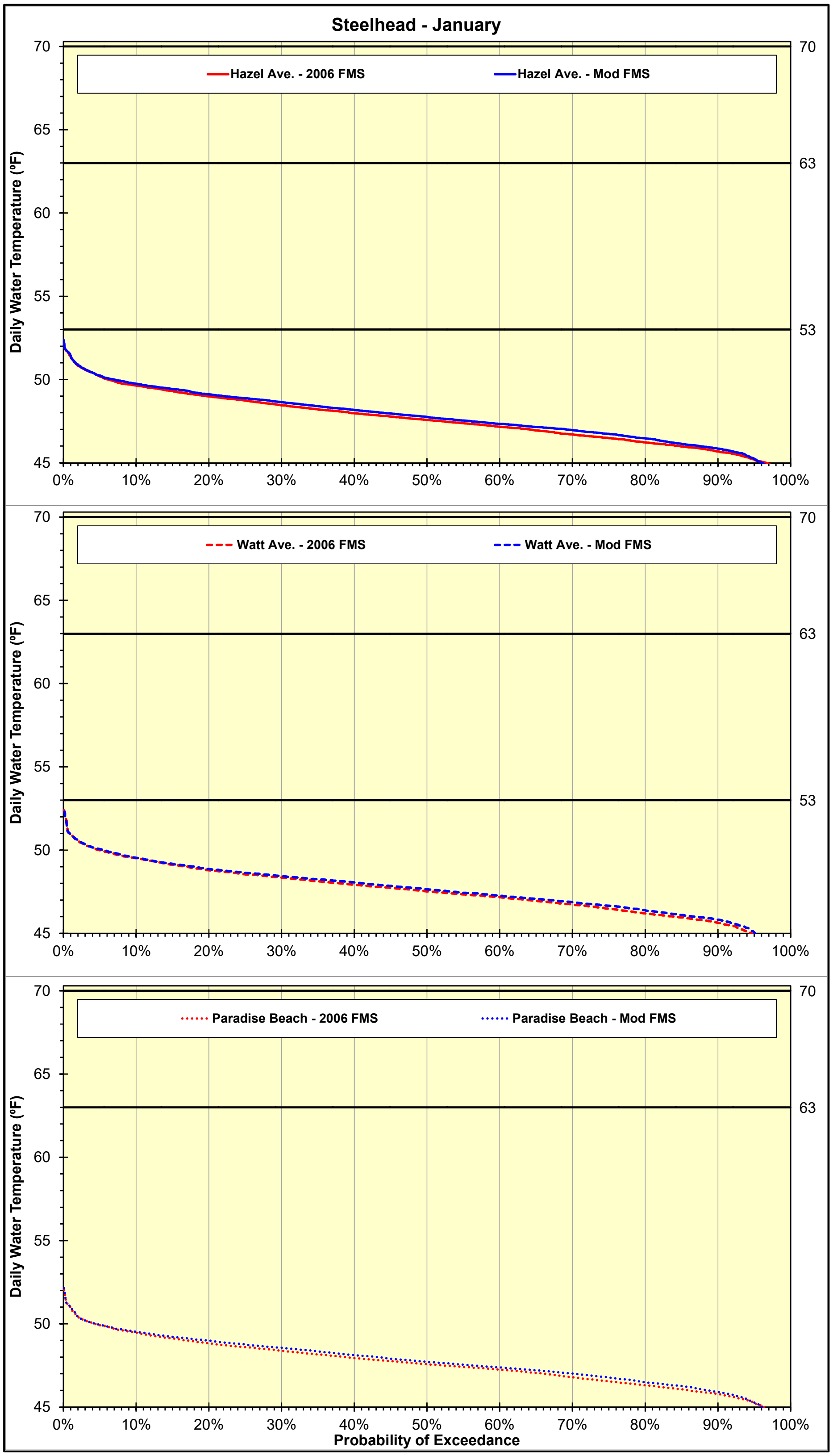

Figure D-28. Daily water temperature exceedance distributions, with the NMFS (2017) identified lifestage-specific WTI values for steelhead, during January at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

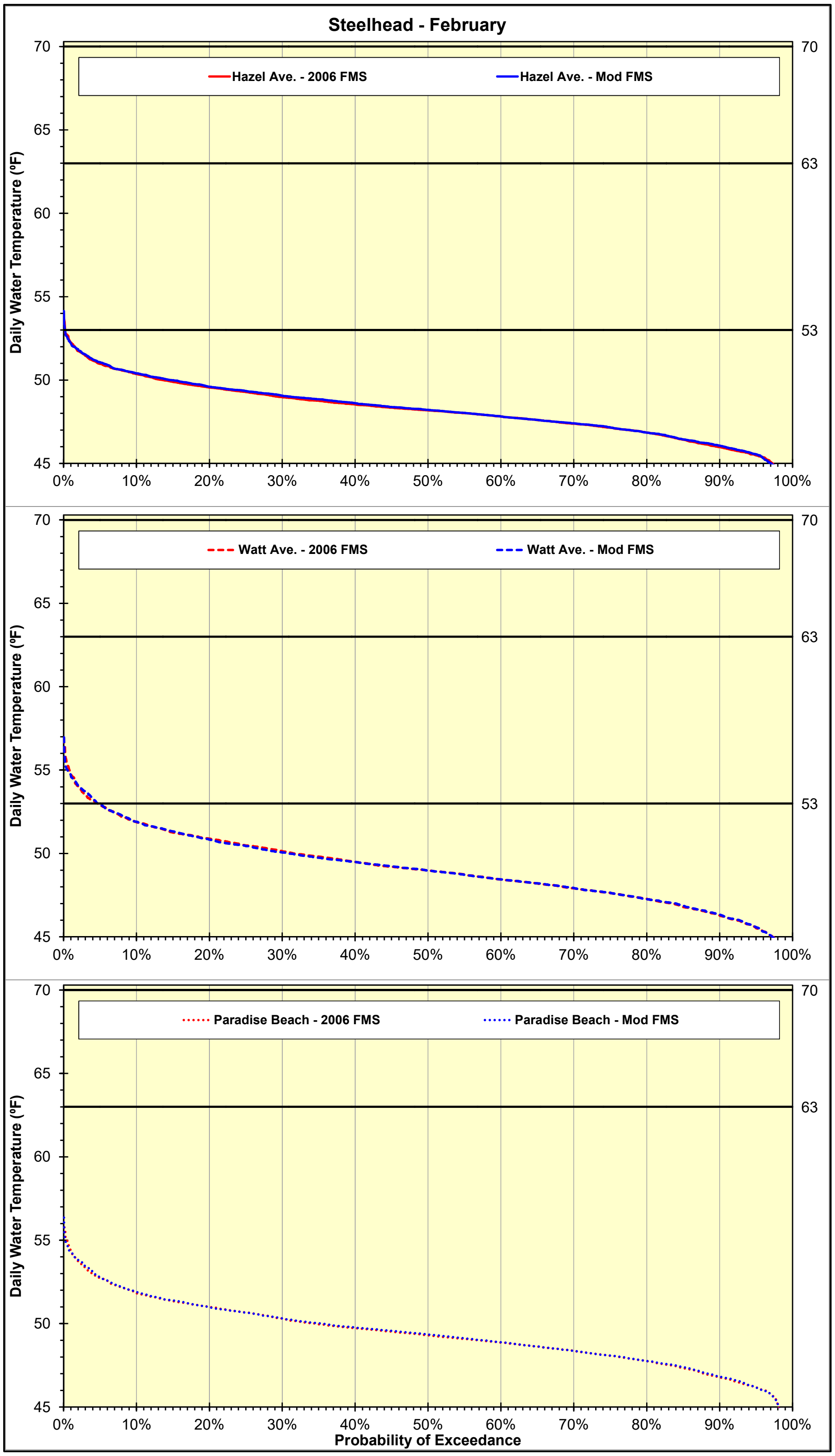

Figure D-29. Daily water temperature exceedance distributions, with the NMFS (2017) identified lifestage-specific WTI values for steelhead, during February at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

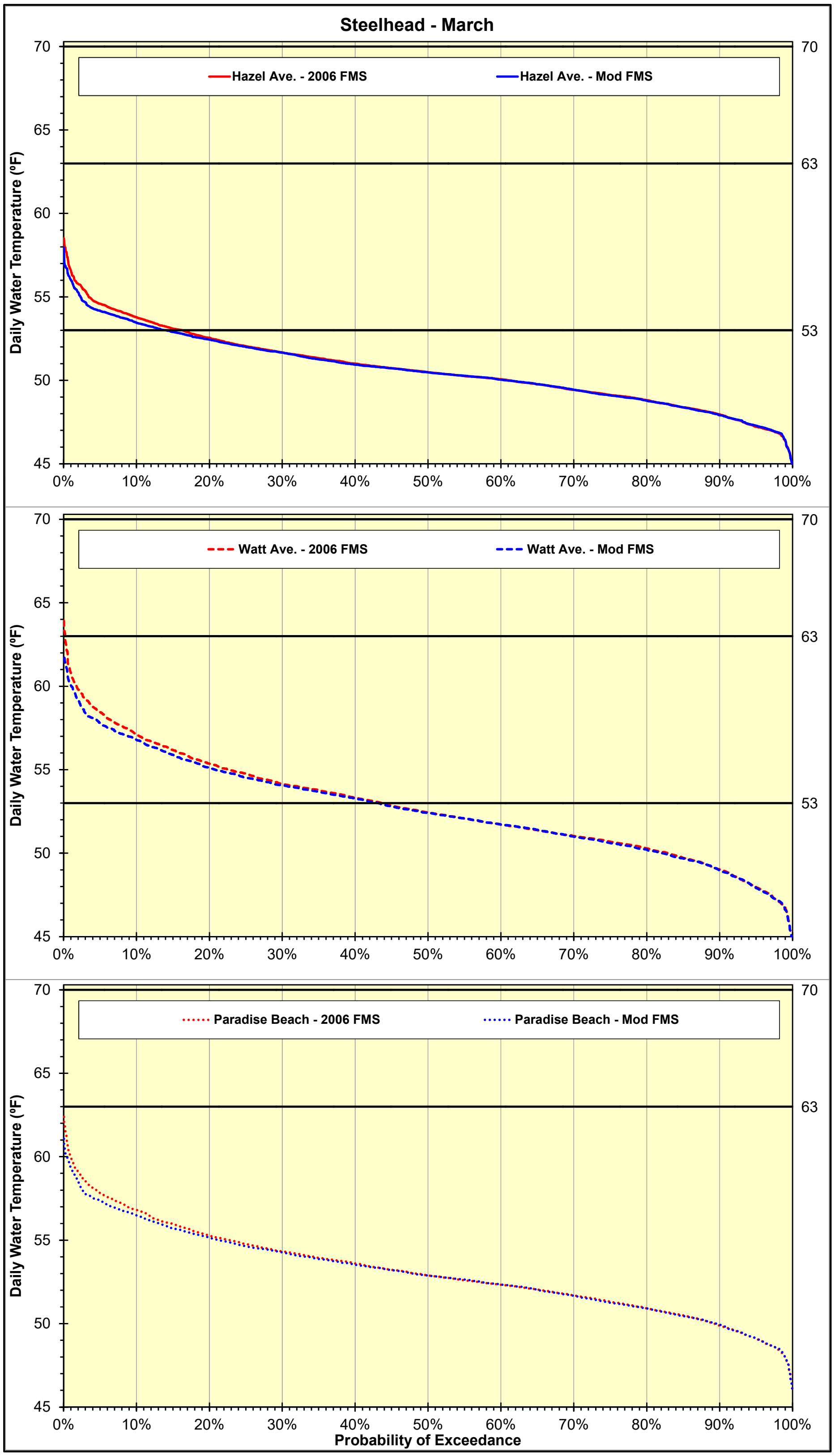

Figure D-30. Daily water temperature exceedance distributions, with the NMFS (2017) identified lifestage-specific WTI values for steelhead, during March at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

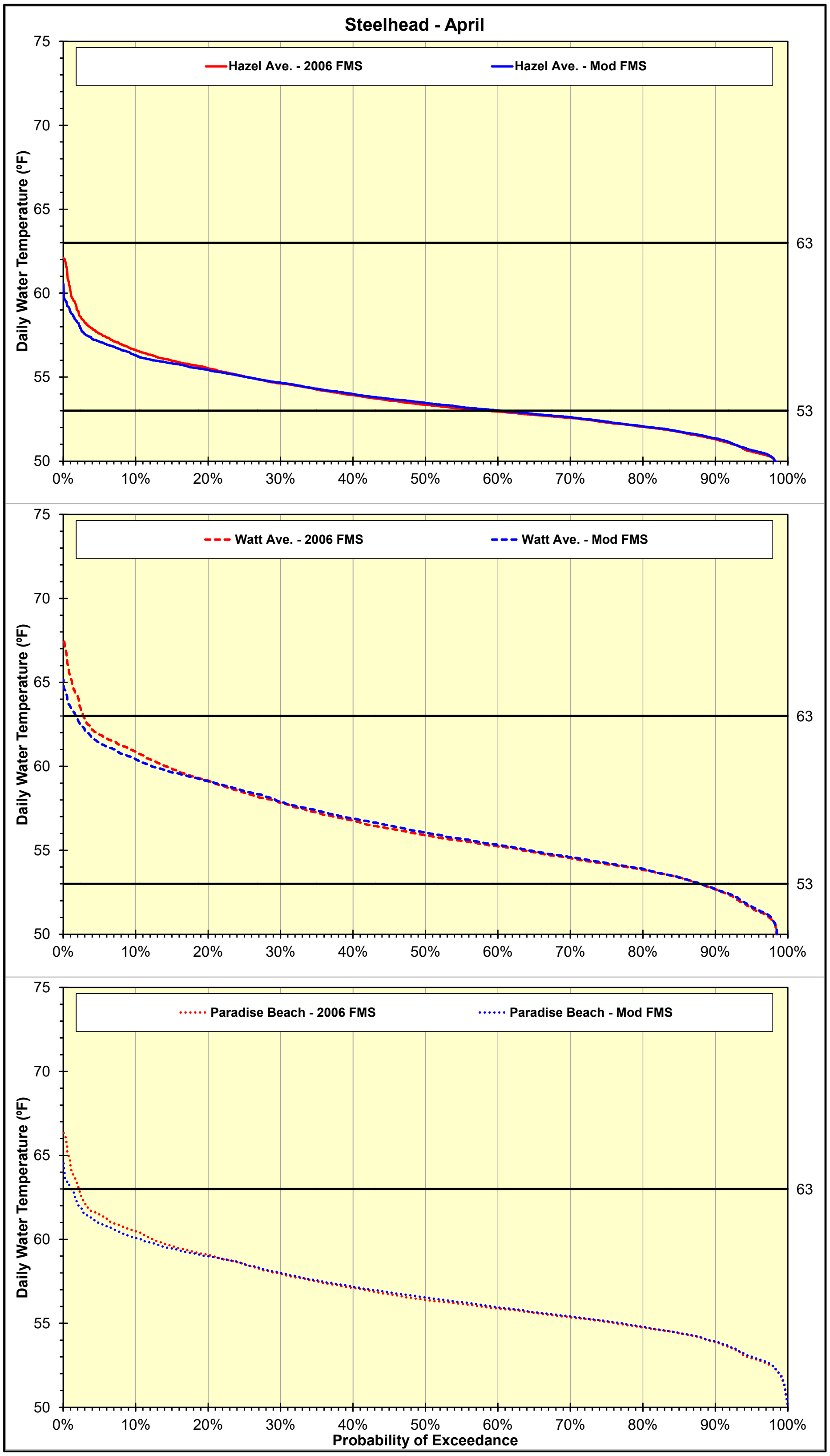

Figure D-31. Daily water temperature exceedance distributions, with the NMFS (2017) identified lifestage-specific WTI values for steelhead, during April at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

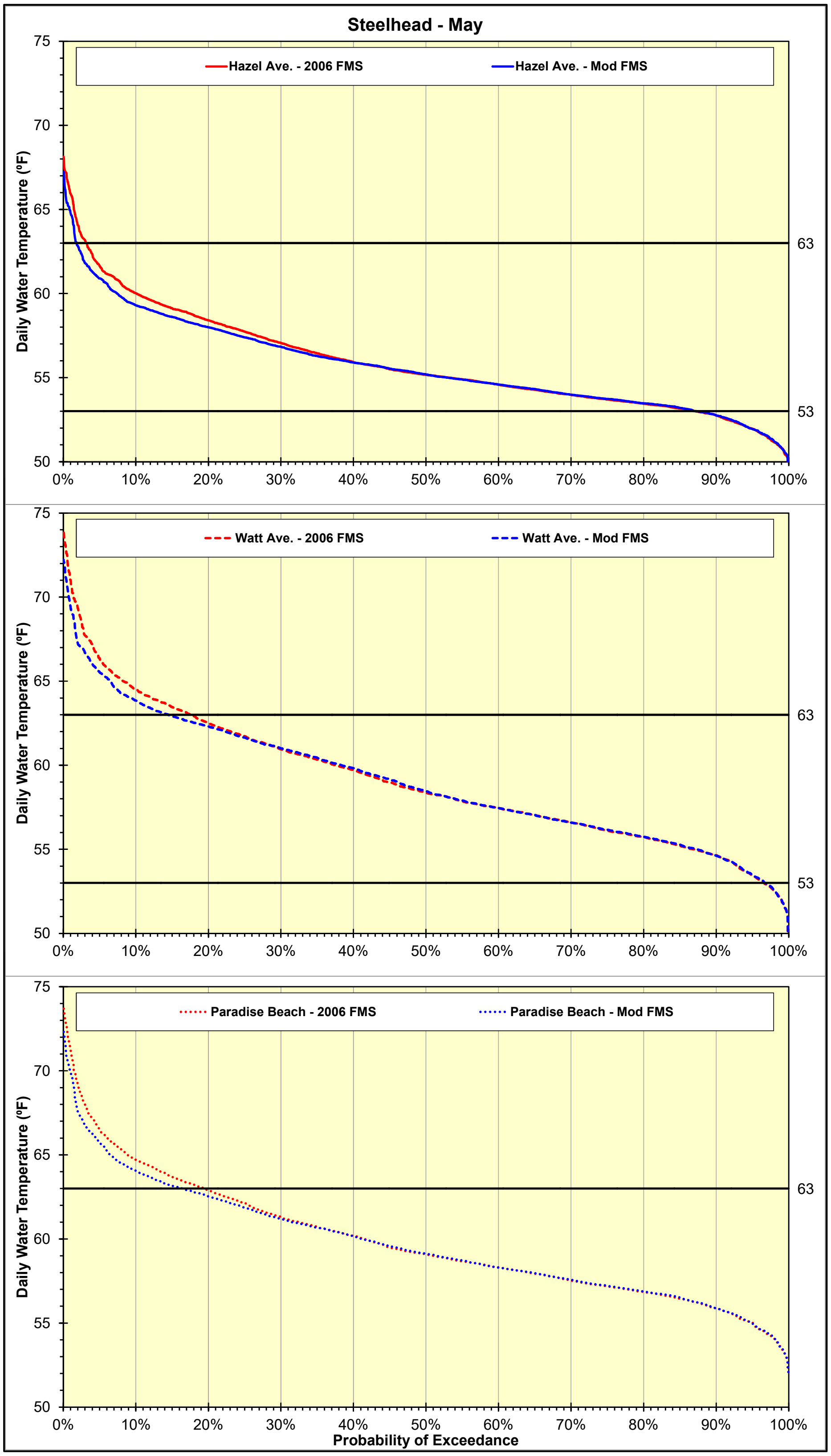

Figure D-32. Daily water temperature exceedance distributions, with the NMFS (2017) identified lifestage-specific WTI values for steelhead, during May at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

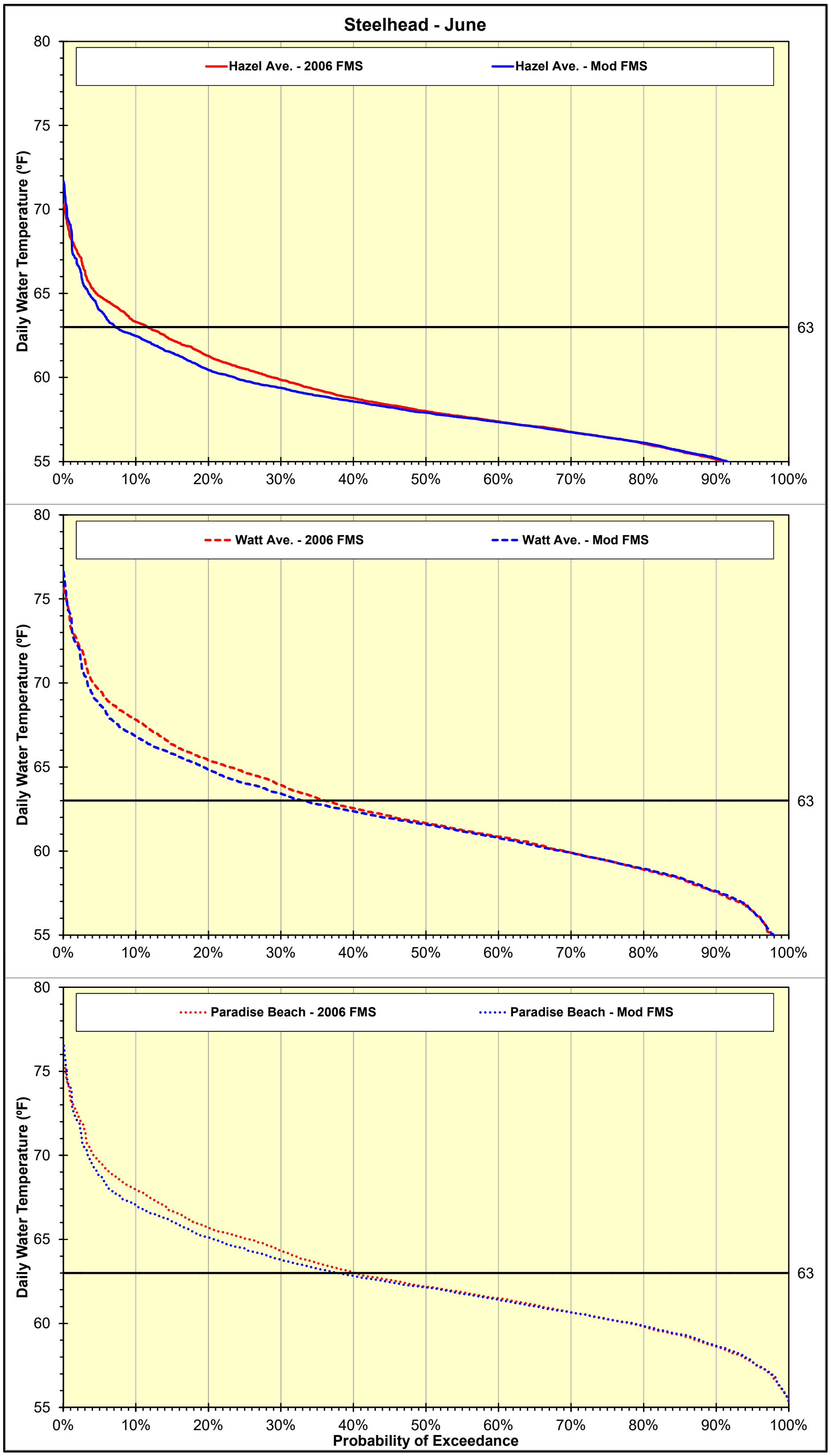

Figure D-33. Daily water temperature exceedance distributions, with the NMFS (2017) identified lifestage-specific WTI values for steelhead, during June at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

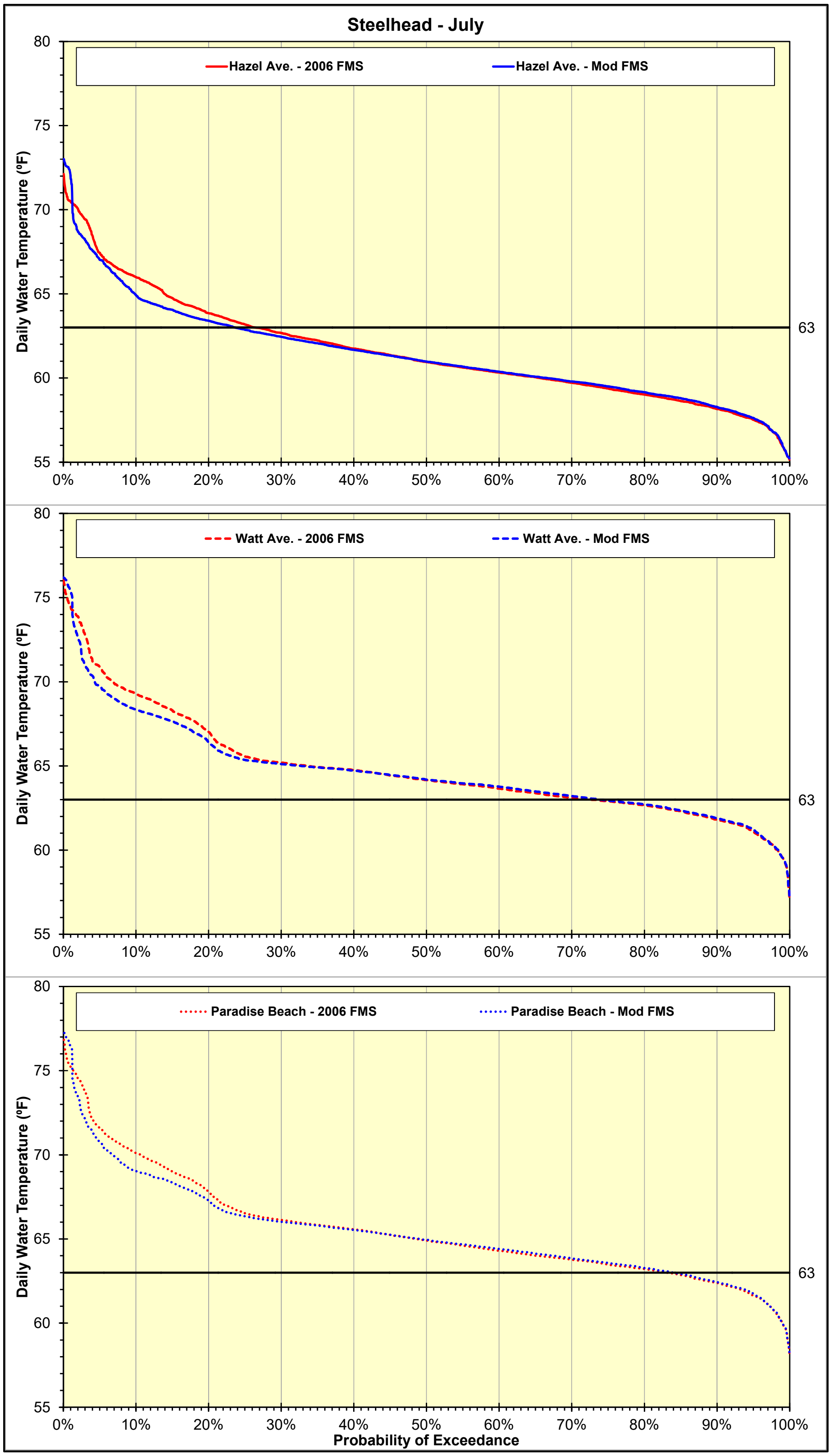

Figure D-34. Daily water temperature exceedance distributions, with the NMFS (2017) identified lifestage-specific WTI values for steelhead, during July at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

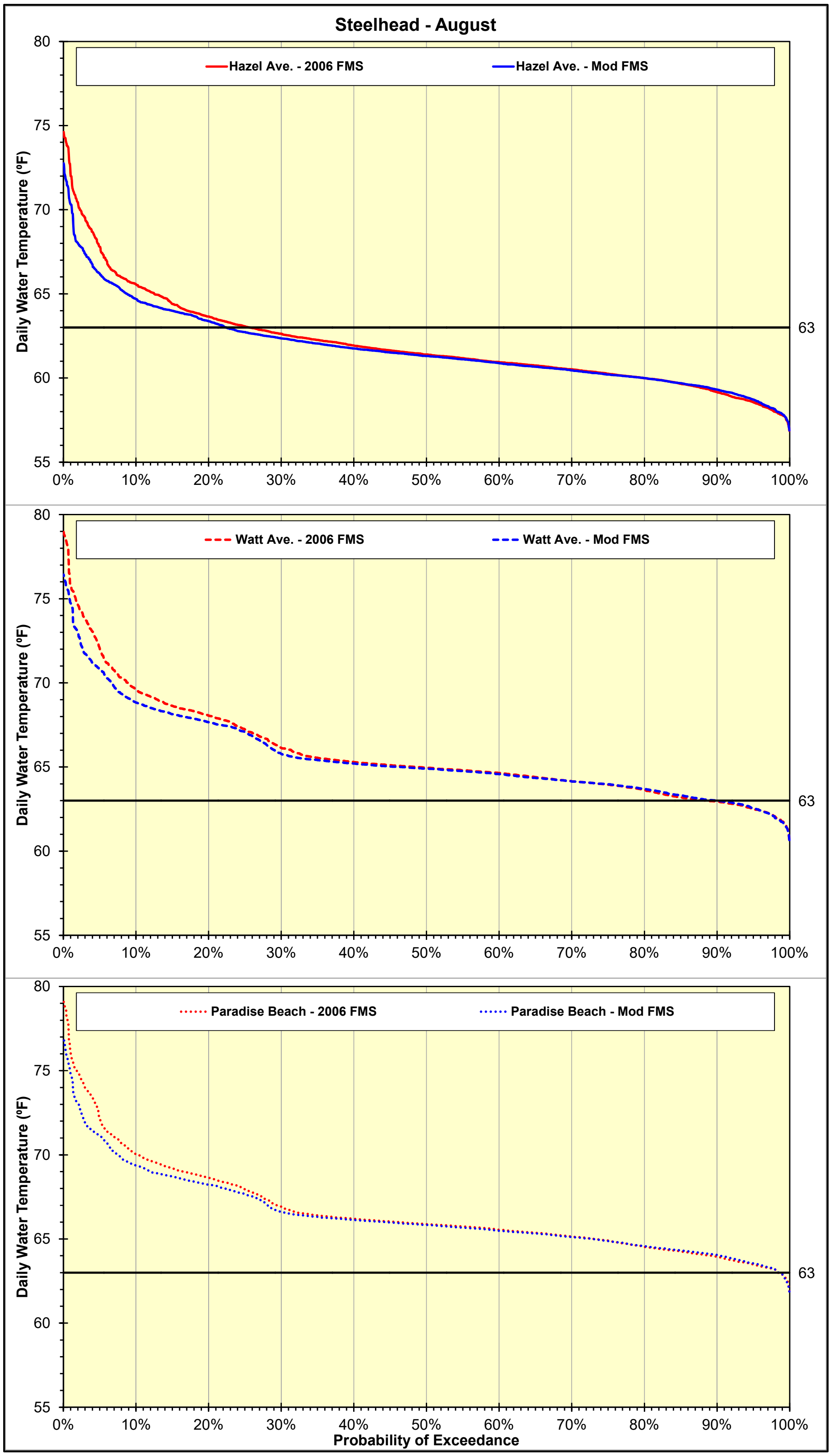

Figure D-35. Daily water temperature exceedance distributions, with the NMFS (2017) identified lifestage-specific WTI values for steelhead, during August at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

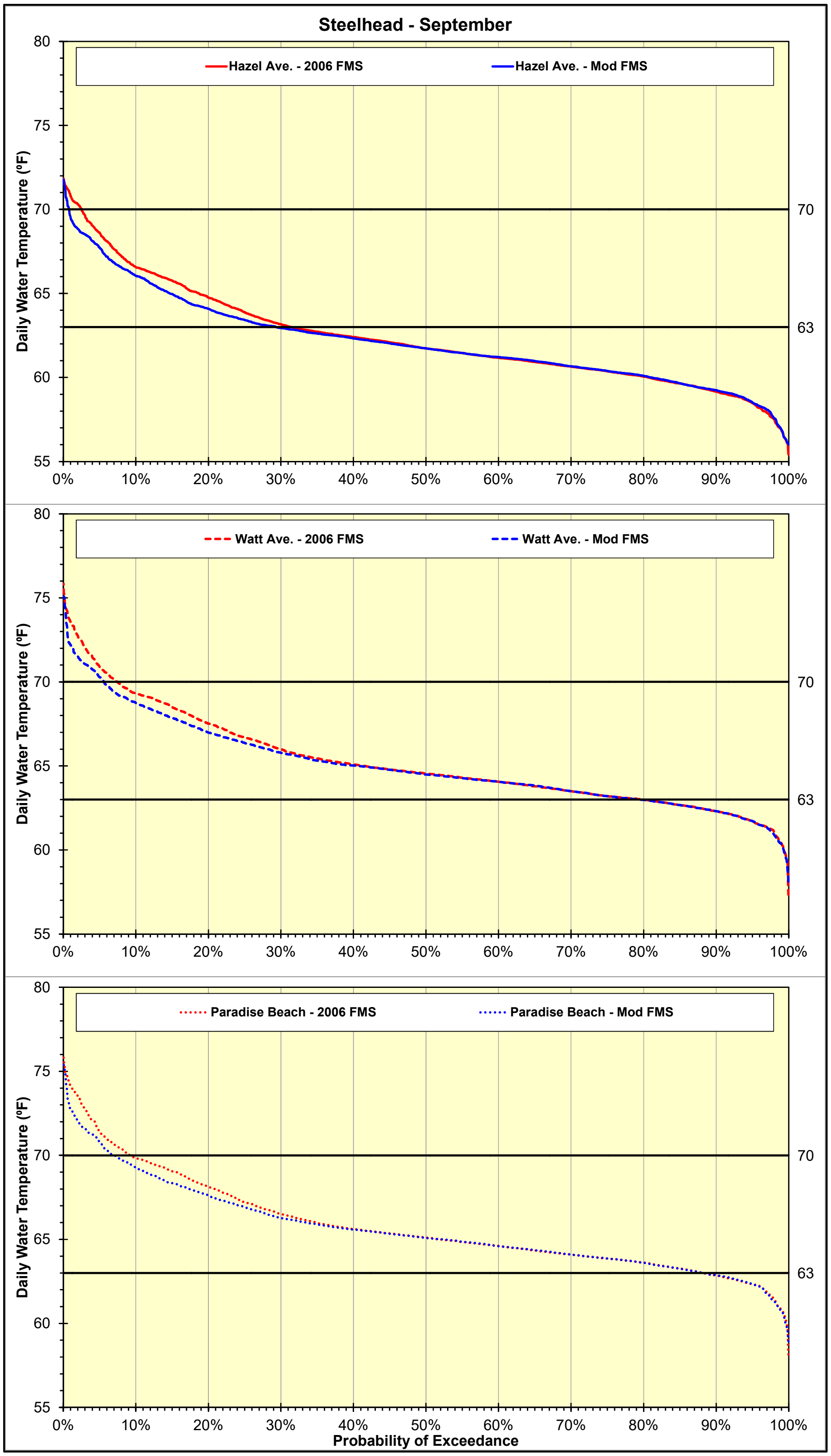

Figure D-36. Daily water temperature exceedance distributions, with the NMFS (2017) identified lifestage-specific WTI values for steelhead, during September at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

Lower American River 7DADM Water Temperature Exceedances

Steelhead

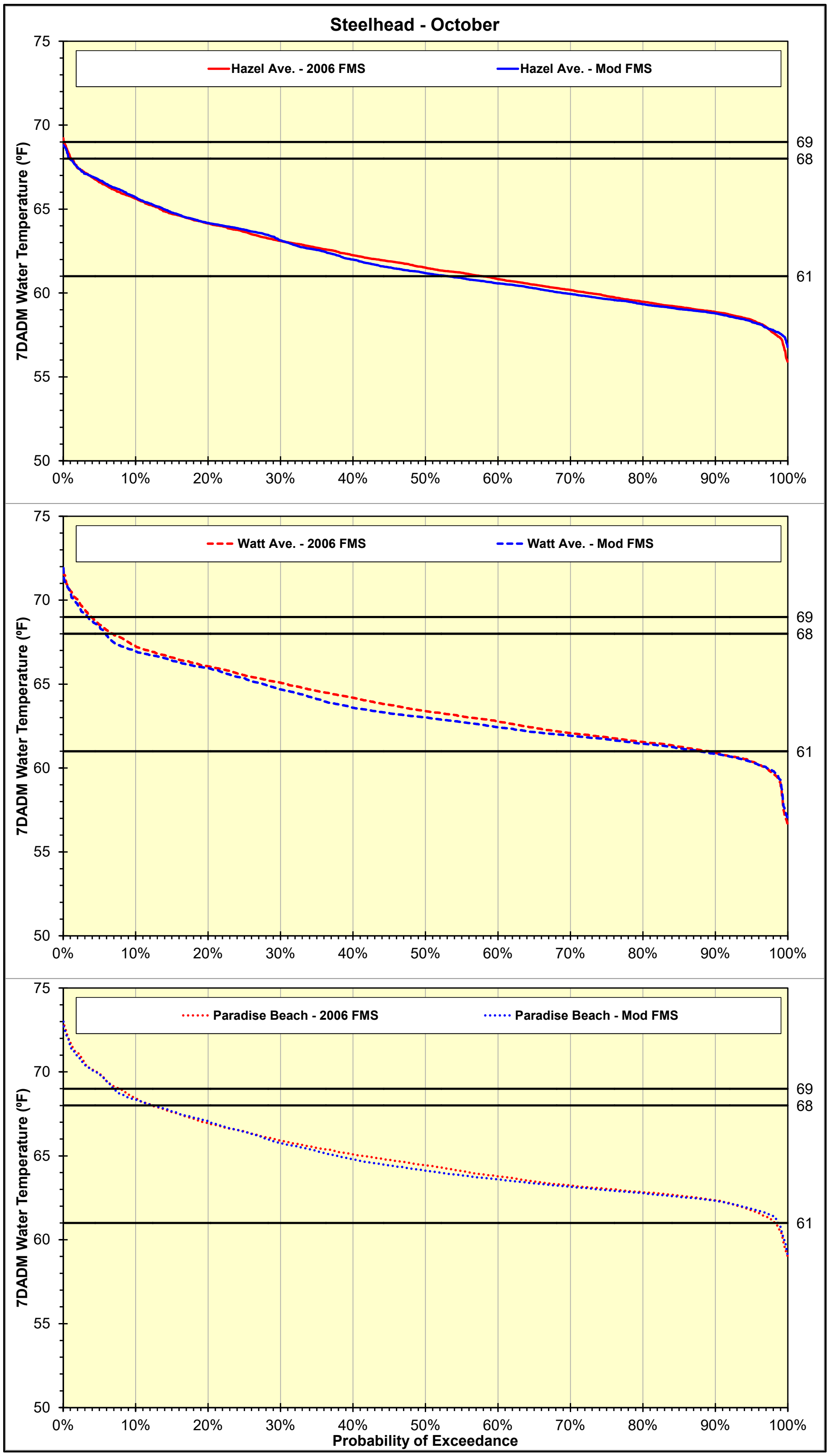

Figure D-37. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for steelhead, during October at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

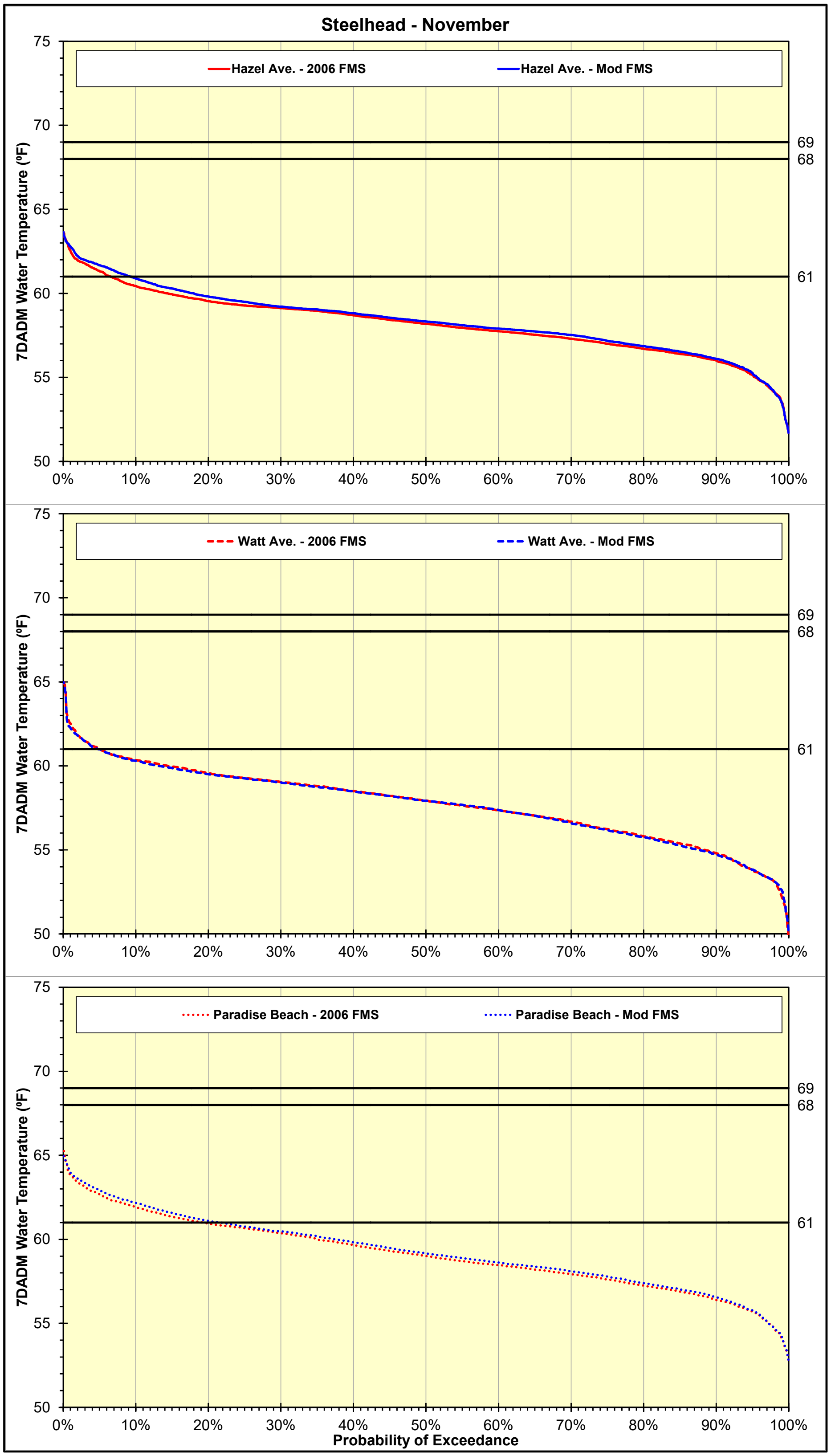

Figure D-38. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for steelhead, during November at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

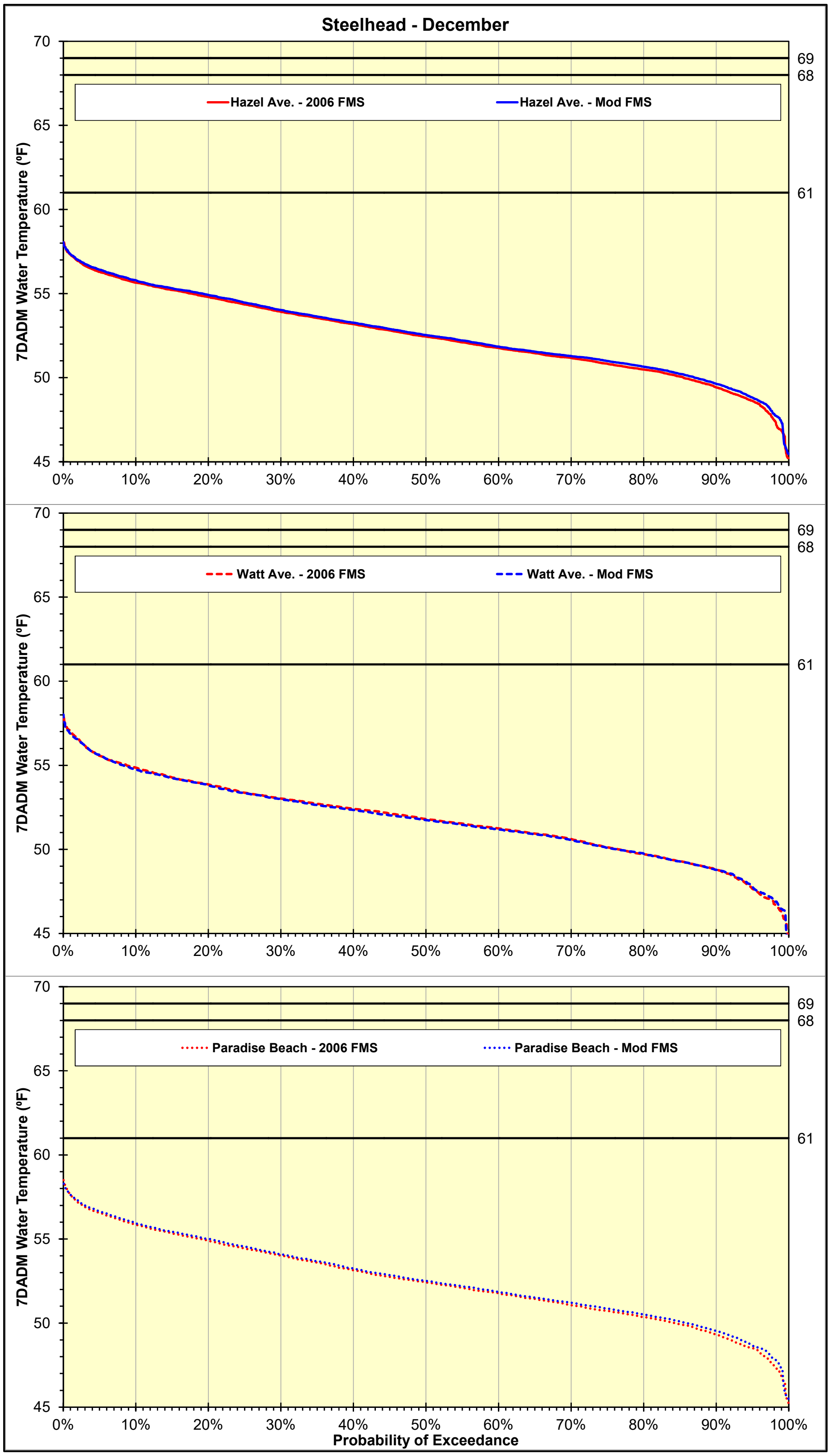

Figure D-39. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for steelhead, during December at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

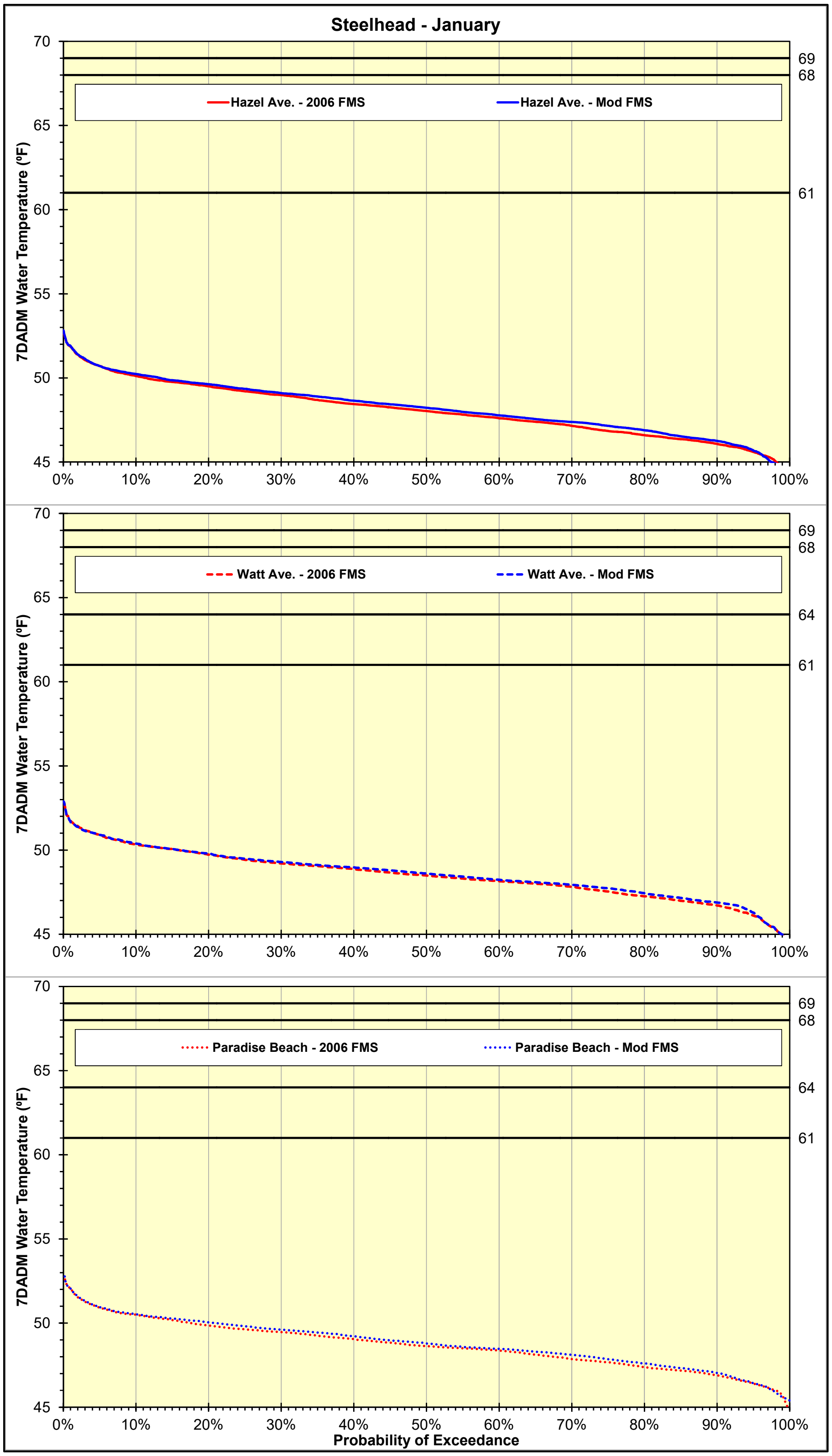

Figure D-40. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for steelhead, during January at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

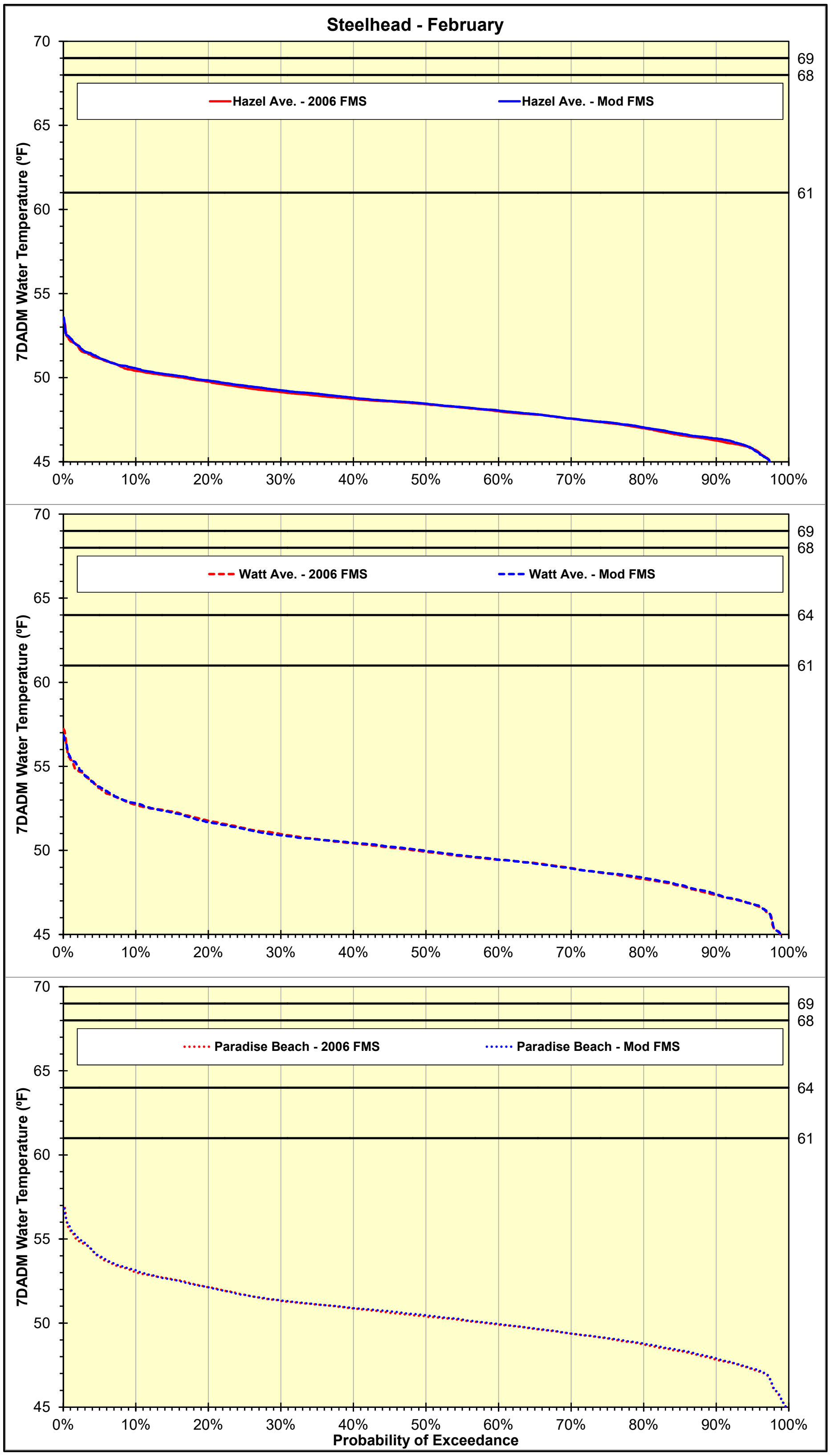

Figure D-41. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for steelhead, during February at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

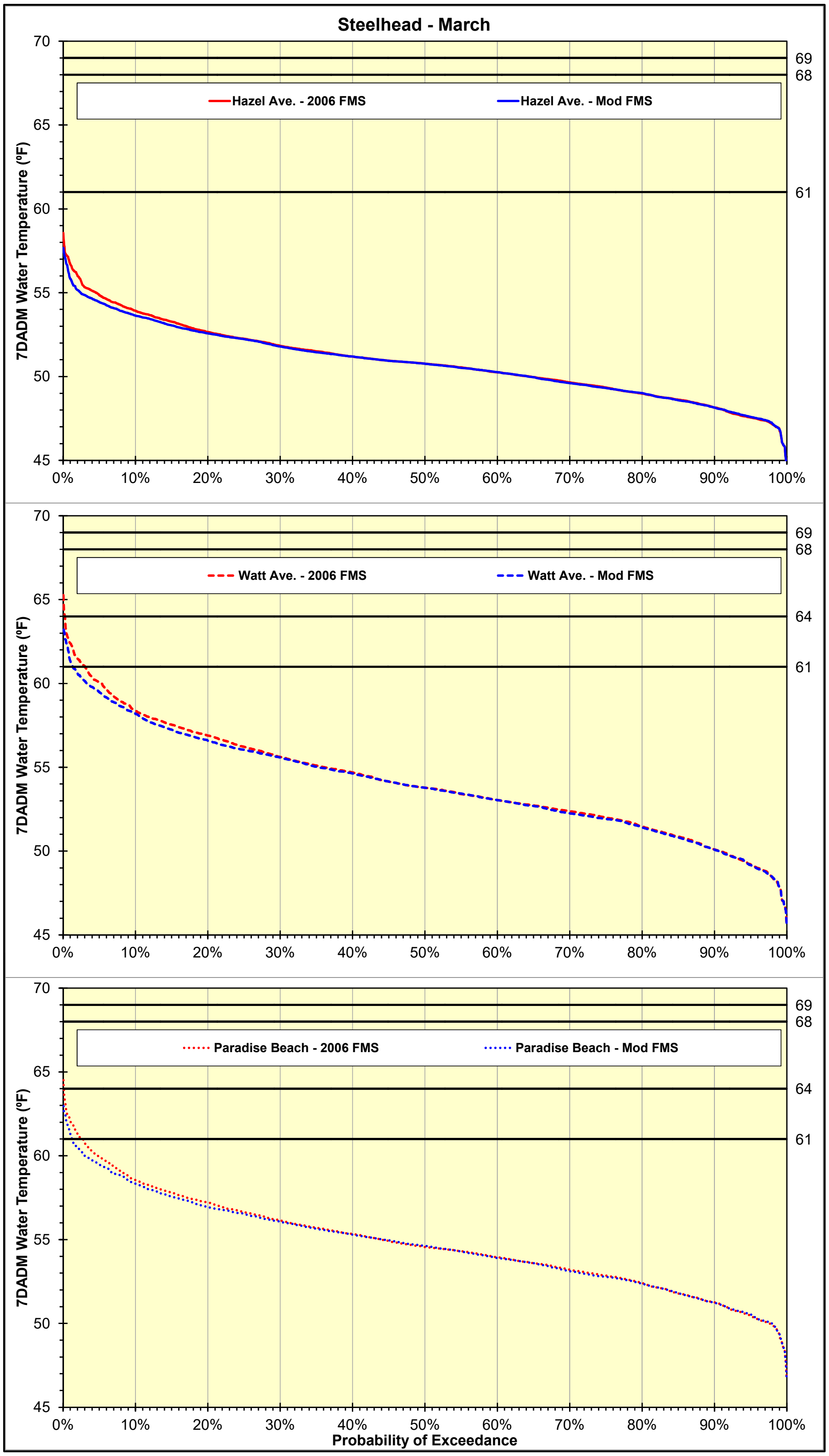

Figure D-42. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for steelhead, during March at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

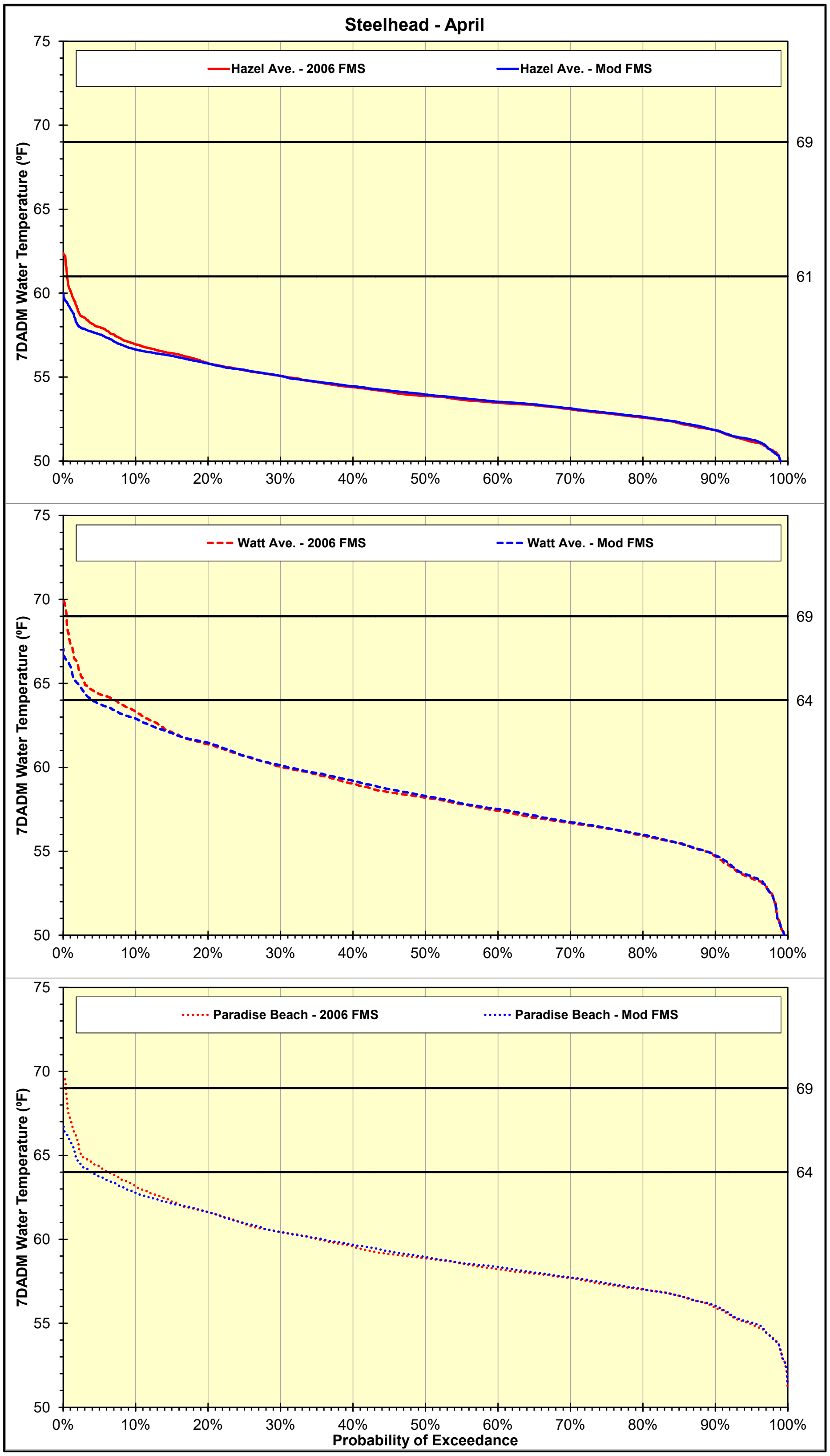

Figure D-43. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for steelhead, during April at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

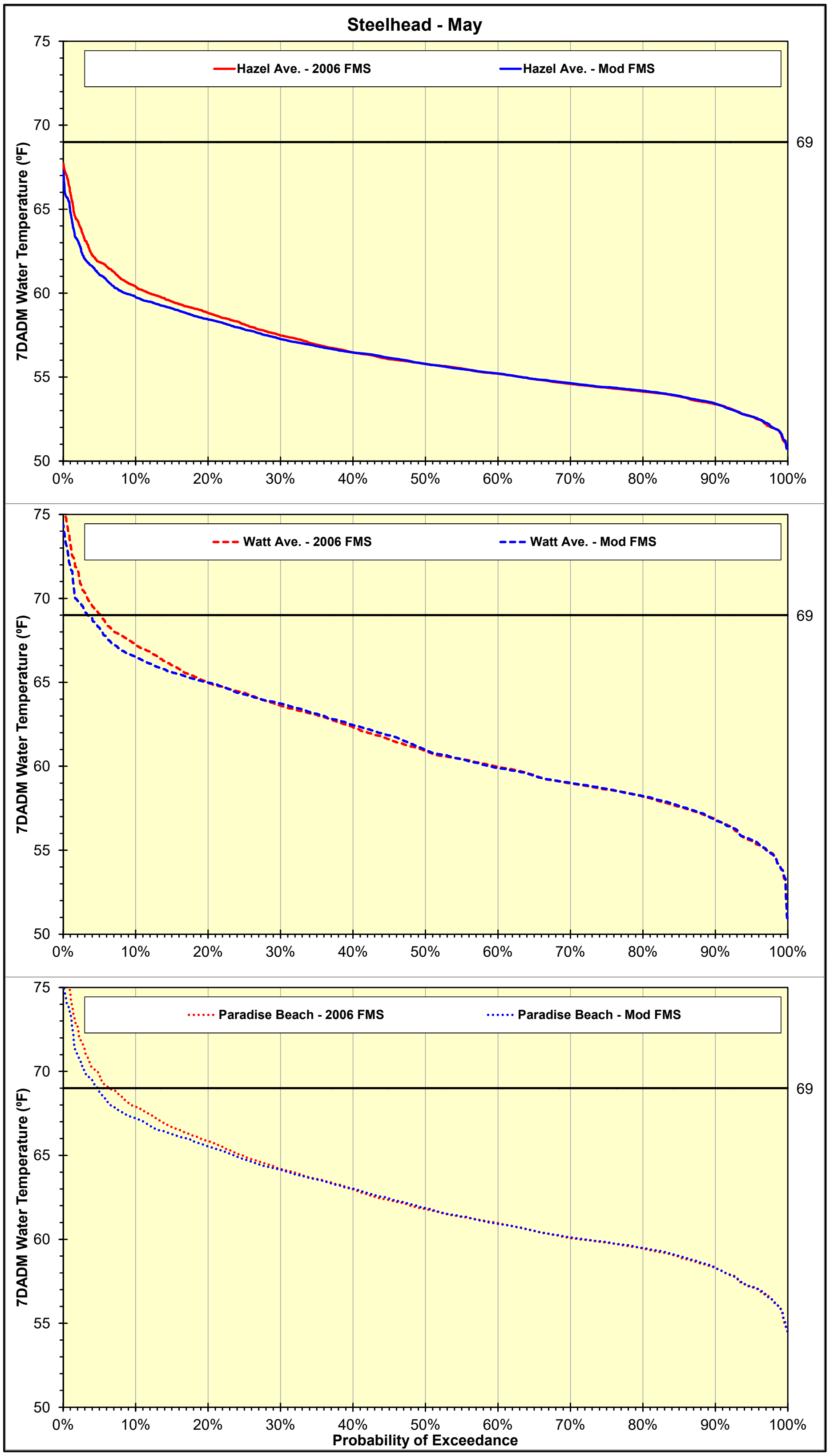

Figure D-44. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for steelhead, during May at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

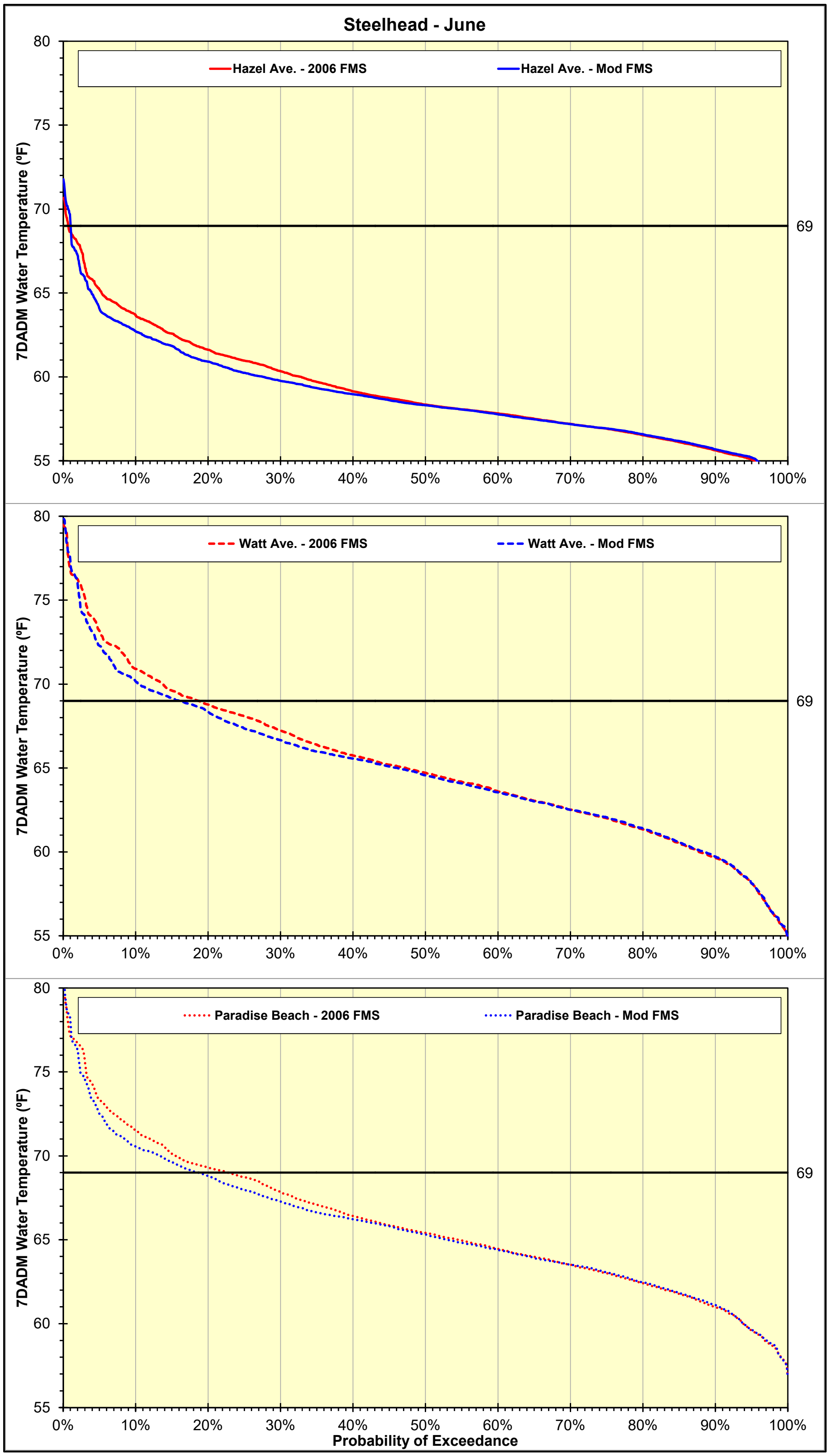

Figure D-45. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for steelhead, during June at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

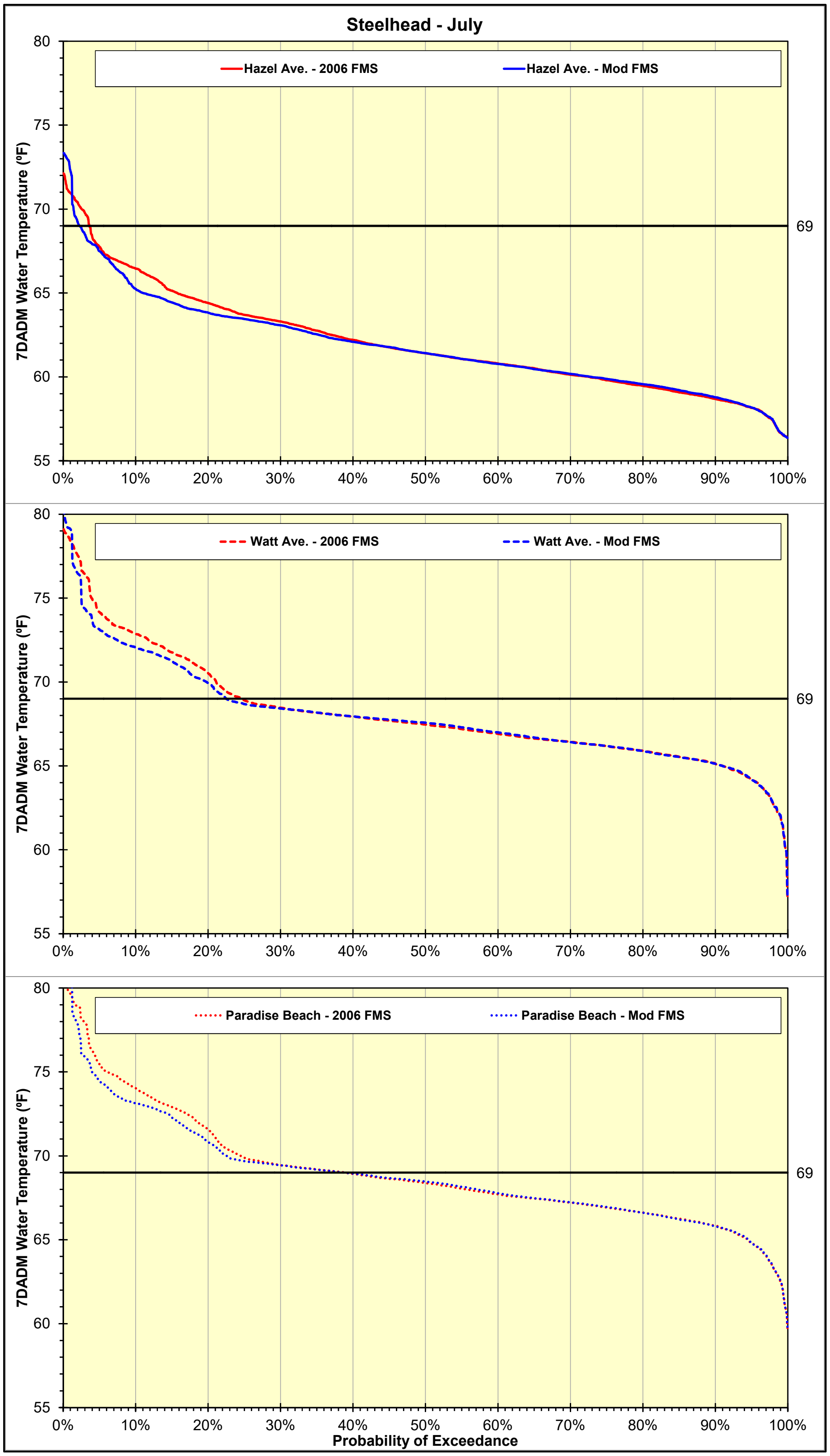

Figure D-46. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for steelhead, during July at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

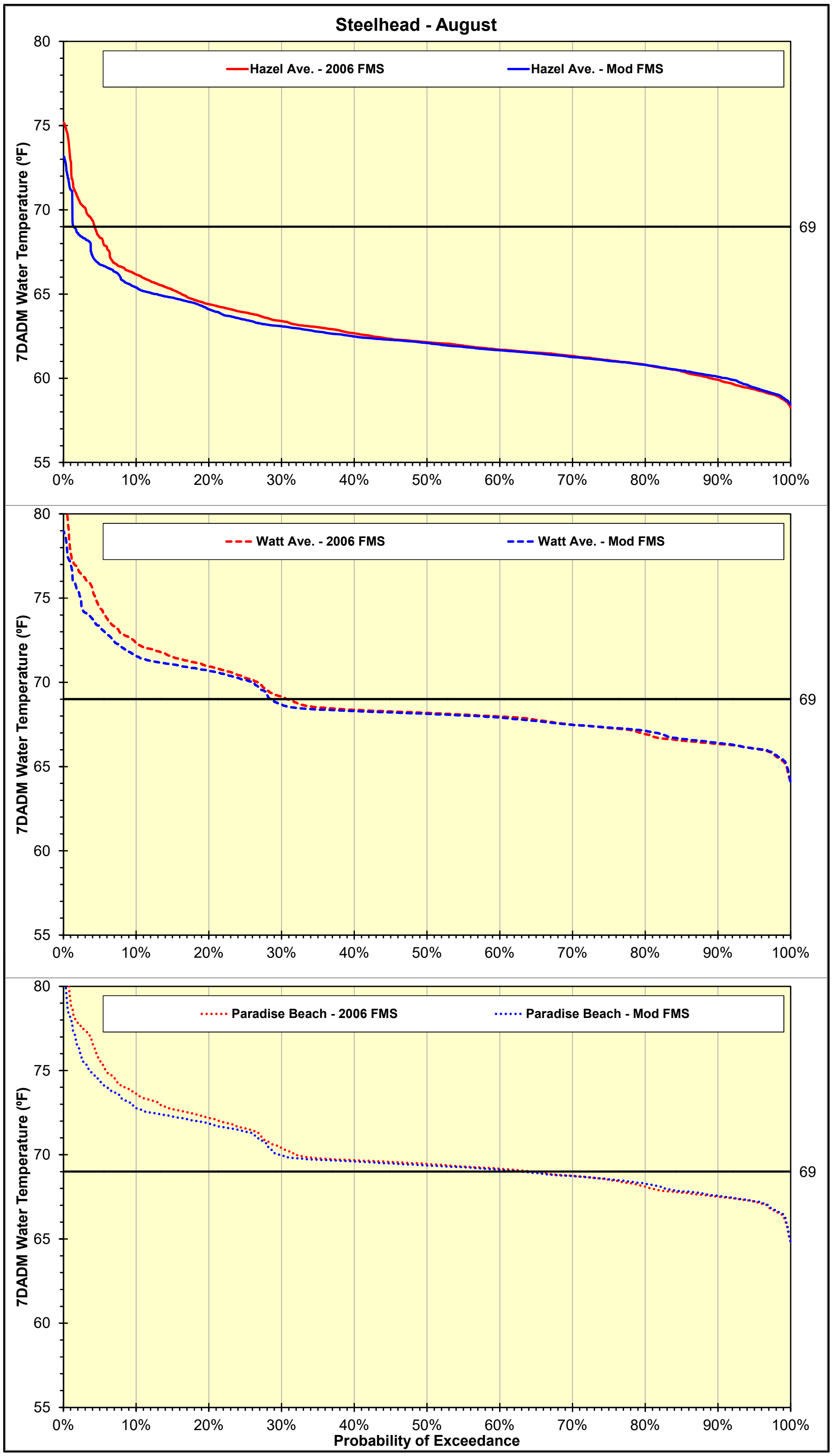

Figure D-47. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for steelhead, during August at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

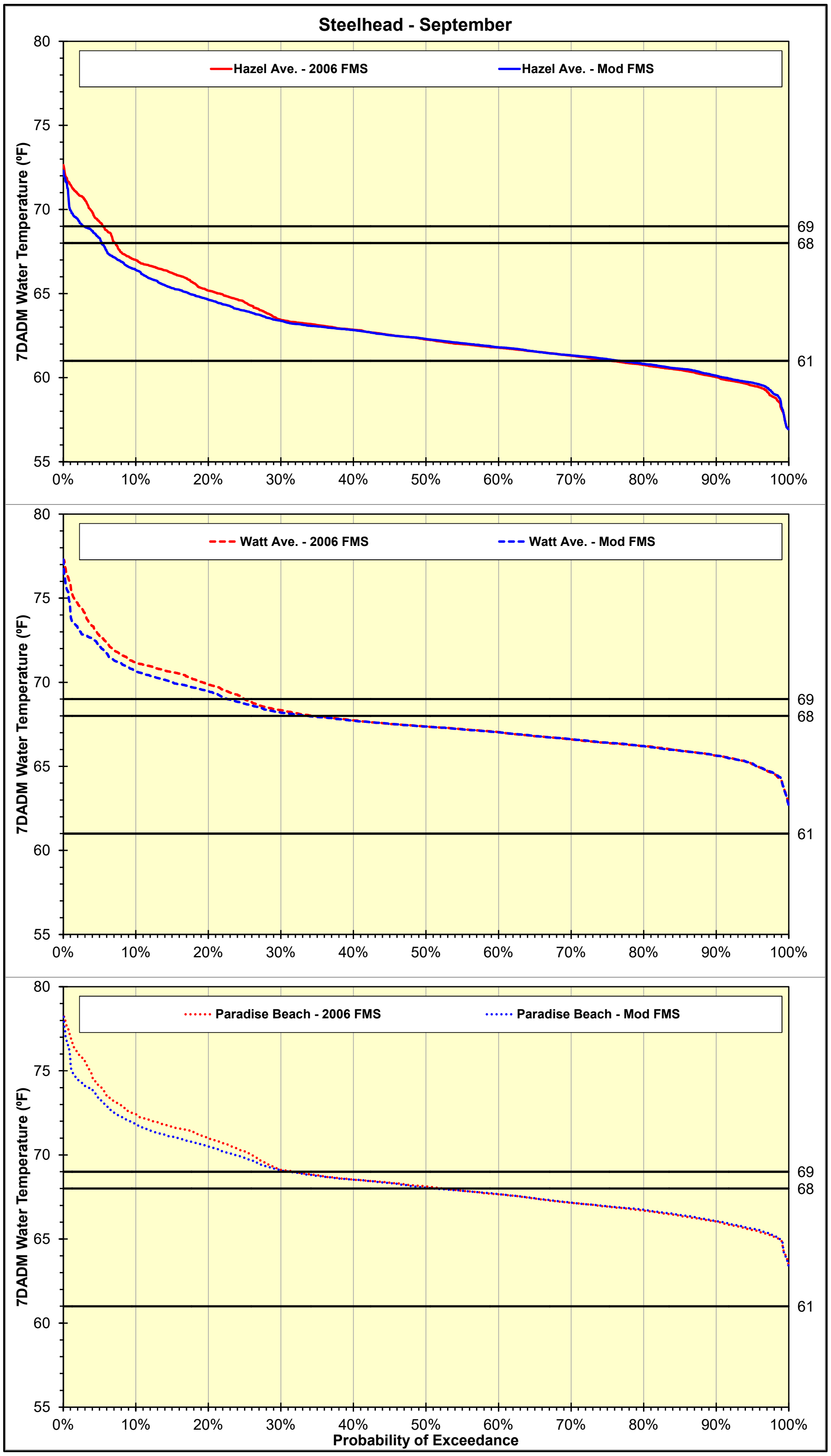

Figure D-48. NMFS (2017) 7DADM water temperature exceedance distributions, with the identified lifestage-specific WTI values for steelhead, during September at Hazel Avenue, Watt Avenue, and Paradise Beach over the 82-year simulation period.

Biological Rationale, Development and Performance of the Modified Flow Management Standard

Attachment E

Lower American River Juvenile Anadromous Salmonid Emigration Pulse Flow

November 29, 2017

1.0 SPRING PULSE FLOW

The Modified FMS includes provision of a pulse flow event in the lower American River under certain circumstances. Provided below are a descriptions of the purpose and the biologic rationale and support.

1.1 Pulse Flow Purpose

The purpose of providing pulse flows in the lower American River during below normal and dry water years is to encourage juvenile salmonid (fall-run Chinook salmon and steelhead) emigration prior to relatively low flow conditions and associated unsuitable thermal conditions later in the spring in the river, and downstream in the lower Sacramento River.

1.2 Pulse Flow Description

Provide a pulse flow event during the period extending from March 15 - April 15 by supplementing normal operational releases from Folsom Dam during dry or below normal water years when no such flow event has occurred between the preceding February 1 and March 1 time frame.

The pulse flow event would only be provided when the MRR for the period extending from February 1 through June (pursuant to the implementation curves for the Modified FMS) range from 1,000 to 1,500 cfs as measured at the USGS Fair Oaks Gage. This range of MRRs during this time period generally corresponds to dry and below normal water year types.

The peak magnitude of the pulse flow would be three times the MRR base flows (pre-pulse flows), not to exceed a peak magnitude of 4,000 cfs as measured at the USGS Fair Oaks Gage.

The pulse flow event would range in duration from 6 - 7.5 days, depending upon the initial MRR base flows (pre-pulse flows). There are no assumed restrictions on the rate of ramp-up from base flows to the peak of the pulse flow, which would last for 2 days. Pursuant to the ramp-down restrictions provided in the NMFS (2009) Biological Opinion for OCAP, flow reductions after the 2-day peak pulse flow will not exceed more than 500 cfs per day and not more than 100 cfs per hour. Consequently, if the peak pulse flow was 3,000 cfs then the pulse flow event would extend 6 days, and if the peak pulse flow was 4,000 cfs then the pulse flow event could extend 7.5 days.

The maximum pulse flow limit of 4,000 cfs was established to minimize stranding of juvenile salmonids. Rearing steelhead fry and juveniles can be exposed to stranding and isolation from main channel flows when high flows are required for flood control or Delta outflow requirements and then subsequently reduced after the requirement subsides (Snider et al. 2001). Reclamation attempts to avoid flow fluctuations during non-flood control events that raise flows above 4,000 cfs and then drop them back below 4,000 cfs as recommended by Snider et al. (2001) and NMFS (2009).

Restriction of implementation of this action to situations when MRR base flows (pre-pulse flows) are equal to or more than 1,000 cfs (i.e., 1,000 - 1,500 cfs) also was to avoid, to the extent possible, juvenile stranding, particularly in side-channel habitats in the lower American River. Side-channels in the lower American River, including those recently constructed as habitat improvement measures through the Anadromous Fish Restoration Program, generally become isolated from the main river channel at flows roughly equal to about 800 cfs (C. Hammersmark, cbec, pers. comm. 2017). Thus, only implementing the pulse flow event when base flows equal or exceed 1,000 cfs avoids the situation in which relatively low (e.g., ≤ 800 cfs) base flows occur, a pulse flow inundates the side channels and introduces rearing salmonids, then a return to base flow strands the juveniles.

The timing of the pulse flow event was based upon timing and magnitude of occurrence of the various lifestages of fall-run Chinook salmon and steelhead in the lower American River:

- Although dependent on water temperatures, typically during dry and below normal water years, fall-run Chinook salmon embryo incubation is complete by mid-March. Thus, the pulse flow event would not be expected to dewater incubating fall-run Chinook salmon redds.
- The pulse flow event would occur during the steelhead spawning and embryo incubation period. However, by having the peak flow only last for 2 days, there would not be sufficient time for steelhead to create redds at the peak flow, because steelhead in the lower American River are reported to require 3 days to build a redd and spawn (Hannon and Deason 2005). Hence, steelhead redd dewatering also would be expected to be avoided/minimized.
- Although it has been reported that steelhead that rear over summer in the lower American River generally emigrate as smolts from January through June (McEwan 2001; Newcomb and Coon 2001; Snider and Titus 2000), most emigrate from January through April (R. Titus, CDFW, pers. comm., 2013, as cited in Reclamation and NMFS 2014). Steelhead smolts (yearling+) may emigrate from the lower American River during this time period in association with storm pulse flows. Therefore, if no storm event has occurred prior to mid-March, providing such an event at that time is intended to assist in steelhead smolt (yearling+) emigration.

During 2014, an investigation was conducted to assess the response of juvenile *O. mykiss* and fall-run Chinook salmon to three pulse flows in the lower American River (PSMFC 2014). Two of those pulse flows were intended to benefit salmonid outmigration in consideration of the low-flow conditions, and the third pulse flow coincided with a rainfall event. The analysis presented in PSMFC (2014) relied on RST data collected immediately downstream of the Watt Avenue Bridge.

Figure E-1 (from PSMFC 2014, Table 2) displays the relationship between the maximum daily discharge at Watt Avenue and the number of juvenile fall-run Chinook salmon that were produced by/emigrated past the American River Rotary Screw Traps (RSTs) during the Nimbus Dam

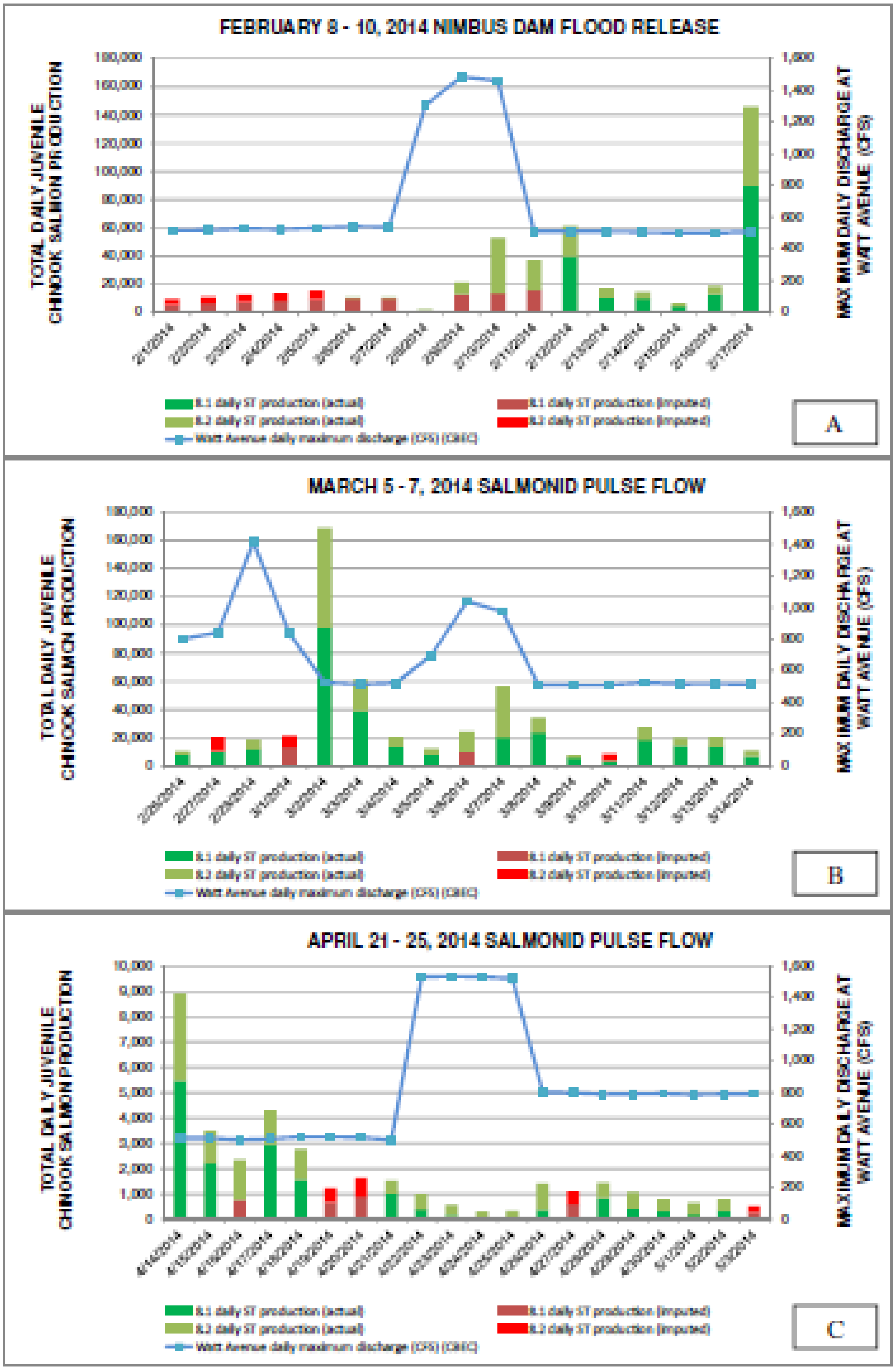

Figure E-1. A, B, and C. Relationship between the maximum daily discharge released from Nimbus Dam and the number of juvenile fall-run Chinook salmon emigrating past the Watt Avenue trap site on the American River in 2014. (Source: PSMFC 2014).

flood release and the two salmonid pulse flows. According to PSMFC (2014), in general, increases in the production of juvenile fall-run Chinook salmon during the February 8 – 10 Nimbus Dam flood release and the March 5 -7 pulse flow coincided with increases in the maximum daily discharge at Watt Avenue. In contrast, the production of juvenile fall-run Chinook salmon appeared to decrease during the elevated river discharges during the April 21 – 25 pulse flow.

Although PSMFC (2014) suggested that the pulse flows may have been associated with a modest increase in the numbers of juvenile *O. mykiss* from the American River, no clear relationship between pulse flow events and RST captures are readily apparent. By contrast, during a water transfer in the lower Yuba River in 2001, flows increased more than 3-fold over a 3-day period, and the daily catch at the RST increased from less than 10 steelhead juveniles (YOY) per day to more than 450 YOY per day (CDFG unpublished data as cited in YCWA et al. 2007).

Although most fall-run Chinook salmon fry emigrate shortly after emergence, some extended rearing also occurs in the lower American River. Overall, the juvenile fall-run Chinook salmon rearing lifestage in the lower American River generally extends from January through May. The juvenile downstream movement period in the lower American River is coincident with the rearing period.

Young-of-the-year (YOY) steelhead historically began appearing in RSTs at the earliest in mid-January, but typically in mid-March. Most YOY steelhead were captured in RSTs from mid-April through June (Snider and Titus 2000). Steelhead YOY, however, began appearing in seine surveys as early as early February, but typically before mid-March, suggesting that emergence and emigration are not coincident (Snider and Titus 1995; Snider et al. 1997; Snider et al. 1998; Snider and Titus 2000; Snider and McEwan 1993; Snider and Keenan 1994; CDFG 2000; Snider and Titus 1996). During RST surveys conducted during 2013, ninety-eight percent (1,019) of the steelhead fry were caught between March 19th and April 22nd (PSMFC 2014). Seventy percent (540) of the steelhead with a parr life stage were caught between April 30th and May 20th during the 2013 survey (PSMFC 2014).

These studies indicate that juvenile steelhead may rear in the lower American River for relatively short periods of time after emergence, or for several months, or even up to a year before moving downstream out of the lower American River. In summary, although it has been reported that steelhead that rear over summer in the lower American River generally emigrate as smolts from January through June (McEwan 2001; Newcomb and Coon 2001; Snider and Titus 2000), most emigrate from January through April (R. Titus, CDFW, pers. comm., 2013, as cited in Reclamation and NMFS 2014). Steelhead juveniles that emigrate from the lower American River as YOY generally do so from March through September (McEwan 2001).

If practicable, lower American River pulse flow events should be coordinated with similar flows that occur naturally in the Sacramento Valley, and/or with storage releases from Shasta and Oroville Reservoirs. Supplementing Sacramento River flows with a pulse flow release on the lower American River is intended to potentially providing additional benefit by assisting juvenile Chinook salmon and steelhead passage into and through the Delta.

Why peak flow for 2 days?

At 1,000 cfs, it takes 1.5 days for water to travel the 23 miles down the lower American River (C. Hammersmark, cbec, inc, pers. comm. 2015). Thus, two days of a pulse flow release ranging from 3,000 to 4,000 cfs provides a full flush of the river.

Why below normal and dry water year types?

The lower American River pulse flow event would only be implemented during below normal or dry water years because: (1) pulse flow events are not necessary in wetter water year types; and (2) pulse flow events would not be implemented during critical years because of the potential impact on water supply, as well as the need to conserve water in storage for instream flow releases and cold water pool management.

1.3 Pulse Flow Analysis

Model simulation results (**Table E-1**) indicate that there would be an additional 13 years when a pulse flow event (as defined above in Section 1.2) would occur under the Modified FMS, relative to the 2006 FMS, over the 1922 through 2003 model simulation period. Additional pulse flow events under the Modified FMS would occur during 2 above normal water years (1926, 1955), 5 below normal years (1933, 1944, 1955, 1966 and 1968), and 6 dry water years (1930, 1947, 1959, 1964, 1981 and 1985). As shown in Table E-1, the magnitude of additional pulse flow events under the Modified FMS would range from 3,072 cfs up to 4,000 cfs.

Table E-1. Additional pulse flow events that would occur under the Modified FMS, relative to the 2006 FMS.

Water Year	Water Year Type	Pulse Flow (cfs)
1926	Above Normal	3,551
1930	Dry	4,000
1933	Below Normal	3,200
1944	Below Normal	3,774
1947	Dry	3,641
1955	Above Normal	4,000
1959	Dry	3,072
1960	Below Normal	4,000
1964	Dry	4,000
1966	Below Normal	3,566
1968	Below Normal	4,000
1981	Dry	3,533
1985	Dry	4,000

2.0 REFERENCES

California Department of Fish and Game (CDFG). 2000. Fall-run Chinook Salmon Weekly Catch Distribution. Preliminary Data Obtained from Bill Snider on July 10, 2000.

Hannon, J. and B. Deason. 2005. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001 – 2005. Central Valley Project, American River, California - Mid-Pacific Region. October 27, 2005.

McEwan, D. 2001. Central Valley Steelhead in Contributions to the Biology of Central Valley Salmonids. Brown, R. L. (ed.), Sacramento, CA: California Department of Fish and Game, pp 1-43.

National Marine Fisheries Service (NMFS). 2009. Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project.

Newcomb, T. J. and T. G. Coon. 2001. Evaluation of Three Methods for Estimating Numbers of Steelhead Smolts Emigrating From Great Lakes Tributaries. North American Journal of Fisheries Management 21:548-560.

Pacific States Marine Fisheries Commission (PSMFC). 2014. Juvenile Salmonid Emigration Monitoring in the Lower American River, California January – May 2014. Unpublished report prepared for the U.S. Fish and Wildlife Service and California Department of Fish and Wildlife, Sacramento, California. 112 pp.

Reclamation and NMFS. 2014. Water Temperature Evaluation Methodology Technical Memorandum. Structural Improvements for Lower American River Water Temperature Management. Value Planning Workshop. Prepared by HDR and cbec.

Snider, B. and N. Keenan. 1994. Fish Community Survey, Lower American River, January through June 1993. Final Report. California Department of Fish and Game. May 1994.

Snider, B. and McEwan, D. 1993. Fish Community Survey, Lower American River, February-July 1992. Department of Fish and Game, Stream Evaluation Program, Environmental Services Division. 94 pp. January 1993.

Snider, B. and R. Titus. 2000. Lower American River Emigration Survey October 1996-September 1997. Stream Evaluation Program Technical Report No. 00-2. California Department of Fish and Game. January 2000.

Snider, B. and R. Titus. 1996. Fish Community Survey, Lower American River, January through June 1995. California Department of Fish and Game, Environmental Services Division. April 1996.

Snider, B. and R. Titus. 1995. Lower American River Emigration Survey: November 1993-July 1994. California Department of Fish and Game, Environmental Sciences Division, Stream Flow and Habitat Evaluation Program. August 1995.

Snider, B., R. Titus, and B. Payne. 1997. Lower American River Emigration Survey: November 1994 September 1995. Draft Report. California Department of Fish and Game, Environmental Sciences Division, Stream Evaluation Program. July 1997.

Snider, B., R. Titus, and B. Payne. 1998. Lower American River Emigration Survey: October 1995–September 1996. California Department of Fish and Game, Environmental Sciences Division, Stream Evaluation Program. September 1998.

Snider, B., R. Titus and K. Vyverberg. 2001. Evaluation of Effects of Flow Fluctuations on the Anadromous Fish Populations in the Lower American River. Prepared by the California Department of Fish and Game for the U.S. Bureau of Reclamation. Stream Evaluation Program Technical Report No. 01 -2. November 2001.

Yuba County Water Agency, Department of Water Resources, and U.S. Bureau of Reclamation (YCWA, DWR and Reclamation). 2007. Draft Environmental Impact Report/ Environmental Impact Statement for the Proposed Lower Yuba River Accord. State Clearinghouse (SCH) No: 2005062111. Prepared by HDR|Surface Water Resources, Inc. June 2007.

Biological Rationale, Development and Performance of the Modified Flow Management Standard

Attachment F

Sacramento River Potential Re-directed Effects Assessment Data

November 29, 2017

Shasta Reservoir May Storage Exceedance

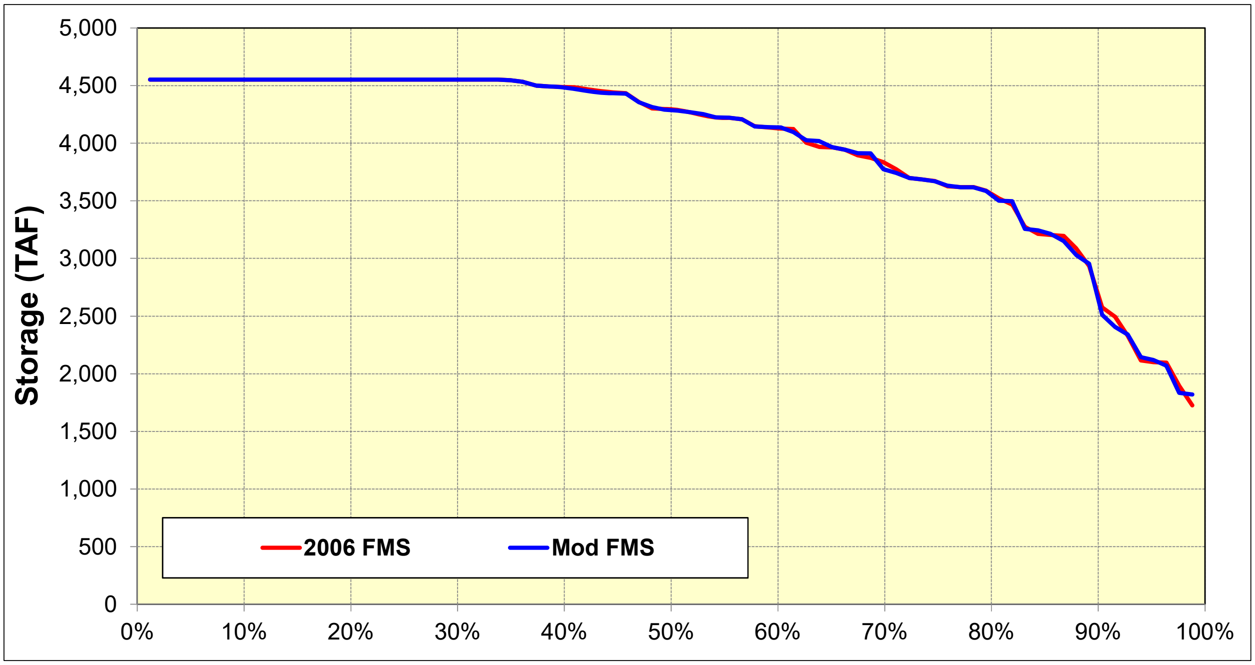

Figure F-1. Exceedance plot of May Shasta Reservoir storage for the Modified FMS and the 2006 FMS for the 82-year period of evaluation.

Sacramento River
Below Keswick Dam
Average Daily Water Temperature
Exceedances

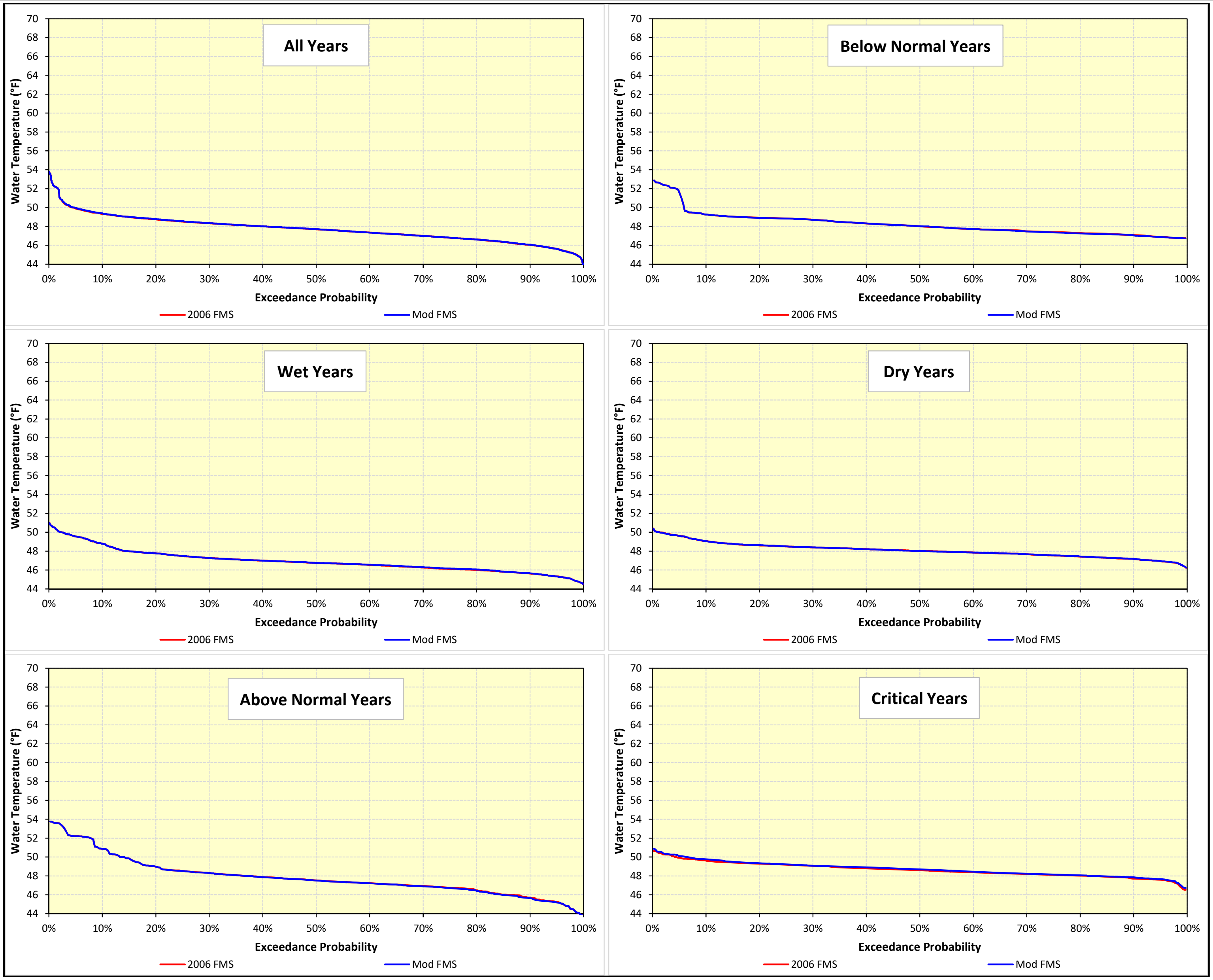

Figure F-2. Daily water temperature exceedance distributions during April below Keswick Dam on the Sacramento River over the 82-year simulation period.

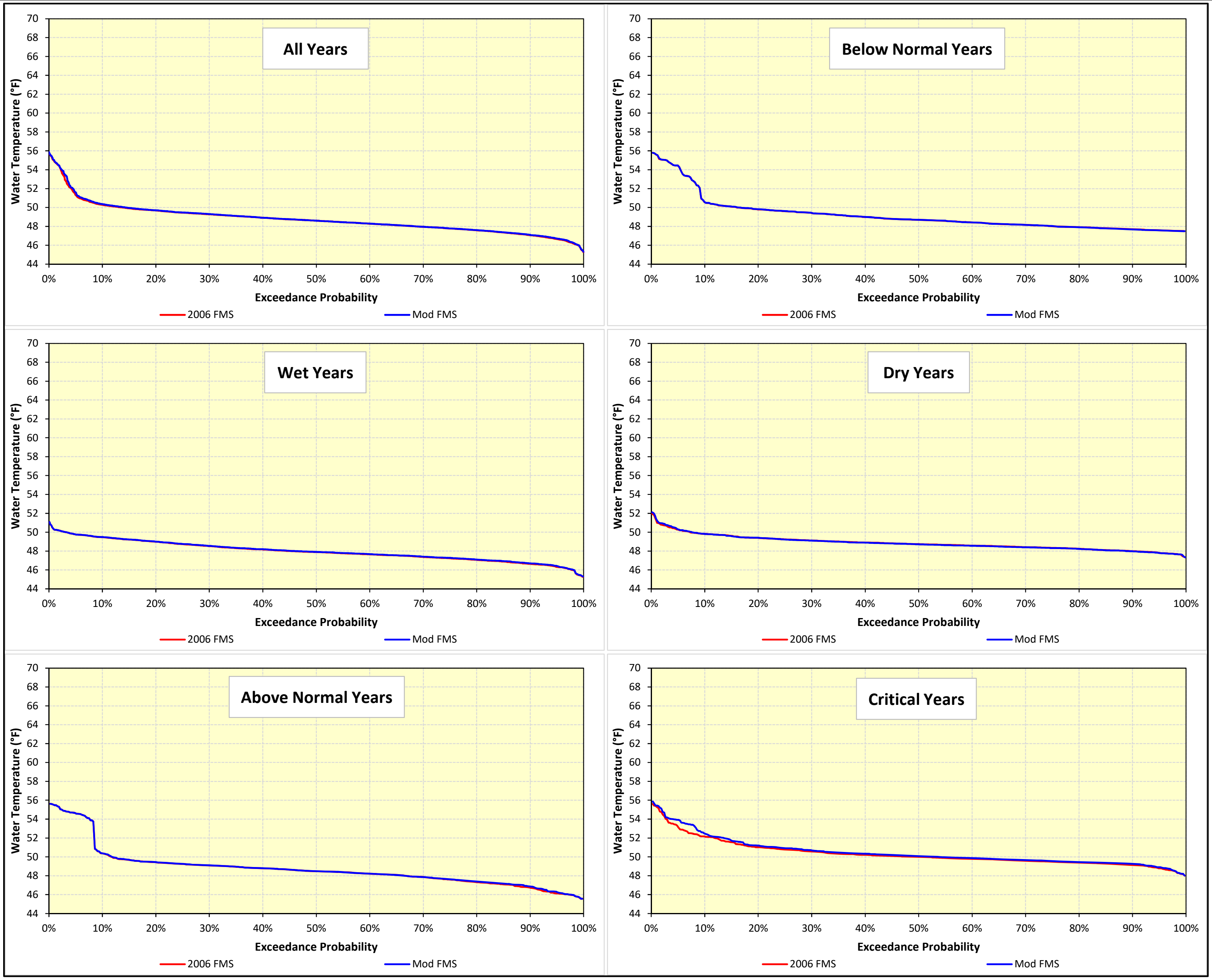

Figure F-3. Daily water temperature exceedance distributions during May below Keswick Dam on the Sacramento River over the 82-year simulation period.

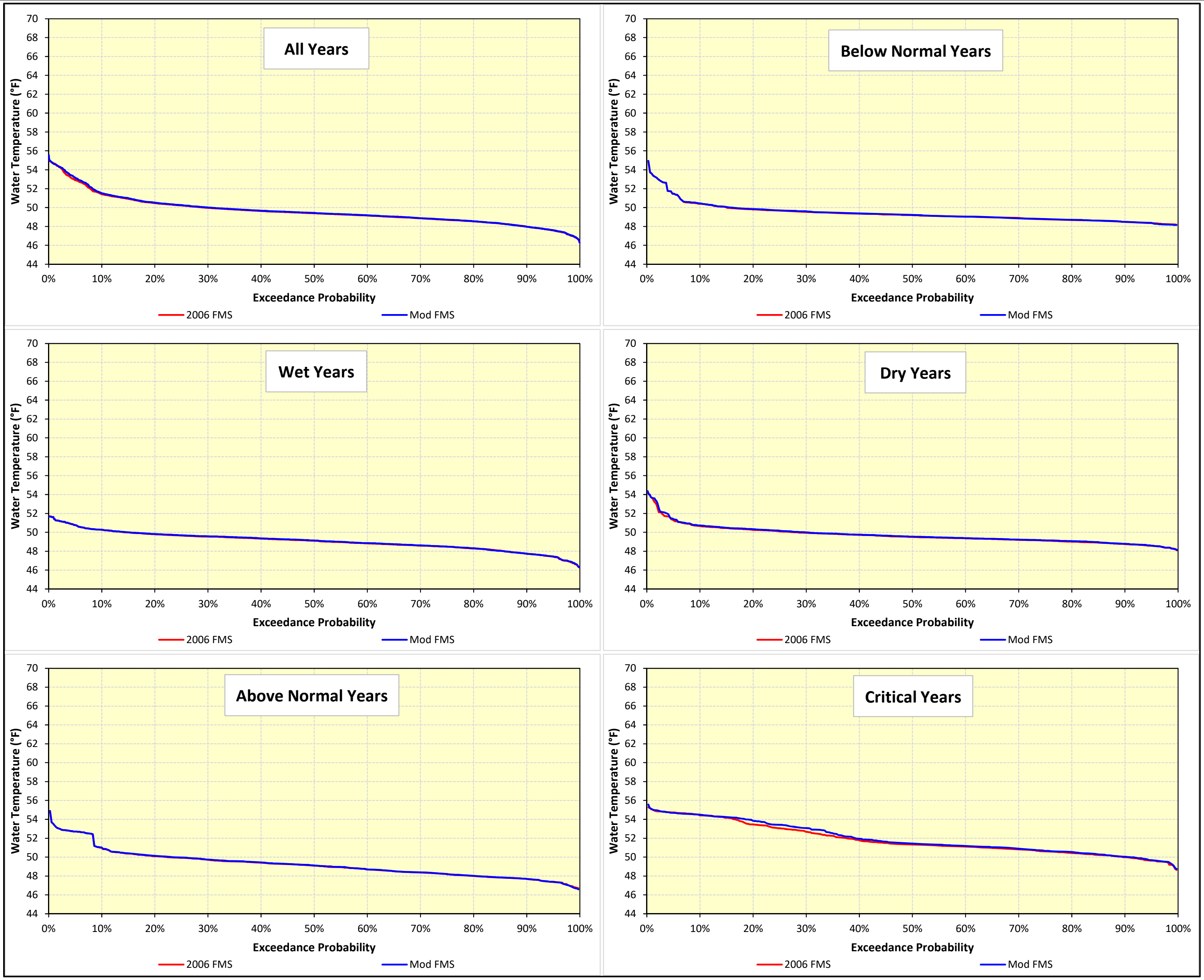

Figure F-4. Daily water temperature exceedance distributions during June below Keswick Dam on the Sacramento River over the 82-year simulation period.

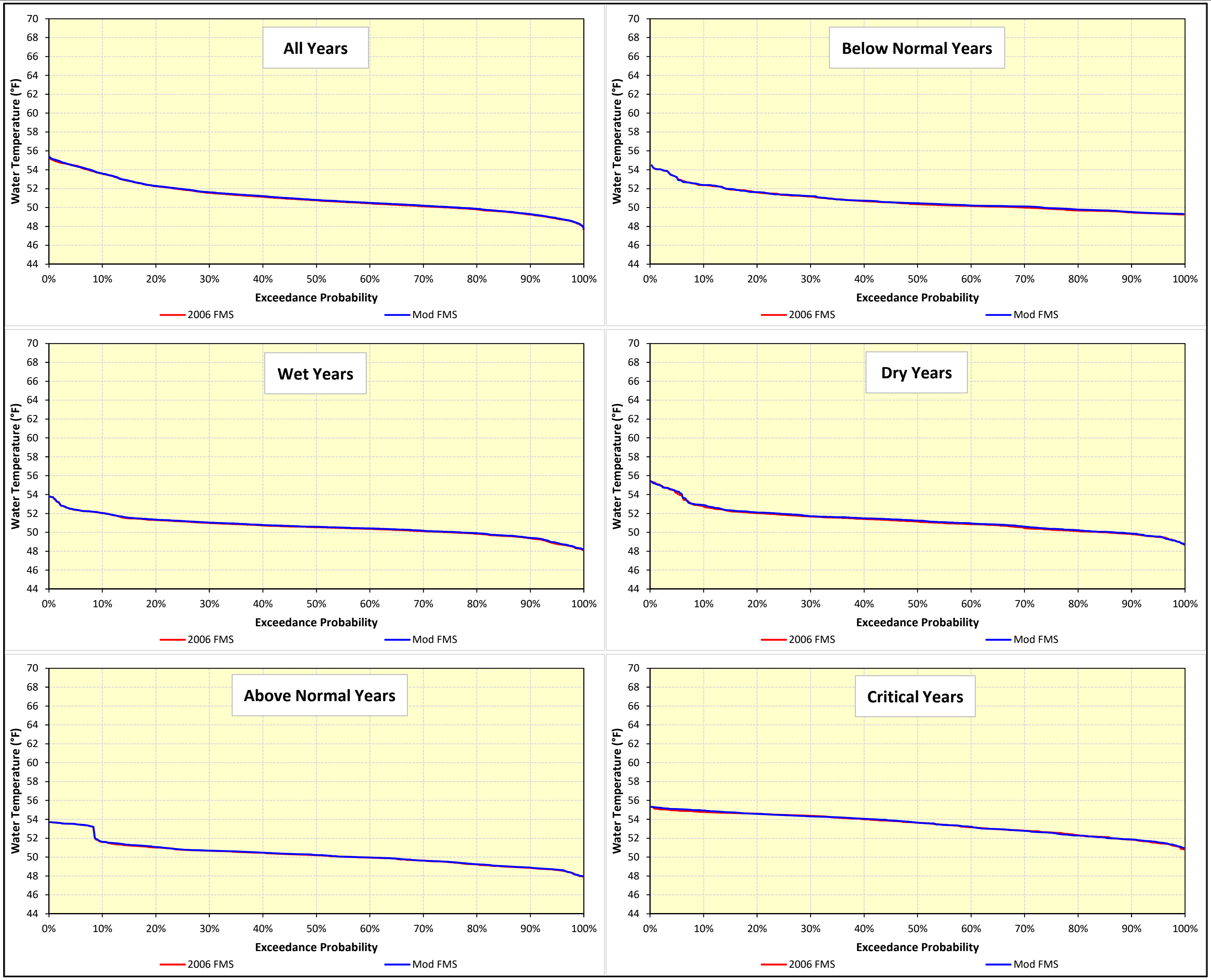

Figure F-5. Daily water temperature exceedance distributions during July below Keswick Dam on the Sacramento River over the 82-year simulation period.

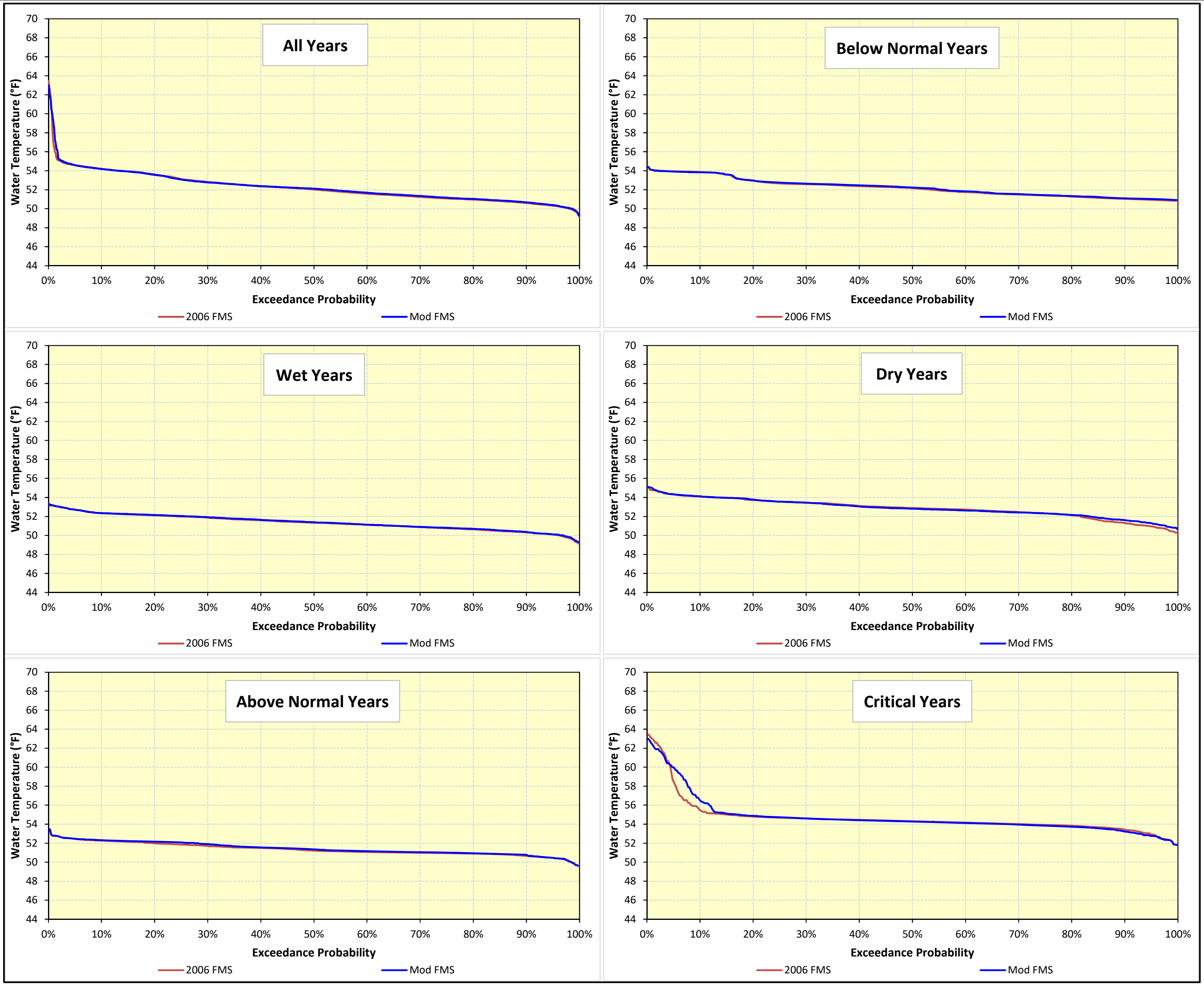

Figure F-6. Daily water temperature exceedance distributions during August below Keswick Dam on the Sacramento River over the 82-year simulation period.

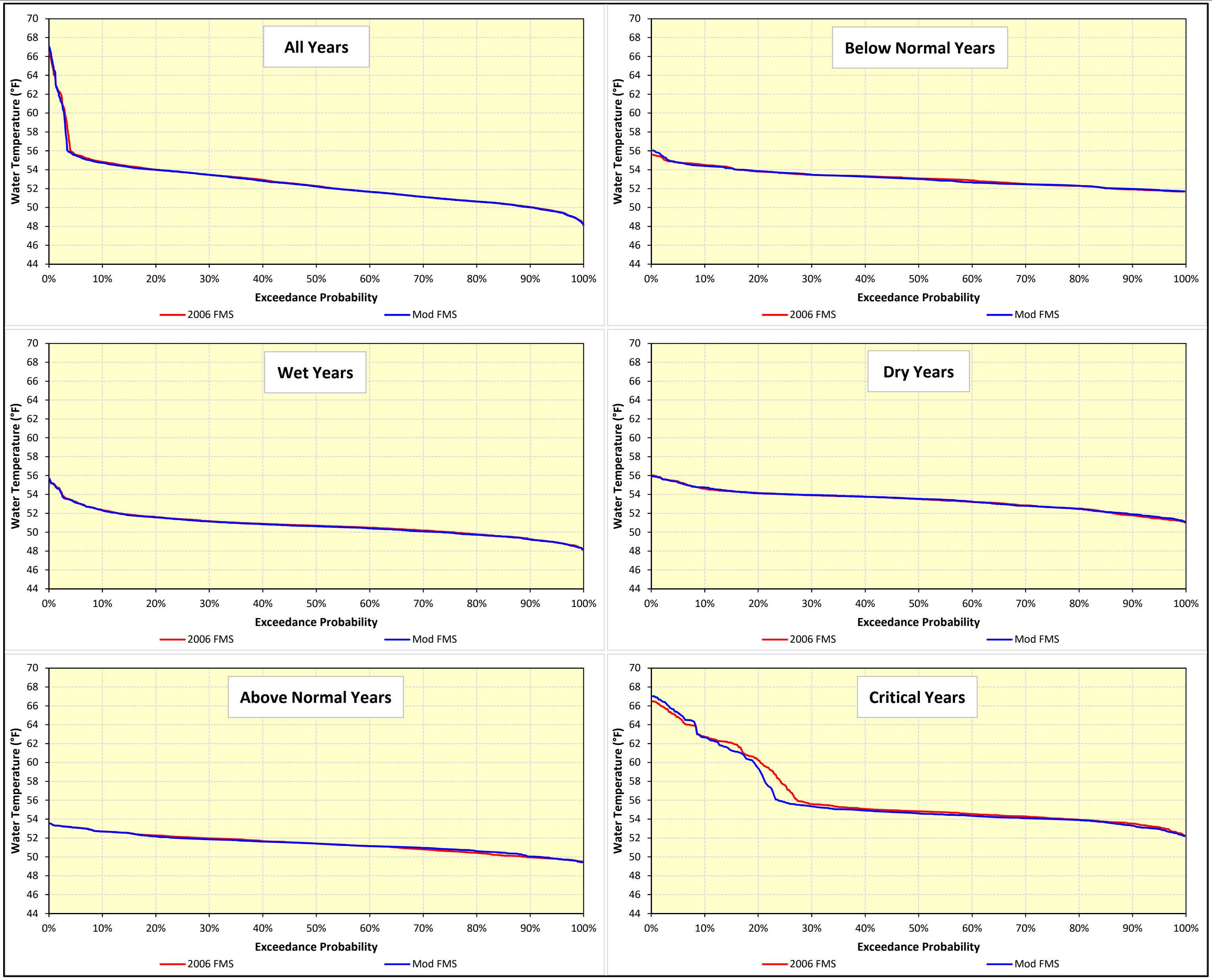

Figure F-7. Daily water temperature exceedance distributions during September below Keswick Dam on the Sacramento River over the 82-year simulation period.

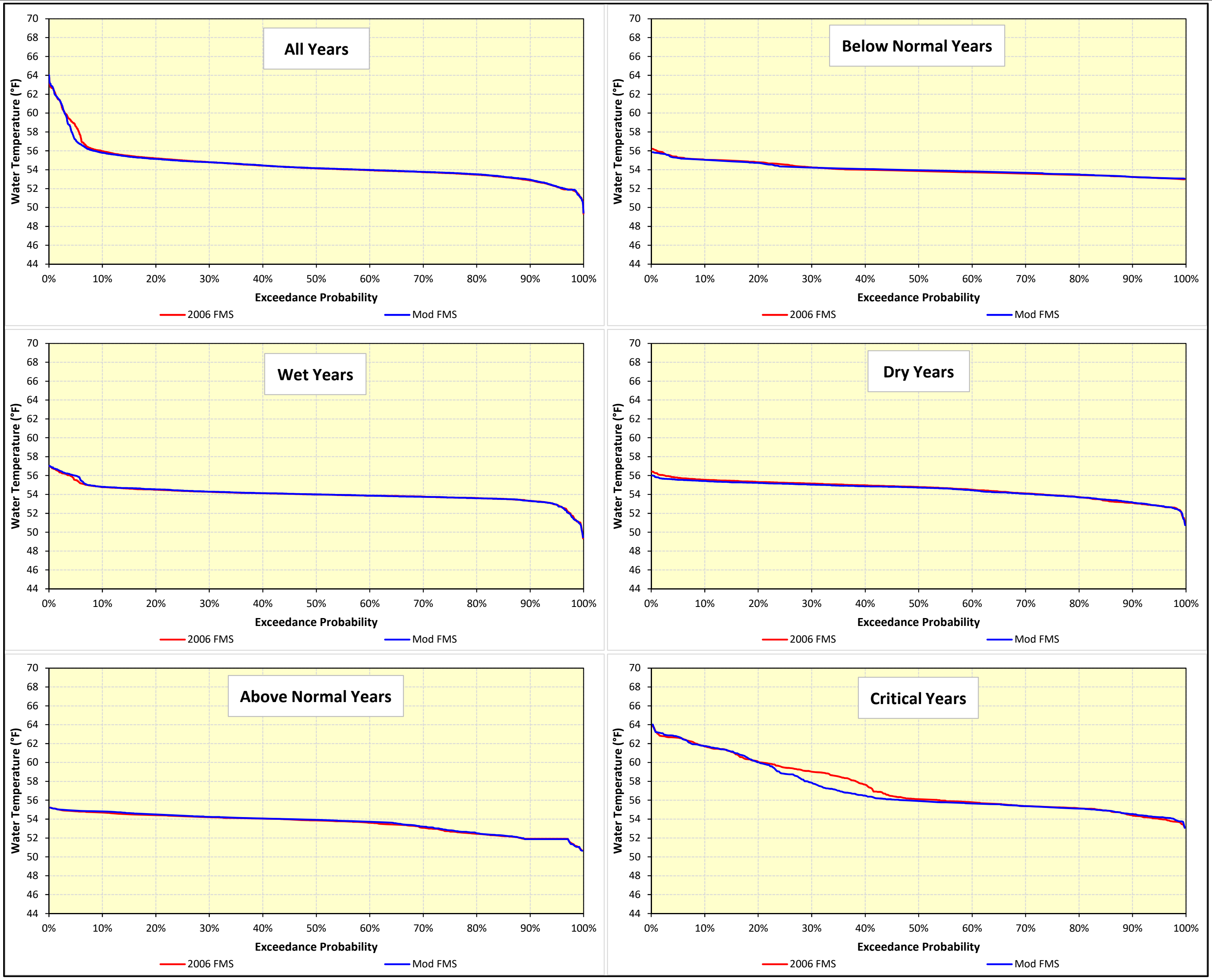

Figure F-8. Daily water temperature exceedance distributions during October below Keswick Dam on the Sacramento River over the 82-year simulation period.

Sacramento River
Balls Ferry
Average Daily Water Temperature Exceedances

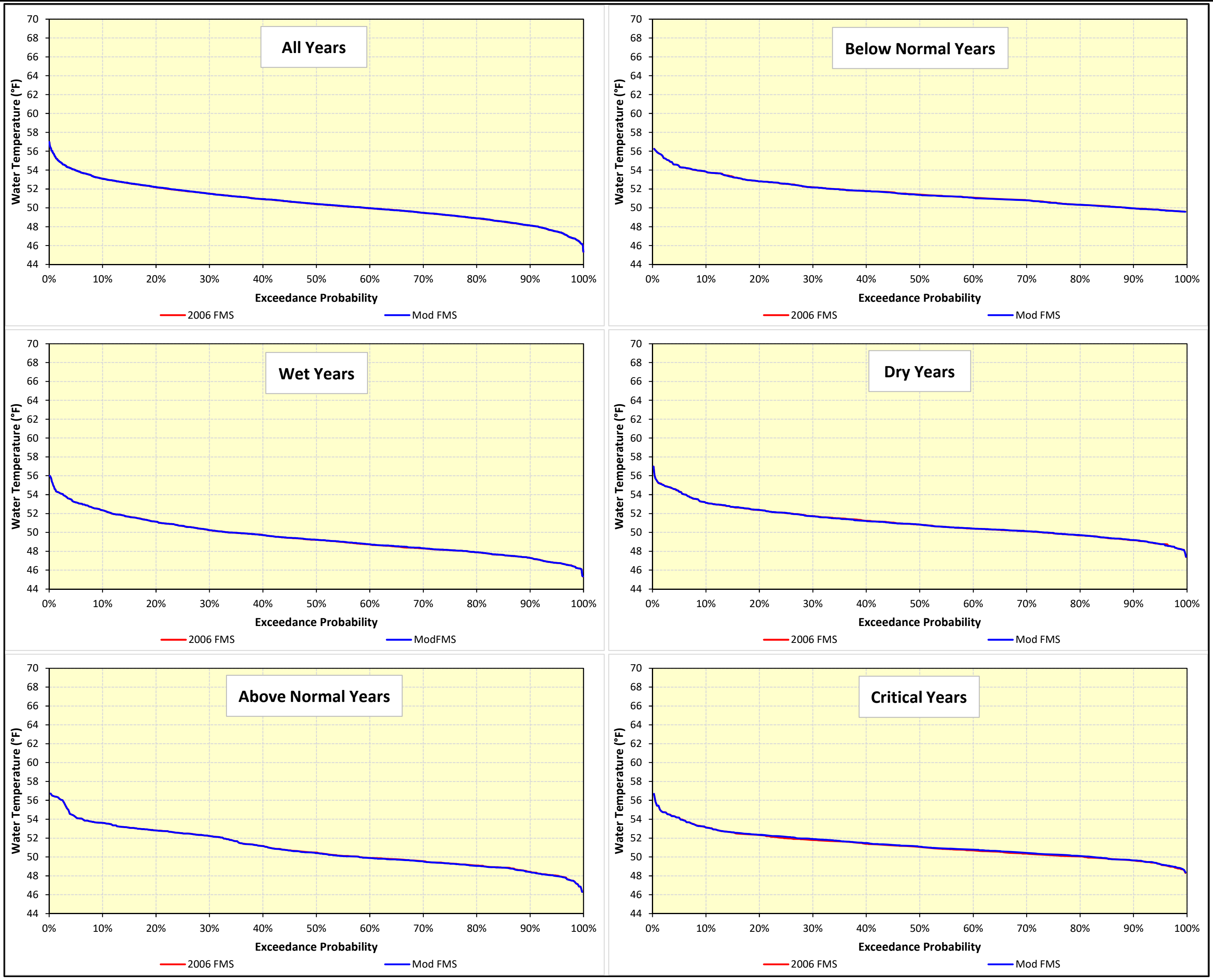

Figure F-9. Daily water temperature exceedance distributions during April at Balls Ferry on the Sacramento River over the 82-year simulation period.

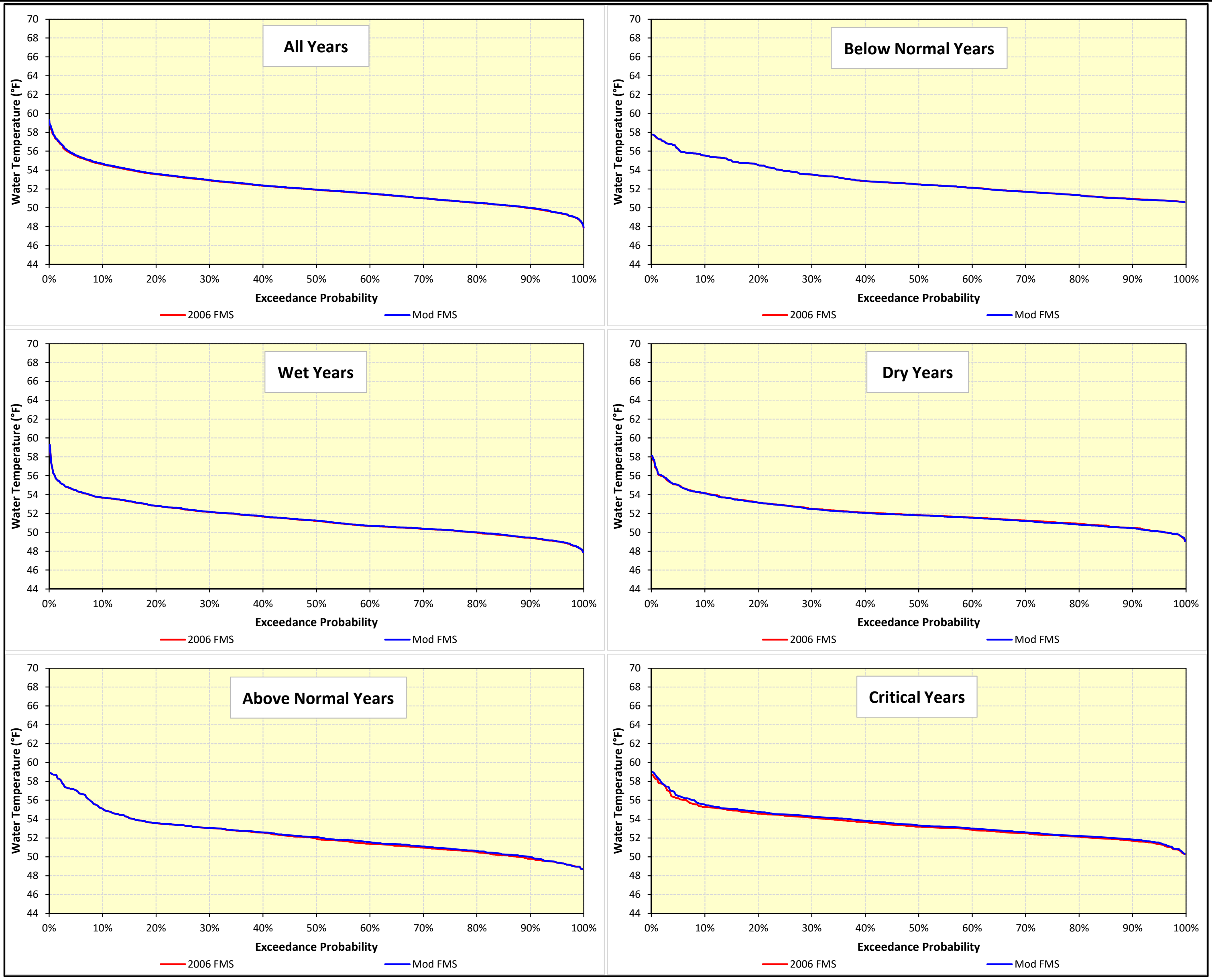

Figure F-10. Daily water temperature exceedance distributions during May at Balls Ferry on the Sacramento River over the 82-year simulation period.

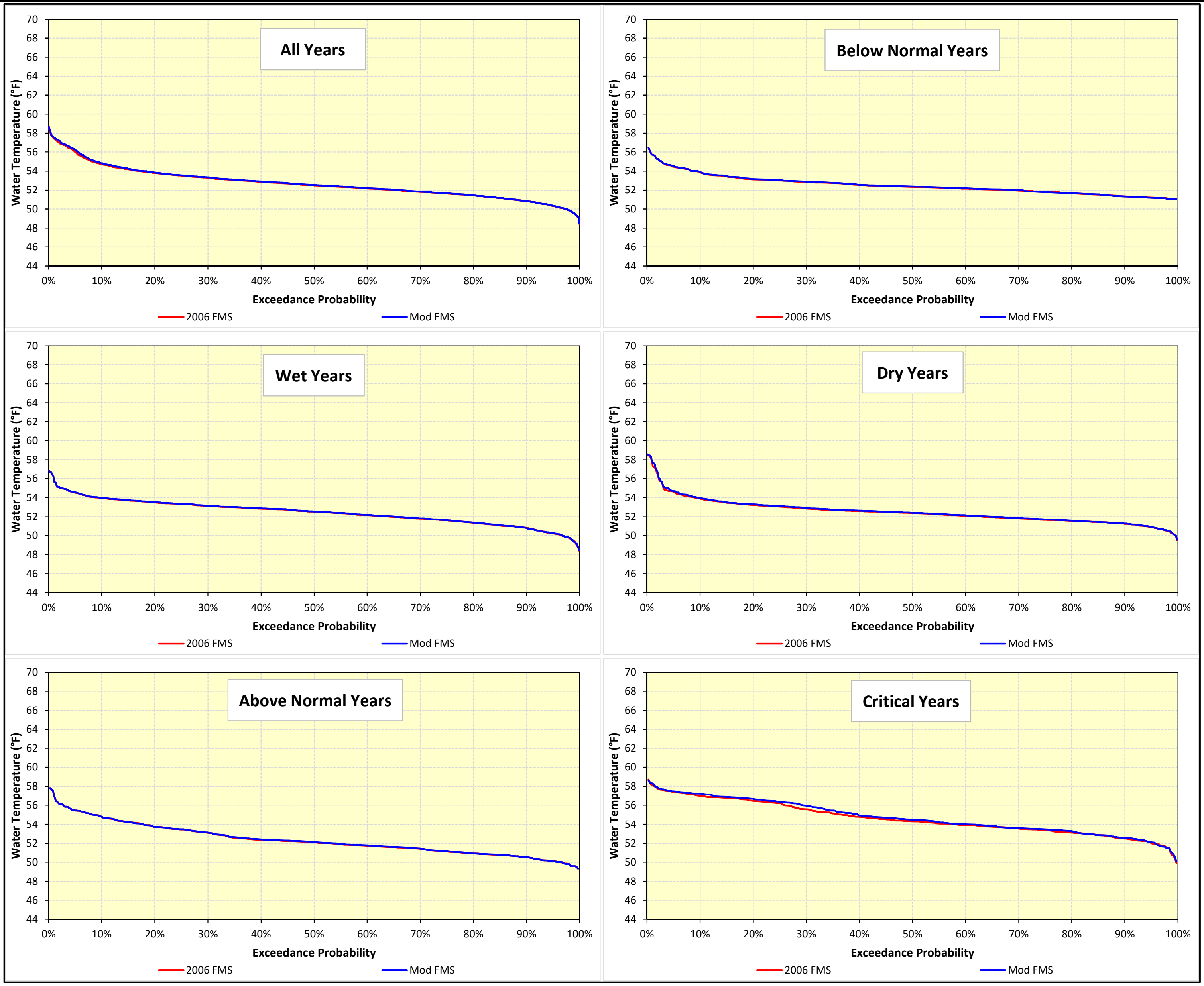

Figure F-11. Daily water temperature exceedance distributions during June at Balls Ferry on the Sacramento River over the 82-year simulation period.

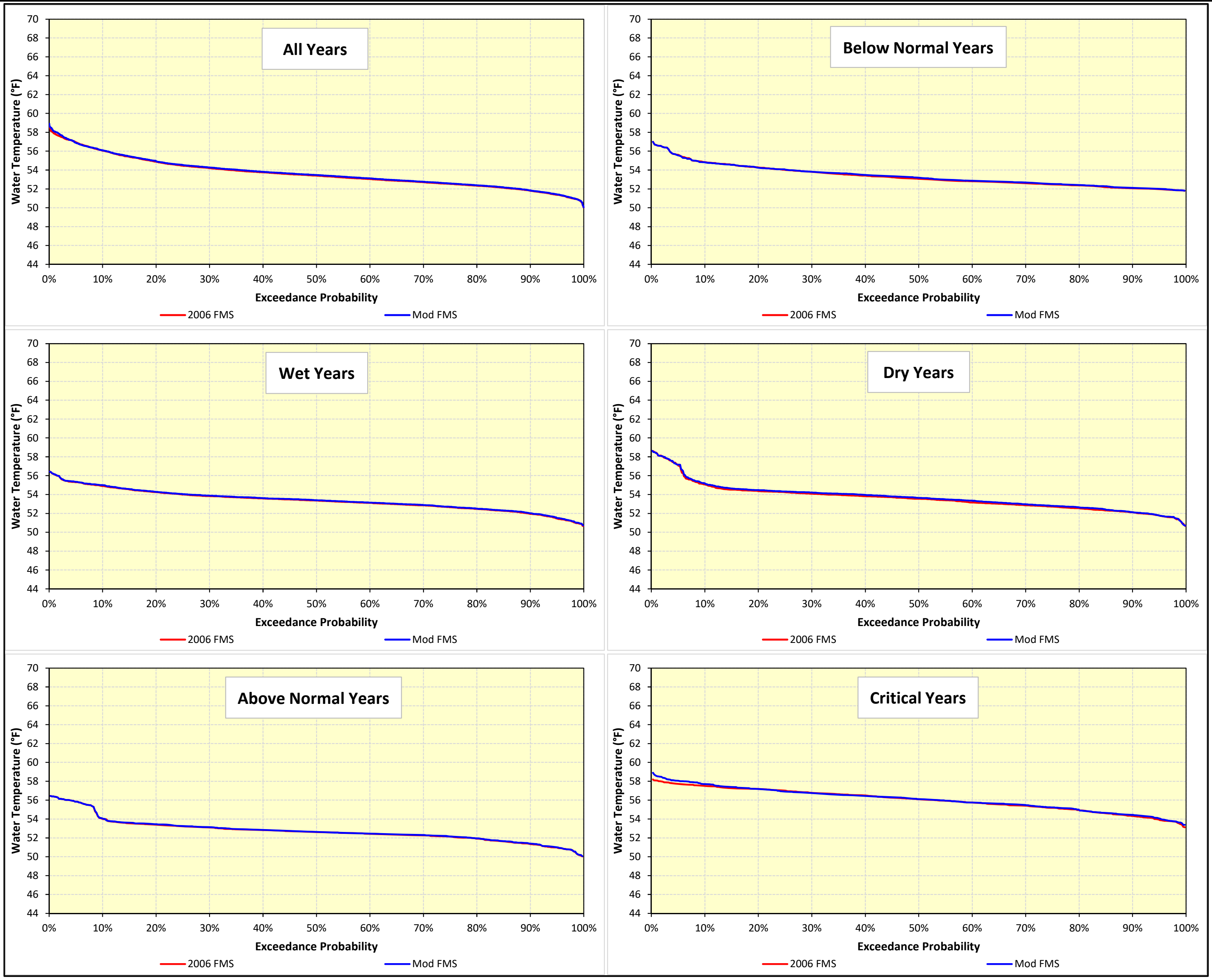

Figure F-12. Daily water temperature exceedance distributions during July at Balls Ferry on the Sacramento River over the 82-year simulation period.

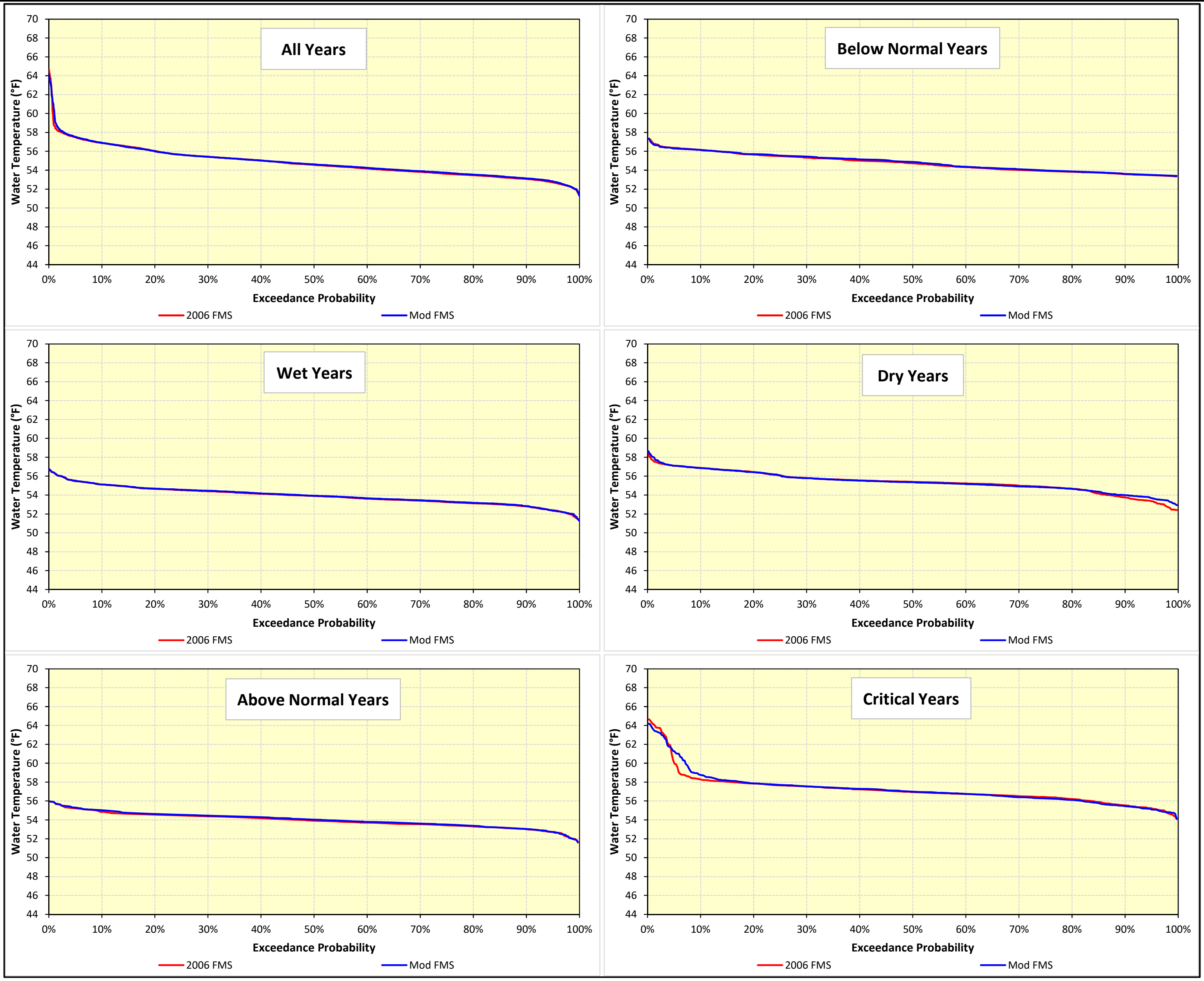

Figure F-13. Daily water temperature exceedance distributions during August at Balls Ferry on the Sacramento River over the 82-year simulation period.

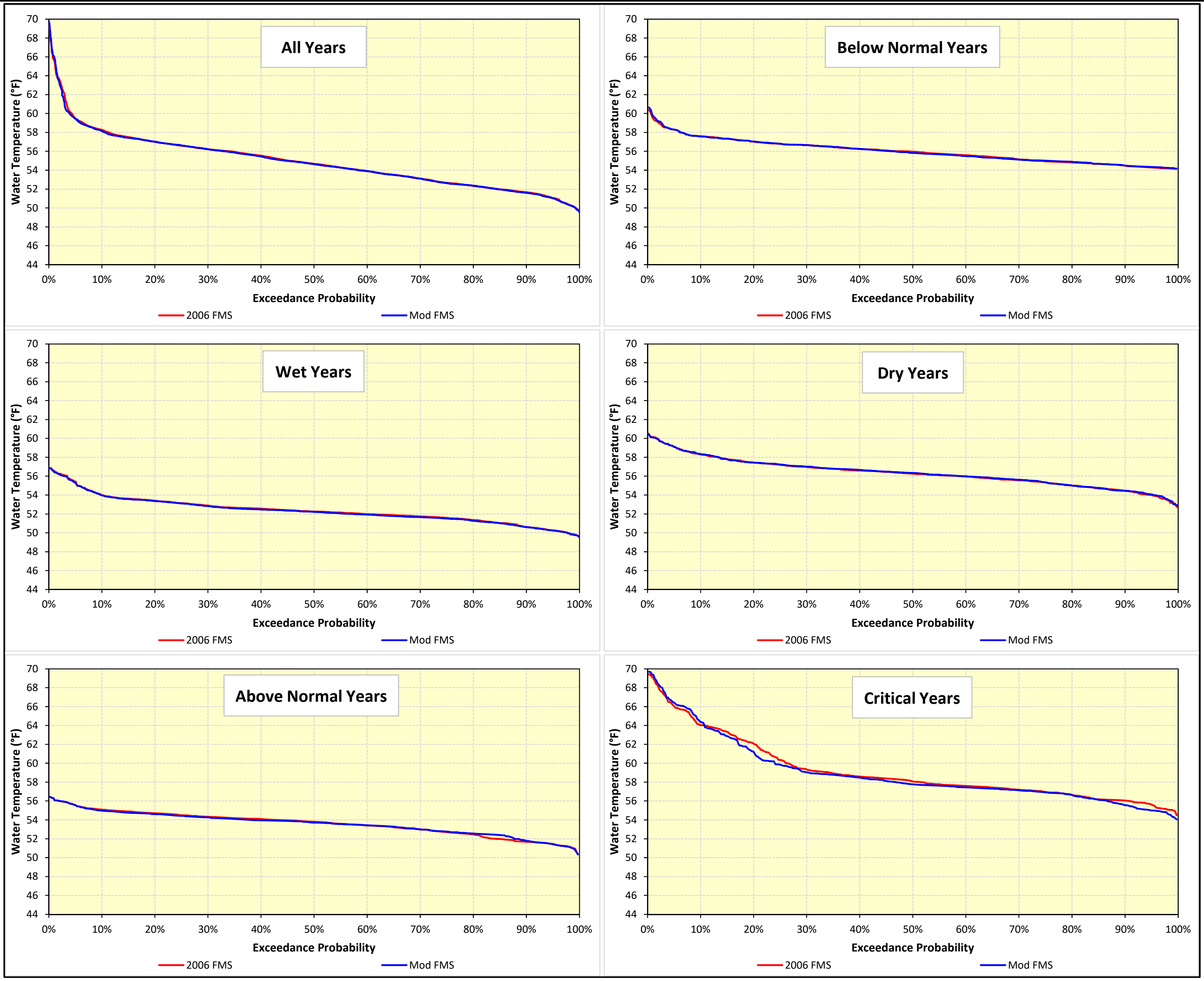

Figure F-14. Daily water temperature exceedance distributions during September at Balls Ferry on the Sacramento River over the 82-year simulation period.

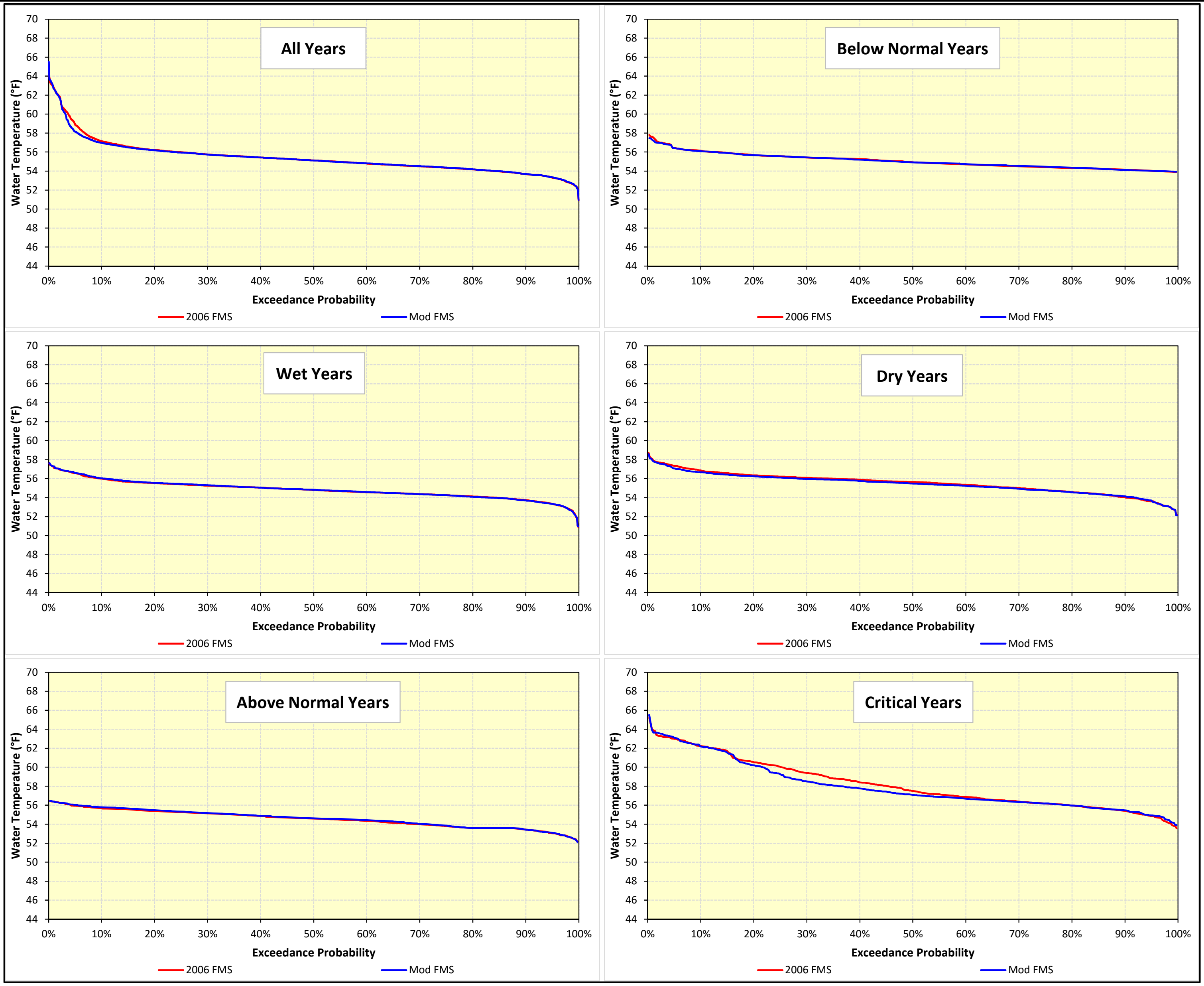

Figure F-15. Daily water temperature exceedance distributions during October at Balls Ferry on the Sacramento River over the 82-year simulation period.

Sacramento River
Red Bluff
Average Daily Water Temperature Exceedances

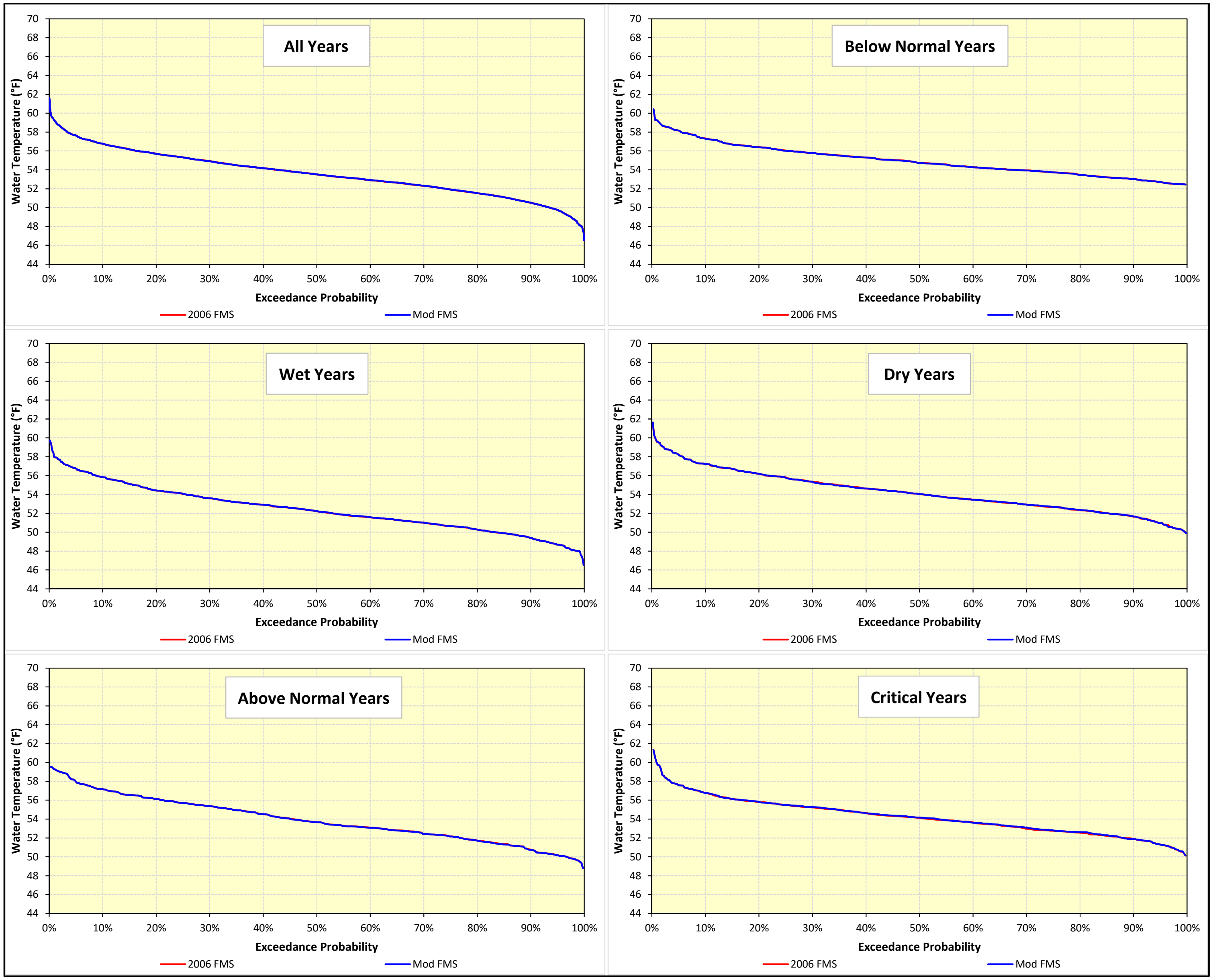

Figure F-16. Daily water temperature exceedance distributions during April at Red Bluff on the Sacramento River over the 82-year simulation period.

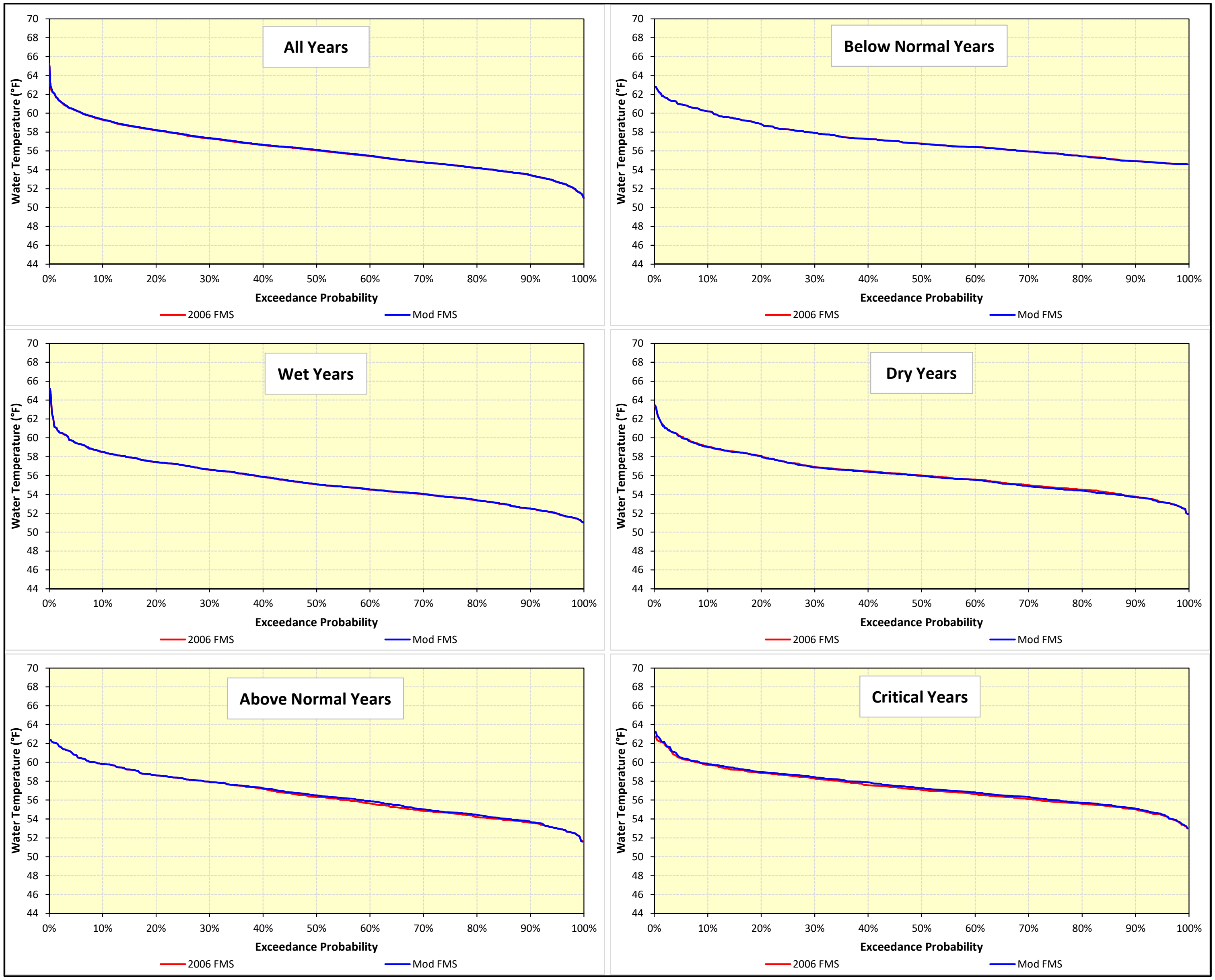

Figure F-17. Daily water temperature exceedance distributions during May at Red Bluff on the Sacramento River over the 82-year simulation period.

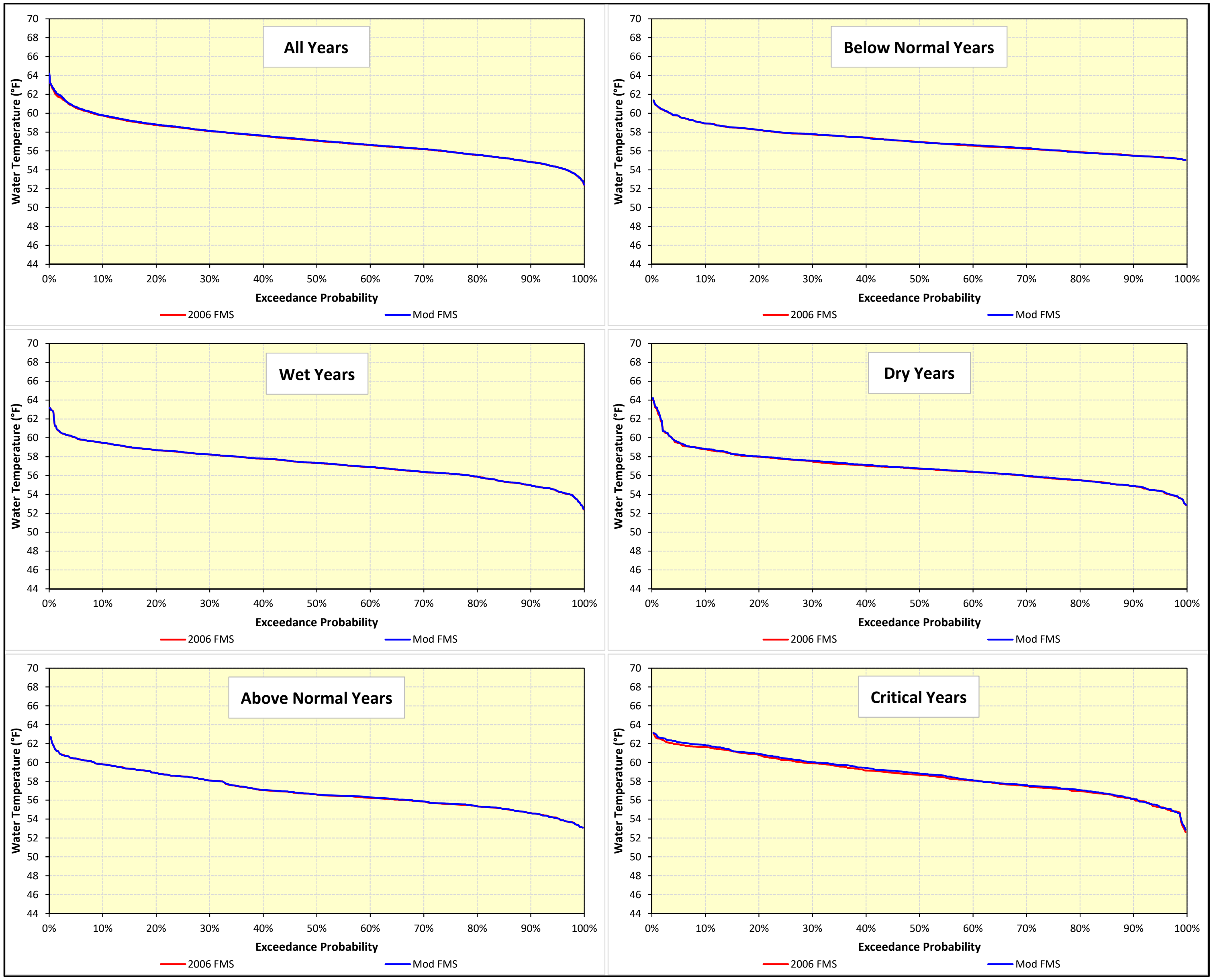

Figure F-18. Daily water temperature exceedance distributions during June at Red Bluff on the Sacramento River over the 82-year simulation period.

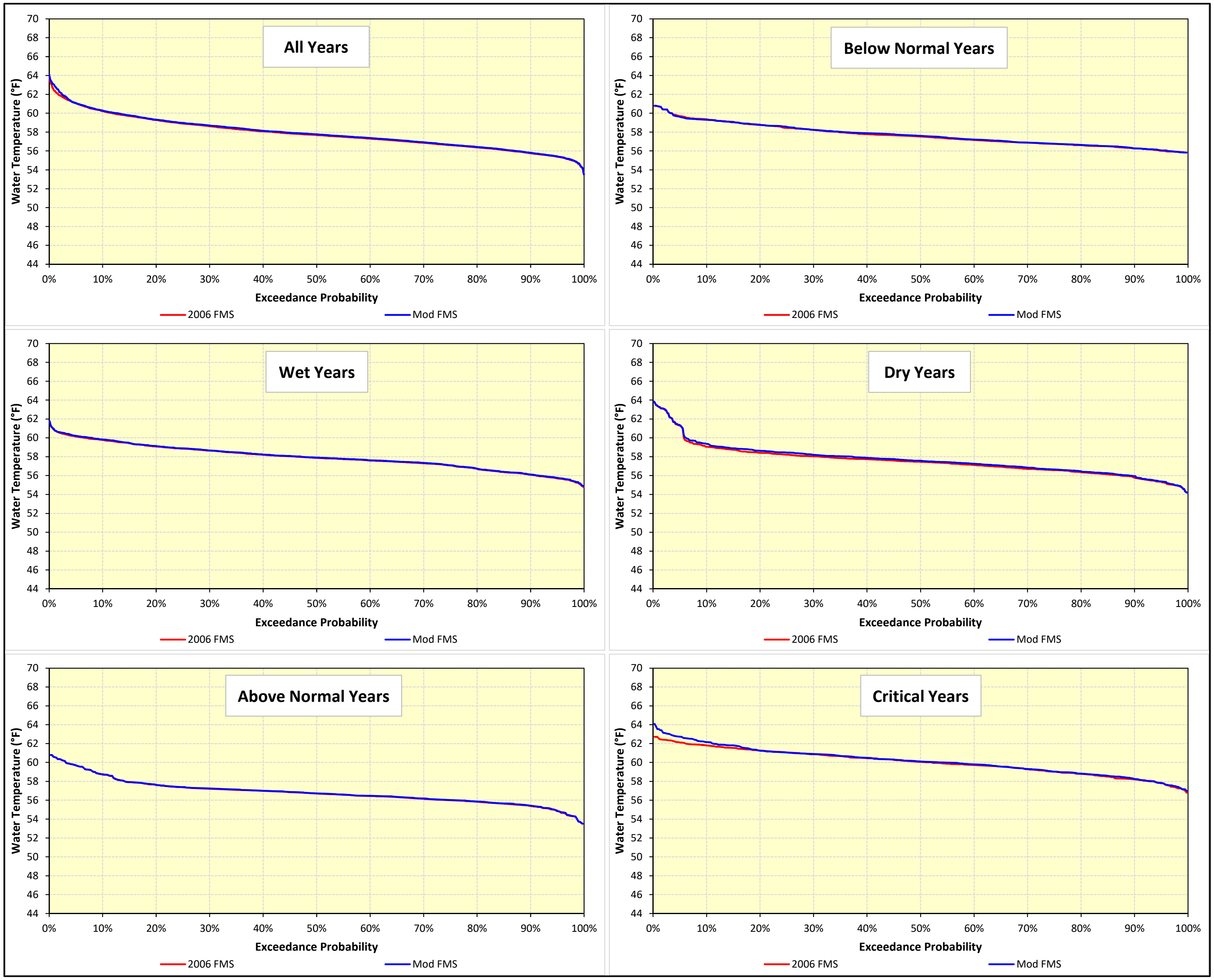

Figure F-19. Daily water temperature exceedance distributions during July at Red Bluff on the Sacramento River over the 82-year simulation period.

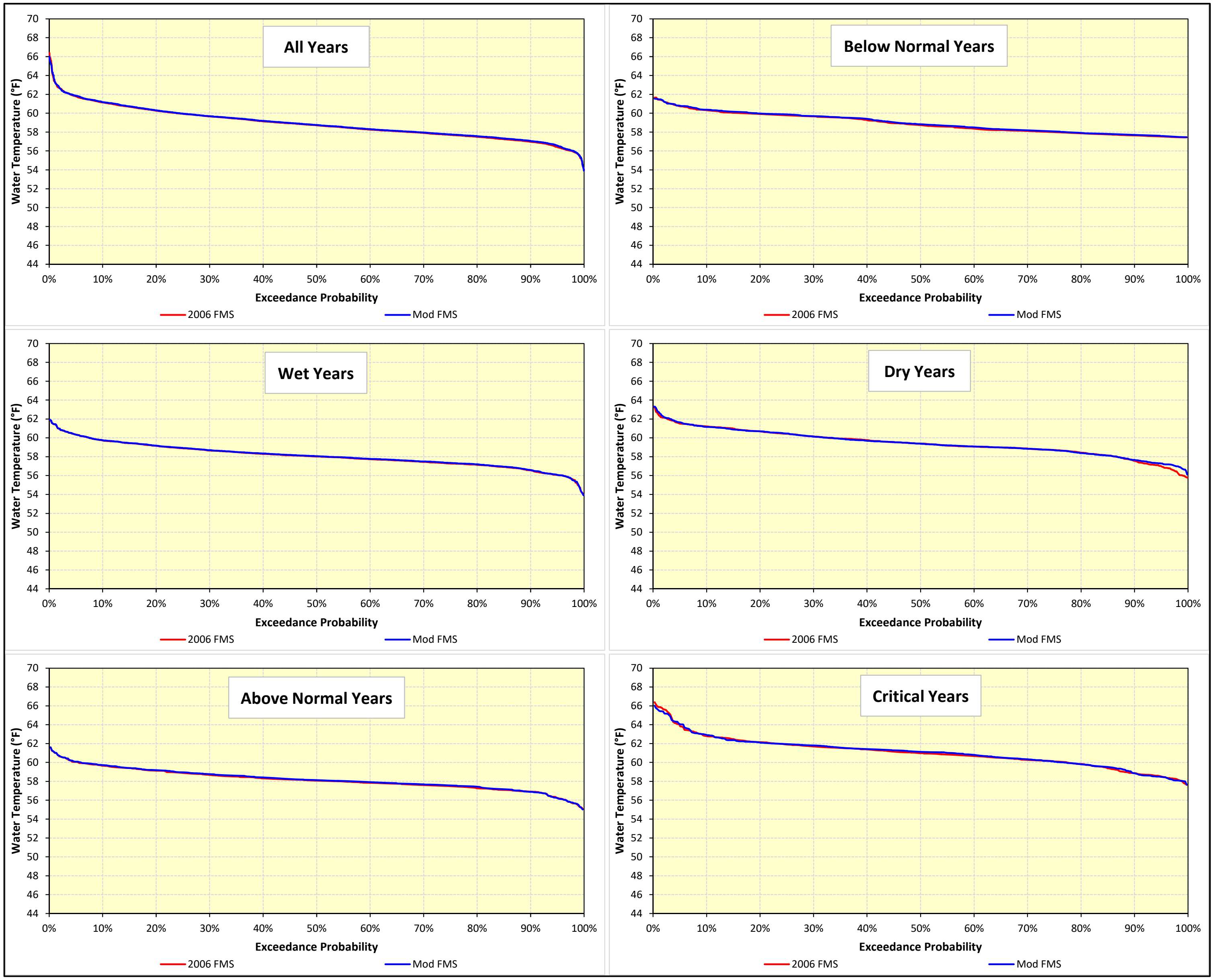

Figure F-20. Daily water temperature exceedance distributions during August at Red Bluff on the Sacramento River over the 82-year simulation period.

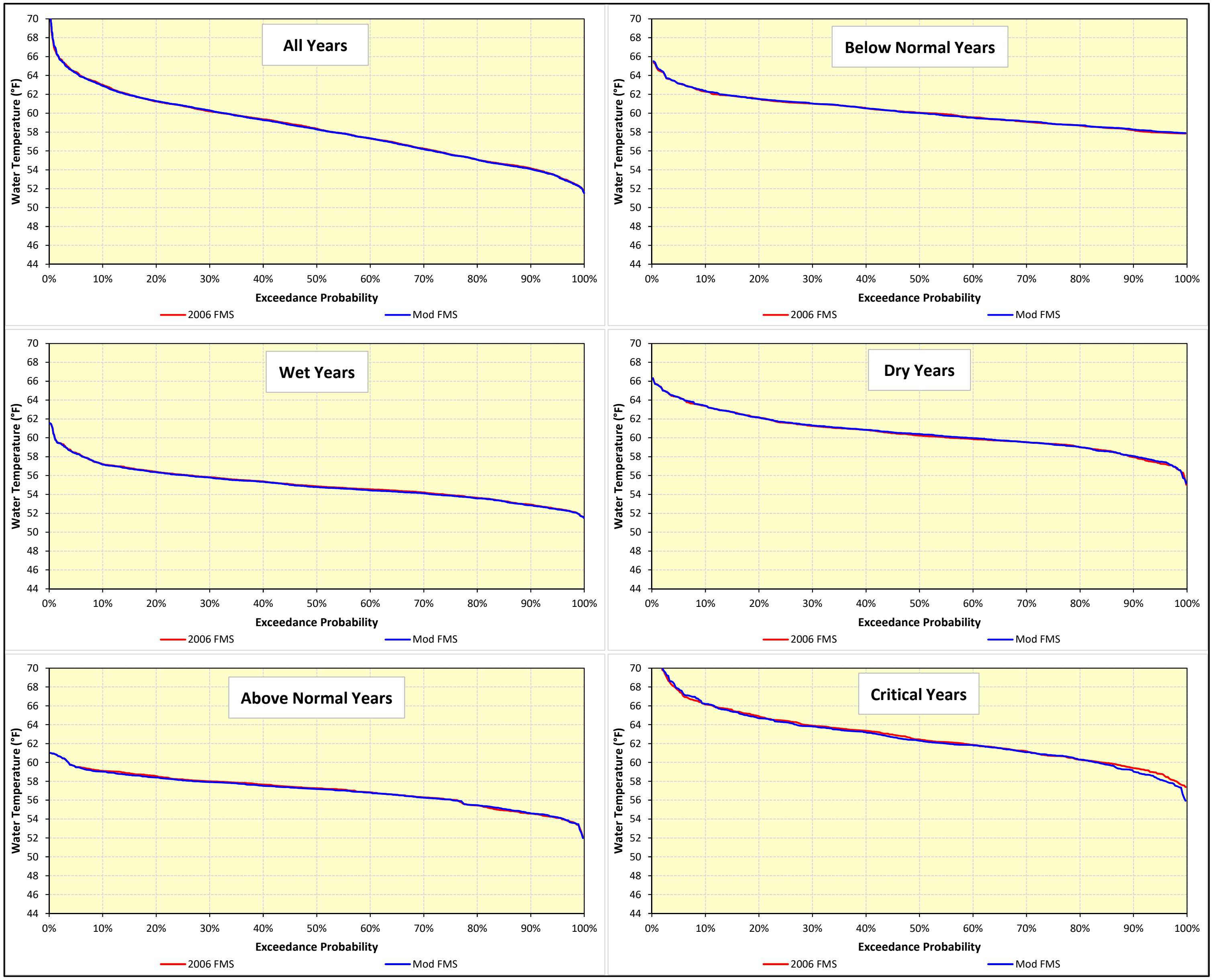

Figure F-21. Daily water temperature exceedance distributions during September at Red Bluff on the Sacramento River over the 82-year simulation period.

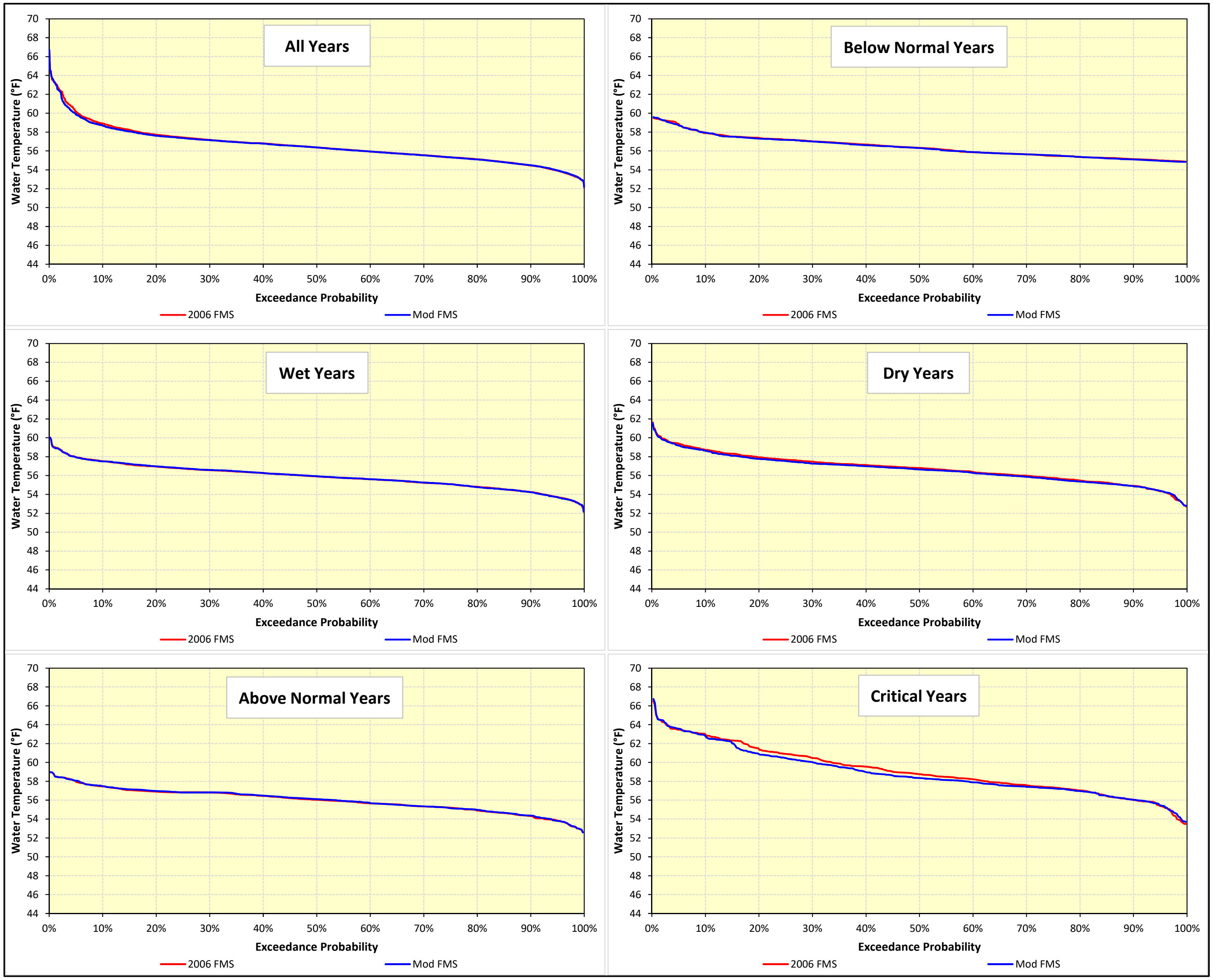

Figure F-22. Daily water temperature exceedance distributions during October at Red Bluff on the Sacramento River over the 82-year simulation period.