Date:

Memorandum to: CVP/SWP Operations Opinion
Administrative Record Number 151422SWR2006SA00268

From: Brycen Swart, Fisheries Biologist

Subject: Shasta RPA Adjustment Memo

Introduction

Since water year 2012, California has experience five consecutive years of below-average rainfall and snowpack. This has resulted in significant adverse effects to juvenile winter-run Chinook salmon populations over the last couple of years. Due to a lack of sufficient inflow and cold water pool in Shasta Reservoir and competing water demands in 2014 and 2015, Sacramento River water temperatures rose to sub-lethal and lethal levels contributing to very low egg-to-fry survival of juvenile winter-run Chinook salmon estimated to pass Red Bluff Diversion Dam (RBDD) in brood years 2014 (5.9%) and 2015 (4.2%), well below the 18-year average of 23.6% survival (Figure 1) (Martin *et al.* 2001; NMFS 2016; Poytress *et al.* 2014, 2015; Poytress 2016). NMFS Southwest Fisheries Science Center (NMFS-SWFSC) found that in 2014 and 2015, temperature dependent mortality alone resulted in a loss of approximately 77% and 85% of the population, respectively (Martin *et al.* 2016).

The 2009 biological and conference opinion on the long-term operation of the Central Valley Project and State Water Project (CVP/SWP operations Opinion, NMFS 2009) highlights the challenging nature of maintaining an adequate cold water pool in critically dry years, extended dry periods, and under future conditions, which will be affected by increased downstream water demands and climate change. In particular, Shasta Division Reasonable and Prudent Alternative (RPA) Action Suite I.2 includes exception procedures to deal with this reality. Despite the Bureau of Reclamation's (Reclamation) best efforts, severe temperature-related effects were not avoided in 2014 and 2015. Based on lessons learned over the last five years, NMFS is adjusting RPA Action Suite I.2 in order to minimize the adverse thermal effects to winter-run Chinook salmon and to meet the objectives of the actions.

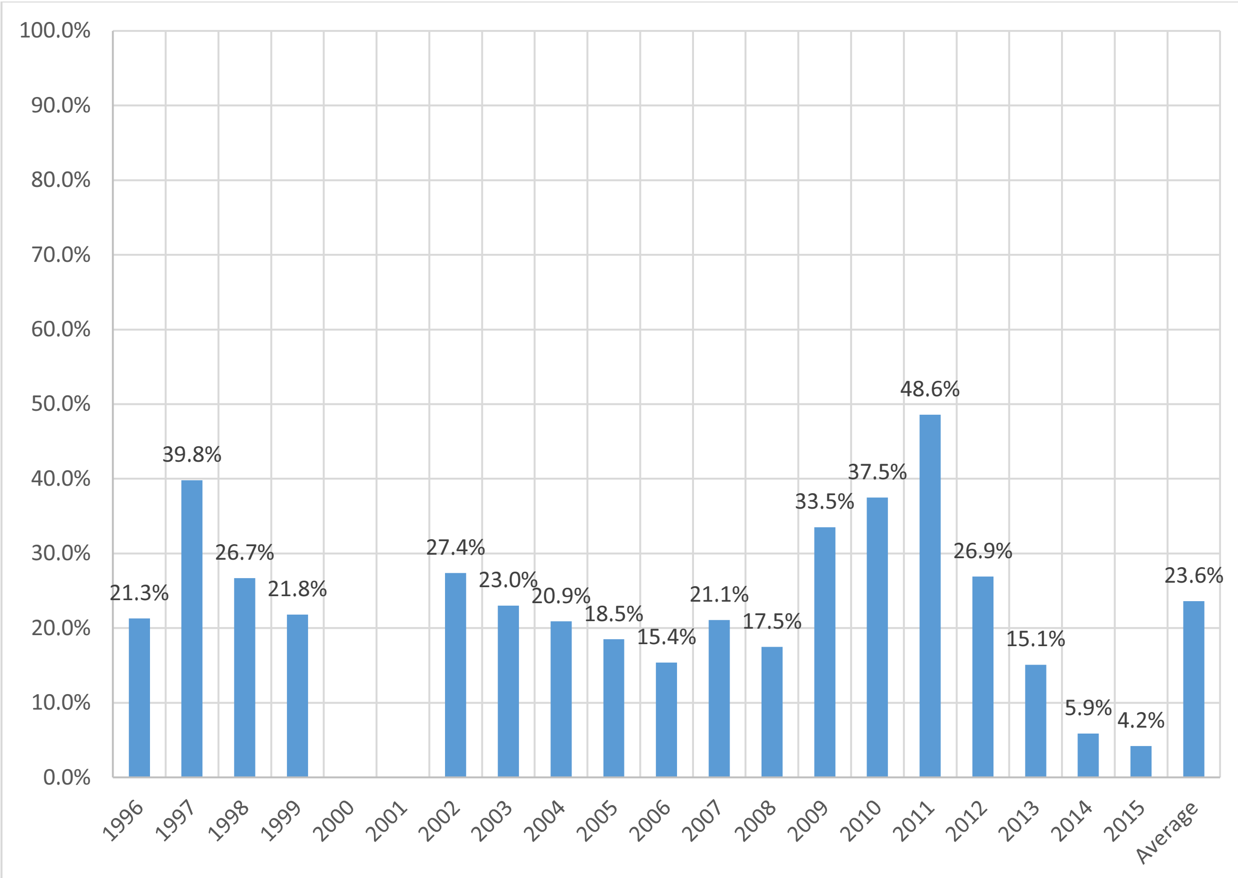

Figure 1. Estimated egg-to-fry survival from passage at Red Bluff Diversion Dam (Martin *et al.* 2001; NMFS 2016; Poytress *et al.* 2014, 2015; Poytress 2016)

<u>Modification of RPA Action I.2.1 Performance measure to Objective-Based Management</u>

The original objective of RPA Action I.2.1 was to establish and operate to a set of performance measures for temperature compliance points and End-of-September (EOS) carryover storage, enabling Reclamation and NMFS to assess the effectiveness of this suite of actions over time. The performance measures were to help ensure that the beneficial variability of the system from changes in hydrology would be measured and maintained. However, over the last five years, NMFS has learned that a 10-year running average is no longer an adequate metric to minimize adverse effects of temperature to the winter-run Chinook population. It does not account for the temperature-related deleterious effects to winter-run in dry and critically dry water years. Instead NMFS proposes to change the performance metrics to annual minimum requirements, as follows.

1. **Shasta Reservoir storage requirements**

Because of the thermal dynamics associated with seasonally stratification in Shasta Reservoir, storage levels are directly linked to cold water pool volume availability. As such, the management of reservoir storage throughout the year has a direct impact on release temperatures and the subsequent thermal dynamics of the mainstem Sacramento River. Before the Shasta Reservoir temperature control device (TCD) was built, NMFS required that a minimum 1.9 MAF EOS storage level be maintained to protect the cold water pool in Shasta Reservoir, in case the following year was critically dry (drought year insurance). This was because a relationship exists between EOS storage and the cold water pool; the greater the EOS storage level, typically the greater the cold water pool the following year. The requirement for 1.9 MAF EOS was a term and condition in NMFS's winter-run opinion (NMFS 1993). Since 1997, Reclamation has been able to control water temperatures in the upper Sacramento River through use of the TCD. The minimum 1.9 MAF EOS required to be imposed as a non-discretionary term and condition in the 2004 CVP/SWP operations Opinion.

In its 2008 CVP/SWP operations biological assessment, Reclamation proposed continuation of the 90 percent exceedance forecast for determining water allocations early in the year, starting with the February 15 forecast. However, Reclamation did not propose to manage Shasta operations to a 1.9 MAF EOS target, although CALSIM assumed this target in all analyses. Given the increased demands for water by 2030 and less water being diverted from the Trinity River, the 2009 CVP/SWP operations Opinion concluded that it will be increasingly difficult to meet the various temperature compliance points, even with a TCD, especially since Reclamation was not proposing any EOS storage target.

Based on the historical 82-year period, CALSIM II results showed that in about 10 percent of years (typically the driest water years) a 1.9 MAF EOS would not be met. Additional model runs revealed that a higher target of 2.2 MAF EOS improved the probability of meeting Balls Ferry temperature target about 10 percent over the previous 1.9 MAF target. Based on these analyses and those in Anderson (2009), the 10-year running average performance measures associated with meeting EOS carryover storage at Shasta Reservoir in order to maintain the potential to meet the various temperature compliance points as required in RPA I.2.1 were set at:

- 87% of years: Minimum EOS storage of 2.2 million acre-feet (MAF)
- 82% of years: Minimum EOS storage of 2.2 MAF and End of April (EOA) storage of 3.8 MAF in following year (to maintain potential to meet Balls Ferry compliance point)
- 40% of years: Minimum EOS storage of 3.2 MAF (to maintain potential to meet Jelly's Ferry compliance point in following year)

However, the current 8-year average also falls short of RPA Action I.2.1 Shasta storage performance metric. Since 2009, 1.9 MAF EOS, let alone 2.2 MAF, has not been met in 4 out of 8 years (*i.e.* 50% of years) (Table 1):

Table 1. End of April and End of September storages by water year from 2009 – 2016. Data source: Reclamation 2016.

Water Year	End of April Storage (MAF)	End of September Storage (MAF)	Water Year Type
2009	3.00	1.77	D
2010	4.39	3.32	BN
2011	4.27	3.34	W
2012	4.44	2.59	BN
2013	3.79	1.91	D
2014	2.41	1.16	C
2015	2.66	1.60	C
2016	4.23	2.81	BN

- 50% (4 out of 8) of Years: Minimum 2.2 MAF EOS storage
- 50% (4 out of 8) of Years: Minimum 2.2 MAF EOS storage and 3.8 MAF EOA storage
- 25% (2 out of 8) of Years: Minimum 3.2 MAF EOS storage

In addition to an EOS storage metric to determine whether the temperature compliance can be met for the following temperature management season, it has become clear from Shasta operations in the drought years that an end of April storage requirement is also a critical metric towards meeting temperature compliance throughout the temperature management season. A minimum of 3.65 MAF in Shasta storage enables use of the TCD upper gates which allows for the blending of warmer upper reservoir levels and less reliance on the cold water pool (Table 2). A primary issue in 2014 and 2015 was that Shasta storage was so low that the upper gates were not available, lending to the release of colder water than necessary from the middle gate and this colder water being released earlier than needed.

Table 2. Shasta Temperature Control Device Gates with Elevation and Storage (Reclamation 2008)

TCD Gates	Shasta Elevation with 35 feet of submergence	Shasta Storage
Upper Gates	1035	~3.65 MAF
Middle Gates	935	~2.50 MAF
Pressure Relief Gates	840	~0.67 MAF
Side Gates	720*	~0.01 MAF

* Low Level intake bottom.

According to analysis done by Reclamation using data from 1998 through 2015, a minimum EOA storage of 3.5 MAF is needed in order to meet a daily average temperature (DAT) of less than 56°F at CCR[1], 3.9 MAF is needed in order to meet a DAT of 53°F at CCR[2], and 4.2 MAF is needed in order to meet a DAT of less than 53°F at CCR (Figure 2).

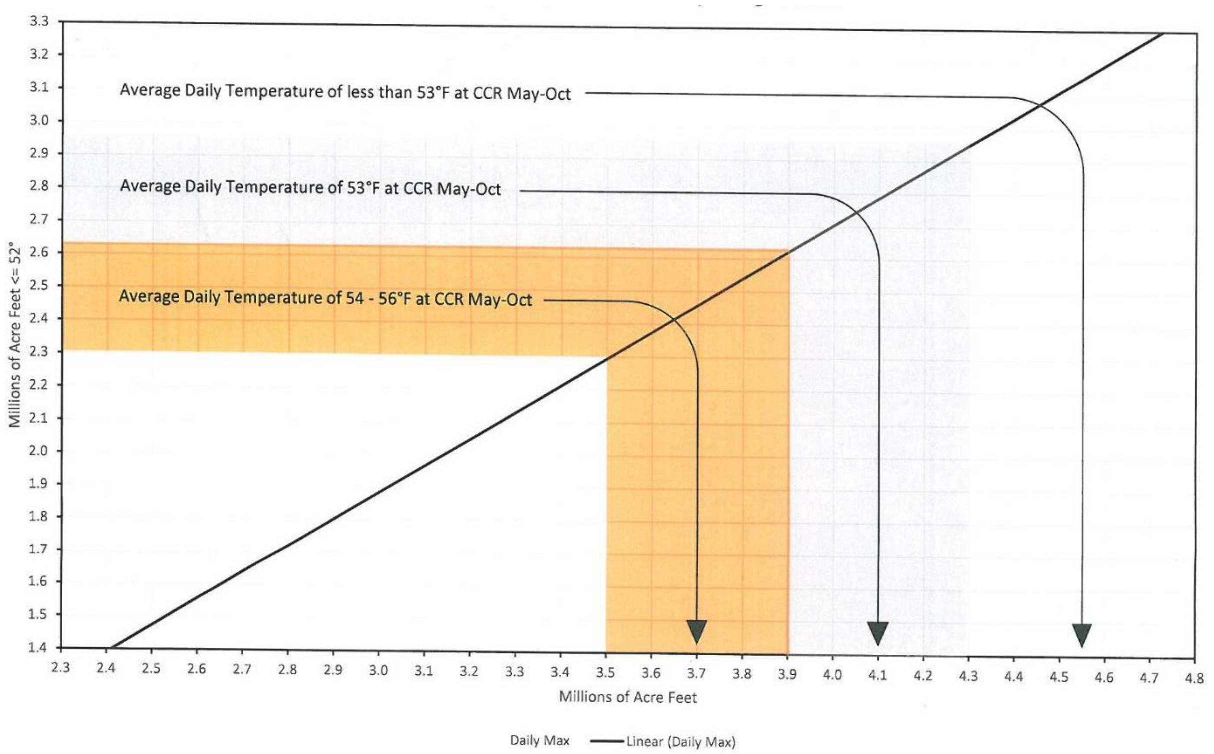

Figure 2. End of April Total Shasta Reservoir storage versus 52°F or less storage (*i.e.* cold water pool) with CCR Average Daily Temperature for May through October. Graph submitted to NMFS from Reclamation on October 27, 2016.

A review of the historical data from Anderson (2009) from 1955 to 2008 shows that minimum EOS storage in a series of critically dry and dry water years must be 1.9 MAF, in order to meet 3.3 MAF in EOA in the following year (3.3 MAF in EOA will meet a 56°F DAT at CCR). While a minimum EOS of 2.2 MAF must be achieved in order to meet 3.8 MAF in EOA that following year (3.8 MAF in EOA will meet 56°F DAT at Balls Ferry). Anderson (2009) did not recommend an EOS to meet 4.2 EOA that following year (4.2 MAF in EOA will meet 56°F DAT at Jellys Ferry).

Instead of using a 10-year running average, annual minimum EOA and EOS Shasta storage requirements based on water year type would be a better metric to provide suitable instream conditions for winter-run Chinook below Keswick Dam, especially in dry and critically dry water years. Table 3 shows the average EOA and EOS storages with corresponding CCR DAT temperatures and temperature dependent mortality (discussed further below in subsection 4) by water year type for water years 1996-2016[3].

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[1] Sacramento River above Clear Creek (CCR) (river mile 292) California Data Exchange Center gauge station

[2] In water year 2016 it was decided that 53°F daily average temperature at CCR was a surrogate for 55°F 7-day average of the daily maxima (7DADM). See section below for changes to the temperature compliance metric.

[3] 1996 is the earliest publicly available Sacramento River temperature data on Reclamation's Central Valley Operations website and it is also the year when the TCD became operational.

Table 3. End of April storage, end of September storage, CCR daily average temperature for May through October, and modeled temperature dependent mortality (from Martin *et al.* 2016) by water year type for water years 1996 to 2016.

Water Year	End of April Storage (MAF)	End of September Storage (MAF)	CCR Daily Average Temperature (May - Oct)	Modeled Temperature Dependent Mortality	Modeled Total ETF Survival	Actual ETF Survival
Critical						
2008	2.95	1.38	54.6	40.9%	18.9%	17.5%
2014	2.41	1.16	56.9	77.0%	7.1%	5.9%
2015	2.66	1.60	56.7	85.4%	4.6%	4.2%
Average	*2.68*	*1.38*	*56.1*	*67.8%*	*10.2%*	*9.2%*
Dry						
2001	4.02	2.20	53.0			
2002	4.30	2.56	52.6	1.4%	23.7%	27.4%
2007	3.90	1.88	53.3	7.0%	29.6%	21.1%
2009	3.00	1.77	54.1	18.9%	24.0%	33.5%
2013	3.79	1.91	54.0	9.6%	25.3%	15.1%
Average	*3.80*	*2.06*	*53.4*	*9.2%*	*25.6%*	*24.3%*
Below Normal						
2004	4.06	2.18	53.5	37.7%	17.9%	20.9%
2010	4.39	3.32	52.2	0.0%	33.1%	37.5%
2012	4.44	2.59	52.4	0.0%	31.9%	26.9%
2016	4.23	2.81	53.0	2.3%		
Average	*4.28*	*2.73*	*52.8*	*10.0%*	*27.6%*	*28.4%*
Above Normal						
2000	4.15	2.99	52.7			
2003	4.54	3.16	52.6	1.4%	24.6%	23.0%
2005	4.21	3.04	53.2	4.8%	17.2%	18.5%
Average	*4.30*	*3.06*	*52.8*	*3.1%*	*20.9%*	*20.8%*
Wet						
1996	4.31	3.10		7.4%	31.1%	21.3%
1997	3.94	2.31		10.5%	28.6%	39.8%
1998	4.06	3.44	52.2	2.7%	24.9%	26.7%
1999	4.26	3.33	51.6	1.2%	31.2%	21.8%
2006	4.06	3.21	51.7	0.3%	18.4%	15.4%
2011	4.27	3.34	52.1	0.0%	33.9%	48.6%
Average	*4.15*	*3.12*	*51.9*	*3.7%*	*28.0%*	*28.9%*

Based on the above information, NMFS recommends a minimum 4.2 MAF EOA storage every year in order to meet temperature management of less than 53°F at CCR in order to minimize the adverse effects to spawning, egg incubation, and fry emergence from temperature related impacts. In recognition that this minimum EOA storage will not occur every year, especially in dry and critically dry water years, NMFS developed the following annual requirements based on water year type:

- Critically dry: 3.3 MAF
- Dry: 3.9 MAF
- Below Normal: 4.2 MAF
- Above Normal: 4.2 MAF
- Wet: 4.2 MAF

In order to ensure a minimum EOS storage level be maintained to protect the cold water pool in Shasta Reservoir for the following year, NMFS developed the following annual requirements based on water year type:

- Critically dry: 1.9 MAF
- Dry: 2.2 MAF
- Below Normal: 2.8 MAF
- Above Normal: 3.2 MAF
- Wet: 3.2 MAF

2. Temperature Compliance Location Criterion

Not only does RPA Action I.2.1 require a 10-year running average performance metric for storage, but also for temperature compliance location. The 10-year running average performance measure for temperature compliance during the summer temperature management season (May 15 to October 31) in RPA Action I.2.1 is required to be:

- Meet Clear Creek compliance point 95% of time
- Meet Balls Ferry compliance point 85% of time
- Meet Jelly's Ferry compliance point 40% of time
- Meet Bend Bridge compliance point 15% of time

Based on daily average temperature data of not in excess of 56°F, since issuance of the CVP/SWP operations Opinion, Reclamation has failed to meet the summer temperature compliance point performance measure. So far the 7-year average (2010-2016) is (Table 4):

- Clear Creek was met 80% of the time
- Balls Ferry was met 67% of the time
- Jellys Ferry was met 51% of the time
- Bend Bridge was met 37% of the time

Table 4. Percentage of days each year in compliance with 56°F daily average temperature compliance location metric from May 15 – October 30, 2010 – 2016. Data source: Reclamation 2016.

Water Year	Clear Creek	Balls Ferry	Jellys Ferry	Bend Bridge
2010	100%	99%	86%	57%
2011	100%	99%	91%	58%
2012	100%	100%	92%	75%
2013	100%	77%	34%	26%
2014	44%	2%	0%	0%
2015	14%	1%	0%	0%
2016	100%	90%	52%	41%
Average	**80%**	**67%**	**51%**	**37%**

Not meeting the Clear Creek temperature compliance location in 2014 and 2015 had substantial adverse impacts to those juvenile winter-run cohorts. Based on the changes to RPA Action I.2.4, described further in this administrative memorandum, the temperature compliance metric to 55°F 7-day average of the daily maxima (7DADM) or equivalent, to the most downstream redd location must be met every year. Even in WY 2011, which was a wet water year type and there was high storage in Shasta Reservoir, the Bend Bridge temperature compliance point could not be met for the entire season. Meeting daily average temperature compliance locations as far downstream as Balls Ferry, Jellys Ferry, and Bend Bridge in water year types based on cold water supply in Shasta Reservoir is no longer appropriate, which is why NMFS is eliminating this performance measure (Anderson *et al.* 2010, 2011, 2013, 2014 and 2015; Deas *et al.* 2008).

3. Objective Based Management

The following conceptual objectives in Table 5 were adapted from the multi-year drought sequence experienced in Victoria, Australia, and applied to the Shasta RPA (Mount *et al.* 2016). Environmental water managers in Victoria use a seasonally adaptive approach that sets different environmental water objectives depending on hydrologic conditions. A change in objective in turn causes changes in the volume, location, and timing of water allocated to environmental uses. Water managers conduct extensive scenario testing to evaluate the consequences of these choices. In addition, environmental water managers have the flexibility to adjust operations depending upon unanticipated meteorological conditions, such as rainfall events and heat waves. Since these adjustments are scenario-tested in advance, this process creates greater certainty for all water users. NMFS intends for Reclamation adopt a similar approach towards their CVP operations in the Sacramento River.

Table 5. Shasta RPA objectives under different water year types.

	Critically Dry	Dry	Below Normal	Above Normal & Wet
Objectives	PROTECT - Avoid critical loss of population - Avoid catastrophic changes to habitat	MAINTAIN - Maintain river function with reduced reproductive capacity - Manage within dry-spell tolerance	RECOVER - Improve ecological health and resilience - Improve recruitment opportunities	ENHANCE - Maximize species recruitment opportunities - Restore key floodplain linkages - Restore key ecological flows
Priorities	- Undertake emergency flows to avoid catastrophic changes - Carry-over water for critical environments in the following year	- Provide priority flow components - Carry-over water for critical environmental components in the following year	- Provide all in-bank flow components - Provide out-of-bank flows if reach dry-spell tolerance - Carry-over water for large watering events	- Provide all ecological functioning flow components

4. Biological metric - temperature dependent mortality

The 2008 CALFED Science Program and Long-term Operation Biological Opinion (LOBO) annual review independent review panel recommended linking the RPA action physical metrics (*i.e.*, flows and temperature) to biological responses of the listed species (Anderson *et al.* 2010, 2011, 2013, 2014 and 2015; Deas *et al.* 2008). Newly developed by the NMFS-SWFSC (Martin *et al.* 2016) for Shasta Operations in water year 2016 was a semi-mechanistic/statistical model of temperature-dependent survival of winter-run Chinook in the Sacramento River. The modeling approach uses information on the timing and distribution of redd locations taken from aerial surveys from 1996-2015. For each known redd, a temperature exposure profile that redd would have experienced from fertilization to emergence is extracted using the River Assessment for Forecasting Temperatures (RAFT) model, a spatially explicitly hydraulic model of the Sacramento River (Pike *et al*. 2013). For each known redd, the temperature-dependent mortality model is run, with daily time steps, to calculate the probability of survival from fertilization to emergence. Predicted temperature-dependent mortality is calculated within a year by aggregating the survival of all redds within a year, and comparing the predicted mortality in a year to estimated yearly survival from egg-to-fry (ETF) by the US Fish and Wildlife Service from 1996-2015. Finally the parameters of the daily temperature-dependent mortality model are estimated by minimizing the deviations between predicted and observed survival across years. Based on laboratory data, field data, and a least squares estimate, the temperature below which there is no mortality due to temperature (or T_{crit} value) was found to be 53.7ºF. As explained in further detail in changes to RPA Action I.2.4, this is a much lower temperature than the 56°F DAT that has been the focus for winter-run Chinook salmon temperature management as required by State

Water Resources Control Board Orders 90-5 and 91-1 and the 2009 CVP/SWP operations Opinion.

Over the last 20 years temperature dependent mortality has fluctuated wildly from 85% in 2015, a critically dry water year and low end of April storage, to 0% in 2010 through 2012, below normal and wet water year types with high end of April storages (Table 3). Although a small sample size, based off these data the average temperature dependent mortality by water year type is:

- 68% in critically dry years
- 9% in dry years
- 10% in below normal years
- 3% in above normal years
- 4% in wet years

Another way to look at temperature dependent mortality and quality of habitat is through the RAFT survival landscape for 1998 to 2015 (Figures 3 to 5). The RAFT survival landscape figures provide the spatiotemporal resolution used to estimate the exposure of the full distribution of redds for that year. Those exposures are applied to the temperature dependent mortality model to develop annual temperature-dependent mortality statistics.

In an effort to improve upon the historical temperature dependent mortality, especially in critically dry but also in all water year types NMFS came up with the following temperature-dependent mortality metrics for forecasting, temperature planning, and impelmentation:

- Critically dry: <30% mortality
- Dry: <8% mortality
- Below Normal: <3% mortality
- Above Normal: <3% mortality
- Wet: <3% mortality

In addition, the NMFS-SWFSC is developing bioenergetics models that characterize effects of temperature on growth and survival across multiple life stages of winter-run Chinook salmon. Once finalized, this information will be incorporated into Sacramento River temperature management to better understand the effects to juvenile winter-run Chinook salmon survival.

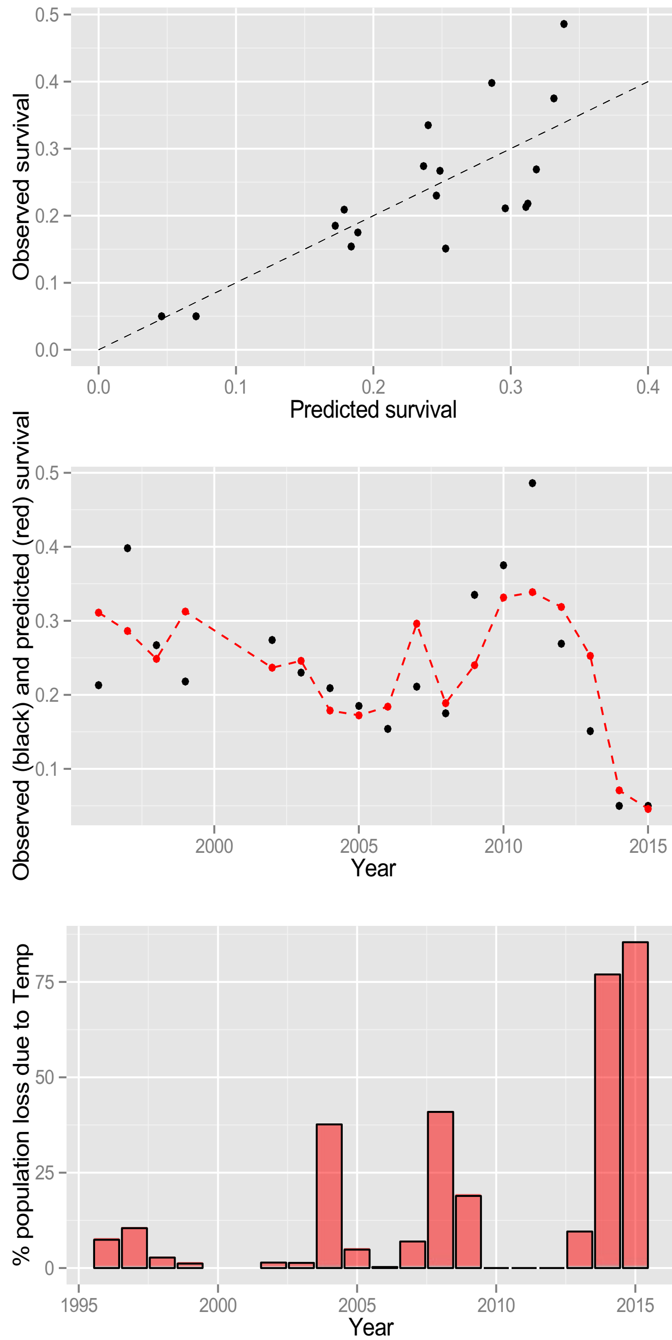
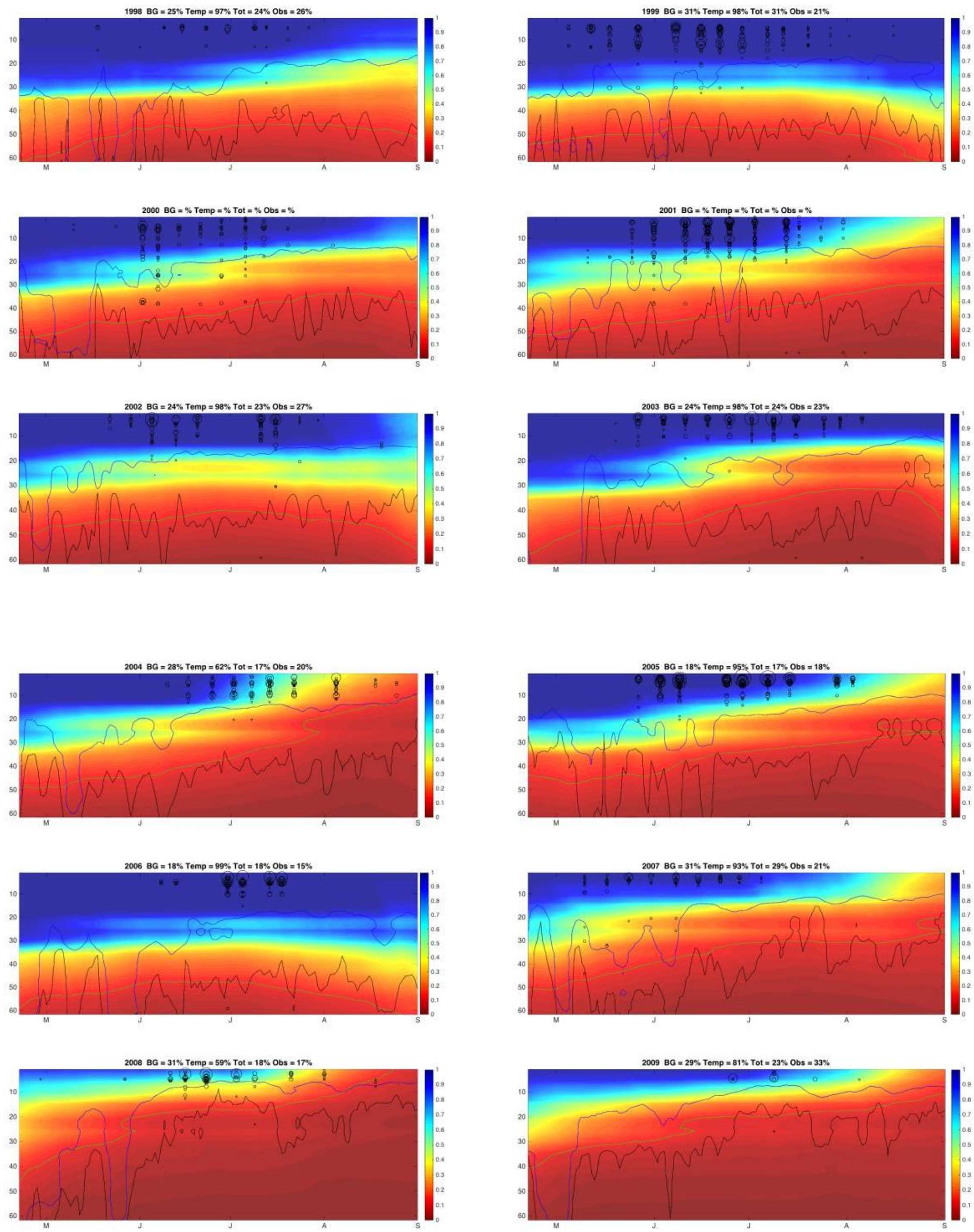


Figure 3. Martin *et al.* (2016) juvenile winter-run Chinook salmon model results include linear regression of predicted survival compared to observed survival (top), predicted survival compared to observed survival over time (middle), and percentage of temperature dependent mortality over time (bottom).


1998 BG = 25% Temp = 97% Tot = 24% Obs = 26%
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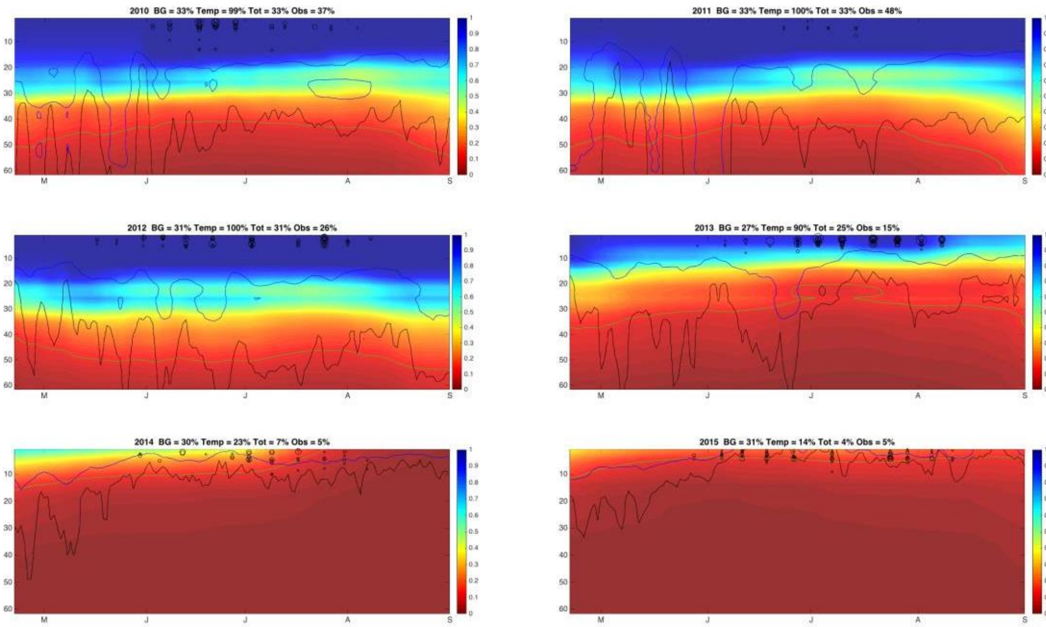

Figure 4. RAFT Sacramento River survival landscape profiles. The Y axis is the distance downstream of Keswick in miles. The X axis is time in months. The black circles represent spawning locations based on aerial redd surveys. The size of the circle indicates number of redds in that location. The colors represents cumulative temeperature based survival throughout each redd's egg incubation period, with redd indicating low survival and blue indicating high surival.

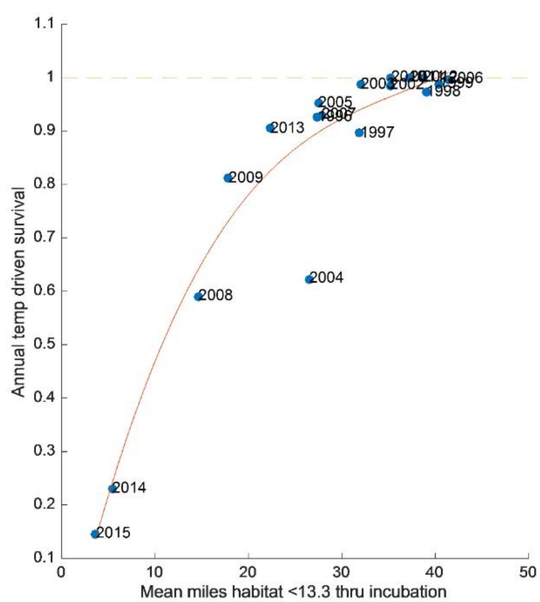

Figure 5. Average miles of habitat < 56ºF (13.3ºC) correlated with annual temperature dependent survival by year.

RPA Action I.2.3 February Forecast; March – May 14 Keswick Release Schedule (Spring Actions)

5. Change to Meteorological and Hydrological Forecasting

Reclamation has a coupled river/reservoir model, the Sacramento River Water Quality Model (SRWQM), that they use to target a temperature at a compliance location along the Sacramento River based on: (1) their most recent Shasta Reservoir profile; (2) a set of operating conditions (made up of TCD gate configurations and Keswick release flows); (3) and a medium range weather forecast. From these set of inputs they generate scenarios of discharge flows from Keswick and temperatures at various points along the Sacramento River for the entire summer and fall salmon temperature management season.

Drought conditions over the last five years have highlighted the uncertainties in Reclamation's SRWQM and its inability to meet the regulatory requirements outlined in the CVP/SWP operations Opinion. Their seasonal forecasts only use the discharge temperature and flow at Keswick predicted by the SRWQM, but to get those values correct for the entire season for all of the scenarios, Reclamation needs to have all of the environmental input variables accurate: the reservoir inflows, weather, operations (gate changes, *etc*.), and reservoir dynamics over a 6-month period. In addition, the SRWQM has a difficult time reflecting actual release temperature and conditions when the critical reservoir thermocline of about 52ºF approaches the elevation of the TCD side gates and/or reservoir outlet works. Given the significant simplification of the input data (which is derived from a 12-month operations outlook), the unknowns regarding future meteorological conditions, and the fact that the actual TCD does not have infinite adjustability, the model can only realistically provide a broad brush picture of future operations and cannot provide sufficient precision to determine future operations. Furthermore, the model was not developed to manage water temperatures on a fine scale, rather it was developed to determine in general where water temperature could be managed down based on a broad set of assumptions.

Due to these limitations and uncertainty, Reclamation has historically overestimated their ability to meet the temperature compliance point (TCP) (Figure 6). Over the past 10 years, the, 56ºF DAT at a TCP specified at the beginning of the season was exceeded ~33% of the time (11% in May, 20% in June, 29% in July, 41% in Aug, 54% in Sept, and 44% in Oct). The TCPs can change over the course of a season, which does minimize the frequency and magnitude of exceeding the 56°F DAT, but Reclamation exceeds the 56°F DAT at any TCP a significant amount of the time, and often by a significant temperature differential (Figure 7). The higher that differential, the higher the likelihood of egg mortality.

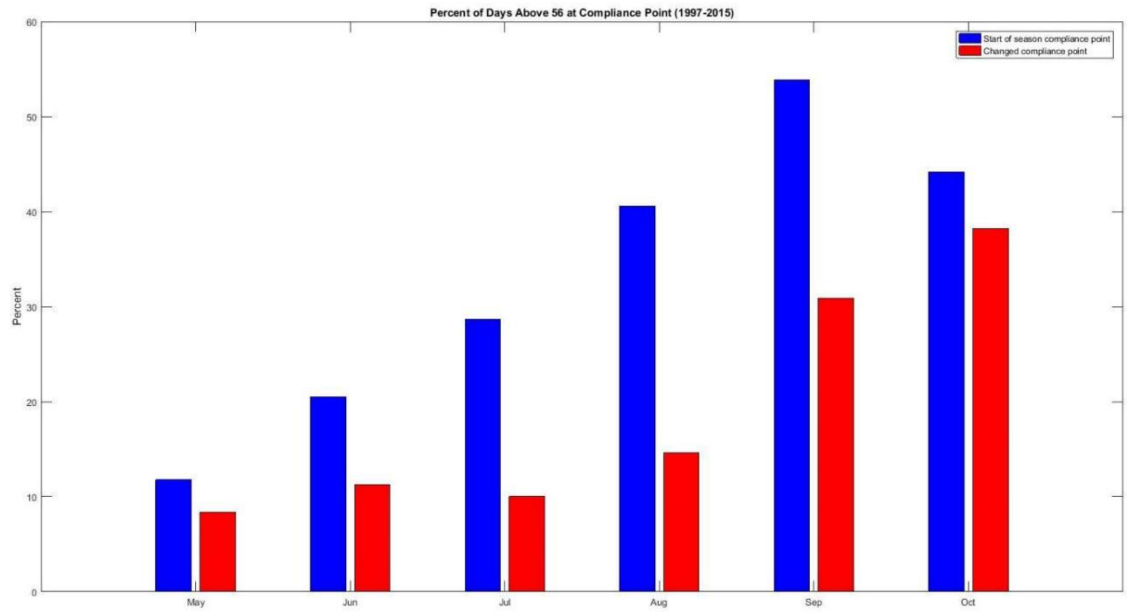

Figure 6. Percent of days above 56°F DAT at temperature compliance point by month (1997-2015). Blue bars indicate start of the season compliance location. Red bars indicate a changed temperature compliance location.

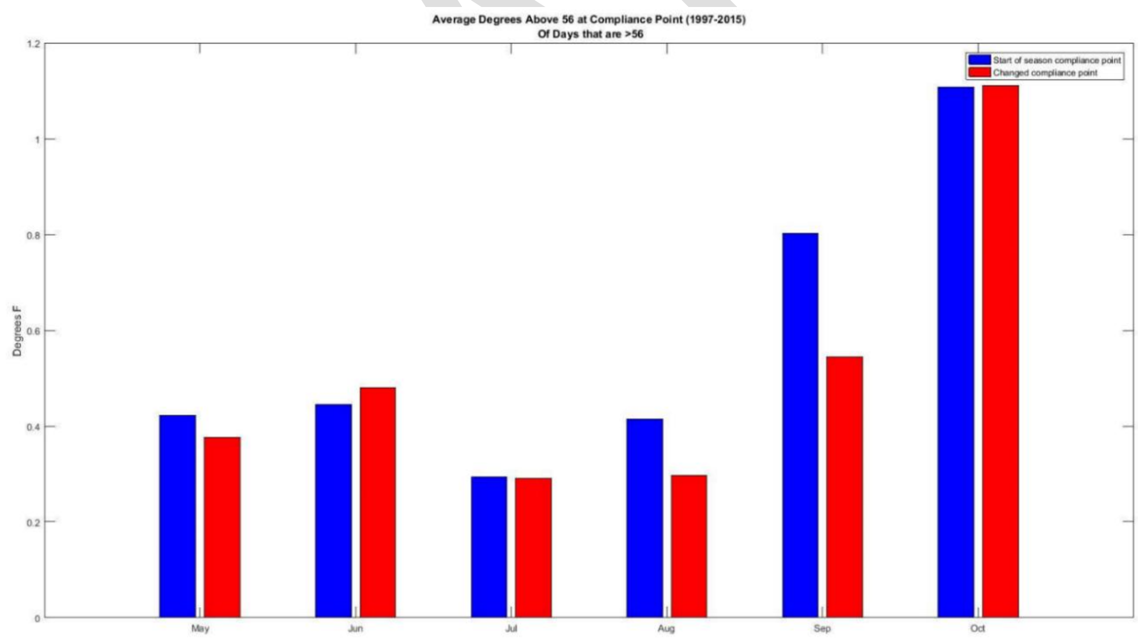

Figure 7. Average degrees (°F) above 56°F DAT at temperature compliance point by month (1997-2015). Blue bars indicate start of the season compliance location. Red bars indicate a changed temperature compliance location.

Some model improvements have been made over time using lessons learned from previous years. For example, in 2014, the upper 5 to 6 miles of the Sacramento River read 0.6°F warmer than the model, so in 2015 Reclamation adjusted the model 0.6°F for better accuracy when they ran simulations for temperature compliance locations at or upstream of CCR. Additionally, due to the higher ambient air temperature in the past few years, in 2015, Reclamation began using more conservative (*i.e.*, warmer) meteorological forecasts from the local 3-month temperature outlook (L3MTO) rather than continuing to use average temperature as an input to the Sacramento River water temperature profile.

Given the poor performance and uncertainties associated with Reclamation's model and the extreme importance to manage for higher juvenile winter-run survival during the temperature management season in 2016, NMFS proposes some buffers to help address the unavoidable uncertainty in temperature model and potential adjustments to the Sacramento River temperature criteria: (1) use the more conservative (*i.e.*, warmer) L3MTO meteorological forecast inputs of 10% and 25% in addition to the standard 50%; (2) use 75% and 99% hydrological forecasts, in addition to the 50% and 90%; and (3) apply a Shasta Reservoir temperature profile stratification scenario from the historical record that shows a steep cold water decline in the spring (*e.g.*, what happened in 2015).

6. Limiting Keswick Releases

In 2014, 2015, and 2016, limiting Keswick releases in June and July was an important and effective strategy to stretch the cold water temperature management season through September and October (Table 6). Table 7 shows the differences in monthly Keswick discharge by water year type over the last 21 years. In critically dry years, Keswick discharges were significantly lower than other water year types.

Table 6. Keswick Dam average monthly releases April to October, 1996-2016. Data source: Reclamation 2016.

Year	WY	Keswick Monthly Mean Discharge (cfs)						
	Type	Apr	May	Jun	Jul	Aug	Sep	Oct
1996	W	5,453	10,590	13,950	14,470	14,330	9,748	5,468
1997	W	5,816	9,122	13,330	14,870	11,140	8,110	5,663
1998	W	11,660	14,770	15,590	14,840	14,700	11,110	4,671
1999	W	8,136	10,510	11,720	13,330	10,400	7,987	6,745
2000	AN	7,841	10,930	12,790	15,070	11,580	7,493	6,298
2001	D	6,308	9,820	13,650	14,900	11,160	8,588	6,043
2002	D	5,488	9,476	12,960	14,600	11,030	7,837	6,048
2003	AN	7,720	16,380	13,030	13,980	10,470	7,847	7,137
2004	BN	8,550	9,970	14,580	15,550	11,130	8,748	6,873
2005	AN	4,087	14,660	12,100	14,200	10,640	8,702	7,249
2006	W	29,270	12,600	14,250	14,580	13,300	9,501	7,749
2007	D	7,799	9,869	12,340	14,720	11,600	8,602	6,160
2008	C	6,823	9,405	11,720	12,750	10,470	7,534	6,488
2009	D	6,249	8,724	10,530	12,560	10,920	7,395	7,102
2010	BN	4,693	8,942	11,970	12,540	10,340	7,542	6,170
2011	W	12,730	8,606	12,540	12,630	11,950	10,020	6,176
2012	BN	4,220	9,142	12,150	14,980	12,560	7,861	7,876
2013	D	7,212	11,980	13,980	14,770	10,840	7,409	6,208
2014	C	3,576	7,496	9,726	9,908	8,364	5,974	6,781
2015	C	4,361	7,578	7,337	7,304	7,210	7,074	5,038
2016	BN	5,049	6,353	8,473	10,340	10,560	8,893	6,361
Average		7,760	10,300	12,300	13,500	11,200	8,280	6,400

Table 7. Keswick Dam monthly flows by water year type 1996 – 2016. Data source: Reclamation 2016.

Year	End of April Storage (MAF)	End of September Storage (MAF)	Keswick Monthly Mean Discharge (cfs)						
			Apr	May	Jun	Jul	Aug	Sep	Oct
Critical									
2008	2.95	1.38	6823	9405	11720	12750	10470	7534	6488
2014	2.41	1.16	3576	7496	9726	9908	8364	5974	6781
2015	2.66	1.60	4361	7578	7337	7304	7210	7074	5038
Average	*2.68*	*1.38*	*4920*	*8160*	*9594*	*9987*	*8681*	*6861*	*6102*
Dry									
2001	4.02	2.20	6308	9820	13650	14900	11160	8588	6043
2002	4.30	2.56	5488	9476	12960	14600	11030	7837	6048
2007	3.90	1.88	7799	9869	12340	14720	11600	8602	6160
2009	3.00	1.77	6249	8724	10530	12560	10920	7395	7102
2013	3.79	1.91	7212	11980	13980	14770	10840	7409	6208
Average	*3.80*	*2.06*	*6611*	*9974*	*12692*	*14310*	*11110*	*7966*	*6312*
Below Normal									
2004	4.06	2.18	8550	9970	14580	15550	11130	8748	6873
2010	4.39	3.32	4693	8942	11970	12540	10340	7542	6170
2012	4.44	2.59	4220	9142	12150	14980	12560	7861	7876
2016	4.23	2.81	5049	6353	8473	10340	10560	8893	6361
Average	*4.28*	*2.73*	*5628*	*8602*	*11793*	*13353*	*11148*	*8261*	*6820*
Above Normal									
2000	4.15	2.99	7841	10930	12790	15070	11580	7493	6298
2003	4.54	3.16	7720	16380	13030	13980	10470	7847	7137
2005	4.21	3.04	4087	14660	12100	14200	10640	8702	7249
Average	*4.30*	*3.06*	*6549*	*13990*	*12640*	*14417*	*10897*	*8014*	*6895*
Wet									
1996	4.31	3.10	5453	10590	13950	14470	14330	9748	5468
1997	3.94	2.31	5816	9122	13330	14870	11140	8110	5663
1998	4.06	3.44	11660	14770	15590	14840	14700	11110	4671
1999	4.26	3.33	8136	10510	11720	13330	10400	7987	6745
2006	4.06	3.21	29270	12600	14250	14580	13300	9501	7749
2011	4.27	3.34	12730	8606	12540	12630	11950	10020	6176
Average	*4.15*	*3.12*	*12178*	*11033*	*13563*	*14120*	*12637*	*9413*	*6079*

Ambient air temperature and volume of Keswick releases may play a more significant role in trying to meet downstream temperature compliance locations at Balls Ferry, Jellys Ferry, and

Bend Bridge. However water temperatures at upstream redd locations (CCR and upstream) are not strongly correlated with flow but are strongly correlated with Keswick release temperatures (i.e., water quality, not water quantity). Based on RAFT model runs using a constant flow and temperature at Keswick, under average meteorological conditions, the NMFS-SWFSC generated contour plots of the 55^{o}F 7DADM at CCR in relation to the flow and temperature at Keswick for each month (*i.e*., the release temperatures at Keswick that would be needed to meet 7DADM at CCR for each month) (Figure 8). In general, there is about a one degree difference in Keswick release temperature between 5,000 and 7,500 cfs in order to meet 55^{o}F 7DADM at CCR, but above that, small increases in flow (*e.g*., 500 cfs) do not make much of a difference in the Keswick release temperature in order to meet 55^{o}F 7DADM at CCR. Figure 9 shows that based on historical data, a mean daily Keswick discharge of 7,500 cfs to 15,000 cfs at approximately 52^{o}F will be able to meet a 53^{o}F DAT at CCR. The figure is just for August but the data shows similar results for the other temperature management season months (May, June, July, September, and October).

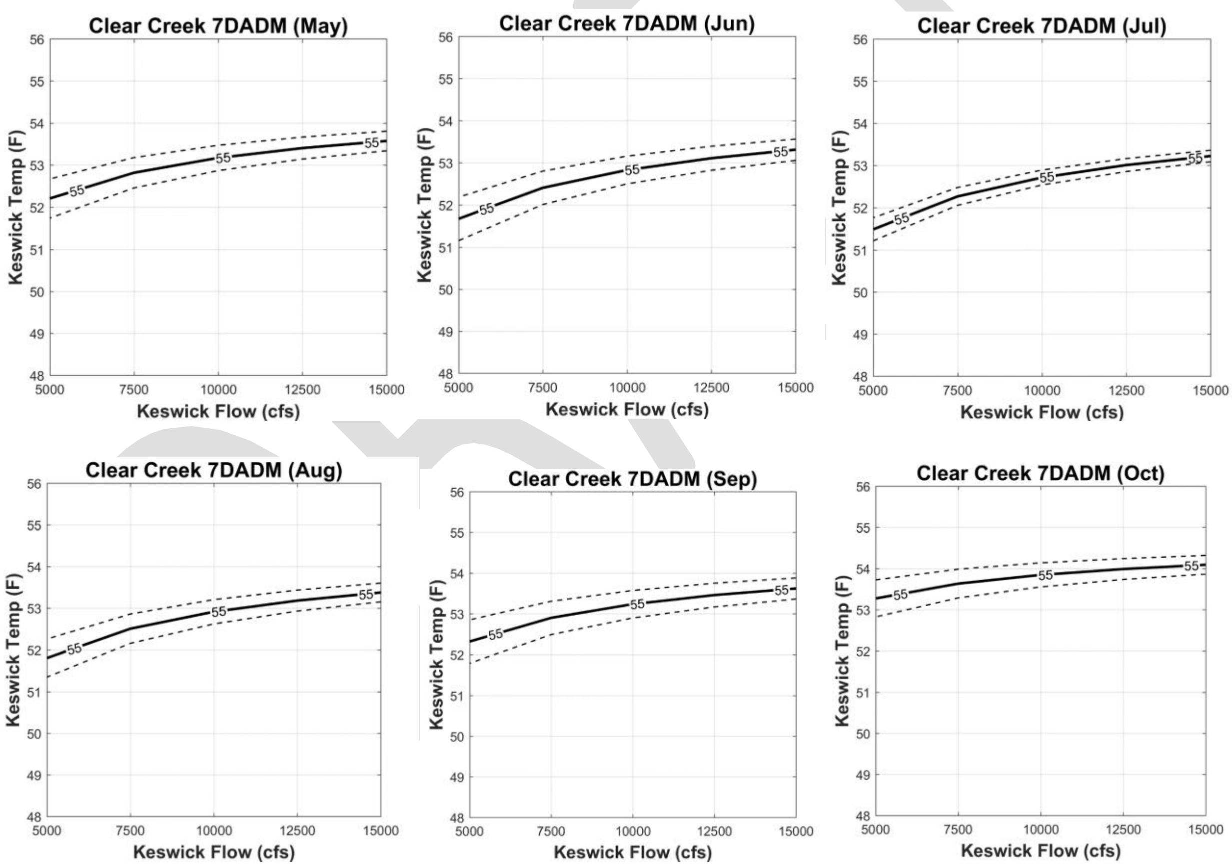

Figure 8. 55^{o}F 7DADM at Clear Creek (CCR) in relation to the flow and temperature at Keswick by month. Dotted lines are 95% contour intervals. Data source: NMFS 2016.

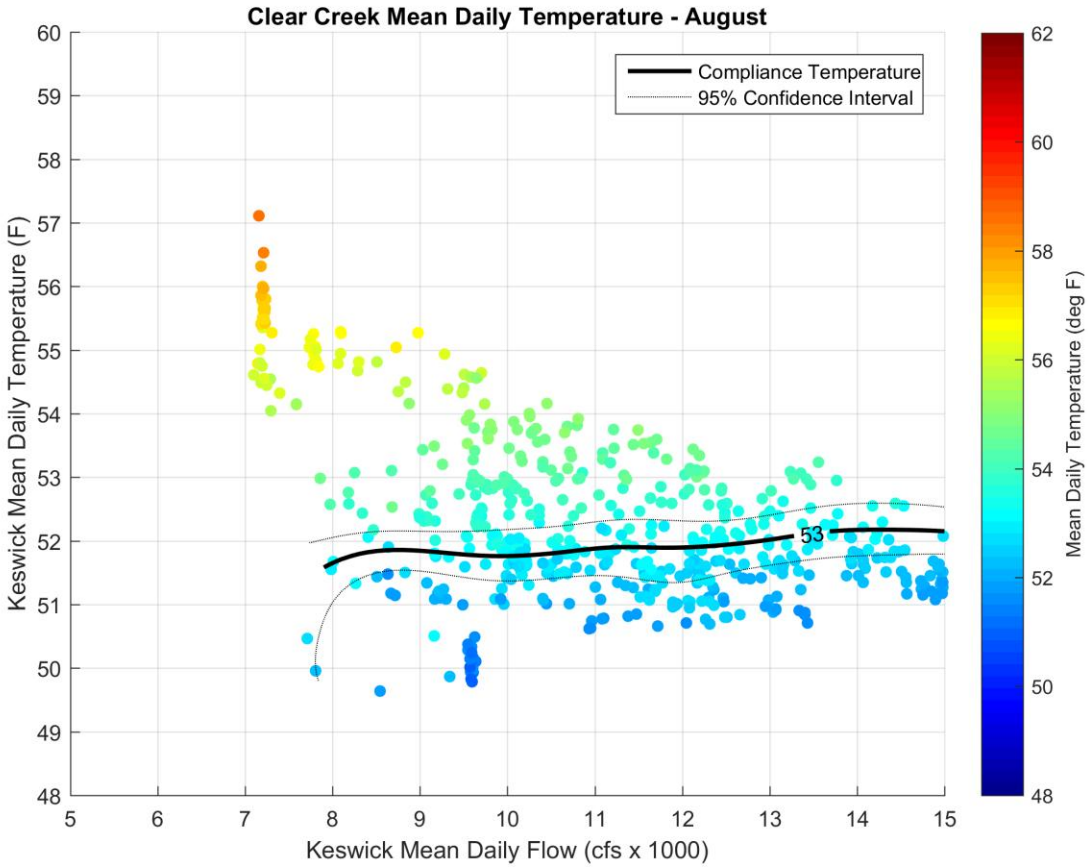

Figure 9. Relationship between discharge temperature and flow, and daily average temperature at Clear Creek. Data source: NMFS 2016.

Based on the historic and modeled information, NMFS proposed the following Keswick maximum release flow schedule in order to ensure the temperature compliance metrics will be met for the entire temperature management season:

Table 10. NMFS proposed monthly Keswick release schedules by water year type (cfs)

	Apr	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Critically Dry	4000	7500	7500	7500	7500	7000	5000
Dry	6000	8000	10000	10000	10000	7500	6000
Below Normal	6000	9000	12000	12000	12000	7500	6500
Above Normal	6500	11000	12500	14500	12000	9000	7000
Wet	8000	12000	13500	14500	12000	10000	7000

7. Change in adult holding temperature compliance criterion of 56ºF daily average temperature to 61ºF 7DADM (or something similar) to Jellys Ferry

Adult winter-run Chinook enter the Sacramento River system usually with gametes not fully developed and move into the upper river where they hold until ready to spawn. After migrating from the ocean as early as December, they hold in deeper areas along the entire Upper Sacramento River from February to June as far downstream as Jellys Ferry[4].

In an effort to develop regional temperature criteria guidance that would be protective of salmonids, the United States Environmental Protection Agency (EPA) Region 10 reviewed several studies on how temperature affects salmonid physiology and behavior, the combined effects of temperature and other stressors on threatened fish stocks, the pattern of temperature fluctuations in the natural environment, and published of guidance recommendations to States and Tribes on how they can designate uses and establish temperature numeric criteria for waterbodies to protect coldwater salmonid species in the Pacific Northwest (EPA 2001, 2003). Based on the literature review in EPA (2001), holding migratory fish at constant temperatures above 55.4-60.1ºF (13-15.6ºC) impedes spawning success due to pronounced adult pre-spawn mortality and decreased survival of eggs to the eyed stage, and maximum constant temperatures of 50-54.5ºF (10-12.5ºC) provide better reproductive conditions. They recommend a 61°F (16°C) maximum 7DADM criterion for the protection of waterbodies used or potentially used for adult salmon holding prior to spawning (EPA 2003). The 7DADM metric is recommended because it describes the maximum temperatures in a stream, but is not overly influenced by the maximum temperature of a single day. Thus, it reflects an average of maximum temperatures that fish are exposed to over a weeklong period. Since this metric is oriented to daily maximum temperatures, it can be used to protect against acute effects, such as lethality, and can also be used to protect against sub-lethal or chronic effects.

Through the development of their life cycle model, NMFS-SWFSC examined the relationship between spawn timing from April to August and monthly water temperatures below Keswick from January through July (Hendrix *et al.* 2014). There is a negative relationship between April temperatures and proportion of fish spawning in May or June, and there is a positive relationship between April temperatures and proportion of fish spawning in July or August. This means that cool water in April results in earlier spawning, while warm water in April results in later spawning. If winter-run Chinook are optimizing for emergence timing of fry, fish will spawn later in warm water temperatures as warmer temperatures lead to faster egg development, and will spawn earlier in cool water temperatures as cold temperatures lead to slower egg development.

[4] Holding winter-run Chinook salmon in the Redding area commonly seen during the late-fall run Chinook survey in February and March and the Livingston Stone National Fish Hatchery adult trapping at Keswick Dam begins collecting winter-run Chinook in late February to early March (D. Killam pers. comm. 2016). Historically some winter-run Chinook never passed RBDD when the gates were in but recently it is believed that unimpeded fish passage and combined with other fisheries and water management have conditioned the adult winter-run Chinook to migrate as far upstream as possible.

RPA Action I.2.4 May 15 through October Keswick release schedule (Summer Action)

8. **Change in spawning, egg incubation, and fry emergence temperature compliance criterion of 56ºF daily average temperature to 55ºF 7-day daily average temperature (or something similar) and the change in temperature compliance location criterion from between Balls Ferry and Bend Bridge to the most downstream redd.**

In order to protect salmon egg incubation and fry emergence from adverse thermal effects, the State Water Resources Control Board Orders 90-5 and 91-1 require Reclamation to operate Keswick and Shasta dams to meet a DAT of 56°F at RBDD or at a TCP modified when the objective cannot be met at RBDD based on Reclamation's other operational commitments, including those to water contractors, D-1641 regulations and criteria, and Shasta Reservoir projected EOS storage volume. RPA Action I.2.4 states that Reclamation shall manage Shasta Division operations to achieve a temperature compliance of not in excess of 56°F DAT between Balls Ferry and Bend Bridge from May 15 through October 31.

Recent investigations into causes of low egg-to-fry survival in 2014 and 2015 revealed that the 56°F (13.3°C) DAT criterion mandated in RPA Action I.2.4 is not adequate to protect the earliest life-stages winter-run Chinook salmon. Based on the literature, temperatures from 39.2 to 53.6°F (4-12°C) tend to produce relatively high survival to hatching and emergence, with approximately 42.8-50°F (6-10°C) being optimum (Seymour 1956, Boles 1988, U.S. Fish and Wildlife Service 1999, EPA 2003). Exposure to temperatures above the optimal range results in sub-lethal or chronic effects (*e.g.*, decreased juvenile growth, which results in smaller, more vulnerable fish; increased susceptibility to disease which can lead to mortality; and decreased ability to compete and avoid predation), as temperatures rise until at some point they become lethal. Managing for 56°F (13.3°C) DAT can still result in a maximum daily temperature of over >60°F (15.5°C), which can result in sub-lethal and lethal effects to salmonids. EPA (2003) recommends a 55°F (13°C) 7DADM criterion for the protection of waterbodies used or potentially used for salmon and trout spawning, egg incubation, and fry emergence and recommends that this criterion apply from the average date that spawning begins to the average date incubation ends (the first 7DADM is calculated 1 week after the average date that spawning begins). NMFS finds that this best available science of 55°F 7DADM shall apply to winter-run Chinook salmon spawning, egg incubation, and fry emergence from the onset of spawning (approximately May 15) to the end of incubation (approximately October 31).

Since the construction of Shasta Dam, winter-run Chinook historically spawned in the upper Sacramento River reach (50 miles) between Keswick Dam and RBDD (Vogel and Marine 1991). However, since the current aerial redd and carcass survey methodologies began in 2003, the vast majority of winter-run redds have occurred in the first 16 miles downstream of Keswick Dam and has continued since the implementation of RPA Action Suite I.2.4 in 2010 (Table 11). EPA (2003) also recommends that the water quality standard should apply to all the river miles including the lowest point downstream for egg incubation and fry emergence. In addition, the 2008 CALFED science program and the LOBO annual independent review panel has suggested that the compliance points should be re-evaluated and moved to better match actual fish habitat usage (Anderson *et al.* 2010, 2011, 2013, 2014 and 2015; Deas *et al.* 2008).

Table 11. 2016 Winter-Run aerial redd counts by river area 2010-2016. Data source: CDFW 2016.

Flight Sections	Redds (2010-2016)	% Average (2010-2016)
Keswick to A.C.I.D. Dam (rm 302 to 298)	**858**	**60.8%**
A.C.I.D. Dam to Highway 44 Bridge (rm 296)	**514**	**36.4%**
Highway 44 Br. to below Clear Crk. (rm 284)	**39**	**2.8%**
Below Clear Crk. to Balls Ferry Br. (rm 275)	**0**	**0.0%**
Balls Ferry Br. to Battle Creek (rm 271)	**0**	**0.0%**
Battle Creek to Jellys Ferry Br. (rm 266)	**1**	**0.1%**
Jellys Ferry Br. to Bend Bridge (rm 257)	**0**	**0.0%**
Bend Bridge to Red Bluff Diversion Dam (rm 242)	**0**	**0.0%**
Red Bluff Diversion Dam to Tehama Br. (rm 229)	**0**	**0.0%**
Total	**1412**	**100.0%**

Based on the best available science, current data that reflect actual spawning habitat usage, and the recommendations from both the EPA and the LOBO independent science panel, the temperature compliance location criterion shall be changed from “between Balls Ferry and Bend Bridge” to “the most downstream redd location.” Because it is not known where that downstream most location is at the onset of spawning, an initial TCP at the Clear Creek California Data Exchange Center (CDEC) location (CCR) is sufficient. The TCP will then be adjusted upstream or downstream based on the location of spawning.

Recognizing the difficulty of changing the regulatory compliance from a DAT to a 7DADM, NMFS analyzed to see what the downstream TCP equivalency would be. Over an 18-year period (1998-2015), CCR 7DADM tracked pretty closely to Balls Ferry (BSF) DAT during the temperature management season, except for 2008, 2009, and 2012 to 2015 (*i.e.*, dry and critically dry years), where CCR 7DADM tracked somewhere between BSF DAT and Jellys Ferry (JLF) DAT. Alternatively, the data show that a 53ºF DAT at CCR is sufficient as an indicator of the ability to meet 55ºF 7DADM at CCR. In recognition that a 55ºF 7DADM or 53ºF DAT at CCR cannot be achieved in some water year types (Table 3), NMFS came up with the following temperature requirements at the downstream-most winter-run redd by water year type:

- Critically dry: < 56°F daily average temperature
- Dry: < 54°F daily average temperature
- Below Normal: < 53°F daily average temperature
- Above Normal: < 53°F daily average temperature
- Wet: < 53°F daily average temperature

Table 12. Daily average temperature over the temperature management season (May through October) at the various temperature compliance locations, 1996 – 2016. Data source: Reclamation 2016.

WY	KWK DAT	CCR DAT	CCR 7DADM	BSF DAT	JLF DAT	BND DAT
1996	52.3			55.0	55.9	56.0
1997	51.8			54.5	55.5	56.3
1998	51.6	52.2	53.3	54.0	55.2	55.4
1999	50.5	51.6	53.3	53.4	54.6	55.1
2000	51.8	52.7	54.3	54.3	55.4	55.8
2001	52.0	53.0	54.6	54.4	55.6	56.0
2002	51.5	52.6	54.3	54.1	55.2	55.7
2003	51.6	52.6	54.2	54.2	55.4	55.9
2004	52.5	53.5	55.1	54.8	55.9	56.4
2005	52.3	53.2	54.7	54.8	56.0	56.4
2006	50.9	51.7	53.1	53.3	54.7	55.0
2007	52.5	53.3	55.0	54.8	55.7	56.2
2008	53.8	54.6	56.6	55.9	56.9	57.4
2009	53.0	54.1	55.9	55.6	56.8	57.2
2010	51.2	52.2	54.0	54.0	55.2	55.6
2011	51.0	52.1	53.8	53.8	55.0	55.5
2012	51.3	52.4	54.3	53.9	55.0	55.5
2013	53.0	54.0	55.8	55.4	56.3	56.6
2014	55.7	56.9	58.8	58.0	59.4	59.8
2015	55.2	56.7	58.8	58.1	59.5	60.1
2016	51.9	53.0	55.0	54.8	56.1	56.7
Average	52.3	53.3	55.0	54.8	56.0	56.4
Difference from CCR 7DADM	-2.7	-1.7		-0.2	1.0	1.4
Difference from KWK		1.0	2.7	2.5	3.7	4.1

9. Delay Shasta releases from full side gates

In 2014, the SRTTG and Reclamation learned that there was a loss of water temperature control when the full Shasta TCD side gates were accessed for water releases. As shown in the figure 10 below, full side gates were accessed on August 26, 2014, as indicated by the over one degree drop at both CCR and Keswick. Daily average temperatures were maintained below 56ºF for about a week before significantly rising throughout the remainder of September and all of October. More than 50% of the eggs and alevin were still in the gravel and were exposed to these lethal temperatures, not to mention the 56ºF DAT at CCR were routinely exceeded in June through August. In order to prevent the loss of cold water pool and temperature control in the future, Reclamation shall delay full side gate operations as long as possible and no earlier than October 15.

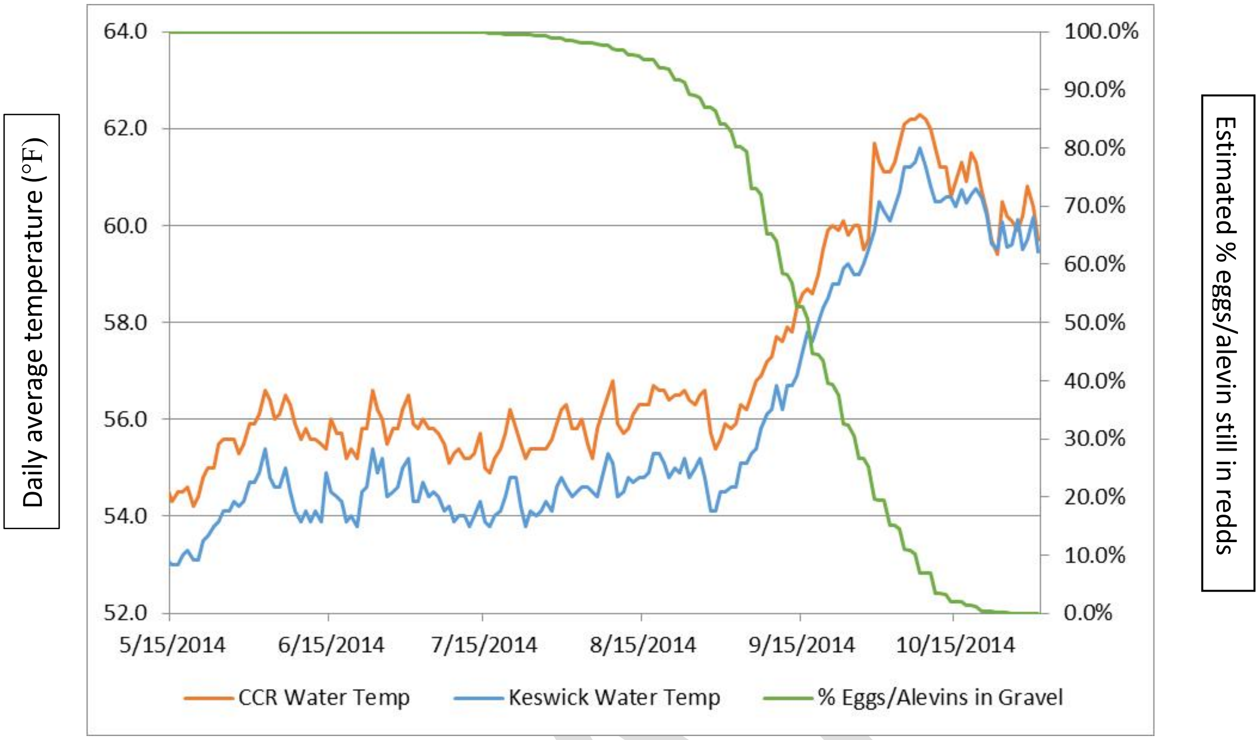

Figure 10. Daily average temperatures at CCR and Keswick (KWK) for the 2014 temperature management season with the cumulative proportion of eggs and alevins in gravel overlaid in green. Data source: CDEC and CDFW 2014.

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