NCWA
Northern California Water Association

To advance the economic, social and environmental sustainability of Northern California by enhancing and preserving the water rights, supplies and water quality.

June 4, 2015

Via Electronic Mail

Felicia Marcus, Chair
Members of the Board
State Water Resources Control Board
P.O. Box 2000
Sacramento, CA 95812-2000

Re: Supplemental Information Related to May 20, 2015 SWRCB Workshop Regarding Drought Activities in the Bay-Delta Watershed

Dear Chair Marcus and Members of the Board:

The Northern California Water Association and certain Sacramento Valley Water Users (collectively "NCWA") formally submit the attached report and executive summary prepared by expert fisheries biologist Dave Vogel, entitled: "Potential Effects of Central Valley Project Operations on Winter-Run Chinook Salmon Egg Incubation in 2015: A Preliminary Analysis (April 8, 2015)." Mr. Vogel's report provides critical information and analysis regarding the circumstances in 2014 that likely underestimated the winter-run salmon juvenile production index, and, in turn, greatly overestimated the egg to juvenile salmon mortality estimate in 2014. With all the various assertions about salmon survival in 2014, we believe it is very important that the State Water Board have the appropriate context in which to base and guide future decisions. Mr. Vogel's report also provides important information regarding potential water temperature effects on salmon egg incubation, with suggestions for additional water temperature modeling, as well as operations to conserve more cold-water storage in Shasta Reservoir for later in the season when most winter-run eggs will be incubating in the river gravels.

Mr. Vogel's report has previously been provided to SWRCB staff and some Board members, but NCWA requests that the report be formally included in the administrative record for the SWRCB's drought activities, including the pending Temporary Urgency Change Petition to Modify Bay-Delta Requirements, as filed by the United States Bureau of Reclamation and California Department of Water Resources.

Finally, NCWA reiterates its on-going commitment to providing for Dave Vogel to conduct and participate in enhanced monitoring of winter-run Chinook salmon and water temperatures in the Sacramento River in 2015. In this regard, we have met with the state and federal fishery agencies to review and discuss an enhanced monitoring plan for 2015, which is expected to include, but not be limited to, more robust monitoring and actions in the following areas: (1) aerial surveys of salmon redds, including use of drone technology; (2) in-river salmon redd surveys, including winter-run and fall-run

Chinook redd dewatering surveys and analyses; (3) water temperature monitoring; (4) carcass surveys; and (5) fry and juvenile salmon surveys including snorkeling and SCUBA surveys, underwater film footage, and sonar camera surveys. This enhanced monitoring is expected to provide vital information to assist with the adaptive management that will be necessary to implement during this extraordinary fourth consecutive drought year.

We appreciate the SWRCB's consideration and inclusion of this information in the administrative record as you make future decisions. Please do not hesitate to contact us if you have any questions.

Sincerely yours,

David J. Guy
President

cc: Tom Howard
Michael Lauffer
Charlton Bonham
Maria Rea
Garwin Yip
Rich Satkowski

Potential Effects of Central Valley Project Operations on Winter-Run Chinook Salmon Egg Incubation in 2015: A Preliminary Analysis

April 8, 2015

Dave Vogel, Senior Scientist
Natural Resource Scientists, Inc.

Background

As California enters a fourth consecutive drought year, water resource managers, natural resource agencies, water users, and others have been working on water project operational scenarios in attempts to balance beneficial uses of water while simultaneously minimizing adverse impacts to the environment, water supplies, and water deliveries. In this regard, the U.S. Bureau of Reclamation (USBR) has modeled some water operation scenarios for key features of the Central Valley Project to estimate effects on water supplies, water deliveries, and threatened and endangered fish. On March 26, 2015, USBR provided the State Water Resources Control Board (SWRCB) staff with modeled outputs of four scenarios. A summary of those scenarios and detailed model outputs are available at: USBR March 26, 2015. Because of the severe drought, none of the scenarios provided ideal conditions for the multiple beneficial uses of extremely limited water supplies. Two of the modeled scenarios [6b(2) and 6b(3)], if implemented, would cause severe adverse impacts to American River fishery resources. However, an alternative scenario [referred hereafter as model scenario 6b(4) (discussed later in this document)], has emerged as a preferred operation for riverine water temperatures for winter-run Chinook salmon in the Sacramento River (a federally-listed endangered species) while balancing other uses of water supplies, including American River fishery resources. The difference between the model scenarios 6b(1) and 6b(4) would result in preserving more cold-water storage in Shasta Reservoir by the end of September (~199,000 acre-ft versus ~305,000 acre-ft, respectively) (USBR March 26, 2015), thereby providing added protection for winter-run Chinook. During a conference call with NOAA Fisheries staff on the afternoon of April 3, 2015 concerning these topics, agency personnel requested additional information on the potential effects model scenario 6b(4) may have on winter-run Chinook. Prompted by that request, this paper describes highlights of the biological rationale.

In 2014, Shasta Reservoir reached the lowest levels since a water-temperature control device (TCD) was installed on the face of Shasta Dam. The TCD was designed to allow selective releases of water from various levels in the reservoir to provide suitable temperatures for winter-run Chinook salmon egg and larval incubation which occurs from late-May to October [Vogel and Marine 1991, California Department of Fish and Wildlife (CDFW) data]. Traditionally, the objective in past years has been to maintain water temperatures at or below 56°F at various compliance points in reaches downstream of Keswick Dam (e.g., Figure 1). The compliance points have changed between and within years based on a variety of conditions affecting seasonal water temperatures and the spawning distribution of winter-run Chinook. In 2014, the compliance point was established at a location several miles upstream of Clear Creek (Bonnyview Bridge and referred to as “CCR”). Despite attempts to maintain temperatures at

56°F at CCR, higher temperatures occurred due to physical limitations of the TCD and low Shasta Reservoir levels. Those problems are described in USBR (2015). As a result, an unanticipated adverse impact on incubating winter-run eggs in the Sacramento River transpired late in the egg incubation period. The fishery resource agencies estimated the loss of winter-run salmon at 95% and attributed the entire loss to unsuitable water temperatures (SWRCB 2015). However, the estimated mortality was not based on modeling of thermal impacts on incubating eggs but, instead, on the monitoring of juvenile salmon emigration past Red Bluff Diversion Dam (RBDD) approximately 50 river miles downstream from the region where most winter-run salmon spawned (Figure 1). The juvenile salmon monitoring program generates juvenile production indices or salmon fry equivalent indices and salmon egg-to-fry equivalent survival estimates (described below). NOAA Fisheries provided a graph of estimated annual survival rates of winter-run Chinook salmon (including the estimates for 2014 showing 95% mortality) to the SWRCB on February 18, 2015 (Figure 2).

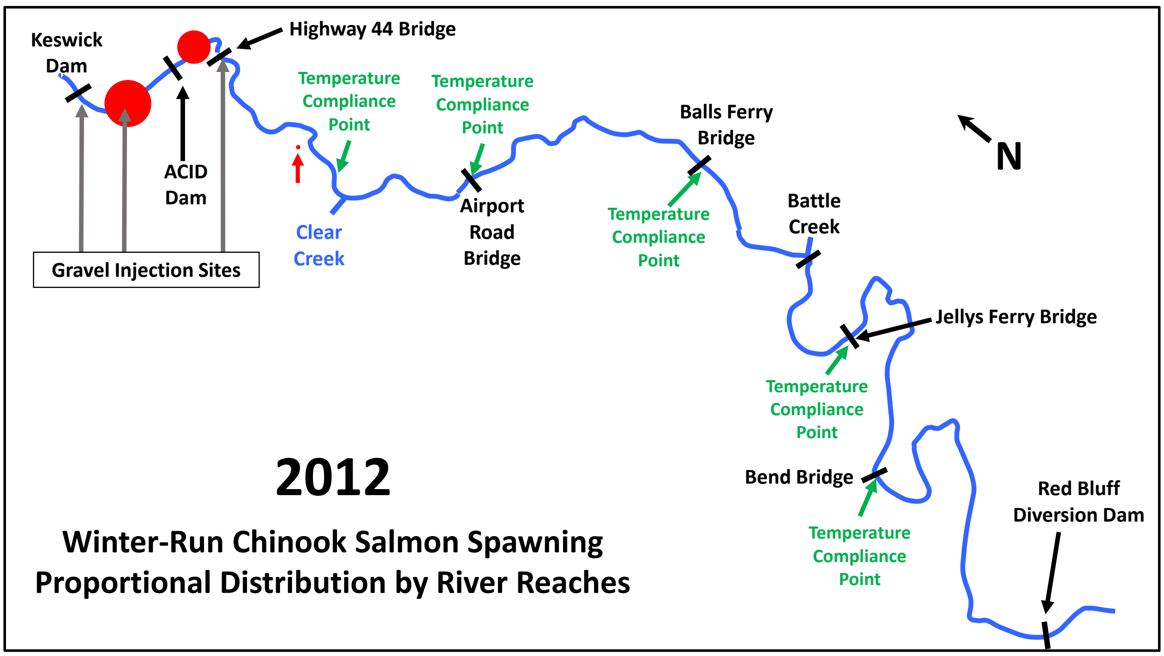

Figure 1. The upper Sacramento River between Keswick Dam (River Mile 302) and Red Bluff Diversion Dam (River Mile 243) showing location of various potential winter-run Chinook salmon water temperature compliance points. This example shows the proportional distribution of winter run spawning in 2012. Data courtesy of the California Department of Fish and Wildlife.

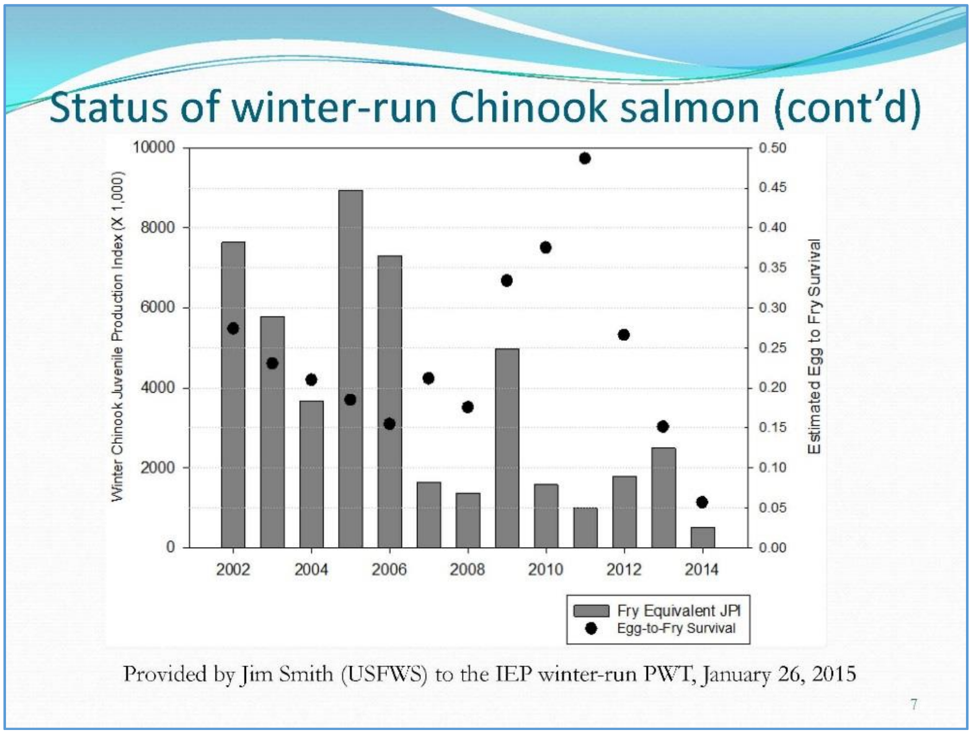

Figure 2. Graph from a PowerPoint presentation by NOAA Fisheries to the State Water Resources Control Board on February 18, 2015.

Description of U.S. Fish and Wildlife Service (USFWS) Juvenile Salmon Emigration Monitoring at Red Bluff Diversion Dam (RBDD)

Data used to develop the graph shown in Figure 2 were generated from estimates provided by Poytress et al. (2014) for 2002 through 2012 and unpublished estimates for 2013 and 2014. It is instructive to describe the methods and limitations used to generate those estimates. The Poytress et al. (2014) report provides an excellent, comprehensive description of the juvenile salmon sampling program at RBDD.

The USFWS has been monitoring the downstream migration of juvenile salmonids passing RBDD since 1994 through the use of rotary-screw traps. It has been a well-executed program and has served multiple purposes resulting in some of the more-useful data to assess juvenile salmon emigration characteristics from the upper Sacramento River. Although the purpose for operation of the traps has evolved over the years, one of the primary present-day functions of this monitoring is to "*obtain juvenile winter Chinook production indices and to correlate these indices with estimated escapement from adult estimates provided by the winter Chinook carcass survey*" (USFWS). Generally, three to four 8-foot-diameter rotary screw traps are operated just downstream of RBDD (Figure 3). Due to the nature of the traps, the traps rotary cone "fishes" with approximately one-half of the cone in the water (under ideal conditions) which translates into approximately 4 feet deep or 25 ft^2 cross-sectional area. The Sacramento River is approximately 700 feet wide where the traps operate. During unsuitable riverine conditions (e.g., high flows and debris loading), the traps are not engaged. Over the years, the relative efficiency of the traps has been estimated by releasing a known number of marked fish 2.5 miles upstream of the traps and counting the number of marked fish entering the traps. Those values are compared to the estimated volume of water entering the traps using flow meters. From 2002 – 2013, for all efficiency tests using both fall-run and winter-run Chinook, the average fish capture efficiency was 2.4% (range: 0.3% - 5.5%) and the average percent of the river flow filtered by the traps was 3.1% (range: 0.7% - 6.9%) (Poytress et al. 2014). Because of the desire to compare all data as salmon fry (≤45 mm fork length) "equivalents", a ratio of 1.7 to 1 is used to expand the numbers of larger-sized salmon (≥46 mm FL) to account for the higher survival rate for larger-sized fish and thereby adjust for fry to pre-smolt/smolt survival. This latter adjustment was developed to compare variability in salmon production between years (Poytress et al. 2014).

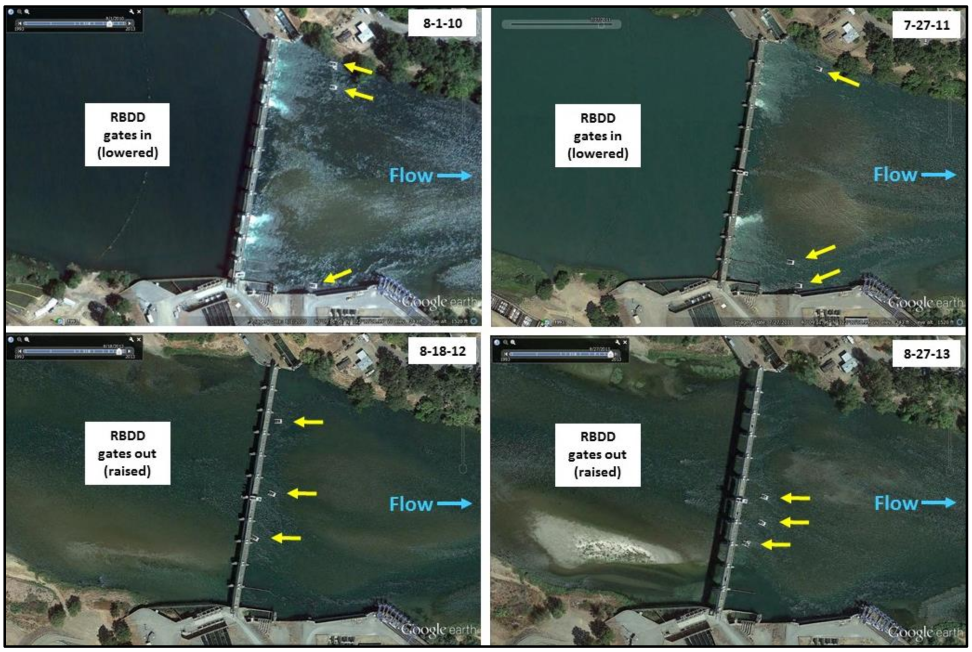

Figure 3. Aerial photographs of the locations of the rotary screw fish traps downstream of RBDD (yellow arrows) during periods when the RBDD gates were lowered and raised.

Poytress et al. (2014) state: "*Moreover, by comparing production*[1] *to the number of adult Chinook females each year (by run) and estimating fecundity data from CNFH*[2] *and Livingston Stone National Fish Hatchery (LSNFH) hatchery production records, estimated recruits per female and egg-to-fry survival estimates were generated*." The following Table 1 [from Poytress et al. (2014), Table 6c] and description provide an example of how the egg-to-fry survival estimates are made. Using 2002, for instance, an estimated number of 5,670 female salmon spawned (1) with an estimated average of 4,923 eggs per female (2) which resulted in an estimated total number of eggs laid in the river gravels of 27,913,410 eggs (not shown in the table). For that year, an estimated 7,635,469 salmon fry equivalents passed RBDD (3). Dividing 7,635,469 by 27,913,410 yields 27.4% (4) or the estimated egg-to-fry (ETF) survival estimate. However, the lower and upper 90% confidence intervals were very low and very high (2,811,132 and 13,144,325, respectively), indicating caution should be used in assuming a high degree of accuracy in the ETF survival estimates. Poytress et al. (2014) indicated that such high ranges in confidence intervals were attributable to periods of lower levels of trapping efforts (Figure 4)

[1] Refers to the "fry-equivalent Chinook production estimates" at RBDD.
[2] Coleman National Fish Hatchery.

(e.g., to reduce "take" of winter-run Chinook) and have had "*profound effects on the precision of passage estimates and confidence intervals*".

Table 6c. Winter Chinook fry-equivalent production estimates, lower and upper 90% confidence intervals (CI), estimates of adults upstream of RBDD (Adult Estimate), estimated female to male sex ratios, estimated females, estimates of female fecundity, calculated juveniles per estimated female (recruits per female) and egg-to-fry survival estimates (ETF) by brood year (BY) for Chinook sampled at RBDD rotary traps between July 2002 and June 2013.

BY	FRY EQ Passage	Lower 90% CI	Upper 90% CI	Adult Estimate	Sex Ratio (F: M)[1]		Estimated Females	Fecundity[2]	Recruits per Female	ETF
2002	7,635,469	2,811,132	13,144,325	7337	0.77	0.23	5,670	4,923	1,347	27.4%
2003	5,781,519	3,525,098	8,073,129	8133	0.64	0.36	5,179	4,854	1,116	23.0%
2004	3,677,989	2,129,297	5,232,037	8635	0.37	0.63	3,185	5,515	1,155	20.9%
2005	8,943,194	4,791,726	13,277,637	15730	0.56	0.44	8,807	5,500	1,015	18.5%
2006	7,298,838	4,150,323	10,453,765	17205	0.50	0.50	8,626	5,484	846	15.4%
2007	1,637,804	1,062,780	2,218,745	2488	0.61	0.39	1,517	5,112	1,080	21.1%
2008	1,371,739	858,933	1,885,141	2850	0.51	0.49	1,443	5,424	951	17.5%
2009	4,972,954	2,790,092	7,160,098	4537	0.60	0.40	2,702	5,519	1,840	33.3%
2010	1,572,628	969,016	2,181,572	1533	0.53	0.47	813	5,161	1,934	37.5%
2011	996,621	671,779	1,321,708	824	0.51	0.49	424	4,832	2,351	48.6%
2012	1,789,259	1,157,240	2,421,277	2581	0.58	0.42	1,491	4,518	1,200	26.6%
Mean	4,152,547	2,265,220	6,124,494	6,532	0.56	0.44	3,623	5,167	1,349	26.4%
CV	70.1%	64.0%	74.9%	85.7%	17.9%	22.9%	83.4%	6.7%	35.5%	37.9%

[1] Annual sex ratio values based on annual carcass survey estimates of female recoveries.
[2] Female fecundity estimates based on annual values from LSNFH winter Chinook spawning data collected between 2002 and 2012.

Table 1. Table 6c from Poytress et al. (2014).

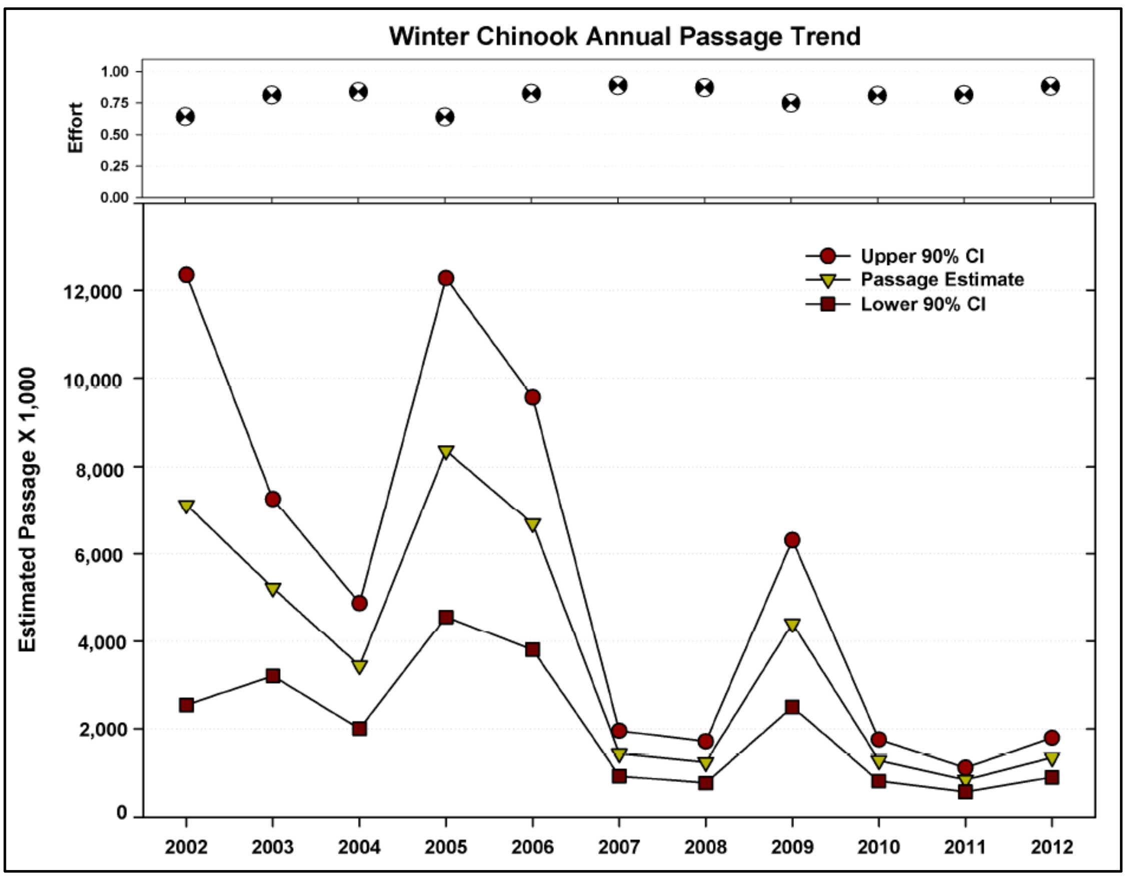

Figure 4. RBDD rotary trap winter Chinook annual sample effort and passage estimates with 90% confidence intervals (CI) for the period July 2002 through June 2013 (from Poytress et al. 2014).

A statistically significant relationship between the estimated annual numbers of female Chinook and the fry-equivalent winter Chinook production estimates was reported by Poytress et al. (2014). If there were uniform estimated annual survival rates and narrow confidence intervals in the juvenile production estimates, such a relationship would not be surprising. However, there is very high variability in annual estimated survival rates (Figure 2) and large confidence intervals of production estimates (Table 1), suggesting that multiple, unaccounted-for factors are affecting results. These factors may be both density-dependent and density-independent.

The emigration of winter-run Chinook fry past RBDD has often been characterized as a "trickle-down effect" of young fry moving from the upstream rearing grounds to areas downstream of RBDD, but not all the way to the Delta during late summer and early fall due to inhospitable environmental conditions in the mid- to lower-Sacramento River. During more-recent years, a much higher proportion of winter-run salmon have been spawning farther upstream from RBDD than earlier years of redd surveys (Historical CDFW Winter-Run Chinook Redd Surveys)[3]. In addition, a combination of fish passage improvements at Anderson-Cottonwood Irrigation District (ACID) dam in Redding and many years of gravels replenishment downstream of Keswick Dam have likely increased winter-run spawning in the upper-most reaches. For example, in 1987 when USFWS divers mapped the riverbed between ACID and Keswick Dams, only 10% of the winter run spawned in that reach (Vogel and Taylor 1987), whereas, in 2013, 76% spawned in that reach (CDFW data). This significant change in winter-run distribution likely has, and will have, an effect on salmon emigration timing as detected approximately 50 miles downstream at RBDD.

However, the most important abiotic[4] factors stimulating winter-run emigration from the upper to the lower river are likely river flow and turbidity. Juvenile salmon downstream migrations tend to occur in groups and pulses; these pulses have shown to correspond to increased flow events. For example, USFWS salmon research by Kjelson *et al.* (1982) and Vogel (1982, 1989) reported increased downstream movements of fry Chinook corresponding to increased river flows and turbidity, respectively. The life stage activities for each run of Sacramento River Chinook salmon are highly correlated with hydrologic conditions during any given year (Vogel and Marine 1991). This phenomenon has been frequently observed through many years of sampling in Central Valley rivers and streams (e.g., Poytress et al. 2014). However, the riverine conditions prompting large-scale emigration of juvenile salmon can also make operations of rotary screw traps very problematic, primarily because of high debris loading in and on the traps. As a result, the traps are often removed to prevent damage to the equipment and excessive mortality or lethal take of captured salmon, thereby significantly reducing sampling effort (e.g., top of Figure 4) at the time when most salmon emigration is likely to occur. Poytress et al. (2014) characterized the problem as follows:

> "*One problem confounding the results of storm and fish passage observations and analyses was that sampling during large storm run-off/discharge events often ceased due to safety concerns, concerns for fish impacts or simply due to the inability to sample the river when woody debris stop rotary traps from operating properly. In some years, storm events resulted in discharge levels too great to*

[3] Data used for the graphics provided by Doug Killam, CDFW.
[4] A biotic factor is smoltification.

> *sample effectively or damaged traps which resulted in numerous days or weeks un-sampled afterwards. The results are typically negative bias in passage estimates if days following the peak discharge or concurrent turbidity events are un-sampled*."

Water year 2014 was classified as critically dry for the Sacramento River valley[5]. During dry water years, juvenile salmon tend to remain in the upper Sacramento River on the rearing grounds until increased flows, turbidity, or a combination of both stimulate downstream migration to the estuary. This is particularly true for juvenile winter-run Chinook salmon. For example, Vogel and Marine (1991) reported that during a representative dry year only 30-40% of the emigration of juvenile winter-run from the upper Sacramento River would be expected to occur by mid-November and only 50-75% by mid-December. In particular, winter-run Chinook salmon can "emigrate *en masse*" during storms and increased river flow in that period (Vogel and Marine 1991). For example, Poytress et al. (2014) describe one attempted 24-hour sampling event in December 2005 that had to be prematurely terminated to avoid impacts to winter run because a "*huge influx of fry and smolt passage*" from 10's to 1,000's of fish per hour occurred.

The predicament apparently happened during the first high flow events following winter-run fry and juvenile rearing in the upper Sacramento River during late 2014. Of those salmon that had survived deleterious effects of water temperatures that year, a high proportion of winter-run would have been expected to emigrate *en masse* during the large storm events in early December 2014; unfortunately, the fish trapping at RBDD mainly ceased during those periods (Figure 5). To account for this dilemma, the USFWS estimated the numbers of fish not sampled during the time when the fish traps were not in operation by interpolating numbers of fish captured prior to and after un-sampled time periods. However, relatively low numbers of salmon were captured during the low-flow periods (as expected) and, undoubtedly, the estimated total numbers of winter-run were substantially underestimated during December 2014. An example calculation is shown using Table 2. From December 3 through December 8, the fish traps were not operated (1). To estimate the numbers of fish during this period, the value of 476 winter run on December 9 (2) (after flows receded and traps could be fished) was used to expand the weekly estimate to 3,332 (i.e., 7 x 476 = 3,332 fish). From December 11 through December 15, the fish traps were not operated (3). The values of 452 on December 10 and 1,487 on December 16 (after flows receded and traps could be fished) were averaged and used to expand the weekly estimate to 6,787 fish (i.e., 7 x 969.5 = 6,787). These values (3,332 + 6,787) were then added to obtain 10,119 for the biweekly total (5).

This consequence would have greatly underestimated the egg-to-fry equivalent production index and, in turn, significantly overestimated fish mortality (approximately 95% in Figure 2). As pointed out by Poytress et al. (2014), "*The importance of the first storm event of the fall or winter period cannot be overstated.*" Therefore, it would be informative to bracket the original estimates by interpolating anticipated higher numbers of fish to a more-reasonable estimate that likely occurred during non-sampled periods and, additionally and importantly, parse out the estimated mortality that occurred due to unsuitable water temperature during the egg incubation period (discussed in the following section).

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[5] http://cdec.water.ca.gov/cgi-progs/iodir/wsihist

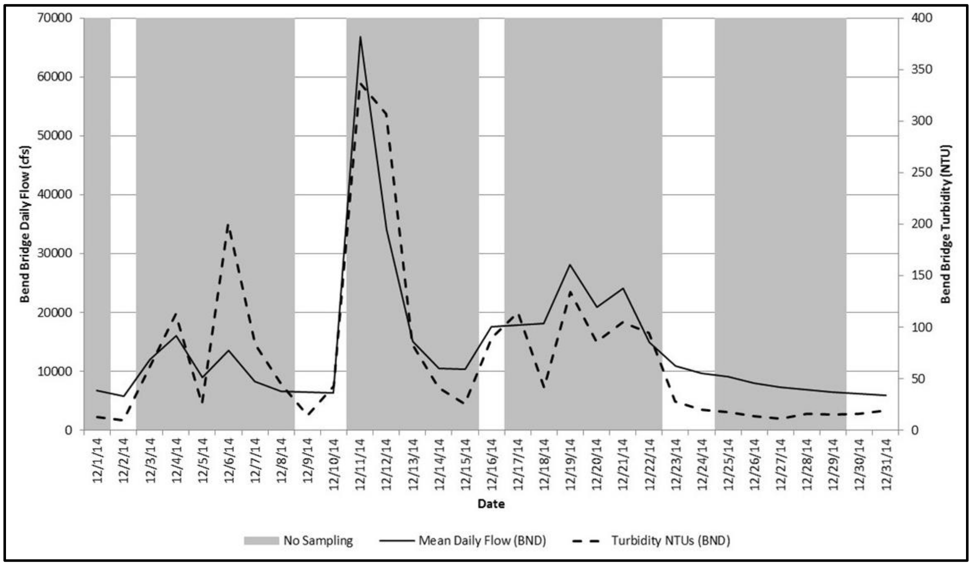

Figure 5. Daily flows (cfs) and turbidity (NTUs) measured at the Bend Bridge gauge upstream from RBDD during December 2014 and the periods when no fish sampling occurred at RBDD (which is used to estimate juvenile salmon production).

Table 1.— Preliminary estimates of passage by brood-year (BY) and run for unmarked juvenile Chinook salmon and steelhead trout captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA, for the dates listed below. Results include estimated passage, peak river discharge volume, water temperature, turbidity, and fork length (mm) range in parentheses. A dash (-) indicates that sampling was not conducted on that date.

				Estimated passage				
Date	Discharge volume (cfs) [1]	Water temperature (°C)	Water turbidity (NTU)	BY14 Winter	BY14 Spring	BY14 Fall	BY14 Late-Fall	BY14 RBT
12/3/2014	6,240	12.7	–	–	–	–	–	–
12/4/2014	31,200	12.4	–	–	–	–	–	–
12/5/2014	17,500	13.2	–	–	–	–	–	–
12/6/2014	15,700	13.6	–	–	–	–	–	–
12/7/2014	16,700	13.1	–	–	–	–	–	–
12/8/2014	8,810	13.1	–	–	–	–	–	–
12/9/2014	6,710	13.3	11.7	476 (58 – 93)	688 (36 – 40)	2,021 (30 – 35)	682 (100 – 143)	0 (–)
12/10/2014	6,570	13.2	11.5	452 (55 – 88)	421 (36 – 38)	1,339 (29 – 35)	332 (98 – 122)	69 (78 – 84)
12/11/2014	39,000	12.5	–	–	–	–	–	–
12/12/2014	106,000	11.8	–	–	–	–	–	–
12/13/2014	36,800	11.7	–	–	–	–	–	–
12/14/2014	16,600	11.2	–	–	–	–	–	–
12/15/2014	10,900	10.8	–	–	–	–	–	–
12/16/2014	22,100	10.3	32.8	1,487 (61 – 83)	1,508 (37 – 43)	10,539 (29 – 37)	493 (111 – 163)	0 (–)
Biweekly Total [2]				**10,119**	**11,568**	**55,720**	**7,662**	**242**
Biweekly Lower 90% Confidence Interval				2,690	3,068	11,310	2,354	-33
Biweekly Upper 90% Confidence Interval				17,547	20,067	100,130	12,969	516
Brood Year Total				**391,138**	**20,036**	**56,992**	**98,093**	**61,699**
Brood year Lower 90% Confidence Interval				235,079	6,589	10,547	45,571	21,716
Brood year Upper 90% Confidence Interval				547,197	33,484	103,437	150,616	101,682

[1] Peak daily discharge values do not account for diversions at RBDD and only represent peak flows registered at the Bend Bridge Gauging station (http://cdec2.water.ca.gov/cgi-progs/queryFx?bnd).
[2] Biweekly totals may be greater than the sum of the daily estimates presented in this table if sampling was not conducted on each day of the biweekly period. A dash (-) denotes those dates. To estimate daily passage for days that were not sampled, we impute missed sample days with the weekly mean value of days sampled within the week.

Table 2. Obtained from: http://www.fws.gov/redbluff/RBDD%20JSM%20Biweekly/2014/Biweekly20141203-20141216.pdf

In addition to the problems associated with the inability to monitor fish passage during high-flow conditions which biases fish production indices low, Poytress et al. (2014) also recognize the relatively recent problem of the important need to more accurately measure the rotary screw traps' efficiency in capturing juvenile salmon due to the RBBD gates being raised year-round and the resultant shifting of the channel's geometry (e.g., Figure 3):

"*The loss of annual maintenance and RBDD gate lowering operations at the rotary trap sample site (Figure 1) will allow the river channel's geometry to change more frequently due to natural flow driven substrate transport mechanisms. RBDD operations of the past virtually "reset" the sample site to facilitate pumping during the gates-out period and improve fish passage at the fish ladders during the gates-in period. As the sample site's channel configuration is allowed to fluctuate in the absence of dam operations, the overall effect could be differing trap efficiency values in relation to flow compared to previous years' data. Annual mark-recapture trials will be needed to evaluate this phenomenon, which has been observed in other uncontrolled channel sampling locations*."

This recommendation is appropriate but may be difficult to achieve for winter-run Chinook because of Endangered Species Act restrictions and the previously described problems resulting in non-sampling during high-flow conditions when large numbers of winter run may emigrate past the traps.

Water Temperature Effects on Egg Incubation

Numerous individuals have conducted literature reviews of the effects of water temperature on salmon egg incubation. Despite some relatively few differences in opinions on specific thresholds for the upper tolerances, the adopted/recommended water temperature for Central Valley Chinook salmon reproductive processes is 56°F (NMFS 2009, Vogel and Marine 1991, Marine 1993). Temperatures greater than 62°F can cause 100% mortality of incubating salmon eggs and alevins. To illustrate this point, NOAA Fisheries provided the following graph to the SWRCB (Figure 6).

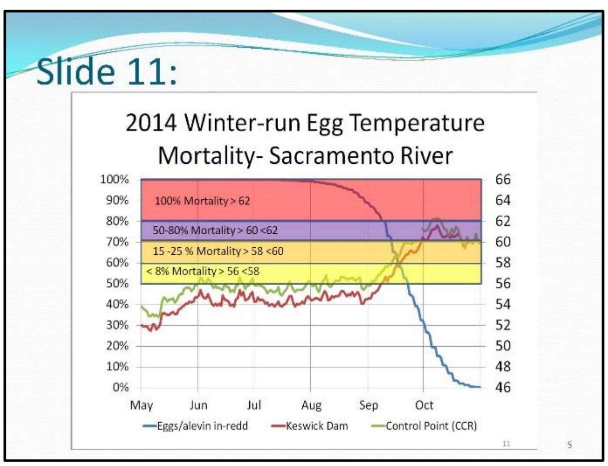

Figure 6. Graph from a PowerPoint presentation by NOAA Fisheries to the SWRC B on February 18, 2015.

What this graph fails to portray is the fact that temperature effects on egg incubation are not linear and are dependent on duration of exposure and egg/larval development stage. These circumstances are provided in Table 3 which is derived from mortality schedules developed by the USFWS and CDFW for use in evaluation of Shasta Dam temperature control alternatives (Richardson and Harrison 1990). Based on these thermal impacts, a model was developed for the Biological Assessment for the Long-Term Central Valley Project Operations Criteria and Plan to evaluate effects on winter-run Chinook salmon (USBR 1992). Pre-emergent fry have better tolerance to elevated temperatures compared to incubating eggs (Table 3) (USFWS 1990, as cited by USBR 1992). There has been an unsubstantiated concern recently expressed that alevins in the gravel may experience thermal impacts if water temperatures are between 55°F to 57.5°F (SWRCB 2015) without supporting documentation.

A review of the scientific literature indicates that the origin of the alevin development concern may relate to circumstances where: 1) adult female salmon exposed to high water temperatures may adversely impact eggs later after the eggs hatch, or 2) abnormal development during early egg development at less-than-favorable temperatures may by implicated in contributing to mortality later in larval development. For example, high mortality of fall-run Chinook salmon eggs was observed at Nimbus Fish Hatchery on the American River, California during its first year of operation in 1955. During that year, adult salmon were exposed to high water temperatures, low dissolved oxygen content, and the presence of sulfides which contributed to poor conditions of eggs taken at the hatchery (Hinze et al. 1956). The authors concluded that "*High water temperatures and the poor quality of the American River water at the time were the major causes of high mortality of the salmon eggs and fry*." High water temperatures during early egg incubation (over 60°F) and exposure of adult salmon to high water temperatures were believed to contribute to egg mortality (Hinze 1956). Regardless, adult winter-run Chinook are not exposed to such warm water temperature cited in the scientific literature due to the period of upstream migration to spawn (i.e., winter and spring months).

Table 3. Relationship between water temperature and mortality of Chinook salmon eggs and pre-emergent fry (from 1992 Biological Assessment for the Central Valley Project).

Water Temperature (°F)[a]	Egg Mortality[b]	Instantaneous Daily Mortality Rate (%)	Pre-Emergent Fry Mortality[b]	Instantaneous Daily Mortality Rate (%)
41-56	Thermal Optimum	0	Thermal Optimum	0
57	8% @ 24d	0.35	Thermal Optimum	0
58	15% @ 22d	0.74	Thermal Optimum	0
59	25% @ 20d	1.40	10% @ 14d	0.75
60	50% @ 12d	5.80	25% @ 14d	2.05
61	80% @ 15d	10.70	50% @ 14d	4.95
62	100% @ 12d	38.40	75% @ 14d	9.90
63	100% @ 11d	41.90	100% @ 14d	32.89
64	100% @ 7d	65.80	100% @ 10d[c]	46.05

[a] This mortality schedule was compiled from a variety of studies each using different levels of precision in temperature measurement the lowest of which was whole degrees Fahrenheit (±0.5°F). Therefore, the level of precision for temperature inputs to this model is limited to whole degrees Fahrenheit.
[b] These mortality schedules were developed by the U.S. Fish and Wildlife Service and California Department of Fish and Game for use in evaluation of Shasta Dam temperature control alternatives in June 1990.[6]
[c] This value was estimated similarly to the preceding values but was not included in the biological assumptions for Shasta outflow temperature control FES (USBR 1991b)

[6] Richardson, T. H., and P. Harrison. 1990. Fish and Wildlife Impacts of Shasta Dam Water Temperature Control Alternatives. Prepared for the U.S. Bureau of Reclamation, Sacramento, California. U.S. Fish and Wildlife Service - Fish and Wildlife Enhancement, Sacramento, California.

To evaluate potential effects of 2015 water operations on winter-run Chinook salmon, this model was adapted using the following algorithm:

Letting $N_t = N_{t-1}(1 - Z_t)$

Where N_t = The proportion of surviving eggs or pre-emergent fry at end of day t

N_{t-1} = The proportion of eggs or pre-emergent fry at beginning of day t

Z_t = The instantaneous daily egg or pre-emergent fry mortality rate for a specific average daily temperature (by tracking the daily accumulation of Temperature Units (TUs) to determine developmental stage, the appropriate egg or larval instantaneous mortality rate can be applied)

The mortality model utilizes daily water temperatures to accumulate TUs and track the developmental stage of eggs and larvae. Survival for the proportion of a total year's brood spawned in a particular week and at two locations in the river (near Keswick and near Bonnyview Bridge) is adjusted for temperature-specific mortality depending on daily water temperatures at those locations and the developmental stage occurring in successive weeks. The arithmetic product of the daily N_t's during the entire incubation period for any given spawning week results in the proportion of any particular week's brood surviving to emergence [1600 ATUs (accumulated temperature units) for one scenario and 1850 ATUs for a second scenario]. By performing this iterative algorithm for each week of spawning and multiplying each resulting product of N_t's by the corresponding week's spawning proportion then summing across all weeks of spawning activity, the overall estimated survival is calculated (modified from USBR 1992). Because the specific timing of winter-run salmon spawning in 2015 is obviously not known, the results should not be viewed as a statistical model or absolute predictions, but rather as an approximation of the biological effects of water temperature conditions affecting winter-run reproduction.

Water temperature data were obtained from the USBR operational scenario 6b(4) provided to the SWRCB on March 26, 2015 (Figure 7) to model effects on winter-run Chinook egg incubation.

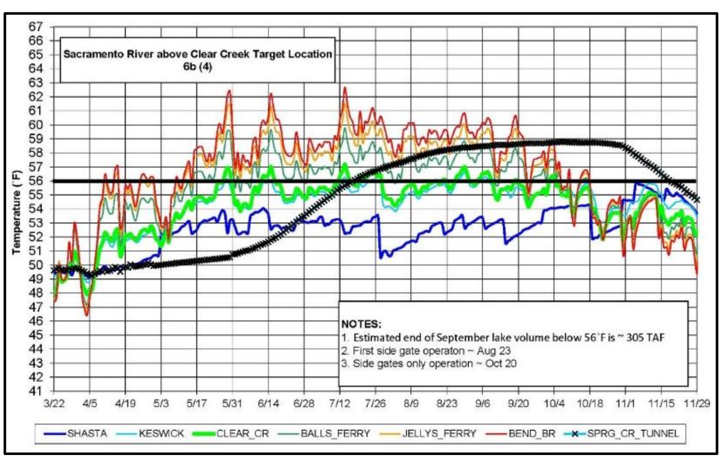

Figure 7. Sacramento River modeled temperature 2015 March 90% - exceedance outlook, 53 degree target at Shasta Dam, Model Scenario 6b(4). Provided by USBR to the SWRCB on March 26, 2015.

CDFW historical data on winter-run spawn timing were used in the model. Only years where greater than 500 salmon spawned were included to obtain a more-robust dataset. Although predicted daily water temperatures are available from the scenario 6b(4) model run, the winter-run spawn timing data are in weekly time steps. Therefore, daily water temperatures were tracked for each weekly increment of the estimated winter-run eggs in the gravel. For the first model run, it was assumed that most winter-run salmon in 2015 will spawn closer to the CCR compliance point (Bonnyview Bridge) and in the second model run, it was assumed that most salmon will spawn closer to Keswick Dam (Figure 1).

To estimate the timing of egg hatchery and fry emergence, two scenarios were used to bracket the estimates. Piper et al. (1982) (Fish Hatchery Management) state that Chinook salmon eggs require 750 ATUs to hatch and 1,600 ATUs to emerge, whereas CDFW assumes that eggs require 900 ATUs to hatch and 1,850 ATUs to emerge. This latter value is based on the high range of 1,650 to 1,850 ATUs observed at the Oregon Department of Fish and Wildlife Willamette Hatchery [U.S. Army Corps of Engineers (2012), as cited by Buccola et al. (2012)]. The higher ATUs requirement means that the eggs and alevins would experience a more-protracted development and be in the gravel longer than that predicted by Piper et al. (1982) as illustrated in Figure 8.

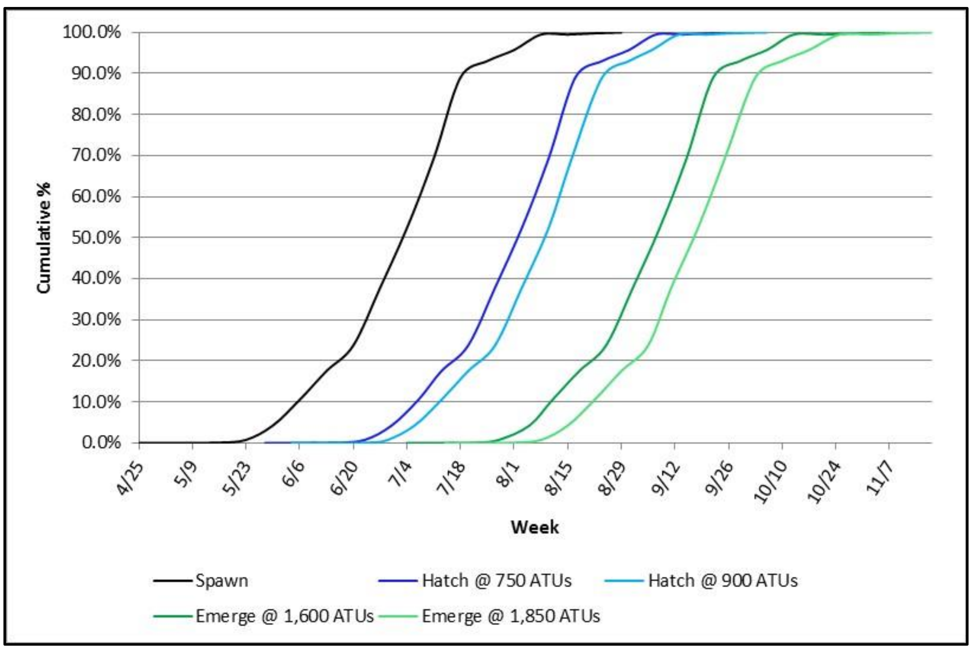

Figure 8. Estimated timing of winter-run Chinook salmon spawning, egg hatching, and fry emergence in 2015.

For the purposes of this paper, no attempt was made to discriminate between higher survival expected for alevins after eggs hatch to reduce the analysis to a "worse-case" scenario. For example, even though prior modeling for the CVP effects on winter-run assumed that alevins exposed to temperatures of 57°F would not experience mortality (Table 3), this analysis assumed alevins would experience the same mortality as eggs (Table 3). Additionally, the more-protracted egg and alevin development assumption was used and it was assumed that all eggs and alevins would be in the gravel during the entire season to, again, portray a worse-case scenario. In this vein, it was also assumed in the first model run that all winter run would spawn closer to the CCR compliance point instead of nearer to Keswick Dam where water is slightly cooler.

Figure 9 shows the results of the first model run. Based on water temperatures shown in Figure 7, the egg model showed that the end-of-season winter-run survival (based solely on water temperatures) would be 96.6% survival or 3.4% mortality. The slight decline in mortality late in the season was attributable to water temperature reaching 56.6°F on one day (September 8, 2015). These results are not surprising because there are only relatively few short-term, intermittent excursions when the CCR water temperatures slightly exceeded 56°F (Figure 7). For the second model run (assuming all the salmon spawn closer to Keswick where water is slightly cooler), there was essentially no mortality (not shown here). There was one day (August 30, 2015) when Keswick Dam temperatures reached 56.6°F, but this was considered insignificant. Although these model runs portray a worse-case scenario, there is substantial reason, based on the scientific literature, to believe the thermal effects on salmon egg incubation would not occur as depicted. For example, Healey (1979), through experiments using fall-run Chinook, found that salmon egg and fry mortalities "*were insignificant when temperatures were between 14.2 and 6.4°C (57.5 and 43.5°F)*". In addition, specific to Sacramento River winter-run Chinook, Slater (1963) identified the temperature of 42.5° – 57.5°F as the ideal temperature range during the May – August period when eggs and alevins would be in the gravel. Also, Combs and Burrows (1957) found no difference in Chinook salmon egg mortality when eggs were incubated at constant temperatures of 57.5°F and cooler. Burrows, R., as cited by Hinze (1956) identified 57.5°F as the upper threshold of tolerance for egg incubation. If these temperatures were used in the egg model described above, there would have been no predicted mortalities because daily temperatures are predicted to never exceed that threshold at CCR or Keswick Dam.

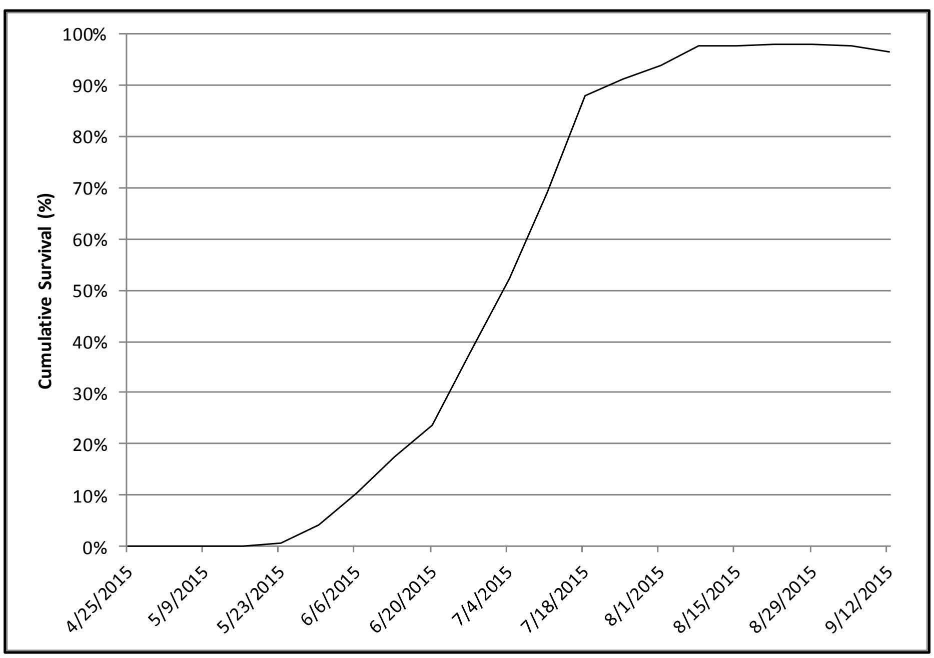

Figure 9. Predicted survival of eggs in the gravel (based solely on water temperature) for the egg development model run assuming all winter-run Chinook spawn closer to Bonnyview Bridge than near Keswick Dam. Note that although egg/larval development may occur after the date shown in this graph, predicted water temperatures later in season do not exceed 56°F and, therefore, no mortality is assumed during that period.

It is useful to compare water temperatures observed last year when winter-run egg mortality undoubtedly occurred, with predicted water temperatures this year. As can be seen in Figures 10 and 11, water temperatures late in the season during 2015 are predicted to be much cooler than observed in 2014 and, therefore, considerably more protective for winter run. The USBR model scenario 6b(4) is estimated to provide ~305,000 acre-feet of cold-water pool remaining in Shasta Reservoir by the end of September (USBR 2015), providing added protection for winter-run Chinook this year as compared to last year. It is postulated here that it would be more beneficial and lower risk for winter-run Chinook over the entire egg incubation season by not consuming too much of the cold-water pool early in the season which could result in high mortality later in the season such as occurred during 2014. Although it has not yet been done, it would be useful to use the egg temperature model described above to parse out mortality that occurred as a result of unfavorable water temperatures [presently estimated as 95% by the SWRCB (2015)] versus other factors (see Conclusions below). In particular, this effort would assist resource managers in improving the historical and future use of the salmon production indices at RBDD previously described and apply to salmon restoration programs.

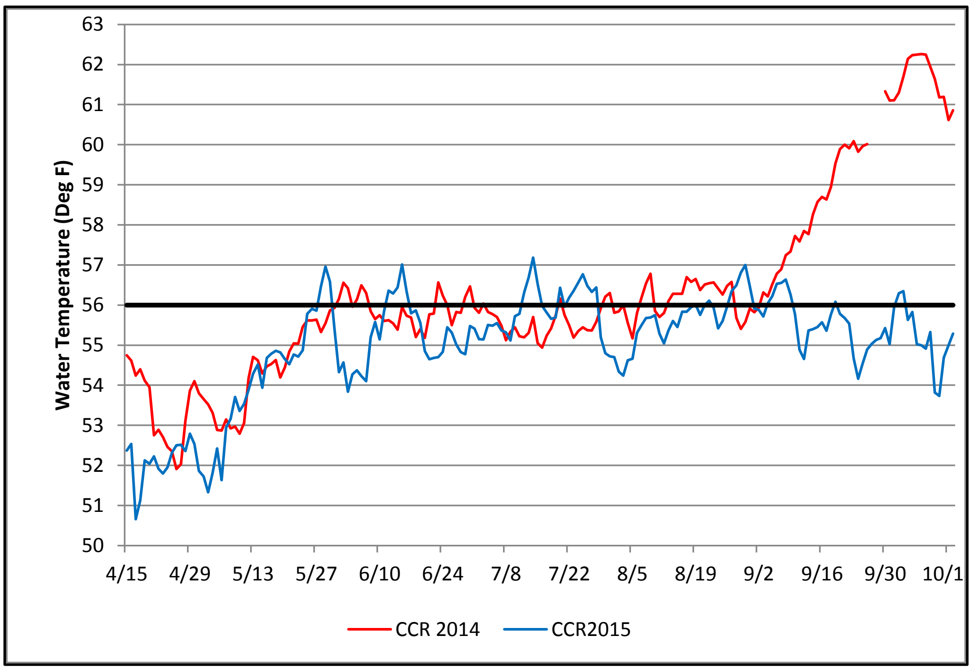

Figure 10. Daily Sacramento River water temperatures at the CCR compliance point (Bonnyview Bridge) in 2014 (actual) and 2015 (predicted).

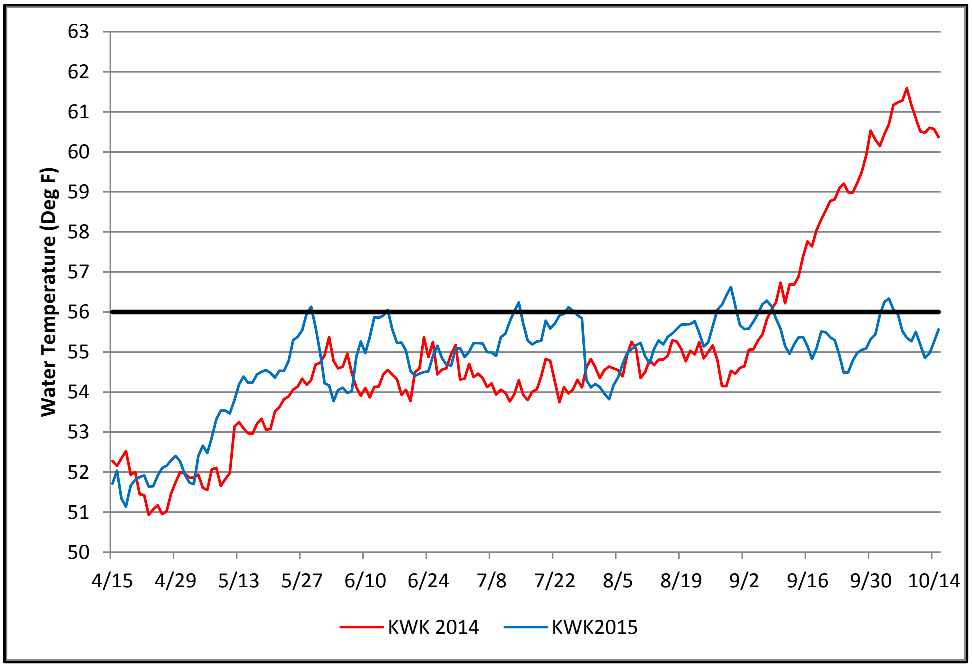

Figure 11. Daily Sacramento River water temperatures at Keswick Dam (KWK) in 2014 (actual) and 2015 (predicted).

During a meeting with CDFW biologists on March 23, 2015, I suggested a potential measure that could be implemented this year to benefit winter-run Chinook and preserve more cold water storage in Shasta Reservoir. This effort would entail use of the river outlets on the upper portion of the Shasta Dam spillway (Figure 12) early in the season. The concept is to utilize warmer, yet still sublethal, water from the upper portion of the reservoir early in the egg incubation season, thereby conserving more cold water for later in the season. The potential benefits of such a process are presently unknown due to the uncertainty in the timing of thermal stratification of the reservoir and other factors. Although this action would bypass the hydroelectric facilities at Shasta Dam, USBR subsequently indicated the agency would implement it if determined to be feasible in the effective mixing of dam releases to preserve more cold-water storage (R. Milligan, USBR, Chief of CVP Operations, pers. comm., March 26, 2015). This potential beneficial action has not yet been modeled.

Figure 12. Shasta Dam showing water discharged through the river outlets on the upper portion of the dam's spillway (USBR photograph).

Conclusions

- The estimated high mortality of 95% for winter-run eggs in 2014 was not based on modeling of thermal impacts on eggs but, instead, on juvenile production indices (JPI) developed from fish trapping operations at Red Bluff Diversion Dam (RBDD), approximately 50 river miles downstream from where most winter-run salmon spawned. For comparison, estimates of winter-run salmon mortality averaged 74% for the years 2002 – 2012.

- Although the RBDD fish monitoring is a well-executed program and provides valuable information on juvenile salmon outmigration characteristics, extreme caution must be used when attempting to translate the JPI into egg-to-fry survival estimates because of numerous limitations in the program and high variability in estimates. Nevertheless, the monitoring program is continually being improved and will continue to be valuable for resource managers into the future.

- During 2014, the RBDD fish sampling program undoubtedly missed a large portion of the outmigration of juvenile winter run salmon because the traps were not in operation during the first heavy storms of the season which cause high flows and turbidity and stimulate large-scale salmon emigration. This circumstance certainly biased winter-run Chinook production indices low and biased estimated fish mortality high in 2014.

- Modeling of thermal effects on egg development should be performed to compare past estimates of juvenile winter-run salmon production to parse out temperature-mortality effects on salmon production from other density-dependent and density-independent factors. For example, although high mortality to winter-run eggs definitely occurred in 2014 late in the egg-incubation season, it would be valuable to determine adverse impacts specifically caused by water temperatures. Normal egg-to-fry mortality may approximate 70%, but the assumption of 95% egg mortality (solely attributed to water temperature) in 2014 estimated from the RBDD JPI implies no other mortality factors were in play.[7] For example, Figure 2 shows the estimated mortality based on the JPI for other years. For the years 2002 – 2012, Poytress et al. (2014) estimated the egg to fry mortality at 73.6%. Modeling would assist in this regard by providing more-informative information on potential cause and effects.

- Among the USBR model scenarios, 6b(4) is the preferred option for protection of winter-run Chinook egg incubation. Modeling of thermal effects resulting from USBR's operational scenario 6b(4) for 2015 CVP operations will cause negligible impacts on winter-run Chinook salmon if salmon spawn primarily in the upper-most reaches of the Sacramento River as has been observed during these recent drought years and predicted

[7] For example, not all eggs from each female are laid in the gravels, 100% fertilization is unlikely to occur, some eggs succumb to disease, less-than-ideal intra-gravel flow may kill some eggs, not all fry emerge due to unfavorable substrate conditions (e.g., sand and silt affecting emergence success), redd superimposition of later-spawning salmon on earlier spawned eggs may displace and kill eggs, fry and juvenile fish may be lost due to stranding during decreased flow events, and fry and juvenile predation by birds and piscivorous fish, etc. may kill fish prior to migration past RBDD.

temperature model outputs are reasonably accurate. This operations scenario will preserve more cold-water storage in the reservoir by the end of September 2015 (~305,000 acre-ft) than was available in a comparable period in 2014 when the cold-water pool was exhausted [i.e., 0 acre-ft (USBR 2015)].

- Although 56°F has been the commonly-used target in the past at various compliance points in the upper Sacramento River, the extraordinary conditions during this fourth drought year should prompt extraordinary pre-emptive actions to avoid a repeat of last year's impact to winter run.

- An additional measure that may benefit this year's production of winter-run Chinook could be the use of the upper river outlets on the Shasta Dam spillway during early season to conserve more cold-water storage in the reservoir later in the season when most winter-run eggs will be incubating in the river gravels.

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