Methods and Modeling

Finer scale conceptual models of spawning adult and early life stages of winter-run Chinook Salmon (*Oncorhynchus tshawytscha*) were modified to identify transition linkages between these stages and the habitat attributes influenced by river environmental drivers (Figure 1-2). Keswick reservoir temperature and flow operations can interact with adult, egg, and juvenile life stages in multiple ways that impact growth, survival, and condition. An updated evaluation of discrete habitat attributes can be undertaken by documenting each of the possible mechanisms and certainty surrounding these mechanisms.

Figure 1. Conceptual model of transition between adult spawner and egg/fry emergence.

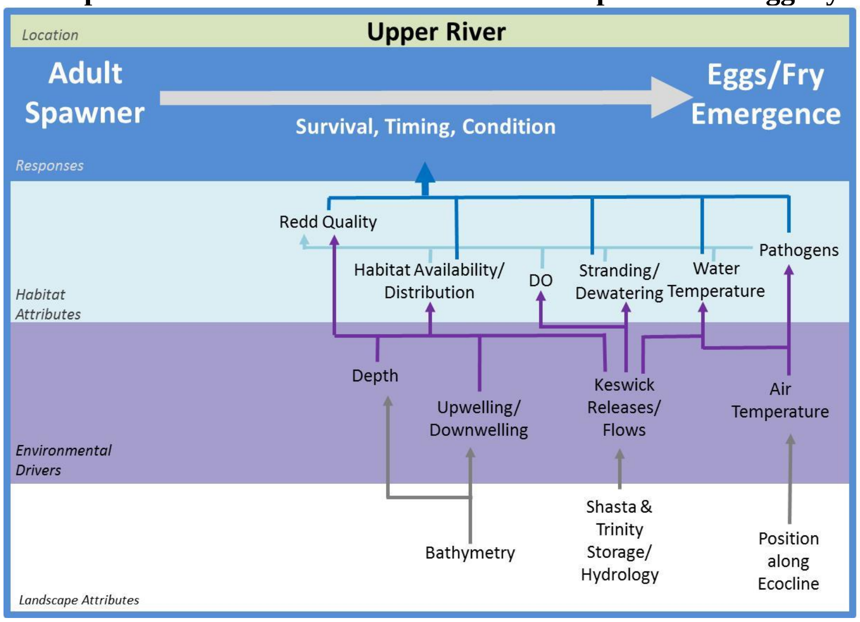
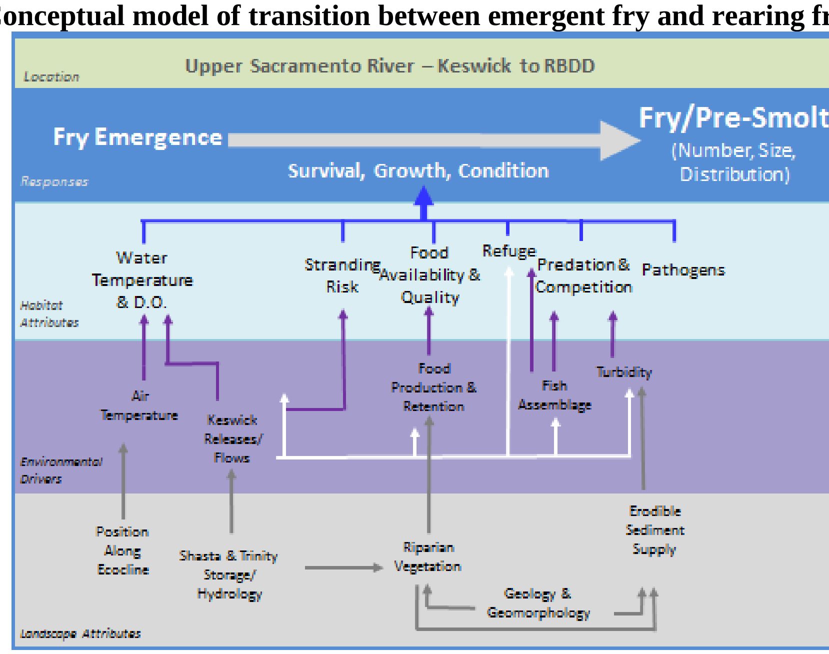


Figure 2. Conceptual model of transition between emergent fry and rearing fry/pre-smolt.



Operational Forecast Model

Changes to the meteorology and temperature profiles stimulated revisions to the temperature forecast modeling since the April 90% Temperature Forecast Model was developed and evaluated in the Biological Review submitted with the Temperature Urgency Change Petition for June 30 through November 30, 2015 (USBR 2015a),. The modeling evolved into an updated temperature forecast scenario including Shasta/Keswick average monthly releases of 7,250 cubic feet per second (cfs) during June through August and reduced releases of 6,500 cfs and 5,000 cfs during September and October, respectively. In support of the updated temperature forecast scenario, an updated Operational Forecast Model was completed to evaluate system wide operations (Table 1).

Storages

Federal End of the Month Storage/Elevation (TAF/Feet)

		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Trinity	1024	870	745	620	530	499	467	451	458	495	562	630	560
	Elev.	2240	2224	2205	2190	2185	2178	2175	2177	2184	2196	2207	2195
Whiskeytown	239	238	238	238	230	206	206	206	206	206	206	238	238
	Elev.	1209	1209	1209	1207	1199	1199	1199	1199	1199	1199	1209	1209
Shasta	2404	2196	1943	1687	1460	1379	1388	1413	1534	1734	2061	2257	2138
	Elev.	968	954	938	923	917	917	919	928	941	961	972	965
Folsom	535	433	238	136	120	126	139	161	194	254	377	538	576
	Elev.	408	375	349	343	345	350	356	365	379	400	421	426
New Melones	453	388	323	265	238	216	211	206	209	217	223	229	228
	Elev.	832	815	798	789	781	780	778	779	782	784	786	786
San Luis	305	220	100	24	-11	6	-3	85	265	357	395	386	311
	Elev.	443	410	380	367	364	380	411	443	465	482	476	463
Total		4345	3587	2970	2567	2432	2407	2521	2866	3263	3824	4277	4050

State End of the Month Reservoir Storage (TAF)

		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Oroville	1565	1357	1126	966	907	897	789	734	854	1009	1226	1455	1402
	Elev.	713	683	659	649	648	629	619	641	666	696	725	719
San Luis	786	679	502	351	298	260	376	528	640	766	915	858	798
Total San Luis (TAF)	1091	900	602	374	287	266	373	613	904	1123	1309	1243	1108

Monthly River Releases (TAF/cfs)

		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Trinity	TAF	47	28	28	27	23	18	18	18	17	18	32	180
	cfs	783	450	450	450	373	300	300	300	300	300	540	2,924
Clear Creek	TAF	9	7	5	9	11	10	11	11	10	11	13	13
	cfs	150	120	85	150	175	175	175	175	175	175	218	216
Sacramento	TAF	431	446	446	387	307	238	246	200	180	200	256	479
	cfs	7250	7250	7250	6500	5000	4000	4000	3250	3250	3250	4300	7800
American	TAF	134	222	126	30	31	30	31	31	44	49	48	136
	cfs	2250	3615	2043	503	500	504	501	500	800	800	800	2215
Stanislaus	TAF	9	9	9	9	35	12	13	16	17	17	9	9
	cfs	150	150	150	150	577	200	206	261	309	280	150	150
Feather	TAF	131	160	101	71	58	57	58	49	44	49	48	136
	cfs	2200	2600	1650	1200	950	950	950	800	800	800	800	2216

Trinity Diversions (TAF)

		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Carr PP		116	98	97	62	15	28	19	6	1	1	38	37
Spring Crk. PP		110	90	90	60	30	19	12	3	3	10	8	30

Table 1. Forecasted Federal and State Storages and Monthly Flow Releases for Updated Temperature Forecast Scenario.

Sacramento River Temperature Forecast Model

The Sacramento River Temperature Forecast Model is a HEC-5Q model that represents operational outlooks, discharge, lake stratification, meteorology, in river temperature gains, and temperature control device (TCD) gate operation in relationship to river temperatures. The temperature model uses a monthly water operation outlook to generate monthly discharge from Shasta, Trinity, Keswick, Spring Creek and Carr Powerplants, and monthly evaporation estimates from Shasta, Trinity and Whiskeytown reservoirs. The monthly data are disaggregated into daily estimates for use in the model, which typically represent month long blocks of constant daily input. Reservoir temperature profiles and starting pool elevations are inputs generated by Reclamation staff once per month during the non-temperature management season and usually twice per month during the April-October time frame.

A meteorological forecast data set is selected, and an average year's information is used until the May through August temperature forecasts. For forecasts completed in these months, a procedure developed by Reclamation's Technical Service Center uses "current" meteorological conditions to attempt to select a subset of "best candidate" historic years that seem to fit the current year. In river temperature gains have been identified as a source of inaccuracy in the model (USBR 2015b). The model used for the 2015 forecasting has recently been modified to better reflect the observed 1.3°F difference between Sacramento River water temperatures just downstream of Keswick Dam (KWK, RM302) and above Clear Creek (CCR, RM 292). This allows some basis for considering using a warmer (or cooler) data set than the average meteorological forecast for the subsequent three months. Also, the updated temperature forecast scenario incorporates a 10% Local 3-month temperature outlook (L3MTO). The HEC-5Q output is plotted and can be plotted visually to evaluate temperatures at the various compliance locations. Output files also provide a forecast for the end-of-September profile, cold water volume, and TCD gate sequence.

Uncertainty in the Sacramento River temperature forecast model is due to the simplification of the input data, the unknowns regarding future meteorological conditions, and actual TCD operations do not provide infinite adjustability. Thus, forecasts are useful for considering broad brush evaluation of temperatures due to possible temperature operations and also relative comparisons between model runs. It does not provide sufficient precision to define specific daily future operations

Winter-run Chinook Salmon Juvenile Production Model

Egg and egg-to-fry mortality can be estimated using a dynamic simulation framework developed by Cramer Fish Science (CFS 2010). This model was originally developed to estimate winter-run Chinook Salmon juvenile production, but provides discretized mortality rate estimates for specific life stages. Relationships for daily temperature-induced mortality of incubating eggs and rearing juveniles (Bartholow and Heasley 2006) are parameterized with results from temperature mortality studies undertaken by the U.S. Fish and Wildlife Service (USFWS 1999). 2014 winter-run Chinook Salmon carcass data was used to reflect spawning time, in which the date of egg deposition was shifted 14 days before a carcass was observed (K. Niemela, pers. comm. in CFS 2010). Thus, daily cohorts of incubating eggs experience the temperature and flow conditions entered from observations or the Sacramento River Temperature Forecast Model to estimate egg mortality and total egg to fry survival.

Differences between estimates of temperature-related egg mortality and egg-to-fry mortality are due to the total egg-to-fry mortality incorporating mortality that occurs 'naturally' without high temperature effects over the entire incubation period. The temperature-related egg mortality estimate reflects effects of extreme temperatures that may be outside the data sets used to derive the egg-to-fry survival function. The function for egg-to-fry survival was based on a stock-recruitment relationship, using escapement and fry production above Red Bluff Diversion Dam from 1996-1999 and 2002-2007. The model runs on a daily time step, and a mean proportional mortality of the incubating eggs is estimated from the daily water temperature using a polynomial daily mortality relationship. The model was run for 100 iterations and the estimates are reported for egg and egg-to-fry stages.

For water year (WY) 2014, results were estimated using the April 2014 temperature forecast scenario's flow and temperatures (USBR 2014) and also a set of 'hindcast' results using observed daily flows measured at Freeport during WY 2014 with temperatures observed at CCR and Bend Bridge (BND, RM 258). For WY 2014, results were estimated from the May 2015 temperature management plan (USBR 2015c, April temperature forecast scenario) and the updated 2015 temperature management scenario. For these, the model used Keswick releases and Clear Creek and Bend Bridge temperatures from the updated temperature forecast scenario past June 1 and observed temperatures and flows for the period between April 1 and May 31.

There remains uncertainty with the results from this model of egg and egg-to-fry mortality. In 2014, the observed temperature difference between KWK and CCR averaged 1.3°F cooler during the temperature control period than observed, and this is not observed in the modeled results for Clear Creek or Bend Bridge temperatures. This positively biases results from the April 2014 temperature forecast scenario. In recent years, modeled egg-to-fry mortality appeared to more closely reflect observed juvenile production and estimated mortality upstream of Red Bluff Diversion Dam when the temperature compliance point was further downstream and poorly reflect the observed juvenile production and mortality estimate when the temperature compliance is further upstream (USBR 2015d). These biases suggest that using temperatures reflecting alevin and fry rearing habitat may be important for accurately estimating egg-to-fry survival. It is not assumed that all mortality of these life stages is directly linked to temperature mortality, and Reclamation (USBR 2015d) suggested that the monitoring strategy consider potential indirect effects linked to temperature (such as increased predation mortality, increase disease mortality, and increased stranding mortality) to understand multiple stressors of the drought mediated by temperature. Additionally, there is uncertainty due to the potential for actual operations during late summer deviating from the temperature management plan if actual storage and temperature conditions in Trinity and Shasta reservoirs are different from the modeled conditions.

RAFT Model

The River Assessment for Forecasting Temperature (RAFT) model makes physically-based predictions of water temperature according to governing 1-dimensional hydrodynamic and heat transport equations (Pike et al. 2013). The model tracks heat movement through processes such as advection, longitudinal dispersion, atmospheric heat fluxes, lateral inflows, streambed heat exchange, and unsteady non-uniform flows. Outputs include a fine scale temperature landscape of the Sacramento River downstream of Keswick Dam with a spatial resolution of 2 km, and temporal resolution of 15 minutes. Mean prediction error is on the order of 0.25°C, depending on the distance from the upstream boundary.

For the purpose of this assessment, RAFT was used to forecast water temperatures for the June-November 2015 period, using flow and temperature estimates at Keswick Dam from the updated temperature forecast scenario (provided by USBR) as upstream boundary conditions. To provide a range of estimates that account for uncertainty in weather, RAFT was run multiple times using meteorology data for the previous 25 years. The relevant meteorological inputs were obtained from the National Center for Environmental Prediction's North American Regional Reanalysis

(NARR) project and downscaled accordingly. When comparing the forecasted biological effects of water temperature to observed 2014 data, the 2014 meteorology was used.

RAFT's fine scale temperature output was used in conjunction with California Department of Fish and Wildlife's 2014 weekly aerial surveys of redds to calculate several biological metrics. Mean maturation rates and mean incubation times were calculated using mean daily temperatures at the redd locations, according to a linear relationship between maturation rate and temperature (Zeug et al. 2012). Temperature exposure was summarized for the calculated incubation times, as well as the first 45 days following emergence for temperatures at the redds and also at Bend Bridge. The temperature landscape for redd and fry assumed the 2014 redd distribution, that redds were deposited on the day they were observed (sampling was done approximately weekly) and that all redds experienced the mean incubation length times from their temperature exposure.

Biological Metrics

Results from the Juvenile Production and RAFT models provide results regarding a number of useful metrics (Table 2). These are used to quantify differences between the proposed temperature management plan's temperature profile, WY 2014 observed and estimated biological metrics, and various flow and temperature compliance location scenarios modeled recently in consideration of the proposed temperature management plan.

Metric	Source	Habitat Attribute considered
Egg mortality	Juvenile Production Model	Temperature, Flow
Egg to fry mortality	Juvenile Production Model	Temperature, Flow
Date of final shutter operation	Sacramento River Temperature Forecast Model	Temperature
End of September Storage <56°F	Sacramento River Temperature Forecast Model	Temperature, Flow
Kilometers of river below 17°C post emergence (45 days)	River Assessment for Forecasting Temperature	Refuge, Temperature
Temperature-Redd Landscape	River Assessment for Forecasting Temperature	Refuge, Temperature
Daily Mean Temperature, 45d Post-Emergence (redd and Bend Bridge locations)	River Assessment for Forecasting Temperature	Temperature
Development Daily Mean Temperature (redd locations)	River Assessment for Forecasting Temperature	Temperature

Table 2. Metric, Source of information, and Conceptual Model Habitat Attribute Considered in the Biological Review

Biological Review

Providing for optimal protection from fertilization through initial fry development requires that constant or acclimation temperatures be maintained below 50°F (10°C) and that individual daily maximum temperatures generally not exceed 56.3°F (13.5°C) (Summarized in NMFS 2015a). Myrick and Cech (2004) published a water temperature review, summarizing a number of studies conducted on the Central Valley Chinook Salmon. Hinze (1959) found that American River fall-run Chinook Salmon eggs incubated in water warmer than 62°F (16.7°C) experienced 100% mortality before reaching the eyed stage. Slater (1963) reported that suitable hatching temperatures for Sacramento River winter-run Chinook Salmon eggs are limited to 42 to 57°F (5.6 to 14°C). Healy (1979) found the highest survival (97%) occurred where the daily maximum exceeded 55°F (12.8°C) only a few times during the first 2 week of development, and noted that survival was still very good (90%-94%) where the initial temperatures were between 55 and 57.5°F (12.8 and 14.2°C). Healey (1979) reported that Sacramento River fall-run Chinook Salmon egg mortality rates exceeded 82% at temperatures over 57°F (13.9°C) and that post-hatching mortality was also higher at the elevated temperatures. Healey (1979) also stated that Sacramento River Chinook Salmon eggs did not appear to be any more tolerant of elevated water temperatures than eggs from more northern races. US Fish and Wildlife Service (1999) reported that fall-run egg mortality increased at temperatures greater than 54°F (12.2°C) and winter-run Chinook Salmon egg mortality increased at temperatures over 56°F (13.3°C). Specifically, winter-run Chinook Salmon cumulative mortality through rearing nearly doubled from 56 to 58°F (13.3 to 14.4°C).

Once alevin emerge from the gravel as fry, temperature continues to affect the survival and growth during this stage. Brett (1952) found the upper lethal temperature of juvenile Chinook Salmon was 77°F (25.1°C) and the preferred temperature range for fry acclimated to temperatures between 50 and 74ºF (10-24ºC) was 53 to 55ºF (12-13ºC). Thus, sublethal effects occur between the preferred temperature range (53 to 55ºF) and the lethal temperature (77ºF). These sublethal effects do not result in immediate mortality of embryos and alevins, but may lead to delayed mortality prior to reproduction due to reduced fry and smolt sizes. Temperatures greater than 60ºF have higher risk of warm water disease mortalities and the greater the thermal stress during the fry life stage (McCollough 1999).

Thermal stress can act in a cumulative manner between the feeding limit (temperatures exceeding 66ºF lead to limits in growth) and the upper lethal temperature. One mechanism influencing growth is behavior, and Brett et al. (1982) observed feeding behavior declined when temperatures exceeded 73ºF. Combined effects of stressors such as food limitation, low oxygen concentration, high turbidity, and competition can result in increased mortality. Marine and Cech (1998) assessed that growth rates of fall-run Chinook under sublethal temperatures (70 to 75ºF) were substantially reduced from growth rates exhibited at 55 to 60ºF. In the Sacramento River, fry typically are exposed to controlled water temperature upstream of Red Bluff into late October, at which time the majority of winter-run Chinook fry have moved passed Red Bluff Diversion Dam. To evaluate temperature effects on refugial rearing habitat quantity, we considered 62.6°F (17°C) a threshold value for when water temperatures have mortality risks related to disease and other associated thermal stressors.

There is uncertainty in how this information translates to field observations since they are from laboratory studies under constant temperature conditions that allow both acclimation and exposure temperatures to be precisely controlled. Acclimation and exposure temperatures can be made either constant or fluctuating, and if fluctuating, they can conform to precise, repeatable cyclic patterns. In river conditions include temperature fluctuation with a maximum temperature in late afternoon and a minimum temperature in early morning. From day to day, these values change, resulting in continually changing conditions in the stream. Fluctuating temperature conditions make it difficult to predict thermal effects. In addition, embryos and alevins are also affected by other factors, including dissolved oxygen and the size of substrate particles. Thus, the combined effects during thermal acclimation and exposure likely result in greater mortality under field conditions than in laboratory settings, in which multiple stressors are limited.

Shasta Operation

Winter-run Chinook Salmon

The updated temperature forecast scenario suggests Shasta and Keswick water operations cannot meet a temperature target of 56°F throughout the temperature compliance season in the Sacramento River above Clear Creek (CCR) location through October. Thus, the updated temperature forecast scenario was developed to achieve maximum duration of the limited cold water reserves in Shasta reservoir. The highest priority for cold water management will be to maintain cold water temperatures in the upper Sacramento River for protection of egg and fry life stages of winter-run Chinook Salmon.

The Juvenile Production Model was used during WY 2014 and 2015 to estimate temperature-related egg mortality and egg-to-fry mortality. As mentioned, the model results from WY2014's April 2014 temperature forecast scenario were positively biased compared to the modeled results from the WY 2014's observed temperature and flow data due to a couple possible explanations. The "hindcast" 2014 egg-to-fry survival estimate of 9% was closest to the 5% estimated by NMFS (Table 3), based on the Red Bluff rotary screw trap estimated juvenile production index (NMFS 2015b), and suggests that modeled results likely overestimate survival even with observed temperatures.

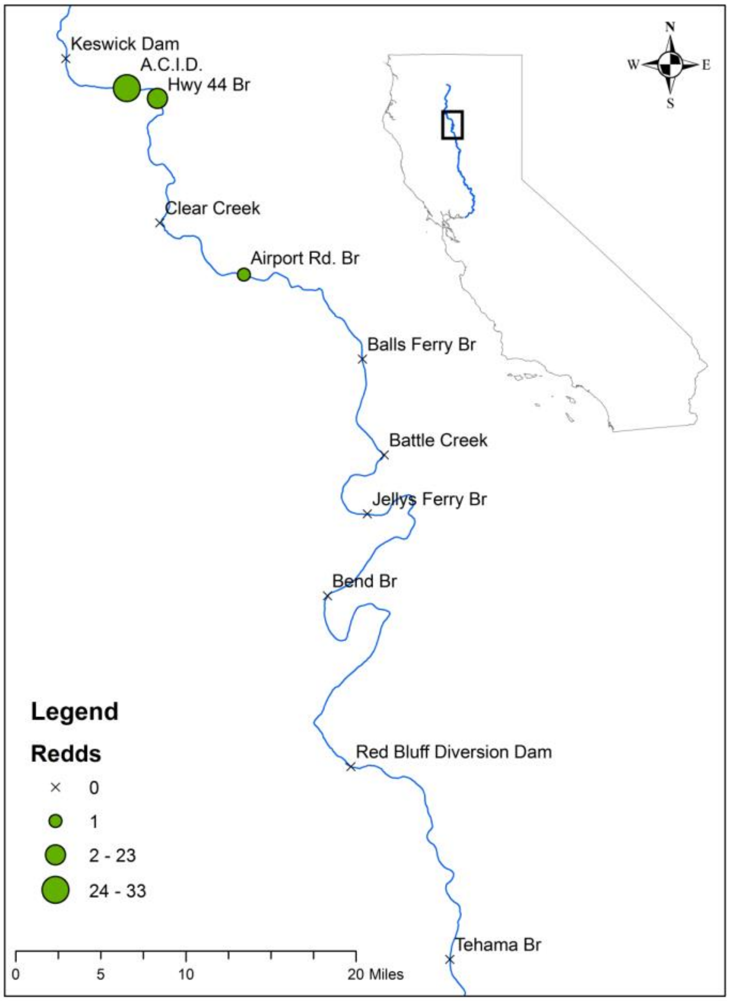
	Updated Temperature Forecast Scenario		April 2015 Temperature Plan		Observed 2014 Temperatures ("hindcast")		April 2014 50% Temperature Plan		Observed 2014 (measured)
	Clear Ck	Bend Bridge	Clear Ck	Bend Bridge	Clear Ck	Bend Bridge	Clear Ck	Bend Bridge	Red Bluff Diversion Dam
Termperature-related Egg mortality	8.4%	85.4%	0.0%	49.3%	9.0%	60.1%	1.0%	56.0%	N/A
Egg to Fry survival	19.4%	3.1%	22.0%	11.0%	36.0%	8.5%	29.0%	12.0%	5%

Table 3. Temperature-related egg mortality and egg to fry survival resulting from the Cramer Fish Science model (CFS 2009).

For WY 2015, egg-to-fry survival was estimated to be 19% for the updated temperature forecast scenario when using Clear Creek temperatures and 3% for the same scenario when using Bend Bridge temperatures (Table 3). These survival estimates are less than the survival estimates from the April 2015 temperature forecast model (USBR 2015c). Based on the April 2015 temperature forecast scenario (USBR 2015c), egg-to-fry survival was estimated to be 36% using the Clear Creek temperatures and 9% using the Bend Bridge temperatures. These WY 2015 egg-to-fry survival estimates suggest that a range of survival estimates resulting from temperature management may occur, and are dependent upon the location of spawning and rearing winter-run Chinook salmon. Currently, the majority of winter-run Chinook salmon are spawning very high in the upper Sacramento and this may reduce water temperature's effect of temperature-related egg mortality compared to the temperature-related egg mortality estimates derived from the scenario's Clear Creek temperature data (Figure 3). The updated temperature forecast scenario's approach to stabilize water temperatures throughout both the egg and fry life stages may prove critical to ensuring egg-to-fry survival, rather than focusing on maintaining colder temperature during an egg incubation period and allowing warmers temperatures during the fry emergence and rearing period.

The updated temperature forecast scenario estimates the Shasta reservoir end of September volume below 56°F to be approximately 265 thousand acre feet (TAF). For comparison, the 2014 May operational forecast's temperature scenario predicted end of September storage below 56°F to be 135 TAF. The updated temperature forecast scenario may allow later operation of the temperature control device's (TCD's) side gate, which decreases the risk associated with temperature control through the TCD (USBR 2015b). Under the updated temperature forecast scenario, the coldest gate configurations (i.e. full gate use) are modeled to occur between October 1 and 9. The 2014 May temperature model scenario has the coldest gate configuration occurring around September 7, while the actual 2014 TCD side gate operations began in late August.

Figure 3. Location of winter-run Chinook Salmon redds in the upper Sacramento River[1].



As mentioned in the Method section, the temperature mortality model appears to underpredict mortality of egg and fry. There is uncertainty if this is related to sources of mortality not directly estimated by the model, actual operations during late summer deviating from the temperature management plan, and actual storage and temperature conditions in Trinity and Shasta reservoirs deviating from the temperature management plan modeling, or some combination of these factors.

Dissolved Oxygen

Expanded monitoring during WY 2014 focused on measuring dissolved oxygen levels during the winter-run, spring-run, and fall-run Chinook Salmon redd incubation periods (Jason Roberts, CDFW, pers. comm.). In 2014, ten dissolved oxygen measuring stations were placed near winter-run Chinook Salmon redds in the ten miles downstream of Keswick Dam, where redds were located. In addition, two real time gages on the California Data Exchange Center (CDEC) were considered at KWK and CCR. Results from these loggers indicated that dissolved oxygen levels in the Sacramento River were likely not detrimental to winter-run Chinook Salmon egg

[1] Redd distribution data provided by California Department of Fish and Wildlife on June 18, 2015.

and fry survival. Dissolved oxygen conditions are likely to be the same in WY 2015 compared to WY 2014. While there remains uncertainty in what actual conditions will be in WY 2015, observations about dissolved oxygen at KWK and CCR may provide real time information for further tracking this water quality concern.

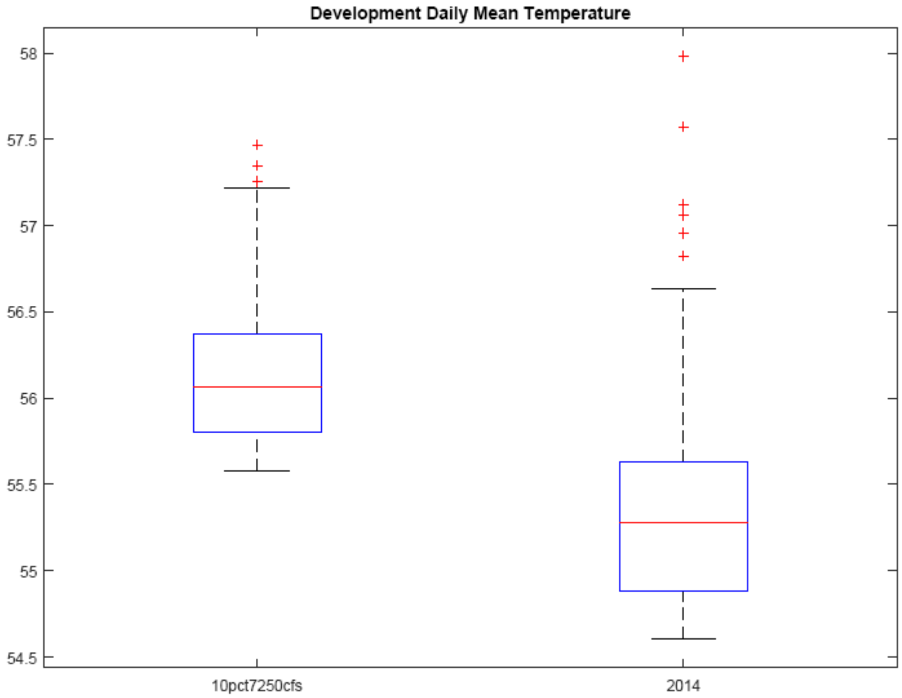
Redd dewatering/stranding

During recent water years, California Department of Fish and Wildlife completed redd dewatering and stranding surveys to determine the effects of reduced Keswick releases on dewatered redds and stranded juveniles in disconnected habitats (USBR 2015d). During fall 2014, minimal redd dewatering was observed to have occurred (Jason Roberts, pers comm.). The proposed timing of reduced releases during Fall 2015 contains similar Keswick releases and is unlikely to dewater winter-run Chinook Salmon redds. The effect of juvenile stranding is unknown, this is due to the location of rearing fish, geology, and geomorphology greatly affecting this habitat attribute. Ramping of decreasing flows through Keswick in the fall will implemented based on the operational guidelines to minimize flow fluctuation effects the NMFS Biological Opinion (NMFS 2011).

Habitat Distribution/ Refuge

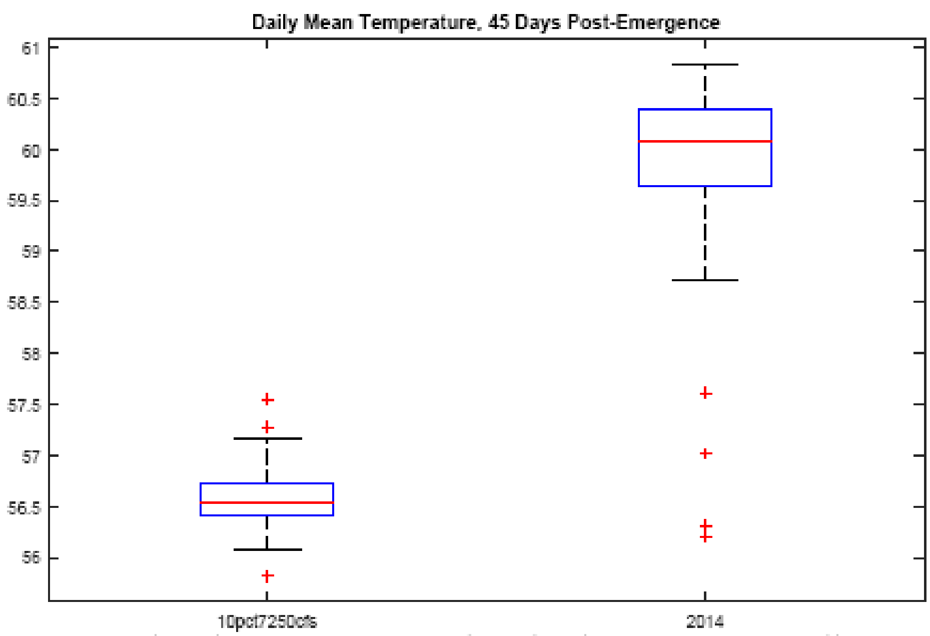
Current distribution of redds show a majority of the redds upstream of the Highway 44 bridge (Figure 3). Differences are observed between the daily mean temperature during the egg development and 45 day post emergence periods with the updated temperature forecast scenario (identified as 10pct7250cfs in figures) compared to the observed 2014 temperatures. These differences include slightly higher temperatures of eggs in the redd but lower temperatures during the post-emergence period close to the redds and even downstream at Bend Bridge during 2015 compared to 2014 (Figure 4-6). These results suggest that winter-run Chinook Salmon eggs were exposed to lower temperatures during the developmental period in 2014 than what they are likely to encounter during the updated forecast scenario’s summer 2015 temperature control period. Also, the winter-run Chinook salmon in 2014 that emerged were exposed to much greater temperatures during the post-emergence period than what is likely to be encountered during the updated forecast scenario’s summer 2015 temperature control period. These results suggest that the range of operations considered for summer 2015 are likely to be more stable throughout the egg development and fry rearing period upstream of Bend Bridge, than the variable conditions observed over these periods in 2014. While forecasted 2015 water temperatures are at the upper extent of the optimal range for eggs and excursions into temperatures causing egg mortality are predicted to occur, the Shasta temperature management plan remains in a range that avoids loss of temperatures during the rearing period and greater loss of alevin and fry during the late summer and fall.

Figure 4. Daily Mean Water Temperature During Development[2]



Daily mean temperature values, in degrees Fahrenheit, during the development period. Calculated using 2014 redd distribution and 2014 meteorology.

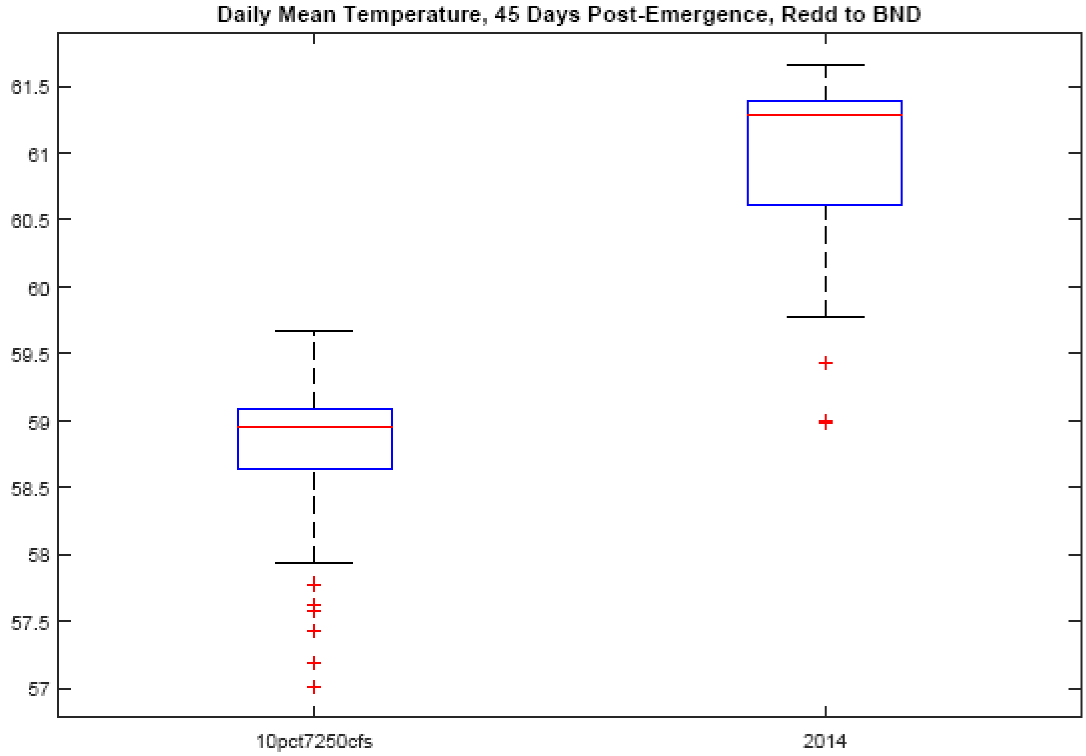
Figure 5. Daily Mean Water Temperature, 45 days Post-Emergence. [3]



Daily mean temperature values, in degrees Fahrenheit, during the first 45 days following emergence at the location of the redd. Calculated using 2014 redd distribution and 2014 meteorology.

[2] Figure provided by NMFS-SWFSC on June 18, 2015.
[3] Figure provided by NMFS-SWFSC on June 19, 2015.

Figure 6. Daily Mean Water Temperature, 45 days Post-Emergence at Bend Bridge [4]



Daily mean temperature values, in degrees Fahrenheit, during the first 45 days following emergence from the location of the redd to BND. Calculated using 2014 redd distribution and 2014 meteorology.

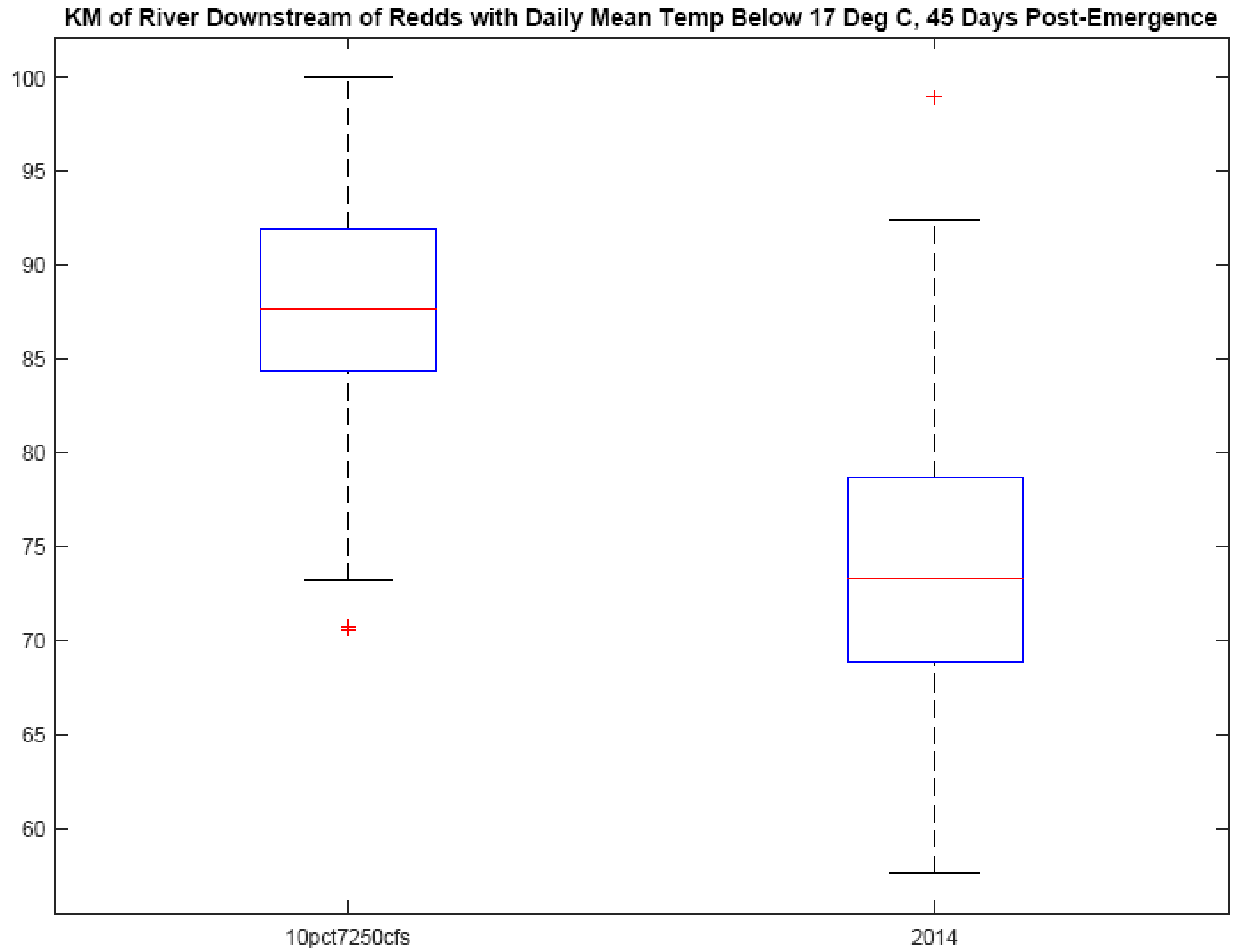
Food availability and quality, refuge, predation and competition, and pathogens

The conceptual model indicates that other hypothesized mechanisms influence mortality, growth, and maturation may be influenced by Shasta discharge and temperature management. However, how they are influenced are not well documented or understood with regards to the upper Sacramento River environment and winter-run Chinook Salmon. These mechanisms include food availability and quality, refuge, predation and competition, and pathogens.

The RAFT model output for the updated temperature forecast scenario and the WY2014 observed temperature were summarized in a box plot of the number of kilometers downstream of redds with daily mean temperature below 62.6°F (17°C). This box plot shows that the updated temperature forecast scenario is predicted to provide greater cold water habitat (refuge) than was observed in WY2014 (Figure 5 and 6). There remains uncertainty in these results since winter-run Chinook Salmon continue to build redds, at the time of this review, and the redd distribution used to evaluate the length of cold water refuge was based on the WY2014 winter-run Chinook Salmon redd distribution.

[4] Figure provided by NMFS-SWFSC on June 19, 2015.

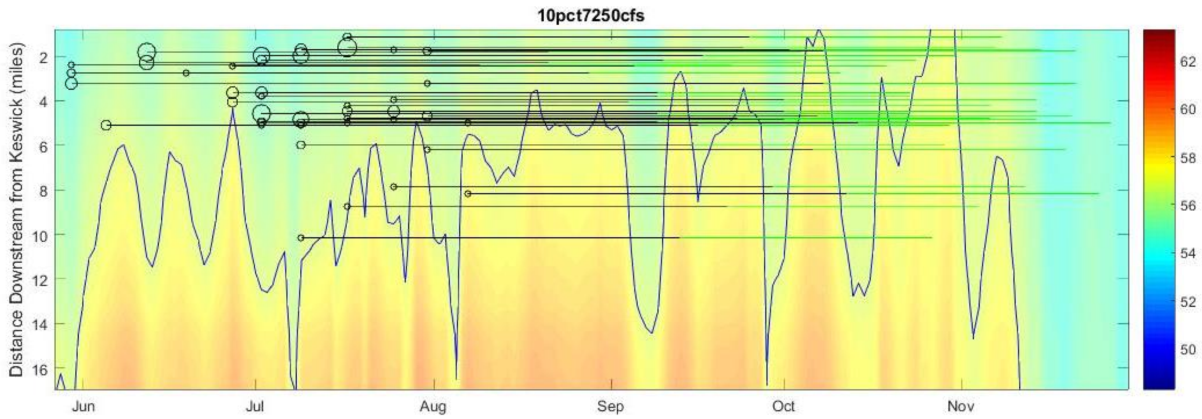
Figure 5. Kilometers of River Downstream of Redds with Daily Mean Temperature Below 17°C 45 Days Post-Emergence[5]

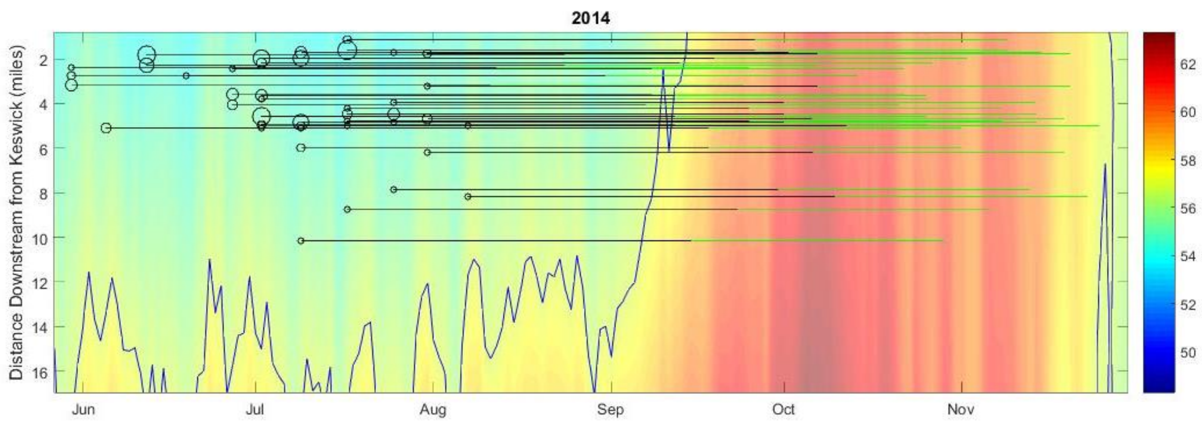


Mean number of kilometers downstream from redds with a daily mean temperature value below 17 degrees Celsius, during the first 45 days following emergence. Calculated using 2014 redd distribution and 2014 meteorology.

[5] Figure provided by NMFS-SWFSC on June 18, 2015.

Figure 6. Temperature Landscapes for Eggs and Fry in the Updated Temperature Forecast Scenario and Actual Observed during 2014[6].





Temperature, in degrees Fahrenheit, below Keswick Dam. The isoline represents 57 degrees. Circles represent redd deposition time, location, and relative number. Black lines show the length of time of incubation, and green lines show the first 45 days following emergence. Calculations were done using the 2014 redd distribution and 2014 meteorology.

While the relationship of predation, competition and pathogen are hypothesized to be negative as water temperature increases, the magnitude of these effects are unknown. Recently, pathogens have been documented to impact migrating salmonid in the Klamath, Sacramento and Fraser rivers (Ray et al. 2013, Foote et al 2013, and Jeffries et al. 2014), and is hypothesized to become a greater threat due to climate change (Miller et al 2014). As water temperatures increase, it is hypothesized that food availability and quality increase. Alternately, increasing stream temperature is hypothesized not to lead to increases in the abundance of drifting macroinvertebrates (McCollough 1999). Regardless, increased temperature will increase metabolic demand, and increase competition for a limited food base. While this directly may reduce growth, it may also cause displacement to habitats with more competitors or predators. The magnitudes of these effects are unknown. Thus, cumulatively these attributes are more likely to have a negative impact on survival and growth than result in a positive effect.

[6] Figure provided by NMFS-SWFSC on June 18, 2015

American River Operation

Conditions in the American River have met the criteria for a conference year under the flow management standard in compliance with the RPA. Therefore, operations will continue to be adaptively managed in partnership with the fishery agencies and the Water Forum to best meet needs under the extreme drought conditions.

Summary

Water temperatures will directly and indirectly affect winter-run Chinook survival this year. While a range of cold water management outcomes is possible, the forecasted meteorology and the quantity and profile of cold water create a situation where modeling does not predict average levels of egg-to-fry survival are achievable. Egg-to-fry survival has ranged from 15% to 49% (average = 26%) between 2002 and 2013 (USBR 2015d) based on juvenile production at Red Bluff Diversion Dam. Although the updated temperature forecast scenario provides cooler water temperatures throughout the egg incubation and fry rearing period, these temperatures are likely to cause egg-to-fry mortality, such that egg-to-fry survival will be measurably lower than average and likely similar to the observed low survival estimates from between 2002 and 2013.

The biological modeling suggests a range of outcomes that depend upon the locality of incubating eggs and rearing fry which reflect possible WY 2015 egg-to-fry survival in the range of what was observed in WY 2014. The current redd distribution is very close to Keswick Dam, which suggests predicted temperatures or management of temperatures at Clear Creek may not reflect the true egg mortality experienced by winter-run Chinook salmon. The water temperatures close to Keswick Dam, just upstream of the location of most of the current redds, are likely to be the coldest in the Sacramento River accessible to winter-run Chinook spawners. The locality of rearing winter-run Chinook salmon fry remains, and will remain, unknown but will influence fry survival based on the range of predicted temperatures occurring downstream of redds late in the summer. Based on a later date for the last TCD gate opening and greater end of September storage predicted with the updated temperature forecast scenario, it is unlikely that egg-to-fry survival in WY 2015 will be as low as the estimated 5% during WY 2014. The updated temperature forecast scenario's approach to maintaining cooler temperatures late in the summer compared to what winter-run Chinook salmon experienced in WY 2014 is likely to provide better fry survival than experienced in WY2014.

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