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Appenidx L Shasta Coldwater Pool Management

L.1 Introduction

This appendix analyzes alternatives for the management of Shasta Reservoir for water temperatures downstream of Keswick Dam. The construction of the Shasta and Keswick Dams blocked passage of winter-run Chinook salmon (and other species) to historical spawning habitats. The last remaining population of winter-run Chinook salmon is below Keswick Dam and relies upon the operation of the Shasta and Trinity Divisions of the Central Valley Project (CVP) to provide cold water for spawning and incubation over the summer months. The Sacramento River provides habitat for spring-run and fall-run Chinook salmon, steelhead, sturgeon, and other fish.

The United States Department of the Interior, Bureau of Reclamation (Reclamation) stores and releases water from Shasta Reservoir as part of the long-term operation of the CVP in coordination with the State Water Project (SWP). Maintaining flood conservation space in Shasta Reservoir and downstream requirements determine releases. Flood control may reserve up to 1.3 million acre-feet (MAF) of storage behind Shasta Dam, leaving 3.2 MAF of storage for other objectives. Downstream requirements include minimum instream flows, meeting senior water rights on the Sacramento River, Sacramento–San Joaquin River Delta (Delta) salinity and outflow, water service contract diversions at the Red Bluff Pumping Plant into the Tehama-Colusa Canal and Corning Canal, and exports from the Delta at the C. W. "Bill" Jones Pumping Plant (Jones Pumping Plant). Reclamation operates a Temperature Control Device to draw water through the Shasta Power Plant from different reservoir elevations. Shasta Reservoir stratifies into warmer and colder vertical layers each year in late April to early May. After the reservoir stratifies, the Temperature Control Device blends warmer and colder layers within Shasta Reservoir to preserve the lowest and coldest water for later in the season while generating hydropower. Keswick Dam and Reservoir re-regulate releases from Shasta Lake to smooth releases to the Sacramento River. Imports from the Trinity River Basin enter Keswick Reservoir through the Spring Creek Tunnel from Whiskeytown Reservoir and comingle with releases from Shasta Reservoir. Imports may be warmer or colder than the waters in Whiskeytown Reservoir, depending on conditions in the Trinity River Basin and Shasta Reservoir. Shasta releases for downstream demands depend, in part, on decisions and actions by parties other than Reclamation and California Department of Water Resources (DWR), including the State Water Resources Control Board, Sacramento River Settlement Contractors, Feather River Service Area contractors, and other Central Valley and Delta diverters.

L.2 Initial Alternatives Report

An Initial Alternative Report (*LTO 2021 Consultation Initial Alternatives Appendix L – Shasta CWP 20220127 DRAFT)* developed potential options for the long-term operation of the CVP and SWP to inform alternative formulation by seeking the bounds of potential decisions and a contrast between approaches. Initial alternative options generally considered flow actions, non-flow actions, and the use of real-time information. Management questions, analyses, and findings provided information for public draft Environmental Impact Statement (EIS) alternatives.

L.2.1 Management Questions

Reclamation's management questions to inform the formulation of alternatives included:

- Does real-time onset and shaping of temperatures improve winter-run Chinook salmon production or does a fixed schedule based on historical observations protect fish with limited water supply impact?
- How do water releases prior to the temperature management season influence the coldwater pool volume and temperature management capability during the temperature management season?
- How do releases within the season influence the temperature management capability for the remainder of the season?
- How do different carryover storage targets influence the coldwater pool volume in subsequent years and corresponding temperature management capability?
- What is the ability of other CVP and SWP operations to support cold water in Shasta reservoir?
- What is the effect of different coldwater pool management strategies on population viability?
- How do temperature control end dates effect loss after the end of spawning?
- What flows are most sensitive to redd dewatering?

L.2.2 Initial Analyses

Reclamation solicited input for the knowledge base paper, *Shasta Coldwater Pool and Storage Management – Chinook Salmon and Steelhead Growth and Survival*.

Reclamation analyzed Shasta Dam operations utilizing the CalSim II models developed for the Exploratory Modeling. Modeling showed the Shasta releases needed for regulatory requirements, Endangered Species Act (ESA) actions, and deliveries through the exploratory layers with increasing operational complexity. Next, CalSim II in position analysis mode used Exploratory Modeling Layer 5P (EXP 5P) to represent operations with full complexity and project deliveries when water was available and Exploratory Modeling Layer 4.95 (EXP 4.95) to represent full operational complexity and Project deliveries at public health and safety levels only. These model runs spanned 18 potential initial end-of-September storage conditions for Shasta

Reservoir and 82 1-year simulations using the 82-year period of record available. The results of these analyses were then passed on to the HEC-5Q (temperature) and temperature-dependent mortality (TDM) models that helped connect operational variability to temperature management and potential fisheries effects.

Reclamation conducted full 82-year CalSim II simulations for Initial Alternative 1, Initial Alternative 2, and Initial Alternative 3; followed by temperature and TDM models for the three initial alternatives described above. Model assumptions and results of these initial alternatives are summarized in Attachment 2 of Appendix AB-L of the Initial Alternative Report (*LTO 2021 Consultation Initial Alternatives Appendix L – Shasta CWP 20220127 DRAFT).*

L.2.3 Initial Findings

Does real-time onset and shaping of temperatures improve winter-run production or does a fixed schedule based on historical observations protect fish with limited water supply impact?

- This finding is under development and will be provided as part of the Public Draft EIS.

How do water releases prior to the temperature management season influence the cold-water pool volume and temperature management capability during the temperature management season?

- Releases include minimum instream flows, D-1641, actions for fish, water delivery, and flood control in October-April.
- Releases for D-1641 depend on the water year type; therefore, uncertainty in forecast hydrology makes forecasting required releases and Spring fill uncertain.
- Reducing minimum instream flow releases for Wilkins Slough and water deliveries for Sacramento River Settlement Contractors and Refuges can potentially increase end-of-April storage by an average of 110 TAF (values range from 0 to 795 TAF depending on the water year type).
- Releases for fish (e.g., redd maintenance, Fall X2, Spring Pulse) depend on the previous water year type and storage. Releases for redd maintenance (fall flow stability) have an average total volume of 180 TAF October–February when September carryover is greater than 2,200 TAF. Releases in October to support Delta outflow for Fall X2 criteria can reach 675 TAF under unique conditions, but average about 210 TAF over all Wet (W) and Above Normal (AN) years. Releases for Spring Pulse flows are only made when fill is likely to reach at least 4,100 TAF, and these are at most 150 TAF by definition.
- During this season, releases for CVP water service contracts and exports can potentially increase end-of-April storage by an average of 60 TAF (values range from 0 to 437 TAF depending on the water year type).
- When combined carryover and inflow is greater than approximately 6 MAF, flood conservation pool controls releases, and other actions have a limited effect.

How do releases within the season influence the temperature management capability for the remainder of the season?

- Releases within the management season are largely driven by minimum instream, fish flows and delivery needs.
- In drier years, the need to reserve cold water for temperature management through the season drives decisions on timing of releases.

How do different carryover storage targets influence the cold-water pool volume in subsequent years and corresponding temperature management capability?

- Temperature management capability is strongly correlated with end-of-April fill and the contributing spring hydrology and meteorology throughout the season.
- Carryover storage can affect end-of-April storage if the subsequent winter and spring are very dry.
- Higher levels of carryover can result in significant spill in the following winter and spring, possibly representing foregone deliveries in the previous year, and increasing flood damage risk.
- In critically dry years, project allocations are minimal, and operations focus is on meeting environmental criteria and delivering water supply as possible to senior water users. A carryover target under such conditions may be hydrologically and operationally impossible to meet.

What is the ability of other CVP and SWP operations to support cold water in Shasta reservoir?

- CVP's facilities are operated collectively, balancing local obligations with overall system needs and taking advantage of opportunities for flexibility. Margins for exploring tradeoffs between Folsom and Shasta, and between Trinity and Shasta are limited in years where water supply conditions present operational challenges.
- Restricting early season releases at Keswick to improve Shasta fill potential shifts the burden of CVP release to Folsom. This can render the role of the December planning minimum for Folsom storage ineffective.
- Tradeoffs with SWP operations have not been evaluated in these studies.

What is the effect of different cold-water pool management strategies on population viability?

- This finding is under development and will be provided as part of the Public Draft EIS.

How does temperature control end dates affect loss after the end of spawning?

- This finding is under development and will be provided as part of the Public Draft EIS.

What flows are most sensitive to redd dewatering?

supply, and power generation. From the knowledge base paper, Reclamation organized the best available information for evaluating the impacts of Shasta cold water pool management as described below.

L.5.1 Literature

Literature describes scholarly and technical works documenting research and studies. From the abundance of material on salmonids, Chinook salmon in general, and Central Valley (CV) winter-run Chinook salmon in particular, the following literature identifies the most relevant information for addressing management questions.

L.5.1.1 Adult Holding and Spawning Winter-Run Chinook Salmon Water Temperature Needs

A radio-tagging study of fall-run Chinook salmon adults in the Columbia River found that migration rate slowed at water temperatures >20°C (Goniea et al. 2006). Laboratory tests of Columbia River Chinook stocks identified water temperatures above 21°C equal or exceed the upper incipient lethal temperature (UILT) (Becker 1973; Coutant 1970, as cited in McCullough 1999). Reiser and Bjornn (1979) report that Pacific Northwest Chinook salmon have had successful migrations in a range of 3.3°C –20.0°C and successful spawning in a range of 2.2°C–20.0°C. Hatchery studies of Chinook salmon found that ideal pre-spawning temperatures were 6°C–14°C, with inhibited maturation and complete pre-spawning mortality at 3.3°C and egg mortality prior to deposition at temperatures above 14°C (Rice 1960; Leitritz and Lewis 1976; and Piper et al. 1982 as cited in McCullough 1999). At water temperatures beyond the range of 13.3°C–15.6°C, pre-spawning mortality of ripe adult females is elevated (CDWR 1988 as cited in McCullough 1999) and >80% prespawning mortality occurred in the Willamette River basin in reaches where the 7-day average of the daily maximum exceeded 20°C (Bowerman 2018). McCullough's (1999) review of literature identifies a threshold of 12.8°C, beyond which spawning is inhibited and at water temperatures above 16°C spawning is unlikely to occur (these values apply to Chinook stocks more generally, and not specifically to CV Chinook).

L.5.1.2 Egg Incubation and Alevin Winter-Run Chinook Salmon Water Temperature Needs

Lab studies and select field studies have evaluated the effects of temperature on the survival of embryonic (i.e., egg) and larval (i.e., alevin) life stages for Chinook salmon in the Central Valley. Lab rearing studies on winter-run Chinook salmon observed increased egg mortality between temperatures of 12.2°C and 13.6°C and increasing egg mortality at temperatures greater than 13.3°C (Slater 1963; USFWS 1999). Models of TDM fit to field-based estimates of egg-to-fry survival for winter-run Chinook salmon suggested temperature-dependent morality occurs at temperatures exceeding 12°C (Martin et al. 2017; Anderson et al. 2022). Lab studies on fall-run Chinook salmon reported total egg loss at temperatures greater than 16.7°C, elevated losses of eggs and fry at temperatures exceeding 14.2°C, and a significant increase in mortality for some embryonic stages between 13.3°C and 14.4°C (Hinze 1959; Healey 1979; USFWS 1999). No specific thermal limits are reported for spring-run Chinook salmon in the Central Valley. In the aggregate, these and other results have led reviewers to recommend optimum upper temperatures for CV Chinook salmon between 12°C and 13.3°C (Myrick and Cech 2004; Bratovich et al. 2012).

Other environmental factors complicate the relative influence of temperature on survival, including the availability of dissolved oxygen to eggs and alevins and the response of dissolved oxygen concentration to water temperature (Martin et al. 2017). Numerous studies have documented the sensitivity of embryonic development to competing factors of temperature and dissolved oxygen, in contrast to past studies that ensured normoxia for eggs and alevins (Del Rio et al. 2019; Martin et al. 2020; Del Rio et al. 2021). In addition to directly influencing survival, these abiotic factors also mediate egg incubation times and the subsequent condition of alevins and post-emergent fry (Steel et al. 2012; Del Rio et al. 2019).

Mortality of eggs and alevins appears to increase at temperatures exceeding either 12°C based on field studies (Martin et al. 2017; Anderson et al. 2022) or temperatures exceeding values between 12.2°C and 13.6°C based on lab studies (Slater 1963; USFWS 1999). Other environmental factors complicate the influences of temperature on survival, including the availability of dissolved oxygen in interstitial gravel.

L.5.1.3 Factors influencing Egg and Alevin Mortality

Besides incubation temperature, a number of direct and indirect factors may lead to egg and alevin mortality (Windell et al. 2017). Viability of the eggs can be affected by conditions experienced by adults prior to spawning. For example, adults holding at temperatures above 60°F have decreased egg viability, as do adults that experience physiological stressors such as incidental fishing and toxins (DWR 1988). During spawning and incubation, direct mortality of eggs due to predation occurs in the Upper Sacramento River. Both native and non-native fish populations have been documented to consume salmon eggs.

Redd disturbance can negatively impact egg and alevin survival. Superimposition mortality, where later-spawning females establish their redds on top of earlier-spawning females' redds, is a density dependent function of adults and available spawning habitat (Bartholow 2004). SALMOD modeling suggests that winter-run Chinook experience especially high (52.3%) superimposition mortality. Likewise, recreational fishing and other human activity such as trampling can reduce survival in the redd (Windell et al. 2017).

Redd quality is another important factor in egg and alevin mortality and is often mediated by flow. Egg and alevin emergence is affected by gravel size and aquatic vegetation, which are the physical characteristics describing redd quality. Increased flow may reduce aquatic vegetation and may improve hydrologic and biological connectivity within the streambed that improve egg survival and alevin emergence. Egg and alevin emergence is also affected by sedimentation and gravel quantity. Increased flows may remove fine sediment, improving egg and alevin essential functions and development (Bennett et al. 2003). Meanwhile, the potential for redd dewatering increases at flows less than 6,000 cfs. Redd dewatering is also affected by redd location, spawning flow, and the magnitude and timing of changes in flow (Gard 2006).

Furthermore, increased flow can improve water quality, with improved outcomes for egg and alevin survival. Chinook salmon egg survival decreases when dissolved oxygen is less than 5.5 mg/l (Del Rio et al. 2019). Dissolved oxygen is negatively correlated with water temperature and positively correlated with flow. Increased flow also provides benefits to egg survival by diluting contaminants. Likewise, increased flows may reduce pathogen concentration and horizontal transmission (Baxa-Antonio et al. 1992), while lower temperatures may reduce pathogen virulence.

L.5.1.4 Factors Influencing Fry Survival

Chinook salmon fry in the Sacramento River experience numerous, interconnected stressors which can influence their survival. Some of these stressors include exposure to toxicity and contaminants, thiamine deficiency, the risk of stranding, sub-optimal water quality conditions (water temperature, dissolved oxygen), exposure to pathogens and disease, access to refuge habitat and quality food, the risk of being entrained, inter- and intra-species competition, and predation (Windell et al. 2017). Many of these listed stressors are discussed in more detail in Appendix AB-D, *Seasonal Operations Deconstruction*. Two stressors discussed in more detail here are thiamine deficiency and predation.

Thiamine, or Vitamin B1, is an essential enzyme for salmonids at all life stages. Anchovies, a main prey source for adult Chinook salmon in the ocean, have thiaminase which destroys thiamine in its consumers (Mantua et al. 2021). It has been hypothesized salmon which consume large volumes of prey deficient in thiamine return as spawning adults and pass a deficiency of thiamine on to their offspring (Mantua et al. 2021, Vuorinen et al. 2021, Bell 2022). In lab-monitored fry from hatchery spawners that were either treated with a thiamine supplemental injection or left as controls, mortality of post-sac absorption fry jumped to 100% at thiamine concentrations below 5 nmol/g (Mantua et al. 2021; Bell 2022). The impact of deficiency in winter-run Chinook salmon fry varies annually with the prey landscape in the ocean; however, it is hypothesized that thiamine deficiency in conjunction with a changing climate (i.e., warm river temperatures) may cause an increased source of mortality for fry. The NMFS Priority Actions (NMFS 2021 Sacramento River Winter-run Chinook Salmon Priority Actions: 2021 – 2015) calls for continued efforts to support egg and fry life stages through management actions.

Predation of Chinook salmon by aquatic and terrestrial species affects migration, growth, and survival of winter-run Chinook and is inherently linked with numerous other stressors (Grossman et al. 2013; Grossman 2017) that Appendix AB-D evaluates. The predation risk fry and juveniles experience is a function of inseparable variables including predator presence, prey vulnerability, and environmental conditions. Competition fry or juvenile could experience is also a function of inseparable variables. The indirect effects of predation and competition related to refuge habitat, water temperature (McInturf and Fangue 2022). Acoustic telemetry studies have documented a negative relationship between increasing density of predator contact points (e.g., diversions, predators) and migratory survival (Cavallo et al. 2013). Susceptibility to predation has been observed to increase with thermal shock and decrease with increasing turbidity (Coutant 1973; Gregory and Levings 1998). Finally, the XT survival model fitted in Steel et al. (2020) postulates that patterns in migratory survival can be explained mostly by random interactions between juveniles and predators, in conjunction with the mediating influence of flow. Lower flows can result in greater risk of predation (Zeug et al. 2014; Michel et al. 2015; Perry et al. 2018). Effects of CVP and SWP operations were evaluated using the XT survival model line of evidence, results are found in Appendix AB-J, *Winter and Spring Pulses and Delta Outflow: Smelt, Chinook Salmon, and Steelhead Migration and Survival*. Predation is an ongoing threat to this ESU, especially in the lower Sacramento River and Delta where there are high densities of nonnative (i.e., striped bass, smallmouth bass, and largemouth bass) and native species (e.g., pikeminnow) that prey on outmigrating juvenile salmon (NMFS 2014 Recovery Plan).

L.5.1.5 Juvenile Winter-Run Chinook Salmon Water Temperature Needs

Temperature thresholds for juvenile life stages are often considered using two types of metrics: optimum temperature for growth and lethal temperature. Laboratory studies for fall-run Chinook salmon growth from the American River observed maximal growth at 19°C and between 17°C and 20°C with abundant available prey resources (Myrick and Cech 2002; Marine and Cech 2004). In a review of studies on Chinook salmon both from and outside the Central Valley, Myrick and Cech (2004) reported the optimal temperature range for the growth of juvenile Chinook salmon is 17°C –20°C provided food is not limited. Studies of growth under different levels of feeding satiation suggest temperatures for optimal growth may be lower if fish feed at levels below satiation. Brett et al. (1982) reported a 5°C decrease in optimal temperature for growth when feeding dropped from satiation to approximately 60% of satiation, the estimated level of feeding for fish in the wild. A rare field study of fall-run Chinook salmon growth in the Central Valley observed high juvenile growth on floodplain habitat (i.e., habitat with abundant prey) with a daily average temperature of 21°C and daily maximum temperatures of 25°C (Jeffres et al. 2008). Little information on optimal temperatures for juvenile growth of spring-run or winter-run Chinook salmon is available for the Central Valley.

Lethal temperatures for juvenile Chinook salmon are often described using the UILT (i.e., the exposure temperature 50% of fish can tolerate for 7 days given previous acclimation to a constant temperature; Elliott 1981), and the critical thermal maximum (i.e., CTM, the temperature at which fish experience loss of equilibrium and death with exposure to increasingly higher temperatures; Becker and Genoway 1979). The range between the UILT and CTM is called the zone of resistance. Studies conducted on fall-run Chinook salmon in the Central Valley conflict, with studies reporting an IULT of 26°C for fall-run Chinook salmon from Feather River but no rearing mortality between 21°C and 24°C for fall-run Chinook salmon from Battle Creek (Hanson 1991; Marine and Cech 2004). Based in part on these conflicting findings, Myrick and Cech (2004) recommended a UILT between 24°C and 25°C for CV Chinook salmon based on studies conducted with Chinook salmon from more northerly populations (Brett 1952; Brett et al. 1982). As expected, estimated CTM values are noticeably greater than UILT values. Lab-estimated CTM values for juvenile fall-run Chinook salmon from the Central Valley are 27°C (Feather River fall-run Chinook salmon acclimated to 18°C; Hanson 1991) and 28.8°C (American River fall-run Chinook salmon acclimated to 19°C; Cech and Myrick 1999). Lab-based CTM values for juvenile winter-run Chinook salmon were 28°C, 29°C, and 29.5°C for fish acclimated to 11°C, 16°C, and 20°C, respectively (Zillig et al. 2020). Little information on lethal temperatures for spring-run Chinook salmon is available for the Central Valley.

These measures of lethal temperature are heavily reliant on acclimation temperature, with increasing resistance times at high temperatures and greater UILT values typically reported at elevated acclimation temperatures (Hanson 1991; Zillig et al. 2020). Furthermore, there are numerous other relevant measures of fish responses to water temperature other than direct mortality, including measures of metabolic rate, behavior, and swimming performance, capable of influencing population dynamics.

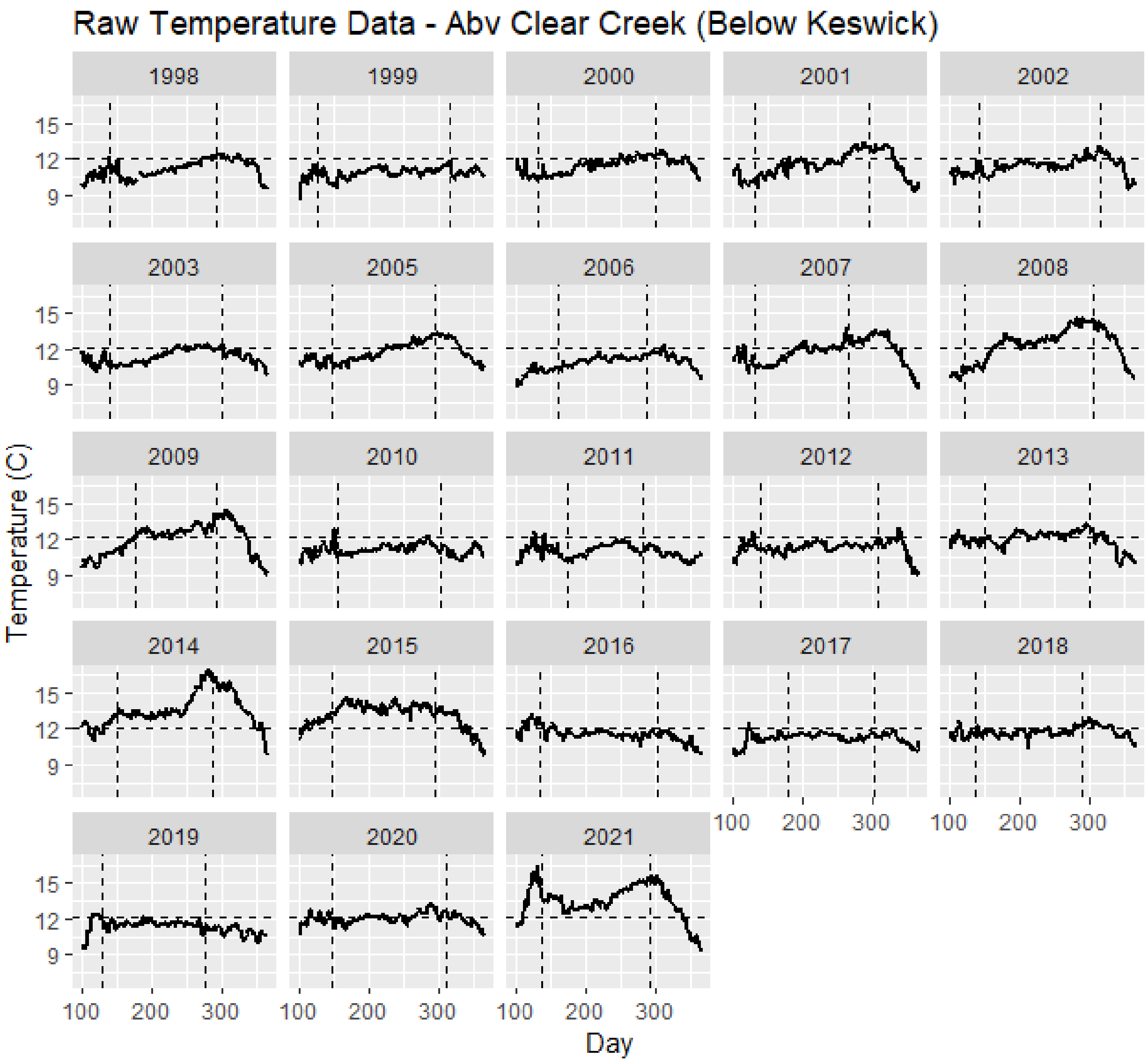
Optimal growth post-emergence juveniles likely occurs between 17°C and 20° C assuming no food limitation (Myrick and Cech 2004). Long-term mortality of juveniles occurs at constant temperatures exceeding 24°C or 25° C and more immediate mortality occurs at temperatures exceeding 28°C.

L.5.2 Datasets

Shasta coldwater pool management impacts Federally listed native fish species which are influenced by multiple factors including hydrology, water quality, and fish population abundance and distribution. Monitoring of hydrodynamics, water quality, and fish populations has been ongoing for over forty years, for some datasets, and covers the full spatial extent of Shasta Reservoir and the upper Sacramento River. These data and the following plots serve as the foundation and to illustrate patterns of interannual variability in historical hydrology and trends in water quality. They also provide data and visualizations of trends in Federally listed native fish population abundances and distribution through the upper Sacramento River.

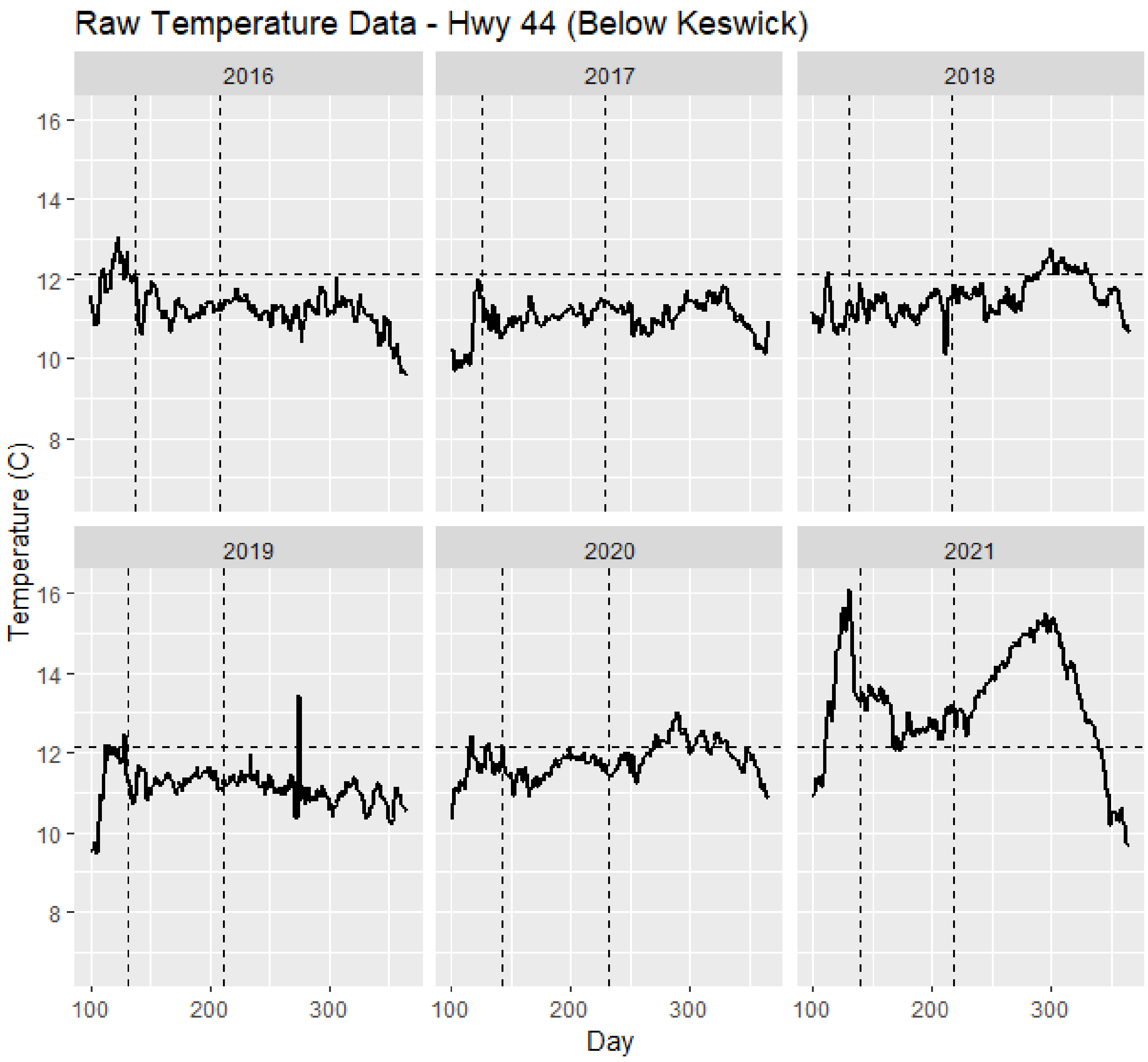
Presented in this section are three themes of empirical data: hydrodynamics, water quality parameters, and biological datasets. Hydrodynamics datasets (Section 5.2.1, *Hydrodynamics*) include monthly releases from Shasta Reservoir and Keswick and river flows at locations. Water quality parameters (Section 5.2.2, *Water Quality Parameters*) include Shasta Reservoir temperature profiles and in-river temperatures. Fish and other biological datasets (Section 5.2.3, *Biological Observations*) include aerial redd survey and carcass surveys, annual Chinook escapement survey datasets, stranding and dewatering datasets, Livingston Stone National Fish Hatchery life-stage estimates, and Red Bluff Diversion Dam juvenile fish monitoring datasets.

While some datasets include data gaps or shorter sampling efforts than others, overall, a large body of historic monitoring data within the upper Sacramento River is available. These data sets, in conjunction with modeled data (i.e., CalSim 3, DSM2, USRDOM), serve as inputs for models that can be used to understand and predict the effects of CVP and SWP operations on environmental conditions and fish distribution and loss. Each data set is incorporated into one of multiple lines of evidence used to inform conclusions about both the magnitude and direction of differences among alternatives regarding hydrology and listed native fish populations abundance and distribution.



Plotted years reflect data availability at each site. The dashed horizontal line is the critical temperature estimated for the stage-independent TDM model (Martin et al. 2017) and the dashed vertical lines are the dates of the first observed redd and the last day before all fry are expected to emerge, based on accumulated thermal units (ATUs).

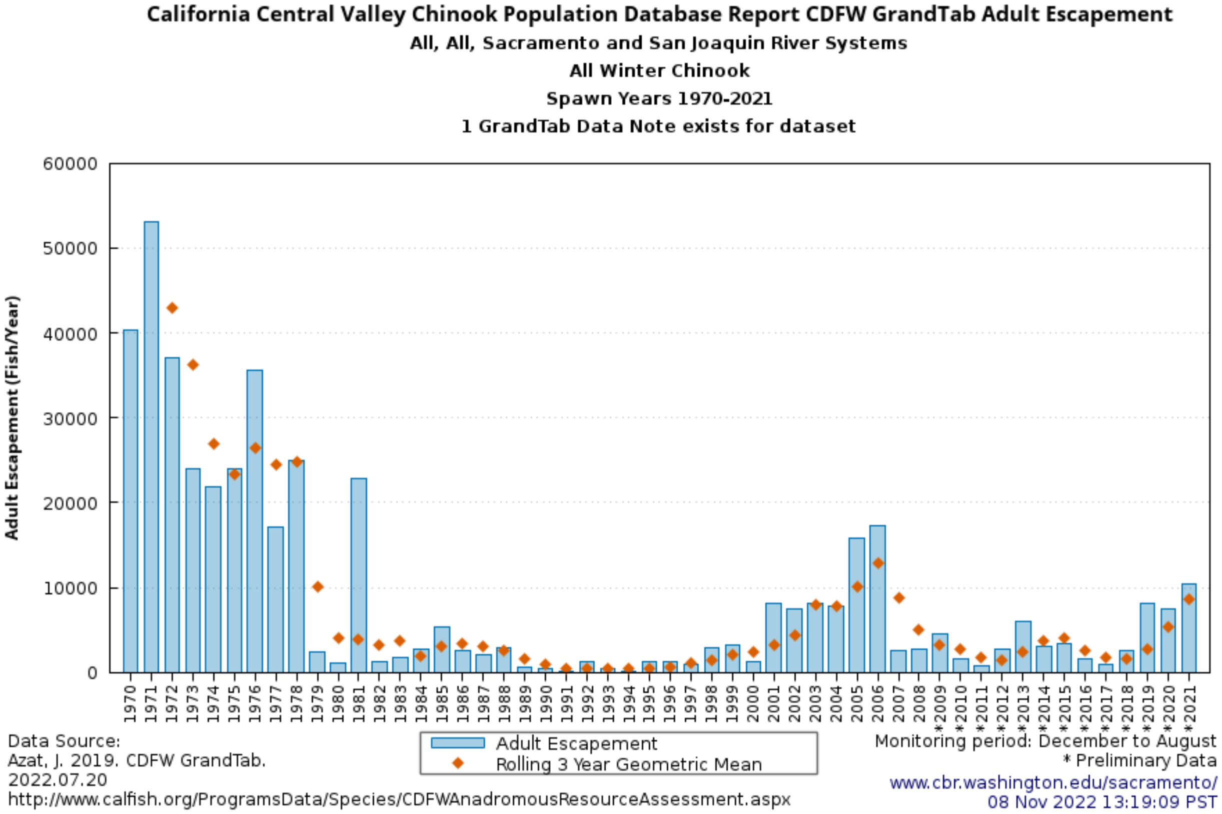
Figure L-8. Stream Gauge Temperatures (Daily Mean), Above the Confluence of Clear Creek



Plotted years reflect data availability at each site. The dashed horizontal line is the critical temperature estimated for the stage-independent TDM model (Martin et al. 2017) and the dashed vertical lines are the dates of the first observed redd and the last day before all fry are expected to emerge, based on accumulated thermal units (ATUs).

Figure L-9. Stream Gauge Temperatures (Daily Mean), at the Highway 44 Bridge

L.5.2.3 *Biological Observations*



Source: https://www.cbr.washington.edu/sacramento/.

Figure L-10. California Central Valley Chinook population adult winter-run escapement and rolling 3-year geometric mean (red diamonds), Sacramento and San Joaquin river systems, spawn years 1970 – 2021

Table L-1. Estimates of total winter-run Chinook salmon escapement in the Sacramento River, along with 90% confidence intervals (in parentheses), from annual reports

Year	Sacramento Escapement (90% CI)	Central Valley Escapement	Mainstem Escapement	LSNFH	Battle Creek
2021	10,254 (9,280, 11,528)	10,494	9,971	298	167
2020	6,386 (5,962, 6,828)	7,428	6,199	191	942
2019	8,032 (7,213, 8,852)	8,128	7,853	180	21
2018	2,638 (2,235, 3,029)	2,639	2,458	180	1
2017	975 (109, 1,888)	979	797	180	0
2016	1,546 (329, 2,763)	1,549	1,411	137	0
2015	3,439 (3,042, 3,836)	3,440	3,182	257	0
2014	3,015 (2,741, 3,290)	3,015	2,627	388	0

Year	Sacramento Escapement (90% CI)	Central Valley Escapement	Mainstem Escapement	LSNFH	Battle Creek
2013	6,404 (5,710, 7,099)	6,086	5,922	164	0
2012	2,674 (2,451, 2,896)	2,671	2,578	93	0
2011	-	827	738	86	1
2010	-	1,596	1,533	63	0
2009	-	4,537	4,416	121	0
2008	-	2,830	2,725	105	0
2007	-	2,541	2,487	54	0
2006	-	17,296	17,197	93	6
2005	-	15,839	15,730	109	0
2004	-	7,869	7,784	85	0
2003	-	8,218	8,133	85	0
2002	-	7,441	7,337	104	0
2001	-	8,224	8,120	104	0
2000	-	1,353	1,261	89	2
1999	-	3,288	3,264	24	-
1998	-	2,992	2,893	99	-
1997	-	880	836	-	44
1996	-	1337	1012	-	325

Source: Azat 2022.
These estimates may include Battle Creek escapement in years other than 2020 and 2021 and may have been subject to revision. Escapement estimates with uncertainty are only available starting in 2012. Estimates of total Central Valley escapement, mainstem Sacramento in-river escapement, Livingston Stone National Fish Hatchery broodstock (LSNFH), and Battle Creek escapement above Coleman Weir.

Year	ACID	HW44	Airport Road	Balls Ferry	Battle	Jellys Ferry	Bend	Red Bluff	Total
2015	0	23	3	0	0	0	0	0	26
2016	0	12	6	0	0	0	0	0	18
2017	0	23	3	0	0	0	0	0	26
2018	54	130	14	0	0	0	0	0	198
2019	9	256	213	36	0	0	1	0	515
2020	229	226	36	0	0	0	0	0	491
2021	331	246	1	0	0	0	0	0	578
2022	215	182	9	0	0	0	0	0	406

Source: CalFish.
Reaches are defined by their downstream reach boundary.

Table L-3. Production of winter-run Chinook salmon juveniles at Red Bluff Diversion Dam by brood year, brood years 2007 – 2021

Brood Year	Run Size
Average (2007 - 2021)	1,279,139
2021	557,652
2020	2,078,101
2019	3,666,516
2018	1,084,961
2017	591,066
2016	498,386
2015	324,246
2014	270,279
2013	1,392,950
2012	1,186,248
2011	742,344
2010	1,228,975
2009	3,274,893
2008	953,310
2007	1,337,160

Source: Killam, D. 2021

Table L-4. Winter-run Chinook salmon fecundity (eggs per female) 2002 – 2022

Year	Eggs/Female
2002	4,820
2003	4,854
2004	5,200
2005	5,251
2006	5,382
2007	5,056
2008	5,424
2009	5,231
2010	5,161
2011	4,776
2012	4,364
2013	4,596
2014	5,191
2015	4,819
2016	-
2017	-
2018	-
2019	-
2020	5,424
2021	-
2022	-

Sources: 2002-2015 Data: USFWS 2016 Memo to File. Documentation of a change in the methodology of estimating winter-run Chinook salmon egg-to-fry survival for brood year 2016. 2019: NMFS 2020 JPE Letter.

Table L-5. Total males and female winter-run chinook salmon adults collected between 1990 and 2008 for hatchery broodstock

Return Year	Collection Location	Females	Males	Total
1990	Keswick	1	1	2
1991	Keswick and RBDD	6	13	19
1992	Keswick	13	13	26
1993	Keswick and RBDD	11	3	14
1994	Keswick	16	11	27

Return Year	Collection Location	Females	Males	Total
1995	Keswick	21	16	37
	Captive Broodstock	21	6	27
1996	Captive Broodstock	38	30a	68
1997	Captive Broodstock	109	45b	154
1998	Keswick	61	35	96
1999	Keswick and RBDD	9	14	23
	Captive Broodstock	20	0	20
2000	Keswick and RBDD	44	34	78
	Captive Broodstock	66	60	126
2001	Keswick and RBDD	50	47	97
	Captive Broodstock	100	32a	132
2002	Keswick	48	40	88
	Captive Broodstock	95	25a	120
2003	Keswick	45	33	78
	Captive Broodstock	99	21a	120
2004	Keswick	37	36	73
	Captive Broodstock	45	23a	68
2005	Keswick	51	44	95
	Captive Broodstock	46	21a	67
2006	Keswick	37	52	89
	Captive Broodstock	60	31a	91
2007	Keswick	19	25	44
2008	Keswick	46	47	93

[a] Males were collected from the Sacramento River and were also used for natural-origin crosses.
[b] Includes cryopreserved milt from 19 captive broodstock males.

Table L-6. Winter-run Chinook salmon run-size and fry equivalent Juvenile Production Index (JPI) for brood years 2007 - 2021

Brood Year	Run Size	Fry Equivalent JPI (90% CI)
Average (2007 – 2021)	1,279,139	-
2021	557,652	-
2020	2,078,101	-
2019	3,666,516	-
2018	1,084,961	1,477,529 (824,706, 2,130,352)

Brood Year	Run Size	Fry Equivalent JPI (90% CI)
2017	591,066	734,432 (471,292, 997,572)
2016	498,386	640,149 (429,876, 850,422)
2015	324,246	440,951 (288,911, 592,992)
2014	270,279	523,872 (301,197, 746,546)
2013	1,392,950	2,481,324 (1,539,193, 3,423,456)
2012	1,186,248	1,814,244 (1,227,386, 2,401,102)
2011	742,344	996,621 (671,779, 1,321,708)
2010	1,228,975	1,572,628 (969,016, 2,181,572)
2009	3,274,893	4,972,954 (2,790,092, 7,160,098)
2008	953,310	1,371,739 (858,933, 1,885,141)
2007	1,337,160	1,637,804 (1,062,780, 2,218,745)

Source: Fry equivalent JPI were obtained from Voss and Poytress (2020). Data are available in Appendix AB-L (Shasta CWP).

Table L-7. Livingston Stone winter-run Chinook egg survival, based on a 2-year average (2006 – 2007) that does not include captive broodstock crosses

	Green Egg to Eyed Egg	Eyed Egg to Ponging	Ponding to Release	Overall Egg to Release
Livingston Stone Winter-Run Chinook	0.92	0.78	0.8	0.58

Source: California Hatchery Scientific Review Group, 2012.

Table L-8. Livingston Stone National Fish hatchery winter-run chinook salmon estimates by life stage, 2000 – 2010

Release Year	Egg Take	Eyed Eggs	Eggs Culled	Fish Ponded	Smolts Released	Egg to Release Survival
2000	216,075	197,511	-	179,399	166,556	77.08%
2001	236,864	225,845	-	214,954	190,732	80.52%
2002	231,375	220,189	-	176,882	164,806	71.23%
2003	223,269	195,689	-	180,205	152,011	68.08%
2004	192,387	177,507	-	165,878	148,385	77.13%
2005	267,803	243,525	-	196,211	160,212	59.82%
2006	279,853	259,348	-	189,881	161,212	57.61%
2007	121,341	111,686	-	100,909	71,883	59.24%

Release Year	Egg Take	Eyed Eggs	Eggs Culled	Fish Ponded	Smolts Released	Egg to Release Survival
2008	260,370	235,279	-	200,696	146,211	56.16%
2009	324,321	302,544	-	267,819	198,582	61.23%
2010	139,349	129,512	-	125,153	123,857	88.88%
Average	226,637	208,967	-	181,635	153,132	68.82%

Source: California Hatchery Scientific Review Group, 2012.

Table L-9. Estimates of egg-to-fry survival based on estimated female spawner abundance, fecundity, and passage of fry-equivalents past RBDD

Year	Percent egg-to-fry survival rate (90% confidence intervals)
2021	2.6
2020	11.5
2019	17.9
2018	26.6 (14.9, 38.4)
2017	48.7 (31.3, 66.2)
2016	23.7 (15.9, 31.5)
2015	4.5 (3.0, 6.1)
2014	5.9 (3.4, 8.4)
2013	15.1 (9.4, 20.8)
2012	26.9 (18.2, 35.6)
2011	48.6 (32.8, 64.5)
2010	37.5 (23.1, 52.0)
2009	33.5 (18.7, 48.0)
2008	17.5 (11.0, 24.1)
2007	21.1 (13.7, 28.6)
2006	15.4 (8.8, 22.1)
2005	18.5 (9.9, 27.4)
2004	20.9 (12.1, 29.8)
2003	23.0 (14.0, 32.1)
2002	27.4 (10.1, 47.1)

Source: Voss and Poytress (2020), estimates 2002-2018; Marcinkevage (2022), estimates 2019-2021.

Table L-10. Coarse estimates of TDM generated from year-specific aerial redd survey data and temperature data from the gauge above Clear Creek

Year	**Stage-independent TDM**	**Stage-dependent TDM**
1998	0.001	0
1999	0	0
2000	0.015	0.03
2001	0.055	0.081
2002	0.006	0.011
2003	0.054	0.06
2005	0.153	0.128
2006	0	0
2007	0.106	0.244
2008	0.661	0.603
2009	0.591	0.664
2010	0	0
2011	0	0
2012	0	0.016
2013	0.416	0.57
2014	0.914	0.926
2015	0.954	0.972
2016	0.008	0.032
2017	0	0
2018	0.007	0.156
2019	0.001	0.007
2020	0.148	0.416
2021	0.901	0.895

Table uses both the stage-dependent (Anderson et al. 2022) and stage-independent (Martin et al. 2017) TDM models implemented on SacPAS (SacPAS Central Valley Prediction and Assessment of Salmon (washington.edu)).

SALMOD

SALMOD evaluates flow- and temperature-related mortality of early life stages of each race of Chinook salmon in the Sacramento River to Red Bluff based on the quality and quantity of physical habitat. The model's premise is that egg and fish mortality are directly related to spatially and temporally variable microhabitat and macrohabitat limitations, which themselves are related to the timing and amount of streamflow and other meteorological variables.

SALMOD has been published in several peer-reviewed articles. General background information can be found in Bartholow et al. (1997). Information related to applying the model to the Sacramento River is summarized in Bartholow (2004). Information specific to analyzing water operations in the Central Valley California, including updates to the spatial and temporal patterns of redds to reflect more recent patterns, can be found in the California WaterFix Biological Assessment, Attachment 5D.2, *SALMOD Model*. SALMOD has been used in other environmental planning documents for projects related to water supply and water resource planning (e.g., California WaterFix Biological Assessment, BiOp, and EIR/EIS; Sites Reservoir Project Biological Assessment and RDEIR/SDEIS; and Delta Conveyance Project Biological Assessment and Draft EIR). SALMOD is free and has been run by agency and consultant hydrologic modeling staff for recent planning efforts.

inSALMO

inSALMO is a modification of inSTREAM (individual-based Stream TRout Environmental Assessment Model), which is an individual-based model of trout in a stream environment that predicts how trout populations respond to environmental and biological change. inSALMO represents the freshwater life stages of anadromous salmonids, including Chinook salmon and steelhead. The model can be used to examine effects of alternative flow and temperature regimes on salmon spawning, rearing and outmigration success. Cal Poly Humboldt developed these models.

inSALMO has been tested, validated, and peer-reviewed in several publications, including Dudley 2018 for the Sacramento River. inSALMO has not been used for other environmental planning documents for projects related to water supply and water resource planning. The models are public domain and free to download and use. Download and background documentation is available at: https://ecomodel.humboldt.edu/instream-and-insalmo-overview**.**

SacSalMort- Egg Mortality Model

Agencies developed SACSALMORT to evaluate Shasta Reservoir water temperature management scenario effects on early lifestage survival of Chinook salmon in the river. The model uses spawning distribution and spawn timing for each Chinook run along with the river water temperatures to estimate survival of Chinook eggs and alevins through incubation to emergence. Water temperature related survival/mortality values were developed from early studies on CV Chinook and in general uses a 56 degree F criteria as the threshold above which survival drops with increasing water temperature.

The model has been applied to the four Chinook runs in the Sacramento River and to Chinook in the Feather, American, Stanislaus, and Trinity rivers using the spawning distribution and timing derived from spawning surveys. It has been set up to utilize the output of the water temperature models in each river.

L.5.3.2 Lifecycle Models

Lifecycle models are especially useful for anadromous species like salmonids because they experience distinct contrasting environments during their lives. Density dependence in salmonid populations is strongest during the freshwater phase due to limited food and space. Estimates of carry capacity during the early life stages are critical for evaluating effectiveness of management actions.

IOS

The Interactive Object-Oriented Simulation (IOS) model is a winter-run Chinook salmon life cycle model developed by Cramer Fish Sciences. IOS is composed of six primary life cycle components that can be affected by water temperature, river flow, or ocean productivity, including: (1) spawning (affected by water temperature); (2) egg incubation (water temperature); (3) fry rearing (water temperature); (4) river migration (flow); (5) Delta passage (flow); and (6) ocean survival (ocean productivity).

IOS has been published in a peer-reviewed journal (Zeug et al. 2012). The model is currently only able to be run by Cramer Fish Sciences. It has been used in other environmental planning documents for projects related to water supply and water resource planning (e.g., California WaterFix Biological Assessment, BiOp, and EIR/EIS; Sites Reservoir Project Biological Assessment and RDEIR/SDEIS; and Delta Conveyance Project Biological Assessment and Draft EIR). Additional background information can be found in the Sites Reservoir Project Draft EIR/EIS, Appendix 11I, Winter-run Chinook Salmon Life Cycle Modeling.

OBAN

The Onchorhynchus Bayesian Analysis (OBAN) Model is a winter-run Chinook salmon life cycle model developed by Noble Hendrix from QEDA Consulting that can be used to evaluate the effect of project operations on winter-run Chinook salmon. OBAN uses a Bayesian analytical framework to assess how a series of environmental driver variables (e.g., temperature and flow) under management control can affect winter-run Chinook salmon population dynamics. The model was built by first establishing which of a suite of parameters covaried with historical abundance patterns and those parameters were then kept for the predictive model.

OBAN development was based on the peer-reviewed literature and years of field data. It is currently only able to be run by QEDA Consulting. It has been used in other environmental planning documents for projects related to water supply and water resource planning (e.g., California WaterFix Biological Assessment and EIR/S; Sites Reservoir Project Biological Assessment and EIR/S; and Delta Conveyance Project Biological Assessment and EIR). Although included in the California WaterFix Biological Assessment, OBAN was not used by NMFS in the 2017 California WaterFix BiOp because “it does not represent the physical area of the Delta in a robust way” (p. 791). Additional background information can be found in Attachment 12B.1 of the Delta Conveyance Project Appendix 12B, Bay-Delta Methods and Results.

L.5.4.3 Coldwater Bypass

Cold water bypasses may occur in the summer and fall to reduce overall temperature of Shasta releases for fisheries benefits. By releasing water from the river outlet gate at elevation 750’ rather than the TCD side gate, which pulls from elevation 720’, it may offset warm water entering the TCD. Warmer water may enter the TCD at a lower elevation due to significant leakage, unique and uncommon thermodynamics around the device, or inaccurate temperature profile. Coldwater bypasses were more common prior to the TCD installation, however, since the TCD was installed, a coldwater bypass has only been used once.

In water year 2014, Reclamation tested a coldwater bypass by releasing a portion of flows through the 750’ river outlet to test for temperature results below Keswick. In this test, 2,000 cfs were drawn from the outlet, while 3,000 cfs were drawn from the TCD side gate intake at 720’. Between September 9-22, the operation saw temperatures increase 4 F the first week and 9F the second week, before Reclamation returned to only using the side gate’s low level intake at 720’(SRTTG Annual Report 2014). No temperature benefit downstream was observed since the water temperature at the side gate intake was less than the river outlets.

L.5.4.4 Temperature Plan Timing

Stratification of Shasta Reservoir occurs during the spring when 52F or cooler temperatures are present at the surface and then at a later date water temperatures greater than 54F are observed. Monthly or more frequent temperature profiles observed this to occur on the following dates. Over the past twenty-five years, the average date when 54°F appear in the profile is April 10. Current year temperature planning can be more accurate at this date or later when the starting coldwater pool volume is known.

Table L-11. Shasta Reservoir stratification: date by water year when 54°F appears in the Shasta Reservoir water temperature profile, 1998 - 2021

Water Year	Date of 54°F appearing in profile
1998	15-Apr
1999	13-Apr
2000	14-Apr
2001	22-Mar
2002	24-Apr
2003	10-Mar
2004	26-Apr
2005	9-Mar
2006	4-May
2007	5-Apr
2008	1-May
2009	2-Apr
2010	3-May

*Exact endpoints fall somewhere between 53.6°F and 56°F (12°C and 13.6°C), with recommended upper thermal optimum of 53.6°F to 55.9°F (12.0°C–13.3°C)3,4

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L.6.2 Personal Communications

Hendrix pers. comm.