— BUREAU OF —
RECLAMATION

Long-Term Operation – Biological Assessment

Appendix L – Shasta Coldwater Pool Management

October 2024

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Appendix 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 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)* 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 L of the Initial Alternative Report (*LTO 2021 Consultation Initial Alternatives Appendix L – Shasta CWP).*

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 (WYT); 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 WYT).
    - Releases for fish (e.g., redd maintenance, Fall X2, Spring Pulse) depend on the previous WYT 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 and above normal 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 WYT).
    - 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?**
    - 80% of winter-run Chinook salmon spawn in locations that are inundated when flows are about 6,200 cfs.
    - Historical dewatering of total winter-run Chinook salmon redds (2013 through 2021) has ranged from 0% (in 2015, 2016, 2017) to 0.67% (in 2020) averaging 0.13%.

L.3 Public Draft Environmental Impact Statement Scenarios

Under the National Environmental Policy Act, Reclamation compares action alternatives to a "no action" alternative. Under the Endangered Species Act, Reclamation's discretionary actions over an environmental baseline determine the effects on listed species. No single environmental baseline to evaluate the effects under ESA or impacts under NEPA. ESA requires a comparison to the environmental baseline which is informed by ROR and Alt 1. NEPA requires a comparison to NA.

L.3.1 No Action

D 90-5. Coldwater pool management approach based on potential seasonal temperature dependent mortality outcomes. The No Action Alternative for the Sacramento River is described in Appendix E, Section 3.3.

L.3.2 Alternative 1 – Water Quality Control Plans

Alternative 1 for the Sacramento River is described in Appendix E, Section 5.1.

L.3.3 Alternative 2 – Multi-Agency Deliberation

Alternative 2 for the Sacramento River is described in Appendix E, Section 6.1.

L.3.4 Alternative 3 – Unimpaired Flow and Storage

Alternative 3 for the Sacramento River is described in Appendix E, Section 7.1.

L.3.5 Alternative 4 – Risk Informed Operation

Alternative 4 for the Sacramento River is described in Appendix E, Section 8.1.

L.4 Performance Metrics

Performance metrics describe criteria that can be measured, estimated, or calculated relevant to informing trade-offs for alternative management actions. Additional performance metrics were considered in the Initial Alternatives Report; however, only the performance metrics below were included to evaluate the effects of Delta operations. Performance metrics include measures or estimates related to water supply, NEPA Resource Areas, and fish. These performance metrics are associated with methods that are available, accessible, peer-reviewed, repeatable, and transparent which are further described in Section L.5, *Methods Selection*.

L.4.1 Fish Metrics

Fisheries metrics consider direct observations and environmental surrogates including:

- Degree-days water temperature at Sacramento River at Clear Creek (CCR) starting from May 15
- TDM
- Egg-to-fry survival
- Juvenile survival probability to Chipps Island
- Percentage of population dewatered redds with viable eggs

L.4.2 Water Supply

Water supply metrics consider the multi-purpose beneficial uses of Shasta Reservoir including:

- North-of-Delta agricultural deliveries (average and critical/dry years)
- South-of-Delta agricultural deliveries (average and critical/dry years)
- Sacramento River Settlement Contractor and Central Valley Project Improvement Act (CVPIA) refuge deliveries
- Bay-Delta Water Quality Control Plan (D-1641) Standards
- Flood Conservation Pool Releases (“Spills”)

CalSim III would support the evaluation of water supply metrics.

L.4.3 National Environmental Policy Act Resources

Analysis of the range of alternatives, as required by the National Environmental Policy Act is anticipated to describe changes in multiple resource areas. Key resources are anticipated to include: surface water supply, water quality, groundwater resources, power, aquatic resources, terrestrial biological resources (e.g., giant garter snake and migratory birds), regional economics, land use and agricultural resources, recreation, cultural resources, socioeconomics, environmental justice, and climate change.

L.5 Methods Selection

Reclamation solicited input from agencies and interested parties for the knowledge base paper *Shasta Cold Water Pool and Storage Management – Chinook Salmon and Steelhead Growth and Survival*, included as Attachment L. Knowledge base paper compile potential literature, datasets, and models for analyzing potential effects from operation of the CVP and SWP on species, water 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 (California Department of Water Resources 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; U.S. Fish and Wildlife Service 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; U.S. Fish and Wildlife Service 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; U.S. Fish and Wildlife Service 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 (California Department of Water Resources 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 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 (National Marine Fisheries Service 2021) 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 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 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 (National Marine Fisheries Service 2014).

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 UILT 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.

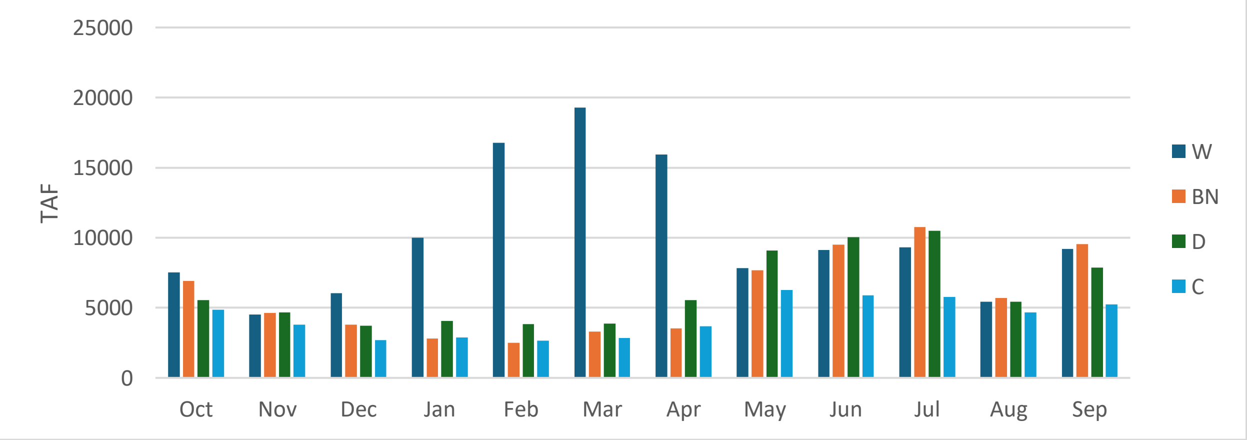
L.5.2 Datasets

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 L.5.2.1, *Hydrodynamics*) include monthly releases from Shasta Reservoir and Keswick and river flows at locations. Water quality parameters (Section L.5.2.2, *Water Quality Parameters*) include Shasta Reservoir temperature profiles and in-river temperatures. Fish and other biological datasets (Section L.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.

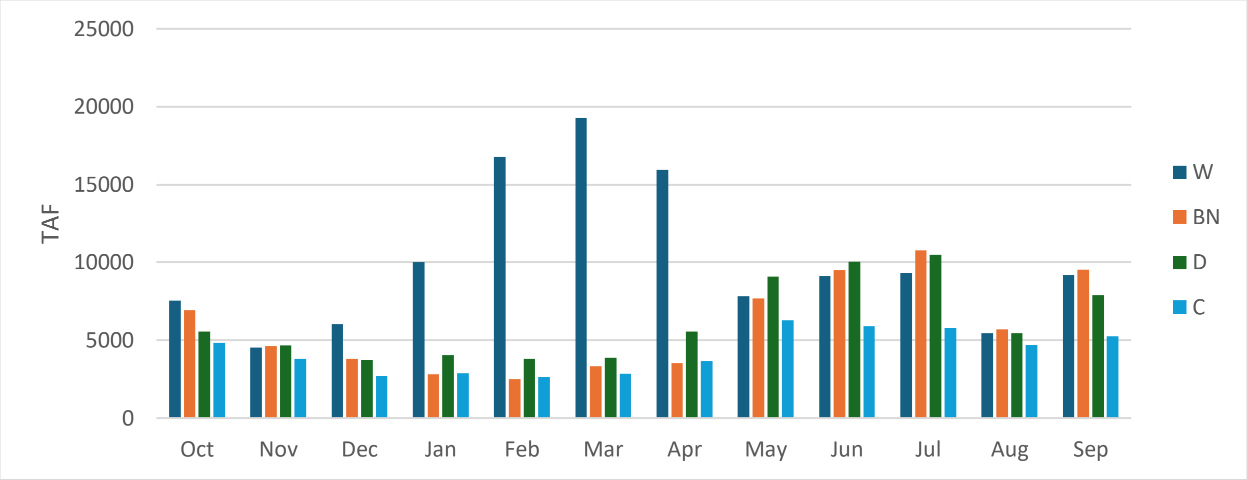
While some datasets include data gaps or shorter sampling efforts than others, overall, a large body of historic monitoring data within the upper Sacramento River is available. These data sets, in conjunction with modeled data (i.e., CalSim 3, DSM2, USRDOM), serve as inputs for models that can be used 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.

L.5.2.1 Hydrodynamics



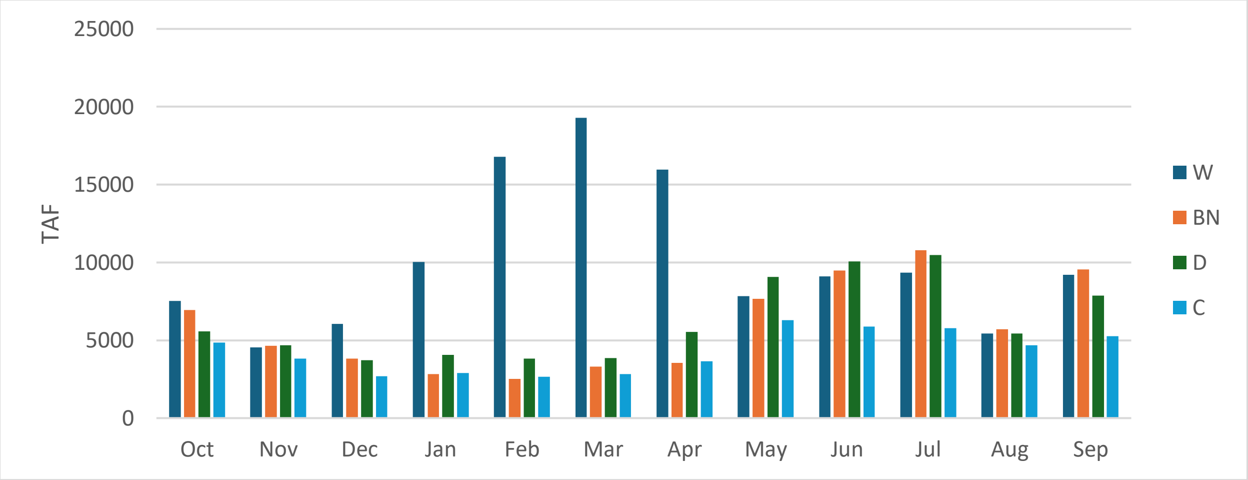
TAF = thousand acre-feet; W = wet; BN = below normal; D = dry; C = critical.

Figure L-1. Monthly Releases from Shasta Dam by Water Year Type for Water Years 1944–2022



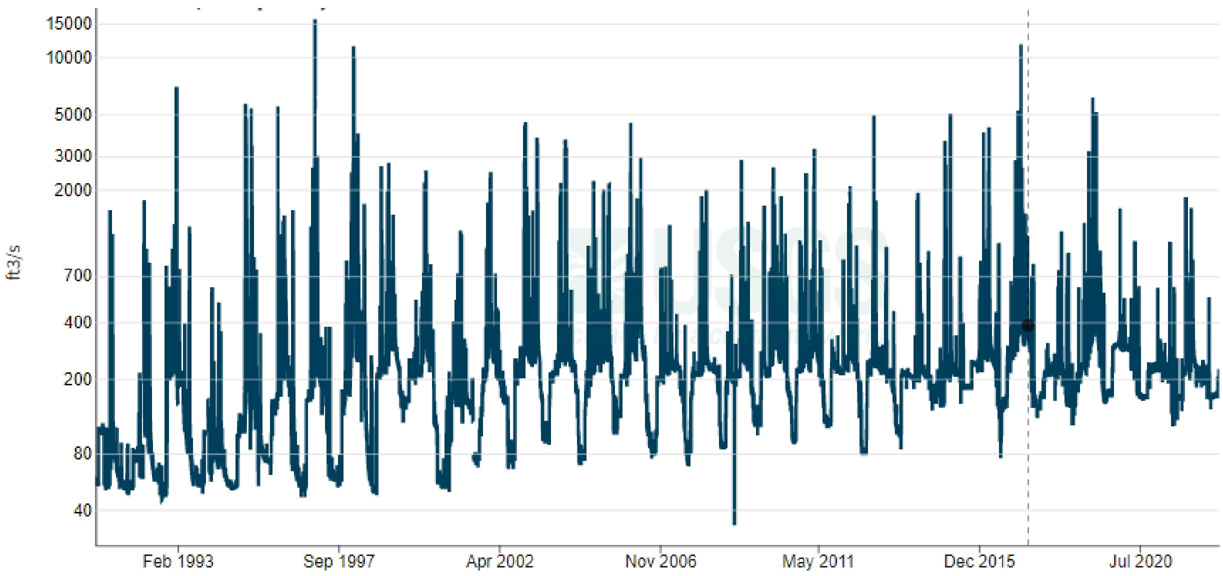
TAF = thousand acre-feet; W = wet; BN = below normal; D = dry; C = critical.

Figure L-2. Monthly Releases from Shasta Dam by Water Year Type for Water Years 2009–2022



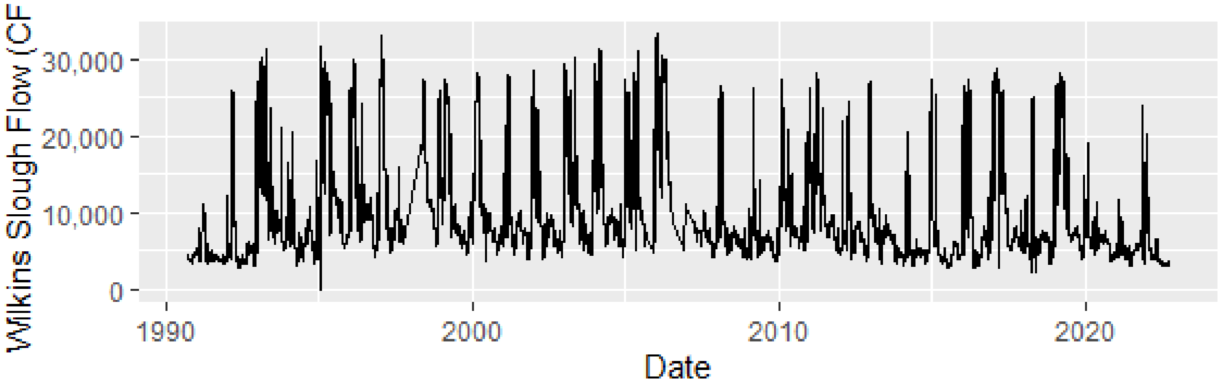
TAF = thousand acre-feet; W = wet; BN = below normal; D = dry; C = critical.

Figure L-3. Monthly Releases from Shasta Dam by Water Year Type for Water Years 1990–2008



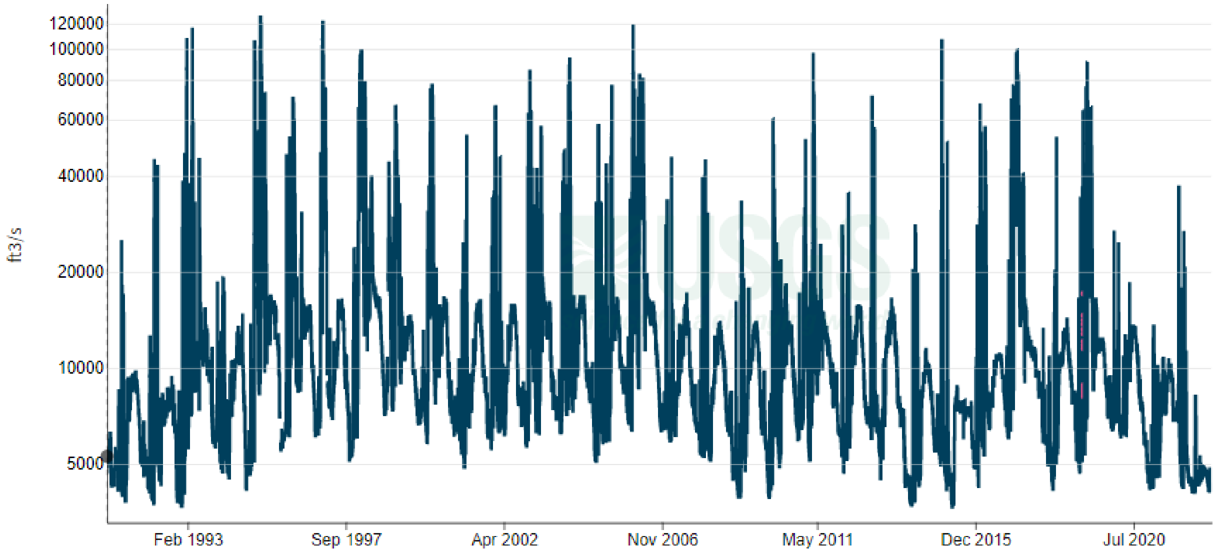
ft3/s = cubic foot per second.

Figure L-4. Flows for Sacramento River at Clear Creek, CCR Gage (Water Years 1991–2022; October 1, 1990 through September 30, 2022)



cfs = cubic feet per second.

Figure L-5. Flows for Sacramento River at Wilkins Slough (Water Years 1991–2022; October 1, 1990 through September 30, 2022)



ft3/s = cubic foot per second.

Figure L-6. Flows for Sacramento River at Bend Bridge, Upstream of Red Bluff Diversion Dam (Water Years 1991–2022; October 1, 1990 through September 30, 2022)

L.5.2.2 Water Quality Parameters

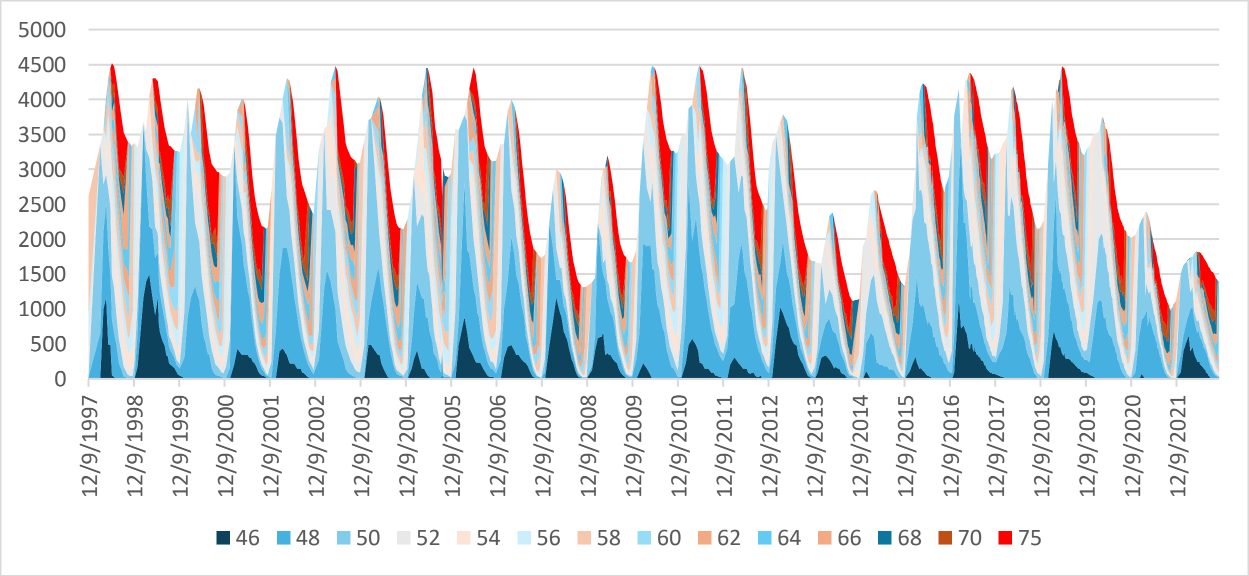
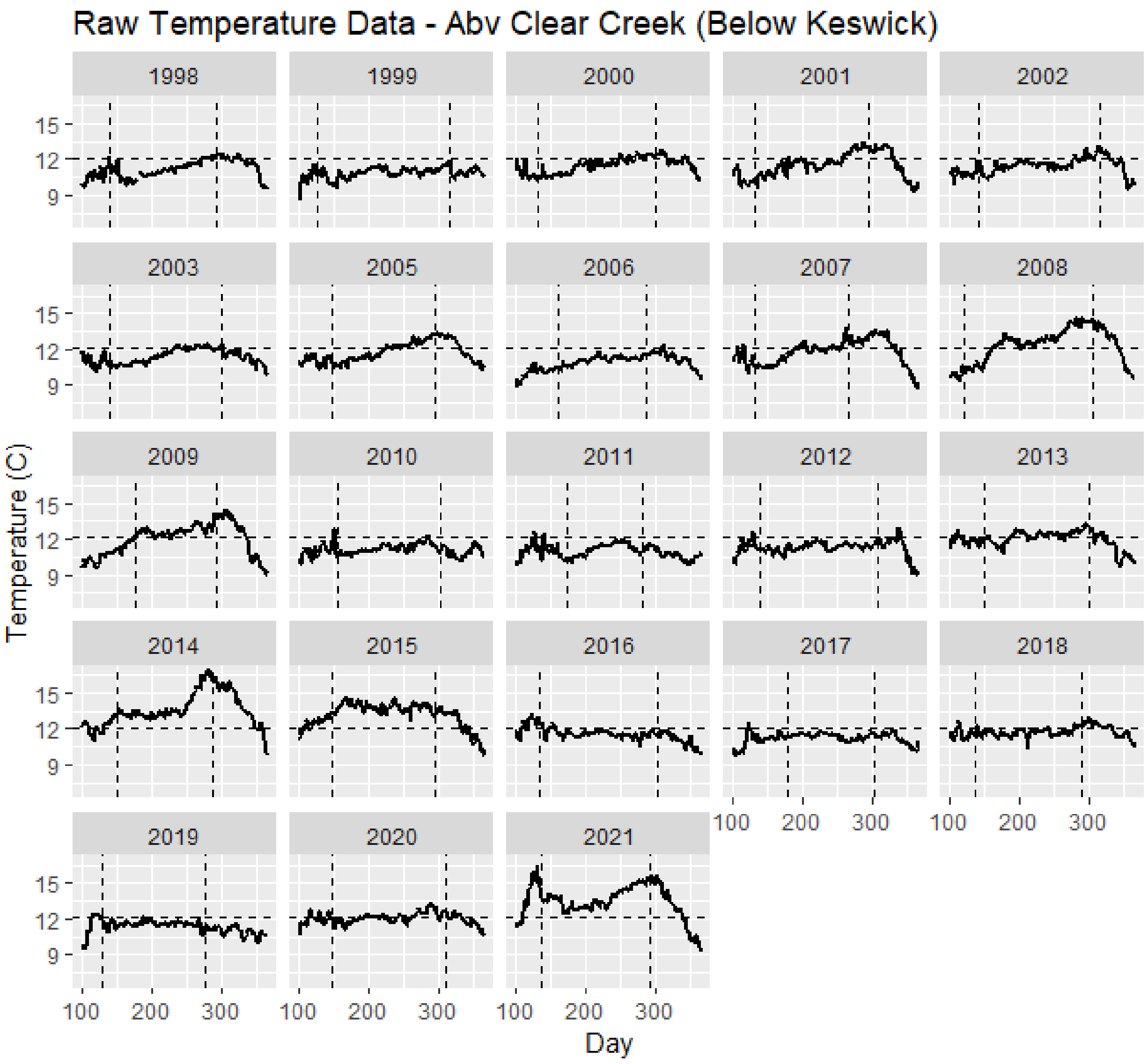


Figure L-7. Temperature Stratification of Shasta Reservoir, 1997–2021

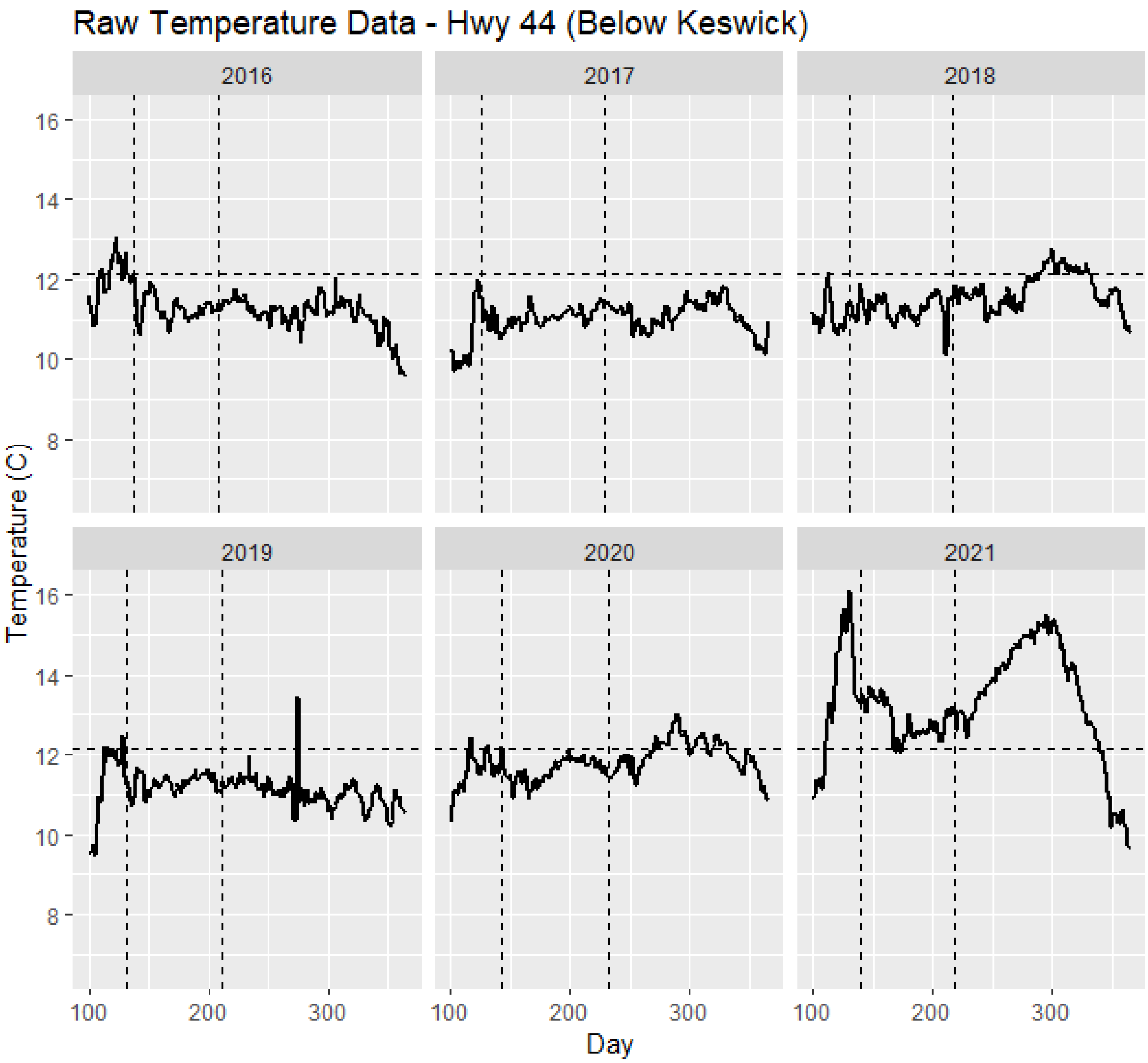


Source: Martin et al. 2017.

C = Celsius.

Plotted years reflect data availability at each site. The dashed horizontal line is the critical temperature estimated for the stage-independent temperature-dependent mortality model 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.

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



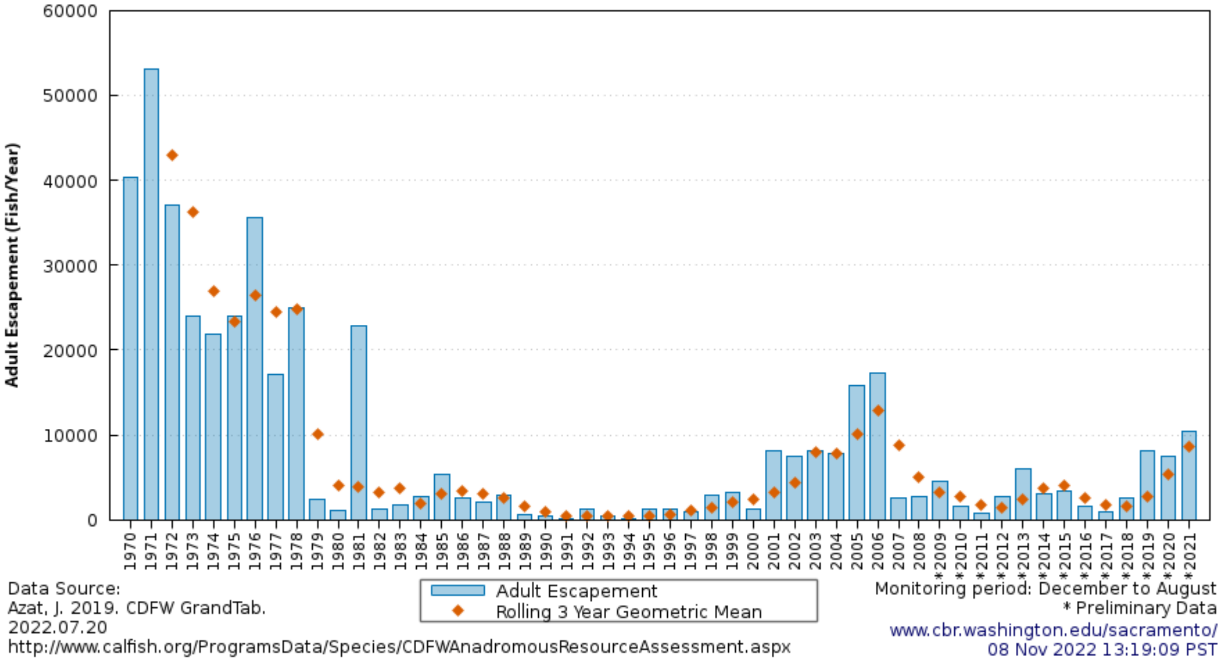
Source: Martin et al. 2017.

C = Celsius.

Plotted years reflect data availability at each site. The dashed horizontal line is the critical temperature estimated for the stage-independent temperature-dependent mortality model) 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.

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

L.5.2.3 Biological Observations



Data Source:
Azat, J. 2019. CDFW GrandTab.
2022.07.20
http://www.calfish.org/ProgramsData/Species/CDFWAnadromousResourceAssessment.aspx

Monitoring period: December to August
* Preliminary Data
www.cbr.washington.edu/sacramento/
08 Nov 2022 13:19:09 PST

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, 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
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.
CI = confidence interval; LSNFH = Livingston Stone National Fish Hatchery.
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, LSNFH, and Battle Creek escapement above Coleman Weir.

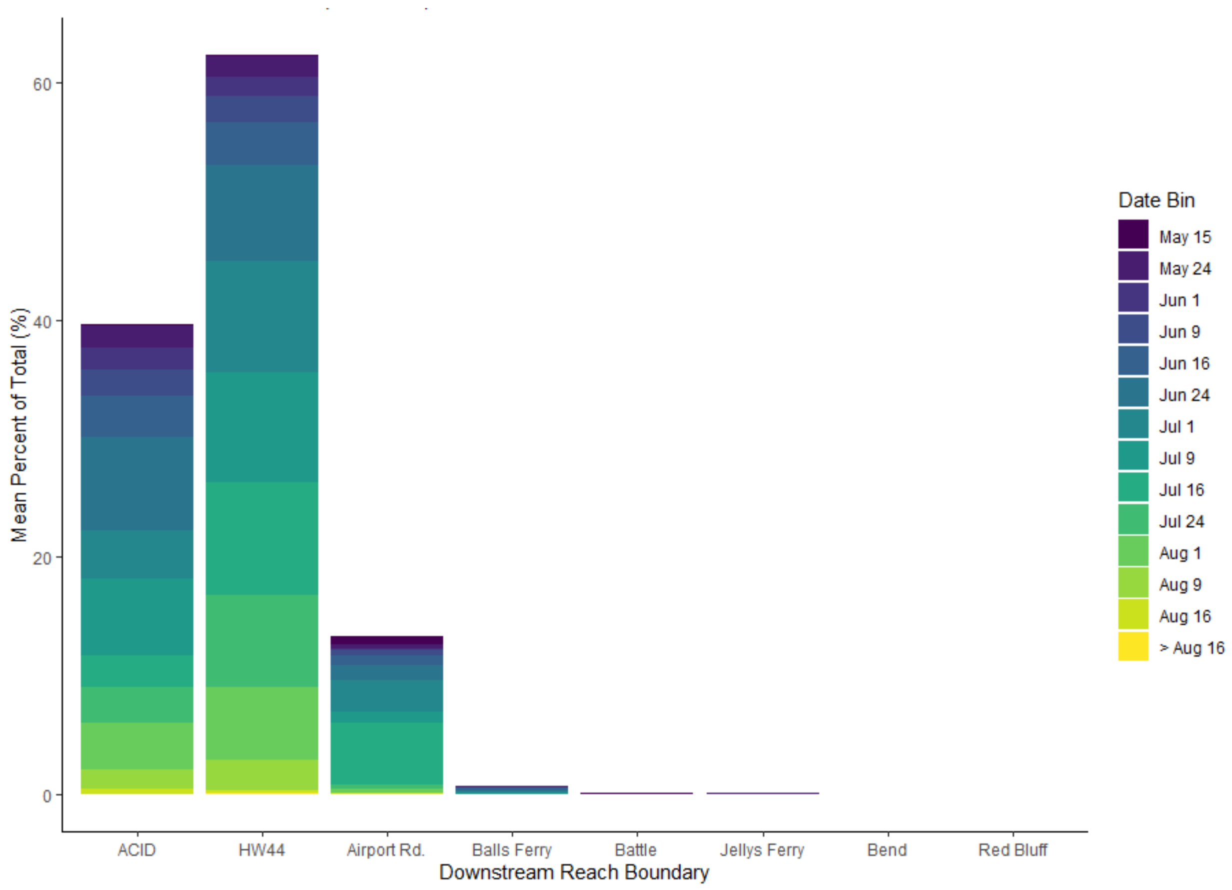


Figure L-11. Mean Timing and Distribution of Winter-run Chinook Salmon Redds in the Upper Reaches of the Sacramento River, 2007–2021

Table L-2. Annual Number of Winter-run Redds per Reach and Total Number of Redds, 2007–2022

Year	**ACID**	**HW44**	**Airport Road**	**Balls Ferry**	**Battle**	**Jellys Ferry**	**Bend**	**Red Bluff**	**Total**
2007	149	90	32	6	5	4	2	0	288
2008	226	180	34	1	0	0	0	0	441
2009	14	72	0	0	0	0	0	0	86
2010	107	107	9	0	0	0	0	0	223
2011	1	13	4	0	0	0	0	0	18
2012	173	87	1	0	0	0	0	0	261
2013	432	128	8	0	0	1	0	0	569
2014	71	47	9	0	0	0	0	0	127
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

Brood Year	Run Size
2012	1,186,248
2011	742,344
2010	1,228,975
2009	3,274,893
2008	953,310
2007	1,337,160

Source: Killam 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: U.S. Fish and Wildlife Service 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: National Marine Fisheries Service 2020 Juvenile Production Estimate Letter.

Table L-5. Total Male 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
1995	Keswick	21	16	37
	Captive Broodstock	21	6	27
1996	Captive Broodstock	38	30 [a]	68
1997	Captive Broodstock	109	45 [b]	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	32 [a]	132
2002	Keswick	48	40	88
	Captive Broodstock	95	25 [a]	120
2003	Keswick	45	33	78
	Captive Broodstock	99	21 [a]	120
2004	Keswick	37	36	73
	Captive Broodstock	45	23 [a]	68
2005	Keswick	51	44	95
	Captive Broodstock	46	21 [a]	67
2006	Keswick	37	52	89
	Captive Broodstock	60	31 [a]	91
2007	Keswick	19	25	44
2008	Keswick	46	47	93

RBDD = Red Bluff Diversion Dam.

[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 for Brood Years 2007–2021

Brood Year	Run Size	Fry Equivalent Juvenile Production Index (90% Confidence Intervals)
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)
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: Voss and Poytress 2020.
Data are available in Appendix L (Shasta CWP).

Table L-7. Livingston Stone Winter-run Chinook Egg Survival

	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.
Data is based on a 2-Year Average (2006–2007) that does not include captive broodstock crosses.

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%
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 Red Bluff Diversion Dam

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)

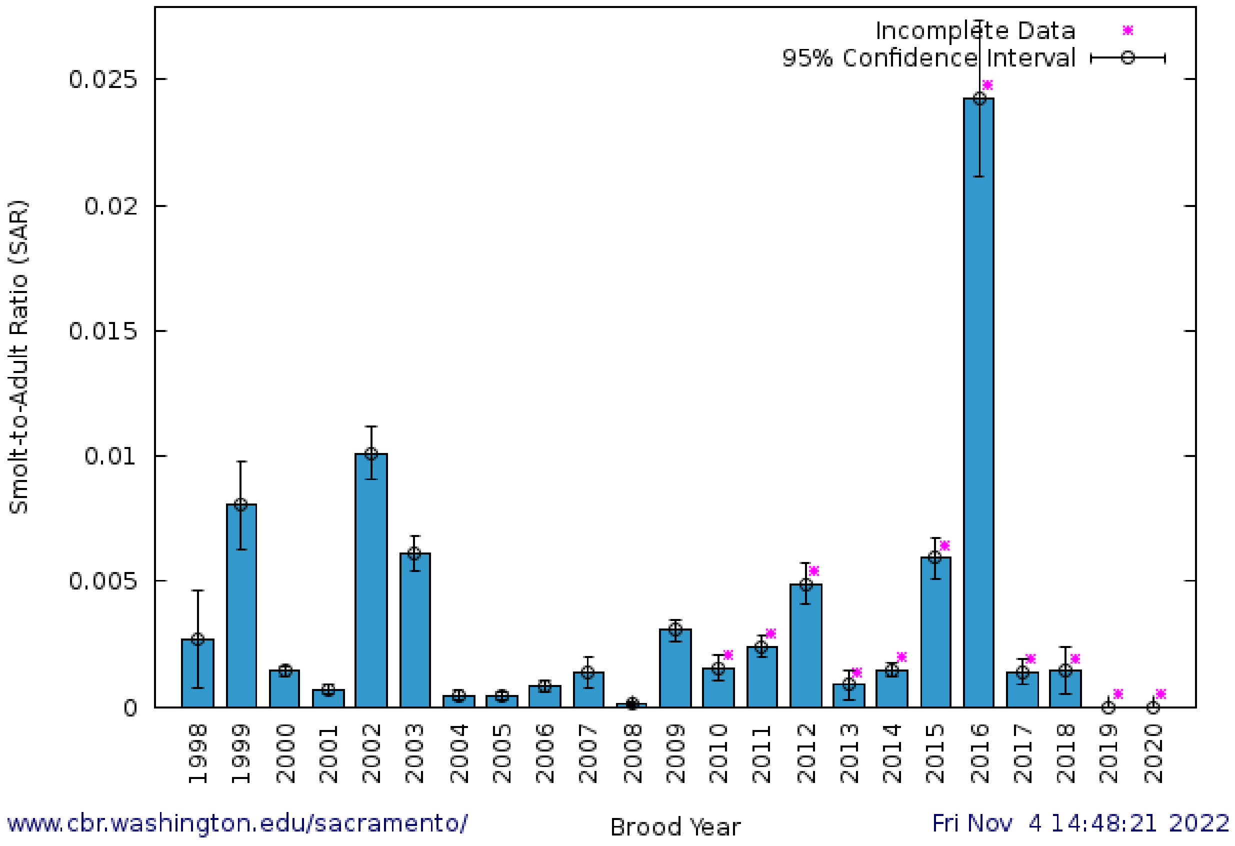
Year	Percent Egg-to-Fry Survival Rate (90% Confidence Intervals)
2005	18.5 (9.9, 27.4)
2004	20.9 (12.1, 29.8)
2003	23.0 (14.0, 32.1)
2002	27.4 (10.1, 47.1)

Sources: Voss and Poytress 2020, estimates 2002–2018; Marcinkevage 2022, estimates 2019–2021.

Table L-10. Coarse Estimates of Temperature-Dependent Mortality Generated from Year-specific Aerial Redd Survey Data and Temperature Data from the Gauge above Clear Creek

	Temperature-Dependent Mortality	
Year	**Stage-independent**	**Stage-dependent**
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

Sources: Martin et al. 2017 (stage-independent data); Anderson et al. 2022 (stage-dependent data).
TDM models implemented on SacPAS (SacPAS Central Valley Prediction and Assessment of Salmon (washington.edu)).



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

Figure L-12. Coded Wire Tagged Livingston Stone National Fish Hatchery Winter-run Chinook Salmon Smolt-to-Adult Ratios, 1998–2020

L.5.3 Models

Numerous quantitative models can be used to evaluate the environmental impacts of the CVP and SWP on listed fishes. A standardized set of criteria was applied to identify the suite of models used in our effects analysis. The necessary criteria include: (1) models are accessible and model output can be reproduced by an independent party, (2) model structure is well documented including model assumptions, (3) model functions are responsive to changing operations such as flow, and (4) model output informs performance metrics. In addition, models also preferably include: (1) focus on target species and/or run-timing group, (2) data collected after 2008, (3) an open and participatory development process, and (4) recent application in regulatory context (e.g., Biological Assessment, Biological Opinions).

L.5.3.1 Early Life-Stage Survival Models

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, Biological Opinion, 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, Biological Opinion, 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/EIS; 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 Biological Opinion 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.

Several models have been developed over the last ten years that provide an analytical basis for estimating the effects of river temperatures on early life-stage survival of winter-run Chinook Salmon. Here we focus on models described in publications by Zeug et al. (2012), Martin et al. (2017), and more recently Anderson et al. (2022). All three publications have been peer reviewed and focus on Sacramento River winter-run Chinook Salmon, but they are built with different data sources and have different functional forms and underlying assumptions. As such, the composition of results from all the three model will provide the bases for evaluating how alternative flow and temperature management strategies may affect early-life stage survival, while providing estimates of model uncertainty that is potentially due to disparate data sources, functional forms, and/or assumptions these models were built from.

L.5.3.3 Water Operations

Reclamation and DWR jointly developed CalSim 3 as a planning model to simulate operations of the CVP and SWP over a range of hydrologic conditions. CalSim 3 represents the best available planning model for CVP and SWP system operations and is an improved and expanded version of CalSim II, which has been the standard planning model for system operations since the early 2000s. A description of CalSim 3 is available in Appendix F, *Modeling*.

L.5.3.4 Egg-to-Fry Survival and Temperature-Dependent Mortality

The Martin et al. (2017) and Anderson et al. (2022) models can be used to predict egg-to-fry survival for winter-run Chinook salmon as a function of temperature-dependent egg mortality, background mortality, and density-dependent mortality. Both models specify egg mortality as a function of temperature (i.e., temperature (i.e., TDM), applied over either the entire embryonic developmental period or only part of it, based on an estimated minimum temperature at which no temperature-dependent mortality occurs and a slope term that describes how much increasing temperatures above the minimum affect egg mortality. Density-dependent mortality is specified following the Beverton-Holt function with a corresponding carrying capacity density term. Model parameters were estimated using known redd locations, estimated temperatures, and annual estimates of egg-to-fry survival from either 1996–2015 (Martin et al. 2017) or 2002–2020 (Anderson et al. 2022; Poytress 2016). Datasets necessary to run the model include the abundance of redds over space and time and corresponding daily temperatures for each redd location; historical aerial redd or carcass survey data and HEC-5Q daily temperature estimates can and have been used as model inputs. These models are available to run as part of the SacPAS Fish Model implementation at: https://www.cbr.washington.edu/sacramento/fishmodel/. The Martin and Anderson models can be used to evaluate the stand-alone TDM and overall egg to fry survival performance metrics for winter-run Chinook Salmon. Model development was not open and participatory. Versions of both models were applied in the 2019 Biological Assessment and Biological Opinion.

L.5.3.5 Hydrodynamic and Temperature

HEC-5Q is a reservoir routing and temperature model. Over the past 15 years, various temperature models were developed to simulate temperature conditions on the rivers affected by CVP and SWP operations (e.g., Sacramento River Water Quality Model [SRWQM], San Joaquin River HEC-5Q model) (Bureau of Reclamation 2008). Recently, these models were compiled and updated into a single modeling package referred to here as the HEC-5Q model. Further updates were performed under the Long-Term Operation EIS modeling that included improved meteorological data and subsequent validation of the Sacramento and American River models, implementation of the Folsom Temperature Control Devices and low-level outlet, implementation of the Trinity auxiliary outlet, improved temperature targeting for Shasta and Folsom Dams, as well as improved documentation and streamlining of the models as well as improved integration with the CalSim II model (Bureau of Reclamation 2015). A summary of previous model calibration and validation details can be found at the following link: DWR-1084 RMA 2003 SRWQM.pdf (ca.gov). Reclamation is developing an updated water temperature modeling platform, but the model is not yet available for broad use.

L.6 Lines of Evidence

During alternative development, rationales behind different concepts and approaches to coldwater pool management strategies were documented. These concepts are described here as lines of evidence. From the full list of quantitative models outlined above (Section L.5.3, *Models*) and the literature, a subset of tools was selected to evaluate the environmental impacts of the CVP and SWP operations on listed fishes. These approaches are included as lines of evidence.

L.6.1 Storage and Coldwater Pool Criteria

NEPA alternatives proposed for the long-term operations of the CVP and SWP have different types of storage and coldwater pool criteria. The Storage and Coldwater Pool Criteria analysis will review these differing criteria and use modeled estimates to the criteria to assess the frequency by which they are met for each of the alternatives.

L.6.2 Warmwater Bypass

Warm water bypasses may occur in the spring to preserve coldwater pool for later use in the summer for fisheries benefits. By using warmer reservoir stratification bands from higher elevations than may be accessed otherwise, it is possible to preserve lower, cooler bands of water. Since the action requires accessing waters of specific known temperatures, it can be considered after the reservoir has begun stratification and the Temperature Control Device (TCD) gate would otherwise be drawing cooler temperatures. Warmwater bypasses were more common prior to the TCD installation, however, since the TCD was installed, these types of bypasses have been used infrequently.

In water year 2021, Reclamation used a warmwater bypass between April 18 and May 25. This action accessed water through river outlets higher on the face of the dam rather than at the elevation of the middle gates of the TCD. The action ended when lake elevation levels and temperature profiles indicated no further benefit to temperature management, given the risk of pre-spawn mortality and reduced gamete viability for winter-run Chinook salmon. Winter-run Chinook salmon early lifestage TDM results for the baseline scenario (i.e., without power bypass) ranged from 78-86% while the TDM results for the warm water power bypass scenario ranged from 67-71%. This action preserved approximately 300 TAF of cold water for later in the year. The power bypass action resulted in a reduction in power value by approximately $5 million (Bureau of Reclamation 2021).

In water year 2015, Reclamation used a warmwater bypass between April 16 and May 27. This action accessed water through a river outlet at a higher elevation than the TCD gates. This action conserved 103 TAF (SRTTG 2015 Report).

L.6.3 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.6.4 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

Water Year	Date of 54°F Appearing in Profile
2007	5-Apr
2008	1-May
2009	2-Apr
2010	3-May
2011	2-May
2012	2-May
2013	3-Apr
2014	9-Apr
2015	10-Mar
2016	7-Apr
2017	28-Mar
2018	3-Apr
2019	23-Apr
2020	15-Apr
2021	31-Mar
Average	*10-Apr*

°F = degrees Fahrenheit.

L.6.5 Winter-run Temperature Synthesis

Winter-run temperature needs were previously described in Section L.5.1.1, *Adult Holding and Spawning Winter-run Chinook Salmon Water Temperature Needs*, and Section L.5.1.2, *Egg Incubation and Alevin Winter-run Chinook Salmon Water Temperature Needs*. The upper temperature thresholds for the egg and alevin life stages, at which higher temperatures are expected to increase mortality varied between 53.6°F and 56.5°F (Table L-12). Optimal, preferred, and lethal temperatures for juveniles were estimated using laboratory studies. Optimal temperatures for growth occurred between 62.6 and 68°F, behaviorally preferred temperatures ranged from 53.6 and 55.4°F, and temperature-induced mortality was observed starting at temperatures between 75.2 and 78.8°F. Temperatures associated inhibition of smolting were estimated with lab studies and varied from 62.6°F to 68°F, while a field-based estimate of a temperature threshold associated with smolt mortality was 73.4°F. Temperature thresholds for adults were estimated using field studies. Preferred pre-spawning temperatures ranged between 42.8°F and 57.2°F, pre-spawn mortality was associated with temperatures thresholds between 55.9°F and 68.0 °F, spawning delay and inhibition were associated with temperatures above 55.0°F and 60.8°F, respectively, and inhibition of migration and direct mortality were associated with temperatures above 68°F and 69.8°F.

Table L-12. Summary of Life Stage-Specific Temperature Thresholds for Winter-run Chinook Salmon

Life Stage	Metric	Value
Egg/Alevin	Threshold at which higher temperatures are associated with increased mortality	55.9°F [a] 56.5°F [b] 53.6°F [c]
	Recommended upper optimum	53.6°F–55.9°F [d, e]
Juvenile	Optimal temperature for growth with no food limitation	66.2°F [f] 62.6°F–68°F [g]
	Behaviorally preferred temperature	53.6°F–55.4°F [h]
	Upper Incipient Lethal Temperature	78.8°F [i] 75.2°F–77.0°F [h]
	Critical Thermal Maximum	82.4°F–85.1°F [j]
Smolt	Threshold at which higher temperatures inhibit smolting	62.6°F–68°F [g]
	Upper Incipient Lethal Temperature	73.4°F [k]
Adult	Threshold at which adult migration is inhibited	68°F [l]
	Upper Incipient Lethal Temperature	69.8°F [m]
	Temperatures associated with elevated pre-spawning mortality	55.9°F–60.1°F [m] 68°F [n]
	Ideal pre-spawning temperatures	42.8°F–57.2°F [m]
	Threshold at which spawning initiation is inhibited	55.0°F [m]
	Threshold at which spawning is expected not to occur	60.8°F [m]

[a] U.S. Fish and Wildlife Service 1999.
[b] Slater 1963.
[c] Martin et al. 2017.
[d] Myrick and Cech 2004.
[e] Bratovich et al. 2012.
[f] Myrick and Cech 2002.
[g] Marine and Cech 2004.
[h] Brett 1952.
[i] Hanson 1991.
[j] Zillig et al. 2020.
[k] Baker et al. 1995.
[l] Goniea et al. 2006.
[m] McCullough 1999.
[n] Bowerman 2018.

L.6.6 Multi-Species Water Temperature Synthesis

Shasta Lake coldwater pool management can be used to provide cold water for fish spawning and incubation over the summer months. The Sacramento River provides habitat for Chinook salmon, steelhead, sturgeon, and other fish. Ranges of water temperature that support specific life stages of chinook salmon, steelhead, and green sturgeon are described in Table L-2.

Table L-13. Ranges of Temperatures That Support Life Stages of Chinook Salmon, Steelhead, and Green Sturgeon

Species	Egg/Alevin	Juvenile	Smolt Outmigration	Adult Migration	Spawning Initiation
Chinook salmon	42.8°F–-56°F (6°C–13.3°C) [*, a, b, c, ,d, e]	62.6°F–68°F (17°C–20°C) [c, f, g]	55.4°F–60.8°F (13°C–16°C) [g, h]	37.9°F–68°F (3.3°C–20°C) [i, j, k]	42.1°F–55°F (5.6°C–12.8°C) [j]
Steelhead	42°F–52°F (5.5°C–11.1°C) [m]	51.8°F–66.2°F (11°C-19°C) [n]	43.7°F–53.4°F (6.5°C–11.9°C) [f, x]	41°F–66°F (5°C–18.9°C) [o]	45°F–55°F (7°C–12.8°C) [l, y]
Green Sturgeon	52.3°F–60.8°F (11.3°C–16°C) [p, q, r]	59°F–66.2°F (15°C–19°C) [s, t]	NA	52°F–69.4°F (11°C–20.8°C) [u, v]	49.3°F–63.7°F (9.6°C–17.6°C) [w]

°F = degrees Fahrenheit; °C = degrees Celsius.

* 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).

[a] Slater 1963.
[b] U.S. Fish and Wildlife Service 1999.
[c] Myrick and Cech 2004.
[d] Bratovich et al. 2012.
[e] Martin et al. 2017.
[f] Myrick and Cech 2001.
[g] Marine and Cech 2004.
[h] Clark and Shelbourn 1985.
[i] Reiser and Bjornn 1979.
[j] McCullough 1999.
[k] Goniea et al. 2006.
[l] Richter and Kolmes 2005.
[m] McCullough et al. 2001.
[n] Myrick and Cech 2005.
[o] Keefer et al. 2009.
[p] Van Eenennaam et al. 2005.
[q] Brown 2007.
[r] Rodgers et al. 2019.
[s] Mayfield and Cech 2004.
[t] Poletto et al. 2018.
[u] Kelly et al. 2007.
[v] Colborne et al. 2022.
[w] Poytress et al. 2015.
[x] Environmental Protection Agency 2003.
[y] Federal Energy Regulatory Commission 1993.

L.6.7 Temperatures During Egg Incubation

Numerous 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 (SRWRC) observed increased mortality for eggs reared at 56.5°F relative to eggs reared at 53.9°F and increasing egg mortality at temperatures greater than 55.9°F (Slater 1963; U.S. Fish and Wildlife Service 1999). Models of TDM fit to field-based estimates of egg-to-fry survival for SRWRC suggested temperature-dependent morality occurs at temperatures exceeding 53.6°F (Martin et al. 2017; Anderson et al. 2022). In aggregate, these results have led reviewers to recommend optimum upper temperatures for CV Chinook salmon between 53.6 and 55.9°F (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, 2021; Martin et al. 2020). 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).

L.6.8 Historical Spawn Timing Analyses (Onset)

The onset of temperature management currently occurs based on either calendar date (May 15) or the start of winter-run Chinook salmon spawning based on real-time monitoring, depending on which is later. We can replicate the use of real-time monitoring to determine onset of temperature management using historical aerial redd survey data obtained from CalFish (CDFW Upper Sacramento River Basin Salmonid Monitoring (calfish.org)) and summarized in Appendix C, *Species Spatial and Temporal Domains*, Table C-2. For example, the earliest a redd has been detected in the past 20 years (i.e., 2002–2021) was April 29; the latest date on which the first redd of the year was detected was June 26. The past 20 years of redd observations indicate that on average the earliest redds were detected around May 8. The 5% quantile of dates corresponding to new redd observations in the past 20 years was June 3.

An alternative method for determining the onset of management can be based on the occurrence of critical windows for developing Chinook salmon embryos. In this framework, temperature management would occur when eggs first enter the critical window, the proposed period of heightened sensitivity to TDM. The end of the critical window occurs after embryos experience 400 accumulated thermal units (ATUs, in °C) and lasts for a total of four days (Anderson et al. 2022). We can estimate when eggs enter the critical window using historical data from aerial redd surveys and historical temperature profiles. The earliest estimated date embryos first reached the critical window in the past 20 years was June 5, and the average earliest estimated data embryos first reached the critical window was June 6. The past 20 years of data indicate that on average the 5% quantile of estimated critical window dates was July 7.

We can also evaluate critical periods of protection based on preliminary work by Anderson (2018), in which onset occurs 37 days after the first annual redd observation. This is consistent with the 2019 Proposed Action. These critical periods can be identified using the redd observation dates provided above. The past 20 years of data indicate that the earliest critical window begun around May 27, and on average the earliest critical window would occur around June 14. The past 20 years of data indicate that on average the 5% quantile of estimated critical window dates was July 10.

L.6.9 Spring Temperature Effects on Spawn Timing

Temperature is an important driver of spawning behavior and timing in salmonids. Delays to migration caused by temperatures from 19°C–23°C can cause delays in spawning events for salmonids (National Marine Fisheries Service 2019). Important temperature ranges and thresholds related to spawning are summarized (Table L-14). Important caveats for these thermal tolerances are that Central Valley populations and individual ESUs within the Central Valley may have local adaptations to slightly warmer temperatures (Zillig et al. 2018). Likewise, hatchery and laboratory studies of thermal tolerances may be slightly different from in situ thermal tolerances due to interactions with flow, dissolved oxygen, and other environmental variables (Deas et al. 2009; Zillig et al. 2018).

Annually, SRWC spawning start timing is relatively constant though the peak varies year to year (Hendrix et al. 2017; Jennings and Hendrix 2020). Cool springtime water temperatures correspond to earlier peak spawning, and warm springtime temperatures are associated with later peak spawning. Specifically, there is evidence that higher April and May water temperatures correspond to increased and delayed peak spawning in July and August.

Warmer April temperatures in the Sacramento River lead to later peak spawn timing of Winter-run Chinook salmon, while cooler spring temperatures lead to earlier peak spawn timing (Jennings and Hendrix 2020). Earlier peak spawn timing could potentially be beneficial for the species because if eggs are laid earlier the redds may also emerge earlier, before the water temperatures below Keswick Dam have risen above the thermal tolerance of the eggs (Jennings and Hendrix 2020). However, subsequent preliminary simulation modeling by Hendrix and Sawyer has shown that under scenarios where April temperatures were decreased by 1°C, relative population abundance fell below baseline levels (Hendrix pers. comm.). This likely occurred because maintaining the lower April temperature resulted in a tradeoff of greater difficulty in maintaining the September temperatures. Under the lower April temperature scenario, September temperatures were assumed to be elevated 1.5°C above the baseline scenario. These elevated September temperatures likely explain the poor population outcomes of this scenario because even under cool temperatures such as those associated with 2008, the majority of redds emerge in October. In an alternative scenario, relative abundance had a 74% chance of exceeding baseline abundance if July and August temperatures were maintained 1°C below the baseline during July and August, at the expense of June and September temperatures running 1°C above the baseline. In addition, maintaining the Jul/Aug temperature reduction action in critical years only was no better an alternative (with regards to population outcomes) than conducting the action in all years. It is also worth noting that relative abundance was considerably higher when reintroductions at McCloud were incorporated into the cooler July/August action, with a 76% probability of exceeding baseline population outcomes.

Table L-14. Important Temperature Ranges, Thresholds, etc. Related to Spawning Behavior, Timing, Stress, and Mortality of Sacramento River Winter-run Chinook Salmon

Metric	SRWC-specific?	Value
Threshold above which direct mortality occurs		26°C [a]
Upper Incipient Lethal Temperature		21°C [b]
7-day average temperature threshold above which >80% pre-spawning mortality occurs		20°C [c]
Threshold above which migration slows [d] or is delayed [e]	Columbia River	20°C [d] 19-23°C [a]
Threshold below which maturation is inhibited and complete pre-spawning mortality occurs		3.3°C [b]
Range above which pre-spawning mortality of ripe adult females is elevated		13.3-15.6°C [b]
Threshold above which egg mortality occurs prior to deposition		14°C [b]
Threshold above which spawning is inhibited		12.8°C [b]
Threshold above which spawning is unlikely to occur		16°C [b]
Temperature range for spawning	Western United States, Canada	2.2°C–20.0°C [e]
Temperature range for holding during the pre-spawning period	SRWC	5.8°C–14.2°C [f]
Temperature range for migration	Western United States, Canada	3.3–20.0°C [e]
Ideal pre-spawning temperature range		6-14°C [b]

[a] National Marine Fisheries Service 2019;
[b] McCullough 1999.
[c] Bowerman 2018.
[d] Goniea et al. 2006.
[e] Reiser and Bjornn 1979.
[f] Slater 1963.

L.6.10 Temperature-Dependent Mortality

This section summarizes results from Attachment L.2, *Egg-to-fry Survival and Temperature-Dependent Mortality*. Results provide an evaluation of TDM for the Proposed Action and each of the alternatives.

Reclamation analyzed daily water temperature estimates from HEC-5Q models, based in turn on monthly CalSim 3 flows, for each alternative to evaluate LTO operations effect on survival of eggs and alevin. Summarized results for the performance metric of TDM are provided in Table L-15 and Figure L-13 through Figure L-16 for the EIS (i.e., NAA, Alt1, all four phases of Alt2, Alt3, and Alt4). Summarized results for the same performance metric are provided in Table L-16 and Figure L-17 through Figure L-19 for the Biological Assessment.

The models are sensitive to the temperature target, locations, and timing. The Proposed Action (i.e., Alternative 2) developed bins with different water temperature management biological goals and objectives (i.e., "Bin Criteria"). The Proposed Action additionally included shaping water temperature management to optimize for low TDM. The models used and updated the 2020 Record of Decision into a strategy that may better represent the outcome of temperature shaping by the real-time groups (i.e., "2021 Updated Tier Strategy"). Reclamation staff present all results for Alternative 2 with "Bin Criteria" temperature target, locations, and timing, in addition to select results in which the "2021 Updated Tier Strategy" is applied instead to the No Action Alternative (NAA) and components of the Proposed Action. Reclamation staff explicitly identify all instances in which results reflect the "2021 Updated Tier Strategy."

- Models of TDM are responsive to daily, location-specific estimates of temperature obtained from HEC-5Q (i.e., at RKM 483, 479, and 474) and the spatial and temporal distribution of redds, based on carcass survey data. Annual redd distributions between 2001 and 2021 were included in modeling to capture expected uncertainty in TDM due to redd distribution for each modeled water year.
- The stage-independent model of TDM was calibrated to spawner abundance, fecundity, and fry production estimates at Red Bluff Diversion Dam for the years 1996–2015 (i.e., the Martin model). The stage-dependent model of TDM was calibrated to the same data types for years 2002–2015 and 2017–2020 (i.e., the Anderson model).
- Models of TDM assume that temperature is the only environmental condition that affects survival and exclude the potential effects of conditions like flow or substrate. The models also generated TDM parameters using estimates of egg-to-fry survival and assumed that environmental conditions affected survival only during pre-emergence life stages (i.e., eggs and alevin). Additionally, there is underlying uncertainty in the model-estimated parameters of TDM models (i.e., the critical temperature and rate of change in mortality with increase temperature) that can be expected to affect uncertainty in estimated TDM values; additional details regarding modeling of parameter uncertainty can be found in Attachment L.2.
- The relevant performance metric presented for these models is temperature-dependent mortality.

For the Anderson model, expected proportional TDM values calculated across all WYTs, for only critical water years, and for only wet water years were 0.094, 0.468, and 0.001, respectively for Alt2woTUCPwoVA. Relative to the Anderson model, expected proportional TDM values were slightly higher for the Martin model across all WYTs and for critical water years, but slightly lower for wet water years (i.e., 0.118, 0.556, and 0.006, respectively, for Alt2woTUCPwoVA). For expected proportional TDM values calculated across all WYTs, mean TDM values ranged from 0.065 to 0.239 across all alternatives for the Anderson model and 0.089 to 0.216 for the Martin model. Water year-specific TDM estimates varied from approximately 0 to 1 across alternatives and models, and were highest in critical water years.

For mean proportional TDM values calculated across each WYT and model, Alt1 resulted in increased TDM relative to the NAA across both TDM models and all WYTs but above normal (i.e., -2.8% to 1096.7% differences in TDM relative to NAA). Alt3 resulted in decreased TDM for all models and WYTs except for the Anderson model in wet water years (i.e., -87.7% to -34.0% differences); for the Anderson model in wet water years, Alt3 resulted in increased TDM (i.e., 75.3% difference). Alt4 also resulted in decreased TDM for all models and all WYTs, with the exception of wet water years for both models (i.e., -85.7% to -0.4% differences relative to NAA); for wet water years, Alt4 resulted in increased TDM (i.e., 16.2% to 60.5% differences). All four components of Alt2 resulted in decreased TDM relative to NAA for both models and every WYT (i.e., -83.1% to -19.4% differences). The Alt2wTUCPwoVA resulted in greater decreases in TDM (i.e., -83.1% to -38.1% differences) than the other three components of Alt2 (i.e., -78.6% to -19.4% differences).

For the Anderson and Martin models, greater than 75% of modeled WYTs for every alternative resulted in expected proportional TDM values less than 0.125 for every alternative but Alt1, which produced greater TDM for a greater fraction of years. For critical water years only, at least 12.5% of modeled water years resulted in expected proportional TDM values less than 0.5 for all alternatives but Alt1. For above normal and wet water years, expected proportional TDM never exceeded 0.125 for all alternatives but Alt1.

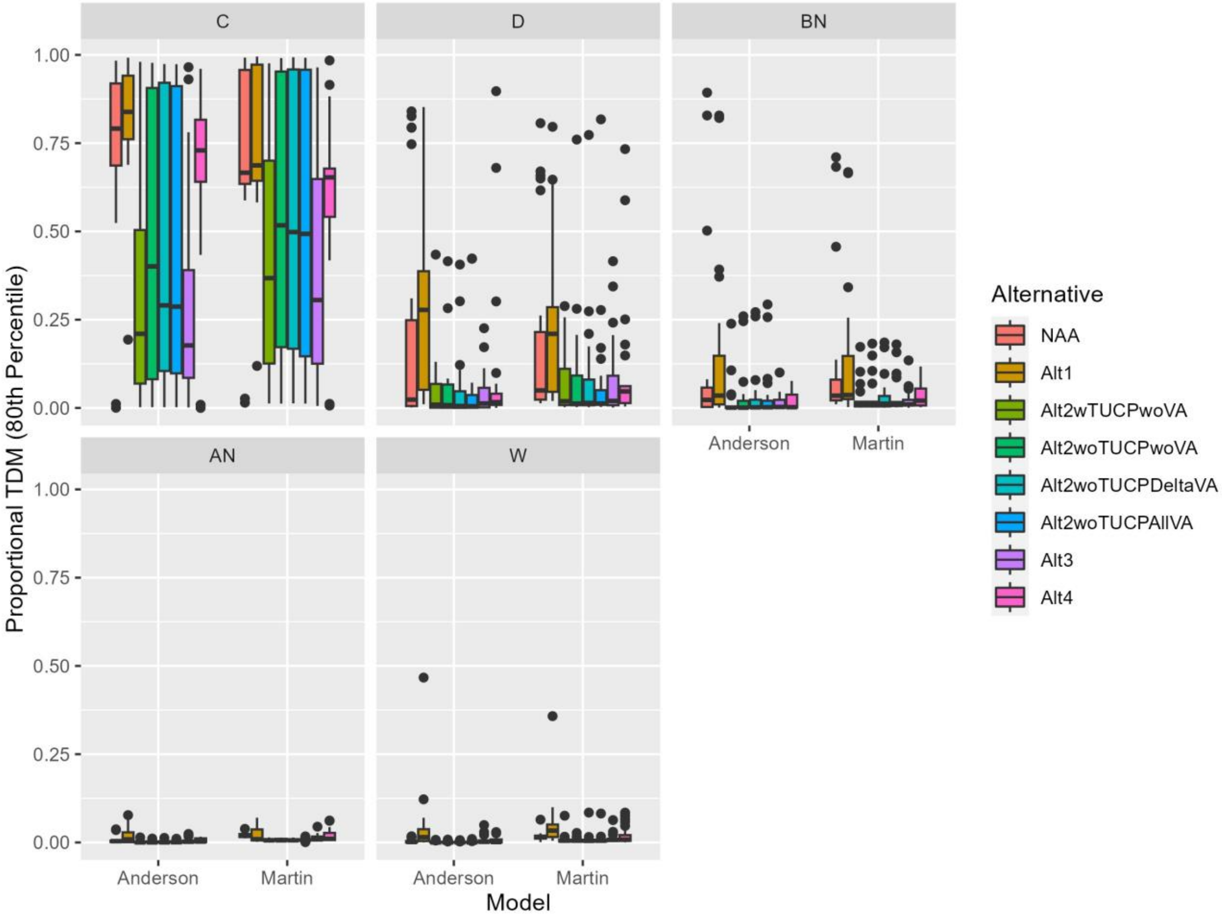
For the model runs with the “2021 Updated Tier Strategy” applied to NAA and all components of Alt2, a greater fraction of water years had equal or lower expected TDM values among the different WYTs relative to the “Bin Criteria”. For critical water years, at least 37.5% of modeled water years resulted in expected proportional TDM values less than 0.5 for all alternatives but Alt1 and Alt4; for both above normal and wet water years, expected TDM never exceeded 0.125 for all alternatives but Alt1.

For recent water years 2011–2020, expected proportional TDM values for Alt2woTUCPwoVA had noticeably greater variation when both redd and parameter uncertainty were included than when only redd uncertainty was included.

Table L-15. Predicted Mean Proportional Temperature-Dependent Mortality Estimates for Different Models and Water Year Types

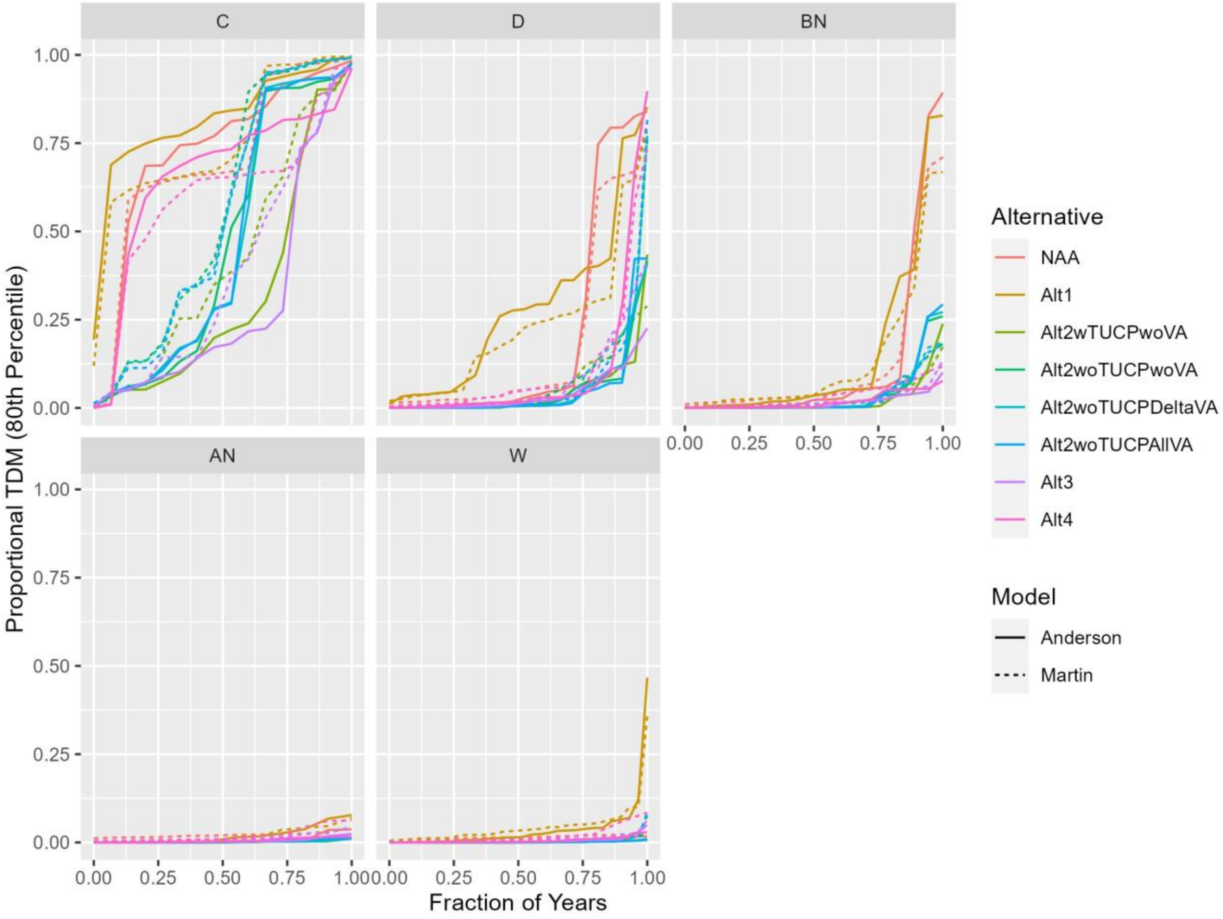
Model	**WYT**	**NAA**	**Alt1**	**Alt2wTUCP woVA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**	**Alt3**	**Alt4**
Anderson	All	0.190	0.239 (26.0)	0.070 (-63.2)	0.094 (-50.4)	0.094 (-50.5)	0.095 (-49.9)	0.065 (-65.6)	0.134 (-29.3)
Anderson	C	0.712	0.811 (13.4)	0.334 (-53.1)	0.468 (-34.3)	0.462 (-35.1)	0.466 (-34.6)	0.312 (-56.2)	0.649 (-9.0)
Anderson	D	0.210	0.286 (36.3)	0.049 (-76.8)	0.051 (-75.8)	0.051 (-75.5)	0.052 (-75.4)	0.042 (-80.0)	0.105 (-49.9)
Anderson	BN	0.135	0.157 (16.1)	0.023 (-83.1)	0.035 (-74.1)	0.038 (-72.0)	0.040 (-70.6)	0.017 (-87.7)	0.019 (-85.7)
Anderson	AN	0.008	0.021 (145.9)	0.002 (-72.7)	0.002 (-78.6)	0.002 (-72.7)	0.002 (-70.9)	0.005 (-38.4)	0.006 (-30.7)
Anderson	W	0.003	0.039 (1096.7)	0.001 (-65.1)	0.001 (-67.0)	0.001 (-69.7)	0.001 (-62.0)	0.006 (75.3)	0.005 (60.5)
Martin	All	0.187	0.216 (15.6)	0.093 (-50.6)	0.118 (-36.8)	0.117 (-37.2)	0.115 (-38.3)	0.089 (-52.2)	0.136 (-27.3)
Martin	C	0.690	0.747 (8.3)	0.427 (-38.1)	0.556 (-19.4)	0.548 (-20.6)	0.543 (-21.2)	0.389 (-43.5)	0.595 (-13.8)
Martin	D	0.193	0.234 (21.4)	0.067 (-65.2)	0.087 (-55.1)	0.085 (-56.1)	0.079 (-58.9)	0.077 (-60.3)	0.111 (-42.4)
Martin	BN	0.132	0.140 (6.2)	0.027 (-79.5)	0.033 (-74.9)	0.036 (-73.0)	0.034 (-74.0)	0.024 (-81.8)	0.036 (-72.5)
Martin	AN	0.021	0.021 (-2.8)	0.007 (-65.8)	0.007 (-66.7)	0.007 (-66.1)	0.008 (-64.1)	0.014 (-34.9)	0.021 (-0.4)
Martin	W	0.016	0.047 (188.8)	0.008 (-49.8)	0.006 (-60.5)	0.008 (-50.3)	0.008 (-49.4)	0.011 (-34.0)	0.019 (16.2)

WYT = water year type; C = critical; D = dry; BN = below normal; AN = above normal; W = wet; NAA = No Action Alternative.
Presented means are the means of 80th percentile TDM values for relevant CalSim water years. Parentheses indicate percent different from the No Action Alternative (negative values indicate a beneficial decrease in expected TDM).



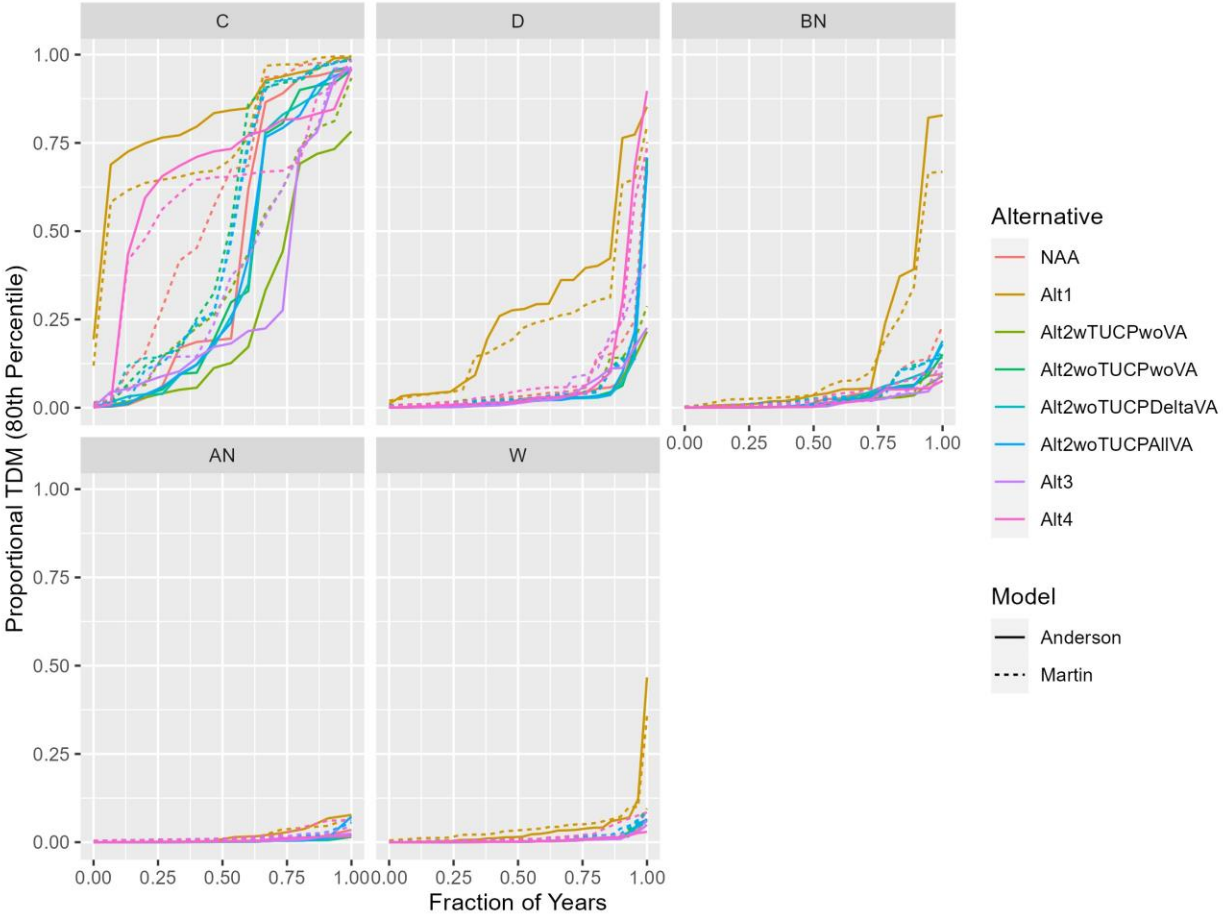
TDM = temperature-dependent mortality; C = critical; D = dry; BN = below normal; AN = above normal; W = wet. Estimates calculated using the 80th percentile of TDM for each water year.

Figure L-13. Summaries of Proportional Temperature-Dependent Mortality (TDM) Estimates for Each Water Year Type (i.e., facets) for the Anderson and Martin TDM Models



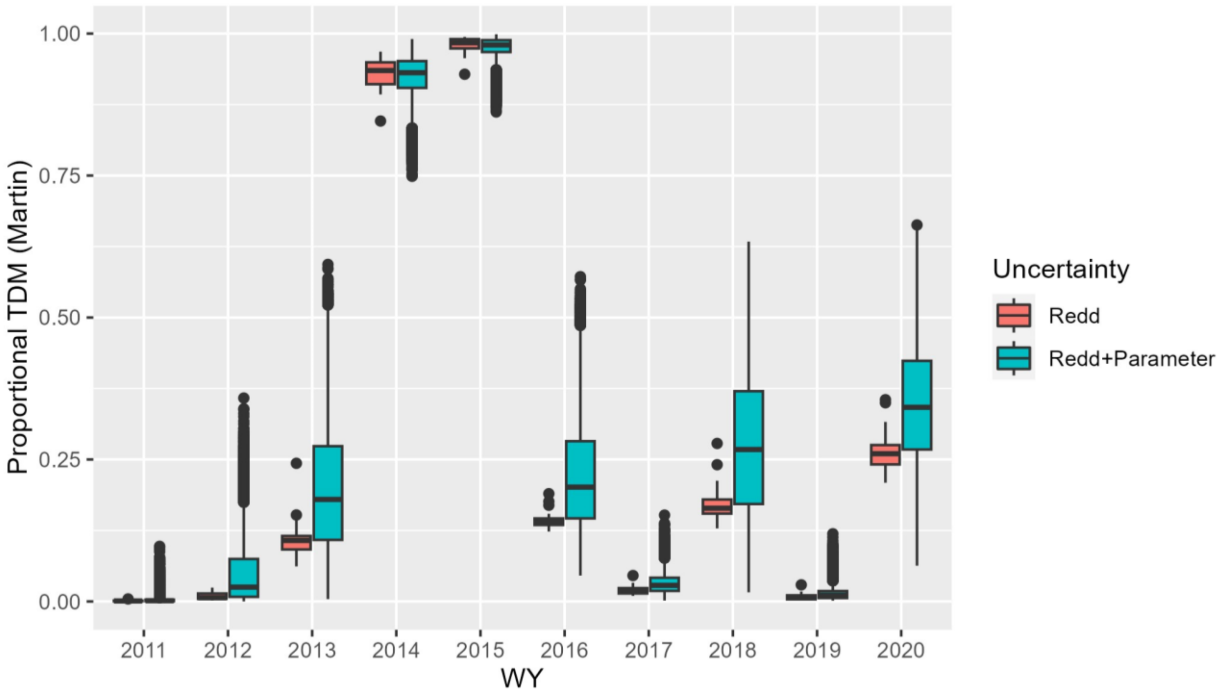
TDM = temperature-dependent mortality; C = critical; D = dry; BN = below normal; AN = above normal; W = wet. Estimates calculated using the 80th percentile of TDM for each water year.

Figure L-14. Exceedance Plots of Proportional Temperature-Dependent Mortality (TDM) Estimates for Each Water Year Type (i.e., facets) for the Anderson and Martin TDM Models



TDM = temperature-dependent mortality; C = critical; D = dry; BN = below normal; AN = above normal; W = wet. Estimates calculated using the 80th percentile of TDM for each water year.

Figure L-15. Exceedance Plots of Proportional Temperature-Dependent Mortality (TDM) Estimates for Each Water Year Type for the Anderson and Martin TDM Models, based on the "2021 Updated Tier Strategy" for the No Action Alternative and Alternative 2



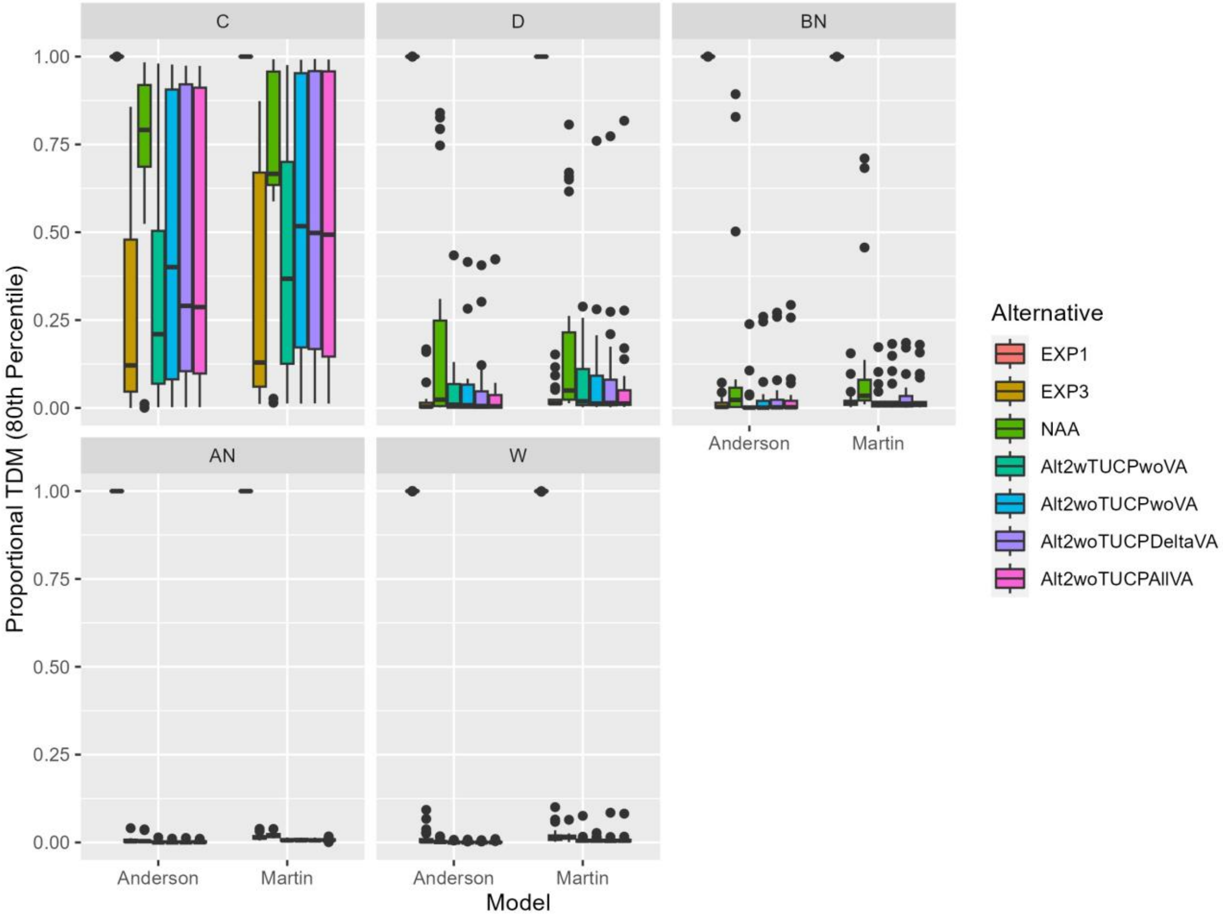
TDM = temperature-dependent mortality; WY = water year.
Boxplots summarize TDM variability across either only different annual redd distributions or both different redd distributions and posterior parameter estimates.

Figure L-16. Trends in Proportional Temperature-Dependent Mortality (TDM) (i.e., Martin model only) for CalSim 3 Water Years 2011–2020 for Alt2woTUCPwoVA

Table L-16. Predicted Mean Proportional Temperature-Dependent Mortality Estimates for Different Models and Water Year Types

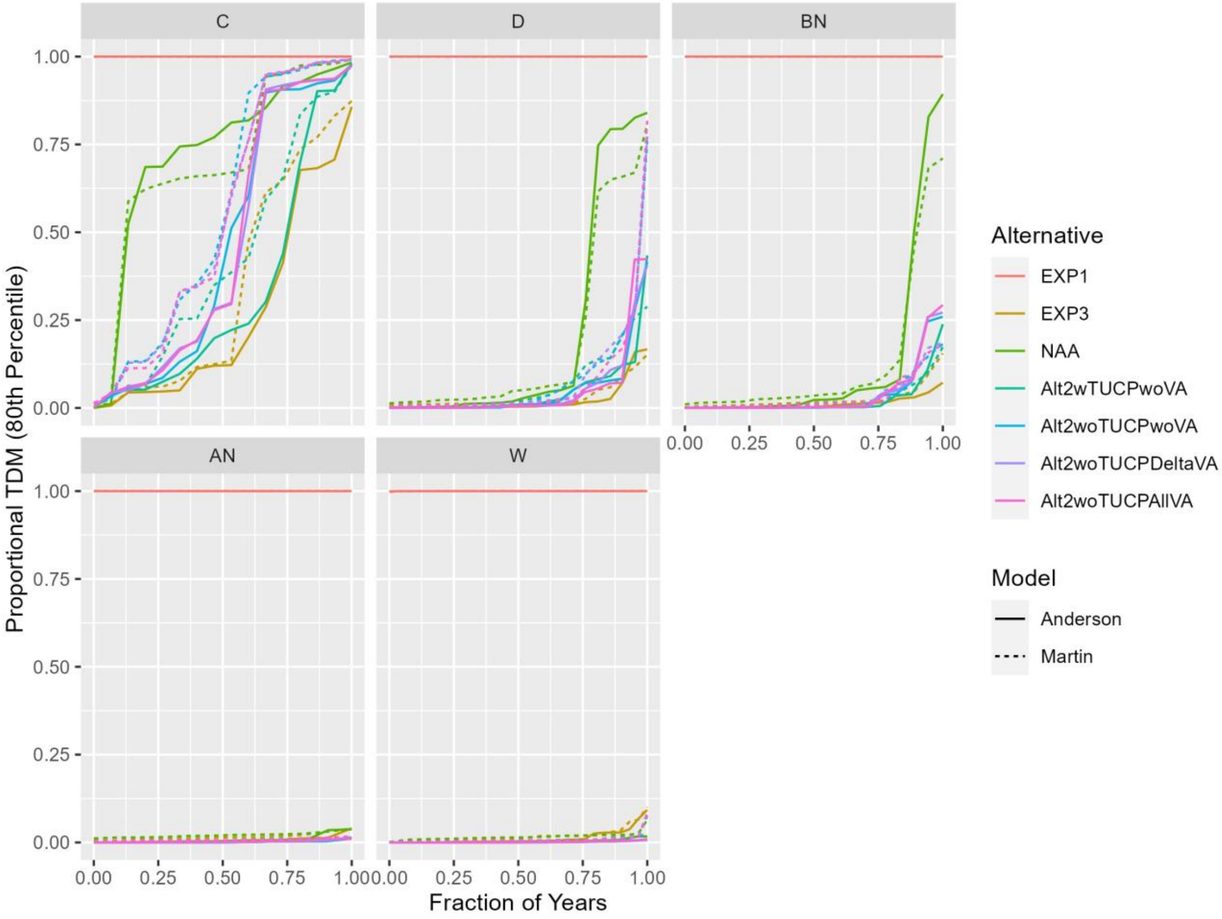
Model	WYT	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Anderson	All	1	0.056	0.190	0.070	0.094	0.094	0.095
Anderson	C	1	0.273	0.712	0.334	0.468	0.462	0.466
Anderson	D	1	0.023	0.210	0.049	0.051	0.051	0.052
Anderson	BN	1	0.013	0.135	0.023	0.035	0.038	0.040
Anderson	AN	1	0.007	0.008	0.002	0.002	0.002	0.002
Anderson	W	1	0.012	0.003	0.001	0.001	0.001	0.001
Martin	All	1	0.077	0.187	0.093	0.118	0.117	0.115
Martin	C	1	0.349	0.690	0.427	0.556	0.548	0.543
Martin	D	1	0.031	0.193	0.067	0.087	0.085	0.079
Martin	BN	1	0.027	0.132	0.027	0.033	0.036	0.034
Martin	AN	1	0.016	0.021	0.007	0.007	0.007	0.008
Martin	W	1	0.019	0.016	0.008	0.006	0.008	0.008

WYT = water year type; C = critical; D = dry; BN = below normal; AN = above normal; W = wet.
Presented means are the means of 80th percentile TDM values for relevant CalSim water years.



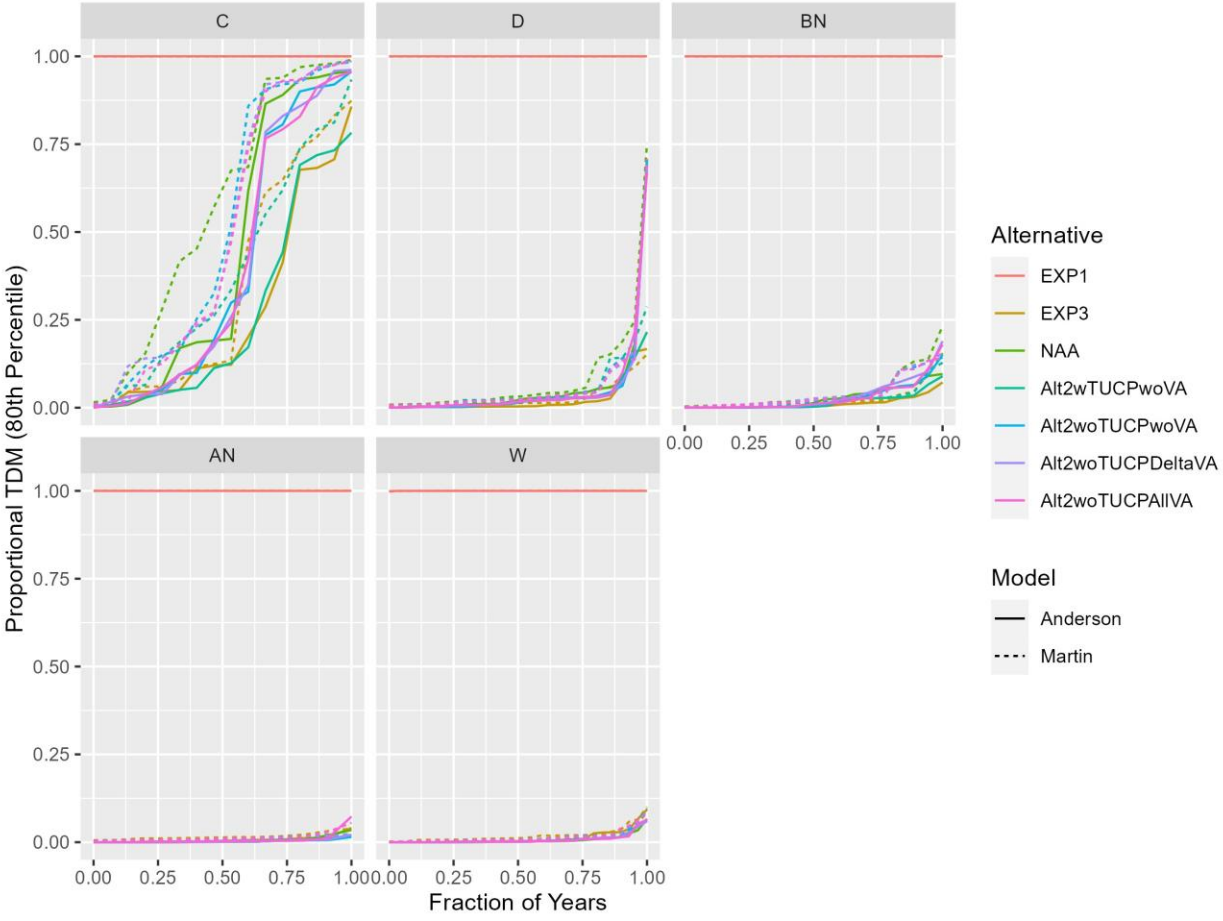
TDM = temperature-dependent mortality; C = critical; D = dry; BN = below normal; AN = above normal; W = wet. Estimates calculated using the 80th percentile of TDM for each water year.

Figure L-17. Summaries of Proportional Temperature-Dependent Mortality (TDM) Estimates for Each Water Year Type (i.e., facets) for the Anderson and Martin TDM Models



TDM = temperature-dependent mortality; C = critical; D = dry; BN = below normal; AN = above normal; W = wet. Estimates calculated using the 80th percentile of TDM for each water year.

Figure L-18. Exceedance Plots of Proportional Temperature-Dependent Mortality (TDM) Estimates for each Water Year Type (i.e., facets) for the Anderson and Martin TDM Models



TDM = temperature-dependent mortality; C = critical; D = dry; BN = below normal; AN = above normal; W = wet.
Estimates calculated using the 80th percentile of TDM for each water year.

Figure L-19. Exceedance Plots of Proportional Temperature-Dependent Mortality (TDM) Estimates for Each Water Year Type for the Anderson and Martin TDM Models, based on the “2021 Updated Tier Strategy” for the No Action Alternative and Alternative 2

L.6.11 Winter-run Chinook Salmon Juvenile Production Index Model

<The winter-run Chinook salmon juvenile production index analysis will include juvenile production index estimates for each alternative when alternatives and modelled water temperatures are available.

See Attachment L.3, *Winter-run Chinook Salmon Juvenile Production Index Model*, for detailed analysis and assumptions. The key takeaways include: <insert a few sentences>

L.6.12 Historical Emergence Timing (Offramp)

The offramp of temperature management currently occurs based on either calendar date (October 31) or when real-time monitoring suggests that 95% of eggs have hatched and alevin have emerged, depending on which is earlier. We can replicate the use of real-time monitoring to determine offramp of temperature management using historical aerial redd survey data obtained from CalFish (CDFW Upper Sacramento River Basin Salmonid Monitoring (calfish.org)) and established relationships between temperature and development time (Zeug et al. 2012). We model alevin emergence from redds to occur after embryos and alevins experience a total of 958 ATUs using SacPAS. The 5%, 50%, and 95% quantiles of expected alevin emergence dates across the past 20 years (i.e., 2002–2021) are August 27, September 23, and October 22.

An alternative method for determining management offramp also can be based on the occurrence of critical windows for embryos. Using historical aerial redd survey data, temperature profiles, assumed critical windows from Anderson et al. (2022), and SacPAS, September 27 was the estimated latest date embryos were in the critical window in the past 20 years. The 5%, 50%, and 95% quantiles of the last date embryos were in the critical window were July 10, August 6, and September 4.

We can also evaluate critical periods of protection based on preliminary work by Anderson (2018), in which offramp occurs 67 days after the last annual redd observation. This is consistent with the 2019 Proposed Action. These critical periods can be identified using the redd observation dates provided in the Historical Spawn Timing Analyses (Onset) Line of Evidence.

L.6.13 Historical Juvenile Salmonid Stranding

Annual total stranding of winter-run, fall-run, and steelhead was monitored by Pacific States Marine Fisheries Commission (PSMFC) and California Department of Fish and Wildlife in the Sacramento River during field seasons from 2012-2013 to 2020-2021 (Table L-17) and results are reported in annual reports (Revnak and Killam 2013; Jarrett and Killam 2014, 2015; Stompe et al. 2016; Revnak et al. 2017; Memeo et al. 2018, 2019; Smith et al. 2021; Chelberg and Greathouse 2022). Stranding efforts varied across field seasons, and a maximum of 269 potential unique stranding locations visited across 103 stranding surveys in the 2016–2017 field season. The 2020–2021 field season was affected by the pandemic and 4 potential unique stranding pools surveyed but number of surveys was not reported. Fish were recovered from pools using seines, which may not be suitable for use in all stranding pool environments (depending on depth, pool area, and presence of debris). When possible, the stranded fish were moved to the main river channel. In some years (e.g., 2016–2017) backpack electrofishing and dip nets were used for rescue efforts. Chinook were identified to race using Central Valley length-at-date criteria (Greene 1992). Starting in the 2018-2019 field season, a depletion removal method was used to generate a more accurate estimate of the number of fish stranded but not captured. Large stranding events from 2013-2014 to 2017-2018 were documented with associated dates and starting/ending flows (Table L-18); note that stranding surveys varied in timing across years (July–February in 2013–2014, August–April in 2014–2015, October–April in 2015–2016, November–May in 2016–2017, June–April in 2017–2018).

Table L-17. Juvenile Salmonid Stranding Counts on the Upper Sacramento River

Year	Species	Run	Effort (number of surveys)	Stranding Direct Count	Stranding Removal Estimate	Stranding Total Estimate
2020–2021	Chinook	Winter	NA	165	203	
2020–2021	Chinook	Fall	NA	17	17	
2020–2021	Chinook	Late-fall	NA	26	62	
2020–2021	*O. mykiss*	NA	NA	NA	NA	
2019–2020	Chinook	Winter	30	1472	1562	1598
2019–2020	Chinook	Fall	30	221	274	304
2019–2020	Chinook	Late-fall	30	93	92	101
2019–2020	*O. mykiss*	NA	30	NA	NA	NA
2018–2019	Chinook	Winter	83	7766	8729	9229
2018–2019	Chinook	Fall	83	5239	4399	6319
2018–2019	Chinook	Late-fall	83	5442	5448	5876
2018–2019	*O. mykiss*	NA	83	2043	NA	NA
2017–2018	Chinook	Winter	42	1092		
2017–2018	Chinook	Fall	42	7016		
2017–2018	Chinook	Late-fall	42	337		
2017–2018	*O. mykiss*	NA	42	857		
2016–2017	Chinook	Winter	103	240		
2016–2017	Chinook	Spring/fall/ late-fall	103	19892		
2016–2017	*O. mykiss*	NA	103	372		
2015–2016	Chinook	Winter	75	181		
2015–2016	Chinook	Fall	75	6748		
2015–2016	*O. mykiss*	NA	75	15		
2014–2015	Chinook	Winter	76	693		
2014–2015	Chinook	Fall	76	2143		
2014–2015	*O. mykiss*	NA	76	515		
2013–2014	Chinook	Winter	70	162		2298
2013–2014	Chinook	Fall	70	6389		10296
2013–2014	Chinook	Late-fall	70	NA		263
2013–2014	*O. mykiss*	NA	70	153		NA
2012–2013	Chinook	Winter	27	665		
2012–2013	Chinook	Fall	27	8165		

Table L-18. Observed Large Juvenile Stranding Events with Associated Dates and Flow

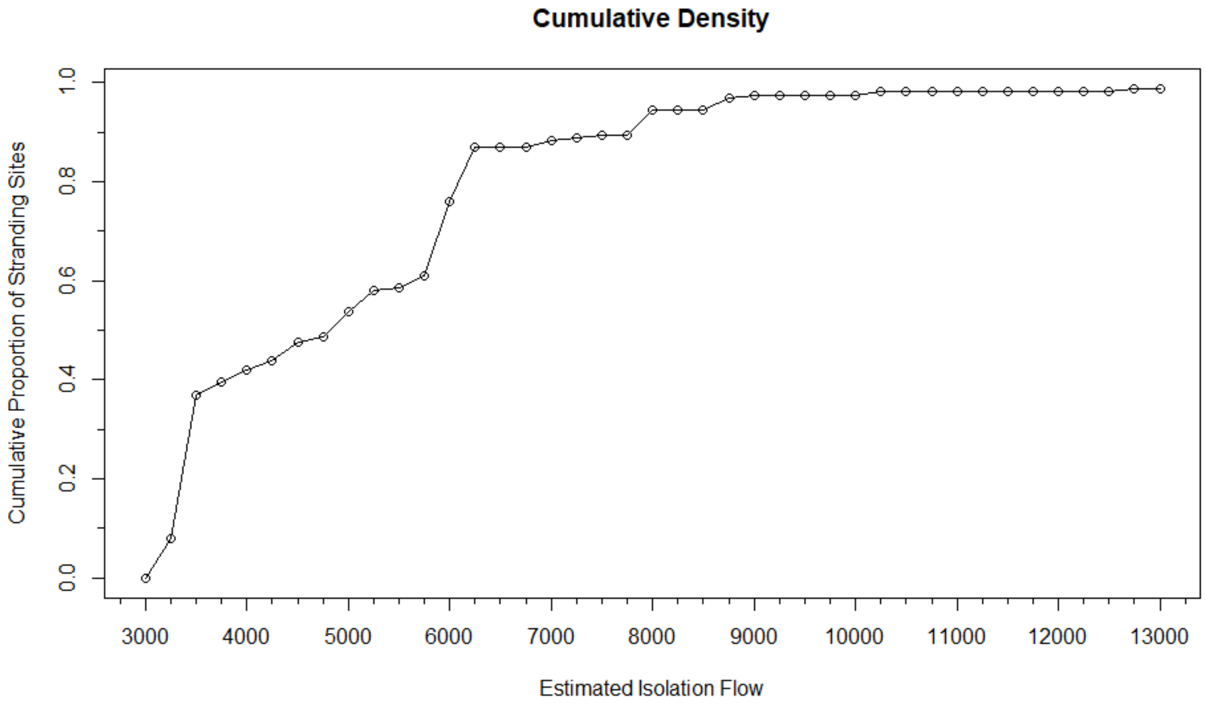
Year	Start Date	End Date	Starting Flow (cfs)	Ending Flow (cfs)	Count
2013–2014	8/1/2013	8/26/2013	13,000	9,000	284
2013–2014	10/30/2013	11/16/2013	6,900	3,800	1,793
2013–2014		1/5/2014		3,250	10,858
2014–2015	8/26/2014	9/5/2014	8,000	7,060	31
2014–2015	9/5/2014	9/27/2014	7,000	5,020	278
2014–2015	10/30/2014	11/11/2014	5,040	4,630	109
2014–2015	12/15/2014	1/30/2015	4,000	3,250	358
2014–2015	2/8/2015	2/11/2015	5,140	3,250	2,326
2015–2016	3/19/2016	3/29/2016	20,000	5,000	>9,000 [a]
2016–2017	2/14/2017	3/15/2017	82,100	8,500	>10,000 [a]
2017–2018	June	June	13,000	10,500	~100
2017–2018	August	August	10,500	9,000	0
2017–2018	October	October	9,000	8,000	~100
2017–2018	November	November	8,000	5,000	~1,000
2017–2018	February	February	5,000	3,250	~5,000
2017–2018	April	April	~35,000 [b]	~60,00 [b]	~3,000

cfs = cubic feet per second.

[a] Represents estimates of minimum.

[b] Represents BND rather than KWK flows.

Greater drops in flow are more likely to cause dewatering and juvenile stranding, but keeping flows above 3,750 cfs can help to avoid substantial juvenile stranding (U.S. Fish and Wildlife Service 2006), which is generally in agreement with the cumulative proportion of stranding sites from years 2014–2015 and 2019–2020 (Figure L-1). For each ESU, USFWS (2006) developed tables of the relationship between salmon spawning flows and redd development flows to show percentage of total redds dewatered if the development flows are less than the spawning flows. Flows at the time of spawning in relation to the flows experienced during the end of the dewatering period influence potential dewatering risks, and these flows are set seasonally and in real-time. With lower late October and early November flows, fall-run Chinook salmon are less likely to spawn in shallow areas that would be subject to dewatering during winter base flows. Early reductions (late October–early November) could balance the potential for dewatering late spawning winter-run Chinook salmon redds and early fall-run Chinook salmon dewatering.



Based on 2014–2015 and 2019–2020 years of Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife stranding monitoring data. Note that isolation flows are estimates because it is not currently feasible to visit all sites immediately after a flow change, especially in years where the flow regime drops every day.

Figure L-20. Number of Juvenile Stranding Sites Observed at Various Isolation Flows

L.6.14 Historical Winter-run Redd Dewatering

Annual redd dewatering of winter-run chinook salmon was monitored by PSMFC and California Department of Fish and Wildlife in the Sacramento River during field seasons from 2012-2013 to 2021-2022 and results are reported in annual reports (Revnak and Killam 2013; Jarrett and Killam 2014, 2015; Stompe et al. 2016; Revnak et al. 2017; Memeo et al. 2018, 2019; Smith et al. 2021; Chelberg and Greathouse 2022). In most years, a small group of shallow redds at risk of dewatering were surveyed intensively. In 2018-2019, gravel removal was used to improve conditions at three critically endangered redds, with the result that only one of the three was dewatered. Monitoring of shallow redds over the past decade has observed between 0 and 28 dewatered redds (Table L-19), representing 0.7% or less of winter-run Chinook salmon redds (mean 0.13% ± 0.002% SD).

Table L-19. Winter-run Sacramento River Chinook Salmon Redd Dewatering, 2013–2022

Year	Dewatered Redds
2013–2014	5
2014–2015	1
2015–2016	0

Year	Dewatered Redds
2016–2017	0
2017–2018	0
2018–2019	1
2019–2020	5
2020–2021	28
2021–2022	4

L.6.15 Redd Dewatering Analysis

The redd dewatering analyses for the Sacramento River is based on the maximum reduction in flow from the initial flow, or *spawning flow*, that occurs during the incubation period of embryos (fertilized egg and alevin) to fry emergence. This period may vary from about two to three months, depending primarily on water temperature (Bratovitch et al. 2017). The minimum flow of the incubation period is referred to herein as the *dewatering flow*. If all flows during the incubation/development period are greater than or equal to the spawning flow, no dewatering is assumed to occur.

L.6.15.1 Upper Sacramento

USFWS (2006) conducted redd dewatering studies in the Sacramento River from Keswick Dam to Battle Creek for Chinook salmon and steelhead. The redd dewatering analyses estimate the percentage of redds dewatered as the percentage of spawning weighted usable area (WUA) present at the spawning flow that, at the dewatering flow, is dewatered or becomes too shallow to maintain adequate intragravel flow to sustain embryo survival (U.S. Fish and Wildlife Service 2006). The Chinook salmon included in this study were winter-run, fall-run, and late fall–run, but not spring-run. As was done for the WUA studies described above, the fall-run salmon results were used to estimate spring-run redd dewatering. The studies developed lookup tables providing the percentage of redds dewatered for any pair of spawning and dewatering flows for each Chinook salmon race or steelhead.

L.6.16 Battle Creek and McCloud TDM

TDM of winter-run Chinook salmon egg and alevin can limit the success of reintroduction into historical spawning habitat, including the McCloud River and Battle Creek. We used daily temperature data collected from the Nature Conservancy Compound on the McCloud River (approximately 5 miles downstream of McCloud Dam; 1998–2021), from the Below North Fork Feeder Dam station on Battle Creek (2001–2022), and from the Reclamation temperature gauge in the Sacramento River above Clear Creek (below Keswick Dam; 1998–2022), in combination with redd survey data collected during the same years downstream of Keswick Dam, to compare expected TDM among sites and years. Estimates of TDM are presented in Table L-20. No estimates of TDM are presented for McCloud River in 1998, 2006, 2007, 2010, 2013, 2017, 2020, and 2022 due to large gaps in data availability.

We are assessing the use of temperature data from other stations on Battle Creek to better reflect conditions experienced by observed redds (e.g., below Baldwin Creek, above North Fork Feeder Dam, and Coleman Canal at top), but have not updated the results below yet. Where reasonable, we filled in missing daily data using the average of the nearest preceding and proceeding temperatures; missing data most often occurred in the McCloud River. We estimated TDM using both the stage-dependent and stage-independent models and default parameters available on SacPAS (SacPAS Central Valley Prediction and Assessment of Salmon (washington.edu)) (Martin et al. 2017; Anderson et al. 2022).

Estimated TDM was consistently similar or greater in the Sacramento River above Clear Creek relative to the McCloud River and appeared to increase starting in the late 2000's. Estimated TDM was highest in the North Fork of Battle Creek. Stage-dependent estimates of TDM tended to exceed stage-independent estimates.

Table L-20. Estimates of Historical Temperature-Dependent Mortality based on Site-Specific Temperature Data and Temporal Redd Distribution Data from the McCloud River (Nature Conservancy Compound), Sacramento River (below Keswick Dam), North Fork Battle Creek (Below Feeder Dam)

Year	Temperature-Dependent Mortality					
	McCloud River		Below Keswick Dam		Battle Creek	
	Stage-independent	Stage-dependent	Stage-independent	Stage-dependent	Stage-dependent	Stage-independent
1998			0.001	0		
1999	0.035	0.128	0	0		
2000	0.017	0.034	0.015	0.03		
2001	0.133	0.413	0.055	0.081	0.95	0.905
2002	0.452	0.497	0.006	0.011	0.947	0.899
2003	0.09	0.128	0.054	0.06	0.957	0.905
2005	0	0.015	0.153	0.128	0.929	0.88
2006			0	0		
2007			0.106	0.244		
2008	0.057	0.005	0.661	0.603		
2009	0.087	0.28	0.591	0.664	0.979	0.954
2010			0	0	0.958	0.948
2011	0	0.012	0	0	0.985	0.907
2012	0	0.022	0	0.016	0.963	0.882
2013			0.416	0.57	0.926	0.875
2014	0.093	0.289	0.914	0.926	0.967	0.928
2015	0.056	0.216	0.954	0.972	0.982	0.955

Year	Temperature-Dependent Mortality					
	McCloud River		Below Keswick Dam		Battle Creek	
	Stage-independent	Stage-dependent	Stage-independent	Stage-dependent	Stage-dependent	Stage-independent
2016	0.041	0.143	0.008	0.032	0.961	0.904
2017			0	0	0.943	0.946
2018	0.059	0.115	0.007	0.156	0.998	0.988
2019	0	0	0.001	0.007	0.988	0.964
2020			0.148	0.416	0.981	0.966
2021	0.18	0.271	0.901	0.895	0.961	0.913
2022			0.803	0.842	0.98	0.954

L.6.17 SacSalMort and Reclamation Egg Mortality Models

L.6.18 IOS

IOS results are provided in Attachment F.5, *Interactive Object-oriented Simulation Model.*

L.6.19 OBAN

L.7 Uncertainty

L.7.1 Egg Incubation Study Plan

With respect to evaluation of egg TDM, several aspects of existing TDM models make forecasting TDM under proposed or modeled temperature conditions difficult, and especially forecasting estimates of TDM along with estimates of model uncertainty. Existing TDM models (e.g., Martin et al. 2017; Anderson et al. 2022) were developed using estimates of egg-to-fry survival, not egg survival, and thus were not intended for forecasting egg-based TDM specifically. Furthermore, reported difficulty in model fitting and covariance among parameter values (i.e., especially covariance among TDM and fry survival terms) makes propagation of model uncertainty using variability in estimated parameter values challenging. Finally, no environmental covariates other than temperature were included in model fitting or comparison, such that temperature effects in these models may be incidentally capturing influences of other environmental conditions.

A special study plan that examines egg incubation mortality in the field could address the uncertainty and challenges associated with existing TDM models. Reclamation developed a special study plan to answer, in part, the following research questions: 1) What are baseline estimates of winter-run Chinook salmon egg and alevin survival in the field, and 2) How do temperature and other environmental factors influence egg and alevin survival. The proposed experimental design includes the use of artificial redds and streamside egg incubators at multiple sites in and along the Upper Sacramento River to examine variability in egg survival. Data on environmental conditions, including temperature, dissolved oxygen, interstitial flow velocity, and infiltration of fine sediments, will be collected at each redd/incubator. When 50% of juveniles are expected to have emerged for each redd and incubator, the redd or incubator will be opened, and survival will be enumerated through counts of unhatched eggs, dead alevin, and live alevin. Effects of environmental conditions on survival will be evaluated using generalized linear modeling with a binomial error distribution. Alternative methods of modeling temperature effects on survival can also be explored, including the estimation of critical temperature (i.e., as estimated in Martin et al. 2017), by building and fitting custom models using optimization or Bayesian methods. Expected outcomes from the research include an improved understanding of winter-run Chinook salmon embryonic survival and models capable of forecasting egg survival, along with its accompanying uncertainty, as a function of environmental attributes. The new models may be used alongside or combined with existing TDM models to evaluate effects of operations.

L.8 References

L.8.1 Printed References

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L.8.2 Personal Communications

Hendrix pers. comm.