BUREAU OF RECLAMATION

Long-Term Operation – Biological Assessment

Chapter 5 – Winter-Run Chinook Salmon

Central Valley Project, California

Interior Region 10 – California-Great Basin

U.S. Department of the Interior

November 2023

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Long-Term Operation – Biological Assessment

Chapter 5 – Winter-Run Chinook Salmon

Central Valley Project, California

Interior Region 10 – California-Great Basin

Contents

Tables

Figures

Chapter 5 Winter-Run Chinook Salmon

The federally listed Evolutionarily Significant Unit (ESU) of Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*) and designated critical habitat occurs in the action area and may be affected by the Proposed Action. Winter-run Chinook salmon exhibit a life-history strategy found nowhere else in the world. Adult winter-run Chinook salmon return to their natal tributary in the winter and spawn during the summer months when air temperatures usually approach their warmest. The last remaining natural spawning area for winter-run Chinook salmon is located on the upper Sacramento River downstream of Keswick Dam. As a result, the natural population of winter-run Chinook salmon depend entirely upon coldwater releases from Shasta Dam to protect incubating eggs from warm ambient conditions.

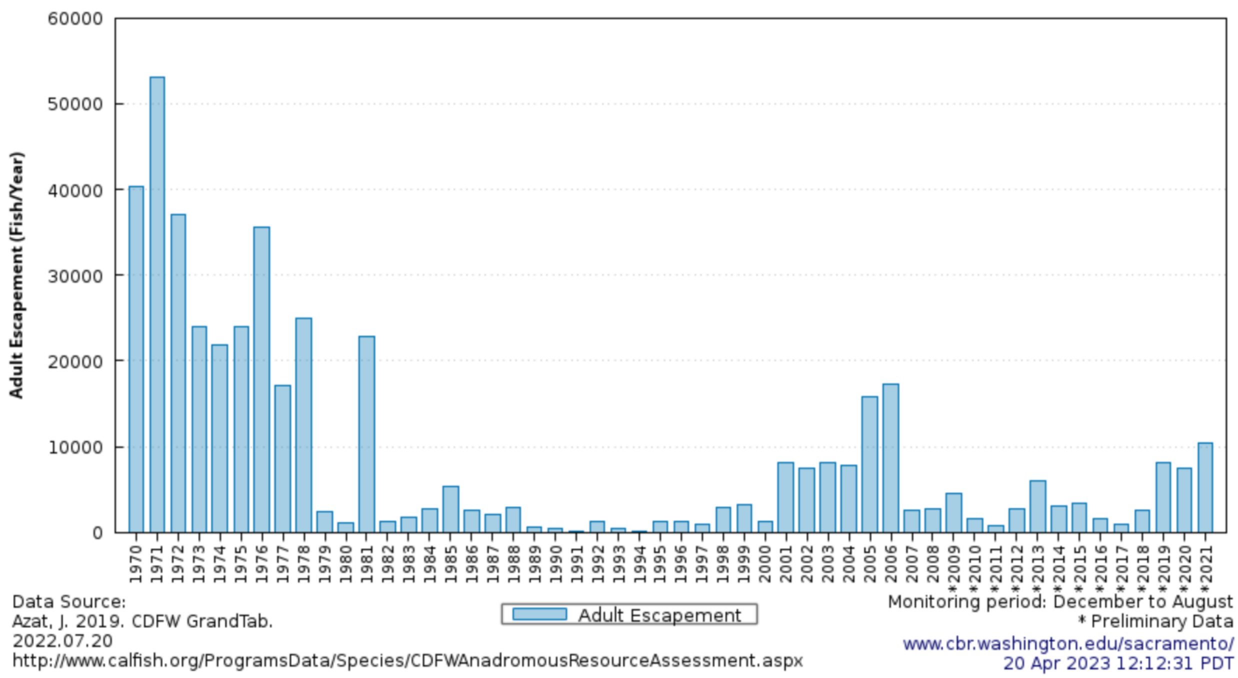
5.1 Status of Species and Critical Habitat

National Marine Fisheries Service (NMFS) first listed Sacramento River winter-run Chinook salmon as threatened on August 4, 1989 (54 *Federal Register* [FR] 32085). NMFS reclassified Sacramento River winter-run Chinook salmon as endangered on January 4, 1994 (59 FR 440); reaffirmed as endangered on June 28, 2005 (70 FR 37160); and reaffirmed as endangered on May 26, 2016 (81 FR 33468). NMFS designated critical habitat for Sacramento River winter-run Chinook salmon on June 16, 1993 (58 FR 33212).

5.1.1 Distribution and Abundance

Winter-run Chinook salmon historically spawned in the high elevation spring-fed streams upstream of Shasta Dam and Reservoir. The distribution of winter-run Chinook salmon spawning and initial rearing historically included the upper Sacramento River (upstream of Shasta Dam), McCloud River, Pitt River, and Battle Creek, where springs provided cold water throughout the summer (Yoshiyama et al. 1998). The construction of Shasta Dam in 1943 blocked access to all these waters except Battle Creek, which also had non-CVP impediments to upstream migration from small hydroelectric dams situated upstream of the Coleman National Fish Hatchery weir. A natural passage barrier created by large boulders in the channel blocks passage below Eagle Canyon Dam. The fish from these populations above Shasta Dam now only spawn as one population downstream of Keswick Dam on the Sacramento River and in the Livingston-Stone National Fish Hatchery. The single wild population of winter-run Chinook salmon has been entirely supported by coldwater management operations at Shasta Dam and through supplementation from the Livingston-Stone National Fish Hatchery. The population of winter-run Chinook salmon in Battle Creek varied between 127 and 942 fish in the last three years.

Winter-run Chinook salmon population estimates were as high as 120,000 fish in the 1960s, but declined to less than 200 fish by the 1990s (National Marine Fisheries Service 2011). During 1970-2021, the highest escapement values were seen in the early 1970s, followed by low values in the early 1990s, increases in the early 2000s, and varying between ~1,000 and ~10,000 individuals since 2007 (Figure 5-1). The period of 1967-1991 defines the “doubling goal” under the Central Valley Project Improvement Act, which targets 110,000 winter-run Chinook salmon. Since 2001, the majority of winter-run Chinook salmon redds have occurred in the first 10 miles downstream of Keswick Dam. Spawning females construct redds, or a protective rock nest, for their eggs.

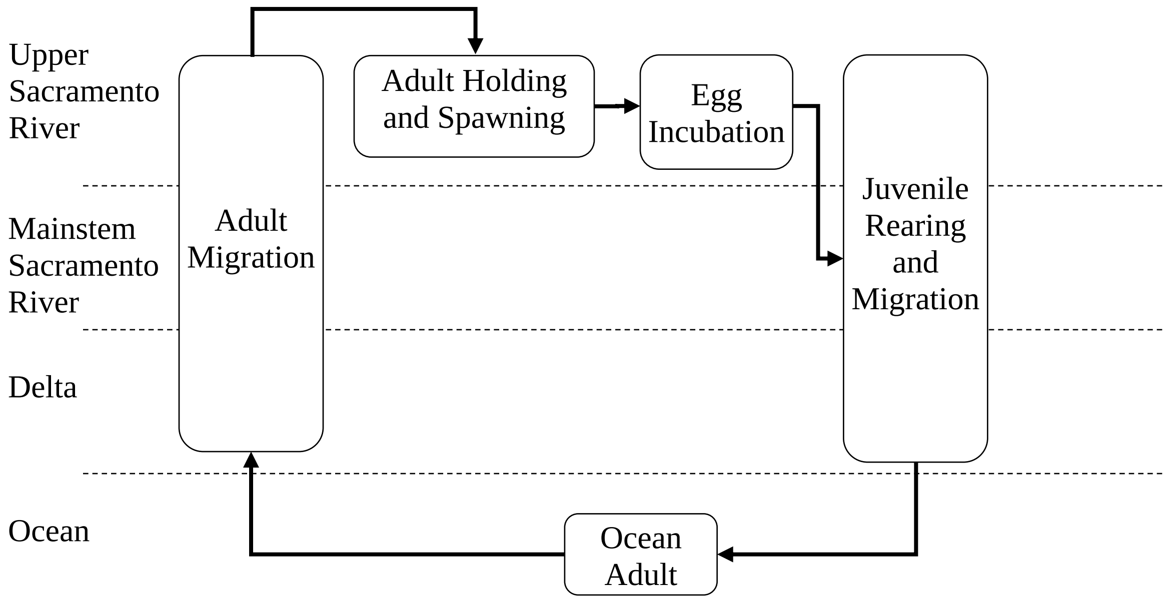


Source: Columbia Basin Research, University of Washington 2023. Note: Includes in-river and hatchery fish.

Figure 5-1. Winter-Run Chinook Salmon Adult Annual Escapement in the Central Valley, 1970–2021.

5.1.2 Life History and Habitat Requirements

The Salmon and Sturgeon Assessment of Indicators by Lifestage (SAIL) conceptual model (Windell et al. 2017) describes life stages and geographic locations for winter-run Chinook salmon (Figure 5-2).



Source: Adapted from Windell et al. 2017, Figure 2).

Figure 5-2. Geographic Life Stage Domains for Winter-Run Chinook Salmon.

Adult winter-run Chinook salmon return from the ocean in the winter and migrate through the Bay-Delta and up the mainstem Sacramento River to reach the upper Sacramento River below Keswick Dam. Adults hold in the upper Sacramento River until spawning in the summer. Eggs incubate in the summer and then fry emerge and juvenile winter-run Chinook salmon migrate downstream through the Delta and to the Pacific Ocean. Monitoring data from snorkeling, carcass surveys, redd surveys, rotary screw traps, trawls, and beach seines describe the timing of winter-run Chinook salmon presence for different life stages (Figure 5-2, Figure 5-3).

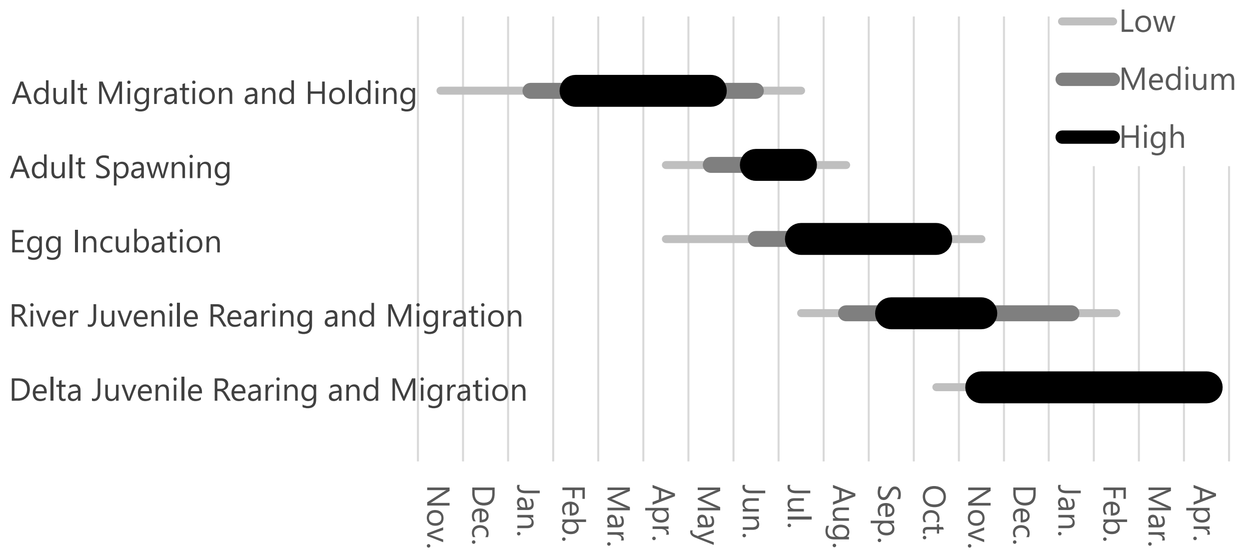


Figure 5-3. Temporal Life Stage Domains for Winter-Run Chinook Salmon

Sacramento River winter-run Chinook salmon spawn during the summer months when air temperatures usually approach their warmest. As a result, winter-run Chinook salmon require stream reaches with coldwater sources to protect their incubating eggs from the warm ambient conditions. While spawning and egg incubation water temperatures are the most critical, Table 5-1 summarizes the water quality requirements identified for analyzing stressors including temperature, dissolved oxygen, and contaminants.

Table 5-1. Chinook Salmon Water Quality Requirements.

Life Stage	**Temperature**	**Dissolved Oxygen (mg/L)**
Adult Migration	37.9°F–68°F (3.3°C–20°C)9, 10, 11	5.0
Spawning Initiation	42.1°F–55°F (5.6°C–12.8°C)10	5.0
Egg/Alevin	42.8°F–56°F (6°C–13.3°C)1, 2, 3,4, 5	5.5
Juvenile Migration	62.6°F–68°F (17°C–20°C)3, 6, 7	5.0
Smolt Migration	55.4°F–60.8°F (13°C–16°C)7, 8	5.0

Sources: Slater 1963; U.S. Fish and Wildlife Service 1999; Myrick and Cech 2004; Bratovich et al. 2012; Martin et al. 2017; Myrick and Cech 2001; Marine and Cech 2004; Clark and Shelbourn 1985; Reiser and Bjornn 1979; McCullough 1999; Goniea et al. 2006.

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

°C = degrees Celsius; °F = degrees Fahrenheit

Suitable water temperatures for adult winter-run Chinook salmon migrating upstream to spawning grounds range from 57 degrees Fahrenheit (°F) to 67°F (National Marine Fisheries Service 1997). However, winter-run Chinook salmon are immature when upstream migration begins and need to hold in suitable habitat for several months prior to spawning. The maximum suitable water temperature reported for holding is 59°F to 60°F (National Marine Fisheries Service 1997).

Adult Chinook salmon reportedly require water deeper than 0.8 feet and water velocities less than 8 feet per second (ft/sec) for successful upstream migration (Thompson 1972). Chinook salmon generally hold in pools with deep, cool, well-oxygenated water. Holding pools for adult Chinook salmon have reportedly been characterized as having moderate water velocities ranging from 0.5 to 1.3 ft/sec (California Department of Water Resources 2000).

Chinook salmon spawn in clean, loose gravel, in swift, relatively shallow riffles, or along the margins of deeper river reaches where suitable water temperatures, depths, and velocities favor redd construction and oxygenation of incubating eggs. Winter-run Chinook salmon were adapted for spawning and rearing in the clear, spring-fed rivers of the upper Sacramento River Basin, where summer water temperatures were typically 50°F to 59°F. Chinook salmon require clean loose gravel from 0.75 to 4.0 inches in diameter for successful spawning (National Marine Fisheries Service 1997). Moyle (2002) reported that water velocity preferences (i.e., suitability greater than 0.5) for Chinook salmon spawning range from 0.98 ft/sec to 2.6 ft/sec (0.3 to 0.8 meters per second (m/sec)) at a depth of a few centimeters (cm) to several meters (m), whereas U.S. Fish and Wildlife Service (USFWS) (2003) reported that winter-run Chinook salmon prefer water velocities range from 1.54 ft/sec to 4.10 ft/sec (0.47 to 1.25 meters per second).

Physical habitat requirements for embryo incubation are the same as the requirements discussed above for spawning. However, it is also important that flow regimes remain relatively constant or at least not decrease significantly during the embryo incubation life stage to maintain sufficient flow of oxygen across the membrane for successful incubation.

Upon emergence from the gravel, fry swim or are displaced downstream (Healey 1991). Fry seek streamside habitats containing beneficial aspects such as riparian vegetation and associated substrates that provide aquatic and terrestrial invertebrates for food, predator avoidance cover, and slower water velocities for resting (National Marine Fisheries Service 1996). As juvenile Chinook salmon grow they move into deeper water with higher current velocities, but still seek shelter and velocity refugia to minimize energy expenditures (Healey 1991). As Chinook salmon begin the smoltification stage, they are found rearing further downstream where ambient salinity reaches 1.5 to 2.5 parts per thousand (Healey 1979). Within the Sacramento–San Joaquin Delta (Delta), juvenile Chinook salmon forage in shallow areas with protective cover, such as tidally influenced sandy beaches and vegetated zones (Healey 1979). Cladocerans, copepods, amphipods, and larvae of diptera, as well as small arachnids and ants are common prey items (Kjelson et al. 1981; MacFarlane and Norton 2002; Sommer et al. 2001a).

5.1.3 Limiting Factors, Threats, and Stressors

The greatest risk factor for winter-run Chinook salmon lies within its spatial structure (National Marine Fisheries Service 2011). The winter-run Chinook salmon ESU comprises only one population that spawns below Keswick Dam. The remnant and remaining population cannot access 95 percent of their historical spawning habitat and must, therefore, be artificially maintained in the Sacramento River by spawning gravel augmentation, hatchery supplementation, and regulation of the finite coldwater pool behind Shasta Dam to reduce water temperatures. The fact that this ESU is comprised of a single population with very limited spawning and rearing habitat increases its risk of extinction due to a potential local catastrophe or poor environmental conditions. There are no other natural populations in the ESU to buffer it from natural fluctuations (National Marine Fisheries Service 2014). Chief among the threats facing winter-run Chinook salmon is small population size (National Marine Fisheries Service 2014). From 2007 to 2017, the population has shown a precipitous decline, averaging 2,733 during this period, with a low of 827 adults in 2011 (California Department of Fish and Wildlife 2018). This recent declining trend is likely due to a combination of factors such as poor ocean productivity (Lindley et al. 2009), drought conditions from 2007 to 2009, low in-river survival (National Marine Fisheries Service 2011), and extreme drought conditions in 2012 to 2016 (National Marine Fisheries Service 2016).

Although the Livingston Stone National Fish Hatchery (LSNFH) winter-run Chinook salmon program is one of the most important reasons that the species still persists, the use of a hatchery program to supplement the population raises concerns about the genetic integrity and fitness of the population (National Marine Fisheries Service 2014). High extinction risk for the population was triggered by the hatchery influence criterion, with a mean of 66 percent hatchery origin spawners from 2016 through 2018. The threshold for high risk associated with hatchery influence is 50 percent hatchery origin spawners (National Marine Fisheries Service 2019).

Specific to the operation of the CVP, water temperature management has improved since the time when the ESU was listed, although warm water temperatures in the Sacramento River downstream of Keswick Dam remain a concern, particularly in drier years. Drought is a threat to winter-run Chinook salmon, and after two years of drought, the coldwater pool in Shasta Reservoir is impacted. When there is insufficient coldwater temperature throughout the winter-run Chinook salmon spawning and embryo incubation season, this may result in partial or complete year class failure. Winter-run Chinook salmon embryonic and larval life stages that are most vulnerable to warmer water temperatures occur during the summer, thus, this run is particularly at risk from climate warming. Water exports in the south Delta are a threat to winter-run Chinook salmon (National Marine Fisheries Service 2014). Juvenile winter-run Chinook salmon from the Sacramento River basin have been observed in salvage at the Tracy Fish Collection Facility and Skinner Delta Fish Protective Facility in the south Delta, indicating that juvenile winter-run Chinook salmon have the potential to be present in the waterways leading to these facilities.

To understand the CVP and SWP stressors on fish, SAIL models describe linkages between landscape attributes and environmental drivers to habitat attributes that may affect fish (stressors) based on life stage. The SAIL models provide life stages and stressors of adult migration, adult holding and spawning, egg incubation to fry emergence, and juvenile rearing to outmigrating. Each stressor is briefly summarized from Windell et al. 2017:

- **Adult Migration**
  - In-river fishery and poaching: Targeted (poaching) or incidental hooking of winter-run Chinook salmon due to in-river fishing has a direct influence on adult survival during migration and can also function to delay migration.
  - Toxicity from contaminants: Urban stormwater, agricultural runoff, past mining activities. The condition of migrating adults, as well as water quality and toxicity can influence their exposure and susceptibility to disease, olfactory navigation cues, and migration success. There remains uncertainty associated with determining the impacts of operations on the toxicity from contaminants stressor, particularly for impacts in the Delta.
  - Stranding risk: Water operations can influence the routing of upper Sacramento River-origin water through agricultural fields into drainage canals and can create false attraction cues that cause salmon to deviate from the mainstem Sacramento River migration corridor and become stranded in agricultural fields behind flood bypass weirs.
  - Water temperature: Water quality influences their exposure and susceptibility to disease, olfactory navigation cues, and migration success.
  - Dissolved oxygen: Water quality influences their exposure and susceptibility to disease, olfactory navigation cues, and migration success.
  - Pathogens: The condition of migrating adults, as well as water quality and toxicity can influence their exposure and susceptibility to disease, olfactory navigation cues, and migration success.
  - Competition, introgression, and broodstock removal: Returning adult hatchery fish can influence natural adult spawners either through competition or genetic introgression. When mortality is high for natural-origin juveniles (e.g., drought years), increasing hatchery production may elevate the overall extinction risk due to genetic impacts of hatchery introgression due to the return of a disproportionately large number of hatchery adults.
- **Adult Holding and Spawning**
  - In-river fishery or poaching: Human activities such as poaching and harassment that temporarily or permanently displace fish from holding or spawning areas, can reduce energy reserves needed for survival or successful spawning in preferred habitats (Cooke et al. 2012).
  - Toxicity from contaminants: Contaminant loading of heavy metals from mines such as Iron Mountain Mine, or oil and other toxins from non-point sources such as stormwater runoff, have been identified as stressors that reduce spawning success or cause mortality. There remains uncertainty associated with determining the impacts of operations on the toxicity from contaminants stressor, particularly for impacts in the Delta.

- Stranding risk: Water operations can influence the routing of upper Sacramento River-origin water through agricultural fields into drainage canals and can create false attraction cues that cause salmon to deviate from the mainstem Sacramento River migration corridor and become stranded in agricultural fields behind flood bypass weirs.
- Water temperature: Warm water temperatures generally decrease dissolved oxygen (DO), increase physiological stress and metabolic rates.
- Pathogens and disease: Warm water temperatures generally decrease DO, and decrease immune responses to pathogens. Decreased flows can concentrate fish within a smaller habitat area, and fish densities increase the potential for lateral transmission of disease and pre-spawn mortality becomes higher.
- Dissolved oxygen: Warm water temperatures generally decrease DO, increasing physiological stress and metabolic rates.
- Spawning habitat: Returning adult hatchery fish can influence natural adult spawners through competition for spawning habitat.
- Competition, introgression, and broodstock removal: Returning adult hatchery fish can influence natural adult spawners either through competition or genetic introgression. When mortality is high for natural-origin juveniles (e.g., drought years), increasing hatchery production may elevate the overall extinction risk due to genetic impacts of hatchery introgression due to the return of a disproportionately large number of hatchery adults.

- **Eggs Incubation to Fry Emergence**
    - In-river fishery and trampling: Human activity, such as recreational fishing, could also negatively impair redds due to disturbances such as trampling.
    - Toxicity and contaminants: Disease and contaminants affect the survival of eggs and the condition of emerging fry. There remains uncertainty associated with determining the impacts of operations on the toxicity and contaminants stressor, particularly for impacts in the Delta.
    - Stranding and dewatering: If flows decrease substantially after adult spawning has occurred, redds face the risk of stranding (when the surface of the redd is above the surface of the water and the redds become disconnected from the main channel) and dewatering (when the water surface drops below the redd).
    - Water temperature: Water temperature affects the rate of development of embryos and alevins.
    - Dissolved oxygen: Dissolved oxygen within the stream has been positively correlated with Chinook salmon larval growth.
    - Pathogens: Pathogens, disease, and contaminants affect the survival of eggs and the condition of emerging fry.

- Sedimentation and gravel quantity: The deposition of fine sediment can affect egg survival, compromising an embryo's ability to acquire oxygen and dispose of metabolic waste, potentially resulting in stunted embryo and alevin development. Gravel augmentation projects increase the availability of suitable spawning habitat.
- Redd quality: Redd quality is affected by gravel size and composition, flow, temperature, dissolved oxygen, contaminants, sedimentation, and pathogens and diseases.
- Predation risk: Native and non-native fish that predate on salmon eggs are present in this portion of the river. Water temperature can also impact the predation rate on eggs, embryos, and fry because predator metabolic demands increase with temperature.

- **Juvenile Rearing to Outmigration**
    - Toxicity and contaminants: Urban stormwater and agricultural runoff may be contaminated with pesticides, herbicides, oil, grease, heavy metals, polycyclic aromatic hydrocarbons, and other organics and nutrients that potentially have direct lethal and sub-lethal physiological and behavioral effects on fry and destroy the aquatic life necessary for salmonid growth and survival. Acid mine drainage still escapes untreated from waste piles and seepage on the north side of Iron Mountain, which eventually flows into the Sacramento River. There remains uncertainty associated with determining the impacts of operations on the toxicity and contaminants stressor, particularly for impacts in the Delta.
    - Stranding risk: Significant flow reductions present a stranding risk to juveniles.
    - Outmigration cues: Storage of unimpeded runoff by Shasta and Keswick dams and the use of stored water for irrigation and export have altered the natural hydrograph by which winter-run Chinook salmon base their migrations.
    - Water temperature and DO: Fry are confined to the low-elevation habitats on the Sacramento River that are dependent on coldwater releases from Shasta Dam to sustain the remnant population.
    - Pathogens and disease: Specific diseases such as C-shasta (*Ceratomyxosis shasta*), columnaris, furunculosis, and infectious hematopoietic necrosis virus, among others are known to affect juvenile winter-run Chinook salmon survival in the Sacramento River (National Marine Fisheries Service 1997).
    - Entrainment risk: Unscreened or poorly screened water diversions lead to direct entrainment and mortality and can also reduce river flow.
    - Refuge habitat: Altered flows have resulted in diminished natural channel formation, and slower regeneration of riparian vegetation. Channelized, leveed, and riprapped reaches typically have low habitat complexity.

- Food availability and quality: Altered flows have resulted in altered food web processes. Channelized, leveed, and riprapped reaches typically have low abundance of food organisms.
- Predation and competition: Channelized, leveed, and riprapped reaches typically offer little protection from predators. Water-diversion infrastructures provide in-river structure that support predation on winter-run Chinook salmon fry by native and non-native fishes.

In addition to the operation of the CVP and SWP, the following stressors have been identified.

- In the years following the Endangered Species Act listing of winter-run Chinook salmon, more information on the impacts of the ocean fisheries on the ESU became available, and it was recognized that the fisheries may play a greater role in the viability of the ESU than previously thought (National Marine Fisheries Service 2014)
- Poor ocean productivity (Lindley et al. 2009)
- 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)

Climate change is likely to result in additional hydrologic changes with warmer air temperatures and more precipitation as rain than snow.

5.1.4 Management Activities

In 2014, NMFS published the *Recovery Plan for the Evolutionary Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead* (National Marine Fisheries Service 2014). The Recovery Plan identifies recovery goals, objectives, and criteria for delisting these Central Valley salmonids. Recovery actions include locations in the Pacific Ocean, San Francisco, San Pablo, and Suisun Bays, the Delta, the Central Valley, the Sacramento River, and Battle Creek.

5.1.4.1 Recovery Plan Activities Related to the Long-Term Operation of the Central Valley Project and State Water Project

The following recovery and research focused management activities, identified in the 2014 Recovery Plan, are focused on winter-run Chinook salmon, spring-run Chinook salmon, and Central Valley steelhead, and are associated with the operation of the CVP and SWP or related facilities. Actions involving winter-run Chinook salmon are listed below by watershed.

- **Central Valley**
  - Maintain remedial actions to reduce heavy metal containments from Iron Mountain Mine. This ongoing activity is concurrent but separate from this Consultation.
  - Evaluate and reduce stranding of juvenile Chinook salmon in side-channels in the reach from Keswick Dam to Colusa, due to flow reductions from Keswick Reservoir, by increasing or stabilizing releases from the reservoir. This ongoing activity is concurrent but separate from this Consultation.
  - Continue to implement and improve comprehensive Chinook salmon monitoring to assess the viability of winter-run and spring-run Chinook salmon. This ongoing activity is concurrent but separate from this Consultation.
- **Sacramento River**
  - Install NMFS-approved, state-of-the-art fish screens at the Tehama Colusa Canal diversion. Implement term and condition 4c from the Biological Opinion on the Red Bluff Pumping Plant Project, which calls for monitoring, evaluating, and adaptively managing the new fish screens at the Tehama Colusa Canal diversion to ensure the screens are working properly and impacts to listed species are minimized (National Marine Fisheries Service 2009c). This activity was completed in 2013.
  - Develop and implement a river flow management plan for the Sacramento River downstream of Shasta and Keswick dams that considers the effects of climate change and balances beneficial uses with the flow and water temperature needs of winter-run Chinook salmon, spring-run Chinook salmon, and steelhead. The flow management plan should consider the importance of instream flows as well as the need for floodplain inundation (Williams et al. 2009). This ongoing activity is part of operations and addressed in this consultation.
  - Operate and maintain temperature control curtains in Lewiston and Whiskeytown Reservoirs to minimize warming of water from the Trinity River and Clear Creek. This is an authorized project feature that does not have discretionary operation.
- **Delta**
  - Modify Delta Cross Channel gate operations and evaluate methods to control access to Georgiana Slough and other migration routes into the Interior Delta to reduce diversion of listed juvenile fish from the Sacramento River and the San Joaquin River (SJR) into the southern or central Delta (National Marine Fisheries Service 2009b). This ongoing activity is part of operations and is addressed in this consultation.
  - Provide pulse flows of approximately 17,000 cubic feet per second (cfs) or higher as measured at Freeport periodically during the winter-run Chinook salmon emigration season (i.e., December-April) to facilitate outmigration past Chipps Island. This ongoing activity is part of operations and addressed in this consultation.

    - Develop, implement, and enforce new Delta flow objectives that mimic historic natural flow characteristics, including increased freshwater flows (from both the Sacramento and San Joaquin rivers) into and through the Delta and more natural seasonal and interannual variability. This ongoing activity is part of operations and addressed in this consultation.
    - Reduce hydrodynamic and biological impacts of exporting water through Jones and Banks pumping plants. This ongoing activity is part of operations and addressed in this consultation.
    - Continue to operate the Suisun Marsh Salinity Control Structure with the boat lock open in order to allow fish passage in and out of Suisun Marsh. This ongoing activity is part of operations and addressed in this consultation.
    - Minimize the frequency, magnitude, and duration of reverse flows in Old and Middle River (OMR) to reduce the likelihood that fish will be diverted from the San Joaquin or Sacramento rivers into the southern or central Delta (National Marine Fisheries Service 2009b). This ongoing activity is part of operations and addressed in this consultation.
    - Through additional releases in the San Joaquin River system, augment flows in the southern Delta and curtail exports during critical migration periods (April-May), consistent with a ratio or similar approach. Operation of New Melones Reservoir is ongoing and part of operations addressed in this consultation.
    - Curtail exports when protected fish are observed at the export facilities to reduce mortality from entrainment and salvage (National Marine Fisheries Service 2009b). This ongoing activity is part of operations and addressed in this consultation.
    - Improve fish screening and salvage operations to reduce mortality from entrainment and salvage (National Marine Fisheries Service 2009b). This ongoing activity is part of operations and addressed in this consultation.
- **San Francisco, San Pablo, Suisun Bays**
    - Improve the timing and extent of freshwater flow to the San Francisco Bay region to the benefit of juvenile and adult salmonids by modifying water operations in the Central Valley to support flows that mimic the natural hydrograph. SWP operations within the Delta and CVP operations and part of operations addressed in this consultation.

5.1.4.2 Other Recovery Plan Activities

Additional recovery and research focused management activities identified in the 2014 Recovery Plan (National Marine Fisheries Service 2014) do not involve the operation of the CVP, SWP nor related facilities. Some of these actions fall within additional U.S. Department of the Interior Bureau of Reclamation (Reclamation) and the California Department of Water Resources (DWR) authorities to contribute to the recovery of listed species as projects and programs with their own administration and consultation processes.

- **Central Valley**
    - Develop and implement an ecosystem-based management approach that integrates harvest, hatchery, habitat, and water management, in consideration of ocean conditions and climate change (Lindley et al. 2009).
    - Establish partnerships and agreements that promote water transactions, water transfers, shared storage, and integrated operations that benefit both species needs and water supply reliability.
    - Develop an incentive-based entrainment monitoring program in the Sacramento River designed to work cooperatively with diverters to develop projects or actions in order to minimize pumping impacts.
    - Develop and apply alternative diversion technologies that reduce entrainment.
    - Implement studies designed to quantify the amount of predation on winter-run Chinook salmon, spring-run Chinook salmon, and steelhead by non-native species in the Sacramento River. If the studies identify predator species and/or locations contributing to low salmonid survival, then evaluate whether predator control actions (e.g., fishery management or directed removal programs) can be effective at minimizing predation on juvenile salmon and steelhead in the Sacramento River; continue implementation if effective.
    - Implement and evaluate actions to minimize the adverse effects of exotic (non-native invasive) species (plants and animals) on the aquatic ecosystems used by anadromous salmonids.
    - Improve instream refuge cover in the Sacramento River for salmonids to minimize predatory opportunities for striped bass and other non-native predators.
    - Implement projects to minimize predation at weirs, diversions, and related structures in the Sacramento River.
    - Conduct a Central Valley-wide assessment of anadromous salmonid passage opportunities at large rim dams including the quality and quantity of upstream habitat, passage feasibility and logistics, and passage-related costs.
- **Sacramento**
    - Develop criteria and a process for phasing out the Livingston Stone winter-run Chinook salmon hatchery program as winter-run Chinook salmon recovery criteria are reached. This hatchery program is expected to play a continuing role as a conservation hatchery to help recover winter-run Chinook salmon.
    - Develop and implement a secondary fish trapping location for the LSNFH winter-run Chinook salmon supplementation program to provide increased opportunity to capture a spatially representative sample and target numbers of broodstock.

- Develop and implement a long-term gravel augmentation plan consistent with Central Valley Project Improvement Act (CVPIA) to increase and maintain spawning habitat for winter-run Chinook salmon, spring-run Chinook salmon, and steelhead downstream of Keswick Dam.
- Restore and maintain riparian and floodplain ecosystems along both banks of the Sacramento River to provide a diversity of habitat types including riparian forest, gravel bars and bare cut banks, shady vegetated banks, side channels, and sheltered wetlands, such as sloughs and oxbow lakes following the guidance of the Sacramento River Conservation Area Handbook (Resources Agency of the State of California 2003).
- Using an adaptive approach and pilot studies, determine if instream habitat for juvenile rearing is limiting salmonid populations, by placing juvenile-rearing-enhancement structures in the Sacramento River. If found to be limiting, add large woody debris/coarse organic material to the upper, middle and lower reaches of Sacramento River to increase the quantity and quality of juvenile rearing habitat.
- In an adaptive management context, implement short- and long-term solutions to minimize the loss of adult Chinook salmon and steelhead in the Yolo Bypass, and Colusa and Sutter-Butte basins. Solutions include the following.
    - Re-operating, to the extent feasible, the Knights Landing outfall gates to help prevent listed fish from entering the Colusa Basin (short-term)
    - Monitoring the Colusa and Sutter-Butte basins during winter and spring for adult salmon presence, and conducting fish rescues as necessary (short-term)
    - Evaluating other potential Colusa Basin Drain entry points for adult salmon along the Sacramento River above Knights Landing, and implementing fish exclusion solutions if necessary (short-term)
    - Providing and/or improving fish passage through the Yolo Bypass and Sutter Bypass allowing for improved adult salmonid re-entry into the Sacramento River (long-term)
    - Installing fish exclusion devices at strategic locations to reduce migration of listed, adult salmonids into the Colusa Basin Drain complex (long-term)
    - Identify management targets for Yolo and Sutter bypass inundation timing, frequency, magnitude, and duration that will maximize the growth and survival of juvenile winter-run Chinook salmon and spring-run Chinook salmon; and then manage the bypasses to those targets
    - Develop and implement a program to reintroduce winter-run Chinook salmon, spring-run Chinook salmon, and steelhead to historic habitats upstream of Shasta Dam; the program should include feasibility studies, habitat evaluations, fish passage design studies, and a pilot reintroduction phase prior to implementation of the long-term reintroduction program

- **Battle Creek**
  - Implement the Battle Creek Salmon and Steelhead Restoration Project Adaptive Management Plan.
  - Develop and apply alternative water diversion technologies that eliminate entrainment in Battle Creek.
  - Implement projects to minimize predation at weirs, diversion dams, and related structures in Battle Creek.
  - Develop an Adaptive Management Plan for Coleman National Fish Hatchery and continue to integrate hatchery operations with Battle Creek Salmon and Steelhead Restoration Project activities.
  - Evaluate the scientific merits of moving Coleman National Fish Hatchery operations for the production of steelhead and late-fall Chinook salmon to minimize adverse impacts to listed species. If warranted, then follow with an assessment of the feasibility of moving the programs.
  - Implement a study designed to evaluate the impact of predation on spring-run Chinook salmon and steelhead in Battle Creek. If the study suggests that predation is an important stressor in Battle Creek, then implement projects to minimize predation, potentially including predator removal and/or harvest management.
  - Develop and utilize the Battle Creek Fisheries Management Plan.
  - Fully fund and implement the Battle Creek Restoration Project through Phase 2.
  - Improve fish passage at natural (rock or wood) fish barriers in the watershed including the ones immediately upstream and downstream of Eagle Canyon, and at the mouth of Digger Creek.
  - Develop and implement a winter-run Chinook salmon reintroduction plan to re-colonize historic habitats made accessible by the Battle Creek Restoration Project.
- **Delta**
  - Conduct landscape-scale restoration of ecological functions throughout the Delta to support native species and increase long-term overall ecosystem health and resilience (Whipple et al. 2012).
  - Coordinate efforts to identify and highlight funding needs for restoration planning, monitoring, tracking, synthesis and adaptive management in the near and long term.
  - Develop and implement a targeted research and monitoring program to better understand the behavior, movement, and survival of steelhead, spring-run Chinook salmon, and winter-run Chinook salmon emigrating through the Delta from the Sacramento and San Joaquin rivers.

- Review and potentially update the through-Delta survival rate objectives included in this recovery plan as new information is obtained.
- Establish Vernalis flow criteria that incorporate the flow schedules of the San Joaquin River and tributaries in order to increase juvenile salmonid outmigration survival.
- Prioritize and screen Delta diversions.
- Implement projects to minimize predation at weirs, diversions, and related structures in the Delta.
- Design and implement project(s) to: (1) allow adult salmonids (and sturgeon) from the Sacramento Deep Water Ship Channel (SDWSC) to pass the channel gates and enter the Sacramento River (or block adult salmonids from entering the SDWSC); and (2) minimize fish passage from the Sacramento River into the SDWSC.
- Restore, improve and maintain salmonid rearing and migratory habitats in the Delta and Yolo Bypass to improve juvenile salmonid survival and promote population diversity.
- Explore and support the development of existing or innovative approaches and tools for centralized tracking of restoration efforts in the Delta.
- Provide access to new floodplain habitat in the South Delta for migrating salmonids from the San Joaquin system.
- Restore 17,000 to 20,000 acres of floodplain habitat (National Marine Fisheries Service 2009b).
- Restore Liberty Island, Cache Slough, and the lower Yolo Bypass (National Marine Fisheries Service 2009b).
- Enhance floodplain habitat in lower Putah Creek and along the toe drain (National Marine Fisheries Service 2009b).
- Improve habitat for juvenile salmonids in Elk, Sutter, and Steamboat sloughs (Siegel 2007).
- Restore tidal wetlands and associated habitats at Brannan Island State Park, northeast tip of Sherman Island, along Seven-Mile slough, and the southwest tip of Twitchell Island.
- Implement the Grizzly Slough Floodplain and Riparian Habitat Restoration Project.
- Evaluate whether predator control actions (e.g., fishery management or directed removal programs) can be effective at minimizing predation on juvenile salmon and steelhead in the Delta.

  - Modify existing water control structures to maintain flows through isolated ponds in the Yolo Bypass to minimize fish stranding, particularly following the cessation of flood flows over the Fremont Weir.
  - Implement the Putah Creek Enhancement Project (National Marine Fisheries Service 2009b).
  - Implement the Lisbon Weir Fish Passage Enhancement Project (National Marine Fisheries Service 2009b).

- **San Francisco, San Pablo, Suisun Bays**
  - Implement tidal marsh restoration projects to promote nitrification and retention of NH4 (Dugdale et al. 2007).
  - Implement studies to develop quantitative estimates of predation on juvenile salmonids by non-native species throughout Suisun, San Pablo, and San Francisco bays.
  - Implement projects to identify predation "hot spots" throughout Suisun, San Pablo, and San Francisco bays and minimize losses of juvenile salmonids at those locations.
  - Evaluate whether predator control actions (e.g., fishery management or directed removal programs) can be effective at minimizing predation on juvenile salmon and steelhead in Suisun, San Pablo, and San Francisco bays; continue implementation if effective.
  - Protect, enhance, and restore a complex portfolio of habitats throughout Suisun, San Pablo, and San Francisco bays to provide cover and prey resources for migrating salmonids.
  - Evaluate, and if feasible implement restoration projects that integrate upland, intertidal, and subtidal habitats; consider the following locations (from California State Coastal Conservancy et al. 2010): (1) San Pablo Bay: study potential resources and restoration activities in areas offshore from Sears Point, San Pablo Bay National Wildlife Refuge and Tubbs Island, and other restoration sites; (2) Corte Madera area: Muzzi Marsh, Corte Madera Ecological Reserve, Heard Marsh: existing wetlands and restored eelgrass, link to living shoreline project; (3) Richardson Bay: wetland restoration linked to existing oyster/eelgrass populations; (4) Breuner Marsh and Point Molate: link to Point San Pablo eelgrass bed; (5) Eastshore State Park: wetland restoration linked with oyster and eelgrass restoration, creek daylighting; (6) Central and North Bay Islands: link rocky habitat with eelgrass and oyster beds; and (7) South Bay Salt Pond sites; Eden Landing and other sites: link to southernmost eelgrass population, native oyster restoration.

5.1.4.3 Monitoring

Assessing the temporal occurrence of each life stage is done through monitoring data in the Sacramento River and Delta as well as salvage data from the Tracy and Skinner fish collection facilities in the south Delta (CVP and SWP).

Annual population estimates for the Upper Sacramento River Basin are determined through methodologies including carcass surveys, hatchery counts, aerial and in-stream redd surveys, snorkel counts (in-water surveys using snorkels which represent a portion of the fish present at the time of the survey), angler interviews, and video, DIDSON (acoustic sonar) or Vaki Riverwatcher counts in streams and in fish ladders. Carcass surveys using modern mark-recapture methodologies were initiated in 1996 on the Sacramento River above Red Bluff Diversion Dam using jet boats. The winter-run Chinook salmon survey begins in late-April or early-May and ends in late-August or early-September.

Aircraft are used to conduct weekly surveys for the winter-run Chinook salmon spawning to enable detailed inspection of winter-run Chinook salmon spawning areas and assist with water temperature management.

Rotary Screw Traps at Red Bluff capture a sample of emigrating juvenile salmonids to estimate the number of fish passing, their timing, and size distribution.

Winter-run Chinook salmon hatchery production released into the Sacramento River and Battle Creek are implanted with acoustic tags prior to release to enable tracking their migration and survival.

Seasonal Fish Assemblage Trawls and Delta Juvenile Fish Monitoring Program (DJFMP) Sacramento, Mossdale, Chipps Island trawls and beach seines monitor salmonids migrating to the Delta, through the Delta, and exiting the Delta to assist with resource management.

Below are summaries of winter-run Chinook salmon take and mortality by life stage for 2020 (Table 5-2), 2021 (Table 5-3), and 2022 (Table 5-4).

Table 5-2. Summary of Winter-run Chinook Salmon Take and Mortality by Life Stage, 2020.

Winter-run Chinook Salmon	Sum of Expected Take	Sum of Actual Take	Sum of Indirect Mortality	Sum of Actual Mortality
Adult	30107	6429	324	3
Egg	2500	0	0	0
Fry	3	0	0	0
Juvenile	173234	50788	4902	687
Smolt	4432	502	83	0
Spawned Adult/Carcass	11834	2940	0	0
Not specified	0	49	0	36
Grand Total	**222110**	**60708**	**5309**	**726**

Table 5-3. Summary of Winter-run Chinook Salmon Take and Mortality by Life Stage, 2021.

Winter-run Chinook Salmon	Sum of Expected Take	Sum of Actual Take	Sum of Indirect Mortality	Sum of Actual Mortality
Adult	40142	5012	15	4
Egg	2500	0	0	0
Juvenile	873308	17251	16422	470
Smolt	4540	555	84	0
Spawned Adult/Carcass	5810	4090	0	0
Not Specified	0	52	0	47
Grand Total	**926300**	**26960**	**16521**	**521**

Table 5-4. Summary of Winter-run Chinook Salmon Take and Mortality by Life Stage, 2022.

Winter-run Chinook Salmon	Sum of Expected Take	Sum of Actual Take	Sum of Indirect Mortality	Sum of Actual Mortality
Adult	34142	6498	15	2
Egg	2500	0	0	0
Juvenile	873464	7133	16421	242
Smolt	4040	1269	74	0
Spawned Adult/Carcass	13810	1119	0	0
Not Specified	0	277	0	199
Grand Total	**927956**	**16296**	**16510**	**443**

5.1.5 Current Incidental Take Statement

Quantitative incidental take from the 2019 NMFS Biological Opinion on the Long-term Operation of the CVP and SWP are described below. NMFS permitted incidental take as:

- **Adults**
    - No incidental take for adult winter-run Chinook salmon was reasonably expected to occur.
- **Eggs**
    - Two consecutive years of egg-to-fry survival of less than 15 percent followed by a third year of less than 21 percent based on fry production at Red Bluff Diversion Dam.

    - Two consecutive Tier 1 years of temperature-dependent mortality of 15 percent (average of 6 percent plus one standard deviation of 9) and egg-to-fry survival of 29 percent.
    - Two consecutive Tier 2 years of temperature-dependent mortality exceeding 31 percent (average of 15 percent plus one standard deviation of 16) and egg-to-fry survival less than 21 percent.
    - Two consecutive Tier 3 years of temperature-dependent mortality exceeds 65 percent (average of 34 percent plus one standard deviation of 31) and egg-to-fry survival is less than 21 percent.
  - One percent of redds are dewatered.
- **Juveniles**
  - Incidental take for juvenile winter-run Chinook salmon was reasonably expected to occur due to operations of the CVP / SWP South Delta facilities. 1.3% of the juvenile production estimate (JPE) on a three-year rolling average or 2.0% of the JPE in any single year.
  - Incidental take for juvenile winter-run Chinook salmon was reasonably expected to occur due to operations of the CVP / SWP South Delta facilities. 0.8% of the estimated hatchery JPE (fish surviving to the Delta from LSNFH released into the upper Sacramento River on a three-year rolling average or 1.0% of the JPE in any single year.
  - Incidental take for juvenile winter-run Chinook salmon was reasonably expected to occur due to operations of the CVP / SWP South Delta facilities. 0.8% of the estimated hatchery JPE (fish surviving to the Delta from LSNFH released into Battle Creek on a three-year rolling average or 1.0% of the JPE in any single year.
  - In the Sacramento River, incidental take for juvenile winter-run Chinook salmon was reasonably expected to occur due to Shasta Dam operations. The anticipated level of take was exceeded if flow decreases occur at a rate greater than the ramping rates described in the 2019 Proposed Action with the exception of flood control and emergency conditions.
  - In the Delta, incidental take for juvenile winter-run Chinook salmon was reasonably expected to occur during the operation of the Delta Cross Channel Gates. The ecological surrogate is the frequency and duration of opening the Delta Cross Channel gates in the October through January time period. Because of the causal relationship of gate opening to exposure of increased stressors within and between life stages, frequency and duration of opening may be used as a surrogate for the amount or extent of take for listed salmonids. The anticipated level of take will be exceeded if the number or duration of openings exceed those described in the Proposed Action.

- Incidental take of winter-run Chinook salmon was reasonably likely to occur due to Barker Slough Pumping Plant Sediment and Weed Control Operations. The anticipated level of take will be exceeded if more than five (5) unclipped listed salmonids (cumulative) are entrained per year through any combination of Sacramento River winter-run Chinook salmon, CV spring-run Chinook salmon, and This is only used twice, so spell out here. steelhead.

The 2019 NMFS Biological Opinion additionally included elements of the Proposed Action as ecological surrogates but did not quantify the effects by life stage.

5.2 Effects Analysis

The following sections summarize potential effects of the Proposed Action to winter-run Chinook salmon by life stage and stressors identified in the Salmon and Sturgeon Assessment of Indicators by Lifestage "SAIL" conceptual model (Windell et. al 2017). Appendix B, *Water Operations and Ecosystem Analyses*, shows how the seasonal operation of the CVP and SWP change river flows, water temperatures, and water quality parameters in different locations and under different hydrologic conditions. Appendix C, *Species Spatial-Temporal Domains*, summarizes when fish may be present in different locations based on historical monitoring in the Central Valley.

Appendix D, *Seasonal Operations Deconstruction*, analyzes potential stressors for the seasonal operation of the CVP and SWP. Deconstruction of the seasonal operation systematically evaluated how each stressor identified by the SAIL conceptual models may or may not change from the proposed operation of CVP and SWP facilities to store, release, divert, route, or blend water. Appendix G, *Specific Facility and Water Operations Deconstruction*, analyzes potential stressors due to facility specific operations, and Appendices H through R analyze conservation measures to minimize or compensate for adverse effects. Stressors not linked to the Proposed Action were identified as "not anticipated to change". Stressors that the Proposed Action may change to an extent that is insignificant or discountable were documented. Insignificant effects relate to the size of the impact and should never reach the scale where take occurs. Based on best judgment, a person would not be able to meaningfully measure, detect, or evaluate insignificant effects. Discountable effects are those extremely unlikely to occur. Based on best judgment, a person would not be able to expect discountable effects to occur.

Stressors that may result in effects on listed species were documented and proposed conservation measures identified.

5.2.1 Adult Migration

Adult winter-run Chinook salmon enter the San Francisco Estuary from the Pacific Ocean to begin their upstream spawning migration from November through July with a peak presence in the Bay-Delta from February to May. The Bay-Delta serves as a transition zone between tidal and riverine sections of the Sacramento River and adults can spend time searching for olfactory cues to follow to natal spawning areas (Keefer et al. 2008).

After passing through the Bay-Delta, adult winter-run Chinook salmon enter the Sacramento River and pass Red Bluff Diversion Dam in January through June with peak passage in February through May.

The Proposed Action is not anticipated to change the stressors: *In-River Fishery and Poaching*, *Stranding Risk*, nor *Dissolved Oxygen*.

Stressors that may change at a level that is discountable or insignificant include:

- The Proposed Action may increase the *toxicity from contaminants* stressor. During the adult migration period, the Proposed Action will store and divert water resulting in decreased flows in the Sacramento River below Keswick Dam, decreased inflow into the Delta, and decreased Delta outflow. Reduced flows may concentrate contaminants if and when contaminants are present. The timing of snowmelt may also play a role in this stressor through deposited pollutants in dust though studies on contaminants present in snowmelt and rainfall runoff have reported differing results (Parajulee et al. 2017; Chen et al. 2018).

  Water quality in the Central Valley, including the Delta, is regulated by the U.S. Environmental Protection Agency. Contaminants are commonly found on floodplains (e.g., methylmercury, selenium). During migration adults do not eat, which reduces their exposure to contaminants in prey during this life stage. Murphy et al. (2022) identifies Chinook salmon as safe to eat; levels safe for human consumption are assumed not likely to impact fish health. On the Sacramento River, releases as part of seasonal operations would be below the bankfull flows that would mobilize present contaminants. Monitoring has not shown fish kills that may be indicative of contaminants at levels likely to affect adult salmon.

- The Proposed Action may increase the *water temperature* stressor. During the adult migration period, the Proposed Action will store and divert water resulting in decreased Delta inflow. Delta water temperature is positively correlated with Delta inflow in the winter. Delta water temperature is negatively correlated with Delta inflow in the spring (Bashevkin and Mahardja 2022).

  The range of potential reservoir operations is unlikely to have a measurable effect on Delta water temperatures as Bay-Delta water temperature is mainly driven by timing of snowmelt (Knowles and Cayan 2002), air temperature, solar radiation, and meteorology (Vroom et al. 2017, Daniels and Danner 2020). The historical record of water temperatures in the Delta at Prisoner's Point shows values greater than 68°F within the Delta in May but not in March and April. There is uncertainty about whether the decreased inflow from reservoir operations would lead to increased Delta water temperatures; however, the correlations include wet years with flood operations. The volume of water required to provide sufficient thermal mass to deviate from ambient air temperatures is substantially larger than releases outside of flood operations.

- The Proposed Action may increase the *pathogens and disease* stressor. During the adult migration period, the Proposed Action will store and divert water resulting in decreased Delta inflow that is correlated with increased water temperatures. Increased water temperatures potentially influence pathogens.

  McCullough (1999) reported a 59.9°F water temperature threshold as the threshold above which diseases affecting Chinook salmon become highly virulent. Water temperatures above 59.9°F can occur in the spring in the Bay-Delta. On average, Prisoner Point water temperature has been lower than 59.9°F in March, but higher in April and May; however decreased spring flow outside of flood control is unlikely to influence Delta water temperatures.

There are no changes in stressors likely to harm, harass, or kill individuals during adult migration. The Proposed Action is not expected to result in incidental take during this life stage.

5.2.2 Adult Holding and Spawning

Winter-run Chinook salmon enter the lower Sacramento River as sexually immature fish and hold in the freshwater for up to several months before spawning. Adults typically hold in deeper pools with cold water. Adults distribute throughout the upper Sacramento River and spawn and rear in clear spring-fed waters typically 50°F – 59°F during the late spring and summer seasons from May through July. Spawning occurs in gravel substrate in water with velocities high enough to favor redd construction and egg oxygenation. Peak spawning normally occurs between June and July.

The Proposed Action is not anticipated to change the stressors: *In-River Fishery and Poaching*, *Stranding Risk*, nor *Competition, Introgression*, and *Broodstock Removal*.

Stressors that may change at a level that is insignificant or discountable include:

- The Proposed Action may increase or decrease the *toxicity from contaminants* stressor. During the adult holding and spawning period, the Proposed Action in the spring will store water and decrease flows. In the summer, the Proposed Action will release water and increase flows in the Sacramento River below Keswick Dam. Reduced flows may concentrate contaminants if, and when contaminants are present, and increased flows may dilute contaminants. Increased flows and pulses may mobilize suspended sediments consisting of contaminants in river systems (van Vliet et al. 2023). The timing of snowmelt may also play a role in this stressor through deposited pollutants in dust though studies on contaminants present in snowmelt and rainfall runoff have reported differing results (Parajulee et al. 2017; Chen et al. 2018).

  Monitoring has not shown fish kills that may be indicative of contaminants at levels likely to affect adult salmon in the Sacramento River. The evidence presented above under Section 5.2.1, *Adult Migration*, is applicable for adult holding and spawning.

- The Proposed Action may decrease the *dissolved oxygen* stressor. During the adult holding and spawning period, the Proposed Action will release water and increase flows in the Sacramento River below Keswick Dam in the summer. Releases of Shasta Reservoir storage may result in cooler water temperatures and higher flows that may provide a higher dissolved oxygen saturation potential.

> Winter-run Chinook salmon wait to migrate when dissolved oxygen is at least 5.0 mg/l (Carter 2005) and historical water quality monitoring has not shown summer dissolved oxygen at levels below 5.0 mg/l in the upper Sacramento River.

Described below are stressors exacerbated by the Proposed Action, potentially resulting in incidental take. Also described below are conservation measures included as part of the Proposed Action to avoid or compensate for adverse effects. Finally, the Proposed Action may also ameliorate certain stressors in the environmental baseline, and a description of these beneficial effects is included.

5.2.2.1 Spawning Habitat Stressor

The proposed release of water may increase the spawning habitat stressor. During the adult holding and spawning period, releases from Trinity and Shasta reservoirs will increase flows and modify water temperature below Keswick Dam during the spawning season. Habitat suitability curves show higher flows reduce areas of spawning habitat quantity and quality (Bureau of Reclamation 2020). Dudley (2019) shows higher flows result in higher velocities and the potential increase of superimposition. Appendix O, *Tributary Habitat Restoration*, presents analysis of effects of proposed releases on spawning habitat based on suitable depths, velocities, and substrate.

The increase in spawning habitat stressors is expected to be **lethal**. Although a lack of sufficient spawning habitat can result in incomplete egg expression and redd superimposition that exposes previously deposited eggs to damage and predation, further analysis revealed that spawning habitat may not be limiting in the Sacramento River.

Changes in the spawning habitat exist in the **environmental baseline** (without the Proposed Action). Hydrology, which then influences the available erodible sediment supply, the bathymetry of the river, and downstream flows drives spawning habitat quantity and quality.

Spawning is also affected by the presence of Shasta and Keswick dams. Winter-run Chinook salmon have been excluded from historical spawning habitat since the construction of Shasta and Keswick dams (National Marine Fisheries Service 2011). Dams also influence the depth, quality, and distribution of spawning habitat. Generally, dams reduce or block the recruitment of spawning gravel, resulting in the winnowing and armoring of downstream substrates. Gravel sources from riverbanks and floodplains can also be reduced by levee and bank protection measures. Levee and bank protection measures restrict the meandering of the river, which would normally release gravel into the river through natural erosion and deposition processes. Flood control of storage further reduces peak flows that could mobilize gravels on the riverbed.

Reclamation has undertaken gravel augmentation to improve spawning habitat at key locations below Keswick Dam. Since 1997, under CVPIA, a total of 358,200 tons of gravel have been placed from 300 yards to 1.5 miles downstream of Keswick Dam to increase the availability of suitable spawning habitat (Table 5-5).

Table 5-5. Gravel Placement in the Sacramento River and Percent of the 10,000 Ton Target.

Year	Tons	Percent of 10,000 Ton Target
1997	31,000	310%
1998	23,000	230%
1999	25,000	250%
2000	32,000	320%
2001	0	0%
2002	15,000	150%
2003	8,800	88%
2004	8,500	85%
2005	7,200	72%
2006	6,000	60%
2007	6,000	60%
2008	8,300	83%
2009	9,900	99%
2010	5,500	55%
2011	5,000	50%
2012	15,000	150%
2013	14,000	140%
2014	0	0%
2015	0	0%
2016	32,000	320%
2017	14,000	140%
2018	0	0%
2019	32,000	320%
2020	2,000	20%
2021	38,000	380%
2022	20,000	200%
Total	**358,200**	**138%**

The **proportion** of the population affected by the Proposed Action depends, in part, on the depths, velocities, and water temperature in areas with suitable substrate. Increased releases may reduce the quality and quantity of spawning habitat; however, early in the spawning period, spawning habitat is not saturated. During summer months when Shasta Reservoir has a sufficient coldwater pool to operate to suitable water temperatures downstream of the Clear Creek confluence, the proportion of the population affected is **likely small**. When Shasta Reservoir lacks sufficient coldwater pool, the proportion of the population affected is **likely medium**.

Literature does not uniquely inform the proportion of the population.

Datasets use historical conditions and observation to inform how winter-run Chinook salmon may respond to the Proposed Action. Historical monitoring may support or refute hypotheses and informs the reasonableness of information generated by models. A review of carcass and redd surveys does not identify redd superimposition. Reports on the Sacramento River identify pre-spawn mortality; however, no attribution has occurred to a lack of available spawning habitat.

Models provide quantitative estimates of future conditions under the Proposed Action. Reclamation evaluated multiple lines of evidence, with different assumptions and complexity, to narrow the likely range of potential effects. Two models estimate the acres of suitable spawning habitat available. The Sacramento Weighted Usable Area (WUA) analysis is a method for estimating the availability of suitable habitat in rivers, streams, and floodplains under different flow conditions (Bovee et al. 1998). The CVPIA SIT Decision Support Model (DSM) are based on flow to suitable habitat area relationships used to estimate Chinook salmon spawning and rearing habitat in all CVP tributaries.

The Sacramento River Weighted Usable Area Analysis, Appendix O, Attachment O.3, *Sacramento River Weighted Usable Area Analysis*, provides context for the weighted usable area available for winter-run Chinook salmon spawning downstream of Keswick Dam releases. Spawning weighted usable area for winter-run Chinook salmon peaks at approximately 10,000 cfs upstream of Cow Creek, where most winter-run Chinook salmon spawn. The WUA habitat value under the Proposed Action phases range from 522,694 to 583,645 (Figure 5-4). Overall, these WUA habitat values do not vary much among water year types (WYTs). This lack of variation suggests the summer flow ranges in the Proposed Action provide stable spawning habitats.

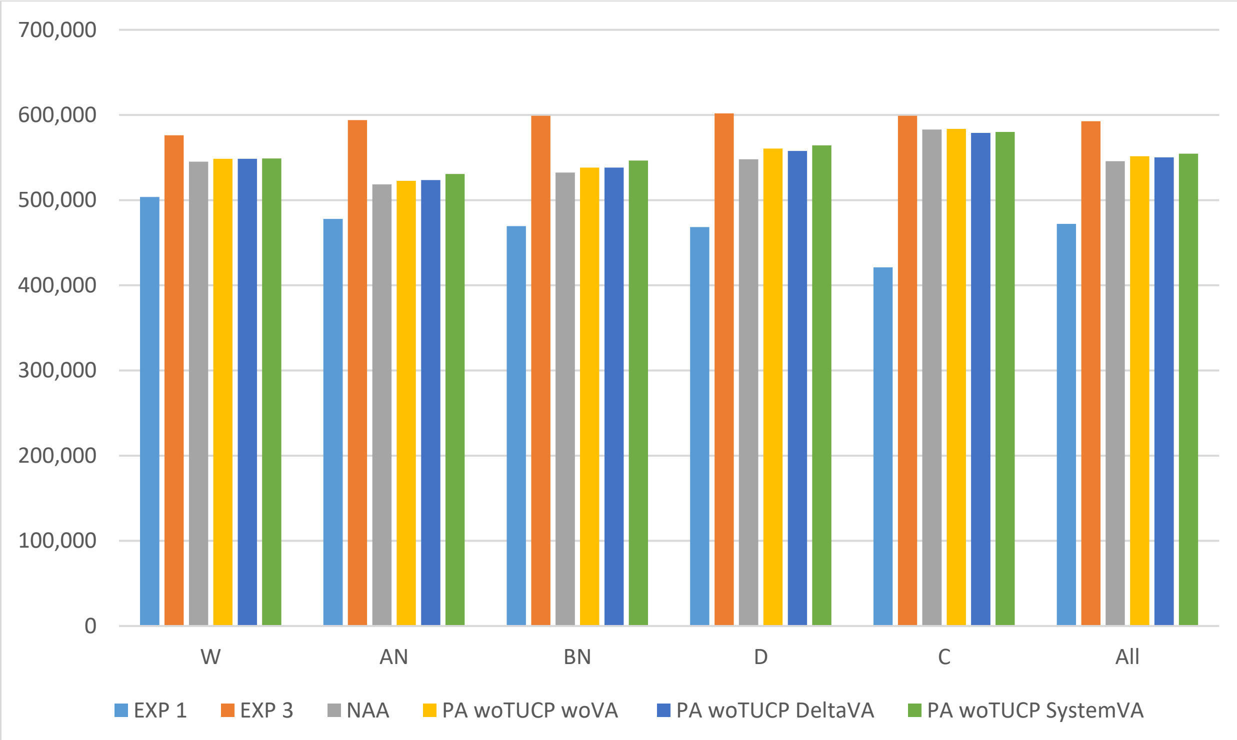
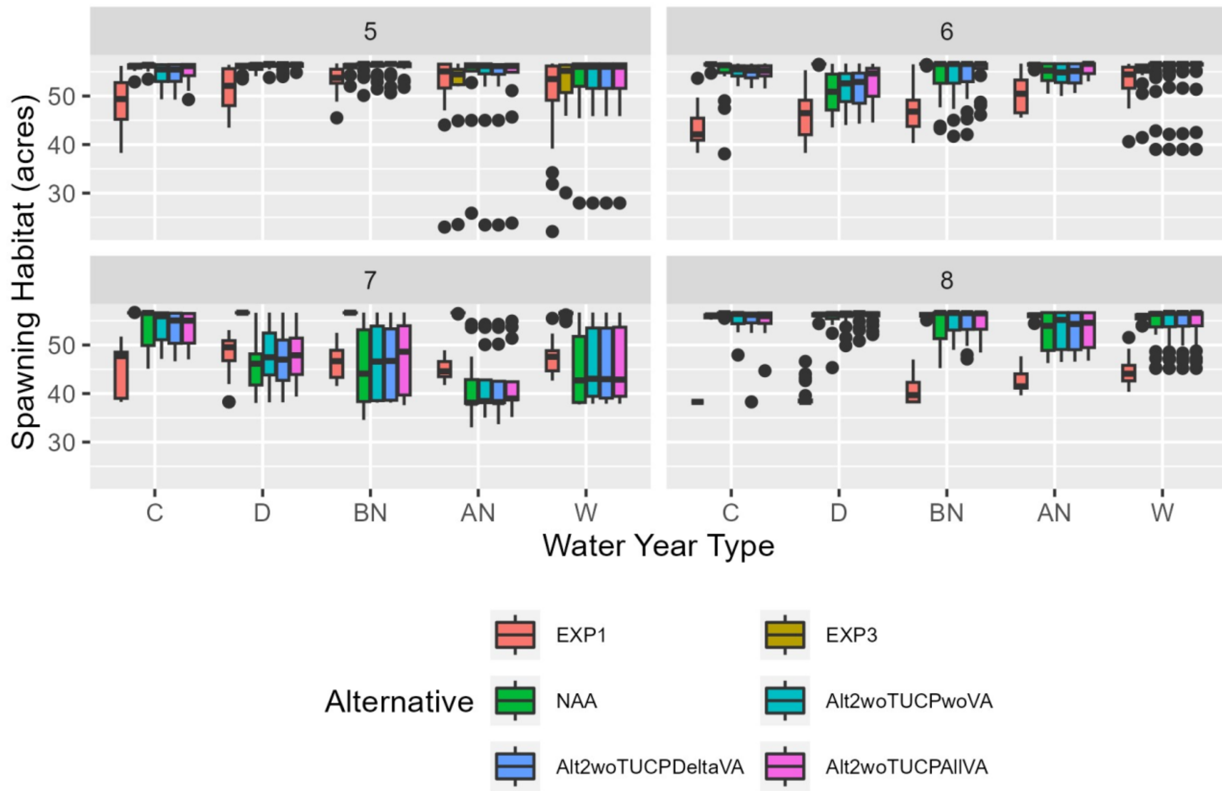


Figure 5-4. Water Year Type Mean Winter-run Chinook Salmon Spawning Weighted Usable Area Habitat Values.

The SIT LCM Habitat Estimates, Tributary Habitat, Appendix O, Attachment O.2, *SIT LCM Habitat Estimates*, provides context for the habitat area available for winter-run Chinook salmon spawning downstream of Keswick Dam from May through August. The monthly habitat value under the Proposed Action phases range from a low of approximately 28 acres to a high of approximately 57 acres (Figure 5-5). Spawning weighted usable area for winter-run Chinook salmon peaks at approximately 10,000 cfs in the Upper Sacramento River, where most winter-run Chinook salmon spawn, and with Anderson-Cottonwood Irrigation District (ACID) boards in, as they typically are during the winter-run Chinook salmon spawning months. Overall, the habitat values do not vary much among months or water year types, with the exception that in July of critical years has more spawning habitat than other water year types, and June of dry years has less spawning habitat than other water year types. However, the narrow range of habitat values suggest the summer flow ranges in the Proposed Action provide stable spawning habitats. The lowest habitat values under the Proposed Action phases occurred in July. Habitat values were relatively consistent across other spawning months (May, June, August) for all Proposed Action phases.



Variability within months (May-August) reflects variation across CalSim Water Years.

Figure 5-5. Estimated Spawning Habitat for Winter-run Adults in the Upper Sacramento River.

While the area of suitable habitat is affected in all years, the **frequency** when habitat impacts occur from limited cold water, particularly in Critical and Dry water year types, is **low** based on historical hydrology and the frequency of temperature constraints. The number of recent spawners has not affected redd superimposition.

To evaluate the **weight of evidence** for the spawning habitat stressor, USFWS (2003) includes habitat suitability curves from the upper Sacramento River for Chinook salmon spawning habitat quantity and quality. Since 2003, habitat use and location of spawning has changed and additional spawning habitat restoration has occurred, so there is uncertainty in these relationships. The CVPIA SIT DSM, similarly uses habitat suitability curves that are species specific, location specific, and quantitative while relying on multiple experts and peer review (Peterson and Duarte 2020).

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- Allocation Reductions for Shasta Reservoir End of September Storage
- Rebalancing between other CVP Reservoirs for Shasta Reservoir End of September Storage
- Reduced Wilkins Slough Minimum Flows for Shasta Reservoir End of September Storage
- Minimum Refuge Summer Deliveries North of Delta
- Drought Actions

Conservation measures in the Proposed Action for other species, life stages and/or stressors that may exacerbate this stressor include:

- Sacramento River Settlement Contractors (SRSC) Diversion Spring Delays and Shifting
- Shasta Operations Team (SHOT) Water Transfer Timing Approvals

5.2.2.2 Water Temperature Stressor

The proposed blending of water released from Shasta Reservoir may generally decrease the water temperature stressor. During the adult holding and spawning period, imports from Trinity Reservoir and operation of a Temperature Control Device (TCD) on Shasta Reservoir are expected to maintain cooler water temperatures; however, as part of the drought toolkit, Reclamation may operate the TCD to release warmer water temperatures during this period to preserve water for egg incubation later in the year. These warmer temperatures associated with exercising the drought toolkit may increase stress on adults taxed from upstream migration and spawning. Appendix L, *Shasta Coldwater Pool Management*, presents analysis of the water temperature management conservation measure for adult holding and spawning.

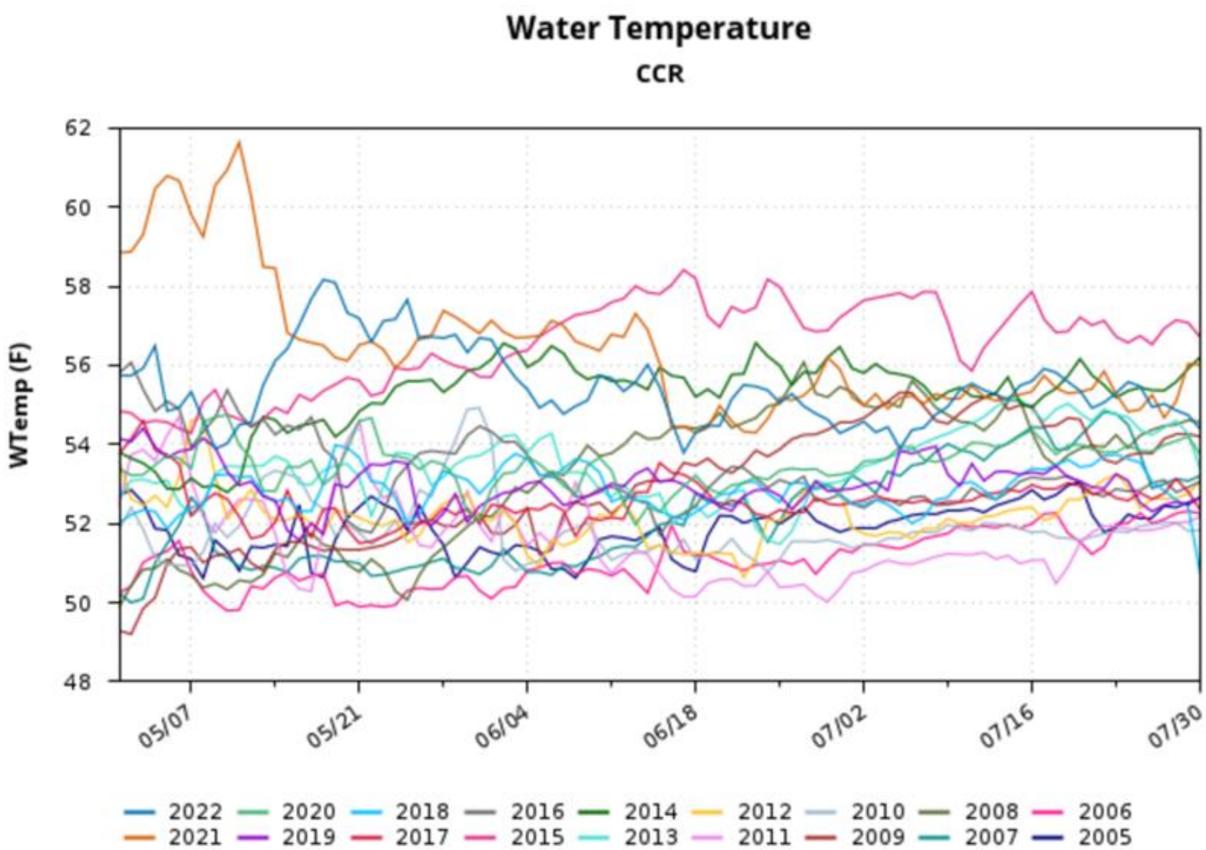
The decrease in water temperature stressor is expected to be **beneficial**; however, the operation of the TCD to release warmer water and preserve the coldwater pool during a drought may have **sub-lethal** effects.

Although the Proposed Action may, at times, increase the water temperature stressor, unsuitable water temperatures for adult winter-run Chinook salmon holding and spawning exists in the **environmental baseline** (without the Proposed Action). The amount of precipitation, local ambient air temperatures and solar radiation drives the water temperature stressor (Windell et al. 2017). It is expected that climate change should result in warmer air temperature and a shift in forms of precipitation, with more precipitation falling as rain, which will exacerbate water temperatures in the reservoirs. In 1997, Reclamation completed the TCD at Shasta Reservoir, which can be used to effectively blend water from the warmer upper reservoir levels and, thereby, extend the time period in which cold water can be provided downstream. Reclamation's past operation of Shasta Reservoir has influenced the flow of water in the Sacramento River. Reclamation has operated the CVP to reduce the water temperature stressor during adult holding and spawning by using the TCD. Different approaches have targeted different water temperatures and locations throughout the years including a warmwater bypass to conserve the limited coldwater pool.

The **proportion** of the population affected by the Proposed Action depends on when temperature management starts, generally in May. Prior to water temperature management, water temperatures are generally colder than adult water temperature criteria for potential water temperature effects. With the majority of winter-run Chinook salmon spawning occurring after May, the proportion of the population affected is **likely large**.

Literature does not uniquely inform the proportion of the population.

Datasets use historical conditions and observation to inform how winter-run Chinook salmon may respond to the Proposed Action. Historical monitoring may support or refute hypotheses and informs the reasonableness of information generated by models. Figure 5-6 shows historic water temperatures on the Sacramento River above Clear Creek (CCR) during the adult spawning period. Water temperatures were elevated during 2015 and 2021, when coldwater pool volume was diminished, and there was little available cold water left to release from Shasta Reservoir.



Source: SacPAS, CDEC.

Figure 5-6. May through July Water Temperatures on Sacramento River above Clear Creek, 2005–2022.

Table 5-6 shows pre-spawn mortality of female winter-run Chinook salmon in the Sacramento River by origin (natural and hatchery) for 2001 – 2020 return years. Between 2001 and 2020, up to 9.1% natural origin (occurred in 2017) and up to 7.1% hatchery origin (occurred in 2006) did not spawn. In WY 2021, a warmwater power bypass was conducted in April to prolong Shasta Reservoir coldwater pool, and pre-spawn mortality of female winter-run Chinook salmon was 5.5% (Reclamation 2021).

Table 5-6. Pre-spawn Mortality for Female Winter-run Chinook Salmon on the Sacramento River, 2001–2020.

Return Year	Natural Origin Total Carcasses	Natural Origin Number not Spawned	Natural Origin Percent not Spawned	Hatchery Origin Total Carcasses	Hatchery Origin Number not Spawned	Hatchery Origin Percent not spawned
2001	1,177	10	0.8	62	0	0
2002	927	19	2	81	3	3.7
2003	1,915	11	0.6	98	0	0
2004	995	7	0.7	74	4	5.4
2005	2,419	36	1.5	600	24	4
2006	1,918	25	1.3	324	23	7.1
2007	518	9	1.7	36	1	2.8
2008	361	6	1.7	25	0	0
2009	488	3	0.6	64	0	0
2010	321	1	0.3	40	1	2.5
2011	147	1	0.7	19	0	0
2012	427	2	0.5	175	5	2.9
2013	977	8	0.8	62	2	3.2
2014	344	3	0.9	73	1	1.4
2015	325	7	2.2	74	1	1.4
2016	106	0	0	22	1	4.5
2017	11	1	9.1	49	0	0
2018	60	0	0	347	3	0.9
2019	661	6	0.9	434	7	1.6
2020	856	21	2.5	765	27	3.5

Source: U.S. Fish and Wildlife Service 2021.

Models provide quantitative estimates of future conditions under the Proposed Action. Reclamation evaluated multiple lines of evidence, with different assumptions and complexity, to narrow the likely range of potential effects. HEC-5Q modeling analysis enumerates the frequency at which mean monthly simulated water temperatures exceed water temperature criteria obtained from scientific literature. Modeled water temperatures (HEC-5Q) during adult winter-run Chinook salmon holding and spawning are as follows.

Results for the 42.1°F to 55°F range are presented in Table 5-7 for the Sacramento River at Keswick and Table 5-8 for the Sacramento River below Clear Creek. At Keswick, the percent of months outside the range under the Proposed Action phases had a range of 5.4% for Dry to 1.8% for Critically dry water year types. In Wet and Above Normal water years (WYs), water temperatures were within the range 100% of the time for each phase of the Proposed Action. Percentages outside the range were 0% throughout the January to July period under the Proposed Action phases.

Table 5-7. Percent of Months Outside the Optimal 42.1°F to 55°F Water Temperature Range for Successful Spawning and Holding of Winter-run Chinook Salmon by Water Year Type and for All Years Combined, Sacramento River at Keswick, January through July.

WYT	**EXP1**	**EXP3**	**NAA**	**Alt2woTUCPwoVA**	**Alt2woTUCPDeltaVA**	**Alt2woTUCPAllVA**
W	35.7	2.6	2.0	0.0	0.0	0.0
AN	42.9	3.3	2.2	0.0	0.0	0.0
BN	50.8	4.0	7.1	2.4	3.2	2.4
D	47.6	4.2	11.3	4.8	4.8	5.4
C	48.2	6.3	6.3	3.6	1.8	1.8
All	44.3	3.9	5.9	2.2	2.0	2.0

At the Sacramento River below Clear Creek, the percent of months outside the 42.1°F to 55 °F range under the Proposed Action phases range from 16.1% during Critical water years to 5.1% of months during wet water years. Overall, the percent of months outside the range increased from wetter to drier water year types.

Table 5-8. Percent of Months Outside the Optimal 42.1°F to 55°F Water Temperature Range for Successful Spawning and Holding of Winter-run Chinook Salmon by Water Year Type and for All Years Combined, Sacramento River below Clear Creek, January through July.

WYT	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
W	42.9	11.7	12.2	5.1	5.1	5.1
AN	48.4	17.6	16.5	9.9	9.9	9.9
BN	54.0	14.3	19.0	7.9	8.7	8.7
D	51.8	22.0	20.8	13.7	14.3	15.5
C	54.5	13.4	32.1	13.4	16.1	13.4
All	49.6	15.7	19.3	9.7	10.4	10.2

[Placeholder: IOS modeling on spawn timing (performance measure is variation in spawn timing)]

Water temperature management occurs in all years, and water temperatures downstream of Shasta Reservoir are dependent on hydrology and meteorology. The **frequency** of when the Proposed Action would provide benefits to adult winter-run Chinook salmon is **high**. Historic May through July temperatures on the Sacramento River above Clear Creek (2001 – 2020) were lower than 56°F in all years.

An exception to the Proposed Action providing benefits is a warmwater bypass action taken as part of the drought toolkit. This action is assumed to occur only when the coldwater pool volume is limited preventing water temperature management for egg incubation. An anecdotal report attributed pre-spawn mortality in 2021 to a warmwater bypass targeting 57°F to 60°F at the Sacramento River upstream from Highway 44 Bridge gage (SAC) (Reclamation 2022). The bypass was conducted to prolong the availability of Shasta Reservoir’s coldwater pool. The **frequency** of this occurring is **low** and likely only occurs in the second or more consecutive critical and/or dry years. In this instance, the **proportion** of the population negatively impacted would be **small**, the **frequency** would be **low**, and the action would not occur without coordination through the SHOT. The implementation of a warmwater bypass action multiple years in a row could negatively impact several sequential brood years that require consideration of potential improvements in egg incubation water temperatures.

To evaluate the **weight of evidence** for the water temperature stressor, there are water temperature thresholds from a synthesis document for Chinook salmon that include species and water specific information. This synthesis in Appendix L did not account for potentially confounding biological factors such as thiamine deficiency.

- Historic temperatures: quantitative, not species-specific (but not expected to be, environmental variable), location-specific, available through multiple sources and QA/QCed data from long time-series, published in technical memos and annual reports from technical teams, not expected to have statistical power

- Historic pre-spawn mortality observations: quantitative, species-specific, location-specific, available through multiple sources and QA/QCed data from long time-series, published in technical memos and annual reports from technical teams, not expected to have statistical power
- Historic spawn-timing observations: quantitative, species-specific, location-specific, available through multiple sources and QA/QCed data from long time-series, published in technical memos and annual reports from technical teams, not expected to have statistical power
- Hec-5Q water temperature modeling: quantitative, not species-specific (but not expected to be, environmental variable), location-specific, model developed to evaluate reservoir system using control points, widely accepted as temperature modeling system for use in the Central Valley upper watershed

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- Adult Migration and Holding Water Temperature Objectives

Conservation measures in the Proposed Action for other species, life stages and/or stressors that may exacerbate this stressor include:

- Drought Tool Kit Warmwater Bypass
- Voluntary Agreement Pulse Flows
- Sacramento River Pulse Flows

5.2.2.3 Pathogens and Disease

The proposed blending of water to reduce water temperatures may generally decrease the pathogens and disease stressor. During the adult spawning period, imports from Trinity Reservoir and operation of a TCD on Shasta Reservoirs are expected to result in cooler water temperatures. The occurrence of pathogen virulence is diminished in cooler waters. Appendix L presents analysis of this stressor.

The decrease in the pathogens and disease stressor is expected to be **beneficial**; however, the operation of the TCD to release warmer water and preserve the coldwater pool during a drought may have **sub-lethal** effects.

Although the Proposed Action may at times increase the pathogens and disease stressor, pathogens and disease that may affect adult winter-run Chinook salmon spawning exists in the **environmental baseline** (without the Proposed Action). Pathogens and disease have been present in the ambient environment since before construction of the CVP and SWP. The amount of precipitation, local ambient air temperatures and solar radiation drives the water temperature stressor, which then influences the pathogens and disease stressors (Windell et al. 2017). It is expected that climate change should result in warmer air temperature and shift in forms of precipitation, with more precipitation falling as rain, which will exacerbate water temperatures in the reservoirs. Low stream flows and higher water temperatures caused by drought can exacerbate disease (National Marine Fisheries Service 1998).

Hatchery production and releases can influence disease and pathogens. While production and conservation hatcheries may increase this stressor from water discharges and the release of hatchery fish, Hatchery and Genetic Management Plans help to minimize effects.

The **proportion** of the population affected by the Proposed Action depends on when temperature management starts, generally in May. Prior to water temperature management, water temperatures are generally colder than the threshold above which diseases affecting Chinook salmon become highly virulent (59.9°F, McCollough 1999). With the majority of winter-run Chinook salmon spawning occurring after May, the proportion of the population affected is **likely large**.

Literature does not uniquely inform the proportion of the population.

For datasets, please see figures in Section 5.2.2.2, *Water Temperature Stressor*.

Models provide quantitative estimates of future conditions under the Proposed Action. HEC-5Q modeling analysis enumerates the frequency at which mean monthly simulated water temperatures exceed water temperature criteria obtained from scientific literature.

Results for the exceedance of the 59.9 °F pathogen virulence temperature threshold are presented in Table 5-9 for the Sacramento River at Keswick and Table 5-10 for the Sacramento River below Clear Creek. At Keswick, the percent of months above the pathogen virulence temperature threshold was 0% for all three phases of the Proposed Action, in all water year types. Percentages above the threshold were 0% throughout the January to July period under the Proposed Action phases.

Table 5-9. Percent of Months Above the 59.9°F Pathogen Virulence Water Temperature Threshold for Adult Winter-run Chinook Salmon Spawning and Holding by Water Year Type and for All Years Combined, Sacramento River at Keswick, January through July.

WYT	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
W	23.5	0.0	0.0	0.0	0.0	0.0
AN	27.5	0.0	0.0	0.0	0.0	0.0
BN	34.1	0.0	0.0	0.0	0.0	0.0
D	32.7	0.0	0.0	0.0	0.0	0.0
C	35.7	0.0	0.0	0.0	0.0	0.0
All	30.2	0.0	0.0	0.0	0.0	0.0

At the Sacramento River below Clear Creek, the percent of months above the pathogen virulence temperature threshold was also 0% for all three phases of the Proposed Action, in all water year types.

Table 5-10. Percent of Months Above the 59.9°F Pathogen Virulence Water Temperature Threshold for Adult Winter-run Chinook Salmon Spawning and Holding by Water Year Type and for All Years Combined, Sacramento River below Clear Creek, January through July.

WYT	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
W	27.6	0.0	0.0	0.0	0.0	0.0
AN	30.8	0.0	0.0	0.0	0.0	0.0
BN	37.3	0.0	0.0	0.0	0.0	0.0
D	38.1	0.0	0.0	0.0	0.0	0.0
C	39.3	0.0	0.0	0.0	0.0	0.0
All	34.2	0.0	0.0	0.0	0.0	0.0

Water temperature management occurs in all years and water temperatures downstream of Shasta Reservoir are dependent on hydrology and meteorology. Historical water temperatures on the Sacramento River above Clear Creek exceeded the 59.9°F threshold for disease virulence one out of 18 years (2021) between 2005 – 2022. The **frequency** of when the Proposed Action would provide benefits to adult winter-run Chinook salmon is **high**.

To evaluate the **weight of evidence** for the pathogens and disease stressor, there are temperature criteria thresholds from published literature for pathogen and disease virulence specific to Chinook salmon. These thresholds, however, are not specific to winter-run Chinook salmon nor to the Sacramento River.

- Historic temperatures: quantitative, not species-specific (but not expected to be, environmental variable), location-specific, available through multiple sources and QA/QCed from a long time-series, published in technical memos and annual reports from technical teams, not expected to have statistical power
- Hec-5Q water temperature modeling LOE: quantitative, not species-specific (but not expected to be, environmental variable, location-specific, model developed to evaluate reservoir system using control points, widely accepted as temperature modeling system for use in the Central Valley upper watershed

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- Adult Migration and Holding Water Temperature Objectives

5.2.3 Egg Incubation and Fry Emergence

Winter-run Chinook salmon egg incubation and emergence occurs in the Sacramento River downstream of Keswick Dam from May through November. The period for incubation of embryos (fertilized egg and alevin) to fry emergence can vary from about two to three months, dependent on water temperature (Bratovitch et al. 2012). Fry emergence can be temporally variable and is dependent on timing of various environmental conditions. Upon emergence, fry either actively swim or are passively transported downstream (Healey 1991) with egg to fry survival measured at the Red Bluff Diversion Dam.

The Proposed Action is not anticipated to change the stressors: I*n-River Fishery or Trampling*, nor *Predation Risk*.

Stressors that may change at a level that is insignificant or discountable include:

- The Proposed Action may decrease the *toxicity from contaminants* stressor. During the egg incubation and fry emergence period, the Proposed Action will release water and increase flows in the Sacramento River below Keswick Dam. Increased flows may dilute contaminants if and when contaminants are present. However, increased flows and pulses can mobilize suspended sediments consisting of contaminants in river systems (van Vliet et al. 2023).

  Water quality monitoring has not shown contaminants at levels likely to affect eggs and toxicity-related adverse effects have not been observed in fish monitoring. Moreover, eggs are not exposed to prey-derived contaminants until post exogenous feeding begins, which reduces their exposure to contaminants during this life stage.

- The Proposed Action may decrease the *dissolved oxygen* stressor. During the egg incubation and fry emergence period, the Proposed Action will release water and increase flows in the Sacramento River below Keswick Dam. Releases of Shasta Reservoir storage may result in cooler water temperatures and higher flows that may provide a higher dissolved oxygen saturation potential.

  Chinook salmon egg and alevin survival decreases when dissolved oxygen levels are less than 5.5 mg/l (Del Rio et al. 2019); however, historical water quality monitoring has not shown summer or fall dissolved oxygen levels at below 5.5 mg/l (California Department of Fish and Wildlife 2017).

- The Proposed Action may decrease the *pathogens and disease* stressor. During the egg incubation and fry emergence period, the Proposed Action will release water and increase flows in the Sacramento River below Keswick Dam and cooler water temperatures potentially influence pathogen and disease presence and virulence.

  Increased water temperatures have been hypothesized to be one of the factors that contributes to coagulated-yolk disease, or white-spot disease, in both eggs and fry along with other environmental conditions like gas supersaturation and low dissolved oxygen (Mazuranich and Nielson 1959). There has been no evidence of white-spot disease in the Sacramento River and this disease appears to be more often observed at hatcheries than in rivers.

- The Proposed Action may decrease the *sedimentation and gravel quantity* stressor. During the egg incubation and fry emergence period, the Proposed Action will release water and increase flows in the Sacramento River below Keswick Dam. Increased flows may provide environmental conditions favorable to redds and developing embryos.

  Increased surface flows may reduce sedimentation. Build-up of fine sediment can decrease permeability for embryos (Bjornn and Reiser 1991). Gravel quantity is addressed in Section 5.2.2.1, *Spawning Habitat Stressor*.

Described below are stressors exacerbated by the Proposed Action, potentially resulting in incidental take. Also described below are conservation measures included as part of the Proposed Action to avoid or compensate for adverse effects. Finally, the Proposed Action may also ameliorate certain stressors in the environmental baseline, and a description of these beneficial effects is provided.

5.2.3.1 Redd Stranding and Dewatering

The proposed storage and release of water associated with the Proposed Action may increase the stranding and dewatering stressor. The release of water from Shasta and Trinity reservoirs results in higher flows in the Sacramento River below Keswick Dam during the redd construction season. Higher flows do not increase the stranding and dewatering stressor; however, reducing releases in the fall reduces flows and shallow water winter-run Chinook salmon redds that are still occupied by incubating eggs may be dewatered. Water temperature management targeting colder temperatures will delay emergence and, thus, increase the likelihood of occupied redds when flows are reduced. Multiple topic-specific appendices address aspects of redd stranding and dewatering in the Sacramento River.

- Appendix L provides historical datasets and redd dewatering curves for relevant flows.
- Appendix H, *Conservation Measure Deconstruction*, presents analyses of "Minimum Instream Flows" and "Fall and Winter Minimum Flows" conservation measures.

The increase in stranding and dewatering stressors from the Proposed Action is expected to be **lethal**. Redds are defined as dewatered when an active redd has, at the minimum, its highest section (the tailspill mound) exposed to the air (Jarrett and Killam 2015). Eggs incubating in a redd that have been dewatered are no longer viable.

Although the Proposed Action may increase the redd stranding and dewatering stressor, winter-run Chinook salmon redd stranding and dewatering exists in the **environmental baseline** (without the Proposed Action). Physical attributes of the habitat and the magnitude of the change in flow drives the redd stranding and dewatering stressor (Windell et al. 2017). Historically, Chinook salmon in California rivers and streams, even before construction of CVP and SWP facilities, have been subject to redd stranding and dewatering. Flow fluctuations due to climate, hydrology and other factors contributed to the risk of redd stranding and dewatering. Natural flows would decrease through the summer without the release of water from Shasta Reservoir. Reclamation's past operation of Shasta Reservoir has influenced the flow of water in the Sacramento River. Reclamation has implemented the Fall and Winter Refill and Redd Maintenance action which coordinates with members of the Upper Sacramento Scheduling Team, a multi-agency group coordinating fall flow reductions to reduce stranding of winter-run Chinook salmon redds.

The **proportion** of the population affected by the Proposed Action depends on spawning timing, and duration of egg incubation, depth distribution of redds, and river stage, and is **likely small**.

Within the literature, winter-run Chinook salmon spawn in deeper water and dewatering has not been observed in fish monitoring during the summer (Memeo et al. 2018, 2019; Smith et al. 2020). Dudley et al (2022) modeled the depths of redds and found a preference for redd construction at 4.0 m but found observed redd depth averaged 2.7 m.

Datasets use historical conditions and observation to inform how winter-run Chinook salmon may respond to the Proposed Action. Historical monitoring may support or refute hypotheses and informs the reasonableness of information generated by models. Historically, a portion of the winter-run Chinook salmon population may be influenced by September to November flow reductions. Shallow redd records from 2021/2022 show that redds first observed as early as July were dewatered. Between 2014 and 2022, 44 out of 2,555 observed redds were dewatered (mean 1.0% +/- 1.5% SD; CalFish.org 2022 Carcass – Redds counts datasheet). Monitoring of shallow redds over the past decade has observed between 0 and 0.7% dewatering of winter-run Chinook salmon redds (mean 0.13% ± 0.002% SD), and the specific number depended on actions to conserve storage and protect fall-run Chinook salmon redds. Table 5-11 shows flows when redds were dewatered during 2021 and 2022. All six redds dewatered during 2021/2022 were in river miles 296 to 298 (ACID to Highway 44), which spatially match historic redd dewatering locations (2007 – 2022). The two 2021 redds represent 0.03% of the 2021 population (CalFish.org 2021 Carcass – Redds counts datasheet) and the four redds from 2022 represent 0.38% of the 2022 population (CalFish.org 2022 Carcass – Redds counts datasheet).

Table 5-11. Six Dewatered Winter-run Chinook Salmon Redds (2021–2022): Start Date, Depth, and Flow with Dewater Flow.

Start Date	Start Depth (in)	Start Flow (cfs)	Dewater Flow (cfs)
7/20/2021	4	9,729	7,000
8/3/2021	5	9,393	7,000
7/19/2022	7	4,511	4,100
7/19/2022	4	4,492	4,100
8/2/2022	4	4,559	3,900
8/2/2022	9	4,559	4,100

Models provide quantitative estimates of future conditions under the Proposed Action.

[Placeholder: for Sacramento River dewatering model (performance measure is redds dewatered)]

The **frequency** of occurrence is **high** and likely to occur annually. In the past 20 years, the frequency of lower releases in October than in August is close to 100%. Hence, after winter-run Chinook salmon construct their redds in August, flows are subsequently reduced in October, resulting in dewatering of some of the redds that were constructed in August with eggs still incubating in them.

To evaluate the **weight of evidence** for the stranding and dewatering stressor, there is a ten-year quantitative historical record of winter-run Chinook salmon redd monitoring and seasonal releases specific to the Sacramento River. There is limited literature regarding redd construction preference and utility are species-specific and location specific.

- Literature, Dudley: quantitative, species-specific, location-specific, both 2018 and 2019 published as peer-reviewed literature in multiple publications, individual-based model using multiple environmental parameters and inclusion of biological processes
- Historic stranding and dewatering observations: quantitative, species-specific, location-specific, available through multiple sources and QA/QCed from a long time-series, published in technical memos and annual reports from technical teams, not expected to have statistical power
- Historic flows associated with stranding and dewatering locations: quantitative, not species-specific (but not expected to be, environmental variable), location-specific, available through multiple sources and QA/QCed from a long time-series, published in technical memos and annual reports from technical teams, not expected to have statistical power

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- Minimum Instream Flows
- SRSC Transfer Delays

Conservation measures in the Proposed Action for other species, life stages and/or stressors that may exacerbate this stressor include:

- Fall and Winter Base Flows for Shasta Reservoir Refill and Redd Maintenance
- SHOT Water Transfer Timing Approvals

5.2.3.2 Redd Quality

The proposed release of water may decrease the redd quality stressor. During the egg incubation and fry emergence period, the Proposed Action will release water from Shasta and Trinity reservoirs to increase flows below Keswick Dam. Increased surface flows are likely to increase hyporheic flows that improve dissolved oxygen and additionally may reduce sedimentation improving egg and alevin essential functions and development (Bennett et al. 2003). Build-up of fine sediment can decrease permeability, decrease interstitial flow, and reduce oxygen availability for embryos (Bjornn and Reiser 1991). Oxygen levels can be variable due to random packing within the cluster and may become depleted as water flows through egg clusters (Martin et al. 2020). Eggs in the downstream half of a cluster can experience lower oxygen levels (Martin et al. 2020).

The decrease in the redd quality stressor is expected to be **beneficial**. In lab studies, Utz et al. (2013) found a statistically significant, positive relationship between mean interstitial flow velocity and survivorship for fall-run Chinook salmon embryos in a uniform porous substratum.

Although the Proposed Action may decrease the redd quality stressor, changes in winter-run Chinook salmon redd quality exists in the **environmental baseline** (without the Proposed Action). Gravel size and composition, flow, water temperature, dissolved oxygen, contaminants, sedimentation, and pathogens and disease drive the redd quality stressor (Windell et al. 2017). Many of these drivers are analyzed separately in this chapter. This particular subsection considers flows. Section 5.2.3.3, *Water Temperature*, considers another driver for the redd quality stressor.

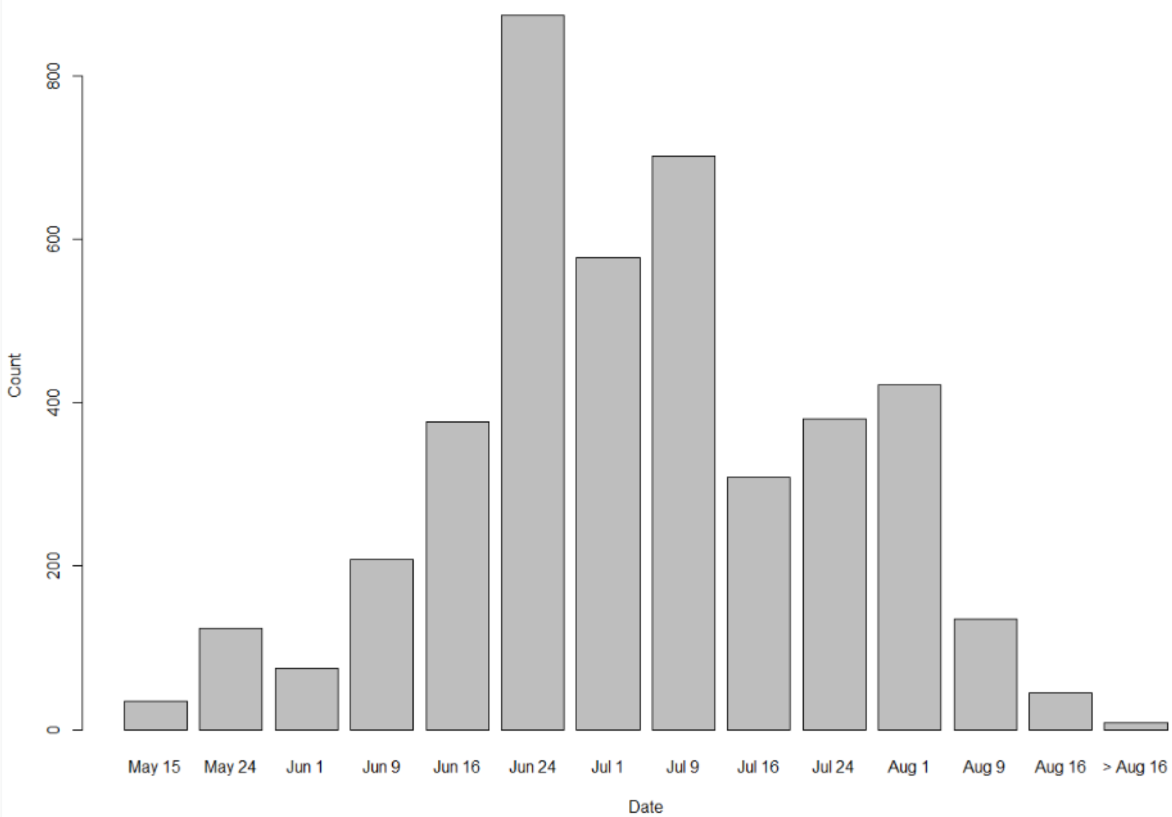
Non-discretionary flood control reduces peak flows that may mobilize the bed. Reclamation operates Shasta Dam in the winter for flood control, including both the channel capacity within the Sacramento River and Shasta Reservoir flood conservation space. Reclamation operates Shasta Dam for flood control in accordance with U.S. Army Corps of Engineers' 1977 *Master Manual of Reservoir Regulation for Shasta Dam and Lake*. Storage space in Shasta Reservoir has variable storage space requirements according to the current flood hazard as measured by the accumulation of seasonal inflow to the reservoir. Additionally, natural flows would decrease through the summer without the release of water from Shasta Reservoir.

Reclamation's past operation of Shasta Reservoir has influenced the flow of water in the Sacramento River. Reclamation has implemented the Fall and Winter Refill and Redd Maintenance action which coordinates with members of the Upper Sacramento Scheduling Team, a multi-agency group coordinating fall flow reductions to reduce stranding of winter-run Chinook salmon redds.

The **proportion** of the population affected by the Proposed Action is **likely large**. Redd quality depends on spawning timing, duration of egg incubation, and river stage. The majority of redds experience elevated flows which may provide more suitable water quality parameters.

Literature does not uniquely inform the proportion of the population.

Datasets use historical conditions and observation to inform how winter-run Chinook salmon may respond to the Proposed Action. Historical monitoring may support or refute hypotheses and informs the reasonableness of information generated by models. Figure 5-7 shows the timing of winter-run Chinook salmon redds, which corresponds to periods of higher flows associated with the Proposed Action. Timing may vary between years, but redd construction still occurs during times of proposed higher flows.



Source: CalFish.org 2022 Carcass – Redds counts datasheet

Figure 5-7. Winter-run Chinook Salmon Redd Timing, 2013–2022.

Models do not uniquely inform the proportion of the population.

The **frequency** of occurrence is **likely high** and occurs annually in all years (1994-2022) during May to July flows increase at Keswick. Flows generally are high during egg incubation.

To evaluate the **weight of evidence** for the redd quality stressor, there is a 20-year quantitative historical record of winter-run Chinook salmon redd monitoring and seasonal releases specific to the Sacramento River. These data are quantitative, species-specific, location-specific, available through multiple sources and QA/QCed from a long time-series, published in technical memos and annual reports from technical teams, but are not expected to have statistical power. Published literature used showing emergence and survival as functions of flow-influenced sedimentation are specific to Chinook salmon, but not specific to winter-run Chinook salmon nor to the Sacramento River.

- Historic winter run timing observations: quantitative, species-specific, location-specific, available through multiple sources and QA/QCed from a long time-series, published in technical memos and annual reports from technical teams, not expected to have statistical power
- Historic flows: quantitative, not species-specific (but not expected to be, environmental variable), location-specific, available through multiple sources and QA/QCed from a long time-series, published in technical memos and annual reports from technical teams, not expected to have statistical power

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- SHOT Water Transfer Timing Approvals

Conservation measures in the Proposed Action for other species, life stages and/or stressors that may exacerbate this stressor include:

- Allocation Reductions for Shasta Reservoir End of September Storage
- Rebalancing between other CVP Reservoirs for Shasta Reservoir End of September Storage
- Reduced Wilkins Slough Minimum Flows for Shasta Reservoir End of September Storage
- SRSC Diversion Spring Delays and Shifting
- Minimum Refuge Summer Deliveries North of Delta
- Drought Actions

5.2.3.3 Water Temperature

The proposed release and blending of water may increase or decrease the water temperature stressor. During egg incubation and fry emergence, the Proposed Action will blend water from different elevations in Shasta Reservoir and import water from Trinity Reservoir to manage water temperatures below Keswick Dam. Appendix L provides an analysis of water temperature related effects on incubating eggs.

Releases are expected to be **beneficial** overall; however, certain temperature management actions may be **lethal** to some individuals. Winter-run Chinook salmon eggs require cool water temperatures to incubate.

Although the Proposed Action may, at times, increase the water temperature stressor, unsuitable water temperatures for winter-run Chinook salmon egg incubation and fry emergence exists in the **environmental baseline** (without the Proposed Action). The amount of precipitation, local ambient air temperatures and solar radiation drives the water temperature stressor (Windell et al. 2017). It is expected that climate change should result in warmer air temperature and shift in forms of precipitation, with more precipitation falling as rain, which will exacerbate water temperatures in the reservoirs.

In the absence of releases of stored water for water service and water temperature management purposes, flows would remain low in the summer and fall. Water temperatures would increase to levels that result in mortality of winter-run Chinook salmon eggs and fry. In 1997, Reclamation completed the TCD at Shasta Dam, which can be used to effectively blend water from the warmer upper reservoir levels, and thereby extend the time period in which cold water can be provided downstream. Reclamation's past operation of Shasta Reservoir has influenced the flow of water in the Sacramento River. Different approaches have targeted different temperatures and locations throughout the years, including a warmwater bypass to conserve limited coldwater pool.

The **proportion** of the population affected by the Proposed Action depends on hydrology, meteorology, storage in Shasta and Trinity reservoirs, releases from Keswick Reservoir, operation of the TCD, distribution of redds, spawning timing, and duration of egg incubation Years with abundant cold water will provide beneficial effects to a proportion of the population that is **likely large** with water temperatures that are lethal affecting a proportion of the population that is **likely small**. Redds further upstream will experience colder water than redds downstream. Eggs and alevin from adults which spawn later in the season (e.g., June or July) may emerge during the period when the coldwater pool volume is diminished, experiencing poor water temperature conditions. Conversely, when adult winter-run Chinook salmon spawn earlier in the season, this provides additional time for eggs to incubate and fry to emerge during more suitable flow and water temperature conditions.

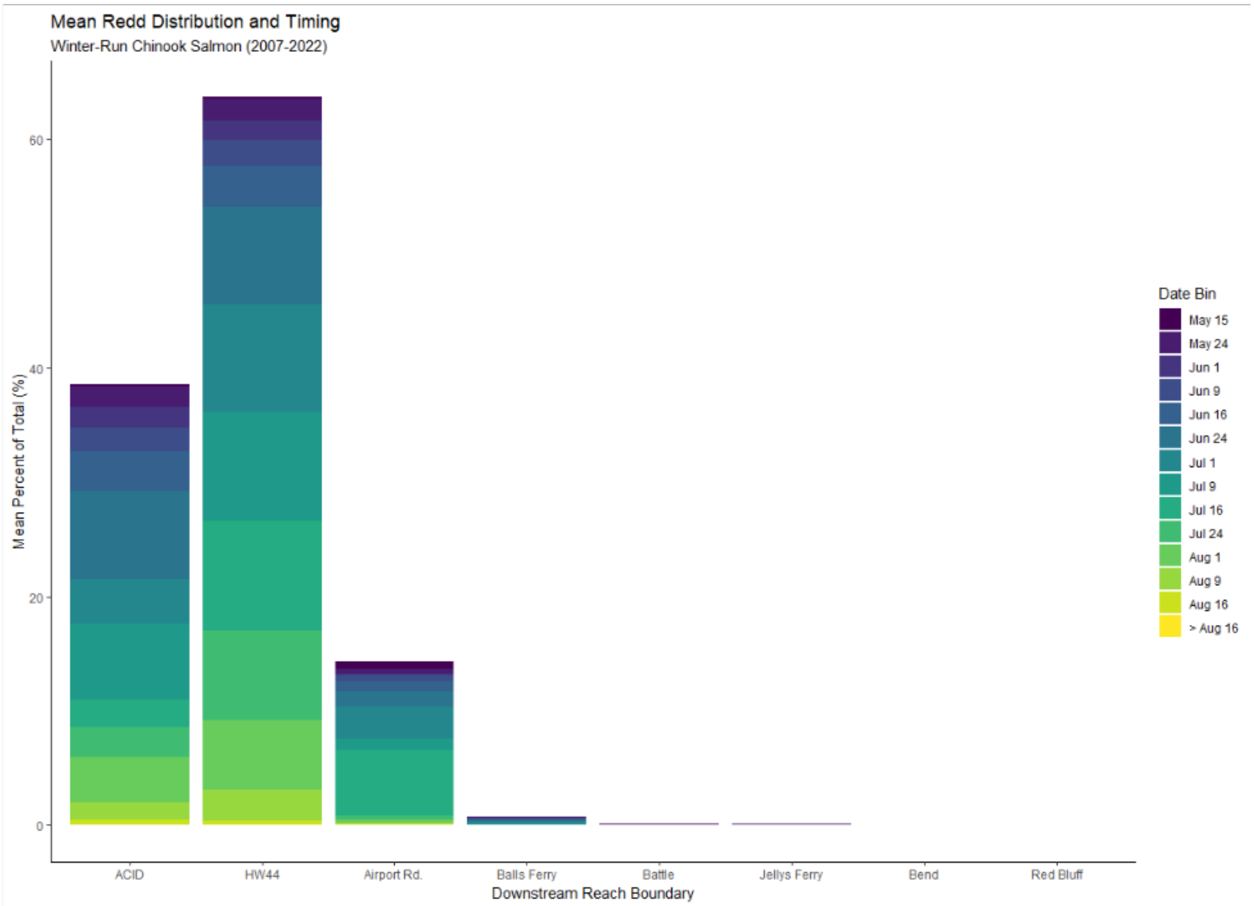
Literature on critical water temperatures historically identified 56°F as the threshold temperature to protect incubating eggs. Martin et al. (2017) applied statistical models calibrated to survival to Red Bluff to identify a critical threshold of 53.5°F at which no mortality would be expected. Subsequent studies, e.g., Del Rio et al. (2019), have explored temperatures and hypoxia to identify temperatures warmer than 53.5°F depending on dissolved oxygen.

Datasets use historical conditions and observation to inform how winter-run Chinook salmon may respond to the Proposed Action. Historical monitoring may support or refute hypotheses and informs the reasonableness of information generated by models. Aerial redd data from 2002-2022 shows 99.2% of all observed redds were observed at or upstream of RKM 470 (Table 5-12).

Table 5-12. Proportion of Winter-run Chinook Salmon Redds by Location and Total Number of Redds, 2002–2022.

Year	Keswick to ACID Dam	ACID Dam to Hwy 44	Hwy 44 to Airport Rd	Airport Rd to Balls Ferry	Balls Ferry to Battle Crk	Number of Redds
2002	0.488	0.220	0.276	0.011	0.005	609
2003	0.661	0.173	0.163	0.003	0	875
2004	0.164	0.346	0.486	0.003	0	621
2005	0.523	0.356	0.119	0.002	0	1968
2006	0.350	0.490	0.161	0	0	715
2007	0.528	0.319	0.113	0.021	0.018	282
2008	0.512	0.408	0.077	0.002	0	441
2009	0.163	0.837	0	0	0	86
2010	0.480	0.480	0.040	0	0	223
2011	0.056	0.722	0.222	0	0	18
2012	0.639	0.358	0.003	0	0	288
2013	0.761	0.225	0.014	0	0	568
2014	0.559	0.370	0.071	0	0	127
2015	0.397	0.592	0.011	0	0	174
2016	0.667	0.333	0	0	0	18
2017	0.885	0.115	0	0	0	26
2018	0.273	0.657	0.071	0	0	198
2019	0.017	0.496	0.411	0.077	0	515
2020	0.466	0.460	0.073	0.073	0	491
2021	0.573	0.423	0.002	0	0	578
2022	0.530	0.448	0.002	0	0	406

Figure 5-8 shows historic redd timing and location. The majority (> 80%) of total redds (2007–2022) were found upstream of Highway 44.



Source: CalFish.org 2022 Carcass – Redds counts datasheet

Figure 5-8. Winter-run Chinook Salmon Redd Distribution and Timing, Mean Percent of Total by Reach and Date, 2007–2022.

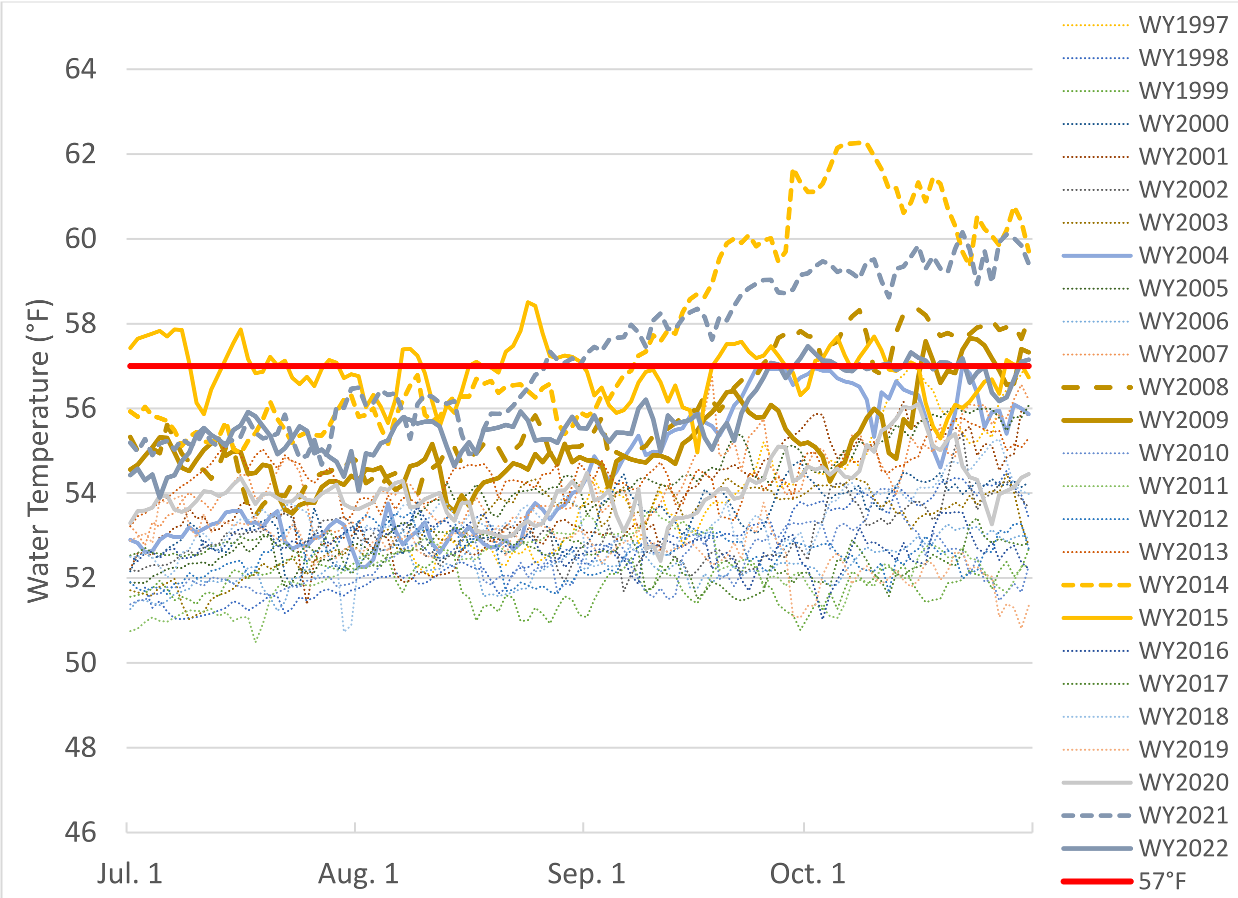
Estimates of temperature dependent mortality for winter-run Chinook salmon redds vary by year, model (stage-dependent and -independent), and critical temperature threshold (T-Crit). Table 5-13 shows estimated historical temperature-dependent mortality (TDM) and measured egg-to-fry survival. Factors such as spawn timing and location affecting proportion vary with different coldwater pool management approaches (Dusek Jennings and Hendrix 2020; Dudley et al. 2022) are assumed not to vary in this qualitative analysis.

Table 5-13. Stage-independent (Martin et al. 2017) and stage-dependent (Anderson et al. 2022) Temperature Dependent Mortality (TDM) and Egg-to-fry Survival at Red Bluff Diversion Dam by Brood Year 2002–2021.

Brood Year	Stage-independent TDM	Stage-dependent TDM	Egg-to-Fry Survival
2021	76%	76%	2.5%
2020	5	5	11%
2019	6	6	18%
2018	0	0	27%
2017	0	0	49%
2016	0	0	24%
2015	90	90	5%
2014	83	83	6%
2013	13	13	15%
2012	0	0	27%
2011	0	0	49%
2010	0	0	38%
2009	30	30	34%
2008	45	45	18%
2007	6	6	21%
2006	0	0	15%
2005	8	8	19%
2004	49	49	21%
2003	2	2	23%
2002	1	1	27%

Based on historic aerial redd survey data and temperature from the gauge above Clear Creek.

Figure 5-9 shows historical water temperatures with years of poor egg to fry survival highlighted. All years have a portion of the end of the season at or above 57°F at CCR.



Source: Slater 1963).

Figure 5-9. Historical Water Temperatures at CCR for the lowest measured historical egg to fry survival with 56.5°F reference line

Figure 5-10 shows years with higher egg to fry survival. Three of the years have temperatures above 53.5°F in October. Water year 2009 was consistently warmer than 53.5°F.

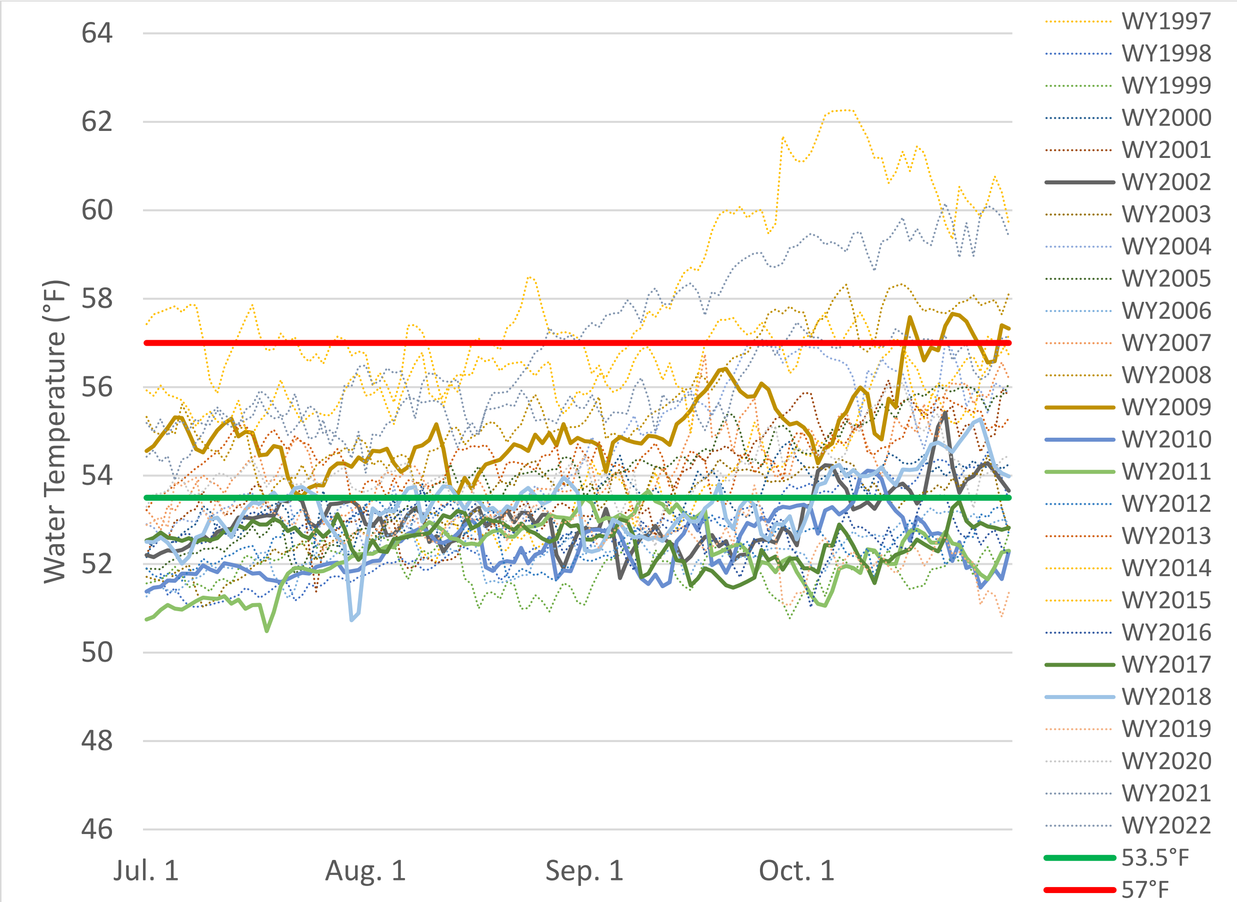


Figure 5-10. Historical Water Temperatures at CCR for the Highest Measured Historical Egg-to-fry Survival with 56.5°F (Slater 1963) and 53.6°F (Martin 2017) Reference Lines.

Models provide quantitative estimates of future conditions under the Proposed Action. Reclamation evaluated multiple lines of evidence, with different assumptions and complexity, to narrow the likely range of potential effects.

Models of temperature-dependent mortality of eggs and alevin (Appendix L, Attachment L.3, *Egg-to-fry Survival and Temperature-Dependent Mortality*) estimate the proportional mortality due to temperature effects using either the Martin et al. (2017) or Anderson et al. (2022) models. Both models specify egg mortality as a function of water temperature (i.e., temperature-dependent mortality, or TDM), applied over either the entire embryonic developmental period 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. The models are sensitive to the temperature target, locations, and timing. The Proposed Action developed bins with different water temperature management biological goals and objectives ("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 ("2021 Updated Tier Strategy").

Figure 5-11 shows the Martin et al. TDM estimates under the Proposed Action with targeting the temperatures, locations, and timing from the Bin Criteria. The No Action Alternative (NAA) included temperature shaping based on the 2021 Updated Tier Strategy.

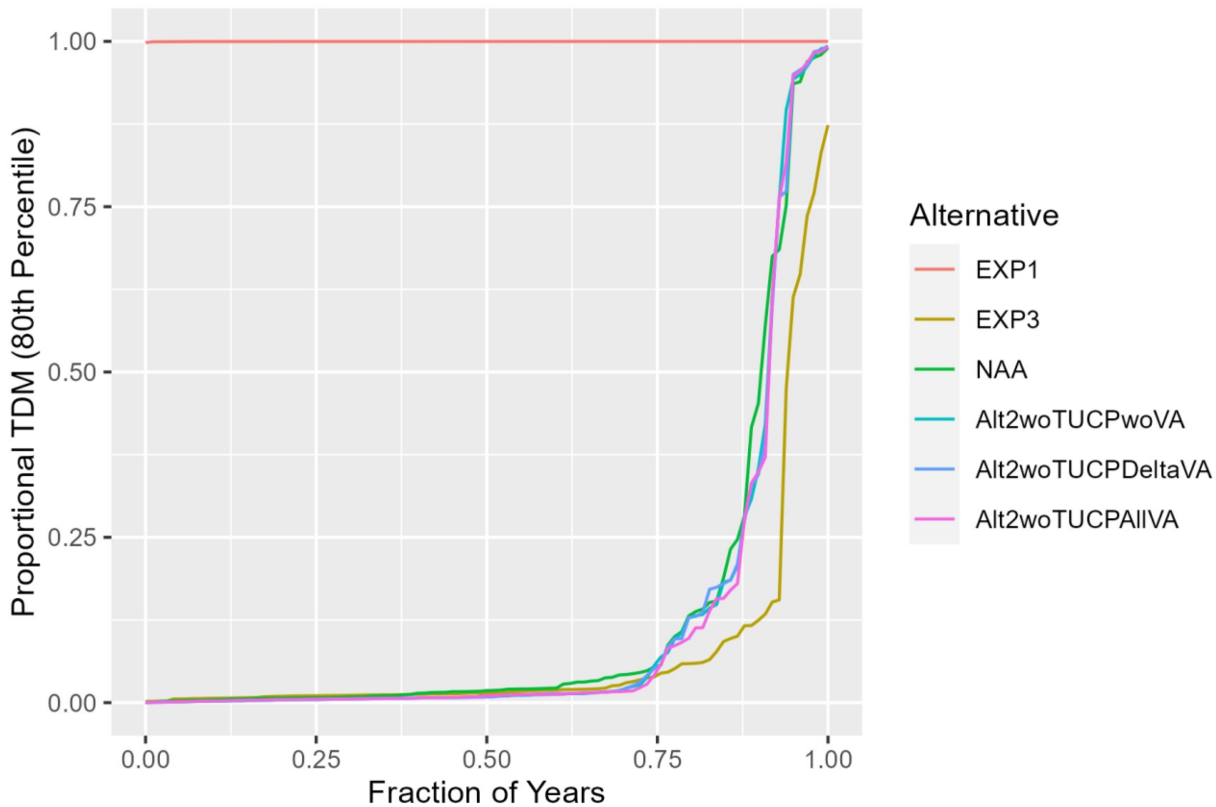


Figure 5-11. Exceedance Plots of Proportional Temperature Dependent Mortality (TDM) Estimates across All Water Years (WY) for the Martin TDM Model and Shasta Management Framework Bin Criteria, Calculated using the 80th Percentile of TDM for each CalSim WY.

The Proposed Action anticipates shaping temperatures to optimize low TDM. Figure 5-12 shows the 2021 Updated Tier Strategy applied to the Proposed Action phases as well as the No Action Alternative.

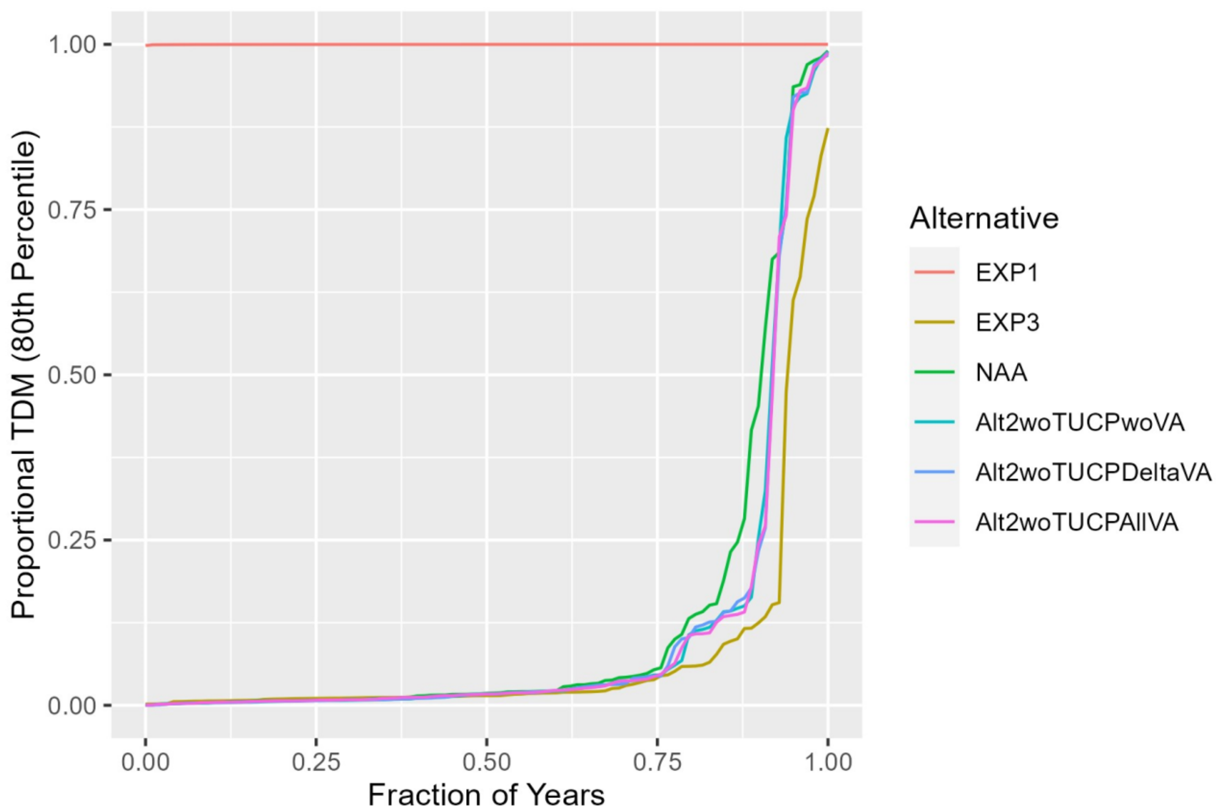


Figure 5-12. Exceedance Plots of Proportional Temperature Dependent Mortality (TDM) Estimates across All Water Years (WY) for the Martin TDM Model and an Updated Tiered Temperature Strategy, Calculated using the 80th Percentile of TDM for each CalSim WY.

The Martin et al. model is independent of egg incubation stages, while the Anderson model is more sensitive to water temperatures at specific egg development stages ("stage-dependent"). Figure 5-13 shows the different estimates in TDM between the two models.

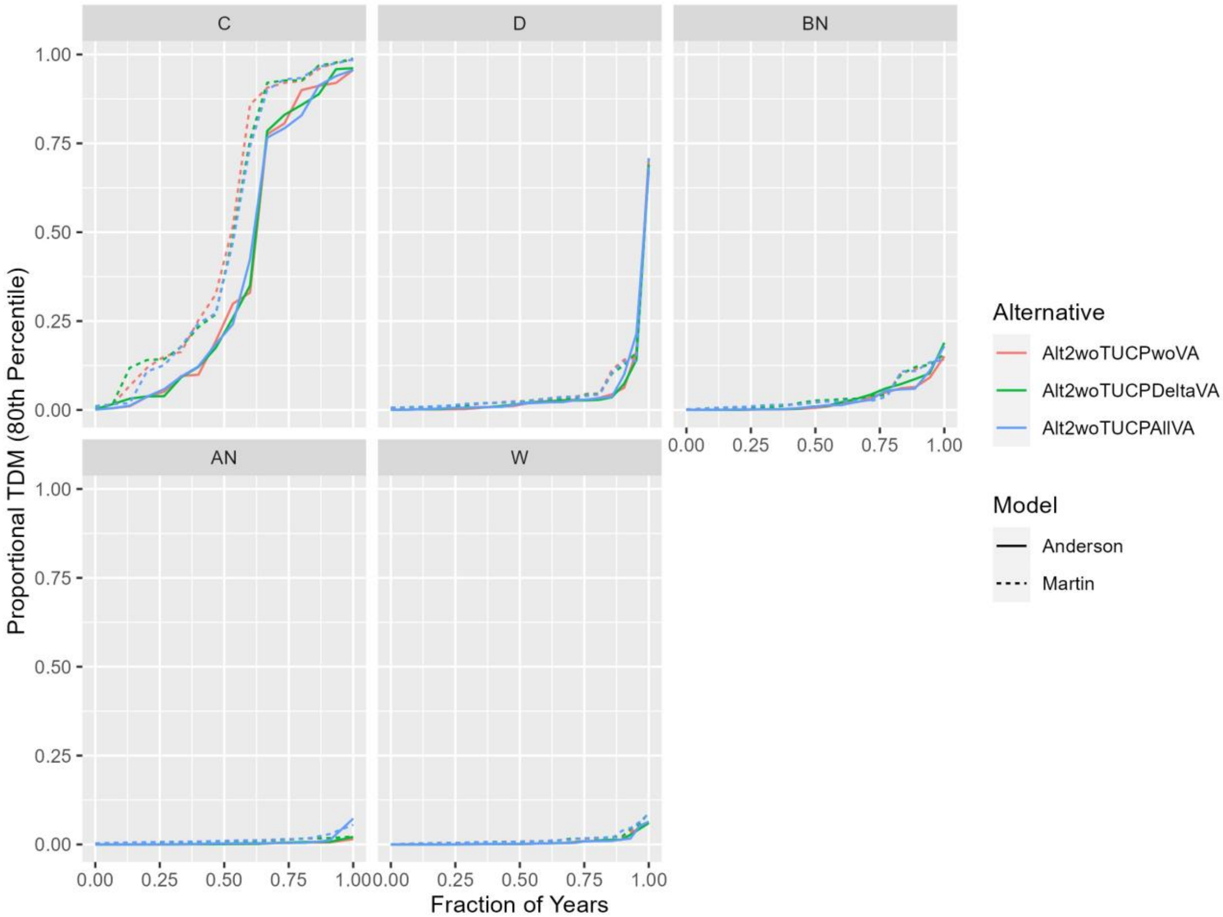
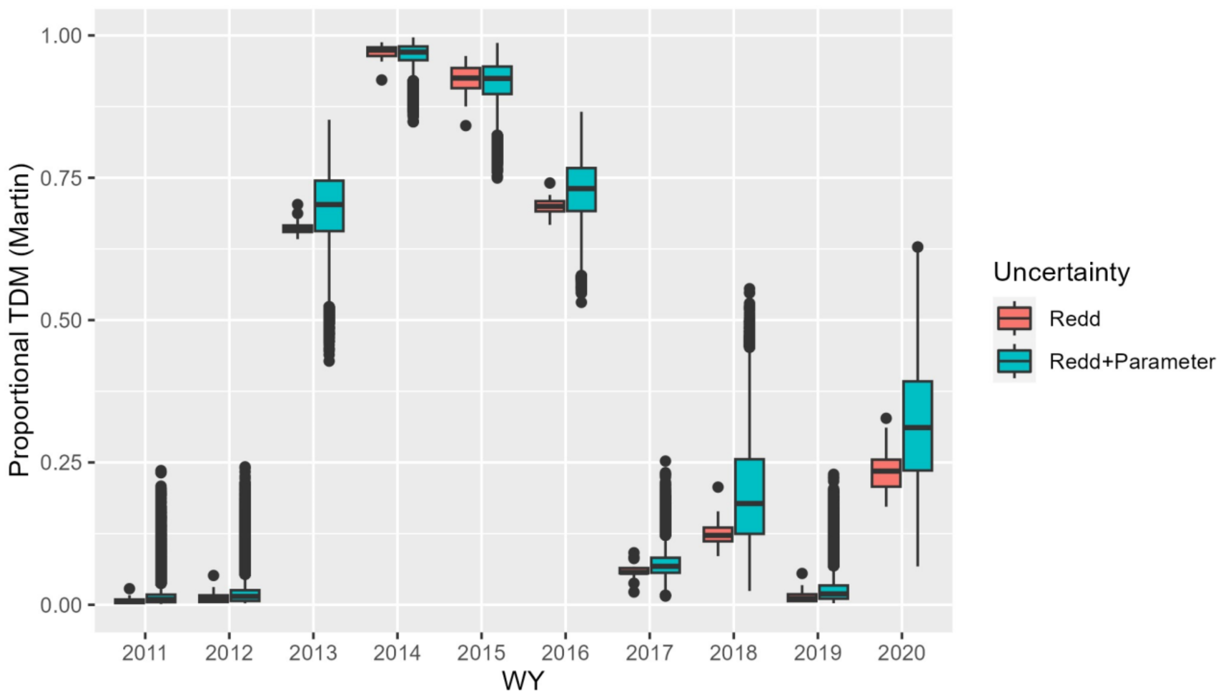


Figure 5-13. Exceedance Plots of Proportional Temperature Dependent Mortality (TDM) Estimates across all Water Years (WY) for the Martin and Anderson TDM Models using the Updated Tiered Temperature Strategy, Calculated using the 80th Percentile of TDM for each CalSim WY.

Overall, the TDM does not vary much except during critical water year types. For select recent WYs, alternatives, and models, annual TDM estimates varied by as much as 0.25 due to uncertainty in spatial and temporal redd distributions (Figure 5-13). For recent CalSim water years 2011-2020, expected proportional TDM values for the NAA with targeting the temperatures, locations, and timing from the Bin Criteria had noticeably greater variation when both redd and parameter uncertainty were included than when only redd uncertainty was included (Figure 5-14). The Proposed Action is anticipated to be similarly sensitive.



Boxplots summarize TDM variability across either only different annual redd distributions or both different redd distributions and posterior parameter estimates.

Figure 5-14. Trends in Proportional Temperature Dependent Mortality (i.e., Martin model only) for CalSim 3 Water Years 2011-2020 for the No Action Alternative.

An analysis of covariates that include flow as well as temperature analyzed factors for egg to fry survival at Red Bluff Diversion Dam, Appendix L, Attachment L.3. The actions to manage for temperatures rely on reducing releases from Shasta Reservoir to increase reservoir storage and the related coldwater pool. Egg to fry survival at Red Bluff Diversion Dam was not sensitive to temperatures within the historical range and was sensitive flows.

[Placeholder: for Winter-run Chinook salmon JPI environmental covariate analysis]

HEC-5Q modeling analysis enumerates the frequency at which mean monthly simulated water temperatures exceed water temperature criteria obtained from scientific literature.

[Placeholder: for Hec-5Q temperature results]

Actions in most years to reduce flows for water temperature management in critical years may affect egg to fry survival during years intended to maintain and recover populations. Colder water temperatures may not benefit survival to Red Bluff Diversion Dam and may be an artifact of TDM model frameworks and statistical fits to certain years.

The **frequency** of occurrence is **likely medium**. The water temperature stressor is dependent on coldwater pool availability and is affected primarily by hydrology and meteorology. 1998 through 2022 historic stage-dependent TDM estimates occurred above 25% occurred 7 times (28%) and historic stage-independent TDM estimates occurred above 25% 8 times (32%). However, the subset of data from the recent historic record has more frequent drought conditions than the longer period of record.

For the Anderson and Martin models, greater than 75% of modeled WYs resulted in expected proportional TDM values less than 0.125 (Figure 5-11). For critical WYTs only, at least 12.5% of modeled WYs resulted in expected proportional TDM values greater than 0.5; for wet WYTs only, expected proportional TDM never exceeded 0.125.

In the Proposed Action, storage and temperature operation Goals and Indicators include End-of April (EOA) storage and project End-of-September (EOS) storage thresholds which sort Shasta actions into various "bins". These Goals and Indicators are operational surrogates for winter-run Chinook salmon temperature management biological objectives. The frequency of these storage targets are measured in Appendix L, Attachment L, *CWP Storage and Coldwater Pool Exceedance Analysis* and can inform the frequency of temperature management being in each bin (Table 5-14 and Table 5-15). The Proposed Action phase without TUCP and with systemwide VA met the EOS storage Bin 1B target most frequently (90% of years) of the Proposed Action phases. Bin 2A EOS targets were met most frequently by the Proposed Action phase without TUCP and with systemwide VA (78%) while it was least frequently met in the Proposed Action phase without TUCP and without VA. Bin 2B EOS storage targets were met all the time in all three Proposed Action phases without TUCPs. Bin 3A EOS targets were met 27% of the years in the proposed Action phase without TUCP and with systemwide VA and least often in the Proposed Action phase without TUCP without VA. Bin 3B EOS was met less frequently ranging from 13% in the Proposed Action phase without TUCP and with Delta VA and the Proposed Action phase without TUCP and with systemwide VA and 0% of the time in the Proposed Action phase without TUCP without VA.

Table 5-14. Percent of Years where Proposed Action End-of-September Storage Targets Are Met for Each Bin.

Bin	**Projected EOS Storage Target**	**Alt2woTUCPwoVA**	**Alt2woTUCPDeltaVA**	**Alt2woTUCPAllVA**
Bin 1A	3.0 MAF	100% (18 of 18)	100% (18 of 18)	100% (19 of 19)
Bin 1B	2.4 MAF	88% (45 of 51)	88% (43 of 49)	90% (44 of 49)
Bin 2A	2.4 MAF	63% (5 of 8)	70% (7 of 10)	78% (7 of 9)
Bin 2B	2.2 MAF	100% (5 of 5)	100% (4 of 4)	100% (4 of 4)
Bin 3A	2.2 MAF or 2.0 MAF	20% (2 of 10)	27% (3 of 11)	27% (3 of 11)
Bin 3B	2.0 MAF	0% (0 of 8)	13% (1 of 8)	13% (1 of 8)

EOS = end of September.

Table 5-15. Bin Assignments in Proposed Action, based on End-of-April Storage.

Bin	**Projected EOS Storage Target**	**Alt2woTUCPwoVA**	**Alt2woTUCPDeltaVA**	**Alt2woTUCPAllVA**
Bin 1	At least 3.7MAF	69	67	68
Bin 2	At least 3.0MAF	13	14	13
Bin 3	Less than 3.0 MAF	18	19	19

EOS = end of September.

To evaluate the **weight of evidence** for the water temperature stressor includes a twenty-year quantitative historic record of winter-run Chinook salmon redd monitoring and seasonal temperature data. Studies have been conducted to identify the critical temperature for material egg mortality and the rate at which mortality increases above that threshold. Studies are both lab-based and location-specific for winter-run Chinook salmon. For more detailed information on studies, refer to Appendix L.

- Literature, Slater (1963): quantitative, species-specific, not location-specific (lab rearing study), single "special scientific report" for USFWS, report presents monitoring records
- Literature, USFWS (1999): quantitative, species-specific, not location specific (lab study), single report for USFWS, report presents results from a lab study for relationship between temperature and mortality
- Literature, U.S. Environmental Protection Agency report (2003): quantitative, not species-specific, not location specific, published report with foundation for guidance reflected in six scientific papers, report presents U.S. Environmental Protection Agency guidance for water temperatures
- Historic water temperatures: quantitative, not species-specific (but not expected to be, environmental variable), location-specific, available through multiple sources and QA/QCed, long time-series and not expected to have statistical power
- Historic ETF values: quantitative, species-specific, location-specific, available through multiple agency publications and QA/QCed, and not expected to have statistical power
- Historic TDM values: quantitative, species-specific, location-specific, available through multiple agency publications and QA/QCed, and not expected to have statistical power.
- Historic spawning timing observations: quantitative, species-specific, location-specific, available through multiple sources and QA/QCed, long time-series and not expected to have statistical power
- CalSim Reservoir Storage modeling LOE: quantitative, not species-specific (but not expected to be, environmental variable), location-specific, model developed to evaluate reservoir storage using control points, widely accepted as monthly flow and storage modeling system for use in the Central Valley

- Hec-5Q water temperature modeling LOE: quantitative, not species-specific (but not expected to be, environmental variable, location-specific, model developed to evaluate reservoir system using control points, widely accepted as temperature modeling system for use in the Central Valley upper watershed
- TDM, Martin - modeling LOE: quantitative, species-specific, location-specific, study published in a peer reviewed journal, considered single covariate
- TDM, Anderson – modeling LOE: quantitative, species-specific, location-specific, single study published in a per-reviewed journal, considered similar framework as Martin (Above) with additional parameters (resolution on background mortality)

The Proposed Action includes a special study to evaluate flow and water temperature management for winter-run Chinook salmon egg to fry survival. Low TDM is a poor predictor of survival to Red Bluff Diversion Dam; however, there are no years with high TDM that also show strong egg to fry survival. Years with high model estimates of temperature dependent mortality correspond to water temperature conditions warmer than 57°F. The Martin and Anderson models' calibration to juveniles at Red Bluff Diversion Dam may be attributing effects to water temperature that are due to low flows. Higher flows that meet a warmer critical temperature may improve egg to fry survival and better support water supply project purposes. The winter-run Chinook salmon early life stage special study will explore mechanistic drivers that continue to refine critical water temperatures for incubating eggs and evaluate fry survival based on flow, habitat, and other conditions.

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- Shasta Reservoir Water Temperature and Storage Management
- Allocation Reductions for Shasta Reservoir End of September Storage
- Rebalancing between other CVP Reservoirs for Shasta Reservoir End of September Storage
- Reduced Wilkins Slough Minimum Flows for Shasta Reservoir End of September Storage
- Minimum Refuge Summer Deliveries North of Delta
- SRSC Diversion Spring Delays and Shifting
- Drought Actions

Conservation measures in the Proposed Action for other species, life stages and/or stressors that may exacerbate this stressor include:

- Voluntary Agreement Pulse Flows
- Sacramento River Pulse Flows
- Adult Migration and Holding Water Temperature Objectives

- SHOT Determination on Temperature Shoulders (requiring releases too cold too early and exhausting coldwater pool)
- SHOT Water Transfer Timing Approvals (Denials that precludes water transfers)

5.2.4 Juvenile Rearing and Outmigration

Juvenile winter-run Chinook salmon begin to emigrate soon after emergence from the gravel. Growing juveniles move into deeper waters with higher current velocities (Healey 1991). Peak passage (50% of run arrival, brood years 2008 – 2021) at Red Bluff Diversion Dam occurs by late October. Winter-run Chinook salmon outmigration historically is complete (95% passage, brood years 2008 – 2021) by middle of December with only a few late fish emerging and emigrating in the spring. The survival of juveniles in the Sacramento River downstream of Red Bluff Diversion Dam is addressed primarily under the outmigration cues stressor while the survival of juveniles in the Delta is addressed primarily by entrainment risk.

Juveniles pass through the upper and middle Sacramento River from Red Bluff Diversion Dam to Knights Landing and the Sacramento Trawls in September through February. By January, juvenile winter-run Chinook salmon are reaching the size that smoltification occurs, and the majority of smolts would be moving downstream to enter the Delta.

Movement of juvenile winter-run Chinook salmon occurs within the Bay-Delta October through April. 95% passage of juvenile winter-run Chinook salmon at Knights Landing on the Sacramento River (brood years 2008 – 2021) historically occurs by middle of February. A portion of juveniles, particularly those which emigrated earlier in the season, may remain in the Bay-Delta rearing and foraging before continuing emigration to the ocean. Peak juvenile winter-run Chinook salmon occurrence is expected in the Delta November through April and 95% passage (brood years 2008 – 2021) at Chipps Island historically occurs by middle of April.

Stressors that may change at a level that is insignificant or discountable include:

- The Proposed Action may increase or may decrease the *pathogens and disease* stressor. During the juvenile rearing and outmigration period, releases of Shasta Reservoir storage may result in cooler water temperatures and higher flows in the Sacramento River while operations will decrease flows in the Delta. The influence of the operation of the CWP and SWP on water temperatures potentially influences pathogens; however, effects of pathogens and disease have not been observed in fish monitoring.

  Juvenile survival is influenced by specific diseases (e.g., *Ceratomyxa shasta*, furunculosis) present in the Sacramento River (reviewed in Lehman et al. 2020). Though a decrease in flows may influence pathogen and disease exposure, including increased transfer from hatchery fish to natural-origin juveniles; transmission directionality is difficult to track and evidence of transfer is lacking (Naish et al. 2007; Kent 2013; Nekouei et al. 2019). McCollough (1999) reported a 59.9°F water temperature threshold as the threshold above which diseases affecting Chinook salmon become highly virulent.

Historic water temperatures in the Bay-Delta (Prisoner's Point) during juvenile outmigration exceed 59.9°F. However, the volumes of water required to overcome ambient air temperatures make the operation of the CVP and SWP unlikely to influence water temperatures in the Delta.

- The Proposed Action may increase the *toxicity and contaminants* stressor. During the juvenile rearing and outmigration period, releases of Shasta Reservoir storage may result in higher flows in the Sacramento River while operations will decrease flows in the Delta. Reduced flows may concentrate contaminants if, and when contaminants are present, and increased flows may dilute contaminants. However, increased flows and pulses can mobilize suspended sediments consisting of contaminants in river systems (van Vliet et al. 2023). The timing of snowmelt may also play a role in this stressor though deposited pollutants in dust though studies on contaminants present in snowmelt and rainfall runoff have reported differing results (Parajulee et al. 2017; Chen et al. 2018).

  On the Sacramento River, releases as part of the Proposed Action would be below the bankfull flows that would mobilize present contaminants. Monitoring has not shown fish kills that may be indicative of contaminants at levels likely to affect juvenile winter-run Chinook salmon.

  Juveniles exposed to toxins may experience effects such as reduced growth or suppression of juvenile immune systems possibly leading to infection and disease (Arkoosh et al. 2001; Kroglund and Finstad 2003Lundin et al. 2021). There is little *in-situ* evidence supporting the presence of toxicity and contaminants in juvenile winter-run Chinook salmon. Historical fisheries monitoring has not reported large-scale evidence of toxicity and contaminants in Bay-Delta fishes. Studies have shown a 0.2 mg/kg threshold for methylmercury as protective of both juvenile and adult fish (Beckvar et al. 2005Tissue concentrations of Feather River Hatchery juveniles were reported for 199 samples, and approximately 1% of sampled fish (n = 2; 0.234 mg/kg in a floodplain fish and 0.269 mg/kg in a Sacramento River fish) in winter floods between 2001 and 2005 were above this threshold (Henery et al. 2010

- The Proposed Action may increase the *predation and competition* stressor. During the juvenile rearing and outmigration period, the Proposed Action reduces Delta inflow and outflow, which may alter hydrodynamic conditions in the Sacramento River and Delta. Storage of water in Shasta Reservoir, particularly in the winter from December through February, may affect juveniles' outmigration travel rates. Increased travel time (slower travel rates) and migration routing, particularly into suboptimal habitat with high predator abundance in the Sacramento River mainstem and the central and south Delta, may lead to increased predation. If fish travel rates through the system increase, the delay increases the risk of exposure to predation. Predation studies in the Sacramento River at Red Bluff Diversion Dam also document predation on Chinook salmon (Tucker et al. 1998). Certain locations in the Delta (e.g., Clifton Court Forebay, the scour hole at Head of Old River, Delta fish collection facilities, the Delta Cross Channel gates) are considered predator hotspots and operations of these facilities are operating, juvenile winter-run Chinook salmon will be exposed to predation. Studies have been conducted as far back as the 1980s on the abundance of predatory fish inhabiting Clifton Court Forebay (Kano 1990;

Gingras and McGee 1997) and more recent studies have predicted high predation hazard for scour holes like the Head of Old River site (Michel et al. 2020). Predation and competition is not independent from other stressors, such as refuge habitat, food availability and quality, entrainment risk, and outmigration cues. Predation effects associated with the Proposed Action are captured in the analysis of these stressors. Any residual effects of predation and competition associated with the Proposed Action is considered insignificant.

Described below are stressors exacerbated by the Proposed Action, potentially resulting in incidental take. Also described below are conservation measures included as part of the Proposed Action to avoid or compensate for adverse effects. Finally, the Proposed Action may also ameliorate certain stressors prevalent in the environmental baseline, and a description of these beneficial effects is provided below.

5.2.4.1 Stranding Risk

The proposed storage and release of water associated with the Proposed Action may increase the stranding risk stressor. During the juvenile rearing and outmigration period, reducing flows from Shasta Reservoir can trap juveniles in habitat disconnected from the main channel. Appendix H presents analyses of "Minimum Instream Flows" and "Ramping Rates" conservation measures.

The increase in stranding risk stressors from the Proposed Action is expected to be **lethal**. Where habitats are desiccated, fish cannot survive, or they may be in isolated pools or shallow areas off the mainstem increasing their exposure to higher levels of predation.

Although the Proposed Action may increase the stranding risk, stranding of juvenile winter-run Chinook salmon exists in the **environmental baseline** (without the Proposed Action). The physical attributes of the habitat and magnitude of the change in flows drive the stranding stressor (Windell et al. 2017). Historically, fish in California rivers and streams, even before construction of CVP and SWP facilities, have been subject to stranding and dewatering. Flow fluctuations due to hydrology and other factors contributed to the risk of dewatering and stranding. As part of routine Chinook salmon monitoring in the Sacramento River, CDFW identifies juveniles stranded in isolated pools and relocates them back to the main channel. Reclamation's past operation of Shasta Reservoir has influenced the flow of water in the Sacramento River. Reclamation has implemented the Fall and Winter Refill and Redd Maintenance action which coordinates with members of the Upper Sacramento Scheduling Team. While the multi-agency group coordinates fall flow reductions mainly to reduce dewatering of winter-run Chinook salmon redds, members also consider whether proposed flows may strand juveniles.

The **proportion** of the population affected by the Proposed Action depends on the presence of juveniles and hydrology and is **small**. Historically, peak passage of winter-run Chinook salmon juveniles at Red Bluff Diversion Dam occurs by late October, in which 90% passage occurred before October 31 in 15 out of 18 years between 2004 and 2021, with outmigration from the Sacramento River completed by the middle of December. After November, when flow reduction starts in the Proposed Action, a portion of the current brood year winter-run Chinook salmon are potentially at risk of stranding.

Literature does not uniquely inform the proportion of the population affected.

Datasets use historical conditions and observation to inform how winter-run Chinook salmon may respond to the Proposed Action. Historical monitoring may support or refute hypotheses and informs the reasonableness of information generated by models. The utilization of minimum flows and ramping rates resulted in an average of 1,382 winter-run Chinook salmon per year stranded between 2013 – 2021 (minimum: 162 fish; maximum: 7,766 fish). This was between 0.003 % and 0.526 % of the annual juvenile production index (JPI) at Red Bluff Diversion Dam (Table 5-16).

Table 5-16. Winter Chinook Fry-equivalent Juvenile Production Indices (JPIlower and upper 90% confidence intervals (CI) by brood year (BY) for Red Bluff Diversion Dam (RKM 391) Rotary Traps between July 2002 and June 2020.

BY	Fry Equivalent JPI	Lower 90% CI	Upper 90% CI	Direct Count of WR Stranded (WY)	Percentage of WR Juveniles Affected	Effort (n surveys)
2002	7,635,469	2,811,132	13,144,325	Not available	Not available	
2003	5,781,519	3,525,098	8,073,129	Not available	Not available	NA
2004	3,677,989	2,129,297	5,232,037	Not available	Not available	
2005	8,943,194	4,791,726	13,277,637	Not available	Not available	
2006	7,298,838	4,150,323	10,453,765	Not available	Not available	
2007	1,637,804	1,062,780	2,218,745	Not available	Not available	
2008	1,371,739	858,933	1,885,141	Not available	Not available	
2009	4,972,954	2,790,092	7,160,098	Not available	Not available	
2010	1,572,628	969,016	2,181,572	Not available	Not available	
2011	996,621	671,779	1,321,708	Not available	Not available	
2012	1,814,244	1,227,386	2,401,102	665	0.037 %	27
2013	2,481,324	1,539,193	3,423,456	162	0.007 %	70
2014	523,872	301,197	746,546	693	0.132 %	76
2015	440,951	288,911	592,992	181	0.041 %	75
2016	640,149	429,876	850,422	240	0.037 %	103
2017	734,432	471,292	997,572	1,092	0.149 %	42
2018	1,477,529	824,706	2,130,352	7,766	0.526 %	84
2019	4,691,764	2,630,095	6,753,433	1,472	0.031 %	30
2020	2,270,968	1,493,511	3,048,424	165	0.003 %	NA
2021	779,427	497,328	1,061,526	347	0.004%	NA
2022	311,058			13		

Sources: Voss and Poytress 2022; Chelberg et al. 2022.
The direct count of stranded winter-run Chinook salmon juveniles is recorded by Water Year and a subsequent calculated percentage of winter-run Chinook salmon population stranded using JPI.

Models provide quantitative estimates of future conditions under the Proposed Action.

[Placeholder: Sacramento River juvenile stranding model (performance measure is juveniles stranded)]

The potential risks may be identified by the number of stranding sites at different flow rates. Figure 5-15 shows cumulative proportion of stranding sites by estimated isolation flows. As isolation flows increase the cumulative proportion of stranding sites also increases.

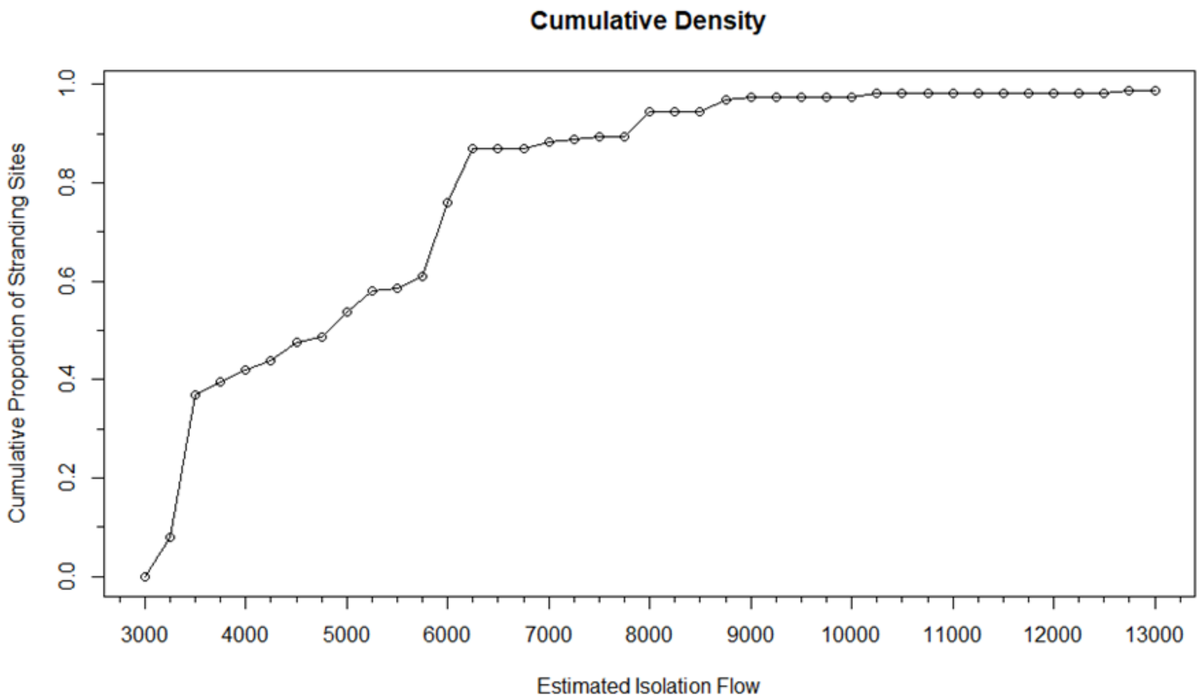


Figure 5-15. Observed Winter-run Chinook Salmon Cumulative Proportion of Stranding Sites by Estimated Isolation Flow.

The **frequency** of occurrence is **high** since it is likely to occur annually in the Proposed Action. Use of Minimum Flows defines a floor, or flow threshold below which habitat can become disconnected and not allow for an area to remain viable for winter-run Chinook salmon juveniles. Additionally, ramping rates provide cues through changes in flows, generating time needed by some juvenile salmon to exit areas that may become disconnected. The frequency within a year depends upon hydrologic conditions which may result in multiple increases and decreases in releases from Shasta Reservoir during the outmigration and rearing period.

To evaluate the **weight of evidence** for stranding stressor, there is a quantitative historical record of winter-run Chinook juvenile stranding monitoring and releases specific to the Sacramento River.

- Literature, Dudley: quantitative, species-specific, location-specific, both 2018 and 2019 published as peer-reviewed literature in multiple publications, individual-based model using multiple environmental parameters and inclusion of biological processes

- Historic stranding observations: quantitative, species-specific, location-specific, available through multiple sources and QA/QCed, long time-series and not expected to have statistical power
- Historic fish releases in the Sacramento River: quantitative, species-specific, location-specific, available online at https://www.cbr.washington.edu/sacramento/data/delta_cwt_tables.html#confirmed, long time-series and not expected to have statistical power
- Historic proportion of population in stranding area: quantitative, species-specific, location-specific, available through multiple sources and QA/QCed, long time-series and not expected to have statistical power
- Historic flows and disconnected sites: quantitative, not species-specific (but not expected to be, environmental variable), location-specific, available through multiple sources and QA/QCed, long time-series and not expected to have statistical power
- Upper Sacramento River Daily Operations Model daily flow modeling LOE: quantitative, not species-specific (but not expected to be), environmental variable, location-specific, model developed to evaluate flows using multiple inputs, widely accepted as daily flow modeling system for use in the Central Valley upper watershed

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- Minimum Instream Flows
- Ramping Rates

5.2.4.2 Outmigration Cues

The proposed storage of water may increase the outmigration cue stressor. During the juvenile rearing and outmigration period, storage of water in Shasta Reservoir associated with the Proposed Action will reduce downstream flows, particularly in the winter from December through February, and may affect juveniles' cue to migrate and their outmigration travel rates. Outmigration cues, for the purposes of this document, are defined and discussed in two ways: (1) fish outmigration behavior being impacted by reduced variation and volume of flows in the upper Sacramento River; and (2) fish travel times being affected and increasing their exposure to predators and poor environmental conditions on the mainstem Sacramento River. Outmigration cues are primarily analyzed for the Sacramento River and migration downstream of Red Bluff Diversion Dam to the Delta. Multiple topic-specific appendices address aspects of juvenile migration from the Sacramento River through the Delta.

- Appendix L analyzes storage and operations needed for Shasta Reservoir coldwater pool management.
- Appendix J, *Winter and Spring Pulses and Delta Outflow—Smelt, Chinook Salmon, and Steelhead Migration and Survival*, presents analysis of the effects of spring Delta outflow on juvenile survival with a focus on route-specific travel time and survival.
- Appendix H presents analysis on the "Minimum Flows" conservation measure.

The increase in outmigration cue stressors is expected to be **lethal**. Fish may stay in the upper Sacramento River longer since they are not cued to outmigrate. This delay increases the risk of exposure to sources of mortality (higher exposure to predation). The impact of outmigration cues is not independent from other stressors which are lethal such as refuge habitat, entrainment risk stressor, and predation and competition. Predation studies in the Sacramento River at Red Bluff Diversion Dam also document predation on Chinook salmon (Tucker et al. 1998). These lethal stressors are described independently in this chapter.

Although the Proposed Action may increase the outmigration cues stressor, changes in outmigration cues that affect winter-run Chinook salmon juveniles exist in the **environmental baseline** (without the Proposed Action). Generally, natural flows in the Sacramento River decrease through the summer and into fall until late-fall and winter rains. Those flows influence fish outmigration behavior and affect fish travel times in the Sacramento River.

The **proportion** of the population affected by the Proposed Action is **large** because reduced releases occur for water temperature management, storage rebuilding, rice decomposition smoothing, and redd dewatering avoidance actions. The proportion of the population affected depends on variation in the combination of releases and natural flows. Outmigration, measured at Red Bluff Diversion Dam, occurred between July and January. Historically. These actions reduced flows as early as August and as late as January. Historic passage data at Red Bluff Diversion Dam shows 5% to 95% passage occurred as early as August and as late as January (Brood Year [BY] 2004 – 2021). Further downstream at Knights Landing, 5% to 95% passage occurred as early as September and as late as March.

In the literature, Del Rosario et al. (2013) found that ≥5% catch at the Knights Landing Rotary Screw Trap coincided with first day of flow of at least ~14,100 cfs (400 cms) at Wilkins Slough. Acoustically tagged fish released at locations in the upper Sacramento River under varying hydrological conditions are used to estimate survival probabilities and travel times rates. As fish migrate downstream towards the Delta, individuals encounter a range of environmental conditions and transition from reaches with unidirectional flow (upstream) to reaches with bidirectional flow (tidally driven, downstream). Outmigrating juveniles may be exposed to predation and as inflow declines and tidal influence moves upstream, travel time and distance may increase leading to higher exposure to predators. Michel et al. (2021) identified an optimal flow threshold condition favorable for outmigration for juvenile Chinook salmon, 10,712 cfs, which could provide an additional 2.7-fold increase in survival. Travel and survival rates of Chinook in upper Sacramento River reaches are strongly correlated (Notch et al. 2020). Authors hypothesize one mechanism for the threshold is faster outmigration rates due to higher flows decrease exposure to possible predation (Michel et al. 2021).

Datasets use historical conditions and observation to inform how winter-run Chinook salmon may respond to the Proposed Action. Historical monitoring may support or refute hypotheses and informs the reasonableness of information generated by models. Empirical estimates of acoustically tagged Chinook salmon can be found in Section 5.2.4.3, *Entrainment Risk*.

Models provide quantitative estimates of future conditions under the Proposed Action.

[Placeholder: Flow survival threshold (performance measure is river survival)]

[Placeholder: XT model (performance measure is river survival)]

The **frequency** of occurrence depends primarily on the timing of exceeding the outmigration cue flow threshold and is **low**. Del Rosario et al. (2013) showed when daily Wilkins Slough flows exceed a 14,126 cfs (400 cms) threshold, winter-run Chinook salmon outmigration cues into the lower Sacramento River increased, and more than 5% of the fish observed annually at the Knights Landing fish monitoring site occurred. The impact will be magnified in years when coldwater pool volume is limited, and releases are limited because of water temperature management, storage rebuilding, and rice decomposition smoothing actions. Table 5-17 shows monthly average flows at Wilkins Slough along with number of days and first date the 14,100 cfs threshold was met or exceeded for water years 2001 – 2022. In four out of 22 years (18%) a flow of 14,100 cfs was met before December 1st. In WY 2021, the threshold was never met.

Table 5-17. WY 2001–2022 Monthly Average Flows at Wilkins Slough (cfs) September through January, First Day the 14,100 cfs Threshold was Exceeded, and Number of Days the Threshold Was Exceeded.

Water Year	Sept	Oct	Nov	Dec	Jan	1st Day > Threshold	Days > Threshold
2001		5795	5837	6511	9086	1/26/2001	21
2002	7464	4806	6844	16539	18582	11/26/2001	46
2003	6683	5338	5706	15156	25080	12/15/2022	111
2004	6987	5444	5424	16567	18398	12/8/2003	86
2005	8270	6949	5378	9527	17105	12/10/2004	75
2006	7569	6765	5782	16023	27347	12/3/2005	159
2007	8903	6452	6004	9967	7894	12/14/2006	12
2008	7363	5889	5131	6596	13136	1/5/2008	27
2009	6349	5018	5634	5098	5430	2/17/2009	19
2010	6408	5085	4126	5365	13948	1/20/2010	58
2011	7396	6200	6139	17379	15556	12/7/2010	106
2012	8823	7930	6115	5364	7727	1/22/2012	18
2013	6739	5354	5624	19367	10405	11/30/2012	22
2014	6666	4771	4982	4606	3811	3/5/2014	6
2015	4893	3983	5088	18097	6810	12/5/2014	27
2016	5917	5538	4193	7381	17235	12/23/2015	50
2017	7571	5810	7986	16488	24480	11/22/2016	150
2018	7693	6514	6564	5333	8101	3/23/2018	9
2019	6960	5517	4456	7654	15625	12/18/2018	114
2020	7972	6347	4397	9007	9042	1/27/2020	3
2021	6318	4493	4147	4402	5217	N/A	0
2022	5537	7803	5575	9363	8550	10/26/2021	11

Source: Del Rosario et al. 2013.

To evaluate the **weight of evidence** for outmigration cue stressors, there is a two-decade quantitative, historic record of flows and Red Bluff and Knights Landing monitoring data for winter-run Chinook salmon. There is a body of literature that is both location- and species-specific that provide flow thresholds relevant to winter-run Chinook salmon outmigration (Michel et al. 2021; Del Rosario et al. 2013). Additionally, an existing predator prey model, the mean free-path length model, has been applied in the Sacramento River using hatchery late fall-run Chinook salmon (location- but not species-specific) to evaluate movement patterns of both predators and prey and the probability of encounters (Steel et al. 2020).

- Literature, Del Rosario et al. 2013: quantitative, species-specific, location-specific, publication in the peer reviewed journal, multiple regressions fit on four covariates
- Historic passage at key locations: quantitative, species-specific, location-specific, available through multiple sources and QA/QCed, long time-series and not expected to have statistical power
- Historic flows: quantitative, not species-specific (but not expected to be, environmental variable), location-specific, available through multiple sources and QA/QCed, long time-series and not expected to have statistical power

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- Minimum Instream Flows
- SRSC Diversion Spring Delays and Shifting

Conservation measures in the Proposed Action for other species, life stages and/or stressors that may exacerbate this stressor include:

- Fall and Winter Base Flows for Shasta Reservoir Refill and Redd Maintenance
- Shasta Reservoir Water Temperature and Storage Management
- Allocation Reductions for Shasta Reservoir End of September Storage
- Rebalancing between other CVP Reservoirs for Shasta Reservoir End of September Storage
- Reduced Wilkins Slough Minimum Flows for Shasta Reservoir End of September Storage
- Minimum Refuge Summer Deliveries North of Delta
- Drought Actions
- SHOT Water Transfer Timing Approvals

5.2.4.3 Entrainment Risk

The proposed diversion of water may increase the entrainment risk stressor. During the juvenile rearing and outmigration period, the proposed diversion of water associated with the Proposed Action alters hydrodynamic conditions in the Sacramento River and Delta. This alteration may influence fish travel time and migration routing in the Sacramento River mainstem and the central and south Delta. Once in the central and south Delta, entrainment into the Jones and Banks pumping plants may occur. Entrainment, for the purposes of this document, is defined and discussed in two ways: (1) fish routed through specific migratory pathways in the Delta (Delta route-specific travel time and survival); and (2) fish encountering CVP and SWP facilities where they may be pulled into diversions or the export facilities. Multiple topic-specific appendices address aspects of juvenile migration through the Delta.

- Appendix G –includes sections for “Tracy Fish Collection Facility” and “Skinner Fish Delta Fish Protective Facility.”
- Appendix I, *Old and Middle River Flow Management*, presents analysis of Old and Middle River management and Delta Cross Channel Closure conservation measures.
- Appendix J presents analysis of the effects of spring Delta outflow on juvenile survival with a focus on route-specific travel time and survival.
- Appendix Q, *Georgiana Slough Barrier*, describes the operation of the Georgiana Slough Non-Physical Barrier, one measure that can be taken to prevent juvenile winter-run Chinook salmon from traveling through Georgiana Slough into the central Delta.

The increase in entrainment risk stressor is expected to be **lethal**. Entrainment can result in indirect mortality by routing fish into areas of poor survival (increased predation, reduced habitat quality) or direct mortality during salvage in the Delta fish collection facilities.

Although the Proposed Action may increase the entrainment risk stressor, entrainment of juvenile winter-run Chinook salmon exists in the **environmental baseline** (without the Proposed Action). Proximity to irrigation diversion operations drives the entrainment stressor (Windell et al. 2017). These diversions exist throughout the Delta and along rivers and streams in the Central Valley. Tides and flood releases can influence hydrodynamic transport and move fish into higher risk entrainment areas surrounding diversions or poor habitats which could lead to increased predation. Tidal conditions can facilitate downstream transport or entrainment depending on the flood and ebb of tides during the fortnightly spring-neap cycle (Arthur et al. 1996).

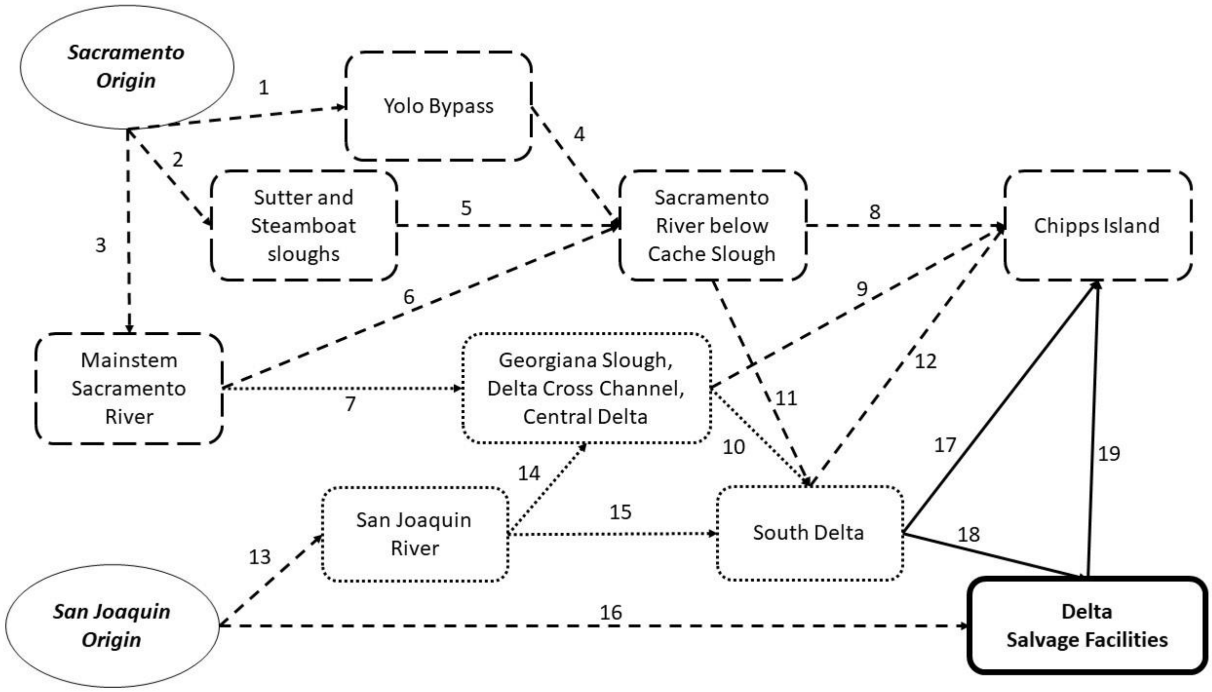
The entrainment risk stressor is influenced by thousands of non-CVP and non-SWP diversions in the rivers and Delta. Senior and junior water users would continue to operate privately-owned facilities to divert water from the Sacramento River and pose a risk of entrainment to juvenile winter-run Chinook salmon, although that risk is reduced where fish screens have been installed. As of 1997, 98.5 percent of the 3,356 diversions included in a Central Valley database were either unscreened or screened insufficiently to prevent fish entrainment (Herren and Kawasaki 2001). Most of the 370 water diversions operating in Suisun Marsh are unscreened (Herren and Kawasaki 2001). Quantification of the effect of small unscreened diversions is limited (Moyle and Israel 2005). The CVPIA Anadromous Fish Screen Program provides grants to screen facilities used to divert water. Diversions greater than 100 cfs are screened on the Sacramento

River. Upstream from the Delta, CVP facilities diverting water under water service contracts and SWP diversions are screened (e.g., Red Bluff Pumping Plant, Freeport Regional Water Project, Barker Slough Pumping Plant, Contra Costa Water District).

In the Delta, Reclamation’s past operation of the Delta Cross Channel Gates and Reclamation and DWR’s past operation of export facilities influenced the flow of water in the Delta. Reclamation and DWR have operated the CVP and SWP to reduce the risk of entrainment under Biological Opinions issued by the USFWS and NMFS in 2004/2005, 2008/2009, and 2019. Under those Biological Opinions, Reclamation and DWR have: (1) closed the Delta Cross Channel Gates; (2) controlled the net negative flows toward the export pumps in Old and Middle rivers to reduce the likelihood that fish would be diverted from the San Joaquin or Sacramento River into the southern or central Delta; and (3) improved fish screening and salvage operations to reduce mortality from entrainment and salvage. Historic data on winter-run Chinook salmon entrainment, salvage, and loss are discussed in detail below. An existing consultation proposes to install operatable gates to increase fish routing into the Yolo Bypass. An existing consultation for the Georgiana Slough Salmonid Migratory Barrier proposed to decrease the existing routing stressor by deterring emigrating juvenile salmonids from entering Georgiana Slough and thereafter the central and south Delta. In the central and south Delta, juvenile survival is lower relative to remaining in the mainstem Sacramento River. This project is intended to improve juvenile survival to Chipps Island.

The **proportion** of the population affected by the Proposed Action varies annually and depends upon flow routing, hydrology, and export rates. The proportion of the population affected would be **medium** based on loss of length-at-date (LAD) and genetically-identified winter-run Chinook salmon prior to 2010 (1996 – 2009, 2 of 14 years exceeded 2% of JPE loss by LAD, 14%; Table 5-16). However, winter-run Chinook salmon loss in years after 2010 are more representative of current OMR management and the Proposed Action and more likely to be **small** based on historic loss of LAD and genetically-identified winter-run Chinook salmon since 2010 (2010 – 2022, 0 of 13 years exceeded 2% of JPE loss by LAD, 0%; Table 5-16).

Winter-run Chinook salmon travel through different migratory pathways. Using a conceptual model, a single fish in any location could have arrived at that location via one of several pathways (Figure 5-16). For example, a fish observed salvage could have arrived via one of many pathways (e.g., Sacramento Origin via the mainstem Sacramento then below Cache Slough, then South Delta or via the Delta Cross Channel and Central Delta then the South Delta). If a proportion of fish is higher down a migratory pathway documented as a route with higher survival rates for juvenile salmonids, then fish migrating through that route will likely have a better chance of surviving to the ocean than fish migrating through a sub-optimal route (e.g., experiencing potential entrainment into the Central Delta through the Delta Cross Channel or Georgiana Slough).



Higher survival symbolized by heavy dashed lines and boxes, medium to lower survival symbolized by thinner dotted lines and boxes, origin noted by ovals, the Delta Salvage facilities symbolized by a heavy solid line and box.

Figure 5-16. Conceptual Model of Delta Regions and Winter-run Chinook Salmon Routing Symbolized by Fish Fate.

The proportion is quantified by through-Delta survival and the detection of winter-run Chinook salmon in salvage as an annual and weekly percent of the winter-run Chinook salmon juvenile production estimate. The knowledge base paper, solicited literature, datasets, and models were used to analyze entrainment.

Literature for winter-run Chinook salmon entrainment primarily addresses historical datasets and models and does not uniquely inform the proportion of the population affected by the Proposed Action. The covariates most relevant from recent literature included: Fremont Weir overtopping and Yolo Bypass flows, Delta Cross Channel Openings, Georgiana Slough Non-Physical Barrier, and Delta hydrodynamics represented by varying Sacramento River inflow, San Joaquin River inflow, and exports or aggregate parameters such as Export to Inflow ratio, Old and Middle River flows, etc.

Empirical estimates of acoustically tagged late-fall run Chinook salmon from Coleman National Fish Hatchery (CNFH) tracked in December 2006, January and December 2007, and January 2008 experienced routing in the mainstem Sacramento from 35.2% to 49.8%, through Georgiana Slough 0% to 31.1%, and through the Sutter and Steamboat sloughs 19.8% to 41.4% (Perry 2010, Table 5-18). Results suggest the proportion of fish entering each route generally follows river flow but is not always in agreement with the proportion of discharge entering that route, suggesting another parameter may affect fish routing. Release groups experienced different discharge and export conditions leading to wide ranges in routing probabilities. Other studies also report proportional flow is a strong predictor of route selection (Kemp et al. 2005; Cavallo et al. 2015; Romine et al. 2021). Additionally, variables like DCC gate status (open / closed) will change routing and survival probabilities for fish traveling along the mainstem Sacramento when they get to both Georgiana Slough and the DCC junctions. Newman and Brandes (2010) reported that exports affect routing of fish released in Georgiana Slough more than fish released at Ryde (upstream of Georgiana Slough on the Sacramento River) and the fraction of fish released in Georgiana Slough recovered at the fish collection facilities increased with increased exports.

Table 5-18. Route-specific Survival and Entrainment Probability for Georgiana Slough and Other Migratory Pathways by Study Period for Acoustically Tagged Coleman National Fish Hatchery Late-fall Chinook Salmon.

Route	2006/2007 Through-Delta Survival	2006/2007 Route-Specific Probability	2007/2008 Through-Delta Survival	2007/2008 Route-Specific Probability	2008/2009 Through-Delta Survival	2008/2009 Route-Specific Probability
December: Sacramento R	0.443	0.352	0.283	0.387	0.448	0.392
December: S/S sloughs	0.263	0.296	0.136	0.345	0.392	0.321
December: Sutter			0.107	0.230	0.281	0.217
December: Steamboat			0.193	0.115	0.632	0.104
December: DCC	0.332	0.235	0.041	0.117	0.117	0.224
December: Georgiana	0.332	0.117	0.087	0.150	0.315	0.164
December: TOTAL	**0.351**		**0.174**		**0.386**	
January: Sacramento R	0.564	0.498	0.244	0.490	0.398	0.459
January: S/S sloughs	0.561	0.414	0.245	0.198	0.432	0.253
January: Sutter			0.192	0.086	0.426	0.096
January: Steamboat			0.286	0.112	0.436	0.158
January: DCC				0.000		0.000
January: Georgiana	0.344	0.000	0.086	0.311	0.163	0.288
January: TOTAL	**0.543**	**0.088**	**0.195**		**0.339**	

Source: Perry 2010.

Between 2016-2021, juvenile winter run Chinook salmon were tagged during the winter and migration survival estimates for reaches of the Sacramento River and Delta. Estimates of through-Delta survival were not observed to be affected by the export/inflow ratio in the interior Delta (Hance et al 2021) at the OMR values studied with the 2014-2018 releases. Earlier coded-wire tag studies completed with winter-run Chinook salmon found migration mortality due to loss at the CVP and SWP (average total loss = 0.2%) was relatively small and variable compared to total migration mortality in the Delta for 178 coded wire tagged winter-run Chinook salmon between 1993-2007 (Zeug and Cavallo 2014). Between 2012 and 2023, where OMRs are more similar to those that will be observed in the Proposed Action, winter-run Chinook salmon coded wire tagged fish most frequently was 0.00%, and when loss occurred it ranged between 0.008% to 0.178% of the release group.

Datasets use historical conditions and observation to inform how winter-run Chinook salmon may respond to the Proposed Action. Historical monitoring may support or refute hypotheses and informs the reasonableness of information generated by models. Additional empirical estimates of tagged spring-run Chinook salmon released throughout the system show varied survival estimates (Table 5-19).

Table 5-19. Acoustic Tagging (AT) Survival Estimates by Project and Water Year for Hatchery and Wild Winter-run and Late fall-run Chinook Salmon, 2018–2022.

Water Year	Project	Tower Bridge Survival (%)	SE	95% L CI	95% U CI	Benicia Bridge Survival (%)	SE	95% L CI	95% U CI	Through-Delta Survival (%)	SE	95% L CI	95% U CI
2022	Hatchery- origin winter-run Chinook Salmon					5.8	1.0	4.2	8.0	43.4	5.7	32.8	54.7
2022	Hatchery- origin Battle Creek winter-run Chinook Salmon					0.1	0.1	0	0.6	7.7	7.4	1.1	39.1
2021	Hatchery- origin late-fall run Chinook salmon	14.3	1.4	11.7	17.3	4.7	0.9	3.3	6.7	32.8	5.1	23.7	43.4
2021	Hatchery- origin winter-run Chinook Salmon	10.1	1.3	7.8	12.9	3.6	0.8	2.3	5.5	35.7	6.4	24.3	49.0
2021	Hatchery- origin Battle Creek winter-run Chinook Salmon	3.3	0.6	2.3	4.7	0.2	0.2	0.1	0.9	6.7	4.6	1.7	23.1
2020	Hatchery- origin late-fall run Chinook salmon	60.4	2	56.4	64.2	16.9	1.5	14.1	20.1	27.9	2.4	23.5	32.7
2020	Hatchery- origin winter-run Chinook Salmon	13.2	1.5	10.5	16.5	3.5	0.9	2.2	5.6	23.9	5.7	14.6	36.7
2020	Hatchery- origin Battle Creek winter-run Chinook Salmon	9.5	2.1	6.1	14.6	No detections yet	NA	NA	NA	Not enough detections	NA	NA	NA
2019	Hatchery- origin late-fall run Chinook salmon	23	2	19.3	27.2	4.8	1	3.1	7.2				
2019	Hatchery- origin winter-run Chinook Salmon	23.3	2.4	19	28.2	25.6	1.7	22.4	29.1				
2019	Hatchery- origin Battle Creek winter-run Chinook Salmon	23.3	4.3	16	32.7	14	1.6	11.2	17.4				
2018	Hatchery- origin winter-run Chinook Salmon	18.4	1.8	15.1	22.2	ND	ND	ND	ND	ND	ND	ND	ND

Minimum survival, SE, 95% lower and upper confidence intervals (L CI, U CI) to [1] Tower Bridge, [2] Benicia Bridge (East Span), and [3] Through-Delta survival (City of Sacramento to Benicia) estimated using a Cormack-Jolly-Seber (CJS) model. For tagging studies with multiple releases, values are reported for all groups combined. Data available online at CalFish Track (https://oceanview.pfeg.noaa.gov/CalFishTrack/pageREAL.html).
CI = confidence interval; ND = no data.

Historic records of winter-run Chinook salmon encountering CVP and SWP fish collection facilities can be compared to the juvenile production estimate, which is the expected population abundance to enter the Delta, to understand the proportion of the population affected. Salvage and loss of winter-run Chinook salmon at the CVP and SWP Delta fish collection facilities (1996 – 2022) shows loss represents greater than 2% of the JPE in 2 out of 27 years (7%) for length-at-date winter-run and in 1 out of 27 years (4%) for genetically identified winter-run Chinook salmon (Table 5-20). The Proposed Action includes measures to use genetic identification, rather than the historically-use length-at-date criteria, for loss at the facilities. In the Proposed Action, exports and OMR conditions are reduced and less negative than the operations since 2009. Based on these trends, loss of winter-run Chinook salmon under the Proposed Action are expected to average 0.28% (range: 0.0% to 1.31%) of the LAD JPE, 0.09% of the genetic JPE (range:0.0% to 0.56%). Loss greater than 1% of the JPE has not occurred since 2001 (using the genetic method).

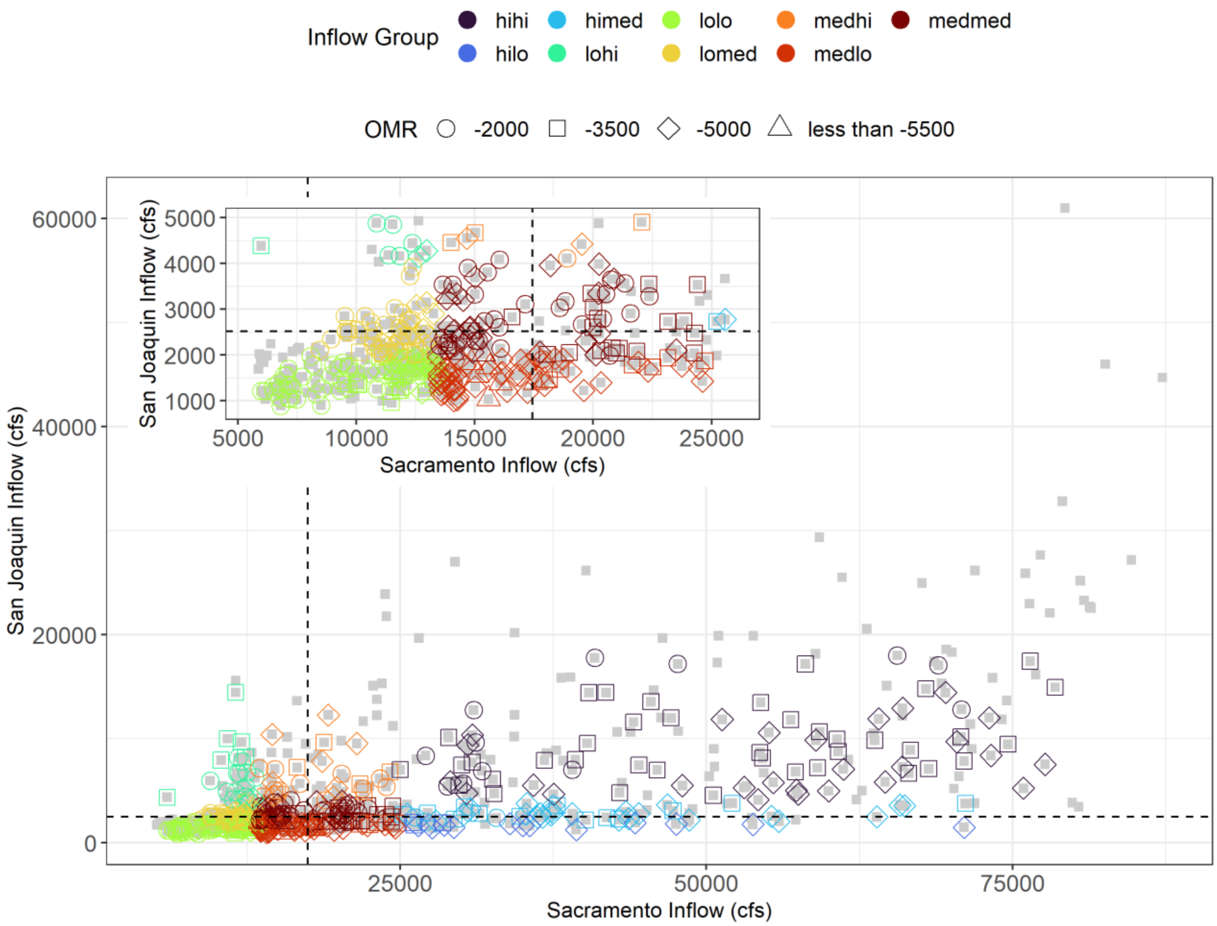
Table 5-20. Winter-run Chinook Salmon Loss at the CVP and SWP Delta Fish Collection Facilities: Genetic and LAD (1996 – 2022), JPE, Percent of JPE (genetic and LAD), Annual Loss Threshold (0.5% of JPE, LAD), and Sacramento Valley Index Water Year Type (WYT).

Water Year	JPE	Loss (LAD)	% JPE (LAD)	Loss (Genetic)	% JPE (genetic)	WYT (Sac Valley Index)
1996	338107	2375.69	0.70	283.97	0.08	W
1997	165069	629.70	0.38	34.17	0.02	W
1998	138316	1525.05	1.10	696.02	0.50	W
1999	454792	3715.09	0.82	1153.54	0.25	AN
2000	289724	5824.00	2.01	563.36	0.19	AN
2001	370221	20061.29	5.42	14042.35	3.79	D
2002	1864802	3330.98	0.18	634.49	0.03	D
2003	2136747	6816.30	0.32	2644.46	0.12	BN
2004	1896649	7778.93	0.41	3032.51	0.16	D
2005	881719	1373.08	0.16	0	0.00	W
2006	3831286	2601.15	0.07	1274.14	0.03	W
2007	3739069	3297.12	0.09	1842.24	0.05	C
2008	589911	1292.10	0.22	750.9	0.13	C
2009	617783	1514.71	0.25	1208.59	0.20	BN
2010	1179633	1656.45	0.14	964.64	0.08	AN
2011	332012	4360.08	1.31	1469.64	0.44	W
2012	162051	2078.84	1.28	900.49	0.56	D
2013	532809	731.65	0.14	198.2	0.04	C
2014	1196387	322.26	0.03	48.45	0.00	C
2015	124521	105.89	0.09	0	0.00	C

Water Year	JPE	Loss (LAD)	% JPE (LAD)	Loss (Genetic)	% JPE (genetic)	WYT (Sac Valley Index)
2016	101716	56.41	0.06	11.47	0.01	D
2017	166189	110.65	0.07	0	0.00	W
2018	201409	670.18	0.33	97.28	0.05	BN
2019	433176	565.71	0.13	212.37	0.05	W
2020	854941	196.71	0.02	76.92	0.01	D
2021	330130	8.21	0.00	3.88	0.00	C
2022	125038	73.03	0.06	0	0.00	C

Models provide quantitative estimates of future conditions under the Proposed Action. Reclamation evaluated multiple lines of evidence, with different assumptions and complexity, to narrow the likely range of potential effects. A "Volumetric Influence" line of evidence considered the proportion of Sacramento inflow in exports as if fish moved in direct proportion to flow. However, fish can swim and may make routing decisions in response to local physical and hydraulic conditions. Local changes in velocities may influence routing; therefore, the hydraulic footprint or "delta export zone of influence" (ZOI) line of evidence evaluates the change in tidally influenced velocities where export levels may influence fish to make a different routing decision and move towards the export facilities. "Flow into Junctions" represents an influence from the routing of water. "Particle Tracking Models" (PTM) captures advection and tidal dispersion to simulate the fate of fish as indestructible passive particles. The ECO-PTM model adds survival terms for particles. The Salmonid Tracking and Routing Simulation "STARS" model used correlations with acoustically tagged salmon to correlate through-Delta survival with environmental covariates. The Delta Passage Model (DPM) similarly estimates survival using coded wire tags. Finally, the negative binomial, salvage density models, and winter-run Chinook CWT salvage model estimate loss and salvage at the facilities.

Models that consider Sacramento Inflow, San Joaquin Inflow, and exports explain observed data with less variability than models relying on OMR alone. Representative tertile categories standardized analyses across low, medium, and high San Joaquin (Vernalis) and Sacramento (Freeport) inflow combinations. OMR bins were based on OMR management thresholds and included values of +/- 500 cfs for -2,000 cfs, -3,500 cfs, and -5,000, and all values less than 5500 cfs. Figure 5-17 shows the nine groups representing combinations of low, medium, or high Sacramento and San Joaquin inflows and OMR bins.



Gray points represent all data. Points outlined in color indicate data points falling within OMR groupings, and used in subsequent modeling. Inset plot zooms in on lower inflow values for greater resolution. Points and inflow' grouping are based CalSim 3 results from the No Action Alternative (NAA).

Figure 5-17. Data Categorized into Sacramento and San Joaquin River Inflow Groupings.

Table 5-21 shows the specific ranges for each of the inflow groups shown in the figure below by Sacramento and San Joaquin flows.

Table 5-21. December – June ZOI Flow Groups Based on CalSim 3 Sacramento (Freeport) and San Joaquin (Vernalis) River Inflows under the No Action Alternative (NAA).

Inflow Group	Description	SR Inflow Range (cfs)	SJR Inflow Range (cfs)	Mean OMR (cfs)	Mean Exports (cfs)
lolo	Low SR Low SJR	5117 - 13415	890 - 1983	-3049	3745
medmed	Med SR Med SJR	13416 - 24725	1984 - 4096	-3758	5328
hihi	High SR High SJR	24726 - 87222	4097 - 61005	-2005	9227
himed	High SR Med SJR	24726 - 87222	1984 - 4096	-4242	6548
medhi	Med SR High SJR	13416 - 24725	4097 - 61005	-2506	6271
lomed	Low SR Med SJR	5117 - 13415	1984 - 4096	-2805	3864
medlo	Med SR Low SJR	13416 - 24725	890 - 1983	-5070	6069
lohi	Low SR High SJR	5117 - 13415	4097 - 61005	-2916	5713
hilo	High SR Low SJR	24726 - 87222	890 - 1983	-4562	6158

Values have been rounded to the nearest integer.

Volumetric Influence (Appendix I, Attachment I.6, *Volumetric Influence Analysis*), provides context for the fraction of exports relative to Delta inflow patterns. The analysis assumes winter-run Chinook salmon enter the Delta with inflows from the Sacramento River, fully mix with all other Delta inflow, and then some are entrained in proportion to flow. When results were grouped by water year type, the lowest mean (non-zero) percent Delta inflow of 20% was estimated in all three Proposed Action phases during wet water years and Proposed Action phase without TUCP and with Delta VA and Proposed Action phase without TUCP and with systemwide VA during above normal years. The greatest mean percent Delta inflow (26%) was estimated in critically dry water years in the Proposed Action phases without TUCP and without VA and with Delta VA.

When results were grouped by inflow group (Figure 5-18 and Figure 5-19), the lowest mean (non-zero) percent Delta inflow was in all three Proposed Action phases in the hihi inflow group at 12%, and the greatest value was 32% for the Proposed Action phase without TUCP and with systemwide VA in the medlo inflow groups. The remaining two Proposed Action phases had percent Delta inflow estimates of 31% within the medlo inflow group, and this percent Delta inflow was estimated for all three Proposed Action phases in the lohi inflow group. Percent Delta inflow estimates increase as the San Joaquin River flow grouping diminished. No more than 65% of delta inflow may be exported at any time per D-1641 and in critically dry years operations to meet human health and safety are maximized to meet that need when Delta inflow would be at its lowest.

W = Wet; AN = Above Normal; BN = Below Normal; CD = Critically Dry; D = Dry.

Figure 5-18. Boxplots of Percent Delta Inflow Exported Grouped by Alternative and Water Year Type.

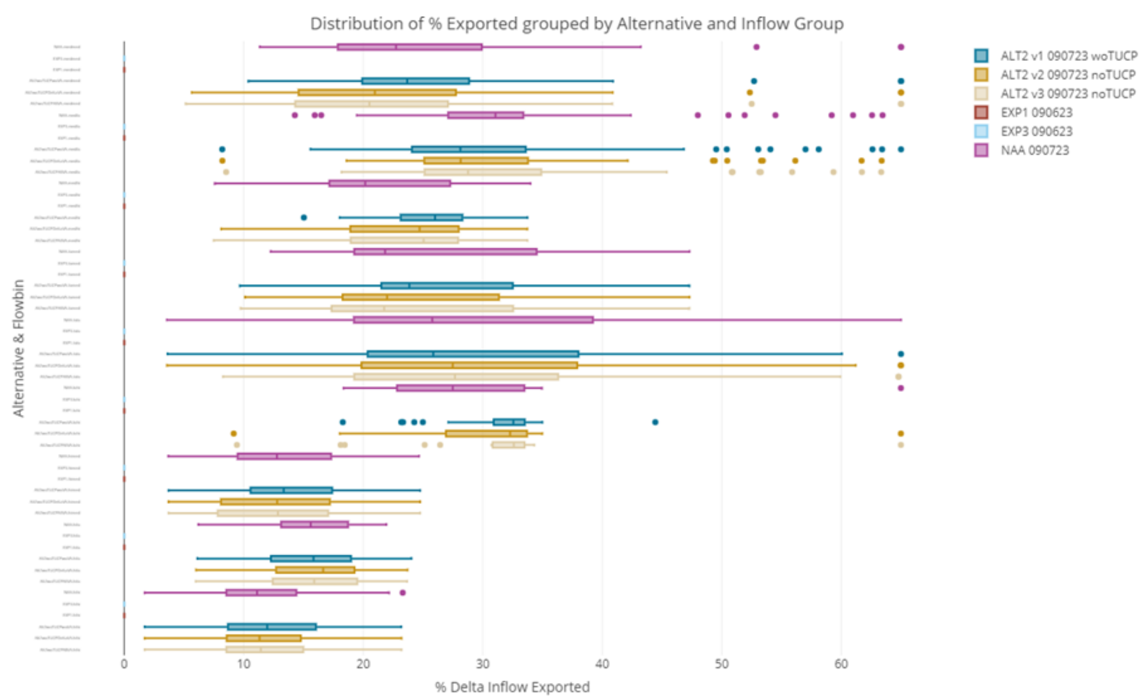


Figure 5-19. Boxplot of the Full Distribution of Each Alternatives' Percent Delta Inflow Exported from All Years Grouped by Alternative And Inflow Group.

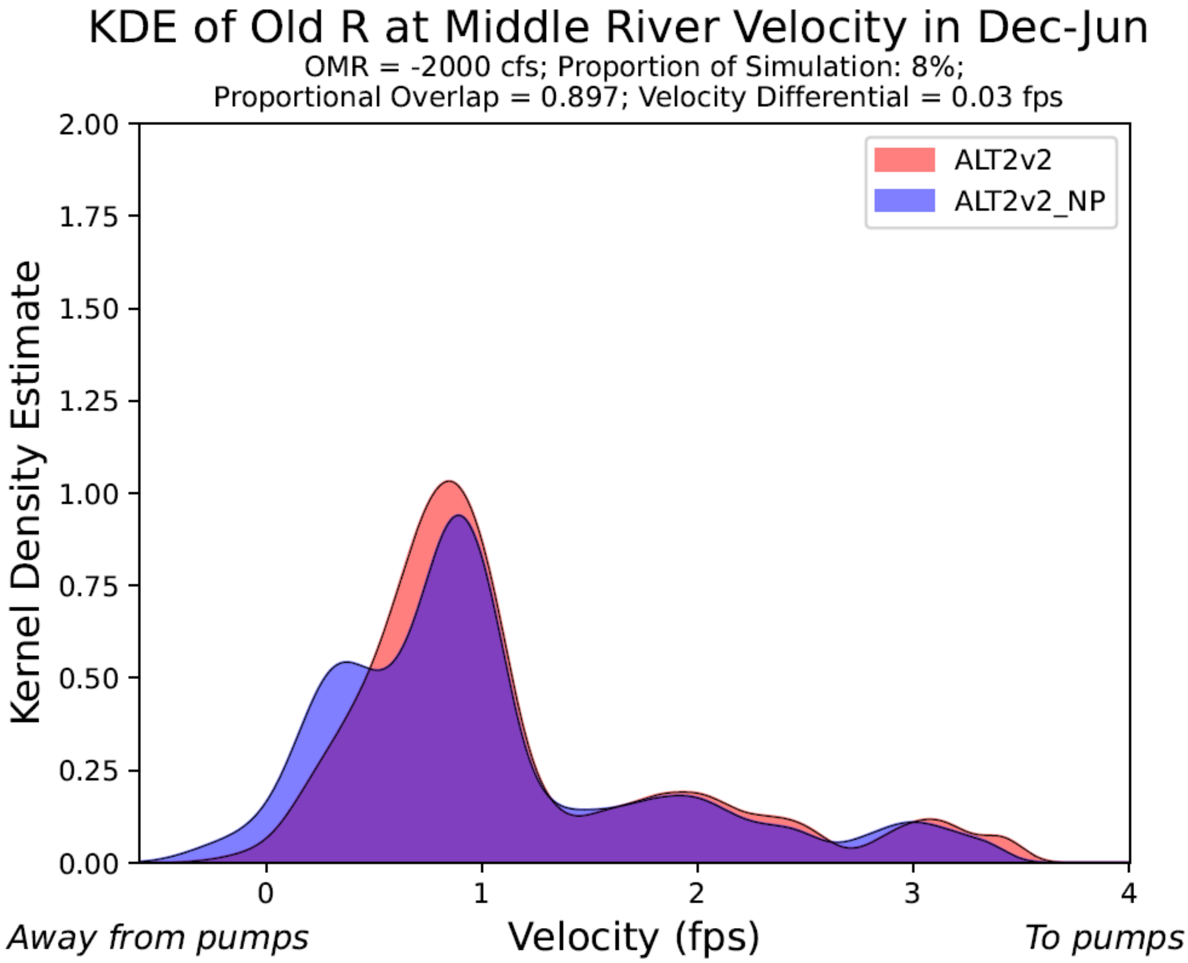
Delta Export Zone of Influence (Appendix I, Attachment I.3, *Delta Export Zone of Influence Analysis*) shows the footprint of velocity changes in the Delta based on exports. The analysis assumes the Proposed Action may change the route selection of winter-run Chinook salmon when exports change the distribution of tidally influenced velocities. Outside of the zone of influence, exports would be unlikely to influence route selection and survival. Within the zone of influence, exports are assumed to have effects on route selection and survival, though the analysis does not account for the magnitude of velocity change, only that there is a difference.

The Gaussian Kernel Density Estimate (KDE) is used to compute Delta Export Zone Influence by comparing hourly velocities at a given location for the component of interest with and without Delta exports. The comparison of KDE results produces an estimate of the overlapping velocity distribution between the pumping and no-pumping KDEs (proportion overlap). Generally, more negative OMRs (Figure 5-20 compared with Figure 5-21) and locations closer to the export facilities (Figure 5-21 and Figure 5-22 compared with Figure 5-23) exhibit lower proportion overlap (greater alteration from pumping).

The proportion overlap values calculated for each node are filtered to indicate where there is low, medium, and high hydrologic influence. Overall, most nodes experienced low hydrologic influence, defined as greater than 75% overlap. Figure 5-24 provides an example for the three levels of hydrologic influence: less than 25% overlap (high influence); between 25%-75% overlap (medium influence); and more than 75% overlap (low influence) for the lomed inflow group.

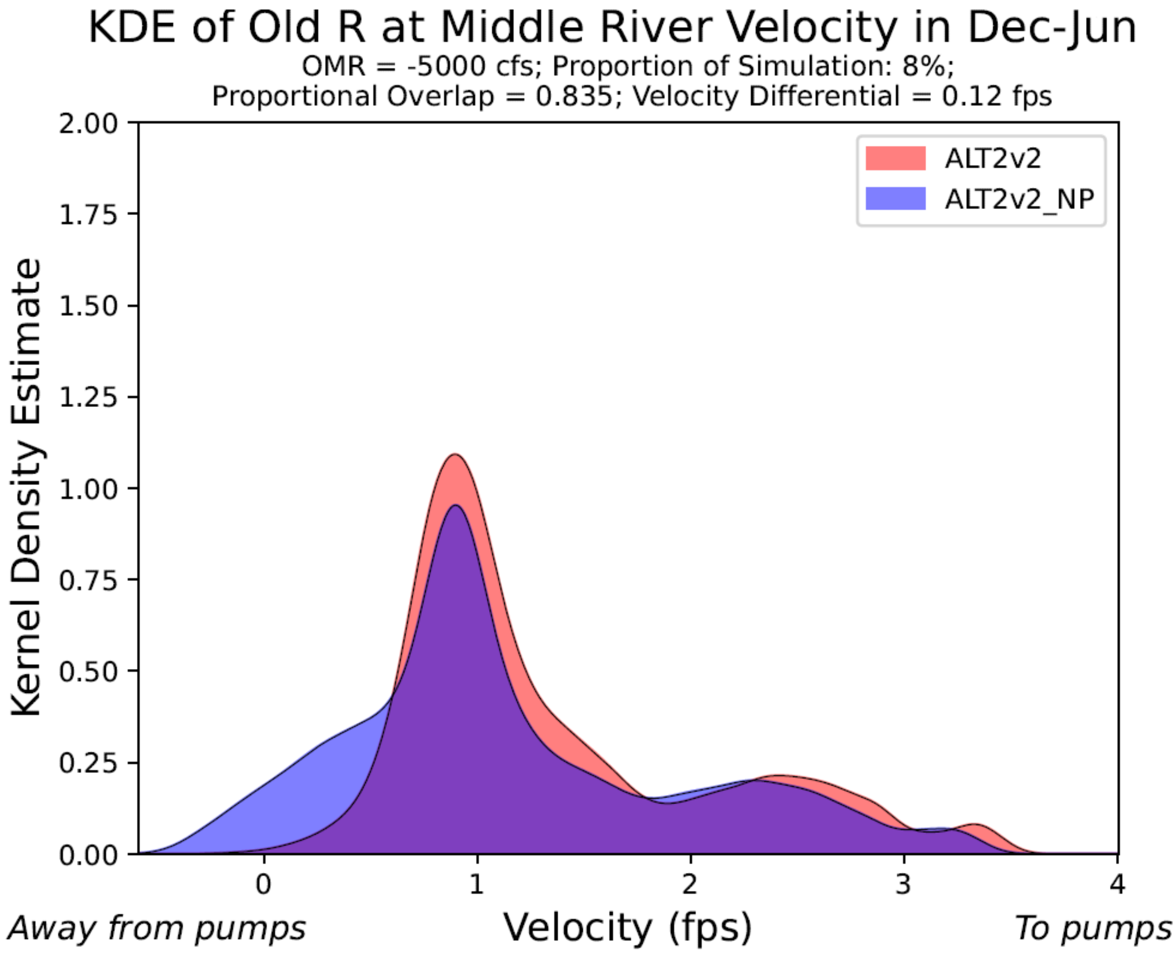
Further examination of the delta export zone of influence at the border of medium and high hydrologic influence and how this is modified by OMR conditions can be observed at the different inflow conditions in the Proposed Action phases and NAA (Figure 5-25–Figure 5-28, Table 5-22). Figure 5-25 through Figure 5-28 include faceted contour plots each representing a different inflow group. The space within each line represents the area experiencing 25-100% alteration (0-0.75 proportional overlap) based on kernel density estimates. Missing contours indicate a lack of historical data, and thus simulation ability.

Channel length altered across the Proposed Action phases range from 45,576 feet (1.2% of the DSM2 grid in Alt2woTUCPDeltaVA) feet to 583,403 feet (15.2% of the DSM2 grid in Alt2woTUCPAllVA) (Table 5-22). The greatest extent of hydrologic alteration occurs in the <-5500 OMR bin, which is likely associated with greater exports. Trends appear consistent across inflow groups containing combinations of low and medium Sacramento and San Joaquin inflow (lolo, lomed, medlo, medmed inflow groups; Figure 5-29 and Figure 5-30). At high Sacramento inflow (hilo, himed, hihi inflow groups), there appears to be little difference in proportional channel length altered between -5000 and <-5500 OMR bins. In the lohi and hihi inflow groups, there also appears to be less difference in proportional channel length altered across all OMR bins.



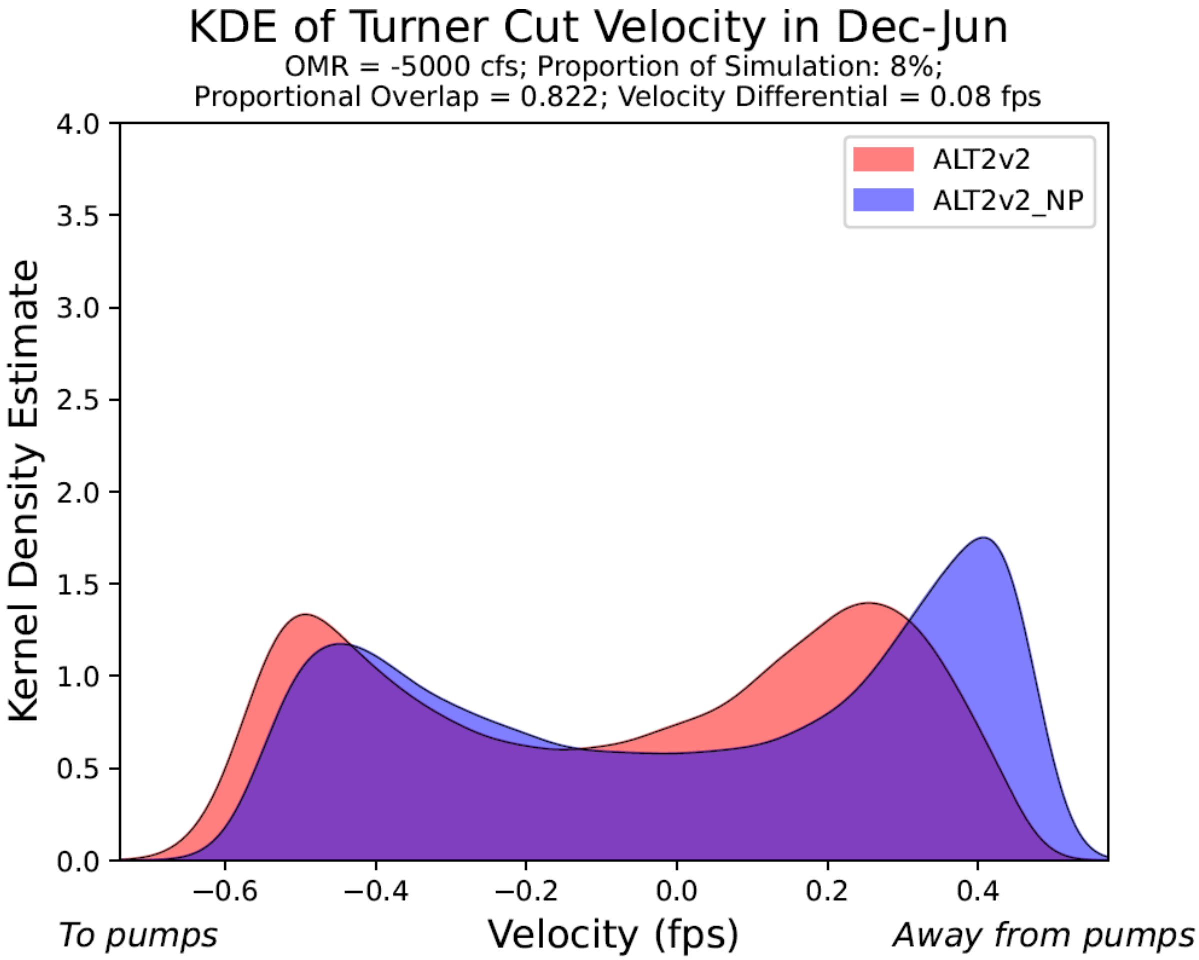
Proportional Overlap value indicates the overlapping density distribution between pumping (red) and no pumping (blue) scenarios. Results apply to Alt2woTUCPDeltaVA.

Figure 5-20. Gaussian KDE of Velocity at Old R at Middle River in December through June with OMR of -2,000 cfs.



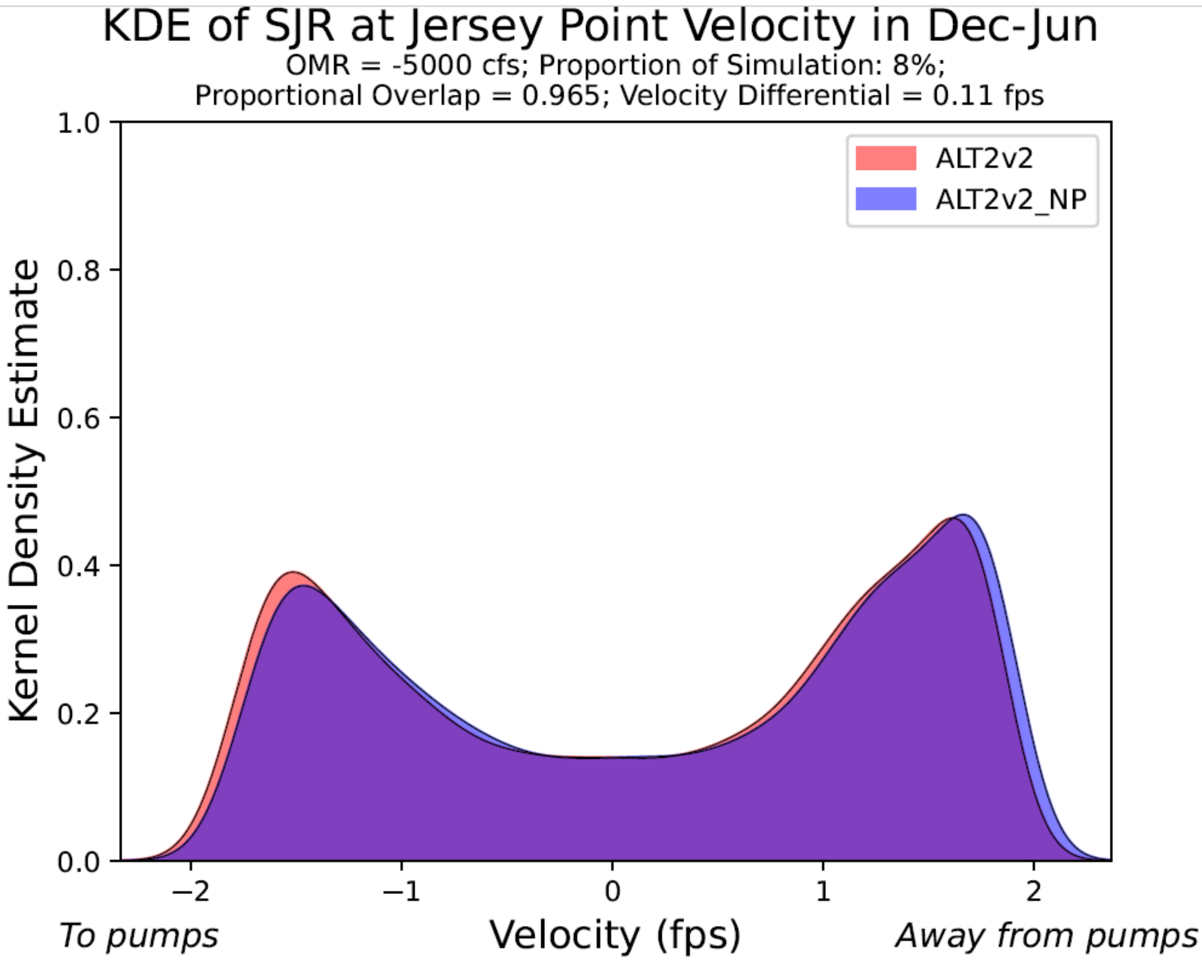
Proportional Overlap value indicates the overlapping density distribution between pumping (red) and no pumping (blue) scenarios. Results apply to Alt2woTUCPDeltaVA.

Figure 5-21. Gaussian KDE of Velocity at Old R at Middle River in December through June with OMR of -5,000 cfs.



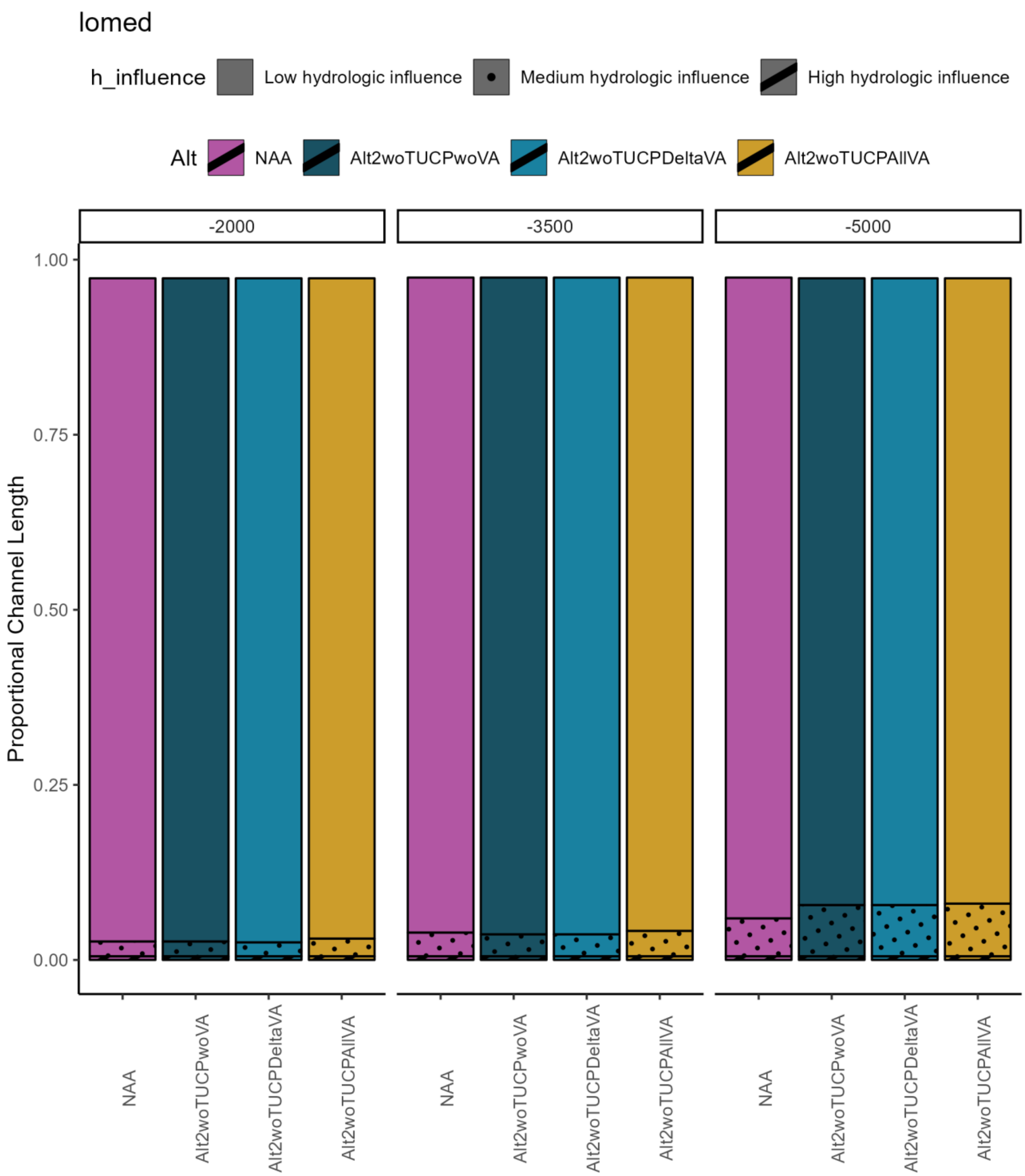
Proportional Overlap value indicates the overlapping density distribution between pumping (red) and no pumping (blue) scenarios. Results apply to Alt2woTUCPDeltaVA.

Figure 5-22. Gaussian KDE of Velocity at Turner Cut in December through June with OMR of -5,000 cfs.



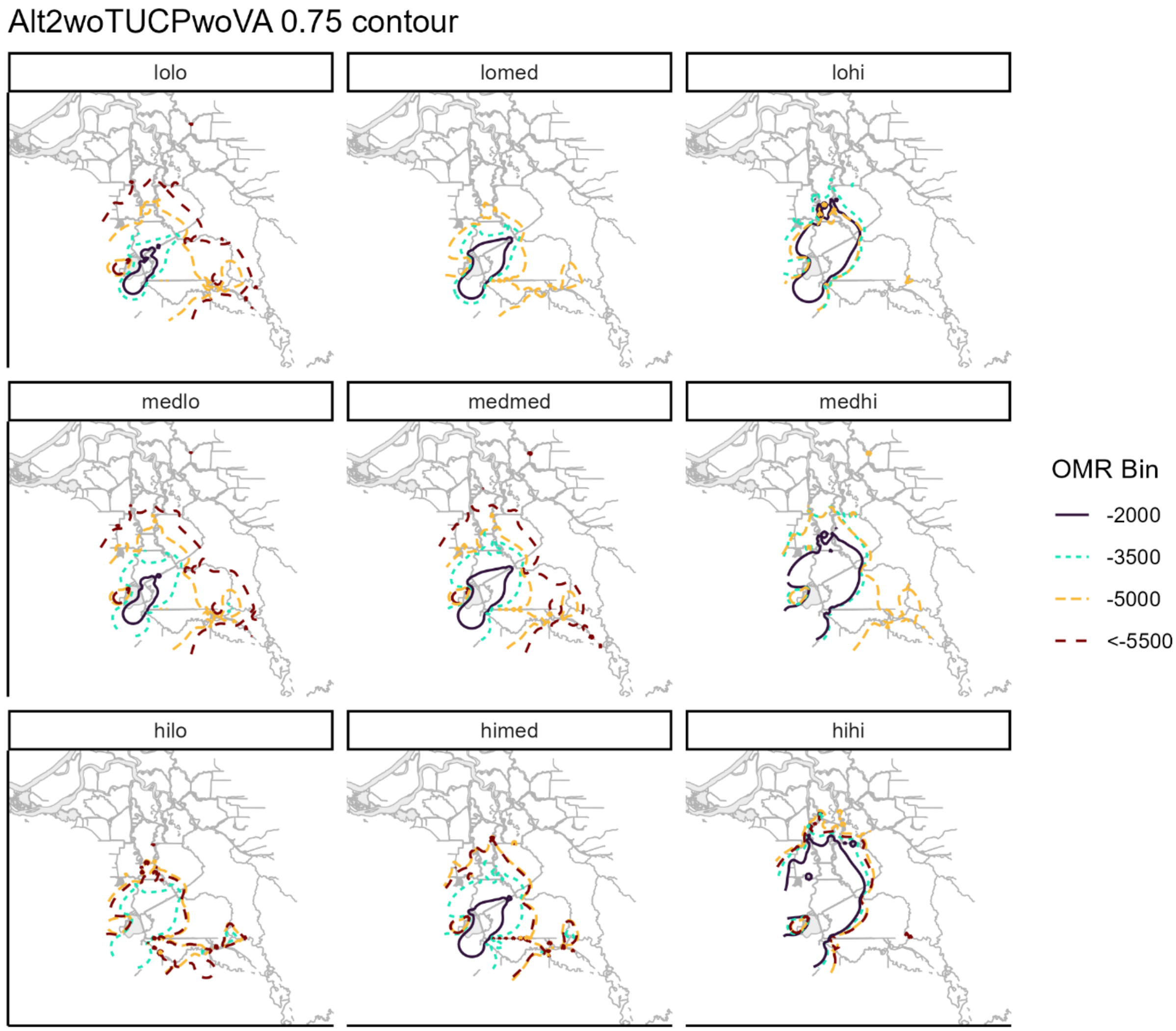
Proportional Overlap value indicates the overlapping density distribution between pumping (red) and no pumping (blue) scenarios. Results apply to Alt2woTUCPDeltaVA.

Figure 5-23. Gaussian KDE of Velocity at SJR at Jersey Point in December through June with OMR of -5,000 cfs.



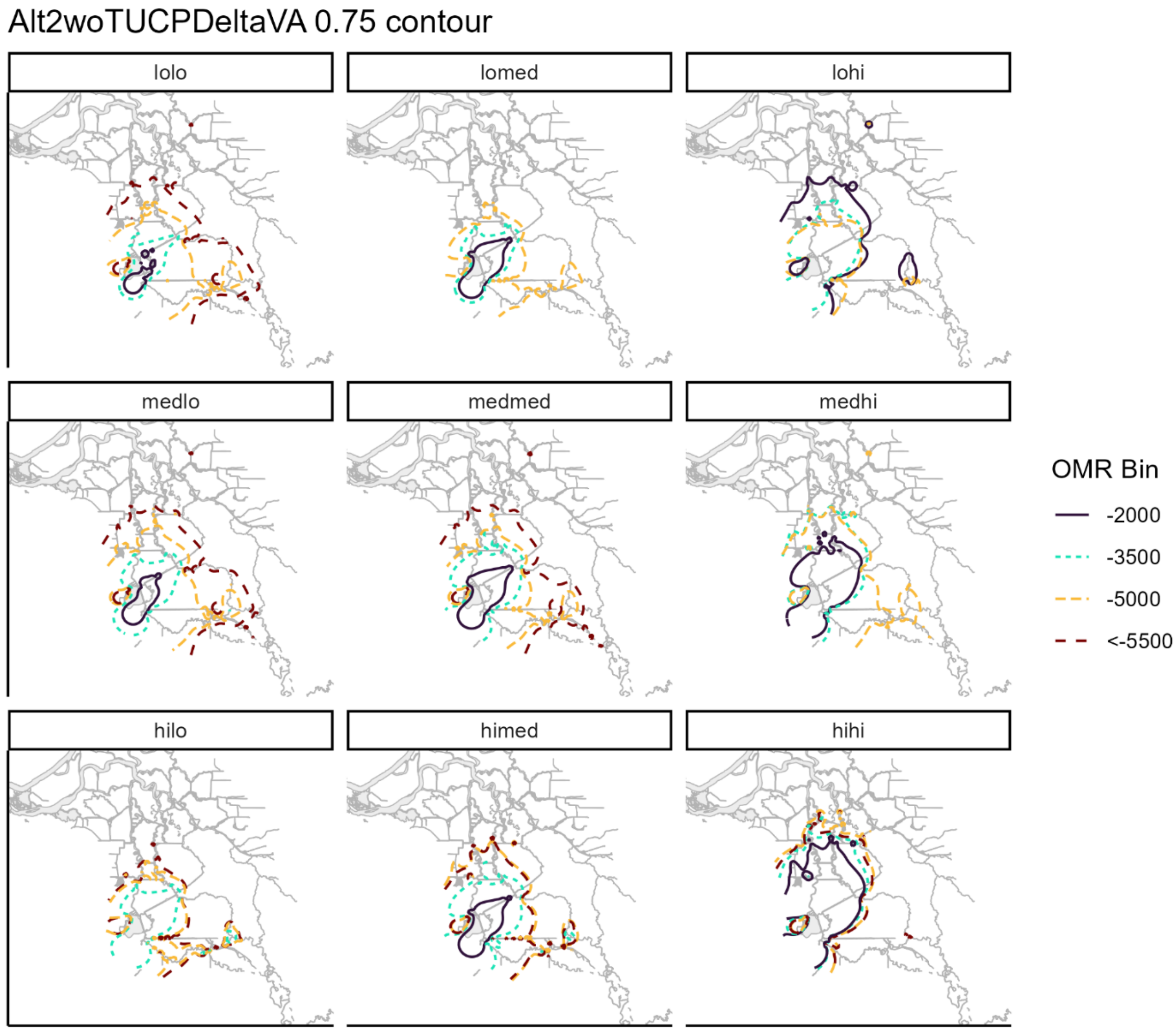
Results apply to the lomed inflow group.

Figure 5-24. Proportion of Total Channel Length in the Delta (DSM2 grid) that Experiences High (<25% proportional overlap), Medium (25-75% proportional overlap) and Low (>75% proportional overlap) Hydrologic Influence across PA Components and across OMR Bins of -2000, -3500, -5000, and Less Than -5500 cfs.



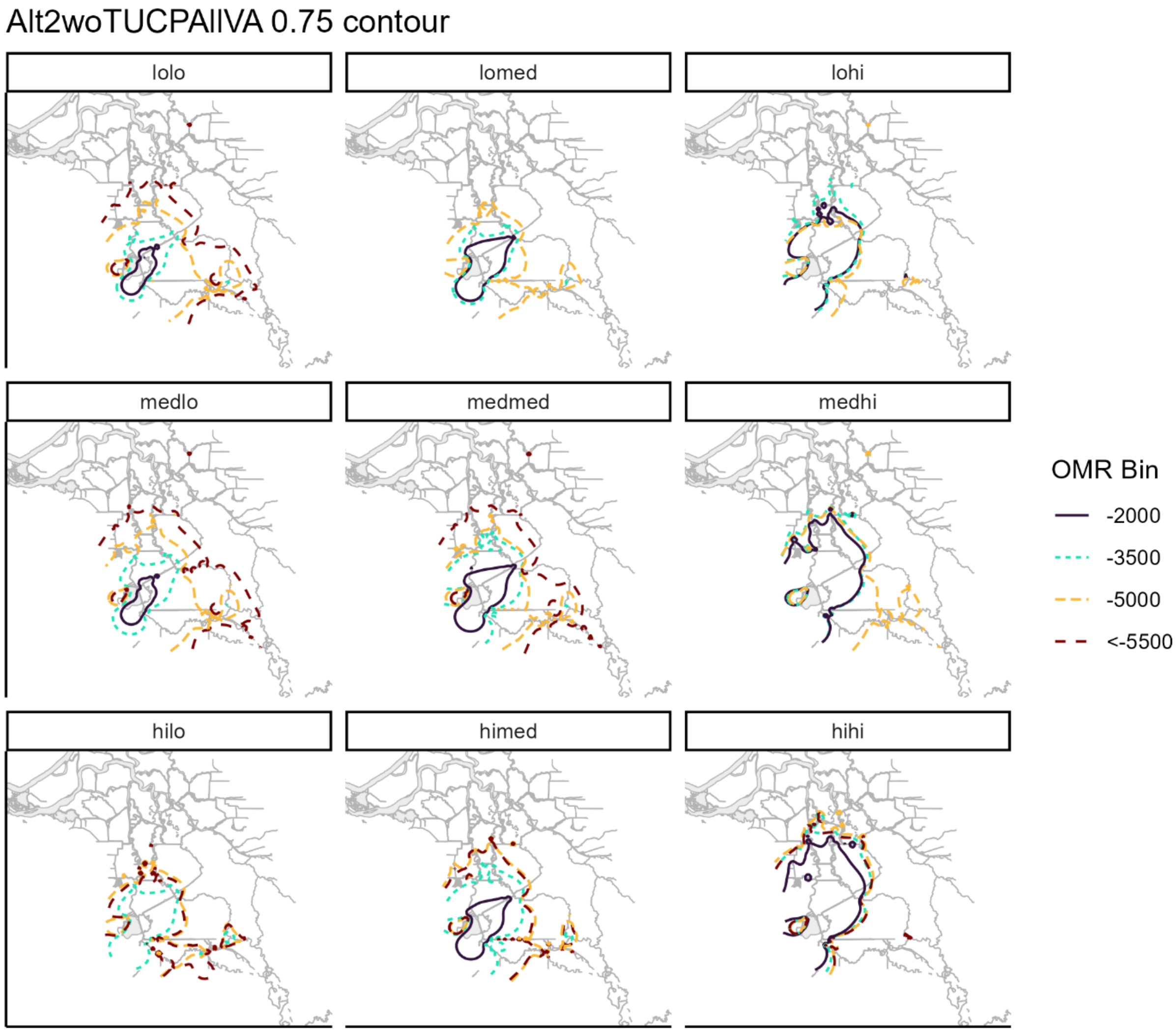
The contours identify where there is up to 75% overlap in velocity distribution with and without CVP exports. Results apply to Alt2woTUCPwoVA. See Figure 5-17 for group designations.

Figure 5-25. Faceted Contour Maps Delineating Delta Export Zone of Influence Under Varying Inflows and OMR Flows.



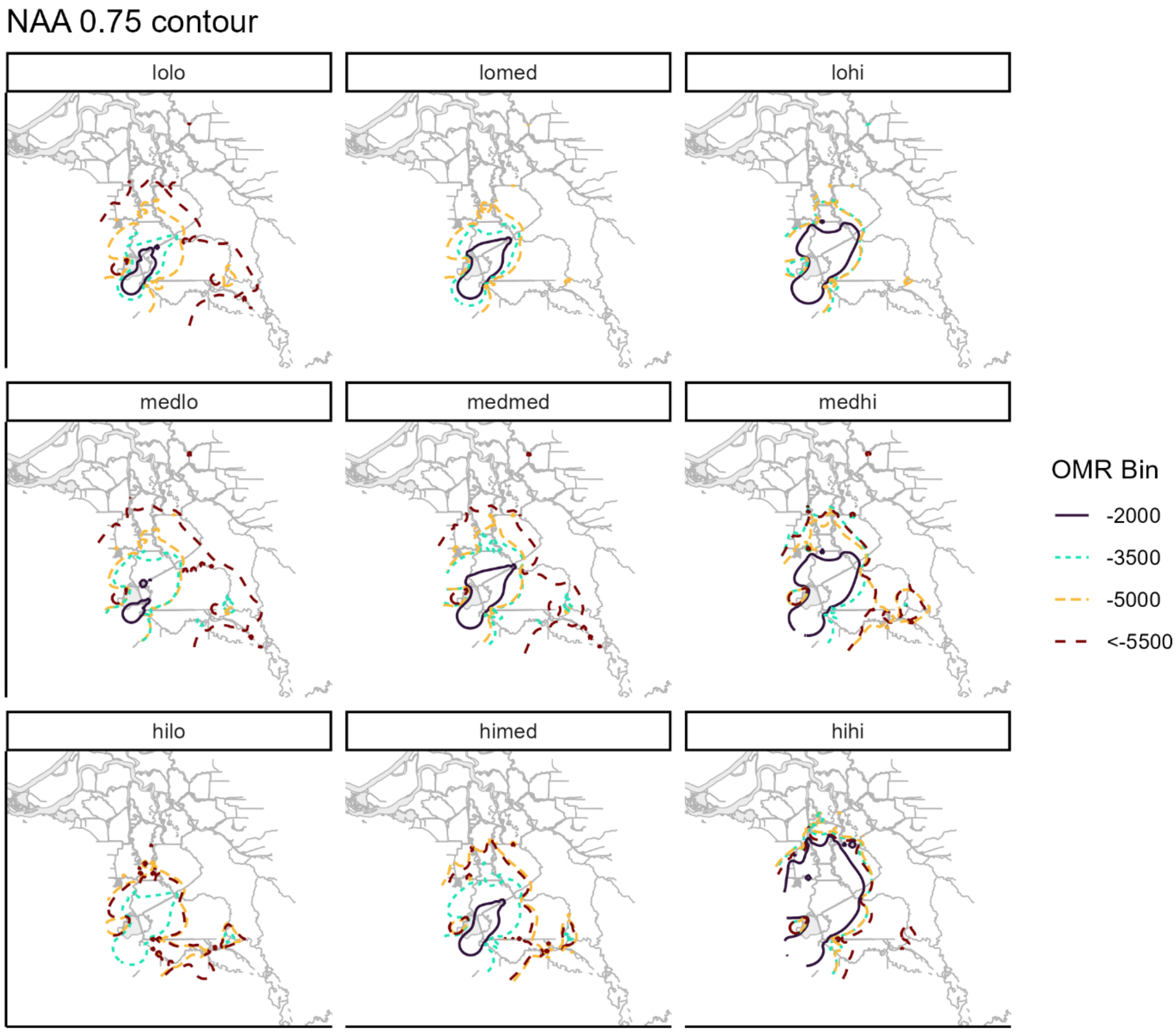
The contours identify where there is up to 75% overlap in velocity distribution with and without CVP exports. Results apply to Alt2woTUCPDeltaVA. See Figure 5-17 for group designations.

Figure 5-26. Faceted Contour Maps Delineating Delta Export Zone of Influence Under Varying Inflows and OMR Flows.



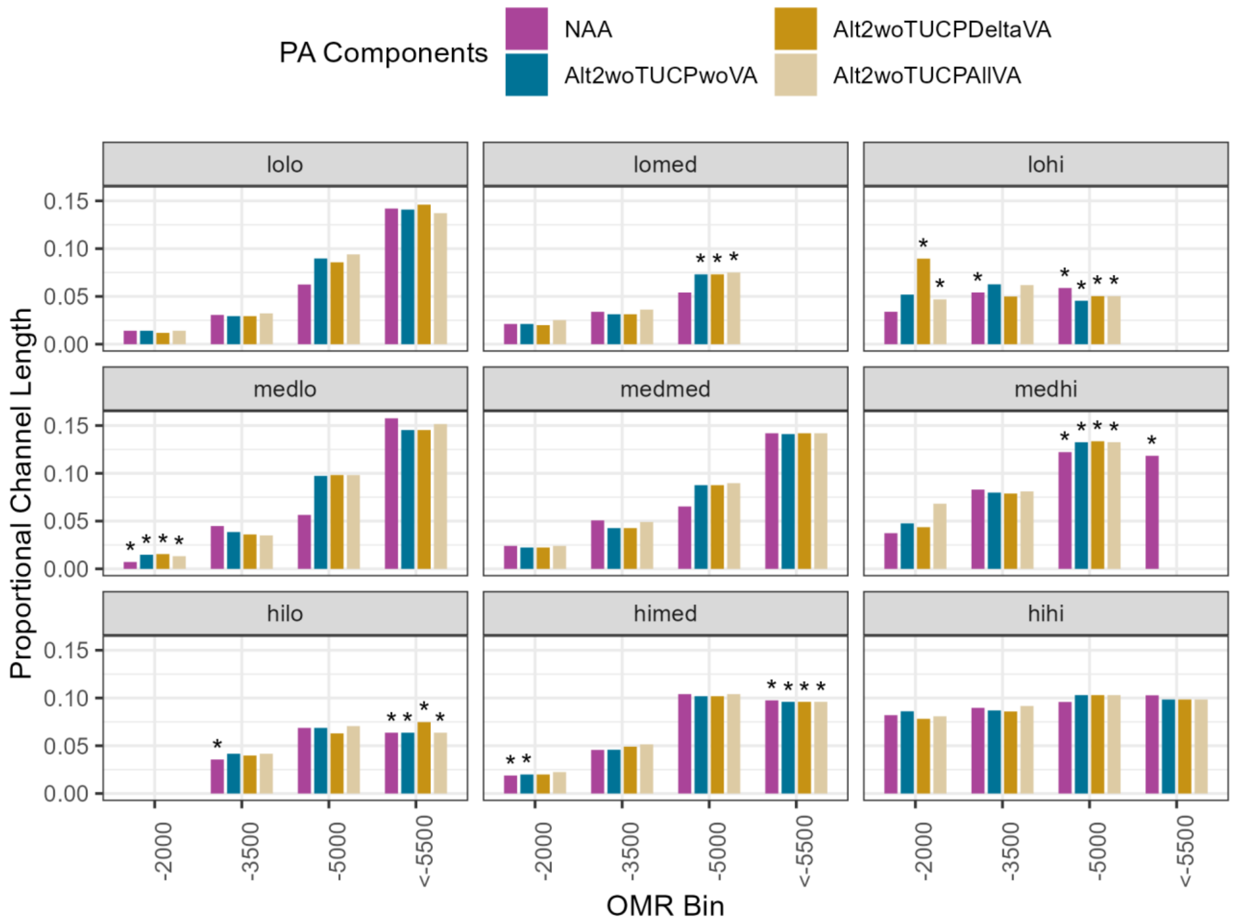
The contours identify where there is up to 75% overlap in velocity distribution with and without CVP exports. Results apply to Alt2woTUCPAllVA. See Figure 5-17 for group designations.

Figure 5-27. Faceted Contour Maps Delineating Delta Export Zone of Influence Under Varying Inflows and OMR Flows.



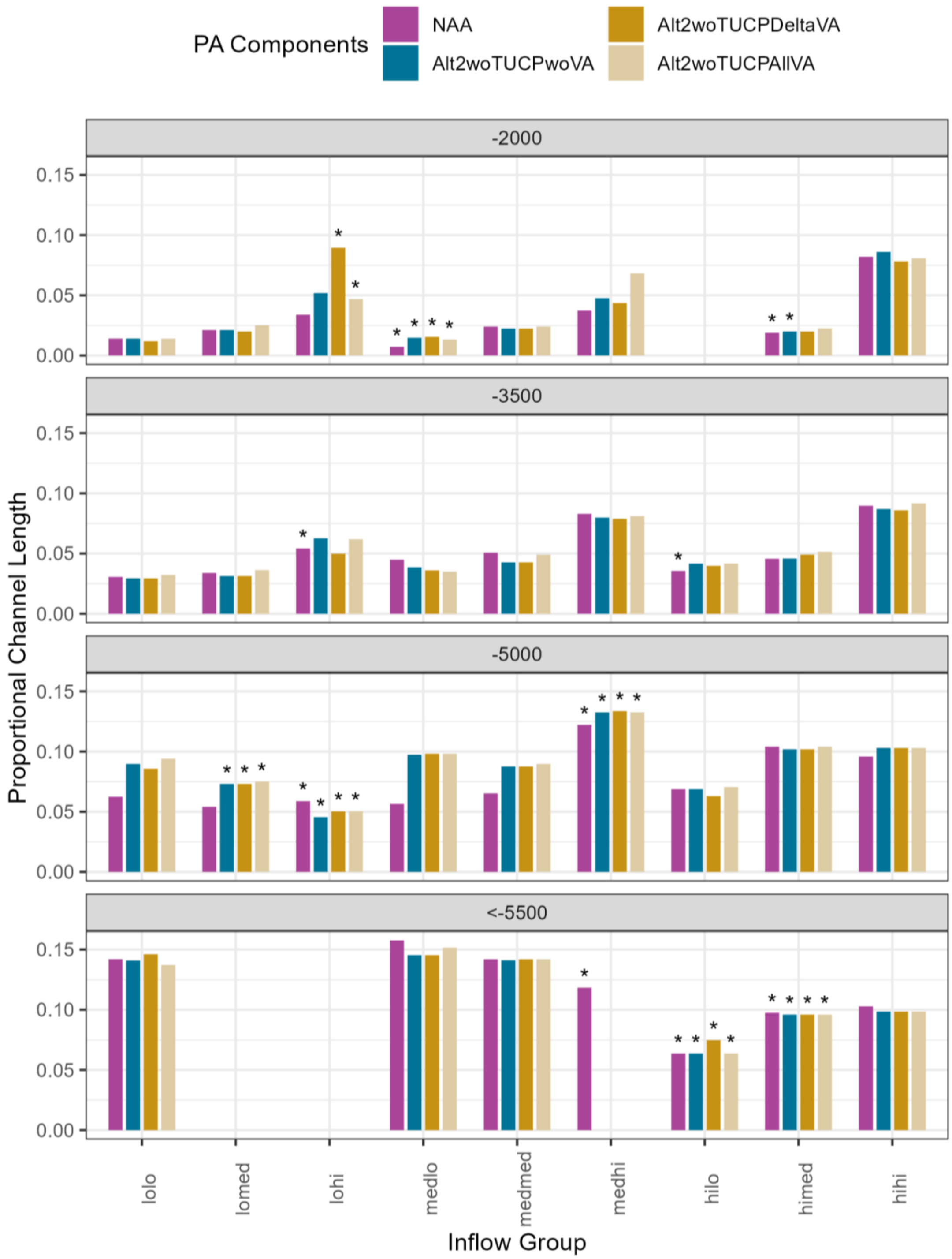
The contours identify where there is up to 75% overlap in velocity distribution with and without CVP exports. Results apply to the No Action Alternative. See Figure 5-17 for group designations.

Figure 5-28. Faceted Contour Maps Delineating Delta Export Zone of Influence Under Varying Inflows and OMR Flows.



Results are displayed across alternatives. Stars indicate combinations with five or less samples (months).

Figure 5-29. Proportion of Total Channel Length in the Delta (DSM2 grid) that Experiences Medium (25-75% proportional overlap) Hydrologic Influence at Standardized Inflow Groups and Across OMR Flows of -2000, -3500, -5000, and Less Than -5500 cfs.



Results are displayed across alternatives. Stars indicate combinations with five or less samples (months).

Figure 5-30. Proportion of Total Channel Length in the Delta (DSM2 grid) that Experiences Medium (25-75% proportional overlap) Hydrologic Influence at Standardized Inflow Groups and Across OMR Flows of -2000, -3500, -5000, and Less Than -5500 cfs.

Table 5-22. Channel Length (feet) Altered by Pumping for No Action Alternative (NAA) and Three Components of the Proposed Action Across Inflow Groups and OMR Bins.

Inflow Group	OMR Bin	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
lolo	-2000	54189	54189	45576	54189
lolo	-3500	117806	113044	113044	124055
lolo	-5000	240433	345257	329891	361840
lolo	<-5500	546547	542342	562344	527855
lomed	-2000	81465	81465	76711	96978
lomed	-3500	130344	120549	120549	139432
lomed	-5000	208217	281435	281435	289043
lomed	<-5500	NA	NA	NA	NA
lohi	-2000	130552	199749	344641	180584
lohi	-3500	208428	241111	191942	238045
lohi	-5000	226351	175053	193470	193470
medlo	-2000	27647	56798	59520	50971
medlo	-3500	172490	148289	138590	134670
medlo	-5000	217383	374670	377919	377919
medlo	<-5500	606560	559302	559302	583403
medmed	-2000	92454	86009	86009	92454
medmed	-3500	195201	164174	164174	188699
medmed	-5000	251330	337165	337165	345232
medmed	<-5500	546334	543002	546334	546334
medhi	-2000	143735	183314	167915	262475
medhi	-3500	319355	307325	303468	311986
medhi	-5000	470418	510174	514154	510385
medhi	<-5500	455531	NA	NA	NA
hilo	-3500	137049	160217	153086	160217
hilo	-5000	264382	264382	242315	271698
hilo	<-5500	245068	245068	287645	245068
himed	-2000	72558	76711	76711	86402
himed	-3500	175651	176405	188818	197951
himed	-5000	400448	392039	392039	400448
himed	<-5500	375420	369417	369417	369417
hihi	-2000	315738	331338	300952	311077
hihi	-3500	345153	334832	330569	352728
hihi	-5000	368941	396491	396491	396491
hihi	<-5500	395764	378812	378812	378812

Values represent total summed channel length between nodes experiencing 0.25-0.75 proportional overlap, or medium hydrologic influence. Absolute values are rounded. .

Flow into Junctions (Appendix I, Attachment XX), shows the alteration of proportion of flow entering routes at key distributaries based on exports. The analysis assumes the Proposed Action's changes in the routing of water may change the route selection of winter-run Chinook salmon when exports change the fraction of flows through junctions. At each junction, exports may have effects on water flow.

[Placeholder: Flow into Junctions (performance measure is proportion of flow entering junctions)]

PTM (Appendix I, Attachment XX) does not assume fish and flows fully mix within the Delta and provides context for the routing of Sacramento-origin particles through different migratory pathways as a result of changes in exports.

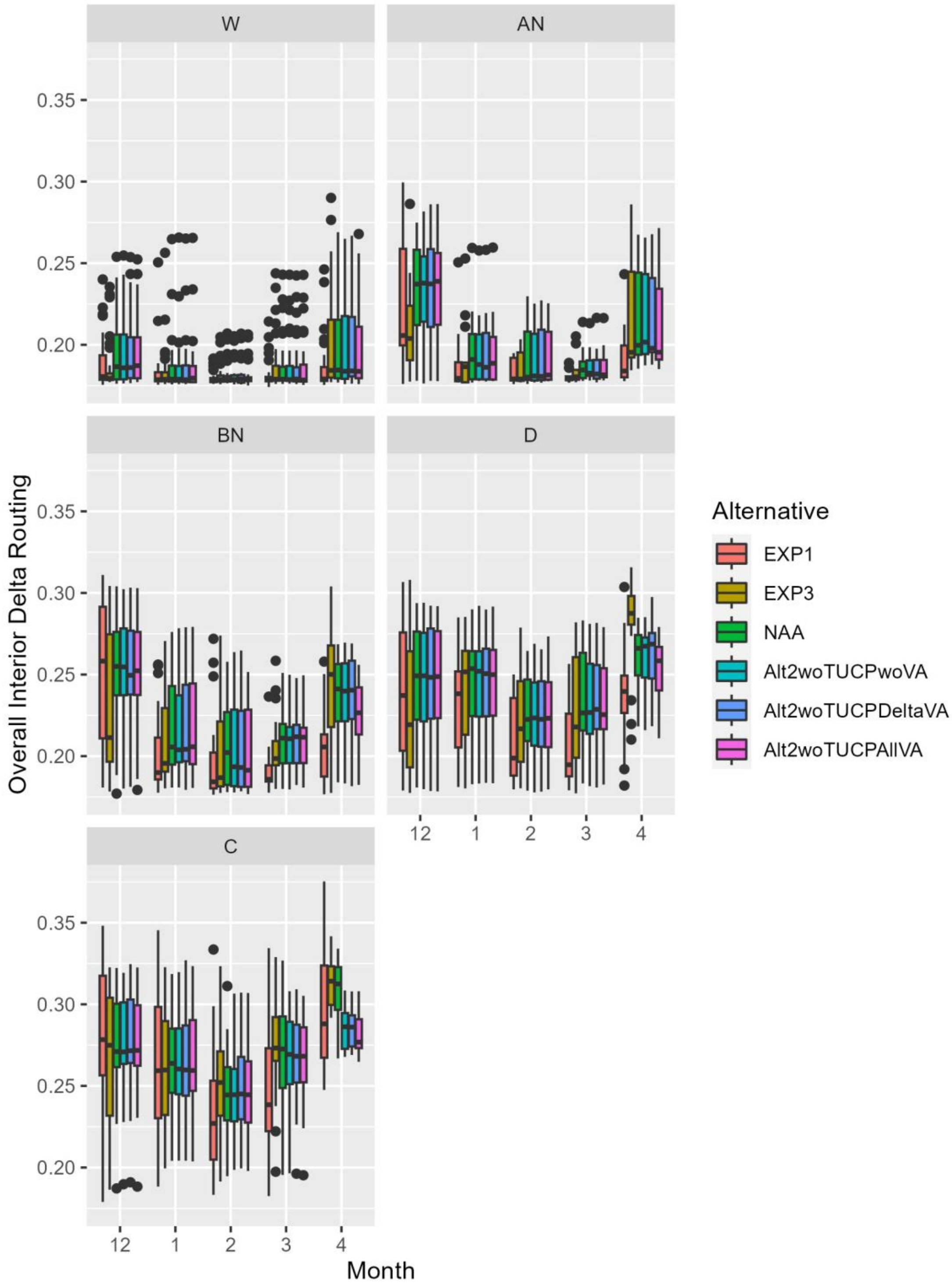
[Placeholder: PTM (performance measure is particle flux at relevant location from relevant release locations)]

ECO-PTM (Appendix I, Attachment XX) does not assume particles are invulnerable. Unlike PTM, ECO-PTM includes a fish behavioral component from acoustically tagged juveniles. This additional layer provides a more biologically grounded evaluation of the effects of flow on the routing of fish from the Sacramento River through different migratory pathways. Like PTM, this analysis assumes the Proposed Action may change the route selection of winter-run Chinook salmon when flows are changed.

[Placeholder: ECO-PTM (performance measure is through Delta survival)]

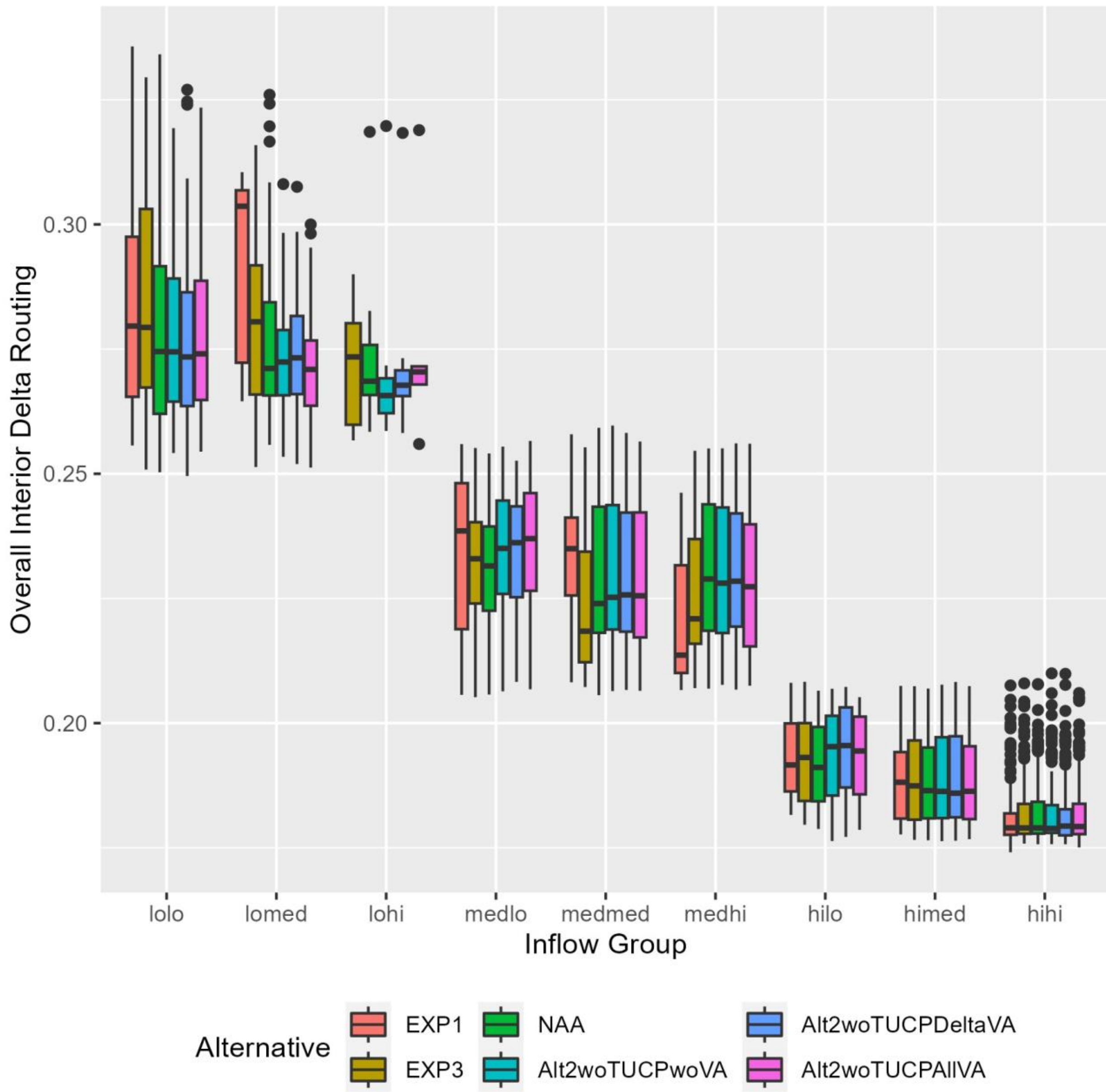
STARS (Appendix I, Attachment XX) simulates the routing, entrainment, and survival of juvenile salmonids migrating through the Delta. The STARS model proportion of salmon routed to the Interior Delta under the Proposed Action phases range from 0.182 to 0.285 (Figure 5-31). Overall, the lowest proportion of winter-run routed in the Delta occurs during Wet years and the highest proportion occurs in Critically Dry years (Figure 5-31). The greatest expected proportions occurred in December or April, depending on WYT.

The range of mean proportion of salmon routed to the Interior Delta for the Proposed Action phases was different across Sacramento River inflow groups and ranged from approximately 0.275 under low inflows to 0.185 under high inflows (Table 5-23; Figure 5-32). Under the Proposed Action phases, fewer Chinook salmon can be expected to be routed to the Interior Delta when Sacramento inflows increase. Within inflow groups, routing proportions did not apparently change as a function of OMR groups (Figure 5-33).



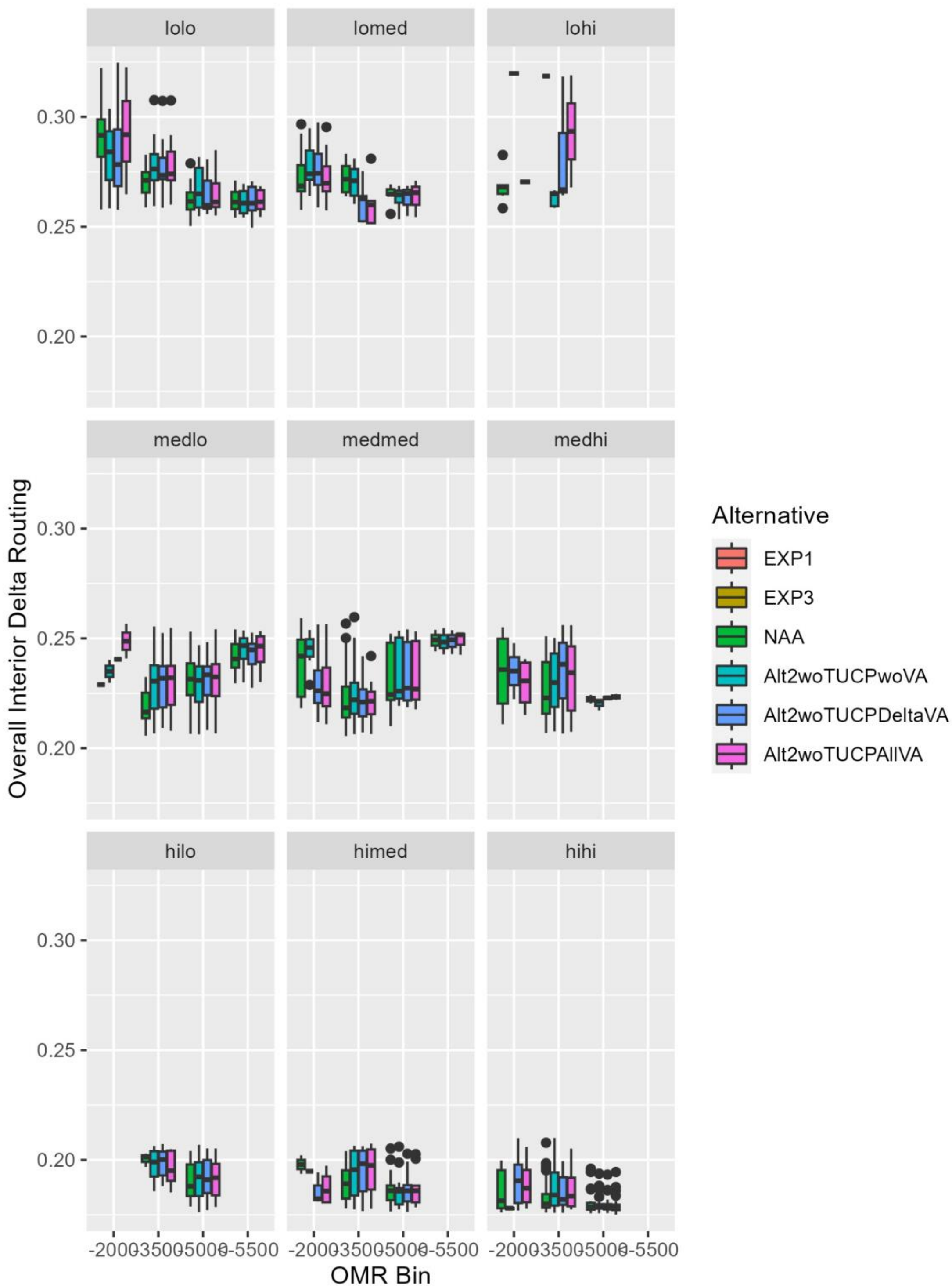
The box edges represent 25th and 75th percentiles, and whiskers are the product of the interquartile range and 1.5.

Figure 5-31. Boxplots of Predicted Routing Proportions to the Interior Delta, Separated by Water Year Type and Month.



The box edges represent 25th and 75th percentiles, and whiskers are the product of the interquartile range and 1.5.

Figure 5-32. Boxplots of Predicted Routing Proportions to the Interior Delta, Separated by Inflow Grouping.



The box edges represent 25th and 75th percentiles, and whiskers are the product of the interquartile range and 1.5.

Figure 5-33. Boxplots of Predicted Routing Proportions to the Interior Delta, Separated by Inflow Grouping (facets) and OMR Bin (x-axis).

Table 5-23. Predicted Mean Proportion of Particles Routed to the Interior Delta (i.e., via either Georgiana Slough or Delta Cross Channel), Averaged by Inflow Grouping.

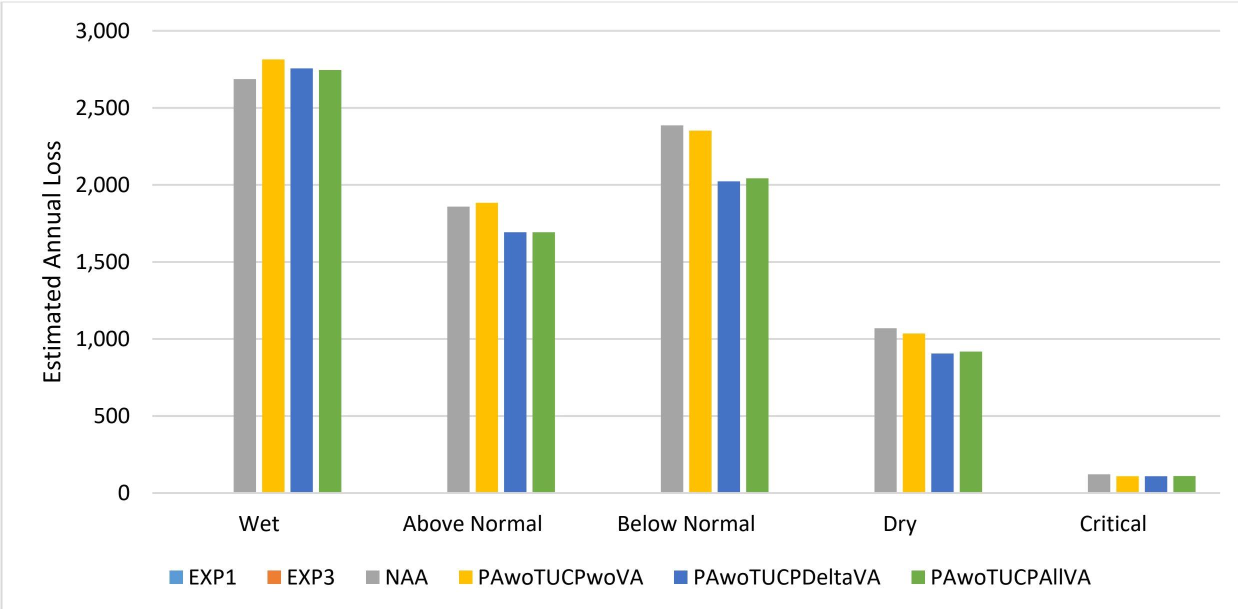
Inflow Group	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
All	0.212	0.221	0.223	0.222	0.222	0.221
lolo	0.283	0.284	0.279	0.278	0.278	0.279
lomed	0.292	0.281	0.279	0.274	0.274	0.272
lohi	NA	0.272	0.276	0.272	0.274	0.277
medlo	0.234	0.232	0.231	0.234	0.233	0.235
medmed	0.234	0.224	0.229	0.230	0.229	0.229
medhi	0.220	0.226	0.230	0.230	0.230	0.229
hilo	0.193	0.193	0.192	0.193	0.194	0.193
himed	0.189	0.189	0.188	0.189	0.189	0.189
hihi	0.181	0.182	0.182	0.182	0.182	0.182

Delta Passage Model (DPM; Appendix I, Attachment XX) simulated the survival, routing, and travel time of Chinook salmon through the Delta. The DPM uses available time-series data and values taken from empirical studies or other sources to parameterize model relationships and inform uncertainty, thereby using the greatest amount of data available to dynamically simulate responses of smolt survival to changes in water management. It is a simulation tool that compares the effects of different water management options on smolt migration survival, with accompanying estimates of uncertainty.

[Placeholder: DPM (performance measure is through Delta survival)]

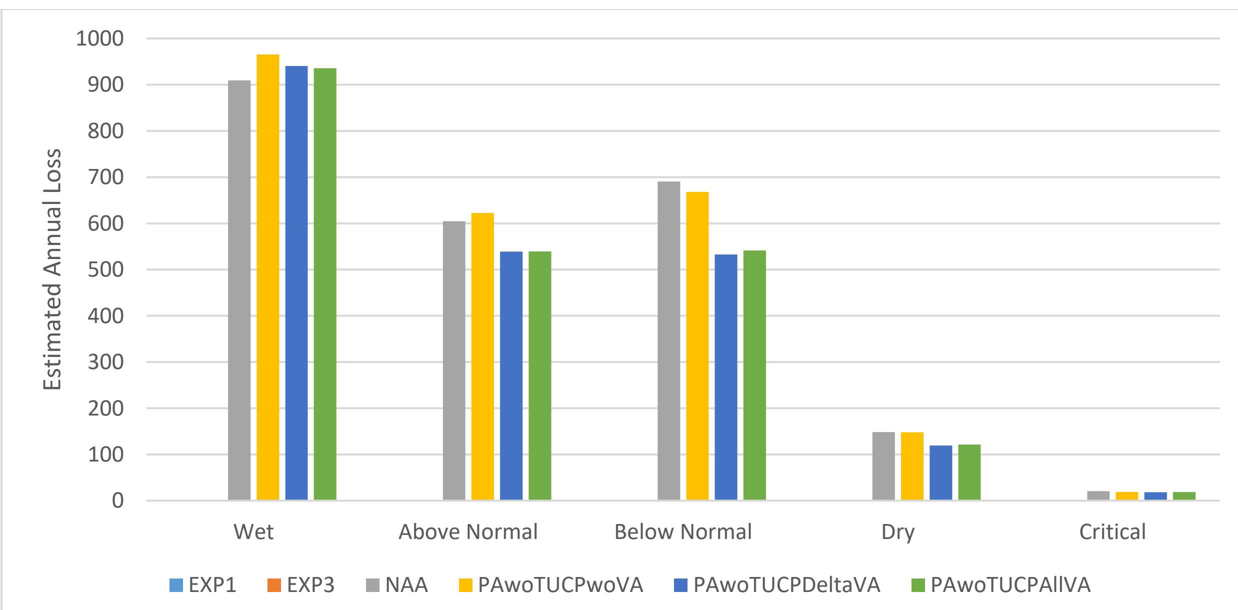
The Salvage Density Analysis, Appendix I, Attachment I.2, *OMR Salvage-Density Model Loss Simulation*, provides context for loss of LAD winter-run Chinook salmon at the export facilities. This analysis weighs south Delta exports at the export facilities by historical salvage per unit volume. Predicted annual loss of LAD winter-run Chinook salmon at the facilities under the Proposed Action phases range from 109 to 2,814 (Figure 5-34). EXP1 and EXP3 predicted loss is 0. Overall, predicted loss varies among water year types. The lowest predicted loss occurred in Proposed Action phases for critical water year types. The highest predicted loss occurred in Proposed Action phases for wet water year types. Loss of LAD winter-run Chinook salmon at the facilities in the Proposed Action phases range over an order of magnitude among water year types, which is similar to historically observed salvage in the recent past.

Predicted annual loss of genetic winter-run Chinook salmon at the facilities under the Proposed Action components ranges from 18 to 965 (Figure 5-35). The lowest predicted loss occurred in Proposed Action phases for critical water year types. The highest predicted loss occurred in Proposed Action phases for wet water year types. Loss of genetic winter-run Chinook salmon is lower than loss of LAD winter-run Chinook salmon.



Under EXP1 and EXP3 exports are set at 0 resulting in a predicted loss of 0.

Figure 5-34. Estimated Annual Cumulative Loss of Sacramento River Origin LAD Winter-run Chinook Salmon at the Export Facilities by Water Year Type based on Salvage-density Method.



Under EXP1 and EXP3 exports are set at 0 resulting in a predicted loss of 0.

Figure 5-35. Estimated Annual Cumulative Loss of Sacramento River Origin Genetic Winter-run Chinook Salmon at the Export Facilities by Water Year Type based on Salvage-density Method.

Negative Binomial Loss model (Appendix I, Attachment I.1, *Negative Binomial Salvage Model*) provides context for estimated salvage of LAD winter-run Chinook salmon at the Delta Fish Collection Facilities, combined. The analysis assumes the Proposed Action may change the presence of winter-run Chinook salmon in the South Delta near the facilities when flows are changed. The model uses species-specific regression equations to predict salvage. The top supported model for winter-run Chinook salmon included month, Sacramento Trawl catch, combined exports from CVP and SWP, and San Joaquin River flow through a model selection process. **Error! Reference source not found.**

Predicted annual salvage of LAD winter-run Chinook salmon at the facilities under the Proposed Action phases ranges from 3 to 15 (Figure 5-36). EXP1 and EXP3 predicted salvage is non-zero but does not vary between runs across water years. Overall, predicted salvage varies among water year types. The highest predicted salvage occurred in Proposed Action phases for wet water year types. Salvage of LAD winter-run Chinook salmon at the facilities in the Proposed Action components range over an order of magnitude among water year types, which is similar to historically observed salvage in the recent past.

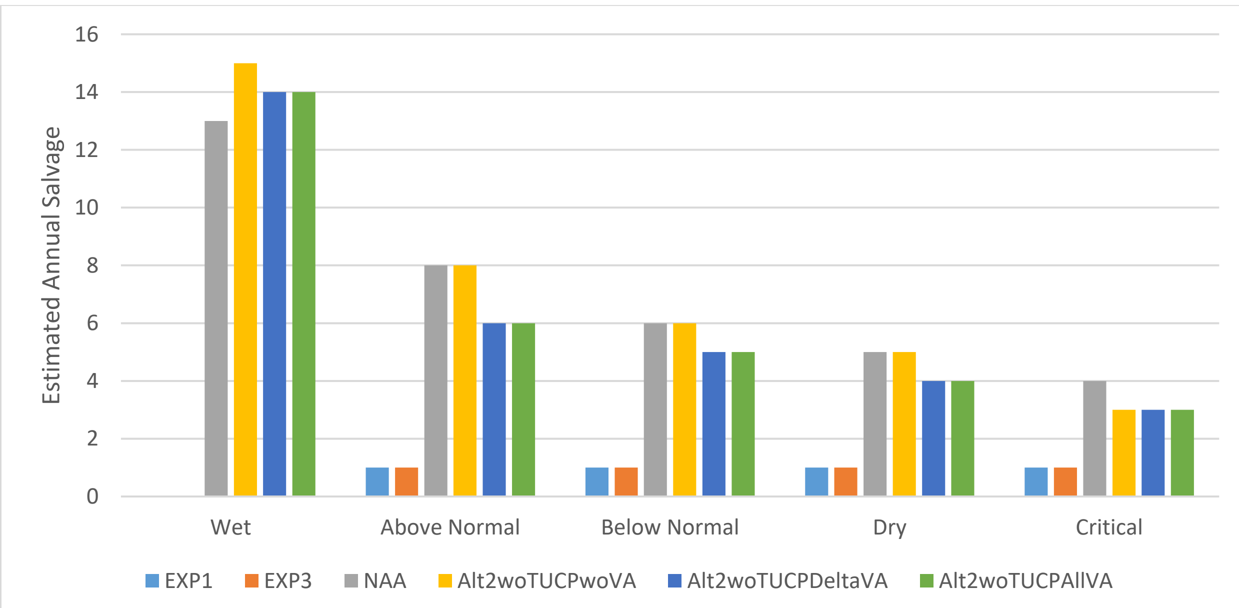


Figure 5-36. Estimated Annual Mean Salvage of Sacramento River Origin LAD Winter-run Chinook Salmon at the Export Facilities by Water Year Type based on Negative Binomial Salvage Method.

Winter-run Chinook CWT salvage model (Appendix I, Attachment XX) provides context for predicted combined salvage of winter-run Chinook salmon at the Delta Fish Collection Facilities. The analysis models predicted proportion of the JPE entrained at the salvage facilities based on the best three predictor variables including mean fork length of fish, Sacramento River flow, and total exports.

[Placeholder: CWT salvage model results]

The **frequency** of occurrence of the stressor is directly linked to hydrology, dependent on the Proposed Action OMR Management actions (e.g., -5,000 OMR, first flush, weekly or monthly winter-run Chinook salmon loss threshold, etc.). The **frequency** of occurrence is **high** and likely to occur annually as the CVP and SWP will operate to no more negative than -5,000 cfs.

The **weight of evidence** for entrainment risk includes empirical species- and route-specific entrainment estimates from acoustically tagged salmonids (hatchery and wild, multiple runs), decades of quantitative OMR flows, decades of historical salvage and loss data from the Delta fish facilities, and location-specific but not species-specific validated models including particle tracking and zone of influence analyses.

- Literature, Kimmerer and Nobriga: quantitative, species-specific, location-specific, publication in a peer reviewed journal, uses widely accepted particle tracking model (PTM) established for the Bay-Delta to estimate particle movement with several covariates
- Historic migration timing: quantitative, species-specific, location-specific, available through multiple sources and QA/QCed, long time-series and not expected to have statistical power
- Historic salvage observations: quantitative, species-specific, location-specific, available through multiple sources and QA/QCed, long time-series and not expected to have statistical power
- Historic acoustic tagging and CWT information: quantitative, species-specific, location-specific, data used in many peer-reviewed publications
- Bulk flow modeling LOE: quantitative, not species-specific (but not expected to be, environmental variable), location-specific, not published, simplified representation of the Bay-Delta (proportion of Sacramento inflow exported)
- Zone of influence modeling LOE: quantitative, not species-specific (but not expected to be., environmental variable), location-specific, not published, widely accepted method for evaluating spatial extent of varying levels of exports within the Bay-Delta
- Flow at Junctions Modeling: quantitative, not species-specific (but not expected to be, environmental variable), location-specific
- PTM modeling LOE: quantitative, not species-specific (but not expected to be, environmental variable), location-specific, used in multiple peer-reviewed publications, PTM is a widely accepted method to estimate particle movement and can be evaluated with covariates
- ECO-PTM modeling LOE: quantitative, species-specific (model developed with tagged Chinook salmon), location-specific, model under development with U.S. Geological Survey and DWR presented at conferences / meetings and used by inter-agency working groups (e.g., Georgiana Slough structured decision-making group), individual-based model combining PTM and swimming behavior from tagged salmonids calibrated and validated with field data

- STARS modeling LOE: quantitative, species-specific, location-specific, multiple publications in peer reviewed journals, stochastic individual-based model using mark-recapture and a single covariate
- DPM modeling LOE: [PLACEHOLDER]
- Salvage Density modeling LOE: quantitative, species-specific, location-specific, widely accepted and historically used as a salvage / loss estimation tool, single covariate
- Negative Binomial modeling LOE: quantitative, species-specific, location-specific, newly developed unpublished method for estimating loss specific to salmonids, final covariates unique to each species from model selection process
- Winter-run CWT proportional loss modeling LOE: [PLACEHOLDER]

The Proposed Action includes a special study to evaluate flow management and operations effects for outmigrating juvenile winter-run Chinook salmon. A series of studies involves a network of acoustic receivers to track acoustically tagged salmon. Real-time and retrospective data will be used to model Delta route-specific entrainment (routing) and survival. The objectives are to provide real-time estimates of reach-specific survival and route entrainment for cohorts of tagged fish in the Sacramento River and Delta.

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- SRSC Transfer Delays
- Delta Cross Channel Gate Closure
- Winter-Run Chinook Salmon Early Season Salvage Threshold
- First Flush and Start of OMR Management
- January 1 and Start of OMR Management
- Winter-Run 50% Annual Loss Threshold
- Winter-Run 75% Annual Loss Threshold
- Winter-Run Weekly Loss Thresholds
- Winter and Spring Delta Outflows
- Salvage Facilities

Conservation measures in the Proposed Action for other species, life stages and/or stressors that may exacerbate this stressor include:

- Fall and Winter Base Flows for Shasta Reservoir Refill
- SHOT Water Transfer Timing Approvals
- Reduced Wilkins Slough Minimum Flows
- Drought Actions

5.2.4.4 Refuge Habitat

The proposed storage of water may increase the refuge habitat stressor. During the juvenile rearing and outmigration period, the Proposed Action's storage of water in Shasta Reservoir in the fall and winter will decrease flows in the Sacramento River and Delta that reduce suitable margin and off-channel habitats available as refuge habitat for juveniles. Due to high velocities from increased releases, potential refuge habitat along the mainstem Sacramento River will decrease until the rivers overflows the channel and inundates off-channel habitats. Appendix O presents analysis of this stressor.

In the Delta, operations are not expected to increase the refuge habitat stressor for rearing and outmigrating juvenile winter-run Chinook salmon. All juveniles outmigrating from the Sacramento River must pass through the Delta on the way to the Pacific Ocean. The Delta is tidally influenced. As such, the effect of Proposed Action storage of water on available shallow-water refuge habitat would be within the daily tidal range near the seaward end of the Delta. Tidal influence dissipated toward the landward edges of the Delta and effects of Proposed Action storage of water would be more similar to that described for the mainstem Sacramento River above. In the Delta, winter-run Chinook salmon utilize side channel and inundated floodplain habitat in the tidal shoreline of the Delta for foraging and growth. The tidal habitat of the Delta also serves the critical role as a physiological transition zone before saltwater entry, with juveniles residing in the Delta for an average of three months (del Rosario et al. 2013). However, only a small fraction of the wetland rearing habitat is still accessible to fish, and much of the modern Delta and bays have been converted to serve agriculture and human population growth (SFEI-ASC 2014). As explained above, the loss of tidal marshes and historical floodplain wetlands have resulted in a loss of refuge habitat for winter-run Chinook salmon. In addition, there are 200 miles of exterior levees in Suisun Marsh; twenty of those miles are along Suisun, Grizzly, and Honker Bays (SMP 2013). Levee construction involves the removal and loss of riparian vegetation (Anderson and Sedell 1979; Pusey and Arthington 2003). There is no known relationship between flows and refuge habitat availability similar to those for the Sacramento River (Gard 2005), inter-annual variation in flows at Freeport during the rearing and outmigration period is greater than at Keswick Dam; thus, flow-dependent refuge habitat is likely limiting less often in the Delta than in the Sacramento River.

The increase in refuge habitat stressor in the Sacramento River is expected to be **sub-lethal**. A decrease in sufficient refuge habitat can result in juveniles lacking cover to avoid predation or habitat to stop and hold during outmigration. Access to off-channel habitats has been linked to higher growth rates and survival (Limm and Marchetti 2009; Zeug et al. 2020). Very low releases decrease potential refuge habitat for juvenile winter-run Chinook salmon by removing access to side-channels, access to refuge, and changing geomorphic processes. Refuge habitat is not independent of food availability and quantity, another sub-lethal stressor discussed below.

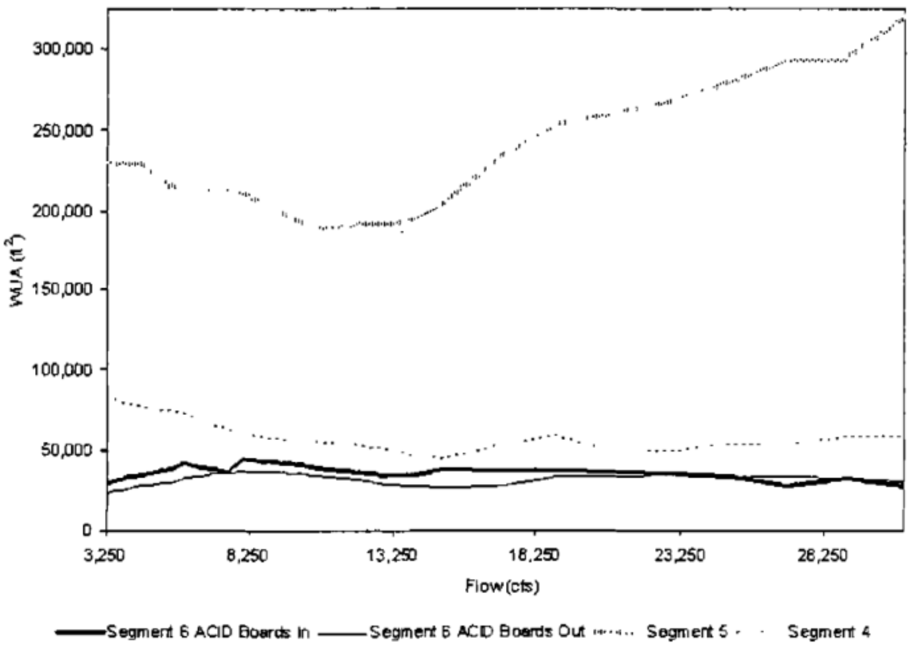
Although the Proposed Action may increase the refuge habitat stressor, changes in refuge habitat of juvenile winter-run Chinook salmon exists in the **environmental baseline** (without the Proposed Action). Turbidity, shallow water habitat, and food production and retention drive this stressor (Windell et al. 2017). Generally, dams impair the recruitment of large woody material to the river channel and floodplain below the dam. Stable year-round flows have resulted in diminished natural channel formation, altered foodweb processes, and slowed regeneration of riparian vegetation.

Since 1900, approximately 95 percent of historical freshwater wetland habitat in the Central Valley floodplain has been lost, typically through the construction of levees and draining for agriculture or residential uses (Hanak et al. 2011). Human expansion has occurred over vast areas in the Delta and Sacramento and San Joaquin Valleys between the 1850s and the early 1930s, completely transforming their physical structure (Thompson 1957, 1965; Suisun Ecological Workgroup 2001; Whipple et al. 2012; Whipple 2010). Levee ditches were built to drain land for agriculture, human habitation, mosquito control, and other human uses, while channels were straightened, widened, and dredged to improve shipping access to the Central Valley and to improve downstream water conveyance for flood management. In addition, constructing and armoring levees changes bank configuration and reduces cover (Stillwater Sciences 2006). Constructed levees protected with rock revetment generally create nearshore hydraulic conditions characterized by greater depths and faster, more homogeneous water velocities than occur along natural banks. Higher water velocities typically reduce deposition and retention of sediment and woody debris, thereby reducing the shoreline variability. This reduction in variability eliminates the shallow, slow-velocity river margins used by juvenile fish as refuge escape from fast currents, deep water, and predators (Stillwater Sciences 2006). Reclamation has completed many side-channel restoration projects in the upper Sacramento River that provide refuge habitat for juveniles. Additional restoration projects are ongoing and outside of this consultation.

Restoration projects along the Sacramento River are intended to improve shallow water habitats for rearing and migrating Chinook salmon. The Yolo Bypass Project is intended to improve shallow water habitat and habitat connectivity for Chinook salmon. Operation of the project is expected to provide improved habitat connectivity for listed fish species to migrate between the Sacramento River and the Yolo Bypass. This enhanced habitat connectivity is expected to improve the ability of anadromous fish to access the Yolo Bypass, resulting in increased growth and decreased stranding events.

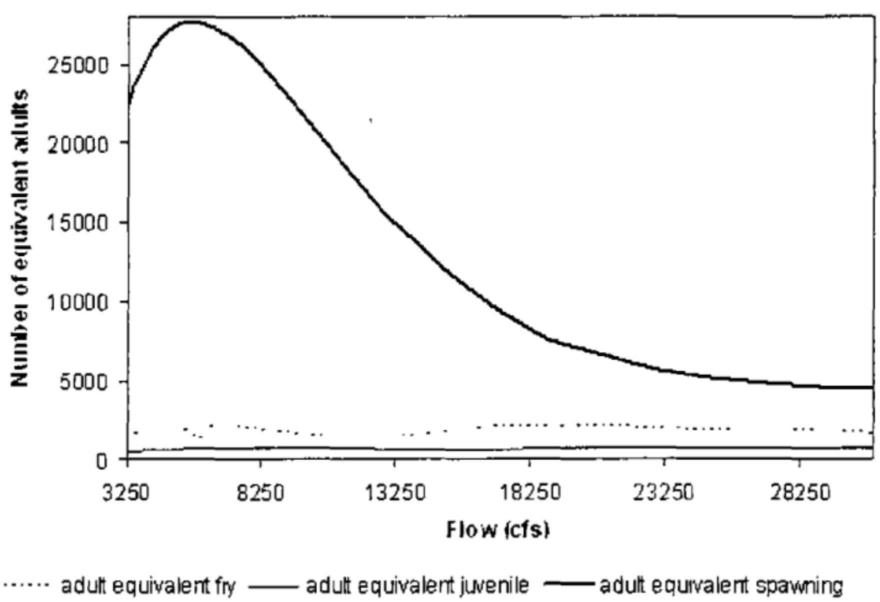
The **proportion** of the population affected by decreased refuge habitat in the Sacramento River depends on bathymetry and hydrology and is **large**.

The literature demonstrates that in most cases, limiting life stage analyses indicated that juvenile habitat is limiting (Gard 2005). The relationships are observable in the figures below show flow-habitat relationships (Figure 5-37) and limiting life stage analyses for juvenile winter-run Chinook salmon by Sacramento River segment 6 (ACID to Keswick Dam, Figure 5-38). Analyses of segments 4 (Battle Creek to Cow Creek) and 5 (Cow Creek to ACID) show a similar trend.



Source: Gard 2005

Figure 5-37. Juvenile Winter-run Chinook Salmon Rearing Flow-Habitat Relationships for Segments 4 through 6 (ACID boards in and out).



Source: Gard 2005.
Adult equivalent juvenile is represented by the solid black line.

Figure 5-38. Limiting Life Stage Analysis for Winter-run Chinook Salmon in Segment 6 (ACID to Keswick Dam, ACID boards out).

The **proportion** of the population affected by decreased refuge habitat in the Delta is **large**. All outmigrating winter-run Chinook salmon must pass through the Delta on the way to the Pacific Ocean. The Delta is tidally influenced. As such, the effect of Proposed Action storage of water on available shallow-water refuge habitat would be within the daily tidal range and would not meaningfully impact the Delta environment.

Datasets use historical conditions and observation to inform how winter-run Chinook salmon may respond to the Proposed Action. Historical monitoring may support or refute hypotheses and informs the reasonableness of information generated by models. [PLACEHOLDER – datasets]

Models provide quantitative estimates of future conditions under the Proposed Action.

The Sacramento River Weighted Usable Area Analysis, Appendix O, Attachment O.3, provides context for the weighted usable area available for winter-run Chinook salmon fry and juvenile rearing downstream of Keswick releases. The greatest quantity and largest variations in the rearing WUA habitat values occur in the river reach between the ACID Dam and Cow Creek. The rearing WUA habitat values in this reach are lowest at a flow of about 9,000 cfs for fry and at flows between 10,000 cfs and 14,000 cfs for juveniles. The WUA habitat values mostly increase with increasing and decreasing flows above and below these levels. The WUA habitat value under the Proposed Action phases ranges from 234,656 to 259,957 for fry (Figure 5-39) and from 422,194 to 436,343 for juveniles (Figure 5-40). Overall, these WUA habitat values do not vary much among water year types. This suggests the late summer and fall flow ranges in the Proposed Action phases provide stable rearing habitats.

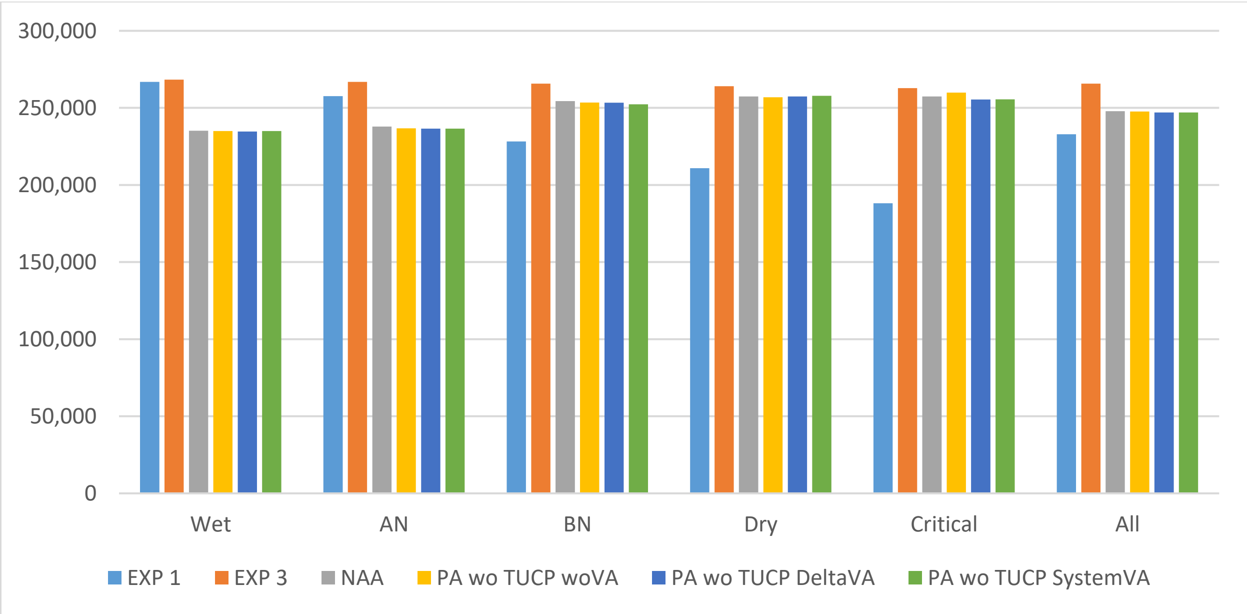


Figure 5-39. Water Year Type Mean Winter-run Fry Rearing Weighted Usable Area Habitats.

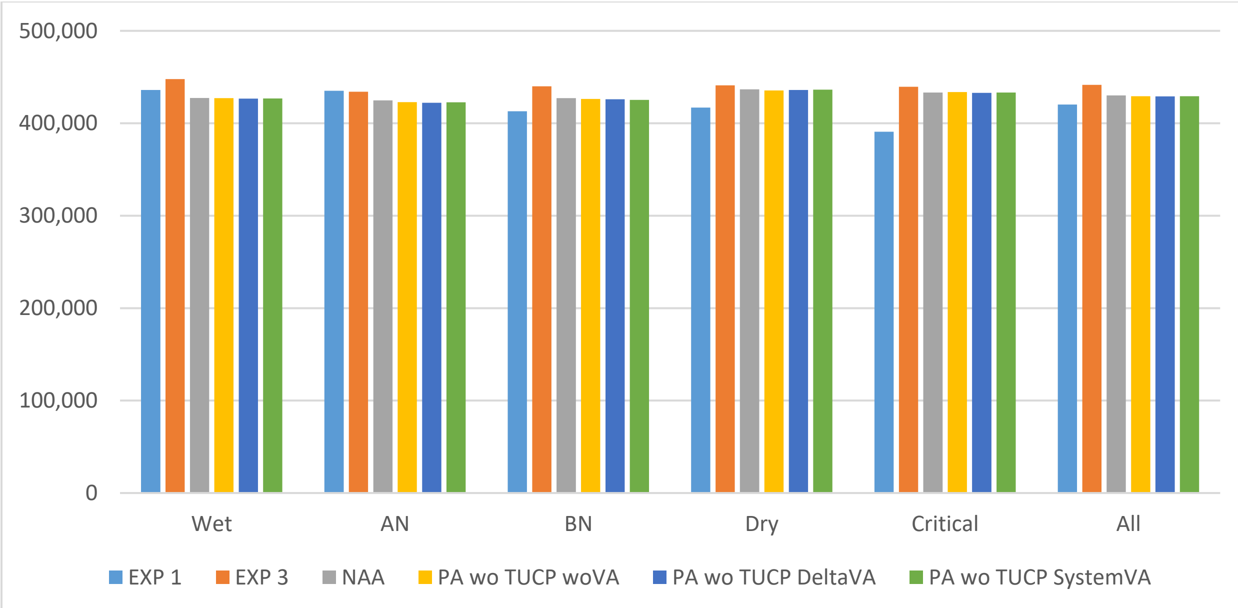
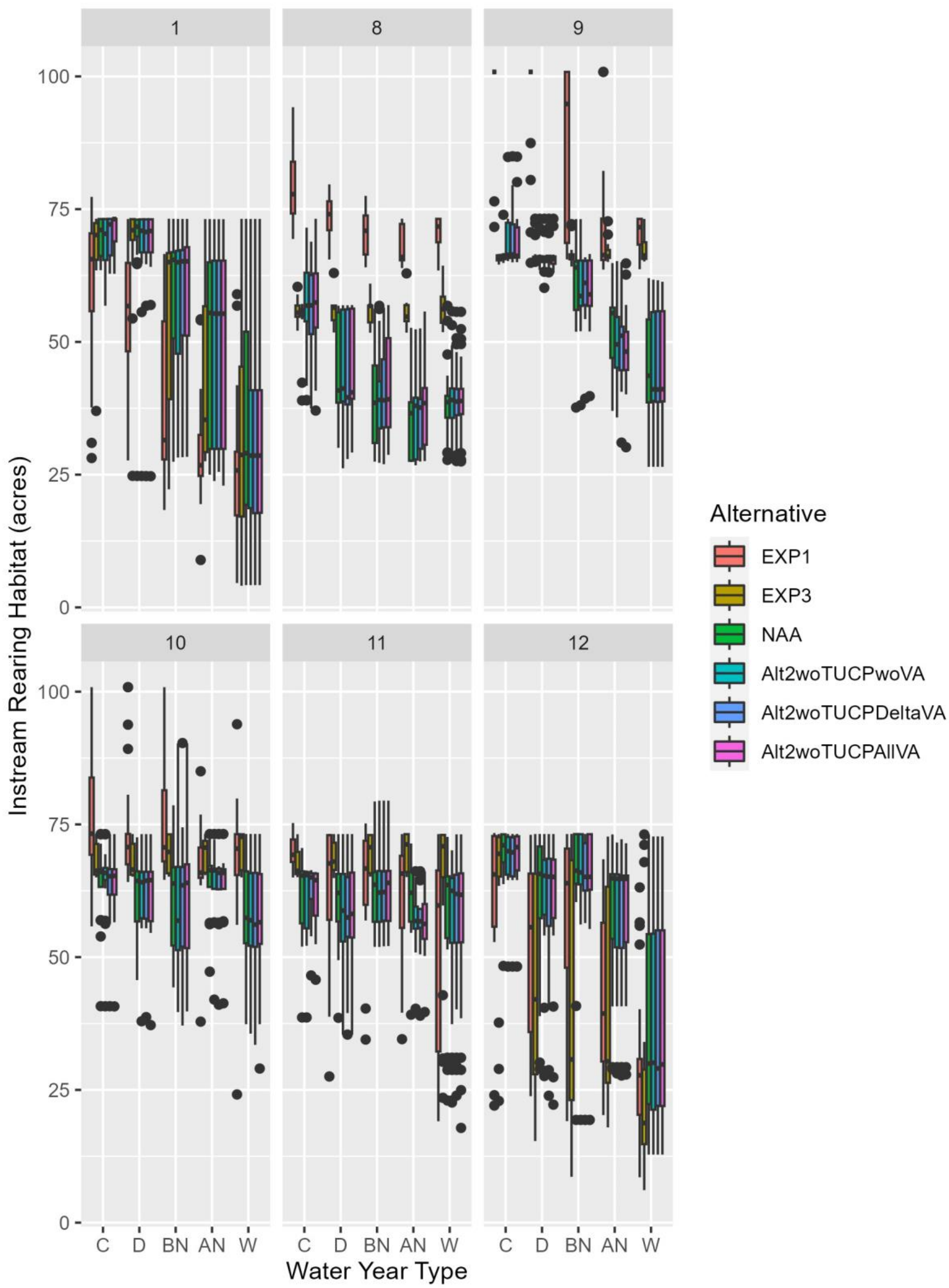


Figure 5-40. Water Year Type Mean Winter-run Juvenile Rearing Weighted Usable Area Habitats.

The SIT LCM Habitat Estimates, Tributary Habitat, Appendix O, Attachment O.2, provides context for the instream and floodplain rearing habitat area available for winter-run Chinook salmon juveniles in the Upper Sacramento River downstream of Keswick Dam from August through January.

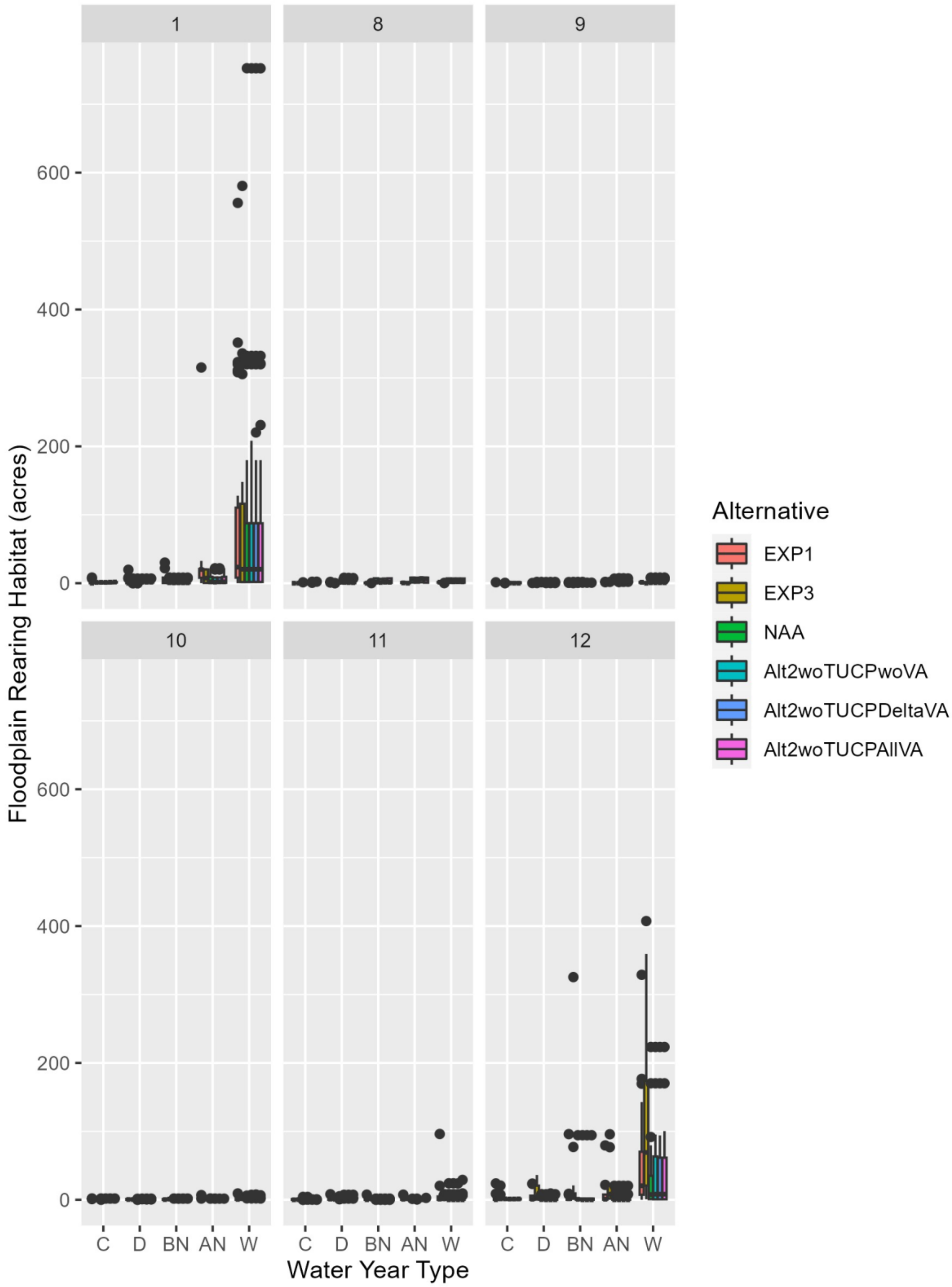
For instream rearing habitat, the monthly habitat values under the Proposed Action phases range from a low of approximately 5 acres to a high of approximately 100 acres (Figure 5-41). Available instream rearing habitat for winter-run Chinook salmon juveniles peaks at low flows and decreases with increasing flows in the Upper Sacramento River. Overall, the habitat values do not vary much among months under the Proposed Action phases, but the lowest habitat values generally occurred in August. Habitat values do vary by water year type, with less instream rearing habitat available in increasingly wet water year types.

For floodplain rearing habitat, the monthly habitat values under the Proposed Action phases range widely from a low of approximately 0 acres to a high of approximately 750 acres (Figure 5-42). Available floodplain rearing habitat for winter-run Chinook salmon juveniles only increases at flows greater than 25,000 cfs and peaks at flows of approximately 175,000 cfs in the Upper Sacramento River. Habitat values do vary in response to the combination of both month and water year type. Floodplain rearing habitat availability peaks in December and January in only Above Normal and Wet water year types.



Variability within months (facets; August-January) reflects variation across CalSim WYs.

Figure 5-41. Estimated Instream Rearing Habitat for Winter-run Juveniles in the Upper Sacramento River.



Variability within months (facets; August-January) reflects variation across CalSim WYs.

Figure 5-42. Estimated Floodplain Rearing Habitat for Winter-run Juveniles in the Upper Sacramento River.

The **frequency** of occurrence in the Sacramento River is annual and depends primarily on meteorology and hydrology and is **medium**. Between the fall and winter months, flows at Keswick Dam generally decrease, with the exception of wet and above normal water year types (e.g., 2005, 2006, 2010, 2011, 2017, 2019, Figure 5-43 and Figure 5-44). Six out of 18 years (33%, 2005 – 2022) were wet or above normal water year types (Sacramento Valley Index) with maximum flows between September and February greater than 15,000 cfs. Seventeen out of 18 years (94%, 2005 – 2022) included days where Keswick Dam flows were greater than 5,750 cfs (Figure 5-38, Figure 5-43, and Figure 5-44).

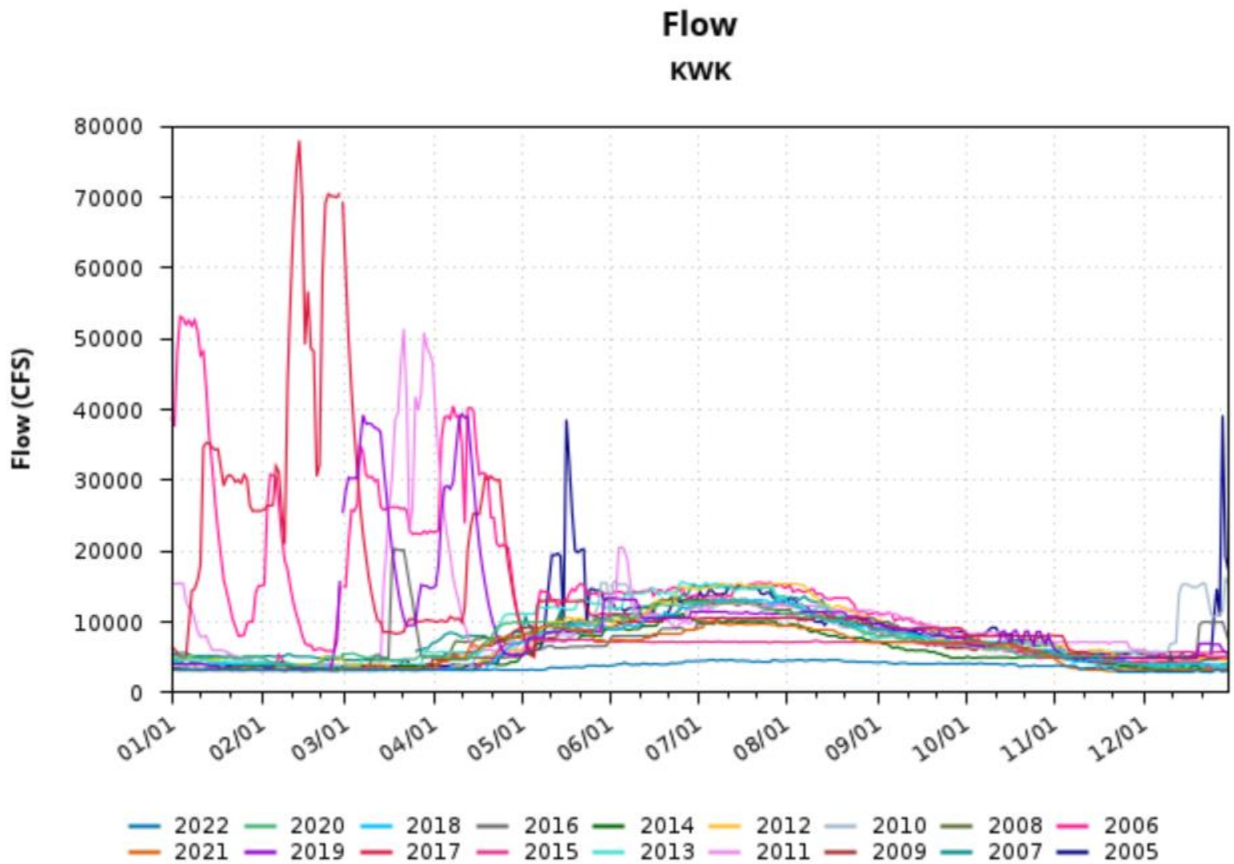


Figure 5-43. Keswick Flows, 2005–2022.

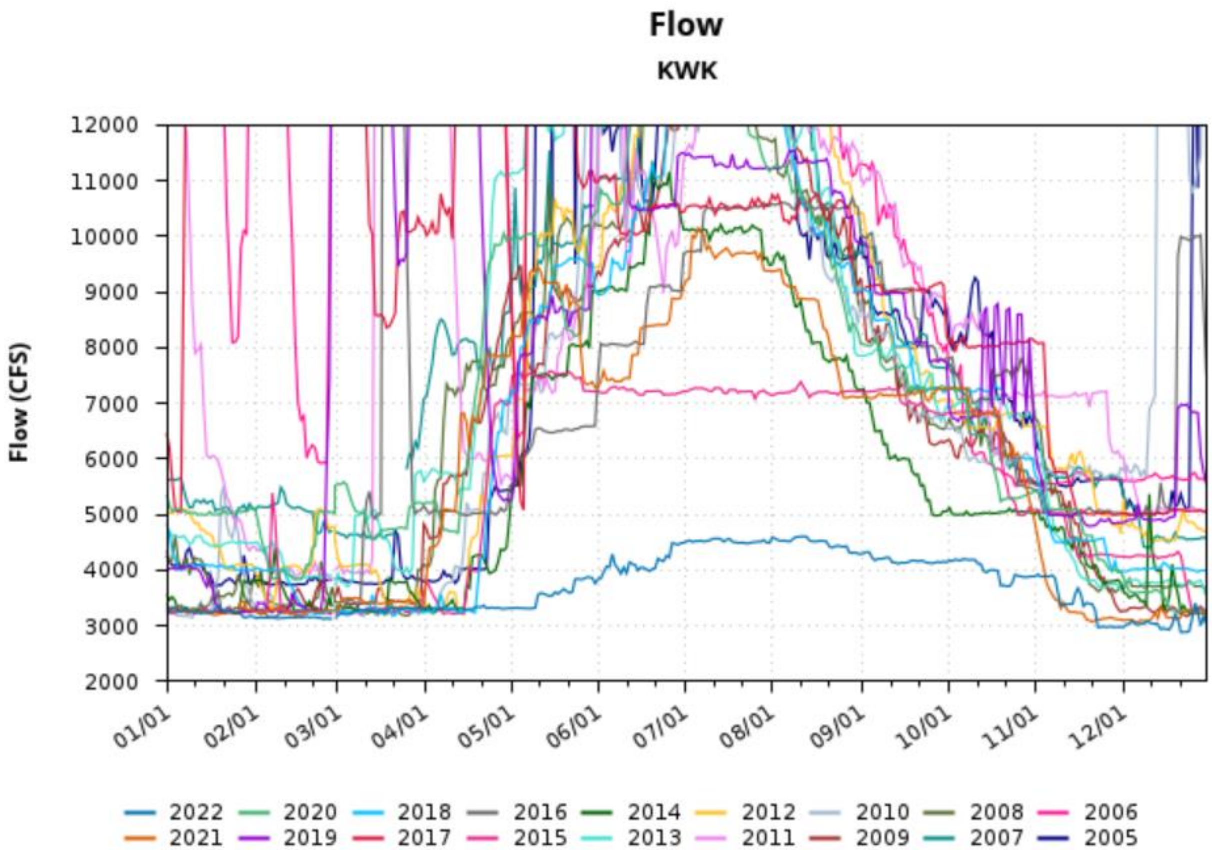


Figure 5-44. Keswick Flows, 2005–2022 (scaled to a maximum of 12,000 cfs).

The **frequency** of occurrence in the Delta is annual and depends primarily on meteorology and hydrology and is **medium**. Although there is no known relationship between flows and refuge habitat availability in the Delta similar to Figure 5-37 for the Sacramento River from Gard (2005), inter-annual variation in flows during winter and spring is greater at Freeport (Figure 5-45) than at Keswick (Figure 5-43, Figure 5-44). As a result, flow-dependent refuge habitat is likely limiting less often than in the Sacramento River.

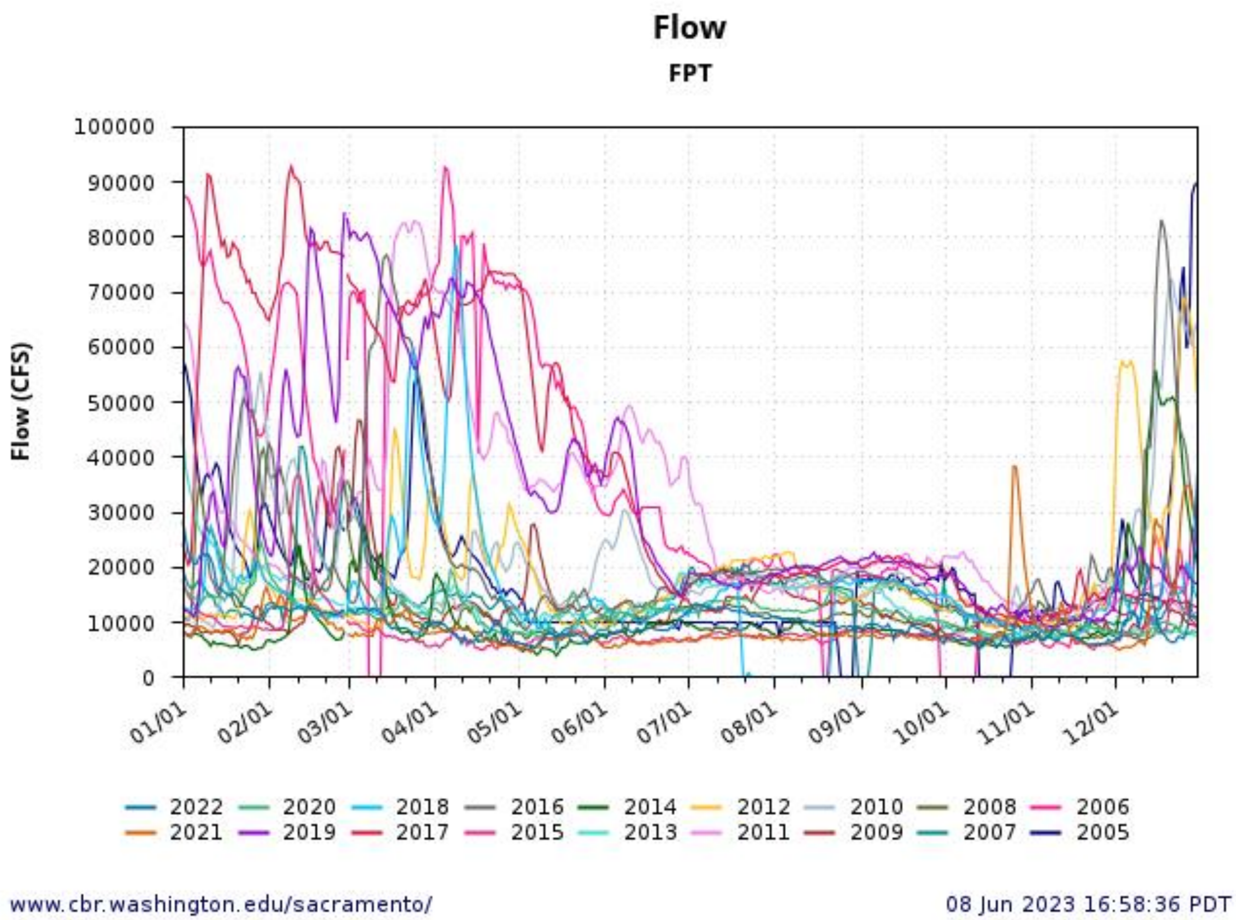


Figure 5-45. Sacramento River at Freeport Flows, 2005–2022.

To evaluate the **weight of evidence** for refuge habitat stressor, location-specific and species-specific information in the literature is used: flow-habitat relationships, limiting life stage analyses (Gard 2005). Studies have shown access to off-channel habitats as linked to higher growth rates and survival (Limm and Marchetti 2009; Zeug et al. 2020).

- Literature, Dudley: quantitative, species-specific, location-specific, both 2018 and 2019 published as peer-reviewed literature in multiple publications, individual-based model using multiple environmental parameters and inclusion of biological processes
- CVPIA SIT habitat modeling LOE: quantitative, species-specific, location-specific, published in peer reviewed journals, rely on multiple experts and peer review
- Sacramento WUA analysis LOE: quantitative, species-specific, location-specific, widely accepted in published literature

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- Minimum Instream Flows
- SRSC Transfer Delays

Conservation measures in the Proposed Action for other species, life stages and/or stressors that may exacerbate this stressor include:

- Fall and Winter Base Flows for Shasta Reservoir Refill and Redd Maintenance
- Reduced Wilkins Slough Minimum Flows
- SHOT Water Transfer Timing Approvals
- Drought Actions

5.2.4.5 Food Availability and Quality

The proposed storage of water may increase the food availability and quality stressor. During the juvenile rearing and outmigration period, the Proposed Action storage of water in Shasta Reservoir in the fall and winter will decrease flows resulting in a change of food web processes and likely a decrease in quality food available to juvenile winter-run Chinook salmon. Appendix P, *Delta Habitat*, presents analyses of fish response to habitat restoration.

In the Delta, operations are not expected to increase the food availability and quality stressor for outmigrating juvenile winter-run Chinook salmon. All juveniles outmigrating from the Sacramento River must pass through the Delta on the way to the Pacific Ocean. The Delta is tidally influenced. As such, the effect of Proposed Action storage of water on food availability would be within the daily tidal range near the seaward end of the Delta. Tidal influence dissipated toward the landward edges of the Delta and effects of Proposed Action storage of water would be more similar to that described for the mainstem Sacramento River above. In the Delta, winter-run Chinook salmon utilize side channel and inundated floodplain habitat in the tidal shoreline of the Delta for foraging and growth. The tidal habitat of the Delta also serves the critical role as a physiological transition zone before saltwater entry, with juveniles residing in the Delta for an average of three months (del Rosario et al. 2013). Side-channel and floodplain habitat are highly productive and can provide nutrients and food nearby portions of the Delta. Historically, the Yolo Bypass experiences at least some flooding in 80% of years (Reclamation 2012), and recent and ongoing modifications to Fremont Weir are intended to increase the frequency of occurrence.

The increase in food availability and quality stressor is expected to be **sub-lethal**. A decrease in quality and quantity of food for foraging juvenile winter-run Chinook salmon will impact growth rates. Additionally, food limitation can weaken juvenile winter-run Chinook salmon, leading to extremes such as starvation, and alter behavior resulting in predation risk. Food availability and quantity is not independent of refuge habitat, another sub-lethal stressor discussed above.

Although the Proposed Action may increase the food availability and quality stressor, changes in food availability and quality for juvenile winter-run Chinook salmon exists in the **environmental baseline** (without the Proposed Action). The level of production and retention drives food availability and quality (Windell et al. 2017). Generally, the presence and operation of dams contribute to channelization, which contributes to a loss of riparian habitat and instream cover, which aquatic and terrestrial invertebrates depend upon. A significant portion of juvenile Chinook salmon diet is composed of terrestrial insects, particularly aphids which are dependent on riparian habitat (National Marine Fisheries Service 1997). Levee construction involves the removal of riparian vegetation, which reduces aquatic macroinvertebrate recruitment resulting in decreased food availability for rearing juveniles (Anderson and Sedell 1979; Pusey and Arthington 2003). Channelized, leveed, and riprapped reaches typically have low habitat complexity and low abundance of food organisms (Lindell 2017).

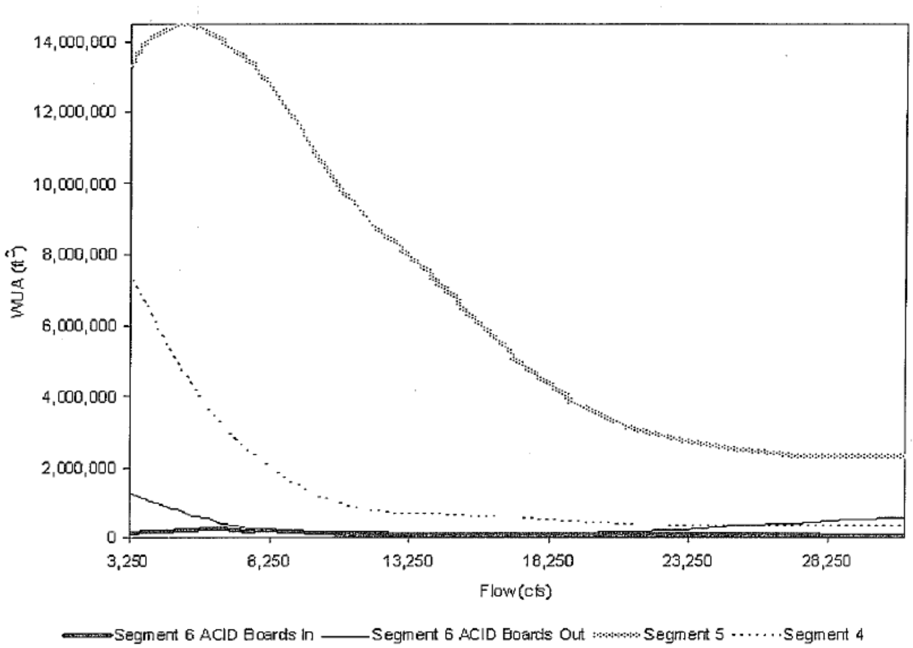
The Yolo Bypass Project is intended to reduce the food availability stressor on Chinook salmon migrating along the Sacramento River. Seasonal inundation of the Yolo Bypass leads to an increase in phytoplankton and other food resources that support fish species residing in the floodplain and provides a source of these food resources to downstream habitats (Sommer et al. 2001b). Also, the Yolo Bypass has more natural banks and riparian vegetation than the Sacramento River, and is better connected to tidal wetlands than the Sacramento River (Goertler et al. 2015). The Yolo Bypass Project should improve food availability and quality for migrating winter-run Chinook salmon. Reclamation and DWR are implementing the Yolo Bypass Project, which is ongoing and outside of this consultation.

In the Delta, levee construction involves the removal and loss of riparian vegetation and reduces aquatic macroinvertebrate recruitment resulting in decreased food availability for rearing juveniles (Anderson and Sedell 1979; Pusey and Arthington 2003). The lack of floodplain connectivity also limits food availability.

Invasive species have also affected food availability in the Delta. Since the introduction and establishment of the invasive overbite clam, *Eurytemora affinis* and other zooplankton have experienced long term declines (Winder and Jassby 2011; Kimmerer 2002), experienced seasonal shifts in peak abundance (Merz et al. 2016) and have been replaced by non-native species (Winder and Jassby 2011). The native mysid species, *Neomysis mercedis* has experienced severe declines since the introduction and establishment of the invasive overbite clam (Winder and Jassby 2011) and has largely been replaced by a non-native mysid species, *Hyperacnthomysis longirostris* (Avila and Hartman 2020, Winder and Jassby 2011).

The **proportion** of the population affected by decreased food availability and quality in the Sacramento River depends on bathymetry and hydrology and is **large**.

The literature demonstrates that in most cases, limiting life stage analyses indicated that juvenile habitat is limiting (Gard 2005). Flow-habitat relationship metrics for juvenile salmonid food supply developed for the Sacramento River, between Keswick Dam and Battle Creek (Gard 2006). Optimal flows for the macroinvertebrate index varied by reach and ranged from 3,250 cfs to 6,000 cfs (Figure 5-46, Gard 2006). Access to off-channel habitats has been linked to higher growth rates and survival (Limm and Marchetti 2009; Zeug et al. 2020). Habitat restoration programs are aimed towards providing benefits to native salmonids (quality habitat, increased food availability, refuge) but these efforts also provide benefits to non-native and native predators possibly increasing predation rates. Reduction or loss of seasonally inundated habitats alters food web processes and riparian vegetation, decreasing food availability and quality, and impacting the successful growth and survival of juveniles (Jeffres et al. 2008, Steel et al. 2017; Goertler et al. 2018, Jeffres et al. 2020; Bellido-Leiva et al. 2021). Reduced releases decrease potential refuge habitat for juvenile winter-run Chinook salmon removing access to side-channels, access to refuge, and changing geomorphic processes. See Section 5.2.4.4, *Refuge Habitat*, for juvenile winter-run Chinook salmon flow-habitat relationships and limiting life stage analyses figures.



Source: Gard 2006.

Figure 5-46. Flow-Habitat Relationship by Reach for Juvenile Chinook Salmon Food Supply (biomass of Baetids, Chironomids, and Hydropsychids).

The **proportion** of the population affected by decreased food availability and quality in the Delta depends on bathymetry and hydrology and is **large**. All winter-run Chinook salmon juvenile Chinook salmon pass through the Delta on their way to the Pacific Ocean. The Delta is tidally influenced. As such, the effect of Proposed Action storage of water on food availability would be within the daily tidal range near the seaward end of the Delta. Tidal influence dissipates toward the landward edges of the Delta and effects of Proposed Action storage of water would be more similar to that described for the mainstem Sacramento River above.

Datasets and models do not uniquely inform the proportion of the population affected.

The **frequency** of occurrence in the Sacramento River is annual and depends primarily on hydrology and is **low**. Between the fall and winter months, flows at Keswick generally decrease, with the exception of wet and above normal water year types (e.g., 2005, 2006, 2010, 2011, 2017, 2019; Figure 5-43, Figure 5-44). 4 out of 18 years (22%, 2005 – 2022) did not have 50% or more daily Keswick flows between September and February in the optimal range (3,250 – 6,000 cfs).

The **frequency** of occurrence in the Delta is annual and depends primarily on hydrology and is **low**. Tidal hydrodynamics results in frequent inundation of wetland habitats, which are highly productive and can provide nutrients and food for nearby portions of the Delta. Historically, the Yolo Bypass experiences at least some flooding in 80% of years (Reclamation 2012), and recent and ongoing modifications to Fremont Weir are intended to increase the frequency of occurrence.

To evaluate the **weight of evidence** for the food availability and quality stressor, multiple location- and species-specific studies have been conducted showing the importance of quality available food for rearing and outmigrating juveniles. Published studies have been conducted in the Sacramento River and Bay-Delta.

- Gard 2006 WUA flow-habitat relationships modeling LOE: quantitative, species-specific, location-specific, published in technical reports

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- Minimum Instream Flows
- SRSC Transfer Delays

Conservation measures in the Proposed Action for other species, life stages and/or stressors that may exacerbate this stressor include:

- Fall and Winter Base Flows for Shasta Reservoir Refill and Redd Maintenance
- Reduced Wilkins Slough Minimum Flows
- SHOT Water Transfer Timing Approvals (denial of water transfers)
- Drought Actions

5.2.4.6 Water Temperature and Dissolved Oxygen

The proposed release and blending of water may decrease or increase the water temperature and dissolved oxygen stressor. During the juvenile rearing and outmigration period, the Proposed Action will release water from Shasta Reservoir resulting in cooler water temperatures with higher dissolved oxygen saturation potential in the Sacramento River below Keswick Dam. Winter-run Chinook salmon require cool water temperature for optimal growth. Additionally, cooler water temperatures may reduce overall harm to juveniles spending time in the Sacramento River preparing for outmigration, particularly early in the outmigration season. The Proposed Action storage of water in Shasta Reservoir in the fall and winter will decrease flows resulting in warmer water temperatures. In the Delta, the Proposed Action is unlikely to significantly influence water temperatures. Appendix L addresses water temperature related effects.

The release of water may result in cooler water temperatures and higher flows in the Sacramento River while operations will decrease flows in the Delta. Higher flows may provide a higher dissolved oxygen saturation potential. The Proposed Action is expected to have an insignificant impact on the dissolved oxygen stressor. Juvenile Chinook salmon swimming performance declines at DO less than 7 mg O2/l at a water temperature at and below 67.1°F (Davis et al. 1963). Historical water quality monitoring has rarely shown dissolved oxygen at levels below 7.0 mg/l in the months when juveniles are rearing and outmigrating in the Sacramento River. Monitoring has not shown this stressor as a factor affecting the juvenile life stage. In the Delta, operations is not anticipated to change during the rearing and outmigration period and historic water quality monitoring has not shown dissolved oxygen at levels below 5.0 mg/L in the winter or spring.

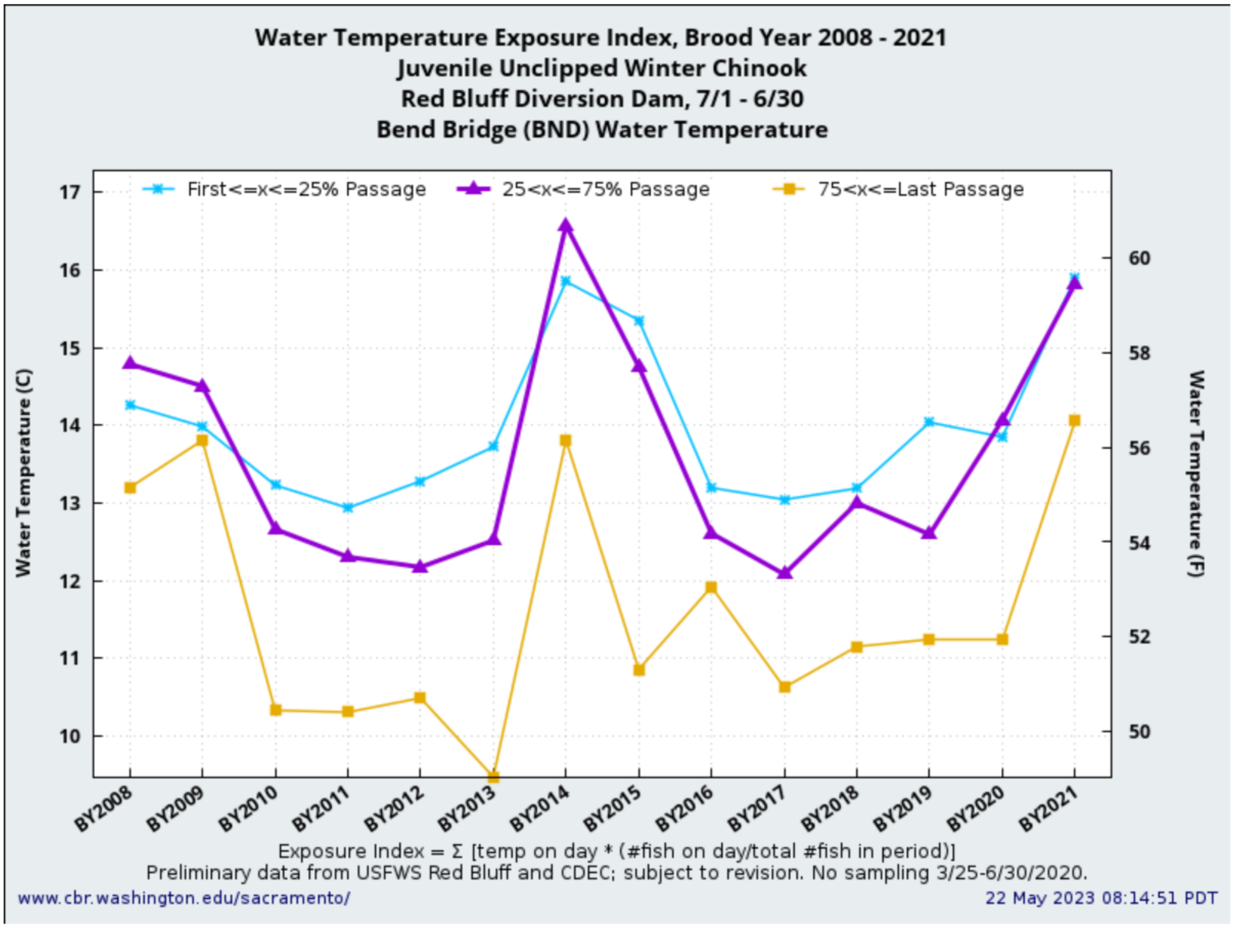
The decrease in water temperature stressor is expected to be **beneficial**. Cooler water temperatures may reduce overall harm to juveniles spending time in the Sacramento River preparing for outmigration, particularly early in the outmigration season. However, winter-run Chinook salmon rearing in the fall (e.g., September and October) may experience warmer temperatures in the Sacramento River and the increase in temperature stressor is expected to be **sub-lethal** and **lethal**. In the Delta, the Proposed Action is unlikely to impact water temperatures.

Although the Proposed Action may, at times, increase the water temperature stressor, unsuitable water temperatures for juvenile winter-run Chinook salmon exists in the **environmental baseline** (without the Proposed Action). The amount of precipitation, local ambient air temperatures, and Keswick Dam releases drive the water temperature stressor (Windell et al. 2017). It is expected that climate change should result in warmer air temperature and shift in forms of precipitation, with more precipitation falling as rain, which will exacerbate water temperatures in the reservoirs. In the Sacramento River, the absence of releases of stored water for water service and water temperature management purposes, would translate to low flows in the summer and fall. Thus, water temperatures would be expected to increase. Reclamation has operated the CVP to reduce the water temperature stressor juvenile rearing and outmigrating period by using the TCD. Different approaches have targeted different water temperatures and locations throughout the years including a warmwater bypass to conserve limited coldwater pool.

The **proportion** of the population affected by the Proposed Action is likely **medium to large**. Water temperature stressors depend on hydrology, meteorology, storage in Shasta and Trinity reservoirs, releases from Keswick Reservoir, operation of the TCD, and outmigration timing. A documented acceptable range of water temperatures for growth of Chinook salmonids, from a synthesis of evidence, is 40.1°F - 66.4°F, with optimum growth occurring between 50°F – 60°F (McCullough 1999). Juvenile winter-run Chinook salmon that outmigrate earlier may experience different conditions than juveniles that outmigrate later may experience.

Literature does not uniquely inform the proportion of the population affected.

Historical monitoring may support or refute hypotheses and informs the reasonableness of information generated by models. The figure below shows water temperature exposure index values for BY 2008 – BY 2021 that juvenile winter-run Chinook salmon experienced during passage at Red Bluff Diversion Dam (Figure 5-47). Water temperature exposure index varied annually; however, was generally decreased as the migration season progressed (e.g., BY 2012: first to 25% passage experienced about 13.75 degrees Celsius (°C), 25% to 75% passage experienced about 12°C, and 75% to last passage experienced about 10.5°C. Fish during the middle of passage experienced between 12°C (BY 2017) and 16.5°C (BY 2014). In 9 out of 14 years (64%, BY 2008 – 2021), water temperatures got progressively cooler as passage of winter-run Chinook salmon increased at Red Bluff Diversion Dam (Figure 5-47).



Exposure calculated as sum of (temperature on day * (*n* fish on day / total # fish)).

Figure 5-47. Water Temperature Exposure Index, Juvenile Winter-run Chinook Salmon BY 2008–2021, Red Bluff Diversion Dam (Bend Bridge).

Models provide quantitative estimates of future conditions under the Proposed Action.

HEC-5Q modeling analysis enumerates the frequency at which mean monthly simulated water temperatures exceed water temperature criteria obtained from scientific literature. Modeled water temperatures (Hec-5Q) during juvenile winter-run Chinook salmon rearing and outmigration are as follows.

Results for the 55.4 °F to 68 °F range are presented in Table 5-24 for the Sacramento River at Keswick, Table 5-25 for the Sacramento River at the Red Bluff Diversion Dam, and Table 5-26 for the Sacramento River at Hamilton City. At Keswick, the percentage of months outside the optimal water temperature range, ranged from 100.0% In Wet water years, to 60.2% in Critical water year types during the period of July through December under the Proposed Action. In general, percentage of months outside of the range increased from drier to wetter water year types, with Critical water year types having notably less percentage of months outside of the optimal temperature range.

Table 5-24. Percent of Months Outside the 55.4°F to 68°F Optimal Water Temperature Range for Juvenile Winter-run Chinook Salmon Rearing and Outmigration, for All Years Combined, Sacramento River at Keswick, July through December.

WYT	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
W	35.1	100.0	100.0	100.0	100.0	100.0
AN	36.3	100.0	100.0	98.8	97.5	100.0
BN	42.6	98.1	100.0	98.1	98.1	98.1
D	40.3	100.0	99.3	97.9	97.9	98.6
C	50.5	76.3	64.5	60.2	60.2	61.3
All	40.3	96.0	94.3	92.7	92.6	93.3

At the Sacramento River at the Red Bluff Diversion Dam, the percent of months outside the 55.4 °F to 56 °F range under the Proposed Action phases range from 45.8% during Wet water years to 30.1% of months during Critical water years. Overall, the percent of months outside the range increased from drier to wetter water year types for all phases of the Proposed Action during the period of July through December.

Table 5-25. Percent of Months Outside the 55.4°F to 68°F Optimal Water Temperature Range for Juvenile Winter-run Chinook Salmon Rearing and Outmigration, for All Years Combined, Sacramento River at the Red Bluff Diversion Dam, July through December.

WYT	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
W	73.8	33.3	44.6	45.8	45.8	45.8
AN	77.5	35.0	40.0	41.3	41.3	41.3
BN	78.7	33.3	37.0	35.2	36.1	37.0
D	81.9	32.6	34.0	34.0	34.0	34.0
C	83.9	23.7	24.7	31.2	31.2	30.1
All	78.8	31.9	36.9	38.1	38.3	38.3

At the Sacramento River at Hamilton City, the percent of months outside the 55.4 °F to 56 °F range under the Proposed Action phases range from 39.8% during Critical water years to 30.6% of months during Below Normal water years. Overall, the percent of months outside the range was similar for all phases of the Proposed Action and all water year types during the period of July through December.

Table 5-26. Percent of Months Outside the 55.4°F to 68°F Optimal Water Temperature Range for Juvenile Winter-run Chinook Salmon Rearing and Outmigration, for All Years Combined, Sacramento River at Hamilton City, July through December.

WYT	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
W	77.4	38.7	33.3	33.9	33.9	33.3
AN	80.0	36.3	35.0	33.8	35.0	35.0
BN	79.6	32.4	32.4	30.6	30.6	30.6
D	78.5	31.9	31.9	30.6	31.3	31.9
C	78.5	29.0	37.6	39.8	39.8	39.8
All	78.6	34.1	33.7	33.4	33.7	33.7

The **frequency** of occurrence of benefits for outmigrating juvenile winter-run Chinook salmon is **high**. The majority of fish from BY 2008 – BY 2021 passing Red Bluff experienced water temperatures optimal for growth. Fish from the same brood years passing Knights Landing experienced water temperatures outside the optimal range mostly during Dry and Critical water year types.

To evaluate the **weight of evidence** for the water temperature stressor, a twenty-year quantitative historic record of winter-run Chinook salmon redd monitoring and seasonal temperature data along with several published temperature thresholds from lab and *in-situ* studies were reviewed.

- Literature, Dudley: quantitative, species-specific, location-specific, both 2018 and 2019 published as peer-reviewed literature in multiple publications, individual-based model using multiple environmental parameters and inclusion of biological processes.
- Historic water temperature observations: quantitative, not species-specific (but not expected to be, environmental variable), location-specific, available through multiple sources and QA/QCed, long time-series and not expected to have statistical power.
- Hec-5Q water temperature modeling LOE: quantitative, not species-specific (but not expected to be, environmental variable, location-specific, model developed to evaluate reservoir system using control points, widely accepted as temperature modeling system for use in the Central Valley upper watershed

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- Minimum Instream Flows
- Shasta Reservoir Water Temperature and Storage Management (preserve cold water)

Conservation measures in the Proposed Action for other species, life stages and/or stressors that may exacerbate this stressor include:

- SHOT Water Transfer Timing Approvals (denial of water transfers)
- SHOT Determination on Temperature Shoulders (requiring releases too cold too early and exhausting coldwater pool)

5.3 Designated Critical Habitat Analysis

The critical habitat designation for winter-run Chinook salmon (58 FR 33212) includes the following waterways, bottom and water of the waterways, and adjacent riparian zones: (1) the Sacramento River from Keswick Dam (river mile 302) to Chipps Island (river mile 0) at the westward margin of the Delta; (2) all waters from Chipps Island westward to the Carquinez Bridge, including Honker Bay, Grizzly Bay, Suisun Bay, and the Carquinez Strait; all waters of San Pablo Bay westward of the Carquinez Bridge; and (3) all waters of San Francisco Bay north of the San Francisco-Oakland Bay Bridge from San Pablo Bay to the Golden Gate Bridge (58 FR 33212). NMFS clarified that "adjacent riparian zones" are limited to only those areas above a stream bank that provide cover and shade to the nearshore aquatic areas (58 FR 33212). Within the Sacramento River, this includes the river water, river bottom (including those areas and associated gravel used by winter-run Chinook salmon as spawning substrate), and adjacent riparian zone used by fry and juveniles for rearing. In the areas west of Chipps Island, including San Francisco Bay to the Golden Gate Bridge, this designation includes the estuarine water column and essential foraging habitat and food resources utilized by winter-run Chinook salmon as part of their juvenile outmigration or adult spawning migrations.

The proposed action area encompasses the entire range-wide riverine and estuarine critical habitat physical and biological features for Sacramento River winter-run Chinook salmon. Each of the features of the critical habitat designation for winter-run Chinook salmon, and potential effects associated with the Proposed Action, is described in subsections below.

5.3.1 Access from the Pacific Ocean to Appropriate Spawning Areas

Adult winter-run Chinook salmon migrate from the Pacific Ocean to spawning grounds south of Keswick Dam. Adult migration corridors should provide satisfactory water quality, water quantity, water temperature, water velocity, cover/shelter and safe passage conditions in order for adults to reach spawning areas. Adult winter-run Chinook salmon generally migrate in the winter and spring months to spawning areas (National Marine Fisheries Service 2009).

As identified in Section 5.2.1, there are no water quality, water quantity, water temperature, or water velocity related stressors that are anticipated to adversely affect adult migration from the Pacific Ocean to their current spawning areas.

5.3.2 Clean Gravel for Spawning Substrate

Spawning habitat for winter-run Chinook salmon requires clean gravel for spawning. Chinook salmon require clean loose gravel from 0.75 to 4.0 inches in diameter for successful spawning (National Marine Fisheries Service 1997). Substrate composition has other key implications to spawning success. Embryos and alevins require adequate water movement through the substrate; however, this movement can be inhibited by the accumulation of fine sediment and sand. Currently, winter-run Chinook salmon spawning habitat occurs in the Sacramento River primarily between Keswick Dam and the decommissioned Red Bluff Diversion Dam. The availability of clean gravel for spawning is described in section 5.2.2.1. The Proposed Action may increase the spawning habitat stressor.

The construction of Shasta and Keswick dams have blocked the flow of sediment to the Sacramento River below Keswick Dam resulting in winnowing and armoring of the channel bed. Historical pits from gravel mining further disrupt sediment continuity. Bank stabilization reduces the natural introduction of sediment downstream of Keswick Dam. Flood control operations attenuate the peak flows required to mobilize bed material. Under CVPIA, separate from this consultation, Reclamation has undertaken gravel augmentation projects to improve spawning habitat at key locations below Keswick Dam. Since 1997, a total of 358,200 tons of gravel have been placed from 300 yards to 1.5 miles downstream of Keswick Dam to increase the availability of suitable spawning habitat (Table 5-5).

During the egg incubation and fry emergence period, the Proposed Action will release water and increase flows in the Sacramento River below Keswick Dam. Increased flows reduces the weighted usable area of suitable spawning habitat for these reaches. However, there is still adequate habitat for egg incubation and fry emergence period as redd superimposition is not documented for winter-run Chinook salmon for the quantity of spawning available under the Proposed Action.

5.3.3 River Flows for Spawning, Incubation, Fry Development and Emergence, and Downstream Transport of Juveniles

Analysis of river flows for spawning, incubation, fry development and emergence, and downstream transport of juveniles draw information from multiple sections.

For spawning, incubation, fry development, and fry emergence flows, Section 5.2.2.1 analyzes the weighted usable area of spawning habitat. Section 5.2.3.2, *Redd Quality*, addresses redd quality. Section 5.2.3.1, *Redd Stranding and Dewatering*, analyzes the maintenance of flows and potential for dewatering.

Spawning is affected by the presence of Shasta and Keswick dams. Winter-run Chinook salmon have been excluded from historical spawning habitat since the construction of Shasta and Keswick dams (National Marine Fisheries Service 2011). Dams influence the depth, quality, and distribution of spawning habitat. Generally, natural flows in the Sacramento River would decrease through the summer and into fall until late-fall and winter rains. Reclamation operates Shasta Dam in the winter for flood control, including both the channel capacity within the Sacramento River and Shasta Reservoir flood conservation space. Non-discretionary flood control reduces peak flows that may mobilize the bed. Additionally, Chinook salmon in California rivers and streams have been subject to redd stranding and dewatering, even before construction of CVP and SWP facilities. Flow fluctuations due to climate, hydrology and other factors contributed to the risk of redd stranding and dewatering. Chinook salmon historically may spawn near a river’s edge where there is an increased likelihood of dewatering when river flows may be low.

During the adult holding and spawning period, releases from Trinity and Shasta reservoirs will increase flows and modify water temperature below Keswick Dam during the spawning season. Habitat suitability curves show higher flows reduce areas of spawning habitat quantity and quality (Bureau of Reclamation 2020). Dudley (2019) shows higher flows result in higher velocities and the potential increase of superimposition. Increased surface flows are likely to increase hyporheic flows that improve dissolved oxygen and may also reduce sedimentation, improving egg and alevin essential functions and development (Bennett et al. 2003). The release of water from Shasta and Trinity reservoirs results in higher flows in the Sacramento River below Keswick Dam during the redd construction season. Higher flows do not increase the stranding and dewatering stressor; however, reducing releases in the fall reduces flows. In turn, dewatering of winter-run Chinook salmon redds may occur.

For downstream transport of juveniles flows, Section 5.2.4.1, *Stranding Risk*, addresses stranding, 5.2.4.2 Outmigration Cues addresses outmigration cues, and 5.2.4.3 Entrainment addresses movement through the Delta.

Reclamation's past operation of Shasta Reservoir has influenced the flow of water in the Sacramento River. Those flows would have historically influenced fish outmigration behavior and affect fish travel times in the Sacramento River.

The proposed storage and release of water may also increase the stranding risk stressor. During the juvenile rearing and outmigration period, reducing flows from Shasta Reservoir can trap juveniles in habitat disconnected from the main channel. Storage of water in Shasta Reservoir will reduce downstream flows, particularly in the winter from December through February, and may affect juveniles' cue to migrate and their outmigration travel rates. Diversion of water alters hydrodynamic conditions in the Sacramento River and Delta and may influence fish travel time and migration routing in the Sacramento River mainstem and the central and south Delta.

Adequate spawning flows for winter-run Chinook salmon in the Sacramento River typically range from approximately 4,000 to 13,000 cubic feet per second (cfs) (U.S. Fish and Wildlife Service 2003). These flows are necessary to create suitable conditions for winter-run Chinook salmon to spawn and for their eggs to survive. The specific flow requirements may vary depending on factors such as water temperature, river depth, velocity and the presence of suitable spawning habitat. Chinook salmon spawn in swift, relatively shallow riffles, or along the margins of deeper river reaches where suitable water temperatures, depths, and velocities favor redd construction and oxygenation of incubating eggs.

5.3.4 Water Temperatures between 42.5°F and 57.5°F for Spawning, Incubation, and Fry Development

Winter-run Chinook salmon were adapted for spawning and rearing in the clear, spring-fed rivers of the upper Sacramento River Basin, where summer water temperatures were typically 50°F to 59°F (National Marine Fisheries Service 2014). Section 5.2.3.3 addresses the operation of the TCD on Shasta Reservoir under the Proposed Action.

Winter-run Chinook salmon embryonic and larval life stages that are most vulnerable to warmer water temperatures occur during the summer, when ambient temperatures are the highest of the year. In 1997, Reclamation completed the temperature control TCD warmer upper reservoir levels and, thereby, extend the time-period in which cold water can be provided downstream. Reclamation's past operation of Shasta Reservoir has influenced the flow of water in the Sacramento River. Reclamation has operated the CVP to reduce the water temperature stressor during adult holding and spawning by using the TCD. Different approaches have targeted different temperatures and locations throughout the years including a warmwater bypass to conserve limited coldwater pool.

During the adult holding and spawning period, proposed imports from Trinity Reservoir and proposed operation of a TCD on Shasta Reservoir are expected to maintain cooler water temperatures. During egg incubation and fry emergence, the proposed releases will blend water from different elevations in Shasta Reservoir and import water from Trinity Reservoir to manage water temperatures below Keswick Dam.

5.3.5 Habitat and Adequate Prey that Are Not Contaminated

Contaminants are addressed in each life stage of the winter-run Chinook salmon effects analysis.

Legacy contaminants such as mercury (and methyl mercury), polychlorinated biphenyls (PCB), heavy metals, and persistent organochlorine pesticides continue to be found in watersheds throughout the Central Valley. Although most of these contaminants are at low concentrations in the food chain, they continue to work their way into the base of the food web, particularly when sediments are disturbed and previously entombed compounds are released into the water column. Exposure to these contaminated food sources may create delayed sublethal effects that reduce fitness at a time when the animal is physiologically stressed, i.e., during smoltification or ocean entry. Contaminants are typically associated with areas of urban development or other anthropogenic activities (e.g., mercury contamination as a result of gold mining or processing). Areas with low human impacts frequently have low contaminant burdens, and therefore lower levels of potentially harmful toxicants in the aquatic system.

Releases of Shasta Reservoir storage under the Proposed Action may result higher flows in the Sacramento River while proposed operations will decrease flows in the Delta. Reduced flows may concentrate contaminants if, and when contaminants are present and increased flows may dilute contaminants. However, increased flows and pulses can mobilize suspended sediments consisting of contaminants in river systems (van Vliet et al. 2023). On the Sacramento River, releases as part of the Proposed Action would be below the bankfull flows that would mobilize present contaminants. Monitoring has not shown fish kills that may be indicative of contaminants at levels likely to affect juvenile winter-run Chinook salmon. There is little in-situ evidence supporting the presence of toxicity and contaminants in juvenile winter-run Chinook salmon. Historical fisheries monitoring has not reported large-scale evidence of toxicity and contaminants in Bay-Delta fishes. Potential increases in toxicity and contaminant stressor associated with the Proposed Action are not expected to be measurable.

5.3.6 Riparian Habitat for Juvenile Development and Survival

A decrease in sufficient refuge habitat can result in juveniles lacking cover to avoid predation or habitat to stop and hold during outmigration. Access to off-channel habitats has been linked to higher growth rates and survival (Limm and Marchetti 2009; Zeug et al. 2020). Section 5.2.4.4, *Refuge Habitat*, and Section 5.2.4.5, *Food Availability and Quality*, address this PCE.

The channelized, leveed, and riprapped river reaches and sloughs that are common in the Sacramento River system typically have low habitat complexity, low abundance of food organisms, and offer little protection from either fish or avian predators. Juvenile life stages of salmonids are dependent on the function of this habitat for successful survival and recruitment. Some complex, productive habitats with floodplains remain in the system [e.g., Sacramento River reaches with setback levees (i.e., primarily located upstream of the City of Colusa)] and flood bypasses (i.e., Yolo and Sutter bypasses). Outside of this consultation, Reclamation has completed many side-channel restoration projects in the upper Sacramento River that provide refuge habitat for juveniles.

During the juvenile rearing, the Proposed Action storage of water in Shasta Reservoir in the fall and winter will decrease flows in the Sacramento River that reduce suitable margin and off-channel habitats available as refuge habitat for juveniles. Increasing releases decrease potential refuge habitat along the mainstem Sacramento River, as well, due to high velocities, until the channel overflows the channel and accesses off-channel habitats. Very low releases decrease potential refuge habitat for juvenile winter-run Chinook salmon by removing access to side-channels, access to refuge, and changing geomorphic processes.

5.3.7 Access Downstream for Juvenile Migration to San Francisco Bay and the Pacific Ocean

Ideal freshwater migration corridors are free of migratory obstructions, with water quantity and quality conditions that enhance migratory movements. Migratory corridors are downstream of the spawning areas and include the mainstem of the Sacramento River. These corridors allow the downstream emigration of outmigrant juveniles. Migratory habitat condition is strongly affected by the presence of barriers, which can include dams (i.e., hydropower, flood control, and irrigation flashboard dams), unscreened or poorly screened diversions, degraded water quality, or behavioral impediments to migration. For successful survival and recruitment of salmonids, freshwater migration corridors must function sufficiently to provide adequate passage. Section 5.2.4.3 addresses migratory obstructions.

The CVPIA Anadromous Fish Screen Program provides grants to screen facilities used to divert water. Diversions greater than 100 cfs are screened on the Sacramento River. Upstream from the Delta, CVP facilities diverting water under water service contracts and SWP diversions are screened (e.g., Red Bluff Pumping Plant, Freeport Regional Water Project, Barker Slough Pumping Plant, Contra Costa Water District). An existing consultation proposes to install operatable gates to increase fish routing into the Yolo Bypass. Another consultation for the Georgiana Slough Salmonid Migratory Barrier proposed to decrease the existing routing stressor by deterring emigrating juvenile salmonid from entering Georgiana Slough and the central and south Delta, wherein survival is lower relative to remaining in the mainstem Sacramento River.

The proposed diversion of water alters hydrodynamic conditions in the Sacramento River and Delta. This alteration may influence migration routing in the Sacramento River mainstem and the central and south Delta. Once in the central and south Delta, entrainment into the Jones and Banks pumping plants may occur, where they may be pulled into diversions or the export facilities. Finally, reduction of flows from Shasta Reservoir can trap juveniles in habitat disconnected from the main channel.

5.4 Life Cycle Analyses

5.4.1 Life Stage Transitions in the Literature

Measurements of fecundity, juvenile production, outmigration survival through the Sacramento River and Bay-Delta, and marine survival have been collected for winter-run Chinook salmon historically. These data represent these life stage transitions during various historical hydrologic periods representing the long-term operations of the CVP and SWP and environmental conditions affecting winter-run Chinook salmon. These data are summarized here by hydrologic periods characterized by drought and non-drought operations and conditions. Drought periods include transitions during critical and dry water years. Non-drought periods include transitions for during wet, above normal, and below normal water years. Ocean survival transitions are likely to represent survival during all years.

Using these transitions values, a replacement rate for winter-run Chinook salmon during historical non-drought (Table 5-27) and drought (Table 5-28) periods can be estimated. The Proposed Action includes Coldwater Pool Management and Spring Outflow actions during drought years that are likely to result in greater egg to fry survival and outmigration survival through the Sacramento River and Bay-Delta, so historical estimates likely represent minimum replacement values during drought years. During non-drought years, historical estimates likely are similar to what may be observed in the Proposed Action.

Table 5-27. Observed Average Transition Rates for Winter-run Chinook Salmon and Estimated Recruitment during Non-drought Water Years.

Location	Life Stage	Observed Average Survival	Estimated Replacement	Data Source
Sacramento	Adult migration and holding	1.00	1.0	1 Female
Sacramento	Adult spawning	5021.00	5,021.0	Appendix C
Sacramento	Egg incubation and emergence	0.33	1,656.9	Average of ETF Appendix C Table 14- W,BN
Sacramento	River juvenile rearing and outmigration	0.49	819.5	Survival of fry to smolts (JPE 2022 letter)
Sacramento	Juvenile rearing and outmigration (release to Sacramento)	0.39	319.6	Hatchery Sacramento winter run Chinook salmon between 2012-2022 (BN,W)
Bay Delta	Juvenile rearing and outmigration (Sacramento to Benicia)	0.65	207.7	
Bay Delta	Juvenile rearing and outmigration (Benicia to Golden Gate)	0.71	147.5	
Ocean	Ocean rearing and migration	0.05	7.4	Appendix C
	Returning females		3.7	

Table 5-28. Observed Average Transition Rates for Winter-run Chinook Salmon and Estimated Recruitment during Drought Water Years.

Location	Life Stage	Observed Average Survival	Estimated Replacement	Data Source
Sacramento	Adult migration and holding	0.99	0.99	
Sacramento	Adult spawning	5021.00	4,970.8	Appendix C
Sacramento	Egg incubation and emergence	0.16	795.3	Average of ETF App C Table 14- D,C
Sacramento	River juvenile rearing and outmigration	0.49	393.4	Survival of fry to smolts (JPE 2022 letter)
Sacramento	Juvenile rearing and outmigration (release to Sacramento)	0.24	94.4	Hatchery Sacramento winter run Chinook between 2012-2022 (C,D)
Bay Delta	Juvenile rearing and outmigration (Sacramento to Benicia)	0.37	34.9	
Bay Delta	Juvenile rearing and outmigration (Benicia to Golden Gate)	0.44	15.4	
Ocean	Ocean rearing and migration	0.05	0.8	Appendix C
	Returning females		0.4	

5.4.2 CVPIA Decision Support Models

The CVPIA winter-run Chinook salmon life cycle model (Appendix F, Attachment F.3, *CVPIA Winter-Run Life Cycle Model*) provides estimates of adult abundance, rearing survival, juvenile production, outmigration survival through the Sacramento River and Bay-Delta, and other transition values. These performance measures are estimated at monthly and annual time steps between 1980 and 2000.

5.4.2.1 Takeaways

Predicted total and natural-origin-only spawner abundances in the upper Sacramento River for deterministic model runs generally peaked in 1986, decreased steadily until 1994, and then generally increased steadily through 1999 (Table 5-29 and Table 5-30; Figure 5-48). The range of natural-origin-only spawner abundances across Proposed Action phases in 1999 at the end of the time series was narrow, ranging from a low of 5,461 to a high of 5,471. Over the entire time series, predicted natural-origin-spawner abundances ranged from 1,575 to 14,738 (Table 5-30). Predicted natural-origin-only spawner abundances varied more widely across stochastic model runs, from a low of approximately 0 to a high of approximately 30,000 spawners (Figure 5-49).

For deterministic model runs, population change over time, defined by mean (i.e., geometric) lambda values (N_t/N_{t+1}), over the entire 1980-1999 time series ranged from only 0.979 to 0.980, and terminal lambda values ($N_{t=19}/N_{t=1}$) ranged from 0.668 to 0.669 across phases of the Proposed Action; these values indicated that predicted spawner abundances declined over the course of the time series (Table 5-31 and Table 5-32). Annual lambda values from deterministic model runs ranged from approximately 0.5 to 1.55 (Figure 5-50). Wet water years had the highest mean annual lambdas (>1.1 for all Alternatives) and Dry water years also had a mean annual lambda greater than 1, indicating that the population grew in Wet and Dry years (Table 5-31). Mean lambdas were less than 1 in Critical and Above normal water years, indicating that populations declined. Across stochastic model runs, mean lambda values over individual stochastic iterations ranged from approximately 0.925 to 1.025 (Figure 5-51) and Critical water years had a lower mean lambda value than other water year types (Figure 5-52). Terminal lambda values under the Proposed Action phases ranged from approximately 0.2 to 1.75 (Figure 5-53), suggesting some model runs resulted in expected population growth over the time series.

Population trends may be explained by differences in life stage-specific demographic parameters. The egg-to-fry survival life stage transition in the DSM is not sensitive to alternative-dependent flow or temperature values, and thus will be constant across alternatives. Across deterministic runs, monthly rearing survival for small juveniles (i.e., <42 millimeters) in the Upper Sacramento River varied from a low of approximately 0.01 to a high of approximately 0.2; rearing survival also varied across months, peaking in November and December (Figure 5-54). Additionally, migratory survival for very large fish also varied across months and WYT along their migratory route in the Sacramento River and the Delta (e.g., from 0.78 to 0.86 in the North Delta, Figure 5-55). Migratory survival often increased moving from a Critical to Dry to Above Normal to Wet WYT and peaked in February and March.

Table 5-29. Predicted Annual Total Winter-run Spawner Abundance in the Upper Sacramento River, including Both Natural- and Hatchery-Origin Fish, from Deterministic Model Runs.

Year	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
1980	8762	8762	8762	8762	8762	8762
1981	9376	9376	9376	9376	9376	9376
1982	6456	8235	8156	8146	8177	8215
1983	2542	8632	8371	8366	8375	8523
1984	2022	11570	11391	11410	11339	11540
1985	3374	13951	14384	14402	14350	14526
1986	3069	14195	14884	14929	14915	15125
1987	1454	13383	13350	13451	13381	13708
1988	585	13647	13113	13230	13118	13558
1989	483	12730	12314	12336	12284	12627
1990	427	9123	8234	8140	8114	8325

Year	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
1991	392	8116	6230	6196	6154	6484
1992	391	8057	6089	6169	6140	6504
1993	390	5103	4015	4148	4155	4288
1994	389	3178	2777	2021	2231	2243
1995	391	3975	3657	1962	2297	2352
1996	392	4535	4052	3066	3220	3295
1997	394	4119	3735	3390	3421	3474
1998	403	4793	4698	4395	4413	4436
1999	421	5855	5946	5859	5848	5853

Table 5-30. Predicted Annual Natural-origin Winter-run Spawner Abundance in the Upper Sacramento River from Deterministic Model Runs.

Year	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
1980	8374	8374	8374	8374	8374	8374
1981	8989	8989	8989	8989	8989	8989
1982	6069	7847	7769	7759	7790	7827
1983	2155	8245	7984	7978	7987	8136
1984	1634	11183	11004	11022	10951	11152
1985	2987	13563	13997	14014	13962	14138
1986	2682	13808	14497	14542	14528	14738
1987	1066	12995	12962	13064	12993	13321
1988	198	13259	12726	12843	12731	13171
1989	96	12343	11927	11948	11897	12240
1990	40	8735	7847	7752	7727	7938
1991	5	7729	5842	5809	5766	6097
1992	4	7670	5702	5782	5753	6117
1993	3	4716	3627	3761	3768	3901
1994	2	2791	2390	1634	1844	1856
1995	3	3588	3270	1575	1909	1965
1996	5	4148	3665	2679	2833	2908
1997	7	3732	3348	3002	3033	3087
1998	16	4405	4311	4008	4026	4049
1999	33	5467	5558	5471	5461	5466

Table 5-31. Predicted Mean Lambda (N_{t+1}/N_t) for Total Winter-run Spawner Abundance in the Upper Sacramento River, including Both Natural- and Hatchery-origin fish, from Deterministic Model Runs.

WYT	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
C	0.840	0.848	0.815	0.778	0.787	0.791
D	1.010	1.038	1.042	1.041	1.042	1.042
AN	0.998	0.633	0.659	0.672	0.677	0.659
W	0.874	1.108	1.129	1.174	1.155	1.157
All	0.852	0.979	0.980	0.979	0.979	0.979

Table 5-32. Predicted Terminal Lambda (N_t=19/$N_{t=1}$) for Total Winter-run Spawner Abundance in the Upper Sacramento River, including Both Natural- and Hatchery-origin Fish, from Deterministic Model Runs.

EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
0.048	0.668	0.679	0.669	0.668	0.668

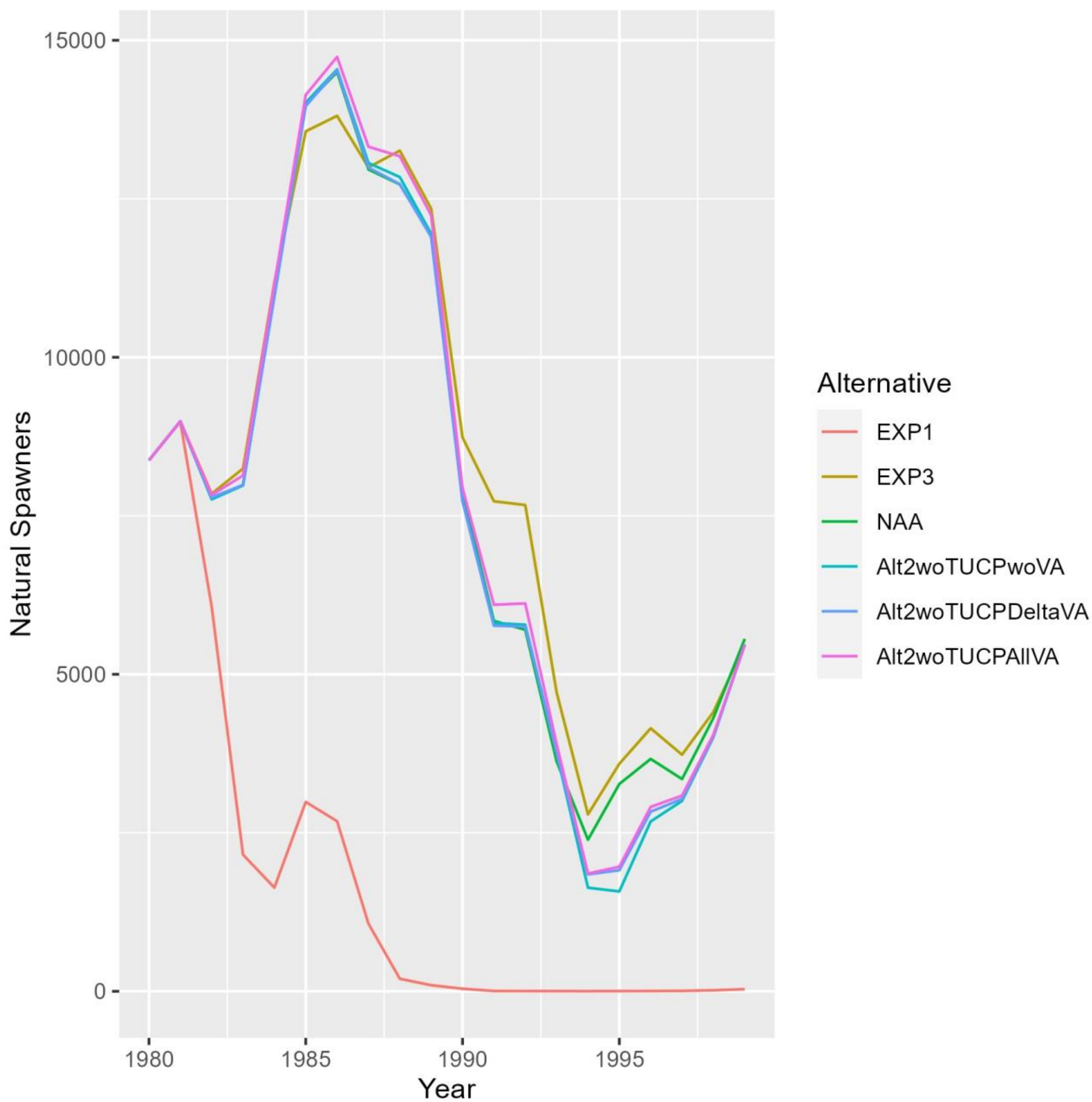
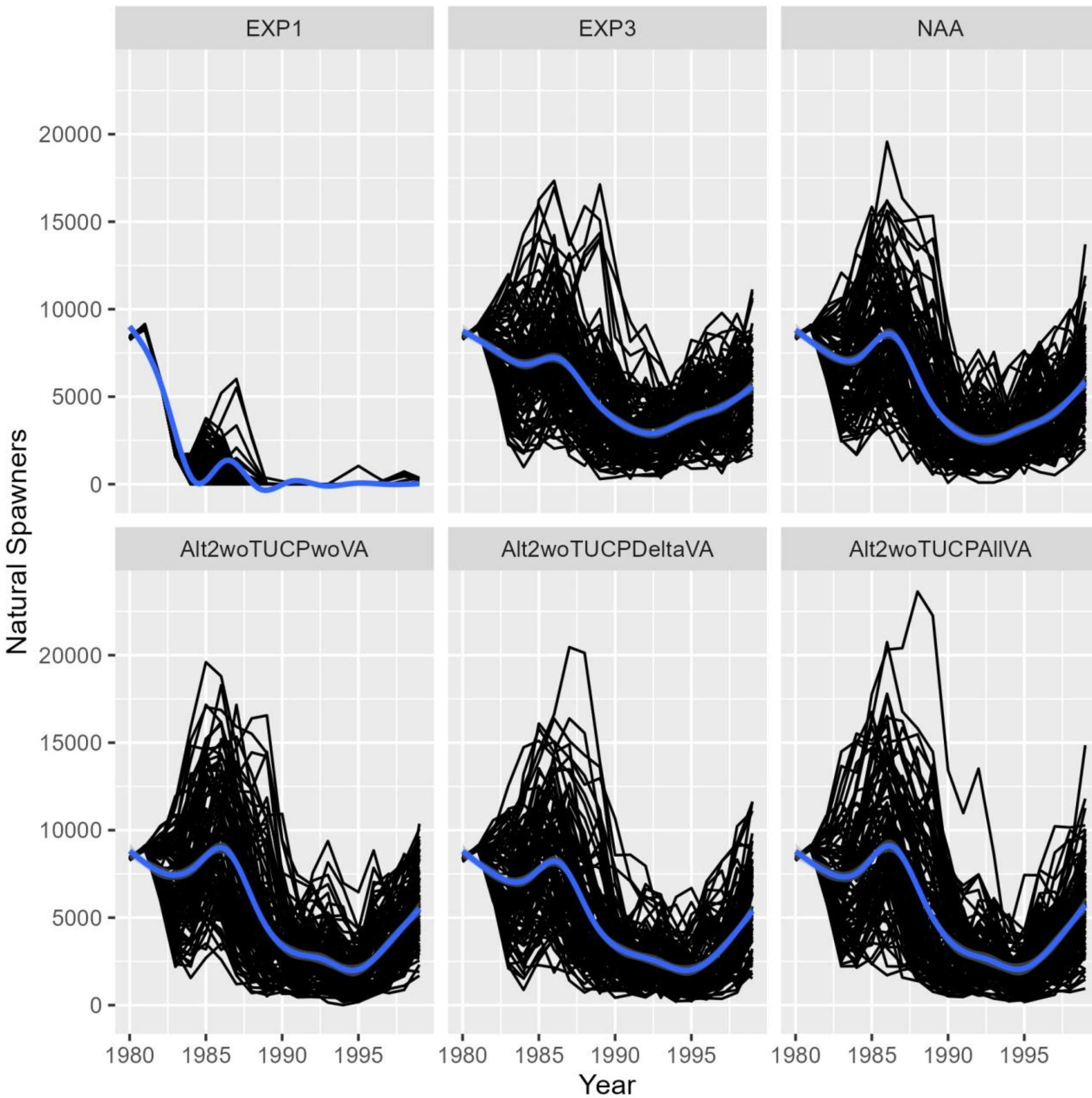


Figure 5-48. Expected Annual Abundances of Natural-origin Winter-run Chinook Salmon Spawners in the Upper Sacramento River from Deterministic Model Runs.



Black lines represent iteration-specific abundances over time and the blue line represents an expected trend obtained by 'gam' smoothing in ggplot2

Figure 5-49. Expected Annual Abundances of Natural-origin Winter-run Chinook Salmon Spawners in the Upper Sacramento River from Stochastic Model Runs.

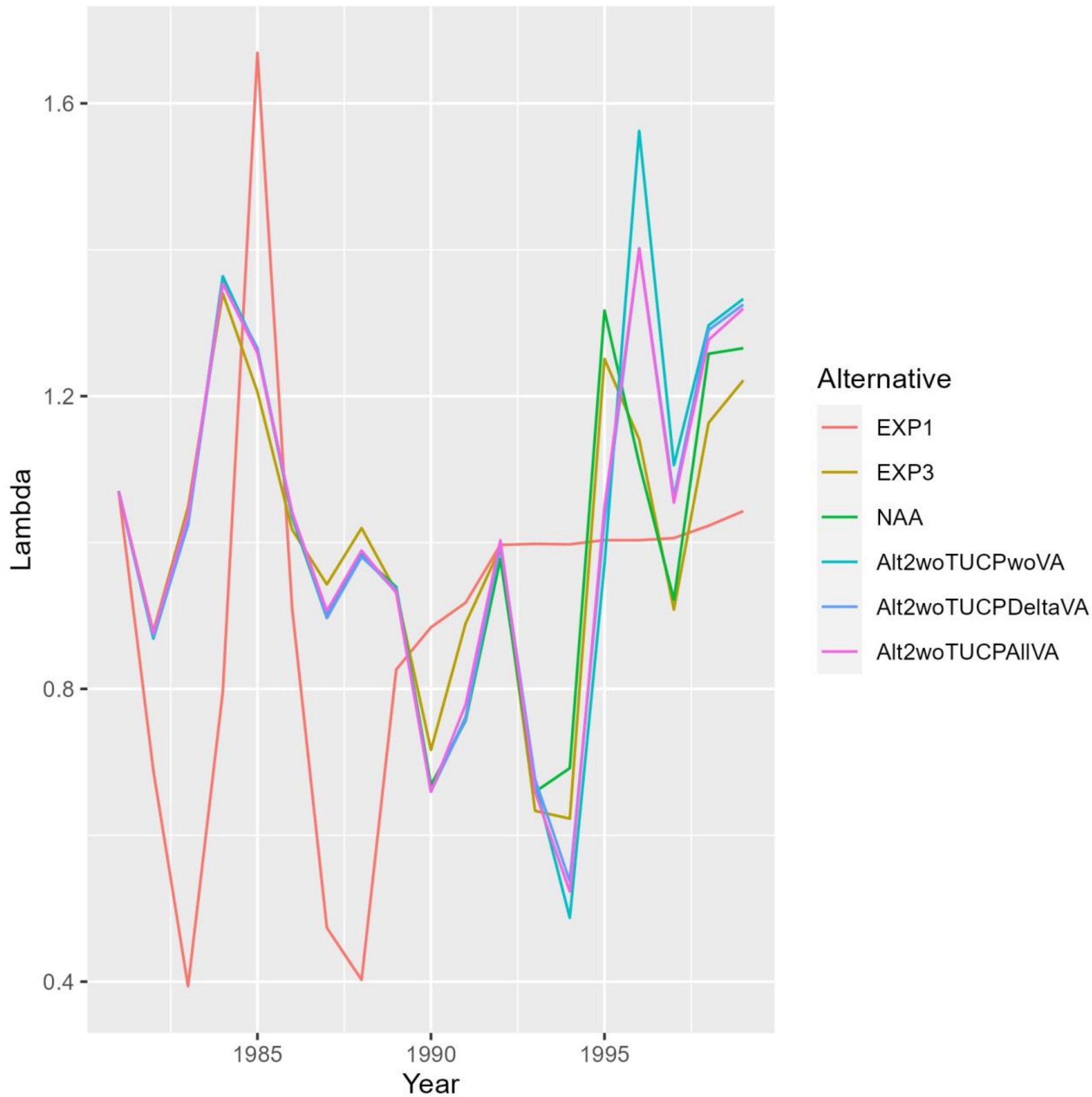


Figure 5-50. Predicted Annual Lambda Values (N_{t+1}/N_t) for Total Winter-run Spawner Abundance in the Upper Sacramento River, including Both Natural- and Hatchery-origin Fish, from Deterministic Model Runs.

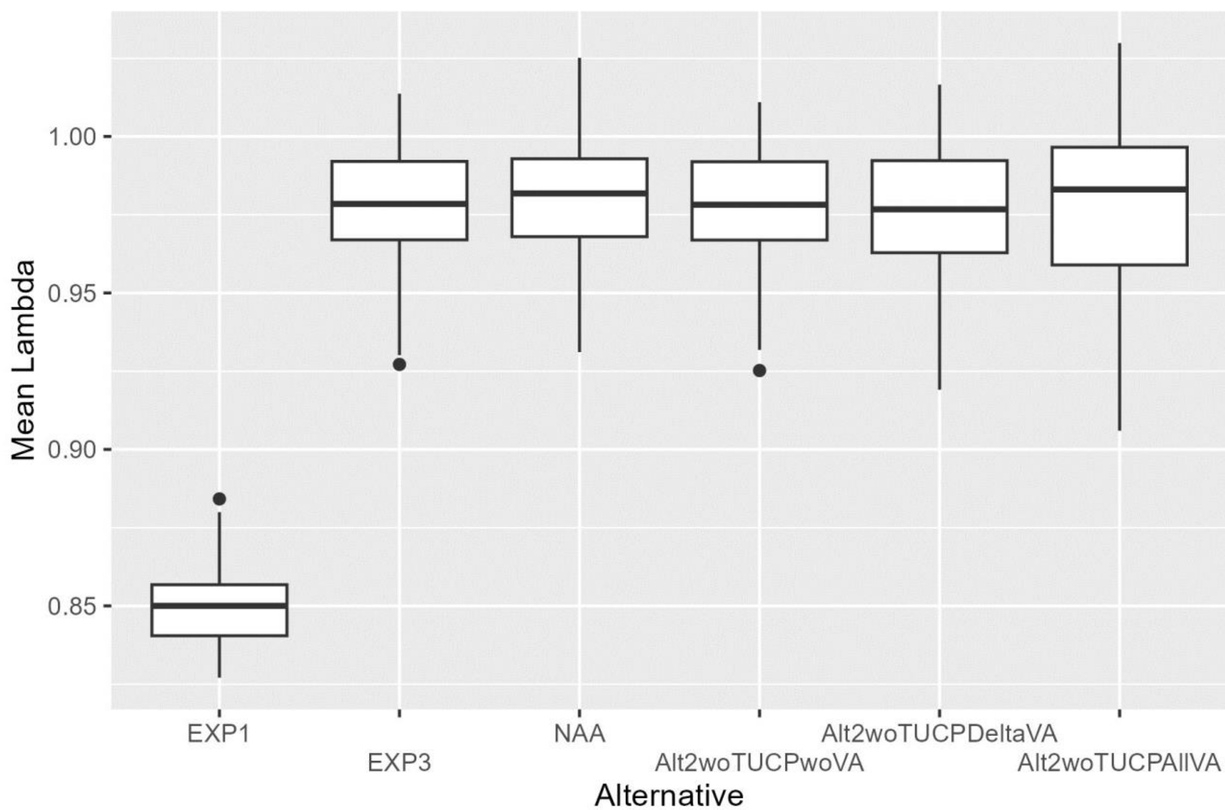


Figure 5-51. Predicted Mean Lambda Values (N_{t+1}/N_t) for Total Winter-run Spawner Abundance in the Upper Sacramento River, including Both Natural- and Hatchery-origin Fish, across 100 Stochastic Model Iterations.

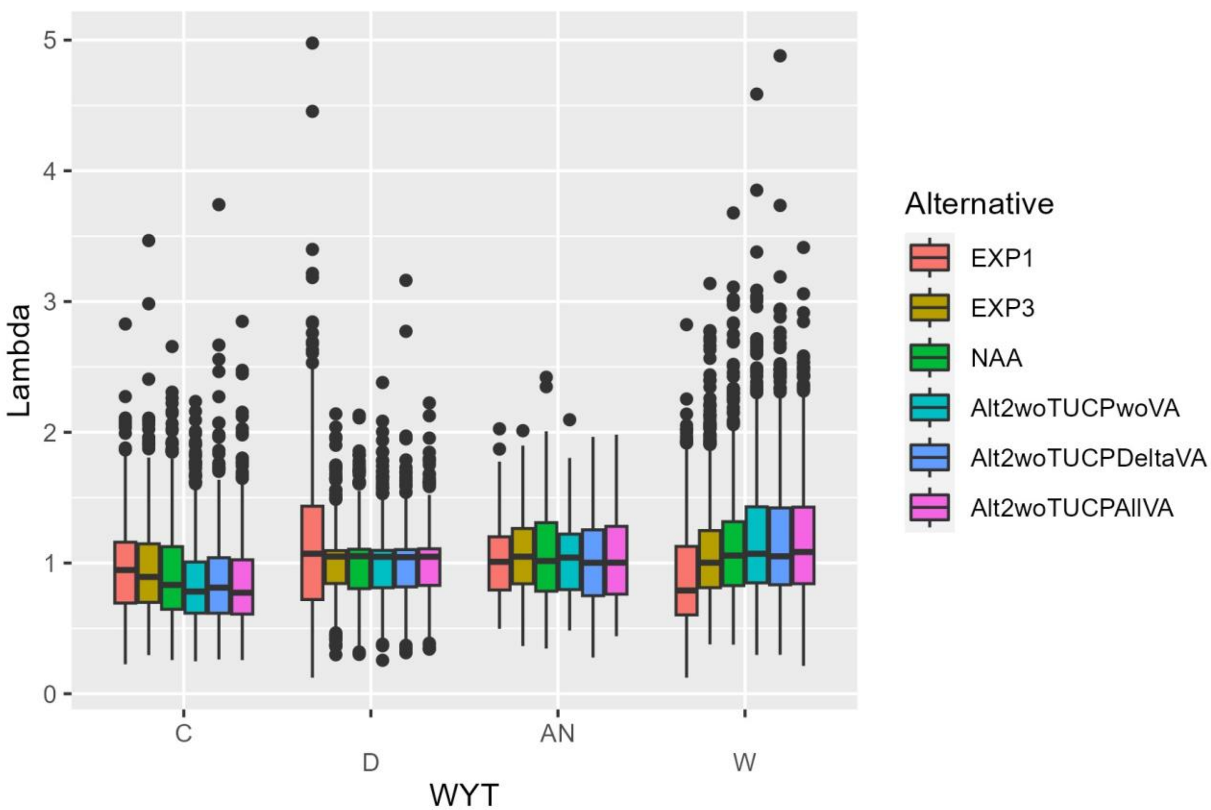


Figure 5-52. Predicted Lambda Values across Water Year Types (N_{t+1}/N_t) for Total Winter-run Spawner Abundance in the Upper Sacramento River, including Both Natural- and Hatchery-origin Fish, across 100 Stochastic Model Iterations.

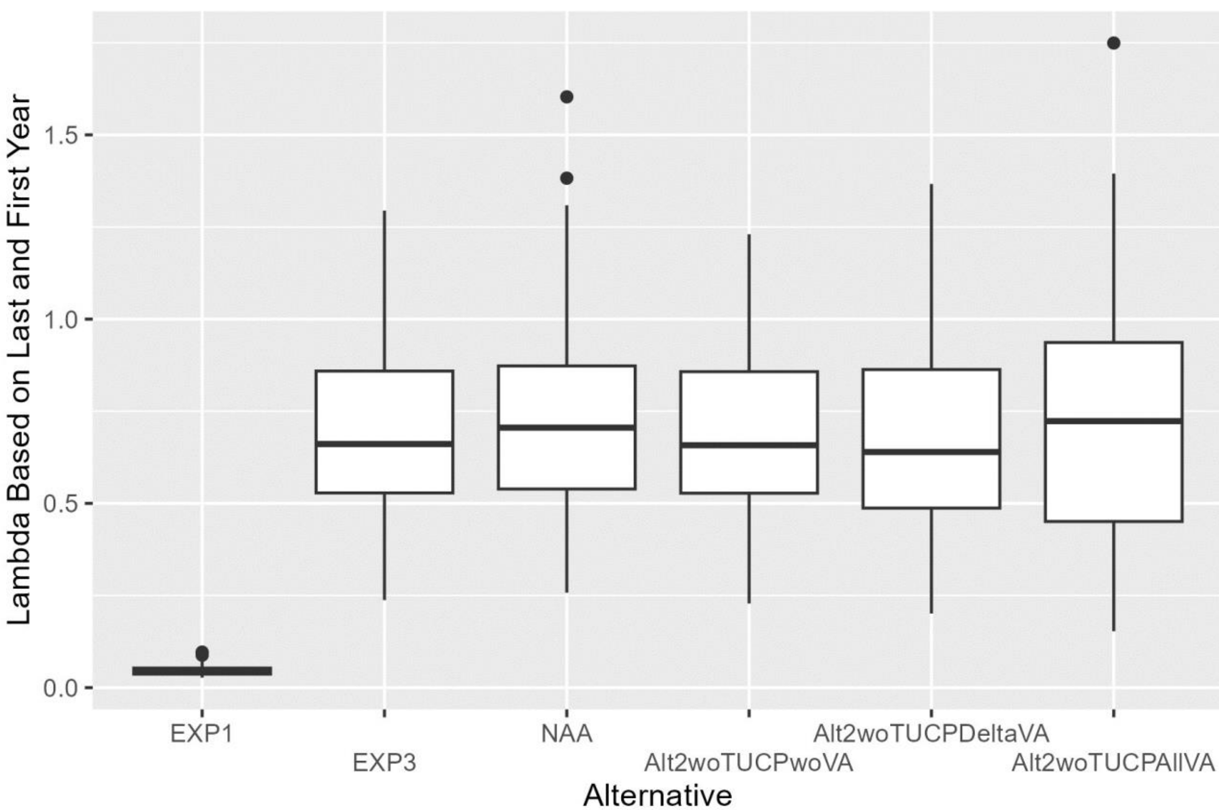


Figure 5-53. Predicted Terminal Lambda Values ($N_{t=19}/N_{t=1}$) for Total Winter-run Spawner Abundance in the Upper Sacramento River, including Both Natural- and Hatchery-origin Fish, across 100 Stochastic Model Iterations.

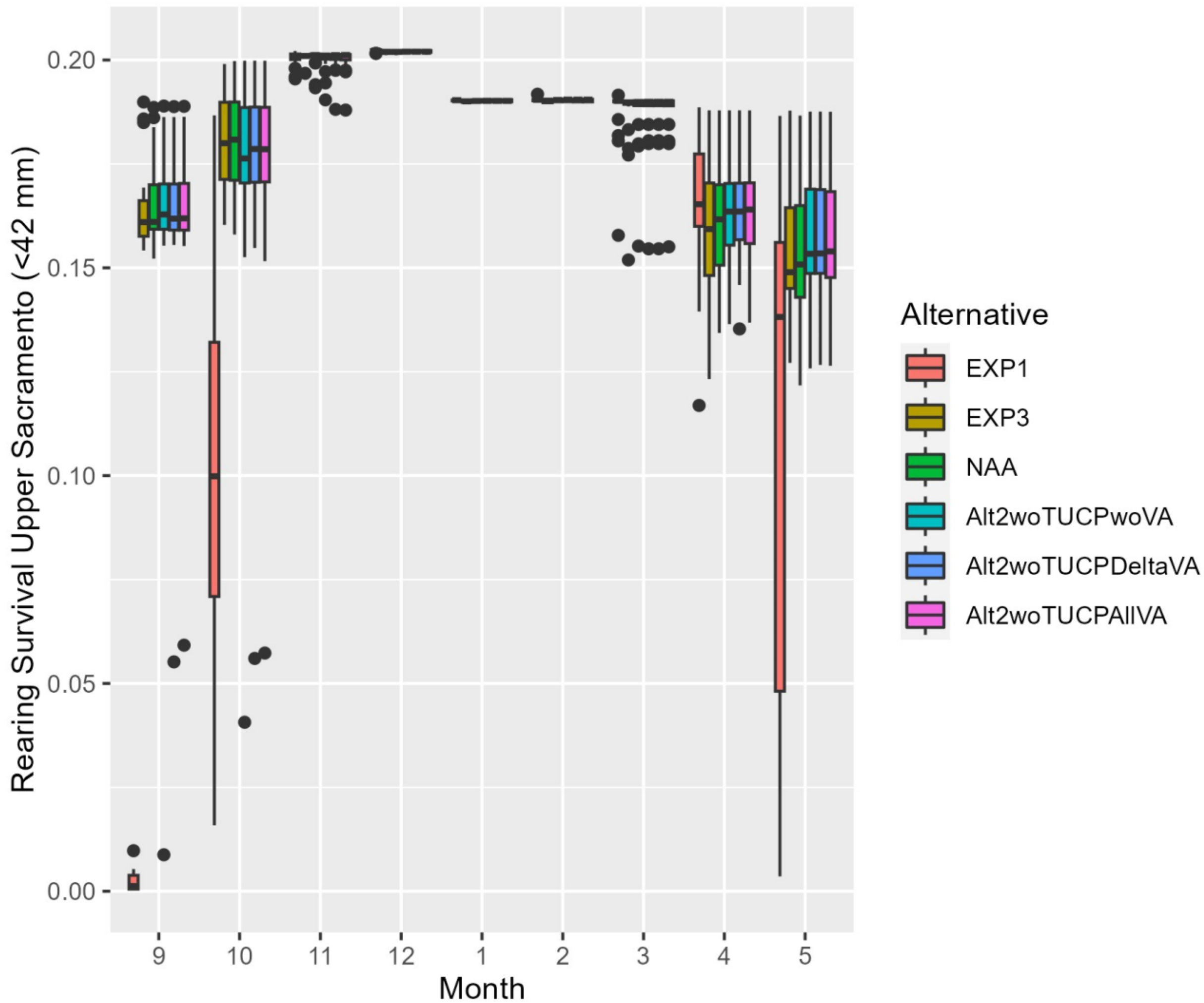


Figure 5-54. Predicted Small Juvenile Rearing Survival for Winter-run Chinook Salmon in the Upper Sacramento River from Deterministic Model Runs across the 20-year Timeseries.

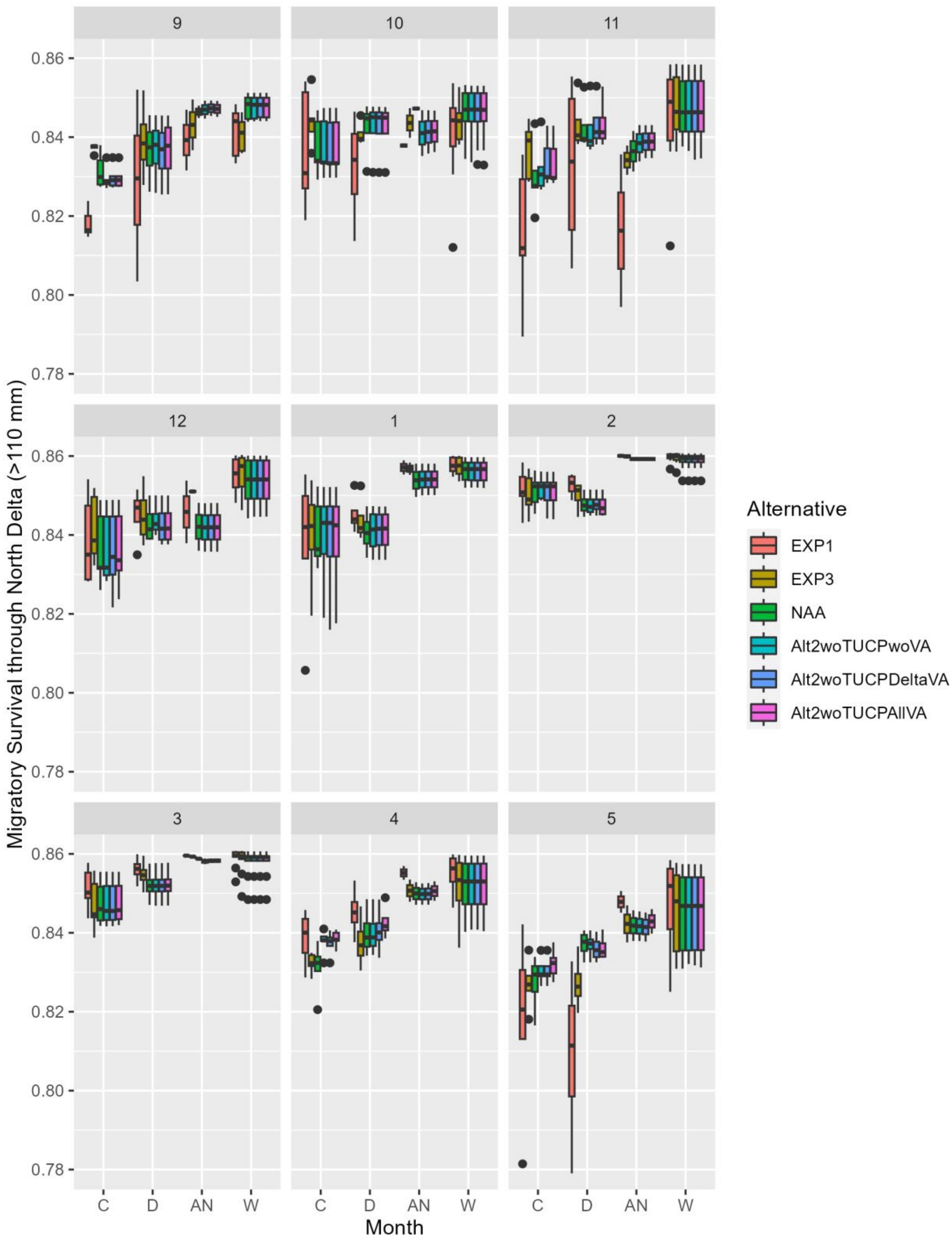


Figure 5-55. Predicted Smolt Migratory Survival for Winter-run Chinook Salmon in the North Delta from Deterministic Model Runs across the 20-year Timeseries, Faceted by Month.

Results are summarized here by hydrologic periods characterized by drought and non-drought operations and conditions. These data are summarized here by hydrologic periods characterized by drought and non-drought operations and conditions. Drought periods include transitions during critical and dry water years. Non-drought periods include transitions for during wet, above normal, and below normal water years.

5.4.3 IOS

The IOS winter-run Chinook salmon life cycle model provides estimates of adult abundance, spawning timing, egg-to-fry survival, juvenile production, outmigration survival through the Sacramento River and Bay-Delta, and other transition values.

[Placeholder: IOS modeling (performance measure is population growth rates, adult abundance, spawning timing, egg-to-fry survival, juvenile production, outmigration survival)]

5.4.4 OBAN

The OBAN winter-run Chinook salmon life cycle model provides estimates of adult abundance, spawning timing, egg-to-fry survival, juvenile production, outmigration survival through the Sacramento River and Bay-Delta, and other transition values.

[Placeholder: OBAN modeling (performance measure is population growth rates, adult abundance, spawning timing, egg-to-fry survival, juvenile production, outmigration survival)]

5.5 References

Anderson and Sedell. 1979.

Anderson, J. J., W. N. Beer, J. A. Israel, and S. Greene. 2022. Targeting river operations to the critical thermal window of fish incubation: Model and case study on Sacramento River winter-run Chinook salmon. *River Research and Applications* 38:895–905, DOI: 10.1002/rra.3965.

Arkoosh, M. R., E. Clemons, P. Huffman, A. N. Kagley, E. Casillas, N. Adams, H. R. Sanborn, T. K. Collier, and J. E. Stein. 2001. Increased Susceptibility of Juvenile Chinook Salmon to Vibriosis after Exposure to Chlorinated and Aromatic Compounds Found in Contaminated Urban Estuaries. *Journal of Aquatic Animal Health* 13:3:257–268. DOI: http://dx.doi.org/10.1577/1548-8667(2001)013<0257:ISOJCS>2.0.CO;2.

Arthur et al. 1996.

Bashevkin, S. M., and B. Mahardja. 2022. Seasonally variable relationships between surface water temperature and inflow in the upper San Francisco Estuary. *Limnology and Oceanography*. DOI: 10.1002/lno.12027.

Beckvar, N., T. Dillon, and L. Read. 2005. Approaches for Linking Whole-Body Fish Tissue Residues of Mercury and DDT to Biological Effects Thresholds. *Environmental toxicology and chemistry / SETAC* 24:2094–2105. DOI: 10.1897/04-284R.1.

Bellido-Leiva, F. J., R. A. Lusardi, and J. R. Lund. 2021. Modeling the effect of habitat availability and quality on endangered winter-run Chinook salmon (*Oncorhynchus tshawytsha*) production in the Sacramento Valley. *Ecological Modelling* 447:109511.

Bennett, D. H., W. P. Connor, and C. A. Eaton. 2003. Substrate Composition and Emergence Success of Fall Chinook Salmon in the Snake River. *Northwest Science* 77(2):93–99.

Bjornn, T. C., and D. W. Reiser. 1991. Habitat Requirements of Salmonids in Streams. Chapter 4 in Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. *American Fisheries Society Special Publication* 19:83–138.

Bovee et al. 1998.

Bratovitch, P., C. Addley, D. Simodynes, and H. Bowen. 2012. *Water Temperature Considerations for Yuba River Basin Anadromous Salmonid Reintroduction Evaluations.* Yuba Salmon Forum Technical Working Group, Sacramento, CA.

Bureau of Reclamation. 2012. *Yolo Bypass Salmonid Habitat Restoration and Fish Passage Implementation Plan.* Mid-Pacific Region. Sacramento, CA. September.

Bureau of Reclamation. 2020. *Sacramento River Gravel Augmentation Study.* Technical Report No. ENV-2020-060. 59 pp.

Bureau of Reclamation. 2021. *2021 Seasonal Report for the Shasta Cold Water Pool Management.* 42 pp.

Bureau of Reclamation. 2022. 2021 *Seasonal Report for the Shasta Cold Water Pool Management.* Central Valley Project, CA. California-Great Basin Region. 60 [[.

CalFish.org 2021 Carcass – Redds counts datasheet

CalFish.org 2022 Carcass – Redds counts datasheet

California Department of Fish and Wildlife. 2017. *Statewide Drought Response: Stressor Monitoring Summary Report 2014–2017.* 177 pp.

California Department of Fish and Wildlife. 2018.

California Department of Water Resources. 2000.

California State Coastal Conservancy et al. 2010.

Carter, K. 2005. The Effects of Dissolved Oxygen on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage. California Regional Water Quality Control Board (North Coast Region).

Cavallo, B., P. Gaskill, J. Melgo, and S. C. Zeug. 2015. Predicting juvenile Chinook Salmon routing in riverine and tidal channels of a freshwater estuary. *Environmental Biology of Fishes* 98:1571–1582.

Chelberg et al. 2022. In prep. 2021-2022 Redds Report 05-18-2022.

Chen, L., X. Zhi, Y. Dai, and G. Aini. 2018. Comparison between snowmelt-runoff and rainfall-runoff nonpoint source pollution in a typical urban catchment in Beijing, China. *Environmental Science and Pollution Research* 25:2377–2388.

Clark, W.C., and J. E. Shelbourn. 1985. Growth and development of seawater adaptability by juvenile fall Chinook salmon (*Oncorhynchus tshawytscha*) in relation to temperature. *Aquaculture* 45:21–31.

Columbia Basin Research, University of Washington. 2022.

Cooke et al. 2012.

Davis et al. 1963.

Daniels, M. E., and E. M. Danner. 2020. The Drivers of River Temperatures Below a Large Dam. *Water Resources Research* 56: e2019WR026751. DOI: https://doi.org/10.1029/2019WR026751.

Del Rio, A. M., B. E. Davis, N. A. Fangue, and A. E. Todgham. 2019. Combined effects of warming and hypoxia on early life stage Chinook salmon physiology and development. *Conservation Physiology* 7. DOI: 10.1093/conphys/coy078.

del Rosario, R. B., Y. J. Redler, P. L. Brandes, T. Sommer, K. Reece, and R. Vincik. 2013, Migration Patterns of Juvenile Winter-run-sized Chinook Salmon (*Oncorhynchus tshawytscha*) through the Sacramento–San Joaquin Delta. *San Francisco Estuary and Watershed Science* 11(1). DOI: https://doi.org/10.15447/sfews.2013v11iss1art3.

Dudley, P. N. 2019. Insights from an individual based model of a fish population on a large regulated river. *Environmental Biology of Fishes* 102:1069–1095. DOI: https://doi.org/10.1007/s10641-019-00891-6.

Dudley, P. N., S. N. John, M. E. Daniels, and E. M. Danner. 2022. Using decades of spawning data and hydraulic models to construct a temperature-dependent resource selection function for management of an endangered salmonid. *Canadian Journal of Fisheries and Aquatic Sciences* 79:73–81. DOI: dx.doi.org/10.1139/cjfas-2021-0022.

Dugdale et al. 2007.

Dusek Jennings, E., and A. N. Hendrix. 2020. Spawn Timing of Winter-Run Chinook Salmon in the Upper Sacramento River. *San Francisco Estuary and Watershed Science* 18(2). DOI: 10.15447///sfews.2020v18iss2art5.

Gard, M. 2005. Flow-Habitat Relationships for Chinook Salmon Rearing in the Sacramento River Between Keswick Dam and Battle Creek. U.S. Fish and Wildlife Service, Sacramento, CA. 258 pp.

Gard, M. 2006. Flow-Habitat Relationships for Macroinvertebrates in the Sacramento River between Keswick Dam and Battle Creek. U.S. Fish and Wildlife Service, Sacramento, CA. 51 pp.

Gingras, M., and M. McGee. 1997. A Telemetry Study of Striped Bass Emigration from Clifton Court Forebay: Implications for Predator Enumeration and Control. Interagency Ecological Program for the San Francisco Bay/Delta Estuary, Technical Report 54, January. 31 pp.

Goertler et al. 2015.

Goertler, P. A. L., T. R. Sommer, W. H. Satterthwaite, and B. M. Schreier. 2018. Seasonal floodplain-tidal slough complex supports size variation for juvenile Chinook salmon (*Oncorhynchus tshawytsha*). *Ecology of Freshwater Fish* 27:580–593.

Goniea, T. M., M. L. Keefer, T. C. Bjornn, C. A. Peery, D. H. Bennett, and L. C. Stuehrenberg. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water temperatures. *Transactions of the American Fisheries Society* 135(2):408–419.

Hanak et al. 2011.

Hance et al 2021.

Healey, M. C. 1991. *Life History of Chinook Salmon.* UBC Press, University of British Columbia. Vancouver, BC. 86 pp.

Henery, R. E., T. R. Sommer, and C. R. Goldman. 2010. Growth and Methymercury Accumulation in Juvenile Chinook Salmon in the Sacramento River and Its Floodplain, the Yolo Bypass. *Transactions of the American Fisheries Society* 139:550–563.

Herren and Kawasaki. 2001.

Jarrett, J., and D. Killam. 2015. *Redd Dewatering and Juvenile Stranding in the Upper Sacramento River Year 2014-2015.* RBFO Technical Report 2-2015.

Jeffres, C. A., J. J. Opperman, and P. B. Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. *Environmental Biology of Fishes* 83:449–458.

Jeffres, C. A., E. J. Holmes, T. R. Sommer, and J. V. E. Katz. 2020. Detrital food web contributes to aquatic ecosystem productivity and rapid salmon growth in a managed floodplain. *PLoS ONE* 15(9): e0216019.

Kano, R. M. 1990. *Occurrence and abundance of predator fish in Clifton Court Forebay, California.* Technical Report 24. Interagency Ecological Program.

Keefer, M. L., C. C. Caudill, C. A. Peery, and C. T. Boggs. 2008. Non-direct homing behaviours by adult Chinook salmon in a large, multi-stock river system. *Journal of Fish Biology* 72:27–44.

Kemp, P. S., M. H. Gessel, and J. G. WilliamsG. 2005. Seaward migrating subyearling chinook salmon avoid overhead cover. *Journal of Fish Biology* 67:1381–1391.

Kent, M. L., S. Benda, S. St-Hilaire, and C. B. Schreck. 2013. Sensitivity and specificity of histology for diagnoses of four common pathogens and detection of nontarget pathogens in adult Chinook salmon (*Oncorhynchus tshawytsha*) in fresh water. *Journal of Veterinary Diagnostic Investigation* 25(3):341–351.

Kimmerer. 2002.

Kjelson et al. 1981.

Knowles, N., and D. R. Cayan. 2002. Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. *Geophysical Research Letters* 29(18):1891. DOI: 10.1029/2001GL014339.

Kroglund, F., and B. Finstad. 2003. Low concentrations of inorganic monomeric aluminum impair physiological status and marine survival of Atlantic salmon. *Aquaculture* 222:119–133.

Limm, M. P., and M. P. Marchetti. 2009. Juvenile Chinook salmon (*Oncorhynchus tshawytsha*) growth in off-channel and main-channel habitats on the Sacramento River, CA using otolith increment widths. *Environmental Biology of Fishes* 85:141–151.

Lindell. 2017.

Lindley et al. 2009.

Lundin, J. I., P. M. Chittaro, G. M. Ylitalo, J. W. Kern, D. R. Kuligowski, S. Y. Sol, K. A. Baugh, D. T. Boyd, M. C. Baker, R. M. Neely, K. G. King, and N. L. Scholz. 2021. Decreased Growth Rate Associated with Tissue Contaminants in Juvenile Chinook Salmon Out-Migrating through an Industrial Waterway. *Environmental Science and Technology* 55:9968–9978.

MacFarlane and Norton. 2002.

Marine K. R., and J. J. Cech Jr. 2004. Effects of high water temperature on the growth, smoltification, and predator avoidance in juvenile Sacramento River Chinook Salmon. *North American Journal of Fisheries Management* 24:198–210.

Martin, B. T., P. N. Dudley, N. S. Kashef, D. M. Stafford, W. J. Reeder, D. Tonina, A. M. Del Rio, J. S. Foott, and E. M. Danner. 2020. The biophysical basis of thermal tolerance in fish eggs. *Proceedings of the Royal Society B: Biological Sciences* 287.

Martin, B. T., A. Pike, S. N. John, N. Hamda, J. Roberts, S. T. Lindley, and E. M. Danner. 2017. Phenomenological vs. biophysical models of thermal stress in aquatic eggs. *Ecology Letters* 20:50–59. DOI: 10.1111/ele.12705.

Mazuranich, J. J., and W. E. Nielson,. 1959. White-Spot Disease of Salmon Fry. *The Progressive Fish Culturalist* 21:172–176.

McCullough, D. A. 1999. A Review and Synthesis of Effects of Alterations to the Water Temperature Regime on Freshwater Life Stages of Salmonids, with Special Reference to Chinook Salmon. Prepared for the U.S. Environmental Protection Agency Region 10. Published as EPA 910-R-99-010, July 1999. 291 [[.

Memeo, M., S. Serritello, J. Graves, and R. Revnak. 2019. Redd Dewatering and Juvenile Stranding in the Upper Sacramento River Year 2018–2019. RBFO Technical Report No. 01-2019.

Memeo, M., S. Serritello, and R. Revnak. 2018. Redd Dewatering and Juvenile Stranding in the Upper Sacramento River Year 2017–2018. RBFO Technical Report No. 01-2018.

Michel, C. J., M. J. Henderson, C. M. Loomis, J. M. Smith, N. J. Demetras, I. S. Iglesias, B. M. Lehman, and D. D. Huff. 2020. Fish predation on a landscape scale. *Ecosphere* 11(6).

Michel, C. J., J. J. Notch, F. Cordoleani, A. J. Ammann, and E. M. Danner. 2021. Nonlinear survival of imperiled fish informs managed flows in a highly modified river. *Ecosphere* 12(5): e03498. DOI: https://doi.org/10.1002/ecs2.3498.

Moyle. 2002.

Moyle and Israel. 2005.

Murphy, S. R., H. T. Pham, and L. ChumneyL. 2022. Statewide Health Advisory and Guidelines for Eating Fish that Migrate: American Shad, Chinook (King) Salmon, Steelhead Trout, Striped Bass, and White Sturgeon in California Rivers, Estuaries, and Coastal Waters. California Environmental Protection Agency, Office of Environmental Health. Available: https://oehha.ca.gov/advisories/advisory-fish-migrate.

Myrick, C. A., and J. J. Cech. 2001. Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations. Bay-Delta Modeling Forum.

Myrick, C. A., and J. J. Cech Jr. 2004. Temperature effects on juvenile anadromous salmonids in California’s central valley: what don’t we know? *Reviews in Fish Biology and Fisheries* 14:113–123.

Naish, K. A., J .E. Taylor, P. S. Levin, T. P. Quinn, J. R. Winton, D. Huppert, and R. Hilborn. 2007. An Evaluation of the Effects of Conservation and Fishery Enhancement Hatcheries on Wild Populations of Salmon. *Advances in Marine Biology* 53:61–194.

National Marine Fisheries Service. 1996.

National Marine Fisheries Service. 1997.

National Marine Fisheries Service. 1998.

National Marine Fisheries Service. 2009. Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and the State Water Project. Southwest Region, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U. S. Department of Commerce. 844 pp.

National Marine Fisheries Service. 2009b.

National Marine Fisheries Service. 2009c.

National Marine Fisheries Service. 2011.

National Marine Fisheries Service. 2014. *Recovery Plan for the Evolutionary Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead*.

National Marine Fisheries Service. 2016.

National Marine Fisheries Service. 2019. *Biological Opinion on Long-Term Operation of the Central Valley Project and the State Water Project.* West Coast Region, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U. S. Department of Commerce. 900 pp.

Nekouei, O., R. Vanderstichel, K. H. Kaukinen, K. Thakur, T. Ming, D. A. Patterson, M. Trudel, C. Neville, and K. M. Miller. 2019. Comparison of infectious agents detected from hatchery and wild juvenile Coho salmon in British Columbia, 2008–2018. *PLoS ONE* 14(9): e0221956. DOI: https://doi.org/10.1371/journal.pone.0221956.

Newman, K. B., and P. L. Brandes. 2010. Hierarchical Modeling of Juvenile Chinook Salmon Survival as a Function of Sacramento–San Joaquin Delta Water Exports. North American *Journal of Fisheries Management* 30:157–169.

Notch, J. J., A. S. McHuron, C. J. Michel, F. Cordoleani, M. Johnson, M. J. Henderson, and A. J. Ammann. 2020. Outmigration survival of wild Chinook salmon smolts through the Sacramento River during historic drought and high water conditions. *Environmental Biology of Fishes* 103:561–576.

Parajulee, A., Y. D. Lei, A. Kananathalingam, D. S. McLagan, C. P. J. Mitchell, and F. Wania. 2017. The transport of polycyclic aromatic hydrocarbons during rainfall and snowmelt in contrasting landscapes. *Water Research* 124:407–414.

Perry, R. W. 2010. *Survival and Migration Dynamics of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in the Sacramento-San Joaquin River Delta.* Ph.D. Dissertation, University of Washington, Seattle, WA. 237.

Peterson, J. T., and A. Duarte. 2020. Decision analysis for greater insights into the development and evaluation of Chinook salmon restoration strategies in California's Central Valley. *Restoration Ecology* 28(6):1596–1609.

Pusey and Arthington. 2003.

Reiser, D. W., and T. C. Bjornn. 1979. Influence of Forest and Rangeland Management on Anadromous Fish Habitat in the Western United States and Canada: Habitat Requirements of Anadromous Salmonids (Vol. 1). Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

Resources Agency of the State of California. 2003.

Romine, J. G., R. W. Perry, P. R. Stumpner, A. R. Blake, and J. R. Burau. 2021. Effects of Tidally Varying River Flow on Entrainment of Juvenile Salmon into Sutter and Steamboat Sloughs. *San Francisco Estuary and Watershed Science* 19(2). DOI: 10.15447/sfews.2021v19iss2art4.

SacPAS, CDEC [in Figure 5-6]

SFEI-ASC. 2014.

Siegel. 2007.

Slater, D. W. 1963. Winter-run Chinook Salmon in the Sacramento River, California with notes on water temperature requirements at spawning. Washington, DC: U.S. Department of the Interior-Fish and Wildlife Service. Special Scientific Report-Fisheries No. 461. 9 p. Available: https://spo.nmfs.noaa.gov/sites/default/files/legacypdfs/SSRF461.pdf. Accessed: March 24, 2020.

Smith, K., J. Chelberg, R. Greathouse, and A. Tasoff. 2020. Redd Dewatering and Juvenile Stranding in the Upper Sacramento River Year 2019–2020. RBFO Technical Report No. 02-2020.

SMP. 2013.

Sommer et al. 2001a.

Sommer et al. 2001b.

Steel, A. E., J. J. Anderson, B. Mulvey, and D. L. Smith. 2020. Applying the mean free-path length model to juvenile Chinook salmon migrating in the Sacramento River, California. *Environmental Biology of Fishes* 103:1603–1617. DOI: https://doi.org/10.1007/s10641-020-01046-8.

Steel, E. A., T. J. Beechie, C. E. Torgersen, and A. H. Fullerton. 2017. Envisioning, Quantifying, and Managing Thermal Regimes on River Networks. *BioScience* 67(6):506–522. DOI: https://doi.org/10.1093/biosci/bix047.

Stillwater Sciences. 2006.

Suisun Ecological Workgroup. 2001.

Thompson. 1957.

Thompson. 1965.

Thompson. 1972.

Tucker, M. E., C. M. Williams, and R. R. Johnson. 1998. Abundance, food habits and life history aspects of Sacramento Squawfish and Striped Bass at the Red Bluff Diversion Complex, including the Research Pumping Plant, Sacramento River, California, 1994−1996. Red Bluff (CA): U.S. Department of the Interior, Fish and Wildlife Service. Annual Report: Red Bluff Research Pumping Plant Report Series Volume 4. 54 pp.

U.S. Fish and Wildlife Service. 1999. Effect of temperature on early-life survival of Sacramento River fall- and winter-run Chinook salmon. U. S. Fish and Wildlife Service Report, Northern Central Valley Fish and Wildlife Office Red Bluff, California.

U.S. Environmental Protection Agency. 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. Region 10 Office of Water, Seattle, WA.

U.S. Fish and Wildlife Service. 2003. Flow-Habitat Relationships for steelhead and fall, late-fall, and winter-run Chinook salmon spawning in the Sacramento River between Keswick Dam and Battle Creek. February 4. Sacramento, CA.

U.S. Fish and Wildlife Service. 2021. Upper Sacramento River Winter Chinook Salmon Carcass Survey 2020 Annual Report. U. S. Fish & Wildlife Service Red Bluff Fish and Wildlife Office. July. 33 pp.

van Vliet et al. 2023.

Voss, S. D., and W. R. Poytress. 2022. 2020 Red Bluff Diversion Dam Rotary Trap Juvenile Anadromous Fish Abundance Estimates. Report of the U.S. Fish and Wildlife Service to the Bureau of Reclamation, Sacramento, CA.

Vroom, J., M. van der Wegen, R. C. Martyr-Koller, and L. V. Lucas. 2017. What Determines Water Temperature Dynamics in the San Francisco Bay-Delta System? *Water Resources Research* 53:9901–9921. DOI: https://doi.org/10.1002/2016WR020062.

Whipple. 2010.

Williams et al. 2009.

Whipple et al. 2012.

Windell, S., P. L. Brandes, L. Conrad, J. W. Ferguson, P. A. L. Goertler, B. N. Harvey, J. Heublein, J. A. Israel, D. W. Kratville, J. E. Kirsch, R. W. Perry, J. Pisciotto, W. R. Poytress, K. Reece, B. G. Swart, and R. C. Johnson. 2017. Scientific Framework for Assessing Factors Influencing Endangered Sacramento River Winter-Run Chinook Salmon (Oncorhynchus tshawytsha) Across the Life Cycle. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-586. 49 p. DOI: http://doi.org/10.7289/V5/TM-SWFSC-586.

Winder and Jassby. 2011.

Yoshiyama et al. 1998.

Zeug and Cavallo. 2014.

Zeug et al. 2019.

Zeug, S. C., K. Sellheim, J. Melgo, and J. E. Merz. 2020. Spatial variation of juvenile Chinook Salmon (*Oncorhynchus tshawytsha*) survival in a modified California river. *Environmental Biology of Fishes* 103:465–479.