# 2021 Seasonal Report for the Shasta Cold Water Pool Management

**Central Valley Project, California**
**California-Great Basin Region**

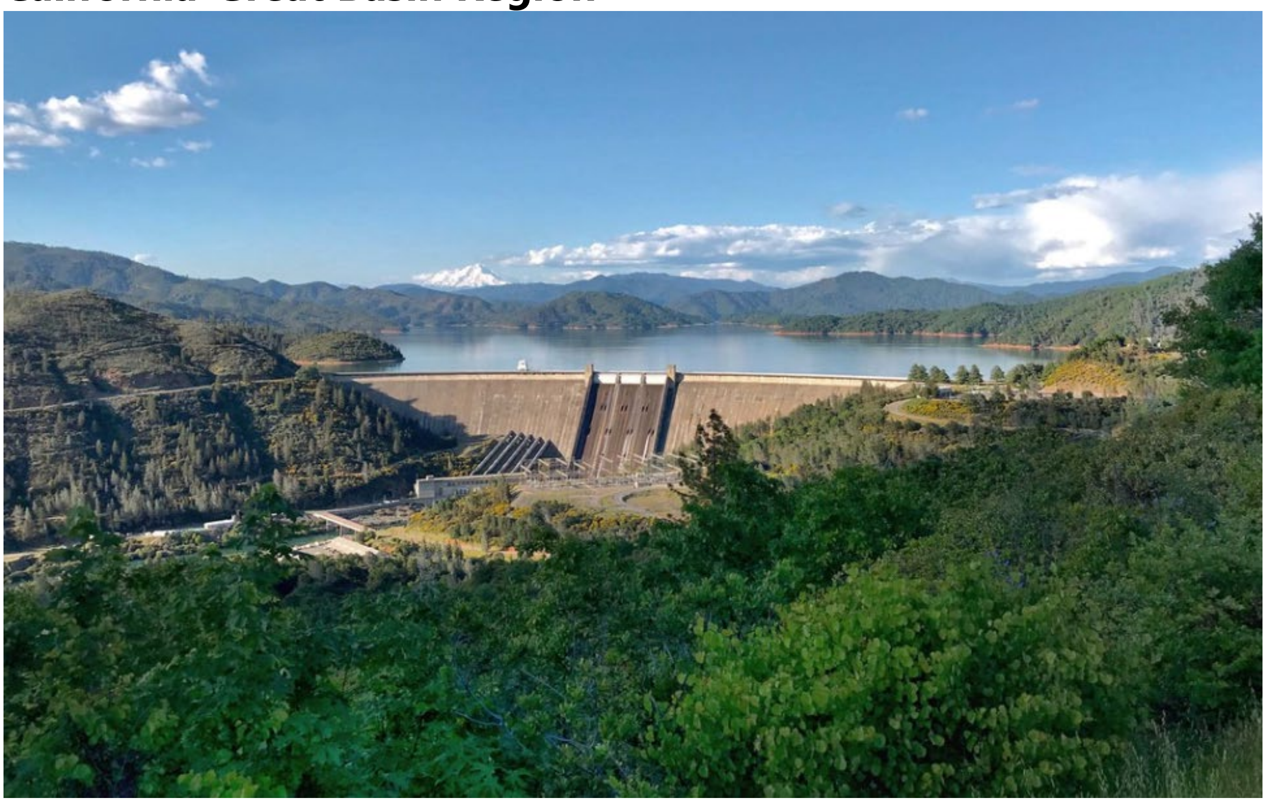

Photo Credit: Reclamation

**U.S. Department of the Interior** **March 2022**

# Mission Statements

The Department of the Interior (DOI) conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

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.

# 2021 Seasonal Report for the Shasta Cold Water Pool Management

**Central Valley Project, California**
**California-Great Basin Region**

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# Purpose

This 2021 Seasonal Report for Shasta Cold Water Pool Management describes Shasta Dam operations leading up to and through the 2021 cold water pool management season. This seasonal report may support improvements, if necessary, to the Shasta Cold Water Pool Management Guidance Document, and may also guide operations in the future. This seasonal report fulfills commitments under the Record of Decision (ROD) signed by the Bureau of Reclamation (Reclamation) in February 2020 for the Reinitiation of Consultation on the Coordinated Long-Term Operations of the Central Valley Project (CVP) and State Water Project (SWP) to produce a Seasonal Report for Shasta Cold Water Pool by the end of December of each year. Additionally, this seasonal report will be used to support the development of Reclamation's Annual Report on the Long-Term Operation of the Central Valley Project and State Water Project for Water Year 2021 (Annual Report). Finally, this document will inform the Four-Year Review Panels adopted under the ROD. The purpose of the independent review will be to evaluate the efficacy of actions undertaken to reduce the adverse effects on listed species.

Compliance with the National Marine Fisheries Service (NMFS) and the United States Fish and Wildlife Service (USFWS) 2019 Biological Opinions' Reasonable and Prudent Measures and associated Terms and Conditions adopted by the aforementioned ROD will be documented and discussed in the Annual Report and not in this document. Although this document strives to provide an integrated view of the system and the factors affecting the coordinated operation of the CVP and SWP, evaluation and discussion is focused on actions taken specifically by Reclamation for Shasta Lake's cold water pool management.

# Background

Shasta Dam and Lake represent about 40% of the total reservoir storage capacity of the CVP and are located in northern California near Redding (**Figure 1**). Reclamation operates Shasta Dam in coordination with state and federal fishery agencies (NMFS, USFWS, and California Department of Fish and Wildlife (CDFW)), the State Water Resources Control Board (State Water Board), Tribes, Western Area Power Administration (WAPA), water contractors and other stakeholders. It is operated in conjunction with other CVP and SWP facilities to provide for the management of floodwater, storage of winter runoff for irrigation in the Sacramento and San Joaquin valleys, Municipal and Industrial water supply, protection of fish in the Sacramento River and Delta, and hydropower generation.

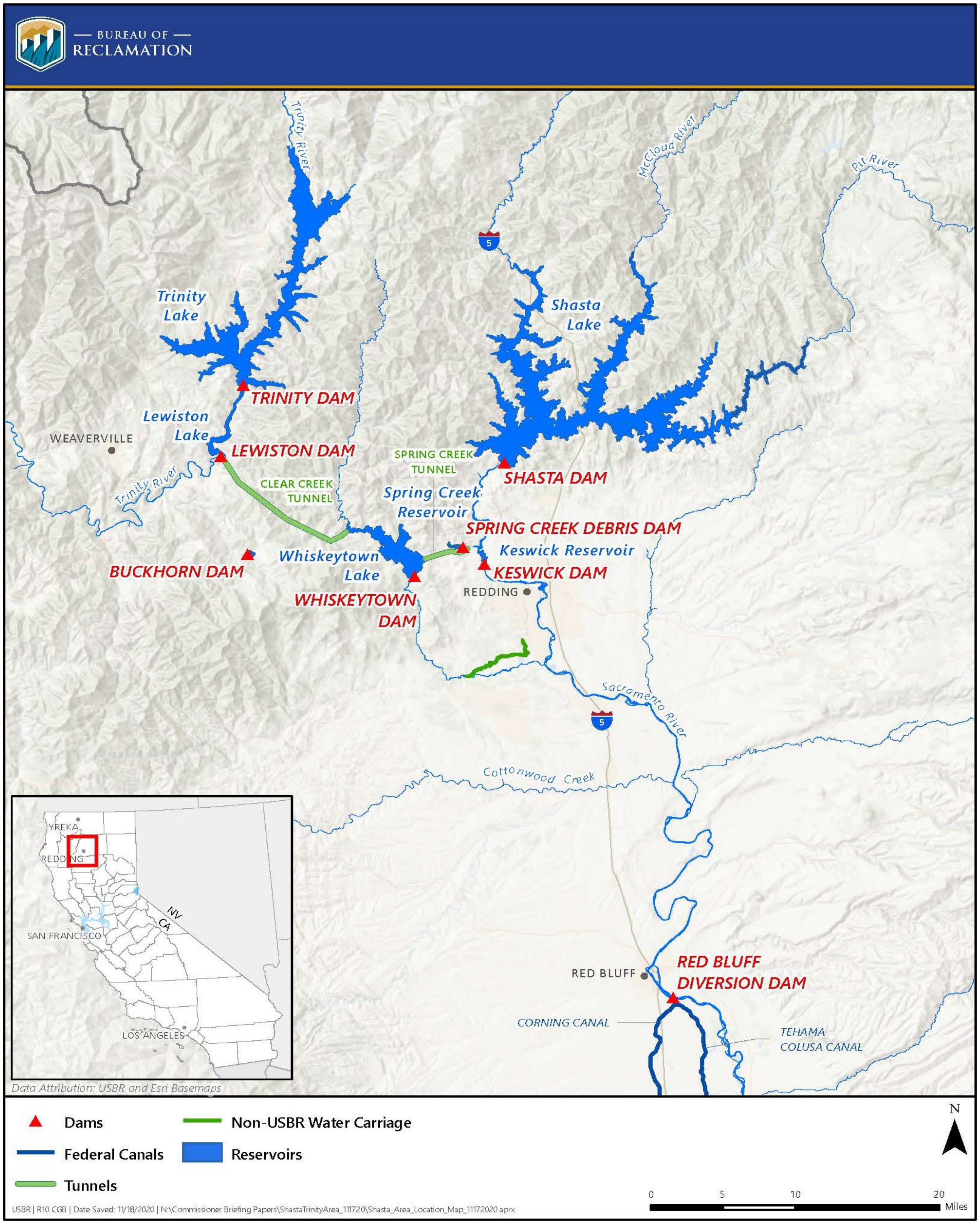


Figure 1. Shasta-Trinity System located in Northern California.

Reclamation consulted under the Endangered Species Act (ESA) with the USFWS and NMFS on potential effects of the Proposed Action on threatened and endangered species. Reclamation submitted to these agencies a Biological Assessment on January 31, 2019. Reclamation provided the final Biological Assessment on October 21, 2019, which included the final Proposed Action description. In turn, the USFWS and NMFS issued their Biological Opinions of the Proposed Action on October 21, 2019. Reclamation signed the ROD, which included the 2019 Biological Opinions from USFWS and NMFS, and began implementing the Proposed Action on February 18, 2020.

The ROD established a tiered cold water management strategy for the summer and fall seasons, based on the projected availability of cold water pool in Shasta Lake. The approach considers meteorology, Delta conditions, and habitat suitability for incoming fish population size and location to determine a pattern of water temperature targets for winter-run Chinook salmon redds. The tiered strategy recognizes that cold water is a scarce resource that can be managed to achieve targeted water temperatures for winter-run Chinook salmon egg-to-fry survival. The Shasta Cold Water Pool Management Guidance Document (Appendix A) provides implementation guidance on the Sacramento River's Cold Water Pool Management pursuant to the ROD. The primary deliverables are Sacramento River Temperature Task Group (SRTTG) notes, a monthly summary of the hydrologic, operational, and water temperature data related to cold water pool management; the Sacramento River Temperature Management Plan (TMP), and documentation of the operations decisions.

Reclamation must also comply with State Water Board Water Rights Order 90-5. State Water Board Water Rights Order 90-5 established a requirement for Reclamation to operate Keswick Dam, Shasta Dam, Spring Creek Power Plant, and the Trinity River Division to meet a daily average water temperature of 56°F on the Sacramento River at Red Bluff Diversion Dam (RBDD) during periods when higher water temperatures will be detrimental to fish. When factors beyond the reasonable control of Reclamation prevent Reclamation from maintaining 56° F at RBDD, Reclamation will consult with CDFW, USFWS, NMFS, and WAPA and submit an operation plan to the State Water Board showing a strategy to meet the temperature requirement at a new location upstream. Water Rights Order 90-5 is found on the State Water Board's website.

# Seasonal Operations

WY 2021 was a critically dry year with below average precipitation in several months, particularly in late winter and early spring. The Northern Sierra Precipitation 8-Station Index indicated that, as of the end of the water year, WY 2021's hydrologic conditions were the driest since 1977. Shasta Lake's cold water pool used to protect winter-run Chinook salmon was the smallest since 1977.

A Tier 3 year would be able to maintain 56°F at the Sacramento River above Clear Creek gage (CCR). In February, it appeared that 56°F at CCR would not be able to be achieved throughout the season based on projected May 1 total Shasta Lake storage and projected cold water pool conditions and a Tier 4 was likely. As such, discussions were initiated on intervention measures including increased hatchery production, a warm water power bypass, and Sacramento River Settlement Contract water transfers. A Shasta Critical Year determination was also made in February. Conditions worsened at the end of April 2021 when expected reservoir inflow from snowmelt had failed to materialize. The May 90% exceedance forecast for the Sacramento Valley Four River Index identified a reduction of expected runoff of 685 TAF from those generated a month earlier.

Development of the TMP involves Temperature Tier selection, which can be based on total Shasta Lake storage volume, Shasta Lake cold water pool volume, or water temperature modeling results. In WY 2021, storage volume and cold water pool volume determined the tier selection. Temperature Tier 4 was selected for the TMP and Reclamation began managing for 57°F at the gage on the Sacramento River upstream of Hwy 44 (SAC) on May 17, 2021. The SAC gage is approximately five river miles downstream of Keswick Dam and about half the distance of the CCR compliance point used in WY 2020. Compliance locations in the past have been at, or downstream of, CCR, including: Airport Road (AND), Balls Ferry (BSF), Jelly's Ferry (JLF) or Bend Bridge (BND) (**Table 2**). The final TMP was transmitted to the State Water Board on May 28, 2021. The water temperature management season ended on October 31, 2021. The daily average water temperature for the SAC and CCR compliance locations compared against the corresponding daily target are shown in **Figure 12**.

A combination of factors challenged temperature management in WY 2021. The Sacramento Valley experienced parched soils, extremely low rainfall, and continued dry and warm conditions. The May 2021 inflow was far less than predicted with available forecasting methods; runoff efficiency was approximately 20 percent of the average. Additionally, the CVP and SWP experienced novel reservoir-balancing circumstances in WY 2021 at Shasta Lake, Oroville Reservoir, and Folsom Reservoir.

## Operational Background Information

Cold water management at Shasta Lake uses a tiered strategy that allows for strategically selected water temperature objectives, based on projected total storage and cold water pool, meteorology, Delta conditions, and habitat suitability for incoming fish population size and location. The following tiers describe the capabilities for water temperatures depending on the cold water pool in the reservoir profile in a given year:

- Tier 1 – Sufficient volume of cold water to target 53.5°F or lower at CCR starting May 15 through October 31;
- Tier 2 – Sufficient volume of cold water to target 53.5°F at CCR during critical egg incubation period;
- Tier 3 – A volume of cold water that can target 53.5-56°F at CCR during critical egg incubation period and consideration of intervention measures;
- Tier 4 – Insufficient storage to maintain 56°F or lower at CCR and consideration of intervention measures.

A conservative forecast is used in seasonal planning of reservoir releases (including developing initial and updated allocations) and temperature management planning, such that monthly release forecasts and associated allocations are typically based on a 90% exceedance inflow forecast through September. A TMP describes the intended operation of Shasta Lake and the Temperature Control Device (TCD) on Shasta Dam. The TMP included modeling and professional expertise to identify the most protective tier that can be achieved given the available cold water volume. Before the reservoir stratifies and the volume of cold water is known, temperature capabilities can be approximated based on projections of storage.

Starting in October 2020, Reclamation convened monthly SRTTG meetings (except in January 2021) to ensure communication and coordination among the parties in preparation for the temperature management season. SRTTG meeting notes can be found on the Sacramento River Temperature Task Group website. Reclamation prepared projections of anticipated temperature management capabilities on a monthly timestep for the SRTTG. In mid-February, Reclamation prepared initial projections of anticipated temperature management capability and considerations based on the February hydrologic and runoff forecasts from the California Department of Water Resources (DWR) and National Weather Service River Forecast Center. Reclamation's February projections estimated that in Shasta Lake the volume of water below 52°F at the end of April was less than 2.5 million acre-feet (MAF), and that a Tier 4 year was the likely tier selection. Reclamation initiated interagency coordination through the Drought and Dry Year activities and stakeholder coordination through the Meet and Confer activities described in the 2020 ROD. The following actions took place prior to the beginning of the temperature management season and are discussed in further detail below: discussion of increased hatchery production at Livingston Stone National Fish Hatchery (NFH); preparing chillers for the hatchery in the event water temperatures become too warm; Shasta Critical Year determination in February which results in a determination of 75% contract total under the Sacramento River Settlement Contract; water transfers and reduced diversions; and a Shasta Lake warm water power bypass.

Reclamation developed a draft TMP and submitted it to the SRTTG on May 5, 2021 for initial review, comment, and discussion. The draft TMP balanced the most protective possible temperature tier with what was achievable and sustainable with the volume of available cold water pool for the duration of the temperature control period through October 31, 2021. SRTTG members were provided the opportunity to comment on the draft TMP. On May 28, 2021, Reclamation developed a final TMP (Appendix B) with substantial coordination and input from the SRTTG. The TMP included temperature locations and targets through October 31, modeled winter-run Chinook salmon egg mortality, dates for operation of the side gates on the TCD, and the end of September storage in Shasta Lake. Further discussion of the final TMP is provided below in the Summer/Fall Water Temperature Management section. Conditions of the cold water pool from 2011 – 2021 are recorded in **Table 1**. Sacramento River temperature compliance point data from 2011 - 2021 are shown in **Table 2**.

**Table 1**. Shasta Lake Storage Volumes and Cold Water Pool Volumes in Thousands of Acre Feet (TAF) from 2011 - 2021.

| Water Year | Peak Storage Volume | Peak Storage Date | End of April Volume < 56°F | Side Gate Opened | End of September Storage Volume | End of September Storage Volume < 56°F | End of September Storage Volume < 52°F | End of September Storage Volume < 50°F |
|---|---|---|---|---|---|---|---|---|
| 2011 | 4492 | 06/02 | 3809 | N/A | 3341 | 1340 | 903 | 707 |
| 2012 | 4483 | 05/07 | 3791 | 09/21 | 2592 | 765 | 598 | 512 |
| 2013 | 3887 | 04/18 | 2809 | 09/11 | 1906 | 425 | 347 | 309 |
| 2014 | 2409 | 04/28 | 1770 | 08/07 | 1157 | 107 | 81 | 63 |
| 2015 | 2722 | 04/15 | 1912 | 09/13 | 1603 | 358 | 270 | 228 |
| 2016 | 4235 | 05/01 | 3267 | 10/23 | 2811 | 938 | 730 | 596 |
| 2017 | 4389 | 05/13 | 3975 | N/A | 3382 | 1146 | 806 | 594 |
| 2018 | 4200 | 04/26 | 3135 | 09/19 | 2405 | 607 | 485 | 388 |
| 2019 | 4477 | 05/31 | 3441 | N/A | 3425 | 1203 | 907 | 707 |
| 2020 | 3750 | 04/21 | 2986 | 08/13 | 2200 | 476 | 344 | 230 |
| 2021 | 2396 | 04/03 | 1587 | 08/06 | 1077 | 111 | 81 | 63 |

**Table 2**. Sacramento River Historic Temperature Control Points 2011-2021. Daily Average Temperature - Degrees Fahrenheit (Days Applied).

| Year | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov |
|---|---|---|---|---|---|---|---|---|---|
| 2011 | BSF-56° | BSF-56° | BSF-56° | JLF-56° | JLF-56° | JLF-56° | JLF-56° | JLF-56° | JLF-56° |
| 2012 | JLF-56° | JLF-56° (01-15) BSF-56° (16-30) | BSF-56° | JLF-56° | JLF-56° | JLF-56° | JLF-56° | BSF-56° | BSF-56° |
| 2013 | BSF-56° | BSF-56° | BSF-56° (01-16) [1]BSF-**56.75°** (17-31) | [1]BSF-**56.75°** | [1]BSF-**56.75°** | [1]BSF-**56.75°** | [1]BSF-**56.75°** | [1]BSF-**56.75°** | [1]BSF-**56.75°** |
| 2014 | BSF-56° (01-27) CCR-**58°** (28-31) | CCR-**58°** (01-24) CCR-56° (25-30) | CCR-56° | CCR-56° | CCR-56° | CCR-56° | CCR-56° | CCR-56° | CCR-56° |
| 2015[2] | CCR-56° | CCR-56° (01-17) CCR-**58°** (18-30) | CCR-**58°** (01-14) CCR-56° (15-31) | CCR-56° (01-04) CCR-**58°** (05-30) | CCR-**58°** | CCR-**58°** | CCR-**58°** | CCR-**58°** | CCR-**58°** |
| 2016 | CCR-**58°** | CCR-**58°** | CCR-**58°** | CCR-**58°** (01-16) BSF-56° (17-30) | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° |
| 2017[3] | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° |
| 2018[4] | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° |
| 2019[5] | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° | BSF-56° |
| 2020[6] | BSF-56° | BSF-56° | BSF-56° CCR - 54.5° (15-30) CCR - 53.5° (31) | BSF-56° CCR - 53.5° (1-29) CCR - 54° (30) | BSF-56° *CCR - 54°* | BSF-56° *CCR - 54°* | BSF-56° (01-20) CCR-56° (21-30) | CCR-56° | CCR-56° |
| 2021 | CCR-56° | CCR-56° (1-18) CCR-60° (18-30) | CCR-60° (1-17) SAC-57° (17-31) | SAC-57° (1-15) SAC-55° (15-30) | SAC-55° | SAC-55° | SAC-55° | SAC-55° | SAC-55° |

1 BSF-56.75°F used as surrogate for Airport Road 56°F
2 Year 2015 July – November the temperature target was 57°F, not to exceed 58°F
3 Year 2017 pilot evaluation study also targeted CCR at 53°F May 15 – Oct 31
4 Year 2018 pilot evaluation study also targeted CCR at 53.5°F May 15 – Oct 31
5 Year 2109 pilot evaluation study also targeted CCR at 53.5°F May 15 – Oct 31 and Airport Road at 53.5°F Aug 7 – Oct 31
6 Year 2020 Temperature Management plan specified a target of 56°F at locations BSF and CCR per State Water Board WR90-5 requirements, targets at CCR are also listed as specified in the Temperature Management Plan
BSF = Balls Ferry, JLF = Jelly's Ferry, CCR = Sacramento River upstream of Clear Creek confluence,

SAC = Sacramento River upstream of Hwy 44

## Historical Overview

Dry and warm conditions near Shasta Lake were prevalent in 2021 compared to historic conditions. Historic Shasta Lake storage volume (from WY 1995 through the beginning of WY 2022) is shown in **Figure 2**. In WY 2021, end of May Shasta Lake storage volume was far below the historic average (1995 – 2021 average: 3.85 MAF; 2021 value: 1.98 MAF). Historic average air temperatures in Shasta County for the summer (June through August for a period of record 1895 - 2021) is shown in **Figure 3**. According to the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information, Shasta County, air temperatures in the summer of 2021 on record. The average air temperature for June through August 2021 was 76°F while the average for June through August 1895-2021 was 70.3°F (NOAA 2021). Widespread wildfire activity throughout the summer months intermittently impacted local meteorological conditions including solar radiation and thermal influences. Smoke and haze may have dampened the effects of unusually warm air temperature conditions on reservoir heating and downstream in-river warming.

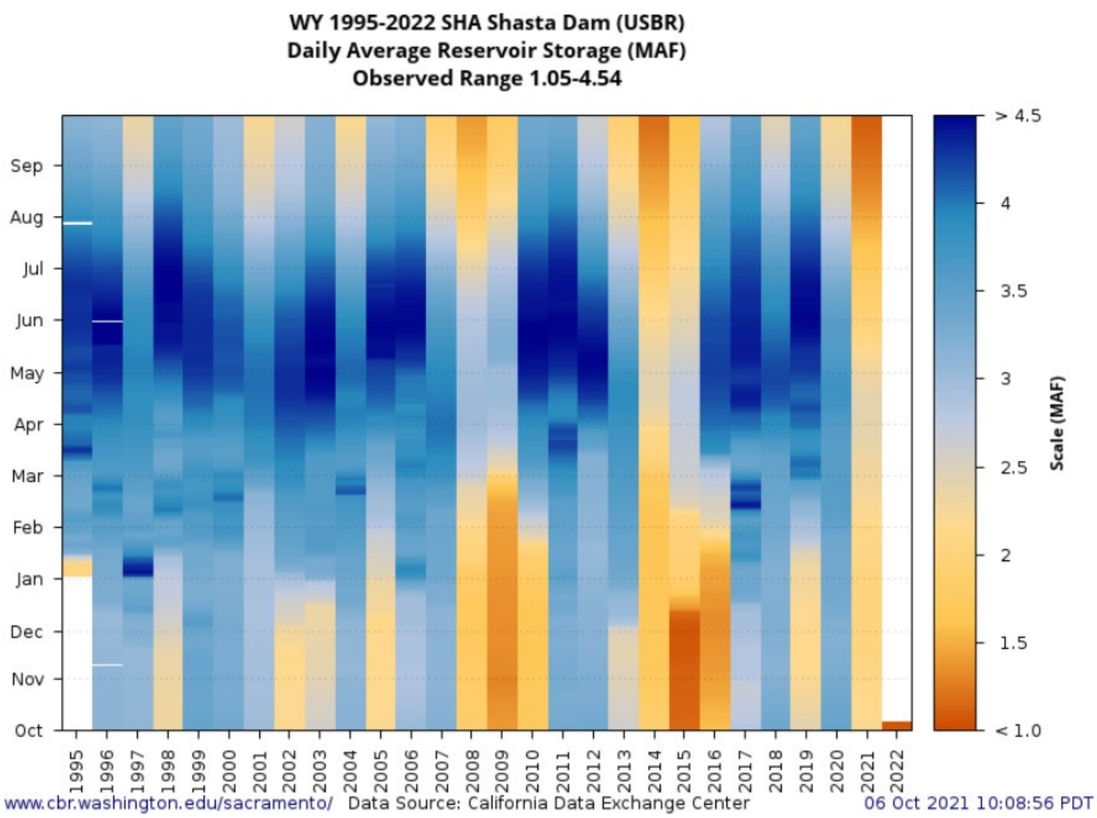


**Figure 2**. Daily average Shasta Lake storage from WY 1995 through the beginning of WY 2022. Source: SacPAS: Central Valley Prediction & Assessment of Salmon.

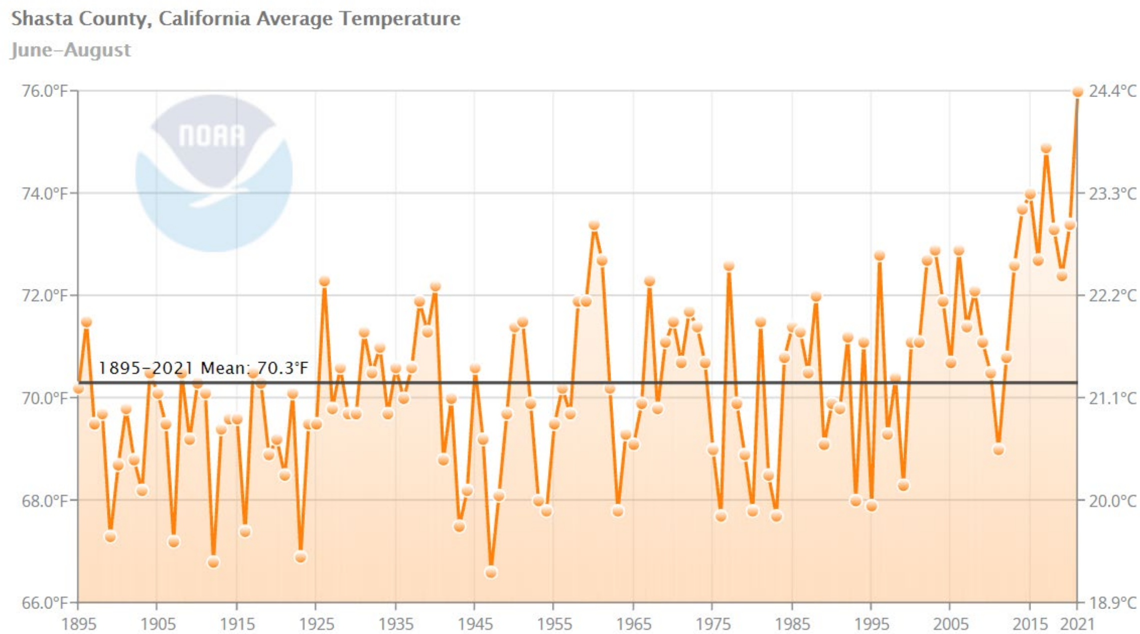


**Figure 3**. Average temperature for June through August for a period of record 1895-2021. Source: National Centers for Environmental Information County Time Series: Shasta County, California Average Temperature.

## General Water Year Conditions and Operations

Operational decisions on the upper Sacramento River are influenced by local, CVP and SWP system-wide multi-purpose objectives, and uncertainty. Factors that contribute to operational actions include forecasted inflows, facility maintenance schedules, physical/mechanical facility limitations, upstream operations, minimum in-stream flow criteria, downstream Delta regulatory requirements, power generation, recreation, fish hatchery accommodations, water temperature management capabilities, and others. In addition, uncertain or unplanned events can also influence real-time operation decisions (e.g., wildfire events, or reservoir release reductions for USACE downstream flood protection). Planned operational targets are regularly updated late winter through early summer depending on hydrologic conditions on Reclamation's website (Bureau of Reclamation Central Valley Operations Office website).

Watershed runoff in the upper Sacramento River basin is typically dominated by cold winter precipitation that refills and replenishes both Shasta Lake's total storage and the cold water pool. The Sacramento River watershed basin runoff forecasted inflow volume and Shasta Lake cold water pool quality (i.e., water temperature) is fundamental to operational planning. The inflow volume projection is updated routinely by DWR and the National Weather Service-California Nevada River Forecast Center (CNRFC), where uncertainty is represented by percent runoff exceedances. While Reclamation utilizes the projections from DWR in its forecasting, **Figure 4** from CNRFC illustrates the wide variability of the runoff exceedances (i.e., 10%, 50%, and 90%) in the winter months and their convergence through time; by May the variability between the 10%, 50% and 90% exceedance forecasts has greatly decreased. The forecasts consider meteorological uncertainty and do not account for hydrologic uncertainties. Beginning in February 2021, the runoff forecasts significantly declined through the spring due to lack of precipitation. By May, water supply forecasts for Shasta Lake inflow runoff ranged between

41% and 43% of the average for the 90% and 50% runoff exceedances, respectively. The actual Shasta Lake inflow volume April through July was 704 TAF and the total WY 2021 Shasta Lake inflow volume was 2,457 TAF (Reclamation 2021).

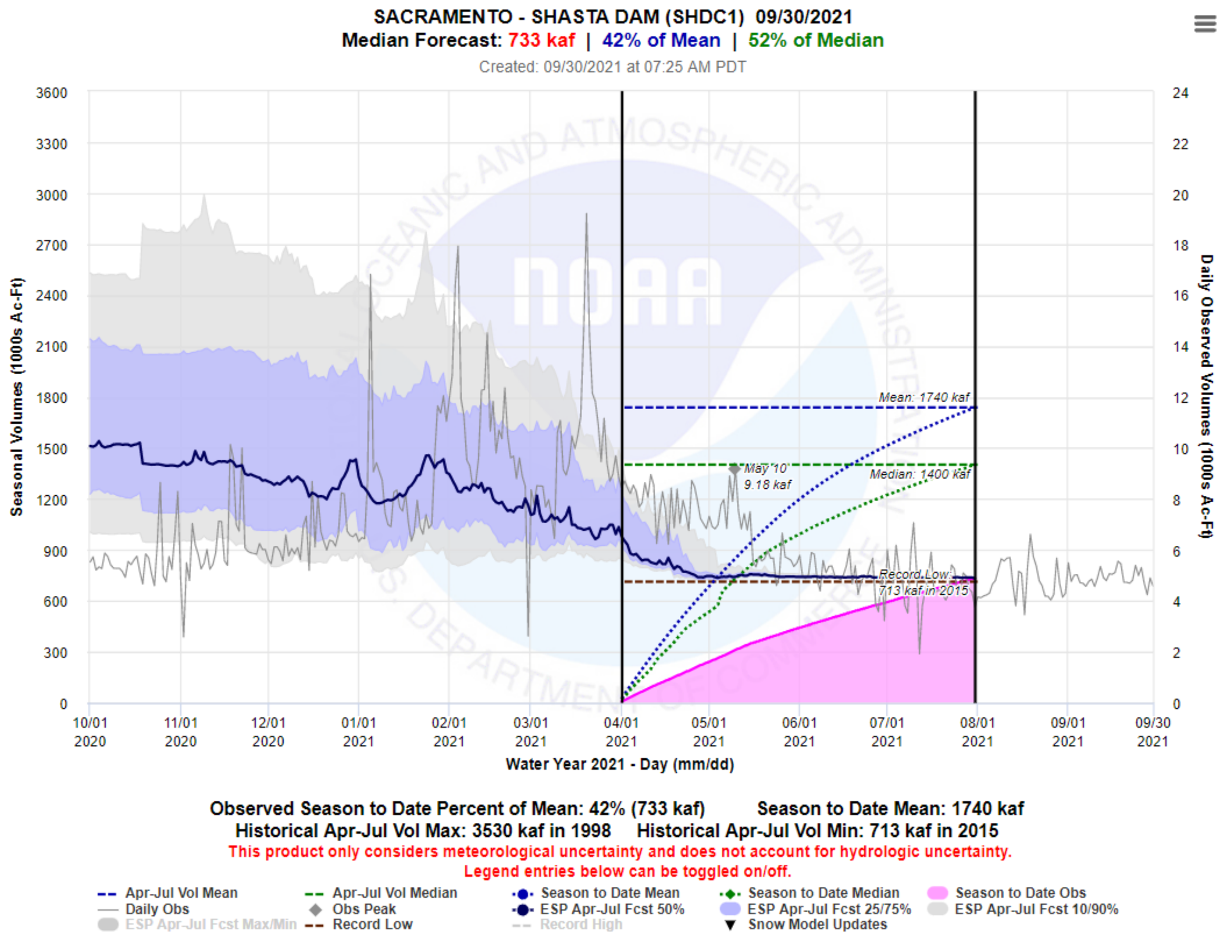


**Figure 4.** WY 2021 forecasted (10%, 50%, 90% exceedance) and actual daily and cumulative inflow volume at Shasta Lake. Source: California Nevada River Forecast Center.

Insight to the hydrologic characteristics of WY 2021 are provided in **Table 3.** Because operational planning is significantly influenced by forecasts, these uncertainties and modified decisions are translated into the performance and efficiency of the system-wide operation.

**Table 3.** WY 2021 Northern Sierra precipitation, Sacramento Basin snowpack, and Sacramento Valley Index statistics by month.

| Water Year 2021 Month[1] | Northern Sierra 8-Station Precipitation (Cumulative water year in inches through month) | Northern Sierra 8-Station percentage of historic monthly average precipitation (for month) | Sacramento River Basin Snowpack (percent of April 1st average) | Sacramento Valley Index (40-30-30 Index 50 percent Exceedance) |
|---|---|---|---|---|
| **November** | 3.5 | 53 | N/A[2] | N/A |
| **December** | 7.1 | 39 | N/A | 5.9 |
| **January** | 14.1 | 78 | 31 | 5.3 |
| **February** | 18.0 | 47 | 45 | 5.0 |
| **March** | 22.1 | 53 | 70 | 4.6 |
| **April** | 22.9 | 21 | 75 | 4.4 |
| **May** | 23.1 | 9 | 20 | 4.0 |

[1] Monthly totals may not add up to seasonal total because of rounding.
[2] N/A = Not Available.

WY 2021 yielded below average rainfall and snow during the late winter and spring months. In general, storage conditions in reservoirs were low in the fall of 2020 as a result of dry hydrologic conditions the previous year. After well below average rainfall, the snowpack in March 2021 indicated that sufficient reservoir inflow was not likely available to meet Tier 1, Tier 2, or Tier 3 temperature targets. Conditions worsened at the end of April 2021 when expected reservoir inflow from snowmelt had failed to materialize. The May 90% exceedance forecast for the water year Sacramento Valley Four River Index identified a reduction of expected runoff of 685 TAF from those generated in April. Approximately one-third of the reduction in expected runoff was attributed to Shasta Lake (230 TAF). The Sacramento Eight Station Index for WY 2021 reported 24.0 inches of precipitation for the region for the water year. Water supply indices reported the Sacramento River Unimpaired Runoff was a “Critical” year for the Sacramento Valley Index (DWR 2021).

## Storage and Flood Conservation Space

Shasta Lake storage conditions and Keswick Dam releases for WY 2021 are shown in **Figure 5** and **Figure 6**. In WY 2021, Shasta Lake storage conditions were below the U.S. Army Corps of Engineers flood control curve and Keswick Dam releases were not increased to make flood space for flood control purposes. Due to dry hydrology following a dry winter, Shasta Lake storage conditions did not refill and end of April storage was 2.29 MAF. Compared to other critically dry water years (2000 – 2021), WY 2021 had higher storage volumes until approximately January (**Figure 7**). Compared to other critically dry water years (2000 - 2021), Keswick Dam releases for downstream requirements were similar to the average until March. In April and May, releases increased due to Delta needs and river demands and were greater than the average, likely due to the dry conditions (**Figure 8**). WY 2021 cold water pool observations suggested below average development compared to all years at 52°F, and tracked most closely to 2014 (**Figure 9**).

The TCD on Shasta Dam draws water from different elevations in the lake, allowing Reclamation to use warmer surface water earlier in the season and preserve cold water for the temperature management season later in the year, while maintaining hydropower generation. The dry conditions and low reservoir storage in WY 2021 prevented pulling water into the TCD from the upper gates and therefore only the middle gates were available to use in the spring. Using these lower-elevation middle gates in the first half of April pulled some of the limited cold water earlier, leaving less cold water for the summer and fall releases. During this period, reduced releases from Shasta Lake (if possible given other constraints in the system) could have helped preserve both reservoir storage and cold water pool; however, reduced releases would not have met downstream requirements and could have increased demands on other reservoirs.

Reclamation and the fisheries agencies agreed to implement a warm water power bypass at Shasta Dam. On April 12, 2021, Reclamation requested technical expertise from fisheries agencies on early season temperature impacts to adult winter-run Chinook salmon. Fisheries biologists conducted a literature review and convened to discuss the best available information related to temperature impacts on adult Chinook salmon and their gametes. Comments were received from the fisheries agencies and recommendations were transmitted to Reclamation on April 23, 2021. The fisheries agencies recommended water temperatures 57-60°F at CCR to protect adult Chinook salmon gamete viability; 57°F was preferred but Shasta Lake storage was so low in WY 2021 that ultimately 60°F at CCR was recommended during the warm water bypass. EPA (2003) recommends 61°F 7-day average of the daily maximums (7DADM), citing McCullough et al. (2001), which states "Hatchery managers have long known that highest survival of chinook adults occurs when water temperatures do not exceed 57.2°F (14°C) (Leitritz and Lewis 1976, Piper et al. 1982)."

Beginning April 18, 2021 Reclamation began partially bypassing power generation at Shasta Dam to draw water through river outlets higher on the face of the dam rather than at the elevation of the middle gates of the TCD. This action ended on May 25, 2021 when lake elevation levels and temperature profiles indicated no further benefit to temperature management, given the risk of pre-spawn mortality and reduced gamete viability for winter-run Chinook salmon. This action preserved approximately 300 TAF of cold water for later in the year. The power bypass action resulted in a reduction in power value by approximately $5 million.

Reservoir releases leading up to and during the bypass were high relative to recent and comparable critically dry years (2014 and 2015) and while the negative ramifications of warmer spring conditions is not quantified, improved summer and fall temperatures can be estimated. The effects of the warm springtime water temperatures on winter-run Chinook salmon adults and eggs will require further study.

In the spring of 2021, in response to the critically dry conditions in California's Central Valley, the Sacramento River Settlement Contractors proposed to enter into forbearance agreements to make available a portion of their Base Supply to purchasers in other areas of the CVP. This action would reduce the releases from Shasta Lake in the summer to satisfy Sacramento River Settlement Contract diversions and would instead provide for releases for delivery in the late summer and early fall of 2021. Reclamation coordinated with the fisheries agencies and determined that the additional spring and summer reservoir storage (estimated at approximately 175 TAF) would support colder water temperatures downstream for winter-run Chinook salmon egg incubation. These transfers require approval from Reclamation which included verifying the water made available, agreeing to temporarily store this water in Shasta Lake, and then increasing releases from Shasta Dam for delivery later in the summer and early fall. As the season progressed and system conditions became drier, the estimated water transfer quantity increased to approximately 200 TAF. As such, Keswick Dam releases in the fall were held higher for longer. This resulted in greater than anticipated impacts on fall-run Chinook salmon than were initially considered in the spring. Additional analyses are being developed for the subsequent Shasta Lake Storage Rebuilding and Spring Pulse Seasonal Report (anticipated June 2022).

Preliminary modeling showed the warm water power bypass and water transfer actions would extend the window of lower water temperatures by an additional approximately two to four weeks and lower temperature dependent mortality (TDM) of winter-run Chinook salmon eggs by approximately 5-10% depending on the final TMP. Winter-run Chinook salmon early lifestage TDM results for the baseline scenario (i.e., without power bypass) ranged from 78-86% while the TDM results for the warm water power bypass scenario ranged from 67-71%. For more information on temperature and TDM modeling assumptions, please refer to Appendix C.

These factors influenced the TMP and conservative decision making for the season. The key events and decisions related to Storage and Flood Conservation Space, Fall and Winter Refill, and Spring Pulses are further described in the Water Year 2021 Shasta Storage Rebuilding and Spring Pulse Seasonal Report.

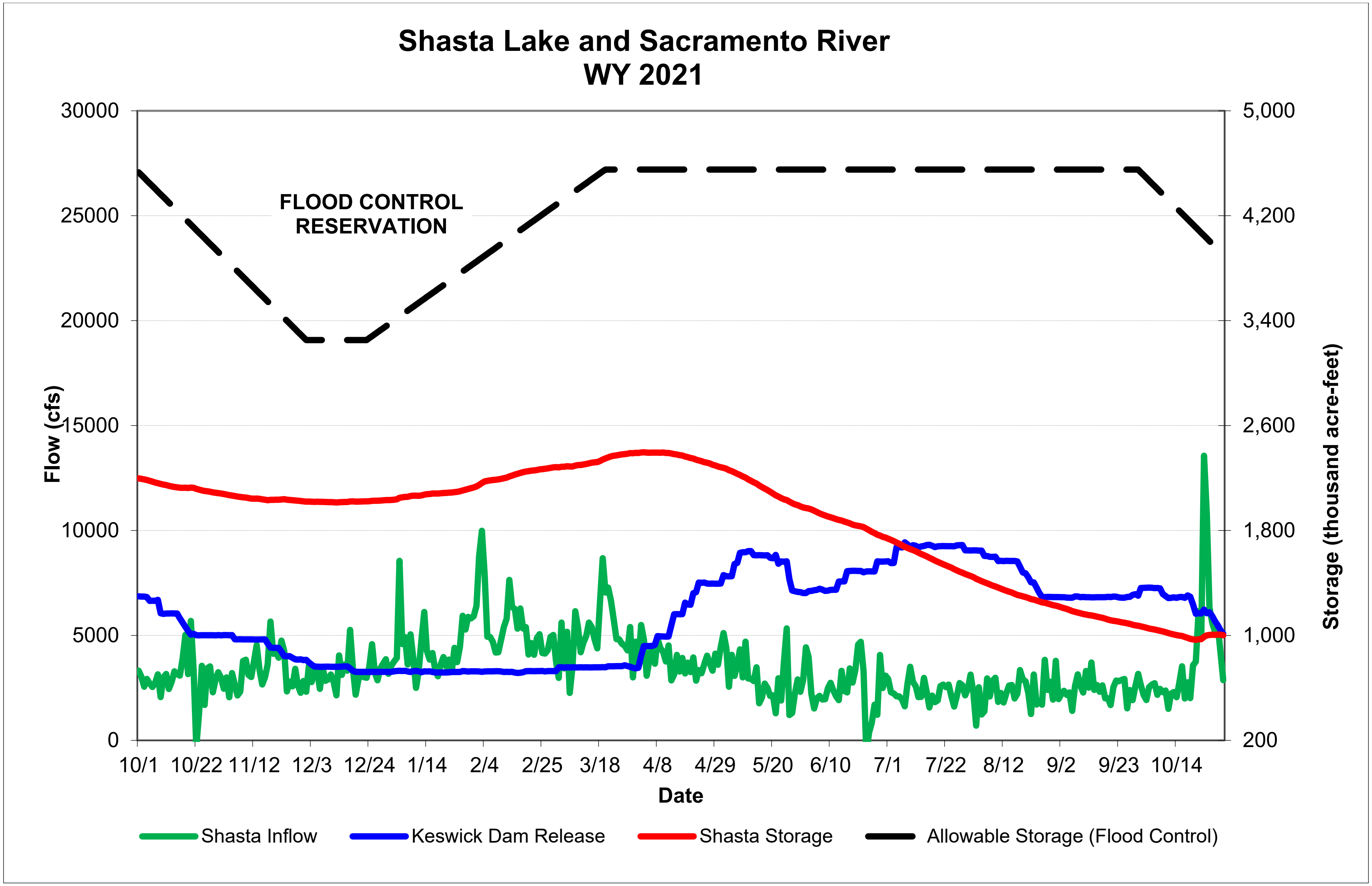


**Figure 5.** Shasta Lake Storage (red line), Allowable Storage for Flood Control (black line), Keswick Dam Release (blue line), and Shasta Inflow (green line) for 10/1/2021 - 10/31/2021.

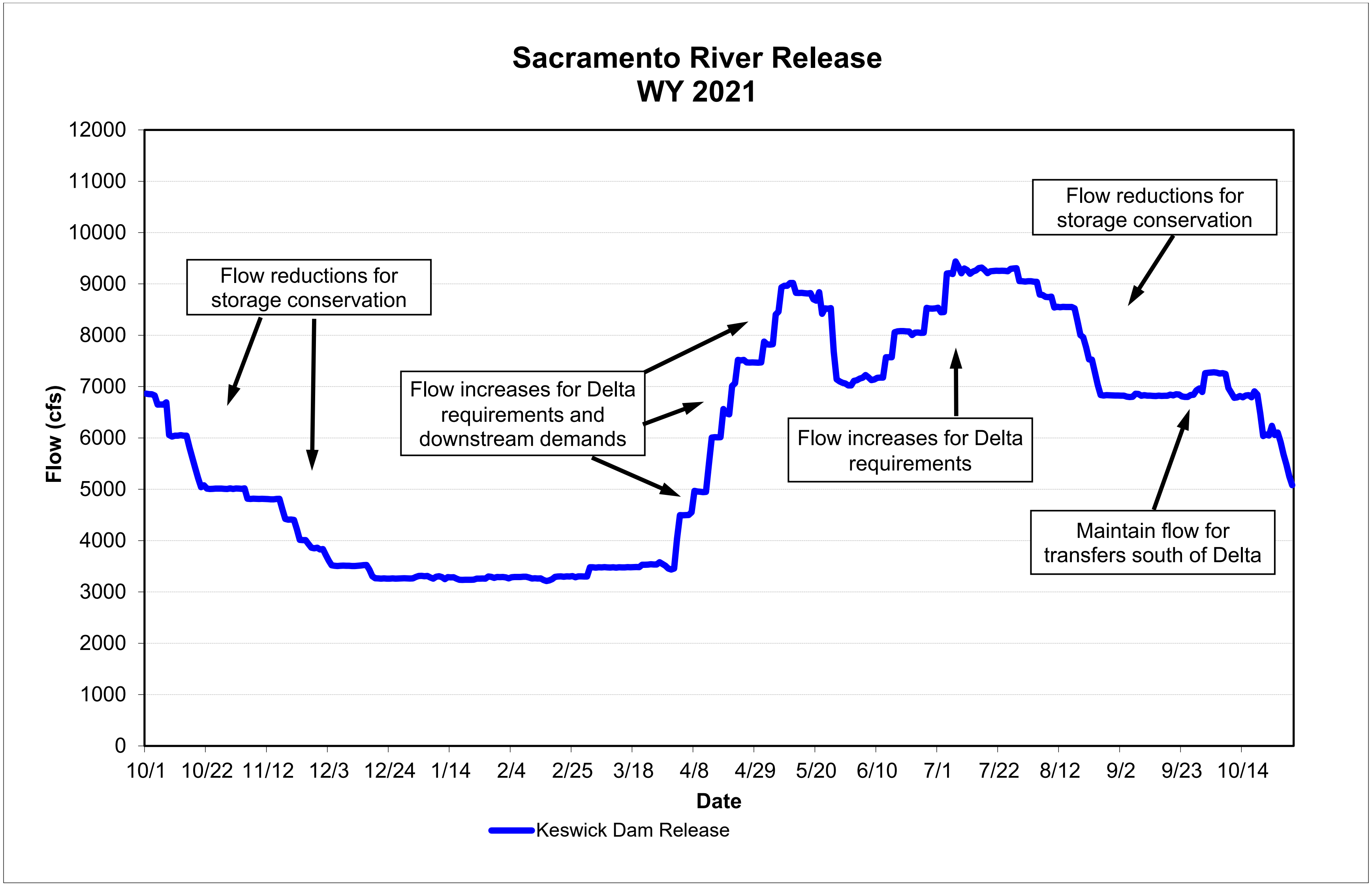


**Figure 6.** Sacramento River releases from 10/1/2020 - 10/31/2021 with major events highlighted.

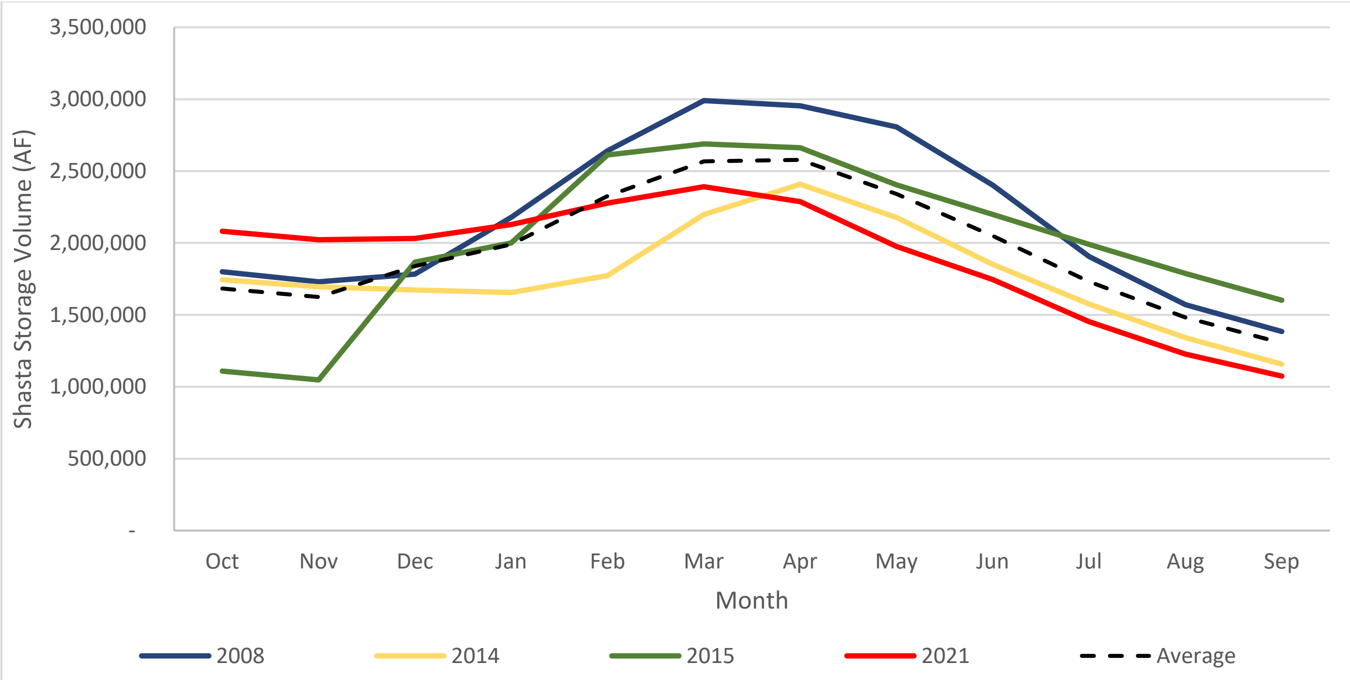


**Figure 7.** Shasta Lake storage in WY 2021 and in Critically Dry Water Years 2008, 2014, and 2015.

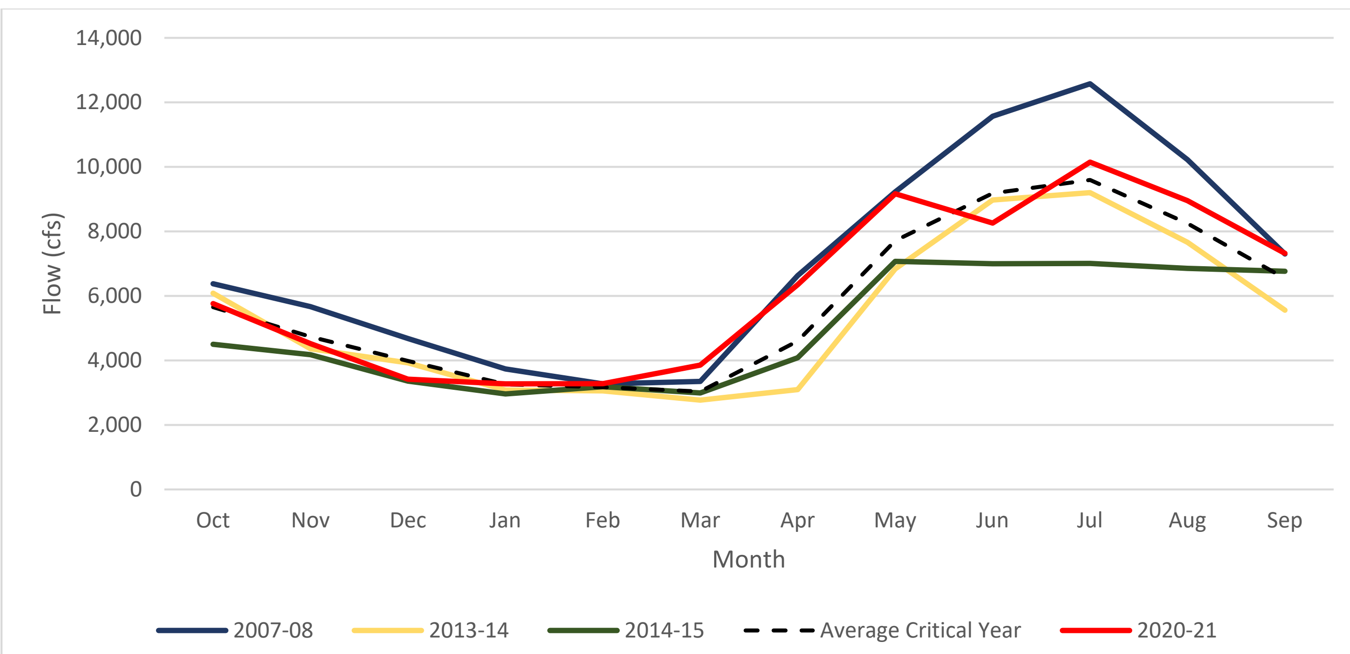


**Figure 8.** Monthly average Keswick Dam releases in WY 2021 and in Critically Dry Water Years 2008, 2014, and 2015.

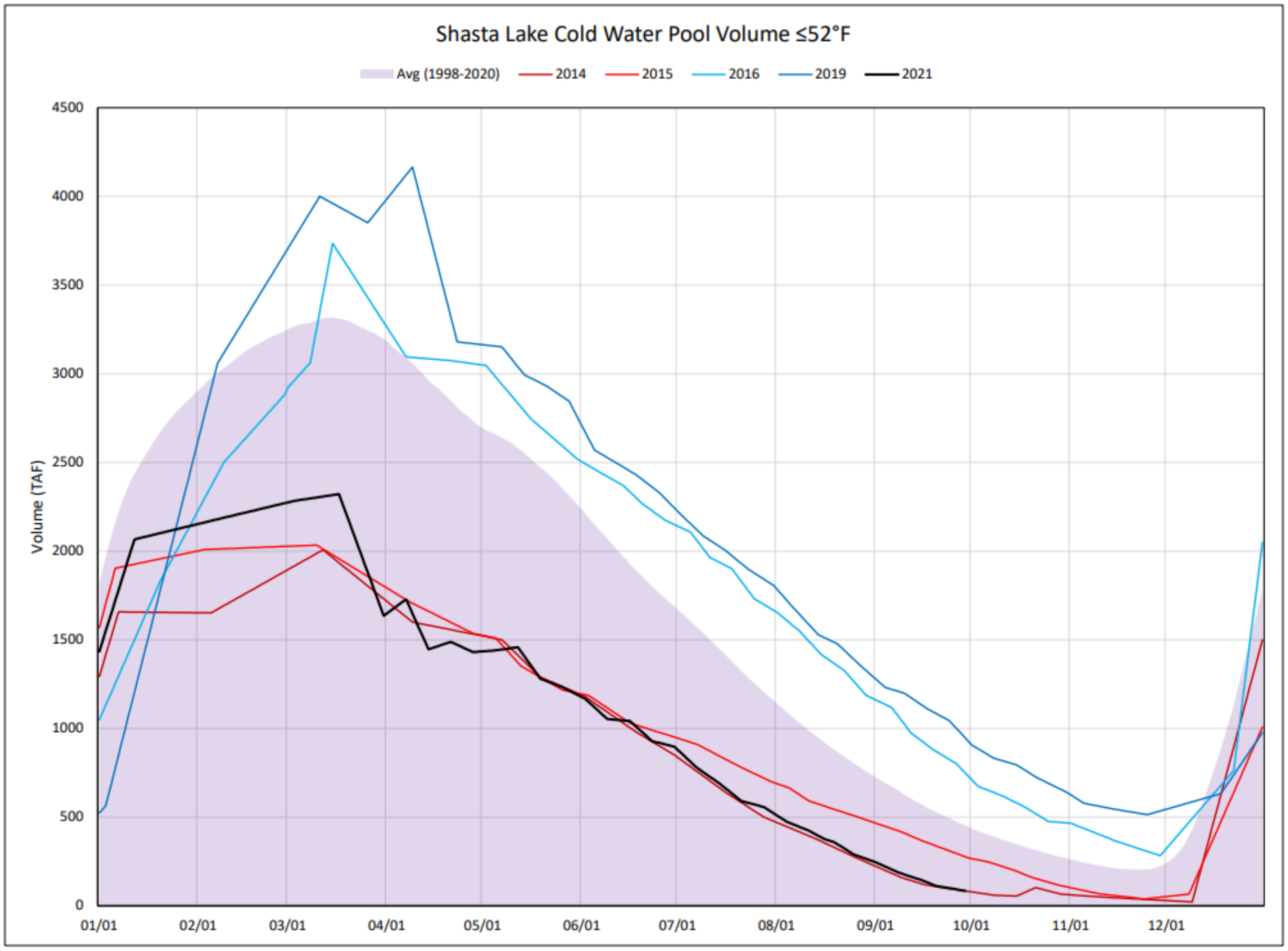


**Figure 9.** Shasta Lake cold water pool volume less than 52°F for WY 2021.

## Summer/Fall Water Temperature Management

The following section describes conditions and actions taken to manage the risk associated with summer and fall water temperature management. To address uncertainty and limited resource availability, conservative estimates of future conditions are used in the modeling assumptions (e.g., hydrology, operations, and meteorology) and projections are updated regularly through the management period. A tiered strategy is applied in limited cold water pool years to strategically apply temperature objectives. Risk management aims to achieve the goal of minimizing undesirable temperature effects for the entire season.

### February

Storage conditions and trending hydrology in the late winter months can offer some insight on the trajectory of the cold water pool management, but should be interpreted cautiously due to variable hydrology during this time. The most productive months for storms, runoff and inflow to Shasta Lake are in the late winter and spring. Keswick Dam releases are traditionally at their lowest point of the year in this period, supporting minimum flows and Delta requirements. Although counterintuitive, drier hydrologic years can require higher than normal releases from storage to support downstream Delta requirements in the late winter and early spring, prior to increased releases for agricultural diversion beginning in mid-April. Additional releases can undermine goals to increase storage, however, hydrology is generally the most significant parameter that drives reservoir refill and cold water pool replenishment in the late fall through spring period.

In February 2021, Shasta Lake inflow was very low due to unusually dry conditions and forecasts suggested continued dry hydrological trends. February storage was roughly similar to the average critically dry year and Keswick Dam releases remained low (around approximately 3,250 cfs) through February. Releases from Keswick Dam were used to maintain flows to protect fall-run Chinook salmon redds from dewatering and to meet Delta requirements.

To examine future in-stream temperature performance in February, two forms of insight to future cold water pool management were assessed: (1) Relationship between total Shasta Lake storage/ cold water pool and potential future temperature compliance; and (2) preliminary water temperature model simulation results. Based on projected May 1 total Shasta Lake storage less being below 2.5 MAF and projected cold water pool conditions, the Tier 3 condition of achieving the 56°F temperature target at CCR would not be able to be met throughout the temperature management season and a Tier 4 year appeared likely.

In February 2021, a multi-agency team discussed increasing Livingston Stone NFH winter-run Chinook salmon production targets for WY 2021. Typically, the USFWS would collect 60 females and 100 males out of the Keswick fish trap; however, due to poor conditions and anticipated low survival of Brood Year (BY) 2021 natural winter-run Chinook salmon, they were granted approval to increase collection for production of hatchery juveniles (for more information see the Conservation Measures Section; **Table 10**). Reclamation also prepared chillers for use later in the season in the event that deliveries to the hatchery become too warm. Additionally, a Shasta Critical Year determination was made in February, which results in a 75% shortage condition under the Sacramento River Settlement Contract.

### March

March is typically a storage and cold water pool building month. However, in March 2021, Shasta Lake storage gained only approximately 66 TAF for the month, and Keswick Dam releases were increased slightly to meet Delta requirements. In March 2021, low seasonal storage was expected as significant precipitation opportunities dwindled and use of the TCD upper gates was assumed unachievable due to existing and projected Shasta Lake storage conditions.

Two forms of insight to future cold water pool management were again assessed: (1) Relationship between total Shasta Lake storage/cold water pool and potential future water temperature compliance; and (2) preliminary water temperature model simulation results. Reclamation determined there was not the volume of cold water pool in Shasta Lake to meet the Tier 3 condition of achieving the 56°F temperature target at CCR throughout the temperature management season and a Tier 4 year appeared likely. Based on guidance, plans to initiate intervention discussions were needed as the March 90% runoff exceedance forecast suggested a May 1 storage condition less than 2.5 MAF. Reclamation began considering ways to mitigate the inability to release from the TCD upper gates at this time, including a potential bypass to the upper river outlets and adjusting the timing of some Trinity diversions to help temperature management.

## April

Hydrologic conditions remained dry through April and real-time conditions tracked closer to the 90% exceedance forecast. Shasta Lake storage peaked for the season on April 3, 2021 at 2.39 MAF and Keswick Dam releases increased steadily to approximately 7,500 cfs to meet downstream demands. Based on guidance, intervention discussions were needed as the April 90% runoff exceedance forecast suggested a May 1 storage condition less than 2.5 MAF. Two early season actions were implemented: Shasta Dam warm water power bypass and Sacramento River Settlement Contractor water transfers (described previously in the Storage and Flood Conservation section).

As with previous month's evaluations, two forms of insight to future cold water pool management were again assessed: (1) Relationship between total Shasta Lake storage/cold water pool and potential future water temperature compliance; and (2) preliminary water temperature model simulation results. Modeling results (with various scenarios) suggested a Tier 4 condition. Considerable discussion covered the topics of timing of the TCD side gate use, uncertainty of the meteorology, limitations of the water temperature model predictions in the fall, and confidence in the end of September cold water pool/fall temperature performance relationship.

Technical assistance from SRTTG members was used to evaluate feasible scenarios. A key difference from previous years was the evaluation of a wider range of modeling than in past years. Specifically, a larger number of inflow scenarios, meteorology, release patterns (Shasta Lake and Trinity Reservoir), and temperature targets were examined. Additional information can be found at: Sacramento River Temperature and Order 90-5 Compliance website.

## May

May initiates the end of typical significant precipitation/runoff, and begins climatic warming and the initial inspection of actual stratified cold water pool volume in Shasta Lake (**Figure 10**). The 90% exceedance forecast for April – July inflow in the DWR Bulletin 120 from May 1, 2021 was 230 TAF less than previously forecasted on April 1, 2021 (**Figure 11**).

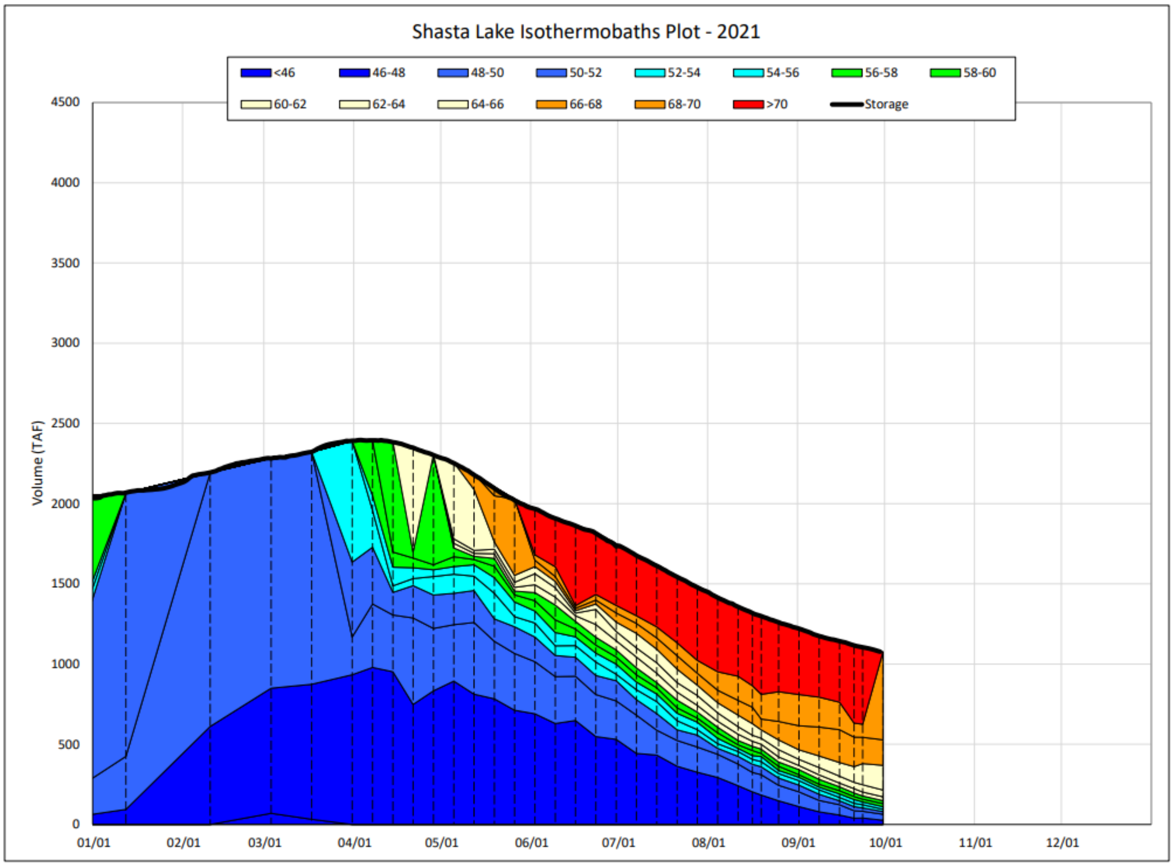


**Figure 10.** Shasta Lake Isothermobaths Plot from January through October 2021.

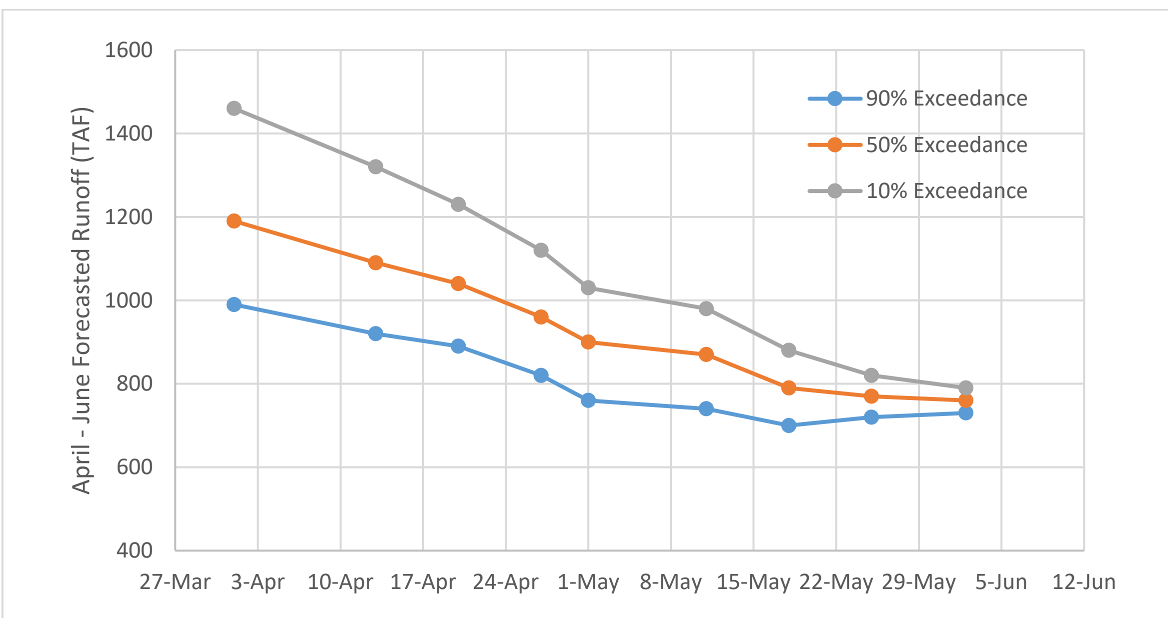


**Figure 11.** April through June Forecasted Runoff (TAF) for Shasta Lake Total Inflow in WY 2021. Source: California Department of Water Resources: California Cooperative Snow Surveys.

In early May, a draft TMP was circulated to SRTTG membership for comment. The draft TMP stated that conditions continued to indicate a Tier 4 temperature management season with a final determination to be made after May 1, to include actual Shasta Lake storage, with modeling based on measured reservoir profiles to confirm conditions. Reclamation crafted a Draft TMP to minimize modelled TDM with available cold water within the following criteria and approaches:

- Fall Certainty: Reclamation would seek to avoid use of the side gates (i.e., full side gate use) until September or later, if possible. Reclamation was able to develop a draft plan with scenarios that would rely on the side gates by August 25 or September 1, 2021.
- Life History Timing Diversity: Reclamation would develop a temperature window to target 2 standard deviations of historical spawning, starting May 15. Reclamation was able to develop a plan that starts June 15 and extends through August.
- Critical Egg Incubation Timing and Shoulder Temperatures: Reclamation was able to develop a plan that targets temperatures of 53.7°F during the critical egg incubation time period and shoulder temperatures near 57°F for holding adult winter-run Chinook salmon in the front end and incubating alevin in the back end.
- Spatial Diversity: Reclamation would seek to preserve redds down to the Hwy 44 Bridge.
- Cold water efficiency: Reclamation would operate to temperatures at SAC (Hwy 44 Bridge) and respond to actual meteorological conditions.

The draft TMP approach, Scenario 11, included an initial shaping of temperatures to best meet the above goals and that would be refined through further SRTTG input on tradeoffs. The TDM estimates for Scenario 11 ranged from 62-73%.

Reclamation began managing for 57°F at the SAC gage on May 17, 2021. A final TMP was submitted to the State Water Board on May 28, 2021. Reclamation coordinated with the SRTTG to choose Scenario 13. This plan approach, Scenario 13, included an initial shaping of temperatures to best meet the above goals and that would be refined through further SRTTG input on tradeoffs. The TDM estimates for Scenario 13 ranged from 64-78%. Scenario 13 considered end of September cold water pool and timing of the side gate operation in addition to modeled biological response in selecting an approach over the duration of the water temperature management season.

### June through October

Real-time implementation of the 2021 TMP did not result in any major unexpected changes or deviations. Keswick Dam releases during this period tracked closely to the average critically dry year releases. In the late spring runoff and Shasta Lake storage were worse than anticipated due to changing forecasts and CVP demands. Monthly simulated water temperature modeling updates were provided to the SRTTG. A summary of upper Sacramento River temperatures is shown in **Figure 12**.

In addition, there were multiple notable events that influenced in-river conditions or real-time operations including:

- Reservoir balancing considerations: Storage in Lake Oroville was extremely low in WY 2021 and storage was projected to drop below critical thresholds in the summer including minimum power pool level and dead pool level. When Lake Oroville falls below the minimum power pool level, the SWP would be unable to generate power from one of the state's major powerplants, which would strain the electrical grid during the hottest part of the summer. When Lake Oroville drops below dead pool level, releases could not be made from the reservoir. To mitigate for this issue, releases from CVP reservoirs, including New Melones Reservoir and Shasta Lake, were increased to help meet Delta requirements and resulted in Reclamation contributing greater than expected water share from the CVP. Shasta Dam releases would have been less during WY 2021 had it not been for the State of California wanting to maintain power generation capabilities from Oroville Dam. This action contributed to a portion of the balance of water owed to the CVP from the SWP, pursuant to the Coordinated Operations Agreement  During WY 2022, Reclamation will update the SRTTG on the status of CVP/SWP water balance during monthly meetings. Additionally, during previous drought years of 2014 and 2015, Delta outflow requirements could be met utilizing higher flows from Folsom Reservoir. However, in WY 2021 with low storage in Folsom Reservoir, there was less opportunity to do so and instead storage from Shasta Lake and New Melones Reservoir were used.

- Carryover storage for the following water year: End of September storage, also referred to as carryover storage, was a significant operational consideration during the temperature management season in WY 2021. An end of September storage target of 1.25 MAF in Shasta Lake was not met, in part due to multi-agency coordination that decided to protect summer hydropower production by the Hyatt Power Plant on the Feather River at Lake Oroville. Reservoir storage volume is the outcome of inflow less releases. Releases are made to meet downstream demands and demands this year included senior water rights, public health and safety, refuge water supply, and meeting Delta standards. There were many efforts to manage releases this year including the Meet and Confer agency meetings, water transfers, Temporary Urgency Change Petition, installation of a salinity barrier, 13 days of curtailments from the State Water Board, and a Reclamation pilot project that used existing groundwater wells to offset water that may have otherwise been released from Shasta Lake.
- TCD Temperature Curtain: Due to low Shasta Lake storage levels and safety concerns, the TCD curtain was not deployed in summer of 2021. Deployment of the middle gate curtain helps reduce warm water leakage into the TCD. Since the initial installation of the curtain six years ago, Shasta Lake storage levels have never been as low as what was experienced in 2021. This made it difficult to anticipate the conflict between deploying the curtain and maintaining the use of the middle gates as the reservoir levels dropped. The blending of the middle gates and the lower gates helped to preserve cold water for later in the season. Once all of the middle gates were closed and not needed anymore, the lake had dropped to a level that would have made deployment of the curtain very dangerous and potentially could have damaged the curtain.

## Daily Average Temperature and Temperature Targets

The daily average water temperatures for the SAC compliance location and CCR compliance location were compared against their respective daily temperature targets for WY 2021 (**Figure 12**). From May 17, 2021 through October 31, 2021, the temperature target at the SAC compliance location was exceeded in 93 days, with the average exceedance at 2.5°F (minimum exceedance: 0.1°F; maximum exceedance 4.9°F).

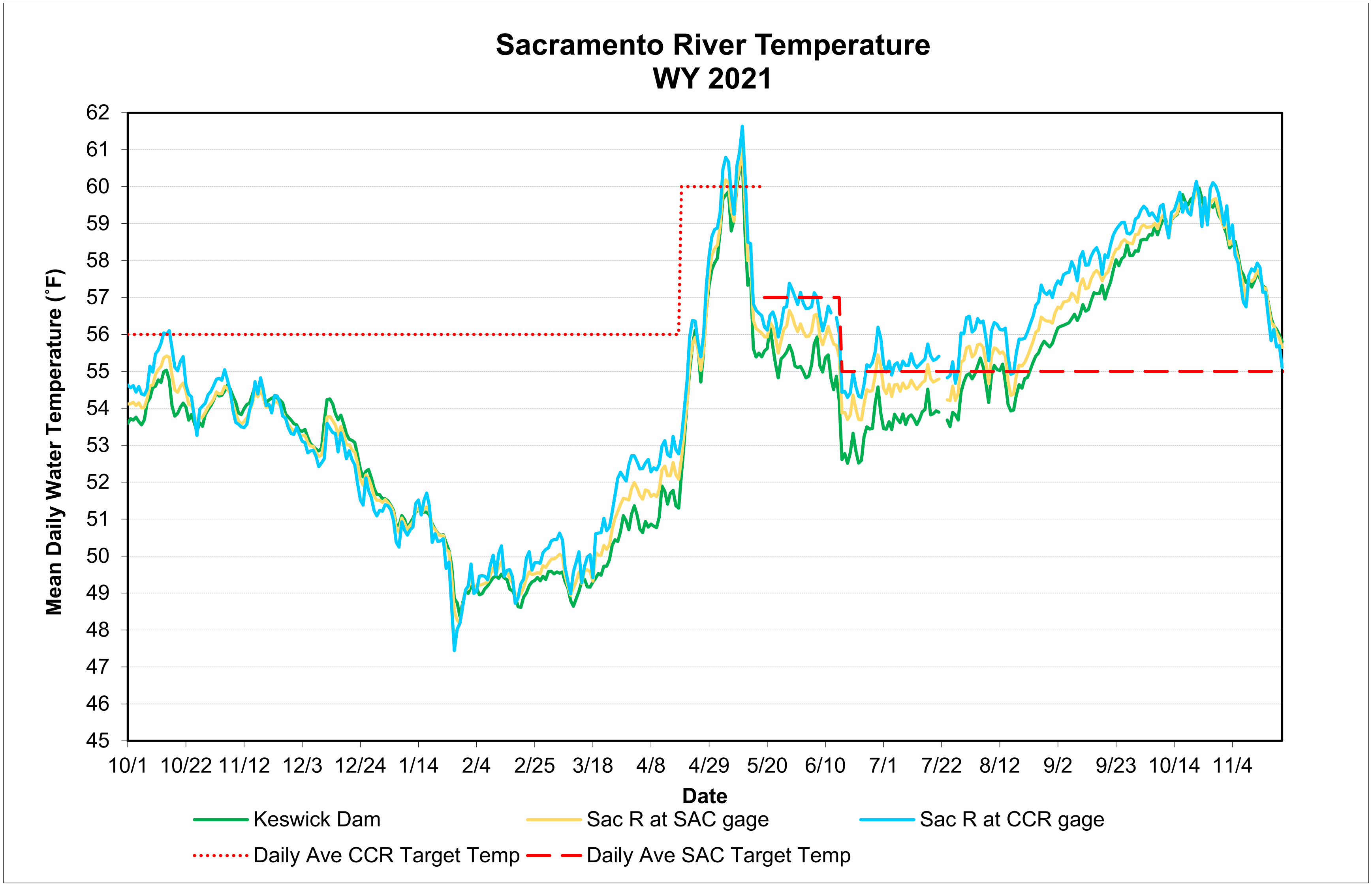


**Figure 12.** Summary of Upper Sacramento River Daily Mean Water Temperature in WY 2021.

## Fisheries

The following section describes the Chinook salmon monitoring efforts undertaken during the WY 2021 temperature management season and juvenile Chinook salmon outmigration.

### Chinook Salmon Spawn Timing and Distribution

Annual population estimates for the upper Sacramento River Basin are determined through a number of methodologies including carcass surveys, hatchery counts, aerial and in-stream redd surveys, snorkel counts, 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 RBDD using jet boats. Traditionally, the Sacramento River carcass surveys are conducted by boat, each having two or more observers. Three multi-month surveys are conducted each year with crews normally on the river year-round. Survey protocols and methods may change slightly in each survey, but in general terms, the protocols have remained similar since 2003. The late-fall-run Chinook salmon survey begins typically in mid-December and ends in early-May. The winter-run Chinook salmon survey begins in late-April or early-May and ends in late-August or early-September. The fall/spring-run Chinook salmon survey begins in early-September and ends in late-December or early-January. The beginning or end of each survey is determined by the number of carcasses observed by the crews at those times. The spawn timing of each run can vary by a few weeks each year so survey dates are flexible and can overlap from one survey to another.

Aircraft are used to conduct monthly surveys for the late-fall-run and fall/spring-run Chinook salmon redd distributions and during the winter-run Chinook salmon spawning period to conduct surveys to enable detailed inspection of winter-run Chinook salmon spawning areas. Aerial redd maps are created by staff on the flights to document the location of spawning areas and distributions in the Sacramento River. These maps are used in conjunction with the corresponding carcass surveys to expand the overall population estimate for each run of salmon. Aerial redd surveys do not provide complete counts of new redds. Variability in turbidity, river depth, riparian vegetation, weather, and wind all affect the ability of the observer to count new redds. Not all redds that are new are able to be counted but it is assumed that the proportion of redds visible in the various sections during a single flight are identical. The aerial redd data should be used with caution and it is recommended to use aerial redd data only for comparisons of redd distributions by river sections or for specific needs such as use of a specific area as a spawning location.

Preliminary CDFW Upper Sacramento River Basin Salmonid Monitoring Program data for the 2021 temperature management season can be accessed on the CalFish Website.

These data from the carcass and aerial redd surveys have not yet undergone CDFW's final quality control process to confirm or otherwise verify its accuracy. As a result, this draft data should not be used, relied upon, or referenced in any way until finalized by CDFW. Upon data finalization by CDFW, the draft data available on CalFish will be superseded and deleted. The preliminary data reported here may not be released to any other entity without the express written permission of CDFW.

The following CDFW preliminary information is presented for the 2021 carcass survey and aerial redd survey data for spatial and temporal spawning distribution as it is applicable to Shasta Lake cold water pool and water temperature management for winter-run Chinook salmon is also subject to revision. This summary information is provided as context for focusing on the SAC (Hwy 44) CDEC gaging station as the spatial water temperature compliance point with temporal compliance beginning May 17, and concluding on October 31, 2021.

The CDFW preliminary 2021 winter-run Chinook salmon carcass survey began on May 3, 2021 following the same protocols and guidelines as in previous years, were conducted weekly, and concluded on September 30, 2021. Temporal distribution of carcasses is as follows: the first carcass was detected on May 4 (0.0% of the cumulative total), 1,238 carcasses were detected by July 1 (25.5% cumulative), 4,200 carcasses were detected by August 1 (86.7% cumulative), and 4,847 carcasses were detected by September 23 (100% cumulative).

The distribution of carcasses by area (**Table 4**) indicates that 49.9% of carcasses were collected between Keswick Dam and the ACID Dam which is higher than the 2003-2020 average. The percent of carcasses collected from the ACID Dam to the Hwy 44 Bridge was 26.9% which is lower than the 2003-2020 average of 38.7%. The percentage of carcasses collected from the Hwy 44 Bridge to the Clear Creek Powerlines was 19.2% and the percent collected from Clear Creek Powerlines to the Balls Ferry Bridge was 4.0% which are generally similar to the 2003-2020 averages. These CDFW preliminary data are as of October 5, 2021 and are likely to be revised after CDFW completes its QA/QC process. Overall, approximately 73% of carcasses were collected above the vicinity of the SAC temperature compliance point and 27% were collected below the vicinity of the SAC temperature compliance point. However, because carcasses are known to drift downstream from the location where the fish spawned, these data are inconclusive as to whether winter-run Chinook salmon spawned below the Clear Creek temperature compliance point. Aerial redd surveys provide another line of evidence for spawning distribution which should be considered in conjunction with carcass survey data.

**Table 4.** Winter-run Chinook salmon carcass counts by river area, as end of season, in 2021. **NOTE: These data are preliminary and subject to change during final analysis that occurs after the season is completed.** **See Calfish winter-run Chinook Update file for final information when available. Link: CalFish CDFW Upper Sacramento River Basin Salmonid Monitoring.

| Section | River Miles | Carcasses | 2021 Percent | % Average (2003-2020) |
|---|---|---|---|---|
| **1**- Keswick Dam to ACID Dam (rm 302 to 298) | 302-298 | 2420 | 49.9% | 34.4% |
| **2**- ACID Dam to Hwy 44 Brg (rm 296) | 298-296 | 1302 | 26.9% | 38.7% |
| **3**- Hwy 44 Brg down to Clear Crk Powerlines (rm 288) | 296-288 | 931 | 19.2% | 22.6% |
| **4**- Clear Crk Pwrl to Balls Ferry Brg (rm 276) | 288-276 | 194 | 4.0% | 4.4% |

| Section | River Miles | Carcasses | 2021 Percent | % Average (2003-2020) |
|---|---|---|---|---|
| **Total** | **26 miles** | **4,847** | 100.0% | 100.0% |

The first winter-run Chinook salmon aerial redd survey was conducted on May 6, 2021 and the final survey was conducted on August 11, 2021. A total of 14 surveys were conducted weekly through July 26, 2021 and less frequently from August through September 2021. The results of these surveys indicate that redd distribution was concentrated upstream of the Hwy 44 Bridge with only one redd located in the section below the vicinity of Hwy 44 Bridge to Clear Creek (**Table 5**). Winter-run Chinook salmon redds observed during the aerial redd surveys in 2021 are shown spatially in **Figure 13** and temporally in **Figure 14**. Historical spawning distribution in the lower reaches are shown in **Figure 15** as the percent of winter-run Chinook salmon redds downstream of CCR gauge near Bonnyview Bridge from 1981 through 2021.

**Table 5.** Winter-run Chinook salmon aerial redd survey counts by river area, as end of season, in 2021. **NOTE: these data are preliminary and subject to change during final analysis that occurs after the season is completed.** **See Calfish winter-run Chinook Update file for final information when available. Link: CalFish CDFW Upper Sacramento River Basin Salmonid Monitoring.

| Flight Sections | River Mile | Redds | 2021 Percent | % Average (2003-2020) |
|---|---|---|---|---|
| Keswick to A.C.I.D. Dam.<br>Carcass Section 1 | 298 | 331 | 57% | 36.3% |
| A.C.I.D. Dam to Highway 44 Bridge.<br>Carcass Section 2 | 296 | 246 | 43% | 49.0% |
| Highway 44 Br. to below Clear Crk<br>Carcass Section 3 | 284 | 1 | 0% | 13.6% |
| Below Clear Crk. to Balls Ferry Br.<br>Carcass Section 4 | 275 | 0 | 0% | 0.2% |
| Balls Ferry Br. to Battle Creek.<br>Below Carcass | 271 | 0 | 0% | 0.6% |
| Battle Creek to Jellys Ferry Br.<br>Below Carcass | 266 | 0 | 0% | 0.1% |
| Jellys Ferry Br. to Bend Bridge<br>Below Carcass | 257 | 0 | 0% | 0.1% |
| Bend Bridge to Red Bluff Diversion Dam<br>Below Carcass | 242 | 0 | 0% | 0.0% |

| Flight Sections | River Mile | Redds | 2021 Percent | % Average (2003-2020) |
|---|---|---|---|---|
| Red Bluff Diversion Dam to Tehama Br. Below Carcass | 229 | n/s | n/s | 0.0% |
| N/A | **Total** | **578** | 100% | 0% |

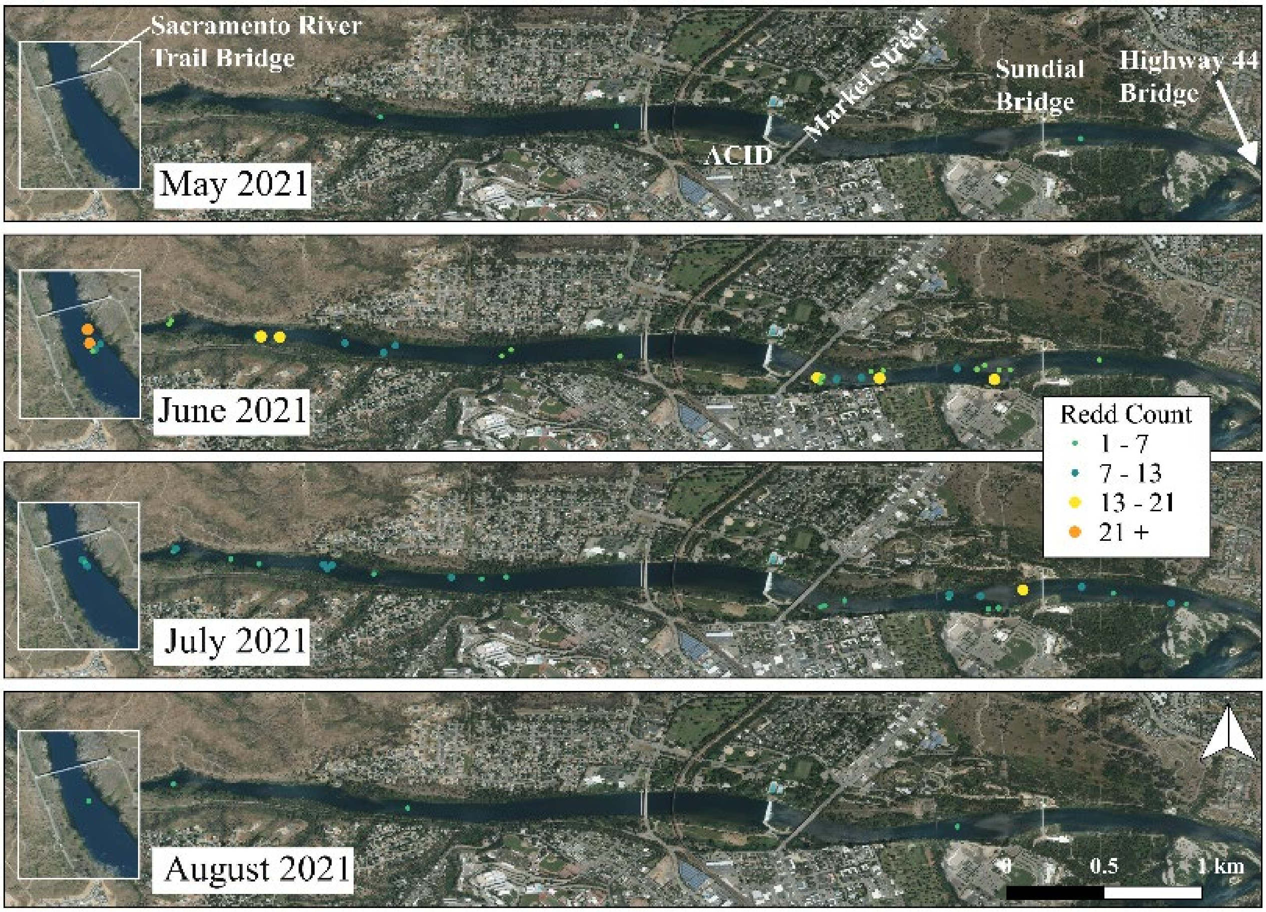


**Figure 13.** Monthly winter-run Chinook salmon spawning on the Sacramento River in 2021, Keswick to Hwy 44 Bridge. Point locations are marked at the center of polygons representing groups of redds identified in aerial surveys from a helicopter. All observed winter-run redds for 2021 are shown here except one redd downstream at Painter's Riffle. The inset at Sacramento River Trail Bridge is about 1.2 kilometers downstream of Keswick. Map by Suzanne Manugian (Reclamation) and aerial surveys by Jamie Chelberg (Pacific States Marine Fisheries Commission).

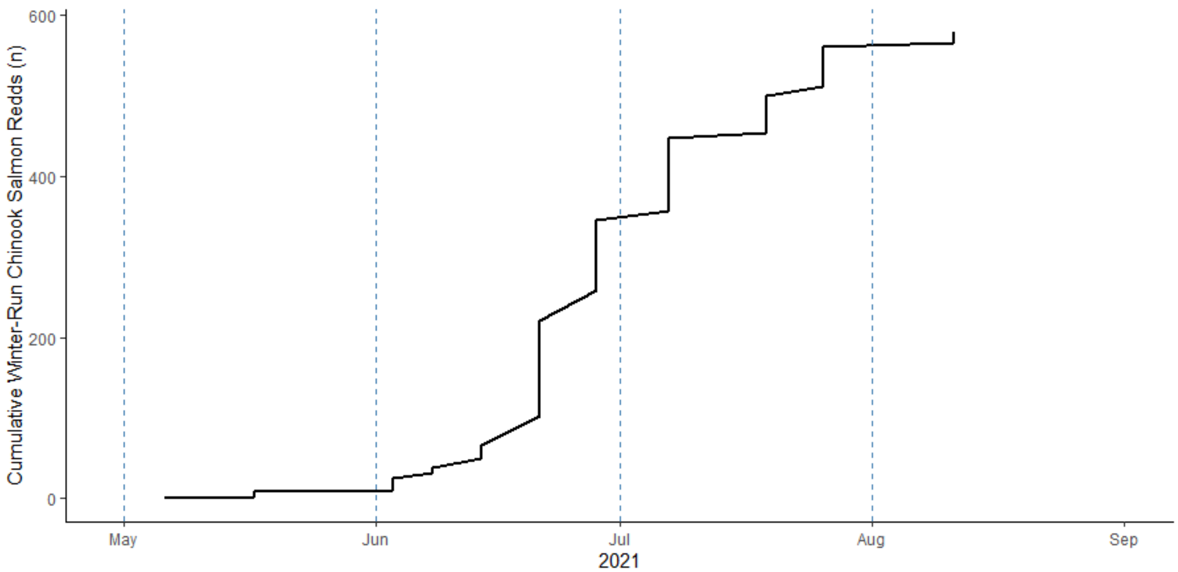


**Figure 14.** Cumulative distribution of winter-run Chinook Salmon redds (n) during 2021 aerial surveys.

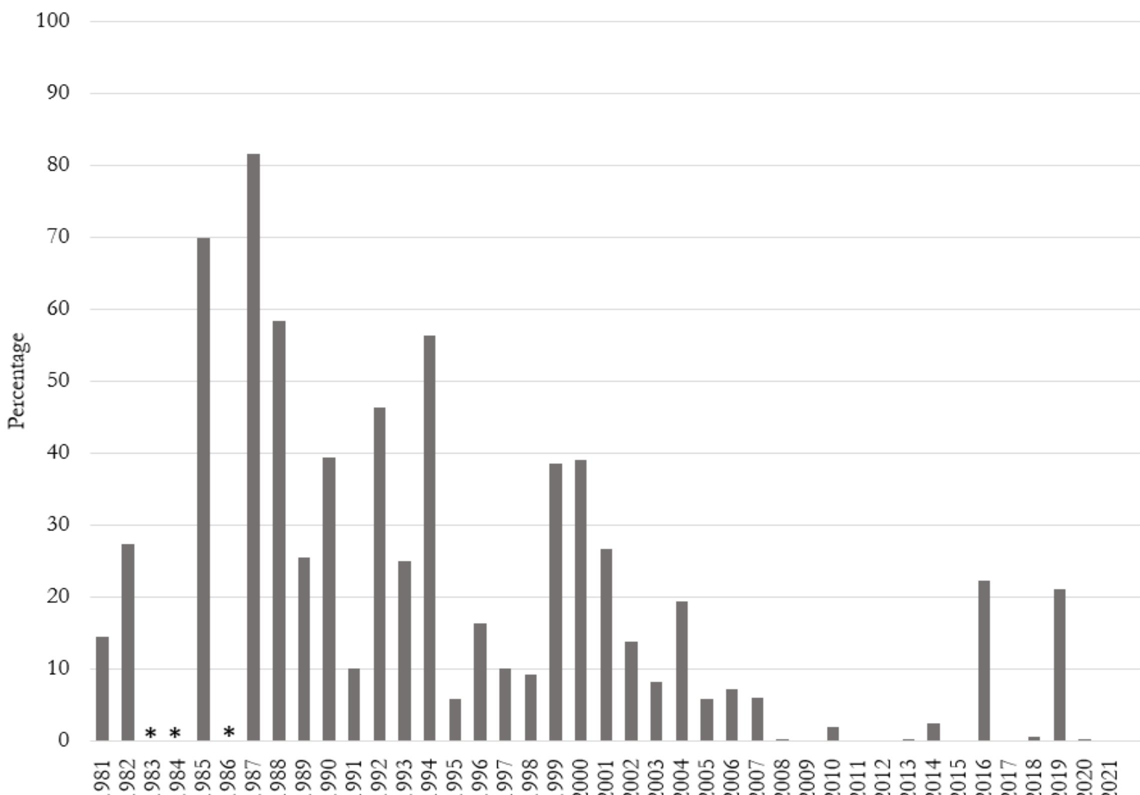


**Figure 15.** Percent of winter-run Chinook salmon redds downstream of CCR gauge near Bonnyview Bridge (1981-2021). Data were not available in 1983-1984 and 1986 (denoted by *).

As noted in the NMFS BY 2021 Juvenile Production Estimate letter, the CDFW estimate for total adult winter-run Chinook salmon escapement in 2021 was 10,269 spawners. Of this total number of spawners, 313 were collected at the Keswick Dam trap site for spawning at

Livingston Stone NFH,  leaving an estimated 9,956 to spawn naturally in-river. An estimated 5,860 of these spawners were females. The NMFS BY 2021 Juvenile Production Estimate can be found at: [NOAA: Juvenile Production Estimates for Brood Year 2021.]

### Juvenile Chinook Salmon Outmigration

A natural winter-run Chinook salmon juvenile production estimate is calculated annually and historically has been delivered late winter (January or February). The winter-run Chinook salmon juvenile production estimate for BY 2021 is 125,038 natural-origin juvenile winter-run Chinook salmon expected to enter the Delta during WY 2022. Estimated daily and biweekly passage of juvenile winter-run Chinook salmon at RBDD from June 18, 2021 to November 30, 2021 is shown in **Figure 16**. Historical and current estimated passage of juvenile winter-run Chinook salmon at RBDD (BY 2008 – BY 2021) is shown in **Figure 17.**

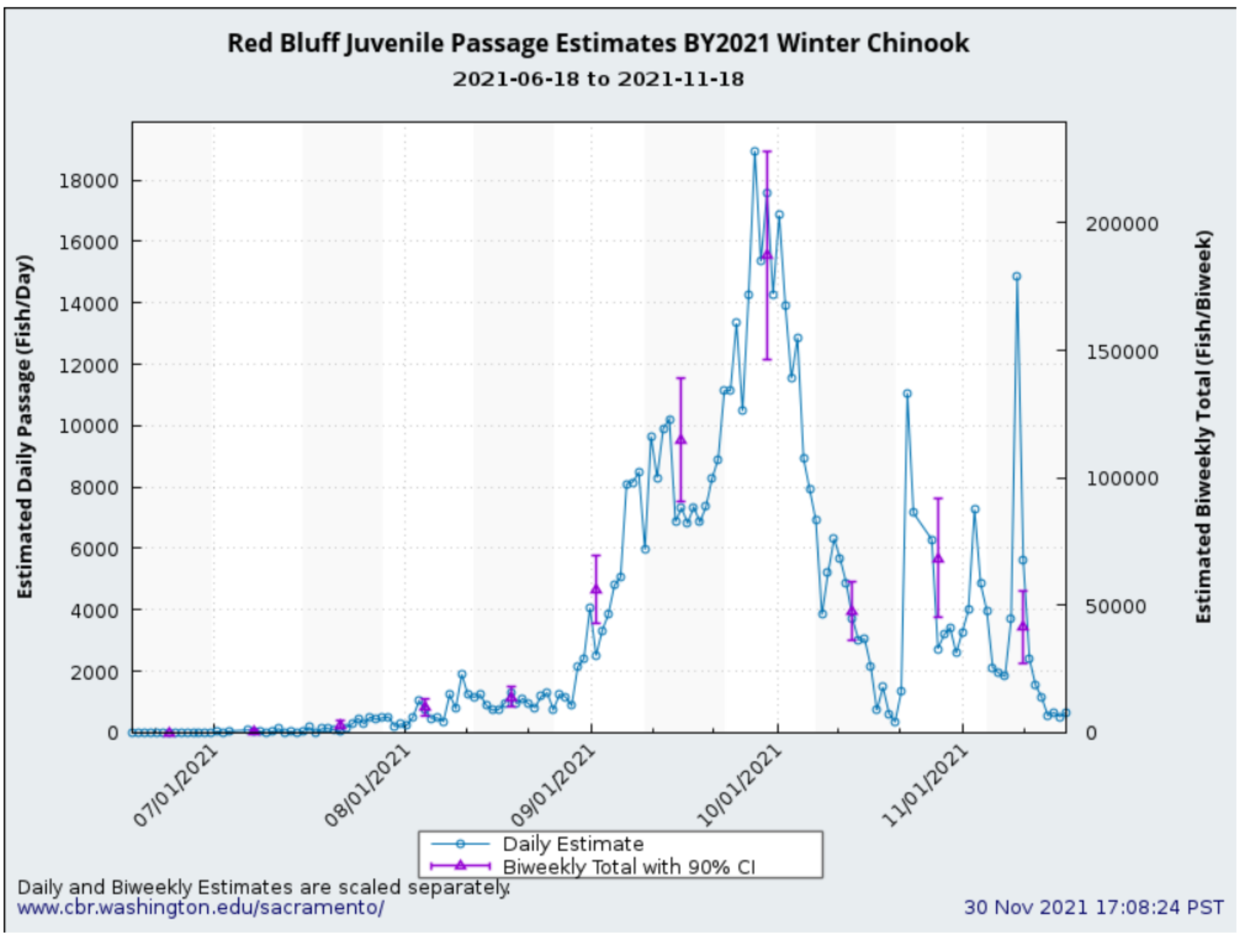


**Figure 16.** Daily and Biweekly (Total with 90% Confidence Interval) Estimates of Juvenile Winter-run Chinook Salmon Passage at Red Bluff from 06/18/2021 – 11/30/2021.

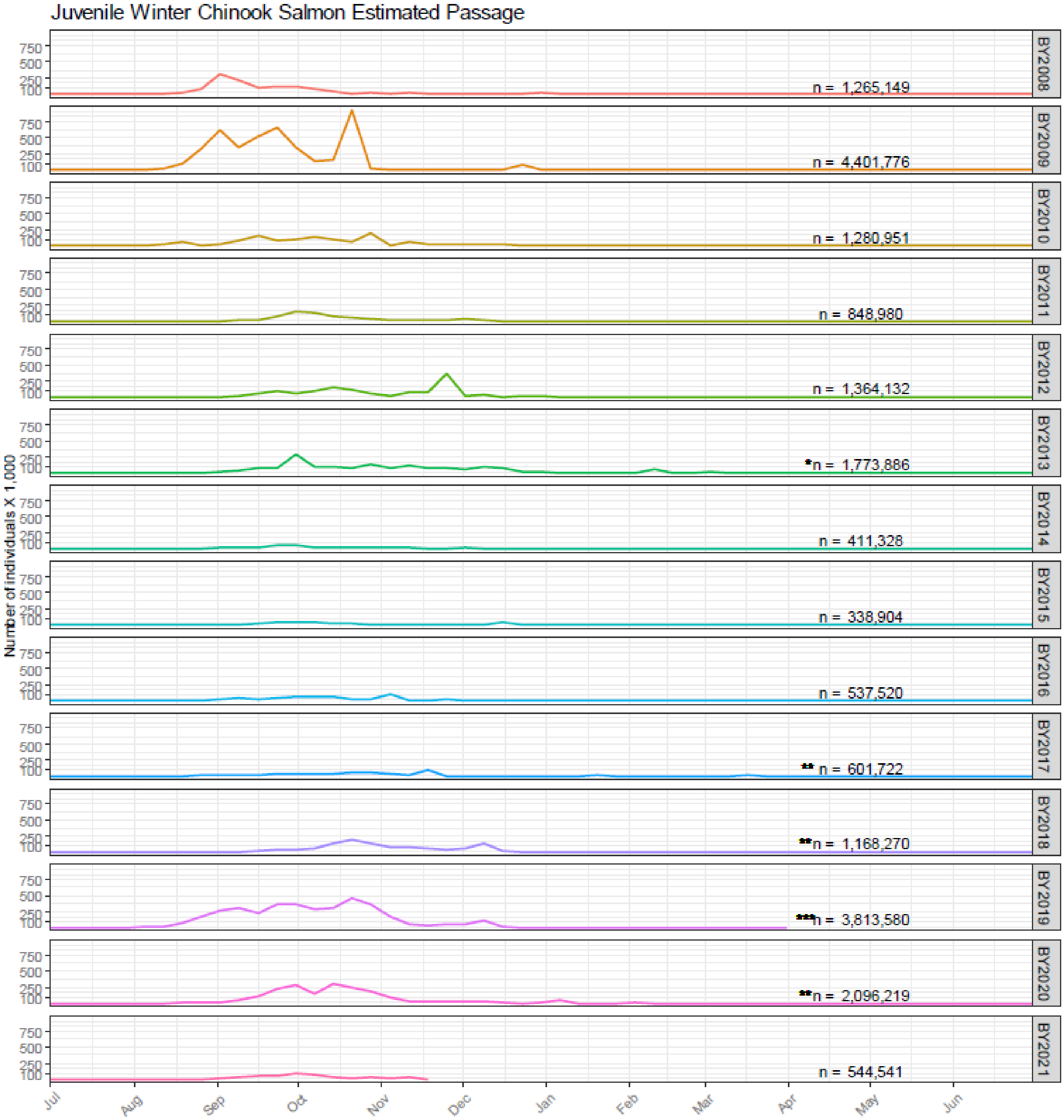


**Figure 17.** Historical and Current Estimated Passage of Juvenile Winter-run Chinook Salmon at Red Bluff Diversion Dam (BY 2008 - BY 2021).

## Operations Summary

The key events and decisions that influenced the 2021 upper Sacramento River Temperature operations include:

- WY 2021 was a critically dry year with below average precipitation in several months, particularly in late winter and early spring. The Northern Sierra Precipitation 8-Station Index indicated that as of the end of the water year, WY 2021's hydrologic conditions were the driest since 1977. Shasta Lake's cold water pool used to protect winter-run Chinook salmon was the smallest since 1977. Inflows to Shasta Lake were over a million acre-feet less than occurred in 2015.
- In February, the Tier 3 condition of achieving the 56°F temperature target at CCR would not be able to be met throughout the temperature management season and a Tier 4 year appeared likely. As such, discussions were initiated on intervention measures including increased hatchery production, a warm water power bypass, and Sacramento River Settlement Contract water transfers.
- The 2021 TMP detailed a Tier 4 performance category and specified both temperature targets and locations.
- A warm water bypass was conducted from April 18 to May 25, 2021 to conserve cold water pool for later in the season.
- Initiation of the water temperature management season began on May 17, 2021 with active management of 57°F at the SAC compliance location.
- Widespread wildfire activity throughout the summer impacted local meteorological conditions including solar radiation and thermal influences.
- The first side gate was opened on August 6, 2021.
- End of September storage was 1.07 MAF.
- Termination of the water temperature management season was on October 31, 2021. Firm data supporting a total population for year 2021 winter-run Chinook salmon population was unavailable in real-time to calculate the date of 95% hatch and alevin emergence.
- No modification or amendment to the 2021 TMP was necessary.

# Performance

In order to determine the accuracy of the water temperature model (e.g., HEC-5Q) and the water temperature-dependent egg mortality models (e.g., Anderson model and Martin models) used to forecast Shasta Lake cold water pool operations, Reclamation performed a hindcast review of these models using actual data observed.

## Models

A discussion of the models used for temperature and temperature-dependent egg mortality, as well as a discussion of how these models performed during the WY 2021 temperature management season is included below.

### Temperature Forecast and Hindcast

A seasonal water temperature forecast describes future expected downstream water temperature. This forecast, or simulation of expected water temperature performance, is based on the targets specified in the TMP. Future water temperature is forecasted at various elevations in the reservoirs and downstream in the river using computational tools. These tools are based on conservative assumptions regarding hydrology, operations and meteorology. Because this forecast (using conservative estimates in May to estimate) can never exactly predict the actual hydrology, operations, and meteorology in advance, the model results are not expected to precisely match actual water temperatures. The expectation is, however, that forecasted downstream water temperature generally have an accepted measure of error regardless of the uncertain future conditions. In this case, there are generally two types of simulation error: uncertainty of the future conditions (e.g., inputs such as meteorology) and inherent model error or bias. To better understand the inherent model error or bias, a hindcast evaluation is typically performed. A hindcast, rather than looking forward to forecast, simply uses the actual input/forcing data after they are observed (e.g., hydrology, operations, and meteorology) to determine how well the model reproduced a condition such as actual downstream water temperatures. This resulting analysis describes how well the model performs given perfect foresight.

**Methods**

The hindcast effort was motivated by a desire to test the HEC-5Q temperature model in forecasts for the SRTTG against year 2021 observed data. Input data from May 18 to November 30 (the run period of the hindcast) were used for river flows from CDEC and United States Geological Survey gages as compiled by Reclamation's Central Valley Operations Office. Temperature targets from the same period were set at the actual temperature at the TCD as measured. Initial vertical temperature profiles for Shasta, Whiskeytown, and Trinity reservoirs were used from dates as close to May 18 as possible. Observed 2021 meteorology data was compiled by RMA Engineers.

Modeled vertical temperature profiles for Shasta Lake and downstream Sacramento River temperatures were compared to 2021 observed data. Four error metrics were calculated for each comparison: Mean bias, Mean Average Error, Root Mean Squared Error, and Nash-Sutcliffe Efficiency. These statistics offer different perspectives on quantification of error. Mean bias depicts systematic over- or underprediction by the model. Mean Average Error shows absolute error, while Root Mean Square Error is similar but scaled to the sample size and more sensitive to outliers. Nash-Sutcliffe Efficiency contains information on how well the model simulates both the mean of the data and variance around that mean.

**Results**

Vertical temperature profile comparison results are shown in **Table 6**. Error metrics were also calculated with the upper 30 feet of the Shasta Lake profile removed (**Table 7**). This was for the purpose of discounting for surface dynamics to evaluate goodness of fit at levels from which water is drawn by the TCD (**Table 8**). Modeled and historical vertical temperature profiles for Shasta Lake on July 28, 2021 are shown in **Figure 18**. The first use of the TCD's side gate in the model run was on August 7; this compares well with the historical date of August 6.

Results indicate a systematic overprediction of temperature below Keswick Dam but more accurate results downriver (**Figure 19**, **Figure 20**, **Figure 21**). The model performed well at predicting lake profiles early in the season but underpredicted temperatures at lower elevations in Shasta Lake later in the season. Overall, the results indicate that given historical flows, Shasta Dam outflow temperatures, and meteorology, the HEC-5Q model performs well at reproducing historical downriver temperatures. This is a positive indicator for in-river temperature and temperature-dependent mortality forecasts. The overprediction of temperature just below Keswick Dam could result in an overprediction of temperature-dependent mortality for the furthest upstream redds. The less accurate prediction of the reservoir's vertical temperature profile in August and afterward, implies that late-season predictions using the HEC-5Q model are less reliable than early-season predictions in a low storage year like 2021.

**Table 6.** Error metrics in degrees Fahrenheit used to compare modeled vertical temperature profiles for Shasta Lake to 2021 observed data for all data. Metrics include Mean Bias, Mean Average Error (MAE), Root Mean Squared Error (RMSE), and Nash-Sutcliffe Efficiency (NSE).

| Date | 5/26 | 6/23 | 7/28 | 8/19 | 9/30 | 10/27 | 11/10 |
|---|---|---|---|---|---|---|---|
| Mean Bias | -0.18 | 0.14 | 0.21 | 0.25 | -1.27 | -2.02 | -1.34 |
| MAE | 0.44 | 0.67 | 1.20 | 1.52 | 4.07 | 4.89 | 3.84 |
| RMSE | 1.03 | 1.31 | 2.28 | 2.82 | 5.34 | 5.50 | 4.45 |
| NSE | 0.97 | 0.98 | 0.95 | 0.94 | 0.63 | -0.16 | -0.35 |

**Table 7.** Error metrics in degrees Fahrenheit used to compare modeled vertical temperature profiles for Shasta Lake to 2021 observed data for data with top 30 feet removed. Metrics include Mean Bias, Mean Average Error (MAE), Root Mean Squared Error (RMSE), and Nash-Sutcliffe Efficiency (NSE).

| Date | 5/26 | 6/23 | 7/28 | 8/19 | 9/30 | 10/27 | 11/10 |
|---|---|---|---|---|---|---|---|
| Mean Bias | -0.23 | -0.17 | -0.37 | -0.60 | -2.48 | -3.10 | -2.32 |
| MAE | 0.28 | 0.41 | 0.67 | 0.82 | 3.56 | 4.73 | 3.53 |
| RMSE | 0.77 | 0.75 | 1.16 | 1.39 | 4.89 | 5.42 | 4.17 |
| NSE | 0.95 | 0.98 | 0.98 | 0.98 | 0.68 | -0.08 | -0.17 |

**Table 8.** Error metrics in degrees Fahrenheit used to compare modeled Sacramento River temperatures to 2021 observed data. Metrics include Mean Bias, Mean Average Error (MAE), Root Mean Squared Error (RMSE), and Nash-Sutcliffe Efficiency (NSE).

| Location | Keswick | Clear Creek | Balls Ferry |
|---|---|---|---|
| Mean Bias | 1.08 | 0.13 | 0.09 |
| MAE | 1.13 | 0.62 | 0.74 |
| RMSE | 1.34 | 0.77 | 0.89 |
| NSE | -1.26 | -3.43 | 0.92 |

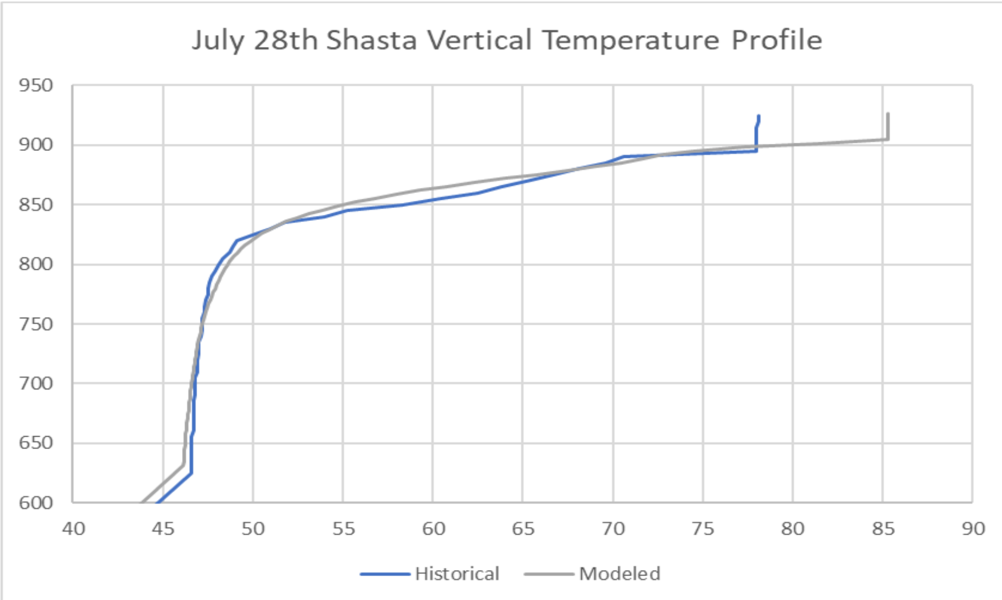


**Figure 18.** Modeled and historical water temperature (degrees Fahrenheit) profile of Shasta Lake on 7/28/2021 by elevation (feet).

For hindcast evaluation, modeled and actual water temperatures at three locations were compared: Sacramento River at Keswick Dam (**Figure 19**), Clear Creek (**Figure 20**), and Balls Ferry (**Figure 21**). Modeled water temperature data were warmer than observed water temperature data through most of the time series at all locations.

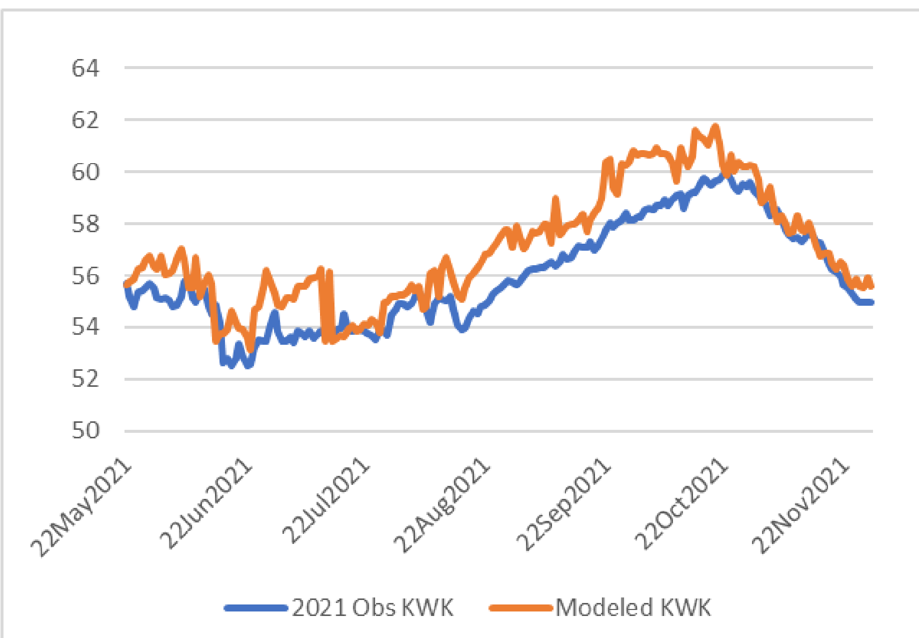


**Figure 19.** Modeled and observed water temperatures (degrees Fahrenheit) at Keswick (KWK) from 5/22/2021 – 11/30/2021.

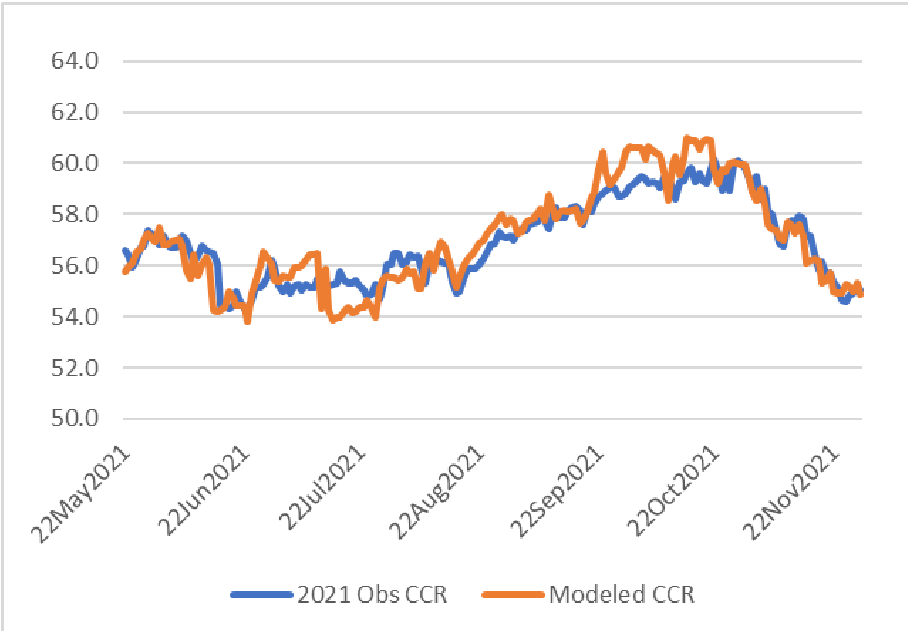


**Figure 20.** Modeled and observed water temperatures (degrees Fahrenheit) at Clear Creek (CCR) from 5/22/2021 – 11/30/2021.

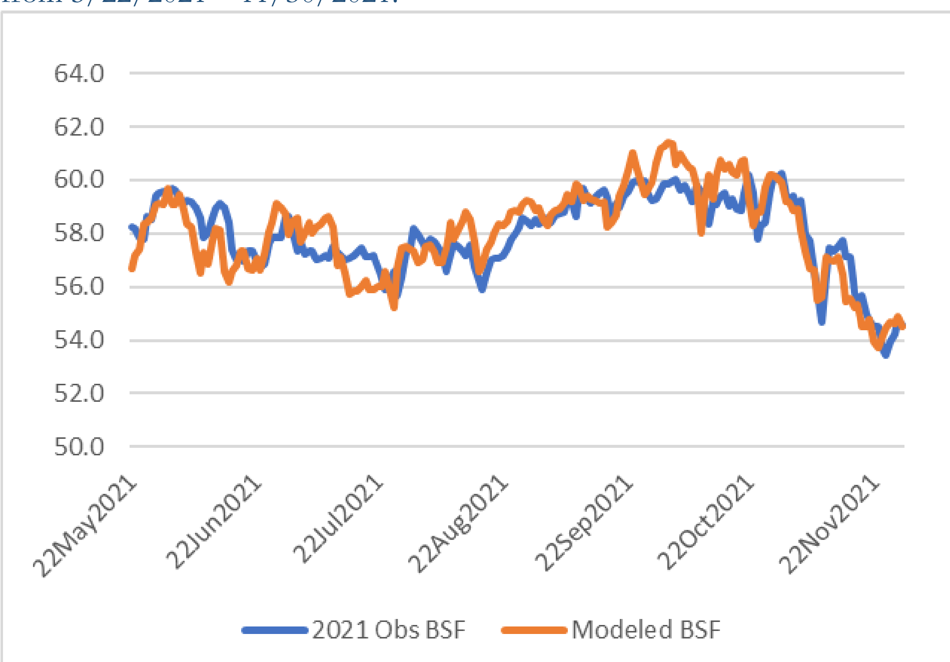


**Figure 21.** Modeled and observed water temperatures (degrees Fahrenheit) at Balls Ferry (BSF) from 5/22/2021 – 11/30/2021.

### Temperature Dependent Mortality Forecasts

Both Reclamation and NMFS provided TDM forecasts for winter-run Chinook salmon eggs in WY 2021. Reclamation's approach uses spatially-explicit daily average Sacramento River water temperature forecasts from the HEC-5Q model results and an empirical relationship, described below, as inputs to generate TDM estimates. When available, historical water temperature data are used to capture actual observed water temperature during the early water temperature management period. Historical water temperatures on the Sacramento River at Shasta Dam, Keswick Dam, CCR, Balls Ferry, Jelly's Ferry, and Bend Bridge are interpolated to estimate temperatures at river miles where simulated redds were located. Between September 15 and October 31, daily water temperatures at the simulated redds' river miles are estimated based on an empirical relationship between cold water pool volume less than 56°F at the end of September in Shasta Lake and water temperatures at CCR derived by Reclamation's Central Valley Operations Office. Reclamation finds this relationship is more reliable in that time period than outputs from the HEC-5Q model (previous evaluations suggest a stronger underestimating bias in October than September). The 90% confidence interval value from this analysis was used as a conservative estimate. The average difference between the simulated water temperatures at CCR and the simulated water temperatures at the redds' river miles during this period are used to adjust estimated water temperatures at CCR for each river mile.

Winter-run Chinook salmon egg TDM estimates were calculated by modeling a redd's lifetime based on the days required to cross a known cumulative degree-day threshold and estimating mortality as an increasing function of water temperature past a temperature threshold. Two models were used: (1) Martin et al. (2017) for stage independent modeling whereby a single temperature threshold is used from spawning and incubation through emergence; and (2) Anderson (2018) for stage dependent modeling for targeting different water temperatures before, during, and after the most sensitive stages during egg incubation. The Anderson model provides an input parameter that factors in eggs needing more oxygen as they develop and are more sensitive immediately prior to hatching due to increased biological demand of oxygen.

The TDM forecasting methods were applied to a set of simulated redds representative of redd construction timing and location from 2012-2020. TDM estimates varied depending on the water temperatures and TDM models used. Reclamation's forecasted estimates for overall TDM in the final TMP ranged from 67 – 88% using the Martin model (stage-independent), while overall TDM estimates using the Anderson model (stage-dependent) ranged from 78 - 97%. TDM forecast estimates for WY 2021 winter-run Chinook salmon from the NMFS Southwest Fisheries Science Center are available at: NOAA Central Valley Temperature Mapping and Prediction website.

### Temperature Dependent Mortality Hindcast

TDM hindcasts methods are similar to TDM forecasts described above. The SacPAS Fish model allows modeling of spawning to emergence in the Sacramento River. Historic winter-run Chinook salmon redd and water temperature data are inputs to the model. Survival from Keswick Dam to RBDD can be modeled as a function of stage-independent (Martin model) or stage-dependent (Anderson model) mortality. The SacPAS Fish Model was used to provide hindcast TDM estimates described below. SacPAS is further described in the Analysis Tools section.

Winter-run Chinook salmon redds further downstream are exposed to water temperatures that are warmer (**Figure 22**). The SacPAS Fish Model has the ability to describe TDM for redds in general locations. Only one redd was observed downstream of the Hwy 44 Bridge, in Painter's Riffle. Reclamation's forecasted mortality estimates for overall TDM in the final TMP ranged from 67 – 88% using the Martin model (stage-independent), while overall mortality estimates using the Anderson model (stage-dependent) ranged from 78 - 97%. Reclamation's hindcast TDM estimate using the SacPAS Anderson model (stage-dependent) is 87% and using the Martin model (stage-independent) is 76%. When providing forecasts of TDM for winter-run Chinook salmon, Reclamation and NMFS rely on previous year's redd data and water temperature data as inputs for these forecasts. When 2021 redd data was replaced with the redd data used for forecasted TDM estimates (2012-2020), Reclamation estimated TDM of 82 - 86% (model assumptions are included in Appendix E; Table 2). These similar TDM estimates indicate that the redd data distribution used for TDM forecasts appears to be representative of this year's redd data distribution and captured that the majority of the redds were constructed upstream of the temperature compliance locations. TDM hindcast estimates for WY 2021 winter-run Chinook salmon from the NMFS Southwest Fisheries Science Center (mean TDM 70%; October 24, 2021) are included in Appendix D.

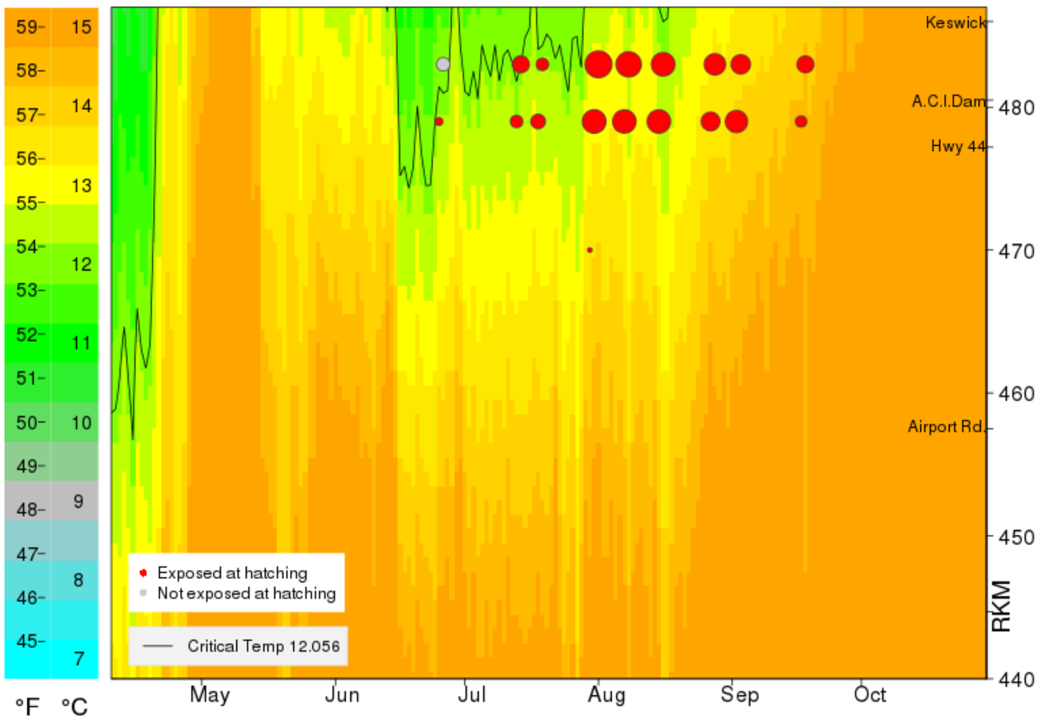


**Figure 22.** WY 2021 distribution and timing of winter-run Chinook salmon hatching with water temperatures using model inputs described in Appendix E: Table 1. All winter-run Chinook salmon redds were exposed to water temperatures that exceed the critical temperature threshold (12°C) during hatch time. Size of circles reflect number of redds (e.g., larger circles indicate more redds at the time and location).

The temporal distribution of observed winter-run Chinook salmon redds, critical hatching periods, and emergence timing in WY 2021 is shown in **Figure 23**. Peak spawning occurred in the last half of June through first half of July. The highest abundance of eggs and alevins in the gravel was from approximately late July through early September. The critical hatching periods were mainly late July through August and fry emergence from the gravel peaked in August and September.

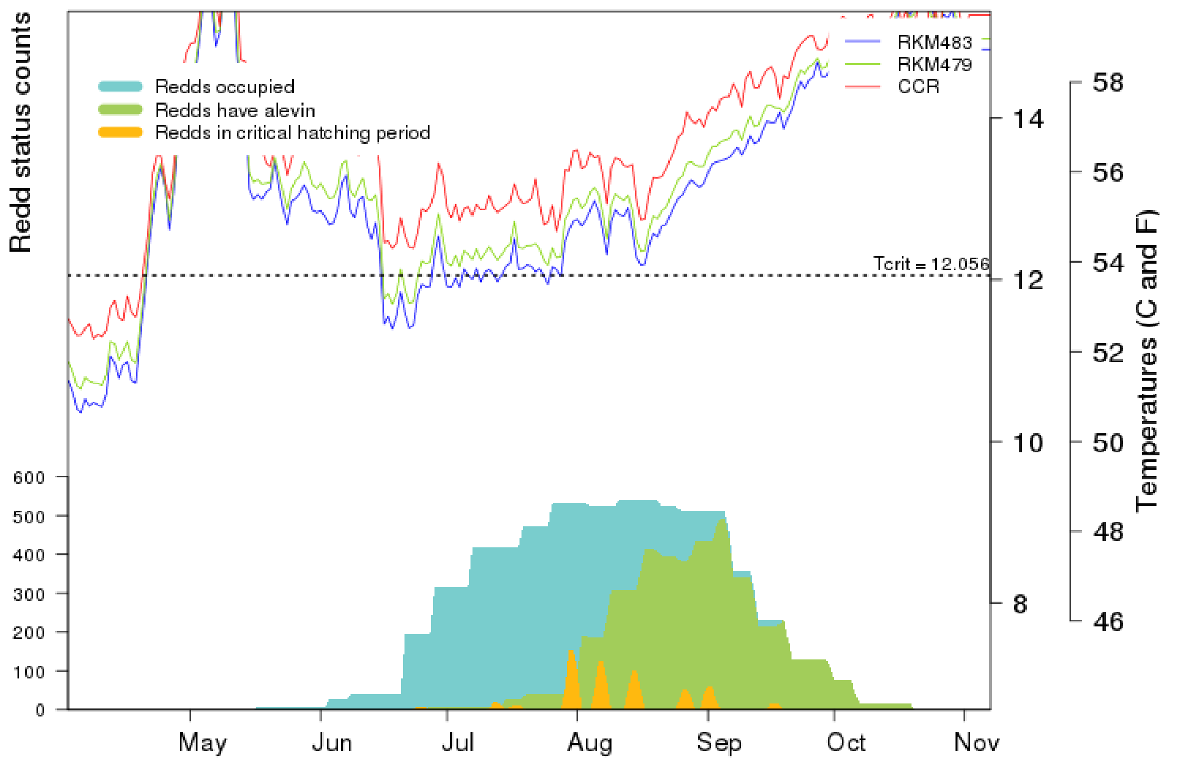


**Figure 23.** Temporal distribution of winter-run Chinook salmon redds and egg development to emergence in WY 2021. Figure is based on aerial redd survey data.

## Performance Metrics

This section discusses the Upper Sacramento Performance Metrics included in the 2020 ROD for TDM and egg-to-fry survival.

### Estimates of Temperature Dependent Mortality

The 2020 ROD includes the following Upper Sacramento Performance Metrics for TDM estimates:

- Tier 1 – Maximum (39%); Average (6%); Median (2%); Minimum (0.4%); Std. Dev (+/-9%)
- Tier 2 - Maximum (46%); Average (15%); Median (9%); Minimum (1%); Std. Dev (+/-16%)
- Tier 3 - Maximum (77%); Average (34%); Median (24%); Minimum (6%); Std. Dev (+/-31%)
- Tier 4 – Appropriate performance metrics will be addressed under "Drought and Dry Year Actions" consistent with the "Governance" section of this Proposed Action.

Tier 4 years have no specific performance criteria and rely on interagency cooperation to achieve the best negotiated outcome. Reclamation's hindcast TDM estimates ranged from 76% – 87% using redd data from 2012 – 2020. Reclamation's hindcast TDM estimates ranged from 82% – 88% using redd data from 2021.

### Estimates of Overall Egg-to-Fry Survival at Red Bluff

Many factors contribute to early life stage survival of salmonids, such as predation, water temperature, water quality, and density dependent effects. In 2019 - 2021, high incidences of thiamine vitamin deficiency have been reported to contribute the mortality of early life stages of Chinook salmon. The 2020 ROD includes the following Upper Sacramento Performance Metrics for egg-to-fry survival:

- Tier 1 - Average (29%); Maximum (49%); Minimum (15%); Median (28%); Std. Dev (10%)
- Tier 2/3 - Average (21%); Maximum (34%); Minimum (15%); Median (20%); Std. Dev (6%)
- Tier 4 - Appropriate performance metrics will be addressed under “Drought and Dry Year Actions” consistent with the “Governance” section

Tier 4 years have no specific performance criteria and rely on interagency cooperation to achieve the best negotiated outcome. USFWS-Red Bluff Office reports on the official egg-to-fry survival estimate. The egg-to-fry survival estimates for BY 2021 are not yet available; however, the final estimates for BY 2002 through 2019 can be found on the US Fish and Wildlife website . Each year, NMFS includes a preliminary estimate of egg-to-fry survival in the Juvenile Production Estimate letter which is usually available in January. The BY 2021 Juvenile Production Estimate letter includes an estimated 2.56% egg-to-fry survival. NMFS attributed the low egg-to-fry survival estimate as
“likely largely due to thiamine deficiency and temperature-related mortality during egg incubation” (pg. 5).

Additionally, a preliminary assessment of estimated egg-to-fry survival to RBDD using the SacPAS Fish Model was conducted. Egg-to-fry survival to RBDD was estimated to be 3% and 6% using the Anderson model (stage-dependent) and Martin model (stage-independent), respectively. For more information about input and outputs of this model run see Appendix E; Table 3.

## Commitment to Tier

WY 2021 was determined to be a Tier 4 year in the TMP and remained in the tier for the duration of the temperature management season.

## Conservation Measures

In WY 2021, there was increased production of winter-run Chinook salmon at Livingston Stone NFH to mitigate for the anticipated temperature related mortality for eggs naturally spawned in the river (**Table 9** and **Table 10**). In addition, three 525 ton semi-trailer sized electric powered water chillers were rented to cool the water coming into Livingston Stone NFH and reduce temperatures to more optimal levels (close to 53° F) for egg-to-fry survival. The system used two running chiller units with one on standby for outages. The system successfully produced acceptable survival despite intermittent chiller outages. The 2021 brood year production included the winter-run Chinook salmon eggs from the Keswick trapped adults, winter-run Chinook salmon captive broodstock reared at Livingston Stone NFH, and Battle Creek winter-run Chinook salmon adult returns trucked to Livingston Stone NFH for egg collection and incubation.

**Table 9.** Livingston Stone National Fish Hatchery Production in WY 2021.

| Release Start | Release End | CWT Tag Race | Hatchery | Release Site | CWT Number Released (Percent Marked) | Confirmed Delta Loss |
|---|---|---|---|---|---|---|
| 1/30/2021 | 1/30/2021 | Winter | Livingston Stone NFH | Sacramento River, Caldwell Park, Redding, CA | 302,166 (100%) | 0 |

**Table 10.** Livingston Stone National Fish Hatchery Projects in WY 2021.

| Project | Females Collected | Females Spawned | Males Collected | Males Spawned | Green Eggs | Eyed Eggs | Fry |
|---|---|---|---|---|---|---|---|
| Mainstem Sacramento River | 135 | 118 | 159 | 129 | 626,778 | 586,489 | 564,826 |
| Battle Creek Jumpstart (Battle Creek Returns) | 27 | 22 | 28 | 18 | 112,433 | 101,773 | 71,297* |
| Battle Creek Jumpstart (Captive Broodstock) | N/A | 128 | N/A | 90 | 121,979 | 87,183 | N/A** |

*Juveniles transferred to Coleman NFH periodically

**Eyed eggs and fry transferred to Mt. Lassen Trout Farm and Coleman NFH, respectively

# Discussion

In WY 2021, a warm water power bypass was conducted in April in order to prolong the availability of Shasta Lake's cold water pool. One tradeoff of conducting a warm water power bypass is the potential for warmer water temperatures earlier in the season, which can impact pre-spawn mortality for winter-run Chinook salmon. In 2021, the pre-spawn mortality for female winter-run Chinook salmon was 5.5%, the highest recorded in the monitoring going back to 1996. The historical average pre-spawn mortality for female winter-run Chinook salmon is 1.3%, and the previous highest recorded under the current monitoring protocol (going back to 2003) was in 2020 at 3%. The average water temperature at CCR during the pre-spawn period in the first half of May 2020 were approximately 54°F. By contrast, the first half of May 2021 had higher water temperatures, averaging 58.8°F at CCR (**Figure 24**). Another consideration for implementation of a warm water power bypass in the upper Sacramento River is the potential for winter-run Chinook salmon to stray into Clear Creek. Winter-run Chinook salmon commonly exhibit milling behavior at the mouth of Clear Creek where the USFWS observe them entering and exiting the Creek within minutes at a video station there. Though rare, adult winter-run Chinook salmon have been detected further upstream in Clear Creek through carcass recovery or spawning activity. The USFWS recovered no winter-run Chinook salmon carcasses in WY 2021, but noted a single fresh redd in May that would indicate winter-run based on timing.

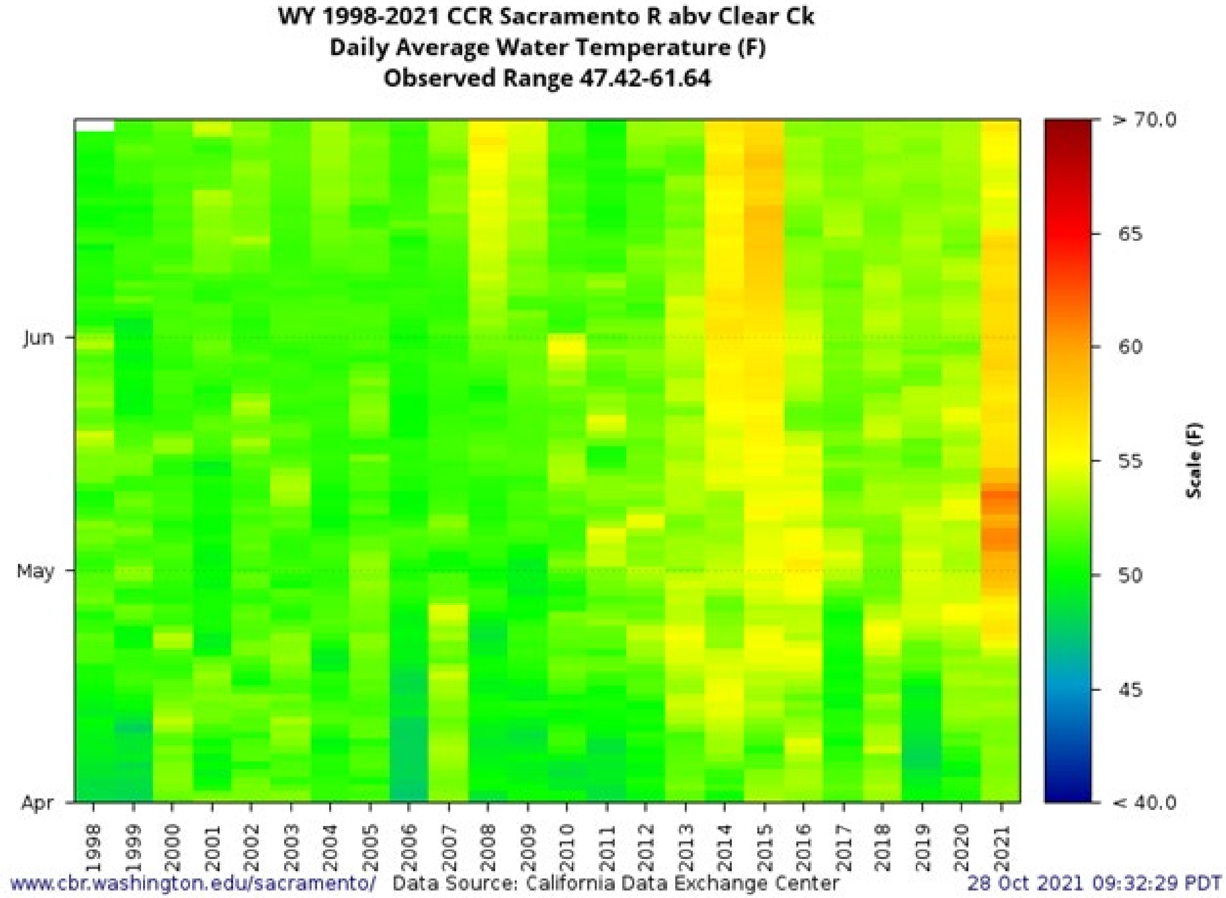


**Figure 24.** Daily Average Water Temperature at CCR for April, May, and June, for a period of record 1998 - 2021.

Warm water power bypasses could potentially impact species other than winter-run Chinook salmon. The power bypass occurred during the last part of the rainbow trout spawning period and aerial surveys recorded 320 trout redds from the first survey on May 6 through June 8, 2021 with redds distributed down as far as the Rio Vista Side Channel at Red Bluff. The majority of these redds were likely from large resident rainbow trout given the late timing in comparison with Central Valley steelhead from Coleman NFH. Rainbow trout redds have similar water temperature requirements to Chinook salmon and egg incubation duration is shorter for trout (about 600 accumulated temperature units and 900-1,000 temperature units, degrees C, for rainbow trout and Chinook salmon, respectively). Temperature effects to the trout have been unquantified. In WY 2021, surveys on Clear Creek showed the largest return of spring-run Chinook salmon on record (1999 – 2021). Around April 21, 2021, the mean daily water temperatures in the Sacramento River (as measured just upstream of the confluence with Clear Creek) began to climb above those of Clear Creek (as measured just upstream of the Sacramento River confluence). This water temperature discrepancy was more significant during May 8–12, 2021 when the Clear Creek spring attraction flows were released from Whiskeytown Dam, and water temperatures in Clear Creek decreased and further deviated from those in the Sacramento

River. It is unclear how these water temperatures affected the movement of spring-run Chinook salmon. For further discussion of spring-run Chinook salmon in Clear Creek, please refer to the Clear Creek Technical Team Water Year 2021 Activity Summary.

Implementation of a warm water power bypass may be considered in future critical years as a way to reduce water temperature impacts on Chinook salmon egg incubation. Given our current understanding that for winter-run Chinook salmon, the egg is the most sensitive lifestage to warm water temperatures, it is reasonable to assume that a warm water power bypass could preserve cold water pool for egg incubation during drought or Tier 4 years. However, there are tradeoffs associated with this action, as there may be some impacts to the adult spawning condition. Uncertainties remain on exactly how beneficial a warm water power bypass may be for Chinook salmon. Some of these uncertainties include assumptions on how accurate early life stage temperature dependent mortality estimates are and how warm water temperatures effect adult spawning behavior, gamete viability, and condition. Controlled experiments may be needed to better understand pre-spawn temperature impacts. Additionally, Reclamation and other agency partners have completed a provisional final Research Strategy for the Spring Management of Spawning Locations Action that describes an approach to gain a better understanding of how water temperatures affect adult spawning distribution and success, as well as how decision-support tools can be improved to better weigh the tradeoffs and evaluate different water temperature management actions.

Typically, the temperature management strategy is to delay opening of the side gates because the earlier the side gate is opened, the earlier Shasta Lake will run out of cold water and upper Sacramento River water temperatures increase from an inability to control water temperatures. However, delaying side gate use would mean that upper Sacramento River temperatures would have warmed up earlier in the summer. The first side gate was opened August 6, 2021 and the second side gate on August 12, 2021. Opening the gates helped maintain water temperature near the target to about the middle of August. Temperatures gradually increased through late October when seasonal cooling began moderating temperatures.

The Temperature Management Plan included a scenario in which operations were shaped in order to allocate colder water during the time period when early life stages of winter-run Chinook salmon were expected to be most sensitive immediately prior to hatching.

The NMFS Juvenile Production Estimate letter for BY 2021 estimated egg-to-fry survival was 2.56%. One factor that likely contributed to low egg-to-fry survival this year is thiamine deficiency complex (Harder et al. 2018). During their ocean phase, adult Chinook salmon may have shifted their diets to feed on fish that have greater concentrations of thiaminase (thiamine-degrading compound). Thiamine deficiency complex in adult salmon can cause high mortality in the early life stages of their progeny (e.g., prior to emergence). During the previous two years, thiamine deficiency complex has been reported to have impacted Chinook salmon in fish hatcheries in the Central Valley (e.g., Feather River Fish Hatchery and Livingston Stone NFH). Currently, the SacPAS Fish Model does not account for thiamine deficiency impacts on egg-to-fry survival.

In WY 2021, spawning distribution was generally similar to historical (2003-2020) patterns however there was an increase in the upstream reach, Keswick Dam to ACID Dam (2021: 49.9%; 2003-2020: 34.4%). Proportions in the lower reaches was generally similar to historical patterns observed in these reaches over the last twenty years. Based on the summary results described in the Fisheries section, both the spatial and temporal requirements for Shasta Lake cold water pool management may over time lead to reduction in the spatial and temporal distribution of winter-run Chinook salmon spawning in the upper Sacramento River.

Drought conditions in 2014 and 2015 resulted in an inability to meet a 56°F temperature target at any of the past temperature gaging locations and a target location using 56°F at CCR (located ten miles downstream of Keswick Dam) was used. Winter-run Chinook salmon spawning distribution has shifted upstream through the years such that nearly all spawning now occurs upstream of CCR and is concentrated near the Sundial Bridge, four miles below Keswick Dam. When the 56°F target was attainable further downstream (i.e., Airport Road, Balls Ferry, Jellys Ferry) the area where most spawning occurred (i.e., upstream of Clear Creek) was well below the 56°F target. Low survival during the 2014 and 2015 drought years showed that the 56°F at CCR appears not to be fully protective of incubating eggs.

Water temperature management in 2014 and 2015 targeted 56-58°F at CCR (**Table 2**). Following the low survival in 2014 and 2015, Martin et al. (2017) and Anderson (2018) modeled temperature dependent mortality for eggs and alevins. Martin et al. (2017) hypothesized and modeled that intra-gravel dissolved oxygen near the eggs becomes depleted from respiration in the eggs and that eggs need temperatures below 53.5°F to compensate for this effect. Lower water temperatures reduce the metabolic rate of the eggs, slow maturation, and increase the oxygen holding capacity of water. Anderson (2018) built on this and using literature on metabolic rates during egg maturation, showed the highest metabolic rate is at the time near hatching. Therefore, he fit a model to historic data using this effect by focusing the cooler water period (53.5°F and below) at the period prior to hatching. In years with limited cold water pool volume, this scenario, if it holds true, could support higher survival than targeting a constant temperature throughout the May to October winter-run Chinook salmon egg incubation season.

Egg-to-fry survival refers to the survival rate of eggs from the time they are deposited in the gravel by a female until the fry emerge from the redd as free-swimming fish at the RBDD rotary screw traps. Estimates in the Sacramento River have referred to egg-to-fry survival based on the locations where enumeration of fish occurs. CDFW, USFWS, and PSMFC collaborate to produce egg-to-fry survival estimates annually. These estimates utilize the following information: an estimated number of spawning females; estimated fecundity of the females derived from egg takes at Livingston Stone NFH; and the estimated number of fry equivalents passing RBDD derived from emigration monitoring using rotary screw traps at that location.

The number of eggs in the gravel compared to fry passing RBDD provides a surrogate estimate for true egg-to-fry survival. An unknown amount of mortality occurs between the time the fry emerge from the gravel and when they make it down to Red Bluff. Water temperature is one factor affecting egg-to-fry survival and is the factor water management has been able to influence. Other factors affecting egg-to-fry survival include fertility rate of the eggs, predation in the gravel by aquatic invertebrates and fish, ability of fry to maneuver their way out of the gravel and into open water, predation of fry after emergence, water temperatures after emergence, food availability and nutrition, habitat, contaminants, and disease. While the egg-to-fry survival estimates from USFWS do not explicitly account for each of these factors, it is assumed they impact survival. Some of these factors are correlated; for example, predation on fry and juveniles is likely higher in warmer water and this relationship becomes a part of the egg-to-fry survival estimates.

A background level of mortality is that mortality which would occur under otherwise optimal conditions for egg incubation and juvenile survival. A way to estimate background mortality is using hatchery survival rates. Hatcheries attempt to optimize conditions for survival and can generally attain a 90% or higher egg survival and overall survival from egg to release of greater than 50% (see Figure 10 in Mackinlay et al. 2004 and Bradford 1995). Livingston Stone NFH egg-to-fry survival for mainstem Sacramento winter-run Chinook salmon in 2021 under sub-optimal water temperature was 90% and for eggs from adults transferred from Battle Creek was 63%. However, adults at Livingston Stone NFH were treated for thiamine deficiency.

Eggs are the most abundant lifestage and changes in this lifestage's survival rate can greatly influence overall cohort productivity. In years of low cold water pool volume in Shasta Lake, water temperatures are harder to meet and in recent years this has been a limiting factor in freshwater productivity. Coupled with lower egg-to-fry survival rates, below normal flows and lack of precipitation-induced pulse flows from tributaries correlate with lower survival down the river to the ocean.

The temperature-dependent mortality and egg-to-fry survival estimates are used to gauge the effectiveness of actions taken to maintain the species in the 2020 ROD. In 2021, the estimated egg-to-fry survival from the NMFS Juvenile Production Estimate letter for BY 2021 (2.56%) was lower than the modeled estimate from the SacPAS Fish Model (3-6%). Other factors outside of model calibrations, such as thiamine deficiency in adults, may have interacted to reduce survival. Attempts to increase survival include physical habitat enhancements, fish passage improvements, flow management, water diversion management, harvest management, control of contaminants and non-native species management. Livingston Stone NFH has been used to compensate for low in-river survival and, even there, water temperature targets are sometimes exceeded without intervention measures such as mechanically cooling the water coming from Shasta Lake (as was done in 2021).

The estimates for temperature-dependent mortality, egg-to-fry survival, and unattributed mortality (which represents other mortality factors upstream of RBDD) for BY 2002 – 2021 is shown in **Figure 25** as point estimates and do not incorporate uncertainty.  Uncertainty in these point estimates include the abundance of fry equivalents passing Red Bluff, variation in fecundity of spawning females, viability of eggs, and temperature and background mortality rates.

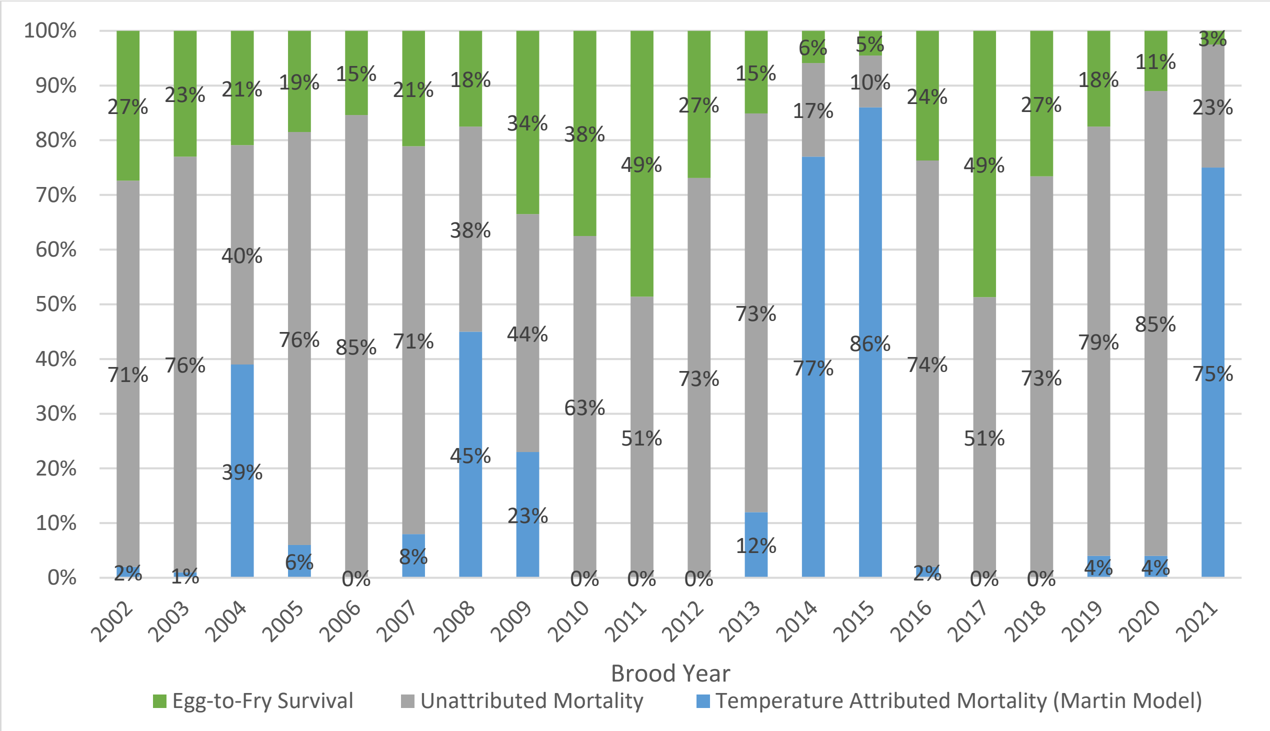


**Figure 25.** Winter-run Chinook salmon temperature attributed mortality (%; in blue), unattributed mortality (%; in gray), and egg-to-fry survival (%; in green) for BY 2002 through 2021. Temperature dependent mortality (i.e., temperature attributed mortality) estimates obtained from NOAA-Southwest Fisheries Science Center. Final egg-to-fry survival for BY 2002 to 2019 were provided by USFWS. Preliminary egg-to-fry survival estimates for BY 2020 and 2021 obtained from the NMFS Juvenile Production Estimate letters. Unattributed mortality (which represents other mortality factors upstream of RBDD) was derived from subtracting temperature attributed mortality from total mortality.

The unattributed mortality occurs during the egg incubation and free swimming lifestages, while the temperature dependent mortality is being estimated only when eggs are in the gravel. There may be temperature impacts outside of the egg incubation lifestage. If temperature dependent mortality was lower, there may have been additional mortality from other sources.

# Improvements

Improvements listed in this section may be evaluated as potential future updates to Shasta Lake cold water pool management, including the Shasta Cold Water Pool Guidance Document, that could assist operations in upcoming water temperature management seasons. Improvements may also be considered or evaluated by the four-year independent review panels.

## Pilot Projects

Potential pilot projects that could be pursued in the future, assuming appropriate legal authorities and appropriations are in place, include:

- The Shasta Dam Fish Passage Evaluation Pilot Implementation Plan could be carried out to learn ways to provide a cool water refuge to winter-run Chinook salmon, especially in, but not limited to, years when temperature goals cannot be met downstream of Keswick Dam. An iterative approach where we can learn more with each pilot year would be beneficial and the sooner tests could be carried out the higher the chance of increasing reproductive success in subsequent years.

Around 2,000 cfs of spring-fed water occurs in the watershed upstream of Shasta Reservoir at year-round temperatures that can support high egg to fry survival. **Figure 26** shows water temperature upstream of Shasta Lake, in the McCloud River five miles below the dam, compared with below Keswick Dam and CCR water temperatures. The McCloud River temperatures are closer to what winter-run Chinook salmon evolved with though the McCloud Dam diversion and the travel time below the dam under lower flows results in warming of the McCloud water by up to 10°F in the warmest part of the year compared to the upstream of McCloud Reservoir temperatures closer to the spring-fed water source. The springs in the upper McCloud River discharge a baseflow of about 600 cfs at 45°F year-round with the main source about 6.5 miles upstream of the reservoir pool.

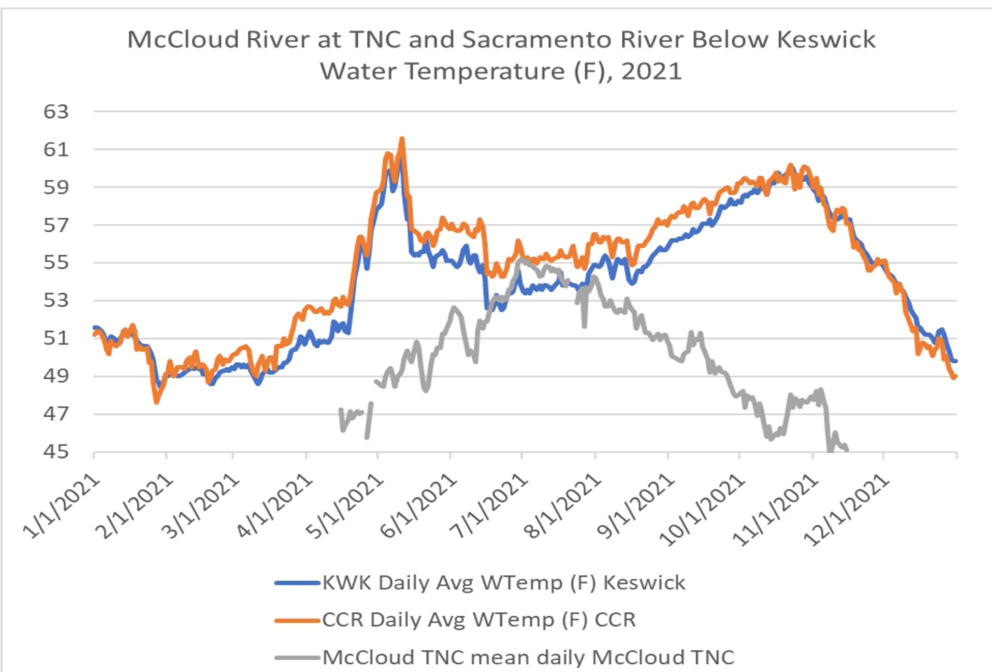


**Figure 26.** Water temperature in 2021 in the primary spawning reach in the lower Sacramento River compared to McCloud River at The Nature Conservancy (TNC) site.

- Reclamation and USFWS could explore moving Livingston Stone NFH to a new location upstream of Shasta Dam where year round cool, clean, spring-fed water sources are available. Potential locations that may be considered could be in the town of Mount Shasta, in the town of McCloud, or near the head of McCloud Lake. Facilities exist at Mount Shasta Hatchery that may be improved to facilitate raising Chinook salmon. This could eliminate

issues with warm water at the hatchery and eliminate disease concerns of feral fish upstream of Shasta Lake infecting Livingston Stone NFH fish. Livingston Stone NFH was initially constructed to be more of a temporary facility and has turned into a long term operation in need of infrastructure upgrades to meet current needs.
- A conservation measure that was in the 2020 ROD was to conduct a trap and haul in years like 2021 to get winter-run down the river. This was not pursued in 2021 and could potentially be considered for future pilot evaluation.

## Recent Study Results

A study recently published in the San Francisco Estuary and Watershed Science Journal relevant to Shasta operations is the Jennings and Hendrix (2020) paper titled "Spawn Timing of Winter-run Chinook in the Upper Sacramento River".

Emerging research indicates the peak spawning timing of Sacramento River winter-run Chinook salmon (SRWC) may be influenced by water management decisions that are intended to conserve cold water for use during the summer temperature management season (Johnson et al. 2017; Windell et al. 2017). Annually, the timing of the SRWC spawning start is relatively constant while the peak varies year to year – with cool springtime temperatures triggering earlier peak spawning, and warm springtime temperatures triggering later peak spawning (Hendrix et al. 2017, Jennings and Hendrix 2020). Specifically, there is evidence that higher April/May water temperatures correspond to increased and delayed peak spawning in July/August. The POLR model using both April and May temperatures as cofactors had the best fit to observed female spawner data based on AIC score
(Jennings and Hendrix 2020). In their historic spring-fed stream habitat, cool spring temperatures are hypothesized to result in an earlier peak in spawning to ensure sufficient time for egg maturation in cool years and prevent egg and alevin mortality in warm years. Findings from these investigations may inform temperature management fishery objectives and affect SRWC reproductive performance on the Upper Sacramento River (NMFS 2014, 2018, Reclamation 2019). In light of this relationship, two possible management strategies are suggested by Jennings and Hendrix (2020):

> To mitigate winter-run Chinook egg and alevin mortality during drought years, two possible strategies for cool-water management are: (1) release cool water early (April-May) to drive the peak of winter-run spawning earlier in an attempt to achieve emergence from gravel before temperatures increase; or (2) hold cool water until later in the season, when the bulk of spawners begin to deposit eggs… ultimately, models that combine reservoir management dynamics with SRWC spawning and egg incubation will be necessary to understand how reservoir management might affect spawn timing, egg and alevin development, and egg-to-fry survival under various climate conditions.

In 2021, peak spawning occurred in the last half of June through first half of July. Compared to historical data (2003 – 2020) it appears coincidence of peak spawning (defined as 20-80% of total annual spawning) in 2021 was high (**Figure 27**). In the historic record 20% of spawning occurred by June 26 and in 2021, 20% of spawning occurred by June 28. In the historic record 80% of spawning occurred by July 26 and in 2021 80% of spawning occurred by July 27.

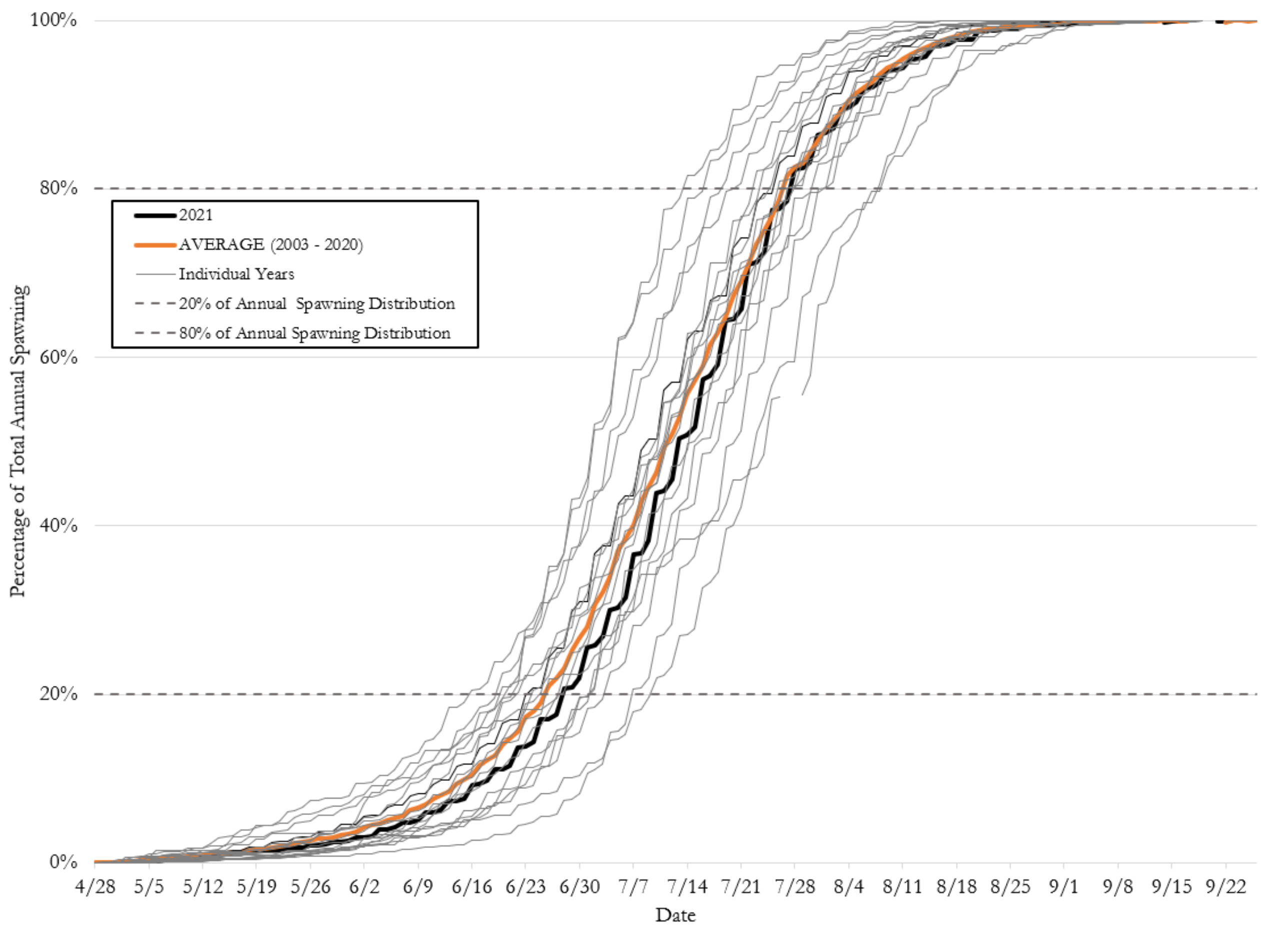


**Figure 27.** Cumulative annual spawning distribution by year 2003 through 2021. The orange average line represents an average of 2003 through 2020, 2021 is plotted independently (thick black line). The plot shows date of carcasses observed and spawning date is a week or two earlier than observed carcass date.

## Modeling Improvements

Reclamation is leading a collaborative effort to develop new temperature models for all CVP reservoirs and key downstream river reaches through the Sacramento River Science Partnership. This includes Shasta Lake and the Sacramento River downstream to Red Bluff. The multi-year project began in 2021 and included two meetings with SRTTG members and other interested stakeholders. Several limitations of the current modeling will be addressed in future development efforts.

In order to conserve cold water in Shasta Lake, a warm water power bypass at Shasta Dam was conducted in the spring of 2021. Since the HEC-5Q temperature model was unable to fully evaluate the impact of this action, Reclamation and the SRTTG relied on HEC-5Q outputs for Shasta Dam target release temperatures, stakeholder analysis and TDM models from NMFS Southwest Fisheries Science Center. In addition, the TCD temperature curtain was not deployed in 2021 and the TCD leakage estimates within the HEC-5Q model were not adjusted. Future modeling efforts should allow for power bypass, various TCD leakage assumptions and the ability to easily share data with SRTTG members.

Similar to the drought in 2015, adjustments were made to the temperature model to address the thermal effects to the low Keswick Dam releases in 2021.

## Monitoring Improvements

A suite of meteorological instruments will be deployed consistent with DWR's statewide monitoring network: California Hydrologic Data Acquisition System Stations (HyDAS) at Shasta Dam station SHS. Work is on-going and station completion is expected in late 2021 or early 2022.

The aerial redd surveys added a redd mapping workflow in 2021 and this could be continued in the future with an effort to increase accuracy of redd locations. This can be used to manage habitat and flows relative to spawning locations.

Dewatered redds could be monitored with increased intensity to look at survival of embryos relative to temperatures experienced at the site. The fish in dewatered redds are assumed to not survive to emergence so this could relieve take issues associated with excavating to check for dead eggs and alevins.

## Analytical Tools

**Central Valley Prediction and Assessment of Salmon (CVPAS/SacPAS)**

Reclamation provides funding support to the University of Washington to develop a webtool to provide information integration services. The web-based services relate fish passage to environmental conditions and provide resources for evaluating the effects of river management and environmental conditions on salmon passage and survival. These tools will be further developed to provide for a new system of forecasting in-season impacts of temperature and flow management. This system will integrate existing monitoring systems and should provide insight into the biological results and effectiveness of actions implemented as part of the Central Valley Project Improvement Act (CVPIA), including temperature management, flow management, and potentially habitat restoration.

SacPAS is publicly-accessible on the SacPAS: Central Valley Prediction & Assessmnet of Salmon website.

The SacPAS website includes the Fish Model, which predicts the timing and survival of juvenile salmon from spawning through smolt passage into the San Francisco Bay at Chipps Island. It links together four model systems:

1. CVTEMP model forecasts the temperature in the winter-run Chinook habitat
2. Emergence model predicts fry emergence timing and egg-to-RBDD survival
3. Migration Model predicts the movement and survival of smolts to the Delta
4. STARS model predicts the movement and survival of fish through the delta.

The current Fish Model and associated life-stage tools predict consequences of water operations on juvenile fish passage and survival. The Fish Model will be further developed with the aim of producing a more integrated system analysis and forecast system for fishes of the Central Valley. A TDM subteam has been formed. This team should review the input parameters in the Fish Model to determine which are best for predicting temperature dependent mortality. After the TDM subteam determines which input parameters are the best, those parameters can be saved as default parameters in the Fish Model to improve the user-friendliness of the Tool.

New features are being developed that would help evaluate performance of cold water pool management. These features include:

- Sacramento River Temperature Task Group page to organize all the information that the SRTTG would be interested in.
- Figures to depict historical migration timing of Chinook salmon.
- Upload water velocity, flow, temperatures and other data generated from physical models including CVTEMP and DMS2 when made available from collaborating agencies. For example, short-term and long-term modeled temperature data will be uploaded from the NOAA CVTEMP website.
- Real-time redd data
- RBDD Passage Model: The life segment between fry emergence and RBDD passage is critical in determining early life survival and ultimately cohort success. The current Fish Model characterizes winter-run Chinook salmon survival in this segment by a fixed background value. Fish survival and growth will be modeled to better resolve time-dependent changes in survival over the migration season. The approach will use a stochastic movement equation that characterizes the movement, growth and survival of fish from fry emergence to passage at RBDD.
  The proposed RBDD Model will link the fry emergence distribution (timing, location) to the RBDD passage distribution (size-number-frequency) by a stochastic process that characterizes the protracted arrival distribution and size-frequency distribution of fish at RBDD. The spatio-temporal distribution of fry emergence is generated by the Emergence Model, and the RBDD passage data are depicted by the daily/weekly size-frequency distributions reported by the fish monitoring program. The two distributions will be linked by four free parameters of a stochastic moment model: fish growth rate, mean and variance of fish migration velocity, and mortality rate.
- SacPAS tutorial recording to assist users in learning how to use these tools.

# Conclusion and Management Summary

WY 2021 had the lowest inflow to Shasta Lake on record and followed a dry year (WY 2020). Various cold water pool management strategies were considered and the SRTTG tried to optimize usage of the limited resource. Reduced releases from Shasta Lake, if possible given other constraints in the system, could have helped preserve both reservoir storage and cold water pool; however, reduced releases would at the same time not make it possible to meet downstream requirements without increasing demands on other reservoirs. While the warm water power bypass may have affected increased pre-spawn mortality of adult winter-run Chinook salmon, the action appeared to benefit winter-run Chinook salmon egg incubation and should be retained for consideration as a management tool. Water transfers likely benefitted winter-run Chinook salmon egg incubation by deferring the required releases from Keswick Dam; however, this created later season tradeoffs that complicated fall-run Chinook salmon redd dewatering. Additional analyses are being developed for the subsequent Shasta Lake Storage Rebuilding and Spring Pulse Seasonal Report (anticipated June 2022). Delayed Sacramento River Settlement Contract deliveries in April were not identified as a beneficial action this year and was not employed.

The 2021 Temperature Management Plan detailed a Tier 4 performance category and specified temperature targets at the SAC gage. Reclamation's hindcast temperature-dependent mortality estimates ranged from 76-87% in 2021. There are no specific Tier 4 Upper Sacramento River Performance Metrics for temperature-dependent mortality in the 2020 ROD. No need was identified by the agencies for an independent panel review for WY 2021.

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# Supporting Links

State Water Board Water Rights Order 90-5 - https://www.waterboards.ca.gov/waterrights/board_decisions/adopted_orders/orders/1990/wro90-05.pdf

Sacramento River Temperature and Order 90-5 Compliance - https://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/sacramento_river/

SRTTG Notes - https://www.usbr.gov/mp/bdo/water-year-2021-rivertask.html

CDFW Upper Sacramento River Basin Salmonid Monitoring Program data on CalFish - https://www.calfish.org/ProgramsData/ConservationandManagement/CDFWUpperSacRiverBasin SalmonidMonitoring/tabid/357/Agg2208_SelectTab/4/Default.aspx

SacPAS - http://www.cbr.washington.edu/sacramento/

NMFS Juvenile Production Estimates - https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/california-central-valley-water-operations-biological