BUREAU OF RECLAMATION

2022 Seasonal Report for the Shasta Coldwater Pool Management

Central Valley Project, California
California-Great Basin Region

Shasta Dam and Lake on July 20, 2022. Photo Credit: Reclamation

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.

2022 Seasonal Report for the Shasta Coldwater Pool Management

Central Valley Project, California
California-Great Basin Region

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Purpose

This 2022 Seasonal Report for Shasta Coldwater Pool Management describes Shasta Dam operations leading up to and through the 2022 coldwater pool management season. This seasonal report may support improvements, if necessary, to the Shasta Coldwater 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 Coldwater 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 2022 (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 coldwater pool management of Shasta Lake.

Background

Shasta Dam and Lake represent about 40% of the total reservoir storage capacity of the CVP, and is 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 interested parties. Shasta Dam 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.

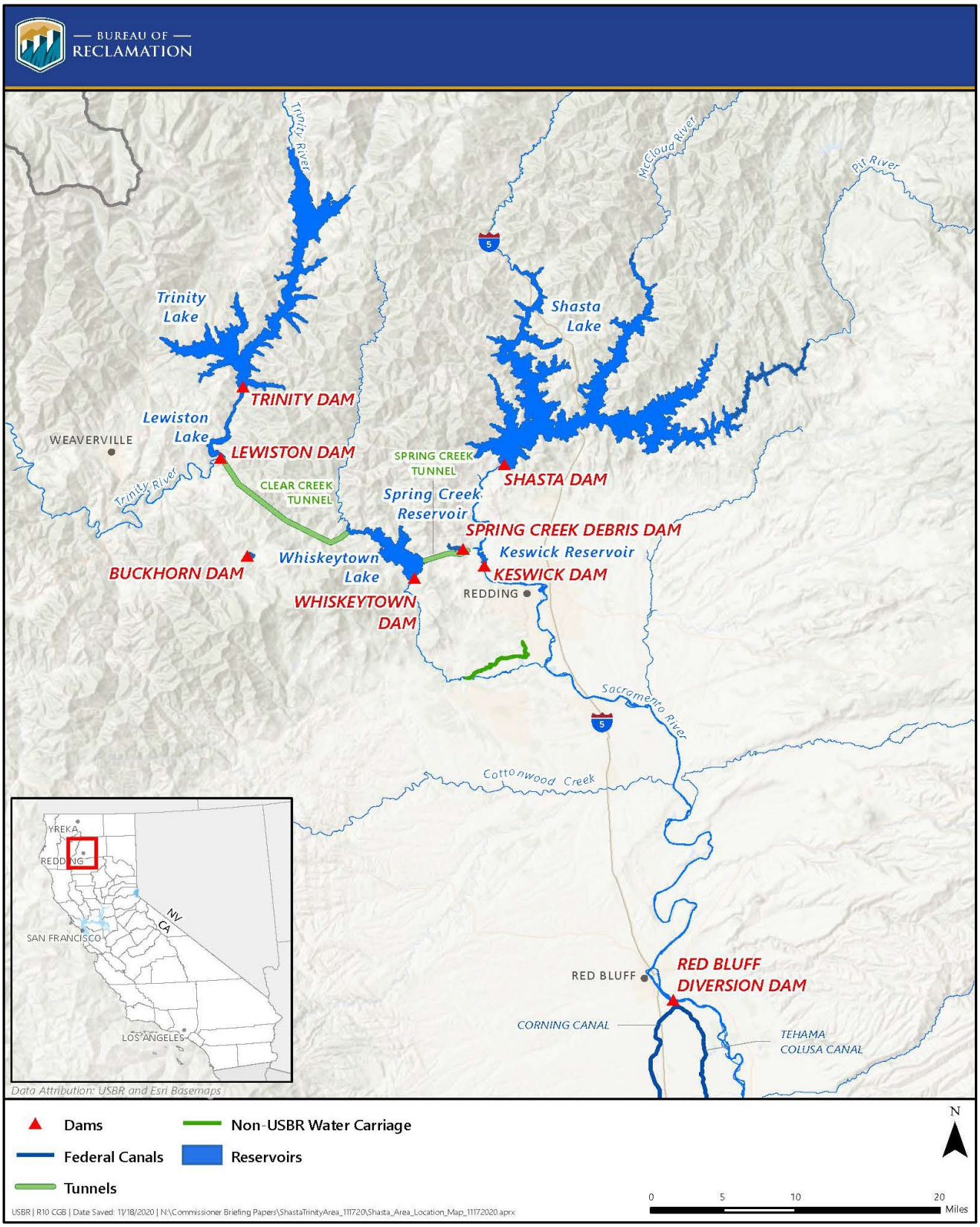

Figure 1. Shasta-Trinity System located in Northern California.

The ROD discussed above established a tiered coldwater management strategy for the summer and fall seasons, based on the projected availability of coldwater 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 coldwater is a scarce resource to be managed to achieve targeted water temperatures for winter-run Chinook salmon egg survival. The Shasta Coldwater Pool Management Guidance Document (Appendix A) provides implementation guidance on the Sacramento River's coldwater 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 coldwater pool management; the Sacramento River Temperature Management Plan (TMP), and documentation of the operations decisions.

Reclamation must also comply with State Water Resource Control Board (State Water Board) Water Rights Order 90-5 which establishes 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 prevent Reclamation from maintaining 56°F at RBDD, Reclamation will consult with CDFW, USFWS, NMFS, and WAPA and submit a temperature management plan to the State Water Board showing a strategy to meet the water temperature requirement at a different location upstream.

Seasonal Operations

This section describes relevant information for Shasta Lake operations during the coldwater pool management season, including operational background information, historic precipitation and water temperature data, winter and spring operations, and a narrative of real-time conditions during the summer and fall of 2022. Additionally, information on winter-run Chinook salmon spawning and outmigration in 2022 is presented.

Operational Background Information

Coldwater management at Shasta Lake uses a tiered strategy that allows for strategically selected water temperature objectives, based on projected total storage and coldwater pool, meteorology, Delta conditions, and habitat suitability for incoming fish population size and location. The following tiers are described in the Proposed Action:

- Tier 1 – Sufficient volume of coldwater to target 53.5°F or lower at Clear Creek temperature gauging station (CCR) starting May 15 through October 31;
- Tier 2 – Sufficient volume of coldwater to target 53.5°F at CCR during critical egg incubation period;
- Tier 3 – A volume of coldwater 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 water 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 includes modeling and professional expertise to identify the most protective tier that can be achieved given the available coldwater volume and anticipated release schedule. Before the reservoir stratifies and the volume of coldwater is known, water temperature management capabilities are approximated based on projections of storage.

Operational decisions on the upper Sacramento River are influenced by local, CVP and SWP system-wide multi-purpose objectives and management uncertainties. 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 U.S. Army Corps of Engineers (USACE) downstream flood protection requirements). Planned operational targets are regularly updated late winter through early summer depending on hydrologic conditions on Reclamation's website (https://www.usbr.gov/mp/cvo/).

Reclamation convenes monthly SRTTG meetings to ensure communication and coordination among the parties in preparation for the temperature management season. SRTTG meeting notes can be found at: https://www.usbr.gov/mp/bdo/water-year-2022-rivertask.html. Reclamation prepares projections of anticipated water temperature management capabilities on a monthly timestep for the SRTTG. In mid-February of each year, Reclamation prepares initial projections of anticipated water temperature management capability and considerations based on the February hydrologic and runoff forecasts from DWR and the National Weather Service California Nevada River Forecast Center (CNRFC).

Reclamation developed a draft TMP and submitted it to the SRTTG on April 4, 2022, 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 coldwater pool for the duration of the temperature control period through October 31, 2022. SRTTG members were provided the opportunity to comment on the draft TMP. On May 2, 2022, Reclamation developed a final TMP (Appendix B) with substantial coordination and input from members of the SRTTG. The TMP included temperature compliance locations and targets through October 31, modeled winter-run Chinook salmon temperature-dependent egg mortality, dates for operation of the side gates on the TCD, and Shasta Lake end of September storage.

Discussion of pre-season actions and the development of the TMP is provided below. Conditions of the coldwater pool from 2012 – 2022 are recorded in **Table 1**. Sacramento River temperature compliance point data from 2012 - 2022 are shown in **Table 2**.

Table 1. Shasta Lake Storage Volumes and Coldwater Pool Volumes in Thousands of Acre Feet (TAF) from 2012 - 2022.

Water Year	Peak Storage Volume	Peak Storage Date	End of April Volume < 56°F	Date 1st Side Gate Opened	End of September Volume Storage	End of September Volume <56°F	End of September Volume <52°F	End of September Volume <50°F
2012	4483	7-May	3791	21-Sep	2592	765	598	512
2013	3887	18-Apr	2809	11-Sep	1906	425	347	309
2014	2409	28-Apr	1770	7-Aug	1157	107	81	63
2015	2722	15-Apr	1912	13-Sep	1603	358	270	228
2016	4235	1-May	3267	23-Oct	2811	938	730	596
2017	4389	13-May	3975	N/A	3382	1146	806	594
2018	4200	26-Apr	3135	19-Sep	2405	607	485	388
2019	4477	31-May	3441	N/A	3425	1203	907	707
2020	3750	21-Apr	2986	13-Aug	2200	476	344	230
2021	2396	3-Apr	1587	6-Aug	1077	111	81	63
2022	1827	20-May	1361	18-Jul	1515	299	184	136

Table 2. Sacramento River Temperature Compliance Point Data for 2012 – 2022. Daily Average Temperature - Degrees Fahrenheit (Days Applied)

Year	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
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°
2022	SAC-55°	SAC-55°	SAC-55° (1) SAC-58° (2-31)	SAC-58° (1-6) SAC-54.5° (7-30)	SAC-54.5°	SAC-54.5°	SAC-54.5°	SAC-54.5°	SAC-54.5°

[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 continued in 2022, as compared to historical conditions. Historical Shasta Lake storage volume (from Water Year (WY) 1995 through the beginning of WY 2023) is shown in **Figure 2**. In WY 2022, end of May Shasta Lake storage volume was far below the historical average (1995 – 2022 average: 3.77 million acre feet (MAF); 2022 value: 1.82 MAF). Historical average air temperatures in Shasta County for May through October for a period of record 1895 - 2022 is shown in **Figure 3**. According to the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information, during the May through October 2022 time period, Shasta County experienced the third highest average air temperatures on record (average temperature of 68.8°F), behind only 2020 and 2021 (both averaged 69.2°F).

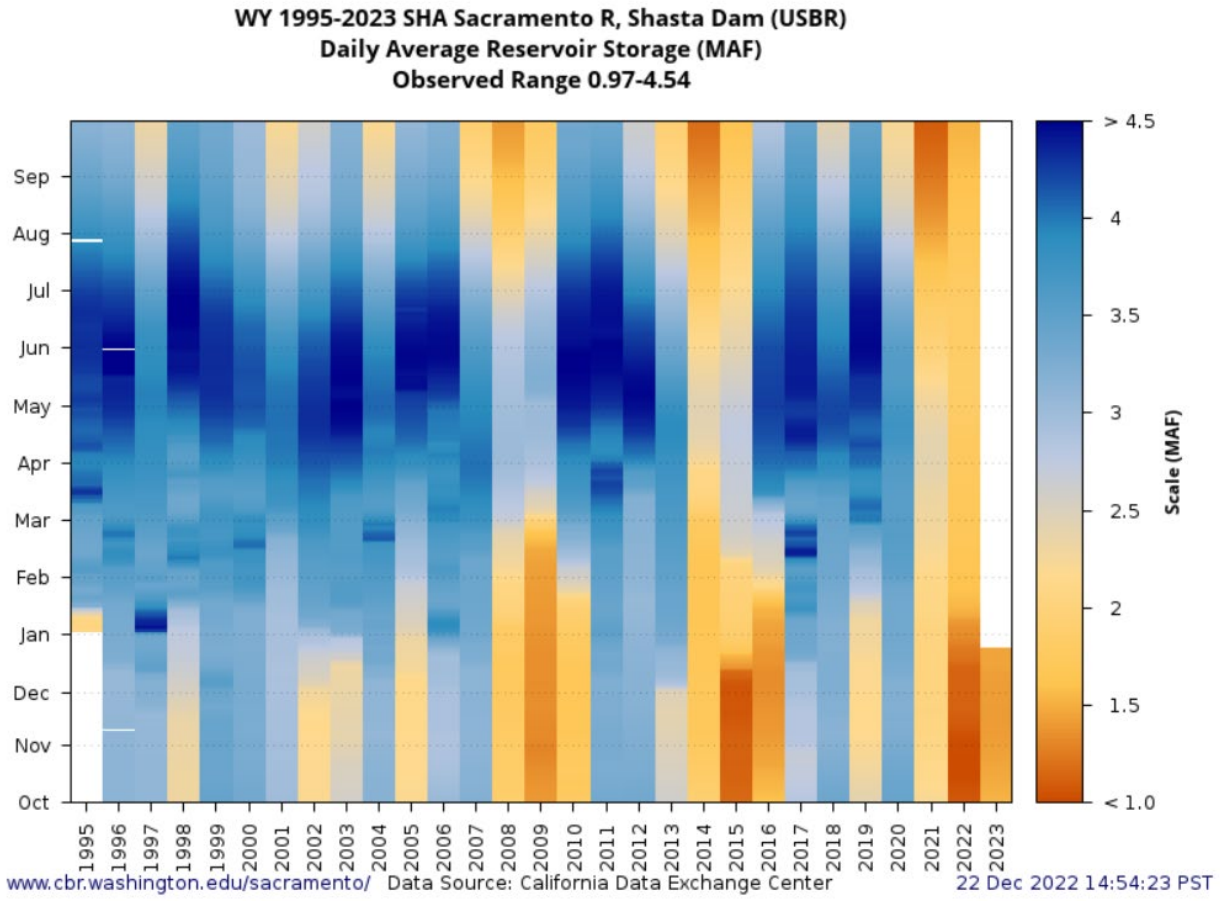

Figure 2. Daily average Shasta Lake storage from WY 1995 through the beginning of WY 2023. Source: http://www.cbr.washington.edu/sacramento/data/query_river_allyears.html

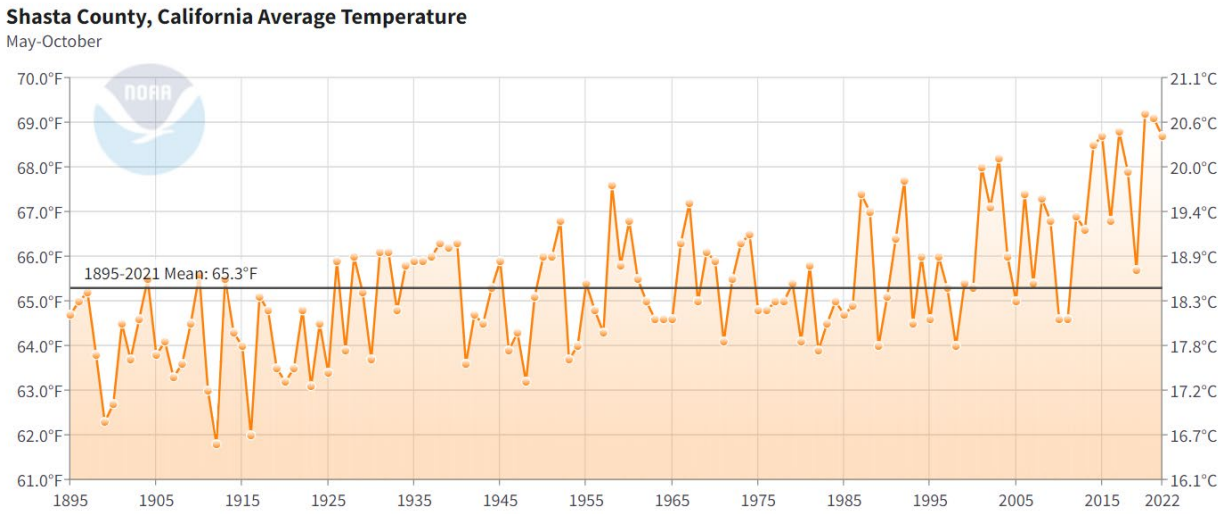

Figure 3. Average air temperature for May through October for a period of record 1895-2022. Source: https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/county/time-series/CA-089/tavg/6/10/1895-2022?base_prd=true&begbaseyear=1895&endbaseyear=2021

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 coldwater pool. The Sacramento River watershed basin runoff forecasted inflow volume and Shasta Lake coldwater pool quality (i.e., the amount of water at different temperatures) is fundamental to operational planning. The inflow volume projection is updated routinely by DWR and the 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 2022. Due to dry conditions, by April 2022 the variability between the 10%, 50% and 90% exceedance forecasts greatly decreased. The forecasts consider meteorological uncertainty and do not account for hydrologic uncertainties.

Beginning in January 2022, 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 45% and 46% of the average for the 90% and 50% runoff exceedances, respectively. The actual Shasta Lake inflow volume April through July was 787 TAF and the total WY 2022 Shasta Lake inflow volume was 2,993 TAF (Reclamation 2022).

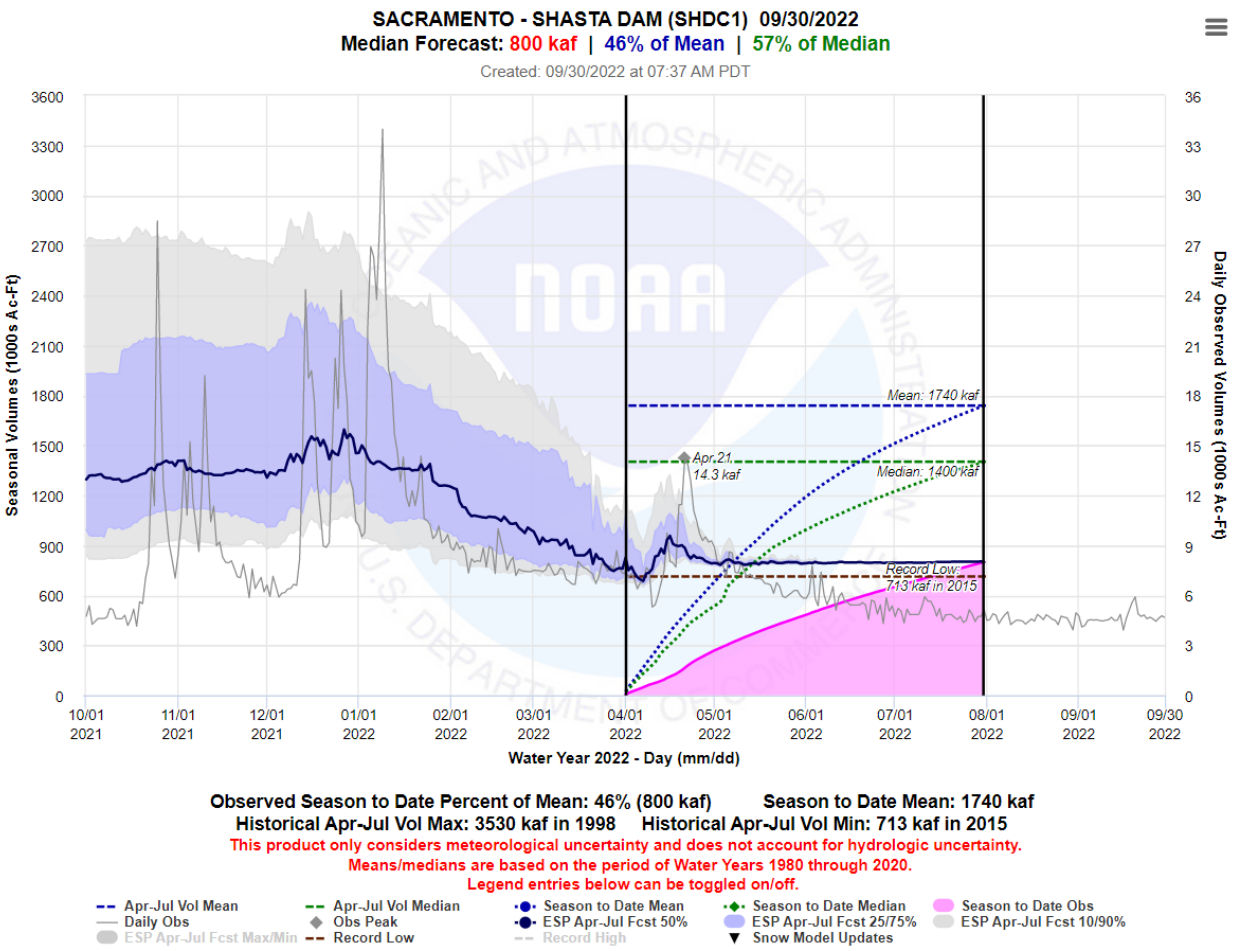

Figure 4. WY 2022 forecasted (10%, 50%, 90% exceedance) and actual daily and cumulative inflow volume at Shasta Lake. Source: https://www.cnrfc.noaa.gov/water_resources_update.php

Insight to the hydrologic characteristics of WY 2022 is 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 2022 Northern Sierra precipitation, Sacramento Basin snowpack, and Sacramento Valley Index statistics by month.

Water Year 2022 Month[1]	Northern Sierra 8-Station Precipitation (Cumulative water year in inches through beginning of 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	15.8	57	NA[2]	NA
December	30.2	143	NA	6.5
January	31.6	15	NA	7.5
February	32.0	4	75	6.2
March	33.3	15	65	4.8
April	39.4	142	35	4.2
May	40.0	22	8	4.5

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

WY 2022 yielded below average rainfall and snow, especially in January through March. In general, storage conditions in reservoirs were low in the fall of 2021 as a result of critically dry hydrologic conditions the previous year. After well below average rainfall, the snowpack in March 2022 indicated that sufficient reservoir inflow was not likely available to meet Tier 1, Tier 2, or Tier 3 temperature targets. The Sacramento Eight Station Index for WY 2022 reported 43.0 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 2022).

Storage and Flood Conservation Space

Shasta Lake storage conditions and Keswick Dam releases for WY 2022 are shown in **Figure 5** and **Figure 6**. In WY 2022, Shasta Lake storage conditions were below the USACE 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 1.82 MAF. Compared to other critically dry water years during WY 2000 – 2022, WY 2022 had lower than average storage volumes until approximately July (**Figure 7**), and Keswick Dam releases for downstream requirements were similar to the average until March; however, beginning in April, releases were below average

(**Figure 8**). Shasta Lake coldwater pool volume less than 52°F for WY 2022 was below average (**Figure 9**).

A series of system-wide drought actions were implemented in WY 2022 to support reduced releases from Shasta Lake in order to support temperature management through the summer of 2022. These additional actions are described in more detail in the May 1, 2022, Drought Contingency Plan (DWR and Reclamation 2022) and are briefly listed below for reference:

- Temporary Urgency Change Order to modify Delta requirements dated April 4, 2022
- Emergency drought barrier to minimize Delta salinity intrusion
- Minimum exports to limit releases needed to support Delta needs
- Urban water conservation to limit releases needed to support system needs
- Curtailments from the SWRCB to reduce demands throughout the system
- Low or zero allocations to CVP and SWP contractors

Additionally, the Interim Operations Plan (IOP), ordered by the US District Court on March 14, 2022, identified priorities and planning efforts for Shasta coldwater pool management to meet operational priorities and species needs. This IOP included establishing a six-agency Shasta Planning Group to work iteratively with the technical groups (e.g., SRTTG and USST) to solicit operational guidance and risk assessments and provide policy guidance as necessary.

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 2022 Shasta Storage Rebuilding and Spring Pulse Seasonal Report.

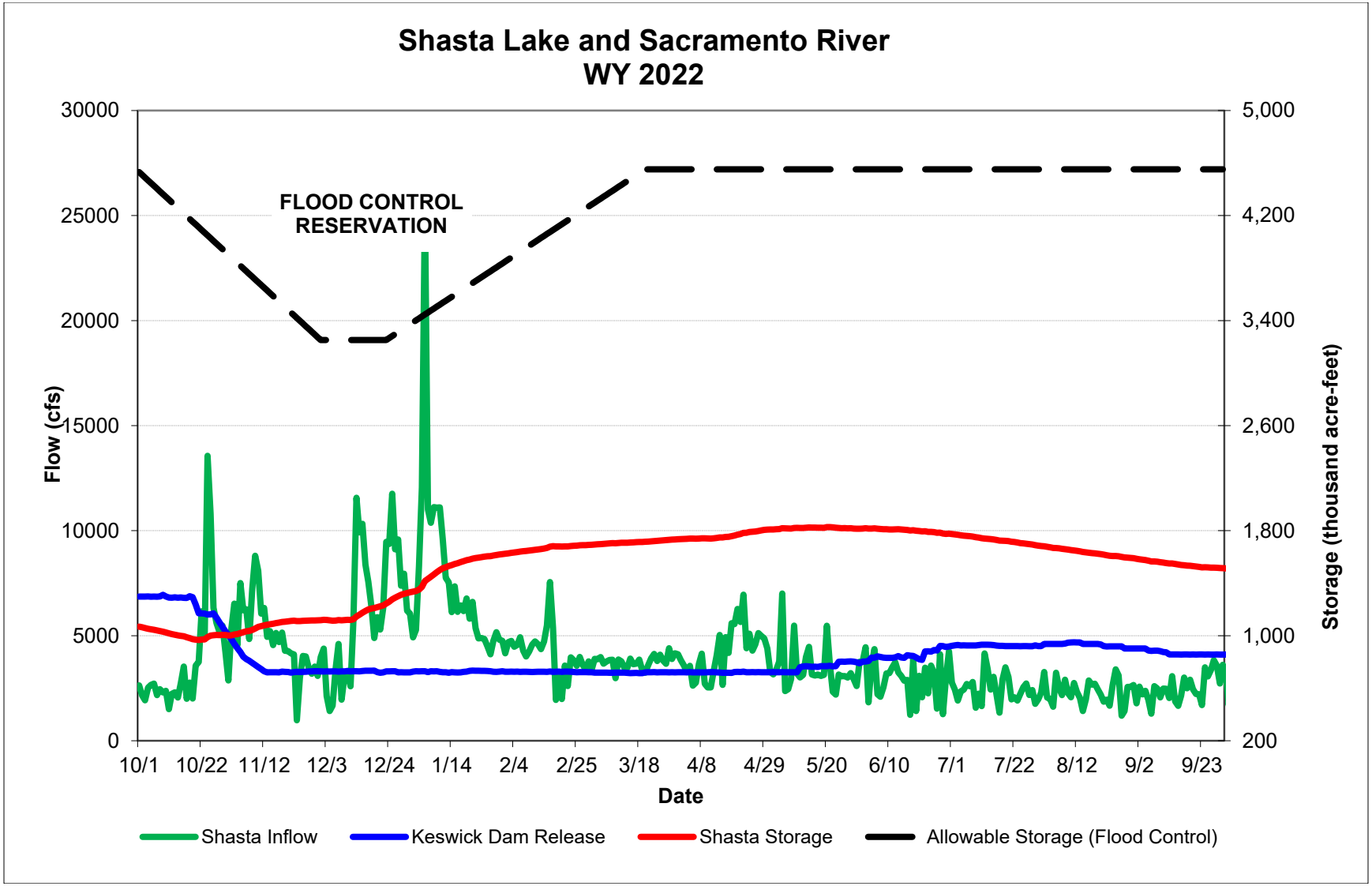

Figure 5. Shasta Lake Storage (red line), Allowable Storage for Flood Control (black line), Keswick Dam Release (blue line), and Shasta Inflow (green line) for 10/1/2021 – 9/30/2022.

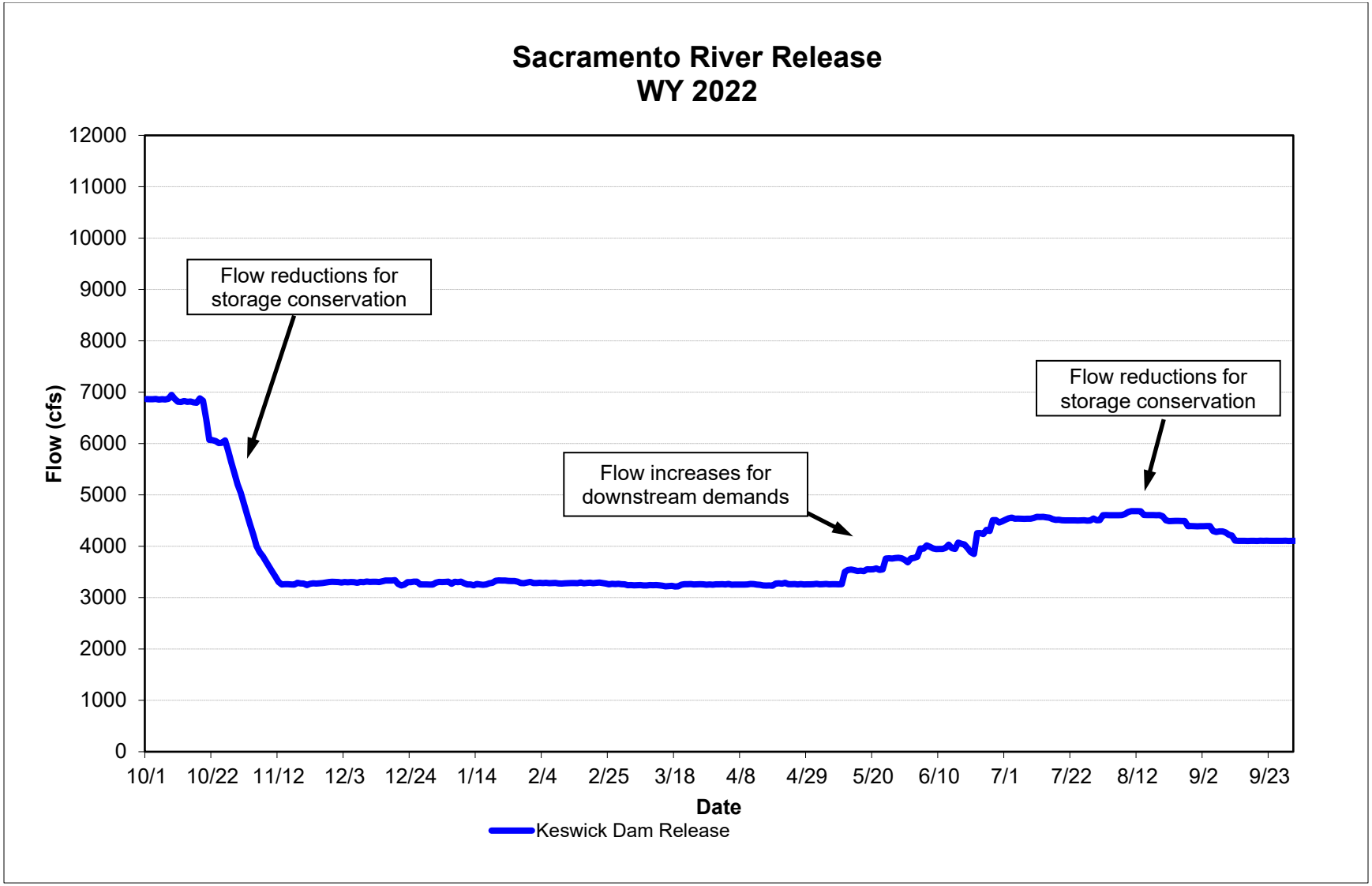

Figure 6. Sacramento River releases from 10/1/2021 – 9/30/2022 with major operations highlighted.

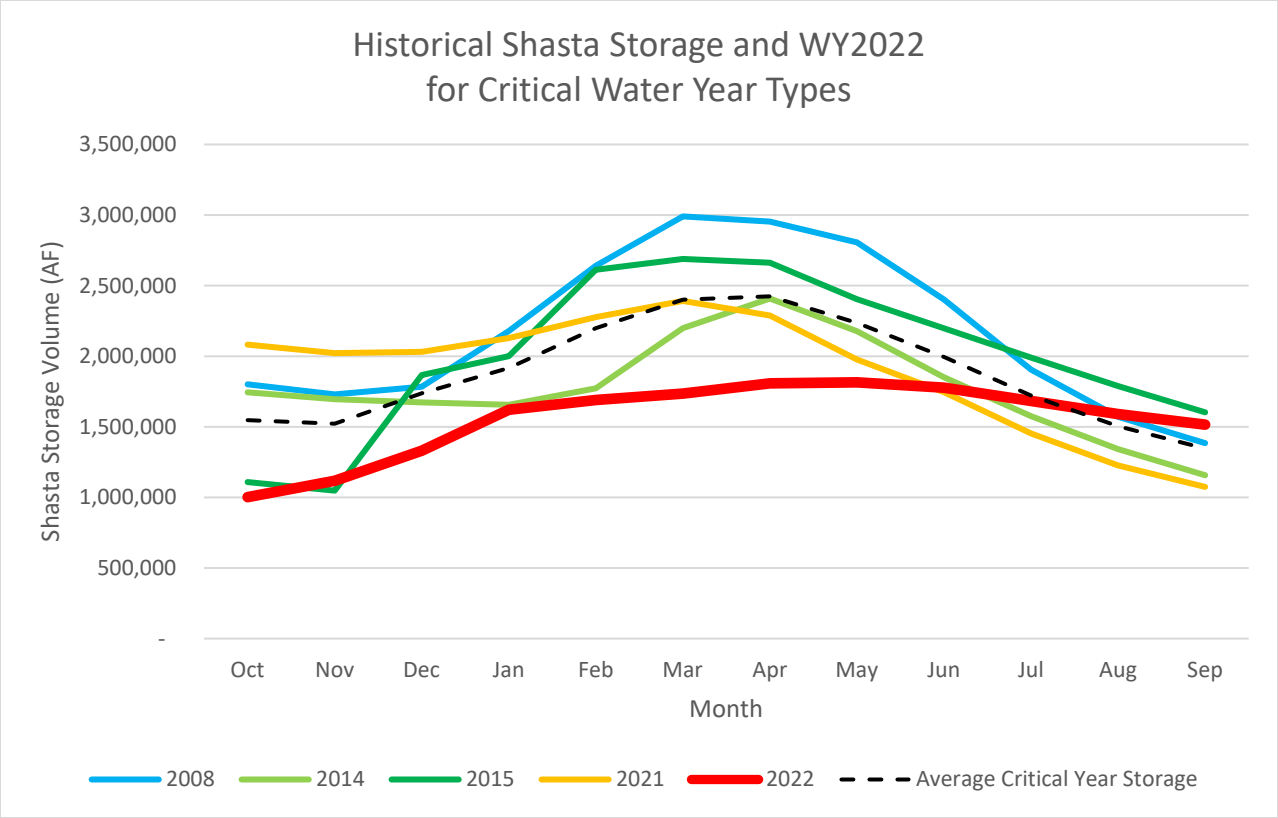

Figure 7. Shasta Lake storage in WY 2022 and in Critically Dry Water Years 2008, 2014, 2015, 2021 and 2022.

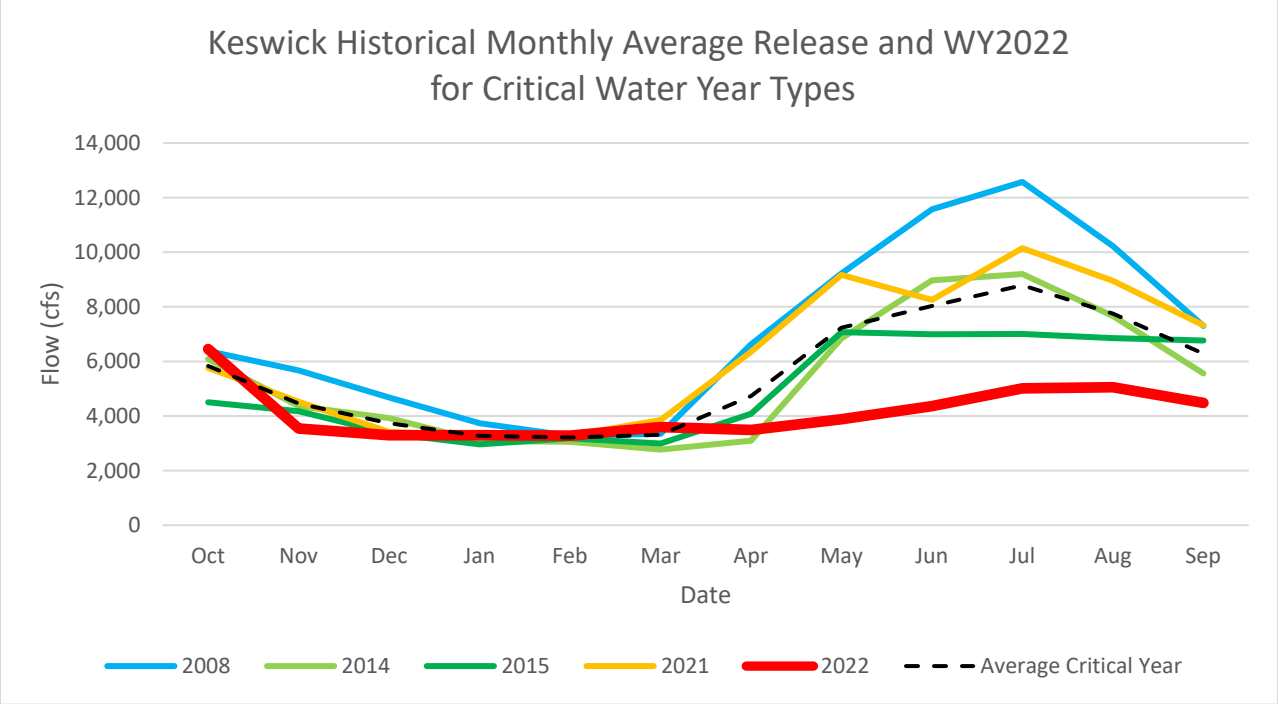

Figure 8. Monthly average Keswick Dam releases in WY 2022 and in Critically Dry Water Years 2008, 2014, 2015 2021, and 2022.

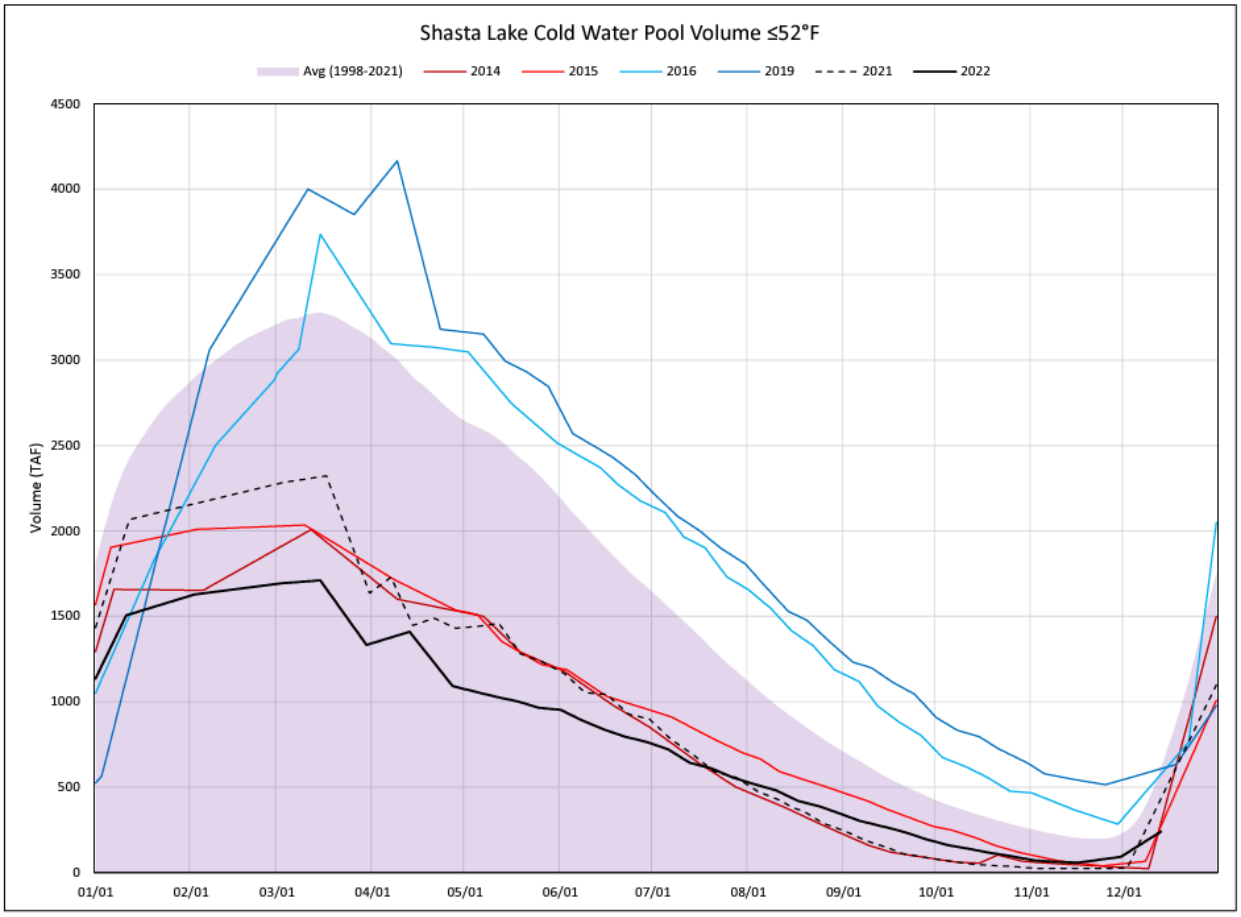

Figure 9. Shasta Lake coldwater pool volume less than 52°F for WY 2022.

Summer/Fall Water Temperature Management

The following sections describe 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 to strategically apply temperature objectives. Risk management aims to minimize 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 coldwater 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. 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 driving reservoir refill and coldwater pool replenishment in the late fall through spring period.

In February 2022, Shasta Lake inflow was very low due to unusually dry conditions, and forecasts suggested continued dry hydrological trends. February storage was below average for critically dry years and Keswick Dam releases remained low (around approximately 3,250 cfs) through February.

In February, to examine future coldwater pool management temperature performance, two forms of insight were considered: (1) relationship between total Shasta Lake storage/coldwater pool and potential future water temperature compliance; and (2) preliminary water temperature model simulation results. Based on projected May 1 total Shasta Lake storage being below 2.5 MAF, projected coldwater pool conditions, and the 56°F temperature target at CCR not being able to be met throughout the temperature management season, a Tier 4 year appeared likely.

Also in February 2022, a multi-agency team discussed increasing Livingston Stone NFH winter-run Chinook salmon production targets for WY 2022 to address the likelihood of a Tier 4 temperature management year. Typically, the USFWS would collect 60 females and 100 males out of the Keswick fish trap; however, due to poor habitat conditions and anticipated low survival of Brood Year (BY) 2022 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 8). Further, Reclamation prepared chillers for use later in the season in the event that water deliveries to the hatchery become too warm. Additionally, a Shasta Critical Year determination was made in February, which results in a shortage condition under the Sacramento River Settlement Contract to 75%. Due to the very low storage at Shasta Lake and the back-to-back years of low egg-to-fry survival for the endangered winter-run Chinook salmon (estimated at the Red Bluff Diversion Dam), Reclamation, DWR, NMFS, FWS, CDFW and the State Water Board worked with the Sacramento River Settlement Contractors (SRSC) to develop a Keswick Dam release plan that conserves Shasta Lake storage and prioritizes temperature management in the Sacramento River, as required by the Interim Operations Plan. This draft release plan identified preliminary quantities of available water for diversion by the SRSC and the wildlife refuges north of the Delta. The estimate was that approximately 18% of the total contract amount would be available for delivery in WY 2022 based on the release assumptions.

March through May

March is typically a storage and coldwater pool building month; however, Shasta Lake storage gained only approximately 45 TAF in March 2022. By the end of the month, the likelihood of low seasonal storage increased 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 coldwater pool management were assessed: (1) relationship between total Shasta Lake storage/coldwater pool and potential future water temperature compliance; and (2) preliminary water temperature model simulation results. Reclamation

determined there was not the volume of coldwater 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 the 2020 ROD, intervention action discussions continued as the March 90% runoff exceedance forecast suggested a May 1 storage condition less than 2.5 MAF.

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. Also in mid-March 2022, the SRSC initiated the meet and confer commitments under the 2020 ROD and began discussions on voluntary measures for Shasta Coldwater Pool Management Dry Years, Drought Years, and Successive Dry Years. Reclamation's Proposed Action Section 4.12.5 describes that in Tier 3 and 4 years, Reclamation shall meet and confer with USFWS, NMFS, DWR, CDFW, and SRSC on voluntary measures to be considered if drought conditions continue into the following year, including measures that may be beyond Reclamation and DWR's discretion.

Reclamation, DWR, NMFS, FWS, CDFW and the State Water Board continued work with the SRSC to develop a Keswick release plan that conserves Shasta Lake storage and prioritizes temperature management in the Sacramento River. This schedule was finalized in late March and included Keswick releases of a monthly average 4,500 cfs for May through September. Reclamation completed preliminary HEC-5Q modeling on April 4, 2022.

Reclamation also prepared initial projections of anticipated temperature management capability based on 90% March hydrologic and runoff forecasts, the Keswick release schedule, and historical performance. These projections and preliminary modeling were provided to the SRTTG as part of the draft TMP shared on April 4, 2022, and discussed during the SRTTG meeting held on April 7, 2022.

The draft TMP targeted 56°F at Highway 44 bridge gage (SAC) throughout the entire temperature management season until the available coldwater was used. This plan resulted in a forecasted temperature dependent mortality above 70% but conserved coldwater for maintaining temperatures in the fall. The draft plan also projected an initial side gate opening of July 16 and full side gate opening of September 1.

Reclamation received feedback from SRTTG members that the tradeoff of having lower TDM with warmer temperatures in the fall was favored and recommended targeting 54.5°F at SAC with the understanding this may mean warmer fall temperatures. This tradeoff was viewed in context with the maximum temperatures allowable by the Livingston Stone National Fish Hatchery which was determined to be 66°F from Shasta Dam assuming 10°F of cooling capability with the chillers. The fall temperatures seen in the temperature modeling targeting 54.5°F were well below 66°F and therefore this was the selected plan for the final temperature management plan. Reclamation also received feedback from SRTTG members that an initial target of 58°F in the spring prior to winter-run spawning would help to conserve coldwater for later during the more critical portion of the temperature management season.

On May 2, 2022, Reclamation distributed the final TMP to NMFS, the State Water Board, and SRTTG. The final temperature management strategy, based on recommendations received from members of the SRTTG, was to target 58°F at SAC during the initial part of the season and then target 54.5°F for 16 weeks around the estimated peak spawning date of August 2. This strategy would result in targeting 54.5°F from June 7 through September 27 or until the coldwater is used.

June through October

Real-time implementation of the 2022 TMP did not result in any major unexpected changes or deviations. Keswick Dam releases during this period tracked the TMP. A summary of upper Sacramento River temperatures is shown in **Figure 10**.

Events that influenced in-river conditions or real-time operation considerations included:

- TCD Operation: 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 coldwater for the temperature management season later in the year, while maintaining hydropower generation. The dry conditions and low reservoir storage in WY 2022 prevented pulling water into the TCD from the upper gates and therefore the middle gates were the highest elevation gates accessible to use in the spring. The first side gate was opened on July 18, 2022, and full side gate operation occurred on August 11, 2022. In early August, a Remote Operated Vehicle (ROV) inspected all of the middle gates on the TCD. Upon inspection, gates 2 and 5 were discovered to be seated improperly; Reclamation operators closed them. Reclamation plans to conduct an annual ROV inspection to make sure the gates seat properly. Deployment of the middle gate curtain helps reduce warm water leakage into the TCD. Due to low water levels and safety concerns, the TCD temperature curtain was not deployed in summer of 2022.
- Coldwater bypass: Implementation of a coldwater bypass was discussed in July and August. Ultimately it was determined by Reclamation that a coldwater bypass should not be pursued. Unless there is an issue with how the TCD functions, typically the TCD has removed the need for a power bypass. Reclamation has attempted power bypasses since the TCD was installed but have not seen much difference in water temperatures in the river.
- Carryover storage and release schedule: End of September storage, also referred to as carryover storage, was an operational consideration during the temperature management season in WY 2022. The end of September storage target of 1.14 MAF in Shasta Lake from the TMP was exceeded due to higher than expected inflows and actual end of September storage was 1.52 MAF. There were many efforts to manage Keswick releases in 2022; average monthly releases in May through September 2022 ranged from 4,363 – 5,054 cfs, approximately 1,800 – 3,800 cfs less compared to releases in the average critical year.
- Trinity River diversions: Trinity Reservoir storage in WY 2022 was low, and therefore minimal diversions from the Trinity River to the Sacramento River were made in the summer of 2022. This reduction in diversions was implemented to help minimize impacts to the Trinity River fisheries.

Daily Average Temperature and Temperature Targets

The daily average water temperatures for the SAC compliance location were compared against its respective daily temperature target for WY 2022 (**Figure 10**). From March through October 31, 2022, the temperature target at the SAC compliance location was exceeded in 53 days, with the average exceedance at 1.5°F (minimum exceedance: 0.1°F; maximum exceedance 2.6°F).

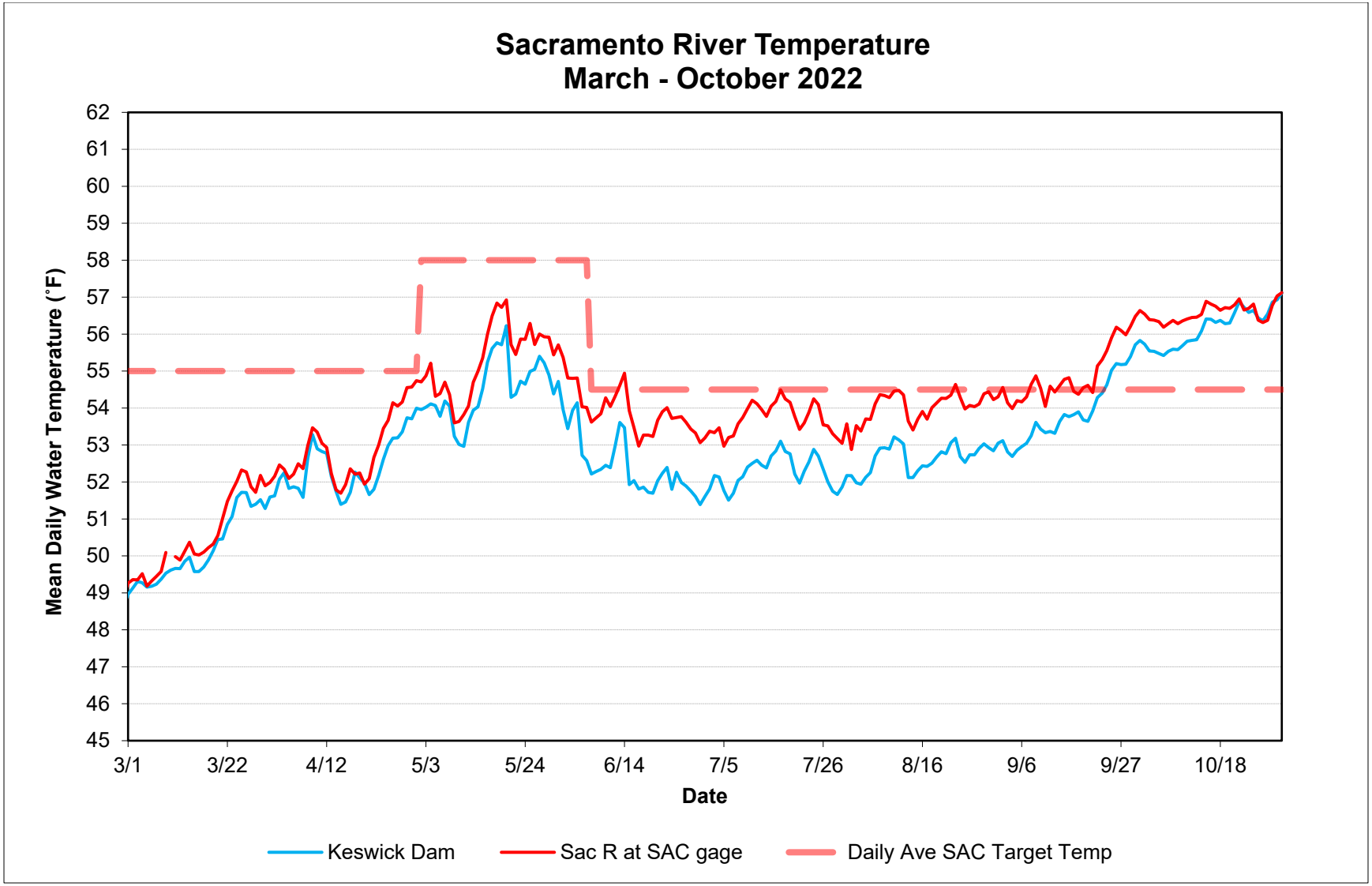

Figure 10. Summary of Upper Sacramento River Daily Mean Water Temperature from March through October 2022.

Fisheries

The following section describes the Chinook salmon monitoring efforts undertaken during the WY 2022 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 mark-recapture methodologies were initiated in 1996 on the Sacramento River above RBDD. 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; thus survey dates are flexible and can overlap from one survey to another.

Aircraft are used to conduct redd surveys for salmon redd distributions. These surveys provide redd distribution data for all four runs of salmon and are conducted year-round if river visibility conditions allow. 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 provide a more accurate 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 new redds 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 the aerial redd data should only be used to compare 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 2022 temperature management season can be accessed on CalFish: https://www.calfish.org/ProgramsData/ConservationandManagement/CDFWUpperSacRiverBasinSalmonidMonitoring/tabid/357/Agg2208_SelectTab/4/Default.aspx

These data from the carcass and aerial redd surveys have not yet undergone CDFW's final quality control process to confirm or otherwise verify their accuracy. As a result, these 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. An annual report is posted on CalFish: https://www.calfish.org/.

The following CDFW preliminary information is 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 in May and concluding on October 31, 2022. The CDFW 2022 winter-run Chinook salmon carcass survey began on May 2, 2022, following the same protocols and guidelines as in previous years, were conducted weekly, and concluded on September 22, 2022. Temporal distribution of carcasses is as follows: the first carcass was detected on May 2 (0.0% of the cumulative total), 447 carcasses were detected by July 1 (27.0%% cumulative), 1,385 carcasses were detected by August 1 (83.6% cumulative), and 1,656 carcasses were detected by September 22 (100% cumulative).

The distribution of carcasses by area (**Table 4**) indicates that 53.8% of carcasses were collected between Keswick Dam and the ACID Dam which is higher than the 2003-2021 average of 35.2%. The percent of carcasses collected from the ACID Dam to the Hwy 44 Bridge was 27.2% which is lower than the 2003-2021 average of 38.1%. Overall, approximately 81% of carcasses were collected above the vicinity of the SAC temperature compliance point and 19% 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 CCR temperature compliance point.

Table 4. Winter-run Chinook salmon carcass counts by river area, as end of season, in 2022. **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:https://www.calfish.org/ProgramsData/ConservationandManagement/CDFWUpperSacRiverBasinSalmonidMonitoring/tabid/357/Agg2208_SelectTab/4/Default.aspx

Section	River Miles	Carcasses	2022 Percent	% Average (2003-2021)
1- Keswick Dam to ACID Dam (rm 302 to 298)	302-298	891	53.8%	35.2%
2- ACID Dam to Hwy 44 Brg (rm 296)	298-296	450	27.2%	38.1%
3- Hwy 44 Brg down to Clear Crk Powerlines (rm 288)	296-288	219	13.2%	22.4%
4- Clear Crk Pwrl to Balls Ferry Brg (rm 276)	288-276	96	5.8%	4.4%
Total	**26 miles**	**1,656**	100.0%	100.0%

Aerial redd surveys provide another line of evidence for spawning distribution which should be considered in conjunction with carcass survey data. The first winter-run Chinook salmon aerial

redd survey was conducted on May 18, 2022, and the final survey was conducted on August 23, 2022. A total of 13 weekly surveys were conducted through August. The results of these surveys indicate that redd distribution was concentrated upstream of the Hwy 44 Bridge (**Table 5**). Winter-run Chinook salmon redds observed during the aerial redd surveys in 2022 are shown temporally in **Figure 11**. Historical spawning distributions are shown in **Figure 12** as the percent of winter-run Chinook salmon redds downstream of the CCR gauge near Bonnyview Bridge from 1981 through 2022.

Table 5. Winter-run Chinook salmon aerial redd survey counts by river area, as end of season, in 2022. **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: https://www.calfish.org/ProgramsData/ConservationandManagement/CDFWUpperSacRiverBasinSalmonidMonitoring/tabid/357/Agg2208_SelectTab/4/Default.aspx

Flight Sections	River Mile	Redds	2022 Percent	% Average (2003-2021)
Keswick to A.C.I.D. Dam Carcass Section 1	298	215	53%	37.4%
A.C.I.D. Dam to Highway 44 Bridge Carcass Section 2	296	182	45%	48.7%
Highway 44 Br. to below Clear Creek Carcass Section 3	284	9	2%	12.9%
Below Clear Crk. to Balls Ferry Bridge Carcass Section 4	275	0	0%	0.2%
Balls Ferry Br. to Battle Creek Below Carcass Survey Area	271	0	0%	0.5%
Battle Creek to Jellys Ferry Bridge Below Carcass Survey Area	266	0	0%	0.1%
Jellys Ferry Br. to Bend Bridge	257	0	0%	0.1%
Bend Bridge to Red Bluff Diversion Dam	242	0	0%	0.0%
Red Bluff Diversion Dam to Tehama Bridge	229	n/s	n/s	0.0%
	Total	**578**	100%	0%

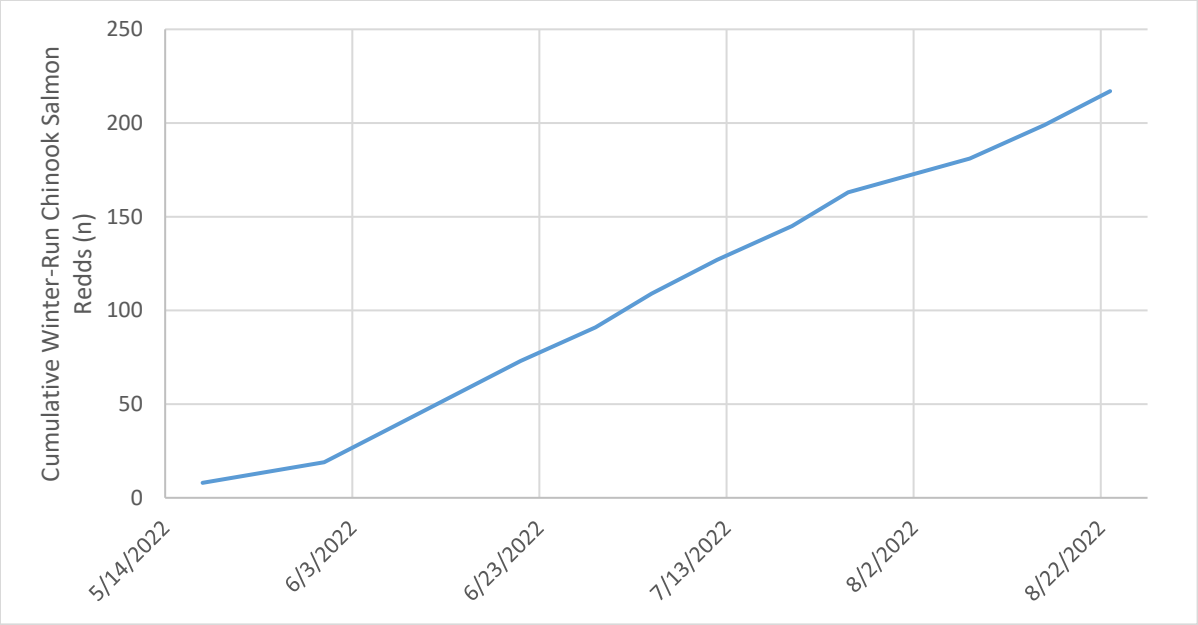

Figure 11. Cumulative distribution of winter-run Chinook Salmon redds (n) during 2022 aerial surveys.

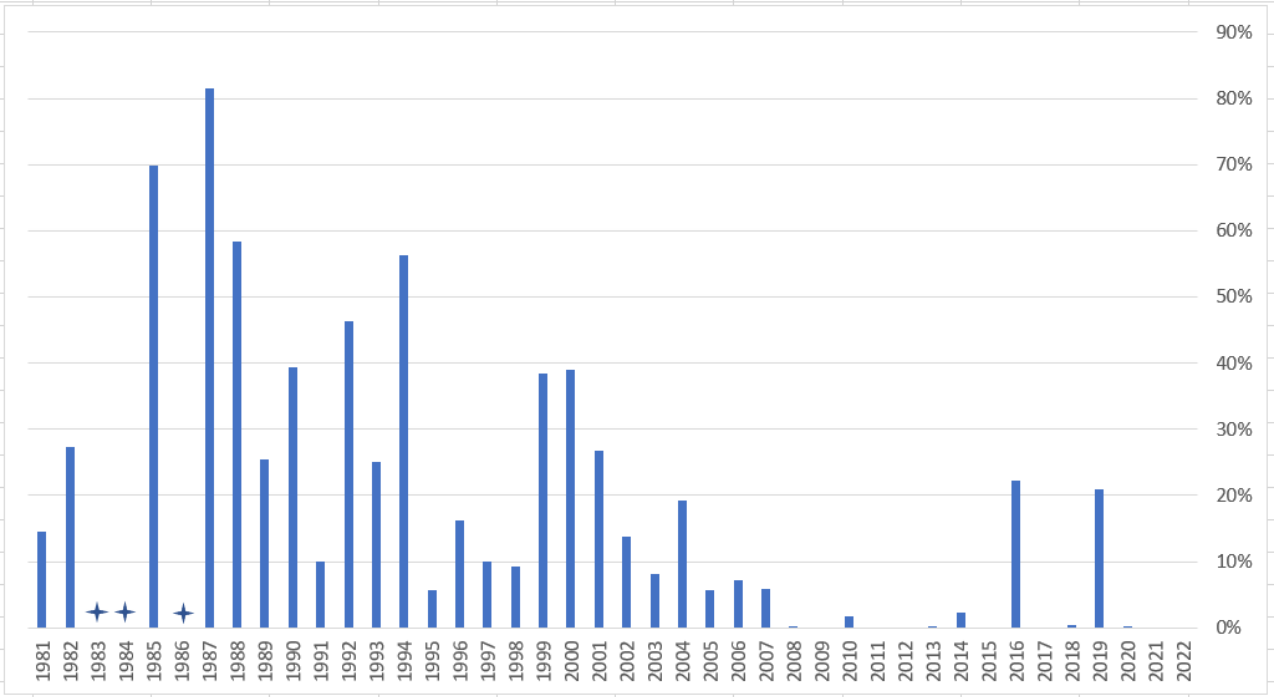

Figure 12. Percent of winter-run Chinook salmon redds downstream of the CCR gauge near Bonnyview Bridge (1981-2022). Data were not available in 1983-1984 and 1986 (denoted by *).

As noted in the NMFS BY 2022 Juvenile Production Estimate letter (https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/california-central-valley-water-operations-biological#juvenile-production-estimates-(jpe)-for-sacramento-river-winter-run-chinook-salmon), the CDFW estimate for total adult winter-run Chinook salmon

escapement in 2022 was 5,927 spawners. Of this total number of spawners, 484 were collected at the Keswick Dam trap site for spawning at Livingston Stone NFH, leaving an estimated 5,437 to spawn naturally in-river. An estimated 2,607 of these spawners were females.

Juvenile Chinook Salmon Outmigration

Winter-run Chinook salmon juvenile production estimates are calculated annually for natural origin and hatchery origin fish, and historically these estimates are been finalized in late winter (January or February). The winter-run Chinook salmon juvenile production estimate for BY 2022 is 49,924 for natural-origin and 190,956 hatchery produced juvenile winter-run Chinook salmon expected to enter the Delta during WY 2023. Estimated daily and biweekly passage of juvenile winter-run Chinook salmon at RBDD from June 18, 2022, to March 9, 2023 **(Figure 13).** Historical and current estimated passage of juvenile winter-run Chinook salmon at RBDD (BY 2008 – BY 2022) (**Figure 14**).

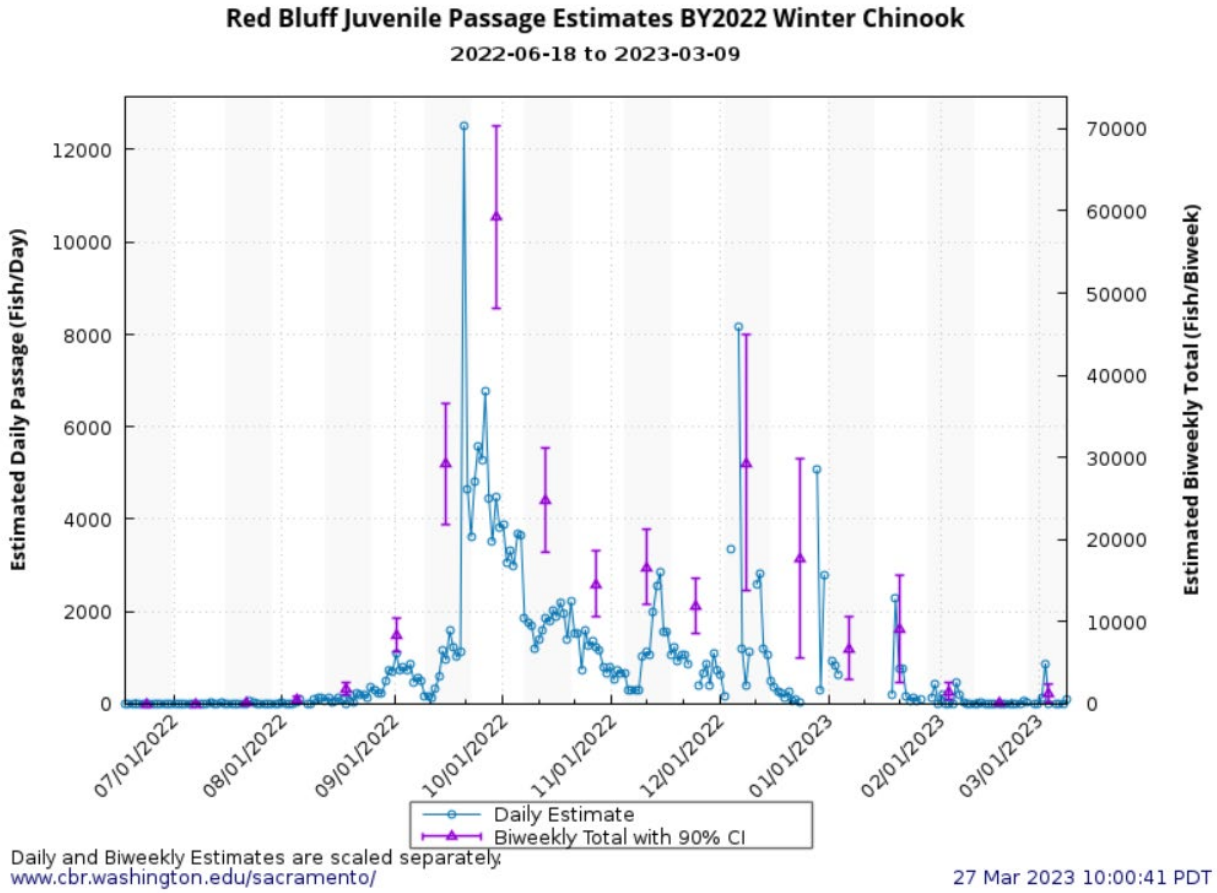

Figure 13. Daily and Biweekly (Total with 90% Confidence Interval) Estimates of Juvenile Winter-run Chinook Salmon Passage at Red Bluff from 06/18/2022 – 3/9/2023.

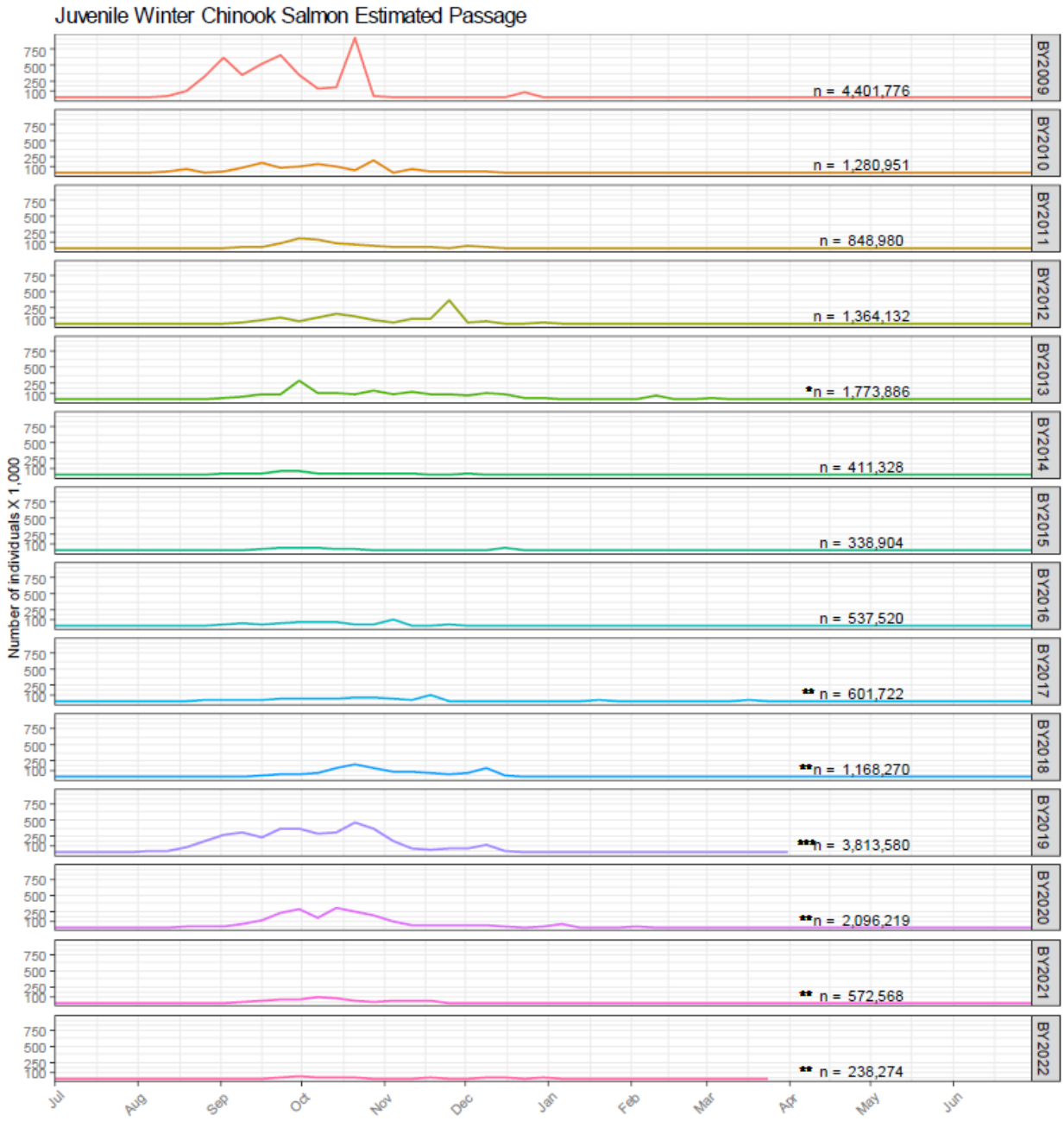

Figure 1. Weekly estimated passage of unmarked juvenile winter Chinook salmon at Red Bluff Diversion Dam (RK391) by brood-year (BY). Fish were sampled using rotary-screw traps for the period July 1, 2009 to present .

*Winter Chinook passage value interpolated using a monthly mean for the period October 1, 2013 - October 17, 2013 due to government shutdown .

**Winter Chinook passage value reflects addition of length-at-date spring Chinook determined to be winter Chinook from genetic analysis during brood years 2017 thru 2022 .

***Rotary-trapping/juvenile fish monitoring operations at the Red Bluff Diversion Dam were suspended March 25, 2020 to June 30, 2020, to protect employee health and safety resulting from COVID-19 global pandemic .

Figure 14. Historical and Current Estimated Passage of Juvenile Winter-run Chinook Salmon at RBDD (BY 2008 - BY 2022).

Operations Summary

The key events and decisions that influenced the 2022 upper Sacramento River Temperature operations include:

- WY 2022 was a critically dry year following a critically dry year in 2021 and a dry year in 2020. WY 2022 had the driest January through March period on record. The Northern Sierra Precipitation 8-Station Index indicates that hydrologic conditions in WY 2022 were nearly 20 inches less than average.
- In the February forecast, 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.
- In mid-March, Shasta Lake's coldwater pool, used to protect winter-run Chinook salmon, was projected to be comparable to other critically dry years such as 2014, 2015 and 2021.
- The 2022 TMP detailed a Tier 4 performance category and specified both temperature targets and locations.
- Initiation of the water temperature management season began in early May 2022 with active management to 58°F at the SAC compliance location.
- There were many efforts to manage Keswick releases in 2022; releases in May through September 2022 ranged from 4,000 – 4,500 cfs, or approximately 1,800 – 3,800 cfs less than compared to releases in the average critical year.
- The first side gate was opened on July 18, 2022, and full side gate operation occurred on August 11, 2022.
- End of September storage was 1.52 MAF.
- Firm data supporting a total population for year 2022 winter-run Chinook salmon population were unavailable in real-time to calculate the date of 95% hatch and alevin emergence. Therefore, termination of the water temperature management season was on October 31, 2022.
- No modification or amendment to the 2022 TMP was necessary.

Performance

This section describes relevant information for model and temperature performance at Shasta Lake during the coldwater pool management season, as well as information on Conservation Measures.

Models

In order to determine the accuracy of the water temperature model (e.g., HEC-5Q) and the water temperature-dependent egg mortality (TDM) models (e.g., Anderson model and Martin models) Reclamation performed hindcast analyses using actual data observed.

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 2022 observed data. Input data from January 1 to October 31 (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 January 1 as possible. Observed 2022 meteorology inputs were generated from California Irrigation Management Information System (CIMIS) data using a processor written by RMA Engineers.

Modeled vertical temperature profiles for Shasta Lake and downstream Sacramento River temperatures were compared to 2022 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

Error metrics for water temperatures in Shasta Lake and Sacramento River are shown in **Table 6** and **Table 7**. Modeled and historical vertical temperature profiles for Shasta Lake on August 3, 2022, are shown in **Figure 15**. The first use of the TCD's side gate in the model run was on July 12; this compares well with the historical date of July 18.

Results indicate a systematic overprediction of temperature at the Clear Creek gauge but more accurate results up- and downriver (**Figure 16**, **Figure 17**, **Figure 18**). The model performed well at predicting lake profiles early in the water temperature management season but underpredicted temperatures at lower elevations in Shasta Lake earlier and 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 in the area near the Clear Creek gauge could result in an overprediction of temperature-dependent mortality for redds deposited in the area. 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 2022.

Table 6. Error metrics in degrees Fahrenheit used to compare modeled vertical temperature profiles for Shasta Lake to 2022 observed data for all data. Metrics include Mean Bias, Mean Average Error (MAE), Root Mean Squared Error (RMSE), and Nash-Sutcliffe Efficiency (NSE).

Date	4/13	5/11	6/1	7/6	8/3	9/6	10/5
Mean Bias	1.05	0.82	0.66	0.83	0.70	1.55	2.56
MAE	1.48	1.35	1.15	1.23	1.07	1.84	2.75
RMSE	2.57	2.45	1.46	1.56	1.45	2.99	4.06
NSE	0.08	0.71	0.95	0.97	0.98	0.94	.084

Table 7. Error metrics in degrees Fahrenheit used to compare modeled Sacramento River temperatures to 2022 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	-0.15	-1.18	-0.27
MAE	1.16	1.93	1.19
RMSE	1.33	1.22	2.08
NSE	0.71	0.04	0.80

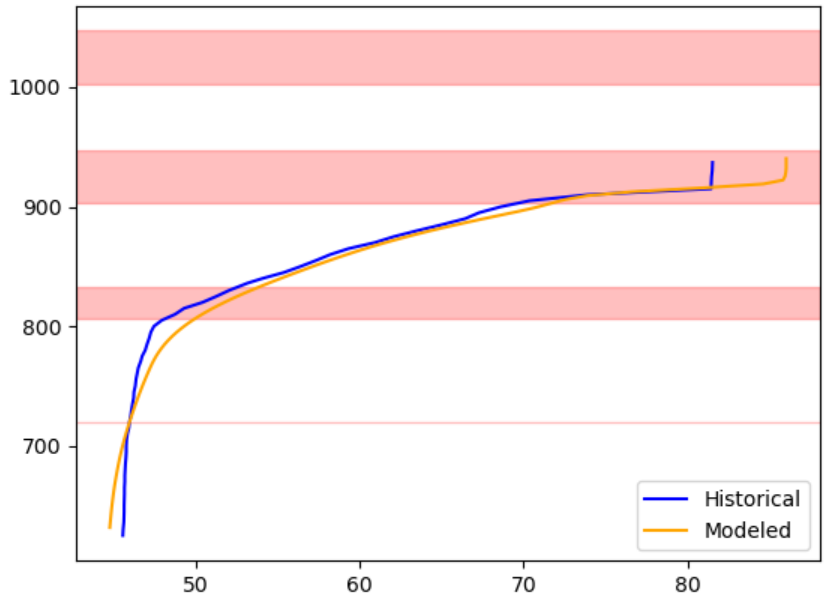

Figure 15. Modeled and historical water temperature (degrees Fahrenheit) profile of Shasta Lake on 8/3/2022 by elevation (feet). Red bands denote elevations of TCD gates.

For hindcast evaluation, modeled and actual water temperatures at three locations were compared: Sacramento River at Keswick Dam (**Figure 16**), Clear Creek (**Figure 17**), and Balls Ferry (**Figure 18**). Modeled water temperature data were warmer than observed water temperature data through the early time series and below at later dates at Keswick and below at later dates at Clear Creek and Balls Ferry. The jump to a lower-than-historical modeled temperature occurs around the date of first side gate use and is likely due to underestimation of Shasta Lake temperatures at the elevations drawn upon by the side gates. The vertical distribution of flow into the side gates is complicated due to the vertical orientation of the gate and the proximity of the lakebed and may not be fully represented in the model.

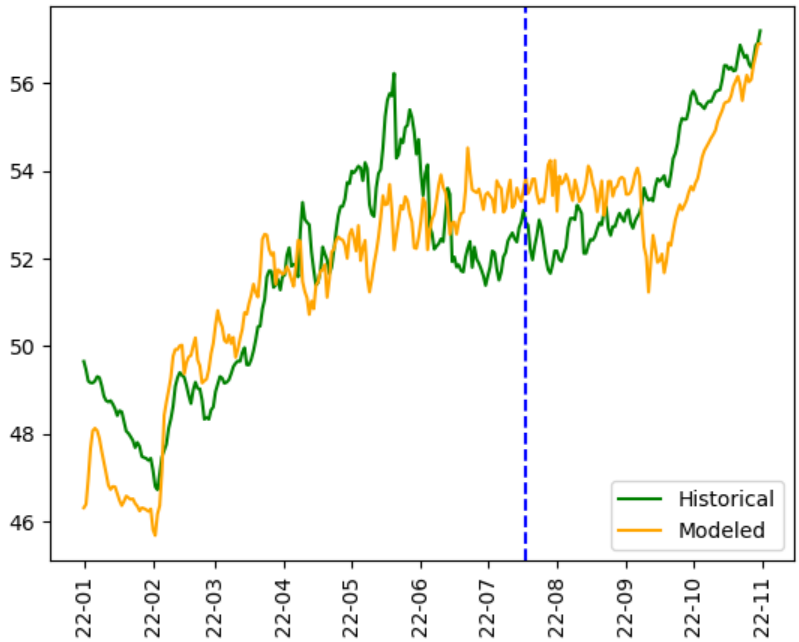

Figure 16. Modeled and observed water temperatures (degrees Fahrenheit) at Keswick (KWK) from 1/1/2022 – 10/31/2022.

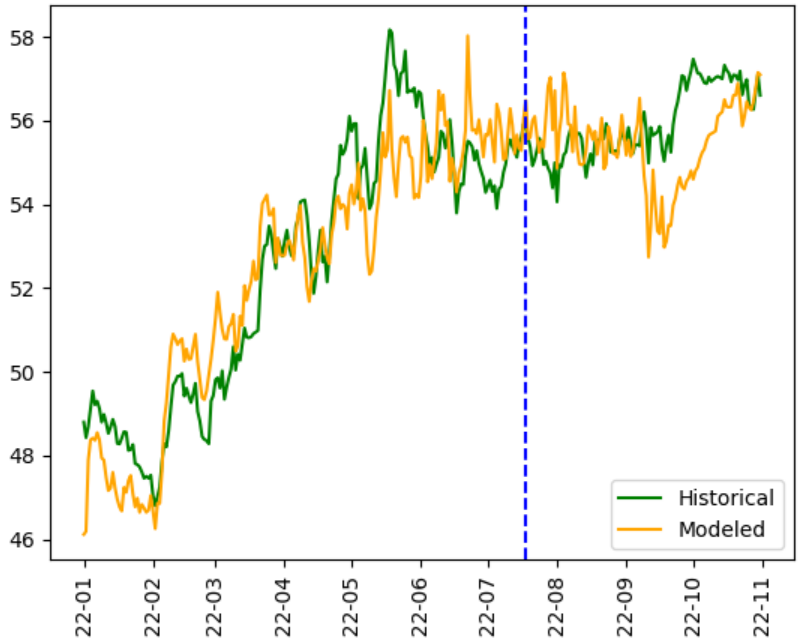

Figure 17. Modeled and observed water temperatures (degrees Fahrenheit) at Clear Creek (CCR) from 1/1/2022 – 10/31/2022.

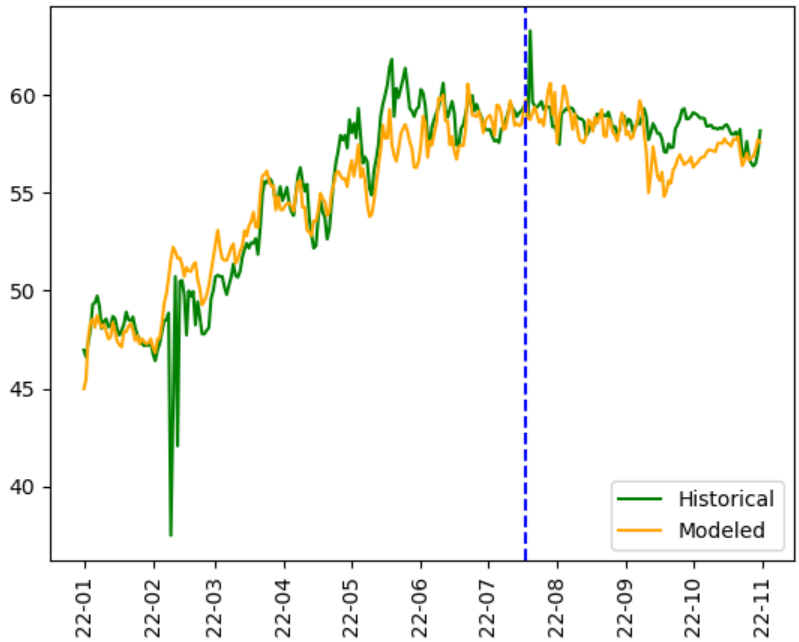

Figure 18. Modeled and observed water temperatures (degrees Fahrenheit) at Balls Ferry (BSF) from 1/1/2022 – 10/31/2022.

Temperature-Dependent Egg Mortality Forecasts

Both Reclamation and NMFS provided TDM forecasts for winter-run Chinook salmon eggs in WY 2022. During 2022, both groups provided early TDM forecasts and then relied on NMFS forecasts throughout most of the temperature management season. 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 coldwater 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. (2020) for stage independent modeling whereby a single temperature threshold is used from spawning and incubation through emergence; and (2) Anderson et al. (2022) 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 2016-2021. TDM estimates varied depending on the water temperatures and TDM models used. Reclamation's forecasted estimates for overall TDM in the final TMP was 51% using the Martin model (stage-independent), while overall TDM estimates using the Anderson model (stage-dependent) was 45%. TDM forecast estimates for WY 2022 winter-run Chinook salmon from the NMFS Southwest Fisheries Science Center are available at: https://oceanview.pfeg.noaa.gov/CVTEMP/download.

Temperature-Dependent Egg 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. 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) egg mortality. The SacPAS Fish Model was used to provide hindcast TDM estimates described below. SacPAS is further described in the Analytical Tools section.

Winter-run Chinook salmon redds further downstream are exposed to water temperatures that are warmer (**Figure 19**). The SacPAS Fish Model has the ability to describe TDM for redds in general locations. Nine redds were observed downstream of the Hwy 44 Bridge, between Hwy 44 and Cypress Avenue. Reclamation's forecasted mortality estimates for overall TDM in the final TMP was 51% using the Martin model (stage-independent), while overall egg mortality estimates using the Anderson model (stage-dependent) was 45%. Reclamation's hindcast TDM estimate using the SacPAS Anderson model (stage-dependent) and Martin model (stage-independent) is 18%. The forecast and hindcast TDM estimates varied greatly because updated temperature and flow management through the season were able to provide water temperatures cooler than originally estimated in the temperature management plan. 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 (model assumptions are included in Appendix B Attachment 3, Table 1). TDM hindcast estimates for WY 2022 winter-run Chinook salmon from the NMFS Southwest Fisheries Science Center are included in Appendix C.

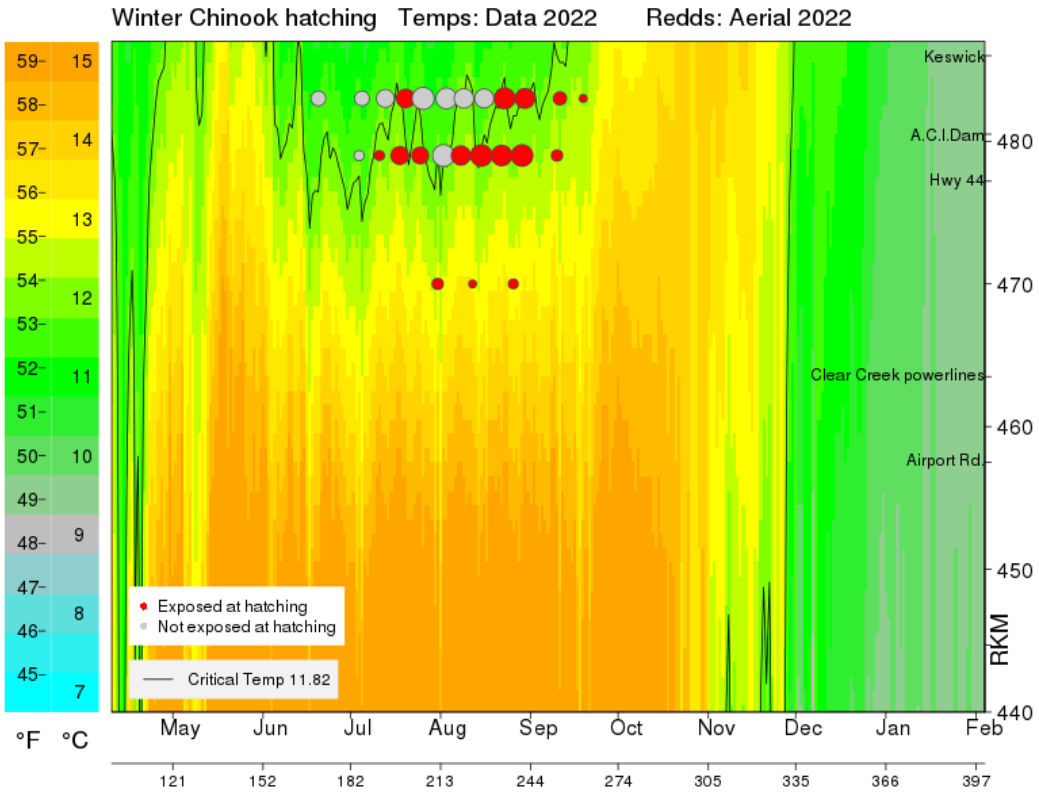

Figure 19. WY 2022 distribution and timing of winter-run Chinook salmon hatching with water temperatures. Winter-run Chinook salmon redds exposed to water temperatures that exceed the critical temperature threshold (12°C) during hatch time are highlighted in red. Size of circles reflect number of redds (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 2022 is shown in **Figure 20**. 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.

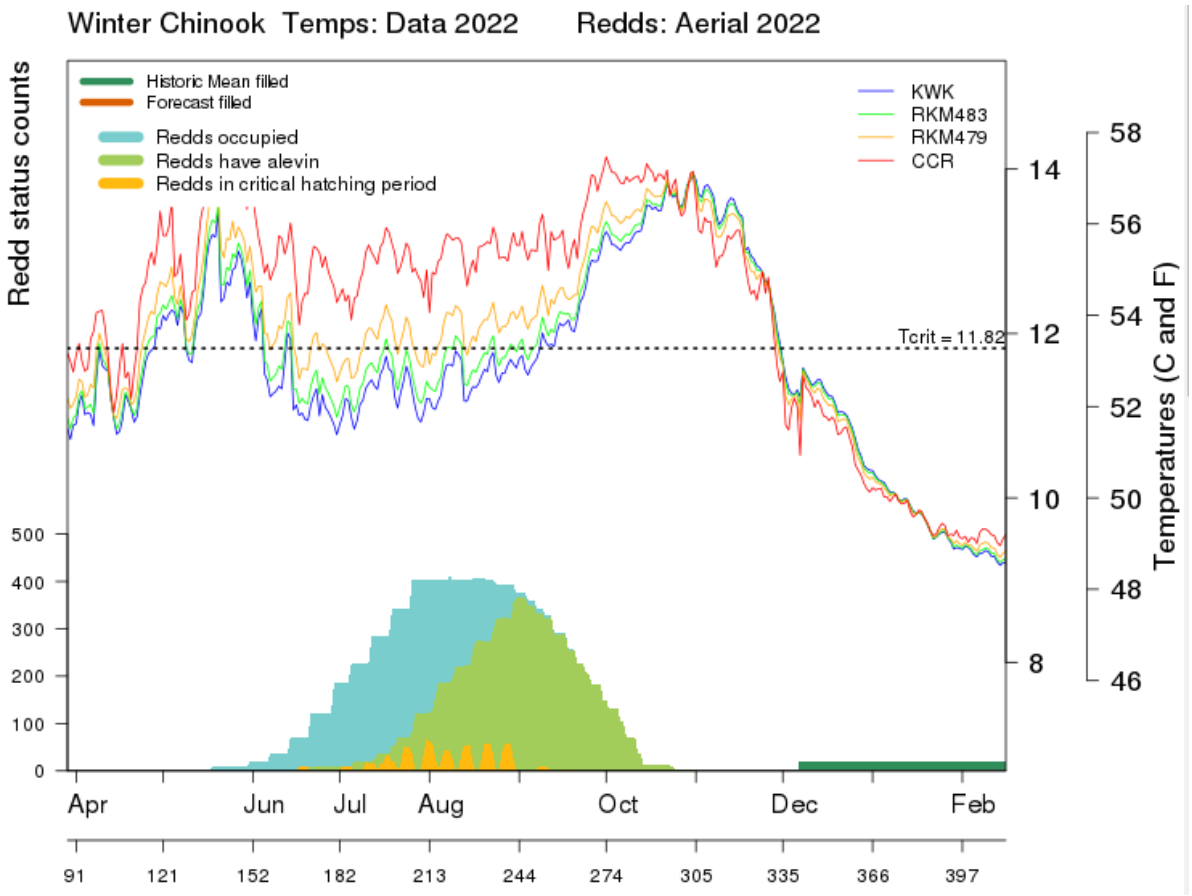

Figure 20. Temporal distribution of winter-run Chinook salmon redds and egg development to emergence in WY 2022. Figure is based on 2022 aerial redd survey data.

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 Egg 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 45% – 51% using redd data from 2016 – 2021. Reclamation's hindcast TDM estimate was 18% using redd data from 2022.

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

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. 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 2022 Juvenile Production Estimate letter (Appendix D) includes an estimated 2.17% egg-to-fry survival.

Many factors contribute to early life stage mortality rates of salmonids, such as predation, water temperature, water quality, and density dependent effects. In 2019 - 2022, high incidences of thiamine deficiency were reported to contribute the mortality of early life stages of Chinook salmon. In the JPE letter, NMFS noted that "naturally-spawning winter-run Chinook salmon adults with low thiamine levels spawned eggs low in thiamine which likely resulted in a decreased number of successful fry upstream of RBDD" (pg. 3).

Commitment to Tier

WY 2022 was determined to be a Tier 4 year in the TMP and remained in the tier for the duration of the water temperature management season.

Conservation Measures

In WY 2022, 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 Sacramento River (**Table 8** and **Table 9**). Due to low storage in Shasta Lake and limited coldwater pool, increased fish production at the Livingston Stone NFH was highly reliant on water chillers to maintain the cool and stable water temperatures necessary for successful reproduction. To fulfill this need, Reclamation contracted the rental of more than 2,500 tons of chilling capacity, including seven chillers and 12 diesel generators. This system successfully produced acceptable water temperatures to promote a high rate of reproductive success. The 2022 brood year production included the offspring of adults trapped at Battle Creek and the Keswick Dam fish traps and juveniles resulting from matings of captive broodstock reared at Livingston Stone NFH. The collection of brood fish from Battle Creek was terminated in March

2022, due the increased broodstock targets and need to conserve adult holding space for brood fish collected from the mainstem Sacramento River; Battle Creek winter-run Chinook salmon collected prior to this decision were integrated into the mainstem Sacramento River supplementation program. In the absence of winter-run Chinook salmon brood fish from Battle Creek, captive broodstock were used to achieve full production targets for the Battle Creek Jumpstart program.

Table 8. Livingston Stone National Fish Hatchery Production in WY 2022.

Release Start	Release End	CWT Tag Race	Hatchery	Release Site	CWT Number Released (Percent Marked)	Confirmed Delta Loss
2/9/2022	3/2/2022	Winter	Livingston Stone NFH	Sacramento River, Caldwell Park, Redding, CA	519,216 (100%)	6.7

Table 9. Livingston Stone National Fish Hatchery Projects in WY 2022.

Project	Females Collected	Females Spawned	Males Collected	Males Spawned	Green Eggs	Eyed Eggs	Fry
Mainstem Sacramento River	170	159	286	186	930,322	902,652	780,023
Battle Creek Jumpstart (Battle Creek Returns)	11	10	1	0	48,445	42,341	35,544*
Battle Creek Jumpstart (Captive Broodstock)	NA	293	NA	128	306,629	239,452	NA**

Transfer of Battle Creek Jumpstart WCS ceased in March 2022. The 10 spawned females were paired with Keswick-trapped males and are accounted for in the totals for the Mainstem Sacramento River

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

Other agencies involved in winter-run Chinook salmon management took actions outside of LTO activities to support winter-run Chinook salmon mortality due to the 2022 drought. Fishery agencies and the Winnemem Wintu tribe incubated 20,000 winter-run eggs in streamside

incubators in the McCloud River at Ah Di Nah as an additional emergency drought action. The eggs survived at rates comparable to hatchery survival despite high turbidity conditions from mudflows down Mount Shasta. CDFW used rotary screw traps and fyke nets to capture the emigrating juveniles before they entered Shasta Lake. They transported the captured juveniles to the Sacramento River in Redding and released them there. These juveniles will be trackable using parental based genetics methods to identify juveniles and adults that originated from this McCloud River action.

Additionally, DWR began first year testing of a juvenile salmonid collection system in the McCloud Arm of Shasta Lake. The project tested hydraulics of the system and future years will include a juvenile collection trap. The project strives to increase capture efficiency for juveniles leaving the McCloud River. A project goal is to create a productive coldwater refuge for Chinook salmon during droughts when conditions in the Sacramento River downstream of Keswick Dam are suboptimal.

Discussion

In WY 2022, spawning distribution was generally similar to historical (2003-2021) patterns, however, there was an increase in the upstream reach, Keswick Dam to ACID Dam (2022: 53.8%; 2003-2021: 37.4%). Based on the summary results described in the Fisheries section, drought management of Shasta Lake coldwater pool reduces the spatial and temporal distribution of cold water and this constricts successful winter-run Chinook salmon spawning to a smaller area and narrower period of time in the upper Sacramento River.

Typically, the temperature management strategy is to delay opening of the TCD side gates because opening the side gate is the last operational action you can take to access coldwater behind Shasta Dam and can result in upper Sacramento River water temperatures increasing while winter-run Chinook salmon eggs are still incubating. However, delaying side gate use also result in upper Sacramento River temperatures warming up earlier in the summer without using all coldwater available. The first side gate was opened July 18, 2022, and the second side gate on August 11, 2022. Opening the gates helped maintain water temperature near the target until approximately the middle of September. Temperatures gradually increased through late October when seasonal cooling began moderating temperatures.

System-wide drought actions and reduced releases from Shasta Lake resulted in Sacramento River water temperatures that were protective for winter-run Chinook salmon in WY2022. Temperature dependent mortality was estimated to be 18%, despite the continued drought conditions. However, estimated egg-to-fry survival was only approximately 2%, and approximately 200,000 juvenile winter-run Chinook salmon were estimated to pass RBDD, which is less than half of the previous brood year and the lowest since detailed monitoring began about 20 years ago.

Estimates of temperature-dependent mortality and egg-to-fry survival are used to gauge the effectiveness of actions taken in the 2020 ROD. In 2022, other factors outside of model calibrations, such as thiamine deficiency in eggs, may have interacted to reduce survival. The NMFS JPE letter states “similar to BY 2020 and BY 2021, BY 2022 was affected by a thiamine deficiency in returning adults. While the thiamine deficiency was addressed in the BY 2022

hatchery stock, it is expected that BY 2022 naturally-spawning winter-run Chinook salmon adults with low thiamine levels spawned eggs low in thiamine which likely resulted in a decreased number of successful fry upstream of RBDD." Thiamine deficiency complex (Harder et al. 2018) can result when adult Chinook salmon shift their diets during their ocean phase 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). No early life stage models account for thiamine deficiency impacts on egg-to-fry survival. In 2022, Livingston Stone NFH was used to compensate for low in-river survival and, even there, water temperature targets were met due to extraordinary efforts such as mechanically cooling the water coming from Shasta Lake.

The estimates for temperature-dependent mortality, egg-to-fry survival, and unattributed mortality (which represents other mortality factors upstream of RBDD) for BY 2002 – 2022 are shown in **Figure 21** 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.

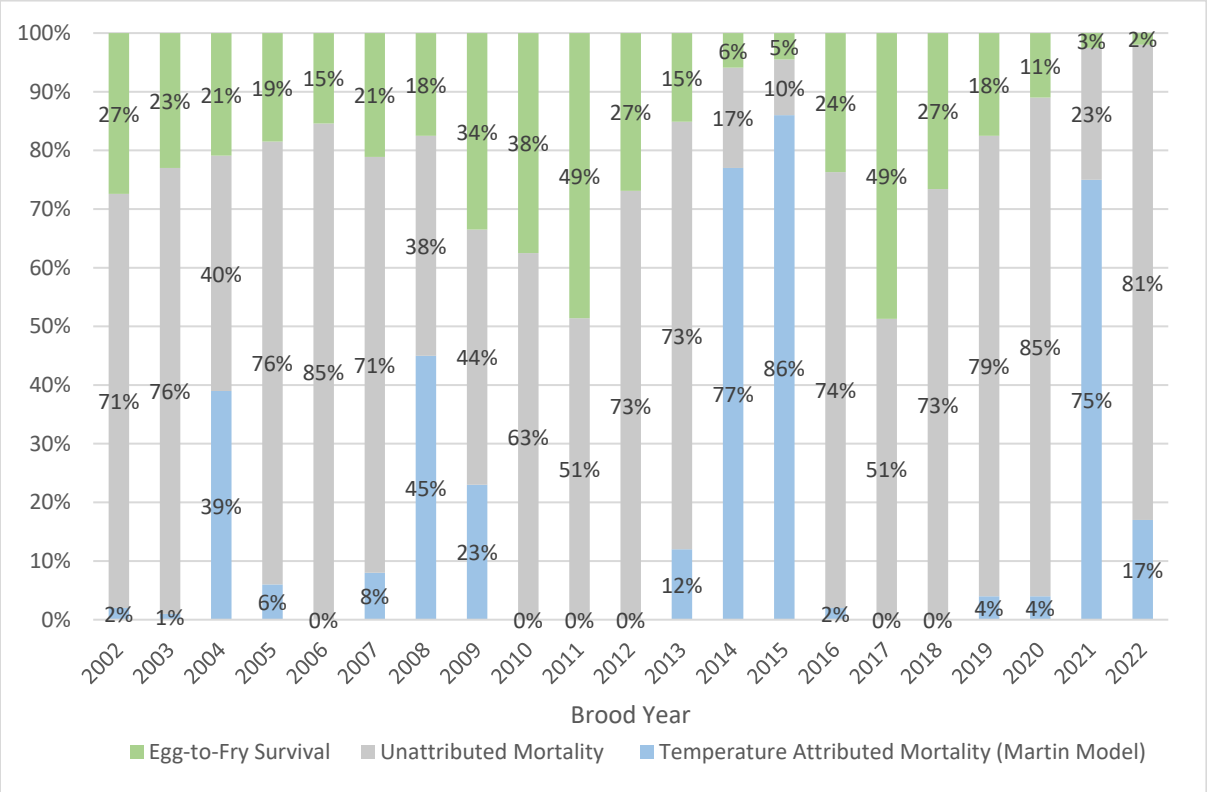

Figure 21. Winter-run Chinook salmon temperature attributed mortality (i.e., temperature-dependent egg mortality; %; in blue), unattributed mortality (%; in gray), and egg-to-fry survival (%; in green) for BY 2002 through 2022. Temperature dependent mortality (i.e., temperature attributed mortality) 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, 2021, and 2022 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 egg mortality is estimated only when eggs are in the gravel. There may be water temperature impacts outside of the egg incubation lifestage. If temperature-dependent egg 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 coldwater pool management, including the Shasta Coldwater 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

Pilot projects conducted in 2022 and 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, learning 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 Lake at year-round temperatures that can support high egg-to-fry survival. 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 McCloud Reservoir pool.

  During 2022 the fishery agencies and the Winnemem Wintu Tribe completed a winter-run emergency action similar to the pilot implementation plan. The group transported 40,000 winter-run eggs (two groups of 20,000 eggs, a month apart) from Livingston Stone NFH to streamside incubators at Ah Di Nah in the McCloud River, upstream of Shasta Lake. The eggs survived at rates around 90%. CDFW and the Winnemem Wintu Tribe used rotary screw traps and fyke nets in the McCloud River just below McCloud Bridge and captured nearly 2,000 of the downstream migrants in fall of 2022. Those fish captured were transported to release in the Sacramento River in Redding. Year 2 of this project is planned for 2023.

  DWR hydraulically tested a juvenile salmonid collection system near the head of McCloud Arm of the reservoir in 2022. Design of a trap to be constructed and deployed with the collection system in 2023 is underway. The goal is to increase collection

efficiency with a combination of in-river and head of reservoir collection systems to provide high productivity upstream of Shasta Lake.

- 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 2022 to get juvenile winter-run Chinook salmon down the river. This strategy has not been pursued and could potentially be considered for future pilot evaluation. Similar to this action, a winter-run Chinook salmon emergency drought measure in 2022 included incubating, releasing and then recapturing winter-run Chinook salmon in the McCloud River. The recaptured fish were transported to release in the Sacramento River in Redding. That effort was successful in hatching, recapturing, transporting, and releasing the juveniles below Keswick Dam.

Recent Study Results

Research has begun on a study by the University of California, Davis, aimed at better understanding temperature-dependent mortality in the upper Sacramento River of early life stages of winter-run Chinook salmon using otolith microstructure analyses. The objectives of the research are to: (1) reconstruct water temperatures experienced by winter-run Chinook salmon juveniles; (2) reconstruct hatch and emergence dates for winter-run Chinook salmon collected at RBDD; (3) crosswalk temperature exposures of surveyed redds with reconstructed temperatures from otoliths; and (4) compare hatch and emergence dates based on otoliths and degree-day development rates from temperature models. To date, oxygen isoscape data were collected in 2021 and 2022 in the Sacramento River corridor, and data from 2021 have been analyzed. These isoscape data will allow estimation of winter-run Chinook salmon thermal exposure once a relationship between oxygen isotope values in otoliths and rearing temperatures are established using experimental fish and oxygen isotope signatures are measured in winter-run Chinook salmon juveniles' otoliths. A validation study with hatchery fish quantified the number of otolith increments from hatch to emergence and verified these increments represent daily checks. Otoliths from brood year 2021 winter-run Chinook salmon juvenile mortalities at RBDD (n=109) have been extracted and prepared, and back-calculations of hatch and emergence dates have been conducted. Preliminary comparisons of expected hatch date based on winter-run Chinook salmon otoliths and degree-day development rates for observed redds indicate differences in hatch date distributions and possibly disproportionately higher survival earlier in summer 2021. Winter-run Chinook salmon juveniles have been collected at RBDD for 2022 and are available for otolith extraction. Otolith samples from experimental Chinook salmon juveniles reared at known temperatures have been prepared for future laboratory analysis of oxygen

isotope values. Sampling of oxygen isoscape data in the Sacramento River and winter-run Chinook salmon juveniles at RBDD will continue through brood year 2023.

Modeling Improvements

Reclamation is leading a collaborative effort to develop new temperature models for all CVP reservoirs and key downstream river reaches (i.e., Water Temperature Modeling Platform) 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 meetings with SRTTG members and other interested stakeholders. Several limitations of the current modeling will be addressed in future development efforts.

Monitoring Improvements

The aerial redd surveys added a redd mapping workflow in 2021, and continued in 2022, in an effort to increase accuracy of redd locations. Greater accuracy 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 water 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.

Genetic analysis can be used as a mark-recapture technique to estimate the number of successfully spawning males and females to test for sources of productivity variation. Also known as Genetic parentage-based tagging methods are being utilized to assess the reproductive success of Chinook salmon (e.g., McCloud-imprinted fish). These data can help to improve our understanding of factors influencing the success of Chinook salmon spawning in the Sacramento River, for example, early vs late spawning, upstream vs downstream spawning, hatchery reared vs naturally spawned adults.

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 at: http://www.cbr.washington.edu/sacramento/

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.

Conclusion and Management Summary

WY 2022 was a critically dry year following a critically dry year in 2021 and a dry year in 2020. WY 2022 also had the driest January through March period on record. There were many efforts to manage Keswick Dam releases in 2022; releases in May through September 2022 ranged from 4,363 – 5,054 cfs, approximately 1,800 – 3,800 cfs less compared to releases in the average critical year. The 2022 Temperature Management Plan detailed a Tier 4 performance category and specified temperature targets at the SAC gage. Reclamation's hindcast temperature-dependent egg mortality estimate was 18% in 2022. The BY 2022 Juvenile Production Estimate letter estimated 2.17% egg-to-fry survival. There are no specific Tier 4 Upper Sacramento River Performance Metrics for temperature-dependent egg mortality in the 2020 ROD. No need was identified by the agencies for an independent panel review for WY 2022.

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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-2022-rivertask.html

CDFW Upper Sacramento River Basin Salmonid Monitoring Program data on CalFish - https://www.calfish.org/ProgramsData/ConservationandManagement/CDFWUpperSacRiverBasinSalmonidMonitoring/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#juvenile-production-estimates-(jpe)-for-sacramento-river-winter-run-chinook-salmon