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# 2023 Seasonal Report for the Shasta Coldwater Pool Management

Central Valley Project, California  
California-Great Basin Region



Shasta Dam and Lake in May 2023. Photo Credit: Reclamation

## **Mission Statements**

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

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

# **2023 Seasonal Report for the Shasta Coldwater Pool Management**

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

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Marine Fisheries Service**

# Contents

	<b>Page</b>
Purpose .....	5
Background .....	5
Seasonal Operations .....	5
Operational Background Information .....	5
Historical Overview .....	8
Storage and Flood Conservation Space .....	10
Summer/Fall Water Temperature Management.....	15
June through October .....	16
Daily Average Temperature and Temperature Targets.....	17
Fisheries .....	19
Chinook Salmon Spawn Timing and Distribution .....	19
Juvenile Chinook Salmon Outmigration .....	23
Operations Summary .....	26
Performance.....	26
Models .....	26
Temperature Forecast and Hindcast.....	26
Mortality Forecasts .....	32
Temperature-Dependent Egg Mortality Hindcast .....	33
Performance Metrics .....	35
Commitment to Tier .....	36
Conservation Measures .....	37
Discussion.....	38
Improvements .....	40
Conclusion and Management Summary .....	40
References .....	42
Supporting Links.....	44
Appendix A – 2023 Sacramento River Temperature Management Plan .....	45
2023 Sacramento River Temperature Management Plan.....	45
Appendix B – Temperature Dependent Mortality Model Inputs.....	46

# Figures

	Page
<b>Figure 1.</b> Shasta Lake Storage (MAF) from WY 1995 through the beginning of WY 2024. Source: <a href="http://www.cbr.washington.edu/sacramento/data/query_river_allyears.html">http://www.cbr.washington.edu/sacramento/data/query_river_allyears.html</a> .....	8
<b>Figure 2.</b> WY 2023 forecasted (10 percent, 50 percent, 90 percent exceedance) and actual daily and cumulative inflow volume at Shasta Lake. Source: <a href="https://www.cnrfc.noaa.gov/water_resources_update.php">https://www.cnrfc.noaa.gov/water_resources_update.php</a> .....	9
<b>Figure 3.</b> Shasta Lake Storage (red line), Allowable Storage for Flood Control (black line), Keswick Dam Release (blue line), and Shasta Inflow (green line) for 10/1/2022 – 9/30/2023. ....	11
<b>Figure 4.</b> Sacramento River releases from 10/1/2022 – 9/30/2023 with major operations highlighted.....	12
<b>Figure 5.</b> Shasta Reservoir storage in WY 2023 and in Wet Water Years 2006, 2011, 2017, 2019 and 2023.....	13
<b>Figure 6.</b> Monthly average Keswick Dam releases in WY 2023 and in Wet Water Years 2006, 2011, 2017, 2019.....	14
<b>Figure 7.</b> Shasta Reservoir coldwater pool volume less than 52°F for 2023. ....	15
<b>Figure 8.</b> Summary of Upper Sacramento River Daily Mean Water Temperature from March through October 2023.....	18
<b>Figure 9.</b> Cumulative temporal distribution of winter-run Chinook Salmon redds (n) during 2023 aerial surveys. ....	22
<b>Figure 10.</b> Percent of winter-run Chinook salmon redds downstream of the CCR gauge near Bonnyview Bridge (1981-2023). Data were not available 1983-1984 and 1986 (denoted by “*”). ....	23
<b>Figure 11.</b> Preliminary Daily and Biweekly (Total with 90% Confidence Interval) Estimates of Juvenile Winter-run Chinook Salmon Passage at Red Bluff from 06/18/2023 – 1/13/2024.....	24
<b>Figure 12.</b> Historical and Current Estimated Passage (Preliminary) of Juvenile Winter-run Chinook Salmon at RBDD (BY 2010 - BY 2023).....	25

**Figure 13.** Modeled and observed water temperature (degrees Fahrenheit) profile of Shasta Lake on 8/2/2023 by depth (feet). ..... 30

**Figure 14.** Modeled and observed water temperatures (degrees Fahrenheit) at Keswick (KWK) from 5/1/2023 – 10/31/2023..... 31

**Figure 15.** Modeled and observed water temperatures (degrees Fahrenheit) at Clear Creek (CCR) from 5/1/2023 – 10/31/2023. .... 31

**Figure 16.** Modeled and observed water temperatures (degrees Fahrenheit) at Balls Ferry (BSF) from 5/1/2023-10/31/2023. .... 32

**Figure 17.** WY 2023 distribution and timing of winter-run Chinook salmon hatching with water temperatures using model inputs described in Appendix B: Table 1. No winter-run Chinook salmon redds were exposed to water temperatures that exceed the critical temperature threshold (12°C) during hatch time in 2023. Size of circles reflect number of redds (e.g., larger circles indicate more redds at the time and location)..... 34

**Figure 18.** Temporal distribution of winter-run Chinook salmon redds and egg development to emergence in WY 2023. Figure is based on 2023 winter carcass survey data as described in Appendix B: Table 1. .... 35

**Figure 19.** 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 yellow) for BY 2002 through 2023. Temperature dependent mortality (i.e., temperature attributed mortality) estimates obtained from NOAA-Southwest Fisheries Science Center and are based on the Martin Model. Final egg-to-fry survival for BY 2002 to 2021 were provided by USFWS. Preliminary egg-to-fry survival estimates for BY 2022 and 2023 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..... 40

# Tables

	Page
<b>Table 1.</b> Shasta Lake Storage Volumes and Coldwater Pool Volumes in Thousands of Acre Feet (TAF) from 2013 - 2023.....	5
<b>Table 2.</b> Sacramento River Temperature Compliance Point Data for 2013 – 2023. Daily Average Temperature - Degrees Fahrenheit (Days Applied) .....	6
<b>Table 3.</b> WY 2023 Northern Sierra precipitation, Sacramento Basin snowpack, and Sacramento Valley Index statistics by month.....	10
<b>Table 4.</b> Winter-run Chinook salmon carcass counts by river area, as end of season, in 2023.....	20
<b>Table 5.</b> Winter-run Chinook salmon aerial redd survey counts by river area, as end of season, in 2023. ....	21
<b>Table 6.</b> Error metrics in degrees Fahrenheit used to compare modeled vertical temperature profiles for Shasta Lake to 2023 observed data for all data. Metrics include Mean Bias, Mean Average Error (MAE), Root Mean Squared Error (RMSE), and Nash-Sutcliffe Efficiency (NSE). ....	28
<b>Table 7.</b> Error metrics in degrees Fahrenheit used to compare modeled Sacramento River temperatures to 2023 observed data from 5/1/2023 to 10/31/2023. Metrics include Mean Bias, Mean Average Error (MAE), Root Mean Squared Error (RMSE), and Nash-Sutcliffe Efficiency (NSE). ....	29
<b>Table 8.</b> Livingston Stone National Fish Hatchery Production in WY 2023. ....	37
<b>Table 9.</b> Livingston Stone National Fish Hatchery Projects in WY 2023.....	37

# Purpose

This is the 2023 Supplement to the 2022 Seasonal Report for Shasta Lake Coldwater Pool Management, which describes Shasta Dam operations leading up to and through the 2023 cold water pool management season.

# Background

No supplemental information for WY 2023.

# Seasonal Operations

This section supplements relevant Shasta Lake operations for WY 2023.

## Operational Background Information

Conditions of the coldwater pool from 2013 – 2023 are recorded in **Table 1**. Sacramento River temperature compliance point data from 2013 - 2023 are shown in **Table 2**.

**Table 1.** Shasta Lake Storage Volumes and Coldwater Pool Volumes in Thousands of Acre Feet (TAF) from 2013 - 2023.

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
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
2023	4467	24-May	3380	N/A	3332	1513	1294	1144

**Table 2.** *Sacramento River Temperature Compliance Point Data for 2013 – 2023. Daily Average Temperature - Degrees Fahrenheit (Days Applied)*

Year	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
2013	BSF-56°	BSF-56°	BSF-56° (01-16) <sup>1</sup> BSF-56.75° (17-31)	<sup>1</sup> BSF-56.75°	<sup>1</sup> BSF-56.75°	<sup>1</sup> BSF-56.75°	<sup>1</sup> BSF-56.75°	<sup>1</sup> BSF-56.75°	<sup>1</sup> 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 <sup>2</sup>	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 <sup>3</sup>	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°
2018 <sup>4</sup>	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°
2019 <sup>5</sup>	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°	BSF-56°
2020 <sup>6</sup>	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°

2023	SAC-54.5°	SAC-54.5°	SAC-54.5° (1-14) CCR-53.5° (15-31)	CCR-53.5°	CCR-53.5°	CCR-53.5°	CCR-53.5°	CCR-53.5°	CCR-53.5°
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<sup>1</sup> BSF-56.75°F used as surrogate for Airport Road 56°F

<sup>2</sup> Year 2015 July – November the temperature target was 57°F, not to exceed 58°F

<sup>3</sup> Year 2017 pilot evaluation study also targeted CCR at 53°F May 15 – Oct 31

<sup>4</sup> Year 2018 pilot evaluation study also targeted CCR at 53.5°F May 15 – Oct 31

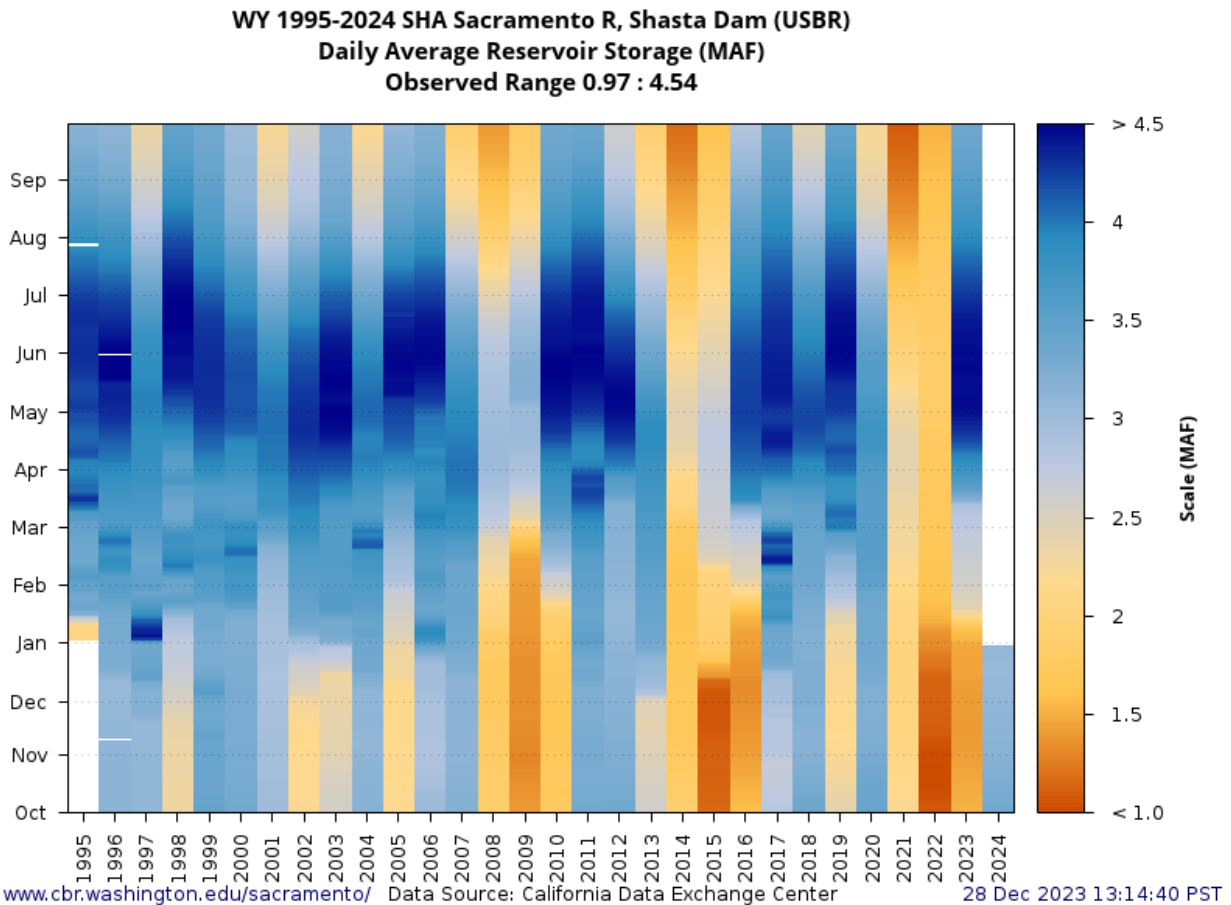
<sup>5</sup> Year 2019 pilot evaluation study also targeted CCR at 53.5°F May 15 – Oct 31 and Airport Road at 53.5°F Aug 7 – Oct 31

<sup>6</sup> 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

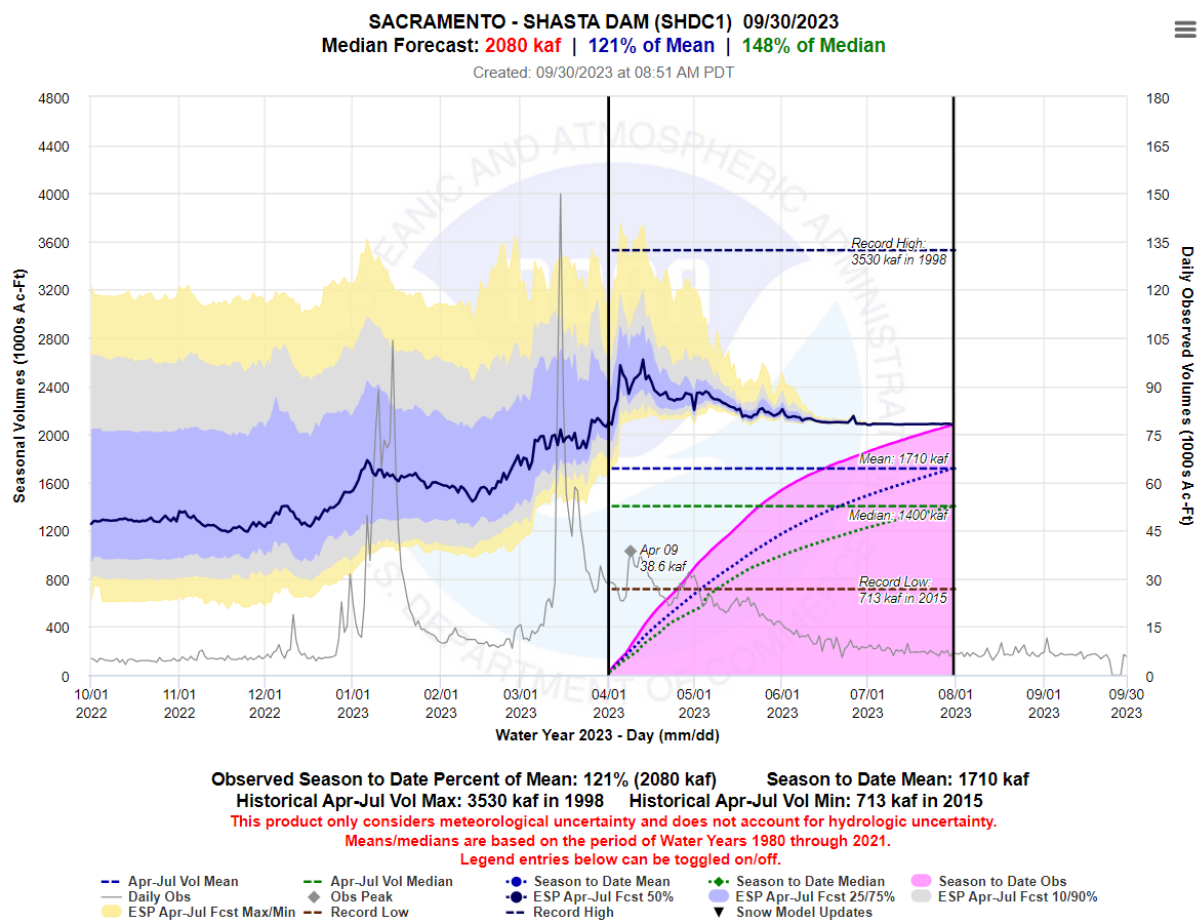
## Historical Overview

In WY 2023, end of May Shasta Lake storage volume was above the historic average (Figure 1, 1995 – 2023 average: 3.79 MAF; 2023 value: 4.46 MAF).



**Figure 1.** Shasta Lake Storage (MAF) from WY 1995 through the beginning of WY 2024.  
Source: [http://www.cbr.washington.edu/sacramento/data/query\\_river\\_allyears.html](http://www.cbr.washington.edu/sacramento/data/query_river_allyears.html)

Large increases in the runoff forecasts occurred in late January 2023 and March 2023 due to several large storm events in those months (**Figure 2**). By May, water supply forecasts for Shasta Lake inflow runoff ranged between 124% and 129% of the average for the 90% and 50% runoff exceedances, respectively. The actual Shasta Lake inflow volume April through July was 2,055 TAF and the total WY 2023 Shasta Lake inflow volume was 5,623 TAF (Reclamation 2023). Water supply indices reported the Sacramento River Unimpaired Runoff was a “Wet” year for the Sacramento Valley Index (DWR 2023). December, January, and March were exceeded historic monthly average precipitation (**Figure 3**).



**Figure 2.** WY 2023 forecasted (10 percent, 50 percent, 90 percent exceedance) and actual daily and cumulative inflow volume at Shasta Lake. Source: [https://www.cnrfc.noaa.gov/water\\_resources\\_update.php](https://www.cnrfc.noaa.gov/water_resources_update.php)

**Table 3.** WY 2023 Northern Sierra precipitation, Sacramento Basin snowpack, and Sacramento Valley Index statistics by month.

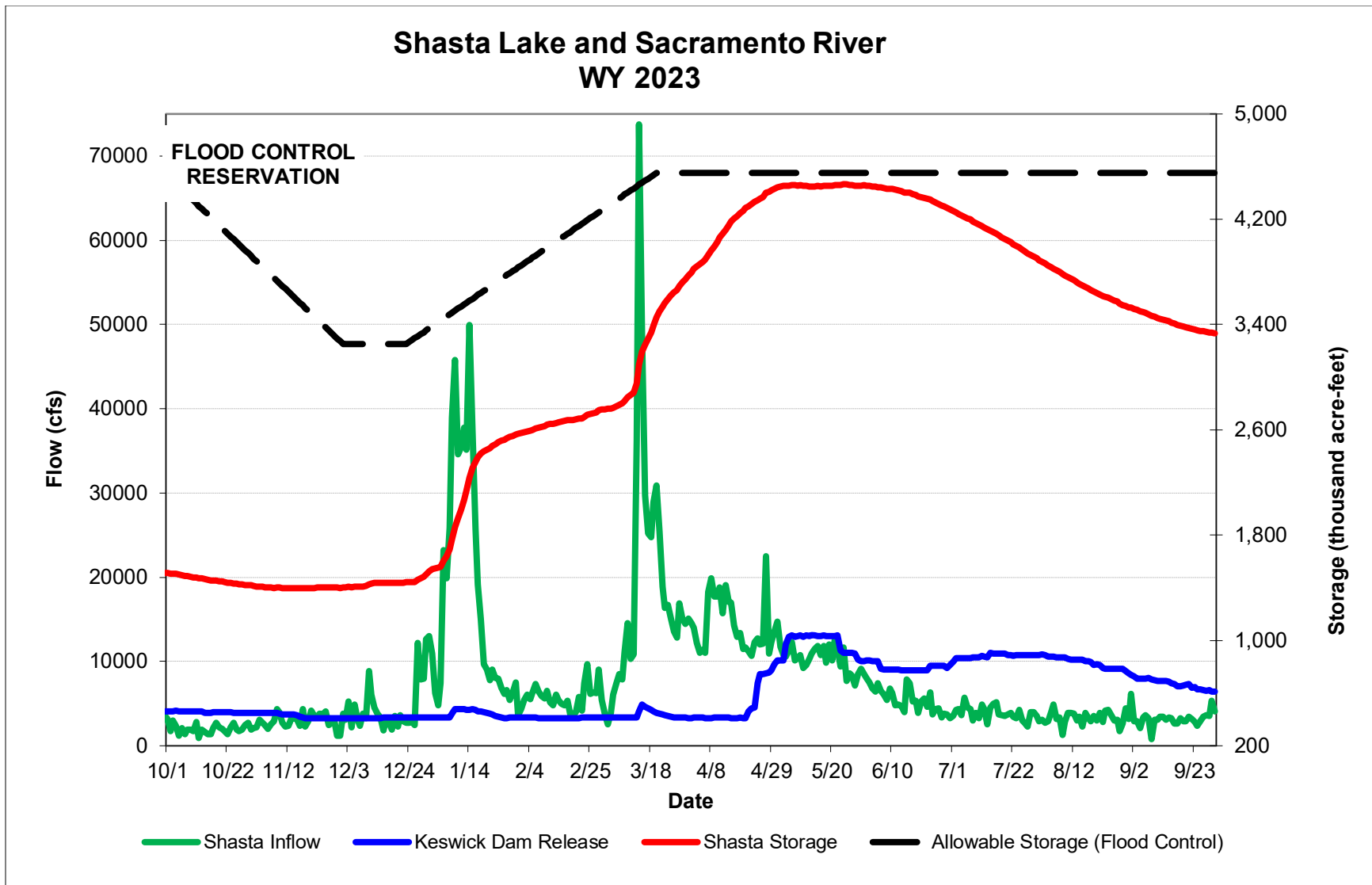
<b>Water Year 2023 Month<sup>1</sup></b>	<b>Northern Sierra 8-Station Precipitation (Cumulative water year in inches through month)</b>	<b>Northern Sierra 8-Station percentage of historic monthly average precipitation (for month)</b>	<b>North Region including Sacramento River Basin Snowpack of April 1 (%)</b>	<b>Sacramento Valley Unimpaired Runoff Index (40-30-30 Index 50 percent Exceedance)</b>
<b>November</b>	4.27	80	9	NA
<b>December</b>	20.10	158	46	12.9
<b>January</b>	37.46	190	105	16.3
<b>February</b>	42.25	54	128	20.0
<b>March</b>	59.39	215	192	20.2
<b>April</b>	61.03	38	163	24.9
<b>May</b>	62.93	69	67	24.2

<sup>1</sup>Monthly totals may not add up to seasonal total because of rounding.

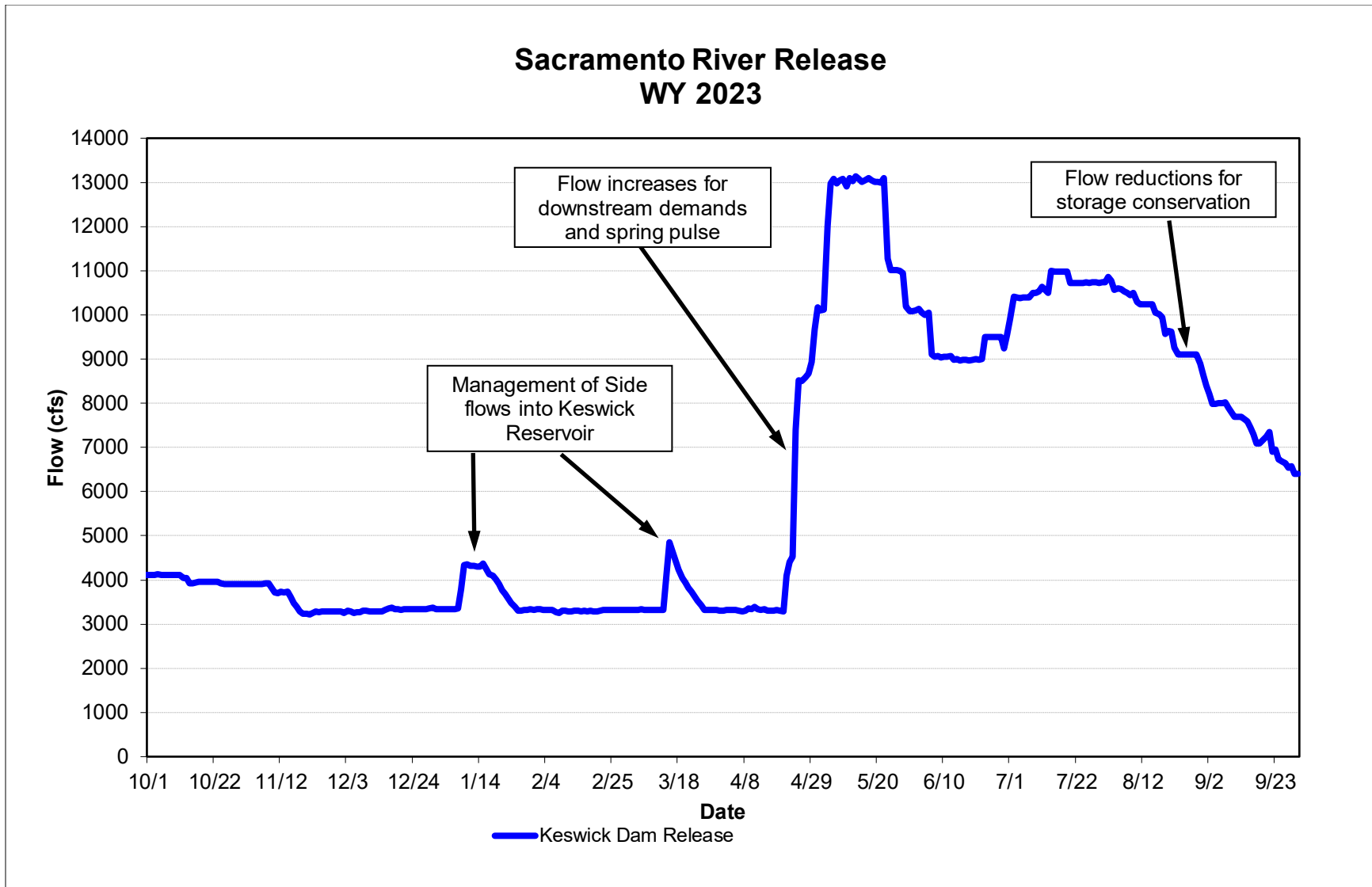
<sup>2</sup>NA = Not Available.

## Storage and Flood Conservation Space

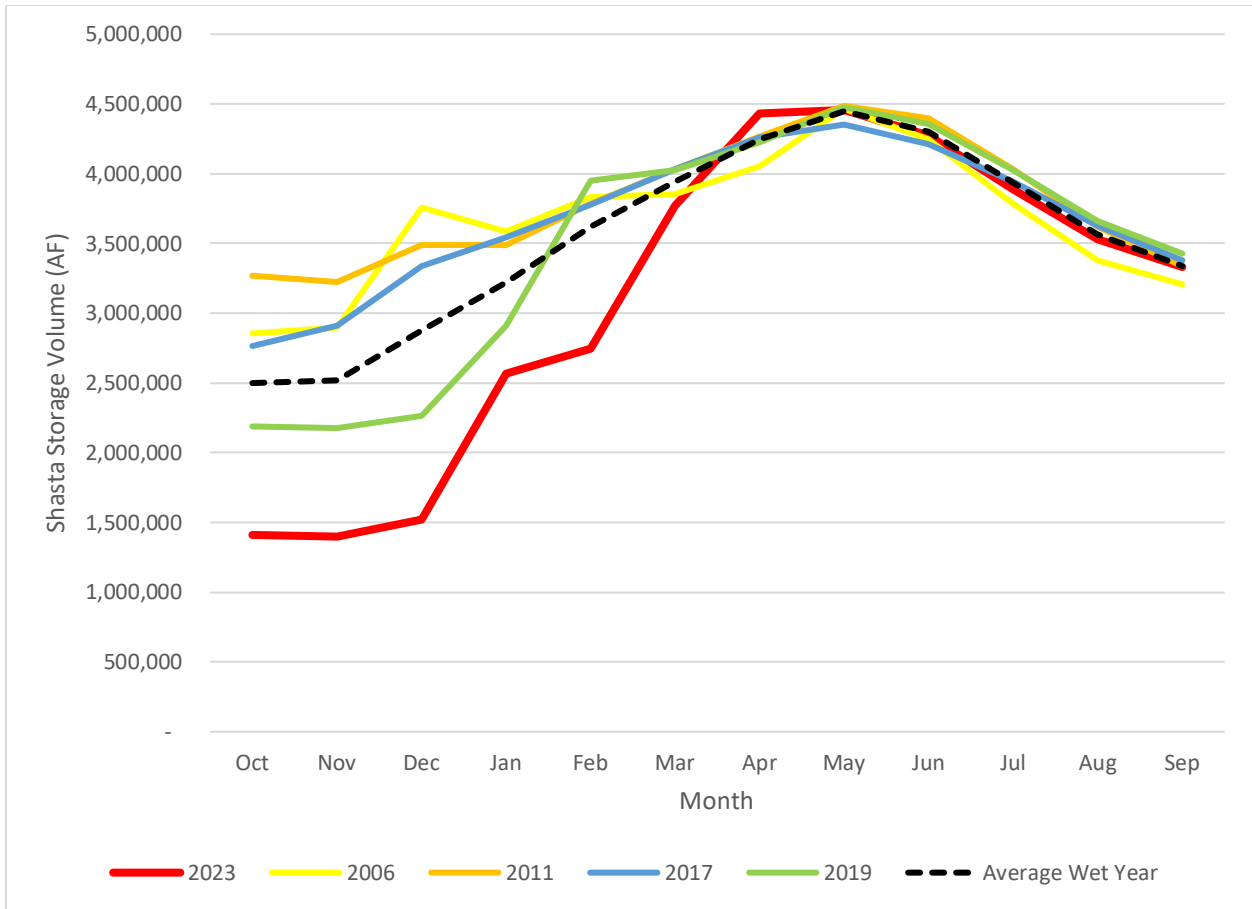
Shasta Lake storage conditions and Keswick Dam releases for WY 2023 are shown in **Figure 3** through **Figure 7**. In WY 2023, Shasta Lake storage conditions were below the USACE flood control curve and Keswick Dam releases were not increased to make flood space for flood control purposes. Due to wet hydrology, Shasta Lake storage conditions refilled, and end of April storage was 4.43 MAF. Compared to other wet water years during WY2000 – 2023, WY 2023 had lower than average storage volumes until approximately March (**Figure 5**) and lower than average releases from Keswick Dam until April (**Figure 6**). The Shasta Lake coldwater pool (i.e. volume less than 52°F) in 2023 was above average (**Figure 7**). These factors influenced the Temperature Management Plan (TMP) 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 2023 Shasta Storage Rebuilding and Spring Pulse Seasonal Report.



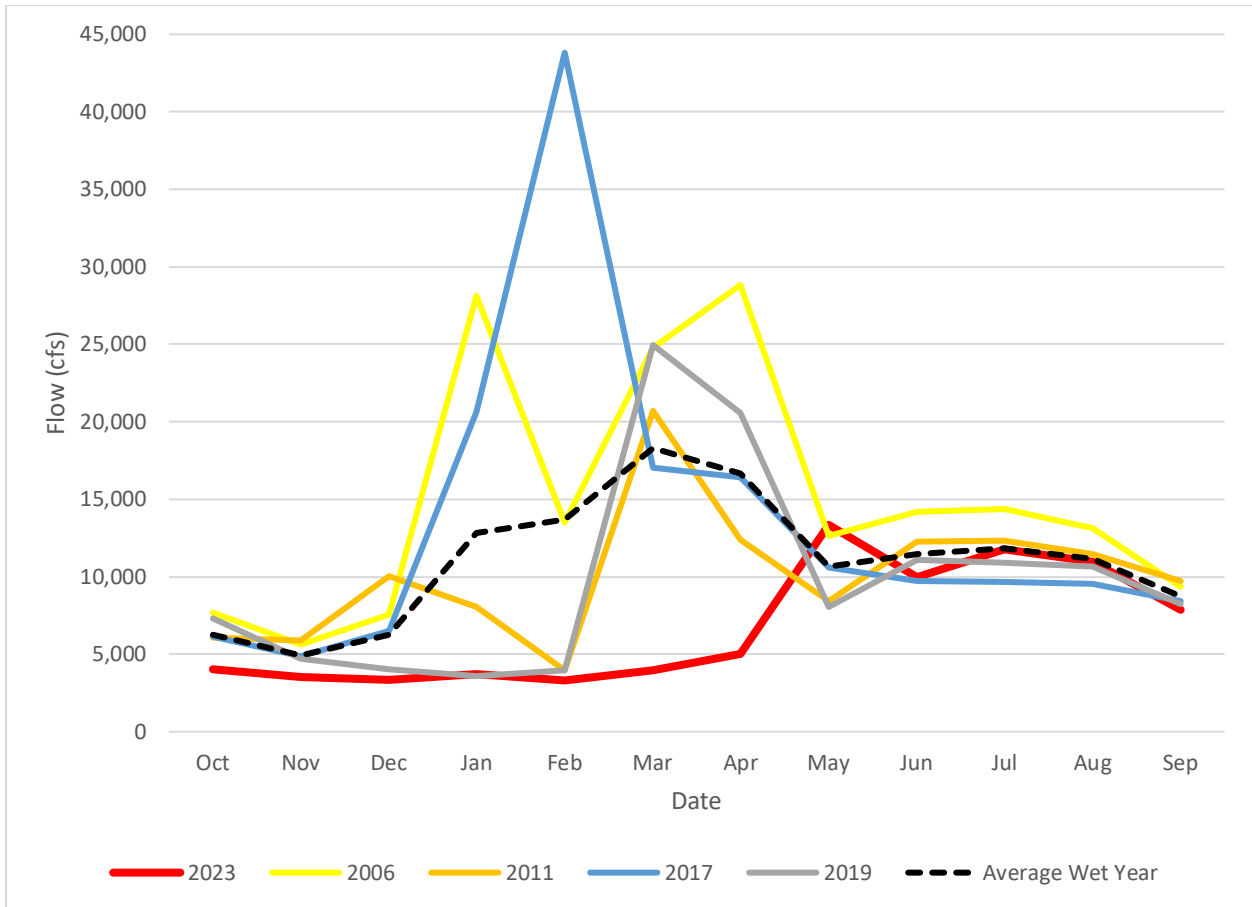
**Figure 3.** Shasta Lake Storage (red line), Allowable Storage for Flood Control (black line), Keswick Dam Release (blue line), and Shasta Inflow (green line) for 10/1/2022 – 9/30/2023.



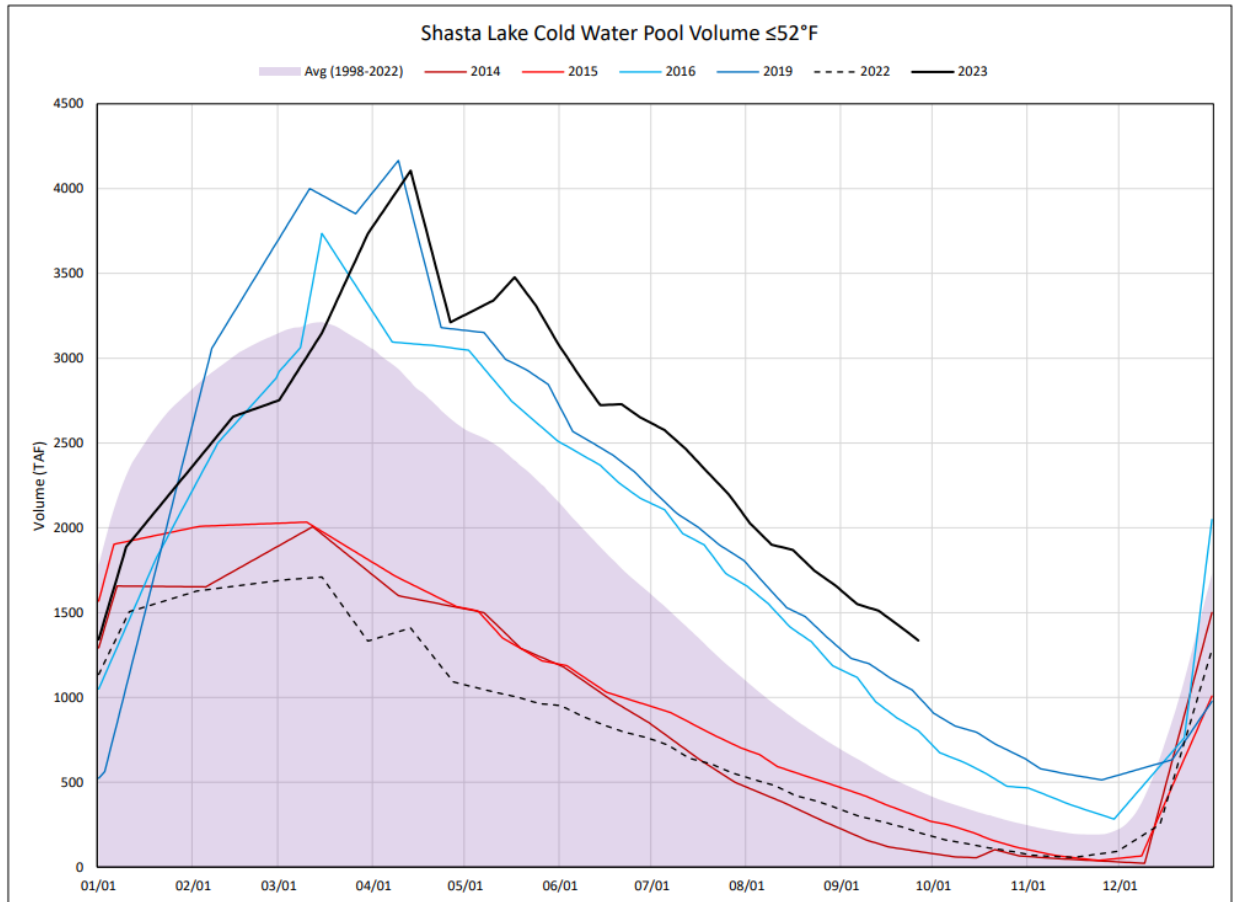
**Figure 4.** Sacramento River releases from 10/1/2022 – 9/30/2023 with major operations highlighted.



**Figure 5.** Shasta Reservoir storage in WY 2023 and in Wet Water Years 2006, 2011, 2017, 2019 and 2023.



**Figure 6.** Monthly average Keswick Dam releases in WY 2023 and in Wet Water Years 2006, 2011, 2017, 2019.



**Figure 7.** Shasta Reservoir coldwater pool volume less than 52°F for 2023.

## Summer/Fall Water Temperature Management

Storage conditions and trending hydrology in the late winter months can offer some insight on the trajectory of 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. Between December 2022 and March 2023, Shasta Lake gained over 2.2 MAF of storage as wetter hydrological trends progressed through the season. Winter storage was below average for wet water years and Keswick Dam releases remained low through April.

In March, April and May, Reclamation examines future in-stream temperature performance and assesses two forms of insight to future coldwater pool management: (1) relationship between total Shasta Lake storage/coldwater pool and potential future water temperature compliance; and (2) preliminary water temperature model simulation results. In each month, Reclamation determined that based on the 90% forecasts there would be sufficient volume of coldwater pool in Shasta Lake to meet the Tier 1 condition of achieving the 53.5°F temperature target at CCR throughout the temperature management season.

A spring pulse flow was attempted in 2023 but was not fully implemented due to higher releases for Shasta Lake storage conservation management needs. Reclamation began releasing 8,100 cfs from Keswick Dam on April 24, 2023. However, shortly after the first pulse flow was initiated, it was realized that storage management had to start occurring and the reduction in releases that defined the initial pulse for experimental testing could not be accomplished. Keswick Dam releases increased in late-April and remained near 13,000 cfs throughout most of May due to storage management needs. The spring pulse action is further described in the 2023 Shasta Storage and Spring Pulse Seasonal Report.

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 Sacramento River Temperature Task Group (SRTTG) as part of the draft TMP shared on April 26, 2023 and discussed during the SRTTG meeting held on April 27, 2023. The draft TMP targeted 53.5 °F at CCR throughout the entire temperature management season. This plan resulted in a forecasted temperature dependent mortality of 0-1% and also projected not needing to utilize the Temperature Control Device (TCD) side gates due to the large volume of coldwater pool. On June 7, 2023, Reclamation distributed the final TMP to National Marine Fisheries Service (NMFS), the State Water Board and SRTTG. The final temperature management strategy targeted 53.5 °F at CCR throughout the entire temperature management season.

### **June through October**

Real-time implementation of the 2023 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 8**.

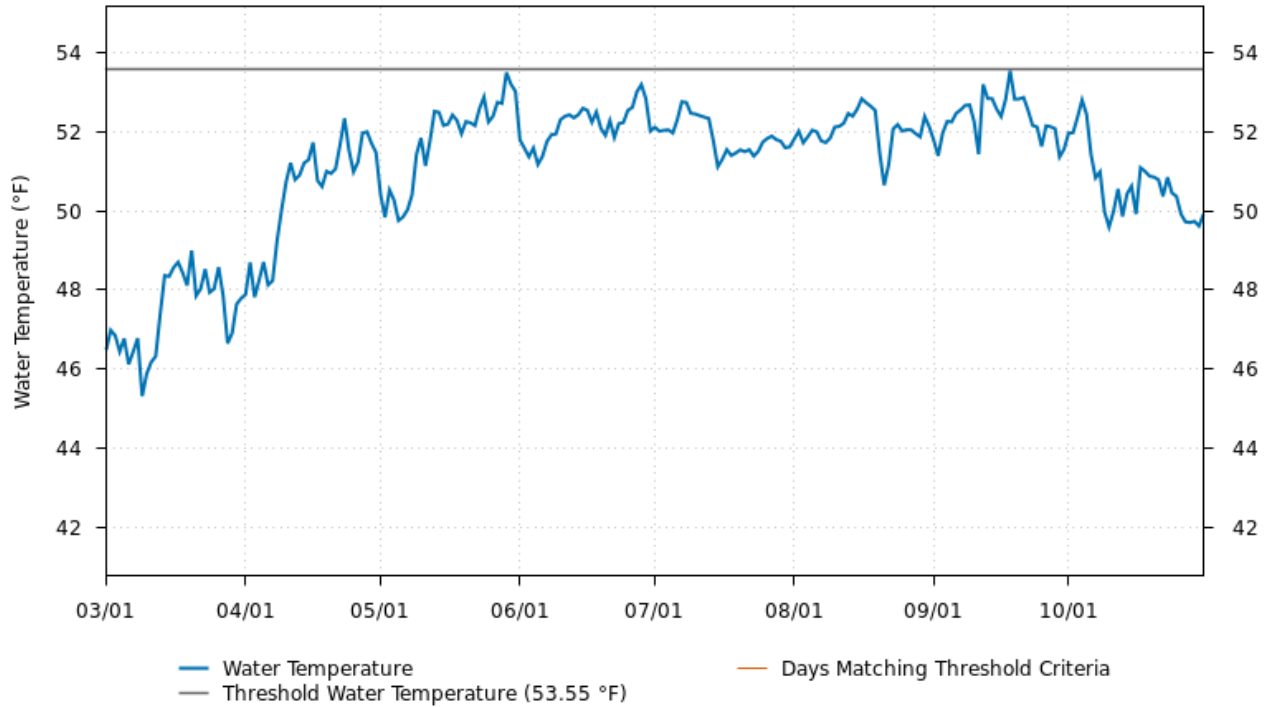
Events that influenced in-river conditions or real-time operation considerations included:

- **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 first Pressure Relief Gates (PRGs) were opened on September 8, 2023, and the TCD side gates were not used throughout the temperature management season.
- **Trinity River diversions:** Despite wet hydrology, Trinity Reservoir storage was relatively low in WY 2023, and therefore minimal diversions from the Trinity River to the Sacramento River were made in the summer of 2023. 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 CCR compliance location was compared against its respective daily temperature target for WY 2023 (**Figure 8**). From March through October 31, 2023, the temperature target at the CCR compliance location was not exceeded.

Sacramento R abv Clear Ck (CCR)  
Water Temperature  
3/1/2023-10/31/2023  
Average for Period 51.08 °F  
0 Days above 53.55 °F (0%)



[www.cbr.washington.edu/sacramento/data/perform](http://www.cbr.washington.edu/sacramento/data/perform)

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**Figure 8.** Summary of Upper Sacramento River Daily Mean Water Temperature from March through October 2023.

## Fisheries

The following section describes the Chinook salmon monitoring efforts undertaken during the WY 2023 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 and aerial spawning surveys are described in Reclamation 2022. Preliminary CDFW Upper Sacramento River Basin Salmonid Monitoring Program data for the 2023 temperature management season can be accessed on CalFish:

<https://www.calfish.org/ProgramsData/ConservationandManagement/CentralValleyMonitoring/CDFWUpperSacRiverBasinSalmonidMonitoring.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 also subject to revision. The CDFW 2023 winter-run Chinook salmon carcass survey began on May 1, 2023, following the same protocols and guidelines as in previous years, were conducted weekly, and concluded on September 21, 2023. Temporal distribution of carcasses is as follows: the first carcass was detected on May 11 (0.2% of the cumulative total), 139 carcasses were detected by July 1 (26.3% cumulative), 483 carcasses were detected by August 1 (91.5% cumulative), and 528 carcasses were detected by September 21 (100% cumulative), with the last carcass detection on August 22.

The distribution of carcasses by area (**Table 4**) indicates that 39.2% of carcasses were collected between Keswick Dam and the Anderson-Cottonwood Irrigation District (ACID) Dam which is lower than the 2003-2022 average of 36.2%. The percent of carcasses collected from the ACID Dam to the Hwy 44 Bridge was 35.2% which is lower than the 2003-2022 average of 37.5%. Overall, approximately 74% of carcasses were collected above the vicinity of the SAC temperature compliance point and 26% 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 2023.

**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/CentralValleyMonitoring/CDFWUpperSacRiverBasinSalmonidMonitoring.aspx>

Section	River Miles	Carcasses	2023 Percent	% Average (2003-2022)
1- Keswick Dam to ACID Dam (rm 302 to 298)	302-298	207	39.2%	36.2%
2- ACID Dam to Hwy 44 Brg (rm 296)	298-296	186	35.2%	37.5%
3- Hwy 44 Brg down to Clear Crk Powerlines (rm 288)	296-288	116	22.0%	21.9%
4- Clear Crk Pwrl to Balls Ferry Brg (rm 276)	288-276	19	3.6%	4.4%
<b>Total</b>	<b>26 miles</b>	<b>528</b>	<b>100.0%</b>	<b>100.0%</b>

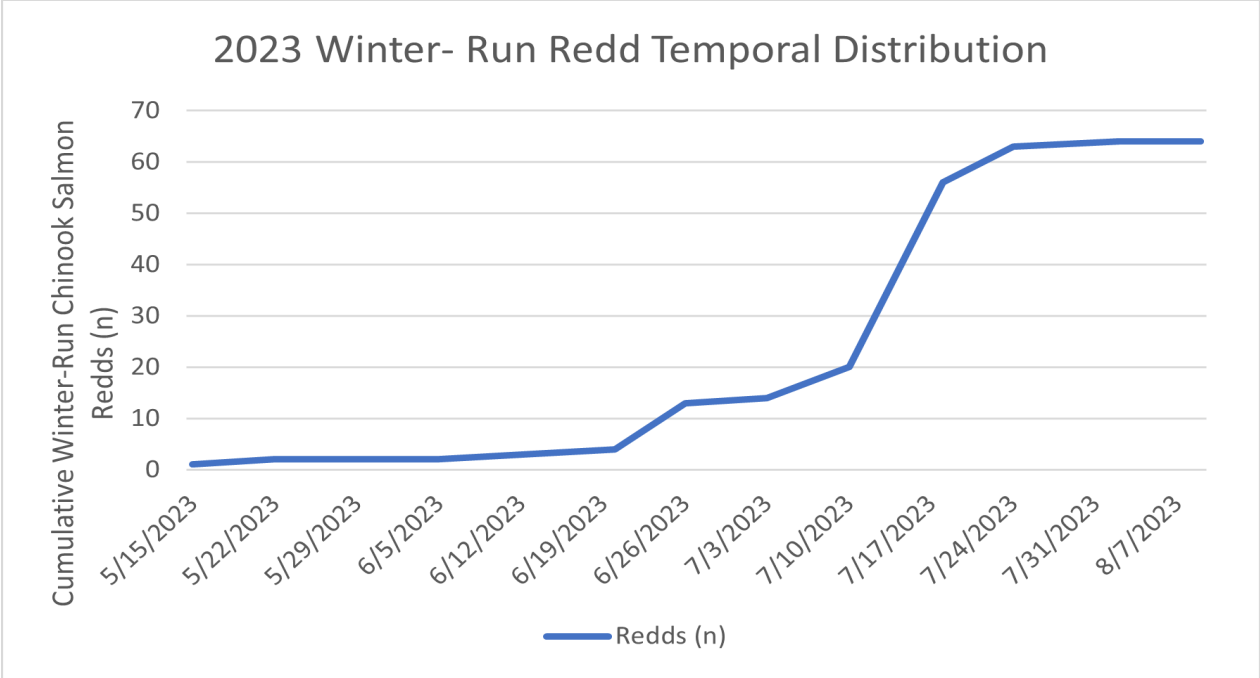
Aerial redd surveys provide another line of evidence for spawning distribution which should be considered in conjunction with carcass survey data. The first winter-run Chinook salmon aerial redd survey was conducted on May 15, 2023, and the final survey was conducted on August 9, 2023. A total of 13 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 2023 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 2023.

**Table 5.** Winter-run Chinook salmon aerial redd survey counts by river area, as end of season, in 2023.

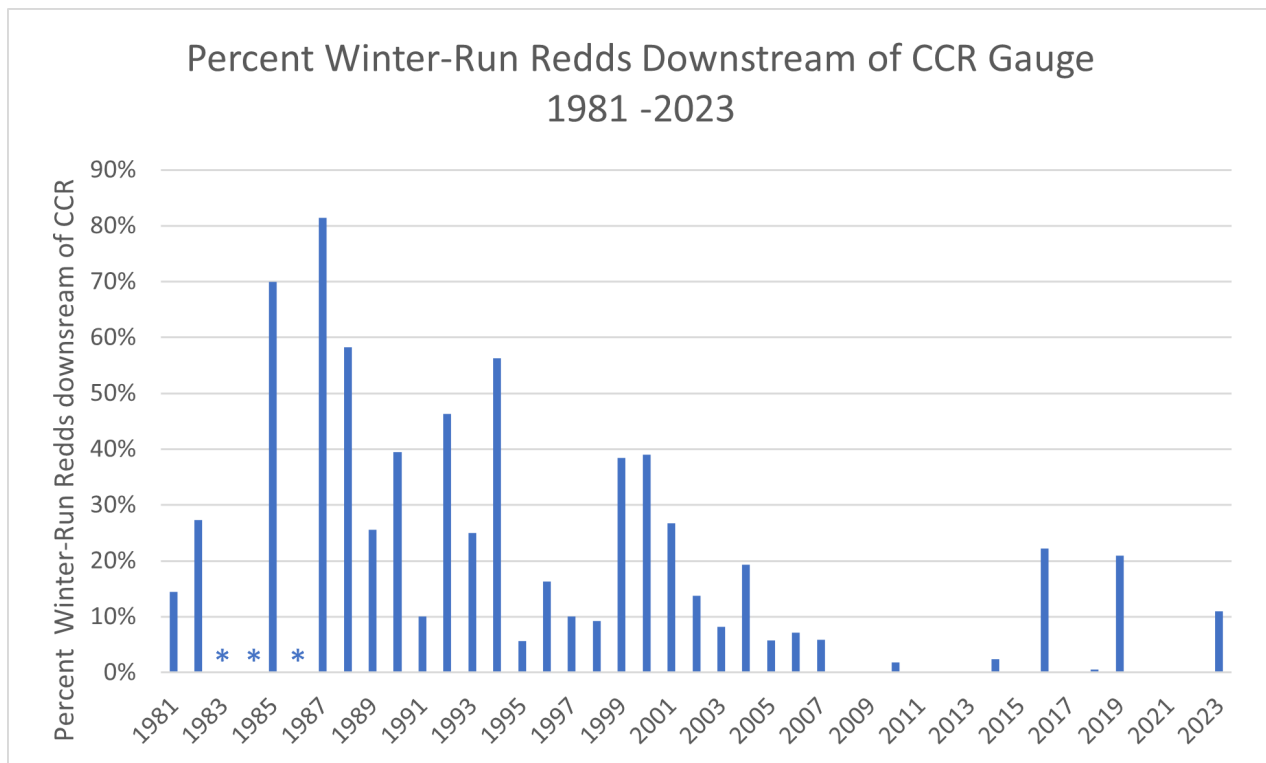
**NOTE: these data are preliminary and subject to change during final analysis that occurs after the season is completed.**

\*\*See Calfish winter-run Chinook Update file for final information when available. Link: <https://www.calfish.org/ProgramsData/ConservationandManagement/CentralValleyMonitoring/CDFWUpperSacRiverBasinSalmonidMonitoring.aspx>

Flight Sections	River Mile	Redds	2023 Percent	% Average (2003-2022)
Keswick to A.C.I.D. Dam Carcass Section 1	298	17	27%	38.2%
A.C.I.D. Dam to Highway 44 Bridge Carcass Section 2	296	32	50%	48.5%
Highway 44 Br. to below Clear Creek Carcass Section 3	284	15	24%	12.4%
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	n/s	0.1%
Bend Bridge to Red Bluff Diversion Dam	242	0	n/s	0.0%
Red Bluff Diversion Dam to Tehama Bridge	229	n/s	n/s	0.0%
	<b>Total</b>	<b>62</b>	100%	0%



**Figure 9.** Cumulative temporal distribution of winter-run Chinook Salmon redds (n) during 2023 aerial surveys.



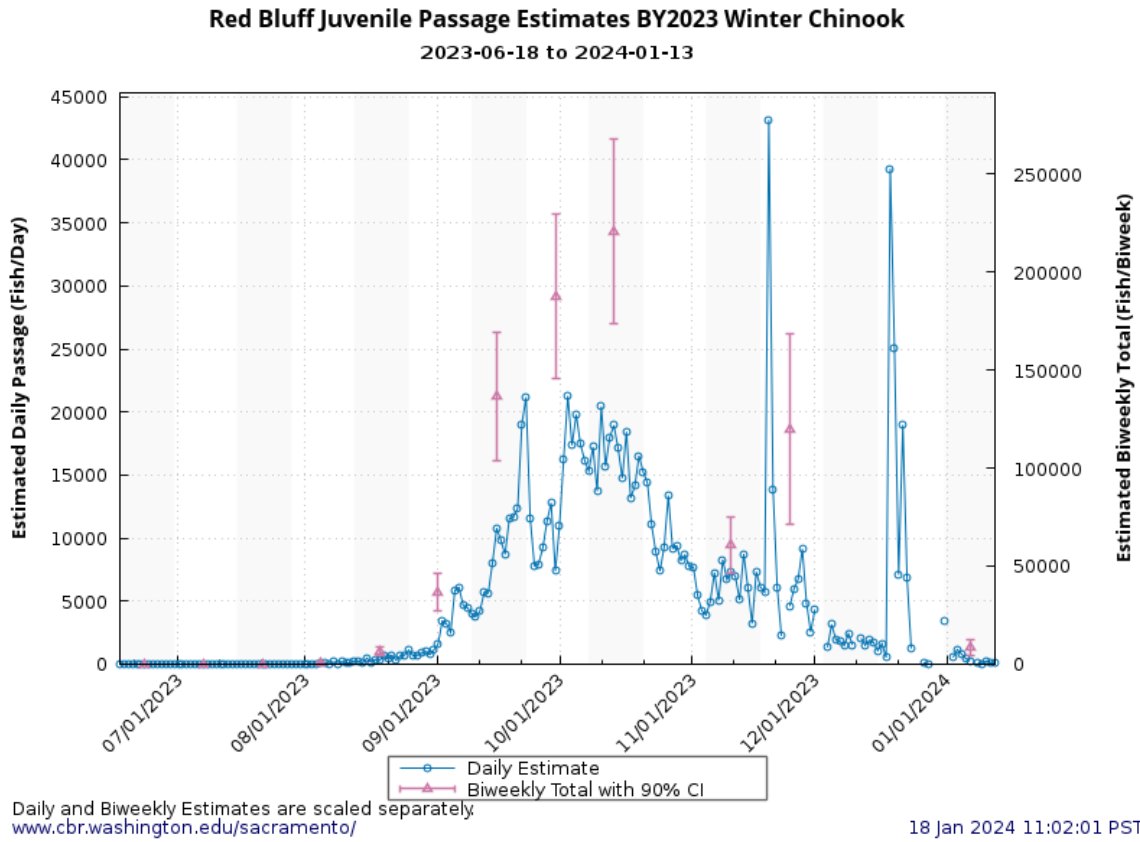
**Figure 10.** Percent of winter-run Chinook salmon redds downstream of the CCR gauge near Bonnyview Bridge (1981-2023). Data were not available 1983-1984 and 1986 (denoted by “\*”).

As noted in the NMFS BY 2023 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](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 2023 was 2,427 spawners. Of this total number of spawners, 507 were collected at the Keswick Dam trap site for spawning at Livingston Stone NFH, leaving an estimated 1,920 to spawn naturally in-river. An estimated 206 of the LSNFH 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 have been finalized in late winter (January or February). The winter-run Chinook salmon juvenile production estimate for BY 2023 is 234,896 for natural-origin and 196,941 hatchery produced juvenile winter-run Chinook salmon expected to enter the Delta during WY 2024. Estimated daily and biweekly passage of juvenile winter-run Chinook salmon at Red Bluff Diversion Dam (RBDD) from June 18, 2023, to January 13, 2024 (**Figure 11**). Historical and current

estimated passage of juvenile winter-run Chinook salmon at RBDD (BY 2010 – BY 2023) (Figure 12).



**Figure 11.** Preliminary Daily and Biweekly (Total with 90% Confidence Interval) Estimates of Juvenile Winter-run Chinook Salmon Passage at Red Bluff from 06/18/2023 – 1/13/2024.

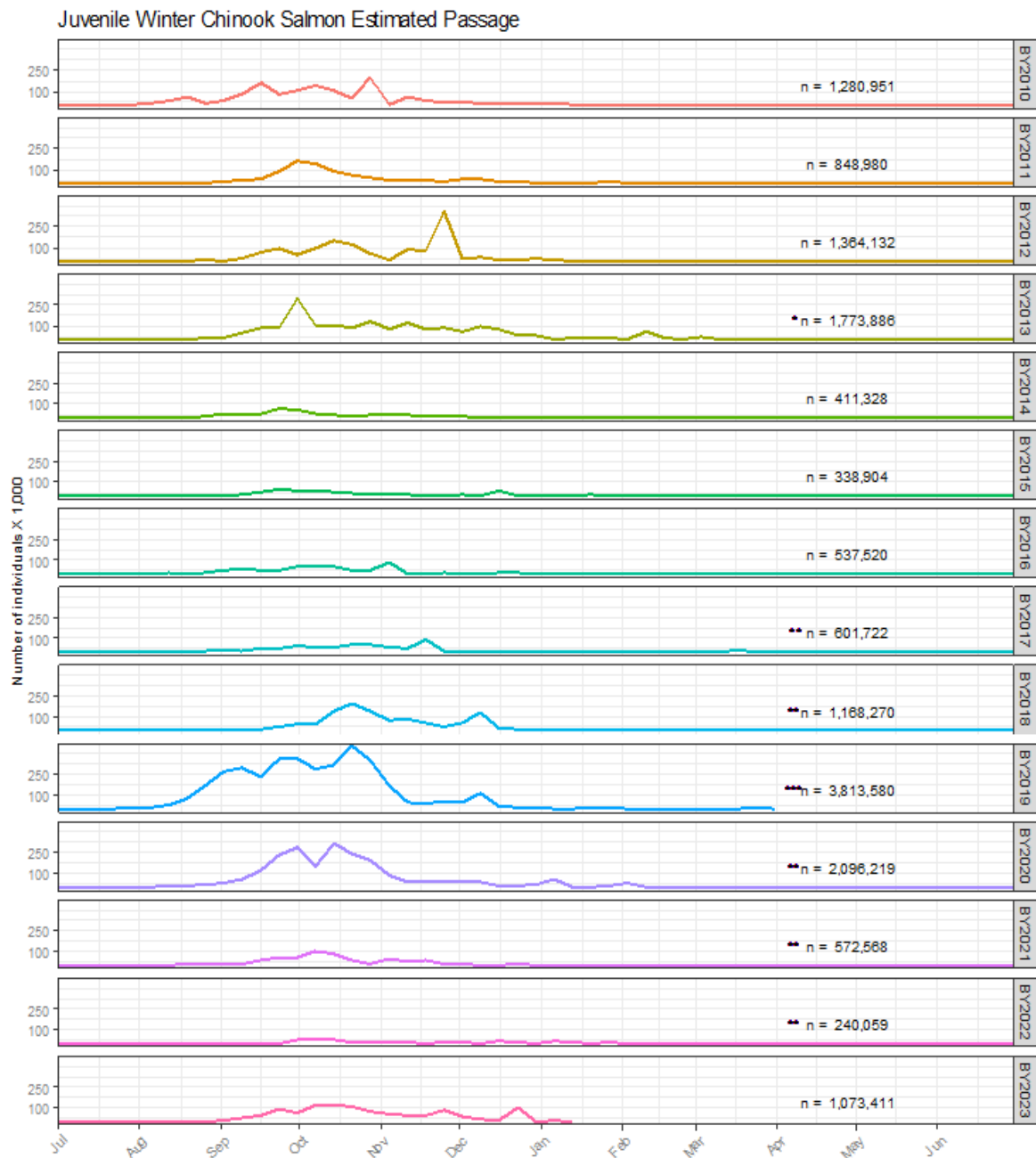


Figure 1. Weekly estimated passage of unmarked juvenile winter Chinook salmon at Red Bluff Diversion Dam (RK391) by brood-year (BY). Fish were sampled using rotary-screw traps for the period July 1, 2010 to present.

\*Winter Chinook passage value interpolated using a monthly mean for the period October 1, 2013 - October 17, 2013 due to government's 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/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 12. Historical and Current Estimated Passage (Preliminary) of Juvenile Winter-run Chinook Salmon at RBDD (BY 2010 - BY 2023).**

## Operations Summary

The key events and decisions that influenced the 2023 upper Sacramento River Temperature operations include:

- WY 2023 was a wet year following three dry or critically dry water years in WY 2020, 2021, and 2022.
- The 2023 TMP detailed a Tier 1 performance category and specified both temperature targets and locations.
- Initiation of the water temperature management season began on May 15, 2023 with active management to 53.5°F at the CCR compliance location.
- The TCD side gates were not opened during the temperature management season.
- End of September storage was 3.3 MAF.
- Firm data supporting a total population for BY23 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, 2023.
- No modification or amendment to the 2023 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 coldwater pool operations, Reclamation performed a hindcast of temperature-dependent egg mortality 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 WY 2023, 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 temperatures 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 2023 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 2023 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**. Modeled and historical vertical temperature profiles for Shasta Lake on August 2, 2023 are shown in **Figure 13**. The first use of the TCD's side gate in the model run was on July 15; this compares well with the historical average use of the side gate.

Results indicate a systematic underprediction of temperature at the Clear Creek gauge and similar behavior up and down river (**Figure 14, Figure 15, Figure 16**). The model, particularly at Keswick and Clear Creek, exhibits more variability than what is present in the observed record. The model performed well at predicting lake profiles early in the water temperature management season but overpredicted temperatures in Shasta Lake as the temperature management season progressed. Overall, the results indicate that given historical flows, Shasta Dam outflow temperatures, and meteorology, the HEC-5Q model performed well at reproducing historical downriver temperatures in 2023. This is a positive indicator for in-river temperature and temperature-dependent mortality forecasts. 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.

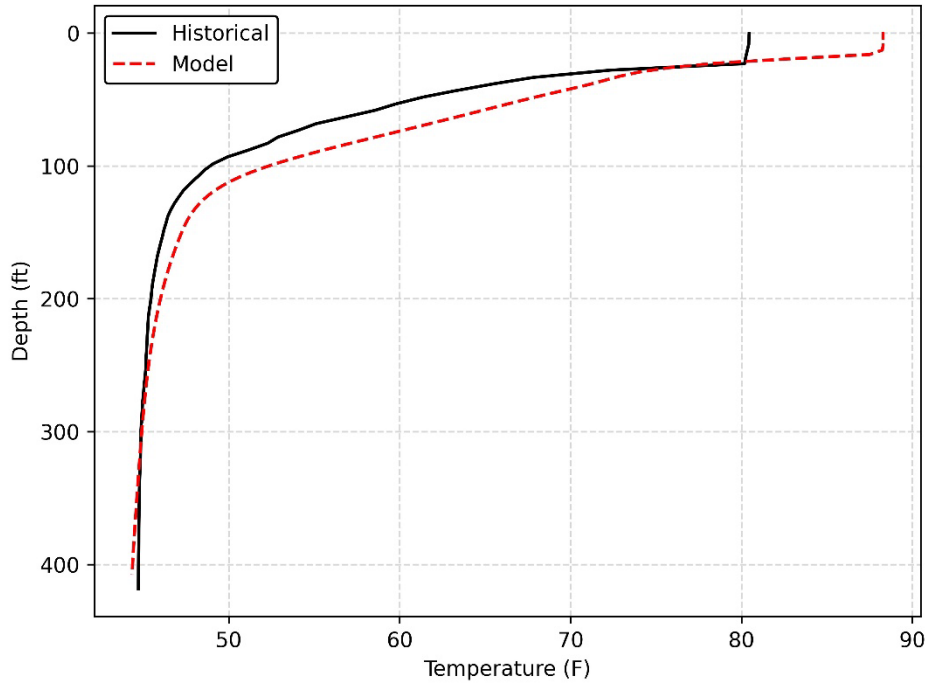
**Table 6.** Error metrics in degrees Fahrenheit used to compare modeled vertical temperature profiles for Shasta Lake to 2023 observed data for all data. Metrics include Mean Bias, Mean Average Error (MAE), Root Mean Squared Error (RMSE), and Nash-Sutcliffe Efficiency (NSE).

Date	Mean Bias	MAE	RMSE	NSE
5/17/2023	0.534	0.831	1.988	0.832
5/31/2023	0.765	1.063	2.563	0.763
6/7/2023	1.029	1.255	2.673	0.848
6/21/2023	0.999	1.244	2.592	0.876
6/27/2023	1.053	1.256	2.530	0.887
7/5/2023	1.009	1.176	2.302	0.925
7/12/2023	1.028	1.298	2.391	0.932
7/19/2023	1.160	1.413	2.517	0.940
7/26/2023	1.488	1.670	2.833	0.911
8/2/2023	1.555	1.709	2.884	0.905
8/9/2023	1.660	1.798	2.895	0.920
8/16/2023	1.885	2.037	3.239	0.910
8/23/2023	1.936	2.061	3.359	0.890
8/30/2023	2.393	2.623	4.081	0.862
9/6/2023	2.686	2.756	4.173	0.827
9/13/2023	2.719	2.800	4.148	0.844
9/20/2023	2.805	2.869	4.207	0.829
9/27/2023	2.786	2.837	4.041	0.815

10/4/2023	3.074	3.124	4.350	0.778
10/11/2023	3.387	3.419	4.553	0.725
10/18/2023	3.628	3.658	4.827	0.694
10/25/2023	4.116	4.144	5.343	0.553
10/31/2023	4.089	4.105	5.120	0.553

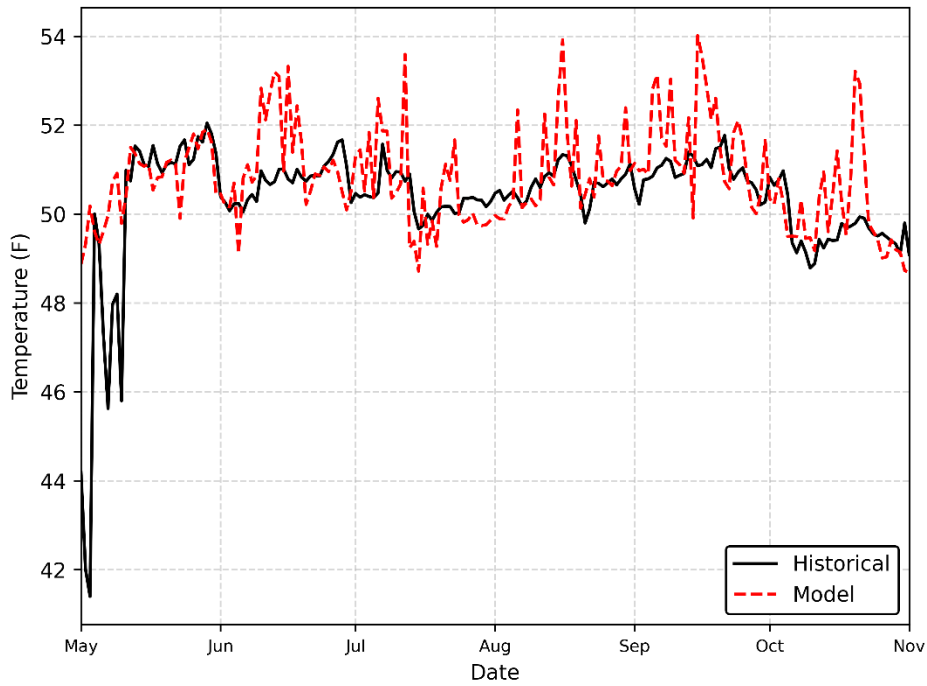
**Table 7.** Error metrics in degrees Fahrenheit used to compare modeled Sacramento River temperatures to 2023 observed data from 5/1/2023 to 10/31/2023. Metrics include Mean Bias, Mean Average Error (MAE), Root Mean Squared Error (RMSE), and Nash-Sutcliffe Efficiency (NSE).

Location	Keswick	Clear Creek	Balls Ferry
<b>Mean Bias</b>	0.497	-0.321	-1.027
<b>MAE</b>	1.231	1.192	1.743
<b>RMSE</b>	1.819	1.470	2.107
<b>NSE</b>	-0.141	-0.104	-0.080

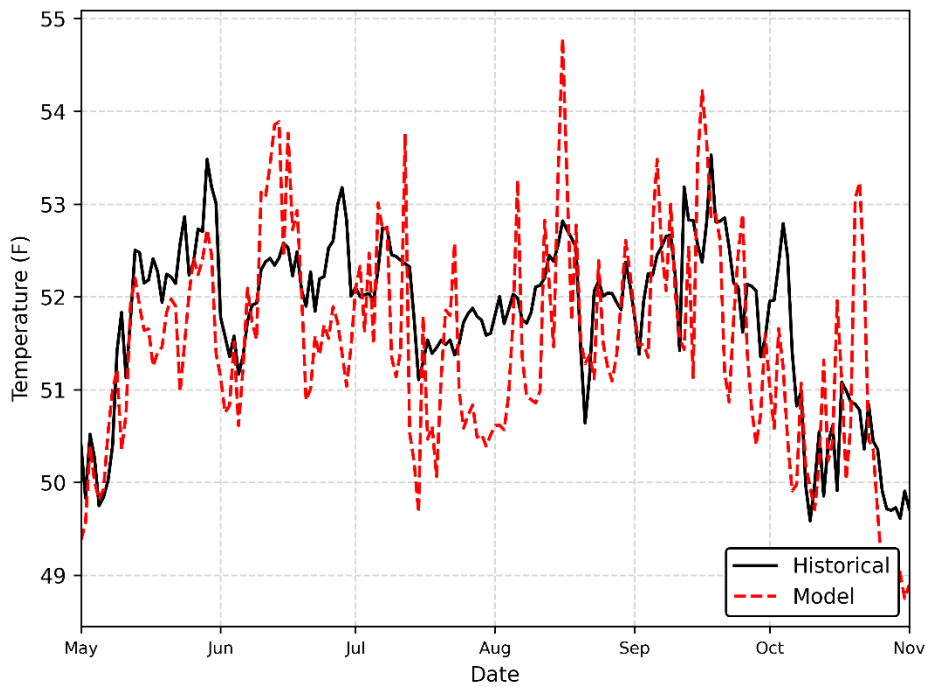


**Figure 13.** Modeled and observed water temperature (degrees Fahrenheit) profile of Shasta Lake on 8/2/2023 by depth (feet).

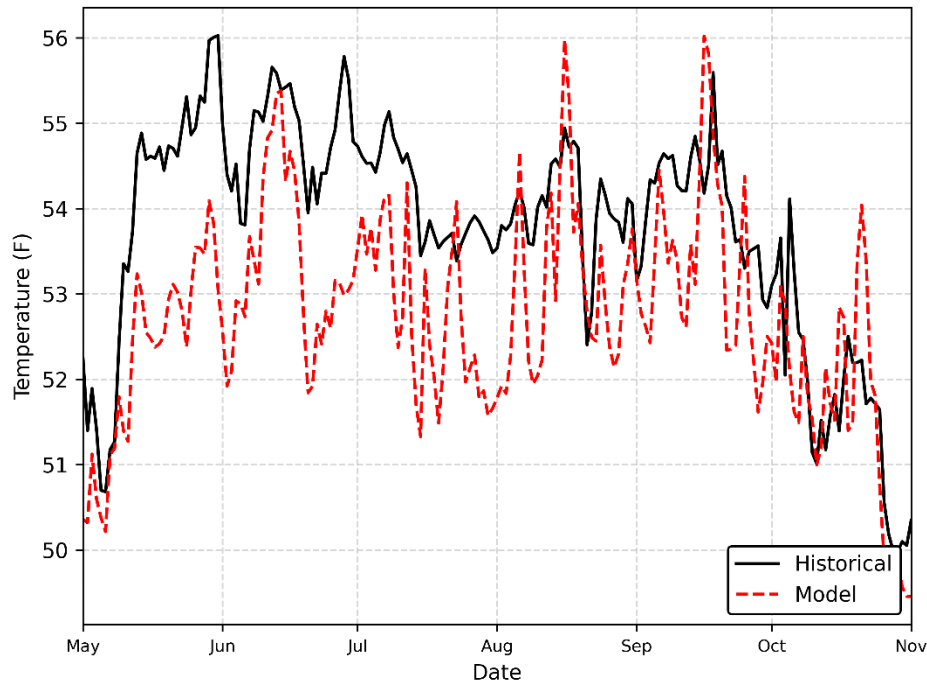
For hindcast evaluation, modeled and actual water temperatures at three locations were compared: Sacramento River at Keswick Dam (**Figure 14**), Clear Creek (**Figure 15**), and Balls Ferry (**Figure 16**). Modeled water temperature data were warmer than observed water temperature data at Keswick but cooler at Clear Creek and Balls Ferry. Biases are systematic across the model period, although the variability of the model does include the observed values for the upstream gages. The increasing negative bias with flow distance indicates that HEC5Q may be underestimating the instream warming.



**Figure 14.** Modeled and observed water temperatures (degrees Fahrenheit) at Keswick (KWK) from 5/1/2023 – 10/31/2023.



**Figure 15.** Modeled and observed water temperatures (degrees Fahrenheit) at Clear Creek (CCR) from 5/1/2023 – 10/31/2023.



**Figure 16.** Modeled and observed water temperatures (degrees Fahrenheit) at Balls Ferry (BSF) from 5/1/2023-10/31/2023.

### Mortality Forecasts

Both Reclamation and NMFS provided TDM forecasts for winter-run Chinook salmon eggs in WY 2023. During 2023, both agencies provided early TDM forecasts and then relied on NMFS forecasts throughout most of the temperature management season. Reclamation’s approach used 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 were 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 were 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 found 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.

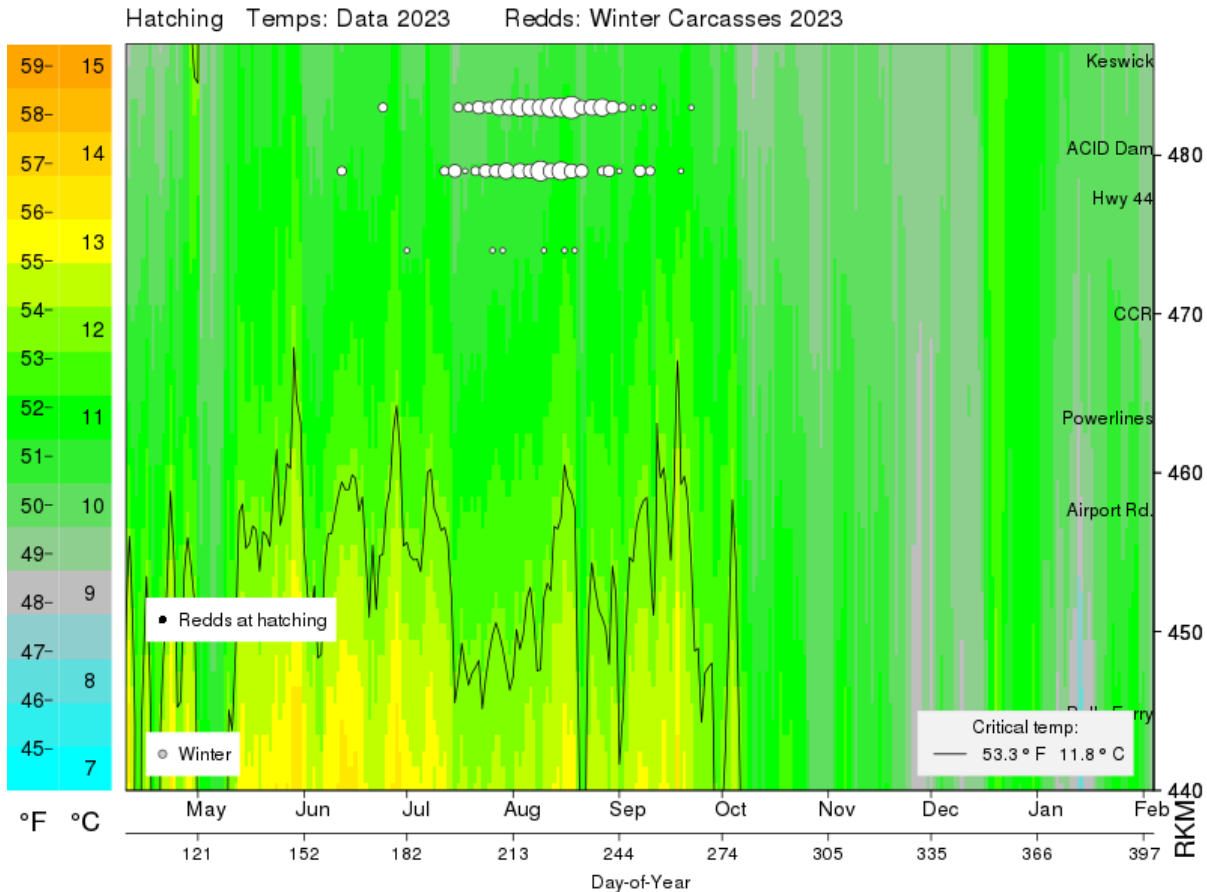
Winter-run Chinook salmon egg TDM estimates were calculated by modeling a redd's lifetime based on the days required to cross a known cumulative degree-day threshold and estimating mortality as an increasing function of water temperature past a temperature threshold. Two models were used: (1) Martin 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 temperature 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 2016-2023. TDM estimates varied depending on the water temperatures and TDM models used. Forecasted estimates for overall TDM in the final TMP was 0.1% using the Martin model (stage-independent), while overall TDM estimates using the Anderson model (stage-dependent) was 0.8%.

#### **Temperature-Dependent Egg Mortality Hindcast**

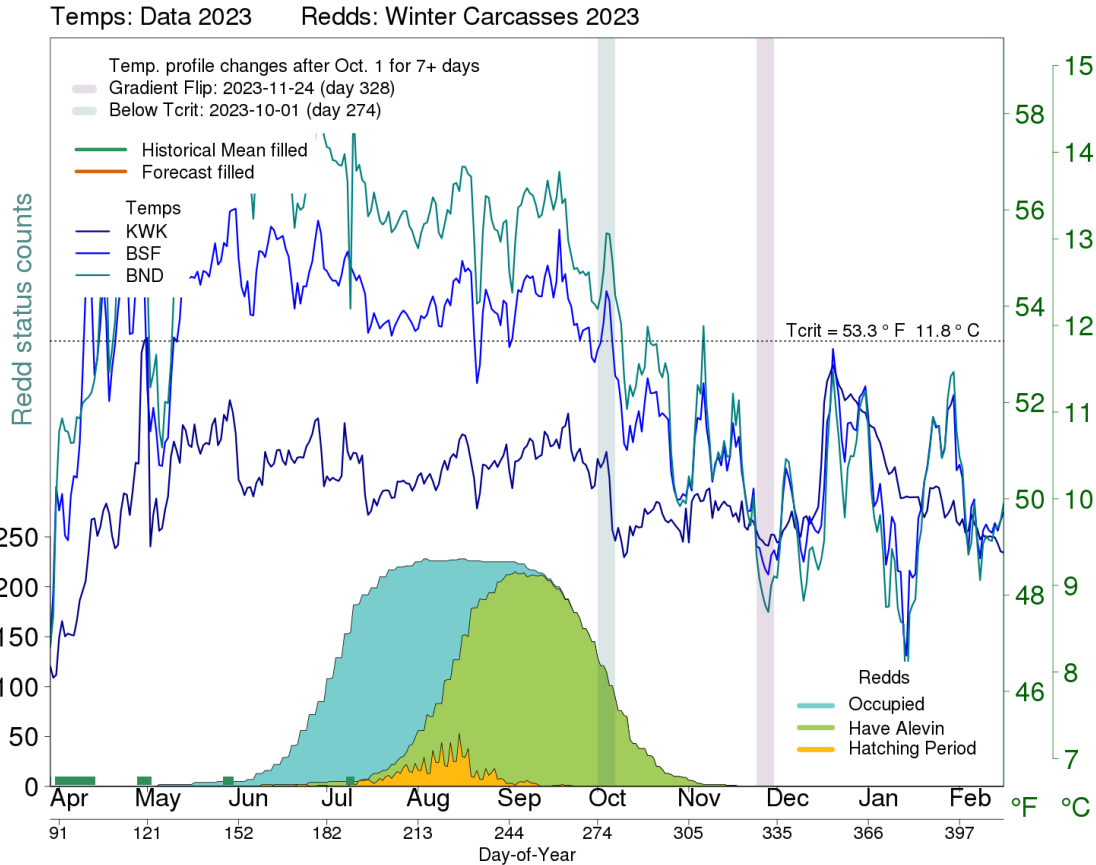
TDM hindcasts methods are similar to TDM forecasts described above. The SacPAS Fish model allows modeling of spawning to emergence in the Sacramento River. Winter-run Chinook salmon redd location and water temperature data are inputs to the model. Survival from Keswick Dam to RBDD can be modeled as a 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 Analysis Tools section.

Winter-run Chinook salmon redds further downstream are exposed to water temperatures that are warmer (**Figure 17**). The SacPAS Fish Model has the ability to describe TDM for redds in general locations. Reclamation's forecasted mortality estimates for overall TDM in the final TMP was 0.1% using the Martin model (stage-independent), while overall egg mortality estimates using the Anderson model (stage-dependent) was 0.8%. Reclamation's hindcast TDM estimate using the SacPAS Anderson model (stage-dependent) and Martin model (stage-independent) is 0%. The forecast and hindcast TDM estimates did not vary greatly from the originally estimated temperature management plan in 2023.



**Figure 17.** WY 2023 distribution and timing of winter-run Chinook salmon hatching with water temperatures using model inputs described in Appendix B: Table 1. No winter-run Chinook salmon redds were exposed to water temperatures that exceed the critical temperature threshold (12°C) during hatch time in 2023. 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 2023 is shown in **Figure 18**. 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 October. The critical hatching periods were mainly late July through August. Fry emergence from the gravel peaked in September and October.



**Figure 18.** Temporal distribution of winter-run Chinook salmon redds and egg development to emergence in WY 2023. Figure is based on 2023 winter carcass survey data as described in Appendix B: Table 1.

## Performance Metrics

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

### Estimates of Temperature-Dependent Egg Mortality

The 2020 ROD included 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.

Reclamation's hindcast TDM estimates was 0% using carcass data from 2023.

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

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 vitamin deficiency have been reported to contribute the mortality of early life stages of Chinook salmon. The 2020 ROD included 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

Each year, NMFS includes a preliminary estimate of egg-to-fry survival in the Juvenile Production Estimate letter which is usually available in January at California Central Valley Water Operations: Biological Opinion Actions | NOAA Fisheries. The BY 2023 Juvenile Production Estimate letter includes an estimated 24.94% egg-to-fry survival. NMFS noted that "Thiamine deficiency complex syndrome contributed to early life stage mortality in 2023, [...] An unpublished model estimated thiamine-dependent fry mortality at 51 percent (95% credible interval of 43-58%). This estimate is based on thiamine concentrations in egg samples from 59 females spawned at LSNFH in 2023, which showed 88 percent of females with thiamine levels low enough (<5.9 nmol/g) that some fry mortality would be expected and 56 percent with critically low levels (<2.7 nmol/g) (SWFSC, pers. comm; NOAA Fisheries 2024). These estimates of mortality related to temperature and thiamine deficiency and assuming background survival of 32 percent predict an estimated egg-to-fry survival of 16 percent." (pg. 14).

Additionally, a preliminary assessment of estimated egg-to-fry survival to RBDD using the SacPAS Fish Model was conducted. Early season estimates for egg-to-fry survival to RBDD was estimated to be 100% using both the Anderson model (stage-dependent) and Martin model (stage-independent). The passage at RBDD is predicted to be about 235,000 juveniles, up only slightly from last year's (2022) estimate of 200,000 which was the lowest since detailed monitoring began about 20 years ago.

### **Commitment to Tier**

WY 2023 was determined to be a Tier 1 year in the TMP and remained in the tier for the duration of the water temperature management season.

## Conservation Measures

In WY 2023, there was increased production of winter-run Chinook Salmon at Livingston Stone NFH to mitigate for the anticipated thiamine-deficiency related mortality for eggs naturally spawned in the Sacramento River and the impacts from previous three consecutive years of drought (**Table 8** and **Table 9**). The 2023 brood year production included the offspring of adults trapped at Battle Creek and the Keswick Dam fish trap.

**Table 8.** Livingston Stone National Fish Hatchery Production in WY 2023.

Release Start	Release End	CWT Tag Race	Hatchery	Release Site	CWT Number Released (Percent Marked)
01/26/2023	03/01/23	Winter	LSNFH	Sacramento River at John F. Reginato River Access	732,324 (100%)

**Table 9.** Livingston Stone National Fish Hatchery Projects in WY 2023.

Project	Females Collected	Females Spawned	Males Collected	Males Spawned	Green Eggs	Eyed Eggs	Fry
Mainstem Sacramento River	197	179	309	200	986,343	924,223	828,273
Battle Creek Jumpstart (Battle Creek Returns)	31	27	11	33*	156,413	147,607	142,213**
Battle Creek Jumpstart (Captive Broodstock)	NA	0	NA	0	0	0	0***

\* Consisted of Battle Creek and Keswick Trapped males.

\*\*Transferred to Mt. Lassen Trout Farm for rearing prior to future release to Battle Creek.

\*\*\*There was no captive brood spawning in 2023 due to out of sync sexual maturity of males and females.

Fishery agencies and the Winnemem Wintu tribe incubated 80,153 winter-run eggs in streamside incubators in the McCloud River at Ah Di Nah as an additional emergency drought action. 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. In 2023, 7,775 juvenile winter-run Chinook salmon were transported from the McCloud River to the Sacramento River.

## Discussion

In WY 2023, spawning distribution was generally similar to historical (2003-2022) patterns, however, there was an increase in the upstream reach, Keswick Dam to ACID Dam (2023: 39.2%; 2003-2022: 36.2%). Based on the summary results described in the Fisheries section, both the spatial and temporal requirements for Shasta Lake coldwater 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. 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.

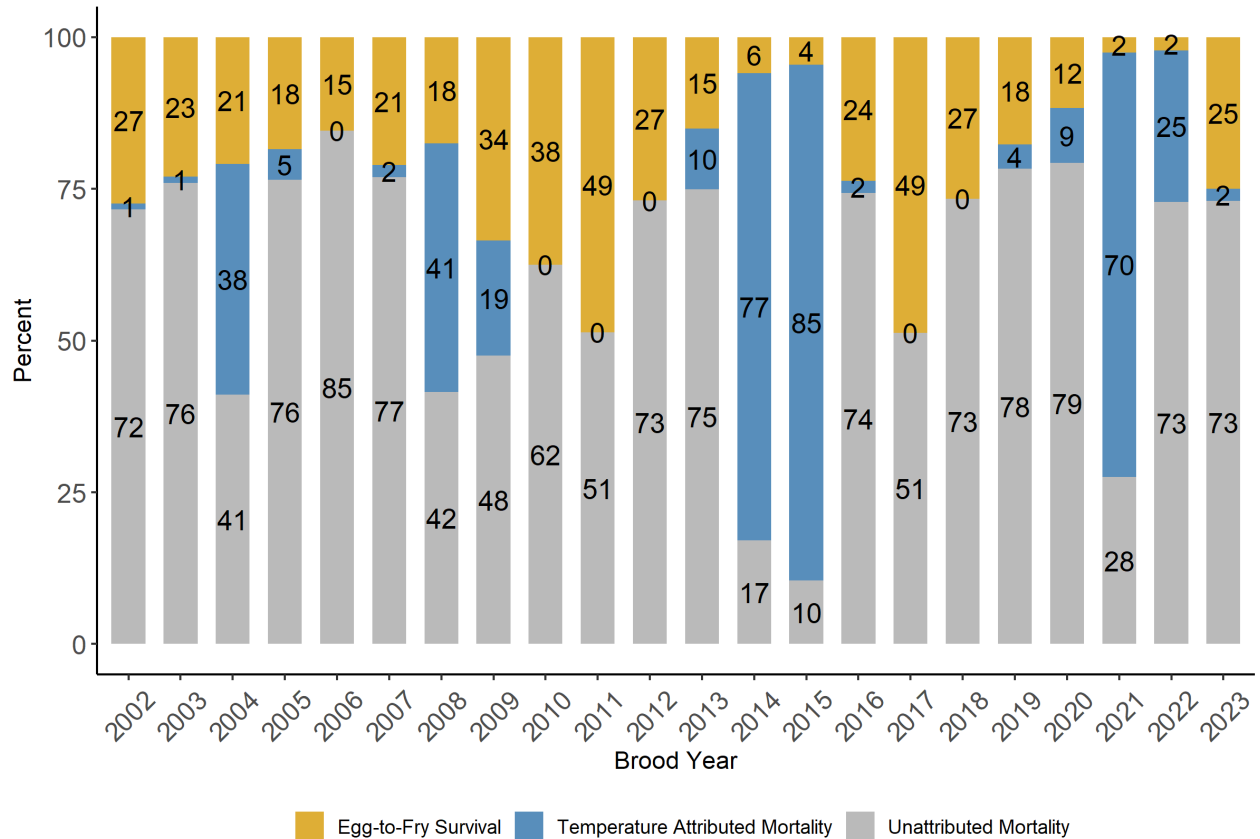
The NMFS Juvenile Production Estimates (JPE) letter states “Similar to BY 2020 to 2022, BY 2023 was affected by a thiamine deficiency in returning adults. While the thiamine deficiency was also addressed in the BY 2023 hatchery stock, BY 2023 naturally-spawning winter-run Chinook salmon adults with low thiamine levels spawned eggs low in thiamine which 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). Currently, the SacPAS Fish Model does not account for thiamine deficiency impacts on egg-to-fry survival.

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 and migrate down to 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. 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 fry emerge from the gravel and when they arrive in Red Bluff. Water temperature prior to emergence is one factor affecting egg-to-fry survival that can be influenced by water management. 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 may all impact survival. Some of these factors are correlated; for example, predation on fry and juveniles is likely higher in warmer water and this relationship can become a part of the egg-to-fry survival estimates.

The temperature-dependent mortality and egg-to-fry survival estimates are used to gauge the effectiveness of actions taken in the 2020 ROD. Other factors outside of model calibrations, such as thiamine deficiency in adults, 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 was used to compensate for thiamine deficiency impacted survival.

The estimates for temperature-dependent mortality, egg-to-fry survival, and unattributed mortality (which represents other mortality factors upstream of RBDD) for BY 2002 – 2023 are shown in Figure 19 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. 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.



**Figure 19.** 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 yellow) for BY 2002 through 2023. Temperature dependent mortality (i.e., temperature attributed mortality) estimates obtained from NOAA-Southwest Fisheries Science Center and are based on the Martin Model. Final egg-to-fry survival for BY 2002 to 2021 were provided by USFWS. Preliminary egg-to-fry survival estimates for BY 2022 and 2023 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.

## Improvements

No supplemental information for WY2023.

## Conclusion and Management Summary

WY 2023 was a wet year following three dry or critically dry water years in WY 2020, 2021, and 2022. The 2023 TMP detailed a Tier 1 performance category and specified a 53.5 °F target at the CCR gage. Reclamation’s hindcast temperature-dependent egg mortality estimate was 0% in 2023. The BY 2023 Juvenile Production Estimate letter estimated 21.75% egg-to-fry survival. The Tier 1 Upper Sacramento River Performance Metrics from

the 2020 ROD for temperature-dependent egg were met in WY 2023. Water temperature model platform peer review efforts occurred through the Delta Stewardship Council during 2023. More information can be found at: [Water Temperature Model Development Independent Advisory Panel](#)

## References

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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](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/](https://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/sacramento_river/)

SRTTG Notes - [Sacramento River Temperature Task Group | BDO | Area Offices | California-Great Basin | Bureau of Reclamation \(usbr.gov\)](#)

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](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-](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)

[coast/endangered-species-conservation/california-central-valley-water-operations-biological#juvenile-production-estimates-\(jpe\)-for-sacramento-river-winter-run-chinook-salmon](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)

CVTEMP - [CVTEMP \(noaa.gov\)](#)

# Appendix A – 2023 Sacramento River Temperature Management Plan

[2023 Sacramento River Temperature Management Plan](#)

# Appendix B – Temperature Dependent Mortality Model Inputs

Table 1. Temperature Dependent Mortality Model Inputs and Assumptions in Water Year 2023

Parameter	Chinook egg to fry development Scenario
Meteorology source	L3MTO Meteorology 25%
Time period	1/1/23-12/31/23: Observed temperature
Reservoir Model used	HEC-5Q
River Model used	HEC-5Q
Shasta Profile date	4/13/23
TCD Gate operations	HEC-5Q
Sacramento water temperatures used	HEC-5Q output at Keswick, Highway 44, Clear Creek, and Balls Ferry.
Biological Model used	SacPAS Fish model (Temperature effect only)
Temperature Mortality Models	Stage-independent mortality Stage-dependent mortality
Egg emergence timing model	Linear. 958 ATUs (degrees C), as indicated for Zeug et al. on SacPAS under Egg to emergence timing model.
TDM redd time distribution	Winter Carcass Surveys 2023 (230 redds)
TDM redd space distribution	Winter Carcass Surveys 2023 (230 redds)
TDM Tcrit (50th percentile)	Stage-independent mortality: 12.14°C Stage-dependent mortality: 11.82°C
TDM bT (50th percentile)	Stage-independent mortality: 0.026°C <sup>-1</sup> d <sup>-1</sup> Stage-dependent mortality: 0.436°C <sup>-1</sup> d <sup>-1</sup>
Critical Days	Stage-independent mortality: All Stage-dependent mortality: 4 days
Model Run Date	01/22/2024