2026 Sacramento River Temperature Management Plan

Executive Summary

This Temperature Management Plan (TMP or Plan) describes how the U.S. Bureau of Reclamation (Reclamation) proposes to operate Shasta Reservoir and the Temperature Control Device (TCD) on Shasta Dam for the 2026 temperature management season. The Plan utilizes data from various sources, including: Reclamation's May 90% exceedance forecast of Central Valley Project (CVP) operations, recent reservoir temperature profiles, seasonal meteorological forecasts, and estimated winter-run chinook salmon temperature dependent mortality (TDM). The Plan is consistent with the 2025 Record of Decision (ROD) to implement the "Action 5" Operations Plan for the Long-Term Operation of the Central Valley Project and State Water Project (LTO) (Reclamation 2025) and State Water Resources Control Board (SWRCB) Water Right Order 90-5 (WRO 90-5) (SWRCB 1990). This year is categorized as a Bin 2A year, in which water temperatures are managed for winter-run spawning habitat on the Sacramento River at Clear Creek (CCR) to a daily average of 53.5°F and temperatures are shaped through Governance. For the purposes of WRO 90-5, this translates to meeting a daily average temperature requirement of 56.0°F on the Sacramento River at Balls Ferry Bridge (BSF). Throughout the season, Reclamation will continue to analyze actual conditions and tradeoffs of establishing alternate temperature locations and increased Shasta Reservoir storage levels. Operational updates, and any needed changes to the TMP as the season progresses, including changes to the location of temperature targets along the Sacramento River, would be reported and discussed through the Sacramento River Group (SRG), Fish and Water Operations Group (FAWOG), and the SWRCB. This Plan considers and incorporates responses to substantive comments provided to Reclamation and the SRG from several organizations on the Draft Plan that was submitted to the SRG and SWRCB on April 29, 2026.

Introduction

The Shasta Division of the CVP is operated for many purposes including flood control, fish and wildlife, water supply, power generation and Sacramento River water quality. Major facilities include the Shasta Dam and Powerplant, Keswick Dam and Powerplant, and a TCD on the upstream face of Shasta Dam. This Plan focuses on the fishery management aspect and attempts to maximize suitable water temperature regimes for the endangered Sacramento River winter-run Chinook salmon.

This Plan describes how Reclamation proposes to operate Shasta Reservoir and the TCD on Shasta Dam consistent with:

- The 2025 ROD on the LTO of the Central Valley Project (Section 2.19 Water Temperature Management). Reclamation will coordinate through the SRG to prepare a draft TMP in April. The draft TMP will include: projected reservoir releases, assumed meteorological conditions, anticipated water temperatures and target locations along the Sacramento River, and TDM estimates based on both Martin (2017) and Anderson et al. (2022). Reclamation will finalize the TMP in May or later through coordination with the SRG and FAWOG. Reclamation may update the TMP through coordination with the SRG and FAWOG throughout the temperature management season.
- WRO 90-5; to consult with the California Department of Fish and Wildlife (CDFW), U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), and Western Area Power Administration on the designation of a location upstream of the Red Bluff Diversion Dam where Reclamation will meet a daily average water temperature of 56°F.
- WRO 90-5; to provide an operation plan to the Chief of the Division of Water Rights of the SWRCB on Reclamation's strategy to meet the temperature requirement at a location upstream of the Red Bluff Diversion Dam.

The temperature management strategy provided by the Plan is based on technical review and input received from the SRG (and FAWOG if applicable). The Plan establishes temperature locations and targets through October 31, 2026, and estimates winter-run Chinook salmon egg mortality, dates for operation of the side gates on the TCD, and end of September cold water pool in Shasta Reservoir. Reclamation will monitor the cold water pool, compare measured conditions to actual performance during implementation, and provide regular updates through the SRG throughout Plan implementation.

Background

Shasta Reservoir management considers drought protection actions in nearly every year and identifies actions that protect storage for multiple project purposes, including temperature management. A key principle of Shasta management is that drought protection and fish protections are linked. The strategy is framed around an objectives-based management framework that establishes different objectives depending on hydrologic conditions and identifies actions that can be taken for fishery management and drought protection. The framework approach is described in Section 2.5 of the "Action 5" Operations Plan of the LTO and includes the establishment of "Bins" to manage water temperature and storage. This includes three Bins that are each divided into two categories: standard (Bin A) and drought protection (Bin B). The B-bins are intended to increase the priority of storage conservation to address the risk that the ensuing year could be a drought. The Bin number (1, 2, or 3) is defined by the actual or projected End of April (EOA) storage, which is primarily driven by hydrology, and the projected End of September (EOS) storage which is primarily driven by expected demands on the reservoir which are a function of hydrology, meteorology, system-wide conditions, contractual requirements and other conditions. Bin classifications must satisfy both the EOA storage condition and the EOS storage condition. The approach establishes biological objectives for each Bin and identifies potential actions based on actual or forecasted EOA storage and forecasted EOS storage. For example, as described in Section 2.14 of the "Action 5" Operations Plan of the LTO, Reclamation will reduce Shasta Reservoir releases for water supply under Bin 2B and Bin 3 conditions to increase EOS Shasta storage. Table 1 is a summary of the temperature management objectives.

Table 1. Water Temperature and Storage Management Framework

Water Temperature & Storage Management Bins	**Category**	**EOA Shasta Storage (MAF)**	**EOS Shasta Storage (MAF)**	**Temperature management objective**
Bin 1 (Enhance)	A	Greater than or equal to 3.7	Greater than or equal to 3.0	53.5°F downstream from CCR
Bin 1 (Enhance)	B	Greater than or equal to 3.7	Greater than or equal to 2.4	53.5°F downstream from CCR
Bin 2 (Recover and Maintain)	A	Greater than or equal to 3.0	Greater than or equal to 2.2	53.5°F at CCR (seasonal shaped if necessary)
Bin 2 (Recover and Maintain)	B	Greater than or equal to 3.0	Greater than or equal to 2.0	53.5°F at CCR (seasonal shaped if necessary)
Bin 3 (Protect)	A	Less than 3.0	Greater than or equal to 2.0	53.5°F upstream from CCR (seasonal shaped if necessary)
Bin 3 (Protect)	B	Less than 3.0	Less than 2.0	53.5°F upstream from CCR (seasonal shaped if necessary)

Footnote:

MAF = million acre-feet

Although some correlation between the water year type (i.e., the Sacramento Valley Water Year Index) and the Bin assignments exists (NMFS 2024), there are exceptions in this trend and an above normal year can result in a Bin 2A assignment. Additionally, NMFS states "…the Bin determination is intended to be based on the EOA storage value and modeling of anticipated conditions,…" (NMFS 2024) NMFS estimates that in Bin 2A years, expected to occur in approximately 12 percent of years, Reclamation's management of Shasta's cold water pool will support an average temperature-dependent egg survival that is approximately 95 to 97 percent (NMFS 2024).

Current Conditions Summary

The Northern California winter of Water Year 2026 has been mild for the most part, with only a few periods of heavy wetness and low snowpack. Consequently, Shasta storage is above average, and the cold water pool volume is below average. Downstream water temperature performance is expected to be more challenging than the last few water years (i.e., 2024 and 2025) but still much improved over the previous drought years of 2020 to 2022. The Northern Sierra Precipitation 8-Station Index indicates that this year's hydrologic conditions are similar to the 30-year average. However, Shasta Reservoir's cold water pool, less than or equal to 48°F, is projected to be comparable to other below average years such as 2015 and 2022. Coordination and active water temperature management began in February 2026, taking advantage of real-time management opportunities to increase storage and cold water pool. These conditions, along with the March 90% forecast, supported implementation of a spring pulse flow action, as described in the 2026 Sacramento River Spring Pulse Operations Plan (Attachment 1).

Methodology: Modeling Assumptions, Limitations, and Other Uncertainties

Reclamation uses a physically-based simulation model, WTMP, to develop a seasonal water temperature strategy, which describes future expected downstream water temperature (Reclamation 2024a). This forecast, or simulation of expected water temperature performance, is based on the targets specified in the Plan. Future water temperature is forecasted using computational tools, offering insight at various elevations in the reservoirs and downstream in the river. These tools are based on conservative assumptions regarding hydrology, operations, and meteorology. Because this forecast (using conservative estimates to estimate what might happen at the end of October) can never exactly predict the actual hydrology, operations, and meteorology, the model results are not expected to precisely match actual water temperatures. The expectation is that modeled downstream water temperatures will contain an acceptable amount of error regardless of the forecasted uncertain future conditions. Reclamation (2024a) presents model calibration, validation, and sensitivity analysis.

With the WTMP modeling, there are generally two types of simulation error: uncertainty of the future conditions (e.g. inputs such as hydrology and meteorology) and inherent model error or bias. For the former, Reclamation has consistently used NOAA-NWS' Local Three-Month Temperature Outlooks (L3MTO) and historical meteorology as a means of estimating air temperature expectations for modeling purposes. In coordination with SRG, Reclamation has the choice of five meteorological exceedance threshold options, varying from those that serve more conservative temperature planning (e.g., 10% exceedance) to those that serve more aggressive planning scenarios (e.g., 90% exceedance). In past years, the SRG has recommended the use of a conservative approach that uses the 25% exceedance L3MTO forecast. Reclamation, in coordination with SRG, will continue to evaluate future meteorological forecast relationships with temperature modeling and TDM. Operational decisions on the upper Sacramento River are influenced by local and CVP and SWP system-wide multi-purpose objectives, including those that are planned (e.g., powerplant maintenance) and uncertain (e.g., weather). The potential and timing of many uncertain factors contribute to future operational actions presented in the forecasts including, but not limited to: flood protection operations, inflows, meteorology, reservoir stratification, pulse flow schedules, facility maintenance, physical/mechanical facility limitations, upstream operations, minimum in-stream flow criteria, public health and safety criteria, downstream Delta regulatory requirements, Delta exports, power generation, recreation, fish hatchery accommodations, temperature management capabilities, and others. In addition, uncertain or unplanned events can also influence real-time operational decisions (e.g., wildfires and equipment malfunctions). To address uncertainty, Reclamation typically uses conservative estimates of future conditions in the modeling assumptions (e.g., hydrology, operations, and meteorology) and projections are updated through the temperature management period.

TDM estimates carry three broad categories of uncertainty. First, forecast uncertainty reflects what is unknown about how the brood-year cohort will deposit redds in space and time. For instance, the Winter-run Chinook salmon Effects Analysis (Reclamation 2024b) reported TDM intraannual variation of as much as 25% based on this category. In the TMP, the 13-year range and standard deviation reflect this category under the fixed 2026 scenario. Second, process error is unmodeled biological variability in egg-to-fry survival. Interstitial flow, dissolved oxygen, gravel composition, maternal thiamine status, and density-dependent effects are absorbed into each model's calibrated background term. Third, model error includes parameter uncertainty and structural uncertainty in TDM estimate. Parameter uncertainty is reflected in parameters, such as Tcrit and rates in each model. These are applied in the TMP as the published point estimates calibrated to aggregate Sacramento River outcomes and are not uniquely identifiable from those data (Schmidt et al. 2019; Zeug et al. 2024). Second, structural uncertainty is reflected in the TDM models representing different hypothesized models of temperature effects on eggs. In the TMP, two TDM models are reported in parallel (Martin et al. 2017; Anderson et al. 2022) rather than selecting a single model, since the actual mechanisms underlying temperature dependent mortality are not fully quantifiable.

Model Inputs

The Shasta Reservoir release strategy included in this Plan and temperature modeling is based on the CVP’s May 90% exceedance forecast of operations. This release schedule is intended to guide the monthly average releases from Keswick Dam. Daily releases may vary from these flows to adjust for real-time operations. Trinity River releases below Lewiston Dam are based on a Dry year type per the 2000 Trinity Record of Decision and diversions through Carr Powerplant were adjusted to balance storage, flow, and water temperature goals. Meteorologic inputs use the

25% exceedance L3MTO data, and the initial conditions use a Shasta Lake temperature profile based on May 19th observations. Table 2 describes the monthly forecasted operations for releases and storage targets referenced in the CVP's May 90% exceedance forecast of operations (Attachment 2).

Table 2. Monthly forecasted operations for Shasta and Keswick reservoir releases and storage estimates from May 90% exceedance forecast.

Operations Information	May	June	July	August	September
Shasta Releases (TAF)	433	574	660	663	366
Keswick Releases (cfs)	8,500	11,500	12,600	12,650	8,000
Keswick Releases (TAF)	523	684	775	778	476
Spring Creek Power Plant (TAF)	90	110	115	115	110
Shasta End-of-Month Storage (TAF)	3,943	3,518	2,981	2,440	2,200

Footnotes:

TAF = thousand acre-feet
cfs = cubic feet per second

Water Temperature Strategy, Results and Discussion

Reclamation identified Water Year 2026 as a Bin 2A year based on the May 90% exceedance forecast. In a Bin 2A year, Shasta Reservoir storage is forecasted to be greater than or equal to 3.0 million acre-feet (MAF) at the end of April; greater than or equal to 2.2 MAF at the end of September; and meet 53.5°F at CCR. Shasta storage was greater than 3.7 MAF at the end of April and the CVP's May 90% exceedance forecast of operations estimates storage at 2.2 MAF at end of September, which identifies this year as a Bin 2A year. Bin 2A biological objectives include: managing winter-run Chinook salmon adult holding temperatures to 58°F to minimize pre-spawning mortality, managing the majority of spawning habitat at CCR to average daily water temperatures of 53.5°F, and targeting temperatures resulting in TDM to be ≤ 3%. For this reason, this Plan proposes to target 53.5°F at CCR during the winter-run spawning and egg incubation period and to shape temperatures through Governance. Reclamation managed water temperatures to 58.0°F at CCR from March 1, 2026 to May 14, 2026 to minimize pre-spawning mortality and then began to manage to 53.5°F on May 15, 2026, after discussions with and feedback from the SRG and the initiation of active winter-run Chinook spawning. Reclamation will continue to analyze actual conditions and tradeoffs of establishing alternate temperature locations, increased Shasta Reservoir storage levels, and balancing the biological goal of maximizing suitable habitat and the risk of running out of cold water. Operational updates, and any needed changes to the TMP as the season progresses, including changes to the location of temperature targets along the Sacramento River, would be reported and discussed through the Sacramento River Group (SRG), Fish and Water Operations Group (FAWOG), and the SWRCB.

In March, the SRG evaluated various spring pulse flow options and Reclamation approved a plan for the potential of multiple pulses from April through May. The purpose of the spring pulse flow is to increase outmigration survival of juvenile Chinook salmon and juvenile steelhead. Based on Reclamation's March 90% exceedance forecast of operations and WTMP modeling, the plan showed the pulse flow action would have minimal effect on temperature management operations. Reclamation deployed approximately 50 TAF of spring pulse flow from April 8 to April 14 to benefit spring-run Chinook salmon and steelhead juveniles. In late April, Reclamation determined that no additional spring pulse flow operations would occur due to the April 90% exceedance operations forecast, Shasta Reservoir temperature profiles, initial temperature modeling runs, and timing of expected increase in Sacramento River diversions. Therefore, the Keswick Reservoir release schedule in this Plan, as part of the CVP's May 90% exceedance forecast of operations, does not include any additional spring pulse flow actions.

The temperature modeling results targeting 53.5°F at CCR for this Plan are presented in Table 3 and Attachment 3. Operating to 53.5°F at CCR provides similar winter-run Chinook temperature mortality estimates as operating to 56.0°F at BSF. For the purposes of WRO 90-5, BSF represents the requirement location to meet a daily average temperature requirement of 56.0°F. Further refinement to the temperature management strategy would occur through coordination with the SRG and FAWOG, as the temperature management season progresses.

Table 3. Estimated average monthly water temperature in degrees Fahrenheit at Shasta, Keswick, CCR, and BSF based on model run of operations targeting 53.5°F at CCR and April 90% exceedance forecast.

Month	Shasta (°F)	Keswick (°F)	CCR (°F)	BSF (°F)
June	50.5	52.1	53.2	55.1
July	50.1	52.0	53.2	55.2
August	50.6	52.4	53.3	54.8
September	50.1	52.4	53.4	54.9
October	53.4	54.1	54.5	55.0
November	55.6	55.5	55.2	54.5

Water temperature forecasts under the proposed 2026 TMP scenario yield temperature dependent mortality (TDM) estimates pooled across brood years 2013-2025 and for 2025 (Table 4; full per-source and per-year detail in Attachment 4). Results from carcass-derived redd distributions, which have been included in recent TMPs and LTO documentation (USBR 2025, NMFS 2024), are presented due to biases with aerial-derived redd distributions caused by water turbidity, depth, and other environmental variable affecting aerial siting of redds. Averaged across brood years 2013–2025, stage-dependent TDM (Anderson, 2022) is 1.1% and stage-independent TDM (Martin et al., 2017) is 2.8%. For 2025, stage-dependent TDM is approximately 0.3% and stage-independent TDM is approximately 4.9%. A comparison with aerial-derived redd distributions is discussed in Attachment 4.

The SRG has an interest in better understanding the needs of fall-run Chinook salmon and improving the tools to manage conditions for the species. Maximizing carryover storage and cold water pool can typically improve temperature conditions for fall-run spawning (which historically runs from September through December, peaking in October) and subsequent egg incubation. Minimizing the drop in the stage of the river (from peak summer flows, to fall and winter flows) reduces winter-run redd dewatering, and in turn allows for earlier stabilization of fall flows to minimize fall-run redd dewatering.

Table 4. Predictions of winter-run Chinook performance measures from biological modeling. Attachment 4 presents additional results and aerial-derived estimates.

Performance Measure	Carcass-derived redd distribution
Stage-dependent TDM, pooled 2013–2025	1.1%
Stage-independent TDM, pooled 2013–2025	2.8%
Stage-dependent TDM, brood year 2025	0.3%
Stage-independent TDM, brood year 2025	4.9%

Reclamation commits to reporting out on the status of temperature management and overall system operations at the monthly SRG meetings. Reclamation will continue to coordinate through the SRG to review these and other model results and may update these TMP and TDM estimates based on those discussions.

Additional modeling results from NOAA Southwest Fisheries Science Center are described in Attachment 5.

References

Bureau of Reclamation, 2025. 2025 Record of Decision to implement the "Action 5" Operations Plan for the Long-Term Operation of the Central Valley Project and State Water Project. U.S. Department of Interior.

Bureau of Reclamation, 2024a. Water Temperature Modeling Platform: Model Development, Calibration, Validation, and Sensitivity Analysis: Central Valley Project Water Temperature Modeling Platform. https://www.usbr.gov/mp/bdo/docs/water-temperature-modeling-platform-model-development-calibration-validation-and-sensitivity-analysis.docx

Bureau of Reclamation, 2024b. Winter run Chinook Salmon Effects Analysis. Biological Assessment for the Long-Term Operation of the Central Valley Project and State Water Project. U.S. Department of Interior.

National Marine Fisheries Service, 2024. 2024 Biological Opinions for the Long-Term Operations of the Central Valley Project and State Water Project. U.S. Department of Commerce.

State Water Resources Control Board, 1990. Water Rights Order 90-5.

2026 Sacramento River Pulse Flows Operations Plan

4/14/2026

Executive Summary

- Reclamation's Shasta Division has been marked by low snow runoff, warmer air temperatures, and above average Shasta reservoir storage during water year 2026. However, forecasted runoff is anticipated to be low and affect End of September storage.
- Reclamation has discussed many spring pulse flow scenarios for April 2026 and identified considerations through the Sacramento Rive Group (SRG) and evaluated a range of scenarios in this operations plan. Based on available tools, SRG feedback from interest holders, agencies, and tribes Reclamation plans the following operation:
    - A 4-day pulse flow starting on April 8, 2026, with an estimated 25% increase in outmigration survival (compared to no pulse) and an estimated water cost of 35 TAF (estimated resulting Keswick release would be 10,000 cfs targeting a flow at Wilkins Slough flow of 11,000 cfs).
- This pulse flow is anticipated to increase outmigration survival for spring-run Chinook in the lower Sacramento River and fall-run chinook salmon released in the Upper Sacramento River from Coleman Fish Hatchery. In addition, Delta water temperatures are approaching unsuitable levels for outmigrating juvenile salmonids; therefore, an earlier season pulse is likely to have better outmigration survival than later season pulse implementation.
- This pulse flow is anticipated to increase temperature dependent mortality, although there remains a high degree of uncertainty about the differences between these values. This pulse flow reduces end of September Shasta storage, although the Shasta Operations Framework year type should remain a Bin 2B. This pulse flow is likely to reduce fall operational flexibility to reduce fall-run Chinook salmon redd dewatering.
- Reclamation will continue to coordinate and evaluate additional Central Valley Project Pulse Flows through the SRG once an April operations forecast and Draft Temperature Management Plan is available.

Background

As part of Action 5 for the Long term Operation of the Central Valley Project and State Water Project (2.11 Central Valley Project Pulse Flows), pulse flows address the outmigration cue stressor on steelhead juveniles and spring-run Chinook salmon juveniles by providing flow cues for outmigration and increasing the outmigration travel rate. Reclamation would release up to 150 thousand acre-feet (TAF) in pulse flow(s) each water year, typically in the spring when the pulse does not interfere with the ability to meet water temperature objectives or other anticipated operations of the reservoir. Reclamation through governance, may discuss the plan and make any appropriate and/or necessary refinements prior to implementation.

Forums are established for the purpose of sharing operational plans via notifications, gathering scientific and commercial data to inform the operation of the CVP and SWP, and for reporting the outcomes of operations. Reclamation would schedule this pulse after coordination through the (SRG) and may include coordinating timing with natural flow events, potential storage management operations and/or pulse flows in tributaries. The timing, magnitude, duration, and frequency of the pulse flows will be refined through the SRG assessment process. The SRG ad hoc pulse flow group convened to discuss pulse flows on 3/17 and 3/24. The SRG convened on 3/26 to discuss, among other items, spring pulse flow. The SRG provided feedback about these conditions and requests included pulse flows in late March. At the March 26 SRG meeting, early observations of coldwater pool stratification were presented and showed very low volumes of coldwater. At the March 31 SRG meeting, a draft of this Operation Plan was shared, and the start date was moved back a day further.

The temperature and flow plans are developed using the best available science including current hydrologic forecasts, CVP operational outlooks, fishery information, and modeling information. Reclamation coordinates through SRG to develop a protocol for agency collaboration regarding temperature and flow models and will strive to create shared understanding of model constraints, uncertainties, limitations, applied assumptions and interpretations; develop management questions and scenarios that may benefit from modeling support; develop and review early season operational scenarios to support temperature management and flow planning. Reclamation, through the Fish and Water Operations Group (FAWOG), will discuss the weekly fish and water outlook operations plan assessment and make any appropriate and/or necessary refinements prior to implementation. SRG meeting notes are posted to Reclamation's webpage at: Sacramento River Temperature Task Group | BDO | Area Offices | California-Great Basin | Bureau of Reclamation.

Forecasted and Current Conditions

Shasta storage is 4.065 MAF as of March 23, 2026, which is 121% of the 15-year average. Total May 1 Shasta Reservoir storage is predicted to be 3.916 MAF based on the preliminary March 90% exceedance forecast and 3.940 MAF based on the preliminary March 50% exceedance forecast. Snowpack levels are 8 percent of average (Figure 1). March Shasta Reservoir temperature profiles as of March 23, consist of low cold-water pool similar to a drought year (sactemprpt.pdf). Water temperatures at Wilkins Slough are approaching 68F (Figure 2).

CVP actual operations do not follow any forecasted operation or outlook; actual operations are based on real-time conditions. CVP operational forecasts or outlooks represent general system-wide dynamics and do not necessarily address specific watershed/tributary details. CVP releases or export values represent monthly averages. CVP Operations are updated monthly as new hydrology information is made available December through May.

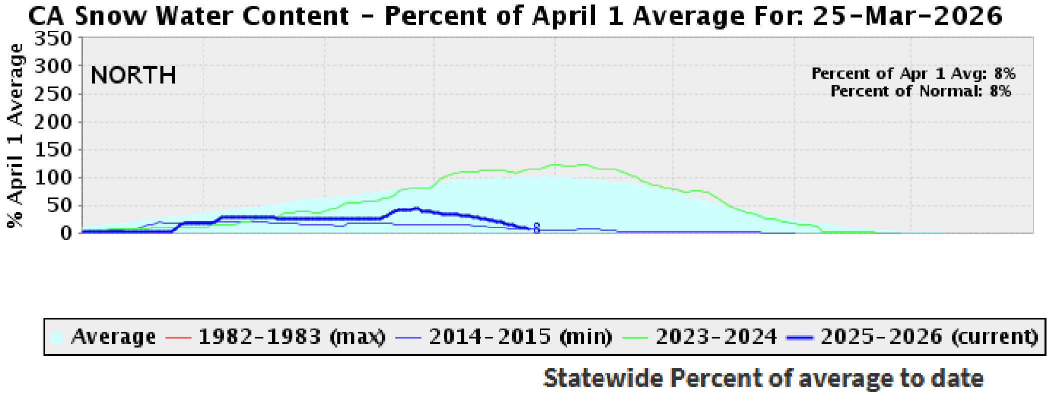

Figure 1. Snowpack Conditions - Snow Water Content Graph

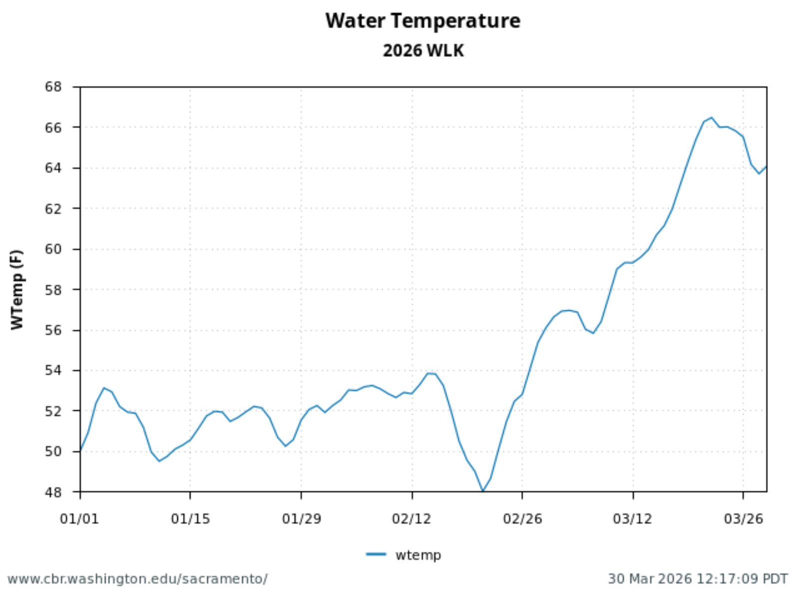

Figure 2. Water temperatures at Wilkins Slough.

Scenario Modeling

655 scenarios were modeled to assess outmigration survival benefits (Attachment 1; 2026 Sacramento River Spring Pulse Flow Scenario Evaluation). Note the tool used to develop these scenarios is not peer reviewed and for discussion purposes only. Many of these scenarios are anticipated to interfere with temperature management objectives and even exceed 150 TAF, which are not being considered. There are also concerns with elevated water temperatures impact to outmigration survival and interest in implementing pulse flow action/s earlier in the early than in previous years.

Temperature Dependent Mortality (TDM) modeling compared the NAA, and pulses of 10, 20,30,40, 50 TAF occurring in the month of April based on the March 90% forecast exceedance (Table 1). Water temperature forecasts were contrary to expectations in which pulse scenarios of lower volumes of 50 TAF were warmer and consequently had higher TDM estimates than the 50 TAF scenario. Also unexpected was the 50 TAF pulse in May scenario was forecasted to be warmer than the 50 TAF in April and 50 TAF in May scenario and therefore was estimated to have higher TDM than that scenario. Overall, the scenarios are fairly similar results, and our tools are likely not precise enough for evaluating 10 TAF volume differences. For more information, refer to Attachment 2.

TDM values described in the tradeoff table do not correspond perfectly with the flow scenarios as more precise estimates for water cost are available for the flow scheduling than is practical for temperature modeling. Water costs for scenarios were rounded to the nearest 10 TAF for assigning TDM values.

Table 1. Water and fish management predicted performance measures for considered scenarios. Survival was estimated with the Burford et al (2025) model.

Metric	**No Pulse**	**3.1**	**3.2**	**3.3**	**3.4**	**4.1**	**4.2**	**4.3**	**4.4**
Scenario description	**No pulse flow**	**1-day pulse 4/7**	**2-day pulse 4/7**	**3-day pulse 4/7**	**4-day pulse 4/7**	**1-day pulse 4/14**	**2-day pulse 4/14**	**3-day pulse 4/14**	**4-day pulse 4/14**
EOA (MAF)	**3.916**	**3.903**	**3.896**	**3.888**	**3.881**	**3.902**	**3.894**	**3.885**	**3.876**
EOS (MAF)	**2.105**	**2.092**	**2.085**	**2.077**	**2.070**	**2.091**	**2.083**	**2.074**	**2.066**
Bin	**2B**	**2B**	**2B**	**2B**	**2B**	**2B**	**2B**	**2B**	**2B**
TDM% (stage-dependent)	**3**	**8**	**4**	**4**	**4**	**8**	**4**	**4**	**7**
TDM% (stage-independent)	**6**	**13**	**9**	**9**	**9**	**13**	**9**	**9**	**12**
Predicted Estimated Survival (%)	**3.9**	**4.2**	**4.4**	**4.6**	**4.7**	**4.4**	**4.8**	**5.5**	**5.9**
% Change in Survival	**0**	**7.1**	**11.1**	**17.5**	**24.5**	**16**	**27.5**	**41.3**	**52.7**
Water Cost (TAF)	**0**	**13**	**20.1**	**27.9**	**35.3**	**14**	**22.4**	**30.8**	**39.3**

Anticipated Salmonid Effects

Spring-run young-of-year outmigrate from the upper Sacramento River through the winter and spring. Between 2010-2024, the mean date of passage by these fish at Red Bluff Diversion Dam is March 15, with 95% passing by April 26. Spring-run Chinook salmon from Mill and Deer Creek and other tributaries demonstrate a shorter outmigration period, typically peaking in late April and May. Between 2010-2024, the mean date of passage entering the Delta (e.g. Sacramento Trawl) for spring-run Chinook salmon was April 8, with 95% entering the Delta by April 27. This periodicity suggests spring-run Chinook salmon rearing in the lower Sacramento River through April and May. Fish monitoring is detecting these fish in the lower Sacramento River and Delta, where spring-run Chinook salmon (Feather River lineage) are being salvaged at the CVP and SWP fish collection facilities. Those outmigrating in April and May experience worse outmigration conditions during this later period of their outmigration. In 2023-2025, pulse flows during late April and early May were predicted to have the greatest improvement in riverine outmigration survival.

Steelhead juveniles migrate past Red Bluff Diversion as early as April and throughout the summer, which likely reflects redistribution of these fish into rearing habitat rather than outmigration through the Sacramento River. Between 2011-2025, the median date for steelhead outmigration passing Knights Landing was March 12 and the median last day of May 3 suggesting many steelhead smolts outmigrate prior to May.

Fall-run Chinook salmon are being released from Coleman National Fish Hatchery in March and April 2026. During water year 2025, fall-run Chinook salmon passage by Red Bluff Diversion Dam was greatest in January and early February when high flows occurred in the upper Sacramento River, and currently very few fall-run Chinook salmon are being sampled at Red Bluff Diversion Dam (Figure 3). This year, water temperatures are already approaching unsuitable levels (i.e., above 68°F; Marine and Cech 2004) for outmigrating salmonids. For example, water temperatures were 67.6°F on March 22 at Wilkins Slough. Historically, temperatures at critical migration points in the river and Delta do not exceed 68°F until late April (Figure 4-5).

Increased reservoir releases can improve outmigration conditions resulting in better survival than under lower releases (Notch et al 2020, Michel et al 2021, Burford et al 2025). Due to warm March water temperatures (Figure 4-5), the SRG has shared feedback to pair WY2026 pulse flow releases with water temperature conditions in early April before it is expected to be too hot downstream. There remains uncertainty as to the mechanism resulting in improved outmigration survival and is likely increased flows resulting in some combination of reduced travel times by juvenile salmon, reduced predation effects, and improvement in other environmental conditions favoring successful outmigration (e.g. cooler temperatures, higher turbidity, greater habitat access).

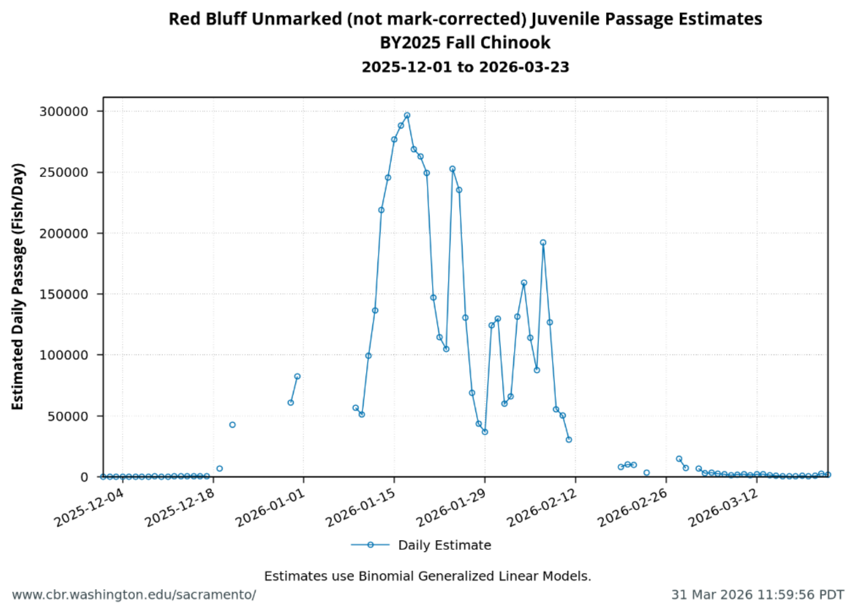

Fig. 3. BY25 fall-run chinook salmon median daily passage at Red Bluff Diversion Dam screw traps.

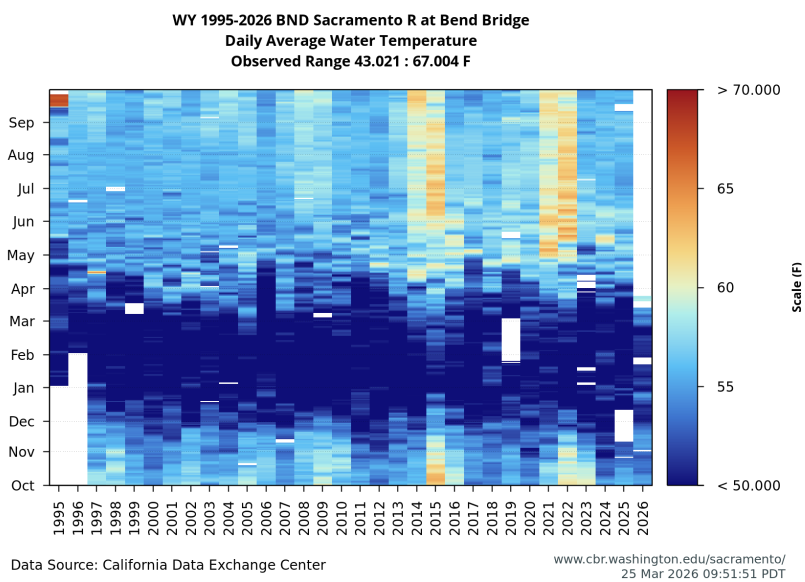

Figure 4. Historical water temperature (degree F) in the Sacramento River at Bend Bridge. This figure demonstrates that in historical wet years water temperatures appear suitable for outmigrating juvenile salmonids in May while in dry years water temperatures are unsuitable.

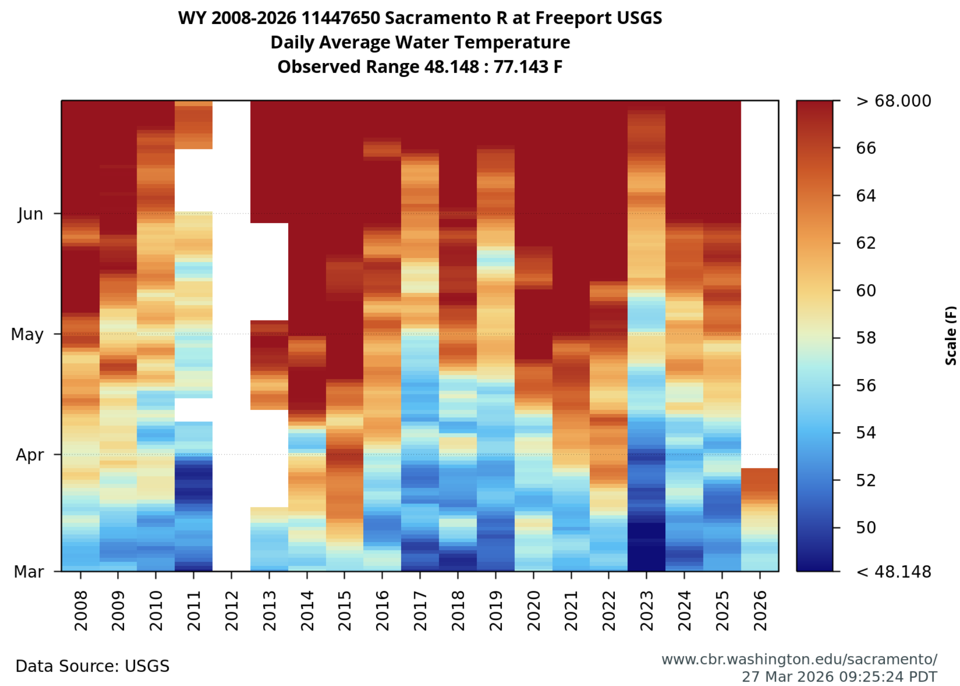

Figure 5. Historical water temperatures in degrees F from 2008 to 2026 at Freeport.

Initial real-time results for this year's Pulse Flow Study as well as previous years are posted to: CalFishTrack. Results will be posted to: Central Valley Enhanced Acoustic Tagging Project (noaa.gov) and will also be reported in the Shasta Winter Storage Rebuilding and Spring Pulse Flow Seasonal Report. In addition, wild *O. mykiss* have been acoustically tagged and released in the Sacramento River to evaluate survival and outmigration rates; however, many of these transmitters may expire before the end of the season CalFishTrack.

Considerations

ACID dam facility

This requires low flow (4,000 to 6,000 cfs) during its installation and cannot sustain high flows greater than 14,000 cfs while fully installed; although flashboards can be removed to adjust flow capacity ACID Dam was installed during the last two weeks of March.

Diversion Schedule

Water Diversions on the Sacramento River are expected to increase mid-April as agricultural water demands begin to ramp up. As these depletions increase, releases from Shasta would increase to meet demands.

Ecological effects

Interested parties have provided observations and described concerns related to reduced insect abundance, juvenile stranding, redd scouring, and other disruptions to spawning events that they believe are associated with pulse/storm flows releases. In 2024, trout guides observed impacts to invertebrate communities following large flood control release that were around 36,000 cfs, which may be three orders of magnitude greater than the spring pulse flows.

Fish Monitoring

Flow fluctuations are anticipated to affect monitoring efforts. For example, efforts for juvenile stranding surveys increase, and effectiveness monitoring for habitat restoration projects is hindered during flow fluctuations. Flows exceeding 20,000 cfs can hinder continuous sampling at Red Bluff rotary screw trap.

GCID Hamilton City Intake Channel Dredging Project

GCID is preparing to start work on Dredging of the Hamilton City Intake Channel pursuant to our permit with CDFW. This is a critical activity to provide sufficient flow through the fish screen and pumping plant to service GCID landowners and the three wildlife refuges served by GCID. Currently, pursuant to the permit, GCID must put in a fish guidance structure 7 days prior to starting dredging activities. Currently, GCID anticipates that occurring on April 2nd and possibly April 3rd to complete. GCID anticipates initiating dredge efforts on April 9th or 10th. There are concerns that the higher river levels associated with a pulse flow could affect dredging work due to high river levels during the pulse flow. GCID prefers if such an action could be complete on or before April 9th. Reclamation updated GCID regarding potential pulse flows on March 30. Continued close coordination with GCID may be able to minimize impacts and ensure their permit condition compliance and complete this important maintenance.

Habitat restoration project implementation

Salmonid rearing habitat project in which 25 to 30 rockwads are being installed upstream of Sundial Bridge during the first week in May. Variable flows could affect barge and stability of craning the rockwads into the river. Higher flows are likely beneficial for building the barge due to deposition at the access site.

Hatchery releases

Coleman National Fish Hatchery fall-run smolts are ready for release early this year. Most of these fish were or are planned to be released in March and early April. Juvenile fall-run Chinook that outmigrate during higher flows and cooler conditions are expected to have better survival.

Hydropower Generation

In terms of power cost impacts, it is generally preferrable to schedule the peak of a pulse flow to occur during the week rather than the weekend, and during warmer periods.

Lunar phase

Outmigration survival is anticipated to increase during a new moon and predation is hypothesized to decrease due to reduced illumination. The new moon is Friday April 17 and May 16.

Recreational and Commercial Fishing

Fishing guides have expressed concerns with variable flows impacting trout behavior and fly hatches, which affect their business.

Redd Dewatering and Juvenile Stranding

WY2026 Spring pulse flows are likely to manage End of September Storage close to the Shasta Framework Bin 2b/3 threshold of 2.0MAF. This may potentially reduce flexibility for higher releases as part of the Wilkins Slough October Maximum Flows and Fall Release Ramp Down (November) actions. Through Governance, Reclamation may determine releases and ramping rates are necessary, that potentially result in higher Chinook salmon stranding and redd dewatering than without pulse flows to maximize the available coldwater pool for water year 2027.

Seepage

Flows exceeding 18,000 cfs at Wilkins Slough have been reported to create seepage problems. Also, weir spills limit the ability for ground preparation and farming within the bypasses, so those thresholds should be considered.

Storage and temperature-dependent mortality

Temperature modeling is unreliable before thermoclines establish in Shasta, typically in late April. In previous years, pulse flow planning occurred simultaneously to temperature management planning during April when temperature stratification allowed for modeling temperature-dependent mortality. Another method is to consider general relationships between Shasta storage and TDM, as shown in Figure 6. In this positional analysis, TDM was estimated using a 53° F, 54°F, and 55° F temperature target at Sacramento at Clear Creek, combining different starting storage levels, hydrology, and meteorology in CalSim2. This produced 100 TDM estimates at individual end-of-April storage values across a range of these storage levels, summarized in boxplots in Figure 4 below. The assumptions for this relationship reflect a deprecated No Action Alternative operations logic, meaning the operational nuances of Action 5 are not reflected. Nonetheless, with few exceptions, TDM remains low when end-of-April Shasta storage is above 3.8 MAF, and end of September

Shasta storage exceeds 2.0 MAF. Current forecasts project end-of-April Shasta storage may or may not exceed 3.8 MAF with implementation of full potential pulse flow volume (150,000 acre feet). Pulse flow action implementation could also result in EOS Shasta storage volume below 2.0 MAF.

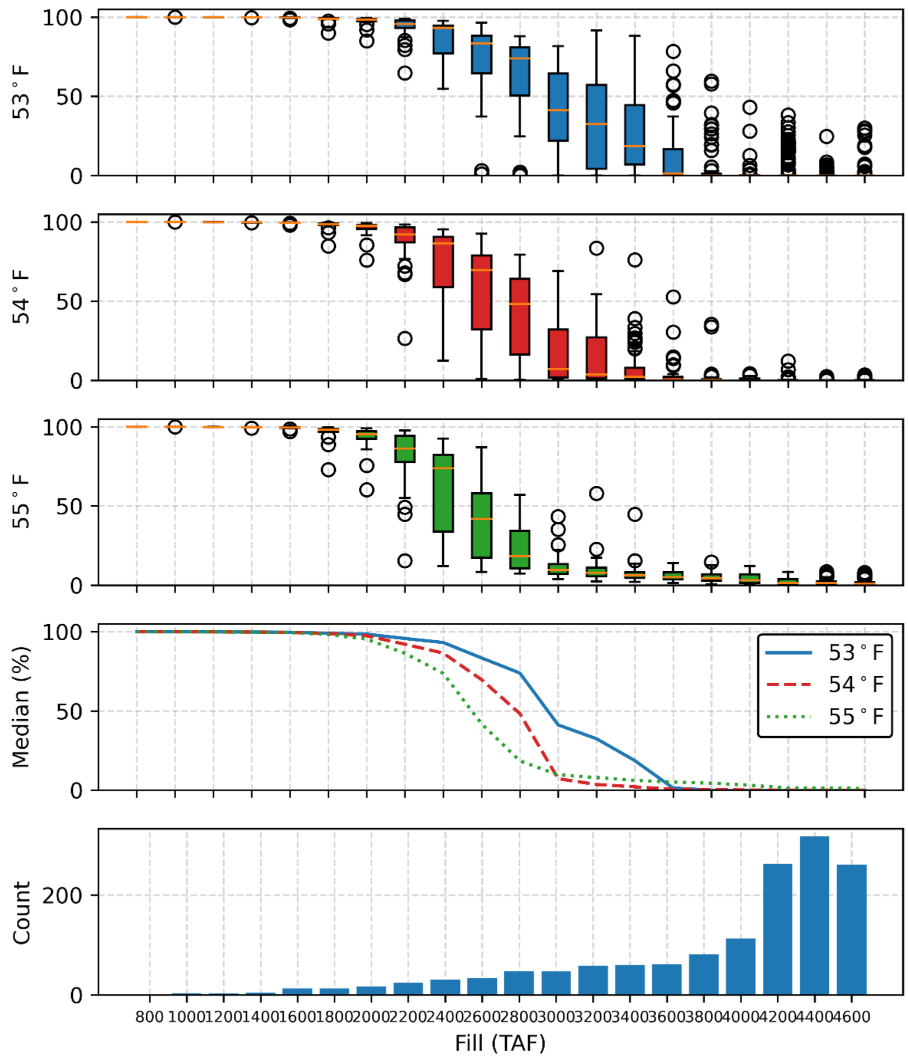

Figure 6. Winter-run Chinook salmon percent temperature dependent mortality (TDM) estimates associated with Shasta fill (e.g., end of April storage; thousand of acre feet (TAF). This figure utilizes the Calsim II model with deprecated No Action Alternative operations logic.

Systemwide releases

The American River Group is discussing a spring pulse flow and the possibility of synching with Sacramento River releases. Stanislaus pulse flows are planned April 11-May 9. Tuolumne River pulse flows are planned to start on April 17.

References

Burford, BP, JJ Notch, WR Poytress, and CJ Michel. 2025. Facilitated migration could bolster migrant passage through anthropogenically altered ecosystems. Ecological Applications.

Marine, KR and JJ Cech. 2004. Effects of high water temperature growth, smoltification, and predator avoidance in juvenile Sacramento River Chinook salmon. Fisheries Management 24:198-210.

Michel, CJ, JJ Notch, F Cordoleani, AJ Ammann, EM Danner. 2021. Nonlinear survival of imperiled fish informs managed flows in a highly modified river. Ecosphere. 12:1-20.

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

Attachment 1: Pulse flow scenario evaluation

Pulse flow scenario evaluation

2026 Spring Pulse Flow Survival Simulations for Flow Scenarios

Prepared by Cyril Michel, UC Santa Cruz, cyril.michel@noaa.gov

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## [1] "Using operational forecasts from file: Spring Pulse Flow Mar23 2026.xlsx"
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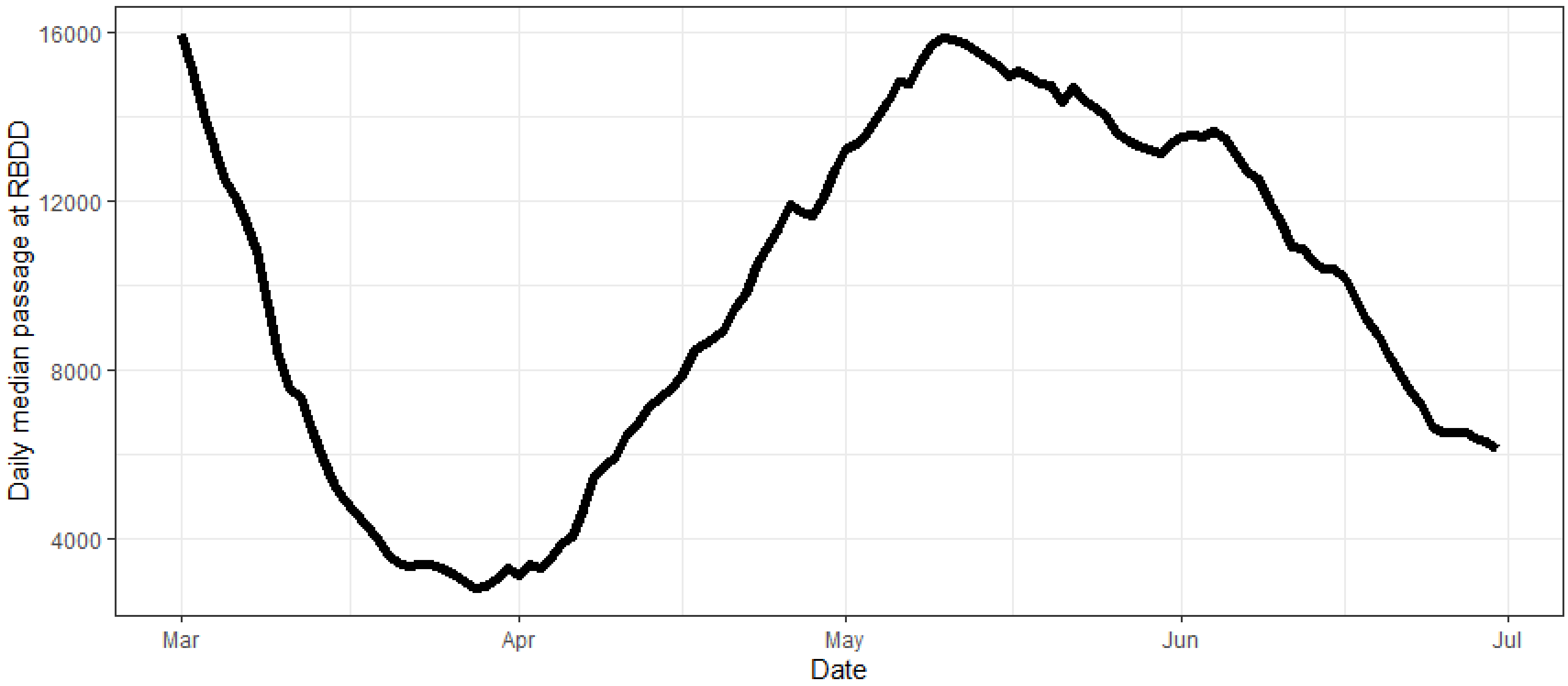


Fig. 1. Historic median daily passage (with 20-day moving average smoothing) at Red Bluff Diversion Dam USFWS Screw traps for all years of data (2006-2019)

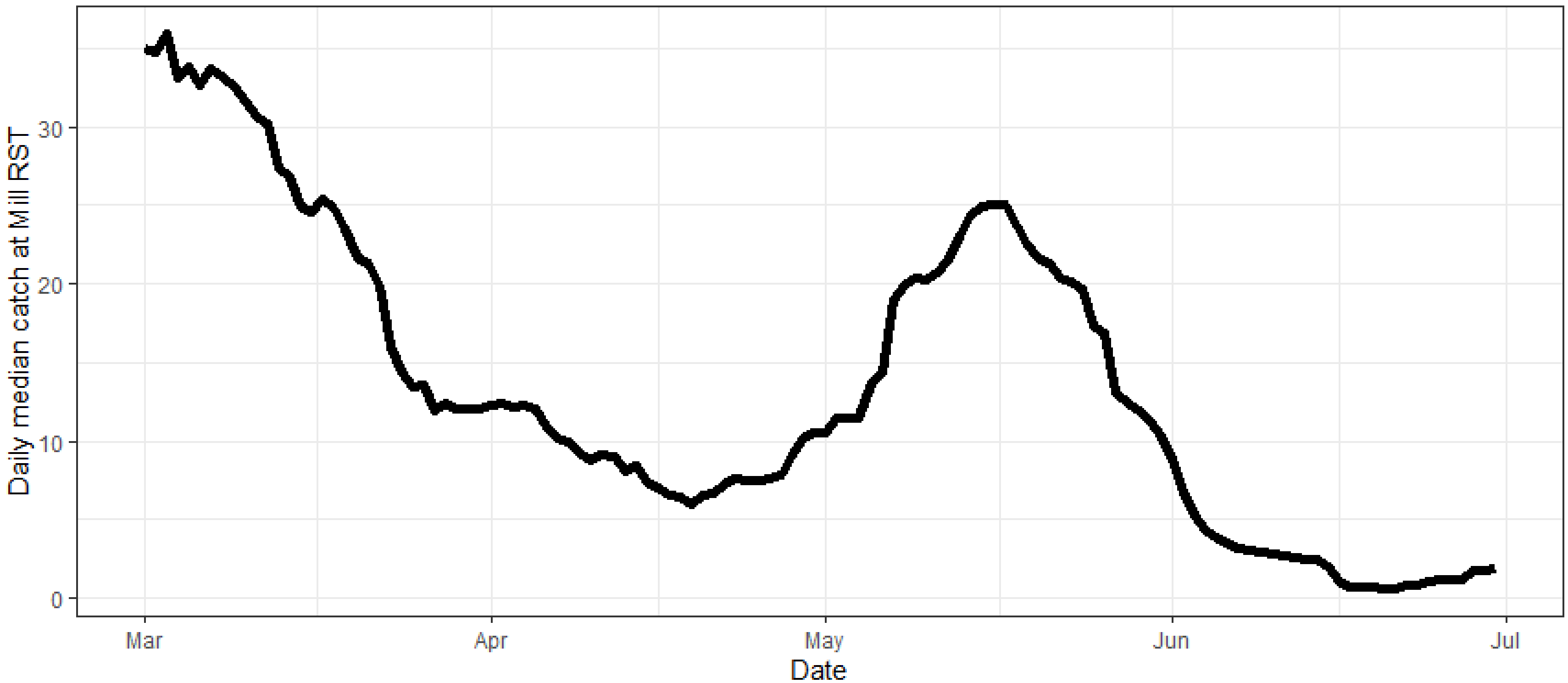


Fig. 2. Historic median daily catch (with 20-day moving average smoothing) at Mill Creek CDFW Screw trap for all years of data (1996, 2000, 2001, 2002, 2003, 2007, 2008, 2009, and 2010)

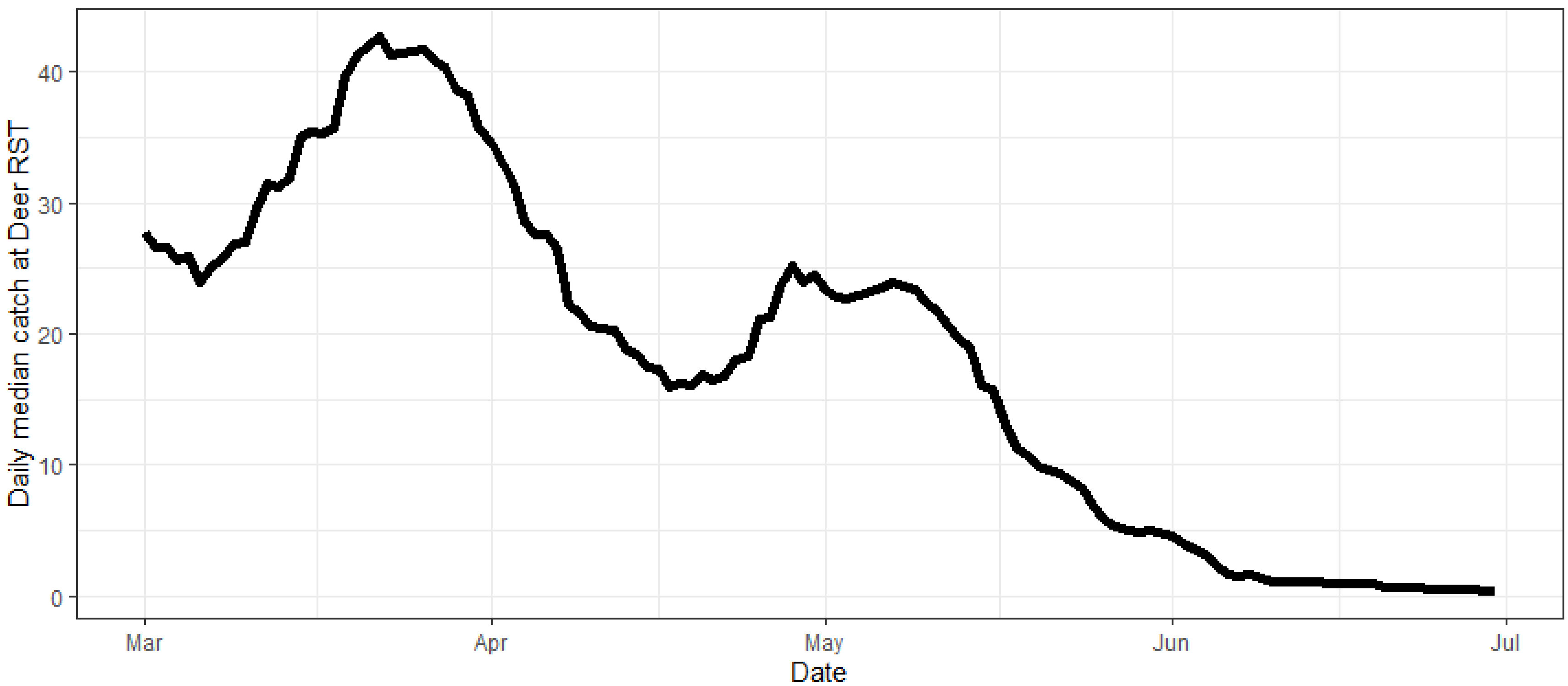


Fig. 3. Historic median daily catch (with 20-day moving average smoothing) at Deer Creek CDFW Screw trap for all years of data (1995, 1996, 2000, 2001, 2002, 2003, 2004, 2005, 2007, 2009, and 2010)

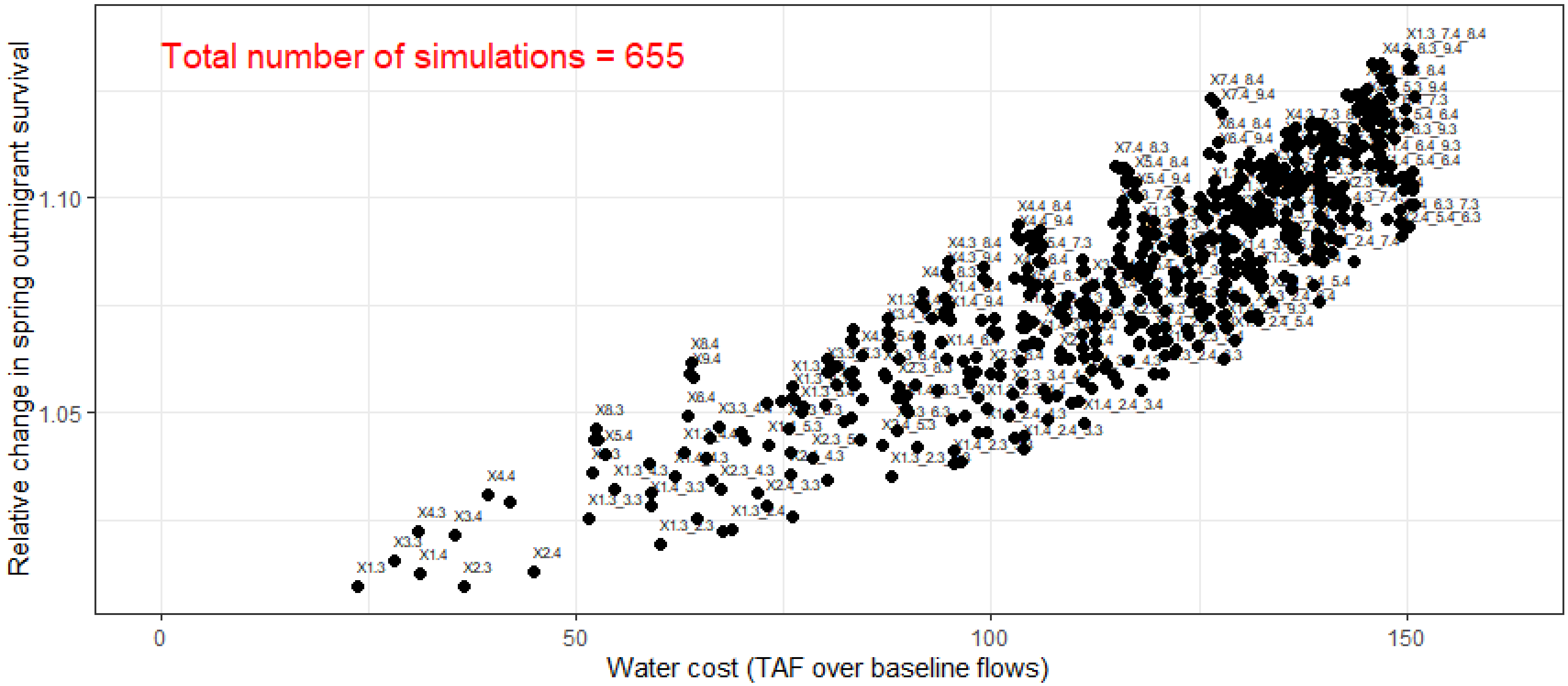


Fig. 4. Relative change in spring outmigration survival (over status quo) as a function of water cost (TAF) for all pulse flow scenarios using all years of fish passage data at RBDD (2006-2019), and using the Michel et al. (2021) nonlinear flow:survival relationship

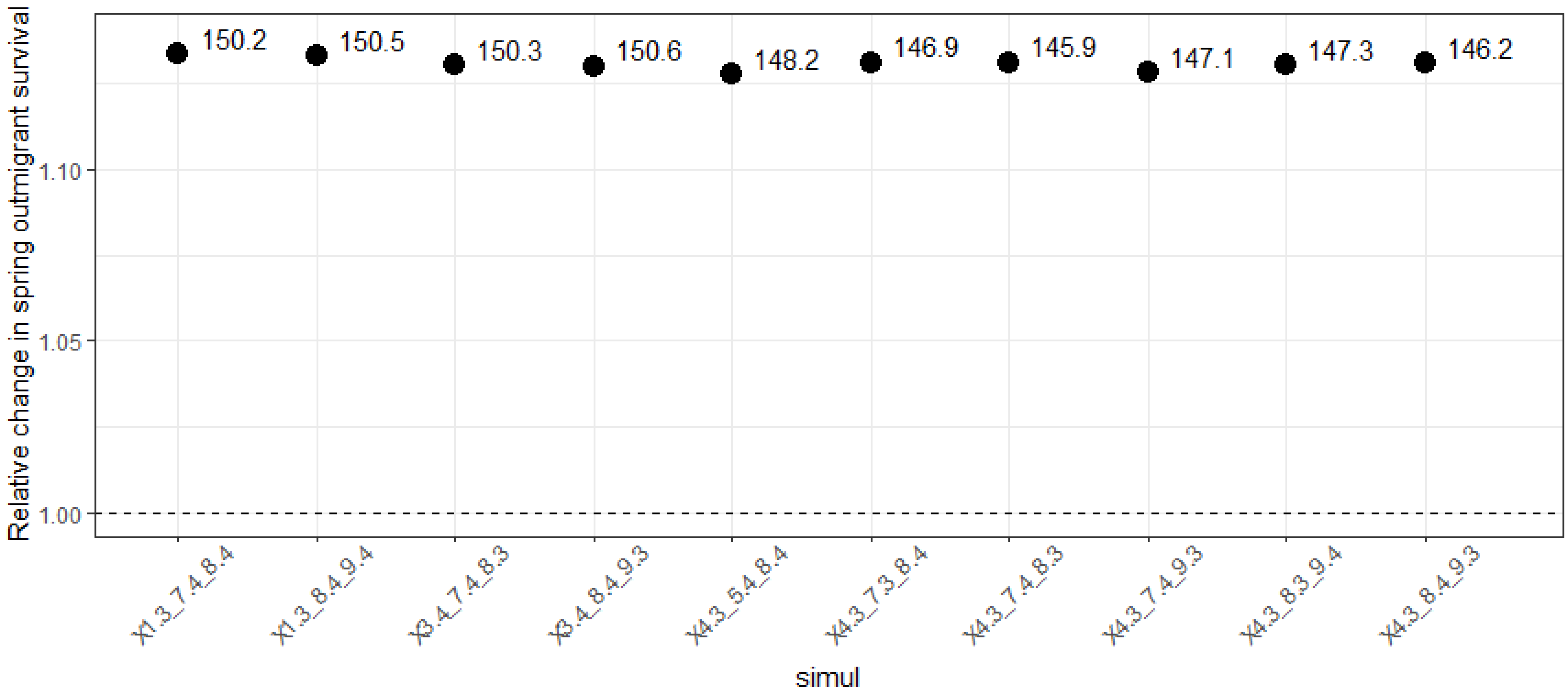


Fig. 5. Top 10 pulse flow scenarios as ranked by best spring season survival relative improvement (over status quo), using all years of fish passage data at RBDD (2006-2019), and using the Michel et al. (2021) nonlinear flow:survival relationship. Water cost is shown as point labels (TAF)

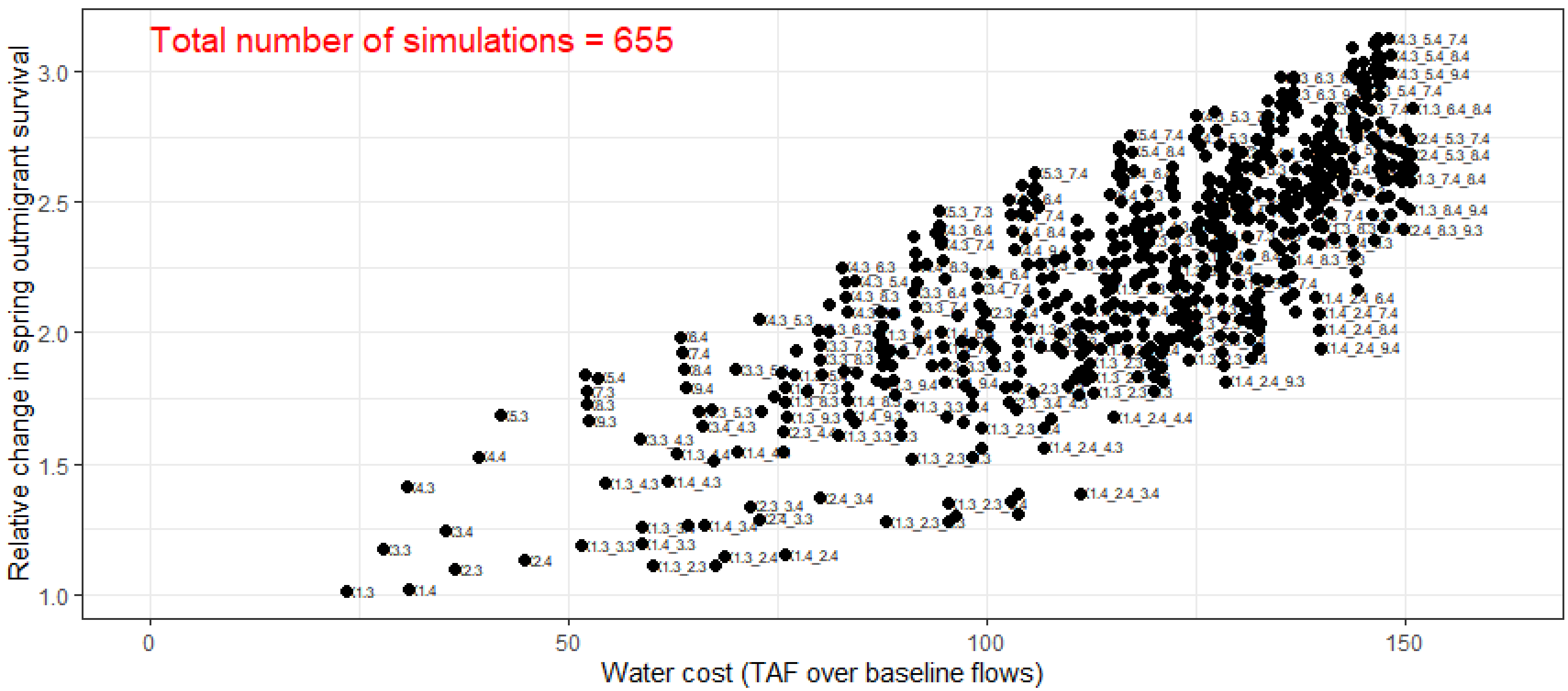


Fig. 6. Relative change in spring outmigration survival (over status quo) as a function of water cost (TAF) for all pulse flow scenarios using the Burford et al. (2025) model. This model is different from the Michel et al. (2021) model in 4 ways: 1. it uses a continuous, non-linear relationship between flow and survival (i.e., not a threshold), 2. it incorporates a seasonal component in the flow survival relationship (e.g., survival is worse in June vs April for the same flow), 3. it incorporates responses in the number of fish initiating migration as a function of flow changes, and 4. it estimates survival to Benicia Bridge rather than the confluence of the Sacramento and Feather Rivers (as in Michel et al. 2021)

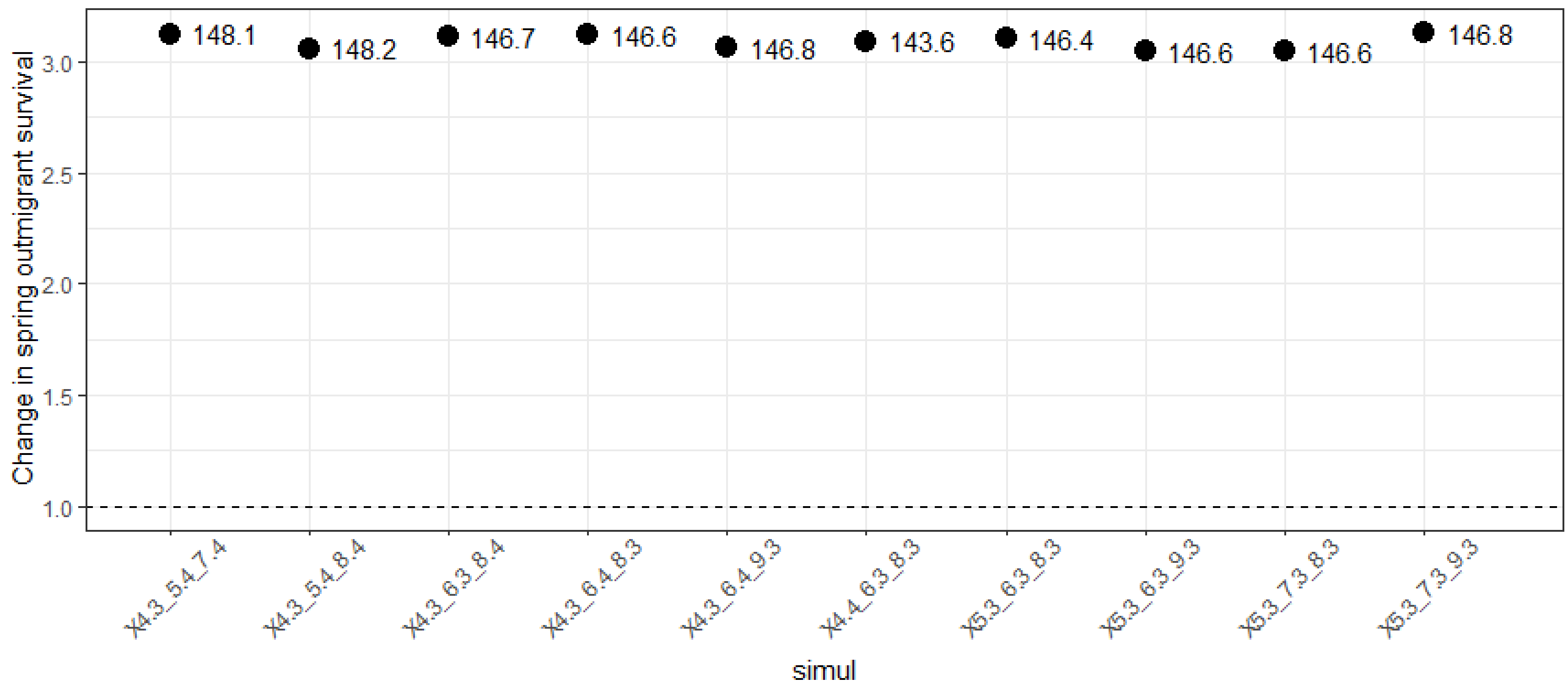


Fig. 7. Top 10 pulse flow scenarios as ranked by best spring season survival relative improvement (over status quo) using an adaptation of the Burford et al. (2025) model. This model is different from the Michel et al. (2021) model in 4 ways: 1. it uses a continuous, non-linear relationship between flow and survival (i.e., not a threshold), 2. it incorporates a seasonal component in the flow survival relationship (e.g., survival is worse in June vs April for the same flow), and 3. it incorporates responses in the number of fish initiating migration as a function of flow changes, and 4. it estimates survival to Benicia Bridge rather than the confluence of the Sacramento and Feather Rivers (as in Michel et al. 2021). Water cost is shown as point labels (TAF)

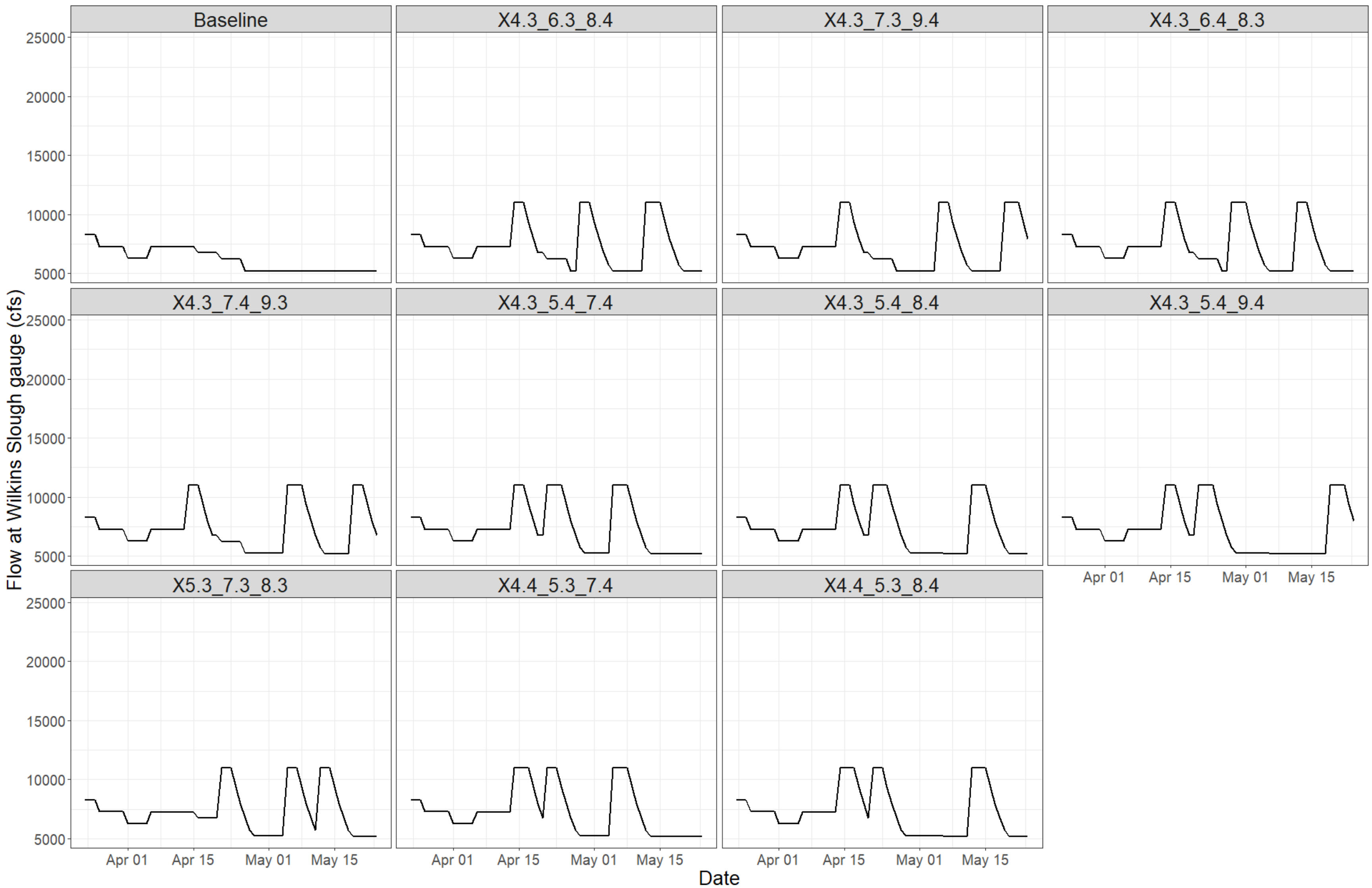


Fig. 8. Spring pulse flow hydrographs for the top 10 scenarios as ranked by both Michel et al. and Burford et al. models, and including baseline flows (dashed black line)

Table 1. Spring season survival estimates, survival improvement over baseline, and rank for the top 10 scenarios as ranked by both Michel et al. and Burford et al. models and including baseline flows. PLEASE NOTE SURVIVAL ESTIMATES ARE INFORMED BY HISTORICAL FISH ABUNDANCES AND PASSAGE TIMING AND SHOULD ONLY BE USED FOR SCENARIO EVALUATION AND NOT USED AT FACE VALUE

Scenarios	TAF	Spring Survival Michel	Relative Survival Improvement over Baseline Michel	Spring Survival Burford	Relative Survival Improvement over Baseline Burford	Rank Michel	Rank Burford
X4.3_5.4_7.4	148.1	0.247	1.125	0.123	3.125	13	2
X4.3_5.4_8.4	148.2	0.248	1.128	0.121	3.061	10	8
X4.3_6.3_8.4	146.7	0.247	1.123	0.123	3.115	21	4
X4.3_7.4_9.3	147.1	0.248	1.128	0.118	3.007	9	16
X4.3_6.4_8.3	146.6	0.246	1.121	0.123	3.123	29	3
X4.3_5.4_9.4	148.4	0.247	1.124	0.118	2.991	14	18
X4.3_7.3_9.4	147.2	0.248	1.128	0.117	2.985	11	21
X5.3_7.3_8.3	146.6	0.246	1.122	0.120	3.048	24	9
X4.4_5.3_7.4	145.1	0.246	1.122	0.119	3.034	26	13
X4.4_5.3_8.4	145.2	0.247	1.125	0.117	2.971	12	27
Baseline	0.0	0.220	1.000	0.039	1.000	655	655

Table 2. Hydrograph at Wilkins Slough for baseflow, as well as for the top 10 scenarios as ranked by both Michel et al. and Burford et al. models

Date	X4.3_5.4_7.4	X4.3_5.4_8.4	X4.3_6.3_8.4	X4.3_7.4_9.3	X4.3_6.4_8.3	X4.3_5.4_9.4	X4.3_7.3_9.4	X5.3_7.3_8.3	X4.4_5.3_7.4	X4.4_5.3_8.4	Baseline
2026-03-23	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275
2026-03-24	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275
2026-03-25	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275
2026-03-26	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275
2026-03-27	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275
2026-03-28	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275
2026-03-29	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275
2026-03-30	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275
2026-03-31	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275	7,275
2026-04-01	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275
2026-04-02	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275
2026-04-03	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275

Date	X4.3_5.4_7.4	X4.3_5.4_8.4	X4.3_6.3_8.4	X4.3_7.4_9.3	X4.3_6.4_8.3	X4.3_5.4_9.4	X4.3_7.3_9.4	X5.3_7.3_8.3	X4.4_5.3_7.4	X4.4_5.3_8.4	Baseline
2026-04-04	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275
2026-04-05	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275	6,275
2026-04-06	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250
2026-04-07	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250
2026-04-08	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250
2026-04-09	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250
2026-04-10	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250
2026-04-11	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250
2026-04-12	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250
2026-04-13	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250	7,250
2026-04-14	11,000	11,000	11,000	11,000	11,000	11,000	11,000	7,250	11,000	11,000	7,250
2026-04-15	11,000	11,000	11,000	11,000	11,000	11,000	11,000	7,250	11,000	11,000	7,250
2026-04-16	11,000	11,000	11,000	11,000	11,000	11,000	11,000	6,750	11,000	11,000	6,750
2026-04-17	9,350	9,350	9,350	9,350	9,350	9,350	9,350	6,750	11,000	11,000	6,750

Date	X4.3_5.4_7.4	X4.3_5.4_8.4	X4.3_6.3_8.4	X4.3_7.4_9.3	X4.3_6.4_8.3	X4.3_5.4_9.4	X4.3_7.3_9.4	X5.3_7.3_8.3	X4.4_5.3_7.4	X4.4_5.3_8.4	Baseline
2026-04-18	7,948	7,948	7,948	7,948	7,948	7,948	7,948	6,750	9,350	9,350	6,750
2026-04-19	6,756	6,756	6,756	6,756	6,756	6,756	6,756	6,750	7,948	7,948	6,750
2026-04-20	6,750	6,750	6,750	6,750	6,750	6,750	6,750	6,750	6,756	6,756	6,750
2026-04-21	11,000	11,000	6,250	6,250	6,250	11,000	6,250	11,000	11,000	11,000	6,250
2026-04-22	11,000	11,000	6,225	6,225	6,225	11,000	6,225	11,000	11,000	11,000	6,225
2026-04-23	11,000	11,000	6,225	6,225	6,225	11,000	6,225	11,000	11,000	11,000	6,225
2026-04-24	11,000	11,000	6,225	6,225	6,225	11,000	6,225	9,350	9,350	9,350	6,225
2026-04-25	9,350	9,350	6,225	6,225	6,225	9,350	6,225	7,948	7,948	7,948	6,225
2026-04-26	7,948	7,948	5,225	5,225	5,225	7,948	5,225	6,756	6,756	6,756	5,225
2026-04-27	6,756	6,756	5,225	5,225	5,225	6,756	5,225	5,743	5,743	5,743	5,225
2026-04-28	5,743	5,743	11,000	5,225	11,000	5,743	5,225	5,225	5,225	5,225	5,225
2026-04-29	5,225	5,225	11,000	5,225	11,000	5,225	5,225	5,225	5,225	5,225	5,225
2026-04-30	5,225	5,225	11,000	5,225	11,000	5,225	5,225	5,225	5,225	5,225	5,225
2026-05-01	5,225	5,225	9,350	5,225	11,000	5,225	5,225	5,225	5,225	5,225	5,225

Date	X4.3_5.4_7.4	X4.3_5.4_8.4	X4.3_6.3_8.4	X4.3_7.4_9.3	X4.3_6.4_8.3	X4.3_5.4_9.4	X4.3_7.3_9.4	X5.3_7.3_8.3	X4.4_5.3_7.4	X4.4_5.3_8.4	Baseline
2026-05-02	5,225	5,225	7,948	5,225	9,350	5,225	5,225	5,225	5,225	5,225	5,225
2026-05-03	5,225	5,225	6,756	5,225	7,948	5,225	5,225	5,225	5,225	5,225	5,225
2026-05-04	5,225	5,225	5,743	5,225	6,756	5,225	5,225	5,225	5,225	5,225	5,225
2026-05-05	11,000	5,225	5,225	11,000	5,743	5,225	11,000	11,000	11,000	5,225	5,225
2026-05-06	11,000	5,225	5,225	11,000	5,225	5,225	11,000	11,000	11,000	5,225	5,225
2026-05-07	11,000	5,200	5,200	11,000	5,200	5,200	11,000	11,000	11,000	5,200	5,200
2026-05-08	11,000	5,200	5,200	11,000	5,200	5,200	9,350	9,350	11,000	5,200	5,200
2026-05-09	9,350	5,200	5,200	9,350	5,200	5,200	7,948	7,948	9,350	5,200	5,200
2026-05-10	7,948	5,200	5,200	7,948	5,200	5,200	6,756	6,756	7,948	5,200	5,200
2026-05-11	6,756	5,200	5,200	6,756	5,200	5,200	5,743	5,743	6,756	5,200	5,200
2026-05-12	5,743	11,000	11,000	5,743	11,000	5,200	5,200	11,000	5,743	11,000	5,200
2026-05-13	5,200	11,000	11,000	5,200	11,000	5,200	5,200	11,000	5,200	11,000	5,200
2026-05-14	5,200	11,000	11,000	5,200	11,000	5,200	5,200	11,000	5,200	11,000	5,200
2026-05-15	5,200	11,000	11,000	5,200	9,350	5,200	5,200	9,350	5,200	11,000	5,200

Date	X4.3_5.4_7.4	X4.3_5.4_8.4	X4.3_6.3_8.4	X4.3_7.4_9.3	X4.3_6.4_8.3	X4.3_5.4_9.4	X4.3_7.3_9.4	X5.3_7.3_8.3	X4.4_5.3_7.4	X4.4_5.3_8.4	Baseline
2026-05-16	5,200	9,350	9,350	5,200	7,948	5,200	5,200	7,948	5,200	9,350	5,200
2026-05-17	5,200	7,948	7,948	5,200	6,756	5,200	5,200	6,756	5,200	7,948	5,200
2026-05-18	5,200	6,756	6,756	5,200	5,743	5,200	5,200	5,743	5,200	6,756	5,200
2026-05-19	5,200	5,743	5,743	11,000	5,200	11,000	11,000	5,200	5,200	5,743	5,200
2026-05-20	5,200	5,200	5,200	11,000	5,200	11,000	11,000	5,200	5,200	5,200	5,200
2026-05-21	5,200	5,200	5,200	11,000	5,200	11,000	11,000	5,200	5,200	5,200	5,200
2026-05-22	5,175	5,175	5,175	9,350	5,175	11,000	11,000	5,175	5,175	5,175	5,175
2026-05-23	5,175	5,175	5,175	7,948	5,175	9,350	9,350	5,175	5,175	5,175	5,175
2026-05-24	5,175	5,175	5,175	6,756	5,175	7,948	7,948	5,175	5,175	5,175	5,175

Table 3. Hydrograph at Keswick for baseflow, as well as for the top 10 scenarios as ranked by both Michel et al. and Burford et al. models

Date	KES	X4.3_5.4_7.4	X4.3_5.4_8.4	X4.3_6.3_8.4	X4.3_7.4_9.3	X4.3_6.4_8.3	X4.3_5.4_9.4	X4.3_7.3_9.4	X5.3_7.3_8.3	X4.4_5.3_7.4	X4.4_5.3_8.4
2026-03-23	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-03-24	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-03-25	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-03-26	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-03-27	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-03-28	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-03-29	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-03-30	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-03-31	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-04-01	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000

Date	KES	X4.3_5.4_7.4	X4.3_5.4_8.4	X4.3_6.3_8.4	X4.3_7.4_9.3	X4.3_6.4_8.3	X4.3_5.4_9.4	X4.3_7.3_9.4	X5.3_7.3_8.3	X4.4_5.3_7.4	X4.4_5.3_8.4
2026-04-02	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-04-03	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-04-04	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-04-05	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2026-04-06	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
2026-04-07	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
2026-04-08	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
2026-04-09	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
2026-04-10	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
2026-04-11	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
2026-04-12	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000

Date	KES	X4.3_5.4_7.4	X4.3_5.4_8.4	X4.3_6.3_8.4	X4.3_7.4_9.3	X4.3_6.4_8.3	X4.3_5.4_9.4	X4.3_7.3_9.4	X5.3_7.3_8.3	X4.4_5.3_7.4	X4.4_5.3_8.4
2026-04-13	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
2026-04-14	8,000	11,750	11,750	11,750	11,750	11,750	11,750	11,750	8,000	11,750	11,750
2026-04-15	8,000	11,750	11,750	11,750	11,750	11,750	11,750	11,750	8,000	11,750	11,750
2026-04-16	8,500	12,750	12,750	12,750	12,750	12,750	12,750	12,750	8,500	12,750	12,750
2026-04-17	8,500	11,100	11,100	11,100	11,100	11,100	11,100	11,100	8,500	12,750	12,750
2026-04-18	8,500	9,698	9,698	9,698	9,698	9,698	9,698	9,698	8,500	11,100	11,100
2026-04-19	8,500	8,506	8,506	8,506	8,506	8,506	8,506	8,506	8,500	9,698	9,698
2026-04-20	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,506	8,506
2026-04-21	9,000	13,750	13,750	9,000	9,000	9,000	13,750	9,000	13,750	13,750	13,750
2026-04-22	9,000	13,775	13,775	9,000	9,000	9,000	13,775	9,000	13,775	13,775	13,775
2026-04-23	9,000	13,775	13,775	9,000	9,000	9,000	13,775	9,000	13,775	13,775	13,775

Date	KES	X4.3_5.4_7.4	X4.3_5.4_8.4	X4.3_6.3_8.4	X4.3_7.4_9.3	X4.3_6.4_8.3	X4.3_5.4_9.4	X4.3_7.3_9.4	X5.3_7.3_8.3	X4.4_5.3_7.4	X4.4_5.3_8.4
2026-04-24	9,000	13,775	13,775	9,000	9,000	9,000	13,775	9,000	12,125	12,125	12,125
2026-04-25	9,000	12,125	12,125	9,000	9,000	9,000	12,125	9,000	10,723	10,723	10,723
2026-04-26	9,000	11,723	11,723	9,000	9,000	9,000	11,723	9,000	10,531	10,531	10,531
2026-04-27	9,000	10,531	10,531	9,000	9,000	9,000	10,531	9,000	9,518	9,518	9,518
2026-04-28	9,000	9,518	9,518	14,775	9,000	14,775	9,518	9,000	9,000	9,000	9,000
2026-04-29	9,000	9,000	9,000	14,775	9,000	14,775	9,000	9,000	9,000	9,000	9,000
2026-04-30	9,000	9,000	9,000	14,775	9,000	14,775	9,000	9,000	9,000	9,000	9,000
2026-05-01	9,000	9,000	9,000	13,125	9,000	14,775	9,000	9,000	9,000	9,000	9,000
2026-05-02	9,000	9,000	9,000	11,723	9,000	13,125	9,000	9,000	9,000	9,000	9,000
2026-05-03	9,000	9,000	9,000	10,531	9,000	11,723	9,000	9,000	9,000	9,000	9,000
2026-05-04	9,000	9,000	9,000	9,518	9,000	10,531	9,000	9,000	9,000	9,000	9,000

Date	KES	X4.3_5.4_7.4	X4.3_5.4_8.4	X4.3_6.3_8.4	X4.3_7.4_9.3	X4.3_6.4_8.3	X4.3_5.4_9.4	X4.3_7.3_9.4	X5.3_7.3_8.3	X4.4_5.3_7.4	X4.4_5.3_8.4
2026-05-05	9,000	14,775	9,000	9,000	14,775	9,518	9,000	14,775	14,775	14,775	9,000
2026-05-06	9,000	14,775	9,000	9,000	14,775	9,000	9,000	14,775	14,775	14,775	9,000
2026-05-07	9,000	14,800	9,000	9,000	14,800	9,000	9,000	14,800	14,800	14,800	9,000
2026-05-08	9,000	14,800	9,000	9,000	14,800	9,000	9,000	13,150	13,150	14,800	9,000
2026-05-09	9,000	13,150	9,000	9,000	13,150	9,000	9,000	11,748	11,748	13,150	9,000
2026-05-10	9,000	11,748	9,000	9,000	11,748	9,000	9,000	10,556	10,556	11,748	9,000
2026-05-11	9,000	10,556	9,000	9,000	10,556	9,000	9,000	9,543	9,543	10,556	9,000
2026-05-12	9,000	9,543	14,800	14,800	9,543	14,800	9,000	9,000	14,800	9,543	14,800
2026-05-13	9,000	9,000	14,800	14,800	9,000	14,800	9,000	9,000	14,800	9,000	14,800
2026-05-14	9,000	9,000	14,800	14,800	9,000	14,800	9,000	9,000	14,800	9,000	14,800
2026-05-15	9,000	9,000	14,800	14,800	9,000	13,150	9,000	9,000	13,150	9,000	14,800

Date	KES	X4.3_5.4_7.4	X4.3_5.4_8.4	X4.3_6.3_8.4	X4.3_7.4_9.3	X4.3_6.4_8.3	X4.3_5.4_9.4	X4.3_7.3_9.4	X5.3_7.3_8.3	X4.4_5.3_7.4	X4.4_5.3_8.4
2026-05-16	9,000	9,000	13,150	13,150	9,000	11,748	9,000	9,000	11,748	9,000	13,150
2026-05-17	9,000	9,000	11,748	11,748	9,000	10,556	9,000	9,000	10,556	9,000	11,748
2026-05-18	9,000	9,000	10,556	10,556	9,000	9,543	9,000	9,000	9,543	9,000	10,556
2026-05-19	9,000	9,000	9,543	9,543	14,800	9,000	14,800	14,800	9,000	9,000	9,543
2026-05-20	9,000	9,000	9,000	9,000	14,800	9,000	14,800	14,800	9,000	9,000	9,000
2026-05-21	9,000	9,000	9,000	9,000	14,800	9,000	14,800	14,800	9,000	9,000	9,000
2026-05-22	9,000	9,000	9,000	9,000	13,175	9,000	14,825	14,825	9,000	9,000	9,000
2026-05-23	9,000	9,000	9,000	9,000	11,773	9,000	13,175	13,175	9,000	9,000	9,000
2026-05-24	9,000	9,000	9,000	9,000	10,581	9,000	11,773	11,773	9,000	9,000	9,000

Table 4. Starting dates for each potential study week of the Spring period, for reference

week	start_date
1	2026-03-23
2	2026-03-30
3	2026-04-06
4	2026-04-13
5	2026-04-20
6	2026-04-27
7	2026-05-04
8	2026-05-11
9	2026-05-18

Attachment 2 - Winter-run Chinook Salmon Temperature Dependent Mortality Estimates

Executive Summary

Water temperature forecasts were contrary to expectations in which pulse scenarios of lower volumes of 50 TAF were warmer and consequently had higher TDM estimates than the 50 TAF scenario. Also unexpected was the 50 TAF pulse in May scenario was forecasted to be warmer than the 50 TAF in April and 50 TAF in May scenario and therefore was estimated to have higher TDM than that scenario. Overall, the scenarios are fairly similar results, and our tools are likely not precise enough for evaluating 10 TAF volume differences.

Temperature modeling described in the tradeoff table do not match up perfectly with the pulse flow scenarios as more precise estimates of water cost are available for the flow scheduling than is practical for temperature modeling. Additionally, information for spring flow forecasts and summer/fall temperature forecasts for informing their associated models are available on different timelines. Water costs for scenarios were rounded to the nearest 10 TAF for assigning TDM values.

Background

To forecast temperature dependent mortality (TDM) of winter-run chinook salmon for the 2026 Sacramento River Spring Pulse Operations Plan, nine scenarios were evaluated. All scenarios targeted 53.5F at Clear Creek (CCR) but consisted of pulse flows in April and/or May of different water volumes described in Table 1.

The modeling framework used spatially explicit, daily average water temperature forecasts from the WTMP model. These forecasts were applied at multiple locations along the Sacramento River, including Keswick Dam and Clear Creek. Observed temperature data were used through March 26, 2026, and modeled forecasts were used thereafter. For locations between these gauges, daily temperatures were estimated by interpolating between nearby model output points. These temperature estimates were then matched to the river mile locations of simulated winter-run Chinook redds constructed based on observed spawning distributions from 2013 to 2022.

TDM was estimated by simulating the thermal history of each redd throughout its incubation period. Mortality was calculated based on cumulative thermal exposure using a degree-day threshold to represent development time, as well as on daily temperature exceedance past critical thresholds known to induce mortality. Two mortality models were applied. The first, based on Martin et al. (2017), assumes stage-independent mortality, using a single temperature threshold (12.14°C) applied consistently from spawning through emergence. The second model, based on Anderson et al. (2022), incorporates stage-dependent mortality, assigning a temperature threshold (11.82°C) and mortality sensitivities across distinct developmental stages. This approach was also applied to all scenarios. Results from the temperature-dependent mortality simulations did not reveal biologically meaningful results among some scenarios and between modeling approaches.

Table 1. Summary of winter-run chinook salmon TDM results for all scenarios developed during the week of March 23, 2026, based on the March 90% exceedance forecast.

Scenario	***Stage Dependent (%)***	***Stage Independent (%)***
Baseline/no pulse	3	5.9
50TAFin April	3.5	7.7
50TAF in May	8.2	14.2
50TAFin April and 50TAF in May	4.3	9.2
50TAFin April and 100TAF in May	7.4	13.8
10TAF in April	7.9	12.9
20TAF in April	4.2	8.6
30 TAF in April	4.4	9
40 TAF in April	7.3	12.3

Table 2. Modeling assumptions for TDM estimates for pulse flow scenarios developed during the week of March 23, 2026.

PARAMETER	**ASSOCIATED INFORMATION**
METEOROLOGY SOURCE	HIST-2015
TIME PERIOD	1/1/2026 – 3/26/2026: Observed temperatures 3/27/2026: Simulated temperatures
RESERVOIR MODEL USED	WTMP
RIVER MODEL USED	WTMP
SHASTA PROFILE DATE	3/2/2026
TCD GATE OPERATIONS	WTMP
SACRAMENTO WATER TEMPERATURES USED	WTMP output at Keswick and Clear Creek
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-run chinook salmon carcass surveys 2013-2022
TDM REDD SPACE DISTRIBUTION	Winter-run chinook salmon carcass surveys 2013-2022
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-1d-1 Stage-dependent mortality: 0.436°C-1d-1
CRITICAL DAYS	Stage-independent mortality: all Stage-dependent mortality: 4 days

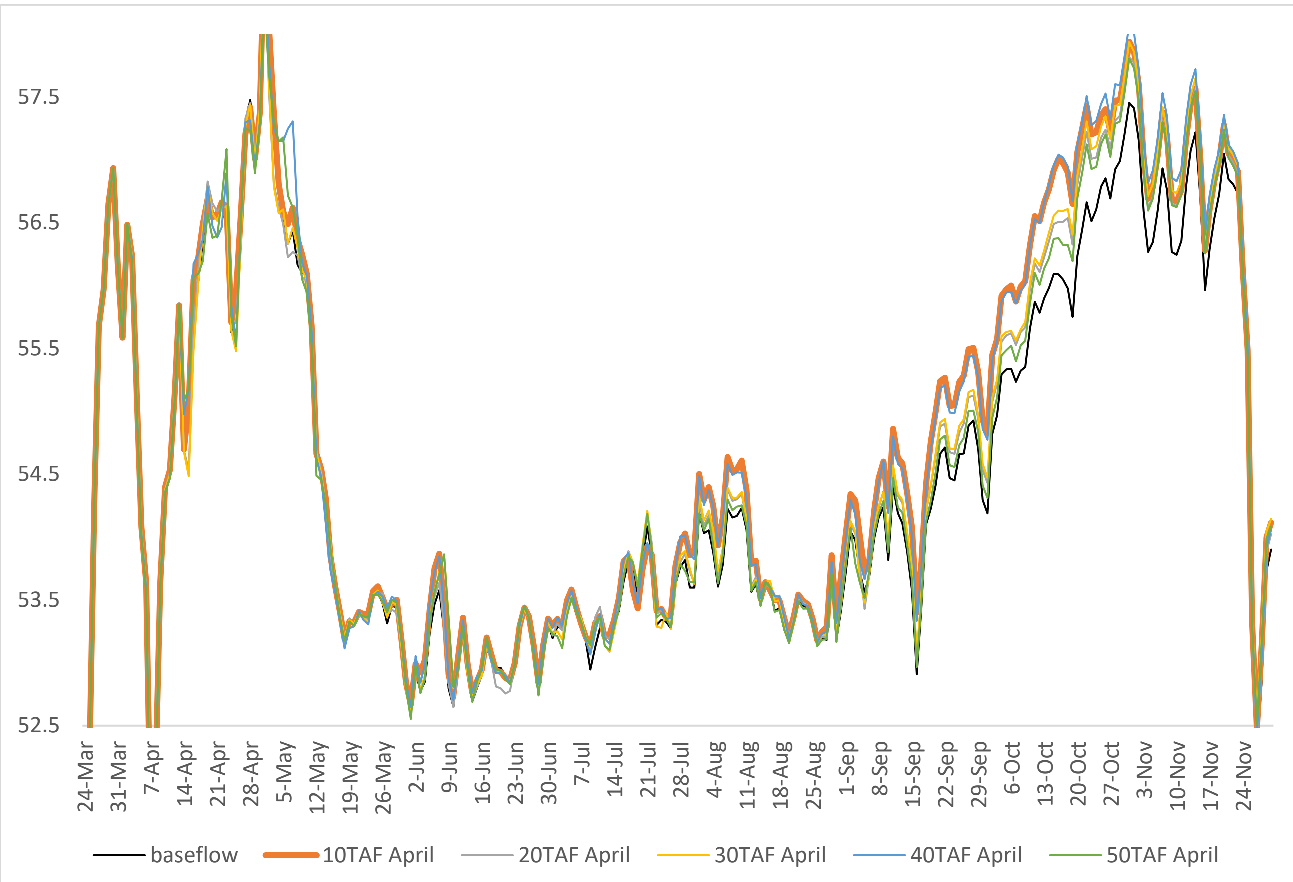


Figure 1. Forecasted daily water temperatures in degrees F at Clear Creek for pulses only occurring in April.

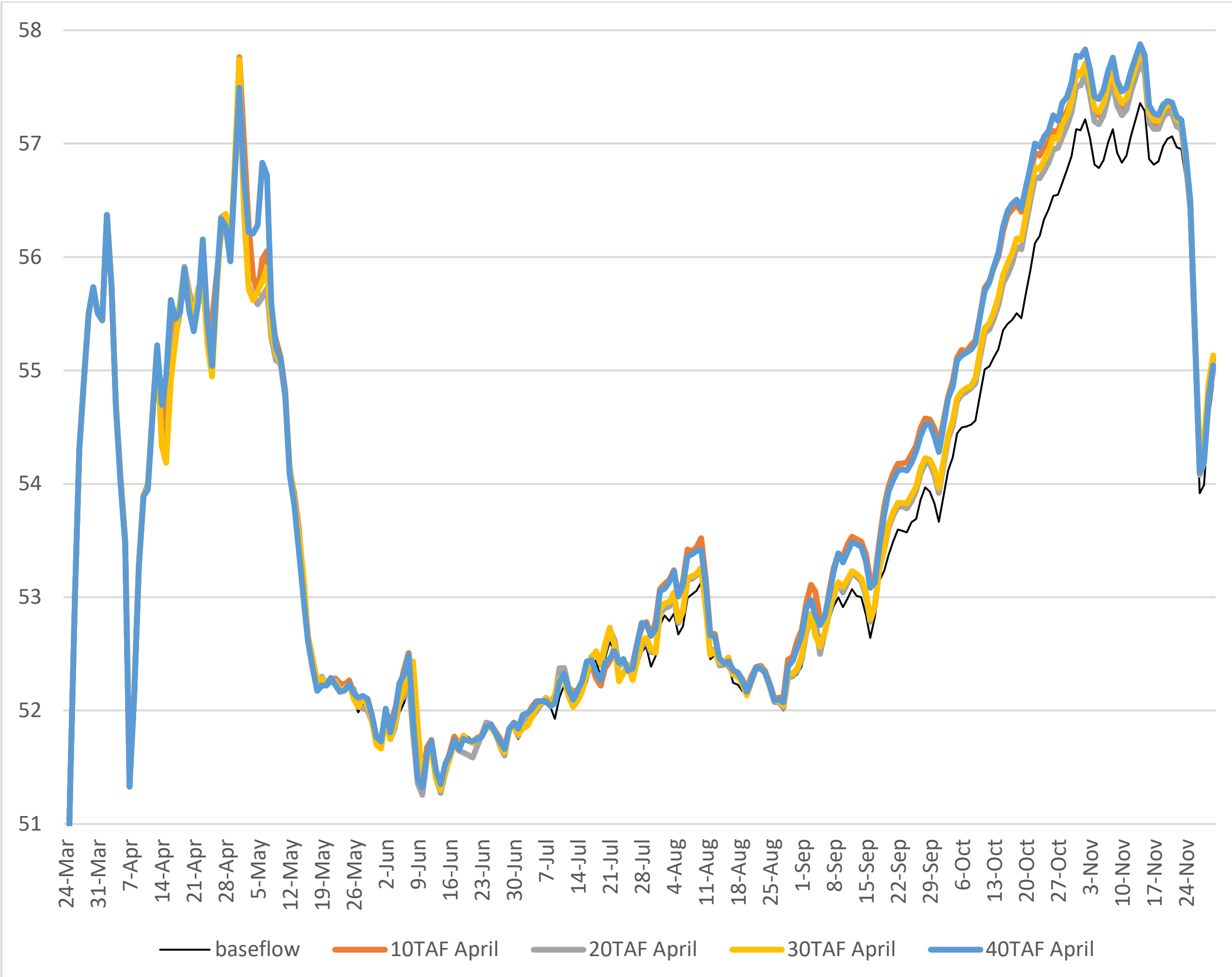


Figure 2. Forecasted daily water temperatures in degrees Fahrenheight at Keswick for pulses only occurring in April.

Attachment 2

Estimated CVP Operations 90% Exceedance

Storages

Federal End of the Month Storage/Elevation (Thousand Acre-Feet (TAF)/feet)

Facility	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Trinity (TAF)	2235	2121	1965	1814	1640	1473	1394	1338	1268	1271	1303	1361	1412
Trinity Elevation (feet)	N/A	2349	2339	2328	2314	2301	2294	2289	2283	2283	2286	2291	2296
Whiskeytown (TAF)	219	238	238	238	238	238	206	206	206	206	206	206	206
Whiskeytown Elevation (feet)	N/A	1209	1209	1209	1209	1209	1199	1199	1199	1199	1199	1199	1199
Shasta (TAF)	4140	3943	3518	2981	2440	2200	2050	2034	2093	2210	2377	2618	2659
Shasta Elevation (feet)	N/A	1046	1029	1007	981	969	960	959	963	969	978	990	992
Folsom (TAF)	922	935	827	503	327	276	269	262	266	280	338	462	515
Folsom Elevation (feet)	N/A	462	452	417	392	383	381	380	381	384	394	412	418
New Melones (TAF)	1868	1786	1683	1606	1546	1498	1438	1435	1433	1439	1397	1376	1256
New Melones Elevation (feet)	N/A	1032	1022	1014	1008	1003	996	996	996	996	992	989	975
Federal San Luis (TAF)	807	718	485	233	209	142	156	116	131	320	281	247	186
Federal San Luis Elevation (feet)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Storage (TAF)	10191	9742	8716	7376	6401	5828	5513	5391	5397	5726	5902	6269	6233

State End of the Month Reservoir Storage (TAF/feet)

Facility	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Oroville (TAF)	3320	3224	3027	2457	1937	1531	1292	1166	1092	1148	1289	1503	1643
Oroville Elevation (feet)	N/A	880	866	823	777	734	705	688	678	686	705	731	747
State San Luis (TAF)	954	824	668	772	920	1055	1062	1042	1029	1058	1001	1007	933
State San Luis Elevation (feet)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total San Luis (TAF)	1761	1542	1153	1006	1129	1198	1218	1159	1159	1379	1282	1254	1119
Total San Luis Elevation (feet)	N/A	503	468	453	465	472	473	468	468	489	480	477	464

Monthly River Releases (TAF/cfs)

Facility	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Trinity (TAF)	N/A	68	47	28	53	52	23	18	78	18	17	28	32
Trinity (cfs)	N/A	1114	789	455	857	870	373	300	1276	300	300	450	540
Clear Creek (TAF)	N/A	18	13	7	6	7	10	12	16	18	17	18	15
Clear Creek (cfs)	N/A	295	215	113	100	120	157	210	260	293	300	286	247
Sacramento (TAF)	N/A	523	684	775	778	476	430	283	200	200	211	277	476
Sacramento (cfs)	N/A	8500	11500	12600	12650	8000	7000	4750	3250	3250	3800	4500	8000
American (TAF)	N/A	191	179	378	237	101	49	50	49	49	44	49	113
American (cfs)	N/A	3100	3008	6142	3859	1704	801	835	800	800	801	800	1907
Stanislaus (TAF)	N/A	69	53	12	12	12	39	12	12	12	57	54	68
Stanislaus (cfs)	N/A	1114	899	200	200	200	635	200	200	200	1019	881	1151
Feather (TAF)	N/A	68	101	430	430	434	227	74	77	77	58	65	83
Feather (cfs)	N/A	1100	1700	7000	7000	7300	3700	1250	1250	1250	1050	1050	1400

Trinity Diversions (TAF)

Facility	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Carr Powerplant (TAF)	N/A	111	121	122	122	118	61	51	12	10	5	0	1
Spring Creek Powerplant (TAF)	N/A	90	110	115	115	110	85	40	0	0	0	2	5

Delta Summary (TAF/cfs/%)

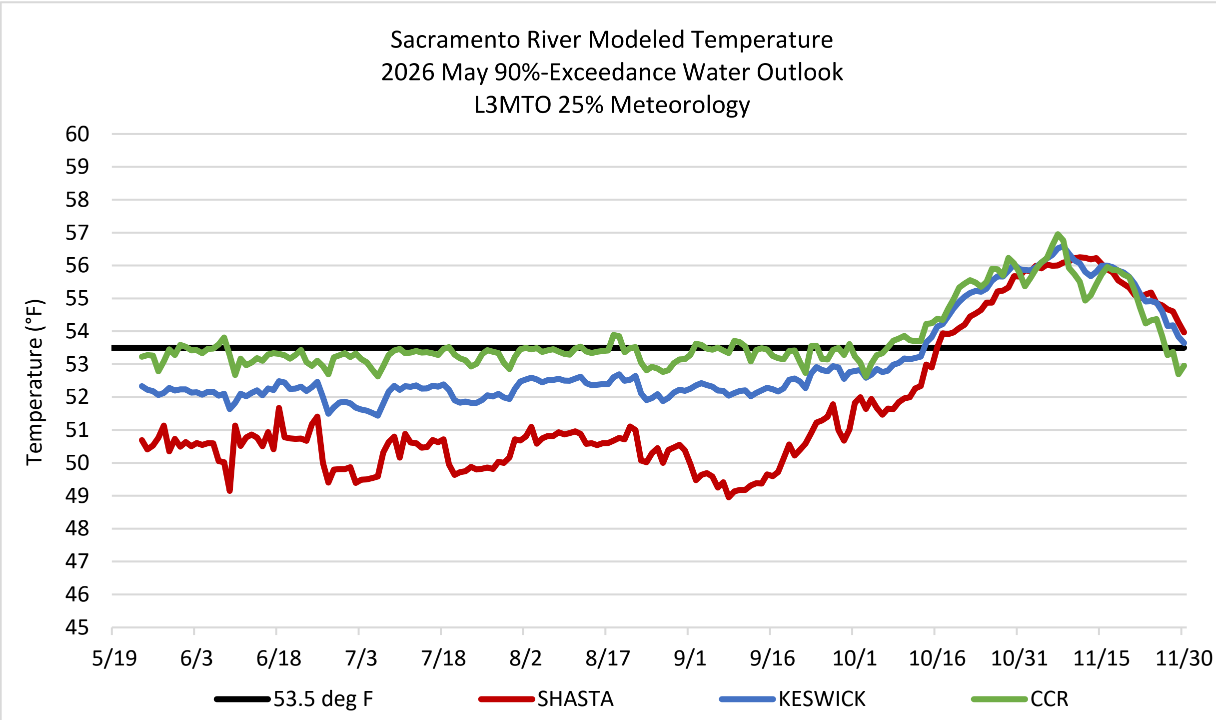
Facility/Location/Metric	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Tracy (TAF)	N/A	172	89	94	260	95	165	48	50	230	49	53	48
USBR Banks (TAF)	N/A	0	0	11	11	41	0	0	0	0	0	0	0
Contra Costa (TAF)	N/A	12.0	10.0	11.0	12.0	12.0	14.0	14.0	14.0	14.0	14.0	12.0	12.0
Total USBR (TAF)	N/A	184	99	116	283	148	179	62	64	244	63	65	60
State Export (TAF)	N/A	37	26	349	379	338	220	124	115	150	60	182	36
Total Export (TAF)	N/A	221	125	465	662	486	399	186	179	394	123	247	95
COA Balance (TAF)	N/A	24	0	0	0	0	0	0	-29	-29	-47	-25	0
Vernalis (TAF)	N/A	129	84	45	40	46	98	74	75	75	127	140	125
Vernalis (cfs)	N/A	2091	1420	737	655	772	1595	1242	1225	1225	2280	2280	2109
Old/Middle River (cfs)	N/A	-2,418	-1,569	-6,083	-8,587	-6,533	-4,870	-2,438	-2,281	-4,974	-1,270	-2,658	-875
Computed Delta Outflow (cfs)	N/A	10818	7094	8508	6605	8001	6507	6505	6507	6735	11400	11403	11397
Excess Outflow (cfs)	N/A	1497	0	0	0	0	0	0	0	228	0	0	0
% Export/Inflow	N/A	21%	15%	36%	50%	43%	43%	28%	27%	50%	15%	26%	10%
% Export/Inflow standard	N/A	35%	35%	65%	65%	65%	65%	65%	65%	65%	45%	35%	35%

Hydrology

Statistic	Trinity	Shasta	Folsom	New Melones
Water Year Inflow (TAF)	1,085	4,662	2,383	807
Year to Date + Forecasted (% of mean)	90	84	88	76

CVP actual operations do not follow any forecasted operation or outlook; actual operations are based on real-time conditions.
CVP operational forecasts or outlooks represent general system-wide dynamics and do not necessarily address specific watershed/tributary details.
CVP releases or export values represent monthly averages.
CVP Operations are updated monthly as new hydrology information is made available December through May.

Attachment 3



Run date: 05/19/2026

<u>EOM Sept storage: 2.2 MAF</u>

Trinity profile date: 05/04/2026

Whiskeytown profile date: 05/05/2026

Shasta profile date: 05/19/2026

Projected Side gates: First Aug 23rd Full Sep 7th

<u>End of September Cold-Water-Pool less than 56 deg F: 333 TAF</u>

<u>End of September Cold-Water-Pool less than 52 deg F: 147 TAF</u>

<u>End of September Cold-Water-Pool less than 48 deg F: 26 TAF</u>

	Shasta deg F	Keswick deg F	CCR deg F
Apr			
May			
Jun	50.5	52.1	53.2
Jul	50.1	52.0	53.2
Aug	50.6	52.4	53.3
Sep	50.1	52.4	53.4
Oct	53.4	54.1	54.5
Nov	55.6	55.5	55.2

Attachment 4: Winter-run Chinook Salmon Temperature Dependent Mortality Estimates

Background

To forecast temperature dependent mortality (TDM) of winter-run Chinook salmon for the 2026 Sacramento River Temperature Management Plan, a scenario was evaluated that targeted 53.5°F at Clear Creek (CCR). The modeling framework used spatially explicit, daily average water temperature forecasts from the WTMP model. These forecasts were applied at five locations along the Sacramento River: Keswick Dam (RKM 483), Sacramento River at Clear Creek (RKM 474), Anderson Airport Rd Bridge (RKM 467), Balls Ferry (RKM 458), and Jellys Ferry (RKM 451). For locations between gauges, daily temperatures were estimated by linear interpolation along the river-kilometer axis. These water temperature estimates were then matched to the river-kilometer locations of simulated winter-run Chinook salmon redds.

Two redd distribution data sources were used in parallel to bracket the structural sensitivity of TDM estimates to this uncertainty: (1) carcass survey-derived redd locations and timing from the winter-run carcass survey record, brood years 2013–2025; and (2) aerial survey-derived redd locations and timing, brood years 2013–2025. Carcass-derived redds occupy four reach bands between Keswick (RKM 483) and approximately RKM 454. Aerial-derived redds occupy six reach centroids between Keswick (RKM 482) and Jellys Ferry (RKM 452), reflecting the broader spatial coverage of aerial surveys. Both sources were carried through the analysis independently; results are reported in parallel and are not combined into a single weighted estimate (Figure 1-2).

TDM was estimated by simulating the thermal history of each redd throughout its incubation period using two mortality models, both of which are referenced in the 2025 Long-Term Operations Record of Decision and supported by SacPAS Fish Model documentation. The stage-independent model (Martin et al., 2017) accumulates mortality continuously throughout the incubation period from spawn to emergence using a single critical-temperature threshold. The stage-dependent model (Anderson et al., 2022) accumulates mortality only during a 4-day pre-hatch critical window. Both models use the linear development model of Zeug et al. (2012), with hatching at 400 accumulated thermal units (ATU) and emergence at 958 ATU. Aggregate TDM is reported as 100 × (1 − mean V), where V is per-redd thermal survival and the mean is taken across all redds for the year. TDM was computed separately for each brood year using that year's observed redd distribution (Figure 3), and pooled values reported below are the simple mean across years.

Assumptions and limitations

Several assumptions and limitations bear on the interpretation of the TDM estimates (Table 2). This is a deterministic forward projection based on a single proposed temperature scenario and the 50th-percentile point estimates of each model's parameters. It does not propagate parameter uncertainty, weather variability, or operational uncertainty in the temperature scenario itself. Year-to-year variation in Table 1 reflects only the variability in observed redd distributions across brood years.

Both models share a calibration assumption that has not been validated in the Sacramento River. They were fit to annual egg-to-fry survival, calculated as fry-equivalent passage at Red Bluff Diversion Dam divided by estimated egg deposition. Because Red Bluff Diversion Dam is approximately 90 km downstream of the primary spawning reach, this metric integrates mortality across adult pre-spawn, egg incubation, fry rearing, and juvenile outmigration. Calibration therefore requires that all non-temperature, non-density-dependent sources of mortality across these life stages are constant across years (a "background survival" term). This assumption implies, among other things, that flow effects on egg, fry, and smolt survival do not vary among years, and that thermal effects on life stages other than incubating eggs do not vary among years. Recent analyses of Sacramento River juvenile salmon survival (e.g., Hassrick et al., 2022; Michel et al., 2021; Munsch et al., 2020) indicate that flow does influence juvenile survival, suggesting this assumption may not hold. The implication for the present analysis is that interannual variation in egg-to-fry survival used to fit the models may reflect drivers other than incubation temperature, and that the calibrated parameter values absorb some of that signal.

The model parameter values applied here are not uniquely identifiable from the calibration data alone. Schmidt et al. (2019) and Zeug et al. (2024) document structural nonidentifiability concerns in models of this form: when the available calibration data are annual aggregate survival values, the critical temperature (Tcrit) and the per-degree-day mortality rate (b) can trade off along a ridge in the likelihood surface, with carrying capacity and background survival further interacting with both. Without strong independent prior information on at least one of these parameters, multiple combinations of parameter values produce comparably good fits to the calibration data. The 50th-percentile parameter values applied here (Tcrit = 12.10 °C and 11.82 °C; b = 0.026 and 0.436 $°C^{-1} \cdot d^{-1}$ for the stage-independent and stage-dependent models, respectively) match SacPAS Fish Model defaults are reported here as point estimates without associated uncertainty, with further discussion about this in Reclamation 2024. The Table 1 TDM values should be interpreted as conditional on this single parameterization rather than as the central tendency of a probability distribution and are most appropriately used for relative comparison among temperature management alternatives rather than as predicted egg-survival outcomes.

The carcass-derived and aerial-derived redd distributions disagree substantially on absolute TDM levels: aerial-derived TDM is approximately 10× higher than carcass-derived TDM under the stage-dependent model and approximately 1.7× higher under the stage-independent model (pooled across brood years). The disagreement reflects methodological differences between the two surveys and is the principal driver of the cross-source TDM gap reported in Table 1. Aerial-derived redd distributions have potential biases associated with water turbidity, depth, and other environmental variables affecting aerial sighting of redds. Carcass-derived redd distributions have potential biases associated with carcass dispersal post-redd construction, scavenger removal and decay, and environmental variable affecting surveyor sighting of redds.

Both sources represent real signal-plus-noise from different sampling and detection methods, and both are reported in parallel rather than combined because choosing a single weighted estimate would require survey-method assumptions that this analysis does not adopt.

Two additional sources of uncertainty apply across models. The Tcrit and rate-parameter values used here are population-mean values calibrated to aggregate Sacramento River outcomes. Within-redd variation in interstitial flow velocity, dissolved oxygen, and gravel composition modulates the effective Tcrit at the individual redd scale; this variation is not represented in either model. In addition, the stage-dependent and stage-independent models embody different hypotheses about which life-stage exposures contribute to thermal mortality. They should not be treated as point estimates of the same quantity.

The in-river analysis envelope extends from Keswick (RKM 483) to Balls Ferry (RKM 458). The simulated proposed-scenario trace covers all five WTMP gauge stations (Keswick, Clear Creek, Anderson Airport Rd, Balls Ferry, Jellys Ferry) from 20 May 2026 onward. For the observed pre-scenario period (1 January – 19 May 2026), CDEC water-temperature data are available for Keswick, Clear Creek, and Balls Ferry but not for Anderson Rd or Jellys Ferry; these two stations remain NA pre-20-May and are populated by the simulated trace 20 May onward. Because the pre-20-May observed anchors do not extend past Balls Ferry, the in-river TDM analysis envelope is bounded at Balls Ferry. Aerial-survey redds past Balls Ferry account for ≤1% of total aerial redds across 2013–2025 (Figure 4) and are excluded from analysis.

References

Anderson, J. J., Beer, W. N., Israel, J. A., & Greene, S. (2022). Targeting river operations to the critical thermal window of fish incubation: Model and case study on Sacramento River winter-run Chinook salmon. *River Research and Applications*, *38*(5), 895–905. https://doi.org/10.1002/rra.3965

Hassrick, J. L., Ammann, A. J., Perry, R. W., John, S. N., & Daniels, M. E. (2022). Factors Affecting Spatiotemporal Variation in Survival of Endangered Winter-Run Chinook Salmon Out-migrating from the Sacramento River. *North American Journal of Fisheries Management*, *42*(2), 375–395. https://doi.org/10.1002/nafm.10748

Martin, B. T., Pike, A., John, S. N., Hamda, N., Roberts, J., Lindley, S. T., & Danner, E. M. (2017). Phenomenological vs. Biophysical models of thermal stress in aquatic eggs. *Ecology Letters*, *20*(1), 50–59. https://doi.org/10.1111/ele.12705

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

Munsch, S. H., Greene, C. M., Johnson, R. C., Satterthwaite, W. H., Imaki, H., Brandes, P. L., & O'Farrell, M. R. (2020). Science for integrative management of a diadromous fish stock: Interdependencies of fisheries, flow, and habitat restoration. *Canadian Journal of Fisheries and Aquatic Sciences*, *77*(9), 1487–1504. https://doi.org/10.1139/cjfas-2020-0075.

Bureau of Reclamation, 2024b. Winter run Chinook Salmon Effects Analysis. Biological Assessment for the Long-Term Operation of the Central Valley Project and State Water Project. U.S. Department of Interior.

Schmidt, P. J., Emelko, M. B., & Thompson, M. E. (2019). *Recognizing Structural Nonidentifiability: When Experiments Do Not Provide Information About Important Parameters and Misleading Models Can Still Have Great Fit*. https://doi.org/10.1111/risa.13386

Zeug, S. C., Bergman, P. S., Cavallo, B. J., & Jones, K. S. (2012). Application of a Life Cycle Simulation Model to Evaluate Impacts of Water Management and Conservation Actions on an Endangered Population of Chinook Salmon. *Environmental Modeling & Assessment*, *17*(5), 455–467. https://doi.org/10.1007/s10666-012-9306-6

Zeug, S. C., Constandache, A., & Cavallo, B. (2024). Considerations for the use of laboratory-based and field-based estimates of environmental tolerance in water management decisions for an endangered salmonid. *PLOS Water*, *3*(10), e0000195. https://doi.org/10.1371/journal.pwat.0000195

Table 1. Summary of winter-run Chinook salmon TDM estimates for the proposed 2026 Sacramento River Temperature Management Plan scenario (53.5°F at CCR target). Pooled values are the simple mean of per-brood-year TDM estimates across the 13 years available for each redd source. Range columns show the minimum and maximum per-year value across the same set of years; the 2025 column is the single-year estimate for brood year 2025 (the most recent year). The SD column reports the standard deviation of the 13 per-year estimates and reflects year-to-year variability in cohort outcomes under the fixed temperature scenario.

Redd source × Model	Pooled mean (%)	Range minimum (%)	Range maximum (%)	SD across brood years (%)	Brood year 2025 (%)
Carcass × Stage-dependent (Anderson et al., 2022)	1.1	0.0	6.2	1.7	0.3
Carcass × Stage-independent (Martin et al., 2017)	2.8	0.7	9.1	2.5	4.9
Aerial × Stage-dependent (Anderson et al., 2022)	11.4	3.0	26.7	7.8	18.1
Aerial × Stage-independent (Martin et al., 2017)	4.7	0.8	16.5	4.7	16.5

Table 2. Modeling assumptions for the TDM estimates in Table 1.

Parameter	Associated information
Meteorology source	25% exceedance L3MTO
Time period	1/1/2026 – 5/19/2026: observed temperatures; 5/20/2026 – 11/30/2026: simulated temperatures
Reservoir model	WTMP CE-QUAL-W2
River model	WTMP HEC-ResSim
Shasta profile date	5/19/2026
TCD gate operations	WTMP CE-QUAL-W2
Sacramento River water temperatures	WTMP CE-QUAL-W2 simulated daily mean output at five gauge stations (Keswick Dam, Clear Creek, Anderson Airport Rd Bridge, Balls Ferry, Jellys Ferry) from 20 May 2026 onward. Pre-20-May observed temperatures pulled from CDEC for Keswick, Clear Creek, and Balls Ferry.
Gauge station RKM convention	All five gauge RKMs are derived from published USGS/CDEC station coordinates using great-circle distance from Keswick Dam. The two upstream RKMs (Keswick = 483, CCR = 474) follow the convention used in the prior TMP analysis (Elissa Buttermore, pers. comm.); the slope between them (≈ −0.821 RKM per km) is then applied to the three downstream stations, yielding Airport = 467, Balls Ferry = 458, and Jellys Ferry = 451. The same formula reproduces the two upstream values exactly and extends them consistently downstream from a single set of station coordinates.
Spatial interpolation between gauges	Linear interpolation along the river-kilometer axis between adjacent gauge stations. Nearest-endpoint extrapolation is applied only outside the Keswick–Balls Ferry analysis

Parameter	Associated information
	envelope (RKM 483–458); all redds in this analysis fall within the envelope and use proper interpolated values.
Biological framework	SacPAS Fish Model framework (temperature effect only). Model parameters, ATU thresholds, and integration conventions match SacPAS v3 manual specifications.
Temperature mortality models	Both models referenced in the 2025 LTO ROD: stage-independent (Martin et al., 2017) continuous hazard over the full incubation period; stage-dependent (Anderson et al., 2022) hazard concentrated in a 4-day pre-hatch critical window.
Model functional form	Both models of the form $V = \exp(-b \times \Sigma \max(T - Tcrit, 0))$, where the summation window and the parameter values differ between models. Aggregate TDM = 100 × (1 − mean V) across redds.
Egg-emergence timing model	Linear (Zeug et al., 2012, as implemented in SacPAS): hatch at 400 ATU (accumulated thermal units, °C·days); emergence at 958 ATU.
T_crit (50th percentile)	Stage-independent: 12.10°C (53.78°F). Stage-dependent: 11.82°C (53.28°F). Both values are 50th-percentile point estimates from the original calibrations and match SacPAS Fish Model defaults.
Model rate parameter (50th percentile)	Stage-independent (α): 0.026 $°C^{-1} \cdot d^{-1}$. Stage-dependent (bδ): 0.436 $°C^{-1} \cdot d^{-1}$. Both values are 50th-percentile point estimates and match SacPAS Fish Model defaults. No parameter uncertainty is propagated; estimates are deterministic at these values.
Critical days (mortality accumulation window)	Stage-independent: full incubation period (spawn through emergence; ~120–180 days depending on incubation temperature). Stage-dependent: 4 days immediately preceding hatch.

Parameter	Associated information
Redd time distribution — source 1	Carcass-survey daily redd counts from the SacPAS dbcarcass record, brood years 2013–2025.
Redd time distribution — source 2	Aerial-survey daily redd counts, brood years 2013–2025.
Redd space distribution — source 1	Carcass-survey reach reporting at four RKMs: 483, 479 (KWK_ACID), 474 (ACID_HWY44), 454 (downstream of CCR).
Redd space distribution — source 2	Aerial-survey reach reporting at six reach-centroid RKMs: 482 (KWK_ACID), 474 (ACID_HWY44), 470 (HWY44_BTL), 463 (Airport→Balls Ferry), 456 (Balls Ferry→Battle Creek), 452 (Battle Creek→Jellys Ferry).
Per-year analysis	TDM was computed for each brood year separately using that year's redd distribution and the same proposed 2026 temperature scenario. Pooled values are the simple mean of per-year TDM.
Treatment of redd sources	The two redd sources are not combined into a single weighted estimate. Both are reported in parallel because each represents real signal-plus-noise from a different sampling method, with different detection biases and different spatial coverage.

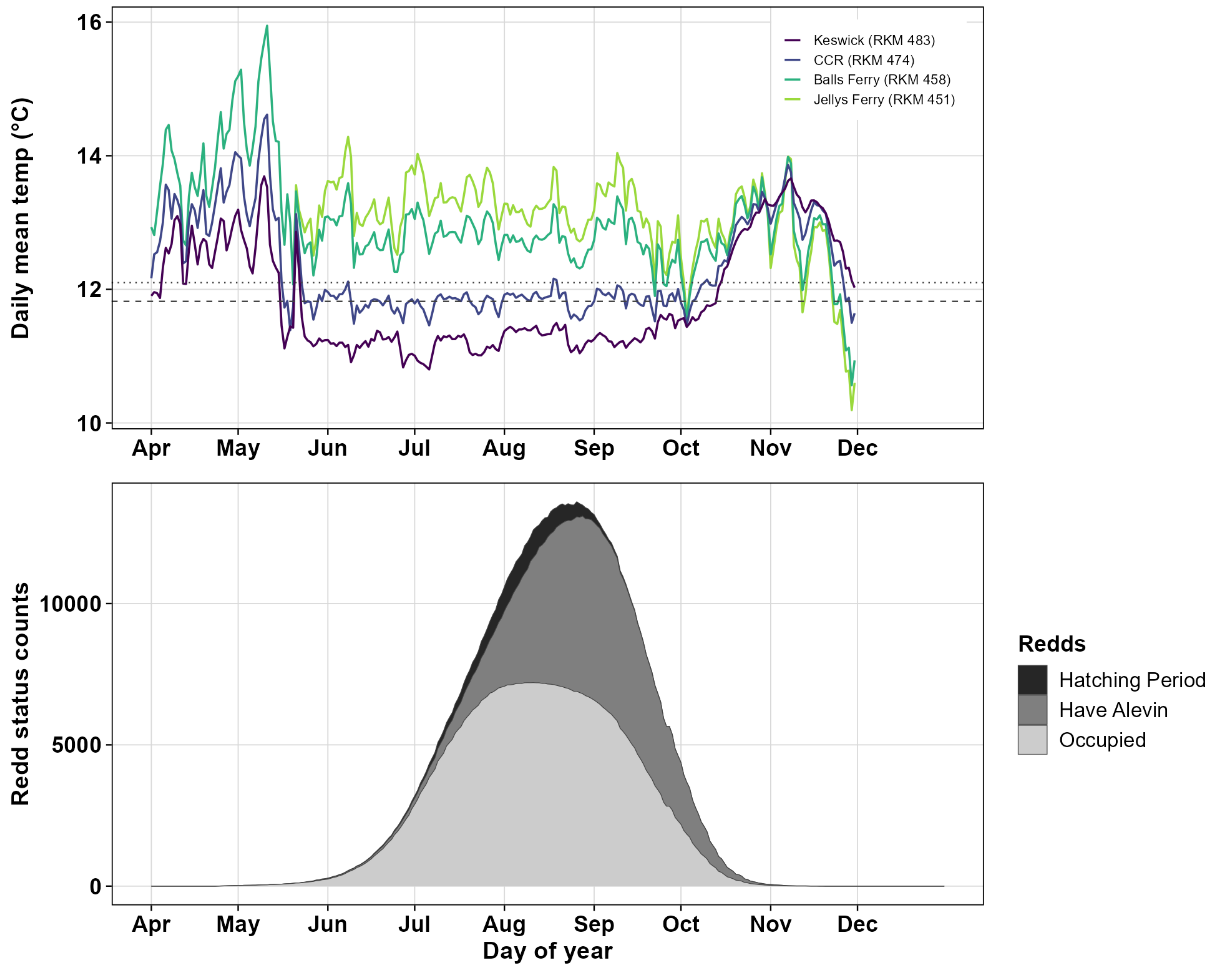


Figure 1. Daily mean water temperature at the WTMP gauge stations (Keswick at RKM 483, Clear Creek at RKM 474, Airport Rd Bridge at RKM 467, Balls Ferry at RKM 458, Jellys Ferry at RKM 451) under the proposed 2026 Sacramento River Temperature Management Plan scenario (53.5°F target at CCR), with daily winter-run Chinook salmon redd-deposition counts summed across reaches and brood years 2013–2025 (carcass-derived). Horizontal reference lines mark each model's temperature threshold: dashed = Anderson et al. 2022 (11.82 °C), dotted = Martin et al. 2017 (12.10 °C).

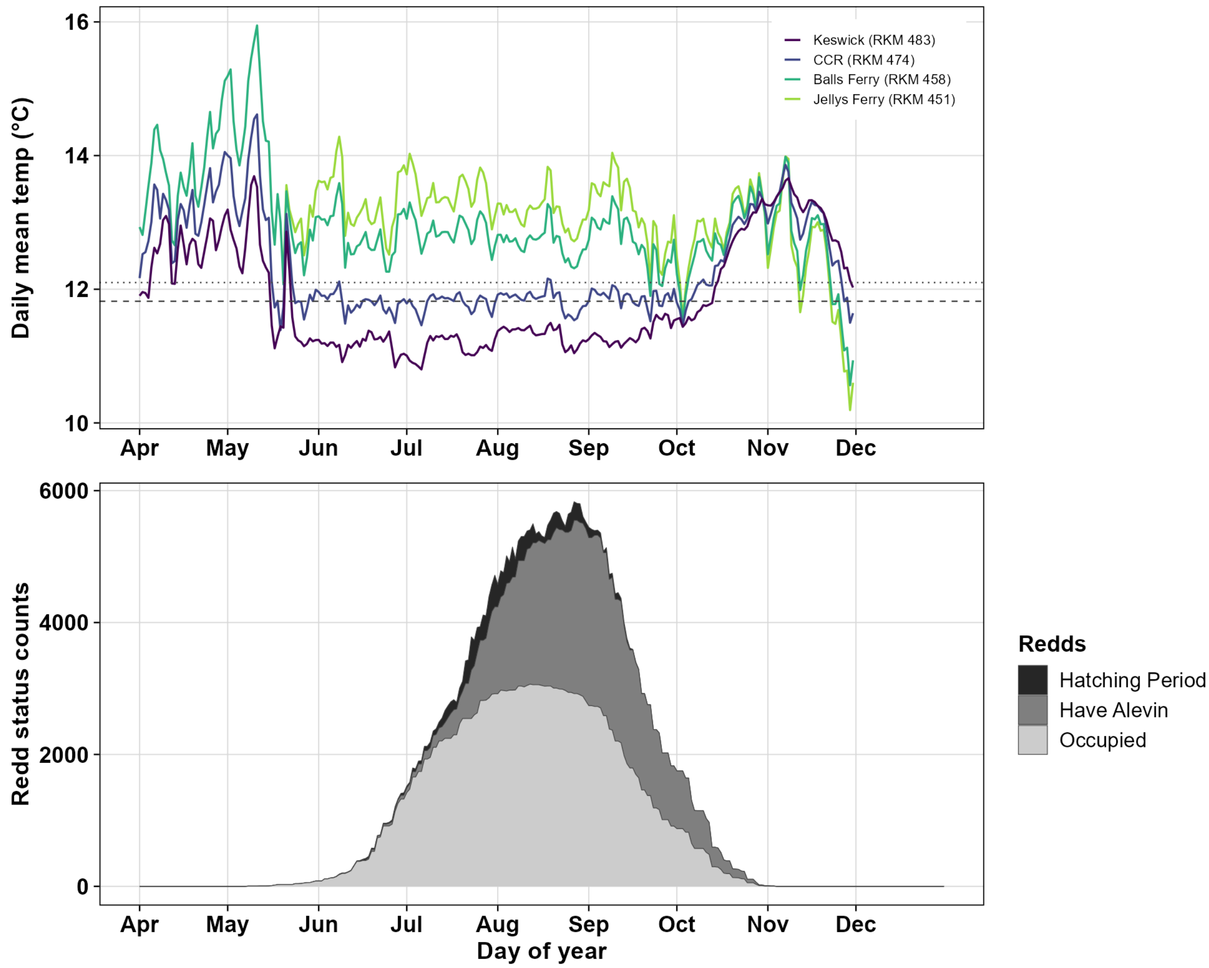


Figure 2. Daily mean water temperature at the five WTMP gauge stations (Keswick, CCR, Airport Rd, Balls Ferry, Jellys Ferry) under the proposed 2026 Sacramento River Temperature Management Plan scenario (53.5°F target at CCR), with daily winter-run Chinook salmon redd-deposition counts summed across reaches and brood years 2013–2025 (aerial-derived). Horizontal reference lines mark each model's temperature threshold: dashed = Anderson et al. 2022 (11.82 °C), dotted = Martin et al. 2017 (12.10 °C).

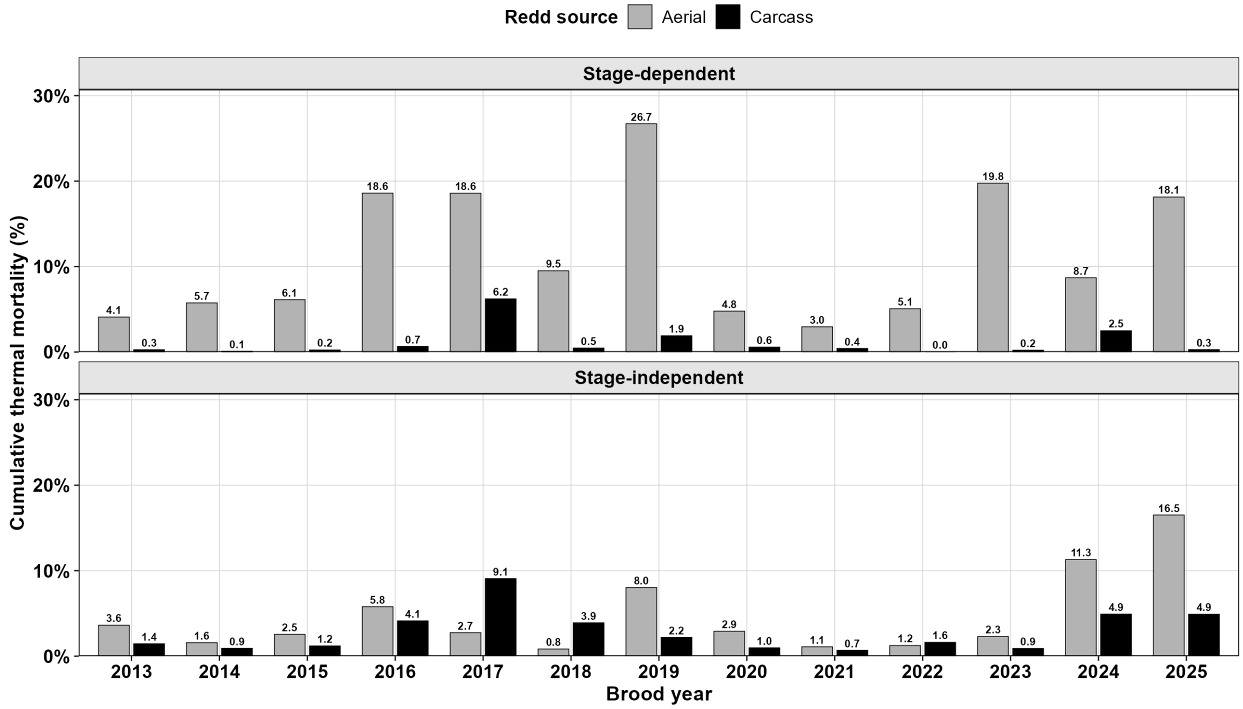


Figure 3. Predicted egg-to-emergence temperature dependent mortality (TDM, %) for winter-run Chinook salmon under the proposed 2026 Sacramento River Temperature Management Plan scenario (53.5°F target at CCR), by brood year (2013–2025), data source, and model. Each year's observed redd distribution was applied to the proposed-scenario temperature trace. Top panel: stage-dependent model (Anderson et al. 2022). Bottom panel: stage-independent model (Martin et al. 2017). Fill: redd source (carcass-derived, black; aerial-derived, gray). Pooled-across-year means for each source × model combination are reported in Table 1.

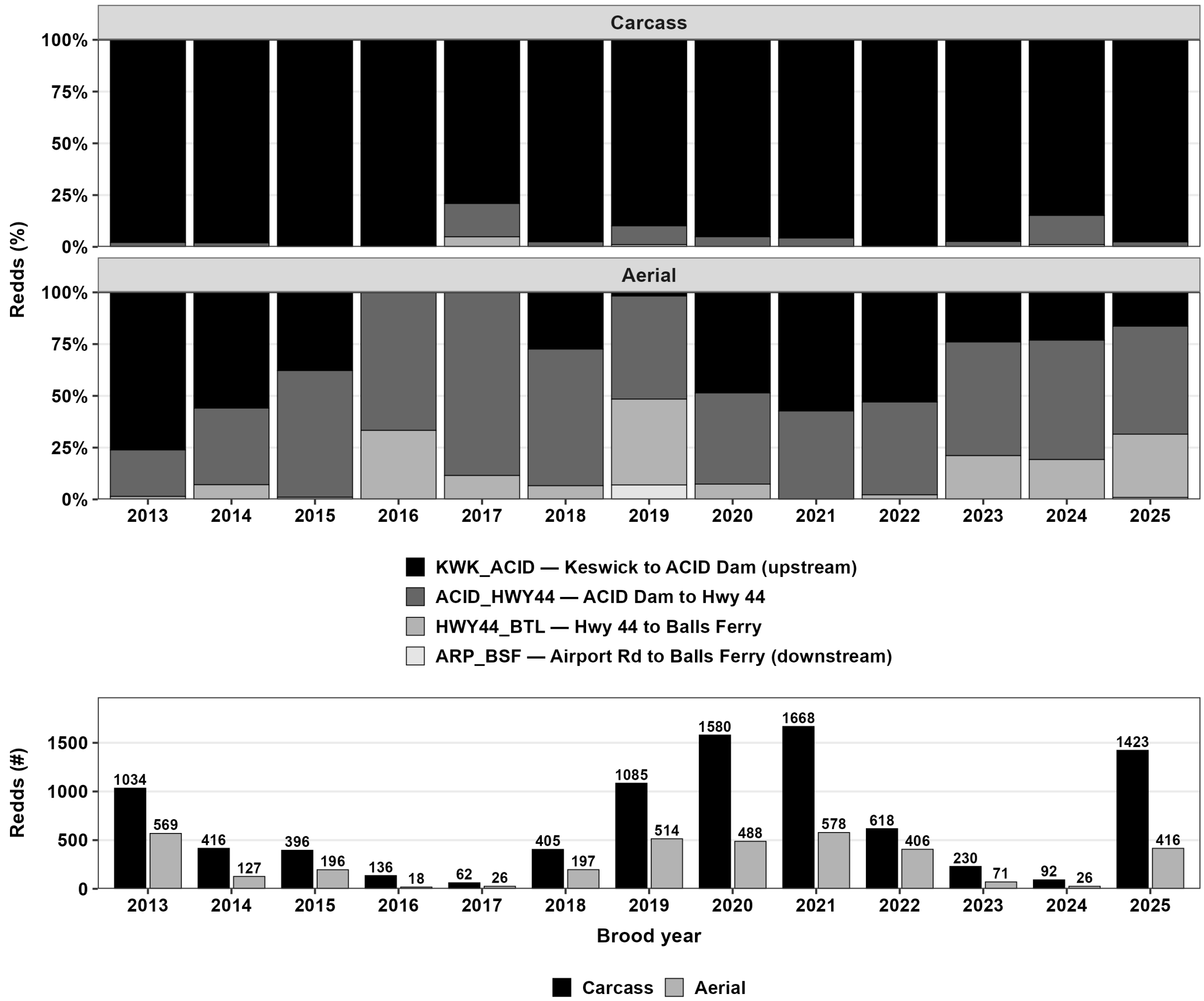


Figure 4. Spatial allocation of winter-run Chinook salmon redds across modeled reaches by brood year and survey method (2013–2025). Top panel: within-year proportion of redds in each reach. Carcass-derived redds occupy four upstream RKM bands (483, 479, 474, 454); aerial-derived redds occupy the four named reaches that lie within the Keswick → Balls Ferry in-river analysis envelope (KWK_ACID, ACID_HWY44, HWY44_BTL, ARP_BSF [Airport Rd to Balls Ferry]). Bottom panel: total redds counted per source per year.

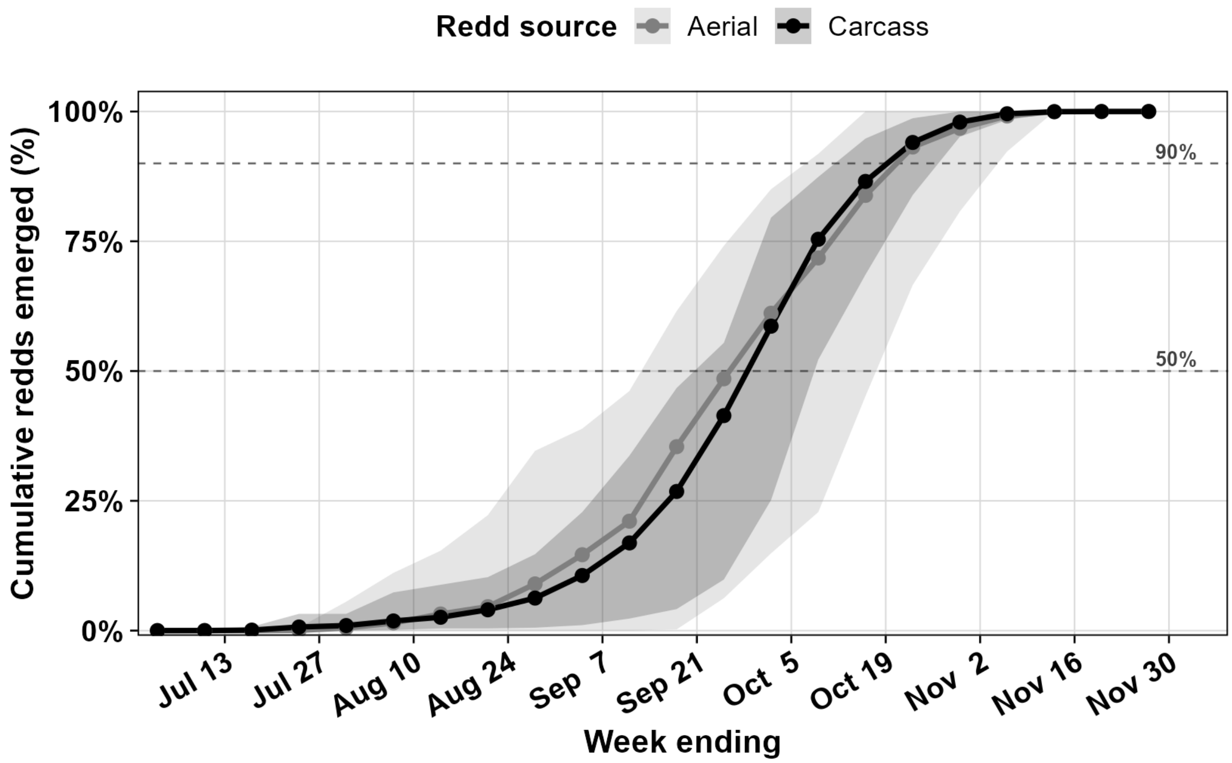


Figure 5. Weekly cumulative percentage of winter-run Chinook salmon redds emerged under the proposed 2026 TMP scenario (53.5°F at CCR), pooled across brood years 2013–2025. Per-redd emergence dates are projected forward from each redd's spawn date using the daily WTMP CE-QUAL-W2 trace at that redd's RKM and the Zeug et al. (2012) constant-ATU development model (hatch at 400 ATU, emerge at 958 ATU). Lines show mean cumulative percent emerged across the 13 brood years; ribbons show the across-year min–max. Black = carcass-derived redd distribution; grey = aerial-derived. Dashed horizontal lines at 50% and 90% mark the dates by which half and most of the cohort have completed incubation in a typical year.

Temperature-Dependent Egg Mortality Estimates for the 2026 Sacramento River Temperature Management Plan

May 27, 2026

Southwest Fisheries Science Center · UC Santa Cruz · CVTEMP Operational Platform

The Southwest Fisheries Science Center (SWFSC) simulated two Keswick release scenarios - a USBR 90th-exceedance forecast (Forecast_90) and a 200 TAF release reduction (Alt_2) - to evaluate temperature-dependent egg mortality (TDM) outcomes under USBR's 2026 Temperature Management Plan. The Forecast_90 values were provided by USBR in the May 90% forecast (dated 5/18/2026), while the Alt_2 scenario was based on achieving an end of September storage of 2.4 MAF of water in Shasta Reservoir by reducing releases in June through August. Both scenarios were forced with the same hydrology (May B120 90th percentile Shasta inflow, identical Trinity imports via Spring Creek), the same meteorology (historical year 2014, selected as a representative warm year consistent with the NOAA seasonal outlook for summer 2026), and the same downstream temperature target at Clear Creek (53.5 °F). TDM was estimated using the stage-independent egg-mortality model (Martin et al., 2017) and the stage-dependent model (Anderson *et al.,* 2022) over 13 historical redd-year distributions (2013–2025).

Predicted mean and maximum monthly water temperatures under the two scenarios are shown in Table 1 and 5. These values are based on daily mean water values. Across May–December, Alt_2 was cooler than Forecast_90 at Shasta, Keswick, and CCR, with the largest mean-monthly differences occurring in October (~1°F at Shasta). Across May–December, the Alt_2 scenario produced maximum-monthly temperatures generally within ~1°F of Forecast_90 at all three locations through the summer, with the largest differences occurring in October - when the maximum-monthly temperatures were 1.3°F cooler at Shasta, 1.0°F cooler at Keswick, and 0.9°F cooler at CCR - reflecting the additional cold water reserve sustaining lower release temperatures later in the season.

Across all 13 redd distribution years (2013–2025), the Alt_2 scenario reduced population-mean TDM relative to Forecast_90 under both models. Under the stage-independent model, mean TDM dropped from 19% (range 11–45%) to 14% (range 7–34%) - a 5-percentage-point (pp) absolute reduction. Under the stage-dependent model, mean TDM dropped from 6% (range 0–26%) to 4% (range 0–20%) - a 2-percentage-point absolute reduction. The upper end of both ranges corresponds to redd-year 2025, the most recent redd-year distribution in the dataset; for that year, the 200 TAF release reduction lowered mean annual TDM from 45% to 34% (11-pp reduction) under the stage-independent model and from 26% to 20% (6-pp reduction) under the stage-dependent model.

Below is a summary of the model setup, followed by results.

1. Overview

Total release scenarios simulated: 2

- Keswick (KWK) release scenario based on USBR May 90% operations forecast **(Forecast_90)**
- 200 TAF reduction **(Alt_2)**

TDM Forecast start date: 04/01/2026
Reservoir Forecast start date: 05/25/2026
Simulation start date: 05/19/2026
Simulation end date: 12/31/2026

Models used:

Shasta Reservoir	CE-QUAL-W2 hydrodynamic model (Cole & Wells, 2006; Daniels et al., 2018)
Keswick Reservoir	CE-QUAL-W2 hydrodynamic model (Cole & Wells, 2006)
Upper Sacramento River	RAFT river temperature model (Pike et al., 2013; Daniels et al., 2018)
Temperature-dependent egg mortality	Stage-independent model (Martin et al., 2017) & Stage-dependent model (Anderson et al., 2022)

2. Reservoir Release Scenarios

Two reservoir release scenarios were simulated. Each scenario was paired with the same Spring Creek (SPP; Trinity import) profile. Reduced Keswick flow in the Alt_2 scenario was assumed to come from Shasta Reservoir.

Keswick Releases (CFS) — monthly mean

Label	Description	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Forecast_90	DWR B120 90th exceedance flow forecast	8500	11500	12600	12650	8000	7000	4200	3250
Alt_2	Release reduction 200 TAF	8500	10404	11504	11554	8000	7000	4200	3250

Trinity Imports via Spring Creek PP (TAF/month)

Month	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Release	90	110	115	115	110	85	40	0

3. Hydrology

All simulations were forced with DWR Bulletin 120 (B120) Shasta Reservoir inflow forecasts at the exceedance level of 90th percentile. Exceedance level affects only Shasta Reservoir inflow.

Inflow method: B120 (DWR Bulletin 120)

B120 file date: May 2026

Exceedance levels tested: 90th percentile

4. Meteorology

All simulations used the meteorological time series from the historical record for year 2014 applied over the full forecast window (5/25/2026 – 12/31/2026). Over the hindcast window (4/01/2026 – 5/25/2026) output from the Global Forecast System (GFS; NCEP 2004) was used. The 2014 meteorological year was selected for this single-year simulation as a representative warm-year condition. Previous analyses (shared 5/11/2026) identified 2014 as a comparatively warm year in the historical record, and the NOAA 90-day seasonal outlook (as of 5/25/2026) projects above-normal temperatures across the Shasta region for June through August.

5. Initial Shasta Conditions

Temperature profile date: 05/19/2026

6. Temperature Window / Target Parameters

All scenarios share the same temperature window shaping parameters.

Target location	Clear Creek (CCR)
Window temperature	12.0°C (53.6°F)
Shoulder temperature	14.4°C (57.9°F)
Window length	26 weeks
Center date	08/15/2026
Window start (derived)	05/16/2026
Window end (derived)	11/14/2026

7. TDM Model Parameters

All scenarios estimated TDM based on two models.

Model	Tcrit (°C)	bT ($°C^{-1}$ day^{-1})	Critical window	Redd data source
Stage-independent	12.00	0.0240	Deposition to emergence	Aerial survey
Stage-dependent	11.82	0.4361	4 days prior to hatch	**Aerial survey

*see references for more information

**note, stage-dependent model was calibrated using carcass survey data

Disclaimer

Results presented here are derived from numerical simulation models. All models are simplifications of complex physical systems subject to structural uncertainty, parameter uncertainty, and errors in boundary condition data. Model outputs should not be interpreted as precise predictions or relied upon as the sole basis for operational or regulatory decisions without independent validation and expert judgment. Specifically, the CE-QUAL-W2 simulations include an automated Temperature Control Device (TCD) gate selection algorithm that adjusts Shasta Dam outlet configurations to minimize deviation from a prescribed downstream temperature target. This algorithm may achieve temperature targets with greater consistency than is attainable in real-world operations. Therefore, simulation results are intended to evaluate the relative merit of alternative strategies, not to guarantee achievable outcomes.

RESULTS

8. Comparison of Mean Monthly Temperatures

To provide context for the TDM results that follow, mean monthly water temperatures from the SWFSC simulation are compared (Table 1) at three locations: Shasta Dam release, Keswick Dam release, and Clear Creek (CCR). SWFSC values represent the mean across a single historical meteorology year (2014) used to drive the simulation. See Table 5 for similar results for maximum monthly water temperatures.

Table 1. Mean monthly water temperatures (°F) based on daily means at Shasta Reservoir, Keswick Reservoir, and Clear Creek Gage (CCR) for May–December 2026 under the Forecast_90 and Alt_2 flow scenarios.

	Forecast_90			Alt_2		
Month	Shasta (°F)	Keswick (°F)	CCR (°F)	Shasta (°F)	Keswick (°F)	CCR (°F)
May	50.5	51.9	54.5	50.5	51.9	54.5
June	50.8	52.0	52.9	50.4	51.8	52.8
July	50.2	52.1	53.2	49.7	51.8	53.0
August	50.4	52.3	53.3	50.1	52.2	53.2
September	51.7	53.9	54.7	51.3	53.6	54.4
October	55.0	55.6	55.9	54.0	54.8	55.2
November	58.4	57.3	57.2	57.8	56.7	56.6
December	57.9	56.8	56.4	57.5	56.5	56.1

9. TDM Results

TDM is computed for each scenario using the stage-independent temperature dependent egg mortality model (Martin *et al*., 2017) and the stage-dependent model (Anderson *et al.,* 2022), run over 13 historical redd-year distributions (2013–2025). Table 2 summarizes the population-mean TDM (with range across redd years) and the redd-year 2025 case, with the corresponding absolute reductions in mortality between scenarios. Full year-by-year values are provided in Table 3 and Table 4 at the end of the document.

Table 2. Summary of predicted TDM by scenario and TDM model. The first row per model reports population-mean annual TDM (range across 13 redd years, 2013–2025) for meteorology year 2014. The second row per model reports values for redd-year 2025, the most recent and most thermally vulnerable distribution. Absolute reduction = Forecast_90 − Alt_2 in percentage points (pp).

Model	Comparison	Forecast_90 TDM (%)	Alt_2 TDM (%)	Absolute reduction in TDM under Alt_2 (pp)
Stage-independent	**Population mean (2013–2025)**	19 (11–45)	14 (7–34)	5
Stage-independent	**Redd-year 2025**	45	34	11
Stage-dependent	**Population mean (2013–2025)**	6 (0–26)	4 (0–20)	2
Stage-dependent	**Redd-year 2025**	26	20	6

Table 3. Mean annual TDM (%) by redd year under the **stage-independent model** for each flow scenario, with absolute reductions between scenarios. Meteorology year = 2014. Values are mean TDM across all redds within each redd year (i.e., population average). Absolute reduction = Forecast_90 – Alt_2 in percentage points (pp). *Estimates of uncertainty are available upon request.

Redd Year	Forecast_90	Alt_2	Absolute reduction from baseline (pp)
2013	23%	15%	8
2014	14%	9%	5
2015	18%	12%	6
2016	18%	14%	4
2017	25%	18%	7
2018	13%	8%	5
2019	18%	13%	5
2020	13%	8%	5
2021	11%	7%	4
2022	14%	9%	5
2023	22%	15%	7
2024	16%	11%	5
2025	45%	34%	11
Population Mean (2013-2025)	**19%**	**14%**	**5**

Notes: Values are weighted by observed redd count per year and represent an annual mean value of TDM for a population.

Table 4. Mean annual TDM (%) by redd year under the **stage-dependent model** for each flow scenario, with absolute reductions between scenarios. Meteorology year = 2014. Values are mean TDM across all redds within each redd year (i.e., population average). Absolute reduction = Forecast_90 – Alt_2 in percentage points (pp). *Estimates of uncertainty are available upon request.

Redd Year	Forecast_90	Alt_2	Absolute reduction from baseline (pp)
2013	5%	3%	2
2014	1%	0%	1
2015	3%	2%	1
2016	12%	11%	1
2017	1%	1%	0
2018	0%	0%	0
2019	7%	6%	1
2020	3%	2%	1
2021	1%	1%	0
2022	1%	1%	0
2023	1%	0%	1
2024	7%	6%	1
2025	26%	20%	6
Population Mean (2013-2025)	**6%**	**4%**	2

Notes: Values are weighted by observed redd count per year and represent an annual mean value of TDM for a population.

Table 5. Maximum monthly water temperatures (°F) based on daily means at Shasta Reservoir, Keswick Reservoir, and Clear Creek Gage (CCR) for May–December 2026 under the Forecast_90 and Alt_2 flow scenarios.

	Forecast_90			Alt_2		
Month	**Shasta (°F)**	**Keswick (°F)**	**CCR (°F)**	**Shasta (°F)**	**Keswick (°F)**	**CCR (°F)**
May	54.2	53.6	57.8	54.2	53.6	57.8
June	51.4	53.0	54.0	50.9	52.7	53.9
July	50.4	52.8	54.2	50.0	52.6	54.0
August	50.8	52.8	53.7	50.4	52.7	53.7
September	53.2	54.9	55.8	52.4	54.4	55.6
October	56.9	56.6	56.7	55.6	55.6	55.8
November	59.7	57.9	57.9	59.7	57.9	57.9
December	59.5	58.2	58.0	59.4	58.0	57.7

References

Anderson, J. J., Beer, W. N., Israel, J. A., & Greene, S. (2022). Targeting river operations to the critical thermal window of fish incubation: Model and case study on Sacramento River winter-run Chinook Salmon. *River Research and Applications*, *38*(5), 895-905. https://doi.org/10.1002/rra.3965

Cole, T. M., & Wells, S. A. (2006). *CE-QUAL-W2: A two-dimensional, laterally averaged, hydrodynamic and water quality model, version 3.5* (Instruction Report EL-06-1). U.S. Army Engineer Research and Development Center.

Daniels, M. E., Sridharan, V. K., John, S. N., & Danner, E. M. (2018). *Calibration and validation of linked water temperature models for the Shasta Reservoir and the Sacramento River from 2000 to 2015* (NOAA Technical Memorandum NMFS-SWFSC-597). U.S. Department of Commerce. https://doi.org/10.7289/V5/TM-NMFS-SWFSC-597

Martin, B. T., Pike, A., John, S. N., Hamda, N., Roberts, J., Lindley, S. T., & Danner, E. M. (2017). Phenomenological vs. biophysical models of thermal stress in aquatic eggs. *Ecology Letters*, *20*(1), 50–59. https://doi.org/10.1111/ele.12705

National Centers for Environmental Prediction (NCEP). (2004). *Global Forecast System (GFS) atmospheric model*. NOAA National Centers for Environmental Prediction. https://repository.library.noaa.gov/view/noaa/11406

Pike, A., Danner, E., Boughton, D., Melton, F., Nemani, R., Rajagopalan, B., & Lindley, S. (2013). Forecasting river temperatures in real time using a stochastic dynamics approach. *Water Resources Research*, *49*(9), 5168–5182. https://doi.org/10.1002/wrcr.20389