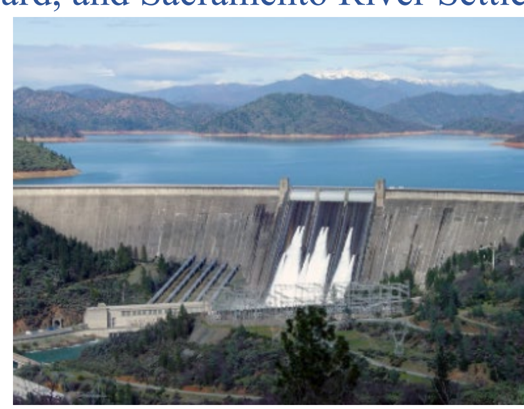
Upper Sacramento River Spring Pulse Flow Study Plan

Central Valley Project, California
California-Great Basin Region

Prepared by
Bureau of Reclamation
Bay-Delta Office
801 "I" Street, Suite 140
Sacramento, CA 95814

Bureau of Reclamation
Central Valley Operations Office
3310 El Camino Avenue, Suite 300
Sacramento, CA 95821

In coordination with
California Department of Water Resources, U.S. Fish and Wildlife Service, National Marine Fisheries Service, University of California Santa Cruz, California Department of Fish and Wildlife, California State Water Resources Control Board, and Sacramento River Settlement Contractors


Shasta Dam (Photo credit: Reclamation)

Introduction

This Pulse Flow Study Plan is designed to plan and monitor an annual pulse flow on the Sacramento River during 2021-2025. The Upper Sacramento Scheduling Team (USST) developed this Study Plan to improve collaborative implementation of Spring Pulse Flows (Section 4.10.1.2) included in the U.S. Bureau of Reclamation (Reclamation) and the California Department of Water Resources (DWR) Proposed Action for the Long-term Operations of the Central Valley Project (CVP) and State Water Project (SWP) implemented through Reclamation's Record of Decision (ROD), dated February 19, 2020. The ROD implements Alternative 1 (Preferred Alternative) as described in the Final Environmental Impact Statement (EIS). Alternative 1 was the Proposed Action consulted upon and analyzed in the Biological Opinions issued in October 2019 by the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS).

The Upper Sacramento Scheduling Team includes technical staff from the National Marine Fisheries Service (NMFS), California Department of Fish and Wildlife (CDFW), U.S. Bureau of Reclamation (Reclamation), California Department of Water Resources (DWR), U.S. Fish and Wildlife Service (USFWS), State Water Resource Control Board (SWRCB), and stakeholder groups (Sacramento Central Valley Project Contractors and Sacramento River Settlement Contractors) with direct interest in the Spring Pulse Flow Operation Plan and Fish Monitoring Plan. Technical staff have designed a multiyear study to evaluate the potential survival benefits for juvenile spring-run Chinook salmon and fall-run Chinook salmon during a managed spring pulse flow on the Sacramento River. Other work teams involved in the multiyear study will include but are not be limited to, the Sacramento River Temperature Task Group (SRTTG) and the Water Operations Management Team (WOMT).

Problem Statement

Wild spring-run Chinook salmon smolts from upper and middle Sacramento River tributaries (i.e., Clear, Battle, Mill, and Deer creeks) outmigrate to the ocean during spring when Sacramento River flows may be low, especially in dry years. Conserving reservoir storage for the temperature management season later in the year (spanning across spring, summer, and fall - May 15th through October 31st) reduces CVP releases and lowers Middle and Lower Sacramento River flows. Additionally, depletions along the river, including agricultural water diversions, further reduce Sacramento River flows in the spring. Those low flows may result in low smolt outmigration survival during spring (Notch et al., 2020). Since historical agricultural water diversions during the spring have not changed over time, environmental factors outside of flow may also impact survival and need to be examined.

Objective

This Study Plan will identify the process for planning, implementing, and reporting managed pulse flows. These pulse flows are hypothesized to improve survival rates of wild and hatchery juvenile spring-run Chinook salmon smolts through the Sacramento River (region of interest: the confluence with Deer Creek to the confluence with Feather River) during their spring outmigration period. Additionally, a pulse flow action may improve survival rates of fall-run Chinook salmon smolts. Though fall-run Chinook salmon are not the focus of this action they may be an indirect beneficiary, since some are found to migrate through the Sacramento River at similar sizes and time as spring run juveniles. Modeling pulse flow scenarios will help plan the action by estimating the potential effect(s) of a spring pulse flow on smolts survival across different hydrological conditions. Modeling will also be used to evaluate any potential increases to winter-run Chinook salmon temperature-dependent mortality (TDM) and estimate potential decreases in the Shasta Reservoir Cold Water Pool (CWP) as a result of different pulse flow(s). Candidate pulse flows will need to avoid a reduction in storage / cold water pool that would result in a Tier 4 year (reduction of CWP resulting in Tier 3 year, changing temperature tiers, etc.).

Monitoring will be implemented to measure these biological and operational responses due to implementation of the pulse flow. Reports as part of this multiyear Study Plan will communicate the operational effects of the water management action taken for the pulse flow, outmigration survival, and other observed biological and ecological responses.

In Reclamation's Proposed Action (PA) and Biological Opinion (BiOp), Reclamation proposes to address cold water management using a tiered strategy that allows for strategically selected temperature objectives, based on projected total storage and cold water pool, meteorology, Delta conditions, and habitat suitability for incoming fish population size and location. The PA and BiOp outline guidelines for determining whether a pulse flow will interfere with the ability to meet cold water pool objectives:

1. Under the Core Water Operation, Reclamation would release spring pulse flows of up to 150 TAF in coordination with the Upper Sacramento Scheduling Team when the projected total May 1 Shasta Reservoir storage indicates a likelihood of sufficient cold water to support summer cold water pool management, and the pulse does not interfere with the ability to meet performance objectives or other anticipated operations of the reservoir.
2. Total storage provides a surrogate for the likely cold water pool prior to stratification of the reservoir, and would inform the decision, in addition to monthly winter reservoir temperature measurements and climate forecasts. Reclamation would evaluate the projected May 1 Shasta Reservoir storage at the time of the February forecast to determine whether a spring pulse would be allowed in March and would evaluate the projected May 1 Shasta Reservoir storage at the time of the March forecast to determine whether a spring pulse would be allowed in April.
3. Reclamation anticipates that a projected May 1 storage greater than 4 MAF provides sufficient cold water pool management for Tier 1 and may release the spring pulse if it does not impact the ability to meet project objectives.
4. Reclamation could also determine, in coordination with the Upper Sacramento scheduling team, that while the reservoir is less than 4 MAF, there is sufficient water to do a pulse of up to 150 TAF.

5. The Upper Sacramento scheduling team could also determine that the benefits of a spring pulse flow do not outweigh the potential negative impacts on the system, in which case Reclamation would not release one.
6. Reclamation would also not make a spring pulse release if the release would cause Reclamation to drop into a Tier 4 Shasta summer cold water pool management (i.e., the additional flow releases would decrease cold water pool such that summer Shasta temperature management drops in Tier 4), would interfere with meeting performance objectives, or would interfere with the ability to meet other anticipated demands on the reservoir.
7. The Upper Sacramento Scheduling Team would determine the timing, duration, and frequency of the spring pulse within the 150 TAF volume. Wet hydrology downstream of Keswick Dam may meet the need for pulse flows without increased releases.

Pulse Flow Study Design

Scenario Design

A modeling exercise was performed to identify a target flow hypothesized to improve survival rates for outmigrating juvenile salmons, using 2013 – 2019 acoustic tagging data from the Sacramento River. This analysis included acoustically tagged fish that were known to have survived to the confluence of Sacramento River and Deer Creek and assessed the survival of these fish with respects to flow down to the confluence of the Sacramento River and the Feather River. Model selection with Cormack-Jolly-Seber (CJS) models for live recaptures was used to assess the shape of the relationship between flow and survival in this region. Results of the model selection indicates that a step function with a flow threshold of approximately 10,712 cfs as measured at the Wilkins Slough Gauge on the Sacramento River, best explains juvenile fish survival relationship to flow. Flows exceeding this threshold are estimated to provide a 2.7-fold survival increase over flows below this threshold (Michel et al. i*n press*).

Based on this modeling exercise, a series of pulse flow scenarios were developed. The parameters manipulated in the proposed pulse flow scenarios are:

- Pulse frequency: 1 or 2 pulses
- Release timing: April and May
- Pulse duration: 2, 3, or 4 days
- Pulse magnitude: >10,800 cfs at Wilkins Slough
- Pulse rate of change: Keswick ramping rates
- Quantity of water: up to 150 TAF

Reclamation's Proposed Action (PA) recommends a series of pulse flow scenarios. The parameters manipulated in the proposed pulse flow scenarios are:

- Pulse frequency: 1 or 2 pulses
- Release timing: April
- Pulse duration: 3 days
- Pulse magnitude: 10,000 cfs at Wilkins Slough when Wilkins Slough flows are < 9,000 cfs
- Pulse rate of change: Keswick ramping rates
- Quantity of water: up to 150 TAF

The USST will discuss each of the two suites of scenarios outlined above (PA compared with modeling exercise) and provide recommendations on pulse flow scenarios to use for the spring pulse action.

Scenario Evaluation Criteria

The impact of each pulse flow scenario on multiple key variables will be assessed to help with the scenario selection process. This includes the following variables:

Water Use

The water use associated with each pulse flow scenario is the amount of water released for the purpose of a pulse flow (above releases needed for other beneficial purposes). It will be estimated for each pulse scenario to help avoid negative impacts to diverters, which include their ability to install water diversion structures in a timely manner, operate their pumps, or make diversions at the time of the pulse.

Shasta reservoir cold water pool

Predictions of Shasta reservoir volume on May 1 through several criteria will be made to consider potential impact of the pulse(s) flow on cold water pool availability:

- Projected May 1 storage (> 4 MAF)
- Potential effects of temperature tiers (estimates of Chinook salmon egg mortality)

Also evaluated will be whether any Tier change will result from water temperature changes. Scenario selection for the Pulse Flow Operations Plan will be iterative during the later winter and early spring months (Figure 1).

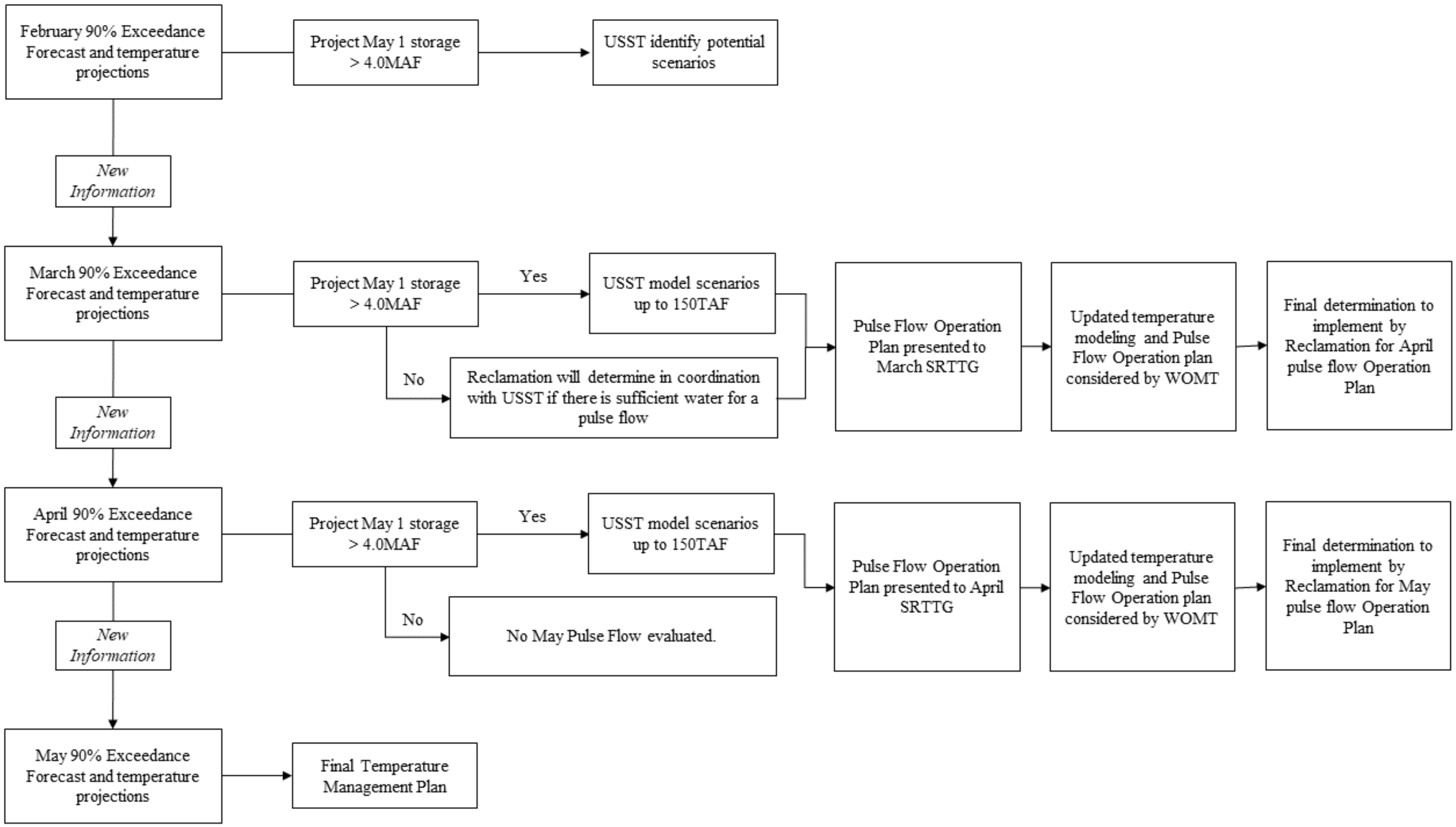


Figure 1. Iterative pulse flow scenario selection.

Winter-run Chinook salmon egg mortality
Temperature dependent mortality (TDM) projections on winter-run Chinook salmon eggs will be coordinated and performed by NMFS and Reclamation.

Outmigrating juvenile travel time and survival rates
A survival CJS model and SacPAS fish migration model will be used in conjunction for determining the potential impact of pulse flow scenarios on modeled outmigrating juvenile travel time and survival rates.

Pulse Flow Scenario Selection

Scenario selection for the Pulse Flow Operations Plan will be iterative during the later winter and early spring months and is separated into the following tasks, by month.

February
The USST will identify a subset of scenarios based on review of Reclamation's monthly operations forecasts. The 90% forecast will be used to evaluate the May 1 Shasta Reservoir storage.

March and April
The USST will use the Pulse Flow Study Plan to identify the pulse flow scenarios most likely to be achievable based on current conditions described by the monthly reservoir temperature measurements and modeling. A suite of potential pulse flow scenarios or single scenario will be presented at the monthly SRTTG meeting where the SRTTG will reserve time for discussion. The USST may also indicate that the benefits of a spring pulse flow do not outweigh the potential negative impacts on the system. Even if a spring pulse flow is not implemented, the USST will still develop a Pulse Flow Operation Plan explaining their reasoning and to ensure the Fish Monitoring Plan still is implemented.

The USST will take the following steps to decide which pulse flow(s), if any, to recommend to the SRTTG:

- In mid-March, Reclamation will provide draft Operational Outlooks suggesting end of April storage conditions (for an associated probability of hydrology) that can be used to estimate the relationship between future temperature performance and total Shasta reservoir storage (Figure 4-2 from the PA). If May 1 Shasta reservoir storage is forecast to be less than 4.0 MAF, Reclamation will determine, in coordination with the USST if there is enough water to do a pulse flow up to 150 TAF. If May 1 Shasta reservoir storage is forecast to be greater than 4.0 MAF on May 1, the USST may recommend scenario(s) to Reclamation up to 150 TAF released for the pulse flow.
- If the exceedance forecast supports a pulse flow, the USST will assess the impact of each selected pulse flow scenario on the scenario evaluation criteria (e.g., water use , juvenile spring-run Chinook salmon outmigration survival and travel time, Shasta Reservoir cold water pool storage, winter-run Chinook salmon egg temperature-dependent mortality).

Pulse flow scenarios selected according to criteria will be advanced while others will be discarded.

- The USST will provide this information to the SRTTG and make a final recommendation based on their review of predicted evaluation criteria for each of the scenarios.

In mid-April, a similar process as above will be used to evaluate possible May pulse flows.

Pulse Flow Evaluation

To inform the effectiveness of a pulse flow action, its effects on the environment and fish will be measured (Table 1a, Table 1b). Preliminary information will be reported in the Shasta Storage Rebuilding and Spring Pulse seasonal report completed annually at the end of June. Specifically, preliminary estimates of 1) changes in Chinook salmon survival, 2) changes in Chinook salmon movement rates, and 3) changes in abiotic river conditions, all as a result of the pulse flow action, will be available in late June. In lieu of information not available in time for June 2021 report (e.g., CWP information, TDM response), the 90% forecast for April and May can be included until data are formalized. Final information on the effectiveness of a pulse flow action will be available by September. Collection of environmental and fish parameters will be implemented annually regardless of a pulse flow action. Data collected in non-pulse actions years (e.g., dry years with no action, average years with natural pulse events, wet years with flood flows and no pulses) will inform baseline conditions for comparison with years with a pulse flow and used to determine if certain conditions/results are due to pulse actions or other environmental conditions.

Environmental changes related to the pulse flow

Data collected from the continuous monitoring of flows at Bend Bridge and Wilkins Slough will provide information on changes in flow and velocity through the Sacramento River before, during and after the pulse(s). Temperature data from CDEC locations along the Sacramento River will also allow the thermal changes related to the pulse(s) to be characterized. There is a gap in turbidity monitoring sites between Red Bluff Diversion Dam and the Feather River, and this information could be important for considering the biological responses of fish during the pulse (see potential improvement section below). The volume of water required from Shasta Reservoir as well as the volume of water diverted for agricultural purposes during the pulse will also be monitored, and the associated pulse flow water use will be determined.

Tagged fish travel time and survival rates

Juvenile salmons will be acoustically tagged and released in groups before, during and after the pulse(s) flow. The effect of the implemented pulse(s) on the travel time and survival of those tagged fish will be measured. See Attachment A: Fish Monitoring Plan for details.

Population mobilization metrics
Fish catch data from rotary screw traps (RSTs) at key monitoring locations along the Sacramento River (e.g., Red Bluff Diversion Dam, Knights Landing, and as available data from trawl locations of Sherwood Harbor on the Sacramento River and Chipps Island) can be used to monitor non-tagged fish metrics such as passage timing, size distribution, and relative abundance. In conjunction with data from telemetry fish, RST data will provide insight into population mobilization. Hatchery releases of coded wire tagged (CWT) fish concurrent to pulse flow releases can also be used to assess survival and movement of larger juvenile groups as well as adult relative survival to spawning ground. Sentinel fish will eliminate, or decrease, the need to sample wild fish if some sampling still occurs for verification of impacts to the population in question.

Shasta Reservoir cold water pool
Measurement of Shasta Reservoir total storage volume and temperature in the summer following the spring pulse will inform the evaluation of impacts of the pulse flow on cold water pool availability and tier change.

Winter-run Chinook salmon egg mortality
Temperature dependent mortality (TDM) projections on winter-run Chinook salmon eggs will be performed after the pulse(s) occurred. Winter-run Chinook salmon redds monitoring will also inform potential pulse flow impact of redd dewatering.

Table 1a. Collected environmental parameters measured at specific locations to measure the effect of a spring pulse flow.

Location	Flow	Velocity	Turbidity	Dissolved Oxygen	Water Temperature
Keswick	X	-	X	X	X
Sacramento River upstream of Hwy 44	-	-	-	-	X
Sacramento River above Clear Creek	-	-	X	X	X
Sacramento River at Balls Ferry Bridge	-	-	X	X	X
Sacramento River at Jellys Ferry	-	-	X	X	X
Sacramento River at Bend Bridge	X	-	X	X	X
Sacramento River at Red Bluff Diversion Dam	-	-	X	X	X
GCID (side channel, near RST)	-	-	X	-	X
Sacramento River below Wilkins Slough	X	-	-	-	X
Sacramento River at Knights Landing	-	-	-	-	-
Sacramento River at Verona	X	-	X	-	X
I80 / I50 Bridge	-	-	-	-	-
Sacramento Trawls	-	-	-	-	-
Chipps Island	-	-	-	-	-

Table 1b. Collected fish parameters measured at specific locations to measure the effect of a spring pulse flow.

Location	Fish Passage Counts (RST)	Fish Presence Fish Survival (telemetry receivers)
Red Bluff Diversion Dam	X	X
Mill/Deer Creek	X (partial)	-
GCID	X	X
Wilkins Slough	-	-
Knights Landing	X	X
Verona	-	X
I80 / I50 Bridge	-	X
Sacramento Trawls	X	X
Chipps Island	X	X

Potential Improvements

Additional monitoring could be considered to improve the assessment of the hypothesis and pulse flow success for Central Valley Chinook salmon populations.

Additional monitoring

- Turbidity loggers could be deployed at the confluence of the Sacramento River at Deer Creek and/or Wilkins Slough to measure the magnitude and the extent of turbidity changes that could be resulting from the pulse(s).
- Monitoring of changes in biotic stressors such as pathogen load and predator abundance, throughout the Sacramento River, before, during, and after the pulse(s) could provide information on how those additional stressors may influence the survival of outmigrating juvenile salmons across different hydrological conditions. Sentinel fish will eliminate, or decrease, the need to sample wild fish if some sampling still occurs for verification of impacts to the population in question.
- Monitoring of additional benefits from projects implemented with the period of the Study Plan (e.g., large-scale habitat projects) attempting to separate benefits of other projects from benefits accredited to pulse actions.

Fish identification

The length at date (LAD) criteria is commonly used to assign run ID to Central Valley Chinook salmons caught at the RSTs. However, limitations in accurate run assignment have been identified and the LAD becomes less accurate in the lower Sacramento River and Delta. Therefore, to improve salmon identification and the population mobilization metric accuracy, a method combining genetic identification and a probabilistic LAD (pLAD) model could be considered. With the potential for each method to continually inform the other, this synergy may further improve confidence in run ID.

Monitoring Sites Evaluations

Currently operating individual monitoring sites should be evaluated to assess if data collected at each site (catch, telemetry detections, etc.) are robust enough to evaluate if the site is valuable to answer questions on how the pulse flow will impact winter-run Chinook salmon and spring-run Chinook salmon. If necessary, additional monitoring sites should be considered to supplement data.

Project Schedule

2021

- Pulse Flow Study Plan draft (1/19/2021)
- Pulse Flow Study Plan finalized (2/4/2021)
- February 2021 through May 2021 (Figure 1)
  - Pulse Flow Operation Plan
  - Identify achievable pulse flow scenarios based on current conditions
  - Narrow to subset of pulse flow scenarios
  - Monitoring efforts and Final Monitoring Plan and Costs
  - Draft Operational Outlooks (Reclamation to USST)
  - Final Operation Plan (USST to Reclamation, applicable for April pulse flow)
  - Draft Temperature Management Plan (Reclamation to SRTTG)
- May 2021
  - Final Temperature Management Plan (Reclamation)
- June 2021
  - Pulse flow results/consequences reported in Shasta Storage Rebuilding and Spring Pulse Seasonal Report

Sources

Michel, C. J., Notch, J. J., Cordoleani, F., Ammann, A. J., & Danner, E. M. Ecological nonlinearities inform the design of functional flows for imperiled fish in a highly modified river. *In press*. Ecosphere.

Notch, J. J., McHuron, A. S., Michel, C. J., Cordoleani, F., Johnson, M., Henderson, M. J., & Ammann, A. J. (2020). Outmigration survival of wild Chinook salmon smolts through the Sacramento River during historic drought and high water conditions. *Environmental Biology of Fishes*, 1-16.

Attachment A: Fish Monitoring Plan

Measuring Effectiveness of Pulse Flow at Increasing Salmonid Survival using Telemetry
The target populations for this study are ESA-listed wild spring-run Chinook salmon. We propose to acoustic-tag outmigrating smolts from these populations to measure survival under non pulse action and pulse-flow action river conditions. Because capture of taggable sized wild spring-run smolts is unpredictable and cannot solely be relied on to provide sufficient sample sizes for appropriate statistical power we are proposing to use Coleman National Fish Hatchery (CNFH) fall-run Chinook salmon smolts as surrogates for this study. Hatchery fall-run Chinook salmon smolts are similar in size to the wild smolts that out-migrate from Mill and Deer Creek in the spring, have overlapping outmigration timing, and migrate through the same migration corridor. The advantage of using hatchery fish is they are readily available in large numbers allowing for statistically appropriate release group sizes.

To assess survival of wild Chinook salmon smolts in addition to CNFH smolts, the Red Bluff Diversion Dam (RBDD) facility can be used to capture and tag relatively large groups of wild spring-run Chinook salmon and fall-run Chinook salmon smolts. There are 3-4 rotary screw traps (RSTs) checked daily at RBDD and out-migrating smolts could be caught and held for 1-2 days prior to tagging in order to obtain a larger sample size.

To estimate a statistically appropriate release group size, a power analysis was performed. Capture-recapture data was simulated given different levels of modeled survival gains from the pulse flow and given different sample sizes: a 50% increase in survival, a 75% increase in survival, a 100% increase in survival, and the 250% increase as predicted by the threshold analysis. These simulated capture-recapture datasets were then analyzed in a CJS-model framework using the Rmark package in R. The above and below threshold survival estimates for the study region were then compared for each model run to determine statistical difference (defined as non-overlapping 95% confidence intervals). Overall, 300 simulated datasets were generated for each survival gain percentage and for various sample sizes. To obtain a 95% or higher chance of accurately detecting a survival gain from the pulse flow, a minimum of 600 tagged fish per release group are needed for the 50% survival improvement scenario (Table 1). At the 75% survival improvement scenario, a minimum of 300 tagged fish per release group are needed to have a higher than 95% chance of accurately detecting a survival gain. Finally, for the 100% and 250% survival improvement scenarios, a release group size of 200 tagged fish is sufficient.

*Table 1. Percent of models detecting significant differences between the above and below threshold release groups (out of 300 model runs per sample size/survival improvement scenario). A detection probability of 95% was applied to all receiver locations for the simulated data. Grayed numbers represent scenarios in which less than 95% of models showed significant differences. * A 250% improvement is similar to what is predicted by the threshold analysis.*

Sample size (per release group)	50% improvement in survival	75% improvement	100% improvement	250% improvement *
200	34.0	79.3	95.7	100.0
300	60.3	95.0	100.0	100.0
400	74.7	99.7	100.0	100.0
500	83.7	100.0	100.0	100.0
600	94.3	100.0	100.0	100.0

Ideally, a release group size of 600 would allow the detection of even modest survival gains (such as a 50% increase). However, the return on investment is much better for a release group size of 300, allowing for the detection 75%, 100% and 250% increases in survival. We therefore propose tagging 300 fish per release group, for a total of 900 hatchery fall-run Chinook salmon smolts (three releases of 300 fish each = 900 fish) with JSATS tags. An additional 50 fish should be held at the hatchery and tagged for a tag retention study. As a minimum release group size of 200 fish is required to at least detect a 100% increase in survival, release group sizes should not be any lower than this minimum.

The fish release schedule is described below:

- Tag and release three groups of 300 fish:
    - Group 1 the week before, but no later than 4 days before, the pulse flow
    - Group 2 during the pulse flow (ideally the first day of the pulse)
    - Group 3 once flows have dropped back to pre-pulse flows (ideally 1-2 weeks after the pulse)
- Fish will be released at Red Bluff Diversion Dam and tracked during outmigration through the Sacramento River.

Fish will be tracked using a combination of existing array of JSATS receivers and additional receivers deployed at locations of interest and transitional reaches (e.g., release site, Butte City, Knights Landing, Feather River confluence, City of Sacramento, Benicia Bridge). Use of additional receiver sites established as part of agency collaborations may increase spatial resolution of survival data.

Standard surgical approaches, trained taggers, tag code coordination, and open data accessibility will be facilitated through the Interagency Telemetry Advisory Group (ITAG). At least one tag battery study will occur annually to support these releases and estimating battery life effects on survival estimates.

Proposed Analysis of Telemetry Data

Initially, survival estimated per release group will be compared to evaluate if the pulse flow release group has higher survival than other release groups. To further evaluate the effectiveness of the pulse flow in improving outmigration survival, a similar survival modeling effort as described in Henderson et al. (2019) will be used. Specifically, numerous spatial and/or temporal environmental covariates, as well as fish-specific covariates, will be collected to determine covariate influence on observed survival data. This will increase ability to evaluate the direct and indirect mechanisms increasing survival, which are related to flow, and mechanisms behind the flow-survival relationship. For example, increased turbidity and increased water velocities during the storm events have been found to increase smolt survival, but most studies are not able to decouple the effects of these variables. It is presumed that a managed pulse flow will likely increase water velocities to mimic conditions during storm events, but likely with a more muted response in turbidity than as seen during storm events (Figure 1). That is because in the Sacramento River, much of the storm-generated turbidity occurs due to increased inputs from tributaries, while during a managed pulse flow, these tributaries would remain unchanged. To this end, turbidity sensors should be deployed at key locations in the study region to supplement the scarce gauges that collect turbidity data.

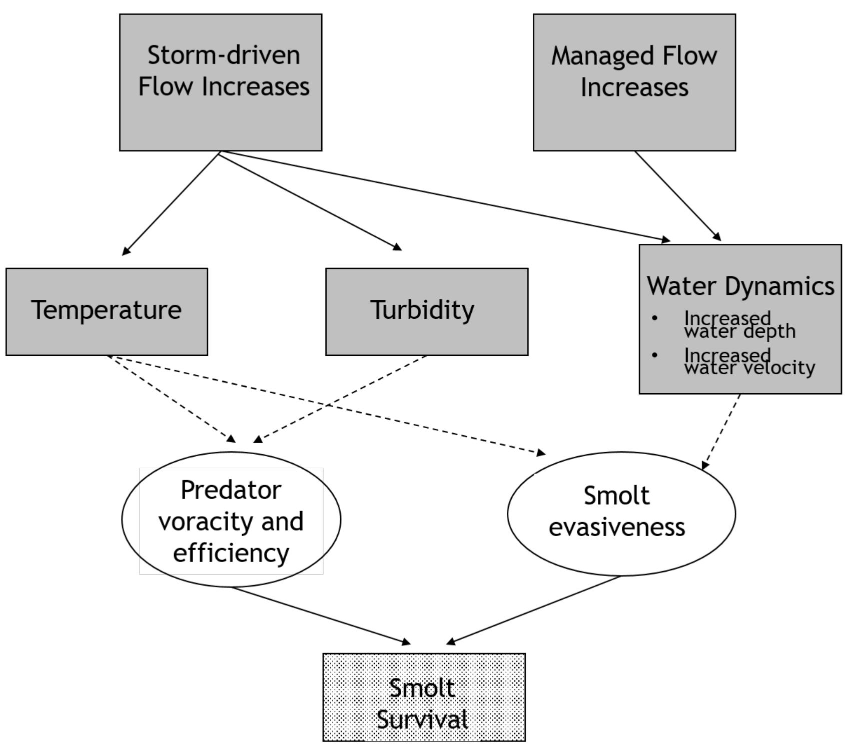


Figure 1. Hypothesized conceptual model for how increases in flow lead to increases in survival. Solid lines represent known relationships, while dashed lines represent hypothesized mechanisms.

Real-time data analytics and download data will be accessible via the Enhanced Acoustic Telemetry for Salmon Monitoring site for each group (https://calfishtrack.github.io/real-time/index.html), giving researchers the ability to have a preliminary assessment of the pulse flow's success in real-time. Final analyses will be conducted through collaborations with funded synthesis and analysis tasks as part of an existing USBR-UCSC/SWFSC Agreements.

References

Henderson, M. J., I. S. Iglesias, C. J. Michel, A. J. Ammann, and D. D. Huff. 2019. Estimating spatial–temporal differences in Chinook salmon outmigration survival with habitat- and predation-related covariates. Canadian Journal of Fisheries and Aquatic Sciences 76:1549-1561.