DRAFT 1/2/19
Sacramento River Spring Pulse Flow Proposal
To Evaluate Potential Benefits for CV Spring and Fall-run Chinook Salmon Out-migration Survival

The National Marine Fisheries Service (NMFS), California Department of Fish and Wildlife (CDFW), and US Bureau of Reclamation (BOR) have designed a multiyear study to evaluate the potential survival benefits for juvenile spring and fall-run Chinook salmon during a managed spring pulse flow on the Sacramento River. Results of the multiyear study proposal will provide technical assistance towards developing and implementing future water management actions , among other salmon restoration actions, in the Sacramento River.

<u>Investigators</u>

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<u>Biological Objective</u>:

The biological objective is to improve survival rates of wild and hatchery juvenile spring- and fall-run Chinook salmon smolts through the Sacramento River using a managed pulse flow during the spring out-migration period.

<u>Biological Rationale:</u>

Existing data from previous telemetry studies (Michel et al. 2015, Notch 2017) show that increases in survival in the upper and lower Sacramento River have been strongly correlated with increases in flow resulting from tributary accretions. Other variables (mentioned below and yet to be evaluated) may also correlate with survival. These increases in flow during past telemetry studies were triggered by storm events resulting in increased outflow from Sacramento River tributaries. We hope to determine if managed pulse flow events (by temporarily increasing dam releases and/or decreasing in stream diversions, as a surrogate for tributary accretions) can still impart measurable survival benefits to outmigrating salmon, in particular the imperiled wild populations of spring-run Chinook salmon.

<u>Scientific Justification</u>

We have strong evidence that:

(1) Among variables examined in recent studies, higher flows created by tributary accretions resulted in higher survival rates of out-migrating Chinook salmon smolts in the Sacramento River. This evidence comes from two separate studies, one on tagged

hatchery late fall-run smolts from 2007 to 2011 (Michel et al. 2015, Henderson et al. 2018), and one on tagged wild Mill Creek wild spring-run smolts from 2013 to 2017 (Notch 2017). However, other variables not examined in those studies may also play a significant role in survival (e.g., turbidity, predator densities, seasonal water temperature as it may affect predator and salmon metabolisms, flood-plain inundation, flow through flood bypasses, degree of smoltification).

(2) Wild spring-run salmon smolts outmigrate during a period when flows in the Sacramento River are artificially low due to water management practices, and this has likely resulted in low outmigration survival - which ultimately may be a considerable component to the population's recent collapse.

Hatchery late fall-run smolt tagging study (2007-2011)

The SWFSC has been using the existing late-fall run Chinook acoustic tagging data to look at relationships between different environmental factors and survival using Cormack-Jolly-Seber survival models (Henderson et al. 2018). However, that study was conducted during December and January whereas the proposed study proposal here would be conducted during May.[1] They tested models that incorporated numerous spatial and/or temporal environmental covariates, as well as fish-specific covariates (see Table 1). Of these variables, flow during outmigration had the strongest relationship with survival. They then used the coefficient estimate for the effect of flow to make a covariate prediction plot based on 95% of the range of daily flow values at Bend Bridge during the study period (175 to 450 cms or 6,180 to 15,900 cfs, Fig. 1). The relationship indicates that there are diminishing returns in survival as flow get higher and near the asymptote of perfect survival (i.e. 1). There does seem to be a point around 350 cubic meters per second (cms - ~12,000 cfs) where the "returns" start to considerably diminish.

[1] This may be an important variable because, for example, there are approximately 4.5 hours more hours at night on January 1 compared to May 1. Assuming most salmon migrate at night and survival is higher at night because of reduced predation, outmigrant survival during the winter could be higher during the winter than spring.

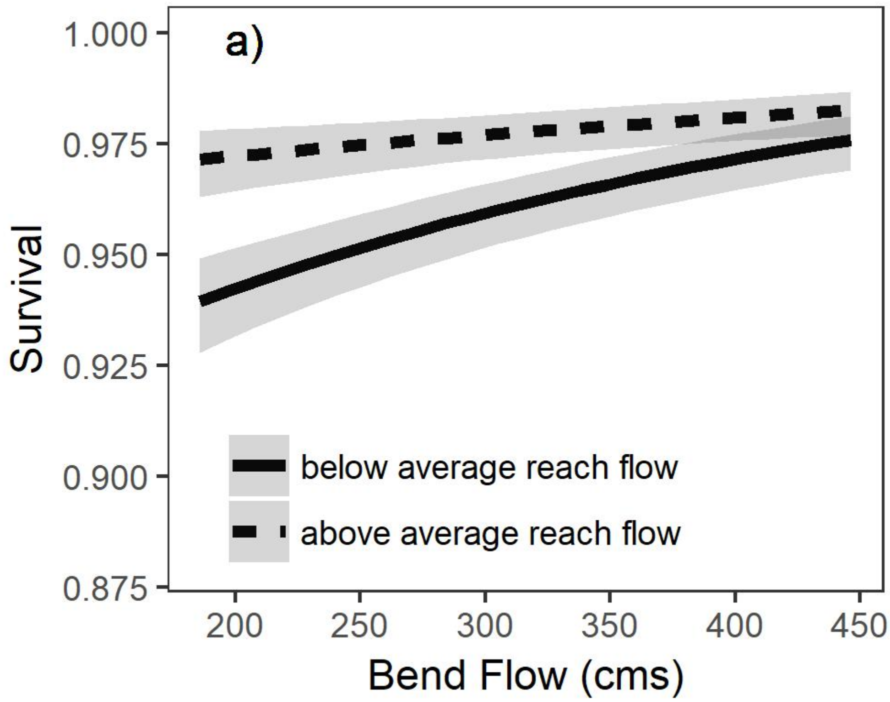

Figure 1: Flow versus survival plot showing the effect of flow on the apparent survival rate (per 10 km reach). The grey shaded region represent the 95% confidence interval. Below average reach flow (solid line) represents the relationship between flow and survival during a low-flow year, while above average reach flow (dashed line) represents the same relationship during a high-flow year. From Henderson et al. (2018).

An important caveat for that study should be mentioned. The one study year when the highest survival was evident was 2010-2011 which exhibited substantial tributary accretions. Shortly after the first release of tagged salmon in mid-December 2010, the accretions were so high that flow over the Tisdale and Fremont flood control weirs occurred. Sacramento River flows into the flood bypasses occurred continuously for slightly over a two-week period. An unknown number of tagged salmon may have used this migratory corridor and would not have been detected by the main stem acoustic receivers. This circumstance may have, in part, resulted in increased salmon survival in the 2010-2011 study.

Table 1: A description of the covariates included in the Henderson et al. (2018) mark recapture modeling efforts.

Category	Covariate	Range	Definition	Hypothesized relationship with survival
Individual	Fish Length[1]	135 - 204 mm	Fork length	Larger fish may exceed gape width of predators
	Fish Condition[1]	0.59 - 1.32	Fulton's K	Increased condition improves predator escape capability
	Transit speed[2]	0.02 - 8.25 km h^{-1}	Reach specific transit speed	Faster moving fish have less exposure to predators
Release group	Batch release[2]	Binary	Tagged fish released concurrently with large hatchery releases.	Predator swamping
	Release reach[1]	Binary	Difference in survival between newly released fish and those released upstream.	Increased susceptibility to predation due to handling stress
	Annual flow[3]	179 - 499 cms	Mean flow measured at Bend Bridge throughout outmigration (December-March).	Increased flows produce more habitat and predator refugia throughout the river
Reach specific	Sinuosity[4]	1.04 - 2.74	River distance divided by Euclidean distance.	More natural habitats have more predator refugia
	Diversion density[5]	0 - 1.05 num km^{-1}	Number of diversions per reach length.	Increased predator densities near diversions
	Adjacent cover density[6]	0.2 - 0.76 %	Percent of non-armored river bank with adjacent natural woody vegetation.	Increased cover produces more predator refugia
	Off-channel habitat density[6]	0 - 1.62 %	Off-channel habitat within 50 m of river expressed as percentage of river area	Increased off-channel habitat produces more predator refugia
Time varying	Temperature[7]	6.2 - 12.9 °C	Mean water temperature per reach	Increased temperatures results in increased predation due to higher metabolic demands of predators
	Reach flow[7]	215 – 447 cms	Mean water flow per reach	Higher flows within a reach will produce more habitat and predator refugia within that reach
	Annual reach flow[7]	129 – 902 cms	Mean water flow per reach and year	Higher intra-annual flows (due to precipitation or dam releases) decreases predation due to increased turbidity and increased predator refugia.

[1]Measured during tagging and release; [2]Observed travel times and mixed effects model estimates; [3]California Water Data Library; [4]National Hydrography Dataset; [5]Passage Assessment Database - verified by field survey; [6]Department of Water Resources; [7]River Assessment for Forecasting Temperature (RAFT) model

Mill Creek spring-run smolt survival study from 2013 to 2017

According to five years (2013-2017) of survival data from JSATS acoustic tagged smolts from Mill Creek, survival in the upper and lower Sacramento River has been strongly correlated with flow, with particularly poor survival during low flows in these regions (Figure 2). The impact of other environmental variables, such as water temperature, was also studied, however flow was the only significant factor found to influence Mill Creek spring-run smolts out-migration survival (Notch 2017).

Its hypothized that low flows in the Sacramento River often result in increased predation rates on juvenile salmon, as predators have improved capture efficiency in clear water and juvenile salmon have less habitat as flows become constrained. High predation rates were observed in the Sacramento River during periods of low flow (2013-2016) on wild salmon smolts which were tagged and released in Mill Creek.

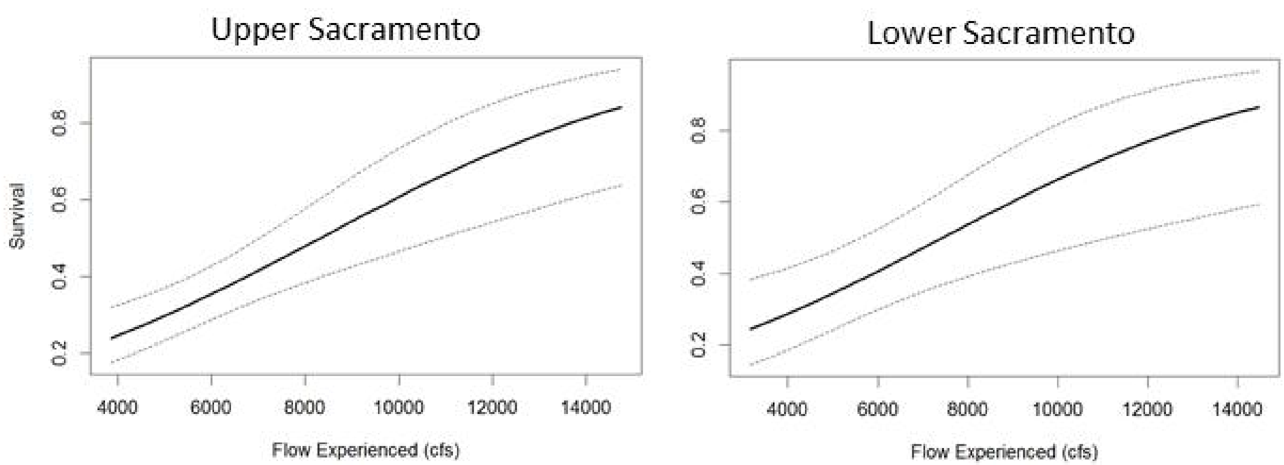

Figure 2. Predicted survival rates of wild spring-run salmon smolts through the upper and lower Sacramento River across a range of flow values experienced between 2013-2017. The range of flow values tagged smolts experienced during the five year study were plotted against predicted survival rates, estimated using a Cormack-Jolly-Seber mark recapture model, and using Sacramento River flow as a covariate. The upper Sacramento River region is designated from the confluence of Mill Creek downstream to Butte City, and the lower Sacramento River region is designated from Butte City downstream to Knights Landing.

Flow conditions in the Sacramento River during spring-run smolt outmigration

According to 15 years of rotary screw trap data (RST; 1995-2010), smolt-sized out-migraants from Mill Creek are observed beginning in mid-April and extends through May. These fish are considered spring run Chinook salmon based on the length-at-date model (river model, Fisher 1992). Some recent genetic analyses done from acoustically tagged fish suggest these fish are not only spring run Chinook salmon, but also fall run Chinook salmon (See Table 2). The movement of smolts from Mill Creek is triggered by spring storm events or snowmelt events caused by warming air temperatures. Smolt out-migration timing from Deer Creek follows a similar pattern to Mill Creek, but is shifted a couple weeks earlier due to the lower elevation at which the juveniles are spawned and rear compared to Mill Creek (Figure 3). Peak outmigration typically occurs during the first week of May for Deer Creek fish, and the third week of May for Mill Creek fish.

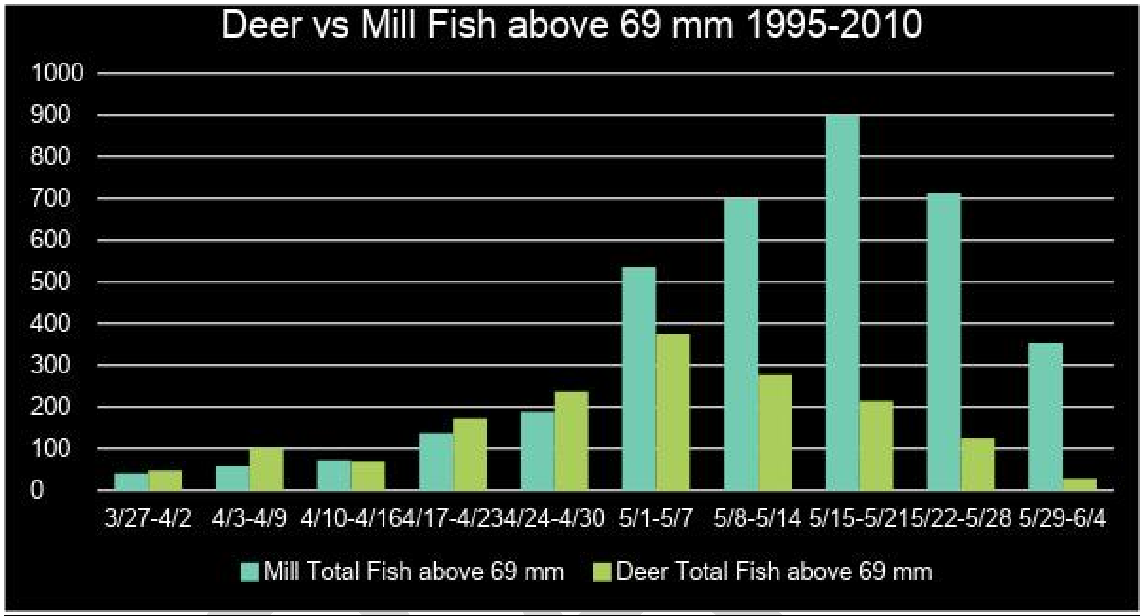

Figure 3. Total number of spring-run sized salmon smolts > 69mm (approximately representing "smolt" sized fish) captured in Mill and Deer Creek RSTs during spring months between 1995-2010.

While Deer and Mill Creek have natural, unmodified hydrographs, the hydrograph of the Sacramento River, into which these tributaries flow, is mostly unnatural and managed to store water in Shasta Reservoir for summer agricultural deliveries, maintaining Delta water quality, and Sacramento River temperature management. Therefore, there is often a mismatch between the ideal outmigration conditions the smolts experience as they leave their natal creeks and the poor outmigration conditions they encounter as the enter the mainstem Sacramento River. In typical years, once these fish make it out of Mill and Deer Creeks, early spring flows in the Sacramento River can vary depending on the winter snowpack and the frequency of spring storms. Generally after April 15th, water deliveries for agriculture increase and flows from Keswick Reservoir increase as a result. However, while flows in the upper Sacramento River see increasing flows, river levels downstream of Glenn Colusa Irrigation District (GCID) and the numerous other large diversions along the Sacramento River are greatly reduced. This reduction in flow increases progressively downstream, and the Sacramento River reaches its lowest flows downstream of Tisdale in the vicinity of the Wilkins Slough gauge. The figures below represent the measured flows in the Sacramento River at various gauging stations, beginning upstream at

Keswick Dam and ending downstream at Wilkins Slough during the spring and fall-run smolt outmigration period of 2012-2017 (fig. 4). Importantly, the lowest flows of the spring season at Wilkins Slough often co-occurs with peak wild spring-run smolt outmigration (see years 2012-2016 in fig. 4).

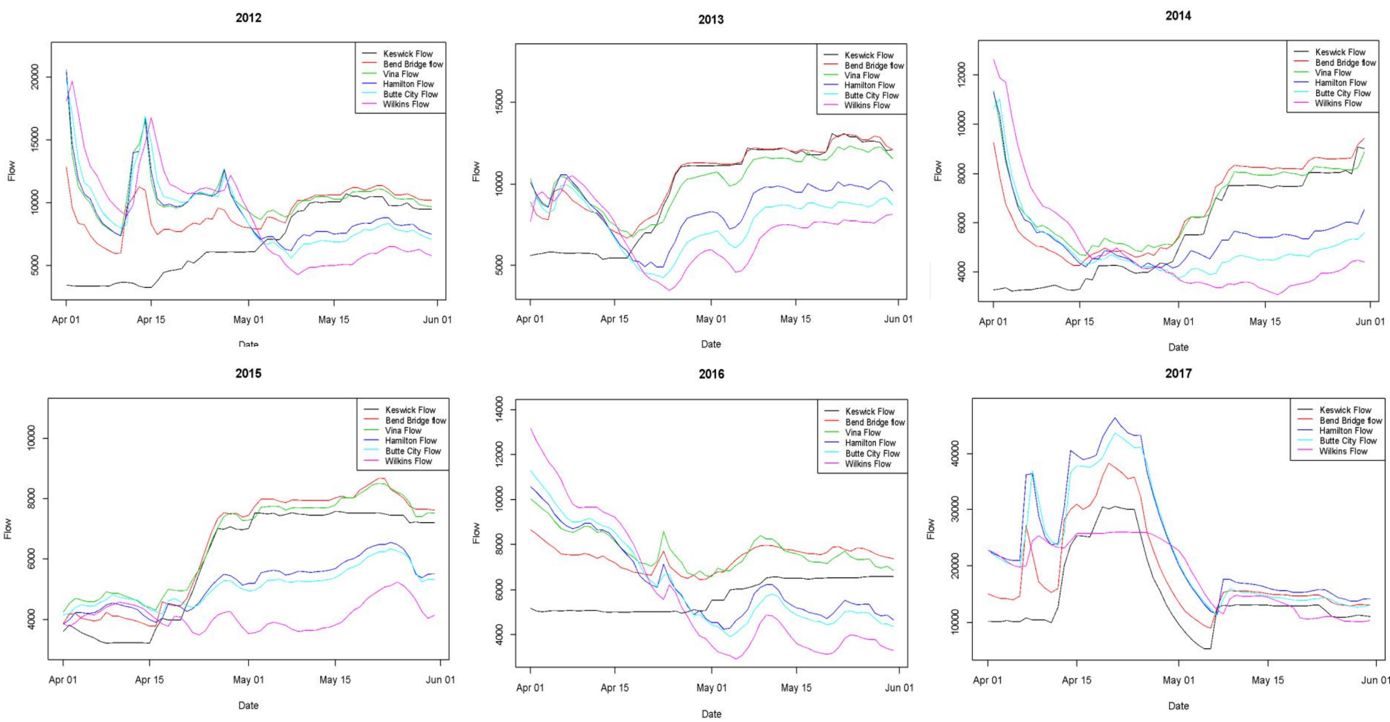

Figure 4. Hydrographs of the Sacramento River from April 1st to June 1st at six different gauges interspersed along the salmon smolt outmigration corridor.

Study Design Background

The concept of the spring pulse flow is therefore to coincide peak smolt out-migration from Mill and Deer Creek with a short-duration pulse of water through the Sacramento River in order to increase survival rates through the mainstem Sacramento River.

Determination of a target flow threshold for pulse flow using existing telemetry data

In order to objectively identify an appropriate target flow threshold that may improve survival rates for out-migrating Chinook salmon smolts, a modeling exercise was performed by the SWFSC. Using five years of data from JSATS acoustic tagged smolts from various late-fall, winter, spring and fall-run populations from the Sacramento River and its tributaries (see Table 2), multiple Cormack-Jolly-Seber survival models were created to test different potential flow thresholds at 200 cfs increments between 4,000 and 22,000 cfs. This exercise was repeated for flows as measured at 4 different gauges on the Sacramento River, Hamilton City, Butte City, Colusa, and Wilkins Slough (27, 81, 117 and 157 river kilometers downstream of the Deer Creek confluence, respectively).

Table 2. Wild and hatchery tagged smolt groups included in analysis from 2013 to 2018.

Population	Origin	Year	Release Dates	N	Genetic Origin
Mill Creek	Wild	2013	Mid-April to mid-May	48	68% Central Valley fall-run 21% Central Valley spring-run
Mill Creek	Wild	2014	Mid-April to mid-May	26	14% Central Valley fall-run 64% Central Valley spring-run
Mill Creek	Wild	2015	Mid-April to mid-May	105	29% Central Valley fall-run 51% Central Valley spring-run
Mill Creek	Wild	2016	Early-May to late-May	31	unknown
Mill Creek	Wild	2017	Mid-April to late-April	23	100% Central Valley fall-run
Mill Creek	Wild	2018	Early-May to late-May	3	unknown
Deer Creek	Wild	2017	Mid-May to late-May	1	unknown
Deer Creek	Wild	2018	Early-May to mid-May	12	unknown
Coleman	Hatchery	2013	Mid-April	274	100% Central Valley fall-run
Coleman	Hatchery	2016	Early-April to late-April	526	100% Central Valley fall-run
Coleman	Hatchery	2017	Early-April to late-April	351	100% Central Valley fall-run

Battle Creek	Wild	2014	Mid-April to early-May	41	15% Central Valley fall-run 60% Central Valley spring-run
RBDD	Unknown	2017	June 6th	28	100% Central Valley fall-run
RBDD	Unknown	2018	Early-May to early-June	165	Unknown
Livingston Stone	Hatchery	2013	February 7th	118	100% Sacramento winter-run
Livingston Stone	Hatchery	2014	February 10th	287	100% Sacramento winter-run
Livingston Stone	Hatchery	2015	Early-February	357	100% Sacramento winter-run
Livingston Stone	Hatchery	2016	Mid-February	529	100% Sacramento winter-run
Livingston Stone	Hatchery	2017	February 2nd	148	100% Sacramento winter-run
Livingston Stone	Hatchery	2018	Early-March	339	100% Sacramento winter-run
Coleman	Hatchery	2018	Late-Dec to early-Jan	423	100% Central Valley late-fall-run
TOTAL		**2013-2018**	**Early-February to early-June**	**3835**	

To determine if a flow threshold explains the survival data, we first needed to determine the flows experienced by each individual fish. To do this, we needed to estimate the flow experience of fish when they were transiting the region of interest, i.e., the mainstem Sacramento River between the spring-run Chinook occupied Deer and Mill Creeks and the confluence with the Feather River. We therefore only used fish that were known to have made it to the beginning of the region of interest from their release point, and for which we had arrival time information (for a total of 3,835 fish, Table 2). We assumed that it took approximately 5 days for a fish to transit this region, and therefore, averaged the flows from each of the four flow gauges over the 5 days following the arrival of each fish to the beginning of the region.

Each survival model assigns individual fish to one of two groups; a below threshold group or an above threshold group, based on the flow threshold for that particular model. Take for example a flow threshold of 10,000 cfs. If the 5-day mean flow recorded for a fish was below the 10,000 cfs threshold, the fish was assigned to the below threshold group, and if the 5-day mean flow was above 10,000 cfs, the fish was assigned to the above threshold group. Each survival model was then run using the Rmark package in R and compared using model selection with AICc scores (see Table 3). Threshold models were also compared to survival models that allowed flow to have a linear relationship with survival rather than a binary threshold relationship. Finally, threshold models were also compared to a "full model" – allowing full spatial and temporal variability to the survival data.

The top survival model by a considerable margin was the model that set the flow threshold at 9,100 cfs at Wilkins Slough gauge (Table 3). In other words, this analysis suggests a significant increase in smolt survival is observed when flows at Wilkins Slough are above 9,100 cfs during the smolt out-migration period. Furthermore, the top 10 models in the exercise were all using 5-day mean flows as measured at the Wilkins Slough Gauge, suggesting that a large portion of the survival gains due to higher 5-day mean flows occur in the lower portions of the study region. These same top 10 models also suggest that a lesser survival threshold also exists when flows are above 4,200 cfs at Wilkins Slough (Figure 5). The top 10 models are also much better supported than any linear flow relationship model, suggesting that the relationship is truly of a threshold nature. Finally, the top 10 models were also much better supported than the "full model", suggesting that flow explains a large portion of the spatial and temporal variability in survival.

Table 3. Model selection results. Npar = number of model parameters. AICc = Akaike's information criterion corrected for small sample size. ΔAICc = difference in AICc score between the given model and the most parsimonious model. Models are ordered from lowest to highest AICc. Lower AICc score indicate greater relative model parsimony. The model with survival rate that included a 9,100 cfs flow threshold at Wilkins Slough is strongly supported as the best model (ΔAICc of second best model much larger than 4). Rows with […] indicate unreported models in between, this was done to show important models that had poor support.

Flow Gauge	Survival model	npar	AICc	ΔAICc
Wilkins	Threshold at 9100	37	9918.6	0.0
Wilkins	Threshold at 4200	37	9931.3	12.7
Wilkins	Threshold at 8600	37	9934.5	15.8
Wilkins	Threshold at 4300	37	9934.8	16.2
Wilkins	Threshold at 8700	37	9935.3	16.7
Wilkins	Threshold at 9000	37	9937.7	19.0
Wilkins	Threshold at 8900	37	9937.7	19.0
Wilkins	Threshold at 4100	37	9942.2	23.5
Wilkins	Threshold at 8100	37	9950.4	31.8
Wilkins	Threshold at 4400	37	9954.2	35.5
Colusa	Threshold at 8400	37	9956.1	37.4
…	…	…	…	…
Butte City	Threshold at 7400	37	9979.1	60.4
…	…	…	…	…
Hamilton City	Threshold at 5600	37	10059.8	141.1

…	…	…	…	…
Wilkins	Linear relationship w/ flow	36	10087.0	168.3
…	…	…	…	…
Colusa	Linear relationship w/ flow	36	10141.1	222.4
…	…	…	…	…
	Reach x Year (full) model	60	10146.5	227.8
…	…	…	…	…
Butte City	Linear relationship w/ flow	36	10147.4	228.8
…	…	…	…	…
Hamilton City	Linear relationship w/ flow	36	10162.5	243.9

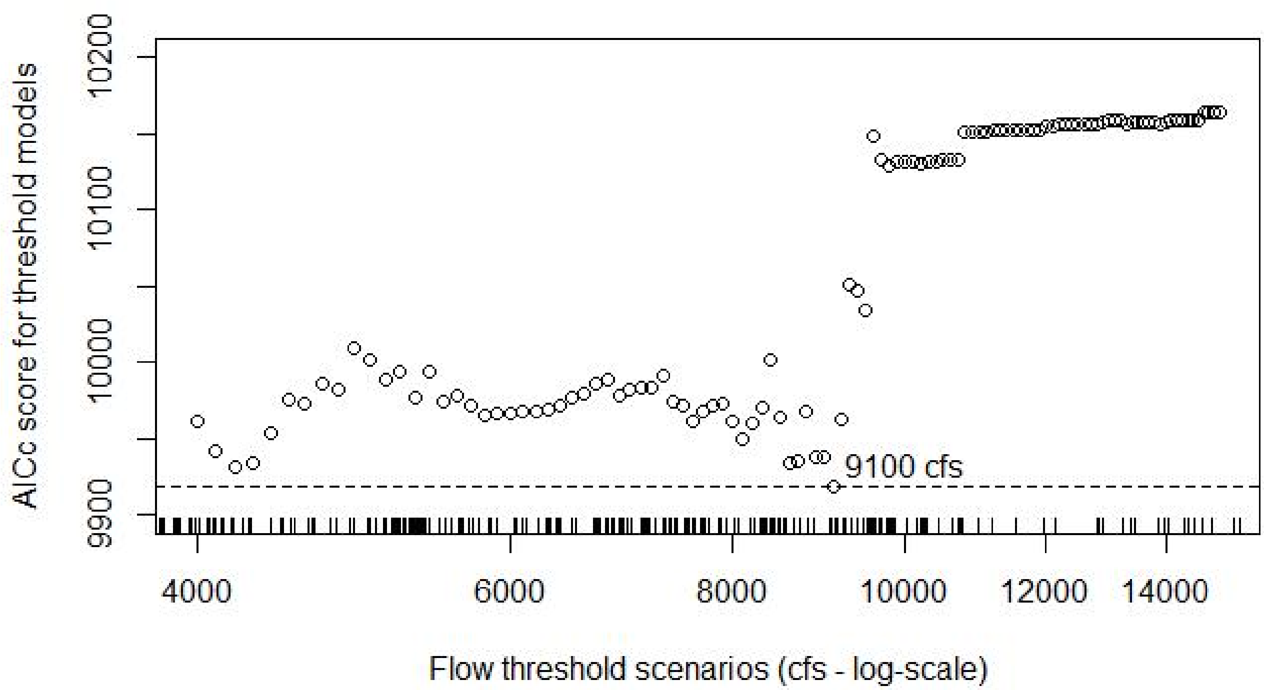

Figure 5. AICc scores for all the Wilkins Slough gauge threshold models. The best model is for the 9,100 cfs threshold, as indicated by the horizontal dotted line (lower AICc scores signify better model fit). A lesser threshold appears to be centered around 4,200 cfs. The black vertical bars at the bottom of the figure represent the 5-day mean flow values of the fish used in the analysis.

Parameter estimates for the Wilkins Slough threshold models were then used to predict above and below threshold survival through the region of interest based on the different threshold flow values (Figure 6). At the best supported threshold, 9,100 cfs, the below threshold group experiences survival of 0.22, while the above group experiences survival of 0.5, a 2.3-fold increase in survival.

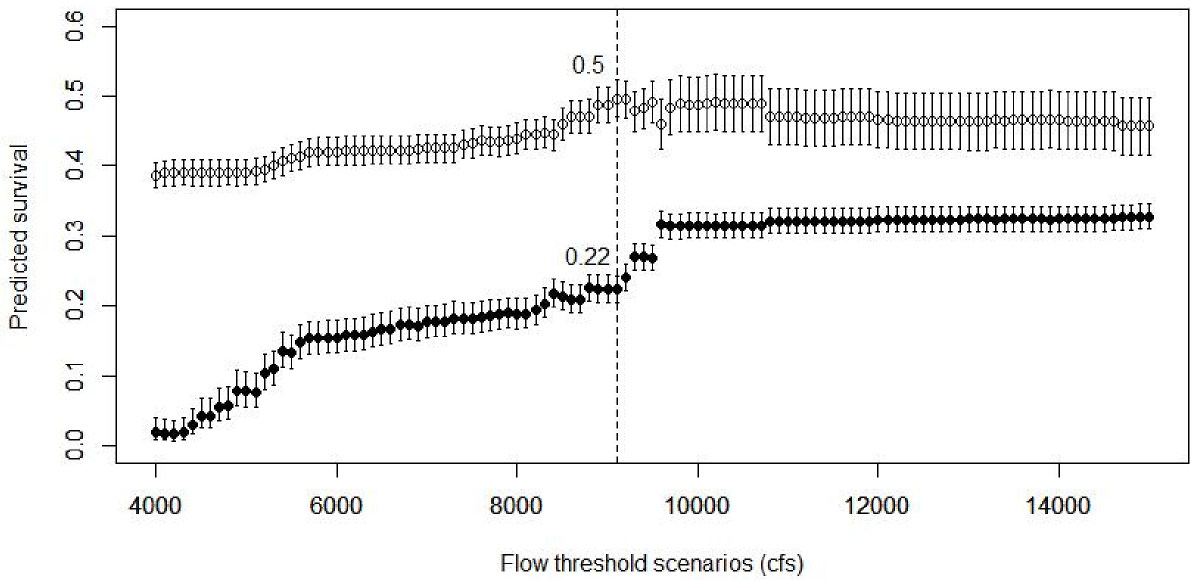

Figure 6. Predicted survival through the study region (confluence with Deer Creek to confluence with Feather River) for the above threshold (white dots) versus the below threshold (black dots) groups based on the different flows threshold survival models (here for just Wilkins Slough gauge). Error bars represent 95% confidence intervals. At the best supported threshold, 9,100 cfs, the below threshold group experiences survival of 0.22, while the above group experiences survival of 0.5, a 2.3-fold increase in survival.

Spring Pulse Flow Proposal

Sacramento River Pulse Flow

We request a pulse flow on the Sacramento River sometime between **May 1st and May 15th** to coincide with the peak smolt out-migration from Mill and Deer Creek (Figure 1), high enough that it would result in **a 3-day sustained 10,000 cfs flow event at Wilkins Slough gauge**. We suggest a target of 10,000 cfs to assure that the flow event is well above the 9,100 cfs threshold. Following the initial three-day pulse targeting 10K cfs at Wilkins, we propose following a Keswick flow reduction ramping rate based on the CVP/SWP 2008 BA which proposes a ramping rate of no more than 15% per night for flows greater than 6,000 cfs, and no more than 200 cfs for flows between 4,000 and 5,999 cfs. The total number of days for this proposed pulse flow, including modified ramping, depends on the base flow before the pulse (see Table 5 for details).

According to the analyses detailed above, a pulse flow of 10,000 cfs is only warranted when flows at Wilkins Slough are predicted to be below 9,000 cfs for the first three weeks of May. In other words, we propose that the pulse flow only occur in dry or below-normal water years, and the determination of whether or not the project should occur can likely be made by a Project Management Team in early April of that year.

Pulse flow duration: 3 days pulse flow
Pulse flow volume: 10,000 cubic feet per second (cfs) at Wilkins Slough gauge
Pulse flow target region: Sacramento at Confluence with Deer Creek downstream to confluence with the Feather River
Pulse flow target year: Dry or below-normal water year (such as 2012-2016)

The mechanisms behind creating a pulse flow on the Sacramento River should be determined by the water resource agencies and water districts. Increased releases out of Shasta Reservoir, as well as temporary curtailment of major water diversions, are both powerful tools that can allow for a pulse flow, and it is likely that a combination of these two actions would be most appropriate. To minimize water costs, water from this pulse flow could be recaptured from downstream of the region of interest (i.e. downstream of the confluence with the Feather River).

Study Duration

The 2019 spring pulse flow study will be the first of up to five years of a study to evaluate the effect of managed pulse flows on out-migration survival and behavior and juvenile salmonids on the Sacramento River, and use these results to further our understanding of the exact mechanisms that relate increases in flow to increases in survival. Due to the fact that some years in that 5-year period may be critical, above normal, or wet water years, it is likely that the pulse flow project will not occur in all five years of the study.

Measuring Effectiveness of Pulse Flow at Increasing Salmonid Survival using Telemetry

The target populations for this study are ESA-listed wild spring-run Chinook and fall-run Chinook of wild and hatchery origin. **We propose to acoustic-tag outmigrating smolts from these populations to measure their survival under normal river conditions and pulse-flow river conditions**. However, 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. Therefore, we are proposing to use Coleman National Fish Hatchery fall-run Chinook salmon smolts as surrogates for wild spring-run smolts. Hatchery fall-run 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.

If we want to look at the survival of wild Chinook salmon smolts in addition to Coleman Hatchery smolts, Red Bluff Diversion Dam would be the best option to capture and tag relatively large groups of wild smolts. There are 3-4 rotary screw traps checked daily at RBDD, and out-migrating smolts could potentially be caught and held for 1-2 days prior to tagging in order to obtain a larger sample size.

For the purpose of estimating the statistically appropriate release group size, we ran a power analysis. Capture-recapture data was simulated given different levels of 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 127% 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 (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 tags per release group are needed for the 50% survival improvement scenario (Table 4). At the 75% survival improvement scenario, a minimum of 300 tags per release group are needed to have a higher than 95% chance of accurately detecting a survival gain. Finally, for the 100% and 127% survival improvement scenarios, a release group size of 200 fish is sufficient.

Table 4. 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. Numbers in red represent scenarios in which less than 95% of models showed significant differences.

Sample size (per release group)	50% improvement in survival	75% improvement	100% improvement	127% improvement (predicted by threshold analysis)
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 127% increases in survival. We therefore propose tagging 300 fish per release group, for a total of **900 hatchery fall-run smolts** with JSATS tags, and tagging an additional 50 to be held at the hatchery for a tag retention study. 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:

- We will tag and release three groups of 300 fish: one group before the pulse flow (mid-April), one group during the pulse flow (sometime within May 1st – May 15th), and one group two weeks after the pulse flow, at which point Sacramento River flows should have dropped back to pre-pulse flows. If flows are for some reason still higher than 8,000 cfs at Wilkins Slough gauge 2 weeks after the pulse, we will delay the final release until flows have dropped under this threshold.
- Fish will be released at Red Bluff Diversion Dam and tracked during their migration through the Sacramento River. We will use the existing array of JSATS receivers and deploy additional receivers at locations of interest and transitional reaches (Release site, Butte City, Knights Landing, Feather River confluence, City of Sacramento, Benicia Bridge, and other sites, see Figure 7).

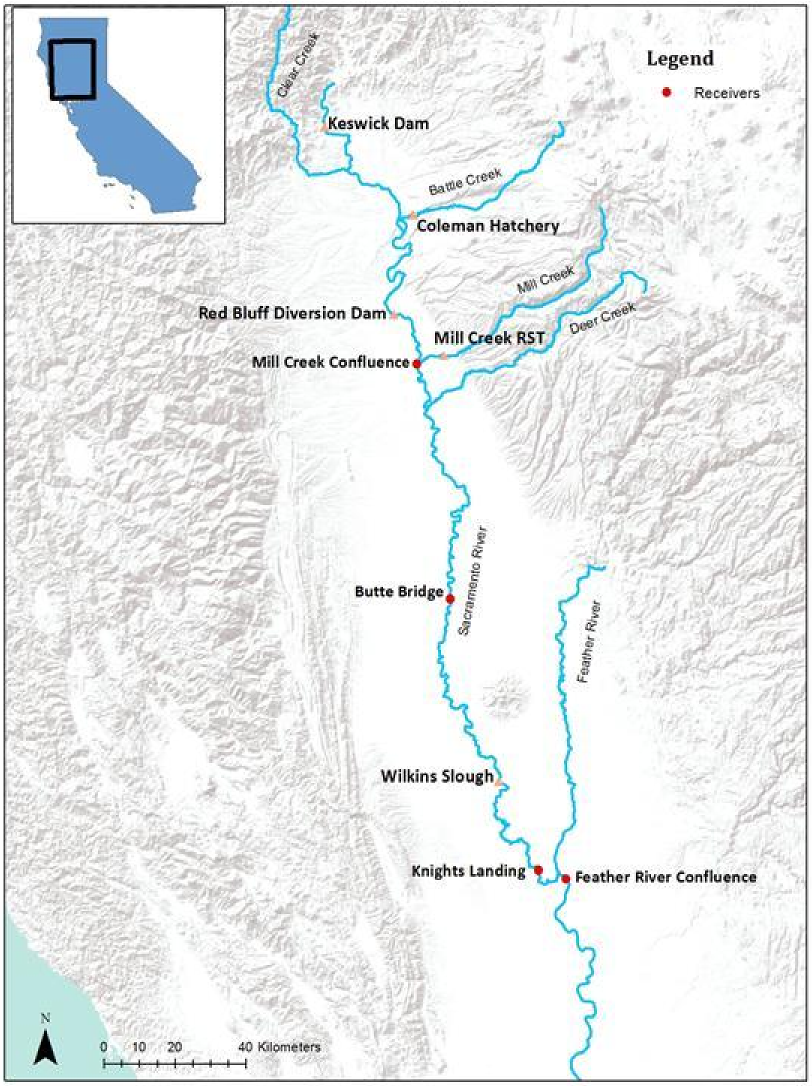

Figure 7. Map of study site and key monitoring locations.

Standard surgical approaches, trained taggers, tag code coordination, and open data accessibility will be facilitated through the Interagency Telemetry Advisory Group (SWFSC reps: Eric Danner and Rachel Johnson; USBR rep: Josh Israel and Towns Burgess). At least one tag battery study will occur annually to support these releases and estimating battery life effects on survival estimates.

In addition to evaluating the survival benefits of the pulse flow via acoustic telemetry, we will evaluate the survival benefits using smolt-to-adult survival rates as measured by coded-wire tags from large hatchery releases. Coleman Hatchery has agreed to release two of their production groups before the pulse flow (date TBD) and the third production group during the pulse flow. Fish will be released in Battle Creek below the Hatchery. The recapture of coded-wire tags from these release groups occurs when salmon mature into the ocean fishery or return to spawn in the Central Valley and are recaptured in the river fishery, from spawning ground surveys, or from hatchery returns. Therefore, results of this secondary evaluation will not be available until approximately 4 years after the pulse flow, but they will yield an entirely independent way of evaluating the survival benefits of the pulse from the acoustic telemetry work.

Synchronizing the Pulse Flow with Peak Spring-run Smolt Outmigration

The date range of the proposed pulse flow (May 1st – May 15th) intends to coincide with peak out-migration timing for wild juvenile spring-run Chinook salmon smolts and detection of wild and hatchery fall-run Chinook salmon smolts at the RBDD rotary screw traps (Poytress et al. 2014). These peak out-migration events co-occur with spring freshets during temperature or rain-driven snowmelt events (Example in Fig. 8). The SWFSC will develop a predictive model using air temperature, snow moisture content, and rainfall data to predict these freshet events on Mill and Deer creeks using weather forecasts alone, with the objective of allowing 5-7 day notice before a freshet is predicted to occur. With the collaboration of water resource agencies and water districts, we hope we can use this predictive model to maximize the synchronicity between peak wild spring-run creek outmigration and the managed pulse flow.

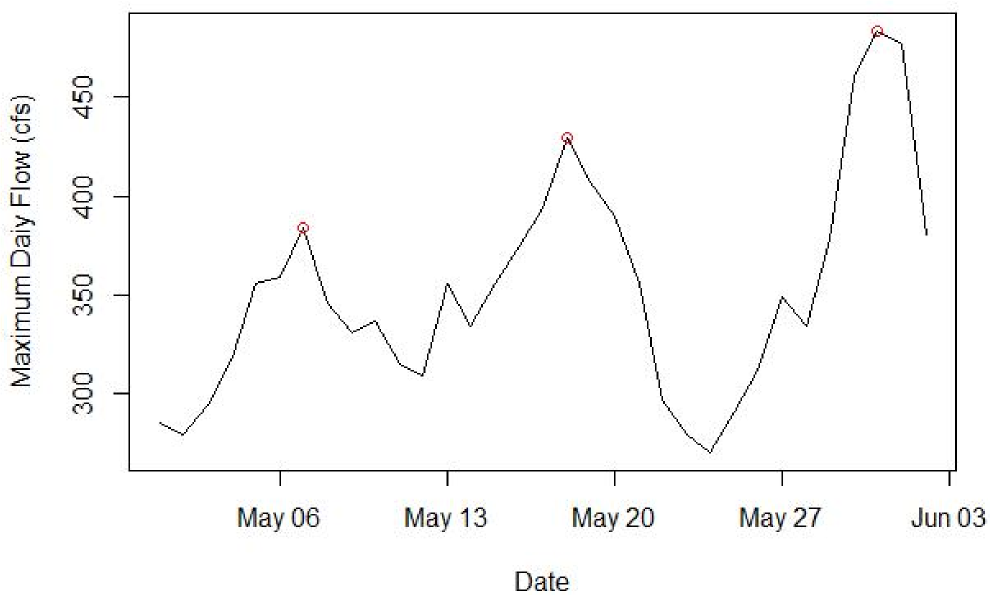

Figure 8. Mean daily flow for Mill Creek in May of 2002. Freshet events are outlined with red circles.

Hypothesis of Study

The null hypothesis for this study is that a managed pulse flow does not influence survival of outmigrating smolts. However, existing data strongly suggests this hypothesis will be refuted. Alternative (and non-mutually exclusive) hypotheses for this study, all of which can be tested through a Cormack Jolly-Seber mark-recapture model, are that:

- flow influences survival but its influence is different depending on the water year type

- flow influences survival similarly in each region (i.e. upper Sacramento River, lower Sacramento River)
- flow influences survival but its influence is different in each geographic region
- Physical parameters such as turbidity and water velocity are the mechanisms driving the relationship between flow and survival (see conceptual model (Figure 9))
- Hatchery releases during natural or managed pulses improve survival by significantly exceeding the predation demand

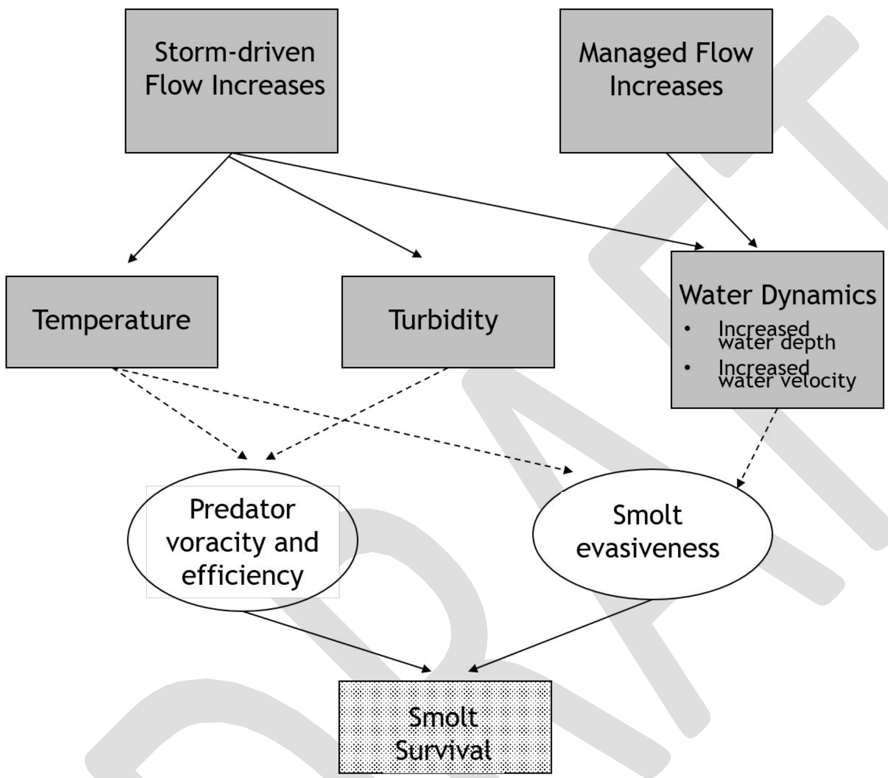

Figure 9. Hypothesized conceptual model for how increases in flow lead to increases in survival. Solid lines represent known relationships, while dashed lines represent hypothesized mechanisms.

It should be noted that the 3-day pulse flow as proposed here is a proof of concept that survival increases that are typically associated with natural high flow events can be triggered by a managed pulse flow. If enacted as a management action in the future, it may be that longer in duration, or more frequent, pulse flows are necessary to impart population-wide survival benefits to salmon populations of interest.

Proposed Analysis of Telemetry Data

To evaluate the effectiveness of the pulse flow in improving outmigration survival, we will use a similar survival modeling effort as described in Henderson et al. (2018). Specifically, we will collect numerous spatial and/or temporal environmental covariates, as well as fish-specific covariates, and determine the influence of each on the observed survival data (Table 1).

This will increase our ability to evaluate the direct and indirect mechanisms increasing survival, which are related to flow. Furthermore, it will allow us to tease apart the mechanisms behind the flow-survival relationship. For example, increased turbidity and increased water velocities are typical during the storm events that have been found to increase smolt survival, but most studies are not able to decouple the effects of these variables. We presume that a managed pulse flow will likely increase water velocities to mimic conditions during storm events, but not increase turbidity as seen during storm events (Figure 9). 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, we will deploy turbidity sensors at key locations in the study region to supplement the scarce gauges that collect turbidity data (which is why Henderson et al. (2018) did not include turbidity in their model, Table 1).

Real-time data analytics, as well as download data will be accessible via the Enhanced Acoustic Telemetry for Salmon Monitoring site for each group (https://oceanview.pfeg.noaa.gov/shiny/FED/CalFishTrack/). Although discussion still needs to occur, results regarding river, Delta, and Bay reach-specific survival estimates may be completed through collaboration with funded synthesis and analysis tasks as part of an existing USBR-UCSC/SWFSC IA in 2020.

Impacts on Water Resources and Biota

Operations and Study Decision-making

Implementing a pulse flow on the Sacramento River can occur through modifying Keswick releases and/or reduced river diversions. During April and May, Keswick releases are made based on one or more state and/or federal regulatory requirement. Using Keswick releases to provide a pulse flow will require NEPA and ESA compliance prior to implementation. While initial discussions on how to address NEPA compliance have just started, Reclamation would likely propose pursuing a categorical exemption during the first year of this study and potentially an Environmental Assessment for the remainder of the five-year study. Additionally, to meet ESA compliance, Reclamation proposes a decision tree (Figure 10) to evaluate if the study's pulse flow may increase potential risks to winter-run Chinook. The decision tree would be utilized in the spring to assess the effects of the pulse release on Shasta Reservoir conditions that are necessary to ensure cold water management into the fall. This decision tree utilizes temperature control location criteria from the 2009 NMFS Biological Opinion RPA Action I.2.3 and rule-of-thumb guidance for End-of-April total storage and End-of-April cold-water-pool volume to determine when a pulse flow is unlikely to adversely affect ESA-listed winter-run Chinook and spring-run Chinook adults, egg, and fry in the Sacramento River.

The Study-Decision making process is proposed to begin using information available at the end of April. This will determine what type of pulse can be achieved, or not, in May. The decision tree will require review of the previous month's operational outlook to determine if the criterion is met (listed below). If the criterion is met, then the previous month's operational outlook will be run a second time including the May pulse flow volume. If the criterion is met a second time with the modeled pulse flow included, then a pulse flow can be planned. If the criteria is not met with the modeled pulse flow, then a pulse flow will not be planned due to such an operation falling outside the expected operations described in the 2009 NMFS BiOp. Alternatively, these conditions may still be favorable for creating a pulse flow through reduced river diversions, and such opportunities for a pulse flow or extension of a freshet to obtain desired pulse flow characteristics by reducing diversions may be reasonable.

<u>Criterion</u>

- End-of-May Shasta Reservoir Storage

Using a 90% exceedance reservoir inflow Operations Outlook, the End-of-May Shasta Storage is projected to exceed **3.7 MAF**, which is likely to result in achieving a Clear Creek compliance location for 54F through October.

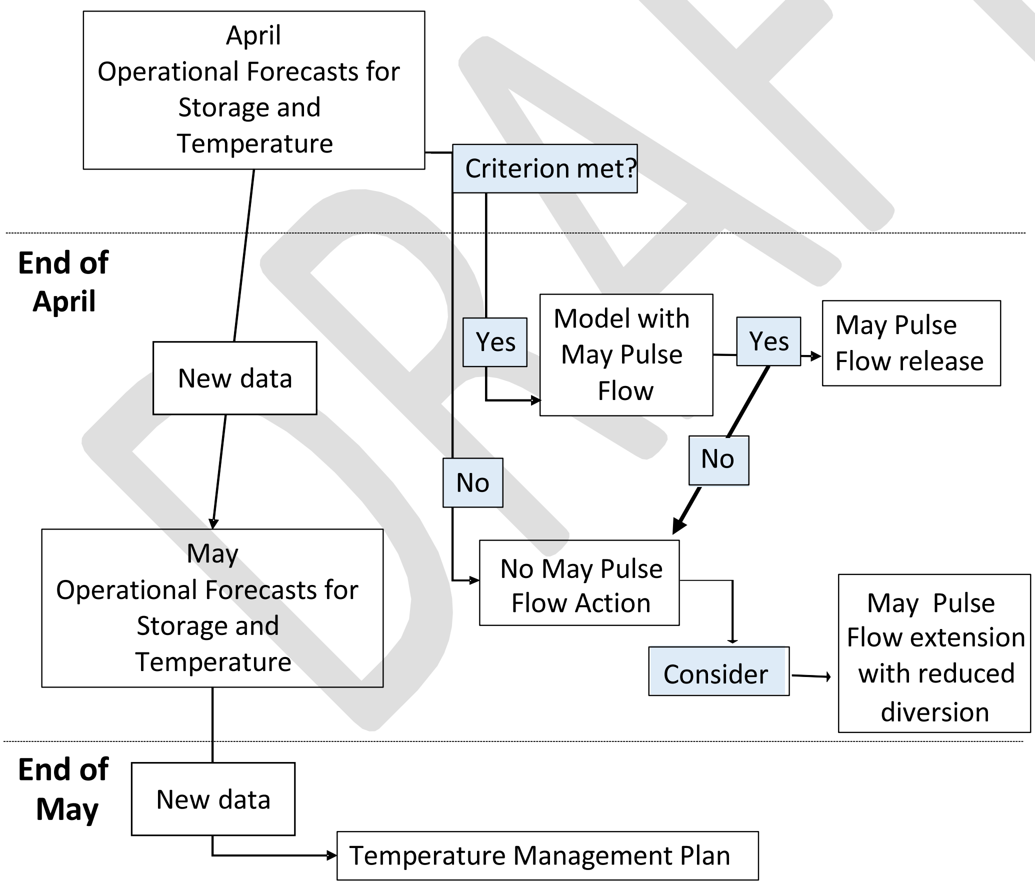

Figure 10. Decision tree to determine if/what type of pulse flow action may be achievable in May.

Historical Pulse Flow Scenarios with impact on Shasta Water Temperature and Winter-run Egg Survival

The influence of a managed spring pulse flow on water temperatures of Shasta discharge and winter-run egg survival was assessed using NMFS hydrological model simulations over historic conditions (2000-2015). We ran scenarios that predicted the impacts had a pulse flow occurred during those years, implemented as proposed in this proposal. We assumed that water operations remained the same otherwise (i.e., no compensatory water management actions were implemented to offset the water cost of the pulse flow). We also assumed that pulse flows were created purely by increased releases from Keswick/Shasta reservoirs, and not due to any curtailments in water diversions. Preliminary results suggest that the simulated increase in Shasta discharge temperature during winter-run egg incubation period due to the water costs associated with the pulse flow is less than 0.5 °F in all but 2 years of the time series (Figure 11). Additionally, the simulated winter-run temperature-dependent egg mortality increase associated with the pulse flow water cost is less than 2 percentage points in all but a few dry and critically dry water years (Figure 12).

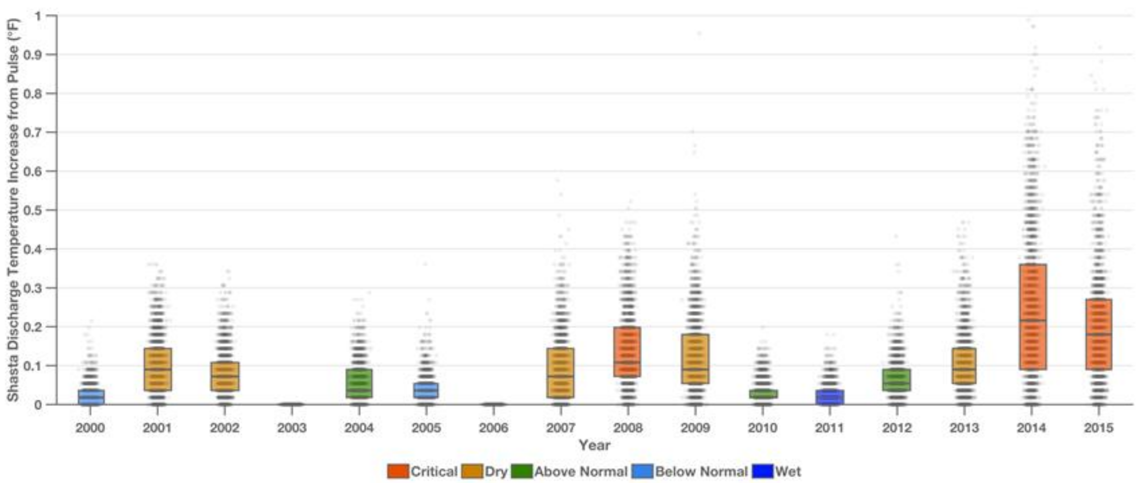

Figure 11. Shasta discharge temperature increase simulations linked to a pulse flow for 2000-2015.

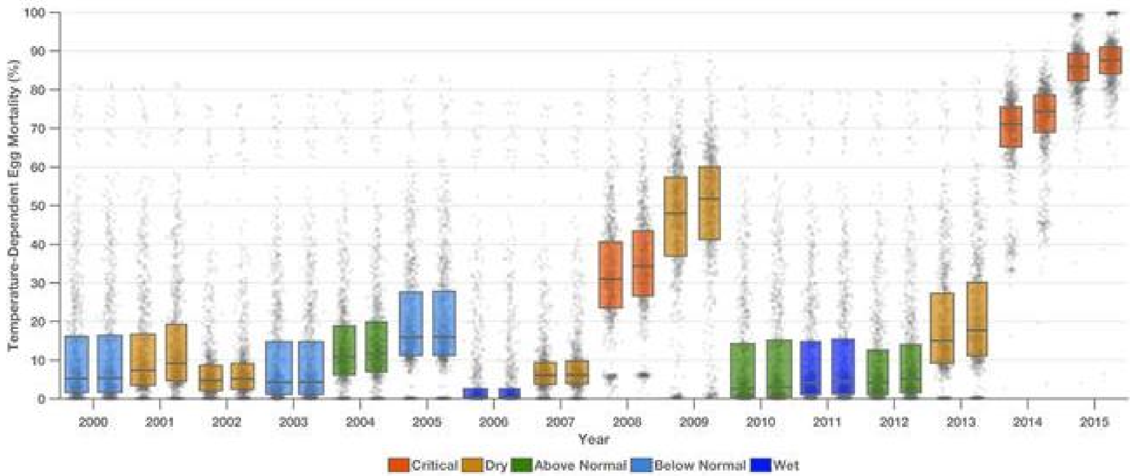

Figure 12. Winter-run egg mortality simulations for a no pulse (left box) versus pulse (right box) flow scenario for 2000-2015.

In order to minimize the risk of jeopardizing winter-run egg survival as a result of the pulse flow, SWFSC can run egg survival models based on pulse flow scenarios given known hydrologic conditions in early April of a potential study year. The results from these analyses can be reviewed by the Project Management Team to assess if the potential for negative impacts to winter-run eggs are negligible enough to proceed with the managed pulse flow in the following May.

Water Costs of the Pulse Flow Event

As part of determining the feasibility of this proposal, it is important to determine the water cost associated with the managed spring pulse flow. We estimated the water cost under two different scenarios: (1) water cost of a pulse is the additional water needed above Keswick base flows (3,250 cfs) to match the flow needed to generate a 10,000 cfs pulse to Wilkins Slough (estimated to be 13,634 cfs out of Keswick), along with ramping down, or (2) water cost is the additional water needed above average Keswick flows during dry to normal water years in May (9,080 cfs) to match the flow needed to generate a 10,000 cfs pulse to Wilkins Slough, along with ramping down. The former water cost is estimated to be 149.8 thousand acre-feet, while the latter is estimated to be 33.9 thousand acre-feet (Table 5). We believe that the latter water cost measurement is the more appropriate measure of the true "cost" of implementing such an action.

Table 5. Estimated water cost per pulse flow for two different base flow scenarios (minimum base flow in green column, historical base flow in yellow column), and for dry to normal water years

			Proposed pulse to Wilkins Slough with CVP/SWP BA ramping rate[2] compared to base Keswick release			Proposed pulse to Wilkins Slough with 15% ramping rate (same as CVP/SWP BA) compared to base historical average Keswick release		
Day #	Base Keswick release (cfs)	Base historical average Keswick release (cfs)	Keswick release (cfs)	Water cost (cfs)	Water cost (TAF)	Keswick release (cfs)	Water cost (cfs)	Water cost (TAF)
1	3,250	9,080	13,634	10,384	20.8	13,634	4,554	9.1
2	3,250	9,080	13,634	10,384	20.8	13,634	4,554	9.1
3	3,250	9,080	13,634	10,384	20.8	13,634	4,554	9.1
4	3,250	9,080	11589	8,339	16.7	11589	2,509	5.0
5	3,250	9,080	9851	6,601	13.2	9851	771	1.5
6	3,250	9,080	8373	5,123	10.2	9080	0	0.0
7	3,250	9,080	7117	3,867	7.7			
8	3,250	9,080	6049	2,799	5.6			
9	3,250	9,080	5849	2,599	5.2			
10	3,250	9,080	5649	2,399	4.8			
11	3,250	9,080	5449	2,199	4.4			
12	3,250	9,080	5249	1,999	4.0			
13	3,250	9,080	5049	1,799	3.6			
14	3,250	9,080	4849	1,599	3.2			
15	3,250	9,080	4649	1,399	2.8			
16	3,250	9,080	4449	1,199	2.4			
17	3,250	9,080	4249	999	2.0			
18	3,250	9,080	4049	799	1.6			
19	3,250	9,080	3849	599	1.2			
20	3,250	9,080	3649	399	0.8			
21	3,250	9,080	3449	199	0.4			
22	3,250	9,080	3250	0	0.0			
Water cost for May pulse					**149.8**			**33.9**

Budget

Labor, travel, equipment and supplies (without tags)

An estimated budget outlining the costs for implementing the project in fiscal year (FY) 2019 is attached below (Table 7). In total, and **not including the costs of acoustic tags**, the budget amounts to **$109,387**. Funding of years beyond FY 2019 can be approximated by including 3% annual cost-of-living increases for salaries and benefits, and therefore would be estimated to cost $111,561 in FY 2020, $113,801 in FY 2021, $116,109 in FY 2022, and $118,485 in FY 2023, for a total of **$569,343 over the 5-year study**.

Table 7. Estimated budget for pulse flow project in 2019 alone.

Personnel Costs

Personnel Costs	*FY19 salaries*	Projected Salary FY20	Time (fraction of yr)	Total w/ fringe*
Project leader (Associate specialist)	*$ 65,000*	$ 66,950	0.17	$ 17,186
Field leader/tagger (Assistant specialist)	*$ 54,000*	$ 55,620	0.08	$ 6,719
Field crew/tagger (SRAI)	*$ 43,952*	$ 45,271	0.08	$ 5,469
Field crew/tagger (SRAI)	*$ 43,952*	$ 45,271	0.04	$ 2,734
Field crew/tagger (SRAI)	*$ 43,952*	$ 45,271	0.04	$ 2,734
Data analyst (Project Scientist)	*$ 78,383*	$ 80,734	0.17	$ 20,725
Criss, Anne (Deputy Director)	*$ 98,522*	$ 101,477	0.04	$ 6,129
* Fringe 51%			**Salaries total**	**$ 61,696**

Supplies

Item	Unit cost	Quantity	Cost
Misc. receiver supplies (batteries, cable, hardware)	$ 4,000.00	1	$ 4,000
Turbidity sensors	$ 9,000.00	2	$ 18,000
Fuel, supplies and repairs for boats (est. $100/day * 1 boat * 6 days)	$ 600.00	1	$ 600
Truck #1 lease GSA 59A 4x4 crew cab (monthly cost)	$ 244.00	2 months	$ 488
Mileage for GSA vehicles ($0.33/mile)	$ 0.33	2000	$ 650
Misc. tagging supplies	$ 500.00	1	$ 500
		Supplies total	**$ 24,238**

Travel

Item	Description	Rate	#Persons	Trip length (days)	Quantity	Total, Year 1
Tagging Lodging	Lodging Daily rate (Red Bluff/Redding)	$ 94	$ 6	3	3	$ 3,384
Tagging M&IE	M&IE Daily rate (Red Bluff/Redding)	$ 55	$ 6	3	3	$ 2,475
Receiver servicing Lodging	Lodging Daily rate (Red Bluff/Redding)	$ 94	$ 2	3	2	$ 752
Receiver servicing M&IE	M&IE Daily rate (Red Bluff/Redding)	$ 55	$ 2	3	2	$ 550
					Travel Total	**$ 7,161**

Subtotal without overhead	**$ 93,095**
Overhead (CESU 17.5%)	**$ 16,292**
Grand total	**$ 109,387**

Funding options for tags

CDFW has already purchased some tags to use for this study. Reclamation will also contribute 205-245 SS300 single battery JSAT tags. These will be delivered in mid-March.

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