DRAFT 12/15/2016
Sacramento River Spring Pulse Flow
To Evaluate CV Spring-run Chinook Salmon Survival

A study of spring pulse flows is being proposed by NMFS and CDFW to evaluate the survival of outmigrating spring run smolts. The proposed study is to implement and evaluate two spring pulse flows paired with JSAT tagged salmon releases. The study is being proposed for spring 2017.

Biological Objective/Rational: The biological objective is to improve survival rates of wild juvenile spring-run Chinook salmon during peak spring emigration periods. Existing data from previous studies show that survival in the upper and lower Sacramento River has been strongly correlated with flow but the exact relationship between flow and survival is less clear. This study will provide a basis to understand the relationship and provide information for potential management actions.

Investigators

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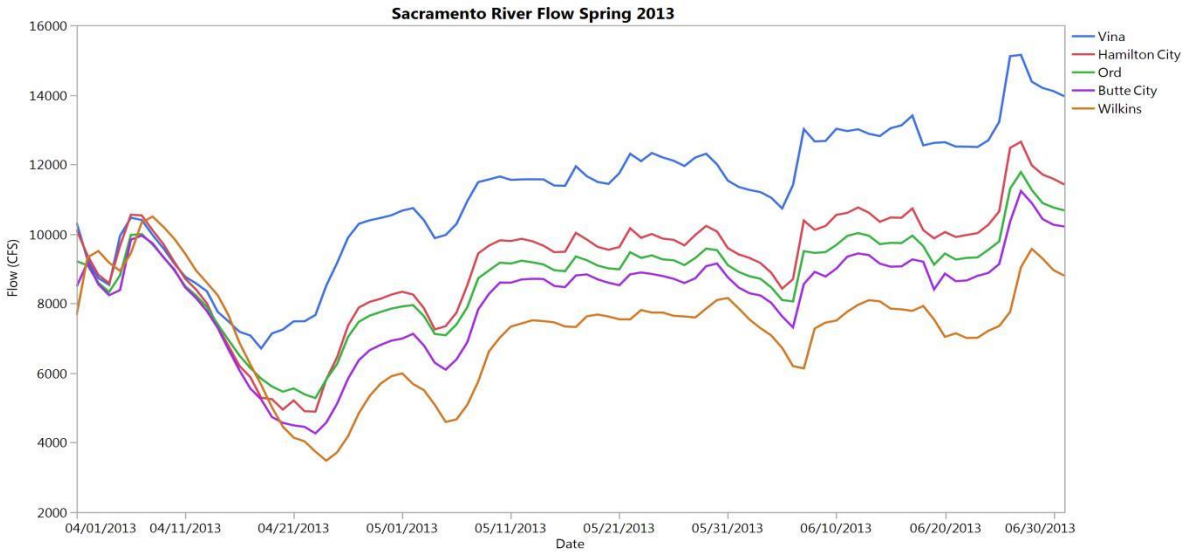
Spring Pulse Flow Proposal

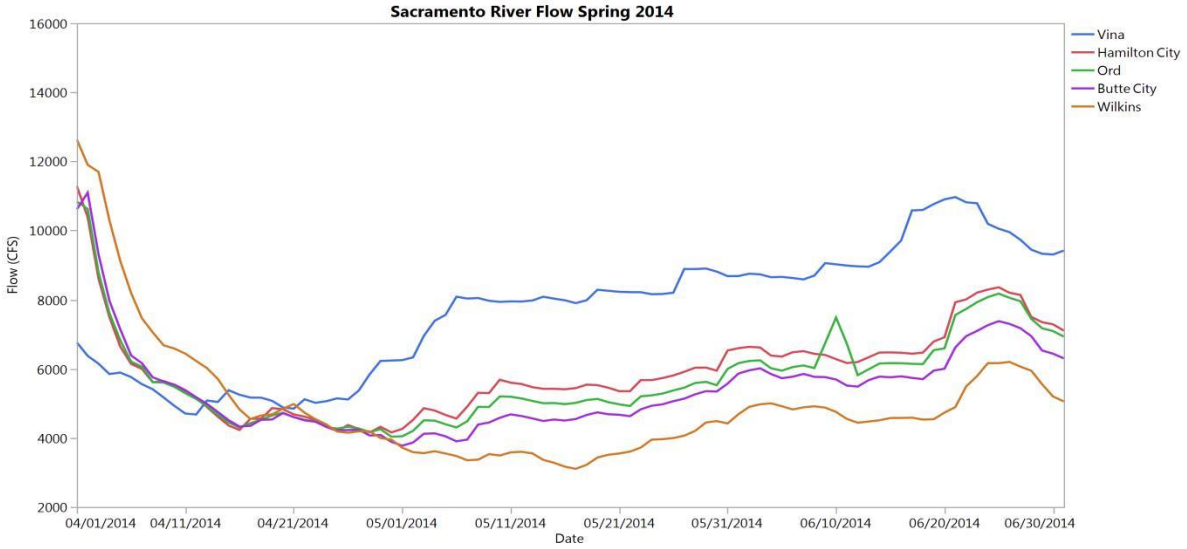
Two Sacramento River pulse flows that double the base flow for a short period of time between April 1 and May 15, 2017.

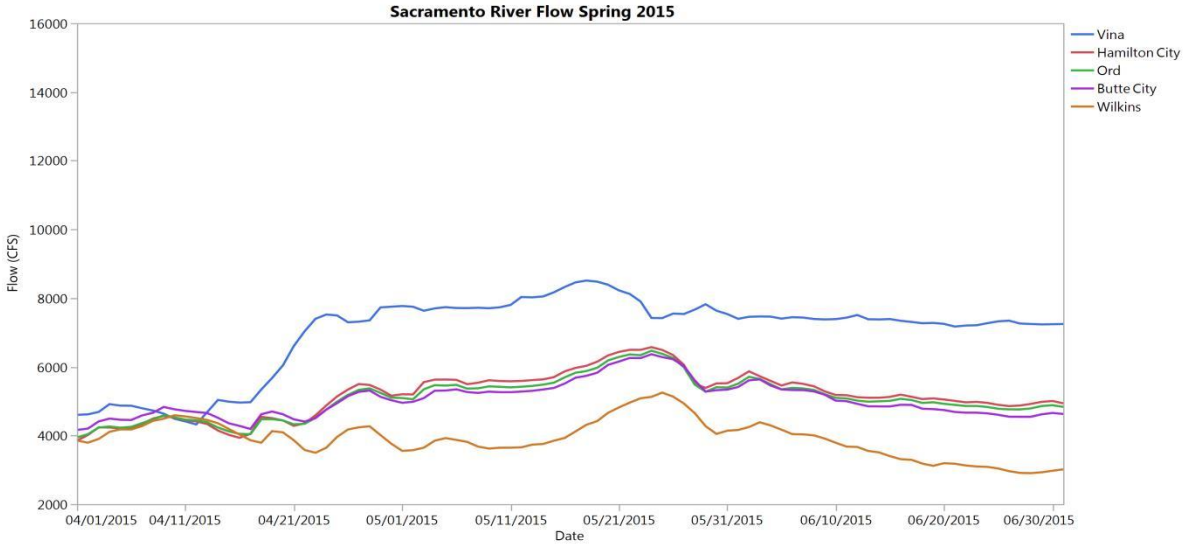
Pulse flow duration: 3 days per pulse, with the following 7 days ramping down to base flows
Pulse flow volume: 12,000 cubic feet per second (cfs) at Wilkins Slough gauge
Pulse flow target reach: Bend Bridge downstream to Wilkins Slough

In order to study the relationship between survival rates and increases in river flow for wild spring-run smolts, two pulse flows from Keswick Reservoir should be scheduled between April 1 and May 15 to coincide with the peak smolt outmigration from Mill and Deer Creek, according to 15 years of rotary screw trap (RST) data. The general concept is to capture as closely as possible the natural migration timing of wild spring-run smolts. Peak smolt outmigration from these tributaries typically occurs during snow melt events caused by warming air temperatures, which sends pulses of cold and turbid water downstream throughout the day. This seems to be a cue for smolts to leave the tributaries, and also triggers the outmigration of steelhead smolts, lamprey ammocoetes, and juvenile pikeminnow and hardhead.

While Deer and Mill Creek still have mostly natural, unmodified hydrographs, the hydrograph of the Sacramento River, into which those creeks flow, is mostly unnatural and managed. Therefore, there is often a mismatch between the conditions in the smolts' natal creeks and the conditions in 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. Flows in the upper Sacramento River upstream of Hamilton City see a pulse, but downstream of the Glenn Colusa Irrigation District (GCID) and other large diversions, flows in the Sacramento 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 Vina-Woodson Bridge and ending downstream at Wilkins Slough during the spring-run smolt outmigration period of 2013, 2014 and 2015.







The target population for this study is ESA-listed wild spring-run Chinook salmon, 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 using 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 spring-run smolts that outmigrate 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. We propose tagging a total of **500 hatchery fall-run smolts** with JSAT tags (125 per release group). Hereafter in the proposal, we will refer to the hatchery fall-run smolts as "surrogates".

For this study, we will also opportunistically acoustic tag **200 wild spring-run salmon smolts** captured from the rotary screw traps located on Mill, Deer, Battle Creeks and/or Red Bluff Diversion Dam on the Sacramento River. Smolts will be held to the extent allowable by permits to allow for larger release groups during each pulse flow and base flow fish release. While we do not predict the sample sizes of wild smolts to be sufficient alone to accept or refute the hypotheses, we view the results of the wild spring-run smolts as potentially corroborative to the hatchery fall-run tagging results.

Hypothesis of Study

The null hypothesis for this study is that flow does not influence survival of outmigrating smolts. We have four alternative hypotheses for this study, all of which can be tested through a Cormack Jolly-Seber mark-recapture model.

A1: Survival increases throughout the river and regardless of season with increases in flow
A2: Survival increases in only specific regions but regardless of season with increases in flow
A3: Survival increases throughout the river but only during certain time periods, with increases in flow
A4: Survival increases only in specific reach x time period combinations, with increases in flow

With the wide range of flow values that the tagged smolts will experience, we can model how the relationship between flow and survival varies throughout the study period and throughout the pulses and troughs in flow. Furthermore, we will collect other water quality variables (such as turbidity, water velocity and temperature) to see how these relate to changes in survival as well. While previous tagging studies have shown strong support for increased flows correlating with increases in survival, the exact mechanisms that lead to flow influencing survival are unclear. This is in large part because these increases in flow were due to storm events, during which many covariates change in synchrony. With a pulse-flow, only a subset of the variables are likely to change drastically, which may lead us to decouple relationships and better understand exact mechanisms behind the flow-survival relationship. Of particular interest, increased turbidity and increased water velocities are typical during storm events, and are both thought to lead to increased outmigrant survival, but most studies are not able to decouple the effects of these variables.

Desired Pulse Flow and Fish Release Schedule

Depending on the water conditions that we are faced with in spring of 2017, we have two plans for the pulse flow experiment: One for a dry/normal winter and one for a wet winter. The plans are:

Plan A, Dry/Normal Winter:

Plan A is enacted if the mean flow at Wilkins Slough from April 1-10th is lower than 10,000 cfs. This would be our criteria for deciding if current base flows are representative of a dry spring.

- We request the release of the first pulse flow from Keswick on April 15th, high enough that it would result in a 3-day sustained 12,000 cfs flow at Wilkins Slough gauge.
- We will then release our tagged Coleman fish hatchery fall-run "surrogates" from Red Bluff as soon as the water pulse arrives to Red Bluff. We will also release any tagged wild spring-run smolts from the trapping locations on Mill and Deer Creeks with appropriate lead time to allow these fish to take advantage of pulse flows on the mainstem Sacramento River.
- Coleman could release one of their production releases a day after our Red Bluff release (coordination with Coleman National Fish Hatchery still pending). Given the one day difference, and the Red Bluff head start, we believe the pulse flow tagged fish should stay ahead. This would ensure that our surrogates don't benefit from any potential predator swamping that occurs due to the Coleman production releases, so as to ensure any survival gains can be attributed to higher flows only.
- We will then release the first non-pulse flow surrogate release from Red Bluff 2 weeks after, at which point Sacramento River flows should have dropped back to base flows. If flows are for some reason still higher than 8,000 cfs at Wilkins Slough gauge, we will delay until flows drop under this threshold. We will also release any available tagged wild spring-run smolts at this time.
- We request a second identical Keswick pulse flow 2 weeks after the base flow fish release, likely sometime around May 15th. We will again release surrogate smolts at Red Bluff once the water pulse arrives. We will also release any available tagged wild spring-run smolts at this time.
- We will then release our 2nd non-pulse flow surrogate release 2 weeks later at Red Bluff, likely around end of May. We will also release any available tagged wild spring-run smolts at this time. By that time, flows will likely be low at Wilkins Slough, and therefore there is probably no need for a threshold flow to allow for a fish release.

Plan B, Wet Winter:

Plan B is enacted if mean flow at Wilkins Slough for April 1-10th is above 10,000 cfs, and if flow forecasts predict that it will stay roughly the same through April 15th. This would be our criteria for deciding if current flows are representative of an average or a "wet" spring.

- For the first fish release, no need for a pulse flow out of Keswick, but take advantage of the existing natural high flows. We will release surrogate fish on April 15th at Red Bluff. Coleman may or may not elect to do the same, but if so, we will coordinate with them so that our fish get released 1 day before theirs. Coleman usually releases some of their production in mid-April. We will also release any available tagged wild spring-run smolts at this time.
- We will then wait until the flows at Wilkins Slough gauge drop by 50% from the flows when the first fish release went out. At this point, we will release the 1st low-flow surrogate release. We will also release any available tagged wild spring-run smolts at this time. If flows at Wilkins *haven't* dropped by 50% by May 15th, we may elect to cancel the remaining fish releases. There wouldn't be enough time to get the other releases in before June, at which point fish releases lose their biological meaningfulness.

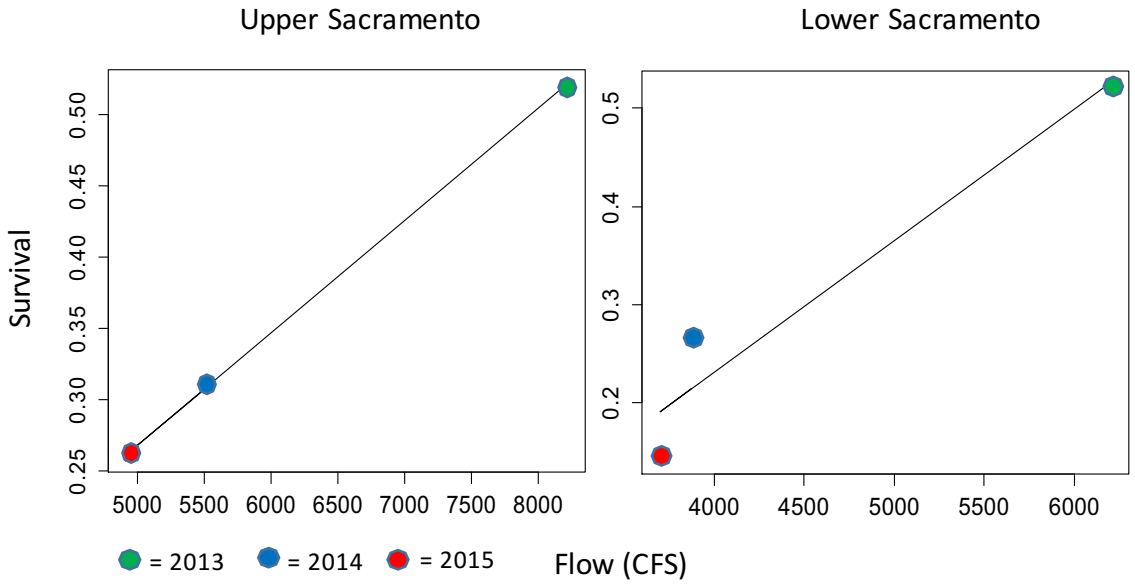
- Then, 2 weeks after the first low-flow fish release, we request a Keswick pulse flow as described in Plan A, i.e. resulting in 3-day sustained flows of 12,000 cfs at Wilkins Slough. When the pulse arrives to Red Bluff, we will release the surrogates at Red Bluff. We will also release any available tagged wild spring-run smolts at this time.
- Finally, 2 weeks later, we will release the final release of surrogates from Red Bluff, at which point the flows in the Sacramento River should be near to base flows. We will also release any available tagged wild spring-run smolts at this time.

Scientific Justification

We have seen strong evidence that higher flows result in higher survival of outmigrating Chinook salmon smolts in the Sacramento River. This evidence comes from two separate studies, one on tagged late fall-run smolts from 2007-2011, and one on tagged wild spring-run smolts from 2013-2015.

Wild spring-run smolt tagging study

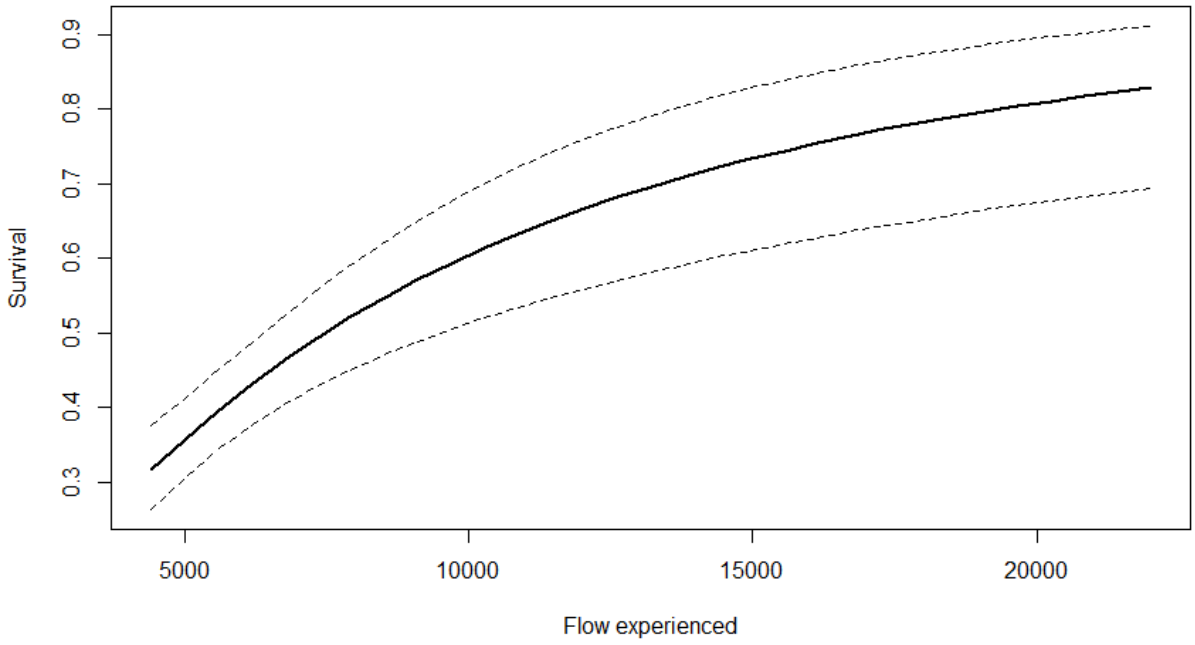
According to three years of survival data from JSAT acoustic tagged smolts from Mill Creek, survival in the upper and lower Sacramento River has been strongly correlated with flow, as seen in the figure below. For this study, the Upper Sacramento River is designated from the confluence of Mill Creek downstream to Butte City, and the lower Sacramento River is designated from Butte City downstream to Knights Landing. The flow value for each year is the average flow that all tagged smolts experienced while going through those regions during the study period, and the survival rate is the proportion of smolts that survived that region. The sample size for the lower Sacramento River is small due to the fact that not many smolts survive downstream through that region on any given year.



Hatchery late fall-run smolt tagging study

From the acoustic tagging work done with late-fall run Chinook smolts, it does seem clear that outmigration survival increases drastically with larger flows, and has been shown in countless other studies throughout the Pacific coast. However, the exact relationship between flow and survival is the harder part to pin down, and can have a serious influence on how effective pulse flows are at increasing survival.

The SWFSC has been using the existing late-fall run Chinook acoustic tagging data to look at relationships between different environmental factors and survival. They used flow, temperature, and turbidity in both the river and in the delta (i.e. 6 different distinct models) to see which had the strongest correlation with survival. The model using flow in the mainstem of the Sacramento River as a covariate had the strongest support, and by a large margin. The next step SWFSC took was to then look at different relationships between survival and Sacramento River flow as measured at Bend Bridge. In particular, is the relationship between the two a simple linear, logarithmic, or quadratic relationship? They tried testing these and other different hypotheses, and the logarithmic model seemed to fit the best. The log(flow) correlated the best with survival during outmigration. They then used the coefficient estimate for the effect of flow to make a covariate prediction plot based on the known extremes in daily flow at Bend Bridge during the study period (4400 to 22000 cfs). The figure below demonstrates that plot.



The logarithmic relationship indicates that there are diminishing returns as flow gets higher, but this shouldn't be too much of a surprise since survival can only be as good as 1, and we presume that even in the wettest years some fish will die during outmigration. However, what this figure demonstrates is there does seem to be a point around 10,000 – 12,000 cfs where the "returns" start to considerably diminish.

A few caveats here, these are late fall-run, so it's unclear how strong this relationship is for wild spring-run. Also, these analyses are using Bend Bridge as the gauging station, but our current hypothesis is focused on low flows near Wilkins Slough.

When these late fall smolts are headed out to sea, if flows at Bend Bridge are 12,000 cfs, it typically means there's a winter storm, meaning runoff, which implies that flows at Wilkins Slough are substantially higher than at Bend Bridge (due to the high runoff inputs from tributaries between Bend Bridge and Wilkins Slough. However, in the spring, if there's 12,000 cfs at Bend Bridge, it's typically due to Keswick releases and much of that water is being diverted along the course of the river, therefore flows at Wilkins Slough would typically be lower than 12,000 cfs. So the question for the proposed study is how much flow at Wilkins do we believe will be sufficient to see measurable gains in survival, and are we comfortable using flow recommendations for the upper river in the lower river? From a quick look at the Bend Bridge in comparison to Wilkins Slough hydrograph, it does seem that flows during smaller winter storms tend to be somewhat similar between the two stations, except that the Wilkins Slough pulse of water tends to be 1-2 days later, and a few thousand cfs higher. So, if we reran the above analyses with Wilkins Slough flow rather than Bend Bridge flow, we would probably see a similar relationship with late-fall run survival. Therefore, we believe 12,000 cfs is a reasonable estimate for how flows need to be in the Wilkins Slough region to potentially cause a measurable increase in outmigration survival.

Funding options for tags and labor

CDFW Funding has already committed to funding the purchase of tags for this project: $149,000 for about 769 tags (~700 tags for fish releases, ~69 for tag life side-study)

As for labor, we are seeking funds. We hope to secure NMFS Phase III funding:
Labor: $180,206
Equipment: $14,340
Note: NMFS phase III funding is regionally competitive source and is not assured. If this does not come through, additional funding support options need to be pursued to maintain study viability.

Other tagging study considerations

To increase the total number of wild spring-run smolts tagged during this study, there are four potential locations we can utilize:

Mill Creek – A RST will be operated and checked by CDFW and NMFS personnel daily for spring-run smolts to tag. Spring of 2017 will likely offer low numbers of spring-run smolts due to only 46 redds being observed in the fall of 2016 in Mill Creek.

Deer Creek – No RST is in place, but options are available to install and operate a RST by CDFW and NMFS personnel daily. A total of 267 adult spring-run were observed holding in

Deer Creek summer of 2016, so there is more potential to tag outmigrating smolts from this system compared to Mill Creek.

Battle Creek – a RST is operated and checked daily by USFWS every spring on Battle Creek. There is potential for USFWS to hold smolts >80mm captured in the RST each day and for NMFS personnel to tag them on site. The 2016 spring-run estimate for Battle Creek has not been calculated, but there seems to be a comparable number of spawners to Mill and Deer. In the past 10 years there has been a strong resurgence of spring-run Chinook in Battle Creek, probably due to restoration efforts and improved summer flows.

Red Bluff Diversion Dam (RBDD) – this would be the best option to capture and tag relatively larger groups of wild smolts, although it will be difficult to know if tagged wild fish are spring or fall run due to the time required for genetic stock assignments. There are 3-4 RSTs checked daily at RBDD, and outmigrating smolts could potentially be caught and held for 1-2 days prior to tagging in order to obtain a larger sample size. This option would definitely be feasible if there is a natural spring pulse flow that triggers the movement of wild smolts upstream of RBDD.

Estimated Water Cost Per Pulse Flow

Day #	Base[1] (cfs)	Study[2] (cfs)	Water cost (cfs)	Water cost (TAF)	Notes
1	5,000	12000	7,000	14.00	
2	5,000	12000	7,000	14.00	
3	5,000	12000	7,000	14.00	
4	5,000	10200	5,200	10.40	[4]Ramping rates apply
5	5,000	8670	3,670	7.34	
6	5,000	7370	2,370	4.74	
7	5,000	6264	1,264	2.53	
8	5,000	5324	324	0.65	[5]Ramping rates apply
9	5,000	5125	125	0.25	
10	5,000	5000	0	0.00	
		Water cost per pulse:		**67.91**	

[1] Base is the assumed base flow at Wilkins Slough, simplified for the calculation of water cost

[2] Study includes the pulse flow to 12,000 cfs for 3 days, plus required ramp down rates per Reclamation's 2008 CVP/SWP BA

[3] Assumes a Keswick increase of 7,000 cfs for the pulse will make it all the way down to Wilkins Slough, with no accreations or depletions (or that both cancel each other out)

[4] CVP/SWP 2008 BA: When Keswick releases are 6,000 cfs or greater, decreases may not exceed 15 percent per night. Decreases also may not exceed 2.5 percent in one hour.

[5] CVP/SWP BA: For Keswick releases between 4,000 and 5,999 cfs, decreases may not exceed 200 cfs per night. Decreases also may not exceed 100 cfs per hour.