

# Juvenile Salmonid Out-migration Monitoring at Hatfield State Park in the Lower Merced River, California

*2009 Annual Data Report*

*Prepared by:*

John Montgomery, Clark B. Watry, Ayesha Gray, and Joseph E. Merz

*Prepared for:*

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## SUMMARY

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The Merced River is currently the southernmost extant population of Chinook salmon *Oncorhynchus tshawytscha* in the Northern Hemisphere. California Department of Fish and Game (CDFG) monitored salmonid out-migration by rotary screwtrap (RST) in the lower Merced River from 1998 - 2002. In 2007, Cramer Fish Sciences (CFS) began a collaborative effort with the U.S. Fish and Wildlife Service (USFWS) Anadromous Fish Restoration Program (AFRP) to implement salmonid out-migration monitoring by RST in the lower Merced River (N 37°21'25.963", W 120°57'51.469") near the town of Stevinson, California (Montgomery et al. 2007). In 2009, CFS and USFWS continued monitoring downstream salmonid migration from 31 March to 29 May 2009, and collected information on various environmental parameters. While no efficiency tests were performed in 2009, we developed abundance estimates using a logistic regression model that predicted daily trap efficiency based on results from ten mark-recapture efficiency tests in 2007 and 2008 and their associated flow levels. We then applied those predicted efficiencies to 2009 count data to get an estimate for the annual juvenile passage. Efficiency tests in 2007 and 2008 represent years of relatively low and high efficiencies, respectively; therefore, while no efficiency tests were performed in 2009, mean daily efficiencies from 2007 and 2008 provided a conservative estimate for the current year's juvenile passage. We captured a total of 11 natural juvenile Chinook salmon and this method resulted in a passage abundance estimate of 968 juvenile Chinook salmon for the 2009 season (range: 588 – 2,751). No *O. mykiss* were captured, as in 2007 and 2008. For Chinook salmon, our results indicate extremely low abundance estimates characteristic of an imperiled population. No fry, parr or yearling emigrants were captured emigrating from the Merced River at Hatfield; only sub-yearling smolts. As a result of low sample size, mean length comparisons are not available. Out-migration timing coincided with the Vernalis Adaptive Management Program (VAMP) flow releases in early May. This dramatic decline in juvenile salmon abundance was expected given severely depressed adult spawning escapement numbers observed during fall 2007 and 2008 following the West Coast Chinook salmon fishery collapse (National Oceanic and Atmospheric Administration (NOAA) 2008). Documentation of population status and recovery trajectory provides valuable information to restoration and fisheries management efforts. Monitoring continues to provide valuable data on the lower Merced River salmonid population to help AFRP and the Comprehensive Assessment and Monitoring Program (CAMP) meet their programmatic goals and objectives.

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## INTRODUCTION

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Historically, Chinook salmon *Oncorhynchus tshawytscha* and steelhead/rainbow trout *O. mykiss* distributions ranged throughout California's Central Valley with spawning reaches extending into streams and rivers of the Coastal Range and Sierra Nevada mountains to elevations above 1,000 m (Yoshiyama et al. 2001; Moyle 2002). The Merced River, a tributary of the San Joaquin River, presently represents the southernmost extent of Chinook salmon distributions in the Northern Hemisphere and provides important spawning and rearing habitats for runs considered as species of concern under the United States Endangered Species Act (ESA). Four different Chinook salmon races (i.e., fall-run, late fall-run, spring-run and winter-run) were common throughout the Central Valley; the spring-run are reasoned to have been the most abundant race in the San Joaquin and its tributaries (Yoshiyama et al. 1998). Heavy snow pack characterizes the Sierra Nevada Mountains, which gain elevation as they move south reaching a height of 4,419 m at Mount Whitney. The resulting high spring runoff historically allowed fish to ascend rivers to elevations where favorable thermal conditions promoted large spring-run populations (Yoshiyama et al. 1998; Williams 2006).

Since the mid-19th century a succession of dams, diversions, and habitat alterations have dramatically reduced or degraded spawning and rearing habitat for Chinook salmon populations throughout the Central Valley (Williams 2006). As a result, viable spring-run populations no longer exist in the San Joaquin or its tributaries (Campbell and Moyle 1991; Yoshiyama et al. 2001); however, limited data have documented early-migrating (i.e., May to June) adult Chinook salmon in small numbers (Anderson et al. 2007). Whether these are hatchery strays, natural production or a combination of both is uncertain. Today, fall-run Chinook salmon populations persist in San Joaquin River tributaries, and extensive work is underway on recovering spring-run populations in the mainstem San Joaquin River. However, in 2008 an Emergency Action under the Magnusson-Stevens Act authority was implemented that declared a commercial fishery failure for West Coast salmon after unprecedented low returns. Various causal factors contributed to poor juvenile salmon ocean survival including shifting ocean conditions and the cumulative effects of habitat degradation (National Oceanic and Atmospheric Administration (NOAA) 2008). Return abundance continued to decline in the fall 2008. Pacific Fishery Management Council reported 66,264 salmon adults returned to the Sacramento River in 2008—well below the 90,000 in 2007 (PFMC 2009). Commercial ocean harvest and recreational fisheries for Central Valley Chinook salmon remained closed through 2009 (CDFG 2009; PMFC 2009). New regulations also prohibited the catch and release of salmon (CDFG 2009).

The 1992 Central Valley Project Improvement Act (CVPIA) granted authority to U.S. Fish and Wildlife Service (USFWS) to develop and implement a series of restoration programs for the benefit of fish and wildlife resources, with the goal of doubling the natural production of anadromous fish in Central Valley rivers. To support this goal, the USFWS established the Anadromous Fish Restoration Program (AFRP) and the Comprehensive Assessment and Monitoring Program (CAMP). These programs set anadromous fish production targets,

recommended fishery restoration actions for Central Valley streams, and formed a juvenile Chinook salmon monitoring program to assess the relative effectiveness of fishery restoration actions. The two programs support informed feedback on population dynamics of target species which allow adjustments or improvements to adaptive management plans and approaches.

Numerous projects to restore and protect channel and riparian habitat have been initiated or completed on the Merced River as a result of CVPIA initiatives; however, consistent monitoring of juvenile Chinook salmon and steelhead *O. mykiss* emigration has been lacking. Monitoring often pales in priority when compared with on-the-ground restoration actions; however, effective monitoring provides a valuable tool for determining optimal [fisheries] management by understanding population dynamics (Adaptive Management Forum Scientific and Technical Panel 2002). By documenting trends, setting baseline conditions, and determining the influences of changing environmental variables (i.e., flow, temperature, turbidity, etc.) management efforts are informed and can be refined.

From 1998 through 2002, California Department of Fish and Game (CDFG) monitored Merced River juvenile Chinook salmon out-migration using rotary screwtraps (RSTs) at Hagaman State Park (Hagaman; rkm 19.3); this sampling complimented concurrent juvenile out-migration monitoring efforts upstream in the Merced River near the bottom of the spawning reach (Natural Resources Scientists, Inc. (NRS); rkm 61.2). No out-migration monitoring occurred in the lower Merced River from 2003 to 2006, leaving a 4-yr gap in available data.

In 2007, Cramer Fish Sciences (CFS) began a partnership with AFRP to establish a juvenile salmonid out-migration monitoring program using RSTs in the lower Merced River at George Hatfield State Park (Hatfield; rkm 3.2). The three main objectives of this study were to:

1. Establish abundance estimates of juvenile Chinook salmon and *O. mykiss* from the Merced River;
2. Determine and evaluate patterns of migration timing and size distribution as they relate to flow and other environmental variables; and,
3. Compare production estimates to upper river estimates, if available, to develop indices of in-river survival.

This juvenile salmon monitoring program helps AFRP and CAMP address their goals to track population dynamics, evaluate the results of past and future habitat restoration efforts, and to understand the impacts of instream flow schedules and management on the fall-run Chinook salmon population. This annual report details results from 2009 RST operations at Hatfield in the lower Merced River and addresses the first two objectives. The third objective relies on currently unavailable data from NRS.

## STUDY AREA

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The Merced River, a major tributary to the San Joaquin River, originates in Yosemite National Park, and drains approximately 3,305 km<sup>2</sup> of the western Sierra Nevada Mountain range (Figure

1). Watershed elevations range from 4,000 m at headwater to 15 m at the San Joaquin River confluence, located 140 km south of Sacramento at rkm 190 near the town of Stevinson (N 37°21'25.963", W 120°57'51.469"). The basin has a Mediterranean climate with dry summers and about 90% of the annual precipitation occurs between November and April (Schneider et al. 2003). The Merced River is regulated by several dams, including New Exchequer, McSwain, Merced Falls, and Crocker-Huffman, which are used for flood protection, power generation, irrigation and municipal water. Details and additional points of interest are listed in Appendix 1. The primary spawning reach, located from Crocker-Huffman (rkm 83.7) to rkm 52.2 (based CDFG spawning surveys). Since mid-1997 typical regulated flow on the Merced River averages ~ 7.08 m<sup>3</sup>/s (250 ft<sup>3</sup>/s). The Army Corps of Engineers permits maximum discharges of 170 m<sup>3</sup>/s (6,000 ft<sup>3</sup>/s) into the Merced River; however, flow exceeded 227 m<sup>3</sup>/s (8,000 ft<sup>3</sup>/s) under emergency circumstances created during the 1997 flood (Stillwater Sciences 2001). Other than seasonal rain events, scheduled water releases for the Vernalis Adaptive Management Program (VAMP) normally result in increased flow during April and May. In 2009, the VAMP flow period was truncated resulting in about five days of increased flow during out-migration period.

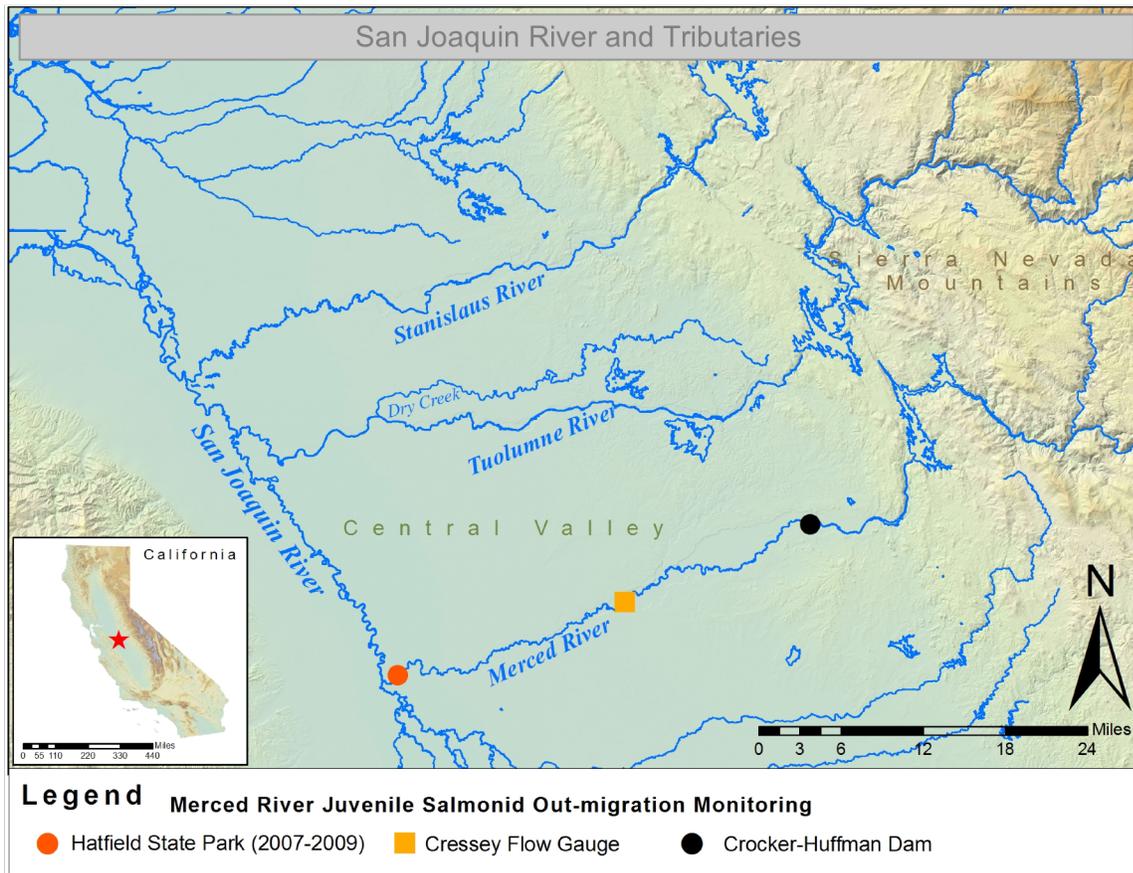


Figure 1. Map of tributaries to the San Joaquin River, including details on the Merced River.

## METHODS

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### Trap Operations

A single RST was operated near Hatfield State Park (Hatfield; rkm 3.2) in 2009, continuing operations undertaken at the site in 2007 and 2008 (Figure 2). Consistent with our primary objectives, several authors have used this methodology to monitor population dynamics and abundance for juvenile salmonid out-migration, including Chinook salmon (e.g., Thedinga et al. 1994; Fleming 1997; Roper and Scarnecchia 1998; Sparkman 2001; Workman 2002 – 2006; Seesholtz et al. 2004; Bottom et al. 2005; Rayton 2006; Johnson and Rayton 2007; Volkhardt et al. 2007; Workman et al. 2007). State park permits allowed CFS access to the site by land or boat if necessary. In 2009, we operated one (1.5 m diameter) RST, manufactured by EG Solutions, Inc. (Corvallis, OR). The trap was secured using 6.35 mm galvanized steel cable leaders fastened to large trees. Trap operations followed standard guidelines (CAMP 1997; Gray et al. 2009). Trap rotations were enumerated by a mechanical counter (Redington Counters, Inc.; Model 29) secured to the pontoon adjacent to the leading edge of the cone; a bolt attached to the front of the cone activated the counter once per revolution. We also recorded stoppages from debris accumulations to better assess the total number of rotations for a sampling period, which provides a useful tool for evaluating trap function. The trap was raised and non-operational on days when sampling did not occur. Significant modifications occurred at the sampling site during the last three seasons, and although we intended to utilize the exact same location as 2008, two large treefalls required a single trap to be relocated near the 2007 site. Following CAMP protocols (CAMP 1997), all trap positions used in the last three years were within 50 m of the original trap site and consistently located in the river channel to maximize trap function while providing for navigability up and down river.



**Figure 2.** Trap installation in March 2009 at Hatfield with warning signs and upstream buoy (left), and example of juvenile Chinook salmon (right).

### Safety Measures

Staff members were trained in RST operational safety, and safety precaution signage was posted to warn river users and park visitors of the inherent dangers of the RSTs (see Figure 3). We

placed signs in conspicuous places at the trap site and on each side of the trap, to warn people of drowning danger as well as “Keep Out” and “Private Property” signs. A warning sign strategically placed upstream of the trap stated “Danger Ahead – Stay Left” with a large arrow pointing in the direction of the best side of the river channel for boaters to pass the traps. Flashing lights and flagging were placed on the traps and along the rigging. All signs were in English and Spanish.

**Fish Capture and Handling**

We followed CFS rotary screw trapping operational protocols and established fish handling procedures (Gray et al. 2009). Trapped fish were collected and processed by CFS staff at least once per day. During high flows (> 500 ft<sup>3</sup>/s) and peak migration times (i.e., after flow changes, generally April to May) traps were processed twice per day (morning and evening). To limit handling injury and stress, all captured fish were anesthetized in groups of 5 to 10 immediately prior to handling using a solution of river water and tricaine methanesulfonate (Western Chemical, Inc.; Tricaine-S; 26.4 mg/L concentration). Litmus strips were used to check pH and baking soda was added to buffer Tricaine-S solution acidity. The effectiveness of Tricaine-S varies with changes in temperature and fish density; therefore, all Tricaine-S solutions were tested with a few fish to determine potency and adjusted if necessary. Furthermore, solution and holding water was cooled with frozen water bottles to reduce temperature and potential for thermal stress. We constantly monitored and maintained water temperature and dissolved oxygen (DO) above critical levels (Gray et al. 2009). StressCoat (Aquarium Pharmaceuticals, Inc.), which helps fish replace their slime coat and scales, was added to the Tricaine-S solution and recovery buckets at a concentration of 2.5 ml per 9.5 L.

We recorded fork length (FL; mm), weight (g), and life stage for 25 randomly-selected salmonids each day; any additional fish were counted. Life stage was determined by assigning a smolt index value based on morphological characteristics (Table 1). Note, the silvery parr designation is only used to describe *O. mykiss*, not Chinook salmon (CAMP 1997). Processed fish were returned to a bucket with fresh river water to recover prior to release. Upon full recovery, captured fish were released ~150 m downstream of the traps in an area with relatively shallow depth (e.g., < 0.5 m) and available cover to decrease predation and recapture risk.

Table 1. Smolt index rating adapted from CDFG.

Smolt Index	Life Stage	Criteria
1	Yolk-sac Fry	-Newly emerged with visible yolk sac
2	Fry	-Recently emerged with sac absorbed; Pigment undeveloped
3	Parr	-Darkly pigmented with distinct parr marks; No silvery coloration; Scales firmly set
4*	Silvery Parr	-Parr marks visible but faded, or completely absent; Intermediate degree of silvering
5	Sub-yearling smolt	-Parr marks highly faded or absent; Bright silver or nearly white coloration; Scales easily shed; Black trailing edge of caudal fin; More slender body
	Yearling smolt	-All the same characteristics as a smolt; Generally larger than 110 mm FL

\*Silvery parr life stage was only used for *O. mykiss*.

## **Catch**

We compared daily catch with flow and summarized our catch by life stage (as determined by the smolt index).

## **Environmental Variables**

We measured physical variables daily (i.e., temperature, dissolved oxygen, turbidity, stage height, and water velocity). HOBO<sup>®</sup> Pendant temperature loggers (Onset Computer Corporation; Part #-UA-001-08) were used to measure hourly water temperature both in-river and inside trap live-boxes. Loggers were downloaded once a week; all temperatures reported are from the in-river logger. Thermograph data was also provided by CDFG from various sites along the river. When available, water temperature and DO were recorded using a digital handheld meter (YSI; Model 550A). Daily instantaneous water temperature and DO measured with the YSI provided in-river conditions for technicians monitoring water temperatures in holding buckets. Instantaneous turbidity was measured in Nephelometric Turbidity Units (NTU) using a turbidity meter (LaMott Company; Model 2020). River stage was recorded daily using an established on-site staff gauge. We measured instantaneous water velocity using a Global Flow Probe (Global Water Instrumentation, Inc.; Model FP101) in front of the trap cone. We obtained average daily flow data from California Data Exchange Center (CDEC), Cressey gauge (CRS; rkm 43.5).

## **Analysis**

### **Trap Efficiency**

Unfortunately, test fish were not available from the Merced River Hatchery (MRH) in 2009 so we could not perform routine trap calibration procedures. Instead, we used data from the 2007 and 2008 mark-recapture experiments to develop conservative passage estimates for the current year. Using data from the previous year provides less rigorous results, but may not materially change the results due to the extremely low catch numbers (i.e., trap efficiency is inconsequential on days when the catch is zero).

In 2007, two 5ft traps (1.5 m) were used in tandem. These smaller traps experienced reduced trap rotation due to consistently low velocities, which resulted in relatively poor trap efficiency estimates. To compensate, in 2008 (at the recommendation of the manufacturer, EG Solutions) we replaced one of the 5 ft traps with an 8 ft trap (2.4 m) and relocated the traps 50 m upstream to an area with higher velocities and more favorable operation conditions. Consequently, 2007 and 2008 represent years of relatively low and high efficiency, respectively. In all, 11 mark-recapture experimental releases were performed at Hatfield in 2007 and 2008, although only 10 release groups were used to estimate trap efficiencies; data from the last test (performed 20 May 2008) were excluded from all analyses, as altered river conditions necessitated relocating the trap (conditions during this test were not comparable with previous release groups). For more details regarding the methodologies employed in the 2007 and 2008 efficiency tests, see Watry et al. (2007; 2008).

### Passage Estimates

A logistic regression was performed to determine the effect of multiple environmental covariates on daily trap efficiencies (using the combined dataset for 2007 and 2008). Environmental factors that were originally considered in our analyses included the natural log of flow (denoted  $\log(\text{flow})$ ), temperature, and turbidity. Fork length at release was also considered, as was the categorical variable ‘year’, to control for between year differences in trap efficiency (e.g., due to differences in trap placement, channel morphology, bank vegetation etc.). We used a backward stepwise regression procedure to determine the ‘best fitting’ model, which was then used to make predictions for daily trap efficiencies.

Briefly, logistic regression is a form of generalized linear model that is applicable to binomial data (McCullach and Nelder 1989; Dobson 2002). (In this case, binomial data would refer to the potential outcomes of fish collection, i.e., either the fish is caught or not.) Here, the binomial probability of interest is the observed trap efficiency ( $q$ ):

$$(3) \quad q = \frac{m}{R},$$

where  $m$  is number of observed recaptures (a binomial variable) of a given release group of size  $R$ . The logistic model with one explanatory variable ( $x$ ) can be expressed in linear form as:

$$(4) \quad y = \beta_0 + \beta_1 x,$$

where  $y$  is the “logit” transform of the observed trap efficiency ( $q$ ):

$$(5) \quad y = \text{logit}(q) = \log\left(\frac{q}{1-q}\right).$$

The coefficients ( $\beta$ ), which are estimated via maximum likelihood, provide predicted values of trap efficiency via the following back-transformation of the logit function:

$$(6) \quad \hat{q} = \frac{\exp(\hat{\beta}_0 + \hat{\beta}_1 x)}{1 + \exp(\hat{\beta}_0 + \hat{\beta}_1 x)}.$$

In the model, we used values of  $\log(\text{flow})$  as the explanatory variable ( $x$ ). Consistent with results for screw traps on the Stanislaus River (CFS, unpublished data), we found greater deviance in this model than that expected due to binomial sampling error alone (McCullach and Nelder 1989; Venables and Ripley 1999). Such extra-binomial variation is represented by a dispersion parameter,  $\phi$ , which is a scalar of the assumed binomial variance. The dispersion parameter is estimated from the fit of a logistic regression and does not affect coefficient point estimates (Venables and Ripley 1999). When estimating standard errors and computing confidence intervals, the coefficient variance-covariance matrix must be multiplied by the  $\phi$  estimate. The daily passage abundance ( $n$ ) of migrating juvenile Chinook salmon was estimated as follows:

$$(7) \quad n = \frac{c}{q},$$

where  $c$  was observed daily count and  $q$  was the estimated trap efficiency for that day based on flow. Standard errors (SE) and confidence intervals for measures of total annual passage were computed using the methods described in Watry et al. 2008.

Passage estimates for 2009 were calculated using the mean daily values for 2007 and 2008 trap efficiencies. In addition, to represent low and high passage estimates, total passage was also calculated for 2009 using the separate 2007 and 2008 data sets. As the efficiencies from 2007 and 2008 represent relatively low and high efficiencies, estimates based on the mean values from these two years should provide a conservative estimate for juvenile passage in 2009. Moreover, estimates based solely on 2007 and 2008 efficiencies will also provide an estimate of high and low passage, as these values are based on years of relatively low and high efficiency, respectively.

**Comparison of Water Temperature**

To address our hypothesis about water temperature among years we compared mean daily water temperature collected at the trap among years (2008–2009). We used ANOVA and a paired t-test to test the following null hypothesis:

*H10: There is no difference in water temperature among years (2008–2009).*

**RESULTS**

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**Trap Operations**

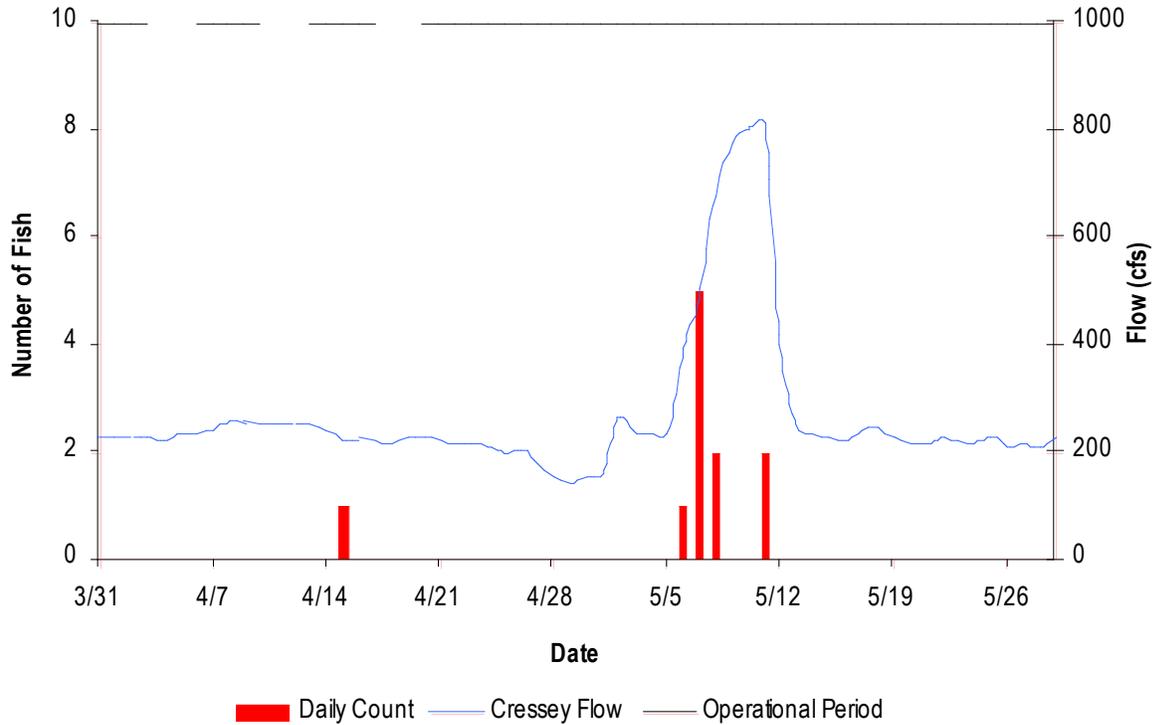
We began sampling immediately following trap installation on 31 March 2009 and terminated operations on 29 May 2009. Daily catch was consistently low (< 2 – 5 juvenile Chinook salmon) and traps were operated for 56 trapping days.

**Catch**

We captured a total of 11 natural, unmarked juvenile Chinook salmon and no *O. mykiss* (Table 2; Figure 4). Catch was too low to effectively evaluate peak daily catch; however, peak catches coincided with controlled flow releases for the Vernalis Adaptive Management Plan (VAMP) which were limited to a 5-day period from 7 May – 12 May 2009. There were no mortalities in 2009.

*Table 2. Catch by life stages (determined by smolt index) of juvenile Chinook salmon at Hatfield, 2009.*

Date Range	Number of Days Sampled	Catch Summary				
		Total	Fry	Parr	Sub-yearling Smolt	Yearling-smolt
3/31 - 4/14	11	0	0	0	0	0
4/15	1	1	0	0	1	0
4/16 – 5/5	18	0	0	0	0	0
5/6 – 5/8	3	8	0	0	8	0
5/9 – 5/10	2	0	0	0	0	0
5/11	1	2	0	0	2	0
5/12 – 5/29	18	0	0	0	0	0
<b>3/31 – 5/29/2009</b>	<b>56</b>	<b>11</b>	<b>0</b>	<b>0</b>	<b>11</b>	<b>0</b>



**Figure 3. Daily catch of juvenile Chinook salmon, Merced River flow at Cressey, and days of operation at Hatfield, 2009; Trap operation period 31 March through 29 May 2009.**

Since trap operations began later in the season, we targeted the sub-yearling smolt out-migration period. As such, only the sub-yearling smolt life history type was captured (Table 3).

*Table 3. Percent of run and range of catch dates for each life stage (according to smolt index) of Chinook salmon from Hatfield, 2008*

Life Stage	Number	Percent of Run	Date Range	Average FL (mm)
Fry	0	0	n/a	n/a
Parr	0	0	n/a	n/a
Sub-yearling smolt	11	100	3/31 – 5/29	99.8 ± 5.9
Yearling-smolt	0	0	n/a	n/a
<b>Cumulative Total</b>	<b>11</b>	<b>100</b>	<b>3/31 – 5/29/2008</b>	

### Environmental Variables

Flow at CRS during the season ranged from 146 to 814 ft<sup>3</sup>/s (4.1 – 23.0 m<sup>3</sup>/s), and were controlled by releases from New Exchequer Dam (Table 4). Daily temperature ranged from 14.5 – 25.7°C during the sample period. Turbidity (NTU) was greatest in the early part of the out-migration season, but decreased as rain events ceased with the onset of spring and summer. Instantaneous DO was never measured below 5.00 mg/L (critically low level); 7.07 mg/L was the lowest measurement recorded.

Table 4. Summary of environmental variables (i.e., mean daily flow reported at Cressey, mean daily water temperature recorded on-site, instantaneous DO and instantaneous turbidity) in the Merced River, 2009.

Date	Daily Flow		Daily Temperature (°C)			DO (mg/L)		Turbidity (NTU)	
	Min	Max	Min	Max	Average	Min	Average	Max	Average
3/26 - 4/1	224	232	15.8	16.6	16.2	9.05	9.10	4.85	4.38
4/2 - 4/8	221	258	15.7	17.8	16.8	8.18	8.76	6.37	4.17
4/9 - 4/15	224	256	14.5	16.2	15.5	8.31	8.77	4.98	3.50
4/16 - 4/22	214	232	15.3	22.4	19.1	7.80	8.46	3.88	2.52
4/23 - 4/29	146	214	17.9	21.8	19.1	7.61	8.46	3.28	2.54
4/30 - 5/6	155	396	18.1	21.3	19.4	7.07	7.89	59.50	15.52
5/7 - 5/13	251	814	18.2	21.3	19.6	7.32	8.11	14.00	6.67
5/14 - 5/20	214	245	19.4	25.5	23.6	7.15	7.59	6.23	3.60
5/21 - 5/27	212	231	21.9	25.4	23.5	7.70	7.91	2.74	2.26
5/28 - 6/3	210	227	24.7	25.7	25.2	7.32	7.64	2.47	2.36

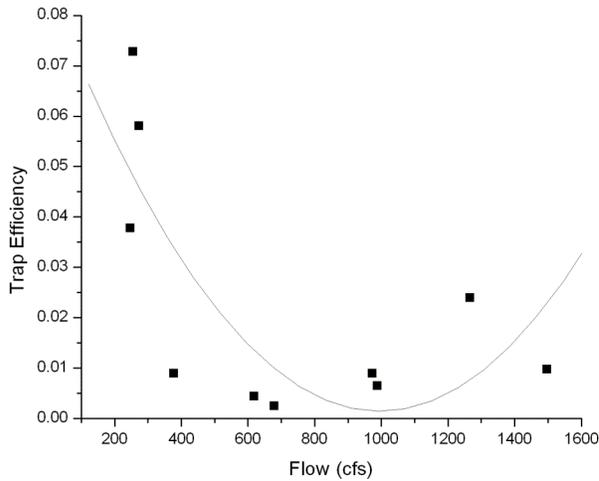
## Analysis

### Trap Efficiency

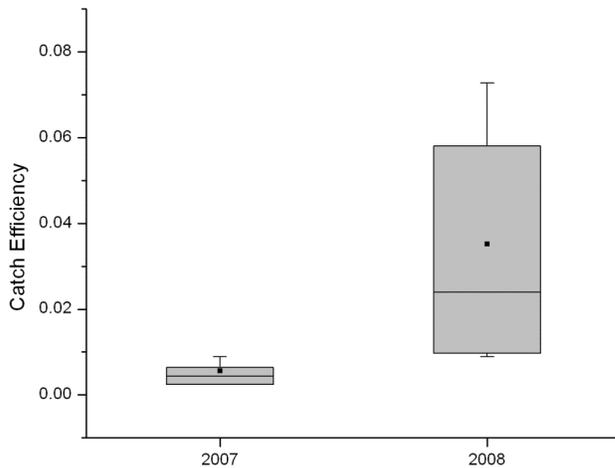
Logistic regression analysis for the 2007-2008 trap efficiency data indicated that trap efficiencies were significantly related to log(flow) and year (Table 5), while a strong negative relationship was observed between trap efficiency and flow (Figure 4). Efficiencies also differed between years, with those recorded in 2008 being greater than those in 2007 (Figure 5). Log(flow) was the dominant explanatory variable (accounting for 52% of the total deviance), while the categorical variable ‘year’ accounted for 37% of the deviance.

Table 5. Analysis of deviance for the logistic model fit to trap efficiencies of 10 mark-recapture releases at the Hatfield trap site in 2007 and 2008 (df = degrees of freedom). Variables originally considered, but ultimately dropped included: temperature, turbidity, and fork length.

Variable	df	Deviance	Residual df	Residual Deviance	F Value	Pr (F)
Intercept			9	289.4		
log(flow)	1	149.0	8	140.4	31.9	<0.001
Year	1	107.4	7	33.0	23.0	0.002
<b>Total</b>	<b>2</b>	<b>256.4</b>	<b>15</b>	<b>33.0</b>		



**Figure 4. Trap efficiencies as a function of flow for the 10 mark-recapture releases at Hatfield (2007 and 2008). Solid lines are exploratory fits of smoothing splines.**



**Figure 5. Mean catch efficiency values for 2007 and 2008 (small solid box), with their minimum and maximum values (whiskers). Solid, inner box represents the mean with 95% confidence; outer lines (whiskers) indicate 1% and 99% quantiles, while inner boxes represent 25%, median and 75% quantiles.**

### Passage Estimates

In 2009, most fish migrated past the trap site between 14 April and 11 May 2009, with peak (median) passage occurring on 7 May 2009. Migration timing appeared to coincide with increases in river discharge related to VAMP flow releases from 6 to 12 May 2009 (Figure 3). Estimates for the total abundance of juvenile Chinook salmon passing the Hatfield trap site between 2007 and 2009 are presented in Table 6. The passage estimate for 2009 was 968 juvenile Chinook salmon, based on mean 2007 and 2008 efficiency values. High and low estimates based on the efficiency values from the separate 2007 and 2008 datasets are 2,751 and

588 fish, respectively. Together, results from 2007-2009 demonstrate a sharp decline in passage estimates over the past three years.

Table 6. Estimated total number of juvenile Chinook salmon passing the Hatfield trap site, 2007-2009. SE = standard error of the estimate. CV = coefficient of variation of the estimate, where % CV = (SE / Total Passage) \* 100. 95% confidence intervals are reported for both normal and lognormal error distributions.

Year	Passage Estimate	SE	CV	Lower 95% CI	Upper 95% CI
2007	28,889	9,122	31.6%	13,218	51,449
2008	4,273	2,243	52.5%	1,593	11,460
2009	968**	-	-	-	-

\*\*Because no calibration fish were available, no associated SE or confidence intervals (CIs) were estimated for 2009; only the range of high and low values based on 2007 and 2008 efficiencies (2,751 and 588, respectively).

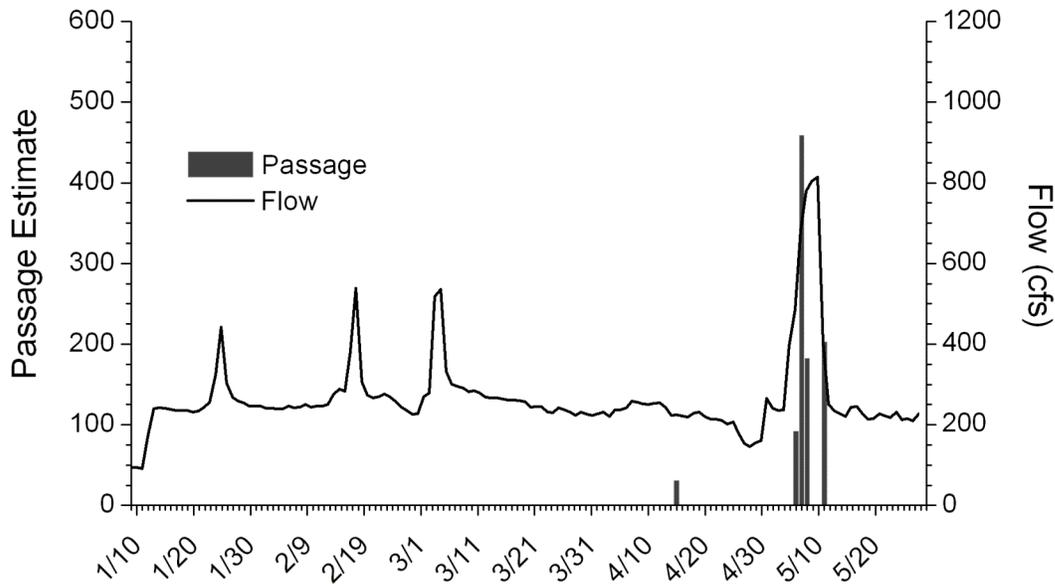


Figure 6. Daily passage of juvenile Chinook salmon and flow at Cressey in the Merced River at Hatfield, 2009.

### Comparison of Water Temperature

We proved Hypothesis 1 false as there were differences in April and May mean daily water temperatures recorded at Hatfield in 2008 and 2009. Mean daily temperatures were significantly higher for both April and May in 2009 compared to 2008 (Table 7; Figure 7).

Table 7. Mean daily water temperature (°C) for April and May measured at Hatfield RST, 2008 and 2009. Bold p-value indicates significance at  $\alpha = 0.05$ .

	April		May	
	2008	2009	2008	2009
Mean	17.5	18.8	18.3	22.7
df	1438		1486	
SE	0.08	0.08	0.10	0.10
F-value	121.8		996.6	
p-value	<b>&lt; 0.0001</b>		<b>&lt; 0.0001</b>	

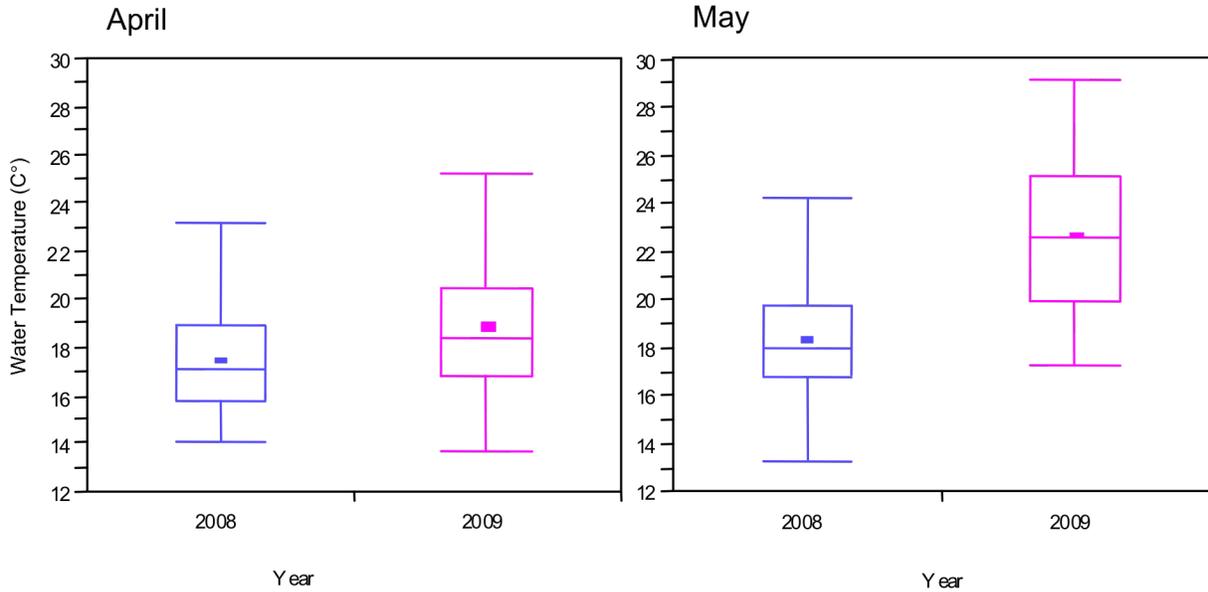


Figure 7. Comparison of mean April and May water temperatures among years at Hatfield for 2008 and 2009. Solid, inner box represents the mean with 95% confidence; outer lines (whiskers) indicate 1% and 99% quantiles, while inner boxes represent 25%, median and 75% quantiles.

## DISCUSSION

On 29 May 2009, we completed the third consecutive year of RST monitoring at Hatfield to determine the abundance, size, and timing of juvenile salmonid out-migrants from the lower Merced River to the San Joaquin River. This effort occurred in partnership with USFWS and was funded by AFRP as a continuation of the CDFG monitoring operations, discontinued at Hagaman in 2002.

In 2008, the Sacramento-San Joaquin River system fall-run Chinook salmon escapement fell far below conservation objective targets of 122,000 – 180,000 natural and hatchery adult spawners to about 66,000 returning fish. This continued the declaration of a West Coast commercial salmon fishery failure under the Magnusson-Stevens Act (NOAA 2008, 2009). Commercial and recreational fisheries for Chinook salmon remained closed during the fall 2008 season (CDFG 2009; PFMC 2009). While the overall cause of this decline is not completely understood,

NOAA (2008) indicates broad-scale effects across the Central Valley and the ocean as possible reasons.

Out-migrant abundance was still expected to be low in 2009 due to the collapse of the West Coast Chinook salmon fishery (NOAA 2008), and results were consistent with these expectations. We caught 11 juvenile Chinook salmon; and, based on the mean 2007 and 2008 trap efficiencies, we estimated out-migrant passage as 968 juvenile Chinook salmon (range: 588 – 2,751). Since 2007 and 2008 represent years of relatively low and high efficiencies, our result based on the mean values from these two years can be viewed as a conservative estimate for total juvenile abundance in 2009.

Catch consisted entirely of sub-yearling out-migrants; however, trapping operations were specifically targeted on this life history type (based on the nearly absent fry life history type found in previous sampling years; Montgomery et al. 2007; 2008). Diversity in salmon early life history is an important factor affecting the adaptability (Thorpe 1989; Mangel 1994a, b) and fitness (Healey and Prince 1995) of salmonid populations. The lack of other lifestages during the 2007-2009 monitoring program indicates serious issues related to the Merced River Chinook salmon population.

Understanding the effects of environmental conditions on life history diversity, survival and the response of salmonid populations in the Merced River is important. Flow, turbidity, and water temperature are all key factors affecting migration patterns and survival of juvenile Chinook salmon (Holtby et al. 1989; Gregory and Levings 1998; Giannico and Healey 1998; Sommer et al. 2001). For example, differing magnitude flow pulses have been found to stimulate juvenile Chinook salmon migration rates. Kjelson et al. (1981) found that peak catches in the Sacramento-San Joaquin Delta were often correlated with flow peaks caused by storm runoff. They suggested flow pulses stimulated fry to emigrate from spawning grounds; a finding supported by USFWS (2003). Turbidity and flow are related terms when evaluating migration triggers, as higher turbidity is usually caused by a freshet or increased flow. Several authors have found increased turbidity to reduce predation on resident and migrating young salmonids by providing a form of protective cover, enabling them to evade detection or capture (Gradall and Swenson 1982; Cezilly 1992; Gregory 1993; Gregory and Levings 1998). This phenomenon could contribute to higher in-river survival resulting in increased catch rates during periods of higher flows and increased turbidity. Other authors have demonstrated the influence of flow and temperature on juvenile Chinook salmon size (Marine 1997; Myrick and Cech 2001) and determined rearing conditions (e.g., water temperature, prey production) to have strong effects on growth and development (Holtby et al. 1989; Sommer et al. 2001).

Each life stage of Chinook salmon and steelhead has different physiological responses to water temperature. These responses may reflect chronic and sub-lethal effects, such as changes in development rate, growth rate or condition, or they may be acute effects resulting in the loss of equilibrium and ultimately mortality (Brett 1971, Boles 1982, Schreck 1982, Rich 1997, Sullivan et al 2000). The thermal tolerance response of each life stage varies in response to a number of factors including (1) acclimation temperature, (2) the absolute exposure temperature, (3) the

duration of exposure to elevated temperature, and (4) the overall health and condition of the organisms (Hanson 1997).

Based on a variety of studies that evaluate the effect of water temperature on emigrating juvenile Chinook salmon fry and smolts, temperature guidelines can be established which represent generally acceptable conditions, stressful conditions, and unacceptable conditions. The SWRCB 1991 Water Quality Control Plan listed a daily mean water temperature of 20°C (68°F) as an upper threshold temperature objective for protection of fall-run Chinook salmon during the spring (April through June) emigration period. Growth rates for juvenile Chinook salmon have been reported to decline, particularly at reduced ration levels, at water temperatures above 18.3°C (65°F). For instance, Banks et al. (1971) did not detect significant differences in body condition or blood chemistry for juvenile Chinook salmon reared at temperatures below 18.3°C (65°F), and juvenile Chinook salmon have been observed, in laboratory tests, to behaviorally avoid temperatures exceeding approximately 18.3°C. Furthermore, juvenile salmon and steelhead have been observed with increased susceptibility to disease (Johnson and Brice 1953), a reduction in the time to death after exposure to pathogens, and increased disease-induced mortality when reared at temperatures above approximately 18.3°C (65°F). Based on these results, stressful temperature conditions for juvenile Chinook salmon and steelhead rearing on the Merced River are believed to occur between 18.3°C and 20°C (65°F to 68°F). A critical threshold for stressful temperatures most likely occurs at or near 18.3°C.

Mean daily water temperature exceeded this critical level during April and May 2009 (18.8°C and 22.7°C, respectively), whereas water temperatures did not exceed this level for the same months in 2008. Myrick and Cech (2001) found that juvenile Chinook salmon in the Sacramento-San Joaquin river systems are more susceptible to the effects of acute and chronic elevated water temperatures. Rich (1987) and Marine (1997) both observed adverse effects due to the exposure to water temperatures > 24°C. In the Merced River at the Hatfield site during April and May 2009, there were 31 total hours over 4 days and 263 total hours over 18 days with water temperatures exceeding 24°C, respectively; whereas 31 May, with a total of two hours, was the only day when water temperatures exceeded 24°C during April or May in 2008. In contrast, from 15 through 31 May 2009 there was an average of 15.2 h/d (range 6 – 22 h/d) with water temperatures above 24°C; no fish were captured after 11 May 2009. The cumulative effects of exposure to increasing water temperatures and related considerations (i.e., acclimation time, duration of exposure, and diel fluctuations) and the influence of water quality (e.g., DO levels, toxins, disease prevalence, etc.) are likely contributing factors to low juvenile Chinook salmon abundances and poor survival on the Merced River.

Effective actions are essential on the Merced River, which may include habitat rehabilitation and improvement in water quality and outflow conditions. Continued work, especially more detailed analysis of available data, may provide critical insight for fisheries managers concerned with population recovery. Results from the 2009 season provide critical information to AFRP and CAMP which may be used to better understand and improve conditions for Chinook salmon and *O. mykiss* within the lower Merced River.

## RECOMMENDATIONS

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Concerns have been raised regarding the low and declining catch experienced over the last three seasons, operational efficiencies, and the ability to test efficiencies when test fish may not be available from the Merced River Fish Facility (MRFF) operated by CDFG. Our team has worked diligently to resolve matters of operational inefficiencies to improve catch, and we demonstrated marked improvements during 2008 compared to 2007 based on measured efficiency rates. Regardless, catch remained very low and resulted in extremely low abundances.

The site at Hatfield State Park experienced significant modification over the last three seasons. Low average trap rotations and measured trap efficiency in 2007 resulted in relocating the traps to a more favorable location (approximately 40 m upstream) in 2008. The new location yielded improved results; however, two large cottonwoods fell into the river where the traps were located in 2008 and required us to modify operations in 2009 by fishing only a single trap and relocating the trap to the 2007 site. Unfortunately, test fish were not available from the MRFF in 2009, eliminating routine trap calibrations.

Considering the degraded trapping conditions at the Hatfield site, we recommend relocating the trap to a more favorable and stable location. Flow and habitat conditions suitable for operating a rotary screw trap are limited in the lower Merced River near the mouth, including the area around Hatfield State Park. We propose to relocate the trap to the area near Hagaman State Park to establish a reliable monitoring program for the lower Merced River as very few marginally acceptable sites exist downstream of this area.

Low detection rates can still provide valuable information to inform future management when population levels cycle out of low periods (years) of abundance similar to current conditions, especially when trap operation (i.e., rotations) have been reliable. A zero catch provides sufficient information to estimate passage, even when trap efficiencies are unavailable. Extremely low numbers provide a baseline in a trend dataset to help measure the cumulative effects of different management actions on juvenile abundance (AFRP 2001). Without this baseline it would be difficult to identify responses to management actions and the relative population recovery at the watershed level.

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## APPENDIX 1: MERCED RIVER POINTS OF INTEREST

Point	Purpose/Significance	Operator	rkm (RM)
New Exchequer Dam/ Lake McClure	Constructed in 1967	Merced Irrigation District	100.0 (62)
	Large storage capacity and long residence time		
	Cold water discharge		
McSwain Dam and Reservoir	Constructed in 1966	Merced Irrigation District	90 (56)
	Short residence time		
Merced Falls Dam and Forebay	Constructed in 1901	Pacific Gas and Electric	88.5 (55)
	Short residence time		
	Northside canal diversion point		
Crocker-Huffam Dam and Reservoir	Constructed in 1910	Merced Irrigation District	83.7 (52)
	Merced Irrigation District main canal diversion point		
	Upstream terminus of fish migration		
Merced River Hatchery	Constructed in 1970	CDFG	83.7 (52)
	Only hatchery in San Joaquin basin		
Primary Spawning Reach	The majority of spawning occurs above RM 45.2 Below RM 32.5 very little suitable spawning habitat exists		52.2 – 83.7 (32.5 – 52)
Hopeton Rotary Screw Traps	Salmonid population studies	Merced Irrigation District	61.2 (38)
Cressey Gauge	Primary flow data	United States Geological Survey (USGS)	43.5 (27)
Hagaman State Park	Former screw trapping site (1998-2002)	CDFG	19.3 (12)
Hatfield State Park	Current screw trapping site (2007)	USFWS-AFRP	3.2 (2)

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