CHAPTER 7

ROUTE ENTRAINMENT ANALYSIS AT HEAD OF OLD RIVER, 2009 AND 2010

Contributed by Rebecca Buchanan, PhD
Columbia Basin Research, School of Aquatic and Fishery Sciences, University of Washington, Seattle ,WA









Methods

Supplementary analyses were conducted of the relationship between river conditions and the probability of remaining in the San Joaquin River at the head of Old River in 2009 and 2010. These analyses were based on the results of the data processing performed in the survival analysis of the 2009 and 2010 VAMP studies (SJRGA 2010, SJRGA 2011). Only detections classified as coming from live salmon smolts were used in this analysis. More information on data processing and the predator filter in the 2009 and 2010 studies is described in SJRGA, 2010 and SJRGA, 2011.

Analysis methods were the same as those used in the 2011 route entrainment analysis (Chapter 5). In addition to the covariates used in the 2011 route analysis, the status of the non-physical barrier at the head of Old River at the time of fish arrival at the barrier was included in the 2009 and 2010 analyses:

$$B_i = \begin{cases} 1, & \text{barrier open at arrival of tag } i \\ 0, & \text{barrier closed at arrival of tag } i \end{cases}$$

(data courtesy of the U. S. Bureau of Reclamation). Interaction effects between the barrier status and river flow, water velocity, and flow proportion were tested in the flow, velocity and flow proportion models, respectively.

Results

2009 Results

A total of 365 tags were observed passing the acoustic receivers in either the San Joaquin River or Old River near the head of Old River in 2009, with associated observations of river conditions. Of these 365 fish, 192 were observed entering Old River, while the other 173 remained in the San Joaquin River past the head of Old River. River flow and water velocity measured at the SJL gaging station in the San Joaquin River near Lathrop were very highly correlated in 2009 (r=0.99), with flow values ranging from -1,287 cfs to 2,133 cfs (average = 898 cfs) when tagged fish were passing the SJL gaging station and the OH1 gaging station in Old River just downstream of its divergence from the San Joaquin River. A description of the gaging station locations can be found in Chapter 4. Negative values of flow indicate reverse flow at the SJL gaging station. At the OH1 gaging station, flow and water velocity were also highly correlated (r=0.96), with flow values ranging from 203 cfs to 2,186 cfs (average = 1,515 cfs) when tagged fish passed the SJL and OH1 gaging stations. No reverse flow was observed at the OH1 station. Flow at the SJL station was moderately negatively correlated with flow at the OH1 gaging station (r=-0.48). Water velocity measures from the two gaging stations were also moderately negatively correlated (r=-0.37). Water velocity at the SJL station ranged from -0.88 ft/s to 1.55 ft/s (average = 0.75 ft/s), while at the OH1 station, it ranged from 0.11 ft/s to 1.58 ft/s (average = 1.03 ft/s) while tagged fish passed the gaging stations. Flow proportion into the San Joaquin River was moderately correlated with flow into the San Joaquin River (r=0.57), with negative values of flow proportion corresponding to reverse flow at the SJL gage. Flow proportion into the San Joaquin River during the time of tagged fish passage of the gaging stations (pQ_{iA}) ranged from -722% to 91% (average = 10%), omitting one extreme negative value of -2,180%. The extreme negative values occurred when flow was reversed at the SJL gage and nearly the same magnitude as the positive flow at the OH1 gage. Because flow proportion was negative only under conditions of reverse flow, the reverse flow covariate (uQ_{iA}) was omitted from the multivariate analysis with the flow proportion model.

Results of the single-variate analyses relating route entrainment at the head of Old River to river conditions found significant effect of both flow and velocity at both the SJL and the OH1 gaging stations (P<0.0005 in each case, Table 7-1). Flow proportion into the San Joaquin River and the occurrence of reverse flow at the SJL gage were also significantly correlated with route entrainment (P<0.0001 in both cases), as was change in both velocity and flow at OH1 (P<0.0001 in both cases). The status of the non-physical barrier (on versus off) was significantly correlated with route entrainment (P=0.0010), as were exports at CVP (P=0.0010) and combined exports throughout the Delta (P=0.0040). However, exports at SWP alone were not significantly correlated with route entrainment at the head of Old River (P=0.2709). Fork length, release group, change in flow and velocity at SJL, and change in flow proportion into the San Joaquin were not significantly correlated with route entrainment, either (P>0.3 in each case; Table 7-1).

The single-variate analyses may suggest possible relationships, but due to confounding among the independent covariates and the possibility of a causal relationship with an unmonitored factor, it is not possible to conclude that changes in any of the significant single-variate measures directly produce changes in route entrainment at the head of Old River. Multi-variate analysis may shed more light on which covariates are worthy of further study, although causal relationships are still not discernible.

Multivariate analyses also found significant effects of flow and velocity at both the SJL and OH1 gaging stations, as well as flow proportion into the San Joaquin River, with significantly different effects when the non-physical barrier was on (barrier = 1) than when it was off (barrier = 0) (Table 7-2). All three models (flow, velocity, and flow proportion) adequately fit the data (P>0.9), but the flow model accounted for more variation in route entrainment than either water velocity (ΔAIC=6.56) or flow proportion (ΔAIC=27.33) (Table 7-2). The flow model predicted the route entrainment probability according to:

$$\widehat{\psi_A} = \frac{exp(-1.20 + 0.002Q_A - 0.001Q_B)}{1 + exp(-1.20 + 0.002Q_A - 0.001Q_B)}$$

when the barrier was off, and

$$\widehat{\psi_A} = \frac{exp(-9.07 + 0.005Q_A + 0.002Q_B)}{1 + exp(-9.07 + 0.005Q_A + 0.002Q_B)}$$

when the barrier was on.

For flow at OH1 fixed at the mean observed value there when tagged fish were passing (1,515 cfs), increases in flow at SJL were predicted to increase the probability of a tagged fish remaining in the San Joaquin River, with a steeper increase if the barrier was on (Figure 7-1). For flow at SJL fixed at its mean observed value (893 cfs), increases in flow at OH1 were predicted to increase the probability of a tagged fish remaining in the San Joaquin River if the barrier was on, but were predicted to decrease the probability of remaining in the San Joaquin if the barrier was off (Figure 7-2).

2010 Results

A total of 430 tags were observed passing the acoustic receivers in either the San Joaquin River or Old River near the head of Old River in 2010, with associated observations of river conditions. Of these 430 tagged fish, 228 were observed entering Old River, while the other 202 fish remaining in the San Joaquin River past the head of Old River. River flow and water velocity measured at the SJL gaging station in the San Joaquin River at times when tagged fish were passing were highly correlated in 2010 (r=0.95). Observed flow values ranged from 909 cfs to 3,595 cfs (average = 2,595 cfs), and observed velocity values ranged from 0.5 ft/s to 2.3 ft/s (average = 1.6 ft/s). River flow and water velocity measured at the OH1 gaging station in Old River when tagged fish were passing were also highly correlated (r=0.92), with flow values ranging from 1,703 cfs to 3,404 cfs (average = 2,777 cfs) and velocity values ranging from 0.9 ft/s to 2.0 ft/s (average = 1.5 ft/s). There was little or no correlation between flow (r=0.04) or

Table 7-1
Results of Single-variate Analyses of Route Entrainment at the Head of Old River in 2009

Year	Covariate	F-test		
		F	df1, df2	P
2009	Velocity at SJL[a]	212.8572	1, 363	<0.0001
2009	Flow at SJL[a]	193.7478	1, 363	<0.0001
2009	Flow proportion into San Joaquin[a]	174.0139	1, 363	<0.0001
2009	Reverse flow into San Joaquin[a]	151.5927	1, 363	<0.0001
2009	Change in velocity at OH1[a]	40.8793	1, 347	<0.0001
2009	Flow at OH1[a]	22.6527	1, 363	<0.0001
2009	Change in flow at OH1[a]	16.8309	1, 347	<0.0001
2009	Velocity at OH1[a]	12.8934	1, 363	0.0004
2009	Barrier[a]	11.0410	1, 363	0.0010
2009	Exports at CVP[a]	10.9377	1, 363	0.0010
2009	Combined Exports[a]	8.3972	1, 363	0.0040
2009	Exports at SWP	1.2159	1, 363	0.2709
2009	Change in velocity at SJL	0.9906	1, 347	0.3203
2009	Fork Length	0.7137	1, 363	0.3988
2009	Release Group	0.8675	6, 358	0.5189
2009	Change in flow proportion into San Joaquin	0.3984	1, 347	0.5283
2009	Change in flow at SJL	0.0628	1, 347	0.8023

[a] Significant at 5% level

Figure 7-1
Fitted Probability of Remaining in the San Joaquin River at the Head of Old River versus River Discharge Measured at the SJL Gaging Station near Lathrop, CA, for River Discharge at OH1 Gaging Station in Old River Fixed at its Average (1,515 cfs), with 95% Confidence Bands, in 2009. Barrier is Non-Physical Barrier at Head of Old River

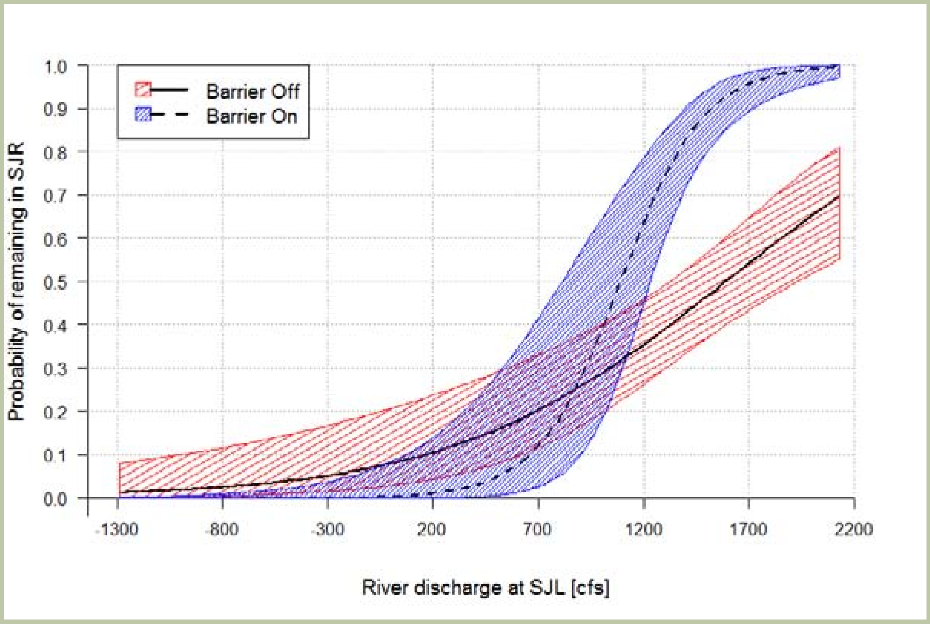


Figure 7-2
Fitted Probability of Remaining in the San Joaquin River at the Head of Old River versus River Discharge Measured at the OH1 Gaging Station in Old River, for River Discharge at SJL Gaging Station near Lathrop, CA, Fixed at its Average (893 cfs), with 95% Confidence Bands, in 2009. Barrier is Non-Physical Barrier at Head of Old River

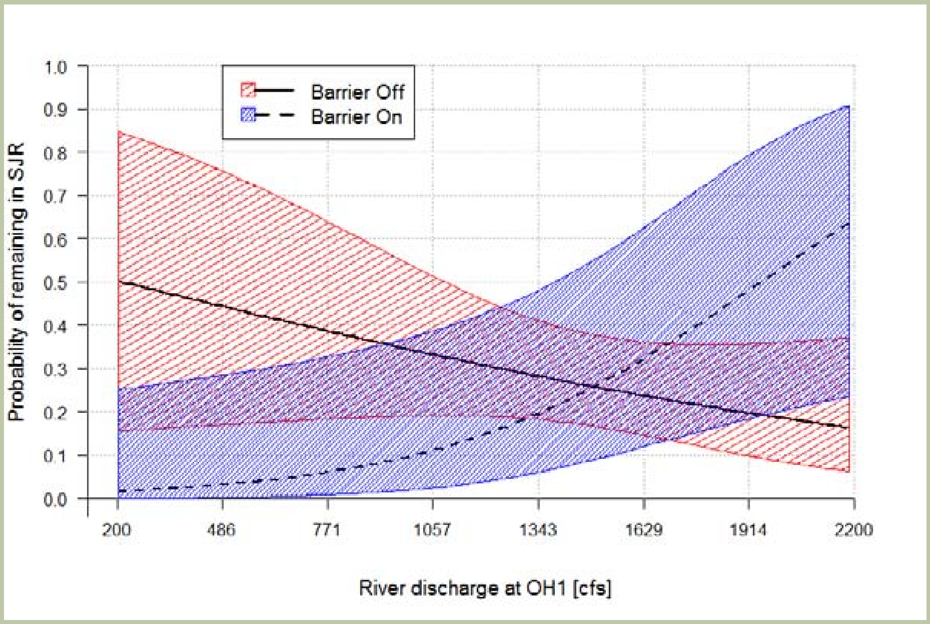


Table 7-2
Results of Multivariate Analyses of Route Entrainment at the Head of Old River in 2009

Model Type	Covariate[a]	Estimate	S.E.	t-Test		
				t	df	P
Flow	Intercept	-1.0723	0.2704	-3.966	359	<0.0001
	Q_A	1.6324	0.3647	4.476	359	<0.0001
	Q_B	-0.2749	0.209	-1.315	359	0.1893
	Barrier	0.0632	0.666	0.095	359	0.9244
	Q_A*Barrier	3.7580	1.2102	3.105	359	0.0021
	Q_B*Barrier	1.0539	0.3813	2.764	359	0.0060
Goodness-of-fit: χ^2=2.5464, df=13, P=0.9991; AIC = 289.60						
Velocity	Intercept	-1.0640	0.2808	-3.776	360	0.0002
	V_A	1.7445	0.3938	4.430	360	<0.0001
	V_B	-0.3070	0.1728	-1.776	360	0.0766
	Barrier	-0.5429	0.8145	-0.667	360	0.5052
	V_A*Barrier	3.3994	1.2618	2.694	360	0.0074
Goodness-of-fit: χ^2=2.9471, df=13, P=0.9981; AIC = 296.16						
Flow Proportion	Intercept	-1.8121	0.5039	-3.596	361	0.0004
	pQ_A	5.7413	1.4593	3.934	361	0.0001
	Barrier	-0.7723	1.3045	-0.592	361	0.5542
	pQ_A*Barrier	7.4123	4.2399	1.748	361	0.0813
Goodness-of-fit: χ^2=6.3064, df=13, P=0.9343; AIC = 316.93						

[a] continuous covariates (Q_A, Q_B, V_A, V_B, pQ_A) are standardized

Table 7-3
Results of Single-variate Analyses of Route Entrainment at the Head of Old River in 2010

Year	Covariate	F-test		
		F	df1, df2	P
2009	Barrier[a]	14.4717	1, 428	0.0002
2009	Flow proportion into San Joaquin[a]	13.5411	1, 428	0.0003
2009	Flow at SJL[a]	9.0700	1, 428	0.0027
2009	Velocity at SJL[a]	7.1774	1, 428	0.0077
2009	Flow at OH1[a]	4.8240	1, 428	0.0286
2009	Change in velocity at OH1	3.1450	1, 413	0.0769
2009	Velocity at OH1	2.8854	1, 428	0.0901
2009	Combined Exports	1.3152	1, 428	0.2521
2009	Change in flow at OH1	1.2129	1, 413	0.2714
2009	Change in velocity at SJL	0.5482	1, 428	0.4595
2009	Fork Length	0.3062	1, 428	0.5803
2009	Release Group	0.7067	6, 423	0.6444
2009	Exports at SWP	0.0752	1, 428	0.7841
2009	Change in flow proportion into San Joaquin	0.0479	1, 413	0.8268
2009	Change in flow at SJL	0.0329	1, 428	0.8562
2009	Exports at CVP	0.0223	1, 428	0.8813

[a] Significant at 5% level

Table 7-4
Results of Multivariate Analyses of Route Entrainment at the Head of Old River in 2010

Model Type	Covariate[a]	Estimate	S.E.	t-Test		
				t	df	P
Flow	Intercept	-0.5463	0.1473	-3.710	426	0.0002
	Q_A	0.3302	0.1054	3.134	426	0.0018
	Q_B	-0.2623	0.1022	-2.568	426	0.0106
	Barrier	0.7947	0.2022	3.930	426	< 0.0001
Goodness-of-fit: χ^2=17.3751, df=18, P=0.4975; AIC = 566.94						
Flow Proportion	Intercept	-0.5432	0.1471	-3.693	427	0.0003
	pQ_A	0.3944	0.1089	3.623	427	0.0003
	Barrier	0.7828	0.2018	3.880	427	0.0001
Goodness-of-fit: χ^2=13.9929, df=18, P=0.7296; AIC = 567.00						
Velocity	Intercept	-0.5470	0.1472	-3.718	426	0.0002
	V_A	0.3606	0.1099	3.282	426	0.0011
	V_B	-0.3044	0.1066	-2.856	426	0.0045
	Barrier	0.7966	0.2023	3.938	426	< 0.0001
Goodness-of-fit: χ^2=12.6394, df=18, P=0.8125; AIC = 567.80						

[a] continuous covariates (Q_A, Q_B, V_A, V_B, pQ_A) are standardized

velocity (r=0.28) at SJL and flow at OH1 during times of fish passage in 2010, although there was moderate correlation between changes in flow at SJL and observed velocity at OH1 (r=-0.48), and between changes in flow at OH1 and observed velocity at SJL (r=0.53). Observed flow proportion into the San Joaquin River at times of fish passage ranged in value from 25% to 62% (average = 48%), and was highly correlated with flow measured at SJL (r=0.91). Because flow was never reversed in the San Joaquin River during the time of fish passage in 2010, the reverse flow covariate (uQ_{iA}) was always equal to 1, and so was omitted from the analyses. There was little variation in CVP exports during fish passage through the head of Old River in 2010 (830 – 1,506 cfs, average = 928 cfs), with only slightly more variation in SWP exports (0 – 709 cfs, average = 574 cfs). Combined exports throughout the Delta ranged from 1,541 to 1,760 cfs (average = 1,663 cfs). There was little or no observed correlation between flow and velocity measures and measures of exports at either CVP, SWP, or combined (|r|<0.3).

Results of the single-variate analyses relating route entrainment at the head of Old River to river conditions found significant effects of changes in barrier status (on *vs.* off; P=0.0002), flow proportion into Old River (P=0.0003), flow (P=0.0027) and velocity (P=0.0077) measured at SJL at time of fish passage, and flow at OH1 at time of fish passage (P=0.0286) (Table 7-3). No other covariates were significant at the 5% level.

Multivariate analyses also found significant effects of flow and velocity at both the SJL and OH1 gaging stations, as well as flow proportion into the San Joaquin River and barrier status (Table 7-4). All three models (flow, velocity, and flow proportion) adequately fit the data (P>0.4). AIC detected little difference among the three models (ΔAIC ≤ 0.86), and estimated regression coefficients were similar among the three models (Table 7-4). The flow model had the lowest AIC, and predicted the route entrainment probability according to:

$$\widehat{\psi_A} = \frac{exp(0.35 + 0.0005Q_A - 0.0008Q_B)}{1 + exp(0.35 + 0.0005Q_A - 0.0008Q_B)}$$

when the barrier was off, and

$$\widehat{\psi_A} = \frac{exp(1.15 + 0.0005Q_A - 0.0008Q_B)}{1 + exp(1.15 + 0.0005Q_A - 0.0008Q_B)}$$

when the barrier was on.

When flow at OH1 was fixed at its mean observed value when tagged fish were passing (2,777 cfs), increases in flow at SJL were predicted to increase the probability of a tagged fish remaining in the San Joaquin River (Figure 7-3). For flow at SJL fixed at its mean observed value (2,595 cfs), increases in flow at OH1 were predicted to decrease the probability of a tagged fish remaining in the San Joaquin River (Figure 7-4). Regardless of the flow level at either

Figure 7-3
Fitted Probability of Remaining in the San Joaquin River at the Head of Old River versus River Discharge Measured at the SJL Gaging Station near Lathrop, CA, for River Discharge at OH1 Gaging Station in Old River Fixed at its Average (2,777 cfs), with 95% Confidence Bands, in 2010. Barrier is Non-Physical Barrier at Head of Old River

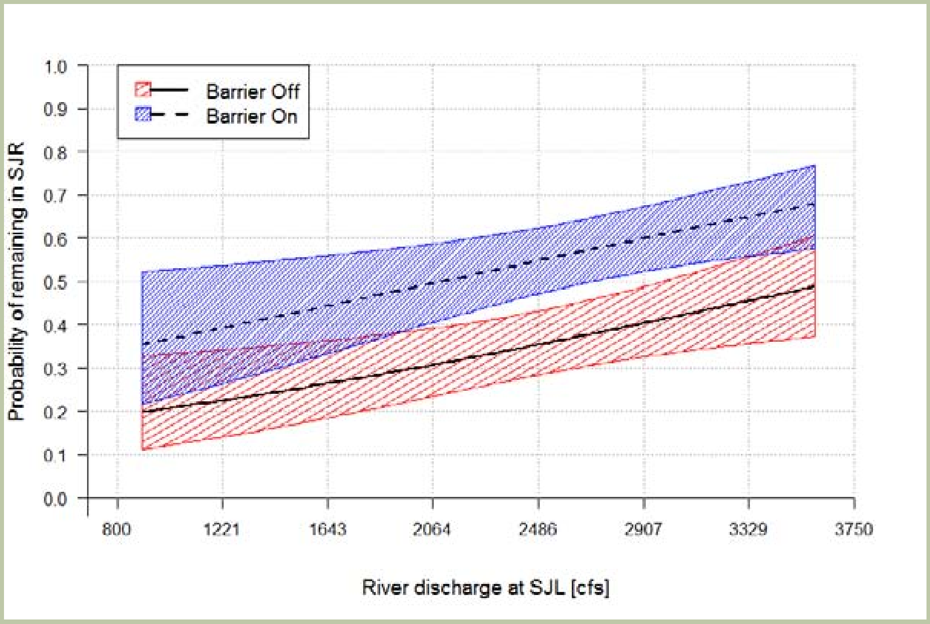
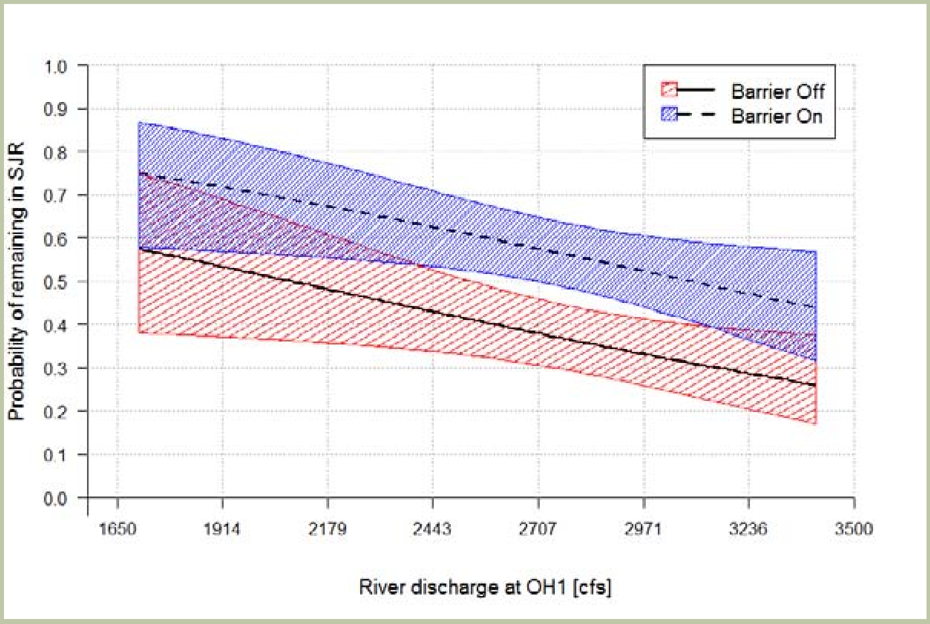


Figure 7-4
Fitted Probability of Remaining in the San Joaquin River at the Head of Old River versus River Discharge Measured at the OH1 Gaging Station in Old River, for River Discharge at SJL Gaging Station near Lathrop, CA, Fixed at its Average (2,595 cfs), with 95% Confidence Bands, in 2010. Barrier is Non-Physical Barrier at Head of Old River



OH1 or SJL, the probability of remaining in the San Joaquin River at the head of Old River was predicted to be higher when the non-physical barrier was turned on than when it was turned off (Figures 7-3 and 7-4; Table 7-4).

Summary

Both the 2009 and 2010 analyses found that increases in flow measured in the San Joaquin River near Lathrop (SJL) were associated with increased probability of remaining in the San Joaquin at the head of Old River. However, the 2009 analysis found an interaction effect between barrier status and flow measured in Old River near its head (OH1), with increases in Old River flow associated with increased probability of entering Old River when the barrier was off, but not when the barrier was on. In 2010, increases in Old River flow were associated with increased probability of entering Old River regardless of barrier status. More fish stayed in the San Joaquin River under all flow conditions in 2010 when the barrier was on than when it was off.