Evaluation of Fish Entrainment in 12 Unscreened Sacramento River Diversions

Final Report

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CVPIA Anadromous Fish Screen Program
(U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation)
and
Ecosystem Restoration Program
(California Department of Fish and Wildlife,
U.S. Fish and Wildlife Service, and NOAA Fisheries)

Prepared by:
Dave Vogel
Natural Resource Scientists, Inc.
P.O. Box 1210
Red Bluff, CA 96080

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Executive Summary

The larger water diversions over 150 cfs in size on the mainstem Sacramento River in California have already been screened or are currently proposed for screening. However, there remain many small- and moderate-sized unscreened diversions (up to 150 cfs) on the Sacramento River. Since there is a general lack of data on the potential effects of these diversions on existing fish populations, the CVPIA Anadromous Fish Screen Program and the Ecosystem Restoration Program initiated a four-year effort in 2009 to screen 12 diversions on the Sacramento River which included the collection of pre-screen fish entrainment monitoring data at each diversion site. The intent was to accumulate fish entrainment monitoring data for two diversion seasons (typically April through September) prior to fish screen installation which would occur at the end of the second irrigation season.[1] The focus of the study was on native anadromous salmonids. The monitoring sites were located on the Sacramento River between Knights Landing (RM 91) and Colusa (RM 143) where the majority of the remaining unscreened diversions on the Sacramento River are located, plus one site in Steamboat Slough. The diversion sites monitored and screened were selected based on relevant information including the size and location of the diversions, suitability for fish entrainment monitoring, suitability for fish screening, voluntary participation of the diverter, and funding availability. A range of diversion sizes and locations were chosen in order to obtain the most useful scientific data. Selected diversion sizes to be monitored and screened were planned to be between 5 cfs and 150 cfs. These biological assessments were intended to analyze the effects of characteristics of Sacramento River diversions on fish entrainment and to lead to a better understanding of the benefits of fish screening for the reach of river monitored and for other locations with similar diversion and river characteristics.[2] Ultimately the assessments will be useful in providing information to assist resource managers in evaluating which irrigation diversions are most important to screen.

This final report on the fish entrainment study represents the four-year effort to obtain monitoring data at 12 agricultural diversions. Fish sampling occurred during the 2009 and 2010 irrigation seasons for three sites (Stage 1), during the 2010 and 2011 seasons for four sites (Stage 2), and during the 2011 and 2012 seasons for five sites (Stage 3). This final technical report describes the methods and results, including all summarized data, for the 12 unscreened diversion sites (ranging in capacity from 9 cfs to 128 cfs) monitored during the 2009 through 2012 study as well as a discussion of factors affecting fish entrainment.

On an overall basis, entrainment of juvenile salmon in the unscreened diversions monitored during this study was low relative to other fish species. This study, like prior studies, indicates that factors affecting salmon entrainment in unscreened water diversions are complex and poorly understood. However, this study demonstrated that some of the most important determinants of salmon entrainment likely include the initial timing of irrigation diversions in the spring, hydrologic conditions preceding the onset of irrigation diversions, and the natural emigration timing of salmon in relation to the spring-time diversion of water. Based on the premise that the middle to lower Sacramento River is not heavily utilized by juvenile salmon for rearing during the late-spring and summer months (which corresponds to when irrigation diversions occur), it is not surprising that relatively few salmon were entrained into the irrigation canals monitored,

[1] Post-screen fish entrainment monitoring was not part of this program.
[2] Note that the results presented in this report may not be applicable to other unscreened diversions in the Central Valley possessing dissimilar characteristics to the diversions in this study.

which is similar to results by Hallock and Van Woert (1959). Among those salmon entrained, the vast majority were fall-run Chinook based on the length-date criteria that are commonly used to assign designation of a salmon run. Based on very limited data on captures of coded-wire tagged salmon released from Coleman National Fish Hatchery, it appears that juvenile salmon were entrained in a much lower proportion than the proportion of flow diverted, similar to results noted by Hanson (2001).

As expected, because most of the diversion intakes were positioned on or near the riverbed, the dominant species entrained were typically bottom-oriented fish. Sacramento sucker, Tule perch, Sacramento pikeminnow, and prickly sculpin dominated the species sampled and were consistent with the types of habitats and seasonable presence expected for those species. Among those species sampled, the fish sizes were small indicating entrainment of younger life stages which could be explained by lesser swimming capabilities for avoiding entrainment or different habitat preferences based on life stage. Exceptions occurred for some diversions which did not have trash racks positioned over the intakes and some larger fish life stages were entrained.

This study's results did not discern measurable effects of factors such as size of the diversion, longitudinal location in the river, water temperatures, localized habitat conditions, intake position in the river channel, and depth of the intakes on salmonid entrainment. However, importantly, there was not a lot of variation among those variables between the monitored sites in order to evaluate their potential effects. For example, if some of the diversion intakes had been positioned near the water surface instead of all being relatively deep, some differences in salmonid entrainment may have been noted. Also, if some of the sites had been located farther upstream in proximity to juvenile salmonid rearing habitats and cooler water, substantially different entrainment rates may have been observed. In particular, if some of the diversions withdrew water earlier in the season (e.g., March), higher entrainment of salmonids would have been likely, but that period does not correspond to when typical agricultural irrigation diversions occur. Prioritization efforts for future screened diversions should closely examine each prospective site's historical and anticipated future water diversion operations to determine the extent of overlap with the onset of irrigation and salmonid emigration timing. Additionally, specific features of potential future sites contemplated for fish screen installation should be compared with the sites monitored during this study where fish entrainment was comparatively lowest and highest to assist in prioritization.

Numerous additional variables not evaluated as part of this study could have affected the study's results. Among these factors include possible predation near the intakes, effects of pumped bypassed flow back to the river, presence or absence of trash racks over the intakes, and specific configuration of trash racks and the intakes.

Introduction

Screening of agricultural diversions has been a common practice in recent years in order to conserve and restore populations of anadromous fishes (including Chinook salmon, *Oncorhynchus tshawytscha*, and steelhead, *O. mykiss*) in the Central Valley of California. Those efforts have focused on protecting winter, spring, fall and late-fall runs of Chinook salmon and steelhead, as they migrate down the Sacramento River. Traditionally, some of the largest runs of Chinook salmon of any west coast river system have been produced in the Sacramento River. However, over recent years there has been a significant decline in winter-run, spring-run, and fall-run Chinook salmon and Central Valley steelhead stocks to the point that under state and federal law the winter run has been listed as Endangered, the spring run and the Central Valley steelhead have been listed as Threatened, and the fall run is currently a Candidate species for listing. Fish screens contribute to the overall restoration of anadromous fisheries by protecting juvenile fish from entrainment at these diversions. Protecting fish from entrainment improves anadromous fish outmigrant success, thereby indirectly enhancing the sport and commercial harvest of these species and the number of returning fish to the rivers.

Under both the Central Valley Project Improvement Act (CVPIA) Anadromous Fish Screen Program[3] (AFSP) and the Ecosystem Restoration Program[4] (ERP) there have been significant efforts to screen agricultural diversions in the Central Valley of California, particularly the larger unscreened diversions (over 150 cfs) on the Sacramento River. There are many small- and moderate-sized agricultural diversions (under 150 cfs) on the Sacramento River that remain unscreened. However, there is a general lack of data available about the potential effects of these agricultural diversions on existing fish populations. In 2009, the AFSP and the ERP initiated a four-year effort to screen up to 15 diversions on the Sacramento River while obtaining essential fish entrainment monitoring data at each diversion site; ultimately, 12 sites were chosen. Fish entrainment monitoring data were collected at each diversion site for two diversion seasons (typically April through September) prior to fish screen installation which usually occurred at the end of the second irrigation season. These biological assessments analyzed the effect of site-specific physical, hydraulic, and habitat characteristics of diversions on fish entrainment and were intended to lead to a better understanding of the benefits of fish screening for the reach of river monitored and for other locations with similar diversion and river characteristics. Ultimately the assessments will be useful in providing information to assist resource managers in evaluating which irrigation diversions are most important to screen.

This final technical report describes the methods and results, including all summarized data, for 12 unscreened agricultural diversion sites monitored in 2009 through 2012.[5] The monitoring sites are located on the Sacramento River between near Knights Landing (RM 91) and Colusa (RM 143) where the majority of the remaining unscreened diversions on the Sacramento River are located, plus one site on Steamboat Slough. The diversion sites monitored and screened were selected based on relevant information including the size and location of the diversion, suitability

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[3] The CVPIA Anadromous Fish Screen Program (AFSP) is jointly implemented by the U.S. Fish and Wildlife Service and the U.S. Bureau of Reclamation.
[4] The Ecosystem Restoration Program (ERP) is implemented by the California Department of Fish and Wildlife, the U.S. Fish and Wildlife Service, and NOAA's National Marine Fisheries Service.
[5] Annual reports previously provided results for the 2009, 2010, and 2011 irrigation seasons (Vogel 2010, 2011a, 2012, respectively). That information plus the data developed during the 2012 irrigation season are provided in this final report.

for fish entrainment monitoring, suitability for fish screening, voluntary participation of the diverter, and funding availability. A range of diversion sizes and locations were chosen in order to obtain the most useful scientific data. Selected diversion sizes monitored and screened were between 9 cfs and 128 cfs. A comprehensive assessment comparing sampling data for all sites and all years is provided in this final report.

Study Sites

Three sites on the Sacramento River were selected by the AFSP to evaluate daily fish entrainment for the 2009 and 2010 irrigation seasons (Stage 1 Sites), four sites for the 2010 and 2011 seasons (Stage 2 Sites), and five sites (including one in Steamboat Slough) for the 2011 and 2012 seasons (Stage 3 Sites)[6] (Table 1, Figure 1).

Table 1. Twelve unscreened diversions on the Sacramento River monitored for fish entrainment.

Site Name	**Site Location**			**Diversion Capacity (cfs)**
Stage 1 Sites (2009-2010)				
	Sacramento River Mile	**Latitude**	**Longitude**	
Sutter Mutual State Ranch (State Ranch)	96.25	38°52'13.31"N	121°45'11.93"W	128
Sycamore Mutual Water Corporation (Sycamore)	132.5	39°08’12.9”N	121°56’23.1” W	65
River Garden Farms #2	96.7	38°51'52.7"N	121°45'28.5"W	38
Stage 2 Sites (2010-2011)				
Site Name	**Sacramento River Mile**	**Latitude**	**Longitude**	**Diversion Capacity (cfs)**
Sutter Mutual Portuguese Bend (Portuguese Bend)	88.2	38°47'53.0"N	121°41'47.0"W	108
RD 108 - South Steiner	114.3	38°59'21.87"N	121°48'59.71"W	30
Oji Brothers (Oji)	103.3	38°53'56.0"N	121°48'8.0"W	28
Windswept Land & Livestock #3 (Windswept)	102.5	38°53'15.0"N	121°48'30.0"W	9
Stage 3 Sites (2011–2012)				
Site Name	**Sacramento River Mile**	**Latitude**	**Longitude**	**Diversion Capacity (cfs)**
River Garden Farms #3 Townsite (Townsite)	90.1	38°48'19.29"N	121°43'25.59"W	62
Alamo Farms #1 (Alamo)	123.3	39° 4'1.0"N	121°51'57.0"W	36
Tisdale Irrigation District #2 (Tisdale)	121.7	39° 3'32.29"N	121°50'19.97"W	44
Sanchez Farms (Sanchez)	Steamboat Slough	38°15'55.8"N	121°35'14.43"W	24
Cranmore Farms #2 (Cranmore)	111.8	38°57'35.74"N	121°49'54.05"W	40

[6] The AFSP adopted the nomenclature for the designation of Stage 1, 2, and 3 sites and, therefore, that terminology is used in this report.

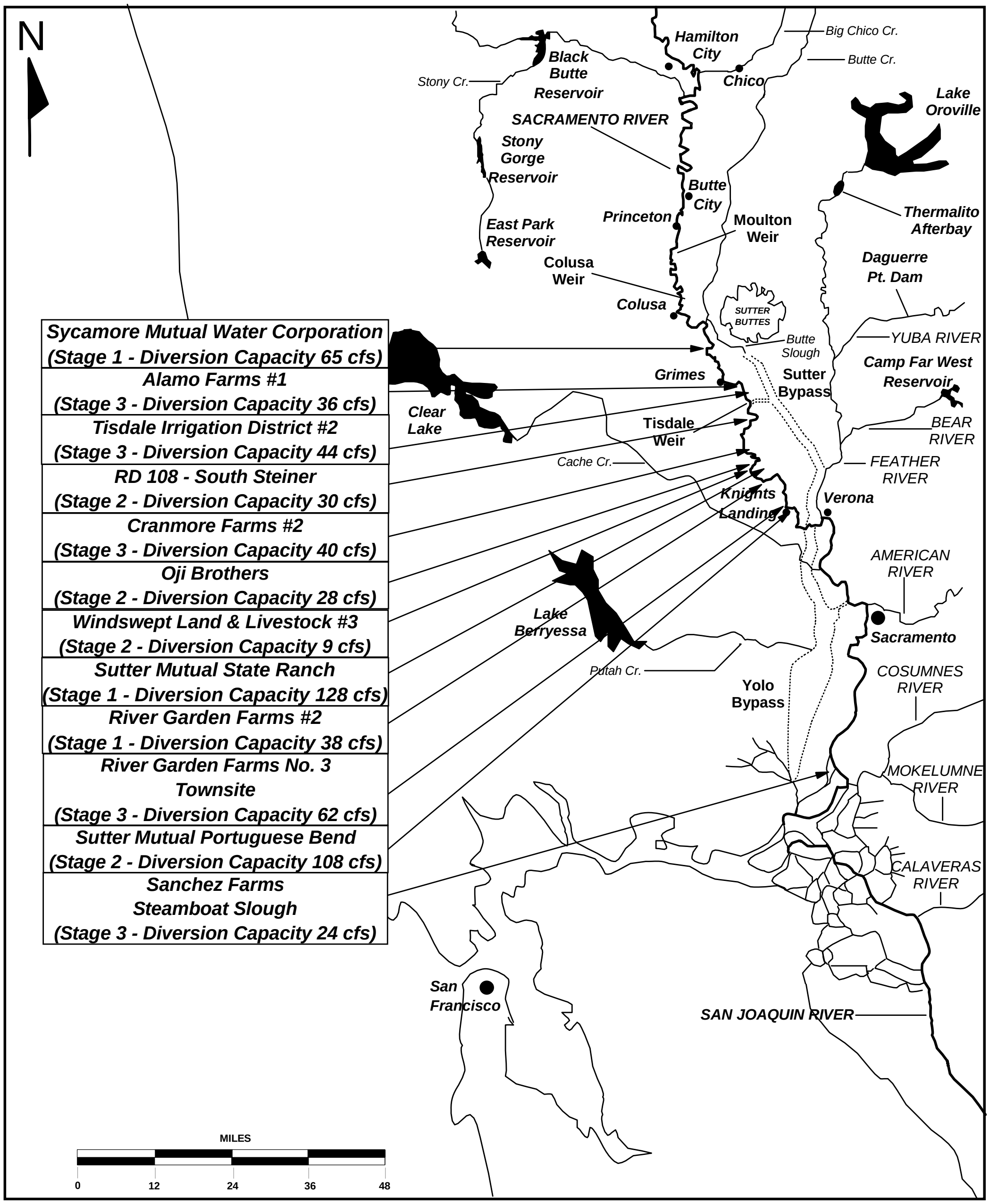

Figure 1. The Sacramento River basin showing the location of 12 unscreened water diversions sampled for fish entrainment.

For the remainder of this report, these 12 locations are referred to as Sycamore, River Garden Farms No. 2, State Ranch, South Steiner, Oji, Windswept, Portuguese Bend, Alamo, Townsite, Tisdale, Cranmore, and Sanchez.

Methods

The study was designed to sample fish that have already been diverted out of the river through irrigation pumps. Rectangular or trapezoidal, ¼-inch knotless nylon mesh fyke nets[7,8] were used

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7 Manufactured by Christensen Nets, Inc., Minnesota

8 Some smaller and larger variations occurred during the study and are described for each site.

to collect the fish in irrigation canals using methods similar to earlier studies (e.g., Vogel 2008a). Past experience has demonstrated that these nets would capture all salmonids of the size anticipated at the diversion sites (e.g., Bigelow and Johnson 1996; Vogel and Marine 1997, Vogel 2008b). The larval life stages of other fish species could filter through the mesh, but the sampling program focused on salmonids. However, some of the smaller life stages of non-salmonids were nevertheless frequently sampled (e.g., suckers). Field crews ensured that the fyke frames were properly positioned directly over the culvert or in the canal each day through visual observation or by using a wooden pole.

Fish collected were identified as to species, enumerated, measured for fork length, and the carcasses put back into the canals. In some instances, fish carcasses were sufficiently damaged (presumably due to passage through the pumps or trauma in the fyke nets[9]) that species identification and length measurements were not possible. Dead juvenile salmon with an adipose fin clip (signifying the presence of a coded-wire tag) were preserved in alcohol for later tag detection and reading. In instances where the sampling equipment was removed for repair, the average of the numbers of fish entrained the days before and after removal was used to interpolate an estimate for the numbers of fish entrained during unsampled periods.

Water velocity entering the approximate mid-point of each fyke net was measured with a General Oceanics® flow meter continuously positioned in the flow when each net was in the water. These flow meters have a propeller (rotor) directly coupled with a digital counter. Using the vendor's formulae for conversions from propeller rotation counts to velocity provide computed average water velocity for the elapsed time between fyke trap checks. Flow filtered through each fyke net was computed by multiplying the average daily water velocity between fyke trap check times the submerged cross-sectional area of the culvert or canal (based on culvert or canal and water elevation measurements) or the fyke net frames in instances where canal flow was purposefully restricted to force all the flow into the nets. Because of physical limitations of the meters[10], the computed flow should not be viewed as a very accurate measurement but can be used to provide a relative indication of the daily volume of water entering the nets. Efforts were made to filter nearly 100% of the flow with the nets to capture 100% of the fish entrained. However, in actuality, a more-realistic estimate was approximately 90% of the fish were sampled at most diversions based on some leakage that occurred between the net, frame, and vertical channels, fish impingement on the frames, and site-specific circumstances described later in this report. As a result, the numbers of fish captured were expanded to account for this circumstance and the expanded values are used throughout this report as estimated numbers of fish entrained. Graphs in the results section often display fractions of fish for daily catches to avoid compounding errors that would occur if numbers were rounded to the nearest fish then summed for monthly or seasonal totals. At some sites, daily water data were provided by the diverter (State Ranch and Portuguese Bend by Sutter Mutual Water Company) or calculated using U.S. Bureau of Reclamation (USBR) flow meter readings. Additionally, USBR provided monthly acre-feet diverted for most sites. Those data were assumed to be more accurate than flow meters installed on the fyke net frames. For example, in prior years' sampling at the State Ranch diversion, a comparison of daily Sutter Mutual Water Company flow records with the fyke net flow meter readings showed that the fyke flow meter readings tracked the seasonal flow diversion patterns but were generally approximately 10% less than the diverter's records. Water elevations were recorded daily and assumed to be representative of the prior 24-hour period.

[9] This study could not distinguish between the two possible sources of mortality.

[10] For example, the single velocity reading in the mouth of the net may not be reflective of average flow and sometimes the flow meter propellers became entangled with debris entering the net.

Fyke nets were checked once daily seven days a week. Site visits were made to each site every day during the state and federally-authorized sampling period (e.g., the beginning of irrigation until September 30th for most sites). However, for some of the sites, diversions did not occur continuously each day. In those instances, a lack of daily diversion was noted and each of those days is displayed in appropriate figures in this report (e.g., see Figure 19 on page 21). The nets were maintained in place each day in the event that irrigation pumps would be turned back on. An Onset® Computer Corporation thermograph was placed in the irrigation canals at each site to record hourly water temperatures. Daily water samples were taken at each site to measure turbidity in nephelometric turbidity units (NTUs). A list of all fish species sampled during the entrainment monitoring project is provided in Appendix A, including the scientific names and if the species are native or non-native. In this report, an asterisk next to the fish species listed in tables or figures designates that the species is non-native. Brief life history accounts for each species observed during this project are provided in Appendix B. Data on characteristics for each diversion site are provided in Appendix C.[11] Details on daily fish entrainment and water measurements at each site (e.g., numbers of each species, fish sizes, etc.) are included in separate Excel® workbooks, spreadsheets, and data sheets provided to the AFSP and the ERP.

Although not part of the scope of work for this project, limited fish efficiency tests were conducted at several sites in 2011 and 2012 by releasing a known number of upper caudal-fin-clipped dead golden shiners upstream of the fyke nets then counting the numbers of marked fish recaptured the following day. At sites equipped with a manifold to distribute flow to various canals, the marked fish were released in the manifold.

Sycamore (Stage 1 Site: 2009 – 2010)

The fyke apparatus at Sycamore consisted of two 29-inch by 45-inch rectangular metal frames and two 29-inch by 45-inch by 15-ft long ¼-inch knotless nylon mesh fyke nets. The end of each fyke net tapered to a 1-ft by 1-ft. by 2-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. The fyke nets were positioned over culverts exiting into the irrigation canal. We estimated that the two fyke nets sampled approximately 90% of the fish entrained into the canal. The fyke frames and nets were raised and lowered within a 3-inch metal channel frame using winches to check for fish entrainment each day (Figure 2).

[11] During the summer of 2008, Natural Resource Scientists, Inc. conducted an in-river survey of all unscreened water diversions in the Sacramento River between Verona and Red Bluff. Bathymetry, hydraulic, physical, and biological characteristics at each site were recorded. The methodology and results are reported by Vogel (2008c). That information was used in this report (Appendix C) to compare characteristics of each site monitored for fish entrainment.

Figure 2. Fyke apparatus and nets used to sample for fish entrainment at the Sycamore canal.

River Garden Farms No. 2 (Stage 1 Site: 2009 – 2010)

The fyke apparatus at River Garden Farms No. 2 consisted of two 31-inch by 36-inch rectangular metal frames and two 31-inch by 36-inch by 15-ft long ¼-inch knotless nylon mesh fyke nets. The end of each fyke net tapered to a 1-ft by 1-ft. by 2-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. The fyke nets were positioned over culverts exiting into the two irrigation canals. We estimated that the fyke nets sampled approximately 90% of the fish entrained into the canals. The fyke frames and nets were raised and lowered within a 3-inch metal channel frame using winches to check for fish entrainment each day (Figure 3).

Figure 3. Fyke apparatus and net used to sample for fish entrainment in one of two canals at River Garden Farms No. 2.

State Ranch (Stage 1 Site: 2009 – 2010)

The fyke apparatus at State Ranch consisted of a 5-ft by 5-ft 10-inch rectangular metal frame and a 5-ft by 5-ft 10-inch by 20-ft long ¼-inch knotless nylon mesh fyke net. The end of the fyke net tapered to a 1-ft by 1-ft. by 3-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. The fyke frame and net were raised and lowered within a 3-inch metal channel frame using a winch to check for fish entrainment each day (Figure 4). We estimated that the fyke net captured approximately 90% of the fish entrained into the canal when the net frame fully covered the culvert opening. In some instances early in the season when debris loads were exceptionally high, the net frame covered approximately half the submerged opening of the culvert and an estimated half of the flow was sampled. In these latter instances, fish catches were expanded to account for the un-sampled flow.

Figure 4. Fyke apparatus, fyke net, and sampling platform used to sample for fish entrainment in the State Ranch canal.

South Steiner (Stage 2 Site: 2010 – 2011)

One earth-lined canal was sampled at South Steiner in 2010. Efforts were made to sample in a second trapezoidal concrete canal which would have allowed 100% sampling efficiency but was abandoned after the equipment was vandalized and local growers ditched a bypass channel around the concrete canal after the onset of the irrigation season. Because of this circumstance, we planned to sample the newly created bypass channel during the 2011 season to increase sampling efficiency. Strong turbulence in the concrete manifold distribution box into the canals likely distributed the fish in proportion to flow although this assumption was not empirically tested. USBR monthly pumping flow records were obtained to compare with total flow filtered by the one fyke net. These comparisons were used to estimate the portion of the total flow sampled each month. Based on the flow records, the following proportions of total pump flow sampled by month were: May 67%, June 33%, July 33%, August 50%, and September 100%. These proportions were used to estimate the daily numbers of fish entrained during each of the respective months.

The fyke apparatus in the earth canal consisted of a 30-inch by 30-inch rectangular metal frame and a 30-inch by 30-inch by 12-ft long ¼-inch knotless nylon mesh fyke net (Figure 5). The end of the fyke net tapered to a 1-ft by 1-ft. by 2-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. The fyke frame and net were raised and lowered within a 3-inch metal channel frame using a winch to check for fish entrainment each day (Figure 5).

Figure 5. Fyke apparatus, fyke net, and sampling platform used to sample for fish entrainment in the South Steiner earth canal.

In 2011, for the reasons described above, to increase sampling efficiency we built an additional (third) fyke net sampling apparatus to sample flows exiting a culvert into a second earthen canal and into the bypass channel constructed during 2010. However, the local growers again changed their operations in 2011 and did not use the culvert that had been used during the 2010 irrigation season. Nevertheless, the bypassed flow was routed through the trapezoidal concrete canal. For much of the season, the net in the trapezoidal concrete canal could not be submerged due to backwater effects causing flooding over the canal lining upstream of the net if the net was completely submerged. In those instances, the fyke net fish catches from the earthen canal were used to extrapolate estimated fish numbers in the trapezoidal concrete canal in a similar manner as described previously for the 2010 season. USBR monthly pumping flow records for 2011 were obtained to compare with total flow filtered by the one earthen canal fyke net. These comparisons were used to estimate the portion of the total pumped flow sampled each month. Based on the flow records, the following proportions of total pumped flow sampled by month were: May 50%, June 50%, July 75%, August 75%, and September 75%. These proportions were used to estimate the daily numbers of fish entrained during each of the respective months when the trapezoidal net could not be used. Otherwise, both net catches were combined when the trapezoidal net could be completely submerged.

The fyke apparatus in the South Steiner concrete canal consisted of a trapezoidal (78-inch by 42-inch by 14-inch by 42-inch) metal frame and a 20-ft long knotless nylon mesh trapezoidal fyke net with the same opening dimensions with 15-ft-long leading panels of 1-inch mesh, followed by 5-ft-long ¼-inch mesh panels tapered to a 1-ft by 1-ft. by 2-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. The fyke frame and net were raised and lowered using a winch to check for fish entrainment (Figure 6). As with most other sites sampled during this study, total fish entrainment was estimated assuming the earthen canal fyke net sampled approximately 90% of the fish entrained.

Figure 6. Fyke apparatus and sampling platform used for fish entrainment sampling in the South Steiner concrete canal.

Oji (Stage 2 Site: 2010 – 2011)

The fyke apparatus in the Oji concrete canal consisted of a trapezoidal (78-inch by 42-inch by 14-inch by 42-inch) metal frame and a 20-ft long knotless nylon mesh trapezoidal fyke net with the same opening dimensions with 15-ft-long leading panels of 1-inch mesh, followed by 5-ft-long ¼-inch mesh panels tapered to a 1-ft by 1-ft. by 2-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. The fyke frame and net were raised and lowered using a winch to check for fish entrainment (Figure 7). We estimated that the fyke net captured approximately 90% of the fish entrained into the concrete canal when the net was fully in the water. In some instances when debris loads and pumping were exceptionally high, the net frame was positioned to cover approximately half the submerged portion of the canal and an estimated half of the canal flow was sampled. In these latter instances, fish catches were expanded to account for the un-sampled flow.

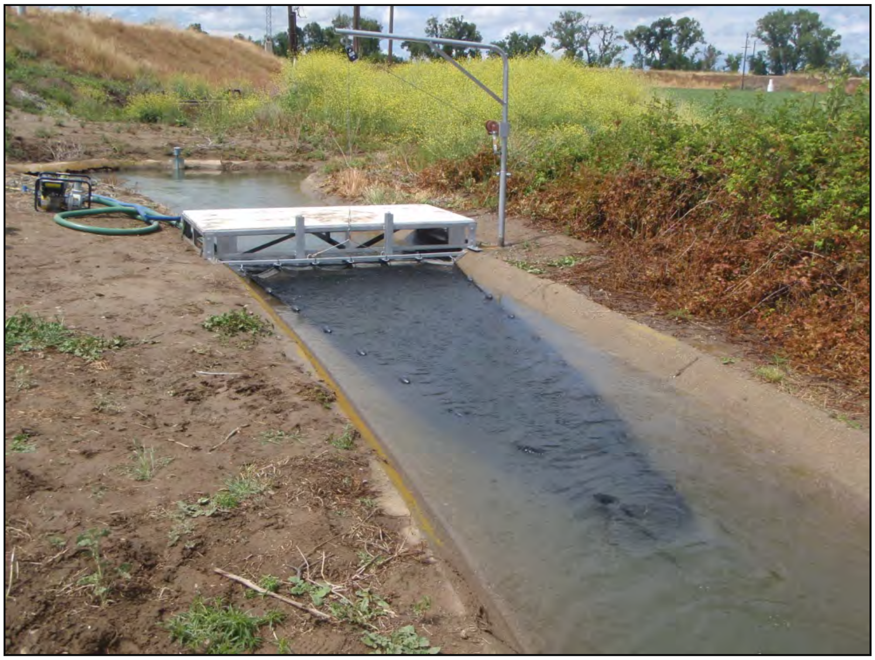

Figure 7. Fyke apparatus, fyke net, and sampling platform used to sample for fish entrainment in the Oji canal.

Windswept (Stage 2 Site: 2010 – 2011)

The fyke apparatus at Windswept consisted of a 56-inch by 36-inch rectangular metal frame and a 56-inch by 36-inch by 14-ft long ¼-inch knotless nylon mesh fyke net. The end of the fyke net tapered to a 1-ft by 1-ft. by 2-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. The fyke frame and net were raised and lowered within a 3-inch metal channel frame using a winch to check for fish entrainment each day (Figure 8). We estimated that the fyke net sampled approximately 90% of the fish entrained into the main canal. A very small culvert exiting into a small ditch was rarely used and was not sampled.

Figure 8. Fyke apparatus, fyke net, and sampling platform used to sample for fish entrainment in the Windswept canal.

Portuguese Bend (Stage 2 Site: 2010 – 2011)

The fish sampling apparatus at Portuguese Bend consisted of three fyke nets fished side-by-side. The center fyke apparatus consisted of a 46-inch by 46-inch rectangular metal frame and a 46-inch by 46-inch by 20-ft long ¼-inch knotless nylon mesh fyke net. The two side nets each consisted of a trapezoidal (57-inch by 44-inch by 48-inch by 12-inch) metal frame and a 20-ft long ¼-inch knotless nylon mesh trapezoidal fyke net with the same opening dimensions. Each of the three nets tapered to a 1-ft by 1-ft. by 3-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. The fyke frames and nets were raised and lowered within a 3-inch metal channel frame using a winch to check for fish entrainment each day (Figure 9). We estimated that the three fyke nets sampled approximately 90% of the fish entrained into the canal when all three nets were positioned in the canal.

Figure 9. Three fyke nets, sampling platform, and associated apparatus used to sample for fish entrainment in the Portuguese Bend canal.

Alamo (Stage 3 Site: 2011 – 2012)

The fish sampling apparatus at Alamo consisted of one fyke net fished in a trapezoidal-shaped concrete canal. The fyke apparatus consisted of a 33-inch by 44-inch approximate rectangular metal frame and an approximate 33-inch by 44-inch by 18-ft long ¼-inch knotless nylon mesh fyke net. The net tapered to a 1-ft by 1-ft. by 2-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. In late July, a new net with the first nine feet consisting of ½-inch mesh and the last nine feet of ¼-inch mesh was installed to accommodate water pressure against the net and water overtopping the canal. The fyke frame and net were raised and lowered within a 3-inch metal channel frame using a winch to check for fish entrainment each day (Figure 10). We estimated that the fyke net captured approximately 90% of the fish entrained into the canal when the net was positioned in the canal.

Figure 10. The fyke net, sampling platform, and associated apparatus used to sample for fish entrainment in the Alamo trapezoidal concrete canal.

Townsite (Stage 3 Site: 2011 – 2012)

The fish sampling apparatus at Townsite consisted of two fyke nets fished in two separate earthen canals. The fyke apparatus in the north canal consisted of a 4-ft, 4-inch by 5-ft rectangular metal frame and a 4-ft, 4-inch by 5-ft by 18-ft long ¼-inch knotless nylon mesh fyke net positioned over a 5-ft diameter culvert. The fyke apparatus in the south canal consisted of a 4-ft, 6-inch by 5-ft rectangular metal frame and a 4-ft, 6-inch by 5-ft by 18-ft long ¼-inch knotless nylon mesh fyke net positioned over a 5-ft diameter culvert. Each of the two nets tapered to a 1-ft by 1-ft. by 2-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. The fyke frames and nets were raised and lowered within a 3-inch metal channel frame using a winch to check for fish entrainment each day (Figures 10 and 11). We estimated that the two fyke nets sampled approximately 90% of the fish entrained into the canals when both nets were positioned in the canals.

Figure 10. The fyke net, sampling platform, and associated apparatus used to sample for fish entrainment in the Townsite north canal.

Figure 11. The fyke apparatus used to sample for fish entrainment in the Townsite south canal.

Tisdale (Stage 3 Site: 2011 – 2012)

The fish sampling apparatus at Tisdale consisted of two fyke nets fished side-by-side. The left fyke apparatus (facing downstream) consisted of a 38-inch by 60-inch rectangular metal frame and a 38-inch by 60-inch by 16-ft long ¼-inch knotless nylon mesh fyke net. The right fyke apparatus consisted of a 38-inch by 42-inch rectangular metal frame and a 38-inch by 42-inch by 16-ft long ¼-inch knotless nylon mesh fyke net. Each of the two nets tapered to a 1-ft by 1-ft. by 2-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. The fyke frames and nets were raised and lowered within a 3-inch metal channel frame using a winch to check for fish entrainment each day (Figure 12). After the onset of irrigation, local growers intermittently diverted water into a small side culvert off the concrete manifold upstream of the nets which could not be sampled. We estimated that the two fyke nets captured approximately 90% of the fish entrained into the canal when both nets were positioned in the canal.

Figure 12. Two fyke nets, sampling platform, and associated apparatus used to sample for fish entrainment in the Tisdale canal.

Cranmore (Stage 3 Site: 2011 – 2012)

The fish sampling apparatus at Cranmore consisted of two fyke nets fished in two separate canals. The fyke apparatus in the rectangular concrete canal consisted of a 42-inch by 46-inch rectangular metal frame and a 42-inch by 46-inch by 16-ft long ¼-inch knotless nylon mesh fyke net. In late June, a new 20-ft long net consisting of 1-inch mesh in the first 15 feet and ½-inch mesh in the last 5 feet was installed to accommodate extreme water pressure on the net and prevent flows from overtopping the irrigation canal. The fyke apparatus deployed over a culvert in an irregular-shaped concrete canal consisted of a 22-inch by 28-inch rectangular metal frame and a 22-inch by 28-inch by 12-ft long ¼-inch knotless nylon mesh fyke net. Each of the two nets tapered to a 1-ft by 1-ft. by 2-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. The fyke frames and nets were raised and lowered within a 3-inch metal channel frame using a winch to check for fish entrainment each day (Figures 13 and 14). During 2012, after the onset of irrigation, the growers buried our fish sampling equipment in the irregular-shaped concrete canal and the culvert and began using another unanticipated side canal on the north side which could not be sampled. Based on a combination of the growers' use of water diverted into a side channel not sampled, the larger-mesh fyke net installed in the main canal, and limited fish sampling efficiency tests, we estimated that we were able to sample approximately 50% of the fish entrained into the canal system.

Figure 13. The fyke net and associated apparatus used to sample for fish entrainment in the Cranmore trapezoidal concrete canal.

Figure 14. The fyke net and associated apparatus used to sample for fish entrainment in the Cranmore irregular-shaped concrete canal.

Sanchez (Stage 3 Site: 2011 – 2012)

The fish sampling apparatus at Sanchez consisted of two fyke nets fished in two separate earthen canals. The fyke apparatus in both the east and west canals consisted of a 24-inch by 24-inch rectangular metal frame and a 24-inch by 24-inch by 14-ft long ¼-inch knotless nylon mesh fyke net positioned over culverts in each canal. Each of the two nets tapered to a 1-ft by 1-ft. by 2-ft long 3/16-inch knotless nylon mesh bag and a Velcro® zippered end to remove fish and debris. In June, a new net consisting of smaller-sized 1/8-inch mesh and a 1/16-inch mesh bag was installed in the west canal to test for larval fish sampling. The fyke frames and nets were raised and lowered within a 3-inch metal channel frame using a winch to check for fish entrainment each day (Figures 15 and 16). We estimated that the two fyke nets filtered approximately 50% of the flow in the two canals. This circumstance was attributable to the unique characteristics of the water delivery system which allowed intentional substantial seepage into underlying highly porous peat soil prior to exiting the culverts. Additionally, limited fish sampling efficiency tests suggested that we were only capturing approximately 50% of the fish. Interestingly, we suspected that this circumstance was likely attributable to catfish residing in the culverts and eating fish prior to and after entry into the fyke nets.

Figure 15. The fyke net, sampling platform, and associated apparatus used to sample for fish entrainment in the Sanchez east canal.

Figure 16. The fyke net, sampling platform, and associated apparatus used to sample for fish entrainment in the Sanchez west canal.

Results

Table 2 provides the periods when fish entrainment sampling was conducted at all 12 diversion sites during the 2009 – 2012 study.

Table 2. Fish sampling periods at all 12 diversion sites monitored during the 2009 – 2012 study. The dates are when the fyke nets were put in place at the beginning of the season and removed at the end of the season and do not represent when irrigation diversions occurred.

Stage	Diversion Site	2009	2010	2011	2012
Stage 1	**Sycamore**	April 24 – September 20	April 26 – September 30		
	River Garden Farms No. 2	April 29 – September 20	May 23 – September 30		
	State Ranch	April 1 – September 30	April 1 – September 30		
Stage 2	**South Steiner**		May 4 – September 30	May 16 – September 30	
	Oji		May 10 – September 30	April 30 – September 30	
	Windswept		May 23 – September 30	May 24 – September 30	
	Portuguese Bend		April 28 – September 30	April 26 – September 30	
Stage 3	**Alamo**			April 25 – September 30	April 20 – September 30
	Townsite			April 23 – September 30	May 4 – September 30
	Tisdale			April 23 – September 30	April 22 – September 30
	Cranmore			April 28, 2011 – January 31, 2012*	April 16 – September 30
	Sanchez			May 24 – October 13	May 15 – September 30

*Note that sampling at Cranmore extended into early 2012 during this period.

Sycamore

In 2009, fish entrainment monitoring at the Sycamore outfall was initiated on April 24th (the onset of pumping operations) (first net pull on April 25th) and continued until September 20th. In 2010, fish entrainment monitoring was initiated on April 26th (the onset of pumping operations) (first net pull on April 27th) and continued until September 30th. Table 3 provides the estimated total numbers of each species entrained during 2009 and 2010. All of the non-salmonid species entrained would normally be expected to be present at this river location during the sampling period (Appendix B).

Table 3. Estimated numbers of each fish species entrained at the Sycamore diversion during the 2009 and 2010 irrigation seasons. (Note: * signifies a non-native fish)		
Species	**2009**	**2010**
Sacramento Sucker	842	1221
Tule Perch	408	480
Prickly Sculpin	78	144
Sacramento Pikeminnow	53	110
Chinook Salmon	97	0
Unidentified Fish	28	34
Unidentified Sunfish*	60	0
Golden Shiner*	13	38
Unidentified Lamprey	48	1
White Catfish*	28	9
Pacific Lamprey	14	22
Hardhead	9	28
River Lamprey	19	7
Brown Bullhead*	20	4
Unidentified Sculpin	0	23
Sacramento Splittail	1	19
Bluegill*	6	13
Black Crappie*	4	11
Riffle Sculpin	13	1
Black Bullhead*	0	13
California Roach	0	10
Bigscale Logperch*	9	0
Largemouth Bass*	1	7
Fathead Minnow*	8	0
Threespine Stickleback	4	1
Unidentified Bass*	2	1
Unidentified Bullhead*	0	3
Wakasagi*	0	3
American Shad*	1	1
Carp*	0	1
Green Sunfish*	0	1
Hitch	1	0
Smallmouth Bass*	1	0
Unidentified Minnow*	1	0
White Crappie*	0	1

In 2009, Sacramento sucker was the dominant species among 23 identifiable species entrained, followed by Tule perch, Chinook salmon, prickly sculpin, and Sacramento pikeminnow. In 2010, Sacramento sucker was again the dominant species among 23 identifiable species sampled, followed by Tule perch, prickly sculpin, and Sacramento pikeminnow (Figure 17). The entrainment of 97 juvenile salmon in 2009 occurred during the earliest portion of the irrigation season (Figure 18). Ninety-four of the salmon were believed to be fall-run Chinook, two were late-fall-run Chinook, and one was a spring-run Chinook based on length-at-date criteria. No Chinook salmon were observed in 2010. The daily numbers of all fish species entrained were highly variable over the 2009 and 2010 irrigation seasons (Figures 19 and 20).

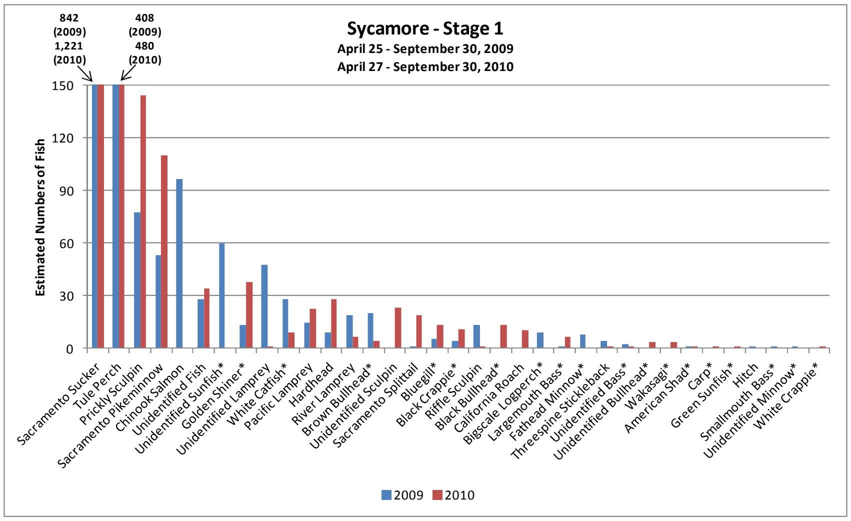

Figure 17. Estimated total numbers of each fish species entrained into the Sycamore canal during the 2009 and 2010 irrigation seasons.

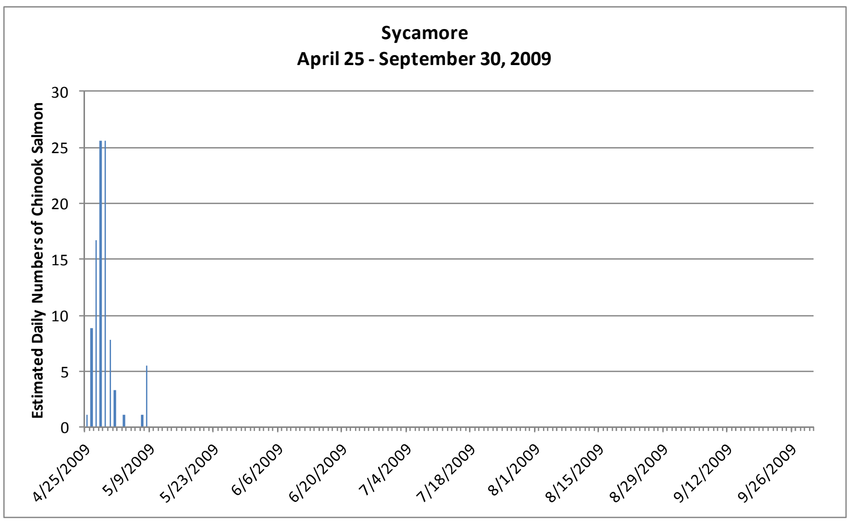

Figure 18. Estimated daily numbers of juvenile Chinook salmon entrained in Sycamore canal during the 2009 irrigation season.

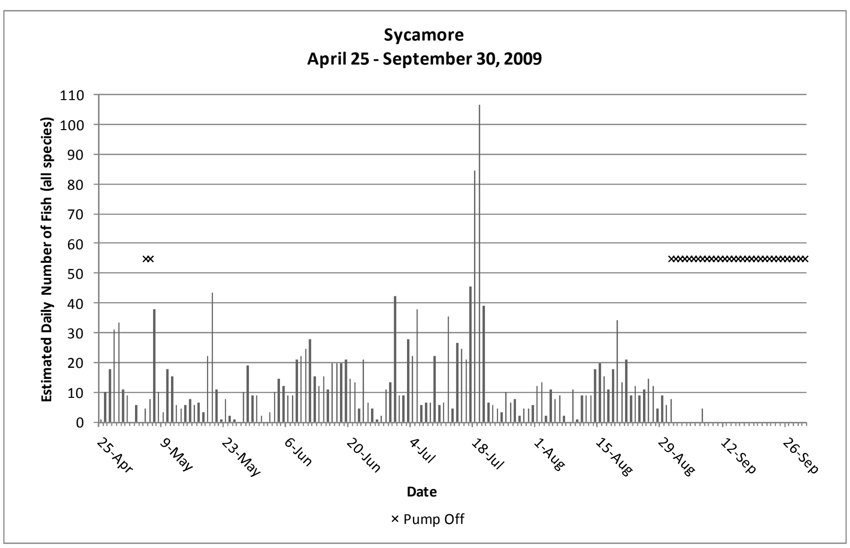

Figure 19. Estimated daily numbers of fish (all species combined) entrained in Sycamore canal during the 2009 irrigation season.

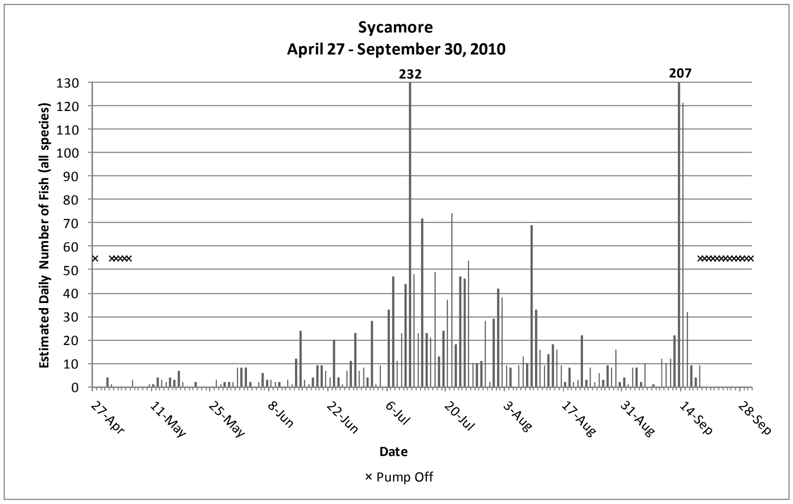

Figure 20. Estimated daily numbers of fish (all species combined) entrained in Sycamore canal during the 2010 irrigation season.

Based on data collected by a thermograph placed at the site in 2009, water temperatures were generally in the high 60's to low 70's degrees Fahrenheit for most of the irrigation season (Figure 21). The relatively high water temperatures observed at the Sycamore diversion site were at levels considered stressful to juvenile salmonids and could partially explain the low numbers of salmonids sampled. The highest numbers of salmon entrained occurred during the early portion of the season when water temperatures were cooler. Periods of elevated temperatures occurred with minimal or no pumping late in the season resulting in warming of canal water. Based on data collected by a thermograph placed at the site in 2010, water temperatures rapidly increased during the spring reaching the high 60's degrees Fahrenheit by early July through early September (Figure 21). Water temperatures observed at the Sycamore diversion site early in the season were tolerable for juvenile salmon. However, the high, sustained river flows in 2010 likely resulted in most juvenile salmon emigrating from the upper river prior to water diversions and could partially explain why no salmonids were sampled (discussed later in this report). Periods of elevated temperatures occurred with minimal or no pumping late in the season resulting in warming of canal water (Figure 21).

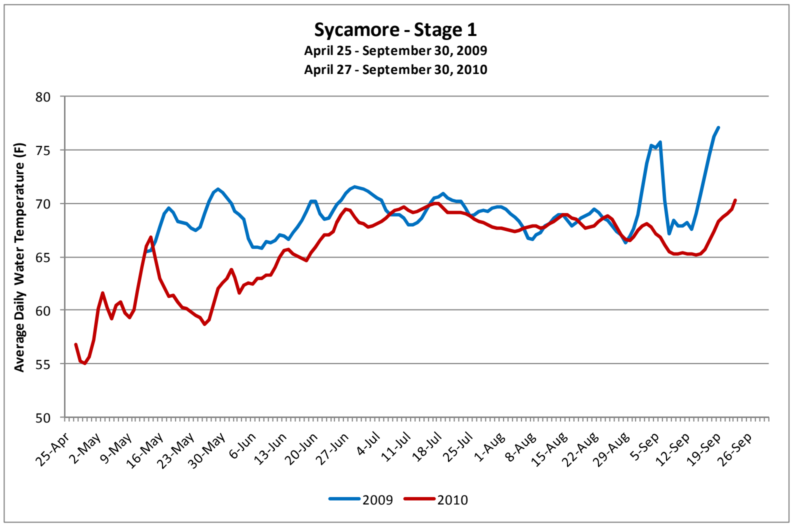

Figure 21. Average daily water temperatures recorded in Sycamore canal during the 2009 and 2010 irrigation seasons.

Based on the flow meters installed in the fyke nets, daily flow in the canal was highly variable in 2009 and 2010 (Figures 22 and 23) but provide a relative indication of the timing of water diversions into the canal. No correlations between flow and numbers of fish entrained were evident.

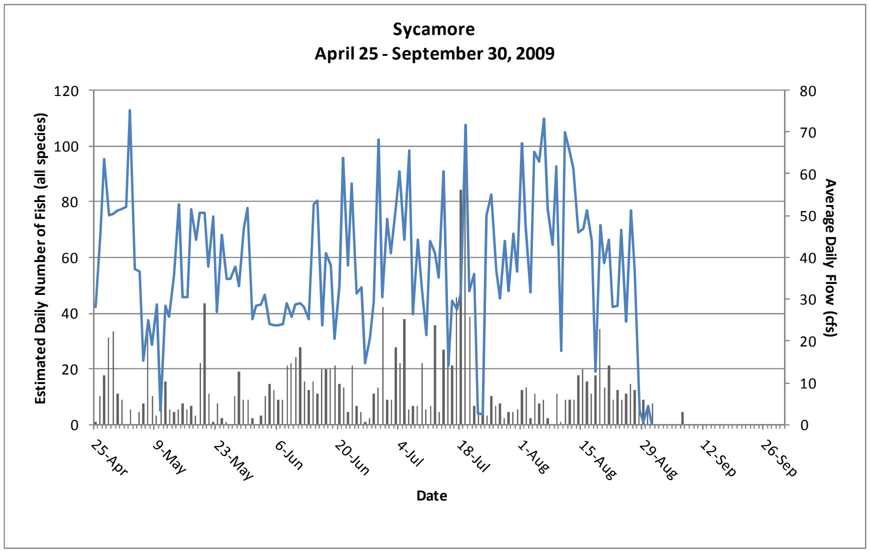

Figure 22. Estimated daily flows (cfs) in the irrigation canal in Sycamore and estimated daily total numbers of fish (all species) entrained during the 2009 irrigation season.

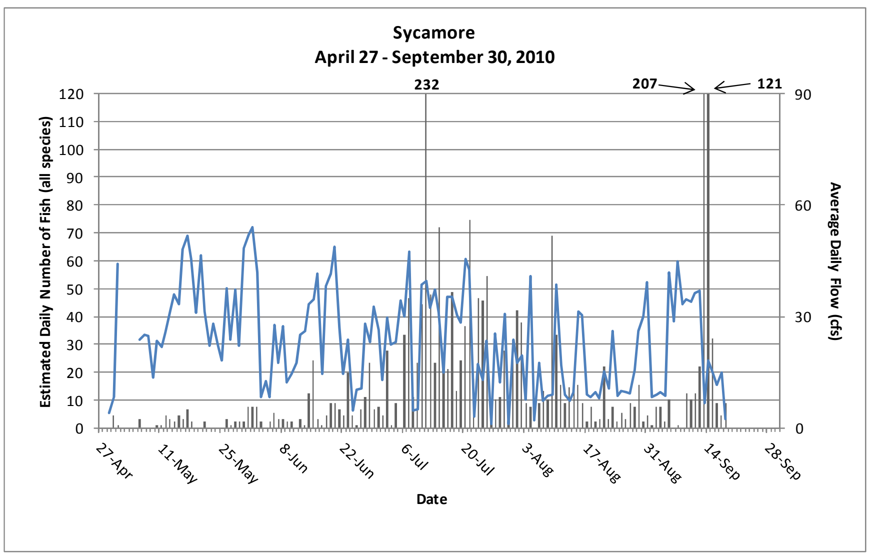

Figure 23. Estimated daily flows (cfs) in the irrigation canal at Sycamore and estimated daily total numbers of fish (all species) entrained during the 2010 irrigation season.

River Garden Farms No. 2

In 2009, fish entrainment monitoring at the outfall for the River Garden Farms No. 2 was initiated on April 29th (the onset of irrigation diversion) (first net pull on April 30th) and continued until September 20th. In 2010, monitoring was initiated on May 23th (the onset of irrigation diversion) (first net pull on May 24th) and continued until September 30th. Table 4 provides the estimated total numbers of each species entrained during 2009 and 2010. All of the non-salmonid fish species entrained would normally be expected to be present at this river location during the sampling period (Appendix B).

Table 4. Estimated numbers of each fish species entrained at the River Garden Farms No. 2 diversion during the 2009 and 2010 irrigation seasons. (Note: * signifies a non-native fish)

Species	2009	2010
Tule Perch	63	26
Sacramento Sucker	21	4
Chinook Salmon	1	18
Brown Bullhead*	11	4
White Catfish*	11	3
Unidentified Fish	2	11
Wakasagi*	0	12
Unidentified Lamprey	10	0
Black Crappie*	6	0
Bigscale Logperch*	4	0
Bluegill*	1	2
White Crappie*	0	3
Hardhead	3	0
Unidentified Bass*	2	0
Black Bullhead*	2	0
Sacramento Pikeminnow	1	1
Carp*	1	1
Unidentified Bullhead*	0	2
Fathead Minnow*	0	2
Golden Shiner*	0	2
Prickly Sculpin	1	0
Unidentified Sunfish*	1	0
River Lamprey	0	1

In 2009, Tule perch was the dominant fish species among 13 identifiable species entrained, followed by Sacramento sucker (Figure 24). Only one juvenile fall-run Chinook salmon was observed. In 2010, Tule perch was again the dominant fish species among 13 identifiable species entrained, followed by Chinook salmon and Wakasagi (Figure 24). Eighteen juvenile Chinook salmon were entrained (Figure 25). One Chinook salmon fry was sampled which was a size indicating that the fish was a late-fall-run Chinook; all other fish were fall-run Chinook. The daily numbers of all fish species entrained were consistently low throughout the irrigation seasons (Figures 26 and 27).

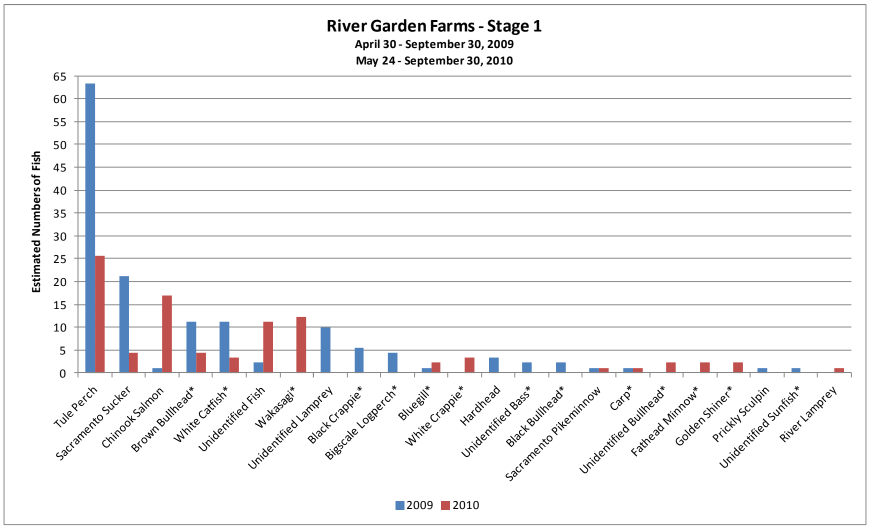

Figure 24. Estimated numbers of all fish species entrained at the River Garden Farms No. 2 canal during the 2009 and 2010 irrigation seasons.

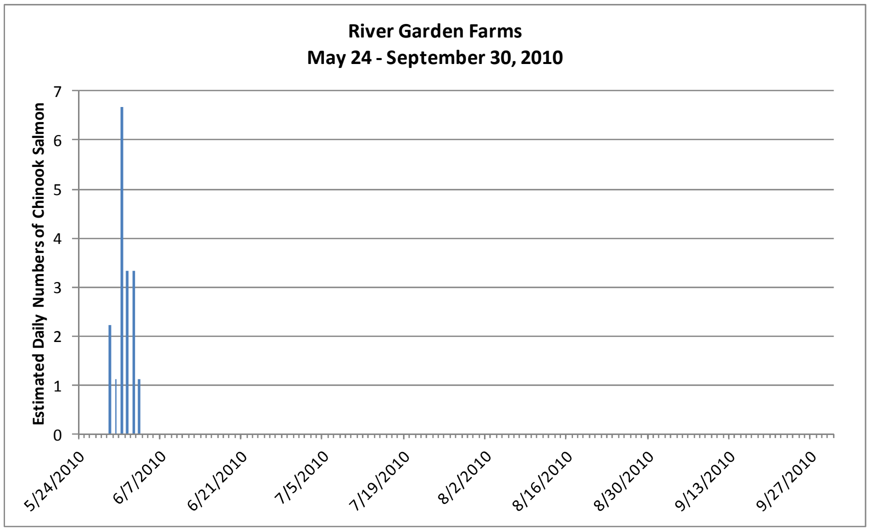

Figure 25. Estimated daily numbers of juvenile Chinook salmon entrained in River Garden Farms No. 2 canals during the 2010 irrigation season.

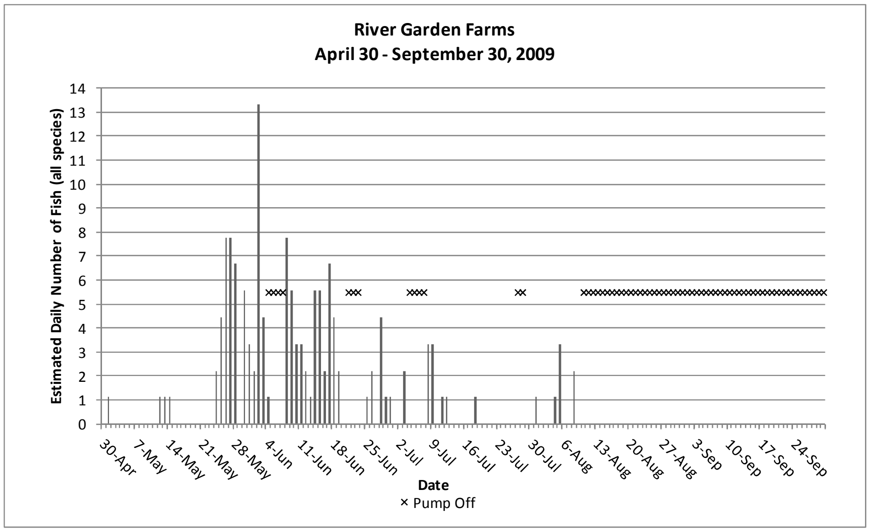

Figure 26. Estimated daily numbers of fish (all species combined) entrained in River Garden Farms No. 2 canals during the 2009 irrigation season.

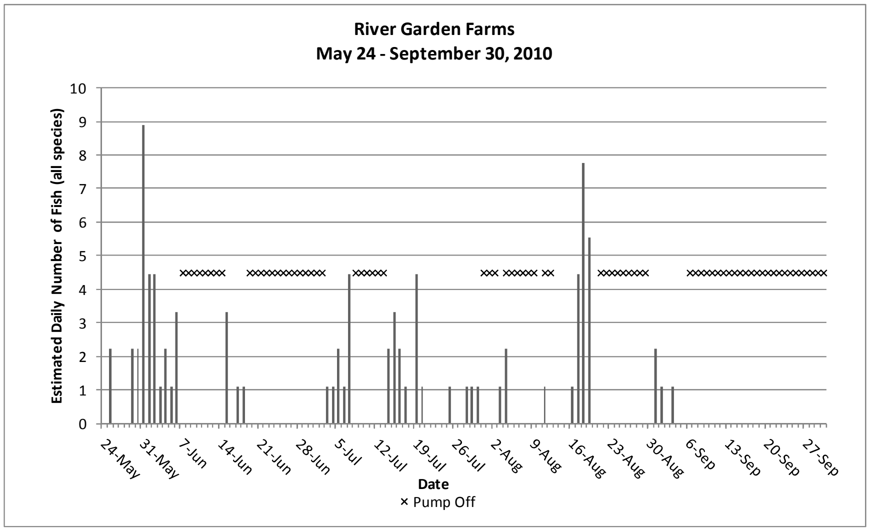

Figure 27. Estimated daily numbers of fish (all species combined) entrained in River Garden Farms No. 2 canals during the 2010 irrigation season.

Based on data from a thermograph at nearby State Ranch canal in 2009, water temperatures during the diversion season generally ranged from the high 60's to low 70's degrees Fahrenheit (Figure 28). In 2010, using the data from a thermograph at State Ranch canal, water temperatures were cool early in the season, rose rapidly in the spring, reaching the high 60's to low 70's degrees Fahrenheit from late June to mid-September (Figure 28).

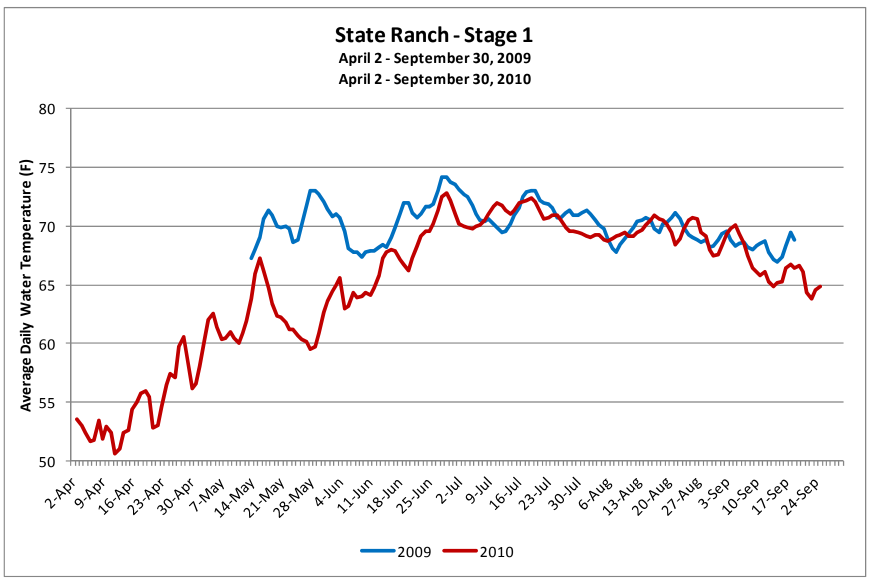

Figure 28. Average daily water temperatures recorded in State Ranch canal (just downstream from River Garden Farms No. 2) in 2009 and 2010.

In 2009, operation of flow meters in the canals did not prove to be feasible due to the very low water surface elevation exiting through the culverts. In 2010, flows and flow meter positioning were more favorable. Based on the flow meters installed in the fyke nets, daily flow in the canals during 2010 was highly variable (Figure 29) but provides a relative indication of the timing of water diversions into the canal. No correlations between flow and numbers of fish entrained were evident.

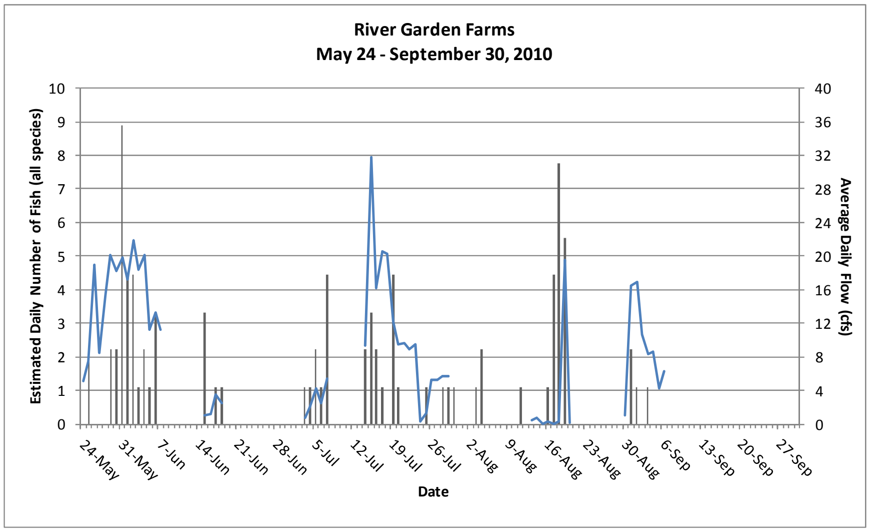

Figure 29. Estimated daily flows (cfs) in River Garden Farms No. 2 canals and estimated total numbers of fish (all species) entrained during the 2010 irrigation season.

State Ranch

In 2009, fish entrainment monitoring at the outfall for the State Ranch pumping station was initiated on April 1st (the federal research permit start date) (first net pull on April 2nd) and continued until September 20th. In 2010, fish entrainment monitoring was initiated on April 1st (the first authorized day of the Section 10 permit period) (first net pull on April 2nd) and continued until September 30th. Like other sampling sites, the nets were kept in place each day, even if diversions were not occurring that day, to ensure that fish may be captured if water diversions resumed. For example, during April 2010, even though no pumps were operating most of the month, the fyke net was positioned over the culvert each day. Table 5 provides the estimated total numbers of each species entrained during 2009 and 2010. All of the non-salmonid species entrained would normally be expected to be present at this river location during the sampling period (Appendix B).

Table 5. Estimated numbers of each fish species entrained at the State Ranch diversion during the 2009 and 2010 irrigation seasons. (Note: * signifies a non-native fish)		
Species	**2009**	**2010**
Sacramento Sucker	2967	654
Tule Perch	487	68
Chinook Salmon	189	12
Carp*	2	151
Sacramento Pikeminnow	104	38
White Catfish*	46	53
Bluegill*	33	32
Black Crappie*	50	9
Hardhead	10	43
Brown Bullhead*	29	23
River Lamprey	36	6
Black Bullhead*	26	9
Unidentified Fish	18	16
Golden Shiner*	14	19
Unidentified Lamprey	0	33
Pacific Lamprey	9	20
Unidentified Bullhead*	6	26
California Roach	1	29
Prickly Sculpin	28	3
Unidentified Lamprey	23	0
Bigscale Logperch*	14	9
Green Sunfish*	12	3
Fathead Minnow*	14	0
Unidentified Minnow*	12	0
Redear Sunfish*	0	11
Channel Catfish*	9	0
American Shad*	6	2
Largemouth Bass*	4	3
Wakasagi*	7	0
Threadfin Shad*	6	0
Riffle Sculpin	2	2
Hitch	3	0
Sacramento Splittail	3	0
Threespine Stickleback	2	1
Unidentified Sculpin	2	0
Spotted Bass*	0	2
Unidentified Bass*	1	0

As observed at Sycamore canal, Sacramento sucker was the dominant species entrained, among 28 identifiable species, at the State Ranch pump station canal outfall in 2009, followed by Tule perch, Chinook salmon, and Sacramento pikeminnow (Figure 30). An estimated 189 juvenile Chinook were entrained in the State Ranch canal which occurred early in the irrigation season (Figure 31). Among that total, six were estimated to be spring-run Chinook with the remainder as fall-run Chinook. The apparent surge in entrainment of suckers on August 22 could not be explained by pumping operations or fish entrainment monitoring procedures. Diversions were moderate during that period compared to earlier in the summer and only two pumps were in operation. It is possible that a school of small suckers happened to encounter the pump intakes on that day. In 2010, 24 identifiable fish species were sampled. Sacramento sucker was again the dominant species sampled, followed by carp and Tule perch (Figure 30). An estimated 11 juvenile Chinook salmon (fall run) were entrained (April 29: three fish, April 30: six fish, May 5: two fish) and an estimated one spring-run Chinook was entrained on May 31. The daily numbers of all fish species entrained at the outfall were highly variable over the irrigation seasons (Figures 32 and 33).

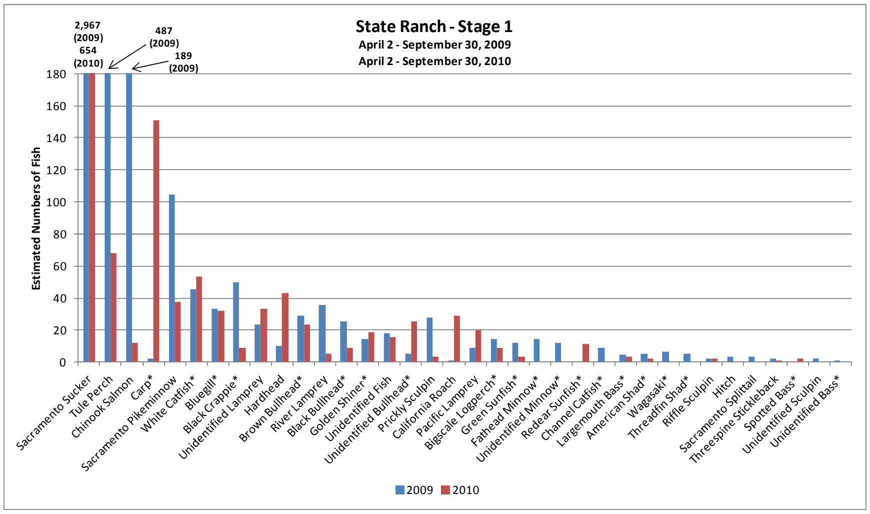

Figure 30. Estimated total numbers of all fish species entrained in State Ranch canal during the 2009 and 2010 irrigation seasons.

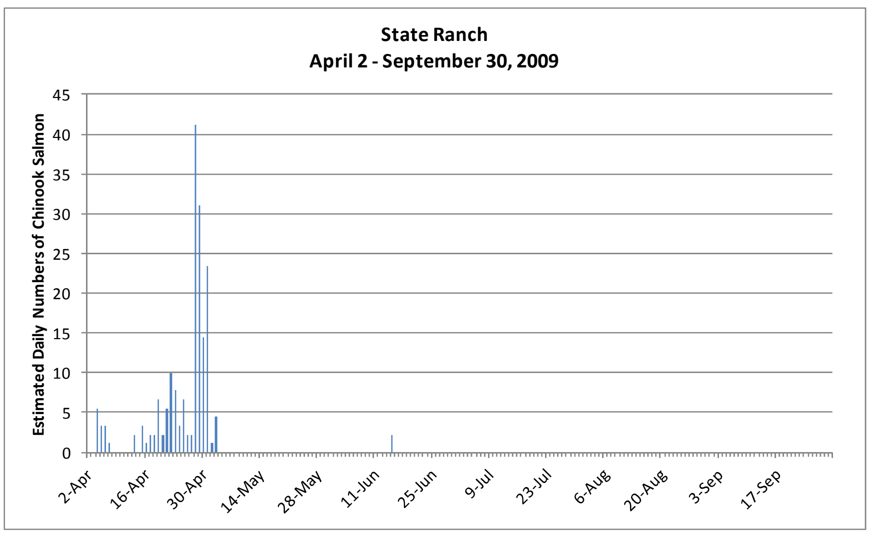

Figure 31. Estimated daily numbers of juvenile Chinook salmon entrained in State Ranch canal during the 2009 irrigation season.

On April 4, 2009, during the fyke net check, a very large wood post, similar in dimensions to a railroad tie, and an enormous amount of vegetative debris were found inside the fyke net. We believe this was a dislodged vertical support post that had been positioned back inside the culvert. After the onset of irrigation pumping, aquatic vegetation probably had become entangled around the post until it broke loose flushing the post and vegetation back into the fyke net. With considerable difficulty, the net frame, net, and debris (estimated at several hundred pounds in weight) were removed from the canal and the equipment was placed back into the canal on April 6th after we assumed any remaining debris had been flushed from the culvert. However, significant damage to the metal frame, channel, and winch davit had occurred. Because of the importance of sampling at the site with the seasonal presence of juvenile Chinook salmon, we continued to use the equipment until May 3rd when it was apparent the submerged portion of the apparatus could be further compromised from the prior damage and much of the remaining sampling program would be lost for the remainder of the season without repair. On May 21, newly fabricated equipment and a new net ordered from the manufacturer were reinstalled at the site. However, these circumstances in combination resulted in a 20-day period when no sampling occurred. Undoubtedly, absent these events, more fish, possibly including salmon, would have been sampled.

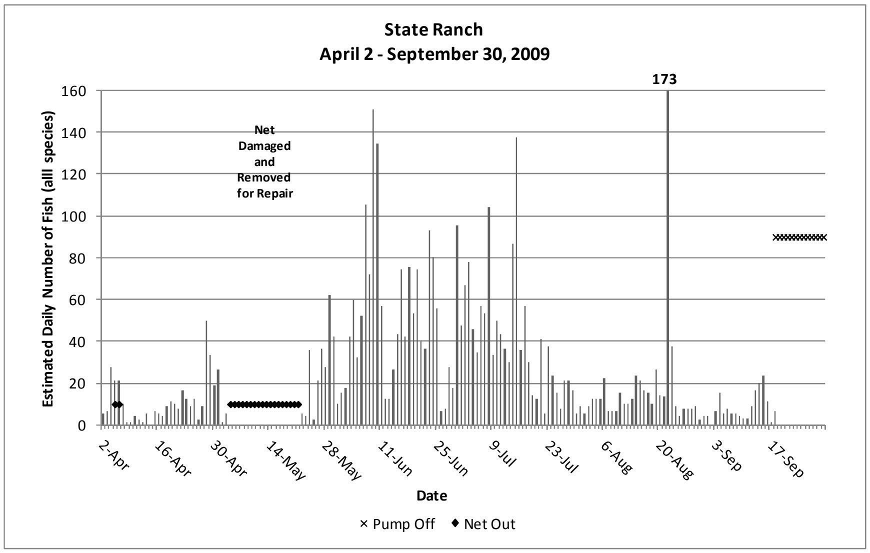

Figure 32. Estimated daily numbers of fish (all species combined) entrained in State Ranch canal during the 2009 irrigation season.

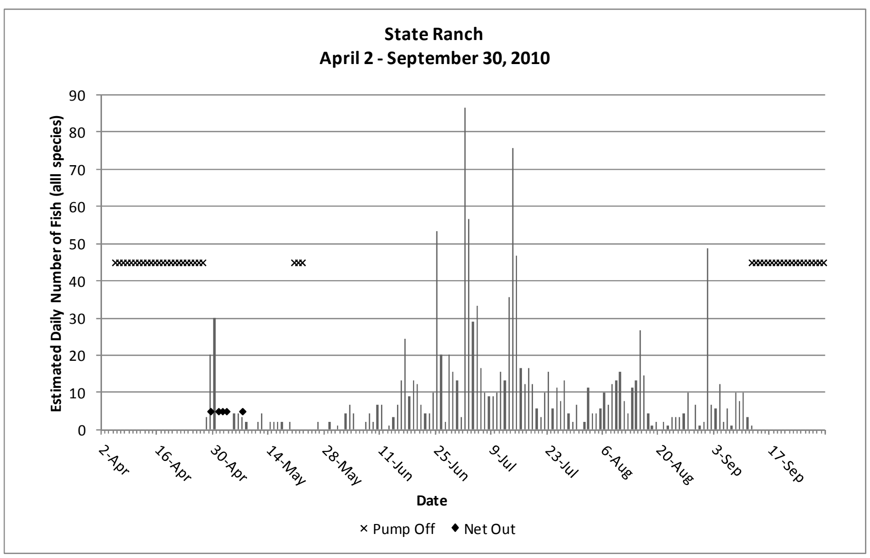

Figure 33. Estimated daily numbers of fish (all species combined) entrained in State Ranch canal during the 2010 irrigation season.

In 2009, based on data from a thermograph at State Ranch canal, water temperatures during the diversion season generally ranged from the high 60's to low 70's degrees Fahrenheit (Figure 34). In 2010, water temperatures were cool early in the season, rose rapidly in the spring, reaching the high 60's to low 70's degrees Fahrenheit from late June to mid-September (Figure 34).

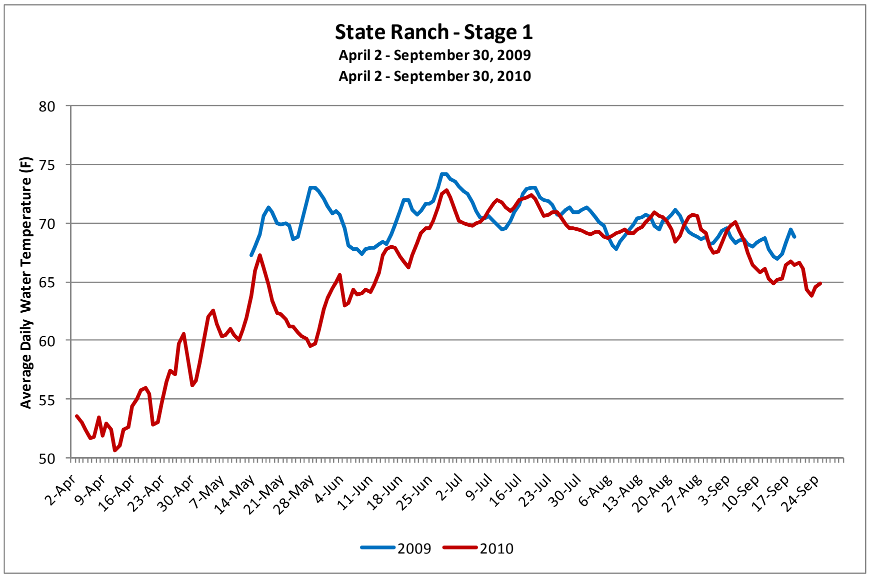

Figure 34. Average daily water temperatures recorded in State Ranch canal during the 2009 and 2010 irrigation seasons.

Based on daily flows recorded by the Sutter Mutual Water Company, daily flow in the State Ranch canal was highly variable during the 2009 and 2010 seasons (Figures 35 and 36) but provides a relative indication of the timing of water diversions into the canal. No correlations between flow and numbers of fish entrained were evident.

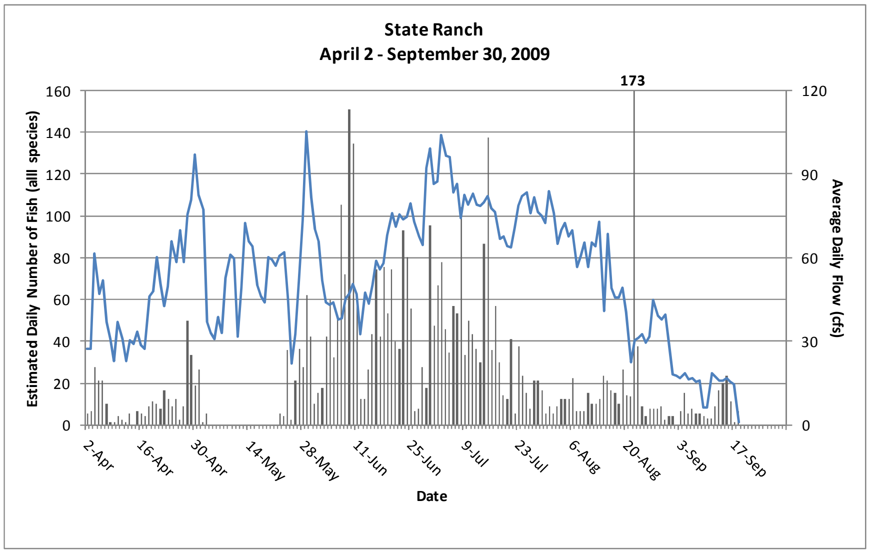

Figure 35. Estimated daily flows (cfs) in State Ranch canal and estimated daily total numbers of fish (all species) entrained during the 2009 irrigation season.

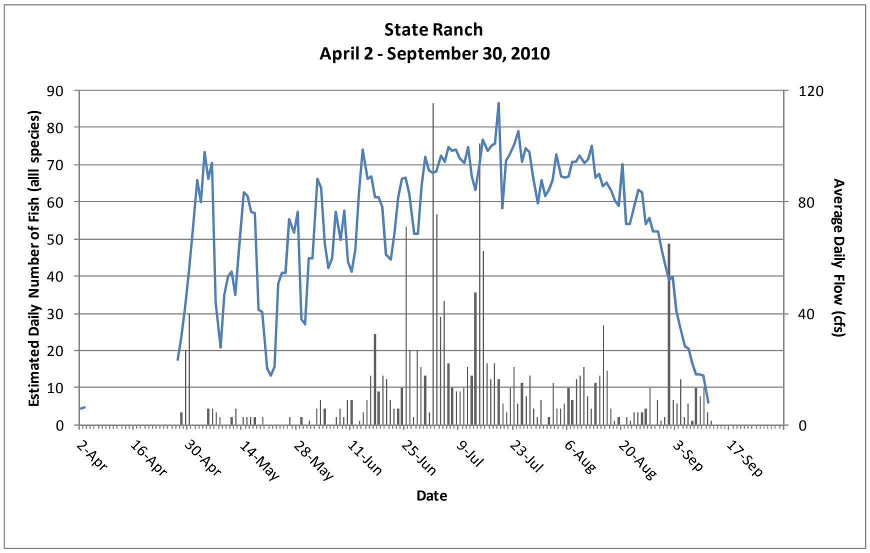

Figure 36. Estimated daily flows (cfs) in State Ranch canal and estimated daily total numbers of fish (all species) entrained during the 2010 irrigation season.

South Steiner

Fish entrainment monitoring at South Steiner canals in 2010 was initiated on May 4th (the onset of pumping operations at that location) (first net pull on May 5th) and continued until September 30th. In 2011 monitoring was initiated on May 16th (the onset of pumping operations at that location) (first net pull on May 17th) and continued until September 30th. Table 6 provides the estimated total numbers of each fish species entrained during 2010 and 2011. All of the non-salmonid species entrained would normally be expected to be present at this river location during the sampling period (Appendix B).

Table 6. Estimated numbers of each fish species entrained at the South Steiner diversion during the 2010 and 2011 irrigation seasons. (Note: * signifies a non-native fish)		
Species	**2010**	**2011**
Sacramento Sucker	548	717
Tule Perch	117	96
Sacramento Pikeminnow	56	78
Hardhead	32	18
Carp*	31	8
River Lamprey	11	11
White Catfish*	11	7
Pacific Lamprey	17	0
White Crappie*	0	17
Black Bullhead*	9	4
Fathead Minnow*	3	8
Brown Bullhead*	7	4
Unidentified Fish	2	9
Unidentified Bullhead*	6	6
Black Crappie*	10	0
Bluegill*	9	0
Prickly Sculpin	6	3
California Roach	0	8
Striped Bass*	4	2
Sacramento Splittail	0	7
Inland Silverside*	3	1
Green Sturgeon	3	1
Unidentified Sculpin	3	0
Green Sunfish*	3	0
Channel Catfish*	0	2
Riffle Sculpin	0	2
Largemouth Bass*	0	2
Chinook Salmon	0	1
Golden Shiner*	0	1
White Sturgeon	0	1

In 2010, of the 18 identifiable fish species observed, Sacramento sucker was the most numerous species entrained, followed by Tule perch and Sacramento pikeminnow (Figure 37). No juvenile Chinook salmon were observed. In 2011, of the 23 identifiable fish species observed, Sacramento sucker was again the most numerous species entrained, followed by Tule perch and Sacramento pikeminnow (Figure 37). No salmon were entrained in 2010. Three green sturgeon were estimated entrained on July 7, 2010. One juvenile Chinook salmon (fall run), one white sturgeon, and one green sturgeon were estimated entrained on May 19, May 30, and July 2, 2011, respectively. With a few exceptions, the daily numbers of all fish species entrained were low and variable over the irrigation seasons (Figures 38 and 39). There were several instances on a few days when a high number of fish were entrained with no readily apparent reason.

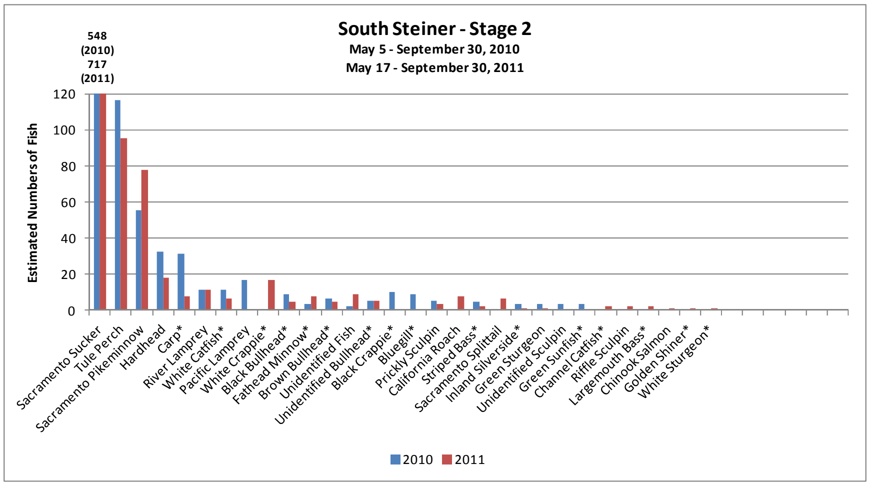

Figure 37. Estimated total numbers of each fish species entrained at the South Steiner canals during the 2010 and 2011 irrigation seasons.

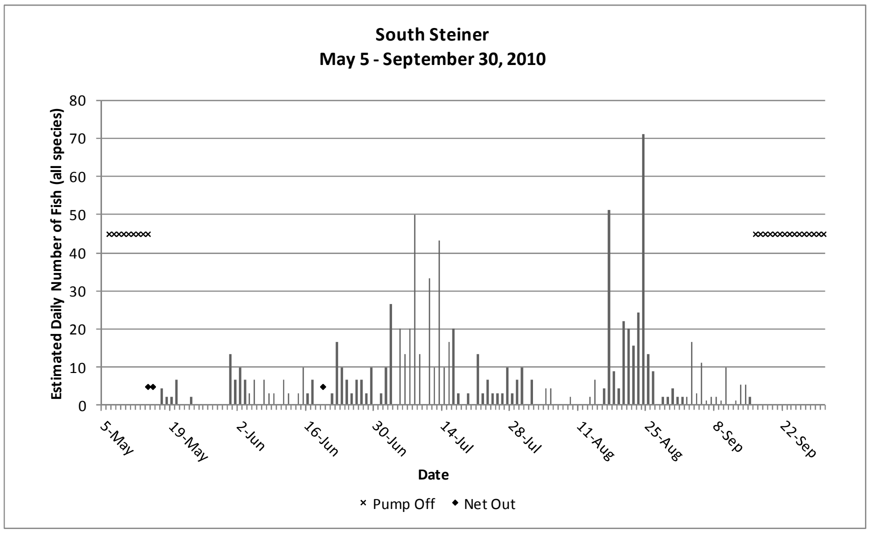

Figure 38. Estimated daily numbers of fish (all species combined) entrained in the South Steiner canals during the 2010 irrigation season.

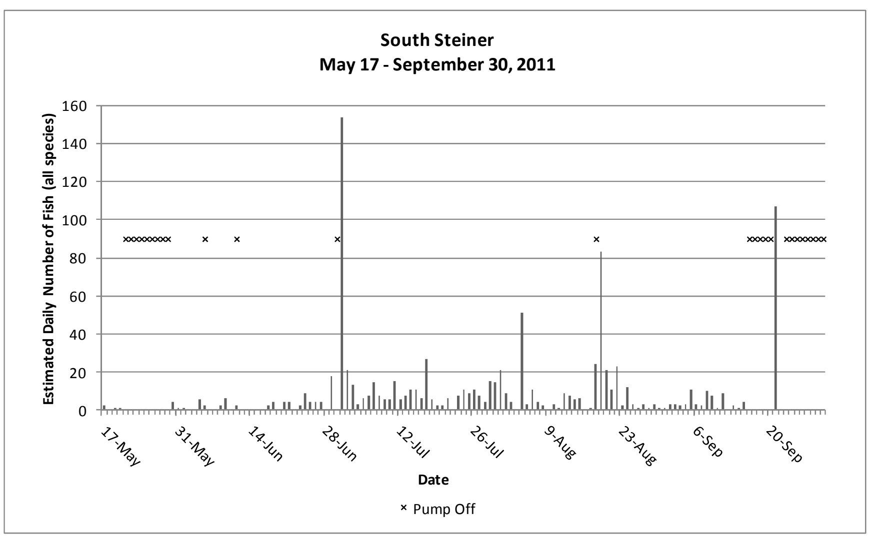

Figure 39. Estimated daily numbers of fish (all species combined) entrained in the South Steiner canals during the 2011 irrigation season.

Based on data from a thermograph installed in South Steiner canal in 2010, water temperatures were cool early in the season, rose rapidly in the spring, reaching the high 60's to low 70's degrees Fahrenheit from late June to mid-September (Figure 40). Similar to 2010, in 2011 water temperatures were cool early in the season, rose rapidly in the late spring, reaching the high 60's to low 70's degrees Fahrenheit from late June to mid-September (Figure 40).

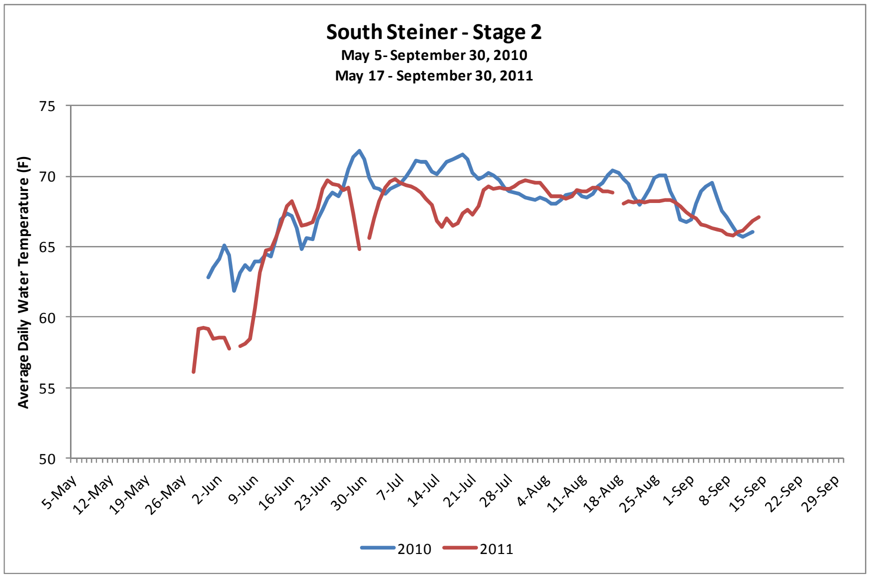

Figure 40. Average daily water temperatures recorded in the South Steiner canal during 2010 and 2011.

Based on flow meters installed in the fyke nets and extrapolation described in the methods section, daily flow in the canal was highly variable during the 2010 and 2011 seasons (Figures 41 and 42) but provides a relative indication of the timing of water diversions into the canal. No correlations between flow and numbers of fish entrained were evident.

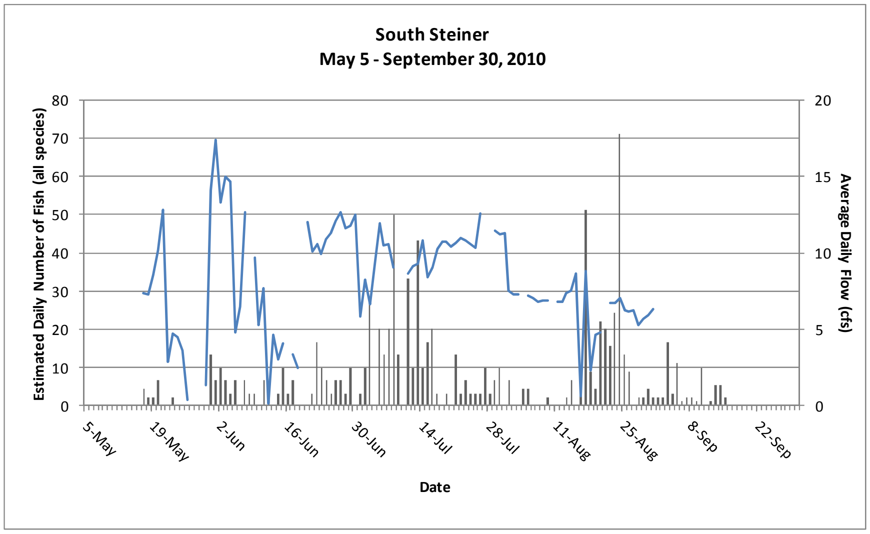

Figure 41. Estimated daily flows (cfs) in the irrigation canals at South Steiner and estimated daily total numbers of fish (all species) entrained during the 2010 irrigation season.

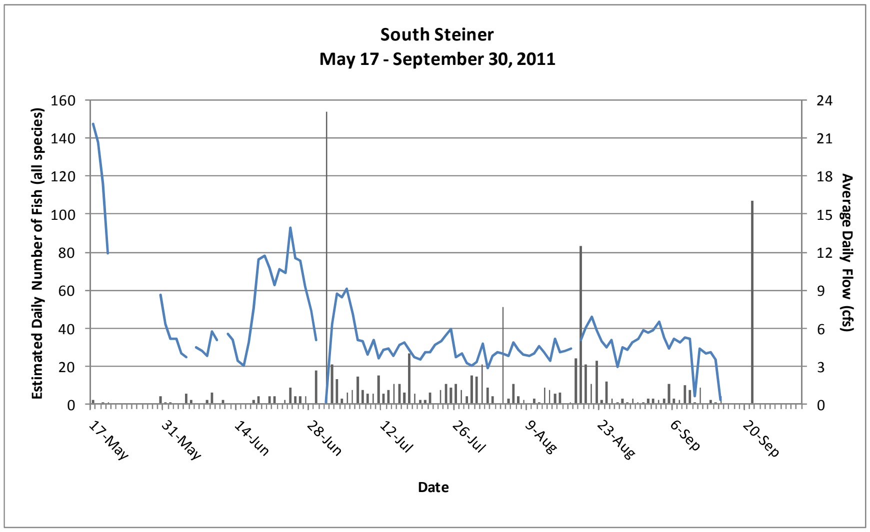

Figure 42. Estimated daily flows (cfs) in the irrigation canals at South Steiner and estimated daily total numbers of fish (all species) entrained during the 2011 irrigation season.

Oji

In 2010, fish entrainment monitoring at the Oji canal was initiated on May 10th (the onset of pumping operations at that location) (first net pull on May 11th) and continued until September 30th. In 2011, monitoring was initiated on April 30th, 2011 (the onset of pumping operations at that location) (first net pull on May 1st) and continued until September 30th. Table 7 provides the estimated total numbers of each fish species entrained during 2010 and 2011. All of the non-salmonid species entrained would normally be expected to be present at this river location during the sampling period (Appendix B).

Table 7. Estimated numbers of each fish species entrained at the Oji diversion during the 2010 and 2011 irrigation seasons. (Note: * signifies a non-native fish)

Species	2010	2011
Tule Perch	21	18
Sacramento Sucker	19	18
Unidentified Fish	8	9
Chinook Salmon	1	20
River Lamprey	3	7
White Catfish*	2	3
Largemouth Bass*	3	0
Pacific Lamprey	2	2
Sacramento Pikeminnow	1	2
California Roach	0	4
Bluegill*	1	0
Fathead Minnow*	1	0
Black Bullhead*	1	0
Redear Sunfish*	1	0
Golden Shiner*	0	2
White Crappie*	0	2
Carp*	0	1

In 2010, 12 identifiable fish species were observed with Tule perch and Sacramento sucker the most numerous (Figure 43). Only one juvenile Chinook salmon (fall run) was observed (May

11, 2010). In 2011, 11 identifiable fish species were observed with Chinook salmon, Tule perch, and Sacramento sucker the most numerous (Figure 43). Twenty juvenile Chinook salmon (fall run) were estimated entrained. All salmon were entrained during May with the majority occurring in early May (Figure 44). The estimated daily numbers of all fish species entrained at the outfall were low and variable over the irrigation seasons (Figures 45 and 46).

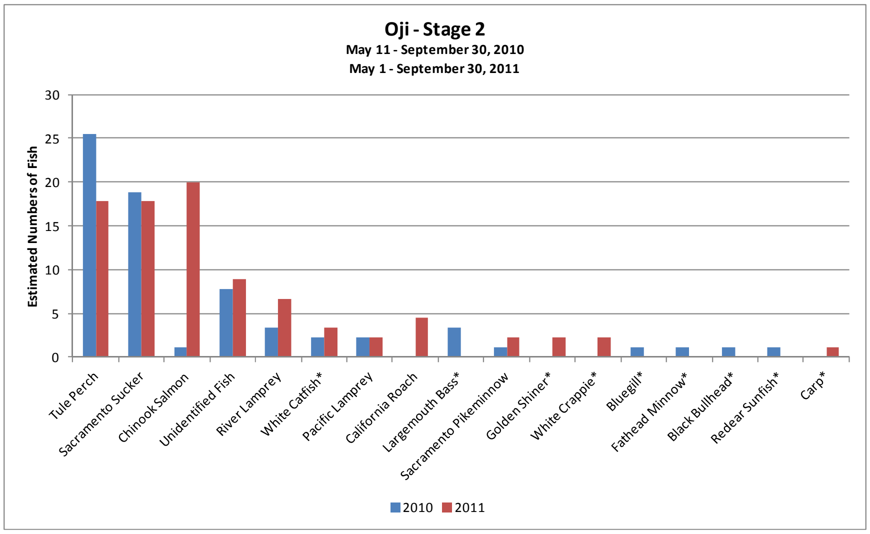

Figure 43. Estimated total numbers of each fish species entrained in Oji canal during the 2010 and 2011 irrigation seasons.

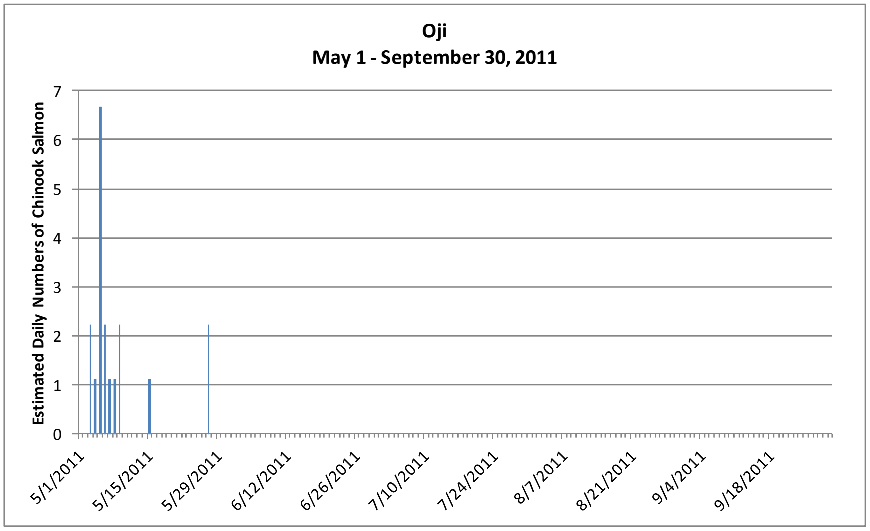

Figure 44. Estimated daily numbers of juvenile Chinook salmon entrained in Oji canal (May 1 – September 30, 2011).

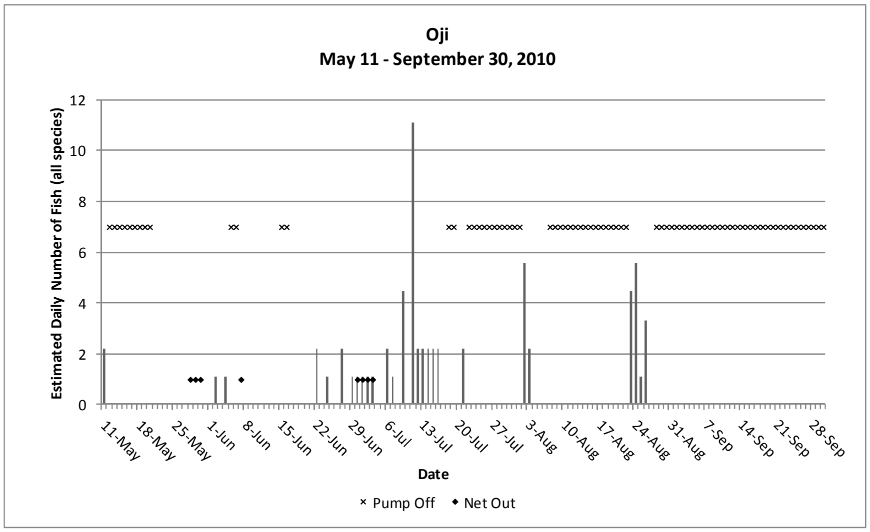

Figure 45. Estimated daily numbers of fish (all species combined) entrained in Oji canal during the 2010 irrigation season.

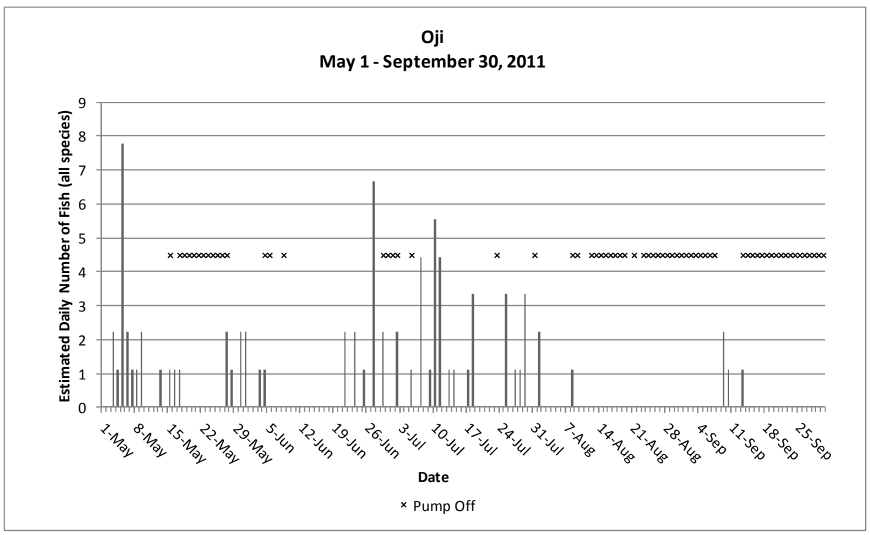

Figure 46. Estimated daily numbers of fish (all species combined) entrained in Oji canal during the 2011 irrigation season.

Due to lack of pumping during significant portions of the irrigation season in 2010, the thermograph placed in the Oji irrigation canal was frequently exposed to ambient air temperatures (Figure 47). Based on partial data from that location when the canal was in operation and a thermograph installed in State Ranch canal located downstream, water temperatures were cool early in the season, rose rapidly in the spring, reaching the high 60's to low 70's degrees Fahrenheit from late June to mid-September (Figure 34). Like 2010, in 2011, due to lack of pumping during significant portions of the irrigation season, the thermograph was frequently exposed to ambient air temperatures. Based on partial data from that location when the canal was in operation, water temperatures rose rapidly in the late spring, reaching the high 60's degrees Fahrenheit during the summer (Figure 47).

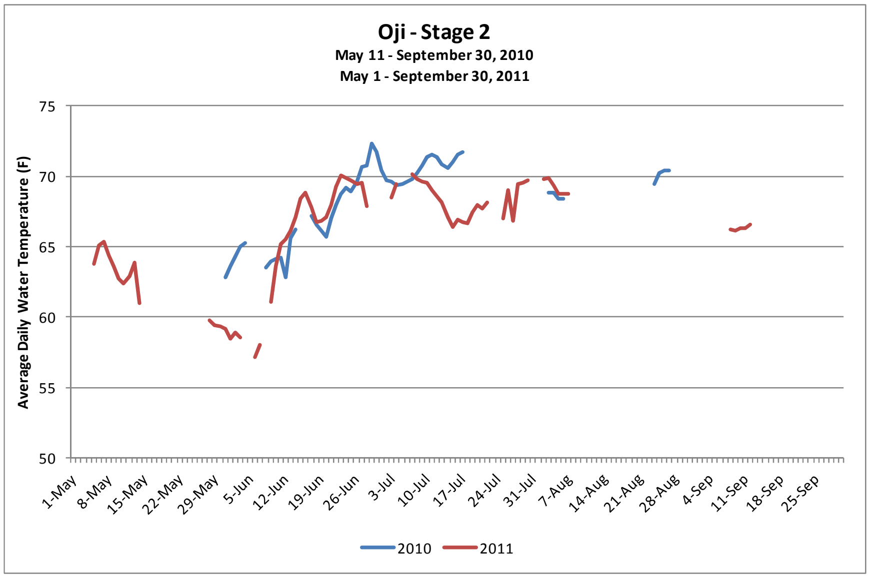

Figure 47. Average daily water temperatures recorded at the Oji canal during 2010 and 2011. Gaps in the data are attributable to periods when no water was diverted and the thermograph was exposed to ambient air temperatures or stagnant water.

Based on data recorded using the USBR flow meter, daily flow in the canal was highly variable during 2010 and 2011 (Figures 48 and 49) but provides a relative indication of the timing of water diversions into the canal. No correlations between flow and numbers of fish entrained were evident.

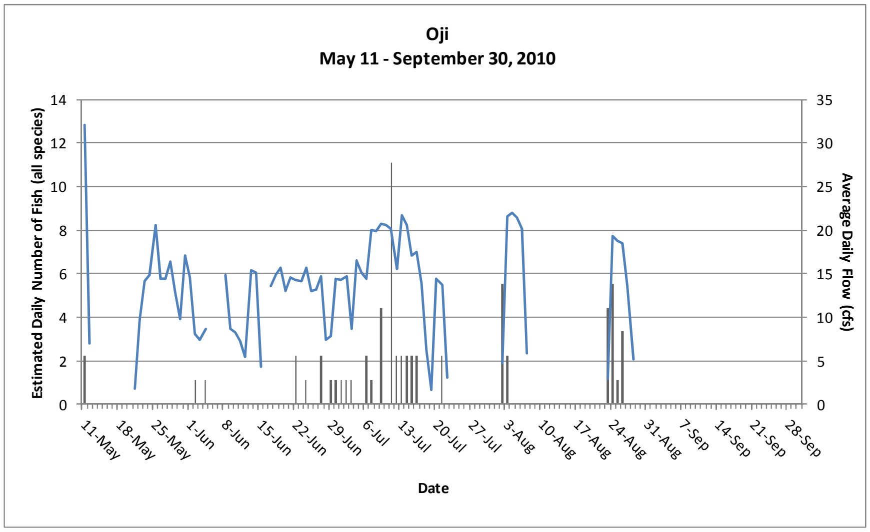

Figure 48. Estimated daily flows (cfs) in Oji canal and estimated daily total numbers of fish (all species) entrained during the 2010 irrigation season.

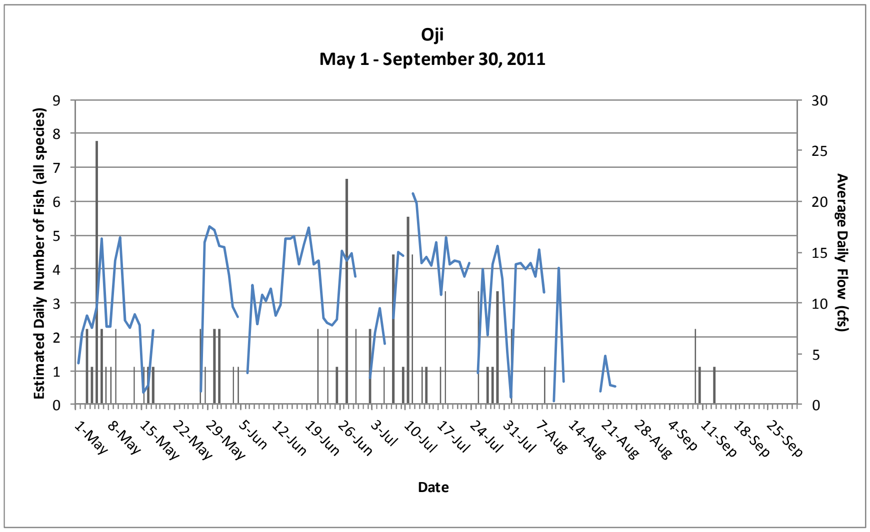

Figure 49. Estimated daily flows (cfs) in the Oji canal and estimated daily total numbers of fish (all species) entrained during the 2011 irrigation season.

Windswept

In 2010, fish entrainment monitoring at the Windswept canal was initiated on May 23rd (the onset of pumping operations at that location) (first net pull on May 24th) and continued until September 30th. In 2011, monitoring was initiated on May 24th (the onset of pumping operations at that location) (first net pull on May 25th) and continued until September 30th. Table 8 provides the estimated total numbers of each fish species entrained during the 2010 and 2011 irrigation seasons.

Table 8. Estimated numbers of each fish species entrained at the Windswept diversion during the 2010 and 2011 irrigation seasons.

Species	2010	2011
California Roach	0	4
Tule Perch	23	4
Hardhead	0	2
Hitch	0	2
River Lamprey	0	1

In 2010, the only fish species observed was Tule perch. It is not known why only this species was sampled because there were no readily apparent physical features or in-river habitat attributes near the intake which would provide an explanation. In 2011, only five fish species were observed. No salmonids were captured. As compared to other sampling sites, the Windswept pump station was frequently not in operation during most of the irrigation seasons in 2010 and 2011 (Figures 50 and 51). USBR pump station records indicated that the total seasonal diversion in 2010 was not unlike past years' operations (Phil Burroughs, Windswept Ranch, pers. comm., January 18, 2011) and the 2011 operations were similar to 2010.

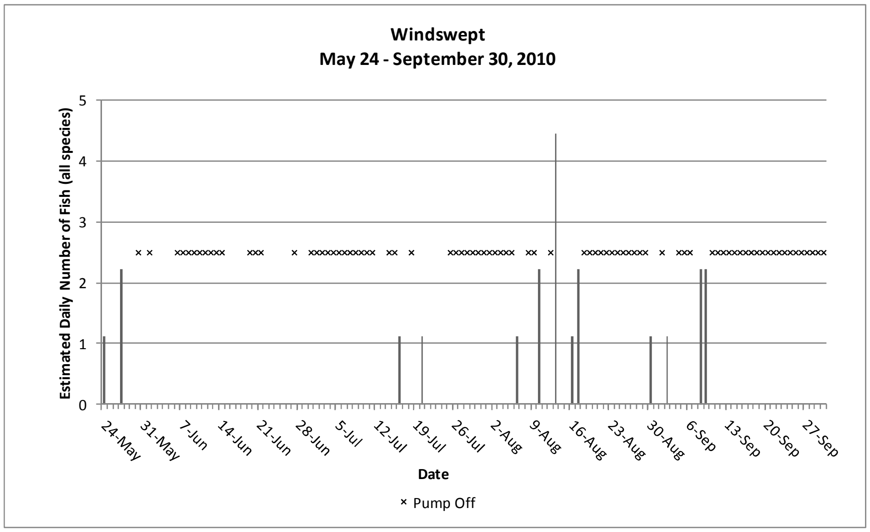

Figure 50. Estimated daily numbers of Tule perch entrained at Windswept canal during the 2010 irrigation season.

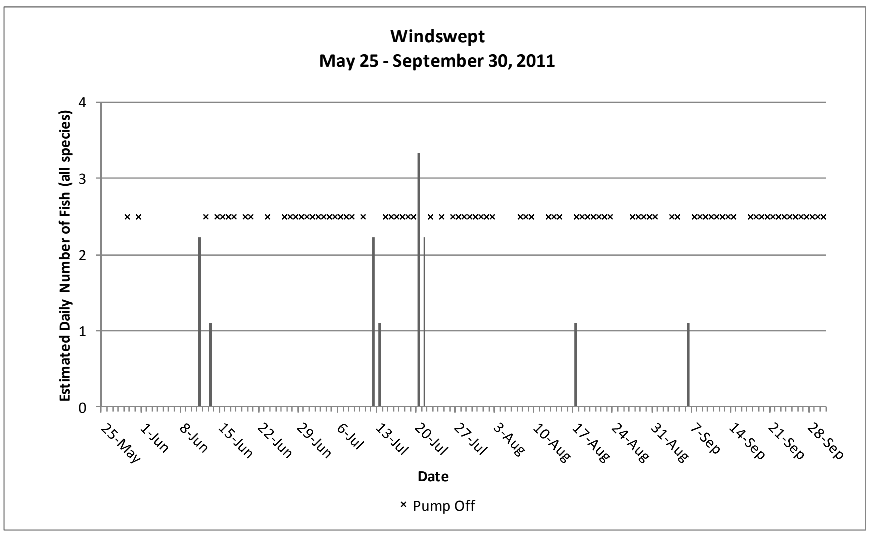

Figure 51. Estimated daily numbers of fish (all species combined) entrained at Windswept canal during the 2011 irrigation season.

Pumping infrequently occurred at the Windswept pump station and, therefore, the thermograph placed in the canal in 2010 and 2011 was frequently exposed to ambient air conditions and did not provide much useful data for the site (Figure 52).

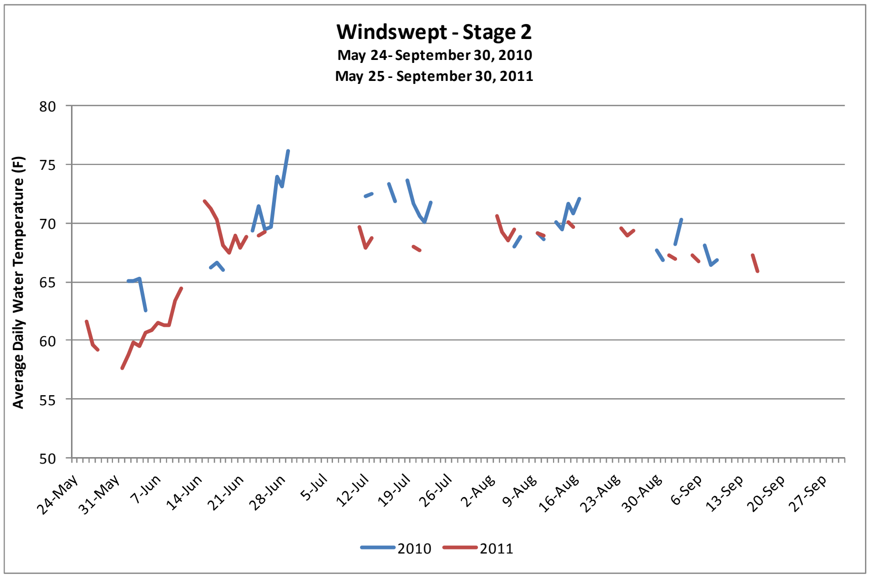

Figure 52. Average daily water temperatures recorded at the Windswept canal during 2010 and 2011. Gaps in the data are attributable to periods when no water was diverted and the thermograph was exposed to ambient air temperatures or stagnant water.

Based on the flow meter installed in the fyke net, daily flow in the canal was low and variable during the 2010 and 2011 seasons (Figures 53 and 54) but provides a relative indication of the timing of water diversions into the canal. Data were sparse and no correlations between flow and numbers of fish entrained were evident.

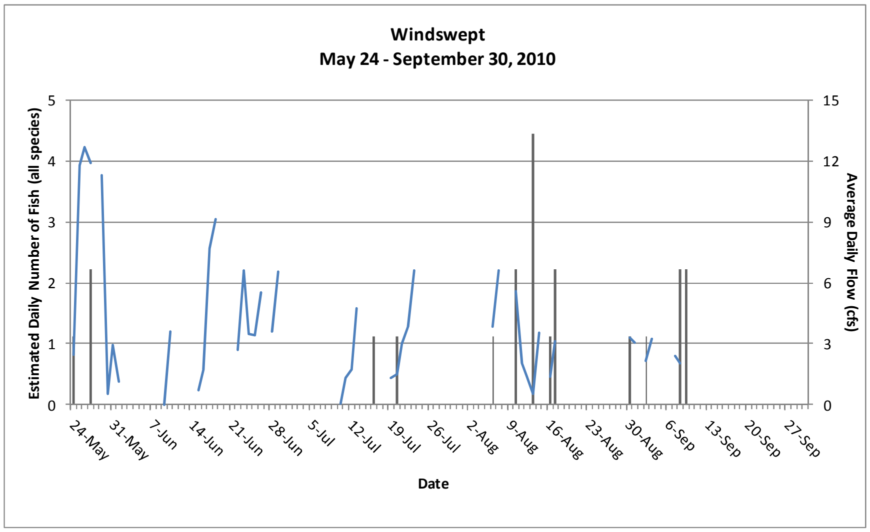

Figure 53. Estimated daily flows (cfs) in the Windswept canal and estimated daily total numbers of fish (all species) entrained during the 2010 irrigation season.

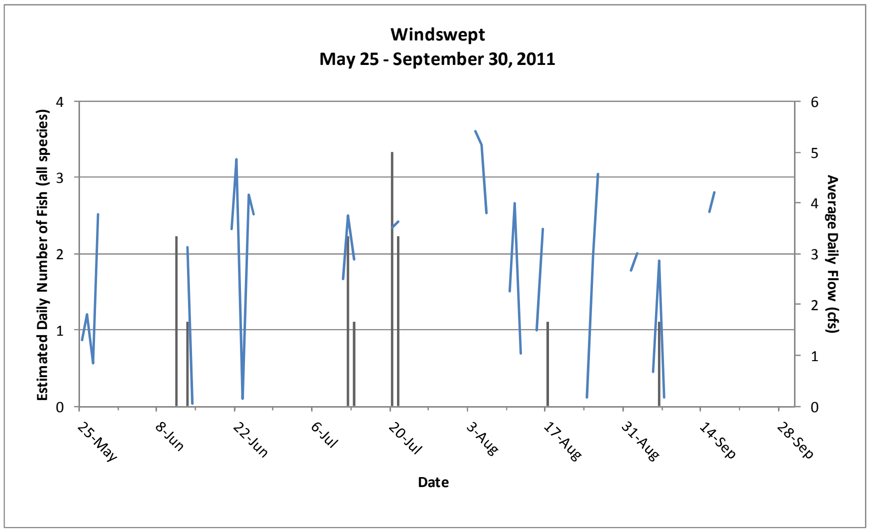

Figure 54. Estimated daily flows (cfs) in the Windswept canal and estimated daily total numbers of fish (all species) entrained during the 2011 irrigation season.

Portuguese Bend

In 2010, fish entrainment monitoring at the Portuguese Bend canal was initiated on April 28th (the onset of pumping operations at that location) (first net pull on April 29th) and continued until September 30th. In 2011, monitoring was initiated on April 26th (the onset of pumping operations at that location) (first net pull on April 27th) and continued until September 30th. Table 9 provides the estimated total numbers of each fish species entrained during the 2010 and 2011 irrigation seasons. All of the non-salmonid species entrained would normally be expected to be present at this river location during the sampling period.

Table 9. Estimated numbers of each fish species entrained at the Portuguese Bend diversion during the 2010 and 2011 irrigation seasons. (Note: * signifies a non-native fish)		
Species	**2010**	**2011**
Carp*	426	563
Sacramento Sucker	630	274
Prickly Sculpin	251	132
Tule Perch	104	137
White Catfish*	63	112
Sacramento Pikeminnow	58	69
Pacific Lamprey	10	80
Channel Catfish*	0	74
Unidentified Fish	53	19
Hardhead	47	9
Black Bullhead*	16	26
Bluegill*	31	10
River Lamprey	6	26
Unidentified Bullhead*	18	13
Unidentified Sculpin	8	22
Brown Bullhead*	19	8
Green Sunfish*	22	1
Bigscale Logperch*	11	10
Black Crappie*	20	0
Fathead Minnow*	1	14
Redear Sunfish*	16	1
White Crappie*	3	11
Riffle Sculpin	9	2
Threespine Stickleback	1	9
Golden Shiner*	9	0
Largemouth Bass*	6	2
Wakasagi*	7	0
Chinook Salmon	1	6
Inland Silverside*	0	6
Spotted Bass*	6	0
California Roach	0	4
Smallmouth Bass*	3	1
Unidentified Bass*	4	0
Goldfish*	0	2
Hitch	0	2
Mosquitofish*	0	2
Unidentified Lamprey	2	0
Red Shiner*	0	1
Sacramento Blackfish	1	0
Striped Bass*	1	0
Threadfin Shad*	1	0

In 2010, 29 identifiable fish species were observed. Sacramento sucker was the most numerous fish species entrained, followed by carp, prickly sculpin, and Tule perch (Figure 55). Only one juvenile Chinook salmon (fall run) was observed (May 1, 2010). In 2011, 29 identifiable fish species were observed. Carp was the most numerous fish species entrained, followed by Sacramento sucker, Tule perch, prickly sculpin, and white catfish (Figure 55). Only six juvenile Chinook salmon (fall run) were estimated entrained; five of those were observed on April 28, May 21, May 25, June 4, and June 11, 2011. The daily numbers of all fish species sampled at the outfall were highly variable over the irrigation seasons (Figures 56 and 57).

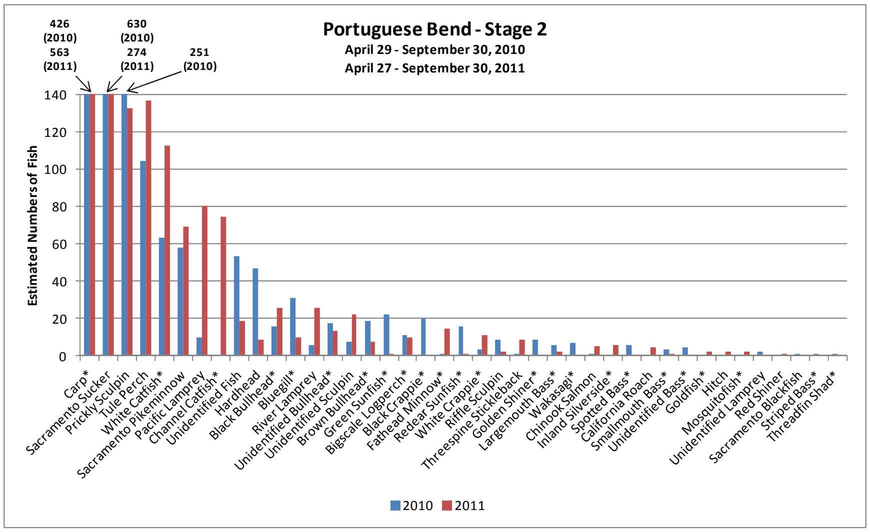

Figure 55. Estimated numbers of each fish species entrained at Portuguese Bend canal during the 2010 and 2011 irrigation seasons.

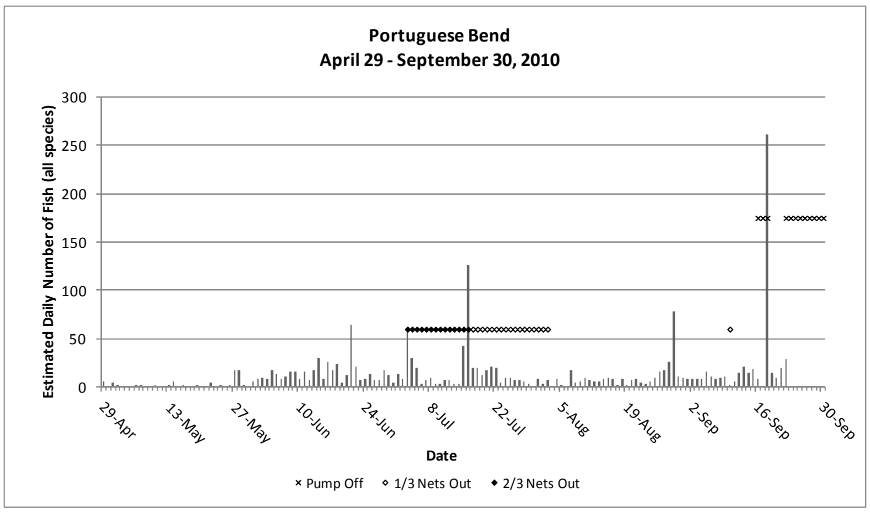

Figure 56. Estimated daily numbers of fish (all species combined) entrained at Portuguese Bend canal during the 2010 irrigation season.

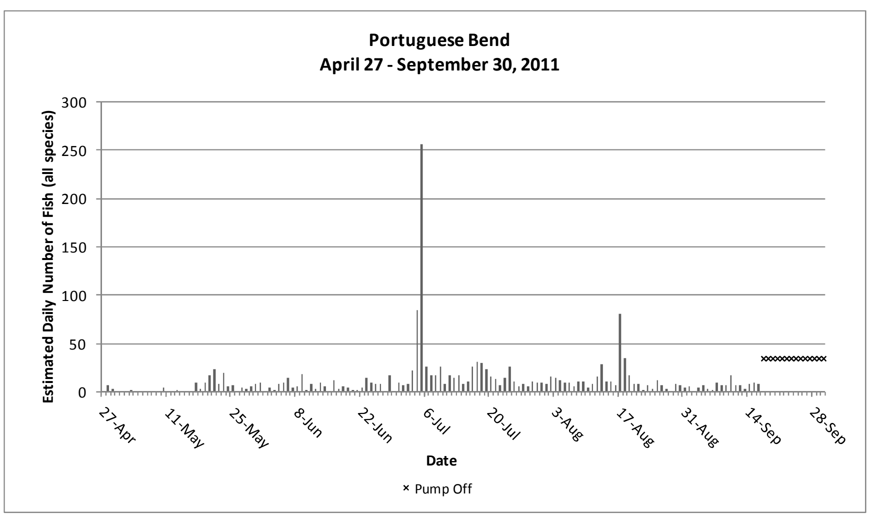

Figure 57. Estimated daily numbers of fish (all species combined) entrained at Portuguese Bend canal during the 2011 irrigation season.

Based on data from a thermograph installed in the Portuguese Bend canal in 2010, water temperatures were cool early in the season, rose rapidly in the spring, reaching the high 60's to low 70's degrees Fahrenheit from late June to early-September (Figure 58). Similar to 2010, in 2011 water temperatures were cool early in the season, rose rapidly in the late spring, reaching the high 60's to low 70's degrees Fahrenheit from late June to early-September (Figure 58). The water temperatures during the period when the salmon were sampled were in the 60's degrees Fahrenheit range.

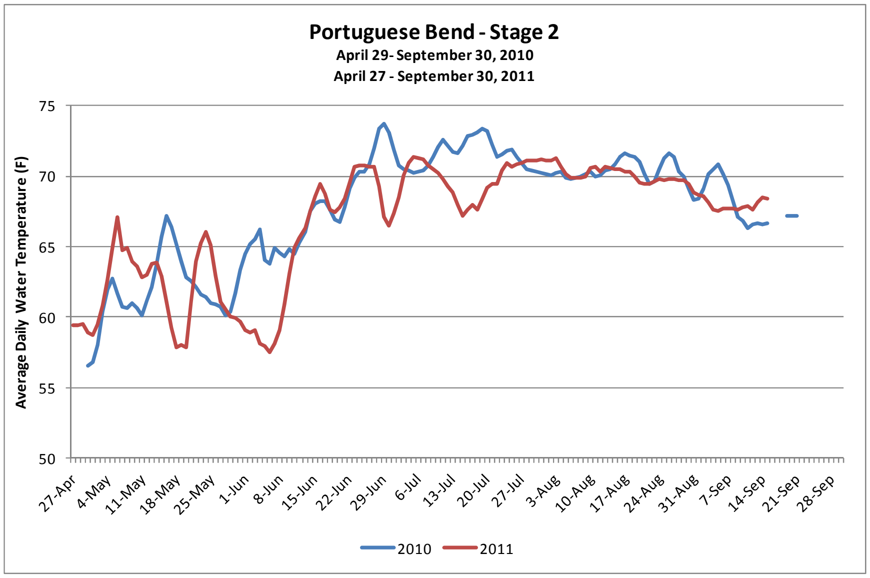

Figure 58. Average daily water temperatures recorded in Portuguese Bend canal during 2010 and 2011.

Sutter Mutual Water Company data were used to depict daily flows in Portuguese Bend Canal. Figures 59 and 60 show a comparison of daily flow in the canal during 2010 and 2011 with estimated daily numbers of fish entrained. Daily flow in the canal was highest during the July through August period which generally corresponded to the highest period of fish entrainment.

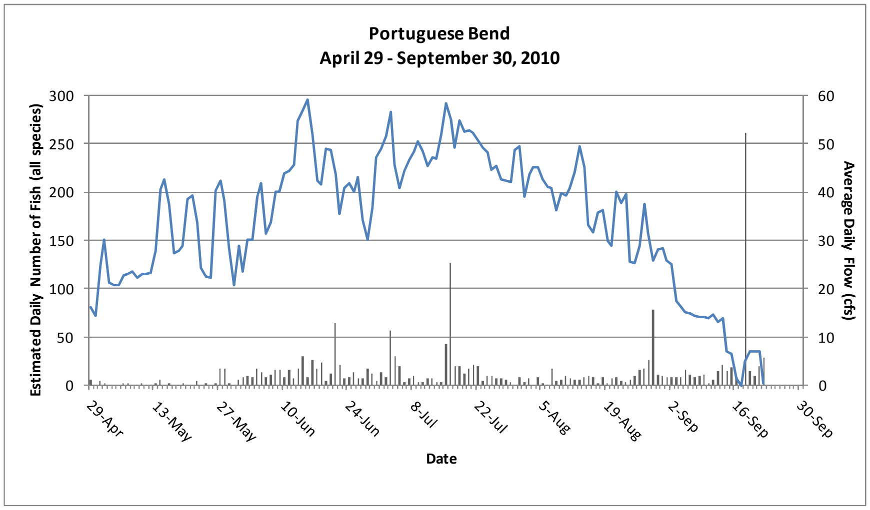

Figure 59. Estimated daily flows (cfs) in the irrigation canal at Portuguese Bend and estimated daily total numbers of fish (all species) entrained during the 2010 irrigation season.

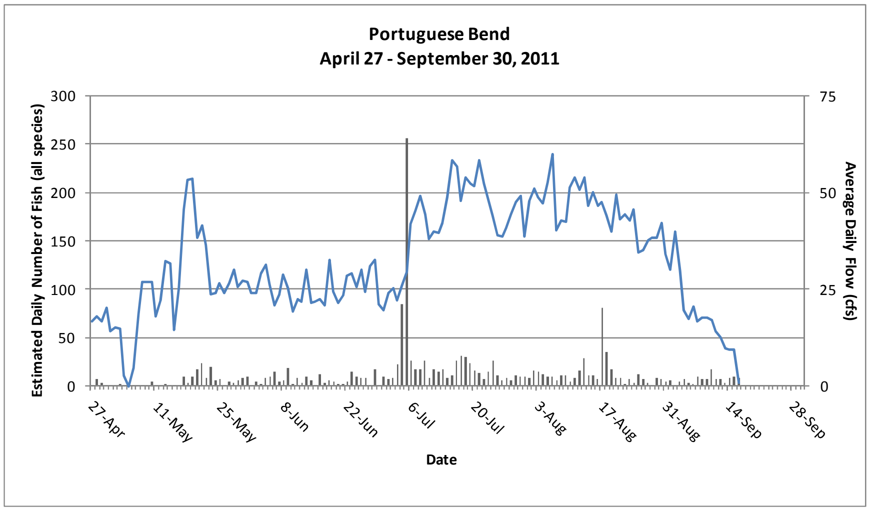

Figure 60. Estimated daily flows (cfs) in the irrigation canal at Portuguese Bend and estimated daily total numbers of fish (all species) entrained during the 2011 irrigation season.

Alamo

In 2011, fish entrainment monitoring at the Alamo canal was initiated on April 25th (the onset of pumping operations at that location) (first net pull on April 26th) and continued until September 30th. In 2012, monitoring was initiated on April 20th (the onset of pumping operations at that location) (first net pull on April 21st) and continued until September 30th. Table 10 provides the estimated total numbers of each fish species entrained during the 2011 and 2012 irrigation seasons. All of the non-salmonid species entrained would normally be expected to be present at this river location during the sampling period (Appendix B).

Table 10. Estimated numbers of each fish species entrained at the Alamo diversion during the 2011 and 2012 irrigation seasons. (Note: * signifies a non-native fish)

Species	2011	2012
Sacramento Sucker	69	227
Tule Perch	79	58
White Crappie*	18	3
River Lamprey	7	11
Unidentified Fish	11	1
Sacramento Pikeminnow	10	2
Chinook Salmon	6	0
Prickly Sculpin	3	1
Carp*	2	2
Pacific Lamprey	2	1
White Catfish*	2	0
Channel Catfish*	2	0
Brown Bullhead*	1	0
Largemouth Bass*	1	0
Hardhead	1	0
Hitch	1	0
Unidentified Herring	1	0
Unidentified Sculpin	1	0
Riffle Sculpin	0	1

In 2011, 15 identifiable fish species were observed. Tule perch was the most numerous fish species entrained followed by Sacramento sucker (Figure 61). Only six juvenile Chinook salmon (fall run) were estimated entrained; five of those were observed on April 26, April 27 (2 salmon), May 10, and June 7, 2011. In 2012, Sacramento sucker was the most numerous species entrained followed by Tule perch (Figure 61). No Chinook salmon were sampled. The daily numbers of all fish species sampled at the outfall were highly variable over the irrigation seasons (Figures 62 and 63).

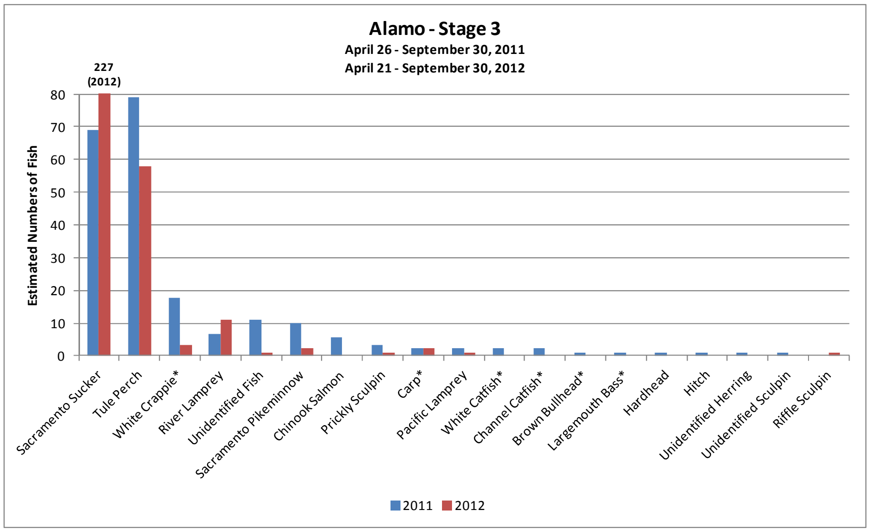

Figure 61. Estimated total numbers of each fish species entrained in Alamo canal during the 2011 and 2012 irrigation seasons.

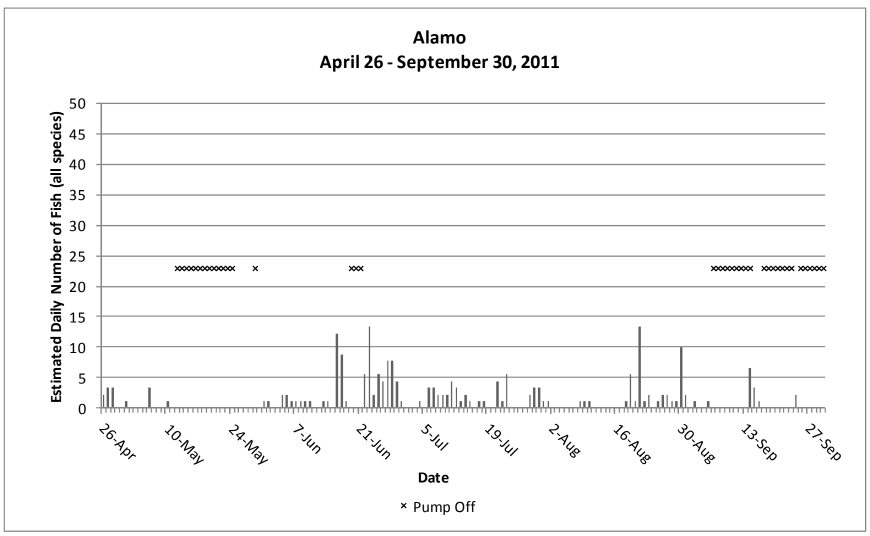

Figure 62. Estimated daily numbers of fish (all species combined) entrained in Alamo canal during the 2011 irrigation season.

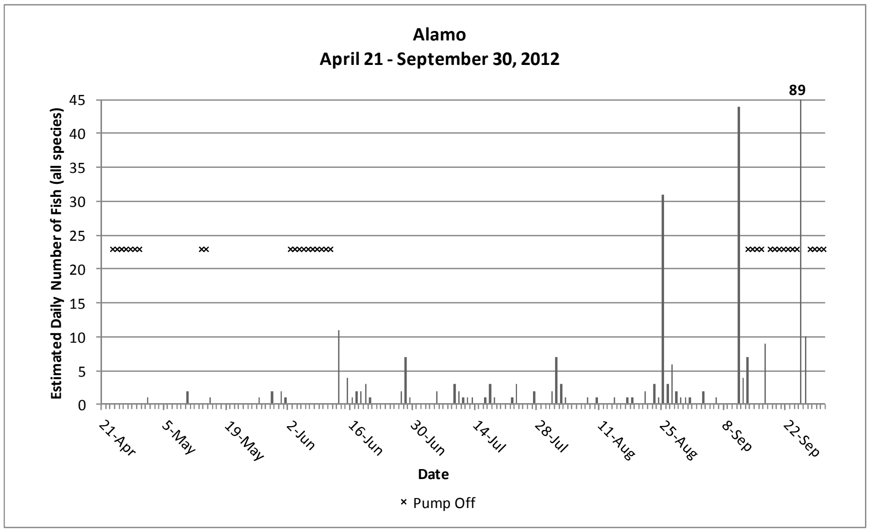

Figure 63. Estimated daily numbers of fish (all species combined) entrained in Alamo canal during the 2012 irrigation season.

Based on data from a thermograph installed in the Alamo canal in 2011, water temperatures were cool early in the season, rose rapidly in the late spring, reaching the high 60's to low 70's degrees Fahrenheit from late June to early-September (Figure 64). The water temperatures during the period when the salmon were sampled were in the 60's degrees Fahrenheit range. Compared to 2011, in 2012 water temperatures were warmer in the spring and slightly cooler in the summer (Figure 64).

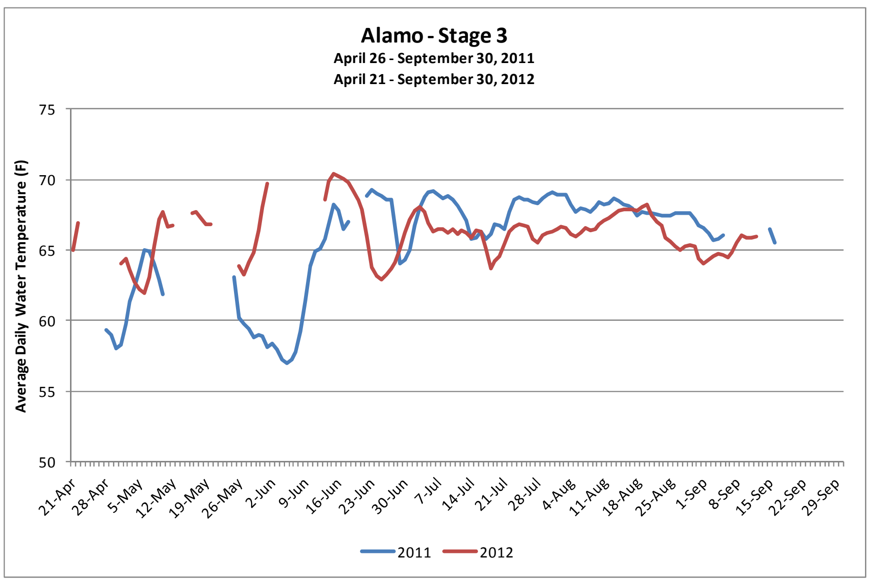

Figure 64. Average daily water temperatures recorded in Alamo canal during 2011 and 2012. Gaps in the data are attributable to periods when no water was diverted and the thermograph was exposed to ambient air temperatures or stagnant water.

Based on daily flow meter records in 2011 and 2012, daily flow in the canal increased during the spring, remained at higher levels (approximately 10 – 20 cfs) during the summer with periodic declines to approximately 5 cfs, then ceased operations in September (Figures 65 and 66). No correlations between flow and numbers of fish entrained were evident.

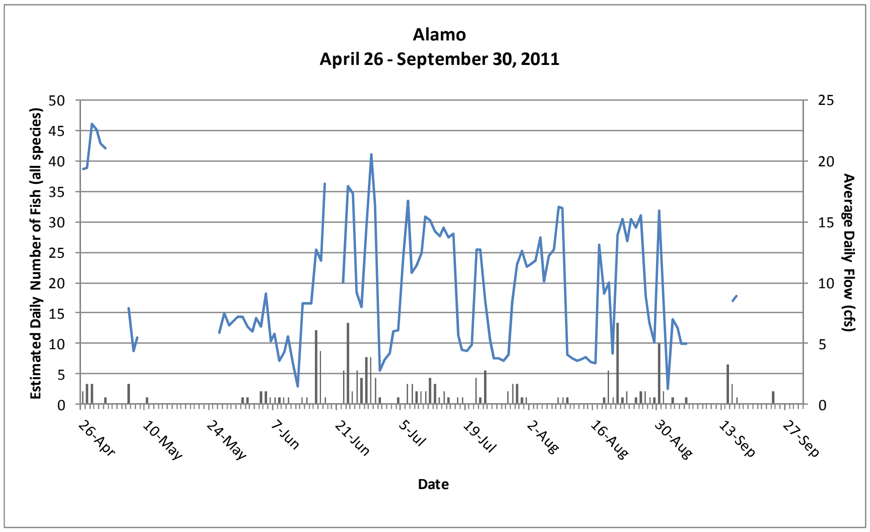

Figure 65. Estimated daily flows (cfs) in the irrigation canal at Alamo and estimated daily total numbers of fish (all species) entrained during the 2011 irrigation season.

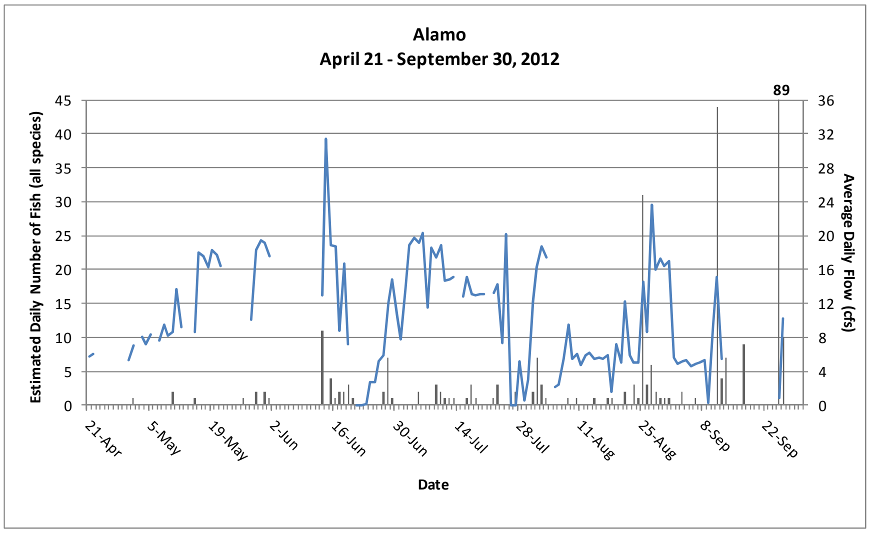

Figure 66. Estimated daily flows (cfs) in the irrigation canal at Alamo and estimated daily total numbers of fish (all species) entrained during the 2012 irrigation season.

Townsite

In 2011, fish entrainment monitoring at the Townsite canals was initiated on April 23rd (the onset of pumping operations at that location) (first net pull on April 24th) and continued until September 30th. In 2012, monitoring began on May 4th (first net pull on May 5th) and continued until September 30th. Table 11 provides the estimated total numbers of each fish species entrained during the 2011 and 2012 irrigation seasons. All of the non-salmonid species entrained would normally be expected to be present at this river location during the sampling period (Appendix B).

Table 11. Estimated numbers of each fish species entrained at the Townsite diversion during the 2011 and 2012 irrigation seasons. (Note: * signifies a non-native fish)		
Species	**2011**	**2012**
Sacramento Sucker	1016	179
Fathead Minnow*	163	980
Tule Perch	138	161
Sacramento Pikeminnow	183	21
Carp*	78	64
Unidentified Herring	40	87
White Catfish*	91	14
Prickly Sculpin	103	2
Chinook Salmon	84	3
California Roach	67	0
Golden Shiner*	43	19
Hitch	51	7
Unidentified Fish	20	37
Unidentified Bullhead*	23	31
White Crappie*	44	10
Hardhead	37	8
Channel Catfish*	16	28
Unidentified Sculpin	29	8
Bigscale Logperch*	4	30
Black Bullhead*	18	6
Brown Bullhead*	10	12
Largemouth Bass*	3	17
River Lamprey	13	7
Black Crappie*	0	16
Sacramento Splittail	3	12
Bluegill*	3	9
Mosquitofish*	1	11
Blue Catfish*	3	8
Green Sunfish*	7	4
Smallmouth Bass*	8	1
Unidentified Catfish*	7	0
Spotted Bass*	0	6
Inland Silverside*	4	1
Pumpkinseed*	0	4
Goldfish*	0	2
Riffle Sculpin	1	1
Rainbow Trout	1	1
Striped Bass*	2	0
Redear Sunfish*	2	0
Threespine Stickleback	0	1
American Shad*	1	0

In 2011, 31 identifiable fish species were observed. Sacramento sucker was the most numerous fish species entrained followed by Sacramento pikeminnow, fathead minnow, and Tule perch (Figure 67). Eighty-four juvenile Chinook salmon were entrained (Figure 68); the highest numbers were entrained in late April but additional salmon were still present into late June. All but one of the estimated entrained salmon were fall run with one spring run entrained on April 28, 2011. One rainbow trout was entrained on July 31, 2011. In late August 2011, the south culvert fish sampling equipment was stolen (despite locking mechanisms in place) and fish sampling did not occur there for a week until new equipment could be re-designed to provide additional deterrent to theft, fabricated, and re-installed. Based on flow meter readings the week prior to the theft, approximately two-thirds of the flow was distributed into the south canal and one-third in the north canal from the single concrete flow distribution chamber. The estimated daily numbers of fish entering the south canal during the period not sampled was extrapolated two-fold based on fish catches in the north canal. In 2012, among 32 identifiable fish species entrained, fathead minnow was the most numerous followed by Sacramento sucker and Tule perch (Figure 67). Only three fall-run salmon were entrained (two fish on May 8th and one fish on May 16th). One rainbow trout was entrained on August 14, 2012. The daily numbers of all fish species sampled in the canals were highly variable over the irrigation seasons (Figures 69 and 70).

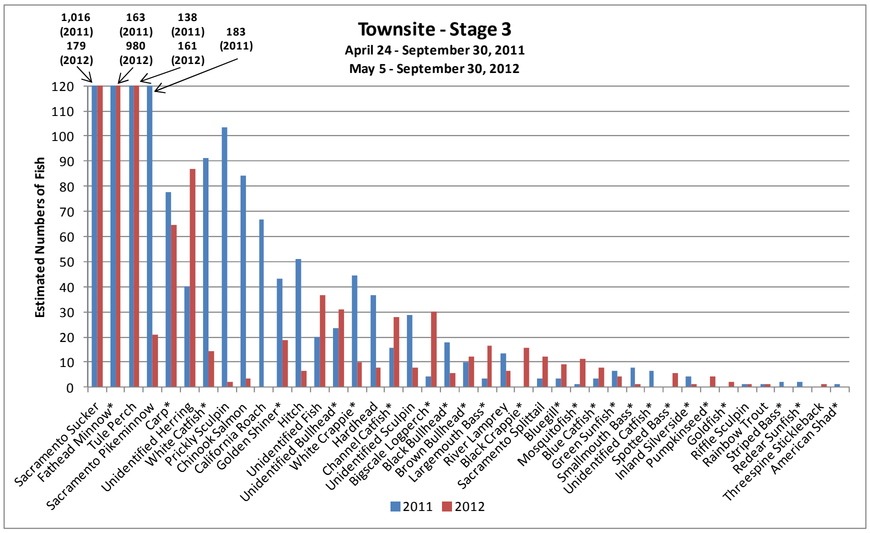

Figure 67. Fish species entrained in Townsite canals during the 2011 and 2012 irrigation seasons.

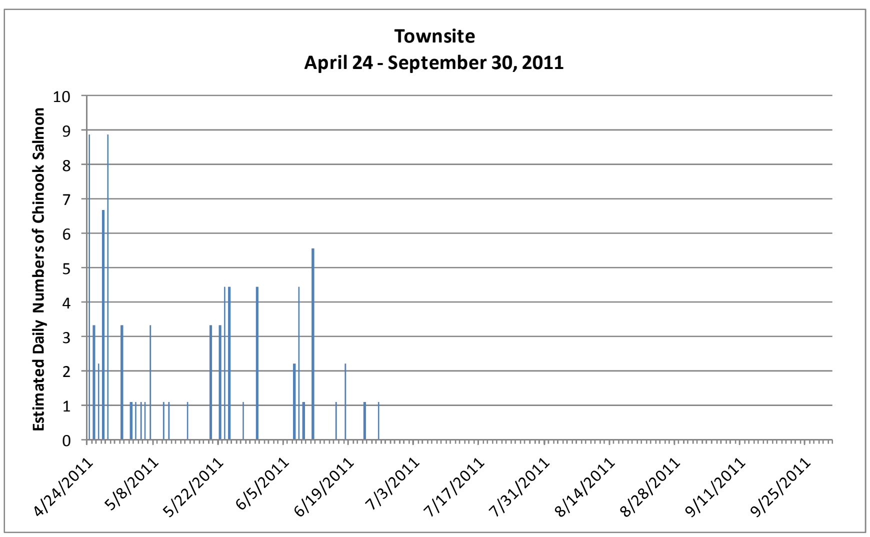

Figure 68. Estimated daily numbers of juvenile Chinook salmon entrained in Townsite canals during the 2011 irrigation season.

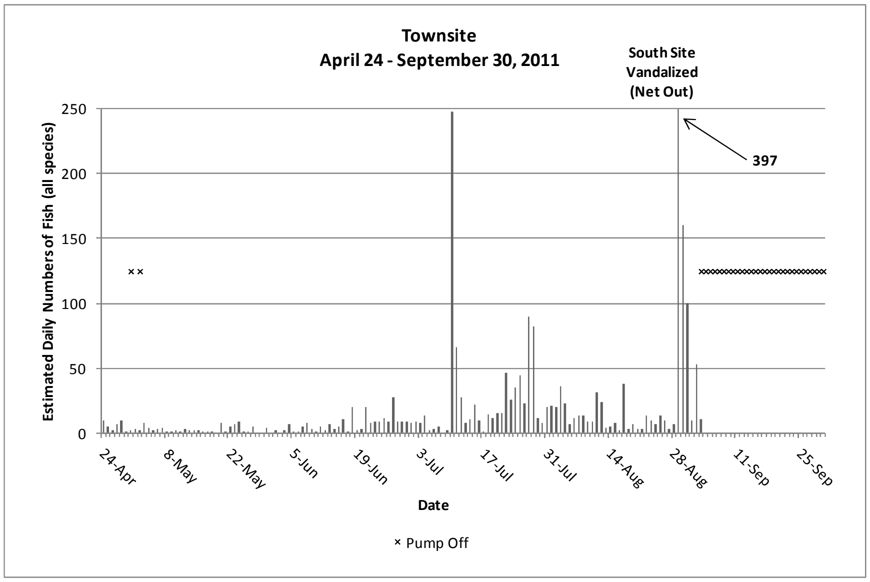

Figure 69. Estimated daily numbers of fish (all species combined) entrained in Townsite canals during the 2011 irrigation season.

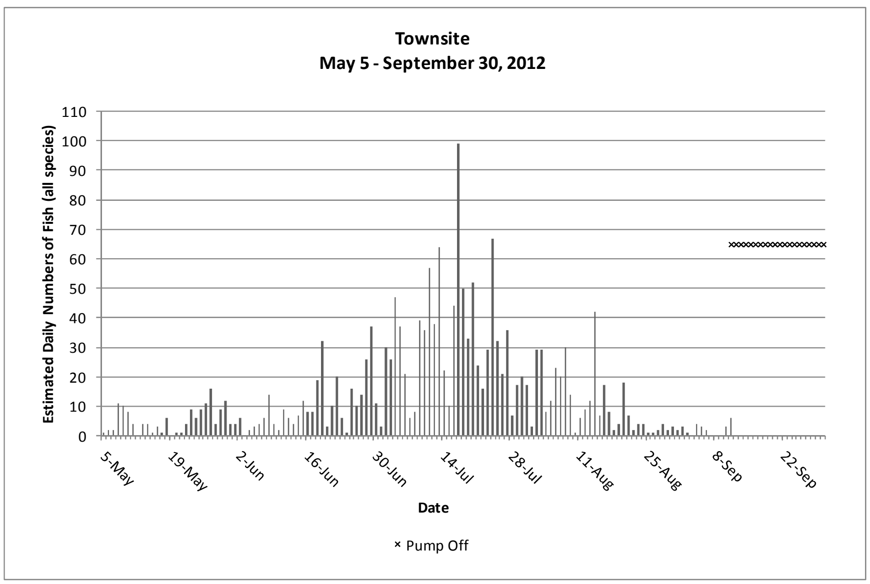

Figure 70. Estimated daily numbers of fish (all species combined) entrained in Townsite canals during the 2012 irrigation season.

Based on data from a thermograph installed in the Townsite canal in 2011, water temperatures were cool early in the season, rose rapidly in the late spring, reaching the high 60's to low 70's degrees Fahrenheit from late June to early-September (Figure 71). The water temperatures during the period when the salmon were sampled were in the 60's degrees Fahrenheit range. Compared to 2011, in 2012 water temperatures were warmer in the spring and slightly cooler in the summer (Figure 71).

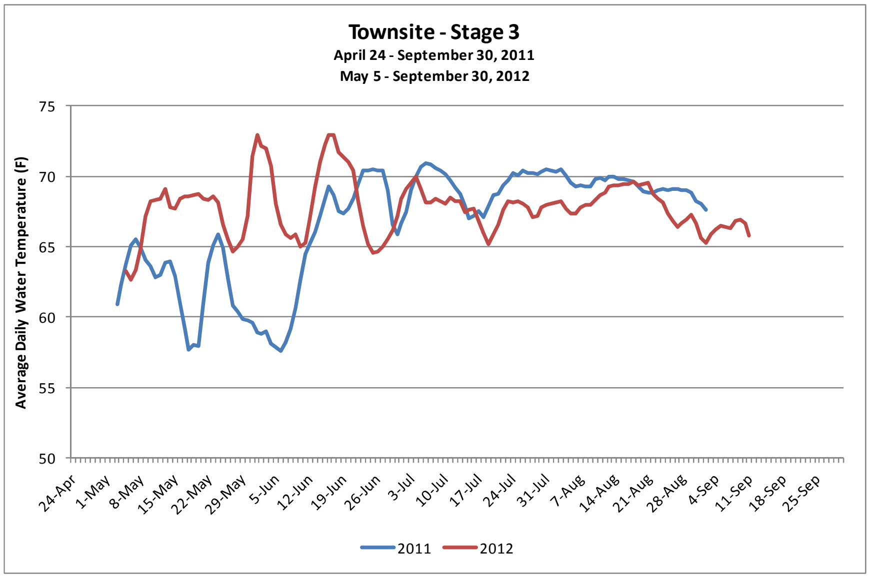

Figure 71. Average daily water temperatures recorded in Townsite canals during 2011 and 2012.

Based on daily flow meter readings, daily flow in the canals was highest during early May, declined during late May and early June, increased during late June through the summer, then ceased operations in September (Figures 72 and 73). No correlations between flow and numbers of fish entrained were evident.

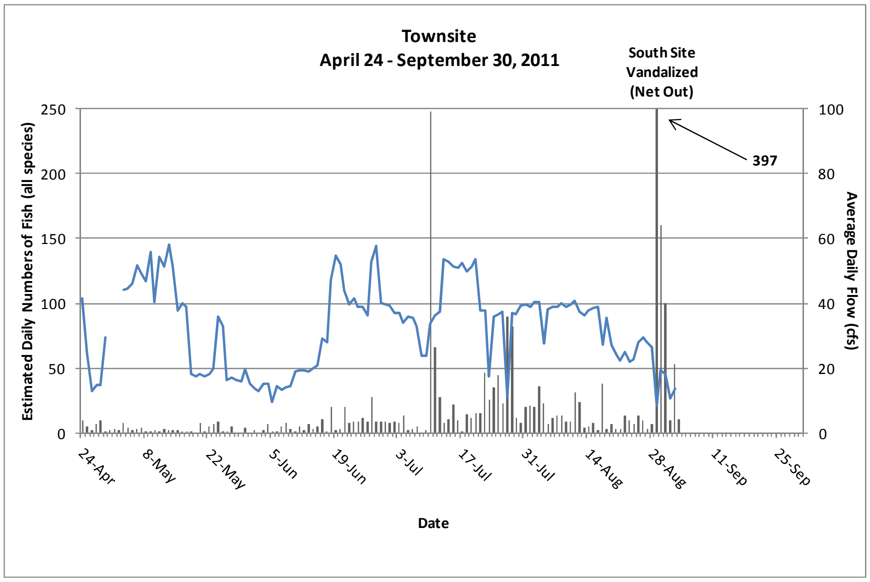

Figure 72. Estimated daily flows (cfs) in the irrigation canal at Townsite and estimated daily total numbers of fish (all species) entrained during the 2011 irrigation season.

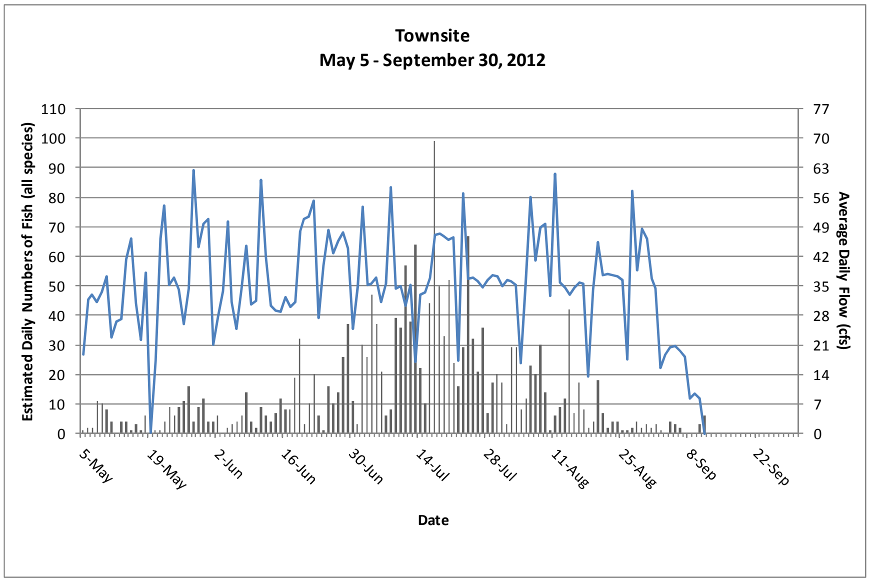

Figure 73. Estimated daily flows (cfs) in the irrigation canal at Townsite and estimated daily total numbers of fish (all species) entrained during the 2012 irrigation season.

Tisdale

In 2011, fish entrainment monitoring at the Tisdale canal was initiated on April 23rd (the onset of pumping operations at that location) (first net pull on April 24th) and continued until September 30th. In 2012, monitoring was initiated on April 22nd (the onset of pumping operations at that location) (first net pull on April 23rd) and continued until September 30th. Table 12 provides the estimated total numbers of each fish species entrained during the 2011 and 2012 irrigation seasons. All of the non-salmonid species entrained would normally be expected to be present at this river location during the sampling period (Appendix B).

Table 12. Estimated numbers of each fish species entrained at the Tisdale diversion during the 2011 and 2012 irrigation seasons. (Note: * signifies a non-native fish)		
Species	**2011**	**2012**
Sacramento Sucker	1044	2598
Tule Perch	103	251
Sacramento Pikeminnow	96	113
Fathead Minnow*	120	4
River Lamprey	18	92
Hardhead	73	1
Green Sunfish*	56	6
California Roach	36	0
Carp*	14	20
Chinook Salmon	24	9
Golden Shiner*	28	4
Prickly Sculpin	17	7
Hitch	12	7
Unidentified Fish	11	6
Threespine Stickleback	13	1
Largemouth Bass*	2	11
Unidentified Sculpin	6	3
Channel Catfish*	6	3
Unidentified Bullhead*	3	3
Black Crappie*	0	7
White Catfish*	6	0
Brown Bullhead*	2	3
Riffle Sculpin	1	4
Pacific Lamprey	4	0
Black Bullhead*	4	0
Bluegill*	3	0
Smallmouth Bass*	0	3
Goldfish*	2	0
White Crappie*	1	1
Spotted Bass*	0	2
Green Sturgeon	1	0
Striped Bass*	0	1

In 2011, 25 identifiable fish species were observed. Sacramento sucker was the most numerous fish species entrained followed by fathead minnow, Tule perch, and Sacramento pikeminnow (Figure 74). Twenty-four juvenile fall-run Chinook salmon were estimated entrained (Figure 75). The highest numbers of salmon were entrained in late May and one salmon was observed in late July. One green sturgeon was entrained on July 10, 2011. During the sampling period, the fyke nets had to be temporarily removed for three days when the diverter dredged silt at the irrigation outfall. Daily fish numbers entrained during those three days were estimated by averaging fish entrained the day before and after the nets were removed. In 2012, among 22 species observed, Sacramento sucker was the most numerous followed by Tule perch and Sacramento pikeminnow (Figure 74). Only nine juvenile fall-run Chinook were estimated entrained; eight of those were observed on April 25th, May 5th (three salmon), May 9th (two salmon), and May 10th (two salmon). The daily numbers of all fish species sampled at the outfall were highly variable over the irrigation season (Figures 76 and 77).

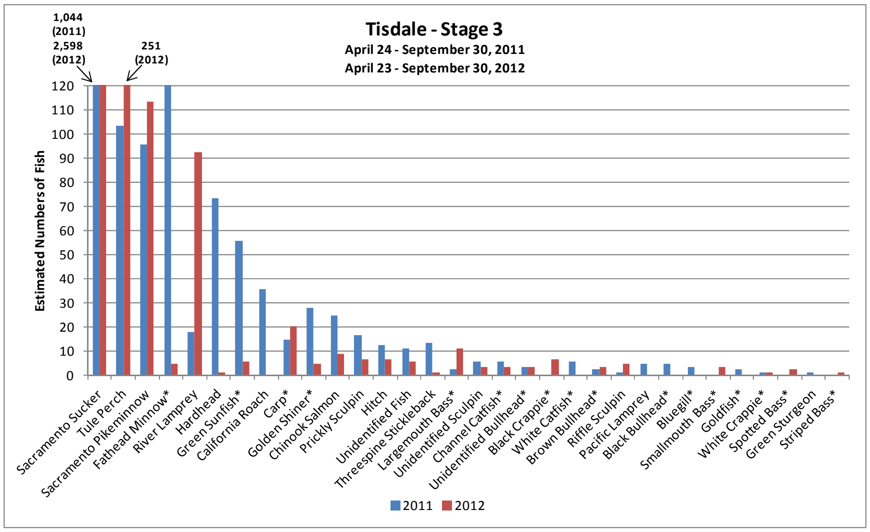

Figure 74. Fish species entrained at the Tisdale canal during the 2011 and 2012 irrigation seasons.

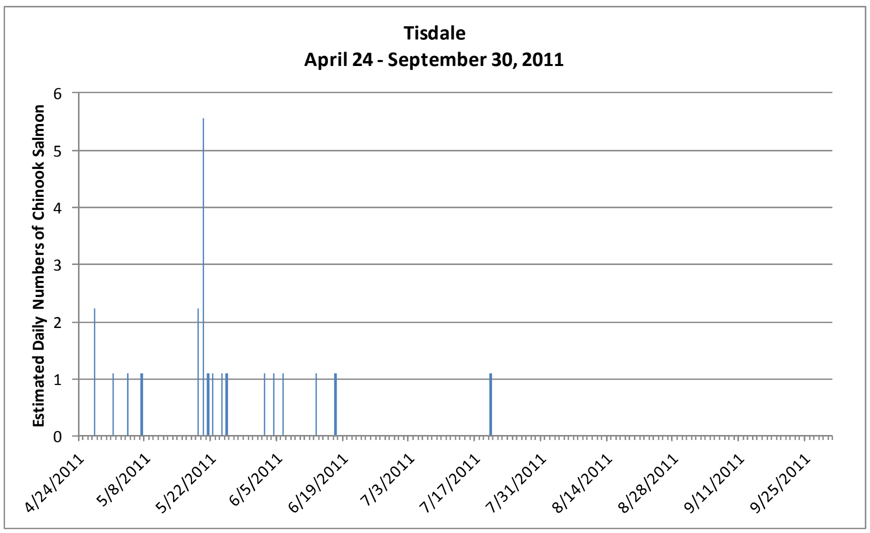

Figure 75. Estimated daily numbers of juvenile Chinook salmon entrained in Tisdale canal during the 2011 irrigation season.

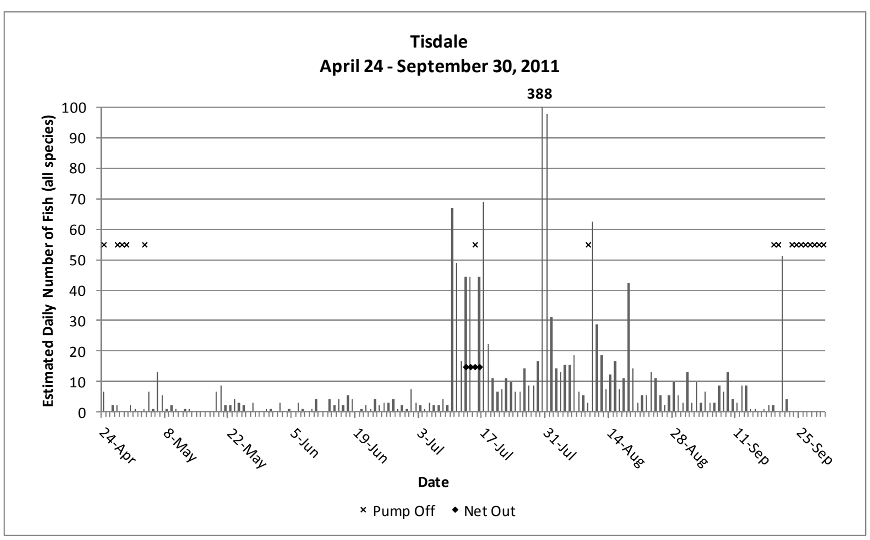

Figure 76. Estimated daily numbers of fish (all species combined) entrained in Tisdale canal during the 2011 irrigation season.

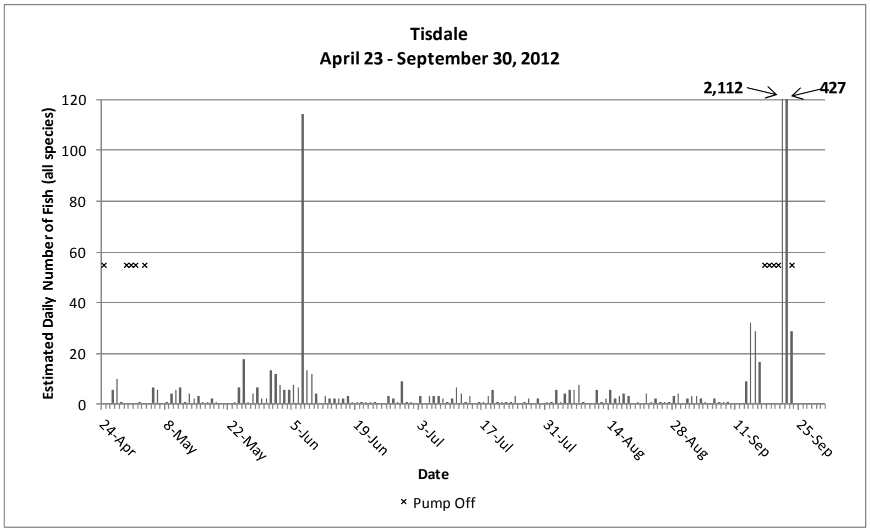

Figure 77. Estimated daily numbers of fish (all species combined) entrained in Tisdale canal during the 2012 irrigation season.

In 2011, based on data from a thermograph installed in the Tisdale canal, water temperatures were cool early in the season, rose rapidly in the late spring, reaching the high 60's to low 70's degrees Fahrenheit from late June to early-September (Figure 78). Compared to 2011, in 2012 water temperatures were warmer in the spring and slightly cooler in the summer (Figure 78).

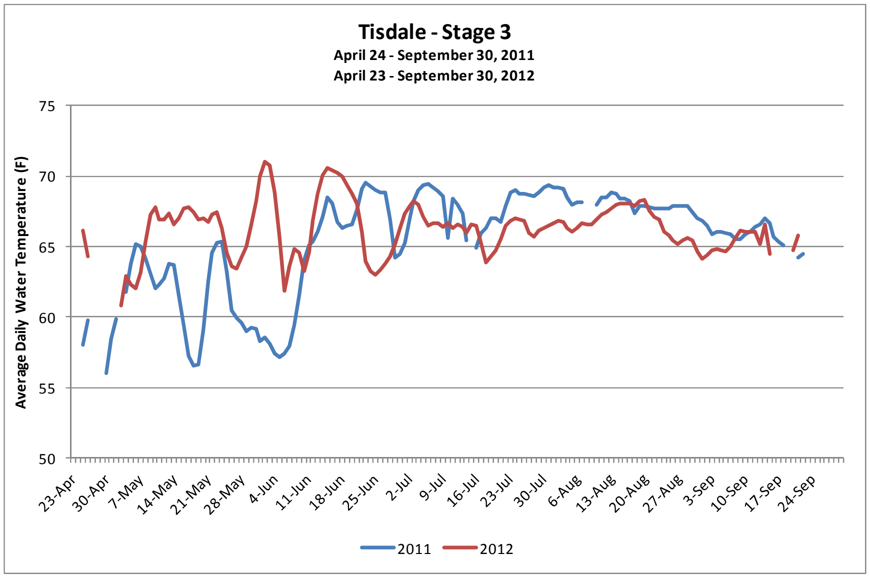

Figure 78. Average daily water temperatures recorded in Tisdale canal during 2011 and 2012. Gaps in the data are attributable to periods when no water was diverted and the thermograph was exposed to ambient air temperatures or stagnant water.

Based on daily flow meter readings in 2011 and 2012, daily flow in the canals increased during May, declined in early June, increased during late June, declined in mid-July, then increased to steady levels through the remainder of the summer prior to ceasing operations in September (Figures 79 and 80). The high numbers of fish captured in late September 2012 were Sacramento suckers that had accumulated in the manifold upstream of the fyke nets and were subsequently captured in the fyke nets as flow in the canal drained when water diversions decreased and ceased. Unlike other species, suckers had a high propensity to accumulate and reside in irrigation manifolds for extended periods. No correlations between flow and numbers of fish entrained were evident.

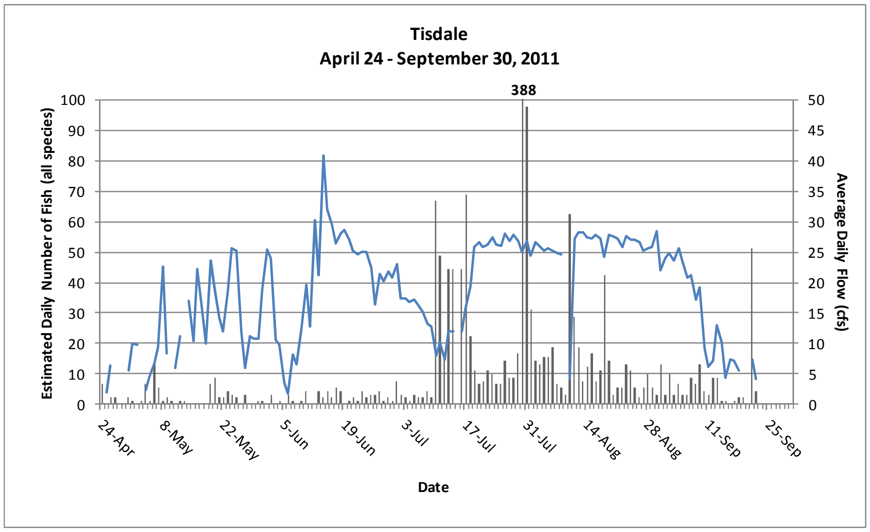

Figure 79. Estimated daily flows (cfs) in the irrigation canal at Tisdale and estimated daily total numbers of fish (all species) entrained during the 2011 irrigation season.

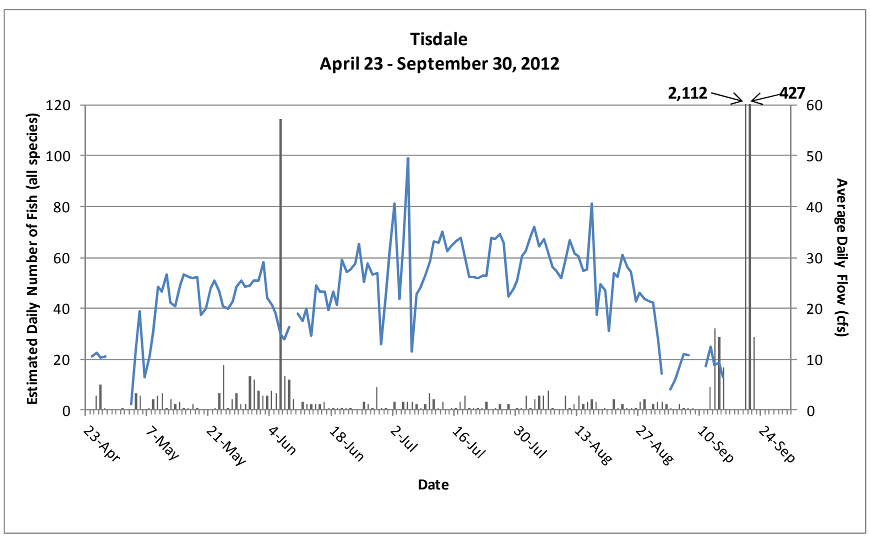

Figure 80. Estimated daily flows (cfs) in the irrigation canal at Tisdale and estimated daily total numbers of fish (all species) entrained during the 2012 irrigation season.

Cranmore

In 2011, fish entrainment monitoring at the Cranmore canal was initiated on April 28th (the onset of pumping operations at that location) (first net pull on April 29th) and continued until January 31, 2012. Unlike other diversion sites sampled, the Cranmore diversion frequently continues diversions in the fall and winter for a wetlands program. As a special circumstance, we were able to continue to monitoring fish entrainment at this site during the fall and part of the winter of 2011 – 2012. In the spring of 2012, monitoring was initiated on April 16th (first net pull on April 17th) and continued until September 30th. Project diverters were given instructions to provide at least two days advance notice prior to beginning irrigation operations. However, that did not occur at Cranmore in 2012 and diversions began several days prior to installing the fyke nets. Table 13 provides the estimated total numbers of each fish species entrained during the

2011 and 2012 irrigation seasons. All of the non-salmonid species entrained would normally be expected to be present at this river location during the sampling period (Appendix B).

Table 13. Estimated numbers of each fish species entrained at the Cranmore diversion during the 2011 and 2012 irrigation seasons. (Note: * signifies a non-native fish)

Species	2011[1]	2012
Sacramento Sucker	326	292
Chinook Salmon	176	278
Tule Perch	296	24
White Catfish*	232	30
California Roach	164	0
Pacific Lamprey	122	30
Golden Shiner*	116	8
Prickly Sculpin	92	0
Unidentified Fish	40	24
Sacramento Pikeminnow	50	10
Carp*	44	6
Hitch	4	46
Channel Catfish*	22	26
Hardhead	36	0
Unidentified Bullhead*	34	0
White Crappie*	20	0
River Lamprey	12	8
Unidentified Sculpin	14	4
Fathead Minnow*	8	2
Brown Bullhead*	4	0
Black Bullhead*	2	0
Unidentified Salmonid	2	0
Riffle Sculpin	2	0
Threadfin Shad*	2	0
Unidentified Herring	0	2
Green Sunfish*	0	2

[1] Note that in 2011, the sampling period extended into January 2012 and was substantially longer than in 2012.

In 2011, of 20 identifiable fish species observed, Sacramento sucker was the most numerous fish species entrained followed by Tule perch, white catfish, Chinook salmon, and California roach (Figure 81). An estimated 176 juvenile Chinook salmon were entrained. Of that total only two were spring run, two were winter run and the rest were fall-run Chinook. Two spring run were entrained in June 2011 and the two winter-run Chinook were entrained in January 2012. The highest numbers of salmon were entrained in late April and early May with a few salmon observed during the summer and early winter months (Figure 82). During June, the sampling equipment was damaged and had to be temporarily removed and repaired. Daily fish numbers entrained during that period were estimated by averaging fish entrained the day before and after the equipment was removed and replaced. In 2012, of the 13 identifiable fish species entrained, Sacramento sucker was the most numerous followed by Chinook salmon (Figure 81). An estimated 278 juvenile Chinook salmon were entrained, mostly from late-April to mid-May (Figure 83). Of that total, only two were spring run and the rest were fall-run Chinook. The two spring-run Chinook were entrained in April 2012. The daily numbers of all fish species sampled at the outfall were highly variable over the irrigation seasons (Figures 84 and 85).

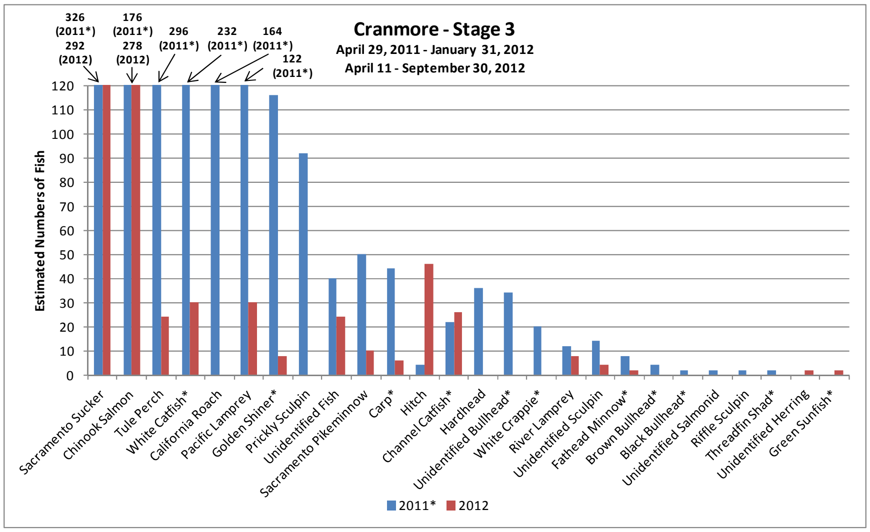

Figure 81. Fish species entrained at the Cranmore diversion during the 2011 and 2012 irrigation seasons.

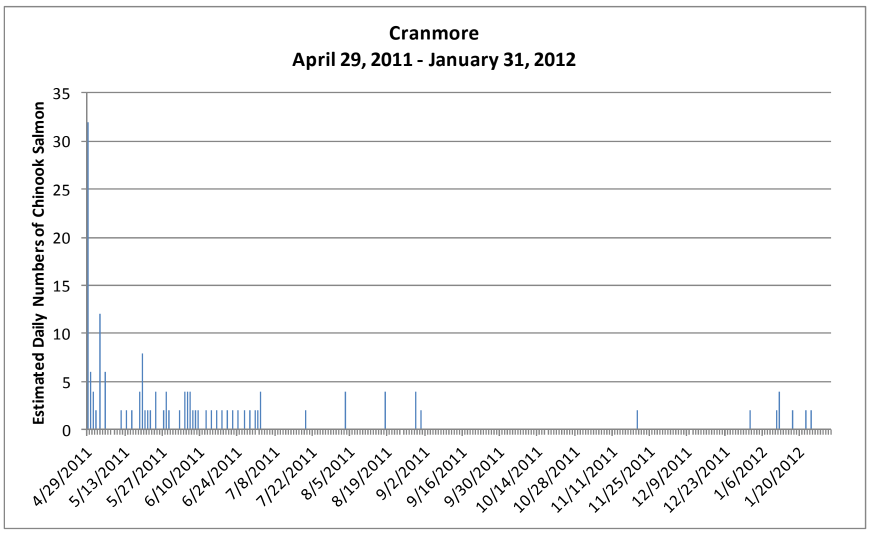

Figure 82. Estimated daily numbers of juvenile Chinook salmon entrained in Cranmore canal during the 2011 irrigation season and the fall and early winter of 2011 - 2012.

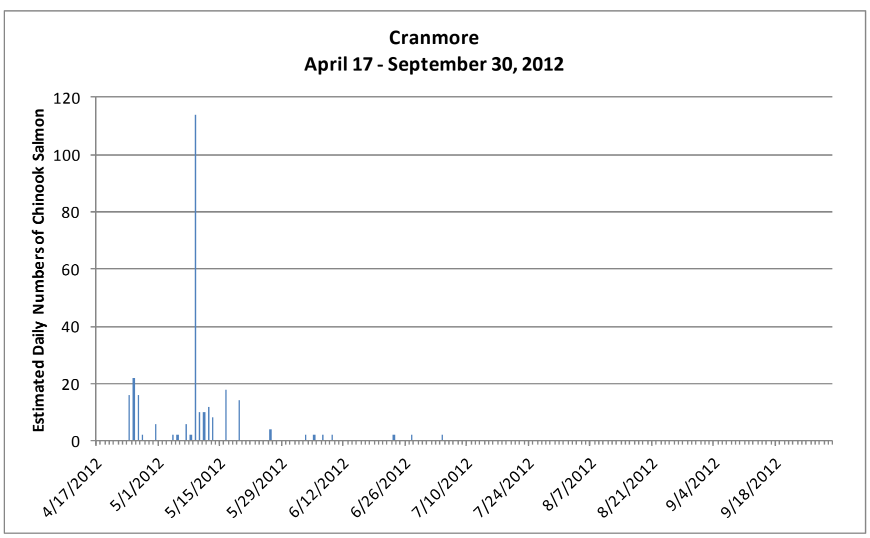

Figure 83. Estimated daily numbers of juvenile Chinook salmon entrained in Cranmore canal during the 2012 irrigation season.

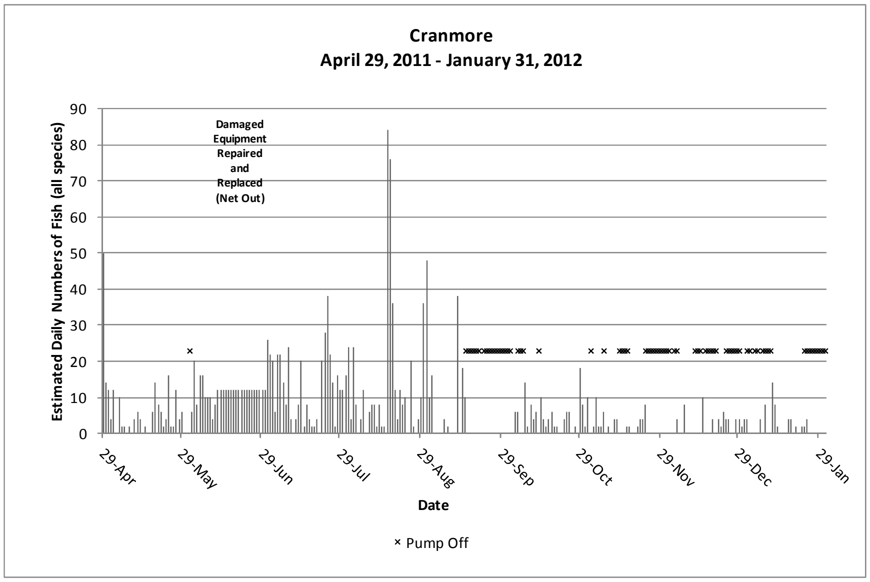

Figure 84. Estimated daily numbers of fish (all species combined) entrained in Cranmore canal during the 2011 irrigation season, including the fall and early winter periods of wetlands operations.

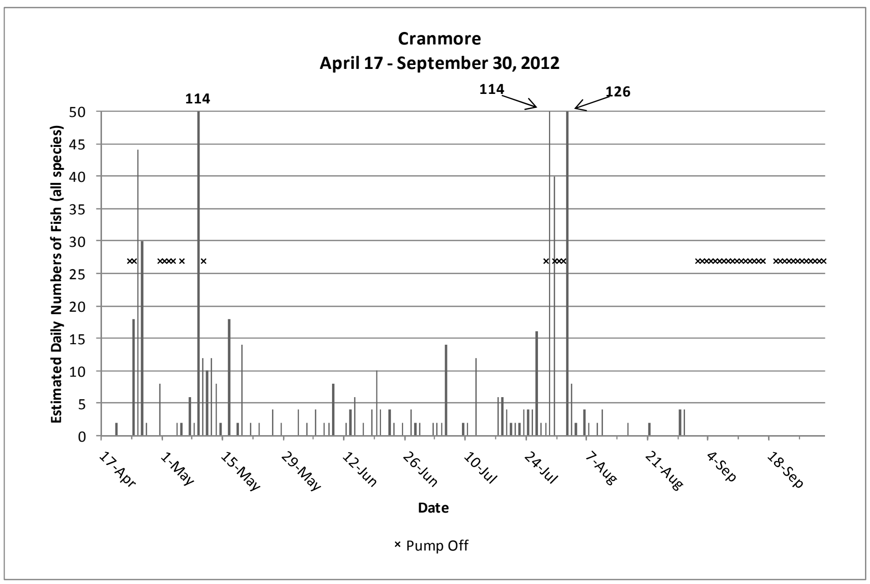

Figure 85. Estimated daily numbers of fish (all species combined) entrained in Cranmore canal during the 2012 irrigation season.

In 2011, based on data from a thermograph installed in the Cranmore canal, water temperatures were cool early in the season, rose rapidly in the late spring, reaching the high 60's to low 70's degrees Fahrenheit from late June to early-September (Figure 86). When fish sampling continued into the fall and winter, temperatures declined to the 40's degrees Fahrenheit. Compared to 2011, water temperatures in 2012 were warmer in the spring and slightly cooler in the summer (Figure 86).

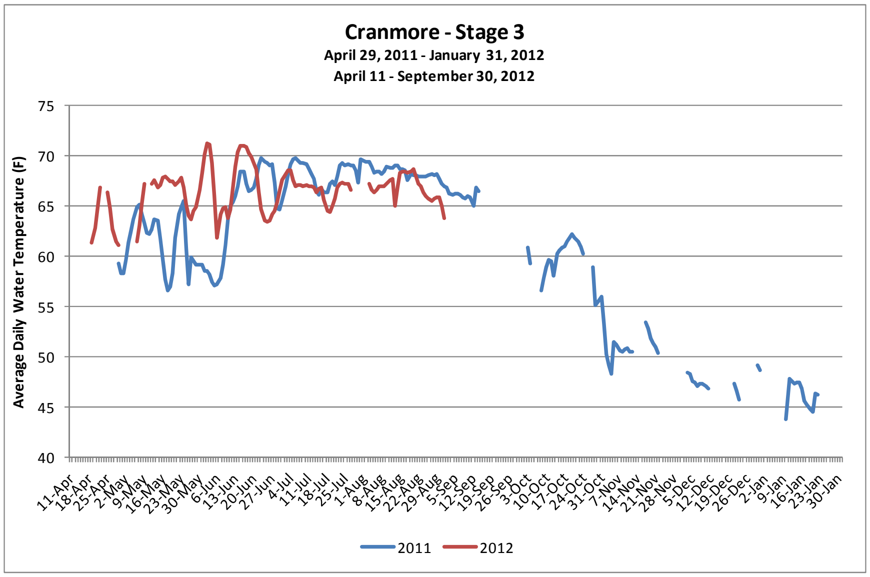

Figure 86. Average daily water temperatures recorded at the Cranmore canal during 2011 and 2012.

Data recorded from the USBR flow meter were used to depict daily flows in Cranmore Canal during the irrigation season. The agency's flow meter was removed during the period November 1, 2011 through January 31, 2012 when fall and winter fish sampling occurred and the General Oceanics® flow meter installed in front of the fyke net was used to estimate daily flows. Based on daily flow meter readings in 2011 and 2012, daily flow was highest during mid-July to mid-August (Figures 87 and 88). No correlations between flow and numbers of fish entrained were evident.

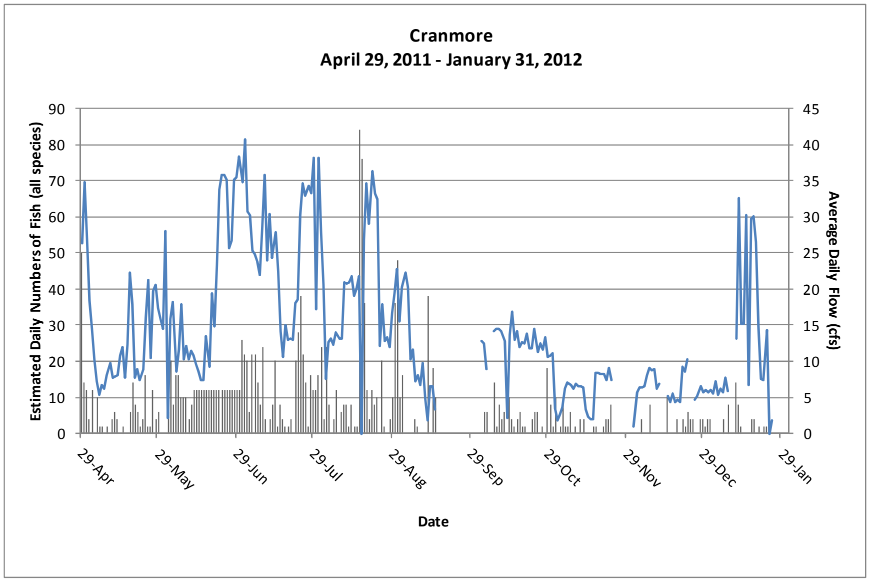

Figure 87. Estimated daily flows (cfs) in Cranmore canal and estimated daily total numbers of fish (all species) entrained during the 2011 - 2012 irrigation season.

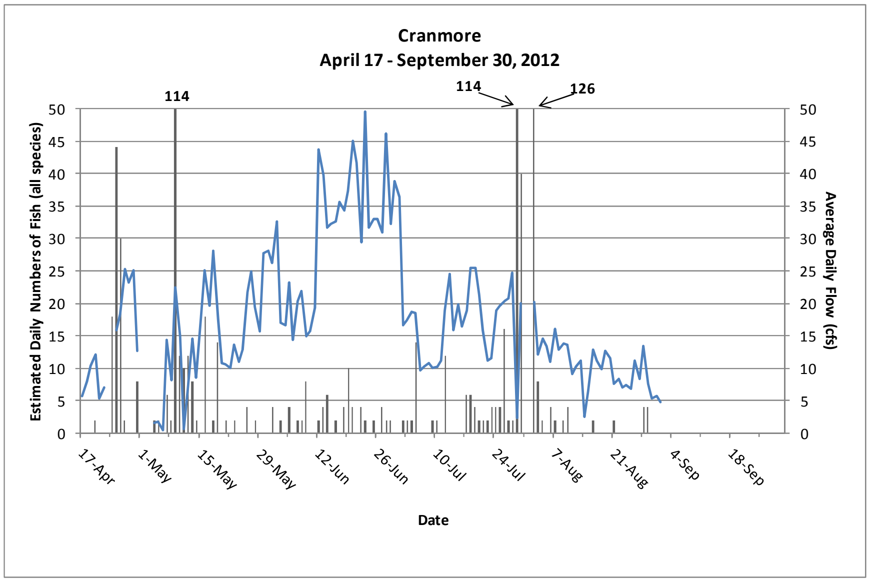

Figure 88. Estimated daily flows (cfs) in Cranmore canal and estimated daily total numbers of fish (all species) entrained during the 2012 irrigation season.

Sanchez

In 2011, fish entrainment monitoring at the Sanchez canals was initiated on May 24th (the onset of siphon operations at that location) (first net pull on May 25th) and continued until October 13th. The siphon diversion was off for the remainder of October 2011. In 2012, monitoring was initiated on May 15th (the onset of siphon operations at that location) (first net pull on May 16th) and continued until September 30th. Table 14 provides the estimated total numbers of each fish species entrained during the 2011 and 2012 irrigation seasons. All of the non-salmonid species entrained would normally be expected to be present at this river location during the sampling period (Appendix B).

Table 14. Estimated numbers of each fish species entrained at the Sanchez diversion during the 2011 and 2012 irrigation seasons. (Note: * signifies a non-native fish)		
Species	**2011**	**2012**
Fathead Minnow*	244	2136
White Catfish*	882	238
Hitch	218	844
Golden Shiner*	20	950
Mosquitofish*	182	508
Hardhead	578	28
Green Sunfish*	124	352
Sacramento Sucker	62	138
Bluegill*	6	108
Brown Bullhead*	0	90
Sacramento Pikeminnow	24	32
Tule Perch	34	12
Unidentified Fish	28	6
Unidentified Bullhead*	0	30
California Roach	28	0
Largemouth Bass*	14	2
Smallmouth Bass*	2	8
Redeye Bass*	6	2
Black Bullhead*	0	6
Wakasagi*	4	0
Pumpkinseed*	0	4
Black Crappie*	0	4
Carp*	0	4
Chinook Salmon	2	0
Unidentified Sunfish*	2	0
Threespine Stickleback	2	0
Goldfish*	2	0
Striped Bass*	2	0
White Crappie*	2	0
Sacramento Splittail	0	2
Channel Catfish*	0	2
Spotted Bass*	0	2

In 2011, 21 identifiable fish species were observed. White catfish was the most numerous fish species entrained followed by hardhead, fathead minnow, and hitch (Figure 89). Only two juvenile Chinook salmon (fall run) were entrained on June 8th and no Delta smelt were observed. In 2012, among 22 species observed, fathead minnow was the most numerous followed by golden shiner, hitch, and mosquitofish (Figure 89). No salmon or Delta smelt were observed. The daily numbers of all fish species sampled at the outfall were highly variable over the two irrigation seasons (Figures 90 and 91).

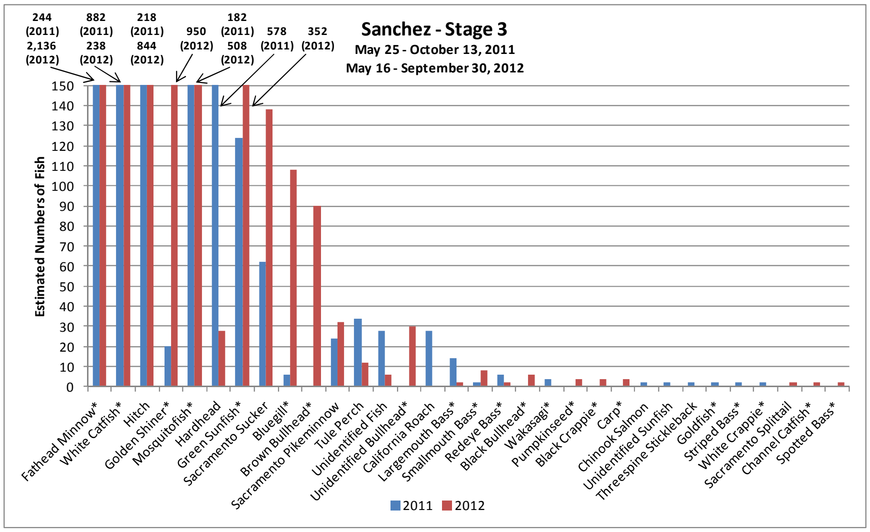

Figure 89. Fish species entrained at Sanchez canals during the 2011 and 2012 irrigation seasons.

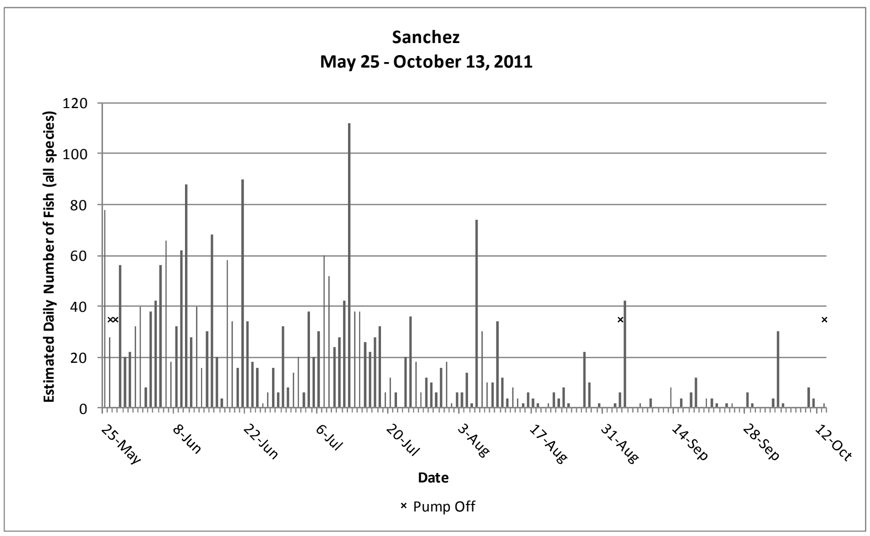

Figure 90. Estimated daily numbers of fish (all species combined) entrained in Sanchez canals during the 2011 irrigation season.

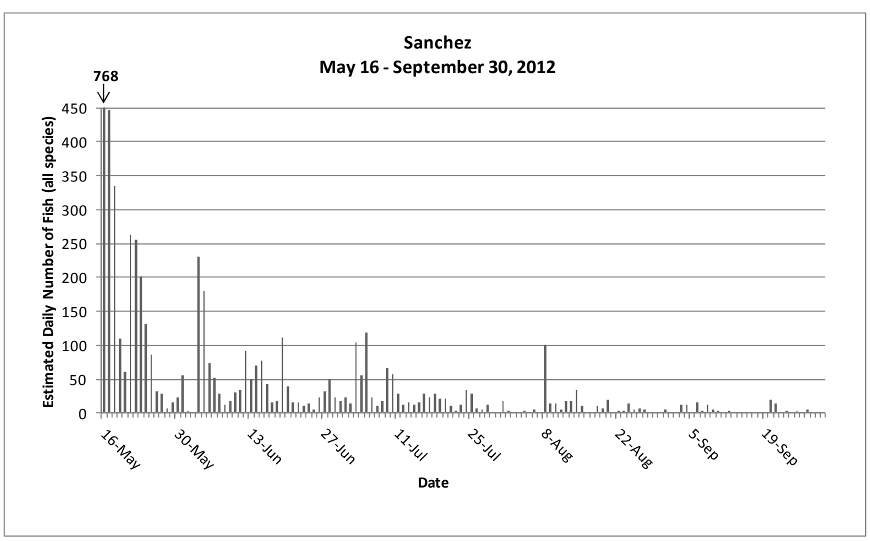

Figure 91. Estimated daily numbers of fish (all species combined) entrained in Sanchez canals during the 2012 irrigation season.

In 2011, based on data from a thermograph installed in the Sanchez west canal, water temperatures were cool early in the season, rose rapidly in the late spring, reaching the high 60's to low 70's degrees Fahrenheit from late June to early-September (Figure 92). In contrast, water temperatures were substantially warmer in the spring of 2012 (Figure 92).

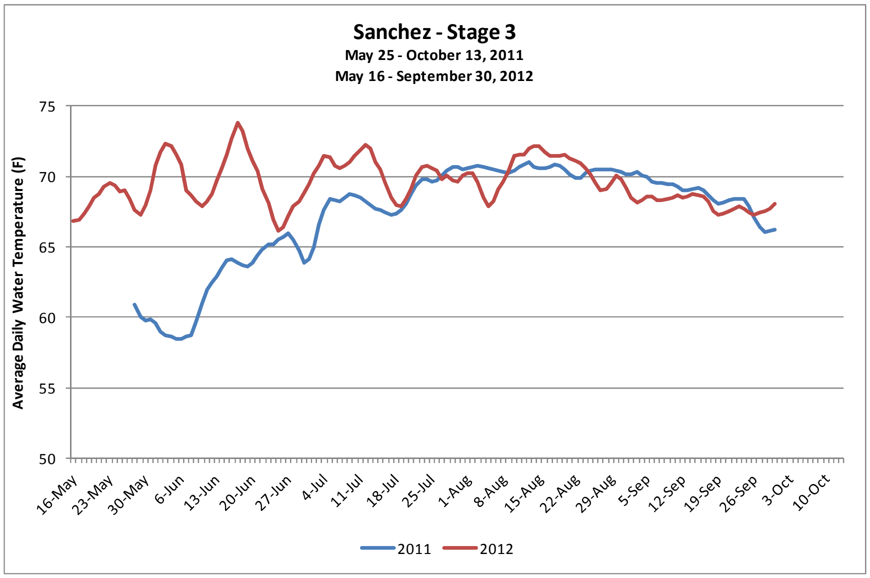

Figure 92. Average daily water temperatures recorded in Sanchez canals during 2011 and 2012.

Based on flow meter readings on each of the two fyke nets, daily flow in the canals fluctuated considerably during the irrigation seasons (Figures 93 and 94). No correlations between flow and numbers of fish entrained were evident.

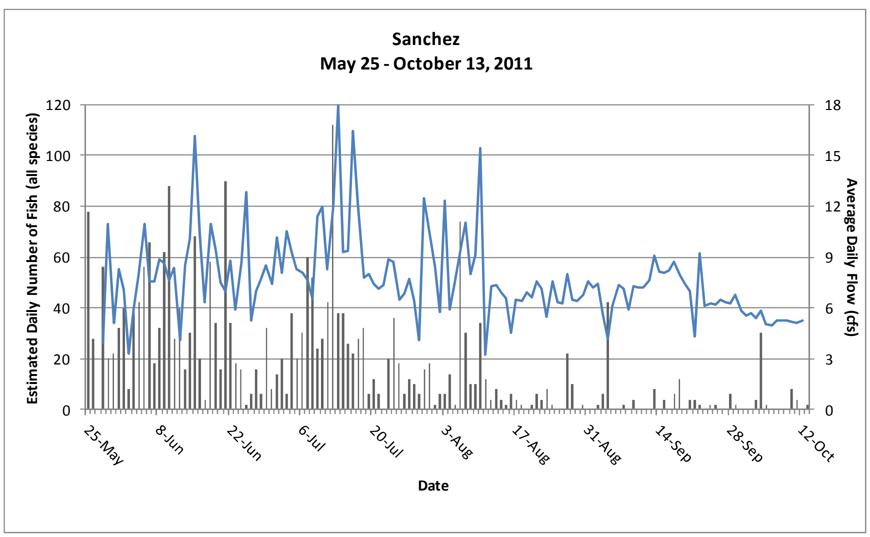

Figure 93. Estimated daily flows (cfs) in Sanchez canals and estimated daily total numbers of fish (all species) entrained during the 2011 irrigation season.

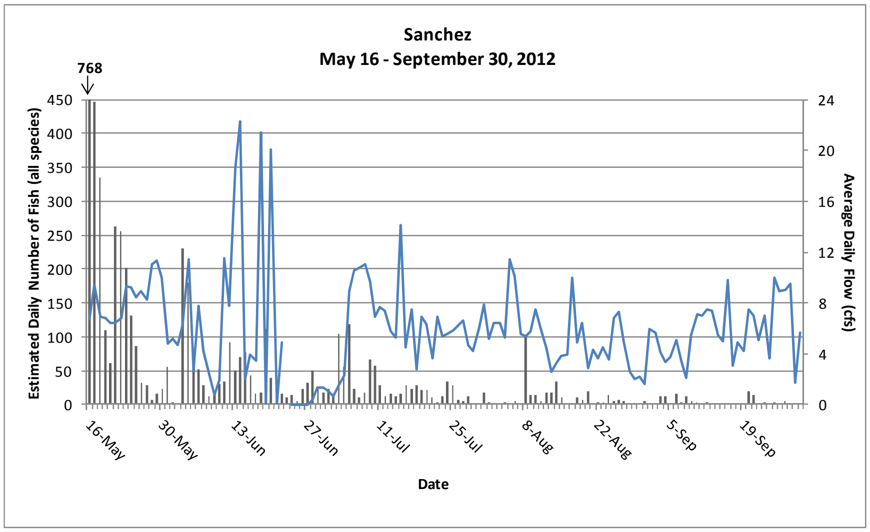

Figure 94. Estimated daily flows (cfs) in Sanchez canals and estimated daily total number of fish (all species) entrained during the 2012 irrigation season.

Discussion

The mortality of young anadromous salmonids at unscreened diversions could be a result of entrainment into the diversion, predation at or near the diversion site, or physical injury associated with the diversion structures. Most investigations of fish losses at diversions have generally focused on the direct losses attributable to entrainment which is the focus of this study. ICF Jones & Stokes (2008), in a literature search and data analysis of fish losses at Central Valley unscreened diversions, concluded that, among those factors examined, salmon smolt entrainment may be primarily a function of proportion of flow diverted from the river and canal flow/pumped discharge. This conclusion was largely based on empirical evidence derived from fish monitoring in the Sacramento River by the U.S. Fish and Wildlife Service (USFWS) using rotary screw traps at the Red Bluff Diversion Dam (RBDD) and the USBR at a large pumped diversion facility adjacent to RBDD. However, physical characteristics of that facility are significantly dissimilar to other much smaller unscreened diversions on the mainstem Sacramento River as determined through a recent extensive in-river survey conducted during 2008 (Vogel 2008c). For example, the Red Bluff 263-cfs pumping facility has a 210-ft long and 26-ft tall trash rack in front of the pump intakes (ICF Jones & Stokes 2008) which could have an important deterrent effect on fish entrainment. None of the unscreened diversions between Red Bluff and Verona, California possess any similar type structures (Vogel 2008c). Additionally, most of the fish monitoring data collection at Red Bluff occurred during different times of year (as early as February) as compared to lower Sacramento River diversions (late spring and summer). Also, the RBDD data were collected in the upper Sacramento River (RM 243) where the temporal presence of anadromous salmonids is substantially different during late-spring and summer than the lower Sacramento River where diversions were monitored for this study (RM 132.5 to the Delta).

Vogel (1995) summarized a variety of studies that have been conducted in the past in an attempt to better define inter-relationships between the numbers of juvenile salmonids diverted into unscreened irrigation intakes and potential factors that may affect entrainment. Many of those past studies concluded that the factors affecting fish entrainment into unscreened diversions are complex and poorly understood. The following probably encompass the majority of the most important factors which could affect fry and juvenile anadromous salmonid losses in *unscreened* diversions (Vogel 1995):

- Salmon run (e.g., fall, late-fall, winter, spring)
- Seasonal timing and magnitude of the water diversion
- Proximity of the diversion to rearing habitat
- Geographic location of the water diversion in the river relative to the proportion of juvenile salmon which would ultimately migrate past the diversion
- Hydrologic conditions preceding the principal downstream migration (e.g., wet or dry water year type)
- Specific life phase of the downstream migrants passing the diversion (e.g., fry versus smolt)
- Physical configuration of the diversion intake and associated facilities
- Location of the diversion intake in the water column
- Concentration of the downstream migrants at various locations in the water column and across the river channel
- Diel changes in fish distribution and behavior
- Diel changes in water diversion rate
- Water velocity near the diversion intake
- Water temperature in the vicinity of the diversion intake
- Location of the diversion intake in the river channel (e.g., oxbow, inside or outside bend, set back or on the river, etc.)
- Absence or presence and concentration of predatory fish at the diversion site

Among these factors, the seasonal timing of young salmon emigration through the lower river and the timing of the irrigation diversions played major roles in the degree of salmon entrainment observed during this study. An excellent database on the emigration of juvenile salmon has been developed by the California Department of Fish and Wildlife (CDFW) in the lower Sacramento River. CDFW operates two eight-foot-diameter rotary screw traps a half mile downstream of Knights Landing at Sacramento River mile 89.5. Among other purposes, the CDFW fish monitoring program is conducted to determine the timing and relative abundance of juvenile anadromous salmonids emigrating from the upper Sacramento River system (Vincik and Bajjaliya 2008). Although the CDFW monitoring program generally ceases in July for the remainder of the summer, the sampling is not conducted then due to minimal or no juvenile salmon presence (likely due to warm water temperatures).

Comparisons of the CDFW data on weekly emigration of juvenile salmon at Knights Landing with river flows near Grimes, California and the periods when this study's daily monitoring of fish entrainment occurred at each study site from 2009 through 2012 are provided in Figures 95 - 98. As a cautionary note, the CDFW data presented in these figures are only used to demonstrate the comparison between the primary salmon outmigration periods and the timing of irrigation. The fish catch data are limited due to variable sampling efforts caused by a variety of factors such as heavy debris loading or low staffing levels affecting trap operations.[12] Also note that the Y-axis scales are different in each figure. However, it is evident from these comparisons that the onset of irrigation diversions at each of the 12 study sites began at the tail end of the primary

[12] Written communication by Douglas Threloff, USFWS, May 10, 2013.

emigration of salmon through the lower Sacramento River. This circumstance largely explains why the numbers of salmon observed were relatively low during each year of the study.

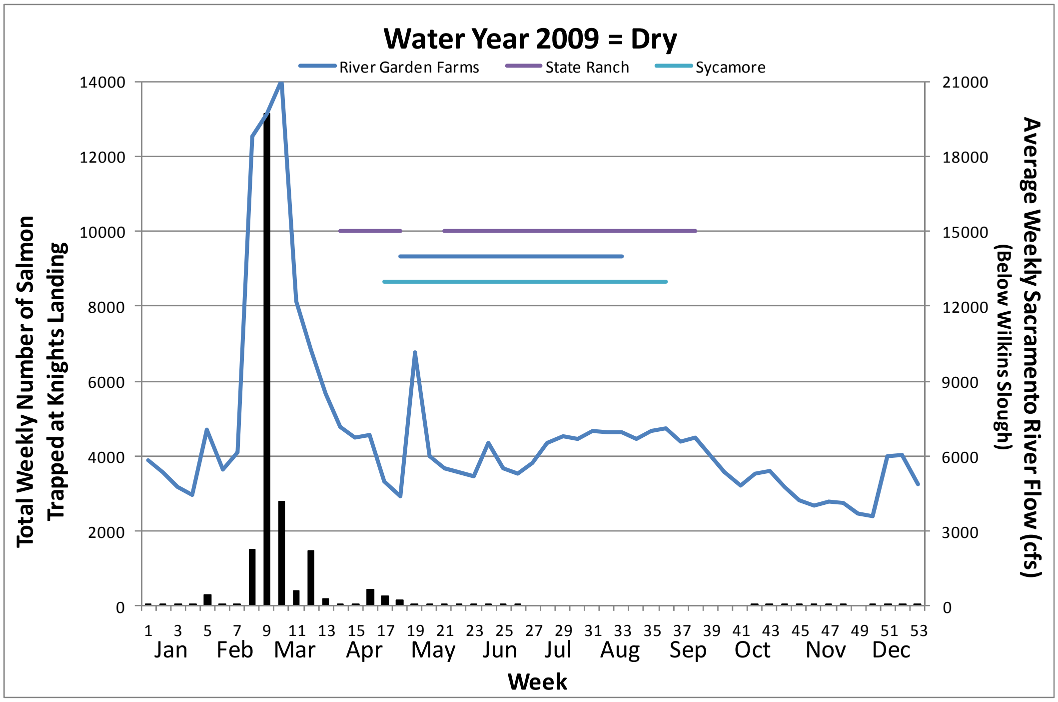

Figure 95. Comparisons between the weekly numbers of juvenile Chinook salmon sampled at CDFW's fish traps in the Sacramento River at Knights Landing (black bars), average weekly Sacramento River flow (cfs) below Wilkins Slough (near Grimes, CA: blue line) and entrainment monitoring periods at River Garden Farms, State Ranch, and Sycamore during 2009 (horizontal bars).

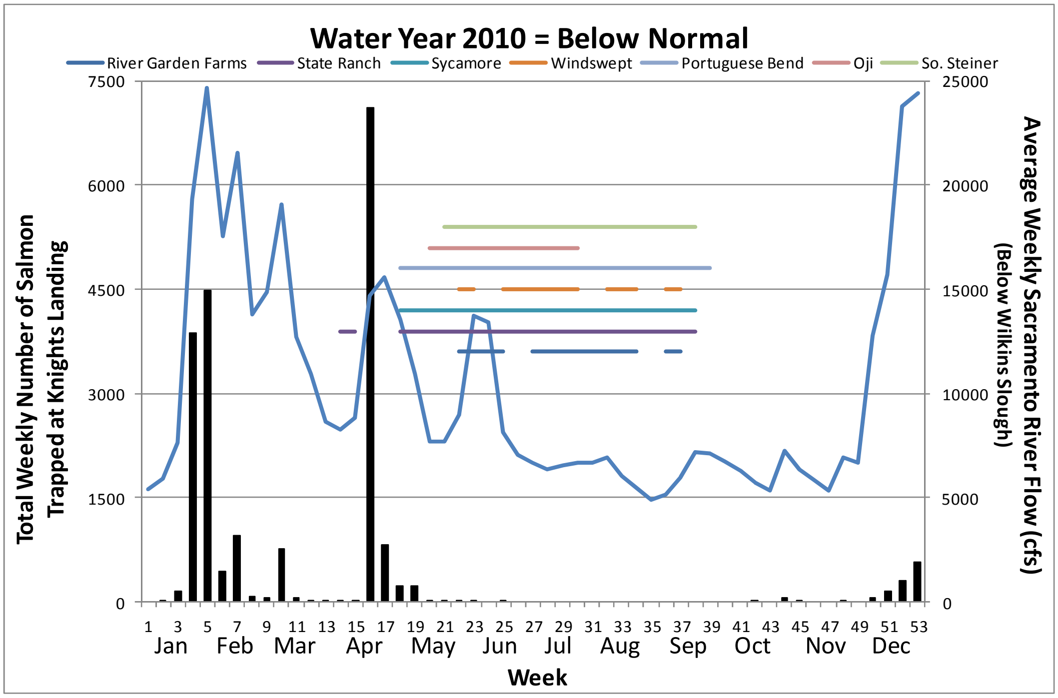

Figure 96. Comparisons between the weekly numbers of juvenile Chinook salmon sampled at CDFW's fish traps in the Sacramento River at Knights Landing (black bars), average weekly Sacramento River flow (cfs) below Wilkins Slough (near Grimes, CA: blue line) and entrainment monitoring periods at River Garden Farms, State Ranch, Sycamore, Windswept, Portuguese Bend, Oji, and South Steiner during 2010 (horizontal bars).

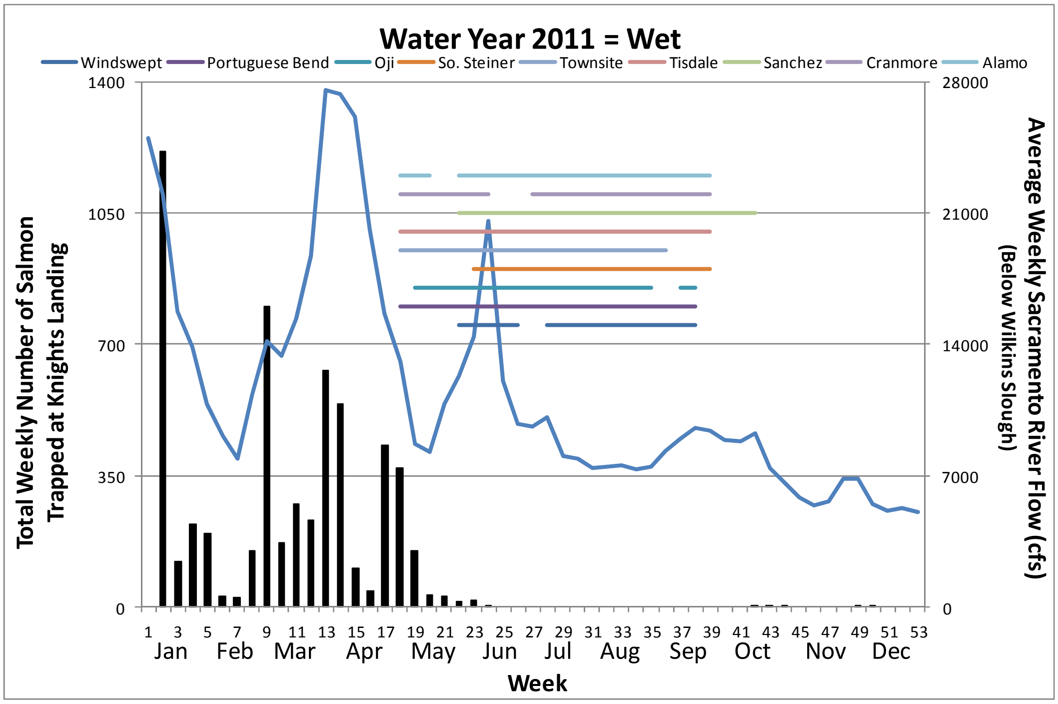

Figure 97. Comparisons between the weekly numbers of juvenile Chinook salmon sampled at CDFW's fish traps in the Sacramento River at Knights Landing (black bars), average weekly Sacramento River flow (cfs) below Wilkins Slough (near Grimes, CA; blue line) and entrainment monitoring periods at Windswept, Portuguese Bend, Oji, South Steiner, Townsite, Tisdale, Sanchez, Cranmore, and Alamo during 2011 (horizontal bars).

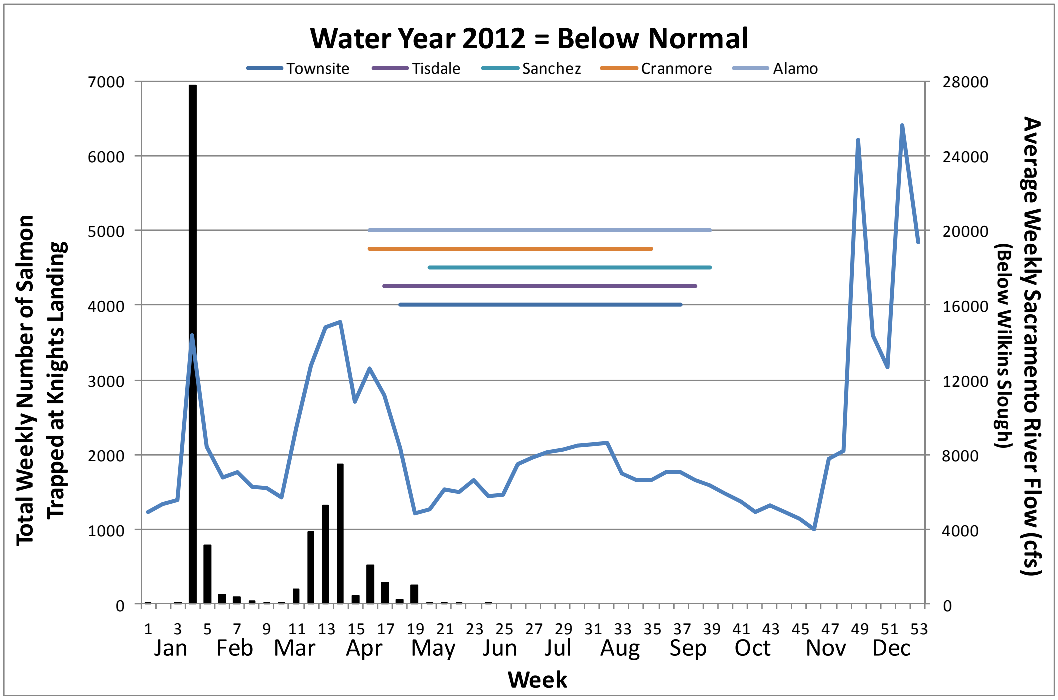

Figure 98. Comparisons between the weekly numbers of juvenile Chinook salmon sampled at CDFW's fish traps in the Sacramento River at Knights Landing (black bars), average weekly Sacramento River flow (cfs) below Wilkins Slough (near Grimes, CA: blue line) and entrainment monitoring periods at Townsite, Tisdale, Sanchez, Cranmore, and Alamo during 2012 (horizontal bars).

Unlike the CDFW fish monitoring program described above, comparisons of the numbers of juvenile salmon sampled at the 12 diversions sites during the four irrigation seasons with

USFWS beach seine programs in the lower and upper Sacramento River would be problematic due to different locations throughout the river and sampling techniques. The beach seine program is designed to sample young salmon rearing in shallow, slow-moving currents whereas the CDFW program is designed to sample salmon outmigrating in the lower river.

As shown in the previous Figures 95 - 98, another factor affecting fish entrainment was attributable to fish emigration from the upper river as a function of natural hydrologic conditions. Juvenile salmon downstream migrations tend to occur in groups and pulses; these pulses may correspond to increased flow events and turbidity (Vogel 2011b). For example, USFWS salmon research by Kjelson *et al.* (1982) and Vogel (1982, 1989) reported increased downstream movements of Chinook fry corresponding to increased river flows and turbidity, respectively. Young Chinook salmon may migrate downstream from Sacramento River tributaries and the mainstem river reaches into the Sacramento-San Joaquin Delta as pre-smolts (fry and parr) or as smolts. The majority of the salmon emigration during wet winter conditions occurs during January through March (Vogel and Marine 1991) and is demonstrated by the CDFW fish sampling program. Storm events increase river flow (Figures 95 - 98) and turbidity (Figures 99 - 102) which causes many salmon to either volitionally or non-volitionally move from the upper river to the Delta. A later emigration of juvenile salmon occurs during April and May as smolts if the fish have not already left the primary rearing grounds in the upper river. Also, this latter period is when most fall-run Chinook salmon produced at Coleman National Fish Hatchery on Battle Creek are released. In this study, fewer salmon were entrained during below-normal water year type conditions than in dry or wet water years (Figure 103). However, regardless of water-year type, the highest salmon entrainment rates were often associated with late-season storm events.

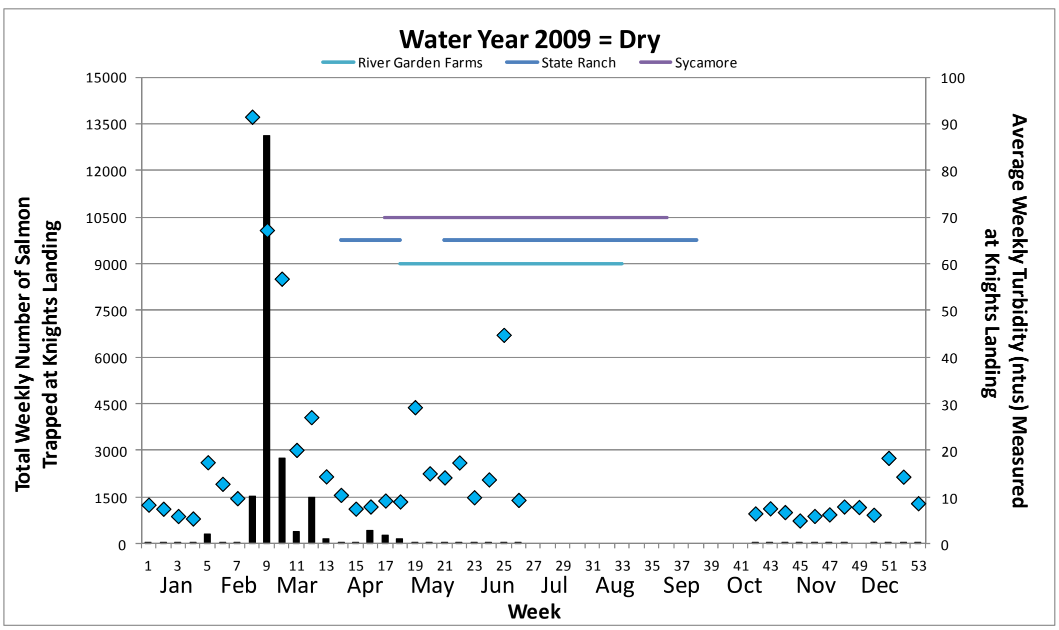

Figure 99. Comparisons between the weekly numbers of juvenile Chinook salmon sampled at CDFW's fish traps in the Sacramento River at Knights Landing (black bars), average weekly Sacramento River turbidity (ntu's) at Knights Landing (blue diamonds), and entrainment monitoring periods at River Garden Farms, State Ranch, and Sycamore during 2009 (horizontal bars).

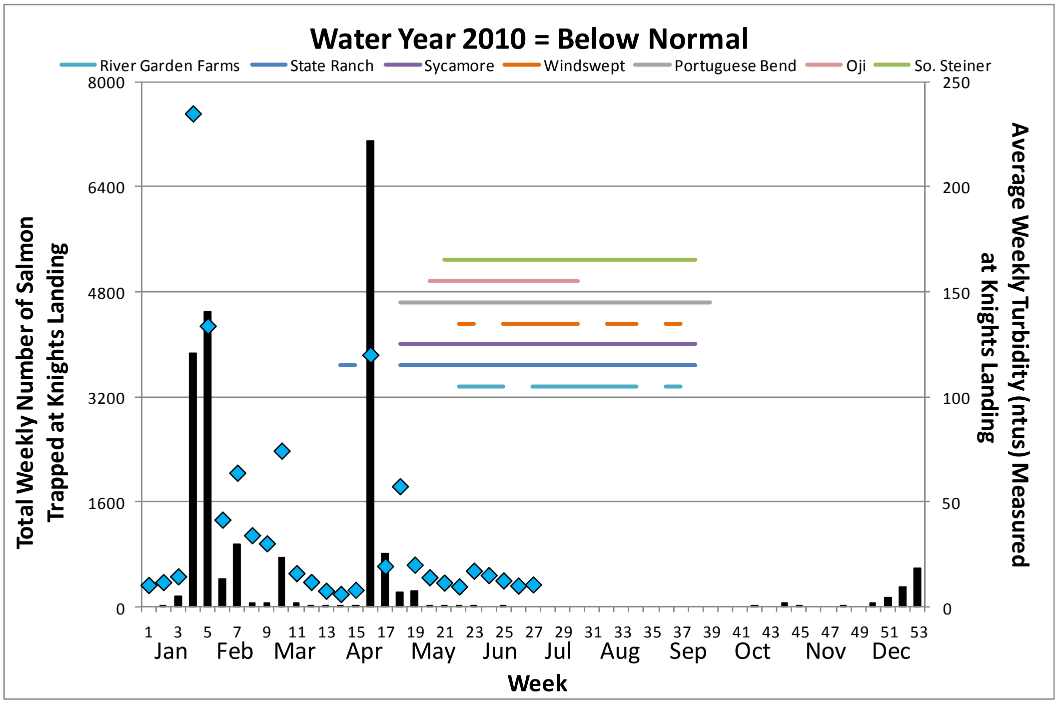

Figure 100. Comparisons between the weekly numbers of juvenile Chinook salmon sampled at CDFW's fish traps in the Sacramento River at Knights Landing (black bars), average weekly Sacramento River turbidity (ntu's) at Knights Landing (blue diamonds), and entrainment monitoring periods at River Garden Farms, State Ranch, Sycamore, Windswept, Portuguese Bend, Oji, and South Steiner during 2010 (horizontal bars).

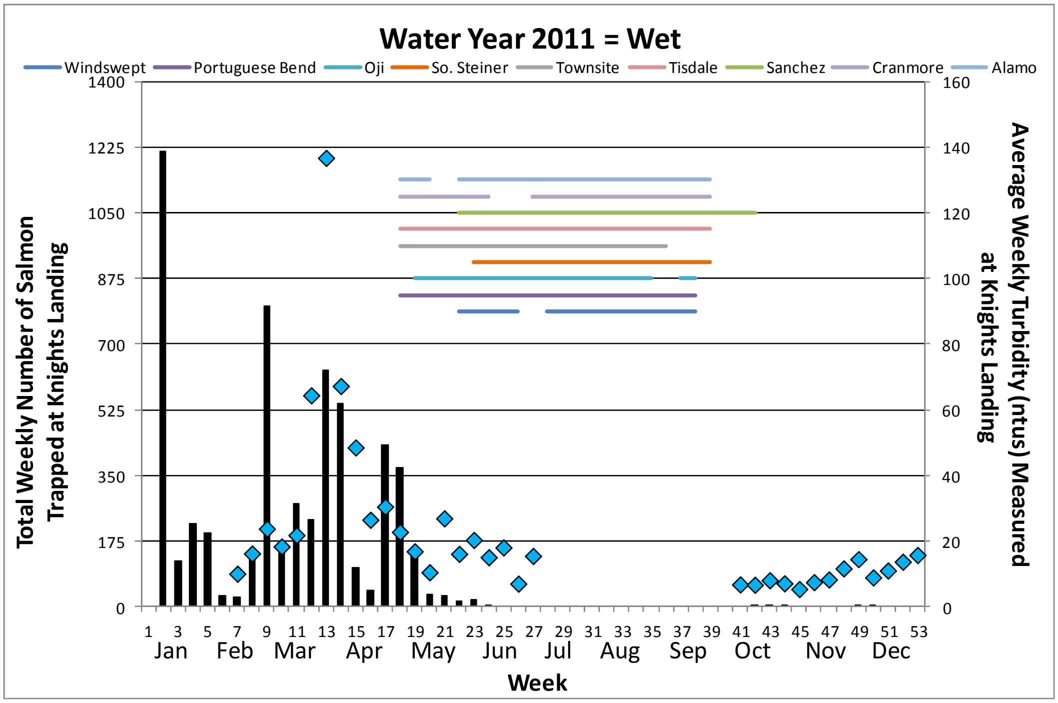

Figure 101. Comparisons between the weekly numbers of juvenile Chinook salmon sampled at CDFW's fish traps in the Sacramento River at Knights Landing (black bars), average weekly Sacramento River turbidity (ntu's) at Knights Landing (blue diamonds), and entrainment monitoring periods at Windswept, Portuguese Bend, Oji, South Steiner, Townsite, Tisdale, Sanchez, Cranmore, and Alamo during 2011. Note that turbidity data were not available in early 2011 (horizontal bars).

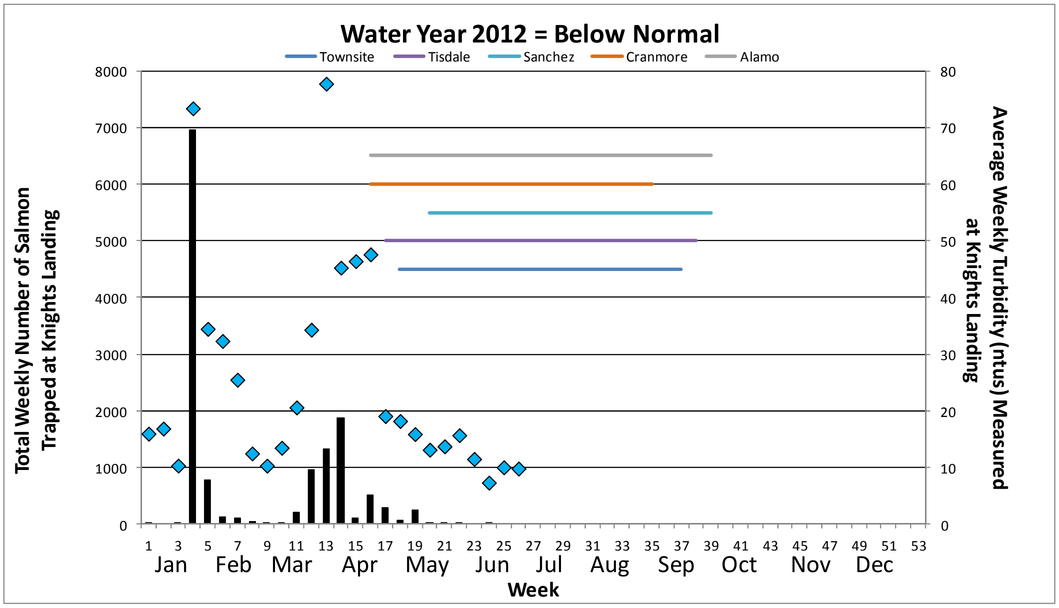

Figure 102. Comparisons between the weekly numbers of juvenile Chinook salmon sampled at CDFW's fish traps in the Sacramento River at Knights Landing (black bars), average weekly Sacramento River turbidity (ntu's) at Knights Landing (blue diamonds), and entrainment monitoring periods at Townsite, Tisdale, Sanchez, Cranmore, and Alamo during 2012 (horizontal bars).

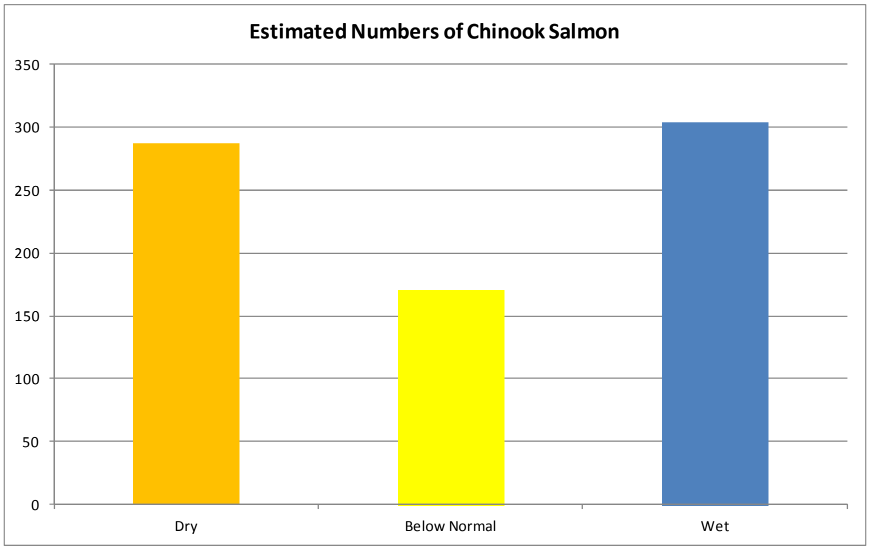

Figure 103. Estimated total numbers of juvenile Chinook salmon entrained at all 12 monitored diversions in comparison to water year type. Note that 2010 and 2012 were below normal water years, so the numbers of salmon for that water year type were averaged.

Additionally, the timing of the onset of irrigation is significantly affected by early spring precipitation events. During this study, regardless of water year type, wet spring conditions due to late-season storms saturated the agricultural lands served by the irrigation canals sampled during this study. This was evident from increased river turbidity during the spring caused by precipitation events (previous Figures 99 - 102). With saturated, muddy fields, growers cannot work in the fields with heavy equipment until the land is sufficiently dry and therefore results in later-than-normal onset of irrigation diversions. Therefore, the combination of the timing of precipitation events with the attendant effects on the start of irrigation and the seasonal timing of salmon emigration also played significant roles in the potential magnitude and duration of exposure of salmonids to entrainment in the monitored unscreened diversions.

Each of the sites monitored are located in the lower Sacramento River (including Steamboat Slough), which, during the primary summer-time irrigation season, possesses unfavorable water temperatures for juvenile salmon.[13] These conditions partially explain the overall generally low numbers of juvenile salmon sampled during the study, although other previously-discussed factors such as the naturally-occurring earlier emigration of salmonids and the late timing of irrigation diversions likely had an overriding influence.

Most salmon entrainment occurred during the spring months (Figure 104) when riverine water temperatures were cooler. This circumstance could be a function of more-favorable physiological conditions for salmon emigration compared to the warmer summer months, a genetically-driven response, or a combination of these factors. The catches were dominated by fall-run Chinook with very few spring-run, late-fall-run, and winter-run Chinook observed (Figure 104). It should be recognized that the designation of salmon run was based on length-at-date criteria which is not definitive, problematic, and can frequently result in a run designation that contradicts those made with genetic markers.[14]

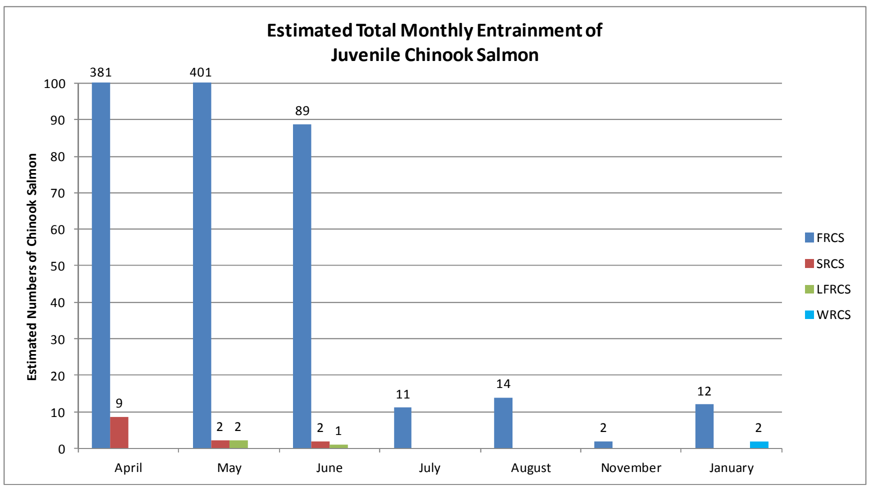

Figure 104. Estimated total monthly entrainment of juvenile salmon by run at the 12 monitored diversions sites. Note that November and December sampling only occurred at the Cranmore diversion in the fall/winter of 2011/12. Also note that in May 2009, equipment damage and repair at State Ranch resulted in a period when fish sampling could not be conducted during a time when salmon emigration likely occurred, otherwise the numbers of salmon would have likely been higher during that month. FRCS = fall-run Chinook salmon, SRCS = spring-run Chinook salmon, LFRCS = late-fall-run Chinook salmon, WRCS = winter-run Chinook salmon.

Among those salmon entrained during the four years of the study, most were parr- or smolt-sized fall-run Chinook (Figures 104 and 105). Only two winter-run salmon were estimated to be entrained and those occurred during the late-season sampling at the Cranmore diversion (Figure 104 and Table 15). Although winter-run fry are present in the upper Sacramento River during the summer months, it is not surprising that none were observed in the lower river during the summer due to relatively warm water temperatures and the fact that winter-run Chinook do not emigrate to the Delta or ocean during the summer months (Vogel and Marine 1991). Similarly, although late-fall-run Chinook are present in the upper Sacramento River during the early summer (Vogel and Marine 1991), the fish are not physiologically smolted at that time and would be expected to remain and rear in the upper river and migrate downstream as smolts

[13] See water temperature graphs in the Results Section.
[14] Written communication by Douglas Threloff, USFWS, May 10, 2013.

during the fall and winter after riverine temperatures are more favorable. This would explain the very low entrainment of late-fall-run salmon (Figure 104 and Table 15). The lower river serves primarily as a migratory corridor for salmon emigrating to the Delta or salt water and not so much as a rearing area, at least during the periods sampled. Because fish sampling could not occur until irrigation diversion operations were initiated, this sampling, by itself, cannot estimate the proportional presence of the various life stages present in the lower river. That information would be more-appropriately developed from the previously-discussed CDFW fish sampling program which occurs during the fall, winter, spring, and early summer months.

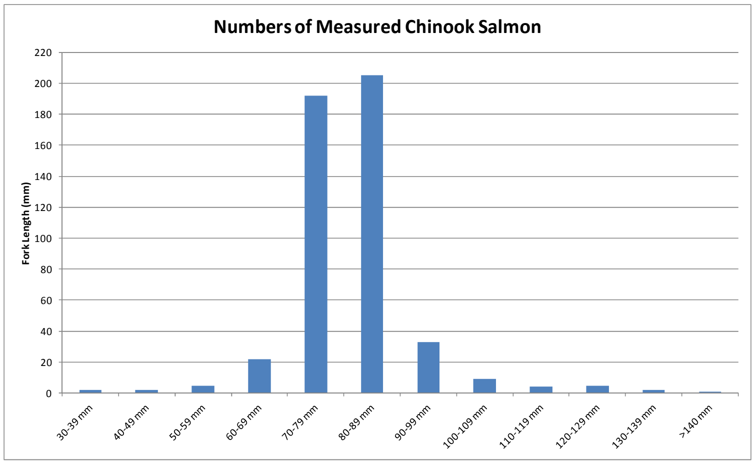

Figure 105. Length/frequency of all measured Chinook salmon captured among the diversions sites sampled, 2009 – 2012.

Table 15. Estimated numbers of anadromous fish entrained at each of the 12 diversion sites. Salmon run or species abbreviations: FRCS = fall-run Chinook salmon, SRCS = spring-run Chinook salmon, LFRCS = late-fall-run Chinook salmon, WRCS = winter-run Chinook salmon, RBT = rainbow trout/steelhead, GST = green sturgeon, WST = white sturgeon, PL = Pacific lamprey.

Diversion Site	FRCS	SRCS	LFRCS	WRCS	RBT	GST	WST	PL
Sycamore	94	1	2	0	0	0	0	36
River Garden Farms No. 2	18	0	1	0	0	0	0	0
State Ranch*	194	7	0	0	0	0	0	29
South Steiner	1	0	0	0	0	4	1	17
Oji	21	0	0	0	0	0	0	4
Windswept	0	0	0	0	0	0	0	0
Portuguese Bend	7	0	0	0	0	0	0	90
Alamo	6	0	0	0	0	0	0	3
Townsite	86	1	0	0	2	0	0	0
Tisdale	33	0	0	0	0	1	0	4
Cranmore	448	4	0	2	0	0	0	152
Sanchez	2	0	0	0	0	0	0	0
Totals	910	13	3	2	2	4	1	335

*Note that in 2009, equipment damage and repair at State Ranch resulted in a period when fish sampling could not be conducted during a time when salmon emigration likely occurred, otherwise the numbers of salmon would have likely been higher.

Very low numbers of other native anadromous fish (rainbow trout/steelhead, green and white sturgeon, and Pacific lamprey) were entrained (Table 16). The observation of only two rainbow trout was not surprising because of the timing of irrigation diversions in the lower river and warm water temperatures. Generally, this species remains in the upper river rearing in cooler water during the summer months and anadromous forms of the species do not emigrate during that period. Very little is known about the early life history, relative abundance, and geographic distribution of green and white sturgeon during the summer. Likewise, Pacific lamprey has not been well studied.

A principal advantage of this sampling program is a comparison of fish entrainment between diversion sites due to comparatively close proximity and similar sampling periods and techniques. Some general observations can be made based on the data collected. Eleven of the 12 sampling sites are located in habitats characterized as poor for juvenile salmon with one considered as fair salmon habitat (Vogel 2008c, Table 16). In contrast, all of the diversions were located in areas where habitats for predatory fish were considered as fair to good (Vogel 2008c, Table 16). If predatory fish consumed salmon in the vicinity of the intakes, those salmon obviously would not have been observed with the entrainment monitoring in the irrigation canals. Additionally, each of the sites has diversion pipes positioned relatively deep in the river water column [i.e., 8 to 17 feet deep (average of 12.4 feet deep), depending on river flows (Table 16)] and generally near the riverbed which are areas presumed to be atypical for the preferences of juvenile salmon. For example, Gaines and Martin (2002) found that the relative abundance of downstream migrating juvenile Chinook salmon was greater in mid-channel areas as compared to river margins and salmon were more abundant in the upper water column than the lower water column. However, the Cranmore diversion, with an intake of 17 feet deep, had the highest entrainment of salmon which is counter-intuitive to the expected results. Among other features associated with the diversions, there was no apparent correlation of those characteristics and the number of salmon entrained (Tables 16 and 17).

Table 16. Physical characteristics of the 12 diversions sites monitored.

Diversion Site	Estimated Water Depth of Intake	Estimated Distance of Intake(s) off River Bottom	Number of Intakes	Bypass Pipe Back to River	Estimated Quality of Predator Habitat	Estimated Quality of Salmonid Rearing Habitat	Channel Configuration at Diversion	Riverbed Substrate at Diversion Intake
Sycamore	11 feet	1 foot	2	Yes	Fair	Poor	Straight	Cobble, Sand
River Garden Farms No. 2	14 feet	8 feet	2	Yes	Fair	Poor	Outside Bend	Rip Rap
State Ranch	13 feet	2 feet	4	No	Good	Poor	Straight	Sand
South Steiner	14 feet	2 feet	2	Yes	Fair	Poor	Outside Bend	Cobble, Sand
Oji	14 feet	3 feet	2	Yes	Fair	Poor	Straight	Sand, Cobble
Windswept	12 feet	3 feet	1	Yes	Fair	Poor	Outside Bend	Cobble
Portuguese Bend	12 feet	2 feet	3	Yes	Good	Poor	Inside Bend	Rip Rap
Alamo	13 feet	3 feet	2	Yes	Fair	Poor	Straight	Cobble, Sand
Townsite	8 feet	1 foot	3	No	Good	Poor	Straight	Silt
Tisdale	13 feet	4 feet	2	No	Good	Fair	Straight	Rip Rap, Silt
Cranmore	17 feet	2 feet	2	Yes	Fair	Poor	Outside Bend	Rip Rap, Sand
Sanchez	8 feet	3 feet	2	No	Fair	Poor	Straight	Rip Rap

Table 17. Estimated total numbers of juvenile Chinook salmon entrained into 12 unscreened diversions, 2009 - 2012.				
Diversion Site	**2009**	**2010**	**2011**	**2012**
Sycamore	97	0	---	---
River Garden Farms No. 2	1	18	---	---
State Ranch*	189*	12	---	---
South Steiner	---	0	1	---
Oji	---	1	20	---
Windswept	---	0	0	---
Portuguese Bend	---	1	6	---
Alamo	---	---	6	0
Townsite	---	---	84	3
Tisdale	---	---	24	9
Cranmore	---	---	176	278
Sanchez	---	---	2	0
Totals	287	32	319	290
*Note that in 2009, equipment damage and repair at State Ranch resulted in a period when fish sampling could not be conducted during a time when salmon emigration likely occurred, otherwise the numbers of salmon would have likely been higher.				

Presumably, higher-pumping-capacity diversions would entrain more fish. However, when examining the total numbers of the dominant species entrained (Sacramento sucker, fathead minnow, and Tule perch) in comparison to the diversions' maximum pumping capacity, no definitive relationship was apparent (Figures 106 - 108); the same was true for salmon (Figure 109). However, as noted in the results section, not all diversions operated continuously during the irrigation season. Additionally, some diversions operated on timers and, to our knowledge, those records of operations are not maintained. These conditions would affect the numbers of fish entrained.

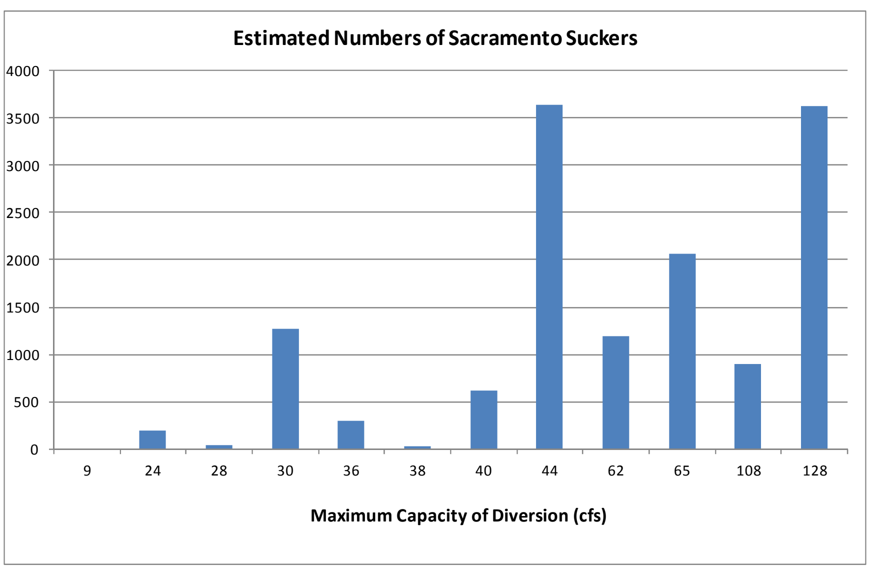

Figure 106. Estimated total numbers of Sacramento suckers entrained in comparison to the maximum pumping capacity of each monitored diversion site.

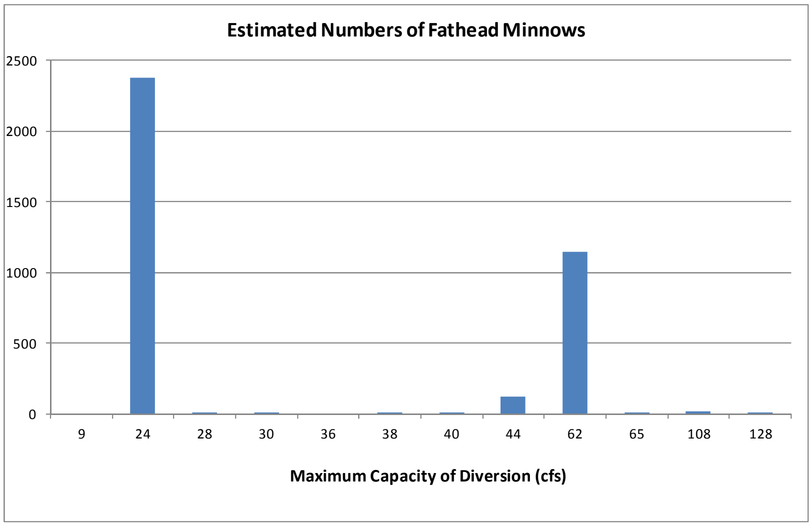

Figure 107. Estimated total numbers of fathead minnow entrained in comparison to the maximum pumping capacity of each monitored diversion site.

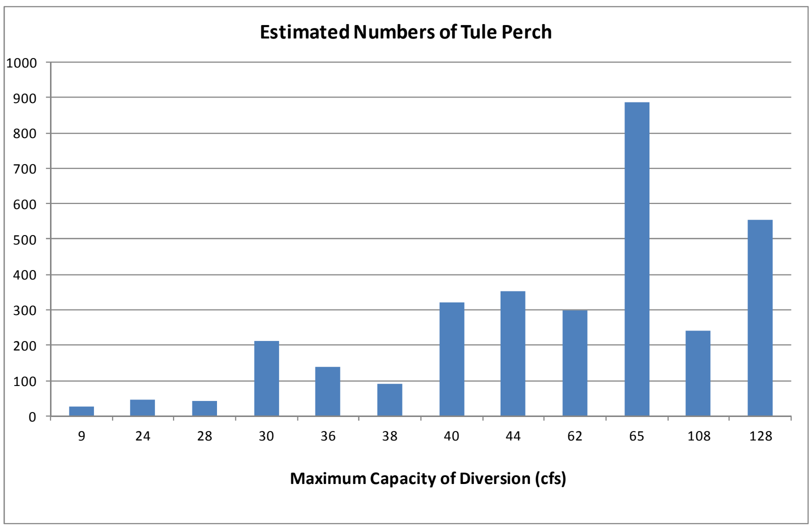

Figure 108. Estimated total numbers of Tule perch entrained in comparison to the maximum pumping capacity of each monitored diversion site.

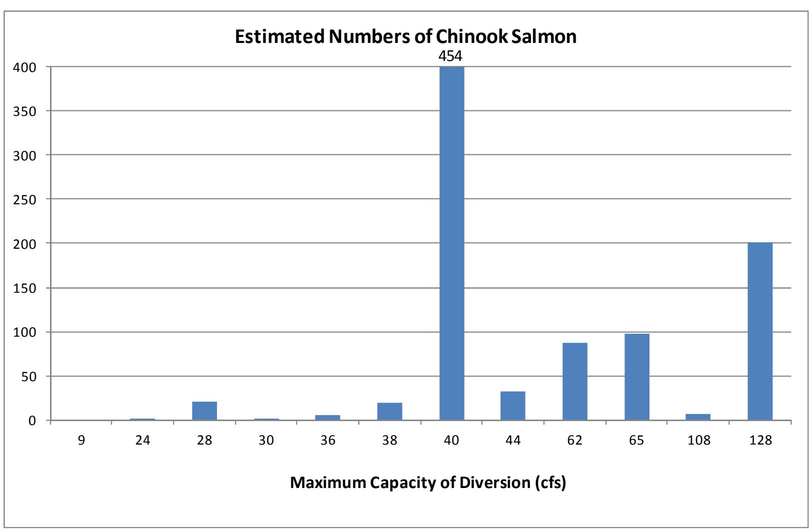

Figure 109. Estimated total numbers of juvenile Chinook salmon entrained in comparison to the maximum pumping capacity of each monitored diversion site.

Although larger diversions would be generally believed to entrain more fish than smaller diversions (a relationship not observed in this study), it is useful to compare the rates of entrainment (e.g., fish/acre-feet) of all fish species combined between diversions. Monthly total diversion data were obtained from the fyke net flow meters, USBR, and Sutter Mutual Water Company to provide a comparison of the numbers of all fish species diverted at each site by month. In 2009, State Ranch (the largest capacity diversion monitored that year) entrained fish at a higher rate in most months compared to Sycamore and River Garden Farms No. 2 (Figure 110). However, in 2010, State Ranch had one of the lowest monthly entrainment rates with South Steiner, one of the smallest diversions, showing the highest monthly entrainment rates for most months (Figure 111). The apparent peak in September entrainment rates for some sites and years was attributable to a combination of lower diversion flows and some fish (primarily juvenile Sacramento sucker) lingering in the distribution system upstream of the fyke nets until pumping ceased. In 2011, two of the smallest diversion sites (Sanchez and South Steiner) exhibited some of the highest fish entrainment rates for some months (Figure 112). In 2012, Sanchez again exhibited the highest entrainment rates in most months (Figure 113). The high entrainment rates observed at Sanchez in May 2011 and 2012 were attributable to large numbers of fathead minnow and golden shiner entrained.

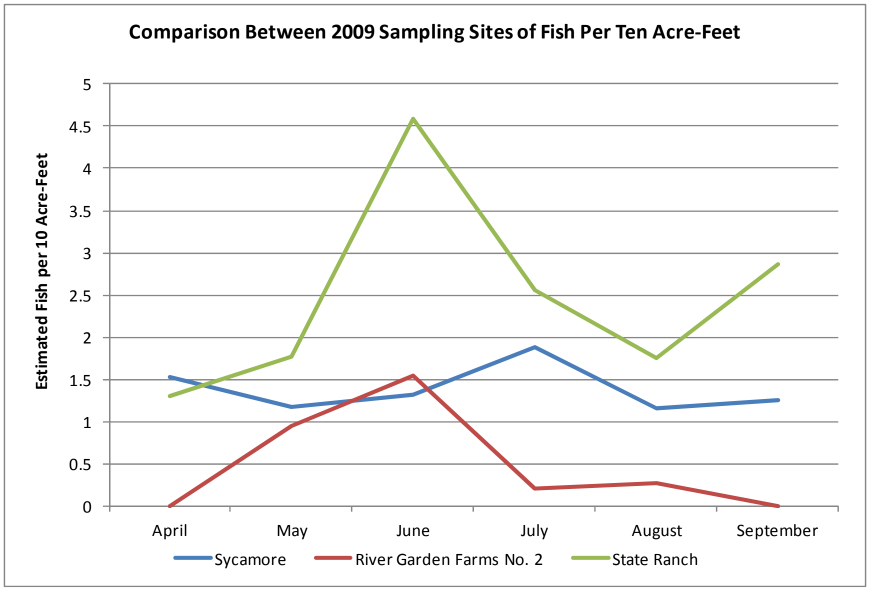

Figure 110. Comparison of the estimated total monthly number of fish (all species combined) per 10 acre-feet for the three diversions sampled during 2009.

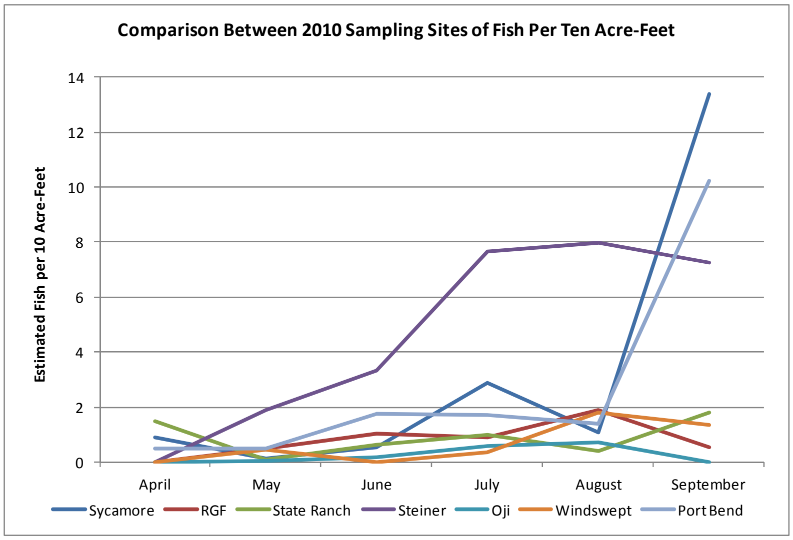

Figure 111. Comparison of the estimated total monthly number of fish (all species combined) per 10 acre-feet for the seven diversions sampled during 2010.

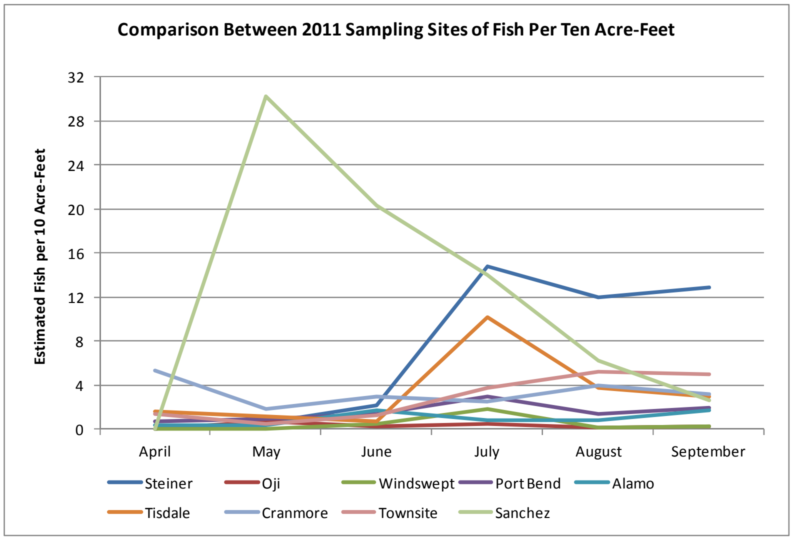

Figure 112. Comparison of the estimated total monthly number of fish (all species combined) per 10 acre-feet for the nine diversions sampled during 2011.

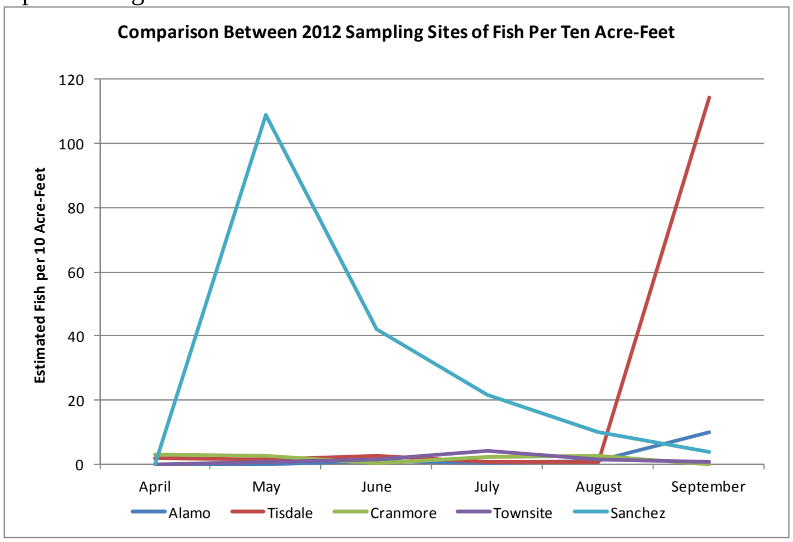

Figure 113. Comparison of the estimated total monthly number of fish (all species combined) per 10 acre-feet for the five diversions sampled during 2012.

Although relatively few salmon were entrained during this study, the salmon diverted per 10 acre-feet at each site for the April and May period during each year are provided in Table 18 to determine if any trends were apparent. The April and May period was chosen because those months were when most salmon were observed. There were no apparent relationships between the rates of salmon entrainment with the amount of water diverted (in this instance, fish/10 acre-feet) based on the size of the diversions.

Table 18. Estimated juvenile Chinook salmon diverted per 10 acre-feet of water at each of the 12 monitored sites by year for the April and May period (shown in ascending order from lowest to highest).

Site - Year	April - May
Portuguese Bend -2010	0.01
Townsite - 2012	0.02
Portuguese Bend - 2011	0.02
River Garden Farms – 2009	0.02
Oji - 2010	0.03
State Ranch - 2010	0.03
South Steiner - 2011	0.07
Tisdale - 2012	0.10
Alamo - 2011	0.12
Tisdale - 2011	0.25
Townsite - 2011	0.29
Sycamore - 2009	0.31
River Garden Farms - 2010	0.33
State Ranch – 2009*	0.45
Oji - 2011	0.47
Cranmore - 2011	1.10
Cranmore 2012	2.30

*Note that State Ranch entrainment in 2009 likely would have been higher but some monitoring was not conducted during a period when the sampling equipment was damaged and repaired.

Comparisons of the total amount of water diverted at the same sites for each of the two years of fish sampling with the estimated numbers of all species and salmon entrained at the corresponding sites did not yield any clear relationships. For many of the sites, total volume of water diverted during each of the two years of monitoring was similar (Figure 114). As examples, the total amount of water diverted in years one and two at South Steiner, Oji, Windswept, Portuguese Bend, Alamo, Townsite, Tisdale, Cranmore, and Sanchez was similar for each site, but the estimated total numbers of fish entrained at each site in years one and two were markedly different, including the numbers of salmon entrained (refer to Results section). Interestingly, the amount of water diverted in the second year at State Ranch was substantially higher than the first year, but the estimated total numbers of all fish entrained were substantially lower, including the numbers of salmon entrained.

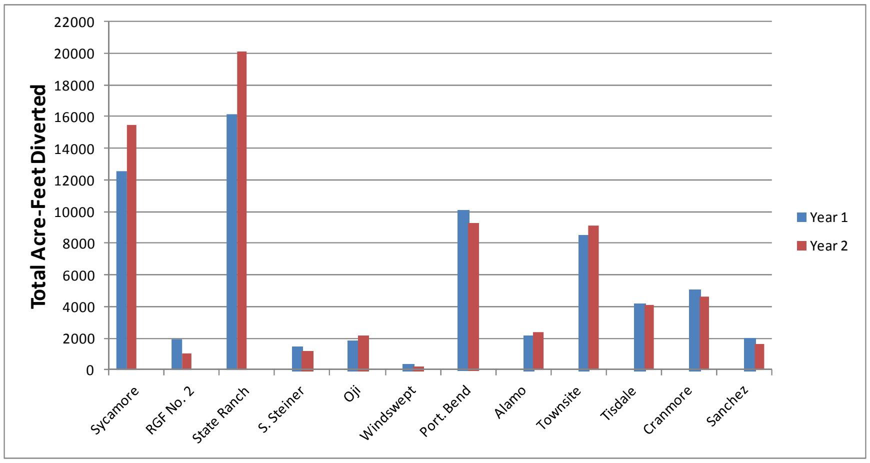

Figure 114. Total amount of water diverted (acre-feet) at each of the monitored sites during the first and second year of fish sampling. Note that the values for Cranmore do not include the late fall and winter diversions in 2011-2012.

During the study, 40 juvenile salmon with identifiable coded-wire tags were obtained (Table 19). All of these fish originated from Coleman National Fish Hatchery. Although the total numbers of specific tag codes for each group of salmon released from the hatchery are known (Table 19), the numbers of those fish reaching the diversion sites are unknown due to probable mortality of some fish in each group. However, even if it is assumed that mortality was high in the river reach between the hatchery and diversion sites (e.g., 50%), it is evident that salmon were diverted in a much lower proportion than the percent of river flow diverted.[15] However, there may have been a general positive linear relationship between the proportion of fish diverted and the proportion of flow diverted.[16] Nevertheless, there were too many uncertainties in the data to derive definitive conclusions. Among those included the likely differential fish mortality between groups of fish over the long distances from the upstream hatchery to the various downstream diversion locations, the uncertain amount of flow actually diverted at each site due to unmeasured diverted bypass flows back to the river (discussed later in this report), the actual river flow at the diversion sites compared to flow measured at the Grimes gauging station, and very low sample sizes.[17] Fish transit times are provided for reference in Table 19 and were approximated for the period from noon on the day of fish release at the hatchery to the time of fyke net check at the diversion site.

[15] The percent of river flow diverted was estimated by comparing the measured flow in the diversion canals with the Sacramento River flow at Grimes (the nearest gauging station). Flow values were computed for the approximate 24-hour period preceding the time of fyke net check when a coded-wire tagged salmon was captured.
[16] Written communication by Douglas Threloff, USFWS, May 10, 2013.
[17] E.g., most recaptures included only one fish.

Table 19. Data on the coded-wire tagged fall-run Chinook salmon from Coleman National Fish Hatchery observed during this study.								
CWT Code	Number Released	Release Date	Recovery Site	Number Observed	Percent of Total Fish in Each CWT Group Entrained at the Recovery Site	Estimated Percent of Flow Diverted	Average Elapsed Days to Recovery	Average Migration Speed (Miles/Day)
055223	101711	4/16/2010	RGF	1	0.00098%	0.15%	43	4.3
055369	107633	4/21/2011	Townsite	1	0.00093%	0.28%	10	18.7
055372	107964	4/21/2011	Cranmore	2	0.00185%	0.21%	8	20.6
055373	116701	4/21/2011	Oji	1	0.00086%	0.20%	17	10.1
055375	116411	4/14/2011	Townsite	1	0.00086%	0.26%	10	18.7
055377	115063	4/14/2011	Townsite	2	0.00174%	0.11%	14	13.2
055380	109950	4/14/2011	Cranmore	1	0.00091%	0.16%	19	8.6
055381	114135	4/14/2011	Townsite	1	0.00088%	0.49%	19	9.8
055383	101916	4/28/2011	Townsite	2	0.00196%	0.17%	26.5	10.1
055384	119464	4/28/2011	Cranmore	1	0.00084%	0.14%	26	6.2
055386	116685	4/28/2011	Tisdale	1	0.00086%	0.01%	39	4.1
055389	120512	4/28/2011	Cranmore	1	0.00083%	0.09%	7	23.5
055390(1)	118968	4/28/2011	Cranmore	1	0.00084%	0.01%	35	4.8
055390(2)	118968	4/28/2011	Townsite	1	0.00084%	0.06%	40	4.6
055392	114339	4/22/2011	Townsite	1	0.00087%	0.31%	32	5.8
055393	120148	4/22/2011	Cranmore	1	0.00083%	0.29%	131	1.2
055395	122975	4/22/2011	Tisdale	1	0.00081%	0.22%	33	4.8
055396	117781	4/22/2011	Cranmore	1	0.00085%	0.21%	7	23.5
055512	104962	4/19/2012	Cranmore	1	0.00095%	0.14%	6	27.4
055516	93426	5/1/2012	Cranmore	1	0.00107%	0.03%	3	55.0
055517	113261	5/1/2012	Cranmore	1	0.00088%	0.51%	8	20.6
055519(1)	119684	5/1/2012	Cranmore	2	0.00167%	0.51%	8	20.6
055519(2)	119684	5/1/2012	Tisdale	1	0.00084%	0.33%	4	38.6
055521	110545	5/1/2012	Cranmore	3	0.00271%	0.33%	12	14.9
055522	118451	5/1/2012	Cranmore	5	0.00422%	0.42%	10	18.2
055523	126404	5/1/2012	Cranmore	2	0.00158%	0.51%	8	20.6
055524	119849	5/1/2012	Cranmore	3	0.00250%	0.51%	8	20.6

In a literature review of unscreened diversions in California, Moyle and White (2002) found that among the few studies conducted on fish entrainment, non-native or abundant native species (e.g., Sacramento sucker) were the primary species diverted, particularly in the smaller diversions. This study corroborates those prior findings. The dominant presence of Sacramento sucker, fathead minnow, and Tule perch (as well as other species sampled) at most of the 12 diversion sites (Figure 115) is consistent with the types of habitats and seasonable presence expected for those species as described by Moyle (2002) (Appendix B). Among those species sampled, the fish sizes were small indicating entrainment of younger life stages which could be explained by lesser swimming capabilities for avoiding entrainment, different habitat preferences based on life stage, and the size of trash racks positioned over some of the intakes. The cumulative effect on the riverine ecosystem resulting from the loss of non-salmonid fish in diversions has never been examined.

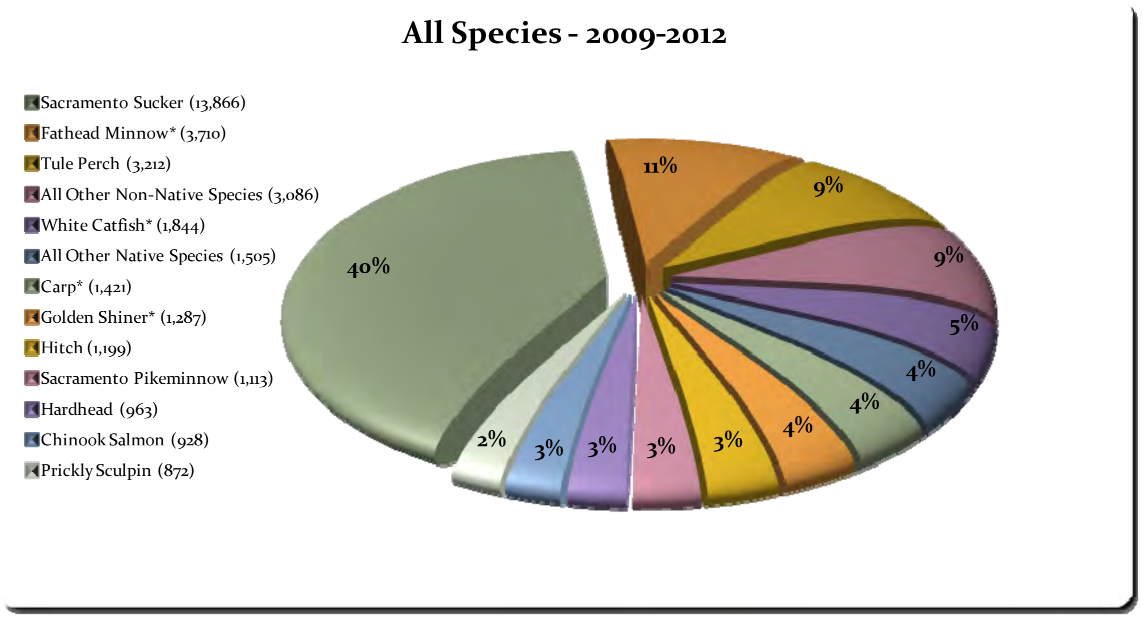

Figure 115. Total combined estimated numbers of each fish species entrained at the 12 unscreened diversions monitored, 2009 – 2012.

There was no apparent relationship between the longitudinal location in the river and the numbers of species observed at the 12 monitored diversions (Figure 116). All of the diversions were located in highly-altered riverine habitats and the non-native species and some of the native species (e.g., Sacramento sucker) would be expected in those disturbed habitat conditions (Moyle 2002, Appendix B).

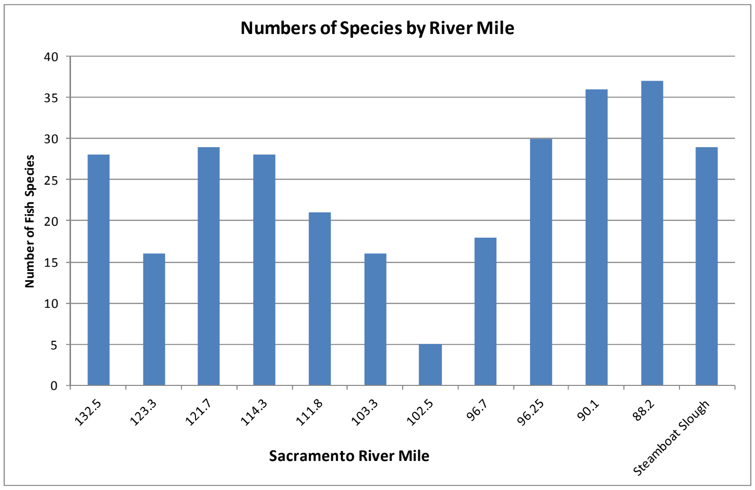

Figure 116. Total numbers of species entrained by river mile location.

There was also no apparent relationship between the estimated numbers of juvenile Chinook salmon entrained based solely on longitudinal location in the river (Figure 117).

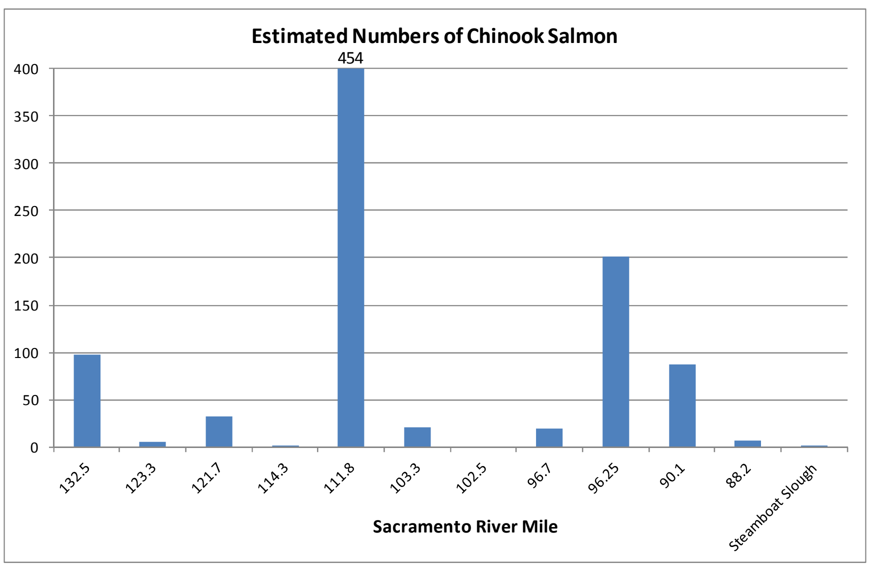

Figure 117. Estimated total numbers of juvenile Chinook salmon entrained by river mile location.

As described below, some of the unscreened diversions on the Sacramento River possess discharge pipes back to the river. This circumstance is because many of the diversions do not have variable-speed water pumps. In these situations, additional pumped flow that is in excess of the irrigation needs at any particular time is diverted back into the river by way of a bypass pipe. An example visible above the river surface is shown in Figure 118. An example of the bypass valves for the two Sycamore intake pipes is shown in Figure 119. In many instances, the discharge pipe is beneath the river surface and, without close inspection or technical knowledge of the diversion, the return discharge pipe could be mistaken as an intake pipe. The significance of this condition is that actual pumped flow from the river is sometimes (and perhaps often) not the same as the flow entering the irrigation canals. However, fish are exposed to the actual pumped flow from the river but may be diverted back into the river before entering the irrigation canal (i.e., the fish would be entrained into the pump intake but not entrained into the irrigation canal). The fish would likely experience physical injury or mortality after passage through the pump's impeller or the pipe system. There is also the potential for bypassed flows to unnaturally attract predatory fish at the site to feed on stressed or injured entrained fish routed back to the river. The timing and magnitude of bypassed flow back to the river may vary frequently during the irrigation season and, to our knowledge, daily records of those operations are not maintained. The resulting fish losses associated with bypassed flows could not be measured during this study and remain unknown.

Figure 118. An example of excess flow at an unscreened diversion being diverted back into the Sacramento River.

Figure 119. Flow bypass valves (red) at the Sycamore diversion. The two large-diameter pipes on the right lead to the Sycamore canal through a levee. Each pipe has a separate flow bypass valve on the left that can be used to route excess pumped flow back to the Sacramento River. The left intake pipe is disconnected for pump maintenance.

An important variable that can affect fish entrainment is the physical characteristics of the intakes (e.g., presence or absence of a trash rack over the diversion intake) (Figure 120). Although physical internal measurements of the intakes were not part of this study, an interview with Russ Berry, Jr. of Intake Screens, Inc. (ISI) provided useful information. Mr. Berry SCUBA dove at most of the unscreened diversion intakes monitored during this study prior to installation of ISI's fish screens. Based on a combination of Mr. Berry's notes and memory, the following provides relevant information on additional physical factors that could have had a significant effect on fish entrainment for some of the diversion sites. However, it is important to emphasize that detailed measurements of each intake were not performed as part of this study and, therefore, no definitive conclusions can be made concerning the effects of variable structure intakes on fish entrainment. The following discussion is provided only to call attention to some general features of the structures and to recommend that future studies should examine potential effects of intake configurations on fish entrainment.

Figure 120. Trash racks (bars) on the Alamo diversion intake pipe shown on its side. Picture was taken after removal from the river prior to installation of an ISI fish screen. Note the individual's boot at the lower left portion of the picture for size reference. Prior to removal, this intake was positioned upwards such that the intake opening and trash racks were horizontal and the river flow went over the top of the intake opening. Photo by ISI.

Some diversion intakes had a submersible pump and pipe positioned at an angle off the river bank into deep water with a trash rack "cage" over the intake opening (Figure 121A). This was the general configuration of the intakes at Sycamore. The 3-dimensional size of the trash rack cage can also influence the water velocities through the openings depending on specific locations and, therefore, affect vulnerability of fish to entrainment. The size and orientation of the trash racks' bars or metal rods vary but can be large enough to entrain small fish through the openings (e.g., 3-inch square). The orientation of the trash racks can be radial (Figure 122A) as at Sycamore; square mesh (Figure 122B, C, and D) as at River Garden Farms No. 2, State Ranch, Portuguese Bend, Cranmore, Sanchez, and Windswept; diamond-shaped expanded metal (Figure 122E) as at Oji; parallel bars (Figure 122F) as at Alamo; or no trash racks as at Townsite and Tisdale. Notably, some diversions had the submersible pump and pipe inserted inside a larger-diameter conductor pipe with a trash rack cage (Figure 121B) as at Portuguese Bend or trash racks welded flush with the conductor pipe opening (Figure 121C, D, E, and F) as at River Garden Farms No. 2, State Ranch, Windswept, Oji, Alamo, and Sanchez. The combination of the pump intake on the bottom of the conductor pipe, the recessed distance of the pump intake back from the opening of the conductor pipe, the diameter of the pump intake, and the diameter of the conductor pipe would affect water velocities at the intake where fish may be entrained. There was no uniformity in the types of trash racks or physical configuration of the intake pipes. However, the Tisdale and Townsite diversions had similar vertical intakes just off the riverbed with no trash racks but there were no apparent differences in the numbers of fish and species at those sites compared to other sites. The configuration of the intakes at South Steiner was not examined by divers and remains unknown.

Table 20 summarizes these features as depicted in Figures 117 and 118 for the monitored diversions. These factors, by themselves, could have been important determinants affecting fish entrainment at the monitored diversions. However, detailed measurements of those characteristics, water velocities at the intake openings, and fish behavior in the immediate vicinity of the intakes were not part of this study and, therefore, no definitive conclusions can be made.

Table 20. Physical and trash rack configurations of the monitored diversions sites as depicted by graphics in Figures 121 and 122.

Stage	Diversion Site	Physical Configuration	Trash Rack Configuration
Stage 1	**Sycamore**	Figure 121 A	122 A
	River Garden Farms No. 2	Figure 121 D	122 C
	State Ranch	Figure 121 C	122 B
Stage 2	**South Steiner**	Unknown	Unknown
	Oji	Figure 121 D	122 E
	Windswept	Figure 121 C	122 B
	Portuguese Bend	Figure 121 B	122 B
Stage 3	**Alamo**	Figure 121 E	122 F
	Townsite	Figure 121 G	No Trash Rack
	Tisdale	Figure 121 G	No Trash Rack
	Cranmore	Figure 121 C*	122 B
	Sanchez	Figure 121 F	122 D

* The configuration of the second pipe is unknown.

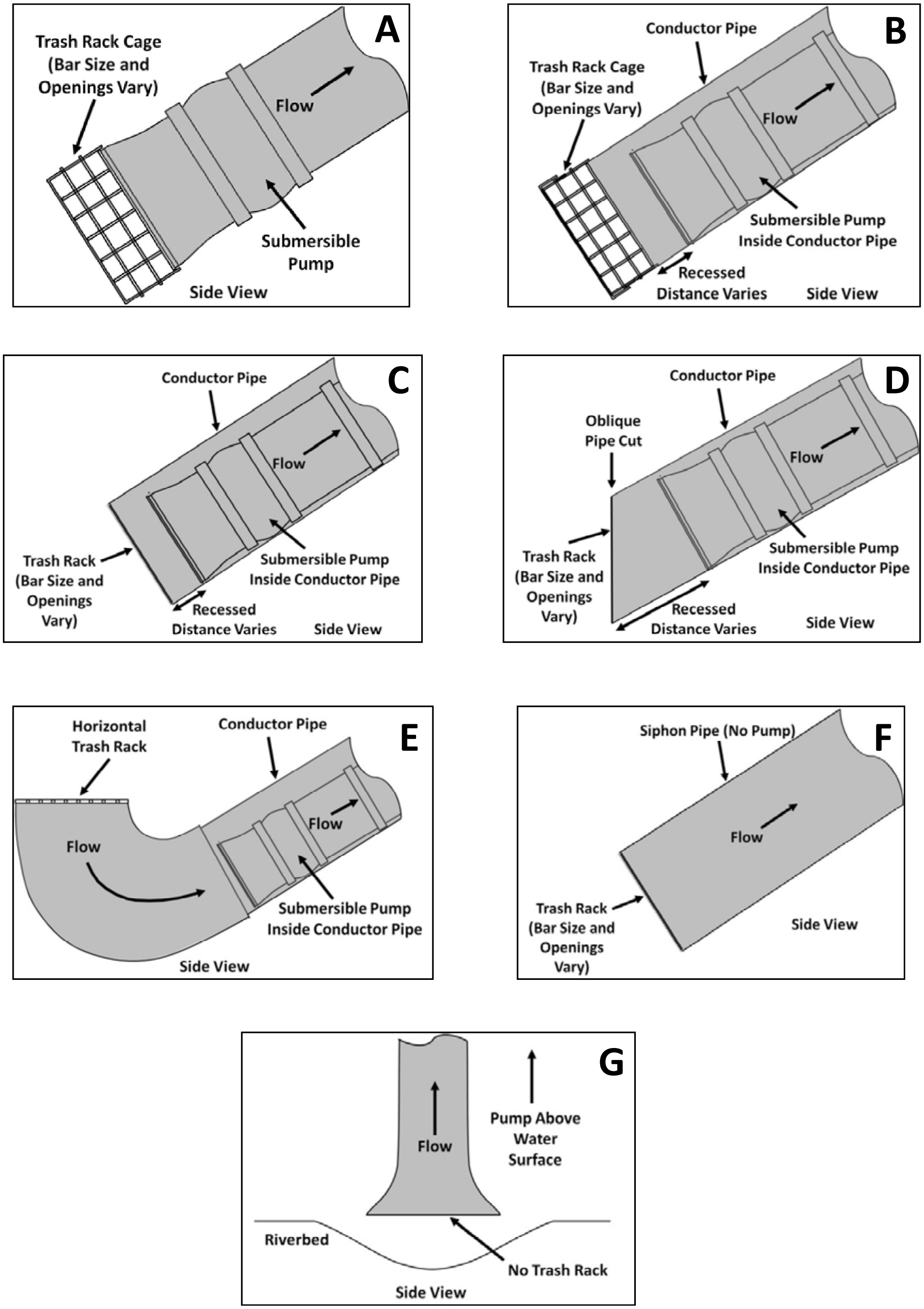

Figure 121. Various physical configurations of unscreened diversion intakes (not to scale).

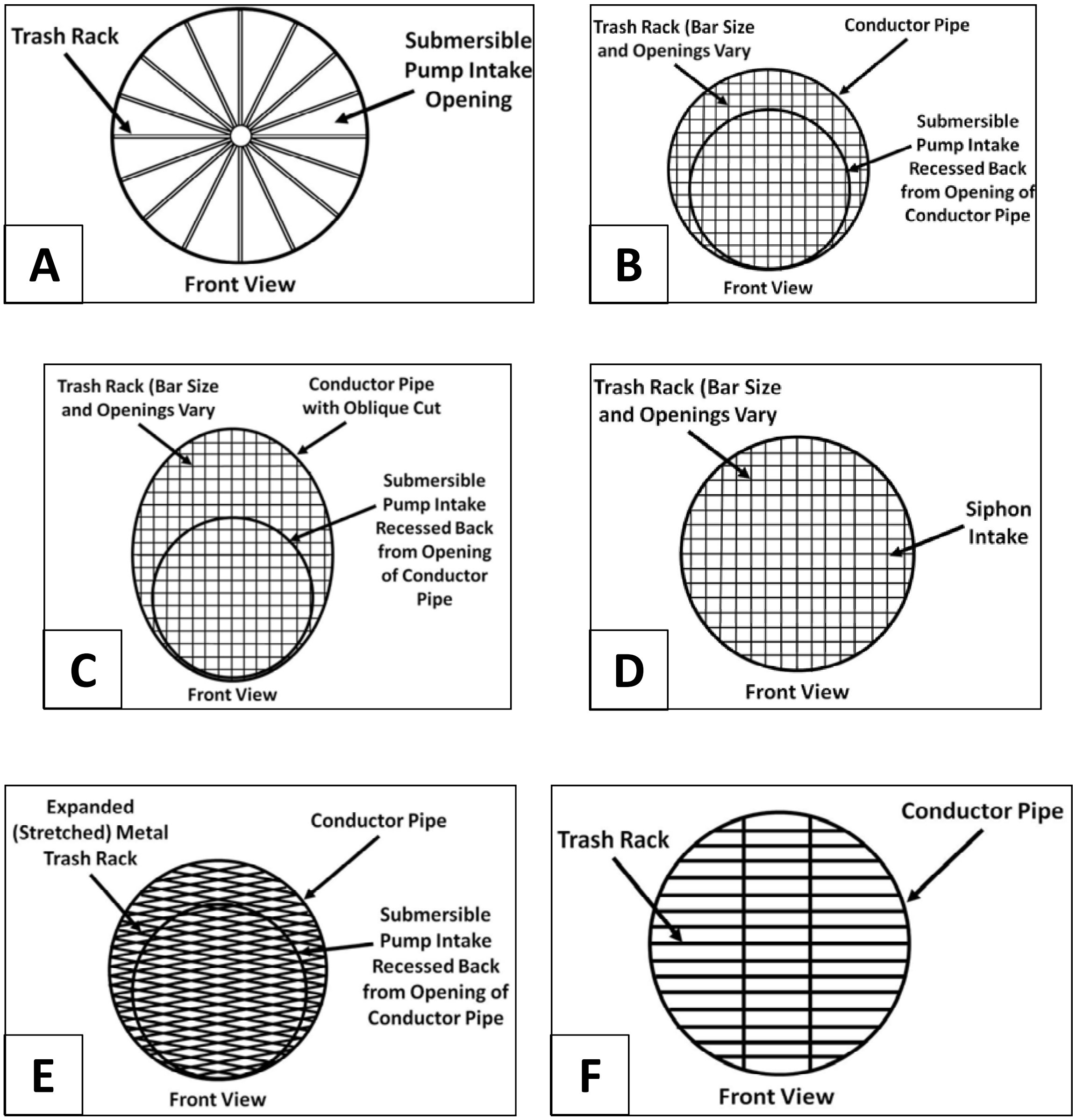

Figure 122. Various trash rack configurations of unscreened diversion intakes (not to scale).

In summary, this study, like prior studies similar in scope, indicates that factors affecting salmon entrainment in unscreened water diversions are complex and poorly understood. However, this research demonstrated that some of the most important determinants of salmon entrainment likely include the initial timing of irrigation diversions in the spring, hydrologic conditions preceding the onset of irrigation diversions, and the natural emigration timing of salmon in relation to the spring-time diversion of water. Based on the premise that the middle to lower Sacramento River is not heavily utilized by juvenile salmon for rearing during the late-spring and summer months (which corresponds to when irrigation diversions occur) it is not surprising that relatively few salmon were entrained into the irrigation canals monitored during this study, which is similar to results by Hallock and Van Woert (1959). Among those salmon entrained, the majority were fall-run Chinook which was attributable to that race's life-cycle timing (Vogel and

Marine 1991). Based on very limited data on captures of coded-wire tagged salmon released from Coleman National Fish Hatchery, it appears that juvenile salmon were entrained in a much lower proportion than that of flow diverted, similar to results noted by Hanson (2001). As expected, because most of the diversion intakes were positioned on or near the river bottom, the dominant species entrained were typically bottom-oriented fish.

This study's results did not discern measurable effects of factors such as size of the diversion, longitudinal location in the river, water temperatures, localized habitat conditions, intake position in the river channel, and depth of the intakes on salmonid entrainment. However, importantly, there was not a lot of disparity among those variables between the monitored sites in order to evaluate their potential effects. For example, if some of the diversion intakes had been positioned near the water surface instead of all being relatively deep, some differences in salmonid entrainment may have been noted. Also, if some of the sites had been located farther upstream in proximity to juvenile salmonid rearing habitats and cooler water, substantially different entrainment rates may have been observed. In particular, if some of the diversions withdrew water earlier in the season (e.g., March), higher entrainment of salmonids would have been likely, but that period does not correspond to when typical agricultural irrigation diversions occur in this region of California.

Numerous additional variables not evaluated as part of this study could have affected the results. Among these factors include possible predation near the intakes, effects of pumped bypassed flow, presence or absence of trash racks over the intakes, and specific configuration of trash racks and of the intakes.

Acknowledgements

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[18] Russ Bellmer was working for the National Marine Fisheries Service during the initial phase of this project and presently works for the California Department of Fish and Wildlife.

permission to sample fish in their irrigation canals. The USFWS in Red Bluff graciously provided training and use of their facilities for reading coded-wire tags collected during this study and Kevin Offill of the same office provided data on the releases of coded-wire tagged salmon from Coleman National Fish Hatchery. Thanks are due to Kevin Kibby (USBR) and William Hazlett (Sutter Mutual Water Company) for providing water diversion data. I appreciate thoughtful comments on an earlier draft of this report by Dan Meier, Douglas Threloff (USFWS), Treva Porter, Mike Healey (CDFW), and Steve Thomas (NMFS). The field work was capably conducted by the Natural Resource Scientists, Inc. staff including Josh Brown, Matt Toney, Chris Geach, Chris Johnson, Matt Manuel, Darren Rocheleau, Chad Dale, and Carlos Overstreet.

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Appendices

Appendix A. Fish species observed during the 2009 – 2012 entrainment monitoring project.			
Species (Common Name)	**Scientific Name**	**Native**	**Non-Native**
American Shad	*(Alosa sapidissima)*		X
Bigscale Logperch	*(Percina macrolepida)*		X
Black Bullhead	*(Ameiurus melas)*		X
Blue Catfish	*(Ictalurus furcatus)*		X
Bluegill	*(Lepomis macrochirus)*		X
Brown Bullhead	*(Ameiurus nebulosus)*		X
California Roach	*(Lavinia symmetricus)*	X	
Carp	*(Cyprinus carpio)*		X
Channel Catfish	*(Ictalurus punctatus)*		X
Chinook Salmon	*(Oncorhynchus tshawytscha)*	X	
Fathead Minnow	*(Pimephales promelas)*		X
Golden Shiner	*(Notemigonus crysoleucas)*		X
Goldfish	*(Carassius auratus)*		X
Green Sturgeon	*(Acipenser medirostris)*	X	
Green Sunfish	*(Lepomis cyanellus)*		X
Hardhead	*(Mylopharodon conocephalus)*	X	
Hitch	*(Lavinia exilicauda)*	X	
Inland Silverside	*(Menidia audens)*		X
Largemouth Bass	*(Micropterus salmoides)*		X
Mosquitofish	*(Gambusia affinis)*		X
Pacific Lamprey	*(Lampetra tridentate)*	X	
Pacific Staghorn Sculpin	*(Leptocottus armatus)*	X	
Prickly Sculpin	*(Cottus asper)*	X	
Rainbow Trout	*(Oncorhynchus gairdneri)*	X	
Red Shiner	*(Cyprinella lutrensis)*		X
Redear Sunfish	*(Lepomis microlophus)*		X
Redeye Bass	*(Micropterus coosae)*		X
Riffle Sculpin	*(Cottus gulosus)*	X	
River Lamprey	*(Lampetra ayresi)*	X	
Sacramento Pikeminnow	*(Ptychocheilus grandis)*	X	
Sacramento Splittail	*(Pogonichthys macrolepidotu)*	X	
Sacramento Sucker	*(Catostomus occidentalis)*	X	
Smallmouth Bass	*(Micropterus dolomieu)*		X
Striped Bass	*(Morone saxatilis)*		X
Threespine Stickleback	*(Gasterostreus aculeatus)*	X	
Tule Perch	*(Hysterocarpus traski)*	X	
Wakasagi	*(Hypomesus nipponensis)*		X
White Catfish	*(Ameiurus catus)*		X
White Crappie	*(Pomoxis annularis)*		X
White Sturgeon	*(Acipenser transmontanus)*	X	

Appendix B. Fish species accounts in the lower Sacramento River.

(Note: The following information on the 44 fish species observed during this study's entrainment monitoring in lower Sacramento River irrigation canals is primarily based on Moyle (2002) "Inland Fishes of California". The following brief descriptions are focused on relevance to the lower Sacramento River and do not include information for areas and habitats outside that geographic region. Additionally, because many of the species sampled were juveniles, emphasis for those species focused on that life stage. For ease of locating the information, the species are listed in alphabetical order, not relative abundance.)

American Shad (*Alosa sapidissima*). American shad is a non-native species commonly found in the lower Sacramento River. The river reach from Colusa to the north Delta is considered a main nursery area for young fish causing a vulnerability to entrainment into unscreened agricultural diversions. American shad feed primarily in the water column but are opportunistic and may feed on abundant bottom organisms.

Bigscale Logperch (*Percina macrolepida*). Bigscale logperch is a non-native species found in the lower Sacramento River. The species is considered to be widespread from the confluence of the Feather River to the Delta. The fish almost exclusively occupy highly disturbed habitats and are most common in slower-moving reaches of warm, clear streams on bottoms of mud, gravel, rock, and woody debris. The fish spend much of their time motionless on the riverbed.

Black Bullhead (*Ameiurus melas*). Black bullhead, like brown bullhead, is a non-native species common in the lower Sacramento River. Typically, among other habitat types, the species prefers river backwaters, sloughs, and pools of low-gradient streams with slow currents, turbid warm water, and muddy bottoms. The fish are often associated with other non-native species that favor highly altered environments. Black bullheads are usually found in loose shoals. All life stages are omnivorous bottom feeders.

Black Crappie (*Pomoxis nigromaculatus*). Like white crappie, black crappie is a non-native species found in the lower Sacramento River, although it is more commonly found in lakes and reservoirs. The fish feed primarily in midwater and hang around large submerged objects during the day. The species prefers quiet water and summer water temperatures in the range of 27-29^{o}C (80.6-84.2^{o}F).

Blue Catfish (*Ictalurus furcatus*). Blue catfish is a non-native species. Moyle (2002) identified the species' presence in the Delta, so it is not surprising to find the fish in the lower Sacramento River. However, blue catfish are not very common. The species is known to occupy deep channels of big rivers residing on the bottom in moderate currents. Blue catfish has a very wide tolerance of water temperatures ranging from 0-37^{o}C (32-98.6^{o}F) with optimal growth at 27^{o}C (80.6^{o}F).

Bluegill (*Lepomis macrochirus*). Bluegill is a widely-distributed, non-native species found in the lower Sacramento River. The fish have a wide temperature tolerance but prefer temperatures in the range of 27-32^{o}C (80.6-89.6^{o}F). The species is often associated with rooted aquatic plants with bottoms of silt, sand, or gravel. The fish are opportunistic feeders, feeding on the bottom, midwater, and the surface.

Brown Bullhead (*Ameiurus nebulosus*). Brown bullhead, like black bullhead, is a non-native species common in the lower Sacramento River. In a riverine environment, the species prefer sluggish, low-gradient areas in association with soft substrates, deep pools, high turbidity, and aquatic plants. Optimal growth temperatures are in the range of 20-33^{o}C (68-91.4^{o}F). The fish are opportunistic, omnivorous, bottom-feeding scavengers.

California Roach (*Lavinia symmetricus*). California roach is a native fish species. Moyle (2002) identifies many of the streams in the Central Valley as areas where the species is widely found but identifies the lower Sacramento River as a former habitat range. It is not known if the California roach observed during the entrainment monitoring in the irrigation canals of the lower Sacramento River reproduce and regularly reside in the lower river or are washed down from upstream areas. The species is tolerant of high water temperatures in the range of 30-35^{o}C (86-95^{o}F) but can also be found in cold-water areas. California roach can be found in heavily modified habitats and in the main channels of rivers. When present within complex fish assemblages, the fish will concentrate in shallow, low-velocity water with fine substrate. The species is primarily an omnivorous bottom feeder but is capable of feeding on drift organisms in swift current.

Carp (*Cyprinus carpio*). Carp is a non-native species commonly found in the lower Sacramento River. The species is generally most abundant in warm, turbid water at low elevations. The fish occupy habitats with silty, soft bottoms. In clear-water environments, the fish utilize cover such as submerged tree branches. Adults and juveniles prefer pools but juveniles will occupy shallow water if sufficient aquatic vegetation is available for cover. The fish can tolerate a wide range of water temperatures, but the optimum growth temperature is around 24^{o}C (75.2^{o}F). Carp are generally omnivorous bottom feeders rooting around in loose sediment.

Channel Catfish (*Ictalurus punctatus*). Channel catfish, a non-native species, are widely distributed throughout California, including the lower Sacramento River. Optimal habitats of the various life stages of the species are in clear warm-water streams with sand, gravel, or rubble substrates. Young-of-the-year can live full time in riffles with rock substrate. Optimal growth temperatures for channel catfish are in the range of 24-30^{o}C (75.2-86^{o}F).

Chinook Salmon (*Oncorhynchus tshawytscha*). Chinook salmon is a native species commonly found in the lower Sacramento River. Four runs of Chinook salmon are present in the Sacramento River based on time of adult salmon entry into freshwater: fall, late-fall, winter, and spring Chinook. The winter run is federally listed as an endangered species and the spring run as a threatened species. Juvenile salmon are present in the lower Sacramento River depending on the season. Favorable growth of juvenile salmon is in the range of 5-19^{o}C (41-66.2^{o}F) and high mortality may be experienced when temperatures reach about 22-23^{o}C (71.6-73.4^{o}F). Young salmon emigrate downstream when freshets cause increased river flow, turbidity, and decreased temperatures. Juvenile salmon move downstream under a wide variety of conditions and fish sizes. Downstream movements of young fish may occur as fry, sub-yearlings, and yearlings. During daytime, juveniles tend to move to the shallow river edges seeking cover. In the riverine environment, juvenile salmon are opportunistic drift feeders on terrestrial and aquatic insects.

Fathead Minnow (*Pimephales promelas*). Fathead minnow is a non-native species found in the lower Sacramento River. The species lives in a wide variety of habitats and prefers water temperatures of 22-23^{o}C (71.6-73.4^{o}F). The fish are opportunistic bottom feeders on algae, small invertebrates, and organic matter.

Golden Shiner (*Notemigonus crysoleucas*). Golden shiner is a widely-distributed, non-native species found in the lower Sacramento River. The species lives in warm, shallow sloughs and are associated with aquatic vegetation, tolerating warm water up to 36-37^{o}C (96.8-98.6^{o}F). The fish feed primarily on the surface or midwater and can form tight shoals.

Goldfish (*Carassius auratus*). Goldfish is a non-native species found in the lower Sacramento River. The species prefers warm water temperatures in the range of 27-37^{o}C (80.6-98.6^{o}F). The fish are found in a wide variety of habitats and do well in highly disturbed surroundings. In clear riverine environments, the species are strongly associated with deep pools in dense cover and in turbid environments also utilize deep pools.

Green Sturgeon (*Acipenser medirostris*). Green sturgeon is a native species found in the lower Sacramento River. It is lower in abundance than white sturgeon and has always been considered to be uncommon. Like white sturgeon, juvenile green sturgeon are benthic feeders. Juveniles appear to migrate toward salt water before the end of their second year, principally during the summer and fall months. Young of the species would be expected in the lower Sacramento River because the primary spawning areas are farther upstream. Primarily due to its present low population, the species is currently listed as a federal threatened species.

Green Sunfish (*Lepomis cyanellus*). Like bluegill, green sunfish is a widely-distributed, non-native species found in the lower Sacramento River. The species is often rare in areas with three or four other species of fish. In rivers, the fish are often found in riprapped areas. Optimal temperatures for green sunfish are in the range of 26-30^{o}C (78.8-86^{o}F). Sunfish are opportunistic predators feeding on invertebrates and small fish. Adult fish tend to be territorial and aggressive, but young-of-the-year fish often shoal.

Hardhead (*Mylopharodon conocephalus*). Hardhead is a native species commonly found in the lower Sacramento River. Most areas where the species exist have summer water temperatures higher than 20^{o}C (68^{o}F) and optimal temperatures are in the range of 24-28^{o}C (75.2-82.4^{o}F). Adult fish prefer clear, deep pools and runs with sand-gravel-boulder substrates and slow water velocities. In the riverine environment, the fish generally remain in the lower half of the water column. The species is always found in association with the Sacramento pikeminnow and usually with the Sacramento sucker. The fish are omnivores foraging on benthic organisms and drifting insects and algae. Early life history of the species is poorly understood.

Hitch (*Lavinia exilicauda*). Hitch is a native species found in the lower Sacramento River. Among other habitats, the species is known to inhabit low-elevation, slow-moving river reaches, preferring quiet water habitat. Hitch has the highest temperature tolerances among the Central Valley's native fish species. The fish are omnivorous open-water feeders feeding primarily on zooplankton but may feed on the surface when insects are abundant.

Inland Silverside (*Menidia audens*). Inland silverside is a non-native species found in the lower Sacramento River. The species prefer shallow water in or near protected areas with sand or gravel substrates. The fish commonly shoal and feed on aquatic organisms such as aquatic insects and crustaceans. The species exhibits a wide water temperature tolerance but optimal growth and survival probably occur in the range of 20-25^{o}C (68-77^{o}F).

Largemouth Bass (*Micropterus salmoides*). Largemouth bass is a widely-distributed, non-native species commonly found in the lower Sacramento River. The fish are abundant in warm, moderately-clear river backwaters with aquatic plants and can tolerate a wide range of water temperatures with optimal growth occurring at temperatures in the range of 25-30^{o}C (77-86^{o}F). Adult fish are solitary predators. Bass may reside in a particular area around cover (e.g., submerged rock or tree branch) or wander.

Mosquitofish (*Gambusia affinis*). Mosquitofish is a widely-distributed, non-native species found in the lower Sacramento River. Although usually found in lacustrine environments, the species may also be found in shallow, calm water along stream edges. In riverine environments, the fish are most abundant among disturbed habitats in low elevation streams. In the presence of submerged and emergent vegetation, the fish tend to reside near those areas. The species is an omnivorous, opportunistic feeder generally consuming prey close to the surface but also feed on the bottom. Although the fish can withstand a wide range in water temperatures, the optimal temperatures for growth and reproduction are in the range of 25-30^{o}C (77-86^{o}F).

Pacific Lamprey (*Lampetra tridentate*). Pacific lamprey, a native species, is the largest among the lamprey species and is commonly found in the lower Sacramento River. Like river lamprey, considerable information on the biology of Pacific lamprey is lacking.

Prickly Sculpin (*Cottus asper*). Prickly sculpin is a native species commonly found in the lower Sacramento River and can co-occur with riffle sculpin. The fish can tolerate warm summer water temperatures of 28-30^{o}C (82.4-86^{o}F). The species is typically found in Central Valley low elevation streams with rubble and sand substrates and utilize a wide variety of habitats with a strong association of cover such as overhanging vegetation, rocks, and logs. The fish spend most of the time residing on the riverbed and feed primarily on benthic organisms.

Pumpkinseed (*Lepomis gibbosus*). Although Moyle (2002) does not identify pumpkinseed, a non-native fish, as being present in the lower Sacramento River, the species has been found in the Delta (albeit uncommon) so it is not surprising that the fish were found in the lower Sacramento River. However, the fish may have also originated from upstream areas. Among other habitat types, the species prefers sluggish streams with beds of aquatic vegetation and have an affinity to cover such as submerged trees. Laboratory studies indicate their water temperature preference in the range of 24-32^{o}C (75.2-89.6^{o}F). The fish feed on hard-shelled invertebrates on the bottom or on plants.

Rainbow Trout (*Oncorhynchus mykiss*). Rainbow trout is a native species seasonally found in the lower Sacramento River. The species may exhibit residency behavior in rivers or migratory behavior to the ocean (i.e., steelhead). Juvenile *O. mykiss* are present in the lower Sacramento River depending on the season. Steelhead smolts migrate to salt water at one to three years of age. Steelhead is a federally listed threatened species. In the riverine environment, trout are primarily drift feeders on aquatic organisms and terrestrial insects. Optimal temperatures for growth of trout occur in the range of 15-18^{o}C (59-64.4^{o}F) and temperatures as high as 24-27^{o}C (75.2-80.6^{o}F) can be lethal.

Red Shiner (*Cyprinella lutrensis*). Red shiner is a non-native species found in the lower Sacramento River. The species does well in highly-disturbed habitats and slow-moving water. The fish tolerate very warm water but prefer temperatures in the range of 25-30^{o}C (77-86^{o}F). The highest numbers of red shiners are generally found in shallow, slow water with silt bottoms and near instream cover. The species usually swims in large schools and feed on a wide variety of food including aquatic organisms, surface insects, and algae.

Redear Sunfish (*Lepomis microlophus*). Redear sunfish is a non-native species found in the lower Sacramento River. The species is not as common as bluegill and green sunfish. Among the habitats preferred by the species are river backwaters and sloughs with beds of aquatic vegetation. The fish commonly feed on bottom organisms.

Redeye Bass (*Micropterus coosae*). Although Moyle (2002) does not identify redeye bass, a non-native fish, as being present in the lower Sacramento River, small numbers are present in the Delta so it is not surprising that the fish were found in the lower Sacramento River. In its original native habitats, the fish typically would be expected to reside in small, clear, upland streams. Among other areas in California, the fish are found in clear and warm streams with summer temperatures in the range of 26-28^{o}C (78.8-82.4^{o}F). The fish are predaceous and feed throughout the water column, including on the bottom.

Riffle Sculpin (*Cottus gulosus*). Although not as wide-spread as prickly sculpin, riffle sculpin (a native species) has a more-scattered distribution but is found in the lower Sacramento River even though the fish are usually found in permanent, cold, headwater streams. In warmer river reaches, the species is generally replaced by prickly sculpin and prefer water temperatures that do not exceed 25-26^{o}C (77-78.8^{o}F) for extended periods. The fish feed on benthic invertebrates.

River Lamprey (*Lampetra ayresi*). The river lamprey is a native species common in the lower Sacramento River although its life history in California has not been well studied. Sub-adult ammocoetes are found in silty river backwaters and eddys.

Sacramento Blackfish (*Orthodon microlepidotus*). Sacramento blackfish is a native species found in the lower Sacramento River. The fish are common in oxbow lakes near rivers and sloughs. Among habitats in which the fish are found, substrates with soft, mud/clay are present. The fish are able to survive in extreme environments tolerating high summer water temperatures and low dissolved oxygen. Optimal water temperatures for the species are in the range of 22-28^{o}C (71.6-82.4^{o}F). The fish are primarily suspension feeders, consuming organisms and organic matter in the water column or on the bottom.

Sacramento Pikeminnow (*Ptychocheilus grandis*). Sacramento pikeminnow is a native species abundant in the lower Sacramento River. The species is characteristically found in low- to mid-elevation streams in habitats of deep pools, slow runs, overhanging vegetation, and undercut banks. The smaller life stages concentrate in shallow riverine areas with low velocities and are often found in small schools mixed with other native cyprinids. Pikeminnow prefer summer water temperatures in the range of 18-28^{o}C (64.4-82.4^{o}F). The fish is an opportunistic predator feeding on the surface, within the water column, and on the bottom.

Sacramento Splittail (*Pogonichthys macrolepidotu*). Sacramento splittail is a native species found in the lower Sacramento River. The fish are typically found in water temperatures in the range of 5-24^{o}C (41-75.2^{o}F) and are well suited to slow-moving reaches of rivers. Young-of-the-year and yearling splittail are generally most abundant in shallow water and are capable of swimming against strong river currents. The species is well-adapted for feeding on bottom organisms and detritus in low to moderate currents.

Sacramento Sucker *(Catostomus occidentalis)*. Sacramento sucker is a common native fish species widely distributed in northern California. The fish are abundant in clear, cool rivers with adults most numerous in larger streams and juveniles abundant in shallow areas of large rivers where adults have spawned. The fish are often associated with Sacramento pikeminnow, hardhead, and California roach but it is also common to find them in areas dominated by alien species. Juveniles stay on or close to the bottom in shallow, slow-moving water along river margins with the smaller fish seeking the shallowest water. The species are found in a wide range of water temperatures, preferring the range of 20-25^{o}C (68-77^{o}F). The fish often occur in small groups feeding on algae, detritus, and invertebrates associated with the river bottom.

Smallmouth Bass (*Micropterus dolomieu*). Smallmouth bass is a non-native species found in the lower Sacramento River. In the riverine environment, the species prefers clear water, abundant cover, and water temperatures in the range of 20-27^{o}C (68-80.6^{o}F) during the summer. Social behavior of the species is similar to largemouth bass but the fish has less of a tendency to wander and may be found in one locality all summer.

Spotted Bass (*Micropterus punctulatus*). Spotted bass is a non-native species found in the lower Sacramento River. The species does well in moderately-sized, clear, low-gradient rivers. The fish have a preference for slower, more-turbid water than smallmouth bass and swifter water than largemouth bass. The fish favors pools and avoids riffles and backwaters with prolific aquatic vegetation. The species prefers summer water temperatures in the range of 24-31^{o}C (75.2-87.8^{o}F). Larger fish are solitary but young-of-the-year shoal. Like largemouth and smallmouth bass, spotted bass are predators on larger invertebrates and fish.

Striped Bass (*Morone saxatilis*). Striped bass is a non-native species commonly found in the lower Sacramento River. The larger fish are opportunistic pelagic predators. Fish 2+ years of age are generally piscivorous and juveniles are principally invertebrate feeders. Adult bass often reside near screened diversions feeding on small fish, such as juvenile salmon, concentrated at the screens.

Threadfin Shad (*Dorosoma pretenense*). Threadfin shad is a non-native species commonly found in the lower Sacramento River. In riverine environments, the fish are generally found in sluggish backwaters. Preferred temperatures for growth and survival exceed 22-24^{o}C (71.6-

75.2°F) during the summer. Adult shad concentrate in surface waters whereas young-of-the-year fish are found in deeper water. The fish are plankton feeders.

Threespine Stickleback (*Gasterostreus aculeatus*). Threespine stickleback is a native species found in the lower Sacramento River. Among the habitats in which it is found, the species lives in backwaters and among emergent vegetation in shallow-water stream margins with gravel, sand, and mud substrates. The fish require water temperatures less than 23-24°C (73.4-75.2°F) for long-term survival. Sticklebacks often form loose shoals and feed primarily on benthic organisms or in aquatic plants.

Tule Perch (*Hysterocarpus traski*). Tule perch is a native species commonly found in the lower Sacramento River. The species occurs in a wide variety of habitats, including lowland clear rivers and are capable of foraging in fast water, utilizing eddies behind in-river structures. In rivers, banks with complex cover (e.g., submerged tree branches), but also including riprap, provide habitats for the fish. The species prefers water temperatures below 22°C (71.6°F). In rivers, the fish often appear in small groups swimming upstream while feeding on the bottom. The species is adapted to feed on bottom organisms but can also feed on zooplankton.

Wakasagi (*Hypomesus nipponensis*). Wakasagi is a non-native species found in the lower Sacramento River. The species forms schools and the fish are pelagic opportunistic plankton feeders. The species has a wide temperature tolerance with maximum temperatures in the range of 27-29°C (80.6-84.2°F) and optimal temperatures for growth and reproduction in the range of 14-21°C (57.2-69.8°F).

White Catfish (*Ameiurus catus*). White catfish is a non-native species commonly found in the lower Sacramento River. The species is a carnivorous bottom feeder usually found during the summer in water temperatures exceeding 20°C (68°F). White catfish prefer slower-moving water than channel catfish.

White Crappie (*Pomoxis annularis*). Like black crappie, white crappie is a non-native species found in the lower Sacramento River but is more commonly found in lakes and reservoirs. The species prefers warm, turbid river backwaters and has a slightly greater tolerance for high turbidity, high water temperatures, and lack of cover than black crappie.

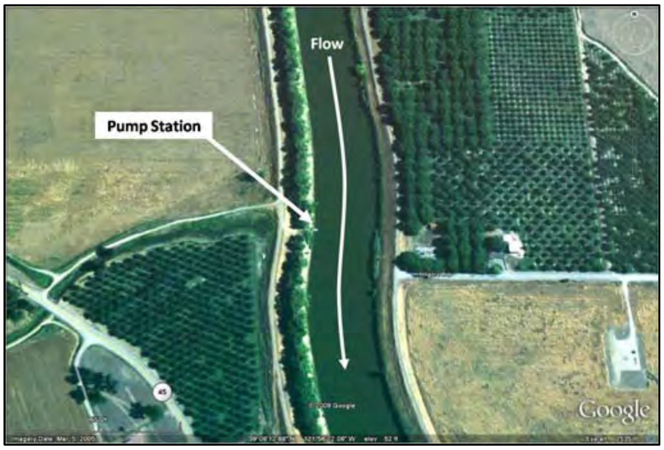
White Sturgeon (*Acipenser transmontanus*). White sturgeon is a native species found in the lower Sacramento River. Young of the species feed on or close to the bottom, eating benthic organisms. Young sturgeon in the lower Sacramento River would be expected because adult white sturgeon spawn primarily in the river between Colusa and Knights Landing.

Appendix C. Physical features of the unscreened diversions intakes.

Stage 1 Sites (2009 – 2010)

Sycamore (RM 132.5)

The Sycamore pump station intakes are located on the right side of the river (facing downstream) in a relatively straight portion or very slight inside bend of the river channel (Appendix Figure 1).



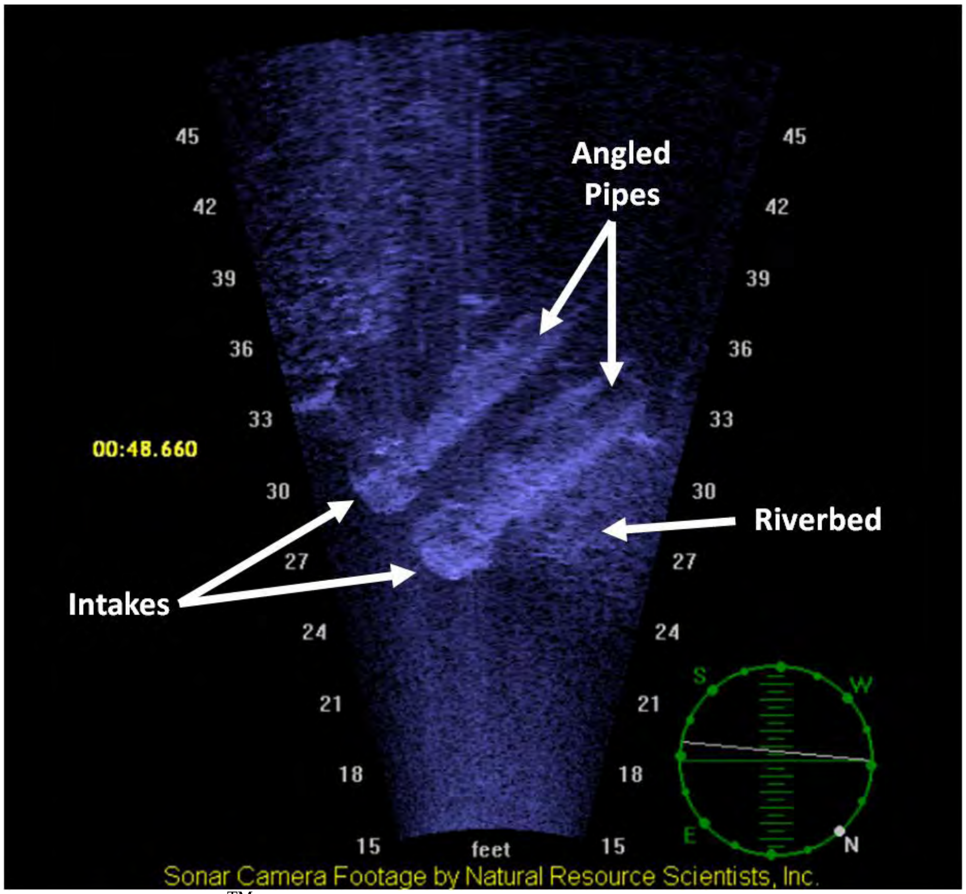
Appendix Figure 1. Location of the Sycamore pump station on the Sacramento River.

Based on in-river surveys conducted during the summer of 2008, the two Sycamore 30-inch diameter pipe intakes enter the water at a 30-degree angle (Appendix Figure 2) (Appendix Table 1). At the time of the survey on July 16, 2008, the water depth at the pipe intakes was 11 feet with the intakes positioned one foot above the cobble riverbed, 30 feet from the river's edge, and flow was unidirectional. Rearing habitat for juvenile salmon was characterized as poor and predatory fish habitat was classified as fair (Vogel 2008c). Additional features of the site are provided in Appendix Table 1.

Appendix Figure 2. The Sycamore pump intakes looking in a downstream direction.

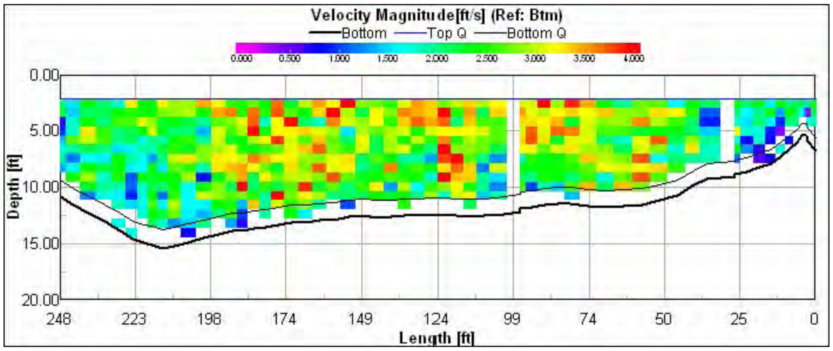
Site Number: 111	APPENDIX TABLE 1. DIVERSION CHARACTERISTICS OF THE SYCAMORE PUMP STATION INTAKE (RIVER MILE 132.5) (DATA FROM VOGEL 2008c AND MODIFIED BY PERS. COMM. WITH RUSS BERRY JR., ISI) 7/16/08									
Location Facing Downstream	**Channel Configuration at Diversion**	**# of Intake(s) (Upstream to Downstream)**	**Intake Opening Size (Outside Diameter in Inches)**	**Distance Between Intakes (Feet)**	**Intake Angle into Water (Degrees)**	**Estimated Distance from Intake Opening to Bank (Feet)**	**Estimated Riverbed Depth Near Intake (Feet)**	**Estimated Distance of Intake Off River Bottom (Feet)**	**Type of Posts In Water for Support Structure**	**# of Support Posts**
Right	Straight	2	30"	2'	30°	30'	11'	1'	I-Beam	2
			30"		30°	30'	11'	1'		
Hydraulic Characteristics	**Riverbank Material**	**Riparian Overstory (Type)**	**Riparian Understory (Type)**	**Estimated Time In Shade (Percent)**	**Debris Near Diversion Intake**	**Natural Instream Structure in General Vicinity of Diversion**	**Estimated Riverbed Substrate Near Diversion Intake**	**Juvenile Salmonid Habitat (Overall Quality)**	**Potential Predator Habitat (Overall Quality)**	
Unidirectional	Co, We	TrC	Sh	5%	WD-L	None	Co, Sa	1	2	
RIPARIAN IDENTIFICATION			**RIVERBED SUBSTRATE IDENTIFICATION**			**DEBRIS NEAR DIVERSION INTAKE**			**JUVENILE SALMON REARING/PREDATOR HABITAT**	
Code	Type		Code	Type		**Code**	**Type**		Code	Quality
Gr	Grasses		Si	Silt		WD-L	Woody Debris - Low Density		1	Poor
Sh	Shrubs		Sa	Sand		WD-M	Woody Debris - Medium Density		2	Fair
So	Soil		Co	Cobble		WD-H	Woody Debris - High Density		3	Good
Mu	Mulberry		RR	Rip-Rap						
TrA	Ash Tree		HP	Hardpan						
TrC	Cottonwood Tree									
TrO	Oak Tree									
TrUn	Unidentified Tree									
TrW	Walnut Tree		Code	Detail			8/21/08	7/16/08		
TrWi	Willow Tree		Non-Op	Non-Operational		Water Temperature:	71°F	66°F		
Ve	Vegetation		NA	Not Applicable		Secchi Depth:	5.5'			
We	Weeds		NE	No Estimates		Turbidity (NTUs):	4.4			

DIDSON™ imaging revealed minimal submerged woody debris around the pipe intakes and a cobble riverbed substrate at the intake location. Appendix Figure 3 shows a DIDSON™ still image taken at the Sycamore pumping station. Motion images (.avi files) were recorded on August 21, 2008 and are provided in a separate report on in-river surveys of Sacramento River water diversions (Vogel 2008c).

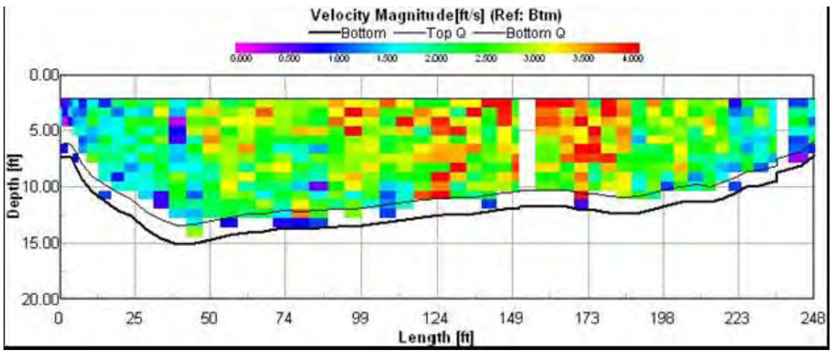


Appendix Figure 3. DIDSON™ still image of two angled pipe intakes at the Sycamore pump station (looking in a downstream direction). Image taken on August 21, 2008.

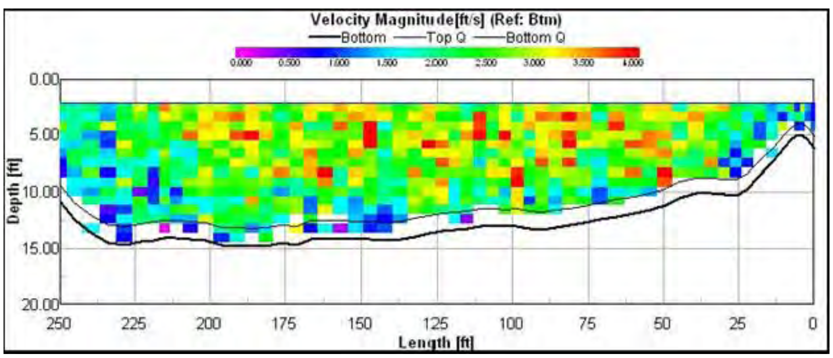
Appendix Figures 4 – 7 show Acoustic Doppler Current Profiler (ADCP) bathymetry profiles and water velocity distributions across the river channel just upstream and downstream of the Sycamore pump station as measured on August 21, 2008. The thalweg is on the left side of the river channel, the opposite side as the pump station. The highest concentration of flow is in the center portion of the channel.



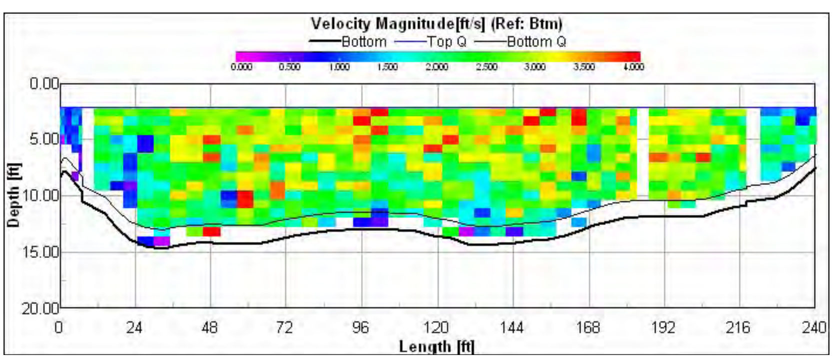
Appendix Figure 4. ADCP transect 1 (facing downstream) measured just downstream of Sycamore pump station (located on right bank). Right bank is ~7' from start of transect and left bank is ~6' from end of transect.



Appendix Figure 5. ADCP transect 2 (facing downstream) measured just downstream of Sycamore pump station (located on right bank). Left bank is ~6' from start of transect and right bank is ~5' from end of transect.



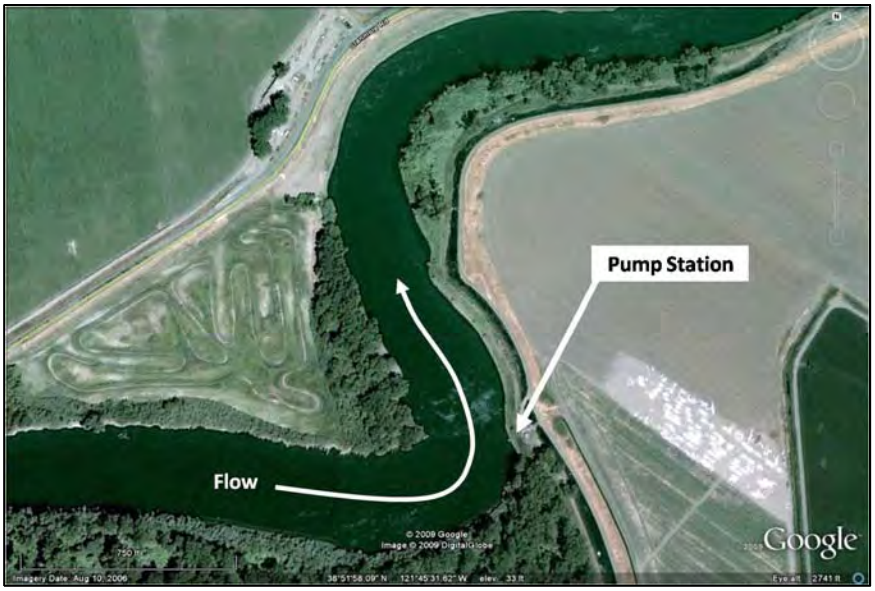
Appendix Figure 6. ADCP transect 3 (facing downstream) measured just upstream of Sycamore pump station (located on right bank). Right bank is ~9' from start of transect and left bank is ~10' from end of transect.



Appendix Figure 7. ADCP transect 4 (facing downstream) measured just upstream of Sycamore pump station (located on right bank). Left bank is ~10' from start of transect and right bank is ~6' from end of transect.

River Garden Farms No. 2 (RM 96.7)

The River Garden Farms No. 2 pump station intakes are located on a sharp outside bend of the river channel (Appendix Figure 8).



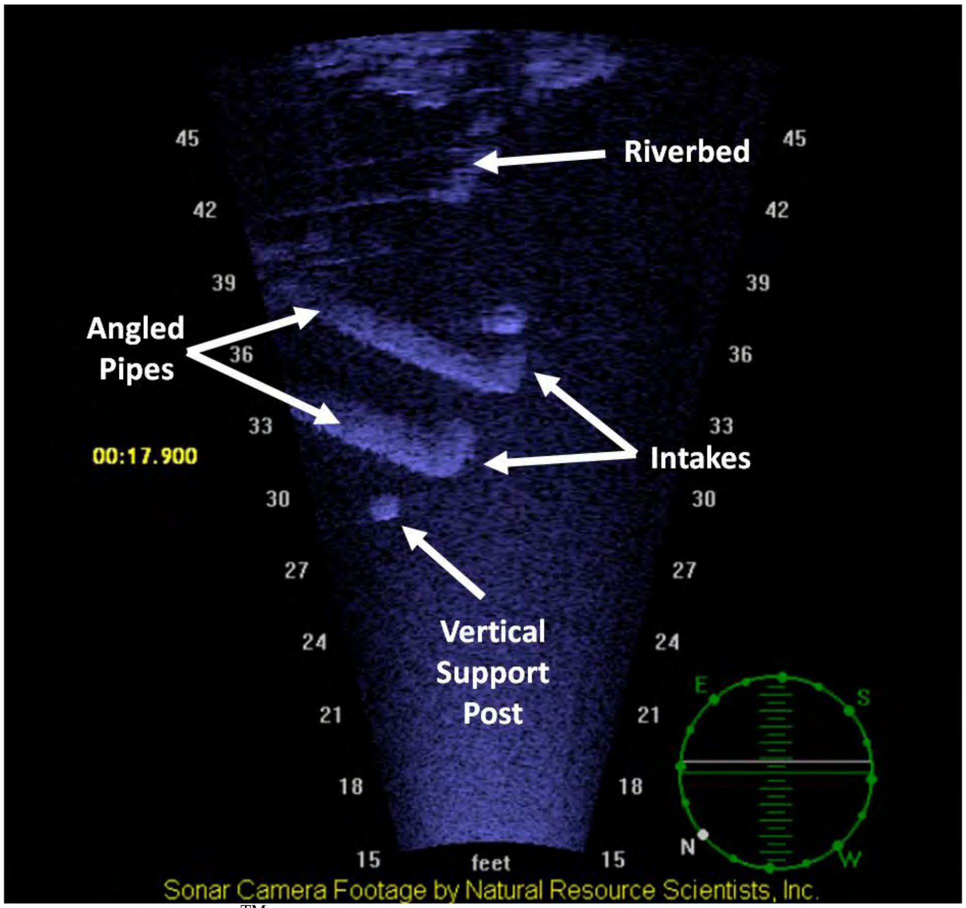
Appendix Figure 8. Location of the River Garden Farms No. 2 pump station on the Sacramento River

Based on in-river surveys conducted during the summer of 2008, the 24-inch and 30-inch diameter River Garden Farms No. 2 pipe intakes enter the water at a 28-degree angle (Appendix Figure 9) (Appendix Table 2). At the time of the survey on June 25, 2008, the water depth at the pipe intakes was 14 feet with the intakes positioned five feet above the riprap riverbed, 22 feet from the river's edge, and flow was swift and unidirectional. Rearing habitat for juvenile salmon was characterized as poor and predatory fish habitat was classified as fair (Vogel 2008c). Additional features of the site are provided in Appendix Table 2.

Appendix Figure 9. The River Garden Farms No. 2 pump intakes looking in a downstream direction.

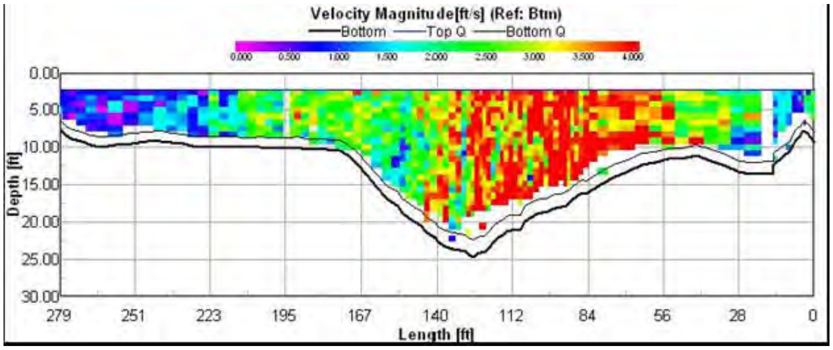
Site Number: 042	APPENDIX TABLE 2. DIVERSION CHARACTERISTICS OF THE RIVER GARDEN FARMS NO. 2 PUMP STATION INTAKE (RIVER MILE 96.7) (DATA FROM VOGEL 2008c AND MODIFIED BY PERS. COMM. WITH RUSS BERRY JR., ISI) 6/25/08									
Location Facing Downstream	**Channel Configuration at Diversion**	**# of Intake(s) (Upstream to Downstream)**	**Intake Opening Size (Outside Diameter in Inches)**	**Distance Between Intakes (Feet)**	**Intake Angle into Water (Degrees)**	**Estimated Distance from Intake Opening to Bank (Feet)**	**Estimated Riverbed Depth Near Intake (Feet)**	**Estimated Distance of Intake Off River Bottom (Feet)**	**Type of Posts In Water for Support Structure**	**# of Support Posts**
Right	Outside Bend	2	24"	2'	28°	22'	14'	8'	Round Post	2 (Not Connected to Pipes)
			30"		28°	22'	14'	8'		
Hydraulic Characteristics	**Riverbank Material**	**Riparian Overstory (Type)**	**Riparian Understory (Type)**	**Estimated Time In Shade (Percent)**	**Debris Near Diversion Intake**	**Natural Instream Structure in General Vicinity of Diversion**	**Estimated Riverbed Substrate Near Diversion Intake**	**Juvenile Salmonid Habitat (Overall Quality)**	**Potential Predator Habitat (Overall Quality)**	
Swift Unidirectional	RR, Gr	None	RR, Gr	15%	None	None	RR	1	2	
RIPARIAN IDENTIFICATION			**RIVERBED SUBSTRATE IDENTIFICATION**			**DEBRIS NEAR DIVERSION INTAKE**			**JUVENILE SALMON REARING/PREDATOR HABITAT**	
Code	Type		Code	Type		**Code**	**Type**		Code	Quality
Gr	Grasses		Si	Silt		WD-L	Woody Debris - Low Density		1	Poor
Sh	Shrubs		Sa	Sand		WD-M	Woody Debris - Medium Density		2	Fair
So	Soil		Co	Cobble		WD-H	Woody Debris - High Density		3	Good
Mu	Mulberry		RR	Rip-Rap						
TrA	Ash Tree		HP	Hardpan						
TrC	Cottonwood Tree									
TrO	Oak Tree									
TrUn	Unidentified Tree									
TrW	Walnut Tree		Code	Detail			7/16/08	6/25/08		
TrWi	Willow Tree		Non-Op	Non-Operational		Water Temperature:	70°F	66°F		
Ve	Vegetation		NA	Not Applicable		Secchi Depth:	4'			
We	Weeds		NE	No Estimates		Turbidity (NTUs):	6.68			

DIDSON™ imaging revealed no woody debris around the pipe intakes and a riprap riverbed substrate at the intake location. Appendix Figure 10 shows a DIDSON™ still image taken at the River Garden Farms No. 2 pumping station. Motion images (.avi files) were recorded on July 16, 2008 and are provided in a separate report on in-river surveys of Sacramento River water diversions (Vogel 2008c).

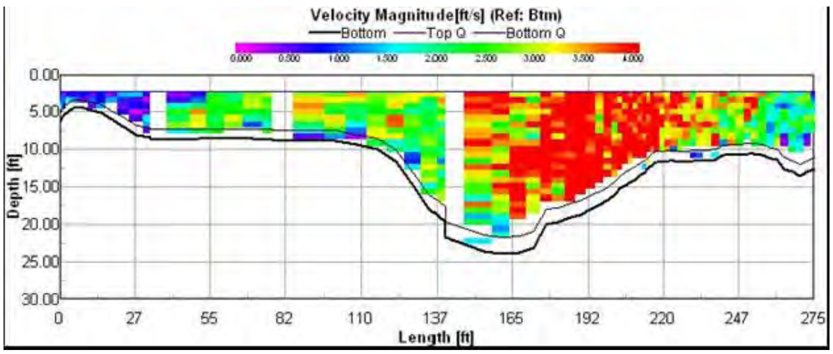


Appendix Figure 10. DIDSON™ still image of two angled pipe intakes at the River Garden Farms No. 2 pump station (looking in an upstream direction). Image taken on July 16, 2008.

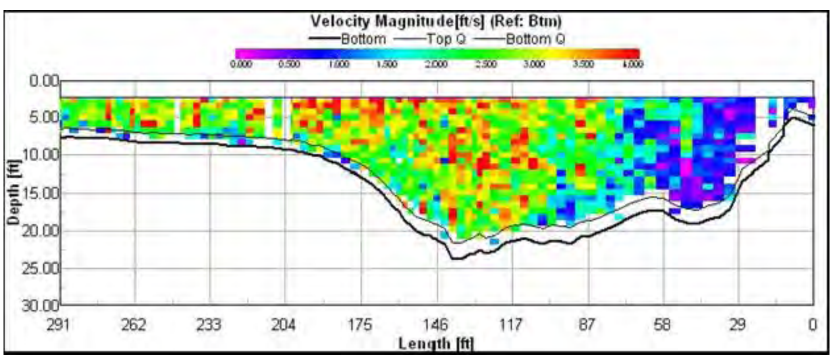
Appendix Figures 11 - 14 show ADCP bathymetry profiles and water velocity distributions across the river channel just upstream and downstream of the River Garden Farms No. 2 pump station as measured on July 16, 2008. The thalweg and the highest concentration of flow are located in the middle of the river channel. The pump station intake is positioned in between an unusual area of high water velocity (downstream of the pump station) and slow moving water (upstream of the pump station, a circumstance resulting from the combination of channel geometry and the sharp bend in the river channel.



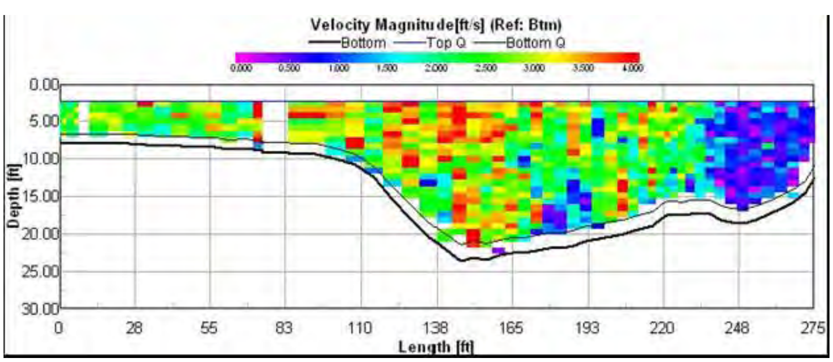
Appendix Figure 11. ADCP transect 1 (facing downstream) measured just downstream of River Garden pump station (located on right bank). Right bank is ~5' from start of transect and left bank is ~9' from end of transect.



Appendix Figure 12. ADCP transect 2 (facing downstream) measured just downstream of River Garden pump station (located on right bank). Left bank is ~9' from start of transect and right bank is ~8' from end of transect.



Appendix Figure 13. ADCP transect 3 (facing downstream) measured just upstream of River Garden pump station (located on right bank). Right bank is ~5' from start of transect and left bank is ~18' from end of transect.



Appendix Figure 14. ADCP transect 4 (facing downstream) measured just upstream of River Garden pump station (located on right bank). Left bank is ~18' from start of transect and right bank is ~8' from end of transect.

State Ranch (RM 96.25)

The State Ranch pump station intakes are located on the left side of the river (facing downstream) in a straight portion of the river channel (Appendix Figure 15).

Appendix Figure 15. Location of the State Ranch pump station on the Sacramento River.

Based on in-river surveys conducted during the summer of 2008, the four State Ranch intake pipe diameters, in an upstream to downstream direction, are 36 inches, 36 inches, 42 inches, and 29 inches and enter the water at a 33-degree angle (Appendix Figure 16) (Appendix Table 3). At the time of the survey on June 25, 2008, the water depth at the pipe intakes was 13 feet with the intakes positioned five feet above the sand riverbed, 30 feet from the river's edge, and flow was unidirectional. Rearing habitat for juvenile salmon was characterized as poor and predatory fish habitat was classified as good (Vogel 2008c). Additional features of the site are provided in Appendix Table 3.

Appendix Figure 16. The State Ranch pump station intakes looking in a downstream direction.

Site Number: 041	APPENDIX TABLE 3. DIVERSION CHARACTERISTICS OF THE STATE RANCH PUMP STATION INTAKE (RIVER MILE 96.25) (DATA FROM VOGEL 2008c AND MODIFIED BY PERS. COMM. WITH RUSS BERRY JR., ISI) 6/25/08

Location Facing Downstream	**Channel Configuration at Diversion**	**# of Intake(s) (Upstream to Downstream)**	**Intake Opening Size (Outside Diameter in Inches)**	**Distance Between Intakes (Feet)**	**Intake Angle into Water (Degrees)**	**Estimated Distance from Intake Opening to Bank (Feet)**	**Estimated Riverbed Depth Near Intake (Feet)**	**Estimated Distance of Intake Off River Bottom (Feet)**	**Type of Posts In Water for Support Structure**	**# of Support Posts**
Left	Straight	4	38"	5'	33°		13'	2'	I-Beam	11
			38"	5'	33°	30'	13'	2'		
			44"	5'	33°	30'	13'	2'		
			30"		33°	30'	13'	2'		

Hydraulic Characteristics	**Riverbank Material**	**Riparian Overstory (Type)**	**Riparian Understory (Type)**	**Estimated Time In Shade (Percent)**	**Debris Near Diversion Intake**	**Natural Instream Structure in General Vicinity of Diversion**	**Estimated Riverbed Substrate Near Diversion Intake**	**Juvenile Salmonid Habitat (Overall Quality)**	**Potential Predator Habitat (Overall Quality)**
Swift Unidirectional	Sa, We, Co	None	None	5%	WD-L	Woody Debris	Sa	1	3

RIPARIAN IDENTIFICATION

Code	Type
Gr	Grasses
Sh	Shrubs
So	Soil
Mu	Mulberry
TrA	Ash Tree
TrC	Cottonwood Tree
TrO	Oak Tree
TrUn	Unidentified Tree
TrW	Walnut Tree
TrWi	Willow Tree
Ve	Vegetation
We	Weeds

RIVERBED SUBSTRATE IDENTIFICATION

Code	Type
Si	Silt
Sa	Sand
Co	Cobble
RR	Rip-Rap
HP	Hardpan

Code	Detail
Non-Op	Non-Operational
NA	Not Applicable
NE	No Estimates

DEBRIS NEAR DIVERSION INTAKE

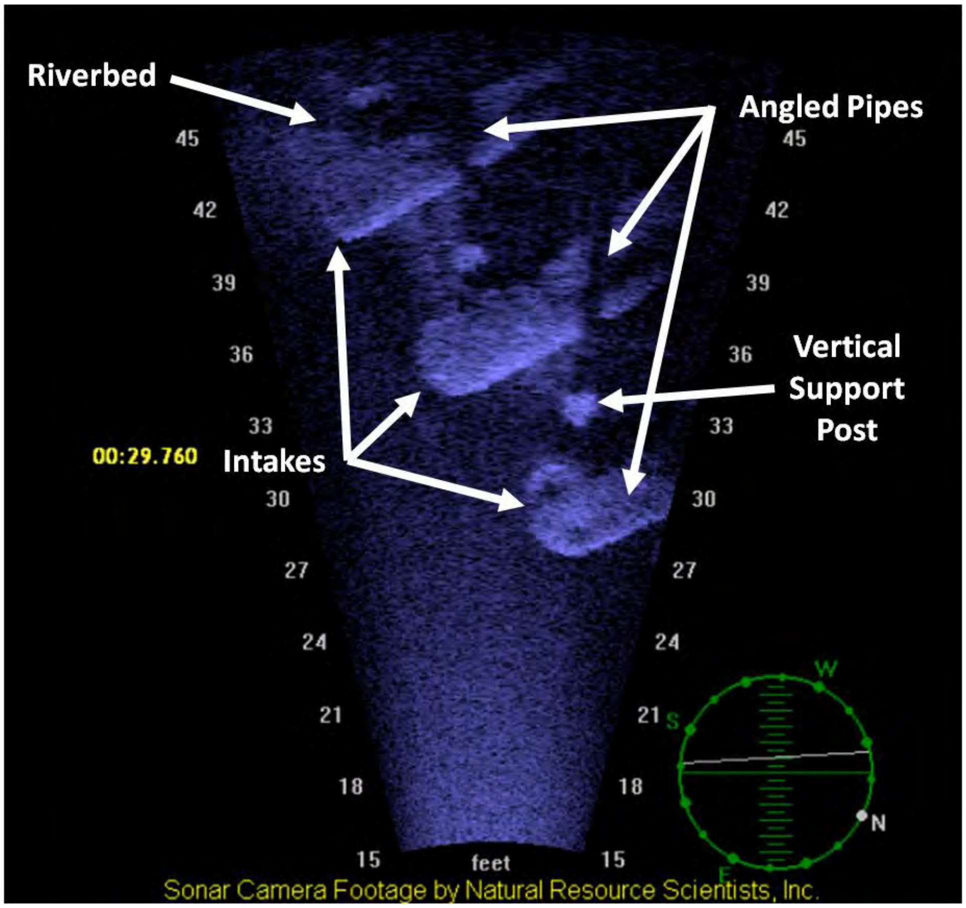
Code	**Type**
WD-L	Woody Debris - Low Density
WD-M	Woody Debris - Medium Density
WD-H	Woody Debris - High Density

JUVENILE SALMON REARING/PREDATOR HABITAT

Code	Quality
1	Poor
2	Fair
3	Good

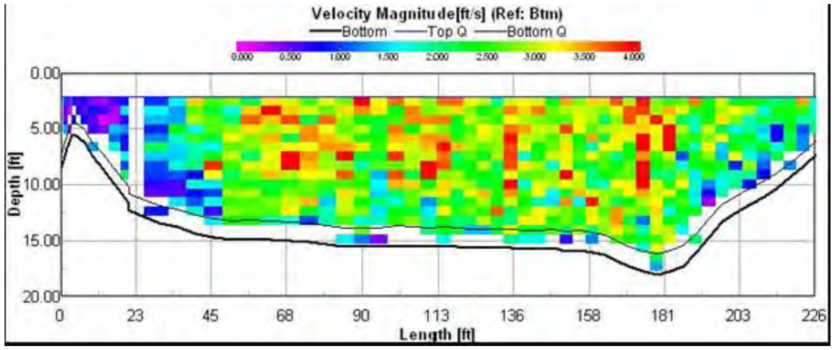
	7/16/08	6/25/08
Water Temperature:	70°F	64°F
Secchi Depth:	4'	
Turbidity (NTUs):	7.89	

DIDSON™ imaging revealed low density of woody debris around the pipe intakes and sand riverbed substrate at the intake location. Appendix Figure 17 shows a DIDSON™ still image taken at the State Ranch pumping station. Motion images (.avi files) were recorded on July 16, 2008 and are provided in a separate report on in-river surveys of Sacramento River water diversions (Vogel 2008c).

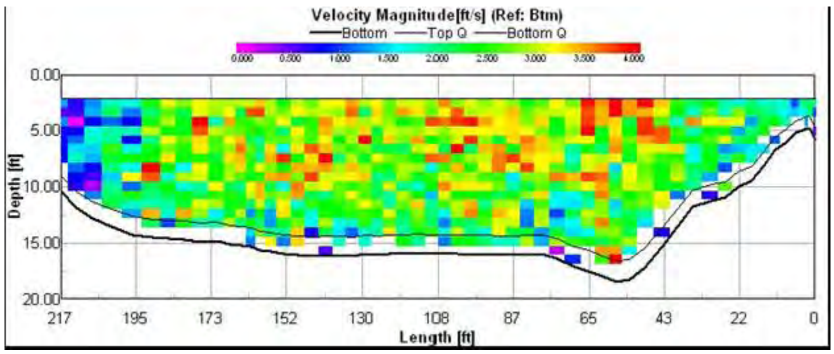


Appendix Figure 17. DIDSON™ still image of three of the four angled pipe intakes at the State Ranch pump station (looking in an upstream direction). Image taken on July 16, 2008.

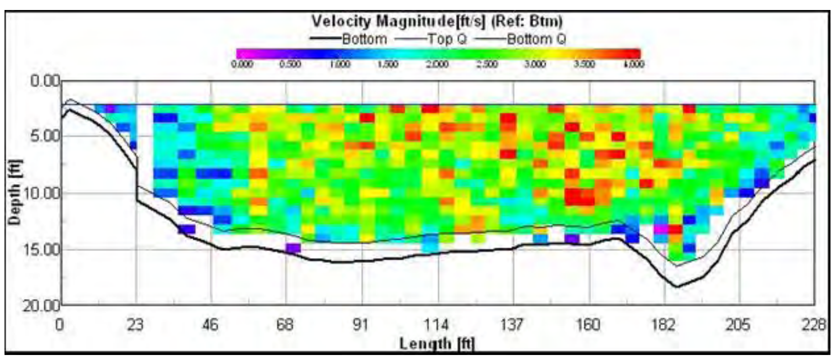
Appendix Figures 18 - 21 show ADCP bathymetry profiles and water velocity distributions across the river channel just upstream and downstream of the State Ranch pump station as measured on July 16, 2008. The thalweg is located on the right side of the river channel opposite the pump station. The highest concentration of flow is distributed across the middle of the river channel.



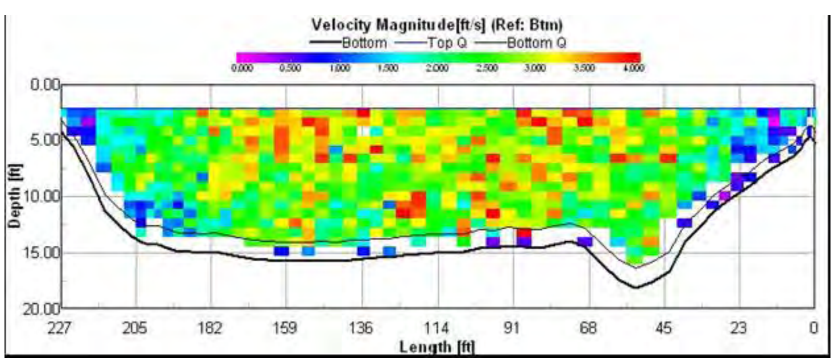
Appendix Figure 18. ADCP transect 1 (facing downstream) measured just downstream of State Ranch pump station (located on left bank). Left bank is ~7’ from start of transect and right bank is ~8’ from end of transect.



Appendix Figure 19. ADCP transect 2 (facing downstream) measured just downstream of State Ranch pump station (located on left bank). Right bank is ~8’ from start of transect and left bank is ~4’ from end of transect.



Appendix Figure 20. ADCP transect 3 (facing downstream) measured just upstream of State Ranch pump station (located on left bank). Left bank is ~3’ from start of transect and right bank is ~6’ from end of transect.

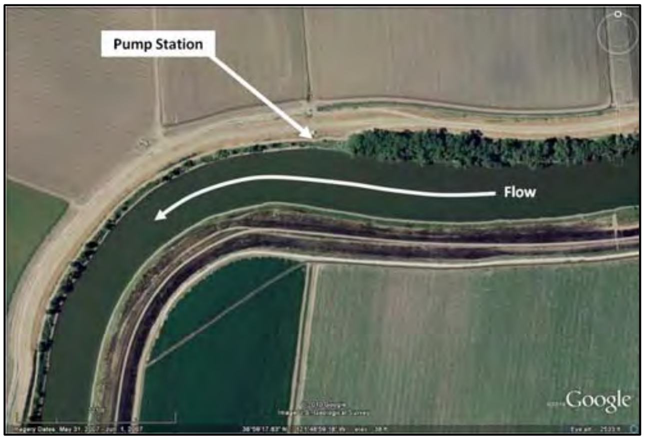


Appendix Figure 21. ADCP transect 4 (facing downstream) measured just upstream of State Ranch pump station (located on left bank). Right bank is ~6’ from start of transect and left bank is ~5’ from end of transect.

Stage 2 Sites (2010 – 2011)

South Steiner (RM 114.3)

The South Steiner pump station intake is located on the right side of the river (facing downstream) on the upper end of an outside bend in the river channel (Appendix Figure 22).



Appendix Figure 22. Location of the South Steiner pump station on the Sacramento River.

Based on in-river surveys conducted during the summer of 2008, the 24-inch diameter South Steiner pipe intakes enter the water at 20-degree and 25-degree angles (Appendix Figure 23) (Appendix Table 4). At the time of the survey on July 8, 2008, the water depth at the pipe intakes was 13-14 feet with the intakes positioned two feet above the cobble and sand riverbed, 25 feet from the river's edge, and flow in the vicinity of the intake was slow and in a back eddy. Rearing habitat for juvenile salmon was characterized as poor and predatory fish habitat was classified as fair (Vogel 2008c). The U.S. Army Corps of Engineers recently implemented an upstream levee improvement project near the diversion intake (Dan Meier, USFWS, pers. comm.). Water district staff or other individuals familiar with that project will be contacted prior to the final report to determine if the project may have significantly changed the site characteristics since the 2008 river surveys. Additional features of the site are provided in Appendix Table 4.

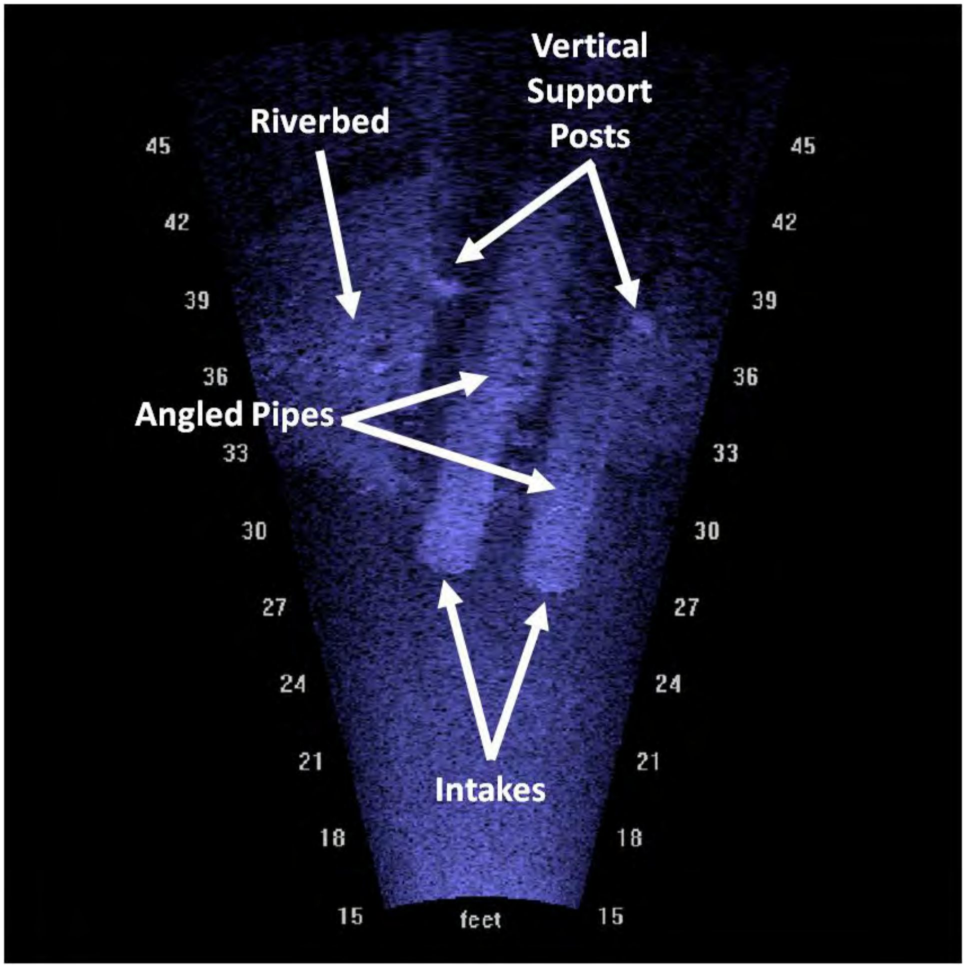
Appendix Figure 23. The South Steiner pump station intakes looking in a downstream direction.

Site Number: 075	APPENDIX TABLE 4. DIVERSION CHARACTERISTICS OF THE SOUTH STEINER PUMP STATION INTAKE (RIVER MILE 114.3) (DATA FROM VOGEL 2008c) 7/8/08									
Location Facing Downstream	**Channel Configuration at Diversion**	**# of Intake(s) (Upstream to Downstream)**	**Intake Opening Size (Outside Diameter in Inches)**	**Distance Between Intakes (Feet)**	**Intake Angle into Water (Degrees)**	**Estimated Distance from Intake Opening to Bank (Feet)**	**Estimated Riverbed Depth Near Intake (Feet)**	**Estimated Distance of Intake Off River Bottom (Feet)**	**Type of Posts In Water for Support Structure**	**# of Support Posts**
Right	Outside Bend	2	24"	22”	20°	25'	14'	2'	Round Metal Post	4
			24"		25°	25'	13'	2'		

Hydraulic Characteristics	**Riverbank Material**	**Riparian Overstory (Type)**	**Riparian Understory (Type)**	**Estimated Time In Shade (Percent)**	**Debris Near Diversion Intake**	**Natural Instream Structure in General Vicinity of Diversion**	**Estimated Riverbed Substrate Near Diversion Intake**	**Juvenile Salmonid Habitat (Overall Quality)**	**Potential Predator Habitat (Overall Quality)**
Slow, Back-Eddy	Co, So, Sa, Gr, We	None	Gr, We	5%	WD-L	None	Co, Sa	1	2

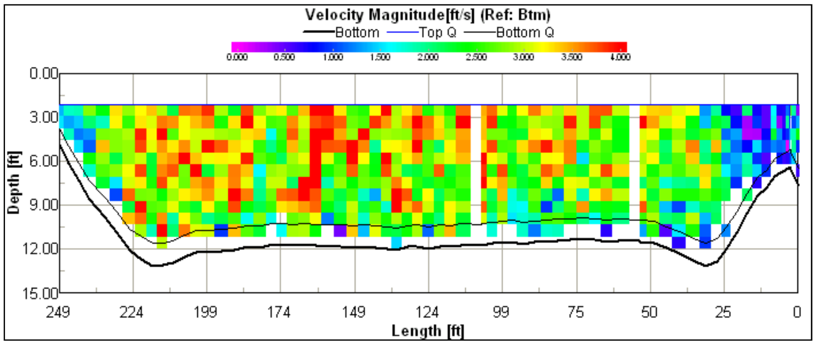
RIPARIAN IDENTIFICATION		**RIVERBED SUBSTRATE IDENTIFICATION**		**DEBRIS NEAR DIVERSION INTAKE**			**JUVENILE SALMON REARING/PREDATOR HABITAT**	
Code	Type	Code	Type	**Code**	**Type**		Code	Quality
Gr	Grasses	Si	Silt	WD-L	Woody Debris - Low Density		1	Poor
Sh	Shrubs	Sa	Sand	WD-M	Woody Debris - Medium Density		2	Fair
So	Soil	Co	Cobble	WD-H	Woody Debris - High Density		3	Good
Mu	Mulberry	RR	Rip-Rap					
TrA	Ash Tree	HP	Hardpan					
TrC	Cottonwood Tree							
TrO	Oak Tree							
TrUn	Unidentified Tree							
TrW	Walnut Tree	Code	Detail		7/23/08	7/8/08		
TrWi	Willow Tree	Non-Op	Non-Operational	Water Temperature:	68°F	69°F		
Ve	Vegetation	NA	Not Applicable	Secchi Depth:	4.6'			
We	Weeds	NE	No Estimates	Turbidity (NTUs):	5.78			

DIDSON™ imaging did not reveal any submerged woody debris around the pipe intakes. Appendix Figure 24 shows a DIDSON™ still image taken at the South Steiner pump station. Motion images (.avi files) were recorded on July 23, 2008 and are provided in a separate report on in-river surveys of Sacramento River water diversions (Vogel 2008c).

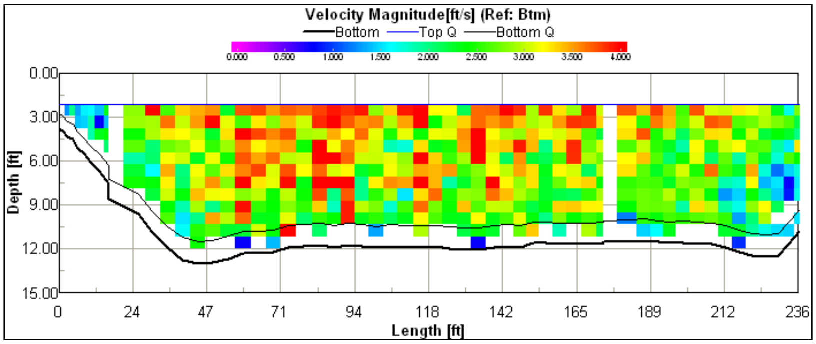


Appendix Figure 24. DIDSON™ still image of the two angled pipe intakes at the South Steiner Ranch pump station (looking toward the levee). Image taken on July 23, 2008.

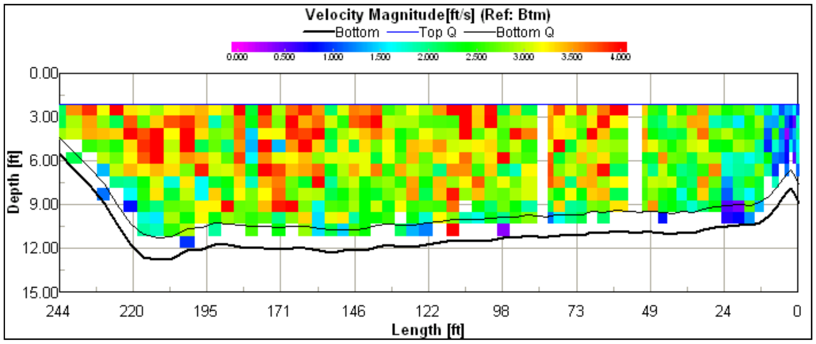
Appendix Figures 25 - 28 show ADCP bathymetry profiles and water velocity distributions across the river channel just upstream and downstream of the South Steiner pump station as measured on July 23, 2008. The cross-section symmetry is relatively uniform with no well-defined thalweg. The highest concentration of flow is distributed across the middle and left side of the river channel opposite the pump station. On the day of the measurements, 45% of the flow was on the right half of the channel and 55% of the flow was on the left half (Vogel 2008c). The pump station intakes are located in slower water velocities compared to other cross-sectional portions of the channel.



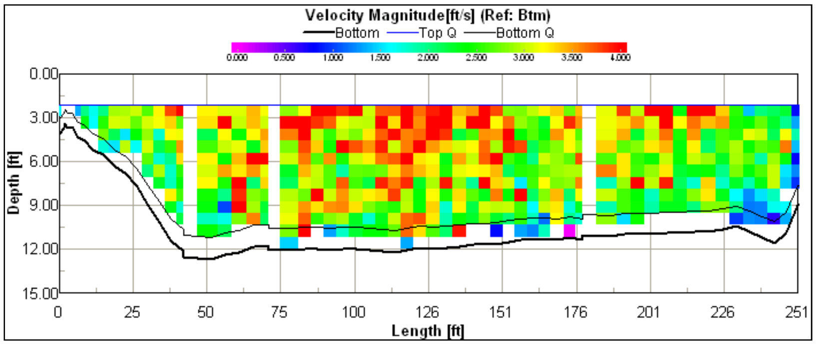
Appendix Figure 25. ADCP transect 1 (facing downstream) measured just downstream of South Steiner pump station (located on right bank). Right bank is ~10' from start of transect and left bank is ~8' from end of transect.



Appendix Figure 26. ADCP transect 2 (facing downstream) measured just downstream of South Steiner pump station (located on right bank). Left bank is ~8' from start of transect and right bank is ~12' from end of transect.



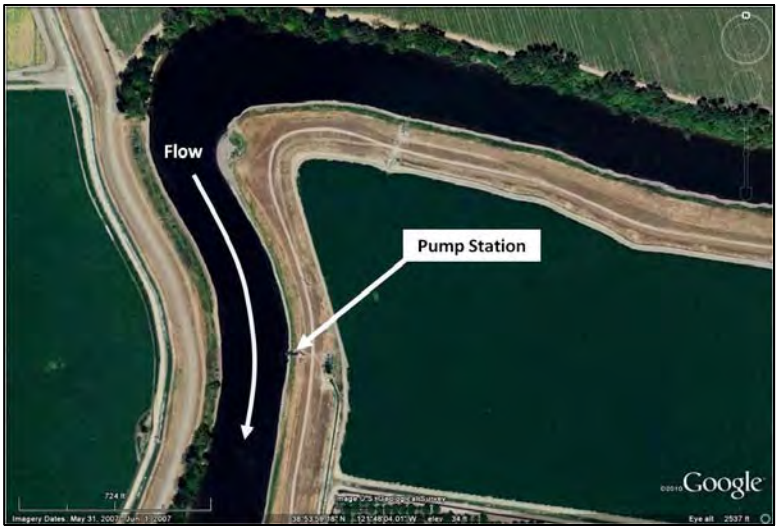
Appendix Figure 27. ADCP transect 3 (facing downstream) measured just upstream of South Steiner pump station (located on right bank). Right bank is ~10' from start of transect and left bank is ~4' from end of transect.



Appendix Figure 28. ADCP transect 4 (facing downstream) measured just upstream of South Steiner pump station (located on right bank). Left bank is ~4' from start of transect and right bank is ~7' from end of transect.

Oji (RM 103.3)

The Oji pump station intakes are located on the left side of the river (facing downstream) on an outside bend in the river channel (Appendix Figure 29).



Appendix Figure 29. Location of the Oji pump station on the Sacramento River.

Based on in-river surveys conducted during the summer of 2008, the 30-inch diameter Oji pipe intakes enter the water at 30-degree angle (Appendix Figure 30) (Appendix Table 5). At the time of the survey on June 30, 2008, the water depth at the pipe intakes was 14 feet with the intakes positioned three feet above the sand and cobble riverbed, 30 feet from the river's edge, and flow in the vicinity of the intake was swift and unidirectional. Rearing habitat for juvenile salmon was characterized as poor and predatory fish habitat was classified as fair (Vogel 2008c). Additional features of the site are provided in Appendix Table 5.

Appendix Figure 30. The Oji pump station intakes looking in a downstream direction.

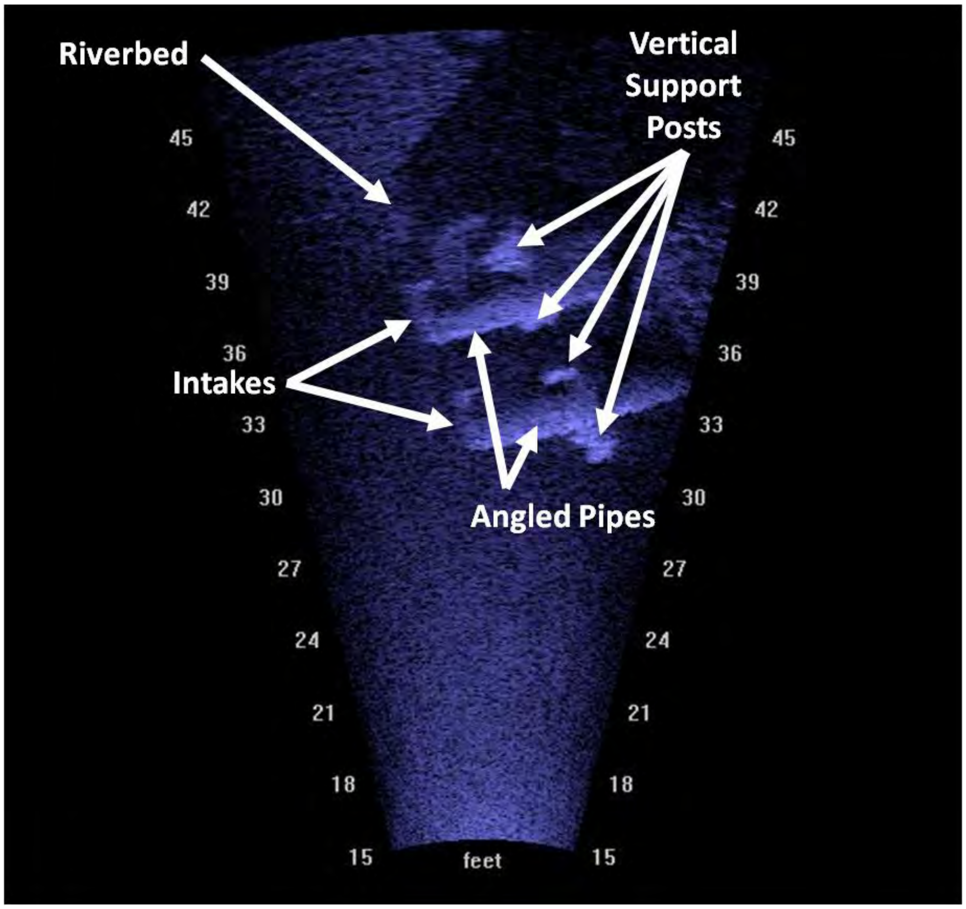
Site Number: 054	APPENDIX TABLE 5. DIVERSION CHARACTERISTICS OF THE OJI PUMP STATION INTAKE (RIVER MILE 103.3) (DATA FROM VOGEL 2008c AND MODIFIED BY PERS. COMM. WITH RUSS BERRY JR., ISI) 6/30/08

Location Facing Downstream	Channel Configuration at Diversion	# of Intake(s) (Upstream to Downstream)	Intake Opening Size (Outside Diameter in Inches)	Distance Between Intakes (Feet)	Intake Angle into Water (Degrees)	Estimated Distance from Intake Opening to Bank (Feet)	Estimated Riverbed Depth Near Intake (Feet)	Estimated Distance of Intake Off River Bottom (Feet)	Type of Posts In Water for Support Structure	# of Support Posts
Left	Straight	2	30"	3’	30°	30'	14'	3'	I-Beam	6
			30"		30°	30'	14'	3'		

Hydraulic Characteristics	Riverbank Material	Riparian Overstory (Type)	Riparian Understory (Type)	Estimated Time In Shade (Percent)	Debris Near Diversion Intake	Natural Instream Structure in General Vicinity of Diversion	Estimated Riverbed Substrate Near Diversion Intake	Juvenile Salmonid Habitat (Overall Quality)	Potential Predator Habitat (Overall Quality)
Swift, Unidirectional	Co, Gr, We	None	None	5%	None	None	Sa, Co	1	2

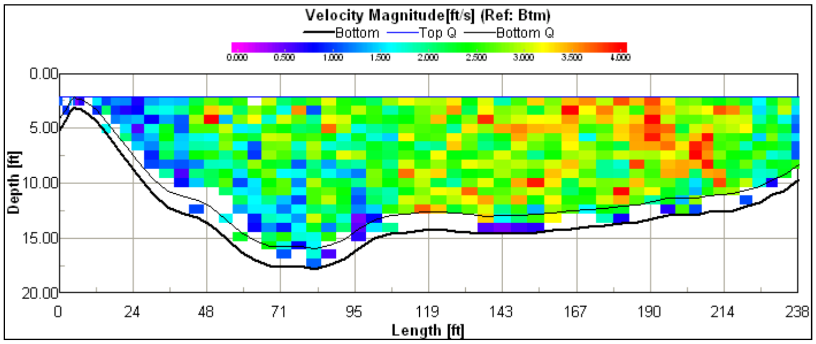
RIPARIAN IDENTIFICATION		RIVERBED SUBSTRATE IDENTIFICATION		DEBRIS NEAR DIVERSION INTAKE			JUVENILE SALMON REARING/PREDATOR HABITAT	
Code	Type	Code	Type	**Code**	**Type**		Code	Quality
Gr	Grasses	Si	Silt	WD-L	Woody Debris - Low Density		1	Poor
Sh	Shrubs	Sa	Sand	WD-M	Woody Debris - Medium Density		2	Fair
So	Soil	Co	Cobble	WD-H	Woody Debris - High Density		3	Good
Mu	Mulberry	RR	Rip-Rap					
TrA	Ash Tree	HP	Hardpan					
TrC	Cottonwood Tree							
TrO	Oak Tree							
TrUn	Unidentified Tree							
TrW	Walnut Tree	Code	Detail		7/17/08	6/30/08		
TrWi	Willow Tree	Non-Op	Non-Operational	Water Temperature:	71°F	68°F		
Ve	Vegetation	NA	Not Applicable	Secchi Depth:	4.1'			
We	Weeds	NE	No Estimates	Turbidity (NTUs):	5.88			

DIDSON™ imaging did not reveal any submerged woody debris around the pipe intakes. Appendix Figure 31 shows a DIDSON™ still image taken at the Oji pump station. Motion images (.avi files) were recorded on July 17, 2008 and are provided in a separate report on in-river surveys of Sacramento River water diversions (Vogel 2008c).

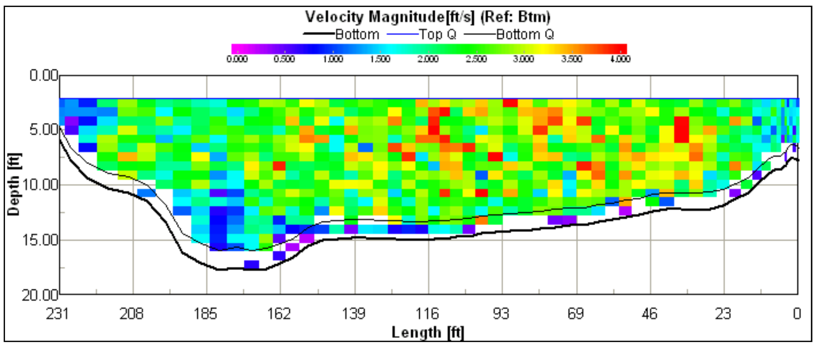


Appendix Figure 31. DIDSON™ still image of the two angled pipe intakes at the Oji pump station (looking upstream). Image taken on July 17, 2008.

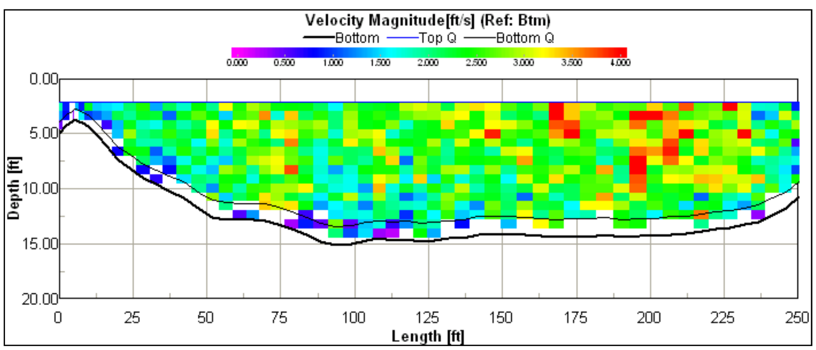
Appendix Figures 32 - 35 show ADCP bathymetry profiles and water velocity distributions across the river channel just upstream and downstream of the Oji pump station as measured on July 17, 2008. Although the pump station is positioned on a left outside bend of the river (facing downstream), the highest water velocities and the greatest portion of the flow are distributed toward the right side of the river channel opposite the pump station. On the day of the measurements, 55% of the flow was on the right half of the river and 45% was on the left half (Vogel 2008c).



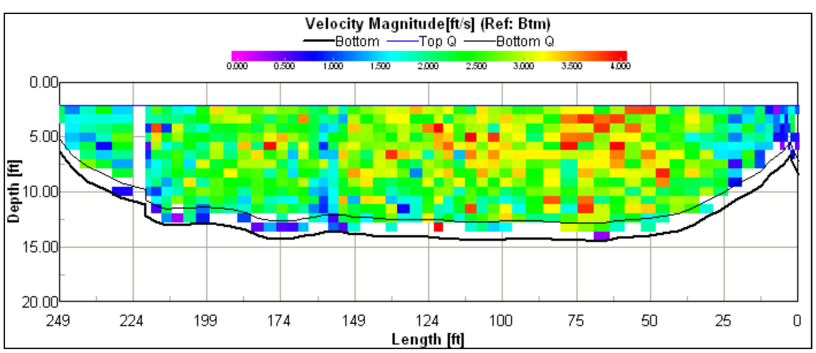
Appendix Figure 32. ADCP transect 1 (facing downstream) measured just downstream of Oji pump station (located on left bank). Left bank is ~3' from start of transect and right bank is ~8' from end of transect.



Appendix Figure 33. ADCP transect 2 (facing downstream) measured just downstream of Oji pump station (located on left bank). Right bank is ~8' from start of transect and left bank is ~3' from end of transect.



Appendix Figure 34. ADCP transect 3 (facing downstream) measured just upstream of Oji pump station (located on left bank). Left bank is ~3' from start of transect and right bank is ~8' from end of transect.



Appendix Figure 35. ADCP transect 4 (facing downstream) measured just upstream of Oji pump station (located on left bank). Right bank is ~8' from start of transect and left bank is ~3' from end of transect.

Windswept (RM 102.5)

The Windswept pump station intake is located on the left side of the river (facing downstream) on an outside bend in the river channel (Appendix Figure 36).

Appendix Figure 36. Location of the Windswept pump station on the Sacramento River.

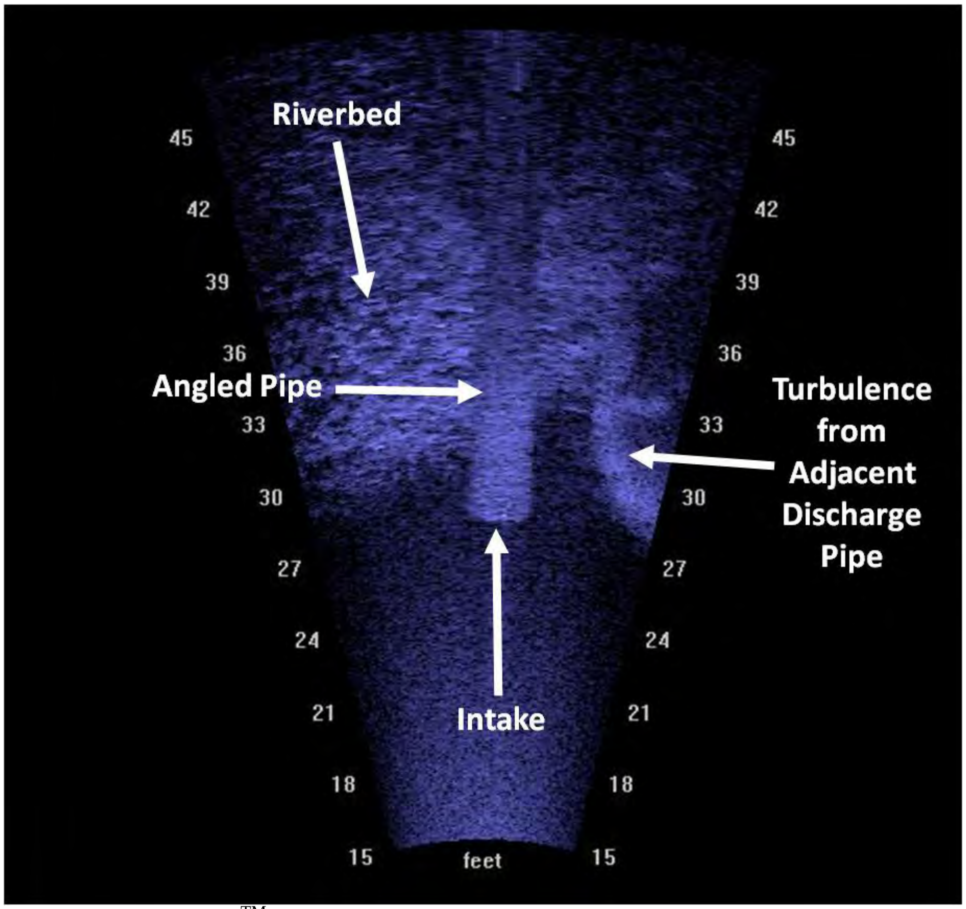
Based on in-river surveys conducted during the summer of 2008, the 24-inch diameter Windswept pipe intake enters the water at 30-degree angle (Appendix Figure 37) (Appendix Table 6). At the time of the survey on June 30, 2008, the water depth at the pipe intake was 12 feet with the intakes positioned three feet above the cobble riverbed and flow in the vicinity of the intake was swift and unidirectional. Rearing habitat for juvenile salmon was characterized as poor and predatory fish habitat was classified as fair (Vogel 2008c). Additional features of the site are provided in Appendix Table 6.

Appendix Figure 37. The Windswept pump station intake looking in a downstream direction\.

Site Number: 052	APPENDIX TABLE 6. DIVERSION CHARACTERISTICS OF THE WINDSWEPT PUMP STATION INTAKE (RIVER MILE 102.5) (DATA FROM VOGEL 2008c) 6/30/08									
Location Facing Downstream	**Channel Configuration at Diversion**	**# of Intake(s) (Upstream to Downstream)**	**Intake Opening Size (Outside Diameter in Inches)**	**Distance Between Intakes (Feet)**	**Intake Angle into Water (Degrees)**	**Estimated Distance from Intake Opening to Bank (Feet)**	**Estimated Riverbed Depth Near Intake (Feet)**	**Estimated Distance of Intake Off River Bottom (Feet)**	**Type of Posts In Water for Support Structure**	**# of Support Posts**
Left	Outside Bend	1	24"	NA	30°	Not Measured	12'	3'	Round Metal Pole	2
Hydraulic Characteristics	**Riverbank Material**	**Riparian Overstory (Type)**	**Riparian Understory (Type)**	**Estimated Time In Shade (Percent)**	**Debris Near Diversion Intake**	**Natural Instream Structure in General Vicinity of Diversion**	**Estimated Riverbed Substrate Near Diversion Intake**	**Juvenile Salmonid Habitat (Overall Quality)**	**Potential Predator Habitat (Overall Quality)**	
Swift, Unidirectional	Co, We	None	None	5%	None	Woody Debris	Co	1	2	

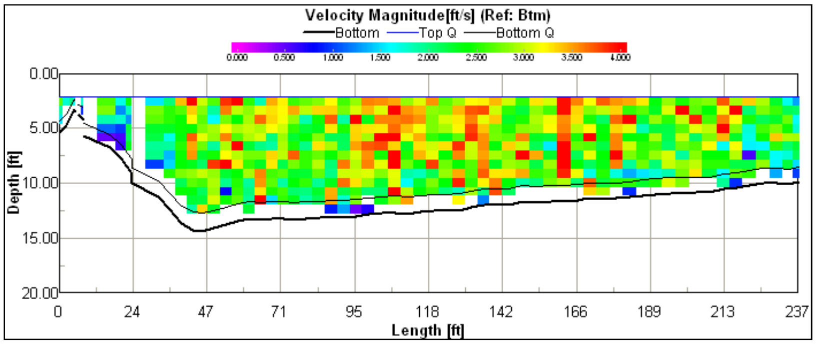
RIPARIAN IDENTIFICATION		**RIVERBED SUBSTRATE IDENTIFICATION**		**DEBRIS NEAR DIVERSION INTAKE**			**JUVENILE SALMON REARING/PREDATOR HABITAT**	
Code	Type	Code	Type	**Code**	**Type**		Code	Quality
Gr	Grasses	Si	Silt	WD-L	Woody Debris - Low Density		1	Poor
Sh	Shrubs	Sa	Sand	WD-M	Woody Debris - Medium Density		2	Fair
So	Soil	Co	Cobble	WD-H	Woody Debris - High Density		3	Good
Mu	Mulberry	RR	Rip-Rap					
TrA	Ash Tree	HP	Hardpan					
TrC	Cottonwood Tree							
TrO	Oak Tree							
TrUn	Unidentified Tree							
TrW	Walnut Tree	Code	Detail		7/17/08	6/30/08		
TrWi	Willow Tree	Non-Op	Non-Operational	Water Temperature:	71°F	67°F		
Ve	Vegetation	NA	Not Applicable	Secchi Depth:	4.1'			
We	Weeds	NE	No Estimates	Turbidity (NTUs):	7.07			

DIDSON™ imaging did not reveal any submerged woody debris around the pipe intakes although woody debris was present on the pipe at the water's edge. Appendix Figure 38 shows a DIDSON™ still image taken at the Windswept pump station. Motion images (.avi files) were recorded on July 17, 2008 and are provided in a separate report on in-river surveys of Sacramento River water diversions (Vogel 2008c).

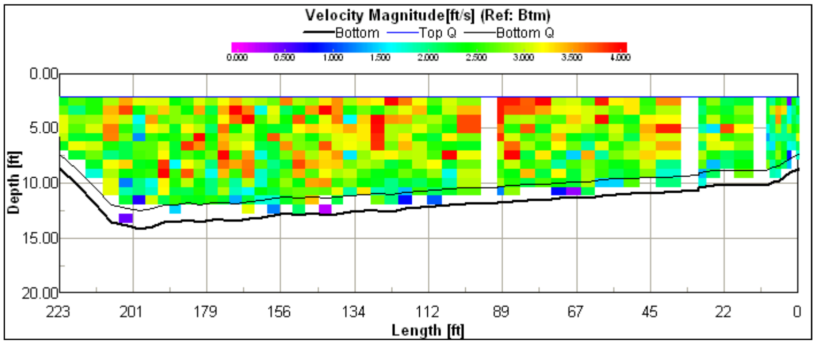


Appendix Figure 38. DIDSON™ still image of the angled pipe intake at the Windswept pump station (looking toward the levee). Image taken on July 17, 2008.

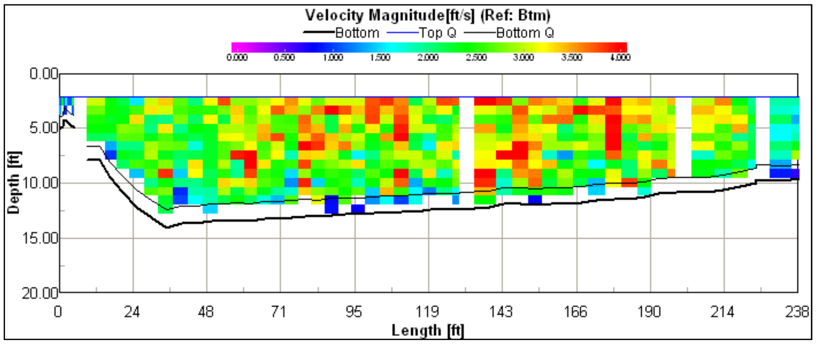
Appendix Figures 39 - 42 show ADCP bathymetry profiles and water velocity distributions across the river channel just upstream and downstream of the Windswept pump station as measured on July 17, 2008. Although the thalweg is located on the left side of the river (facing downstream) on the same side of the channel as the pump intakes, the highest portion of the flow is distributed in the middle of the river channel. On the day of the measurements, 45% of the flow was on the right half of the river channel and 55% on the left half (Vogel 2008c).



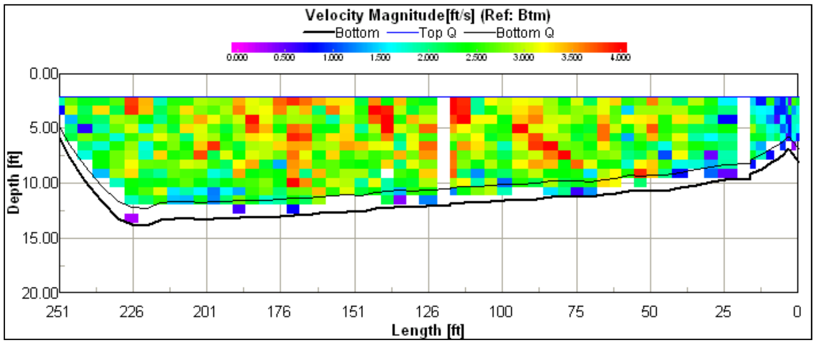
Appendix Figure 39. ADCP transect 1 (facing downstream) measured just downstream of Windswept pump station (located on left bank). Left bank is ~3' from start of transect and right bank is ~12' from end of transect.



Appendix Figure 40. ADCP transect 2 (facing downstream) measured just downstream of Windswept pump station (located on left bank). Right bank is ~12' from start of transect and left bank is ~4' from end of transect.



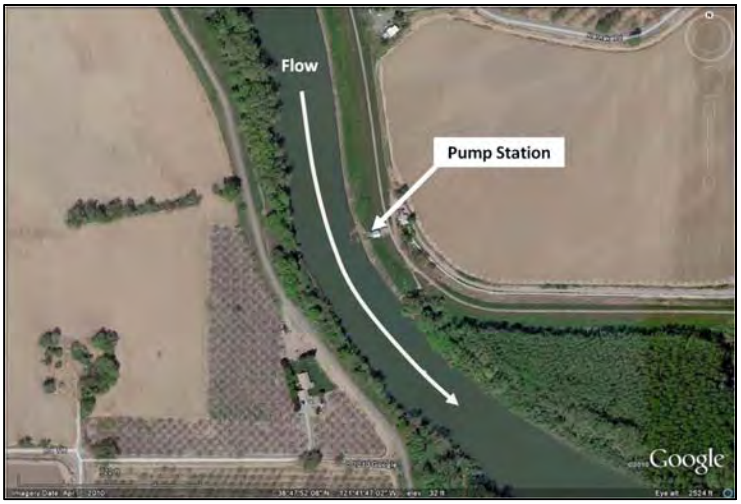
Appendix Figure 41. ADCP transect 3 (facing downstream) measured just upstream of Windswept pump station (located on left bank). Left bank is ~6' from start of transect and right bank is ~12' from end of transect.



Appendix Figure 42. ADCP transect 4 (facing downstream) measured just upstream of Windswept pump station (located on left bank). Right bank is ~12' from start of transect and left bank is ~5' from end of transect.

Portuguese Bend (RM 88.2)

The Portuguese Bend pump station intakes are located on the left side of the river (facing downstream) on an inside bend in the river channel (Appendix Figure 43).



Appendix Figure 43. Location of the Portuguese Bend pump station on the Sacramento River.

Based on in-river surveys conducted during the summer of 2008, the four Portuguese Bend intake pipe diameters, in an upstream to downstream direction, are 36 inches, 46 inches, 40 inches, and 22 inches and enter the water at a 20-degree angle (Appendix Figure 44) (Appendix Table 7). At the time of the survey on June 19, 2008, the water depth at the pipe intakes was 12 feet with the intakes positioned three feet above the riprap substrate riverbed, 33 feet from the river's edge, and flow was swift and unidirectional. Rearing habitat for juvenile salmon was characterized as poor and predatory fish habitat was classified as good (Vogel 2008c). Additional features of the site are provided in Appendix Table 7.


Appendix Figure 44. The Portuguese Bend pump station intakes looking in a downstream direction.

Site Number: 020	APPENDIX TABLE 7. DIVERSION CHARACTERISTICS OF THE PORTUGUESE BEND PUMP STATION INTAKE (RIVER MILE 88.2) (DATA FROM VOGEL 2008c AND MODIFIED BY PERS. COMM. WITH RUSS BERRY JR., ISI) 6/19/08

Location Facing Downstream	Channel Configuration at Diversion	# of Intake(s) (Upstream to Downstream)	Intake Opening Size (Outside Diameter in Inches)	Distance Between Intakes (Feet)	Intake Angle into Water (Degrees)	Estimated Distance from Intake Opening to Bank (Feet)	Estimated Riverbed Depth Near Intake (Feet)	Estimated Distance of Intake Off River Bottom (Feet)	Type of Posts In Water for Support Structure	# of Support Posts
Left	Inside Bend	3	30"	5'	20°	33’	12'	2'	I-Beam Round Poles Trash Deflect Poles I-Beam	4 4 1 Group
			40"	5'	20°	33'	12'	2'		
			34"	3'	20°	33'	12'	2'		

Hydraulic Characteristics	Riverbank Material	Riparian Overstory (Type)	Riparian Understory (Type)	Estimated Time In Shade (Percent)	Debris Near Diversion Intake	Natural Instream Structure in General Vicinity of Diversion	Estimated Riverbed Substrate Near Diversion Intake	Juvenile Salmonid Habitat (Overall Quality)	Potential Predator Habitat (Overall Quality)
Swift Unidirectional	RR	None	Gr	5%	WD-L	Woody Debris	RR	1	3

RIPARIAN IDENTIFICATION

Code	Type
Gr	Grasses
Sh	Shrubs
So	Soil
Mu	Mulberry
TrA	Ash Tree
TrC	Cottonwood Tree
TrO	Oak Tree
TrUn	Unidentified Tree
TrW	Walnut Tree
TrWi	Willow Tree
Ve	Vegetation
We	Weeds

RIVERBED SUBSTRATE IDENTIFICATION

Code	Type
Si	Silt
Sa	Sand
Co	Cobble
RR	Rip-Rap
HP	Hardpan

Code	Detail
Non-Op	Non-Operational
NA	Not Applicable
NE	No Estimates

DEBRIS NEAR DIVERSION INTAKE

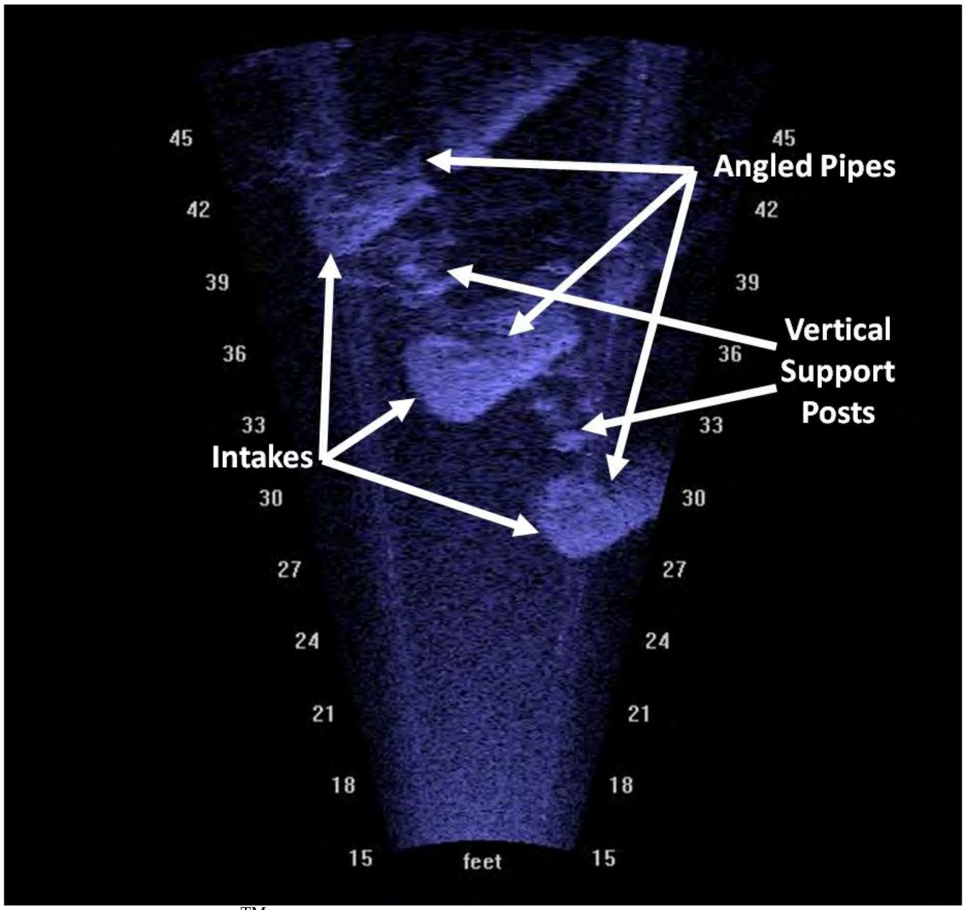
Code	**Type**
WD-L	Woody Debris - Low Density
WD-M	Woody Debris - Medium Density
WD-H	Woody Debris - High Density

	7/3/08	6/19/08
Water Temperature:	73°F	72°F
Secchi Depth:	2.3'	
Turbidity (NTUs):	12.6	

JUVENILE SALMON REARING/PREDATOR HABITAT

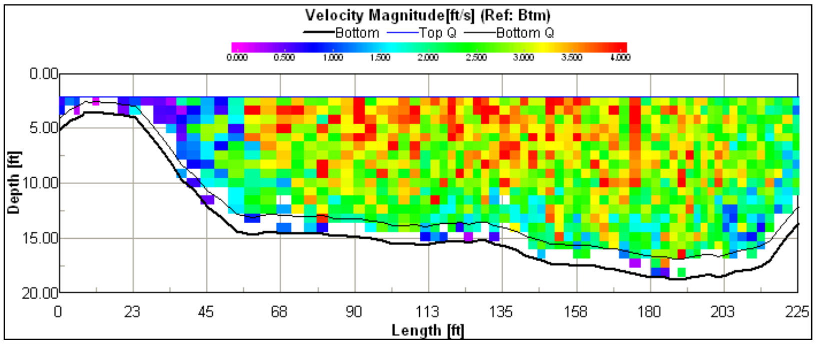
Code	Quality
1	Poor
2	Fair
3	Good

DIDSON^{TM} imaging revealed some submerged woody debris and large fish at the downstream end of the pipe intakes. Appendix Figure 45 shows a DIDSON^{TM} still image taken at the Portuguese Bend pump station. Motion images (.avi files) were recorded on July 3, 2008 and are provided in a separate report on in-river surveys of Sacramento River water diversions (Vogel 2008c).

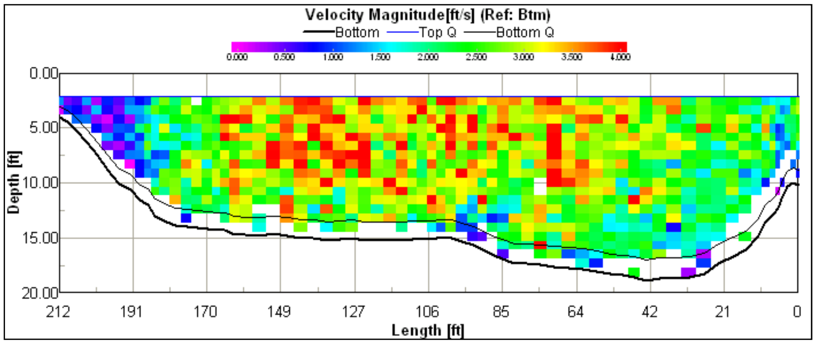


Appendix Figure 45. DIDSON^{TM} still image of the angled pipe intakes at the Portuguese Bend pump station (looking upstream). Woody debris at the downstream end of the pipe intakes is not shown. Image taken on July 3, 2008.

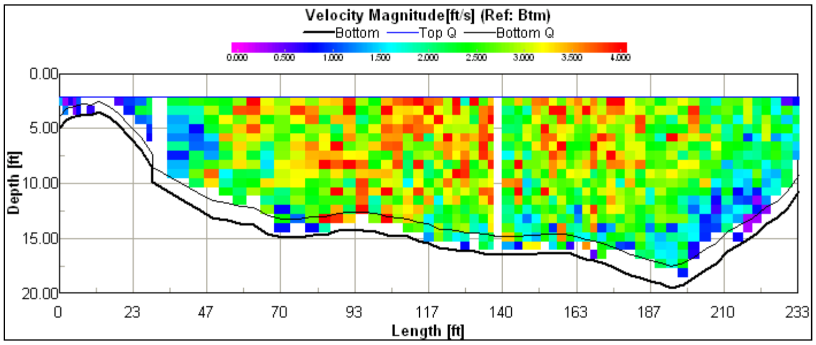
Appendix Figures 46 - 49 show ADCP bathymetry profiles and water velocity distributions across the river channel just upstream and downstream of the Portuguese Bend pump station as measured on July 3, 2008. The thalweg is located on the right side of the river (facing downstream) opposite the pump station intakes. The highest portion of the flow is distributed in the middle of the river channel. On the day of the measurements, 56% of the flow was on the right half of the channel and 44% on the left half (Vogel 2008c).



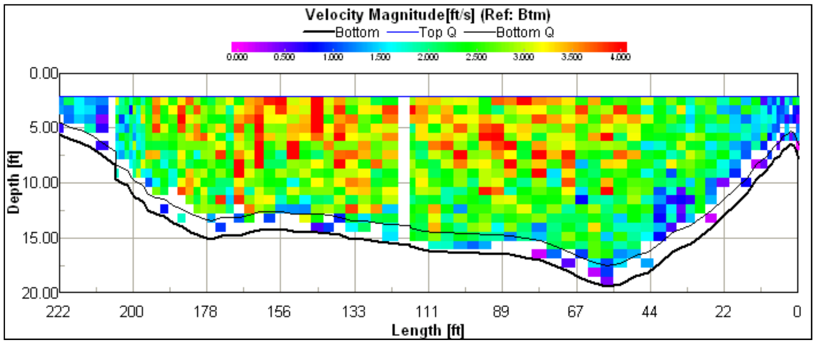
Appendix Figure 46. ADCP transect 1 (facing downstream) measured just downstream of Portuguese Bend pump station (located on left bank). Left bank is ~3' from start of transect and right bank is ~10' from end of transect.



Appendix Figure 47. ADCP transect 2 (facing downstream) measured just downstream of Portuguese Bend pump station (located on left bank). Right bank is ~10' from start of transect and left bank is ~3' from end of transect.



Appendix Figure 48. ADCP transect 3 (facing downstream) measured just upstream of Portuguese Bend pump station (located on left bank). Left bank is ~3' from start of transect and right bank is ~8' from end of transect.



Appendix Figure 49. ADCP transect 4 (facing downstream) measured just upstream of Portuguese Bend pump station (located on left bank). Right bank is ~8' from start of transect and left bank is ~6' from end of transect.

<u>**Stage 3 Sites (2011 – 2012)**</u>

Alamo (RM 123.8)

The Alamo pump station intake is located on the right side of the river (facing downstream) on a relatively straight reach of the river just downstream of a left river bend (Appendix Figure 50).

Appendix Figure 50. Location of the Alamo pump station on the Sacramento River.

Based on in-river surveys conducted during the summer of 2008, the two Alamo 42-inch and 26-inch diameter pipe intakes enter the water at a 30-degree angle (Appendix Figure 51) (Appendix Table 8). At the time of the survey on July 14, 2008, the water depth at the pipe intakes was 13 feet with the intakes positioned three feet above the cobble and sand riverbed, 25 and 30 feet from the river's edge, respectively, and flow was swift and unidirectional. Rearing habitat for juvenile salmon was characterized as poor and predatory fish habitat was classified as fair (Vogel 2008c). Additional features of the site are provided in Appendix Table 8.

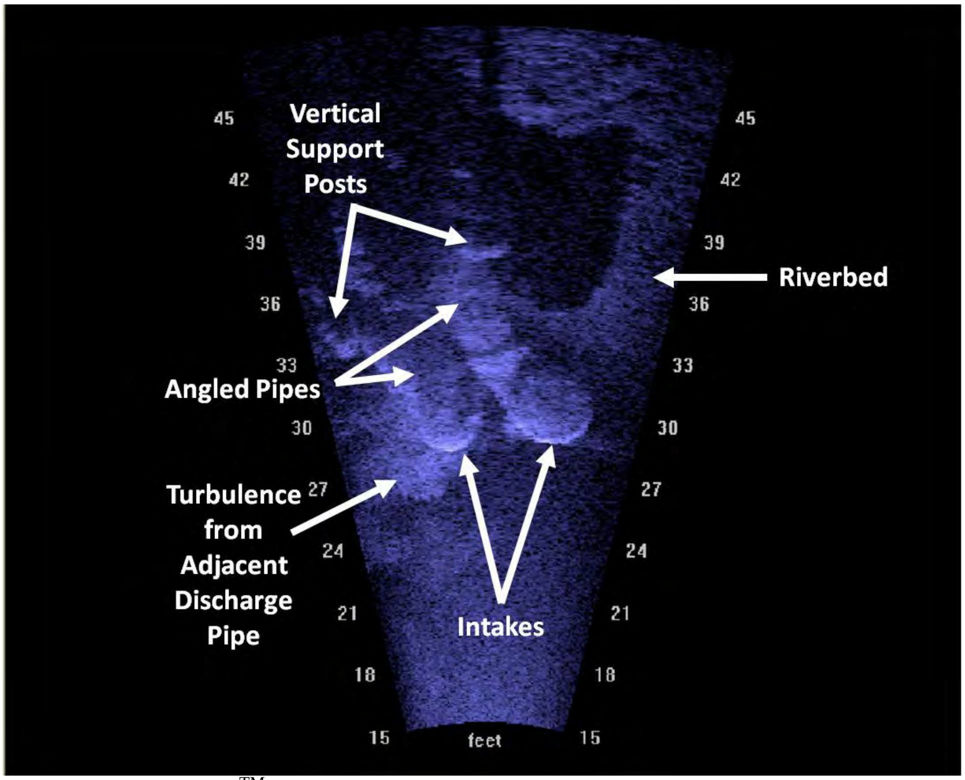
Appendix Figure 51. The Alamo pump intakes looking in an upstream direction.

Site Number: 096	APPENDIX TABLE 8. DIVERSION CHARACTERISTICS OF THE ALAMO PUMP STATION INTAKE (RIVER MILE 123.8) (DATA FROM VOGEL 2008c AND MODIFIED BY PERS. COMM. WITH RUSS BERRY JR., ISI) 7/14/08									
Location Facing Downstream	**Channel Configuration at Diversion**	**# of Intake(s) (Upstream to Downstream)**	**Intake Opening Size (Outside Diameter in Inches)**	**Distance Between Intakes (Feet)**	**Intake Angle into Water (Degrees)**	**Estimated Distance from Intake Opening to Bank (Feet)**	**Estimated Riverbed Depth Near Intake (Feet)**	**Estimated Distance of Intake Off River Bottom (Feet)**	**Type of Posts In Water for Support Structure**	**# of Support Posts**
Right	Straight	2	36"	2'	30°	25'	13'	4'	Round Metal Post	2
			22"		30°	30'	13'	4'		

Hydraulic Characteristics	**Riverbank Material**	**Riparian Overstory (Type)**	**Riparian Understory (Type)**	**Estimated Time In Shade (Percent)**	**Debris Near Diversion Intake**	**Natural Instream Structure in General Vicinity of Diversion**	**Estimated Riverbed Substrate Near Diversion Intake**	**Juvenile Salmonid Habitat (Overall Quality)**	**Potential Predator Habitat (Overall Quality)**
Swift Unidirectional	RR, Sh	TrWi, TrO, TrC, TrW	Gr, Sh	20%	None	Woody Debris	Co, Sa	1	2

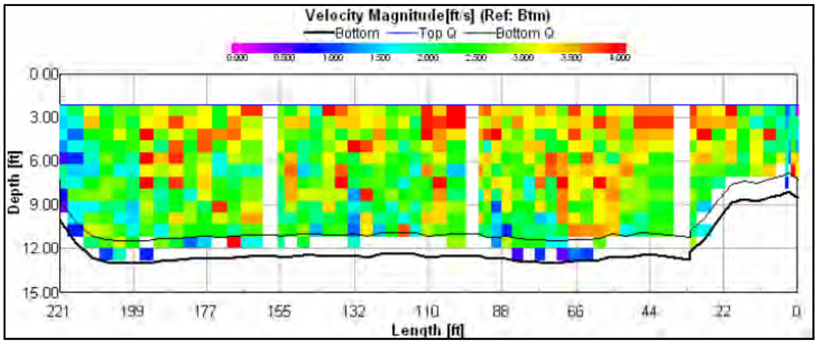
RIPARIAN IDENTIFICATION		**RIVERBED SUBSTRATE IDENTIFICATION**		**DEBRIS NEAR DIVERSION INTAKE**			**JUVENILE SALMON REARING/PREDATOR HABITAT**	
Code	Type	Code	Type	**Code**	**Type**		Code	Quality
Gr	Grasses	Si	Silt	WD-L	Woody Debris - Low Density		1	Poor
Sh	Shrubs	Sa	Sand	WD-M	Woody Debris - Medium Density		2	Fair
So	Soil	Co	Cobble	WD-H	Woody Debris - High Density		3	Good
Mu	Mulberry	RR	Rip-Rap					
TrA	Ash Tree	HP	Hardpan					
TrC	Cottonwood Tree							
TrO	Oak Tree							
TrUn	Unidentified Tree							
TrW	Walnut Tree	Code	Detail		8/6/08	7/14/08		
TrWi	Willow Tree	Non-Op	Non-Operational	Water Temperature:	70°F	68°F		
Ve	Vegetation	NA	Not Applicable	Secchi Depth:	5.7'			
We	Weeds	NE	No Estimates	Turbidity (NTUs):	5.87			

DIDSON™ imaging did not reveal any submerged woody debris around the pipe intakes. Appendix Figure 52 shows a DIDSON™ still image taken at the Alamo pump station. Motion images (.avi files) were recorded on August 6, 2008 and are provided in a separate report on in-river surveys of Sacramento River water diversions (Vogel 2008c).

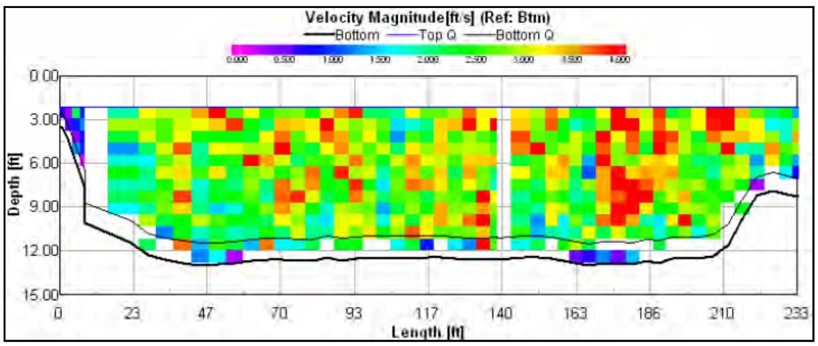


Appendix Figure 52. DIDSON™ still image of the angled pipe intakes at the Alamo pump station (looking upstream). Image taken on August 6, 2008.

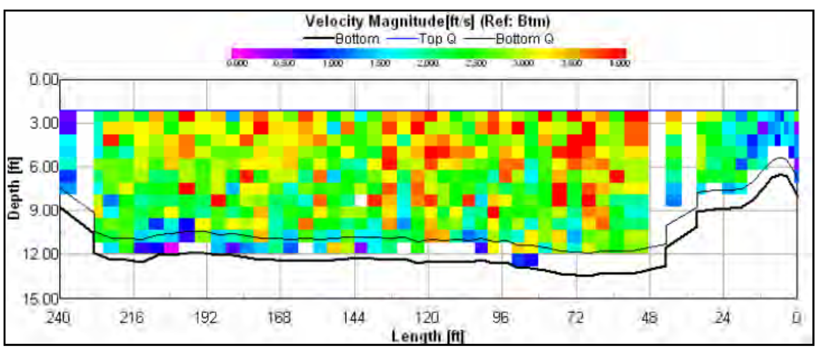
Appendix Figures 53 - 56 show ADCP bathymetry profiles and water velocity distributions across the river channel just upstream and downstream of the Alamo pump station as measured on August 6, 2008. The channel geometry and distribution of flow is relatively uniform across the river with 51% of the flow on the right half of the river and 49% on the left half on the day of measurements (Vogel 2008c).



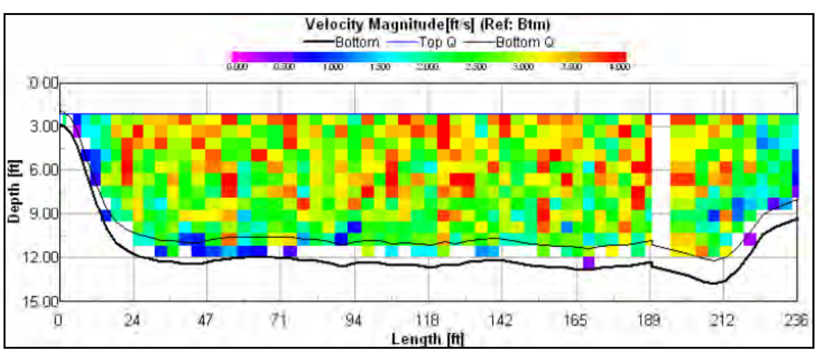
Appendix Figure 53. ADCP transect 1 (facing downstream) measured just downstream of the Alamo pump station (located on right bank). Right bank is ~12' from start of transect and left bank is ~6' from end of transect.



Appendix Figure 54. ADCP transect 2 (facing downstream) measured just downstream of the Alamo pump station (located on right bank). Left bank is ~6' from start of transect and right bank is ~8' from end of transect.



Appendix Figure 55. ADCP transect 3 (facing downstream) measured just upstream of the Alamo pump station (located on right bank). Right bank is ~7' from start of transect and left bank is ~3' from end of transect.



Appendix Figure 56. ADCP transect 4 (facing downstream) measured just upstream of the Alamo pump station (located on right bank). Left bank is ~3' from start of transect and right bank is ~9' from end of transect.

Townsite (RM 90.1)

The Townsite pump station intake is located on the right side of the river (facing downstream) on a straight reach of the river (Appendix Figure 57).

Appendix Figure 57. Location of the Townsite pump station on the Sacramento River.

Based on in-river surveys conducted during the summer of 2008, the Townsite two 34-inch diameter and one 20-inch diameter pipe intakes enter the water vertically at a 90-degree angle (Appendix Figure 58) (Appendix Table 9). At the time of the survey on June 19, 2008, the water depth at the pipe intakes was 8 feet with the intakes positioned ranging from one to three feet above the silt riverbed, 33 feet from the river's edge, and flow was swift and unidirectional. Rearing habitat for juvenile salmon was characterized as poor and predatory fish habitat was classified as good (Vogel 2008c). Additional features of the site are provided in Appendix Table 9.

Appendix Figure 58. The Townsite pump intakes looking in an upstream direction.

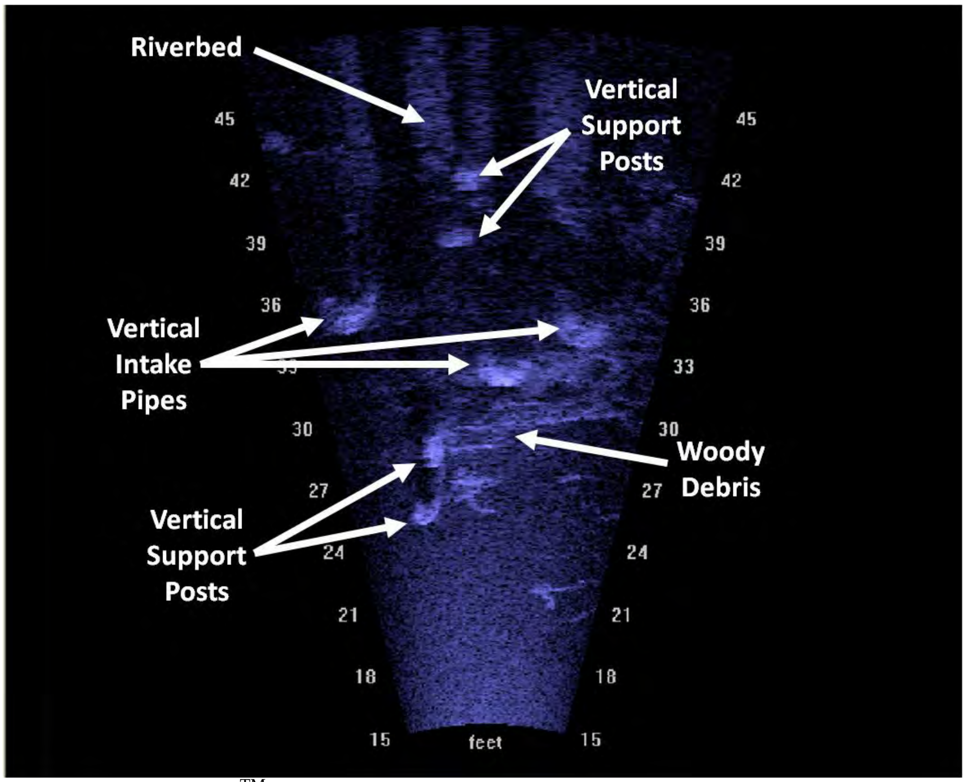
Site Number: 026	APPENDIX TABLE 9. DIVERSION CHARACTERISTICS OF THE TOWNSITE PUMP STATION INTAKE (RIVER MILE 90.1) (DATA FROM VOGEL 2008c AND MODIFIED BY PERS. COMM. WITH RUSS BERRY JR., ISI) 6/19/08									
Location Facing Downstream	**Channel Configuration at Diversion**	**# of Intake(s) (Upstream to Downstream)**	**Intake Opening Size (Outside Diameter in Inches)**	**Distance Between Intakes (Feet)**	**Intake Angle into Water (Degrees)**	**Estimated Distance from Intake Opening to Bank (Feet)**	**Estimated Riverbed Depth Near Intake (Feet)**	**Estimated Distance of Intake Off River Bottom (Feet)**	**Type of Posts In Water for Support Structure**	**# of Suppor t Posts**
Right	Straight	3	54"	2'	90°	33’	8'	1'	Wooden Post	10
			48"	5'	90°	33'	8'	1'	I-Beam	9
			34"		90°	33'	8'	1'		

Hydraulic Characteristics	**Riverbank Material**	**Riparian Overstory (Type)**	**Riparian Understory (Type)**	**Estimated Time In Shade (Percent)**	**Debris Near Diversion Intake**	**Natural Instream Structure in General Vicinity of Diversion**	**Estimated Riverbed Substrate Near Diversion Intake**	**Juvenile Salmonid Habitat (Overall Quality)**	**Potential Predator Habitat (Overall Quality)**
Swift Unidirectional	RR	TrC	Sh, Gr	35%	WD-M	**Woody Debris**	Si	1	3

RIPARIAN IDENTIFICATION		**RIVERBED SUBSTRATE IDENTIFICATION**		**DEBRIS NEAR DIVERSION INTAKE**		**JUVENILE SALMON REARING/PREDATOR HABITAT**	
Code	Type	Code	Type	**Code**	**Type**	Code	Quality
Gr	Grasses	Si	Silt	WD-L	Woody Debris - Low Density	1	Poor
Sh	Shrubs	Sa	Sand	WD-M	Woody Debris - Medium Density	2	Fair
So	Soil	Co	Cobble	WD-H	Woody Debris - High Density	3	Good
Mu	Mulberry	RR	Rip-Rap				
TrA	Ash Tree	HP	Hardpan				
TrC	Cottonwood Tree						
TrO	Oak Tree						
TrUn	Unidentified Tree						
TrW	Walnut Tree	Code	Detail				
TrWi	Willow Tree	Non-Op	Non-Operational				
Ve	Vegetation	NA	Not Applicable				
We	Weeds	NE	No Estimates				

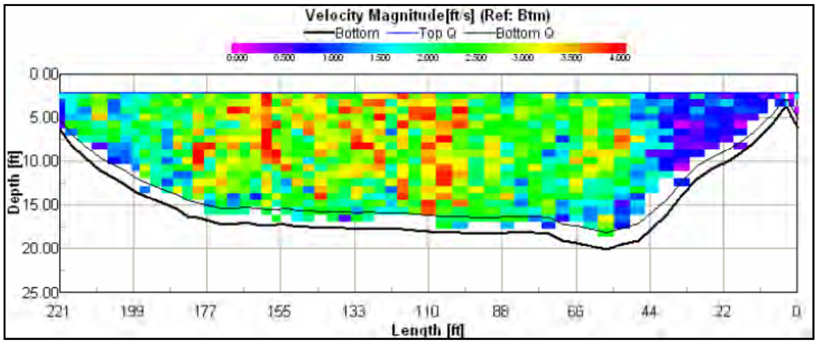
	7/8/08	6/19/08
Water Temperature:	73°F	72°F
Secchi Depth:	3.4'	
Turbidity (NTUs):	8.8	

DIDSON™ imaging revealed a substantial amount of submerged woody debris around the upstream side of the pump station support structure. Appendix Figure 59 shows a DIDSON™ still image taken at the Townsite pump station. Motion images (.avi files) were recorded on July 8, 2008 and are provided in a separate report on in-river surveys of Sacramento River water diversions (Vogel 2008c).

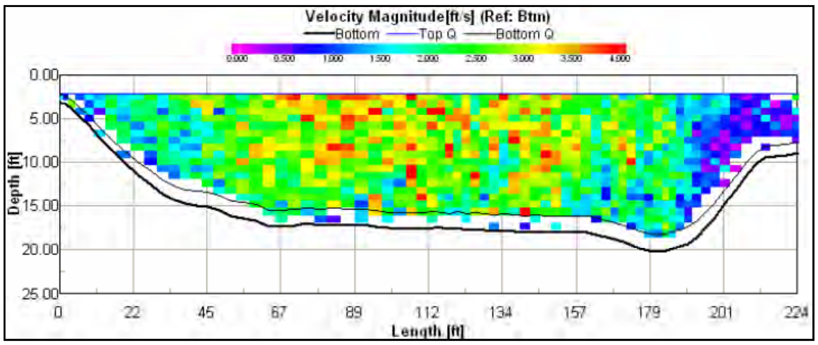


Appendix Figure 59. DIDSON™ still image of the vertical pipe intakes at the Townsite pump station (looking toward the river bank). Image taken on July 8, 2008.

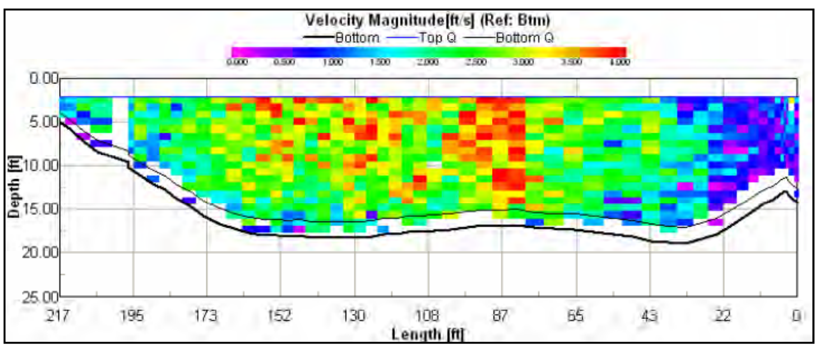
Appendix Figures 60 - 63 show ADCP bathymetry profiles and water velocity distributions across the river channel just upstream and downstream of the Townsite pump station as measured on July 8, 2008. Although the thalweg is located on the right side of the river (facing downstream) near the pump station intakes, relatively low water velocities are near the intakes. Forty-five percent of the flow was on the right half of the channel and 55% of the flow was on the left half on the day of the measurements (Vogel 2008c).



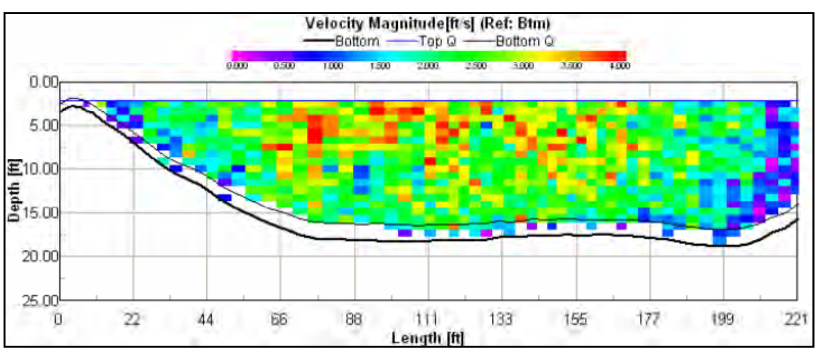
Appendix Figure 60. ADCP transect 1 (facing downstream) measured just downstream of the Townsite pump station (located on right bank). Right bank is ~9' from start of transect and left bank is ~5' from end of transect.



Appendix Figure 61. ADCP transect 2 (facing downstream) measured just downstream of the Townsite pump station (located on right bank). Left bank is ~4' from start of transect and right bank is ~10' from end of transect.



Appendix Figure 62. ADCP transect 3 (facing downstream) measured just upstream of the Townsite pump station (located on right bank). Right bank is ~9' from start of transect and left bank is ~8' from end of transect.



Appendix Figure 63. ADCP transect 4 (facing downstream) measured just upstream of the Townsite pump station (located on right bank). Left bank is ~5' from start of transect and right bank is ~12' from end of transect.

Tisdale (RM 121.7)

The Tisdale pump station intake is located on the left side of the river (facing downstream) on a straight reach of the river just downstream of a right river bend (Appendix Figure 64).

Appendix Figure 64. Location of the Tisdale pump station on the Sacramento River.

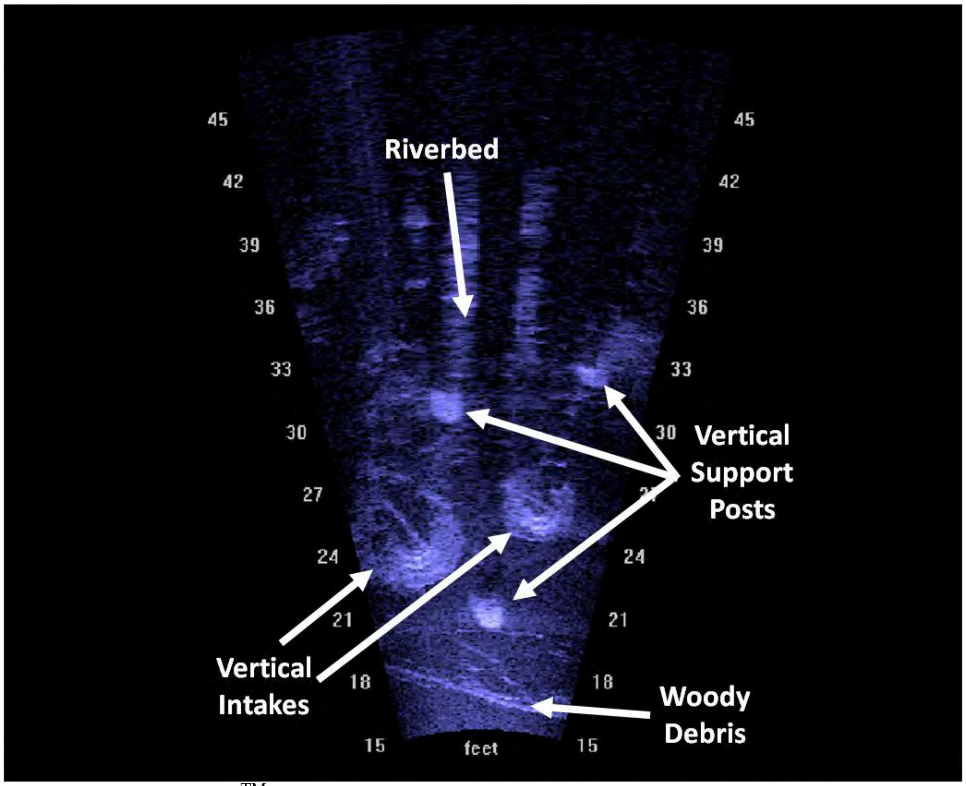
Based on in-river surveys conducted during the summer of 2008, the two Tisdale 24-inch and 18-inch diameter pipe intakes enter the water vertically at a 90-degree angle (Appendix Figure 65) (Appendix Table 10). At the time of the survey on July 10, 2008, the water depth at the pipe intakes was 13 feet with the intakes positioned five and four feet, respectively, above the riprap and silt riverbed, 30 feet from the river's edge, and flow was swift and unidirectional. Rearing habitat for juvenile salmon was characterized as fair and predatory fish habitat was classified as good (Vogel 2008c). Additional features of the site are provided in Appendix Table 10.

Appendix Figure 65. The Tisdale pump intakes looking in an upstream direction.

Site Number: 093	APPENDIX TABLE 10. DIVERSION CHARACTERISTICS OF THE TISDALE PUMP STATION INTAKE (RIVER MILE 121.7) (DATA FROM VOGEL 2008c) 7/10/08									
Location Facing Downstream	**Channel Configuration at Diversion**	**# of Intake(s) (Upstream to Downstream)**	**Intake Opening Size (Outside Diameter in Inches)**	**Distance Between Intakes (Feet)**	**Intake Angle into Water (Degrees)**	**Estimated Distance from Intake Opening to Bank (Feet)**	**Estimated Riverbed Depth Near Intake (Feet)**	**Estimated Distance of Intake Off River Bottom (Feet)**	**Type of Posts In Water for Support Structure**	**# of Support Posts**
Left	Straight	2	24"	4'	90°	30'	13'	5'	Round Metal Post	6
			18"		90°	30'	13'	4'		
Hydraulic Characteristics	**Riverbank Material**	**Riparian Overstory (Type)**	**Riparian Understory (Type)**	**Estimated Time In Shade (Percent)**	**Debris Near Diversion Intake**	**Natural Instream Structure in General Vicinity of Diversion**	**Estimated Riverbed Substrate Near Diversion Intake**	**Juvenile Salmonid Habitat (Overall Quality)**	**Potential Predator Habitat (Overall Quality)**	
Swift Unidirectional	We	None	None	15% From Pier	WD-H	None	RR, Si	2	3	

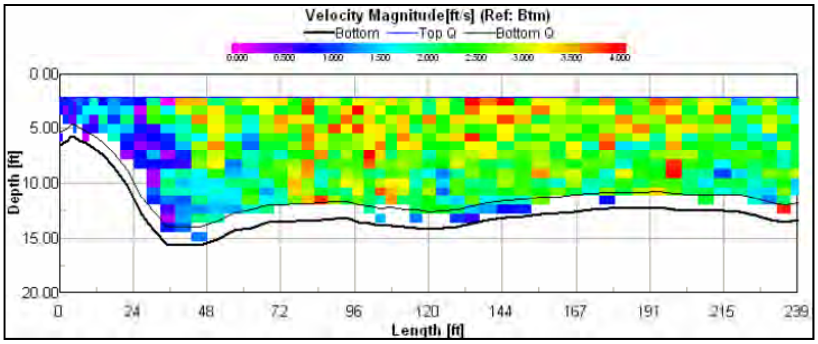
RIPARIAN IDENTIFICATION		**RIVERBED SUBSTRATE IDENTIFICATION**		**DEBRIS NEAR DIVERSION INTAKE**			**JUVENILE SALMON REARING/PREDATOR HABITAT**	
Code	Type	Code	Type	**Code**	**Type**		Code	Quality
Gr	Grasses	Si	Silt	WD-L	Woody Debris - Low Density		1	Poor
Sh	Shrubs	Sa	Sand	WD-M	Woody Debris - Medium Density		2	Fair
So	Soil	Co	Cobble	WD-H	Woody Debris - High Density		3	Good
Mu	Mulberry	RR	Rip-Rap					
TrA	Ash Tree	HP	Hardpan					
TrC	Cottonwood Tree							
TrO	Oak Tree							
TrUn	Unidentified Tree							
TrW	Walnut Tree	Code	Detail		8/5/08	7/10/08		
TrWi	Willow Tree	Non-Op	Non-Operational	Water Temperature:	71°F	68°F		
Ve	Vegetation	NA	Not Applicable	Secchi Depth:	5.6'			
We	Weeds	NE	No Estimates	Turbidity (NTUs):	4.36			

DIDSON™ imaging revealed submerged woody debris around the pump station support structure. Appendix Figure 66 shows a DIDSON™ still image taken at the Tisdale pump station. Motion images (.avi files) were recorded on August 5, 2008 and are provided in a separate report on in-river surveys of Sacramento River water diversions (Vogel 2008c).

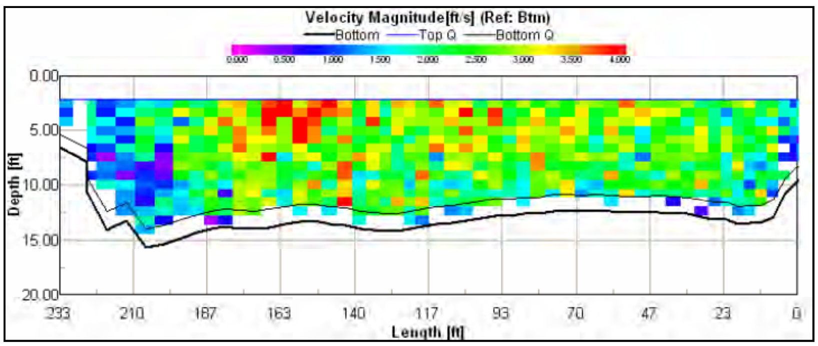


Appendix Figure 66. DIDSON™ still image of the vertical pipe intakes at the Tisdale pump station (looking toward the river bank). Image taken on August 5, 2008.

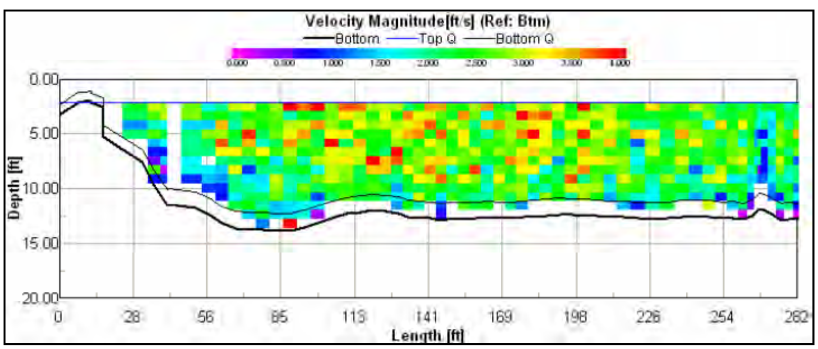
Appendix Figures 67 - 70 show ADCP bathymetry profiles and water velocity distributions across the river channel just upstream and downstream of the Tisdale pump station as measured on August 5, 2008. The highest portion of the flow is distributed in the middle of the river channel with 52% of the flow on the right half of the channel and 48% of the flow on the left half on the day of the measurements (Vogel 2008c).



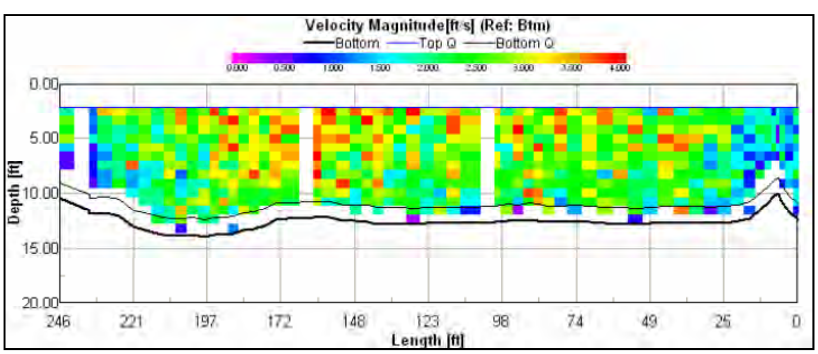
Appendix Figure 67. ADCP transect 1 (facing downstream) measured just downstream of the Tisdale pump station (located on left bank). Left bank is ~9' from start of transect and right bank is ~10' from end of transect.



Appendix Figure 68. ADCP transect 2 (facing downstream) measured just downstream of the Tisdale pump station (located on left bank). Right bank is ~10' from start of transect and left bank is ~9' from end of transect.



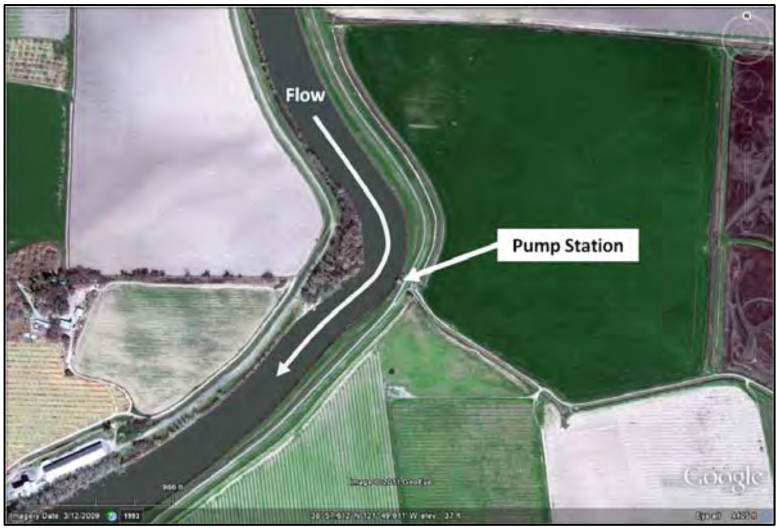
Appendix Figure 69. ADCP transect 3 (facing downstream) measured just upstream of the Tisdale pump station (located on left bank). Left bank is ~3' from start of transect and right bank is ~0' from end of transect.



Appendix Figure 70. ADCP transect 4 (facing downstream) measured just upstream of the Tisdale pump station (located on left bank). Right bank is ~6' from start of transect and left bank is ~4' from end of transect.

Cranmore (RM 111.8)

The Cranmore pump station intake is located on the left side of the river (facing downstream) on an outside right river bend (Appendix Figure 71).



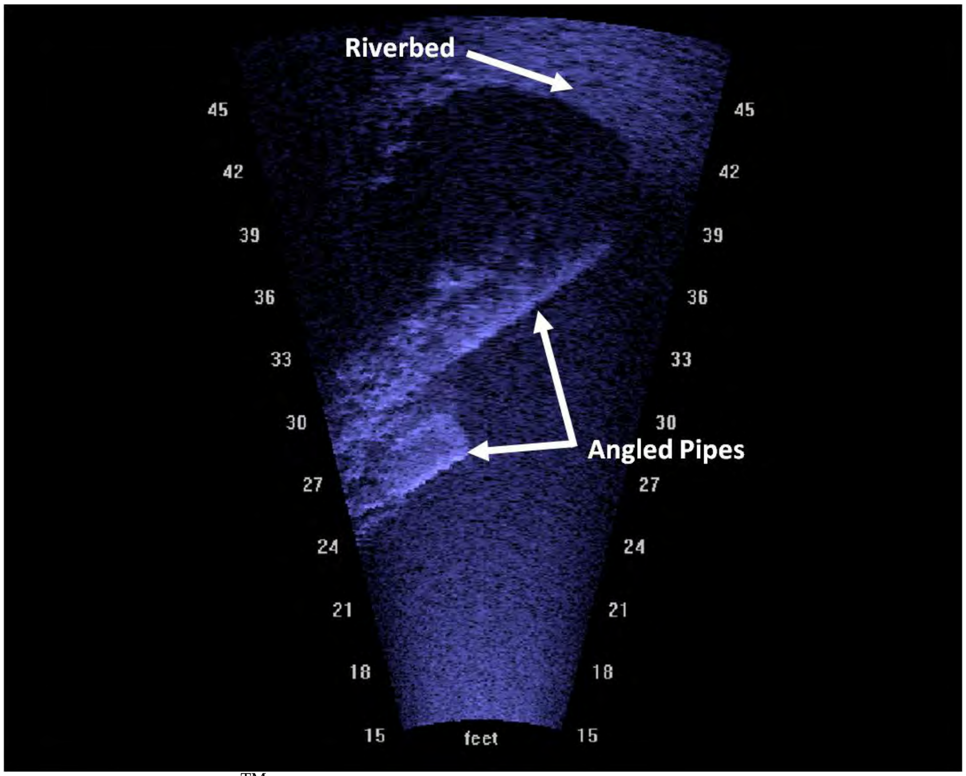
Appendix Figure 71. Location of the Cranmore pump station on the Sacramento River.

Based on in-river surveys conducted during the summer of 2008, the two Cranmore 36-inch and 26-inch diameter pipe intakes enter the water at a 45-degree angle (Appendix Figure 72) (Appendix Table 11). At the time of the survey on July 7, 2008, the water depth at the pipe intakes was 17 feet with the intakes positioned two feet above the riprap and sand riverbed, 30 feet from the river's edge, and flow was swift and unidirectional. Rearing habitat for juvenile salmon was characterized as poor and predatory fish habitat was classified as fair (Vogel 2008c). Additional features of the site are provided in Appendix Table 11.

Appendix Figure 72. The Cranmore pump intakes (foreground) looking in an upstream direction.

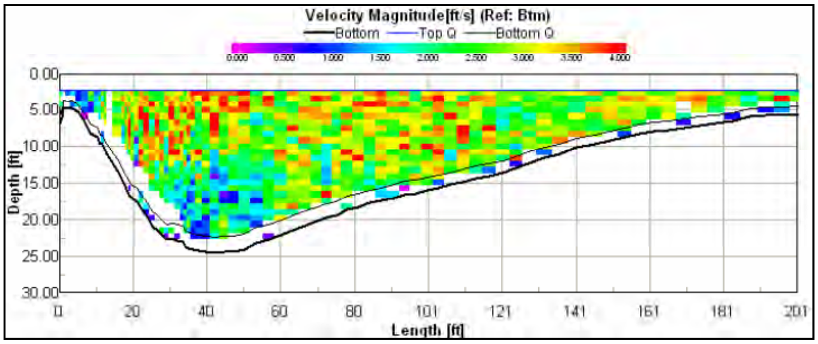
Site Number: 070		APPENDIX TABLE 11. DIVERSION CHARACTERISTICS OF THE CRANMORE PUMP STATION INTAKE (RIVER MILE 111.8) (DATA FROM VOGEL 2008c) 7/7/08								
Location Facing Downstream	**Channel Configuration at Diversion**	**# of Intake(s) (Upstream to Downstream)**	**Intake Opening Size (Outside Diameter in Inches)**	**Distance Between Intakes (Feet)**	**Intake Angle into Water (Degrees)**	**Estimated Distance from Intake Opening to Bank (Feet)**	**Estimated Riverbed Depth Near Intake (Feet)**	**Estimated Distance of Intake Off River Bottom (Feet)**	**Type of Posts In Water for Support Structure**	**# of Support Posts**
Left	Outside Bend	2	36"	2'	45°	30'	17'	2'	I-Beam	4
			26"		45°	25'	15'	2'		
Hydraulic Characteristics	**Riverbank Material**	**Riparian Overstory (Type)**	**Riparian Understory (Type)**	**Estimated Time In Shade (Percent)**	**Debris Near Diversion Intake**	**Natural Instream Structure in General Vicinity of Diversion**	**Estimated Riverbed Substrate Near Diversion Intake**	**Juvenile Salmonid Habitat (Overall Quality)**	**Potential Predator Habitat (Overall Quality)**	
Swift Unidirectional	RR, We, Gr	None	We, Gr	5%	None	None	RR, Sa	1	2	
RIPARIAN IDENTIFICATION			**RIVERBED SUBSTRATE IDENTIFICATION**			**DEBRIS NEAR DIVERSION INTAKE**			**JUVENILE SALMON REARING/PREDATOR HABITAT**	
Code	Type		Code	Type		**Code**	**Type**		Code	Quality
Gr	Grasses		Si	Silt		WD-L	Woody Debris - Low Density		1	Poor
Sh	Shrubs		Sa	Sand		WD-M	Woody Debris - Medium Density		2	Fair
So	Soil		Co	Cobble		WD-H	Woody Debris - High Density		3	Good
Mu	Mulberry		RR	Rip-Rap						
TrA	Ash Tree		HP	Hardpan						
TrC	Cottonwood Tree									
TrO	Oak Tree									
TrUn	Unidentified Tree									
TrW	Walnut Tree		Code	Detail			7/22/08	7/7/08		
TrWi	Willow Tree		Non-Op	Non-Operational		Water Temperature:	68°F	69°F		
Ve	Vegetation		NA	Not Applicable		Secchi Depth:	5'			
We	Weeds		NE	No Estimates		Turbidity (NTUs):	4.06			

DIDSON™ imaging did not revealed submerged woody debris around the pipe intakes. Appendix Figure 73 shows a DIDSON™ still image taken at the Cranmore pump station. Motion images (.avi files) were recorded on July 22, 2008 and are provided in a separate report on in-river surveys of Sacramento River water diversions (Vogel 2008c).

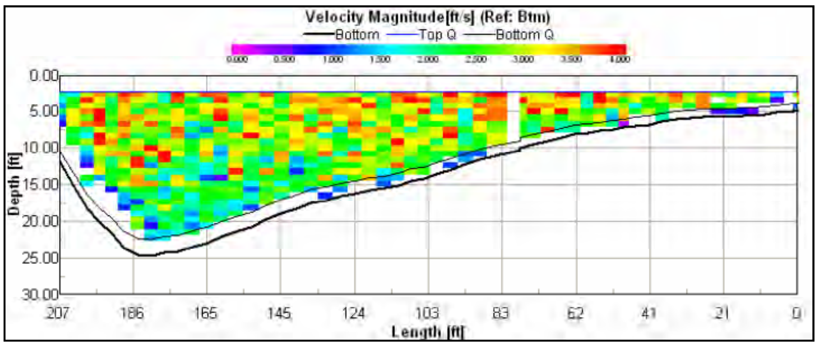


Appendix Figure 73. DIDSON™ still image of the angled pipe intakes at the Cranmore pump station (looking in a downstream direction). Image taken on July 22, 2008.

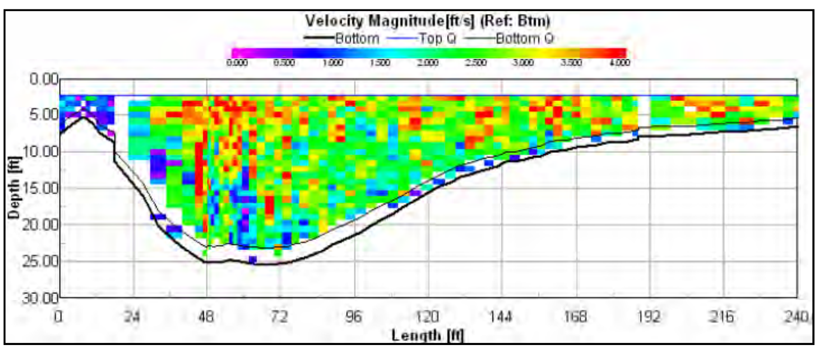
Appendix Figures 74 - 77 show ADCP bathymetry profiles and water velocity distributions across the river channel just upstream and downstream of the Cranmore pump station as measured on July 22, 2008. The thalweg is located on the left side of the river (facing downstream) on the same side as the pump station intakes. The highest portion of the flow is distributed in the left side of river channel with 36% of the flow on the right half of the channel and 64% on the left half on the day of the measurements (Vogel 2008c).



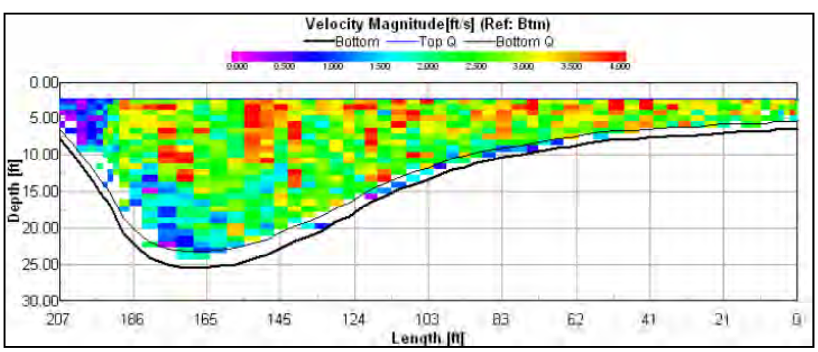
Appendix Figure 74. ADCP transect 1 (facing downstream) measured just downstream of the Cranmore pump station (located on left bank). Left bank is ~4' from start of transect and right bank is ~10' from end of transect.



Appendix Figure 75. ADCP transect 2 (facing downstream) measured just downstream of the Cranmore pump station (located on left bank). Right bank is ~10' from start of transect and left bank is ~4' from end of transect.



Appendix Figure 76. ADCP transect 3 (facing downstream) measured just upstream of the Cranmore pump station (located on left bank). Left bank is ~3' from start of transect and right bank is ~15' from end of transect.



Appendix Figure 77. ADCP transect 4 (facing downstream) measured just upstream of the Cranmore pump station (located on left bank). Right bank is ~15' from start of transect and left bank is ~4' from end of transect.

Sanchez (Steamboat Slough)

The Sanchez siphon station intake is located in Steamboat Slough on the east side of the slough on a relatively straight reach but generally just after an outside bend regardless of ebb or flood tide conditions (Appendix Figure 78). Flow past the site occurs in both directions due to tidal influence. In-channel measurements and features of the Sanchez siphon station were not included in the 2008 river survey but a similar-type survey was conducted on December 10, 2012.

Appendix Figure 78. Location of the Sanchez siphon station on Steamboat Slough.

Based on in-river surveys conducted on December 10, 2012, the two Sanchez 24-inch and 18-inch diameter pipe intakes enter the water at a 28-degree angle (Appendix Figure 79) (Appendix Table 12). At the time of the survey, the water depth at the pipe intakes was 10 feet with the intakes positioned 3 feet above the riprap riverbed, 25 feet from the river's edge, and flow was swift and unidirectional. Rearing habitat for juvenile salmon was characterized as poor and predatory fish habitat was classified as fair. Additional features of the site are provided in Appendix Table 12.

Appendix Figure 79. The Sanchez siphon intakes (foreground) looking in an upstream direction. The fish screen has been installed but is out of the water in this picture.

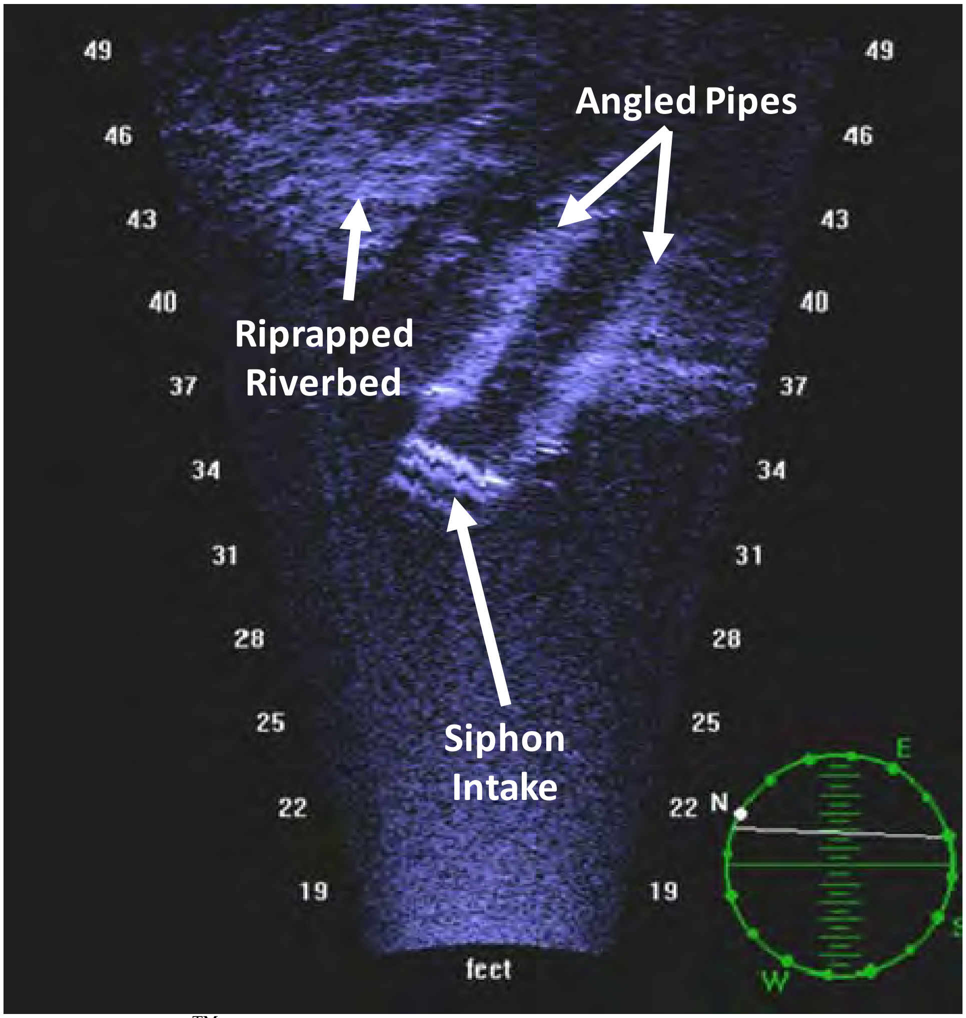
APPENDIX TABLE 12. DIVERSION CHARACTERISTICS OF THE SANCHEZ FARMS SIPHON STATION INTAKE (STEAMBOAT SLOUGH) 12/10/12

Location Facing Downstream	Channel Configuration at Diversion	# of Intake(s) (Upstream to Downstream)	Intake Opening Size (Outside Diameter in Inches)	Distance Between Intakes (Inches)	Intake Angle into Water (Degrees)	Estimated Distance from Intake Opening to Bank (Feet)	Estimated Riverbed Depth Near Intake (Feet)	Estimated Distance of Intake Off River Bottom (Feet)	Type of Posts In Water for Support Structure	# of Support Posts
Left	Straight	2	24”	24”	28°	25'	10'	3'	N/A	N/A
			18”		28°	25'	10'	3'		

Hydraulic Characteristics	Riverbank Material	Riparian Overstory (Type)	Riparian Understory (Type)	Estimated Time In Shade (Percent)	Debris Near Diversion Intake	Natural Instream Structure in General Vicinity of Diversion	Estimated Riverbed Substrate Near Diversion Intake	Juvenile Salmonid Habitat (Overall Quality)	Potential Predator Habitat (Overall Quality)
Bi-Directional Tidal	Gr, We, RR	None	Gr, We	5%	None	None	RR	1	2

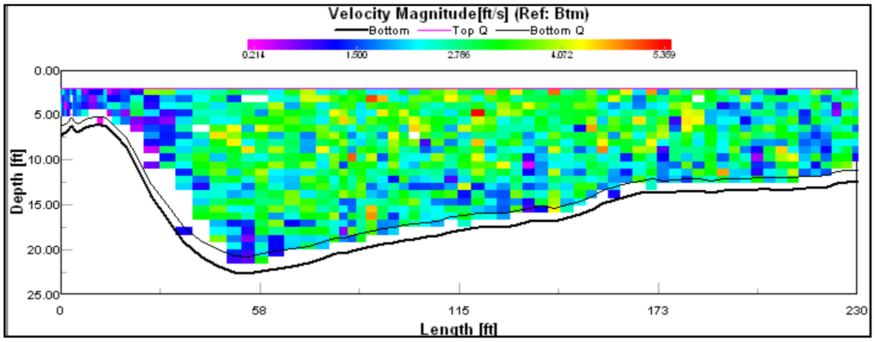
RIPARIAN IDENTIFICATION		RIVERBED SUBSTRATE IDENTIFICATION		DEBRIS NEAR DIVERSION INTAKE		JUVENILE SALMON REARING/PREDATOR HABITAT	
Code	Type	Code	Type	**Code**	**Type**	Code	Quality
Gr	Grasses	Si	Silt	WD-L	Woody Debris - Low Density	1	Poor
Sh	Shrubs	Sa	Sand	WD-M	Woody Debris - Medium Density	2	Fair
So	Soil	Co	Cobble	WD-H	Woody Debris - High Density	3	Good
Mu	Mulberry	RR	Rip-Rap				
TrA	Ash Tree	HP	Hardpan				
TrC	Cottonwood Tree						
TrO	Oak Tree						
TrUn	Unidentified Tree						
TrW	Walnut Tree	Code	Detail		7/22/08		
TrWi	Willow Tree	Non-Op	Non-Operational	Water Temperature:	54°F		
Ve	Vegetation	NA	Not Applicable	Secchi Depth:	0.5'		
We	Weeds	NE	No Estimates	Turbidity (NTUs):	101		

DIDSON™ imaging did not revealed submerged woody debris around the pipe intakes positioned over the riprapped riverbed. Appendix Figure 80 shows a DIDSON™ still image taken at the Sanchez siphon pipes intake.

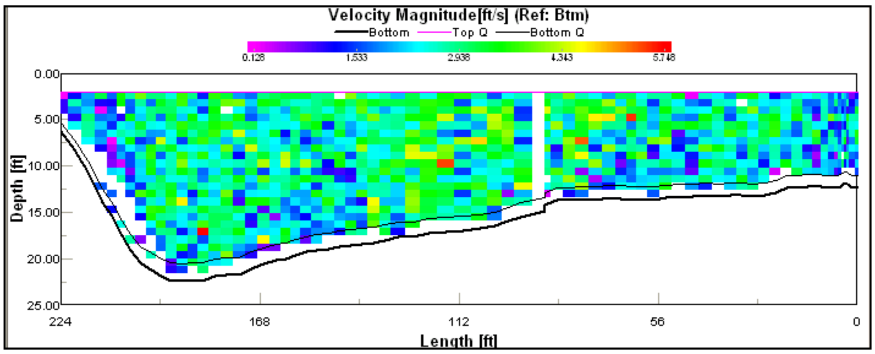


Appendix Figure 80. DIDSON™ still image of the angled pipe intakes at the Sanchez siphon station in Steamboat Slough (looking in an upstream direction). Image taken on December 10, 2012.

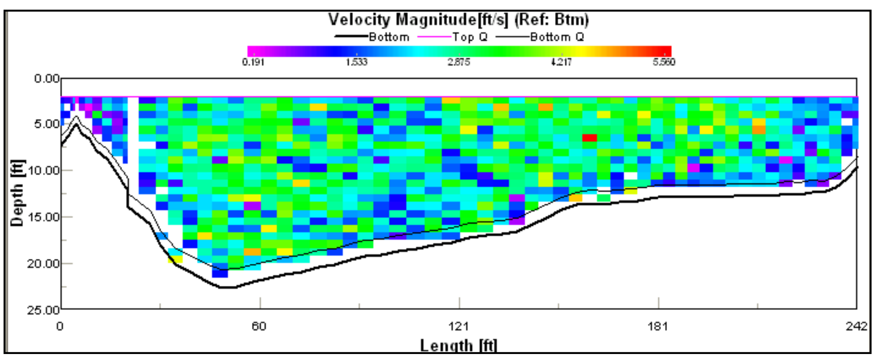
Appendix Figures 81 - 84 show ADCP bathymetry profiles and water velocity distributions across the river channel just upstream and downstream of the Sanchez siphon station as measured on December 10, 2012. The thalweg is located on the left side of the river (facing downstream) on the same side as the pump station intakes. Because the area is subject to strong ebb and flood tidal influence, the distribution of flow across the channel constantly changes but it can be assumed that the highest portion of the flow during either tidal condition is distributed in the left side of river channel due to the location of the thalweg and cross-sectional configuration of the river channel. At the time of the flow measurements, the ebb tide increased from 8,612 cfs during the first transect to 8,959 cfs during the last transect.



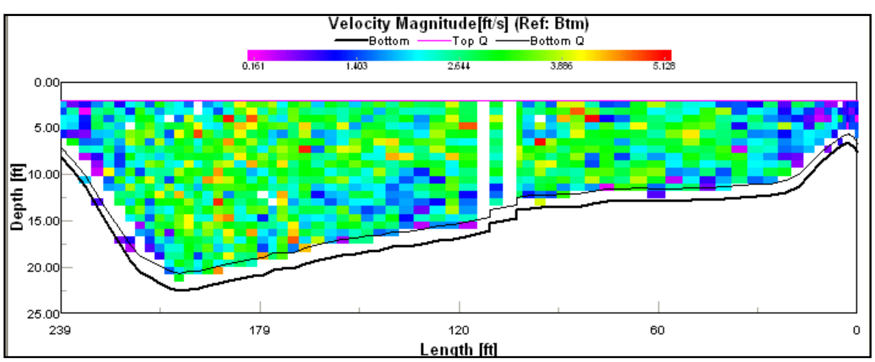
Appendix Figure 81. ADCP transect 1 (facing downstream) measured just downstream of the Sanchez siphon station (located on left bank). Left bank is ~12' from start of transect and right bank is ~20' from end of transect.



Appendix Figure 82. ADCP transect 2 (facing downstream) measured just downstream of the Sanchez siphon station (located on left bank). Left bank is ~5' from start of transect and right bank is ~20' from end of transect.



Appendix Figure 83. ADCP transect 3 (facing downstream) measured just upstream of the Sanchez siphon station (located on left bank). Left bank is ~5' from start of transect and right bank is ~12' from end of transect.



Appendix Figure 84. ADCP transect 4 (facing downstream) measured just upstream of the Sanchez siphon station (located on left bank). Left bank is ~3' from start of transect and right bank is ~10' from end of transect.