Potential Fish Benefits from Screens or Screening Modifications at Sutter Mutual Water Company, Reclamation District 108, and M&T Ranch/Llano Seco

Steven P. Cramer, Doug B. Demko, Colin G. Chapman
Michele L. Simpson, and Gabriel J. R. Kopp
S.P. Cramer & Associates, Inc
demko@spcramer.com

[June 20, 2005]

Abstract

We estimated the annual increase in juvenile Chinook and steelhead survival from screen installation/restoration at four water diversion locations on the Sacramento River (Wilkins Slough, Tisdale, M&T Ranch, and the Consolidated Pumping Facility). Of these four diversions, the largest benefit to salmonids was estimated to come from screen installation at the Tisdale diversion and the Consolidated Pumping Facility diversion. At the Tisdale diversion, late-fall Chinook, steelhead, and fall Chinook would benefit the most from screen installation, with an estimated 1.88%, 1.68%, and 1.42% annual increase in total outmigrant survival, respectively. At the Consolidated Pumping Facility diversion, late-fall Chinook, steelhead, and fall Chinook would also benefit the most from screen installation, with an estimated 0.59%, 0.52%, and 0.44% annual increase in total outmigrant survival, respectively. The majority of fish passage through the section of river adjacent to each of the four diversions is taking place at a time when water diversion is generally low. This temporal separation between run timing and peak water diversion limits the number of fish threatened by any deficiency in screen function, and results in relatively small benefits gained from screen restoration or installation.

Keywords

Fish Screens, Sedimentation, Entrainment, Chinook Salmon, Steelhead, Survival

Table of Contents

Introduction 3
Project Background and Status 3
  Reclamation District 108 5
    Wilkins Slough 5
    Consolidated Pumping Facility 6
  Sutter Mutual Water Company 6
  M&T Ranch/Llano Seco 7
Methods 8
Results 12
Discussion 27
References 29

Introduction

Water diversions, particularly unscreened diversions, are one of many factors that have contributed to the decline of Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) within the Sacramento River watershed (CALFED 2001; NOAA Fisheries 1996, 1997, and 2000). According to the CALFED Bay Delta program (2000),

> the vision … is to reduce the adverse effects of water diversions …by installing fish screens, consolidating or moving diversions to less sensitive locations, removing diversions, or reducing the volume of water diverted.

During Stage 1 of the CALFED implementation program, the expectation is to ensure that screens are installed at all diversions with capacities greater than 7.1 cubic meters per second (cms; 250 cubic feet per second (cfs)) and at a majority of diversions between 2.8-7.1 cms (100-250 cfs; CALFED 2000) In addition, installation of screens at diversions less than 2.8 cms (100 cfs) will be prioritized. As part of Stage 1, several priority restoration activities were identified including consolidating and screening Reclamation District 108's (RD 108) diversions from the Sacramento River; screening Sutter Mutual Water Company's diversions from the Sacramento River; and relocating M&T Ranch/Llano Seco Pumping Plant (CALFED 2001).

As of today, these projects are in varying stages of implementation and there are uncertainties regarding the fish benefits of each. This report provides an overview of the status of each project, and the estimated benefits to salmonids from full implementation of improvements at Wilkins Slough, and an evaluation of the costs.

Project Background and Status

Table 1 provides a summary of four different restoration projects. Each project is described in greater detail immediately following the summary.

Table 1. Summary of proposed restoration actions for Reclamation District 108, Sutter Mutual Water Company, and M&T/Llano Seco diversion facilities.

Restoration Project	Facility	Diversion Maximum Capacity	Problems	Restoration Type	Total Proposed Project Costs	Status
Reclamation District No. 108 Wilkins Slough Positive Barrier Fish Screen-Sediment Removal Project	Wilkins Slough Diversion Fish Screen	2.4 cms (830 cfs)	Unexpected sediment build-up causing reduced screen effectiveness.	Sediment remediation.	$990,000	Funds granted and project under construction. Expected completion: November 2005.
Reclamation District No. 108 Consolidated Pumping Facility and Fish Screen	"Consolidated Pumping Facility" which consists of the consolidation of three existing unscreened diversions (Boyer's Bend, Howell's Landing, and Tyndall Mound) into one screened diversion	Consolidated capacity 7.4 cms (260 cfs)	Three unscreened diversions: • Boyer's Bend- 3.3 cms (116 cfs) • Howell's Landing- 2 cms (71 cfs) • Tyndall Mound- 5.4 cms (190 cfs).	Replace three pumping stations with one pumping station and install fish screen.	$14,400,000	$630,000 awarded for first year. Currently seeking construction funding.
Sutter Mutual Water Company-Tisdale Positive Barrier Fish Screen and Pumping Plant	Tisdale Pumping Plant No. 1 and Tisdale Pumping Plant No. 2	27.2 cms (960 cfs)	Two unscreened pumping plants with six centrifugal pumps.	Install fish screen in front of two existing pumping plants.	$17,453,000	Funds granted and project under construction. Expected completion: May 2007.
M&T/Llano Seco Fish Screen Facility Short-Term/Long-Term Protection Project	M&T/Llano Seco Diversion Fish Screen	4.2 cms (150 cfs)	Unexpected sediment build-up causing reduced screen effectiveness and potentially reduced diversion capacity.	Sediment remediation.	$2,159,850	$636,650 for Tasks 1-7. Two long-term options identified (February 2005). Amendment request to CALFED underway.

Reclamation District 108

Reclamation District No. 108 (RD 108) has several diversion facilities identified by CALFED as screening priorities including Wilkins Slough, Boyer's Bend, Howell's Landing, and Tyndall Mound. These facilities are located on the west side of the side of the Sacramento River between river kilometer (RKM) 169.9 and 189.6 and (river mile (RM) 105.6-117.8) and approximately 72.4 Km (45 miles) northwest of Sacramento, California. The Wilkins Slough facility is composed of seven vertical pumps capable of diverting a combined total of 2.4 cms (830 cfs), while the other facilities are capable of diverting 3.3 cms (116 cfs; Boyer's Bend), 2 cms (71 cfs; Howell's Landing), and 5.4 cms (190 cfs; Tyndall Mound). These latter three facilities are being considered for consolidation into one facility (Consolidated Pumping Facility) that would be located at RKM 177.8 (RM 110.5) and have a maximum capacity of 7.4 cms (260 cfs). RD 108 diversion facilities may be operated from February 1 through October 31 (Witts 2004).

Wilkins Slough

For Wilkins Slough, a vertical flat plate screen with 0.093 inch slot-screen spacing was installed in 1999. The system was designed to meet CDFG and NMFS screening criteria and included numerous advancements such as a single mechanical sediment brush to remove accumulated debris in five minute increments (Proposal 1997). According to the CALFED proposal (CALFED 1997), the total project cost for the project was $11.6 million dollars with a federal contribution of $5.8 million and a CALFED contributed of $5.1 million dollars.

Post-construction monitoring in 1999 and 2000 indicated that, "at peak diversion flows, average approach velocities on individual screen panels were in excess of the 0.33 feet per second performance criterion (CALFED 2004a)." Upon further investigation, it was found that sediment was collecting on the back of the screen at an unexpected rate (i.e., approximately one inch per day; CALFED 2004a). It was determined that sediment deposition would continue to affect the performance of the screen when diversions were near maximum capacity. Therefore, it was agreed that a sediment removal system should be installed to meet the performance criteria (CALFED 2004a)." A pilot sediment removal system study was successfully conducted in 2000 (CH2MHill 2001a) and design plans and specifications were subsequently prepared for construction of the sediment removal system (CH2MHill 2001b).

RD 108 subsequently requested construction funding from CALFED in 2002 and was denied. In 2004, RD 108 submitted a revised proposal for "Reclamation District No. 108 Wilkins Slough Positive Barrier Fish Screen-Sediment Removal Project" to CALFED requesting $495,000 to match a federal contribution of $495,000 (total project cost= $990,000). This project has received a "fund as is" recommendation by CALFED reviewers (CALFED 2004b). RD 108 indicated that as soon as CALFED funding became available, presumably in October of 2004, they were prepared to complete construction by summer 2005 and "performance testing would be during the 2005 irrigation season when the irrigation system could accommodate the maximum diversion rate of 830 cfs

(CALFED 2004a)." The project is currently under construction with an expected completion date of November 2005.

Consolidated Pumping Facility

RD 108 conducted a reconnaissance investigation (CH2MHill 2001c) to evaluate the engineering feasibility, costs, and benefits to screen Boyers Bend, Howells Landing, and Tyndall Mound to reduce the incidental take of protected fish species. The results of this investigation indicated the best solution would be to consolidate the three pumping plants into one facility with a 7.4 cms (260 cfs) capacity and a vertical plate fish screen (CALFED 2002a).

RD 108 requested first year funding of $630,000 from CALFED for the proposed "Reclamation District No. 108 Consolidated Pumping Facility and Fish Screen" which was approved through a directed action in 2003 (CALFED 2003a). The total project cost is estimated at $14,400,000 with an expected total State cost share amount of $7,055,000 (CALFED 2002a). The first year funded project includes design completion, environmental documentation and permitting for the consolidated pumping facility. Currently, efforts are being made to secure construction funding and it is unknown when the project will be completed.

Sutter Mutual Water Company

The Sutter Mutual Water Company's (SMWC) Tisdale diversion facility is located on an east side bend of the Sacramento River at RKm 190.7 (RM 118.5) approximately 72.4 Km (45 miles) northwest of Sacramento, California. The facility consists of two unscreened pumping plants with six centrifugal pumps and a combined intake capacity of 27.2 cms (960 cfs). "Diversions at the Tisdale Pumping Plant typically occur between late March and December (diversion schedules vary between years) depending on water demands (Hanson Environmental, Inc. and Miriam Green Associates 2003)."

Tisdale diversion has been identified as a threat to entrainment and mortality of winter, spring, and fall-run Chinook salmon, steelhead, and other high-risk species, such as Sacramento splittail (*Pogonichthys macrolepidotus*), by both State and Federal fishery agencies (CALFED 2004c). The facility is considered high priority due to its large capacity which is capable of diverting up to nearly 20% of Sacramento River flows (CALFED 2004d).

Over the past several years, SMWC has investigated screening options at the Tisdale diversion facility and has completed a feasibility study, preliminary design and modeling, and environmental documentation in collaboration with state and federal agencies. Based on these investigations, the proposed solution includes consolidating the two pumping plants into one location and providing protection with a vertical flat plate screen that meets screening performance criteria. The screen design consists of an 88.4 m long, 6.7 m wide, 12.2 m high (290 feet X 22 feet X 40 feet) screen and includes 16 screen bays and one blowout panel bay (CALFED 2004c). Each screen bay will be safeguarded against sediment buildup by way of a 150 hp pump-driven sediment removal system and the system will be computer operated to allow for any necessary daily adjustments and screen maintenance (CALFED 2004c).

In 2004, SMWC requested construction funding of $6,856,500 from CALFED for the "Sutter Mutual Water Company Tisdale Positive Barrier Fish Screen Pumping Plants Project" with a total project cost of $17,453,000. Other funding sources were identified as previous CALFED and Proposition 204 funding of $1,870,000, and the U.S. Bureau of Reclamation's 50 percent share of $8,726,500 (CALFED 2004c). This project received a "fund as is" recommendation by CALFED reviewers (CALFED 2004d) and is currently under construction with an expected completion date of May 2007.

M&T Ranch/Llano Seco

In 1997, the M&T/Llano Seco Pumping Facility was relocated from its historic location in Big Chico Creek to a new point of diversion in the Sacramento River (CALFED 2002b). The M&T/Llano Seco diversion facility is now located at the confluence of Big Chico Creek and the Sacramento River approximately six miles southwest of Chico, California. The facility is located on the east bank of the Sacramento River at RKm 311 (RM 193). Above the diversion is a meandering gravel bar and approximately 91.4 m (300 feet) below is the City of Chico's wastewater treatment outfall (Stillwater Sciences 2001). The diversion facility consists of four centrifugal pumps with a 4.2 cms (150 cfs) capacity and cylindrical manifold tee screens (3/32" wedge wire) equipped with an automated air burst cleaner. Operation is allowed from April 1 through December 30 (Witts 2004). Water is diverted to M&T Chico Ranch and Llano Seco Ranch for irrigation, State and Federal Wildlife wetlands to preserve sufficient inundation of wetlands, and Butte Creek to assist in temperature control for salmonids.

In 1997, the relocation of the screening facility cost over $5 million dollars and funding was provided by CALFED and the Central Valley Improvement Act (CALFED 2002b). After construction, river dynamics created substantial sediment depositions causing a significant gravel bar and eddy in front of the pumping plant fish screens and intake, which reduced the screen's ability to meet screen performance criteria and threatens to affect pumping capacity. To correct for the rapidly depleting state of the screen, a short-term solution was implemented in 2001 whereby excavation crews modified the channel and set back the gravel bar to its initial shape in 1995. While the short-term fix temporarily eased concerns, it did not provide a long-term solution.

In 2002, M&T/Llano Seco requested funding of $2,159,850 for the proposed "M&T/Llano Seco Fish Screen Facility Short-Term/Long-Term Protection Project" from CALFED (CALFED 2002b). In 2003, CALFED awarded partial funding (total of $636,650 for Tasks 1-7) for costs associated with forming a Steering Committee and further developing the long-term planning study, with funds set aside to address the short-term fix (CALFED 2003b). The project is designed to achieve short-term protection for the M&T/Llano Seco Fish Screen Facility and the City of Chico's Wastewater Treatment Plant outfall from sediment depositions while a long-term solution to sediment deposition problems is developed with assistance from the Steering Committee. In the event that dredging is need again prior to implementation of the long-term solution, then the District may use the $325,000 set aside for this purpose.

The Steering Committee conducted a two-day workshop in February of 2005 and identified two options for a long-term solution: Ranney collectors and spur dikes (TAC 2005). Ducks Unlimited is leading the study, and an amendment to the current application is being written for CALFED (TAC 2005).

Methods

A key to estimating smolt entrainment in water diversions is to determine the overlap in timing between smolt migration and water diversion. Therefore, it was necessary to first identify two key pieces of information relative to each diversion: 1) the average proportion of the total annual juvenile population passing the river section each week, and 2) the average proportion of mainstem river flow entering the specific diversion each week.

In order to estimate the proportion of total outmigrants (of each race) migrating past each diversion at a given time, we examined juvenile migration data from screw traps operated by the California Department of Fish and Game (CDFG) and the US Fish and Wildlife Service (USFWS). For the Wilkins Slough diversion, the Tisdale diversion, and the Consolidated Pumping Facility (CPF) diversion, juvenile emigration data at Knights Landing (RM 89.5) from 1995-1999 were used to determine relative passage timing (Snider and Titus 1998, Snider and Titus 2000, Snider and Titus 2000a, Snider and Titus 2000b). For the M&T Ranch diversion, juvenile emigration data from a screw trap located in the Glenn-Colusa Irrigation District (GCID) bypass channel (RM 205) from 1997-2000 were used to determine relative passage timing (data provided by Diane Coulon, CDFG). For the screw trap at Knights Landing, it was not necessary to expand the raw catch data to estimate relative passage timing, due to the trap location in the mainstem river (not in a bypass channel) and distance from any water diversion. However, the raw data from GCID needed to be expanded to account for possible bias in fish counts relating to trap placement (in the bypass channel) and varied GCID diversion rates (adjacent to the trap). No mark-recapture studies had been done for this trap, therefore no trap efficiency data was available. However, because juveniles in the Sacramento-San Joaquin River Basin tend to migrate coincidentally with downstream flow, the proportion of the total river volume sampled by the trap was used to expand the catches. Average weekly flow data was obtained from the California Department of Water Resources' California Data Exchange Center (CDEC) at three locations: the mainstem Sacramento River directly above the GCID bypass channel, in the bypass channel itself, and the mainstem Sacramento River directly below the bypass channel. Due to the fact that the trap is located in the GCID bypass channel, the trap numbers had to be expanded twice. The first expansion factor accounted for the proportion of the bypass channel volume not sampled by the trap. The second expansion factor accounted for the proportion of total mainstem volume not diverted into the bypass channel. All trap catches were expanded by the average weekly expansion factors (Appendix A, Table

D). From the trap data at Knights Landing and GCID we were able to estimate the average annual proportion of juveniles (of each race) passing each section of river on a weekly basis (Appendix A, Tables B & C).

Similarly, it was necessary to obtain the average proportion of mainstem flow entering each diversion each week, so that the portion of juvenile migrants encountering the diversion could be estimated (we define the term “encounter” to mean a behavioral response from a juvenile fish resulting directly from the presence of the diversion). Because not every juvenile will encounter the diversion during emigration, it is important that any diversion-related mortality be assessed only on the portion of juvenile migrants encountering the diversion.

We assumed that the proportion of fish encountering the diversions (i.e., the encounter rate) was equal to the proportion of mainstem flow diverted through the pump(s). For example, if on a given week an average of 5% of the mainstem flow was diverted, we assumed that 5% of all the outmigrants passing by the facility that week would encounter the diversion. Average weekly Sacramento River flow at Wilkins Slough from 1989-1994, as well as average weekly diversion rates at Wilkins Slough from 1989-1994 were obtained from Cramer et al. 1993 and Demko et al. 1994 (Appendix A, Table A). However, for the Tisdale diversion, the CPF diversion, and the M&T Ranch diversion we were unable to identify diversion rate data without directly contacting the diversion owner/operator. Therefore, alternate methods were developed to estimate the average proportion of mainstem flow entering these diversions each week.

For both the Tisdale diversion and the CPF diversion, which are located within approximately 2 miles from the Wilkins Slough diversion, we chose to use the average weekly diversion rate (i.e. % of mainstem flow diverted) from Wilkins Slough as a baseline, and scale this value (either up or down) depending on the maximum withdrawal volume at the other two diversions. The maximum withdrawal volume for the Wilkins Slough diversion is ~800 cfs. The maximum withdrawal volume for the Tisdale diversion is ~960 cfs (or 1.2 times that of Wilkins Slough). The maximum withdrawal volume for the CPF diversion is ~300 cfs (or 0.375 times that of Wilkins Slough). Therefore, to estimate the average weekly diversion rate at Tisdale we multiplied the average weekly diversion rate at Wilkins Slough by a factor of 1.2. Similarly, to estimate the average weekly diversion rate at the CPF we multiplied the average weekly diversion rate at Wilkins Slough by a factor of 0.375. For example, if in a given week 5% of the mainstem flow was diverted into Wilkins Slough, we assumed that 6% was diverted into Tisdale (e.g. 5% * 1.2= 6%), and 1.9% was diverted into the CPF (e.g. 5% * 0.375= 1.9%) that same week.

For the M&T Ranch diversion we used a slightly different method to estimate the average weekly diversion rate. Due to the substantial difference in mainstem flow at this location compared to the other three diversion locations (much higher flows at M&T Ranch), simply scaling the average weekly diversion rate at Wilkins Slough by the maximum allowed withdrawal volume at M&T Ranch (as was done at Tisdale and the Consolidated Pumping Facility) would not suffice; it was necessary to also adjust for the higher flow.

This was accomplished through two steps: 1) estimate the average weekly volume of water diverted into the M&T Ranch diversion, and 2) calculate the average weekly proportion of mainstem flow diverted utilizing flow data near the M&T Ranch diversion.

We estimated the average weekly volume of water diverted into M&T Ranch by first calculating the average weekly volume of water diverted into Wilkins Slough. Next, we scaled this value (either up or down) depending on the maximum allowed withdrawal volume at M&T Ranch. The maximum withdrawal volume for the Wilkins Slough diversion is ~800 cfs, and for the M&T Ranch diversion is ~150 cfs (or 0.188 times that of Wilkins Slough). Therefore, to estimate the volume of water diverted into M&T Ranch we multiplied the volume of water diverted into Wilkins Slough by a factor of 0.188. For example, if in a given week 200 cfs was diverted into Wilkins Slough, we assumed that 37.5 cfs was diverted into M&T that same week (e.g. 200 * 0.1875= 37.5).

Once we estimated the average weekly volume of water diverted into M&T Ranch, it was then necessary to calculate the average weekly proportion of mainstem flow diverted utilizing flow data near the M&T Ranch diversion location. Flow data from the mainstem Sacramento River at Hamilton City from 1991-2003 was used to estimate average weekly flow volume. The average weekly proportion of flow diverted into M&T Ranch was then calculated by dividing the average weekly volume of water diverted by the average weekly mainstem flow volume (Appendix A, Table E).

After acquiring the necessary data, estimation of potential gains to juvenile survival at the population level from screen installation or restoration was calculated for each race, at each location, through a multi-step process:

1. Determine the average proportion of the total annual juvenile population passing the river section each week
2. Determine the average proportion of mainstem river flow entering the specific diversion each week
3. Multiply the above proportions to estimate the proportion of the emigrating population that encountered the diversion each week (i.e. the encounter rate)

4a. For diversions with a screen currently installed: Multiply the encounter rate by a range of assumed screen-related mortality rates (2%, 10%, 20%, and 30%) to determine the proportion of fish (of those encountering the screen) killed by the screen encounter.

4b. For diversions without a screen currently installed: Assume that the encounter rate is equal to the proportion of fish killed by the diversion encounter (i.e. all fish directly encountering the diversion are entrained and killed).

5. Sum the weekly proportion of fish *not* encountering the diversion/screen, and the weekly proportion of fish *surviving* the diversion/screen encounter, to obtain a weekly estimate of the overall survival rate of a given race.
6. Sum the weekly estimates of overall survival to obtain an annual estimate of total outmigrant survival past the diversion for each race.
7. Calculate the increase in total annual outmigrant survival between the 2% screen-related mortality rate (representing the installed, unsedimented screen condition) and

either: 1) the 10, 20, or 30% screen-related mortality rate (representing a range of current, sedimented screen conditions), or 2) the general encounter rate (representing the current unscreened condition where all encounters result in mortality).

As a hypothetical example for a screened diversion, if 10% of all outmigrants encountered the screen, and 50% of those died (representing an inefficient screen), then the overall population mortality is 5% (95% survival rate). If, on the other hand, 10% of all outmigrants encountered the screen, and only 2% of those died (representing an updated/efficient screen), then the overall population mortality is 0.02% (99.8% survival rate). Therefore, the overall increase in survival after updating the screen would be 4.8% (99.8%-95%).

As a hypothetical example for an unscreened diversion, if 10% of all outmigrants encountered the diversion, and all of those were entrained and died, then the overall population mortality is 10% (90% survival rate). If, on the other hand, a screen was installed and 10% of all outmigrants encountered the screen, and only 2% of those died (representing an updated/efficient screen), then the overall population mortality is 0.2% (99.8% survival rate). Therefore, the overall increase in survival after screen installation would be 9.8% (99.8%-90%).

A Microsoft Excel spreadsheet was formatted to calculate (for each race at each diversion) the weekly proportion of all juveniles encountering the given diversion as well as the proportion of individuals surviving downstream migration under different screen/diversion related mortality rates. For both the Wilkins Slough and the M&T Ranch diversion, data were not available from which to estimate the degree of current screen sedimentation and the subsequent effect on juvenile salmonids. Modern fish screens are generally constructed to meet or exceed the NOAA fish screen criteria of an average approach velocity (water velocity perpendicular to the screen) less than 0.33 feet per second for fry and less than 0.80 feet per second for fingerlings in streams (NOAA 1997). However, when a screen becomes clogged with sediment the screen is less efficient and will presumably kill a greater proportion of fish. For example, if a screen operating at a 200 cfs diversion and exhibiting a 0.33 feet per second approach velocity becomes 50% clogged with sediment, that same screen, at the same diversion rate, will now exhibit a 0.66 feet per second approach velocity. This increased approach velocity resulting from increased sediment loads would likely impinge more juveniles, and thus kill a greater proportion of fish than would a clean screen.

Under optimal conditions, a modern fish screen has been shown to function with ~98% efficiency (NOAA 1994). That is, a properly installed, clean fish screen will likely only kill up to ~2% of all fish encountering the screen. Therefore, for both the Wilkins Slough and the M&T Ranch diversion, we chose to calculate juvenile survival at four assumed levels of sedimentation: no sedimentation (2% screen related mortality), light sedimentation (10% screen related mortality), moderate sedimentation (20% screen related mortality), and heavy sedimentation (30% screen related mortality).

The annual increase in outmigrant survival from fish screen restoration at both the Wilkins Slough and the M&T Ranch diversion was estimated (for each run) as the difference in total annual survival between the range of assumed current conditions (10, 20, and 30% screen related mortality), and the restored condition (2% screen related mortality). The annual increase in outmigrant survival from fish screen installation at the CPF and Tisdale diversions was estimated (for each run) as the difference in total annual survival between the current condition (no screen, where the current mortality rate is equal to the encounter rate), and the updated condition (2% screen related mortality).

Results

Results from analyses of the Wilkins Slough and M&T Ranch diversions (i.e. diversions with screens) are presented in Table 1. The table displays the estimated annual increase in total outmigrant survival (for each race) resulting from screen restoration at each diversion (based on assumed levels of current screen-related mortality per encounter). The increase in survival is estimated as the difference between the proportion of fish surviving passage with a properly functioning screen (2% mortality per encounter rate), and the proportion of fish surviving passage with a poorly functioning screen (10%, 20%, or 30% mortality per encounter rate).

Table 1. Estimated annual increase in total outmigrant survival resulting from screen restoration at both Wilkins Slough and M&T Ranch at three assumed levels of screen-related mortality.

Diversion	Run	Annual Increase in Total Outmigrant Survival		
		10% Screen-Related Mortality Per Encounter	20% Screen-Related Mortality Per Encounter	30% Screen-Related Mortality Per Encounter
Wilkins Slough	Fall Chinook	0.10%	0.22%	0.34%
	Spring Chinook	0.01%	0.03%	0.04%
	Winter Chinook	0.02%	0.05%	0.07%
	Late-Fall Chinook	0.13%	0.29%	0.45%
	Steelhead	0.11%	0.26%	0.40%
M&T Ranch	Fall Chinook	0.01%	0.01%	0.02%
	Spring Chinook	0.01%	0.01%	0.02%
	Winter Chinook	0.00%	0.01%	0.01%
	Late-Fall Chinook	0.00%	0.01%	0.01%
	Steelhead	0.00%	0.01%	0.01%

Results from the analyses of the CPF diversion and the Tisdale diversion (i.e. diversions with no screens currently in place) are presented below in Table 2. The main body of the table displays the estimated annual increase in total outmigrant survival (for each race) resulting from screen installation. The increase in survival is estimated as the difference between the proportion of fish surviving passage with a properly functioning screen (2% mortality per encounter rate), and the proportion of fish surviving passage without any screen covering the diversion (where the current mortality rate is equal to the encounter rate).

Table 2. Estimated annual increase in total outmigrant survival resulting from screen installation at the Tisdale diversion.

Diversion	Run	Increase in total outmigrant survival
Tisdale	Fall Chinook	1.42%
	Spring Chinook	0.17%
	Winter Chinook	0.31%
	Late-Fall Chinook	1.88%
	Steelhead	1.68%
CPF	Fall Chinook	0.44%
	Spring Chinook	0.05%
	Winter Chinook	0.10%
	Late-Fall Chinook	0.59%
	Steelhead	0.52%

The figures below show the timing and magnitude of the Wilkins Slough diversion (Figure 1) and the M&T Ranch diversion (Figure 2) in relation to total (i.e., Chinook and steelhead combined) juvenile salmonid fish passage as observed at either Knight's Landing or GCID. The Wilkins Slough water diversion generally operates from the middle of February through the end of September, with peak diversion rates from May through early September. No data were available to quantify the precise timing or magnitude of water diversion at Tisdale, M&T Ranch, or the CPF diversion. However, because all diversions are used exclusively for irrigation of agricultural fields in California's Central Valley, it is reasonable to assume a general similarity in water diversion timing.

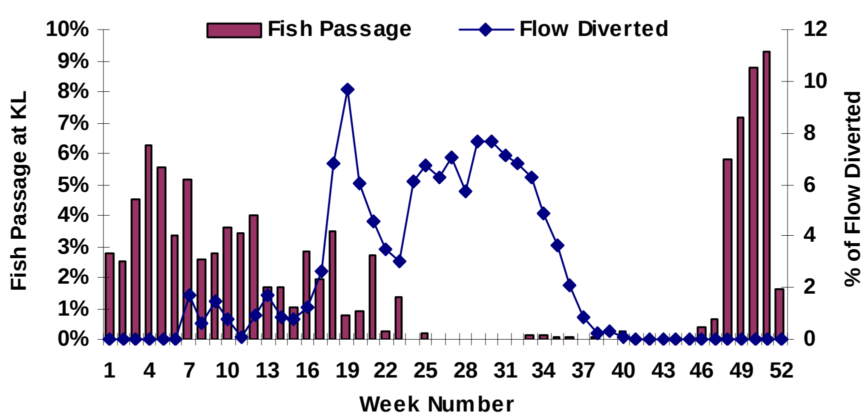

Figure 1. Timing and magnitude of the Wilkins Slough diversion in relation to combined (Chinook and steelhead) juvenile salmonid passage as observed at Knight's Landing. Fish passage data at Knights landing, 1995-1999 (Snider and Titus 1998, Snider and Titus 2000, Snider and Titus 2000a, Snider and Titus 2000b). Flow data at Wilkins Slough, 1989-1994 (Cramer et al. 1993 and Demko et al. 1994).

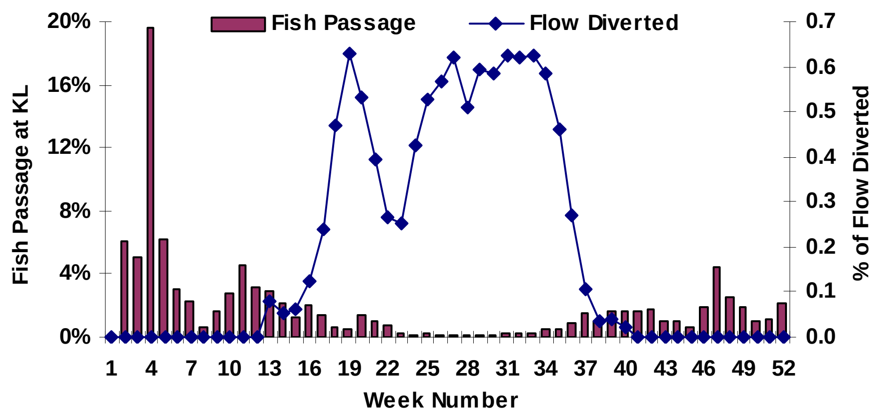

Figure 2. Timing and magnitude of the M&T Ranch diversion in relation to combined (Chinook and steelhead) juvenile salmonid passage as observed at GCID. Fish passage data at GCID, 1997-2000 (Diane Coulon, CDFG). See methods section for derivation of diverted flow.

Given these times of operation, it is apparent that the majority of fish passage through these two sections of river is taking place at a time when water diversion is either low or not taking place at all (Figures 1 and 2). This temporal and spatial separation between run timing and peak water diversion limits the number of fish threatened by any deficiency in screen function. This, in turn, effectively reduces the estimated encounter rate, and the overall benefit gained from screen restoration or installation.

For example, for Fall-run Chinook at Wilkins Slough, the overall encounter rate (i.e. the annual proportion of all outmigrants encountering the diversion) was estimated at only 1.21%. That is, on average, only 1.21% of all juvenile Fall Chinook will encounter the Wilkins Slough diversion each year. Overall encounter rates for all runs at each diversion were as follows (Table 3):

Table 3. Overall encounter rates at Wilkins Slough, Tisdale, CPF, and M&T Ranch diversions for each run of salmonid.

Diversion	Run	Overall Encounter Rate
Wilkins Slough	Fall Chinook	1.21%
	Spring Chinook	0.14%
	Winter Chinook	0.26%
	Late-Fall Chinook	1.60%
	Steelhead	1.43%
Tisdale	Fall Chinook	1.45%
	Spring Chinook	0.17%
	Winter Chinook	0.32%
	Late-Fall Chinook	1.92%
	Steelhead	1.71%
CPF	Fall Chinook	0.45%
	Spring Chinook	0.05%
	Winter Chinook	0.10%
	Late-Fall Chinook	0.60%
	Steelhead	0.53%
M&T Ranch	Fall Chinook	0.08%
	Spring Chinook	0.06%
	Winter Chinook	0.03%
	Late-Fall Chinook	0.05%
	Steelhead	0.04%

Wilkins Slough

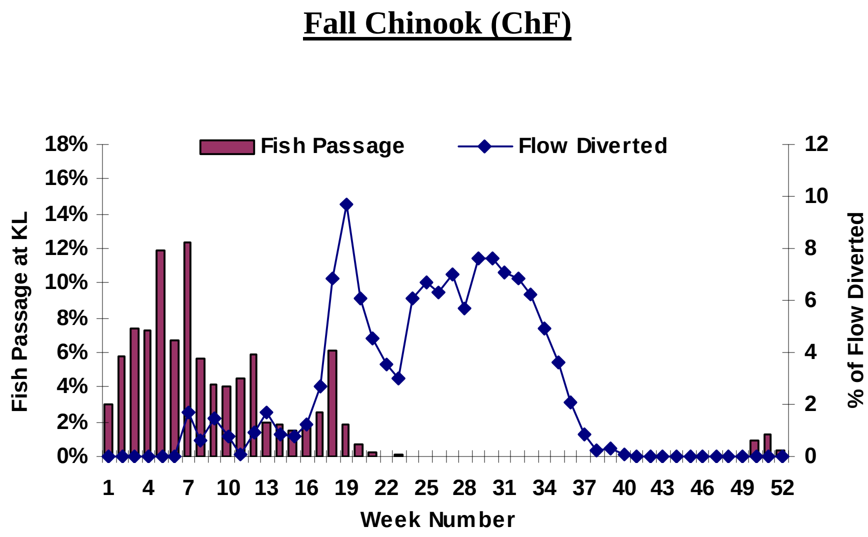

Figure 3. Timing and magnitude of the Wilkins Slough diversion in relation to juvenile fall Chinook passage as observed at Knight's Landing. Fish passage data at Knights landing, 1995-1999 (Snider and Titus 1998, Snider and Titus 2000, Snider and Titus 2000a, Snider and Titus 2000b). Flow data at Wilkins Slough, 1989-1994 (Cramer et al. 1993 and Demko et al. 1994).

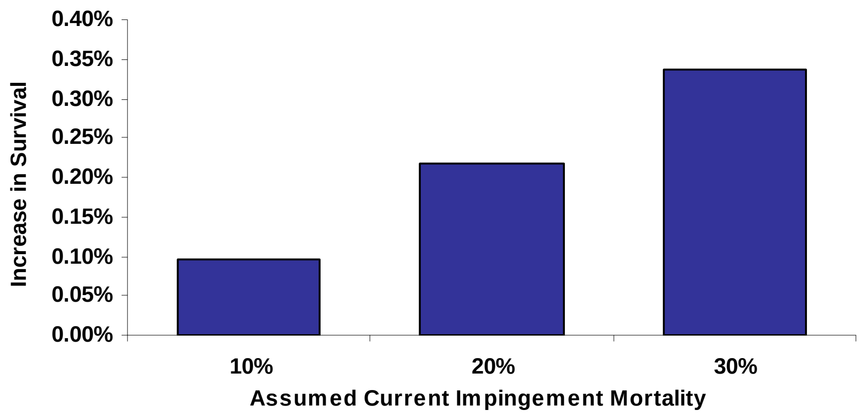

Figure 4. Estimated annual increase in juvenile fall Chinook survival at three levels of assumed current screen related mortality at the Wilkins Slough diversion.

Spring Chinook (ChS)

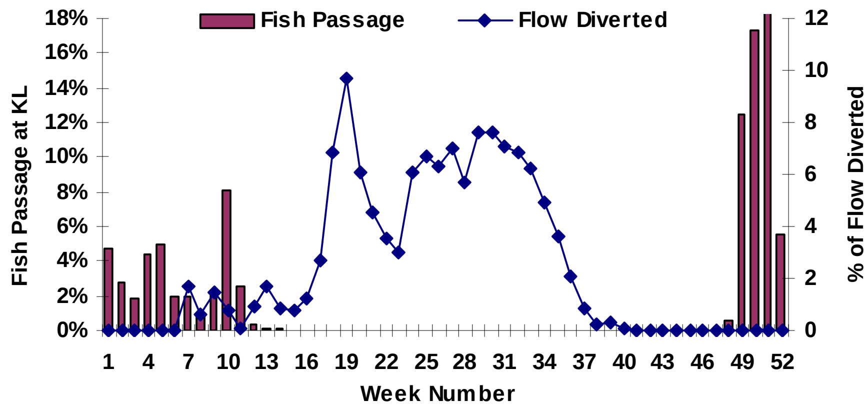

Figure 5. Timing and magnitude of the Wilkins Slough diversion in relation to juvenile spring Chinook passage as observed at Knight's Landing. Fish passage data at Knights landing, 1995-1999 (Snider and Titus 1998, Snider and Titus 2000, Snider and Titus 2000a, Snider and Titus 2000b). Flow data at Wilkins Slough, 1989-1994 (Cramer et al. 1993 and Demko et al. 1994).

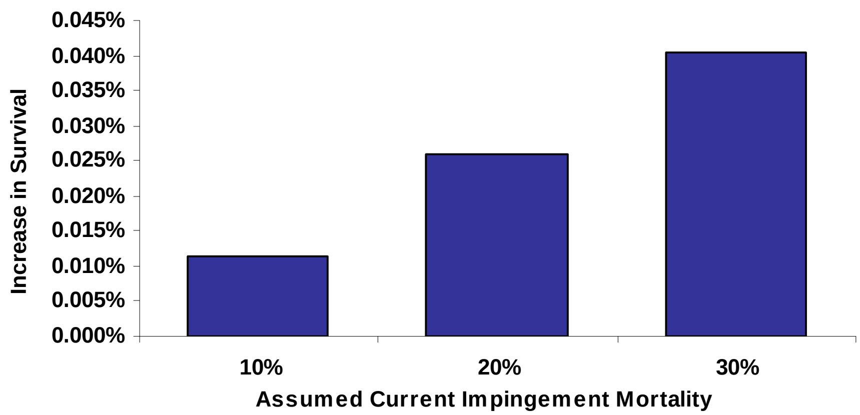

Figure 6. Estimated annual increase in juvenile spring Chinook survival at three levels of assumed current screen related mortality at the Wilkins Slough diversion.

Winter Chinook (ChW)

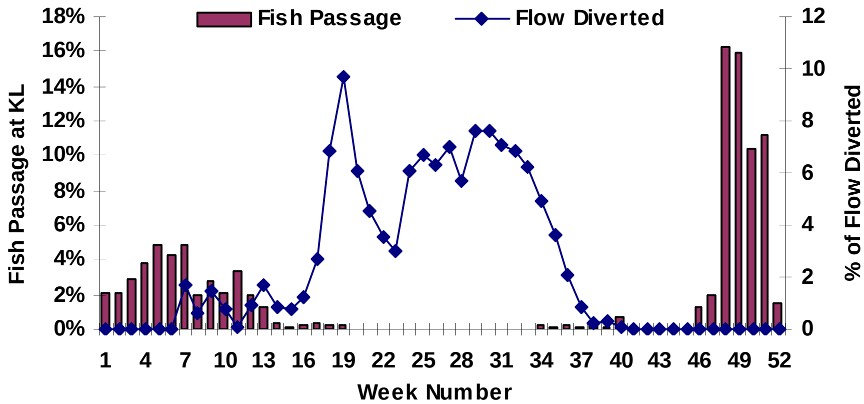

Figure 7. Timing and magnitude of the Wilkins Slough diversion in relation to juvenile winter Chinook passage as observed at Knight's Landing. Fish passage data at Knights landing, 1995-1999 (Snider and Titus 1998, Snider and Titus 2000, Snider and Titus 2000a, Snider and Titus 2000b). Flow data at Wilkins Slough, 1989-1994 (Cramer et al. 1993 and Demko et al. 1994).

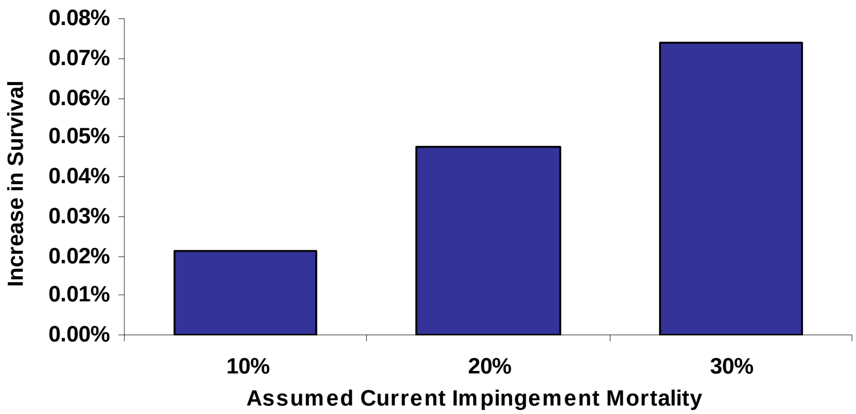

Figure 8. Estimated annual increase in juvenile winter Chinook survival at three levels of assumed current screen related mortality at the Wilkins Slough diversion.

Late-Fall Chinook (ChLF)

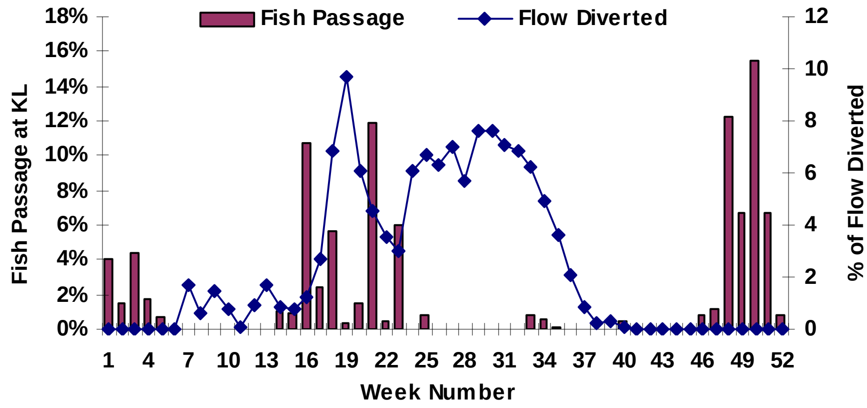

Figure 9. Timing and magnitude of the Wilkins Slough diversion in relation to juvenile late-fall Chinook passage as observed at Knight's Landing. Fish passage data at Knights landing, 1995-1999 (Snider and Titus 1998, Snider and Titus 2000, Snider and Titus 2000a, Snider and Titus 2000b). Flow data at Wilkins Slough, 1989-1994 (Cramer et al. 1993 and Demko et al. 1994).

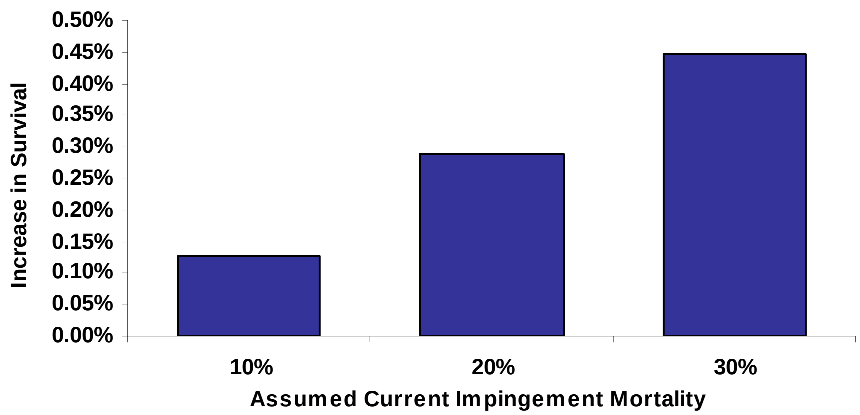

Figure 10. Estimated annual increase in juvenile late-fall Chinook survival at three levels of assumed current screen related mortality at the Wilkins Slough diversion.

Steelhead (StH)

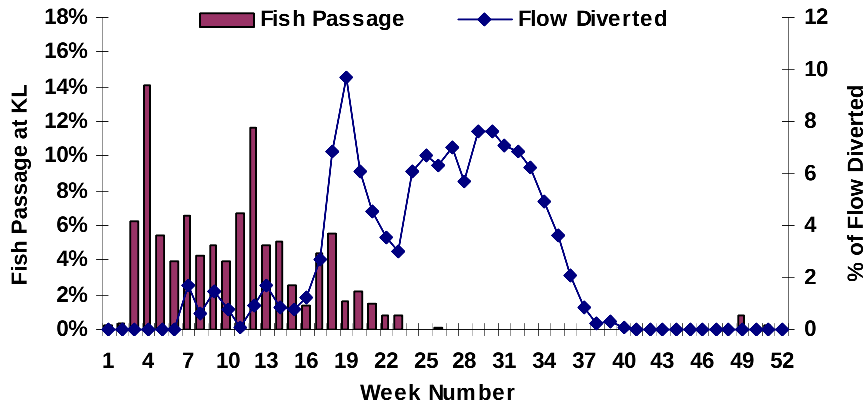

Figure 11. Timing and magnitude of the Wilkins Slough diversion in relation to juvenile steelhead passage as observed at Knight's Landing. Fish passage data at Knights landing, 1995-1999 (Snider and Titus 1998, Snider and Titus 2000, Snider and Titus 2000a, Snider and Titus 2000b). Flow data at Wilkins Slough, 1989-1994 (Cramer et al. 1993 and Demko et al. 1994).

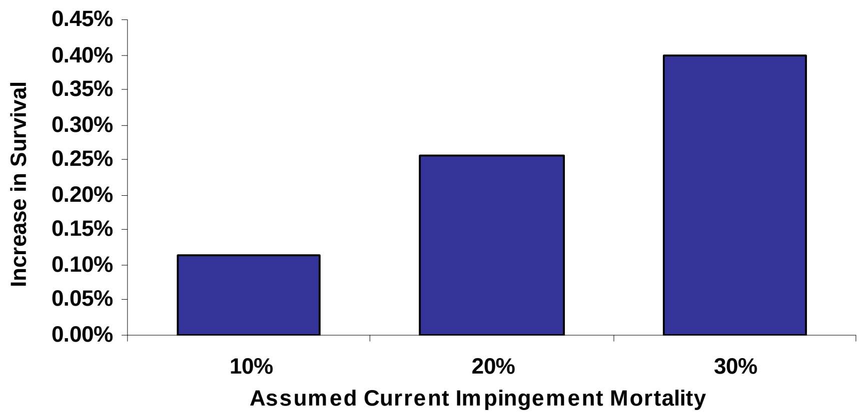

Figure 12. Estimated annual increase in juvenile steelhead survival at three levels of assumed current screen related mortality at the Wilkins Slough diversion.

Tisdale

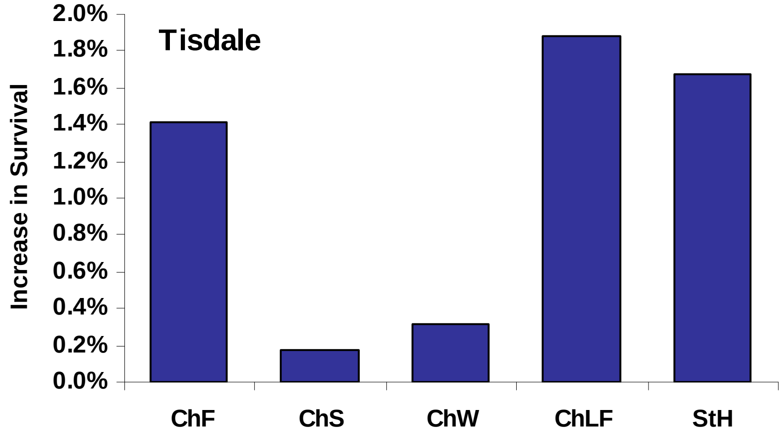

Figure 13. Estimated annual increase in juvenile salmonid survival (all runs) from screen installation at the Tisdale diversion.

Consolidated Pumping Facility

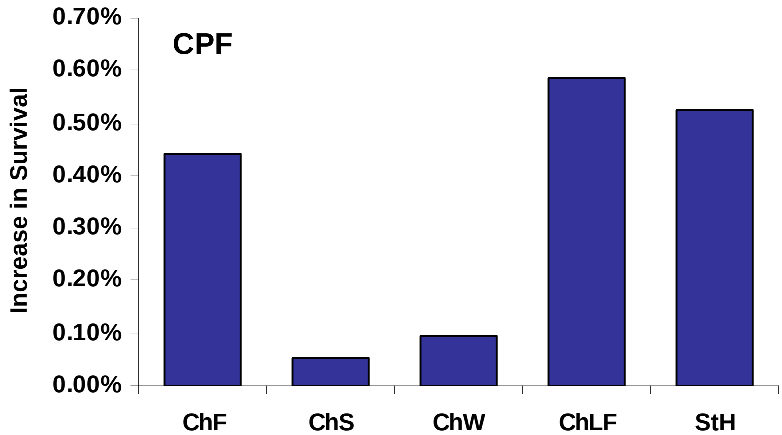

Figure 14. Estimated annual increase in juvenile salmonid survival (all runs) from screen installation at the CPF diversion.

M&T Ranch

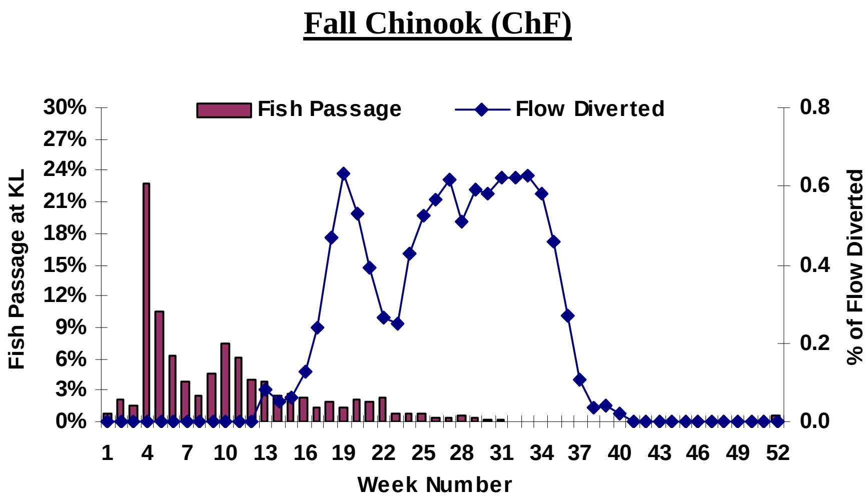

Figure 15. Timing and magnitude of the M&T Ranch diversion in relation to juvenile fall Chinook passage as observed at GCID. Fish passage data at GCID, 1997-2000 (Diane Coulon, CDFG). See methods section for derivation of diverted flow.

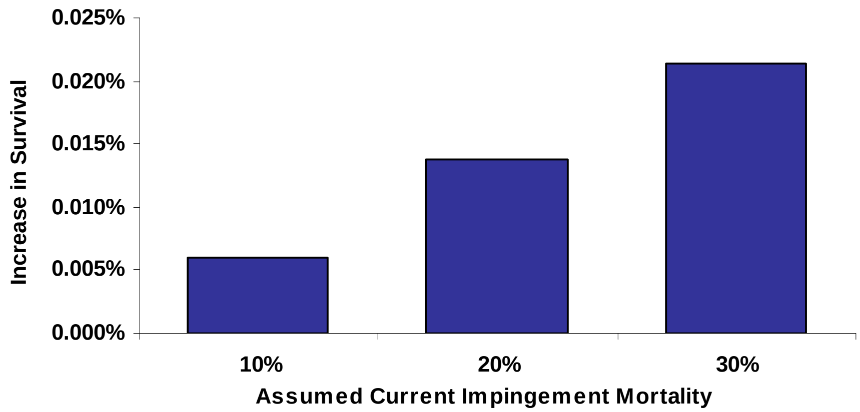

Figure 16. Estimated annual increase in juvenile fall Chinook survival at three levels of assumed current screen related mortality at the M&T Ranch diversion.

Spring Chinook (ChS)

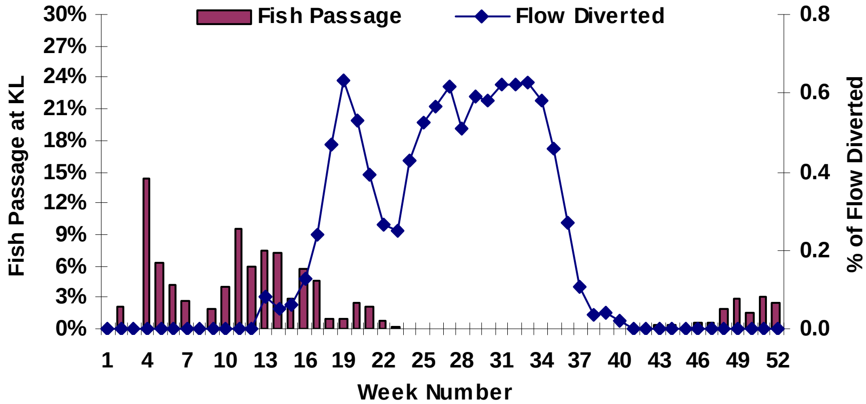

Figure 17. Timing and magnitude of the M&T Ranch diversion in relation to juvenile spring Chinook passage as observed at GCID. Fish passage data at GCID, 1997-2000 (Diane Coulon, CDFG). See methods section for derivation of diverted flow.

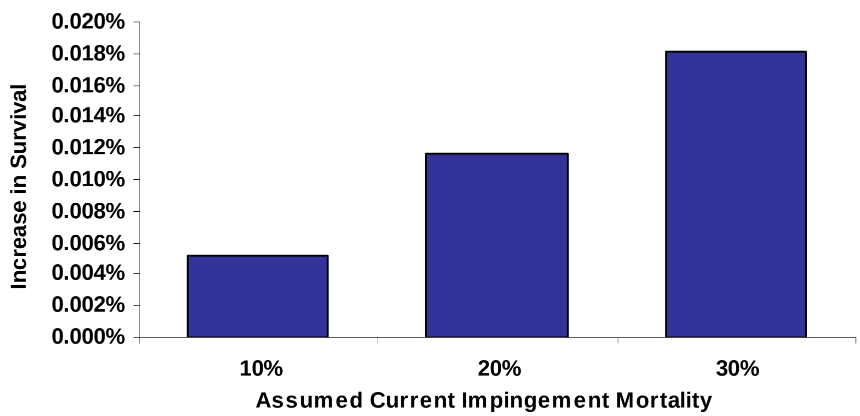

Figure 18. Estimated annual increase in juvenile spring Chinook survival at three levels of assumed current screen related mortality at the M&T Ranch diversion.

Winter Chinook (ChW)

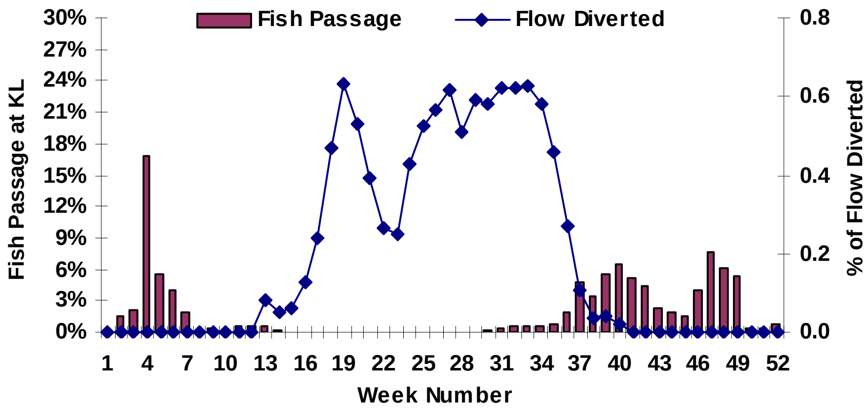

Figure 19. Timing and magnitude of the M&T Ranch diversion in relation to juvenile winter Chinook passage as observed at GCID. Fish passage data at GCID, 1997-2000 (Diane Coulon, CDFG). See methods section for derivation of diverted flow.

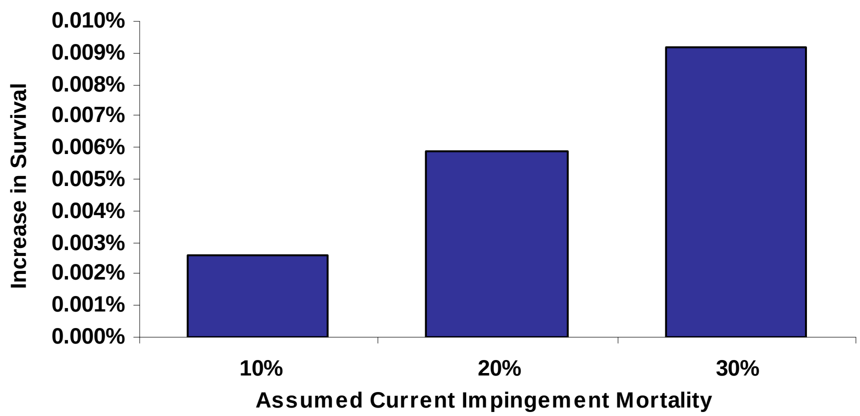

Figure 20. Estimated annual increase in juvenile winter Chinook survival at three levels of assumed current screen related mortality at the M&T Ranch diversion.

Late-Fall Chinook (ChLF)

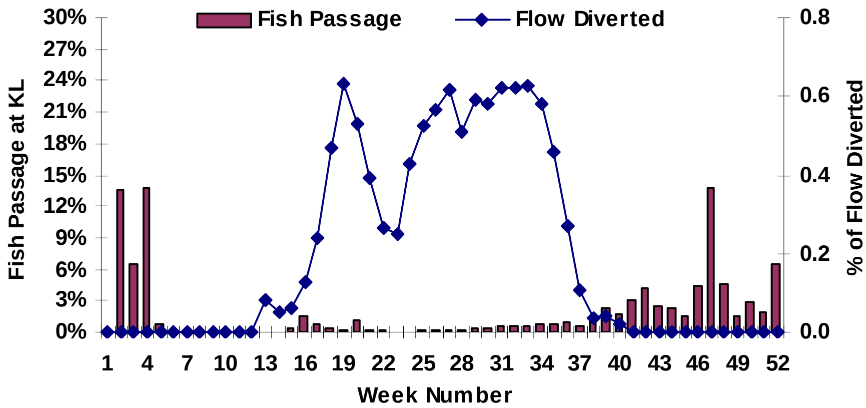

Figure 21. Timing and magnitude of the M&T Ranch diversion in relation to juvenile late-fall Chinook passage as observed at GCID. Fish passage data at GCID, 1997-2000 (Diane Coulon, CDFG). See methods section for derivation of diverted flow.

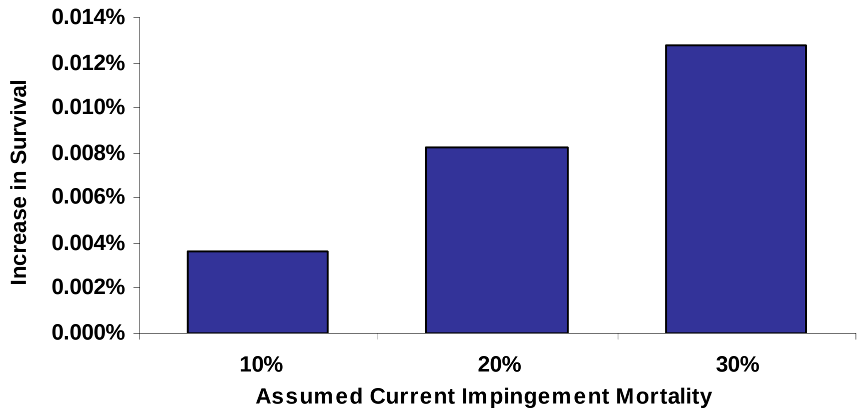

Figure 22. Estimated annual increase in juvenile late-fall Chinook survival at three levels of assumed current screen related mortality at the M&T Ranch diversion.

Steelhead (StH)

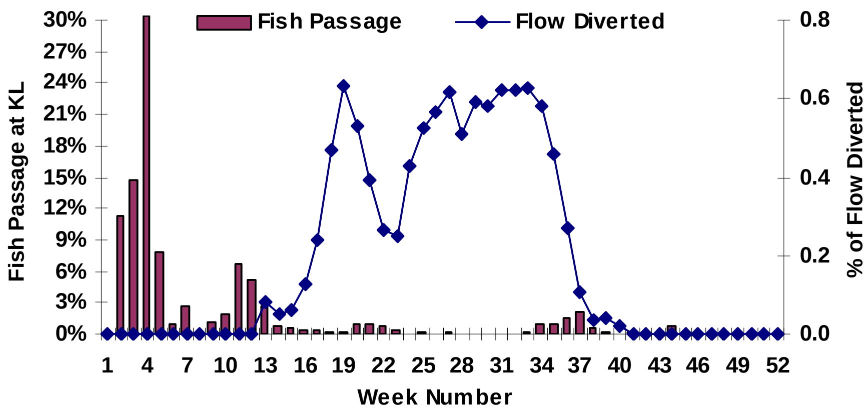

Figure 23. Timing and magnitude of the M&T Ranch diversion in relation to juvenile steelhead passage as observed at GCID. Fish passage data at GCID, 1997-2000 (Diane Coulon, CDFG). See methods section for derivation of diverted flow.

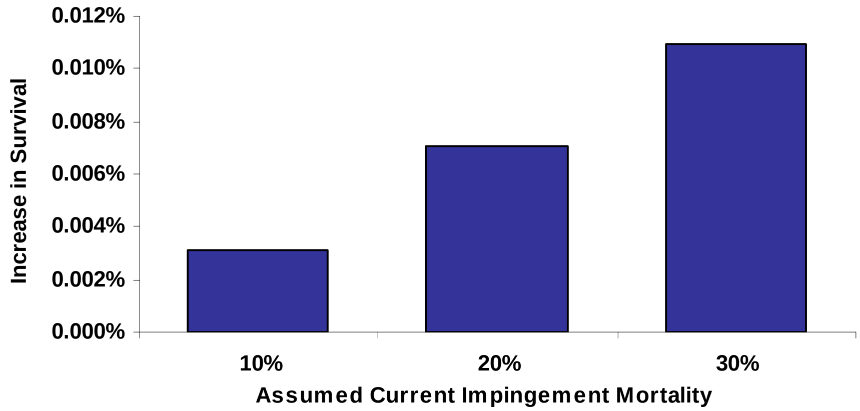

Figure 24. Estimated annual increase in juvenile steelhead survival at three levels of assumed current screen related mortality at the M&T Ranch diversion.

Discussion

From the four diversions analyzed in this study, the largest benefit to salmonids from screen installation/restoration was estimated to come from screen installation at the Tisdale diversion and the CPF diversion. These diversions are currently unscreened, and as a result all fish that come in direct contact with either diversion are entrained and killed. The other two diversions have a screen in place, which blocks entrainment of the majority of fish coming in contact with the diversion. At the Tisdale diversion, late-fall Chinook, steelhead, and fall Chinook would benefit the most from screen installation, with an estimated 1.88%, 1.68%, and 1.42% annual increase in total outmigrant survival, respectively. At the CPF diversion, late-fall Chinook, steelhead, and fall Chinook would also benefit the most from screen installation, with an estimated 0.59%, 0.52%, and 0.44% annual increase in total outmigrant survival, respectively.

When estimating the benefits of screen installation or restoration, the effect of the partition between run timing and water diversion is evident, not only in the encounter rate, but in the small proportional gains to survival estimated for all runs from screen installation or restoration activities. Fall Chinook, late-fall Chinook, and steelhead generally exhibited the most temporal overlap between run timing and water diversion activity. As a result, these runs tended to show the highest percent increase in survival from screen installation/restoration at all the diversions (however, spring Chinook showed the second largest increase in survival at M&T). That being said, the benefit to these fish is still small (<1%) at the diversion locations where a screen currently exists (even if 30% of all encounters resulted in death). At the two unscreened diversion locations, benefits increase substantially, however still remain below 2%. If the migration timing of juvenile salmonids overlapped more with the timing of a given water diversion, which may be the case for other water diversions sites on the Sacramento River, the estimated benefits to survival from screen installation/restoration would be greater per volume of water diverted.

It is important to note that the estimates of mortality rate presented here are built on a number of assumptions, and should only be used to determine if potential benefits make the project reasonably cost effective compared to other options for investment. Studies at Wilkins Slough and the Princeton Pumping Plant (Hanson 2001) have shown that juvenile Chinook entrainment was less than one tenth the proportion of flow diverted. If that were true at the sites we analyzed, we have over estimated benefits (by assuming the encounter rate is proportional to % of flow diverted). On the other hand, studies by Cramer and Demko (1993) have demonstrated that juvenile Chinook entrainment (per volume of water diverted) increased linearly as the volume of the diversion increased. That is, more fish are entrained per acre-foot of water as the flow into the diversion increases. Although diversion and encounter rates may differ from our assumptions, the values we generated should provide a reasonable estimate for these sites.

Additionally, there is some evidence that the location of a diversion may affect fish encounter rates. Acoustic tracking studies near the Delta cross-channel (USBR 2004) suggest that juvenile Chinook tend to be more concentrated in the heavier flows on the outside of bends in the river channel (as compared to the slower flows on the inside of the bends). However, even though most fish are on the outside bend, the proportion of fish encountering the diversion is still dependent on the volume of the diversion. Water diversions are frequently constructed on the outside of bends in the river channel to take advantage of the larger flows. All diversions in this study were constructed on the outside of bends in the river channel.

Ultimately, entrainment rates at a given location will be determined by diversion timing, channel configuration, and the pumping rate. These questions leave us with a high level of uncertainty about theoretical estimates of entrainment at any given diversion. If the investment in screening appears warranted, we recommend actual studies of fish entrainment at the subject sites be conducted to more accurately determine diversion-specific entrainment rates, and the overall benefits to fish from screen installation/restoration. Additionally, actual diversion rate data must be obtained to precisely characterize specific diversion timing and magnitude.

Cost-Benefit Analysis

Jim Watson is conducting a cost-benefit evaluation.

References

CALFED [CALFED Bay-Delta Program]. 2004a. Reclamation District No. 108 Wilkins Slough Positive Barrier Fish Screen-Sediment Removal Project. Available at: http://calwater.ca.gov/Programs/EcosystemRestoration/2004_DirectedActions/Wilkins_Slough_Positive_Barrier.pdf

CALFED. 2004b. CALFED Panel proposal review: Reclamation District No. 108 Wilkins Slough Positive Barrier Fish Screen-Sediment Removal Project. Available at: http://calwater.ca.gov/Programs/EcosystemRestoration/2004_DirectedActions/Review_Wilkins_Slough_Postitive_Barrier.pdf

CALFED. 2004c. CALFED Fish Screen Funding Proposal Sutter Mutual Water Company Tisdale Positive Barrier Fish Screen Pumping Plants (September 29, 2004). Available at: http://calwater.ca.gov/Programs/EcosystemRestoration/2004_DirectedActions/Sutter_Mutual_Water_Company.pdf

CALFED. 2004d. CALFED Panel proposal review: Sutter Mutual Water Company Tisdale Positive Barrier Fish Screen Pumping Plants. Available at: http://calwater.ca.gov/Programs/EcosystemRestoration/2004_DirectedActions/Review_Sutter_Mutual_Water_Company.pdf

CALFED. 2003a. Directed actions awarded: Proposal # 116DA Reclamation District No. 108 Consolidated Pumping Facility and Fish Screen. Available at: http://calwater.ca.gov/Programs/EcosystemRestoration/Ecosystem2003DirectedActionsAwarded.asp

CALFED. 2003b. Directed actions awarded: Proposal # 89DA M&T/Llano Seco Fish Screen Facility - Short-Term/Long-Term Protection Project. Available at: http://calwater.ca.gov/Programs/EcosystemRestoration/Ecosystem2003DirectedActionsAwarded.asp

CALFED. 2002a. Reclamation District No. 108 Consolidated Pumping Facility and Fish Screen. Available at: https://ecosystem.calfed.ca.gov/WRRC/CalFed/people/luhintz/proposal/100093813651/compilation-b

CALFED. 2002b. M&T/Llano Seco Fish Screen Facility Short-Term/Long-Term Protection Project. Available at: http://calwater.ca.gov/Programs/EcosystemRestoration/2002_Proposals/MT_Llano_Seco_89DA.pdf

CALFED. 2002c. ERP Directed Actions proposal review: M&T/Llano Seco Fish Screen Facility – Short-Term/Long-Term Protection Project. Available at: http://calwater.ca.gov/Programs/EcosystemRestoration/2002_Proposals/Review_89DA.pdf

CALFED. 2001. Ecosystem Restoration Program Draft Stage 1 Implementation Plan August 6, 2001.

CALFED Bay-Delta Program. 2000. Ecosystem Restoration Program Plan Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIR Technical Appendix.

CALFED. 1997. Positive barrier fish screen project Wilkins Slough Pumping Plant. Available at: http://calwater.ca.gov/Programs/EcosystemRestoration/PSPs/1997/1997.pdf (#F1-175)

CH2MHill. 2001a. RD108 Wilkins Slough positive barrier fish screen sediment removal pilot study. February 2001.

CH2MHill. 2001b. RD108 Wilkins Slough positive barrier fish screen sediment removal facility. Plans and Specifications. August 2001.

CH2MHill. 2001c. RD 108 fish screen reconnaissance investigation report. September.

Cramer, S.P., E.S. Van Dyke, and D.B. Demko. 1993. Evaluation of sound and electrical fish guidance systems at the Wilkins Slough diversion operated by Reclamation District 108. 1993 Annual Report. Report submitted to Reclamation District 108 and the US Bureau of Reclamation by S.P. Cramer and Associates, Inc.

Cramer, S.P. and D.B. Demko. 1993. Evaluation of juvenile chinook entrainment at six unscreened water diversions along the Sacramento River by Reclamation District 108. 1992 Annual Report. Report submitted to Downey, Brand, Seymour, and Rohwer Attorneys by S.P. Cramer and Associates, Inc.

Demko, D.B., S.P. Cramer, D. Neeley, and E.S. Van Dyke. 1994. Evaluation of sound and electrical fish guidance systems at the Wilkins Slough diversion operated by Reclamation District 108. 1994 Annual Report. Report submitted to Reclamation District 108 and the US Bureau of Reclamation by S.P. Cramer and Associates, Inc.

Hanson Environmental, Inc. and Miriam Green Associates. 2003. Final Mitigated Negative Declaration and Draft Environmental Assessment/Initial Study for the Sutter Mutual Water Company Tisdale Pumping Plant Positive Barrier Fish Screen Project. Prepared for Reclamation District No. 1500 by Hanson Environmental, Inc. and Miriam Green Associates.

NOAA Fisheries [National Marine Fisheries Service]. 1994. Experimental fish guidance devices: position statement of National Marine Fisheries Service, Northwest Region. November 1994. NOAA Fisheries, Seattle WA. http://www.nwr.noaa.gov/1hydrop/exp_tech1.htm

NOAA Fisheries [National Marine Fisheries Service].1996. Factors for decline: a supplement to the notice of determination for West Coast Steelhead under the Endangered Species Act. NOAA Fisheries, Protected Resources Division, Portland OR and NMFS Protected Species Management Division, Long Beach, CA. 82 pp.

NOAA Fisheries [National Marine Fisheries Service]. 1997. Fish screening criteria for anadromous salmonids. National Marine Fisheries Service, Southwest Region. January 1997. NOAA Fisheries, Long Beach, CA. http://swr.ucsd.edu/hcd/fishscrn.htm

NOAA Fisheries [National Marine Fisheries Service]. 1997. Proposed recovery plan for the Sacramento River Winter-run Chinook salmon. NOAA Fisheries, Southwest Region, Long Beach, CA. Available at http://swr.ucsd.edu/hcd/recweb.htm

NOAA Fisheries [National Marine Fisheries Service]. 1998. Status review of Chinook salmon from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-35. Seattle WA.

NOAA Fisheries [National Marine Fisheries Service]. 2000. Factors contributing to the decline of Chinook salmon: an addendum to the 1996 West Coast Steelhead factors for decline report. NOAA Fisheries, Protected Resources Division, Portland OR.

Snider, B. and R. Titus. 1998. Evaluation of juvenile anadromous salmonid emigration in the Sacramento River near Knights Landing, November 1995- July 1996. California Department of Fish and Game, Environmental Services Division, Stream Evaluation Program.

Snider, B. and R. Titus. 2000. Timing, composition, and abundance of juvenile anadromous salmonid emigration in the Sacramento River near Knights Landing, October 1996- September 1997. California Department of Fish and Game, Environmental Services Division, Stream Evaluation Program.

Snider, B. and R. Titus. 2000a. Timing, composition, and abundance of juvenile anadromous salmonid emigration in the Sacramento River near Knights Landing, October 1997- September 1998. California Department of Fish and Game, Environmental Services Division, Stream Evaluation Program.

Snider, B. and R. Titus. 2000b. Timing, composition, and abundance of juvenile anadromous salmonid emigration in the Sacramento River near Knights Landing, October 1998- September 1999. California Department of Fish and Game, Environmental Services Division, Stream Evaluation Program.

TAC. 2005. Sacramento River Conservation Area Forum Technical Advisory Committee (TAC) Meeting Notes, March 1, 2005. Available at: http://www.sacramentoriver.ca.gov/publications/03-29-2005/Mar_1_tac%20notes.pdf

USBR [US Bureau of Reclamation]. 2004. Acoustic tracking of juvenile chinook salmon movement in the vicinity of the delta cross channel: 2001 study results. Technical Memorandum No. 8220-04-04. U.S. Bureau of Reclamation. Sacramento, CA.

Witts, K. 2004. Fish screen and fish passage project screen data. Consolidated by the California Department of Fish and Game.

Appendix A.

Table A. Flow data for the mainstem Sacramento River and the RD 108 water diversion at Wilkins Slough.

	1989			1990			1991			1992			1993			1994			Avg weekly % Diverted
Week #	Wkly Sac cfs	Wkly pump cfs	% diverted	Wkly Sac cfs	Wkly pump cfs	% diverted	Wkly Sac cfs	Wkly pump cfs	% diverted	Wkly Sac cfs	Wkly pump cfs	% diverted	Wkly Sac cfs	Wkly pump cfs	% diverted	Wkly Sac cfs	Wkly pump cfs	% diverted	
6	No pumping weeks 1-6																		**0.00**
7	6827	0		7563	0		6052	102	1.7	4574	0								**1.70**
8	6296	9	0.1	6137	0		4070	48	1.2	23226	0								**0.65**
9	7258	24	0.3	6754	0		3917	105	2.7	23614	0								**1.50**
10	10305	0		6420	0		5998	0		13212	0								***0.80***
11	18528	0		9163	0		14132	7	0.1	12243	0								**0.10**
12	20913	0		7563	0		11383	0		14041	0								***0.90***
13	16356	0		5707	97	1.7	14319	0		15358	0								**1.70**
14	21128	3	0	5419	137	2.5	17265	2	0	8997	0								**0.83**
15	13411	27	0.2	5054	125	2.5	9085	1	0	6755	25	0.4							**0.78**
16	9194	19	0.2	6630	166	2.5	6749	0		6349	79	1.3				4418	42	0.95	**1.24**
17	5750	89	1.6	6608	254	3.9	4661	1	0	6959	278	4	17217	41	0.2	3605	228	6.32	**2.67**
18	6012	239	4	5832	783	13.4	4006	215	5.4	5667	453	8	11868	140	1.2	4542	407	8.96	**6.83**
19	4678	381	8.2	4386	840	19.1	3934	388	9.9	4510	425	9.4	9717	289	3	4206	350	8.33	**9.66**
20	6786	379	5.6	5200	361	6.9	4692	353	7.5	3550	295	8.3	8113	342	4.2	6186	237	3.82	**6.05**
21	7756	276	3.6	6106	174	2.9	5591	195	3.5	3589	370	10.3	7554	295	3.9	5981	193	3.23	**4.57**
22	8015	141	1.8	7624	47	0.6	4580	317	6.9	3332	170	5.1	8643	206	2.4	5835	246	4.21	**3.50**
23	7129	140	2	12118	185	1.5	4812	211	4.4	3183	142	4.5	14340	59	0.4	5635	294	5.22	**3.00**
24	7256	205	2.8	5742	345	6	4019	310	7.7	3189	427	13.4	21093	48	0.2	5241	337	6.43	**6.09**
25	4779	194	4.1	4800	372	7.7	4088	443	10.8	3605	307	8.5	13699	281	2	4851	350	7.22	**6.72**
26	6756	244	3.6	5484	373	6.8	4090	282	6.9	3750	348	9.3	10486	330	3.2	5237	415	7.92	**6.29**
27	6519	336	5.2	5197	391	7.5	4666	148	3.2	3611	507	14	7583	410	5.4	4813	326	6.77	**7.01**
28	6070	248	4.1	5569	365	6.6	4526	171	3.8	4274	380	8.9	7348	372	5.1				**5.70**
29	5686	281	4.9	5189	397	7.7	4330	323	7.5	3780	495	13.1	6995	351	5				**7.64**
30	6973	270	3.9	5410	401	7.4	4325	374	8.7	3549	454	12.8	6464	346	5.4				**7.64**
31	8539	405	4.7	5410	331	6.1	4376	427	9.8	3644	386	10.6	7162	311	4.3				**7.10**
32	9095	254	2.8	5320	428	8.1	4198	439	10.5	3769	355	9.4	8754	301	3.4				**6.84**
33	9159	241	2.6	5726	344	6	4142	331	8	3725	414	11.1	8336	301	3.6				**6.26**
34	7307	341	4.7	5885	235	4	4356	352	8.1	4674	188	4	8151	301	3.7				**4.90**
35	6723	234	3.5	6504	146	2.3	4334	277	6.4	4680	145	3.1	8985	257	2.9				**3.64**
36	5666	127	2.2	6196	18	0.3	4151	155	3.7	5409	86	1.6	8015	216	2.7				**2.10**
37	5471	28	0.5	5951	18	0.3	3997	17	0.4	5062	70	1.8	8357	97	1.2				**0.84**
38	6149	3	0.1	5606	0		4191	0		5686	20	0.3	9022	24	0.3				**0.23**
39	9054	0		4995	0		4037	0		5674	16	0.3							**0.30**
40	6888	0		4729	0		3810	0		5532	8	0.1							**0.10**
41	No pumping weeks 41-52																		**0.00**

Table B. Average weekly proportion of run passing Knights Landing, 1995-1999.

Week #	ChF	ChS	ChW	ChLF	StH
1	0.02963	0.04700	0.02022	0.04021	0.00259
2	0.05827	0.02799	0.02055	0.01543	0.00335
3	0.07332	0.01893	0.02828	0.04398	0.06224
4	0.07316	0.04393	0.03823	0.01775	0.14065
5	0.11838	0.05006	0.04901	0.00694	0.05427
6	0.06668	0.01996	0.04239	0.00000	0.03917
7	0.12403	0.01977	0.04797	0.00000	0.06629
8	0.05635	0.00892	0.01990	0.00000	0.04226
9	0.04122	0.02137	0.02808	0.00000	0.04870
10	0.04026	0.08040	0.02114	0.00000	0.03933
11	0.04504	0.02490	0.03323	0.00000	0.06689
12	0.05896	0.00347	0.01959	0.00000	0.11665
13	0.02001	0.00076	0.01294	0.00000	0.04897
14	0.01869	0.00163	0.00398	0.01023	0.05081
15	0.01505	0.00000	0.00098	0.00939	0.02513
16	0.01914	0.00000	0.00196	0.10752	0.01435
17	0.02539	0.00000	0.00294	0.02424	0.04330
18	0.06065	0.00000	0.00196	0.05627	0.05488
19	0.01834	0.00000	0.00196	0.00296	0.01592
20	0.00711	0.00000	0.00000	0.01479	0.02234
21	0.00270	0.00000	0.00000	0.11930	0.01446
22	0.00051	0.00000	0.00000	0.00444	0.00787
23	0.00075	0.00000	0.00000	0.06045	0.00787
24	0.00014	0.00000	0.00000	0.00000	0.00000
25	0.00010	0.00000	0.00000	0.00847	0.00000
26	0.00007	0.00000	0.00000	0.00000	0.00151
27	0.00004	0.00000	0.00000	0.00000	0.00000
28	0.00002	0.00000	0.00000	0.00000	0.00000
29	0.00000	0.00000	0.00000	0.00000	0.00000
30	0.00001	0.00000	0.00000	0.00000	0.00000
31	0.00001	0.00000	0.00000	0.00000	0.00000
32	0.00001	0.00000	0.00000	0.00000	0.00000
33	0.00001	0.00000	0.00000	0.00771	0.00000
34	0.00001	0.00000	0.00203	0.00572	0.00000
35	0.00001	0.00000	0.00105	0.00148	0.00000
36	0.00002	0.00000	0.00175	0.00000	0.00000
37	0.00000	0.00000	0.00133	0.00000	0.00000
38	0.00000	0.00000	0.00407	0.00000	0.00000
39	0.00000	0.00000	0.00105	0.00000	0.00000
40	0.00000	0.00000	0.00702	0.00495	0.00000
41	0.00000	0.00000	0.00071	0.00000	0.00000
42	0.00000	0.00000	0.00000	0.00000	0.00000
43	0.00000	0.00000	0.00000	0.00000	0.00000
44	0.00000	0.00000	0.00000	0.00000	0.00000
45	0.00000	0.00000	0.00036	0.00000	0.00000
46	0.00000	0.00000	0.01230	0.00771	0.00000
47	0.00001	0.00000	0.01986	0.01190	0.00000
48	0.00000	0.00622	0.16298	0.12194	0.00000
49	0.00039	0.12491	0.15885	0.06727	0.00787
50	0.00954	0.17263	0.10341	0.15448	0.00000
51	0.01275	0.27154	0.11242	0.06675	0.00232
52	0.00323	0.05561	0.01548	0.00771	0.00000

Table C. Average weekly proportion of run passing GCID, 1997-2000.

Week #	ChF	ChS	ChW	ChLF	StH
1	0.00686	0.00000	0.00027	0.00032	0.00000
2	0.02103	0.02071	0.01535	0.13511	0.11283
3	0.01561	0.00172	0.02086	0.06548	0.14665
4	0.22755	0.14266	0.16777	0.13763	0.30418
5	0.10544	0.06268	0.05592	0.00761	0.07760
6	0.06255	0.04151	0.04017	0.00038	0.00994
7	0.03851	0.02676	0.01948	0.00000	0.02630
8	0.02512	0.00000	0.00114	0.00000	0.00256
9	0.04601	0.01901	0.00417	0.00000	0.01155
10	0.07428	0.04033	0.00253	0.00000	0.01952
11	0.06107	0.09461	0.00660	0.00000	0.06675
12	0.04051	0.05855	0.00535	0.00000	0.05185
13	0.03900	0.07465	0.00560	0.00000	0.02678
14	0.02418	0.07199	0.00123	0.00000	0.00764
15	0.02606	0.02904	0.00007	0.00374	0.00618
16	0.02381	0.05696	0.00024	0.01528	0.00438
17	0.01244	0.04497	0.00008	0.00764	0.00406
18	0.01880	0.00863	0.00000	0.00317	0.00193
19	0.01286	0.00994	0.00000	0.00152	0.00224
20	0.02166	0.02545	0.00045	0.01230	0.00911
21	0.01882	0.02102	0.00000	0.00222	0.00978
22	0.02228	0.00770	0.00000	0.00272	0.00796
23	0.00713	0.00222	0.00000	0.00057	0.00323
24	0.00711	0.00091	0.00000	0.00044	0.00081
25	0.00784	0.00053	0.00000	0.00145	0.00133
26	0.00353	0.00000	0.00000	0.00115	0.00000
27	0.00355	0.00000	0.00000	0.00146	0.00126
28	0.00498	0.00000	0.00040	0.00255	0.00048
29	0.00325	0.00000	0.00023	0.00378	0.00000
30	0.00271	0.00000	0.00165	0.00349	0.00000
31	0.00244	0.00000	0.00356	0.00483	0.00054
32	0.00095	0.00000	0.00527	0.00631	0.00000
33	0.00070	0.00000	0.00551	0.00523	0.00241
34	0.00071	0.00000	0.00628	0.00717	0.01030
35	0.00033	0.00000	0.00711	0.00810	0.00885
36	0.00035	0.00000	0.01825	0.00926	0.01561
37	0.00022	0.00000	0.04838	0.00583	0.02195
38	0.00017	0.00000	0.03437	0.01180	0.00526
39	0.00081	0.00000	0.05611	0.02285	0.00186
40	0.00016	0.00000	0.06510	0.01633	0.00086
41	0.00016	0.00000	0.05177	0.03120	0.00230
42	0.00036	0.00096	0.04437	0.04284	0.00088
43	0.00022	0.00373	0.02227	0.02436	0.00027
44	0.00007	0.00367	0.01957	0.02230	0.00754
45	0.00007	0.00000	0.01620	0.01610	0.00060
46	0.00007	0.00631	0.04069	0.04402	0.00083
47	0.00020	0.00529	0.07614	0.13695	0.00053
48	0.00000	0.01865	0.06136	0.04505	0.00127
49	0.00018	0.02822	0.05318	0.01541	0.00000
50	0.00057	0.01515	0.00354	0.02891	0.00064
51	0.00142	0.02973	0.00396	0.01935	0.00000
52	0.00529	0.02575	0.00743	0.06579	0.00059

Table D. Expansion factors used to expand daily trap counts at GCID from 1997-2000.

Week #	Avg % of bypass flow sampled by trap	Avg % of mainstem flow diverted into oxbow
1	0.0580630	0.3277183
2	0.0492137	0.2607060
3	0.0464940	0.2393478
4	0.0451372	0.2319080
5	0.0488236	0.2513915
6	0.0531774	0.3029590
7	0.0462423	0.2384597
8	0.0500597	0.2689090
9	0.0424860	0.2027222
10	0.0656275	0.1679057
11	0.0966302	0.1213639
12	0.0510780	0.2788270
13	0.0573762	0.1788670
14	0.0686209	0.2096090
15	0.0772805	0.2299147
16	0.0822694	0.2558703
17	0.0983496	0.2796419
18	0.0935860	0.2758577
19	0.1113455	0.3042984
20	0.0814362	0.2350026
21	0.0881347	0.2316349
22	0.0761726	0.2261734
23	0.0877760	0.2124839
24	0.0962936	0.2190415
25	0.0901365	0.2173653
26	0.0887489	0.2393513
27	0.0788773	0.2531446
28	0.0739207	0.2508540
29	0.0702439	0.2439201
30	0.0676545	0.2388110
31	0.0713681	0.2311276
32	0.0783652	0.2294177
33	0.0897678	0.2493438
34	0.1065111	0.2568978
35	0.1113099	0.2550077
36	0.0975719	0.2475293
37	0.0935376	0.2360374
38	0.0952440	0.2150509
39	0.0961568	0.1955644
40	0.1034427	0.2025601
41	0.1102398	0.2414039
42	0.1121773	0.2718128
43	0.1157461	0.2904181
44	0.1130302	0.2844746
45	0.1095155	0.2730180
46	0.1041072	0.2516468
47	0.1001313	0.2383565
48	0.0902091	0.2213533
49	0.0916215	0.2284910
50	0.0824382	0.2421412
51	0.0532840	0.2247317
52	0.0575432	0.2395258

Table E. Data and calculations used to estimate the proportion of flow diverted into the M&T Ranch diversion.

Week #	Avg weekly flow _HC 91-03	Avg Weekly flow_WS 89-94	Avg weekly pump cfs_WS	pred avg weekly pump cfs_M&T	Pred % flow diverted M&T Ranch
1-6	No Pumping a Wilkins Slough weeks 1-6				
7	27081	6254	102		
8	32887	9932	29		
9	29288	10386	65		
10	27823	8984	36		
11	27759	13517	7		Pumping at M&T
12	23464	13475	52		begins April 1
13	22876	12935	97	18.19	**0.079505**
14	16597	13202	47	8.88	**0.053473**
15	13572	8576	45	8.34	**0.061479**
16	11410	6668	77	14.34	**0.125707**
17	11699	7467	149	27.84	**0.237996**
18	14860	6321	373	69.91	**0.470447**
19	13265	5239	446	83.53	**0.629725**
20	11574	5755	328	61.47	**0.531113**
21	11966	6096	251	46.97	**0.392514**
22	13348	6338	188	35.22	**0.263855**
23	12854	7870	172	32.22	**0.250651**
24	12247	7757	279	52.25	**0.426618**
25	11546	5970	325	60.84	**0.526952**
26	10977	5967	332	62.25	**0.567094**
27	10699	5398	353	66.19	**0.618654**
28	11269	5557	307	57.60	**0.511146**
29	11686	5196	369	69.26	**0.592695**
30	11861	5344	369	69.19	**0.583343**
31	11200	5826	372	69.75	**0.622774**
32	10729	6227	355	66.64	**0.621114**
33	9790	6218	326	61.16	**0.624753**
34	9115	6075	283	53.14	**0.582939**
35	8636	6245	212	39.71	**0.459868**
36	8417	5887	120	22.58	**0.268209**
37	8127	5768	46	8.63	**0.106126**
38	8130	6131	16	2.94	**0.036130**
39	7709	5940	16	3.00	**0.038913**
40	7159	5240	8	1.50	**0.020954**
41	No Pumping a Wilkins Slough weeks 41-52				Pumping after week 40 Assumed to be small