Final

Effects of the South Delta Agricultural Barriers on Emigrating Juvenile Salmonids

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Prepared for:

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Project Report Reviews

The *Effects of the South Delta Agricultural Barriers on Emigrating Juvenile Salmonids* study report has gone through a technical review process. The review process included editorial (technical editor), contributor reviews (primary report authors; see Acknowledgements), draft edition, management edition, two final draft editions, and final edition review (California Department of Water Resources' Bay-Delta Office Chief and Temporary Barriers and Lower San Joaquin Chief). All comments received during the review process were addressed and resolved. A review certification by the California Department of Water Resources' Bay-Delta Office, Chief, Temporary Barriers and Lower San Joaquin (Jacob McQuirk, P.E.), and Primary Author (Mark Bowen, Ph.D., Environmental Science Associates) is provided herein. A summary of study report reviews follows:

Study team/contributor review, including review by staff from the California Department of Water Resources, U.S. Geological Survey, AECOM Technical Services, Inc., Environmental Science Associates, and Hydroacoustic Technology, Inc. (October 2016);

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Review Certification:

Jacob McQuirk, P.E. — Date: 11/21/2018

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ACRONYMS AND OTHER ABBREVIATIONS

(including **Executive Summary** and **Appendices**)

*	times symbol (mathematical)
→	route selection pathway joint probability
>	greater than
<	less than
≤	less than or equal to
%	percent
°C	degrees Celsius
°F	degrees Fahrenheit
.ftp	file transfer protocol
.RAT	raw acoustic telemetry (file type)
1D	one-dimensional
2D	two-dimensional
®	registered trademark symbol
™	unregistered trademark symbol
x	times symbol (mathematical)
Ψ	route selection
AECOM	AECOM Technical Services, Incorporated
ANOVA	analysis of variance
ATR	acoustic tag receiver
ATTS	acoustic tag tracking system
BAFF	Bio-Acoustic Fish Fence
BiOp	biological opinion
CAD	computer-aided design
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
CFR	Code of Federal Regulations
CFP	Certified Fisheries Professional
cfs	cubic feet per second
CHTR	DWR Collection, Holding, Transportation, and Release Facility
cm	centimeter(s)
cm/s	centimeters per second
cms	cubic meters per second
CVP	federal Central Valley Project
Delta	Sacramento-San Joaquin Delta
DICU	Delta Island Consumptive Use Model
DIDSON	Dual Frequency Identification Sonar
DPS	distinct population segment
DSM2	Delta Simulation Model II
Durham Ferry	Durham Ferry State Recreation Area
DWR	California Department of Water Resources
E	easting or east
e.g.	exempli gratia (Latin for “for example”)
ESA	Environmental Science Associates
ESU	evolutionarily significant unit
et al.	et alia (Latin for “and others”)
et seq.	et sequentes (Latin for “and the following”)
FL	fork length
ft	foot/feet
ft/s	feet per second
g	gram(s)

gal	gallon(s)
GLC	Grant Line Canal
GLCB	Grant Line Canal Barrier
GLCS	Grant Line Canal South
GLM	generalized linear model(ing)
GPS	global positioning system
HOR	Head of Old River
HORB	Head of Old River Barrier
HTI	Hydroacoustic Technology, Incorporated
i.e.	id est (Latin for "that is")
ID	identification
ID code	tag period
in	inch(es)
kg	kilogram(s)
kHz	kilohertz(s)
km	kilometer(s)
L	liter(s)
lb	pound(s)
m	meter(s)
m/s	meters per second
m^3	cubic meter(s)
mi	mile(s)
mm	millimeter(s)
MRB	Middle River Barrier
MRN	Middle River North
MRS	Middle River South
MS-222	tricaine methanesulfonate
n	number in a subsample; n^{th} root of survival ($\hat{S}$)
N	northing, north, or number in a full sample
NA	not applicable/not available
NMFS	National Marine Fisheries Service
OCAP	Long-Term Operational Criteria and Plan
OLD	Old River Near Tracy Gauge (CDEC)
OMR flows	cumulative Old and Middle river flows
ORE	Old River East
ORN	Old River North
ORS	Old River South
ORT	Old River at Tracy channel
ORTB	Old River at Tracy Barrier
oz	ounce(s)
P	probability
P.E.	Professional Engineer
PKD	proliferative kidney disease
P-value	The P-value is defined as the probability of obtaining a result equal to or "more extreme" than what was actually observed, when the null hypothesis is true
Reclamation	U.S. Bureau of Reclamation
RGU	hydrophone gate: radial gates-upstream
RPA(s)	Reasonable and Prudent Alternative(s)
$\hat{S}$	survival estimate
SD	standard deviation
SDAB(s)	South Delta Agricultural Barrier(s)
SDIP	South Delta Improvement Program
SE	southeast or standard error
SJRGA	San Joaquin River Group Authority

SJRRP	San Joaquin River Restoration Program
spp.	more than one species
SR 4	State Route 4
SWP	California State Water Project
TBP	South Delta Temporary Barriers Project
TFCF	Tracy Fish Collection Facility
TIV	time-in-vicinity
TL	total length
USER 4	User-Specified Estimation Routine, version 4
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator conformal projection
VAMP	Vernalis Adaptive Management Plan
vs.	versus
WGS 84	World Geodetic System 1984 datum
Z-test	A Z-test is a statistical test for which the distribution of the test statistic under the null hypothesis can be approximated by a normal distribution
$\bar{x}$	mean value

Table TOC-1. Metric Conversion Table

Measurement	To Convert from Metric Unit	To Customary Unit	Multiply Metric Unit By	To Convert to Metric Unit, Multiply Customary Unit By
Length	millimeters (mm)	inches (in)	0.03937	25.4
	centimeters (cm)	inches (in)	0.3937	2.54
	meters (m)	feet (ft)	3.2808	0.3048
	kilometers (km)	miles (mi)	0.62139	1.6093
Volume	liters (L)	gallons (gal)	0.26417	3.7854
Volume	cubic meters (m^3)	cubic feet (ft^3)	35.3147	0.0283168
Volumetric Flow Rate (Discharge)	cubic meters per second (cms or m^3/s)	cubic feet per second (cfs)	35.315	0.0283168
Mass	grams (g)	ounces (oz)	0.035274	28.3495
	kilograms (kg)	pounds (lb)	2.2046	0.45359
Velocity	meters per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1.8 x °C) + 32	(°F - 32) x 0.5555

STYLE CONVENTIONS

Unless stated otherwise herein the report style conventions follow the guidance provided in the *U.S. Government Publishing Office Style Manual*, January 12, 2017.

EXECUTIVE SUMMARY

ES-1 INTRODUCTION

The California Department of Water Resources' (DWR) Temporary Barriers Project (TBP) is an ongoing project that installs, operates, and monitors up to four temporary rock-fill barriers constructed in waterways located in the southern portion of the Sacramento-San Joaquin Delta (Delta) near the cities of Tracy and Lathrop in San Joaquin County, California (**Figure 1-1**). Three of the temporary barriers—Old River at Tracy (ORTB), Middle River (MRB), and Grant Line Canal (GLCB), collectively, the south Delta agricultural barriers (SDABs)—are constructed and operated during the agricultural irrigation season, usually April through November. The SDABs are designed to act as flow control structures, retaining tidal fresh water behind each barrier following a flood tide. The fourth barrier, Head of Old River Barrier (HORB), is installed during the spring and fall as a fish guidance barrier. The HORB is normally installed in the spring to prevent juvenile fall-run San Joaquin River Chinook Salmon (*Oncorhynchus tshawytscha*) and juvenile Central Valley steelhead (*Oncorhynchus mykiss*) [2] from emigrating through Old River toward the south Delta water export facilities at the intakes of the State Water Project (SWP) and federal Central Valley Project (CVP). In the fall, the HORB helps to guide adult San Joaquin River Chinook Salmon to spawning locations in the upper watershed.

Installation, operation, and removal of the SDABs has the potential to harm, harass, or cause mortality to fish species of management concern to the National Marine Fisheries Service (NMFS), specifically, juvenile fall-run Chinook Salmon which are NMFS Species of Concern (NMFS 2010), juvenile Central Valley steelhead which is a threatened species, an Endangered Species Act (ESA) Section 10j experimental population (63 Federal Register [FR] 13347), and juvenile Green Sturgeon (*Acipenser medirostris*), also a federally listed threatened species (71 FR 17757).

The TBP is implemented in compliance with the terms and conditions of two NMFS Biological Opinions (BiOp) (NMFS 2008, 2009). To comply with the requirements of the NMFS BiOps, a study of the effects of the three SDABs (i.e., ORTB, MRB, and GLCB) on emigrating (i.e., out-migrating) juvenile salmonids was conducted (2010–2011) and the results are reported in this document. There were four effects considered in this study: 1) survival of juvenile salmonids ($\hat{S}$); 2) juvenile salmonid time-in-vicinity (TIV) of a barrier; 3) predation on juvenile salmonids; and 4) predatory fish density evaluations near the barriers before-, during-, and after-construction during each study year. For one barrier, the ORTB, two-dimensional (2D) acoustic fish tracks for juvenile salmonids were used to evaluate: 1) the rates of successful passage through the barrier; and 2) route selection through the barrier. In addition, utilizing the ORTB 2D fish tracks for both juvenile salmonids and predatory fish, a mixture model (Romine et al. 2014) approach was employed to determine the probability that a juvenile salmonid had been eaten by a predatory fish in the vicinity of the ORTB.

ES-2 SUMMARY OF KEY FINDINGS

Based upon the results of this study, it was concluded the SDABs significantly reduced juvenile salmonid survival when one-way flap gates were installed and operated tidally for a substantial portion of the salmonid juvenile migratory period. For example, in 2010 survival analysis indicated that juvenile steelhead survival ($\hat{S}$) was 89.3 percent between April 1 and May 9 before construction of the ORTB for steelhead emigrating via the Old River-

[2] The common names of fishes follow the conventions established by the American Fisheries Society in *Common and Scientific Names of Fishes from the United States, Canada, and Mexico*, Seventh Edition (Page et al. 2013). A more detailed explanation of the naming convention is found in Footnote 6 in Chapter 1 Introduction.

South (ORS: **Figure 2-5** and **Table 2-8**) migration route, followed by a significant decline in survival to 57.7 percent between June 4 and July 7 after construction of the ORTB (**Table 3-16**). It was concluded that the most likely contributing factors to this decline in survival at the ORTB were:

1) Reduced passage availability through the nine ORTB culvert gates because the flap gates were not tied open for 79 percent (26 of the 33 days) of the ORTB After-Construction Period (**Table 2-2**);

2) Predatory fish density increased in the ORTB After-Construction Period, 3.6 percent downstream of the barrier and 67.3 percent upstream of the barrier (**Table 3-70**), compared to the ORTB Before-Construction Period; and

3) The increased temperature in the After-Construction Period was approximately 5.3°C (9.5°F) (**Table 3-1**) warmer on average and this might have reduced steelhead physiological condition (Viant et al. 2003) making them more vulnerable to predation. Thus, the ORTB may have caused potentially thermally-stressed steelhead to look for passage in the presence of an expanded predatory fish population.

Important evidence for why the SDABs significantly reduce salmonid survival comes from intensive monitoring of the ORTB in this study:

1) At the ORTB, 2D tracking data showed that the ORTB was an impediment blocking passage of a significant proportion of juvenile steelhead emigrants (73.5 percent in 2010; 30.8 percent in 2011) (**Tables 3-38** and **3-40**) and juvenile Chinook Salmon emigrants (5.5 percent in 2011) (**Table 3-39**);

2) Juvenile Chinook Salmon and steelhead TIVs were significantly increased by the presence of the ORTB (**Tables 3-51** and **3-56**). Thus, the ORTB delayed emigrating juvenile salmonids causing them to search for passage routes through the barrier; and

3) It was significantly more likely that a tag would be defecated/regurgitated on the upstream side of the ORTB compared to the downstream side (**Table 3-63**). This finding is consistent with the hypothesis that the ORTB caused migrating juvenile salmonids to spend more time on the upstream side of the barrier searching for a pathway through the barrier and this delay led to increased predation probabilities.

Operations of the Barriers During this Study

In 2010, two barriers were operated according to environmental permit requirements and standard management practices. The MRB was closed on May 24 and the ORTB was closed June 3 (**Table 2-2**). The flap gates of the culverts through each barrier (i.e., six gates for the MRB and nine gates for the ORTB) were open until June 11 at which time they were untied. After that date, fish could only pass through the culverts at these two barriers when the flap gates were forced open by a flood tide. In 2010, the GLCB was under construction from June 16 until July 7 and thus had a three-week-long During-Construction Period (**Table 2-2**). The salmonid juvenile migratory period had ended by July 7 due to high water temperatures (**Table 3-1**). Thus, juvenile salmonids approaching the GLCB area on or after June 16 experienced only construction-related activities because the culverts were not yet in operation.

In 2011, the MRB and the ORTB were closed on June 6 and June 10, respectively (**Table 2-4**). However, the flap gates were tied open until August 23 providing for constantly open-passage routes at these two barriers throughout the juvenile salmonid spring/early summer migratory period. GLCB construction was initiated on June

10 but the barrier was not closed until July 14 (**Table 2-4**). This delay in closure was due to the high water levels that occurred in 2011 during a "wet" water year (California Data Exchange Center 2016a at http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST) in the San Joaquin River basin precluding the need for agricultural barriers during the juvenile salmonid migratory period.

Note that in 2010 the GLCB During-Construction Period started so late that no telemetered salmonids approached the GLCB after construction began and, therefore, there were no During- or After-Construction Period data. In 2011, no telemetered salmonids approached the GLCB after closure and, therefore, there were no After-Construction Period data.

Barrier operations varied at the Head of Old River (HOR) during the two years of this study. The rock barrier at the HOR was not installed in 2010. Instead, an experimental non-physical barrier called the Bio-Acoustic Fish Fence (BAFF) (Fish Guidance Systems Ltd, Southampton, United Kingdom), was tested there (DWR 2015a). In 2011, no HORB could be placed due to the high flows creating unsafe installation conditions.

Conditions in the South Delta

2010 was an "above normal" water year in the San Joaquin River watershed. In contrast, 2011 was a wet water year (California Data Exchange Center 2016a at http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST). This difference manifested itself in a number of ways, but one critical environmental parameter was water temperature. In the 2010 ORTB After-Construction Period (June 4–July 7), water temperature averaged 21.9°C (71.4°F) (**Table 3-1**) and these temperatures could thermally stress juvenile salmonids causing decreased metabolic condition (Viant et al. 2003). In the 2010 ORTB Before-Construction Period (April 1–May 9), water temperature averaged 16.6°C (61.9°F), a 5.3°C (9.5°F) difference. In contrast, the average temperature in the 2011 ORTB After-Construction Period (June 11–July 14), water temperature averaged 19.8°C (67.6°F). In the 2011 ORTB Before-Construction Period (March 22–May 26), water temperature averaged 15.6°C (60.1°F), a 4.2°C (7.6°F) difference (**Table 3-2**).

Acoustic Telemetry 2010

Juvenile steelhead were obtained from the California Department of Fish and Wildlife's (CDFW) Mokelumne River Hatchery (Clements, California). Juvenile fall-run Chinook Salmon were obtained from the CDFW's Merced River Hatchery (Snelling, California). These hatchery-produced fish were used as surrogates for wild fish. The fish were transported to DWR's Collection, Holding, Transport, and Release (CHTR) Laboratory (Byron, California). The juvenile steelhead and Chinook Salmon were held at the CHTR Laboratory until acoustic transmitter insertion surgery began approximately five days before a fish release.

Acoustic tags, Models 795-E and 795-Lm (Hydroacoustic Technology Incorporated [HTI], Seattle, Washington) were programmed and surgically implanted into juvenile steelhead and Chinook Salmon, respectively. Surgical implantation of the acoustic tags took place during tagging events according to the procedure described by the San Joaquin River Group Authority (SJRGA 2011).

In 2010, two types of releases were made and each type at a separate location:

1) Tagged juvenile Chinook Salmon (N = 342) and steelhead (N = 480) intended for use in survival modeling were released at the "Old River 1D Fish Release Site (2010)" that was located 1.44 kilometers (km) (0.9 miles [mi]) downstream of the Head of Old River (**Figure 2-5**); and

2) Tagged steelhead (N = 90) intended for use in determining passage, route selection and mixture modeling analysis were released at the "Old River 2D Fish Releases Site (2010)" that was 1.76 km (1.1 mi) upstream of the ORTB footprint in 2010 (**Figure 2-5**).

After the initial tagging period between April 26 and May 4 (**Table 2-6**), the Chinook Salmon held in the laboratory for June releases began showing signs of disease and substantial mortality was observed. Pathology evaluations performed by the CDFW revealed cells of the myxozoan parasite *Tetracapsuloides bryosalmonae*, the causative agent of proliferative kidney disease (PKD). All remaining Chinook Salmon were subsequently euthanized and because there were no additional hatchery Chinook Salmon available, no additional tagging occurred in 2010. Thus, no telemetered Chinook Salmon juvenile release took place after May 7.

Acoustic Telemetry 2011

In 2011, juvenile Chinook Salmon and steelhead were available from the Merced River Hatchery and Mokelumne River Hatchery, respectively. As done in 2010, these hatchery-produced fish were used as surrogates for wild fish and were transported from the hatchery to two locations. Chinook Salmon were held at the Tracy Fish Collection Facility (TFCF) and the steelhead were held at the CHTR Laboratory. Acoustic tagging was coordinated with the Vernalis Adaptive Management Plan (VAMP) Study team and with the Operational Criteria and Plan (OCAP) Six-Year Steelhead Study team (SJRGA 2013: Chapters 5 and 6). Tagging was led by FISHBIO (Oakdale, California). Acoustic tagging followed the same surgical procedures used in the 2010 VAMP Study and is described for 2011 in SJRGA (2013). Acoustic tags (HTI Models LD and Lm) were programmed and surgically implanted into juvenile steelhead and Chinook Salmon, respectively (**Tables 2-11** and **2-12**).

In 2011, two types of releases were made and each type occurred at a separate location:

1) Tagged Chinook Salmon (N = 1,900) and steelhead (N = 2,195) juveniles intended for use in survival modeling were released at "Durham Ferry State Recreation Area 1D Fish Release Site (2011)" (Durham Ferry) that was located 23.96 km (14.9 mi) upstream of the Head of Old River (**Figure 2-5**); and

2) Tagged Chinook Salmon (N = 200) and steelhead (N = 120) juveniles intended for use to determine passage, route selection and mixture modeling analysis were released at the "Old River 2D Fish Release Site (2011)" that was 8.22 km (5.1 mi) upstream of the ORTB footprint in 2011 (**Figure 2-5**).

Hydrophone Networks

The hydrophone networks were of two types: One-Dimensional (1D) Fixed Station Receiver Grids; and 2D Receiver Arrays (ORTB only). In 2010, the 1D Fixed Station Grids were deployed during February–March. The network of fixed-point acoustic tag data loggers were designed to cover the south Delta, including Old River, Middle River, Grant Line Canal (GLC), SWP Clifton Court Forebay intake on Old River, and the intake of the CVP on Old River (**Figure 2-5**). In 2011, the 1D Fixed Station Grids were deployed during January–March by a multi-agency team. The network of fixed-point receivers was designed to cover the south Delta including Old River, Middle River, GLC, the SWP Clifton Court Forebay intake, and the CVP fish facility (**Figure 2-5**). The receiver networks were installed and evaluated for detection efficiency and range prior to tagged fish being released.

The second type of hydrophone network was a 2D Receiver Array. In 2010, a 2D biotelemetry system was used to track fish in the vicinity of the ORTB (Kumagai et al. 2010). After the ORTB was constructed (after June 4), the

2D fish tracking system was deployed and tested. Five hydrophones were deployed upstream of the barrier, and five hydrophones were deployed downstream of the barrier (**Figure 2-7**). In 2011, a 2D biotelemetry system was again deployed at the ORTB to track fish in the vicinity of the ORTB (Tunnicliffe et al. 2012). After the ORTB was constructed (after June 11), the 2D fish tracking system was deployed and tested. Five hydrophones were deployed upstream of the barrier, and five hydrophones were deployed downstream of the barrier (**Figure 2-11**).

ES-3 RESULTS

SJRGA (2011, 2013) Predator Filters Applied to the 1D Detection History Data

A "predator filter" developed for the 2010 VAMP Study to distinguish juvenile salmonid swimming behavior from non-salmonid predatory fish swimming behavior (SJRGA 2011: Chapter 5) was applied to SDAB study fish for 2010. In 2010, application of the predator filter resulted in 30.6 percent, or 87 of 284 tagged juvenile Chinook Salmon to be removed from the number of tagged juveniles arriving at "exit points"[3] from the south Delta study area (i.e., CVP, RGU, ORN, and MRN; see **Table 3-10** and **Figure 2-5**) used in calculating survival. For juvenile steelhead in 2010, 95.2 percent were removed, or 220 of 231 (**Table 3-11**). So few steelhead remained after application of the predator filter that the predator filter was not used for calculating survival in 2010. Graphic analysis suggested Chinook Salmon behavior measured as distance travelled per unit time, showed clear differences between migratory behavior and non-migratory behavior (**Figure 4-1**). But steelhead did not show clear differences between migratory and non-migratory behavior for distance travelled per unit time, causing most steelhead to be classified as predators.

It was concluded that 2010 Chinook Salmon survival with the "Predator Filter Employed" via the ORS migration route, 0.6191 (Standard Error [SE] = 0.0277) (**Table 3-15**), was closer to the actual juvenile Chinook Salmon survival because of the results of the predator filter analysis. It should be noted that juvenile Chinook Salmon only moved through the study area in the Before-Construction Period due to a PKD outbreak in the laboratory (**Table 3-15**). Furthermore, for 2010 data, it was concluded that overall steelhead survival (considering the entire spring/early summer steelhead migration period) with the "Predator Filter Not Employed," 0.7359 (SE = 0.0267) (**Table 3-11**), was closer to the actual steelhead juvenile survival because of the results of the predator filter analysis. Hypothesis tests were conducted for steelhead survival for all tagged fish (Predator Filter Not Employed) and are described in this report.

The 2010 predator filter was modified for application to the 2011 VAMP Study (SJRGA 2013: Chapter 5); the modified 2011 predator filter was applied to SDAB study fish for 2011. Application of the 2011 predator filter excluded only 1.4 percent (6 of 441) of tagged juvenile Chinook Salmon individuals (**Table 3-22**), and 4.9 percent (22 of 447) of tagged juvenile steelhead individuals (**Table 3-23**) arriving at the study exit points. These differences may be due to the higher flows in the study area during the migration period in 2011 compared to 2010. These higher discharges in 2011 likely influenced the migration rate of juvenile salmonids and other parameters, producing detection histories that were easier for the predator filter to differentiate salmonids from predators. It was concluded that 2011 Chinook Salmon survival with the Predator Filter Employed via the ORS migration route, 0.6957 (SE = 0.0189) (**Table 3-22**), was closer to the actual juvenile Chinook Salmon survival because of the results of the predator filter analysis. In addition, for 2011 data, it was concluded that overall steelhead survival with the Predator Filter Employed, 0.8764 (SE = 0.0158) (**Table 3-23**), was closer to the actual

[3] "Exit points" or "gates" are specific locations where juvenile salmonids are recorded as successfully "exiting" the south Delta for calculation of survival statistics.

juvenile steelhead survival because of the results of the predator filter analysis. Hypothesis tests were conducted for Chinook Salmon and steelhead survival for salmonid tags that remained after the predator filer was employed and those results are described herein.

Route Selection

From the divergence of the Old and Middle rivers, the two routes available for juvenile salmonid migration were Old River and Middle River (**Figure 2-5**). During both years, few Chinook Salmon or steelhead emigrants passed through the MRS route during any barrier construction period.

In 2010, 100 percent of juvenile Chinook Salmon (all during the period before any barrier construction began, since there were no releases in the During- or After-Construction Periods), and 99.4 percent of juvenile steelhead used the ORS route overall with the Predator Filter Not Employed (**Tables 3-12** and **3-13**). During the Before-Construction Period for ORTB and MRB, 100 percent of steelhead passed through the ORS route, while 98.0 percent passed through the ORS route and 2.0 percent through MRS in the After-Construction Period of the ORTB and MRB with the Predator Filter Not Employed (**Table 3-19**). For GLCB, 99.4 percent passed through the ORS route and 0.6 percent passed through MRS route in the Before-Construction Period of the GLCB with the Predator Filter Not Employed (**Table 3-20**).

In 2011, during all construction periods combined with the Predator Filter Not Employed, 97.9 percent of Chinook Salmon and 93.0 percent of steelhead used the ORS route, while 2.1 percent of Chinook Salmon and 7.0 percent of steelhead used the MRS route (**Tables 3-24** and **3-25**). For Chinook Salmon with the Predator Filter Employed, 2.7 percent, 1.6 percent, and 0 percent used the MRS route in the Before-, During-, and After-Construction Periods of the ORTB, respectively, and 2.7 percent, NS percent (no releases), and 0.7 percent during Before-, During-, and After-Construction Periods of the MRB (**Tables 3-32** and **3-33**). Also, 2.6 percent, 0.5 percent, and NS percent (no releases) used the MRS route during the Before-, During-, and After-Construction Periods of GLCB, respectively (**Table 3-34**). Steelhead used the MRS route 5.8 percent, NS percent (no releases), and 4.8 percent during the Before-, During-, and After-Construction Periods of the ORTB and MRB, respectively, and 5.8 percent, 4.8 percent, and NS percent (no releases) used the MRS route during the Before-, During-, and After-Construction Periods of GLCB, respectively (**Tables 3-35** and **3-36**).

Survival

2010 Survival Related to Temporary Barrier Construction

Chinook Salmon

Comparisons of survival ($\hat{S}$) in the various construction periods were not possible for the juvenile Chinook Salmon releases since they all occurred prior to barrier construction. Chinook Salmon experienced an outbreak of PKD in the laboratory in 2010 that made it impossible to execute During- and After-Construction Period releases.

Steelhead

In 2010, through the ORS route, there was significantly lower survival through the ORTB and MRB for the After-Construction Period ($\hat{S}$ = 0.5774; SE = 0.0544) compared to the Before-Construction Period ($\hat{S}$ = 0.8931; SE = 0.0303) (Z-test [Z] = 5.0699; $P < 0.0001$) (**Table 3-16**).

These results demonstrated that the SDABs significantly reduce steelhead survival when operated according to current management practices. It was concluded that the most likely contributing factors to this decline were:

1) Reduced passage availability through culverts in the ORTB and the MRB because the flap gates were not tied open (**Tables 2-2 and 2-4**) for 79 percent (26 of the 33 days) of the ORTB After-Construction Period;

2) Mean water temperature increased from 16.6 (61.9°F), in the ORTB Before-Construction Period, to 21.9°C (71.4°F), in the ORTB After-Construction Period, (**Table 3-1**); and

3) Predatory fish density increased through time at all three SDABs in 2010 (**Table 3-70**).

2011 Survival Related to Temporary Barrier Construction

Chinook Salmon

Survival increased for juvenile Chinook Salmon in the After-ORTB Construction Period ($\hat{S}$ = 0.7494; SE = 0.0354) compared to the Before-ORTB Construction Period ($\hat{S}$ = 0.6633; SE = 0.0251) and the During-ORTB Construction Period ($\hat{S}$ = 0.6571; SE = 0.0462) (**Tables 3-26** and **3-27**). However, neither of these comparisons represented a statistically significant change in survival for juvenile Chinook Salmon between the Before-, During-, and After-ORTB Construction Periods because the P-value was not less than the critical P-value for three comparisons (α' = 0.01695).

Through the ORS route, there was significantly lower survival for the Before-GLCB Construction Period ($\hat{S}$ = 0.6502; SE = 0.0313) as compared to the During-GLCB Construction Period ($\hat{S}$ = 0.7611; SE = 0.0323) (Z = 2.4657; P = 0.0137) (**Table 3-29**). So, Chinook Salmon survival increased significantly through time in 2011. Many factors were studied to determine what might have caused these differences. It was concluded that the most likely parameters that led to the increased survival of Chinook Salmon in the During-GLCB Construction Period were: 1) the high discharges (**Table 3-5**); 2) increased flow proportion entering the GLC as time progressed (**Table 3-6**); and 3) SDAB operations provided for open migratory routes that remained available throughout the salmonid migratory period (**Table 2-4**).

Steelhead

In 2011, there was no significant differences (Z = 1.2557; P = 0.2092) between the Before-Construction Period ($\hat{S}$ = 0.8838; SE = 0.0160) compared to the After-Construction Period ($\hat{S}$ = 0.7929; SE = 0.0706) of the ORTB and MRB (**Table 3-30**). In addition, through the ORS route, there was no significant difference (Z = 1.2557; P = 0.2092) between the Before-GLCB Construction Period ($\hat{S}$ = 0.8838; SE = 0.0160) compared to the During-GLCB Construction Period ($\hat{S}$ = 0.7929; SE = 0.0706) (**Table 3-31**).

In 2010, steelhead survival decreased significantly from the 4/1/10–5/9/10 period to the 6/4/10–7/7/10 period. In contrast, steelhead survival did not decrease through time in 2011. Many factors were studied to determine what might have caused these differences. It was concluded that the most likely explanation for the consistently high survival of steelhead in 2011 was: 1) the high discharges derived from a wet water year's (CDEC 2016a) precipitation (see Delta Simulation Modeling II [DSM2] output presented in **Tables 3-4 and 3-6**); 2) better and consistent SDAB-passage route availability in 2011 compared to 2010 (**Tables 2-2** and **2-4**); 3) an increased flow proportion into the GLC as time passed (DSM2 modeling presented in **Table 3-6**); and 4) in 2011, there was a smaller density of predators in the GLCB area in the GLCB During-Construction Period compared to the Before-Construction Period (**Table 3-71**).

Important Survival Analysis Note

It is very possible that the estimates of Chinook Salmon and steelhead survival in 2010 and 2011 may overestimate survival in the south Delta in most years. This conclusion was made because the GLCB did not close until July 7 in 2010 (**Table 2-1**) and until July 14 in 2011 (**Table 2-3**). During both 2010 and 2011 the GLC route was wholly to partially open for the entire study period. If the GLCB closed in May or June (the period in which the GLCB has closed in every year since 2011), then the GLCB may have further reduced survival. There is a substantial possibility that survival was overestimated in 2010 and 2011 because GLC provided the migration route for the majority, by a wide margin, of juvenile salmonids compared to Old River or Middle River (**Tables 3-14** and **3-21**).

Successful Passage Rates and Passage Route Selection at the ORTB

Chinook Salmon

In 2011, 94.5 percent (120 of 127) of the juvenile Chinook Salmon passed the ORTB successfully (**Table 3-39**). Yet, this passage rate was found to be significantly less (Kruskal-Wallis chi-squared = 65.700; $P = 5.25 \times 10^{-16}$) than the ratio predicted from survival estimates: 0.9951 expected to pass and 0.0049 expected to not pass. The passage route was successfully determined for 79 of the 120 passes. Sixty-four Chinook Salmon (81.0 percent) used the culvert route. It is hypothesized that the culvert route was used more than the weir route because the culvert route was always available (culvert flap gates were tied open in 2011 [**Table 2-2**]) regardless of when a juvenile Chinook Salmon arrived. In contrast, the weir was only overtopped during the highest water of flood and ebb tides. Therefore, a Chinook Salmon could utilize the culvert route even when the weir route was unavailable. Furthermore because the culvert flap gates were tied open during the entire tagged salmonid migration period, for much of the migratory period water flowed downstream through the culvert pipe.

Steelhead

In 2010, 73.5 percent (50 of 68) of juvenile steelhead did not pass the ORTB successfully (**Table 3-38**). This ratio of 18 passing and 50 not passing deviated significantly from the ratio expected 0.9988(expected to pass):0.0012(expected to not pass) (Kruskal-Wallis chi-squared = 30,574.000; $P = 2.2 \times 10^{-16}$). This suggests that in 2010, the ORTB was a significant impediment to migration of juvenile steelhead. Several factors could have influenced this significantly low passage rate including: 1) lower flows in 2010 (**Table 3-3** compared to **Table 3-5**) may have produced less time during which the weir was overtopped; and 2) water temperatures were slightly higher in 2010 (**Table 3-1** compared to **Table 3-2**). But, the greatest influence on successful passage rate was hypothesized to be passage route availability, i.e., in 2010 the culvert flap gates were not tied open (**Table 2-2**). Therefore, a portion of each day when the flap gates were not tied open, when a juvenile steelhead arrived it would have had to wait until a flood or ebb tide occurred that overtopped the weir or a flood tide forced the flap gates open.

Of the steelhead that did pass successfully in 2010, the passage route was successfully determined for 13 of these 18 passes. Eight steelhead (61.5 percent) of 13 used the weir route (**Figure 3-4**) and 5 used the culverts (**Table 3-38**) and there was no statistical difference between the proportion of fish using these routes. It was hypothesized that the weir route was used more than the culvert route because the culverts were more difficult to use. The culvert flap gates only opened on a flood tide when head differential existed to open the flap gate. In addition to this head differential, there would have been velocity flowing upstream through the flap gate. To use the culvert a juvenile steelhead must enter the darkened interior of the culvert pipe and swim against this current for the 18.9 m (62 ft) length of the culvert.

In 2011, 69.2 percent (36 of 52) of juvenile steelhead passed the ORTB successfully (**Table 3-40**). This ratio of 36 fish passing and 16 fish not passing deviated significantly (Kruskal-Wallis chi-squared = 3,306.100; P = 2.2 x 10^{-16}) from the ratio expected 0.9985:0.0015 (see Section 2.21 for the development of the ratio expected from survival data). These results indicated that the ORTB was a significant impediment to passage, but a greater number of steelhead passed than failed to pass. These results suggest that in a wet water year with high discharges and consistently available passage routes both juvenile steelhead and Chinook Salmon can pass through the ORTB with a much higher success rate than in a year like 2010 with lower discharges and less available passage routes.

In 2011, there were 36 successful steelhead passage events. The passage route was able to be determined for 24 of these 36 passes. Twenty-four steelhead (100 percent) of 24 used the culvert route (**Table 3-40**). Similar to juvenile Chinook Salmon, it is hypothesized that the culvert route was used more than the weir route because the culvert route was always available regardless of when a juvenile steelhead arrived. This was true because the culvert flap gates were tied open for the entire After-Construction Period in 2011 (**Table 2-4**). In contrast, the weir was only overtopped during, and shortly after, the peak of flood tide events. Furthermore in 2011, during much of the migratory period water flow would have been downstream through the culvert pipe—this downstream flow through the culvert pipes did not occur in 2010 after June 11. After June 11, 2010, salmonid juveniles had to swim against the flow to enter the culvert pipe because the flap gates only opened when a flood tide forced it open.

Time-In-Vicinity of Barriers

GLCB

Steelhead

In 2010, tagged steelhead only approached the GLCB during the Before-Construction Period. No hypothesis test was possible since no steelhead approached the GLCB in the During- or After-Construction Periods in 2010. In 2011, juvenile steelhead TIV in the GLCB's upstream area (**Table 3-48**) and the downstream area (**Table 3-49**) was significantly shorter in the Before- compared to the During-Construction Period. This result likely occurred because: 1) water temperatures were cooler and predator densities were higher in the Before-Construction Period stimulating steelhead to leave the area; and 2) lower discharges in the During-Construction Period compared to the Before-Construction Period (**Table 3-6**) could have slowed water velocities and slowed the steelhead migration rate.

ORTB

Chinook Salmon

In 2011, it was concluded that the ORTB caused a statistically-significant delay of juvenile Chinook Salmon on the upstream side of the barrier (**Table 3-51**). In addition, the TIV on the upstream side of the ORTB was significantly greater than the TIV for juvenile Chinook Salmon on the downstream side of the barrier (**Table 3-53**), suggesting that once the Chinook Salmon found a route through the barrier they continued migration very quickly. Furthermore, this significant delay in upstream TIV began with the onset of construction and not when the barrier was closed. After closure of the ORTB, the flap gates were tied open from June 10 until August 23. By August 23, all tagged juvenile Chinook Salmon had passed through the ORTB area.

Steelhead

In 2011, there was a significantly shorter TIV in the Before- compared to the After-Construction Period in the ORTB-upstream area (**Table 3-60**). This result was similar to that for juvenile Chinook Salmon. However, there were many similarities in behavior of steelhead and predatory fish (see Section 3.5.1 2010 Survival Results Related to the Predator Filter and Section 3.9 Mixture Model results in 2010 and 2011). Furthermore, predatory fish density was lower in the Before- compared to the After-Construction Period at the ORTB (**Table 3-71**), suggesting a larger proportion of tags could have been in predators in the After-Construction Period compared to the Before-Construction Period. Therefore, it is suggested that while this result was significant, this relationship should be studied further with steelhead. In this particular case, there seems real value in studying this issue using an acoustic transmitter that changes transmission characteristics after consumption of the tag by a predatory fish and the predator's stomach enzymes dissolve the special coating on the tag (Schultz et al. 2017).

Defecated and Regurgitated Tags

When acoustic tags are inserted in salmonid juveniles which are then released, those juveniles can be consumed by predators. In this situation, the acoustic tags can be either defecated or regurgitated and clearly indicate that some salmonid juveniles were eaten. Defecated/regurgitated tags were easily identified using the techniques described in Section 2.22 Defecated and Regurgitated Tags. In two years, only eight tags were defecated/regurgitated within the 2D ORTB array; presumably other tags left the area in the stomachs of predatory fish. However, of the eight tags identified as defecated/regurgitated, only one of those was defecated/regurgitated on the downstream side of the ORTB. If a tag had an equal chance of being defecated/regurgitated on the upstream and downstream sides of the barrier, the cumulative binomial probability of only one tag (out of eight) being defecated/regurgitated on the downstream side of the barrier is 0.035. Therefore, it was concluded in Section 3.8 Defecated and Regurgitated Tags, that there was a significantly higher probability of being defecated/regurgitated on the upstream side of the barrier than the downstream side.

This result suggested that predatory fish predation on juvenile salmonids might be more likely on the upstream side of the barrier. Predation might be more likely on the upstream side of the ORTB for many reasons but two of these were supported by observations made in this study. First, TIV was greater on the upstream side of the ORTB for both juvenile Chinook Salmon (**Table 3-51**) and steelhead in 2011 (**Table 3-60**), showing that migratory juvenile salmonids were delayed. Second, at the ORTB, the predatory fish density remained the same (2010; **Table 3-70**) or was higher (2011; **Table 3-71**) on the upstream side of the barrier in the After- compared to the Before-Construction Period.

Mixture Model

The 2010 tags and 2D track segments that satisfied all requirements for mixture modeling were derived from 68 juvenile steelhead, 5 Largemouth Bass, 4 Striped Bass, and 1 White Catfish. The predator tracks (i.e., Largemouth Bass, Striped Bass, and White Catfish) were, in general, more tortuous than the juvenile steelhead tracks (**Figure**

3-6). However the distributions heavily overlapped for both tortuosity and the Lévy exponent. The behavior of juvenile steelhead was similar to that of the observed predatory fish, with few fish passing directly through the array. This resulted in a larger proportion of the juvenile steelhead track segments being classified as predatory fish (247 of 504 = 49.0 percent) rather than salmonids (210 of 504 = 41.7 percent; **Table 3-65**).

In 2010, the mixture model had difficulty in distinguishing predatory fish and juvenile steelhead due to the similar behaviors of both groups. The predatory fish tracks were more tortuous than steelhead tracks. However, the predator and steelhead distributions of tortuosity and the Lévy coefficients overlapped to such an extent (**Figure 3-6**) that the mixture model's ability to distinguish between predators and steelhead was compromised (**Table 3-65**). These overlaps were strongest for Largemouth Bass and steelhead because: 1) Largemouth Bass displayed unidirectional patrolling along shorelines and rarely left river margins resulting in lower tortuosity than was observed for Striped Bass; and 2) juvenile steelhead when approaching the ORTB often exhibited apparent searching behavior for a passage route though the barrier that displayed small step-length and large turning angles resulting in very tortuous 2D tracks upstream of the barrier (see **Figure 3-3**).

In 2011, the mixture model performed better than with the 2010 data but again had trouble distinguishing predatory fish from juvenile salmonids. This was due primarily to the similarities in behavior of predators and salmonids. Lévy coefficient distributions overlapped so extensively (**Figure 3-7**) that this metric was abandoned as a means to distinguish between predators and salmonids. Thus, tortuosity alone was used and 86.0 percent of juvenile Chinook Salmon track segments (222 of 258) were classified as having low probability of being in a predator (**Table 3-67**). For steelhead this value fell to 65.8 percent (123 of 187) classified as having low probability of being in a predator (**Table 3-67**), again suggesting that juvenile steelhead behave differently from juvenile Chinook Salmon. In addition, the mixture model performed better for predators in 2011 predicting the probability was high (probability 0.66–1) of being a predator for Largemouth Bass (60.0 percent) and Striped Bass (64.3 percent) (**Table 3-67**).

In 2010 and 2011, juvenile salmonids exhibited behavior that was characterized by highly tortuous tracks compared to juvenile salmonid tracks observed at the HOR (DWR 2015a: Figures 5-10 and 5-11) when no rock barrier was present, and at Georgiana Slough (DWR 2012: Figure 3-5; DWR 2015b: Figures 3.2-5 and 3.2-11). These ORTB results are likely due to juvenile salmonid hesitation at the barrier and searching behavior to find a passage route through the barrier. This hesitation and searching behavior resulted in tracks with small step-length and large turning angles generating highly tortuous tracks compared to other locations in the Delta that did not have physical barriers. This explanation was supported by comparing the juvenile salmonid tracks obtained in 2010 and 2011 at the ORTB and the juvenile salmonid tracks obtained in 2012 at the rock barrier at the HOR (DWR 2015a) in which the tracks showed a great deal of similarity with apparent searching behavior on the upstream side of the rock barrier.

Other approaches than tortuosity and Lévy coefficients, such as state-space modeling, may aid in producing another track metric that could be used to feed into a mixture model approach. However, dynamic environments such as the study area where fish may stall at a barrier and experience bidirectional flows, further supports the development and use of predation tags to identify tagged salmonids that may have been consumed by predatory fish.

DIDSON Monitoring of Predators

As discussed in Section 3.10 DIDSON Analysis, overall trends in predatory fish density were calculated for the DIDSON sampling. Generally, for periods when DIDSON sampling was conducted, there was an increase in predatory fish densities during or after the barriers were installed compared to periods before the barriers were installed for both 2010 and 2011 (**Tables 3-70** and **3-71**). The noted exception to this was at the GLCB in 2011 where Before-Construction Period predator density (0.86 predatory fish/1000 cubic meters [24.35 predatory fish/1000 cubic feet]) was 33.7 percent greater than the During-Construction Period (0.57 predatory fish/1000 cubic meters [16.14 predatory fish/1000 cubic feet]) (**Table 3-71**). This result made sense when discharge regime and GLCB installation activities were considered. From fall 2010 through to June 10, 2011, the GLC was a completely open channel because the GLCB abutments were removed (**Table 2-4**). Furthermore, after June 10, 2011, high flow events regularly displaced material downstream that had been placed in the GLC to form the foundation of the GLCB. Thus, the GLC was typically a completely open channel for an estimated 81 percent (93 of 115 days) of the tagged salmonid migratory period (March 22, 2011 [1st release of fish] until June 22, 2011 [last juvenile Chinook Salmon detection in the study area]). It was hypothesized that this combination of the wet water year with high discharge and an open channel in which few or no velocity refugia were present changed the bioenergetic landscape in the vicinity of the GLCB footprint—high swimming cost and faster migrating juvenile salmonids made predatory fishes' net energetic return lower in the During-GLCB Construction Period and therefore some proportion of the predators may have left the area.

ES-4 RECOMMENDATIONS

Five recommendations are made based on the research completed for this report. Each recommendation is followed by a summary of the data in this report supporting the recommendation. The recommendations chapter is divided into three sections: the first section identifies design improvements to the SDABs; the second section identifies operational improvements to the SDABs; and the third section addresses barrier priorities for improvements.

Design Improvements

The results of this investigation demonstrate that the SDABs designs could be improved to benefit emigrating juvenile steelhead and Chinook Salmon survival through the south Delta.

Recommendation 1. Open Passage Route through Barriers

In Years in Which the Head of Old River Barrier is Not Installed

As soon as feasible, an open passage route should be maintained through each SDAB for as much of the spring/early summer salmonid migratory period as possible. The open passage routes should be maintained until water temperatures are lethal to juvenile salmonids: ≥ 24.0°C (75.2°F) for steelhead (Bell 1990; Nielsen et al. 1994) and Chinook Salmon (Moyle 2002).

In Years in Which the Head of Old River Barrier is Installed

As soon as feasible, on open passage route should be maintained through each SDAB when the HORB is not operational and water temperatures are not lethal to juvenile salmonids, i.e., < 24.0°C (< 75.2°F) for steelhead (Bell 1990; Nielsen et al. 1994) and Chinook Salmon (Moyle 2002).

Data Supporting Recommendation 1

In the April 1, 2010 to May 9, 2010 period, steelhead survival route in the ORTB Before-Construction Period was 89.3 percent (SE = 3.0 percent) (**Table 3-16**). In the June 4, 2010 to July 7, 2010 period, steelhead survival in the ORTB After-Construction Period was 57.7 percent (SE = 5.4 percent) (**Table 3-17**). It should be noted that the ORTB Before-Construction Period corresponds closely to the Before-Construction Periods of the GLCB and the MRB; in addition, the ORTB After-Construction Period completely encompasses the During-GLCB Construction Period. In addition, the ORTB After-Construction Period corresponds closely to the MRB After-Construction Period (**Table 2-1**). The juvenile steelhead survival difference between these two periods (4/1/10–5/09/10 and 6/4/10–7/7/10) was a statistically-significant 35.3 percent. There were six possible mechanisms explored to explain the steelhead survival difference between these two periods: 1) the status and operations of the SDABs (**Table 2-2**); 2) flow magnitude and its effects; 3) distribution of flow in the three channels of interest (**Tables 3-3** and **3-4**); 4) export rate (**Table 3-7**); 5) water temperature (**Table 3-1**); 6) and predatory fish density (**Table 3-70**) (see Section 4.1.2.2 *Comparing Survival and Covariates from April 1, 2010–May 15, 2010 to May 16, 2010–July 7, 2010*). It was concluded that the increase water temperature, increased predatory fish density, and reduced passage availability through barrier culverts were most likely the largest contributing factors to the survival decrease. Thus, maintaining an open passage route through each barrier could improve juvenile salmonid survival. For example, one culvert could have the flap gate tied open to provide a passage route.

In the March 22, 2011 to June 9, 2011 period, Chinook Salmon survival in the GLCB Before-Construction Period was 65.0 percent (SE = 3.1 percent) (**Table 3-29**). In the June 10, 2011 to July 14, 2011 period, Chinook Salmon survival during the GLCB During-Construction Period was 76.1 percent (SE = 3.2 percent) (**Table 3-29**). This difference in before- and during-construction survival for juvenile Chinook Salmon was a statistically-significant 17.1 percent improvement in survival. This increase in survival was most likely due to: 1) the flow proportion entering the GLC increased substantially in the second time period compared to the first (**Table 3-6**); and 2) open migratory routes were available through the GLCB, through the ORTB, and through the MRB (**Table 2-4**) (see Section 4.1.3 *2011 Juvenile Chinook Salmon*). Abutment removal in fall 2010 and high discharges in the wet water year of 2011 provided a completely open GLC channel for approximately 81 percent of the salmonid migratory season. In addition, the GLCB was not completely closed until July 14—after the end of the salmonid migratory period. Therefore, no telemetered salmonids experienced a completely closed GLCB in 2011. In 2011, construction was complete on the ORTB (June 10) and the MRB (June 6) but their culverts' flap gates were tied open until August 23 (**Table 2-4**) and so migrating salmonids did not have to wait for a particular tidal state to pass these two barriers; and 3) the results highlight how if passage availability is consistently maintained, survival need not decline through the migratory season as observed for steelhead in 2010 (**Table 3-16**). In fact, survival for Chinook Salmon juveniles could possibly improve through time if passage availability is maintained throughout the juvenile salmonid migratory period. The greater the proportion of the migratory season that a route is kept open through a barrier, the greater the probability that migrating salmonids will be able to pass through the barrier quickly and this result could improve survival. For example, flashboards installed in the GLCB could allow flexible management of water flow over the flashboards and provide more passage availability than tidally-operated flap gates.

One barrier, the ORTB, was studied intensely using 2D acoustic tracks to analyze barrier passage. In 2010, 68 steelhead were detected at the ORTB area and 50 of these fish failed to pass (**Table 3-37**). This ratio of 18 fish passing and 50 fish not passing deviated significantly from the ratio expected from survival estimates, successful passage expected was 0.9988:0.0012 expected to not pass (Kruskal-Wallis chi-squared: 30,574.000; $P = 2.2 \times 10^{-16}$) (see Section 3.6 *Successful Passage and Route Through the Old River at Tracy Barrier*). This result demonstrated that a closed barrier with flap gates operating tidally, i.e., not tied open, was a significant impediment to steelhead migration in 2010. In 2011, the ORTB remained a statistically significant impediment to steelhead migration (Kruskal-Wallis chi-squared = 3,306.100; $P = 2.2 \times 10^{-16}$) and Chinook Salmon migration (Kruskal-Wallis chi-squared = 65.700; $P = 5.25 \times 10^{-16}$). However, in 2011 with flap gates tied open, 36 steelhead passed and 16 did not pass (**Table 3-39**). Furthermore, in 2011, 120 Chinook Salmon passed and 7 did not pass (**Table 3-38**). Thus in 2011, for both steelhead and Chinook Salmon, more individuals passed than did not pass and this reversed the pattern seen for 2010 steelhead. So, when the culverts were tied open in 2011 more steelhead and Chinook Salmon successfully passed than failed to pass. These results demonstrate that open passage routes could provide substantial benefits to migrating salmonids. Open passage routes could be provided by tying open culvert flap gates or installing flashboards.

Recommendation 2. Operable Gates at Each South Delta Agricultural Barrier

As part of a long-term solution to salmonid passage, an improved design at each SDAB should include an operable gate that would allow the barrier to be opened in less than four hours when the upstream water-level protection was not necessary or when emigrating salmonids were passing the barriers in high numbers.

Data Supporting Recommendation 2

The analysis of defecated/regurgitated tags for 2010 and 2011 indicated that predation was more likely on the upstream side of the ORTB than the downstream side (**Table 3-63**). The most likely explanation for this finding is: 1) Chinook Salmon and steelhead TIVs were significantly greater in the upstream area ORTB After-Construction Period compared to the ORTB Before-Construction Period (**Table 3-51** for 2011 Chinook Salmon and **Table 3-60** for 2011 steelhead); and 2) predatory fish density was lower in the Before-Construction Period compared to the 2010 GLCB During-Construction Period and the 2010 and 2011 After-Construction Periods of the ORTB and MRB (**Tables 3-70** and **3-71**). An operable gate would allow Chinook Salmon and steelhead to move through a barrier area more quickly, reducing TIV, and this should further reduce the predator-prey encounter rate.

An operable gate could be opened when high densities of juvenile steelhead or Chinook Salmon were in the south Delta. Juvenile salmonid densities should be monitored to determine if salmonids are actively migrating in the south Delta, and ORTB and MRB construction activities temporarily halted until salmonid densities decrease to “acceptable” levels. “Acceptable” salmonid densities could not be defined herein because these thresholds were not investigated in this study and will depend on the water year type. For example, CVP and SWP salvage data augmented by the CDFW/USFWS’s Mossdale trawl information (Interagency Ecological Program 2017) could be used to monitor the presence and relative abundance of emigrating salmonids in the south Delta. The operable gate could be lowered when high salmonid densities were present and this would reduce the time required to locate and use a passage route because a far greater proportion of the channel’s cross-section would be available for juvenile salmonid use.

If the operable gate was designed to have a passage route available, e.g., on an ebb tide, even when in the closed position, survival might be further improved. For example, a self-regulating notch with an automated depth control structure could be placed within the barrier structure, adjacent to the operable gate, and opened on ebb tides to maintain a passage route through the barrier at all times.

Operational Improvements

The results of this investigation demonstrate that the SDABs operations could be improved to benefit juvenile steelhead and Chinook Salmon emigrating through the south Delta.

Recommendation 3. Minimize the Duration of In-Water Construction at Each Barrier

During barrier construction activities, carefully plan to minimize in-water work in order to reduce impacts to migrating salmonids.

Juvenile salmonid densities could be monitored by the DWR and Reclamation to determine if salmonids are actively migrating toward the south Delta from the anadromous salmonid-bearing tributaries of the south San Joaquin River. Juvenile salmonid monitoring could be accomplished in the San Joaquin River (e.g., at Sturgeon Bend (37°40'12.75"N, 121°14'38.78"W)). This density monitoring would also be very valuable for CVP/SWP Delta export operations. Reclamation, DWR, NMFS, USFWS, and CDFW could cooperatively determine how this new source of fish abundance data can be used to inform export operations and minimize construction related impacts of the SDABs. When "high" densities of juvenile salmonids are detected, in-water construction activities could cease until juvenile salmonid density decreases to "acceptable" densities. "High" and "acceptable" salmonid densities could not be defined herein because these thresholds were not studied in this analysis and will depend on the water year type. Potential considerations in implementing this recommendation include:

1) Consider using contract language that rewards the barrier construction contractor for quick installation that meets all construction specifications;

2) Without compromising safety, allow sufficient resources to effect the fastest barrier construction possible;

3) If possible, install flashboards in the barrier structure during construction and use the flashboards to quickly close the barrier when NMFS and USFWS regulators approve complete closure. If flashboards are installed, open the flashboards when possible to improve salmonid passage efficiency; and

4) Minimize predator refugia in the SDAB footprint areas during in-water construction. Specifically, minimize water velocity refugia that are present in the SDAB footprint areas that could be used by predators as ambush habitat. As soon as a barrier is built remove all in-water velocity refugia created by the construction process.

Data Supporting Recommendation 3

In 2011, it was concluded that the ORTB, with flap gates tied open, caused a statistically significant emigration delay of juvenile Chinook Salmon on the upstream side of the barrier (see Section 3.7.3.2 *2011 Juvenile Chinook Salmon*; **Table 3-51**). Furthermore, this significant delay in TIV began with the onset of construction and not when the barrier was closed. Also in 2011 during ORTB construction, predatory fish density in the During-ORTB construction period was more than double the Before-ORTB construction predatory fish density (**Table 3-71**). So, in the During-Construction Period, juvenile salmonids were required to find a route through the barrier construction area in the presence of higher predatory fish density. In the After-Construction Period of 2011, juvenile Chinook Salmon TIV on the ORTB upstream side was significantly longer than on the ORTB downstream side (**Table 3-53**). Thus, immediately after finding a route through the barrier, Chinook Salmon very quickly continue their migration.

The 2011 steelhead TIV in the During-Construction Period could not be tested because no steelhead was detected at the ORTB in that period. However, 2011 steelhead Before-Construction TIV in the ORTB upstream area was significantly shorter than the After-Construction Period TIV (**Table 3-60**). Therefore, there is no obvious reason why the recommendation for avoiding in-water work for the benefit of Chinook Salmon should not also benefit steelhead.

The recommendation that special juvenile salmonid monitoring be conducted in the San Joaquin River is based on the approach used in the north Delta, described in NMFS's RPA IV.3: the catch indices at Knights Landing or Sacramento are used to provide the "Third Alert" (NMFS 2009, pg. 652). This alert is used by the Water Operations Management Team to determine how to operate the CVP and SWP diversions and at what rate. This "early warning" system on the Sacramento River is utilized to minimize entrainment impacts at the export facilities and a similar approach could be used in the San Joaquin River/south Delta to minimize entrainment impacts and minimize SDAB-construction impacts on migrating juvenile salmonids.

Real-time information regarding when juvenile emigrant salmonid densities increase to "levels of concern" during the SDABs in-water construction season could be an important management tool to reduce construction impacts and improve emigrant survival. The best field practice for monitoring emigrant salmonids could be selected based on testing several technologies including rotary screw traps (E. G. Solutions, Corvallis, OR), DIDSON sonar (Sound Metrics, Bellevue, Washington), a VAKI system (Riverwatcher by VAKI Aquaculture Systems Limited., Akralind, Iceland), environmental DNA (Wilcox et al. 2016), or other technology. Furthermore, a research project evaluating these technologies could also study where the optimal monitoring location would be to provide precise counts and sufficient time for managers to halt work temporarily if emigrant salmonid densities had exceeded the trigger count.

Minimizing predatory fish refugia in the SDAB footprint areas, specifically, minimizing water velocity refugia that are present in the SDAB footprint areas that could be used by predators as ambush habitat is of importance and is supported by these results:

1) The highest predatory fish density estimates were observed during and after the barriers were installed (**Tables 3-70** and **3-71**). The construction of and the presence of the barriers creates a condition of increased artificial structure, which provides velocity refugia, habitat complexity, and locations where a predatory fish can hold and ambush prey; and

2) There was one exception to the results described in the item 1). At the GLCB in 2011, Before-Construction Period predatory fish density of 0.86 predatory fish per 1,000 cubic meters (0.024 predatory fish/1000 cubic feet) was 33.7 percent greater than the During-Construction Period of 0.57 predatory fish per 1,000 cubic meters (0.016 predatory fish/1,000 cubic feet) (**Table 3-71**). After June 10, 2011, high flow events regularly moved rock downstream that had been placed in GLC to form the foundation of the GLCB. It was hypothesized (Section 4.7 *DIDSON Monitoring of Predators*) that high discharges, increased water temperature in the During-Construction Period (**Table 3-2**), and an open channel in which few or no velocity refugia were present in the vicinity of the GLCB footprint made this area less energetically profitable for fish predators. This decrease in predatory fish density through time at the GLCB in 2011 suggests that minimizing water velocity refugia for predatory fish could reduce predation probabilities on migrating juvenile salmonids.

Recommendation 4. Coordinate Operations Between the HORB and the SDABS

It is recommended that the operations of the HORB and SDABs be coordinated.

Data Supporting Recommendation 4

During the spring, the HORB is scheduled for construction to begin each year on March 1 (NMFS 2013: Table 1). The HORB is scheduled to be closed each year on April 1 and to operate at most for two months (NMFS 2013: Table 1), i.e., April 1 through May 31.

As recommended previously in Recommendation 1 (Open Passage Route Through Barriers), juvenile salmonid passage routes through each SDAB should be maintained March 1 through April 1 during construction of the ORTB and MRB. During April 1 through May 31 when the HORB is in place, very few juvenile salmonids enter the Old River because the HORB protection efficiency is very high, e.g., protection efficiency at the HORB was measured at 100 percent in 2012 (DWR 2015a). During the April 1 through May 31 period, open passage through the SDABs is not critical because few salmonid emigrants are present. The HORB is scheduled to end operation on May 31 (NMFS 2013: Table 1). So, after May 31 of each year, many more emigrating juvenile salmonids may enter the Old River. When the HORB operation is terminated each spring, open passage routes through the SDABs become critical again. The potential interaction between the HORB operations timing and the SDABs operations timing leads to the recommendation that these south Delta operations be coordinated at an appropriate level to improve juvenile salmonid emigration survival.

Where possible, improve coordination with NMFS and the USBR in identifying the timing of the April–May San Joaquin River pulse flows so that HORB and SDAB construction activities can be adaptively managed to minimize effects on migrating juvenile salmonids.

Joint Design and Operational Improvements

The priority ranking of SDAB design and operational improvements is important to the survival of emigrant juvenile salmonids.

Recommendation 5. Barrier Priority Order for Improvements

It is recommended that design and operational improvements be initiated at the GLCB first, the ORTB second, and the MRB last.

Data Supporting Recommendation 5

A much larger proportion of telemetered emigrant Chinook Salmon and steelhead (range: 84.6–98.9 percent) used Grant Line Canal in comparison to Middle River (range: 0–6.0 percent) or Old River at Tracy (range: 1.1–9.8 percent) channels (**Tables 3-14** and **3-21**). Therefore, to have the most substantial impact on Chinook Salmon and steelhead populations, improvements, whether related to SDAB design or operations, if any are undertaken, should be initiated at the GLCB first, the ORTB second, and the MRB last.

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1 INTRODUCTION

1.1 PURPOSE OF THE SOUTH DELTA AGRICULTURAL BARRIERS

The South Delta Improvements Program (SDIP) implemented cooperatively by the California Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (Reclamation), proposed a series of actions to improve water quality and protect anadromous salmonids[4] in the southern part of the Sacramento-San Joaquin Delta (Delta), while allowing the State Water Project (SWP) to operate more effectively to meet California's existing and future water needs. For a comprehensive overview see DWR's SDIP website at http://baydeltaoffice.water.ca.gov/sdb/sdip/index_sdip.cfm. In summary, the SDIP has a two-stage evaluation process: 1) Stage 1 addresses physical/structural and agricultural diversion modifications; and 2) Stage 2 addresses the proposed operational component to increase water deliveries south of the Delta. Stage 2 begins after the Stage 1 evaluations are completed.

DWR's Temporary Barriers Project (TBP) is one element of the SDIP Stage 1 program. The TBP, initiated in 1991, is an ongoing project that installs, operates, and monitors up to four seasonal rock-fill barriers constructed in the southern Delta south of State Route 4 near the cities of Tracy and Lathrop in San Joaquin County, California (**Figure 1-1**). Three of the seasonal barriers—Old River at Tracy (ORTB), Middle River (MRB), and Grant Line Canal (GLCB), collectively, the south Delta agricultural barriers (SDABs)—are constructed and operated during the agricultural irrigation season, usually April through November. The SDABs are designed to act as flow control structures, retaining tidal fresh water behind each barrier following a flood tide.

The fourth barrier, Head of Old River Barrier (HORB), is installed during the spring and again in the fall as a fish guidance barrier. Historically, the HORB was installed to prevent juvenile fall-run/late fall-run San Joaquin River Chinook Salmon (*Oncorhynchus tshawytscha*)[5] and juvenile Central Valley steelhead (*Oncorhynchus mykiss*)[6] from emigrating through Old River toward the south Delta water export facilities at the intakes of the State Water Project (SWP) and federal Central Valley Project (CVP) (i.e., the Harvey O. Banks Pumping Plant and C. W. "Bill" Jones Pumping Plant, respectively) (**Figure 1-1**). The HORB would function to keep emigrating juvenile salmonids in the San Joaquin River where survival was determined to be higher. However, a biological opinion (BiOp) issued by the U.S. Fish and Wildlife Service (USFWS) has restricted the spring installation of the HORB in order to protect the federally threatened Delta Smelt (*Hypomesus transpacificus*)[7] (USFWS 2008: BiOp Appendix B, Action 5). In the fall, the HORB is constructed to help guide adult fall/late fall-run Chinook Salmon to spawning locations in the San Joaquin River watershed. Because of varying hydrological conditions and concerns for threatened and endangered fish species, the number of barriers installed and the installation schedules have been slightly different each year.

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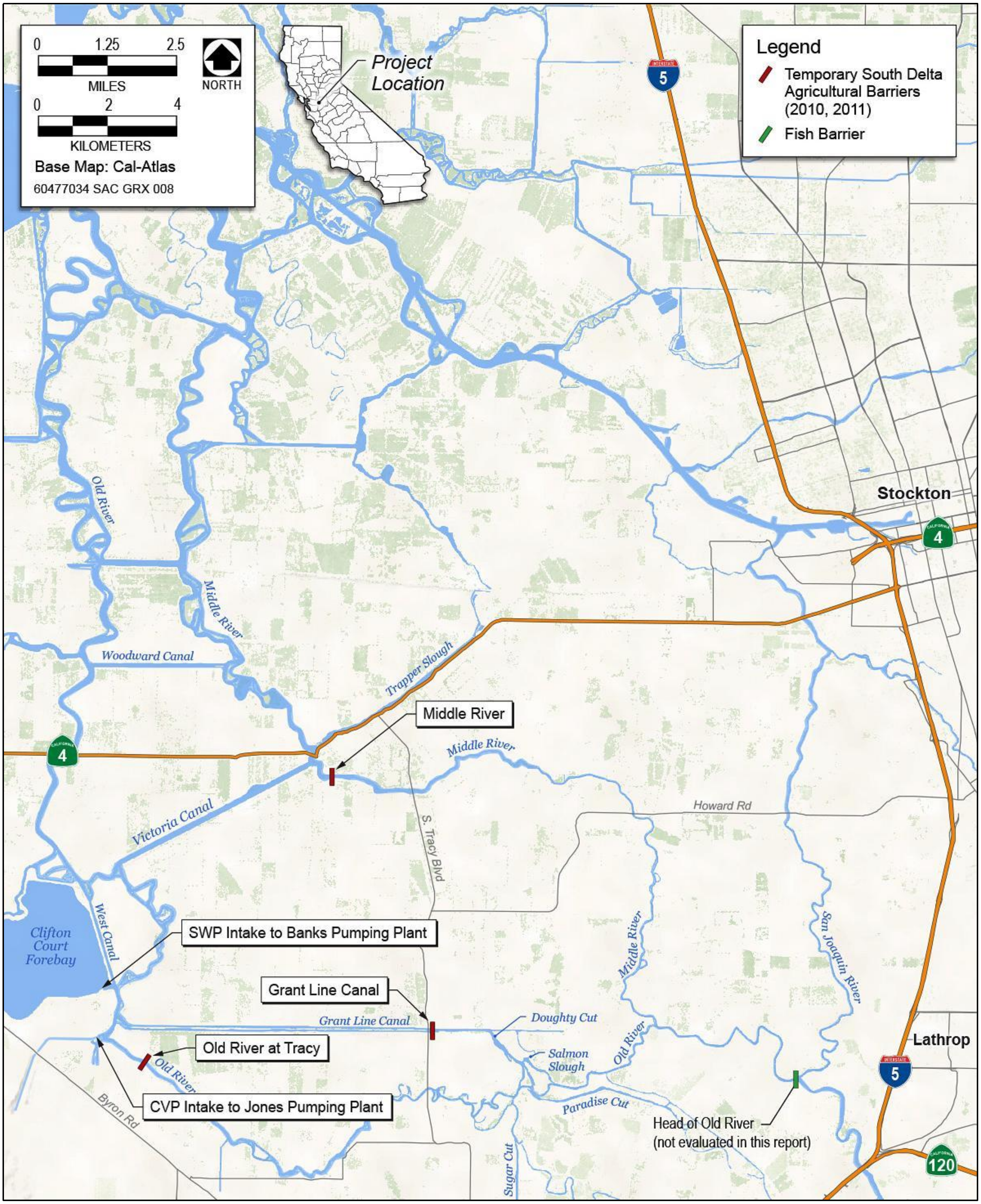
[4] The common names of fishes follow the convention established by the American Fisheries Society in *Common and Scientific Names of Fishes from the United States, Canada, and Mexico*, Seventh Edition (Page et al. 2013). The American Fisheries Society recognizes "steelhead" as a life history variant of Rainbow Trout, the recognized name for the full species, so the name "steelhead" is not capitalized.

[5] Both the fall-run and late fall-run were added to the National Marine Fisheries Service's (NMFS) list of Species of Concern on April 15, 2004 (NMFS 2010). The California Department of Fish and Wildlife (CDFW) lists the fall-run only as a Species of Special Concern (CDFW 2017).

[6] Originally listed as threatened pursuant to the Endangered Species Act on March 19, 1998 (63 Federal Register [FR] 13347) and reaffirmed as threatened in 2006 (71 FR 834). No State of California designation pursuant to the California Endangered Species Act (CDFW 2017).

[7] Listed as a federally threatened fish on March 5, 1993 (58 FR 12854). The USFWS determined that the Delta Smelt was a candidate for uplisting to endangered status on April 7, 2010 (75 FR 17667). The uplisting, while warranted, was precluded by other higher priority listing actions. Listed as a state threatened fish pursuant to the California Endangered Species Act (California Fish and Game Code Sections 2050—2069) on December 9, 1993 and elevated to endangered status on January 20, 2010.



Source: AECOM this study.

Figure 1-1. Project Area Illustrating the Locations of Temporary South Delta Agricultural Barriers and the Head of Old River Fish Passage Barrier

In 2014, efforts were initiated by state and federal resource agencies to establish a non-essential experimental population of the historically extirpated Central Valley spring-run Chinook Salmon (*Oncorhynchus tshawytscha*) in the San Joaquin River downstream of Friant Dam (78 FR 79622). Out-migrating juvenile spring-run Chinook Salmon derived from this effort presumably would be affected by the SDABs in a manner similar to juvenile fall/late fall-run Chinook Salmon. Additionally, because adult spring-run fish return to freshwater holding habitats from March through September before spawning later in the fall, their upstream migration could be potentially affected by TBP management practices if restoration of this run is successful.

1.2 STUDY PURPOSE AND OVERVIEW

Installation, operation, and removal of the temporary barriers has the potential to harm, harass, or cause mortality to several special-status anadromous fish species, including Chinook Salmon, steelhead, and Green Sturgeon (*Acipenser medirostris*). The National Marine Fisheries Service's (NMFS 2008, pg. 86) TBP-project specific BiOp required "fisheries monitoring programs to examine predation effects associated with the TBP." Furthermore, the TBP is implemented in compliance with the terms and conditions of the (NMFS 2009) BiOp for the Long-Term Operations of the CVP and SWP that evaluates conservation measures for federally-listed anadromous fishes. Reasonable and Prudent Alternative [RPA] Action IV.1.1 "Monitoring and Alerts to Trigger Changes in the Delta Cross Channel Operations") required that a fisheries monitoring program be established to examine the movements and survival of listed[1] anadromous fish species through the channels of the south Delta (NMFS 2009, pg. 674). In addition, RPA IV.6 specifically prohibits reconsultation on SDIP-phase 1, including construction of permanent operable gates, until after the completion of the study reported herein (NMFS 2009, pg. 659).

To comply with the requirements of the NMFS Biological Opinions (2008, 2009), a study of the three SDABs (i.e., ORTB, MRB, and GLCB) was conducted from 2009 to 2011. A pilot study was conducted in 2009. The information gained in the field logistics of the pilot study was applied to the full-scale study conducted in 2010 and 2011. Results were insufficient in 2009 for inclusion in this report with one exception—predatory fish externally tagged with acoustic transmitters in 2009 were detected in 2010—therefore, the 2009 predatory fish tagging data are presented herein. All results for 2010 and 2011 are reported in this document. The objective of this study was to estimate the following effects of the three SDABs on out-migrating juvenile steelhead and Chinook Salmon: 1) survival of juvenile salmonids; 2) juvenile salmonid time-in-vicinity (TIV) of a barrier; 3) predatory fish predation on juvenile salmonids; and 4) predatory fish density evaluations before-, during-, and after-barrier installations. For one barrier, the ORTB, two-dimensional (2D) fish tracks of acoustically tagged salmonids were evaluated in both 2010 and 2011 to determine successful passage rates and routes through the barrier to determine if one route was preferred over others. In addition, at the ORTB the 2D fish tracks were evaluated by a mixture model (Romine et al. 2014) to determine the probability that a juvenile salmonid had been eaten by a predatory fish in the vicinity of the ORTB.

[1] Federally listed pursuant to the Endangered Species Act of 1973.

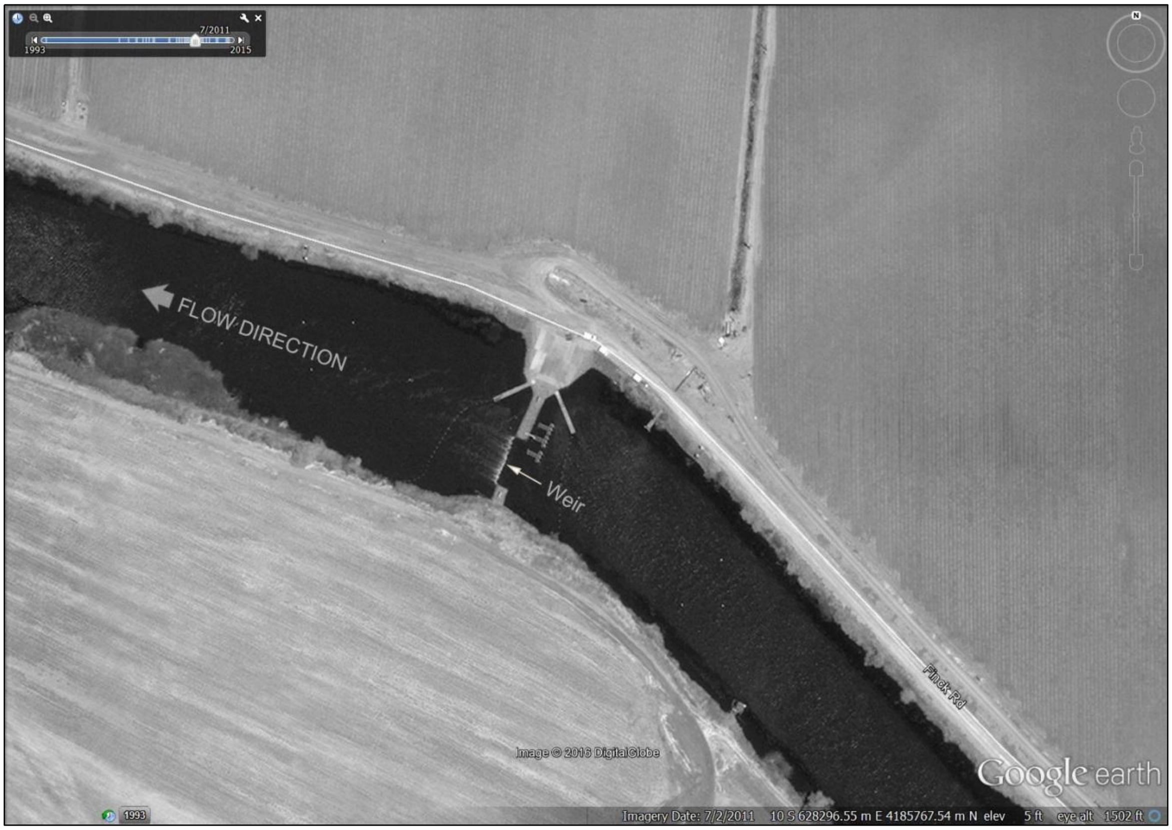
1.3 SOUTH DELTA SETTING

1.3.1 Physical and Chemical Characteristics

For over 160 years, the Delta has experienced wetland conversion and levee construction (Thompson 1957). Large scale reclamation activities transformed the historic complex distributary pattern of Delta watercourses (Mount 1995) and anabranching[8] channels (Nanson and Knighton 1996) into a more simplified channel network, with smaller channels branching off from fewer large channels, producing hundreds of individual watercourses. The simplified anabranching channels of the south Delta are typically protected by earthen and rip-rapped levees. The channels are either natural (e.g., Old River) or constructed (e.g., Grant Line Canal [GLC]).

The south Delta is influenced by daily tides. The water surface elevation differential between low and high tide can be as great as 1.5 meters (m) (4.9 feet [ft]), but is on average about 0.5 m (1.7 ft). Twice daily the flow at the SDABs reverses. These physical events are used by DWR to capture freshwater upstream of the SDABs, i.e., an incoming (i.e., flood) tide pushes open the culvert's unidirectional flap gates at each barrier and freshwater flows upstream of the barriers. Also, a barrier's weir can also be overtopped with water flowing upstream during a flood tide's peak period. As the tide reverses (i.e., ebb tide) and the water velocity flowing upstream decreases, the flap gates at each barrier close trapping freshwater upstream of the barriers. In addition, when the tide turns and an ebb tide is beginning, the weir can be overtopped and water can flow downstream over the crest of the weir (**Figure 1-2**). The results of these activities are changes to the physical habitat and the hydrodynamics in the immediate vicinity of the barriers. The SDABs can partially isolate the south Delta hydrodynamically from the remainder of the Delta (Grossman et al. 2013). In summary, the SDABs cause hydrodynamic changes that may have substantial effects on juvenile salmonid emigration patterns, salmonid and predatory fish TIVs at the barriers, and salmonid survival rates.

8 Naturally anabranching rivers consist of multiple channels separated by vegetated, semi-permanent alluvial islands excised from existing floodplain or formed by within-channel or deltaic accretion.



Source: Google Earth Pro historical imagery.

Figure 1-2. The Weir on the Old River at Tracy Barrier Overtopped by an Ebb Tide on July 2, 2011

In the south Delta and the San Joaquin River and its tributaries, steelhead and Chinook Salmon are geographically approaching the most southerly latitudes of their occurrence in North America. One of the primary environmental factors limiting the distribution of anadromous salmonids and affecting habitat suitability is water temperature. The upper lethal limit for juvenile steelhead is 24 degrees Celsius (°C) (75 degrees Fahrenheit [°F]) (Bell 1990; Nielsen et al. 1994). For juvenile Chinook Salmon, very few individuals can survive water temperatures greater than (>) 24°C (> 75°F) (Moyle 2002). Baker et al. (1995) reported upper lethal temperatures for juvenile Chinook Salmon of 23.0 to 25.1°C (73.4–77.2°F) depending on acclimation temperature. In 2010, the south Delta water temperatures exceeded 24°C (75°F) routinely after June 26[9]. Increased water temperatures in the south Delta may cause impairment of smoltification, decrease growth rates, and increase susceptibility to predation (Marine and Cech 2004), e.g., by reducing maximum swimming speed (Lehman et al. 2017). In addition, in the south Delta near the end of June, direct mortality from elevated water temperatures becomes a real danger to juvenile salmonids.

As previously stated, there are two large water diversions located in the south Delta: the CVP and SWP intakes (**Figure 1-1**). The CVP intake, leading to the Jones Pumping Plant near Tracy, can divert (i.e., pump/export) up to a maximum of 144.4 cubic meters per second (cms) (5,100 cubic feet per second [cfs]). The SWP's, intake leading to the Banks Pumping Plant near Byron, can divert up to 291.7 cms (10,300 cfs)[10]. When both diversions are operated together they can export 436.1 cms (15,400 cfs) from the Delta. Whether operated alone or in

9 As recorded at California Data Exchange Center station "Old River Near Tracy" (OLD).
10 Physically the SWP intake at Clifton Court Forebay can divert more than 10,300 cfs, however operationally DWR typically keeps the diversion to under 12,000 cfs to avoid channel scour.

conjunction, the CVP and SWP intakes can divert sufficient quantities of water to cause negative flows (i.e., reverse from the natural pattern of flow) in lower Old River and Middle rivers. When reverse flows occur, the hydrodynamics in the south Delta for emigrating juvenile salmonids may be substantially more difficult to navigate.

The southern part of California's Central Valley exhibits long summers with little rainfall, mild winters with most moisture falling between November and April. Precipitation on the valley floor ranges on average from 13 to 38 centimeters (cm) (5–15 inches [in]) annually depending on location (U.S. Geological Survey [USGS] 2011). The discharge of the San Joaquin River is sporadic with pulse flows occurring between November and April during intense rainfall events and during the spring and early summer due to snowmelt in the Sierra Nevada. Stream discharge may be greater during rainstorms but the duration of these rain-triggered flow pulses may be shorter than pulses that are driven by snowmelt (Mussetter Engineering, Incorporated and Jones & Stokes Associates, Incorporated 2000).

Discharge has been positively associated with juvenile salmonid survival in the Delta (Newman 2008). This observation may be due to decreased salmonid travel time through the Delta associated with higher flows (Cavallo et al. 2013). The reduced travel time resulting from higher discharges would reduce the probability of a juvenile salmonid encountering a predator due to a reduction in exposure time to predation.

1.3.2 Water

1.3.2.1 *Quantity*

The 2010 water year was rated "above normal" and the 2011 water year was rated "wet" (California Data Exchange Center [CDEC] 2016a at http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST). These results were reflected in the discharge patterns through the south Delta. For example, 2010 exhibited considerably lower spring and summer flow rates than observed in 2011 (see Section 3.2 *Flow Distribution Through The Study Area*).

1.3.2.2 *Flow Patterns and Flow Splits at Junctions*

Flows entering the south Delta via Old River at the divergence of Old River and the San Joaquin River (i.e., at the Head of Old River [HOR]), are a function of San Joaquin River discharge, the CVP and SWP export rates, and the tidal cycle. Without water exports and with no SDABs present, the proportion of flow into each channel, or "flow split" at the HOR is roughly 50/50. With water exports, a higher proportion of the San Joaquin River flow is diverted into the south Delta via Old River. The presence of the SDABs, especially the GLCB, has a significant effect on the flow split at the HOR. The SDABs decrease the hydraulic gradient at the HOR thereby reducing the flow rate into Old River. In addition, when installed, the presence of the HORB physically blocks a large proportion of the flow, limiting what can be conveyed through the HORB's to its eight culverts plus leakage. The HORB was not installed during the two years reported in this study (2010–2011).

In Old River downstream of the HOR, the flow splits are governed more by channel geometry, sedimentation, local agricultural diversions and returns, and the presence and operations of the SDABs. Water exports have a limited effect on these flow splits. Downstream of the HOR, without the SDABs installed, approximately 3 to 5 percent of Old River flows into Middle River, approximately 10 percent into Old River downstream of Doughty Cut, and approximately 85 percent into GLC via Doughty Cut (**Figure 1-1**). These flow splits can vary somewhat depending on water year precipitation and runoff.

An important contributing factor for the flow proportions in Old River, Middle River, and GLC is restricted conveyance caused by sedimentation at various points in the south Delta. At the Old River/Middle River divergence, the majority of the water stays in Old River because of sedimentation in the upper part of Middle River creating a shallow channel which substantially restricts flow. Similarly, the channel in and around Doughty Cut and Salmon Slough (**Figure 1-1**) is very shallow, restricting flow into Old River downstream of Doughty Cut. Due to these geomorphic characteristics, the majority of the water (approximately 85 percent) flows through the less restricted path into the GLC.

Once all SDABs are fully closed and operational, the flow splits are affected more by tidal hydraulics, agricultural demand, barrier weir elevations, and culvert operations. The presence of the SDABs also has a significant effect on net flows in south Delta channels. It is not uncommon to encounter zero net flows in various parts of Middle River, Old River, and the GLC once agricultural irrigation demands increase as the growing season progresses. In addition, daily tidal flood and ebb flows in south Delta channels are typically much larger than the daily net flows.

Lower Middle River and lower Old River, downstream of the SWP intake (**Figure 1-1**), are affected by water exports drawing reverse flows from the central Delta. This central Delta water which is pushed upstream of the SDABs on flood tides, typically contributes improved water quality with lower electrical conductance in channels in the study area.

1.3.3 Predation

The SDABs have been identified as “hot spots” for predatory fish in the south Delta (Grossman et al. 2013; Vogel 2011). The construction of rock barriers creates in-channel structures that can be used by predatory fish to conserve energy to hold position, provide ambush cover, take advantage of disoriented out-migrating juvenile salmonids, or increase the chances of encountering salmonids. A predatory fish’s chances of encountering a juvenile salmonid are increased by increasing the amount of time salmonids spend in the area of a barrier.

An example of how in-channel structures can affect predation on juvenile salmonids was evaluated in a study conducted by Sabal et al. (2016). They found that a small diversion dam in the Delta (Woodbridge Irrigation District Dam on the Mokelumne River, a tributary to the San Joaquin River) was associated with higher Striped Bass (*Morone saxatilis*) abundance compared to less altered sites. In addition, Striped Bass per capita consumption of juvenile Chinook Salmon was higher at the diversion dam than less altered sites. Furthermore, they found a 10.2 percent Chinook Salmon survival increase through removal of Striped Bass at the Woodbridge Irrigation District Dam.

One study at the HORB included the evaluation of predatory fish predation on telemetered juvenile Chinook Salmon that took place in the vicinity of that barrier through: 1) evaluation of the percentage of juvenile Chinook Salmon eaten in the vicinity of the barrier; 2) generalized linear modeling (GLM) of factors affecting the probability of predation; and 3) anecdotal observations of the fates of Chinook Salmon that passed through the rock barrier (DWR 2015a).

Univariate analysis showed that 39.4 percent of juvenile Chinook Salmon that approached the area of the rock-fill HORB in the spring of 2012 were eaten by predatory fish. This was significantly higher than for no barrier (10.1 percent eaten in spring 2011) at the same location. However, there was considerable difference in the discharge regimes in those two years: 2011 exhibited much higher flow rates than did 2012. In addition, one GLM analysis suggested that higher predation probability on juvenile Chinook Salmon was associated with higher density of small fish less than (<) 30 cm (< 11.8 in) in the study area; higher numbers of small fish might induce more predatory fish to migrate to and/or remain in the study area due to increased prey availability. Other GLM analyses suggested that higher predation probability on juvenile Chinook Salmon was associated with better visibility (higher ambient light, lower turbidity) in the study area. Higher predation probability with higher ambient light and lower turbidity is consistent with the observation that many of the piscine predators at this location were primarily visual predators: Striped Bass, Largemouth Bass (*Micropterus salmoides*), and Spotted Bass (*Micropterus punctulatus*). One anecdotal observation of note was that of the two juvenile Chinook Salmon that passed through the HORB culverts in 2012, both were classified as eaten by predatory fish on the downstream side of the barrier. All of these observations collectively indicate that rock barriers in the south Delta may be structures with high predation risk for out-migrating juvenile salmonids.

1.3.4 Water Diversions in the South Delta

As noted in Section 1.3.1 *Physical and Chemical Characteristics*, the SWP and CVP projects combined are capable of exporting up to 436.1 cms (15,400 cfs)[11] of water. When diverting large quantities of water, the CVP and SWP can induce flow reversals in the lower Old and Middle rivers. These cumulative flows in lower Old and Middle rivers are known as "OMR flows" and are commonly used to manage flows in the south Delta to assist out-migrating juvenile salmonids. For example, during the period of January 1 through June 15, exports are reduced to maintain negative OMR flows to a range of -70.8 to -141.6 cms (-2,500– -5,000 cfs) (NMFS 2009: RPA IV.2.3 "Old and Middle River Flow Management"), and even more restrictions are placed on exports when salmonid salvage reaches certain triggers (NMFS 2009: RPA IV.3 "Reduce Likelihood of Entrainment or Salvage at the Export Facilities").

1.3.4.1 *Individual Water Users*

A survey of diversions (Michael Burns, DWR, unpublished data from 1999–2002) showed that there are between 145 and 200 individual water siphons and diversion pumps in the south Delta in the three channels of interest—Middle River, the GLC, and Old River. These siphons and pumps typically range in size from 30.5 to 50.8 cm (12–20 in) in diameter. Therefore, there is substantial diversion capacity from individual water users in the south Delta. Many of these water diversions are unscreened and represent a potential mortality source for juvenile salmonids. In addition, these water diversions further complicate the hydrodynamics in the south Delta by exacerbating the complex flow conditions that salmonids must navigate during their out-migration.

1.4 CHINOOK SALMON IN THE SAN JOAQUIN RIVER

During data collection in 2010 and 2011, only one form of juvenile Chinook Salmon—fall-run—emigrated through the study area. However in 2014, spring-run Chinook Salmon were reintroduced to the San Joaquin River and juvenile emigrants of this run of Chinook Salmon could also be affected by construction and operation of the SDABs. Information about fall- and spring-run Chinook Salmon life histories is summarized in **Appendix A**.

1.5 STEELHEAD IN THE SAN JOAQUIN RIVER

Another species of salmonid emigrating through the south Delta is the Central Valley steelhead. Information about steelhead life history is summarized in **Appendix B**.

[11] See Footnote 13.

1.6 PISCINE PREDATORS OF SALMONIDS

There are a number of species of predatory fish in the south Delta that are large enough to eat juvenile salmonids. In **Appendix C**, four piscine predator species are briefly described. The one native predator, the Sacramento Pikeminnow (*Ptychocheilus grandis*), is in the minnow family Cyprinidae and has coevolved in the Central Valley with anadromous salmonids. The Largemouth Bass (Centrarchidae: sunfish family), is a temperate zone predator introduced into the Delta in the 1890s (Dill and Cordone 1997). White Catfish (*Ameiurus catus*), introduced to California in 1874 (Dill and Cordone 1997), is a member of the bullhead catfish family Ictaluridae, and larger individuals of this species prey on juvenile salmonids in the Delta (Buchanan et al. 2013). In 1879, Striped Bass (Moronidae: white basses family) were introduced into the estuary (Skinner 1962; Dill and Cordone 1997) and are a sportfish that is prized by anglers in the Delta.

2 METHODS

2.1 TEMPORARY BARRIERS CONSTRUCTION SCHEDULE

Historically, construction of the SDABs began as early as April 15. However, the HORB was not installed in 2010, so the installation of the SDABs began in May rather than April (**Table 2-1**). In 2010, an experimental non-physical barrier called the Bio-Acoustic Fish Fence (BAFF) (Fish Guidance Systems, Southampton, United Kingdom) was installed in place of the HORB and was evaluated for juvenile Chinook Salmon deterrence efficiency (DWR 2015a). In 2010, the MRB was closed on May 24 (**Table 2-1**) and aerial photographs of the Before-, During-, and After-Construction Periods can be viewed in **Figure 2-1**. In 2010, the ORTB was closed on June 3 and aerial photographs of the Before-, During-, and After-Construction Period can be viewed in **Figure 2-2**. The GLCB was substantially different in construction schedule than the MRB and the ORTB. Construction on the GLCB began on June 16, 2010. But, the GLCB barrier was not closed until July 7 and aerial photographs of the Before- and After-Construction Period can be viewed in **Figure 2-3**. In the fall of 2010, the GLCB abutments and culverts were completely removed. This was not standard operating procedure because in most years the abutments and culverts were normally left in place through the winter in the GLC (see the abutments and the three culvert-support structures in the water in the photograph in **Figure 2-3a**). The abutments and culvert structures partially restrict flow. Because they were removed in the fall of 2010, the GLCB had a completely open channel in the winter and spring of 2011 until June 10, 2011 when construction began on the 2011 GLCB (see **Table 2.3**).

Table 2-1. Construction Periods of the Three South Delta Agricultural Barriers Installed in 2010

Barrier	Construction Period	Start Date	End Date
Old River at Tracy	Before	April 1	May 9
Old River at Tracy	During	May 10	June 3
Old River at Tracy	After	June 4	July 7
Middle River	Before	April 1	May 18
Middle River	During	May 19	May 24
Middle River	After	May 25	July 7
Grant Line Canal	Before	April 1	June 15
Grant Line Canal	During	June 16	July 7
Grant Line Canal	After	July 8	July 31

Source: DWR data summarized by Environmental Science Associates this study.
Note: The Before-Construction Period was the time period in which no staging had commenced.
The During-Construction Period was the time period from the commencement of staging to closure of the barrier.
The After-Construction Period was from closure of the barrier to removal of hydrophones.

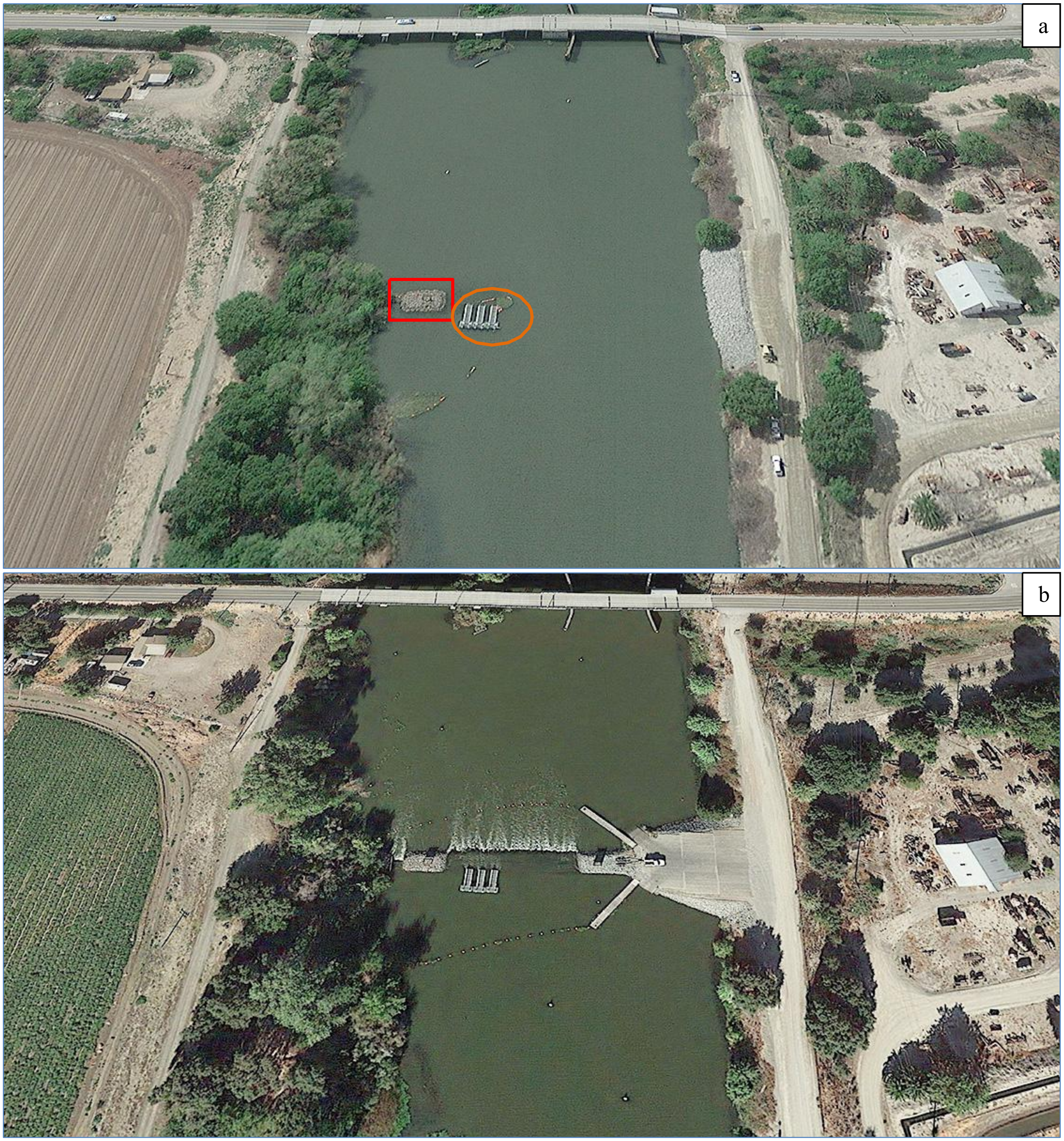
After the barriers are installed they can be manipulated depending on irrigation demand, discharge magnitudes, and fish passage management objectives. In 2010, the MRB was closed on May 24 and the ORTB on June 3, but both the MRB's and the ORTB's culvert flap gates were tied open until June 11 (**Table 2-2**). Operationally, this meant that the flap gates operated tidally after June 11 until these two barriers were removed in October.

Source: Google Earth Pro historical imagery.

Figure 2-1. Middle River Barrier in a Typical Construction Pattern with a) Before-, b) During-, and c) After-Construction Period Aerial Photographs

Source: Google Earth Pro historical imagery.

Figure 2-2. Old River at Tracy Barrier in a Typical Construction Pattern with a) Before-, b) During-, and c) After-Construction Period Aerial Photographs



Source: Google Earth Pro historical imagery.

Figure 2-3. Grant Line Canal Barrier in a Typical Construction Pattern with a) Before- and b) After-Construction Period Aerial Photographs; red box indicates abutments and orange circle indicates culverts

Table 2-2. 2010 Flap Gate Operations

Date	Middle River Barrier Culverts Always In		Old River at Tracy Barrier Culverts Removed When Out		Grant Line Canal Barrier Culverts Always In	
January 1	Out	○○○○○○	Out		Out	○○○○○○
May 24 (MRB in)	In (Weir 1')	○○○○○○	Out		Out	○○○○○○
June 3 (ORTB in)	In (Weir 1')	○○○○○○	In	○○○○○○○○○	Out	○○○○○○
June 11	In (Weir 1')	●●●●●●	In	●●●●●●●●●	Out	○○○○○○
July 7 (GLCB in)	In (Weir 1')	●●●●●●	In	●●●●●●●●●	In	●●●●●●
July 26	In (Weir 1')	●●●●●●	In	●●○○○○○●●	In	●●●●●●
July 30	In (Weir 1')	●●●●●●	In	●●●●●●●●●	In	●●●●●●
August 6	In (Weir 1')	●●●●●●	In	●●○○○○●●●	In	●●●●●●
August 13	In (Weir 1')	●●●●●●	In	●●●●●●●●●	In	●●●●●●
August 20	In (Weir 1')	●●●●●●	In	●●○○○○○●●	In	●●●●●●
August 26	In (Weir 1')	●●●●●●	In	●●●●●●●●●	In	●●●●●●
September 1 (MRB weir raised)	In (Weir 2')	●●●●●●	In	●●●●●●●●●	In	●●●●●●
October 1	In (Weir 2')	●●●●●●	In	●●○○○○●●●	In	●●●●●●
October 8	In (Weir 2')	●●●●●●	In	●●●●●●●●●	In	●●●●●●
October 14 (GLCB out)	In (Weir 2')	●●●●●●	In	●●●●●●●●●	Out (Culverts removed)	
October 20 (ORTB out)	In (Weir 2')	●●●●●●	Out		Out (Culverts removed)	
October 28 (MRB out)	Out	○○○○○○	Out		Out (Culverts removed)	

Source: DWR and ESA this study.

Note: 2010 flap gate operations at the SDABs with empty red circles: flap gates tied open; red circles filled with black: flap gates operating on the tidal cycle; black empty circles: barrier was out but the culvert structures were in place. “Out (Culverts Removed)”: entire structure and culverts were out of the channel, and “Out” with no circles: entire structure, culverts, and supports were out of the channel.

In 2011, the installation of the SDABs began in May or June (**Table 2-3**). Neither an experimental non-physical barrier nor a rock barrier was installed in 2011 at the HOR due to safety concerns. In 2011, the MRB and the ORTB were closed on June 6 and June 10, respectively. The GLCB's construction was delayed due to several June flood events that displaced the GLCB foundation boulders before the barrier could be closed. The GLCB was not closed until July 14 (**Table 2-3**).

Table 2-3. Construction Periods of the Three South Delta Agricultural Barriers Installed in 2011

Barrier	Construction Period	Start Date	End Date
Old River at Tracy	Before	March 22	May 26
Old River at Tracy	During	May 27	June 10
Old River at Tracy	After	June 11	July 14
Middle River	Before	March 22	May 31
Middle River	During	June 1	June 6
Middle River	After	June 7	July 14
Grant Line Canal	Before	March 22	June 9
Grant Line Canal	During	June 10	July 14
Grant Line Canal	After	NA	NA

Source: Pope et al. 2013: Table 8-1, as summarized by ESA this study.
Note: The Before-Construction Period was the time period in which no staging had commenced.
The During-Construction Period was the time period from the commencement of staging to closure of the barrier.
The After-Construction Period was from closure of the barrier to removal of hydrophones.

In 2011, both the MRB's and the ORTB's culvert flap gates were tied open until August 23 (**Table 2-4**) until these barriers were removed in October. In 2011 during the entire period when juvenile salmonids out-migrated through the south Delta there was always a fish passage route at the MRB and the ORTB through culvert flap gates that were tied open. In addition, the GLCB was not closed until July 14. This meant that there was an open channel in the GLC for most of the salmonid migratory period.

2.2 HYDRODYNAMIC MODELING OF DISCHARGES IN THE SOUTH DELTA

Modeling the hydrodynamics in south Delta channels was conducted by the DWR using the Delta Simulation Model II (DSM2) (DWR 2013). DSM2, an estuary model which includes effects from land-based processes such as consumptive use and agricultural runoff, employs a finite difference implicit solution scheme to simulate 15-minute flows (i.e., discharges), water velocities, and water level stages at any location in the Delta. DSM2 is routinely used to simulate historical and forecasted Delta hydrodynamics and water quality conditions. In order to run DSM2, five historical information input parameters are required: 1) downstream boundary stage; 2) boundary inflows; 3) boundary exports; 4) gate and barrier operations; and 5) in-Delta consumptive use. Daily boundary stage, inflows, and exports were obtained from DWR's CDEC website (California Data Exchange Center. 2016b at http://cdec.water.ca.gov/queryTools.html). Current and historical data were available from the same website. Monthly Delta consumptive use was generated through DWR's Delta Island Consumptive Use Model (DICU) (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dicu/dicu.cfm). The operation of SWP intake gates was obtained from DWR's Operation and Maintenance Division. The yearly operation and configuration of the SDABs was obtained from DWR's TBP personnel.

Table 2-4. 2011 Flap Gate Operations

Date	Middle River Barrier Culverts Always In		Old River at Tracy Barrier Culverts Removed When Out		Grant Line Canal Barrier	
January 1	Out	○○○○○○	Out		Out (Culverts removed)	
June 6 (MRB in)	In (Weir 1')	○○○○○○	Out		Out (Culverts removed)	
June 10 (ORTB in)	In (Weir 1')	○○○○○○	In	○○○○○○○○○	Out (Culverts removed)	
July 14 (GLCB in)	In (Weir 1')	○○○○○○	In	○○○○○○○○○	In	●●●●●●
August 2	In (Weir 1')	○○○○○○	In	○○○○○○○○○	In	○○○○○○
August 23	In (Weir 1')	●●●●●●	In	●●●●●●●●●	In	○○○○○○
October 11 (MRB and ORTB out)	Out	○○○○○○	Out		In	○○○○○○
October 19 (GLCB out)	Out	○○○○○○	Out		Out	○○○○○○

Source: DWR and ESA this study.

Note: 2011 flap gate operations at the SDABs with empty red circles: flap gates tied open; red circles filled with black: flap gates operating on the tidal cycle; black empty circles: barrier was out but the culvert structures were in place. "Out (Culverts Removed)": entire structure and culverts were out of the channel, and "Out" with no circles: entire structure, culverts, and supports were out of the channel.

DSM2 modeling of volumetric flow rate was conducted by the DWR for the three channels (i.e., Middle River, Old River, and the GLC) at the locations (flow splits or divergences) shown in **Figure 2-4** and listed in **Table 2-5**. Two divergences were of particular interest: 1) Old River flow at hydraulic node ORS and Middle River flow at hydraulic node MRS; and 2) the GLC at hydraulic note GLCS and Old River downstream of Tom Payne Slough at hydraulic node ORBS.

Table 2-5. Hydraulic Modeling Node Labels and Names

Channel	Node Abbreviation	DSM2 Node Cross-Reference	Name of Node
Middle River	MRS	104	Middle River Split immediately downstream of Middle River/Old River flow split (DSM2 Model Node 104)
Old River	ORS	53	Old River South immediately downstream of Middle River/Old River flow split (DSM2 Model Node 53)
Old River	ORBS	60	Old River downstream of Tom Paine Slough (DSM2 Model Node 60)
Grant Line Canal	GLCS	172	Grant Line Canal Split upstream of the GLCB (DSM2 Model Node 172)

Source: For the DSM2 model nodes see http://www.arcgis.com/home/webmap/viewer.html.
Note: See **Figure 2-4** for locations of these nodes.

For each modeling node, flow rate in cms was determined for each 15-minute increment for the April 1 through July 1 periods in 2010 and 2011. These modeled estimates of discharge at each of the nodes were used to generate descriptive statistics for the Before-, During-, and After-Construction Periods for the GLCB, MRB, and ORTB.

The mean flow rate of each construction period was determined for MRS and ORS. Then the proportion of discharge that flowed into Middle River and Old River was determined. Next, the proportion of flow in the GLC (GLCS) relative to the Old River at node ORBS was determined.

The proportion of flow in Middle River at hydraulic node MRS relative to that in Old River at hydraulic node ORS was determined as:

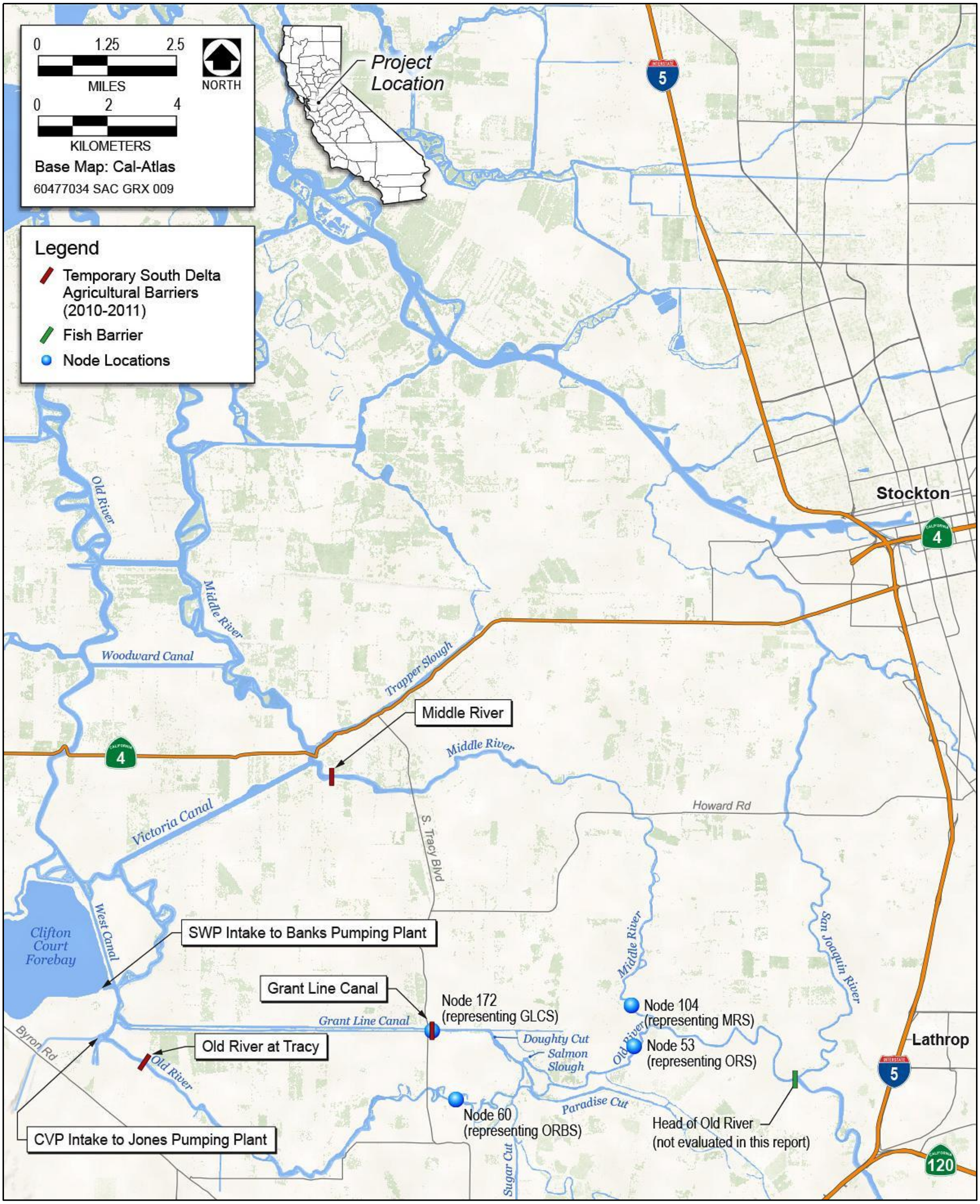
$$MRS_{Proportion} = MRS_{cms}/(MRS_{cms} + ORS_{cms})$$

where:

- MRS_{cms} = the modeled volumetric flow rate in the Middle River at hydraulic node MRS in cms; and
- ORS_{cms} = the modeled volumetric flow rate in Old River at hydraulic node ORS in cms.

The modeled flow proportion in Old River at the ORS hydraulic node was determined as:

$$ORS_{Proportion} = 1 - MRS_{Proportion}$$



Source: AECOM this study.
Note: See **Table 2-5** for node abbreviations and full names.

Figure 2-4. Locations of Delta Simulation Model II Hydraulic Modeling Nodes

The proportion of flow in the GLC at hydraulic node GLCS relative to that in Old River at hydraulic node ORBS was determined as:

where:

- $GLCS_{Proportion} = GLCS_{cms}/(GLCS_{cms} + ORBS_{cms})$
- $GLCS_{cms}$ = the modeled volumetric flow rate in the Grant Line Canal at hydraulic node GLCS in cms; and
- $ORBS_{cms}$ = the modeled volumetric flow rate in Old River at hydraulic node ORBS in cms.

The proportion of flow in the Old River at hydraulic node ORBS relative to that in the Grant Line Canal at hydraulic node GLCS was determined as:

$$ORBS_{Proportion} = 1 - GLCS_{Proportion}$$

2.3 2010 DATA COLLECTION METHODS

2.3.1 Acoustic Tag Surgical Insertion

Juvenile Central Valley steelhead were obtained from the Mokelumne River Hatchery at Clements, California. Juvenile fall-run Chinook Salmon were obtained from the Merced River Hatchery at Snelling, California. These hatchery fish were used as surrogates for wild fish and were transported to the DWR's Collection, Holding, Transportation, and Release (CHTR) holding facility at Byron, California. The juvenile steelhead and Chinook Salmon were held at the CHTR facility until acoustic transmitter implant surgery began approximately five days before a scheduled fish release.

Acoustic tags, Models 795-E and 795-Lm (Hydroacoustic Technology, Incorporated [HTI], Seattle, Washington) were programmed and surgically implanted into juvenile steelhead (N= 480) and Chinook Salmon (N = 342) for survival analysis (**Table 2-6**). Ninety juvenile steelhead received Model 795-E tags for 2D analysis (**Table 2-7**). Implantation of the acoustic tags took place during tagging events according to the procedure described by the San Joaquin River Group Authority (SJRGA) (SJRGA 2011: Chapter 5). These procedures are summarized herein. Steelhead and Chinook Salmon were individually netted from holding tanks and placed into 18.9 liter (L) (5 gallon [gal]) buckets containing an anesthetizing solution of water and tricane methanesolfonate (MS-222). The fish were in the buckets for one to five minutes until anesthetized. The anesthetized fish were removed from the buckets and their fork length (FL) in millimeters (mm) and mass in grams (g) were recorded (**Tables 2-6** and **2-7**). The fish were checked for any abnormalities. Abnormal fish were those that suffered from extremely eroded fins, abnormal body shape, or other structural deformities that could impair normal behavior. Abnormal fish were not tagged.

Table 2-6. Summary of Acoustically Tagged Juvenile Salmonid Groups Released in 2010 for Survival Modeling

Species	Tagging Date (month/day/year)	Fish Transported and Released (N[1])	Minimum Fish Length (FL in mm[1])	Maximum Fish Length (FL in mm)	Minimum Fish Mass (g[1])	Maximum Fish Mass (g)	Minimum Tag Burden (Tag Mass/ Maximum Fish Mass) (%)	Maximum Tag Burden (Tag Mass/ Minimum Fish Mass) (%)	Mortality or Tag Not Functional (%)	Release Start Date (month/day/year)
Steelhead	3/29/2010	57	200	285	87	253.68	0.59	1.72	3.39	4/1/2010
Steelhead	3/30/2010	63	205	290	81.69	313.45	0.48	1.84	0.00	4/2/2010
Steelhead	4/12/2010	60	210	310	85.84	341.51	0.44	1.75	0.00	4/15/2010
Steelhead	4/13/2010	60	195	325	71.04	406.16	0.37	2.11	0.00	4/16/2010
Steelhead	6/1/2010	60	230	330	123.71	430.94	0.35	1.21	0.00	6/4/2010
Steelhead	6/2/2010	60	220	330	99.94	355.53	0.42	1.50	0.00	6/5/2010
Steelhead	6/7/2010	60	225	340	88.35	338.02	0.44	1.70	0.00	6/10/2010
Steelhead	6/8/2010	60	224	315	117.15	397.77	0.38	1.28	0.00	6/11/2010
Total		**480**								
Chinook Salmon	4/26/2010	88	97	120	13.01	22.41	2.90	5.00	2.22	4/29/2010
Chinook Salmon	4/27/2010	86	100	120	13.02	21.55	3.02	4.99	4.44	4/30/2010
Chinook Salmon	5/3/2010	83	95	124	14.16	26.11	2.49	4.59	6.52	5/6/2010
Chinook Salmon	5/4/2010	85	99	125	13	24.76	2.63	5.00	5.56	5/7/2010
Total		**342**								

Source: DWR this study.
Note: [1] N = number of fish in each release group; FL in mm = Fork Length in millimeters; g = mass in grams; % = percent; NA = Not Available.

Table 2-7. Summary of Acoustically Tagged Juvenile Salmonid Groups Released in 2010 for Two-Dimensional Analysis

Species	Tagging Date (month/day/year)	Fish Transported and Released (N[1])	Minimum Fish Length (FL in mm[1])	Maximum Fish Length (FL in mm)	Minimum Fish Mass (g[1])	Maximum Fish Mass (g)	Minimum Tag Burden (Tag Mass/ Maximum Fish Mass) (%)	Maximum Tag Burden (Tag Mass/ Minimum Fish Mass) (%)	Mortality or Tag Not Functional (%)	Release Start Date (month/day/year)
Steelhead	6/3/2010	30	225	305	125.35	354.22	0.42	1.20	0.00	6/7/2010
Steelhead	6/10/2010	30	220	305	108.27	373.24	0.40	1.39	0.00	6/14/2010
Steelhead	6/14/2010	30	245	305	157.43	333.71	0.45	0.95	0.00	6/18/2010
Total		**90**								

Source: DWR this study.
Note: [1] N = number of fish in each release group; FL in mm = Fork Length in millimeters; g = mass in grams; % = percent; NA = Not Available.

The literature suggests that fish may be tagged successfully with tags up to five percent of a fish's body mass or even slightly higher (Brown et al. 1999). Because the 795-E tags weighed 1.5 g (0.05 ounce [oz]) in the air, steelhead were not tagged if they weighed < 30 g (< 1 oz) to maintain a maximum five percent tag to body mass ratio (**Table 2-6**). The 795-Lm tags weighed 0.65 g (0.02 oz) in the air, and Chinook Salmon were not tagged that weighed < 13 g (< 0.5 oz). Steelhead tag burdens ranged from 0.35 to 2.11 percent of body weight and Chinook Salmon tag burdens ranged from 2.49 to 5.00 percent of body weight (**Tables 2-6** and **2-7**).

The still-anesthetized steelhead and Chinook Salmon were placed into a holding cradle treated with a 25 percent solution of Stress Coat® (Aquarium Pharmaceuticals, Incorporated, Chalfont, Pennsylvania). Handling fish causes damage to the fish's external mucosal layer, and Stress Coat replaces the fish's natural mucosal coat with a synthetic one, thereby reducing stress. The fish's gills were irrigated with a maintenance solution of water and MS-222 through a soft rubber tube to maintain anesthesia during surgery.

Using a micro-scalpel equipped with a five mm (0.20 in) blade for steelhead and three mm (0.12 in) blade for Chinook Salmon, a two to five mm-long (0.08–0.20 in) incision to one side of the mid-ventral line immediately anterior to the pelvic girdle was made. The acoustic tag was inserted into the body cavity through this incision. The incision was closed with two or three simple interrupted sutures using Vicryl Plus® 4-0 suture material (Ethicon, Incorporated, Somerville, New Jersey) for steelhead and Vicryl Plus 5-0 suture material for Chinook Salmon. During the final stages of surgery, the gill irrigation water supply was switched from the MS-222 maintenance solution to fresh water to begin the recovery process. Once the surgical procedure was completed, the fish were immediate placed into aerated holding tanks to recover. Fish were observed for a minimum of two days to ensure proper recovery prior to release.

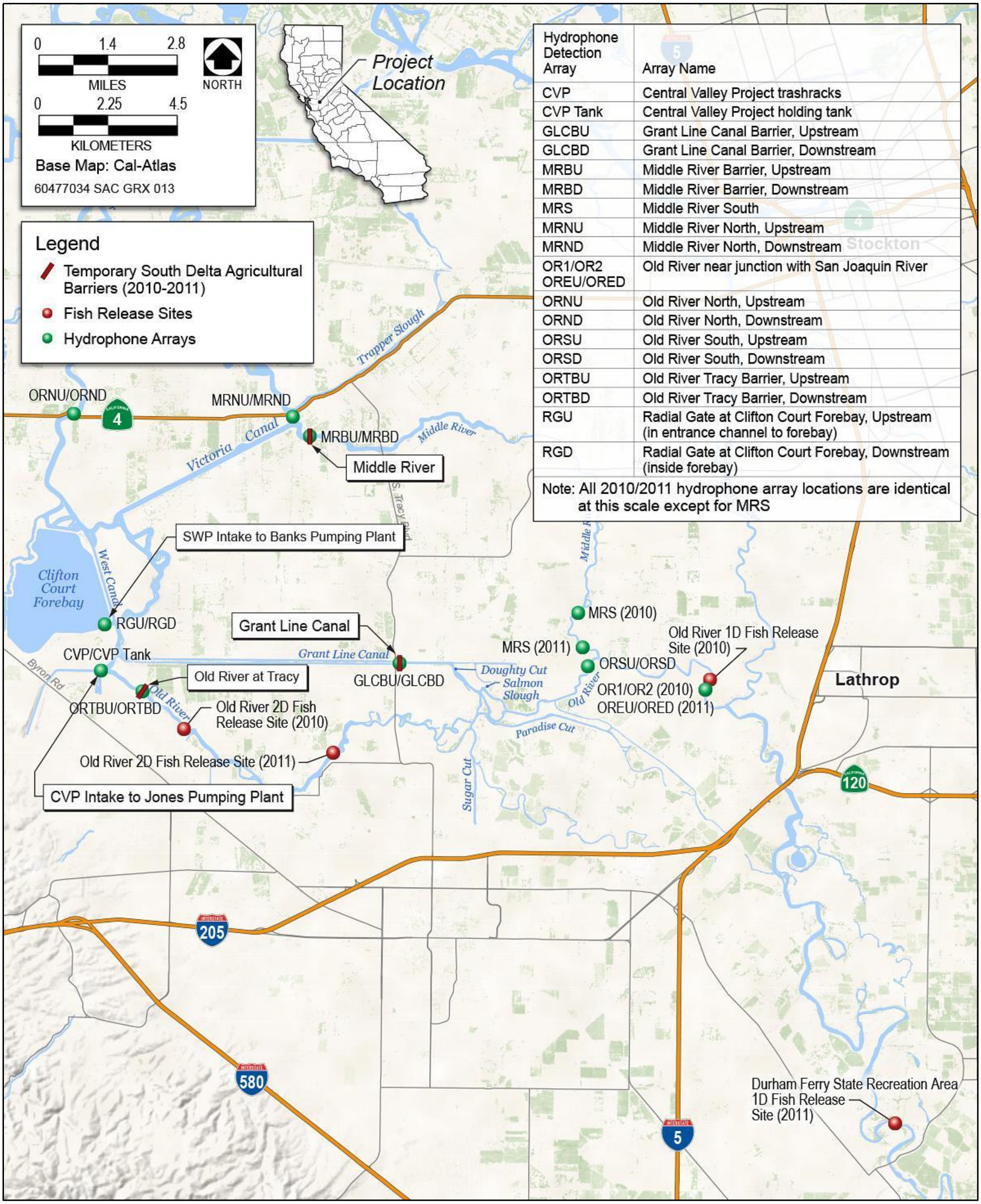
In 2010, tagged juvenile Chinook Salmon were released at the one-dimensional (1D) Fish Release Site illustrated in **Figure 2-5** that was located on Old River 1.44 kilometers (km) (0.89 mile [mi]) downstream from the Old River confluence with the San Joaquin River. The 2D Fish Release Site was located on Old River 1.76 km (1.09 mi) upstream of the ORTB in 2010. After those releases occurred, the Chinook Salmon held at the CHTR holding facility for June releases began showing signs of disease and a large die-off occurred. A pathology evaluation was performed by the CDFW and the results revealed cells of the myxozoan parasite *Tetracapsuloides bryosalmonae* which is the causative agent of proliferative kidney disease (PKD).

All remaining Chinook Salmon were subsequently euthanized. No more Chinook Salmon were tagged because no additional fish were available from the hatchery. Subsequently, the CDFW deemed that the CHTR facility was not suitable for holding Merced River Hatchery juvenile Chinook Salmon due to the lack of water temperature controls. In addition, the pathogen that causes PKD was known to be present in the Merced River water supply.

2.3.2 Acoustic Tag Tracking System and Tags

Two-dimensional acoustic tag tracking was conducted using an HTI Model 290 Acoustic Tag Tracking System (ATTS). The primary components of the ATTS include the Model 290 acoustic tag receiver (ATR), hydrophones, and a user interface/data storage computer. The system uses a fixed array of underwater hydrophones to track movements of fish tagged with the HTI Model 795-Series acoustic tags.

Each acoustic tag transmits an underwater sound signal or acoustic "ping" that sends identification information about the tag to hydrophones. As tagged fish approach the study area, the tag signal is detected and the arrival time recorded at several hydrophones. For 2D tracking, tags signals must be received on at least three



Hydrophone Detection Array	Array Name
CVP	Central Valley Project trashracks
CVP Tank	Central Valley Project holding tank
GLCBU	Grant Line Canal Barrier, Upstream
GLCBD	Grant Line Canal Barrier, Downstream
MRBU	Middle River Barrier, Upstream
MRBD	Middle River Barrier, Downstream
MRS	Middle River South
MRNU	Middle River North, Upstream
MRND	Middle River North, Downstream
OR1/OR2 OREU/ORED	Old River near junction with San Joaquin River
ORNU	Old River North, Upstream
ORND	Old River North, Downstream
ORSU	Old River South, Upstream
ORSD	Old River South, Downstream
ORTBU	Old River Tracy Barrier, Upstream
ORTBD	Old River Tracy Barrier, Downstream
RGU	Radial Gate at Clifton Court Forebay, Upstream (in entrance channel to forebay)
RGD	Radial Gate at Clifton Court Forebay, Downstream (inside forebay)

Note: All 2010/2011 hydrophone array locations are identical at this scale except for MRS

Source: AECOM this study.

Figure 2-5. Fish Release Sites and Hydrophone Locations used in 2010 and 2011

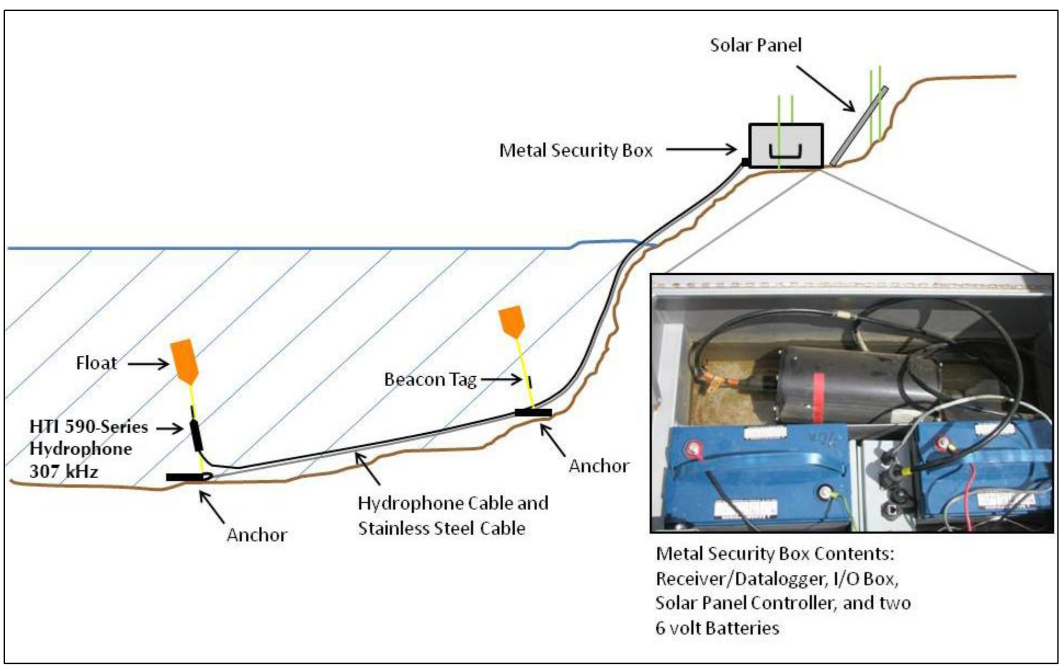
hydrophones. The differences in tag signal arrival times at each hydrophone are used to calculate the 2D position of each tagged fish. The ATTS includes the following hardware and software components:

1) A tag programmer that activates and programs the tag (HTI 490-LP *Tag Programmer*);
2) Acoustic tags each transmitting a pulse of sound at regular intervals (HTI Model 795-E or 795-Lm);
3) Hydrophones that function like underwater microphones, listening within a defined volume of water (HTI Model 590-Series);
4) Cables connecting hydrophones to tag receivers (HTI 690-Series); and
5) A tag receiver that receives the tag signal from the hydrophones, conditions the signal, and using specialized software, outputs the data into a format that is stored in computer data files (HTI 395 *Data Logger*).

2.3.3 2010 Fixed-Station Receiver Grid (1D Hydrophone Array)

In order to track acoustically tagged salmonids and predatory fish throughout the south Delta an acoustic receiver network was deployed in February–March 2010. The network of fixed-point acoustic tag data loggers (HTI Model 295-X and HTI Model 295-I) was designed to cover key channels in the south Delta, including Old River, Middle River, the GLC, the SWP radial gates at Clifton Court Forebay, and the CVP intake (**Figure 2-5**).

The receiver array called the 2010 1D hydrophone array because it provided information on fish traveling through Delta channels and also provided data for input into a reach-specific survival model. The receiver array was installed prior to tagged fish being released. Also, before tagged fish were released the receivers' detection efficiency and range were evaluated. Each receiver setup included on-shore locked job boxes with data loggers (**Figure 2-6**). Downloads of the receivers' internal memory occurred weekly or more frequently, as needed.



Source: DWR this study as modified by AECOM.

Figure 2-6. Hydrophone and Receiver Set-Up for Collection of Survival Data in 2010 and 2011

2.3.3.1 *2010 1D Positioning*

The 2010 Fixed-Station Receiver Grid detected and identified tagged salmonids at each detection site identified in **Figure 2-5**. A list of 2010 individual hydrophone sites, their abbreviations, and locations is provided in **Table 2-8**. Detections at single hydrophone sites produced arrival time and departure time, but did not position the tag within the channel where the hydrophone was deployed. All sites except MRS[12] had two hydrophones deployed nearby to enable the calculation of detection probability at the site. MRS had one hydrophone nearby. Detection probability was used in survival modelling to estimate the error associated with survival results.

Table 2-8. Abbreviations, Descriptions and Locations of Individual Hydrophone Sites

Individual Hydrophone Site Abbreviation	Combined Site Abbreviation	2010 Temporary Barriers Hydrophone Locations Site Description	Decimal Degrees Latitude	Decimal Degrees Longitude
CVP	CVP	Central Valley Project Upstream of Trash Rack	37.816952	-121.558354
CVP Tank	CVP Tank	Central Valley Project Holding Tank	37.816820	-121.561400
GLCBD	GLC	Grant Line Canal Barrier Downstream	37.819755	-121.449255
GLCBU	GLC	Grant Line Canal Barrier Upstream	37.819849	-121.447902
MRBD	MRB	Middle River Barrier Downstream	37.885517	-121.483146
MRBU	MRB	Middle River Barrier Upstream	37.885608	-121.480723
MRBND	MRBN	Middle River North Downstream of MR Barrier	37.892577	-121.490634
MRBNU	MRBN	Middle River North Upstream of MR Barrier	37.890015	-121.489422
MRS	-	Middle River South Downstream of Old River Split (1 array only)	37.834812	-121.383695
OR1	OR	Old River Downstream of Junction with San Joaquin River	37.81247	-121.33541
OR2	OR	Old River Downstream of Junction with San Joaquin River	37.81226	-121.33532
ORND	ORN	Old River North Downstream	37.891604	-121.568445
ORNU	ORN	Old River North Upstream	37.890152	-121.572439
ORSD	ORS	Old River South Downstream of Middle River Split (Downstream Hydrophones)	37.818813	-121.379997
ORSU	ORS	Old River South Downstream of Middle River Split (Upstream Hydrophones)	37.820212	-121.377935
RGD	RGD	Clifton Court Forebay Radial Gates Downstream of Gates		
RGU	RGU	Clifton Court Forebay Radial Gates Upstream of Gates	37.829613	-121.556951
ORTBD	ORTB	Old River at Tracy Barrier Downstream of Barrier	37.810940	-121.545336
ORTBU	ORTB	Old River at Tracy Barrier Upstream of Barrier	37.809776	-121.542268

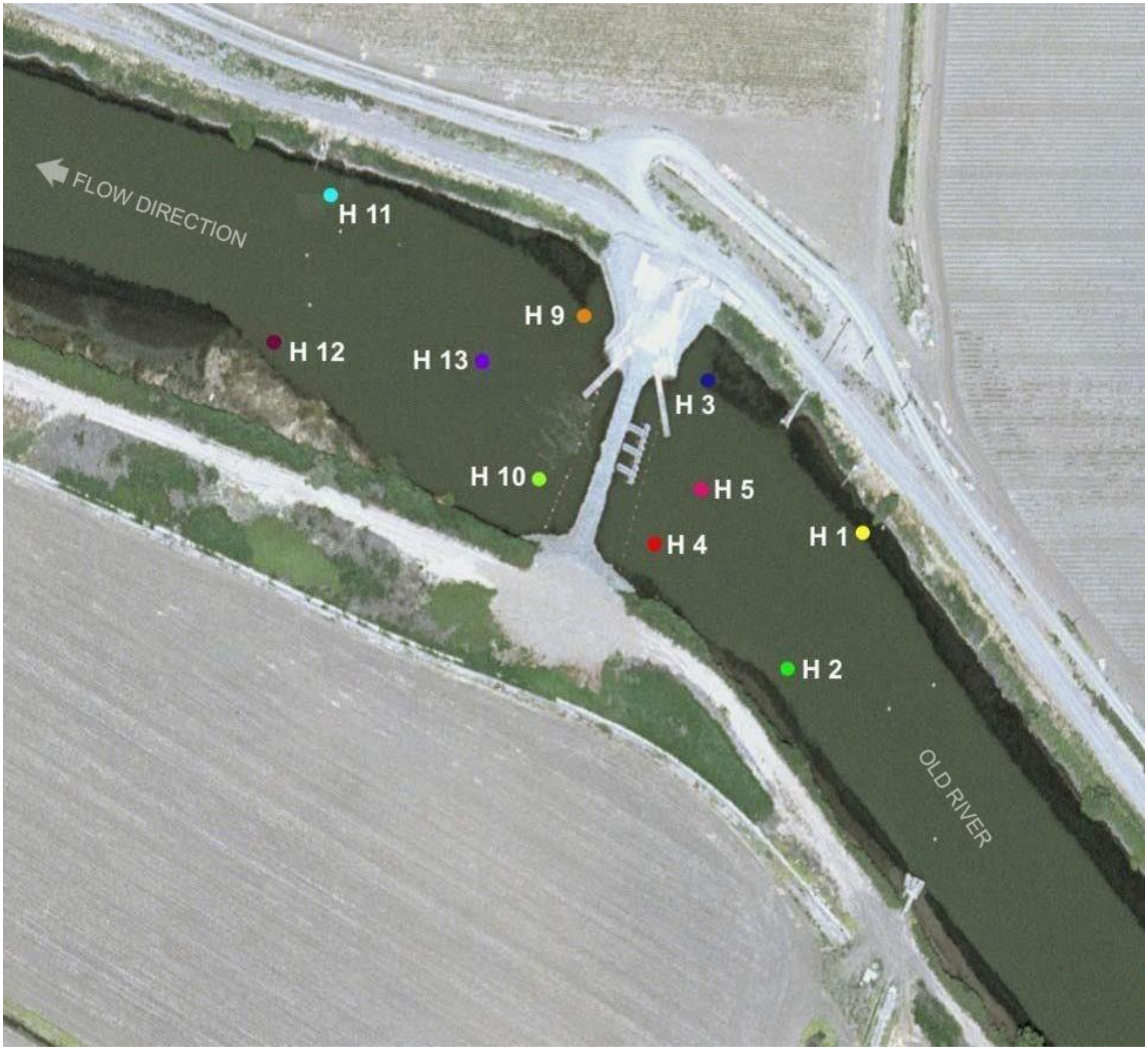
Source: HTI this study and SJRGA (2011: Table 5-5).

All detections from each tagged salmonid were summarized and combined to develop detection histories of the migration of each individual fish. While the location within the channel of individual fish was not known, data regarding time spent in the area, multiple visits to the area, and migration rates between the detection sites were all used to characterize the overall behavior of out-migrating salmonids.

[12] Hydrophone array MRS was located in a different location in 2010 compared to 2011. Also, hydrophone array MRS (Middle River South) should not be confused with DSM2 Model Hydraulic Node 104: MRS (Middle River Flow Split) on **Figure 2-4**.

2.3.4 2010 Two-Dimensional Receiver Array

In addition to the south Delta 1D fixed hydrophone receiver network, a 2D telemetry system consisting of an HTI 16-port Model 290 ATR and 10 hydrophones were used to track fish in the vicinity of the ORTB (Kumagai et al. 2010). After the ORTB was constructed, the 2D fish tracking system was deployed and tested over a one-week period. Five hydrophones were deployed upstream of the barrier and five hydrophones were deployed downstream of the barrier (**Figure 2-7**). Acoustic data were stored on a laptop computer connected to the HTI receiver for subsequent post-processing and data analysis.



Source: HTI 2010.

Figure 2-7. 2010 Hydrophone Locations in Two-Dimensional Receiver Array at the Old River at Tracy Barrier

2.3.4.1 *2010 2D Positioning*

Detection of a tagged fish by a single hydrophone is sufficient to confirm the presence and identity of the tag, but a tag signal must be simultaneously detected by at least three hydrophones to be accurately positioned in space. Accurate acoustic tag positions require knowledge of the location of individual hydrophones. In addition, the hydrophones detecting the tag signal must have a direct "line of sight" path to the tag. As tagged salmonids moved through the ORTB 2D hydrophone array, multiple hydrophones received tag transmissions. For any combination of three hydrophones, the difference in the arrival times of the tag signals to each hydrophone was used to calculate the location of the tagged fish.

Many sequential tag positions were derived for each fish, providing a time-series of locations or "track." These positions were associated to define a swimming path for each fish which was mapped and presented in a 2D display. The underlying detection data were stored for additional analyses. The method that was used to determine acoustic tag positions by the HTI system followed the same basic principles employed by Global Positioning System (GPS) satellite technology. In the case of acoustic tag positioning however, the acoustic tag is the transmitter and there are many hydrophones that receive the tag transmissions. At the ORTB 2D hydrophone array, the five upstream hydrophones were physically separated from the five downstream hydrophones by the ORTB, thereby separating the system into two separate positioning hydrophone arrays.

Assuming that h_{ix}, h_{iy}, define the x and y coordinate location of the ith hydrophone, and F_x, F_y represent the unknown x and y coordinates of the tagged fish, the signal travel time from the tagged fish to the i^th hydrophone, t_i is given by:

> The constant c in the equation defines the underwater sound velocity. While this equation cannot be solved for a single hydrophone detection, given the two unknown fish coordinates, a solution can be determined based on the convergence of multiple hydrophone measurements. The differences between the arrival times of the signal at the multiple hydrophones ($t_i - t_j$) is described as:

$$t_i - t_j = \frac{1}{c}\left[\sqrt{(h_{ix} - F_x)^2 + (h_{iy} - F_y)^2} - \sqrt{(h_{jx} - F_x)^2 + (h_{jy} - F_y)^2}\right]$$

For three hydrophones, there are two such distinct signal arrival time difference equations. The system of nonlinear equations is determined by solving the tagged fish coordinates, such that the mean squared difference between the measured (left side of the foregoing equation) and calculated (right side of the foregoing equation) time differences are minimized. Hydrophone positions were expressed in Universal Transverse Mercator (UTM) (World Geodetic System 1984 datum [WGS 84]) coordinates, so resulting tag positions were also expressed in UTM coordinates.

2.4 2009 AND 2010 PREDATORY FISH COLLECTION AND ACOUSTIC TAGGING

Predatory fish were captured, externally tagged with an acoustic tag, and released within the south Delta. Predatory fish sampling primarily focused on the capture of Striped Bass and Largemouth Bass. In 2010, some observations of predatory fish tagged in 2009 occurred; thus, the 2009 predators are included herein. Sampling was conducted in 2009 and continuously through the 2010 study period. Striped Bass, Largemouth Bass, and White Catfish were captured by hook-and-line sampling. Hook-and-line capture rates of predatory fish were generally low, with the exception of capture rates in Clifton Court Forebay. Sampling efforts were not equal at all locations within the south Delta. As SDABs were constructed late in the study period, efforts to collect predatory fish at the barrier locations when the barriers were present were limited. In 2009, a total of 12 predatory fish of 3 species were captured, tagged, and released (**Table 2-9**). In 2010, a total of 54 predatory fish of 3 species were captured, tagged, and released (**Table 2-10**).

Table 2-9. 2009 Predatory Fish Tag Data Summary

Acoustic Tag Identification	Predatory Fish Species	Release Location Longitude (UTM)[1]	Release Location Latitude (UTM)	Release Date (month/day/year)	Universal Coordinated Release Time	Fish Length (TL in cm[1])
4255.01	Largemouth Bass	NA[1]	NA	6/11/09	14:42	44
4143.01	Striped Bass	NA	NA	6/11/09	14:55	44.5
4199.01	Largemouth Bass	NA	NA	6/11/09	15:03	37
4129.01	Largemouth Bass	627139	4186368	4/24/09	09:05	50.5
4101.01	Largemouth Bass	633089	4194273	4/24/09	11:03	36.5
4003.01	Striped Bass	628161	4186705	4/29/09	09:44	37
4087.01	Striped Bass	628616	4186706	4/29/09	10:30	46.5
4115.01	Striped Bass	628616	4186706	4/29/09	10:55	45
4045.01	Striped Bass	628616	4186706	4/29/09	12:30	47
4185.01	Largemouth Bass	627916	4190753	5/15/09	08:47	55
4227.01	Largemouth Bass	NA	NA	6/25/09	NA	NA
4073.01	White Catfish	NA	NA	6/26/09	NA	NA

Source: DWR this study.

[1] Note: UTM = Universal Transverse Mercator; NA = Not Available; TL in cm = Total Length in centimeters.

Table 2-10. 2010 Predatory Fish Tag Data Summary

Acoustic Tag Identification	Predatory Fish Species	Release Location (Longitude/Latitude or General Location) Longitude (UTM)[1]	Release Location (Longitude/Latitude or General Location) Latitude (UTM)	Release Date (month/day/year)	Universal Coordinated Time Release Time	Fish Length (TL in cm[1])
4437.01	Striped Bass	Clifton Court Forebay		*3/17/2010	08:45	45
4465.01	Striped Bass	Clifton Court Forebay		*3/17/2010	09:00	40
4311.01	Striped Bass	Clifton Court Forebay		*3/17/2010	09:15	56
4381.01	Striped Bass	Clifton Court Forebay		*3/17/2010	09:30	49
4521.01	Striped Bass	Clifton Court Forebay		*3/17/2010	09:30	45
4745.01	Striped Bass	Clifton Court Forebay		*3/17/2010	09:30	46
4675.01	Striped Bass	Clifton Court Forebay		*3/17/2010	09:30	41
4479.01	Striped Bass	Clifton Court Forebay		*3/17/2010	NA[1]	44
4703.01	Striped Bass	Clifton Court Forebay		*3/17/2010	10:40	46
4367.01	Striped Bass	Clifton Court Forebay		*3/17/2010	10:40	53.5
4451.01	Striped Bass	Clifton Court Forebay		*3/17/2010	NA	45.5
4549.01	Striped Bass	Clifton Court Forebay		*3/17/2010	NA	45.5
4283.01	Striped Bass	Clifton Court Forebay		*3/17/2010	NA	51
4353.01	Striped Bass	Clifton Court Forebay		*3/17/2010	NA	65
4269.01	Striped Bass	Clifton Court Forebay		*3/17/2010	NA	52
4591.01	Striped Bass	Clifton Court Forebay		*3/17/2010	NA	60.5
4689.01	Striped Bass	Clifton Court Forebay		*3/17/2010	NA	55

Table 2-10. 2010 Predatory Fish Tag Data Summary (continued)						
		Release Location (Longitude/Latitude or General Location)			Universal Coordinated	
Acoustic Tag Identification	Predatory Fish Species	Longitude (UTM)[1]	Latitude (UTM)	Release Date (month/day/year)	Time Release Time	Fish Length (TL in cm[1])
4409.01	Striped Bass	Clifton Court Forebay		*3/17/2010	NA	50
4647.01	Striped Bass	Clifton Court Forebay		*3/17/2010	NA	52
4619.01	Striped Bass	Clifton Court Forebay		*3/17/2010	NA	49
5935.01	Largemouth Bass	642599	4187059	*3/24/2010	13:52	NA
5991.01	Largemouth Bass	642599	4187059	*4/9/2010	11:13	30.5
5949.01	Largemouth Bass	642511	4189159	**4/20/2010	05:51	NA
5963.01	Largemouth Bass	648778	4184217	**5/19/2010	11:00	NA
5011.01	Largemouth Bass	626786	4185728	*4/27/2010	09:43	52
5921.01	Largemouth Bass	626786	4185728	*4/27/2010	09:50	47.5
5977.01	Largemouth Bass	626786	4185728	*4/27/2010	12:03	49
4325.01	Largemouth Bass	626786	4185728	*4/27/2010	12:50	52
5767.01	Striped Bass	Upstream of Radial Gates		*5/12/2010	NA	56
5697.01	Striped Bass	Upstream of Radial Gates		*5/12/2010	NA	40.5
4339.01	Striped Bass	Upstream of Radial Gates		*5/12/2010	NA	50
5725.01	Striped Bass	Upstream of Radial Gates		*5/12/2010	NA	40
4395.01	Striped Bass	Upstream of Radial Gates		*5/12/2010	NA	40
5781.01	Striped Bass	Upstream of Radial Gates		*5/12/2010	NA	43
5907.01	Striped Bass	Upstream of Radial Gates		*5/12/2010	NA	40.5
5851.01	Striped Bass	Upstream of Radial Gates		*5/12/2010	NA	40.5
5865.01	Striped Bass	Upstream of Radial Gates		*5/12/2010	NA	40.5
5809.01	Striped Bass	Upstream of Radial Gates		*5/12/2010	NA	42
5795.01	Largemouth Bass	629636	4184599	*5/13/2010	13:39	38
5837.01	Largemouth Bass	643667	4187062	*5/25/2010	12:03	38
5445.01	Striped Bass	628252	4185775	*6/4/2010	12:51	40
5431.01	Striped Bass	628248	4185775	*6/4/2010	13:25	43
5893.01	Striped Bass	628248	4185775	*6/4/2010	14:20	40.5
5529.01	Largemouth Bass	NA		*6/8/2010	13:00	40.5
5487.01	Striped Bass	NA		*6/8/2010	13:48	45.5
5543.01	Striped Bass	NA		*6/8/2010	13:48	43
5515.01	White Catfish	NA		*6/8/2010	13:50	38
5459.01	Largemouth Bass	NA		*6/9/2010	12:00	48
5501.01	Largemouth Bass	NA		*6/9/2010	13:00	40.5
5473.01	Largemouth Bass	NA		*6/9/2010	13:00	43
5879.01	Largemouth Bass	NA		*6/9/2010	14:10	NA
5053.01	Largemouth Bass	NA		*6/16/2010	10:10	43
5067.01	Largemouth Bass	NA		*6/16/2010	10:27	37
5081.01	Largemouth Bass	NA		*6/16/2010	12:43	40
5823.01	Largemouth Bass	NA		**5/21/2010	07:21	37

Source: DWR this study.

Note: [1] UTM = Universal Transverse Mercator; NA = Not Available; TL in cm = Total Length in centimeters; * Release Date; ** First detection by a hydrophone.

External tagging of Striped Bass was similar to the method described by Chadwick (1963), Gingras and McGee (1997), and Clark et al. (2009). Each predatory fish was captured by hook-and-line fishing, placed into a live well on the boat and observed for signs of physical injury and stress, e.g., loss of equilibrium. When an uninjured fish was no longer showing signs of stress from capture and handling, it was weighed using a spring-loaded suspension scale (Boga-Grip, Estaboga Tackle Manufacturing Company, Estaboga, Alabama) and transferred to a canvas cradle. The fish was then measured for total length (TL) and was externally tagged with an acoustic transmitter (HTI Model 795-X). For respiration, a soft tube attached to a pump was used to irrigate the gills for the duration of the tagging procedure. Prior to tagging, stainless steel wires were attached to each acoustic tag by cable ties along with a neoprene foam pad to act as a cushion against the fish's skin. Using hypodermic syringe needles, the acoustic tag was externally attached under the dorsal fin by threading the wires through the needles and body of the fish. The wires and tag were then secured in place by crimping the wires and trimming away any excess wire (**Figure 2-8**). Each tagged predatory fish was released at approximately the same location where it was captured. The external tagging operation lasted approximately four minutes per fish. The tag identification number, species, date, total length, and collection location were recorded (**Table 2-9** and **Table 2.10**).

Source: DWR 2009.

Figure 2-8. Largemouth Bass Captured, Acoustically Tagged, and Released in 2009

2.5 2010 TAG LIFE AND SURGICAL PROCEDURE CONTROL GROUPS

To monitor the battery life of the acoustic tags and the long-term effects of surgical implantation of acoustic tags on fish mortality, a subsample of Chinook Salmon (n = 16) and steelhead (n = 32) were implanted with acoustic tags and observed for the duration of the 2010 study. These salmonids were tagged following the same procedures as the salmonids tagged for release into the south Delta and placed into laboratory holding tanks. An HTI Model 290 Acoustic Tag Receiver was used to record the tag signals so that the date and time that the acoustic tag batteries were expended could be determined.

2.6 2010 ACOUSTIC TAGGED STEELHEAD AND CHINOOK SALMON RELEASES

Based on recommendations developed from a pilot 2D tracking study conducted in 2009 (HTI 2012), 480 tagged steelhead and 342 Chinook Salmon were released into Old River, approximately 2 km (1.2 mi) downstream from the Head of Old River (**Figure 2-5**), in order to develop an estimate of the survival of steelhead and Chinook Salmon through the south Delta. Modifications to the planned steelhead and Chinook Salmon release schedule were necessary given the installation schedule for the SDABs and the high mortality of Chinook Salmon caused by PKD. Steelhead and Chinook Salmon were scheduled to be released both before and after the installation of the temporary barriers. Four juvenile steelhead and four Chinook Salmon releases were conducted prior to the installation of the barriers (**Table 2-6**). No Chinook Salmon were tagged or released after the barriers were installed due to the PKD outbreak. Installation of the SDABs began in mid-May, and water temperatures in the south Delta channels were increasing and nearing the incipient lethal level for steelhead. Four releases of steelhead were conducted after the closure of the ORTB and MRB, but before the closure of the GLCB (**Table 2-6**).

Live wells were set up in a boat on a trailer. A small amount of water from the CHTR facility holding tanks was added to the live wells. Tagged salmonids were netted from the CHTR facility holding tanks and placed into 18 L (5 gal) buckets. The fish were then poured into the live wells on the boat. Water temperature and dissolved oxygen concentration monitoring began in the live wells using a YSI™ Model 85 Meter (YSI Incorporated, Yellow Springs, Ohio) for dissolved oxygen, conductivity, salinity, and water temperature. Dissolved oxygen concentrations were maintained throughout the release process with observations recorded at the CHTR facility, boat launch, and release site. Compressed oxygen, silicone tubing, and aquarium grade air stones were used to supply oxygen during transport to the release site. The boat was trailered to and then launched at the Mossdale Crossing Regional Park (Lathrop, San Joaquin County, California) boat launch. The boat was then driven to the release location. If the water temperature of the San Joaquin River at the release site was > 2.0°C (> 3.6°F) different than the water temperature in the live wells, then San Joaquin River water was added to the live wells every 15 minutes to acclimate the fish by 0.25°C (0.45°F) per 15-minute interval until the live well water temperature was < 2.0°C (< 3.6°F) different from the San Joaquin River ambient water temperature. Once the water temperatures in the live wells were within 2°C (3.6°F) of the San Joaquin River water temperature, then fish were transferred from the live wells to 120 L (31.7 gal) lidded, plastic release pens held in the river. Before use, perforations were drilled in the release pens to allow free flow of water through the pens while fish were held at the release site. The fish were held in the release pens for a minimum of two hours prior to release. At the release time the lid was removed and the release pen was rotated to look for any dead or impaired fish. The release pen was then slowly inverted to allow the fish to be released into the river. After the release pen was inverted, the time was recorded as the release time. As the release pens were righted, they were inspected to ensure that no juvenile salmonids remained in the pen.

In addition to these survival releases, three releases of steelhead were conducted in Old River approximately 2 km (1.2 mi) upstream of the ORTB (**Figure 2-5**) using the same release methodology described in the preceding paragraph. These releases of steelhead were intended to generate 2D fish tracks around the ORTB. Steelhead releases were conducted after the ORTB was closed and elevated water temperatures may have impacted the behavior of fish. Additionally, problems were encountered with the first steelhead release because the boat transporting the tagged steelhead to the release site became beached on a sandbar. Steelhead were held in the coolers on the boat for an extended period of time and multiple water exchanges were conducted to alleviate water quality problems. However, low dissolved oxygen levels and high water temperatures were experienced during this event and may have impacted the behavior of the first 2D release group. One tagged steelhead was confirmed dead prior to the first 2D release, likely due to the combined stress of low dissolved oxygen concentrations, high water temperatures, and time spent in a confined container. This fish was not released into Old River.

2.7 2010 RECEIVER

An HTI Model 290 ATR can receive acoustic tag information simultaneously on up to 16 separate channels. Each ATR channel is assigned to a single hydrophone. The ATR is connected to the data collection computer which analyzes and stores the acoustic data. An individual raw data file is automatically created for each sample hour and it contains the complete set of information describing each tag detection for all hydrophones. Data acquisition filters in the ATR are configured to identify the acoustic tag sound pulse and discriminate tag transmissions from background noise that may be present.

The ATR pulse measurements are automatically reported for each tag signal from each hydrophone and are written to Raw Acoustic Tag (*.RAT) files by the HTI *Acoustic Tag* data collection software program. Each *.RAT file contains header information describing all data acquisition parameters followed by the raw tag signal data. Each raw tag signal data file contains all acoustic signals detected during the time period, including signals from tagged fish as well as some amount of unfiltered noise which is removed during the data analysis processes.

2.8 2010 HYDROPHONES WITH DEPLOYED POSITIONS

The Model 590 hydrophones operate at 307 kilohertz (kHz) and include a low-noise pre-amplifier and water temperature sensor. Hydrophone directional coverage is approximately 330 degrees, with equivalent sensitivity in all directions, except for a 30-degree limited sensitivity cone directly behind the hydrophone where the cable is attached. The hydrophone sensor element tip is encapsulated in specially treated rubber with acoustic impedance close to that of water to ensure maximum sensitivity and long-term reliability. The hydrophone and connector housing are made of corrosion resistant aluminum-bronze alloy. Specially designed cables incorporating twisted pair wire and double shields for noise reduction are used to connect each deployed hydrophone to the ATR.

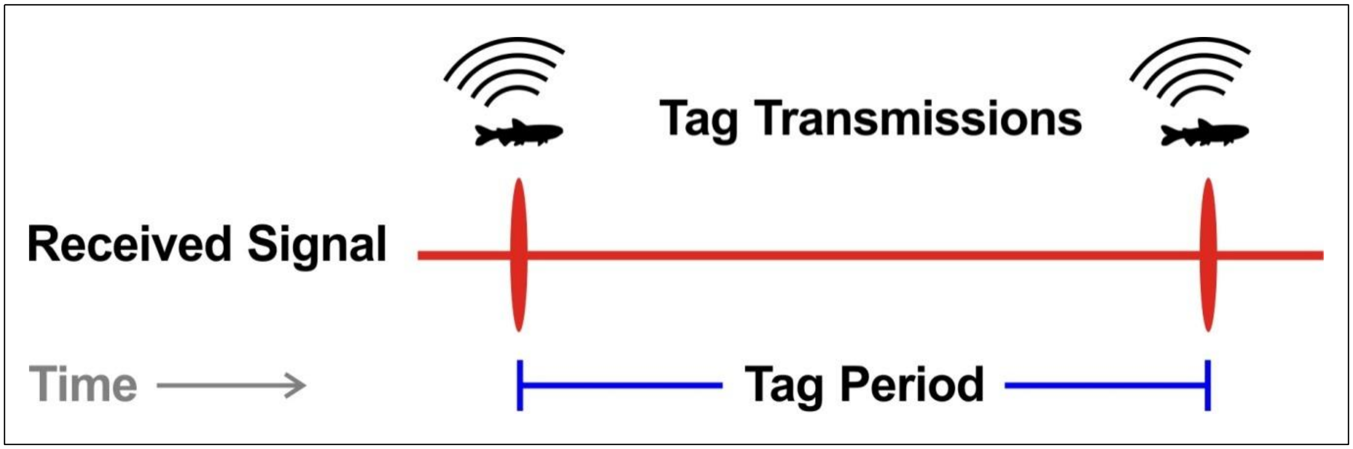
The hydrophone pre-amplifier circuit provides signal conditioning and background noise filtering for transmission over long cable lengths and in acoustically noisy environments. A calibration circuit in the pre-amplifier provides a method for field testing hydrophone operation and is used to measure the signal time delays between hydrophones in the array. Measurement of the signal delays is used to verify the absolute position of each hydrophone within the sampling array, which is a critical part of the monitoring equipment deployment. This process of measuring the hydrophone positions via the signal travel times between each hydrophone is typically referred to as the “ping around” and is discussed later in this report. The Model 590 hydrophones include water temperature sensors to measure temperature at each location within the array, which is used to precisely estimate the sound velocity in water needed during the “ping around” procedure.

2.8.1 2010 Hydrophone Deployment

The Model 590 hydrophones were deployed to detect and position tagged fish at the ORTB. For the 2010 evaluation, a total of 10 hydrophones were installed, 5 hydrophones positioned both up and downstream of the ORTB at depths ranging from 2.7 to 3.4 m (8.8–11.2 ft) (**Figure 2-7**).

2.8.2 2010 Tags

The HTI Model 795 acoustic tags operate at 307 kHz frequency and are encapsulated with a non-reactive, inert, low toxicity resin compound. The tags utilize “pulse-rate encoding” which provides increased detection range, improves the signal-to-noise ratio and pulse-arrival resolution, and decreases position variability when compared to other types of acoustic tags (Ehrenberg and Steig 2003). Pulse-rate encoding uses the interval between each transmission to detect and identify the tag (**Figure 2-9**). Each tag is programmed with a unique pulse-rate encoding to detect and track the behavior of individually tagged fish moving within the array.



Source: HTI 2016 this study.

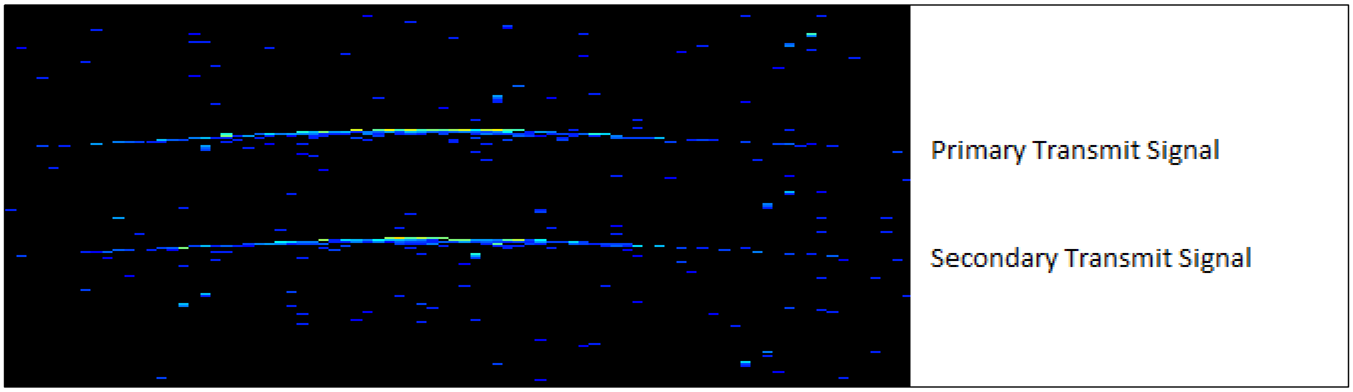
Note: Pulse-rate interval, also referred to as the “tag period” or “ping” rate, describes the amount of elapsed time between each primary tag transmission.

Figure 2-9. HTI Tag Signal

The pulse-rate is measured from the leading edge of one pulse to the leading edge of the next pulse in sequence. By using slightly different pulse-rates, tags can be uniquely identified. The timing of the start of each transmission is precisely controlled by a microprocessor within the tag. Each tag is programmed to have its own tag period to uniquely identify each tag.

In addition to the tag period, the HTI tag double-pulse mode or “subcode” option can be used to increase the number of unique tag identification (ID) codes available. Using this tag coding option, each tag is programmed with a defined primary tag period, and also with a defined secondary transmit signal, called the subcode. This subcode defines a precise elapsed time period between the primary and secondary tag transmissions (**Figure 2-10**). There are 31 different subcodes possible for each tag period, resulting in over 100,000 total unique tag ID codes.

Each tag was programmed to have its own tag period to uniquely identify between tags. For the 2010 study, 342 juvenile Chinook Salmon were tagged, and 480 juvenile steelhead were tagged, and 55 predatory fish were tagged, for a total of 887 tags. Juvenile Chinook Salmon tag periods ranged from 4.021 to 9.985 seconds. Juvenile steelhead tag periods ranged from 2.059 to 8.474 seconds. Predatory fish tag intervals ranged from 4.269 to 5.991 seconds. These acoustic tag transmission intervals provided fine time-scale fish position information within the 2D positioning arrays.



Source: HTI 2016 this study.

Note: Example graphic from the data collection program showing the primary (tag period) and secondary (subcode) transmit signal returns from a Model 795 acoustic tag.

Figure 2-10. Tag Subcode Signal

In addition to the tag period, the HTI tag double-pulse mode or subcode option was used to increase the number of unique tag ID codes available. Tagged juvenile steelhead, Chinook Salmon and predatory fish were assigned different subcodes. The use of consistent and unique tag identification subcodes by fish species/group and tag type facilitated quick identification of targets during the sampling period. Tags used for this study had a two millisecond pulse width.

2.9 2011 DATA COLLECTION METHODS

In 2011, juvenile steelhead, juvenile Chinook Salmon, adult Largemouth Bass, adult Striped Bass, and adult White Catfish were tagged, released, and tracked in the south Delta. The 2011 full-scale study was coordinated with the Vernalis Adaptive Management Plan (VAMP) Study team and the Long-Term Operational Criteria and Plan (OCAP) Six-Year Steelhead Study team (see SJRGA 2013: Chapters 5, 6, 7, and 8).

2.10 2011 FIXED-STATION RECEIVER GRID (1D HYDROPHONE ARRAY)

In order to track tagged salmonids and predatory fish throughout the south Delta, an acoustic receiver network was deployed in January–March 2011 by a multi-agency team. The network of fixed-point receivers (HTI Model 295X and 295G) was designed to cover the south Delta including Old River, Middle River, the GLC, and the SWP and CVP intakes (**Figure 2-5**). **Appendix E** includes close-up aerial photographs for each group of hydroacoustic arrays and their deployment locations for 2011. The receiver array was called the 2011 1D hydrophone array because it provided information on fish traveling through Delta channels and it also provided data for input into a reach-specific survival model. The receiver array was installed prior to tagged fish being released. Also, before fish releases the receivers' detection efficiency and range were evaluated. Downloads of the receivers' internal memory occurred weekly or more frequently, as needed. The 2011 study utilized remote telemetry equipment at key locations. This technology was developed by the USGS for the 2011 VAMP Study (see SJRGA 2013: Chapter 5) and allowed for real-time communication with the dataloggers. USGS or USFWS personnel checked the remote-telemetered receiver stations daily and coordinated site repairs with DWR staff. Downloads of the remote-telemetered receivers' internal memory occurred hourly via a file transfer protocol (.ftp) site.

2.10.1 2011 1D Positioning

The 2011 Fixed-Station Receiver Grid was similar to the 2010 receiver grid, with only minor changes in some of the hydrophone locations. **Table 2-8** provides a combined list for 2010 and 2011 of the names, abbreviations, and GPS locations of the individual hydrophone arrays. In 2011, on-board GPS receivers were included with the ATRs. GPS receivers were used to provide very accurate time synchronization between receivers. This improvement allowed for more accurate detection timing between receiver systems throughout the SDAB-monitoring area.

2.11 2011 TWO-DIMENSIONAL RECEIVER ARRAY

In addition to the broader-scale receiver network, a 2D telemetry system consisting of an HTI Model 290 16-port receiver and 10 hydrophones was used to track fish in the vicinity of the ORTB (Tunnicliffe et al. 2012). After the ORTB was constructed, the 2D fish tracking system was deployed and tested over a one-week period. Five hydrophones were deployed upstream of the barrier, and five hydrophones were deployed downstream of the barrier (**Figure 2-11**). Acoustic return data were stored on a laptop computer connected to the HTI receiver for subsequent post-processing and data analysis.

Source: HTI this study.

Figure 2-11. 2011 Hydrophone Locations in Two-Dimensional Receiver Array at the Old River at Tracy Barrier

2.12 2011 CHINOOK SALMON AND STEELHEAD ACOUSTIC TAGGING

In 2011, juvenile fall-run Chinook Salmon and juvenile steelhead were available from the Merced River Hatchery and Mokelumne River Hatchery, respectively. These hatchery fish were used as surrogates for wild fish and were transported from the hatchery to two locations. Chinook Salmon were held at the Tracy Fish Collection Facility (TFCF) and the steelhead were held at the CHTR Laboratory. Acoustic tagging was coordinated with the VAMP Study and OCAP Six-Year Steelhead Study teams (see SJRGA 2013: Chapters 5 and 6) and tagging was led by FISHBIO (Oakdale, California). Acoustic tagging followed the same surgical procedures used in the 2010 VAMP Study and is described for 2011 in SJRGA (2013). Acoustic tags (HTI Models 795-LD and 795-Lm) were programmed and surgically implanted into juvenile steelhead and Chinook Salmon. The LD tags weighed 1.1 g (0.04 oz) and Lm tags weighed 0.65 g (0.02 oz). Tag mass to fish body mass ratio was kept to below five percent. There were some minor differences in the recovery and transportation processes between the 2011 VAMP Study and 2010 SDABs Study. In 2011, the tagged Chinook Salmon and steelhead were placed into perforated 19 L (5 gal) buckets and perforated 68 L (18 gal) tubs, respectively.

There were differences in the number of salmonids released that had received a tag through surgical insertion. For survival analysis, 2,195 steelhead and 1,900 Chinook Salmon were released (**Table 2-11**) at Durham Ferry. For 2D analysis, 120 steelhead and 200 Chinook Salmon (**Table 2-12**) were released at the 2D Fish Release Site (2011) (**Figure 2-5**).

The recovery buckets and tubs had high dissolved oxygen concentrations (110–130 percent of saturation) to allow the fish to recover from anesthesia effects. The fish were then monitored with a receiver and hydrophone to confirm the operational status and acoustic tag identification number of each fish (**Table 2-11**). Buckets of tagged Chinook Salmon were then held in a flume until transported to the release site. After monitoring the steelhead tags the tubs were immediately loaded into a modified transport tank that allowed CHTR Laboratory water to flow through the transport tank until transported to the release site.

2.13 2011 PREDATORY FISH COLLECTION AND ACOUSTIC TAGGING

Predatory fish were captured, externally tagged following a similar procedure to that utilized in 2010 with one modification (i.e., heat-shrink tubing was used to attach the stainless steel wire to the tag rather than cable ties with an acoustic tag), and released within the south Delta near their point of capture to gain behavioral information. Predatory fish sampling primarily focused on Striped Bass and Largemouth Bass using hook-and-line sampling. Sampling was conducted continuously throughout the study period. A total of 31 predatory fish were captured, tagged, and released (**Table 2-12**).

Table 2-11. Summary of Acoustically Tagged Juvenile Salmonid Groups Released in 2011 for Survival Modeling										
Species	Tagging Date (month/ day/year)	Fish Transported and Released (N[1])	Minimum Fish Length (FL in mm[1])	Maximum Fish Length (FL in mm)	Minimum Fish Mass (g[1])	Maximum Fish Mass (g)	Minimum Tag Burden (Tag Mass/ Maximum Fish Mass)[2] (%)	Maximum Tag Burden (Tag Mass/ Minimum Fish Mass)[2] (%)	Mortality or Tag Not Functional (%)	Release Start Date (month/ day/year)
Steelhead	3/21/2011	118	195	310	68.5	289.8	0.35	1.46	0.00	3/22/2011
Steelhead	3/22/2011	119	207	302	85.1	302.5	0.34	1.19	0.83	3/23/2011
Steelhead	3/23/2011	120	196	307	72.3	274.6	0.36	1.37	0.00	3/24/2011
Steelhead	3/24/2011	120	177	304	59.2	269.8	0.37	1.69	0.00	3/25/2011
Steelhead	5/2/2011	118	215	335	103.0	480.0	0.21	0.99	0.00	5/3/2011
Steelhead	5/3/2011	119	217	345	101.4	386.0	0.26	1.01	0.00	5/4/2011
Steelhead	5/4/2011	119	165	360	79.6	386.1	0.26	1.26	0.83	5/5/2011
Steelhead	5/5/2011	118	175	351	75.4	495.0	0.20	1.34	0.00	5/6/2011
Steelhead	5/16/2011	119	220	387	121.7	372.3	0.27	0.84	0.00	5/17/2011
Steelhead	5/17/2011	120	224	319	108.6	382.3	0.26	0.92	0.00	5/18/2011
Steelhead	5/18/2011	119	205	339	102.2	500.5	0.20	1.00	0.00	5/19/2011
Steelhead	5/19/2011	120	215	395	91.4	391.9	0.26	1.11	0.00	5/20/2011
Steelhead	5/21/2011	120	228	338	114.3	414.6	0.24	0.87	0.00	5/22/2011
Steelhead	5/22/2011	120	220	352	114.3	505.2	0.20	0.89	0.00	5/23/2011
Steelhead	5/23/2011	120	149	396	114.7	458.0	0.22	0.90	0.00	5/24/2011
Steelhead	5/24/2011	120	234	345	123.2	454.5	0.22	0.80	0.00	5/25/2011
Steelhead	6/14/2011	118	179	370	76.6	505.2	0.20	1.36	0.83	6/15/2011
Steelhead	6/15/2011	120	180	355	78.0	540.9	0.19	1.33	0.00	6/16/2011
Steelhead	6/16/2011	48	154	354	36.8	500.0	0.20	2.74	0.00	6/17/2011
Total		**2,195**								
Chinook Salmon	5/16/2011	120	99	115	12.1	20.0	3.45	5.52	0.00	5/17/2011
Chinook Salmon	5/17/2011	118	95	115	12.1	18.8	3.51	5.48	0.83	5/18/2011
Chinook Salmon	5/18/2011	117	99	116	12.1	19.6	3.21	5.54	2.50	5/19/2011
Chinook Salmon	5/19/2011	119	101	115	12.2	20.7	3.24	5.61	0.83	5/20/2011
Chinook Salmon	5/21/2011	119	99	122	11.6	21.3	3.00	5.62	0.83	5/22/2011
Chinook Salmon	5/22/2011	120	99	121	12.1	20.9	2.97	5.45	0.00	5/23/2011
Chinook Salmon	5/23/2011	115	101	122	12.1	21.8	3.08	5.45	3.36	5/24/2011
Chinook Salmon	5/24/2011	120	102	121	12.1	21.8	2.85	5.57	0.00	5/25/2011
Chinook Salmon	6/6/2011	119	105	124	12.2	23.4	2.65	5.16	0.83	6/7/2011
Chinook Salmon	6/7/2011	120	104	130	12.4	27.5	2.32	5.16	0.00	6/8/2011

Table 2-11. Summary of Acoustically Tagged Juvenile Salmonid Groups Released in 2011 for Survival Modeling (continued)										
Species	Tagging Date (month/ day/year)	Fish Transported and Released (N[1])	Minimum Fish Length (FL in mm[1])	Maximum Fish Length (FL in mm)	Minimum Fish Mass (g[1])	Maximum Fish Mass (g)	Minimum Tag Burden (Tag Mass/ Maximum Fish Mass)[2] (%)	Maximum Tag Burden (Tag Mass/ Minimum Fish Mass)[2] (%)	Mortality or Tag Not Functional (%)	Release Start Date (month/ day/year)
Chinook Salmon	6/8/2011	119	107	125	12.8	25.3	2.54	5.14	1.67	6/9/2011
Chinook Salmon	6/9/2011	120	105	126	13.0	22.5	2.89	5.07	0.00	6/10/2011
Chinook Salmon	6/14/2011	119	104	123	12.7	24.6	2.62	5.23	0.83	6/15/2011
Chinook Salmon	6/15/2011	118	102	125	12.4	26.9	2.49	5.24	1.67	6/16/2011
Chinook Salmon	6/16/2011	117	94	128	12.2	27.9	2.37	5.49	1.68	6/17/2011
Chinook Salmon	6/17/2011	120	100	140	10.3	34.6	1.97	6.50	0.00	6/18/2011
Total		**1,900**								

Source: DWR this study.
Note: [1] N = sample size; FL in mm = Fork Length in millimeters; g = grams; % = percent.
[2]Juvenile Chinook Salmon were tagged with HTI Model 795-Lm tags and it was assumed they had a tag mass of 0.65 g. Juvenile steelhead were tagged with HTI Model 795-LD tags and it was assumed they had a tag mass of 1.1 g (based on data from HTI).

Table 2-12. Summary of Acoustically Tagged Juvenile Salmonid Groups Released in 2011 for Two-Dimensional Analysis		
Release Date	Species[2]	Fish Transported and Released (N[1])
6/15/2011	Steelhead	30
6/16/2011	Steelhead	30
6/17/2011	Steelhead	30
6/18/2011	Steelhead	30
Total		**120**
6/15/2011	Chinook Salmon	50
6/16/2011	Chinook Salmon	50
6/17/2011	Chinook Salmon	50
6/18/2011	Chinook Salmon	50
Total		**200**

Source: DWR this study.
Note: [1] N = sample size.
[2]Juvenile Chinook Salmon were tagged with HTI Model 795-Lm tags and it was assumed they had a tag mass of 0.65 g. Juvenile steelhead were tagged with HTI Model 795-LD tags and it was assumed they had a tag mass of 1.1 g (based on data from HTI).

Table 2-13. 2011 Predatory Fish Tag Data Summary					
Acoustic Tag Identification	Predatory Fish Species	Release Location	Release Date (month/day/year)	Universal Coordinated Release Time	Fish Length (TL in cm[1])
2589.01	Largemouth Bass	Durham Ferry	6/21/11	10:00	32.5
2360.01	Largemouth Bass	Durham Ferry	6/21/11	10:15	42.5
2617.01	Largemouth Bass	Durham Ferry	6/21/11	12:00	45
2673.01	Striped Bass	Durham Ferry	6/23/11	09:45	39
2575.01	Striped Bass	Durham Ferry	6/23/11	10:10	34
2561.01	Striped Bass	Durham Ferry	6/23/11	12:20	34.5
2631.01	Largemouth Bass	Durham Ferry	6/23/11	17:18	32.5
2659.01	White Catfish	Durham Ferry	6/23/11	18:20	32
2603.01	Striped Bass	Durham Ferry	6/23/11	19:20	33
2393.01	Striped Bass	Durham Ferry	6/15/11	11:15	50
2519.01	Striped Bass	Durham Ferry	6/8/11	12:00	38
2533.01	Striped Bass	Durham Ferry	5/17/11	11:22	45
2155.01	Striped Bass	Durham Ferry	5/11/11	14:21	42
2407.01	Largemouth Bass	Durham Ferry	5/11/11	15:05	40
2071.01	Striped Bass	Durham Ferry	5/3/11	11:34	42
2183.01	Striped Bass	Durham Ferry	5/3/11	13:10	41.5
2337.01	Striped Bass	Durham Ferry	5/3/11	13:15	71.5
2211.01	Striped Bass	Durham Ferry	5/3/11	14:22	48
2057.01	Striped Bass	Durham Ferry	4/13/11	NA[1]	50.5
2141.01	Striped Bass	Durham Ferry	4/13/11	NA	46
2029.01	Striped Bass	Durham Ferry	4/13/11	NA	43
2113.01	Striped Bass	Durham Ferry	4/13/11	NA	42
2057.01	Striped Bass	Durham Ferry	4/13/11	NA	50.5
2141.01	Striped Bass	Durham Ferry	4/13/11	NA	38
2197.01	Striped Bass	Durham Ferry	4/13/11	NA	42.5
2169.01	Striped Bass	Durham Ferry	4/13/11	NA	41
2099.01	Striped Bass	Durham Ferry	4/13/11	NA	50.5
2043.01	Striped Bass	Durham Ferry	4/13/11	NA	44
2015.01	Striped Bass	Durham Ferry	4/13/11	NA	45
2379.01	Striped Bass	Durham Ferry	4/13/11	NA	45.5
2085.01	Striped Bass	Durham Ferry	4/13/11	NA	42

Source: DWR this study.

[1] Note: NA = Not Available; TL in cm = Total Length in centimeters.

2.14 2011 TAG LIFE

Three tag life studies were conducted by FISHBIO and DWR to monitor the battery life of the acoustic tags (see SJRGA 2013: Chapters 5 and Chapter 6). A stratified random subsample was taken from all of the HTI 795-Lm and 795-LD tags. Tags were programmed with representative tag periods and pulse width to those tags released. Fifty Model 795-Lm tags were placed into a mesh bag and then suspended in a tank. In a separate tank, 25 Model 795-LD tags were placed in a mesh bag and then suspended in the tank. Into this second tank, 25 juvenile steelhead fitted with Model 795-LD tags were held for over three months to evaluate delayed mortality, tag shedding, and tag life. All tag life tags were then monitored and the dates and times the tags failed were recorded. The lifespan of each tag was calculated as the time between tag programming and time of tag failure.

2.15 2011 SURGICAL AND TRANSPORT PROCEDURE CONTROL GROUPS

In 2011, 16 juvenile Chinook Salmon were tagged and retained as a control group. Similarly, 25 juvenile steelhead were tagged and held as a control group. In 2011, the USFWS also performed fish health evaluations on 82 dummy-tagged juvenile Chinook Salmon (see SJRGA 2013: Chapters 5 and 6). The dummy tags were identical in size and shape to that of the live tags used in the survival study. The dummy-tagged fish were transported to the release site and held along with the study fish that were tagged with active tags. Dummy-tagged fish were evaluated for mortality, condition, smoltification, and health by the USFWS.

2.16 2011 ACOUSTIC TAGGED STEELHEAD AND CHINOOK SALMON RELEASES

Tagged juvenile steelhead and Chinook Salmon were transported and released into the San Joaquin River near Durham Ferry to meet the needs of multiple studies (see SJRGA 2013: Chapters 5, 6, and 8). Modifications to the planned steelhead and Chinook Salmon release schedule were necessary given the installation schedule for the SDABs and the size of the Chinook Salmon. The releases were intended to cover the time before, during, and after installation of the temporary barriers. The schedule for the release of fish in coordination with the other studies is summarized in **Table 2-14**.

Table 2-14. Juvenile Chinook Salmon and Steelhead Release Schedules During the 2011 Studies

TBP[1] Chinook Salmon Release Dates	TBP Steelhead Release Dates	VAMP[1] Chinook Salmon Release Dates	Six-Year[1]/VAMP Steelhead Release Dates
6/7	5/22	5/17	3/22
6/8	5/23	5/18	3/23
6/9	5/24	5/19	3/24
6/10	5/25	5/20	3/25
6/11	6/15	5/21	5/3
6/15	6/16	5/22	5/4
6/16	6/17	5/23	5/5
6/17		5/24	5/6
6/18		5/25	5/17
6/19		5/26	5/18
			5/19
			5/20

Source: Release dates from Tables 5-3, 5-4 and 6-10 in SJRGA (2013).

Note: [1] TBP = Temporary Barriers Project Study; VAMP = Vernalis Adaptive Management Plan Study; Six-Year = Six-Year Steelhead Study.

Steelhead and Chinook Salmon were scheduled to be released both before and after the installation of the SDABs (**Table 2-3**). Several juvenile Chinook Salmon and steelhead releases were successfully completed prior to the installation of the barriers. The installation of the SDABs began in the middle of May and as construction continued snowmelt and rainfall was heavy. The MRB was closed on June 6 and the ORTB was closed on June 10 (**Table 2-3**). The GLCB was washed out several times due to high discharges. Consequently, results were available for the Before- and After-Construction Period for the MRB and the ORTB. Only Before- and During-Construction Period data were available for the GLCB.

The transportation and release methods were different in 2011 than for the 2010 SDABs study. In 2011, the Chinook Salmon and steelhead were transported to the release site on the same day as tagging (see SJRGA 2013: Chapter 5). Once at the release site, the buckets or tubs were removed from the transport tanks and the fish were transferred to perforated live pens in the river. Releases of tagged fish began a minimum of 24 hours later. The lids were removed from the live pens and inspected for mortalities. The live pens were then inverted to release a small subgroup of fish. Fish were released in the small subgroups every 6 hours over a 24-hour period.

2.17 2010 PREDATOR FILTER METHODS

Previous studies have shown that predation may play an important role in the survival of migrating juvenile salmonids in the south Delta (SJRGA 2011, 2013). One important consideration in evaluating acoustic tag data is that if a tagged salmonid is eaten by a predatory fish, the acoustic tag within the tagged fish will continue transmitting. These transmissions will be recorded by any receiver when the predatory fish swims within range. Recording will continue until the predatory fish regurgitates or defecates the tag and the tag becomes motionless. Thus, during the time that the tag remains inside the predatory fish movements of the tag represent movements of a predator fish and not movements of a juvenile salmonid.

In an effort to measure only movements of tags that are in free-swimming juvenile salmonids, a method called a "predator filter" was developed by Rebecca Buchannan and others (SJRGA 2011, 2013) to remove detections that were suspected to be from juvenile salmonids that had been eaten by predatory fish. Overall, the method utilized suspected behavioral differences between predatory fish and actively migrating juvenile salmonids. The details of the development and implementation of the predator filter for the VAMP studies in 2010 and 2011 can be found in the SJRGA reports (SJRGA 2011, 2013).

For the 2010 and 2011 SDAB Study, the same predator filter used during the VAMP studies was adapted and applied to detection data from SDAB-tagged fish. The same parameter values used during the VAMP studies were used as maximum and minimum limits of behavioral characteristics, such as migration rates or residence times. Where flow was a part of the decision process, the same environmental monitoring sites used during the VAMP studies were used. In addition, the SDAB detection data were summarized in the same way as the VAMP detection data prior to implementing the filter. For the 2010 predator filter, all detection data from the SDAB-tagged juvenile salmonids released at the Old River release site were evaluated from the release point to the SDAB four "exit points"[13] (i.e., points CVP, RGU, ORN, MRB) (**Figure 2-5**).

[13] "Exit points" are specific locations for calculation of survival statistics where juvenile salmonids are recorded as either arriving successfully "exiting" the south Delta or not successfully arriving. For each emigration route there is an *initial* point at the beginning of the route that is the starting point for the survival statistics. There is also for each route, and a *final* point (terminal location) at the end of the emigration route where it is assumed that a fish reaching this "exit" survived passage through the south Delta via that route. Salmonid survival estimates are calculated for each potential emigration route between these two points. See Section 2.19 Survival Estimates for additional details.

Some of the decision parameters of the predator filter relate to how the local environment might affect behavior at or between detection sites. For example, a tagged juvenile migration rate measured between two detection sites might be faster if flows were high or slower if flows were low. The eight environmental monitoring sites used in this study are (CDEC 2016b):

1) OH1: Old River at Head;
2) OH4: Old River at Highway 4;
3) ORI: Old River at Clifton Court Intake;
4) OLD: Old River near Tracy;
5) ODM: Old river at Delta-Mendota Canal;
6) GLC: Grant Line Canal;
7) MRU: Middle River at Undine Road; and
8) MDM: Middle River at Middle River.

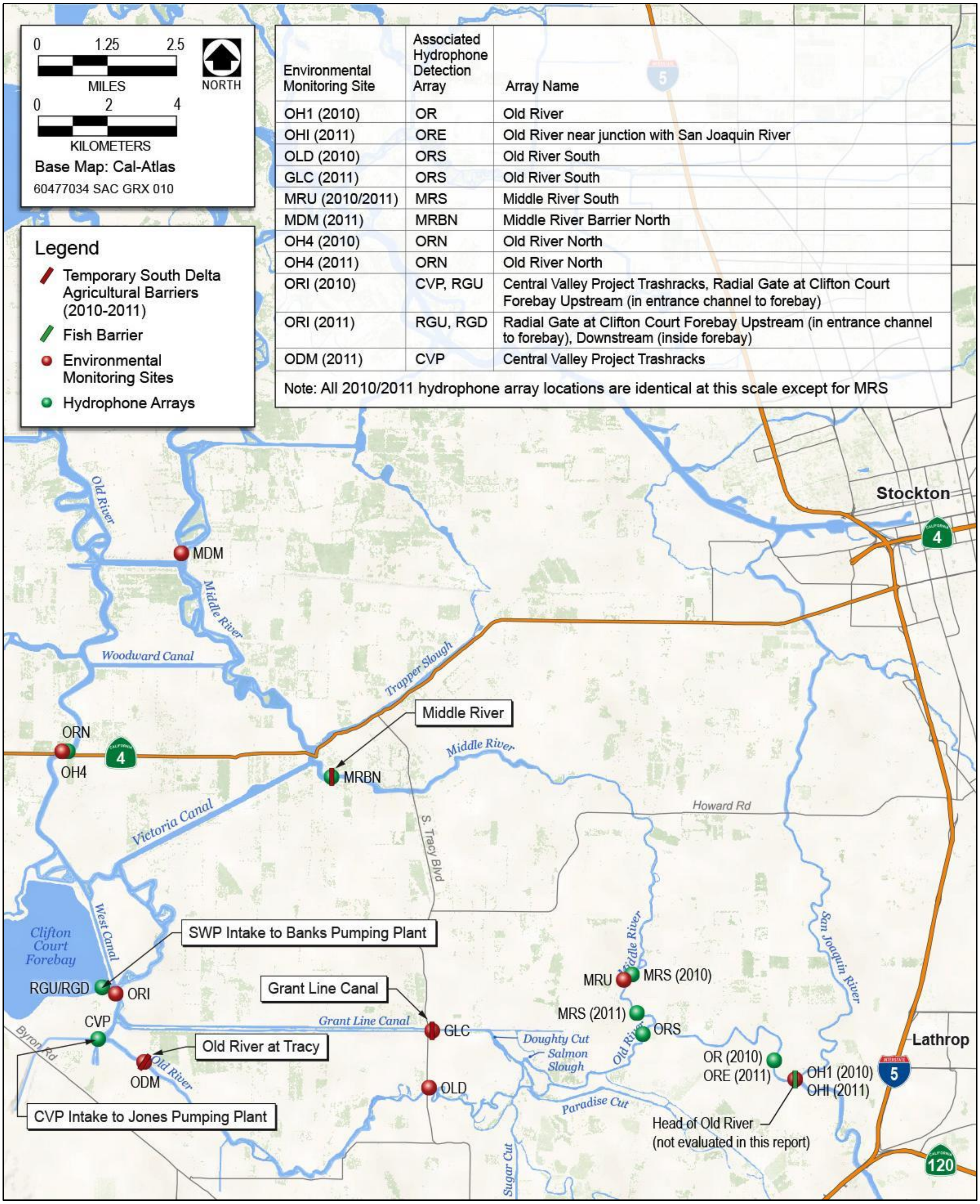
Table 2-15 lists the eight environmental sites used for implementation of flow-related criteria used in the predator filter for both 2010 and 2011 (SJRGA 2011, 2013). **Figure 2-12** illustrates the proximity of each environmental monitoring site to its respective hydrophone detection site. Historical data for 2010 and 2011 were downloaded from the CDEC website at http://cdec.water.ca.gov/queryTools.html (CDEC 2016b).

2.17.1 Detection Data Summarization

For the 2010 SDAB Study juvenile salmonid detection data from individual hydrophones were summarized into records representing a single visit of that tag to the detection site. For the purpose of survival modelling (both for VAMP and SDAB studies), some nearby hydrophone pairs were combined into a single detection site.

Detection data from the 2010 SDAB Study were summarized in the same way as for the VAMP studies in 2010 and 2011. Each record of a tag 'visit' to an individual hydrophone was a group of tag detections starting with the first detection at that hydrophone and ending with the last detection until there was a 12-hour gap in detections, after which a new 'visit' was started. Residence time for a given visit at a given detection site was calculated by the difference between the last and first detection of one visit. The last detection of the previous detection site and the first detection at the following site were used to calculate the travel time between detection sites.

Juvenile salmonids were assumed to be actively emigrating downstream and were expected to exhibit behavior consistent with this general assumption. **Table 2-16** lists the parameters used in making the decision to classify detections as likely coming from a juvenile salmonid that had been eaten by a predatory fish in 2010. Cutoff values for each parameter were the same values used in the predator filter described in SJRGA (2011) for the 2010 VAMP Study. For the sites evaluated in the 2010 SDAB Study, no formal flow criteria were defined as was done during the 2010 VAMP Study (see SJRGA 2011: Table 5-6). However, similar to the 2010 VAMP Study, flow values and raw observation data were used to evaluate residence time at some sites, specifically to determine if juvenile salmonids were moving back and forth with tidal currents.



Environmental Monitoring Site	Associated Hydrophone Detection Array	Array Name
OH1 (2010)	OR	Old River
OHI (2011)	ORE	Old River near junction with San Joaquin River
OLD (2010)	ORS	Old River South
GLC (2011)	ORS	Old River South
MRU (2010/2011)	MRS	Middle River South
MDM (2011)	MRBN	Middle River Barrier North
OH4 (2010)	ORN	Old River North
OH4 (2011)	ORN	Old River North
ORI (2010)	CVP, RGU	Central Valley Project Trashracks, Radial Gate at Clifton Court Forebay Upstream (in entrance channel to forebay)
ORI (2011)	RGU, RGD	Radial Gate at Clifton Court Forebay Upstream (in entrance channel to forebay), Downstream (inside forebay)
ODM (2011)	CVP	Central Valley Project Trashracks

Source: AECOM this study.

Figure 2-12. Locations of Environmental Monitoring Sites Relative to their Respective Hydrophone Detection Sites

Table 2-15. 2010 and 2011 Environmental Monitoring Sites Used for Implementing Flow-Related Criteria of the Predator Filter

Environmental Monitoring Site	Detection Site(s)	Monitoring Site		Data Available		River Stage
		Latitude	Longitude	River Flow	Water Velocity	
OH1 (2010)	OR	37.8080	-121.3290	Yes	Yes	Yes
OHI (2011)	ORE	37.8080	-121.3290	Yes	Yes	Yes
OLD (2010)	ORS	37.8050	-121.4490	No	No	Yes
GLC (2011)	ORS	37.8201	-121.4497	Yes	Yes	Yes
MRU (2010 and 2011)	MRS	37.8339	-121.3860	Yes	Yes	No
MDM (2011)	MRBN	37.9425	-121.5340	Yes	Yes	Yes
OH4 (2010)	ORN	37.8911	-121.5692	Yes	Yes	Yes
OH4 (2011)	ORN	37.8900	-121.5697	Yes	Yes	Yes
ORI (2010)	CVP, RGU	37.8280	-121.5526	Yes	Yes	No
ORI (2011)	RGU, RGD	37.8280	-121.5526	Yes	Yes	Yes
ODM (2011)	CVP	37.8101	-121.5419	Yes	Yes	Yes

Sources: SJRGA (2011: Table 5-5); SJRGA (2013: Table 5-7), and HTI this study.

Table 2-16. Predator Filter Cutoff Values for 2010 South Delta Agricultural Barriers Detection Sites

Detection Site	Previous Site	Residence Time [a] Maximum (hours)	Transit Time Minimum (hours)	Transit Time Maximum (hours)	Migration Rate Minimum (km/hour)	Migration Rate Maximum (km/hour)	Comment
ORS	Release	4	1.2	6	1	5	
ORS	ORS, GLU, GLD, TBD	0	100	0	100	0	Unlikely transition if migrating
GLU	ORS, GLD	4			0.35	NA	
	Release	4			0.35	NA	
	ORN, RGU, TBU, GLU	0	100	0	100	0	Unlikely transition if migrating
GLD	ORS, GLU	4			0.35	NA	
	Release	4			0.35	NA	
	ORN, RGU, RGD, TBU, TBD, GLD	0	100	0	100	0	Unlikely transition if migrating
MRS	ORS	4	2	10	1	5	
MRS	Release	4	2	7	1	5	
MRBU	MRB	4			0.4	NA	
MRBD	MRN	4			0.4	NA	
MRN	MRB	5	NA	50	0.4	NA	

Table 2-16. Predator Filter Cutoff Values for 2010 South Delta Agricultural Barriers Detection Sites (continued)								
Detection Site	**Previous Site**	**Residence Time [a] Maximum (hours)**	**Transit Time Minimum (hours)**	**Transit Time Maximum (hours)**	**Migration Rate Minimum (km/hour)**	**Migration Rate Maximum (km/hour)**	**Comment**
MRN	MRN, Release, ORN, RGU, CVP	0	100	0	100	0	Unlikely transition if migrating
TBU	ORS	4			0.35	NA	
	TBU, TBD, CVP, RGU, ORN	0	100	0	100	0	Unlikely transition if migrating
TBD	TBU	4			0.35	NA	
	TBD, CVP, RGU, GLD, GLU, ORN	0	100	0	100	0	Unlikely transition if migrating
RGU	GLD, GLU, TBD, TBU	4 [b]	NA	24	0.35	NA	
RGU	RGU	24 [b]	NA	NA	NA	NA	
RGU	CVP	4 [b]	NA	15	0.1	NA	
RGU	RGD	4 [b]	NA	5	NA	NA	
RGU	ORN	4 [b]	NA	12	0.6	NA	
RGD	RGU	4 [b]	NA	5	NA	NA	
RGD	RGD	0	100	0	100	0	Unlikely transition if migrating
RGD	ORN	0	100	0	100	0	Unlikely transition if migrating
RGD	CVP	4 [b]	NA	15	0.1	NA	
RGD	GLD	4 [b]	NA	24	0.35	NA	
RGD	TBD	4 [b]	NA	15	0.1	NA	
CVP	GLD, GLU, TBD, TBU	4[a]	NA	50	0.4	NA	
CVP	CVP, MRN	0	100	0	100	0	Unlikely transition if migrating
CVP	RGU	4 [b]	NA	15	0.1	NA	
CVP	ORN	4 [b]	NA	24	0.4	NA	
ORN	RGU	24 [b]	NA	24	0.3	NA	
ORN	ORN	48 [b]	NA	NA	NA	NA	
ORN	CVP, GLD, MRN, TBD, TBU	24 [b]	NA	24	0.3	NA	

Source: HTI this study and SJRGA (2011: Table 5-6).
Notes: km = kilometers; NA = Not Available.
[a] Residence time includes up to 12 hours missing between detections.
[b] Evaluate raw observation data when interpreting residence time: Was tag present continuously or moving with the tide?

The decision process used to select salmonids suspected of being eaten by predatory fish included local detection site factors and larger-scale between-site factors, as listed in the columns of **Table 2-16**. Decisions were made for each site visit record. Four TRUE or FALSE fields were maintained for each visit record:

1) Did the tag represent a free swimming salmonid at the site?;
2) Did the tag represent a salmonid that had already been eaten by a predatory fish at the site?;
3) Did the tag arrive at the site as a free-swimming salmonid?; or
4) Did the tag leave the site as a free-swimming salmonid?.

The specific decisions for each site, based on parameters in **Table 2-16** were implemented using Microsoft® Access database functions and summarized in Microsoft® Excel. Any site visit that had been determined to represent a salmonid that had been eaten by a predatory fish (i.e., if the determination for Question 2 as TRUE) was removed from the survival modelling calculations. In addition, any subsequent site visits to any location by that same tag were also removed from survival modelling. If insufficient individual tagged site visit records remained after the predator filter was applied to the data, then the filter was not used. In such cases, all site visit data for that year/species were used for survival modelling.

2.18 2011 PREDATOR FILTER METHODS

For the 2011 predator filter, detection data from the juvenile salmonids released at the Durham Ferry release site were evaluated. The SDAB barrier detection sites were evaluated in conjunction with the previously evaluated sites surrounding the SDAB sites (SJRGA 2013). The same environmental monitoring sites were used to implement flow related predator filter parameters as were used for the 2010 filter (**Table 2-15**).

For the 2011 SDAB Study, salmonid detection data from individual hydrophones at the SDAB sites were summarized into records representing a single visit of that tag to the detection site. Detection data for 2011 were summarized the same way as for 2010 and the 2011 VAMP studies (SJRGA 2013).

Detection data previously summarized from the 2011 VAMP Study at sites surrounding the SDAB detection sites, were combined with the detection summaries for the SDAB sites. Some hydrophone pairs were combined into a single detection site. **Table 2-17** lists the hydrophone detection sites and combined locations for 2011. None of the paired upstream and downstream barrier detection sites were combined into single sites.

Table 2-18 lists the parameters used in making the decisions to classify detections as likely coming from a juvenile salmonid that had been eaten by a predatory fish in 2011. Cutoff values for each parameter were the same values used in the predator filter described in SJRGA (2013) for the 2011 VAMP Study.

2.19 SURVIVAL MODELING

The 2010 and 2011 SDABs survival analysis utilized a multi-state statistical release-recapture model similar to the models developed for the 2010 and 2011 San Joaquin River Group Authority's analysis of the VAMP studies for those years (SJRGA 2011, 2013). The model was used to estimate juvenile Chinook Salmon and steelhead survival and route entrainment for Before-, During-, and After-Construction Periods of the three SDABs. The models developed for this analysis expanded on previous analyses in the areas upstream and downstream of the SDABs at Old River at Tracy, Middle River, and the GLC using the software *User Specified Estimation Routine 4* (USER 4) (Lady and Skalski 2009). The USER 4 program fits the observed salmonid detection data to a multinomial likelihood model to estimate survival and entrainment proportions.

Table 2-17. Locations and Descriptions of Individual Hydrophone Sites and Abbreviations for those Sites that were Combined for 2011

Individual Hydrophone Site Abbreviation	Combined Site Abbreviation	2011 Temporary Barriers Hydrophone Locations Site Description	Hydrophone Site	
			Latitude	Longitude
CVPD	CVP	Tracy Fish Collection Facility Downstream of Trash Rack	37.816952	-121.558354
CVPU	CVP	Tracy Fish Collection Facility Upstream of Trash Rack	37.816952	-121.558354
GLCBD		Grant Line Canal Barrier Downstream	37.819755	-121.449255
GLCBU		Grant Line Canal Barrier Upstream	37.819849	-121.447902
MRBD		Middle River Barrier Downstream	37.892577	-121.490634
MRBU		Middle River Barrier Upstream	37.885608	-121.480723
MRND		Middle River North Downstream of MR Barrier (Downstream Node)	37.892264	-121.490199
MRNU		Middle River North Downstream of MR Barrier (Upstream Node)	37.890200	-121.489479
MRS		Middle River Approximately 1.5 km (0.9 mi) Downstream of Old River Split	37.824913	-121.380829
ORND	ORN	Old River North, Downstream of Clifton Court Forebay (Downstream Node)	37.892072	-121.567887
ORNU	ORN	Old River North, Downstream of Clifton Court Forebay (Upstream Node)	37.889961	-121.572875
ORSD	ORS	Old River Downstream of Middle River Split (Downstream Node)	37.818843	-121.379814
ORSU	ORS	Old River Downstream of Middle River Split (Upstream Node)	37.819709	-121.379215
RGDL	RGD	Clifton Court Forebay Radial Gates Downstream of Gates (Left)	37.829852	-121.557694
RGDR	RGD	Clifton Court Forebay Radial Gates Downstream of Gates (Right)	37.829906	-121.557670
RGU1	RGU	Clifton Court Forebay Radial Gates Upstream of Gates	37.829600	-121.556949
RGU2	RGU	Clifton Court Forebay Radial Gates, Upstream of Gates	37.829591	-121.556949
ORTBD		Old River at Tracy Barrier Downstream of Barrier	37.810940	-121.545336
ORTBU		Old River at Tracy Barrier Upstream of Barrier	37.809776	-121.542268

Source: HTI this study.

Table 2-18. Parameters Used in Making the Decisions to Classify Detections as Likely Coming from a Tagged Juvenile Salmonid that had been Eaten by a Predatory Fish in 2011

Detection Site	Previous Site	Maximum Residence Time[a] (hours)	Minimum Migration Rate[b,c] (km/hour)	Maximum Migration Rate[b,c] (km/hour)	Maximum Number of Visits (N)	Flow[d] At Arrival (cfs)	Flow[d] At Departure (cfs)	Water Velocity[d] At Arrival (ft/s)	Water Velocity[d] At Departure (ft/s)	Average Water Velocity During Transition	Extra Conditions	Comment
ORS	ORE	12	0.2	5	3	> -2,500		>-0.5				Allow 3 upstream forays if coming from ORE
	MRS, TBU, TBD, GLU, GLD	4			2							
	CVP	4	1.5	4	2	<-2,500	< -900	<-0.5	<-0.5		CVP pumping <1,500 cfs at departure[e]	
	ORS	4			2	< -2,500 (>-2,500)[g]	>-2,500 (<-2,500)[g]	< -0.5 (>-0.5)[g]	<-0.5 (>-0.5)[g]			
MRS	ORE, ORS	12	0.2	5	2							
	MRBU, MRBD	0	100	NA	0							Not Allowed
	MRS	12	0.2	5	2							
GLU, GLD	ORS	10	0.2	4	1							
	TBU, TBD, CVP, RGU, RGD	4			2							
	MRBU, MRBD, ORN	0	100	NA	0							Not Allowed
	GLU, GLD	12	0.2	5	2							
TBU, TBD	ORS	10	0.2	4	1							
	GLU, GLD	4			2							
	CVP, RGU, RGD	4			2							
	MRBU, MRBD, ORN	0	100	NA	0							Not Allowed
	TBU, TBD	12	0.2	5	2							
MRBU, MRBD	MRS, MRN	40	0.2	5	2	>-6,000	>-0.5					
	CVP, ORN, RGU, RGD	40	0.2	5	1	<-5,000		<-0.5			CVP pumping <1,500 cfs at departure[e]	See "extra conditions" if coming from CVP

Table 2-18. Parameters Used in Making the Decisions to Classify Detections as Likely Coming from a Tagged Juvenile Salmonid that had been Eaten by a Predatory Fish in 2011 (continued)

Detection Site	Previous Site	Maximum Residence Time[a] (hours)	Minimum Migration Rate[b,c] (km/hour)	Maximum Migration Rate[b,c] (km/hour)	Maximum Number of Visits (N)	Flow[d] At Arrival (cfs)	Flow[d] At Departure (cfs)	Water Velocity[d] At Arrival (ft/s)	Water Velocity[d] At Departure (ft/s)	Average Water Velocity During Transition	Extra Conditions	Comment
MRN	ORS, MRS, MRBU, MRBD	40	0.2	5	2	>-6, 000	>-0.5					
	CVP[f], ORN, RGU, RGD	40	0.2	5	1	<-5,500		<-0.5			CVP pumping <1,500 cfs at departure[e]	See "extra conditions" if coming from CVP
	MRN	20			2	<-2,500 (>-2,500)[g]	>-2,500 (<-2,500)[g]	<-0.5 (>-0.5)[g]	> -0.5 (<-0.5)[g]			
CVP	ORE, ORS, TBU, TBD, GLU, GLD	80 (40)[f]	0.2	4	1 (2 from ORS)	>-900		>-0.5				alternative values if arrive at CVP after end of VAMP
	ORN	40 (20)[f]	0.8	5	2		<-700		<-0.3	<0		alternative values if arrive at CVP after end of VAMP
	RGU, RGD	40 (20)[f]	0.2	5	2		<-1,500		<-0.3	<0	CCFB inflow <2,500 cfs at departure[e]	alternative values if arrive at CVP after end of VAMP
	MRN	40	1.1	5	2							alternative values if arrive at CVP after end of VAMP
	CVP tank	8 (4)[f]	0.02	0.3	2							alternative values if arrive at CVP after end of VAMP
	CVP	40 (20)[f]			2						pumping <1,500 at departure, >1,000 at arrival	alternative values if arrive at CVP after end of VAMP
ORN	MOS, ORE, ORS	40	0.15	4	1	>-700		>-0.3				
	MRN, RGU, RGD, GLU, GLD, TBU, TBD	40	0.15	4	2	>-700[f]	>-1,500[f]	>-0.3[f]	>-0.3[f]			Flow and water velocity limits only if coming from RGU/RGD

Table 2-18. Parameters Used in Making the Decisions to Classify Detections as Likely Coming from a Tagged Juvenile Salmonid that had been Eaten by a Predatory Fish in 2011 (continued)

Detection Site	Previous Site	Maximum Residence Time[a] (hours)	Minimum Migration Rate[b,c] (km/hour)	Maximum Migration Rate[b,c] (km/hour)	Maximum Number of Visits (N)	Flow[d] At Arrival (cfs)	Flow[d] At Departure (cfs)	Water Velocity[d] At Arrival (ft/s)	Water Velocity[d] At Departure (ft/s)	Average Water Velocity During Transition	Extra Conditions	Comment
	CVP	40	0.15	4	2	>-700	>-900	>-0.3	>-0.5		CVP pumping <1,500 cfs at departure[e]	
	ORN	25			2	<-700 (>-700)[g]	>-700 (< -700)[g]	<-0.3 (>-0.3)[g]	>-0.3 (<-0.3)[g]			
RGU, RGD	ORE, ORS, MRN, GLU, GLD, TBU, TBD	10 (80)[h]	0.2	4	1							
	ORN	10 (80)[h]	0.2	4	2	<-750	< -700	<-0.1	<-0.3	<0.2		
	CVP	10 (80)[h]	0.2	4	2	>-750		>-0.1		>-0.2	CVP pumping <1,500 cfs at departure[e]	

Source: HTI this study.

Notes:

km = kilometers; N = number of visits; cfs = cubic feet per second; ft/s = feet per second.

[a] Near field residence time includes up to 12 hours missing between detections.

[b] Approximate migration rate was calculated on most direct pathway.

[c] Missing values for transitions to and from single site (or between CVP and Delta-Mendota Canal): travel times must be 12 to 24 hours.

[d] Flow or velocity condition, if any, must be violated for predator classification.

[e] Condition at departure from previous site.

[f] See comments for alternative criteria.

[g] High flow/velocity on departure requires low values on arrival (and vice versa).

[h] If present in detection range <70 percent of residence time, and most detections were at RGU (not RGD).

Survival statistical methods were provided in the 2010 (SJRGA 2011) and 2011 (SJRGA 2013) annual technical reports. The tagged fish that entered Old River from the San Joaquin River at the HOR had the opportunity to emigrate via one of two routes: 1) Old River South (ORS); or 2) Middle River South (MRS). Immediately downstream of the divergence of Old and Middle rivers there were detection sites named ORS and MRS (**Figure 2-12**). Both of these detections sites, ORS and MRS were the *initial* starting points (or locations) for estimating salmonid survival via each route, respectively (see Footnote 17). The survival model utilized the detections at ORS and MRS along with the downstream detections at "exit" survival points (located at MRB, ORN, RGU and CVP) (**Figure 2-12**), to estimate the proportion of the fish and the survival of the fish that emigrated via each of the MRS and ORS routes. However, since there are multiple routes to reach exit points MRB, ORN, RGU, and CVP through either the ORS or MRS routes, the model was unable to separately estimate survival ($\hat{S}$) and route selection (Ψ) between either ORS to MRB, ORN, RGU, and CVP, or MRS to MRN, ORN, RGU, and CVP. Therefore the model calculated the joint probability of survival times route proportion ($\hat{S}*\Psi$). The sum of the joint probabilities from the same branching point equals 1, as shown in the following equations:

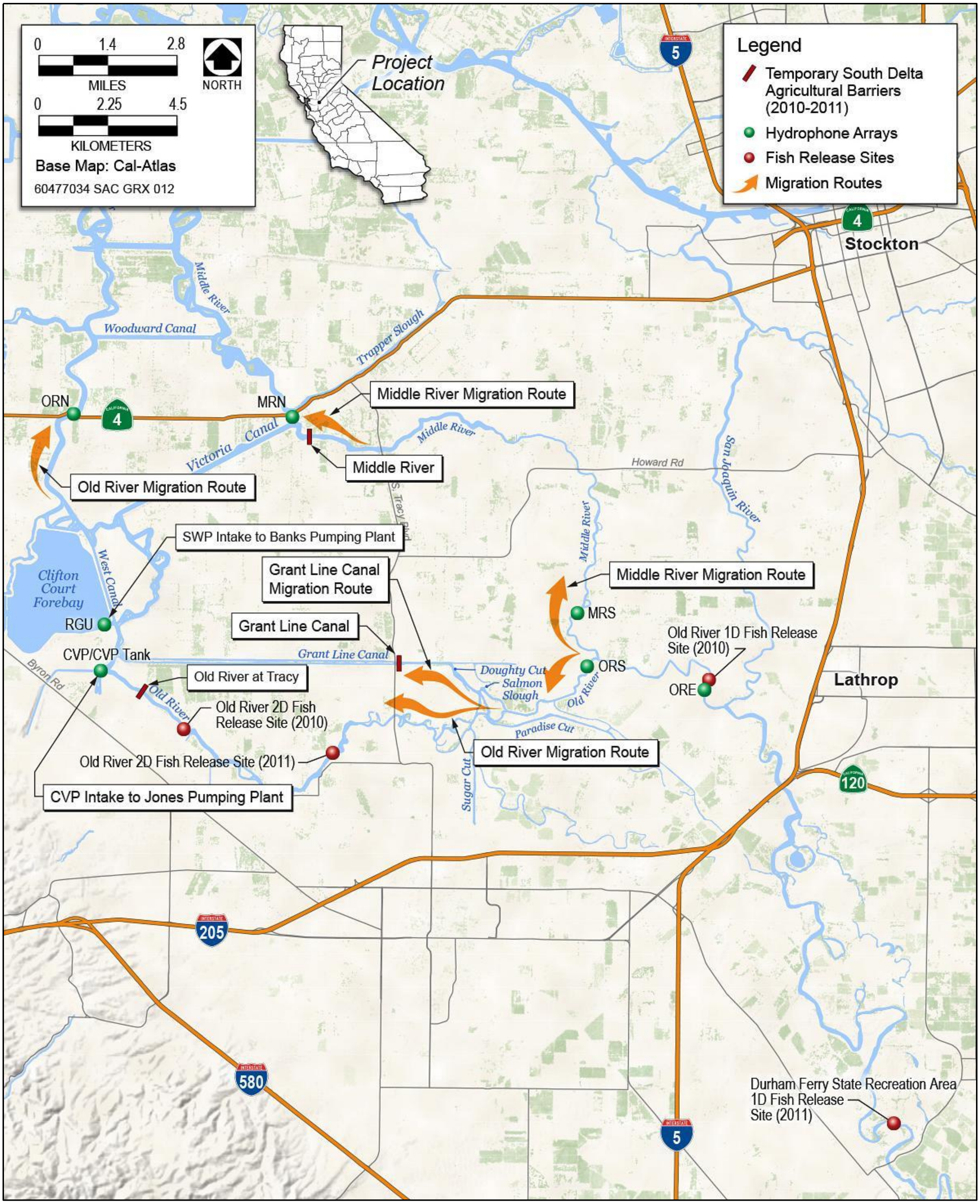
1) $(\hat{S}_{MRS\rightarrow MRN} * \Psi_{MRS\rightarrow MRN}) + (\hat{S}_{MRS\rightarrow ORN} * \Psi_{MRS\rightarrow ORN}) + (\hat{S}_{MRS\rightarrow RGU} * \Psi_{MRS\rightarrow RGU}) + (\hat{S}_{MRS\rightarrow CVP} * \Psi_{MRS\rightarrow CVP}) = 1$

2) $(\hat{S}_{ORS\rightarrow MRN} * \Psi_{ORS\rightarrow MRN}) + (\hat{S}_{ORS\rightarrow ORN} * \Psi_{ORS\rightarrow ORN}) + (\hat{S}_{ORS\rightarrow RGU} * \Psi_{ORS\rightarrow RGU}) + (\hat{S}_{ORS\rightarrow CVP} * \Psi_{ORS\rightarrow CVP}) = 1$

Since the sum of the joint probabilities equals 1, and all tagged fish are accounted for in the summed joint probabilities, the survival to all "exit" points from the south Delta combined is known. The joint probabilities were calculated from ORS and MRS to the first detection at the four possible south Delta exit locations: Middle River North (MRN), Old River North (ORN), Radial Gates Upstream (RGU), and CVP (**Figure 2-13**). These four exit points are the exit points in this SDAB study of the south Delta and are not the same exit points used in the VAMP studies (SJRGA 2011, 2013). In addition, this study reports "survived" if a tagged salmonid reached one of these four points. A tagged salmonid could experience mortality downstream of these four exit points (i.e., MRN, ORN, RGU, and CVP), but they would still count toward "survival" in the south Delta because they successfully transited the south Delta.

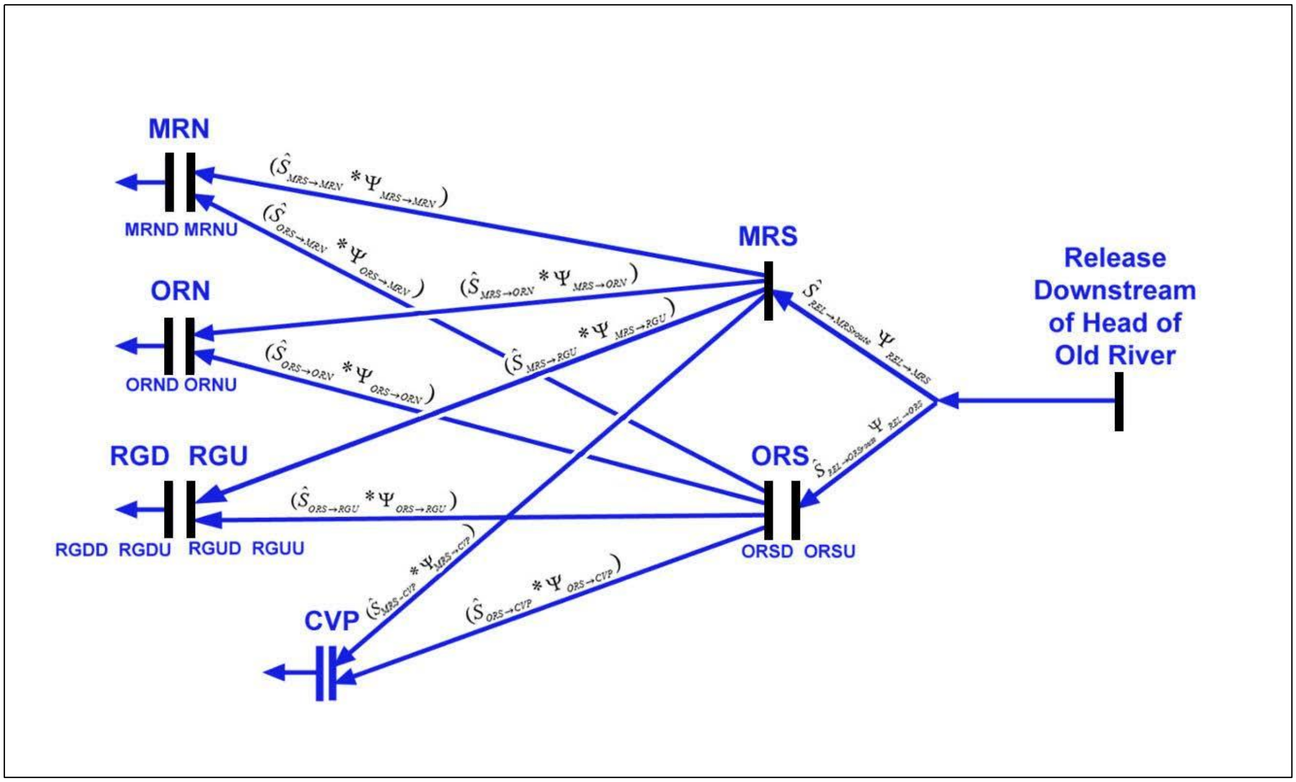
The salmonid survival analysis release site in 2010 was located approximately 1 km (0.6 mi) downstream of the HOR (**Figure 2-13**) and in 2011 the survival analysis release site was at Durham Ferry State Recreation Area (**Figure 2-13**). The area of interest was from the HOR through various routes and concluded at the four possible exit locations. There were two major routes that ended at the exit locations: 1) Old River which includes the GLC; and 2) Middle River. The USER 4 model schematic of the survival detection sites and estimable parameters are displayed in **Figure 2-14** for the 2010 data and in **Figure 2-15** for the 2011 data.

One objective of this study was to compare survival rates through the various juvenile salmonid out-migration routes during three barrier construction Before-, During-, and After-Construction Periods. These comparisons were facilitated by the implementation and refinement of predator filters for each year (described in Sections 2.17 and 2.18 *Predator Filter Methods*). Both the "Predator Filter Not Employed" and the "Predator Filter Employed" results are reported.



Source: AECOM this study.

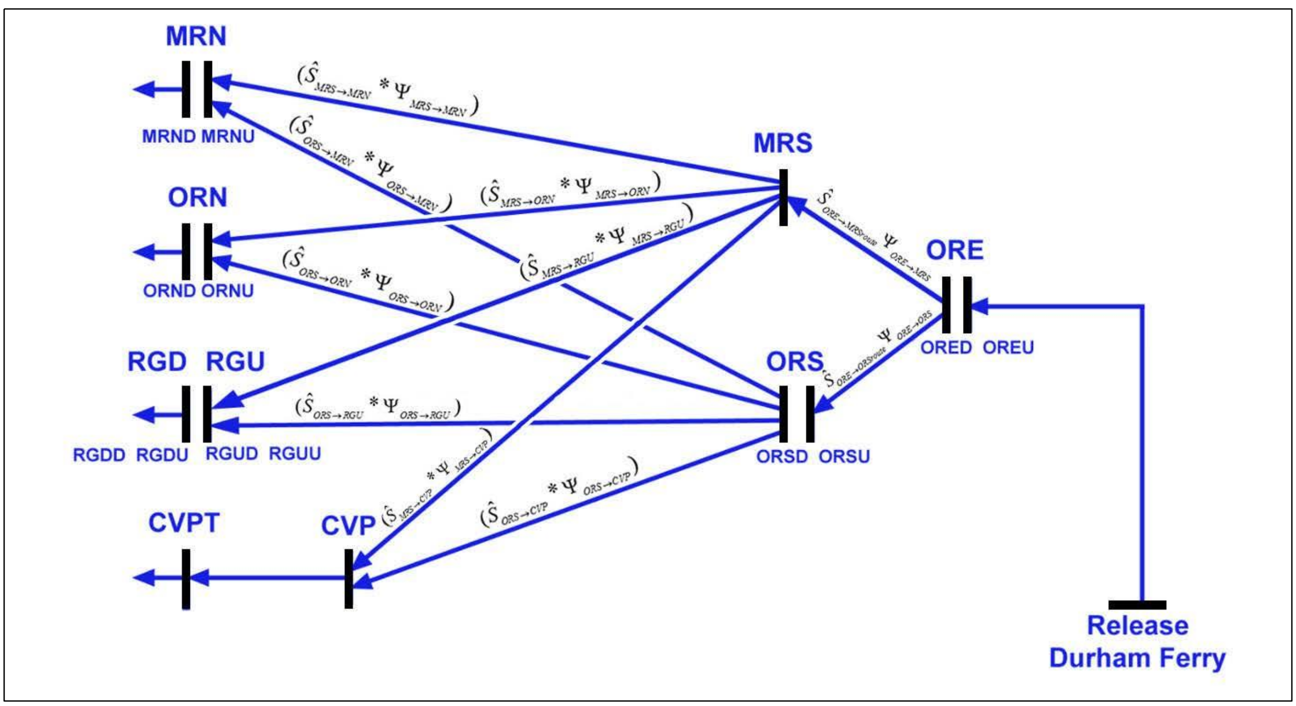
Figure 2-13. Survival Study Area Showing the South Delta Agricultural Barriers, Migration Routes, and Survival Detection Gates (ORE, ORS, MRS, MRN, ORN, RGU, CVP)



Source: HTI this study.

Note: The parameters include survival (Ŝ) and route selection (Ψ) and the joint probability (Ŝ*Ψ) for the various routes.

Figure 2-14. Schematic of Mark-Recapture Model Showing the Estimated Parameters for the 2010 Acoustic Tag Study



Source: HTI this study.

Note: The parameters include survival (Ŝ) and route selection (Ψ) and the joint probability (Ŝ*Ψ) for the various routes.

Figure 2-15. Schematic of Mark-Recapture Model Showing the Estimated Parameters for the 2011 Acoustic Tag Study

For the 2010 analysis, the data set “Predator Filter Not Employed” or “Predator Filter Employed” that produced the most robust estimates of survival was used in analyses of survival during different barrier construction periods:

1) The “Predator Filter Not Employed” data set was used for the analyses of 2010 juvenile steelhead survival during all of the different barrier construction periods. Observed steelhead behavior was very different than juvenile Chinook Salmon in 2010, with steelhead exhibiting much slower migration rates and longer travel times between detection sites. Because of this behavior, the predator filter eliminated 95 percent of the steelhead detection records and the resultant sample sizes were too small to conduct meaningful survival analyses during the different barrier construction periods; and

2) The “Predator Filter Employed” data set was used for the analyses of survival for the 2010 juvenile Chinook Salmon during all of the different barrier construction periods. The application of the predator filter eliminated approximately 30 percent of Chinook Salmon detection records and the remaining sample sizes were adequate to conduct robust survival analyses during the different barrier construction periods in 2010.

For the 2011 analysis, the data set “Predator Filter Employed” was used in analyses of survival for both Chinook Salmon and steelhead during all of the different barrier construction periods.

The final data set that emerged from predator filtering was then used to determine survival at various time periods related to the construction of the SDABs. As part of this analysis, the fish detection results were categorized according to when the fish were released in relation to the construction of the three SDABs for three time periods: 1) Before-Construction of the barrier; 2) During-Construction of the barrier; and 3) After-Construction of the barrier. This resulted in a total of nine possible groups depending on the three time periods for each of the three barrier installations.

Two hypotheses were tested regarding survival. The first hypothesis was:

1) $S1_0$: Juvenile salmonid survival was equal for the “Predator Filter Not Employed” and for the “Predator Filter Employed” detection-history sets.

The second hypothesis tested was:

2) $S2_0$: Juvenile salmonid survival was equal in the Before-, During-, and After-Construction Periods.

Both of these hypotheses were tested for Chinook Salmon and steelhead. A two-sided Z-test (Sheskin 2000) was used to evaluate these hypotheses since the estimated parameters of survival and entrainment were asymptotically normally distributed (following the procedure of SJRGA [2013]). The equation for the Z-test was given by:

$$Z = \frac{|\,\hat{S}_1 - \hat{S}_2\,|}{\sqrt{(SE_1)^2 + (SE_2)^2}}$$

where:

- $\hat{S}_1$ = the first survival estimate;
- $\hat{S}_2$ = the second survival estimate to be compared to the first;
- SE_1 = the standard error of the first survival estimate; and
- SE_2 = the standard error of the second survival estimate.

Planned comparisons of survival rates at times included multiple comparisons. In these situations, the Dunn-Šidák (following Ury [1976] in Sokal and Rohlf [1995]) method was employed to control the experimentwise error rate. Thus, the critical α' is calculated as:

$$\alpha' = 1 - (1 - \alpha)^{1/k}$$

where:

- α is the selected experimentwise Type I error rate (0.05); and
- k is the number of comparisons.

For example, three planned 2011 Chinook Salmon survival rate comparisons were executed: Before- vs. During-Construction Periods, Before- versus (vs.) After-Construction Periods, and During- and After-Construction Periods. The critical α', 0.01695, was calculated for three comparisons and thus if the P-value was smaller than α' then the null hypothesis was rejected.

The 2010 time periods used to define the Before-, During-, and After-Construction Periods of the three barriers are presented in **Table 2-19** for the juvenile Chinook Salmon and steelhead releases. The 2010 Chinook Salmon groups were released during four days in late April and early May. The dates of these release groups were April 29 and 30, and May 6 and 7. These four releases consisted of 342 juvenile Chinook Salmon. The specific details describing the employed tagging, handling and release methods can be found in SJRGA (2011). All of these release groups occurred during the Before-Construction Period (**Table 2-19**). Therefore, barrier installation time period comparisons could not be conducted for the reach survival analysis for the Chinook Salmon released in 2010.

The 2010 steelhead release groups occurred during eight days in early and mid-April and early June. The dates of these 2010 release groups were April 1, 2, 15, 16 and June 4, 5, 10, and 11. These 8 releases consisted of 480 juvenile steelhead (**Table 2-19**). The specific details describing the employed tagging, handling and release methods can be found in SJRGA (2011). The timing of the first four release groups occurred during the Before-Construction Period for all three barriers. At the GLCB, the timing of the other four steelhead release groups also fell into the Before-Construction Period. Thus, steelhead survival could only be calculated in the Before-GLCB Construction Period. There were no steelhead releases that occurred for the barrier installation During-Construction Period for the ORTB or MRB. However, the four steelhead releases that took place in June (**Table 2-19**) took place in the After-Construction Period of the ORTB and the MRB.

Table 2-19. 2010 Time Periods of the Barrier Installation (Before-, During- and After-Construction)			
Barrier	**Before-Construction**	**During-Construction**	**After-Construction**
Old River at Tracy	4/1/2010–5/9/2010	5/10/2010–6/3/2010	6/4/2010–7/7/2010
Middle River	4/1/2010–5/18/2010	5/19/2010–5/24/2010	5/25/2010–7/7/2010
Grant Line Canal	4/1/2010–6/15/2010	6/16/2010–7/7/2010	7/8/2010–7/31/2010[1]
Chinook Salmon Release Numbers			
Old River at Tracy	342	None	None
Middle River	342	None	None
Grant Line Canal	342	None	None
Steelhead Release Numbers			
Old River at Tracy	240	None	240
Middle River	240	None	240
Grant Line Canal	480	None	None
Source: HTI this study.			

The 2011 time periods of the Before-, During-, and After-Construction Periods of the three barriers are presented in **Table 2-20** for the Chinook Salmon and steelhead releases. The 2011 Chinook Salmon release groups occurred during eight days in May and eight days in June (**Table 2-11**). These 16 releases consisted of 1,900 Chinook Salmon. The specific details describing the tagging, handling and release methods can be found in SJRGA (2013). The timing of these 2011 releases encompassed most, but not all, of the barrier construction periods for the three SDABs.

Table 2-20. 2011 Time Periods of the Barrier Installation (Before-, During- and After-Construction)			
Barrier	**Before-Construction**	**During-Construction**	**After-Construction**
Old River at Tracy	3/22/2011–5/26/2011	5/27/2011–6/10/2011	6/11/2011–7/27/2011
Middle River	3/22/2011–5/31/2011	6/1/2011–6/6/2011	6/7/2011–7/27/2011
Grant Line Canal	3/22/2011–6/9/2011	6/10/2011–7/14/2011	7/15/2011–8/2/2011[1]
Chinook Salmon Release Numbers			
Old River at Tracy	948	478	474
Middle River	948	None	952
Grant Line Canal	1,306	594	None
Steelhead Release Numbers			
Old River at Tracy	1,909	None	286
Middle River	1,909	None	286
Grant Line Canal	1,909	286	None
Source: HTI this study.			

The 2011 steelhead release groups occurred during 4 days in late March, 12 days throughout May and 3 days in mid-June. These 19 releases consisted of 2,195 steelhead (**Table 2-20**). The specific details describing the tagging, handling and release methods can be found in SJRGA (2013). The barrier installation Before-Construction Period consisted of the first 20 release groups and was the same for the three barriers. The timing of the other four steelhead release groups occurred during the barrier installation After-Construction Period for ORTB and MRB. These same four releases occurred in the installation During-Construction Period for the GLCB. There were no steelhead releases that occurred during the barrier installation During-Construction Period for the ORTB and MRB. Likewise, no releases occurred during the barrier installation After-Construction Period for the GLCB. Therefore, the calculated survival results were equivalent during the ORTB and MRB After-Construction Period, as well as during the GLCB During-Construction Period.

2.20 TIME-IN-VICINITY

The 1D data from the fixed-station receiver grids in 2010 and 2011 were utilized to obtain survival information for modeling (see Section 2.19 *Survival Modeling*). In 2010 and 2011, the fixed-station grids also provided time-in-vicinity (TIV) data. In addition, in both 2010 and 2011 the 2D hydrophone arrays produced TIV data for Chinook Salmon and steelhead at the ORTB during the After-Construction Period. The TIV was defined as the elapsed time spent in or near a specific area of a barrier.

For the fixed-station receiver data during the Before- and During-Construction Periods, signals from the tags (i.e., pings) could be received on both the upstream and downstream hydrophones at a particular barrier because the barrier was not yet closed. For each TIV observation the barrier area was categorized in one of these categories:

1) Upstream: the acoustic tag was considered to be upstream of a barrier's footprint during the entire TIV observation;

2) Downstream: the acoustic tag was considered to be downstream of a barrier's footprint during the entire TIV observation; and

3) Both Upstream and Downstream: the acoustic tag spent some time upstream of a barrier's footprint and some time downstream of a barrier's footprint and together these comprised the TIV observation. It was impossible to discern the quantity of time spent in the upstream area relative to the downstream area and vice versa.

Category 3 – Both Upstream and Downstream, was required because a 1D hydrophone array could not always distinguish when the transition was made between upstream and downstream areas. If sample size was too small for a hypothesis test using only Category 1 or Category 2 area data, then Category 3 was utilized when it was appropriate. The Category 3 observations could be included with either Category 1 or Category 2 depending on the comparison being executed. For example if it was desired to compare Before-Construction Period TIV on the upstream side of a barrier to After-Construction Period TIV, then both Category 1 and Category 3 observations were included in the hypothesis test.

For each barrier the TIV data were segregated by construction period. TIV descriptive statistics (minimum, maximum, mean, standard deviation, and sample size) were reported for every barrier/construction period combination for which sufficient data were obtained.

2.20.1 Hypothesis Testing

After the descriptive statistics were reported the following hypothesis was tested:

- $H1_0$: Juvenile salmonid TIV is equal in the Before-, During-, and After-Construction Periods.

It was hypothesized that there might be considerable differences in TIVs with barrier state and location (upstream vs. downstream) in relation to a closed barrier when the TIV observations were obtained. For example, a emigrating salmonid on the upstream side of a closed barrier might be required to wait until a flood tide occurred to open a culvert flap gate or for the peak of a flood tide for the weir to be overtopped. Therefore, After-Construction Period-Upstream areas were compared statistically to Before- and During-Construction Periods (where there are no clear upstream and downstream areas since the barrier had not yet been installed and closed). These comparisons were executed by comparing After-Construction Period-Upstream (Category 1) observations to Before-Construction Period-Upstream (Category 1) observations combined with Before-Construction Period-Both Upstream and Downstream (Category 3) observations.

Next, After-Construction Period-Downstream areas were compared statistically to Before- and During-Construction Periods. These comparisons were executed by comparing After-Construction Period-Downstream (Category 2) observations to Before-Construction Period Downstream (Category 2) observations combined with Before-Construction Period-Both Upstream and Downstream Elements (Category 3) observations.

In some cases, no After-Construction Period observations were recorded and only Before- and During-Construction Period were collected, e.g., at the GLCB in 2011. In these cases, similar comparisons were conducted but the During-Construction Period observations replaced the After-Construction Period observations. These comparisons are clearly marked by headings in Chapter 3 Results.

A hypothesis test of $H1_0$ was undertaken for every barrier/barrier area combination. The observation sets for a combination were evaluated to determine if the data met the assumptions of analysis of variance (ANOVA): distribution normality, homogeneity of variance, and independence of observations. The assumption of normality was tested by the Shapiro-Wilk test (Shapiro and Wilk 1965). The homogeneity of variance assumption was tested via Bartlett's test (Bartlett 1937 as described in Zar [1996]). The independence of observations was validated by inspection of the methods and results for a given comparison. If the data met the assumptions of ANOVA then a one-way, Model I ANOVA (*sensu* Sokal and Rohlf 1995) was conducted and then an *a priori* comparison of means was also conducted, for example, $\bar{x}_1$(TIV Before-Construction Period) compared to $\bar{x}_2$(TIV After-Construction Period).

If the data failed to meet the assumptions of ANOVA, nonparametric techniques were employed. A Kruskal-Wallis test (Sokal and Rohlf 1995), also known as the one-way ANOVA on ranks, was conducted on the observation sets. For ANOVA and Kruskal-Wallis tests, the test statistic F or chi-squared, respectively, was determined and reported along with the probability of obtaining that test statistic or one more extreme (P-value). Traditional hypothesis testing techniques were employed to resolve the null hypothesis. If the P-value was smaller than the critical value, generally $\alpha' = 0.05$ was used, the null hypothesis was rejected.

For each species/year/barrier/construction period combination (e.g., juvenile Chinook Salmon/2010/ORTB/Before-Construction Period), the following hypothesis was tested:

- $H2_0$: Predatory fish TIV is equal to juvenile salmonid TIV.

An example of one of these comparisons used juvenile steelhead TIV at the MRB in 2011. The TIV observations of each piscine predator species that were made in the Category 1 (Upstream) and Category 3 (Both Upstream and Downstream) areas combined were compared to the same barrier areas for juvenile steelhead TIV observations.

Similar hypothesis testing procedures were executed following the methods described previously for salmonid TIV hypothesis testing of $H1_0$.

The TIV that each salmonid spent at a single hydrophone detection site was calculated by the difference between the last detection and the first detection of a series of continuous detections received by that hydrophone. Gaps in detections up to less than or equal to (≤) 15 minutes long were allowed in a series of continuous detections, but gaps > 15 minutes were not included in the TIV total.

For barrier site upstream and downstream hydrophones, it was possible that tags could be detected by both hydrophones at the same time (depending on the barrier construction phase, water level, and barrier operation). If a tag was detected simultaneously on both upstream and downstream hydrophones at a given site, the duration of simultaneous detections was divided in half and apportioned equally to the TIV for each hydrophone.

For TIV of 2D track data at ORTB, the calculations were the same, except 2D positions were used, rather than individual hydrophone detections. It was not possible for 2D positions to appear on both sides of a barrier at once because the 2D hydrophone arrays were deployed only after the ORTB had been installed.

2.20.2 Old River at Tracy Barrier Combined 1D and 2D Data Sets

The comparison of juvenile salmonid TIV observations upstream of the TIV was conducted first, if possible. Each group to be tested had to contain three or more tagged salmonids for the comparison to be considered valid. The 2D TIV upstream-of-the-ORTB observations were concatenated into a combined TIV data set with the 1D TIV observations for the ORTB. This combined TIV data set was used to test hypothesis $H1_0$ at the ORTB-Upstream area (Category 1). Next, ORTB-Downstream area (Category 2) observations were counted to determine if sufficient sample size existed for the downstream area to test hypothesis $H1_0$ using the methodology described in Section 2.20.1 *Hypothesis Testing*. The 2D TIV downstream observations were concatenated into a combined TIV data set for the ORTB. This combined TIV data set was used to test hypothesis $H1_0$ at the ORTB-Downstream area (Category 2).

The 2D TIV observations provided improved power to resolve the $H1_0$ hypothesis at the ORTB due to increased sample size. It was not possible to produce a combined TIV data set (1D and 2D data) at the MRB or the GLCB because no 2D array was installed at those barriers.

2.21 SUCCESSFUL PASSAGE AND ROUTE SELECTION THROUGH THE OLD RIVER AT TRACY BARRIER

The proportion of juvenile salmonids successfully passing the ORTB was tested based on the following hypothesis:

- $H3_0$: The ratio of juvenile salmonids successfully passing to salmonids not successfully passing the ORTB was equivalent to the ratio of Predicted ORTB Survival Rate:(1 - Predicted ORTB Survival Rate).

Predicted ORTB Survival Rate was determined by the following equation:

$$S_P = S_{pk}^{L}$$

where:

- S_P = Predicted ORTB Survival Rate in the vicinity of the Old River at Tracy Barrier;
- S_{pk} = Survival per kilometer; and
- L = Length (km) of the ORTB hydrophone array.

S_{pk} was obtained by determining the n^{th} root of $\hat{S}$, for a given species and year, where n is the distance (km) from ORS to the closest survival end point, CVP (ORS and CVP [defined in **Table 2-16**]), and that distance was 18.14 km (11.27 mi). The use of the release point distance to CVP produced the smallest S_{pk} of the four possible S_{pk}s from the four possible endpoints (i.e., CVP, RGU, ORN, and MRN). Thus, the S_{pk}, derived from the distance to CVP, was the smallest and therefore was conservative—survival per km had to be that value or greater.

The parameter value of L was obtained by determining the linear distance from the hydrophone array start line to the hydrophone array finish line. The hydrophone array start line was defined as the line between the two most easterly (upstream) hydrophones in the ORTB 2D hydrophone array: 1) yellow and green filled circles in **Figure 2-7** for 2010; and 2) yellow and green filled circles in **Figure 2-12** for 2011. The hydrophone array finish line was defined as the line between the two most westerly (downstream) hydrophones in the ORTB 2D hydrophone array: 1) light blue and dark magenta filled circles in **Figure 2-7** for 2010; and 2) light blue and dark magenta filled circles in **Figure 2-12** for 2011.

S_P was calculated for each species and year. Then, the complement Predicted ORTB Survival Rate, $(1-S_P)$ for that species and year was obtained. Next, the expected ratio was constructed for the proportion successfully passing to the proportion not successfully passing the ORTB: $S_P:(1-S_P)$.

The assumption is that percentage of fish executing successful passage is equivalent to the probability of surviving a short reach of the Old River channel when there was no barrier in place. This assumption is valid if three conditions are met:

1) Detection probability was high. This condition was met because of the simple geometry of the channel in the area. Estimates of detection probability at ORTB hydrophones ranged from 96.97 to 100 percent for Chinook Salmon and steelhead in 2010 and 2011;

2) Time spent in the array presented a minimal probability of tag failure while tags were within the array. This condition was met because these tags were designed to last sufficiently long for migrating salmonids to transit from their release points (**Figures 2-5** and **2-11**) in the south Delta to Chipps Island in the far west Delta. In 2010, 82 percent of tags remained active on the 20th day after activation (SJRGA 2011) and in 2011, mean time to tag failure was 28 days (SJRGA 2013). Therefore, for 2010 and 2011 there was a minimal probability of tag failure while the tags were in the ORTB 2D array in the south Delta; and

3) Detected tags within the array are representative of juvenile salmonids and not predatory fish. This was met for Chinook Salmon and steelhead in 2011 when the predator filter removed from survival modeling all those tags that met the criteria for "predator" described in Section 2.18 *2011 Predator Filter Methods*. All tags used for survival modeling had been categorized "salmonid" by the predator filter. This condition, and whether it was met for steelhead in 2010, could not be evaluated due to steelhead behavior

in 2010 that was dissimilar to that of Chinook Salmon (see Section 4.1.5.3 *2010 Juvenile Steelhead*) and often similar to that of predators (see Section 4.1.2 *2010 Juvenile Steelhead*).

The comparison was made via a chi-square goodness-of-fit test (Sokal and Rohlf 1995). The extrinsic hypothesis described in the preceding paragraphs was that the ratio would be S_P:(1-S_P). The Kruskal-Wallis chi-squared statistic was calculated and reported. Then, the resulting probability of achieving that chi-squared value or one more extreme (P-value) was reported. If the P-value was smaller than the critical α', typically 0.05, the null hypothesis was rejected.

This comparison was made for each salmonid species separately because it was known that juvenile Chinook Salmon and juvenile steelhead behaved differently in the vicinity of rock barriers in the south Delta (DWR 2015a). This comparison was carried out for each year, 2010 and 2011, for which sufficient data were obtained.

After 2D positioning, the position echo (*PosEchoes* in HTI's *Acoustic Tag* software) tables were extracted from the tag databases to create a tabular text file for import into the *Eonfusion* program (V2.4 Echoview® Software Proprietary Limited, Tasmania, Australia). Tag data were combined with environmental covariate data and further explored to illustrate the interrelatedness of data sets.

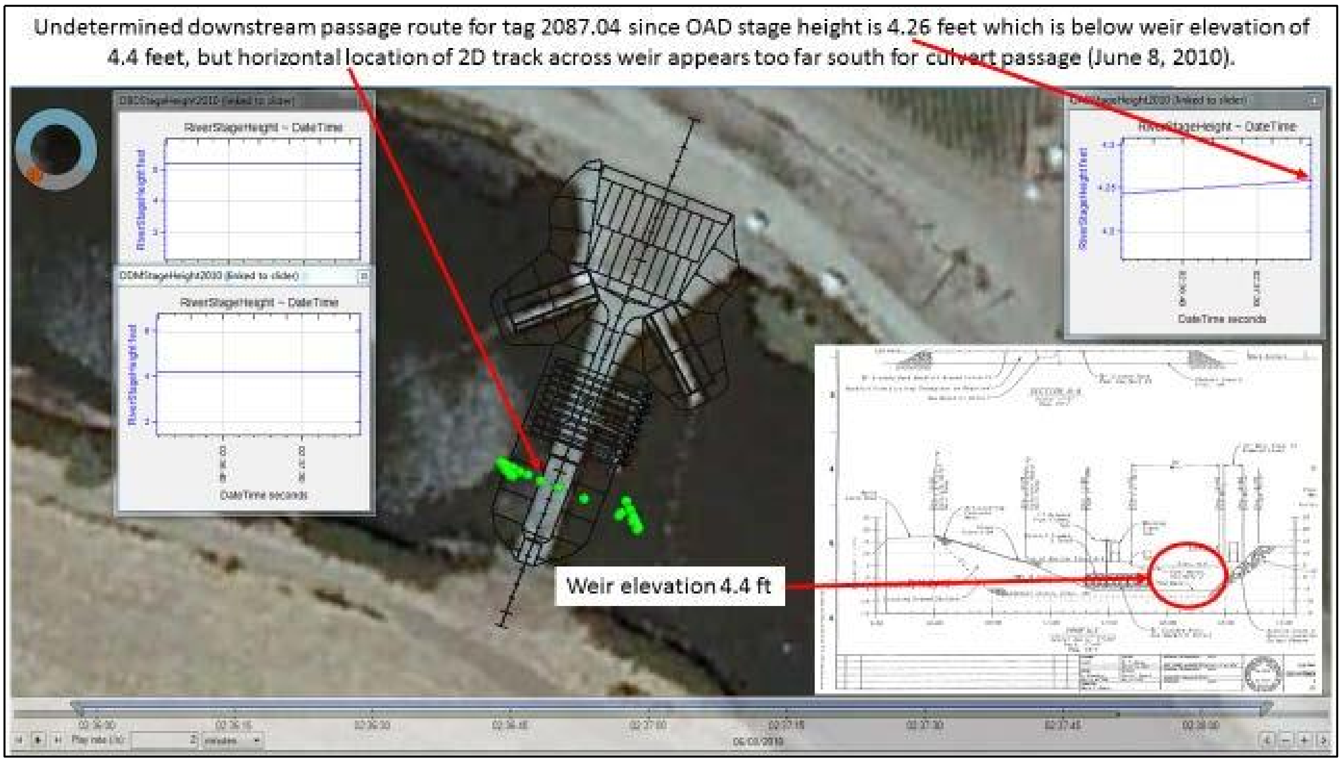
To determine passage routes, each 2D track was viewed independently in *Eonfusion* and the time at which the tag crossed the barrier was recorded. This time was used to obtain the river stage height, to the nearest 15-minute interval, for OAD (CDEC station upstream of the ORTB identified as "Old River Near DMC [Delta-Mendota Canal] Above [upstream of] Dam") and OBD (CDEC station downstream of the ORTB identified as "Old River Near DMC Below [downstream of] Dam"). The synchronization of the 2D tracks, river stage heights, and computer-aided design (CAD) drawing of the ORTB structures (culverts and weir) overlaid on the 2010 or 2011 (for corresponding year of 2D track) ortho-image aided in the determination of passage routes. When the river stage was greater than the designed weir crest elevation, 1.3 m (4.4 ft), and the tag passed on the weir side (river left), the tag was classified crossing over the weir. When the river stage was < 2.0 m (< 6.5 ft) and a tag crossed the barrier on the culvert side, the tag was classified as passing through the culvert. When the river stage was > 2.0 m (> 6.5 ft) and the tag crossed the barrier on the culvert side, or if a tag crossed the barrier in the vicinity of the weir, where the culvert passes underneath the rocks of the weir, and the river stage height did not provide conclusive evidence as to whether the tag passed through the culvert or over the weir, the passage was noted as "passed barrier, route undetermined." If the river stage height was lower than the designed weir crest elevation but the tag appeared to cross over the weir the passage was classified as "passed barrier, route undetermined" (**Figure 2-16**).

2.22 DEFECATED AND REGURGITATED TAGS

To determine tag regurgitation/defecation by predatory fish, each 2D track was viewed independently in *Eonfusion* and the time at which the tag appeared in the same location for an extended time period was recorded. Using this time as a starting point, the raw detection data were reviewed in HTI's *MarkTags* software program. Upon verifying a flat line detection signal pattern (Schultz et al. 2015), the defecated tag's 2D location was recorded in *Eonfusion*.

All tags regurgitated /defecated in the area of the ORTB were determined for 2010 and 2011. For each defecated/regurgitated tag, the 2D track and detection history were evaluated to determine if the tag had been consumed on the upstream or downstream side of the barrier, or if the location of the consumption could not be identified. All defecated/regurgitated tags were plotted on a base photo of the ORTB area with an overlay of the ORTB on the base photo.

If there was no ORTB installed, then it was assumed the probability of being defecated/regurgitated on the upstream and downstream side of the ORTB footprint would be equal, 0.5:0.5. Using the total number of defecated/regurgitated tags, the cumulative binomial probability of the number of tags defecated/regurgitated on the upstream side of the ORTB was calculated. If the cumulative binomial probability was < 0.05 then it was concluded that there was not an equal probability of a tag being defecated/regurgitated on the upstream and downstream side of the ORTB.



Source: HTI this study.

Figure 2-16. Example of Undetermined Fish Passage Route with 2D Track Synchronized with River Stage Heights, 2010 Ortho-Image and CAD Drawing of Old River at Tracy Barrier

2.23 MIXTURE MODEL

Two-dimensional telemetry tracks encompassing the entire detection history of juvenile Chinook Salmon, juvenile steelhead, Striped Bass, and Largemouth Bass were used in this analysis. Tracks were broken into discrete track segments if the time between successive detections was > 30 minutes. Each track segment was analyzed separately. In other words, if a tag moved through the array out of the study area and then returned after > 30 minutes, each of those periods were treated as separate track segments. This resulted in some tracks consisting of multiple-track segments. Tracks with fewer than 60 2D positions were omitted from the analyses. The ping rates of tags varied from two to four seconds. Therefore, track segments were discretized at a time step of eight seconds using the *adehabitatLT* package in R (R Development Core Team 2011) to normalize telemetry data and avoid potential bias in track statistics that might arise due to different ping rates between tags (Laube and Purves 2011). Discretizing uses linear interpolation to estimate a tag's location based on the measured locations occurring prior to and after the 'missing' location. Track segments that had an average speed of < 0.0009 meters per second (m/s) (< 0.0030 feet per second [ft/s]) over the span of four days were also removed from the analyses because these were motionless tags that were likely defecated by predatory fish or were post-release salmonid mortalities.

Two statistics were estimated for each track segment for each fish, tortuosity (τ) and the Lévy exponent (b). Tortuosity (τ) was calculated as a function of the turning angle (θ):

$$\tau = \sqrt{\bar{x}^2 + \bar{y}^2}$$

where:

- $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} \cos\ (\theta_i)$

and:

- $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} \sin\ (\theta_i)$

Here n is the number of relocations and the turning angle (θ) is the change in direction between three successive relocations. A track with tortuosity close to one (1) is considered linear whereas a track with tortuosity near 0.5 is more tortuous or complex.

In Lévy walks,[14] the relation between step length (l) and the frequency of occurrence of a step length follows a power function, $f(l) = al^{-b}$, where a is an intercept parameter and b is the Lévy exponent. Lévy exponents were estimated using the logarithmic binning method following Sims et al. (2007). The Lévy exponent was estimated from the slope of the linear regression between log-transformed geometric bin widths and log-transformed bin frequencies of step lengths. A step length is the distance between two successive locations and the frequency is the number of occurrences of each step length.

After track statistics were estimated for tagged juvenile salmonid and predatory fish, finite mixture models were fitted to the distributions of track statistics using the *mixtools* package for R (Benaglia et al. 2009). Finite mixture models are a form of model-based clustering, which uses the expectation maximization algorithm to maximize the likelihood function and estimate parameters of mixed distributions for observations with unknown group membership. In this study, the bivariate distribution of track statistics (the tortuosity τ and the Lévy exponent b) was formed from a mixture of two underlying bivariate normal distributions—one for predatory fish and one for juvenile salmonids. The goal was to use the finite mixture model to estimate the parameters of each assumed Gaussian component of the distribution which then allowed an estimate of the probability that a track segment came from a predatory fish or juvenile salmonid from the posterior probability distribution.

A mixture model was used and it was assumed that the distribution was a mixture of two bivariate normal distributions, each with an associated mean (μ) and standard deviation (σ). Thus, the mixture model estimated the parameters of a normal distribution for salmonid- and predator-specific tortuosity and the Lévy exponents, resulting in eight parameters: $\mu_{S,b}$; $\sigma_{S,b}$; $\mu_{P,b}$; $\sigma_{P,b}$; $\mu_{S,\tau}$; $\sigma_{S,\tau}$; $\mu_{P,\tau}$; and $\sigma_{P,\tau}$. Here, $\mu_{j,k}$ and $\sigma_{j,k}$ are the mean and standard deviation of a normal distribution for population j (for the predator [P] or salmonid [S]) and for track

[14] A Lévy flight, named for French mathematician Paul Lévy, is a random walk in which the step-lengths have a probability distribution that is heavy-tailed. When defined as a walk in a space of dimension greater than one, the steps made are in isotropic random directions.

statistic k (the Lévy exponent b or tortuosity τ). In addition, the model also estimates λ_P, the proportion of track segments that are from predators ($1 - \lambda_P = \lambda_S$ is the proportion of track segments that are from salmonids). To classify track segments as from a predatory fish or salmonid, the estimated parameters were used along with the observed track statistics of each track segment to estimate p_{ik}, the probability that track segment (i) could have been produced by a salmonid (k = S) or predator (k = P). Track segments were then classified as from a predatory fish if $p_{i,P} > p_{i,S}$ or from a salmonid if $p_{i,P} \leq p_{i,S}$. The standard errors for the parameter estimates were estimated from 500 parametric bootstrap runs. Each bootstrap sample was randomly drawn from the distributions described by the maximum likelihood estimates. The model was then then fitted to each bootstrap sample. This was repeated 500 times to generate estimates of the standard error for the parameter estimates (Benaglia et al. 2009). This algorithm was implemented using the *boot.se* function in the *mixtools* package for R. The methods were validated via the correct classification of predator tracks from known tagged predators (**Table 2-9** 2009 Predatory Fish Tag Data Summary; **Table 2-10** 2010 Predatory Fish Tag Data Summary; and **Table 2-13** 2011 Predatory Fish Tag Data Summary). For known tagged predatory fish, the percentage of segments that were correctly identified as from predators was calculated. However, the study was unable to validate the classification for tagged salmonids since it was impossible to recapture tagged salmonids to verify their status.

2.24 DIDSON METHODOLOGY

The duel-frequency identification sonar (DIDSON) is a multibeam unit employing up to 96 beams (when run in high-frequency mode) with an angle of 30-degree in the horizontal dimension and 15-degrees in the vertical dimension, producing an approximate 30-degree by 15-degree beam.

When deployed on mobile boat surveys the sonar head was mounted approximately one meter below the survey vessel and typically viewed perpendicular to the current (channel) although the angle varied throughout and between surveys. The vertical orientation of the DIDSON varied from site to site. Sonar heading, roll, and pitch were not recorded.

Processing of DIDSON data using DIDSON software (DIDSON *Control and Display*, V5.25.41, SoundMetrics, Bellevue, Washington) includes the following series of steps, resulting in a final output of positively identified fish targets: 1) examine the raw data; identify all fish targets > 30 cm TL (> 11.8 in TL); 2) identify targets > 30 cm TL that are Common Carp (*Cyprinus carpio*) or sturgeon (*Acipenser* spp.); 3) submit target lists to second biologist/analyst; 4) perform quality assurance on all identified fish targets; and 5) create spreadsheet summaries of: a) all targets; and b) predator targets through removal of Common Carp and sturgeon targets from the tallies.

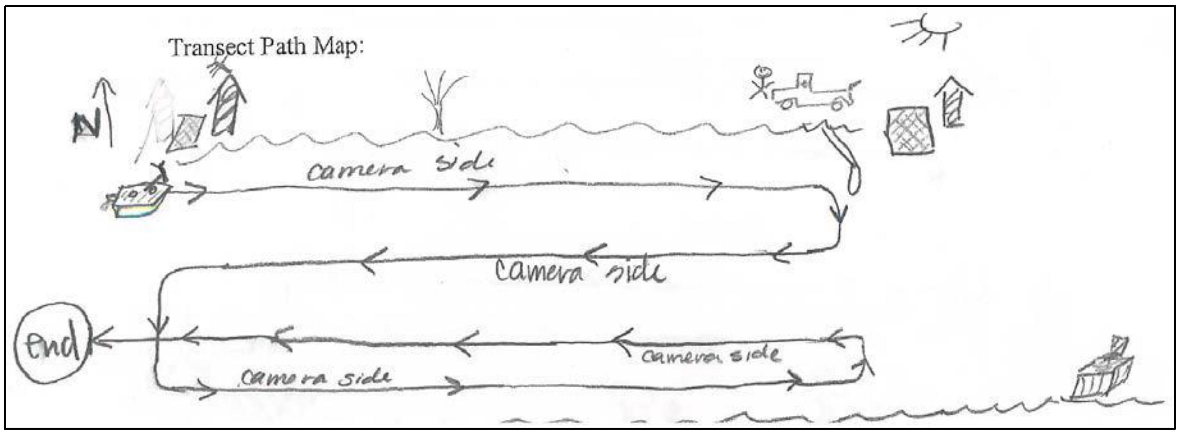
Examining the raw data allowed the analyst to determine conditions associated with each data file (e.g., barrier construction status), special circumstances, and where potential processing problems might arise. Some data files had to be deleted from analysis because the DIDSON sonar was not aimed correctly.

All potential targets were reviewed. During this phase it was necessary to detect targets and to filter targets according to fish profile, length criteria, swimming behavior, swimming angle, acceleration or movement that distinguished the target from passive particles, schooling behavior, and pixel intensity. Utilizing these characteristics, shadows and debris were removed from consideration. A subset of all targets (25 percent) were reviewed to certify that fish targets were not removed inappropriately.

Next all fish targets > 30 cm TL (> 11.8 in TL) were submitted to a second biologist/analyst. Each fish target > 30 cm TL was identified as Common Carp, sturgeon, or predatory fish. Tallies were made of all fish targets and of predator-only targets by removing the Common Carp and sturgeon targets.

2.24.1 Transect and Pan Data Collection

The DIDSON sonar was deployed from a boat at different times before, during, and after the installation of the SDABs. Repeatable transects were conducted to collect DIDSON imagery of the area around the barriers. Mobile DIDSON surveys were generally performed once per week with each survey lasting up to approximately 10 minutes at each of the barriers. During data collection a hand sketch was made of the transect size and shape with reference to fixed objects on the bank or in the channel (**Figure 2-17**). The sketch was used to digitize the transect on a georeferenced photograph: **Figure 2-18** shows a DIDSON monitoring transect at the ORTB installation location digitized in Google Earth Pro during the Before-Construction Period made from the sketch in **Figure 2-17**. **Figure 2-19** shows an example of a DIDSON monitoring transect at the ORTB installation location digitized in Google Earth Pro during the After-Construction Period.



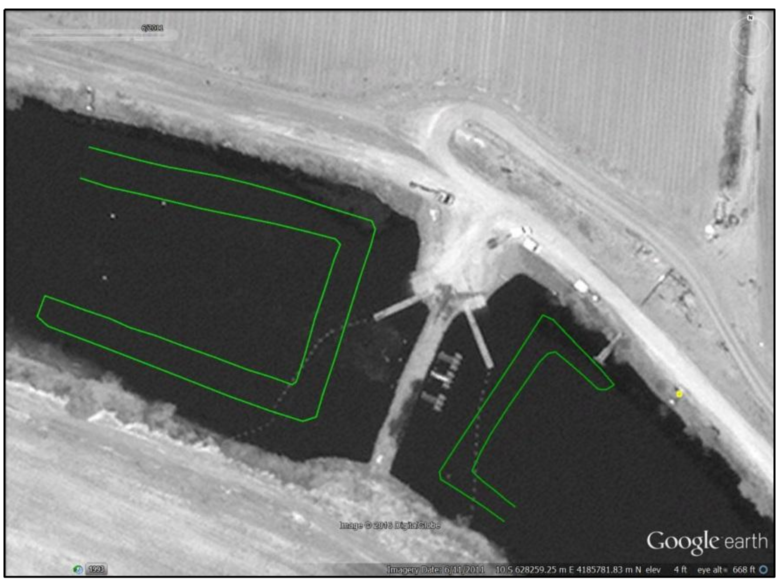
Source: DWR this study.
Note the wooden walkway sketch near the end of Limb 1 and USGS gaging stations near the start and end of the Limb 1 (cylindrical shapes with conical tops).

Figure 2-17. Example of a DIDSON Data Sheet Transect Sketch Obtained on May 12, 2011 at the Old River at Tracy Barrier Installation Site

After-Construction Period observations were occasionally obtained by submersing the DIDSON imaging head in a fixed position and then panning instead of transiting a transect. In these cases “Pan” was recorded and the method of volume determination was slightly different. All other methods described herein were the same.

Source: Google Earth Pro and Environmental Science Associates this study. “ORTB installation location.” 628273.43 m East and 4185764.79 m North. Photo: March 4, 2011. Accessed: August 25, 2016. Note the wooden walkway near the end of Limb 1 and USGS gaging stations near the start and end of the Limb 1 (bright silver dots).

Figure 2-18. The Digitized Transect on a Georeferenced Photograph Prepared for a Before-Construction Period at the Old River at Tracy Barrier Installation Location from a Freehand Sketch



Source: Google Earth Pro and ESA this study. “ORTB installation location.” 628273.43 m East and 4185764.79 m North. Photo: June 11, 2011. Accessed: August 25, 2016. Note the USGS gaging stations near the start of the Limb 1 on the downstream side (bright silver dot). One transect was completed on the upstream side of the ORTB (lower right of image) and one on the downstream side of the ORTB (center left of image).

Figure 2-19. The Digitized Transects on a Georeferenced Photograph Prepared for an After-Construction Period at the Old River at Tracy Barrier Installation Location (Water Flows Right to Left) from Freehand Sketches

2.24.1.1 *Total Large Target (> 30 cm TL) Fish Density*

Data were analyzed using two different methods, depending on the data collection technique, transect or panning. Volume of habitat surveyed was then calculated by: 1) the transect method (see Section 2.24.1.2: *Method 1: Transect Method*); or 2) the panning method (see Section 2.24.1.2 *Method 2: Panning Method*). The total numbers of fish targets (> 30 cm TL [> 11.8 in TL]) detected were calculated for each transect or panning file. Fish counts were then divided by the water volume to determine relative fish densities. These data were then standardized and reported as number of all targets (> 30 cm TL) per 1,000 cubic meters (per 35,315 cubic feet). Separate notations were made for barrier site and barrier construction status for each transect survey in order to conduct comparative analyses for the different sites and barrier construction periods.

2.24.1.2 *Calculation of Volume Ensonified by DIDSON*

Calculation of water volume ensonfified through DIDSON sampling was required in order to normalize fish target data to a unit of volume. Two methods, one for transect and one for panning, were used to calculate volume ensonified by DIDSON sampling.

Method 1: Transect Method

As stated previously, the DIDSON sonar lens has a horizontal field of view of approximately 30 degrees and a vertical field of view of approximately 15 degrees. The volume ensonified by each DIDSON imaging pass was carried out by modifying the approach of Bronshtein et al. (2007). First, the precursor values of coverage are determined for the volume of a truncated rectangular pyramid (frustum of a pyramid):

The horizontal coverage at R_{end} is:

$$a = R_{end} * \sin(FOV°) = R_{end} * \sin(\sim30°) \sim= R/2$$

The vertical coverage at range R_{end} is similarly:

$$b = R_{end} * \sin(FOV°) = R_{end} * \sin(\sim15°) \sim= R/4$$

The horizontal coverage at R_{start} is:

$$c = R_{start} * \sin(FOV°) = R_{start} * \sin(\sim30°) \sim= R/2$$

The vertical coverage at range R_{start} is similarly:

$$d = R_{start} * \sin(FOV°) = R_{start} * \sin(\sim15°) \sim= R/4$$

where:

- R_{end} = terminal window length in a search volume (e.g., 10.5 m [34.4 ft] in **Figure 2-21**);
- FOV^{O} = field of view in degrees; and
- R_{start} = start of window length in a search volume (e.g., 1.5 m [4.9 ft] in **Figure 2-21**).

Parameters a and b are defined using the end range for R and c and d are defined using the start range for R.

Then, the volume for a truncated rectangular pyramid (frustum of a pyramid) Bronshtein et al. (2007) is:

$$V = 1/6 * h * (a * b + (a + c) * (b + d) + c * d)$$

where:

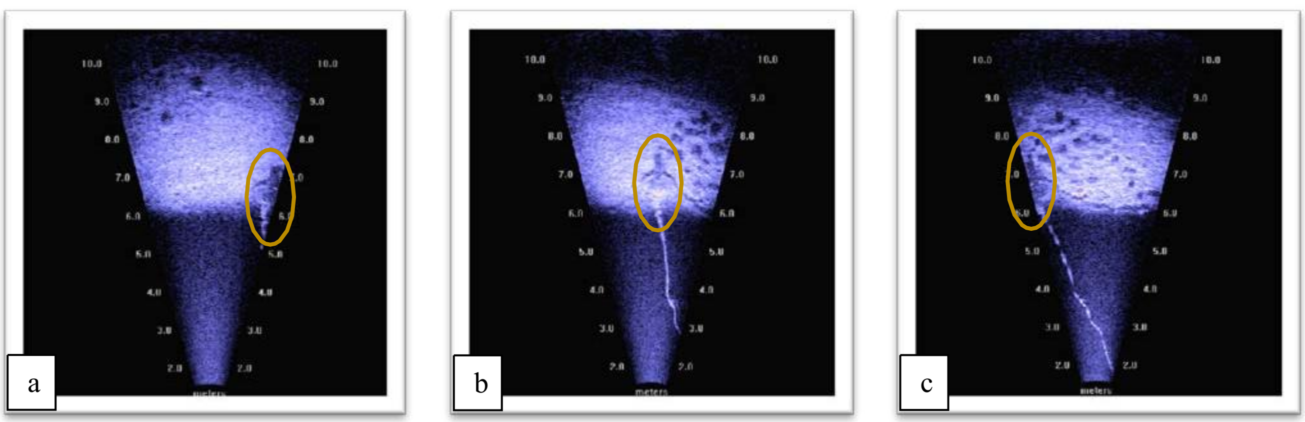
- $h = R_{end} - R_{start}$.

In certain cases, the DIDSON imaging head was not oriented into open water, had a negative tilt angle, and the image intersected the river bed. In these cases, the calculated volume of the frustum was reduced by subtracting the volume of the prism that lay beneath the substrate's surface because the DIDSON's high-frequency sound impulses do not penetrate the substrate.

Next, the volume ensonified by the beam was then multiplied by the distance surveyed for any one transect to determine the total volume ensonified for the particular transect. Distance surveyed was derived from digitized transects in paths drawn in Google Earth Pro (e.g., see examples in **Figures 2-18** and **2-19**).

Method 2: Panning Method

The number of pyramid frustums that had been executed in a single pan were obtained by inspection of the DIDSON image file from beginning to end. First, in the initial image an object was identified on screen (see ellipse indicating anchor in **Figure 2-20a**). That object was then tracked across the viewscreen (**Figure 2-20b**). When that image exited the viewscreen during the pan (**Figure 20c**), it was recorded as one frustum. The number of frustums was calculated for the entire pan in a DIDSON imaging file.



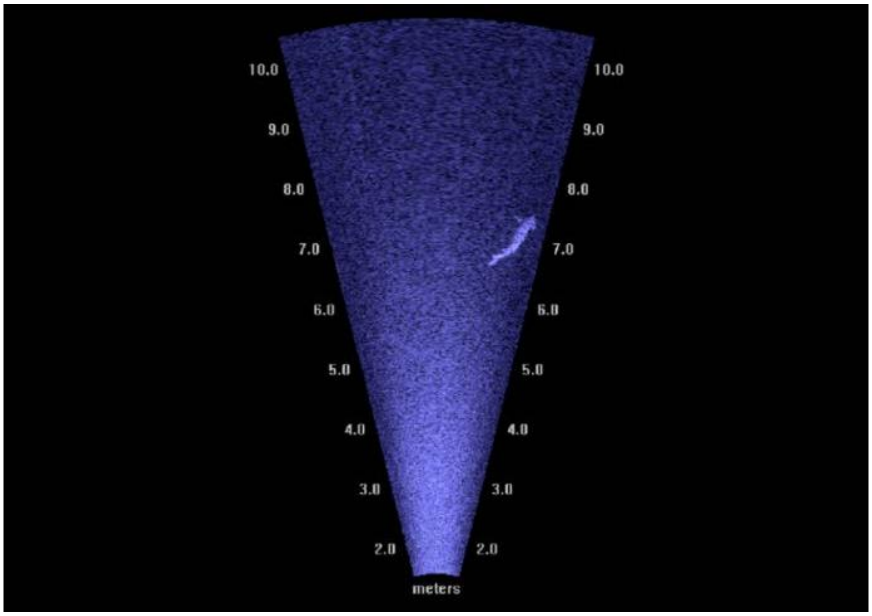
Source: ESA this study.

Figure 2-20. Example Imaging of the Pan Method

The initial estimate from the Pan Method was then trimmed to exclude that volume beneath the substrate because it could not be queried by the DIDSON imaging method. Thus, similar to the Transect Method, in certain cases the DIDSON imaging head was not oriented into open water, had a negative tilt angle, and the image intersected the river bed (e.g., **Figures 2-20a**, **b**, and **c**). So, for every frustum identified in the pan, the calculated volume of the frustum was reduced by subtracting the volume of the prism that lay beneath the substrate's surface for that frustum. Then, the volume ensonified by all of these frustums was summed to get the total volume interrogated for each individual DIDSON imaging file. This method was repeated for all DIDSON imaging files that used panning.

2.24.1.3 *Predator Density Determination*

Targets that were identified as Common Carp or sturgeon (e.g., **Figure 2-21**) were removed from the counts. Once Common Carp and sturgeon observations were removed from the target only "predatoy fish" target density remained. These densities were standardized and reported as predatory fish per 1000 cubic meters (predatory fish per 1,000 cubic feet).



Source: ESA this study.

Note: This individual's total length was estimated to be greater than 1.0 m (3.3 ft).

Figure 2-21. Sturgeon Image Obtained via DIDSON Imaging During the Execution of Transect Data Collection

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3 RESULTS

3.1 WATER TEMPERATURE

3.1.1 2010 Water Temperature

In 2010 at DWR Station OLD (http://cdec.water.ca.gov/queryTools.html), daily water temperature extremes ranged from 13.2 to 24.5°C (55.8–76.1°F) in the Before-Construction Period for the GLCB (**Table 3-1**). Daily water temperature extremes warmed considerably through the spring and ranged in the During-Construction Period from 18.2 to 26.7°C (64.8–80.1°F). The daily water temperature was on average 4.5°C (8.1°F) warmer in the During-Construction Period compared to the Before-Construction Period.

The water temperature records were evaluated in a similar way but for the specific dates of ORTB construction. In 2010 at DWR Station OLD (http://cdec.water.ca.gov/queryTools.html), daily water temperature extremes ranged from 13.2 to 19.2°C (55.8–66.6°F) in the Before-Construction Period for the ORTB (**Table 3-1**). South Delta water temperatures warmed considerably through the spring and daily extremes ranged in the After-Construction Period from 18.2 to 26.7°C (64.8–80.1°F). The daily water temperature was on average about 5.3°C (9.5°F) warmer in the After-Construction Period compared to the Before-Construction Period.

Table 3-1. 2010 Water Temperature Statistics at Old River Department of Water Resources Station "OLD" for the Before- and After-Construction Periods of the Grant Line Canal Barrier and Old River at Tracy Barrier

Construction Period	Start Date	End Date	Minimum Water Temperature (°C)	Mean and (Standard Deviation) in Water Temperature (°C)	Maximum Water Temperature (°C)	Sample Increment (minutes)
GLCB						
Before	April 1	June 15	13.2	17.7 (2.2)	24.5	15
During	June 16	July 7	18.2	22.2 (1.7)	26.7	15
ORTB						
Before	April 1	May 9	13.2	16.6 (1.4)	19.2	15
After	June 4	July 7	18.2	21.9 (1.6)	26.7	15

Source: CDEC (2016c) as summarized by ESA this study.

3.1.2 2011 Water Temperature

In 2011 at DWR Station OLD (http://cdec.water.ca.gov/queryTools.html), daily water temperatures extremes ranged from 10.5 to 19.9°C (50.9–67.8°F) in the Before-Construction Period for the GLCB (**Table 3-2**) and from 17.1 to 25.1°C (62.8–77.2°F) in the During-Construction Period. Similar to 2010, south Delta water temperatures warmed considerably through the spring and were on a daily average about 4.9°C (8.8°F) warmer in the During-Construction compared to the Before-Construction Period. However, 2011 mean daily water temperature was 0.8°C (1.4°F) cooler in the Before-Construction Period when compared to 2010. This occurred even though the Before-Construction Period continued on for three weeks later in 2011 compared to 2010. Furthermore, mean daily water temperatures in 2011 were 0.3°C (0.5°F) cooler on average in the During-Construction Period even though the During-Construction Period continued one week later in 2011 than in 2010.

The water temperature records were evaluated in a similar way but for the specific dates of ORTB construction. In 2011 at DWR Station OLD (http://cdec.water.ca.gov/queryTools.html), mean daily water temperatures extremes ranged from 10.5 to 19.9°C (50.9–67.8°F) in the Before-Construction Period for the ORTB (**Table 3-2**) and from 14.9 to 25.1°C (58.8–77.2°F) in the After-Construction Period. Similar to 2010, south Delta water temperatures warmed considerably through the spring and they were on a daily average about 4.2°C (7.6°F) warmer in the After-Construction Periods compared to the Before-Construction Period. However, 2011 mean daily water temperature was 1°C (1.8°F) cooler in the Before-Construction Period when compared to 2010. This occurred even though the Before-Construction Period continued on for more than two weeks later in 2011 compared to 2010. Furthermore, mean daily water temperatures in 2011 were 2.1°C (3.8°F) cooler on average in the After-Construction Period compared to 2010. Similarly, the After-Construction Period continued one week later in 2011 than in 2010.

Table 3-2. 2011 Water Temperature Statistics at Old River at Department of Water Resources Station "OLD" for the Before- and After-Construction Periods of the Grant Line Canal Barrier and Old River at Tracy Barrier

Construction Period	Start Date	End Date	Minimum Water Temperature (°C)	Mean and (Standard Deviation) Water Temperature (°C)	Maximum Temperature (°C)	Sample Increment (minutes)
GLCB						
Before	March 22	June 9	10.5	15.8 (1.8)	19.9	15
During	June 1	July 14	17.1	20.7 (1.7)	25.1	15
ORTB						
Before	March 22	May 26	10.5	15.6 (1.8)	19.9	15
After	June 11	July 14	14.9	19.8 (2.3)	25.1	15

Source: CDEC (2016c) as summarized by ESA this study.

3.2 FLOW DISTRIBUTION THROUGH THE STUDY AREA

3.2.1 2010 Flow Distribution

The discharges in Old River at DSM2 Model hydraulic node ORS in **Figure 2-4** were remarkably consistent in the spring/early summer of 2010. Mean flow rates during these periods ranged from 57.8 to 64.5 cms (2,040–2,277 cfs) (**Table 3-3**). These flow rates comprised 93.8–94.9 percent of the flow that traveled west from the HOR. So, the proportion of flow conveyed by Middle River (at hydraulic node MRS) was also consistent: 5.1–6.2 percent of the total flow that entered Middle River from Old River.

Table 3-3. 2010 Distribution of Flow into Old and Middle Rivers at DSM2 Model Hydraulic Nodes ORS and MRS							
Date Range	Construction Period	Mean Old River Discharge at ORS cms (cfs)	Standard Deviation in Old River Discharge at ORS cms (cfs)	Old River Proportion of Discharge at ORS	Mean Middle River Discharge at MRS cms (cfs)	Standard Deviation in Middle River Discharge at MRS cms (cfs)	Middle River Proportion of Discharge at MRS
April 1–May 17	Before-MRB	64.5 (2,277)	15.6 (550)	0.938	4.2 (149)	1.2 (43)	0.062
May 18–May 24	During-MRB	60.1 (2,121)	10.6 (374)	0.941	3.7 (132)	1.1 (39)	0.059
May 25–July 7	After-MRB	57.8 (2,040)	13.3 (468)	0.949	3.1 (109)	1.8 (63)	0.051
April 1–July 7	All	61.2 (2,161)	14.7 (518)	0.943	3.7 (130)	1.6 (56)	0.057

Source: DWR this study.

Table 3-4. 2010 Distribution of Flow into Old River near Tracy and Grant Line Canal at DSM2 Model Hydraulic Nodes ORBS and GLCS							
Date Range	Construction Period-Barrier	Mean Old River Discharge at ORBS cms (cfs)	Standard Deviation in Old River Discharge at ORBS cms (cfs)	Old River Proportion of Discharge at ORBS	Mean Grant Line Canal Discharge at GLCS cms (cfs)	Standard Deviation in Grant Line Canal Discharge at GLCS cms (cfs)	Grant Line Canal Proportion of Discharge at GLCS
April 1–May 9	Before-ORTB	11.0 (390)	9.5 (336)	0.178	50.8 (1,795)	59.9 (2,114)	0.822
May 10–June 3	During-ORTB	10.4 (369)	9.5 (336)	0.156	50.7 (1,818)	59.4 (2,114)	0.844
June 4–July 7	After-ORTB	1.5 (52)	13.3 (486)	0.028	51.1 (1,806)	64.9 (2,293)	0.972
April 1–June 15	Before-GLCB	16.0 (566)	7.2 (253)	0.154	87.8 (3,102)	37.3 (1,316)	0.846
June 16–July 7	During-GLCB	8.4 (298)	5.0 (175)	0.098	77.4 (2,734)	39.5 (1,394)	0.902
April 1–July 7	All	8.1 (287)	11.5 (405)	0.138	50.9 (1,796)	61.2 (2,162)	0.862

Source: DWR this study.

Note: In the During-GLCB Construction Period, only periods when both ORBS and GLCS discharges were positive were used to calculate mean, SD and proportion of discharge.

The flow split in Old River downstream of ORS was not as consistent as the Old River/Middle River divergence. In the Before- and During-ORTB Construction Periods mean flow rate in Old River at hydraulic node ORBS (**Figure 2-4**) ranged from 10.4 to 11.0 cms (369–390 cfs) and this was 15.6 to 17.8 percent of the flow in Old River at ORBS and the GLCS combined (**Table 3-4**). But, in the After ORTB-Construction Period the mean flow rate in Old River at ORBS was 1.5 cms (52 cfs) and this comprised only 2.8 percent of the flow in ORBS and the GLCS combined.

3.2.2 2011 Flow Distribution

The discharge in Old River at hydraulic node ORS (**Table 3-5**) was considerably greater in the spring/early summer of 2011 than in 2010. Mean flow rates during the three construction periods ranged from 139.0 to 209.0 cms (4,910–7,380 cfs). These flow rates comprised 87.3–92.1 percent of the flow that traveled west from the

HOR (**Table 3-5**). The proportion of flow conveyed by Middle River at node MRS was generally greater in 2011 (7.9–12.7 percent) than in 2010 (6.2–6.7 percent) relative to that proportion conveyed by Old River.

The discharge in Old River at hydraulic node ORBS was not consistent in the spring/early summer of 2011. Mean flow rate during the Before-ORTB Construction Period was 65.2 cms (2,301 cfs) at ORBS and this comprised 22.5 percent of combined flow in the GLC and Old River (**Table 3-6**). The discharge fell in the During-ORTB Construction Period and so did the proportion of flow conveyed by Old River compared to the GLC. In the After-ORTB Construction Period, Old River at ORBS averaged 17.0 cms (602 cfs). These Old River flows comprised only 12.4 percent of total flow in the combined GLC and Old River channels. However, the 12.4 percent of combined flow conveyed by Old River in 2011 was substantially greater than the 2.8 percent of flow in the After-ORTB Construction Period in 2010.

Table 3-5. 2011 Distribution of Flow into Old and Middle Rivers at DSM2 Model Hydraulic Nodes ORS and MRS

Date Range	Construction Period-Barrier	Mean Old River Discharge at ORS cms (cfs)	Standard Deviation in Old River Discharge at ORS cms (cfs)	Old River Proportion of Discharge at ORS	Mean Middle River Discharge at MRS cms (cfs)	Standard Deviation in Middle River Discharge at MRS cms (cfs)	Middle River Proportion of Discharge at MRS
April 1–May 31	Before-MRB	209.0 (7,380)	44.5 (1,572)	0.873	30.4 (1,074)	14.6 (517)	0.127
June 1–June 6	During-MRB	147.5 (5,208)	7.2 (254)	0.921	12.6 (444)	1.2 (41)	0.079
June 7–July 14	After-MRB	139.0 (4,910)	14.0 (496)	0.916	12.8 (452)	1.6 (58)	0.084
April 1–July 14	All	178.1 (6,291)	48.3 (1,704)	0.888	22.5 (793)	14.0 (494)	0.112

Source: DWR this study.

Table 3-6. 2011 Distribution of Flow into Old River near Tracy and Grant Line Canal at DSM2 Model Hydraulic Nodes ORBS and GLCS

Date Range	Construction Period-Barrier	Mean Old River Discharge at ORBS cms (cfs)	Standard Deviation in Old River Discharge at ORBS cms (cfs)	Old River Proportion of Discharge at ORBS	Mean Grant Line Canal Discharge at GLCS cms (cfs)	Standard Deviation in Grant Line Canal Discharge at GLCS cms (cfs)	Grant Line Canal Proportion of Discharge at GLCS
April 1–May 26	Before-ORTB	65.2 (2,301)	31.2 (1,103)	0.225	225.5 (7,963)	87.2 (3,080)	0.775
May 27–June 10	During-ORTB	25.1 (886)	10.2 (358)	0.178	116.2 (4,104)	42.5 (1,501)	0.822
June 11–July 14	After-ORTB	17.0 (602)	5.5 (193)	0.124	120.2 (4,244)	51.1 (1,805)	0.876
March 22–June 9	Before-GLCB	57.2 (2,019)	32.5 (1,148)	0.216	207.0 (7,310)	93.8 (3,313)	0.784
June 10–July 14	During-GLCB	18.0 (636)	6.4 (226)	0.130	120.1 (4,243)	52.1 (1,840)	0.870
July 15–August 2	After-GLCB	34.3 (1,212)	3.1 (108)	0.304	78.7 (2,779)	18.7 (660)	0.696
April 1–July 21	All	43.6 (1,539)	31.7 (1,121)	0.202	172.6 (6,097)	92.3 (3,259)	0.798

Source: DWR this study.

3.3 EXPORTS: STATE WATER PROJECT AND CENTRAL VALLEY PROJECT COMBINED

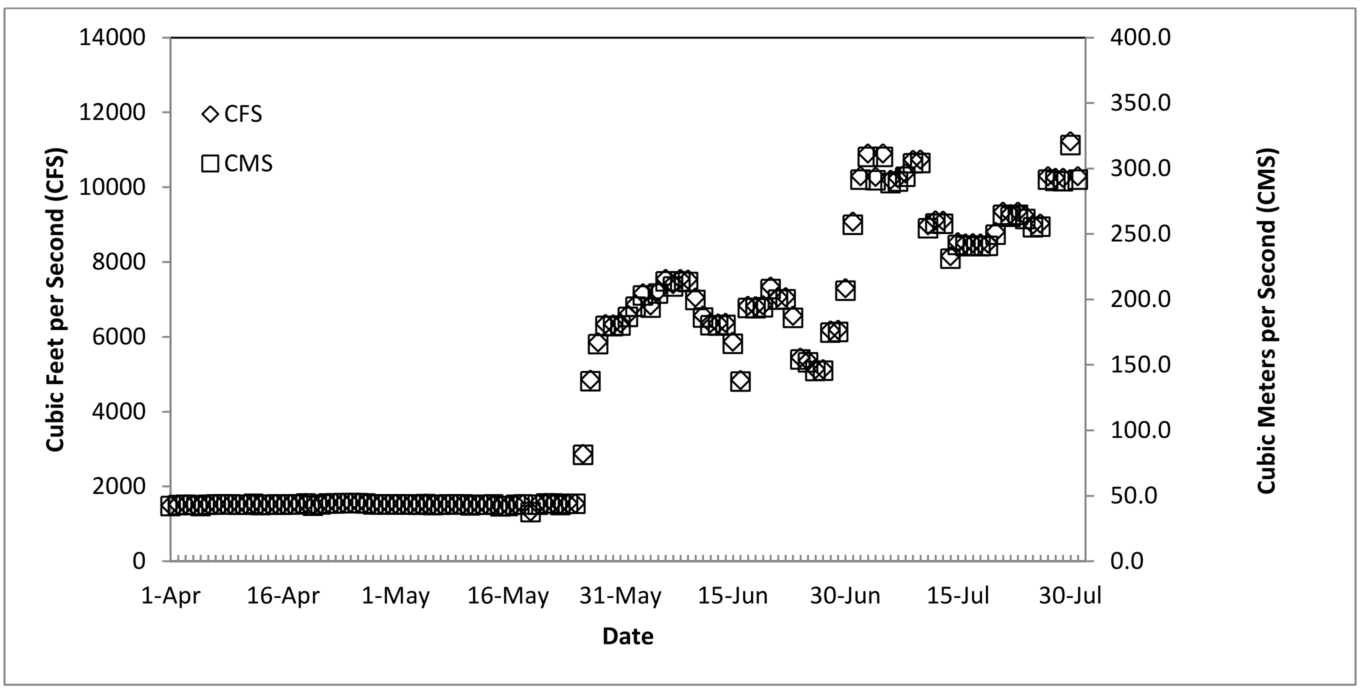
3.3.1 2010 Exports

In 2010, there were three distinct periods of export flow rates (flow rate through California Aqueduct [SWP] and Delta-Mendota Canal [CVP] combined) (**Table 3-7** and **Figure 3-1**)) during the SDAB Study period. In the first period, April 1 to May 26, the export rate was lowest—remaining lower than 48 cms (1,700 cfs) on all but one day. In the second period, May 27 to June 30, the export rate ramped up to over 170 cms (6,000 cfs). In the final period, July 1 to August 2, the export rate ramped up again and remained over 255 cms (9,000 cfs).

Table 3-7. 2010 Descriptive Statistics Describing the Combined Export Rate from the Delta through the California Aqueduct and the Delta-Mendota Canal Combined

Period	Minimum Flow cms (cfs)	Mean Flow cms (cfs)	Standard Deviation of Flow cms (cfs)	Maximum Flow cms (cfs)
April 1–May 26	39.5 (1,398)	45.9 (1,620)	5.2 (183)	83.3 (2,942)
May 27–June 30	139.2 (4,917)	185.8 (6,561)	22.1 (779)	215.7 (7,618)
July 1–August 2	233.3 (8,237)	275.8 (9,741)	25.9 (914)	325.1 (11,482)

Source: DWR this study.



Source: DWR and ESA this study.

Figure 3-1. Combined Export Rate of the Banks Pumping Plant and the Jones Pumping Plant During the 2010 Study Period

3.3.2 2011 Exports

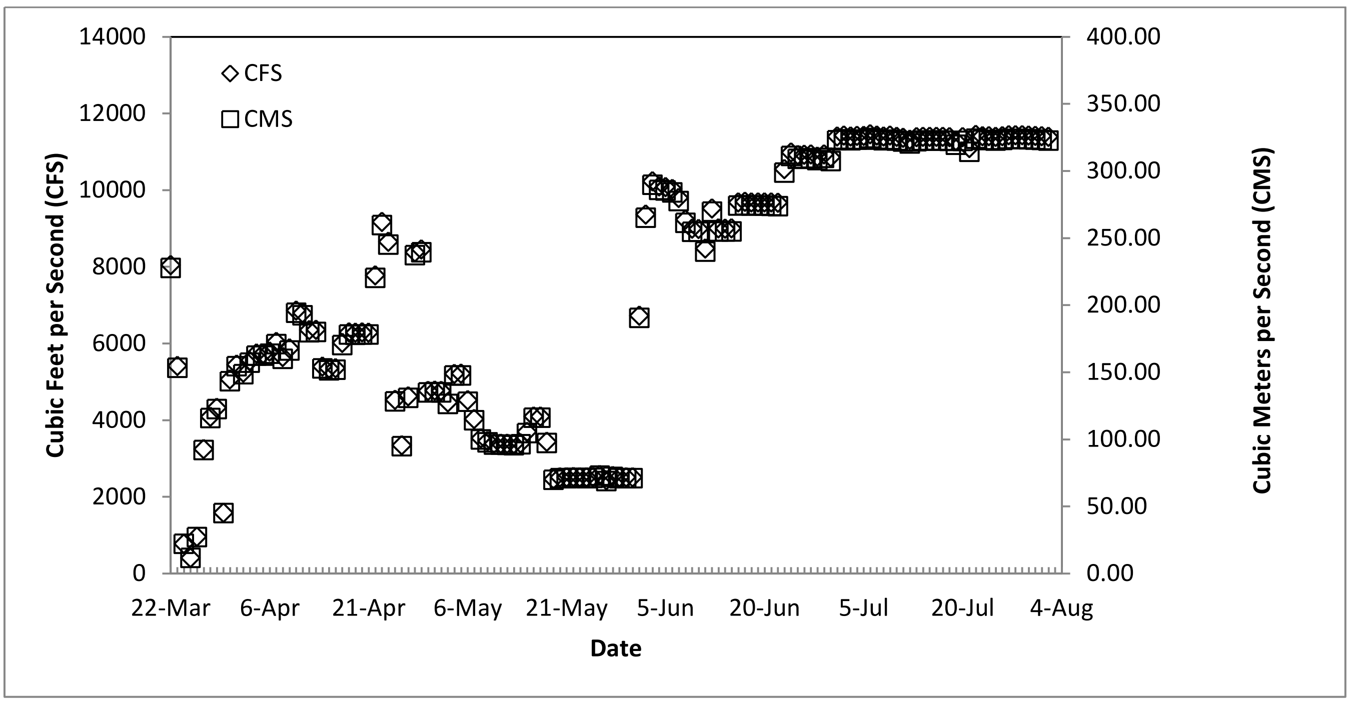
In 2011, there was no export rate period that corresponded to the low rate period seen from April 1 to May 26, 2010. There were only two distinct periods of export flow rates (**Table 3-8** and **Figure 3-2**) during the 2011 SDAB Study period. In the first period, March 22 to May 31, the export rate was lower than the second period.

Table 3-8. 2011 Descriptive Statistics Describing the Combined Export Rate from the Delta through the California Aqueduct and the Delta-Mendota Canal Combined

Period	Minimum Flow cms (cfs)	Mean Flow cms (cfs)	Standard Deviation of Flow cms (cfs)	Maximum Flow cms (cfs)
March 22–May 31	11.6 (408)	128.8 (4,548)	54.6 (1,927)	259.5 (9,165)
June 1–August 2	190.3 (6,722)	300.7 (10,619)	29.2 (1,032)	324.3 (11,454)

Source: DWR this study.

The export rate data for the SWP and CVP combined were assembled into two subsets of observations: one subset in 2010 and one subset in 2011. The time period included in the subset for each year corresponded to the time period in which tagged salmonids approached the SDABs (**Table 3-9**). Export rates were significantly greater in 2011 than in 2010 (Kruskal-Wallis chi-squared = 13.293; P = 0.0003) during the periods in which tagged salmonids approached the SDABs.



Source: DWR and ESA this study.

Figure 3-2. Combined Export Rate of the Banks Pumping Plant and the Jones Pumping Plant During the 2011 Study Period

Table 3-9. 2010 and 2011 Descriptive Statistics Describing the Combined Export Rate from the Delta through the California Aqueduct and the Delta-Mendota Canal Combined					
Period	**Minimum Flow cms (cfs)**	**Mean Flow cms (cfs)**	**Standard Deviation of Flow cms (cfs)**	**Maximum Flow cms (cfs)**	**Sample Size (days)**
April 1, 2010–August 2, 2010	37.6 (1,328))	111.5 (3,938)	84.0 (2,966)	308.8 (10,905)	75
March 22, 2011–August 2, 2011	11.6 (410)	150.7 (10,619)	71.1 (2,511)	289.6 (10,227)	82

Source: DWR this study.
Note: Combined for the time periods in 2010 and 2011 during which tagged juvenile salmonid approached the SDABs.

3.4 STEELHEAD AND CHINOOK SALMON CONTROL ASSESSMENTS

For a review of the 2010 surgical control methods see Section 2.5 *2010 Tag Life and Surgical Procedure Control Groups*. In 2010, only two of the 16 tagged Chinook Salmon control fish survived a minimum of 30 days. The Chinook Salmon control fish started dying within 10 days of tagging. This mortality was likely related to the PKD outbreak which was identified by the CDFW. Both Chinook Salmon that survived showed neither signs of open wounds nor encapsulation. Sixteen of the 32 tagged steelhead controls survived > 50 days. The 16 steelhead that survived were all from the first round of steelhead tagging and releases in April. The 16 steelhead that died were all from the second round of steelhead tagging and releases conducted in June. These steelhead died when water temperatures at the CHTR Laboratory were > 23°C (> 73.4°F). Of the 16 steelhead that survived 4 had open wounds at the suture site. Three of those four had sutures that failed to absorb. One acoustic tag was shed and two other tags were encapsulated. One tag was beginning to enter the intestinal tract of the steelhead.

For a review of the 2011 surgical control methods see Section 2.15 *2011 Surgical and Transport Procedure Control Groups*. In 2011, 24 of the 25 tagged steelhead controls held at the CHTR Laboratory survived from April 22 to July 15 when they were euthanized for further examination. Four of the 24 steelhead controls showed signs of irritation at the suture sites. One of the 24 tagged steelhead controls had fungus present on the caudal peduncle. One steelhead had shed its tag and two others showed signs of tag expulsion.

Health assessments were also conducted on Chinook Salmon used in the VAMP Study and SDABs Study by the USFWS. In summary, external infections with *Flavobacterium columnare* (the bacteria which causes columnaris disease) and *Ichthyophthirius multifiliis* (the protozoan which causes ich or white spot disease) were observed. *Tetracapsuloides bryosalmonae* parasites, the causative agent of PKD, were detected in zero (0) to seven percent of fish at one-day post-transfer to the California/Nevada Fish Health Center and 27 to 46 percent of fish at 30 days post-transfer. Survival for the 30-day holding periods was high and ranged from 96 to 100 percent. Overall, the health assessments demonstrated low mortality and only mild PKD prevalence, indicating fish health was not a concern in survival of 2011 VAMP and SDAB study fish.

In 2011, USFWS also performed fish health evaluations on dummy-tagged Chinook Salmon and steelhead. These fish were evaluated for mortality, condition, smoltification, and health. Results of the evaluations were presented in Chapters 5 and 6 of SJRGA (2013).

3.5 SURVIVAL MODELING

3.5.1 2010 Survival Results Related to the Predator Filter

The 2010 survival ($\hat{S}$) results with the Predator Filter Employed and with the Predator Filter Not Employed data are presented in **Tables 3-10** and **3-11** for Chinook Salmon and steelhead, respectively.

The overall Chinook Salmon survival via the ORS route in 2010 was 0.8910 (SE = 0.0189) for the Predator Filter Not Employed data, and 0.6191 (SE = 0.0277) for the Predator Filter Employed data (**Table 3-10**); there was a significant reduction in survival for the Predator Filter Employed data ($Z = 8.108$; $P < 0.0001$). The individual channel joint probability ($\hat{S}*\Psi$) through the ORS route ranged from 0.0898 (ORS to ORN) to 0.4087 (ORS to RGU) for the Predator Filter Not Employed data. For the Predator Filter Employed data, the individual channel joint probability ($\hat{S}*\Psi$) ranged from 0.0497 (ORS to ORN) to 0.3230 (ORS to RGU). The overall sample size decreased by approximately 30.6 percent for the fish that traveled through the ORS route with the Predator Filter Not Employed versus the Predator Filter Employed (i.e., from 284 fish versus 197 fish). There were no Chinook Salmon that traveled through the MRS route.

Table 3-10. 2010 Survival Results for Juvenile Chinook Salmon Releases Comparing Predator Filter Not Employed Data with Predator Filter Employed Data

Chinook Salmon	Predator Filter Not Employed			Predator Filter Employed			Significance Test	
Survival Location	Value	SE	N	Value	SE	N	Z	P-value
Through MRS route ($\hat{S}$)	NA[2]	NA	0[1]	NA	NA	NA	NA	NA
Through ORS route ($\hat{S}$)	0.8910	0.0189	322	0.6191	0.0277	322	8.1083	<0.0001
MRS to MRN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA	NA	NA
MRS to ORN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA	NA	NA
MRS to RGU ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA	NA	NA
MRS to CVP ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA	NA	NA
ORS to MRN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA	NA	NA
ORS to ORN ($\hat{S}*\Psi$)	0.0898	0.0159	29	0.0497	0.0121	16	2.0070	0.0448
ORS to RGU ($\hat{S}*\Psi$)	0.4087	0.0274	132	0.3230	0.0261	104	2.2647	0.0235
ORS to CVP ($\hat{S}*\Psi$)	0.3925	0.0282	123	0.2464	0.0247	77	3.8973	0.0001

Source: HTI this study.
Note: [1] No juvenile Chinook Salmon emigrated via the MRS route in 2010.
[2] NA = Not Applicable.

The overall steelhead survival through the ORS route in 2010 was 0.7359 (SE = 0.0267) for the Predator Filter Not Employed data and 0.1293 (SE = 0.0367) for the Predator Filter Employed data (**Table 3-11**). There was a significant reduction in steelhead survival when the predator filter was employed ($P < 0.0001$). The individual channel joint probability ($\hat{S}*\Psi$) through the ORS route ranged from 0.0653 (ORS to ORN) to 0.3728 (ORS to RGU) for the Predator Filter Not Employed data. For the Predator Filter Employed data, the individual channel joint probability ($\hat{S}*\Psi$) ranged from 0.0575 (ORS to RGU) to 0.0718 (ORS to CVP). The overall sample size decreased by 95.2 percent for the fish that traveled through the ORS route with the Predator Filter Not Employed compared to the Predator Filter Employed (i.e., from 231 fish to 11 fish). Thus, the Predator Filter Not Employed data were used for subsequent steelhead analyses in 2010.

Table 3-11. 2010 Survival Results for Juvenile Steelhead Releases Comparing Predator Filter Not Employed Data with Predator Filter Employed Data

Steelhead	Predator Filter Not Employed			Predator Filter Employed			Significance Test	
Survival Location	Value	SE	N	Value	SE	N	Z	P-value
Through MRS route ($\hat{S}$)	NA[2]	NA	2[1]	NA	NA	NA	NA	NA
Through ORS route ($\hat{S}$)	0.7359	0.0267	324	0.1293	0.0367	87	13.3657	<0.0001
MRS to MRN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA	NA	NA
MRS to ORN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA	NA	NA
MRS to RGU ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA	NA	NA
MRS to CVP ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA	NA	NA
ORS to MRN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA	NA	NA
ORS to ORN ($\hat{S}*\Psi$)	0.0653	0.0138	21	NA	NA	NA	NA	NA
ORS to RGU ($\hat{S}*\Psi$)	0.3728	0.0278	118	0.0575	0.0250	5	8.4333	<0.0001
ORS to CVP ($\hat{S}*\Psi$)	0.2947	0.0264	92	0.0718	0.0286	6	5.7268	<0.0001

Source: HTI this study.
Note: [1] Only two juvenile steelhead emigrated via the MRS route in 2010. Sample size too small for analysis.
[2] NA = Not Applicable.

The proportions of juvenile salmonids that traveled via the MRS route versus the ORS route in 2010 are presented in **Tables 3-12** and **3-13**, for Chinook Salmon and steelhead, respectively. Very few fish traveled via the MRS route in 2010. For Chinook Salmon, 100 percent traveled through the ORS route (**Table 3-12**). A total of 99.39 percent of steelhead were estimated to have traveled via the ORS route versus only 0.61 percent that traveled via the MRS route (**Table 3-13**).

Table 3-12. 2010 Route Proportion Results for Juvenile Chinook Salmon Releases Comparing Predator Filter Not Employed Data with Predator Filter Employed Data

Chinook Salmon	Predator Filter Not Employed			Predator Filter Employed		
Route Proportion	Value	SE	N	Value	SE	N
MRS Route (Ψ)	0.0000	NA[1]	NA	0.0000	NA	NA
ORS Route (Ψ)	1.0000	NA	322	1.0000	NA	322

Source: HTI this study.
Note: [1] NA = Not Applicable.

Table 3-13. 2010 Route Proportion Results for Juvenile Steelhead Releases Comparing Predator Filter Not Employed Data with Predator Filter Employed Data

Steelhead	Predator Filter Not Employed			Predator Filter Employed		
Route Proportion	Value	SE	N	Value	SE	N
MRS Route (Ψ)	0.0061	0.0043	2	0.0000	NA[1]	NA
ORS Route (Ψ)	0.9939	0.0043	324	1.0000	NA	87

Source: HTI this study.
Note: [1] NA = Not Applicable.

3.5.2 2010 Distribution of Acoustic Tags in South Delta Channels

Of 342 tagged and released Chinook Salmon in 2010 (for the Old River 1D fish release site see **Figure 2-5**), 322 fish arrived at ORSU or MRS (**Table 3-14**). Thus, 5.8 percent either swam upstream, potentially using another route to the ocean, suffered mortality before arriving at ORSU or MRS, or were undetected for an unknown reason. Among the 322 Chinook Salmon that arrived at ORSU or MRS, zero (0) were detected at MRS. This is a smaller percentage (0 percent) than would be expected if Chinook Salmon went "with the flow" because 6.2 percent of the flow entered Middle River during the period of time in which Chinook Salmon approached the Old River/Middle River divergence (**Table 3-3**). Among the 322 Chinook Salmon that arrived at ORSU or MRS, all were identified by the predator filter as "salmonid."

Of those 322 Chinook Salmon, 280 tags eventually were detected in the area of one of the SDABs. Of those 280, 98.9 percent (277/280) arrived at the GLCB footprint area and only 1.1 percent (3/280) arrived at the ORTB area (**Table 3-14**). The percentage arriving at the ORTB was much smaller than the percentage that would have been expected if Chinook Salmon went "with the flow." The percentage of water entering Old River ranged from 2.8 percent in the After-Construction Period to 17.8 percent in the Before-Construction Period (**Table 3-4**). These results suggested that in 2010, the Middle River and Old River channels were not selected for migration through the south Delta in proportion to the amount of water they conveyed. Furthermore, the GLCB route was preferred compared to the Middle River and the Old River routes.

Table 3-14. 2010 Overall Numbers of Tagged Juvenile Salmonids that Arrived at Key South Delta Hydrophone Arrays

	Tagged Juvenile Chinook Salmon[1]				Tagged Juvenile Steelhead[1,2]			
Array[3]	Arrived as Juvenile	Proportion that Arrived as Juvenile	Arrived as Predator	Proportion that Arrived as Predator	Arrived as Juvenile	Proportion that Arrived as Juvenile	Arrived as Predator	Proportion that Arrived as Predator
ORSU	322	1.000	0	0.000	324	NA	NA	NA
MRS	0	NA	0	NA	1	NA	NA	NA
MRBU	0	NA	0	NA	0	NA	NA	NA
GLCBU	277	0.923	23	0.077	175	NA	NA	NA
ORTBU	3	1.000	0	0.000	19	NA	NA	NA

Source: HTI this study.

Note: [1] These values represent raw detections, not adjusted for individual detection site detectability.

[2] Application of the predator filter to steelhead caused too high a proportion of steelhead to be classified as predators to make use of predator-filtered data for steelhead in 2010 survival calculations (see Section 3.5.3 *2010 Survival Results Related to the Temporary Barrier Construction*). Therefore, for all steelhead in this table the Predator entry is NA: Not Applicable.

[3] See **Table 2-18** for descriptions of all arrays.

Of the 480 tagged and released steelhead for 2010, 325 arrived at ORSU or MRS (**Table 3-14**). The predator filter was not used in 2010 for steelhead because of the very high proportion (95 percent) of steelhead that were classified as predators due to the much slower migration rates and longer travel times between detection sites compared to Chinook Salmon. Based on the raw detection data alone, 32.3 percent of steelhead either swam upstream, potentially using another route to the ocean, or suffered mortality before arriving at ORSU or MRS. Among the 325 steelhead that did arrive at ORSU or MRS, 1 was detected at MRS. This is a smaller percentage (0.3 percent) than would be expected if steelhead went "with the flow" because 6.2 percent of the flow entered Middle River during the period of time in which steelhead approached the Old River/Middle River divergence (**Table 3-3**).

Of the 325 steelhead that arrived at the ORS/MRS divergence, 194 eventually were detected in the area of one of the SDABs. Of those 194, 90.2 percent (175/194) arrived at the GLCB footprint area and 9.8 percent (19/194) arrived at the ORTB area (**Table 3-14**). The GLCB route was preferred compared to the Middle River and the Old River routes.

3.5.3 2010 Survival Results Related to the Temporary Barrier Construction

The 2010 Chinook Salmon survival results for the data showing the Before-, During-, and After-Construction Periods for the ORTB, MRB, and GLCB are presented in **Table 3-15**. The Chinook Salmon releases occurred only during Before-Construction Period of all three barriers, so it was not possible to calculate survival estimates under During- and After-Construction Periods. In addition, no Chinook Salmon were observed transiting via the MRS route in 2010. Overall estimated Chinook Salmon survival via the ORS route in 2010 was 0.6191 (SE = 0.0277). The individual channel joint probability ($\hat{S}*\Psi$) via the ORS route ranged from 0.0497 (ORS to ORN) to 0.3230 (ORS to RGU) for the Before-Construction Period data.

Table 3-15. 2010 Survival Results for Juvenile Chinook Salmon "Predator Filter Employed" Data Comparing Before-, During-, and After-Construction Periods of Old River at Tracy Barrier, Middle River Barrier, and Grant Line Canal Barrier

Chinook Salmon Survival Location	Old River at Tracy Barrier, Middle River Barrier, and Grant Line Canal Barrier								
	Before-Construction			During-Construction			After-Construction		
	Value	SE	N	Value	SE	N	Value	SE	N
Through MRS route ($\hat{S}$)	0.0000	NA[1]	NA	No Data	No Data	No Data	No Data	No Data	No Data
Through ORS route ($\hat{S}$)	0.6191	0.0277	322	No Data	No Data	No Data	No Data	No Data	No Data
MRS to MRN ($\hat{S}*\Psi$)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to ORN ($\hat{S}*\Psi$)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to RGU ($\hat{S}*\Psi$)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to CVP ($\hat{S}*\Psi$)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS to MRN ($\hat{S}*\Psi$)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS to ORN ($\hat{S}*\Psi$)	0.0497	0.0121	16	No Data	No Data	No Data	No Data	No Data	No Data
ORS to RGU ($\hat{S}*\Psi$)	0.3230	0.0261	104	No Data	No Data	No Data	No Data	No Data	No Data
ORS to CVP ($\hat{S}*\Psi$)	0.2464	0.0247	77	No Data	No Data	No Data	No Data	No Data	No Data

Source: HTI this study.
Note: [1] NA = Not Applicable.

For all subsequent 2010 survival calculations comparing the SDABs, the predator filter was employed prior to the analyses, except for the 2010 steelhead data, where application of the filter resulted in a small sample size. The 2010 steelhead survival estimates were calculated using the Predator Filter Not Employed data. The same steelhead releases occurred for the Before- and After-Construction Periods for both the ORTB and MRB (**Table 3-16**).

Table 3-16. 2010 Survival Results for Juvenile Steelhead "Predator Filter Not Employed" Data Comparing Before- and After-Construction Periods of Old River at Tracy Barrier and Middle River Barrier

Steelhead Survival Location	Old River at Tracy Barrier and Middle River Barrier: Before-Construction Value	SE	After-Construction Value	SE	Significance Test Z	P-value
Through MRS route ($\hat{S}$)	0.0000	NA[1]	0.0000	NA	NA	NA
Through ORS route ($\hat{S}$)	0.8931	0.0303	0.5774	0.0544	5.0699	<0.0001
MRS to MRN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
MRS to ORN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
MRS to RGU ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
MRS to CVP ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
ORS to MRN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
ORS to ORN ($\hat{S}*\Psi$)	0.1050	0.0222	0.0076	0.0075	4.1566	<0.0001
ORS to RGU ($\hat{S}*\Psi$)	0.5231	0.0413	0.2045	0.0351	5.8782	<0.0001
ORS to CVP ($\hat{S}*\Psi$)	0.2651	0.0319	0.3653	0.0535	1.6086	0.1077

Source: HTI this study.
Note: [1] NA = Not Applicable.

The overall steelhead survival through the ORS route in 2010 was 0.8931 (SE = 0.0303) Before-Construction and 0.5774 (SE = 0.0544) After-Construction (**Table 3-16**) for the ORTB and MRB. There was a significant reduction in survival After-Construction as compared to Before-Construction ($Z = 5.070$; $P < 0.0001$). The joint probability ($\hat{S}*\Psi$) through the ORS route ranged from 0.1050 (ORS to ORN) to 0.5231 (ORS to RGU) for the Before-Construction Period as compared to ORS channel joint probability ($\hat{S}*\Psi$) that ranged from 0.0076 (ORS to ORN) to 0.3653 (ORS to CVP) After-Construction Period. There were no steelhead detected transiting through the MRS route in 2010.

The GLCB 2010 steelhead survival results for the data showing the Before-, During-, and After-Construction Periods are presented in **Table 3-17**. The steelhead releases occurred only during the GLCB Before-Construction Period , so it was not possible to make survival comparisons under GLCB During- and After-Construction Periods. The overall steelhead survival through the ORS route in 2010 was 0.7359 (SE = 0.0267) Before-Construction (**Table 3-17**) for the GLCB.

Table 3-17. 2010 Survival Results for Juvenile Steelhead "Predator Filter Not Employed" Data Set Comparing Before-, During-, and After-Construction Periods Grant Line Canal Barrier									
	Before-Construction			During-Construction			After-Construction		
Survival Location	Value	SE	N	Value	SE	N	Value	SE	N
Through MRS route (Ŝ)	0.0000	NA[1]	2	No Data	No Data	No Data	No Data	No Data	No Data
Through ORS route (Ŝ)	0.7359	0.0267	324	No Data	No Data	No Data	No Data	No Data	No Data
MRS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS to ORN (Ŝ*Ψ)	0.0653	0.0138	21	No Data	No Data	No Data	No Data	No Data	No Data
ORS to RGU (Ŝ*Ψ)	0.3728	0.0278	118	No Data	No Data	No Data	No Data	No Data	No Data
ORS to CVP (Ŝ*Ψ)	0.2947	0.0264	92	No Data	No Data	No Data	No Data	No Data	No Data

Source: HTI this study.
Note: [1] NA = Not Applicable.

The proportions of Chinook Salmon that traveled through the MRS route versus the ORS route in 2010 under all SDAB construction conditions are presented in **Table 3-18**. **Table 3-19** presents the proportions of steelhead that traveled through the MRS route versus the ORS routed for ORTB and MRB Before-, During-, and After-Construction Periods. The proportion of steelhead that traveled through the MRS versus ORS route are presented in **Table 3-20** for the GLCB construction periods. No Chinook Salmon traveled through the MRS route in 2010. For steelhead, the estimated proportion of tagged fish that traveled through the ORS route was 98.0 percent (**Table 3-19**), with 2.0 percent estimated to have travelled through the MRS route for the After-Construction Periods for ORTB and MRB. For the GLCB Before-Construction Period, it is estimated that 99.4 percent traveled through the ORS route and 0.60 percent through the MRS route (**Table 3-20**). No steelhead traveled through the MRS route in 2010 in the During-Construction Periods for ORTB and MRB.

Table 3-18. 2010 Route Proportion Results for Juvenile Chinook Salmon "Predator Filter Not Employed" Data Comparing Before-, During-, and After-Construction Periods of Old River at Tracy Barrier, Middle River Barrier, and Grant Line Canal Barrier									
	Old River at Tracy Barrier, Middle River Barrier, and Grant Line Barrier								
Chinook Salmon Route Proportion	Before-Construction			During-Construction			After-Construction		
	Value	SE	N	Value	SE	N	Value	SE	N
MRS Route (Ψ)	0.0000	NA[1]	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS Route (Ψ)	1.0000	NA	322	No Data	No Data	No Data	No Data	No Data	No Data

Source: HTI this study.
Note: [1] NA = Not Applicable.

Table 3-19. 2010 Route Proportion Results for Juvenile Steelhead "Predator Filter Not Employed" Data Comparing Before-, During-, and After-Construction Periods of Old River at Tracy Barrier and Middle River Barrier									
	Old River at Tracy Barrier and Middle River Barrier								
Steelhead Route Proportion	Before-Construction			During-Construction			After-Construction		
	Value	SE	N	Value	SE	N	Value	SE	N
MRS Route (Ψ)	0.0000	NA[1]	NA	No Data	No Data	No Data	0.0199	0.9003	2
ORS Route (Ψ)	1.0000	NA	193	No Data	No Data	No Data	0.9801	0.9003	132

Source: HTI this study.
Note: [1] NA = Not Applicable.

Table 3-20. 2010 Route Proportion Results for Juvenile Steelhead Releases Comparing Before-, During-, and After-Construction Period of Grant Line Canal Barrier									
	Grant Line Canal Barrier								
Steelhead	Before-Construction			During-Construction			After-Construction		
Route Proportion	Value	SE	N	Value	SE	N	Value	SE	N
MRS Route (Ψ)	0.0061	0.0043	2	No Data	No Data	No Data	No Data	No Data	No Data
ORS Route (Ψ)	0.9939	0.0043	324	No Data	No Data	No Data	No Data	No Data	No Data

Source: HTI this study.
Note: [1] NA = Not Applicable.

3.5.4 2011 Distribution of Acoustic Tags in South Delta Channels

Of 1,900 tagged Chinook Salmon released at Durham Ferry (see **Figure 2-13** for the 1D Fish Release Site (2011)), the predator filter determined that 654 fish arrived at ORSU or MRS (**Table 3-21**) as a juvenile Chinook Salmon and not as a predator. Therefore, 1,246 fish (65.6 percent) selected another route to the ocean, or suffered mortality before arriving at ORSU or MRS. Among the 654 Chinook Salmon that arrived at ORSU or MRS, 7 were detected at MRS. This is a smaller percentage (1.1 percent) than would be expected if Chinook Salmon went "with the flow" because 11.2 percent of the flow entered Middle River during the period of time in which Chinook Salmon approached the Old River/Middle River divergence (**Table 3-5**). Among the 656 Chinook Salmon that arrived at ORSU or MRS, 2 were identified by the predator filter as a predator (**Table 3-21**).

Of the 654 Chinook Salmon that arrived at the ORS divergence, 549 eventually were detected in the area of one of the SDABs. Of those 549, 91.1 percent (500/549) arrived at the GLCB footprint area and only 7.8 percent (43/549) arrived at the ORTB area (**Table 3-21**). The percentage of fish arriving at the ORTB area was smaller than the percentage that would have been expected if Chinook Salmon went "with the flow." The percentage of water entering Old River ranged from 12.4 percent in the After-Construction Period to 22.5 percent in the Before-Construction Period (**Table 3-6**).

Of 2,195 steelhead released at Durham Ferry (**Figure 2-13**), the predator filter determined that 490 fish arrived at ORSU or MRS (**Table 3-21**) as a steelhead and not as a predator. Therefore, 1,705 fish (77.7 percent) either swam upstream, selected another route to the ocean, or suffered mortality before arriving at ORSU or MRS. Among the 490 steelhead that arrived at ORS or MRS, 25 were detected at MRS. This is a smaller percentage (5.1 percent) than would be expected if steelhead went "with the flow" because 11.2 percent of the flow entered Middle River during the period of time in which steelhead approached the Old River/Middle River divergence (**Table 3-5**).

Among the 531 steelhead that arrived at ORSU or MRS, 41 were identified by the predator filter as a predator (**Table 3-21**).

Of the 490 steelhead that arrived at the ORS/MRS divergence, 469 eventually were detected in the area of one of the SDABs. Of those 469, 84.6 percent (397/469) arrived at the GLCB footprint area and only 9.4 percent (44/469) arrived at the ORTB area (**Table 3-21**). The GLCB route was preferred compared to the Middle River and the Old River routes.

Table 3-21. 2011 Overall Numbers of Tagged Juvenile Salmonids that Arrived at Key South Delta Hydrophone Arrays from the Durham Ferry Release Site

	Tagged Juvenile Chinook Salmon				Tagged Juvenile Steelhead			
Array	Arrived as Juvenile	Proportion that Arrived as Juvenile	Arrived as Predator	Proportion that Arrived as Predator	Arrived as Juvenile	Proportion that Arrived as Juvenile	Arrived as Predator	Proportion that Arrived as Predator
ORSU	647	0.997	2	0.003	465	0.938	31	0.063
MRS	7	1.000	0	0.000	25	0.714	10	0.286
MRBU	6	0.857	1	0.143	28	0.966	1	0.034
GLCBU	500	0.992	4	0.008	397	0.936	27	0.064
ORTBU	43	0.915	4	0.085	44	0.917	4	0.083

Source: HTI this study.

Note: These values represent raw detections, not adjusted for individual detection site detectability. The locations of hydrophone gates ORSU and MRS are illustrated in **Figure 2-5**.

The general trend in these 2011 data were that the Middle River channel and the Old River channel were not selected for migration by salmonids through the south Delta in proportion to the amount of water they conveyed. Furthermore, the Grant Line Canal route exhibited a higher percent of tags (**Table 3-21**) arriving at the GLCB compared to the percentage of flow conveyed by the Grant Line Canal (**Table 3-6**). It is concluded that the GLC route was preferred compared to the Middle River and the Old River routes in 2011.

3.5.5 2011 Survival Results Related to the Predator Filter

It was concluded that 2011 Chinook Salmon survival with the Predator Filter Employed via the ORS emigration route, 0.6957 (SE = 0.0189) (**Table 3-22**), was closer to the actual juvenile Chinook Salmon survival because of the results of the predator filter analysis. The overall juvenile Chinook Salmon survival through the MRS route in 2011 was 0.7792 (SE = 0.2005) for the Predator Filter Not Employed data and 0.9286 (SE = 0.1562) for the Predator Filter Employed data. Although there was an increase in survival through the MRS route after the Predator Filter was employed, this difference was not significant due to the small remaining sample size through the MRS route (N = 7).

Table 3-22. 2011 Survival Results for Juvenile Chinook Releases Comparing Predator Filter Not Employed Data with Predator Filter Employed Data								
Chinook Salmon	**Predator Filter Not Employed**			**Predator Filter Employed**			**Significance Test**	
Survival Location	**Value**	**SE**	**N**	**Value**	**SE**	**N**	**Z**	**P-value**
Through MRS route ($\hat{S}$)	0.7792	0.2005	7	0.9286	0.1562	7	0.5878	0.5567
Through ORS route ($\hat{S}$)	0.6885	0.0190	650	0.6957	0.0189	648	0.2687	0.7882
MRS to MRN ($\hat{S}*\Psi$)	0.7792	0.2005	6	0.9286	0.1562	5	0.5878	0.5567
MRS to ORN ($\hat{S}*\Psi$)	NA[1]	NA	NA	NA	NA	NA	NA	NA
MRS to RGU ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA	NA	NA
MRS to CVP ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA	NA	NA
ORS to MRN ($\hat{S}*\Psi$)	0.0017	0.0017	1	0.0016	0.0016	1	0.0428	0.9658
ORS to ORN ($\hat{S}*\Psi$)	0.1167	0.0127	74	0.1205	0.0129	73	0.2099	0.8337
ORS to RGU ($\hat{S}*\Psi$)	0.2986	0.0186	190	0.2981	0.0185	188	0.0191	0.9848
ORS to CVP ($\hat{S}*\Psi$)	0.2715	0.0173	176	0.2755	0.0172	173	0.1640	0.8698

Source: HTI this study.
Note: [1] NA = Not Applicable.

The individual channel joint probability ($\hat{S}*\Psi$) through the ORS route for juvenile Chinook Salmon ranged from 0.0017 (ORS to MRN) to 0.2986 (ORS to RGU) for the Predator Filter Not Employed data. For the Predator Filter Employed data, the individual channel joint probability ($\hat{S}*\Psi$) ranged from 0.0016 (ORS to MRN) to 0.2981 (ORS to RGU). The overall sample size decreased by approximately 1.4 percent for fish that traveled through the ORS route (from 441 fish to 435 fish) for the Predator Filter Employed data. The individual channel survival for MRS to MRN was equivalent to the calculated route survival, as only the MRN channel was referenced. For the MRS route, the sample size decreased by one Chinook Salmon for the Predator Filter Employed data (from six fish to five fish).

For the 2011 data, it was concluded that the overall juvenile steelhead survival through the ORS route was 0.8764 (SE = 0.0158) for the Predator Filter Employed data (**Table 3-23**), was closer to the actual steelhead juvenile survival because of the results of the predator filter analysis. The overall steelhead survival through the MRS route in 2011 was 0.5876 (SE = 0.0899) for the Predator Filter Not Employed data and 0.7179 (SE = 0.0944) for the Predator Filter Employed data. The individual channel joint probability ($\hat{S}*\Psi$) through the ORS route ranged from 0.0278 (ORS to MRN) to 0.3435 (ORS to RGU) for the Predator Filter Not Employed data. For the Predator Filter Employed data, the individual channel joint probability ($\hat{S}*\Psi$) ranged from 0.0305 (ORS to MRN) to 0.3609 (ORS to RGU). The overall sample size decreased by 4.9 percent for the fish that traveled through the ORS route (from 447 fish to 425 fish) for the Predator Filter Employed data. Thus, the Predator Filter Employed data were used for subsequent analyses.

The individual channel joint probability ($\hat{S}*\Psi$) for MRS to MRN was similar to the route joint probability ($\hat{S}*\Psi$) estimates, as only the MRN channel data was referenced. For the MRS route, the sample size decreased by 1 juvenile steelhead after applying the predator filter (from 18 fish to 17 fish).

Table 3-23. 2011 Survival Results for Juvenile Steelhead Releases Comparing Predator Filter Not Employed Data with Predator Filter Employed Data								
Steelhead	Predator Filter Not Employed			Predator Filter Employed			Significance Test	
Survival Location	Value	SE	N	Value	SE	N	Z	P-value
Through MRS route ($\hat{S}$)	0.5876	0.0899	31	0.7179	0.0944	24	0.9996	0.3175
Through ORS route ($\hat{S}$)	0.8437	0.0165	538	0.8764	0.0158	492	1.4314	0.1523
MRS to MRN ($\hat{S}$*Ψ)	0.5876	0.0899	18	0.7179	0.0944	17	0.9996	0.3175
MRS to ORN ($\hat{S}$*Ψ)	NA[1]	NA	NA	NA	NA	NA	NA	NA
MRS to RGU ($\hat{S}$*Ψ)	NA	NA	NA	NA	NA	NA	NA	NA
MRS to CVP ($\hat{S}$*Ψ)	NA	NA	NA	NA	NA	NA	NA	NA
ORS to MRN ($\hat{S}$*Ψ)	0.0278	0.0071	15	0.0305	0.0078	15	0.2560	0.7980
ORS to ORN ($\hat{S}$*Ψ)	0.2341	0.0182	123	0.2482	0.0194	119	0.5301	0.5961
ORS to RGU ($\hat{S}$*Ψ)	0.3435	0.0209	182	0.3609	0.0221	175	0.5720	0.5673
ORS to CVP ($\hat{S}$*Ψ)	0.2383	0.0182	127	0.2368	0.0190	116	0.0570	0.9545

Source: HTI this study.
Note: [1] NA = Not Applicable.

The proportions of juvenile salmonids that traveled through the MRS route versus the ORS route in 2011 are presented in **Tables 3-24** and **3-25**, for Chinook Salmon and steelhead, respectively. Few fish of either species traveled through the MRS route in 2011. For the Chinook Salmon, 97.6 percent and 97.9 percent of fish were estimated to have traveled through the ORS route with and without the Predator Filter Employed, respectively, relative to only 2.4 and 2.1 percent of fish with and without the Predator Filter Employed through the MRS route (**Table 3-24**). For juvenile steelhead, it was estimated that 5.8 percent of fish traveled through the MRS route with the Predator Filter Employed data relative to 94.2 percent of fish that traveled through the ORS route with the Predator Filter Employed data (**Table 3-25**).

Table 3-24. 2011 Route Proportion Results for Juvenile Chinook Releases Comparing With and Without Utilizing the Predator Filter						
Chinook Salmon Route Proportion	Predator Filter Not Employed			Predator Filter Employed		
	Value	SE	N	Value	SE	N
MRS Route (Ψ)	0.0208	0.0065	7	0.0239	0.0064	7
ORS Route (Ψ)	0.9792	0.0065	650	0.9761	0.0064	648

Source: HTI this study.

Table 3-25. Route Proportion Results for the 2011 Juvenile Steelhead Releases Comparing With and Without Utilizing the Predator Filter						
Steelhead Route Proportion	Predator Filter Not Employed			Predator Filter Employed		
	Value	SE	N	Value	SE	N
MRS Route (Ψ)	0.0696	0.0116	31	0.0579	0.0107	24
ORS Route (Ψ)	0.9304	0.0116	538	0.9421	0.0107	492

Source: HTI this study.

3.5.6 2011 Survival Results Related to Temporary Barrier Construction

The 2011 juvenile Chinook Salmon survival results for the data comparing the Before-Construction Period versus the During-Construction Period are presented in **Table 3-26** for ORTB. The ORTB comparison of the Before-Construction Period versus the After-Construction Period is presented in **Table 3-26**. The comparison of the During-Construction Period versus the After Construction Period is presented in **Table 3-27** for ORTB.

Table 3-26. 2011 Survival Results for Juvenile Chinook "Predator Filter Employed" Data Comparing the Before-Construction Period with the During-Construction Period for the Old River at Tracy Barrier

Chinook Salmon Survival Location	Old River Tracy Barrier Before-Construction Value	SE	Old River Tracy Barrier During-Construction Value	SE	Significance Test Z	P-value
Through MRS route (Ŝ)	0.6429	0.2409	1.0000	NA[1]	NA	NA
Through ORS route (Ŝ)	0.6633	0.0251	0.6571	0.0462	0.1179	0.9061
MRS to MRN (Ŝ*Ψ)	0.6428	0.2409	1.0000	NA	NA	NA
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	NA	NA	NA
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	NA	NA	NA
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	NA	NA	NA
ORS to MRN (Ŝ*Ψ)	0.0030	0.0030	NA	NA	NA	NA
ORS to ORN (Ŝ*Ψ)	0.2030	0.0212	0.0082	0.0082	8.5699	<0.0001
ORS to RGU (Ŝ*Ψ)	0.2292	0.0223	0.3046	0.0447	1.5097	0.1311
ORS to CVP (Ŝ*Ψ)	0.2280	0.0221	0.3420	0.0491	2.1167	0.0343

Source: HTI this study.
Note: [1] NA = Not Applicable.

The Chinook Salmon survival through the ORS route in 2011 was 0.6633 (SE = 0.0251) Before-Construction Period as compared to 0.6571 (SE = 0.0462) During-Construction Period for ORTB (**Table 3-26**), which was not significantly different (Z = 0.118; P = 0.9061). The individual channel joint probability (Ŝ*Ψ) through the ORS route ranged from 0.0030 (ORS to MRN) to 0.2292 (ORS to RGU) in the Before-Construction Period and from 0.0082 (ORS to ORN) to 0.3420 (ORS to CVP) in the During-Construction Period.

The Chinook Salmon survival through the ORS route in 2011 was 0.6633 (SE = 0.0251) Before-Construction Period as compared to 0.7494 (SE = 0.0354) After-Construction Period for ORTB (**Table 3-27**), which was not a significant increase in survival because the P-value, 0.0472 (Z = 1.984), was not less than the critical α' for three comparisons, 0.01695. The individual channel joint probability (Ŝ*Ψ) through the ORS route ranged from 0.0030 (ORS to MRN) to 0.2292 (ORS to RGU) in the Before-Construction Period and from 0.0056 (ORS to ORN) to 0.4219 (ORS to RGU) in the After-Construction Period.

Table 3-27. 2011 Survival Results for Juvenile Chinook "Predator Filter Employed" Data Comparing Before-Construction Period with After-Construction Period for the Old River at Tracy Barrier

Chinook Salmon Survival Location	Old River Tracy Barrier				Significance Test	
	Before-Construction		After-Construction			
	Value	SE	Value	SE	Z	P-value
Through MRS route ($\hat{S}$)	0.6429	0.2409	0.0000	NA[1]	NA	NA
Through ORS route ($\hat{S}$)	0.6633	0.0251	0.7494	0.0354	1.9841	0.0472
MRS to MRN ($\hat{S}*\Psi$)	0.6428	0.2409	NA	NA	NA	NA
MRS to ORN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
MRS to RGU ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
MRS to CVP ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
ORS to MRN ($\hat{S}*\Psi$)	0.0030	0.0030	NA	NA	NA	NA
ORS to ORN ($\hat{S}*\Psi$)	0.2030	0.0212	0.0056	0.0055	9.0129	<0.0001
ORS to RGU ($\hat{S}*\Psi$)	0.2292	0.0223	0.4219	0.0395	4.2491	<0.0001
ORS to CVP ($\hat{S}*\Psi$)	0.2280	0.0221	0.3220	0.0348	2.2793	0.0226

Source: HTI this study.
Note: [1] NA = Not Applicable.

The Chinook Salmon survival through the ORS route in 2011 was 0.6571 (SE = 0.0462) During-Construction Period as compared to 0.7494 (SE = 0.0354) After-Construction Period for ORTB (**Table 3-28**), which was not significantly different ($Z = 1.586$; $P = 0.1128$). The individual channel joint probability ($\hat{S}*\Psi$) through the ORS route ranged from 0.0082 (ORS to ORN) to 0.3420 (ORS to CVP) During-Construction Period and from 0.0056 (ORS to ORN) to 0.4219 (ORS to RGU) After-Construction Period.

Table 3-28. 2011 Survival Results for Juvenile Chinook "Predator Filter Employed" Data Comparing During-Construction Period with After-Construction Period for the Old River at Tracy Barrier

Chinook Salmon Survival Location	Old River Tracy Barrier				Significance Test	
	During-Construction		After-Construction			
	Value	SE	Value	SE	Z	P-value
Through MRS route ($\hat{S}$)	1.0000	NA[1]	0.0000	NA	NA	NA
Through ORS route ($\hat{S}$)	0.6571	0.0462	0.7494	0.0354	1.5858	0.1128
MRS to MRN ($\hat{S}*\Psi$)	1.0000	NA	NA	NA	NA	NA
MRS to ORN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
MRS to RGU ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
MRS to CVP ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
ORS to MRN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
ORS to ORN ($\hat{S}*\Psi$)	0.0082	0.0082	0.0056	0.0055	0.2633	0.7923
ORS to RGU ($\hat{S}*\Psi$)	0.3046	0.0447	0.4219	0.0395	1.9664	0.0493
ORS to CVP ($\hat{S}*\Psi$)	0.3420	0.0491	0.3220	0.0348	0.3323	0.7396

Source: HTI this study.
Note: [1] NA = Not Applicable.

There were very few Chinook Salmon that traveled through the MRS route during all of the ORTB construction periods in 2011. The estimates of survival and SE in the MRS route are not considered reliable due to insufficient sample size.

For the GLCB, the Chinook Salmon survival through the ORS route in 2011 was 0.6502 (SE = 0.0313) in the Before-Construction Period and was 0.7611 (SE = 0.0323) in the During-Construction Period (**Table 3-29**). There were no Chinook Salmon released during the After-Construction Period of the GLCB. The survival through the ORS route significantly increased in the During-Construction Period as compared to the Before-Construction Period (Z = 2.466; P = 0.0137). The individual channel joint probability ($\hat{S}*\Psi$) through the ORS route ranged from 0.0024 (ORS to MRN) to 0.2444 (ORS to CVP) Before-Construction Period and from 0.0046 (ORS to ORN) to 0.4253 (ORS to RGU) During-Construction Period. The survival for the MRS route must be considered anecdotal because of the extremely small sample size; survival ranged from 0.7111 (SE = 0.2120) Before-Construction Period to 1.0000 in the During-Construction Period.

Table 3-29. 2011 Survival Results for Juvenile Chinook "Predator Filter Employed" Data Comparing Before-Construction Period with During-Construction Period for the Grant Line Canal Barrier

Chinook Salmon Survival Location	Grant Line Canal Barrier				Significance Test	
	Before-Construction		During-Construction			
	Value	SE	Value	SE	Z	P-value
Through MRS route ($\hat{S}$)	0.7111	0.2120	1.0000	NA[1]	NA	NA
Through ORS route ($\hat{S}$)	0.6502	0.0313	0.7611	0.0323	2.4657	0.0137
MRS to MRN ($\hat{S}*\Psi$)	0.7111	0.2120	1.0000	NA	NA	NA
MRS to ORN ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
MRS to RGU ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
MRS to CVP ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
ORS to MRN ($\hat{S}*\Psi$)	0.0024	0.0024	NA	NA	NA	NA
ORS to ORN ($\hat{S}*\Psi$)	0.1675	0.0178	0.0046	0.0046	8.8606	<0.0001
ORS to RGU ($\hat{S}*\Psi$)	0.2359	0.0206	0.4253	0.0364	4.5284	<0.0001
ORS to CVP ($\hat{S}*\Psi$)	0.2444	0.0205	0.3267	0.0318	2.1752	0.0296

Source: HTI this study.
Note: [1] NA = Not Applicable.

The 2011 juvenile steelhead survival results for the data comparing Before-Construction Period with After-Construction Period are presented in **Table 3-30** for ORTB and MRB. For ORTB and MRB, the overall juvenile steelhead survival through the ORS route in 2011 was 0.8838 (SE = 0.0160) Before-Construction Period and 0.7929 (SE = 0.0706) After-Construction Period (**Table 3-30**). The overall survival for the MRS route ranged from 0.7359 (SE = 0.0963) Before-Construction Period to 0.5000 (SE = 0.3536) After-Construction Period. There were no steelhead releases in the During-Construction Period of ORTB and MRB. In both the ORS and MRS routes survival decreased from Before- to After-Construction Period at ORTB and MRB, however this decrease was not statistically significant (ORS Z = 1.256; P = 0.2092 and MRS Z = 0.644; P = 0.5198). The individual channel joint probability ($\hat{S}*\Psi$) through the ORS route ranged from 0.0331 (ORS to MRN) to 0.3627 (ORS to RGU) Before-Construction Period and from 0.3429 (ORS to RGU) to 0.4500 (ORS to CVP) After-Construction Period.

Table 3-30. 2011 Survival Results for Juvenile Steelhead "Predator Filter Employed" Data Comparing Before-Construction Period with After-Construction Period for Old River at Tracy Barrier and Middle River Barrier

Steelhead Survival Location	Old River Tracy and Middle River Barrier				Significance Test	
	Before-Construction		After-Construction			
	Value	SE	Value	SE	Z	P-value
Through MRS route ($\hat{S}$)	0.7359	0.0963	0.5000	0.3536	0.6437	0.5198
Through ORS route ($\hat{S}$)	0.8838	0.0160	0.7929	0.0706	1.2557	0.2092
MRS to MRN ($\hat{S}*\Psi$)	0.7360	0.0963	0.5000	0.3536	0.6440	0.5196
MRS to ORN ($\hat{S}*\Psi$)	NA[1]	NA	NA	NA	NA	NA
MRS to RGU ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
MRS to CVP ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
ORS to MRN ($\hat{S}*\Psi$)	0.0331	0.0084	NA	NA	NA	NA
ORS to ORN ($\hat{S}*\Psi$)	0.2697	0.0208	NA	NA	NA	NA
ORS to RGU ($\hat{S}*\Psi$)	0.3627	0.0230	0.3429	0.0807	0.2360	0.8135
ORS to CVP ($\hat{S}*\Psi$)	0.2183	0.0192	0.4500	0.0787	2.8602	0.0042

Source: HTI this study.
Note: [1] NA = Not Applicable.

The 2011 steelhead survival results for the data comparing Before-Construction Period with During-Construction Period are presented in **Table 3-31** for the GLCB. For the GLCB, the overall steelhead survival through the ORS route in 2011 was 0.8838 (SE = 0.0160) Before-Construction Period and 0.7929 (SE = 0.0706) During-Construction Period (**Table 3-31**). The overall survival for the MRS route ranged from 0.7359 (SE = 0.0963) Before-Construction Period to 0.5000 (SE = 0.3536) During-Construction Period. There were no steelhead releases in the After-Construction Period of the GLCB. In both the ORS and MRS routes survival decreased from Before- to During-Construction Period at the GLCB, however not significantly (ORS Z = 1.256; P = 0.2092 and MRS Z = 0.644; P = 0.5198). The individual channel joint probability ($\hat{S}*\Psi$) through the ORS route ranged from 0.0331 (ORS to MRN) to 0.3627 (ORS to RGU) Before-Construction Period and from 0.3429 (ORS to RGU) to 0.4500 (ORS to CVP) During-Construction Period.

Table 3-31. 2011 Survival Results for Juvenile Steelhead "Predator Filter Employed" Data Comparing Before-Construction Period with During-Construction Period for the Grant Line Canal Barrier

Steelhead Survival Location	Grant Line Canal Barrier				Significance Test	
	Before-Construction		During-Construction			
	Value	SE	Value	SE	Z	P-value
Through MRS route ($\hat{S}$)	0.7359	0.0963	0.5000	0.3536	0.6437	0.5198
Through ORS route ($\hat{S}$)	0.8838	0.0160	0.7929	0.0706	1.2557	0.2092
MRS to MRN ($\hat{S}*\Psi$)	0.7360	0.0963	0.5000	0.3536	0.6440	0.5196
MRS to ORN ($\hat{S}*\Psi$)	NA[1]	NA	NA	NA	NA	NA
MRS to RGU ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
MRS to CVP ($\hat{S}*\Psi$)	NA	NA	NA	NA	NA	NA
ORS to MRN ($\hat{S}*\Psi$)	0.0331	0.0084	NA	NA	NA	NA
ORS to ORN ($\hat{S}*\Psi$)	0.2697	0.0208	NA	NA	NA	NA
ORS to RGU ($\hat{S}*\Psi$)	0.3627	0.0230	0.3429	0.0807	0.2360	0.8135
ORS to CVP ($\hat{S}*\Psi$)	0.2183	0.0192	0.4500	0.0787	2.8602	0.0042

Source: HTI this study.
Note: [1] NA = Not Applicable.

The proportions of juvenile Chinook Salmon that traveled through the MRS route versus the ORS route in 2011 are presented in **Tables 3-32**, **3-33**, and **3-34** for ORTB, MRB, and the GLCB, respectively. For Chinook Salmon, 97.3 percent, 98.4 percent, and 100 percent traveled through the ORS route Before-, During- and After-Construction Periods at the ORTB, respectively (**Table 3-32**). Conversely, 2.70 percent, 1.61 percent, and 0 percent traveled through the MRS route Before-, During- and After-Construction Periods of ORTB, respectively. For MRB, 97.3 percent and 99.3 percent of the Chinook Salmon traveled through the ORS route Before- and After-Construction Periods, respectively (**Table 3-33**). There were 2.70 percent and 0.66 percent Chinook Salmon that traveled through the MRS route Before- and After-Construction Periods of MRB, respectively. No Chinook Salmon releases occurred in the During-Construction Period of MRB. The proportions of Chinook Salmon that traveled through the ORS route were 97.4 percent and 99.5 percent Before- and During-Construction Periods at the GLCB, respectively (**Table 3-34**). Conversely, the proportion of Chinook Salmon that traveled through the MRS route was 2.6 percent and 0.5 percent Before- and During-Construction Periods at the GLCB, respectively. No Chinook Salmon releases occurred in the After-Construction Period of the GLCB.

Table 3-32. 2011 Route Proportion Results for Juvenile Chinook "Predator Filter Employed" Data Comparing Before-, During-, and After-Construction at the Old River at Tracy Barrier

Chinook Salmon Route Proportion	Old River Tracy Barrier								
	Before-Construction			During-Construction			After-Construction		
	Value	SE	N	Value	SE	N	Value	SE	N
MRS Route (Ψ)	0.0270	0.0108	5	0.0161	0.0113	2	0.0000	NA[1]	0
ORS Route (Ψ)	0.9730	0.0108	357	0.9839	0.0111	114	1.0000	NA	177

Source: HTI this study.
Note: [1] NA = Not Applicable.

Table 3-33. 2011 Route Proportion Results for Juvenile Chinook "Predator Filter Employed" Data Set Comparing Before-, During-, and After-Construction of Middle River Barrier

Chinook Salmon Route Proportion	Middle River Barrier								
	Before-Construction			During-Construction			After-Construction		
	Value	SE	N	Value	SE	N	Value	SE	N
MRS Route (Ψ)	0.0270	0.0108	5	No Data	No Data	No Data	0.0066	0.0046	2
ORS Route (Ψ)	0.9730	0.0108	357	No Data	No Data	No Data	0.9934	0.0046	291

Source: HTI this study.

Table 3-34. 2011 Route Proportion Results for Juvenile Chinook "Predator Filter Employed" Data Set Comparing Before-, During-, and After-Construction of Grant Line Canal Barrier

Chinook Salmon Route Proportion	Grant Line Canal Barrier								
	Before-Construction			During-Construction			After-Construction		
	Value	SE	N	Value	SE	N	Value	SE	N
MRS Route (Ψ)	0.0264	0.0092	6	0.0046	0.0046	1	No Data	No Data	No Data
ORS Route (Ψ)	0.9736	0.0092	436	0.9954	0.0046	212	No Data	No Data	No Data

Source: HTI this study.

The proportions of steelhead that traveled through the MRS route versus the ORS route in 2011 are presented in **Table 3-35** for ORTB and MRB, and in **Table 3-36** for the GLCB. For the steelhead, 94.2 percent and 95.2 percent traveled through the ORS route Before- and After-Construction Periods of ORTB and MRB, respectively. Conversely, 5.8 percent and 4.8 percent traveled through the MRS route Before- and After-Construction Periods of the ORTB and MRB, respectively. There were no steelhead releases for the During-Construction Period of the ORTB and MRB. For steelhead, 94.2 percent and 95.2 percent traveled through the ORS route Before- and During-Construction Periods at the GLCB, respectively. Conversely, 5.8 percent and 4.8 percent traveled through the MRS route Before- and During-Construction Periods at the GLCB, respectively. There were no steelhead releases in the After-Construction Period of the GLCB.

Table 3-35. 2011 Route Proportion Results for Juvenile Steelhead "Predator Filter Employed" Data Set Comparing Before-, During-, and After-Construction of Old River at Tracy Barrier

Steelhead Route Proportion	Old River Tracy and Middle River Barrier								
	Before-Construction			During-Construction			After-Construction		
	Value	SE	N	Value	SE	N	Value	SE	N
MRS Route (Ψ)	0.0584	0.0112	22	No Data	No Data	No Data	0.0476	0.0329	2
ORS Route (Ψ)	0.9416	0.0112	452	No Data	No Data	No Data	0.9524	0.0329	40

Source: HTI this study.

Table 3-36. 2011 Route Proportion Results for Juvenile Steelhead "Predator Filter Employed" Data Set Comparing Before-, During-, and After-Construction of Grant Line Canal Barrier

Steelhead Route Proportion	Grant Line Canal Barrier								
	Before-Construction			During-Construction			After-Construction		
	Value	SE	N	Value	SE	N	Value	SE	N
MRS Route (Ψ)	0.0584	0.0112	22	0.0476	0.0329	2	No Data	No Data	No Data
ORS Route (Ψ)	0.9416	0.0112	452	0.9524	0.0329	40	No Data	No Data	No Data

Source: HTI this study.

3.6 SUCCESSFUL PASSAGE AND ROUTE THROUGH THE OLD RIVER AT TRACY BARRIER

The expected ratio of the proportion of emigrating salmonids successfully passing the ORTB to the proportion not successfully passing was obtained from the survival ($\hat{S}$) estimates found in Section 3.5 *Survival Modeling*. The relative proportion expected to successfully pass was equivalent to the survival expected in that segment of the Old River channel before ORTB construction began. So $\hat{S}$ for each species and year were used to determine the Predicted ORTB Survival Rate (S_P). The derived values of S_P and its complement ($1-S_P$) may be found in **Table 3-37**.

Table 3-37. Predicted Old River at Tracy Barrier Survival Rate and its Complement for Chinook Salmon and Steelhead in 2010 and 2011 in the Before-Construction Period at the Old River at Tracy Barrier				
Parameter	**Chinook Salmon 2010**	**Steelhead 2010**	**Chinook Salmon 2011**	**Steelhead 2011**
Survival ($\hat{S}$)	0.6191	0.8931	0.6633	0.8838
Minimum distance travelled: ORS to CVP (km)	18.14	18.14	18.14	18.14
Survival per km (S_{pk})	0.9739	0.9938	0.9776	0.9932
Length (L) of 2D Array (km)	0.197	0.197	0.217	0.217
Predicted ORTB Survival Rate (S_P)	0.9948	0.9988	0.9951	0.9985
Complement ($1-S_P$)	0.0052	0.0012	0.0049	0.0015

Source: ESA this study.
Note: km = kilometer.

3.6.1 2010 Juvenile Chinook Salmon

In 2010, no tagged Chinook Salmon approached the ORTB after the ORTB was completed on June 3. Therefore, no ORTB route passage data were available for Chinook Salmon in 2010.

3.6.2 2010 Juvenile Steelhead

In 2010, 90 tagged steelhead were released at the 2D Fish Release Site (**Figure 2-5**). Twenty-two (24.4 percent) of the 90 fish were never detected 1.8 km (1.1 mi) downstream at the ORTB (**Table 3-38**). Thus, 68 steelhead were detected in the area of the ORTB and 18 of these passed through/over the barrier.

The proportion expected to successfully pass was estimated from the survival modeling results and apportioned according to the length of channel queried by the hydrophone array; that proportion expected to pass was 0.9988 (**Table 3-37**). This ratio of 18 fish passing and 50 fish not passing deviated significantly from the ratio expected if the expected ratio of successful passage:no passage was 0.9988:0.0012 (Kruskal-Wallis chi-squared = 30,574.000; $P = 2.2 \times 10^{-16}$). This suggests that in 2010, the ORTB was a significant impediment to migration of juvenile steelhead.

Table 3-38. 2010 Steelhead Old River at Tracy Barrier Route Selection					
Number of Steelhead By Route Selected					
Culvert	**Weir**	**Undetermined Passage Route**	**No Passage**	**Not Detected at ORTB**	**Total**
5	8	5	50	22	90

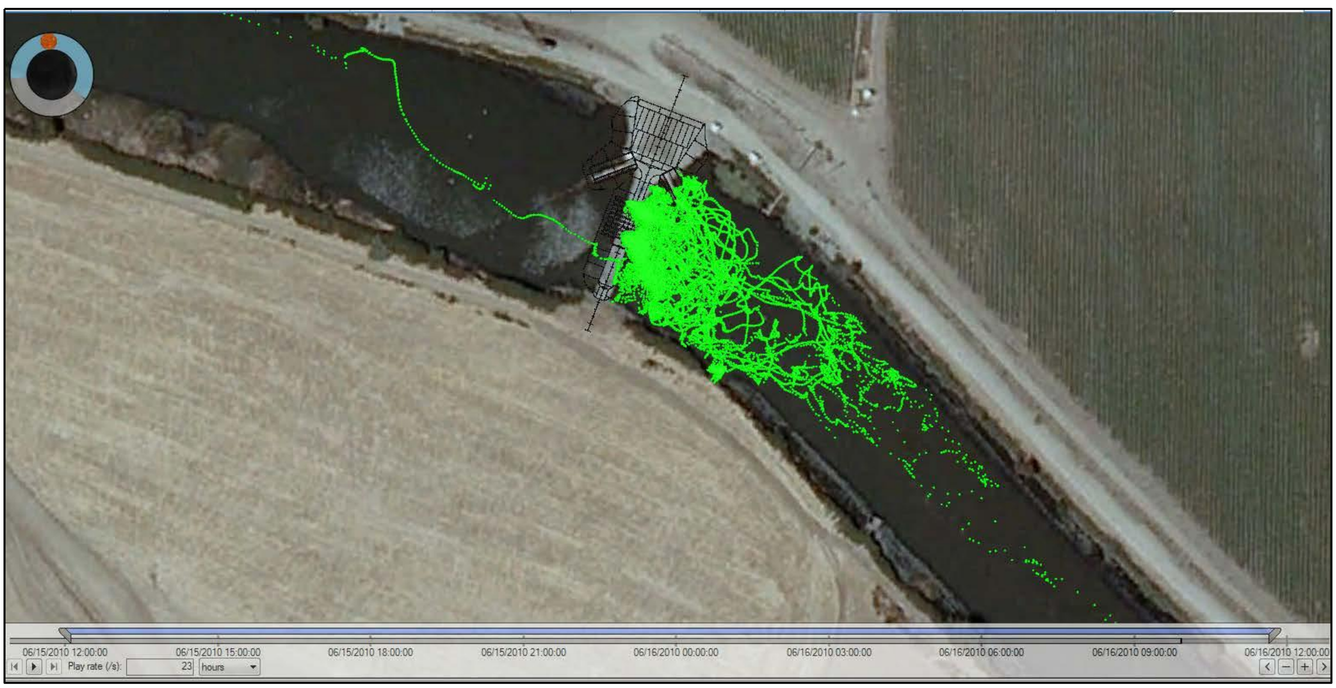
Source: ESA this study.

In 2010, the route selected was determined for only 13 steelhead. Two of these passage routes are shown in **Figures 3-3** and **3-4**. The ratio of route selected five culvert:eight weir (**Table 3-38**) did not deviate from the ratio expected if route selection was random, 0.5:0.5 (Kruskal-Wallis chi-squared = 0.692; P = 0.4054). Thus, neither the culvert nor the weir route were preferred by steelhead in 2010.

Source: HTI this study.

Note: Steelhead 2143.04 passed the ORTB downstream through a culvert on June 7, 2010 at 21:36:01 hours. It was certain the passage was made through a culvert because at the time that the 2D track (pictured) was recorded, the water elevation on both sides of the ORTB was more than 30 cm (1 ft) below the crest of the weir.

Figure 3-3. Steelhead 2143.04 Culvert Passage



Source: HTI this study.

Note: Steelhead 2493.04 passed the ORTB downstream over the weir on June 16, 2010 at 11:31:56 hours. It was certain the passage was made over the weir from the 2D track and because at that time the water elevation on both sides of the ORTB was more than 10 cm (0.34 ft) above the crest of the weir.

Figure 3-4. Steelhead 2493.04 Weir Passage

3.6.3 2011 Juvenile Chinook Salmon

In 2011, 198 tagged Chinook Salmon were released 8.2 km (5.1 mi) upstream of the ORTB (**Figure 2-11**). Seventy-one (35.9 percent) of the 198 fish were never detected 8.2 km (5.1 mi) downstream at the ORTB (**Table 3-39**). Thus, 127 Chinook Salmon were detected in the area of the ORTB and 120 of these fish passed through/over the barrier. This ratio of 120 fish passing and 7 fish not passing deviated significantly from the ratio expected 0.9951:0.0049 (**Table 3-39**) (Kruskal-Wallis chi-squared = 65.700; P = 5.25 x 10^{-16}). This passage success was a big improvement compared to the 2010 steelhead result in which 18 fish passed while 50 did not pass. However, the ORTB was a statistically-significant impediment to Chinook Salmon passage in 2011.

Table 3-39. 2011 Juvenile Chinook Salmon Old River at Tracy Barrier Route Selection

Number of Chinook Salmon By Route Selected					
Culvert	Weir	Undetermined Passage	No Passage (upstream only)	Not Detected at ORT	Total
64	15	41	7	71	198

Source: ESA this study.

In 2011, the route selected was determined for 79 Chinook Salmon. The ratio of route selected 64 culvert:15 weir (**Table 3-39**) deviated significantly from the ratio expected if route selection was random, 0.5:0.5 (Kruskal-Wallis chi-squared = 30.392; P = 3.52 x 10^{-8}). It is concluded that the culvert route was preferred by Chinook Salmon in 2011.

3.6.4 2011 Juvenile Steelhead

In 2011, 120 tagged steelhead were released 8.2 km (5.1 mi) upstream of the ORTB (**Figure 2-11**). Sixty-eight (56.7 percent) of the 120 steelhead were never detected 8.2 km (5.1 mi) downstream at the ORTB (**Table 3-40**). Thus, 52 steelhead were detected in the area of the ORTB and 36 of these fish passed through/over the barrier. This ratio of 36 fish passing and 16 fish not passing deviated significantly from the ratio expected 0.9985:0.0015 (**Table 3-40**) (Kruskal-Wallis chi-squared = 3,306.100; P = 2.2 x 10^{-16}). The 2011 steelhead passage success was an improvement compared to the 2010 steelhead result in which 18 fish passed while 50 did not pass. However, the ORTB was still a statistically-significant impediment to steelhead passage in 2011.

Table 3-40. 2011 Juvenile Steelhead Old River at Tracy Barrier Route Selection

Number of Steelhead By Route Selected					
Culvert	Weir	Undetermined Passage	No Passage (upstream only)	Not Detected at ORT	Total
24	0	12	16	68	120

Source: Environmental Science Associates this study.

In 2011, the route selected was determined for 24 juvenile steelhead. The ratio of route selected 24 culvert:0 weir (**Table 3-40**) deviated significantly from the ratio expected if route selection was random, 0.5:0.5 (Kruskal-Wallis chi-squared = 24.0; P = 9.6 x 10^{-7}). It is concluded that the culvert route was preferred by steelhead in 2011.

3.7 TIME-IN-VICINITY OF BARRIERS

TIV was analyzed for the three SDABs (MRB, GLCB, and ORTB) over two years (2010 and 2011) for tagged Chinook Salmon and steelhead at two barrier areas (upstream and downstream). For every comparison the Shapiro-Wilks normality test showed the data to not be normal. Thus, no ANOVA results are reported for TIV. All hypothesis tests were conducted with Kruskal-Wallis tests.

3.7.1 Middle River Barrier

3.7.1.1 *2010 Juvenile Chinook Salmon, Steelhead, and Predatory Fish*

In 2010 no tagged juvenile Chinook Salmon, juvenile steelhead, or predatory fish approached the MRB. Thus, no estimates of TIV were available. No hypothesis testing was possible that compared predatory fishes TIV, Chinook Salmon TIV, or steelhead TIV.

3.7.1.2 *2011 Juvenile Chinook Salmon*

Upstream Area Combined with Both Upstream and Downstream Areas

In 2011, Chinook Salmon only approached the MRB during the Before-Construction and the After-Construction Periods. Therefore, there were no data available for the During-Construction Period. At the MRB, five Chinook Salmon released at Durham Ferry (**Figure 2-11**) approached the MRB in the Category 1 (Upstream) or Category 3 (Both Upstream and Downstream) areas. Of these five, three approached in the Before-Construction Period and the TIV ranged from 0.01 to 0.57 hours for these fish (**Table 3-41**). In the After-Construction Period, two Chinook Salmon approached the MRB Category 1 (Upstream) area and Category 3 (Both Upstream and Downstream) areas and the TIV ranged from 0.27 to 4.39 hours (**Table 3-41**). No hypothesis test was possible because only two fish were detected in the After-Construction Period.

Table 3-41. 2011 Juvenile Chinook Salmon TIV at the Middle River Barrier Upstream Area Combined with Both Upstream and Downstream Areas

Construction Period	Minimum TIV (hours)	Mean (Standard Deviation) TIV (hours)	Maximum TIV (hours)	Number of Fish (N)
Before	0.01	0.32 (0.225)	0.57	3
After	0.27	2.33 (2.91)	4.39	2

Source: ESA this study.

Downstream Area Combined with Both Upstream and Downstream Areas

No downstream area analysis was possible in 2011 at the MRB. There were several reasons for this: 1) there were no Chinook Salmon TIV observations in the Category 2 (Downstream) area; 2) there were only two Chinook Salmon TIV observations in the Category 3 (Both Upstream and Downstream) areas; and 3) the two TIV observations in the Category 3 area were used in the upstream analysis (**Table 3-41**).

3.7.1.3 *2011 Juvenile Steelhead*

Upstream Area Combined with Both Upstream and Downstream Areas

In 2011, steelhead only approached the MRB during the Before-Construction and the After-Construction Periods. Therefore, there were no data available for the During-Construction Period. At the MRB, 27 steelhead released at Durham Ferry (**Figure 2-11**) approached the MRB (**Table 3-42**) in the Category 1 (Upstream) or Category 3

(Both Upstream and Downstream) areas. Of these 27 fish, 25 fish approached in the Before-Construction Period and the TIV ranged from 0.02 to 1.44 hours (**Table 3-42**). In the After-Construction Period, two steelhead approached the MRB areas and the TIV ranged from 0.10 to 2.00 hours for these fish. No hypothesis test was possible because only two fish were detected in the After-Construction Period.

Table 3-42. 2011 Juvenile Steelhead TIV at the Middle River Barrier Upstream Area Combined with Both Upstream and Downstream Areas

Construction Period	Minimum TIV (hours)	Mean (Standard Deviation) TIV (hours)	Maximum TIV (hours)	Number of Fish (N)
Before	0.02	0.29 (0.341)	1.44	25
After	0.10	0.79 (1.05)	2.00	2

Source: ESA this study.

Downstream Area Combined with Both Upstream and Downstream Areas

In 2011, steelhead only approached the MRB during the Before-Construction and the After-Construction Periods. Therefore, there were no data available for the During-Construction Period. At the MRB, 28 steelhead released at Durham Ferry (**Figure 2-11**) approached the MRB (**Table 3-43**) in the Category 2 (Downstream) or Category 3 (Both Upstream and Downstream) areas. However, 17 of these fish were Category 3 (Both Upstream and Downstream) area fish that appeared in the analysis presented in **Table 3-42**. In addition, more unique steelhead juveniles TIV observations were found in the first analysis (Category 1 combined with Category 3) than were found in second analysis (Category 2 combined with Category 3). There was considerable overlap from these 17 fish. Therefore, the results of these analyses must be viewed with caution. In addition, since there were only two observed steelhead in the After-Construction Period, no hypothesis test could be conducted.

Table 3-43. 2011 Juvenile Steelhead TIV at the Middle River Barrier Downstream Area Combined with Both Upstream and Downstream Areas

Construction Period	Minimum TIV (hours)	Mean (Standard Deviation) TIV (hours)	Maximum TIV (hours)	Number of Fish (N)
Before	0.01	0.28 (0.326)	1.44	26
After	0.08	0.15 (0.110)	0.28	2

Source: ESA this study.

3.7.1.3 *2011 Predatory Fish*

No tagged predatory fish were detected in the area of the MRB in 2011. Thus, no estimates of the TIV could be obtained. No hypothesis testing was possible that compared the TIV of predatory fishes with Chinook Salmon or steelhead.

3.7.2 Grant Line Canal Barrier

3.7.2.1 *2010 Juvenile Chinook Salmon*

In 2010, there were 286 juvenile Chinook Salmon that approached the GLCB area and the mean TIV for this group of fish of 0.27 hours was similar to the mean for the ORTB of 0.20 hours (**Table 3-44**).

Table 3-44. 2010 Chinook Salmon TIV at the Grant Line Canal Barrier and the Old River at Tracy Barrier				
Barrier	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Number of Fish (N)**
Grant Line Canal	0.03	0.27 (0.351)	2.51	286
Old River at Tracy	0.12	0.20 (0.066)	0.26	3
Source: ESA this study.				

Downstream Area Combined with Both Upstream and Downstream Areas

As noted previously in Section 3.5.3 *2010 Survival Results Related to the Temporary Barrier Construction*, no tagged Chinook Salmon approached the GLCB in the During- or After-Construction Periods because the tagged fish were all released during the Before-Construction Period in 2010. In addition, since no barrier staging or construction had begun, it meant that the upstream and downstream areas were essentially the same for a migrating salmonid. Thus, no comparisons could be made of the upstream areas separately from the downstream areas for Chinook Salmon in 2010 at the GLCB.

3.7.2.2 *2010 Juvenile Steelhead*

Downstream Area Combined with Both Upstream and Downstream Areas

In 2010, tagged steelhead only approached the GLCB during the Before-Construction Period. No hypothesis test was possible since no steelhead approached the GLCB in the During or After-Construction Periods. Observations were obtained in Category 2 (Downstream) and Category 3 (Both Upstream and Downstream) areas (**Table 3-45**).

Table 3-45. 2010 Steelhead TIV at the Grant Line Canal Barrier with the Downstream Area Combined with Both Upstream and Downstream Areas				
Construction Period	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Number of Fish (N)**
Before	0.10	0.68 (0.741)	2.75	20
Source: ESA this study.				

3.7.2.3 *2010 Predatory Fish and Steelhead*

There were only two predatory fish detected at the GLCB in 2010, both Striped Bass. One of these striped bass arrived in the Before-Construction Period and the other arrived in the During-Construction Period. The descriptive statistics are reported in **Table 3-46**. The number of predators detected at the GLCB in 2010 was too small to allow hypothesis testing. However, the observations were consistent with the hypothesis that, during construction, predatory fish remain in the area of a barrier longer than they do before construction begins.

Table 3-46. 2010 Predatory Fish and Juvenile Steelhead TIV at the Grant Line Canal Barrier with Both Upstream and Downstream Areas					
Fish Group	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Species**	**Number of Fish (N)**
Predatory Fish, Before Construction	0.17	0.19(NA)	0.22	Striped Bass	1
Predatory Fish, During Construction	1.23	1.50(NA)	1.77	Striped Bass	1
Juvenile Salmonids, Before Construction	0.1	0.68 (0.741)	2.75	Steelhead	20

Source: ESA this study.

Note: For both Striped Bass the minimum TIV was observed in the upstream area of the barrier's footprint and the maximum TIV was observed in the downstream area of the GLCB.

3.7.2.4 *2011 Juvenile Chinook Salmon and Steelhead*

In 2011, only tagged juvenile Chinook Salmon and steelhead were used in the TIV analyses if they had successfully passed through the predator filter and were determined to be a "salmonid." This led to a reduced sample size at times but increased the probability that the analysis was evaluating juvenile salmonids and not tags that had been consumed by predatory fish.

3.7.2.5 *2011 Juvenile Chinook Salmon*

GLCB Upstream Area

In 2011, tagged Chinook Salmon only approached the GLCB Category 1 (Upstream) area during the Before- and During-Construction Periods. No Category 2 (Downstream) area fish were observed during the After-Construction Period in 2011. At the GLCB, 224 Chinook Salmon approached the GLCB in the Before-Construction Period and the TIV ranged from 0.03 to 19.66 hours (**Table 3-47**). At the GLCB, 117 Chinook Salmon approached in the During-Construction Period and the TIV ranged from 0.02 to 7.27 hours. There was no significant difference between the During-Construction TIV and the Before-Construction Period TIV in the upstream area (Kruskal-Wallis chi-squared = 0.1584; P = 0.9239).

Table 3-47. 2011 Juvenile Chinook Salmon TIV at the Grant Line Canal Barrier Upstream Area				
Construction Period	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Number of Fish (N)**
Before	0.03	0.68 (2.653)	19.66	224
During	0.02	0.28 (1.031)	7.27	117

Source: ESA this study.

GLCB Downstream Area Combined with Both Upstream and Downstream Areas

In 2011, tagged Chinook Salmon only approached the GLCB Category 2 (Downstream) and Category 3 (Both Upstream and Downstream) areas during the Before- and During-Construction Periods. No Chinook Salmon were observed in the downstream area of a closed GLCB during the After-Construction Period in 2011. At the GLCB, 207 Chinook Salmon approached the GLCB Category 2 and 3 areas in the Before-Construction Period and the TIV ranged from 0.01 to 0.67 hours (**Table 3-48**). At the GLCB, 113 Chinook Salmon approached the downstream area in the During-Construction Period and the TIV ranged from 0.005 to 1.33 hours and there was no statistically significant difference between the During-Construction TIV and the Before-Construction Period TIV (Kruskal-Wallis chi-squared = 0.7952; P = 0.6719).

Table 3-48. 2011 Juvenile Chinook Salmon TIV at the Grant Line Canal Barrier Downstream Area Combined with Both Upstream and Downstream Areas

Construction Period	Minimum TIV (hours)	Mean (Standard Deviation) TIV (hours)	Maximum TIV (hours)	Number of Fish (N)
Before	0.01	0.05 (0.053)	0.67	207
During	0.005	0.06 (0.128)	1.33	113

Source: ESA this study.

2011 Predatory Fish and Juvenile Chinook Salmon

No tagged predatory fish approached the GLCB in 2011. Therefore, there was no hypothesis test for predatory fish in 2011.

3.7.2.6 *2011 Juvenile Steelhead*

In 2011, tagged steelhead only approached the upstream area of the GLCB during the Before-Construction Period and the During-Construction Period. No Category 1 observations were obtained upstream of the closed GLCB during the After-Construction Period in 2011. In the GLCB upstream area, 301 steelhead released at Durham Ferry (**Figure 2-11**) approached during the Before-Construction Period. In the Before-Construction Period, the TIV ranged from 0.02 to 4.08 hours (**Table 3.49**). At the GLCB, 21 steelhead were observed in the upstream area in the During-Construction Period. In the During-Construction Period, the TIV ranged from 0.04 to 6.41 hours (**Table 3.49**). The During-Construction Period TIV was significantly longer than the Before-Construction Period TIV (Kruskal-Wallis chi-squared = 17.764; P = 0.00003).

Table 3-49. 2011 Juvenile Steelhead TIV at the Grant Line Canal Barrier Upstream Area

Construction Period	Minimum TIV (hours)	Mean (Standard Deviation) TIV (hours)	Maximum TIV (hours)	Number of Fish (N)
Before	0.02	0.24 (0.713)	4.08	301
During	0.04	2.58 (2.955)	6.41	21

Source: ESA this study.

In 2011, tagged steelhead only approached the downstream area of the GLCB during the Before-Construction Period and the During-Construction Period. No Category 2 observations were obtained downstream of the closed GLCB during the After-Construction Period in 2011. In the GLCB downstream area, 262 steelhead released at Durham Ferry (**Figure 2-11**) approached during the Before-Construction Period. In the Before-Construction Period, the TIV ranged from 0.0003 to 6.21 hours (**Table 3-50**). At the GLCB, 24 steelhead were detected in the downstream area in the During-Construction Period. In the During-Construction Period, the TIV ranged from 0.01 to 6.19 hours (**Table 3-50**). The During-Construction Period TIV was significantly longer than the Before-Construction Period TIV (Kruskal-Wallis chi-squared = 7.020; P = 0.0081).

Table 3-50. 2011 Juvenile Steelhead TIV at the Grant Line Canal Barrier Downstream Area				
Construction Period	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Number of Fish (N)**
Before	0.0003	0.14 (0.662)	6.21	262
During	0.01	2.17 (2.868)	6.19	24

Source: ESA this study.

3.7.3 Old River at Tracy Barrier

3.7.3.1 *2010 Juvenile Chinook Salmon*

In 2010, only three juvenile Chinook Salmon released at the 2010 Fish Release Site (**Figure 2-5**) approached the ORTB. The TIV ranged from 0.12 to 0.26 hours for these fish (**Table 3-44**). There were insufficient observations to conduct hypothesis testing for Chinook Salmon at the ORTB in 2010.

3.7.3.2 *2011 Juvenile Chinook Salmon*

ORTB Upstream Area

In 2011, tagged Chinook Salmon approached the ORTB upstream area during the Before-, During- and the After-Construction Periods. At the ORTB upstream area, 130 Chinook Salmon released at Durham Ferry (**Figure 2-11**) approached the ORTB (**Table 3-51**). Of these 133 fish, 13 fish approached in the Before-Construction Period and the TIV ranged from 0.03 to 0.78 hours. In the During-Construction Period seven Chinook Salmon approached the ORTB upstream area and the TIV ranged from 0.05 to 7.34 hours. The Before-Construction Period TIV observations were significantly shorter than the During-Construction Period TIV observations (Kruskal-Wallis chi-squared = 5.841; P = 0.0156).

In the After-Construction Period, 113 Chinook Salmon approached the ORTB upstream area and the TIV ranged from 0.06 to 16.12 hours. The Before-Construction Period TIV observations were significantly shorter than the After-Construction Period TIV observations (Kruskal-Wallis chi-squared = 25.329; P = 0.0000005). The During-Construction Period TIV observations were not significantly different than the After-Construction Period TIV observations (Kruskal-Wallis chi-squared = 0.429; P = 0.5124). It is concluded that the ORTB caused a statistically significant delay of juvenile Chinook Salmon migration in 2011 on the upstream side of the barrier and this delay began during construction and not only after closure of the ORTB.

Table 3-51. 2011 Juvenile Chinook Salmon TIV at the Old River at Tracy Barrier Upstream Area				
Construction Period	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Number of Fish (N)**
Before	0.03	0.12 (0.201)	0.78	13
During	0.05	2.14 (3.061)	7.34	7
After	0.06	1.38 (2.283)	16.12	113

Source: ESA this study.

ORTB Downstream Area

In 2011, 128 tagged Chinook Salmon approached the ORTB downstream area (Category 2) during the Before-, During- and the After-Construction Periods (**Table 3-52**). Of these 128 fish, 13 fish approached in the Before-Construction Period and the TIV ranged from 0.04 to 1.14 hours (**Table 3-52**). In the During-Construction Period, eight juvenile Chinook Salmon approached the ORTB downstream area and the TIV ranged from 0.02 to 0.49 hours. In the After-Construction Period, 107 Chinook Salmon approached the ORTB downstream area and the TIV ranged from 0.02 to 5.72 hours (**Table 3-52**).

Multiple planned comparisons of the TIV observation sets were executed. In Section 2.19 *Survival Modeling*, the Dunn- Šidák equation was reported that provided the critical α', 0.0170, for three comparisons: Before- vs. During-Construction Periods; Before- vs. After-Construction Periods; and During- vs. After- Construction Periods. For the first of the three comparisons, Before-Construction Period TIV observations were not significantly different than the During-Construction Period observations (Kruskal-Wallis chi-squared = 0.257; P = 0.6121).

In a second comparison, the After-Construction Period TIV observations were not significantly different from the Before-Construction Period TIV observations (Kruskal-Wallis chi-squared = 5.474; P = 0.0193) because 0.0193 > 0.0170 (the critical α'). The During-Construction Period TIV observations were not significantly different than the After-Construction Period TIV observations (Kruskal-Wallis chi-squared = 0.175; P = 0.6760). It is concluded that on the downstream side of the ORTB there was no statistically significant delay in Chinook Salmon migration caused by the barrier.

Table 3.52. 2011 Juvenile Chinook Salmon TIV at the Old River at Tracy Barrier Downstream Area

Construction Period	Minimum TIV (hours)	Mean (Standard Deviation) TIV (hours)	Maximum TIV (hours)	Number of Fish (N)
Before	0.04	0.18 (0.292)	1.14	13
During	0.02	0.22 (0.182)	0.49	8
After	0.02	0.34 (0.628)	5.72	107

Source: ESA this study.

Upstream Compared to Downstream

In 2011, tagged Chinook Salmon approached the Category 1 (Upstream) and Category 2 (Downstream) areas in the After-Construction Period. At the ORTB upstream area, 113 Chinook Salmon had TIVs that ranged from 0.06 to 16.12 hours (**Table 3-53**). In the ORTB downstream area, 107 Chinook Salmon passed through and the TIV ranged from 0.02 to 5.72 hours. The TIV observations in the upstream area were significantly greater in duration than the TIV observations in the downstream area (Kruskal-Wallis chi-squared = 46.987; $P = 7.14 \times 10^{-12}$). It was concluded that the closed ORTB, with flap gates tied open, caused a statistically significant delay in Chinook Salmon migration on the upstream side of the barrier compared to those on the downstream side.

Table 3-53. 2011 Juvenile Chinook Salmon at the Old River at Tracy Barrier during the After-Construction Period				
Barrier Area	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Number of Fish (N)**
Category 1 (Upstream)	0.06	1.38 (2.283)	16.12	113
Category 2 (Downstream)	0.02	0.34 (0.628)	5.72	107

Source: HTI and ESA this study.
Note: These data were derived from the 1D and 2D hydrophone arrays combined.

2011 Predatory Fish Before- and During-Construction Periods

In 2011, tagged predatory fish only approached the ORTB Category 3 (Both Upstream and Downstream) area during the Before-Construction Period. Thirty Chinook Salmon approached the ORTB in the Before-Construction Period and the TIV ranged from 0.04 to 2.05 hours (**Table 3-54**). One predator, a Striped Bass, approached the Category 3 area and executed two track segments that ranged from 0.26 to 8.23 hours. No hypothesis test was possible because only one Striped Bass entered the area during the Before-Construction Period. An individual fish could produce two track segments, e.g., one on the upstream hydrophone array and one on the downstream hydrophone array. So, it was possible for one fish to produce a mean and standard deviation.

In the During-Construction Period, no predatory fish executed track segments in the Category 1 (Upstream) area or the Category 2 (Downstream) area. In the During-Construction Period, seven tagged Chinook Salmon were detected in the upstream area and those same seven then exhibited track segments in the downstream area—these fish were part of the groups found in **Tables 3-51** and **3-52**. However, not one of these tagged Chinook Salmon was tracked in a manner that required a Category 3 (Both Upstream and Downstream) areas status. It was concluded that no direct statistical comparison could be made between predatory fish TIV and Chinook Salmon TIV in the During-Construction Period.

Table 3-54. 2011 Chinook Salmon and One Predatory Fish TIV at Old River at Tracy Barrier					
Construction Period	**Species**	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Number of Fish (N)**
Before	Chinook Salmon	0.04	0.37 (0.378)	2.05	30
Before	Striped Bass	0.26	4.24 (5.638)	8.23	1

Source: ESA this study.

After-Construction Period – Categories 2 and 3 Combined

There were only six predatory fish that spent time in the Category 2 (Downstream) and Category 3 (Both Upstream and Downstream) areas of the ORTB during the After-Construction Period and their TIVs ranged from 0.44 to 103.96 hours (**Table 3-55**). There were 109 tagged Chinook Salmon that spent time in the Category 2 and 3 areas and the TIV ranged from 0.02 to 5.72 hours (**Table 3-55**). The Chinook Salmon TIV observations were significantly shorter in duration than the predatory fish TIV observations (Kruskal-Wallis chi-squared = 17.416; P = 0.00003). It is concluded that Chinook Salmon track segments from the downstream area combined with track segments from both the upstream and downstream areas were significantly shorter than predatory fish TIV observations with the same types of track segments.

Table 3-55. 2010 Predatory Fish TIV and Juvenile Chinook Salmon TIV that were Detected at the Old River at Tracy Barrier Downstream Area Combined with Both Upstream and Downstream Areas					
Fish Group	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Species**	**Number of Fish (N)**
Predatory Fish	0.44	29.18 (38.102)	103.96	Striped Bass	4
				Largemouth Bass	1
				White Catfish	1
Juvenile Salmonids	0.02	0.37 (0.696)	5.72	Chinook Salmon	109
Source: ESA this study.					

3.7.3.3 *2010 Juvenile Steelhead*

ORTB Upstream Area

In 2010, tagged steelhead only approached the ORTB upstream area during the Before-Construction and the After-Construction Periods (**Table 3-56**). There were no data available for the During-Construction Period. At the ORTB upstream area, 58 steelhead released at the 2D Fish Release Site (**Figure 2-5**) approached the ORTB. Of these 58 fish, only 2 fish approached in the Before-Construction Period and the TIV ranged from 0.27 to 0.85 hours (**Table 3-56**). In the After-Construction Period, 56 steelhead approached the ORTB upstream area and the TIV ranged from 0.32 to 93.35 hours. Insufficient sample size existed to conduct a hypothesis test with only two steelhead in the Before-Construction Period. However, there was very little overlap in the ranges of the TIVs of these two groups (**Table 3-56**). It is concluded that the delay of steelhead in the Before- and After-Construction Periods should be studied further; a larger sample size might allow a clear resolution of the hypothesis that these TIV observation sets are different.

Table 3-56. 2010 Juvenile Steelhead TIV that were Detected at the Old River at Tracy Barrier Upstream Area				
Construction Period	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Number of Fish (N)**
Before	0.27	0.49 (0.317)	0.85	2
After	0.32	14.65 (18.481)	93.35	56
Source: ESA this study.				

2010 Predatory Fish Compared to Juvenile Steelhead Upstream Area

In 2010, 56 tagged steelhead passed through the ORTB upstream area during the After-Construction Period and the TIV ranged from 0.32 to 93.35 hours (**Table 3-57**). Eight tagged predatory fish spent time in the ORTB upstream area and the TIV ranged from 0.89 to 172.52 hours (**Table 3-57**). The steelhead TIV observations were not significantly different from the predatory fish TIV observations (Kruskal-Wallis chi-squared = 0.7787; P = 0.3775). It is concluded that there was no statistically significant difference but a considerable differences existed between all the descriptive statistics reported for the two groups, with predatory fish TIV greater in every category. These differences could be biologically significant and it is suggested that further research in this area may be warranted.

Table 3-57. 2010 Predators and Juvenile Steelhead TIV that were Detected at the Old River at Tracy Barrier Upstream Area					
Fish Group	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Species**	**Number of Fish (N)**
Predatory Fish	0.89	43.45 (59.292)	172.52	Striped Bass	3
				Largemouth Bass	4
				White Catfish	1
Juvenile Salmonids	0.32	14.65 (18.481)	93.35	Steelhead	56
Source: ESA this study.					

2010 Steelhead Downstream

In 2010, tagged steelhead only approached the ORTB downstream area during the After-Construction Period which made comparisons between construction periods impossible. Descriptive statistics were calculated for the ORTB downstream area and are reported as part of the analysis ORTB "2010 Predatory Fish Compared to Juvenile Steelhead Downstream Area" that follows next.

2010 Predatory Fish Compared to Juvenile Steelhead Downstream Area

Fifteen tagged steelhead passed through the ORTB downstream area in 2010 and the TIV ranged from 0.11 to 21.85 hours (**Table 3-58**). Five tagged predatory fish spent time in the ORTB downstream area and the TIV ranged from 0.03 to 39.98 hours. The steelhead TIV observations were not significantly different from the predatory fish TIV observations (Kruskal-Wallis chi-squared = 2.608; P = 0.1064). It is concluded that there was no statistically significant difference, but a considerable difference between the means of the two groups existed. These observations suggested that further research in this area may be justified.

Table 3.58. 2010 Predatory Fish TIV and Juvenile Steelhead TIV that were Detected at the Old River at Tracy Barrier Downstream Area					
Fish Group	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Species**	**Number of Fish (N)**
Predatory Fish	0.03	16.36 (16.483)	39.98	Striped Bass	4
				Largemouth Bass	1
Juvenile Salmonids	0.11	2.99 (5.969)	21.85	Steelhead	15
Source: ESA this study.					

2010 Juvenile Steelhead Downstream Area

In 2010, only eight tagged steelhead approached the ORTB downstream area during the After-Construction Period which made comparisons between construction periods impossible. Descriptive statistics were calculated for the ORTB downstream area steelhead TIV observations in the After-Construction Period and these statistics are included in **Table 3-59** which also includes predatory fish TIV data.

Table 3-59. 2010 Predatory Fish TIV and Juvenile Steelhead TIV that were Detected at the Old River at Tracy Barrier Downstream Area					
Fish Group	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Species**	**Number of Fish (N)**
Predatory Fish	0.03	16.36 (16.483)	39.98	Striped Bass	4
				Largemouth Bass	1
Juvenile Steelhead	0.27	1.04 (0.710)	2.20	Steelhead	8
Source: ESA this study.					

2010 Predatory Fish Compared to Juvenile Steelhead Upstream

Eight tagged steelhead passed through the ORTB downstream area in 2010 and the TIV ranged from 0.27 to 2.20 hours for these fish (**Table 3-59**). Five tagged predatory fish spent time in the ORTB downstream area and the TIV ranged from 0.03 to 39.98 hours. The steelhead TIV observations were not significantly different from the predatory fish TIV observations (Kruskal-Wallis chi-squared = 2.535; P = 0.1113). It is concluded that there was no statistically significant difference, but a considerable difference between the means of the two groups existed. In addition, sample sizes were just five predatory fish and eight steeelhead. These observations suggested that further research in this area may be warranted .

3.7.3.4 *2011 Juvenile Steelhead*

ORTB Upstream Area

In 2011, tagged steelhead only approached the ORTB upstream area during the Before-Construction Period and the After-Construction Period. There were no data available for the During-Construction Period. At the ORTB upstream area, 65 steelhead released at Durham Ferry (**Figure 2-11**) approached the ORTB (**Table 3-60**). Of these 65 fish, 15 fish approached in the Before-Construction Period and the TIV ranged from 0.02 to 1.70 hours. In the After-Construction Period, 50 steelhead approached the ORTB upstream area and the TIV ranged from 0.07 to 39.98 hours. The After-Construction Period TIV observations were significantly longer than the Before-Construction Period TIV observations (Kruskal-Wallis chi-squared = 24.371; P = 0.0000008). It is concluded that the ORTB caused a statistically-significant delay in steelhead migration in 2011 on the upstream side of the barrier. It is unknown how many tagged steelhead in this analysis were actually consumed by a predator.

Table 3-60. 2011 Juvenile Steelhead TIV that were Detected at the Old River at Tracy Barrier Upstream Area				
Construction Period	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Number of Fish (N)**
Before	0.02	0.25 (0.462)	1.70	15
After	0.07	6.69 (9.113)	39.98	50
Source: ESA this study.				

ORTB Downstream Area

In 2011, 48 tagged steelhead released at Durham Ferry (**Figure 2-11**) approached the ORTB downstream area during the Before-Construction Period and the After-Construction Period. There were no data available for the During-Construction Period. Of these 48 fish, 14 approached in the Before-Construction Period and the TIV ranged from 0.04 to 5.73 hours (**Table 3-61**). In the After-Construction Period, four juvenile steelhead approached the ORTB downstream area and the TIV ranged from 0.10 to 0.17 hours. The After-Construction Period TIV observations were not significantly different from the Before-Construction Period TIV observations (Kruskal-Wallis chi-squared = 1.025; P = 0.3113). It is concluded that the ORTB did not appear to cause statistically significant delay in the migration of steelhead in the area downstream of the barrier. It is logical that once through the barrier the steelhead that were actively migrating to the ocean would continue without delay. However, it is uncertain how many tagged steelhead may have been in the data due to the observed overlap in steelhead and predatory fish behavior.

Table 3-61. 2011 Juvenile Steelhead TIV that were Detected at the Old River at Tracy Barrier Downstream Area

Construction Period	Minimum TIV (hours)	Mean (Standard Deviation) TIV (hours)	Maximum TIV (hours)	Number of Fish (N)
Before	0.04	0.53 (1.501)	5.73	14
After	0.10	0.13 (0.287)	0.17	4

Source: ESA this study.

3.7.3.5 *2011 Predatory Fish Compared to Juvenile Steelhead Upstream Area*

Before- and During-Construction Periods

In 2011, one tagged Largemouth Bass spent time in the vicinity of the ORTB during the Before-Construction Period and this fish displayed movements in the Category 3 (Both Upstream and Downstream) areas. The TIV for this Largemouth Bass was 13.79 hours. Fifty tagged steelhead passed through the ORTB upstream area and the TIV ranged from 0.07 to 39.98 hours (**Table 3-60**). No hypothesis test was possible with only one observation in the predatory fish group.

In the During-Construction Period, no predatory fish were detected in the Category 1 (Upstream) area or the Category 2 (Downstream) area. One predator, a Striped Bass, was detected in the ORTB Category 3 (Both Upstream and Downstream) areas during the During-Construction Period and it exhibited a range of TIV from 3.10 to 14.04 hours. In the During-Construction Period, no tagged steelhead were detected in the vicinity of the ORTB. It was concluded that no direct statistical comparison could be made between predatory fish TIV and steelhead TIV in the During-Construction Period.

After-Construction Periods

There were six predatory fish that spent time in the Category 2 (Downstream) and Category 3 (Both Upstream and Downstream) areas of the ORTB during the After-Construction Period, and their TIVs ranged from 0.44 to 103.96 hours (**Table 3-62**). There were 35 tagged steelhead that spent time in the Category 2 (Downstream) area and the Category 3 (Both Upstream and Downstream) area, and the TIVs ranged from 0.04 to 42.32 hours (**Table 3-62**). The steelhead TIV observations were significantly shorter in duration than the predatory fish TIV observations (Kruskal-Wallis chi-squared = 10.188; P = 0.0014). It is concluded that steelhead track segments from the downstream area and track segments from both upstream and downstream areas exhibited TIV observations that were significantly shorter than those of predatory fish TIV observations with the same types of track segments. This significant result occurred even though some of the steelhead tags may have been predatory fish. This result suggests there were very significant differences in the amount of time steelhead and predatory fish remained in the vicinity of the ORTB in the After-Construction Period.

Table 3-62. 2011 Predatory Fish TIV and Juvenile Steelhead TIV that were Detected at the Old River at Tracy Barrier Downstream Area Combined with Both Upstream and Downstream Areas					
Fish Group	**Minimum TIV (hours)**	**Mean (Standard Deviation) TIV (hours)**	**Maximum TIV (hours)**	**Species**	**Number of Fish (N)**
Predatory Fish	0.44	29.18 (38.102)	103.96	Striped Bass	4
				Largemouth Bass	1
				White Catfish	1
Juvenile Salmonids	0.04	2.56 (7.162)	42.32	Steelhead	35

Source: ESA this study.

3.8 DEFECATED AND REGURGITATED TAGS

A total of eight tags were defecated/regurgitated by predatory fish in the ORTB area in 2010 and 2011; all tags were defecated/regurgitated in the After-Construction Period of the respective year because the ORTB 2D hydrophone array was installed after ORTB barrier construction was complete (**Table 3-63**). Seven tags were defecated/regurgitated on the upstream side of the ORTB (**Figure 3-5**). One tag was defecated/regurgitated on the downstream side of the ORTB and the cumulative binomial probability of one or fewer tags being defecated/ regurgitated on the downstream side of the ORTB was 0.035. It is concluded that there was not an equal probability of a tag being defecated/regurgitated on the upstream or downstream side of the ORTB. It is significantly more likely that a tag would be defecated/regurgitated on the upstream side of the ORTB.

Table 3-63. All Salmonid Tags that Became Stationary in the Vicinity of the Old River at Tracy Barrier in 2010 and 2011								
Year	**Period**	**SubCode**	**Tagcode**	**Species**	**Defecation/ Regurgitation Time**	**Defecation/ Regurgitation Location**	**Predation**	**Symbol**
2010	2129	4	2129.04	Steelhead	6/10/2010 1318:25	Upstream	Upstream	Red circle
2010	2283	4	2283.04	Steelhead	6/12/2010 2219:10	Upstream	Unknown	Yellow triangle
2010	2437	4	2437.04	Steelhead	6/10/2010 1611:26	Downstream	Unknown	Yellow triangle
2010	2717	4	2717.04	Steelhead	6/20/2010 0630:46	Upstream	Upstream	Red circle
2010	2829	4	2829.04	Steelhead	6/20/2010 0631:11	Upstream	Upstream	Red circle
2010	2871	4	2871.04	Steelhead	6/18/2010 2310:57	Upstream	Upstream	Red circle
2010	3249	4	3249.04	Steelhead	6/21/2010 0219:36	Upstream	Upstream	Red circle
2011	3804	15	3804.15	Chinook Salmon	6/18/2011 1656:32	Upstream	Upstream	Orange circle

Source: HTI this study.

There was one tag defecated/regurgitated on the downstream side of the barrier and the predation location could not be definitely determined for this tag. There were seven tags defecated/regurgitated on the upstream side of the ORTB. Of these seven, six were determined to have been consumed on the upstream side of the barrier. These findings are consistent with the hypothesis that a juvenile salmonid is more likely to be consumed on the upstream side of the ORTB and that the tag is significantly more likely to be defecated/regurgitated on the upstream side of the ORTB. The sample size of defecated/regurgitated tags was small and, therefore, it is suggested that further research in this area may be warranted.

Source: HTI this study.
Note: Red circles: 2010 steelhead where predation occurred on the upstream side of the ORTB; Yellow triangle: 2010 steelhead where predation location was not determinable; and orange circle: 2011 Chinook Salmon predation occurred on the upstream side of the ORTB.

Figure 3-5. Defecated/Regurgitated Tags at the Old River at Tracy Barrier in 2010 and 2011

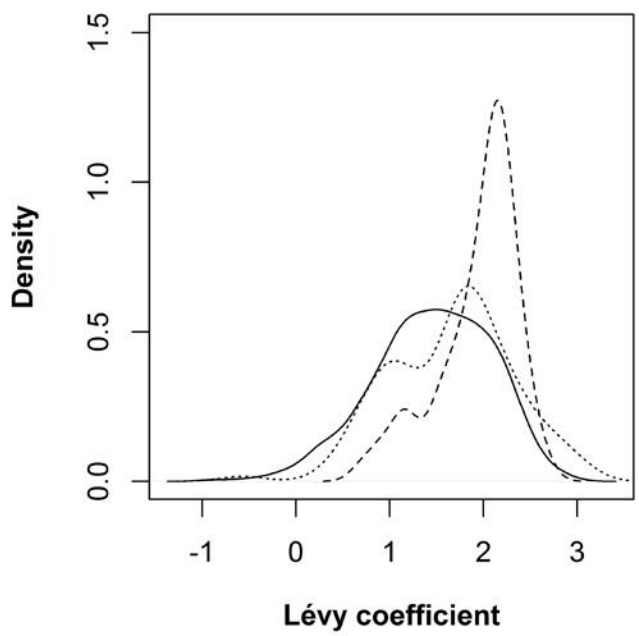
3.9 MIXTURE MODEL

The 2010 tags and 2D track segments that satisfied all requirements (requirements outlined in Section 2.23 *Mixture Model*) were derived from 68 steelhead, 5 Largemouth Bass, 4 Striped Bass, and 1 White Catfish (**Table 3-64**). The predatory fish tracks (i.e., Largemouth Bass, Striped Bass, and White Catfish) were, in general, more tortuous than the steelhead tracks (**Figure 3-6**). However the distributions heavily overlapped for both tortuosity and the Lévy exponent. The behavior of steelhead was similar to that of the observed predatory fish, with few fish passing directly through the array. This resulted in a larger proportion of the steelhead track segments being classified as having a high probability of being a steelhead (247/504 = 0.4901 or 49 percent; **Table 3-65**) than being classified as having a low probability of being a steelhead (210/504 = 0.41667 or 42 percent; **Table 3-65**).

The probability of being a predatory fish was determined and then a segment was classified as “low” (probability: 0–0.33), “medium” (probability: 0.33–0.66), or “high” (probability: 0.66–1.0) of being a predatory fish. Approximately 8 percent (57/678) of track segments fell into the middle region of the probability scale (0.33–0.66) (**Table 3-65**) suggesting these segments should be further analyzed to determine if the tags were in predatory fish. The model classified 83 percent (60/72) of the Striped Bass segments as having a high probability of being a predator (**Tables 3-64** and **3-65**). The model did not perform as well for Largemouth Bass. Only 36 percent (36/101) of the track segments were classified as having a high probability of being a Largemouth Bass (**Table 3-65**). This is likely due to their behavior within the array, which was typified by stationary behavior or unidirectional patrolling along the shorelines. This behavior pattern resulted in track segments that had low tortuosity. Largemouth Bass rarely departed the shoreline, whereas Striped Bass patrolled the entire channel.

Table 3-64. 2010 Mixture Model Data Set Description		
Species	**Acoustic Tags (N)**	**Track Segments (N)**
Juvenile Steelhead	68	504
Largemouth Bass	5	101
Striped Bass	4	72
White Catfish	1	1

Source: USGS this study.



Source: USGS this study.

Note: Distribution of metrics used in the mixture model for 2010. Note the similarity in distributions of the Lévy coefficients for juvenile steelhead (salmonid) and Largemouth Bass.

Figure 3-6. 2010 Mixture Model Metrics

Table 3-65. 2010 Results of Track Segment Probability Classification			
Species	**Low (N)**	**Middle (N)**	**High (N)**
Juvenile Steelhead	210	47	247
Largemouth Bass	56	9	36
Striped Bass	11	1	60
White Catfish	0	0	1

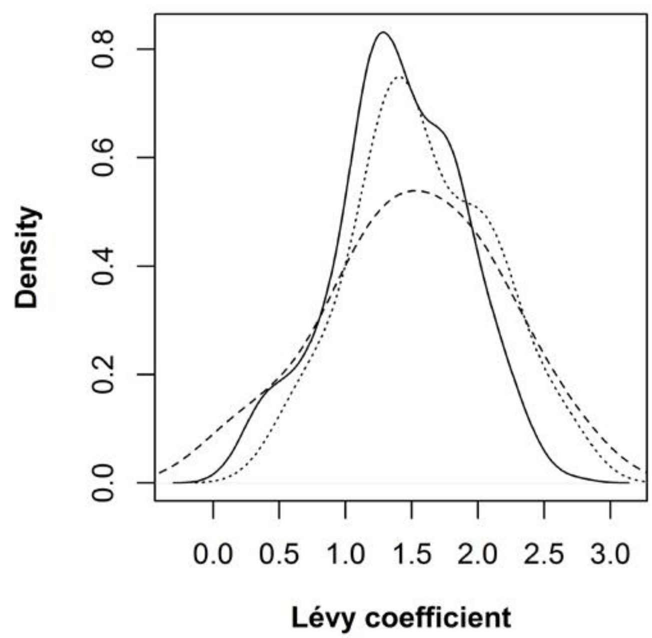
Source: USGS this study.

In 2011, 127 Chinook Salmon, 51 steelhead, 5 Striped Bass, 2 Largemouth Bass and 1 White Catfish were used in the analyses (**Table 3-66**). The behavior of salmonid tags and predator tags was very similar in 2011. Lévy coefficient distributions were very similar between salmonid tags and predator tags (**Figure 3-7**), therefore track tortuosity was used to assign probabilities to track segments. Of the 258 Chinook Salmon segments, 86 percent (222/258) were classified as having low probability of being eaten by a predatory fish (**Table 3-67**). Of the 187 juvenile steelhead segments, 66 percent (123/187) were classified as having a low probability of being eaten by a predatory fish (**Table 3-67**). Just using the tortuosity metric resulted in more accurate classification of the predators in 2011 compared to 2010. Approximately 60 percent (18/30) of the Largemouth Bass segments were classified as having a high probability of being a predator and 64 percent (9/14) of the Striped Bass segments were classified as having a high probability of being a predator (**Table 3-67**).

Table 3-66. 2011 Mixture Model Data Set Description

Species	Acoustic Tags (N)	2D Track Segments (N)
Juvenile Chinook Salmon	127	258
Juvenile Steelhead	51	187
Largemouth Bass	2	30
Striped Bass	5	14
White Catfish	1	1

Source: USGS this study.
Note: The fish species, number of acoustic tags, and number of track segments that were derived from those acoustic tags.



Source: USGS this study.
Note: Distribution of metrics used in the mixture model for 2011. Note the similarity in distributions of the Lévy coefficients for all fish groups.

Figure 3-7. 2011 Mixture Model Metrics

Table 3-67. 2011 Results of Track Segment Probability Classification

Species	Low (N)	Middle (N)	High (N)
Juvenile Chinook Salmon	222	13	23
Juvenile Steelhead	123	14	50
Largemouth Bass	8	4	18
Striped Bass	4	1	9
White Catfish	1	0	0

Source: USGS this study.

3.10 DIDSON ANALYSIS

DIDSON sampling and data processing techniques cannot differentiate between species of the same size without careful visual evaluation of every fish's morphological characteristics which can be time consuming when processing entire data sets. Therefore, the ability to separate predatory from non-predatory fish introduces an unknown amount of error when utilizing automated processing techniques. So, automated processing techniques were not used in this study. Generally, by using a fish size threshold, e.g., 30 cm TL, it is possible to manually remove many smaller fish species that can be present in high numbers and would otherwise confound results. A small number of large-bodied fish, specifically, Common Carp and sturgeon, are essentially the only large non-predatory species continuously present in the study area. Both of these species can be readily distinguished from predatory fish species through visual analysis of fish size, shape and swimming behavior (see **Figure 2-21**). For comparison, **Figure 3-8** depicts a frame grab of a DIDSON image illustrating a target (65.6 cm TL [25.8 in TL]) that was identified as a predatory fish in the data analysis. Total fish numbers > 30 cm TL (> 11.8 in TL) were determined and summed and Common Carp and sturgeon counts were removed from the data (**Table 3-69** and **Table 3-70**) for 2010 and 2011 results, respectively.

Table 3-68. 2010 Total Number of Fish Targets Greater than 30 cm TL Identified in DIDSON Imagery Collected at a South Delta Agricultural Barrier

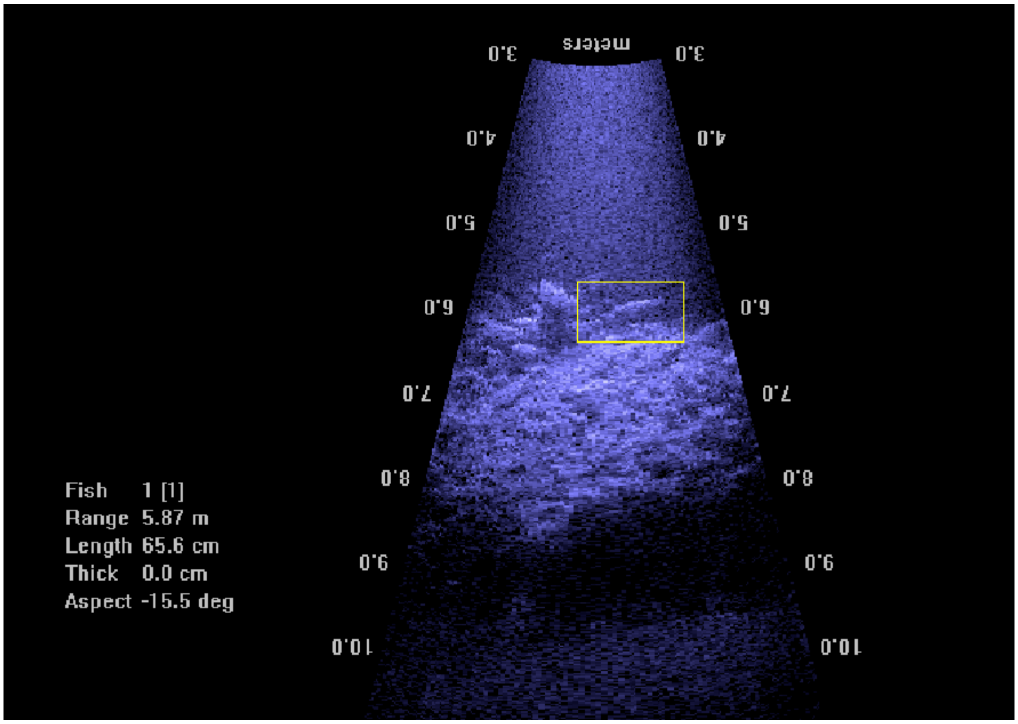
Total Fish (N) by SDAB	
GLCB	42
MRB	38
ORTB	47
Predatory Fish (N) by SDAB	
GLCB	38
MRB	38
ORTB	44

Source: Turnpenny Horsfield Associates this study.

Table 3-69. 2011 Total Number of Fish Targets Greater than 30 cm TL Identified in DIDSON Imagery Collected at a South Delta Agricultural Barrier

Total Fish (N) by SDAB	
GLCB	44
MRB	25
ORTB	48
Predatory Fish (N) by SDAB	
GLCB	44
MRB	24
ORTB	44

Source: Turnpenny Horsfield Associates this study.



Source: Turnpenny Horsfield Associates this study.

Note: A frame grab of a DIDSON image illustrating a target (65.6 cm TL [25.8 in TL]) that was identified as a predatory fish in the data analysis.

Figure 3-8. DIDSON Predatory Fish

Summary statistics of results for DIDSON sampling (predatory fish density by SDAB, installation status, and predatory fish location) are presented in **Tables 3-70** and **3-71**. Overall trends in predatory fish density were observed for the DIDSON sampling. Generally, for periods when DIDSON sampling was conducted, there was an increase in predatory fish densities during or after the barriers were installed compared to periods before the barriers were installed for both 2010 and 2011, with only one exception. In 2011 at the GLCB, the predator density estimate was greater in the Before- compared to the During-Construction Period.

Of the predatory fish observed after the installation of the SDABs, the highest density of predatory fish were located in the After-Construction Period on the downstream side of the MRB in both 2010 and 2011(**Tables 3-70** and **3-71**). For logistic reasons, only downstream sampling was conducted after the MRB was installed.

Table 3-70. 2010 Predatory Fish Density by South Delta Agricultural Barrier, Installation Status, and Detection Location

Barrier/Predatory Fish Detection Location	Barrier Installation Status		
	Density Before-Construction[1] (Predatory Fish/1000 m^3)	Density During-Construction[1] (Predatory Fish/1000 m^3)	Density After-Construction (Predatory Fish/1000 m^3)
GLCB			
Upstream and Downstream	0.64	1.84	NS
MRB			
Upstream and Downstream	2.03	3.56	NS
Downstream	NS	NS	14.05
ORTB			
Upstream and Downstream	1.93	2.08	NS
Downstream	NS	NS	3.23
Upstream	NS	NS	2.00

Source: Turnpenny Horsfield Associates this study.

[1] Note that sampling location for Before- and During-Construction Periods includes both upstream and downstream sampling because the barrier is not in place to partition the total area.

m^3 = cubic meters.

NS = No DIDSON sampling occurred during this barrier installation period.

Table 3-71. 2011 Predatory Fish Density by South Delta Agricultural Barrier, Installation Status, and Detection Location

Barrier / Predatory Fish Detection Location	Barrier Installation Status		
	Density Before-Construction[1] (Predatory Fish/1000 m^3)	Density During-Construction[1] (Predatory Fish/1000 m^3)	Density After-Construction (Predatory Fish/1000 m^3)
GLCB			
Upstream and Downstream	0.86	0.57	NS
MRB			
Upstream and Downstream	0.73	2.55	NS
Downstream	NS	NS	3.27
ORTB			
Upstream and Downstream	0.87	2.01	NS
Downstream	NS	NS	2.42
Upstream	NS	NS	2.95

Source: Turnpenny Horsfield Associates this study.

[1] Note that sampling location for before and during barrier installation status includes both upstream and downstream sampling because the barrier is not in place to partition the total area.

m^3 = cubic meters.

NS = No DIDSON sampling occurred during this barrier installation status period.

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4 DISCUSSION

4.1 SURVIVAL MODELING

In general, the results show that survival is dependent on many factors including salmonid species, river flow, SDAB installation and operation, predatory fish density, and water year. The results of this investigation point out the complexity of providing safe emigration routes for Chinook Salmon and steelhead through the SDABs.

One of the more important results from this analysis was that very few Chinook Salmon or steelhead utilized the Middle River route through the study area in both 2010 and 2011. This observation was supported by the flow results that showed a very small proportion of the total south Delta discharge in the study area, 5.7 percent in 2010 (**Table 3-3**) and 11.2 percent in 2011 (**Table 3-5**), passed through the Middle River route during the salmonid juvenile migratory period in spring/early summer. As a result, there was little or no effect on survival or route proportion due to the existence of the MRB.

The 2011 results showed very little difference between the survival before and after the predator filter was employed for both overall survival and route proportion for the ORS route (**Table 3-22** for Chinook Salmon; **Table 3-23** for steelhead). However, applying a predator filter for the 2010 data was problematic, especially for the steelhead data (**Table 3-11**). In 2010, survival for steelhead was significantly less through the ORS route after applying the predator filter. In addition, in 2010 the resultant sample size for the steelhead data after application of the predator filter for the ORS route was too small (N = 87) to conduct subsequent survival analyses. Thus, all reported results for steelhead in 2010 using the ORS route were based on all tagged steelhead (**Table 3-11**; N = 324) with the Predator Filter Not Employed.

There were differences in river flow between the 2010 and 2011 study periods. In general, the river flow was higher in 2011, a wet water year (see mean daily Old River discharge in **Table 3-5**) compared to 2010, an above normal water year (see mean daily Old River discharge in **Table 3-3**) (also see Section 1.3.2.1 *Quantity for Water Year Source Data*). The predator filters for both years relied on assumptions about fish behavior and migration rates. While the predator filter uses flow and adjusts various parameter limits based on flow, water years with very different flow patterns may have additional effects on fish behavior. In addition, different fish species may respond differently to flow patterns. Therefore, the development of a predator filter tailored to the 2010 river conditions for each species might be appropriate prior to performing further survival analyses.

4.1.1 2010 Juvenile Chinook Salmon

For those Chinook Salmon released as part of this study's survival research (**Table 2-6**), it was not possible to evaluate survival in various 2010 barrier construction periods. Chinook Salmon releases only occurred during the Before-Construction Period of all three of the SDABs (**Table 2-1**).

There was a second set of tagged juvenile Chinook Salmon that were released in the south Delta (SJRGA 2011: Table 5-1). Further analyses utilizing the SJRGA Chinook Salmon releases may provide more comparisons of the barrier construction periods. For example, in 2010 the VAMP Study Chinook Salmon releases occurred over the period April 26 to May 18, which overlaps with the During-Construction Period for the ORTB. Thus, by identifying the second set of tags and building detection histories in the same way done in this study, it would allow a comparison of the Before- and During-Construction Periods for the ORTB.

4.1.2 2010 Juvenile Steelhead

In 2010, the predator filter was applied to the 1D steelhead detection history data and 95.2 percent (220/231) of the steelhead were categorized as "predator." This result was similar to that of the mixture model (see Section 3.9 *Mixture Model*). The mixture model, using the 2D detection data, identified more steelhead with a high probability of being a predatory fish (49 percent) than as a steelhead (low probability of being a predator (42 percent; **Table 3-65**). Thus, both techniques indicated that steelhead behavior was very difficult to distinguish from predatory fish behavior in 2010. Stated another way, the techniques applied did not work well in distinguishing predatory fish behavior from steelhead behavior in 2010.

4.1.2.1 *Results Relating to the Predator Filter for 2010*

In 2010, the predator filter caused 30.6 percent, or 87 of 284 Chinook Salmon, to be removed from the number of tagged juveniles arriving at exit points used in calculating survival. For steelhead in 2010, the percent of tagged fish that were classified as predators was 95.2 percent. So few steelhead remained after application of the predator filter that the predator filter was not used for calculating survival in 2010.

Migration patterns of steelhead in 2010, as determined by tag detection histories, were very different from those of Chinook Salmon. Steelhead moved more slowly between detection sites, had higher residence times, and showed more variability in direction of movement. **Table 4-1** compares Chinook Salmon and steelhead travel times in 2010 from release to hydrophone detection array Old River South (ORS) (i.e., hydrophones ORSU and ORSD), than from array ORS to array GLC (i.e., hydrophones GLCU and GLCD) for those fish that travelled this route. This route was the most commonly used route by fish of both species in 2010. The travel times between each segment of the route were much longer and more variable for steelhead than for Chinook Salmon.

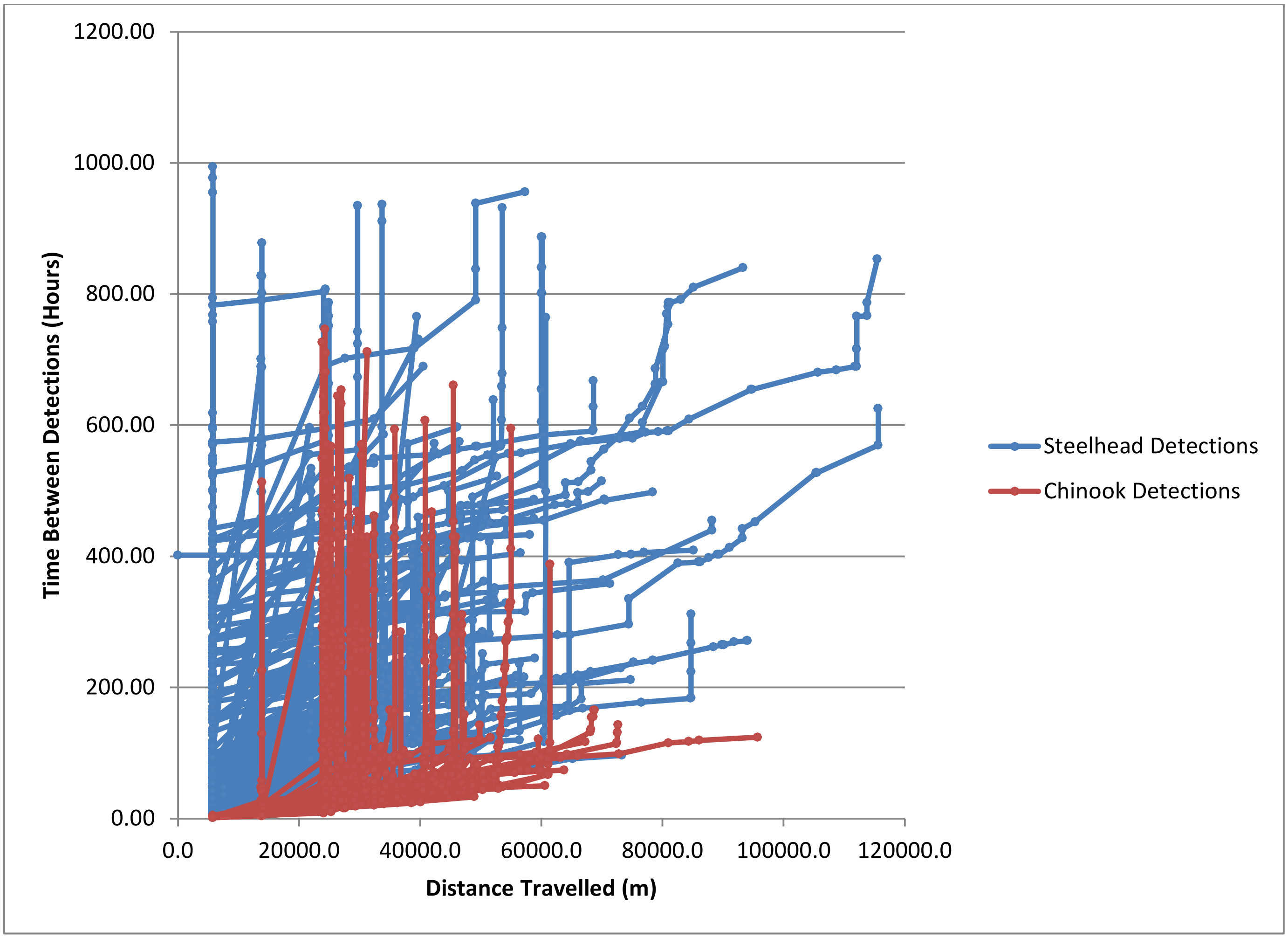
Table 4-1. Travel Times for the Most Common First Two Route Segments for Chinook Salmon and Steelhead in 2010

	Chinook Salmon Travel Times (hours)			Steelhead Travel Times (hours)		
Route	Travel Time Average	Standard Deviation	Number of Fish (N)	Travel Time Average	Standard Deviation	Number of Fish (N)
Release to ORS	1.99	0.3526	322	53.56	95.1174	324
ORS to GLC	4.60	2.6314	300	39.33	68.1145	182

Source: ESA this study.

Figure 4-1 plots all 2010 detection histories of Chinook Salmon (red) and steelhead (blue) as distance travelled (X) through time (Y). Detection history lines start at site ORS, and continue increasing in distance through time (note that distance only is plotted with no directional component). Rapid migration is represented by nearly horizontal lines, slower migration is represented by diagonal lines of increasing slope, and stationary tags or tags with repeated detections at a single site are indicated by vertical lines. Overall, steelhead showed much slower and more variable migration patterns than Chinook Salmon. For this reason, steelhead in 2010 often fell outside the predator filter cutoff values and were classified as predators (**Table 2-16**).

The difference in migration patterns exhibited by steelhead compared to Chinook Salmon in 2010 may be due to the difference in the possible life histories of steelhead, compared to the possible life histories of Chinook Salmon in the Delta. For Chinook Salmon, emigration is required for survival; individuals must exit the Delta and enter the ocean in order to survive (Williams 2010). Steelhead have more variable life histories and may continue to the ocean or remain in fresh water and residualize in upstream environments that meet the suitable environmental criteria of the species. Environmental conditions likely play a role in determining the migration patterns exhibited by juvenile steelhead in any given year.



Source: ESA this study.

Figure 4-1. Detection Histories of Chinook Salmon and Steelhead in 2010 Shown as Distance Travelled by Time

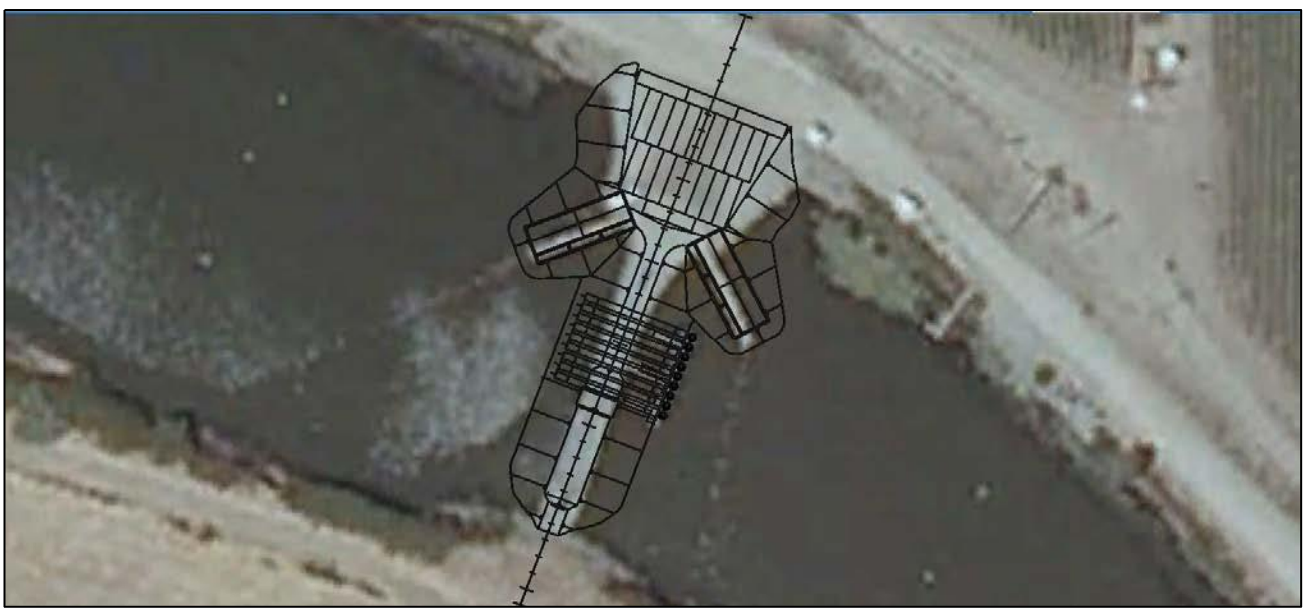
4.1.2.2 *Comparing Survival and Covariates from April 1, 2010–May 9, 2010 to June 4, 2010–July 7, 2010*

During the Before-Construction Period of the ORTB, April 1, 2010 through May 9, 2010 (**Table 2-1**), steelhead survival via the ORS route was 89.3 percent (**Table 3-16**) and in the After-Construction Period, June 4, 2010 through July 7, 2010 (**Table 2-1**), survival was significantly lower, 57.7 percent (**Table 3-16**) ($Z = 5.069$; $P < 0.0001$). There were several possible mechanisms explored to explain the steelhead survival difference between these two periods: 1) the status and operations of the SDABs; 2) flow magnitude and its effects; 3) distribution of flow in the three channels of interest; 4) export rate; 5) water temperature; and 6) predatory fish density.

During 2010, the ORTB Before-Construction Period was April 1 through May 9; MRB construction began on May 19 and GLCB construction began on June 16. Thus, for the entire April 1-May 9 period all routes through the south Delta were open without constrictions or constraints from the SDABs. It is concluded that open migratory routes at all three SDAB sites could have contributed substantially to high survival between April 1 and May 9, 2010.

During 2010, the ORTB After-Construction Period was June 4 through July 7 (**Table 2-1**). For 12 days of this period, the GLCB was in a Before-Construction Period, June 4 through June 16. But then, on June 16 construction began on the GLCB and continued for the next 21 days. Thus, for 64 percent of the ORTB After-Construction Period the GLCB was in the During-Construction phase. Also, between June 4 and July 7, 2010, the MRB was wholly in the After-Construction Period (**Table 2-1**).

When construction on the ORTB was completed; its flap gates were tied open. In total, the ORTB spent eight days, June 3 through June 11, 2010, in place but with the culverts' flap gates tied open (**Table 2-2** and **Figure 4-2**). Thus for 79 percent (26 of 33 days) of the June 11 to July 7 period , the ORTB's flap gates were not tied open and operated tidally (**Table 2-2**). The MRB was completed on May 24, but the culverts' flap gates were tied open until June 11. Similar to the ORTB, for 79 percent (26 of 33 days) of the June 11 to July 7 period , the MRB's flap gates were not tied open and operated tidally (**Table 2-2**). It is concluded that constraints placed on juvenile salmonids by the SDABs and operation of the flap gates could have contributed to reduced survival in the June 4 through July 7, 2010 period.



Source: DWR this study.

Note: Graphical representation of the flap gate position (closed: note the closed black circles on the upstream side of the ORTB culvert's flap gates) during a substantial portion of the 2010 juvenile salmonid migratory period (June 11 through October 28). The flap gates only opened when a flood tide forced water upstream with sufficient force to push the one-way flap gates open.

Figure 4-2. 2010 Flap Gate Operation

Functionally, the ORTB and the MRB had two routes available for migration past these barriers once the flap gates were untied: weir or culvert. If a juvenile salmonid arrived during a tidal state during which the weir was overtopped, the fish could use the weir route—there would be two of these periods each day. For example, for the ORTB on the last day of the During-Construction Period, July 7, the weir was overtopped from 00:00 hours through 12:00 hours, and then again from 19:45 hours through 24:00 hours, for a total of 16.25 hours out of 24 hours. If a steelhead arrived between 12:00 hours and 19:45 hours that individual would have to wait until the next flood tide or weir overtopping event to be able to pass the ORTB over the weir; in this example the weir was overtopped at 19:45 hours. During this waiting period, the steelhead would have an increased risk of encountering a predatory fish and therefore an increased risk of mortality. This conclusion was supported by the results of Section 3.6.2 *2010 Juvenile Steelhead* (**Table 3-38**) where 68 juvenile steelhead entered the area of the ORTB and 18 of these fish passed through/over the barrier. This ratio of 18 fish passing and 50 fish not passing (**Table 3-38**) deviated significantly from the ratio expected from survival modeling ratio (**Table 3-37**) 0.9988(expected to pass):0.0012(not expected to pass) (Kruskal-Wallis chi-squared = 30,574.000; $P = 2.2 \times 10^{-16}$). It was concluded that in 2010, the ORTB was a significant impediment to migration of juvenile steelhead.

The importance of the three SDABs and their potential effects on south Delta juvenile salmonids' survival was also evaluated using assessment of the proportion of flow in each channel and the proportion of tagged salmonids using each channel. The proportion of flow through Middle River was nearly identical in 2010 during barrier operations, 5.1 to 6.2 percent compared to 93.8 to 94.9 percent through Old River (**Table 3-3**). But, no tagged steelhead used the Middle River route in 2010 (**Table 3-16**).

In 2010, the proportion of flow through GLC relative to Old River increased in the ORTB After-Construction Period (June 4–July 7; 97.2 percent) compared to the Before-Construction Period (April 1–May 9; 82.2 percent) (**Table 3-4**). In addition, the GLC was the most heavily used juvenile migration route among the three studied, 98.9 percent of steelhead utilized the GLC (**Table 3-14**). The increased proportion of flow through the GLC should have served only to improve survival because the GLC was the only channel of the three studied that did not have a closed barrier during the period of June 4 through July 7. It is concluded that changes in flow proportion between the three channels was not likely to explain the significant decrease in survival from the ORTB Before-Construction Period to the After-Construction Period.

The GLC discharge was slightly higher in the After- compared to the Before-Construction Period (**Table 3-4**) and higher flows should lead to faster salmonid juvenile transit speeds and lower predation rates (see DWR 2015a). However, the After-Construction Period mean flow (51.1 cms [1,806 cfs]) was only 0.6 percent higher than the Before-Construction Period mean flow (50.8 cms [1,795 cfs]) (**Table 3-4**) and this seemed unlikely to have a highly significant effect on survival alone.

The export flow rates (flow rate through Banks Pumping Plant (SWP) and the Jones Pumping Plant (CVP) combined) were increasing during the spring and summer of 2010 and were higher in the ORTB After-Construction Period compared to the ORTB Before- Construction Period (**Table 3-7** and **Figure 3-1**)). This should have only served to increase juvenile salmonid transit rates and lower predation rates (DWR 2015a). Yet, the opposite occurred and survival declined. It is concluded that export flow rate changes had not led to the decreased survival to the end points studied: hydrophone arrays CVP, RGU, ORN, and MRN.

Water temperature was, on average, 5.3°C (9.5°F) warmer in the ORTB After-Construction Period compared to the Before-Construction Period with a mean daily water temperature of 21.9°C (71.4°F) during the After-Construction Period (**Table 3-1**). Higher temperature would cause thermal stress and salmonid swimming efficiency to decrease when the temperatures approached critical upper thresholds. At the same time, fish predators that evolved in temperate zones, e.g., Largemouth Bass, Striped Bass, Sacramento Pikeminnow, Channel Catfish (*Ictalurus punctatus*), and White Catfish, would have increased swimming efficiency with increased water temperature through this temperature range, 18.2 to 26.7°C (64.8–80.1°F) (**Table 3-1**: After-

Construction Period). Furthermore, the predatory fishes' energy demand rate would increase with water temperature and the predators may have been capable of eating a larger biomass of prey, e.g., Largemouth Bass (Niimi and Beamish 1974). It was concluded that water temperature was likely to have contributed to the lower survival rate observed in the After-Construction Period.

In 2010, predatory fish density increased through time (**Table 3-70**). At the ORTB, the increase ranged from 3.6 (downstream of the barrier) to 67.3 percent (upstream of the barrier) in predatory fish density from the period of April 1 through May 9 compared to the period of June 4 through July 7. At the GLCB the number of predator fish per 1,000 cubic meters (35,315 cubic feet) increased 75.4 percent from the ORTB Before-Construction Period to the During-Construction Period. At the MRB, the number of predator fish per 1,000 cubic meters (35,315 cubic feet) increased 158.3 percent from the ORTB Before-Construction Period to the After-Construction Period. It was concluded there were fewer predatory fish in the vicinity of the barriers in the period of April 1 through May 9 than the period of June 4 through July 7. Thus, it is possible that predatory fish density could have contributed to the significant decrease in survival observed in the ORTB After- Construction Period, June 4 through July 7, 2010, compared to the Before-Construction Period.

Six factors were considered to explain the 2010 survival decrease in steelhead: 1) SDABs installation and operation; 2) discharge magnitude; 3) proportions of flow and juvenile salmonids into the three channels studied; 4) export flow rates; 5) water temperature; and 6) predatory fish density. It is concluded that the most likely explanation was that all of these factors could have been involved, but the increased water temperature, increased predatory fish density, and reduced passage availability through culverts were most likely the largest contributing factors to the survival decrease. In addition, these three factors could have worked synergistically. As the water temperature increased exceeding 20°C (68°F), steelhead may have been thermally stressed exhibiting decreased metabolic condition (Viant et al. 2003) making them more vulnerable to predation by the increasing local predatory fish population. Furthermore, for a part of each day from June 11 through July 7, when a steelhead arrived at the ORTB or the MRB, that individual might be forced to wait for a passage route to become available, thereby increasing the risk of predation (i.e., a potentially thermally-stressed steelhead arrives at a barrier and is forced to wait for passage in the presence of an expanded predatory fish population).

4.1.3 2011 Juvenile Chinook Salmon

The 2011 Chinook Salmon analyses showed that there was not a significant increase in survival via the ORS route during the After-ORTB Construction Period (0.6633) compared to the Before-ORTB Construction Period (0.7494) (**Table 3-27**). However, this lack of statistical significance arose from the critical α', 0.01695, that was necessary due to these three comparisons of survival: 1) Before- vs. During-Construction Periods; 2) Before- vs. After-Construction Periods; and 3) During- vs. After-Construction Periods (see Section 2.19 *Survival Modeling*). The P-value for the Before- vs. After-Construction Period comparison via the ORS route was 0.0472 (**Table 3-27**). So, while the survival in these two periods was not statistically different, according to the designed hypothesis-testing procedure, it seems like an area that warrants further research.

Survival via the ORS route increased in the During-GLCB Construction Period (0.7611) compared to the Before-GLCB Construction Period (0.6502) (**Table 3-29**) and this increase was significant ($Z = 2.4657$; $P = 0.0137$). One possible explanation for the increased survival was the increase in export rates (**Table 3-8**) during the periods of GLCB barrier construction and continued after the construction of all three SDABs. A possible mechanism for such an effect could be that increased export rates: 1) increased average channel velocity in the GLC; 2) decreased travel time for Chinook Salmon; and 3) decreased the probability of encountering a predatory fish because

Chinook Salmon spent less time transiting the barrier area. However, TIV was not statistically significantly different in the Before- and During-Construction Periods in the GLCB's upstream area (**Table 3-47**) (Kruskal-Wallis chi-squared = 0.1584; P = 0.9239) or the GLCB's downstream area (**Table 3-48**) (Kruskal-Wallis chi-squared = 0.7952; P = 0.6719) of the GLCB. It is concluded that export rates probably did not cause the increase in survival that was observed.

Another factor that could have contributed to the significant increase in survival for Chinook Salmon during the period from June 11 to July 14, 2011 was that there was no completely closed route through the south Delta. The GLCB-footprint area experienced several May and June high flow events that moved most GLCB-foundation boulders that had been placed in the GLC downstream leaving an open channel. All Chinook Salmon and steelhead arrived at the GLCB before the barrier was finally closed on July 14. Furthermore, the flap gates were tied open at the MRB and the ORTB (**Table 2-4**) allowing free fish movement through culverts during the June 7 through July 14 period at the MRB and June 11 through July 14 period at the ORTB (**Figure 4-3**).

Source: DWR this study. Note: Graphical representation of the "open" flap gate position (note the open red circles on the upstream side of the ORTB culverts' flap gates) maintained during all of the salmonid migratory period of spring/early summer 2011 after the ORTB was closed (June 11 through July 14).

Figure 4-3. 2011 Flap Gate Operation

The distribution of flow changed in the south Delta through the spring and early summer of 2011 (i.e., April 1 through July 1). The proportion of flow into Middle River decreased through the study period (**Table 3-5**). In addition, the proportion of flow into Old River, relative to the GLC, decreased through the study period (**Table 3-6**). So the proportion of flow into the GLC was increasing and the GLC route was the most open migration corridor of the three channels studied. As noted previously, numerous high-water events displaced material downstream from repeated attempts to install the GLCB.

It is concluded that the most likely explanation for the increased survival of Chinook Salmon in the GLCB During-Construction Period was the high discharges, increased flow proportion entering the GLC as time progressed, and SDAB operations provided for open migratory routes that remained available throughout the salmonid migratory period.

It is possible that higher survival in the period of June 11 through July 14 may have been part of a regionally higher survival trend in the Delta in 2011. It was reported by SJRGA (2013) that survival in the Delta did not decrease through time in the spring/early summer of 2011 over the course of the studies they conducted. For example, survival was 0.01 for Chinook Salmon released from May 17 through May 25, but was higher (0.03) for Chinook Salmon released from June 7 through June 18 (SJRGA 2013).

4.1.4 2011 Juvenile Steelhead

The 2011 steelhead showed no significant increases or decreases in survival between the Before-, During- or After-Construction Periods of the SDABs. This is in contrast to the results from 2010 where: 1) steelhead survival decreased significantly through time if the ORS route was used (**Table 3-17**); and 2) migratory routes were closed during some portion of each day due to tidally-operated culvert flap gates. In 2011, during the spring and early summer, the Old River at ORS discharge rates averaged 178.1 cms (6,291 cfs) (**Table 3-5**) while in 2010 flow rate averaged 61.2 cms (2,161 cfs) (**Table 3-3**). In Section 4.1.3 *2011 Juvenile Chinook Salmon*, SDAB operations were described that showed how open migratory routes were maintained through the 2011 salmonid migratory period in the three channels studied. These results showed that in a year with high flow rates and slightly lower mean daily water temperatures (**Tables 3-1** and **3-2**) survival may not decrease through time if migratory routes remain open.

In contrast to Chinook Salmon, steelhead survival in 2011 via the ORS route did not change significantly during the GLCB During-Construction Period (0.7929) compared to the Before-Construction Period (0.8838) (**Table 3-31**). Another factor potentially contributing to these results is the increase in export rates (**Table 3-8**) during the periods of the GLCB barrier construction and continued after the construction of all three SDABs. A possible mechanism for such an effect could be that increased export rates: 1) increased average channel velocity in the GLC; 2) decreased TIV for steelhead; and 3) decreased the probability of encountering a predatory fish because steelhead spend less time transiting the barrier area. However, steelhead TIV was significantly longer in the During-Construction Period (mean TIV = 2.58 hours) compared to the Before-Construction Period (mean TIV = 0.24 hours; **Table 3-49**) in the GLCB's upstream area (Kruskal-Wallis chi-squared = 17.764; P = 0.00003). In addition in the GLCB's downstream area the During-Construction Period mean TIV (2.17 hours) was significantly longer than the Before-Construction Period (mean TIV = 0.24 hours) (Kruskal-Wallis chi-squared = 7.020; P = 0.0081; **Table 3-50**). Thus, there was an increase in Chinook Salmon TIV, in the upstream and downstream areas, of the GLCB in the 2011 During-Construction Period. Therefore, if export rates were an important driver of survival in 2011 there should have been a decrease in TIV and there was not. Furthermore, if export rates were an important driver of survival, then there should have been an increase in survival in the During-Construction Period and there was not. These results suggest that export rates were not an important driver of steelhead survival in 2011.

The importance of the three channels studied and their potential effects on south Delta 2011 steelhead survival, was also evaluated using an assessment of the proportion of flow in each channel and the proportion of tagged salmonids using each channel. The proportion of flow through Middle River varied in the three construction periods, ranging from 7.9 to 12.7 percent (**Table 3-5**), compared to 87.3 to 92.1 percent of flow through Old River at hydrophone array ORSU (**Table 3-5**). Only 1.1 percent of tagged steelhead used the Middle River route in 2011 (**Table 3-21**).

The proportion of flow through the GLC, relative to Old River, increased in the During-GLCB Construction Period (87.0 percent) compared to the Before-Construction Period (78.4 percent) (**Table 3-6**). In addition, the

GLC was the most heavily used route among the three studied, 98.9 percent of steelhead utilized the GLC (**Table 3-14**). The increased proportion of flow through the GLC could have served to maintain survival because the GLC was the only channel of the three channels studied that did not have a closed barrier during the period of June 11 through July 14. It is concluded that changes in flow proportion between the three studied channels was an important factor preventing a decline in steelhead survival through time like that exhibited in 2010. Specifically, the increase in flow proportion into the GLC through time may have increased survival because the GLC route provided the best fish passage availability among the three available routes.

It is concluded that many factors could have contributed to the maintenance of survival at a high level through the GLCB Before-Construction Period (0.8838) and continuing throughout the During-Construction Period (0.7929) (**Table 3-31**); this decline was not statistically significant. Among the variables studied in this research that appeared to contribute to the consistently high steelhead survival in 2011 were: 1) the high discharges derived from a wet water year's precipitation (CDEC 2016a); 2) better and consistent passage route availability in 2011 among all three routes compared to 2010; 3) increased flow proportion into the GLC as time passed; and 4) a lower density of predatory fish in the During-GLCB Construction Period compared to the Before-GLCB Construction Period.

4.1.5 Predation on Juvenile Chinook Salmon and Juvenile Steelhead

4.1.5.1 *2010 Juvenile Chinook Salmon*

There were 322 tagged Chinook Salmon of the 342 tagged fish that were released 5.6 km (3.5 mi) upstream (**Figure 2-5**) that arrived at ORSU hydrophone array and 100 percent of these were identified as a "juvenile salmonid" and not as a "predator" (**Table 3-14**). Thus, 5.8 percent (20/342) either swam upstream, potentially using another route to the ocean, or were eaten and the predators that consumed the tags never approached the ORSU hydrophone array. Of the 322 tags that approached the ORSU hydrophone array it seems possible that some of these were in predatory fish. This suggests that more work on the predator filter may be required to improve precision in discriminating Chinook Salmon from predatory fish.

As the 322 Chinook Salmon proceeded downstream from ORSU, 300 fish arrived at GLCBU (the hydrophone array immediately upstream of the GLCB) (**Table 3-14**). Of these 300 fish, 23 fish (7.7 percent) were classified as arriving at GLCBU in a predatory fish.

As the juvenile Chinook Salmon proceeded downstream from ORSU, three tags arrived at ORTBU (i.e., the hydrophone array immediately upstream of ORTB). Of these three fish, none were classified as arriving at ORTBU in a predatory fish (**Table 3-14**).

These values, 7.7 percent and 0 percent were considerably less than that reported at the HOR in 2010 when a mean of 21.2 percent of the Chinook Salmon were classified as eaten. The 21.2 percent mean was taken from samples collected when the non-physical barrier (i.e., BAFF) was not in operation at the HOR. It is possible that the infrastructure of the BAFF caused increased predation rates. These results suggest that in 2010, Old River and the GLC channels upstream of the barriers were safer than the HOR area. Alternatively, the predator filter employed may be overly conservative and some proportion of tags arriving at GLCBU and ORTBU that were in predators may have been incorrectly classified as Chinook Salmon.

4.1.5.2 *2011 Juvenile Chinook Salmon*

In 2011, there were 649 tagged Chinook Salmon out of the 1,900 fish that were released 31.0 km (19.3 mi) upstream at Durham Ferry that arrived at the ORSU hydrophone array, and 99.7 percent (647/649) of these fish were identified as a "juvenile salmonid" not as a "predator" (**Table 3-21**). This again suggests that the predator filter may not have been sufficiently precise to discriminate Chinook Salmon from predatory fish because it seems improbable only 0.3 percent of Chinook Salmon were eaten between the release site and the ORSU hydrophone array. However, it is possible that only 0.3 percent of Chinook Salmon were eaten in this river segment and, if that was the case, it would suggest that in 2011 predation risk in the south Delta was low.

As Chinook Salmon proceeded downstream from ORSU, 504 fish arrived at GLCBU (i.e., the hydrophone array immediately upstream of the GLCB). Of these 504 fish, 4 fish (0.8 percent) were classified as arriving at GLCBU in a predatory fish (**Table 3-21**).

As Chinook Salmon proceeded downstream from ORSU, 47 fish arrived at ORTBU (the hydrophone array immediately upstream of ORTB). Of these 47 fish, 4 fish (8.5 percent) were classified as arriving at ORTBU in a predatory fish (**Table 3-21**).

These values, 0.8 percent and 8.5 percent were similar of less than that reported at the HOR in 2011 where a mean of 8.7 percent of Chinook Salmon were classified as eaten (DWR 2015a). These results suggest that in 2011, like 2010, Old River and the GLC channels upstream of the barriers were similar or safer than the HOR area. Alternatively, these results suggest again like 2010 results, that the predator filter employed may be overly conservative and some proportion of tags arriving at GLCBU and ORTBU that were in predators may have been incorrectly classified as Chinook Salmon.

4.1.5.3 *2010 Juvenile Steelhead*

There were 325 tagged steelhead out of a total of 480 tagged fish that were released 5.6 km (3.5 mi) upstream (**Figure 2-5**) that arrived at the ORSU hydrophone array (**Table 3-14**). Therefore, 32.3 percent (155/480) swam upstream and chose another route to the ocean or were eaten and the predators that consumed the tag(s) never approached the ORSU hydrophone array. The 32.3 percent value that never appeared at ORSU was considerably greater than the observed for Chinook Salmon, 5.8 percent in 2010—these results suggest that these two species may have different options regarding life history choices as discussed in Section 4.1.2.1 *Results Relating to the Predator Filter for 2010*), or have different susceptibilities to predation.

Several lines of evidence suggested that in 2010 steelhead behaved quite differently from Chinook Salmon. First, the predator filter classified 95.2 percent of steelhead as piscine predators. This is not hard to understand when a steelhead 2D track is inspected (**Figure 3-3**). Steelhead 2143.04 exhibited a linear "migratory mode" track as it entered the 2D hydrophone array. Then, as it neared the ORTB it switched from a "migrating mode" to something that could be described as a "searching mode." Steelhead 2143.04 spent considerable time searching for a route before it finally executed passage through a culvert. Similarly, steelhead 2493.04 showed considerable time searching for a route before executing passage over the weir (**Figure 3-4**). The steelhead searching-mode behavior patterns looked a great deal like predator-type movements (**Figures 4-7** and **4-8**).

Second, the mixture model exhibited difficulty in distinguishing steelhead from piscine predators. For example, the mixture model classified 49 percent of steelhead tag track segments as a predator fish in 2010 (**Table 3-65**). The mixture model classified only 42 percent of steelhead tag track segments as "salmonid" (**Table 3-65**). In addition to these classifications, it is evident that steelhead overlapped predatory fish, especially Largemouth Bass, substantially for tortuosity and the Lévy coefficient (**Figure 3-6**).

Third, TIV data showed significant overlap between steelhead and piscine predators. There was no statistical difference between steelhead TIV and predatory fish TIV in the ORTB upstream or the ORTB downstream areas. Thus, steelhead and predatory fish remained in the vicinity of the ORTB for long periods of time (**Tables 3-57** and **3-58**).

There are many possible explanations for the steelhead behavior in 2010. Three of the most likely are: 1) steelhead do not have to reach the sea to survive and execute their complete life cycle. They can terminate their migration, swim back upstream and residualize (Williams 2010); 2) steelhead (range 195–340 mm FL [7.7–13.4 in FL]) used in this study were considerably larger than Chinook Salmon (range 95–125 mm FL [3.7–4.9 in FL]). Thus, steelhead were stronger swimmers than Chinook Salmon and were more likely to be able to resist tidal forcing and stronger currents; and 3) the SDABs were operated differently in 2010 compared to 2011. In 2010, the MRB and the ORTB culvert flap gates were untied on June 11 and thus only opened on flood tides when sufficient head differential forced the flap gates open (**Table 2-2**). This resulted in restricted periods when a passage route was available at the MRB and ORTB. The GLCB was closed on July 7 in 2010, but not until July 14 in 2011 (**Table 2-4**) resulting in smaller duration of open channel route availability in 2010. Of course, all three of these mechanisms could have been at work in 2010: steelhead were experiencing warmer temperatures in 2010 compared to 2011 (see Section 3.1 *Water Temperature*), were larger and thus better swimmers than Chinook Salmon, and so, when presented with partially-closed migration routes some proportion of the steelhead may have returned upriver to complete their life cycle.

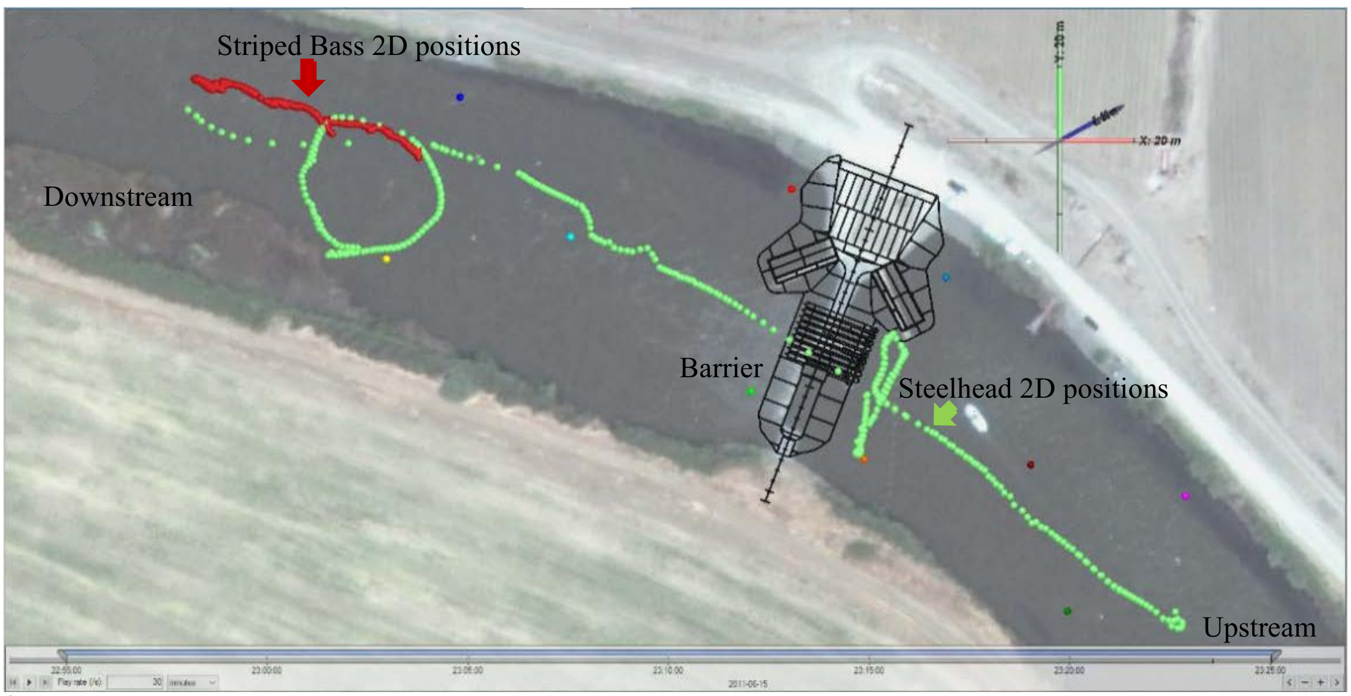
4.1.5.4 *2011 Juvenile Steelhead*

There were 2,195 tagged steelhead that were released 31.0 km (19.3 mi) upstream at Durham Ferry and of those 496 arrived at the ORSU hydrophone array. Therefore, 77.4 percent (1,699/2,195) of steelhead released swam upstream, chose another route to the ocean, or were eaten and the predator that consumed the tag never approached the ORSU hydrophone array. Of the 496 tagged steelhead that arrived at the ORSU array, 6.3 percent of these fish were identified as a predatory fish (**Table 3-21**). If only 6.3 percent of steelhead were eaten in this river segment, it would suggest that in 2011 predation risk in the south Delta was low. This conclusion is consistent with the Chinook Salmon proportion-eaten data at the HOR that showed the lowest observed proportion eaten in 2011 compared to 2009, 2010, and 2012 (DWR 2015a).

As the steelhead proceeded downstream from the ORSU array, 424 fish arrived at GLCBU (i.e., the hydrophone array immediately upstream of the GLCB). Of these 424 fish, 27 fish (6.4 percent) were classified as arriving at GLCBU in a predatory fish (**Table 3-21**).

As steelhead proceeded downstream from ORSU, 48 fish arrived at ORTBU (i.e., the hydrophone array immediately upstream of ORTB). Of these 48 fish, 4 fish (8.3 percent) were classified as arriving at ORTBU in a predatory fish (**Table 3-21**). Some steelhead may have encountered predators but been able to avoid them. For example, steelhead 3363.11 (384 mm FL [15.1 in FL]) showed downstream migration, searching, and fish passage behaviors as well as predator avoidance to Striped Bass 2393.01(500 mm TL [19.7 in TL]) that was holding in the middle of the river downstream of the ORTB (**Figure 4-4**). Striped Bass 2393.01 was captured, tagged, and released on June 15. After release, at approximately 11:15 hours, this Striped Bass held in the middle of Old River approximately 40 m (131 ft) downstream of the ORTB and within 10 m (33 ft) of its release location. Striped Bass 2393.01 remained in this location for almost 12 hours. On that same day, at 23:05:21 hours, steelhead 3363.11 entered the 2D array upstream of the ORTB. Upon encountering the barrier, steelhead 3363.11 spent about four minutes searching before executing passage downstream. During this time period, Striped Bass 2393.01 continued to hold in the middle of the river channel approximately 40 m (131 ft) downstream of the ORTB. Approximately nine minutes after passing the barrier at 23:14:13 hours, steelhead 3363.11 passed near Striped Bass 2393.01. For the next five minutes, the steelhead moved in a counter-clockwise direction downstream of the ORTB (**Figure 4-4**) and it was hypothesized these movements were motivated by an attempt to avoid Striped Bass 2393.01. Subsequently, steelhead 3363.11 continued downstream and the left the 2D array at 23:19:55 hours. The Striped Bass 2393.01 also moved downstream but separated from the steelhead by more than 4 m (13 ft) and so it was concluded that Striped Bass 2393.01 had not successfully preyed upon steelhead 3363.11. It should be noted that steelhead 3363.11 and Striped Bass 2393.01 locations in **Figure 4-4** had a positioning precision of < 1.0 m (< 3.3 ft) (Tunnicliffe et al. 2012). Thus, there was very good confidence in movements of steelhead 3363.11 and Striped Bass 2393.01 that took place over distances of > 1.0 m (> 3.3 ft). Conversely, less confidence was possible in movements at scales < 1.0 m (< 3.3 ft).

The percentage of steelhead arriving at the GLCB and the ORTB as steelhead and not in predators, 6.4 percent and 8.3 percent, respectively, were within 2.3 percent of the proportion eaten reported at the HOR in 2011 ($\bar{x}$ = 8.7 percent) (DWR 2015a). These results suggested that in 2011, the GLC and Old River channels upstream of the barriers were similar to, or perhaps a little safer, than the HOR area.



Source: HTI this study.

Figure 4-4. Steelhead Movements Including Downstream Migration, Searching, Fish Passage, and Predator Avoidance of a Striped Bass at the Old River at Tracy Barrier During 2010

4.1.6 Survival Past Barriers

It is very possible that the estimates of Chinook Salmon and steelhead survival in 2010 and 2011 may overestimate survival in the south Delta. This conclusion seems plausible because the GLCB did not close until July 7 in 2010 (**Table 2-1**) and until July 14 in 2011 (**Table 2-3**). During both 2010 and 2011 the GLC route was wholly to partially open for the entire study period. If the GLCB closed in May or June (the period in which the GLCB has closed in every year since 2011), then the GLCB may have caused reduced survival. There is a substantial possibility that survival was overestimated in 2010 and 2011 because the GLC provided the migration route for the majority, by a wide margin, of salmonid juveniles compared to Old River or Middle River (**Tables 3-14** and **3-21**).

4.2 SUCCESSFUL PASSAGE THROUGH THE OLD RIVER AT TRACY BARRIER

From the 2D fish releases in 2010, only steelhead were detected at the ORTB during the After-Construction Period (**Figure 2-5**). The ORTB was found to be a significant impediment (Kruskal-Wallis chi-squared = 30,574.000; P = 2.2 x 10^{-16}) to steelhead with 73.5 percent (50/68) failing to pass the barrier (**Table 3-38**). In 2010, the culvert flap gates were not tied open for 79 percent (27 of 34 days) of the After-Construction Period (**Tables 2-1** and **2-2**) like they were in 2011. Therefore, the 5 steelhead (**Table 3-38**) that did use the culvert route (e.g., **Figure 3-3**) had to wait until a flood tide forced open the flap gates then swim 19 m (62 ft) against the current through the culvert pipe's barrel. Based upon the results reported herein, this was an uncommon occurrence.

In 2011, 127 Chinook Salmon released at the 2D Fish Release Site (**Figure 2-11**) were detected at the ORTB. Of these 127, 120 passed successfully and 7 did not pass and it was concluded that the ORTB was a significant impediment to ORTB passage (Kruskal-Wallis chi-squared = 65.700; P = 5.25 x 10^{-16}). However, 120 Chinook Salmon successfully passing and 7 not passing was a reversal of the 2010 steelhead trend of fewer fish passing compared to the number that did not pass. Thus, it appeared that the tied-open flap gates in 2011 provided a constantly open route through the ORTB and this allowed more Chinook Salmon to pass than did not pass.

In 2011, 52 steelhead released at the 2D Fish Release Site (**Figure 2-11**) were detected at the ORTB. Of these 52, 36 passed successfully and 16 did not pass and it was concluded that the ORTB was a significant impediment to ORTB passage (Kruskal-Wallis chi-squared = 3,306.100; P = 2.2 x 10^{-16}). Similar to Chinook Salmon, 2011 steelhead passage saw a reversal in the 2010 trend of fewer fish passing compared to the number that did not pass. Thus, it appeared that the tied-open flap gates in 2011 provided a constantly open route through the ORTB and this allowed more steelhead to pass than did not pass.

4.3 ROUTE THROUGH THE OLD RIVER AT TRACY BARRIER

4.3.1 Juvenile Chinook Salmon

In 2011, 94.5 percent (120/127) of the Chinook Salmon passed the ORTB successfully (**Table 3-39**). The passage route was successfully determined for 79 of these 120 passes. Sixty-four Chinook Salmon (81.0 percent) of 79 used the culvert route. It is hypothesized that the culvert route was used more than the weir route because the culvert route was always available in 2011 regardless of when a Chinook Salmon arrived. In contrast, the weir was only overtopped during the peak of flood and ebb tides. Therefore, a Chinook Salmon could utilize the culvert route even when the weir route was unavailable. Furthermore in 2011, because the flap gates were tied open, on an ebb tide water velocity would have been downstream through the pipe making passage through the route much easier energetically than in 2010 when the only time the culvert route was available there was water velocity upstream through the pipe.

4.3.2 Juvenile Steelhead

In 2010, 73.5 percent (50/68) of steelhead did not pass the ORTB successfully (**Table 3-38**). The passage route was successfully determined for 13 of 18 successful passes. There was no statistically significant difference between the proportions of steelhead using each route but 8 (61.5 percent) of 13 steelhead used the weir route (e.g., **Figure 3-4**), while 5 steelhead used the culvert route. It is hypothesized that the weir route was used more than the culvert route because the culvert was more difficult to use for passage. For a steelhead to use the culvert route in 2010, it had to swim against the current caused by the head differential that forced open the culvert flap gate. In addition, that steelhead had to swim against that current through the entire length of the culvert barrel, i.e., 18.9 m (62 ft).

In 2011, 69.2 percent (36/52) of steelhead passed the ORTB successfully (**Table 3-40**). The passage route was successfully determined for 24 of these 36 passes. Twenty-four (100 percent) of 24 steelhead used the culvert route. Similar to Chinook Salmon, it is hypothesized that the culvert route was used more than the weir route because the culvert route was always available regardless of when a steelhead arrived. This was true because the culvert flap gates were tied open for the entire After-Construction Period in 2011 (**Tables 2-3** and **2-4**). In contrast, the weir was only overtopped during the peak of flood and ebb tides. Therefore, a steelhead could utilize the culvert route even when the weir route was unavailable. Furthermore in 2011, as was noted for Chinook Salmon (see Section 4.3.1 *Juvenile Chinook Salmon*), because the flap gates were tied open, on an ebb tide water velocity would have been downstream through the culvert pipe making passage through the route much easier energetically than in 2010 when the only time the culvert route was available there was water velocity upstream through the pipe.

4.4 TIME-IN-VICINITY OF BARRIERS

There were many scenarios in the 2010 and 2011 TIV data sets that exhibited insufficient sample size (n < three fish in one of the groups) to execute a test of hypothesis $H1_0$: Juvenile salmonid TIV is equal in the Before-, During-, and After-Construction Periods. However, sufficient TIV observations were obtained that allowed hypothesis tests in some situations, and those results are discussed.

It was noted that a small proportion of tagged salmonids spent just 0.05 hours (3 minutes) or less in the area of a barrier. The fish that carried these tags probably did not have sufficient time to enter the area and pass both the barriers' upstream and downstream hydrophones and then exit the area in that amount of time. This suggests that some of these tags may have been in predatory birds or fish and some of tags these may have been Chinook Salmon or steelhead that entered the barrier area and left upstream after only a very short stay.

4.4.1 Middle River Barrier

4.4.1.1 *Juvenile Chinook Salmon*

There was insufficient sample size to conduct a hypothesis test in 2010 or 2011. However, inspection of **Table 3-41** showed that in 2011, when the Category 1 (Upstream) area and Category 3 (Both Upstream and Downstream) areas observations were combined, the TIV range and mean are longer in the After-Construction compared to the Before-Construction Period. These results were consistent with the hypothesis that closing of the MRB created longer TIV for Chinook Salmon.

4.4.1.2 *Juvenile Steelhead*

Similar to Chinook Salmon, no hypothesis test was possible in 2010 or 2011 for steelhead. The mean TIV was lower in the Before- compared to the After-Construction Period (**Table 3-42**). However, the ranges of the Before-Construction Period and After-Construction Period TIVs overlapped more for steelhead than it did for Chinook Salmon. The support for the hypothesis that closing of the MRB created longer TIV for salmonids was still present but was less strong with steelhead than Chinook Salmon.

4.4.2 Grant Line Canal Barrier

4.4.2.1 *2010 Juvenile Chinook Salmon*

No comparisons of construction periods were possible in 2010 because Chinook Salmon only approached the GLCB in the Before-Construction Period (see Section 3.7.2.1 *2010 Juvenile Chinook Salmon*).

4.4.2.2 *2010 Juvenile Steelhead*

No comparisons of construction periods were possible in 2010 because steelhead only approached the GLCB in the Before-Construction Period (see Section 3.7.2.2 *2010 Juvenile Steelhead*).

4.4.2.3 *2011 Juvenile Chinook Salmon*

In 2011, in the Category 1 (Upstream) area, there was no statistically significant difference in TIV in the Before-Construction Period compared to the During-Construction Period (**Table 3-47**) (Kruskal-Wallis chi-squared = 0.1584; P = 0.9239). In addition, when Category 2 (Downstream) area and Category 3 (Both Upstream and Downstream) areas TIV observations were combined, there was no TIV difference in the Before-Construction compared to the During-Construction Periods (**Table 3-48**) (Kruskal-Wallis chi-squared = 0.7952; P = 0.6719). These results did not seem surprising because the GLCB was never closed in 2011 and, therefore, a route through the area of the GLCB footprint was always open in both the Before-Construction Period and During-Construction Period.

4.4.2.4 *2011 Juvenile Steelhead*

Juvenile steelhead TIV in the GLCB’s Category 1 (Upstream) area (**Table 3-49**) and Category 2 (Downstream) area (**Table 3-50**) was significantly shorter in the Before-Construction Period compared to the During-Construction Period. Water temperature, GLC discharge, export rates, and predatory fish density were investigated to determine what might have resulted in this significant difference.

Water temperature averaged 4.9°C (8.8°F) warmer in the During-Construction Period (**Table 3-2**). Yet, warmer water temperatures that were approaching steelhead upper thermal tolerances should have stimulated the steelhead to migrate out of the area more quickly. However, it is possible that increasing water temperatures that were less than the upper lethal temperature of 24°C (75.2°F) (Bell 1990; Nielsen et al. 1994) might cause steelhead to hesitate or terminate their migration to the sea. Juvenile steelhead can terminate their out-migration and return upstream and residualize (Williams 2010).

Stream discharge averaged 207.0 cms (7,310 cfs) in the Before-Construction Period and 120.1 cms (4,243 cfs) in the During-Construction Period (**Table 3-6**). This substantial decrease in flow could have created several impacts to hydrodynamics in the vicinity of the GLCB footprint and these changes could have affected steelhead. For example, lower discharges in the During-Construction Period could have lowered average channel velocities, slowed the movement of steelhead and thereby increased TIVs.

Combined Banks and Jones Pumping plants export rates changed considerably between the two periods of interest. In the Before-Construction Period export rates were substantially smaller than in the During-Construction Period (**Table 4-2**). This was unusual because export rates went up considerably but discharge (see previous paragraph) went down simultaneously. The primary mechanism through which export rates would influence steelhead TIV is through GLC flow, e.g., export rates increase, GLC flow increases and steelhead TIV might respond by going down. So, it was concluded that since discharge rates fell substantially while export rates increased, the discharge was likely the proximate factor more likely to have influenced steelhead TIV rather than export rates.

Table 4-2. 2011 Export Rates Through Banks Pumping Plant and the Jones Pumping Plant Combined During Grant Line Canal Barrier Construction Periods

Period	Minimum cms (cfs)	Mean cms (cfs)	Standard Deviation cms (cfs)	Maximum cms (cfs)
Before	11.6 (408)	144.2 (5,093)	68.1 (2,405)	289.6 (10,226)
During	239.9 (8,471)	297.2 (10,495)	27.3 (963)	324.3 (11,454)

Source: ESA this study.

Piscine predator density was estimated at 0.86 predatory fish per 1,000 cubic meters (0.024 predatory fish/cubic feet) in the Before-Construction Period and 0.57 predatory fish per 1,000 cubic meters (0.016 predatory fish/1,000 cubic feet) in the During-Construction Period (**Table 3-71**). Thus, predatory fish density estimates were smaller in the second period compared to the first period. More predators in the Before-Construction Period could have many possible effects but at least one effect was readily apparent—more predatory fish might stimulate steelhead to migrate out of the area faster in the Before-Construction Period.

It is concluded that many factors could have caused the increased 2011 steelhead TIV observations in the GLCB Category 3 (Both Upstream and Downstream) areas in the During-Construction Period relative to the Before-Construction Period. Two factors seemed the most likely factors that caused this increase. First, predator density estimates were 50.9 percent higher (**Table 3-71**) in the Before-Construction Period while temperatures were still cool (15.6°C [60.1°F]; **Table 3-2**). This combination could have created predator-steelhead encounters and those steelhead that survived might have been stimulated to leave the GLCB area. Second, discharge decreased substantially in the second period relative to the first period (**Table 3-6**). Lower discharges might produce lowered average channel velocities and this could slow down steelhead utilizing stream flow to assist them in their emigration to the sea. It is possible that lowered discharges and increased water temperatures could have worked synergistically to cause steelhead to hesitate and even terminate their emigration, i.e., faced with decreasing discharges and increasing water temperatures a steelhead might choose instead to return upstream to a large river with coldwater refugia. Finally, the During-Construction Period steelhead TIV values could have been inflated because some tags may have been consumed by predatory fish. The During-Construction Period was approximately 4.2°C (7.6°F) warmer on average and this might have reduced steelhead physiological condition (Viant et al. 2003) making them more vulnerable to predation. In summary, the significantly greater steelhead TIV observations in the During-Construction Period should be viewed with caution.

4.4.3 Old River Tracy Barrier

The combining of the 1D and 2D TIV data sets substantially increased the number of hypothesis tests that could be conducted. This was primarily due to improved sample size in the After-Construction Period from the 2D data set. However, before the 2D tracks were combined into the 1D TIV data set, the 2D tracks were inspected. The inspections suggested that some tagged salmonids might have been eaten thus inflating TIV values.

Tags were removed from TIV analyses if strong predation evidence existed. Strong predation evidence was defined as: 1) tags made multiple passages through or over the ORTB; and/or 2) became stationary—thus meeting the defecation/regurgitation criteria. Therefore, no expert interpretation was used in determining predation.

No predation-determinations by expert interpretation were used to eliminate "eaten" tags because examination of the 2D tracks and mixture model results both suggested that discrimination of 2D tracks of juvenile salmonids from that of predatory fish was problematic in this study due to the SDABs. The problematic nature is evident from the following figures.

In **Figure 4-5** it is evident that this tag made many turns and was tortuous. Inspection suggested that this tag like many others showed large turning angles compared to Chinook Salmon (determined to be "uneaten" by expert analysis) 2D tracks at the HOR (see DWR 2015a: Figures 5-10 and 5-11) or Georgiana Slough (see DWR 2012: Figure 3-5; DWR 2015b: Figures 3.2-5 and 3.2-11). It is unknown if and when Chinook Salmon 3524.15 was eaten. Thus, it is possible, part or all of this 2D track was the track of a predatory fish. However, the mixture model results suggested this was a Chinook Salmon throughout this track. The mixture model identified three path segments for this fish and determined the probability of being a predatory fish for each was: 0.0701, 0.0654, and 0.0656. Thus, this tag was determined to have a "low" probability (low range: 0–0.33) of being a predatory fish.

In **Figure 4-6** it is evident that small step-length and large turning angles resulted in a steelhead track that was more tortuous than Chinook Salmon 3524.15. This tag exhibited a track that was far more tortuous than that of steelhead at the HOR or at Georgiana Slough (e.g., see DWR 2015a: Figure 7-2 or DWR 2015b: Figure 3.2-11). In fact, steelhead 2423.04 bears more resemblance to the Largemouth Bass in **Figure 4-8** than to the steelhead identified as uneaten by expert analysis (DWR 2015a, 2015b). This illustrates the problem of distinguishing steelhead 2D tracks from predatory fish, especially Largemouth Bass, using mixture modeling. The mixture model identified five path segments for this tag and determined the probability of being a predatory fish for each was: 0.0002, 0.0150, 0.0416, 0.2324, and 0.2494. Thus, this tag was determined to have a "low" probability (low range: 0–0.33) of being a predatory fish.

In **Figure 4-7** it is evident that Striped Bass 5445.01 remained offshore and its tag track was tortuous. Inspection suggested this arose from searching behavior away from river margins as the Striped Bass patrolled for prey. This illustrates the problem of distinguishing Chinook Salmon 2D tracks from predatory fish, especially Striped Bass, using mixture modeling. The mixture model identified seven path segments for this tag and determined the probability of being a predatory fish ranged from 0.584 to 0.850. Two of the seven probabilities were determined to have an "intermediate" probability (intermediate range: 0.333–0.667) of being a predatory fish. Five of the seven probabilities were determined to have a "high" probability (high range: 0.667–1.000) of being a predatory fish.

In **Figure 4-8** it is evident that Largemouth Bass 5529.01 remained near shore or the ORTB and its tag track was much more tortuous that Striped Bass 5445.01. This near-structure behavior might have arisen as a result of the ambush predatory strategy commonly employed by Largemouth Bass. This predator's 2D track illustrates the problem of distinguishing steelhead 2D tracks from predatory fish, especially Largemouth Bass, using mixture modeling. The mixture model identified 27 path segments for this Largemouth Bass and determined the probability of being a predatory fish ranged from 0.0002 to 0.831. Twenty of the 27 probabilities were determined to have a "low" probability (low range: 0.000–0.333) of being a predatory fish. Two of the 27 probabilities were determined to have an "intermediate" probability (intermediate range: 0.333–0.667) of being a predatory fish. Five of the 27 probabilities were determined to have a "high" probability (high range: 0.667–1.000) of being a predatory fish.

After all of the 2D tracks were inspected and the mixture model results were reviewed, it is concluded that it was difficult to identify those tags that had been eaten or when they may have been eaten. Therefore, only those tags that had strong evidence of predation (multiple barrier passages or regurgitation/defecation) were removed.

It was impossible to determine definitively why the salmonid 2D tracks did not look like salmonid tracks from the HOR (2009–2011) or Georgiana Slough (2011–2012) studies. It was hypothesized that the ORTB, when closed, provided a near complete blockage of the channel. A salmonid must search the ORTB to find a route through the culverts or over the crest of the weir. In addition, salmonids might have to wait for the tide to overtop the weir or force open the culverts' flap gates on a flood tide to be able to find an open passage route. This was not the case at the HOR in 2009, 2010, or 2011 (DWR 2015a) or at Georgiana Slough in 2011 or 2012 (DWR 2012, 2015b). In all five of these five cases, there were two open channels available:

1) At the HOR, a salmonid approaching the HOR divergence in 2009–2011 had a choice: the Old River channel or the San Joaquin River channel; and

2) At the Sacramento River/Georgiana Slough divergence, a salmonid approaching the divergence in 2011–2012 had two choices: the Sacramento River channel or the Georgiana Slough channel.

A salmonid could physically choose either of the two available routes at each of these two divergences: HOR or Sacramento River/Georgiana Slough divergence. At the ORTB after it was closed, a salmonid must search for and find a route through the barrier because the only option to passage was to swim upstream to Middle River or the San Joaquin River.

There were 2D tracks collected by telemetry at the HOR that did look similar to the ORTB 2D tracks. Chinook Salmon HOR-4716 (**Figure 4-9**) and steelhead HOR-4989 (**Figure 4-10**) tracks from HOR in 2012 showed similarities to those obtained at the ORTB in 2010 and 2011. It is hypothesized these similarities arose from the near-complete blockage of the channel by the rock-fill ORTB and by the rock-fill HORB in 2012.

In 2010 no hypothesis testing was possible for Chinook Salmon TIV for different construction periods of the ORTB. This was due to the fact that only three Chinook Salmon that were released at the 2010 release location approached the ORTB (**Table 3-44**). After the ORTB was closed in 2010, the 2D hydrophone array was installed. But, by ORTB closure on June 3, all Chinook Salmon had died in the lab or been euthanized due to an outbreak of PKD (see Section 2.3.1 *Acoustic Tag Surgical Insertion*). Thus, no Chinook Salmon were available to receive acoustic transmitters in the After-Construction Period when the 2D hydrophone array was installed.

Source: HTI this study.

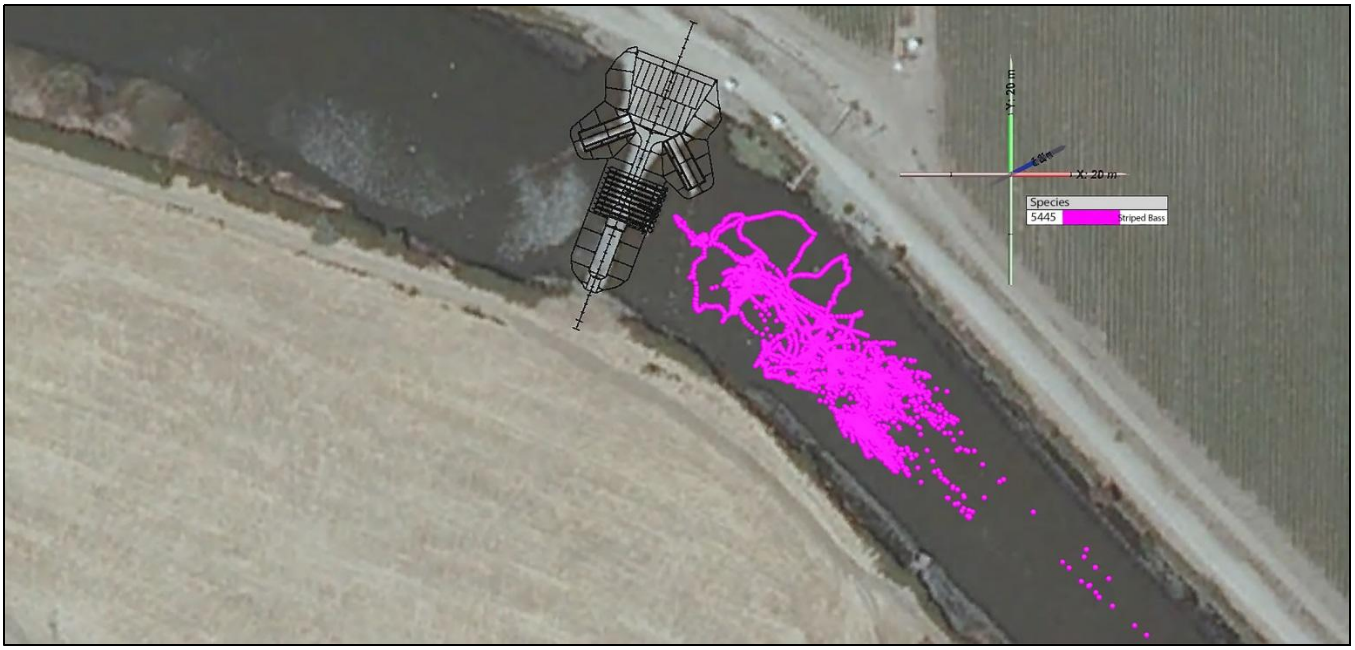
Note: Juvenile Chinook Salmon 3524.15 approached the ORTB from upstream on June 17, 2011 at 02:06:03 hours and departed downstream on June 18, 2011 at 05:34:53 hours.

Figure 4-5. Juvenile Chinook Salmon 3524.15 Tracks at the Old River at Tracy Barrier

Source: HTI this study.

Note: Juvenile steelhead 2423.04 approached the ORTB from upstream on June 8, 2010 at 06:05:07 hours and departed downstream on June 16, 2010 at 10:31:05 hours.

Figure 4-6. Juvenile Steelhead 2423.04 Tracks at the Old River at Tracy Barrier



Source: HTI this study.

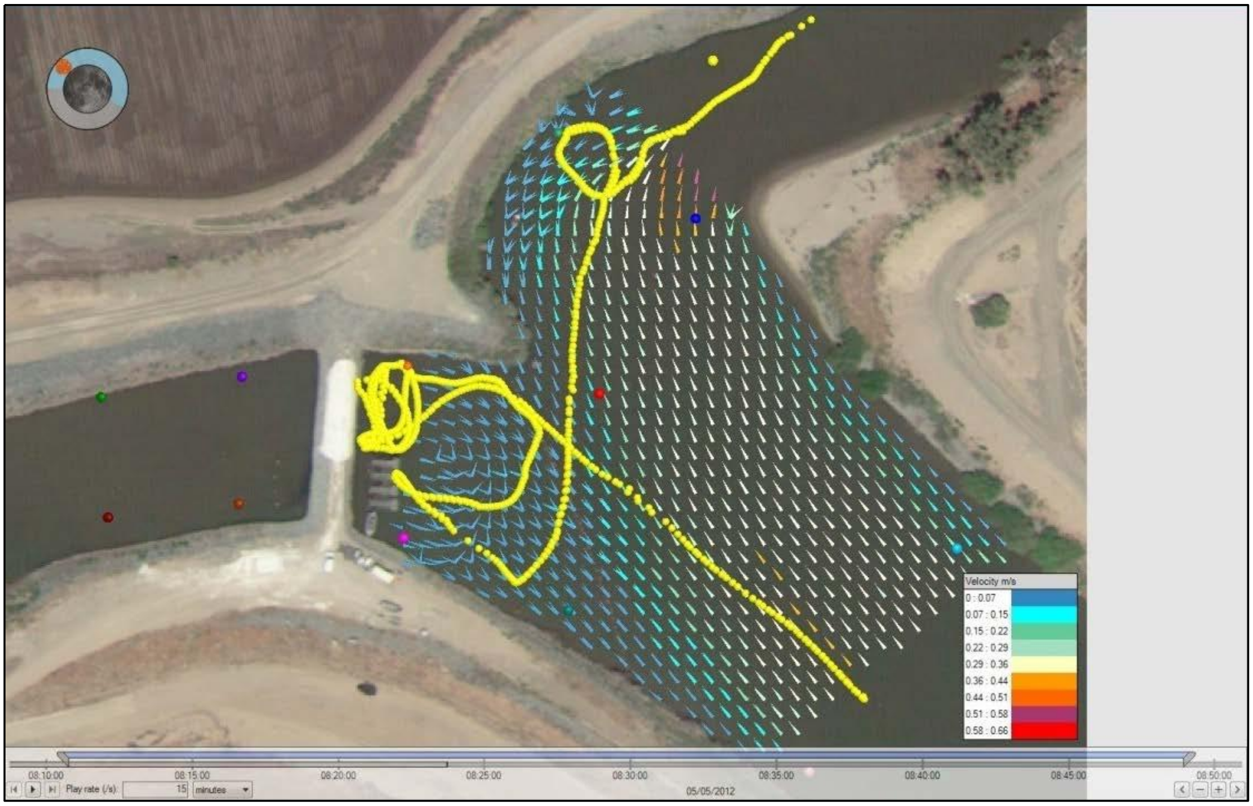
Note: Striped Bass 5445.01 approached the ORBT from upstream on June 13, 2010 at 14:13:45 hours and exited upstream on June 29, 2010 at 13:24:34 hours.

Figure 4-7. Striped Bass 5445.01 Tracks at the Old River at Tracy Barrier

Source: HTI this study.

Note: Largemouth Bass 5529.01 approached the ORTB from upstream on June 8, 2010 at 13:00:08 hours and exited upstream on July 12, 2010 at 12:21:52 hours.

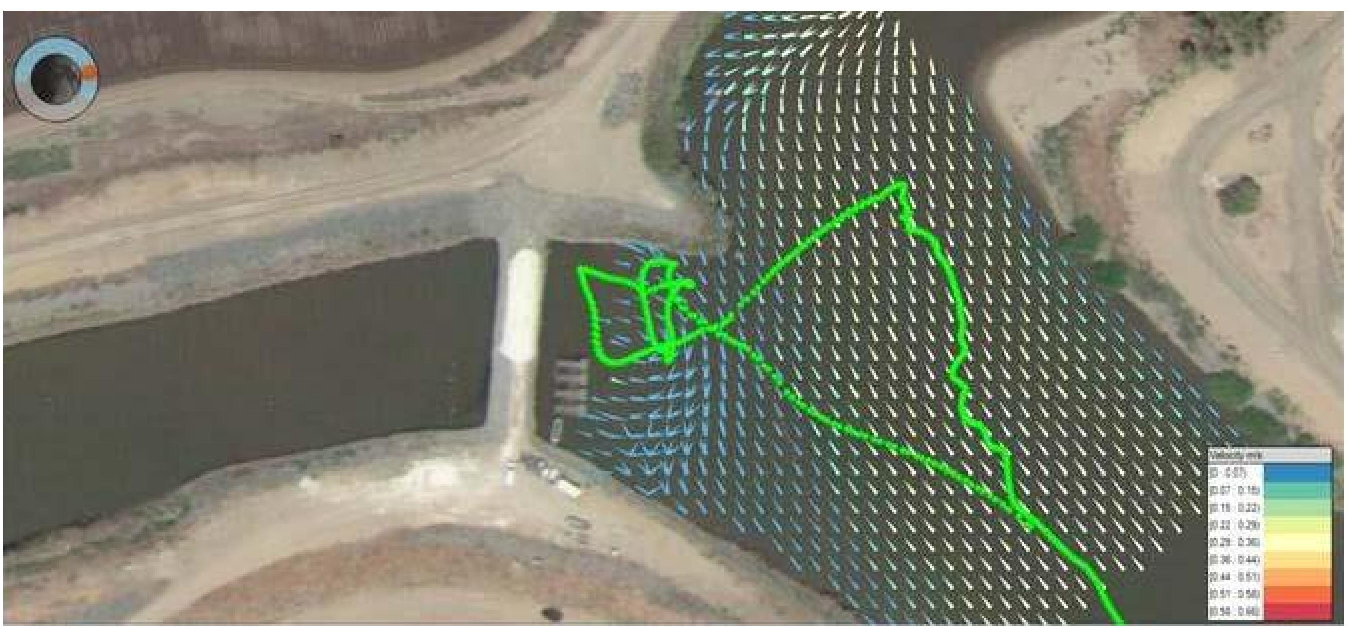
Figure 4-8. Largemouth Bass 5529.01 Tracks at the Old River at Tracy Barrier



Source: HTI this study.

Note: The vectors indicate the direction and velocity of water in the vicinity during this period of approximately 35 minute duration. Chinook Salmon 4716.03 approached the HORB from upstream on May 5, 2012 at approximately 08:11:00 hours and departed down the San Joaquin River on May 5, 2012 at approximately 08:46:00 hours.

Figure 4-9. Chinook Salmon 4716.03 Track at the Head of Old River Barrier



Source: HTI this study.

Note: The vectors indicate the direction and velocity of water in the vicinity during this period of approximately 77 minute duration. Steelhead 4989.03 approached the HORB from upstream on May 28, 2013 at 16:41:38 hours and spent time in apparent "search" mode and then swam back upstream on May 28, 2013 at 17:18:09 hours.

Figure 4-10. Juvenile Steelhead 4989.03 Track at the Head of Old River Barrier

In 2011, it was concluded that the ORTB caused a statistically-significant delay in the migration of Chinook Salmon on the upstream side of the barrier (Section 3.7.3.2 *2011 Juvenile Chinook Salmon* and **Table 3-51**). In addition, the TIV on the upstream side of the ORTB was significantly greater than the TIV for Chinook Salmon on the downstream side of the barrier (**Table 3-53**) suggesting that once the Chinook Salmon find a route through they continue migration very quickly. Furthermore, this significant TIV delay began with the onset of construction and not when the barrier was closed. After closure of the ORTB, the flap gates were tied open from June 10 until August 23. By August 23, all Chinook Salmon had passed through the ORTB area. It was hypothesized that the delays that raised TIV in the During- and After-Construction Periods may have been caused by: 1) construction activities because there was a significant difference between the Before-Construction and the During-Construction Periods (Kruskal-Wallis chi-squared = 5.841; P = 0.0156); and 2) the rock barrier forcing Chinook Salmon to search for a route through the ORTB because the flap gates were always open and thus a route always existed but had to be located to be used. It appeared that Chinook Salmon began searching for a route through the ORTB when they arrived on the upstream side of the barrier (**Figure 4-5**). In addition, this behavior looked similar to that observed on the upstream side of the HORB in 2012 (**Figure 4-9**). One potential difference in the behavior at the ORTB (**Figure 4-5**) was there was no immediately available route alternative unlike the alternative available at the HORB in 2012 (**Figure 4-9**).

In the ORTB downstream area, there was no significant delay of juvenile Chinook Salmon in 2011 (**Table 3-52**). This occurred because the P-value of the test, 0.0193, was greater than the Dunn-Šidák adjusted critical α' of 0.01695. However, due to the small P-value it is suggested that further study be conducted comparing the TIV for Chinook Salmon in the Before-Construction and After-Construction Periods.

4.4.3.1 *Juvenile Chinook Salmon TIV Compared to Piscine Predator TIV*

In 2011, only one hypothesis test was possible for Chinook Salmon TIV and piscine predator TIV: in the After-Construction Period, Category 2 (Downstream) area and Category 3 (Both Upstream and Downstream) areas TIV observations. The result of this test showed that Chinook Salmon TIV ranged from 0.02 to 5.72 hours and was significantly shorter than predator TIV which ranged from 0.44 to 103.96 hours (**Table 3-55**). These results suggested than when sufficient juvenile salmonid and predator sample sizes (n < three fish in any group) were obtained, there were very clear differences between TIV observations for each group. In the After-Construction Period, Chinook Salmon spent less time in the area of the ORTB than did piscine predators (**Table 3-55**). The species present in this piscine predator group, four Striped Bass, one Largemouth Bass, and one White Catfish, showed that there was diversity of predatory fish species and, as a group, they remained longer than Chinook Salmon. Several possible mechanisms could explain why piscine predators remain in the vicinity of the ORTB compared to Chinook Salmon: 1) predators receive an energetic advantage using velocity refugia in the ORTB area; 2) predators more commonly encounter prey in the vicinity of the ORTB than in other areas; 3) predator probability of successful capture increases in the vicinity of the ORTB; 4) Chinook Salmon that move quickly through the ORTB area might experience lower probability of encountering a predator; and 5) Chinook Salmon may encounter predatory fish in the vicinity of the ORTB and this might stimulate them to leave the area quickly.

4.4.3.2 *Juvenile Steelhead*

Unfortunately, the distribution of steelhead approaching the ORTB was not advantageous for hypothesis testing in 2010; insufficient numbers of steelhead were detected at the ORTB in the After-Construction Period. Thus, it is impossible to say definitively what the effect of the ORTB was on steelhead TIV in 2010. It should be noted that in 2010 the mean TIV was 0.49 hours in the ORTB Category 1 (Upstream) area Before-Construction Period (**Table 3-56**) and the mean TIV was 14.65 hours in the ORTB Category 1 (Upstream) area After-Construction

Period (**Table 3-56**). These results were consistent with the hypothesis that the ORTB caused juvenile steelhead migratory delays.

In 2011, there was a significantly shorter TIV in the Before-Construction Period compared to the After-Construction Period in the ORTB Category 1 (Upstream) area (**Table 3-60**). This result was similar to that for Chinook Salmon (**Table 3-51**). However, there were many similarities in behavior of steelhead and predatory fish (see Section 3.5.1 *2010 Survival Results Related to the Predator Filter* and Section 3.9 *Mixture Model Results for 2010 and 2011)*. Furthermore, predatory fish density was lower in the Before- compared to the After-Construction Period at the ORTB (see Section 3.10 *DIDSON Analysis*) suggesting a larger proportion of tags could have been in predators in the After-Construction Period compared to the Before-Construction Period. Thus, it is suggested that while this result was significant, this relationship should be studied further with steelhead. In this particular case, there seems real value in studying this issue using an acoustic transmitter that changes transmission characteristics after consumption of the tag by a predatory fish and the predator's stomach enzymes dissolve the special coating on the tag (Schultz et al. 2017).

In 2011 there was a significantly shorter TIV for steelhead in the Before-Construction Period compared to the After-Construction Period in the ORTB downstream area (**Table 3-61**). This result was in contrast to that for Chinook Salmon (**Table 3-52**). However, as noted in the previous paragraph, there were many similarities in behavior of steelhead and predatory fish. Therefore, it is suggested that while this result was significant, this relationship should be studied further with steelhead. Again, there seems real value in studying this issue using an acoustic transmitter that changes transmission characteristics after consumption of the tag by a predatory fish (Schultz et al. 2017).

4.4.3.3 *Juvenile Steelhead TIV Compared to Piscine Predator TIV*

In 2010, steelhead TIV was not significantly different from predatory fish TIV in the ORTB Category 1 (Upstream) area (**Table 3-57**) (Kruskal-Wallis chi-squared = 0.727; P = 0.3939) or the Category 2 (Downstream) area (**Table 3-58**) (Kruskal-Wallis chi-squared = 2.608; P = 0.1064). In 2011, only one hypothesis test was possible due to small sample size of tagged predatory fish—in the After-Construction Period for the ORTB, Category 2 (Downstream) area and Category 3 (Both Upstream and Downstream) areas track segments. For this hypothesis test, the steelhead TIV observations were significantly shorter in duration that those of piscine predators (**Table 3-62**) (Kruskal-Wallis chi-squared = 10.188; P = 0.0014). It seemed clear that circumstances differed in 2011 compared to 2010. In 2011 the predator filter categorized only 6.2 percent of steelhead that arrive at the ORSU hydrophone array as "predator" (31/496; **Table 3-21**) (see Section 3.5.1 *2010 Survival Results Related to the Predator Filter*). But, in 2010, the predator filter categorized 95.2 percent of steelhead as "predator" (see Section 3.5.4 *2011 Distribution of Acoustic Tags in South Delta Channels*). There are two possible explanations for the results: 1) steelhead behaved more like predatory fish in 2010 than 2011; or 2) predation rate on steelhead was higher in 2010 than in 2011.

The lower predation rate on salmonids in 2011 compared to 2010 occurred elsewhere in the south Delta: the proportion of Chinook Salmon eaten at the HOR was 8.7 percent in 2011, but in 2010 when the BAFF was not in operation, 21.2 percent were eaten (DWR 2015a). It was possible that the infrastructure of the BAFF contributed to the increased predation rate in 2010. Nevertheless, it appeared that it was possible that higher predation rates in 2010 caused a higher proportion of steelhead tags to have been in predators in 2010 compared to 2011. Thus, the 2010 steelhead TIV observations could have been inflated and that is why no significant difference was observed in 2010. It is concluded that the ORTB caused significant delays to steelhead migration in 2011.

4.5 MIXTURE MODEL

In 2010, the mixture model had difficulty in distinguishing predators and salmonids due to the similar behaviors of both groups. In 2010, only steelhead were available to be acoustically tracked through the After-Construction Periods. The predator tracks were more tortuous than steelhead tracks. However, the predator and steelhead distributions of tortuosity and the Lévy coefficients overlapped to such an extent (**Figure 3-6**) that the mixture model's ability to distinguish between predators and steelhead was compromised (**Table 3-64**). These overlaps were strongest for Largemouth Bass and steelhead because: 1) Largemouth Bass displayed unidirectional patrolling along shorelines and rarely left river margins resulting in lower tortuosity than was observed for Striped Bass; and 2) steelhead, when approaching the ORTB, often exhibited apparent searching behavior, possibly for a passage route though the barrier, that displayed small step-length and large turning angles resulting in very tortuous 2D tracks upstream of the barrier (see **Figure 3-3**).

In 2011, the mixture model performed better than with the 2010 data but again had trouble distinguishing predators from salmonids. This was due primarily to the similarities in behavior of predators and salmonids. Lévy coefficient distributions overlapped so extensively (**Figure 3-7**) that this metric was abandoned as a means to distinguish between predators and salmonids. Thus, tortuosity alone was used and 86 percent of Chinook Salmon track segments were classified as having low probability of being in a predator (**Table 3-66**). For steelhead this value fell to 66 percent, classified as having low probability of being in a predator (**Table 3-66**), again suggesting that steelhead behave differently from Chinook Salmon. In addition, the mixture model performed better for predators in 2011 predicting the probability was high (probability 0.66–1.00) of being a predator for: 1) Largemouth Bass (60 percent); and 2) Striped Bass (64 percent).

In 2010 and 2011, salmonids exhibited behavior that was characterized by highly tortuous tracks compared to salmonid tracks observed at the HOR (DWR 2015a: Figures 5-10 and 5-11) when no rock barrier was present, and Georgiana Slough (DWR 2012: Figure 3-5; DWR 2015b: Figures 3.2-5 and 3.2-11). These results are likely due to salmonid hesitation at the barrier and searching behavior to find a passage route through the barrier. This hesitation and searching behavior resulted in tracks with small step length and large turning angles generating highly tortuous tracks compared to other locations in the Delta that did not have a physical barrier. This explanation was supported by comparing the salmonid tracks obtained in 2010 and 2011 at the ORTB and the salmonid tracks obtained in 2012 at the rock barrier at the HOR (DWR 2015a): the tracks showed similarity with apparent searching behavior on the upstream side of the rock barriers.

Other approaches than tortuosity and Lévy coefficients, such as state-space modeling,[15] may aid in producing another track metric that could be used to feed into a mixture model approach. However, dynamic environments such as the study area discussed here, where fish may stall at a barrier and experience bidirectional flows further supports the development and use of predation tags to identify tagged salmonids that may have been consumed by predators.

4.6 DEFECATED AND REGURGITATED TAGS

Defecated/regurgitated tags were easily identified using the techniques described in Section 2.22 *Defecated and Regurgitated Tags*. In two years, only eight tags were within the 2D ORTB array (**Table 3-63**). However, only one of those was defecated/regurgitated on the downstream side of the ORTB. If a tag had an equal chance of

[15] State-space models are models that use state variables to describe a system by a set of first-order differential or difference equations, rather than by one or more *n*th-order differential or difference equations.

being defecated/regurgitated on the upstream and downstream side of the barrier, the cumulative binomial probability of only one tag (out of eight) being defecated/regurgitated on the downstream side of the barrier was 0.035. Thus, it was concluded in Section 3.8 *Defecated and Regurgitated Tags*, that there was a significantly higher probability of being defecated/regurgitated on the upstream side of the barrier than the downstream side.

This result suggested that predation might be more likely on the upstream side of the barrier. In addition, inspection of 2D tracks showed that of the eight defecated/regurgitated tags: 1) six of the salmonids appeared to have been eaten on the upstream side of the ORTB; and 2) two of the salmonids' locations when eaten could not be determined (**Table 3-62**). Predation might be more likely on the upstream side of the ORTB for many factors but two factors were identified and were supported by observations made in this study. First, TIV was greater on the upstream side of the barrier for both Chinook Salmon and steelhead in 2011 (**Tables 3-50** and **3-59**). Second, at the ORTB, the predatory fish density was higher on the upstream side of the barrier in the During-Construction and After-Construction Periods compared to the Before-Construction Periods (**Tables 3**-**69** and **3-70**).

4.7 DIDSON MONITORING OF PREDATORS

As described previously, tagged fish can be tracked and their movement patterns mapped in relation to the barriers and other features. While this type of analysis is extremely useful in describing fish movement patterns around the barriers, the results are limited by the number of fish that are tagged. For example, the analysis does not allow for an estimate of total potential predatory fish population density in a specific area to be determined. The active acoustic component of this study was designed to gather data to determine how predatory fish densities vary through time in the study area and to correlate densities and changes in distributions with and without barriers in place.

As discussed in Section 3.10, *DIDSON Analysis*, overall trends in predatory fish density were calculated utilizing the DIDSON sampling. Generally, for periods when DIDSON sampling was conducted, there was an increase in predatory fish densities during or after the barriers were installed compared to periods before the barriers were installed for both 2010 and 2011. The noted exception to this was at the GLCB in 2011 where Before-Construction Period density of 0.86 predatory fish per 1,000 cubic meters (0.024 predatory fish/1,000 cubic feet) was 33.7 percent greater than the During-Construction Period of 0.57 predatory fish per 1,000 cubic meters (0.016 predatory fish/1,000 cubic feet) (**Table 3-70**). This result made sense when discharge regime and the GLCB installation activities were considered. From fall 2010 through to June 10, 2011, the GLC was a completely open channel because the GLCB abutments and culverts were removed by October 14, 2010 (see Section 2.1 *Temporary Barriers Construction Schedule*). Furthermore, after June 10, high flow events regularly moved rock downstream that had been placed in the GLC to form the foundation of the GLCB. Thus, the GLC was principally a completely open channel for an estimated 81 percent (93 of 115 days) of the salmonid migratory period (March 22, 2011 [1st release of fish] until June 22, 2011 [last Chinook Salmon detection in the study area]). It was hypothesized that the combination of the wet water year (CDEC 2016a), high discharges, increased water temperature in the During-Construction Period (**Table 3-2**), and an open channel in which few or no velocity refugia were present changed the bioenergetic landscape in the vicinity of the GLCB footprint , i.e., high swimming cost and faster migrating salmonids made predators' net energetic return lower in the During-Construction Period and therefore some proportion of the predatory fish left the area.

The highest predatory fish density estimates were observed during and after the barriers were installed (**Tables 3-70** and **3-71**). The increases in predatory fish densities associated with the barriers being installed can be attributed to several factors. The presence of the barrier creates a condition of increased artificial structure, which provides velocity refugia, habitat complexity, locations where a predator can hold and ambush prey species, and other attributes that may be preferred by predatory fish. The affinity (or high use) for artificial structure habitat is typical for several species of predatory fish because these species tend to occupy areas with high habitat complexity, potentially reducing the distance between predator and prey at first encounter. In addition, artificial habitat often provides some form of cover and structure which may be more frequently used by piscine predators (Moyle 2002). Furthermore, anthropogenic-origin in-water structures can be associated with increased Striped Bass abundance and increased per capita consumption of juvenile Chinook Salmon at those sites compared to less altered sites (Sabal et al. 2016).

The presence of a barrier influences local hydrodynamics conditions in a manner that may also be deemed more favorable for predatory fish species. First, the presence of a barrier changes hydrologic conditions from being more dynamic (through discharge and tidal flows) to one that is more static. Second, a more static condition has higher potential to result in increased water temperatures and decreases in turbidity. Predatory fish species present in the south Delta that are not native to the Delta, evolved with more temperate water conditions and also tend to be visually-oriented feeders. As a result, environmental conditions that are associated with the barriers being in place are generally more suitable compared to conditions when the barriers are not in place. It was not surprising that, in general, predatory fish density estimates increased through time. Water temperature was warming in the south Delta during the spring and early summer during the two years of this study (**Tables 3-1** and **3-2**). As the water temperatures rose above a threshold, i.e., 22.0°C (71.6°F) for Chinook Salmon (Moyle 2002) and 21.0°C (69.8°F) for steelhead (Hooper 1973), the swimming efficiency for Chinook Salmon and steelhead began to decline. At the same time, swimming efficiency for the temperate-evolved predatory fish was improving in the water temperature range observed in 2010 and 2011. The piscine predators may have slowly, through time and temperature change, gained an advantage in swimming capacity over the salmonids. Thus, as water temperatures increased the temperate-evolved predators may have become more successful at preying on salmonids. This circumstance would tend to promote longer TIV for predatory fish than for salmonids. Longer TIV for predatory fish compared to Chinook Salmon (at the ORTB in 2011; **Table 3-54**) and steelhead (at the ORTB in 2010; **Table 3-56**) was observed in this study. It seems plausible that a different type of barrier construction process could reduce predation in the During-Construction Period. Predation on migrating salmonids might be reduced by minimizing the time necessary for in-water construction activities to limit velocity refugia to the extent possible. Furthermore, if possible, in-water work could be ceased temporarily when large numbers of migrating salmonids are in the south Delta. The density of migrating salmonids could be monitored through salvage at the CVP and SWP fish facilities or through direct monitoring, e.g., at the GLCB.

5 RECOMMENDATIONS

This chapter presents five recommendations stemming from this report. Each recommendation is followed by a summary of the data in this report supporting the recommendation. The recommendations chapter is divided into three sections: the first section identifies design improvements to the SDABs; the second section identifies operational improvements to the SDABs; and the third section addresses barrier priorities for improvements.

5.1 DESIGN IMPROVEMENTS

The results of this investigation demonstrate that the SDABs designs could be improved to benefit emigrating juvenile steelhead and Chinook Salmon survival through the south Delta.

5.1.1 Recommendation 1. Open Passage Route through Barriers

5.1.1.1 *In Years in Which the Head of Old River Barrier is Not Installed*

As soon as feasible, an open passage route should be maintained through each SDAB for as much of the spring/early summer salmonid migratory period as possible.

5.1.1.2 *In Years in Which the Head of Old River Barrier is Installed*

As soon as feasible, on open passage route should be maintained through each barrier when the HORB is not operational and water temperatures are not lethal to juvenile salmonids, i.e., < 24°C (< 75.2°F) for steelhead (Bell 1990; Nielsen et al. 1994) and Chinook Salmon (Moyle 2002).

5.1.1.3 *Data Supporting Recommendation 1*

In the April 1, 2010 to May 9, 2010 period, steelhead survival route in the ORTB Before-Construction Period was 89.3 percent (SE = 3.0 percent) (**Table 3-16**). In the June 4, 2010 to July 7, 2010 period, steelhead survival in the ORTB After-Construction Period was 57.7 percent (SE = 5.4 percent) (**Table 3-16**). It should be noted that the ORTB Before-Construction Period corresponds closely to the Before-Construction Periods of the GLCB and the MRB; in addition, the ORTB After-Construction Period completely encompasses the During-GLCB Construction Period. In addition the ORTB After-Construction Period corresponds closely to the MRB After-Construction Period (**Table 2-1**). The juvenile steelhead survival difference between these two periods (4/1/10–5/09/10 and 6/4/10–7/7/10) was a statistically-significant 35.3 percent. There were six possible mechanisms explored to explain the steelhead survival difference between these two periods: 1) the status and operations of the SDABs (**Table 2-2**); 2) flow magnitude and its effects; 3) distribution of flow in the three channels of interest (**Tables 3-3** and **3-4**); 4) export rate (**Table 3-7**); 5) water temperature (**Table 3-1**); and 6) predatory fish density (**Table 3-70**) (see Section 4.1.2.2 *Comparing Survival and Covariates from April 1, 2010–May 9, 2010 to June 4, 2010–July 7, 2010*). It was concluded that the increase water temperature, increased predatory fish density, and reduced passage availability through barrier culverts were most likely the largest contributing factors to the survival decrease. Thus, maintaining an open passage route through each barrier could improve juvenile salmonid survival. For example, one culvert could have the flap gate tied open to provide a passage route.

In the March 22, 2011 to June 9, 2011 period, Chinook Salmon survival in the GLCB Before-Construction Period was 65.0 percent (SE = 3.1 percent) (**Table 3-29**). In the June 10, 2011 to July 14, 2011 period, Chinook Salmon survival during the GLCB During-Construction Period was 76.1 percent (SE = 3.2 percent) (**Table 3-29**). This difference in before- and during-construction survival for juvenile Chinook Salmon was a statistically-significant 17.1 percent improvement in survival. This increase in survival was most likely due to: 1) the flow proportion entering the GLC increased substantially in the second time period compared to the first (**Table 3-6**); and 2) open migratory routes were available through the GLCB, through the ORTB, and through the MRB (**Table 2-4**) (see Section 4.1.3 *2011 Juvenile Chinook Salmon*). Abutment removal in fall 2010 and high discharges in the wet water year of 2011 provided a completely open GLC channel for approximately 81 percent of the salmonid migratory season. In addition, the GLCB was not completely closed until July 14—after the end of the salmonid migratory period. Therefore, no telemetered salmonids experienced a completely closed GLCB in 2011. In 2011, the ORTB was constructed by June 10 but its culverts' flap gates were tied open until August 23 (**Table 2-4**) and so migrating salmonids did not have to wait for a particular tidal state to pass these two barriers; and 3) the results highlight how if passage availability is consistently maintained, survival need not decline through the migratory season as observed for steelhead in 2010 (**Table 3-16**). The greater the proportion of the migratory season that a route is kept open through a barrier, the greater the probability that migrating salmonids will be able to pass through the barrier quickly and this result could improve survival. For example, flashboards installed in the GLCB could allow flexible management of water flow over the flashboards and provide more passage availability than tidally-operated flap gates.

One barrier, the ORTB, was studied intensely using 2D acoustic tracks to analyze barrier passage. In 2010, 68 steelhead were detected at the ORTB area and 50 of these fish failed to pass (**Table 3-37**). This ratio of 18 fish passing and 50 fish not passing deviated significantly from the ratio expected from survival estimates, successful passage expected was 0.9988:0.0012 expected to not pass (Kruskal-Wallis chi-squared: 30,574.000; $P = 2.2 \times 10^{-16}$) (see Section 3.6 *Successful Passage and Route Through the Old River at Tracy Barrier*). This result demonstrated that a closed barrier with flap gates operating tidally, i.e., not tied open, was a significant impediment to steelhead migration in 2010. In 2011, the ORTB remained a statistically significant impediment to steelhead migration (Kruskal-Wallis chi-squared = 3,306.100; $P = 2.2 \times 10^{-16}$) and Chinook Salmon migration (Kruskal-Wallis chi-squared = 65.700; $P = 5.25 \times 10^{-16}$). However, in 2011 with flap gates tied open, 36 steelhead passed and 16 did not pass (**Table 3-39**). Furthermore, in 2011, 120 Chinook Salmon passed and 7 did not pass (**Table 3-38**). Thus in 2011, for both steelhead and Chinook Salmon, more individuals passed than did not pass and this reversed the pattern seen for 2010 steelhead. So, when the culverts were tied open in 2011 more steelhead and Chinook Salmon successfully passed than failed to pass. These results demonstrate that open passage routes could provide substantial benefits to migrating salmonids. Open passage routes could be provided by tying open culvert flap gates or installing flashboards.

5.1.2 Recommendation 2. Operable Gates at Each Barrier

As part of a long-term solution to salmonid passage, an improved design at each SDAB should include an operable gate that would allow the barrier to be opened in less than four hours when the upstream water-level protection of water was not necessary or when emigrating salmonids were passing the barriers in high numbers.

5.1.2.1 *Data Supporting Recommendation 2*

The analysis of defecated/regurgitated tags for 2010 and 2011 indicated that predation was more likely on the upstream side of the ORTB than the downstream side (**Table 3-63**). The most likely explanation for this finding is: 1) Chinook Salmon and steelhead TIVs were greater in the upstream area ORTB After-Construction Period compared to the ORTB Before-Construction Period (**Table 3-51** for 2011 Chinook Salmon and **Table 3-60** for 2011 steelhead); and 2) predatory fish density was greater in the During-Construction Period compared to the Before-Construction Period during 2010 and 2011 (**Tables 3-70** and **3-71**). An operable gate would allow Chinook Salmon and steelhead to move through a barrier area more quickly, reducing TIV, and this result should further reduce the predator-prey encounter rate.

An operable gate could be lowered when high densities of juvenile steelhead or Chinook Salmon were in the south Delta. Juvenile salmonid densities should be monitored to determine if salmonids are actively migrating in the south Delta, and ORTB and MRB construction activities temporarily halted until salmonid densities decrease to “acceptable” levels. “Acceptable” salmonid densities could not be defined herein because these thresholds were not investigated in this study and will depend on the water year type. For example, CVP and SWP salvage data augmented by the CDFW/USFWS’s Mossdale trawl information (Interagency Ecological Program 2017) could be used to monitor the presence and relative abundance of emigrating salmonids in the south Delta. The operable gate could be lowered when high salmonid densities were present and this would reduce the time required to locate and use a passage route because a far greater proportion of the channel’s cross-section would be available for juvenile salmonid use.

If the operable gate was designed to have a passage route available, e.g., on an ebb tide, even when in the closed position, survival might be further improved. For example, a self-regulating notch with an automated depth control structure could be placed within the barrier structure, adjacent to the operable gate, and opened on ebb tides to maintain a passage route through the barrier at all times.

5.2 OPERATIONAL IMPROVEMENTS

The results of this investigation demonstrate that the SDABs operations could be improved to benefit juvenile steelhead and Chinook Salmon emigrating through the south Delta.

5.2.1 Recommendation 3. Minimize the Duration of In-Water Construction at Each Barrier

During barrier construction activities, carefully plan to minimize in-water work in order to reduce impacts to migrating salmonids.

Juvenile salmonid densities could be monitored by the DWR and Reclamation to determine if salmonids are actively migrating toward the south Delta from the anadromous salmonid-bearing tributaries of the south San Joaquin River. Juvenile salmonid monitoring could be accomplished in the San Joaquin River (e.g., at Sturgeon Bend (37°40'12.75"N, 121°14'38.78"W)). This density monitoring would also be very valuable for CVP/SWP Delta export operations. Reclamation, DWR, NMFS, USFWS, and CDFW could cooperatively determine how this new source of fish abundance data can be used to inform export operations and minimize construction related impacts of the SDABs. When “high” densities of juvenile salmonids are detected, in-water construction activities could cease until juvenile salmonid density decreases to “acceptable” densities. “High” and “acceptable” salmonid densities could not be defined herein because these thresholds were not studied in this analysis and will depend on the water year type. Potential considerations in implementing this recommendation include:

1. Consider using contract language that rewards the barrier construction contractor for quick installation that meets all construction specifications;

2. Without compromising safety, allow sufficient resources to execute the fastest barrier construction possible;

3. If possible, install flashboards in the barrier structure during construction and use the flashboards to quickly close the barrier when NMFS and USFWS regulators approve complete closure. If flashboards are installed, open the flashboards when possible to improve salmonid passage efficiency; and

4. Minimize predator refugia in the SDAB footprint areas during in-water construction. Specifically, minimize water velocity refugia that are present in the SDAB footprint areas that could be used by predators as ambush habitat. As soon as a barrier is built remove all in-water velocity refugia created by the construction process.

5.2.1.1 *Data Supporting Recommendation 3*

In 2011, it was concluded that the ORTB, with flap gates tied open, caused a statistically significant emigration delay of juvenile Chinook Salmon on the upstream side of the barrier (see Section 3.7.3.2 *2011 Juvenile Chinook Salmon*; **Table 3-51**). Furthermore, this significant delay in TIV began with the onset of construction and not when the barrier was closed. Also in 2011 during ORTB construction, predatory fish density in the During-ORTB construction period was more than double the Before-ORTB construction predatory fish density (**Table 3-71**). So, in the During-Construction Period, juvenile salmonids were required to find a route through the barrier construction area in the presence of higher predatory fish density. In the After-Construction Period of 2011, juvenile Chinook Salmon TIV on the ORTB upstream side was significantly longer than on the ORTB downstream side (**Table 3-53**). Thus, immediately after finding a route through the barrier, Chinook Salmon very quickly continue their migration.

The 2011 steelhead TIV in the During-Construction Period could not be tested because no steelhead was detected at the ORTB in that period. However, 2011 steelhead Before-Construction TIV in the ORTB upstream area was significantly shorter than the After-Construction Period TIV (**Table 3-60**). Therefore, there is no obvious reason why the recommendation for avoiding in-water work for the benefit of Chinook Salmon should not also benefit steelhead.

The recommendation that special juvenile salmonid monitoring be conducted in the San Joaquin River is based on the approach used in the north Delta, described in NMFS's RPA IV.3: the catch indices at Knights Landing or Sacramento are used to provide the "Third Alert" (NMFS 2009, pg. 652). This alert is used by the Water Operations Management Team to determine how to operate the CVP and SWP diversions and at what rate. This "early warning" system on the Sacramento River is utilized to minimize entrainment impacts at the export facilities and a similar approach could be used in the San Joaquin River/south Delta to minimize entrainment impacts and minimize SDAB-construction impacts on migrating juvenile salmonids.

Real-time information regarding when juvenile emigrant salmonid densities increase to "levels of concern" during the SDABs in-water construction season could be an important management tool to reduce construction impacts and improve emigrant survival. The best field practice for monitoring emigrant salmonids could be selected based on testing several technologies including rotary screw traps (E. G. Solutions, Corvallis, OR), DIDSON sonar (Sound Metrics, Bellevue, Washington), a VAKI system (Riverwatcher by VAKI Aquaculture Systems Limited., Akralind, Iceland), environmental DNA (Wilcox et al. 2016), or other technology. Furthermore, a research project evaluating these technologies could also study where the optimal monitoring location would be to provide precise counts and sufficient time for managers to halt work temporarily if emigrant salmonid densities had exceeded the trigger count.

Minimizing predatory fish refugia in the SDAB footprint areas, specifically, minimizing water velocity refugia that are present in the SDAB footprint areas that could be used by predators as ambush habitat is of importance and is supported by these results:

1) The highest predatory fish density estimates were observed during and after the barriers were installed (**Tables 3-70** and **3-71**). The construction of and the presence of the barriers creates a condition of increased artificial structure, which provides velocity refugia, habitat complexity, and locations where a predatory fish can hold and ambush prey; and

2) There was one exception to the results described in the item 1). At the GLCB in 2011, Before-Construction Period predatory fish density of 0.86 predatory fish per 1,000 cubic meters (0.024 predatory fish/1000 cubic feet) was 33.7 percent greater than the During-Construction Period of 0.57 predatory fish per 1,000 cubic meters (0.016 predatory fish/1,000 cubic feet) (**Table 3-71**). After June 10, 2011, high flow events regularly moved rock downstream that had been placed in GLC to form the foundation of the GLCB. It was hypothesized (Section 4.7 *DIDSON Monitoring of Predators*) that high discharges, increased water temperature in the During-Construction Period (**Table 3-2**), and an open channel in which few or no velocity refugia were present in the vicinity of the GLCB footprint made this area less energetically profitable for fish predators. This decrease in predatory fish density through time at the GLCB in 2011 suggests that minimizing water velocity refugia for predatory fish could reduce predation probabilities on migrating juvenile salmonids.

5.2.2 Recommendation 4. Coordinate Operations Between the HORB and the SDABS

It is recommended that the operations of the HORB and SDABs be coordinated.

5.2.2.1 *Data Supporting Recommendation 4*

During the spring, the HORB is scheduled for construction to begin each year on March 1 (NMFS 2013: Table 1). The HORB is scheduled to be closed each year on April 1 and to operate at most for two months (NMFS 2013: Table 1), i.e., April 1 through May 31.

As recommended previously in Section 5.1.1 *Recommendation 1 (Open Passage Route Through Barriers)*, juvenile salmonid passage routes through each SDAB should be maintained March 1 through April 1 during construction of the ORTB and MRB. During April 1 through May 31 when the HORB is in place, very few juvenile salmonids enter the Old River because the HORB protection efficiency is very high, e.g., protection efficiency at the HORB was measured at 100 percent in 2012 (DWR 2015a). During the April 1 through May 31 period, open passage through the SDABs is not critical because few salmonid emigrants are present. The HORB is scheduled to end operation on May 31 (NMFS 2013: Table 1). So, after May 31 of each year, many more emigrating juvenile salmonids may enter the Old River. When the HORB operation is terminated each spring, open passage routes through the SDABs become critical again. The potential interaction between the HORB operations timing and the SDABs operations timing leads to the recommendation that these south Delta operations be coordinated at an appropriate level to improve juvenile salmonid emigration survival.

Where possible, improve coordination with NMFS and the USBR in identifying the timing of the April–May San Joaquin River pulse flows so that HORB and SDAB construction activities can be adaptively managed to minimize effects on migrating juvenile salmonids.

5.3 JOINT DESIGN AND OPERATIONAL IMPROVEMENTS

The priority ranking of SDAB design and operational improvements is important to the survival of emigrant juvenile salmonids.

5.3.1 Recommendation 5. Barrier Priority Order for Improvements

It is recommended that design and operational improvements be initiated at the GLCB first, the ORTB second, and the MRB last.

5.3.1.1 *Data Supporting Recommendation 5*

A much larger proportion of telemetered emigrant Chinook Salmon and steelhead (range: 84.6–98.9 percent) used Grant Line Canal in comparison to Middle River (range: 0–6.0 percent) or Old River at Tracy (range: 1.1–9.8 percent) channels (**Tables 3-14** and **3-21**). Therefore, to have the most substantial impact on Chinook Salmon and steelhead populations, improvements, whether related to SDAB design or operations, if any are undertaken, should be initiated at the GLCB first, the ORTB second, and the MRB last.

6 IMPLICATIONS FOR THE SOUTH DELTA IMPROVEMENTS PROGRAM

This study has provided valuable insight regarding the SDIP (see Section 1.1 *Purpose of the South Delta Agricultural Barriers*). The lessons learned throughout this study can help guide final design and operation of the facilities in the south Delta. Suggestions to alter the gate design and operation could help improve juvenile salmonid survival past the barriers. Examples of possible changes to the previously proposed design and operation are noted herein and include details explaining the rationale for the recommendations.

Results show that the rock barriers delay fish passage whether through the culverts (flap gates), or over the weir. The barriers delay emigration of juvenile Chinook Salmon for up to 15 hours, and for juvenile steelhead for up to 38 hours (see **Tables 3-50** and **3-59**). The rock barriers are fixed structures that only allow water to pass through 122 cm (48 in) diameter culverts and/or over a fixed-height weir. The barriers delay passage during periods when the flap gates are closed (ebb tide), and when there is no water flowing over the weir. If the flap gates are tied open, or water is flowing over the weir, fish can pass the barrier. Even when fish are able to pass, their travel time is increased, and their odds of survival decrease when compared to periods when the barriers are not installed.

The SDIP could allow for individualized operation of multiple gates, opening the channel multiple times per day, while regulating water surface elevations and allowing fish passage when the gates are down (open) simultaneously. The gates could be opened completely, or partially, depending on agricultural needs and incoming flow. Complete blockage of the channel, with no alternate routes, is one of the biggest reasons for lower survival during the period that the rock barriers are in place. Opening the channel regularly would give fish more opportunity to pass the facility with less overall delay. Juvenile salmonids that are delayed or blocked at the barriers are subject to higher predation and lower survival rates.

The rock barriers provide predatory fish habitat. Predators accumulate around the rock barriers for multiple reasons. The structures provide velocity refugia, which give the predatory fish lower energetic swimming cost while ambushing prey. When juvenile salmonids become delayed on the upstream side of a barrier the probability of encountering a predatory fish increases. Also, the piscine predators can have problems passing the barrier as well, which could increase the number of predatory fish per unit volume of water. The new SDIP barriers would be bottom-hinged lift gates, which would operate multiple times per day and allow for more salmonid passage than the rock barriers. The SDIP facilities would be an improvement upon the existing TBP. The biggest advantage new SDIP barriers would have over the rock barriers is the ability to control the gates and flow through the channel. Management can quickly react to changing variables to provide the best scenario for water diverters and salmonid resources. This would provide a balance between agricultural demands and juvenile salmonid protection.

There are many ways to optimize the design and operations of the SDIP gates. The design and operations should be evaluated and adaptively managed depending on the many changing variables throughout the changing seasons and years.

Each barrier could have two or three separate gates; each gate would have a different invert height. This would allow for flow control without raising or lowering any gate partially. The ability to completely open a section of the barrier would allow for downstream salmonid passage while limiting the quantity of water flowing downstream during ebb tides.

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7 SUGGESTED STUDIES FOR THE FUTURE

The following seven studies are identified for potential future implementation under the SDIP:

1) It was recommended in this report (see Chapter 5 *Recommendations*) that juvenile salmonid densities could be monitored by the DWR and Reclamation to determine if salmonids are actively migrating toward the south Delta from the anadromous salmonid-bearing tributaries of the south San Joaquin River. Juvenile salmonid monitoring could be accomplished in the San Joaquin River (e.g., at Sturgeon Bend (37°40'12.75"N, 121°14'38.78"W)). Real-time information regarding when juvenile emigrant salmonid densities increase to "levels of concern" during the SDABs in-water construction season could be an important management tool to reduce construction impacts and improve emigrant survival. The best field practice for monitoring emigrant salmonids could be selected based on testing several technologies including rotary screw traps (E. G. Solutions, Corvallis, OR), DIDSON sonar (Sound Metrics, Bellevue, Washington), a VAKI system (Riverwatcher by VAKI Aquaculture Systems Limited., Akralind, Iceland), environmental DNA (Wilcox et al. 2016), or other technology. A research project evaluating these technologies could also study where the optimal monitoring location would be to provide precise counts and sufficient time for managers to halt work temporarily if emigrant salmonid densities had exceeded the trigger count;

2) Test downstream juvenile salmonid passage efficiency at the GLCB and ORTB for three types of passage structures:

    1) Culvert flap gate tied open;

    2) Flashboard structure; and

    3) A notch in the crest of the barrier;

3) A bioenergetics modeling study of an operable gate would allow an assessment of how to optimize operable gate design and operations to minimize net energy acquisition by predatory fish in the vicinity of the barrier. Reduction of predator-net energy acquisition would make an agricultural barrier with an operable gate a less attractive location for predatory fish to reside or take refuge;

4) The SDABs need to be studied when the GLCB is closed before July 7—the earliest closing date in the two years of this study;

    1) In 2010, the GLCB was closed on July 7. In 2011, the GLCB was closed on July 14. It is recommended that a study of juvenile salmonid survival, TIV, and passage route through the GLCB and the immediate vicinity be conducted in a three-year study in which at least one of those years the GLCB is closed in May or June. This would be similar to the period in which the GLCB has been operated since 2011 with the GLCB closure dates of: May 5, 2012; June 19, 2013; June 3, 2014; and June 18, 2015;

5) Survival at the ORTB should be studied in the Before- vs. After-Construction Periods because the P-value for the 2011 Chinook Salmon survival comparison was 0.0472. This value was not statistically significant, but the P-value was very small suggesting that a larger sample size might allow a more robust evaluation of the hypothesis $S2_0$;

6) It is recommended that TIV of the SDABs be studied using an acoustic transmitter that changes transmission characteristics after consumption of the tag by a predatory fish and the predator's stomach enzymes dissolve the special coating on the tag (Schultz et al. 2017). Research with such acoustic transmitters would allow many of the tags that were subsequently eaten to be removed from the analysis; and

7) If juvenile salmonid survival past the SDABs are evaluated by acoustic telemetry in the future, a hydrophone array that extends 1 km (0.6 mi) upstream would allow the behavior of the approaching fish 2D tracks to be distinguished from the behavior of fish in the immediate upstream vicinity of the barriers.

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APPENDIX A

TARGET FISH SPECIES DESCRIPTION — CHINOOK SALMON IN THE SAN JOAQUIN RIVER

FOCAL SALMONID SPECIES FOR PROTECTION AT THE SOUTH DELTA AGRICULTURAL BARRIERS

Chinook Salmon

This appendix provides a general synopsis of what is known about the life history and behavior of Central Valley stocks of Chinook Salmon (*Oncorhynchus tshawytscha*). Chinook Salmon in the Central Valley have been in a long decline in abundance. The Sacramento River system supports four runs of Chinook Salmon that are named for the season when the majority of the run enters freshwater as adults: spring, fall, late-fall, and winter-run (Kjelson et al. 1982; Williams 2006). By contrast, the San Joaquin River system has historically supported only three runs: fall, late fall, and spring, with the latter two runs extirpated in the 1940s (Fisher 1994). Recently in 2014, spring-run Chinook Salmon were reintroduced to the San Joaquin River as an experimental population (78 Federal Register [FR] 79622).

Legal Status

Fall-Run and Late Fall-Run Chinook Salmon

The Central Valley fall-run Chinook Salmon evolutionarily significant unit (ESU) covers both fall-run and late fall-run salmon in the Sacramento-San Joaquin river systems (Lindley et al. 2004; Moyle 2002). This ESU always has been the most abundant run in the Central Valley watershed, historically numbering over one million spawning fish in some years (Yoshiyama et al. 1998). Although the Central Valley fall-run Chinook Salmon is not listed under either the federal or state endangered species acts, it was classified in 2004 as a Species of Concern by the National Marine Fisheries Service (NMFS). Similarly, the California Department of Fish and Wildlife (CDFW) classifies this run as a Species of Special Concern. This run is the most common Chinook Salmon run in the southern Central Valley and offspring from this run comprised all of the juvenile Chinook Salmon that outmigrated through the South Delta Agricultural Barriers (SDABs) study area on their way to the Pacific Ocean in 2010 and 2011.

Spring-Run Chinook Salmon

The Central Valley spring-run Chinook Salmon ESU has been reduced from an estimated 17 historical populations to only four extant populations with consistent spawning runs: Mill, Deer, and Butte creeks and the Feather River (California Department of Water Resources [DWR] 2004; NMFS 2008). The reintroduction of spring-run Chinook Salmon into the San Joaquin River began in spring 2014 with a program to establish an experimental population (i.e., the San Joaquin River Restoration Program [SJRRP]). If this program is successful, then juvenile spring-run Chinook Salmon will also migrate through the SDAB study area during their out-migration to the ocean; however, this salmon run was not present in the study area at the time of the studies in 2010 and 2011.

Historically, spring-run Chinook Salmon were likely the most abundant species in the San Joaquin River watershed (Williams 2006; Yoshiyama et al. 1998). However, they have undergone one of the most dramatic declines among the four Chinook Salmon runs in the Central Valley, mainly as a result of intensive in-river harvest pressure and the massive loss (70–90 percent) of spawning and rearing habitats in the upper watershed due to construction of hydropower and irrigation diversion projects that blocked upstream passage (NMFS 2008; Yoshiyama et al. 1998).

In the mainstems of the Sacramento and the Feather rivers, spring-run Chinook Salmon have undergone significant hybridization with fall-run. Because of the small number of non-hybridized populations remaining and low population abundance, the Central Valley spring-run Chinook Salmon ESU was listed as threatened by the State of California in 1998 pursuant to the California Endangered Species Act (California Fish and Game Code Sections 2050–2069) and by the federal government pursuant to the Endangered Species Act in 1999 (64 FR 50394, September 16, 1999). At the federal-level, critical habitat was designated in 2005 by the NMFS (70 FR 52488, September 2, 2005).

Life History

Chinook Salmon are semelparous, i.e., they only have a single reproductive episode before death, and the species shows a wide array of life history adaptations that have allowed it to take advantage of diverse and highly variable lotic environments. There are two basic types of life history strategies: 1) stream-type; and 2) ocean-type. Stream-type juvenile Chinook Salmon overwinter in freshwater before entering the ocean and they typically spend more than one year in freshwater. Ocean-type fish become sexually mature during the ocean phase of their lives and spawn soon after entering freshwater. Juvenile ocean-type fish migrate to the ocean early in their first year of life. Both life stage types of Chinook Salmon are present in California (Moyle 2002); however, both San Joaquin River fall-run and spring-run Chinook Salmon exhibit an ocean-type life history (SJRRP 2008).

Chinook Salmon Adult Migration and Spawning

Adult Chinook Salmon are the largest of any of the seven ocean-dwelling Pacific salmon species (i.e., genus *Oncorhynchus*), typically measuring 75 to 80 centimeters (cm) (30–31 inches [in]) in standard length and weighing 9 to 10 kilograms (kg) (20–22 pounds [lb]). Adults can grow to 140 cm (55 in) long and weigh up to 45 kg (99 lb) (Healey 1991; Moyle 2002). Males vary more in size than females at maturity, and for most populations, males are smaller than females (Quinn 2005). Growth is variable, but often rapid in the ocean.

To spawn, Chinook Salmon leave the Pacific Ocean and return often over great distances to their natal rivers. Upstream migration takes place mainly during the day, with fish apparently tracking stream odors on which they imprinted as juveniles (Healey 1991). Although most fish home to their natal stream, some stray and spawn in a different stream. Straying presumably is an adaptive mechanism that allows salmon to (re)colonize newly opened areas and mix genetically with other runs, especially those in streams close to their natal streams (Moyle 2002). Upstream-migrating adults may travel via Old River, moving upstream through the SDAB study area.

Despite the large variation in run timing in most rivers, spawning times tend to be similar among runs. Female salmon excavate redds in gravel deposits. When each redd is dug, the female essentially cleans an area measuring 2 to 10 square meters (22–108 square feet), loosening gravel and mobilizing fine sediments (particles < 2 mm [< 0.08 in] in diameter), so that the future embryos will have access to a steady flow of oxygen-containing water (Healey 1991). Females deposit eggs and males fertilize the eggs, and the eggs are covered with substrate immediately after fertilization. Chinook Salmon have been observed digging redds and spawning at a variety of depths from a few centimeters to several meters, and at water velocities of 15 to 190 cm/s (0.5–6 feet per second [ft/s]), but most seem to spawn at depths between 25 and 100 cm (10–39 in) and velocities of 30 to 80 cm/s (1.0–2.6 ft/s) (Healey 1991). Regardless of depth, the key to successful spawning is having an adequate flow of water around developing embryos, which means they have to be buried in coarse substrate with low silt content.

The adult fall-run spawning migration is heavily concentrated from August through November. Fall-run Chinook Salmon are adapted for spawning in lowland reaches of large rivers and their tributaries. Historical spawning habitat of the fall-run remains available downstream of dams. These fish spawn shortly after entering their natal river. The strategy allows fall-run salmon to take advantage of extensive high-quality spawning and rearing areas in valley reaches of rivers that are often too warm to support salmon in the summer. Because of the timing of the fall-run, most adult fish are expected to pass through the SDAB study area prior to the construction of the barriers.

Fall-run Chinook Salmon spawn in gravel and cobble areas, primarily at the head of riffles. Gravel and cobble substrates can range from 0.2 to 15 cm (0.08–6 in) (DWR 2004). Preferred water velocities for spawning range from 0.4 to 1.2 meters per second (m/s) (1.3–3.9 ft/s). Spawning typically begins when the water temperature cools to approximately 14 to 15 degrees Celsius (°C) (57–59 degrees Fahrenheit (°F). Spawning can occur from late September to December, but spawning typically peaks in late October (Fisher 1994; Williams 2006).

Adult spring-run Chinook Salmon enter freshwater in the spring, over-summer in pools while their gametes mature, and spawn in late August to early October, with peak spawning occurring in mid-September (Fisher 1994). Adults pass upstream into their holding areas from February into early July, with the migration peaking in mid-April in Butte Creek, mid- to late May in Mill and Deer creeks, and May and June in the Feather River (Williams 2006). If the restored spring-run Chinook Salmon run in the San Joaquin River is similar in run timing to run timing in the Sacramento River system, then adult fish might pass by any of the three SDABs in the study area when they are installed.

In rivers, adult spring-run Chinook Salmon select large, deep (usually > 2 meter (m) [> 6.6 ft]) pools before spawning. These pools typically have bedrock bottoms. In California, spring-run Chinook Salmon usually hold where mean water column velocities are 0.15 to 0.8 m/s (0.49–2.62 ft/s), often under ledges, in deep pockets, or under the “bubble curtain” formed by water plunging into pools (Moyle et al. 1995). The fish do not necessarily stay in the same pool all summer long, but move between pools, usually with a net upstream movement. Holding areas often are near spawning areas. Spawning areas may occur at the tailouts of holding pools. Typically, spring-run Chinook Salmon spawn farther upstream and at higher elevations than fall-run. In these areas, water cools to suitable temperatures earlier than in the fall-run spawning areas.

Historically, spatio-temporal segregation helped to maintain reproductive isolation between the fall-run and spring-run Chinook Salmon in the McCloud River (California Department of Fish and Game [CDFG] 1998) and in the Sacramento River downstream of Shasta Dam (Moffett 1949). However, Slater (1963) reported that the spawning periods of the two runs overlapped, resulting in hybridization. Hybridization between spring- and fall-run Chinook Salmon also has occurred in the Feather River (Lindley et al. 2004).

Chinook Salmon Eggs

Generally, female Chinook Salmon produce 2,000 to 17,000 eggs. Although the number of eggs increases with body size of the female fish, this relationship is not as strong in Chinook Salmon as in other salmonids and varies among populations and runs (Moyle 2002). Survival of eggs in the Central Valley is highly variable between runs and years, but overall is considered generally low (Williams 2006). For maximum embryo survival, water temperatures must be between 5 and 13°C (41–55°F), and oxygen levels must be close to saturation (Healey 1991; Moyle 2002). Under such conditions, embryos hatch in 40 to 60 days and remain in the gravel as alevins for another four to six weeks until the yolk sac is fully absorbed when they emerge as fry. Size at hatching and emergence depends on water temperature, with optimal water temperatures ranging between 5 and 8°C (41–46°F) (Williams 2006).

Fall-run Chinook Salmon appear to have exceptionally high fecundity for their size (Healey 1991). The average fecundity of females in the Sacramento River has been estimated to be about 5,500 eggs (Fisher 1994). The average spring-run Chinook Salmon fecundity of females in the Sacramento River has been estimated to be approximately 4,900 eggs (Fisher 1994).

Chinook Salmon Fry and Juveniles

Fry generally are 30 to 40 mm (1.2–1.6 in) long when they emerge from the gravel (Williams 2006). After emergence, fry typically are passively washed downstream into back- or edge-water areas, where velocities are slower than the main stream channel, cover is dense, and prey items are abundant. Many fry actively disperse downstream, especially if high-flow events correspond with emergence (Healey 1991; Moyle 2002). Dispersal behavior shows variations among fry that emerge from a single redd, with larger individuals most likely to disperse (Bradford and Taylor 1997). Movement occurs mostly at night. Ocean-type Chinook Salmon fry may begin movement immediately after emergence.

For Central Valley fall-run Chinook Salmon fry, optimal water temperatures for growth and survival are 13 to 18°C (55–64°F) (Marine 1997), although throughout the range of Chinook Salmon, positive growth is experienced at water temperatures of 5 to 19°C (41–66°F) (McCullough 1999). At 22 to 23°C (72–73°F), mortality is experienced in wild populations, and very few individuals can survive water temperatures greater than 24.0°C (75.2°F) for even short periods of time (Moyle 2002). At sublethal water temperatures, growth is reduced and predation rates increased as a consequence. Water temperature in the Delta in June is inversely proportional to the survival of juvenile Chinook Salmon as they pass through and out of the Delta (Baker et al. 1995; Kjelson et al. 1982).

Optimal juvenile rearing habitat contains instream structure (e.g., undercut banks, large woody debris) and canopy cover, an adequate food supply (aquatic and terrestrial invertebrates), suitable water velocities and depth, and low turbidity (DWR 2003). In general, microhabitat use by juvenile Chinook Salmon occurs in deeper and faster water as they grow larger. Microhabitat use and foraging behavior can be influenced, however, by the presence of predators (i.e., other fish, American Bullfrogs [*Lithobates catesbeiana*], piscivorous birds, Northern River Otters [*Lontra canadensis*], Harbor Seals [*Phoca vitulina*], and California Sea Lions [*Zalophus californianus*]), which may force Chinook Salmon to select areas of heavy cover and suppress foraging in more open areas. During the night, juvenile Chinook Salmon may abandon their foraging areas in swift-moving water and retreat to quiet edge-waters or pools (Moyle 2002) as an energy-conserving measure or as a way to avoid nocturnal predators (e.g., Sacramento Pikeminnow [*Ptychocheilus grandis*] in the Central Valley) (Moyle 2002).

While in freshwater, juvenile Chinook Salmon are opportunistic drift feeders and eat a wide variety of terrestrial and aquatic insects. Juveniles feed mostly during the day, with peaks at dawn and during the afternoon. In the Delta, terrestrial insects are the most important food, but crustaceans also are eaten (Moyle 2002).

Fall-run fry emerge from December into April, depending on the date of spawning and water temperature during incubation. They exhibit two main patterns within their ocean-type life-history strategy. Most begin migrating as fry, shortly after emergence (Hatton 1940), and most of these apparently rear for one to three months in the Delta before moving into the San Francisco Bay estuary. However, some continue directly through Carquinez Strait into San Pablo Bay (Hatton 1940). Of the Chinook Salmon that do not leave the spawning reaches as fry, most do so as juveniles by May or early June, before the higher river water temperatures become lethal or near lethal. These fish pass fairly quickly through the Delta. The relative contributions of fall-run fry and juveniles migrants to adult escapement are not known, but Williams (2006) has suggested that fry do not survive as well as juvenile migrants.

For spring-run fry emergence period occurs from November through March (Fisher 1994). Fry and juveniles may rear in the Delta for three to 15 months, depending on flow conditions (Fisher 1994). Spring-run Chinook Salmon require cool water while they grow in freshwater over the summer. Since most cool-water habitat is now located upstream of impassable dams, water temperature is a limiting factor for spring-run.

Chinook Salmon Smoltification and Seaward Migration

Juvenile Chinook Salmon undergo a set of physiological and behavioral changes before they migrate to the sea. These changes are associated with their downstream migration and the transition from freshwater to marine habitats, and with the transformation from juveniles into smolts, a physiological process known as smoltification (Williams 2006). Smoltification typically occurs in the spring; if the fish do not migrate, most of these physiological changes reverse and the fish remain juveniles, but often these fish smolt again the next spring (Williams 2006).

Downstream migration of fall-run Chinook Salmon smolts occurs from March through July (Fisher 1994) at sizes ranging from 30 to 50 mm fork length (FL) (1.2–2.0 in FL) to rear in the San Francisco Bay estuary. Movement into the estuary varies with year (Moyle 2002). Reservoirs increase the over-winter water temperatures of rivers more than was the case historically and it was observed that juvenile fish developed more rapidly following construction of dams. Monitoring indicates that Chinook Salmon fall-run fry migrants in the Sacramento River downstream of Shasta Dam begin their migration approximately one month earlier (Snider and Titus 2000a, 2000b, 2000c) than indicated by pre-dam monitoring as reported by Rutter (1904) and Hatton and Clark (1942). The consequences of the change in timing are unknown, but it could be significant (Williams 2006).

The peak exit period for Chinook Salmon juveniles and smolts out of the Delta and into the San Francisco Bay estuary is from April through June (Kjelson et al. 1982). Presumably, a peak exists in emigration to the ocean by Chinook Salmon, as they pass by the SDAB study area during that same period (**Table A-1**). Kjelson et al. (1982) have suggested that the migration is driven by water temperature. For this reason, it is speculated that the exit of smolts from the San Joaquin River may be earlier than the exit from the Sacramento River because of higher water temperatures due to the more southerly position of the San Joaquin River in the Central Valley.

Table A-1. Dates of Chinook Salmon Salvage from January 1 through July 31 for Nine Years of Data Collected at the Skinner Delta Fish Protective Facility at Byron, California

Year	First Salvage	Beginning Peak	End Peak	Last Salvage
2003	January 1	January 13	April 24	June 27
2004	January 1	January 14	May 11	June 17
2005	January 1	January 28	June 9	July 3
2006	January 1	February 21	June 22	July 5
2007	January 5	February 23	May 3	June 12
2008	January 13	January 31	May 29	June 7
2009	February 4	April 19	May 16	June 11
2010	January 23	January 26	June 2	July 6
2011	January 1	February 18	June 22	July 21

Source: Compiled by Turnpenny Horsfield Associates and AECOM this study.

Spring-run Chinook Salmon in the Sacramento River exhibit an ocean-type life history, emigrating as fry, sub-yearlings, and yearlings. Most spring-run emigrate from December through March, primarily as newly emerged fry, especially in Butte Creek, but some migrate as larger juveniles from March through June. As noted previously, attempts began in 2014 to restore spring-run Chinook Salmon to the San Joaquin River; therefore, the progeny of this restoration effort are likely to encounter a SDAB if it is in place from April through June.

Another group of spring-run Chinook Salmon juveniles hold over through the summer and migrate in the fall or winter. Only a few hold over until the following spring and migrate as one year old or older juveniles (Williams 2006).

Chinook Salmon in the Pacific Ocean

Once reaching the Pacific Ocean, juvenile Chinook Salmon from California rivers tend to stay along the California coast, although a general northward movement of fish may occur resulting in a few fish that are found off Washington state. Concentration of California salmon in nearby marine waters is not surprising, considering their high productivity. This productivity is caused by upwelling that is generated by the California Current, a southward-moving current originating in the Gulf of Alaska. In these food-rich waters, juvenile Chinook Salmon swim at depths that vary with the season (0 to 100 m; 0–328 ft), but they typically swim deeper than most other salmon. Ocean survival of salmon declines during years when the California Current does not flow as strongly and upwelling decreases (Moyle 2002). Chinook Salmon spend a few months to seven years at sea (Williams 2006).

Once reaching the Pacific Ocean, juvenile Chinook Salmon switch to a fish diet and growth is rapid. At age two, Sacramento River-origin fall-run average approximately 55 cm FL (22 in); at age three, approximately 70 cm FL (28 in FL); at age four, approximately 90 cm FL (35 in FL); and at age five, approximately 100 cm FL (39 in FL) (Moyle 2002). Considerable variation exists in length at different ages. Fall-run Chinook Salmon spend one to four years at sea, although fall-run from the San Joaquin River spend the least amount of time, and late fall-run Chinook Salmon spend the most time (Myers et al. 1998).

Spring-run Chinook Salmon have a wider ocean distribution than fall-run, often leaving nearshore waters in their first year of life and seeking more northerly high-sea areas (Healey 1991). Recent observations show that while the vast majority of spring-run Chinook Salmon leave Butte Creek as young-of-the-year, yearling outmigrants account for approximately 25 percent of the ocean catch of Butte Creek spring-run Chinook Salmon (Ward et al. 2002).

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APPENDIX B

TARGET FISH SPECIES DESCRIPTION — STEELHEAD IN THE SAN JOAQUIN RIVER

FOCAL SALMONID SPECIES FOR PROTECTION AT THE SOUTH DELTA AGRICULTURAL BARRIERS

Steelhead

The steelhead (*Oncorhynchus mykiss*) (Page et al. 2013), one of the seven species of ocean-dwelling Pacific salmonids, is the anadromous form of the stream-resident form known as Rainbow Trout (Moyle 2002). Steelhead occur in both the Sacramento and San Joaquin rivers and their tributaries. In this report, *O. m.* is used to refer to steelhead and Rainbow Trout collectively. Resident Rainbow Trout can have offspring that become anadromous. This rare characteristic is strongly related to parental genetic composition (Stillwater Sciences 2006). Also, the progeny of anadromous *O. m.* can become resident fish under optimal rearing conditions in freshwater (Cramer and Beamesderfer 2006). For example, streams with water temperatures consistently averaging 11 to 15 degrees Celsius (°C) (52–59° Fahrenheit [°F]) during summer and rarely exceeding 18.0°C (64.4°F) would provide *O. m.* with suitable water temperatures to complete all life history stages. All other environmental parameters being satisfactory, a juvenile fish could choose to remain as a resident fish in lieu of the anadromous life history strategy.

Historically, the greatest steelhead production in the Central Valley came from Sacramento River populations (Lindley et al. 2006). Most observations reported herein derive from these populations because few studies of San Joaquin River watershed steelhead were completed until 2001 (McEwan 2001). Historically, steelhead were widely distributed throughout the Sacramento River and San Joaquin River watersheds. Both summer- and winter-runs of steelhead existed. Presently, only the winter-run persists in the Central Valley (Williams 2006). Due to the construction of dams, summer-run steelhead were prevented from reaching the upper reaches of tributaries where they previously over-summered in deep, cool pools. As a consequence, summer-run steelhead in the Central Valley are now extirpated (McEwan 2001).

Legal Status and Distribution

The California Central Valley steelhead distinct population segment (DPS)[16] was listed as threatened in 1998 (63 Federal Register [FR] 53: 13347–13371) under the federal Endangered Species Act. The listing of the Central Valley steelhead DPS was affirmed in 2006 (71 FR 834–862) (Good et al. 2005). Steelhead have no state status designation. The term "evolutionarily significant unit" (ESU) also is found in literature. In this case, ESU and DPS are equivalent terms, meaning "species" under the federal Endangered Species Act (71 FR 834–862). The Central Valley steelhead DPS (**Figure B-1**) includes all naturally spawned populations of steelhead in the Sacramento and San Joaquin rivers and their tributaries downstream of major dams that block upstream passage. The populations in the two artificial propagation programs at the Coleman National Fish Hatchery, Anderson, California, and the Feather River Steelhead Hatchery, Oroville, California, are also part of the DPS, but steelhead from the two other hatchery programs (Nimbus Fish Hatchery on the American River, Rancho Cordova, California, and the Mokelumne River Hatchery, Clements, California) are not.

[16] West Coast steelhead (*O. mykiss*) includes 10 DPSs (National Oceanic and Atmospheric Administration 2006). DPS policy is found at 61 FR 4722, February 7, 1996.

Source: Modified by AECOM 2016 from National Oceanic and Atmospheric Agency, 2013 (January). http://www.westcoast.fisheries.noaa.gov/publications/gis_maps/maps/salmon_steelhead/esa/steelhead/ccv_steelhead.pdf.

Figure B-1. California Central Valley Steelhead Distinct Population Segment

An estimated 95 percent of the historically available spawning habitat is inaccessible to steelhead because of dam construction primarily related to hydropower generation, flood control, and water supply development (McEwan 2001; Lindley et al. 2006). The lost habitat resulted in a significant decrease in the total steelhead population considered collectively from an estimated 1 to 2 million wild adult steelhead (i.e., non-hatchery produced naturally spawning fish) in the Sacramento River and San Joaquin River watersheds to as few as 40,000 individuals in the 1960s, and to less than 10,000 in the early 1990s (McEwan 2001).

In addition to habitat loss due to dam construction, other factors contributing to the decline of Central Valley steelhead include habitat alteration, such as bank protection (rip-rap and armoring), dredging, and gravel mining. Some biological stressors also have been identified as contributing to the decline of steelhead: predation, invasive species, and disease (McEwan 2001). Physical degradation of water quality and increased water temperatures have contributed to the decline as well. Poor ocean conditions for growth and survival of steelhead, both physical and biological, have been identified. The National Marine Fisheries Service (NMFS 1997) has suggested that the decline in the steelhead population has curtailed the species' resiliency to natural factors such as predation, drought, and poor ocean conditions. Lindley et al. (2006) concluded that insufficient information existed to adequately assess the risk of population extinction for Central Valley winter-run steelhead.

Life History

Steelhead Adults

After spending one to four years at sea, adult Central Valley steelhead return to the Sacramento River weighing between 1.4 to 5.4 kilograms (kg) (3.1–11.9 pounds [lb]) (Moyle 2002) and measure 35 to 65 centimeters (cm) (14–26 inches [in]) total length (TL). Steelhead rely on olfactory cues to find their natal stream during the spawning migration. Most steelhead make their way into freshwater beginning in August, with a peak migration in September and October (McEwan 2001). However, in nearly every month of the year, steelhead migrate up the Sacramento River (Moyle 2002). During the upstream spawning migration to the San Joaquin River and its tributaries, adult steelhead may travel through the SDAB study area.

Williams (2006) and McEwan (2001) have suggested that some Central Valley steelhead may hold for months in spawning streams while gamete maturation is completed, but now this life history pattern is rare because of the loss of suitable holding habitat. Most steelhead become sexually mature in the ocean and spawn soon after reaching their spawning sites (Williams 2006). Spawning in the upper Sacramento River generally occurs between November and late April with a peak from early January through late March (U.S. Bureau of Reclamation [Reclamation] 2004). The spawning peak occurs when water temperatures throughout much of the Sacramento River are suitable to support egg incubation and fry emergence. It is believed that these conditions would be similar in the San Joaquin River watershed.

In the Sacramento River watershed steelhead spawn in low numbers in Battle, Butte, Deer, and Mill creeks and the Feather, Yuba and American rivers, as well as the Sacramento River downstream of Keswick Dam. In the San Joaquin River watershed steelhead spawn in the Cosumnes, Calaveras, Mokelumne, Stanislaus, Tuolumne, and Merced rivers (**Figure B-1**) (Eilers et al. 2010; Moyle 2002). Under historical conditions, steelhead spawned in much higher gradient reaches in the Sacramento River and its tributaries than any other steelhead DPS in western North America (McEwan 2001; Zimmerman et al. 2009).

Spawning occurs where well-oxygenated water exists, good hyporheic flow is found, and water temperatures are appropriate (McEwan and Jackson 1996). The female digs a redd in a riffle, successively digging, spawning, and resting as she moves upstream. Water velocity varies between 0.2 to 1.5 meters per second (m/s) (0.66–4.92 feet per second [ft/s]), and depth varies from 0.1 to 1.5 meters (m) (0.3–4.9 feet [ft]). Typically, one dominant male will spawn with one female, but other males also can participate (Moyle 2002). Larger steelhead spawn in the higher range of water velocity (McEwan 2001). Steelhead redds generally are found in substrates ranging from 0.6 to 10 cm (0.2–4 in) in diameter (Bjornn and Reiser 1991).

Steelhead are iteroparous, i.e., surviving post-spawners can return to the ocean. After a year or more, gamete rematuration occurs and steelhead migrate back to their natal stream to spawn again. Although some kelts (post-spawned adults) have been documented in the Sacramento River, probably few repeat spawners exist in this population (U.S. Bureau of Reclamation 2004). Repeat spawners are observed returning every other year (Moyle 2002). Photoperiod, streamflow, and water temperature appear to influence emigration timing (Holubetz and Leth 1997). Adult post-spawning outmigration occurs from March through July. Steelhead kelts moving from the San Joaquin River and its tributaries from April to June will travel through the SDAB study area while the barriers are in place.

Steelhead Eggs

Female steelhead lay approximately 2,000 eggs per kilogram (approximately 4,400 eggs per pound) of body mass and leave the spawning ground soon after laying their eggs, while males remain to have a chance to spawn with more than one female (Moyle 2002). Egg hatching is water temperature dependent and typically requires four weeks. No Central Valley-specific information exists about water temperature requirements for successful spawning and incubation, but values derived from other steelhead stocks in more northerly locations suggest that optimal spawning water temperatures are between 4.0 to 11.0°C (39.2–51.8°F), with egg mortality occurring at water temperatures > 13.0°C (> 55.4°F) (Bell 1990; Bovee 1978; Hooper 1973; McEwan and Jackson 1996; Reiser and Bjornn 1979).

Steelhead Fry

After hatching, sac-fry will remain in the gravel four to six weeks before emerging (McEwan and Jackson 1996; Shapovalov and Taft 1954). Once the yolk sac is fully digested, fry less than or equal to 50 millimeters (mm) total length (TL) (less than or equal to 2 in TL) emerge and become free-swimming (Quinn 2005). The timing of emergence by fry also is strongly influenced by water temperature (Shapovalov and Taft 1954). Fry congregate along the bank in shallow water (Barnhart 1986) where velocity is low.

Steelhead Juveniles: Parr and Smolt

In rivers, juvenile *O. mykiss* utilize energetically advantageous positions (Bowen 1996). They tend to select velocity shelters adjacent to swift velocities that provide abundant drifting invertebrates. These shelters allow them to maximize energy intake while minimizing the cost of swimming to maintain position (Everest and Chapman 1972; Fausch 1984). Steelhead may remain in these velocity shelters for a long time if the position is of sufficient quality, affording low focal velocity and high-velocity shear. These energetically advantageous positions can increase growth and survival, and individual fish may display aggressive behavior to defend them (Bowen 1996). In more open habitat (e.g., large pools), juveniles are not as territorial and are more prone to school with similar-size congeners (Moyle 2002).

The preferred water temperature range for juveniles is between 7.0 to 14.0°C (44.6–57.2°F) (Bell 1990). At water temperatures > 21.0°C (> 69.8°F), steelhead have trouble extracting oxygen from the water (Hooper 1973). The upper lethal thermal limit is 24.0°C (75.2°F) (Bell 1990) and this was confirmed by the field report of

Nielsen et al. (1994).

The triggers that influence whether or not juvenile steelhead migrate to the Pacific Ocean are complex (Quinn 2005). Juvenile steelhead produced by adult steelhead that migrated from the ocean to spawn may become resident (i.e., residualize) and spend their entire life in freshwater. Thus, tagged steelhead released in migration studies upstream of the SDABs could conceivably swim upstream and survive to reproduce. However, for those individuals that choose anadromy, they spend one to three years in freshwater before out-migrating. A tiny proportion of juvenile steelhead in California, perhaps 0.3 percent, emigrate when older than four years (Quinn 2005). Hatcheries in the Central Valley produce steelhead that emigrate to the ocean when older than one year.

In 2010 and 2011, the Mokelumne River Hatchery at Clements, California, provided the juvenile steelhead used to evaluate the SDABs in this report. Brood stock for steelhead are collected and spawned in November and December (Smith, pers. comm., 2013). The hatchery maintains the juveniles for more than one year to mimic the winter-run steelhead life history.

The Mokelumne River Hatchery uses the following stages of development in rearing Central Valley steelhead (Smith, personal communication, 2013):

1) Eggs are incubated at 11.1 to 12.2°C (52.0–54.0°F) until they hatch;
2) Once the sac-fry fully absorb their yolk sacs, the fry are fed at a high rate with a target of an 18 to 20 percent body mass increase per week;
3) At a size of 60 to 80 mm TL (2.4–3.1 in TL), the parr are then moved to outdoor raceway ponds and are fed two percent of their total body mass per day; and
4) In the autumn, the juveniles are starved on alternating weeks to keep the growth rate slow and meet the stocking target of 180 mm TL (7.1 in TL) in February, when the fish are approximately 15 months old.

The parr may undergo the behavioral and physiological changes of smoltification. For the 2010 and 2011 SDAB Study, the fish were held past the stocking target and used in the period of experimental releases from April through June. The juveniles were parr or smolts, depending on the degree of smoltification of each individual, and ranged in size from 149 to 396 mm fork length (FL) (5.9–15.6 in FL) for 2010 and 2011 tagged fish combined (see **Tables 2-6** and **2-11** in this report). The juveniles produced in the hatchery were used in this research as surrogates for naturally produced steelhead.

Juvenile steelhead measuring 100 to 250 mm FL (3.9–9.8 in FL) that are between one and three years old emigrate to the ocean (Moyle 2002; Reynolds et al. 1993). Fish from the Central Valley emigrate between November and late June, with a peak in out-migration from early January through late March (U.S. Bureau of Reclamation 2004) (**Table B-1**). Therefore, juvenile steelhead pass through the SDAB study area mostly from November through June. These juveniles could come in contact with any of the SDABs in the study area during this period if they chose to emigrate via Old River instead of the San Joaquin River.

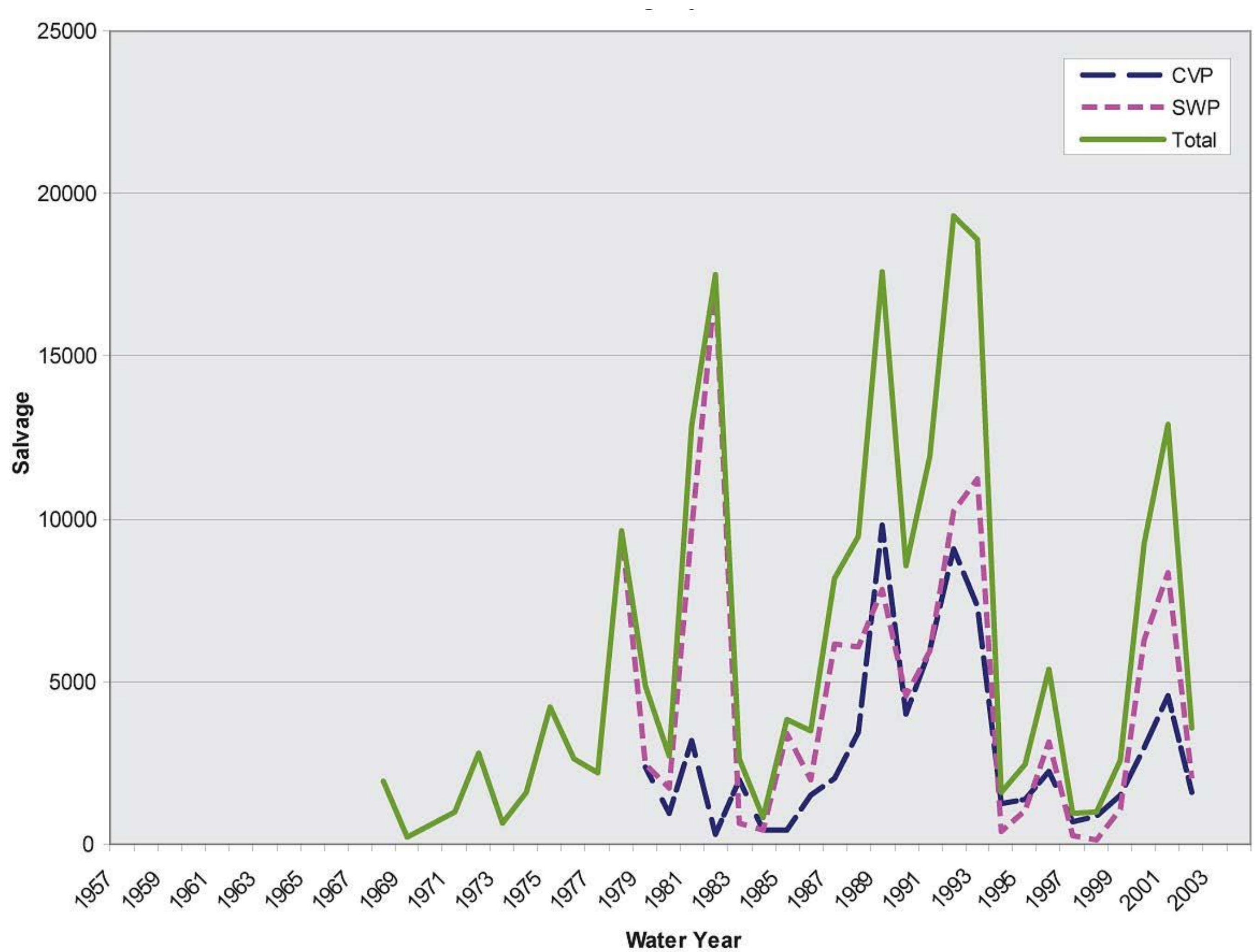
Table B-1. Dates of Steelhead Salvage January 1 through June 30 for 10 Years of Data Collected at the John E. Skinner Delta Fish Protective Facility (Byron, California)

Year	First Salvage	Beginning Peak	End Peak	Last Salvage
2003	January 1	January 11	February 10	June 24
2004	January 6	February 15	March 2	May 19
2005	January 8	January 26	March 2	June 27
2006	January 4	February 18	April 11	June 28
2007	January 14	February 26	April 25	May 30
2008	January 25	February 15	March 1	June 10
2009	January 18	February 25	March 26	May 23
2010	January 19	February 7	March 10	June 27
2011	January 18	February 18	March 13	June 29
2012	January 5	March 29	April 18	June 3

Source: DWR this study.

Some steelhead older than one year old moving down the Sacramento River are captured in rotary screw traps at Red Bluff Diversion Dam, Glenn Colusa Irrigation District, and Knights Landing. These captures represent a large group of out-migrating juveniles that are experiencing the parr-smolt transition, and could theoretically spend some time rearing in the Delta. However, little information is available about the use of the Delta by steelhead as rearing habitat (Stillwater Sciences 2006).

All species of fish using the Delta are affected by CVP and SWP operations (71 FR 834–862). The potential effects of water diversions on steelhead have not been comprehensively evaluated (McEwan 2001). However, pre-screen loss at Clifton Court Forebay is 82 to 87 percent (Clark et al. 2009). Steelhead are salvaged at the CVP and SWP, and the number salvaged varies depending on the year (**Figure B-2**).



Source: Dan B. Odenweller, California Department of Fish and Wildlife

Figure B-2. Combined Number of Steelhead Salvaged from Tracy Fish Collection Facility (CVP) and Skinner Delta Fish Protective Facility (SWP)

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APPENDIX C

PISCINE PREDATORS OF SALMONIDS IN THE SOUTH DELTA

PISCINE PREDATORS OF SALMONIDS IN THE SOUTH DELTA

A number of predatory fish species are known to reside year-round in the southern Sacramento-San Joaquin Delta (Delta), including in the vicinity of the South Delta Agricultural Barriers (SDABs) study area. These species include the native Sacramento Pikeminnow (*Ptychocheilus grandis*) and non-native fish including the Striped Bass (*Morone saxatilis*), Largemouth Bass (*Micropterus salmoides*), and multiple species of catfish (*Ameiurus* spp. and *Ictalurus* spp.). Previous field studies have shown evidence of predation on juvenile salmonids in the Delta including predation at the non-physical barrier (i.e., the Bio-Acoustic Fish Fence, or BAFF) in the lower San Joaquin River at the Head of Old River (Feyrer and Healey 2002; Feyrer and Healey 2003; Nobriga and Feyrer 2007; Hanson 2009).

SACRAMENTO PIKEMINNOW

The native Sacramento Pikeminnow is most often associated with lotic habitats (Moyle 2002). Long-term trends in Sacramento Pikeminnow abundance are unknown, but it is common in the Central Valley (May and Brown 2002). Sacramento Pikeminnow spawn in non-tidal streams and rivers; they often complete their life cycle within these habitats (Brown 1990). However, some age-one and older individuals are transported into the Delta by winter-spring flow pulses and likely remain resident until maturity (Nobriga et al. 2006). Sacramento Pikeminnow is not targeted by a sport fishery in the Delta, although it has been harvested for bounty in the upper Sacramento River to reduce presumed predatory effects on emigrating salmonid fishes (Moyle 2002).

STRIPED BASS

Striped Bass are a large anadromous non-native fish species introduced into the San Francisco Estuary in 1879 to support commercial and recreational fisheries (Dill and Cordone 1997). Commercial fishing for Striped Bass is no longer allowed; however, the species supports one of the largest recreational fisheries within the Delta.

Striped Bass begin spawning in the spring when the water temperature reaches 15.6 degrees Celsius (°C) (60.1 degrees Fahrenheit (°F), with most spawning occurring at temperatures between 16.1 to 20.6°C (61.0–69.1°F), the spawning period usually extends from April to mid-June. Striped Bass spawn in pelagic freshwater, especially the Delta and lower San Joaquin River between the Antioch Bridge and the mouth of Middle River, and other channels in this vicinity. Another important spawning area is the Sacramento River between Sacramento and Princeton. About one-half to two-thirds of the eggs are spawned in the Sacramento River and the remainder are spawned in the Delta. Female Striped Bass usually spawn for the first time in their fourth or fifth year, when they are 53 to 64 cm (21–25 in) long. Some males mature when they are two years old and only about 28 cm (11 in) long. Most males are mature at age three and nearly all females at age five (Moyle 2002).

LARGEMOUTH BASS

Unlike Striped Bass, Largemouth Bass are primarily a freshwater fish that cannot successfully reproduce in brackish water (Moyle 2002). Largemouth Bass also were introduced to the San Francisco Estuary watershed in the latter 19th Century (Dill and Cordone 1997), although their numbers in the Delta have increased more recently (Brown and Michniuk 2007). This increase appears to be associated with increasing water clarity and submerged macrophyte abundance in the Delta.

Over the past decade the Delta has become known as a world-class fishery for Largemouth Bass. Both northern and Florida strains of Largemouth Bass have been introduced into the Delta (northern strain in the late 1800s and Florida strain in the 1960s) to support recreational fisheries. Largemouth Bass typically inhabit areas of the Delta having relatively shallow water with associated emergent vegetation, submerged vegetation, or other cover and structures. Largemouth Bass are abundant in habitat along major channels, sloughs, and backwaters with salinities less than about three parts per thousand (Moyle 2002). Largemouth Bass are a major predatory fish within the Delta. Juvenile and adult Largemouth Bass forage aggressively on crayfish, other fishes, and frogs. Largemouth Bass spawn in the spring (April–June) in nests that are guarded by the adult until the fry emerge and begin feeding.

CATFISHES

A variety of species of catfish (*Ameiurus* spp. and *Ictalurus* spp.) inhabit the Delta and are harvested in the local recreational fisheries. These species include Black Bullhead (*Ameiurus melas*), Brown Bullhead (*Ameiurus nebulosus*), Yellow Bullhead (*Ameiurus natalis*), White Catfish (*Ameiurus catus*), and Channel Catfish (*Ictalurus punctatus*). These catfish were primarily introduced into the Delta during the late 1800s to support local recreational fisheries (Moyle 2002). White catfish are among the more common species and may be considered the most important catfish species harvested by recreational anglers within the Delta. Catfish typically inhabit areas characterized by lower water velocities (e.g., sluggish channels, sloughs, and backwaters) where turbidity is high and waters are relatively warm. Catfish inhabit areas of the Delta where salinity is low, because most species have a low salinity tolerance. Catfish feed on a variety of organisms including shrimp and other macroinvertebrates, clams, worms, and small fish. Hydrologic conditions within the Delta influence the geographic distribution of catfish, primarily through regional variation in salinity.

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APPENDIX D

JUVENILE CHINOOK SALMON AND STEELHEAD SURVIVAL — COMPLETE RESULTS INCLUDING SAMPLE SIZE

Table D-1. Survival Results for the 2010 Juvenile Chinook "Predator Filter Employed" Data Set Showing Before-, During-, and After-Construction ORTB

	Before-Construction			During-Construction			After-Construction		
Survival Location	Value	SE	N	Value	SE	N	Value	SE	N
through MRS route (Ŝ)	0.0000	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
through ORS route (Ŝ)	0.6191	0.0277	322	No Data	No Data	No Data	No Data	No Data	No Data
MRS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS to ORN (Ŝ*Ψ)	0.0497	0.0121	16	No Data	No Data	No Data	No Data	No Data	No Data
ORS to RGU (Ŝ*Ψ)	0.3230	0.0261	104	No Data	No Data	No Data	No Data	No Data	No Data
ORS to CVP (Ŝ*Ψ)	0.2464	0.0247	77	No Data	No Data	No Data	No Data	No Data	No Data

Source: HTI this study.

Table D-2. Survival Results for the 2010 Juvenile Chinook "Predator Filter Employed" Data Set Showing Before-, During-, and After-Construction MRB

	Before-Construction			During-Construction			After-Construction		
Survival Location	Value	SE	N	Value	SE	N	Value	SE	N
through MRS route (Ŝ)	0.0000	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
through ORS route (Ŝ)	0.6191	0.0277	322	No Data	No Data	No Data	No Data	No Data	No Data
MRS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS to ORN (Ŝ*Ψ)	0.0497	0.0121	16	No Data	No Data	No Data	No Data	No Data	No Data
ORS to RGU (Ŝ*Ψ)	0.3230	0.0261	104	No Data	No Data	No Data	No Data	No Data	No Data
ORS to CVP (Ŝ*Ψ)	0.2464	0.0247	77	No Data	No Data	No Data	No Data	No Data	No Data

Source: HTI this study.

Table D-3. Survival Results for the 2010 Juvenile Chinook "Predator Filter Employed" Data Set Showing Before-, During-, and After-Construction GLCB

	Before-Construction			During-Construction			After-Construction		
Survival Location	Value	SE	N	Value	SE	N	Value	SE	N
through MRS route (Ŝ)	0.0000	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
through ORS route (Ŝ)	0.6191	0.0277	322	No Data	No Data	No Data	No Data	No Data	No Data
MRS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS to ORN (Ŝ*Ψ)	0.0497	0.0121	16	No Data	No Data	No Data	No Data	No Data	No Data
ORS to RGU (Ŝ*Ψ)	0.3230	0.0261	104	No Data	No Data	No Data	No Data	No Data	No Data
ORS to CVP (Ŝ*Ψ)	0.2464	0.0247	77	No Data	No Data	No Data	No Data	No Data	No Data

Source: HTI this study.

Table D-4. Survival Results for the 2010 Juvenile Steelhead "Predator Filter Not Employed" Data Set Showing Before-, During-, and After-Construction ORTB									
	Before-Construction			During-Construction			After-Construction		
Survival Location	Value	SE	N	Value	SE	N	Value	SE	N
through MRS route (Ŝ)	0.0000	NA	NA	No Data	No Data	No Data	0.0000	NA	2
through ORS route (Ŝ)	0.8931	0.0303	193	No Data	No Data	No Data	0.5774	0.0544	132
MRS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
ORS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
ORS to ORN (Ŝ*Ψ)	0.1050	0.0222	20	No Data	No Data	No Data	0.0076	0.0075	1
ORS to RGU (Ŝ*Ψ)	0.5231	0.0413	94	No Data	No Data	No Data	0.2045	0.0351	27
ORS to CVP (Ŝ*Ψ)	0.2651	0.0319	51	No Data	No Data	No Data	0.3653	0.0535	41

Source: HTI this study.

Table D-5. Survival Results for the 2010 Juvenile Steelhead "Predator Filter Not Employed" Data Set Showing Before-, During-, and After-Construction MRB									
	Before-Construction			During-Construction			After-Construction		
Survival Location	Value	SE	N	Value	SE	N	Value	SE	N
through MRS route (Ŝ)	0.0000	NA	NA	No Data	No Data	No Data	0.0000	NA	2
through ORS route (Ŝ)	0.8931	0.0303	193	No Data	No Data	No Data	0.5774	0.0544	132
MRS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
ORS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
ORS to ORN (Ŝ*Ψ)	0.1050	0.0222	20	No Data	No Data	No Data	0.0076	0.0075	1
ORS to RGU (Ŝ*Ψ)	0.5231	0.0413	94	No Data	No Data	No Data	0.2045	0.0351	27
ORS to CVP (Ŝ*Ψ)	0.2651	0.0319	51	No Data	No Data	No Data	0.3653	0.0535	41

Source: HTI this study.

Table D-6. Survival Results for the 2010 Juvenile Steelhead "Predator Filter Not Employed" Data Set showing Before-, During-, and After-Construction GLCB									
	Before-Construction			During-Construction			After-Construction		
Survival Location	Value	SE	N	Value	SE	N	Value	SE	N
Through MRS route (Ŝ)	0.0000	NA[1]	2	No Data	No Data	No Data	No Data	No Data	No Data
Through ORS route (Ŝ)	0.7359	0.0267	324	No Data	No Data	No Data	No Data	No Data	No Data
MRS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS to MRN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	No Data	No Data	No Data
ORS to ORN (Ŝ*Ψ)	0.0653	0.0138	21	No Data	No Data	No Data	No Data	No Data	No Data
ORS to RGU (Ŝ*Ψ)	0.3728	0.0278	118	No Data	No Data	No Data	No Data	No Data	No Data
ORS to CVP (Ŝ*Ψ)	0.2947	0.0264	92	No Data	No Data	No Data	No Data	No Data	No Data

Source: HTI this study.
Note: [1] NA = Not Applicable.

Table D-7. Survival Results for the 2011 Juvenile Chinook "Predator Filter Employed" Data Set Showing Before-, During-, and After-Construction ORTB

	Before-Construction			During-Construction			After-Construction		
Survival Location	Value	SE	N	Value	SE	N	Value	SE	N
through MRS route (Ŝ)	0.6429	0.2409	5	1.0000	NA	2	0.0000	NA	0
through ORS route (Ŝ)	0.6633	0.0251	357	0.6571	0.0462	114	0.7494	0.0354	177
MRS to MRN (Ŝ*Ψ)	0.6428	0.2409	3	1.0000	NA	2	NA	NA	NA
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	NA	NA	NA	NA	NA	NA
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	NA	NA	NA	NA	NA	NA
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORS to MRN (Ŝ*Ψ)	0.0030	0.0030	1	NA	NA	NA	NA	NA	NA
ORS to ORN (Ŝ*Ψ)	0.2030	0.0212	71	0.0082	0.0082	1	0.0056	0.0055	1
ORS to RGU (Ŝ*Ψ)	0.2292	0.0223	82	0.3046	0.0447	35	0.4219	0.0395	71
ORS to CVP (Ŝ*Ψ)	0.2280	0.0221	82	0.3420	0.0491	35	0.3220	0.0348	56

Source: HTI this study.

Table D-8. Survival Results for the 2011 Juvenile Chinook "Predator Filter Employed" Data Set Showing Before-, During-, and After-Construction MRB

	Before-Construction			During-Construction			After-Construction		
Survival Location	Value	SE	N	Value	SE	N	Value	SE	N
through MRS route (Ŝ)	0.6429	0.2409	5	No Data	No Data	No Data	1.0000	NA	2
through ORS route (Ŝ)	0.6633	0.0251	357	No Data	No Data	No Data	0.7203	0.0289	291
MRS to MRN (Ŝ*Ψ)	0.6428	0.2409	3	No Data	No Data	No Data	1.0000	NA	2
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
ORS to MRN (Ŝ*Ψ)	0.0030	0.0030	1	No Data	No Data	No Data	NA	NA	NA
ORS to ORN (Ŝ*Ψ)	0.2030	0.0212	71	No Data	No Data	No Data	0.0133	0.0093	3
ORS to RGU (Ŝ*Ψ)	0.2292	0.0223	82	No Data	No Data	No Data	0.3757	0.0300	106
ORS to CVP (Ŝ*Ψ)	0.2280	0.0221	82	No Data	No Data	No Data	0.3214	0.0269	91

Source: HTI this study.

Table D-9. Survival Results for the 2011 Juvenile Chinook "Predator Filter Employed" Data Set Showing Before-, During-, and After-Construction GLCB

	Before-Construction			During-Construction			After-Construction		
Survival Location	Value	SE	N	Value	SE	N	Value	SE	N
through MRS route (Ŝ)	0.7111	0.2120	6	1.0000	NA	1	No Data	No Data	No Data
through ORS route (Ŝ)	0.6502	0.0313	436	0.7611	0.0323	212	No Data	No Data	No Data
MRS to MRN (Ŝ*Ψ)	0.7111	0.2120	4	1.0000	NA	1	No Data	No Data	No Data
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	NA	NA	NA	No Data	No Data	No Data
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	NA	NA	NA	No Data	No Data	No Data
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	NA	NA	NA	No Data	No Data	No Data
ORS to MRN (Ŝ*Ψ)	0.0024	0.0024	1	NA	NA	NA	No Data	No Data	No Data
ORS to ORN (Ŝ*Ψ)	0.1675	0.0178	72	0.0046	0.0046	1	No Data	No Data	No Data
ORS to RGU (Ŝ*Ψ)	0.2359	0.0206	102	0.4253	0.0364	86	No Data	No Data	No Data
ORS to CVP (Ŝ*Ψ)	0.2444	0.0205	105	0.3267	0.0318	68	No Data	No Data	No Data

Source: HTI this study.

Table D-10. Survival Results for the 2011 Juvenile Steelhead "Predator Filter Employed" Data Set Showing Before-, During-, and After-Construction ORTB

Survival Location	Before-Construction			During-Construction			After-Construction		
	Value	SE	N	Value	SE	N	Value	SE	N
through MRS route (Ŝ)	0.7359	0.0963	22	No Data	No Data	No Data	0.5000	0.3536	2
through ORS route (Ŝ)	0.8838	0.0160	452	No Data	No Data	No Data	0.7929	0.0706	40
MRS to MRN (Ŝ*Ψ)	0.7360	0.0963	16	No Data	No Data	No Data	0.5000	0.3536	1
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
ORS to MRN (Ŝ*Ψ)	0.0331	0.0084	15	No Data	No Data	No Data	NA	NA	NA
ORS to ORN (Ŝ*Ψ)	0.2697	0.0208	119	No Data	No Data	No Data	NA	NA	NA
ORS to RGU (Ŝ*Ψ)	0.3627	0.0230	162	No Data	No Data	No Data	0.3429	0.0807	13
ORS to CVP (Ŝ*Ψ)	0.2183	0.0192	98	No Data	No Data	No Data	0.4500	0.0787	18

Source: HTI this study.

Table D-11. Survival Results for the 2011 Juvenile Steelhead "Predator Filter Employed" Data Set Showing Before-, During-, and After-Construction MRB

Survival Location	Before-Construction			During-Construction			After-Construction		
	Value	SE	N	Value	SE	N	Value	SE	N
through MRS route (Ŝ)	0.7359	0.0963	22	No Data	No Data	No Data	0.5000	0.3536	2
through ORS route (Ŝ)	0.8838	0.0160	452	No Data	No Data	No Data	0.7929	0.0706	40
MRS to MRN (Ŝ*Ψ)	0.7360	0.0963	16	No Data	No Data	No Data	0.5000	0.3536	1
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	No Data	No Data	No Data	NA	NA	NA
ORS to MRN (Ŝ*Ψ)	0.0331	0.0084	15	No Data	No Data	No Data	NA	NA	NA
ORS to ORN (Ŝ*Ψ)	0.2697	0.0208	119	No Data	No Data	No Data	NA	NA	NA
ORS to RGU (Ŝ*Ψ)	0.3627	0.0230	162	No Data	No Data	No Data	0.3429	0.0807	13
ORS to CVP (Ŝ*Ψ)	0.2183	0.0192	98	No Data	No Data	No Data	0.4500	0.0787	18

Source: HTI this study.

Table D-12. Survival Results for the 2011 Juvenile Steelhead "Predator Filter Employed" Data Set Showing Before-, During-, and After-Construction GLCB

Survival Location	Before-Construction			During-Construction			After-Construction		
	Value	SE	N	Value	SE	N	Value	SE	N
through MRS route (Ŝ)	0.7359	0.0963	22	0.5000	0.3536	2	No Data	No Data	No Data
through ORS route (Ŝ)	0.8838	0.0160	452	0.7929	0.0706	40	No Data	No Data	No Data
MRS to MRN (Ŝ*Ψ)	0.7360	0.0963	16	0.5000	0.3536	1	No Data	No Data	No Data
MRS to ORN (Ŝ*Ψ)	NA	NA	NA	NA	NA	NA	No Data	No Data	No Data
MRS to RGU (Ŝ*Ψ)	NA	NA	NA	NA	NA	NA	No Data	No Data	No Data
MRS to CVP (Ŝ*Ψ)	NA	NA	NA	NA	NA	NA	No Data	No Data	No Data
ORS to MRN (Ŝ*Ψ)	0.0331	0.0084	15	NA	NA	NA	No Data	No Data	No Data
ORS to ORN (Ŝ*Ψ)	0.2697	0.0208	119	NA	NA	NA	No Data	No Data	No Data
ORS to RGU (Ŝ*Ψ)	0.3627	0.0230	162	0.3429	0.0807	13	No Data	No Data	No Data
ORS to CVP (Ŝ*Ψ)	0.2183	0.0192	98	0.4500	0.0787	18	No Data	No Data	No Data

Source: HTI this study.

APPENDIX E

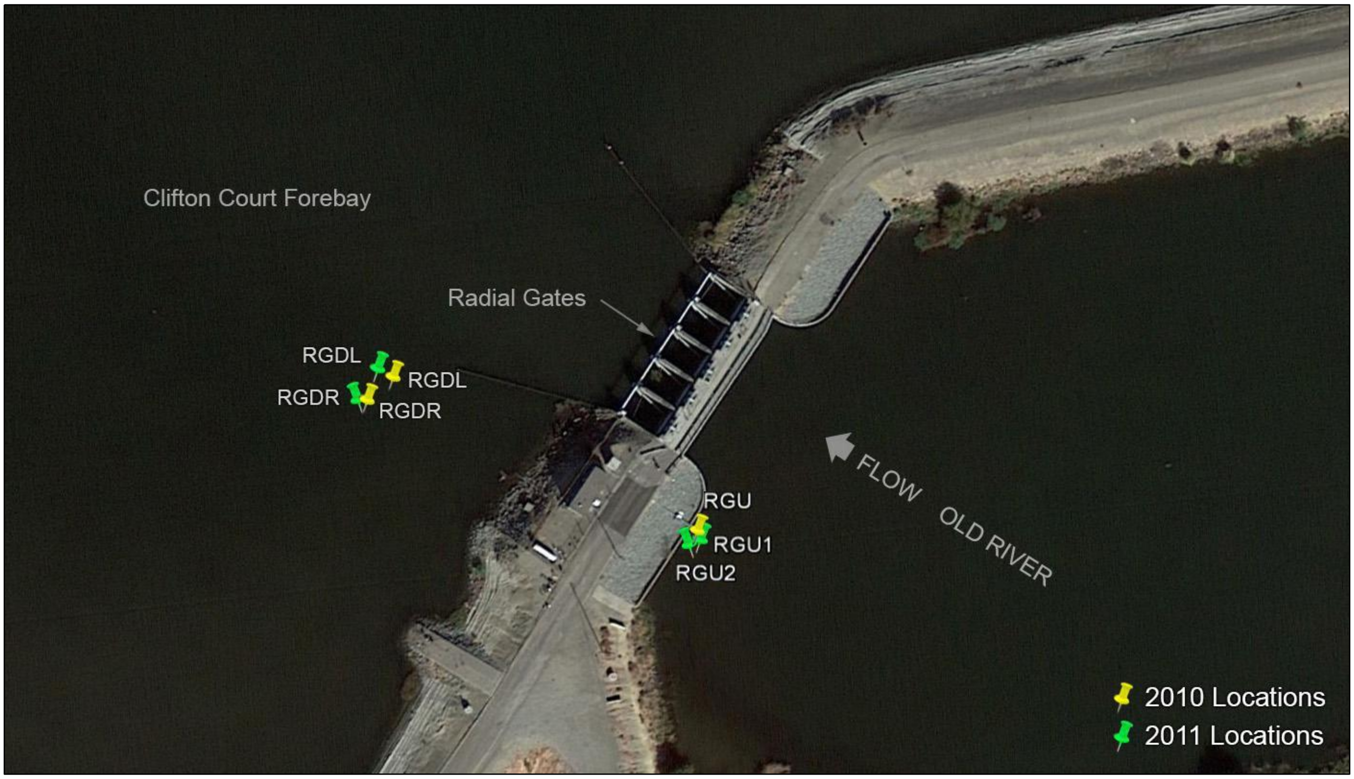
AERIAL PHOTOGRAPHS OF HYDROPHONE ARRAY LOCATIONS AND DEPLOYMENT IN 2010 AND 2011

Source: Google Earth Pro Historical Imagery; Adapted by AECOM 2017

Figure E-1. 2010/2011 Old River North Upstream and Downstream Hydrophone Array Locations

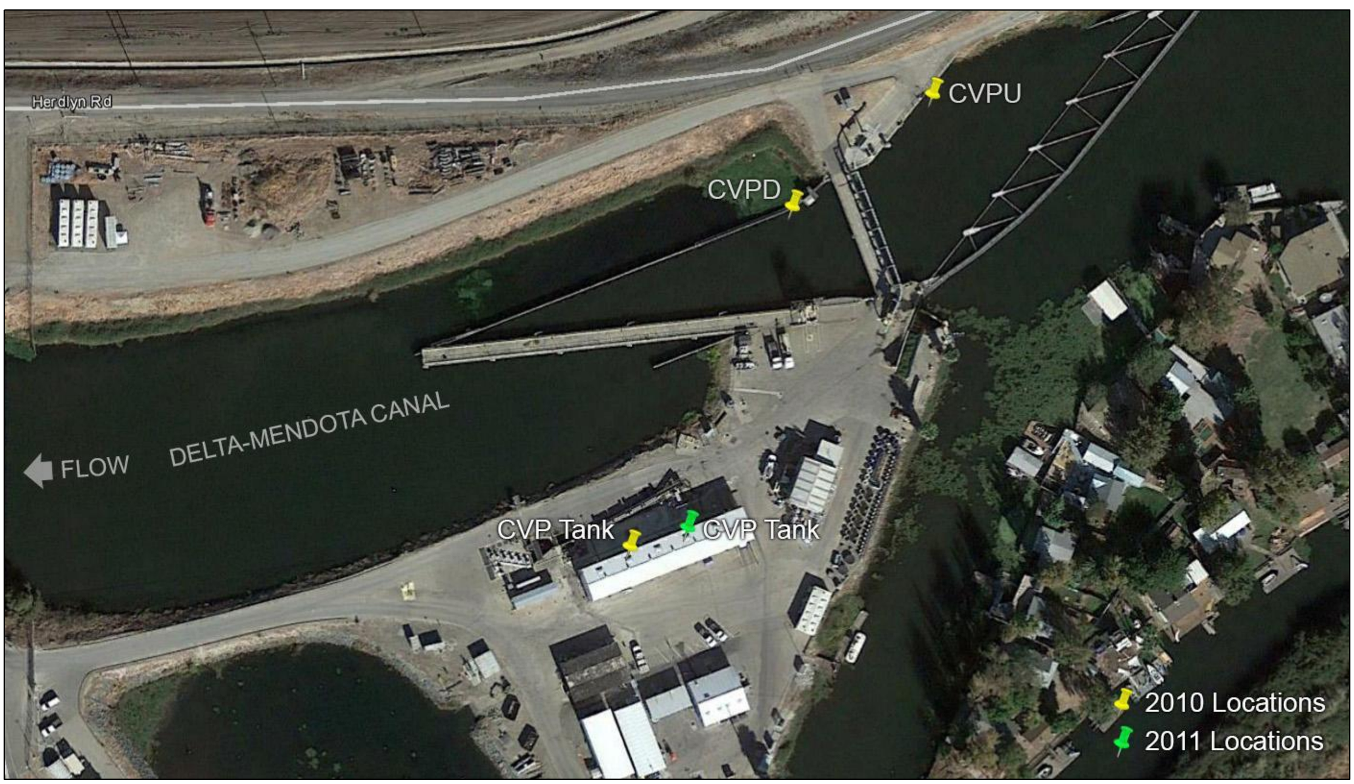
Source: Google Earth Pro Historical Imagery; Adapted by AECOM 2017

Figure E-2. 2010/2011 Middle River North Upstream and Downstream Hydrophone Array Locations



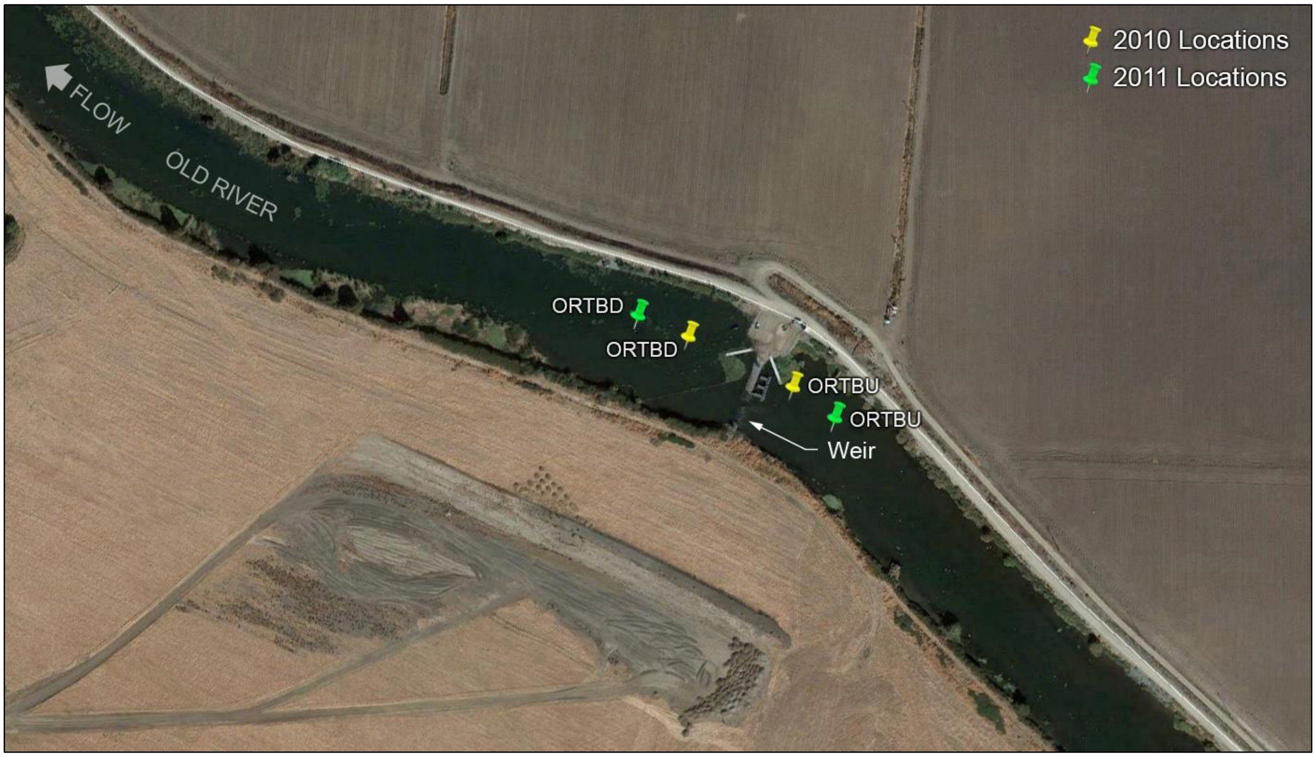
Source: Google Earth Pro Historical Imagery; Adapted by AECOM 2017

Figure E-3. 2010/2011 Radial Gate at Clifton Court Forebay Upstream and Downstream Hydrophone Array Locations



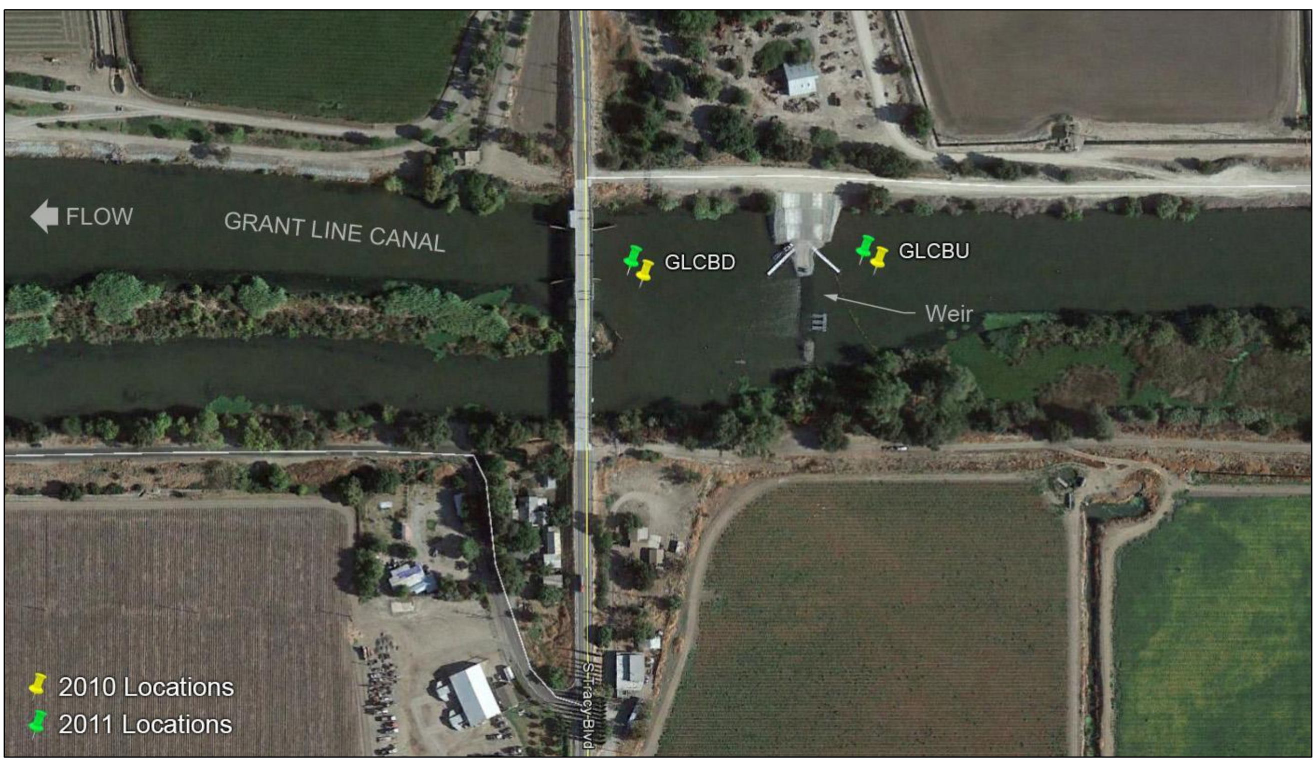
Source: Google Earth Pro Historical Imagery; Adapted by AECOM 2017

Figure E-4. 2010/2011 CVP Upstream and CVP Tank Hydrophone Array Locations



Source: Google Earth Pro Historical Imagery; Adapted by AECOM 2017

Figure E-5. 2010/2011 Old River at Tracy Barrier Upstream and Downstream Hydrophone Array Locations

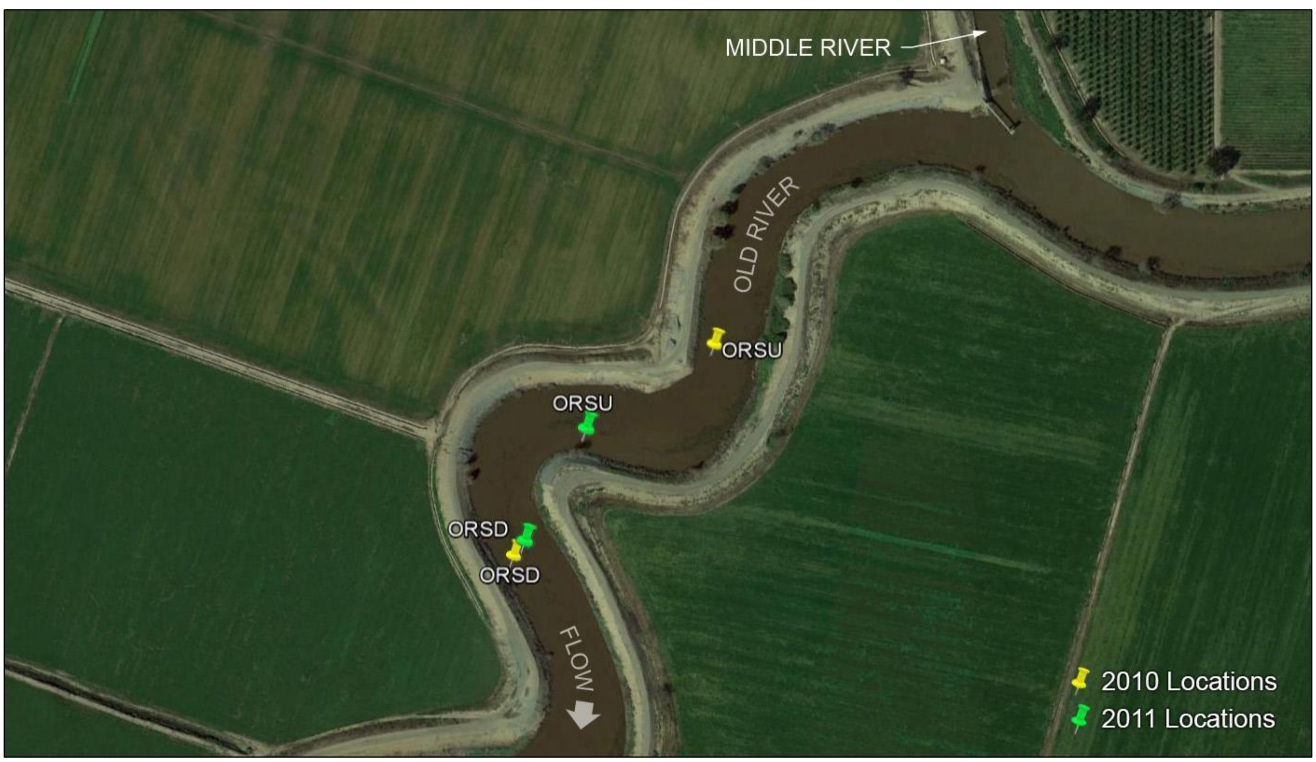


Source: Google Earth Pro Historical Imagery; Adapted by AECOM 2017

Figure E-6. 2010/2011 Grant Line Canal Barrier Upstream and Downstream Hydrophone Array Locations

Source: Google Earth Pro Historical Imagery; Adapted by AECOM 2017

Figure E-7. 2010/2011 Middle River South Upstream and Downstream Hydrophone Array Locations



Source: Google Earth Pro Historical Imagery; Adapted by AECOM 2017

Figure E-8. 2010/2011 Old River South Upstream and Downstream Hydrophone Array Locations

Source: Google Earth Pro Historical Imagery; Adapted by AECOM 2017

Figure E-9. 2010/2011 Old River Near Junction with San Joaquin River Upstream and Downstream Hydrophone Array Locations

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