State of California

The Natural Resources Agency

DEPARTMENT OF WATER RESOURCES

Bay-Delta Office

Engineering Solutions to Further Reduce Diversion of Emigrating Juvenile Salmonids to the Interior and Southern Delta and Reduce Exposure to CVP and SWP Export Facilities

Phase II — Recommended Solutions Report

Prepared in Response to the

National Marine Fisheries Service 2009 Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project, Reasonable and Prudent Alternative Action IV.1.3

March 2015

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ACRONYMS AND OTHER ABBREVIATIONS

λ	wavelength
°C	degrees Celsius
°F	degrees Fahrenheit
2D	two-dimensional
3D	three-dimensional
Action	NMFS Action IV.1.3, "Consider Engineering Solutions to Further Reduce Diversion of Emigrating Juvenile Salmonids to the Interior and Southern Delta, and Reduce Exposure to CVP and SWP Export Facilities"
ACV	Average Channel Velocity
BAFF	Bio-Acoustic Fish Fence
BDCP	Bay Delta Conservation Plan
BGS	behavioral guidance structure
BiOp	Biological and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project
CCF	Clifton Court Forebay
CDFG	California Department of Fish and Game (*see* CDFW)
CDFW	California Department of Fish and Wildlife (formerly California Department of Fish and Game)
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
cm	centimeter
CPUE	catch-per-unit of effort
CPUV	catch-per-unit of volume
CV	Central Valley
CVP	Central Valley Project
DCC	Delta Cross Channel
D_E	Deterrence efficiency
Delta	Sacramento–San Joaquin River Delta
DPS	Distinct Population Segment
DSM2	Delta Simulation Model II
DWR	California Department of Water Resources
EFH	Essential Fish Habitat
ELAM	Eulerian-Lagrangian-Agent Method
EMC	electromagnetic compatibility
ESA	Endangered Species Act

ACRONYMS AND OTHER ABBREVIATIONS

ESU	Evolutionarily Significant Unit
FC	final coefficient
FFAS	Fishing Facility Access Structure
FFGS	Floating Fish Guidance Structure
FGS	Fish Guidance Systems, Ltd.
Fisheries Foundation	FF
FL	fork length
GCID	Glenn Colusa Irrigation District
GLM	generalized linear model
GSNPB	Georgiana Slough Non-Physical Barrier
GSNPB	Georgiana Slough Non-Physical Barrier
HIL	High Intensity Light
HOR	Head of Old River
HORB	Head of Old River Barrier
Hz	Hertz
IFF	Infrasound Fish Fence
kW	kilowatt
LED	light-emitting diode
LSZ	low-salinity zone
m	meter
M	million
m/s	meters per second
mm	millimeters
NAVD88	North American Vertical Datum of 1988
nm	nanometer
nm	nanometers
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPB	non-physical barrier
OCC	option choice coefficient
OE	overall efficiency
OMR	Old and Middle River
PCR	Polymerase Chain Reaction
P_E	Protection efficiency
Phase I Report	Engineering Solutions to Further Reduce Diversion of Emigrating Juvenile Salmonids to the Interior and Southern Delta and Reduce Exposure to CVP and SWP Export Facilities Phase I Initial Findings Report

ACRONYMS AND OTHER ABBREVIATIONS

Phase II Report	Engineering Solutions to Further Reduce Diversion of Emigrating Juvenile Salmonids to the Interior and Southern Delta and Reduce Exposure to CVP and SWP Export Facilities – Phase II Recommended Solutions Report [this document]
RBDD	Red Bluff Diversion Dam
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RIC	relative importance coefficient
RPA	Reasonable and Prudent Alternative
SD	Standard Deviation
SDIP	South Delta Improvement Program
SE	standard error
SFPF	Skinner Fish Protection Facility
SJR	San Joaquin River
SWP	State Water Project
TFCF	Tracy Fish Collection Facility
TL	total body length
TWG	Technical Working Group
UCD	University of California, Davis
UCSC	University of California, Santa Cruz
USACE	U.S. Army Corps of Engineers
USBR	*See* Reclamation
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UV	ultraviolet
UV	ultraviolet
VAMP	Vernalis Adaptive Management Plan
WES	Waterways Experiment Station
WRAM	Water Resource Assessment Methodology

EXECUTIVE SUMMARY

ES.1 INTRODUCTION

The California Department of Water Resources (DWR) has completed this document, *Engineering Solutions to Further Reduce Diversion of Emigrating Juvenile Salmonids to the Interior and Southern Delta and Reduce Exposure to CVP and SWP Export Facilities – Phase II Recommended Solutions Report* (Phase II Report), in response to requirements of Action IV.1.3 of the Reasonable and Prudent Alternative (RPA) developed by the National Marine Fisheries Service (NMFS) in its Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project (CVP) and State Water Project (SWP) (BiOp) in 2009 in accordance with Section 7 of the federal Endangered Species Act (ESA) of 1973 (16 U.S.C. 1531 et seq.) (NMFS 2009a). A multi-year study consisting of three phases to address Action IV.1.3 consists of: Phase I – Initial Findings (2011–2013), Phase II – Recommended Solutions (2012–2015), and Phase III – Implementation of Preferred Option (to be determined).

This report is the culmination of Phase II and presents potential engineering solutions for five key Delta locations (Georgiana Slough, Threemile Slough, Head of Old River, Turner Cut, and Columbia Cut) Figure ES-1. These potential solutions are based on consideration of aspects of engineering, biological, and social importance including: fish deterrence ability, upstream fish migration, piscivorous predation effects, environmental constraints and opportunities, flow and tidal effects, recreational boat passage, feasibility, uncertainties, construction and operational costs, and operation and maintenance.

The RPA developed by NMFS in the BiOp contained the following action:

> **Action IV.1.3 Consider Engineering Solutions to Further Reduce Diversion of Emigrating Juvenile Salmonids to the Interior and Southern Delta, and Reduce Exposure to CVP and SWP Export Facilities.**
>
> **Objectives:** Prevent emigrating salmonids from entering the Georgiana Slough channel from the Sacramento River during their downstream migration through the Delta. Prevent emigrating salmonids from entering channels in the south Delta (e.g., Old River, Turner Cut) that increase entrainment risk to the Central Valley steelhead migrating from the San Joaquin River through the Delta.
>
> **Action:** Reclamation and/or DWR shall convene a working group to consider engineering solutions to further reduce diversion of emigrating juvenile salmonids to the interior Delta and consequent exposure to CVP and SWP export facilities. The working group, comprised of representatives from [U.S. Bureau of] Reclamation, DWR, NMFS, USFWS [U.S. Fish and Wildlife Service], and CDFG [California Department of Fish and Game], shall develop and evaluate proposed designs for their effectiveness in reducing adverse impacts on listed fish and their critical habitat. Reclamation or DWR shall subject any proposed engineering solutions to external independent peer review and report the initial findings to NMFS by March 30, 2012. Reclamation or DWR shall provide a final report on recommended approaches by March 30, 2015. If NMFS approves an approach in the report, Reclamation or DWR shall implement it. To avoid duplication of efforts or conflicting solutions, this action should be coordinated with

USFWS' Delta smelt biological opinion and BDCP's [Bay Delta Conservation Plan] consideration of conveyance alternatives.

Rationale: One of the recommendations from the CALFED Science Panel peer review was to study engineering solutions to "separate water from fish." This action is intended to address that recommendation. Years of studies have shown that the loss of migrating salmonids within Georgiana Slough and the Delta interior is approximately twice that of fish remaining in the Sacramento main stem (Kjelson and Brandes 1989; Brandes and McLain 2001; Vogel 2004, 2008; and Newman 2008). Based on the estimated survival rate of 35 percent in Georgiana Slough (Perry and Skalski 2008), the fraction of emigrating salmonids that would be lost to the population is 6 to 15 percent of the number entering the Delta from the Sacramento River basin. Keeping emigrating fish in the Sacramento River would increase their survival rate. This action is also intended to allow for engineering experiments and possible solutions to be explored on the San Joaquin/Southern Delta corridor to benefit out-migrating steelhead. For example, non-physical barrier (i.e., "bubble curtain") technology can be further vetted through this action.

The Action requires the U.S. Department of the Interior, Bureau of Reclamation (Reclamation) and/or DWR to consider engineering solutions to further reduce diversion of emigrating juvenile salmonids into the interior and southern Sacramento–San Joaquin River Delta (Delta), and reduce exposure to entrainment at both the CVP and SWP water export facilities. The Action specifically directed Reclamation and/or DWR to "convene a working group to consider engineering solutions." DWR convened a technical working group (TWG) comprising representatives of Reclamation, DWR, NMFS, USFWS, and CDFG (now the California Department of Fish and Wildlife: CDFW).

ES.1.1 Goals and Objectives

The Phase II Report primary objective is to inform NMFS of available engineering solutions that could potentially reduce exposure to entrainment at the CVP and SWP water export facilities. The Phase II Report:

- Summarizes or references results of completed or ongoing pilot engineering projects that are complimentary to the Action;
- Presents conceptual-level engineering details and drawings and estimated order of magnitude costs of engineering options to reduce the diversion of juvenile salmonids at each of the five study locations (sites);
- Presents a comparative evaluation of potential engineering solutions (based on available information), including the use of the U.S. Army Corps of Engineers' (USACE) Water Resource Assessment Methodology (WRAM) (Solomon et al. 1977) to evaluate engineering options;
- Identifies unknowns, prioritizes additional information needed to potentially eliminate or reduce the number of unknowns, assesses the risks of not gathering additional information, and identifies additional studies and analyses; and
- Informs NMFS on potential options to reduce the diversion of juvenile salmonids at each of the five study sites.

Source: AECOM 2013

Figure ES-1. Action IV.1.3 Study Locations

ES.2 BACKGROUND

The Action IV.1.3 evaluations were focused on Georgiana Slough and Threemile Slough on the Sacramento River and Head of Old River, Turner Cut, and Columbia Cut on the San Joaquin River and were divided into three phases:

- Phase I – Initial Findings;
- Phase II –Evaluate and Determine Potential Recommend Solutions; and
- Phase III – Implementation of Option Directed by NMFS.

Multiple options to deter juvenile salmonids have previously been tested in the past, primarily at Georgiana Slough. None have been proven to be adequate by NMFS, USFWS, and CDFW to be implemented on a permanent basis. In addition to considering a gate option at each of the sites, technologies that have not been implemented or tested in the tidally influenced Delta were emphasized. A summary of technologies considered are summarized in the Phase I Initial Findings Report and listed below:

- Physical Barriers
  - Fish Screen
  - Overflow Gate
  - Underflow Gate
  - Rock Barrier
  - Floating Fish Guidance System (FFGS)
- Non-Physical Barriers
  - Bio-Acoustic Fish Fence (BAFF)
  - Electrical Fish Guidance System
  - Infrasound Fish Fence (IFF)
- Other
  - Transportation/Barging

Each of the technologies listed are discussed in detail in this report.

ES.3 METHODS

DWR performed the engineering evaluation using a combination of methods, including research, collaboration, modeling, full-scale technology testing, and assessment of engineering options. The evaluation of engineering options included: forming the Technical Working Group (TWG) with representatives from Reclamation, DWR, NMFS, USFWS, and CDFW, and holding regular meetings; identifying deterrence sites; developing potential conceptual alternatives; field testing BAFF and FFGS deterrence technologies; conducting preliminary site environmental assessments; identifying biological design considerations; reviewing related studies; conducting hydrodynamic monitoring and analysis; conducting computer modeling; developing and implementing an evaluation framework; and assessing and ranking potential engineering options.

ES.3.1 Technical Working Group

The Action required that "Reclamation and/or DWR shall convene a working group to consider engineering solutions composed of representatives from USBR, DWR, NMFS, USFWS, and DFG [now CDFW]." DWR coordinated the formation of the TWG to satisfy this requirement. The TWG, whose members have unique scientific and engineering expertise, provided valuable input on potential options including identification of additional options for consideration. Based on a general understanding of the deterrence site characteristics and the behavior of fish species of concern, the TWG assisted in the evaluation of options to advance to more detailed analysis. These options included both physical and non-physical technologies. The TWG assisted in application of the WRAM and the detailed comparative option analysis.

ES.3.2 Field Testing of Engineering Options

DWR conducted field testing of two options to collect salmonid deterrence data, a BAFF and a FFGS. BAFF testing first began at the Head of Old River (HOR) site as part of the DWR Temporary Barriers Program. Subsequently, the BAFF was considered under RPA Action IV.1.3 for testing at the Georgiana Slough site, considered to be a key site where deterrence benefits could be maximized. The BAFF was tested in 2009 and 2010 at the HOR (DWR 2014b in prep.), and also in 2011 (DWR 2012) and 2012 at Georgiana Slough (DWR 2014a in prep.). USGS researchers, assisting DWR with the Georgiana Slough field studies, observed that juvenile salmonid entrainment was related to the fish's cross-stream position in the Sacramento River whether the BAFF was on or off.

An additional field test was developed in 2014 to evaluate the effectiveness of another flow-neutral technology to alter the fish stream position farther upstream from Georgiana Slough. The technology was a guidance barrier, or FFGS, which was hypothesized to alter fish stream position by the fish's response to its presence in the river. The FFGS test was performed in 2014 and analysis is ongoing. Results from the 2014 field test are still being analyzed at the time of this report.

ES.3.3 Site Environmental Evaluations

Preliminary evaluations were conducted for each of the five study sites to identify environmental issues that may require further evaluation before finalizing project designs. The preliminary evaluation generally used the environmental checklist form in Appendix G of the California Environmental Quality Act (CEQA) Guidelines (California Code of Regulations, Title 14, Division 6, Chapter 3, Sections 15000-15387). The preliminary evaluation included an assessment of permits or authorizations that may be required from federal, state, regional, and local agencies with regulatory jurisdiction over the environmental resources identified at each site.

Appendix C, "Environmental Checklists," contains site-specific environmental constraints and regulatory requirements information for each of the five sites.

ES.3.4 Water Quality and Flow Modeling/Hydraulic Analysis

Water quality and flow modeling was conducted by the DWR Modeling Support Branch of the Bay-Delta Office using the Delta Simulation Model II (DSM2) model. The purpose for this modeling was to simulate the conceptual gate designs at each site through a variety of operational strategies to deter juvenile salmonids. The model results were analyzed, and the resulting impacts on existing water quality and flow parameters are provided in Appendix E.

Velocity data were collected and analyzed by USGS for each of the sites with the exception of Threemile Slough. The analysis focused on streaklines and velocity mapping at the junctions over full tidal conditions. The streakline analysis was completed to locate and geo-reference the naturally occurring flow split at each inlet to the channels of interest. This streakline information and velocity mapping was used to assist in the conceptual designs for the placement and alignment of the proposed juvenile salmonid deterrence behavioral barriers. The full USGS report is provided in Appendix D.

ES.4 ENGINEERING EVALUATIONS

Fish screens, electrical guidance systems, rock barriers, and habitat restoration were options removed from consideration by the TWG after discussion of the assessment of each option. The final options carried through conceptual design were the BAFF, FFGS, IFF, Gate, SDIP Gate and Franks Tract Gate at Threemile Slough.

ES.4.1 CRITERIA INCORPORATED INTO DESIGNS

DWR identified eleven evaluation criteria and presented them to the TWG for discussion. DWR staff considered project-level and site-specific criteria, as well as general and common feasibility study-level criteria, to evaluate engineering options. The final evaluation criteria and their definitions considered are shown in Table ES-1.

Table ES-1. Final Evaluation Criteria to Evaluate Engineering Options

Criterion	Description
Boat Passage	The ability of an option to allow for the passage of boat traffic.
Cost	The cost of initial, annual, and long-term implementation of an option.
Deterrence Ability	The ability of an option to deter emigrating salmonids from entering a non-preferred migration route.
Environmental Impacts	Potential impacts of an option on the environment, including aquatic, terrestrial, and air quality resources.
Flow Effects	Potential impacts of an option on water flow, based on implementation.
Implementation	The ability of an option to be constructed in a timely manner in response to the need to deter emigrating or moving salmonids.
Operation and Maintenance	The effort required to keep an option operating and maintained.
Predation Effects	The effects of an option on predation beyond that which would occur naturally.
Tidal Effects	The effects of tidal stage variations as well as reverse flows on the performance of an option.
Uncertainties	The uncertainties associated with an option.
Upstream Migration	The effects of an option on the upstream migration of fish that should not be deterred.

Source: Compiled by DWR in 2014

ES.4.2 CONCEPTUAL-LEVEL ENGINEERING DETAILS

Four conceptual designs at each of the study sites were created and evaluated during the Phase II process. A BAFF, FFGS, IFF, and Gate were considered for Georgiana Slough, Threemile Slough, Turner Cut, and Columbia Cut while a BAFF, FFGS, Gate, and SDIP Gate were considered for the Head of Old River. Each of the conceptual designs took into consideration the evaluation criteria discussed above. The conceptual designs for each of the options are in Appendix B.

The cost comparison of each of the options including the initial construction, annual operations and maintenance, and present worth cost are shown in Figure ES-2.

Cost Comparison - Site Specific Engineering Options				
		Initial Construction	Annual O&M	Present Worth
Georgiana Slough	Bio-Acoustic Fish Fence	$12,800,000	$510,000	$25,600,000
	Floating Fish Guidance Structure	$6,300,000	$340,000	$18,200,000
	Infrasound Fish Fence	$7,600,000	$390,000	$21,400,000
	Gate	$47,100,000	$200,000	$50,600,000
Threemile Slough	Bio-Acoustic Fish Fence	$35,400,000	$880,000	$59,900,000
	Floating Fish Guidance Structure	$12,800,000	$710,000	$38,800,000
	Infrasound Fish Fence	$17,400,000	$790,000	$45,400,000
	Franks Tract Project	$148,400,000	$210,000	$152,300,000
Head of Old River	BAFF	$6,800,000	$440,000	$17,700,000
	FFGS	$800,000	$130,000	$3,600,000
	South Delta Improvements Program	$41,200,000	$200,000	$44,800,000
	Gate	$43,200,000	$200,000	$46,800,000
Turner Cut	Bio-Acoustic Fish Fence	$18,500,000	$860,000	$40,000,000
	Floating Fish Guidance Structure	$7,200,000	$390,000	$20,000,000
	Infrasound Fish Fence	$6,500,000	$390,000	$18,700,000
	Gate	$70,000,000	$200,000	$73,700,000
Columbia Cut	Bio-Acoustic Fish Fence	$16,600,000	$840,000	$37,600,000
	Floating Fish Guidance Structure	$7,600,000	$450,000	$23,400,000
	Infrasound Fish Fence	$8,400,000	$440,000	$23,300,000
	Gate	$82,100,000	$270,000	$85,800,000

Source: DWR 2015

Figure ES-2. Summary of Options Costs by Locations

ES.5 ENGINEERING EVALUATION RESULTS

The WRAM assessments conducted for engineering evaluations, summarizes assessments results, and discusses assessment limitations. The WRAM assessment method utilizes the four steps below to evaluate each option:

- Step 1 - identifying the evaluation criteria;
- Step 2 - weighting the importance of each criterion (calculating the relative importance coefficients [RICs]);

- Step 3 - scaling (weighting) the beneficial and adverse impacts of each potential option on the criterion (calculating the option choice coefficients [OCCs]); and
- Step 4 - calculating each option's relative score (calculating the final coefficients [FCs]).

The WRAM assessment was applied per site to compare each of the four options against one another considering each of the eleven evaluation criteria based on the best available information that currently exists. The final coefficients for each of the study sites are shown in Table ES-2.

Table ES-2. WRAM Final Coefficients

Site	Option				
	BAFF	FFGS	IFF	Gate	SDIP Gate
Georgiana Slough	0.29	0.28	0.25	0.18	NA
Threemile Slough	0.29	0.28	0.26	0.17	NA
Head of Old River	0.29	0.30	NF	0.21	0.19
Turner Cut	0.31	0.28	0.28	0.13	NA
Columbia Cut	0.30	0.28	0.28	0.13	NA

Notes: BAFF = Bio-Acoustic Fish Fence; FFGS = Floating Fish Guidance Structure; IFF = Infrasound Fish Fence; NA = not applicable; NF = not feasible; SDIP = South Delta Improvement Program; WRAM = Water Resource Assessment Methodology
Source: Data submitted from NMFS, CDFW, and DWR compiled by DWR in 2014

ES.6 RECOMMENDATIONS

In implementing options in Phase III, additional research and monitoring should be considered, including:

- Reviewing current studies related to the Action when they are completed,
- An additional field study of an FFGS pending results from the 2014 study,
- A field testing of an IFF to determine deterrence ability,
- Modeling specific gate operations for any gate options,
- Additional hydrodynamic modeling coinciding with field study to observe engineering technology performance,
- Implementing Eulerian-Lagrangian-Agent Method (ELAM) modeling of technologies at the junctions when the model is fully developed,
- Additional tagged juvenile salmonid behavioral studies coinciding with field studies and testing to observe engineering technology deterrence performance,
- Additional predation monitoring coinciding with field testing of engineering technology and predator interaction, and

- In lieu of engineering solutions, transporting juvenile salmonids by truck or barge past the junctions of concern similarly to an effort in 2014 to transport salmonids to Chipps Island due to extreme drought conditions.

Significant information has been collected over the last few years regarding engineering options to address the Action. Field studies of two options (BAFF and FFGS) were conducted at Georgiana Slough and one option (BAFF) was conducted at the Head of Old River. No field studies took place at Threemile Slough, Turner Cut, or Columbia Cut. Results for one of the options (FFGS), is in the process of being evaluated and results were not available to be included in this report. Additional information should be evaluated and collected which could potentially change the preferred option for each site. The TWG group believes the IFF technology has potential to be an effective engineering option but would need to be tested to examine potential adverse effects on larval fish. Testing would be done in a laboratory or appropriate field setting prior to consideration for implementation in order to evaluate the need, if any, of incidental take under FESA and CESA.

Based on current information that was evaluated by the TWG, if there is a demonstrated need to implement an engineering solution at one or more of the five junctions, the following are the currently preferred options for implementation:

- Georgiana Slough – BAFF
- Threemile Slough – BAFF
- Head of Old River – FFGS
- Turner Cut – BAFF
- Columbia Cut – BAFF

Before a decision to implement an engineering option is made, a science-based evaluation of the improvement to salmonid outmigration and survival that would result by implementing the option should be conducted. The evaluation should at minimum consider the time and cost to implement the option, adverse impacts of the option to the environment, and the number of salmonids using the channel that might be deterred by the option.

The engineering options that are eventually implemented at one or more of the five sites reviewed in this report would be subject to an adaptive management and monitoring program. The program would be designed to use new information and knowledge gained during the course of implementing a specific engineering solution to help develop and potentially implement alternative strategies to achieve the biological goals and objectives identified in the NMFS BiOp (2009). Barriers (non-physical and physical) may be installed and operated from October to June or when monitoring determines that salmonid smolts are present in the target areas.

Compliance monitoring will consist of documenting the installation and operation of engineered fish barriers. Project monitoring will consist of assessing the effectiveness of each barrier. Results of effectiveness monitoring to determine whether operations of barriers results in measurable benefits to juvenile salmonids and to identify adjustments to funding levels, methods, or other related aspects of the program would improve its biological effectiveness.

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1 INTRODUCTION

1.1 INTRODUCTION

The National Marine Fisheries Service (NMFS) issued its Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project (CVP) and State Water Project (SWP) (BiOp) in 2009 in accordance with Section 7 of the federal Endangered Species Act (ESA) of 1973 (16 U.S.C. 1531 et seq.) (NMFS 2009a). The Reasonable and Prudent Alternative (RPA) developed by NMFS in the BiOp contained the following action: Action IV.1.3, "Consider Engineering Solutions to Further Reduce Diversion of Emigrating Juvenile Salmonids to the Interior and Southern Delta, and Reduce Exposure to CVP and SWP Export Facilities" (Action).

The California Department of Water Resources (DWR) has completed this document, *Engineering Solutions to Further Reduce Diversion of Emigrating Juvenile Salmonids to the Interior and Southern Delta and Reduce Exposure to CVP and SWP Export Facilities – Phase II Recommended Solutions Report* (Phase II Report), in response to requirements of the Action. The Action requires the U.S. Department of the Interior, Bureau of Reclamation (Reclamation) and/or DWR to consider engineering solutions to further reduce diversion of emigrating juvenile salmonids into the interior and southern Sacramento–San Joaquin River Delta (Delta), and reduce exposure to entrainment at both the CVP and SWP water export facilities. The Action specifically directed Reclamation and/or DWR to "convene a working group to consider engineering solutions." DWR convened a technical working group (TWG) comprising representatives of Reclamation, DWR, NMFS, U.S. Fish and Wildlife Service (USFWS), and the California Department of Fish and Game (CDFG) (now the California Department of Fish and Wildlife: CDFW).

The Action is a multi-year study consisting of three phases:

- Phase I – Initial Findings (2011–2013);
- Phase II – Recommended Solutions (2012–2015); and
- Phase III – Implementation of Preferred Options (to be determined).

This Phase II Report is the culmination of Phase II and presents potential engineering solutions for five key Delta locations (study sites). These potential solutions are based on consideration of aspects of engineering, biological, and social importance including: fish deterrence ability, upstream fish migration, piscivorous predation effects, environmental constraints and opportunities, flow and tidal effects, recreational boat passage, feasibility, uncertainties, construction and operational costs, and operation and maintenance.

The five locations are (Figure 1-1):

- Sacramento River.
    - Georgiana Slough
    - Threemile Slough
- San Joaquin River.
    - Head of Old River (HOR)
    - Turner Cut
    - Columbia Cut

Source: AECOM 2014

Figure 1-1. Map of Delta Study Locations

Engineering options discussed in detail in this Phase II Report include:

- Bio-Acoustic Fish Fence (BAFF);
- Floating Fish Guidance Structure (FFGS);
- Infrasound Fish Fence (IFF);
- Electrical Fish Guidance System;
- Gates with Boat Lock and Fish Ladder;
- Fish Screen; and
- Rock Barrier.

In addition to the engineering options, three additional non-engineering options were identified: 1) transportation of juvenile salmonids through the Delta by barging/trucking; 2) habitat restoration; and 3) no action. These options were included for further consideration during Phase III should no engineering option be apparent for a given project location.

1.2 GOALS AND OBJECTIVES

1.2.1 STUDY GOALS

The overall study goal is to identify engineering options that have the potential to further reduce diversion of emigrating juvenile salmonids into the interior and southern Delta, thereby reducing exposure to entrainment at both the CVP and SWP water export facilities. The specific Phase II study goal is to recommend engineering options at each of the five locations identified in Phase I, with information and analyses to support implementation of a preferred option, if any, at each location.

1.2.2 PHASE II REPORT OBJECTIVE

The Phase II Report primary objective is to inform NMFS of available engineering solutions that could potentially reduce exposure of emigrating juvenile salmonids to entrainment at the CVP and SWP water export facilities. The Phase II Report:

- Summarizes results of completed or ongoing pilot engineering projects that are complimentary to the Action;

- Presents conceptual-level engineering details and drawings and estimated order of magnitude costs of engineering options to reduce the diversion of salmonids at each of the five study locations;

- Presents a comparative evaluation of potential engineering solutions, including the use of the U.S. Army Corps of Engineers' (USACE) Water Resource Assessment Methodology (WRAM) (Solomon et al. 1977) to evaluate engineering options;

- Identifies unknowns, prioritizes additional information needed to potentially eliminate or reduce the number of unknowns, assesses the risks of not gathering additional information, and identifies additional studies and analyses; and

- Informs NMFS on potential options to reduce the diversion of salmonids at each study site.

1.3 REPORT ORGANIZATION

The chapters and appendices of the Phase II Report are as follows:

- Chapter 1, “Introduction,” briefly describes the focus of this Phase II Report, goals and objective, and report organization;
- Chapter 2, “Background,” includes background information on Phase I accomplishments. The *Engineering Solutions to Further Reduce Diversion of Emigrating Juvenile Salmonids to the Interior and Southern Delta and Reduce Exposure to CVP and SWP Export Facilities Phase I Initial Findings Report* (Phase I Report) presents site information for each of the five diversion locations considered in the Action, summarizes initial findings, describes fish species of concern, and summarizes the evaluation of engineering options considered in Phase I;
- Chapter 3, “Methods,” describes the approaches to conducting work for Phase II, the methodologies used to evaluate potential success and feasibility of each engineering solution, input from the TWG meetings, summaries of engineering options testing progress, environmental and regulatory constraint reviews for each of the diversion locations, biological design considerations, review of related Delta studies, water quality and flow modeling, and the WRAM evaluation process;
- Chapter 4, “Engineering Evaluations,” presents the assessment of the engineering options carried forward into Phase II, highlights evaluation criteria incorporated into option designs, and presents conceptual-level engineering details at each of the study sites;
- Chapter 5, “Results and Discussion of the Engineering Evaluations,” presents the results from the WRAM evaluations, including scoring summaries, and discusses how Phase II engineering options integrate with other studies and programs;
- Chapter 6, “Recommendations,” includes DWR’s recommended approach to the Action, identifies additional research and monitoring needs, describes constraints and unknowns, addresses ongoing studies and analyses, and defines an adaptive management implementation strategy for the Action;
- Appendix A, “Technical Working Group Meeting Summaries,” presents meeting summaries from the TWG meetings which occurred throughout Phase II;
- Appendix B, “Conceptual Engineering Design Details,” presents conceptual engineering design details for Phase II engineering options;
- Appendix C, “Environmental Checklists,” presents initial evaluations of environmental constraints regarding biological resources, cultural resources, and regulatory requirements at each of the study sites;
- Appendix D, “Hydrodynamics,” presents flow, water quality, and hydraulic information developed by the U.S. Geological Survey (USGS) (USGS 2014); and
- Appendix E, “Modeling Physical Barriers,” presents hydraulic modeling information on the potential impact on flow, water quality, and water level of gate-type barriers at each of the study sites.

2 BACKGROUND

2.1 INTRODUCTION

NMFS issued its BiOp on the Long-Term Operations of the CVP and SWP on June 4, 2009, in accordance with Section 7 of the ESA (NMFS 2009a). The BiOp evaluated the effects on listed anadromous fishes and marine mammal species and their designated and proposed critical habitats. The BiOp concluded that the CVP and SWP long-term operations are likely to jeopardize the continued existence of several federally listed species:

- Endangered Evolutionarily Significant Unit (ESU) of Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*);
- Threatened ESU of Central Valley spring-run Chinook salmon (*O. tshawytscha*);
- Threatened Distinct Population Segment (DPS) of California Central Valley steelhead (*O. mykiss*);
- Threatened Southern DPS of North American green sturgeon (*Acipenser medirostris*); and
- Endangered DPS Southern Resident Killer Whales (*Orcinus orca*).

NMFS also concluded that the CVP and SWP long-term operations are likely to destroy or adversely modify the designated or proposed critical habitats of these same species. As required under the ESA, NMFS further identified an RPA to the proposed CVP and SWP long-term activities that is expected to avoid the likelihood of jeopardy to listed species and adverse modification of their designated and proposed critical habitats. The RPA includes a suite of actions to be implemented by Reclamation and DWR, to prevent jeopardy to the listed species and avoid destroying or adversely modifying designated critical habitats. NMFS developed the Action for the proposed long-term operation of the CVP and SWP, to meet the criteria of Title 50, Section 402 of the Code of Federal Regulations (CFR) which codifies the regulations for compliance with the ESA.

The objectives, proposed actions, and rationale behind the Action are described in the NMFS BiOp as follows:

> **Action IV.1.3 Consider Engineering Solutions to Further Reduce Diversion of Emigrating Juvenile Salmonids to the Interior and Southern Delta, and Reduce Exposure to CVP and SWP Export Facilities.**
>
> **Objectives:** Prevent emigrating salmonids from entering the Georgiana Slough channel from the Sacramento River during their downstream migration through the Delta. Prevent emigrating salmonids from entering channels in the south Delta (e.g., Old River, Turner Cut) that increase entrainment risk to the Central Valley steelhead migrating from the San Joaquin River through the Delta.
>
> **Action:** Reclamation and/or DWR shall convene a working group to consider engineering solutions to further reduce diversion of emigrating juvenile salmonids to the interior Delta and consequent exposure to CVP and SWP export facilities. The working group, comprised of representatives from Reclamation, DWR, NMFS, USFWS, and CDFG [now CDFW], shall develop and evaluate proposed designs for their effectiveness in reducing adverse impacts on listed fish and their critical habitat. Reclamation or DWR shall subject any proposed engineering solutions to external independent peer review and report the initial findings to NMFS by March 30, 2012. Reclamation or DWR shall provide a final report on recommended approaches by

March 30, 2015. If NMFS approves an approach in the report, Reclamation or DWR shall implement it. To avoid duplication of efforts or conflicting solutions, this action should be coordinated with USFWS' Delta smelt biological opinion and BDCP's [Bay Delta Conservation Plan] consideration of conveyance alternatives.

Rationale: One of the recommendations from the CALFED Science Panel peer review was to study engineering solutions to "separate water from fish." This action is intended to address that recommendation. Years of studies have shown that the loss of migrating salmonids within Georgiana Slough and the Delta interior is approximately twice that of fish remaining in the Sacramento main stem (Kjelson and Brandes 1989; Brandes and McLain 2001; Vogel 2004, 2008; and Newman 2008). Based on the estimated survival rate of 35 percent in Georgiana Slough (Perry and Skalski 2008), the fraction of emigrating salmonids that would be lost to the population is 6 to 15 percent of the number entering the Delta from the Sacramento River basin. Keeping emigrating fish in the Sacramento River would increase their survival rate. This action is also intended to allow for engineering experiments and possible solutions to be explored on the San Joaquin/Southern Delta corridor to benefit out-migrating steelhead. For example, non-physical barrier (i.e., "bubble curtain") technology can be further vetted through this action.

DWR developed a strategic three-phased approach to address the Action. The approach breaks down the steps necessary for multiple agencies and experts to collaboratively assess, evaluate, and recommend engineering solutions at each of the locations identified in the BiOp, to reduce juvenile salmonid exposure to CVP and SWP export facilities. Each phase, including timeline, is described next.

2.1.1 Phase I – Initial Evaluation (2011–2013)

Phase I included convening a TWG, reviewing possible locations to reduce the diversion of salmonids, identifying potential engineering solutions for their effectiveness, and subjecting the Phase I Report to independent peer review (DWR 2013b).

In June 2011, DWR convened the TWG and began hosting quarterly meetings. During these meetings, a variety of topics were discussed: evaluating and finalizing diversion locations to include in the study; identifying technologies and options to include in the study; coordinating with other project working groups, such as the Bay Delta Conservation Plan Governance Working Group, Smelt Working Group (formerly the Delta Smelt Working Group), and the Yolo Bypass Working Group; coordinating with an independent review group, and identifying criteria and methodologies to assess proposed engineering options. Phase I TWG meeting summaries are included in the Phase I Report (DWR 2013b). As noted in Chapter 1, the agencies comprising the TWG were CDFW, DWR, NMFS, Reclamation, and USFWS.

DWR's Phase I Report identified Delta locations where salmonid entrainment could be reduced by engineering deterrence barriers (see Figure 1-1), researched and presented available and applicable engineering technologies, determined which fish species could be affected (beneficially or adversely) by engineered barriers, identified engineering options, and selected evaluation criteria and methodologies to be used in option assessments.

During the initial stages of Phase I, several engineering options were deemed to be ineffective, had potentially adverse effects on non-salmonid fish species of concern, or were cost prohibitive. These options were not included in the evaluation stage of Phase I. Details regarding eliminated options are summarized in Section 2.2.3, "Engineering Options Removed from Consideration," and are presented in greater detail in the Phase I Report (DWR 2013b).

In February 2012, DWR informed NMFS that the report submittal would be delayed past the specified RPA March 30, 2012 date. The delay provided DWR additional time to address technical peer review questions. DWR initiated Phase II work during the delay period, including more detailed option analyses and field study work. On December 6, 2013, DWR submitted the Phase I Report to NMFS (DWR 2013b). The report discussed the five locations and engineering options presented above to be carried into Phase II, summarized information on fish species of concern and other potential species of interest, and presented information on potential engineering solutions, including previous engineering solutions and results. A summary of the Phase I Report initial findings is presented in Section 2.2, "Summary of Phase I Initial Findings Report."

2.1.2 PHASE II – RECOMMENDED SOLUTIONS (2009–2015)

► Phase II, the focus of this report, included gathering additional information not included in the Phase I Report, conducting a detailed evaluation of options presented in the Phase I Report, conducting field studies in 2011 (BAFF), 2012 (BAFF), and 2014 (FFGS) at Georgiana Slough, conducting field studies in 2009 (BAFF) and 2010 (BAFF) at the Head of Old River, preparing conceptual barrier design details, and developing recommended engineering solutions for each of the five study locations. Engineering options deemed to have potential significant adverse effects on non-salmonid fish species of concern or would be cost prohibitive to implement were eliminated from further consideration. DWR continued to facilitate TWG meetings to obtain evaluation input and discuss ongoing and future work related to the Action. Notes from these Phase II TWG meetings are provided in Appendix A and summarized in Section 3.2, "Technical Working Group Review Meetings."

2.1.3 PHASE III – IMPLEMENTATION OF RECOMMENDED OPTIONS (2015)

► In Phase III, NMFS will review the Phase II Report and is expected to either direct further analysis of options or implementation of recommended options at each of the five locations evaluated. Ultimately, NMFS will direct Reclamation and/or DWR to proceed with permitting, final design, construction, and implementation of recommended options in this phase. Phase III implementation will be coordinated with the USFWS delta smelt biological opinion (USFWS 2008) and the conveyance alternatives for the BDCP (DWR 2013a) to avoid duplication of efforts and conflicting solutions.

2.2 SUMMARY OF PHASE I INITIAL FINDINGS REPORT

The Phase I Report was developed through an interagency collaborative process, conducted as a result of brainstorming efforts. Topics included identifying diversion locations for the study, identifying fish species of concern, identifying and reviewing possible engineering solutions, and developing criteria to be used in evaluation methodologies.

The Phase I Report provided site descriptions for five locations, or study sites, for which engineering solutions are proposed. These sites encompass areas where entrainment of emigrating juvenile salmonids occurs and where engineered solutions may further reduce salmonid diversion to the interior and south Delta, and reduce their exposure to SWP and CVP export facilities. Three of these locations are identified in the Action and include one location on the Sacramento River —Georgiana Slough—and two locations on the San Joaquin River—HOR and Turner Cut. Two additional locations were added by the TWG: Threemile Slough on the Sacramento River and

Columbia Cut on the San Joaquin River. The hydrologic, migratory, and entrainment pathways and recreational characteristics vary among these study sites. More detailed descriptions are presented in Section 2.2.1, "Site Descriptions."

The Action is focused on reducing exposure of juvenile salmonids to CVP and SWP export facilities and reducing entrainment of emigrating juvenile salmonids into the interior and south Delta; however, the study sites provide habitat for many fish species. During Phase I, the TWG added a number of other fish species in addition to salmonids in the study scope. The Phase I Report presents information about the importance of various fish species in the Delta and San Francisco Bay Estuary, the occurrence of Essential Fish Habitat (EFH) and critical habitat in the study area, the presence of species listed under the ESA and the California Endangered Species Act (CESA) (Fish and Game Code Sections 2050-2116), and the importance of recreational and commercial fisheries. The Phase I Report presents a list of special-status species that could be affected by implementing one of the alternatives. Additional information about special-status species are presented in the Phase I Report (DWR 2013b) as well as in Section 2.2.2, "Fish Species of Concern" and Chapter 3, "Methods" of this report.

The Phase I Report summarized completed and ongoing pilot projects that have been implemented under the Action, including pilot projects at Georgiana Slough and HOR. Ongoing DWR studies, including the South Delta Improvement Project and the Franks Tract Project, provided additional information for use in the Phase II evaluations. Additional information regarding relevant engineering experiments and results discussed in the Phase I Report (DWR 2013b) are summarized in Section 2.2.3, "Previous Engineering Solutions and Outcomes" of this report.

The TWG determined during Phase I that an unbiased assessment methodology was appropriate for assessing engineering options that would have the potential to meet the goals of the Action. The TWG adopted the USACE's Water Resource Assessment Methodology (WRAM) (Solomon et al. 1977) to help evaluate engineering options at each site. The WRAM was used as a tool to help ensure that the TWG was looking at all of the criteria at all of the sites, and also to help quantify the potential advantages that one option may have over another. All options that were assessed in the WRAM were thought to be feasible. The WRAM process provides resource managers and engineers with a systematic weighting-ranking technique to assess potential project impacts and alternatives. The WRAM process is explained in Section 3.3.7, "Evaluation Framework Including Application of the Water Resource Assessment Methodology."

Phase I efforts included investigating a range of technologies with the potential to meet the goals of the Action. These engineering options are listed in Chapter 1. Each option was evaluated using the WRAM process. The TWG proposed eleven variables for use in the WRAM process. These variables (discussed further in Section 2.2.4, "Engineering Options Evaluated," and Chapter 3, "Methods") include engineering, biological, and social data. To reach an implementable strategy, aspects of engineering, biological, permitting, recreation, and costs, including initial construction, operations, and maintenance, were considered during the evaluation process. Certain options were "screened-out" in the initial Phase II work, based on the TWG expertise, to prevent expending time and resources when evaluating, designing, and costing options that would be neither feasible nor effective.

2.2.1 Site Descriptions

A brief description is provided for each of the five study sites (Figure 1-1).

2.2.1.1 GEORGIANA SLOUGH

The Georgiana Slough study site is located at the divergence of the Sacramento River and Georgiana Slough, just downstream from Walnut Grove in Sacramento County (Latitude 38.23947º, Longitude -121.51726º). The land use in the vicinity of the site includes the urban area of Walnut Grove surrounded by farmlands (Figure 2-1).

Georgiana Slough is a migratory corridor for a variety of native and non-native anadromous fish species passing between the Sacramento and San Joaquin rivers and for juvenile salmonids emigrating to the Pacific Ocean. These fish species include Chinook salmon, steelhead, green sturgeon, white sturgeon (*Acipenser transmontanus*), striped bass (*Morone saxatilis*), and American shad (*Alosa sapidissima*). A variety of native and non-native resident fish species are known to inhabit in the vicinity of the Georgiana Slough study site including largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), spotted bass (*Micropterus punctulatus*), tule perch (*Hysterocarpus traski*), Sacramento pikeminnow (*Ptychocheilus grandis*), Sacramento splittail (*Pogonichthys macrolepidotus*), and white catfish (*Ictalurus catus*).

Georgiana Slough provides a variety of public recreational opportunities, such as fishing and boating. Boaters choose this route for its scenic quality, ease of navigation, and linkages to other Delta destinations. Approximately 15 to 20 percent of the Sacramento River flow enters the interior Delta through Georgiana Slough, depending on river flows and the tidal cycle. Average net monthly flow ranges between 2,200 to 6,200 cubic feet per second (cfs) flow down Georgiana Slough from the Sacramento River. Georgiana Slough is approximately 200 feet wide and 20 to 30 feet deep at its divergence from the Sacramento River during average river flows.

2.2.1.2 THREEMILE SLOUGH

The Threemile Slough study site is located at the divergence of Sacramento River and Threemile Slough within Solano and Contra Costa counties (Latitude 38.1067º, Longitude -121.7023º). The site is downstream from Rio Vista and is bounded by the area formed by the Sacramento and lower San Joaquin rivers (Figure 2-2). The study area includes Sherman and Brannan islands. The Threemile Slough location was not specifically identified in the Action but was included because of its importance as a route to the interior and south Delta, contribution to entrainment, and exposure to export and diversion facilities. Threemile Slough is the next point of divergence downstream from Georgiana Slough on the Sacramento River.

This study site is a migratory corridor for of a variety of native and non-native anadromous fish species, including Chinook salmon, steelhead, green and white sturgeon, striped bass, and American shad. Other fish species at this study site are similar to those species identified for Georgiana Slough. Threemile Slough provides similar recreational opportunities as Georgiana Slough. Net monthly flows average 2,000 cfs, depending on the river flows and the tidal cycle. Net positive flows are from Threemile Slough into the Sacramento River. Maximum tidal flows are approximately 30,000 cfs. The slough is over 600 feet wide, with depths between 20 and 30 feet in the vicinity of its divergence from the Sacramento River.

2.2.1.3 HEAD OF OLD RIVER

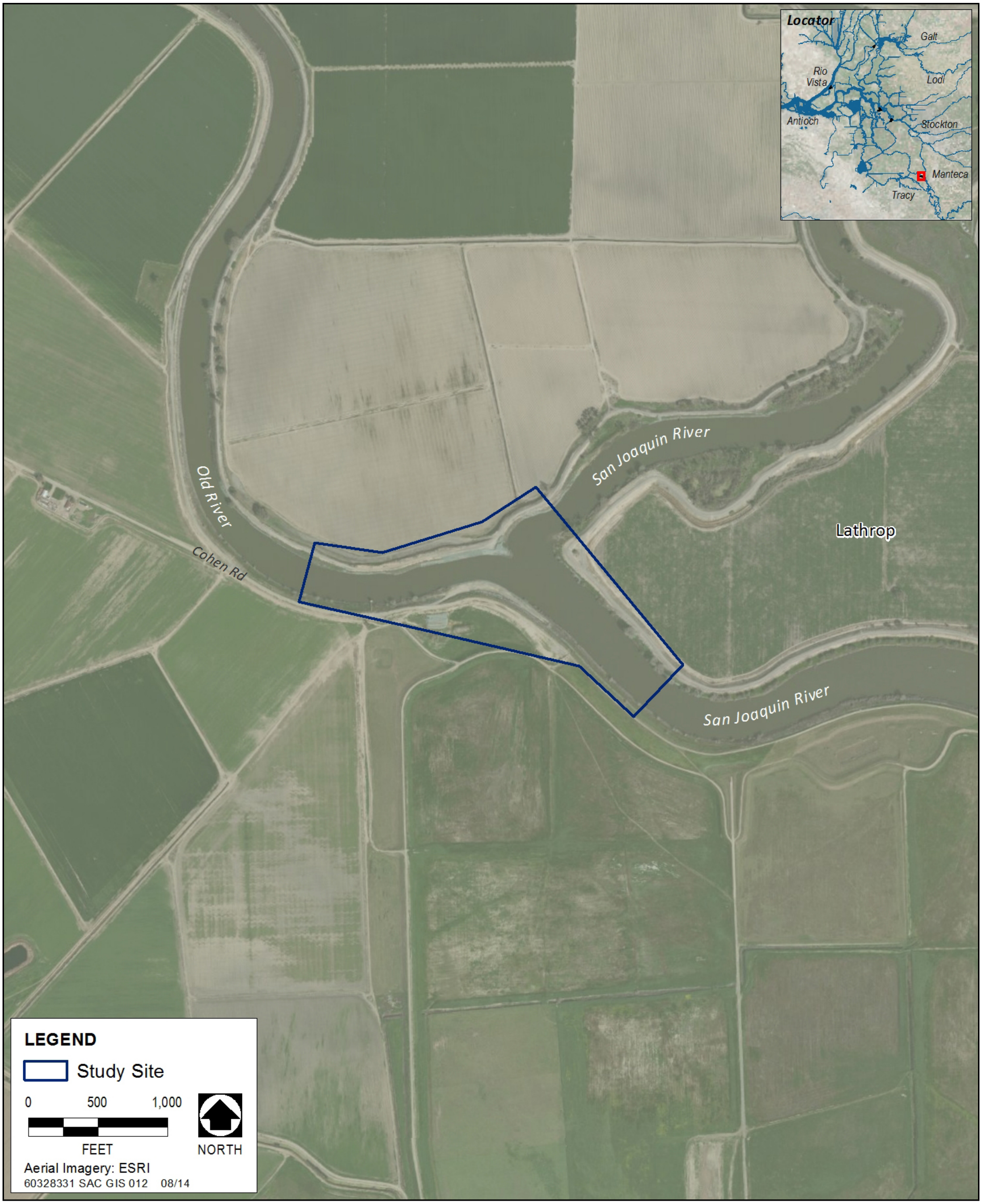
The HOR study site is located near Lathrop at the divergence of the San Joaquin and Old rivers (Latitude 37.8076º, Longitude -121.3277°) (Figure 2-3). Current adjacent land use is primarily agricultural with future plans to develop housing communities.

Source: Data provided by DWR in 2014 and adapted by in AECOM 2014

Figure 2-1. Georgiana Slough

Source: Data provided by DWR in 2014 and adapted by AECOM in 2014

Figure 2-2. Threemile Slough



Source: Data provided by DWR in 2014 and adapted by AECOM in 2014

Figure 2-3. Head of Old River

This study site area is a migratory corridor for of a variety of native and non-native anadromous fish species, including Chinook salmon, steelhead, white sturgeon, and striped bass, and non-anadromous Sacramento pikeminnow and Sacramento splittail. The HOR location provides similar recreational opportunities as Georgiana and Threemile sloughs.

Approximately 50 percent of the net San Joaquin River flow enters the interior Delta through the divergence at the HOR location. Average monthly net flow ranges between 1,000 and 3,000 cfs. However, flows can vary substantially, depending on flows in the San Joaquin River upstream from the HOR location. Old River is approximately 225 feet wide and on average 3 to 8 feet deep at the point of divergence from the San Joaquin River. A large scour hole exists in the San Joaquin River just downstream from the divergence where a large number of piscivorous predatory fish are suspected to congregate. The number of predatory fish in the vicinity of the scour hole is likely influenced by seasonal flow and tidal stage.

2.2.1.4 TURNER CUT

The Turner Cut study site is located near Stockton at the divergence of the San Joaquin River and Turner Cut (Latitude 37.9990°, Longitude -121.4489°). Turner Cut is split into two equivalent secondary channels before its junction with the mainstem of the San Joaquin River; the land between the two channels forms Acker Island. The adjacent land use is farming (Figure 2-4).

This study site is a migratory corridor for a variety of native and non-native anadromous fish species, including Chinook salmon, steelhead, green and white sturgeon, American shad, and striped bass, as well as non-anadromous delta smelt (*Hypomesus transpacificus*), Sacramento pikeminnow, Sacramento splittail, and various catfish species. Like the aforementioned study sites, Turner Cut provides similar recreational opportunities.

Approximately 20 to 25 percent of the San Joaquin River flow enters the interior Delta from the San Joaquin River through Turner Cut during a flood tide. Average monthly net flow ranges between 1,800 and 2,300 cfs, depending on San Joaquin River flow and the tidal cycle. Tidal cycle flow reversal occurs at Turner Cut approximately 50 percent of the time based on historic data. The two secondary channels of Turner Cut at the divergence with the mainstem San Joaquin River are each approximately 275 to 285 feet wide and 20 to 30 feet deep. Turner Cut’s main channel is approximately 360 feet wide at the confluence of the two secondary channels and is 20 to 30 feet deep. This is based on average flows.

2.2.1.5 COLUMBIA CUT

The Columbia Cut study site is located in the Delta near Stockton (Latitude 38.0344°, Longitude -121.4855°) and is split into two secondary channels before flowing into the San Joaquin River. Farmland and public/private properties (Figure 2-5) are adjacent to this study site. The Columbia Cut location was not specifically identified in the Action but was included because of its importance as a route that juvenile salmonids use to access to the interior and south Delta, contribution to entrainment, and exposure to export and diversion facilities.

This study site is a migratory corridor for a variety of native and non-native anadromous fish species, including Chinook salmon, steelhead, green and white sturgeon, striped bass, and American shad, as well as native and non-native non-anadromous delta smelt, Sacramento pikeminnow, Sacramento splittail, and various catfish species. Columbia Cut provides similar recreational opportunities as the other sites.

Source: Data provided by DWR in 2014 and adapted by AECOM in 2014

Figure 2-4. Turner Cut

Source: Data provided by DWR in 2014 and adapted by AECOM in 2014

Figure 2-5. Columbia Cut

Approximately 30 to 35 percent of the San Joaquin River flow enters the interior Delta through Columbia Cut during a flood tide. Tidal cycle flow reversal occurs at Columbia Cut approximately 50 percent of the time due to pumping for water export. Average monthly flow ranges between 3,000 and 4,000 cfs, depending on San Joaquin River flow and the tidal cycle. The two secondary channels of Columbia Cut at the divergence with the main San Joaquin River are each approximately 350 feet wide and 10 to 15 feet deep. The main channel is approximately 550 feet wide at the confluence of the two secondary channels and is 20 to 35 feet deep. This is based on average flows.

2.2.2 FISH SPECIES OF CONCERN

The San Francisco Bay Estuary hosts a variety of fish species that support recreational and commercial fisheries. These species include fall-run Chinook salmon, Pacific herring (*Clupea pallasii*), northern anchovy (*Engraulis mordax*), starry flounder (*Platichthys stellatus*), striped bass, largemouth bass, and white sturgeon. Essential Fish Habitat (EFH) for Pacific salmon, northern anchovy and certain species of Pacific groundfish (e.g., starry flounder) has been delineated within the Estuary and Delta. The EFH is defined in the Magnuson–Stevens Fishery Conservation and Management Act (16 U.S.C. §§ 1801-1884), better known as the Magnuson-Stevens Act, as those waters and substrates necessary to fish for breeding, spawning, feeding, or growth to maturity.

NMFS and USFWS are also required to designate critical habitat for all species listed under the federal ESA. Critical habitat is defined as specific areas:

- Within the geographical area occupied by the species at the time of listing, if they contain physical or biological features essential to conservation, and those features may require special management considerations or protection; and
- Outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation.

The majority of the Delta is designated critical habitat for delta smelt, California Central Valley (CV) steelhead (hereafter referred to as California CV steelhead or simply as CV steelhead) , and green sturgeon. Portions of the Delta, in particular the Sacramento River and channels within the Delta, are designated critical habitat for Sacramento River winter-run Chinook salmon and CV spring-run Chinook salmon.

The abundance, distribution, and habitat use of these species has been studied for many years through investigations conducted by DWR, NMFS, USFWS, CDFW, and other entities. Study results have documented changes in species composition and abundance within the Delta over the past several decades (DWR 1988; CDFG 1998; DWR and Reclamation 2000). Many fish species within the Delta have experienced a general decline in abundance (Moyle et al. 1995). Consequently, many of these species require special management strategies, including Sacramento River winter-run Chinook salmon, CV spring-run Chinook salmon, CV steelhead, green sturgeon, delta smelt, and longfin smelt (*Spirinchus thaleichthys*). These species are listed under the federal ESA and/or CESA.

Reclamation and DWR are considering engineering solutions to further reduce diversion of emigrating juvenile salmonids into the interior and south Delta. However, engineering solutions also need to be protective of other listed species. The listed species occurring in the Delta that could be affected by implementing engineering solutions to reduce diversion and entrainment are listed in Table 2-1. Detailed life history and migration information is provided in the following sections for Sacramento River winter-run Chinook salmon, CV spring-run Chinook salmon, CV steelhead, green sturgeon, and delta smelt. Although not the focus of this study, green sturgeon and delta smelt are discussed because of their listing status, annual or seasonal presence at the study sites, and potential to be affected by proposed engineering options.

Table 2-1. Federally and State-listed Fish, Candidate Fish for Listing, and Fish Species of Concern in the Delta

Species	Listing Status		Designated Habitat[3]
	Federal[1]	State[2]	
Sacramento River winter-run Chinook salmon ESU (*Oncorhynchus tshawytscha*)	FE	SE	CH, EFH
Central Valley spring-run Chinook salmon ESU (*O. tshawytscha*)	FT	ST	CH, EFH
Central Valley fall-run Chinook salmon ESU (*O. tshawytscha*)	FC	SSC	CH, EFH
Central Valley late fall-run Chinook salmon ESU (*O. tshawytscha*)	FC	SSC	CH, EFH
California Central Valley steelhead DPS (*O. mykiss*)	FT	--	CH
Delta smelt (*Hypomesus transpacificus*)	FT	ST	CH
Southern DPS green sturgeon (*Acipenser medirostris*)	FT	SSC	CH
Longfin smelt (*Spirinchus thaleichthys*)	FC	ST	--
River lamprey (*Lampetra ayresii*)	--	SSC	--
Hardhead (*Mylopharodon conocephalus*)	--	SSC	--
Sacramento perch (*Archoplites interruptus*)	--	SSC	--
Tidewater goby (*Eucyclogobius newberryi*)	FE	SSC	--
Rough sculpin (*Cottus asperrimus*)	--	ST; FP	--

Notes:
[1] Federal Status: FE = Endangered, FT = Threatened, FC = Federal species of concern
[2] State Status: SE = Endangered, ST = Threatened, SSC = Species of special concern, FP = Fully protected
[3] Designated Habitat: CH = Critical habitat, EFH = Essential fish habitat
Source: DWR 2013b

2.2.2.1 SALMONIDS

Chinook salmon and steelhead are anadromous fishes; they spawn and rear in freshwater, spend a portion of their juvenile life in freshwater before emigrating to the ocean as smolts, and live most of their life in the ocean before returning to freshwater to spawn as adults. The five runs of anadromous salmonids present in the Delta and Sacramento River are:

- Sacramento River winter-run Chinook salmon ESU
- Central Valley spring-run Chinook salmon ESU
- Central Valley fall-run Chinook salmon ESU
- Central Valley late fall-run Chinook salmon ESU
- California Central Valley steelhead DPS

Sacramento River winter-run Chinook salmon ESU, CV spring-run Chinook salmon ESU, and CV steelhead DPS (covers both Sacramento and San Joaquin rivers) are listed under ESA and CESA (Table 2-1). Life history characteristics that differentiate runs include the time of year adults return to freshwater, state of sexual maturity at freshwater entry, and the amount of time juveniles rear in freshwater before ocean entry. Adult and juvenile

Chinook salmon and steelhead can be present in the Delta year-round. Chinook salmon and steelhead are present in the Sacramento and San Joaquin rivers in the months presented in Table 2-2. The presence time ranges are estimates, and annual variation is influenced by many factors including stock characteristics, hydrologic conditions, local conditions, ocean conditions, and water quality (Moyle 2002). Fork length ranges of juvenile Chinook salmon have been historically and are currently used to differentiate winter-run and spring-run among the four CV Chinook salmon races. However, recent analysis has demonstrated that there is a high degree of overlap in fork length ranges among the four races. Also, empirical growth rates were found to be well below those rates from which length-at-date criteria were derived (Harvey et al. 2014). These findings suggest that genetic assignment be used at least as a supplemental approach to improve CV Chinook salmon race identification and management.

Adult stream-type Chinook salmon (winter-run and spring-run) enter freshwater months before spawning and hold in deeper, cooler mainstem pools while gonads mature; juveniles reside in freshwater for a year or more following emergence (Healey 1991). Winter-run Chinook salmon possess characteristics of both stream- and ocean-type life histories (Healey 1991). Adults enter freshwater in winter or early spring, and delay spawning until spring or early summer (stream-type). However, juvenile winter-run Chinook salmon emigrate to the ocean after rearing in freshwater for approximately 4 to 7 months (ocean-type). Adult spring-run Chinook salmon enter freshwater in spring, hold in deep, cool pools during summer, and spawn in early fall. Some juveniles may rear in freshwater for a year or more before emigrating to the ocean but although many juveniles emigrate to the ocean in the first spring following emergence.

Adult ocean-type Chinook salmon (fall-run and late fall-run) enter freshwater with fully mature gonads and spawn soon after freshwater entry; juveniles emigrate to the ocean within their first year (Healey 1991).

Only winter-run steelhead are present in Central Valley rivers and streams (McEwan and Jackson 1996), although indications show that summer-run steelhead historically were present in the Sacramento River system (Moyle 2002). Although adult CV steelhead exhibit very plastic life history strategies, they generally leave the ocean and return to the estuary and rivers from August through May (Busby et al. 1996; NMFS 2014; unpublished data CDFW and USFWS). Spawning generally occurs from December through at least April with peaks from January through March in small streams and tributaries where cool, well-oxygenated water is available year-round (Hallock et al. 1961; McEwan and Jackson 1996; NMFS 2014). Most juvenile CV steelhead spend 2 years in fresh water (Busby et al. 1996) and emigrate through the Delta to the Pacific Ocean in January through June with the peak migration occurring in the Delta in March and April (NMFS 2014).

Sacramento River Winter-Run Chinook Salmon ESU

Sacramento River winter-run Chinook salmon ESU originally was federally listed as threatened by an emergency interim rule, published on August 4, 1989 (54 FR 32085). A new emergency interim rule was published on April 2, 1990 (55 FR 12191). A final rule, listing Sacramento River winter-run Chinook salmon as threatened, was published on November 5, 1990 (55 FR 46515). The ESU consists of one population confined to the upper Sacramento River. The ESU was reclassified as endangered on January 4, 1994 (59 FR 440) because of increased variability of run sizes, weak returns resulting from two small year classes in 1991 and 1993, and a 99 percent decline between 1966 and 1991. Hatchery fish from the Livingston Stone National Fish Hatchery are included in the ESU (70 FR 37160, June 28, 2005). In 2010, NMFS conducted a 5-year status review and concluded that the most recent biological information suggests the extinction risk of this ESU has increased since the last status review and several of the listing factors have contributed to the decline, including recent years of drought and poor ocean conditions (NMFS 2011a). The best available information on the biological status of the ESU and continuing and new threats to the ESU indicate that its ESA classification as an endangered species is appropriate (NMFS 2011a).

NMFS designated critical habitat for winter-run Chinook salmon on June 16, 1993 (58 FR 33212). Critical habitat was delineated as the Sacramento River from Keswick Dam at river mile (RM) 302 to Chipps Island (RM 0) at the westward margin of the Delta, including Kimball Island, Winter Island, and Brown's Island; all waters from Chipps Island westward to the Carquinez Bridge, including Honker Bay, Grizzly Bay, Suisun Bay, and the Carquinez Strait; all waters of San Pablo Bay westward from the Carquinez Bridge; and all waters of San Francisco Bay north of the San Francisco–Oakland Bay Bridge.

Critical habitat includes the water, benthic habitat, and the adjacent riparian zone. Riparian zones on the Sacramento River are considered essential for the conservation of winter-run Chinook salmon because they provide important areas for fry and juvenile rearing. For example, studies of Chinook salmon smolts in the middle reaches of the Sacramento River found higher densities in natural, eroding bank habitats with woody debris than in other habitat types (Michny and Hampton 1984).

Dam construction has greatly diminished the range and spawning and rearing habitat of Sacramento River winter-run Chinook salmon. Historically, high winter flows during upstream migration enabled adults to access headwater spawning habitat in the upper Sacramento, McCloud, Pit, and Fall rivers. Juveniles reared through summer in cool, spring-fed pools available in the lava and basalt regions of the southern Cascades. The upper reaches of Battle Creek, Feather River, and American River also may have supported a winter-run population before the development of hydroelectric dams (Yoshiyama et al. 2001). Construction of Shasta, Oroville, and Folsom dams has limited Sacramento River winter-run Chinook salmon to spawning in the cool tailwaters below Shasta Dam in the mainstem Sacramento River and within the upper reaches of Battle Creek, where they are highly dependent on the presence of cool water for their survival.

In contemporary records, Sacramento River winter-run Chinook salmon have been less numerous than spring-run or fall-run. A dramatic decline has occurred in the abundance of returning adult winter-run salmon in the Sacramento River in the last half-century (NMFS 2011a). Adult returns have declined from about 120,000 in the 1960s to a few hundred in the early 1990s (NMFS 2011a). Populations began increasing in the mid-1990s, and annual adult escapement was estimated to be in the thousands (Good et al. 2005); peak escapement of approximately 17,000 adults occurred in 2006. Escapement then declined dramatically again, since 2006, to historically low numbers (NMFS 2011a).

Adequate stream flows allow adult passage to upstream holding habitats and likely are an important migratory cue. The preferred water temperature range for upstream migration is 38 degrees Fahrenheit (ºF) to 56ºF (Bell 1991), but water temperatures up to 67ºF are suitable (Berman and Quinn 1991; NMFS 1997). Adult winter-run Chinook salmon enter San Francisco Bay from November through June (Hallock and Fisher 1985) and migrate past Red Bluff Diversion Dam (RBDD) from mid-December through early August (NMFS 1997a). The majority of the run passes RBDD from January through May and peaks in mid-March (Hallock and Fisher 1985). Migration timing varies because of changes in river flows, upstream dam operations, and water year type.

Table 2-2. Presence for Winter-Run, Spring-Run, Fall-Run, and Late Fall-Run Chinook Salmon and Steelhead in the Sacramento (SR) and San Joaquin (SJR) rivers and Delta

Life Stage	Species	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Adult Migration	Winter-Run												
	Spring-Run												
	Fall-Run SR												
	Fall-Run SJR												
	Late Fall-Run												
	Steelhead SR												
	Steelhead SJR												
Spawning	Winter-Run												
	Spring-Run												
	Fall-Run SR												
	Fall-Run SJR												
	Late Fall-Run												
	Steelhead SR												
	Steelhead SJR												
Egg Incubation and Emergence	Winter-Run												
	Spring-Run												
	Fall-Run SR												
	Fall-Run SJR												
	Late Fall-Run												
	Steelhead SR												
	Steelhead SJR												
Juvenile Rearing	Winter-Run												
	Spring-Run												
	Fall-Run SR												
	Fall-Run SJR												
	Late Fall-Run												
	Steelhead SR												
	Steelhead SJR												
Smolt Emigration	Winter-Run												
	Spring-Run												
	Fall-Run SR												
	Fall-Run SJR												
	Late Fall-Run												
	Steelhead SR												
	Steelhead SJR												

Note:

= Delta Migration

Source: NMFS 2014; unpublished data CDFW and USFWS 2014; del Rosario et al. 2013; Moyle 2002.

Adults hold in deep, cold pools until they are sexually mature and ready to spawn in spring or summer. Holding occurs in the Sacramento River primarily between Bend Bridge and Keswick Dam (NMFS 1997a). This section of the Sacramento River is confined between natural bluffs and volcanic formations, and pools between 20 and 60 feet deep have formed at the tail of high-gradient sections. Water temperatures between 55ºF and 56ºF are ideal for gamete development and egg viability. Suitability for holding adults begins to decline when water temperatures rise above 59ºF to 60ºF (DWR 1988; NMFS 1997). Water temperatures above 69.8ºF begin to cause mortality (McCullough 1999).

Sacramento River winter-run Chinook salmon primarily mature at 2 years of age (25 percent) and 3 years of age (67 percent; the remaining 8 percent are 4+ year olds), unlike spring- and fall-run Chinook salmon that primarily mature as 3- and 4-year-olds (NMFS 1997a; Fisher 1994). Spawning typically begins in late April, peaks in May and June, and usually subsides by mid-August (NMFS 1997a). Compared to other runs, winter-run may select deep spawning sites over seemingly equally suitable shallow spawning sites; spawning at depths in excess of 21 feet has been documented (NMFS 1997a). Most of the population spawns in the upper reach of the Sacramento River downstream of Keswick Dam.

Juvenile Sacramento River winter-run Chinook salmon emigrate down the Sacramento River from July through April and may arrive in the Delta as early as November (NMFS 2014) with median catch typically occurring in March at Chipps Island (del Rosario et al. 2013). Movement through the system depends on flows and turbidity during the emigration period, but peak emigration generally occurs between December and April (NMFS 2014). Juveniles rear in freshwater portions of the Delta for approximately 2 months before moving downstream into the estuary (Kjelson et al. 1981). They rear in fresh and estuarine waters for approximately 5 to 9 months, based on size at ocean entry (NMFS 1997a). Juveniles tend to school in the surface waters of main and secondary channels and sloughs as they increase in length, and follow the tide into shallow water habitats to feed (Allen and Hassler 1986). In Suisun Marsh, Moyle et al. (1986) reported that juvenile Chinook salmon tend to remain close to the banks and vegetation, near protective cover, and in dead-end tidal channels. Ocean entry generally occurs from January through June when juveniles measure approximately 4.6 inches in length (Fisher 1994). Before ocean entry, juveniles undergo smoltification that allows them to adapt to the saltwater environment.

Information on the ocean distribution of Sacramento River winter-run Chinook salmon is scarce. Available data are derived from ocean fisheries and are biased towards locations where ocean fisheries occur. Returns from marked adults indicate that most are captured in the ocean between Monterey, Monterey County and Fort Bragg, Mendocino County, California; mixed results make it difficult to determine whether captures occurred north of Fort Bragg (Hallock and Fisher 1985). Regardless, the general consensus is that Sacramento River winter-run Chinook salmon, like all CV Chinook salmon, remain localized, primarily in California coastal waters.

Central Valley Spring-Run Chinook Salmon ESU

The CV spring-run Chinook salmon ESU is listed as threatened under the ESA and CESA. Federal and state listing decisions were finalized in September 1999 and February 1999, respectively. Critical habitat was designated on September 2, 2005 (70 FR 52489), and the spring-run ESU was re-listed as threatened in 2005 (70 FR 37160) following litigation challenging the listing decision. Critical habitat includes the mainstem Sacramento River to Keswick Dam and its major tributaries from Clear Creek downstream to the Delta. Critical habitat includes stream reaches such as those of the Feather and Yuba rivers; Big Chico, Butte, Deer, Mill, Battle, Antelope, and Clear creeks; the Sacramento River; and portions of the north Delta. Designated critical habitat includes the stream channel lateral extent, as defined by the ordinary high-water line. In areas where the ordinary high-water line has not been defined, the lateral extent is defined by the bankfull elevation. The bankfull elevation is defined as the level at which water begins to leave the channel and move into the floodplain; it is reached at a discharge that generally has a recurrence interval of 1 to 2 years on the annual flood series (Bain and Stevenson 1999; 70 FR 52488).

The CV spring-run Chinook salmon populations once occupied the headwaters of all major river systems in the Central Valley up to any natural barrier (Yoshiyama et al. 2001). The run was at least the second most abundant in the Central Valley before the twentieth century (CDFG 1998) and may have been the most abundant (NMFS 1997a). Central Valley river drainages are estimated to have supported spring-run populations as large as 600,000 fish in the early 1880s in the Sacramento–San Joaquin River basin. Runs were estimated to be between 127,000 and 600,000 during the late 1800s. A gill-net fishery in the Delta, established around 1850, targeted spring-run Chinook salmon because of their fresh appearance and high meat quality (Fisher 1994). Gill-net landings between 1881 and 1882 reportedly were in excess of 300,000 annually (CDFG 1998). Spring-run were the most commercially important Chinook salmon in the Central Valley until 1900 (Fisher 1994).

By the early part of the twentieth century, declines in spring-run Chinook salmon abundance became evident and likely were the result of the inland gill-net fishery, and habitat degradation and loss from mining, water diversion from construction, and dams (CDFG 1998). Approximately 72 percent or 1,066 miles of available salmon spawning, holding, and rearing habitat has been lost due to the construction of dams and barriers, and the dewatering of streams in the Sacramento–San Joaquin River basin (Yoshiyama et al. 2001).

The loss and degradation of habitat has diminished current annual escapement of CV spring-run Chinook salmon to between 5,000 and 15,000 adults (CDFG 2002). Numerous restoration efforts have been attempted, focused on spring-run recovery such as gravel augmentation and channel restoration on Clear Creek, improvement of fish passage with the construction or reconstruction of fish ladders, and dam removal on Mill, Deer, Butte, and Clear creeks. More recently, the San Joaquin River Restoration Program began a comprehensive long-term effort to restore flows and a self-sustaining spring-run Chinook salmon population between Friant Dam and the Merced River confluence, where the run has been extirpated since the early 1950s (Yoshiyama et al. 1998). Regulatory agencies also have negotiated agreements with hydroelectric plant operators and water agencies to increase flows during holding and spawning periods in mainstem river tributaries.

Adult CV spring-run Chinook salmon enter the Sacramento River between mid-February and July, with peak migration occurring in May (DFG 1998). Adults hold in deep, cold pools in proximity to spawning areas until they are sexually mature and ready to spawn in late summer and early fall (CDFG 1998). High spring flows caused by snowmelt allow access to the upper reaches of Sacramento River tributaries. The largest populations are found in Mill, Deer, and Butte creeks, and the Feather River; however, the Feather River population is primarily comprised of hatchery origin fish (Sommer et al. 2001). Clear and Cottonwood creeks also support populations of spring-run Chinook salmon, and small numbers have been observed intermittently in the recent past in other Sacramento River tributaries (CDFG 1998).

Survival of CV ESU spring-run Chinook salmon during summer is contingent on access to habitat that provides cool water temperatures. This habitat is found in mid- to high-elevation creeks or is provided in the lower tailwater sections of damned watersheds through cold water releases from dams. Access to historic habitat in the upper watershed of the Feather and Sacramento rivers, important to sustaining spring-run populations in these rivers, was eliminated by construction of small hydroelectric dams in the upper watersheds as well as construction of Oroville and Shasta dams. Conversely, the distribution of natural populations in Mill, Deer, and Butte creeks remains much the same as it was historically (CDFG 1998). Spring-run Chinook salmon may hold and spawn in the Sacramento River between the RBDD and Keswick Dam, but the number of these fish has declined substantially since the late 1980s. Since the early 1990s, the annual number of spawning adults in the mainstem Sacramento River has declined to a few hundred and as low as fifty. Hatchery operations and elimination of access to historic spawning habitat have fostered spatial and temporal overlap in spawn timing between spring-run and fall-run Chinook salmon in the Sacramento and Feather rivers. As a result, natural production by spring-run Chinook salmon has declined due to superimposition by later spawning fall-run that causes nest failure (CDFG 1998). In addition, temporal and spatial overlap in spawn timing between runs has led to genetic introgression, and the current genetic integrity of the CV spring-run salmon ESU is likely compromised.

The CV spring-run Chinook salmon spawn from mid-August through early October. Spawn timing varies by stream and elevation of holding fish. Fish that are holding in cooler, upper elevation reaches tend to begin spawning earlier (CDFG 1998). The NMFS and CDFW definition of the spring-run spawning period extends farther into fall than the historic spawning time. This may reflect hybridization (i.e., genetic introgression) between spring- and fall-run Chinook salmon (DWR and Reclamation 2000). Approximately 3 to 6 months elapse between egg deposition and fry emergence; the duration depends on water temperature. In Butte and Big Chico creeks, fry begin to emerge in November after an incubation period of approximately 3 months. In Mill and Deer creeks, where water temperature regimes are colder, incubation can occur over a 6-month period (CDFG 1998) because of the slower development of the eggs and fry.

Emigration timing is positively correlated to water flows with large numbers of juveniles emigrate during high flows while low flows may delay emigration (CDFG 1998). Some spring-run Chinook juveniles over-summer in natal streams and emigrate as yearlings (CDFG 1998). Juveniles primarily occur in the Delta from October through early May (CDFG 1998). Yearlings that have spent their first year rearing in natal tributaries tend to emigrate downstream in late fall and early winter. Young-of-the-year juveniles emigrate downstream in the first winter and spring following emergence. Young-of-the-year spring-run Chinook salmon tend to rear in the more upstream, freshwater portions of the Delta for approximately two months before moving downstream to the estuary (Kjelson et al. 1981). Little information is available concerning the residence of juvenile CV spring-run Chinook salmon in the estuary. MacFarlane and Norton (2002) concluded that unlike other salmonid populations in the Pacific Northwest, CV Chinook salmon show little dependence on estuaries after smoltification begins and may benefit from expedited ocean entry. MacFarlane and Norton (2002) found that juvenile Chinook salmon spent about 40 days rearing in the estuary and demonstrated little or no real estuarine dependence on growth or development.

Information on the ocean distribution of CV spring-run Chinook salmon is scarce. Available data are derived from ocean fisheries and are biased towards locations where ocean fisheries occur. The general consensus is that spring-run Chinook salmon, like all Central Valley Chinook salmon, remain localized primarily in California coastal waters.

California Central Valley Steelhead DPS

CV steelhead DPS was listed as threatened under the ESA in March 1998 (63 FR 53:13347–13371, March 19, 1998). The threatened status was reaffirmed on January 5, 2006 (71 FR 834). In 2010, NMFS conducted a 5-year status review, concluding that the biological status of this DPS had worsened and its ESA classification as a threatened species was appropriate (NMFS 2011b). CV steelhead DPS critical habitat was designated on September 2, 2005 (70 FR 170:52488–52627, September 2, 2005). Critical habitat includes the mainstem Sacramento River and its major tributaries from Clear Creek downstream to the legal Delta, Suisun Bay, San Pablo Bay, and San Francisco Bay north of the Bay Bridge, as well as the mainstem San Joaquin River south to the Merced River, and much of the Delta and Estuary. Critical habitat includes the river, river bottom, and adjacent riparian zones. Riparian habitat is defined as the ordinary high water mark or other bank-full elevation where water leaves the stream channel and enters the floodplain. Riparian zones are considered essential for the conservation of CV steelhead because they provide important rearing habitat.

CV steelhead is the anadromous form of stream-resident rainbow trout. Distribution throughout the Central Valley has been greatly reduced due to the construction of dams for hydroelectricity, water diversion, and storage. The range of CV steelhead in the Sacramento River drainage likely was as extensive as that recorded for Chinook salmon and likely stretched farther into headwater reaches (Yoshiyama et al. 2001). CV steelhead currently is present in the Sacramento River downstream from Keswick Dam and in the major rivers and creeks in the watershed. Major populations are present in Battle, Mill, Deer, and Butte creeks. Other populations occur in many of the smaller tributaries, including Stony and Thomes creeks (Yoshiyama et al. 2001; McEwan 2001). The tributary creeks support naturally spawning populations, although Battle Creek populations are augmented by Coleman National Fish Hatchery. In the San Joaquin Valley system, naturally producing populations are found in the eastside watersheds and the mainstem San Joaquin River upstream possibly to Friant Dam when flows are suitable.

Life history traits of CV steelhead are similar to that described for Chinook salmon. However, steelhead is iteroparous, thus capable of spawning across multiple years before dying (Barnhart 1986; Busby et al. 1996). Nevertheless, it is rare for CV steelhead to spawn more than twice before dying; most that do so are females (Busby et al. 1996). Iteroparity is more common among southern steelhead populations than northern populations (Busby et al. 1996). Although one-time spawners are the great majority, Shapovalov and Taft (1954) reported that repeat spawners are relatively numerous (17.2 percent) in California streams. Steelhead are divided into two life history types, summer-run steelhead and winter-run steelhead, based on timing of freshwater entry, state of gonad development at freshwater entry, and the duration of the spawning migration. Summer-run steelhead enter freshwater with immature gonads and must spend several months holding in pools while gonads mature before they spawn. Winter-run steelhead gonads are mature at freshwater entry; individuals spawn fairly soon after entering freshwater (McEwan 2001). Currently, only winter-run steelhead are present in Central Valley streams (McEwan and Jackson 1996), although there are indications that summer-run steelhead were historically present in the Sacramento and San Joaquin river systems. Summer-run steelhead are present only in North Coast California drainages, mostly in tributaries of the Eel, Klamath, and Trinity river systems (McEwan and Jackson 1996).

Historic populations of CV steelhead were estimated to have been between 1 and 2 million adults (McEwan 2001). Annual escapement in the 1960s was estimated at approximately 26,000 adults (CDFG 1996). Counts at RBDD showed obvious declines in escapement to the upper Sacramento River between 1967 and 1993. Current escapement data are not available for naturally spawned CV steelhead, mainly because of the more frequent gates-out operations at RBDD after 1993 and the lack of monitoring programs elsewhere in the Central Valley (CDFG 1996). The majority of CV steelhead historical spawning habitat is now inaccessible due to dam construction; an estimated 80 percent of the spawning habitat in the Central Valley has been blocked because of power and irrigation dams (CDFG 1996; McEwan 2001).

Adults generally enter freshwater from August through April (Busby et al. 1996; NMFS 2014) and spawn from December through at least April. Peak spawning occurs from January through March in small streams and tributaries where cool, well oxygenated water is available year-round (Hallock et al. 1961; McEwan and Jackson 1996). Spawning typically occurs fairly soon after freshwater entry. Spawning habitat is characterized as streams with gravel or cobble substrates, moderate current, and water depths between 6 and 24 inches (Reiser and Bjornn 1979). Substrates containing small amounts of silt and sand (less than or equal to 5 percent) are important for successful spawning (CDFG 1996). Optimal water temperatures for spawning are between 48°F and 52°F (Bjornn 1971; Bjornn and Reiser 1991). Eggs usually hatch within four weeks, depending on water temperature (CDFG 1996; Moyle 2002). Fry remain in gravels for approximately four to six weeks before emergence (CDFG 1996).

Following emergence, juveniles inhabit shallow areas along stream margins and appear to prefer areas with cobble substrates (CDFG 1996). A variety of additional habitats are used as fish grow older (CDFG 1996). Habitat use is affected by the presence of predators, and juvenile CV steelhead survival increases when cover (e.g., woody debris and large cobble) is present (Mitro and Zale 2002). Estuaries can be important rearing areas for juvenile CV steelhead, especially in small coastal tributaries (CDFG 1996). Summer water temperatures are moderated by the marine influence of nearby San Francisco Bay and the Pacific Ocean (Lindley et al. 2006). Because of this, estuarine residence time tends to be longer for CV steelhead than for other salmonids. Pumping operations of the CVP and SWP can have detrimental impacts on smolt escapement to the ocean during estuarine residency (CDFG 1996). Juvenile CV steelhead typically rear in freshwater for 1 to 3 years before emigrating to the ocean (CDFG 1996).

The timing of smolt emigration varies widely. Smoltification and emigration does not necessarily occur at a set age or season, and may not occur at all (CDFG 1996). Some individuals rear, mature, and spawn in freshwater without ever emigrating to the ocean. Others emigrate at less than a year old, and some return to freshwater after spending less than a year in the ocean (CDFG 1996). Attempts to classify CV steelhead into seasonal runs have led to confusion rather than clarification (Lindley et al. 2006; McEwan 2001; DFG 1996). Hallock et al. (1961) reported that juvenile CV steelhead migrated downstream during most months of the year with peak emigration occurring in spring, followed by a much smaller peak in fall. The emigration period for naturally spawned CV steelhead smolts migrating past Knights Landing on the lower Sacramento River in 1998 ranged from late December through early May and peaked in mid-March (McEwan 2001).

2.2.2.2 SALMONID EMIGRATION THROUGH THE DELTA

Juvenile and smolt emigration to the Pacific Ocean through the Delta, which includes all Central Valley Chinook salmon and steelhead runs, occurs year round, depending on the particular species and run (Vogel 2011; NMFS 2014; unpublished data CDFW and USFWS). Emigration tends to occur in groups and pulses, and pulse timing may be correlated to increased flow events (Vogel 2011). Kjelson et al. (1982) and Vogel (1982) reported increased downstream movements of Chinook salmon fry corresponding to increased river flows and turbidity. Many complex and poorly understood variables and consequent interactions influence the migratory behavior of juvenile Chinook salmon (Kreeger and McNeil 1992). Abiotic factors that may have primary influence on juvenile salmon migration include photoperiod, date, water temperature, and flow. Other abiotic or biotic factors which may affect migration include barometric pressure, turbidity, flooding, rainfall, wind, species, life history stage, degree of smoltification, parental origin (e.g. hatchery or wild), size of juveniles, location (e.g. distance from ocean), and food availability (Vogel 2011).

Juvenile Chinook salmon movements are dictated by tidal cycles in estuarine habitat. Juveniles follow rising tides into shallow water habitats and return to deep, main channels when tides recede (Levy and Northcote 1982; Livings et al. 1986; Healey 1991). Juvenile Chinook salmon tend to school in surface waters of main and secondary channels and sloughs as they grow in length, and they follow tides into shallow water habitats to feed (Allen and Hassler 1986). Moyle et al. (1989) reported that in Suisun Marsh, Chinook salmon fry had a tendency to remain close to channel banks and vegetation, near protective cover, and in dead-end tidal channels. Kjelson et al. (1982) reported that juvenile Chinook salmon demonstrated a diel migration pattern, occupying near shore cover and structure during the day and moving into more open, offshore waters at night. These fish also distributed themselves vertically in relation to ambient light. At night, juveniles were distributed randomly in the water column and, during the day, would school into the upper 10 feet of the water column. Available data indicate that juvenile Chinook salmon use Suisun Marsh extensively during emigration as a migratory route and rearing habitat.

Studies indicate that juvenile fall-run Chinook salmon spend about 40 days migrating through the San Francisco Bay Estuary and grow little in length or weight until they reached the Gulf of the Farallons (MacFarlane and Norton 2002). This estuarine migration was measured starting at Chipps Island, and does not include the period of time fish may have spent rearing in the lower salinity habitats in the Delta. Based on the mainly ocean-type life history observed (i.e. fall-run), MacFarlane and Norton (2002) concluded that unlike other salmonid populations in the Pacific Northwest, Central Valley Chinook salmon showed little estuarine dependence and may benefit from expedited ocean entry.

The Delta is a vast and complex system of channels and bypasses. Fish have multiple route options during emigration down the Sacramento and San Joaquin rivers to the Pacific Ocean. Route selection through the Delta by emigrating juvenile salmonids is correlated with survival. Each route presents unique characteristics that could be beneficial or detrimental to survival and growth (Vogel 2011). Studies using coded wire-tagged fish have shown that juvenile salmon using Steamboat Slough or Sutter Slough generally exhibit higher survival than fish exposed to the Delta Cross Channel (DCC) and Georgiana Slough (Kjelson and Brandes 1989; Vogel 2011). Studies using coded wire-tagged fry- and smolt-sized Chinook salmon have demonstrated that fish survival is lower in the central Delta compared to the north Delta (Vogel 2011). Emigrating juveniles selecting routes through the central and south Delta are exposed to a number of adverse conditions that likely lower survival rate. Studies of juvenile Chinook salmon emigration from the Sacramento River basin have shown mortality of approximately 65 percent for fish selecting routes through the interior and south Delta, a considerably higher loss than for fish remaining in the mainstem Sacramento River (Perry 2010). Movement and/or diversion of juvenile salmonids into the interior and south Delta increases the likelihood of mortality through predation, entrainment into non-project Delta diversions, and loss associated with the CVP and SWP pumping facilities in the south Delta (Perry 2010; NMFS 2009a).

2.2.2.3 Other Fish Species of Concern

Green Sturgeon

The DPS delineations are based on the rivers in which green sturgeon spawn and results from preliminary genetic studies. NMFS identified two green sturgeon DPSs: the Northern and Southern, and listed the later as threatened on April 7, 2006 (71 FR 17757). Additionally, Southern DPS green sturgeon are listed by CDFW as a California Species of Special Concern. The listing of the Northern DPS under CESA was assessed but was determined to be unwarranted. Critical habitat was designated for the Southern DPS on October 9, 2009 (74 FR 52300).

The Southern DPS includes all green sturgeon populations south of the Eel River. Green sturgeon are distributed throughout San Francisco Bay and its associated river systems; this population represents the southern-most spawning population. Juveniles are found throughout the Delta and San Francisco Bay Estuary. The species also occurs in the coastal waters of the Pacific Ocean off California and in coastal rivers. Small numbers have been documented in Tomales (Marin County) and Bodega (Sonoma County) bays. Small numbers of adults and juveniles have been observed in the Eel River (Humboldt County) and fertilized eggs were collected in the Feather River in 2011 indicating that successful spawning has occurred in that river system. No documentation exists of green sturgeon spawning in the San Joaquin River, although due to the watershed's characteristics, it is plausible that they did inhabit the watershed at one time. Juveniles have been occasionally collected in the Santa Clara Shoal area in the San Joaquin River, but it is speculated that they originated from the Sacramento River (NMFS 2003).

The Southern DPS green sturgeon population size is not known but is considered substantially smaller than that of the Northern DPS (NMFS 2003). During tagging studies by CDFW, the majority of sturgeon captured were white sturgeon, and an average of one adult green sturgeon was captured for every 134 adult white sturgeon; adult green sturgeon abundance appears to be much lower than adult white sturgeon abundance. In addition, preliminary genetics information supports the notion that green sturgeon population densities are low in the Sacramento River system; fewer than 20 green sturgeon that spawned upstream of RBDD contributed to juvenile production in 2003 and 2004 (NMFS 2003). Although no direct evidence shows that populations of green sturgeon are declining in the Sacramento River, the small population size increases the risk that a decline in numbers would be difficult to detect until a collapse occurred. The population is threatened by habitat loss and degradation, lethally high water temperatures, entrainment in water diversions, and exposure to toxic materials (Moyle et al. 1995).

Green sturgeon are slow growing and well-adapted for benthic feeding. In the Delta, juveniles feed on opossum shrimp (*Neomysis mercedis*) and amphipods (*Corophium* sp.). Adult diets include shrimp, mollusks, amphipods, and small fish (NMFS 2003). Adults can grow to be 386 pounds and 106 inches long, but do not often exceed 198 pounds and 39 inches in the Delta (Moyle 2002). Females typically become sexually mature at 13 to 27 years of age and at a total body length (TL) ranging between 57 and 81 inches (Nakamoto et al. 1995; Van Eenennaam et al. 2006). Male green sturgeon sexually mature at a younger age and shorter length. Male green sturgeons typically sexually mature between 8 and 18 years of age and have a TL ranging from 47 inches to 73 inches (Nakamoto et al. 1995; Van Eenennaam et al. 2006). Variation in size and age at sexual maturity is a reflection of growth and nutritional history, genetics, and exposure to environmental conditions during early growth years (Nakamoto et al. 1995; Van Eenennaam et al. 2006).

Green sturgeon show fidelity to spawning sites (Bemis and Kynard 1997) and return to freshwater to spawn about every two to five years (Beamesderfer and Webb 2002; Moyle 2002; NMFS 2003). Females produce between 60,000 and 140,000 eggs, depending on body size, with a mean egg diameter of 0.17 inch (Moyle et al. 1992; Van Eenennaam et al. 2001). Green sturgeon has the largest egg size of any sturgeon species, and the volume of yolk provides an ample supply of energy for the developing embryo. The outside of the eggs are adhesive and denser than those of white sturgeon (Kynard and Parker 2005). Spawning occurs from March through July and peaks from mid-April through mid-June (Moyle 2002). Spawning habitat is characterized as turbulent, mainstem channels that host large cobble and rocky substrates with crevices and interstices. Green sturgeon are broadcast spawners; females release eggs into the water column over suitable spawning substrates while males release milt. Fertilization occurs externally in the water column, and the fertilized eggs sink into the substrate interstices where they incubate and hatch (Kynard and Parker 2005). Spawning has been documented in the Sacramento and Feather rivers within the Sacramento River watershed system. On the Sacramento River, spawning occurs upstream from Hamilton City (Glenn County) and possibly as far upstream as Keswick Dam (Shasta County) (CDFG 2002). Prior to the 2009 Long-Term Operational Criteria and Plan RPA to open the gates for longer periods, opening the RBDD gates during the winter-run Chinook salmon migration has likely benefited green sturgeon by allowing access to additional, quality spawning habitat (NMFS 2002). The gates are now open year round. A number of larval and post larval green sturgeon up to 16 inches in length are captured each year in rotary screw traps at the RBDD on the Sacramento River; however, no larvae have been captured in any of the upper tributaries, suggesting that spawning occurs in the mainstem (Beamesderfer et al. 2004).

Fertilized green sturgeon eggs were recovered from the Feather River during monitoring activities in 2011, following a high water year. In addition, the presence of larval green sturgeon in salmon out-migrant traps on the Feather River has been reported. Egg and larvae captures suggest that the Feather River may support a spawning green sturgeon population (Environmental Protection Information Center et al. 2001). Green sturgeon may have spawned elsewhere in the Sacramento–San Joaquin river basin before the development of major hydroelectric and water projects (NMFS 2002) The impediment to upstream migration in lower flows at Shanghai Bend blew out a couple of years ago which should make it easier for adults to move farther upstream to spawn in lower flow conditions.

Green sturgeon has a complex anadromous life history and is the most widely distributed and most marine-oriented member of the sturgeon family Acipenseridae (Moyle 2002). The species spawns in freshwater in the Sacramento Valley and returns to San Francisco Bay and near-shore marine waters to feed and mature. USFWS estimated that green sturgeon spawn in the Sacramento River between April and July, and that spawning occurs about 20 river miles upstream and nine river miles downstream from the RBDD (Poytress et al. 2009). The upper and lower extent of the spawning area on the Sacramento River is not known definitively, but the lower extent is thought to be in the vicinity of Hamilton City. The upper extent may be limited by cold water temperatures in the Redding area. In the laboratory, embryos thrived at water temperatures between 62°F and 64°F; hatching rates and the length of embryos began to decrease at 57°F (Van Eenennaam et al. 2005). Egg depths (using artificial substrate mats) ranged from two to 25 feet, with an average depth of 15 feet (Poytress et al. 2009). The dominant substrate was medium-sized gravel in areas where eggs were found.

Water temperatures above 68ºF are lethal during the incubation life stage (Cech et al. 2000). Eggs hatch in about seven to nine days at 59ºF, and larvae develop into juvenile fish in about 45 days (Van Eenennaam et al. 2001). USFWS found green sturgeon juveniles to be much less common in rotary screw traps in years having low flows in spring. This may be because fewer adults migrate upstream and spawn in low flow years (Poytress et al. 2009).

In the laboratory, Klamath River hatchlings preferred cover, were poor swimmers, and could not move farther than one to two inches to cover. For this reason, females may be adapted to depositing eggs in places along the stream bottom that provide cover for early life stages. Larvae do not exhibit the initial pelagic swim-up behavior that is characteristic of other Acipenseridae. They are strongly oriented to the bottom and exhibit nocturnal activity patterns. Larvae exhibit nocturnal swim-up activity and nocturnal downstream migrational movements approximately 6 days following hatching (Deng et al. 2002; Kynard and Parker 2005). Juvenile fish continue to exhibit nocturnal behavior beyond the metamorphosis from larvae to juvenile stages and continue to migrate downstream at night for the first 6 months of life (Kynard and Parker 2005). Juveniles appear to prefer deep pools with low light and rock structure (Kynard and Parker 2005). Downstream migrational behavior diminishes and holding behavior increases when ambient water temperatures reach 46.4°F. Thus, 9 to 10-month-old juveniles may hold in natal rivers during the first winter at a location downstream from spawning grounds. Mayfield and Cech (2004) found that water temperatures between 59ºF and 66ºF were optimal for bioenergetic performance of green sturgeon juveniles. Growth is substantially impaired once water temperatures become as warm as 75ºF. Spring and summer water temperature management for winter-run Chinook salmon in the Sacramento River likely have improved conditions for larval green sturgeon (NMFS 2003).

Juveniles spend from one to three years rearing in fresh and brackish water before emigrating to the Pacific Ocean. Optimal water temperatures for rearing is 57°F to 61°F (Mayfield and Cech 2004), and optimal salinities range from 10 parts per thousand (ppt; mesohaline) to 33 ppt (euhaline). Green sturgeon are approximately one to 2.5 feet long at ocean emigration (Moyle et al. 1995; Beamesderfer and Webb 2002). They disperse widely throughout the ocean and have been detected between Baja California, Mexico and the Bering Sea (Erickson et al. 2002; Moyle 2002). Bays and estuaries of non-natal rivers are frequented during summer and early fall (Moser and Lindley 2007). In the ocean, green sturgeon typically occupy water less than 328 feet deep (Erickson and Hightower 2007).

Larval and juvenile green sturgeon are susceptible to entrainment in pumps and diversions in the Delta and other waterways. Juvenile green sturgeon interacted with fish exclusion screens more frequently than white sturgeon of the same size and behave differently. Additionally, green sturgeon showed increased contact with screens as flow velocity increased (Poletto et al. 2014). Screens designed to protect Chinook salmon, steelhead and white sturgeon may not protect green sturgeon. However, larval and juvenile behavior may preclude encounters with diversions and pumps. For example, larval and juvenile sampling conducted at the RBDD experimental pumping plant (Borthwick and Weber 2001) indicated that entrainment of green sturgeon is rare.

Delta Smelt

Delta smelt was listed as threatened under the ESA on March 5, 1993 (58 FR 12854). A petition seeking to relist delta smelt as endangered was submitted to USFWS in July 2008 (73 FR 39639). The proposal remains under review (75 FR 17667). In June 2007, the California Fish and Game Commission accepted a petition to change the status of delta smelt from threatened to endangered under CESA. On January 20, 2010, delta smelt was officially listed as endangered under CESA. Critical habitat for delta smelt was designated by USFWS on December 19, 1994 (59 FR 65256) and includes much of the Delta and estuary. Critical habitat is defined as areas and all water and all submerged lands below ordinary high water and the entire water column bounded by and contained in Suisun Bay (including the contiguous Grizzly and Honker bays); the length of Goodyear, Suisun, Cutoff, Mallard (Spring Branch), and Montezuma sloughs; and the existing contiguous waters contained within the Delta. Primary constituent elements are physical habitat, water, river flow, and salinity concentrations required to maintain delta smelt habitat for spawning, larval and juvenile transport, rearing, and adult migration (59 FR 65279).

Delta smelt is endemic to the Bay–Delta estuary and is restricted to the area from San Pablo Bay upstream to Verona (Sutter County) on the Sacramento River and Mossdale (San Joaquin County) on the San Joaquin River (Moyle 2002). The species once was one of the most common fish species in the Delta (Moyle 2002); however, delta smelt, along with other pelagic fish species, has experienced a substantial decline in population abundance in recent decades. Substantial declines in delta smelt abundance indices in recent years, as well as declines in the abundance of other pelagic fish species, have led to widespread concern regarding the pelagic fish community of the Bay–Delta estuary. Ongoing analyses have focused on identifying factors potentially influencing the status and abundance of delta smelt and other pelagic fish species in the estuary. Environmental and biological factors affecting the abundance of delta smelt in the Delta include the following (Moyle 2002):

- Changes in the seasonal timing and magnitude of freshwater inflow to the Delta and outflow from the Delta;
- Impingement and entrainment of larval, juvenile, and adult delta smelt at numerous unscreened water diversions (primary agricultural) located throughout the Delta;
- Impingement, entrainment, and salvage mortality at CVP and SWP water export facilities;
- Predation by striped bass, largemouth bass, and other fish species inhabiting the estuary;
- Toxic substances and variation in the quality and availability of low-salinity habitat in the Delta and Suisun Bay, in response to seasonal and inter-annual variability in hydrologic conditions in the Delta; and
- Reduced food (prey) availability related to reduced primary production, which is related, in part, to a reduction in seasonally inundated wetlands, competition for food resources with non-native fish and macroinvertebrates, and competition among native and non-native zooplankton species.

Delta smelt are relatively short (two to four inches long) and have a one year life cycle, although some individuals may live two years and reach lengths of 3.5 to 4.7 inches. Juveniles and adults are pelagic and typically inhabit open waters of the Delta, away from the bottom and shore-associated structural features (Nobriga and Herbold 2008). Occurrence is primarily in or just upstream from the mixing zone between the fresh and salt water interface in the estuary. Suisun Bay usually is the vicinity of this mixing zone, although changes in stream flow can affect how far downstream low salinity waters occur (Moyle 2002). Delta smelt can tolerate a wide range of salinities; however, salinity requirements vary by life stage (Moyle 2002).

Delta smelt spends its entire life within the Delta and estuary. Abundance and distribution fluctuate substantially within and among years. Distribution and movements of all life stages are influenced by water transport associated with flows, which also affect the quality and location of suitable open-water habitat (Dege and Brown 2004; Nobriga et al. 2008). Delta smelt are short burst swimmers that feed on plankton, and therefore are typically found in low water velocity habitats where the water is cool and well oxygenated (Moyle 2002). Water turbidity and salinity also affect distribution.

Beginning in September or October (Moyle 2002), adult delta smelt may tend to move eastward toward fresher water (Sommer et al. 2011) continuing the migration during winter to prepare for spawning. Spawning occurs between February and July with peak spawning occurring from April through mid-May (Moyle 2002). Delta smelt spawn in shallow, fresh, or slightly brackish water upstream from the mixing zone (Wang 1991). Most spawning occurs in tidally influenced backwater sloughs and channel edgewaters in the north and west Delta (Moyle 1976, 2002; Wang 1986, 1991; Moyle et al. 1992). Spawning takes place mostly at night during forays into shallow water, where demersal, adhesive eggs are broadcast onto littoral cover such as submergent vegetation or gravel (Moyle 2002). Water temperatures that are suitable for spawning range from 44.6°F to 59°F (Moyle 2002). Embryonic development to hatching takes nine to 13 days at 57°F to 61°F (Moyle 2002). Eggs hatch, releasing planktonic larvae that are passively dispersed downstream by river flow. Optimal water temperatures for embryo and larva have not yet been determined, but survival likely decreases as water temperature increases above 64.4°F (Moyle 2002). Delta smelt have a large fat reserve, much of it in a globule, and therefore they are neutrally buoyant. This buoyancy makes it possible for themto maintain position near the substrate. There they feed on microscopic prey, e.g. rotifers (Moyle 2002). Larvae become more buoyant as the swim bladder develops and rise up higher in the water column. At a length of approximately 0.6 to 0.7 inch total length, juveniles become part of the planktonic drift and are dispersed passively downstream to rearing areas in the western Delta, Suisun, Honker, or Grizzly bays. This area has high primary productivity and is where zooplankton populations (on which delta smelt feed) usually are most dense (Knutson and Orsi 1983; Orsi and Mecum 1986).

Juvenile and adult delta smelt are most abundant in the central and west Delta during winter and early summer, as is reflected in CVP and SWP fish salvage records. Juveniles and adults typically do not inhabit the south Delta during summer when water temperatures exceed approximately 77°F. High water clarity tends to keep delta smelt out of the south Delta during fall (Nobriga et al. 2008; Feyrer et al. 2007). Larvae and juveniles rear in the estuary for six to nine months before beginning the upstream spawning movement into freshwater areas of the lower Sacramento and San Joaquin rivers. Adults generally mature in spring, spawn, and die by summer. Growth is rapid and juveniles are 1.6 to 2.0 inches total length by early August (Erkkila et al. 1950; Ganssle 1966; Radtke 1966). Juveniles require shallow, food-rich rearing habitat for survival. Adequate flow and suitable water quality is required for adult access to spawning habitat and transport of juveniles to estuarine rearing habitat (Moyle 2002). Estuarine rearing habitat for juvenile and adult delta smelt typically is found in the waters of the lower Delta and Suisun Bay where salinity is between two and seven ppt.

Delta smelt are most likely to be affected at the five study sites considered here at two life stages: upstream migrating adults that are preparing to spawn and larvae and juveniles that are migrating back to the western Delta and Suisun Bay and surrounding environs. For both of these life stages, the period of greatest potential influence for the five study sites are October to June when the spawning migration occurs (Sommer et al. 2011) and the migration of young back toward rearing areas in the western Delta (Moyle2002). During this period, October to June, changes to flow patterns that send a greater proportion of water toward major diversion points in the southern Delta (CVP and SWP intakes) would tend to increase entrainment of delta smelt into the CVP and SWP systems. Previous Engineering Solutions and Outcomes

As part of the Phase II process, multiple studies were conducted to deter juvenile salmonids from entering Georgiana Slough and the HOR and to retain juvenile salmonids in the mainstem of the San Joaquin and Sacramento rivers during their emigration to the Pacific Ocean. Results from these studies are presented in the Phase I Initial Findings and in Section 3.3, “Field Testing of Engineering Options.”

Studies conducted at Georgiana Slough since 1993 have included rock barriers, non-physical acoustic barriers, and physical barrier treatments. Studies and ongoing implementation of a rock barrier at the HOR began in 1963. More recently, an updated non-physical barrier known as a BAFF was studied in 2009 and 2010 at the HOR Reclamation 2012a, b, and in 2011 (DWR 2012) and 2012 at Georgiana Slough (DWR 2014c in prep.). In 2014, a study of a physical barrier known as an FFGS was conducted at Georgiana Slough (DWR 2014a in prep.). The 2014 study at Georgiana Slough was conducted directly in response to the Action.

2.2.3 ENGINEERING OPTIONS EVALUATED

Many different options were identified during Phase I and have been considered and evaluated in the Phase II process. Each option was categorized by being either physical or non-physical. The engineering alternatives that use structural components as the primary deterrence were considered to be physical barriers. The alternatives that use behavioral stimuli to guide fish were considered to be non-physical options.

2.2.3.1 PHYSICAL BARRIERS

Physical barriers rely on human-made or natural materials such as steel or rocks to keep fish out of undesirable areas. The alternatives that have been evaluated in Phase II include fish screens, operable gates, rock barriers, and the FFGS. Physical barriers disrupt the existing flow patterns but can provide more dependable deterrence, depending on the associated operational strategy.

Fish Screen

Fish screens are physical barriers designed to protect fish from being entrained into a diversion while allowing for the passage of water. A wide variety of designs have been used for fish protection, the most common of which are the vertical flat plate, drum or rotating, traveling, and horizontal flat plate screens. Each of these designs has been developed based on the fish species of interest, hydraulics, other site specific conditions, and regulatory requirements (Reclamation 2006).

Description

Fish screen design depends on the physiological and behavioral characteristics of the targeted fish species, including age, size, behavior, and swimming ability. Fish screens are highly effective for deterring fish, but hydraulic conditions must be considered to prevent fish injury or mortality from impingement on the screens or delay in migratory passage. For example, if smaller, weaker swimming fish are targeted, then the opening sizes for fish screens and approach velocities (i.e., water velocity vector component perpendicular to the screen face) must be reduced to prevent fish impingement and injury on the screen. Fish screens typically are used in areas where the flows and velocities are relatively predictable and consistent. Fish screens are set at an angle to the flow to reduce the flow velocity normal (90 degrees) to the screens to safe levels for fish and establish flow parallel to the screen to guide fish past the screen with appropriate sweeping velocities. A uniform velocity distribution should be maintained over the screen surface to minimize approach velocities. To maintain uniform velocity, adjustable porosity control or baffles on the downstream side of screens and/or flow training walls may be installed (Reclamation 2006). If screens are oriented normal (perpendicular) to the channel flow, the fish tend to hold in front of or are impinged on the screen. Fish screens can be highly susceptible to debris fouling and sediment deposition. Cleaning mechanisms and sediment control devices typically are included in the design.

CDFW and NMFS developed a set of criteria to protect fish passing a screen (CDFW 2013). The screens must be designed to meet current regulatory criteria for salmon, steelhead, and delta smelt as established by CDFW, NMFS, and USFWS. Some of the criteria set forth by these agencies address issues such as structure placement, approach velocity, sweeping velocity (i.e., water velocity vector component parallel and adjacent to the screen face), screen opening dimensions, and other construction and operational concerns. The following is a summary of agency criteria for designing fish screens in California (NMFS 1997b):

Uniform approach velocity must be provided across the face of screen. Approach velocity must be less than 0.33 feet/second where USFWS has selected a 0.20 feet/second approach velocity where delta smelt are present. The screen must be sloping parallel to river flow to minimize fish injuries. Upstream and downstream transitions must minimize eddies for potential predators habitat. Sweeping velocity must be at least two times the approach velocity, and exposure time to the screens must be less than 60 seconds unless a juvenile fish bypass system is provided. Screen cleaning mechanism must be in placed to clear debris from the screen automatically, as necessary to prevent accumulation of debris. If the screen is made from woven wire perforated plate, the screen opening size must not exceed 3/32 inch (2.38 millimeters); otherwise, the screen opening must not exceed 0.0689 inch (1.75 millimeters). Screen material shall provide a minimum of 27 percent open area. The screen must be constructed of non-corrosive rigid material without sharp edges.

Background

As noted, many types of fish screens are available and in use. However, vertical flat plate screens are the only type that would possibly work at the proposed locations because they do not require a controlled operating water depth as needed for other types of screens. Vertical flat plate screens are not limited to relatively small diversions as other screen types. For example, drum screens are applicable only to sites with well-regulated and stable water surface elevations, such as canals and in-diversion pools where water surface elevation can be controlled. Horizontal flat plate screens are only applicable to relatively small diversion (less than 100 cfs) (Reclamation 2006).

Vertical flat panel screens are made up of several flat panels mounted side by side and placed at an angle to the approach flow. The screen is fixed; it does not move and must be in place in such a way that a relatively uniform approach and sweeping flow occurs across the full length of the screen. The screen depth and area of coverage depends on the geometry of the waterway and the limitations of the systems components. Vertical fish screens are normally designed with either self-cleaning or automatically operated screen cleaners. However, fish protection criteria state that screens are to be automatically cleaned as frequently as necessary. This is to prevent debris accumulation that impedes flow and violates approach velocity criteria. The cleaning system and protocol must be effective, reliable, and satisfactory to regulatory agencies (Reclamation 2006, 2009a). Examples of vertical flat plate screen installations are discussed next.

Tehama-Colusa Canal Authority: Red Bluff Pumping Plant and Fish Screen

The Red Bluff Pumping Plant and Fish Screen are located on the west bank of the Sacramento River near the City of Red Bluff. The screen is 1,100 feet long with a diversion capacity of 2,500 cfs. The facility provides irrigation to the west side of the Sacramento River valley (Reclamation 2009b). Figure 2-6 shows an aerial view of the Red Bluff Pumping Plant and Fish Screen.

Source: Tehama Colusa Canal Authority 2014

Figure 2-6. Red Bluff Pumping Plant and Fish Screen

Glenn Colusa Irrigation District

Glenn Colusa Irrigation District's (GCID's) Hamilton City Pump Station is approximately 100 miles north of the City of Sacramento. GCID diverts a maximum of 3,000 cfs of river flow from the Sacramento River. Diverted flow passes through a 1,100-foot-long fish screen structure, and a portion of it is pumped into GCID's main irrigation canal. The remaining flow passes by the screens and then back into the mainstem of the Sacramento River (GCID 2013). Figure 2-7 shows an aerial view of the GCID fish screen.

Source: Glen Colusa Irrigation District 2014

Figure 2-7. Glenn Colusa Irrigation District Fish Screen

City of Stockton, Department of Municipal Utilities

The City of Stockton's Delta Water Supply Project and Pumping Facility is located at the southwest tip of the Empire Tract, adjacent to the Stockton Deep Water Ship Channel. The project diverts water from the Delta for treatment and distribution to the City of Stockton metropolitan area. The intake structure is designed for a maximum 124 cfs flow rate. The screen is about 37 feet long and 21 feet high (HDR 2007). Figure 2-8 shows the City of Stockton Pumping Facility's fish screen.

Source: DWR.2014

Figure 2-8. City of Stockton Pumping Facility Fish Screen

Advantages

As with all physical barriers, fish screen performance has been widely applied and proven. The key advantage of using a fish screen technology is that it provides high fish deterrence while allowing flows to pass. Better deterrence would be achieved by having a full column instead of a partial column fish screen.

Other advantages of fish screens are that they can be designed to provide a barrier for different fish species and their life stages.

Disadvantages

One possible disadvantage is that a full column fish screen may not be feasible because of adult upstream fish migration unless a fish ladder is incorporated. One alternative is to consider a partial column screen to allow passage for adult fish. However, this option may not provide the maximum deterrence that a full column screen would provide.

Another drawback with this technology is that to meet the required maximum approach velocity criteria of 0.33 feet per second on channel, the surface area of the screen face can be massive because of high flow events (e.g., 100-year flood events) and shallow water elevations. This may not be realistic or feasible at some of the proposed locations.

As with all physical barriers, the fish screen technology does affect or impact river flow. A large amount of system structure would be placed into the water, thus potentially affecting local and regional hydraulic patterns.

Another disadvantage associated with this type of technology is the potential for debris accumulation. Debris may obstruct or damage parts of the screen, which potentially could lead to minimizing the effectiveness of the system. Therefore, CDFW and NMFS screening criteria may not always be met. Debris issues would require constant monitoring and maintenance to assure that the system is working properly.

Boat navigation also may be affected. Some type of boat lock may be necessary to accommodate recreational boat passage.

Typically, a screen is built with one alignment for one location. In waterways where there are dynamic hydraulics such as reversing flow, there would be potential for fish impingement.

Overflow Gate

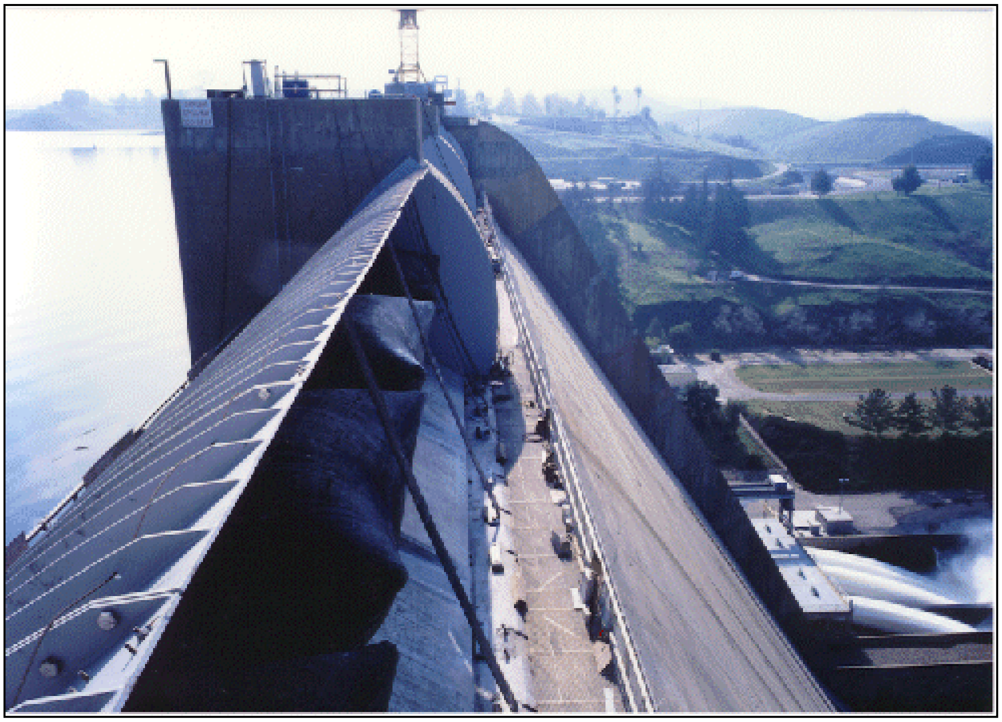
Overflow gates are physical barriers used around the world for flood control, agricultural and drinking water storage, recreation, water quality improvements, and fish guidance. An overflow gate typically is a bottom-hinged gate, and its non-hinged side is raised to control water flow. An overflow gate can be used to deter fish in a portion of or the entire water column.

Description

An overflow gate allows the passage of water, from zero to 100 percent. This type of gate typically is bottom-hinged and includes steel face plates and mechanisms to push them into position. Air bladders or hydraulic arms generally are used to force the gates into the desired position. When the gate is fully open, the gate lies flat on the bottom of the waterway, allowing 100 percent of the water to pass. When the gate is fully closed, blocking 100 percent of the water, the non-hinged side of the gate is raised to an elevation that exceeds the water surface elevation. The gate can be operated to accommodate a range of flows by adjusting the elevation of the gate between fully open and fully closed. An example of a bottom-hinged overflow gate is shown in Figure 2-9.

An overflow gate barrier system can include multiple gates, operated together or individually to meet specific site goals. An overflow gate can be used as a fish deterrent by redirecting the water and the fish simultaneously.

Numerous designs are available to construct and operate this type of gate. Previous designs have incorporated hydraulic arms or air bladders to control the gate position. These mechanisms force the gate up at an appropriate angle to achieve the desired effect. This type of gate can be operated to maintain constant water surface elevation upstream from the gate or can be used to provide constant flow on the downstream side of the gate.



Source: Gracom 2013

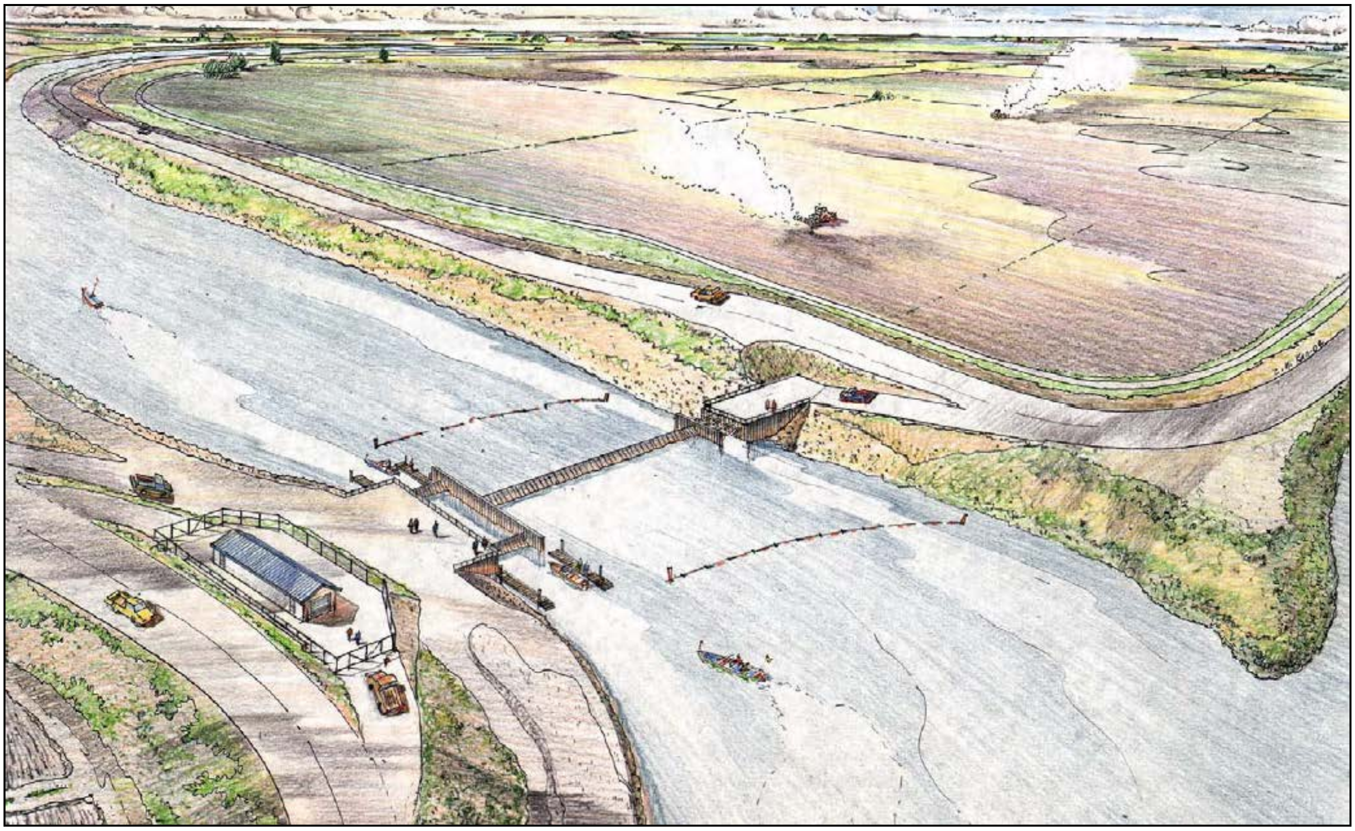
Figure 2-9. Bottom-Hinged Overflow Gate

Background

DWR proposed the use of a bottom-hinged overflow gate at the HOR as part of the proposed South Delta Improvements Program that included three other overflow gates to control water surface elevations (DWR 2010). The purpose of the bottom-hinged overflow gate is to help improve water quality in the south Delta by reducing both the tidally influenced salinity input and the number of juvenile salmonids entrained into Old River.

The HOR gate structure was designed to allow upstream migration and boat passage. The design included a vertical slot fishway for upstream migration of adult salmonids and a boat lock for boat passage. The lock included two additional bottom-hinged gates to control water levels inside the lock (Figure 2-10).

Reclamation and DWR also proposed the use of bottom-hinged overflow gates at Threemile Slough for the proposed Franks Tract Project. Gates with hydraulic arms, as opposed to the air bladder, have been proposed for use at the project site. The primary objective of this project is to improve water quality by reducing the tidally influenced salinity input into the central and south Delta. The proposed gates also influence target fish species to remain in the mainstem of the Sacramento River (DWR 2011a).



Source: DWR 2011

Figure 2-10. Illustration of an Overflow Gate, Fish Ladder, and Boat Lock located at the Head of Old River

Advantages

A key advantage of an overflow gate is its capability to provide a high level of fish deterrence because of its nature in being a full column physical barrier. This is achieved when water is not allowed to pass over the gate. When the gate is operated to redirect 100 percent of the flow, fish would be expected to be redirected as well.

Another advantage of the overflow gate is its ability to be adjusted in a timely manner to address changing conditions. This provides flexibility to the operator to adaptively manage the hydraulic conditions. The gate can be raised, lowered, or set to a specific height relatively quickly to address changes in flow, fish migration patterns, boat passage, or other site-specific conditions.

Disadvantages

An overflow gate, if operated to block 100 percent of a channel flow, significantly alters the existing flow regime and surrounding hydraulic conditions. If the goal for a specific site is to deter fish while maintaining the existing flow regime, this physical barrier option would not be ideal. In some cases, a decrease in flow downstream from a gate can negatively affect both downstream water users and fish.

The rationale section of the Action explains that the intent of the Action is to follow the CALFED Bay Delta Program Science Panel's recommendation to study engineering solutions to "separate water from fish." An overflow gate option does not separate water from fish; it redirects both water and fish. To meet the Science

Panel's recommendation, some level of flow augmentation may be required. Systems to pump or siphon water past the gate and deliver it to the downstream side of the gate may be necessary in a design that includes a full column physical barrier, such as an overflow gate. Further studies and analyses are needed to evaluate the potential impact of the gate's operation at each of the sites evaluated in this report.

Some disadvantages arise when the gate is not blocking 100 percent of the flow. When the gate is operated to allow flow over or through the system, fish deterrence may be expected to decrease substantially. Also, such a gate may attract certain fish species when it is partially open. If the target fish species exhibits epipelagic behavior (surface-oriented), water flows over the top of the gate can be a potential disadvantage. Furthermore, when the gate is positioned any way but fully lowered, the channel bottom is blocked off. This hinders the movement or upstream migration of non-targeted fish, such as adult salmonids, striped bass, American shad, and splittail, as well as benthic species such as sturgeon and catfish. Also, a boat lock may be needed for boat passage, which is typical for any physical barrier.

Underflow Gate

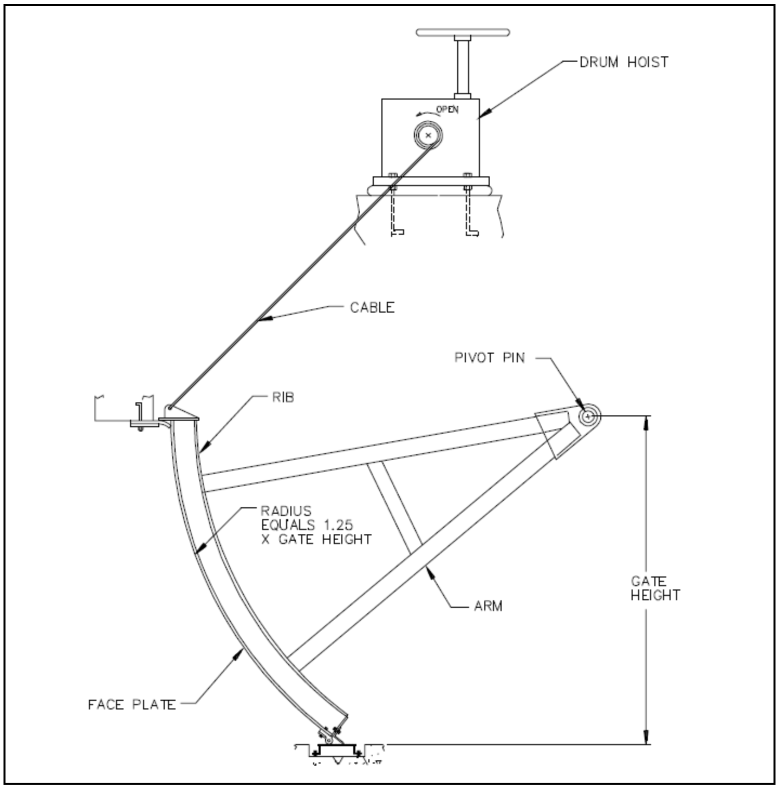
Underflow gates are structures that can be used as physical barriers to protect fish from entrainment at a diversion. Although their common use is for water supply or irrigation flow control, an underflow gate can provide a physical diversion in the top portion of the water column where emigrating juvenile salmon tend to be located. This can be done while keeping the bottom portion open for the passage of adult salmonids, sturgeon, and other species while allowing water to pass.

Description

Underflow gates typically have one of two designs—the radial arm gate (or Tainter gate) and the vertical lift gate (or sluice gate). Either of these designs provides a positive barrier system that can be lowered or raised to specific elevations to meet environmental, fish passage, and water export needs. Such gates can physically divert fish from areas of concern. The basic hydraulic principles for the two gate designs are the same; the difference is that the radial gate is easier to manipulate, requiring minimal lifting force, compared to a vertical gate (Hydro Gate 2013).

A typical radial arm gate has a curved face plate, support structure, and a mechanism to open and close the gate (Figure 2-11). The gate's face plate is connected to a support structure consisting of support arms, a pivot pin, a cable, and a drum hoist system that typically is used to open and close the gate. The hoist can be motorized or operated manually, depending on the size, accessibility, and weight of the gate. The gate design primarily is based on the water depth as measured from the invert of the gate. The gate is secured by piles along the diversion alignment and on either side of the waterway. A radial arm gate with a single gate is shown in Figure 2-12.

A typical vertical lift gate consists of a vertical metal gate panel that often slides vertically on a frame to open or close (Figure 2-13). A wide variety of vertical lift gate systems can be designed, depending on channel width and hydraulics. Many vertical lift gates are moved by means of a threaded rod system, and when these gates are used in applications with a large amount of water pressure, such as for dams, they are raised and lowered by hydraulic systems. Vertical lift gates are secured primarily by piles along the diversion alignment and on either side of the waterway (Waterman Industries 2013).



Source: Hydro Gate 2013

Figure 2-11. Schematic Drawing of a Typical Radial Arm Gate System

Source: Hydro Gate 2013

Figure 2-12. Typical Radial Arm Gate

Source: Waterman Industries 2013

Figure 2-13. Vertical Lift Gate with Multiple Panels

Background

The DCC gates are an example of a radial arm gate system (Figure 2-14). The DCC gates were constructed in 1951 and used to divert water from the Sacramento River to the San Joaquin and Mokelumne rivers when open. The DCC gates use two radial arm gates to control the water flow. The DCC gates in the open position are shown in Figure 2-14.

The DCC gates are operated in accordance with the State Water Resources Control Board's Decision 1641. The gates are closed for juvenile salmonid protection between November 1 and January 31 (for up to 45 days), from February 1 through May 20, and between May 21 and June 15 (for up to 14 days). The DCC gates are also operated in accordance with the salmonid decision tree, and the 2009 NMFS BiOp. The DCC gate operations alter flows throughout the Delta. These changes in flow alter the pathways and survival of emigrating juvenile salmonids. DCC gate operations also change the amount of water from the Sacramento River entering the central Delta, which, in turn, alters the position and movement of the salinity field. Therefore, management of juvenile salmonid emigration, water quality in the central and south Delta, and water supply are inextricably interconnected at the DCC. For example, closures of the DCC gates often are required in fall to protect emigrating juvenile salmon. DCC gate closures at this time of year invariably increase salinities at Jersey Point and Rock Slough—locations in the Delta where the CVP and the SWP are required to meet maximum allowable salinity standards regulated by the State Water Resources Control Board. When the DCC gates are closed, water exports typically are reduced to meet required water quality standards, reducing surface water supplies south of the Delta. High flows on the Sacramento River, unplanned fish protection actions by resource regulatory agencies, or water quality compliance in the Delta also may dictate required short-term closure of the DCC gates (Reclamation and USGS 2004; USGS 2013).

Source: DWR 2014

Figure 2-14. Delta Cross Channel Radial Arm Gates on the Sacramento River

Advantages

As with all physical barriers, a key advantage of using an underflow gate is the high level of fish deterrence because of this full-column physical barrier. This is accomplished if the gate is fully closed. When the gate is closed only part of the time or only blocks part of the channel, the ability to deter fish is decreased or eliminated.

Another advantage of the underflow gate is its ability to be adjusted in a timely manner to address changing conditions. This provides flexibility to the operator to adaptively manage the hydraulic conditions. The gate can be raised or lowered relatively quickly to address changes in flow, fish migration patterns, boat passage, or other site-specific conditions.

Disadvantages

The key disadvantage of an underflow gate is that it substantially alters existing flow characteristics. Changing the existing flow regime negatively affects the majority of water users downstream from the gate, and some level of flow augmentation may be required. To achieve 100 percent deterrence, the gate must be fully closed. However, this blocks the movement and migration routes of fish, such as striped bass, sturgeon, and adult salmonids. Also, during the operations of the gate, there is a potential for injury or death to fish that may get impinged from a gate closure. Therefore, a fish passage structure is needed to accommodate fish movements around an underflow gate. Also, a boat lock may be needed for boat passage, which is typical for any physical barrier. Another disadvantage of the underflow gate is that the initial construction of the gate has the largest footprint compared to other engineering options. Further studies and analyses are needed to evaluate the potential impact of the gate's operation at each of the sites evaluated in this report.

Rock Barrier

A rock barrier is a physical barrier that can be used to deter migrating fish from leaving the mainstem of a river or stream. Some rock barriers in the Delta are used as fish barriers, while others are used to maintain water elevations for agricultural water diversions or improve water quality. Figure 2-15 is an aerial view of the HOR rock barrier placed at the divergence of Old River from the San Joaquin River during spring.

Source: DWR 2014

Figure 2-15. Aerial View of the Head of Old River Rock Barrier

Description

A rock barrier typically is used to block fish and other aquatic wildlife from entering portions of a river or stream. Another rock barrier application is to prevent upstream movements of non-native fishes into streams with native fish populations. The barrier usually is composed of rocks of varied size and also may include hydraulic structures, such as culverts or weirs, to allow water passage. Equipment and vehicles such as bulldozers, cranes, hauling trucks, and excavators typically are used for installing and removing a rock barrier, which is a fairly straight forward procedure. Generally, machinery is operated from both banks of a channel to place or remove the rock material as well as any additional materials (e.g., culverts, concrete reinforcing mats, or other structures). Rock barriers can be permanent or temporary. Rock barriers installed at the HOR are temporary and used in the spring of some years under certain water flow and conditions.

Background

DWR began using temporary rock barriers in south Delta channels in 1968. Three rock barriers are placed annually in three south Delta channels (i.e., Grant Line Canal, Old River, and Middle River), and they are operated during the agricultural water diversion season, usually from April through November. They were designed as a short-term solution to improve water level and circulation patterns for agricultural irrigation and to collect data for the design of permanent barriers (DWR 2013c).

The HOR barrier is installed twice each year, once in the spring and again in the fall. The HOR fish barrier (Figure 2-16) has been installed annually in the spring since 1992 to prevent juvenile fall-run Chinook salmon and juvenile Central Valley steelhead from leaving the mainstem of the San Joaquin River during their emigration to the ocean. Entering Old River exposes outmigrating salmonids to potential entrainment at the CVP and SWP export facilities. The HOR fish barrier normally operates annually from April 15 to May 15. The fall HOR barrier is generally installed only when requested by the CDFW between September 15 and November 30. The purpose of the fall HOR barrier is to improve dissolved oxygen levels in the SJR between the HOR and Medford Island to aid adult salmon migration in the SJR. (DWR 2011a).

Source: DWR 2013

Figure 2-16. Head of Old River Rock Barrier

The HOR fish barrier is a rock barrier with eight 48-inch operable culverts. It is approximately 225 feet long, 85 feet wide at its base, has a crest elevation of 12.3 feet (North American Vertical Datum of 1988 [NAVD88]), and is composed of approximately 12,500 tons of rock. The middle section includes a 75-foot-long clay weir at an elevation of 8.3 feet. A HOR barrier may also be installed in the fall of some years to reduce the quantity of San Joaquin River flow into Old River. Installation and removal will typically be done between September and November. The flow reduction will result in increased net outflow in the San Joaquin River for the benefit of upmigrating adult salmonids.

Advantages

A key advantage of using a rock barrier is the high level of fish deterrence resulting from this full-column physical barrier, which is typical for any full-column physical barrier. However, if the barrier includes culverts to allow the passage of some flow, the level of deterrence may be reduced depending on flow conditions and how often the culverts remain open. Flexibility in the design and general arrangement options of the rock barrier is another advantage. Having the flexibility to move the barrier seasonally can be beneficial. The barrier can be put in place or removed fairly quickly and easily compared to other physical options.

Disadvantages

As with all full-column physical barriers, a rock barrier is effective in prohibiting entry of juvenile salmonids and other fishes into channels, but it also substantially alters flow dynamics. Changing the existing flow characteristics is not advantageous; changing the existing flow regime negatively affects a majority of downstream water users. To achieve 100 percent deterrence, the barrier must be fully closed. However, this blocks movements of migratory fish such as striped bass, sturgeon, and salmonids. Therefore, a fish passage structure would be needed to accommodate fish movement. Also, a boat lock may be needed for boat passage, which is typical for any physical barrier.

Floating Fish Guidance Structure

The FFGS is a physical, partial-column fish deterrence system that provides a positive physical barrier and evokes behavioral guidance as well. The FFGS has evolved from trash/debris boom technology and now is being used to guide emigrating juvenile salmonids. When emigrating fish encounter the floating structure, they are guided away from or along the structure to follow a preferred route.

Description

A typical FFGS is a physical structure made up of floating buoys, supporting submerged solid metal plates. The structure is formed by separate plate sections that are linked together with heavy duty hardware and a flexible rubber material attached between the plates to prevent gaps (Figure 2-17). The sectioning provides flexibility for transporting, installing, aligning, and storing the FFGS, as well as guiding fish and debris. This technology is designed to have a relatively small in-water footprint in order to minimize changes to the existing hydraulic conditions.

Source: Worthington Waterway Barriers 2013

Figure 2-17. Three Sections of a Floating Fish Guidance Structure

The theory behind this technology is that fish exhibit a behavioral response to the hydraulic influence of the submerged wall and its presence. By taking advantage of this behavioral response, the FFGS can be placed in an optimal position to guide fish away from harmful areas. Emigrating juvenile salmonids prefer to travel in the epipelagic portion of the water column while staying in or near the thalweg. A floating guidance system creates hydraulic signals that fish detect with their eyes and lateral lines, causing a change in swimming direction to remain in the thalweg. In addition to the behavioral response, fish also are guided by the physical presence of the floating barrier walls.

The FFGS can be designed and constructed in many different ways to optimize effectiveness in specific applications. When designing an FFGS barrier, many variables need to be considered. These variables include buoyancy, strength, depth of plate or net, length of the barrier, and shape of the alignment to take advantage of the existing hydraulics. The structure design must be flexible to accommodate site and target species characteristics. Site geometry, vertical distribution of target species in the water column by life stage, water velocity, and other site-specific needs help determine the optimal FFGS design.

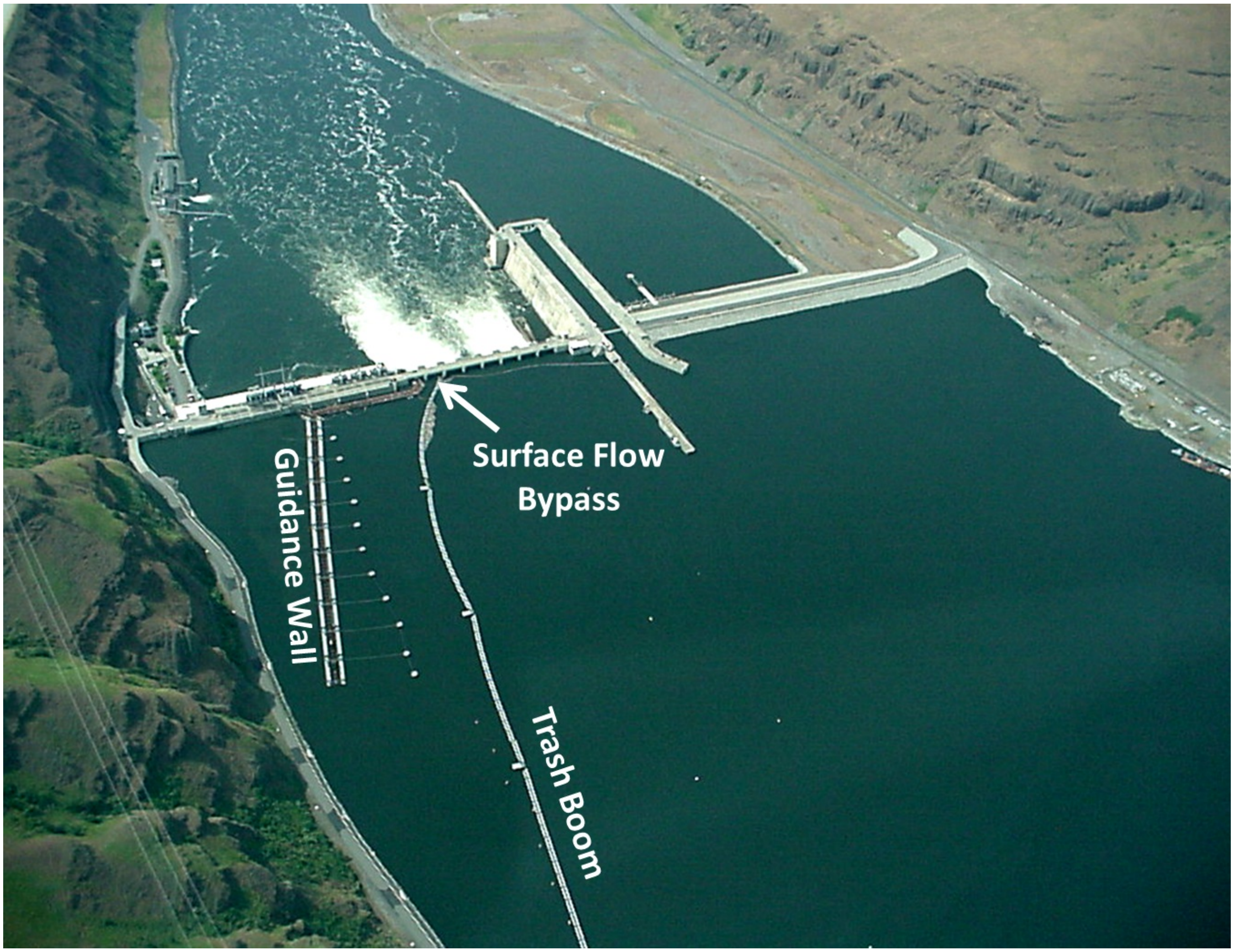
Background

FFGSs evolved from technologies that protect dams, diversions, and intake areas from trash, ice, debris, and other floating, hazardous materials. To protect dams, water intakes, and other safety related areas, cables with log-shaped floats that were tied together were assembled and arranged in an alignment to catch or deflect hazardous materials. To create an effective debris barrier, some systems were designed with metal plates or nets to form a wall hanging from the floats, to deflect submerged debris. This made it possible to provide protection in the upper portion of the water column, where floating debris exists.

In 1998, a behavioral guidance structure (BGS) was constructed in the forebay of Lower Granite Dam on the Snake River near Colfax, Washington (Figure 2-18). The BGS included a relatively large floating wall, measuring over 1,000 feet long and between 55 and 78 feet deep. The purpose of this installation was to alter the horizontal distribution of emigrating juvenile salmonids to guide them into the surface bypass and collector. To prevent harmful debris from entering the turbines, a debris boom was installed upstream from the BGS, turbines, and surface bypass and collector (Cash et al. 2002). The BGS and the debris boom were aligned at similar angles.

Using biotelemetry and hydroacoustics, results indicated that the juvenile salmonids actually were guided along the trash boom and had greater success reaching the surface bypass and collector compared to the BGS. Based on these results and other experiments and applications using floating fish guidance walls, manufacturers started designing smaller and shallower walls. This made the cost of manufacturing and installing the FFGSs more economical while maintaining their effectiveness.

Other installations of FFGSs have achieved varying degrees of effectiveness. Some reports show guidance efficiencies ranging between 53 percent and 92 percent, depending on location and target species (Scott 2011). These reports present study data for installations at dams in Washington and on an installation at a hydroelectric intake in Maine. The targeted species in these studies were Chinook salmon, steelhead, coho salmon and Atlantic salmon.



Source: USGS presentation given by Noah Adams April 2013

Figure 2-18. Behavioral Guidance Structure and Trash/Debris Boom at Lower Granite Dam near Colfax, Washington

Advantages

The floating aspect of an FFGS provides a key advantage for deterring surface-oriented fish such as juvenile salmonids. In an environment where surface-oriented fish are targeted and tidally influenced stage changes occur, having a system that follows the water surface elevation is beneficial. In essence, the guidance wall can follow the position of the target fish. Also, having a relatively small in-water footprint minimizes any unwanted changes to naturally existing hydraulic patterns.

Another advantage is that an FFGS allows the passage of non-targeted species. Adult salmonids, American shad, and striped bass can move upstream during their spawning migration. Sturgeon travel on the bottom of the channel, and the barrier never blocks the bottom half of the water column.

Existing flow conditions will not be changed because the FFGS is designed as a partial column barrier, and is aligned at angles to not obstruct the natural flow.

Not only can a FFGS be effective in a specific part of the water column, it also can create partial horizontal coverage. This is an important advantage because the wall can be designed to guide fish to stay in the bulk flow of a waterway and provide for boat passage. Whether a gap is left open, or multiple and staggered guidance walls are used, an FFGS can be designed to allow boat passage without blocking off the entire channel.

Flexibility in the design and general arrangement options of the FFGS is another advantage. A system that can be built in different lengths, depths, and shapes can optimize the efficiency of the operation. Having the flexibility to move or rearrange the alignment seasonally also can be beneficial. A relatively simple system such as the FFGS can be adjusted or moved fairly quickly and easily compared to other, more complex fish deterrence systems that may be fixed. It also is possible to install, remove from, or maintain an FFGS in the water, which is beneficial when land access is a challenge.

Disadvantages

A key disadvantage of the FFGS is how its effectiveness is not consistent throughout all ranges of flow, especially reversing flow. Changes in water velocities occur daily because of tidal effects in the Delta.

Another disadvantage of this type of system is the potential for target fish species to swim under the guidance wall. Although emigrating juvenile salmonids tend to stay in the upper portion of the water column, some may swim deeper in the water column and under the wall. This behavior should be evaluated at specific locations to assess the significance of this issue.

Another disadvantage with an FFGS is that it will impede navigation to some degree.

2.2.3.2 NON-PHYSICAL BARRIERS

Non-physical barriers (NPB) are essentially flow neutral and rely on behavioral stimuli for deterrence with minimal in-water structural components to physically divert target fish species. The non-physical barriers evaluated in Phase II include an IFF, a BAFF, and electrical fish guidance systems. These three engineering alternatives would minimize impacts on existing flow and use one or more of a variety of stimuli—electrical current, bubbles, lights, sound, and particle acceleration—to achieve juvenile fish species deterrence.

Bio-Acoustic Fish Fence

A BAFF is a non-physical fish deterrence system developed by Fish Guidance Systems Ltd. (FGS) of Southampton, United Kingdom. This multi-stimulus fish barrier uses low-frequency sound generators, strobe lights, and compressed air to create an underwater curtain of bubbles, light, and sound that can deter fish. The application of the BAFF technology was tested by DWR in the San Joaquin River just upstream from the divergence of Old River (HOR) in 2009 and 2010 (Reclamation 2012a, b), and in the Sacramento River just upstream from the divergence of Georgiana Slough in 2011 (DWR 2012) and 2012 (DWR 2014c). General information on the BAFF application in the Delta is presented in this section with more detailed information presented in Section 3.3, "Field Testing of Engineering Options."

The BAFF is a patented device that creates a "wall of sound" at specific frequencies ranging from 5 to 600 Hertz (Hz) (DWR 2014). These sound levels are reported to deter certain fish species like Atlantic salmon, brown trout, and European eel. Sound is trapped within the bubble curtain, producing a well-defined sound field that fish do not detect until they are within a few yards of the barrier. Strobe strip-lights (360 to 434 nanometers [nm] wavelength for steelhead) at the base of the BAFF illuminate the bubble curtain, increasing the likelihood of a response from approaching fish. This combination of elements achieves a multi-stimulus barrier to deter targeted fish species (Reclamation 2012a).

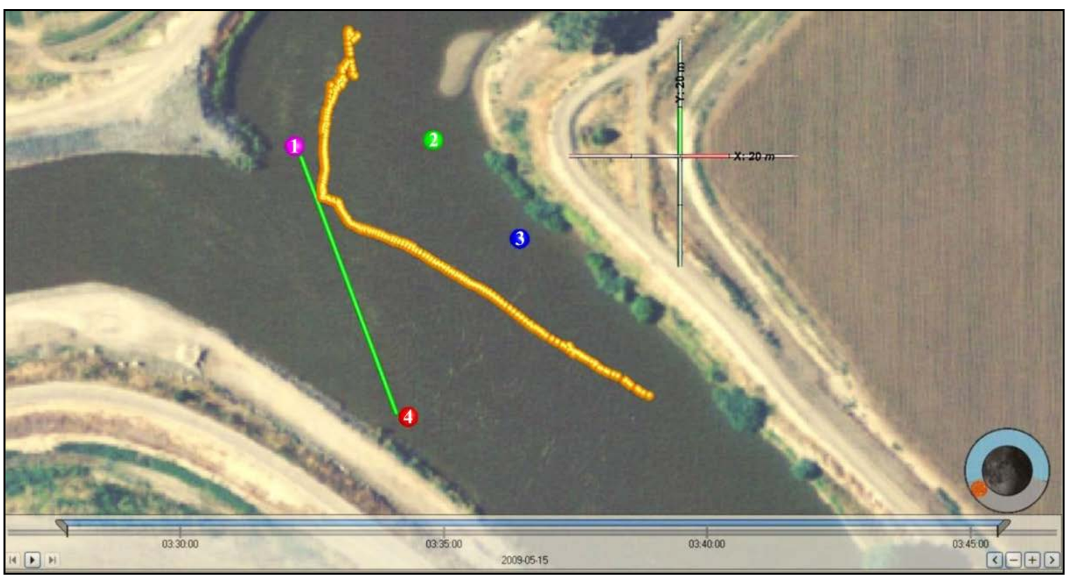
Background

The purpose of DWR's respective studies between 2009 and 2012 was to evaluate the effectiveness of a NPB at keeping juvenile emigrating salmonids either in the San Joaquin or the Sacramento rivers while preserving natural flow splits at the divergences. The results of these studies are discussed next.

2009–2010 Head of Old River BAFF Barrier Study

DWR installed and tested this NPB during the Vernalis Adaptive Management Plan (VAMP) period in April and May of 2009 and 2010. The BAFF monitoring was conducted by Reclamation and DWR in cooperation with the VAMP team.

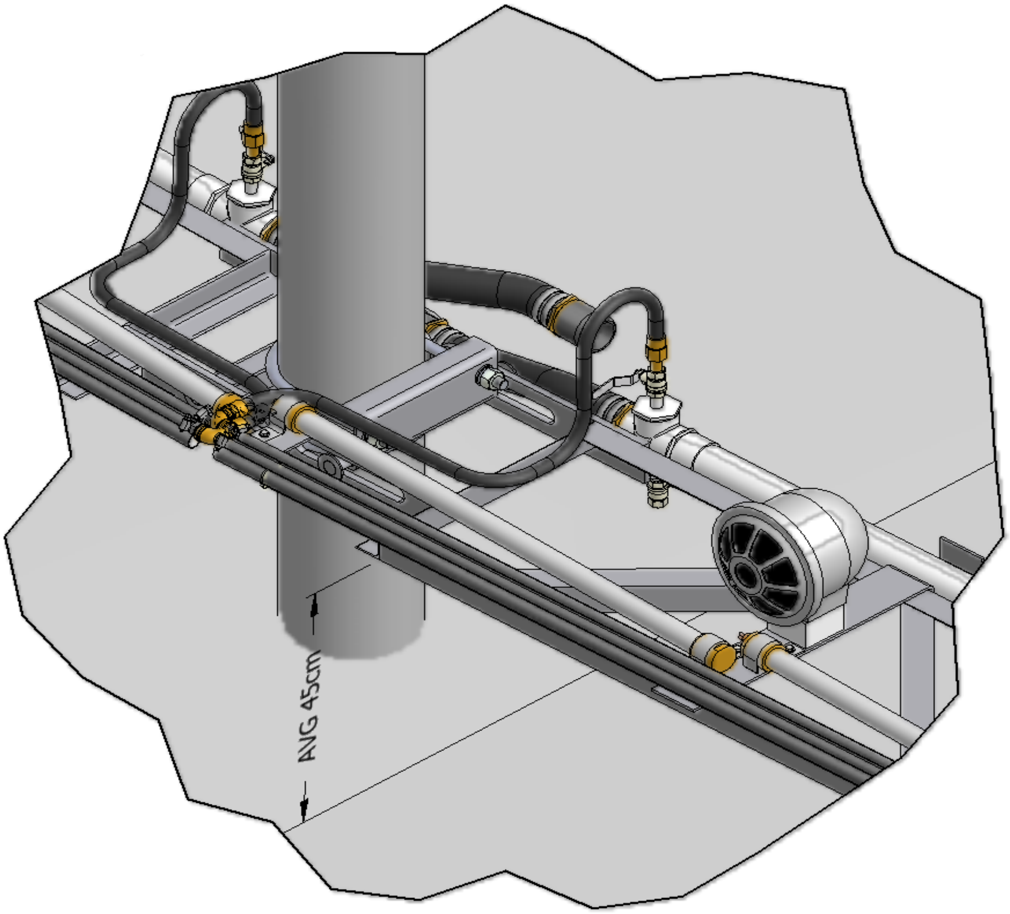
In 2009, the length of the barrier was approximately 367 feet, and it was oriented at a 24-degree angle toward the shoreline from the point of origin on the San Joaquin River's west shore (left bank). This alignment was designed to allow the BAFF to maximize fish guidance down the mainstem of the San Joaquin River away from Old River. Figure 2-19 shows a two-dimensional (2D) trace of a tagged juvenile Chinook salmon at the divergence during the 2009 study. The green line indicates the BAFF location and the colored circles indicate the location of four hydrophones.



Source: DWR 2010

Figure 2-19. Two-Dimensional Trace of a Tagged Juvenile Chinook at the Head of Old River in 2009

A typical frame section of the BAFF that was used at the HOR is shown in Figure 2-20. Each frame included sound projectors, strobe lights, and perforated bubble pipe. The barrier had 17 separate sections, supported by two piles and 68 sound projectors.



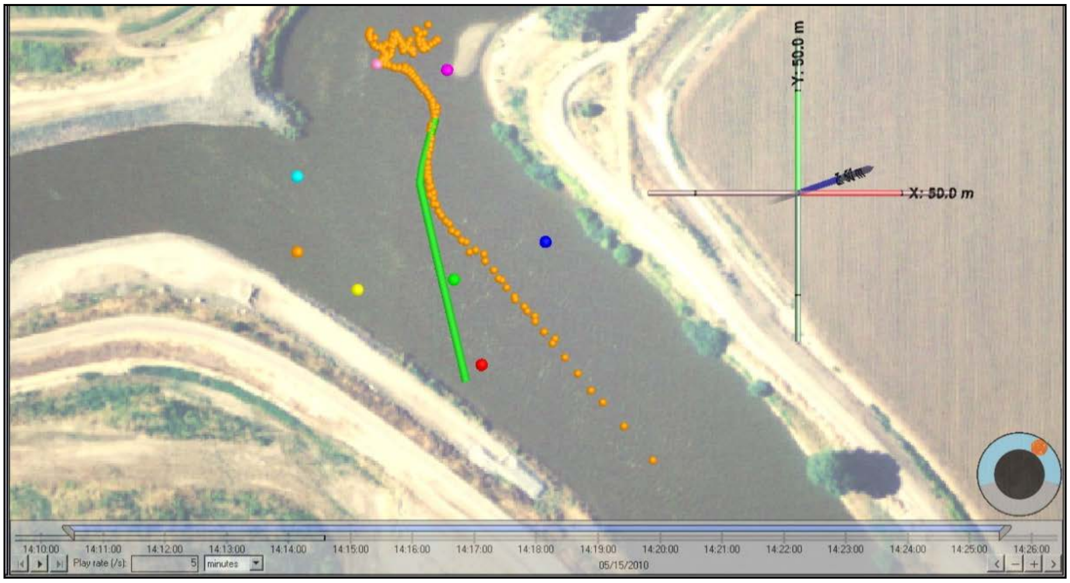
Source: Reclamation (2012a)

Figure 2-20. Components of the BAFF System Installed at the Head of Old River

The VAMP team released 947 hatchery-raised juvenile Chinook salmon, each implanted (“tagged”) with an acoustic transmitter. These fish were released in seven groups upstream from the barrier at Durham Ferry, San Joaquin County (approximately 16 miles upstream from the HOR). Approximately 135 juvenile Chinook were in each release. To monitor the acoustic tags implanted in the juvenile Chinook salmon, four hydrophones were deployed to allow 2D tracking in the vicinity of the barrier. Each hydrophone was connected by cable to a four-port receiver. The hydrophones were placed at known locations within the array to maximize resolution in positioning and 2D tracks.

In 2010, the VAMP team released 508 hatchery-raised juvenile Chinook salmon in seven groups at Durham Ferry; each fish was tagged with an acoustic transmitter. The barrier was installed with the same deterrence components, but it was approximately 446 feet long and had a 30-degree angle toward the shore from the point of origin. This alignment allowed the BAFF to maximize fish guidance down the mainstem of the San Joaquin River away from Old River. Figure 2-21 shows a 2D trace of a tagged juvenile Chinook at the divergence. The green line indicates the BAFF location and the colored circles indicate the location of eight hydrophones.

The main objectives of the studies were to collect data assessing the effects of the BAFF on the flow and to evaluate barrier fish deterrence efficiency at the HOR. The results indicated that the BAFF did not impede flow down Old River.



Source: DWR 2011

Figure 2-21. Two-Dimensional Trace of a Tagged Juvenile Chinook Salmon at the Head of Old River in 2010

Deterrence Efficiency (D) is the total number of fish deterred, summing all seven releases, divided by the sum of all fish for which the response could be determined.

The barrier's Deterrence Efficiency was calculated as:

D = E/(E+U)

where:

D = Deterrence Efficiency,

E = the number of fish deterred by the barrier, and

U = the number of fish undeterred by the barrier.

Deterrence Efficiency results are summarized in Table 3-2 in Chapter 3 (Methods).

Protection Efficiency (P) is the total percentage of acoustic-tagged fish that moved through the area and continued downstream in the San Joaquin River.

The barrier's Protection Efficiency was calculated as:

P = S/(S+O)

where:

P = Protection Efficiency,

S = the number of Chinook juveniles passing down into the San Joaquin River, and

O = the number of Chinook juveniles passing down into Old River.

Protection Efficiency results are summarized in Table 3-2 in Chapter 3 (Methods).

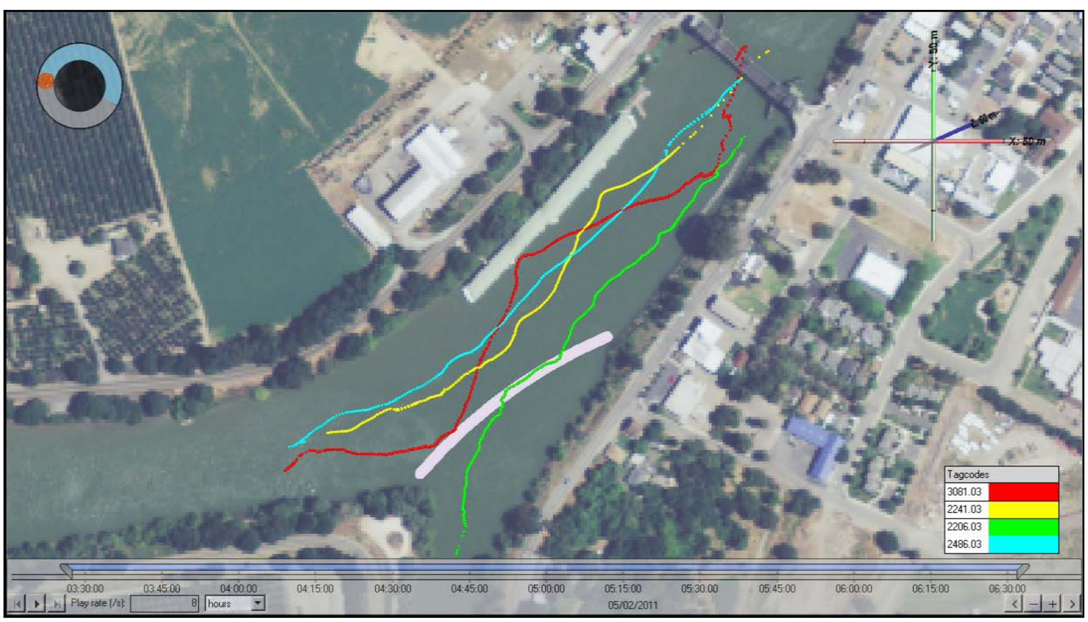
In 2011, DWR planned to conduct an additional BAFF test, based on the 2009 and 2010 study results. The 2011 BAFF was to be installed at the 2009 test angle of 24 degrees but at a longer length with no curved section. The longer length was proposed to study the barrier's effectiveness in deterring fish past the downstream scour hole. However, the proposed 2011 BAFF was not installed because of high river discharges in 2011 which prevented installation.

2011 and 2012 Georgiana Slough Bio-Acoustic Fish Fence Pilot Study

DWR installed and tested a BAFF at the divergence of Georgiana Slough from the Sacramento River from March to May 2011 and from March to April 2012. This testing was done to evaluate the BAFF's effectiveness as a behavioral deterrent to prevent out-migrating juvenile salmonids from entering Georgiana Slough. The testing was conducted to provide data to support the feasibility evaluation of this engineering option and evaluate barrier fish deterrence efficiency at Georgiana Slough.

Approximately 1,500 hatchery-raised, tagged juvenile late fall-run Chinook salmon were released approximately 6 miles upstream from Georgiana Slough near the divergence of Steamboat Slough from the Sacramento River. An acoustic tag tracking system was used to continuously monitor the area surrounding the barrier for fish presence, position, and passage through the area.

The 2011 BAFF was approximately 630 feet long, with 15 piles and 16 separate frame sections, each about 39 feet in length. Figure 2-22 shows four 2D traces of tagged juvenile Chinook salmon at the Georgiana Slough/ Sacramento River divergence. The white line indicates the BAFF location.



Source: DWR 2011

Figure 2-22. Two-Dimensional Traces of Four Tagged Juvenile Chinook Salmon at Georgiana Slough

A typical frame section of the BAFF that was used at Georgiana Slough is shown in Figure 2-23. Each frame included six FGS sound projectors (emitted sound in the range of 5 to 600 Hz), spaced approximately 6.5 feet apart, and two lengths of perforated bubble pipe. The bubble pipe was positioned along each frame below and upstream from the sound projectors. The tracking system included approximately 30 hydrophones, deployed in both the Sacramento River and Georgiana Slough to monitor the tagged fish.

The main objectives of the study were to collect data to assess the feasibility evaluation of this engineering option and subsequent field testing required under the Action, and to evaluate barrier fish deterrence efficiency at Georgiana Slough. The results showed a Deterrence Efficiency of 50.4 percent when the barrier was on. The Protection Efficiency when the barrier was on was 90.5 percent (AECOM 2012).

The barrier's Deterrence Efficiency was calculated as:

$$D = B/(B+C)$$

where:

D = Deterrence Efficiency,

B = the number of fish deterred by the barrier, and

C = the number of fish undeterred by the barrier.

The barrier's Protection Efficiency was calculated as:

$$P = F/(F+G)$$

where:

P = Protection Efficiency,

F = the number of salmonid smolts passing down into the Sacramento River, and

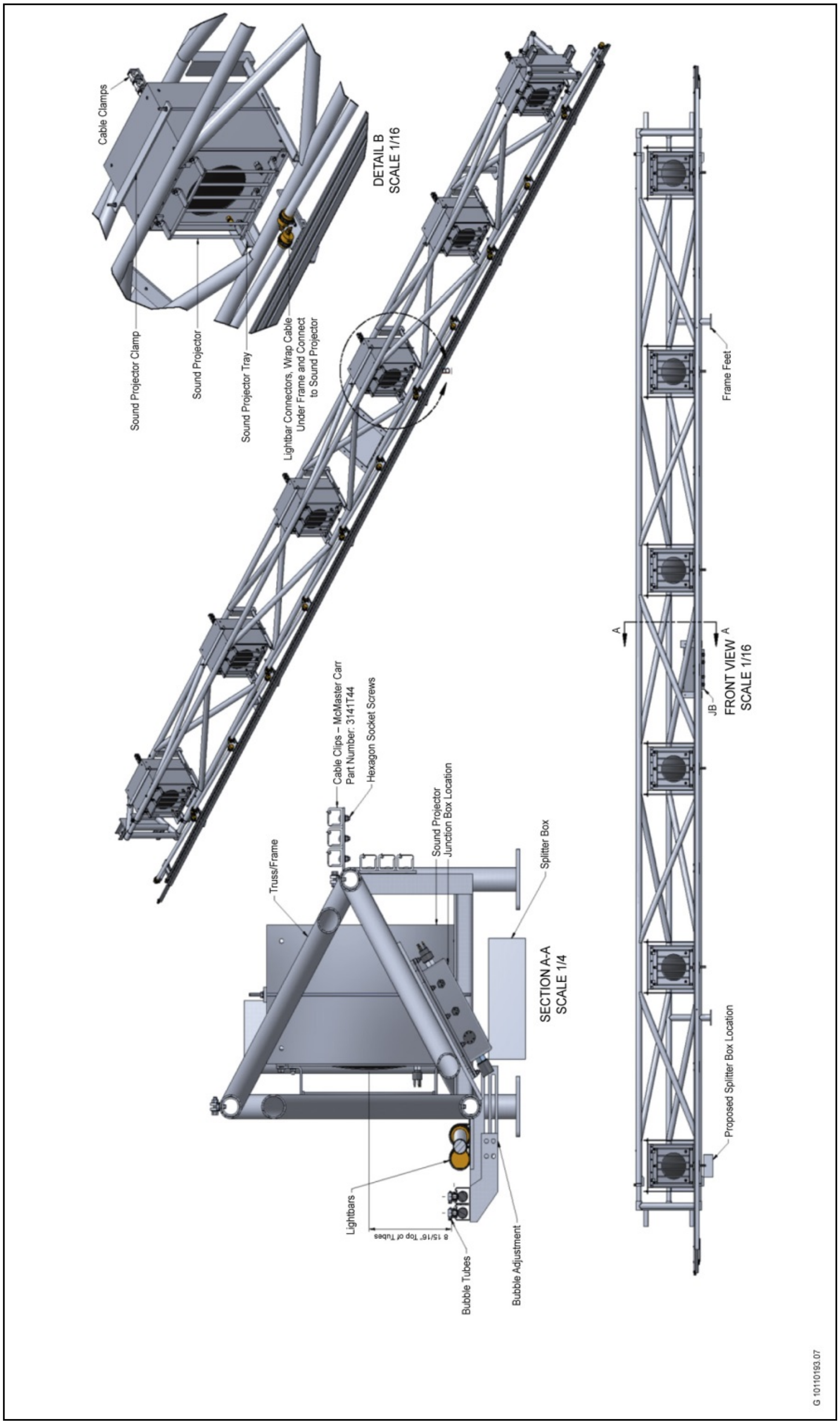
G = the number of salmonid smolts passing down into the Georgina Slough.

A similar study was conducted at Georgiana Slough in spring 2012. The 2012 BAFF was approximately 630 feet long, and 1,501 hatchery-raised, tagged juvenile Chinook salmon were released approximately 6 miles upstream from Georgiana Slough near the divergence of Steamboat Slough from the Sacramento River. The results of the 2012 study showed a Deterrence Efficiency of 56.1 percent when the barrier was on. The Protection Efficiency when the barrier was on was 89 percent (AECOM 2014).

Advantages

A key advantage of a BAFF is that it is flow-neutral, so it has minimal effect on naturally occurring flow. This is because water can flow around piles and through the BAFF itself, and not be blocked or redirected.

Another advantage of a BAFF is that it allows movement and migration of fishes, such as striped bass, sturgeon, and adult salmonids, to pass junctions freely by swimming under the barrier frames which were located 45 centimeters (cm) above the substrate, or through the bubble curtain. A fish passage structure is not necessary to accommodate fish movements.



Source: DWR 2011

Figure 2-23. Components of the BAFF System Installed at Georgiana Slough

The BAFF is a boat passage-friendly system, because of the small amount of structure in the water compared to full water column structures. Boats can pass over the barrier when sufficient water depth exists.

The BAFF is also relatively flexible with regards to its alignment and placement between different deployments. The BAFF's infrastructure is merely piles that can be driven into the channel bottom, and taken out if necessary, which may allow for small changes in the alignment in order to optimize its effectiveness throughout different water type years.

Disadvantages

A possible disadvantage of a BAFF is when water velocity reach a certain speed, juvenile fish may not have the swimming capabilities to avoid the BAFF before being swept through it. This may render the BAFF less effective because fish may have a behavioral response, but physically would not be able to avoid entrainment. This could also during reverse flow conditions.

Another disadvantage of a BAFF is that it needs to be operated 24 hours per day throughout emigration periods of juvenile salmonids. This could be an issue in areas where the lights and sounds could be considered a nuisance to the local residents.

Electrical Fish Guidance System

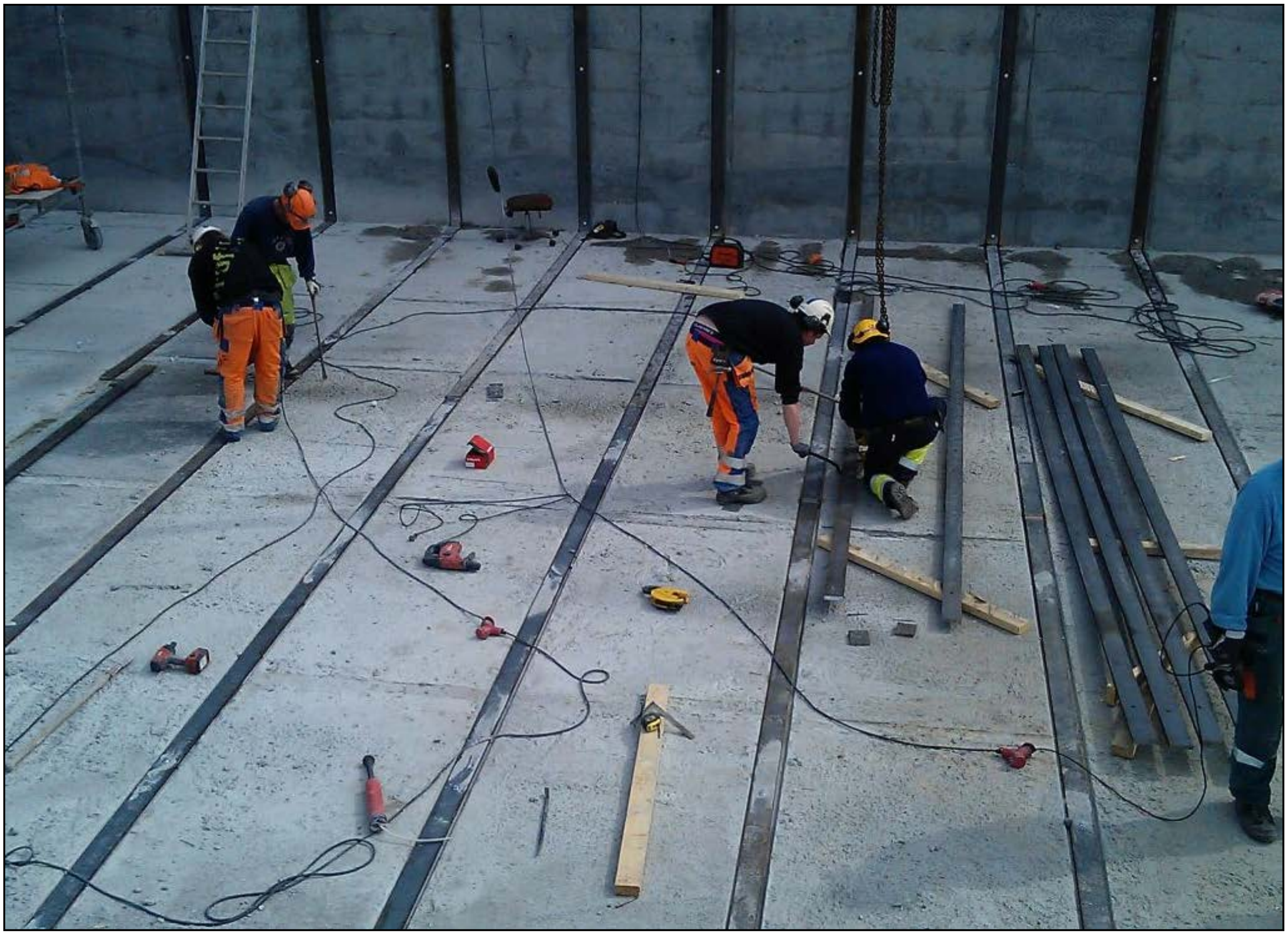
An electrical fish guidance system, sometimes referred to as an electrical fish barrier, is a fish deterrence technology that uses a submerged array of electricity to guide fish toward a designated area, or block fish from entering or escaping designated areas. These systems can be designed in many different ways and may be permanent or portable. Electrical fish guidance systems are used to deter invasive aquatic species from entering particular waterways and areas, reduce entrainment into turbines at hydroelectric and nuclear cooling facilities, and guide the movements of fish and emigration routes of juvenile anadromous fishes. The success of the electrical fish guidance systems depends on a multitude of variables including hydrodynamics, target fish species and their life stage, geometry of the waterway, and complexity of the local watershed and ecosystem.

Description

An electrical fish guidance system works by effecting the physiology of the fish's nervous and muscular systems while taking advantage of local hydraulics to guide the fish. When used as a guidance system rather than as a deterrence barrier, graduated intensity fields are used to evoke a behavioral response as opposed to a physical response (Figure 2-24). Electrical fish guidance systems use a wide variety of voltages and pulses, depending on the application and the fish species of concern.

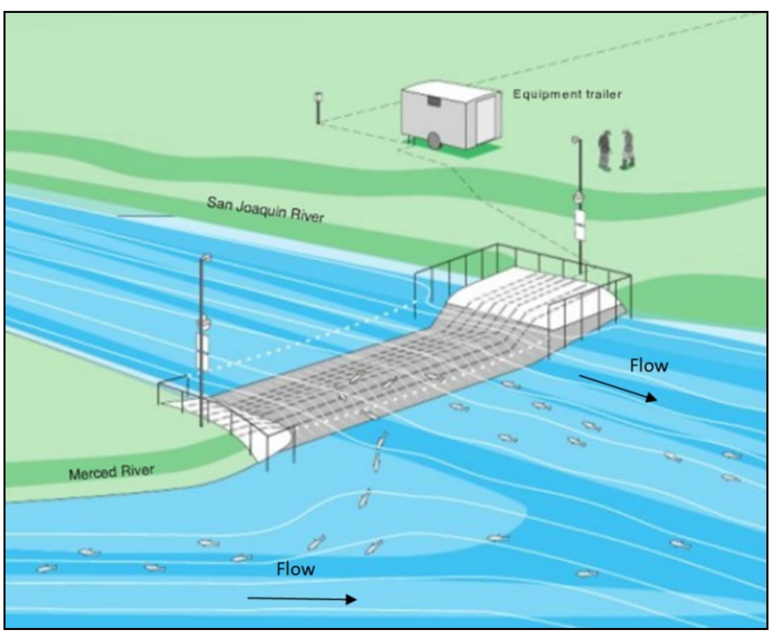
When the system is being used to guide downstream emigrating juvenile salmonids, it typically is designed using a graduated electrical field. This system deploys a less intense electrical field on the upstream side and gets stronger as the fish move downstream. The theory behind this type of design is to trigger a behavioral reaction which deters the fish with a less intense electrical signal.

In previous and some current applications, the fields are uniform and the electrical intensity is set to a level where fish will have a physiological response to the electrical array. This application is designed to interfere with fish nervous and muscular systems, to eliminate their ability to swim out of the array (Figure 2-25). The array is aligned strategically to take advantage of local hydraulics and sweep fish away from the area of concern.



Source: Smith-Root 2013

Figure 2-24. Installation of an Electrical Fish Guidance System



Source: Smith-Root 2013

Figure 2-25. Illustration of a Portable Electrical Fish Guidance System

Background

Only one previous study of an electrical fish guidance system has been conducted with goals similar to those set forth in this document. In the early to mid-1990s, Reclamation and Reclamation District 108 tested an electrical fish guidance system designed by Smith-Root. The study objective was to test the effectiveness of the guidance system in reducing entrainment of emigrating juvenile Chinook salmon into the Wilkens Slough diversion along the Sacramento River. The estimated reduction in juvenile Chinook salmon entrainment was 79 percent based on captures of marked (spray dyed) juvenile Chinook salmon, and 66 percent based on captures of unmarked juvenile Chinook salmon (Demko et al. 1994). The captures were made using fyke nets on the discharge side of the pumping facility. Two rotary-screw traps were used side-by-side in the Sacramento River to index emigrating juvenile Chinook salmon. Reclamation adjusted the electrode array three times during the testing to increase efficiency. Initial results by Reclamation demonstrated that efficiencies may be increased if additional time is spent adjusting the alignment, experimenting with the number of electrodes, and other modifiable parameters, such as amplitude, pulse duration, and intervals between the pulses of electricity (Smith-Root 2013c).

Advantages

An advantage of using an electrical fish guidance system to guide and deter fish is that it does not impact or change river flows or hydraulics. A minor amount of system structure is installed into the water column, but is negligible when compared to a full-column physical barrier.

An electrical fish guidance system can be designed to move in response to changes in stage. For example, the design team suspended the electrodes from floating docks in Wilkens Slough to maintain a constant distance from the surface. This allowed the electrical array to adjust with the river stage changes.

Maintaining a constant distance from the surface may prove to be advantageous when designed to deter emigrating juvenile salmonids because they tend to swim in the epipelagic portion of the water column.

This technology can be realigned, or relocated, relatively simply compared to the physical options. The infrastructure that supports the electrical guidance system is merely piles that can be driven into the river bottom, and removed and replaced as necessary, or as different water type years occur.

Disadvantages

A disadvantage of an electrical fish guidance system is that fish deterrence is reduced as water velocities increase. When velocities exceed the swimming speed of fish, the fish may be swept into the array where the electrical field immobilizes the fish, eliminating its ability to swim away from the system. Electrical fish guidance systems are most effective at deterring fish when used in locations where water velocities do not exceed 1.0 to 1.6 feet per second and when controlled and relatively constant.

The length and weight ranges of the fish species potentially present where electrical fish guidance systems are deployed is an important consideration. For electricity to be an effective deterrent, the current is set relative to the surface area of the target fish. Larger-sized fish are exposed to a higher current than smaller fish, which renders this option ineffective when multiple size ranges and ages of fish are present.

Debris accumulation may interfere with or damage parts of the system and reduce the system’s effectiveness. Debris clearing requires regular monitoring and maintenance to ensure a safe and effective system.

Safety is a concern when using electricity around water. Manufacturers of electrical fish guidance systems describe the charged electrical field as non-lethal, but the actual risk factor is unknown. The possibility of someone being exposed to the charged field and being injured is a valid safety concern. Most, if not all operating systems include exclusion zones where access is restricted to only trained and designated staff. Additional exclusion methods also must be considered if the potential exists for other terrestrial or aquatic species to come in contact with the charged field.

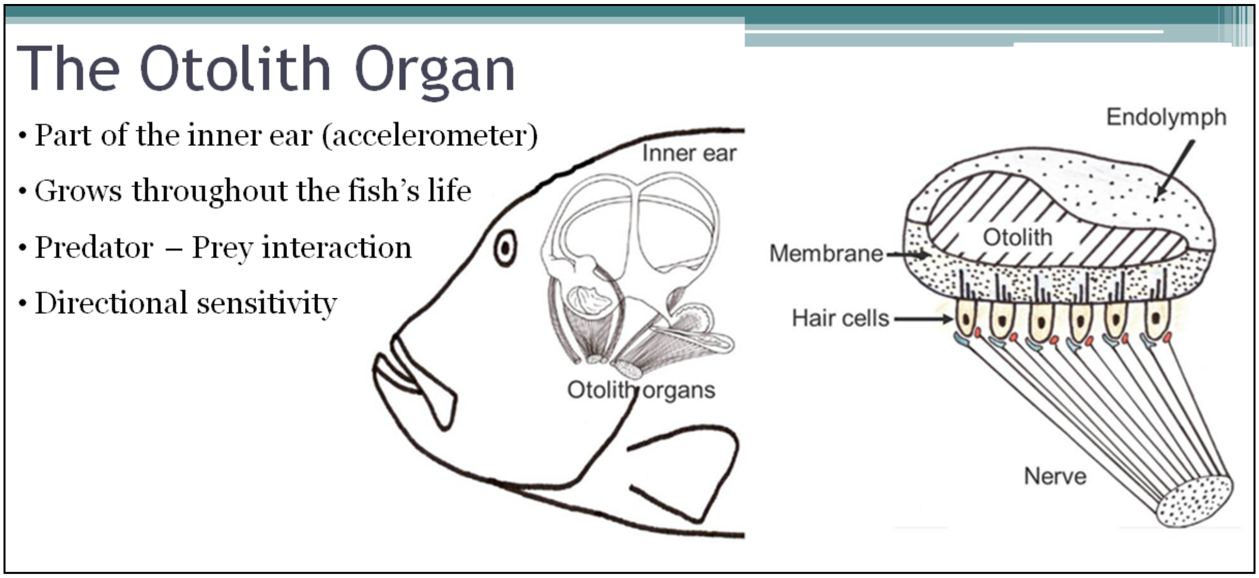
Infrasound Fish Fence

The IFF is a non-physical barrier developed by Profish, a Belgian company. The IFF uses water particle acceleration to create a strong directed flight reaction in fish, as opposed to other stimuli which totally disorient the fish (Environmental XPRT 2014). This technology was developed after more than 15 years of research at the University of Oslo, Norway. Profish began its development of the technology in 2007, with the first installation completed in 2008. IFF systems currently are being used on hydroelectric and nuclear plant cooling water intakes in Belgium and Germany, and field testing is continuing in Europe and North America.

Description

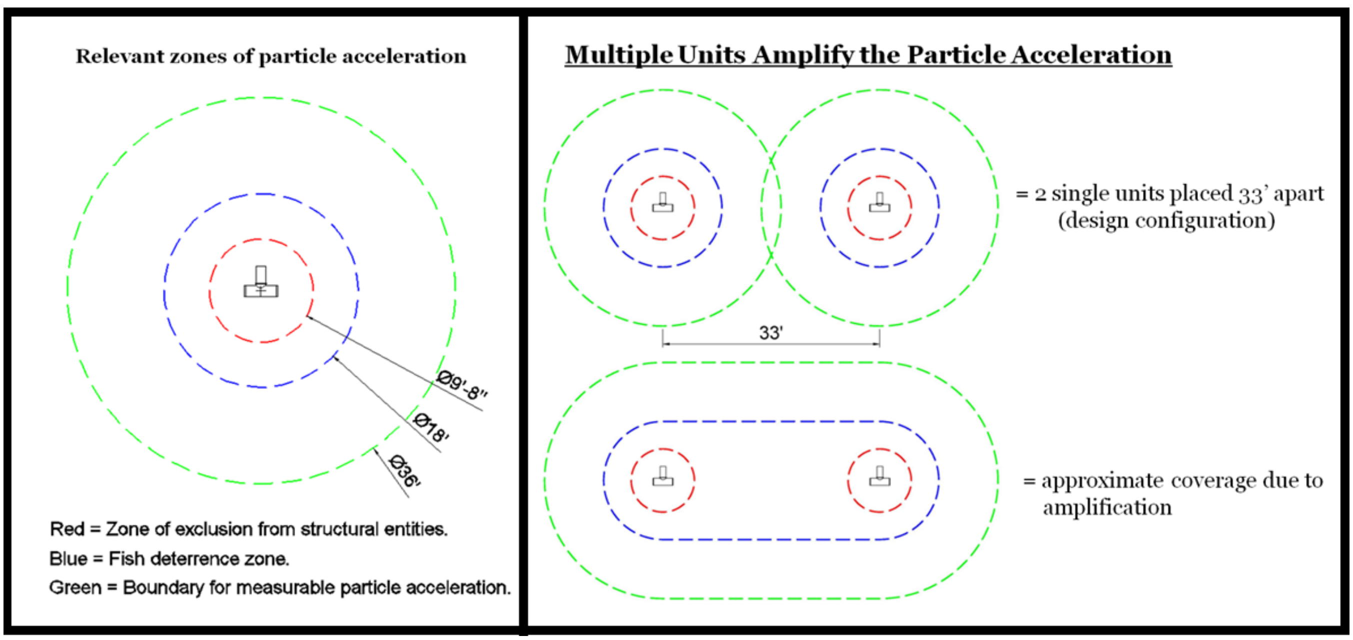
Sound contains both particle acceleration and pressure variations and is more efficiently conducted in water than in air. Sound also has both pressure and kinetic components, with the latter responsible for triggering the physiological recognition of the sensations in the otoliths (ear bones) of fish. The otoliths organ is composed of three pairs of otoliths (sagittae, lapilli, and asteriscii) composed of calcium carbonate located behind the brain of fish. Otoliths are capable of detecting infrasound. Otoliths can act as a sound accelerometer (Figure 2-26). Infrasound frequency ranges between 1-20 Hz. Infrasound is below the level of human detection, but other animal species are capable of hearing in the infrasonic ranges. Most fish are capable of detecting sound in the range of 3-50 Hz, while eels (Anguillidae) and salmonids hear in the infrasound range and American shad and other herring (Clupeidae) hear in the ultrasonic range (>100 kilohertz). The IFF produces particle acceleration through a range of frequencies between 5 and 16 Hz, targeting fish less than 8 inches in total length. Responses resulting from particle acceleration are related to a direct interaction between particle motion and the otoliths. Sound pressure interacts with the otoliths indirectly via the swim bladder in fish species with a swim bladder present.

The IFF has multiple infrasound generators arranged in a site-specific array. The particle acceleration is created by the opposing movement of two pistons, in an air-filled chamber, 180 degrees out of phase along the same axis. This is accomplished by using a 1.5 kilowatt (kW) electric servomotor to move the pistons. The infrasound from these generators is transmitted nearly omni-directionally, resulting in a spherical signal pattern. The spherical coverage of measurable particle acceleration reaches an approximately 16.5- to 20-foot radius from the center of the generator. The intensity of the signal is reduced quickly. Lab results show a single generator producing 10 percent of the signal at 13 feet when compared to the measured signal at 6.5 feet. The radius of influence with regards to fish deterrence is about 9 feet (Figure 2-27). Typical installations place multiple units in line about 33 feet apart, to amplify the signal and create a solid zone of deterrence.



Source: DWR 2014

Figure 2-26. Schematic of an Otolith Organ



Source: DWR 2014

Figure 2-27. Zones of Influence in Particle Acceleration

A single infrasound generator weighs about 300 pounds in air or about 65 pounds when submerged. Two cables and a compressed air line connect the underwater unit to control systems located on-shore. A power cable transmits power to the servomotor, which uses about 0.5 kW when running. Also, a data cable conveys information that is crucial to operate the machinery. A compressed airline is used to equilibrate the pressure of the air inside the unit and the water pressure created by the hydrostatic head. This equilibration serves two purposes: to lessen the stress on the moving parts of the system and to maintain efficiency of the moving parts (Figure 2-28).

Source: Profish Technologie

Figure 2-28. Infrasound Fish Fence (left) and Infrasound Generators (right)

The IFF system can be designed to operate while anchored to the bottom of the channel or suspended from the top of the surface from buoyant structures. It also is possible to mount the units on a fixed structure, such as a pile, because the generator itself does not vibrate. Because the pistons move 180 degrees out of phase, the energy is transferred to water particle acceleration outside the unit rather than creating vibration of the unit itself.

Background

Some experiments have used acoustic tubes or closed chambers and electric signals to quantify fish responses to the infrasound (Sand and Karlsen 1986).

Other experiments produced qualitative results. Hatchery and captured wild juvenile Pacific salmonids were placed in tanks for observation (Knudsen et al. 1997). The tanks were outfitted with an infrasound generator and video cameras. Juvenile salmonids were exposed to on/off cycles to differentiate behavior relative to the infrasound exposure. All of the salmonid species tested showed a significant response to the infrasound. Wild juvenile Chinook salmon showed the highest response relative to other juvenile salmonids tested (i.e., rainbow trout and hatchery-reared juvenile Chinook salmon) (Mueller 1997). The scientists theorized that such a response possibly resulted from a strong, natural predator–prey instinct, still strongly intact, and that the hatchery-reared juvenile salmonids probably lost or did not develop some of that instinct because of the relatively safe hatchery environment in which they were raised.

One field study included juvenile salmonids and took place at an irrigation diversion near Wenatchee, Washington in 1995. An array of single cylinder, ground-mounted infrasound generators was placed upstream from the intake to deter 3- to 8-inch yearling salmonids from entering the canal. Moderate success was reported in deterring the target species (Dolat et al. 1995).

Profish studied the deterrence efficiency of the IFF in cooling water at Tihange Nuclear Power Plant in Belgium in 2008 and 2009. Data were gathered using echo-sounding and hand counting of fish that were collected on intake screens. Some of the fish species included roach (*Rutilus rutilus*), common bleak (*Alburnus alburnus*), common bream (*Abramis brama*), common nase (*Chondrostoma nasus*), and perch (*Perca fluviatilis*). Profish used on/off cycling to differentiate behavior relative to the operation of the infrasound system. An average of 80 percent deterrence efficiency was reported (Lieve 2009).

Advantages

As with all non-physical barriers, the IFF technology does not affect or impact river flow. Being flow neutral is an advantage because it minimizes impacts on local hydrodynamics, water quality, and ecosystems.

Another advantage is the expected ability to allow larger, non-targeted fish species to pass freely through the array. Because of the nature of the infrasound deterrence, only fish 8 inches and smaller are affected and respond to this type of stimulus. This is beneficial for deterring juvenile salmonids while allowing adults and other species to move freely upstream and downstream.

This technology has the flexibility to be realigned easily to meet changed conditions or to increase its effectiveness. When suspended from buoyant structures, connected by cables, the IFF can be shortened (by removing units), lengthened (by adding units), or realigned. This may prove to be advantageous if different alignments are needed for different seasons because of differing flow patterns. Also, having the ability to change the alignment will allow fine tuning over time, possibly increasing the overall efficiency of the guidance system.

Disadvantages

Similar to other behavioral deterrents, an issue with water velocity related to the target species' swimming speed can occur. As water velocities approach and/or exceed the target species' swimming capabilities, the guidance system becomes less effective. If the water velocity and direction change, the system can be rendered ineffective until the hydrodynamics of the river return back to the ideal design parameters.

Furthermore, one technical issue has slowed down the IFF technology's potential use as a consistent and reliable tool for fish deterrence. The rubber membrane that transfers the energy between the air and water has shown substantial flaws during testing. The problem is the short life span of the membrane. Profish has changed manufacturers in an effort to find a longer lasting combination of material and design. Progress has been made, and Profish expects to meet its goal of a 1-year membrane, although the membrane currently lasts only 3 months. The unit itself can run full-time for 3 years before needing to be rebuilt.

Although it has been tested using hatchery-reared juvenile Chinook salmon in the lab with promising results, it needs to be tested in the field to verify its effectiveness.

Also, the effect that the vibration within the zone of exclusion has on its local environment needs to be considered structurally and ecologically. The unit itself does not vibrate, but the output that the infrasound generator produces creates intense particle acceleration at low frequencies. This can create substantial vibrations on surrounding structures and living organisms. Substantial vibrations on nearby structures, such as bridge supports and levees, have been noted in previous field testing. Understanding the limitations of proximity between the infrasound generators and potentially affected structural entities in the area of concern is important. The ecological impacts of the intense vibration have not been explored yet. Issues such as soil disturbance may affect turbidity and the existing interactions of living organisms, which is another uncertainty that needs to be considered when evaluating this technology as a possible permanent solution.

The infrasound signal has been known to interfere with other electrical systems in the vicinity. In previous installations and applications, Profish was able to comply with electromagnetic compatibility (EMC) regulations by using filters, and no issues have been reported. Depending on the location and the electromagnetic fields that exist, EMC criteria may be challenging or impossible to meet.

2.2.3.3 OTHER OPTIONS

In addition to the physical and non-physical alternatives discussed in the Phase I Initial Findings report, the alternatives of transporting juvenile salmonids by barging or trucking them downstream on the San Joaquin and Sacramento rivers or no action were included. Although these alternatives are not "engineering" options, they should be considered if the physical and non-physical alternatives are ultimately deemed infeasible or would result in unacceptable adverse effects.

Transportation (Barging/Trucking)

Transporting emigrating anadromous juvenile salmonids to downstream release sites is a management strategy that has been implemented for decades, particularly in the Sacramento and Columbia River watersheds. Transportation is a strategy to increase juvenile and smolt survival that is successful during years of low flows or otherwise poor water quality. Trucking is used as a management tool in the Sacramento and Columbia River watersheds and barging is used in the Columbia River watershed. Only hatchery-reared juvenile salmonids are transported downstream in the Sacramento River.

Transporting juvenile hatchery-reared Chinook salmon downstream has been shown to increase smolt survival through ocean entry with increased smolt to adult survival resulting in a larger population of adult salmon available for commercial and recreational harvest, and likely higher instream and hatchery production. However, transport practices can increase straying and have long-term impacts on the genetic diversity and fitness of natural populations (Lindley et al. 2009).

In the Sacramento River watershed, trucking involves receiving hatchery-reared juvenile salmonids from hatcheries and driving them to pre-determined release locations closer to the ocean. Barging is most often used in systems where dams are present along juvenile salmonid emigration routes. In the Columbia River watershed, naturally produced and hatchery-produced fish, acquired from hatcheries and dam fish screen facilities, are trucked and barged to downstream release sites.

Barging is similar to trucking except that during barge transport, water is constantly circulated from the river into holding tanks. Transportation programs are often criticized for contributing to straying and associated adverse effects (e.g., disease and parasite transfer). The natal homing capability of salmonids is believed to be an olfactory-related imprinting process, driven primarily by water quality characteristics, that occurs sequentially as juveniles begin the smoltification process while emigrating downstream toward the ocean. Therefore, the objective of circulating river water in holding tanks during barge transport is to provide juveniles with the imprinting and smoltification processes needed to relocate their natal streams to spawn, thus minimize straying.

Protocols at release sites vary but usually fall into one of two strategies. Some release sites have permanent facilities that include release tubes. At these facilities, fish from transport vehicles are transferred directly to the release tubes and into receiving waters. Piscivorous fishes, birds, and aquatic mammals often become habituated to these sites. These operations do not provide an acclimation period for the transported fish before their release.

Stress from transport and water quality differences between the transport vehicles and release sites can cause post-release shock and exhibit abnormal behaviors, resulting in increased predation rates.

Other release sites incorporate floating, mobile holding net pens. At these release sites, transported fish are transferred directly into holding net pens and acclimated before being released. Predation can also be an issue at these release sites. Mobile net pens allow the juvenile salmonids to participate in a near normal smoltification process which is known to increase survival and reduce straying to non-natal streams.

Trucking operations in the Sacramento River watershed began decades ago. Six hatcheries currently produce anadromous salmonids and service California's Central Valley. Two of the hatcheries are operated by USFWS and four are operated by CDFW. The two federal hatcheries are part of the Coleman National Fish Hatchery Complex. Four hatcheries, all located in the Sacramento River watershed, are involved in CDFW's trucking program.

Hatchery production goals and the percentage of production trucked downstream vary annually among species, runs, and hatcheries. The data provided in Table 2-3 consist of estimates based on annual hatchery production goals and the number of fish received at release facilities in 2011 (Kennedy, pers. comm., 2011).

Table 2-3. Annual Production Goals and Percent Trucked for Central Valley Hatcheries that Produce Anadromous Salmonids

Hatchery	Run Produced		Operator/Owner	Annual Production Target		Percent Trucked		Release Location
	Chinook Salmon	Steelhead		Chinook Salmon	Steelhead	Chinook Salmon	Steelhead	
Coleman	Fall, Late-fall	Winter	USFWS/Reclamation	F = 12 million, LF = 1 million	600,000	F = 10%, LF = 0%	0%	San Pablo Bay
Livingston Stone	Winter	NA	USFWS/Reclamation	250,000	NA	0%	NA	NA
Feather River	Fall, Spring	Winter	CDFW/DWR	F = 8 million, S = 5 million	450,000	F = 100%, S = 25%	0%	San Pablo Bay
Nimbus	Fall	Winter	CDFW/Reclamation	4 million	400,000	40%	0%	San Pablo Bay
Mokelumne River	Fall	Winter	CDFW/EBMUD	5 million	250,000	100%	0%	San Pablo Bay
Merced River	Fall	NA	CDFW/MID	1 million	NA	0%	NA	NA

Notes: CDFW = California Department of Fish and Wildlife; DWR = California Department of Water Resources; EBMUD = East Bay Municipal Utility District; F = fall-run; LF = late fall–run; MID = Merced Irrigation District; NA = not applicable; Reclamation = U.S. Bureau of Reclamation; S = spring-run

Source: Data compiled by AECOM in 2014

Since 1993, the Fishery Foundation of California, a contractor to CDFW, has received trucked juvenile hatchery-reared salmonids and has acclimated and released them in San Pablo Bay. The fish are transferred directly into holding net pens and held for a period of time to allow them to acclimate to ambient water temperatures and salinity conditions before release. The trucking program successfully circumvents sources of juvenile mortality in the Sacramento River and the Delta, but creates potential predation hotspots at release sites in San Pablo Bay. Large numbers of piscivorous predators have a tendency to congregate at frequently used release sites. Therefore, the mobile holding pens are moved often during acclimation and release to address conditioning and predation by piscivorous fish, birds, and aquatic mammals.

Barging has not been used historically in the Central Valley as a means of transportation to increase smolt survival through ocean entry. However, CDFW, with the support of the Commercial Salmon Trollers Advisory Committee, initiated a 3-year study in 2012 to determine whether barging increases smolt survival. During each study year, approximately 100,000 juveniles were barged downstream and released in San Francisco Bay. Two control groups of 100,000 juveniles each were transported downstream via truck and released in different locations at the same time as the barge release to provide a basis for comparison. All juveniles were implanted with coded wire tags to allow researchers to compare survival rates, through return rates, among study groups.

Much of what is known about transporting juvenile anadromous salmonids was learned through research conducted in the Columbia River watershed. Fish passage research began in the 1950s in that watershed in response to high rates of fish loss at hydroelectric dam facilities. The first fish-barging experiment took place on April 19, 1955, when the Washington Department of Fisheries placed 200,000 juvenile Chinook salmon in net pens at the mouth of the Klickitat River and towed them downstream through Bonneville Dam (the most downstream dam in the watershed) to a release site near Skamokawa, Washington. Adult returns from this experiment were low because, according to NMFS biologists, the net pens lacked baffles causing impingement and mortality during transport.

Nonetheless, the transportation experiment continued. In 1968, USACE funded a pilot study implemented by NMFS to collect juvenile salmon and steelhead at Ice Harbor Dam on the Snake River, transport them downstream in tanker trucks, and release them below Bonneville Dam on the Columbia River. The program was expanded during the 1977 drought and included transportation via barging; these barges transported juvenile salmonids onboard in holding tanks. River water was continually circulated through the holding tanks to minimize metabolite buildup and to avoid interference with the homing imprinting process (McCabe et al. 1979). During that same year, alternatives included transportation and aerial release using airplanes. The results from the aerial transportation experiments were not compatible with program objectives, so aerial releases were discontinued. Approximately 47 dams currently operate in the Columbia River watershed. A total of 178 hatchery programs operate in the watershed to mitigate impacts on fish resources caused by construction and operation of hydroelectric dam facilities (Hatchery Scientific Review Group 2009). Most hatcheries are involved in programs to transport juvenile salmonids. Basin-wide strategies to improve passage through hydroelectric dam facilities and increase smolt survival to ocean entry incorporate multiple methods. Among these methods are:

- Providing passage through turbines;
- Using engineered bypass systems, which consist of a series of pipes and channels that channel fish away from turbines and deposit them on the downstream side of dams;
- Opening spill gates to create an aquatic pathway up and over the dam; and
- Transporting fish by truck and barge.

Turbine passage is the most lethal and least desirable passage option, although there are issues associated with each option. Not all fish can be deflected away from turbines into bypass systems. Regardless, diversion screens have been installed in front of the turbines at all but The Dalles Dam. Spillway passage is effective, but this option can expose fish to nitrogen bubbles below the dams when spill volumes are high; this can lead to gas bubble disease. Fish can also be injured as they tumble down the concrete spillways.

All in-river passage strategies leave juvenile salmonids susceptible to predation, especially below dams where conditions are favorable for piscivorous fish, birds, and aquatic mammals. Barging and trucking has proven to be an effective option but may contribute to straying effects. Research shows that transported fish survive to the downstream release points in larger numbers than fish that migrated in the river, but fish that migrate downstream in the river return as adults in greater numbers than transported fish (Arkoosh et al. 2006; Clemens et al. 2009; Halvorsen et al. 2009). The delayed mortality of transported fish is a subject of ongoing research.

No Action

Multiple alternatives have been identified and assessed to identify a solution that would meet the objective of reducing the diversion of emigrating juvenile salmonids to the interior and south Delta. Although an unlikely solution, the alternative of no action also is being considered. Taking no action would be considered if no other alternatives are deemed feasible and/or result in unacceptable adverse effects.

3 METHODS

DWR performed the engineering evaluation using a combination of methods, including research, collaboration, modeling, full-scale technology testing, and assessment of engineering options. The evaluation methods and test results that provide the basis for Chapter 4, "Engineering Evaluations," are described in this chapter.

3.1 INTRODUCTION

The evaluation of engineering options included: forming the TWG with representatives from Reclamation, DWR, NMFS, USFWS, and CDFW, and holding regular meetings; identifying deterrence sites; developing potential conceptual alternatives; field testing BAFF and FFGS deterrence technologies; conducting preliminary site environmental assessments; identifying biological design considerations; reviewing related studies; conducting hydrodynamic monitoring and analysis; conducting computer modeling; developing and implementing an evaluation framework; and assessing and ranking potential engineering options.

3.2 TECHNICAL WORKING GROUP REVIEW MEETINGS

The Action required that "Reclamation and/or DWR shall convene a working group to consider engineering solutions… composed of representatives from USBR, DWR, NMFS, USFWS, and DFG [now CDFW]." DWR coordinated the formation of the TWG to satisfy this requirement. The TWG met six times during Phase I, and 16 times during Phase II and identified potential fish deterrent methods and important evaluation criteria, assisted in the initial screening of deterrent methods and WRAM application development, and participated in the WRAM assessments. Appendix A contains Phase II TWG meeting notes. The Phase I TWG meeting notes are found in the Initial Findings Report (DWR 2013).

The TWG, whose members have unique scientific and engineering expertise, provided valuable input on potential options including identification of additional options for consideration. Based on a general understanding of the deterrence site characteristics and the behavior of fish species of concern, the TWG assisted in the evaluation of options to advance to more detailed analysis. These options included both physical and non-physical technologies. The TWG assisted in application of the WRAM and the detailed comparative option analysis.

3.3 FIELD TESTING OF ENGINEERING OPTIONS

DWR conducted field testing of two options to collect salmonid deterrence data, a BAFF and a FFGS. Testing was directed toward the non-physical BAFF technology about which performance data were limited for tidal riverine systems. BAFF technology is considered to be "flow neutral," a desirable characteristic based on Delta environmental sensitivity and regulatory constraints regarding flow and water quality. BAFF testing first began at the HOR site as part of the DWR Temporary Barriers Program. Subsequently, the BAFF was considered under RPA Action IV.1.3 for testing at the Georgiana Slough site, considered to be a key site where deterrence benefits could be substantial. The BAFF was tested in 2009 and 2010 at the HOR (DWR 2014b in prep.) and in 2011 (DWR 2012) and 2012 at Georgiana Slough (DWR 2014a in prep.). USGS researchers, assisting DWR with the Georgiana Slough tests, observed that juvenile salmonid entrainment was related to the BAFF operation and the fish stream position in the Sacramento River.

As a result of these observations, an additional field test was developed to evaluate the effectiveness of another flow neutral technology to alter the fish stream position farther upstream from Georgiana Slough. The technology was a guidance barrier, or FFGS, which was hypothesized to alter fish stream position by the fish's response to its presence in the river. The FFGS test was performed in 2014 and analysis is ongoing.

The aforementioned field tests and general results are further described in the following subsections.

3.3.1 2009 and 2010 Head of Old River Bio-Acoustic Fish Fence

In 2009 and 2010, a field study of a BAFF was conducted at the San Joaquin River and the confluence of the HOR (DWR 2014b in prep.). Environmental details of the study area are presented in Section 2.2.1, "Site Descriptions." The following is a summary of the 2009 and 2010 studies.

3.3.1.1 Study Purpose, Objectives, and Overview

In April and May of both 2009 and 2010, DWR worked in coordination with Reclamation to design and implement BAFF experimental testing at the divergence of the San Joaquin River and Old River. This divergence is referred to as the HOR. The BAFF was tested as an engineering solution to prevent outmigrant juvenile salmonids from leaving the main stem of the San Joaquin River during downstream migration and entering the Old River channel which leads to the CVP and SWP export facilities. The HOR BAFF studies reflect the idea that some data support the view that juvenile salmonid survival is lower via the Old River route to the Pacific Ocean. For example, in 2008 joint fish-tag survival through the Older River route was 0.05 ± 0.01 while survival through the mainstem San Joaquin River route was 0.09 ± 0.01 (Holbrook et al 2009). The primary objectives of the 2009 and 2010 BAFF studies were:

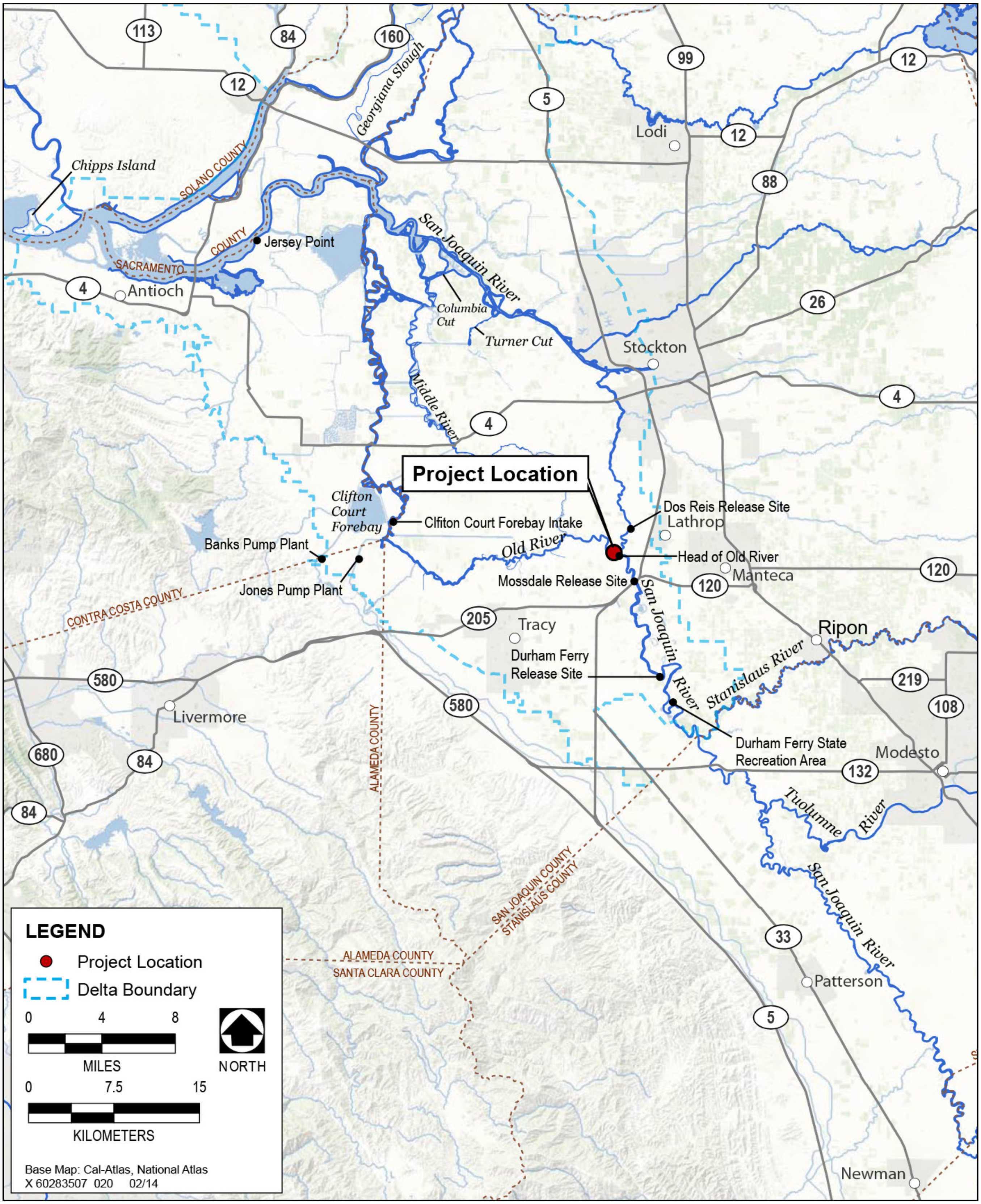
- To determine whether the BAFF was effective in deterring juvenile Chinook salmon from traveling down Old River from the divergence of the San Joaquin River and Old River; and

- To collect and evaluate data to determine how water flows, water quality, and other environmental variables affect BAFF effectiveness.

3.3.1.2 Key Components of 2009 and 2010 Experimental Tests

During the 2009 and 2010 HOR BAFF studies, acoustically tagged juvenile Chinook salmon were released into the San Joaquin River upstream of the divergence with Old River at Durham Ferry (Figure 3-1) State Recreation Area and their downstream migration was monitored past the BAFF. Fish releases were scheduled so that study fish would pass in relatively equal numbers through the HOR study area under a variety of environmental conditions. For example, releases and BAFF operation were scheduled so that 50 percent of fish would pass by the barrier when the barrier was operating (i.e., "ON") and 50 percent would pass by the barrier when the barrier was not operating (i.e., "OFF"). In addition, tidal cycles and daytime/nighttime conditions also were taken into scheduling consideration.

In both 2009 and 2010, fish were tagged at the Tracy Fish Collection Facility and transported to Durham Ferry in two transport trucks with specialized holding tanks. Buckets were carried from the trucks to the San Joaquin River and held in the river for 24 hours, and then the fish were boated out into mid-channel and released. Components and study design of the 2009 and 2010 studies were very similar. A summary is shown in Table 3-1.



Source: DWR 2011

Figure 3-1. Overview of the 2009 and 2010 Head of Old River Non-Physical Barrier Study Area

Table 3-1. Key Components of 2009 and 2010 Testing at the Head of Old River Study Area		
	2009	2010
Dates of Fish Releases	April 22, 2009– May 13, 2009	April 27, 2010–May 19, 2010
Number of Study Fish	933	504
Source of Fish	Fall-Spring hybrid run Chinook Salmon from Feather River Fish Hatchery	Fall-run Chinook Salmon from Merced River Hatchery
Release Location	Durham Ferry, San Joaquin River	Durham Ferry, San Joaquin River
Release Details	Seven releases of about 135 juveniles per release, two releases per day (17:00=daylight release, 21:00 nighttime release)	Seven release days of about 74 juveniles per release group, four release groups per release day. Releases occurred approximately at 1400, 2000, 0200, and 0800 (SJRGA 2011:Table 5-1)
Array Details	Four hydrophones installed around the BAFF (2D array) and one fixed station in the Old River downstream	Eight hydrophones installed around the BAFF, four upstream and four downstream
Barrier Length and Configuration	Barrier length was 367 feet and was oriented at a 24-degree angle eastward from the point of origin on the San Joaquin River west shore (left bank). “Straight” layout.	Barrier length was 446 feet and was oriented at a 30-degree angle eastward from the point of origin on the San Joaquin River west shore (left bank). “Hockey stick” layout.
Source: Data provided by DWR compiled by AECOM 2014		

Figures 3-2 and 3-3 show the hydrophone array (colored dots) and BAFF configuration in the HOR study area in 2009 and 2010, respectively.

In addition to telemetered juvenile Chinook salmon movements, environmental data were collected during the 2009 and 2010 study. Discharge and tidal regime data were gathered from USGS gauge stations near the study area for 2009 and 2010. Hydrodynamic data were collected in 2009 to provide information on the velocity field at the HOR study area. The hydrodynamic data set provided a three-dimensional (3D) water velocity field at discrete time periods. Hydrodynamic data were not collected in 2010. Water temperature and turbidity were also obtained at gauges at or near the HOR study area in 2009 and 2010.

During both the 2009 and 2010 studies, predator fish were captured and acoustically tagged. Residence time and spatial distribution of predatory fish at the HOR study area was provided by acoustic tagging and hydroacoustic surveys. Additional information on predatory fish location was obtained by examining the locations of stationary tags from tags originally inserted into juvenile salmonids. Stationary tags likely represent juvenile Chinook salmon that were preyed on and subsequently defecated by predatory fish (or other predators) (Vogel 2011).

BAFF efficiencies at different photoperiod light levels and channel velocities were evaluated. The light levels considered were dark (less than 5.4 lux) and light (greater than or equal to 5.4 lux), reflecting the threshold above which ambient light may affect juvenile Chinook salmon reactions to strobe lights (Anderson et al. 1988). The channel velocity levels that were considered were “low” (less than or equal to 0.61 meters per second (2.00 feet per second) average channel velocity), and “high” (greater than 0.61 meters per second average channel velocity), derived from the sustained swimming speed capability of juvenile Chinook salmon to swim the necessary distance to avoid the BAFF. The analysis considered these different light levels and channel velocities and how these independent variable might affect barrier effectiveness because of the visibility of the BAFF and the ability of juvenile salmonids to swim at sufficient speed to avoid the BAFF and remain in the mainstem San Joaquin River.

Source: DWR 2014

Figure 3-2. Head of Old River Study Area – 2009 Hydrophone Array and BAFF in Place (red line). The bubble line is visible in this photograph just downstream of the red line that indicates the location of the physical infrastructure that produced the BAFF.

Note: The colored circles represent the locations of hydrophones.
Source: DWR 2014

Figure 3-3. Head of Old River Study Area – 2010 Hydrophone Array and BAFF in Place (red line).

Details about the BAFF technology and deterrence features are presented in Section 2.2.4, “Engineering Options Evaluated.”

3.3.1.3 BARRIER PERFORMANCE EVALUATION METRICS

The HOR study area barrier evaluation determined efficiency, defining “more efficient” as greater juvenile salmonid routing into the San Joaquin River route over that of Old River:

- *Deterrence efficiency* (D_E), the number of juveniles approaching the BAFF that were deterred from continuing their approach to the BAFF, divided by the local numbers of telemetered salmonid juveniles approaching the BAFF. D_E is a measure of the percentage of fish that exhibited movements that appear to be movements away from the BAFF and toward the San Joaquin River, or movements of a fish guided along the line of, and past the end of, the BAFF. This metric was specific to the BAFF and evaluated its efficacy in producing stimuli noxious to the juvenile salmonids approaching it, demonstrated by their lack of motivation to cross the BAFF.

- *Overall efficiency* (O_E), the number of tagged juveniles exiting downstream from the study area via the San Joaquin River, divided by the number of tagged juveniles entering the study area from upstream. This metric provided the most comprehensive measure of barrier effectiveness, as it integrated both routing and loss from predation.

- *Protection efficiency* (P_E), the number of tagged uneaten juveniles exiting downstream from the study area via the San Joaquin River, divided by the number of tagged uneaten juveniles exiting via the San Joaquin River plus the number of tagged uneaten juveniles exiting via Old River. The determination of “eaten” for a telemetered smolt was made by expert opinion. P_E provided a measure of salmonid juvenile routing through the study area, excluding telemetered salmonid juveniles that had been eaten.

3.3.1.4 RESULTS OF BAFF PERFORMANCE BETWEEN 2009 AND 2010 FOR JUVENILE CHINOOK SALMON

Results in this section are based on DWR’s draft report, *An Evaluation of Juvenile Salmonid Routing and Barrier Effectiveness, Predation, and Predatory Fishes at the Head of Old River, 2009-2012* (DWR 2014b in prep.). A summary of mean efficiency values can be found in Table 3-2.[1]

The analysis of barrier effectiveness determined that the BAFF effectively deterred juvenile Chinook salmon from approaching the BAFF in 2009. Of the three measures of efficiency examined (i.e., O_E, P_E, and D_E), only D_E showed a difference between light levels, and it was significantly higher with the BAFF ON in high light conditions in both years. This result may reflect a greater ability of juvenile Chinook salmon to orient away from the BAFF’s principal stimulus (the acoustic deterrent) in high light because of the increased visibility of the BAFF. Overall, D_E was higher in 2009 than 2010, possibly because the discharge was lower in 2009, a larger proportion of the water column was occupied by the BAFF, and the barrier alignment was different. D_E with the

1 Note that the original analyses of BAFF performance in 2009 and 2010 were reported in Reclamation (2012a) and (2012b), respectively. The results summarized in Table 3-2 differ from the original analyses. For example, for Deterrence Efficiency, Reclamation 2009a reported that D_E with the BAFF ON was 81.39% (vs 73.2% reported in DWR 2014b. The reason the reported results are different is that in the Reclamation reports the investigators treated the sample unit as a fish release. But, during analysis for DWR 2014b the investigators decided that approach was less appropriate than analyzing samples with similar states of the BAFF’s operation, light, and velocity. So, they placed the tags into samples based on BAFF, light, and velocity and reanalyzed and the analysis was more robust, provided more samples, and produced better statistical power. Therefore, the results from DWR 2014b are reported herein.

BAFF OFF in 2009 and 2010 was 31.1 percent and 12.0 percent, respectively. These movements may have occurred because the BAFF infrastructure took up some portion of the water column, which may create turbulence or reflect ambient light. In 2009, all fish passed through the barrier under “low velocity” conditions. Thus, no comparisons of D_E in 2009 under various velocity ranges were possible. In 2010, BAFF improved D_E under both low- and high-velocity conditions.

Table 3-2. Summary of Mean Efficiency Values

Year	Overall Efficiency (O_E)				Protection Efficiency (P_E)				Deterrence Efficiency (D_E)			
	On	Off	% Change	Statistically Significant	On	Off	% Change	Statistically Significant	On	Off	% Change	Statistically Significant
2009	20.9%	18.4%	2.5%	No	33.8%	23.4%	10.4%	No	73.2%	31.1%	42.1%	Yes
2010	35.5%	24.5%	11.0%	No	44.1%	28.6%	15.5%	Yes	15.0%	1.2%	13.8%	Yes

Notes: Statistical comparisons based on Kruskal-Wallis Tests.
Source: Data compiled by Turnpenny Horsfield Associates, provided in DWR (2014b in prep.), and adapted by AECOM in 2014

Although the BAFF’s deterrence stimuli were successful in deterring fish from approaching (D_E), the BAFF was not efficient in terms of allowing more juvenile Chinook salmon to leave the HOR study area via the San Joaquin River route (O_E). No significant difference occurred between BAFF ON and BAFF OFF treatments in either 2009 or 2010, and only in 2010 was P_E significantly higher with the BAFF ON. These results reflected predation rates that occurred during BAFF operations. There was no significant difference in O_E and P_E between 2009 and 2010. Discharge was not found to be an important predictor of predation probability.

Salmonid juvenile proportion eaten with BAFF ON was 29 percent in 2009 and 21.7 percent in 2010. The proportion eaten was significantly higher for BAFF ON (29 percent) in 2009 than with BAFF OFF (13.8 percent) (DWR, 2014d). High tag burden of small juvenile Chinook salmon in 2009 (DWR, 2014d: Table 5-3) made the difference between BAFF ON and BAFF OFF hard to interpret. Never the less, it is possible that BAFF operations contributed to increased predation rate in 2009, because the high tag burden was in effect for telemetered Chinook juveniles with BAFF ON and BAFF OFF. There was no significant difference in proportion eaten between BAFF ON and BAFF OFF in 2010. Thus, in 2009, lower discharges and associated lower Average Channel Velocities (ACVs), could have contributed to higher proportion eaten with BAFF ON compared to BAFF OFF. It is possible, in years with low discharge and low ACVs, the BAFF can contribute to higher juvenile salmonid proportion eaten. Any future deployment of a BAFF should carefully monitor predation associated with the BAFF’s operation and predator relocation from the vicinity of the BAFF should be seriously considered.

Data showed time spent in the HOR study area by tagged predatory fishes varied. A single largemouth bass that was tagged in 2009 spent an appreciable amount of time (nearly 50 percent of all detections) within 17 feet of the BAFF. But, that largemouth bass was unique in the study in how much time it spent near the BAFF. Little evidence was shown of striped bass spending much time close to the BAFF in 2009 or 2010, although the number of tagged striped bass during both years was extremely low (N=4). Mobile hydroacoustic surveys in 2011 and 2012 showed that many detections of fish greater than 30 centimeters total length (cm TL) (predator-sized fish) were located in the scour hole just downstream of the divergence in the mainstem San Joaquin River. In 2011, acoustic tag detections of striped bass were highest in the scour hole compared to other areas within the HOR study area (DWR 2014d: Figure 6-20). These data suggest that any technology that directs juvenile salmonids into the scour hole may induce high levels of predation that might not otherwise occur.

Analysis using a generalized linear model (GLM) for both years assessed the potential influence of several environmental variables on the probability of predation of juvenile Chinook salmon in the HOR study area. It also tested the null hypothesis of no difference in predation probability of juvenile Chinook salmon between BAFF ON and BAFF OFF conditions, and suggested that the probability of predation was greater under BAFF on treatments, and that the probability of predation was greater under higher light conditions (presumably because predators could see the juvenile Chinook salmon more easily). These results support the idea that the BAFF's operation could increase predation rates on juvenile salmonids. Therefore, any BAFF deployment should evaluate predation with the BAFF ON and with BAFF OFF. Furthermore, predator relocations away from the BAFF deployment location should be considered. Deterrence away from Old River to a deep scour hole just downstream also may increase predation probability at the HOR study area with the BAFF turned on or with the physical rock barrier installed, as the scour hole was shown to form important habitat for predatory fishes.

3.3.1.5 STUDY CONCLUSIONS

Results of the 2009 and 2010 tests showed no significant difference in overall efficiency between BAFF ON and BAFF OFF treatments. Because of the generally limited effectiveness of the BAFF, study conclusions include recommendations to further study alternative barriers, habitat modification, or predatory fish relocation.

Predation on juvenile Chinook salmon was high in both years, range: 22.9 – 25.9 percent. Overall, it did appear that BAFF operations could increase predation rate. However, there were difficulties with the interpretation of the data and alternative explanations were provided, e.g. BAFF operations could effectively deter Chinook and this deterrence increased the probability that Chinook would enter the scour hole and be eaten. DWR (2014b in prep.) suggested there was a need to conduct a pilot predator relocation study. If the pilot predator relocation study was successful then a full predator relocation component should be implemented with future BAFF deployments. In addition, there is a need to assess the spatial-temporal density and species composition of predatory fish in relation to predation hotspots and related habitat modification could be made, e.g.at the HOR, filling in the scour hole could reduce predation rates locally.

3.3.2 2011 AND 2012 GEORGIANA SLOUGH BIO-ACOUSTIC FISH FENCE

In 2011 and 2012, a field study of a BAFF was conducted at Georgiana Slough (DWR 2012; DWR 2014c in prep.).

3.3.2.1 STUDY PURPOSE, OBJECTIVES, AND OVERVIEW

The primary purpose of the 2011 and 2012 Georgiana Slough Non-Physical Barrier (GSNPB) study was to further test the effectiveness of a BAFF in preventing outmigrating juvenile Chinook salmon and steelhead from entering Georgiana Slough.

The objectives of the 2011 and 2012 GSNPB study were:

- To estimate the effectiveness of the BAFF to successfully deter juvenile Chinook salmon and steelhead from entering Georgiana Slough and encourage them to continue their migration downstream in the Sacramento River;
- To determine the relative contribution of various factors, such as the status of the BAFF (ON/OFF), water velocity, ambient light, and location of fish (2D and 3D) in the channel cross section in the Sacramento River; and

- To examine the behavior, movement, and response of predatory fish, such as striped bass, near the BAFF, and estimate predation on juvenile salmon and the survival of salmon passing through the study area.

The basic concepts of the 2011 and 2012 GSNPB study were similar: to release hatchery-raised juvenile late fall–run Chinook salmon (as well as steelhead in 2012) that had surgically implanted acoustic tags with unique codes into the Sacramento River immediately downstream from Steamboat Slough (Figure 3-4), approximately 5.5 miles upstream from Georgiana Slough, and then to compare the proportion of tagged salmon (and steelhead) entering the study area that successfully migrated downstream in the Sacramento River when a non-physical barrier, the Bio-Acoustic Fish Fence, was ON compared to when the barrier was OFF.

The experimental design of these studies enabled testing of the response of fish encountering the Sacramento River and Georgiana Slough site when the barrier was ON and when it was OFF under a range of environmental conditions (e.g., tidal conditions, day and night, Sacramento River flows, rate of flow entering Georgiana Slough). The overall goal of implementing a barrier at this location would be to reduce the migration of juvenile anadromous salmonids into the interior Delta through Georgiana Slough, where they would be less likely to survive and their vulnerability to entrainment into the SWP and CVP south Delta export facilities would be greater (Perry 2010).

3.3.2.2 KEY COMPONENTS OF 2011 AND 2012 EXPERIMENTAL TESTS

The 2011 and 2012 experimental tests included the following key components:

- Approximately 1,500 late fall-run Chinook salmon for 2011 and 2012, and 299 steelhead for 2012 were produced at the Coleman National Fish Hatchery, were acoustically tagged and released into the Sacramento River. Their downstream migration past the non-physical barrier was monitored;
    - Fish were released every 3 hours, 24 hours a day from March 15 to May 16, 2011, and from March 6 through April 23, 2012, during important migration periods for salmonids.
    - Releases into the Sacramento River were made approximately 5.5 miles upstream from the non-physical barrier to maximize the number of fish that encounter the barrier while also allowing the fish time to adjust to the river conditions and disperse into the channel before encountering Georgiana Slough.
    - Passage of acoustically-tagged salmon and steelhead was monitored upstream from, in the immediate area of, and downstream from the barrier in the Sacramento River and Georgiana Slough, both when the barrier was ON and when it was OFF.
    - Several species of predatory fish were captured, acoustically tagged, released, and monitored to evaluate behavior, movement patterns, and potential predation of tagged juvenile Chinook salmon and steelhead, in association with the presence and operations of the non-physical barrier.

Source: Data provided by DWR and adapted by AECOM in 2012

Figure 3-4. Overview of the 2011 and 2012 Georgiana Slough Non-Physical Barrier Study Area

- Multiple hydrophones were installed in the Sacramento River, immediately upstream from, downstream from, and adjacent to the barrier to monitor movements of tagged fish as they encountered and responded to the barrier. These hydrophones are referred to as the array at the barrier or study array. The study array allowed for 3D positioning of the acoustic transmitters (tags). The pathway of a tag, over or under the BAFF, was determined for each tag that crossed the BAFF alignment. Additional hydrophones, referred to as the peripheral hydrophones, were installed to detect tagged fish in channels upstream and downstream from the study array.

- Multiple acoustic Doppler current profilers were installed in the Sacramento River in the vicinity of the barrier to monitor local currents, water velocities, and general hydrodynamics; and

- Active multi-beam hydroacoustic devices, including a DIDSON (Dual-Frequency Identification Sonar) camera, were installed to monitor fish densities in the immediate vicinity of the barrier.

3.3.2.3 BARRIER PERFORMANCE EVALUATION METRICS

The following evaluation metrics of barrier performance were compared between barrier ON and barrier OFF conditions using the results of acoustic tracking in the 2011 and 2012 GSNPB study:

- *barrier efficiency* was evaluated three ways (D_E, P_E, and O_E):
  - D_E: the proportion of tagged juvenile Chinook salmon and steelhead detected in the hydrophone array that moved away from the non-physical barrier infrastructure line;
  - P_E: the proportion of tagged juvenile Chinook salmon and steelhead that were detected by the hydrophone array, survived to the barrier (i.e., avoided predation or other sources of mortality), moved past the barrier, and reached the peripheral hydrophones downstream in the Sacramento River at Ryde Hotel, rather than reaching the peripheral hydrophones in Georgiana Slough; and
  - O_E: the proportion of tagged juvenile Chinook salmon and steelhead entering the study area (i.e., detected by the hydrophone array) that subsequently were detected at the peripheral hydrophones downstream in the Sacramento River at Ryde Hotel, accounting for losses of fish migrating into Georgiana Slough and predation losses in the area where the study array was located adjacent to the barrier.

- *probability of entrainment*: generalized linear modeling of tagged fish to predict fates based on several factors, including BAFF operation and environmental conditions; and

- *survival and route entrainment probabilities*: model predictions of fish survival from one location to another based on route entrainment/selection and other factors.

3.3.2.4 STUDY RESULTS AND FINDINGS

The results and findings of the 2011 and 2012 GSNPB study are summarized as follows (DWR 2012; DWR 2014c in prep.):

- Statistical analysis of the 2012 data showed that the percentage of juvenile Chinook salmon entrained into Georgiana Slough was reduced from 24.4 percent (BAFF OFF) to 11.8 percent (BAFF ON), a reduction of approximately one-half. During the 2011 study period, operation of the BAFF reduced the percentage of juvenile Chinook salmon passing into Georgiana Slough from 22.1 percent (BAFF OFF) to 7.4 percent (BAFF ON); a reduction of approximately two-thirds of the fish that would have been entrained. The magnitude of juvenile Chinook salmon migration into Georgiana Slough when the BAFF was OFF was similar between the 2 years as was the percentage reduction in the risk of entrainment into Georgiana Slough when the BAFF was ON (a reduction of 12.6 percentage points in 2012 and 14.7 percentage points in 2011). In both years, operation of the BAFF contributed to a reduction in the movement of juvenile Chinook salmon from the Sacramento River into Georgiana Slough;

- A comparison of the 2012 and 2011 data for juvenile Chinook salmon found no statistically significant differences in deterrence efficiency, protection efficiency, or overall efficiency when the BAFF was ON compared to Off in either of the two study years (Table 3-3). In addition there were no statistically significant differences between years for the three metrics of interest: 1) the deterrence efficiency when the BAFF was ON was 56.1 percent in 2012 and 49.8 percent in 2011; protection efficiency when the BAFF was ON was 89.0 percent in 2012 and 88.7 percent in 2011; overall efficiency when the BAFF was on was 89.7 percent in 2012 and 89.1 percent in 2011. Similarly, no statistically significant differences were detected in D_E, P_E, or O_E when the BAFF was ON under low and high light levels or during low and high water velocities between 2012 and 2011. These results suggest that despite the large differences in Sacramento River flows during the 2012 and 2011 surveys, operation of the BAFF provided consistent P_E and O_E in reducing the risk of juvenile Chinook salmon entrainment into Georgiana Slough;

Table 3-3. Summary of Mean Efficiency Values

Year	Overall Efficiency (O_E)				Protection Efficiency (P_E)				Deterrence Efficiency (D_E)			
	On	Off	% Change	Statistically Significant	On	Off	% Change	Statistically Significant	On	Off	% Change	Statistically Significant
2011	89.1%	73.4%	15.7%	Yes	88.7%	72.7%	16.0%	Yes	49.8%	28.5%	21.3%	Yes
2012	89.7%	75.2%	14.5%	Yes	89.0%	74.6%	14.4%	Yes	56.1%	40.9%	15.2%	Yes

Notes: Statistical comparisons based on Kruskal-Wallis Tests.
Source: Data compiled by Turnpenny Horsfield Associates, provided in DWR (2014b in prep.), and adapted by AECOM in 2014

- The estimated survival probability for juvenile Chinook salmon in the Sacramento River upstream from the BAFF (from point of release to the BAFF) in 2012 was 78.3 percent, which was 17.4 percentage points lower than the survival estimated in 2011 (95.7 percent). Flows and turbidity in the river were lower in 2012 compared to 2011, which may have contributed to greater predation mortality in the river upstream from the BAFF. The hypothesis is that high flows in the Sacramento River and corresponding increased water velocities and turbidity levels may have contributed to the relatively low level of predation on juvenile Chinook salmon estimated during the 2011 tests. Based on the similarity between estimates of P_E and O_E observed in both the 2012 and 2011 studies, the effects of predation on juvenile Chinook salmon in the immediate vicinity and downstream from the BAFF were low;

- Analysis using a GLM for both the 2012 and 2011 studies found that river discharge (which is correlated with water velocities), the cross-sectional location of the fish in the Sacramento River, and BAFF operations were important predictors of fish behavioral response to the BAFF and entrainment into Georgiana Slough in both study years;

- Results of the 2012 tests showed that at substantially lower Sacramento River flow rates, BAFF operation consistently reduced the probability that juvenile Chinook salmon would be entrained into Georgiana Slough. Simulation model results using the 2012 test data showed that under very low Sacramento River flows, tidally driven reverse flow into Georgiana Slough increases the risk of juvenile Chinook salmon entrainment, although operation of the BAFF is predicted to reduce this risk (DWR 2014c in prep.). Under relatively high river flows during the 2011 tests (approximately 43,000–45,000 cfs river flow entering the river junction at Georgiana Slough), BAFF operations consistently reduced the probability that juvenile Chinook salmon would be entrained into Georgiana Slough;

- The interaction of the cross-sectional position of the fish with river flow was the predominant factor that influenced the risk of juvenile salmonids entrainment into Georgiana Slough. Under the GLM, the location of a fish in the river channel cross-section was the most important driver of an individual fish's probability of entrainment into Georgiana Slough in both 2011 and 2012. Under conditions of relatively lower river flow and velocity in 2012 (compared to 2011), juvenile salmonids may have had a greater opportunity to respond to the BAFF and flows entering Georgiana Slough, although results of the 2012 study were consistent with those from 2011 in showing that the location of fish in the river channel was a strong influence on the risk of entrainment into Georgiana Slough. Under the high flow (and high-velocity) conditions in 2011, BAFF operation was less effective for fish located close to the east side of the river channel (left bank). These results suggest that fish in this area cannot behaviorally respond to the BAFF and swim away from it fast enough under high-flow conditions to avoid being swept across the barrier and into Georgiana Slough;

- Results of a comparison of the 2011 and 2012 studies using juvenile Chinook salmon found no statistically significant differences in deterrence efficiency, protection efficiency, or overall efficiency when the BAFF was ON compared to OFF in either of the two study years. The deterrence efficiency when the BAFF was ON was 56.1 percent in 2012 and 49.8 percent in 2011. Protection efficiency when the BAFF was ON was 89.0 percent in 2012 and 88.7 percent in 2011. Overall efficiency when the BAFF was ON was 89.7 percent in 2012 and 89.1 percent in 2011. Similarly, no significant differences were detected in deterrence, protection, or overall efficiency when the BAFF was on under low and high light levels or during low and high water velocities in either 2011 or 2012. These results suggest that despite the large differences in Sacramento River flows during the 2011 and 2012 surveys, operation of the BAFF provided consistent protection and overall efficiency in reducing the risk of juvenile Chinook salmon entrainment into Georgiana Slough;

- Acoustic telemetry data indicated that predators were located primarily near the river margin, which reduced the rate of encounters with juvenile salmonids that tended to migrate closer to the center of the channel. The relatively low Sacramento River discharges in 2012 may have provided a different bioenergetic landscape than occurred under higher flow conditions in 2011. Estimates of the probability of survival for juvenile salmonids in the river upstream from the BAFF showed higher predation mortality when flows were lower in 2012, compared to the higher flow conditions in 2011; and

- The analysis hypothesized that a non-physical barrier such as the BAFF may attract predatory fish, thus increasing predation mortality for juvenile salmonids. To examine this hypothesis, predation frequencies were estimated for areas within 3 feet of the BAFF and were compared to predation rates farther from the BAFF in the Sacramento River. The results did not support the hypothesis that the presence of the BAFF increases predation mortality for juvenile salmonids in the immediate vicinity of the non-physical barrier. The similarity between protection and overall efficiency observed in 2012 when the BAFF was ON and OFF supports the findings in 2011, which showed that one predation event occurred within 3 feet of the BAFF and 48 events occurred in the larger array area. If the BAFF were to be used as a long-term management tool, predators could become conditioned to BAFF operations, which may allow them to alter their behavior from that observed in 2012 and 2011. In addition, the habitat selected by predators and the movement patterns of predators in the Sacramento River adjacent to the BAFF might vary within and between years, in response to factors such as river flow and velocities, water temperatures, prey abundance, and recreational harvest. These factors, in combination with possible conditioning to BAFF operations, could result in different predation rates than those observed during 2012 and 2011.

3.3.2.5 STUDY CONCLUSIONS

The results of the 2012 tests showed that when the BAFF was ON, a statistically significant increase occurred in D_E, P_E, and O_E for juvenile Chinook salmon and steelhead; that is, fewer of the tagged Chinook salmon and steelhead migrated into Georgiana Slough when the BAFF was ON than when it was OFF. For example, The BAFF ON operations resulted in greater deterrence (15.2 percentage point improvement), protection (14.4 percentage point improvement), and overall efficiency (14.5 percentage point improvement) than the BAFF OFF operations. Results of route selection and entrainment analyses were consistent with D_E, P_E, and O_E analyses, showing an approximate 52 percent reduction occurred in entrainment into Georgiana Slough when the BAFF was ON (11.8 percent) compared to when it was OFF (24.4 percent) for juvenile Chinook salmon in 2012, with a similar reduction (approximately 50 percent) observed for steelhead when the BAFF was ON (11.6 percent) and when it was OFF (26.4 percent). The cross-sectional location of fish in the Sacramento River channel when migrating past Georgiana Slough, river flow, and BAFF operation were determined to be important factors, influencing the probability that a juvenile Chinook salmon would migrate from the Sacramento River into Georgiana Slough during both 2012 and 2011. Overall, based on a variety of alternative methods and metrics for data analysis, study results in 2012 and 2011 over a range of Sacramento River flow conditions consistently showed that BAFF operations contributed to a reduction in the migration of juvenile salmonids into Georgiana Slough. Thus, BAFF operations would likely result in an incremental increase in through-Delta survival of emigrating Sacramento River juvenile salmonids. The study design for the 2012 and 2011 tests did not include acoustic tag monitoring downstream at Chipps Island or the Golden Gate; therefore, the effects of BAFF operations on juvenile salmonid survival to these sites could not be determined.

The results of BAFF evaluations at Georgiana Slough were different from those at the Head of Old River. DWR (2012 and 2014c) showed the BAFF consistently contributed to a reduction of juvenile salmonid entrainment into Georgiana Slough. In addition, the BAFF in the Sacramento River did not appear to cause increased mortality due to predation when ON. At the HOR, DWR (2014b) showed the BAFF consistently deterred juvenile salmonids just like the BAFF at Georgiana Slough. But, DWR (2014b) showed that the BAFF may increase the probability of predation when ON. The key difference was that at Georgiana Slough the BAFF did not direct the juvenile salmonids toward an area of high predator density that could lead to predation. But, at the HOR the BAFF directed the smolts toward the scour hole which exhibited high predator density and resulted in a high proportion of defecated tags. Thus, the local river morphology/conditions may have an important influence on a BAFF's ability to meet management objectives.

3.3.3 2014 Georgiana Slough Floating Fish Guidance Structure

In 2014, a field study of a FFGS was conducted at the divergence of Georgiana Slough and the Sacramento River DWR 2013d). Environmental details of the study area are presented in Section 2.2.1, “Site Descriptions.” The following is a summary of the 2014 study.

3.3.3.1 Study Purpose, Objectives, and Overview

In April 2014, DWR implemented FFGS experimental testing at the divergence of the Sacramento River and Georgiana Slough. The FFGS was tested as an engineering solution to prevent outmigrant juvenile salmonids from leaving the main stem of the Sacramento River during downstream migration and entering the Georgiana Slough channel which leads to increased vulnerability to entrainment into the CVP and SWP export facilities. The Georgiana Slough FFGS study reflects the general view that juvenile salmonid survival is lower via the Georgiana Slough route through the Delta. The primary objectives of the 2014 FFGS study were:

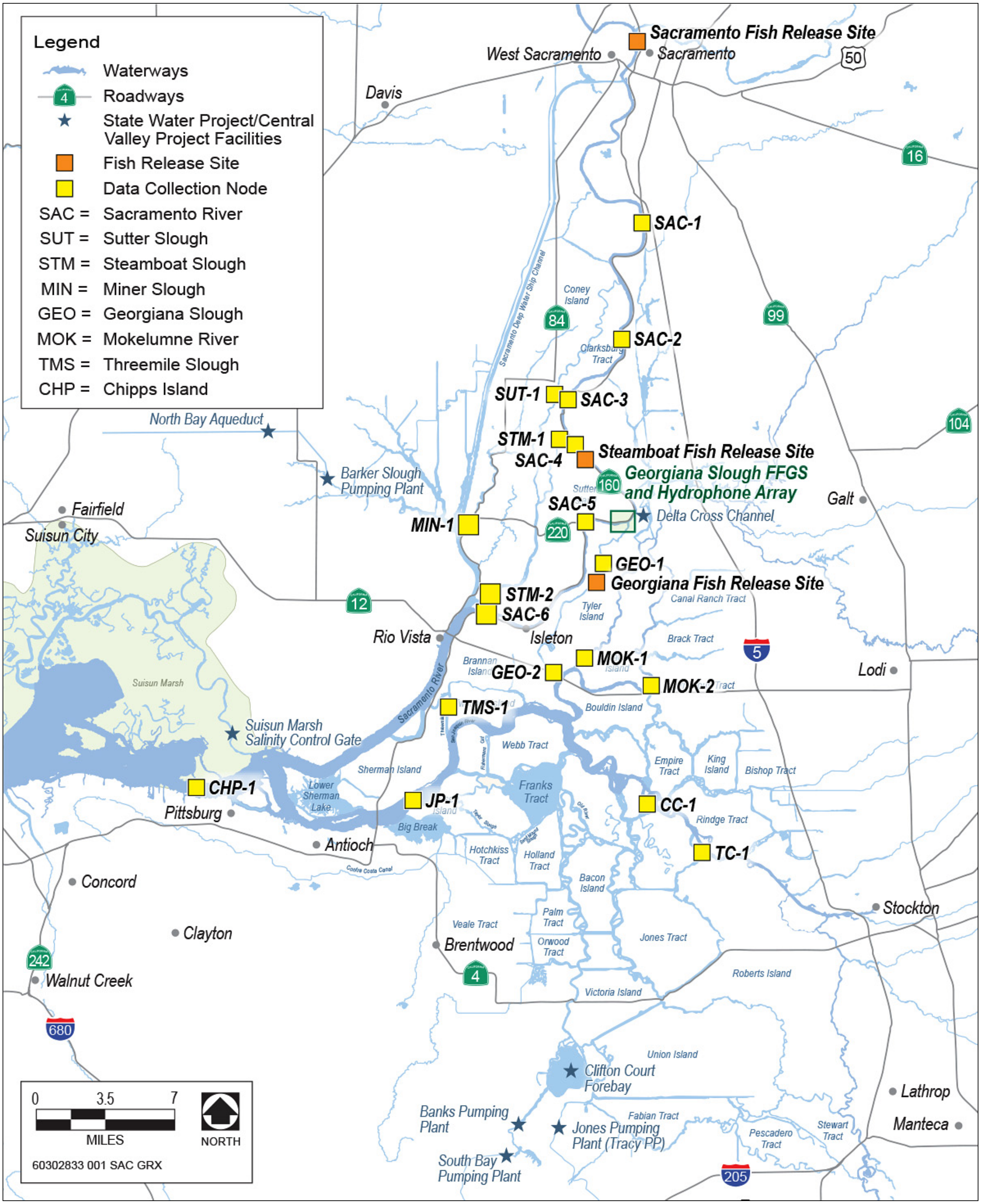
- Gain understanding of the behavioral response of fish that encountered the FFGS;
- Compare the reduction of migration of juvenile salmon into the interior Delta through Georgiana Slough between the FFGS ON and OFF positions; and
- Calculate the difference in survival out of the Delta between the different routes and the contribution of relative survival the FFGS provided.

3.3.3.2 Key Components of the 2014 Experimental Tests

During the 2014 Georgiana Slough FFGS study, 5,500 late fall-run acoustically tagged juvenile Chinook salmon were released into the Sacramento River at the City of Sacramento (Old Sacramento) located approximately 35 river miles upstream of Georgiana Slough, and at one location in Georgiana Slough approximately 3 miles downstream of the divergence (Figure 3-5). A summary of key components of the 2014 study is presented in Table 3-4. Fish released at Sacramento were monitored as they migrated past the FFGS. Fish releases were scheduled so that study fish would pass in relatively equal numbers through the Georgiana Slough study area under a variety of environmental conditions when the FFGS was turned ON (i.e., deployed in the river at the design angle) and OFF (i.e., deployed immediately adjacent and parallel to the left bank of the Sacramento River. Figures 3-6 and 3-7 show the FFGS configuration in the study area and the hydrophone array (colored dots) and in 2014, respectively.

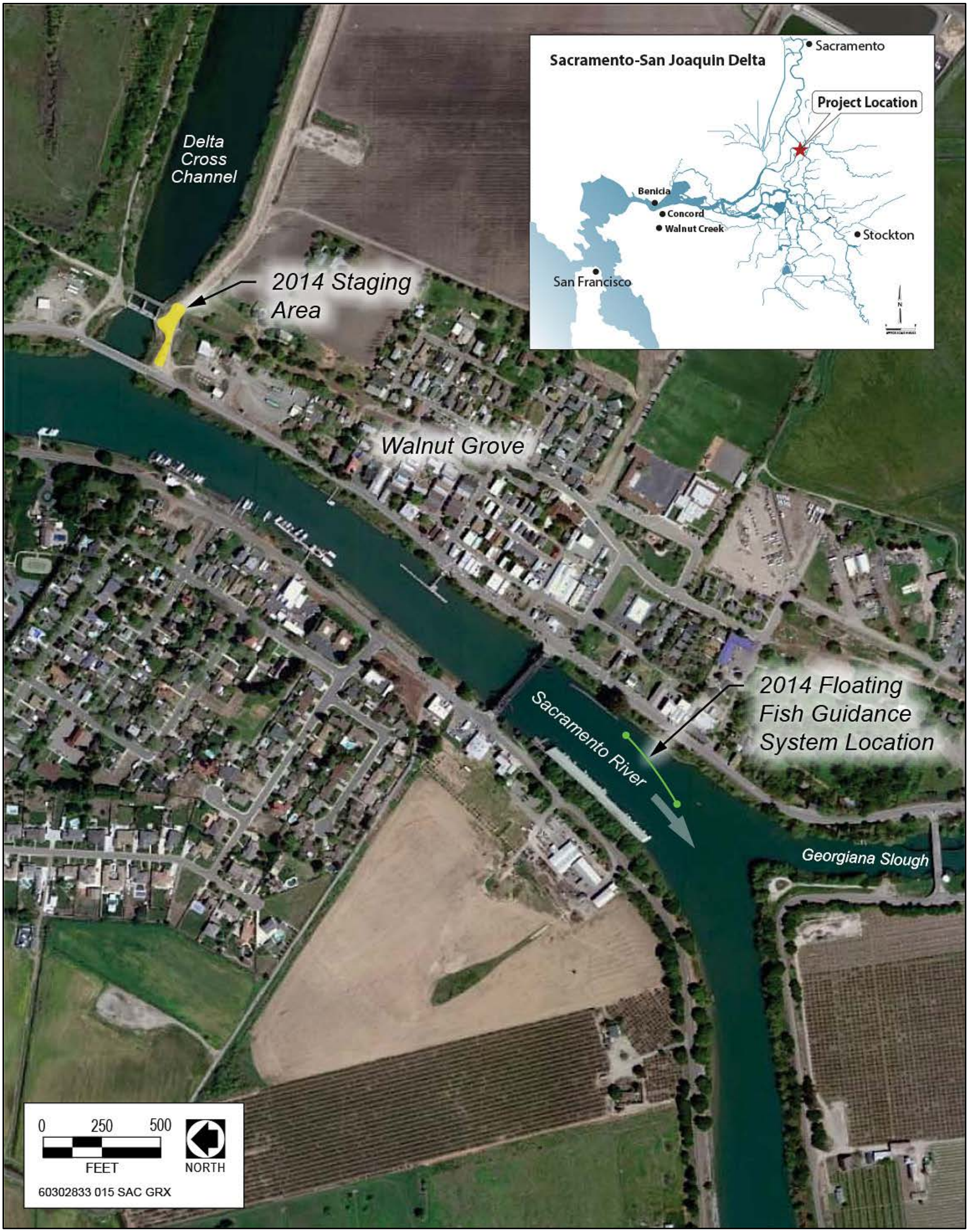
Also during the 2014 study, 195 predatory fish were captured in the vicinity of the FFGS and acoustically tagged.

In addition to fish movement, environmental data were collected during the 2014 study. Discharge and tidal regime data were gathered from USGS gauge stations near the study area. Hydrodynamic data were also collected to provide information on the velocity field at the study area. These data sets provided a multidimensional water velocity field at discrete time periods. Water temperature, turbidity, and ambient light were also measured in the FFGS study area.



Source: AECOM 2013

Figure 3-5. Study Area Location



Source: DWR 2013 adapted by AECOM 2013

Figure 3-6. FFGS Location

Source: DWR 2013

Figure 3-7. Preliminary Hydrophone Placement for Monitoring the Georgiana Slough 2014 Physical Barrier (inset) and Surrounding Area

Table 3-4. Key Components of 2014 Testing at the Georgiana Slough Study Area	
Dates of Fish Releases	February 28, 2014 – April 18, 2014
Number of Study Fish	5,500 juvenile Chinook salmon and 195 predatory fish
Study Fish Species	Late fall-run Chinook salmon from Coleman Fish Hatchery
Release Locations	Juvenile Chinook salmon released from Sacramento River at the City of Sacramento located approximately 35 river miles upstream of Georgiana Slough Juvenile Chinook salmon released into Georgiana Slough approximately 3 miles downstream from the divergence with the Sacramento River Predatory fish released in the Sacramento River just upstream from the divergence of Georgiana Slough from the public dock in the town of Walnut Grove.
Juvenile Chinook Release Details	Sacramento River releases were conducted 8 times per day (0000, 0300, 0900, 1200, 1500, 1800, 2100) Georgiana Slough releases were conducted 4 times per day (0300, 0900, 1500, 2100)
Array Details	About 50 hydrophones were installed around the FFGS (2D array)
Barrier Length and Configuration	Barrier length was 350 feet with fish guidance solid plate panels extending downward into the water a maximum of 5 feet and was orientated in a southwesterly direction from the point of origin on the Sacramento River east shore (left bank) just upstream of Georgiana Slough. Slightly convex in layout.
Source: Data provided by DWR and compiled by AECOM 2014	

3.3.3.3 BARRIER PERFORMANCE EVALUATION METRICS

Barrier evaluation will judge efficiency, defining "more efficient" as a greater use by juveniles of the Sacramento River route (over that of Georgiana Slough) to leave the study area. The following efficiency measurements will be calculated:

- *Overall efficiency* (O_E), the number of tags, originally inserted in juvenile chinook salmon, exiting downstream from the study area via the Sacramento River, divided by the number of tags, originally inserted in juvenile chinook salmon, entering the study area. This metric provides the most comprehensive measure of barrier effectiveness, as it measures losses from all sources, including routing and predation.

- *Protection efficiency* (P_E), the number of tagged juveniles exiting downstream from the study area via the Sacramento River, divided by the number of tagged juveniles exiting via the Sacramento River plus the number of tagged individuals exiting via Georgiana Slough, but considering only those juveniles that were not eaten in the study area. This metric provides a measure of salmonid juvenile routing through the study area, excluding fish that were preyed on.

3.3.3.4 RESULTS OF FFGS PERFORMANCE FOR JUVENILE CHINOOK SALMON

The 2014 FFGS data collection effort was completed in April 2014. A complete analysis of the FFGS performance is on-going (as of December 2014).

3.4 SITE ENVIRONMENTAL EVALUATIONS

A preliminary evaluation was conducted for each of the five study sites to identify environmental issues that may require further evaluation before finalizing project designs. The preliminary evaluation generally used the environmental checklist form in Appendix G of the California Environmental Quality Act (CEQA) Guidelines (California Code of Regulations, Title 14, Division 6, Chapter 3, Sections 15000-15387). A discussion of the study sites is presented in Section 2.2.1, "Site Descriptions." Site access, staging areas, and material stockpile areas were not identified outside the boundaries of each location, and therefore were not assessed for potential environmental issues. The preliminary evaluation included an assessment of permits or authorizations that may be required from federal, state, regional, and local agencies with regulatory jurisdiction over the environmental resources identified at each site.

Appendix C, "Environmental Checklists," contains site-specific environmental constraints and regulatory requirements information for each of the five sites.

3.5 BIOLOGICAL DESIGN CONSIDERATIONS

Biological design considerations are essential to develop and evaluate engineering solutions aimed at reducing the entrainment of emigrating juvenile salmonids into the interior and south Delta, and decreasing their exposure to CVP and SWP water export facilities. This section identifies and discusses the following biological design considerations and their implications to juvenile salmonid behavior in the Delta: sensory modalities, swimming capacities, migratory behavior, cognitive ecology, abiotic factors affecting behavior at barriers, and potential barrier effects on other fish species of concern.

3.5.1 JUVENILE SALMONID SENSORY MODALITIES

Virtually all fish, including salmonids, use the same sensory systems to monitor their surroundings and maintain regular swimming position, but the sensitivity and importance of the different systems can vary among species, at different life stages, and under different environmental conditions (Mussen and Cech 2014). Light, sound, and pressure are addressed in this section relative to their effects on juvenile and smolt Chinook salmon and steelhead physiology and behavior.

3.5.1.1 LIGHT

The eye provides salmonids with the capacity for vision and is composed of an anterior chamber, an iris, a lens, and a posterior chamber lined by light-sensitive cells, i.e. the retina. The retina provides information to the brain which assists fish with navigating through and recognizing obstructions in the water column, maintaining swimming positions, and locating prey by detecting differences in contrasting light levels. When vision is reduced or absent, fish rely on their other sensory systems, such as the lateral line or olfactory capabilities (Mussen et al. 2014). The wavelengths visible to salmonids change between alevin to parr, parr to smolt, and smolt to adult life stages (Flamarique 2005). For example, ultraviolet sensitivity diminishes during the parr to smolt transformation in preparation for ocean emigration and the light conditions of the epipelagic marine habitat. In contrast, ultraviolet sensitivity returns as adults re-enter freshwater habitat to spawn in their natal stream (Flamarique 2000; Allison et al. 2003).

Chinook Salmon

Salmonids have four cone visual pigments. The maximum absorbance for ultraviolet (UV) (λmax: 357–382 nanometers [nm]), blue (λmax: 431–446 nm), green (λmax: 490–553 nm), and red (λmax: 548–607 nm) parts of the spectrum. They also possess a rod visual pigment with peak absorbance (λ_{max}) of 504-531 nm (Flamarique 2005).

Synchronized High Intensity Lights (HILs, based on light-emitting diode (LED) technology, and known previously as strobes) were tested as part of a multiple-component NPB (that included HIL, acoustic, and bubble stimuli) in the laboratory with juvenile Chinook salmon (Bowen et al. 2010a). In the laboratory trial, modelled on the Sacramento River–Georgiana Slough bifurcation, juvenile Chinook were deterred by an NPB that included synchronized HILs, which emit light ranging between 431 and 607 nm (Lambert, pers. comm., 2014).

In rivers where flow direction and speed may direct fish movement, strobe light systems can be less effective at repelling juvenile Chinook salmon (Mussen et al. 2014). In addition, light avoidance behaviors can delay fish from migrating downstream, increasing their predation risk (Perry et al. 2010).

Amaral et al. (1998) reported that caged juvenile Chinook salmon exhibited strong avoidance to strobe lights during night testing, but little or no reaction during day or early evening tests. This supports findings by the Electric Power Research Institute (EPRI 1994); background illumination during the day often dilutes light from the stimulus, making it less effective, while at night the ambient light is reduced and strobe lights may have greater deterrence efficiency. However, in a flume simulation, LED strobe lights were 18 percent more efficient in repelling juvenile Chinook salmon during day than at night (Mussen et al. 2014). In addition, Baker (2008) reported that the juvenile Chinook salmon impingement rate increased during nighttime hours, together with higher dissolved oxygen and lower temperatures; however, no statistical evidence showed that these abiotic factors were affecting the efficiency of strobe light, sound, and hybrid deterrent systems.

Perry et al. (2014) reported that a BAFF located in the Sacramento River to divert juvenile Chinook salmon from Georgiana Slough had similar performance in deterring fish between day and nighttime; this may have been because of high turbidity that was muting the BAFF's light intensity and was limiting the use of visual cues by salmon. These results possibly were affected by the fact that some juvenile Chinook show lower activity levels during the day to hide from predators (Bradford and Higgins 2001; Zajanc et al. 2013). The BAFF tested in 2009 and 2010 at the HOR showed substantial deterrence efficiency for juvenile Chinook salmon during the day, although the deterrence efficiency was lower at night (DWR 2014d). The authors attributed this improved deterrence during the day to the presence of additional visual cues available to avoid the BAFF (DWR 2014d). Tests conducted in a cement raceway showed that juvenile Chinook salmon showed a variety of behaviors in response to strobe and mercury lights, such as active, passive, and hiding behavior, primarily influenced by ambient light intensity (Nemeth and Anderson 1992). The greatest change produced by both type of lights was in night testing, using juvenile Chinook and coho adapted to normal conditions, when exposure to light greatly increased fish activity (Nemeth and Anderson 1992).

There appears from this variety of publications that a Chinook juvenile's response to light, especially strobe lights, may be due to the exact combination of life stage/smoltification/size of fish, strobe light characteristics (emittance spectrum, flash rate, flash duration, etc.), ambient light, and turbidity/water clarity. With the advent of "smart lighting," strobe light performance may be controlled in the short-term for a particular location, season, time of day, and species of fish targeted. The only way to fine-tune the optimal operating characteristics would be to conduct studies of juvenile Chinook response to various strobe light models and various light operation characteristics. In addition, in these experiments light operation can be changed according to the season (day length, turbidity levels expected), time of day (sunrise/sunset, ambient light expected) and altered during each of these to dynamically change to maximize responses. Experimentation could develop the optimal settings for this type of dynamic control now that smart light programming is available in many strobe light operational systems.

Steelhead

Juvenile steelhead possesses retinal photoreceptor mechanisms, able to detect ultraviolet, short, middle, and long wavelengths (Browman and Hawryshyn 1992). They also have rods and single and double cones containing five spectrally distinct visual pigments or photoreceptors with mixtures of visual pigments. The mean λ_{max} of the α-bands are 521 nm in the rods, 365 and 434 nm in single cones, and 531 and 576 nm in double cones. The relative amounts of pigments are dependent on life stage in relation to ocean migration, seasonality, and environmental factors such as photoperiod and temperature (Hawryshyn and Harosi 1994). For steelhead from the Cowichan River (Vancouver Island, Canada), the spectral sensitivity ranged from 340 to 660 nm, with elevated sensitivity in the range of 360 to 640 nm (Parkyn and Hawryshyn 2000). Thus, lights used to deter steelhead should be in the range of 360 to 640 nm.

Response to strobe lights and other lights often is dependent on the time of day; this effect probably is because of the ambient light present. For example, Puckett and Anderson (1988) carried out tests on hatchery-reared pre-smolt steelhead to investigate their response to strobe and mercury vapor lights. During night testing, the fish showed avoidance behavior to strobe lights that were produced by an EG&G Electro-Optics Model SS-122 strobe light with flash frequency of 300 flashes per minute. No avoidance to the same treatment was observed during daytime testing. Moreover, pre-smolt steelhead under-yearlings were attracted to mercury vapor light during night testing, but not during day testing. The mercury vapor light was produced by a Hydro-Products Model L2 light (1,000 Watt).

DWR (2014e) reported that the BAFF that was located at the divergence of the Sacramento River and Georgiana Slough in 2012 produced substantially higher overall steelhead efficiency under low light compared to high light. Johnston et al. (2004) reported that juvenile steelhead, when given the choice between light and darkness, showed a preference for the latter. This behavior seems to be especially present in younger juveniles perhaps because they are more vulnerable to predation than older fish (Bradford and Higgins 2001; Johnston et al. 2004). Effectiveness of strobe lights in diverting fish from a power plant forebay was tested; results showed that juvenile steelhead actively swam away from the test strobe lights at night, and showed no preferred swimming direction when the strobe lights were off at night (Johnston et al. 2004). The same response to the strobe lights was not found during the day; moreover, flow seemed to be an important factor in determining whether the fish avoided the strobe lights, especially at night when the flows were lower (Johnston et al. 2004).

3.5.1.2 SOUND AND PRESSURE

Fish have several organs capable of sound and pressure (vibration) perception. These organs include the swim bladder, otoliths, and lateral lines. Some species have all organs present, while others have only one. The swim bladder can be absent (e.g., Pacific lamprey, *Entosphenus tridentatus*), open or physostomous (e.g., salmonids), or closed or physoclistous (e.g., bluegill, *Lepomis macrochirus*). Additionally, most fish that are physoclistous as adults are physostomous as larvae which enabled initial swim bladder inflation by gulping air (e.g., striped bass) (Bailey and Doroshov 1995). Sound can affect fish in a range of ways, such as act as an attractant, deterrent, and under extreme circumstances cause tissue damage and mortality. The swim bladder type and characteristics of the sound and pressure are important factors that can influence fish behavior and the effects are species and life stage specific. See Popper and Hastings (2009) for a detailed review of the effects of anthropogenic sources of sounds on fish.

The sensitivity of several fish species to acoustic deterrents was investigated by Fish Guidance Systems (Southampton, United Kingdom), which reported that the most effective acoustic deterrents for multiple species applications fall within the sound frequency range of 5 to 600 Hz (DWR 2014). This concurs with findings that different salmonid species detect sounds from below 30 Hz to over 600 Hz (Halvorsen et al. 2009).

Chinook Salmon

Chinook salmon have a physostomous swim bladder, otoliths, and lateral lines. Measurements from Oxman et al. (2007) and Halvorsen et al. (2009) showed that juvenile Chinook salmon can detect sounds from 50 to 1,000 Hz, with the highest sensitivity ranging from 60 to 250 Hz. However, two studies report avoidance responses to a 10 Hz infrasound frequency in young-of-the-year Chinook salmon of 40 to 45 millimeters (mm) total length (Knudsen et al. 1997; Mueller et al. 2001). Another study subjected wild juvenile Chinook salmon of 30 to 70 mm total length to low (7 to 14 Hz) and higher frequency (150, 180, and 200 Hz) sound fields. Wild juvenile Chinook salmon responded to infrasound with an initial startle response followed by a flight path away from the sound source (Mueller et al. 1998). However, after repeated exposures from more than five tests, the fish became habituated to the sound and in some instances were attracted to the area near the sound source. Hatchery-reared juvenile Chinook salmon also were used in these experiments, but they did not show any response sensitivity to 150, 180, or 200 Hz high intensity sound (Mueller et al. 1998). These results were obtained in tests conducted in laboratory tanks and not in the field, which could explain some of the behaviors observed, such as habituation and attraction to the sound source. These results suggest that engineering options which include the use of sound as a deterrent should be tested with hatchery and wild juvenile Chinook salmon before selection because these two groups exhibit different behavioral reactions to sound frequencies.

A pressure-related field study provided evidence that juvenile Chinook salmon can perceive velocity and turbulence cues and respond to these by varying their behavior during downstream migration (Tiffan et al. 2009). Swanson et al. (2004) conducted flume tests and reported movement of juvenile Chinook salmon along a screen. The movement was controlled by sweeping velocity and the fish swimming behavior; a moderate sweeping flow of 1 foot per second prevented fish from holding position despite their strongly directed velocity-dependent swimming. Moreover, nighttime testing revealed that Chinook detected and responded to flow; however, they were unable to avoid the screen. It was hypothesized that this resulted from the porous nature of the screen and a reduced turbulent boundary layer near its surface that may have alerted the fish to its presence (Swanson et al. 2004). Fish screens (such as the one used in Swanson et al. 2004) are designed to facilitate uniform flow conditions near the screen surface, which could represent an area of low hydraulic strain and low velocity (see Section 3.5.4, "Salmonid Cognitive Ecology") and, under conditions of low visibility, possibly an undetectable structure that they are incapable of responding to or avoiding (Swanson et al. 2004; Goodwin et al. 2006).

Another flume study found that a greater percentage of juvenile Chinook salmon avoided passing over weirs when swimming in a flume under illuminated conditions than those tested in darkness (Kemp et al. 2006). These findings suggest that visual cues can mediate screen perception and avoidance in conditions with adequate light and water clarity, allowing fish to detect and avoid screens before contact (Mussen and Cech 2013). Louver-type behavioral fish barriers are operated in the south Delta at Tracy Fish Collection Facility (TFCF) and the Skinner Fish Protection Facility (SFPF). These facilities operate on the concept that fish, including juvenile Chinook salmon, avoid turbulence.

Steelhead

Studies conducted on juvenile steelhead revealed that this species can detect sounds between 30 and 300 Hz, with highest sensitivity above 150 Hz (Wubbels et al. 1993). A field study that evaluated the effectiveness of transducers for guiding juvenile steelhead away from turbine units showed a blend of sounds of 300 and 400 Hz did not have a significant effect on juvenile steelhead distribution or behavior (Ploskey et al. 2000). The juvenile steelhead tested by Ploskey et al. (2000) showed a response to frequencies near 150 Hz; the range of sounds tested in the study was 20 to 400 Hz. Moreover, laboratory tests showed that wild juvenile steelhead (1-3 inches in total length), when subjected to infrasound of 7 to 14 Hz, responded with an initial startle response followed by a flight path away from the sound source to deeper water (Mueller et al. 1998). No effects were observed when hatchery-reared juveniles were exposed to 150, 180, and 200 Hz high-intensity sound. Thus, similar to juvenile Chinook salmon, wild and hatchery steelhead may respond differently to sound stimuli; therefore, both wild and hatchery steelhead should be tested for behavioral responses before the engineering options are selected and implemented.

A statistically significant proportion of the juvenile steelhead were protected by a multi-dimensional BAFF in 2012 (DWR 2014b: Table 3.2-15) at Georgiana Slough. One component of the BAFF was acoustic and was produced by transducers emitting sound in the range of 5 to 600 Hz (DWR 2012). These results suggest showed juvenile steelhead can be deterred by sound in this frequency range.

Liao (2006) found that juvenile steelhead adopt energetically favorable strategies, by changing body shape and amplitude, to hold station in fast flow. Similarly, Przybilla et al. (2010) reported that steelhead, when holding position in the wake (entraining) of a D-shaped cylinder or sideways in a semi-infinite flat plate displaying a rounded leading edge, moved into specific positions close to and beside the objects where they maintained their position without corrective body and/or fin motions. These results suggest that steelhead can reduce drag drastically and reduce their energy expenditure during station holding by tilting their body into the mean flow direction at an angle where the resulting lift force and wake suction force eliminate the drag. Proposed engineering options may take advantage of steelhead mechanoreception by designing locations immediately upstream from the screen that have low drag, allowing individual fish to swim near the screen and evaluate it before responding to the screen.

At the TFCF, louver-type behavioral fish barriers are operated. The TFCF operates on the concept that juvenile steelhead, like juvenile Chinook salmon, avoid turbulence. The louver array created a visual and turbulent barrier that guided fish to a bypass and produced high secondary louver efficiency for juvenile steelhead (100 percent) in 1996–1997 (Bowen et al. 2004). However, the sample size for this species was small (n=22).

River observations report that out-migrating juvenile steelhead were prevented from leaping between different pools by areas of high velocity and turbulence. In fact, burst speed and jumping height are reduced by excessive turbulence, air entrainment, and unstable pools that disorient and reduce a fish's leap trajectory (Ruggerone 2008).

Summary

Results from the literature on sensory modalities (e.g., light, sound, and pressure) suggest the importance of integrating biological design considerations with juvenile salmonid physiology to implement effective deterrent and/or attractant treatments. Ambient light seems to be an important factor in determining the degree of success of behavioural deterrents such as strobe lights or sound barriers (EPRI 1994).

Proposed engineering solutions which include the use of light will need to consider the relationships between the wavelengths emitted by structure-related aerial and submerged devices and the life stage of the Chinook salmon and steelhead. Designing engineering solutions emitting the wavelengths visible to juveniles (pre-smolts), smolts, and adults will be important for effective deterrence. Additionally, the effectiveness of light as a deterrent or attractant will need to be assessed for predator species known to prey upon juvenile and adult salmonids.

Proposed engineering solutions which include the use of sound and/or vibration will need to consider the relationships between the frequencies of sound emitted by the submerged devices and the life stage of the target species. Additionally, the effectiveness of sound and or vibration as a deterrent or attractant will need to be assessed for predator species known to prey upon juvenile and adult salmonids.

3.5.2 JUVENILE SALMONID SWIMMING CAPACITIES

Chinook Salmon

DWR (2014d) summarized Central Valley juvenile Chinook salmon swimming capacities, reporting both critical swimming speeds (U-crit) and maximum sustained swimming speeds. The lowest U-crit value provided is 4.37 body lengths per second (BL/s) at a water temperature of 12ºC (53.6ºF). Because of the limited data available on Central Valley Chinook salmon swimming capacity, the literature reviewed was expanded to include relevant examples outside California's Central Valley (Table 3-5). Overall, DWR estimates (2014d) seem to be in line with the additional information found, barring a single study that estimated U-crit at 2.37 to 3.06 BL/s (Muir et al. 1994). However, Muir et al. (1994) worked at temperatures that were lower than in other studies reviewed and lower than those typically found in the Central Valley's smolt migratory pathways. Thus, it was concluded that the most conservative mean sustained swimming speeds in Central Valley juvenile Chinook were 4.37 BL/s at

12ºC and 4.91 BL/s at 19ºC (66.2ºF). These values may be used by bioengineers in the design of fish guidance features for fish in the Delta and likely expanded to the Central Valley.

Table 3-5. Reported Swimming Capacity of Juvenile Chinook Salmon in North America

Fish Length (mm)	Water Temperature (°C)	Source	Swimming Metric	Swimming Speed (body lengths per second)	Swimming Speed Time Interval (minutes)	Origin
87–96 (SL)[1]	17	Wild	U-crit	5.91–6.26	20	Central Valley, CA
62–79 (SL)[2]	12	Hatchery	Sustained	4.37–5.56	120	Central Valley, CA
56–77 (SL)[2]	19	Hatchery	Sustained	4.91–6.75	120	Central Valley, CA
91–125 (FL)[3]	13–16	Wild	U-crit	4.34 ± 1.30 (SD)	30	Columbia River, WA
122–198 (FL)[4]	16.8–17	Hatchery	U-crit	4.22–4.92	15	Priest Rapids Hatchery, WA

Notes: °C = degrees Celsius; FL = Fork length; mm = millimeters; SL = standard length; U-crit = critical swimming speed

[1] For Katzman (2001), swimming speed reported is the range.

[2] For Swanson et al. (2004), the swimming speed is the mean, in body lengths per second, for the reported size range.

[3] For Brown et al. (2006), the swimming speed is the U-crit mean ± Standard Deviation (SD), in body lengths per second, for the reported size range.

[4] For Anglea et al. (2004), the swimming speed reported is the range.

Sources: [1] Katzman 2001; [2] Swanson et al. 2004; [3] Brown et al. 2006; [4] Anglea et al 2004. Table compiled by Turnpenny Horsfield Associates 2014.

Steelhead

DWR (2014d) has summarized juvenile steelhead swimming capacity, reporting U-crit from a number of sources. Similar to juvenile Chinook salmon, little information exists on specific studies addressing swimming capacity in steelhead for Central Valley populations. Thus, the literature review was expanded to include relevant examples outside California's Central Valley (Table 3-6). The lowest U-crit value found was 3.75 BL/s at 11ºC (51.8ºF) and 4.72 BL/s at 19ºC.

Table 3-6. Reported Swimming Capacity of Hatchery-Reared Steelhead in North America

Fish Length (mm)	Water Temperature (°C)	Swimming Metric	Swimming Speed (body lengths per second)	Swimming Speed Time Interval (minutes)	Origin
100.1 ± 9.9 (FL ± SD)[1]	10–19	U-crit	7.50 ± 0.27 (SE)	15	Washington State Hatchery, WA
110 ± 0.4 (FL ± SD)[2]	13.5 ± 1º C	U-crit	5.25	20	Miracle Springs Hatchery, British Columbia, Canada
148.6 ± 1.9 (FL ± SE)[3]	10.5–12	U-crit	3.90–5.52	5	Rainbow Springs Trout Farm, Ontario, Canada
115 ± 10 (FL ± SE)[4]	11–12	U-burst	7.53 ± 0.14 (SE) 7.66 ± 0.16 (SE)	1	Miracle Springs Hatchery, British Columbia, Canada
124 ± 20 (FL ± SE)[5]	11 ± 0.5 (SD)	U-crit	3.75	2	Ontario Ministry of Aquaculture and Fisheries Research Station, Ontario, Canada
109 ± 6.1 (TL ± SE)[6]	19	U-crit	4.72–5.76	10	Central Valley, CA

Notes: °C = degrees Celsius; FL = Fork length; mm = millimeters; SD = standard deviation; SE = standard error; TL = Total length

Source: Compiled by Turnpenny Horsfield Associates 2014.

Summary

Results on juvenile salmonid swimming capabilities suggest that values of 4.37 BL/s at 12ºC and 4.91 BL/s at 19ºC may be used by bioengineers in the design of fish guidance features for juvenile Chinook in the Delta. In addition, values of 3.75 BL/s at 11ºC and 4.72 BL/s at 19ºC may be used by bioengineers in the design of fish guidance features for juvenile steelhead in the Delta.

3.5.3 JUVENILE SALMONID MIGRATION BEHAVIOR

Juvenile Chinook salmon and steelhead emigrating from natal tributaries of the Central Valley must navigate through the Delta on their way to the Pacific Ocean. Route selection by salmonids as they navigate these channels contributes to the probability of their survival or mortality. Understanding the physical and environmental factors that affect migratory behavior can help direct salmonids along routes that will increase their survival rates.

3.5.3.1 WATER COLUMN

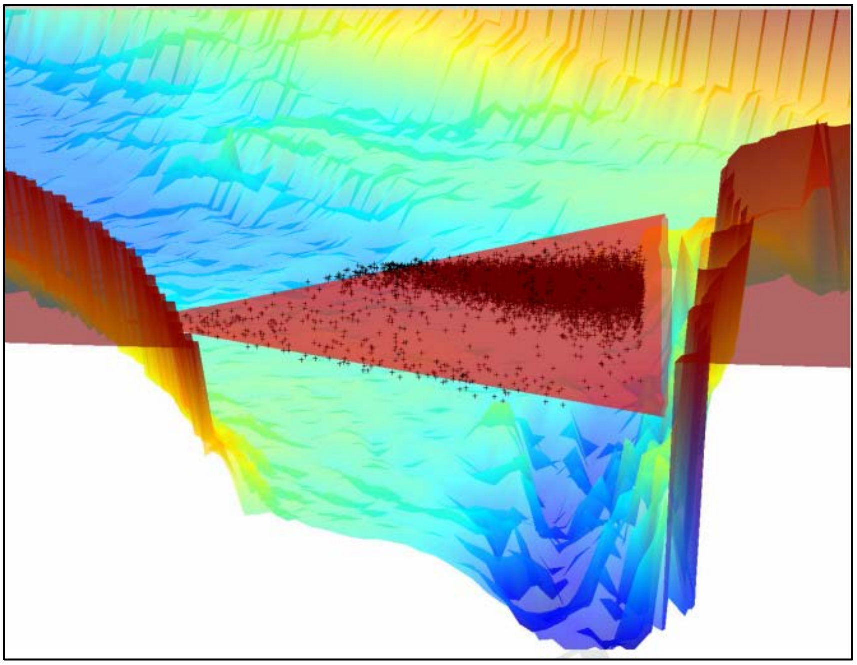
Gaines and Martin (2001, citing Azevedo and Parkhurst 1957) state that, in studies conducted near Red Bluff Diversion Dam (RBDD) on the Sacramento River, emigrating juvenile Chinook salmon numbers were greatest 0.6 to 1.2 meters (m) (2.0 to 3.9 feet) below the surface and fewest at 1.2 to 1.8 m (3.9 to 5.9 feet) below the surface. These observations agree with that of Long (1968) who found that, at two dams on the Columbia River in Oregon, greater than 70 percent of the age 1+ Chinook salmon and steelhead were emigrating in the top 4.4 m (14.4 feet) of a 13.6-m (44.6-foot) water column. Beeman and Maule (2001) noted that juvenile Chinook salmon at McNary Dam on the Columbia River spent 83 percent of their time in an 18-m-deep (59.0 feet) gatewell at 9 m (29.5 feet) or less, while juvenile steelhead spent 96 percent of their time in the upper 11 m (36.0 feet).

3.5.3.2 DEPTH AND CIRCULATION

A study by Blake and Horn (2014a; 2014b) showed that the proportion of juvenile Chinook salmon approaching channel junctions is not related to the distribution of flows. They hypothesized that juvenile Chinook in the Sacramento River downstream from its junction with Georgiana Slough (water depth approximately 10 m [32.8 feet]) are not homogenously distributed in the water column. Figure 3-8 shows the majority of juvenile Chinook were observed on the outside of the bend, in the upper portion of the water column.

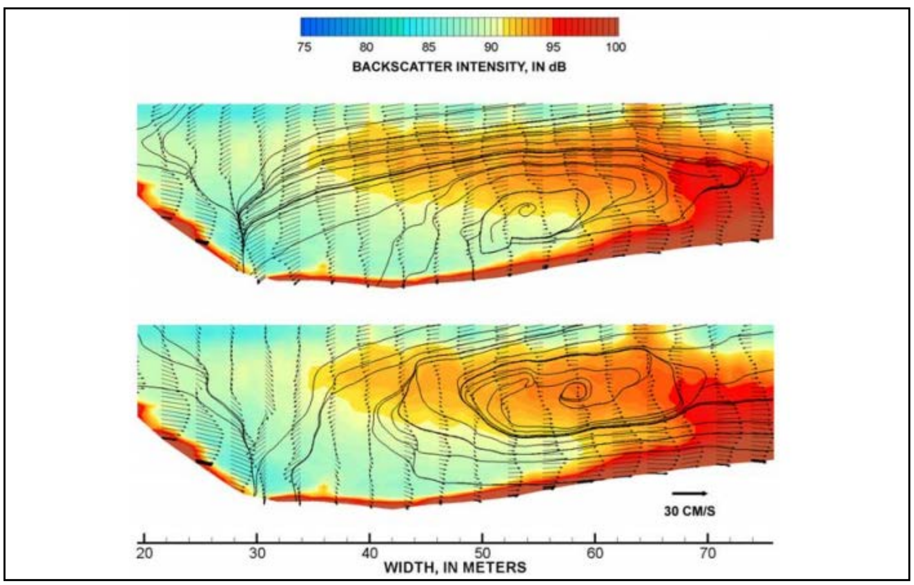
Figure 3-8 shows the majority of juvenile Chinook were observed on the outside of the bend, in the upper portion of the water column. Dinehart and Burau (2005) suggested that this observed distribution is caused by secondary circulation, formed by centrifugal and pressure forces in bends (Figure 3-9).

Secondary circulation may play a key role in the distribution of juvenile Chinook among the channels of the north Delta, and therefore this should be a key consideration to be taken into account when designing engineering options in the Delta. Outmigrating juvenile salmonids may be in the upper half of the water column and may be concentrated nearer the outside shore on river bends.



Note: The location is a bend in the Sacramento River immediately downstream from its junction with Georgiana Slough.
Source: Blake and Horn in press (a, b); as cited in Burau et al. 2007.

Figure 3-8. Detections of Juvenile Chinook Salmon in the Sacramento River near Georgiana Slough



Notes:
[1] Cross-stream velocity vectors in averaged velocity grids at Clarksburg Bend before and after reorientation to radial front (Section 8, March 14, 2004).
[2] This example section was rotated 5 degrees.
[3] Secondary circulation in each averaged velocity grid is represented by stream traces. Every third velocity ensemble is shown for clarity.
[4] Views are upstream.
Source: Dinehart and Burau 2005.

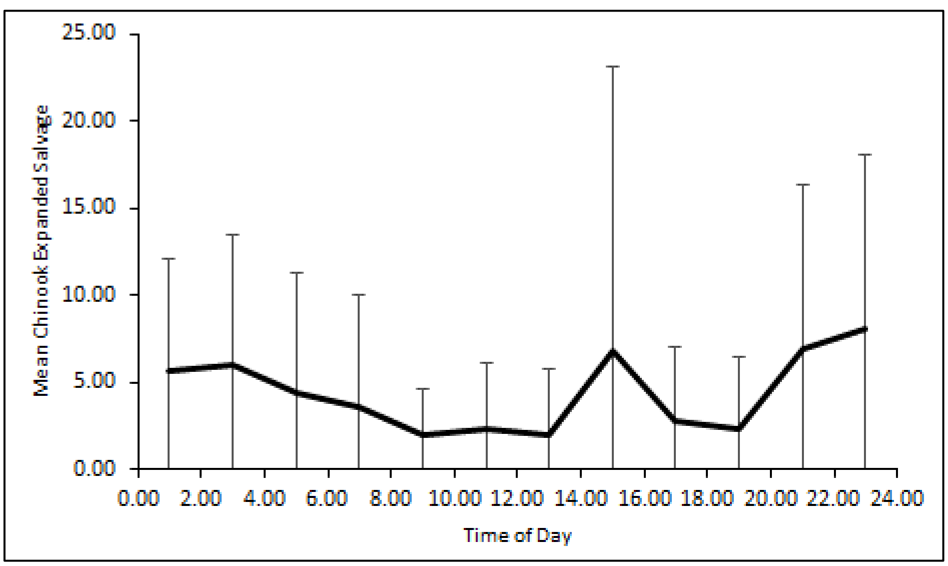
Figure 3-9. Cross-Stream Velocity Vectors at Clarksburg Bend, Sacramento River, CA

3.5.3.3 DIEL AND NOCTURNAL

Chapman et al. (2013) used ultrasonic telemetry to determine the movements of late-fall hatchery-reared smolt Chinook salmon and steelhead during emigration from the Sacramento River, through the San Francisco Bay estuary and into the Pacific Ocean from 2007 to 2010. Chinook salmon smolts showed a nocturnal pattern of movement after release. The ratio of night:day detections decreased with distance traveled downriver, although a significant preference was noted towards nocturnal migration in every reach of the river with the exception of the estuary. Steelhead resided upriver longer following release. Less diel pattern existed in their entire migration. Chapman et al. (2013) concluded that closely related salmonid species, with the same ontogenetic pattern of out-migration as yearlings, have very different diel migration tactics.

Gaines and Martin (2001) found that juvenile Chinook salmon demonstrated distinct diel patterns of emigration at Red Bluff Diversion Dam on the Sacramento River. The catch-per-unit volume (CPUV) for juveniles and smolts was greater for nocturnal and crepuscular periods than for diurnal periods. Findings by Dauble et al. (1989) (also citing Smith 1974; Sims and Miller 1977) concurred and showed that principal downstream movement of juvenile Chinook salmon and steelhead at Hanford Reach on the Columbia River occurred between 2200 and 0400 hours. Long (1968) found that juvenile Chinook salmon (94 percent) and steelhead (85 percent) were caught at night on the Columbia River in Oregon. Long (1968) also reported similar findings in earlier studies (e.g., Mains and Smith 1956).

The diel patterns exhibited by emigrating juvenile Chinook salmon are confirmed in data from the SFPF. Figure 3-10 shows 2009 data and highlights the diel pattern of migration, with the majority of juveniles emigrating between 2100 and 0500 hours. However, the temporally patchy nature of juvenile Chinook migration also is clear in the 1500 hour peak. This 1500-hour peak was the result of one large school of migrating juveniles that possibly were cued to emigrate by another abiotic environmental variable (e.g., turbidity or tide) or predator assemblage (fish, avian, or aquatic mammal).



Notes: Values are mean expanded salvage (error bar is 1 standard deviation) for each 30-minute salvage sample in the twelve 2-hour sample windows of the 24-hour salvage cycle. The data were collected between April 14 and May 11, 2009, during the peak of the spring Chinook migratory period.
Source: Compiled by Turnpenny Horsfield Associates 2014.

Figure 3-10. Juvenile Chinook Expanded Salvage at the Skinner Fish Protection Facility, Byron, California

Bradford and Higgins (2001) observed the diel patterns of juvenile Chinook salmon and steelhead across four seasons in Bridge River, British Columbia, Canada. In a location with high flows, fish were active nocturnally all year-round. In a location with low flows, some fish became active in the water column during daylight hours. Parr and older fish were found to be more nocturnal in summer. All fish were active nocturnally in winter. The researchers hypothesized the difference in behavior resulted from habitat conditions that affected the trade-off between risky daytime foraging and less efficient (but safer) nighttime foraging.

The diel pattern of seaward-migrating juvenile Pacific salmonids passing the John Day Dam on the Columbia River during 1987–1989 and 1991–1993 were observed by Brege et al. (1996). Yearling Chinook salmon passed at night on average 80.7 percent of the time, while 75.7 percent of sub-yearling Chinook salmon passed at night. Steelhead passed at night 77.9 percent of the time.

These movement patterns, with more juvenile salmonids moving at night in the wild, also affect behavior in human-constructed environments. The stress response of juvenile Chinook salmon and steelhead to passage through three flumes (i.e., small baffled, large baffled, and unbaffled with corrugations) was determined by Congleton and Wagner (1988) by testing plasma cortisol concentrations before and after fish passage. Flumes were observed in three light conditions: daylight, partial darkened (400-900 lux), and completely darkened (1-4 lux). The design of the flume significantly affected post-passage cortisol concentrations in steelhead but not juvenile Chinook salmon. Steelhead had the lowest cortisol concentration in the corrugated flume.

3.5.3.4 LUNAR CYCLE

DeVries et al. (2004) reported that lunar gravitation affected the timing during which juvenile Chinook, coho, and chum salmon (*Oncorhynchus keta*) moved from Lake Washington into Puget Sound, Washington, although they did not suggest a mechanism by which the fish may have sensed it. However, it is widely known that the pineal gland, dorsally located on the brain in fishes, has light sensitivity. Juvenile salmonids may be more likely to move when the moon is waning or new (Roper and Scarnecchia 1999), although this effect is untested in California's Central Valley, it is likely similar.

At a hatchery in New Zealand, Hopkins and Sadler (1987) measured plasma concentrations of throxine (T_4) in juvenile Chinook salmon via radio-immunoassay. Plasma T_4 levels exhibited a cyclic form, with maximum concentrations occurring near each new moon. Because an elevation in T_4 is linked to the onset of smoltification in juvenile Chinook salmon and steelhead (Björnsson et al. 2011; Barron 1986; Dickhoff et al. 1982), and T_4 specifically initiates the onset of smoltification and transition to sea water survival (Roper and Scarnecchia 1999), the lunar phase (particularly around each new moon) may play a part in the onset of juvenile Chinook salmon downstream migration.

3.5.3.5 HOLDING

The majority of juvenile Chinook salmon and steelhead undertake a rapid migration, using hydraulic characteristics often associated with the thalweg (see Section 3.5.4, "Juvenile Salmonid Cognitive Ecology"). However, observed diel patterns of migration or movement suggest that holding behavior is common, particularly during daylight hours. Holding behavior in juvenile Chinook salmon and steelhead has been documented by Zajanc et al. (2013), Burau et al. (2007), and Williams (2006).

Williams (2006) states that juvenile Chinook salmon migrating past the Delta Cross Channel in late fall tend to hold along the edges or the bottom of the channel during the day, and to move out into the main current near the surface at night. Zajanc et al. (2013) suggest that cover, in-channel structure (e.g., large woody debris and pilings), canopy cover, and lower water velocities (minimizing metabolic costs), may be the most important habitat features eliciting holding behavior and duration.

Beerman and Maule (2001) observed that fish released midday and in the evening generally exited the gatewell at McNary Dam on the Columbia River in the evening. This indicates that fish entering a gatewell during daylight will have prolonged holding times.

3.5.3.6 SCHOOLING

Jackson (1992) observed habitat use by stream resident juvenile Chinook salmon (FL range: 2-3 inches) in late April and early May at two flows (350 cfs in 1991 and 3,700 cfs in 1989). Schooling fish always were in areas of cover, visual cover, and/or velocity cover, with velocity shelter being used most often. As the juveniles reached 3–5 inches FL, they moved to deeper, higher velocity habitat. Larger fish could be found in pairs but more often were solitary and used large cobble/boulder substrate as velocity cover. Individuals in the larger group, 3–5 inches FL, exhibited more aggressive and territorial behavior than did individuals of the smaller group.

Vogel (2001; 2002) studied juvenile Chinook salmon movement in the Delta using radio tags. After release of tagged fish, rapid dispersal was observed. Although the short battery life and wide dispersal of the fish tested limited the ability to determine how the fish actually exited the Delta, schooling behavior was not observed.

Summary

Results on juvenile salmonid activity patterns suggest that design specifications of engineered options in the Delta will likely have different effects on juvenile Chinook salmon and steelhead, as well as hatchery-reared versus wild fish sources. Therefore, distinguishing the features of juvenile salmonid behavioral patterns related to water column distribution, depth and circulations, diel and nocturnal photoperiods, lunar cycle, holding, and schooling are important when designing fish guidance systems in the Delta.

Recommendations related to migratory behavior are as follows:

- The engineering designs recommended should be studied in the laboratory:
  - Designs may be optimized to reduce stress response in both juvenile Chinook salmon and steelhead before full field implementation is undertaken; and
  - With any system that incorporates a strobe light component, smart lighting (short-term programming control) should be evaluated:
    - For each species (Chinook, steelhead, and green sturgeon) that a system is designed to deter, the ambient conditions should be manipulated including the following.
      - Winter conditions, day: lower maximum ambient light level (compared to summer conditions), higher turbidity.

        - Winter conditions, crepuscular: lower ambient light level than Winter/Day and changing ambient light wavelength distribution (with less short wavelengths of visible light present).
        - Winter conditions, night: lowest ambient light level.
        - Spring conditions, day: higher maximum ambient light level and lower turbidity than Winter/day.
        - Spring conditions, crepuscular: intermediate ambient light level and changing ambient light wavelengths distribution and lower turbidity level.
        - Spring conditions, night: low ambient light level and low turbidity level.
    - For each of these six condition sets, strobe light illuminance, flash rate, flash duration, and other strobe light operational parameters should be manipulated and the resulting response from the target fish species/life stage monitored to determine the optimal strobe light operational program for a particular design.
- For a FFGS design, a number of design parameters could be fine-tuned for Central Valley locations and specific conditions.
    - Angle of the FFGS incident to the thalweg.
    - Porosity of the FFGS.
    - Length of the FFGS.
    - Height of the FFGS.
- For an audible sound or infrasound behavioral deterrent system, a number of design parameters could be fine-tuned for Central Valley locations and specific conditions.
    - The exact frequency range to use for target fish species/life stage or combinations of target fish species/life stages.
    - Characteristics of array of transducers.
        - Arrangement (Shape of the array)
        - Number of transducers

- Further research should be conducted to study the relationship of lunar phase on juvenile Chinook salmon movement. For example, an analysis of 2-hour salvage data at the TFCF and SFPF could be conducted to discern whether an increase in juvenile Chinook salmon movements occur around the time of the new moon and/or a waning moon. If such a relationship exists, engineered barrier operations could be modified on appropriate nights to deter higher numbers of migrating juvenile Chinook salmon. “Smart” strobe lighting control systems could be programmed to change flash rates or other strobe light characteristics in response to the moon phase, as appropriate.

3.5.4 JUVENILE SALMONID COGNITIVE ECOLOGY

The science of cognitive ecology may be employed to design effective structures to aid fish passage. In short, cognitive ecology addresses questions of why fish behave as they do, but also addresses how well they are equipped to deal with new situations that they may never have encountered. Consequently, it is perhaps the best place to start when considering predictive models of fish moving through structures which are yet to be built.

Cognitive ecology was originally defined by Real (1993) in an attempt to integrate the fields of behavioral ecology and cognitive science. Pragmatically, this is important and useful because cognitive ecology is concerned specifically with the rules and parameters of individual-based models of animals, and such models have proven uniquely effective in developing predictions of animal movement patterns from first principles (Camazine et al. 2003).

The basic tenet with respect to using a sensory ecological approach to fish passage is that the way fish have evolved to swim through a natural riverine environment is likely to be a good predictor about the way fish deal with an artificial structure. Nestler et al. (2008) encoded rules and parameters (that were inferred from natural movements) into an individual-based model used to predict the navigational behavior of fish around an artificial structure which the fish had not encountered before. The fundamental approach was based on observations and inferences of the way the fish navigated in their natural environment and crucially this was combined with an analysis of the sensory physiology of fish to derive a plausible combined model. This is important because combined models of fish and hydrodynamic models that incorporate internally modeled cues for fish navigation are more powerful predictors than those assuming some navigational capability external to the model, and thus it can be assumed only that it will be unchanged in a new environment (Willis 2011). Although the Nestler et al. model (2008) is an excellent example of cognitive ecology in action, the researchers made the implicit assumption that fish would act in a consistent mechanical way to changes in stimuli. The model did not include higher cognitive functions, such as overall spatial awareness, reactions to conspecifics (e.g., schooling), and memory.

An example of the application of cognitive ecology to fish passing through complex human constructed environments already has been conducted for juvenile downstream migrating salmonids (Goodwin et al. 2006). Furthermore, Smith et al. (2012) showed that this application may be extended to other species and other geographical settings. Goodwin et al. (2006) showed that downstream migrating juvenile salmonids navigate a river system to reach the ocean to: 1) avoid an area of increasing hydraulic strain like those of high-velocity gradients that occur near shore and substrate, created by friction resistance of the river bed; 2) avoid high free-shear flow gradients that exhibit increasing water velocity such as a nearing obstruction may cause; and 3) avoid high-pressure change gradients. In keeping with these avoidance patterns, a smolt Chinook can navigate the Columbia River and complex human-constructed environments (Goodwin et al. 2006). In conclusion, an engineering option in the Delta could deter fish away from areas of increasing hydraulic strain and decreased water velocity.

3.5.5 ABIOTIC FACTORS AFFECTING JUVENILE SALMONID BEHAVIOR AT BARRIERS

3.5.5.1 WATER DEPTH

Whether a fish can pass a physical or non-physical barrier or not depends on the hydraulic conditions above and at the base of the obstacle. In addition the barrier's physical configuration is important in relation to the swimming and jumping capacities of the species concerned (FAO 2001).

The louver screens at the TFCF and SFPF are arrays of vertical slats, aligned across the water at a specified angle to the flow direction (15 degrees incident to the centerline of the channel), designed to guide fish towards the bypass. Louvers generally are considered for sites with relatively high approach velocities, uniform flow, heavy debris load, and relatively shallow depths (FAO 2001). Originally, louvers usually were installed over the full depth of the approach channel. However, because migrating juvenile Atlantic salmon and juvenile clupeids (shad and herring) generally were observed to migrate in the upper portion of the water column, "partial-depth" systems were tested and installed. Odeh and Orvis (1998) reviewed a partial-depth system in an intake channel at the Holyoke Hydroelectric Power Station on the Connecticut River, Massachusetts. The partial-depth system was found to have an efficiency of 86 percent for juvenile clupeids and 97 percent for juvenile Atlantic salmon.

In general, suitable fish screen areas must be based on the minimum operating water level at the highest diversion flows. The highest flows determine the maximum approach velocities, which should not exceed the criteria for the fish species concerned (Reclamation 2006).

3.5.5.2 Flow Volume

Flow volume (river discharge) is the total volume of water through a channel per unit time at any given point and is typically measured in cubic feet per second (cfs). As juvenile salmonids enter the Delta from upstream rivers and streams, they disperse among its complex network. The dispersal process is driven by the flow entering each channel and the horizontal distribution of the fish in the water column as they approach a channel. Tidal cycles affect the flow patterns at some river junctions, thus altering the juvenile fish's direction. After a channel has been chosen, the fish are subject to channel-specific processes that ultimately affect their survival (Perry et al. 2010).

Juvenile Chinook salmon and steelhead emigration to the ocean often is preceded by substantial increases in river flow along with rising water temperatures (Bell 1991). River discharge can influence the speed of juvenile and smolt movement through a channel, and several studies show that fish migrate more quickly with increases in flow, in particular juvenile Chinook salmon (Raymond 1979; Friesen et al. 2007).

Chapman et al. (2013) found that flow influenced the diel tactics of juvenile Chinook salmon more than juvenile steelhead. After the juvenile salmonids reach the Delta, many channels and sloughs exist through which they can move and migrate. Because their movements can be heavily influenced by the tides, juvenile salmonids, especially steelhead, often make repeated upstream and downstream movements before successfully emigrating to the ocean. When flow is increased, juvenile Chinook salmon were more likely to be detected (i.e., actively migrating) during the day. For steelhead, the influence of the flow was not found to alter their diel tactics as much.

In studies of a BAFF conducted at the divergence of the San Joaquin and Old rivers, DWR (2014c in prep.) showed that in a year with lower discharge (2009), a substantially higher rate of juvenile Chinook salmon deterrence was observed than occurred in 2010 when the river discharge (flow) was much higher throughout the salmonid migratory period monitored. There were other differences between 2009 and 2010 but this result suggests that discharge may influence fish deterrent system performance.

In 2012, DWR tested the efficiency of a BAFF at the divergence of Georgiana Slough from the Sacramento River over a range of river discharges, tidal conditions, and diel conditions for migrating juvenile Chinook salmon and steelhead. When the BAFF was on, protection efficiency increased substantially with decreasing river discharges.

These studies provided some evidence for the hypothesis that lower discharge leads to lower approach velocity and provide more time for a juvenile to alter its path and move away from a behavioral barrier (DWR 2013a).

Perry et al. (2012) found that the same non-physical barrier, the BAFF, when operated at Georgiana Slough, also demonstrated reduced entrainment at high flows; however, BAFF efficiency was reduced at high river discharge when fish were located close to the Georgiana Slough side of the river channel. It is likely that fish under the high river discharge conditions were unable to alter their course away from the BAFF, resulting in their being swept through the barrier into Georgiana Slough. Based on typical burst speeds of juveniles and smolts (see Table 3-5; Perry et al. 2012) relative to water velocities, it was hypothesized that even if the juveniles were deterred by the BAFF, they physically may not have been able to avoid entrainment into Georgiana Slough.

Vogel (2002) released radio tagged juvenile Chinook salmon into lower Old River near Woodward Island. Two export levels (river discharges) were tested, with the outcome that fish released at 8,000 to 10,000 cfs (medium river discharge) were more likely to be entrained than those experiencing 2,000 to 5,000 cfs (low river discharge). Fish experiencing low river discharge rates moved north (away from the facilities), while fish experiencing medium discharge moved south (towards the facilities). The results indicate a high probability of entrainment for fish at medium river discharges, although no tagged juvenile Chinook were recovered.

3.5.5.3 APPROACH VELOCITY

"Approach velocity" is the speed of the water approaching (i.e., flowing onto) a physical or behavioral fish barrier, and is an important variable that may limit the barrier's efficiency because fish may not be able to respond to a barrier if velocities surpass their swimming capabilities. The approach velocity is the vector component of velocity perpendicular to the face of the barrier.

If the approach velocity to a fish barrier exceeds the swimming ability of a fish, the fish may either be drawn into the flow passing the barrier (entrained) or become stuck onto it physically (impinged) (Boys et al. 2013). Both of these outcomes reduce the survival chances of the fish. Criteria used in barrier design must ensure that flows allow fish to avoid entrainment and impingement, but are also sufficiently high to provide directional cues to fish.

Pugh et al. (1971) found that guidance at an electrical behavioral barrier on the Yakima River, Washington, a tributary of the Columbia River, decreased with increasing water velocities, and suggested that the use of electricity to guide juvenile Chinook salmon and steelhead is feasible only in environments where velocities do not exceed 1 foot per second (see Section 4.2, "Engineering Options Removed from Consideration").

3.5.5.4 WATER TEMPERATURE

Pacific salmonids are considered stenothermic (capable of surviving a narrow temperature range), with an optimal water temperature of approximately 15ºC (59.0º F) (Feist and Anderson 1991). In temperature extremes, salmonid swimming performance, as well as behavior, is strongly affected (Lee et al. 2003). In some cases, this can lead to decreased performance of fish guidance systems because the biotic variables on which the systems are designed (i.e., swimming capacity) may change as a result of temperature fluctuations. Swimming performance will decrease as water temperatures exceed the optimal physiological performance levels of these fish and voluntary avoidance will diminish as swimming performance diminishes.

Large-scale movement of juvenile Chinook salmon and steelhead throughout a river catchment can be dictated by water temperature as well as by local movements around behavioral and physical barriers. Temperature can dictate the arrival of fish at a screening facility; very few fish will arrive after the water temperature has exceeded the critical thermal maximum.

Water temperature changes should be avoided in fish guidance systems because they could induce stress in fish (Feist and Anderson 1991). In addition, compound passage through a number of barriers in high temperature environments may lead to a decrease in the condition of the fish and increase mortality.

The efficacy of BAFFs also has been shown to be affected by temperature, with higher deterrence being correlated with higher temperature, possibly as a factor of increasing swimming capacity. However, this becomes more complex when temperatures move toward critically warmer temperatures, giving predators an advantage over the juvenile salmonids in swimming performance and thus increasing predation rates within the vicinity of the BAFF, depending on how the BAFF is operated (DWR 2012).

3.5.5.5 TURBIDITY

Turbidity affects the response of fish to barriers and their ability to perceive them, which can increase or decrease barrier efficiency. Bowen et al. (2010a) showed that, in a laboratory setting with a through NPB velocity of 2.5 fps, chinook juveniles were deterred by a BAFF at 10 and 30 NTUs with deterrence ranging from 41.6 to 86.9 percent. But, Bowen et al. (2010b) found that when the through NPB velocity was 1.1 fps that there was no significant deterrence at 30 NTUs for trials conducted at night. This suggests that turbidity effects on BAFF performance may be in part dependent on ambient light.

Perry et al. (2012) indicated that BAFF efficiency can be affected by high turbidity because it can inhibit fish navigating visually during the day, leading to comparable deflection efficiencies between darkness and daylight. Irradiance of bubble curtains has been shown to be seriously reduced under turbid conditions (Patrick et al. 1985), which has a direct impact on deterrence, with avoidance rates of 73 to 71 percent under clear to low turbidity, dropping to 59 to 38 percent under highly turbid conditions.

Swanson et al. (2004) suggested that under turbid conditions, physical screens (which are designed to facilitate uniform flow conditions and reduce boundary layer effects) actually may prove undetectable to fish and may lead to fish physically coming into contact with them. This could lead to a reduction in the condition of the fish, potentially leading to their mortality.

Turbidity encountered at barriers and fish bypasses also has the potential to lead to slower swimming rates (Feist and Anderson 1991), which has the potential to increase residency time and may produce greater susceptibility to predation. Conversely, in some cases, higher turbidity may serve to conceal juvenile salmonids from predators, and may lead to lower predation rates (Gregory and Levings 1998). Studies have found a positive relationship between turbidity and survival of native fishes in the Delta, both in the field (Chinook salmon: Newman 2003) and in the laboratory (delta smelt: Ferrari et al. 2013), presumably because the visual range of predators is reduced under higher turbidity (Aksnes and Giske 1993).

3.5.6 POTENTIAL BARRIER EFFECTS ON OTHER FISH SPECIES OF CONCERN

An engineering option with substantial adverse effects on delta smelt and green sturgeon could require additional design modifications to minimize and avoid potential impacts. Pertinent life history features of these two species are summarized below such that they can be considered in design and selection of engineering options.

3.5.6.1 DELTA SMELT

Delta smelt is a short-lived species of low fecundity. The species' life strategy is unusual and requires specific water quality and biotic conditions at certain times of the year to be successful. Delta smelt are highly adapted to the Delta's natural conditions; however, the Delta has changed considerably over the past 100 years. Delta waters are more consistently fresh and less similar to estuarine conditions, and they accommodate invasive species that are adapted to similar conditions in other systems. Two delta smelt life stages are most vulnerable to direct influences by the operation of fish barriers at this Study's five proposed locations. First, adult delta smelt must be able to migrate upstream from the area of the Low Salinity Zone (LSZ) to spawning areas from winter through spring (generally December through March/April). Second, post-larvae and juveniles must be able to move from spawning areas back to the LSZ (generally from March through June).

Reclamation (2008) reported on modeling studies that showed the installation of a temporary rock barrier at the HOR on April 15 led to negative Old and Middle River (OMR) flows. Negative flows in the Old River may increase delta smelt entrained to the TFCF and SFPF. This is one reason why rock barriers were removed from consideration – known negative effects on delta smelt.

Delta smelt were deterred by the multiple-stimulus (light/sound/bubble) BAFF (Bowen et al. 2010b) in a laboratory setting; this was the same BAFF (equipment provided by Fish Guidance Systems, Southampton, United Kingdom) that was evaluated at the HOR (DWR 2014d) and Georgiana Slough (DWR 2012, 2014e). In a laboratory model that simulated the Sacramento River–Georgiana Slough bifurcation, a statistically significant proportion of delta smelt were deterred from entering the Georgiana Slough side of the model when the approach velocity into Georgiana Slough was 1 foot per second. Thus, the potential barrier effects on delta smelt should be evaluated both in the design and planning phases of any deployment of a BAFF at any of the five proposed locations.

3.5.6.2 GREEN STURGEON

Long lifespan, delayed maturation, large body size, high fecundity, iteroparity, and anadromy are life history traits of the green sturgeon. These traits would not lend themselves toward overcoming the challenges (e.g., predation, entrainment, and introduced species) at the proposed barrier sites. Juveniles may spend an appreciable duration of time in the Delta, but they are difficult to study because they do not seem to school and they are rare. Therefore, identifying local threats and vulnerabilities in the Delta and estuary can be difficult. The principal threats to green sturgeon in the Delta are thought to be pollution, loss of habitat, and entrainment at water diversion systems.

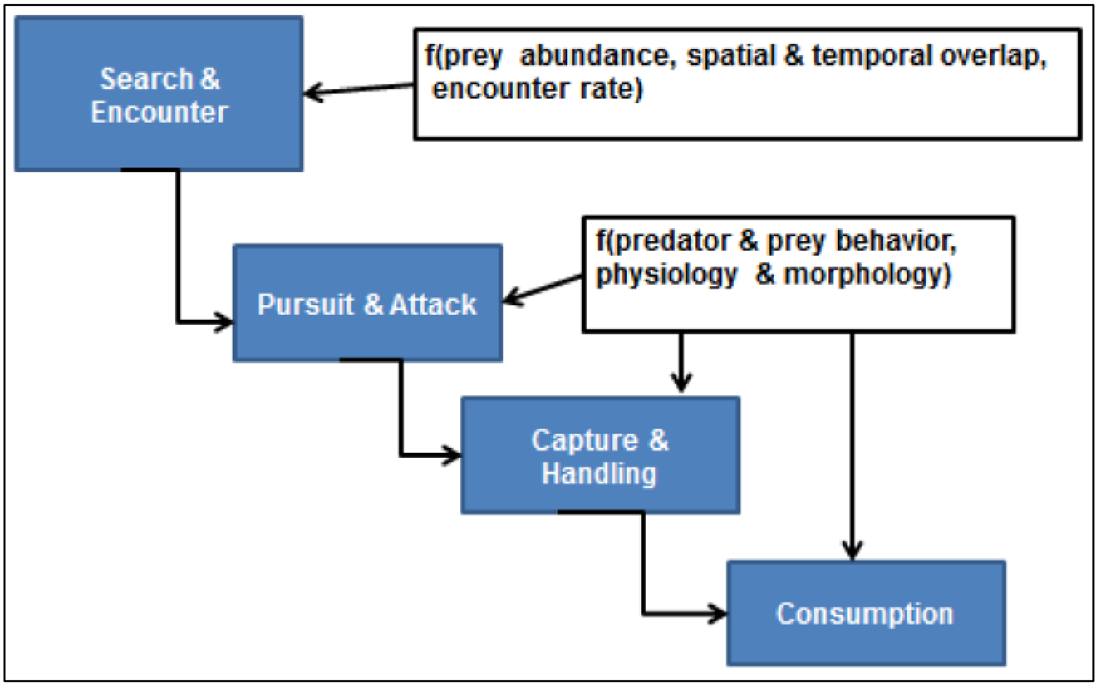
3.6 ENGINEERING DESIGN CONSIDERATIONS TO REDUCE PREDATION

Several engineering options are being considered to further reduce diversion of emigrating juvenile salmonids into the interior and south Delta, and all of them include placing structures into Delta channels. In-water structures often create important habitat locations for predatory fish, and therefore they could provide an elevated risk of predation for juvenile salmonids and other native fish (Vogel 2011). This section provides a general background on factors affecting juvenile salmonid predation; insights into predation and predatory fishes from the existing engineering options studies at Georgiana Slough and the Head of Old River; specific considerations to reduce predation risk to juvenile salmonids from in-water engineering options; and supplemental methods to reduce predation risk such as habitat manipulation or predator relocation that could be considered in tandem with engineering options.

3.6.1 General Background on Juvenile Salmonid Predation

As noted in the introduction to this section, engineering options for reducing diversion of emigrating juvenile salmonids into the interior and south Delta involve placement of in-water structures into Delta channels that could create habitat for predatory fish and therefore increase the risk of predation for juvenile salmonids and other native fish. Within the Delta, high levels of predation have been observed in association with various artificial structures. High mortality rates of juvenile salmonids attributed to predation within Clifton Court Forebay and the intake channels leading to the SFPF are well described (Gingras 1997; Clark et al. 2009), and striped bass tend to spend considerable portions of time near the radial gates and the intake channel (Clark et al. 2009). Sabal (2012) found that striped bass aggregated at the Woodbridge Irrigation District Diversion Dam (Mokelumne River) more than at other altered and natural sites, and that survival of juvenile Chinook salmon increased substantially following experimental predator removal by electrofishing. Vogel (2010) assessed predation of juvenile Chinook salmon to be very high in the vicinity of the Mossdale Bridge over the San Joaquin River, which may have been related to the very high concentration of bridge piers and docks in this area. In the south Delta, survival of juvenile salmonids past barrier locations after installation of the Temporary Barriers Project was statistically lower for juvenile Chinook salmon at the Grant Line Canal barrier (although the survival still was very high, so the statistical difference may not have been biologically relevant), whereas the lower survival rate at the Old River barrier (97 percent before installation versus 83 percent after installation) was not statistically different (although statistical power may have been low) (San Joaquin River Group Authority 2011). No statistical difference was shown in survival of juvenile steelhead before and after barrier installation. Vogel (2011) reviewed the locations at which predation may be an issue in the Delta and noted that little study has been conducted about the effects of boat docks and marinas, although these structures appear to provide suitable predatory fish habitat (with in-water structure and shade cover).

A science panel report on juvenile salmonid predation in the Delta provided a conceptual model for the important elements affecting the process of predation (Figure 3-11). As noted by Grossman et al. (2013), the ultimate outcome of the predation process (consumption) is the result of several components, including search and encounter, pursuit and attack, and capture and handling. Engineering options being considered to further reduce diversion of emigrating juvenile salmonids to the interior and south Delta have the potential to modify important aspects of each component of the predation process. Overall, the engineering solutions are intended to reduce the spatial overlap and encounter rate of juvenile salmonids with predators by guiding them away from channels that lead to high-predation areas. However, the engineering solutions may affect predation in other ways (e.g., by changing travel times, and therefore encounter rate) and behavior (e.g., if juvenile salmonids are avoiding the noxious stimuli from a BAFF, they could be more susceptible to predation).



Source: Grossman et al. 2013

Figure 3-11. Schematic of Components of the Predation Process

Reclamation (2006) summarized the main characteristics of locations at fish exclusion facilities where predation predominates. With respect to juvenile salmonids, which the facilities often are focused on protecting, such high-predation areas tend to be characterized by conditions that:

- favor juvenile salmonid holding, thus making them more accessible to predators;
- concentrate juvenile salmonids, leading to greater potential for successful predation; and
- weakened or disorient juvenile salmonids, making them less capable of escaping.

In addition, Reclamation (2006) noted that predation at fish exclusion facilities can be reduced/minimized by reducing fish passage delay. This is achieved by designing facilities to provide flow conditions and hydraulics that disperse or eliminate predators from zones where intense predation could otherwise occur, while avoiding excessive turbulence that could injure juvenile salmonids.

As noted by Grossman et al. (2013), foraging theory predicts that predators should select prey that maximizes their net energy gain. Juvenile salmonids may be of particular value in this regard because they are energy dense, easy to handle (because of soft rays and fusiform shape), and may be naïve to invasive predators, especially if the juvenile salmonids are of hatchery origin. Reclamation (2006) recommended the elimination of flow zones from fish exclusion facilities, where predators can hold and feed on passing fish with minimal energy output. This would be achieved by avoiding creation of slack water and eddy zones. Boundary points at which predators may aggregate to find favorable velocity (e.g., slow areas <0.1 meters per second (m/s) to adjacent to fast areas >0.1 m/s) were recommended by Reclamation (2006) to be removed in order to maintain consistent velocities, thus limiting the area for predator holding.

3.6.2 INSIGHTS FROM DELTA STUDIES

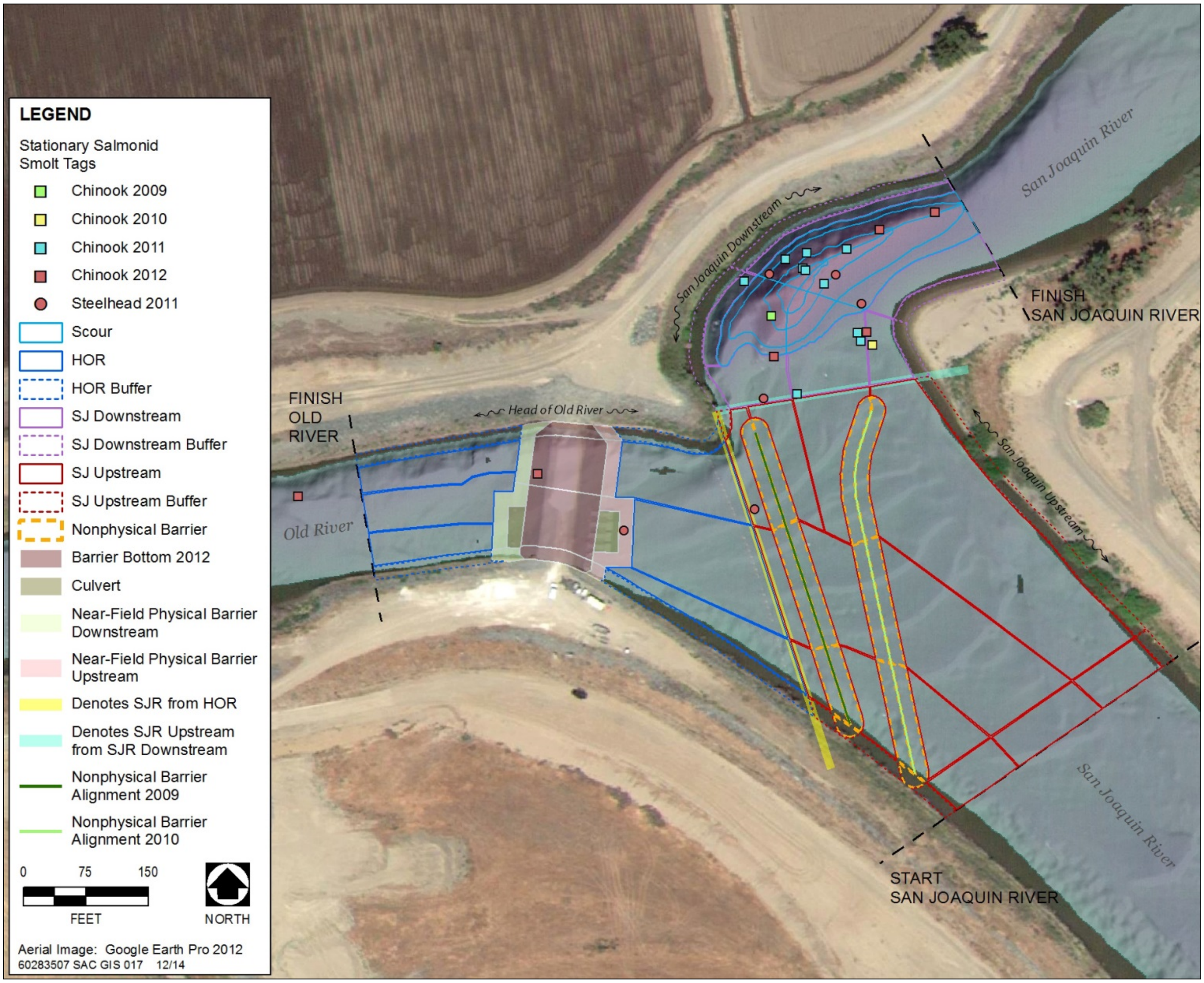
Important design insights for reducing predation by engineering solutions, thereby further reducing diversion of emigrating juvenile salmonids, have come from the studies summarized in Section 3.3, "Field Testing of Engineering Options." The main findings are summarized herein.

The HOR studies have provided information on the effectiveness of a BAFF and a physical barrier (rock barrier) (DWR 2014b). High levels of juvenile Chinook salmon predation in the HOR study area were observed with the BAFF ON in 2009–2010 (22 – 29 percent) and with the rock barrier in 2012 (just under 40 percent mortality) (DWR 2014b). In contrast, predation was less with the BAFF OFF (14 – 21.2 percent mortality). Of the 4 years studied, predation was lowest when no barrier was installed in 2011 (9 percent mortality), a year in which river discharge was very high and precluded BAFF installation (see Section 3.3.1 "2009 and 2010 Head of Old River Bio-Acoustic Fish Fence"). The HOR studies also have found considerably greater predation in light conditions compared to dark conditions, across treatments (i.e., BAFF ON/OFF, rock barrier, no barrier). These studies were notable in confirming the importance of the scour hole and immediately adjacent areas on the San Joaquin River just downstream from the HOR as predatory fish habitat (from both hydroacoustics and movements of acoustically tagged predatory fish), and as locations where predation has occurred (inferred from the location of stationary acoustic tags that presumably were defecated by predatory fish after consuming juvenile salmonids; Figure 3-12).

Predation associated with the scour hole appears to have limited the effectiveness of the BAFFs and the rock barrier, because fish being deterred or prevented from entering Old River were susceptible to being eaten in the scour hole. Limited data are available in 2009–2010 to assess the association of predatory fish and the BAFF. Only four striped bass were acoustically tagged, and only two of these were in the study for any substantial length of time (both in 2010), during which they spent less than 1 percent of their time near (within 15 feet of) the BAFF, and this does not suggest any considerable association with the BAFF (DWR 2014b). In contrast, a single largemouth bass that was tracked in 2009 spent nearly half its time within 15 feet of the BAFF, both within and just beyond 15 feet from shore.

Three largemouth bass that were tagged and released adjacent to the Old River side of the 2012 rock barrier spent a considerable proportion of their time very close to the barrier and used this habitat substantially more than would be predicted relative to its area. However, none of the predatory fish (i.e., largemouth bass, channel (*Ictalurus punctatus*) catfish, and striped bass) that were released on the San Joaquin River side of the rock barrier spent considerable periods of time near the 2012 barrier (DWR 2014c in prep.).

The 2011 BAFF study at Georgiana Slough coincided with high-flow conditions, and predation of juvenile Chinook salmon was very low (less than 4 percent mortality) compared to the studies at the HOR described above (DWR 2012). This was hypothesized because of: 1) relatively fast transport speeds, giving relatively low rates of encounter between predators and juvenile salmonids; 2) relatively high turbidity, also giving relatively low encounter rates; and 3) relatively low water temperature, conveying an energetic advantage to juvenile Chinook salmon over temperate predators common in the area (striped bass and smallmouth bass [*Micropterus dolomieu*]) (DWR 2012). Predation probability increased with water temperature for several reasons. Higher water temperatures impair burst swimming speeds to evade predators, reduce growth rates resulting in higher predation rates on smaller fish, and accelerate the metabolism of predator fish, increasing their ability to prey upon juvenile salmonids (Marine and Cech 2004; Coutant et al. 1979).



Note:
[1] Suggestive of defecation after consumption by predators.
Source: DWR 2014b in prep.

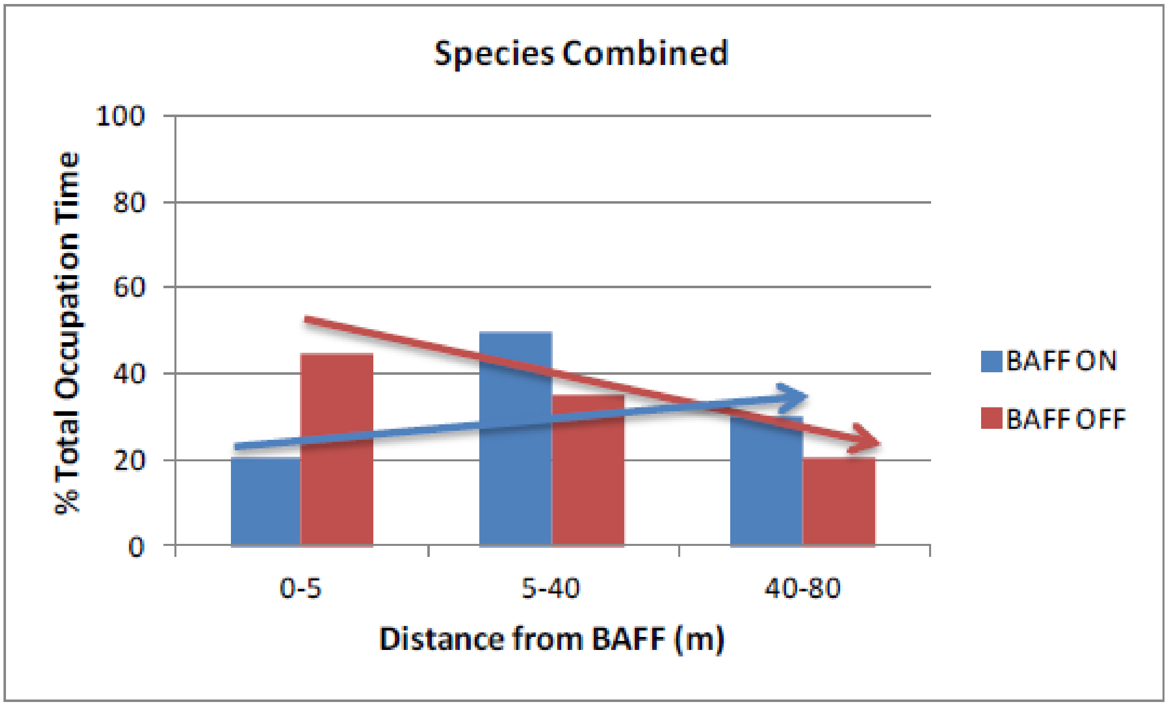
Figure 3-12. Locations of Stationary Juvenile Salmonid Tags at the Head of Old River, 2009–2012

No evidence was shown that the BAFF's physical infrastructure (i.e., piles and scaffolding) provided velocity refuge and ambush habitat for predatory fish because only one predation event occurred close (less than 15 feet) to the BAFF, with the remainder (48 classified predation events) being 15 feet or more away from the BAFF, and the majority of these being more than 260 feet away from the BAFF. Most (65 percent) of the predation events occurred with the BAFF OFF, and combined with some evidence from acoustically tagged predators (Figure 3-13), suggests that predatory fishes may have been startled by the BAFF when it was turned ON (DWR 2012).

Notes: A striped bass (3138.21) was tagged and released on April 15, 2011, at approximately 11:30 a.m. It moved to the BAFF and remained there for just under 8 hours. At approximately 8 p.m., the bubble screen was started and this fish moved across the river, away from the BAFF. About 5 minutes later, the sound projectors and modulated intense lights were turned on.
Source: DWR 2012

Figure 3-13. Striped Bass Movements during a Change in BAFF Operations (OFF to ON), 2011 Study at Georgiana Slough

The 2012 BAFF study at Georgiana Slough took place at considerably lower flow conditions than the 2011 study, and it examined predatory fish behavior and predation in greater detail (DWR 2014c in prep.). Little effect of the BAFF’s structural features (i.e., piles and scaffolding) occurred on predator distribution in the study area, as assessed by comparing the distribution with the BAFF OFF to the distribution in the study area before the BAFF was installed. As with the 2011 study, some evidence showed that the BAFF deterred predatory fish in the immediate vicinity when it was turned ON (Figure 3-14). An assessment of the evidence for predatory fish becoming conditioned to the BAFF over time gave mixed results, with the general conclusion being that predatory fish as a group showed increasing avoidance of the BAFF over time, whereas individual species (i.e., striped bass and smallmouth bass) displayed some evidence of potential conditioning over time (DWR 2014c in prep.). Predation of juvenile Chinook salmon in 2012 was considerably higher (23 percent mortality) than in 2011. Steelhead also had a relatively high predation rate (33 percent mortality). Spatial patterns of 116 juvenile Chinook salmon and 42 juvenile steelhead predation events analyzed in 2012 suggested that the BAFF’s structural and deterrence features did not contribute to increased predation in the area close to the BAFF, although DWR (2014c in prep.) noted that the comparison of BAFF ON versus BAFF OFF does not provide an indication of baseline predation rates in the absence of a BAFF.



Note: Trends are shown by the arrows.
Source: DWR 2014c in prep.

Figure 3-14. Percentage of Total Occupation Time by Spatial Polygon for Predatory Fish Species Combined under BAFF ON and BAFF OFF Conditions

3.6.3 Specific Considerations to Reduce Predation on Juvenile Salmonids

To reduce (limit) predation associated with the engineering options being proposed to further reduce diversion of emigrating juvenile salmonids to the interior and south Delta, several basic principles are important to consider that are related to the basic conceptual model summarized in Figure 3-11:

- Reduce predator-prey encounter rates; and
  - Limit creation of habitat suitable for predators
  - Limit direction of juvenile salmonids toward areas with suitable predator habitat

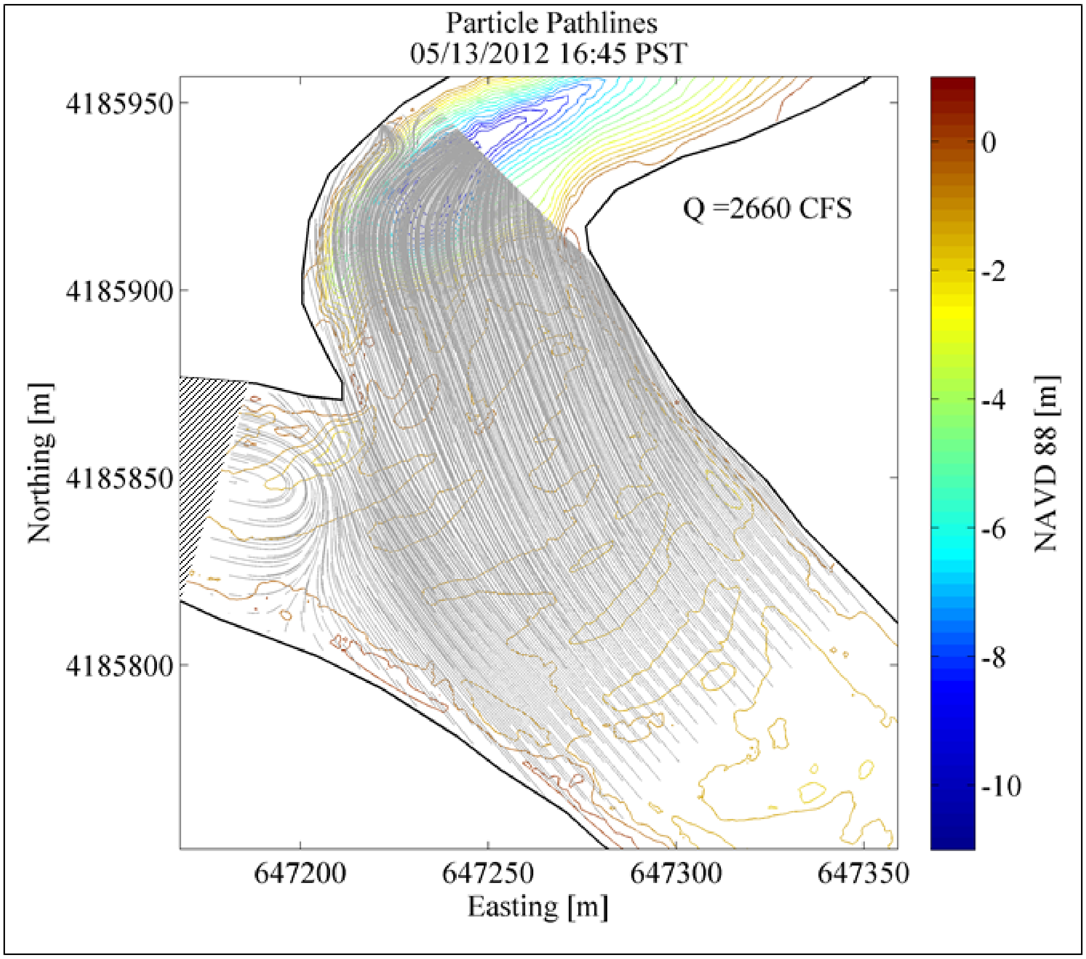
- Reduce negative effects to juvenile salmonid behavior.
  - Limit disorienting hydraulic effects (i.e., high hydraulic strain, flow patterns and turbulence)
  - Limit other physical stimuli (i.e., lights, noises) in the area of the behavioral deterrent system so that an approaching fish may more easily distinguish the noxious stimuli from ambient conditions.

Because all the engineering solutions would include placement of structures at key Delta channel junctions, they all would have the potential to form suitable physical structural habitat for predatory fish. However, as noted previously, the available evidence suggests that the structure associated with BAFFs (i.e., pilings and scaffolding) has little effect on suitable predator habitat (and the deterrence stimuli also may function to keep predatory fish away from the BAFF). Presumably similar observations also would apply to an IFF, although these remain to be studied in the Delta. Predatory fish association with the FFGS is still to be analyzed as part of the 2014 pilot study. Specific to the proposed engineering solutions, only operable gates appear to have the potential to create major changes in flow patterns at or near the channel divergences where they could be installed and appreciably change the potential extent of habitat suitable for predatory fish. Hankin et al. (2010) considered the installation of a physical barrier at the HOR to be potentially beneficial because, in addition to facilitating use of the more desirable mainstem San Joaquin River route by juvenile salmonids, it would "ensure that essentially all San Joaquin flow proceeds down the main channel, thereby presumably enhancing (juvenile) smolt survival via a mainstem flow effect." With respect to the design of a physical barrier, the following recommendation was suggested (Hankin et al. 2010):

> If an Obermeyer Gate is considered, it should be located near the edge of the hydraulic flow line of the main channel of the San Joaquin River. Data support that in-river structures such as a fill dam, but also bridge abutments, scour holes, piers and pump stations, provide habitat for predators in this reach of the river (Vogel, pers. comm., 2010). The position of the original HORB [Head of Old River Barrier] was set back into the entrance of the channel leading into Old River. This site was chosen most likely for ease and cost to construct and remove. Unfortunately, it also set up hydraulic conditions ideally suited for predators: slack water and cover. If a future barrier at the HOR is constructed, alignment along the San Joaquin embankment would create a higher sweeping velocity down the main channel, would move smolts more swiftly past this location, and should reduce predator habitat.

The results from the HOR study in 2012 tend to support this recommendation of Hankin et al. (2010). Predation at the HOR with a rock barrier installed was estimated to be 39.4 percent of tagged juvenile Chinook salmon entering the area (DWR 2014b). This appeared to be at least partly attributable to unfavorable hydraulic conditions, including an eddy adjacent to the rock barrier (Figure 3-15). The conceptual design for a physical barrier (i.e., gates with boat lock and fish ladder) at the HOR contemplates a structure that is appreciably closer to the mainstem San Joaquin River (Figure 3-16; and is more in keeping with the recommendation of Hankin et al. (2010)) than the alignment of the rock barrier installed in 2012. Hydrodynamic modeling could be used to optimize the position of such barriers with respect to minimizing eddies and areas of slack water that may harbor predatory fish. Although juvenile salmonids do not behave as passive particles during migration through the Delta (Delaney et al. 2014), hydrodynamic modeling of passive particles would be informative to visualize flow patterns near physical barriers (e.g., at the HOR just upstream from a potential barrier location), so that alternative designs could be screened for their potential to create areas with eddies and potential predator holding habitat.

Regarding design criteria specific to suitable predatory fish habitat, the HOR study (DWR 2014b) assessed near-surface water velocity in areas occupied by predatory fish. This study described the general preference of channel catfish and largemouth bass for slow velocity areas (a velocity less than 0.3 feet per second; Figure 3-17 and Figure 3-18), whereas striped bass occurred across a range of velocities that were encountered during the study without specific preference (Figure 3-19). The habitat preference values in these figures, at least those for channel catfish and largemouth bass, could be used to evaluate habitat suitability for predatory fish based on modeled water velocity for different designs of engineering solutions. Similar analyses of velocity preference for predatory fish are to be conducted as part of the study of the Georgiana Slough FFGS in 2014, for striped bass and black basses (i.e., smallmouth bass, spotted bass [*Micropterus punctulatus*], and redeye bass [*Micropterus coosae*], plus hybrids), which would further inform velocity criteria.



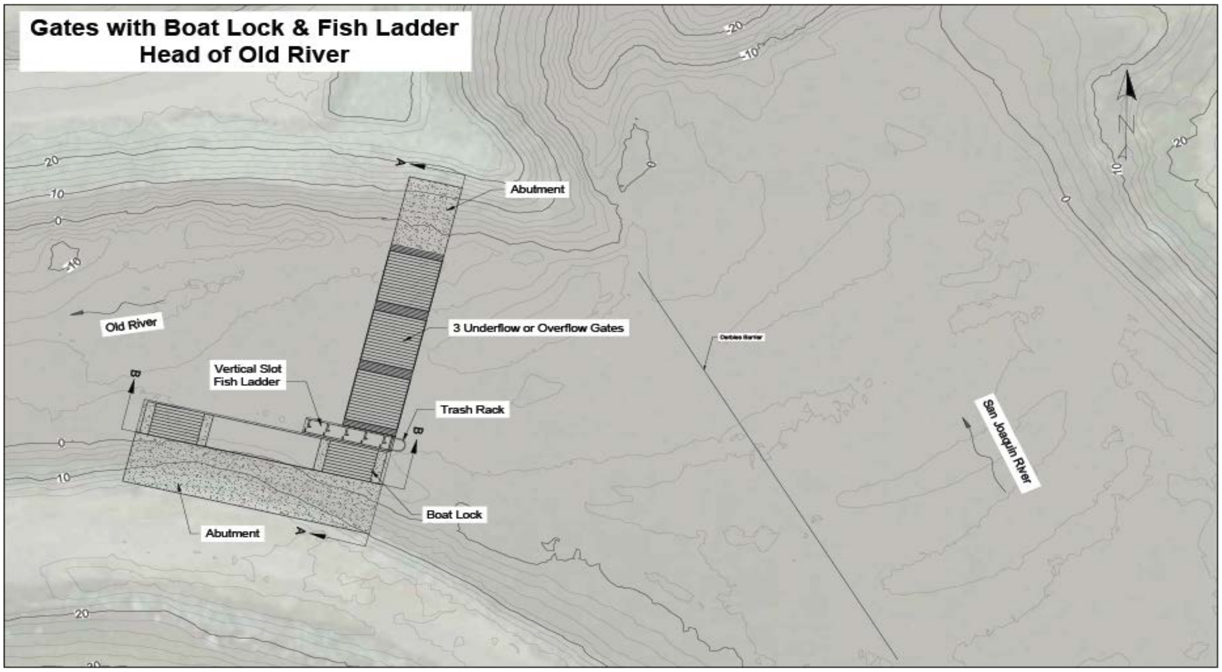
Notes:

1 Hatching indicates approximate location of the rock barrier; note adjacent eddy.

2 Estimated from data collected with a side-looking acoustic Doppler current profiler at the HOR, May 13, 2012, 4:45 p.m. PST, with river discharge in the San Joaquin River near Lathrop (Q) of 2,660 cfs.

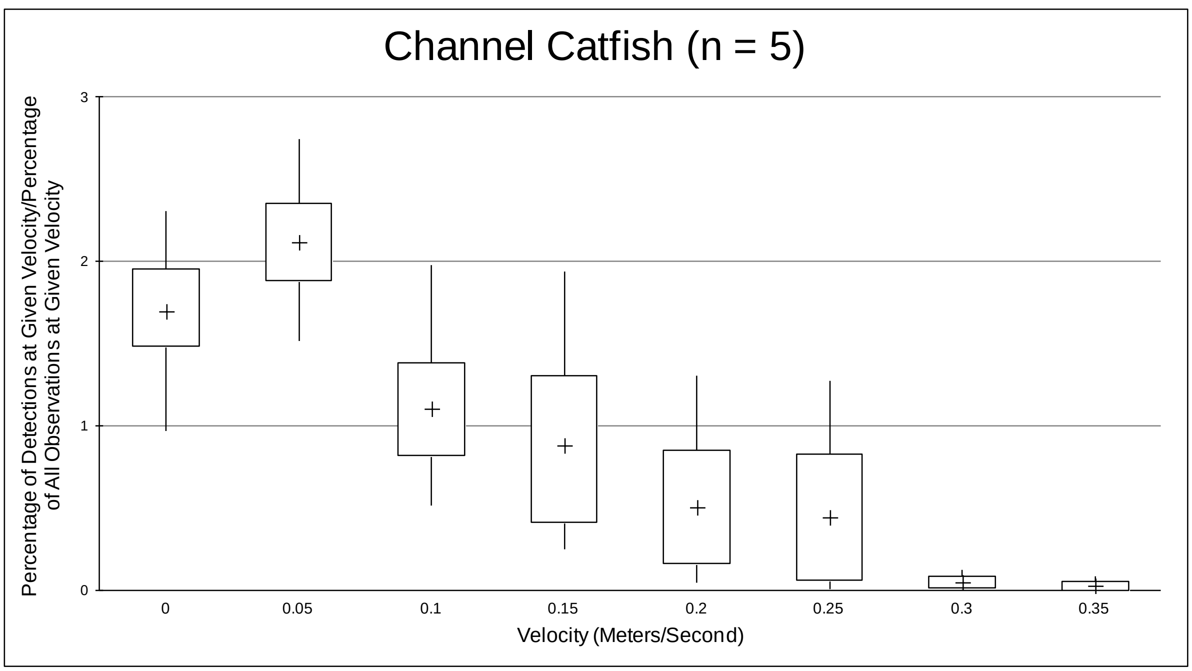
Source: Adapted by AECOM from DWR 2014c in prep.

Figure 3-15. Two-Dimensional Near-Surface Particle Pathlines at the Head of Old River, May 2012



Source: DWR 2014

Figure 3-16. Conceptual Design for Physical Barrier at the Head of Old River



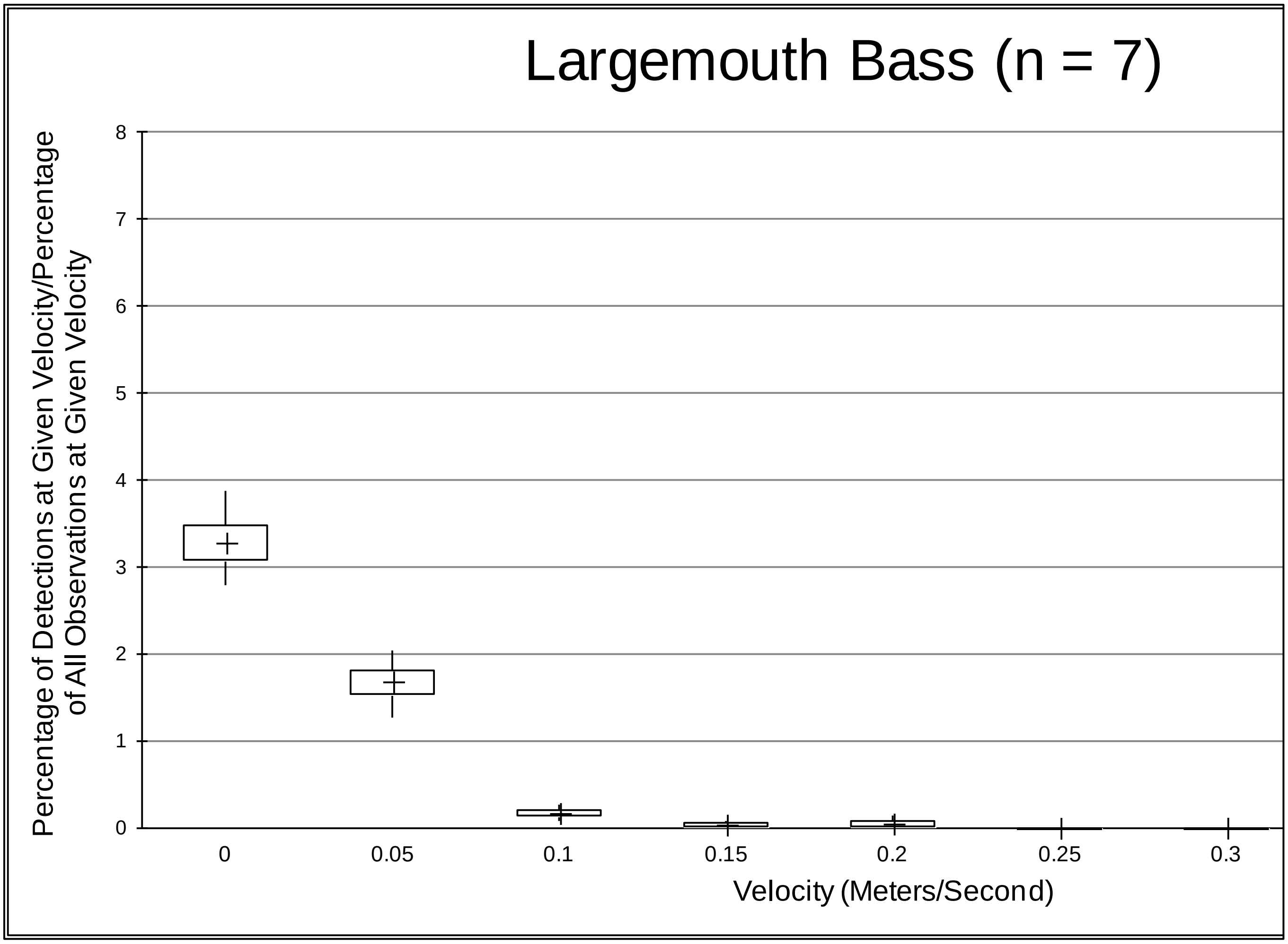
Notes:

[1] Velocity is rounded to the nearest 0.05 meter per second. The y-axis represents a measure of velocity preference, wherein 1 represents proportional use of a velocity range (fish occupied the velocity range in equal proportion to its availability), values above 1 represent disproportionately greater use of a velocity range than its availability, and values below 1 represent disproportionately less use of a velocity range than its availability.

[2] Percentage of tag detections for five channel catfish at different near-surface velocities in the HOR study area, divided by percentage of all near-surface velocities in the HOR study area, upstream from the 2012 physical rock barrier: bootstrapped mean (+), interquartile range (box), and 95% confidence interval (whiskers).

Source: DWR 2014c in prep.

Figure 3-17. Percentage of Tag Detections for Five Channel Catfish at Different Near-Surface Velocities at the Head of Old River Study Area



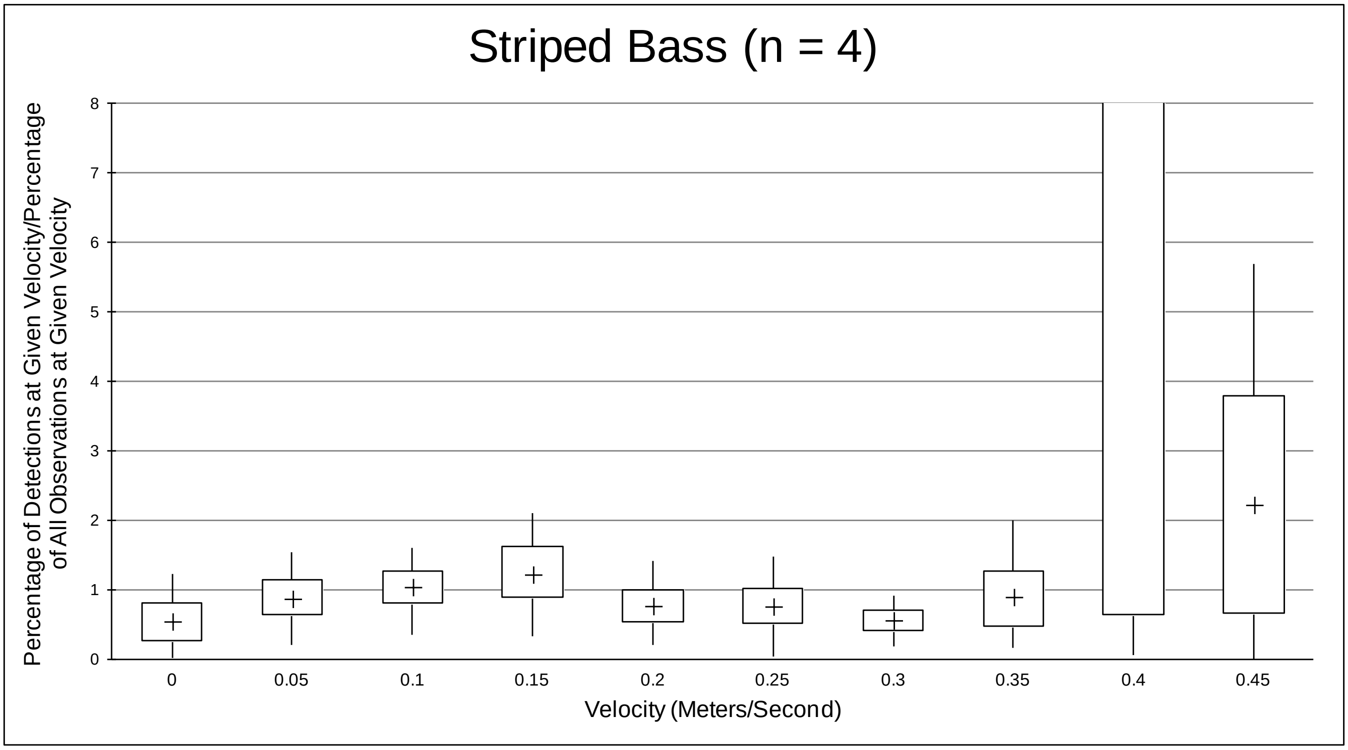
Notes:

[1] Velocity is rounded to the nearest 0.05 meter per second. The y-axis represents a measure of velocity preference, wherein 1 represents proportional use of a velocity range (fish occupied the velocity range in equal proportion to its availability), values above 1 represent disproportionately greater use of a velocity range than its availability, and values below 1 represent disproportionately less use of a velocity range than its availability.

[2] Percentage of tag detections for seven largemouth bass at different near-surface velocities in the HOR study area, divided by percentage of all near-surface velocities in the HOR study area, upstream from the 2012 physical rock barrier: bootstrapped mean (+), interquartile range (box), and 95% confidence interval (whiskers)

Source: DWR 2014c in prep.

Figure 3-18. Percentage of Tag Detections for Seven Largemouth Bass at Different Near-Surface Velocities at the Head of Old River Study Area



Notes:

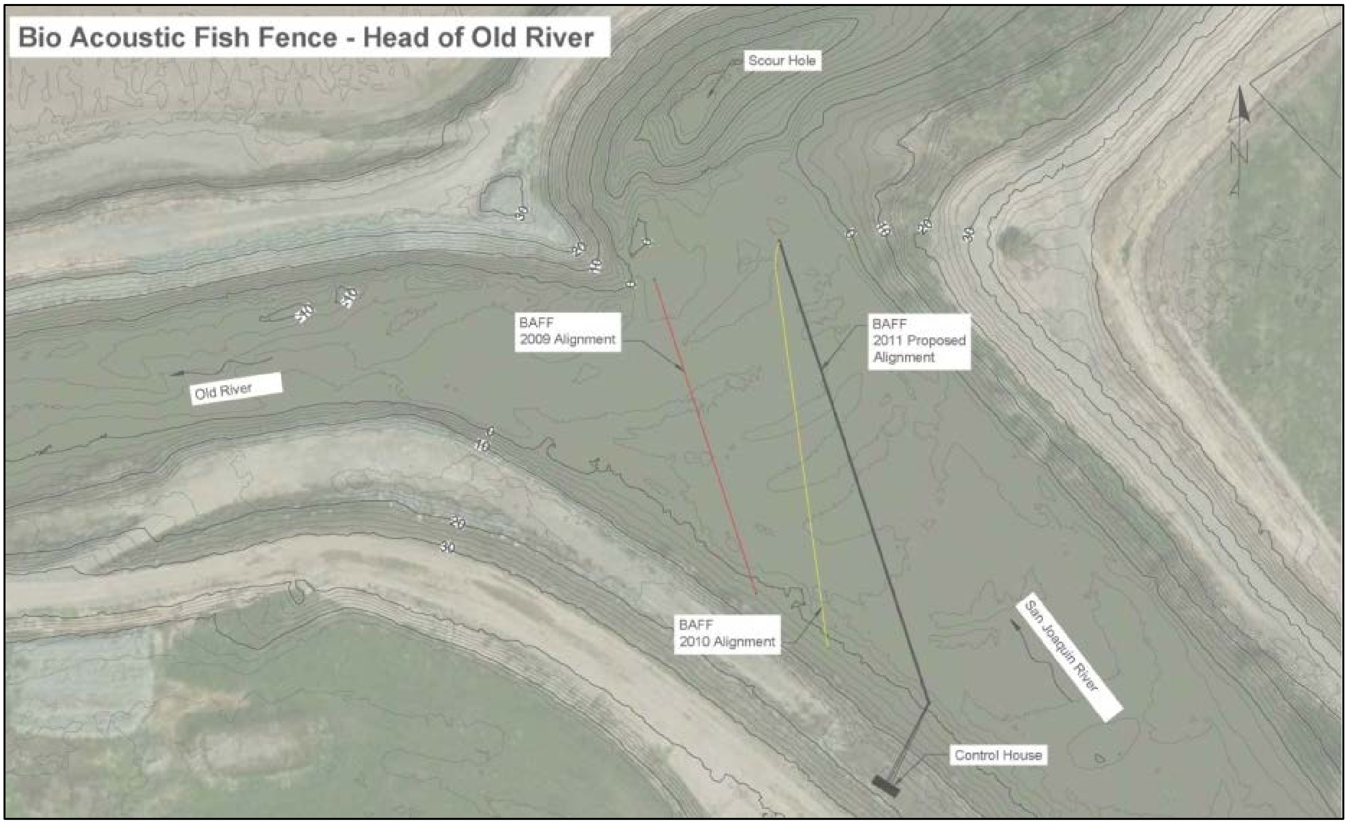
[1] Velocity is rounded to the nearest 0.05 meter per second. The y-axis represents a measure of velocity preference, wherein 1 represents proportional use of a velocity range (fish occupied the velocity range in equal proportion to its availability), values above 1 represent disproportionately greater use of a velocity range than its availability, and values below 1 represent disproportionately less use of a velocity range than its availability.

[2] Percentage of tag detections for four striped bass at different near-surface velocities in the HOR study area, divided by percentage of all near-surface velocities in the HOR study area, upstream from the 2012 physical rock barrier: bootstrapped mean (+), interquartile range (box), and 95% confidence interval (whiskers)

Source: DWR 2014c in prep.

Figure 3-19. Percentage of Tag Detections for Four Striped Bass at Different Near-Surface Velocities at the Head of Old River Study Area

Although the BAFF, IFF, and FFGS engineering solutions would not alter flow patterns appreciably and, therefore, would not be expected to change the availability of predator-suitable habitat because of changes in water velocity, they could influence predator-prey encounter rates if juvenile salmonids are guided to areas with suitable predator habitat. The clearest example of this is from the HOR study, as discussed previously. Therefore the design of engineering solutions should consider likely pathways of juvenile salmonids after redirection, and to the extent possible should avoid areas with suitable predator habitat where predator-prey encounter rates may be relatively high. At the HOR, placement of the BAFF farther into the channel in 2010 than in 2009 aimed to limit the potential for juvenile salmonids to encounter the scour hole, although this did increase survival. The intended 2011 design was a further refinement to the position but could not be tested because of high flows (Figure 3-20).



Note: The 2011 BAFF was not installed because of high flows.
Source: DWR 2012

Figure 3-20. Alignments of BAFFs Installed at the Head of Old River in 2009 and 2010, shown with Proposed Alignment for 2011 BAFF

Physical barriers, including the proposed gates investigated as an engineering solution, would have both near-field and far-field effects on migrating juvenile salmonids. As previously described, Hankin et al. (2010) suggested one benefit of a physical barrier at the HOR would be to keep flow in the mainstem San Joaquin River, and therefore presumably enhance juvenile salmonid survival (by increasing migration speed). Cavallo et al. (2013) showed that river inflow to the Delta has an important effect on the extent of the channel under appreciable tidal influence (i.e., with bi-directional flows much of the time). The tidal transition zone is the portion of a river in which flow changes from unidirectional to bi-directional. Cavallo et al. (2013) hypothesized that predation mortality likely would be greater and growth may be impaired if the tidal transition zone occurs where habitat conditions are poor or where predator densities are high, because tidal areas have greater residence time caused by bi-directional flow; Cavallo et al. (2013) suggested that this should be studied more fully. The gates proposed to be installed at the less tidally influenced locations (i.e., Georgiana Slough and HOR) would cause much of the river flow to remain in the mainstem rivers, shifting the tidal transition zone downstream compared to where it would be located otherwise without the gates. Examination of the locations where predation hotspots occur (see San Joaquin River Group Authority 2010, 2011, 2013) may be necessary to evaluate their relationship to the location of the tidal transition zone and how implementation of gates as engineering solutions may affect the relationship of these locations (i.e., it would be undesirable for gates to relocate the tidal transition zone to an area with known high mortality). However, predation mortality hotspots may move with the tidal transition zone, as predatory fish move. Therefore the static habitat features coinciding with the tidal transition zone also would be an important consideration (i.e., shallow-water habitat with refuge from predatory fish may offer better prospects for survival).

With respect to reducing negative changes in juvenile salmonid behavior, an important consideration for engineering solutions would be the need to limit disorienting effects that could make the juvenile salmonids more susceptible to predation. For example, the upwelling caused by the bubble curtain may disorient smaller fish increasing their vulnerability to predators. The BAFF, FFGS, or IFF would be unlikely to create hydraulic effects that would disorient juvenile salmonids because they would not be intended to change flow patterns to any appreciable extent. Gates with a boat lock and fish ladder may have potentially adverse hydraulic effects on juvenile salmonids that enter the fish ladder. Reclamation (2006) recommended that fish exclusion facilities should avoid creating hydraulic jumps, regions where high-velocity water discharges into low-velocity water and raises water surface elevations with turbulent flow. However, this may not be compatible with the turbulent flow that may be necessary to attract upstream-migrating adult salmonids and other species to the fish ladder. Because of the potential for predator aggregation at such features, supplemental methods may be necessary to reduce predation risk (see Section 3.6.4, “Supplemental Methods”).

The proposed BAFF and IFF engineering options would include deterrence of juvenile salmonids from undesirable migration pathways using primarily acoustic stimuli. The BAFF and IFF designs should avoid acoustic stimuli that would cause disorienting effects on juvenile salmonids, possibly affecting their behavior and increasing their susceptibility to predation, while maintaining their deterrence effectiveness. In addition, other stimuli such as strobe lights should only be employed to the extent necessary to enhance the effectiveness of the acoustic stimuli by improving the visibility of source of the acoustic stimuli; excessive strobe lighting can increase the potential for disorientation and result in greater entrainment into undesirable locations (Kock et al. 2009, as cited by Perry et al. 2014), presumably also increasing the risk of predation. Any disorienting effect of the BAFF tested at Georgiana Slough appears minimal given the relatively high deterrence effectiveness (Perry et al. 2014).

In addition, all the proposed engineering solutions should avoid installation of more lights than are necessary to facilitate navigation and security, as greater illumination may increase the risk of predation. As described in Section 3.6.2, “Insights from Delta Studies,” predation during the day (higher light levels) was considerably greater than during the night (DWR 2014c in prep.). Anthropogenic light employed at the engineering solutions should be considered in the context of the wavelengths of light that are used by predatory fishes, birds, and aquatic mammals, so that the light emitted does not facilitate increased predation.

3.6.4 SUPPLEMENTAL METHODS

Although engineering solutions to further reduce diversion of emigrating juvenile salmonids into the interior and south Delta may be designed to reduce predation to the greatest extent possible, fundamental constraints are likely to be present at individual locations that would affect predation risk regardless of the designs of the engineering solutions. For example, although engineering solutions should be designed to attempt to route juvenile salmonids past the scour hole at the HOR, many juvenile salmonids still are likely to encounter the scour hole. This suggests that supplemental methods may be necessary to augment the design of engineering solutions. Two potential methods are outlined next: habitat manipulation and localized predator reduction.

Habitat manipulation may be warranted for further investigation at locations where engineering solutions may interact with existing habitat features and affect predation rates of juvenile salmonids. At the HOR, for example, modification of the scour hole’s bathymetry by filling it with suitable substrate could enhance the effectiveness of engineering solutions designed to guide fish away from Old River. Such an action would require a detailed modeling effort to ascertain the potential effects on the river near the scour hole, particularly with respect to effects on the river banks and levees. It also would be important to assess the far-field effects of such an action on river hydrodynamics upstream and particularly downstream from the scour hole, to assess whether the action would have the potential to change habitat characteristics elsewhere in such a way that predation risk would be altered (see discussion regarding far-field effects of physical barriers in Section 3.6.3, "Specific Considerations to Reduce Predation").

Reduction of piscivorous predatory fish (e.g., by capture and relocation or by deterrence) at sites where engineering solutions may be implemented would aim to reduce predation risk. The feasibility of capturing and relocating predators to the degree that predation would be measurably reduced is highly uncertain and problematic (Gingras and McGee 1997). This is particularly true at open areas where the engineering solutions are being considered for implementation. For example, removal efforts in Clifton Court Forebay yielded a large quantity of predatory fish (particularly striped bass) but did not seem to reduce predatory fish population size in the forebay (Coulston 1993).

However, in a study on the North Fork Mokelumne River, Cavallo et al. (2013) demonstrated that predator removal to improve the survival rate of juvenile salmonids may be feasible at some locations, if a sustained effort is made. Electrofishing was used to catch predatory fish in a 1-mile impact reach; the survival rates of tagged juvenile Chinook salmon were compared before and after the removal in the impact reach and in an upstream 1.25-mile control reach. Survival was greater than 99 percent in the reach after the removal, compared to less than 80 percent before the removal. Survival in the control reach was variable and did not differ before and after the removal. However, survival in the impact reach declined to initial levels after a second predator removal effort, before increasing to very high levels (again greater than 99 percent) after a considerable increase in discharge caused by the opening of the Delta Cross Channel gates. Also on the Mokelumne River, Sabal (2014) found that juvenile Chinook salmon survival below Woodbridge Irrigation District Dam on the lower Mokelumne River increased by approximately 25 to 30 percent following removal of predatory fish by electrofishing.

With respect to the proposed locations where engineering solutions are being assessed, NMFS's Southwest Fisheries Science Center began a 2-year study in 2014 to experimentally manipulate predatory fish density at the HOR and adjacent areas. The results of this study will inform the potential for reduction of predatory fish during future implementation of engineering solutions. As noted previously, evidence shows that predatory fish may be deterred by operating BAFFs, possibly because of the stimuli (principally noise). Depending on the engineering solution that is most appropriate for a given location where juvenile salmonids are to be deterred, development of hybrid designs may be possible that would aim to deter predators (e.g., gates with boat lock and fish ladder that would incorporate an acoustic deterrent stimulus or other form of stimulus to limit predator congregation). Such stimuli should consider risks from predatory fish, piscivorous birds, particularly species such as cormorants (*Phalacrocorax* spp.) for which strong evidence exists from Clifton Court Forebay that conditioning to water operations results in greater predation (Clark et al. 2009), and aquatic mammals.

The reduction of predatory fish numbers at hotspots through habitat manipulation, predator relocation, and other methods is under consideration in other planning efforts for the Delta (e.g., as part of the Bay Delta Conservation Plan's conservation measure 15, *Localized Reduction of Predatory Fishes*; see Chapter 3 of the public draft BDCP; DWR 2013a). Coordinating such efforts with implementation of the proposed engineering solutions would increase the potential for greater effectiveness in further reducing the diversion of emigrating juvenile salmonids.

3.7 RECENT RELATED STUDIES CONDUCTED IN THE LEGAL DELTA

The related research topics summarized in this section include diet analysis, piscivorous predator behavior (fish and avian), juvenile salmonid route selection, and juvenile salmonid survival as listed in Table 3-7. Each subsection provides brief summaries (i.e., purpose, findings, and recommendations, if applicable) of related studies by topic that are being conducted (2014 and going forward) in the Delta that may provide useful recommendations related to the proposed engineering options. In addition, recently completed (2012–2014) studies are included.

The discussion concludes with a brief presentation of some of the study topics for which more information and/or study are warranted.

3.7.1 SCIENCE WORKSHOP FINDINGS FOR PREDATION ON JUVENILE SALMONIDS (2013)

In July 2013, CDFW and others sponsored the *State of the Science Workshop on Fish Predation on Central Valley Salmonids in the Bay–Delta Watershed*. The purpose was to have an independent panel of experts summarize the current understanding about piscivorous fish predation of Central Valley salmonids. Grossman et al. (2013) published the following comments about the conclusions of this workshop:

> The findings from the independent panel found that it was not clear what proportion of juvenile salmonid mortality can be directly attributed to fish predation given the extensive flow modification, altered habitat conditions, native and non-native fish and avian predators, water temperature and dissolved oxygen limitations, and overall reduction in historical salmon population size. Furthermore, although it is assumed that much of the short-term (<30 d[ay]) mortality experienced by these fish is likely due to predation, there are very few data establishing this relationship. Stress caused by harsh environmental conditions or toxicants will render fish more susceptible to all sources of mortality including predation, disease or physiological stress. In summary, the lack of common research methodologies and coordination of research projects has inhibited the abilities of researchers and managers to build on previous studies, which are necessary for management of the Delta. Panel recommendations related to engineering options include designing studies which provide an understanding of the hydrological processes and their effects on fish behavior around predation hotspots, and test the effectiveness of predator removal experiments across large-time and space scales.

Table 3-7. Summary of Current and Recently Completed Related Studies in the Legal Delta

Study Title	Diet Analysis	Piscivorous Predator Behavior	Salmonid Route Selection	Salmonid Survival	Completion Date	Study Location	Lead Agency	Principal Investigator	Funding Source
Current Studies									
Clifton Court Forebay Predation Full-Scale Studies	✓	✓		✓	2017	South Delta	DWR	Wunderlich	DWR
Survival and Migratory Patterns of Juvenile Spring and Fall Run Chinook			✓	✓	2016	Delta	UCD	Klimley	
Central Valley Project Improvement			✓	✓	2016	Delta	USFWS	Brandes	TBD
Six-Year Steelhead Study			✓	✓	2016	Delta	USBR	Israel	
San Joaquin River Predator Project		✓		✓	2015	San Joaquin River	NOAA	Hayes	
North Delta Predation Study	✓				2014	North Delta	UCD DWR	Baerwald	
Sacramento River Diversion Predator Project	✓	✓		✓	2014	Sacramento River	NOAA	Michel	ERP
Recently Completed									
Clifton Court Forebay Predation Pilot Studies	✓	✓		✓	2013/14	South Delta	DWR	Wunderlich	DWR
Head of Old River Predator Study		✓			2014	Head of Old River	FF	Kennedy	
Habitat Alteration and Predator Study	✓	✓			2014	Mokelumne River	UCSC NOAA	Sabal	
Effects of Predator and Flow Manipulation on Juvenile Chinook Salmon Survival		✓		✓	2014	Delta	CFS	Cavallo	
Georgiana Slough Non-Physical Barrier Study 2012		✓	✓	✓	2014	Georgiana Slough	DWR	McQuirk	DWR
Central Valley Project Improvement			✓	✓	2014	Delta	USFWS	Brandes	
Distribution, Habitat Use, and Movement Patterns of Sub-adult Striped Bass		✓			2012	Bay-Delta	UCD DWR	LeDoux-Bloom	
Juvenile Salmonid Routing and Barrier Effectiveness, Predation, and Predatory Fishes at the Head of Old River, 2009-2012		✓	✓	✓	2012	Head of Old River	DWR	McQuirk	DWR

Table 3-7. Summary of Current and Recently Completed Related Studies in the Legal Delta

Study Title	Diet Analysis	Piscivorous Predator Behavior	Salmonid Route Selection	Salmonid Survival	Completion Date	Study Location	Lead Agency	Principal Investigator	Funding Source
Stipulation Study			✓	✓	2012	Old Middle River	DWR	Clark	DWR
Georgiana Slough Non-Physical Barrier Study 2011		✓	✓	✓	2011	Georgiana Slough	DWR	McQuirk	DWR

Notes: CFS = Cramer Fish Science; DWR = Department of Water Resources; FF = Fisheries Foundation; NOAA = National Oceanic and Atmospheric Administration; UCD = University of California, Davis; UCSC = University of California, Santa Cruz; USBR = U.S. Department of the Interior, Bureau of Reclamation; USFWS = US Fish and Wildlife Service.
Piscivorous Predators = fish and avian; Completion Date = Date/Year presented extracted from the study proposal or provided by author
Source: AECOM 2014

3.7.2 CURRENT RELATED STUDIES CONDUCTED IN THE LEGAL DELTA

3.7.2.1 DIET ANALYSIS STUDIES

Clifton Court Forebay Predation Full-Scale Studies (DWR)

DWR is conducting two diet analysis predation studies for the Clifton Court Forebay (CCF). The purpose of both studies is to identify the prey consumed by piscivorous predatory fish and avian species in and around CCF, using genetic analysis to assess fish gut contents and avian pellets and feces. This study is ongoing and scheduled to be completed by 2017.

3.7.2.2 PISCIVOROUS PREDATOR BEHAVIOR

Fish Species Studies

Clifton Court Forebay Predation Full-Scale Studies (DWR)

The purpose of this study is to assess the seasonal predator assemblage of potentially predatory fish species preying on juvenile salmonids in the CCF. The species being investigated include white catfish, channel catfish, blue catfish (*Ictalurus furcatus*), striped bass, largemouth bass, smallmouth bass, Sacramento pikeminnow, black crappie (*Pomoxis nigromaculatus*), and brown bullhead (*Ameiurus nebulosus*). Fish are being collected by various methods, with some fish included in mark-recapture biotelemetry studies. In addition, roving creel censuses will assess fishing exploitation before and after Fishing Facility Access Structure (FFAS) construction. This study is ongoing and scheduled to be completed by 2017.

San Joaquin River Predator Project (NOAA)

The purposes of this study are to acoustically survey the fish community, measure predation rate using tethering, estimate survival of the acoustically tagged fish, and conduct extensive predator removal activities. This project is ongoing and scheduled to be completed by 2015.

Avian Studies

Clifton Court Forebay Predator Full-Scale Studies (DWR)

The purposes of this study include estimating the abundance of predatory avian species near the radial gates and trash rack, monitoring the seasonality of predatory avian population, and calculating the maximum consumption of salmonids by predatory birds via bioenergetic modeling. This study is ongoing and scheduled to be completed by 2017.

3.7.2.3 SALMONID ROUTE SELECTION

Survival and Migratory Patterns of Juvenile Spring- and Fall-Run Chinook Salmon (UCD)

The purpose of this study is to evaluate the effects of natural and anthropogenic changes in flow and related water project operations on the survival and movement patterns of acoustically tagged, hatchery-reared spring- and fall-run juvenile Chinook salmon in the Sacramento River and Delta. Analyses will examine the relationships between flow, survival, and movement patterns of juvenile salmonids in the Sacramento River and Delta. This study is ongoing and findings are anticipated in 2016.

Central Valley Project Improvement Act (USFWS)

The purposes of this study are to estimate acoustically tagged, hatchery-reared juvenile Chinook salmon survival through the Delta in April and May, and compare it with data on the releases made in previous years (i.e., 2010–2014) to identify proportional causes of mortality as the juveniles migrate downstream. Findings are anticipated in 2016. See Section 3.7.3.4 "Juvenile Salmon Route Selection" for recent results from previous (CVPIA) and VAMP studies.

Six-Year Steelhead Study (Reclamation)

The purpose of this study is to assess the behavior and movement of hatchery-reared, acoustically-tagged juvenile steelhead in the lower San Joaquin River. The data collected by the acoustic monitors will provide information about juvenile steelhead migration and route selection. Study results are expected to be published by Reclamation in 2016, to meet its obligations under the BiOp. This study and the CVPIA are complementary in combining the juvenile steelhead and juvenile Chinook dataset to conduct an integrated synthesis.

3.7.2.4 JUVENILE SALMONID SURVIVAL

The Clifton Court Forebay Full-Scale Studies (DWR), San Joaquin River Predation Project (NOAA), Survival and Migratory Patterns of Juvenile Spring and Full Run Chinook Salmon (UCD), CVPIA (USFWS) and Six-Year Steelhead Study (Reclamation) also contain salmonid survival components in the study designs.

3.7.2.5 ELAM MODELING

The environmental and internal factors that determine how fish navigate through open river environments are poorly understood. Monitoring all the possible factors that could contribute to fish movement in a large, open system is not possible, so assumptions and simplifications underlie any type of analysis. The present study proposes to use an Eulerian-Lagrangian-Agent Method (ELAM) in order to provide detailed insight into how environmental and internal factors may influence juvenile Chinook salmon migration through the study area at the divergence of Georgiana Slough from the Sacramento River.

3.7.3 RECENTLY COMPLETED RELATED STUDIES CONDUCTED IN THE LEGAL DELTA

3.7.3.1 DIET ANALYSIS STUDIES

Clifton Court Forebay Predation Pilot Studies (DWR)

The pilot study elements were scheduled to be completed by October 2013. However, the findings and conclusions currently are unknown.

North Delta Predation Study (UCD and DWR)

The purpose of this study was to investigate incidence of predation across the north Delta and to find potential correlations between "undesirable" predation and these biotic and abiotic factors using genetic analysis. DNA (deoxyribonucleic acid) was extracted from the homogenized gut contents and detected the prey genetically, using real time Polymerase Chain Reaction (PCR). The results are unavailable, although some preliminary results are to be presented at the Bay–Delta Science Conference in fall 2014. Full results are to be published in 2015.

Sacramento River Diversion Predator Project (NOAA)

The purposes of this study were to investigate whether predator density, predatory fish diet, and predation rates on tethered Chinook smolts differ between bank and channel habitat, and water diversion at two sites located on the Sacramento River. In addition, predatory fish were acoustically tagged to investigate home ranges. The findings showed that the predatory fish density was equal between the two sites; however, the density was highest at the Freeport Diversion Zone. Gastric lavage of predatory fish showed less than 2 percent contained smolt parts. Generally, striped bass did not exhibit residence, but pikeminnow remained in the area post-tagging. The results of this investigation are not yet published.

3.7.3.2 FISH SPECIES STUDIES

Clifton Court Forebay Predation Pilot Studies (DWR)

The pilot study elements were scheduled to be completed by October 2013. However, the findings and conclusions currently are unknown.

Head of Old River Predator Study (Fishery Foundation and AECOM)

From March through mid-June 2013, Kennedy et al. (2014) investigated the predatory fish assemblage near the HOR at four sites: a scour hole, the location where the 2009 and 2010 BAFF was placed, the location of the rock barrier, and a reference site. A portion of the fish captured was tagged for mark-recapture evaluation. The purpose of the study was to evaluate residency and calculate the catch-per-unit effort (CPUE) by site for correlation with water temperature, depth, turbidity, sample date, and photoperiod. The fish assemblage included striped bass, catfish, and largemouth and spotted bass. The tagged striped bass did not exhibit residence. However, other species resided in the area post-tagging. Important correlations existed between CPUE and water temperature, sample date, and site.

Distribution, Habitat Use, and Movement Patterns of Sub-Adult Striped Bass (UCD and DWR)

From June 2010 through December 2011, LeDoux-Bloom (2012) investigated the seasonal distribution, habitat use, and movement patterns of sub-adult striped bass. The findings showed that as water temperatures decreased in late fall, winter, and early spring, the population shifted downstream toward San Francisco Bay, San Pablo Bay, and into the Pacific Ocean. In late spring, some fish migrated upstream, likely in response to increasing water temperatures and/or the onset of sexual maturity of the males. During summer, the population was distributed from the Golden Gate Bridge to the City of Colusa. In 2011, very few fish moved upstream, which likely was associated with the unusual high flow. Fish were detected most often on shoals (less than 13 feet), except in winter when channels (greater than 13 feet) and shoals were inhabited equally. Three residence patterns were observed: riverine, estuarine, and bay residence. In summary, sub-adult striped bass moved toward habitat with the seasonally warmest water temperatures (less than 28°C [82.4°F]), such as shoals, and high flows retarded upstream migration. Sub-adult striped bass exhibited movement patterns possibly related to salinity.

Habitat Alteration and Predator Study (UCSC and NOAA)

During May 2013, Sabal (2014) investigated how striped bass and habitat alterations (small diversion dam and other altered habitats) interacted to influence mortality on native juvenile Chinook salmon on the lower Mokelumne River. The purpose of the study was to estimate relative abundance and diet surveys across natural and human-altered habitats to assess functional and aggregative responses of striped bass. The findings showed that striped bass had an elevated per capita consumption of juvenile salmon and behavioral aggregation at a small diversion dam over other altered and natural habitats, creating a localized area of heightened predation (seasonal hotspot). Experimental predator removals, diet energetic analysis, and before-after impact assessment estimated striped bass consumption of the population of out-migrating juvenile salmon to be between 10 to 29 percent. Striped bass per capita consumption rates among the three approaches were 0.92 percent, 1.01 to 1.11 percent, and 0.96 to 1.11 percent, respectively.

Effects of Predator and Flow Manipulation on Juvenile Chinook Salmon Survival (Cramer Fish Sciences)

The purpose of this study was to measure the effects of non-native, piscivorous fish removal and artificial flow manipulation on survival and migration speed of acoustically tagged, juvenile Chinook salmon emigrating through the Delta using a before-after-control-impact study design. The findings showed that survival increased substantially after the first predator reduction in the impact reach. However, survival estimates returned to pre-impact levels after the second predator removal. When flow increased and tidal effect decreased, juvenile salmon emigration time decreased and survival increased substantially through the impact reach. In summary, the results demonstrated that predator control and habitat manipulation in the Delta tidal transition zone may be effective management strategies to enhance juvenile salmon survival. See Cavallo et al. (2013) for additional study details.

Georgiana Slough Non-Physical Barrier Evaluation (DWR)

Aspects of the study were to assess acoustically tagged predatory fish and acoustically tagged, hatchery reared juvenile Chinook salmon behavior around a BAFF. Predatory fish movement patterns were tracked in response to environmental conditions, presence of juvenile Chinook salmon, and the potential for salmon predation. The findings showed that when the BAFF was operating, substantial increases in deterrence, protection, and overall efficiency for juvenile salmon were observed. Variation in light levels did not affect the deterrence, protection, and overall efficiency. Behavior and movement patterns of juvenile salmon were influenced by the high river flows. Predation rates were relatively low, and no evidence showed that BAFF operations attracted predators or increased predation on juvenile Chinook salmon. The BAFF while operating reduced the entrainment of juvenile salmon from the Sacramento River into Georgiana Slough; therefore, the BAFF is expected to increase survival rates of juvenile Chinook salmon. Study results represent the response of juvenile Chinook salmon smolts and do not necessarily reflect the response of juvenile steelhead. See DWR (2012) for additional study details.

The purpose of the 2012 GSNPB was to continue to investigate ways to improve outmigrant survival through the Delta. Final data analyses and findings are anticipated in early 2015. See DWR (2014c) for additional study details.

Juvenile Salmonid Predation at the Head of Old River, 2012 (DWR)

In 2012, a rock barrier was installed across the entire channel width of the Old River at the beginning of April and removed at the end of May. The rock barrier had eight culverts to allow passage of a small proportion of flow and juvenile salmonids that chose that route. With the rock barrier in place, a proportion of the water that would normally flow down the Old River is diverted into the San Joaquin River, this benefits outmigrating juvenile salmonids. In 2012, two telemetered juvenile salmonids passed through the culverts but were eaten before they departed the hydrophone array. Therefore these two smolts fate was recorded as “predation” rather than “Old

River". The overall efficiency of the physical rock barrier for all conditions combined was 61.8 percent. That is 61.8 percent of tags, that were originally inserted into juvenile Chinook, continued down the San Joaquin River; the remainder of tags were eaten and passed out of the HOR area in predators (upstream, downstream (San Joaquin River or Old River), were defecated in the HOR area, or disappeared (e.g. avian predation). When tags from smolts that had been eaten were removed from consideration the rock barriers protection efficiency was 100%.

A fate of "predation" was assigned to 39.4 percent of tagged Chinook smolts. This was considerably higher than any other year at HOR for every treatment/year combination. Analysis of differences in operational efficiency during low-light and high-light conditions, showed 42.3 percent more smolts being eaten in high-light conditions than low-light conditions. The large difference in predation rates during high and low light condition is expected as smolt predators at the HOR are primarily visual. The rock barrier implementation at the HOR had the highest proportion of tags eaten in the study area (39.4 percent), but also had the highest proportion of tags in smolts released that never arrived (53.9 percent). This may indicate that the high rate of predation was not solely due to the presence of the rock barrier, but other factors in 2012 leading to greater predator numbers and/or greater capture success. In 2012 juvenile Chinook salmon may have been more vulnerable to predation due to eddies that form near the rock barrier coupled and with the greater density of large fish observed (predators), via hydroacoustic monitoring, around the rock barrier. This form of physical barrier may be creating favorable habitats for predation.

Juvenile Salmonid Routing and Barrier Effectiveness, Predation, and Predatory Fishes at the Head of Old River, 2009-2012 (DWR)

The purposes of this study were to describe the residence time of predatory fish at the HOR study site and the habitat areas (spatial and velocity) occupied by predatory fish at the HOR study site, and to evaluate juvenile salmonid routing, including barrier effects.

The findings on the behavior of predatory fish included striped bass, largemouth bass, channel catfish, and white catfish that were captured and fitted with acoustic tags, primarily in 2011 and 2012. The time spent at the HOR study site by acoustically tagged predatory fish varied. Generally, however, channel catfish, white catfish, and largemouth bass spent appreciably longer amounts of time there than striped bass (i.e., days or weeks rather than minutes or hours). Most striped bass left the study area in a downstream direction.

The significance of the results for management is that turnover of striped bass generally was appreciable, with most fish spending a limited amount of time at the HOR study site. Thus, efforts to control fish numbers by removal/relocation would require a sustained effort (e.g., daily or twice weekly removal). See Table ES-6 in the HOR report for recommendations. The study details for the juvenile salmonid route selection are listed in the Salmonid Route Selection subsection.

3.7.3.3 AVIAN SPECIES STUDIES

Clifton Court Forebay Predation Pilot Studies (DWR)

The pilot study elements were scheduled to be completed in October 2013, and the bioenergetic modeling was to be completed by August 2014. The findings and conclusions are not yet available.

3.7.3.4 JUVENILE SALMONID ROUTE SELECTION

Evaluation of Barrier Effectiveness at the Head of Old River, 2009-2012 (DWR)

The purpose of this study was to evaluate juvenile salmonid routing, including barrier effects. The findings of juvenile salmonid route selection showed that the proportion of juveniles that remained in the San Joaquin River was similar to the proportion that went down Old River, with the remaining fish being preyed upon. The proportion of juvenile Chinook salmon remaining in the San Joaquin River ranged from 9 percent with the BAFF ON in the dark to 84 percent for the rock barrier in the dark. The proportion of juvenile Chinook salmon entering Old River ranged from 0 percent for the rock barrier to 78 percent BAFF OFF in the dark. The proportion of juvenile Chinook salmon that were preyed upon ranged from 3 percent no barrier in the dark to 45 percent rock barrier in the light. Of the juvenile steelhead entering the study area, 38 percent remained in the San Joaquin River, 38 percent entered Old River, and 24 percent were preyed upon. Little difference existed in routing or predation between light and dark conditions for juvenile steelhead. The predatory study details are presented in the "Piscivorous Fish Species" subsection.

Central Valley Project Improvement Act (USFWS)

In 2014, the CVPIA study has continued to focus on estimating juvenile Chinook salmon survival through the San Joaquin River and Delta (and routes contained within) and relating it to water temperature, flow, and water export with a physical barrier at the HOR. The CVPIA studies (2012–2014) have maintained similar objectives to the VAMP studies (2000–2011). See San Joaquin River Group Authority (2010; 2011; 2013) for past findings.

The purpose of this study is to estimate juvenile Chinook salmon survival through the Delta in April and May, and compare the data to the releases made in previous years (i.e., 2010–2014), to identify proportional causes of mortality as the fish migrate downstream. The results from 2013 and 2014 have not yet been analyzed. The results from the 2012 study are scheduled to be released by December 2014. See Buchanan et al. (2013) for additional study details.

Stipulation Study (DWR)

Juvenile salmon and steelhead migrating downstream in the San Joaquin River are vulnerable to mortality by numerous natural and anthropogenic stressors, such as predation and entrainment at SWP and CVP facilities.

The objectives of the 2012 Stipulation Study were to evaluate the effects of Old and Middle River (OMR) flows on survival, migration rate, and migration direction, estimate route selection under different OMR flow conditions, and to provide steelhead tag detection data that could be used to adaptively manage OMR flows. The quantitative statistical analyses determined that the Delta Simulation Model 2 Hydro Particle Tracking Model (DSM2 Hydro PTM) was not able to predict the movement of steelhead tags because the model greatly underestimated steelhead tag movement through the study area. Diurnal and nocturnal movement patterns of steelhead tags may be occurring, but these patterns were location-specific and found to be worthy of future study. In summary, acoustically tagged, hatchery-reared juvenile Chinook salmon and steelhead exhibited different movement patterns. See Delaney et al. (2014) for additional study details.

Juvenile Chinook route selection findings for DWR's Georgiana Slough Non-Physical Barrier Evaluations 2011 and 2012 (DWR 2012; DWR 2014c in prep.), and the evaluation of barrier effectiveness at the HOR from 2009 to 2011 (DWR 2014b in prep.) are described in Section 3.3, "Field Testing of Engineering Options."

3.7.3.5 JUVENILE SALMONID SURVIVAL

The Clifton Court Forebay Full-Scale Studies (DWR), Head of Old River Predator Study (Fisheries Foundation), Effects of Predator and Flow Manipulation on Juvenile Chinook Salmon Survival (Cramer Fish Sciences), Georgiana Slough Non-Physical Barrier Evaluations 2011 and 2012 (DWR), CVPIA (USFWS), Six-Year Steelhead Study (Reclamation), and Stipulation Study (DWR) also contain salmonid survival components in the study designs. See specific references for additional study details.

3.8 WATER QUALITY AND FLOW MODELING

Water quality and flow modeling was conducted by the DWR Modeling Support Branch of the Bay-Delta Office using the DSM2 model. The purpose for this modeling was to simulate the conceptual gate designs at each site through a variety of operational strategies to deter juvenile salmonids. The goal of the modeling was to realize the feasibility of operating individual, or a combination of, full column gates within a range of allowable flow blockages and operational timing with the tides. The model results were analyzed, and the resulting impacts on existing water quality and flow parameters are provided in Appendix E.

3.9 HYDRAULIC ANALYSIS: STREAK-LINE AND VELOCITY MAPPING

Velocity data were collected and analyzed by USGS for each of the sites. The analysis focused on streak-lines and velocity mapping at the junctions over full tidal conditions. The streak-line analysis was done to locate and geo-reference the naturally occurring flow split at each inlet to the channels of interest. This streak-line information and velocity mapping was used to assist in the conceptual designs for the placement and alignment of the behavioral barriers. The velocity mapping information also was used for the bioenergetics calculations to determine juvenile fish capabilities to escape entrainment velocities. The full USGS report is provided in Appendix D.

3.10 EVALUATION FRAMEWORK INCLUDING APPLICATION OF THE WATER RESOURCE ASSESSMENT METHODOLOGY

The evaluation of engineering solution options began during Phase I and has continued in Phase II. The evaluation framework has included five general steps, two completed in Phase I and three completed in Phase II. The Phase I steps included: (1) an initial identification of deterrence options; and (2) identification of evaluation criteria. In addition, a review and selection of potential locations or sites to reduce the salmonid diversion was completed, although this was not part of the evaluation framework. The site review and selection is described in the Phase I report.

The Phase II steps included: (3) a prioritization of the evaluation criteria; (4) a comparative evaluation of initial options, applying the prioritization; and (5) identification of preferred options for each study site. The evaluation followed a conventional engineering alternatives development and screening format and application of the USACE Waterways Experiment Station (WES) Water Resources Assessment Methodology (WRAM) (Solomon et al. 1977).

3.10.1 INITIAL IDENTIFICATION OF DETERRENCE OPTIONS

DWR completed the initial identification of deterrence options through literature research, written and verbal contact/review with fish deterrence and screening technology vendors, and review and discussion with the TWG.

The TWG, whose members have unique scientific and engineering expertise, provided valuable input on potential options and identified additional options for consideration based on a general understanding of deterrence site characteristics and the behavior of fish species of concern. These options included three general deterrence and screening technology types: physical, non-physical, and hybrid (multiple technologies). The options that were recommended for further evaluation during Phase II are described in Section 4.4, "Conceptual-Level Engineering Details."

3.10.2 IDENTIFICATION OF EVALUATION CRITERIA

DWR identified the evaluation criteria and presented them to the TWG for discussion. DWR staff considered project-level and site-specific criteria, as well as general and common feasibility study-level criteria, to evaluate engineering options. These criteria included the main objective of the Action (to consider engineering solutions to further reduce diversion of emigrating juvenile salmonids to the interior Delta and consequent exposure to CVP and SWP export facilities), local and regional hydrologic conditions, aquatic and terrestrial habitats, land and water uses, technology types (i.e., established, emerging, conceptual), effectiveness, operation and maintenance requirements, potential environmental impacts, regulatory and public acceptance, and cost. These initial, general evaluation criteria were classified under twelve more specific criteria: *deterrence ability, environmental impacts, upstream migration, flow effects, predation effects, tidal effects, boat passage, implementation, operation and maintenance, maturity, land acquisition/easement*, and *cost*. The criteria were further reduced to eleven final criteria, adding the *land acquisition/easement* category under *implementation*, and then revision of the criteria term to *implementation*. In addition, *maturity* was moved to a new category, *uncertainties*. *Uncertainties* were selected to address overall option unknowns, including whether an option was established, emerging, or conceptual.

The final evaluation criteria and their definitions are shown in Table 3-8.

Table 3-8. Final Evaluation Criteria to Evaluate Engineering Options

Criterion	Description
Boat Passage	The ability of an option to allow for the passage of boat traffic.
Cost	The cost of initial, annual, and long-term implementation of an option.
Deterrence Ability	The ability of an option to deter emigrating salmonids from entering a non-preferred migration route.
Environmental Impacts	Potential impacts of an option on the environment, including aquatic, terrestrial, and air quality resources.
Flow Effects	Potential impacts of an option on water flow, based on implementation.
Implementation	The ability of an option to be constructed in a timely manner in response to the need to deter emigrating or moving salmonids.
Operation and Maintenance	The effort required to keep an option operating and maintained.
Predation Effects	The effects of an option on predation beyond that which would occur naturally.
Tidal Effects	The effects of tidal stage variations as well as reverse flows on the performance of an option.
Uncertainties	The uncertainties associated with an option.
Upstream Migration	The effects of an option on the upstream migration of fish that should not be deterred.

Source: Compiled by DWR in 2014

3.10.3 PRIORITIZATION OF THE EVALUATION CRITERIA

The next step was to prioritize the evaluation criteria through application of USACE's WES WRAM (Solomon et al. 1977). The WRAM was developed to aid evaluation of potential water resource project impacts (beneficial and adverse) and alternatives. The WRAM is a parametric method that uses a systematic weighting-ranking technique. WES considered 54 weighting-ranking methods from various sources, determining that eight methods were to be considered for assessment of USACE water resource project alternatives. These eight methods were used to define the WRAM. The salient feature of the WRAM is the weighting of the importance of affected criteria and scaling the impacts of the alternatives. Through weighting and scaling, an evaluator cognizant of proposed objectives, sighting needs and constraints, regulatory requirements, and public preferences as well as other considerations can prioritize and rank the importance of each criterion and evaluate alternatives on a comparable basis.

The WRAM prioritization and criteria importance ranking was performed by a variable-by-variable pair-wise comparison. Each criterion was compared with each of the other criteria. A "1" was assigned to the most important criterion for each pair, a "0" to the least important, and "0.5" was assigned to both when each criterion was of equal importance.

This step was followed by calculating a relative importance coefficient (RIC) value for each criterion. A variable RIC value was determined by adding the importance comparison values for all criteria to generate a total, and dividing this by the importance comparison value for each individual criterion. The RIC values established the numerical ranking of importance for each criterion.

3.10.4 COMPARATIVE EVALUATION OF INITIAL OPTIONS

The next step was to compare potential option impacts (beneficial and adverse) on each criterion. The WRAM identifies the comparison as "impact scaling" in which project options are comparatively analyzed for their relative impact on a variable, and the comparisons are done through a "choice comparison" process. Like the RIC criterion-by-criterion comparison above, a pair-wise comparison was done for the options. Each option was compared with each of the other options, and for each pair a "1" was assigned to the option with the most benefit (or least impact), a "0" to the option with the least benefit (or most impact), or "0.5" when the option had an equal impact. Similar to the determination of RIC values, an option choice coefficient (OCC) was determined for each option and corresponding criterion. The OCC established a ranking of impact of each option on a criterion, relative to each other. An option OCC value was determined by adding the impact comparison values for all option-criterion comparisons to generate a sum, then adding the impact comparison values for all options, and dividing this sum by the impact comparison sum value for each individual option.

The OCC values then were combined with RIC values for each option, to calculate a final coefficient (FC). Each OCC value for an option was multiplied by the corresponding RIC value to generate intermediate coefficient values for each option/criterion combination. This was repeated for each criterion. The FC for a given option then was calculated by adding together all of the intermediate coefficient values. The FC values provided a quantitative method by which options with larger FC values could be considered as potential preferred options.

3.10.5 Identification of Preferred Options

Options with the largest FC value for each site were considered as preferred options based on the information available at the time of the comparisons. However, the TWG considered the WRAM process more as a valuable tool to aid in decision-making rather than the method to determine final numerical results and preferred options. The TWG recommended that the results be used semi-quantitatively, and selection of preferred options to be made through dialog and agreement. The primary reason for this recommendation was that not all options have been tested to the same degree, resulting in substantial uncertainty regarding overall effectiveness between options.

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4 ENGINEERING EVALUATIONS

4.1 INTRODUCTION

During the Phase I process, multiple options were identified for consideration and were presented in the Phase I Initial Findings report. During Phase II, the options were further researched, evaluated, presented, and discussed during the TWG meetings. This resulted in some options being eliminated from further consideration while the remaining options were evaluated further and conceptual designs developed.

4.2 ENGINEERING OPTIONS REMOVED FROM CONSIDERATION

During Phase II, after assessments of the options and discussion during TWG meetings, four options were eliminated from further consideration. A consensus of TWG members was required to eliminate each option. The rationale for removing the options from further consideration is discussed below.

4.2.1 FISH SCREENS

The use of fish screens as a deterrence option was evaluated and discussed for each site. Typically, maximum flow diversions are used to size fish screens and meet CDFW and NMFS screening requirements. Given the range of high maximum flows over the Delta daily tidal cycles at the five sites, fish screens would be unreasonably large to meet these requirements. Average flow diversions were also used but resulted in screen sizes that were still large and exceptionally long. These results were presented to the TWG at its January 28, 2014 meeting (see Appendix A). The TWG decided to remove fish screens from further consideration based on the required large structure sizes and concerns over the ability to meet CDFW and NMFS screening criteria.

4.2.2 ELECTRICAL FISH GUIDANCE

The use of electrical fish guidance technology was evaluated and discussed for each site. This technology has been used effectively in controlled hydraulic environments, most notably near hydroelectric installations, to keep both juvenile and adult fish species away from diversions. The technology has not been used extensively in river junction environments other than to deter upstream migrating adult salmon. When evaluating the possibility of deterring juvenile salmonids emigrating downstream, concerns were expressed with respect to electrical shocks. Because juvenile salmonids would be emigrating downstream, they could be temporarily disoriented and carried farther into the electrical array and ultimately pushed downstream into the channel to be avoided. Also, the electrical current necessary for deterring small fish (juvenile salmonids) is higher relative to larger fish. This electrical current would have the potential to injure or kill larger fish in the area. Another concern was that the five sites are in publically accessible areas, and thus the potential would exist for human injury if someone entered the electrical array. For these reasons, the TWG decided to eliminate this technology from further consideration at its December 20, 2012 meeting (see Appendix A).

4.2.3 ROCK BARRIERS

The use of a rock barrier was evaluated and discussed for each of the sites. This technology is used for agricultural barriers to control stage in the south Delta and to deter fish at the HOR. The rock barriers include multiple culverts to control flows and stage within the south Delta. Concerns about voids within the barrier providing residency for predators and potential juvenile salmonid impingement were discussed by the TWG. The group decided that an engineered technology which could be installed, operated, and removed in a timely manner was preferred. The TWG decided to eliminate this technology from further consideration at its December 20, 2012 meeting (see Appendix A).

4.2.4 HABITAT RESTORATION

Implementing habitat restoration was discussed for each site. Of the five sites, Turner Cut and Columbia Cut are man-made channels. Georgiana Slough, Threemile Slough, and HOR are natural channels that have not been disturbed beyond levee armoring. Because of the potential adverse impacts of reduced flows through the sites, and a variety of private and public uses, habitat restoration was eliminated from further consideration.

4.3 CRITERIA INCORPORATED INTO DESIGNS

The primary criterion for evaluating options was how well the option would deter juvenile salmonids from entering certain channels and keep them emigrating along the San Joaquin River or Sacramento River. The following additional criteria were established by the TWG and were considered in the conceptual designs:

- Deterrence Ability –the ability of an option to deter emigrating juvenile salmonid from entering a non-preferred migration route.
- Boat Passage – Measure of the ability of an option to allow passage of boat traffic.
- Cost –the initial, annual, and long-term implementation costs of an option.
- Environmental Effects –the potential effects of an option on the environment, including effects on aquatic, terrestrial, and air resources.
- Flow Effects –the effects of an option on water flows in each channel.
- Implementability –the ability of an option to be constructed in a timely manner in response to the need to deter emigrating juvenile salmonids.
- Operations and Maintenance –the effort required to keep an option properly operating and maintained.
- Predation Effects –the effects of an option on predation beyond that which would be considered to be naturally occurring.
- Tidal Effects –the effects of tidal stage variations as well as reverse flows on the performance of an option.
- Uncertainties –the uncertainties associated with an option.
- Upstream Migration –the effects of an option on the upstream migration of fish species that should not be deterred.

4.4 CONCEPTUAL-LEVEL ENGINEERING DETAILS

Physical and non-physical engineering options were researched during Phase I and were evaluated during Phase II. Operable gates, FFGSs, IFFs, and BAFFs were the types of barriers that were considered applicable for the Action sites. A complete drawing set that includes plan views, elevation views, and relevant detail drawings for each of the sites and options is provided in Appendix B.

4.4.1 GEORGIANA SLOUGH

The engineering options that are considered applicable for Georgiana Slough include Operable Gates, FFGS, IFF, and BAFF. Each engineering option was evaluated using the criteria set forth in the WRAM process, and a conceptual design was created for each option using the same criteria applied specifically to the Georgiana Slough site.

4.4.1.1 BIO-ACOUSTIC FISH FENCE

Description

A BAFF would be installed in the Sacramento River, crossing the entire Georgiana Slough divergence. The BAFF barrier would start at the end of the dock immediately downstream of the Walnut Grove bridge on the left bank, and would terminate in the Sacramento River just past the divergence point. The barrier would cross the critical streakline and would have a minimal angle relative to the flow under most hydraulic conditions. The barrier would be made up of nine steel-framed modular sections spanning 100 feet each between pile supports. A total of ten piles would be installed to support the barrier. The infrastructure (e.g., piles and connection hardware) would stay in place year-round, and the modular BAFF sections and other working components would be installed only during juvenile salmonid emigration periods. This modular design would minimize potential environmental impacts by minimizing seasonal construction time and would allow most maintenance to be performed out of the water.

A control house would be necessary to contain the BAFF's control components. It would be located on the landside of the adjacent levee. Electrical power would be provided by dedicated overhead power lines. The in-water components of the barrier, with the exception of support piles and navigational aids, would be removed annually for general maintenance and to minimize potential impacts resulting from debris and sediment accumulation. These components would be stored in either an on-site or remote storage facility and would be re-installed before the juvenile salmonid emigration period or as directed by the regulatory agencies. The BAFF could be deployed multiple times in any given year. See Appendix B for detailed drawings of the BAFF at Georgiana Slough.

Alignment

This BAFF would be aligned to guide fish across the critical streakline into the Sacramento River streamlines that lead past the Georgiana Slough divergence and continue downstream in the Sacramento River (Figure 4-1). Results from the 2011 and 2012 Georgiana Slough Non-Physical Barrier (GSNPB) Performance Evaluation Project reports show the barrier's angle relative to the flow and the cross-stream position of each fish are two important factors related to entrainment. In these prior studies the barrier alignment was curved so it would reposition fish across the streakline. The proposed alignment would be straight at the upstream end, which would reduce the barrier's angle relative to the flow. This would require less energy for an approaching fish trying to avoid the barrier, and would decrease the number of fish entrained because of a hydraulic disadvantage.

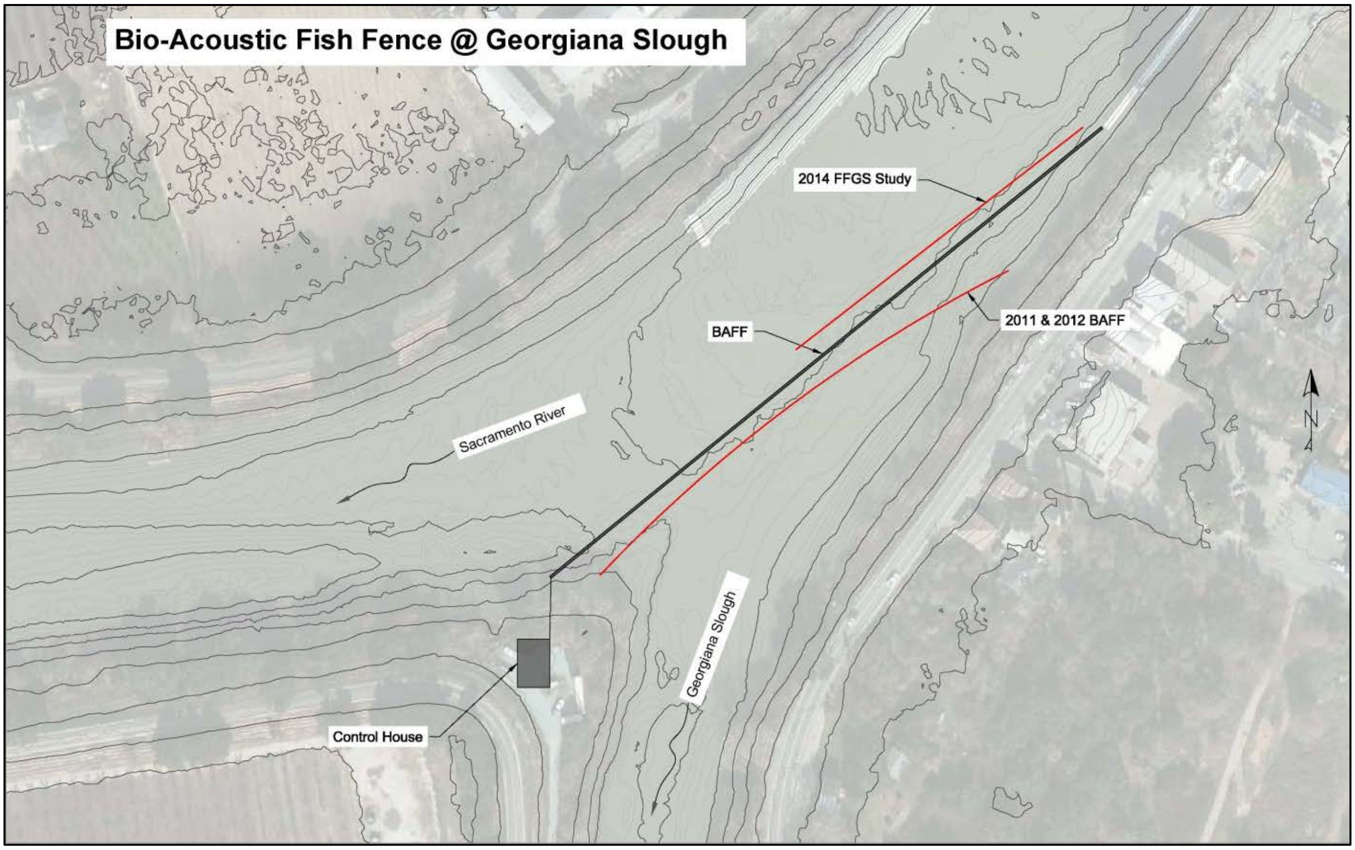
Source: DWR – Bay-Delta Office 2011

Figure 4-1. 2011 BAFF Study Installation

The proposed BAFF's alignment was chosen based on the lessons learned from all of the recent studies, including the 2014 FFGS study (see Section 4.4.1.2) at the Georgiana Slough divergence.

To maximize fish deterrence, a continuous barrier that crosses the entire Georgiana Slough divergence is proposed (Figure 4-2). The upstream end of the barrier would be about 750 feet upstream from the point of divergence, to provide fish enough time to sense and react to the barrier. The barrier would extend downstream about 150 feet beyond the divergence point and would end in the Sacramento River past the divergence. The total length of the barrier would be about 885 feet.

The barrier would be set at a 15-degree angle relative to the flow of water approaching the upstream section of the barrier. This would create a gradual guidance to minimize a fish's effort to avoid the barrier. The gradual angle also minimizes any undesirable hydrodynamic interactions between the barrier and the flow.



Source: DWR – Bay-Delta Office 2014

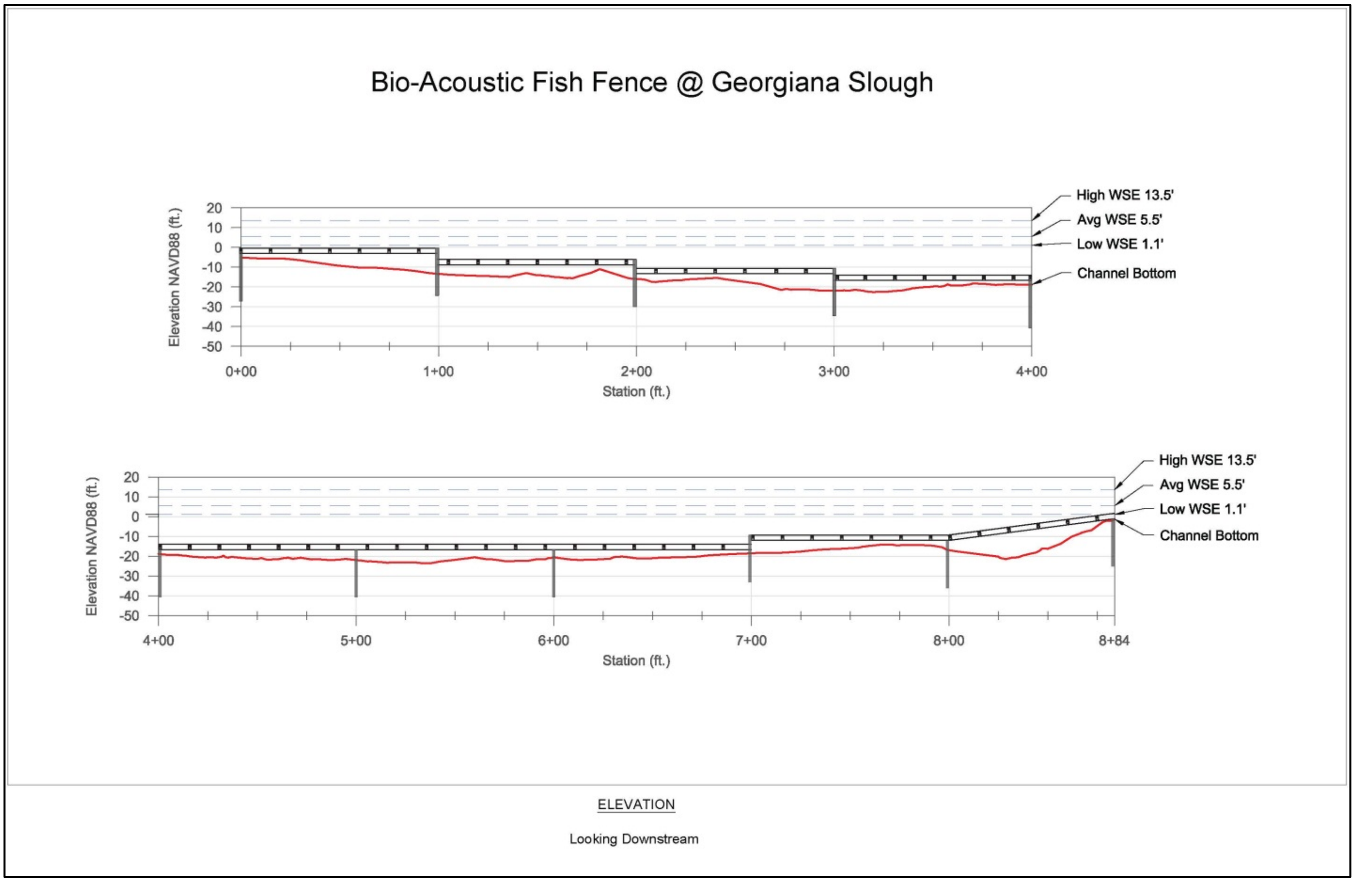
Figure 4-2. Alignment of the Proposed BAFF at Georgiana Slough (in black) and Recent Study Alignments (in red)

The Georgiana Slough divergence experiences dynamic tidally influenced hydraulic conditions. The Sacramento River flow can go slack, or even reverse at times. The proposed BAFF would cross the entire divergence of Georgiana Slough to guide juvenile salmonids approaching from downstream on the Sacramento River resulting from rare occasions of tidally influenced reverse flows. In rare events, some portions of the barrier would experience high velocities at an angle perpendicular to the barrier. The effectiveness of the FFGS in deterring juvenile salmonids during these events currently is difficult to predict.

Boat Passage

Boat passage between the Sacramento River and Georgiana Slough would be possible along most of the barrier alignment. The non-physical nature of the BAFF would allow navigation by most recreational boats and small barges across the bubble curtain. Navigation would not be permitted near the shorelines where the BAFF frames would be too close to the water surface (Figure 4-3). These areas would be clearly marked with signage and buoy lines. Staff gauges indicating draft depth would be placed near the barrier to inform boaters of the available clearance above the BAFF frames.

If an emergency required a construction vessel with a very large draft to pass, a 100-foot section of the BAFF could be temporarily removed.



Source: DWR – Bay-Delta Office 2014

Figure 4-3. Elevation View of the Alignment of the Proposed BAFF at Georgiana Slough

Upstream Migration

The BAFF design would allow the movement and passage of other sensitive non-targeted fish species (e.g., green sturgeon and adult salmonids). The BAFF frames would be set with a minimum two-foot clearance between the bottom of a frame and the channel bottom. This clearance would provide ample space for the passage of green sturgeon, which tend to travel along channel bottoms. Also, green sturgeon show only a limited response to acoustic signals. They would be traveling below the lights and air bubbles so their passage likely would not be hindered by the BAFF. (Lambert, pers. comm., 2014.)

Adult salmonids do not respond well to behavioral barriers when migrating upstream to spawn. They focus on their main objective of spawning, and stimuli to which they would normally respond are ignored. The BAFF would not impede adult salmonids during their spawning migration. (Lambert, pers. comm., 2014.)

If this option is implemented, green sturgeon and adult salmonid behavior at the BAFF should be monitored to validate these assumptions.

Deterrence

A BAFF was deployed across the Georgiana Slough divergence in 2011 and 2012 to study its effectiveness in deterring emigrating juvenile salmonids. Study results showed that the most important covariate was the cross-stream position of the fish as it approached the barrier. To minimize salmonid entrainment into Georgiana Slough, a barrier should shift the horizontal fish distribution from the “river-left” to the “river-right” side of the critical streakline. The following discussion presents the results from both study years (AECOM 2012, 2014):

> During the 2011 study period, the non-physical barrier reduced the percentage of juvenile salmon passing into Georgiana Slough from 22.1% (BAFF OFF) to 7.4% (BAFF ON), a reduction of approximately two-thirds of the fish that would have been entrained. This improvement produced an overall efficiency rate of 90.8%; that is, 90.8% of fish that entered the area with the BAFF ON exited by continuing down the Sacramento River.
>
> Overall, during the 2012 tests, the BAFF reduced the percentage of juvenile Chinook salmon passing into Georgiana Slough from 24.8% with the BAFF OFF to 10.3% with the BAFF ON, representing an overall reduction in entrainment into Georgiana Slough of 14.5 percentage points. The observed reduction in entrainment for juvenile Chinook salmon was highly statistically significant with the BAFF ON (P=<0.0001). This improvement produced an overall efficiency rate of 89.7%; that is, 89.7% of Chinook salmon that entered the area with the BAFF ON exited by continuing down the Sacramento River. The BAFF reduced the percentage of steelhead passing into Georgiana Slough from 25.6% with the BAFF OFF to 12.3% with the BAFF ON, representing an overall reduction in entrainment into Georgiana Slough of 13.3 percentage points. The improvement produced an overall efficiency rate of 87.7%; that is, 87.7% of steelhead that entered the area with the BAFF ON exited by continuing down the Sacramento River.

These results are representative of the hydraulic condition and barrier alignment that existed during the studies. Although the BAFF alignment during these studies was slightly different than what is being proposed for a more permanent engineering option (see Figure 4-3), deterrence results are expected to be similar. If the BAFF with this alignment is chosen as the preferred engineering option, additional monitoring of its effectiveness is recommended to validate these results.

Flow and Tidal Effects

The BAFF would have minimal effects on the naturally occurring flow, flow split, and tidal conditions at Georgiana Slough. This is because water could flow around the piles and through the BAFF itself, and would not block or redirect flow. Some minor eddies and changes in flow direction may occur near the piles and frames.

The length and angle of the barrier have been designed to give fish ample time to react to the stimuli throughout the majority of possible velocities. During extremely high velocities, the bubble curtain bends with the flow, potentially diminishing the integrity of the deterrence stimuli. The effect that this may have on the performance of the barrier has not been quantified yet. However, the BAFF operations in 2011 occurred during very high discharges and produced good results described immediately above (“Deterrence” Section). The barrier would cross the entire divergence, which would provide protection for fish entering the area from both upstream and downstream. During extreme high flow events, the integrity of the bubble curtain may diminish in the upper portion of the water column.

Operations and Maintenance

Operations and maintenance of the BAFF would involve the general activities described in the “Bio-Acoustic Fish Fence” Chapter 2, subsection 2.2.4.2, “Non-Physical Barriers. BAFF operations would be ongoing 24 hours per day throughout the juvenile salmonid emigration periods. The BAFF air supply, light, and sound levels would be controlled and monitored from mechanical and computer systems located in the control house. Operation could be automated and minimal personnel time required to conduct regular barrier inspections. The barrier would be removed during periods when juvenile salmonids are not expected to be traveling through the divergence. Removal/installation would require divers to make underwater connections/disconnections of the BAFF frames. Boat or shore mounted cranes would be required to lift the frames in and out of the water. The frames would then be transported and stored.

Regular preventative maintenance, checks, and services would be required for all mechanical and electrical systems. Some in-water work by divers would be required to replace in-water failed components (light or sound projector) or a damaged component. An inventory of specialty BAFF equipment (lights, sound projectors, and controllers) would be required to minimize replacement time. Debris buildup would be monitored and debris removed as necessary.

Construction and Implementation

The initial construction for this option would include: building a control house for the BAFF air compressor and light, sound, and power/control systems; installing 10 piles to support the BAFF frames; and obtaining power from nearby overhead power lines. These components would remain in place year-round. Installation and connection of the modular components (e.g., air hoses, data cables, power cords, BAFF frames, and navigation markers) would occur prior to juvenile salmonid emigration periods which would be defined seasonally by regulatory agencies. These tasks would require the use of barge mounted equipment (crane, pile driver), work boats and divers. The control house and overhead power and pole installation would require shore/bank access near the downstream pile location. Installation would be done using conventional building and utilities equipment and methods.

This BAFF could be installed reasonably quickly (within two weeks) to respond to incoming information regarding the timing of an out-migration period. Once in place, the frames could be removed or re-installed in a relatively short period in response to changing flow conditions, in particular low flow events.

Potential Environmental Impacts

The BAFF option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance. General environmental requirements and considerations for the Georgiana Slough site are described in Appendix C, “Environmental Checklists” Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those unique to in-water and near shore actions. These unique impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the control building foundation and structure. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The BAFF operation would require seasonal installation of the BAFF frames prior to a migration event and removal of the frames following the event. Most installation/removal activities would be done by boat and barge, with minimal shore-based activities. Because the frame support piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the BAFF was operating would include minor changes to ambient noise levels due to the BAFF sound projectors and the occasional air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. Regular system monitoring and servicing of equipment in the control building would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by divers then the associated equipment (and frame) may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

The existing interaction between juvenile salmonids and piscivorous predators has not been studied extensively and is not well understood at this divergence. During the 2011 and 2012 GSNPB studies, piscivorous fish predators were caught and tagged. The data were analyzed to compare BAFF ON versus BAFF OFF conditions. BAFF OFF conditions means that the bubbles, lights, and sound were turned off, but the piles, frames, and all other components were still in the water. Data from Section 3.6 of the 2011 GSNPB report (AECOM 2012) show no statistically significant differences in survival probabilities when comparing BAFF ON and BAFF OFF conditions. This suggests that predation in this area is independent of BAFF operations. Specifically, the report states the following:

> The survival probability for juvenile Chinook salmon in the Sacramento River reach downstream of the BAFF was 93% when the BAFF was on and 93% when the BAFF was off, suggesting that survival, relative to predation, in this reach was independent of BAFF operation.

The predator fish studies conducted in this area do not indicate that installation of a BAFF at this junction would affect the existing conditions or efficiency of predator fish. However, baseline densities of piscivorous fish, avian, and aquatic mammal predators have not been established, and long term studies have not been conducted for this area, and thus determining the potential long-term impacts of the BAFF on predators is not possible.

Cost

A rough order-of-magnitude estimated cost for the BAFF at Georgiana Slough is $12.8 million (M). The estimated annual operation and maintenance cost is $510,000. The estimated present worth cost based on a 50-year life is $25.6 M.

4.4.1.2 FLOATING FISH GUIDANCE STRUCTURE

Description

A Floating Fish Guidance Structure (FFGS) would be installed in the Sacramento River, crossing the entire Georgiana Slough divergence. The barrier would start at the end of the dock immediately downstream of the Walnut Grove Bridge on the left bank, and would terminate in the Sacramento River just beyond the divergence point. The barrier would cross the streakline and be aligned at a gradual angle to the flow under most hydraulic conditions. The barrier would have steel sections 20 feet wide and either 5 or 10 feet deep (depending on stage), with bolt connections for adding or removing panels. The modular design would allow flexibility in barrier depth, and could be adaptively managed depending on water type year. A section of BAFF, located just beyond the vertex of the FFGS, has been incorporated into the design to provide boat passage. A control house on the landside of the adjacent levee would house the BAFF's above-water components. Electrical power would be provided by dedicated overhead power lines. The in-water components of the barrier, with the exception of support piles and navigation aids, would be removed annually for general maintenance and to minimize potential impacts resulting from debris and sediment accumulation. These components would be stored at either an on-site or remote storage facility and would be re-installed before the juvenile salmonid migration period or as directed by regulatory agencies. See Appendix B for detailed drawings of the FFGS at Georgiana Slough.

Alignment

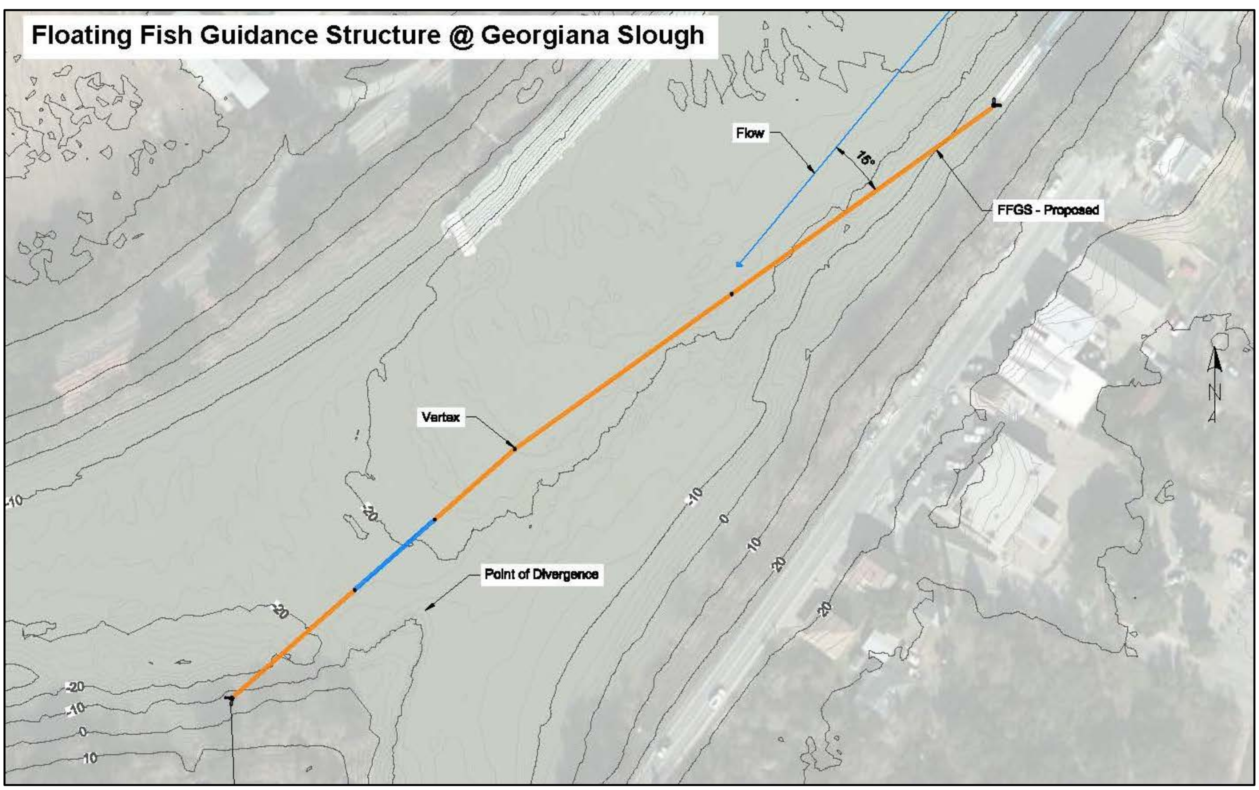
This barrier option would be designed to shift the horizontal fish distribution from the "river-left" to the "river-right" side of the critical streakline, and into Sacramento River streamlines that lead past the Georgiana Slough divergence and continue downstream in the Sacramento River.

To maximize fish deterrence, a continuous barrier that crosses the entire Georgiana Slough divergence is proposed (Figure 4-4). The upstream end of the barrier would be about 750 feet upstream from the point of divergence, to provide fish enough time to sense and react to the barrier. The barrier would extend downstream about 150 feet beyond the divergence point and would end in the Sacramento River past the divergence. The barrier would extend out into the river about 250 feet from the left bank, across the critical streakline, and would turn back toward the left bank to maintain an optimum angle-to-flow throughout the entire alignment. The barrier would be set at a 15-degree angle (Figure 4-5) relative to the flow of water approaching the farthest upstream section of the barrier. This would create a gradual guidance to minimize a fish's effort to avoid the barrier. The gradual angle also would minimize any undesirable hydrodynamic phenomena (e.g., down currents, eddies, and turbulence). See the "Floating Fish Guidance Structure" in subsection 2.2.4.1, "Physical Barriers," for details regarding experimental studies.

The Georgiana Slough divergence experiences regular changes in stage, velocity, and flow direction resulting from tidal influences and hydrologic conditions. Because this barrier would float, it would self-adjust (vertically) to the changes in stage. The barrier's angle to flow would be gradual enough to accommodate high velocities. The variation in flow direction would be addressed by the continuous barrier that would span the entire Georgiana Slough divergence. The downstream section of the barrier would extend beyond the point of divergence to help guide juvenile salmonids approaching from downstream because of tidal influences (e.g., reversing flows). Infrequently, some portions of the barrier would experience high flow velocities at an angle perpendicular to the barrier. The effectiveness of the FFGS in deterring juvenile salmonids during these events has not been quantified, but is anticipated to be reduced.

Source: DWR – Bay-Delta Office 2014

Figure 4-4. 2014 FFGS Study Installation

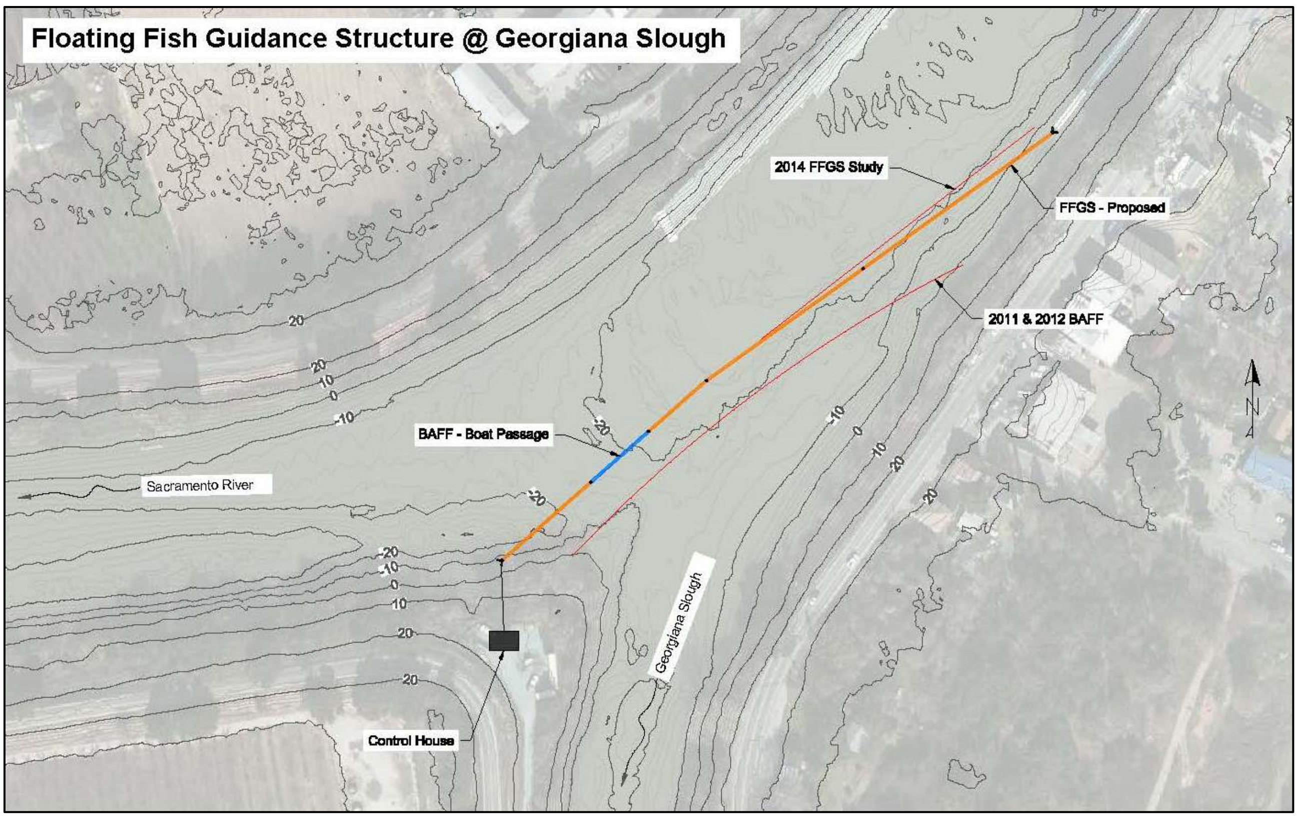


Source: DWR – Bay-Delta Office 2014

Figure 4-5. Plan View of the Proposed FFGS at Georgiana Slough, Showing Angle-to-Flow, Vertex, and Point of Divergence

Boat Passage

Boat passage between the Sacramento River and Georgiana Slough would be provided by a 100-foot opening in the FFGS. To maintain fish deterrence across this opening, a 100-foot section of BAFF would be placed in the opening (Figure 4-6). The opening would be located toward the downstream end of the barrier, where the channel is the deepest. This would minimize impacts on navigation caused by low stage and impacts on boats with large drafts. The 100-foot opening would also provide passage for larger, barge-type vessels for construction or emergency response purposes. This type of boat passage system would create a continuous barrier, while allowing unrestricted boat passage. The BAFF control system and above-water equipment would be housed in a control house located above the historical high-stage elevation, on the land adjacent to the downstream pile cluster. Electrical power would be provided by overhead power lines.



Source: DWR – Bay-Delta Office 2014

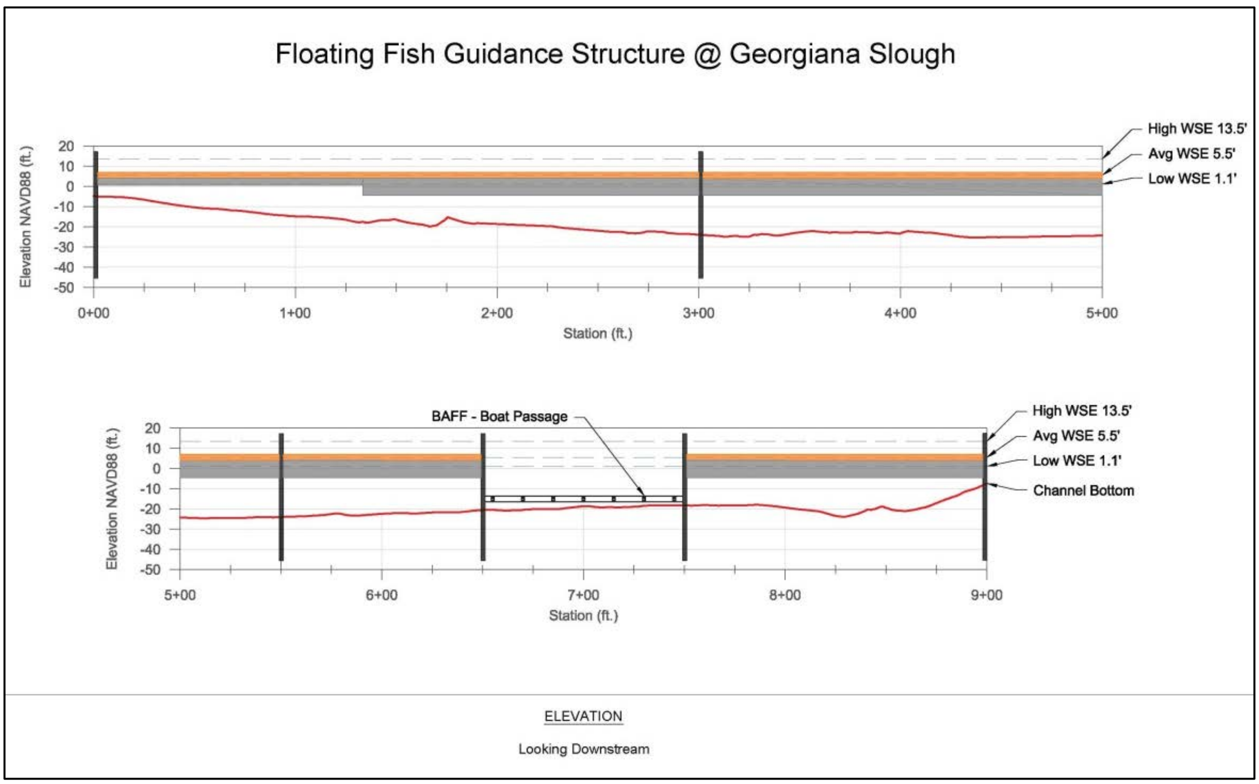
Figure 4-6. Plan View of the Proposed FFGS at Georgiana Slough, Including Alignment and Boat Passage

Emigrating juvenile salmonid behavior, swimming speeds, and expected fish population density also were factors considered in determining the placement of the boat passage opening. The opening would be located just downstream from the barrier's vertex. As a fish passed the vertex of the barrier, it would be guided to the "river-right" side of the critical streakline, minimizing the opportunity to swim through the boat passage opening. The barrier would also be slightly angled toward the left bank at this point. This would be done to create a longer swim distance back toward the barrier, and take advantage of the fish's swimming disadvantage versus the current.

The reasons for using a 100 foot BAFF as the boat passage solution are twofold. A non-physical barrier would be necessary to create an opening for navigation while still providing fish deterrence. Also, it would be necessary to have enough space to accommodate large vessels under all flow conditions. The BAFF can span long openings, supported by minimal infrastructure. Currently, the only other viable non-physical deterrence option is the IFF. However, because of the large stage changes at this site, each IFF unit would require surface floats to move up and down, and they would be limited to a maximum 30-foot spacing. This spacing would not meet the criteria set for this specific design.

Upstream Migration

The FFGS design would allow the movement and passage of other sensitive non-targeted fish species (e.g., green sturgeon and adult salmonids). A minimum of 50 percent of the lower water column (depending on stage) would be unobstructed and would allow free movement of upstream migrants, green sturgeon, and other fish species navigating the divergence (Figure 4-7). The BAFF boat passage opening could also be used for passage by non-targeted fish species (e.g., striped bass). A minimum two-foot clearance under the BAFF frame would be provided for passage, but non-targeted fish species may actually pass through the bubble curtain as well.



Source: DWR – Bay-Delta Office 2014

Figure 4-7. Elevation View of the Proposed FFGS at Georgiana Slough, Showing Depth of Barrier and Boat Passage Location

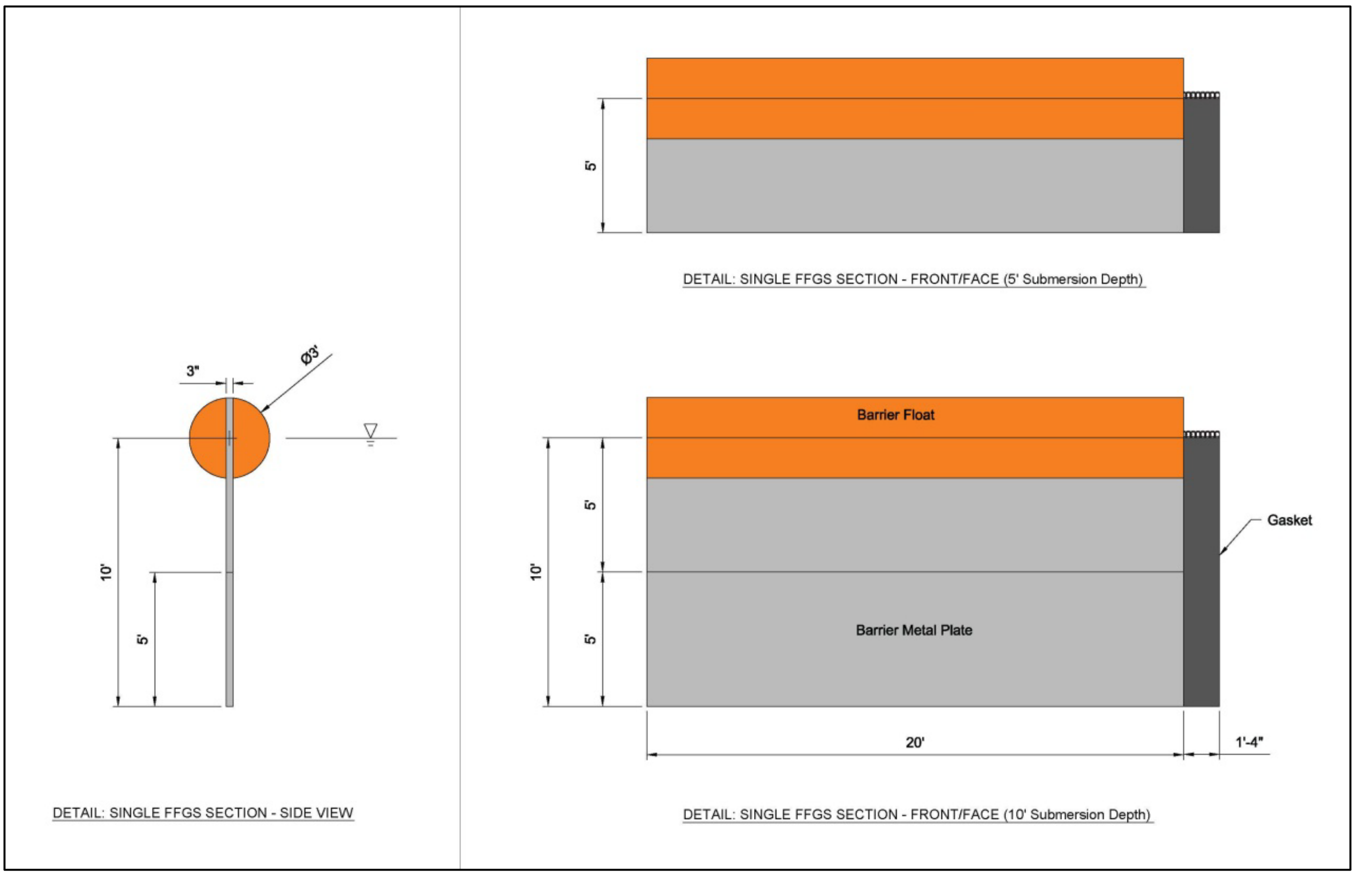
Deterrence

The potential effectiveness of the FFGS deterrence at Georgiana Slough is not well understood. This type of deterrence technology has been used elsewhere. Some studies show deterrence efficiencies to be between 53 and 92 percent (Scott 2011), but none were completed in a tidally influenced environment like the Georgiana Slough divergence. An FFGS typically has been used in much lower water velocities and in unidirectional flow, primarily upstream from dams and at openings of water intakes. The Georgiana Slough site experiences a wide range of velocities and variable flows, and even reverse flows due to tidal influences.

An FFGS was studied at the Georgiana Slough divergence in February and March 2014. Study results from this study are expected to provide some understanding of potential deterrence effectiveness.

Flow and Tidal Effects

This FFGS design would have minimal impacts on the existing flow patterns at this site. The physical in-water footprint of this barrier would provide optimal deterrence while having minimal effects on the naturally existing hydraulic conditions. The floats at the top of the barrier would provide continuous adjustments to the changing stage (Figure 4-8). This would keep the barrier in the upper portion of the water column where the emigrating juvenile salmonids are expected to reside. It also would keep the majority of the water column, below the barrier, open to pass water and non-targeted fish species.



Source: DWR – Bay-Delta Office 2014

Figure 4-8. Detail Drawing of the Proposed FFGS at Georgiana Slough, Showing the 5-foot and 10-foot Panels

Some amplified turbulence and redirection of flow could occur near the barrier. The significance of these potential impacts on the naturally existing flow patterns should be studied throughout the full spectrum of possible hydraulic conditions. Some additional design features may be required to minimize these potential effects.

The barrier floats would keep the barrier at a constant depth (5 or 10 feet depending on the selected panel) below the surface throughout all conditions. In times of low flow and low stage, panels could be removed so the barrier would not extend more than 50 percent into the water column. Barriers extending more than 50 percent are expected to result in undesirable turbulence and underflow.

This particular site experiences flow reversals caused by tidal forces. This design accounts for these conditions by having the barrier cross the entire Georgiana Slough opening. The possibility for the reversing flow to bring fish along with it exists. In this case the fish may encounter the barrier before they reach Georgiana Slough. This would shift the fish's position toward river right, and minimize the opportunity for entrainment into Georgiana Slough.

A system would be put into place to monitor and forecast changes in stage at locations along the barrier where a potential existed for adding or removing barrier panels. This system would alert staff when to add or remove panels to keep the barrier at the correct submergence depth, depending on stage.

Operations and Maintenance

Operations and maintenance of the FFGS would involve the general activities described in the "Floating Fish Guidance Structure" Chapter 2, subsection 2.2.4.2 "Non-Physical Barriers FFGS operations would be limited because the barrier would be in a fixed position. After the construction crew completes barrier placement, including the BAFF, the barrier would remain in the same alignment. A change from 5-foot to 10-foot panels may be necessary if a substantial change in stage should occur. BAFF operations would be ongoing 24 hours per day throughout the juvenile salmonid emigration periods. The BAFF air supply, light, and sound levels would be controlled and monitored from a mechanical and computer system located in the control house. Operation could be automated and minimal personnel time required to conduct regular barrier inspections. The barrier would be removed during periods when juvenile salmonids are not expected to be traveling through the divergence. Removal (and re-installation) would require in-water work by divers to disconnect (and re-connect) the FFGS panels and BAFF frames. The panels and frames would require the use of boat or shore mounted cranes to lift the panels and frames from (into the water). The panels and frames would then be transported and stored at either an on-site or off-site storage area.

Regular preventative maintenance, checks, and services would be required for all mechanical and electrical systems. Some FFGS components, such as the floats, hardware, and rubber panel section connectors, would deteriorate overtime because of exposure to the sun and water. Some in-water work by divers would be required to replace in-water failed components (light or sound projector) or a damaged component. An inventory of specialty FFGS components and BAFF equipment (lights, sound projectors, and controllers) would be required to minimize replacement time. Debris buildup would be monitored and removed as necessary.

Construction and Implementation

The FFGS initial construction would include the installation of five piles, 30 and floats, a BAFF frame (and connecting cables and hoses), a control house, overhead power and poles, and navigation buoys and warning lights. Power and control systems as well a compressor system for the BAFF would be installed inside the control house. This FFGS deterrence system would be made up primarily of modular components (e.g., FFGS panels and floats, BAFF frames, and cabling). This would make it possible to install or remove the system relatively quickly (within a week) in response to or following juvenile salmonid emigration. To minimize construction time and potential environmental impacts, the modular components would be secured to permanent piles and brackets. In-water work would be done using barges, cranes, and divers. The control house and overhead power and pole installation would require shore/bank access near the downstream pile location. Installation would be done using conventional building and utilities equipment and methods.

This FFGS could be installed reasonably quickly (within a week) to respond to incoming information regarding the timing of an out-migration period. Once in place, the panels could be removed or re-installed in a relatively short period in response to changing flow conditions, in particular low flow events.

Potential Environmental Impacts

The FFGS option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance As noted above for the BAFF option, general environmental requirements and considerations for the Georgiana Slough site are described in Appendix C, “Environmental Checklists”, Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and BAFF frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the control house foundation and structure. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The FFGS and BAFF operation would require seasonal installation of the FFGS panels and BAFF frames prior to a migration event and removal of this equipment following the event. Most installation/ removal activities would be done by boat and barge, with minimal shore-based activities. Because the system piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the FFGS was in operation would be insignificant. Impacts when the BAFF was operating would include minor changes to ambient noise levels due to the BAFF sound projectors and the occasional air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. Regular system monitoring and servicing of equipment in the control house would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of the FFGS panels and BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by boat or divers then the associated equipment may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Power and control systems as well a compressor system for the BAFF would be installed inside the control house.

Predation Effects

Implementation of this FFGS may have an effect on piscivorous predator species assemblage, density, and behavior, but the extent of its influence on predator and prey interactions is not well understood. To address potential inland avian predation, anti-roosting wires could be installed on top of the floats to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for the FFGS at Georgiana Slough is $6.3 M. The estimated annual operations and maintenance cost is $340,000. The estimated present worth cost based on a 50-year life is $18.2 M.

4.4.1.3 INFRASOUND FISH FENCE

Description

An Infrasound Fish Fence (IFF) would be installed in the Sacramento River and would cross the entire Georgiana Slough divergence. It would start at the end of the dock immediately downstream of the Walnut Grove Bridge on the left bank and would terminate in the Sacramento River just past the divergence point. The barrier would cross the streakline and would be aligned to have a gradual (15 degree or less) angle to the flow under most hydraulic conditions. The barrier would be a series of floats that would support surface-oriented IFF units (Figure 4-9). For each barrier, a continuous line of cylindrical buoys would wrap around the entire IFF alignment, except the boat passages, so that all of the surface-mounted power, data, and air lines would be protected from debris. Boat passage would be accommodated by incorporating a 100-foot section of BAFF as part of the barrier alignment. The IFF and BAFF would be anchored to a total of five piles. The IFF control system and above-water equipment would be housed in one of two control houses located above the historical high-stage elevation, on the land adjacent to the upstream and downstream piles. The BAFF control system and above-water equipment would be housed in the control house located on land near the downstream pile cluster. Electrical power to both control houses would be provided by overhead power lines.

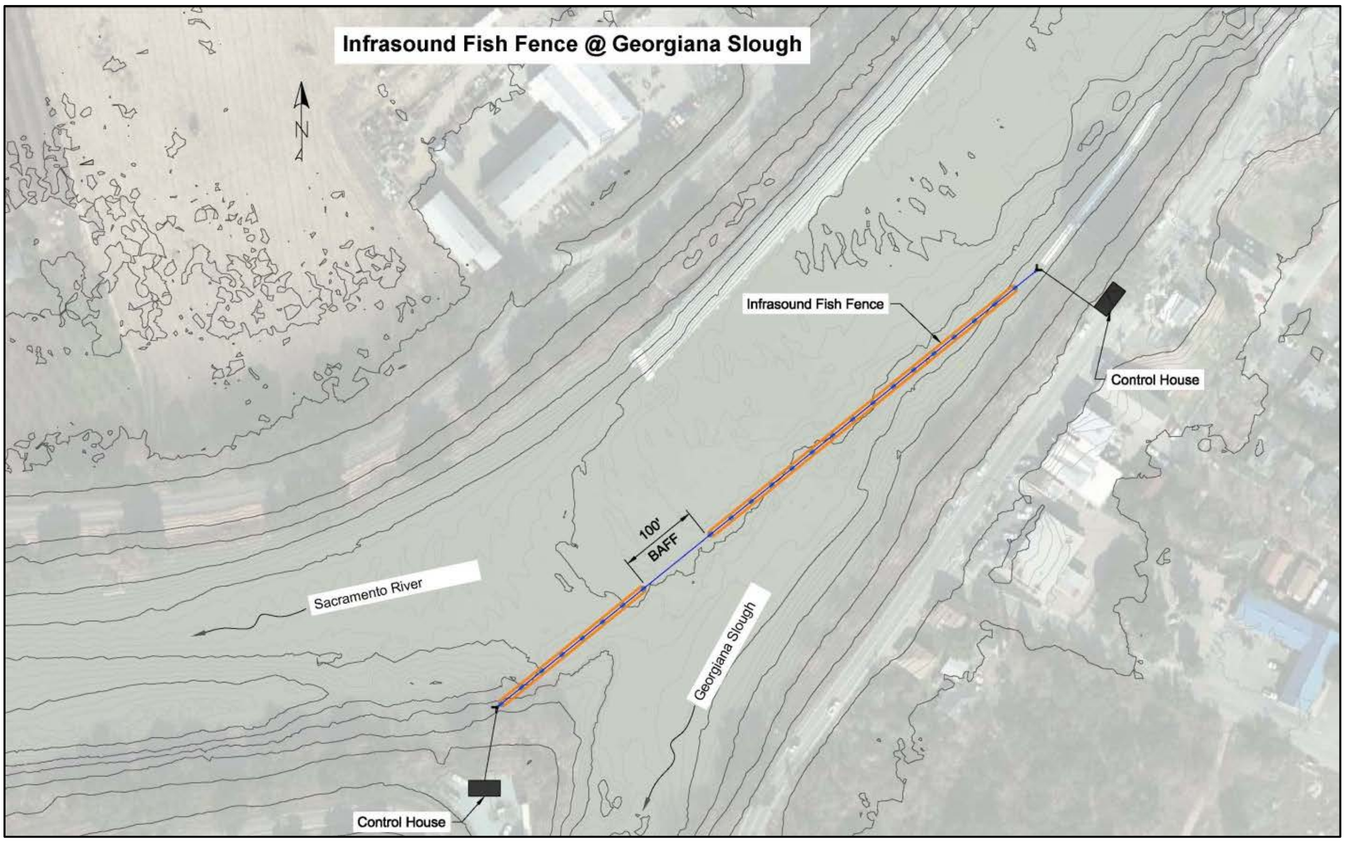
Source: Profish Technolgie 2014

Figure 4-9. Images Showing Two IFF Units per Pallet (left) and Example IFF Alignment with Floats and Cables (right)

All of the seasonal barrier components would be removed during periods when juvenile salmonids are not emigrating. The piles would stay in year-round, which would minimize potential impacts on the environment. See Appendix B for detailed drawings of the IFF at Georgiana Slough.

Alignment

The alignment of the IFF at Georgiana Slough would guide fish across the critical streakline while simultaneously allowing boat passage. The barrier would have 24 IFF units, spaced 33 feet apart, and a 100-foot section of BAFF (Figure 4-10). The barrier would be set at a 15-degree angle relative to the flow of water approaching the upstream section of the barrier. This would create a gradual guidance to minimize a fish's effort to avoid the barrier. The barrier would begin about 750 feet upstream from the point of divergence. This would allow the emigrating juvenile salmonids to have sufficient time to respond to the signal before entering Georgiana Slough. The barrier would be 875 feet long and would cross the entire Georgiana Slough entrance, where it would end about 150 feet past the divergence point.



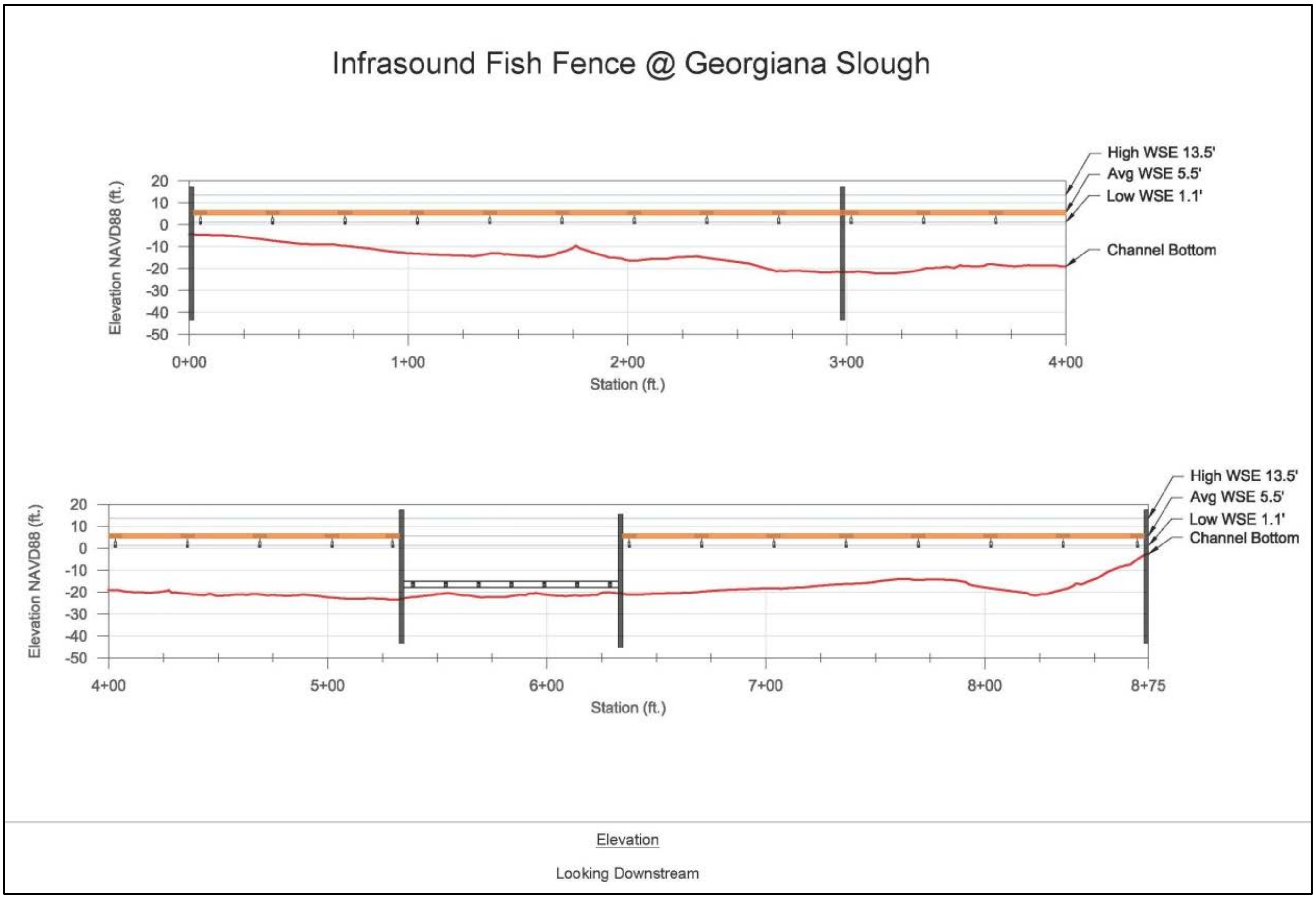
Source: DWR – Bay-Delta Office 2014

Figure 4-10. Plan View of the Proposed IFF at Georgiana Slough Showing Locations of the IFF and the Boat Passage BAFF

The Georgiana Slough divergence experiences regular changes in stage, velocity, and flow direction resulting from tidal influences and hydrologic conditions. The effectiveness of the IFF in deterring fish during a variety of hydraulic conditions is not known. However, the following design considerations were given to maintain as high a level of effectiveness as possible. Because this barrier is designed to float, it would self-adjust to changes in stage, maintaining its effectiveness. The barrier's angle to flow would be gradual enough to provide fish deterrence effectiveness over a wide range of flows and velocities. The assumed decrease in effectiveness as a result of tidal variation in flow direction would be addressed by the proposed continuous barrier alignment that would span the Georgiana Slough divergence. The downstream section of the barrier would extend beyond the point of divergence to help guide juvenile salmonids approaching from downstream because of tidal influences (e.g., reversing flows). Infrequently, some portions of the barrier would experience high velocities at an angle perpendicular to the barrier. The effectiveness of the IFF in deterring fish during these events is currently difficult to predict, but is expected to be diminished.

Boat Passage

Boat passage between the Sacramento River and Georgiana Slough would be provided by a 100-foot opening in the IFF. To maintain continuous fish deterrence along the entire alignment, a 100-foot section of BAFF would be placed in the opening (Figure 4-11). The opening would be toward the downstream end of the barrier, where the channel is the deepest. This would minimize impacts on navigation caused by low stage and impacts on boats with large drafts. A 100-foot opening also would provide passage for larger, barge-type vessels for construction or emergency purposes. The 100 foot BAFF section would be operated to provide continuous fish deterrence, and unrestricted boat passage.



Source: DWR – Bay-Delta Office 2014

Figure 4-11. Elevation View of the Proposed 875-foot-long IFF at Georgiana Slough Including the 100-foot BAFF

A BAFF was chosen for boat passage because it currently is the only non-physical barrier that can span long distances between piles while self-adjusting to stage change. Also, its frame would be located deep enough in the water column to make it possible for boats to pass over it. The IFF units would be surface oriented, and would be limited to a maximum 30-foot spacing, which would not meet boat passage criteria for this site.

Upstream Migration

The IFF design would allow the movement and passage of sensitive non-targeted fish species (e.g., green sturgeon and adult salmonids). The manufacturer claims that only small juvenile fish are known to react to infrasound, thus larger mature fish are not affected because their otolith organs, which are considered to be responsible for the juvenile fish response to the IFF may not be as sensitive. Although this explanation is plausible, field collected data in the Sacramento River system is not available. Further testing should be conducted to confirm these assumptions. Adult salmonids and green sturgeon would be able to pass through the divergence undisturbed. A minimum two foot clearance under the BAFF frame would be provided for passage of non-targeted species. Non-targeted fish species may pass above the BAFF frame through the bubble curtain as well.

Deterrence

This technology has been tested in the laboratory and in the field; however, it has not been tested on juvenile salmonids in an environment similar to Georgiana Slough. The results from previous laboratory and field tests have shown promise in deterring fish, but the IFF would need to be studied at this location with a focus on juvenile salmonids.

Flow and Tidal Effects

This IFF would have minimal impacts on the existing flow patterns at this site. The barrier would have very little in-water infrastructure (five piles) and its relatively small mechanical components (25 IFF units and floats and a 100-foot BAFF section) would have a negligible influence on the natural movement of water.

The IFF is expected to be effective under a wide range of tidal flows, including tidal reverse and low flows when water velocities will be low in comparison to salmonid swimming speeds. Similar to the BAFF, the IFF is expected to be less effective during high flow periods when water velocities exceed salmonid swimming speeds and the water direction is more perpendicular to the barrier alignment. The floats attached to each of the units would allow the IFF to constantly adjust to the changes in stage. This would keep the barrier in the upper portion of the water column, where the out-migrating fish are expected to reside. If low stage conditions occur, the IFF has the capability to have individual units turned off or even removed, to allow proper operation while maintaining a continuous deterrence signal.

A system would be put in place to monitor and forecast changes in stage at locations along the barrier where the potential existed for the need to turn off a unit or remove it.

Operations and Maintenance

Operations and maintenance of the IFF would involve the general activities described in the “Infrasound Fish Fence” Chapter 2, subsection 2.2.4.2, “Non-Physical Barriers. The IFF and BAFF modular components would be installed and the system operated 24 hours per day during the juvenile salmonid emigration periods. These components would be removed during periods when juvenile salmonids are not expected to be traveling through the divergence. Operation of the IFF and the BAFF would be automated, but they could also be controlled remotely or manually on site if the need arose. The control system, along with all applicable components, would be monitored and maintained on a regular basis. If one of the IFF units failed, it would need to be removed and serviced out of the water. A spare IFF unit would be required and installed to maintain barrier integrity if necessary. Similarly, if a BAFF light or sound projector fails, spare units would be required. The failed units could be removed and spare units installed by divers without the need to remove and service the BAFF frame out of water. The data lines, power cables, and air hoses that connect to the control house to the in-water mechanisms would receive preventative maintenance, checks, and services on a regular basis.

Construction and Implementation

The IFF initial construction would include the installation of five piles, 25 IFF units and floats, a BAFF frame (and connecting cables and hoses), a control house, overhead power and poles, and navigation buoys and warning lights. Power and control systems as well a compressor system for the BAFF would be installed inside the control house. This proposed IFF system would have modular components (e.g., floats, IFF units, BAFF frames, and cabling). This would make it possible to install or remove the system relatively quickly (within two weeks) in response to and following juvenile fish out-migration periods. Permanent infrastructure (e.g., piles, control house) would be placed along the alignment to provide anchorage and power and control for the IFF and BAFF components. To minimize construction time and potential environmental impacts, the modular components would then be secured to the piles. In-water work would be done using barges, cranes, and divers. The control house and overhead power and pole installation would require shore/bank access near the downstream pile location. Installation would be done using conventional building methods and utilities equipment.

This IFF (and BAFF) could be installed reasonably quickly (within two weeks) to respond to incoming information regarding the timing of an out-migration period. Once in place, the IFF units and BAFF frames could be removed or re-installed in a relatively short period of time (within two weeks) in response to seasonally predicted weather patterns which could affect a significant change in flow conditions, or in response to an extended low flow condition.

Potential Environmental Impacts

The IFF option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance. As noted above for the BAFF and FFGS options, general environmental requirements and considerations for the Georgiana Slough site are described in Appendix C, “Environmental Checklists”, Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and BAFF frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the control house foundation and structure. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The IFF and BAFF operation would require seasonal installation of the IFF units and BAFF frames prior to a migration event and removal of this equipment following the event. Most installation/removal activities would be done by boat and barge, with minimal shore-based activities. Because the system piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the IFF and BAFF were in operation would include: potential minor changes to ambient noise levels resulting from the low-frequency IFF pulses, potential impacts to benthic organisms in the immediate vicinity to the IFF units, the BAFF sound projectors and occasional air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. Regular system monitoring and servicing of equipment in the control building would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by divers then the associated equipment (and frame) may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

Implementation of this IFF and BAFF may have an effect on piscivorous predator species assemblage, density, or behavior, but the extent of its influence on predator and prey interactions is not well understood. To address potential inland avian predation, anti-roosting wires could be installed on top of the floats to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for the IFF at Georgiana Slough is $7.6 M. The estimated annual operations and maintenance cost is $390,000. The estimated present worth cost based on a 50-year life is $21.4 M.

4.4.1.4 GATES WITH BOAT LOCK AND FISH LADDER

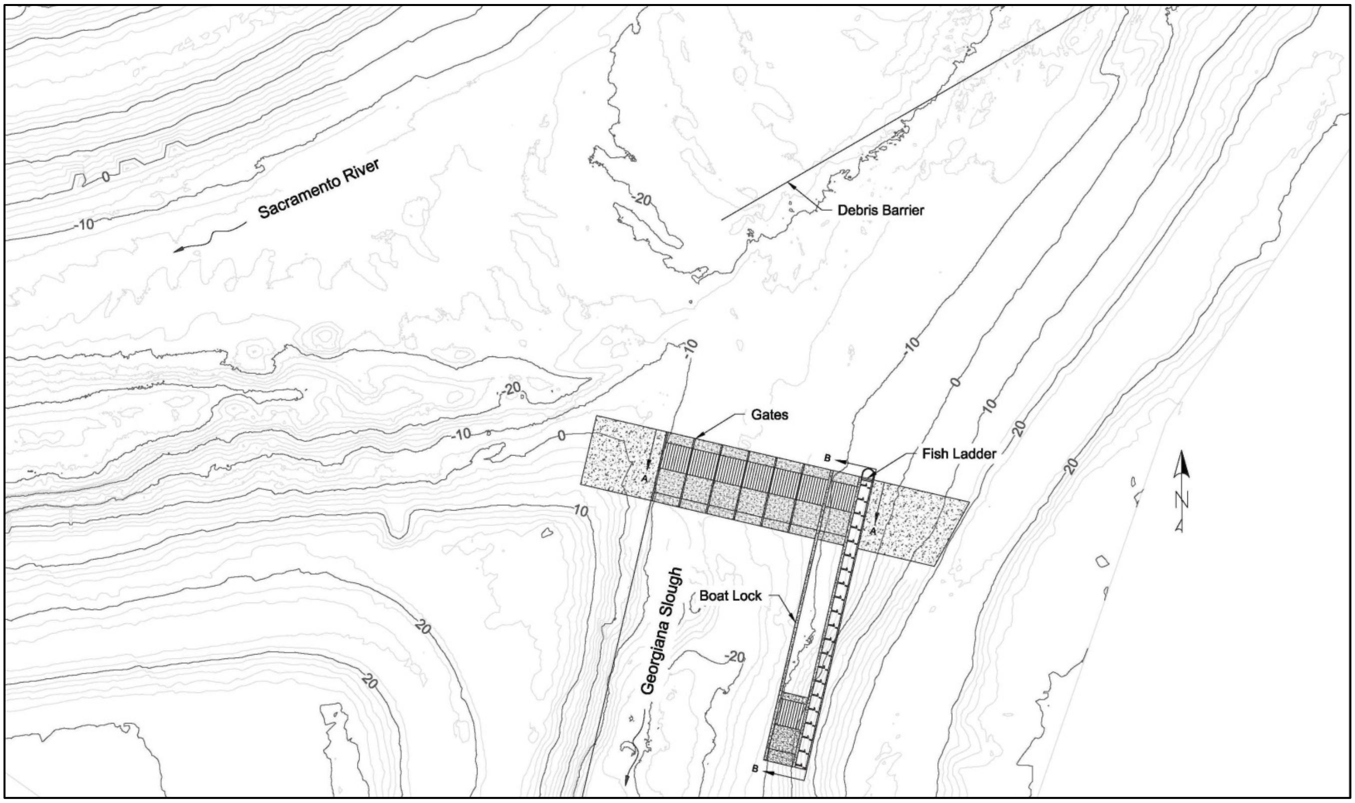
Description

A gate option at the Georgiana Slough site would include operable gates, a boat lock, and a fish ladder. The operable gates could be overflow gates, under flow gates, or a combination of both; this decision will be made if the gate option is selected as a recommended solution. Detailed studies regarding juvenile salmonid horizontal and vertical distribution within close proximity of the gate system would be important for gate type selection (overflow versus underflow). Passage for sturgeon would be included during the gate design criteria development.

Preliminary hydraulic modeling results show that any amount of flow restriction to Georgiana Slough would negatively affect the interior and south Delta. For this gate option to work as a fish deterrence option, all potential diverted flow would need to be supplemented at an equal volume compared to what was diverted. This could be accomplished by building a screened pumping station and piping water from upstream and delivering it into Georgiana Slough. The physical and financial feasibility of using a pumping station would be studied in detail before further consideration of this option. See Appendix B for detailed drawings of the gate, boat lock and fish ladder at Georgiana Slough.

Alignment

The gate structure would be placed at the entrance of Georgiana Slough, oriented perpendicular to the direction of the flow entering the slough (Figure 4-12). This alignment would minimize unwanted hydraulic conditions, such as eddies, turbulence, and scouring. The gates would allow the naturally existing maximum flow into the slough, creating an opening of about 150 feet wide, which would be greater than the narrowest existing boat passage in Georgiana Slough. The gates would provide two feet of freeboard over the stage determined to provide an adequate margin for operation and structure protection.



Source: DWR – Bay-Delta Office 2014

Figure 4-12. Plan View of the Proposed Gates with Boat Lock and Fish Ladder at Georgiana Slough Showing the Gate System Alignment

Boat Passage

A boat lock is included in this conceptual design to provide boat passage. The boat lock would be 20 feet wide and 100 feet long, and would accommodate typical recreational boats that frequent this area. Passage of vessels larger in width will require the opening of multiple overflow bottom-hinged main gates. These gates could be lowered to allow passage (see Appendix B for detailed drawings).

Upstream Migration

Upstream migration of sensitive, non-targeted fish species (e.g., green sturgeon and adult salmonids) would be possible by the fish ladder and the opening of the boat lock gates or the main gates. During periods when the main gates were in operation, adult salmonids could use the fish ladder for passage. Drawings provided in Appendix B show details and the dimensions of the vertical slot fish ladder. Green sturgeon would be able to pass if the boat lock gates were open. Also, one or more of the main gates could be designed as an underflow gate. If the hydraulic conditions permitted, an underflow gate could be partially opened to allow passage of green sturgeon along the bottom of the channel. The increase in velocity due to the smaller opening of a partially opened underflow gate may result in the inability for some fish to pass due to insufficient swimming capabilities relative to water velocity. This should be modeled in detail before any permanent installation of the gates.

Deterrence

The effectiveness in deterring fish using this option would be related directly to the percentage of time that the gates were operated and the percentage of flow allowed to pass through the gate system. If the gates were operated to block off the entire slough during the full emigration period, almost 100 percent deterrence would be achieved; if the gates were operated only part of the time and blocked only part of the channel, then the ability to deter fish would be greatly diminished. The exact relationship between gate operations and deterrence efficiency would need to be studied and quantified.

Flow and Tidal Effects

The gate option would change the naturally existing flow and stage patterns at the Georgiana Slough site. The potential impacts of these changes are not well understood and would depend on the gate operational strategies. The goal, if deemed feasible, would be to mimic the natural flow split and stage patterns through coordinated operations of the gates and delivery of water to the slough via the pumping system. Limitations may exist on the volume of water that could be pumped, with estimated quantities to be determined through a detailed engineering and cost feasibility study. A limitation on the pumped volume may require opening the gates more often resulting in decreased deterrence of juvenile salmonids.

Operations and Maintenance

Operations and maintenance of a gate structure would involve the general activities described in the “Overflow” and ”Underflow” gate, Chapter 2, subsection 2.2.4.1 “Physical Barriers”. A detailed operational strategy for this site has not been determined because of a lack of detailed information about engineering (hydraulic) criteria and fish species distribution. Preliminary hydraulic modeling has shown the importance of Georgiana Slough in the delivery of fresh water to the interior and south Delta. Water quality is an important criterion that is being considered during this phase of the Action, and more detailed modeling would be conducted in the event that this gate option is advanced as a potential recommended solution.

A gate system at Georgiana Slough would require regular preventive maintenance, checks, and services. This would include clearing any debris from the gates and fish ladder. The screens at the pumping station also would need to have a cleaning system integrated into the design, and this system also would require regular maintenance. Because of the size of the facilities, the requirements for safety and security, and the amount of equipment necessary for operations, this option would require more time and effort to operate and maintain than the other three options at Georgiana Slough.

Construction and Implementation

The gate construction would include the installation of a reinforced concrete foundation (including abutments, boat lock channel, and fish ladder), five main bottom-hinged gates and one top-hinged gate, four boat lock bottom-hinged gates, a control house, overhead power and poles, and navigation buoys and warning lights. Power and control systems for the gates would be installed inside the control house. In-water work would be done using both water and shore based equipment (e.g., excavators, cranes, concrete pumpers). A cofferdam installation would be required to allow in-channel foundation excavation and placement of concrete and gate components. The control house and overhead power and pole installation would require shore/bank access near the downstream gate location. Installation would be done using conventional building and utilities equipment and methods.

This gate structure could be operated quickly (within hours) to respond to incoming information regarding the timing of the out-migration period. The gates could be opened, closed, or adjusted to provide deterrence, allow specific flow bypasses, or large vessel passage in a short period.

Potential Environmental Impacts

The gate option would have a significant effect on the natural environment during installation of the permanent infrastructure and during operation and maintenance. As noted above for the other options, general environmental requirements and considerations for the Georgiana Slough site are described in Appendix C, "Environmental Checklists". Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include significant disruption of river sediment habitat and aquatic habitat during in-channel excavation and foundation installation, and disruption of riverine shore habitat during mobilization, excavating and installation of the gate abutments, control house foundation and structure.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The gate operation would include raising and lowering the hinged gates, either to allow the flow of water or the passage of boats. The top hinged gate would be operated or left partially open at all times to allow the passage of surgeon. The fish ladder would require no operation unless ladder maintenance was required and the ladder slide gates would be closed. Environmental impacts when the gates were in operation would include potential minor changes to ambient noise levels resulting from raising or lowering a gate. Regular system monitoring and servicing of the gates and equipment in the control house would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of the gates may be required. If the servicing could not be completed in water or by divers then the associated equipment may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

The piscivorous predator activity in this area is not well understood or well documented. The addition of an in-water structure because of the gate system and the pumping system may affect piscivorous predator species' assemblage, densities, and behavior, but the benefit from increased deterrence versus the negative impact from predation would need to be studied after sufficient data become available. To address potential inland avian predation, anti-roosting wires could be installed on top of the structure to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for a gate system at Georgiana Slough is $47.1 M. The estimated annual operation and maintenance cost is $200,000. The estimated present worth cost based on a 50-year life is $50.6 M. If lowhead pumps are included in this option to supplement flows due to negative impacts shown in initial modeling scenarios, additional costs of $500 M or higher would be added to maintain flows in Georgiana Slough.

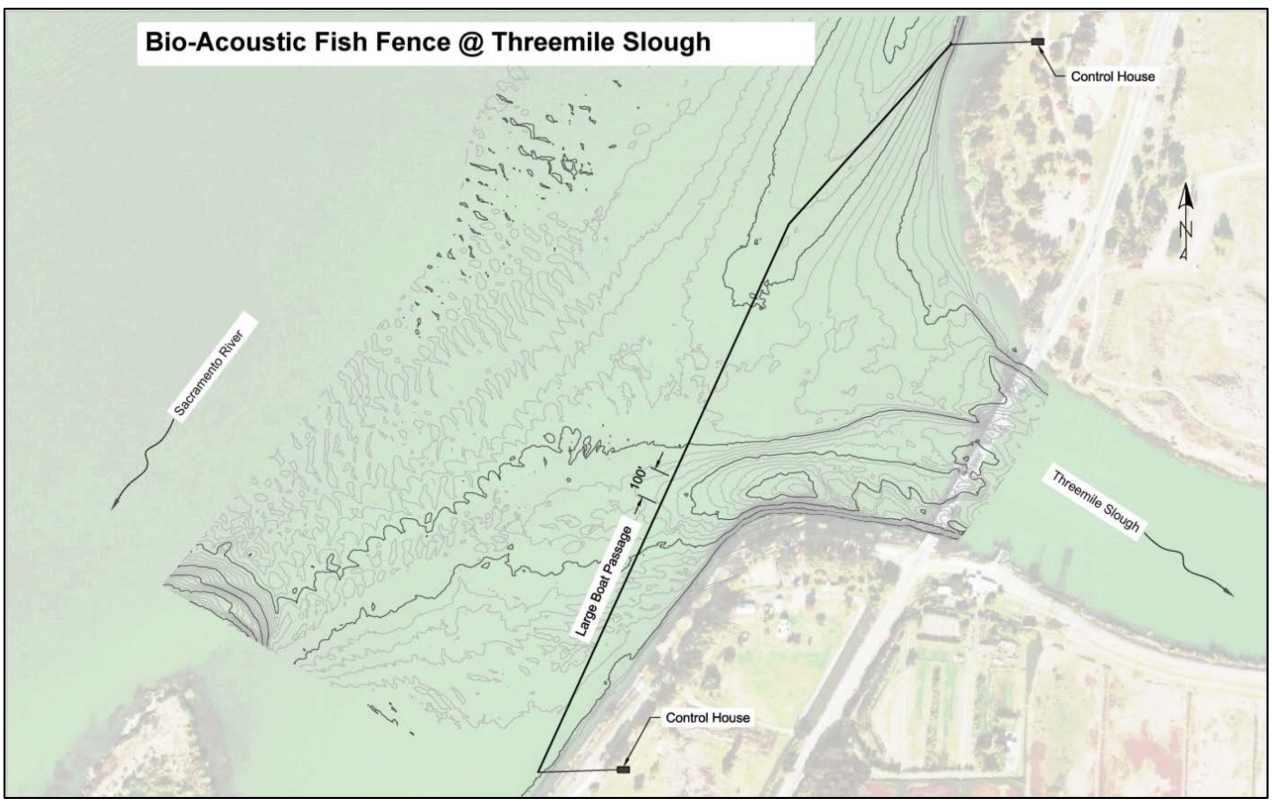
4.4.2 THREEMILE SLOUGH

The engineering options that are considered applicable for Threemile Slough include Operable Gates, FFGSs, IFFs, and BAFFs. Each engineering alternative was evaluated using the criteria set forth in the WRAM process, and a conceptual design was created for each option using the same criteria applied specifically to the Threemile Slough site.

4.4.2.1 BIO-ACOUSTIC FISH FENCE

Description

A Bio-Acoustic Fish Fence would be installed in the Sacramento River, crossing the entire Threemile Slough divergence (Figure 4-13). The BAFF barrier would be set at an angle parallel to the direction of the Sacramento River flow to take advantage of the streamlines in an attempt to guide fish past the point of divergence. Two control houses housing the barrier's power supply and air systems would be located on the landside of the adjacent levees. Electrical power would be provided by overhead or buried power lines. The in-river components of the barrier, with the exception of support piles and navigation aids, would be removed annually for general maintenance and to minimize potential levee impacts resulting from debris and sediment accumulation. These components would be stored in either an on-site or remote storage facility and would be re-installed before the juvenile salmonid emigration period or as directed by the regulatory agencies. See Appendix B for detailed drawings of the BAFF at the Threemile Slough.

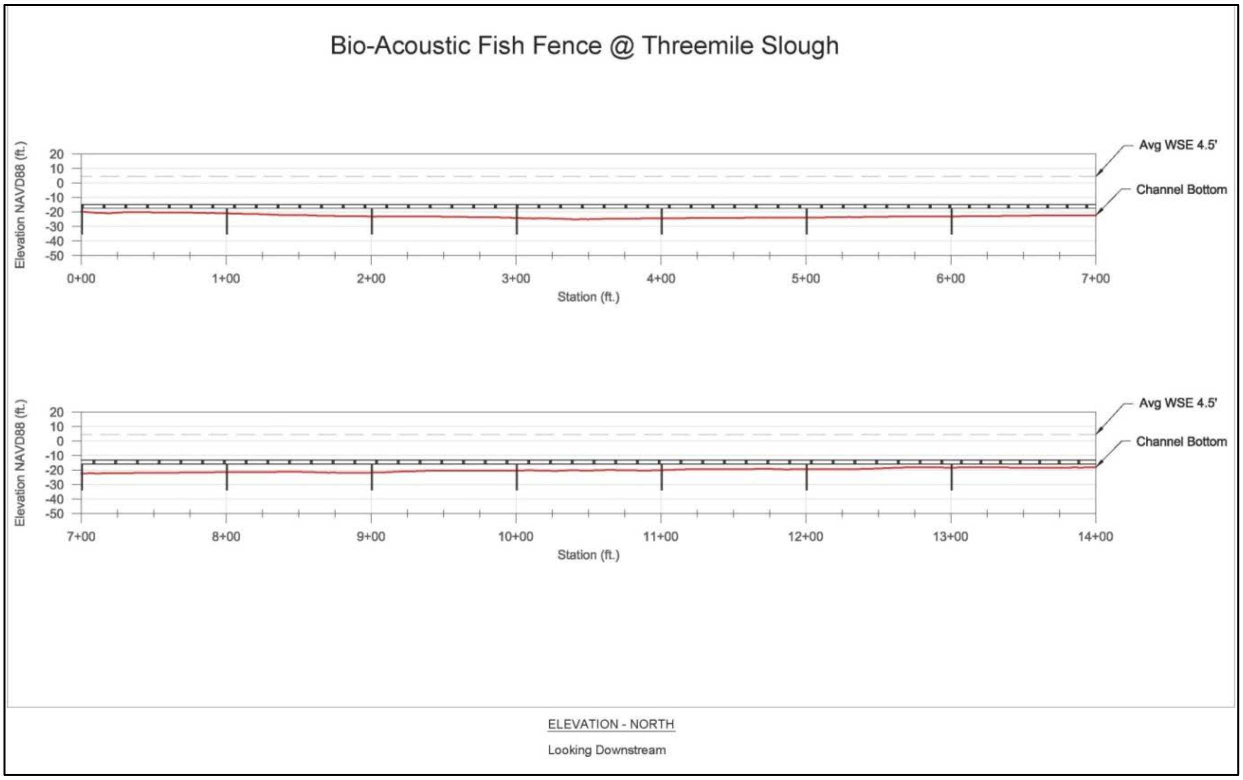


Source: DWR – Bay-Delta Office 2014

Figure 4-13. Alignment of the Proposed BAFF at Threemile Slough

Alignment

This proposed BAFF barrier would guide fish past the point of divergence at Threemile Slough and allow them to continue their migration in the Sacramento River. To maximize fish deterrence, the BAFF would form a continuous barrier crossing the channel. The proposed barrier would be approximately 2,800 feet long and would use 29 piles (Figure 4-13 and Figure 4-14). Each barrier frame would be installed approximately two feet above the channel bottom to provide a minimum depth of water over the barrier under low-tide and low-flow conditions.



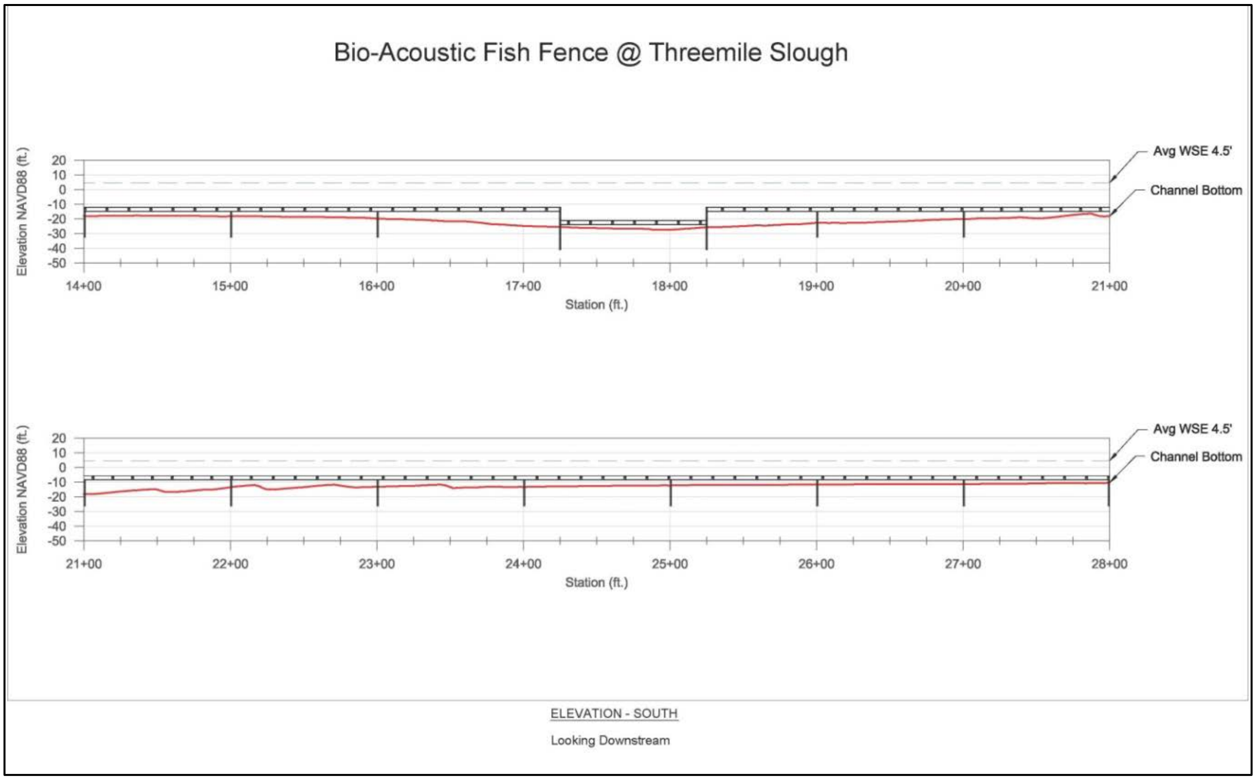
Source: DWR – Bay-Delta Office 2014

Figure 4-14. Elevation View of the Alignment of the Proposed BAFF at Threemile Slough (Stations 0+00 through 14+00)

The Threemile Slough divergence regularly experiences changes in stage, velocity, and flow direction resulting from tidal influences and hydrologic conditions. To address the variation in flow direction, a continuous barrier would span the mouth of the divergence and would be angled appropriately to account for both positive and negative flows. This alignment would guide juvenile salmonids that approach from downstream from tidal influences such as reverse flows.

Boat Passage

Boat passage between the Sacramento River and Threemile Slough would be possible along most of the barrier alignment. The non-physical nature of the BAFF would allow navigation by most recreational boats and small barges across the bubble curtain. Navigation would not be permitted near the shorelines where the BAFF frames would be too close to the water surface (Figures 4-14 and 4-15). A 100-foot section of the BAFF would be placed near the bottom of the deepest section of the channel to accommodate passage by an emergency or construction vessel with a very large draft. Navigational buoys and lights would be installed for boater safety. Staff gauges indicating draft depth would be placed near the barrier to inform boaters of the clearance above the BAFF frame.



Source: DWR – Bay-Delta Office 2014

Figure 4-15. Elevation View of the Alignment of the Proposed BAFF at Threemile Slough (Stations 14+00 through 28+00)

Upstream Migration

Upstream migration would be relatively unimpaired by a BAFF at this location. The BAFF frames would be set with a minimum two-foot clearance between the bottom of the frames and the channel bottom. This clearance would provide ample space under and over the barrier for the movement of upstream migrants such as green sturgeon and adult salmonids (Figures 4-14 and 4-15).

As noted previously for a BAFF installation at Georgiana Slough site, green sturgeon and adult salmonids show limited response or do not respond well to a behavioral barrier. If this option is implemented, green sturgeon and adult salmonid behavior should be monitored to validate these assumptions.

Deterrence

This technology has not been tested in an environment like Threemile Slough, which is heavily influenced by tidal forces. The deterrence ability or effectiveness of a BAFF at Threemile Slough depends on many factors, including barrier alignment, flow direction, water velocities, and swimming ability of the fish. Based on the results of previous studies at the Head of Old River and Georgiana Slough, the BAFF shows great promise in deterring fish. However, additional monitoring would be needed to validate the BAFF effectiveness at this location.

Flow and Tidal Effects

The BAFF would have minimal effects on the naturally occurring flow and tidal conditions at Threemile Slough. This is because water could flow around the piles and through the BAFF itself, and would not block or redirect flow. The proposed alignment would account for tidal flows, particularly reverse flows that occur in the Sacramento River during flood tide conditions. During reverse flows, fish moving up the river would be deterred from straying into Threemile Slough and would stay in the Sacramento River.

The BAFF is a fixed structure that would not adjust itself with stage changes caused by tidal effects. During low-stage conditions, some of the speakers and lights close to the shoreline might be exposed. The exposed speakers and lights could overheat and fail and would need to be turned off, as described in Operations and Maintenance.

Operations and Maintenance

Operations and maintenance of the BAFF would involve the general activities described in the "Bio-Acoustic Fish Fence" Chapter 2, subsection 2.2.4.2, "Non-Physical Barriers" and as described above for a BAFF installed at Georgiana Slough in subsection 4.4.1.1. The BAFF would be operated 24 hours per day throughout the juvenile out-migration periods. The barrier would be removed during periods when juvenile fish are not expected to travel past the divergence point. At the Threemile Slough location, some sound projectors and lights could become exposed during low-stage conditions. These sound projectors and lights would be turned off automatically from the control house and turned back on at the return of suitable stage conditions. The control system will be connected to a gauging station that will inform the computers when the stage drops below a specific criterion. Debris buildup would be monitored and debris would be removed as necessary. Navigation aids, particularly lights, would be inspected and serviced periodically.

Construction and Implementation

Construction and implementation of the BAFF would involve the same general activities as described above in subsection 4.4.1.1 for a BAFF installed at Georgiana Slough. A total of 29 in-water piles and other necessary infrastructure components would be installed at the Threemile Slough site and would stay in place year-round. Two control houses would be built on the Sacramento River's left bank, one upstream of the BAFF and one downstream. These control houses would contain the air system and computers to run the BAFF's air, light, and sound components BAFF in-water components, including frame assemblies and connecting lines, would be installed when needed. Depending on fisheries needs, BAFF removal and installation activities could occur multiple times during the year as described above under Operations and Maintenance.

This BAFF could be installed reasonably quickly (within two weeks) to respond to incoming information regarding the timing of an out-migration period. Once in place, the frames could be removed or re-installed in a relatively short period in response to changing flow conditions, in particular low flow events.

Potential Environmental Impacts

The BAFF option would have some potential in-water and terrestrial impacts on the environment. Potential environmental impacts from installing and operating a BAFF at Threemile Slough would be similar to the impacts described above in subsection 4.4.1.1 for a BAFF installed at Georgiana Slough. General environmental requirements and considerations for the Threemile Slough site are described in Appendix C, "Environmental Checklists"

The BAFF option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those unique to in-water and near shore actions. These unique impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the control building foundation and structure.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The BAFF operation would require seasonal installation of the BAFF frames prior to a migration event and removal of the frames following the event. Most installation/removal activities would be done by boat and barge, with minimal shore-based activities. Because the frame support piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the BAFF was operating would include minor changes to ambient noise levels due to the BAFF sound projectors, air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. There are no nearby residences so these impacts are expected to be insignificant. Regular system monitoring and servicing of equipment in the control building would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by divers then the associated equipment (and frame) may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

Implementation of this BAFF may have an effect on piscivorous predator species' assemblage, density, and behavior, but the extent of its influence on predator and prey interactions is not well understood because baseline predator densities at Threemile Slough are unknown. During the related 2011 and 2012 GSNPB BAFF studies, piscivorous fish predators were caught and tagged, and their movement and interaction with tagged juvenile Chinook salmon was analyzed. The results of these fish predator studies suggest that survival of juvenile Chinook salmon was independent of BAFF operation.

Cost

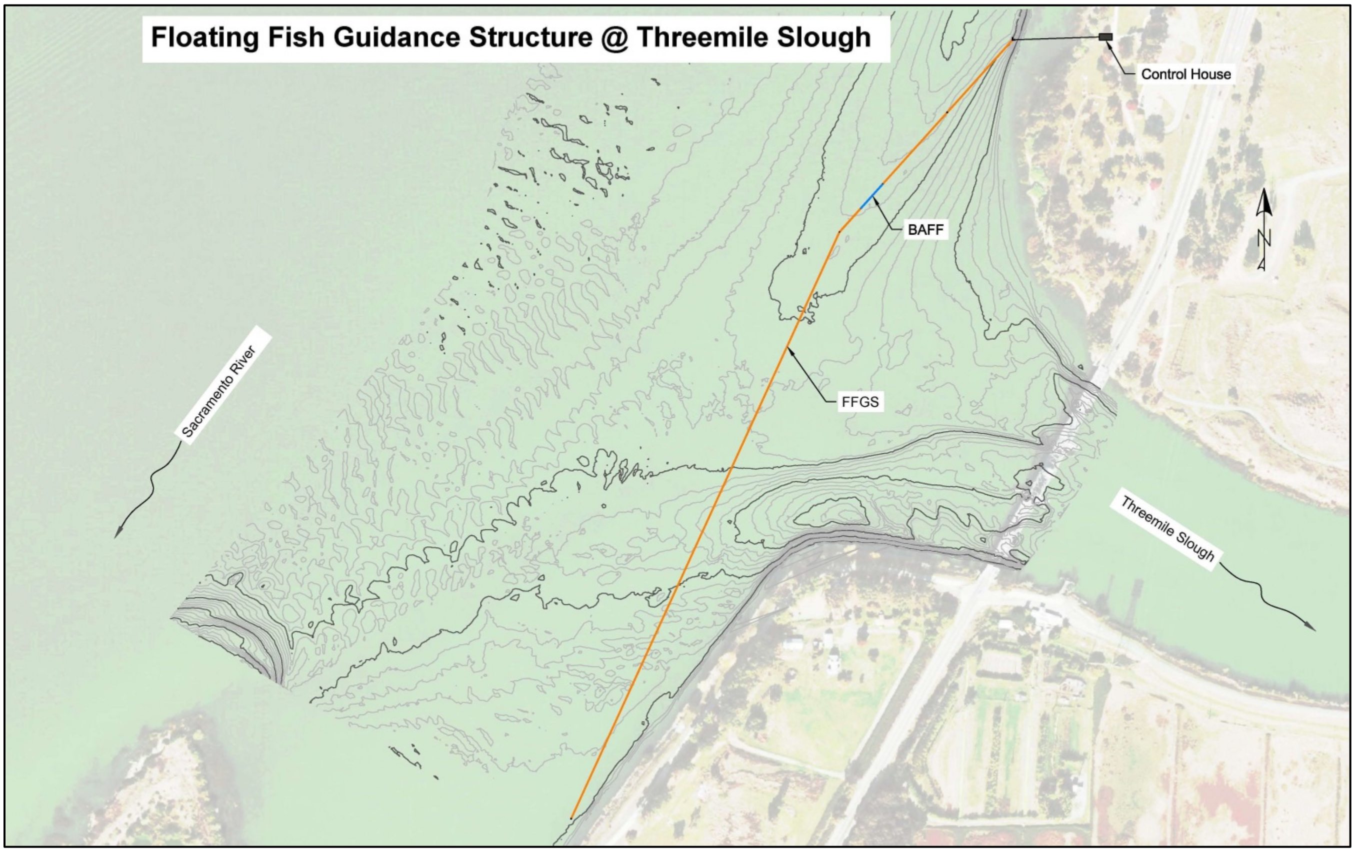
A rough order-of-magnitude estimated cost for the BAFF at Threemile Slough is $35.4 M. The estimated annual operations and maintenance cost is $880,000. The estimated present worth cost based on a 50-year life is $59.9 M.

4.4.2.2 FLOATING FISH GUIDANCE STRUCTURE

Description

An FFGS would be installed in the Sacramento River crossing the entire Threemile Slough divergence (Figure 4-16). The FFGS barrier would be aligned to have a small angle to flow relative to the Sacramento River's main flow direction under most hydrodynamic conditions. The barrier would have steel sections 20 feet wide and either five or 10 feet deep (depending on stage), with bolt connections for adding or removing panels.

The modular design would allow flexibility in operation resulting from changing hydraulic conditions. A section of BAFF has been incorporated into the design to provide boat passage. A control house would be provided to house the BAFF's power and control and air supply components and it would be located on the landside of the adjacent levee. Electrical power would be provided by either dedicated overhead or buried power lines. The in-water components of the barrier, with the exception of support piles and navigation aids, would be removed annually for general maintenance and to minimize potential impacts resulting from debris and sediment accumulation. These components would be stored in an on-site or remote storage facility and would be reinstalled before the juvenile salmonid emigration period or as directed by the regulatory agencies. See Appendix B for detailed drawings of the FFGS at the Threemile Slough.



Source: DWR – Bay-Delta Office 2014

Figure 4-16. Plan View of the Proposed FFGS at Threemile Slough

Alignment

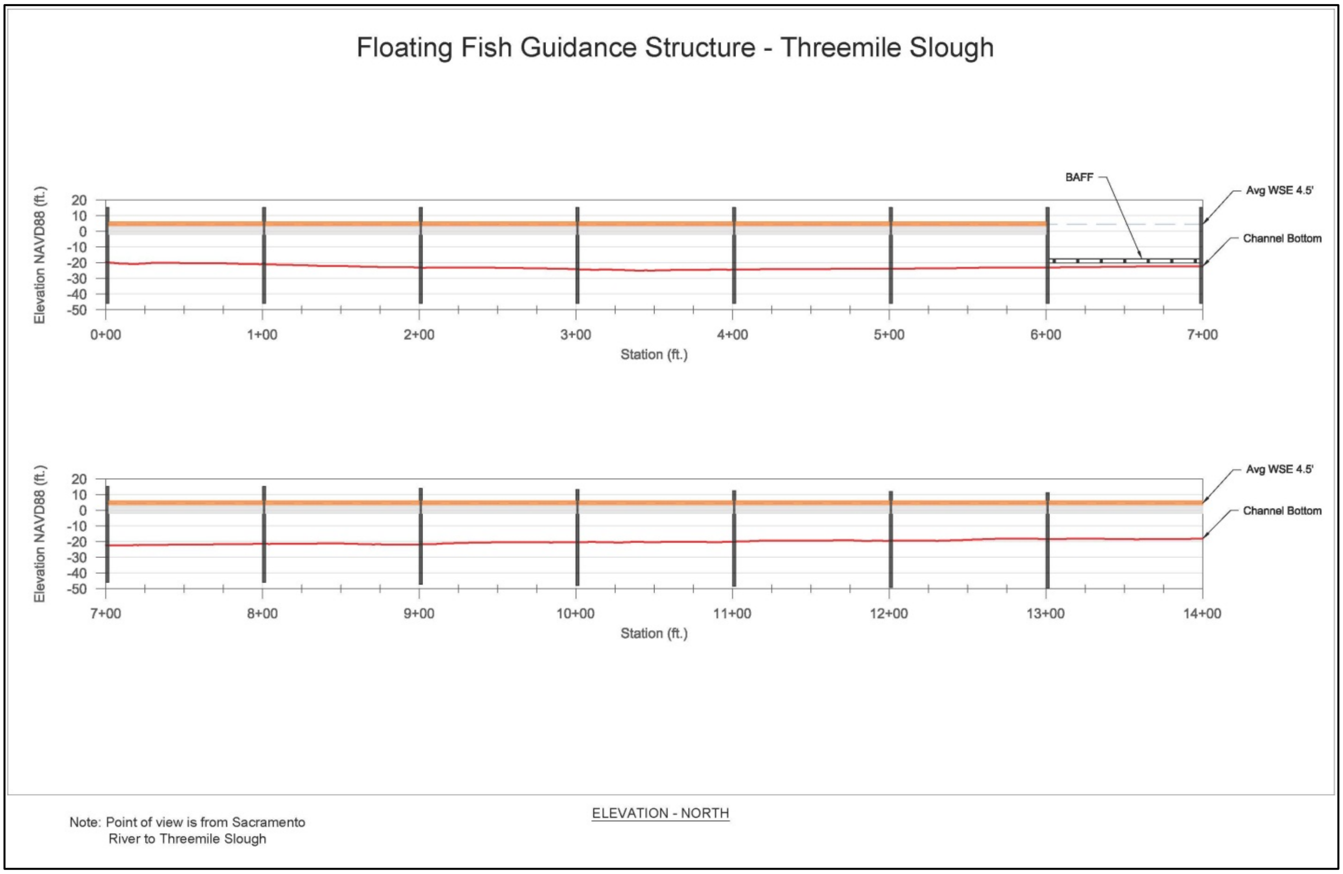
This barrier option would guide fish past the point of divergence at Threemile Slough to keep fish moving in the Sacramento River toward the ocean. To maximize fish deterrence, a continuous barrier is proposed that would cross the entire Threemile Slough divergence, extending above and below the divergence. (Figure 4-16).

The Threemile Slough divergence experiences regular changes in stage, velocity, and flow direction resulting from tidal influences and hydrologic conditions. Because this barrier would float, it would self-adjust (vertically) to the changes in stage. To address the variation in flow direction, a continuous barrier would span the mouth of the divergence and would be appropriately angled upstream and downstream to account for both positive and negative flows. This alignment would guide juvenile salmonids that approach from upstream on ebb tides and downstream on flood tides as a result of tidal influences such as reverse flows.

In rare incidences, some portions of the barrier may experience high velocities at an angle perpendicular to the barrier. The effectiveness of the FFGS in deterring juvenile salmonids during these incidences is not well understood.

Boat Passage

Boat passage between the Sacramento River and Threemile Slough would be provided by a 100-foot opening in the FFGS. To maintain continuous fish deterrence along the entire alignment, a 100-foot section of BAFF would be placed in the opening (Figure 4-17). The opening would be on the upstream side of the barrier, where the water depth is adequate to pass boats. This would minimize impacts on navigation resulting from low stage, and impacts on boats with large drafts. This type of boat passage system would be operated around the clock. The BAFF would have a control house located adjacent to the upstream end of the barrier on the landside of the levee. Electrical power would be provided by overhead power lines.



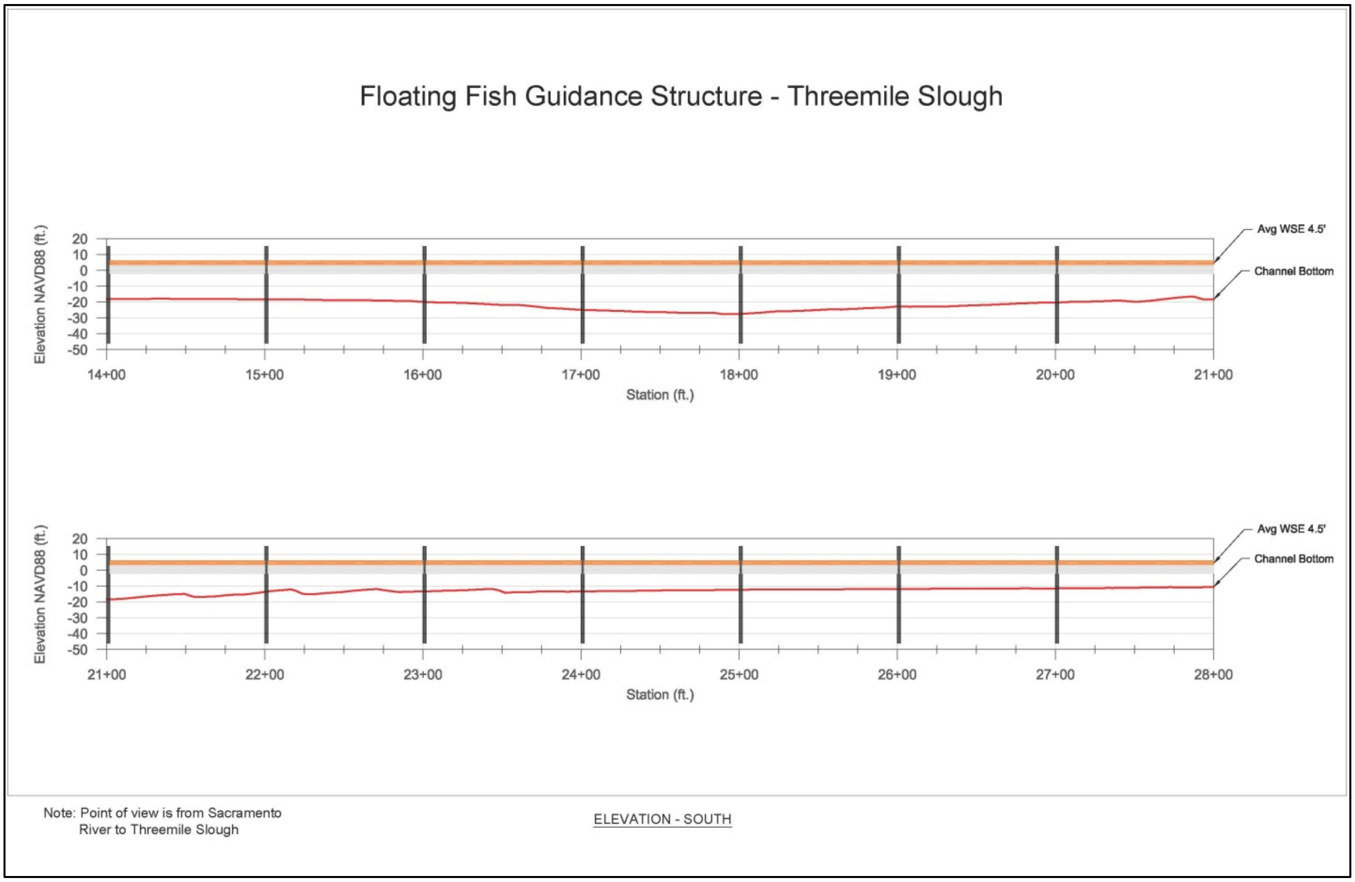
Source: DWR – Bay-Delta Office 2014

Figure 4-17. Elevation View of the Northern Portion of the Proposed FFGS at Threemile Slough

The reasons for using a BAFF as the boat passage solution are the same as described for the Georgiana Slough site in subsection 4.4.1.2, "Floating Fish Guidance Structure." The boat passage location for the FFGS is different than the non-physical barriers. This was done in order to potentially guide fish (in a physical manner) coming from the downstream side of the river during higher velocities that would normally push fish through a non-physical barrier.

Upstream Migration

The FFGS design would allow the movement and passage of other sensitive non-targeted fish species (e.g., green sturgeon and adult salmonids). A minimum of 50 percent of the lower water column (depending on stage) would be unobstructed and would allow free movement of upstream migrants, sturgeon, and other fish navigating the divergence (Figure 4-17 and Figure 4-18). The BAFF also could be used for passage by non-targeted fish. A minimum two feet clearance under the BAFF frame would be provided for passage, but non-target fish species actually may pass above the frame through the bubble curtain as well.



Source: DWR – Bay-Delta Office 2014

Figure 4-18. Elevation View of the Southern Portion of the Proposed FFGS at Threemile Slough

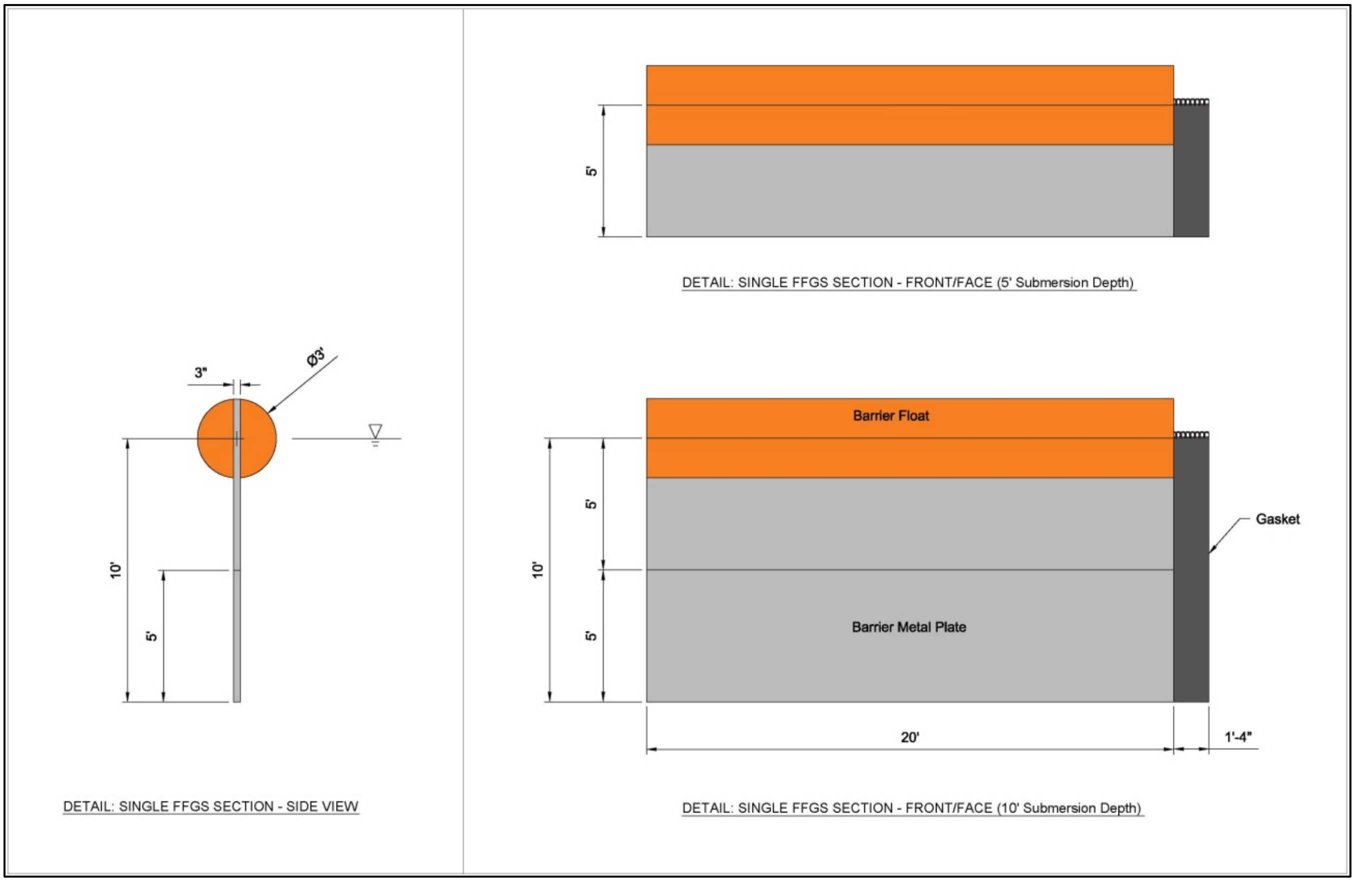
Deterrence

The potential effectiveness of the FFGS deterrence at Threemile Slough is not well understood. This option is expected to reduce entrainment into Threemile Slough, but there are too many unknowns to be able to quantify the benefits. As described for an FFGS at the Georgiana Slough site in subsection 4.4.1.2, "Floating Fish Guidance Structure," this type of deterrence technology has been used elsewhere but not in a tidally influenced environment. The Threemile Slough site experiences a wide range of velocities and variable flows and frequent reverse flows primarily caused by tidal influences that in some instances may adversely impact barrier deterrence.

The results of the 2014 FFGS study at Georgiana Slough should be studied further and more detailed hydraulic studies conducted at the Threemile Slough divergence to aid in addressing the aforementioned unknowns.

Flow and Tidal Effects

This FFGS design would have minimal impacts on the existing flow patterns in Threemile Slough. The physical in-water footprint of this barrier would provide optimal deterrence while having minimal effects on the naturally existing hydraulic conditions. The floats at the top of the barrier would provide continuous adjustments to the changing stage (Figure 4-19). This would keep the barrier in the upper portion of the water column where the emigrating juvenile salmonids are expected to reside. It would also keep the majority of the water column below the barrier open for the passage of water and other non-targeted fish species.



Source: DWR – Bay-Delta Office 2014

Figure 4-19. Detail Drawing of the Proposed FFGS at Threemile Slough, Showing the 5-foot and 10-foot Panels

Some amplified turbulence and redirection of flow could occur near the barrier. The significance of these potential impacts on the naturally existing flow patterns would be studied throughout the full spectrum of possible hydraulic conditions. Some additional design features may be feasible to minimize these impacts.

The floats would keep the barrier at a constant five or 10 feet below the surface throughout all conditions. In times of low flow and low stage, panels could be removed so that the barrier walls would not extend more than 50 percent down into the water column.

This particular site experiences flow reversals caused by tidal forces. This design accounts for these conditions by having the barrier cross the entire mouth of the Threemile Slough divergence. If the reversing flow would happen to bring juvenile salmonids and other fish species along with it they would encounter the barrier before they reached Threemile Slough.

A system would be put into place to monitor and forecast changes in stage at locations along the barriers where a potential existed for adding or removing barrier panels. This system would alert staff when to add or remove panels to keep the barrier at the correct submergence depth, depending on stage.

Operations and Maintenance

Operations and maintenance of the FFGS and BAFF would involve the general activities described for the "Floating Fish Guidance Structure" and "Bio-Acoustic Fish Fence" subsection 2.2.4.2, "Non-Physical Barriers" and as described above for an FFGS installed at Georgiana Slough in subsection 4.4.1.1. Operations for the FFGS would be limited because the barrier would be in a fixed position. After the construction crew finished placement of the barrier and BAFF for boat passage, the FFGS would remain in the same alignment until it was no longer needed and removed. A change from 5-foot to 10-foot panels may be necessary should a substantial change in stage occur.

Periodic maintenance and replacement of barrier components would occur because the environment would certainly cause them to deteriorate. Some components, such as the floats, hardware, and rubber section connectors, would deteriorate because of exposure to the sun and water. The BAFF components (e.g., speakers, air hoses, and lights) also would be monitored and replaced as necessary. The accumulation of debris on the floats and piles would be monitored and removed as necessary.

Construction and Implementation

The FFGS initial construction would include the installation of 30 piles, 127 panels and floats, a BAFF frame (and connecting cables and hoses), a control house, underground or overhead power and poles, and navigation buoys and warning lights. Power and control systems as well a compressor system for the BAFF would be installed inside the control house. This FFGS deterrence system would be made up primarily of modular components (e.g., FFGS panels and floats, BAFF frames, and cabling). This would make it possible to install or remove the system relatively quickly (within a week) in response to or following juvenile salmonid emigration. To minimize construction time and potential environmental impacts, the modular components would be secured to the permanent piles and brackets. In-water work would be done using barges, cranes, and divers. The control house and underground or overhead power and pole installation would require shore/bank access near the upstream pile location. Installation would be done using conventional building and utilities equipment and methods.

Potential Environmental Impacts

The FFGS option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance As noted above for the BAFF option, general environmental requirements and considerations for the Threemile Slough site are described in Appendix C, "Environmental Checklists", Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and BAFF frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the control house foundation and structure.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The FFGS and BAFF operation would require seasonal installation of the FFGS panels and BAFF frames prior to a migration event and removal of this equipment following the event. Most installation/removal activities would be done by boat and barge, with minimal shore-based activities. Because the system piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the FFGS was in operation would be insignificant. Impacts when the BAFF was operating would include minor changes to ambient noise levels due to the BAFF sound projectors and the occasional air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. There are no nearby residences so these impacts are expected to be insignificant. Regular system monitoring and servicing of equipment in the control house would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of the FFGS panels and BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by boat or divers then the associated equipment may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

Implementation of this FFGS may have an effect on piscivorous predator species' assemblage, density, and behavior, but the extent of its influence on predator and prey interactions is not well understood. Study results from the previously mentioned 2014 Georgiana Slough FFGS study are expected to provide some understanding of potential effects.

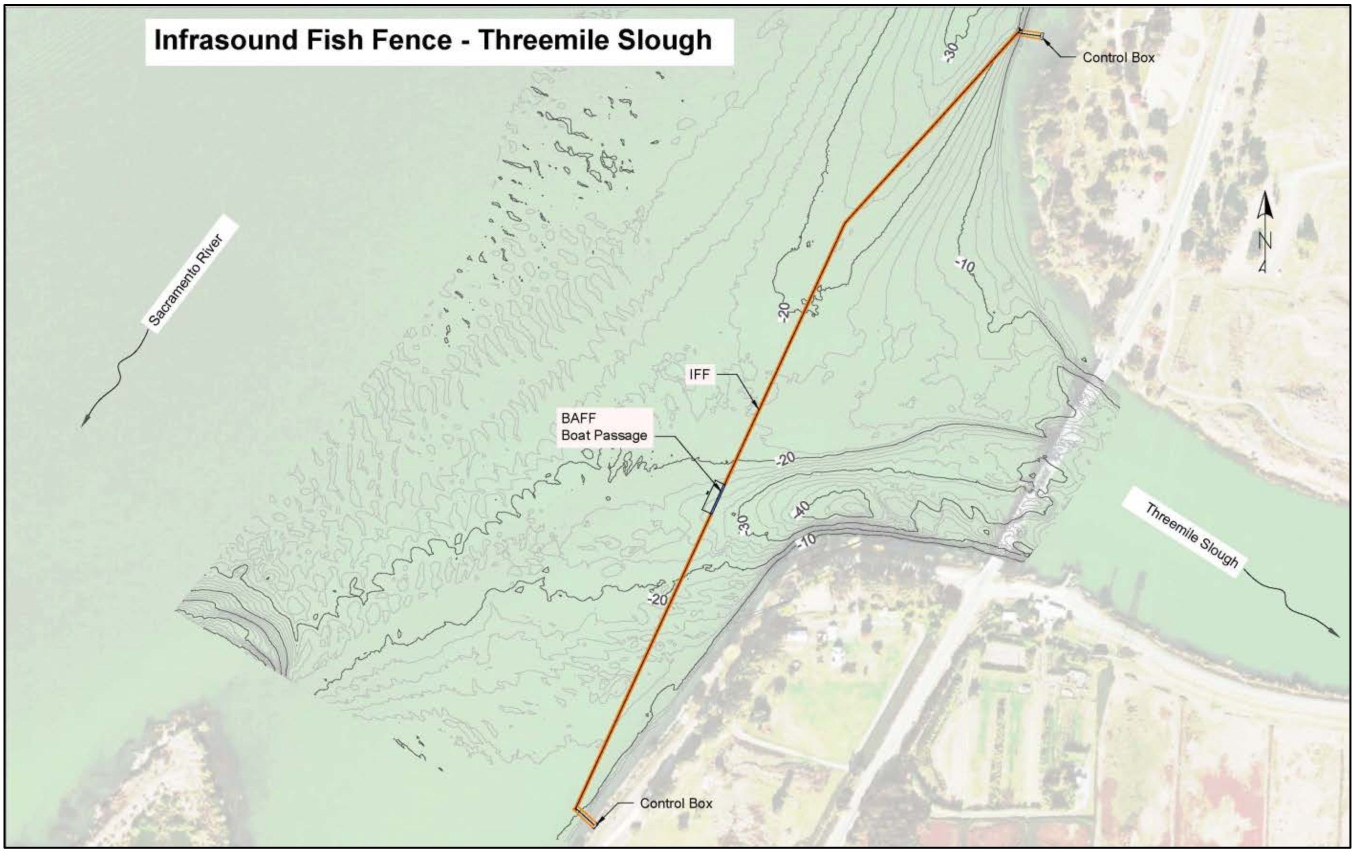
Cost

A rough order-of-magnitude estimated cost for the FFGS at Threemile Slough is $12.8 M. The estimated annual operations and maintenance cost is $710,000. The estimated present worth cost based on a 50-year life is $38.8 M.

4.4.2.3 INFRASOUND FISH FENCE

Description

An IFF would be installed in the Sacramento River and cross the entire Threemile Slough divergence (Figure 4-20). The IFF barrier would be set at an angle parallel to the direction of the Sacramento River flow to take advantage of the streamlines in an attempt to guide fish past the point of divergence. See Appendix B for detailed drawings of the IFF at the Threemile Slough.



Source: DWR – Bay-Delta Office 2014

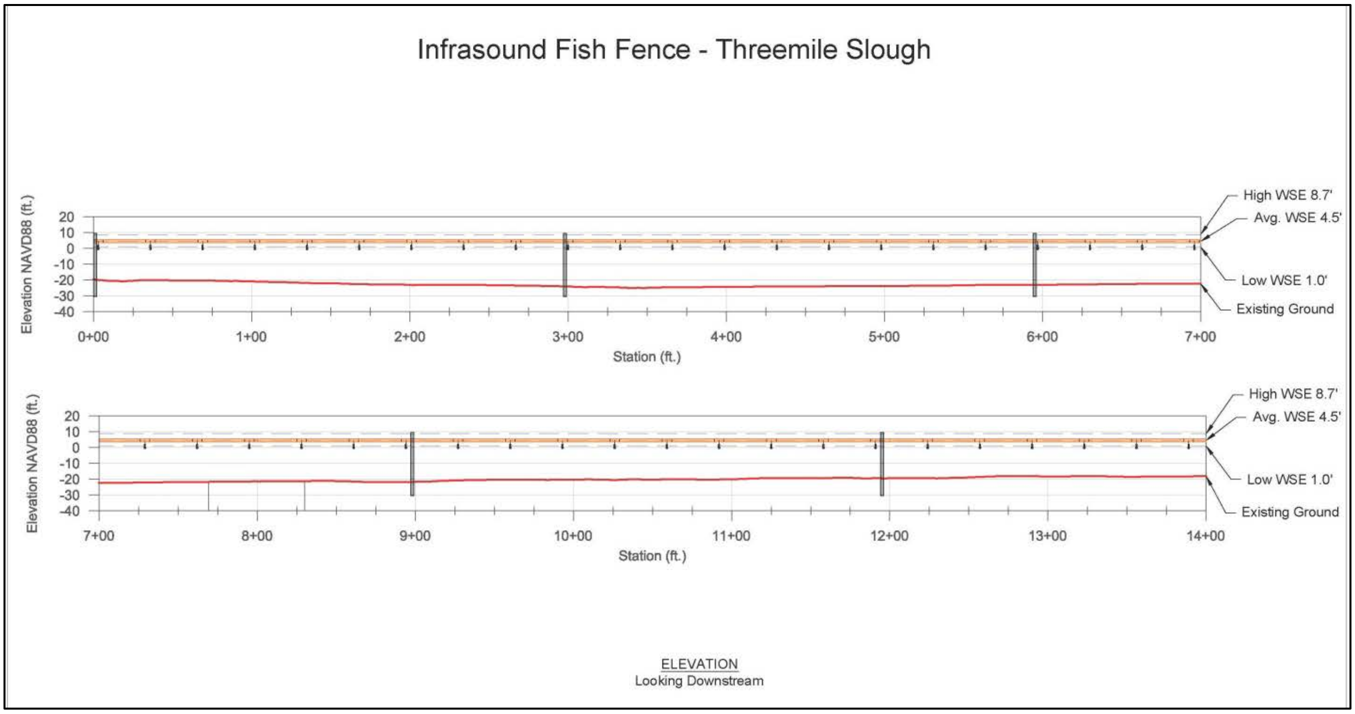
Figure 4-20. Layout of the Proposed IFF at the Threemile Slough Divergence

A continuous line of cylindrical buoys would wrap around the entire IFF alignment, minus the boat passage, to protect the surface-mounted power, data, and air lines from debris (Figure 4-9). Two control houses housing the barrier's power supply and air system would be located on the landside of the adjacent levee. Electrical power would be provided by dedicated buried or overhead power lines. The barrier's in-river components, with the exception of support piles and navigation aids, would be removed annually for general maintenance and to minimize potential impacts resulting from debris and sediment accumulation. These components would be stored at either an on-site or remote storage facility and would be re-installed before the juvenile salmonid migration period or as directed by regulatory agencies.

Alignment

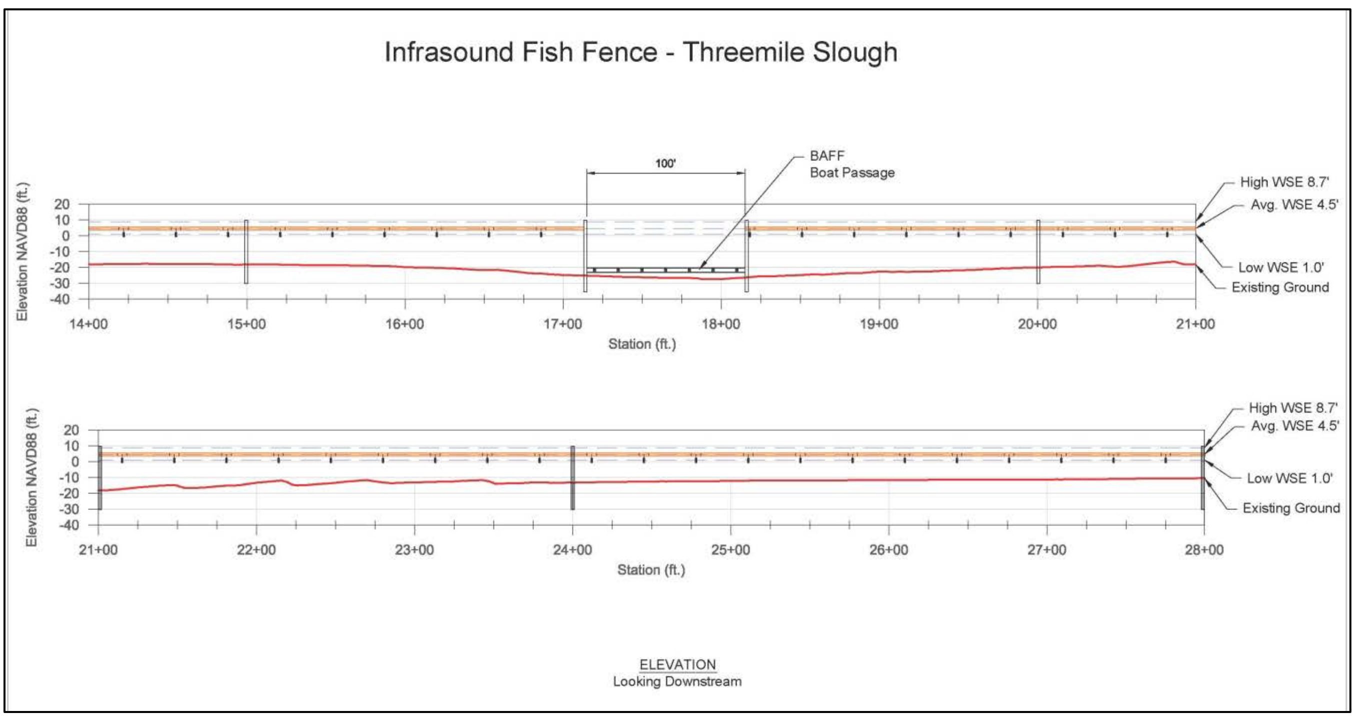
The alignment of the IFF at Threemile Slough would guide fish past the point of divergence at Threemile Slough and allow them to continue their migration in the Sacramento River. To maximize fish deterrence, a continuous barrier crossing the entire Threemile Slough divergence is proposed. The proposed IFF would be approximately 2,800 feet long and would use a total of 12 piles (Figures 4-21 and 4-22).

The Threemile Slough point of divergence experiences regular changes in stage, velocity, and flow direction resulting from tidal influences and hydrologic conditions. To address the variation in flow direction, a continuous barrier would spans the mouth of the divergence and would be angled appropriately to account for both positive and negative flows. This alignment would guide juvenile fish that approach from downstream, resulting from tidal influences such as reverse flows.



Source: DWR – Bay-Delta Office 2014

Figure 4-21. Elevation View of the Alignment of the Proposed IFF at Threemile Slough (Stations 0+00 through 14+00)



Source: DWR – Bay-Delta Office 2014

Figure 4-22. Elevation View of the Alignment of the Proposed IFF at Threemile Slough (Stations 14+00 through 28+00)

Boat Passage

Boat passage between the Sacramento River and Threemile Slough would be provided by a 100-foot opening in the IFF. To maintain continuous fish deterrence along the entire alignment, a 100-foot section of BAFF would be placed in the opening (Figure 4-22). The opening would be located where the water is the deepest. This would minimize impacts on navigation resulting from low stage, and impacts on boats with large drafts. A 100-foot opening also would provide passage for larger, barge-type vessels for construction or emergency purposes. Navigational buoys and lights would be installed for boater safety. Staff gauges indicating draft depth would be placed near the barrier to inform boaters of the clearance above the BAFF frame. This type of boat passage system would be operated around the clock.

Upstream Migration

Upstream migration would be relatively unimpaired by the IFF. The manufacturer claims that only salmonid and eel species are known to detect infrasound, thus other fish species are not affected because their otoliths are not as sensitive to this frequency of sound. Adult salmonids and green sturgeon would be able to pass through the divergence undisturbed. A minimum of two feet clearance under the BAFF frame would be provided for passage, but non-targeted fish species may actually pass through the bubble curtain as well.

Deterrence

This technology has been tested in the laboratory and in the field; however, it has not been tested on juvenile salmonids in an environment similar to Threemile Slough. The deterrence ability or effectiveness of an IFF at Threemile Slough depends on many factors, such as barrier alignment, flow direction, water velocities, and swimming ability of the fish. Based on the results of previous laboratory and field tests, the IFF shows promise in deterring fish but it should be studied at this location with a focus on juvenile salmonids.

Flow and Tidal Effects

This IFF would have minimal impacts on the existing flow patterns at this site. The barrier would have very little in-water infrastructure (12 piles) and its relatively small mechanical components (80 IFF units and floats and a 100-foot BAFF section) would have a negligible influence on the natural movement of water.

The IFF is expected to be effective under a wide range of tidal flows, including tidal reverse and low flows when water velocities will be low in comparison to salmonid swimming speeds. Similar to the BAFF, the IFF is expected to be less effective during high flow periods when water velocities exceed salmonid swimming speeds and the water direction is more perpendicular to the barrier alignment. The floats attached to each of the units would allow the IFF to constantly adjust to the changes in stage. This would keep the barrier in the upper portion of the water column, where the out-migrating fish are expected to reside. If low stage conditions occur, the IFF has the capability to have individual units turned off or even removed, to allow proper operation while maintaining a continuous system of deterrence.

A system would be put in place to monitor and forecast changes in stage at locations along the barrier where the potential existed for the need to turn off a unit or remove it.

Operations and Maintenance

Operations and maintenance of the IFF would involve the general activities described in the subsection titled "Infrasound Fish Fence" in Chapter 2, Section 2.2.4.2, "Non-Physical Barriers" and as described in Section 4.4.1.3 "Infrasound Fish Fence" for an IFF at Georgiana Slough. The IFF (and BAFF) would be operated 24 hours per day throughout the juvenile out-migration periods. Operation would be automated but could also be controlled remotely or manually. The barrier would be removed during periods when juvenile fish are not expected to travel past the Threemile Slough divergence point. Regular preventive maintenance would be performed on all equipment. Navigation aids, particularly lights, would be inspected and serviced periodically. Debris buildup would be monitored and the debris removed as necessary.

Construction and Implementation

Two control houses would be located on the Sacramento River's left bank to provide power and controls for the IFF and BAFF. Electrical power would be provided by dedicated overhead power lines. This proposed IFF system would have modular components. This would make it possible to install or remove the system relatively quickly (within two weeks) in response to juvenile fish out-migration timing. To minimize construction time, environmental impacts, and wear and tear on the system, the piles and frame brackets would stay in-place year-round. Navigation aids would also be left in place. The modular components of the IFF would be removed annually and stored at a nearby facility. This IFF (and BAFF) could be installed reasonably quickly (within two weeks) to respond to incoming information regarding the timing of an out-migration period. Once in place, the IFF units and BAFF frames could be removed or re-installed in a relatively short period in response to changing flow conditions, in particular low flow events.

Potential Environmental Impacts

The IFF option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance. As noted above for the BAFF and FFGS options, general environmental requirements and considerations for the Threemile Slough site are described in Appendix C, "Environmental Checklists", Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and BAFF frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the two control house foundations and structures.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The IFF and BAFF operation would require seasonal installation of the IFF units and BAFF frames prior to a migration event and removal of this equipment following the event. Most installation/removal activities would be done by boat and barge, with minimal shore-based activities. Because the system piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the IFF and BAFF were in operation would include: potential minor changes to ambient noise levels resulting from the low-frequency IFF pulses, the BAFF sound projectors and occasional air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. There are no nearby residences so these impacts are expected to be insignificant. Regular system monitoring and servicing of equipment in the control building would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by divers then the associated equipment (and frame) may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

Implementation of this IFF may have an effect on piscivorous predator species' assemblage, density, and behavior, but the extent of its influence on predator and prey interactions is not well understood because baseline predator densities at Threemile Slough are unknown. Baseline piscivorous predator species' assemblages and densities should be established to address the potential predator presence in this area. To address potential inland avian predation, anti-roosting wires could be installed on top of the floats to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for the IFF at Threemile Slough is $17.4 M. The estimated annual operations and maintenance cost is $790,000. The estimated present worth cost based on a 50-year life is $45.4 M.

4.4.2.4 GATE STRUCTURE

Description

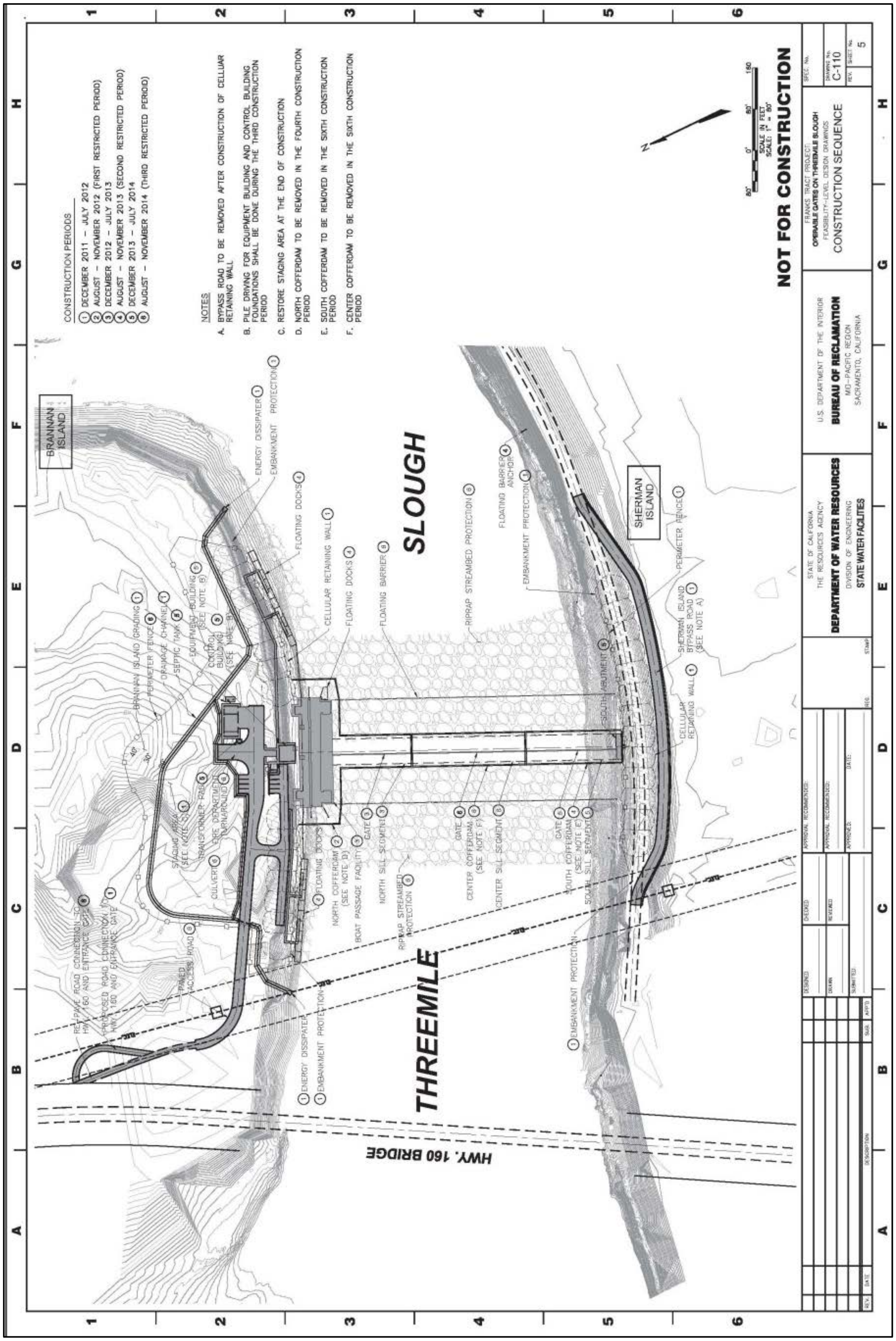
As proposed, a gate structure at the Threemile Slough/Sacramento River divergence (Franks Tract Project) would be placed in Threemile Slough about 650 feet beyond the Highway 160 Bridge (Figure 4-23). The gate structure has been proposed to improve water quality in the Delta and reduce the entrainment of juvenile fish. Bottom-hinged gates would be used as the gate type for this site. The gate structure would consist of 11 gates, each 50 feet wide, each of which could be operated individually or simultaneously. This proposed gate structure would also include a two-lane boat lock. This option would not include a fish ladder. Fish would pass when the gates were down or would use the boat locks during their operation. See Appendix B for general detail drawings of the proposed gate and boat lock structures.

Alignment

The proposed gate structure at Threemile Slough would be about 600 feet long. The gates could open up to be around 32 feet tall. The gate structure would be set back into the entrance of the channel where the water flow would be perpendicular to the gate faces (Figure 4-23).

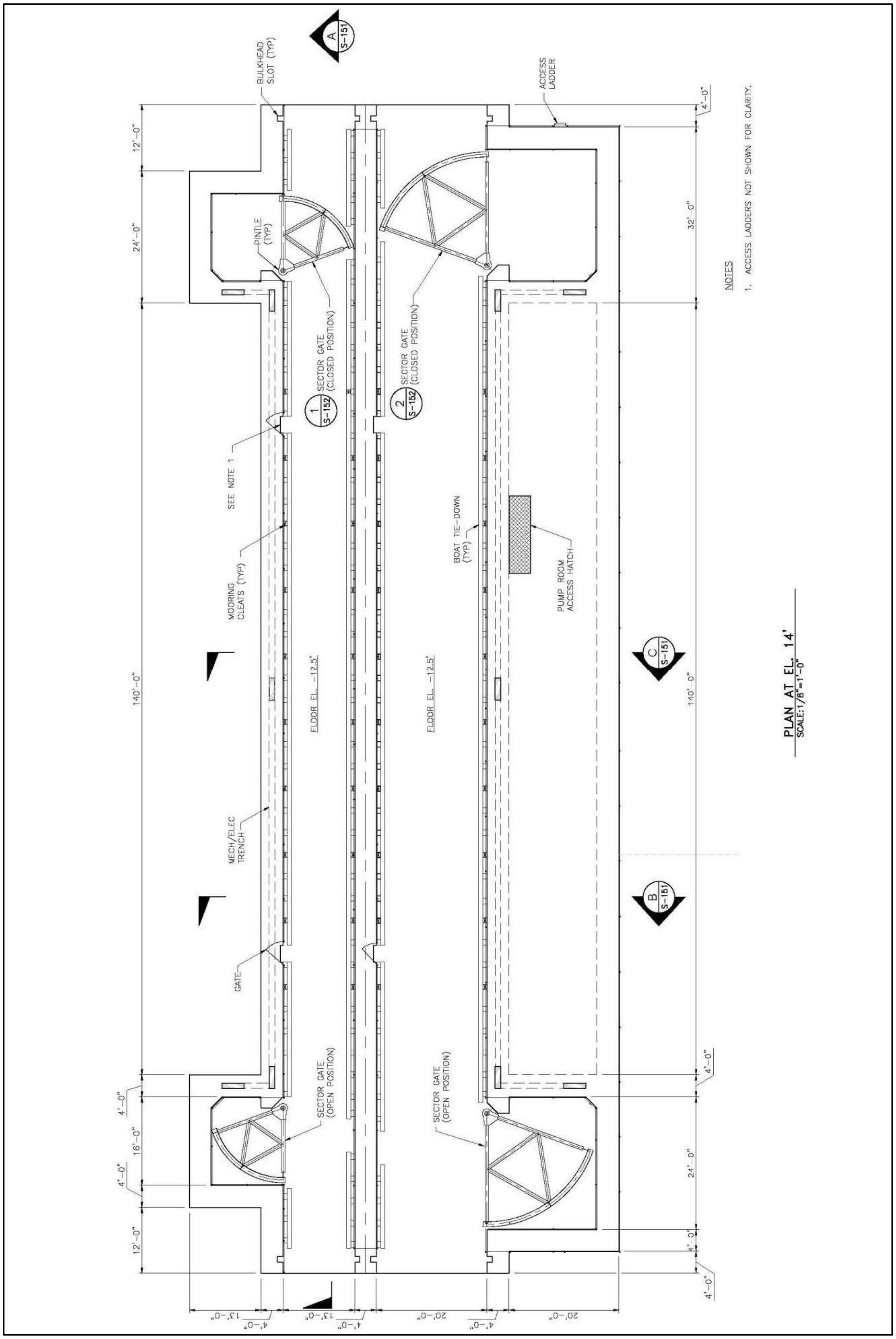
Boat Passage

The proposed gate structure would include two boat locks, one smaller and one larger. The locks would be 140 feet long between the entrance and exit gates (sector gates). The smaller lock would be 13 feet wide and the larger lock would be 20 feet wide (Figure 4-24). The locks would have a water depth capacity of about 26 feet. Barges and larger vessels would be able to transit the structure when the main gates were lowered or in the open position. Navigational buoys and lights would be installed for boater safety. This type of boat passage system would be operated around the clock.



Source: DWR/Reclamation 2010

Figure 4-23. Plan View of the Proposed Gate Structure at Threemile Slough



Source: DWR/Reclamation 2010

Figure 4-24. Proposed Boat Lock System for the Threemile Slough Location

Upstream Migration

The proposed Franks Tract Project gate structure would not include a fish ladder. Fish passage would be possible when the main gates are open to allow water passage, and when the boat lock gates are open.

Deterrence

A gate structure at the Threemile Slough divergence would provide fish deterrence. The gates' deterrence efficiency would depend on the timing of gate operations relative to the tidal cycle, and on the percentage of the time that the gates would be positioned to block water from entering the slough. The exact relationship between gate operations and deterrence efficiency has not been quantified.

Flow and Tidal Effects

The proposed Franks Tract Project gate structure at Threemile Slough would change the existing flow and stage characteristics. As described above under "Description", the gate structure has been proposed to improve water quality in the Delta and reduce the entrainment of juvenile fish. The operational strategy that would best meet both of those objectives has not been determined. The Reclamation web site http://www.usbr.gov/mp/frankstract/ has the latest information regarding this project.

Operations and Maintenance

Operations and maintenance of the gate structure would involve the general activities described for the "Underflow Gate" and "Overflow Gate", Chapter 2, subsection 2.2.4.2, "Physical Barriers" and as described above in subsection 4.4.1.4 for a gate structure installed at Georgiana Slough. As stated above under "Flow and Tidal Effects", the operational strategy for the proposed gate structure has not yet been determined. The proposed gate structure would require the operation of gates and boat locks, but the frequency of such operations would not be determined until the final design stages.

Like all other options, a gate structure at Threemile Slough would require regular preventive maintenance, checks, and servicing of all mechanical equipment and the structure itself. Debris would also be monitored and removed as appropriate.

Construction and Implementation

Construction of the gate structure would involve some of the general activities described above in subsection 4.4.1.4 for a gate structure installed at Georgiana Slough. The gate construction would include the installation of a paved access road, reinforced concrete foundation (including abutments and boat lock channel), xx main bottom-hinged gates, eight boat lock vertical-hinged sector gates, a control building, overhead power and poles, and navigation buoys and warning lights. Power and control systems for the gates would be installed inside the control building. In-water work would be done using both water and shore based equipment (e.g., excavators, cranes, concrete pumpers). A cofferdam installation would be required to allow in-channel foundation excavation and placement of concrete and gate components. The paved access road would be installed from nearby Highway 160 to the gate location where the control building would be installed. Rip-rap would be installed along the channel bottom and to protect the adjacent levees. Installation would be done using conventional building and utilities equipment and methods.

Potential Environmental Impacts

The gate option would have a significant effect on the natural environment during installation of the permanent infrastructure and during operation and maintenance. As noted above for the other options, general environmental requirements and considerations for the Threemile Slough site are described in Appendix C, "Environmental Checklists". Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include significant disruption of river sediment habitat and aquatic habitat during in-channel excavation and foundation installation, and disruption of riverine shore habitat during mobilization, access road installation, excavating and installation of the gate abutments, control building foundation and structure.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The gate operation would include raising and lowering the hinged gates, either to allow the flow of water or the passage of boats. The top hinged gate would be operated or left partially open at all times to allow the passage of sturgeon. Environmental impacts when the gates were in operation would include potential minor changes to ambient noise levels resulting from raising or lowering a gate. Regular system monitoring and servicing of the gates and equipment in the control building would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of the gates may be required. If the servicing could not be completed in water or by divers then the associated equipment may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

In addition to deterring targeted fish species, the gate structure would potentially become a point where piscivorous predatory fish and other species would congregate to hold and prey on passing fish. The proposed location is set back far enough from the main flow of the Sacramento River that it has potential to become advantageous habitat for piscivorous fish, avian, and aquatic mammal predators.

The existing interaction between juvenile salmonids and piscivorous predators at the Threemile Slough divergence is not well understood. Baseline piscivorous predator species' assemblage and density are unknown for this area, so determining the impacts of the gate is extremely difficult to determine. Baseline piscivorous predator species' assemblage and densities should be established for this area before any engineering option is installed, and monitoring should occur after installation to determine whether an increase in or change of predator species has occurred and, if so, to what extent this may result in an increase of predation on juvenile salmonids.

Cost

A rough order-of-magnitude estimated cost for the proposed Franks Tract Project gate structure at Threemile Slough is $148.4 M. The estimated annual operation and maintenance cost is $210,000. The estimated present worth cost based on a 50-year life is $152.3 M.

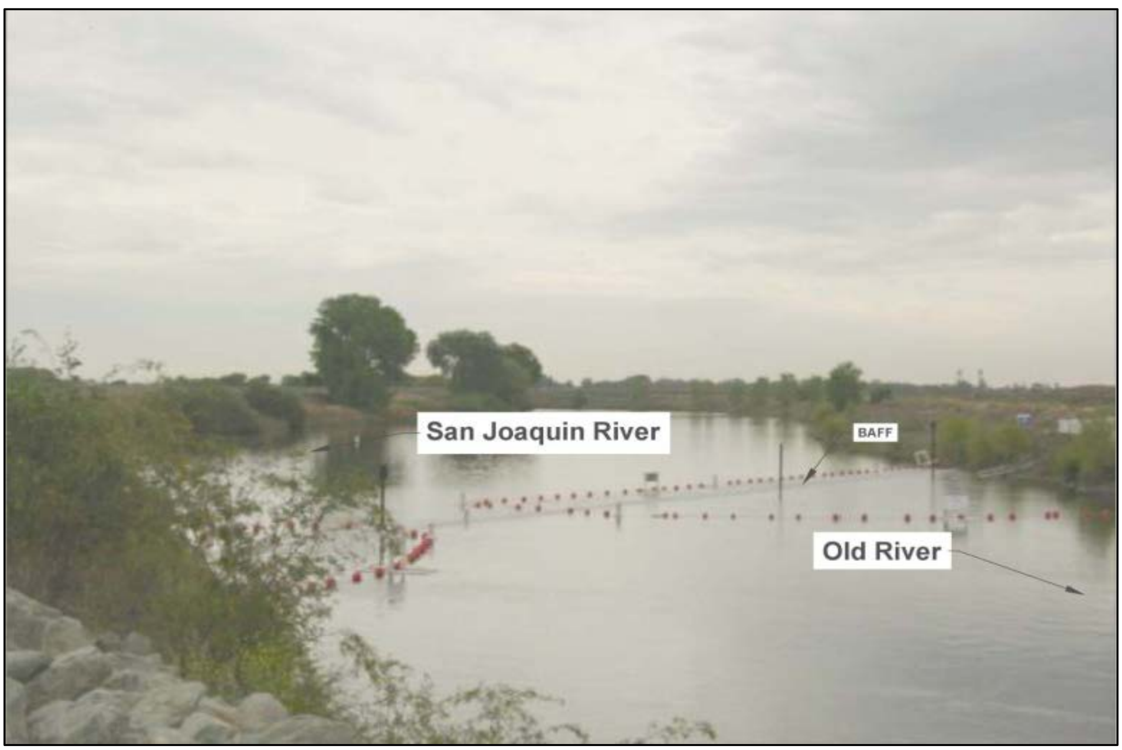
4.4.3 HEAD OF OLD RIVER

The engineering alternatives that were considered applicable for Head of Old River included Operable Gates, FFGSs, and BAFFs. The IFF was not considered for the HOR site due to the narrow channel configuration which would result in adverse impacts to special-status fish should the IFF be installed there. Each engineering option was evaluated using the criteria set forth in the WRAM process, and a conceptual design was created for each option using the same criteria applied specifically to the Head of Old River site. Although predation impacts is a criteria for all sites and options, the HOR site includes a unique predation consideration as a result of a known predation site located just downstream of the HOR divergence. All option evaluations include consideration of how effective an option would be at guiding fish past or away from this predation site.

4.4.3.1 BIO-ACOUSTIC FISH FENCE

Description

This BAFF would be installed just upstream from the divergence (Figure 4-25). The barrier would partially extend from the left bank of the San Joaquin River with boat passage provided around the barrier's downstream terminus. A control building to house the barrier's power supply and air systems would be located on the landside of the left bank levee. Electrical power would be provided by dedicated buried or overhead power lines. The in-river components of the barrier, with the exception of support piles and navigation aids, would be removed annually for general maintenance and to minimize potential levee impacts resulting from debris and sediment accumulation. These components would be stored at either an on-site or remote storage facility and would be re-installed before the juvenile salmonid migration period or as directed by regulatory agencies.



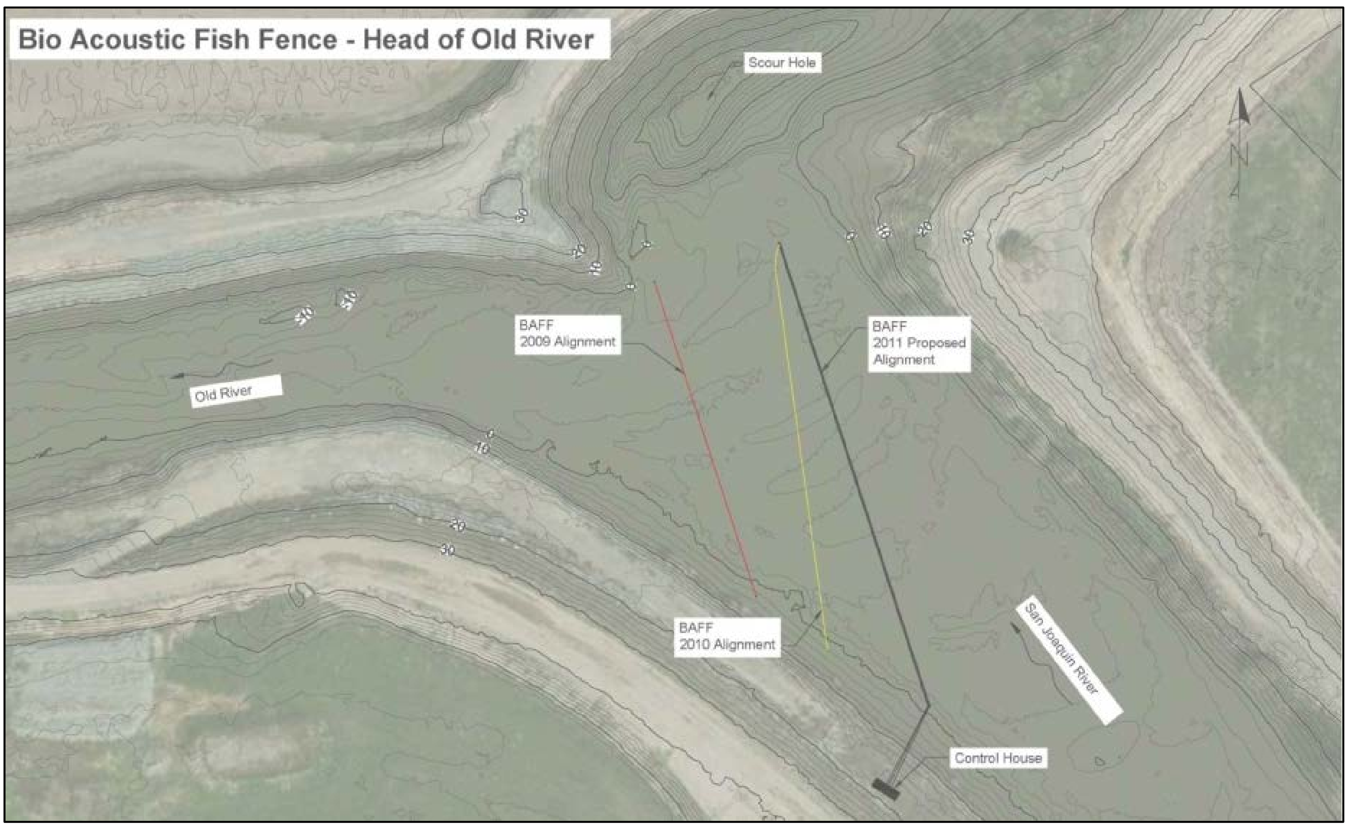
Source: DWR – Bay-Delta Office 2014

Figure 4-25. BAFF at the HOR during the 2009 Test Period

Figure 4-25 shows the general arrangement of the above-water navigation buoys and support piles for the BAFF design that was tested in 2009 at the HOR. The below-water BAFF features included multiple frames, each having four sound projectors, eight modulated intense lights, and multiple air bubble hoses. See Appendix B for detailed drawings of the BAFF at the HOR.

Alignment

The proposed barrier would be positioned to guide juvenile salmonids away from Old River and allow them to continue their emigration along the San Joaquin River. The BAFF would be approximately 520 feet long and would be installed at a 24-degree angle relative to the river's flow direction (Figure 4-26). The downstream end of the barrier would be extended farther downstream from the Old River divergence to guide juvenile salmonids away from the scour hole, a known piscivorous fish predation congregation location. The barrier alignment would be identical to the proposed 2011 HOR BAFF study design that was never implemented due to high river discharges. The barrier frame would be installed approximately one to two feet off the channel bottom, to provide passage under the barrier for benthic fishes (e.g., green sturgeon). To maximize fish deterrence, the barrier would start approximately 450 feet upstream from the HOR junction. This would provide sufficient time for fish to sense the barrier and react to it.



Note: The bold black line was the proposed 2011 alignment indicating the preferred BAFF alignment for this site.
Source: DWR – Bay-Delta Office 2014

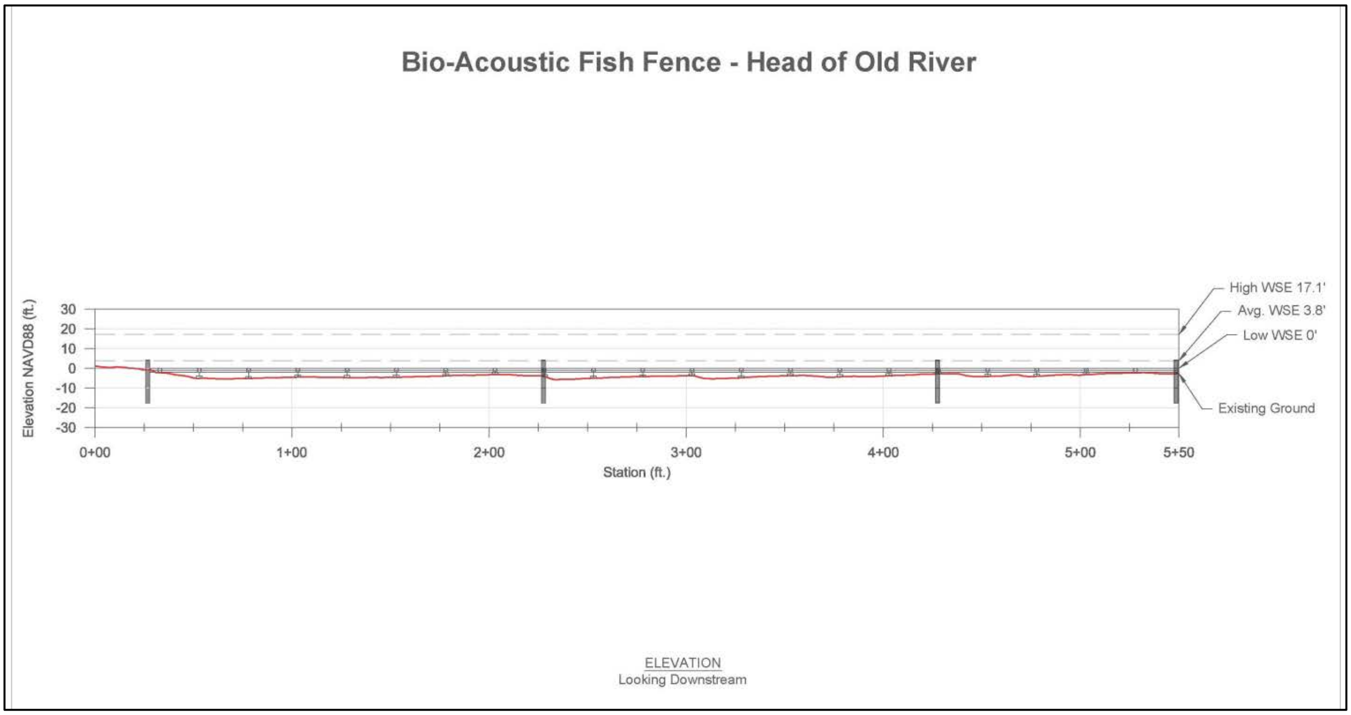
Figure 4-26. Layout of the Proposed BAFF at the Head of Old River

In 2009 and 2010, BAFFs were deployed in the San Joaquin River immediately upstream from the HOR junction. In 2009, the length of the BAFF was approximately 367 feet, at an angle of 24 degrees. In 2010, the length of the BAFF was approximately 446 feet, at an angle of 30 degrees, and a curved BAFF section was added at the barrier downstream end to evaluate its effectiveness at guiding fish away from the downstream scour hole.

In 2011, DWR planned to conduct an additional BAFF test, based on the 2009 and 2010 study results. Two-dimensional (2D) fish monitoring tracks from both years showed that steeper angles and higher velocities could give fish insufficient time to react to the barrier, allowing them to pass through the barrier rather than being deterred. Also, the 2010 2D tracks showed that many fish passed through the added downstream curved section rather than being guided away. Based on these results, the 2011 BAFF was proposed to be installed at the 2009 test angle of 24 degrees, but with a longer length and having no curved section. The longer length was intended to examine the barrier's effectiveness in deterring fish past the downstream scour hole. The proposed 2011 BAFF was not installed because of higher river discharges, but the proposed configuration is considered to be the best available information for comparison and planning purposes.

Boat Passage

An approximate 75-foot opening would be provided at the downstream end of the barrier to accommodate safe boat navigation (Figure 4-26). Boats also would be allowed to pass over the barrier when sufficient water depth existed. Historically, the San Joaquin River at the HOR junction is extremely shallow during low-flow and low-stage events, with only up to three feet of clearance from the channel bottom (Figure 4-27). Thus, larger vessels can navigate only during higher flow periods. Navigational buoys and lights would be installed to provide boater safety and staff gauges to inform vessel operators of water depth and available clearance.



Source: DWR – Bay-Delta Office 2014

Figure 4-27. Elevation View of the Proposed BAFF at the Head of Old River

Upstream Migration

Upstream migration would be unimpaired by the BAFF. Upstream migrants such as green sturgeon and adult salmonids would be able to pass the junction by swimming around or under the barrier, or between the barrier frames. The barrier frames would be approximately one to two feet above the channel bottom, continuing to allow movement of upstream migrants under the barrier in expected flow conditions. Upstream migrants also could pass the junction by going in front or back of the barrier, because the barrier would be oriented at an angle instead of blocking the entire channel. No additional fish passage accommodation is proposed.

Deterrence

The BAFF deterrence ability or effectiveness at the HOR is somewhat understood. BAFF deterrence efficiencies for prior studies are presented in Chapter 3, section 3.3.1.4 of this report. These calculated efficiencies varied significantly. The most probable explanation for the variance is that: 1) smaller Chinook juveniles were used in the 2009 trials and they bore a much higher tag burden as a proportion of weight (AECOM 2014a), 2) much higher river flows existed during the 2010 study period than in 2009 and 3) the BAFF alignment in 2010 included the curved section at the downstream end. The median San Joaquin River flow was 2,721 cfs in 2010, and it was 1,158 cfs in 2009 during the study period (AECOM 2014a). The proposed alignment angle of 24 degrees without a curved downstream section, matching the 2009 study, suggests that a higher efficiency would be possible.

Flow and Tidal Effects

The BAFF performance would be affected by the expected HOR flow and tidal conditions. Depending on San Joaquin River flow levels, reverse flows (upstream during flood tide conditions) do occur at this site. During reverse flows, fish traveling up the San Joaquin River would unlikely be deterred and remain in the river, and they potentially could follow the Old River route. To address this issue, the barrier alignment would need to cross or block the entire Old River. However, such an alignment would not achieve the design objective of guiding fish away from the downstream scour hole under ebb tide conditions, and is not recommended for this site.

The BAFF would be a fixed structure that would not adjust to stage changes resulting from tidal effects. During low-stage conditions, some of the speakers and lights on the left bank would need to be turned off because of potential exposure resulting in overheating and failing. Also, in years where the water depth is not sufficient to pass boats over the BAFF frame, navigational aids must be placed along the barrier to prevent boats from traveling through the bubble curtain and direct boaters around the barrier.

Operations and Maintenance

Operations and maintenance of the BAFF would include the general activities described in “Bio-Acoustic Fish Fence” in Chapter 2, subsection 2.2.4.2, “Non-Physical Barriers.” and subsection 4.4.4.1 “Bio-Acoustic Fish Fence for the Georgiana Slough site.

BAFF operations would be ongoing 24 hours per day throughout the juvenile salmonid emigration periods. The BAFF air supply, light, and sound levels would be controlled and monitored from mechanical and computer systems located in the control house. Operation could be automated and minimal personnel time required to conduct regular barrier inspections. To avoid the potential for overheating and failure of any sound projectors and lights that were exposed during low-stage conditions, they would be turned off from the control house and would be turned back on when stage conditions returned to normal. Because no operable boat passage structure is proposed for the BAFF, no associated operations and maintenance would be necessary. The barrier would be removed during periods when juvenile salmonids are not expected to be traveling through the divergence. Removal/installation would require divers to make underwater connections/disconnections of the BAFF frames. Boat or shore mounted cranes would be required to lift the frames in and out of the water. The frames would then be transported and stored.

Regular preventative maintenance, checks, and services would be required for all mechanical and electrical systems. Some in-water work by divers would be required to replace in-water failed components (light or sound projector) or a damaged component. An inventory of specialty BAFF equipment (lights, sound projectors, and controllers) would be required to minimize replacement time. Debris buildup would be monitored and debris removed as necessary.

Construction and Implementation

Construction and implementation of the BAFF would involve the same general activities as described above in subsection 4.4.1.1 for a BAFF installed at Georgiana Slough. Because the HOR divergence has historically been the site of the annual DWR Temporary Barriers Program HOR spring and fall barriers, existing access roads should provide adequate site access. A total of four in-water piles and other necessary infrastructure components would be installed at the site and would stay in place year-round. Navigation aids would also be installed and left in place. A control house would be located on the left bank of the San Joaquin River to provide power, air, and controls for the BAFF components. Electrical power would be provided by dedicated buried or overhead power lines. BAFF in-water components, including frame assemblies and connecting lines, would be installed when needed. Depending on fisheries needs, BAFF removal and installation activities could occur multiple times during the year as described above under Operations and Maintenance.

This BAFF could be installed reasonably quickly (within two weeks) to respond to incoming information regarding the timing of an out-migration period. Once in place, the BAFF units could be turned off or removed or re-installed in a relatively short period in response to changing flow conditions, in particular low flow events.

Potential Environmental Impacts

Potential environmental impacts from installing and operating a BAFF at the HOR would be similar to the impacts described above in subsection 4.4.1.1 for a BAFF installed at Georgiana Slough. General environmental requirements and considerations for the HOR site are described in Appendix C, "Environmental Checklists"

The BAFF option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those unique to in-water and near shore actions. These unique impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the control house foundation and structure. Because the HOR divergence has historically been the site of the annual DWR Temporary Barriers Program spring and fall barriers, the site area is highly disturbed and only supports non-native, ruderal vegetation.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The BAFF operation would require seasonal installation of the BAFF frames prior to a migration event and removal of the frames following the event. Most installation/removal activities would be done by boat and barge, with minimal shore-based activities. Because the frame support piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the BAFF was operating would include minor changes to ambient noise levels due to the BAFF sound projectors, air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. There are no nearby residences at this time, so these impacts are expected to be insignificant. However, there is potential for some nearby urbanization, and these potential environmental issue should be looked at if that occurs. Regular system monitoring and servicing of equipment in the control house would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by divers then the associated equipment (and frame) may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

BAFF grand protection efficiencies for prior studies are presented in Chapter 3, section 3.3.1.4 of this report. The most probable explanation for the decreased protection efficiency in 2009 is that much lower river flows occurred during in the study period compared to 2010. The baseline piscivorous fish predation rates recorded during the study period in the absence of a BAFF are unknown; therefore, whether the BAFF would contribute to predation rates by fish on juvenile salmonids remains undetermined. Based on the 2009 and 2010 studies, a piscivorous fish predation congregation area exists in the scour hole just downstream from the divergence. Based on the 2009 and 2010 data, much of the gains accomplished by the BAFF's deterrence of juvenile Chinook salmon may have been offset by the piscivorous fish predators located in the scour hole (Reclamation 2012b). To address potential inland avian predation, anti-roosting wires could be installed on top of the floats to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for the BAFF at HOR is $6.8 M. The estimated annual operations and maintenance cost is $440,000. The estimated present worth cost based on a 50-year life is $17.7 M.

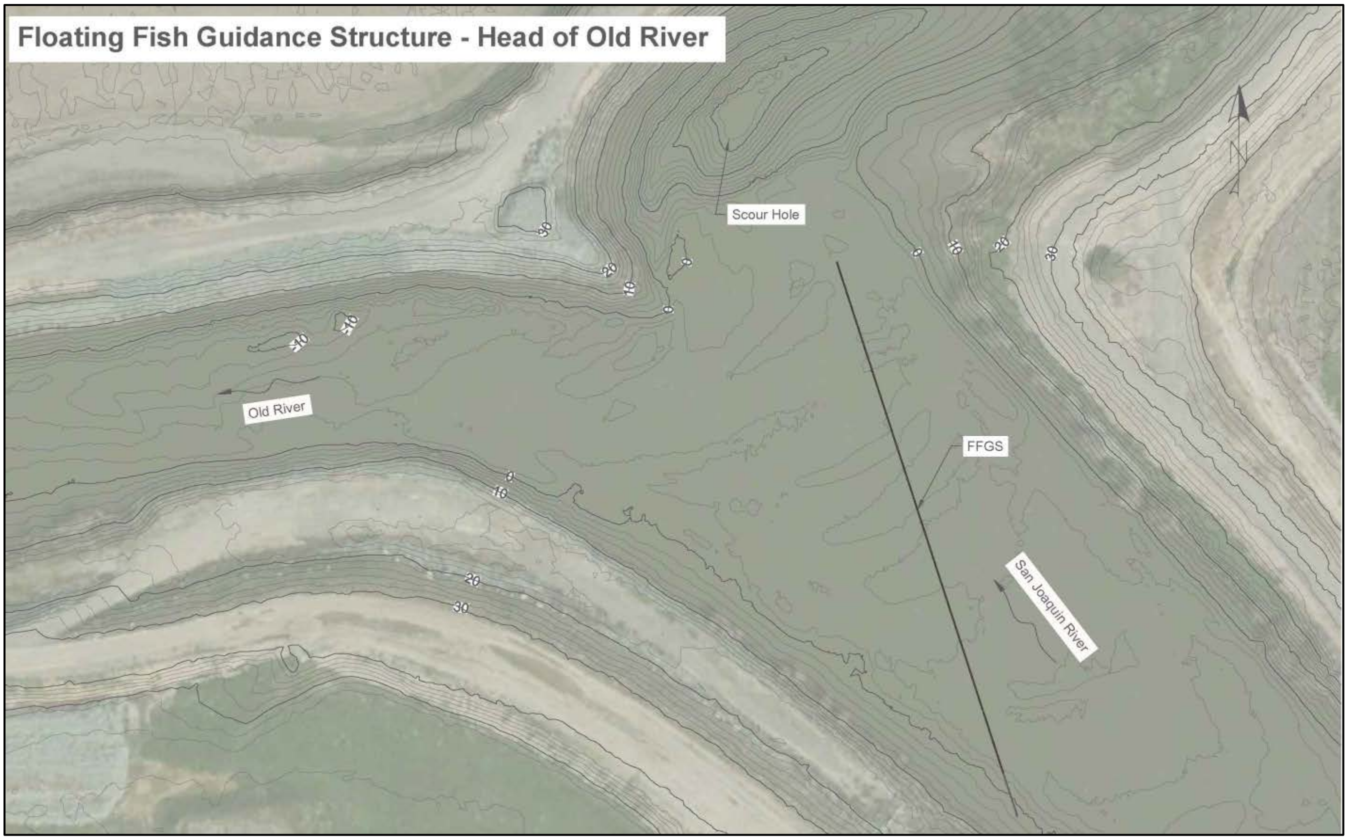
4.4.3.2 FLOATING FISH GUIDANCE STRUCTURE

Description

An FFGS at HOR would be installed just upstream from the divergence (Figure 4-28). The barrier would partially extend into the San Joaquin River, with boat passage provided just past and around the barrier's downstream terminus. The barrier would include 20-foot-wide and two-foot-deep flat plate steel sections, each mounted to floats and secured to support piles, and marked with navigation buoys and lights. The in-river components of the barrier, with the exception of the support piles and navigation aids, would be removed annually for general maintenance and to minimize potential levee impacts resulting from debris and sediment accumulation. These components would be stored at either an on-site or remote storage facility and would be re-installed before the juvenile salmonid migration period or as directed by regulatory agencies. See Appendix B for detailed drawings of the FFGS at the HOR.

Alignment

The proposed barrier would be positioned to guide juvenile salmonids away from Old River and allow them to continue their emigration along the San Joaquin River. The FFGS would be approximately 520 feet long and would be installed at a 24-degree angle relative to the river's flow direction. The downstream end of the barrier would extend farther downstream from the Old River divergence to guide juvenile salmonids away from the existing downstream scour hole and known piscivorous fish predation area (Figure 4-28).



Source: DWR – Bay-Delta Office 2014

Figure 4-28. Layout of the Proposed FFGS at the Head of Old River

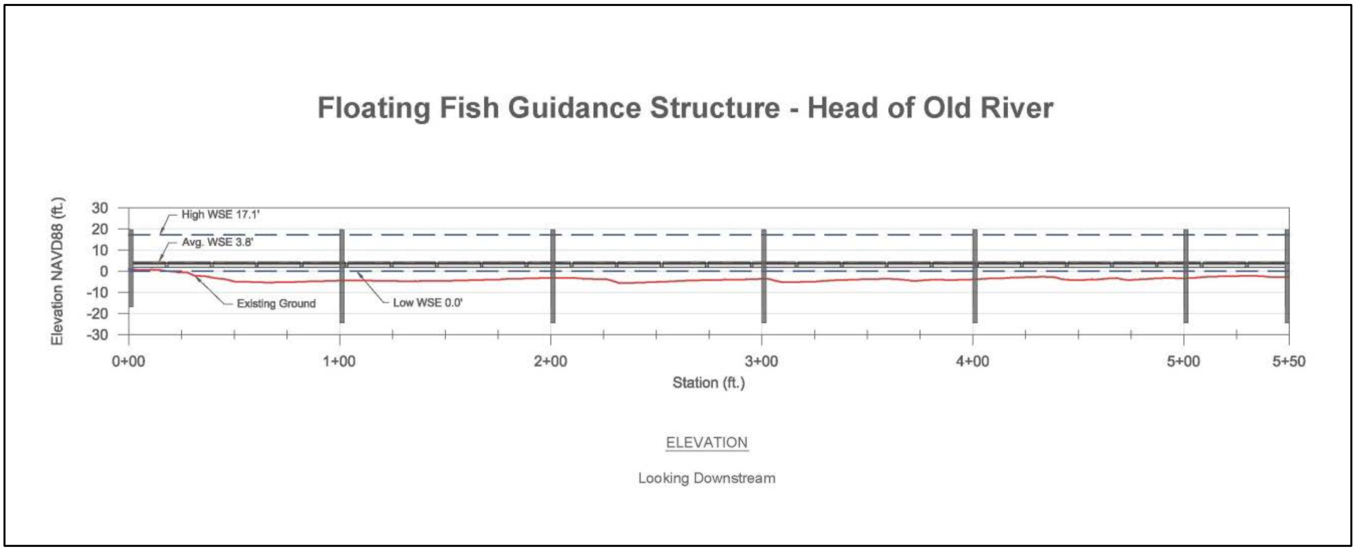
The 24-degree angle would create a gradual guidance to minimize juvenile salmonids effort to avoid the barrier and would minimize any undesirable hydrodynamic phenomena, such as down currents, eddies, and turbulence. The two-foot barrier depth would provide a minimum of one-foot depth of water under the barrier during historically low tide and flow conditions. During average stage conditions, there is 6 feet of clearance beneath the FFGS panels, which provides sufficient clearance for upstream migrant passage. To maximize fish deterrence, the barrier would start approximately 450 feet upstream from the HOR junction. This should provide sufficient time for juvenile salmonids to sense and react to the barrier. This junction experiences regular changes in stage, velocity, and flow direction because of tidal influences and changing hydrologic conditions. The FFGS is a semi-fixed floating structure; it is designed to self-adjust (vertically) to changes in tidal stage and river flow velocity.

Boat Passage

Boat passage would be accommodated by an approximate 75-foot opening at the barrier's downstream end (Figure 4-28). Navigational buoys and lights would be installed to provide boater safety. Because of the limited channel depths with only up to three feet of water during low-flow and low-stage events, larger vessels would only be able to navigate the junction during higher flow periods.

Upstream Migration

Upstream migration would be relatively unimpaired by the FFGS. Upstream migrants such as green sturgeon and adult salmonids would be able to pass the junction by swimming around or under the barrier. A minimum of one foot of the lower water column (during low stage) would be unobstructed, to allow free movement of upstream migrants (Figure 4-29). No additional fish passage accommodation is proposed.



Source: DWR – Bay-Delta Office 2014

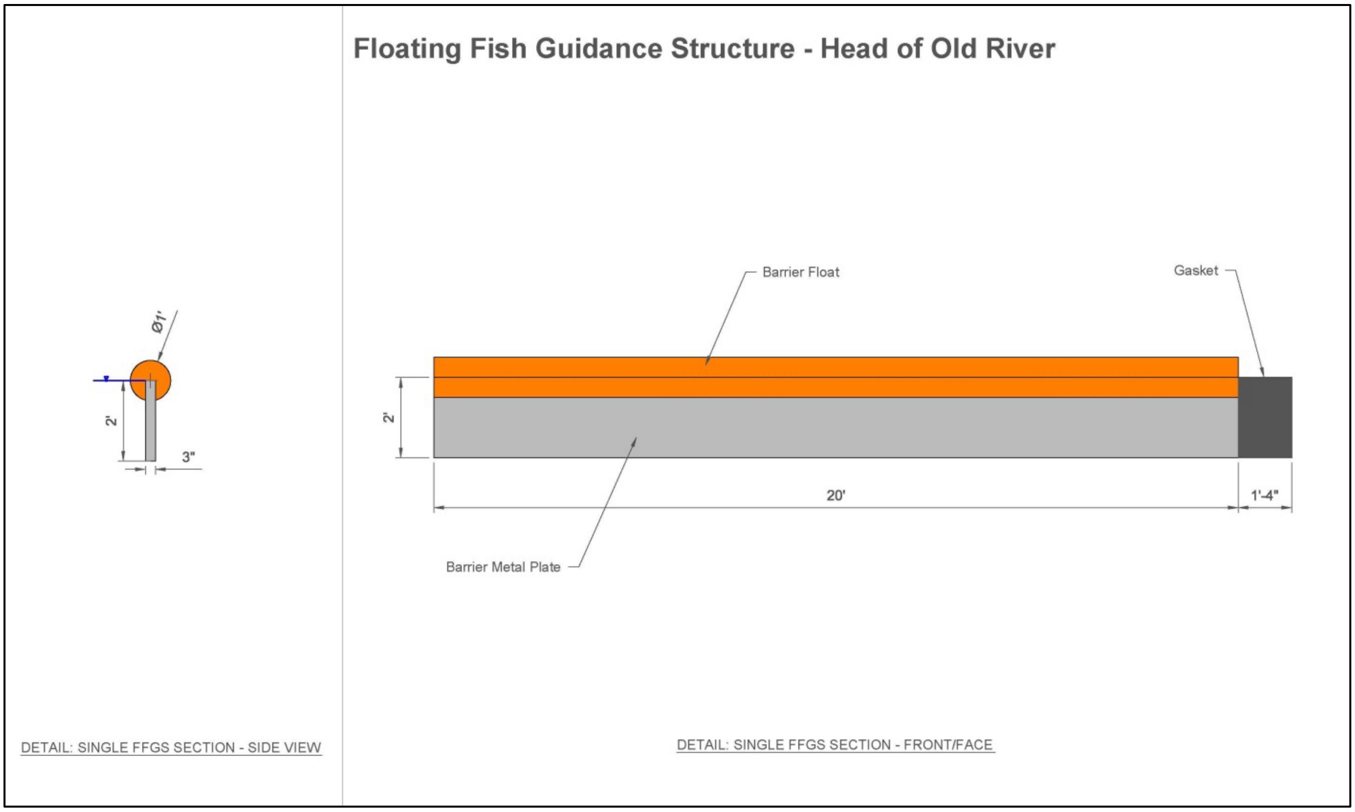
Figure 4-29. Elevation View of the Proposed FFGS at the Head of Old River

Deterrence

The FFGS deterrence ability or effectiveness at the HOR is not well understood. This type of deterrence technology has been used elsewhere but not at the HOR. Some studies show the deterrence efficiencies to be between 53 and 92 percent (Scott 2011), but not in an environment such as the HOR junction. This technology typically has been used in much lower flow velocities and in unidirectional flow, primarily upstream from dams and at openings of water intakes. The HOR site experiences a wide range of velocities and variable flows and even reverse flows caused by tidal influences and water exports.

Flow and Tidal Effects

The FFGS performance would be affected by flow and tidal conditions although its effects are anticipated to be minimal. The San Joaquin River experiences regular flow reversals, and during these reversals the FFGS would be more likely to guide juvenile salmonids into rather than away from Old River. To address this issue, the barrier alignment would cross or block the entire Old River. However, this alignment would not achieve the design objective of guiding juvenile salmonids away from the downstream scour hole under ebb tide conditions. The FFGS at HOR would minimize impacts on the existing flow patterns while providing optimal deterrence during ebb tides. The floats at the top of the barrier would allow the FFGS to continuously adjust to the changing stage (Figure 4-30). This would keep the barrier in the upper portion of the water column where the emigrating juvenile salmonids are expected to reside. It also would function so that the water column below the barrier would be open for the passage of water and non-targeted fish species.



Source: DWR – Bay-Delta Office 2014

Figure 4-30. Detailed Drawing of the 2-foot FFGS Panel

Operations and Maintenance

Operations and maintenance of the FFGS would include the general activities described in "Floating Fish Guidance Structure" in subsection 2.2.4.1, "Physical Barriers," The FFGS would have limited operations because it would be in a fixed position. After construction, it would remain in the same alignment until it was no longer needed and removed. Because no operable boat passage structure is proposed for the FFGS, no associated operation and maintenance would occur.

Construction and Implementation

This FFGS deterrence system would be primarily made up of modular components (e.g., FFGS panels and floats) and installed, operated, and removed as generally described in in "Floating Fish Guidance Structure" in subsection 2.2.4.1, "Physical Barriers." The FFGS initial construction would include the installation of four piles, 26 panels and floats, and navigation buoys and warning lights. The navigation warning lights would be battery powered. As noted above for the BAFF option, the HOR divergence has historically been the site of the annual DWR Temporary Barriers Program HOR spring and fall barriers so existing access roads should provide adequate site access. After the initial installation and operation, the modular components would be removed and the piles and connecting hardware would be left in place year-round. Each modular component then could be put back in place when needed, in less time than occurred during the initial installation. Navigation aids also would be left in place and would be used to alert boaters of the barrier system year-round. When removed, the FFGS modular components would be stored at a nearby off-site or on-site storage facility. Installation and removal activities would be performed by divers and workers using barge-mounted cranes.

This FFGS could be installed reasonably quickly (within a week) to respond to incoming information regarding the timing of an out-migration period. Once in place, the panels could be removed or re-installed in a relatively short period in response to changing flow conditions, in particular low flow events.

Potential Environmental Impacts

The FFGS option would have some potential environmental in-water and terrestrial impacts. The FFGS option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance. General environmental requirements and considerations for the HOR site are described in Appendix C, “Environmental Checklists”. Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include disruption of river sediment habitat and aquatic habitat during pile installation, disruption of riverine shore habitat during mobilization and general construction.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The FFGS operation would require seasonal installation of the FFGS panels prior to a migration event and removal of this equipment following the event. Most installation/removal activities would be done by boat and barge, with minimal shore-based activities. Because the system piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the FFGS was in operation would be insignificant. Occasional schedule and unscheduled servicing of the FFGS panels and navigation aids may be required. If the servicing could not be completed by boat or divers then the associated equipment may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

Based on the 2009 and 2010 BAFF studies, piscivorous fish congregate in the scour hole in the San Joaquin River just downstream from the divergence. The occurrence of predatory fish in the scour hole may result in high predation rates on outmigrant salmonids. Based on the 2009 and 2010 data, much of the gains accomplished by the BAFF’s deterrence of juvenile salmonids may have been offset by the piscivorous fish predators congregating in the scour hole (Reclamation 2012b). Implementation of the FFGS at the HOR may have an effect on piscivorous predator species’ assemblage, density, and behavior, but the extent of its influence on predator and prey interactions remains unstudied. Study results from the previously mentioned 2014 Georgiana Slough FFGS study are expected to provide some understanding of potential effects. To address potential inland avian predation, anti-roosting wires could be installed on top of the structure to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for the FFGS at HOR is $800,000. The estimated annual operations and maintenance cost is $130,000. The estimated present worth cost based on a 50-year life is $3.6 M.

4.4.3.3 SDIP Gates with Boat Lock and Fish Ladder

Description

As part of the South Delta Improvement Program (SDIP), DWR is considering a proposed Head of Old River Fish Control Gate structure. This gate would be placed in Old River near the San Joaquin River and could be used to meet the Action objectives. An Obermeyer (bottom hinged) style gate structure has been considered for this site (Figure 4-31) and is discussed in additional detail in subsection 2.2.4.1, “Physical Barriers,” “Overflow Gate.”

Source: SamMcCoy.com 2014

Figure 4-31. Typical Obermeyer Gates *Installed in the Kinta River, Perak, Malaysia*

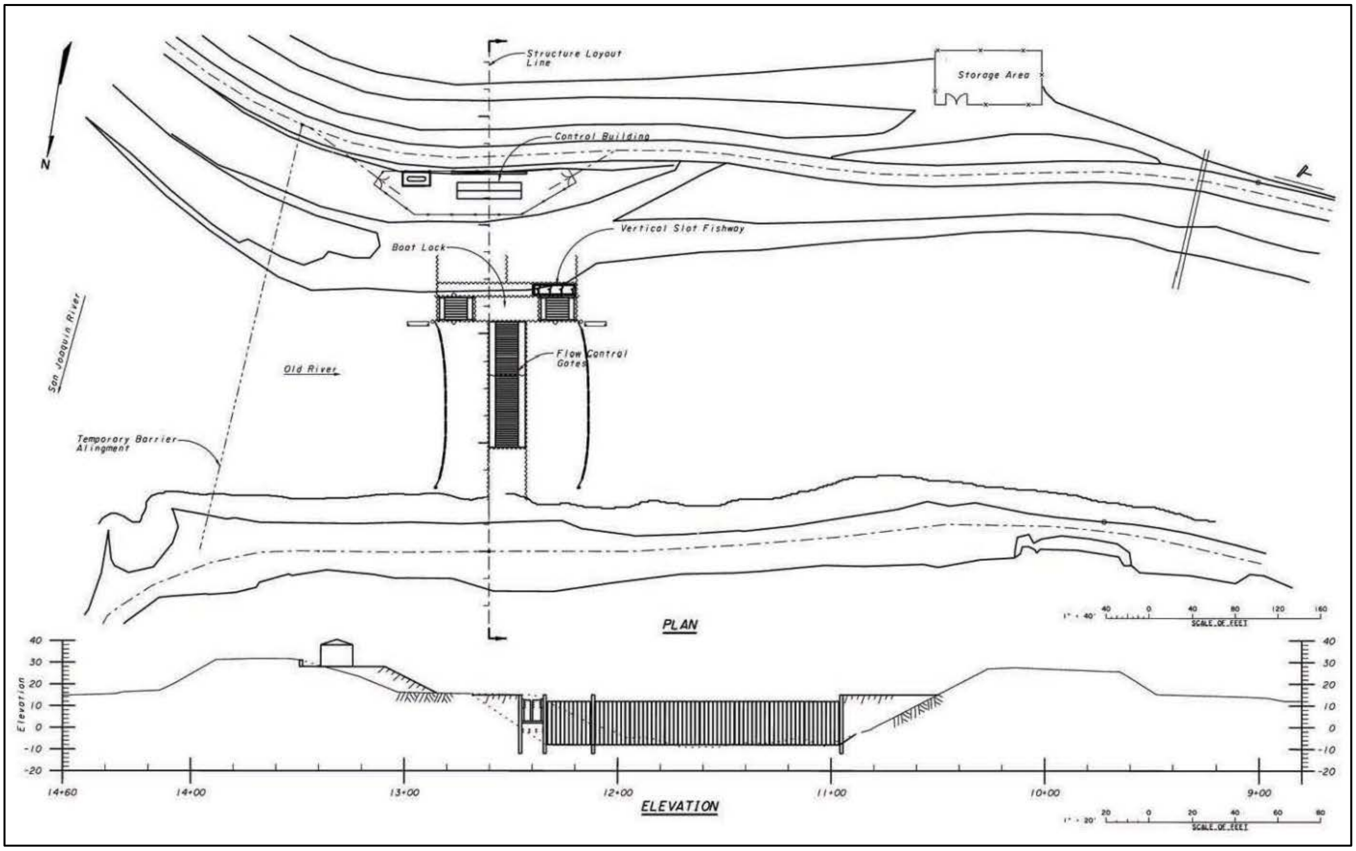
The SDIP HOR gate structure design includes a vertical slot fish ladder to aid in the upstream migration of adult salmonids and a boat lock to allow boat passage (Figure 4-32). The SDIP gate structure would contain seven individual gate sections with an approximate total length of 125 feet. Multiple gate sections would allow individual sections to be raised and lowered independently or simultaneously. Other components associated with the gate structure would include a debris barrier, warning signs, and navigation lights. A control house would be built to contain gate power and control systems including an air compressor system to provide air to the Obermeyer gates. See Appendix B for general detail drawings of the proposed gate and boat lock structure.

Alignment

The overall SDIP gate structure would be 210 feet long, 30 feet wide, with a top elevation of 15 feet (NAVD88). The proposed gate would be set back into the entrance of Old River and aligned approximately perpendicular to the adjacent levees. The gate location would ease construction and removal as well as minimize costs (Figure 4-32). This location is not ideal for fish deterrence, because the setback would create eddies, promote vegetation and habitat for predators, and collect debris.

Boat Passage

The SDIP gate structure would include a boat lock, 20 feet wide and 70 feet long, and would include two bottom-hinged (overflow) gates at each end. The gates would be opened to allow recreation boat passage, and closed during other times. Barges and larger vessels would be able to transit the structure when the main gates were lowered or in the open position.



Source: DWR 2014

Figure 4-32. Proposed SDIP Gate Structure at the Head of Old River

Upstream Migration

A vertical slot fish ladder would provide passage for adult salmon and other fish species. The approximate 40-foot-long and 8-foot-wide ladder would be constructed according to NMFS and USFWS guidelines. The fish ladder would have a slope of 10 percent, equally divided across the ladder steps from ladder entrance to exit; the number of steps would be determined by the maximum forebay to tailwater head differential. Stoplogs would be used to close the ladder when not in use. Sturgeon passage could be periodically accommodated when one or more main gate was opened or the boat lock gates were opened.

Deterrence

The SDIP gate structure would provide a high level of fish deterrence due to it being a full column physical barrier. This would be only accomplished if all gates are fully closed. If the gates are operated part-time or only blocking part of the channel, then the ability to deter fish would be less than the intended design. The exact relationship between gate operations and deterrence efficiency has not yet been quantified, but should be studied in detail before option is considered as a preferred solution.

Flow and Tidal Effects

The SDIP gate structure could potentially change existing flow and stage characteristics and negatively impact downstream water users. This impact could be significant or minor depending on how often and long the gates needed to remain closed to meet deterrence objectives. The potential impacts are not well understood and would need to be clarified with additional modeling of operational scenarios.

Operations and Maintenance

Operations and maintenance of the gate structure would involve the general activities described for the "Underflow Gate" and "Overflow Gate" subsection 2.2.4.2, "Physical Barriers" and as described above in subsection 4.4.1.4 for a gate structure installed at Georgiana Slough. The specifics regarding an operational strategy for this site could vary from completely open to completely closed, with the potential for operations in between that would allow partial flow. The actual gate operations would be determined by real-time operations, based on actual flows and/or fish presence.

Gate operations would be ongoing 24 hours per day throughout the juvenile salmonid emigration periods. The gate and boat lock operations would be controlled and monitored by a mechanical and computer system located in the control house. Operation could be automated and minimal personnel time required to conduct regular barrier inspections.

Regular preventative maintenance, checks, and services would be required for all mechanical and electrical systems. Some in-water work by divers would be required to service the gates or replace a damaged component. Debris buildup would be monitored and debris removed as necessary.

Construction and Implementation

The gate construction would include the installation of a reinforced concrete foundation (including abutments, boat lock channel, and fish ladder), seven main bottom-hinged gates, two boat lock bottom-hinged gates, a control house, underground or overhead power and poles, and navigation buoys and warning lights. Power and control systems for the gates would be installed inside the control house. In-water work would be done using both water and shore based equipment (e.g., dredgers, excavators, cranes, concrete pumpers). A cofferdam installation would be required to allow in-channel foundation excavation and placement of concrete and gate components. The control house and underground or overhead power and pole installation would require shore/bank access on the left channel levee. Installation would be done using conventional building and utilities equipment and methods.

This SDIP gate could be operated quickly (within hours) to respond to incoming information regarding the timing of the out-migration period. The SDIP gate could be opened, closed, or adjusted to provide deterrence or allow specific flow bypasses or large vessel passage in a short period.

Potential Environmental Impacts

The gate option would have an effect on the natural environment during installation of the permanent infrastructure and during operation and maintenance. As a permanent structure, the SDIP gate option would have an environmental impact. The land and in-water footprint would be much bigger than the other options at this site. This would include construction activities that would significantly disturb or modify the channel bottom and channel banks. As noted above for the other options, general environmental requirements and considerations for the HOR site are described in Appendix C, "Environmental Checklists." Additionally, environmental impacts of the SDIP gate structure are discussed in detail in Chapter 6 of the Environmental Impact Statement/Environmental Impact Report (DWR 2006). Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include significant disruption of river sediment habitat and aquatic habitat during in-channel excavation and foundation installation, and disruption of riverine shore habitat during mobilization, excavating and installation of the gate abutments, control house foundation and structure.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The gate operation would include raising and lowering the hinged gates, either to allow the flow of water, the passage of large boats, or the passage of sturgeon. The fish ladder would require no operation unless ladder maintenance was required and the ladder slide gates would be closed. Environmental impacts when the gates were in operation would include potential minor changes to ambient noise levels resulting from raising or lowering a gate. Regular system monitoring and servicing of the gates and equipment in the control house would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of the gates may be required. If the servicing could not be completed in water or by divers then the associated equipment may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

The proposed position of the SDIP gate potentially could set up hydraulic conditions ideally suited for piscivorous fish, avian, and aquatic mammal predators. In addition to deterring juvenile salmonids, the gate structure would be expected to be a potential location where piscivorous predatory fish and other species would congregate to hold, roost, and rest while preying upon passing juvenile salmonids and other fish species. The structure would cause flow disturbances that potentially could disorient juvenile salmonids and create eddy currents in which fish predators could hold. This could lead to a potential piscivorous predation increase at the junction. It should be noted that a known predation hotspot exists immediately downstream of the junction.

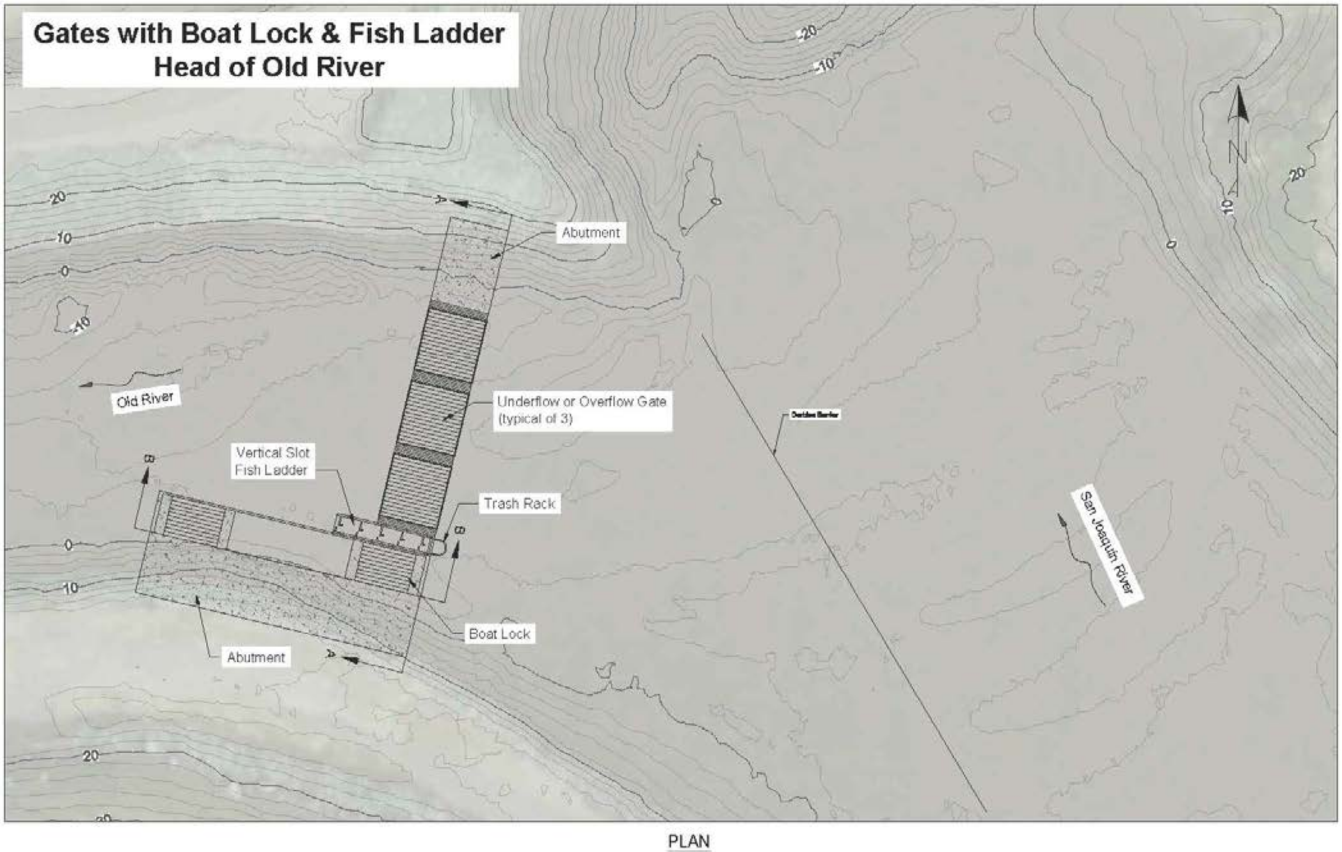
Cost

A rough order-of-magnitude estimated cost for the SDIP gate structure at HOR is $41.2 M. The estimated annual operations and maintenance cost is $200,000. The estimated present worth cost based on a 50-year life $44.8 M.

4.4.3.4 Gates with Boat Lock and Fish Ladder

Description

A gate structure at Head of Old River (HOR) similar to the SDIP gate structure would be placed closer to the San Joaquin River (SJR) at the entrance of Old River (Figure 4-33). Possible gate-styles include an overflow gate (weir gate) or an underflow gate (radial arm gate). Each is discussed in additional detail in subsection 2.2.4.1, “Physical Barriers,” “Overflow Gate.” A decision has not yet been made about what style of gate would be best suited for this site but will be made once more detailed information becomes available. A better understanding of how the flow and stage characteristics would impact water supply and water quality downstream of the structure would help in the selection of gate types and operational strategies.



Source: DWR – Bay-Delta Office 2014

Figure 4-33. Proposed Head of Old River Gate Structure Design.

The proposed gate structure would contain three individual gate sections with an approximate total length of 96 feet. Multiple gate sections would allow individual sections to be raised and lowered independently or simultaneously. Other components associated with the gate structure would include a debris barrier, warning signs, and navigation lights. A control house would be built to contain gate power and control systems including an air compressor system to provide air to the overflow gates. Figure 4-34 shows typical underflow (left) and overflow (right) gates. See Appendix B for general detail drawings of the proposed gate and boat lock structure.

Source: DWR 2014 and SamMcCoy.com 2014

Figure 4-34. Delta Cross Channel Radial Arm Gates on the left and Obermeyer Gates Installed in Kinta River, Perak Malaysia on the right.

Alignment

The proposed HOR gate structure would be positioned with the aim of guiding juvenile salmonids away from Old River allowing them to continue their emigration along the SJR (Figure 4-33). The gate would be placed at the entrance of HOR, oriented perpendicular to the direction of the flow entering Old River. The overall gate structure would be 222 feet long, 30 feet wide, with a top elevation of 19 feet (NAVD88).

Boat Passage

The gate structure would include a boat lock, 20 ft wide and 140 ft long, and would include two bottom-hinged (overflow) gates, one at each end. The gates would be opened for the passage of recreational boats and would be operable when the gates are closed. Barges and larger vessels would be too large to use the lock but would be able to pass the structure when the main gates were lowered or in the open position.

Upstream Migration

A vertical slot fish ladder is would provide passage for adult salmon and other fish species. The approximate 50-foot-long and 8-foot wide ladder would be constructed according to NMFS and USFWS guidelines. The fish ladder would have a slope of 10 percent, equally divided across the ladder steps from ladder entrance to exit; the number of steps would be determined by the maximum headwater to tailwater head differential. Stoplogs would be used to close the ladder when not in use. Sturgeon passage could be periodically accommodated when one or more main gate was opened or the boat lock gates were opened.

Deterrence Ability

The gate structure would provide a high level of fish deterrence due to it being a full column physical barrier. This would only be accomplished if all gates are fully closed. When the gates are only closed part-time or only blocking part of the channel, the ability to deter fish would be less than the intended design. The exact relationship between gate operations and deterrence efficiency has not yet been quantified, but should be studied in detail before this option should move to final design.

Flow/Tide Effects

The gate structure at HOR, when completely or partially closed to deter fish, would change existing flow and stage characteristics. This impact could be significant depending on how often and long the gats needed to remain closed to meet deterrence objectives. The potential impacts are not well understood and would need to be clarified with additional modeling of operational scenarios.

Operation and Maintenance

Operations and maintenance of the gate structure would involve the general activities described for the “Underflow Gate” and “Overflow Gate” subsection 2.2.4.2, “Physical Barriers” and as described above in subsection 4.4.1.4 for a gate structure installed at Georgiana Slough. The specifics regarding an operational strategy for this site could vary from completely open to completely closed, with the potential for operations in between that would allow partial flow. The actual gate operations would be determined by real-time operations, based on actual flows and/or fish presence.

Gate operations would be ongoing 24 hours per day throughout the juvenile salmonid emigration periods. The gate and boat lock operations would be controlled and monitored by a mechanical and computer system located in the control house. Operation could be automated and minimal personnel time required to conduct regular barrier inspections.

Regular preventative maintenance, checks, and services would be required for all mechanical and electrical systems. Some in-water work by divers would be required to service the gates or replace a damaged component. Debris buildup would be monitored and debris removed as necessary.

Construction and Implementability

The gate construction would include the installation of a reinforced concrete foundation (including abutments, boat lock channel, and fish ladder), three main bottom-hinged gates, two boat lock bottom-hinged gates, a control house, underground or overhead power and poles, and navigation buoys and warning lights. Power and control systems for the gates would be installed inside the control house. In-water work would be done using both water and shore based equipment (e.g., dredgers, excavators, cranes, concrete pumpers). A cofferdam installation would be required to allow in-channel foundation excavation and placement of concrete and gate components. The control house and underground or overhead power and pole installation would require shore/bank access on the left channel levee. Installation would be done using conventional building and utilities equipment and methods.

This gate could be operated quickly (within hours) to respond to incoming information regarding the timing of the out-migration period. The gate could be opened, closed, or adjusted to provide deterrence or allow specific flow bypasses or large vessel passage in a short period.

Environmental Impacts

The gate option would have a significant effect on the natural environment during installation of the permanent infrastructure and during operation and maintenance. As a permanent structure, the gate option would have an environment impact. The land and in-water footprint would be much bigger than the non-physical options at this site. This would include construction activities that would disturb or modify the channel bottom and channel banks. As noted above for the other options, general environmental requirements and considerations for the HOR site are described in Appendix C, “Environmental Checklists”. Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include significant disruption of river sediment habitat and aquatic habitat during in-channel excavation and foundation installation, and disruption of riverine shore habitat during mobilization, excavating and installation of the gate abutments, control house foundation and structure. Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The gate operation would include raising and lowering the hinged gates, either to allow the flow of water, the passage of large boats, or the passage of sturgeon. The fish ladder would require no operation unless ladder maintenance was required and the ladder slide gates would be closed. Environmental impacts when the gates were in operation would include potential minor changes to ambient noise levels resulting from raising or lowering a gate. Regular system monitoring and servicing of the gates and equipment in the control house would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of the gates may be required. If the servicing could not be completed in water or by divers then the associated equipment may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

The proposed position of the gate potentially could set up hydraulic conditions ideally suited for piscivorous fish, avian, and aquatic mammal predators. In addition to deterring juvenile salmonids, the gate structure would be expected to be a potential location where piscivorous predatory fish and other species would congregate to hold, roost, and rest while preying upon passing juvenile salmonids and other fish species. The structure would cause flow disturbances that potentially could disorient juvenile salmonids and create eddy currents in which fish predators could hold. This could lead to a potential piscivorous predation increase at the junction. It should be noted that a known predation hotspot exists immediately downstream of the junction. To address potential inland avian predation, anti-roosting wires could be installed on top of the structure to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for the gate structure at HOR is $43.2 M. The estimated annual operations and maintenance cost is $200,000. The estimated present worth cost based on a 50-year life is $46.8 M.

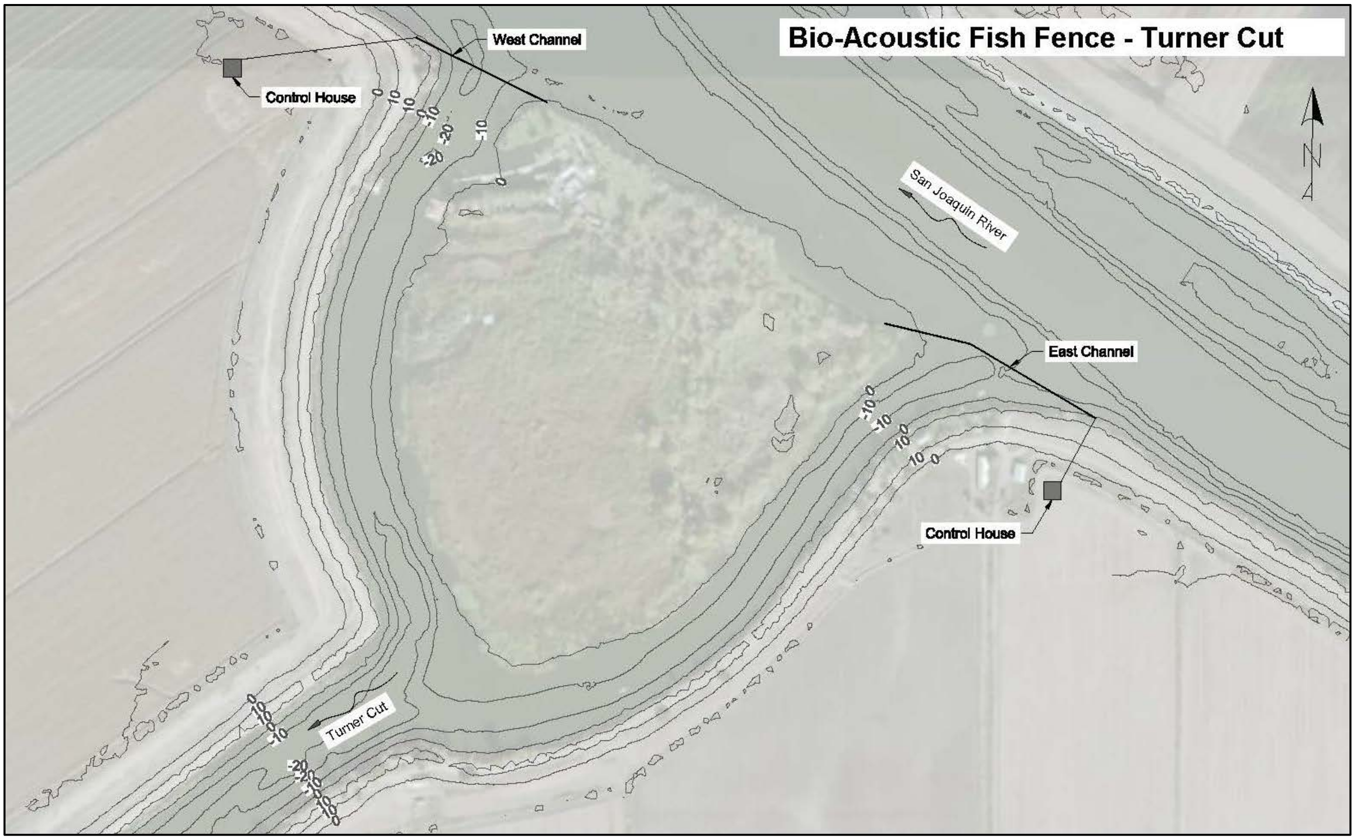
4.4.4 TURNER CUT

The engineering alternatives that were considered applicable for Turner Cut include Operable Gates, FFGS, IFFs, and BAFFs. Each engineering option was evaluated using the criteria set forth in the WRAM process, and a conceptual design was created for each option using the same criteria applied specifically to the Turner Cut site.

4.4.4.1 BIO-ACOUSTIC FISH FENCE

Description

The BAFF barrier at Turner Cut, actually two individual barriers, would be installed on the cut's East and West channels where they connect with the San Joaquin River (Figure 4-35). Each barrier would be set at an angle parallel to the direction of the river flow, taking advantage of the streamlines to guide juvenile salmonids pass the junctions. Separate control houses would house each barrier's power supply, control system, and air system and would be located on the landside of the adjacent levees for each barrier. Electrical power would be provided by dedicated underground or overhead power lines. The in-river components of the barriers, with the exception of support piles and navigation aids, would be annually removed for general maintenance and to minimize potential levee impacts resulting from debris and sediment accumulation. These components would be stored at either an on-site or remote storage facility and would be re-installed before the juvenile salmonid migration period or as directed by regulatory agencies. See Appendix B for detailed drawings of the BAFF at the Turner Cut.



Source: DWR – Bay-Delta Office 2014

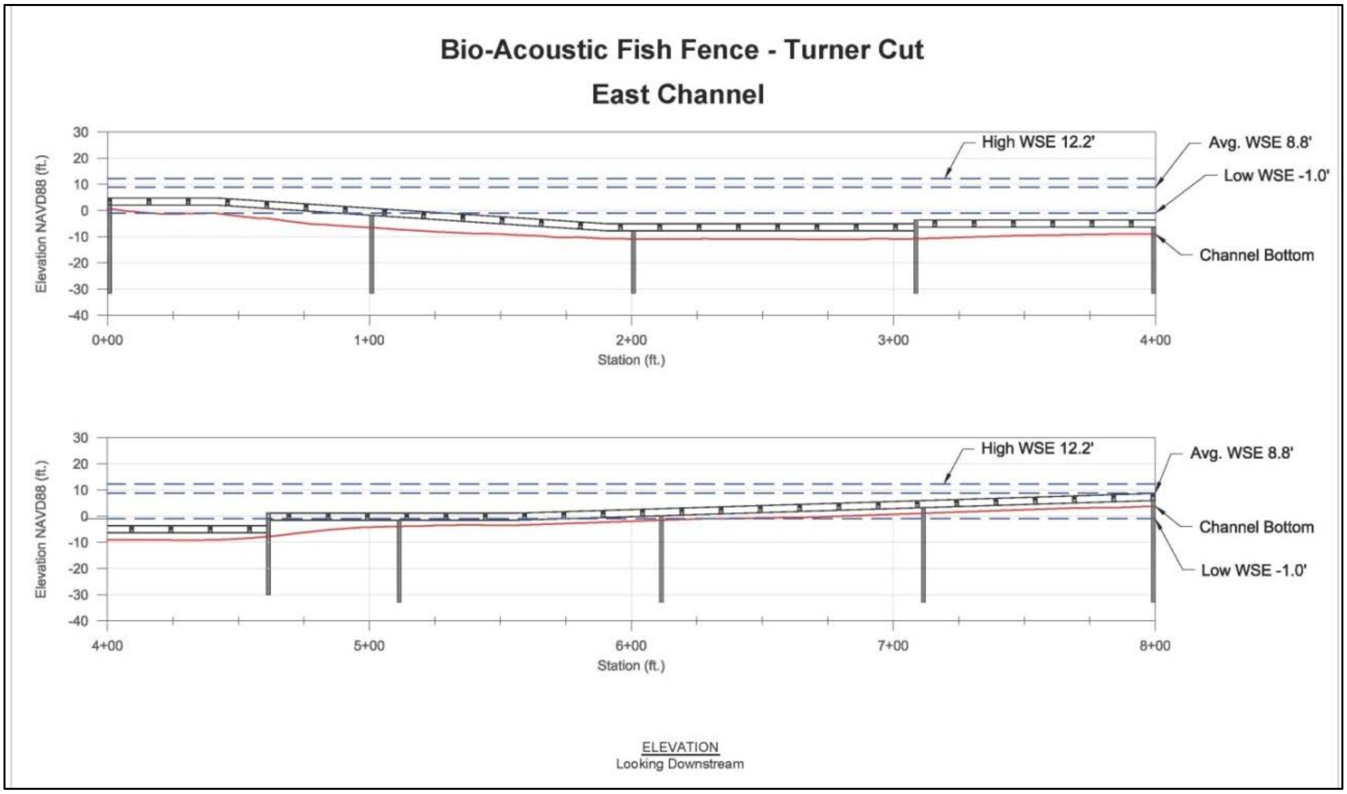
Figure 4-35. Layout of the Proposed BAFFs at Turner Cut

Alignment

The proposed barriers would be positioned to guide fish away from Turner Cut and allow them to continue their migration along the river. To maximize fish deterrence, each barrier would form a continuous barrier crossing the respective East and West channels. The BAFF's stimuli would create a zone of influence extending into the river where the flow streamlines would aid in guiding fish past the junctions. Because the barriers would be aligned parallel to these streamlines, the barriers are expected to deter fish during both positive and negative (reverse) flows. The angle-to-flow is almost always perpendicular at these locations; therefore, the optimal alignment and location for the barriers would be where the two channels meet the river. The proposed barrier on the East Channel would be approximately 800 feet long, and the barrier on the West Channel would be approximately 500 feet long (Figure 4-36 and Figure 4-37). Each barrier frame would be installed approximately two feet above the channel bottom, to provide a minimum depth of water over the barrier under low tide and flow conditions. The East Channel barrier would require 10 piles, and the West Channel barrier would require seven piles.

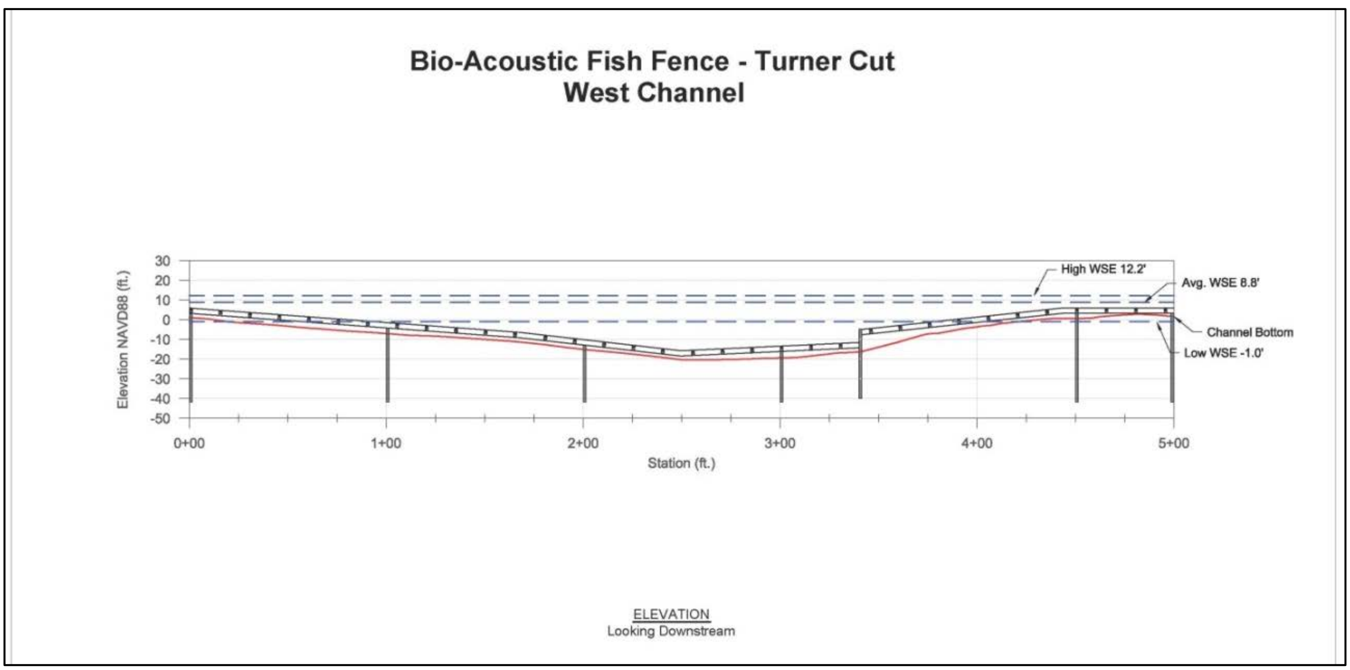
Boat Passage

Boat passage between the San Joaquin River and Turner Cut would be possible along most of each barrier. The non-physical nature of the BAFF would allow navigation for most recreational boats and small barges across the bubble curtain. Navigation would not be permitted near the shorelines where the BAFF frames would be too close to the water surface (Figure 4-36 and Figure 4-37).



Source: DWR – Bay-Delta Office 2014

Figure 4-36. Elevation View of the Proposed East Channel BAFF Alignment



Source: DWR – Bay-Delta Office 2014

Figure 4-37. Elevation View of the Proposed West Channel BAFF Alignment

Navigational buoys and lights would be installed to provide boater safety. Staff gauges indicating draft depth would be placed near each barrier to inform boaters about the clearance above the BAFF frame. If an emergency or construction vessel with a very large draft required passage, a 100-foot section of the BAFF could be temporarily removed.

Upstream Migration

Upstream migration would be relatively unimpaired with the BAFF. The barrier frames would be installed approximately two feet above the channel bottom, which would provide sufficient clearance under each barrier to allow movement of upstream migrants, such as green sturgeon and adult salmonids (Figure 4-36 and Figure 4-37). As described for a BAFF at Georgiana Slough in subsection 4.4.1, both sturgeon and adult salmonids are expected to have only a limited response or ignore the BAFF acoustic signals, lights and air bubbles. If this option is implemented, green sturgeon and adult salmonid behavior would be monitored to validate these assumptions

Deterrence

This technology has not been tested in an environment such as Turner Cut, which is heavily influenced by tidal forces. The deterrence ability or effectiveness of a BAFF at Turner Cut would depend on many factors including: the barrier alignment, direction of flow, water velocities, and juvenile salmonids swimming ability. The results from previous HOR and Georgina Slough BAFF studies have shown great promise in BAFF deterring juvenile salmonids. However, to validate BAFF effectiveness at this location additional monitoring of BAFF effectiveness is proposed.

Flow and Tidal Effects

The BAFF would have minimal effects on the naturally occurring flow and tidal conditions at Turner Cut. This is because water would flow around the piles and through the BAFF, and would not be blocked or redirected. Some minor eddies and changes in flow direction may occur in close proximity to the piles and frames, but the potential effects are expected to be minor. Also, the natural flow split would remain the same.

The tidal influences on velocity, flow direction, and stage would have minimal effect on the BAFF performance. The proposed design length and angle of the barrier would provide fish ample time to react to the stimuli throughout the majority of expected tidal velocities. During extremely high velocities, the BAFF bubble curtain would be expected to bend with the tidal flow, potentially diminishing the deterrence stimuli integrity although this effect on barrier performance barriers has not been quantified yet. The barriers would cross the entire junction, which would protect fish entering the area from both upstream and downstream. During extremely high stage events, the integrity of the bubble curtain possibly may diminish towards the upper portion of the water column as the bubbles disperse.

The BAFF is a fixed structure that does not adjust itself with stage changes caused by tidal effects. During low-stage conditions some of the speakers and lights close to the shoreline may be exposed. The exposed speakers and lights could overheat and fail and would need to be turned off, as described below under Operations and Maintenance.

Operations and Maintenance

Operations and maintenance of the BAFF would include those general activities described in Chapter 2, subsection 2.2.4.2, "Non-Physical Barriers." The BAFF would be operated 24 hours per day throughout juvenile salmonid emigration periods. The BAFF air supply, light, and sound levels would be controlled and monitored from mechanical and computer systems located in the control house. Operation could be automated and minimal personnel time required to conduct regular barrier inspections. The barriers would be removed during periods when juvenile salmonids are not expected to be traveling by the junction. Removal/installation would require divers to make underwater connections/disconnections of the BAFF frames. Boat or shore mounted cranes would be required to lift the frames in and out of the water. The frames would then be transported and stored.

At the Turner Cut location, the potential would exist for some sound projectors and lights to become exposed during low-stage conditions; they would be turned off from the control house and would be turned back on when stage conditions were suitable. Regular preventative maintenance, checks, and services would be required for all mechanical and electrical systems. Some in-water work by divers would be required to replace in-water failed components (light or sound projector) or a damaged component. An inventory of specialty BAFF equipment (lights, sound projectors, and controllers) would be required to minimize replacement time. Navigation aids, particularly lights, would require periodic inspection and servicing. Debris buildup would be monitored and debris removed as necessary.

Construction and Implementation

The initial construction for this option would include: building two control houses for the BAFF air compressors and lights, sound, and power/control systems; installing 17 piles to support the BAFF frames and navigation aids, and obtaining power from nearby overhead power lines. The control houses would be located on the San Joaquin River's left bank to provide power, air, and controls for the BAFF components in both the East Channel and West Channel barrier locations. To minimize construction time, potential environmental impacts, and wear and tear on the system, these components would stay in place year-round. Installation and connection of the modular components (e.g., air hoses, data cables, power cords, BAFF frames, and navigation makers) would occur prior to juvenile salmonid emigration periods which would be defined seasonally by regulatory agencies. These tasks would require the use of barge mounted equipment (crane, pile driver), work boats and divers. The control house and overhead power and pole installation would require shore/bank access near the downstream pile location. Installation would be done using conventional building and utilities equipment and methods.

The BAFF components could be installed reasonably quickly (within two weeks) to respond to incoming information regarding the timing of an out-migration period. Once in place, the BAFF frames could be removed or re-installed in a relatively short period in response to changing migration or flow conditions.

Potential Environmental Impacts

The BAFF option would have some potential environmental in-water and terrestrial impacts.

Potential environmental impacts from installing and operating a BAFF at Turner Cut would be similar to the impacts described above in subsection 4.4.1.1 for a BAFF installed at Georgiana Slough. General environmental requirements and considerations for the Turner Cut site are described in Appendix C, "Environmental Checklists"

The BAFF option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those unique to in-water and near shore actions. These unique impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the control house foundations and structures.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The BAFF operation would require seasonal installation of the BAFF frames prior to a migration event and removal of the frames following the event. Most installation/removal activities would be done by boat and barge, with minimal shore-based activities. Because the frame support piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the BAFF was operating would include minor changes to ambient noise levels due to the BAFF sound projectors, air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. There are no nearby residences so these impacts are expected to be insignificant. Regular system monitoring and servicing of equipment in the control building would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by divers then the associated equipment (and frame) may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

Implementation of this BAFF may have an effect on piscivorous predator species' assemblage, density, and behavior, but the extent of its influence on predator and prey interactions remain unstudied. During the 2011 and 2012 Georgiana Slough Non-Physical Barrier BAFF studies, piscivorous fish predators were caught and tagged, and their movement and interaction with tagged juvenile Chinook salmon were analyzed. The results of these predator studies suggest that survival of juvenile Chinook salmon was independent of the BAFF operation. However, baseline piscivorous predator species' assemblages and densities would be established to address any potential predators present in the Turner Cut area.

Cost

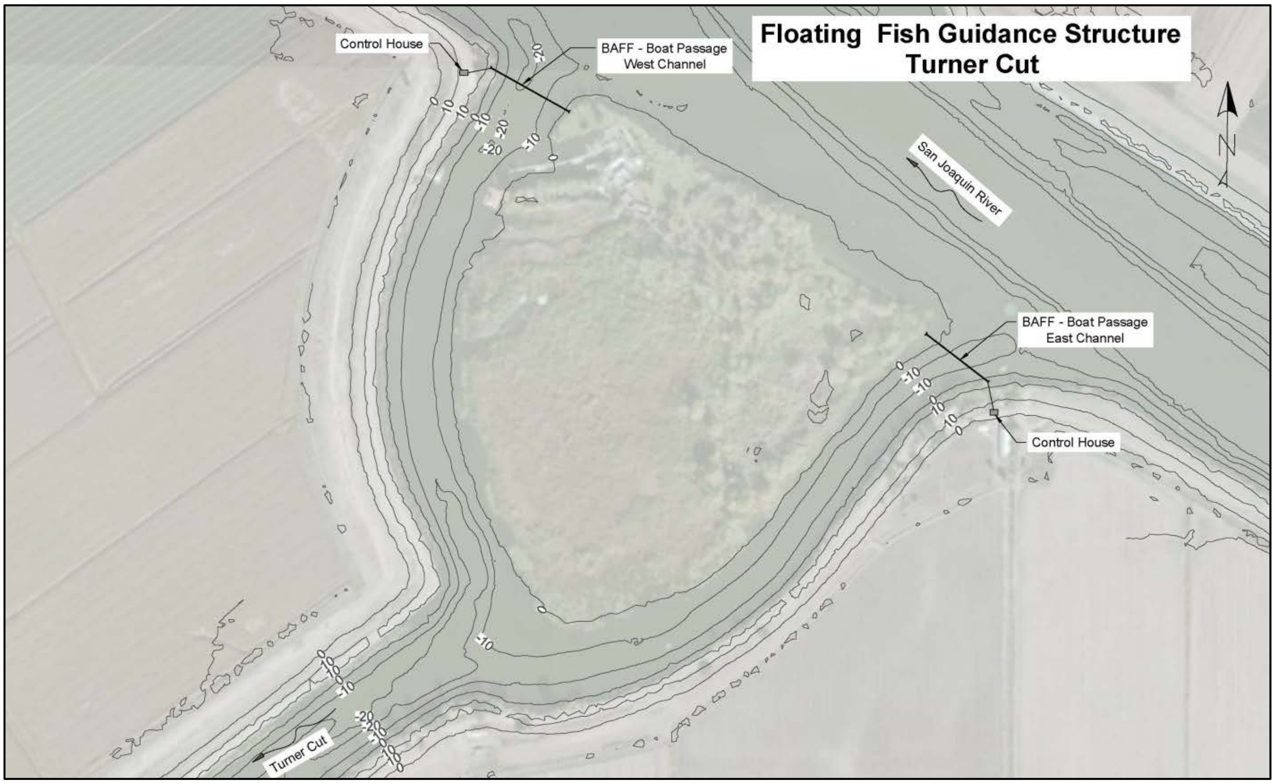
A rough order-of-magnitude estimated cost for the BAFF at Turner Cut is $18.5 M. The estimated annual operations and maintenance cost is $860,000. The estimated present worth cost based on a 50-year life is $40.0 M.

4.4.4.2 FLOATING FISH GUIDANCE STRUCTURE

Description

Two FFGS barriers at Turner Cut would be installed where the two junctions lead into Turner Cut (Figure 4-38). Two barriers would be set at angles parallel to the direction of the river flow, taking advantage of the streamlines to guide fish pass the East and West Channel junctions. The barriers would include 20-foot-wide and 5- or 10-

foot-deep (depending on stage) flat-plate steel sections, each mounted to floats and secured to support piles, and navigation buoys and lights. A section of a BAFF would be incorporated into the design to provide boat passage. A control house would house the BAFF's above-water components, and it would be located on the landside of the adjacent levee. Electrical power would be provided by dedicated overhead power lines. The in-river components of the barriers, with the exception of support piles and navigation aids, would be removed annually for general maintenance and to minimize potential levee impacts resulting from debris and sediment accumulation. These components would be stored at either an on-site or remote storage facility and would be re-installed before the juvenile salmonid migration period or as directed by regulatory agencies. See Appendix B for detailed drawings of the FFGS at the Turner Cut.

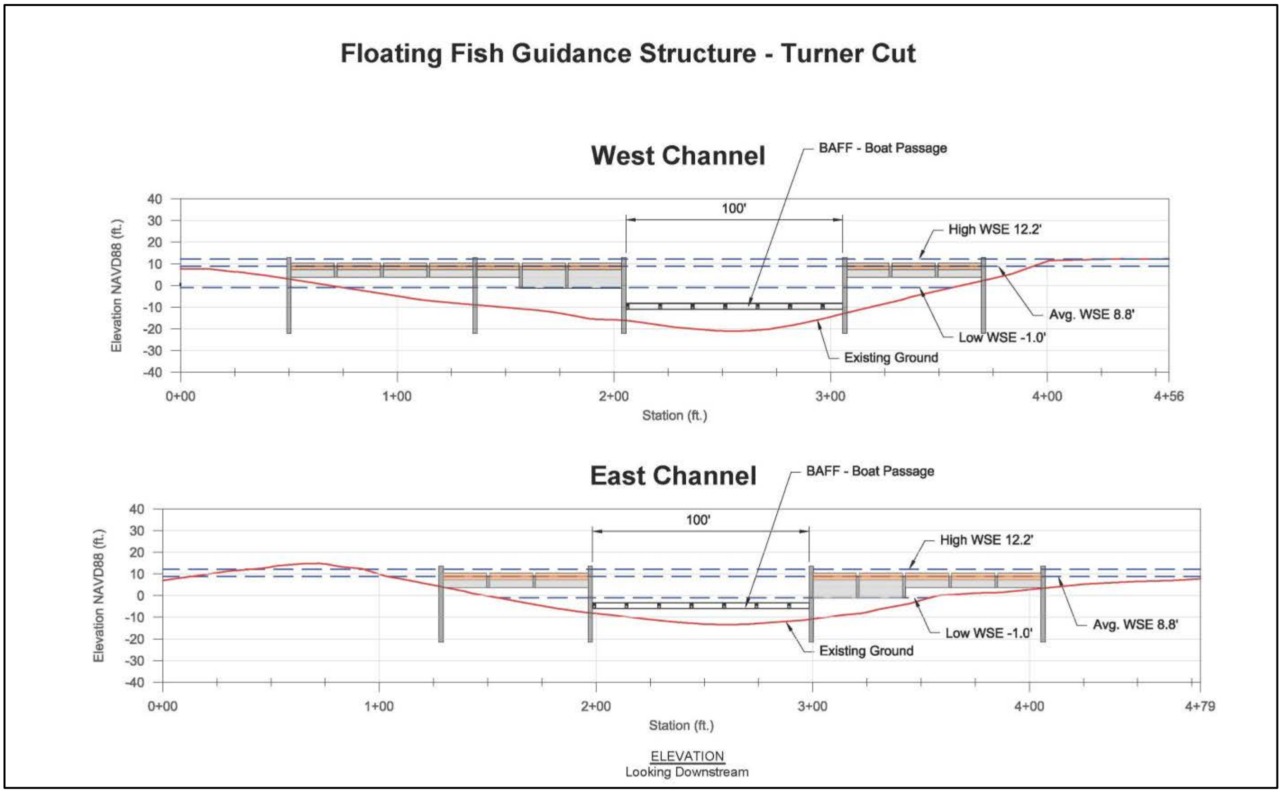


Source: DWR – Bay-Delta Office 2014

Figure 4-38. Layout of the Proposed FFGS at Turner Cut

Alignment

The proposed FFGS (and BAFF) barrier alignments at Turner Cut would be made up of two different alignments, one on both the East and West channels. To maximize juvenile salmonid deterrence, continuous barriers are proposed across the two junctions. The two barrier alignments would be positioned to guide juvenile salmonid away from Turner Cut and allow them to continue their migration along the river. Flow direction at this location is complex and dynamic. The angle-to-flow is almost always perpendicular to where a barrier could be placed at the single channel location; therefore, the optimal alignment and location for the barriers would be at the location where the two channels converge on the river. The FFGS at the East Channel would be approximately 275 feet long, and the FFGS at the West Channel would be approximately 320 feet long (Figure 4-39).



Source: DWR – Bay-Delta Office 2014

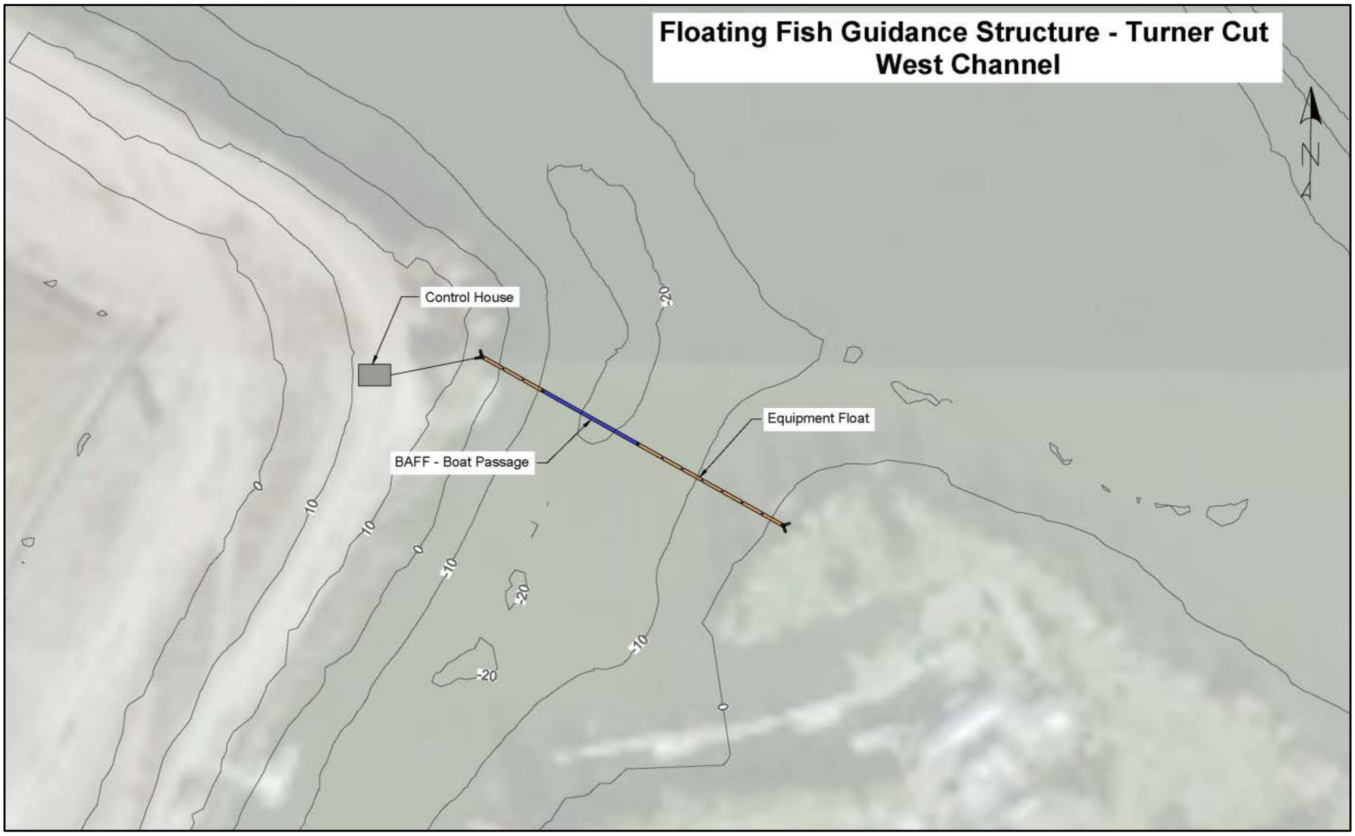
Figure 4-39. Elevation View of the Proposed FFGSs and the Barrier Depth at Turner Cut

The BAFF's frames would be installed at least two feet above the channel bottoms located at the deepest sections of the FFGS's alignments, to provide a minimum depth of water over the barriers under low tide and flow conditions for boat passage. The East Channel alignment would require four piles, and the West Channel alignment would require five piles.

This junction experiences regular changes in stage, velocity, and flow direction because of tidal influences and changing hydrologic conditions. Because the FFGSs are semi-fixed floating structures, they are designed to self-adjust (vertically) to changes in stage.

Boat Passage

Boat passage would be accommodated through an approximately 100-foot opening in the FFGSs. To maintain continuous fish deterrence along the entire alignment, a 100-foot section of BAFF would be placed in the openings (Figure 4-40). The openings would be in the middle of the barriers where the channels are the deepest. This would minimize impacts on navigation resulting from low stage and boats with large drafts. The BAFF system would be operated around-the-clock. Navigational buoys and lights would be installed to provide boater safety.



Source: DWR – Bay-Delta Office 2014

Figure 4-40. Plan View of the Proposed FFGS at the West Channel of Turner Cut

Upstream Migration

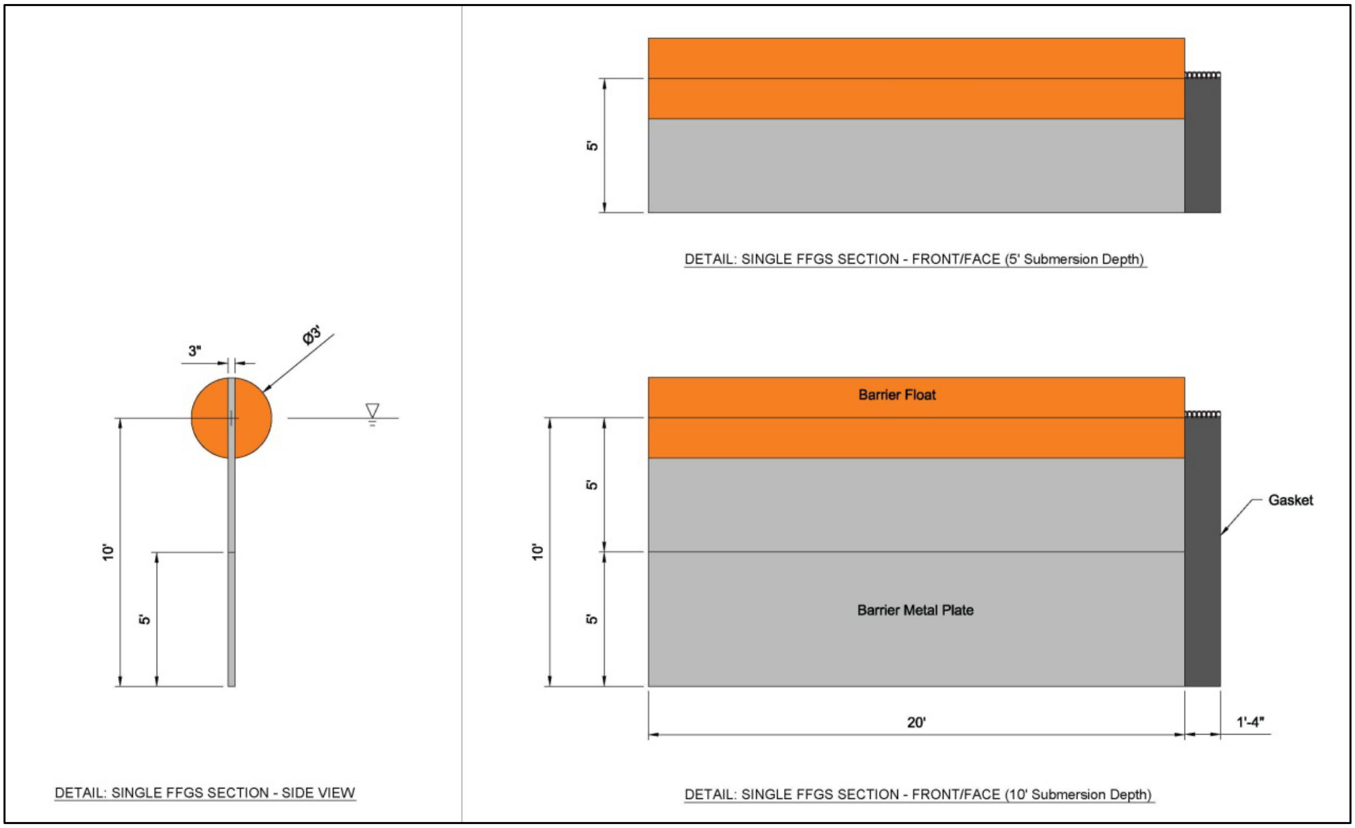
Upstream migration would be relatively unimpaired with the FFGSs. Upstream migrants such as green sturgeon and adult salmonids would be able to pass the junction freely by swimming under the barrier. A minimum of 50 percent of the lower water column (depending on stage) would be unobstructed and would allow free movement for upstream migrants (Figure 4-39). The BAFF section of the barriers could also be used for passage by non-targeted fish species. A minimum two foot clearance would exist under each BAFF frame, but non-target fish species may also pass through the bubble curtains as well.

Deterrence

The potential FFGS's deterrence ability or effectiveness at Turner Cut is not well understood. This type of deterrence technology has been used elsewhere but not at Turner Cut. Some studies show the deterrence efficiencies to be between 53 and 92 percent (Scott 2011), but not in an environment such as Turner Cut. The technology typically has been used in much lower water velocities and in unidirectional flow, primarily upstream from dams and at openings of water intakes. The Turner Cut site experiences a wide range of velocities and variable flows and reverse flows resulting from tidal influences. However, to validate the FFGS's effectiveness at this location, testing and monitoring would be needed.

Flow and Tidal Effects

The FFGSs would have minimal effect on flow and tide stages. The FFGSs at Turner Cut would minimize impacts on the existing flow patterns while providing optimal deterrence during ebb tides. The San Joaquin River experiences regular flow reversals (upstream during flood tide conditions).the proposed FFGS alignment would account for those conditions. During reverse flows, fish moving up the river would be deterred by the FFGSs and would stay in the river. The floats at the top of the barriers would continuously adjust to the changing stage (Figure 4-41). This would keep the barriers in the upper portion of the water column where the out-migrating fish are expected to reside. It also would keep the water column below the barriers open for the passage of water and non-targeted fish.



Source: DWR – Bay-Delta Office 2014

Figure 4-41. Detailed Drawing of the 5-foot and 10-foot FFGS Panels

Operations and Maintenance

Operations and maintenance of the FFGSs would include the general activities described in the subsection titled "Floating Fish Guidance Structure" in Chapter 2, Section 2.2.4.1, "Physical Barriers." FFGS operations would be limited because the barrier would be in a fixed position. After barrier placement, including the BAFF, the barriers would remain in the same alignment. A change from 5-foot to 10-foot panels may be necessary if a substantial change in stage should occur. BAFF operations would be ongoing 24 hours per day throughout the juvenile salmonid emigration periods. The BAFF air supply, light, and sound levels would be controlled and monitored from a mechanical and computer system located in the control houses. Operation could be automated and minimal personnel time required to conduct regular barrier inspections. The barriers would be removed during periods when juvenile salmonids are not expected to be traveling through the divergence. Removal (and re-installation) would require in-water work by divers to disconnect (and re-connect) the FFGS panels and BAFF frames. The panels and frames would require the use of boat or shore mounted cranes to lift the panels and frames from (into the water). The panels and frames would then be transported and stored.

Construction and Implementation

The FFGSs deterrence system primarily would have modular components, and they would be installed, operated, and removed as generally described in the subsection titled "Floating Fish Guidance Structure" in Chapter 2, Section 2.2.4.1, "Physical Barriers." The FFGS initial construction would include the installation of piles, panels and floats, BAFF frames (and connecting cables and hoses), a control house, overhead power and poles, and navigation buoys and warning lights in or on both the East and West channels. Power and control systems as well a compressor system for the BAFF would be installed inside each control house. This FFGS deterrence system would be made up primarily of modular components (e.g., FFGS panels and floats, BAFF frames, and cabling). This would make it possible to install or remove the system relatively quickly (within a week) in response to or following juvenile salmonid emigration. To minimize construction time and potential environmental impacts, the modular components would be secured to permanent piles and brackets. In-water work would be done using barges, cranes, and divers. The control house and overhead power and pole installation would require shore/bank access near the downstream pile location. Installation would be done using conventional building and utilities equipment and methods.

The FFGSs (and BAFFs) could be installed reasonably quickly (within a week) to respond to incoming information regarding the timing of an out-migration period. Once in place, the panels and BAFF frames could be removed or re-installed in a relatively short period in response to changing flow conditions, in particular low flow events.

Potential Environmental Impacts

The FFGS option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance As noted above for the BAFF option, general environmental requirements and considerations for the Turner Cut site are described in Appendix C, "Environmental Checklists", Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and BAFF frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the control house foundation and structure.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The FFGS and BAFF operation would require seasonal installation of the FFGS panels and BAFF frames prior to a migration event and removal of this equipment following the event. Most installation/ removal activities would be done by boat and barge, with minimal shore-based activities. Because the system piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the FFGS was in operation would be insignificant. Impacts when the BAFF was operating would include minor changes to ambient noise levels due to the BAFF sound projectors and the occasional air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. Regular system monitoring and servicing of equipment in the control house would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of the FFGS panels and BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by boat or divers then the associated equipment may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

Implementation of the FFGSs at Turner Cut may have an effect on piscivorous predator species' assemblage, density, and behavior, but the extent of its influence on predator and prey interactions remains unstudied. Study results from the previously mentioned 2014 Georgiana Slough FFGS study are expected to provide some understanding of potential effects. To address potential inland avian predation, anti-roosting wires could be installed on top of the floats to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for the FFGS at Turner Cut is $7.2 M. The estimated annual operations and maintenance cost is $390,000. The estimated present worth cost based on a 50-year life is $20.0 M.

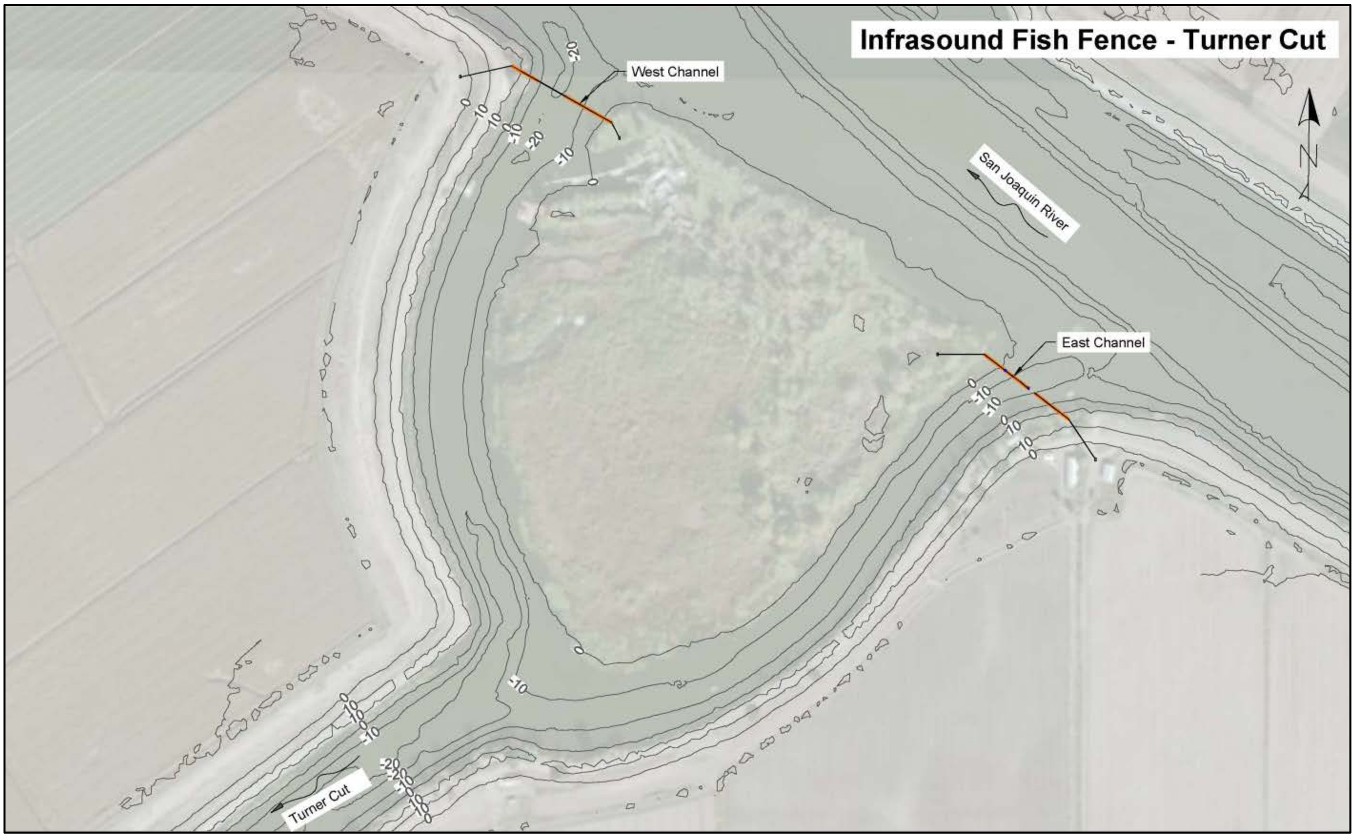
4.4.4.3 INFRASOUND FISH FENCE

Description

The IFF with two individual barriers at Turner Cut would be installed on the East Channel and West Channel, where they connect with the river (Figure 4-42). A small opening in the East Channel IFF barrier and a BAFF included in the West Channel barrier would provide for boat passage. Each barrier would be set at an angle parallel to the direction of the river flow, taking advantage of the streamlines to guide juvenile salmonid pass the junctions. See Appendix B for detailed drawings of the IFFs at Turner Cut. For each barrier, a continuous line of cylindrical buoys would wrap around the entire IFF alignment, except the boat passages, so that all of the surface-mounted power, data, and air lines would be protected from debris. Separate control houses housing the barrier power supplies and controls would be located on the landsides of the adjacent levees for each barrier. Electrical power would be provided by dedicated overhead power lines. The in-river components of the barriers, with the exception of support piles and navigation aids, would be removed annually for general maintenance and to minimize potential levee impacts resulting from debris and sediment accumulation. These components would be stored at either an on-site or remote storage facility and would be re-installed before the juvenile salmonid migration period or as directed by regulatory agencies.

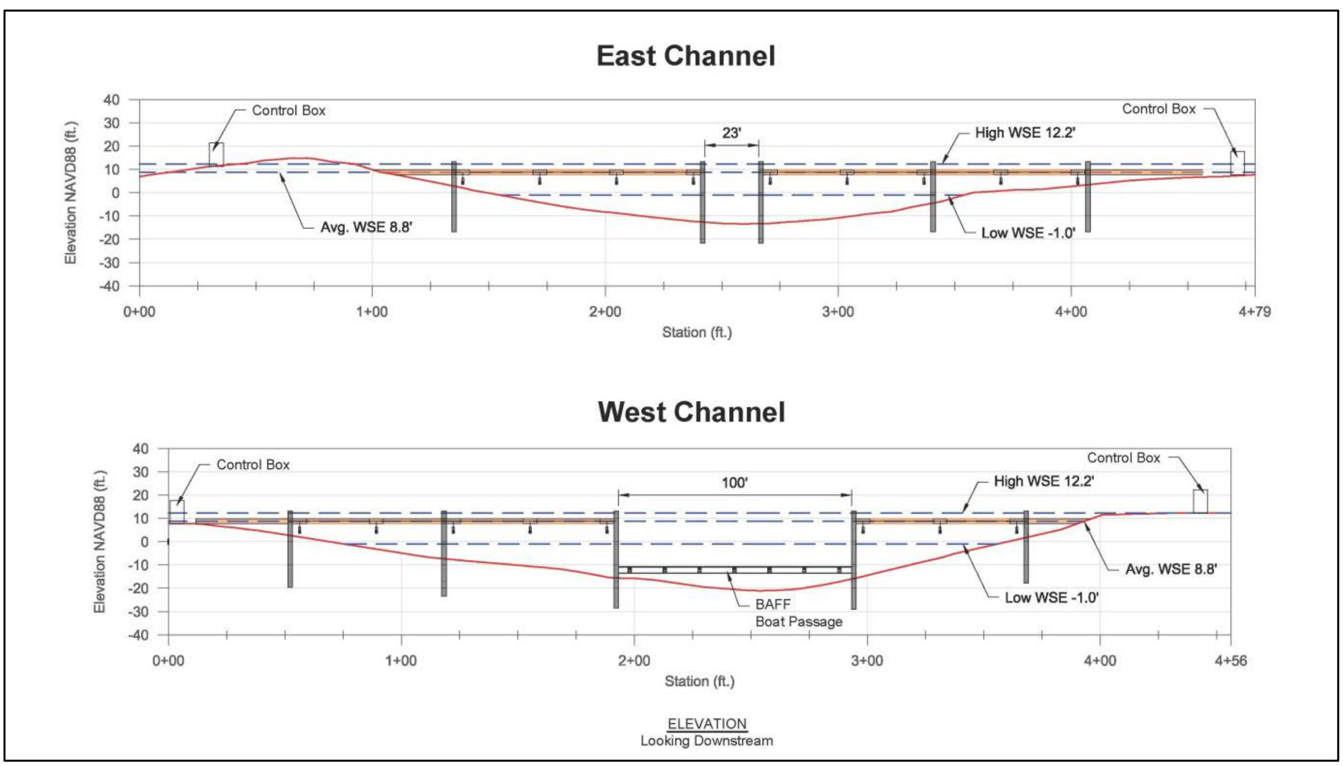
Alignment

The proposed IFF would comprise two barriers, one barrier installed on the East Channel and the other barrier installed on the West Channel. The two barriers would be positioned to guide juvenile salmonid away from Turner Cut, allowing them to continue migrating along the river. To maximize juvenile salmonid deterrence, each barrier would form a continuous alignment across its respective channel. The angle-to-flow is almost always perpendicular at this location; therefore, the optimal alignment and location for the barriers would be where the two channels meet the river. The proposed barrier on the East Channel would be approximately 275 feet long, and the barrier on the West Channel would be approximately 320 feet long (Figure 4-43). The East and West channel barriers would each require five piles.



Source: DWR – Bay-Delta Office 2014

Figure 4-42. Layout of the Proposed IFF at Turner Cut



Source: DWR – Bay-Delta Office 2014

Figure 4-43. Elevation View of the Proposed East Channel and West Channel IFF Alignment

Boat Passage

Boat passage between the San Joaquin River and Turner Cut would be provided at both of the barrier locations. Boat passage in the East Channel would be provided through a 23-foot opening, mainly intended for the passage of recreational boats. Boat passage in the West Channel would be provided over a 100-foot BAFF, mainly intended for the passage of larger vessels such as barges for construction or emergency purposes (Figure 4-43). The larger boat passage has been proposed for the West Channel barrier where the water is the deepest. This would minimize impacts on navigation resulting from low stage and boats with large drafts. Navigational buoys and lights would be installed to provide boater safety. Staff gauges indicating draft depth would be placed near the barrier to inform boaters of the clearance above the BAFF frame. This type of boat passage system would work around the clock.

Upstream Migration

Upstream migration would be relatively unimpaired by the IFF option. The manufacturer claims that only small juvenile fish are known to react to infrasound, thus larger fish are not affected because their otoliths are not as sensitive. Adult salmonids and green sturgeon would pass through the junction undisturbed. A minimum two-foot clearance would be under the BAFF frame would be provided for passage, but non-targeted fish may actually pass through the bubble curtain as well.

Deterrence

This technology has been tested both in the laboratory and in the field; however, it has not been tested on Pacific juvenile salmonids or in an environment similar to Turner Cut. The deterrence ability or effectiveness of an IFF at Turner Cut would depend on many factors. The barrier alignments, direction of flow, water velocities, and swimming ability of the fish are some key factors that would be considered for the design. The results from previous laboratory and field tests have shown promise in deterring fish, but the IFF would need to be studied at this location with a focus on juvenile salmonids.

Flow and Tidal Effects

The IFF would have minimal effects on the naturally occurring flow and tidal conditions at Turner Cut. This is because the IFF would have very little in-water infrastructure and its relatively small mechanical components (IFF units and floats and BAFF section) would have a negligible influence on the natural movement of water. The IFF is expected to be effective under a wide range of tidal flows, including tidal reverse and low flows when water velocities will be low in comparison to salmonid swimming speeds. Similar to the BAFF, the IFF is expected to be less effective during high flow periods when water velocities exceed salmonid swimming speeds and the water direction is more perpendicular to the barrier alignment. The floats attached to each of the units would constantly adjust to the changes in stage. This would keep the barriers in the upper portion of the water column where the out-migrating fish are expected to reside. If low stage conditions occur, the IFF has the capability to have individual units turned off or even removed, to allow proper operation while maintaining a continuous system of deterrence.

A system would be put in place to monitor and forecast changes in stage at locations along the barrier where the potential existed for the need to turn off a unit or remove it.

Operations and Maintenance

Operations and maintenance of the IFF would include the general activities described in the subsection titled "Infrasound Fish Fence" in Chapter 2, subsection 2.2.4.2, "Non-Physical Barriers." and as described in Section 4.4.1.3 "Infrasound Fish Fence" for an IFF at Georgiana Slough. The IFF (and BAFF) would be operated 24 hours per day throughout juvenile salmonid emigration periods. Operation would be automated but could also be controlled remotely or manually. The barriers would be removed during periods when juvenile salmonids are not expected to be traveling by the junction. Regular preventive maintenance would be performed on all equipment. Navigation aids, particularly lights, would be inspected and serviced periodically. Debris buildup would be monitored, and debris would be removed as necessary.

Construction and Implementation

The IFF initial construction would include the installation of 10 piles, 17 IFF units and floats, a BAFF frame (and connecting cables and hoses), two control houses, overhead power and poles, and navigation buoys and warning lights. Power and control systems as well a compressor system for the BAFF would be installed inside the West Channel control house. This proposed IFF system would have modular components (e.g., floats, IFF units, BAFF frames, and cabling). This would make it possible to install or remove the system relatively quickly (within two weeks) in response to and following juvenile fish out-migration periods. Permanent infrastructure (e.g., piles, control house) would be placed along the alignment to provide anchorage and power and control for the IFF and BAFF components and remain in-place year round. Navigation aids would also be left in place. To minimize construction time and potential environmental impacts, the modular components would then be secured to the piles. In-water work would be done using barges, cranes, and divers. The control houses and overhead power and pole installation would require shore/bank access. Installation would be done using conventional building and utilities equipment and methods.

This IFF (and BAFF) could be installed reasonably quickly (within two weeks) to respond to incoming information regarding the timing of an out-migration period. Once in place, the IFF units and BAFF frames could be removed or re-installed in a relatively short period in response to changing flow conditions, in particular low flow events.

Potential Environmental Impacts

The IFF option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance. As noted above for the BAFF and FFGS options, general environmental requirements and considerations for the Turner Cut site are described in Appendix C, "Environmental Checklists", Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and BAFF frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the control house foundation and structure.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The IFF and BAFF operation would require seasonal installation of the IFF units and BAFF frames prior to a migration event and removal of this equipment following the event. Most installation/removal activities would be done by boat and barge, with minimal shore-based activities. Because the system piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the IFF and BAFF were in operation would include: potential minor changes to ambient noise levels resulting from the low-frequency IFF pulses, the BAFF sound projectors and occasional air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. Regular system monitoring and servicing of equipment in the control building would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by divers then the associated equipment (and frame) may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

Implementation of this IFF may have an effect on piscivorous predator species' assemblage, density, and behavior, but the extent of its influence on predator and prey interactions remains unstudied. Baseline assemblage and densities would be established to address the piscivorous predators present in the Turner Cut area. To address potential inland avian predation, anti-roosting wires could be installed on top of the floats to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for the IFF at Turner Cut is $6.5 M. The estimated annual operations and maintenance cost is $390,000. The estimated present worth cost based on a 50-year life is $18.7 M.

4.4.4.4 Gates with Boat Lock and Fish Ladder

Description

A gate structure would be placed just downstream from Acker Island where Turner Cut merges into a single channel (Figure 4-44). The location of the gate at the single channel was selected to facilitate construction, economic feasibility, and minimize the gate footprint by reducing submerged structure size. Possible gate styles would include an overflow gate (weir gate) or an underflow gate (radial arm gate) structure; each is discussed in detail in the subsection titled "Overflow Gate" or "Underflow Gate" in Section 2.2.4.1, "Physical Barriers." The style of gate best suited for this site remains unresolved, but a determination will be made after more detailed information becomes available. A better understanding of how the flow and stage characteristics would affect water supply and water quality downstream from the structure will assist in the selection of gate types and operational strategies.

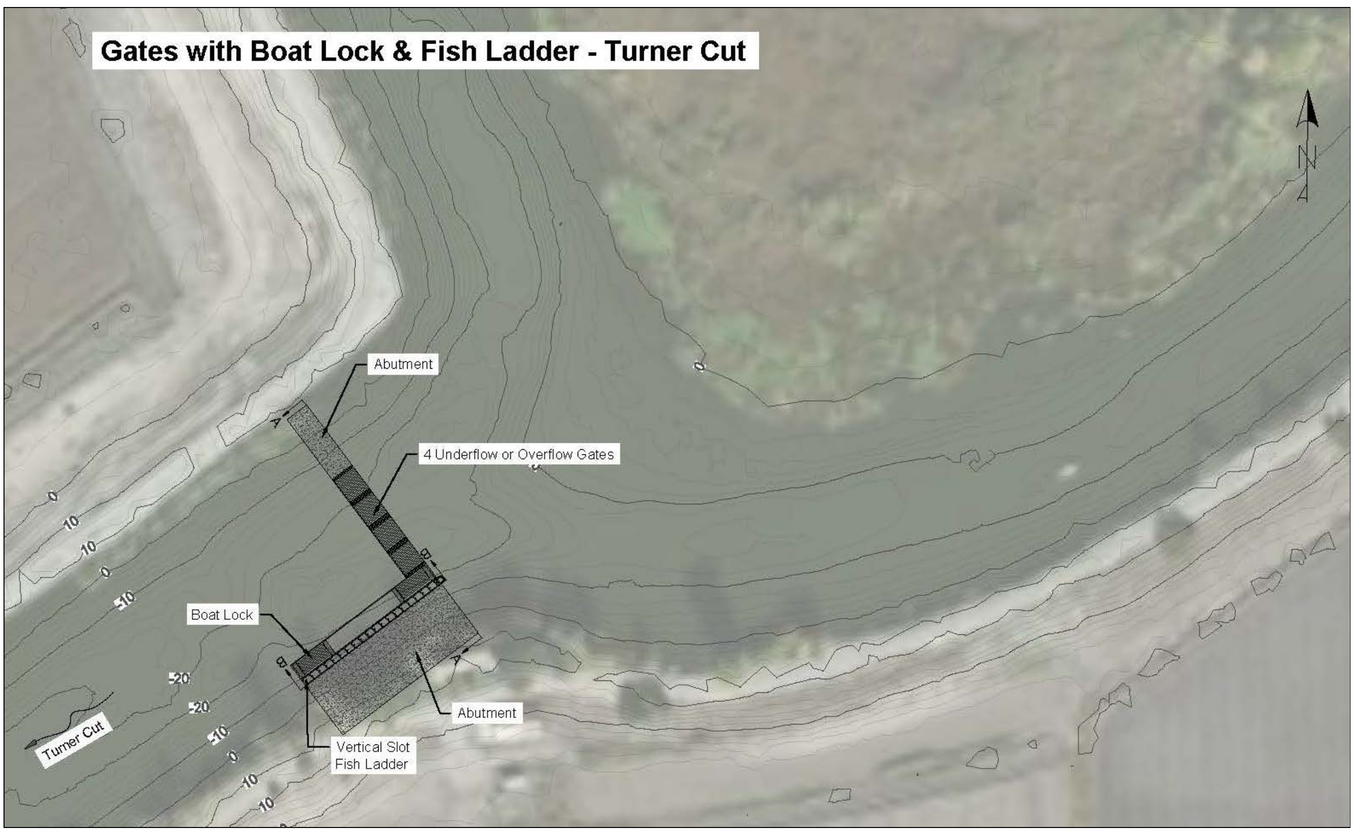
Source: DWR 2014 and SamMcCoy.com 2014

Figure 4-44. Delta Cross Channel Radial Arm Gates on the left and Obermeyer Gates Installed in Kinta River, Perak, Malaysia on the right.

The proposed gate structure would have four individual sections. Multiple sections would allow individual sections to be raised and lowered independently or simultaneously. Each gate section would be approximately 37 feet high and 32 feet wide. A fish passage structure and a boat lock would be part of the gate design. Other components associated with the gate structure would include a debris barrier, warning signs, and navigation lights. Figure 4-44 shows typical overflow (right) and underflow (left) gates.

Alignment

The proposed gate structure would be positioned to guide juvenile salmonid away from Turner Cut, allowing continued emigration along the river and access to riverine habit around Acker Island, while minimizing impacts on local marinas. The gate structure would be placed across the 300-foot-wide single channel, perpendicular to the normal flow direction, and as close as feasible to where the two upstream channel sections merge (Figure 4-45). The placement of the gate structure at this location would provide more opening than if the gate was set back into the entrance of the channel leading into Turner Cut. The gate structure would have a top elevation of approximately 12 feet mean sea level (NAVD88) based on the historical high stage plus two feet of freeboard.



Source: DWR – Bay-Delta Office 2014

Figure 4-45. Proposed Turner Cut Gate Structure Design

Boat Passage

The gate structure would include a boat lock, 20 feet wide and approximately 210 feet long. The lock would include two bottom-hinged (overflow) gates, one at each end for the passage of recreational boats, and would be operable when the gates were either open or closed. Barges and larger vessels would be too large to use the lock but would be able to transit the structure when the main gates were lowered or in the open position.

Upstream Migration

A vertical slot fish ladder is proposed for this location to provide passage for adult salmon. The approximately 210-foot-long and 8-foot-wide ladder would be constructed according to NMFS and USFWS regulatory criteria and guidelines. The ladder would have a slope of 10 percent, equally divided across the ladder steps from ladder entrance to exit; the number of steps would be determined by the maximum forebay to tailwater head differential. Stoplogs would be used to close the ladder when not in use. Green sturgeon passage would be accommodated through periodic opening of the boat lock or the main gates. The entrance threshold height of the lock and gates would be designed to be less than one foot or as directed by the regulatory agencies. See Appendix B for additional details and dimensions for a Turner Cut vertical slot fish ladder.

Deterrence

A gate structure would provide a high level of fish deterrence because it would be a full column physical barrier. This would be accomplished if all the gates were fully closed. When the gates were closed only part-time or blocking only part of the channel, the ability to deter juvenile salmonids would be lessened. The relationship between gate operations and deterrence efficiency has not been quantified yet but would need to be studied in greater detail before final design of this option.

Flow and Tidal Effects

A gate structure at Turner Cut, when completely or partially closed to deter juvenile salmonids, would change existing flow and stage characteristics. These changes would have a potentially negative impact on water supply and water quality downstream from the structure. The magnitude of the impact has not been evaluated but could be lessened by the use of varied tidal operational strategies. The goal, if feasible from an operations perspective, would be to mimic the natural flow split and stage patterns through coordinated gate operations. Limitations on feasible gate closures may require opening the gates more often resulting in decreased deterrence of juvenile salmonids

Operations and Maintenance

Operations and maintenance of a gate structure at Turner Cut would involve the general activities described in the “Overflow” and ”Underflow” gate subsection 2.2.4.1 “Physical Barriers. The operations and maintenance of a Turner Cut gate structure in general would be consistent with a typical standard water control gate installation. The gates and boat lock would require regular maintenance of the mechanical, electrical, and control systems. Based on the preliminary hydraulic modeling, the gates would be operated tidally, closed during ebb tide when water was flowing into Turner Cut and open during flood tide when water was flowing into the San Joaquin River. This operation scenario is based on normal year conditions. However, a detailed gate operational strategy for extremely dry or wet year conditions would be determined after engineering criteria and agency regulatory criteria have been determined.

The gate operations would be automated to provide quick response to the changing tides and would have the flexibility to automatically adjust the close-open cycle. This would help to provide effective gate operation, to benefit fish. The boat lock operations also would be automated with local controls for boater use, to open and close the lock gates. Operation of the main gates for passage of barges or larger boats may require similar local controls for boat use or the presence of an operator to control the gates and oversee the passage.

Construction and Implementation

The gate construction would include the installation of a reinforced concrete foundation (including abutments, boat lock channel, and fish ladder), three main bottom-hinged gates and one top-hinged gate, two boat lock bottom-hinged gates, a control house, overhead power and poles, and navigation buoys and warning lights. Power and control systems for the gates would be installed inside the control house. In-water work would be done using both water and shore based equipment (e.g., excavators, cranes, concrete pumpers). A cofferdam installation would be required to allow in-channel foundation excavation and placement of concrete and gate components. The control house and overhead power and pole installation would require shore/bank access near the downstream gate location. Installation would be done using conventional building and utilities equipment and methods.

This gate structure could be operated quickly (within hours) to respond to incoming information regarding the timing of the out-migration period. The gates could be opened, closed, or adjusted to provide deterrence, allow specific flow bypasses, or large vessel passage in a short period.

Potential Environmental Impacts

The gate option would have a significant effect on the natural environment during installation of the permanent infrastructure and during operation and maintenance. As noted above for the other options, general environmental requirements and considerations for the Turner Cut site are described in Appendix C, "Environmental Checklists". Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include significant disruption of river sediment habitat and aquatic habitat during in-channel excavation and foundation installation, and disruption of riverine shore habitat during mobilization, excavating and installation of the gate abutments, control house foundation and structure.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The gate operation would include raising and lowering the hinged gates, either to allow the flow of water or the passage of boats. The top hinged gate would be operated or left partially open at all times to allow the passage of surgeon. The fish ladder would require no operation unless ladder maintenance was required and the ladder slide gates would be closed. Environmental impacts when the gates were in operation would include potential minor changes to ambient noise levels resulting from raising or lowering a gate. Regular system monitoring and servicing of the gates and equipment in the control house would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of the gates may be required. If the servicing could not be completed in water or by divers then the associated equipment may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

In addition to deterring targeted juvenile salmonids, the gate structure would be expected to be a point where piscivorous predatory fish, avian, and aquatic mammals may congregate to hold, roost, or rest and prey on passing juvenile salmonids and other fish species. The structure would cause flow disturbances that potentially could disorient the juvenile salmonids and create eddy currents in which piscivorous predators could hold. This may lead to a potential piscivorous predation increase at the junction. As noted in Section 3.6, "Engineering Design

Considerations to Reduce Predation," design features (e.g., smooth entrance and exit structure abutments and support structures) would be incorporated to minimize these flow disturbances. To address potential inland avian predation, anti-roosting wires could be installed on top of the structure to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for a gate structure at Turner Cut is $70.0 M. The estimated annual operations and maintenance cost is $200,000. The estimated present worth cost based on a 50-year life is $73.7 M.

4.4.5 COLUMBIA CUT

The engineering alternatives that were considered applicable for Columbia Cut included Operable Gates, FFGSs, IFFs, and BAFFs. Each engineering option was evaluated using the criteria set forth in the WRAM process, and a conceptual design was created for each option using the same criteria applied specifically to the Columbia Cut site.

4.4.5.1 BIO-ACOUSTIC FISH FENCE

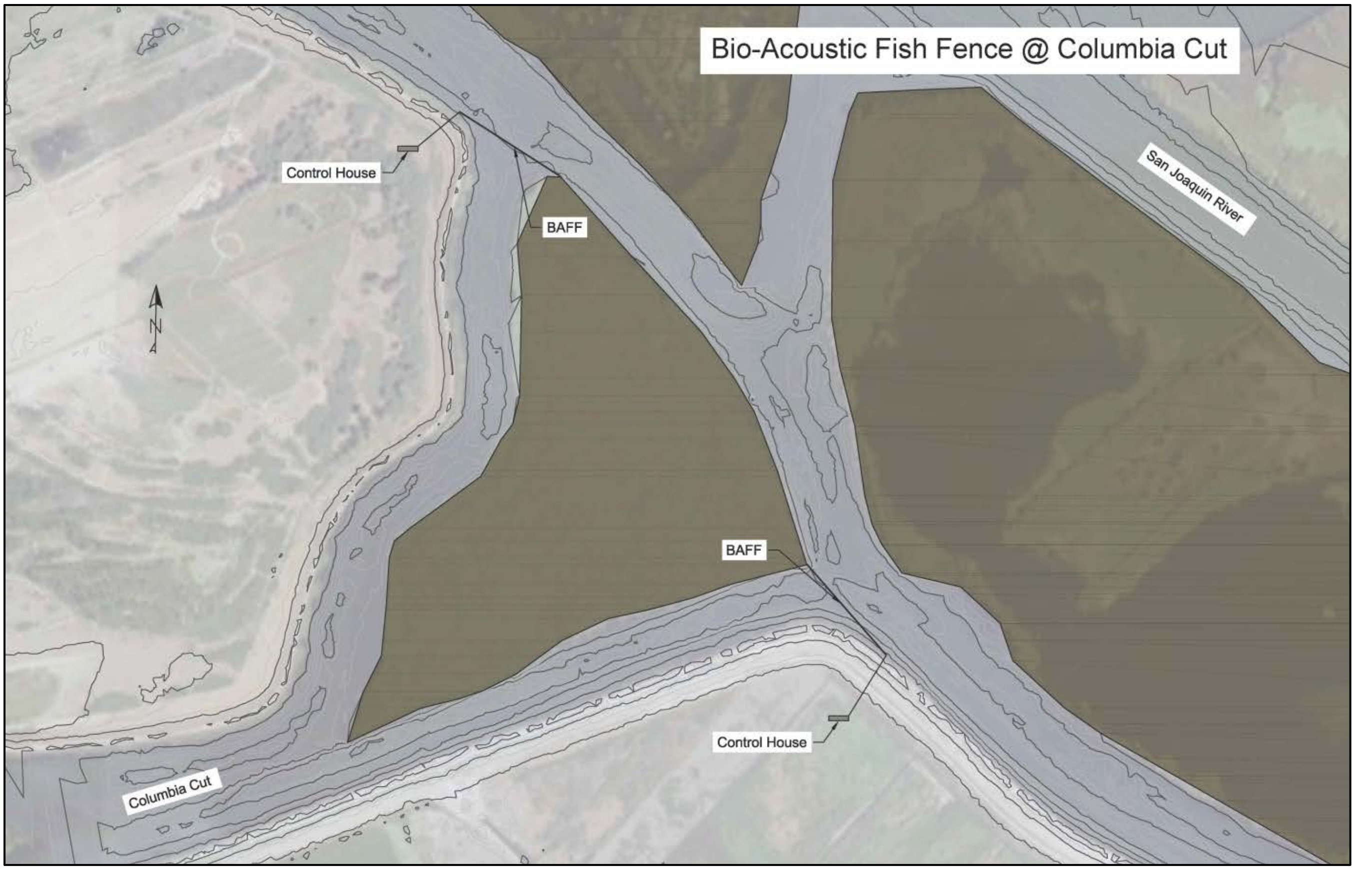
Description

A BAFF made up of two individual barriers would be installed crossing each of the two junctions leading into Columbia Cut (Figure 4-46). The barriers would be aligned parallel to the main river flow direction. They would be made up of steel-framed modular sections, spanning 100 feet between pile supports. The infrastructure (i.e., piles and connection hardware) would stay in place year-round, and the modular BAFF sections and other working components would be installed only during juvenile salmonid emigration periods. This modular design would minimize environmental impacts by minimizing seasonal construction time and would allow most maintenance to be performed out of the water.

A control house on the landside of the adjacent levees would be necessary for each barrier. Electrical power would be provided by dedicated overhead power lines. The in-water components of the barriers, with the exception of support piles and navigational aids, would be removed annually for general maintenance and to minimize potential impacts resulting from debris and sediment accumulation. These components would be stored at either an on-site or remote storage facility and would be re-installed before the juvenile salmonid migration period or as directed by regulatory agencies. See Appendix B for detailed drawings of the BAFF at Columbia Cut.

Alignment

The barriers would be aligned to guide fish past the junctions that lead into Columbia Cut. Each barrier would be continuous, about 600 feet in length, crossing a respective junction and set at an angle that would be parallel to the mid-stream river flow direction (Figure 4-46). The BAFF's stimuli would create a zone of influence extending into the river where the flow streamlines would aid in guiding fish past the junctions. Because the barriers would be aligned parallel to these streamlines, the barriers are expected to deter fish during both positive and negative (reverse) flows. Each barrier frame would be installed approximately two feet above the channel bottom, to provide a minimum depth of water over the barrier under low tide and flow conditions. The East Channel barrier would require seven piles, and the West Channel barrier would require seven piles.



Source: DWR – Bay-Delta Office 2014

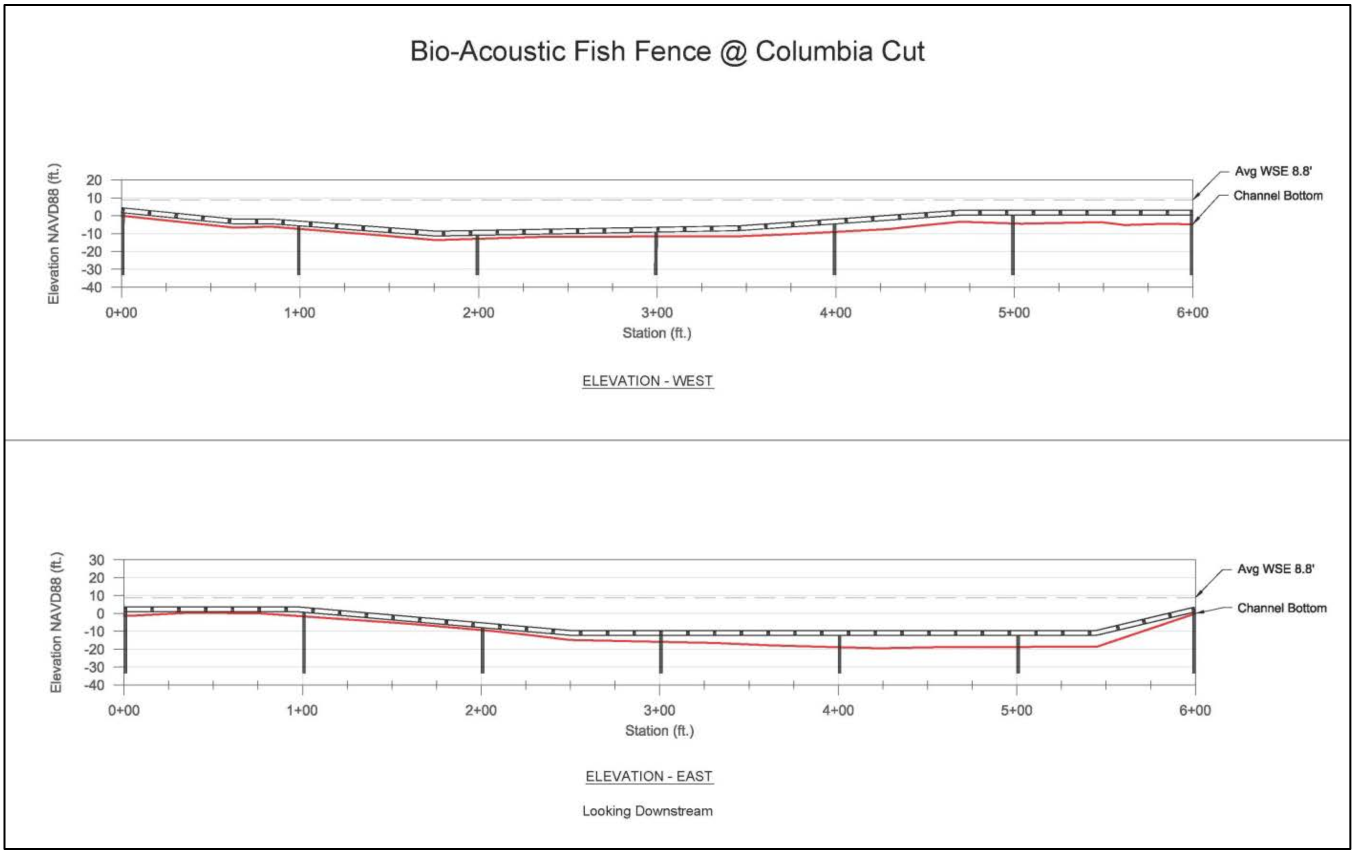
Figure 4-46. BAFF Alignment at Columbia Cut

Boat Passage

Boat passage would be possible along most of the BAFF alignment. The non-physical nature of the barriers would allow most recreational boats and small barges to navigate across the bubble curtain. Navigation would not be permitted near the shorelines where the BAFF frames would be too close to the water surface (Figure 4-47). These areas would be clearly marked with signage and buoy lines. Staff gauges indicating draft depth would be placed near the barriers to inform boaters about the clearance above the BAFF frame. If an emergency or construction vessel with a very large draft required passage, a 100-foot section of the BAFF could be removed temporarily.

Upstream Migration

The BAFF design would allow the movement and passage of other sensitive non-targeted fish species (e.g., green sturgeon and adult salmonids). The BAFF frame would be set with a minimum two-foot clearance between the bottom of the frame and the channel bottom. As described for a BAFF at Georgiana Slough in Chapter 4, subsection 4.4.1, both sturgeon and adult salmonids are expected to have only a limited response or ignore the BAFF acoustic signals, lights and air bubbles. If this option is implemented, green sturgeon and adult salmonid behavior would be monitored to validate these assumptions.



Source: DWR – Bay-Delta Office 2014

Figure 4-47. Elevation View of the Proposed BAFF Alignment

Deterrence

The deterrence ability or effectiveness of a BAFF at Columbia Cut would depend on many factors. The barriers' alignment, direction of flow, water velocities, and swimming ability of the juvenile salmonids are some key factors for design. The hydrodynamics in the Columbia Cut area are highly variable; therefore, the effectiveness of the BAFF design would vary as well. The BAFF alignments in the conceptual design were chosen with these factors in mind, but the actual quantifiable deterrence ability would be known only after pilot testing occurs.

The 2011 and 2012 BAFF studies at Georgiana Slough proved successful in reducing entrainment, and that site experiences higher velocities than Columbia Cut. The BAFF's effectiveness at deterring juvenile salmonids at Columbia Cut should be similar to the results from the 2011 and 2012 GSNPB studies.

If this option is chosen, additional monitoring of its effectiveness is recommended to validate these assumptions.

Flow and Tidal Effects

The BAFF would have minimal effects on the naturally occurring flow and tidal conditions at Columbia Cut. This is because water would flow around the piles and through the BAFF, and would not be blocked or redirected. Some minor eddies and changes in flow direction may occur in close proximity to the piles and frames, but the potential effects are expected to be minor. Also, the natural flow split would remain the same.

The tidal influences on velocity, flow direction, and stage would have minimal effect on the BAFF performance. The proposed design length and angle of the barrier would provide fish ample time to react to the stimuli throughout the majority of expected tidal velocities. During extremely high velocities, the BAFF bubble curtain would be expected to bend with the tidal flow, potentially diminishing the deterrence stimuli integrity although this effect on barrier performance barriers has not been quantified yet. The barriers would cross the entire junction, which would protect fish entering the area from both upstream and downstream. During extremely high stage events, the integrity of the bubble curtain possibly may diminish towards the upper portion of the water column as the bubbles disperse.

Operations and Maintenance

Operations and maintenance of the BAFF would include those general activities described in Chapter 2, subsection 2.2.4.2., "Non-Physical Barriers." The BAFF would be operated 24 hours per day throughout juvenile salmonid emigration periods. The BAFF air supply, light, and sound levels would be controlled and monitored from mechanical and computer systems located in the control house. Operation could be automated and minimal personnel time required to conduct regular barrier inspections. The barriers would be removed during periods when juvenile salmonids are not expected to be traveling by the junction. Removal/installation would require divers to make underwater connections/disconnections of the BAFF frames. Boat or shore mounted cranes would be required to lift the frames in and out of the water. The frames would then be transported and stored.

At the Columbia Cut location, the potential would exist for some sound projectors and lights to become exposed during low-stage conditions; they would be turned off from the control house and would be turned back on when stage conditions were suitable. Regular preventative maintenance, checks, and services would be required for all mechanical and electrical systems. Some in-water work by divers would be required to replace in-water failed components (light or sound projector) or a damaged component. An inventory of specialty BAFF equipment (lights, sound projectors, and controllers) would be required to minimize replacement time. Navigation aids, particularly lights, would require periodic inspection and servicing. Debris buildup would be monitored and debris removed as necessary.

Construction and Implementation

The initial construction for this option would include: building two control houses for the BAFF air compressors and lights, sound, and power/control systems; installing 14 piles to support the BAFF frames and navigation aids, and obtaining power from nearby overhead power lines. The control houses would be located on the San Joaquin River's left bank to provide power, air, and controls for the BAFF components in both the East Channel and West Channel barrier locations. To minimize construction time, potential environmental impacts, and wear and tear on the system, these components would stay in place year-round. Installation and connection of the modular components (e.g., air hoses, data cables, power cords, BAFF frames, and navigation makers) would occur prior to juvenile salmonid emigration periods which would be defined seasonally by regulatory agencies. These tasks would require the use of barge mounted equipment (crane, pile driver), work boats and divers. The control house and overhead power and pole installation would require shore/bank access near the downstream pile location. Installation would be done using conventional building and utilities equipment and methods.

The BAFF components could be installed reasonably quickly (within two weeks) to respond to incoming information regarding the timing of an out-migration period. Once in place, the BAFF frames could be removed or re-installed in a relatively short period in response to changing migration or flow conditions.

Potential Environmental Impacts

Potential environmental impacts from installing and operating a BAFF at Columbia Cut would be similar to the impacts described above in subsection 4.4.1.1 for a BAFF installed at Georgiana Slough. General environmental requirements and considerations for the Columbia Cut site are described in Appendix C, “Environmental Checklists”

The BAFF option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those unique to in-water and near shore actions. These unique impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the control house foundations and structures.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The BAFF operation would require seasonal installation of the BAFF frames prior to a migration event and removal of the frames following the event. Most installation/removal activities would be done by boat and barge, with minimal shore-based activities. Because the frame support piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the BAFF was operating would include minor changes to ambient noise levels due to the BAFF sound projectors, air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. There are no nearby residences so these impacts are expected to be insignificant. Regular system monitoring and servicing of equipment in the control building would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by divers then the associated equipment (and frame) may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

In addition to deterring juvenile salmonids, the BAFF barriers would be expected to be a point where piscivorous predatory fish, avian, and aquatic mammals may congregate to hold, roost, or rest and prey on passing juvenile salmonids and other fish species. The barrier frames and support piles would cause minor flow disturbances that potentially could disorient the target juvenile salmonids and create eddy currents in which piscivorous predators could hold.

The existing interaction between juvenile salmonids and piscivorous predators has not been studied extensively, and is not well understood at this junction. During the 2011 and 2012 Georgiana Slough Non-Physical Barrier studies, piscivorous fish predators were caught and tagged, and their movement and interaction with tagged juvenile Chinook were analyzed. The results of these studies suggest that survival of juvenile Chinook salmon was independent of the BAFF operation.

Baseline densities of predators are not known for the Columbia Cut area, and thus determining the impacts of predation is difficult to predict. Baseline densities would be established for the area before any option is selected, and then follow-up monitoring would occur after installation, to monitor for any problems.

Cost

A rough order-of-magnitude estimated cost for the BAFF at Columbia Cut is $16.6 M. The estimated annual operations and maintenance cost is $840,000. The estimated present worth cost based on a 50-year life is $37.6 M.

4.4.5.2 FLOATING FISH GUIDANCE STRUCTURE

Description

An FFGS would be installed crossing each of the two junctions leading into Columbia Cut (Figure 4-48). The two barriers would be aligned parallel to the main river flow direction. The barriers would be steel sections, 20 feet wide and either 5 or 10 feet deep (depending on stage), with bolt connections for adding or removing panels. The modular design would allow flexibility in operations resulting from changing hydraulic conditions. A section of BAFF would be incorporated (at both barrier locations) to provide boat passage. Two control houses would be built to house the BAFF's above-water components, and they would be located on the landside of the adjacent levees. Electrical power would be provided by dedicated overhead power lines. The in-water components of the barriers, with the exception of support piles and navigation aids, would be removed annually for general maintenance and to minimize potential impacts resulting from debris and sediment accumulation. These components would be stored at either an on-site or remote storage facility and would be re-installed before the juvenile salmonid migration period or as directed by regulatory agencies. See Appendix B for detailed drawings of the FFGS at the Columbia Cut.

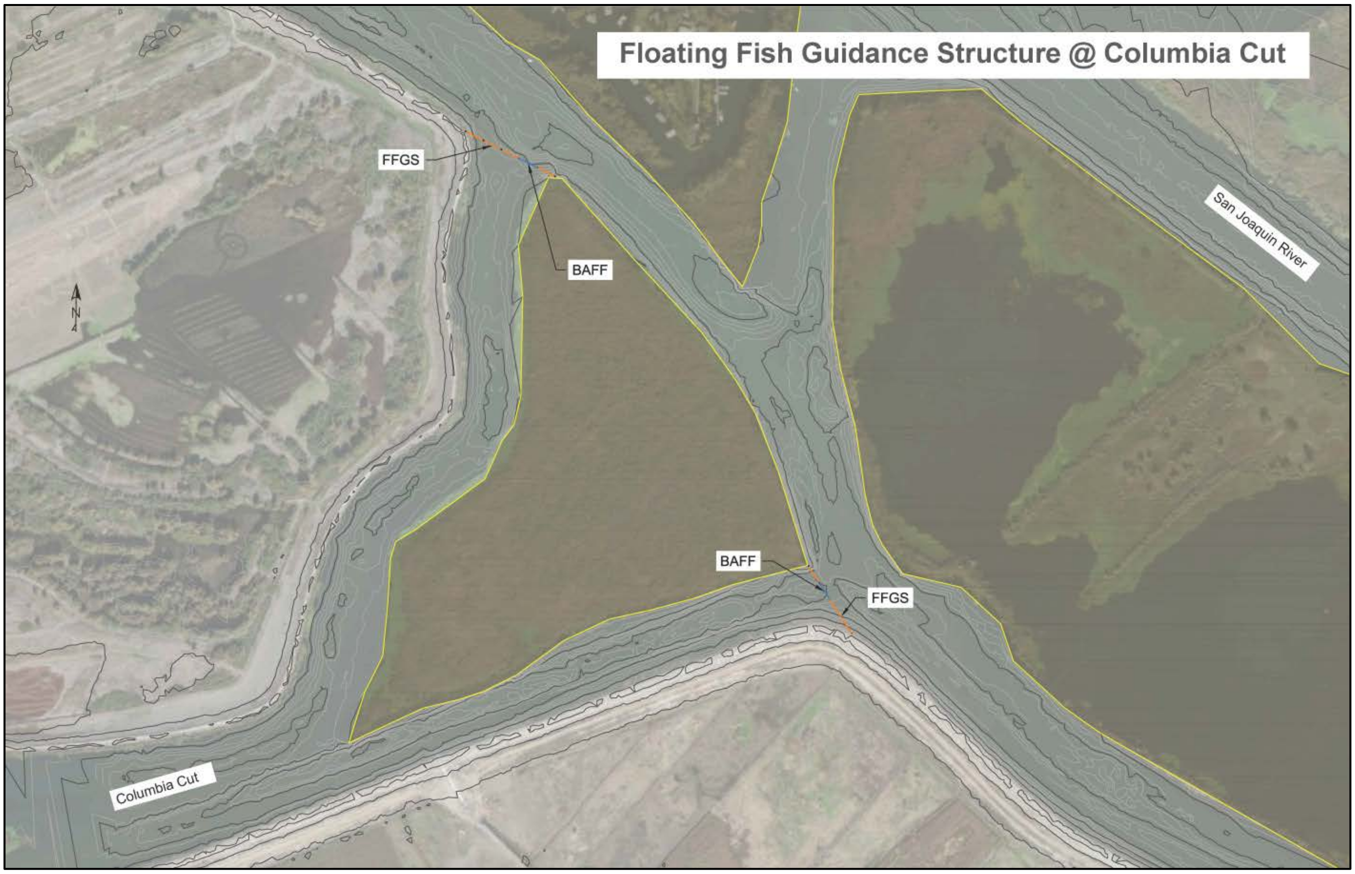
Alignment

This FFGS option would guide juvenile salmonids past the junctions leading to Columbia Cut to keep their movement in the river towards the ocean. To maximize fish deterrence, continuous barriers would cross both junctions (Figure 4-47).

These junctions would experience regular changes in stage, velocity, and flow direction because of tidal influences and hydrologic conditions. Because these barriers would float, they would self-adjust (vertically) to the changes in stage. The variation in flow direction would be addressed by the continuous barriers that would span both junctions. This alignment would guide juvenile fish approaching from downstream because of tidal influences, such as reversing flows. In rare incidences, some portions of the barriers would experience high velocities at an angle perpendicular to the barriers. The effectiveness of the FFGS in deterring juvenile salmonids during these incidences is not well understood.

Boat Passage

Boat passage would be provided through a 100-foot opening in both of the barriers. To maintain continuous juvenile salmonid deterrence along the entire alignment, a 100-foot section of BAFF would be placed in each barrier. The openings would be placed where the channels are the deepest (Figure 4-49). This would minimize impacts on navigation because of low stage and boats with large drafts. This type of boat passage system would be operated around-the-clock.



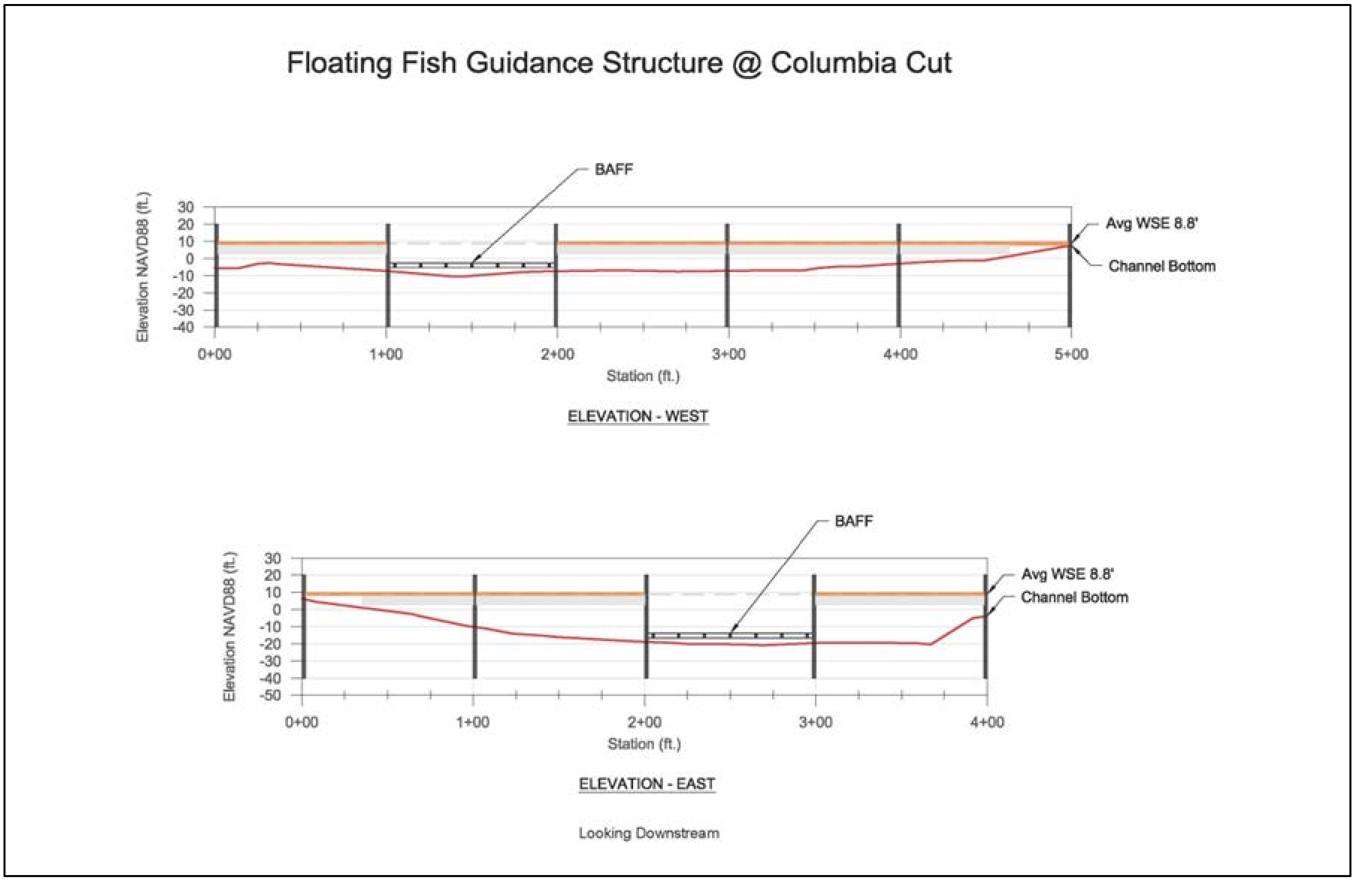
Source: DWR – Bay-Delta Office 2014

Figure 4-48. Plan View of the FFGS at Columbia Cut

The reason for using a BAFF as the boat passage solution is two-fold. A non-physical barrier would allow an opening for navigation while still providing fish deterrence. Also, it would allow enough space to accommodate large vessels under all flow conditions. A BAFF can span long openings that are supported by minimal infrastructure. Currently, the only other viable non-physical deterrence option would be the IFF. However, because of large stage changes at the Columbia Cut site, the IFF units would require surface floats to move up and down, and they would be limited to a maximum 30-foot spacing. This spacing would not meet the criteria set for this specific design.

Upstream Migration

The FFGS option would allow the movement and passage of other sensitive non-targeted fish species (e.g., green sturgeon and adult salmonids). A minimum of 50 percent of the lower water column (depending on stage) would be unobstructed and would allow the movement of upstream migrants, green sturgeon, and other fish species navigating the junction (Figure 4-48). The BAFF also could be used for passage by non-targeted fish species. A minimum of a 2-foot clearance would exist under the BAFF frame and non-target fish may pass through the bubble curtain as well.



Source: DWR – Bay-Delta Office 2014

Figure 4-49. Elevation View of Both Channels

Deterrence

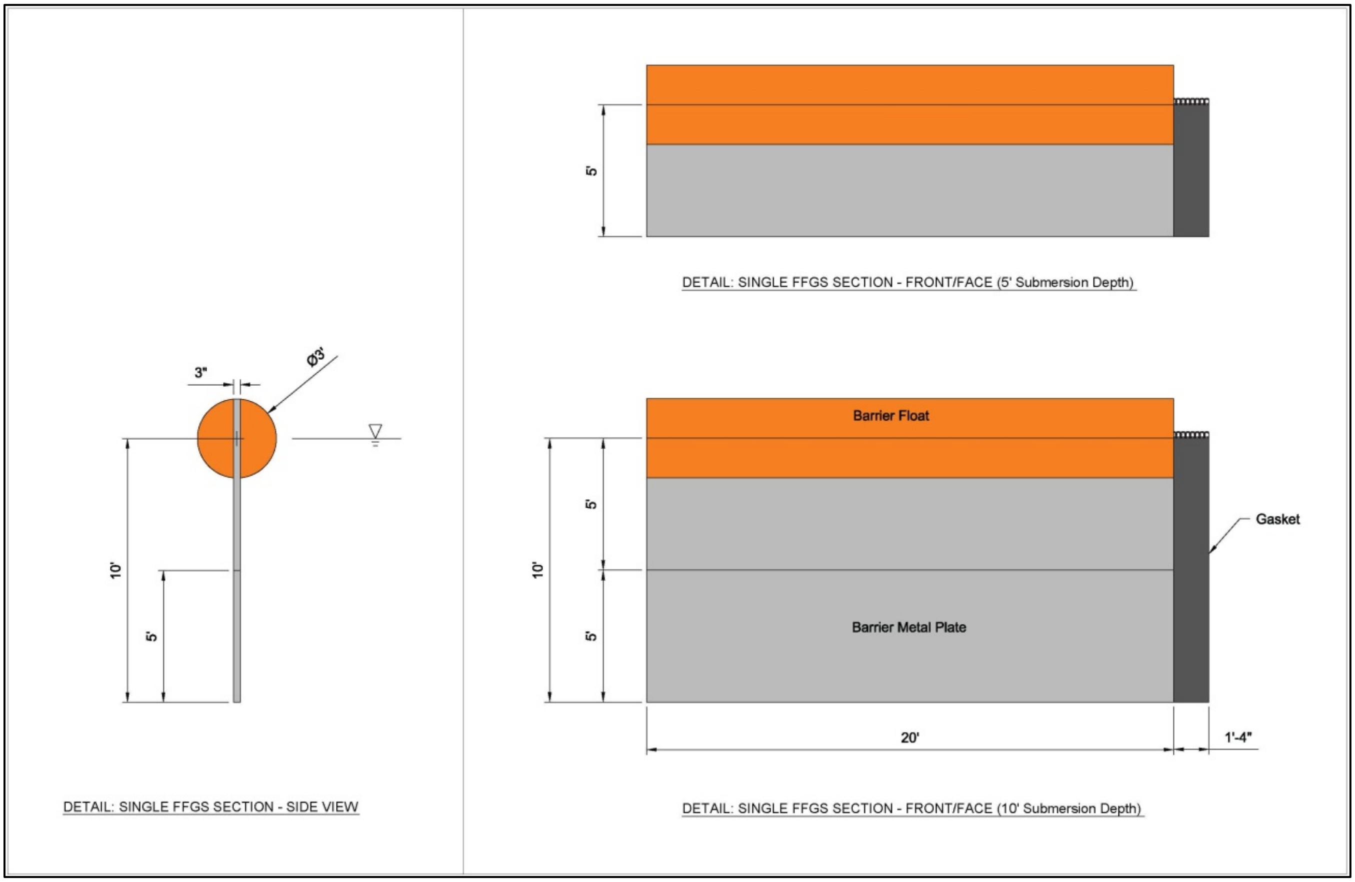
The potential FFGS deterrence effectiveness at Columbia Cut is not well understood. This option is expected to reduce entrainment of juvenile salmonids into Columbia Cut; however, too many unknowns exist to be able to quantify the benefits.

This type of deterrence technology has been used elsewhere in the recent past. Some studies show the deterrence efficiencies to be between 53 and 92 percent (Scott 2011), but not in an environment such as Columbia Cut. It typically has been used in much lower water velocities and in unidirectional flow, primarily upstream from dams and at openings of water intakes. Columbia Cut experiences a wide range of velocities, variable flows, and frequent reverse flows primarily because of tidal influences.

An FFGS was studied at Georgiana Slough in 2014 to summarize the deterrence ability of that alignment under conditions that existed during the study. Further consideration of that study, in conjunction with more detailed hydraulic studies at Columbia Cut, would be conducted before installing any permanent FFGS system.

Flow and Tidal Effects

This option would minimize impacts on existing flow patterns. The physical in-water footprint of these barriers would provide optimal deterrence while having minimal effects on the naturally existing hydraulic conditions. The floats at the top of the barriers would continuously adjust to the changing stage (Figure 4-50). This would keep the barriers in the upper portion of the water column where out-migrating fish are expected to reside. It also would keep the majority of the water column, below the barriers, open for the passage of water and other non-targeted fish.



Source: DWR – Bay-Delta Office 2014

Figure 4-50. Detailed Drawing of the FFGS showing the 5-foot and 10-foot Panels

Some amplified turbulence and redirection of flow could occur in close proximity to the barriers. The significance of these potential impacts on the naturally existing flow patterns would be studied throughout the full spectrum of possible hydraulic conditions. Some additional design features may be feasible to minimize these potential impacts.

The floats would keep the barriers at a constant 5 or 10 feet below the water surface under all conditions. In times of low flow and low stage, panels could be removed so that the barrier walls would not extend more than 50 percent down into the water column.

Columbia Cut experiences flow reversals because of tidal forces. This option would accounts for such conditions by the barriers crossing the entire mouth of both junctions. If the reversing flow happened to bring juvenile salmonids and other fish species along with it, they would encounter the barriers before they reached the entrance to Columbia Cut.

A system would be implemented to monitors and forecasts changes in stage at locations along the barriers where the potential exits for adding or removing barrier panels. This system could alert staff when to add or remove panels, to keep the barriers at the correct submergence depth depending on stage.

Operations and Maintenance

FFGS operations would be limited because the barrier would be in a fixed position. After barrier placement, including the BAFF, the barriers would remain in the same alignment. A change from 5-foot to 10-foot panels may be necessary if a substantial change in stage should occur. BAFF operations would be ongoing 24 hours per day throughout the juvenile salmonid emigration periods. The BAFF air supply, light, and sound levels would be controlled and monitored from a mechanical and computer system located in the control houses. Operation could be automated and minimal personnel time required to conduct regular barrier inspections. The barriers would be removed during periods when juvenile salmonids are not expected to be traveling through the divergence. Removal (and re-installation) would require in-water work by divers to disconnect (and re-connect) the FFGS panels and BAFF frames. The panels and frames would require the use of boat or shore mounted cranes to lift the panels and frames from (into the water). The panels and frames would then be transported and stored.

Construction and Implementation

The FFGS initial construction would include the installation of piles, panels and floats, BAFF frames (and connecting cables and hoses), a control house, overhead power and poles, and navigation buoys and warning lights in or on both the East and West channels. Power and control systems as well a compressor system for the BAFF would be installed inside each control house. This FFGS deterrence system would be made up primarily of modular components (e.g., FFGS panels and floats, BAFF frames, and cabling). This would make it possible to install or remove the system relatively quickly (within a week) in response to or following juvenile salmonid emigration. To minimize construction time and potential environmental impacts, the modular components would be secured to permanent piles and brackets. In-water work would be done using barges, cranes, and divers. The control house and overhead power and pole installation would require shore/bank access near the downstream pile location. Installation would be done using conventional building and utilities equipment and methods.

The FFGSs (and BAFFs) could be installed reasonably quickly (within a week) to respond to incoming information regarding the timing of an out-migration period. Once in place, the panels and BAFF frames could be removed or re-installed in a relatively short period in response to changing flow conditions, in particular low flow events.

Potential Environmental Impacts

The FFGS option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance As noted above for the BAFF option, general environmental requirements and considerations for the Columbia Cut site are described in Appendix C, “Environmental Checklists”, Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and BAFF frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the control house foundation and structure.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The FFGS and BAFF operation would require seasonal installation of the FFGS panels and BAFF frames prior to a migration event and removal of this equipment following the event. Most installation/ removal activities would be done by boat and barge, with minimal shore-based activities. Because the system piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the FFGS was in operation would be insignificant. Impacts when the BAFF was operating would include minor changes to ambient noise levels due to the BAFF sound projectors and the occasional air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. Regular system monitoring and servicing of equipment in the control house would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of the FFGS panels and BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by boat or divers then the associated equipment may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

Selection of this FFGS option may have an effect on piscivorous predator species' assemblage, density, and behavior, but the extent of its influence on predator and prey interactions is not well understood. Study results from the previously mentioned 2014 Georgiana Slough FFGS study are expected to provide some understanding of potential effects. To address potential inland avian predation, anti-roosting wires could be installed on top of the floats to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for the FFGSs at Columbia Cut is $7.6 M. The estimated annual operations and maintenance cost is $450,000. The estimated present worth cost based on a 50-year life is $23.4 M.

4.4.5.3 INFRASOUND FISH FENCE

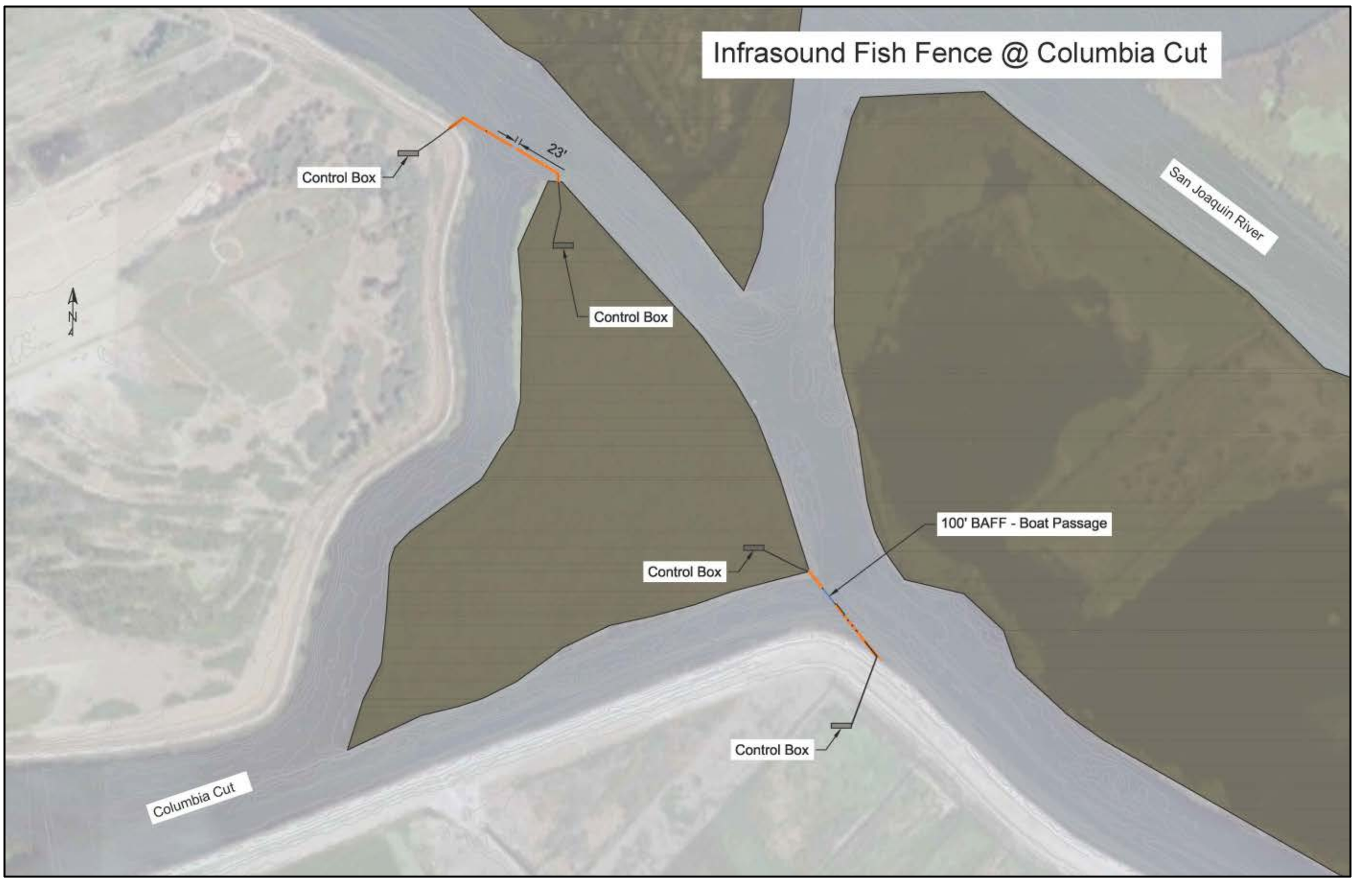
Description

An IFF at Columbia Cut would be made up of two barriers placed where the cut splits into two channels and meets the San Joaquin River. A continuous fish barrier using surface-oriented IFF units (Figure 4-9), with a 23-foot-wide boat passage, would be at the western location. The eastern location would have surface-oriented IFF units as well, but the boat passage would be 100 feet wide and would use a BAFF to provide simultaneous fish guidance and boat passage. A continuous line of cylindrical buoys would wrap around the entire IFF alignment, minus boat passage, so that all of the surface mounted power, data, and air lines would be protected from debris. The in-river components of the barriers, with the exception of support piles and navigation aids, would be removed annually for general maintenance and to minimize potential levee impacts resulting from debris and sediment accumulation. These components would be stored at either an on-site or remote storage facility and would be re-installed before the juvenile salmonid migration period or as directed by regulatory agencies.

Alignment

The IFF at Columbia Cut would be made up of two different alignments. To take advantage of streamlines that potentially could help move fish past the junctions, the IFF system would be placed where the river converges on the two-channel split (Figure 4-51). The river flow direction at this location is complex and dynamic. The angle-to-flow almost always is perpendicular to where a barrier could be placed at the single channel location; therefore, the optimal alignment and location for the barriers would be at the places where the two channels converge on the river. At these locations, the barriers would experience flows that would approach the IFF at angles more suitable for diverting fish away from the interior Delta.

The IFF proposed for the western channel would be 600 feet long, and the IFF proposed for the eastern channel would be 500 feet long. Each alignment would require four piles (see Appendix B for a detailed drawing).



Source: DWR – Bay-Delta Office 2014

Figure 4-51. Plan View of the IFF at the Two-Channel Split

Boat Passage

Boat passage between the San Joaquin River and Columbia Cut would be provided at both of the barrier locations. Boat passage in the West Channel would be provided through a 23-foot opening, mainly intended for the passage of recreational boats. Boat passage in the East Channel would be provided over a 100-foot BAFF, mainly intended for the passage of larger vessels such as barges for construction or emergency purposes (Figure 4-51).

The larger boat passage has been proposed for the West Channel barrier where the water is the deepest. This would minimize impacts on navigation resulting from low stage and boats with large drafts. Navigational buoys and lights would be installed to provide boater safety. Staff gauges indicating draft depth would be placed near the barrier to inform boaters of the clearance above the BAFF frame. This type of boat passage system would work around the clock.

Upstream Migration

The IFF option would allow the movement and passage of other sensitive non-targeted fish species (e.g., green sturgeon and adult salmon). The manufacturer claims that only small juvenile fish are known to react to infrasound, thus large fish are not affected because their otoliths are not as sensitive. Adult salmonids and green sturgeon would be able to pass through the junction undisturbed. A minimum two foot clearance would exist under the BAFF frame for passage, but non-targeted fish may pass through the bubble curtain as well.

Deterrence

This technology has been tested both in the laboratory and in the field; however, it has not been tested on juvenile salmonids in an environment similar to Columbia Cut. The results from previous laboratory and field testing have shown great promise in deterring fish, but the IFF would be need to be studied at this location with a focus on juvenile salmonids.

Flow and Tidal Effects

The IFF would have minimal effects on the naturally occurring flow and tidal conditions at Turner Cut. This is because the IFF would have very little in-water infrastructure and its relatively small mechanical components (IFF units and floats and BAFF section) would have a negligible influence on the natural movement of water. The IFF is expected to be effective under a wide range of tidal flows, including tidal reverse and low flows when water velocities will be low in comparison to salmonid swimming speeds. Similar to the BAFF, the IFF is expected to be less effective during high flow periods when water velocities exceed salmonid swimming speeds and the water direction is more perpendicular to the barrier alignment. The floats attached to each of the units would constantly adjust to the changes in stage. This would keep the barriers in the upper portion of the water column where the out-migrating fish are expected to reside. If low stage conditions occur, the IFF has the capability to have individual units turned off or even removed, to allow proper operation while maintaining a continuous system of deterrence.

A system would be put in place to monitor and forecast changes in stage at locations along the barrier where the potential existed for the need to turn off a unit or remove it.

Operations and Maintenance

Operations and maintenance of the IFF would include the general activities described in the subsection titled “Infrasound Fish Fence” in Chapter 2, Section 2.2.4.2, “Non-Physical Barriers.” and as described in Section 4.4.1.3 “Infrasound Fish Fence” for an IFF at Georgiana Slough. The IFF (and BAFF) would be operated 24 hours per day throughout juvenile salmonid emigration periods. Operation would be automated but could also be controlled remotely or manually. The barriers would be removed during periods when juvenile salmonids are not expected to be traveling by the junction. Regular preventive maintenance would be performed on all equipment. Navigation aids, particularly lights, would be inspected and serviced periodically. Debris buildup would be monitored, and debris would be removed as necessary.

Construction and Implementation

The IFF initial construction would include the installation of 8 piles, 25 IFF units and floats, BAFF frames (and connecting cables and hoses), two control houses, overhead power and poles, and navigation buoys and warning lights. Power and control systems as well a compressor system for the BAFF would be installed inside the West Channel control house. This proposed IFF system would have modular components (e.g., floats, IFF units, BAFF frames, and cabling). This would make it possible to install or remove the system relatively quickly (within two weeks) in response to and following juvenile fish out-migration periods. Permanent infrastructure (e.g., piles, control house) would be placed along the alignment to provide anchorage and power and control for the IFF and BAFF components and remain in-place year round. Navigation aids would also be left in place. To minimize construction time and potential environmental impacts, the modular components would then be secured to the piles. In-water work would be done using barges, cranes, and divers. The control houses and overhead power and pole installation would require shore/bank access. Installation would be done using conventional building and utilities equipment and methods.

This IFF (and BAFF) could be installed reasonably quickly (within two weeks) to respond to incoming information regarding the timing of an out-migration period. Once in place, the IFF units and BAFF frames could be removed or re-installed in a relatively short period in response to changing flow conditions, in particular low flow events.

Potential Environmental Impacts

The IFF option would affect the natural environment during installation of permanent infrastructure, during seasonal in-water construction, and during operation and maintenance. As noted above for the BAFF and FFGS options, general environmental requirements and considerations for the Columbia Cut site are described in Appendix C, "Environmental Checklists", Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include disruption of river sediment habitat during pile installation, disturbing aquatic habitat during pile and BAFF frame installation, and disruption of riverine shore habitat during mobilization, grading and installation of the control house foundation and structure.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The IFF and BAFF operation would require seasonal installation of the IFF units and BAFF frames prior to a migration event and removal of this equipment following the event. Most installation/removal activities would be done by boat and barge, with minimal shore-based activities. Because the system piles would already be in-place, minimal disruption of river sediments and the local aquatic habitat would occur. Environmental impacts when the IFF and BAFF were in operation would include: potential minor changes to ambient noise levels resulting from the low-frequency IFF pulses, the BAFF sound projectors and occasional air supply compressor operation, and minor changes to the night-time ambient light levels due to the BAFF strobe lights. Regular system monitoring and servicing of equipment in the control building would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of BAFF lights, sound projectors, or air distribution components may be required. If the servicing could not be completed by divers then the associated equipment (and frame) may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

Implementation of this IFF may have an effect on piscivorous predator species' assemblage, density and behavior, but the extent of its influence on predator and prey interactions is not well understood. . To address potential inland avian predation, anti-roosting wires could be installed on top of the floats to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for the IFF at Columbia Cut is $8.4 M. The estimated annual operations and maintenance cost is $440,000. The estimated present worth cost based on a 50-year life is $23.3 M.

4.4.5.4 GATES WITH BOAT LOCK AND FISH LADDER

Description

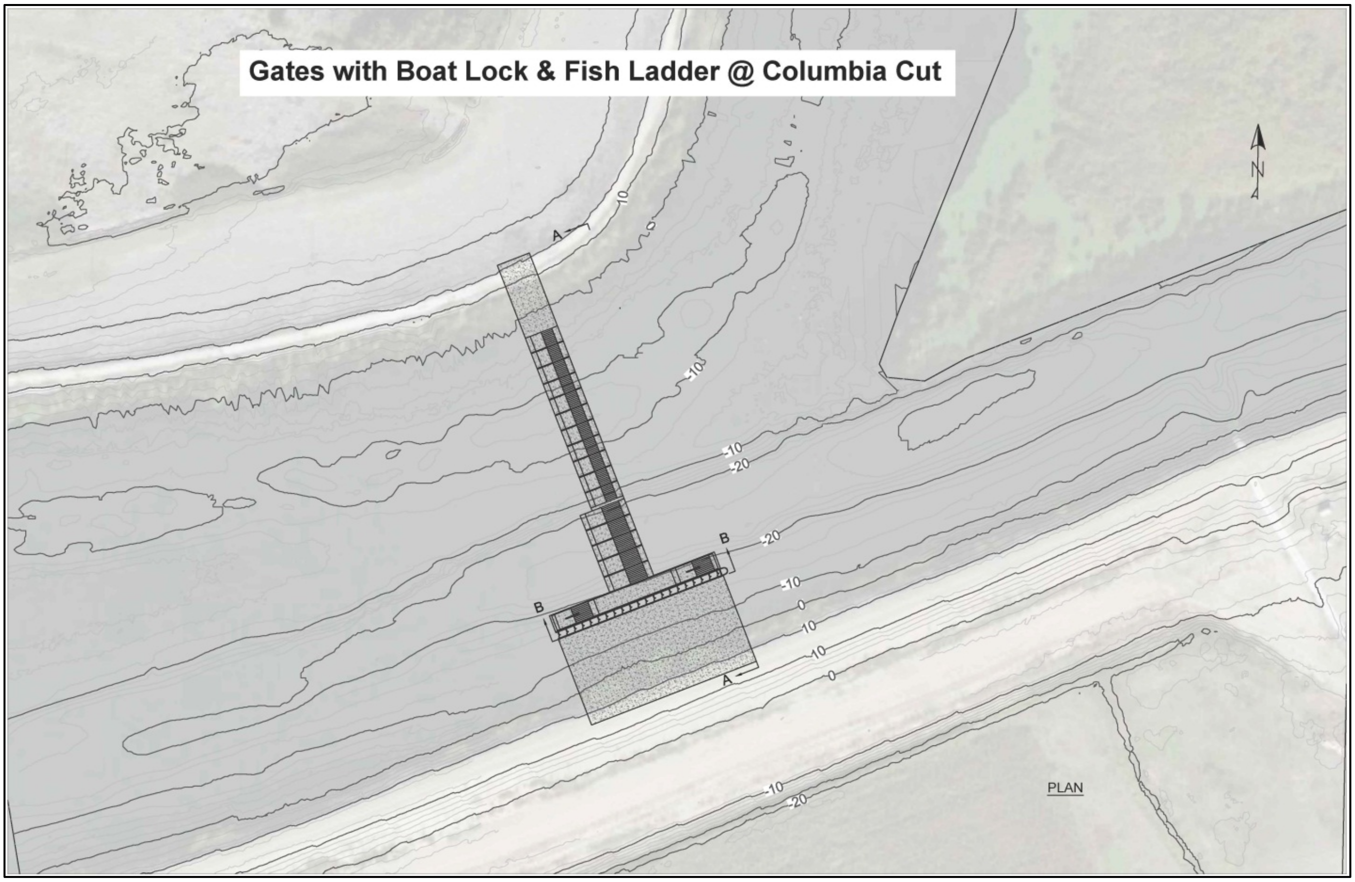
A gate option would be installed where the channels leading from the San Joaquin River merge into a single channel at Columbia Cut (Figure 4-52). The design would include operable gates, a boat lock, and a fish ladder (see Appendix B for the complete conceptual design details). The operable gates could be overflow gates, under flow gates, or a combination of both, and the specific design would be selected after more detailed information becomes available. Detailed studies regarding juvenile salmonid horizontal and vertical distribution within close proximity of the proposed gate system would be important for gate type selection (overflow versus underflow). A better understanding of how green sturgeon would react to a gate structure at Columbia Cut also would help in the selection of gate types and operational strategies.

The channel bottom where the gates would be located is not uniform in depth, and thus two different gate heights would be required. A total of 11 gates are proposed for the northern side of the gate structure, each one being 20 feet wide and approximately 24 feet tall. The southern side of the gate structure would have five gates, each one being 20 feet wide and approximately 38 feet tall (Figure 4-53). The boat lock would be located on the deeper side of the channel to pass boats with large drafts. The fish ladder also would be located on the deeper side of the channel to provide passage throughout large changes in stage.

Alignment

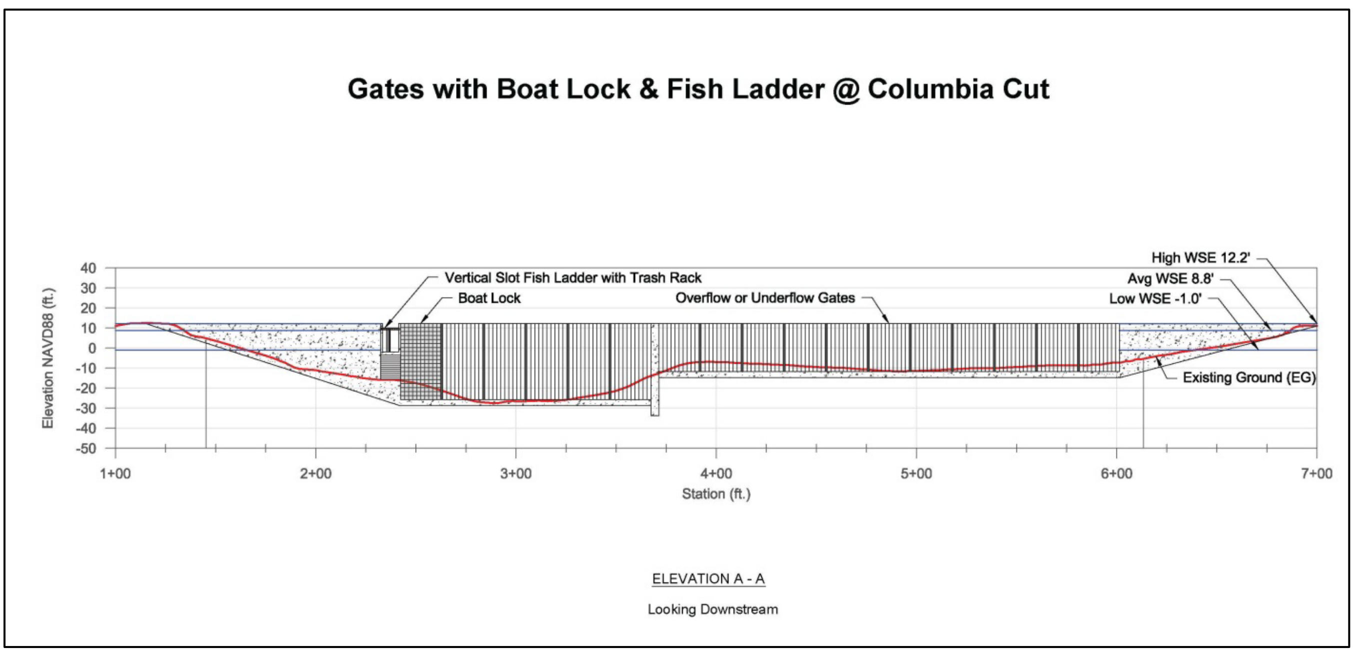
The gate structure would be placed at the entrance to Columbia Cut and would be oriented perpendicular to the river flow direction (Figure 4-53). The main objective for this gate alignment is to physically block juveniles from entering Columbia Cut and keep them in the river. The gate structure alignment and placement would minimize unwanted hydraulic conditions, such as eddies, turbulence, and scouring.

This gate system would allow the naturally existing maximum flow into the slough. The gates would create an approximate 340-foot-wide opening, greater than the narrowest location in Columbia Cut.



Source: DWR – Bay-Delta Office 2014

Figure 4-52. Plan View of the Gates, Vertical Slot Fish Ladder, and Boat Lock



Source: DWR – Bay-Delta Office 2014

Figure 4-53. Elevation View of the Gate Structure at Columbia Cut

Boat Passage

Boat passage would be accommodated by a 20-foot-wide boat lock, which would accommodate most recreational boats. The boat lock would have about 200 feet between each of the two bottom-hinged lock gates (see the detailed drawing in Appendix B). The main gates could be lowered if a large vessel required passage.

Upstream Migration

Upstream migration of sensitive non-targeted fish species (e.g., green sturgeon and adult salmonids) would be possible through the fish ladder and the opening of the boat lock gates and the main gates. The fish ladder would be designed according to the NMFS and USFWS regulatory criteria and guidelines. A detailed drawing is provided in Appendix B. During periods when the main gates would be up adult salmonids could use the fish ladder for passage (Appendix B provides details about and dimensions of the vertical slot fish ladder). Green sturgeon would be able to pass when the boat lock gates or the main gates were opened. The possibility also exists that one or more of the main gates could be an underflow gate. If the hydraulic conditions permit, an underflow gate could be partially opened to allow fish passage at the bottom of the channel.

Deterrence

The effectiveness in deterring fish using this option is directly related to the percentage of time that the gates would be operated and the percentage of flow allowed to pass through the gate system. If the gates could be operated to block off the entire slough during the entire out-migration period, 100 percent deterrence could be expected; however, if the gates could be operated only part of the time and would block only part of the channel, the ability to deter fish would be diminished. The exact relationship between gate operations and deterrence efficiency has not been quantified yet, but this would need to be studied in detail before selection of this option.

Flow and Tidal Effects

A gate structure at Columbia Cut, when completely or partially closed to deter juvenile salmonids, would change existing flow and stage characteristics. These changes would have a potentially negative impact on water supply and water quality downstream from the structure. The magnitude of the impact has not been evaluated but could be lessened by the use of varied tidal operational strategies. The goal, if feasible from an operations perspective, would be to mimic the natural flow split and stage patterns through coordinated gate operations. Limitations on feasible gate closures may require opening the gates more often resulting in decreased deterrence of juvenile salmonids.

Operations and Maintenance

Operations and maintenance of a gate structure at Columbia Cut would involve the general activities described in the “Overflow” and ”Underflow” gate in Chapter 2, subsection 2.2.4.1 “Physical Barriers. The operations and maintenance of a Columbia Cut gate structure in general would be consistent with a typical standard water control gate installation. The gates and boat lock would require regular maintenance of the mechanical, electrical, and control systems. Based on the preliminary hydraulic modeling, the gates would be operated tidally, closed during ebb tide when water was flowing into Columbia Cut and open during flood tide when water was flowing into the San Joaquin River. This operation scenario is based on normal year conditions. However, a detailed gate operational strategy for extremely dry or wet year conditions would be determined after engineering criteria and agency regulatory criteria have been determined.

The gate operations would be automated to provide quick response to the changing tides and would have the flexibility to automatically adjust the close-open cycle. This would help to provide effective gate operation, to benefit fish. The boat lock operations also would be automated with local controls for boater use, to open and close the lock gates. Operation of the main gates for passage of barges or larger boats may require similar local controls for boat use or the presence of an operator to control the gates and oversee the passage.

Construction and Implementation

The gate construction would include the installation of a reinforced concrete foundation (including abutments, boat lock channel, and fish ladder), 15 main bottom-hinged gates and one top-hinged gate, 2 boat lock bottom-hinged gates, a control house, overhead power and poles, and navigation buoys and warning lights. Power and control systems for the gates would be installed inside the control house. In-water work would be done using both water and shore based equipment (e.g., excavators, cranes, concrete pumpers). A cofferdam installation would be required to allow in-channel foundation excavation and placement of concrete and gate components. The control house and overhead power and pole installation would require shore/bank access near the downstream gate location. Installation would be done using conventional building and utilities equipment and methods.

This gate structure could be operated quickly (within hours) to respond to incoming information regarding the timing of the out-migration period. The gates could be opened, closed, or adjusted to provide deterrence, allow specific flow bypasses, or large vessel passage in a short period.

Potential Environmental Impacts

The gate option would have a significant effect on the natural environment during installation of the permanent infrastructure and during operation and maintenance. As noted above for the other options, general environmental requirements and considerations for the Columbia Cut site are described in Appendix C, “Environmental Checklists”. Environmental impacts would be those commonly occurring during construction activities (noise, traffic, air quality, etc.) and those associated with in-water and near shore actions. The in-water impacts would include significant disruption of river sediment habitat and aquatic habitat during in-channel excavation and foundation installation, and disruption of riverine shore habitat during mobilization, excavating and installation of the gate abutments, control house foundation and structure.

Environmental impacts during operation and maintenance would be those commonly occurring with in-water and near shore facilities. The gate operation would include raising and lowering the hinged gates, either to allow the flow of water or the passage of boats. The top hinged gate would be operated or left partially open at all times to allow the passage of surgeon. The fish ladder would require no operation unless ladder maintenance was required and the ladder slide gates would be closed. Environmental impacts when the gates were in operation would include potential minor changes to ambient noise levels resulting from raising or lowering a gate. Regular system monitoring and servicing of the gates and equipment in the control house would be required. This work would primarily be done on or from shore. Occasional unscheduled servicing of the gates may be required. If the servicing could not be completed in water or by divers then the associated equipment may need to be removed, serviced and re-installed. Environmental impacts during servicing would be similar to those associated with the initial equipment installation. These impacts would likely be mitigated to not pose a significant threat to the environment or community through careful planning and monitoring.

Predation Effects

The piscivorous predator species' assemblage and density in the Columbia Cut area are not well documented. The addition of an in-water structure (i.e., the gate system and the pumping system) may affect piscivorous predator assemblage and densities in the area, but the benefit from increased deterrence of juvenile salmonids versus the negative impact from potential changes in current piscivorous predation rates would be studied after data becomes available. To address potential inland avian predation, anti-roosting wires could be installed on top of the structure to discourage bird roosting.

Cost

A rough order-of-magnitude estimated cost for a gate structure at Columbia Cut is $82.1 M. The estimated annual operations and maintenance cost is $270,000. The estimated present worth cost based on a 50-year life is $85.8 M.

5 ENGINEERING EVALUATION RESULTS

This chapter reviews the WRAM assessments conducted for engineering evaluations, summarizes assessment results, and discusses assessment limitations. The WRAM and its parameters were introduced in Chapter 3, "Methods," and are referred to herein.

5.1 INTRODUCTION

The engineering evaluations described in Chapter 4, "Engineering Evaluations," provided the basis for assessing the proposed options to deter juvenile salmonids from entrainment into the interior and south Delta. The results of these evaluations – including both general and unique site-specific considerations, best available site and technology information, and initial findings regarding the engineering options – have been used to identify potential preferred options for each of the five study sites. Each set of results has provided DWR with supporting information useful for comparing options and applying the WRAM.

5.2 WRAM ASSESSMENTS

The WRAM assessments involved four steps:

- Step 1 - identifying the evaluation criteria;
- Step 2 - weighting the importance of each criterion (calculating the relative importance coefficients [RICs]);
- Step 3 - scaling (weighting) the beneficial and adverse impacts of each potential option on the criterion (calculating the option choice coefficients [OCCs]); and
- Step 4 - calculating each option's relative score (calculating the final coefficients [FCs]).

Options with larger FC values are considered potential preferred options. Step 1 was completed during Phase I and is not discussed further. See the Phase I - Initial Findings Report [DWR 2013] for background information. Steps 2 through 4 have been completed as part of Phase II and are described further below.

5.2.1 OPTIONS EVALUATED

As described in Chapter 2, "Background," eight discrete physical and non-physical engineering options were advanced for consideration from Phase I:

- *Physical options:* fish screen, gate, rock barrier, FFGS, and habitat restoration; and
- *Non-physical options:* BAFF, electrical fish guidance system, and IFF.

Two additional non-engineering options were also identified: transportation (barging/trucking of juvenile salmonids) and no action. These options were included for consideration should no preferred engineering option emerge for any given site.

As described in Chapter 4, the eight discrete engineering options for consideration were reduced to five after a preliminary screening review with the TWG. Options removed from further consideration included the fish screen, rock barrier, habitat restoration, and electrical fish guidance system. The four options advanced for

WRAM assessment were the BAFF, FFGS, IFF, and gate. No WRAM assessments were done for the "transportation (barging/trucking)" or the no action non-engineering options.

5.2.2 RELATIVE IMPORTANCE COEFFICIENTS

As described in Chapter 3, 11 final criteria were considered during the WRAM assessments. Each criterion was ranked in order of importance relative to the other criteria. The ranking values were then used to calculate an index called the RIC. All RIC values are less than 1 and presented with an accuracy level to two significant figures. The RIC degree of accuracy is discussed further in Section 5.4, "Significance of Findings.

The 11 RIC values ranged from a high (most important) of 0.17 for deterrence ability to a low (least important) of 0.02 for cost (Table 5-1).

Table 5-1. WRAM Relative Importance Coefficients

Criterion	Relative Importance Coefficient (RIC)
Boat passage	0.08
Cost	0.02
Deterrence ability	0.17
Environmental impacts	0.12
Flow effects	0.14
Implementability	0.08
Operation and maintenance	0.08
Predation effects	0.05
Tidal effects	0.07
Uncertainties	0.07
Upstream migration	0.14

Note: WRAM = Water Resource Assessment Methodology
Source: Data compiled by DWR in 2014

5.2.3 OPTION CHOICE COEFFICIENTS

The four general options advanced for the WRAM assessments described in Section 5.2.1, "Options Evaluated," were used to develop WRAM OCCs for each site and applicable option. Based on general bathymetric and hydrodynamic considerations not all options were considered appropriate for all sites (e.g., the IFF was not considered feasible for the Head of Old River site due to insufficient channel depth) and no assessment was completed for that combination of option and site.

The relative impact of an option on each of the 11 criterion compared to every other individual option was evaluated or scaled. The scaling values were used to calculate 11 OCC coefficients, one for each option-criterion pair. The largest OCC value for a criterion indicates the option considered to have the most benefit or least impact on the criterion. Like the RIC values, all OCC values are less than one and presented with an accuracy level to two significant figures. The degree of accuracy is discussed further in 5.4, "Significance of Findings." The OCC values by site and option are shown in Table 5-2.

Table 5-2. WRAM Option Choice Coefficients

Criteria	Georgiana Slough			
	BAFF	FFGS	IFF	Gate
Boat Passage	0.42	0.31	0.28	0.00
Cost	0.19	0.47	0.33	0.00
Deterrence Ability	0.25	0.08	0.17	0.50
Environmental	0.31	0.42	0.28	0.00
Flow Effects	0.36	0.28	0.36	0.00
Implementability	0.25	0.36	0.22	0.17
O & M	0.17	0.50	0.14	0.19
Predation Effects	0.36	0.22	0.39	0.03
Tidal Effects	0.22	0.11	0.17	0.50
Uncertainties	0.39	0.22	0.08	0.31
Upstream Migration	0.28	0.39	0.33	0.00

Criteria	Head of Old River			
	BAFF	FFGS	SDIP Gate	Gate
Boat Passage	0.39	0.33	0.14	0.14
Cost	0.33	0.50	0.14	0.03
Deterrence Ability	0.19	0.08	0.33	0.39
Environmental	0.36	0.47	0.08	0.08
Flow Effects	0.44	0.39	0.06	0.11
Implementability	0.28	0.33	0.19	0.19
O & M	0.19	0.50	0.14	0.17
Predation Effects	0.31	0.33	0.14	0.22
Tidal Effects	0.17	0.11	0.36	0.36
Uncertainties	0.25	0.14	0.31	0.31
Upstream Migration	0.36	0.36	0.14	0.14

Criteria	Three Mile Slough			
	BAFF	FFGS	IFF	Gate
Boat Passage	0.44	0.28	0.28	0.00
Cost	0.22	0.47	0.31	0.00
Deterrence Ability	0.25	0.14	0.19	0.42
Environmental	0.31	0.39	0.31	0.00
Flow Effects	0.33	0.25	0.33	0.08
Implementability	0.25	0.33	0.25	0.17
O & M	0.17	0.44	0.14	0.25
Predation Effects	0.33	0.22	0.42	0.03
Tidal Effects	0.28	0.17	0.22	0.33
Uncertainties	0.31	0.22	0.06	0.42
Upstream Migration	0.31	0.39	0.31	0.00

Criteria	Turner Cut			
	BAFF	FFGS	IFF	Gate
Boat Passage	0.42	0.31	0.28	0.00
Cost	0.17	0.36	0.47	0.00
Deterrence Ability	0.31	0.19	0.25	0.25
Environmental	0.31	0.39	0.31	0.00
Flow Effects	0.39	0.25	0.36	0.00
Implementability	0.25	0.36	0.22	0.17
O & M	0.17	0.44	0.14	0.25
Predation Effects	0.33	0.22	0.42	0.03
Tidal Effects	0.28	0.17	0.22	0.33
Uncertainties	0.31	0.22	0.11	0.36
Upstream Migration	0.33	0.36	0.31	0.00

Legend (values)	
Criteria	A larger OCC Value Indicates Most Benefit or Least Impact
Boat Passage	Least Impact (easier passage)
Cost	Least Impact (less cost)
Deterrence Ability	Most Benefit (better deterrence)
Environmental	Least Impact (less environmental impacts)
Flow Effects	Least Impact (less flow impacts)
Implementability	Most Benefit (easier seasonal installation
O & M	Most Benefit (easier O&M)
Predation Effects	Least Impact (less predation)
Tidal Effects	Least Impact (less performance impacts)
Uncertainties	Least Impact (less uncertainty)
Upstream Migration	Least Impact (less migration impacts)

Criteria	Columbia Cut			
	BAFF	FFGS	IFF	Gate
Boat Passage	0.39	0.31	0.31	0.00
Cost	0.17	0.39	0.44	0.00
Deterrence Ability	0.31	0.19	0.25	0.25
Environmental	0.31	0.39	0.31	0.00
Flow Effects	0.39	0.25	0.36	0.00
Implementability	0.25	0.36	0.22	0.17
O & M	0.17	0.44	0.14	0.25
Predation Effects	0.33	0.22	0.42	0.03
Tidal Effects	0.28	0.17	0.22	0.33
Uncertainties	0.31	0.19	0.11	0.39
Upstream Migration	0.33	0.36	0.31	0.00

Table 5-2 comprises five individual sub-tables, one for each site, and a legend. The legend provides a general explanation of the significance of larger OCC values for each criterion. The larger an OCC value the more benefit or less impact an option is considered to have on a respective criterion.

As shown in the Table 5-2 sub-tables there are 44 OCC values for each site, 11 for each of the four potential options. The comparison of general interest is the OCC values for a given site by criterion for each of the four general options, read left to right for a given criterion (e.g., for Georgiana Slough, Boat Passage, the OCC values range from 0.42 [BAFF] to 0.00 [Gate]). For the boat passage criterion at Georgiana Slough, the BAFF is considered to have the least impact (largest OCC) on passage and would allow easier passage. DWR considers all OCC values as general indicators of comparable benefit or impact rather than precise indicators.

The OCC values were used to calculate the FCs described below (Section 5.2.4 Final Coefficients).

5.2.4 Final Coefficients

The OCC and RIC values were used calculate the FCs for each site-option pair. Calculation of FCs was completed in two steps. In Step 1, the 11 OCC values for each site option described in Section 5.2.3 were multiplied by the respective criterion RIC values described in Section 5.2.2 to generate 11 intermediate coefficients. Separate calculations of intermediate coefficients were completed for each site-option-criterion combination. These coefficients were not evaluated, but were used solely as intermediate values to support the FC calculations. In Step 2, an option's 11 intermediate coefficient values were then summed to generate the option's FC for a given site.

The FC values by site and option are shown in Table 5-3 and discussed further in Section 5.3, "Options Scoring Summary."

Table 5-3. WRAM Final Coefficients

Site	Option				
	BAFF	FFGS	IFF	Gate	SDIP Gate
Georgiana Slough	0.29	0.28	0.25	0.18	NA
Threemile Slough	0.29	0.28	0.26	0.17	NA
Head of Old River	0.29	0.30	NF	0.21	0.19
Turner Cut	0.31	0.28	0.28	0.13	NA
Columbia Cut	0.30	0.28	0.28	0.13	NA

Notes: BAFF = Bio-Acoustic Fish Fence; FFGS = Floating Fish Guidance Structure; IFF = Infrasound Fish Fence; NA = not applicable; NF = not feasible; SDIP = South Delta Improvement Program; WRAM = Water Resource Assessment Methodology
Source: Data submitted from NMFS, CDFW, and DWR compiled by DWR in 2014

5.3 OPTIONS SCORING SUMMARY

WRAM FC values were calculated for potential options at each of the five sites. Potential general options by site included:

- *Georgiana Slough, Threemile Slough, Turner Cut, and Columbia Cut:* BAFF, FFGS, IFF, and Gate (Franks Tract Gate at Threemile Slough); and
- *Head of Old River:* BAFF, FFGS, Gate, and the South Delta Improvements Program (SDIP) bladder gate.

The FC ranges from highest to lowest for the five sites, as shown in Table 5-3, are: Georgiana Slough options, 0.29 to 0.18; Threemile Slough options, 0.29 to 0.17; HOR options, 0.30 to 0.19; Turner Cut options, 0.31 to 0.13; and Columbia Cut options, 0.30 to 0.13. The BAFF options were scored the highest at all sites except for the HOR where the FFGS was scored the highest. The gate options were scored the lowest for all sites. The FFGS scores were 0.01 to 0.02 below the BAFF scores for all sites. The IFF scores were 0.02 to 0.04 below the BAFF scores except at the HOR where its use would not be feasible.

Based solely on the largest FC values, the assessment results indicate that the following options are ranked the highest for a given study site and are the potentially preferred options.

- Georgiana Slough – BAFF
- Threemile Slough – BAFF
- Head of Old River – FFGS
- Turner Cut – BAFF
- Columbia Cut – BAFF

The BAFF option at four of the sites would provide nearly full water column deterrence, have minimal flow influence, and allow nearly unimpeded boat navigation. Because of the shallow water column at the HOR, the FFGS option was scored slightly higher than the BAFF based on providing up to 50% water column deterrence, having minimal flow influence, and allowing boat navigation around the barrier structure.

As noted previously the WRAM assessment has been based on best available site and technology information. Not all options have undergone field testing and significant unknowns exist regarding fish behavior and response. Multiple fish behavioral and technology studies are ongoing or may be conducted in the future that would provide relevant information from which a more refined assessment could be repeated. The assessment should be repeated as additional studies are completed and data has been assessed.

5.4 SIGNIFICANCE OF FINDINGS

Application of the WRAM has provided a structured approach to identify and prioritize important evaluation criteria and to evaluate and compare potential options. Although a more detailed breakdown of criteria could be developed to support a more quantitative analysis, DWR has used general criteria for this feasibility-level study and used the WRAM semi-quantitatively.

The WRAM's numerical accuracy is based on assignment of 1, 0, or 0.5 to all RIC and OCC analyses. These values have been utilized in accordance with the WRAM to generate the RIC and OCC coefficients and support the calculation of the FC values described previously. These values have just one significant figure, but they are not measurements. Rather, these values represent subjective decision making based on the best available information for each option. Thus, although it could be argued that the FC values should have no more than one significant figure, the use of two figures has provided the TWG better resolution from which to consider the selection of potentially preferred options. The WRAM as presented by the USACE WES (Solomon et al. 1977) presented findings to four significant figures.

5.5 ENGINEERING OPTIONS INTEGRATION WITH OTHER STUDIES AND PROGRAMS

To help reduce entrainment of juvenile salmonids into the interior and south Delta, the assessment results indicate that the BAFF should be installed at 4 of the 5 study sites with the FFGS used at one site. Findings show that the BAFF is the preferred option at Georgiana and Threemile sloughs, and Columbia and Turner cuts. The FFGS is the preferred option at the HOR.

The Phase II findings concur with the BDCP in that the BDCP lists these sites as likely locations for nonphysical barrier placement. Additionally, there are several current and recently completed studies which may contribute relevant findings toward engineering options due to their study site or focus. (See Table 3-7 for a complete list of studies.) Other studies conducted at the study sites include Georgiana Slough Non-Physical Barrier Studies (2011 and 2012), Georgiana Slough FFGS Study (2014), HOR Predator Study, and Juvenile Salmonid Routing and Barrier Effectiveness, Predation, and Predatory Fishes at the Head of Old River, 2009-2012. Additionally, several studies are being conducted within the interior and south Delta. These studies include: Clifton Court Predation Studies, Survival and Migratory Patterns of Juvenile Spring and Full Run Chinook, Six-Year Steelhead Study, Effects of Predator and Flow Manipulation on Juvenile Chinook Salmon Survival, Central Valley Project Improvement and Stipulation Study.

6 RECOMMENDATIONS

6.1 INTRODUCTION

Since the inception of Action IV.1.3 in 2009, a great deal of time and effort by many individuals has been spent researching and testing engineering technologies to further reduce diversion of emigrating juvenile salmonids into the interior and southern Delta, and reduce entrainment exposure to CVP and SWP export facilities. Technologies investigated were classified as either physical (FFGS and Gate) or non-physical (BAFF and IFF). Field studies of a BAFF in 2009 and 2010 at the Head of Old River, a BAFF in 2011 and 2012 at Georgiana Slough, and a FFGS in 2014 at Georgiana Slough were conducted. Though not field tested in the Central Valley of California, the IFF also shows promise to deter juvenile salmonids.

The importance of understanding the hydrodynamics at each of the junctions became clearer after performing data collection and analysis for each of the field studies. Quantifying the relationship between seasonal flow variability, daily tides, and fine-scale turbulence on the ability of a particular fish guidance technology to perform was a challenging task due to the complexities of the sites that were used as test areas. However, much progress was made in understanding the particular technologies and furthering the development of technology design tools.

6.2 CONSTRAINTS AND UNKNOWNS

In spite of the research and testing performed since 2009, there remain unknowns regarding understanding how effective each of the technologies would be over a full range of flows. Untested engineering technologies, hydrodynamic interactions with engineering technologies, specific gate operations, and piscivorous predation interactions with the engineering technologies should be better understood.

6.3 ADDITIONAL RESEARCH AND MONITORING FOR CONSIDERATION

In implementing options in Phase III, additional research and monitoring should be considered, including:

- Reviewing current studies related to the Action when they are completed,
- An additional field study of an FFGS pending results of the 2014 study,
- A field study of an IFF to determine deterrence ability,
- Modeling specific gate operations for any gate options,
- Additional hydrodynamic modeling coinciding with field studies to observe engineering technology performance,
- Implementing ELAM modeling of technologies at the junctions when the model is fully developed,
- Additional tagged fish release studies coinciding with field studies to observe engineering technology deterrence performance,
- Additional piscivorous predation monitoring coinciding with field studies of engineering technology and piscivorous predator interactions, and

- In lieu of engineering solutions, transporting juvenile salmonids by truck or barge past the junctions of concern similarly to an effort in 2014 to transport salmonids to Chipps Island due to extreme drought conditions.

6.4 ONGOING STUDIES AND ANALYSES

The 2014 FFGS study results and ELAM model are currently being analyzed and developed, and thus were not available for use at the time of this report release. Both the FFGS and ELAM provide information related to the assessment of engineering technologies that would be useful. The 2014 FFGS report should be reviewed when it is completed and the WRAM assessments related to the FFGS re-evaluated. The ELAM model should be utilized, if successfully developed, to assess engineering technologies at the junctions since field studies of only two technologies (BAFF and FFGS) and at two of the junctions were completed.

In addition, other on-going studies may provide useful information and should be considered in re-evaluating the WRAM assessments when the study results become available.

6.5 PREFERRED OPTIONS

Significant information has been collected over the last few years regarding engineering options to address the Action. Field studies of two options (BAFF and FFGS) being were conducted at Georgiana Slough and one option (BAFF) was conducted at the Head of Old River. No field studies took place at Threemile Slough, Turner Cut, or Columbia Cut. Results for one of the options (FFGS), is in the process of being evaluated and results were not available to be included in this report. Additional information should be evaluated and collected which could potentially change the preferred option for each site. The TWG group believes the IFF technology has potential to be an effective engineering option but would need to be tested to examine potential adverse effects on larval fish. Testing would be done in a laboratory or appropriate field setting prior to consideration for implementation in order to evaluate the need, if any, of incidental take under FESA and CESA.

Based on current information that was evaluated by the TWG, if there is a demonstrated need to implement an engineering option at one or more of the five junctions, the following are the currently preferred options for implementation:

- Georgiana Slough – BAFF
- Threemile Slough – BAFF
- Head of Old River – FFGS
- Turner Cut – BAFF
- Columbia Cut – BAFF

Before a decision to implement an engineering option is made, a science-based evaluation of the improvement to salmonid outmigration and survival that would result by implementing the option should be conducted. The evaluation should at minimum consider the time and cost to implement the option, adverse impacts of the option to the environment, and the number of salmonids using the channel that might be deterred by the option.

6.6 ADAPTIVE MANAGEMENT IMPLEMENTATION

Potential engineering solutions that are implemented at one or more of the five junctions reviewed in this report should be subjected to an adaptive management and monitoring program. This program would include the latest information and knowledge gained during the course of implementing a specific engineering solution to help develop and potentially implement alternative strategies to achieve the biological goals and objectives identified in the NMFS BiOp (2009). Engineering solutions may be non-physical (e.g., BAFF) or physical in design (e.g., FFGS). The goal of implementing engineering solutions is to redirect juvenile salmonids away from channels and river reaches where survival through the Delta has been shown to be lower than in other areas. Barriers (non-physical and physical) may be installed and operated from October to June or when monitoring determines that juvenile salmonids are present in the target areas and redirecting salmonids could improve outmigration conditions and survival.

Compliance monitoring would consist of documenting the installation and operation of engineered fish barriers. Effectiveness monitoring would consist of assessing the effectiveness of each barrier, including the pilot testing now under way in the Delta (e.g., Georgiana Slough). DWR would use results from effectiveness monitoring to determine whether operation of barriers result in measurable benefits (higher survival) to juvenile salmonids and to identify adjustments to funding levels, methods, or other related aspects of the program that would improve its biological effectiveness. Effectiveness monitoring actions may include tagging hatchery-reared juvenile salmonids, releasing these fish upstream of barriers, and monitoring their downstream migration both with and without the fish barrier operating. Different configurations of fish barriers may be deployed to determine the differences in effectiveness.

Table 6-1 provides potential monitoring actions, metrics, success criteria, timing, and duration for monitoring. These monitoring elements may be modified as necessary to best assess the effectiveness of any given solution based on the best available information at the time of implementation.

Table 6-1. Effectiveness Monitoring of Engineering Solutions

Monitoring Action	Metric	Success Criteria	Timing and Duration
Site-level Assessment	Migration	Monitor the effectiveness of fish barriers in deterring juvenile salmonids from migrating into interior Delta and other waterways known to result in reduced survival	Annually for five years beginning at permit authorization, reevaluating monitoring needs after year 5

Table 6-2 lists key uncertainties and research actions relevant to monitoring engineering solutions. If any changes to the program are warranted based on the results of research and effectiveness monitoring, they would be implemented through the adaptive management decision-making process, and through subsequent annual work plans.

In applying adaptive management principals to the evaluation of engineering solutions the practicality of the goal of the NMFS BiOp (2009) of reducing entrainment into the interior and south Delta at the five locations reviewed can be evaluated.

Table 6-2. Key Uncertainties and Potential Research Actions Relevant to Evaluating Engineering Solutions

Key Uncertainties	Potential Research Actions
How effective are barriers over the long-term?	• Evaluate change in survival of juvenile salmonids. • Evaluate effectiveness of barriers in high-flow areas. • Monitor changes in proportion of juvenile salmonid distribution and abundance upstream and downstream of barrier. • Evaluate behavioral response(s) of juvenile salmonids relative to the barriers. • Evaluate the effectiveness of barriers with studies using tagged juvenile salmonids.
How do barriers affect predators?	• Determine the abundance of piscivorous predators within the area of the barriers, both before and after installation, and evaluate the effect of the barriers on the survival of outmigrating juvenile salmonids. • Evaluate effectiveness of deterrents on green sturgeon, steelhead, and Chinook salmon. • Evaluate potential attraction of piscivorous predators to fish barriers (e.g., type/species and number). • Evaluate the extent of piscivorous predator aggregation at barriers before and after installation. • Evaluate piscivorous predator composition before and after installation of barriers. • Evaluate piscivorous predator response to operation of barriers.

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